

Guide to the Global Observing System

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PREFACE

The first edition of the WMO *Guide on the Global Observing System* was completed in 1977 as the result of a decision adopted by the sixth session of the WMO Commission for Basic Systems, which was held in Belgrade in 1974. In 1983, the eighth session of the Commission noted that it had become necessary to revise and expand the Guide in light of the publication of the *Manual on the Global Observing System*, which comprised Annex V to the *Technical Regulations* and contained all the regulatory material pertaining to the Global Observing System. The Commission therefore requested its Working Group on the Global Observing System to prepare a draft of a new version of the Guide, which was approved by the ninth session of the Commission in January/February 1988.

Considering the crucial role of regulatory material related to the Global Observing System and changes adopted in the operational practices of National Meteorological and Hydrological Services, the Commission for Basic Systems decided at its thirteenth session in St Petersburg in 2005 that additional steps should be taken to review and update the Guide as soon as possible, in particular:

- (a) Take into account the updated observing regulations and procedures contained in the *Manual on the Global Observing System* and the *Guide to Meteorological Instruments and Methods of Observation*;
- (b) Incorporate developments in Global Observing System operations;
- (c) Bear in mind recent proposals and recommendations related to the space-based subsystem of the Global Observing System and the establishment of a WMO Space Programme;
- (d) Include guidance material related to quality management.

Based on these recommendations, Part II, Observational data requirements, and Part IV, The space-based subsystem, were fully updated. A new Part VIII, Quality management, was added to the Guide.

The Task Team on Regulatory Material met in February 2006 in Geneva and decided to apply the following criteria when reviewing and updating the Guide:

- (a) The original text of the Guide should be retained as far as possible;
- (b) No parts of the Guide should be deleted unless the material concerned was erroneous, outdated, irrelevant or not part of the regulatory material.

Additional new material has been included where considered necessary.

I am pleased to present the third edition of the *Guide to the Global Observing System*.



M. Jarraud
Secretary-General

INTRODUCTION

General

As laid down in the Convention, one of the principal purposes of the World Meteorological Organization (WMO) is to facilitate worldwide cooperation in the establishment of networks of stations for the making of meteorological observations or other geophysical observations related to meteorology, and to promote the establishment and maintenance of meteorological centres charged with the provision of meteorological services. Another aim of the Organization is to promote standardization of meteorological observations and to ensure the uniform publication of observations and statistics. With a view to ensuring the required standardization of practices and procedures in meteorology, the World Meteorological Congress adopts Technical Regulations laying down the meteorological practices and procedures to be followed by the Member countries of the Organization. The Technical Regulations include manuals relating to various aspects of the Organization's activities and are supplemented by a number of guides which describe in more detail the practices, procedures and specifications which Members are invited to follow in establishing and conducting their arrangements for compliance with the Technical Regulations and in developing meteorological services in their respective countries. The present Guide deals with the organization and implementation of the Global Observing System, one of three essential components of the WMO World Weather Watch Programme (WWW).

World Weather Watch

World Weather Watch, a core WMO Programme, combines observing systems, telecommunication facilities, and data-processing and forecasting centres operated by Members to provide meteorological and related geophysical information for efficient service delivery in all countries.

WMO Members coordinate and implement by means of the WWW Programmes standardized measuring methods and common telecommunication procedures, and present observed data and processed information in a manner understood by all, regardless of language.

These arrangements and the operation of World Weather Watch facilities are coordinated and monitored by WMO with a view to ensuring that every country has access to all the information it needs to provide weather services on a day-to-day basis and to conduct long-term planning and research activities. A key objective of the WWW Programme is to provide the basic infrastructure for obtaining observational data and related services needed for relevant international programmes that address global environmental issues.

World Weather Watch operates at global, regional and national levels. It involves the design, implementation, operation and further development of the following three interconnected, and increasingly integrated, core elements:

- (a) The Global Observing System (GOS), which consists of facilities and arrangements for making observations at stations on land and at sea, and from aircraft, meteorological operational satellites and other platforms. It is designed to provide observational data for use in both operational and research work;
- (b) The Global Telecommunication System (GTS), composed of integrated networks of telecommunication facilities and centres, especially regional telecommunication hubs, for the rapid, reliable collection and distribution of observational data and processed information;
- (c) The Global Data-processing and Forecasting System (GDPFS), made up of World, Regional/Specialized and National Meteorological Centres to provide processed data, analyses and forecast products.

The implementation, integration and efficient operation of the three core elements are achieved by means of the following support programmes:

- (a) The World Weather Watch Data Management programme, which monitors and manages the information flow within the World Weather Watch system to ensure quality and the timely availability of data and products and the use of standard representation formats to meet the requirements of Members and other WMO Programmes;

(b) The World Weather Watch System Support Activities programme, which provides specific technical guidance, training and implementation support, the World Weather Watch Operational Information Service and supports cooperative initiatives.

Further specifications and details of the functions and organization of the three World Weather Watch core components are provided in Volume I of the respective Manuals on the Global Observing System, the Global Data-processing and Forecasting System and the Global Telecommunication System manuals, which are annexes to the Technical Regulations.

Purpose of the *Guide to the Global Observing System*

The main purpose of the Guide is to provide practical information on the development, organization, implementation and operation of the Global Observing System in order to enhance both the participation of individual Members in the System and the benefits they may obtain from it. The Guide explains and describes Global Observing System practices, procedures and specifications and is aimed at assisting the technical and administrative staff of National Meteorological Services responsible for the networks of observing stations in preparing national instructions for observers.

The Guide supplements the regulatory material on observational matters contained in the *Technical Regulations* and the *Manual on the Global Observing System* and, for ease of reference, follows roughly the same structure as the Manual. The Guide also

complements the *Guide to Meteorological Instruments and Methods of Observation*, while the *Guide on the Global Data-processing System* is used to complement the *Guide to the Global Observing System*.

A list of publications which are related to and may be used in conjunction with the *Guide to the Global Observing System* is given below.

- Guide on Meteorological Observation and Information Distribution Systems at Aerodromes* (WMO-No. 731), first edition
- Guide on the Global Data-processing System* (WMO-No. 305)
- Guide to Agricultural Meteorological Practices* (WMO-No. 134)
- Guide to Climatological Practices* (WMO-No. 100)
- Guide to Hydrological Practices* (WMO-No. 168)
- Guide to Marine Meteorological Services* (WMO-No. 471)
- Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8)
- Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology* (WMO-No. 258)
- Information on Meteorological and Other Environmental Satellites* (WMO-No. 411)
- International Cloud Atlas* (WMO-No. 407)
- Manual on Codes* (WMO-No. 306)
- Manual on the Global Data-processing and Forecasting System* (WMO-No. 485)
- Manual on the Global Observing System* (WMO-No. 544)
- Manual on the Global Telecommunication System* (WMO-No. 386)
- Sixth WMO Long-term Plan (2004–2011)* (WMO-No. 962)
- Technical Regulations* (WMO-No. 49)
- World Weather Watch: <http://www.wmo.int/web/www/www.html>

PART I

PURPOSE, SCOPE, REQUIREMENTS AND ORGANIZATION OF THE GLOBAL OBSERVING SYSTEM

1.1 PURPOSE AND SCOPE OF THE GLOBAL OBSERVING SYSTEM

The Global Observing System (GOS) provides from the Earth and outer space observations of the state of the atmosphere and ocean surface for the preparation of weather analyses, forecasts and warnings for all WMO Programmes and relevant environmental programmes of other international organizations. It is operated by National Meteorological Services, national or international satellite agencies, and involves several consortia dealing with specific observing systems or geographic regions.

The Global Observing System is a coordinated system of different observing subsystems, the main purpose of which is to provide in a cost-effective way high-quality standardized meteorological and related environmental and geophysical observations from all parts of the globe and outer space, as they are required for the real-time preparation of weather analyses and forecasts, including warnings. The Global Observing System also provides observational data for research purposes in support of other WMO Programmes or relevant programmes of other international organizations, as agreed by the Organization.

Main long-term objectives

The main long-term objectives of the Global Observing System are as follows:

- (a) To improve and optimize global systems for observing the state of the atmosphere and the ocean surface in order to meet effectively and efficiently the requirements for the preparation of increasingly accurate weather analyses, forecasts and warnings, and for the conduct of climate and environmental monitoring activities under programmes of WMO and other relevant international organizations;
- (b) To provide for the necessary standardization of observing techniques and practices, including the planning of networks on a regional basis to meet user requirements with respect to quality, spatial and temporal resolution and long-term stability.

1.2 GLOBAL OBSERVING SYSTEM REQUIREMENTS

The requirements to be met by the Global Observing System are defined by Members of the Organization through the regional associations and Technical Commissions set out in the various WMO Programmes. Essentially, the Global Observing System must provide the basic data for the services rendered by the National Meteorological Services or other organizations in contributing to public safety, socio-economic well-being and development in their respective countries. These services fall into three main categories:

- (a) Weather forecasts, including reports on current weather, warnings of hazardous weather phenomena and predictions of weather on varying timescales up to one month and sometimes beyond;
- (b) Climate information and advice on the application of meteorological data and knowledge;
- (c) Hydrological services, including flood warnings.

These three categories cover a variety of specialized services and applications of meteorology which require different types of meteorological observations and measurements on varying scales. These include short-, medium- and long-range weather forecasting; the provision of severe weather warnings for the occurrence of such phenomena as tropical cyclones, polar lows, hail storms, floods and heavy snowfalls; services for aviation, shipping and agriculture and other diverse areas such as energy production, environmental protection, the construction industry and tourism. In general, the requirements to be met by the Global Observing System for each of these areas are established by the WMO Technical Commissions for Basic Systems, Climatology, Atmospheric Sciences, Hydrology, Aeronautical Meteorology, Agricultural Meteorology, and Oceanography and Marine Meteorology.

A number of international programmes also use World Weather Watch facilities and those of the Global Observing System in particular, and have their own special requirements. These include: the World Climate Research Programme of WMO, the International Council for Science, the World Area Forecast System, the United Nations Environment

Programme Global Environment Monitoring System and the Integrated Global Ocean Services System of the United Nations Educational, Scientific and Cultural Organization's (UNESCO) Intergovernmental Oceanographic Commission (IOC) and WMO.

The formulation of data requirements is an evolving process based on experiences with observing systems and improvements in data assimilation techniques. The process balances demands of users with the technical feasibility of data resolution. Part II provides more detailed information on this topic.

1.3 ORGANIZATION AND IMPLEMENTATION OF THE GLOBAL OBSERVING SYSTEM

In order to meet these requirements, the Global Observing System is designed as a composite system consisting of surface- and space-based satellite subsystems. The former, discussed in detail in Part III of the Guide, comprises the regional basic synoptic networks and other networks of land, sea and airborne stations; it also includes agricultural meteorological stations, climatological stations and special stations. The space-based subsystem (see Part IV) is composed of meteorological operational polar-orbiting and geostationary satellites, environmental research and development satellites, and has a ground segment for data reception and processing and a space segment.

The composite system provides observational information that falls broadly into two categories:

- (a) Quantitative information, derived directly or indirectly from instrument measurements;
- (b) Qualitative, descriptive information.

Examples of quantitative information, which specify the physical state of the atmosphere, are measurements of atmospheric pressure, humidity, air temperature and wind speed, whereas qualitative or descriptive information includes such observations as the amount and type of clouds and types of precipitation.

At the behest of the World Meteorological Congress, the Commission for Basic Systems studied the evolution of the Global Observing System and issued the *Implementation Plan for Evolution of Space- and Surface-based Subsystems of the Global Observing System* (WMO/TD-No. 1267). A key aim of the Plan is to help Members prepare for anticipated changes in the Global Observing System over the next two decades.

Implementation of the new Global Observing System should facilitate cooperation among Members at national, regional and global levels. The future Global Observing System in developing countries will have to address issues such as infrastructure, training, equipment and consumables.

Implementation activities

Global Observing System implementation components are aimed at achieving the following objectives:

- (a) Enhanced standardization of observing techniques and practices and their improvement, including the redesign, optimum planning and the implementation of redesigned observational networks on a regional basis;
- (b) Improved performance of the global network to meet in the most efficient manner the stated requirements in terms of accuracy, temporal and spatial resolution, and timeliness of meteorological observations;
- (c) Assessment of cost-effectiveness, long-term sustainability and innovative collaborative arrangements between National Meteorological and Hydrological Services related to operations of the upgraded Global Observing System;
- (d) Analysis of evolving observational data requirements from various application programmes and preparation of guidance for the further development of the Global Observing System.

With respect to the implementation of the Global Observing System, the guiding principle is that all activities and facilities connected with the establishment and operation of the System in the territories of individual countries are the responsibility of the countries themselves and should be met to the extent possible with national resources. Where this is not possible, assistance may be provided by the United Nations Development Programme, through other multilateral or bilateral assistance programmes or by the WMO Voluntary Cooperation Programme.

Implementation of the Global Observing System outside the territories of individual countries, such as outer space, the oceans and the Antarctic, is based on the principle of voluntary participation of countries that are willing and able to contribute by providing facilities and services individually or jointly from their national resources or through collective financing.

The Global Observing System is a flexible and continuously evolving system with a choice and mix of observing components that may be adjusted

to take full advantage of new technology or to meet new requirements. As a general rule, however, the evolution of the system should be based on proven techniques and represent the best mix of observing components which fully meet the following requirements:

- (a) Agreed-upon data requirements in respect of required accuracy, temporal and spatial resolution and timeliness;
- (b) Operational and technical feasibility;
- (c) Members' cost-efficiency requirements.

Throughout the Global Observing System, standardized quality control procedures are applied (see Part VI of the Guide) to all observing system components in order to ensure high quality and compatible data.

Certain levels of redundancy are required for quality assurance purposes and to ensure against catastrophic failure in any single component; multi-purpose components or stations are encouraged in order to comply with cost-efficiency requirements.

PART II

OBSERVATIONAL DATA REQUIREMENTS

2.1 GENERAL

Weather prediction and other environment-related activities involve observational data analyses. Weather prediction, in particular, is based on precise meteorological analyses. All analyses require highly reliable observational data received in a timely manner at analysis centres from a sufficiently dense network or other observation source. In meteorological analyses, the required accuracy, temporal and spatial resolution and timeliness of these data are dependent on the following factors:

- (a) The different scales of meteorological phenomena to be analysed;
- (b) The resolution and other characteristics of the techniques used to perform the analyses and modelling based upon them.

Observational data requirements are always specific to purpose and change with time as techniques improve. In general, they have become more demanding as the power of computers has increased and operational numerical weather prediction and associated models have become better able to represent smaller-scale phenomena.

Varying scales of meteorological phenomena co-exist in the atmosphere. For example, one cell of a thunderstorm is only several kilometres on a horizontal scale and has a lifetime of several hours, whereas a tropical cyclone is about 1 000 kilometres on a horizontal scale and has a lifetime of 10 days or more; many thunderstorm cells appear and disappear during the life cycle of a tropical cyclone. Therefore, the frequency and spacing of observations should be adequate to obtain observational data that describe temporal and spatial changes of the meteorological phenomena with sufficient resolution to meet user requirements. If the spacing of observations is more than 100 km, meteorological phenomena with a horizontal scale of less than 100 km are not usually detectable. The classification of horizontal scales of the meteorological phenomena given in Volume I of the *Manual on the Global Observing System* (WMO-No. 544) is as follows:

- (a) Microscale (less than 100 m) for agricultural meteorology, for example, evaporation;

- (b) Toposcale or local scale (100 m⁻³ km), for example, air pollution, tornadoes;
- (c) Mesoscale (3 km–100 km), for example, thunderstorms, sea and mountain breezes;
- (d) Large scale (100 km–3000 km), for example, fronts, various cyclones, cloud clusters;
- (e) Planetary scale (more than 3000 km), for example, long upper tropospheric waves.

Horizontal scales are closely related to the time-scales of the phenomena. Larger horizontal-scale perturbations are likely to survive for a longer time period (Figure II.1). Therefore, short-range weather forecasts require more frequent observations from a denser network over a limited area in order to detect any small-scale phenomena and their development. As the length of the forecast period increases, so does the area over which observations are required. Owing to dynamic interaction between the meteorological phenomena on different scales, it may not be possible to provide definitive requirements for individual scales.

There are generally three types of requirements:

- (a) Global requirements refer to observational data needed by WMO Members for a general description of large- and planetary-scale meteorological phenomena and processes;
- (b) Regional requirements are related to observations needed by two or more WMO Members to describe in greater detail the large- and planetary-scale atmospheric phenomena, as well as to describe smaller ones on the mesoscale and small scales as may be agreed by regional associations;
- (c) National requirements are determined by each WMO Member in the light of its own interests.

Although the above discussion has been focused upon processes taking place in the atmosphere and meteorological uses of the data, similar considerations apply to processes occurring on the Earth's surface and for applications such as hydrology and agricultural meteorology. The controlling physical and chemical processes set the scale that analyses must resolve, and interactions between them determine the domain from which data are required.

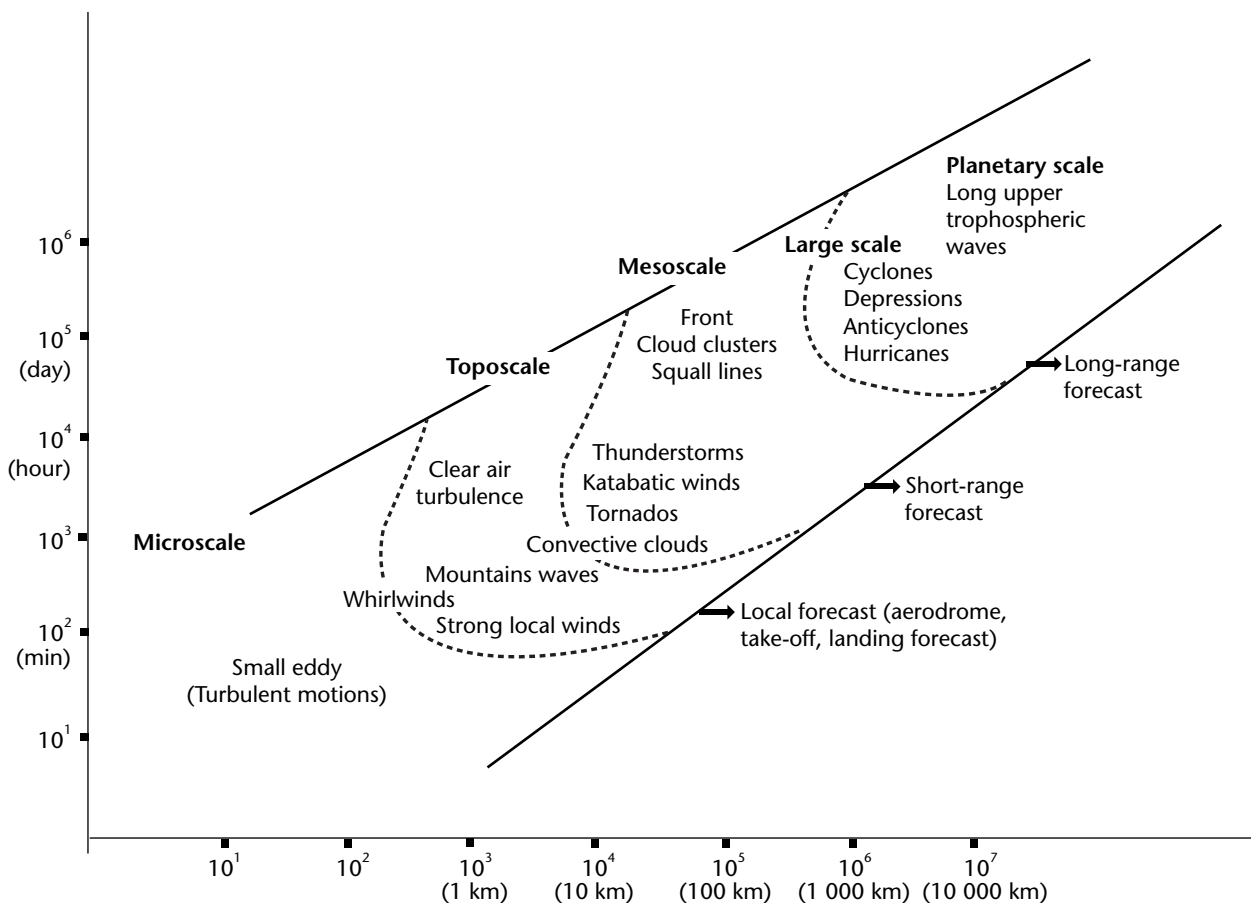


Figure II.1. Horizontal scales and timescales of meteorological phenomena

2.2 **ASSESSMENT AND FORMULATION OF OBSERVATIONAL DATA REQUIREMENTS**

The assessment of data requirements is an ongoing process based on the need for information services and an evolving level of experience with actual and candidate observing systems. A number of techniques and tools are available to carry out the assessments. Some require substantial resources and are best deployed to test specific hypotheses.

2.2.1 **Data sensitivity tests or observing system experiments**

Such tests require actual observations, from operational, pilot, demonstration or research networks and systems and a numerical weather prediction capability. Most straightforward experiments may be characterized as data-denial or data-inclusion experiments. Typically, an assimilation and prediction system is run with a control data set, and then with one or more data types withheld, or reduced in quantity. Analyses or forecasts are verified against observations. Comparison of the two runs indicates the effect of data denial, or, equivalently, the value

of the observing system when included. Observing system experiments are valuable, for example, in examining the impact of temporal or spatial changes in the network configuration or of adding or deleting existing observing systems, without actually making operational changes.

2.2.2 **Observing system simulation experiments**

Those experiments deal with hypothetical or simulated data sets and are useful for estimating how an entirely new observing system might affect forecast accuracy. A historical forecast is usually designated as the control run; it describes the “true” atmosphere. Hypothetical observations with plausible error characteristics are then manufactured from the control run at designated locations and times. The observational data set to be examined is then assimilated by a prediction model, and a new forecast is generated along with the control forecast. The impact of the simulated observing system is approximated by the difference between the two forecasts. Despite their limitation to hypothetical observations, observing system simulation

experiments are an important part of assessing the potential utility of data from a system before it is implemented.

2.2.3 **Theoretical studies and simulations**

Theoretical studies and simulations of expected data utility from potential future sensor systems can be important in planning changes to the existing observing system. For example, substantial theoretical studies and simulations were conducted prior to the launch of the first geostationary operational environmental satellite (GOES) 1-M series to predict sensor performance. The results provided an important part of the basis for designing the ground data processing system and many other aspects of the support facilities required. As systems become increasingly complex and costly, the need for well-planned theoretical studies and simulations should increase. They are an important way of reducing the risk in making decisions to develop and implement systems still in the conceptual or research stage.

2.2.4 **Laboratory assessments**

Some assessments, particularly of data processing and display techniques, are best and/or more economically conducted in a controlled laboratory environment. Several WMO Members have the capability to develop and test techniques for data processing and display. In the past, results derived from their work have been instrumental in designing both individual sensor suites and networks.

2.2.5 **System design and analysis activities**

System design and analysis activities are concerned primarily with identifying the cost and operational impact of recommended changes stemming from the scientific studies. These activities also include the design and coordination of any field and/or pilot projects that may be needed.

2.2.6 **Field site assessments**

Existing field sites offer the opportunity to examine the impact new data sets could have on forecasting and on the generation of products and services. Such evaluations become especially important in both the early and late stages of development and deployment to ensure that operational support is defined properly, is in place when needed and that field personnel are trained to obtain the best results from new systems.

2.2.7 **End-user application areas**

Observational data requirements are specific to the end-user application areas for which services are being provided, beyond weather forecasting. They include the following areas:

- (a) Agriculture and food production;
- (b) Aviation;
- (c) Land transport;
- (d) Marine resources and shipping services;
- (e) Hydrology and water resources;
- (f) Industry;
- (g) Environmental monitoring;
- (h) Disaster mitigation and prevention, emergency response;
- (i) Energy;
- (j) Public weather services, health and safety;
- (k) Climatology and climate services.

2.3 **EVALUATION OF REQUIREMENTS AGAINST SYSTEM CAPABILITIES**

It is a challenging exercise to bring together the expertise as described above and develop a consensus view on the design and implementation of composite observing systems. This is particularly true where the need and implementation occur on global or regional scales. The Commission for Basic Systems has encouraged the development of a procedure or process to accomplish this as objectively as possible: the Rolling Requirements Review. It applies to each of the application areas covered by WMO Programmes, namely:

- (a) Global numerical weather prediction;
- (b) Regional numerical weather prediction;
- (c) Synoptic meteorology;
- (d) Nowcasting and very short-range forecasting;
- (e) Seasonal and inter-annual forecasts;
- (f) Atmospheric chemistry;
- (g) Aeronautical meteorology;
- (h) Climate variability;
- (i) Climate change;
- (j) Marine meteorology;
- (k) Hydrology;
- (l) Agricultural meteorology.

2.3.1 **The Rolling Requirements Review process**

The process jointly reviews users' evolving requirements for observations and the capabilities of existing and planned observing systems. Statements of Guidance describing the extent to which such capabilities meet requirements are produced as a result. Initially, the process was

applied to the requirements of global numerical weather prediction and the capabilities of the space-based subsystem, but more recently the range of requirements has been expanded and the technique has begun to be applied successfully to surface-based observing systems and other application areas.

The process consists of four stages:

- (a) A review of user requirements for observations, within an area of application covered by WMO Programmes;
- (b) A review of the observing capabilities of existing and planned observing systems;
- (c) A Critical Review of the extent to which the capabilities (b) meet the requirements (a);
- (d) A Statement of Guidance based on (c).

The aim of the Statement of Guidance and the Critical Review is as follows:

- (a) To inform WMO Members about the extent to which their requirements are met by present systems, will be met by planned systems, or would be met by proposed systems. It also provides the means whereby Members, through the Technical Commissions, can check whether their requirements have been correctly interpreted and can update them if necessary, as part of the Rolling Requirements Review process;
- (b) To provide resource materials useful to WMO Members for dialogue with observing system agencies as to whether existing systems should be continued, modified or discontinued; whether new systems should be planned and implemented; and whether research and development is needed to meet unfulfilled user requirements.

Clearly, the Rolling Requirements Review process needs to be repeated periodically as requirements change and further information becomes available. Figure II.2 indicates the anticipated interactions with observing system agencies and user groups.

2.3.2 **User requirements and observing system capabilities database**

To facilitate the Rolling Requirements Review process, the World Weather Watch Department has been collecting the observation requirements to meet the needs of all WMO Programmes, based on techniques such as those listed in 2.2, and has been cataloguing the current and planned provision of observations, initially from environmental satellites and now extended to in situ observing systems. The resulting database is called the Database on

User Requirements and Observing System Capabilities and is accessible via the WMO Space Programme web page: <http://www.wmo.int/pages/prog/sat/Databases.html>. For example, Appendix II.1, extracted from this database, tabulates a part of the observations required currently for global numerical weather prediction.

2.3.2.1 **User requirements**

The user requirements are system independent: they are intended to be technology-free in that no consideration is given to what type of measurement characteristics, observing platforms or data processing systems are necessary, or even possible, to meet them. A 2005–2015 time frame has been set to meet those requirements. The database has been constructed in the context of a given application, or use. The observation requirements are stated quantitatively in terms of a set of relevant parameters, of which the most important are horizontal and vertical resolution, frequency (observation cycle), timeliness (delay in availability), and accuracy (acceptable root mean square error and any limitations on bias). For each application, there is usually no abrupt transition in the utility of an observation as its quality changes; improved observations, in terms of resolution, frequency or accuracy, for example, are generally more useful, whereas degraded observations, although less useful, are on the whole not useless. Moreover, the range of utility varies from one application to another. The requirements for each parameter are expressed in terms of two values, a maximum or goal and a minimum, or threshold requirement. The maximum requirement or goal is an optimal value: if exceeded, no significant improvement in performance is expected for the application in question. Therefore the cost of enhancing the observations beyond this maximum requirement would not be matched by a corresponding increased benefit.

Maximum requirements are likely to change as applications progress; they develop a capacity to make use of better observations. The minimum requirement is the threshold below which the observation is not significantly useful for the application in question, or below which the benefit derived does not compensate the additional cost involved in using the observation. Assessment of minimum requirements for any given observing system is complicated by assumptions concerning which other observing systems are likely to be available. It may be unrealistic to try to state the minimum requirement in an absolute sense because the very existence of a given application relies on

- (a) The presentation must be concise and attractive, and understandable to senior managers and decision makers, whilst retaining sufficient detail to represent adequately the full range of observational requirements and observing system capabilities;
- (b) The presentation of user requirements must be accurate; although it is necessarily a summary, it must be recognizable to experts in each application as a correct interpretation of their requirements;
- (c) The presentation of the observing system capabilities must be accurate; although it is also a summary, it must be recognizable to expert data users as a correct interpretation of the system's characteristics and potential;
- (d) The results must accurately reflect the extent to which current systems are useful in practice, whilst drawing attention to those areas in which they do not meet some or all of the user requirements;
- (e) The process must be as objective as possible.

An example of the output of the Rolling Requirements Review of the space-based and surface-based subsystems capabilities to meet the requirement to measure wind profiles for the numerical weather prediction application is shown in Appendix II.2. This is a single parameter for a single applications area. The process produces hundreds of these charts, but software tools have been developed which provide the required subsets of charts to experts involved in the Rolling Requirements Review.

2.3.4 Statements of Guidance

Statements of Guidance are designed to provide an interpretation of the output of the Critical Review, draw conclusions and identify priorities for action. The process of preparing such a Statement is necessarily more subjective than that of the critical review. Moreover, whilst a Review attempts to provide a comprehensive summary, a Statement of Guidance is more selective, drawing out key issues. At this stage, judgements are required concerning, for example, the relative importance of observations of different variables.

Since the *Preliminary Statement of Guidance* was published by WMO in 1998, several updates and additions have been completed in order to extend the process to new application areas, take into account the evolving nature of requirements and include the capabilities of surface-based sensors (WMO, 1999, 2001).

The latest Statements of Guidance can be found via the WMO Space Programme web page: <http://www.wmo.int/pages/prog/sat/Refdocuments.html>.

2.4 NETWORK DESIGN AND NATIONAL REQUIREMENTS

In addition to the Global Observing System, observing networks may be required at the national level for the derivation of local weather parameters from forecast fields, verification of the quality of issued forecasts and warnings and other real or non-real-time applications. The observational data required for this purpose include surface and upper-air data obtained from land stations and ships, aircraft and buoys, as well as weather radar data and satellite information.

National observing networks are designed by Members to meet their individual needs or in agreement with other Members, in accordance with WMO regulatory and guidance material.

Network design should take into account special observational data requirements and forecast products of the end-user groups for whom the services are being provided. Much of the data requirements for individual services may often require additional data, denser networks or higher observation frequency.

2.5 EVOLUTION OF THE GLOBAL OBSERVING SYSTEM

The Global Observing System gradually evolves to address global, regional and national requirements for observational data. Many of the requirements stated cannot be met without space-based observing systems. In most cases, a combination of satellite and in situ data is needed to obtain adequate resolution and to ensure remote sensing system calibration stability. The Global Observing System will, therefore, continue to be composed of surface-and space-based subsystems. However, owing to resource constraints, careful judgements should be made regarding the value of increased quality of Global Data-processing and Forecasting System output products weighed against the costs of additional observations. The definition of requirements and Global Observing System design are largely influenced by cost and countries' ability to operate Global Observing System components and facilities. It is, therefore, important to define

realistic and achievable goals for Members in respect of the composite Global Observing System.

Based on the Statements of Guidance mentioned above, a Vision for the Global Observing System in 2015 and beyond was developed and agreed by the Commission for Basic Systems at its extraordinary session in December 2002. The evolution for the Global Observing System was framed in the 42 recommendations of final report CBS/IOS/ICT-2 (2002). Twenty-two recommendations relating to the Global Observing System surface-based component address more complete and timely data distribution; enhanced aircraft meteorological data relay (AMDAR), especially over data-sparse areas; optimized rawinsonde launches; targeted observations; inclusion of a ground-based global positioning system (GPS), radars and wind profilers; increased oceanic coverage through expanded Automated Shipboard Aerological Programme (ASAP) observations, drifting buoys and ARGOS, the data relay and platform location system; and possible use of unmanned aerial vehicles. The 20 recommendations for the Global Observing System space-based component state the need for six operational geostationary and four optimally spaced polar-orbiting satellites complemented by satellites for research and development; they call upon rigorous calibration of remotely sensed radiances and improved spatial, spectral, temporal and radiometric resolution. The wind profiling and global precipitation missions are

singled out for their importance to the Global Observing System.

The *Implementation Plan for Evolution of Space and Surface-based Subsystems of the GOS* (WMO/TD-No. 1267) was endorsed by CBS-XIII in February 2005. The *Implementation Plan* is subject to regular review and provides essential guidance for the Global Observing System as it advances towards its vision for 2015.

References

- Abridged Final Report with Resolutions and Recommendations of the Extraordinary Session (2002) of the Commission for Basic Systems* (general summary, 6.1.14 to 6.1.24), WMO
- Implementation Plan for Evolution of Space and Surface-based Subsystems of the GOS Developed by the CBS Open Programme Area Group on the Integrated Observing Systems (OPAG/IOS)* (WMO/TD-No. 1267)
- Preliminary Statement of Guidance Regarding How Well Satellite Capabilities Meet WMO User Requirements in Several Application Areas* (WMO/TD-No. 913, SAT-21)
- Statement of Guidance Regarding How Well Satellite and In Situ Sensor Capabilities Meet WMO User Requirements in Several Application Areas* (WMO/TD-No.1052, SAT-26)
- Statement of Guidance Regarding How Well Satellite Capabilities Meet WMO User Requirements in Several Application Areas* (WMO/TD-No. 992, SAT-22)

APPENDIX II.1

EXTRACT FROM USER REQUIREMENTS AND OBSERVING SYSTEM CAPABILITIES DATABASE—EXAMPLE OF GLOBAL NUMERICAL WEATHER PREDICTION REQUIREMENTS FOR SOME VARIABLES

Geophysical variable	Horizontal resolution	Vertical resolution	Observing cycle	Delay of availability	Accuracy	Confidence	Remarks	Identifier	Requirement source
Sea-surface bulk temperature	Goal (km)	Goal (km)	Goal	Goal	Goal	Firm		WMO_ Sfc_006C	20/10/2003, ET ODRRGOS, Geneva, November 2003
	Threshold (km)	Threshold (km)	Threshold	Threshold	Threshold				
Sea-ice thickness	Goal (km)	Goal (km)	Goal	Goal	Goal	Speculative		WMO_ Sfc_021	20/10/2003, ET ODRRGOS, Geneva, November 2003
	Threshold (km)	Threshold (km)	Threshold	Threshold	Threshold				
Significant wave height	Goal (km)	Goal (km)	Goal	Goal	Goal	Firm		WMO_ Sfc_N059	20/10/2003, ET ODRRGOS, Geneva, November 2003
	Threshold (km)	Threshold (km)	Threshold	Threshold	Threshold				
Soil moisture	Goal (km)	Goal (km)	Goal	Goal	Goal	Reasonable		WMO_ Sfc_012A	20/10/2003, ET ODRRGOS, Geneva, November 2003
	Threshold (km)	Threshold (km)	Threshold	Threshold	Threshold				
Specific humidity profile – higher troposphere	Goal (km)	Goal (km)	Goal	Goal	Goal	Firm	Accuracy 5% in RH	WMO_ UA_006A	20/10/2003, ET ODRRGOS, Geneva, November 2003
	Threshold (km)	Threshold (km)	Threshold	Threshold	Threshold				
Specific humidity profile – lower troposphere	Goal (km)	Goal (km)	Goal	Goal	Goal	Firm	Accuracy 5% in RH	WMO_ UA_006	20/10/2003, ET ODRRGOS, Geneva, November 2003
	Threshold (km)	Threshold (km)	Threshold	Threshold	Threshold				
Specific humidity profile – total column	Goal (km)	Goal (km)	Goal	Goal	Goal	Firm		WMO_ Sfc_N044A	20/10/2003, ET ODRRGOS, Geneva, November 2003
	Threshold (km)	Threshold (km)	Threshold	Threshold	Threshold				
Wind profile (horizontal component) – higher troposphere	Goal (km)	Goal (km)	Goal	Goal	Goal	Firm		WMO_ UA_001A	20/10/2003, ET ODRRGOS, Geneva, November 2003
	Threshold (km)	Threshold (km)	Threshold	Threshold	Threshold				
Wind profile (horizontal component) – lower stratosphere	Goal (km)	Goal (km)	Goal	Goal	Goal	Firm		WMO_ UA_0010	20/10/2003, ET ODRRGOS, Geneva, November 2003
	Threshold (km)	Threshold (km)	Threshold	Threshold	Threshold				

RH Relative humidity

APPENDIX II.2





OUTCOME OF THE ROLLING REQUIREMENTS REVIEW PROCESS: EXAMPLES

Below is an assessment of the adequacy of space-based and surface-based observing system capabilities compared with the requirement for a specific variable (horizontal wind component in the high troposphere) in a specific application area (global numerical weather prediction).

Wind profile 500–100 hPa (HT)

Analysis for global numerical weather prediction (in situ and space-based observing systems)

Requirement summary and assessment key

	Colour key	Horizontal resolution <i>km</i>	Vertical resolution <i>km</i>	Observation cycle <i>h</i>	Delay <i>h</i>	Accuracy <i>m s⁻¹</i>
Optimum		50.0	1.0	1.0	1.0	1.0
Median		107.7	2.2	2.3	1.6	2.0
		232.1	4.6	5.2	2.5	4.0
Threshold		500.0	10.0	12.0	4.0	8.0

Note: Shaded assessment based on a constellation of two polar-orbiting satellites (one geostationary)

Instruments for wind profile 500–100 hPa (HT)

Instrument	Horizontal resolution	Vertical resolution	Observation cycle	Delay	Accuracy	Mission		Orbit
	<i>km</i>	<i>km</i>	<i>h</i>	<i>h</i>	<i>m s⁻¹</i>	name	rating	
ACARS P RA-VI WE	175.0	0.1	2.0	1.0	2.00	WWW		G
ACARS FL RA-VI WE	38.0	0.6	8.0	1.0	2.00	WWW		G
SEVIRI	100.0	5.0	1.0	1.0	4.00	WWW		G
ACARS FL RA-VI EE	159.0	0.6	8.0	1.0	2.00	WWW		G
ACARS FL RA-V SW	167.0	0.6	12.0	1.0	2.00	WWW		G
IMAGES	150.0	5.0	1.0	1.0	5.00	WWW		G
IMAGES/MTSAT	150.0	5.0	1.0	1.0	5.00	WWW		G
SOUNDER	150.0	5.0	1.0	1.0	5.00	WWW		G
ACARS FL RA-II S	310.0	0.6	12.0	1.0	2.00	WWW		G
ACARS FL RA-IV N	318.0	0.6	12.0	1.0	2.00	WWW		G
ACARS FL RA-IV C	380.0	0.6	12.0	1.0	2.00	WWW		G
ACARS FL RA-II W	429.0	0.6	12.0	1.0	2.00	WWW		G
MVIRI	150.0	5.0	1.0	2.0	5.00	WWW		G
VISSR (GMS-5)	150.0	5.0	1.0	2.0	5.00	WWW		G
VHRR	150.0	5.0	1.0	2.0	6.00	WWW		G
WND P 449 RA-IV C	700.0	0.3	1.0	0.5	1.50	WWW		G

Instrument	Horizontal resolution	Vertical resolution	Observation cycle	Delay	Accuracy	Mission	Orbit
	km	km	h	h	m s ⁻¹	name rating	
ACARS FL NAO CST	50.0	0.6	24.0	1.0	2.00	WWW	G
WND P 915 RA-IV C	1000.0	0.1	1.0	0.5	2.00	WWW	G
ACARS P RA-VI EE	692.0	0.1	2.0	1.0	2.00	WWW	G
ACARS FL MED	156.0	0.6	24.0	1.0	2.00	WWW	G
ACARS FL NAO OPN	223.0	0.6	24.0	1.0	2.00	WWW	G
ACARS P RA-V NW	3821.0	0.1	6.0	1.0	2.00	WWW	G
ACARS P RA-V SW	644.0	0.1	6.0	1.0	2.00	WWW	G
ACARS FL ARC	270.0	0.6	24.0	1.0	2.00	WWW	G
ACARS FL RA-I S	330.0	0.6	24.0	1.0	2.00	WWW	G
ACARS FL NIO CST	334.0	0.6	24.0	1.0	2.00	WWW	G
ACARS FL RA-I N	375.0	0.6	24.0	1.0	2.00	WWW	G
ACARS FL RA-I T	402.0	0.6	24.0	1.0	2.00	WWW	G
ACARS FL SAO CST	414.0	0.6	24.0	1.0	2.00	WWW	G
RAOBS RA-VI WE	218.0	0.3	16.0	1.5	2.00	WWW	G
ACARS FL RA-III N	455.0	0.6	24.0	1.0	2.00	WWW	G
ACARS FL NIO OPN	498.0	0.6	24.0	1.0	2.00	WWW	G
ACARS FL RA-II E	998.0	0.6	12.0	1.0	2.00	WWW	G
ACARS FL RA-II N	614.0	0.6	12.0	1.0	2.00	WWW	G
ACARS FL RA-IV S	690.0	0.6	12.0	1.0	2.00	WWW	G
ACARS FL RA-V NW	550.0	0.6	12.0	1.0	2.00	WWW	G

PART III

THE SURFACE-BASED SUBSYSTEM

3.1 GENERAL

The surface-based subsystem is divided into primary and secondary components. The subsystem's primary components are as follows: surface synoptic stations, upper-air synoptic stations and aircraft meteorological stations. For a detailed composition of the subsystem, see the *Manual on the Global Observing System* (WMO-No. 544), Volume I, Part III, section 1. The WMO Regional Associations define regional basic networks of surface and upper-air stations adequately to meet the requirements of Members and the World Weather Watch. A listing and description of all surface and upper-air stations and the corresponding observing programme are published in *Weather Reporting* (WMO-No. 9), Volume A – Observing Stations.

The primary components of the surface-based subsystem also include additional surface and upper-air synoptic stations, in particular, fixed and mobile, manned and automatic sea stations and aircraft meteorological stations, the latter generally operating at non-synoptic hours. Stations on ships and aircraft are especially important for the provision of information from data-sparse areas.

The other subsystem components comprise a variety of more or less specialized observing stations and include aeronautical meteorological stations, research and special-purpose vessel stations, climatological stations, agricultural meteorological stations and special stations.

3.1.1 Design of observational networks

The following criteria apply to observational networks:

- (a) The location of each station should be representative of conditions in space and time;
- (b) The station spacing and interval between observations should correspond with the desired spatial and temporal resolution of the meteorological variables to be measured or observed;
- (c) The total number of stations should, for reasons of economy, be as small as possible but as large as necessary to meet requirements.

In principle the air-mass properties should be sampled at a station covering the smallest possible area, although instruments should be positioned so that they do not affect each other's measurements. In selecting station sites, the intention is to obtain data that are representative of a larger area. Ideally, all measurements and visual observations at all stations would be made at the same time, that is, at a predetermined synoptic hour. However, as this is not practical, measurements should be made within the shortest possible time.

For purposes of uniformity, the following terms are used in this Guide:

- (a) Standard time of observation (see the *Manual on the Global Observing System* (WMO-No. 544), Volume I, Part III, 2.3 and Appendix (Definitions, part A);
- (b) Scheduled time of observation.

In addition to these times, there will be an "actual time of observation", that is, the time when an observation is actually carried out at the station. This time must not deviate by more than a few minutes from the "scheduled time of observation". Wherever variables may change considerably within the period normally required for completing an observation, arrangements should be made to obtain information on critical variables as close as possible to the scheduled time.

Permanent real-time and near-real-time monitoring of availability of observational data on completeness and timeliness should be performed by the National Meteorological Service. In addition, availability of data from regional basic synoptic network stations is monitored by quantity monitoring coordinated by the WMO Secretariat within the framework of the World Weather Watch Programme. When the National Meteorological Service does not follow regulations regarding the standard times of observation determined by the *Manual on the Global Observing System* (WMO-No. 544), the National Meteorological Service can expect negative results of the monitoring provided by WMO.

Station spacing should be such as to provide sufficiently accurate values for the meteorological variables required at any point between two stations by means of visual or numerical interpolation,

taking due account of the effects of topography on the variation of variables of interest. The same consideration applies to time series of observations obtained at the same location that require a relatively short distance between observing sites and an accuracy of measurement better than that to be obtained by interpolation. On the other hand, a very dense network or high frequency of observation could lead to more data than are necessary and thus to unnecessarily high cost.

Variations in space and time differ for individual meteorological variables and depend on the topography of the area. If any information is available or can be obtained on spatial or temporal variations, it can be used to decide upon the network configuration which is necessary to provide data of the required uncertainty (see *The Planning of Meteorological Station Networks* (Technical Note No. 111, WMO-No. 265)). For certain variables, such as precipitation, a separation of 10 km between stations may be required in some areas for several purposes, such as very-short-period forecasting, climatology and hydrological forecasting, although, in the case of rainfall, data from more widely separated weather radars can also satisfy many requirements. For variables such as atmospheric pressure and upper winds, a separation of 100 km between stations will suffice. In general, a fairly homogeneous distribution of observing stations is most suited to support numerical analyses and forecasts. However, a relatively higher station density may be necessary to support local or area forecasting, for example, to reflect the differences between coastal and inland conditions or valley and mountain weather, whereas a lower density is likely to be sufficient in regions of low population and little topographical variation.

It is generally not practicable within one network to achieve an optimization of such vastly differing requirements without severely prejudicing either operational and scientific requirements or economic considerations. The solution to this problem is to establish different types of networks within the subsystem, such as the regional basic synoptic network and its selected stations for global exchange, as well as stations established on a national level and the special networks observing "other variables". For details, refer to 3.2 to 3.9 below covering individual types of network and stations.

3.1.2 Planning of networks and stations

When a National Meteorological Service has difficulties in solving a problem due to a lack of observations within its own area of responsibility, it should first

assess which data are required and from which area, location or height. The next step in decision-making is to determine the type of network or station most suitable to provide the required data.

If a station is to be integrated into a network, its site has to be chosen primarily based on network configuration. This can be done by adding a task to or shifting an existing station, or by the establishment of a new station.

Key considerations for spacing stations within an optimized station network should also be borne in mind when developing a system of station indicators with consecutive numbers or letters. It is never practicable to install all the stations required for a network at once, and some indicators should be kept in reserve to fill the remaining gaps. If no such provision is made, new stations may create increasing chaos in the system.

For the study of small-scale phenomena, arrangements of a non-network type will sometimes also prove to be adequate and at the same time more economical. These may apply to agricultural meteorological observations at a single representative station or to precipitation measurements along a more or less straight line across a mountainous barrier providing typical values for the amounts of precipitation along the windward and leeward slopes.

Decision-making must include cost and benefit considerations. The most suitable method of achieving the highest cost-benefit ratio is normally the co-location of stations. This can be achieved by establishing a station of another type close to an existing one, or by gradually augmenting the task of a one-variable observing station to a multi-variable one. This may begin with the measurement of precipitation only and end up with a round-the-clock programme of a fully equipped surface and upper-air synoptic station requiring larger facilities and additional personnel.

Before setting up a new station, and if there is a possible choice of site, the following questions will be helpful in the decision-making process:

- (a) Is the site representative of the required meteorological data?
- (b) Will the site remain representative in view of existing or anticipated construction plans or change of vegetation, for example?
- (c) Can steps be taken to improve or safeguard the site's representativeness, such as cutting down trees or reserving rights to building and planting limits in the vicinity?

- (d) Is the site sufficiently accessible to personnel who operate the station or carry out inspection and maintenance?
- (e) Does the site provide housing and storage facilities, or can they be made available if necessary?
- (f) Are facilities such as electric power, telecommunications and running water available if required?
- (g) To what extent are security measures against lightning, flooding, theft or other interferences required and how can they be taken?
- (h) Can difficulties of posting personnel be overcome by part- or full-time automation or by locally available staff? Part-time staff from the public services sector are especially suitable for certain work at weather stations, as the continuity is ensured, regardless of staff changes.

Several points should be taken into account when planning a new observing station or its network. During this phase, the management of the National Meteorological Service responsible for the development of the observing network should ask itself the following questions:

- (a) Which system to choose for the required observation?
- (b) What is the representativeness of meteorological observations of an area in accordance with application for which they are used?
- (c) What are the standards for and definitions of measurements?
- (d) What are the standardization procedures?
- (e) What instruments are required?
- (f) What are the achievable uncertainties and required accuracy?
- (g) What are a station's or network's general requirements for siting and exposure, inspection and maintenance, system performance monitoring and availability and quality of data?
- (h) How to carry out meteorological observations?
- (i) How to establish effective liaison procedures between those responsible for monitoring and maintenance in order to facilitate prompt remedial actions?
- (j) What type of metadata related to meteorological observations is needed?
- (k) What measures have been provided for training?

Furthermore, it is wise to choose land that is in public or governmental hands, for there will be less chance of having to move the station later. A long-term contract should be established with the authorities concerned or with the landowner, if necessary, with the help of an estate

agent. The validity of the contract should be based on the usual international standard period for climatological measurements and have a duration of at least 30 years. It should prohibit changes such as the construction of buildings near the measuring site. The contract should provide for the installation and operation of instruments and other necessary equipment, transmission and power lines, and a regulation governing the right of access.

There is an understandable tendency to select a station site which cannot otherwise be utilized and whose cost is therefore relatively low. Only in very rare circumstances will such a site correspond with meteorological requirements, which should primarily determine its suitability. It must be borne in mind that nothing is more costly and frustrating than long observation records that subsequently prove to be useless or even misleading. Therefore, the following rule should be observed: "Keep the quality standard as high as necessary and the cost as low as possible".

More detailed guidance on the location of the observing site can be found under 3.2.1.2.

3.1.3 Management of manned station networks

3.1.3.1 General

The responsibility for the management of a meteorological station network, the primary task of which is the production of data of the best possible quality, lies with the Member concerned. The Member should establish an appropriate organizational unit or units within the Meteorological Service in charge of the operation, maintenance and supervision of the stations, logistics, procurement, supply and the repair of equipment and other material necessary to ensure uninterrupted operation. The unit should function operationally within the Service, be responsible for national standards and have an appropriate status. This unit will also need to liaise and coordinate its activities with data users at the national level and support services, administration and finance. A continuous survey of new technological developments is required with a view to introducing improved types of instruments, equipment and techniques. Further information on the management of the observational network can be found in the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part III, Chapter 1.

3.1.3.2 Organization of the station network management unit

The organization of the unit should take into account the size of the network. In the case of a country with very large networks it may be necessary to have a central unit with sub-centres. The location of such sub-centres depends on the Member's needs. Economic considerations as well as problems of a technical and logistic nature, such as personnel, communications and transport facilities, should be taken into account.

A different approach to station management may be based on the specific functions of the stations that comprise the network: synoptic, aviation, climatological and agricultural meteorological stations.

The unit must have means of transportation to carry out its various activities.

3.1.3.3 Administrative arrangements

The unit should have a filing system containing all relevant and up-to-date documentation of a scientific, technical, operational, and administrative nature (metadata documentation). A station gazetteer with information on geographical conditions, staff and activity programmes should be available.

The instruments at the station play a major role in the system. Particular attention should be paid to maintaining appropriate records relating to the instruments in use, including an up-to-date equipment inventory. The technical specifications of an instrument, its movement and periodical test certificates should be available and carefully maintained. For more information, see the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part I, Chapter 1, 1.3.4, and Part III, Chapter 1, 3.5.

Station breakdowns, defects, requests for repairs, supply needs and other matters requiring prompt action, should be stated in brief on an "action card". Card entries should be prioritized and action taken on that basis. In addition, the metadata should include a log of instrument faults, exposure changes and remedial actions taken. Depending on the type of instrument—mechanical, electric, electronic or mixed—and the nature of the fault, various types of workshops and laboratories may be involved.

3.1.3.4 Station network management unit staff

Unit staff members must be qualified and specially trained for their work in meteorology. In addition, the personnel must be sensitive to the human

dimension within the Meteorological Service and in their contacts with voluntary observers, private institutions or other government agencies outside the Service.

An experienced meteorologist¹ specialized in observing work should be in charge of the unit. He or she should also be a good administrator and an able organizer, whose main responsibility will be to produce the best observational information for the users, in the most economical way.

The unit may be divided into smaller sections as necessary, for example, when the network is managed on a geographical or functional basis (see 3.1.3.2). Each section head should also be a highly qualified, seasoned meteorologist, or hydrologist or engineer and should be capable of providing direct fieldwork supervision.

Depending on the size of the station network, there should be one or more inspectors who are members of the meteorological staff—at least qualified as a meteorological technician—with experience in running observing stations.

Provision should be made for technical staff: station network technicians and technical assistants. The former are specially trained to cope with all technical problems and activities connected with station management, involving tasks to be performed both in the field and at the duty station. The latter should be responsible for carrying out technical tasks involving logistics and links with the stations.

Finally, the necessary clerical staff should be available for administrative work.

3.1.3.5 Station network management unit operational tasks

The operational tasks are based on the activities and the performance of individual stations. The unit will carry out the following tasks:

- (a) Formulate plans and policy for network development, maintenance and operation;
- (b) Maintain network functions;
- (c) Monitor network performance, recommend and implement improvements;
- (d) Monitor and review network efficiency and effectiveness;

¹ For a description of the classification of meteorological personnel and their duties, see *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology* (WMO-No. 258).

- (e) Develop and define performance and calibration standards, procedures and functional requirements for observations, instruments and equipment, and issue relevant instructions;
- (f) Exercise functional control and inspection of the network;
- (g) Provide liaison between users of meteorological observations and data and equipment suppliers;
- (h) Advise on technical training for all those involved in the network;
- (i) Produce and maintain observation specifications which detail installation specifications for network observations;
- (j) Provide consumables for network measurements;
- (k) Advise on long-term re-equipment plans.

Station activities are set forth in the prescribed programme which must be carried out according to a routine day-to-day schedule. The unit should issue instructions relating to the correct implementation of standard procedures, the operation of the instrumentation, including reliability tests, and the use of official communication. It should provide relevant tables, forms and manuals, and issue directives regarding relationships with local weather data users.

The unit should appoint an inspector responsible for the activities of a group of stations, the quality of their observations and the smooth working of the instruments.² A scheme should be worked out with the users to ensure that incoming observational data and all relevant charts and forms from a station are routinely checked for errors and the inspector responsible for the station is notified accordingly. Information about malfunctioning instruments or requests for remedial action must be evaluated by the inspector so as to enable the unit to rectify discrepancies and ensure that the stations are operating properly.

Periodic activity reports from the stations should be sent to the unit.

Station personnel must be kept informed about the organization of the National Meteorological Service, and in particular about the station network. This can be done through a circular letter or a printed bulletin, which would also be a medium for the dissemination of communications or messages to and from the stations. Special attention should be given to recognizing events such as anniversaries, distinguished service and retirements.

² See *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part I, Chapter 1, 1.3.5, for the main purpose of inspections.

3.1.3.6 Logistics and supplies

Each type of station should have its own standards for activities, equipment, instrumentation and operational procedures; these must be in accordance with the regulations of WMO and of the relevant Member. An up-to-date inventory of instruments, office equipment and other types of material at the station should be available.

An efficient communication system must be worked out within the organization to allow the smooth transmission of messages and information, with more than one type of communication medium if possible.

The meteorological assistant in charge of the station is responsible for its principal activities and upkeep of the instrument site. Vegetation around the station and within its perimeter must not interfere with the operation of the instruments. Installation, repair and major maintenance work on the equipment is the responsibility of a maintenance staff from the station network management unit.

A system for ordering forms, charts and other expendables for the stations, preferably on a half-yearly basis, should be developed and implemented. Necessary supplies should be forwarded on demand to the station by means of a reliable system, bearing in mind that most of the material is fragile; special packing providing adequate protection such as boxes, cardboard, cushions or pads should be used as needed.

3.1.3.7 Establishment of a new station

The first step following the decision to establish a station is to visit the site. All the requirements must be assessed so as to ensure that the instruments to be installed can operate unhampered. It must be ascertained whether appropriate working conditions for the observer, office accommodation and other required facilities such as running water, electricity and communications are available.

The unit should prepare well in advance all instruments, equipment, supplies and material required for a new station.

The task of setting up a new station is assigned to a team that includes an inspector, a technician and assistants. The team should be trained for the specific job to be carried out in the most efficient manner according to a detailed standard plan.

During the installation of the equipment, the necessary explanations should be given to the meteorological assistant to be placed in charge of

the station to enable him/her to assume full responsibility for its operation.

A detailed report is to be written on the new station. This should include, preferably in the form of a checklist, a description of the site and its surroundings, accompanied by a drawing and an extract from a detailed map of the area. A visibility chart should be prepared for a surface station. The report should include details about instruments, their operation, test results, tables to be used and an inventory. It is recommended that pictures taken from the four main directions be included.

The operation and performance of a newly established station should be closely monitored by the unit. The documentation that arrives after the first month of operation must be carefully reviewed. Following the checking of data and evaluation of any deficiency, further visits to the station may become necessary. Thereafter, a system of regular inspections should be adopted.

3.1.3.8 Regular inspections

Regular inspections, including routine maintenance activities at automatic stations, help to ensure the smooth functioning of a meteorological station. A detailed schedule is to be worked out by the unit, spacing the inspections according to national practices. The inspection should follow a standardized checklist whereby information accumulated from the previous inspection, relevant station files, notification by other users and, if necessary, from special inquiries made before departure, will provide additional guidance to the inspector. Field tests of instruments at the station should be included among the items requiring the inspector's attention (see 3.1.3.10 and 3.1.3.11). See the *Manual on the Global Observing System* (WMO-No. 544), Part III, section 3, for the range and frequency of regular inspections.

The findings of regular inspections should be documented in an inspection report which can be less elaborate than the report referred to in 3.1.3.7. Copies of the report should be circulated to the users of the observational data within the organization, the administration and others involved in the meteorological station's activities.

3.1.3.9 Other station network management unit activities

The unit may provide technical assistance to other bodies outside the National Meteorological Service if requested. Such assistance may be provided in

writing or by active participation in various projects involving the performance of instruments and the application of meteorology and operational hydrology.

3.1.3.10 Procurement of instruments and equipment

The equipment used in the observing station network of a Member should be in accordance with the general requirements of meteorological instruments as laid down in 1.4, Chapter 1, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8). The instruments should be standardized and suitable for operation under prevailing climatic conditions. The standard instrument should be carefully selected, taking into account both economic and technical considerations, so as to ensure introduction of the best possible type of instrument into the system.

Instruments should be introduced only after a series of intercomparison tests and other checks have been performed. Intercomparisons of instruments should subsequently be carried out during each regular station inspection. Portable standard instruments used by inspectors should be checked against the relevant standards used by the Service before and after each tour of inspection.

Once a decision to procure a certain type of instrument has been made, the necessary administrative steps should be taken. Testing procedures should be instituted following the arrival of the shipment to determine if the instrument deviates in any way from the national standard, particularly in the operational scale range. Test certificates will be issued for each instrument. An instrument that falls short of the required uncertainty should not be introduced into the system. A separate record card will be established for each new instrument (see 3.1.3.3).

A minimum stock of instruments to be used must be established; the personnel in charge of procurement must make sure that it is maintained at the required level. An emergency reserve is recommended, especially for items difficult to replace. The system for keeping the spare instruments should be well organized.

An ordering and issuing system should be introduced within the Service. It should be applied to all instruments delivered to the organization from an outside supplier and allocated to individual stations in the network through the station network management unit.

Constant efforts must be made to introduce improvements in the quality, performance and price competitiveness of the various supplies. In the case of equipment, the search for improved ideas and means is very important.

Perishable items should be stocked properly and used regularly. Where items such as meteorological balloons or batteries are concerned, quality tests should be made from time to time.

A computerized information system may be of great advantage in managing the equipment. In organizations where these facilities do not exist, a manual follow-up system must be implemented.

3.1.3.11 Instrument checks and maintenance

A system for checking the instruments at a station regularly should be introduced so that faults can be discovered at an early stage. The system should include regular reliability tests. If faults are discovered or suspected, the unit should be notified immediately. Depending on the nature of the fault and the type of station, the unit will decide whether the instrument is to be changed or a field repair carried out.

The station inspector shall assist the unit in keeping the instruments in the best possible working order and in carrying out periodic intercomparisons with national standards. (See 3.1.3.8 and 3.1.3.10.)

3.1.3.12 Coordination

In addition to the circulation of inspection reports within the divisions or sections concerned and the notification of discrepancies or likely errors in the observational data, close coordination between the various users of the observational data in other branches of the organization and the unit should be arranged. Periodic meetings should be held to discuss and decide on desirable improvements or changes. Appropriate working arrangements within the unit for different types of repairs, such as electrical or mechanical repairs, for example, including familiarization with new equipment, will also be necessary.

3.1.3.13 Planning and budgeting

Planning, which should be short-term (one to two years) as well as medium- and long-term (five years or more), is concerned mainly with changes and improvements in the system, priorities to be set, development and new technology. Owing to financial implications, the cost-effectiveness of

any new type of equipment will be an important factor to be taken into consideration. Planning-related decisions may have important effects on the organizational structure for management of the station network and staff and training requirements.

3.1.3.14 Network performance monitoring

As real-time quality control procedures implemented by the National Meteorological Service have their limitations and some errors can go undetected, National Meteorological Centre (NMC) quality control monitoring at the network level is required by network managers at the Centre. Real-time quality control monitoring should include checks of the following items:

- (a) Completeness of observations at the observing station;
- (b) Quality of data transmitted from the station;
- (c) Completeness and timeliness of observational data at the Centre.

Quality control monitoring is intended to identify deficiencies and errors, monitor them and activate appropriate remedial procedures.

Quality control monitoring requires the preparation of summaries and various statistics. Therefore, it is necessary to build up a quality control monitoring system to collect statistics on observational errors of individual meteorological variables through a series of flags indicating the results of each check, and generate hourly, daily, weekly, monthly and yearly statistics. Stations with a large percentage of failed observations probably experience hardware or software failures or inappropriate maintenance. These should be referred back to the network manager.

The quality control monitoring system should keep station monitoring statistics on the frequency and magnitude of observation errors encountered at each station. The statistics provide information aimed at:

- (a) Monitoring station performance;
- (b) Locating persistent biases or failures in observations;
- (c) Evaluating improvement of observation data quality, performance and maintenance of station/network.

3.1.4 Management of automatic surface land station networks

3.1.4.1 General

Since automatic meteorological land stations are generally used to expand a basic manned station network, the management of automatic station

networks should, in principle, follow the same general rules and practices as for the management of manned station networks (see 3.1.3). This is to guarantee the acquisition of an observational data set with comparable quality and accuracy, as can be achieved by a manned station network. According to the *Manual on the Global Observing System* (WMO-No. 544), Volume I, Part III, 3.1.10, automatic stations should be inspected not less than once every six months.

Detailed information on automatic stations can be found in 3.2.1.4 of the present Guide and in the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part II, Chapter 1.

For reasons of compatibility and homogeneity of data generated by automatic stations with similar data from manned stations, the responsibility for the management of an automatic station network should rest with the same organizational unit or units within the meteorological authority in charge of the management of manned station networks. The main aim should be to implement a composite observing system of consistent quality at global, regional and national levels.

3.1.4.2 Administrative arrangements

The station network management unit should have access to all technical details of the configuration and the sensor files for each automatic station installed in an operational network.

Experience in operational system evaluations and scientific networks studies have shown that the preparation of national operating instructions for weather stations equipped with devices for automatic data acquisition is essential for the satisfactory employment of new components such as automatic weather stations.

In view of the special position of an automatic weather station within the flow of data from the observing site to the national data-processing centre, many system features must be taken into account when preparing the necessary guidance material.

Since the technology used at automatic weather stations is changing rapidly, more emphasis should be placed on new areas of automation, for example, in the field of data acquisition, processing and local archiving techniques for meteorological measurements. In an automated system, a large

number of different algorithms are used to define the quality control routines: to evaluate with appropriate smoothing the physical quantities from the digital measurements and translate the resulting list of measured quantities into the WMO code format. International standardization remains to be achieved.

3.1.4.3 Operational tasks of the automatic station network supervising unit

The operational tasks of the network supervising unit may vary according to the type of automatic station used.

(a) Supervision of a semi-automatic station network

As with manned station networks, instructions on the observation of standard procedures must be prepared and strictly followed by the personnel in charge. The instructions should include guidance on the operation of instrumentation and on preventive maintenance measures and, where feasible, may include small repairs of some automatic instrumentation or sensors carried out at observing sites. The unit should perform regular inspections of these stations in order to check the operation of automatic instruments or sensors.

Where appropriate, a diagnostic check of the operation can be carried out together with the data quality control at the national data-collection centre. Information on possible malfunctioning should be transmitted as soon as possible to the maintenance experts (see also 3.1.3.14).

(b) Supervision of a fully automatic station network

Since the technology used in automatic surface observing systems is complicated, the unit may need to consult specialists in order to address various problems in electronics, software, telecommunications and sensor engineering. It is useful for the unit to be involved in network management from the initial stages of its deployment starting with delivery, site preparation, check-out and activation. The unit should have access to all documentation concerning equipment, system configuration, site specification, software system and engineering services.

To ensure the reliability of sensors, data-acquisition systems and data quality, the staff should be provided with guidance material on manned and automatic test requirements. Equipment control procedures for remote automatic tests

may include duty-checks performed on a daily basis. Nevertheless, regular on-site instrument field tests and inspections are needed to guarantee proper functioning of the automatic station network.

The unit should provide engineering support for the operation of the network and guidance material to the technical staff. Likely system modifications, additions and site relocations in the future also require engineering support and in some cases revised operational software versions. Operational tasks of the automatic station network supervising unit also include the organization of training courses. (See 3.1.3.5.)

3.2 SURFACE SYNOPTIC STATIONS

3.2.1 Organizational aspects

3.2.1.1 General

Surface synoptic stations may be on land or at sea, manned or automatic. For the purpose of the present Guide, surface synoptic stations are dealt with under three categories, namely land stations, sea stations and automatic stations.

The establishment of a network of stations, their operation in accordance with prescribed standards and their maintenance involve many questions of an organizational nature of varying degrees of complexity, depending on the type of station, its location, functions, instrumental equipment, communication links for data transmission and requirement for trained personnel of different levels. The broad aspects of such questions, as they apply to each type of station falling under the three surface synoptic station categories referred to above, are discussed in 3.2.1.2, 3.2.1.3 and 3.2.1.4 below.

3.2.1.2 Land stations³

3.2.1.2.1 Station siting or location

Each station making surface synoptic observations should be located at a site where the meteorological data obtained are representative of the state of the

atmosphere over a large region. The dimensions of this region, or area of representativity, may range from 2 000 km² to 10 000 km² for a plane or homogeneous relief.

The station should have a plot of land specially assigned to it. The optimum area is approximately 1 ha.

The location of the observing posts, or meteorological instrument areas, should be typical of geographical conditions of the surrounding area and protected from the influence of industry. Therefore, a meteorological instrument area should be located in an open site far from any constructions or woods. The minimum distance from constructions and groups of trees should be greater than 10 and 20 times their heights, respectively. The site should also be farther than 100 m from bodies of water, except where coastal measurements are required.

3.2.1.2.2 Meteorological observing area

The meteorological observing area is where most of the instruments and devices are situated. Where there are many installations, the observing area should ideally be no smaller than 25 m × 25 m, but in cases where there are relatively few installations, as in Figure III.1, the area may be considerably smaller. The sides of the observing area should be oriented north-south and east-west. An adequate north-south dimension is very important for measurements which can be strongly influenced by shadow, for example, radiation, sunshine duration and temperature gradients just below and above the ground.

The instruments and equipment should be set out in a definite order, in several rows or lines. In the northern hemisphere the sensors are arranged as follows: wind-measuring equipment on the north side, along with temperature and humidity equipment, then a row of precipitation gauges with soil temperature measurement taking place in the southern part of the observing area. Figure III.1 provides an example of the layout of an observing station in the northern hemisphere showing minimum distances between installations.

The meteorological observing area should be surrounded by open fencing or palings to keep out unauthorized persons. In the Arctic, desert and certain other regions the observing area may not need to be fenced and may simply be marked.

³ The requirements for station siting and instrument exposure given in this section apply to an "ideal" situation, which should be attained where possible. It is understood that these requirements cannot always be fully met for one reason or another.

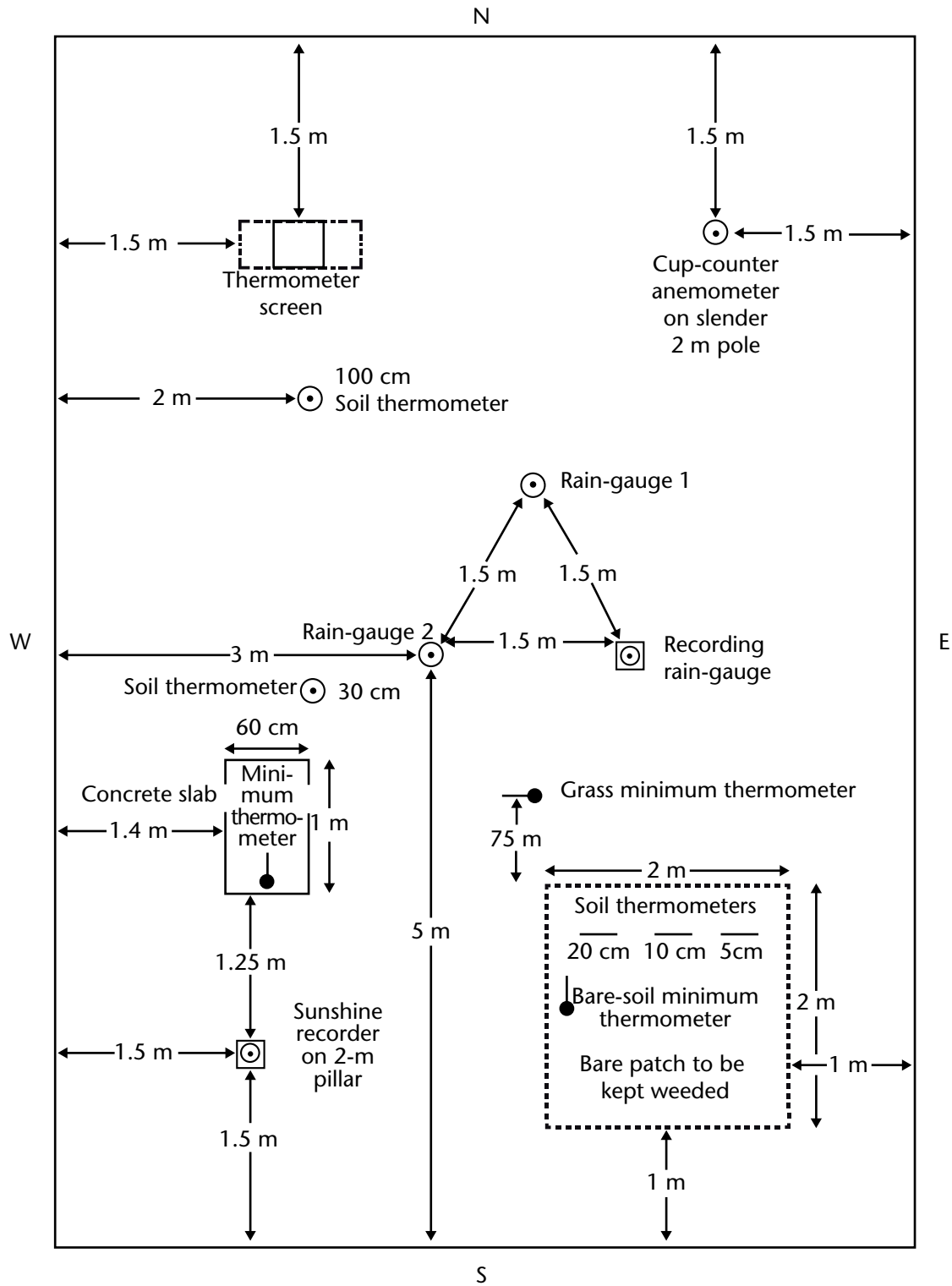


Figure III.1. Layout of an observing station in the northern hemisphere showing minimum distances between installations

Source: *The Observer's Handbook*, Meteorological Office, United Kingdom, 1982

The observing area surface must be left in its natural state, and grass should be kept down to 20 cm. The area should not be walked on except along paths or tracks. Paths should not be of asphalt or concrete. In the interest of safety, the electrical voltage supplied to the equipment shall not exceed 24 or 36 volts. Installations should preferably be painted white; any other colour may be used for masts and fencing.

If the area covers one or more hectares, special protected zones extending about 200 m in all directions from the boundaries of the station area should be provided around the plots. Where possible, these zones should be left unchanged and their use shall be agreed with the National Meteorological Service.

Particular attention should be given to the following points in selecting the site for the measurement of precipitation:

- (a) Any precipitation-measuring method should aim at obtaining a sample representative of the true amount falling over the area that the measurement is intended to represent. The site choice and systematic measurement error are therefore important;
- (b) The systematic wind field deformation above an elevated gauge orifice, as well as the effects of the site itself on the air trajectories, should be considered when choosing a site;
- (c) For each site, the average vertical angle of obstacles should be estimated, and a site plan made. Sites on a slope or roof should be avoided. The surface surrounding the precipitation gauge can be covered with short grass or gravel or shingle, but hard flat surfaces, such as concrete should be avoided to prevent excessive in-splashing;
- (d) In areas where there is homogeneous dense vegetation, such vegetation should be clipped regularly to keep it at the same level as the gauge orifice;
- (e) Sites selected for measurement of snowfall and/or snow cover should be sheltered from the wind as much as possible. The best sites are often found in clearings within forests or orchards, among trees, in scrub or shrub forests, or where other objects act as an effective windbreak for winds from all directions.

Further information on siting and exposure can be found in 1.1.2 and 1.3.3.1, Chapter 1, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.2.1.2.3 *Observatory premises*

To ensure normal operations, each station should be provided with premises suitable for the working staff, with optimum floor space, heating and/or cooling system as required, safety and fire-fighting equipment and an emergency electricity supply.

3.2.1.2.4 *Observing station staff*

Every station must be provided with personnel whose number and functions are established in conformity with the Member's regulations and standards, taking into account the observation programme and other work carried out by the particular station. The work at land stations should preferably not be interrupted between the observation times.

A station working around the clock to collect and transmit emergency information on dangerous weather phenomena, in addition to the standard observations carried out at the eight synoptic times, usually has a staff of five. For a station that only carries out observations at the eight synoptic times and is not continuously attended, three are sufficient.

Official staff titles, such as senior technician, technician, senior observer and observer, are determined by the type and importance of the data gathered by the station, the degree of complexity of the measuring equipment used, staff duties and National Meteorological Service practice.

Observers who are not full-time officials of a National Meteorological Service but are designated to make meteorological observations at any synoptic station shall be certified by the appropriate Service as having a sound knowledge of observing instructions and being capable of observing meteorological variables with the accuracy required. Similarly, the National Meteorological Service should certify the competence of any other observers who are responsible for meteorological observations.

3.2.1.2.5 *Station staff training*

Each station should be provided with trained personnel according to the WMO classification scheme; for more details, see the *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology* (WMO-No. 258). Training of meteorological staff and other specialists for work at the station is arranged by the

Member within the country, or appropriate courses are sought abroad. In addition to the original training in the area of specialization, staff should undergo periodic refresher courses to maintain their efficiency. General and specific staff training guidelines are contained in relevant WMO publications, for example, the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part III, Chapter 5.

In order to ensure reliable observations and information, it is recommended that the observing personnel be trained at the following levels:

- (a) Chiefs of meteorological stations making standard observations (see 3.2.2): intermediate specialized training (completion of a technical college or equivalent);
- (b) Technicians selected amongst the most experienced of the junior technicians or observers: same as above;
- (c) Junior technicians or observers: special training or courses at special schools lasting no less than six months.

Notes:

1. Up to two observers can be trained on the job at the station itself (for no less than one month), preferably with subsequent training provided by courses at special training centres or by correspondence.
2. For a description of the classification of meteorological personnel and their duties, see *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology* (WMO-No. 258).

Stations should be provided with all necessary documentation, manuals, guides, other instructions and guidelines to which all staff should have access, and which they should study regularly.

3.2.1.2.6 *Station identification*

A surface station included in the regional basic synoptic network shall be identified by a station index number assigned by the relevant Member in compliance with the scheme set out in the *Manual on Codes* (WMO-No. 306), Volume I.1, Part A. The list of station index numbers, observing programmes and other relevant information is published by the WMO Secretariat in *Weather Reporting* (WMO-No. 9), Volume A – Observing stations.

Each Member operating synoptic stations is required to provide the WMO Secretariat with the necessary information for this purpose in compliance with the regulations laid down in the *Manual on the Global Observing System* (WMO-No. 544), Volume I, Part III, 2.3.2.

Each Member should keep an up-to-date list, or directory, of the synoptic stations on its territory, providing the following information for each station:

- (a) Name, and where appropriate, station index number;
- (b) Geographical coordinates with a resolution of 1 in 1 000;⁴
- (c) Elevation of the station in whole metres, elevation of barometer above sea level;
- (d) Geopotential of the datum level in whole metres to which the pressure is reduced, or the reference isobaric surface the geopotential of which is reported;
- (e) Category of the station and observing programme;
- (f) Times at which synoptic observations are made and reported;
- (g) Brief description of surrounding topography;
- (h) Instrument exposure, in particular height above ground of thermometers, rain-gauges and anemometers;
- (i) Station history: date regular observations were initiated, transfers, interruptions in observations, name changes and any substantial changes made to the observing programme;
- (j) Name of supervising organization or institution;
- (k) Any other information required for completion of the entries in *Weather Reporting* (WMO-No. 9), Volume A – Observing stations.

3.2.1.2.7 *Telecommunications*

All stations shall be provided with means of telecommunication to transmit their data as fast as possible to meet the needs of forecasting services (global, regional and national requirements), and of local users, on a permanent basis and on request. The equipment used at the stations to transmit and receive information may be of various kinds, including telephone, telegraph and radio. General and specific guidelines on the collection and transmission of information are contained in the *Manual on the Global Telecommunication System* (WMO-No. 386).

Each synoptic station whose reports are included in the list for international exchange shall be provided with such telecommunication equipment as will guarantee regular and reliable transmission of the necessary reports and other information to the established addressees of messages.

⁴ See *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part I, Chapter 1, 1.3.3.2.

3.2.1.2.8 **Quality standards**

Reference should be made to:

- (a) *Manual on the Global Data-processing and Forecasting System* (WMO-No. 485), Part II, 2.1.3 – Minimum standards;
- (b) *Guide on the Global Data-processing System* (WMO-No. 305), Chapter 6.

3.2.1.3 **Sea stations**

3.2.1.3.1 **General**

About 70 per cent of the Earth's surface is covered by the oceans. Obtaining regular and adequate meteorological and oceanographic information from these vast areas is an important task because timely and precise weather forecasts and services for marine interests depend heavily on observations from the oceans.

3.2.1.3.2 **Fixed sea stations**

3.2.1.3.2.1 Ocean weather stations

(a) General

Ocean weather stations are the most sophisticated of the meteorological sea stations. Owing to high costs, ocean weather station networks are generally organized as a joint project of participating Members, individual Members being responsible for operating the ships from national harbours. An example is the North Atlantic Ocean Stations network, which is operated on this basis under WMO auspices.

(b) Station design

An ocean weather station consists of a ship specially built or refurbished for that purpose. To keep a continuous observing programme at a certain location, more than one ship is needed. The ship must have deck space for launching balloons for upper-air observations and adequate space for meteorological instruments. There must also be space for supplies and expendables for 30 to 40 days with the safety measures necessitated by the use of hydrogen. The main storage area should, however, be located in the harbour from which the ship operates. The ship must have sufficient accommodation for the crew and meteorological personnel.

The variables comprising a surface synoptic observation from an ocean weather station are listed in 2.3.3.11, Volume I, Part III, of the *Manual on the Global Observing System* (WMO-No. 544) and many of them are the same as for land stations given elsewhere in this Guide (see 3.2.2.2). For sea stations, there are different ways of obtaining the

meteorological variables in some cases. Generally, meteorological instrument exposure may be more difficult for sea stations because of the limited area and the influence of the superstructure of a ship or other installations. Figure III.2 offers information on where to expose different instruments.

(c) Site selection

Station positions should be chosen in the best interests of the National Meteorological Services and the Global Observing System. The harbours from which the ships operate should be chosen in such a way as to minimize the distance to the positions they occupy during operation at sea.

(d) Operations

National Meteorological Services operating the ships should be responsible for technical and scientific standards and calibration and maintenance of the instruments on board. A supervisor from the National Meteorological Service should ensure that all observational work is done efficiently and in accordance with the regulations. He or she should also ensure that the personnel are properly trained and that all relevant manuals and other documents are available to the personnel.

(e) Identification

The ocean weather stations—ships—shall be identified by an alphanumeric name assigned to the station position, not the name of the individual ship, for example, C7R.

(f) Communications

The types of equipment suitable for timely data transmission from ocean weather stations can include the following:

- (i) Interface with public communication networks;
- (ii) Telegraphs;
- (iii) Telex typewriters;
- (iv) Radioteleprinters;
- (v) Radio facsimile broadcasts;
- (vi) Radios;
- (vii) Global system for mobile communication;
- (viii) Satellites.

There should be at least one alternative in case of failure or disruption of the primary link.

(g) Personnel and training

Three types of personnel are needed to operate ocean weather ships:

- (i) Ship's crew;
- (ii) Meteorological personnel (observers and technicians);
- (iii) Telecommunication personnel.

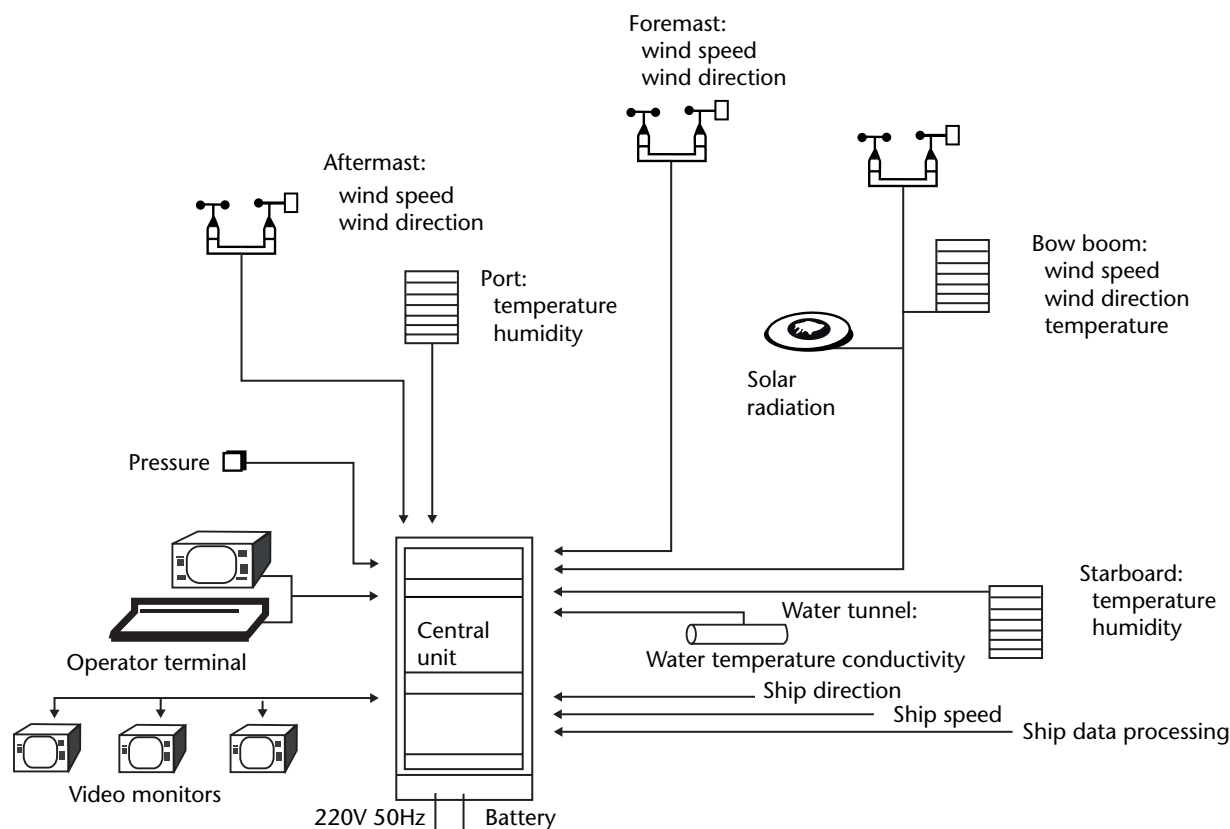


Figure III.2. Instrument exposure on an ocean weather station in Vaisala Oy, Finland

The number of staff in (ii) and (iii) depends upon the equipment used and the level of expertise required. Observers can be given the responsibility to carry out the data dissemination procedure over the GTS. If given adequate training, they can also be responsible for the operation and maintenance of the equipment on board.

Using the ordinary crew as observers or operators under an experienced meteorological supervisor has proved, at least for one of the North Atlantic Ocean Stations, to be a very efficient way to reduce operating costs. Some of the crew members must then be properly trained to make the observations. The number of people required to operate an ocean weather ship may be reduced considerably in this manner.

(h) Quality standards

Reference should be made to the *Guide to the Applications of Marine Climatology* (WMO-No. 781), 3.1.4 – Quality control, processing and archiving data, Appendix I – Minimum Quality Control Standards; the *Guide to Marine Meteorological Services* (WMO-No. 471), 3.2.9 – Quality control, Annex 3E – Minimum Quality Control Standards;

the *Manual on Marine Meteorological Services* (WMO-No. 558), Volume I, 5.6.3 – Quality control of data and Appendix I.15, Minimum Quality Control Standards; and the *Manual of Quality Control Procedures for Validation of Oceanographic Data*, Manuals and Guides, No. 26, UNESCO.

3.2.1.3.2.2 Lightship stations, island and coastal stations

(a) General

These stations may be important for the regional basic synoptic network and the global network. Members should take this into consideration when planning and maintaining their national network of such stations.

(b) Station design

A lightship station is a meteorological observing station on board a lightship whose primary function is to serve as a lighthouse in coastal waters. The meteorological instruments must be properly exposed, generally in accordance with the rules given in the section dealing with ocean weather stations. Care should be taken to avoid influence of the lightship's special superstructure.

Island and coastal stations should be equipped in the same way as a land station. In addition, the stations should be able to measure sea-surface temperature and observe the state of the sea and sea-ice conditions. They could also be designed to make upper-air observations.

(c) Site selection

The siting of island and coastal stations should be made in accordance with the rules given elsewhere in this Guide for land stations (3.2.1.2.1 and 3.2.1.2.2). In addition, care should be taken to ensure the observation of the state of the sea and the sea-surface temperature.

(d) Operations

National Meteorological Services shall operate or be responsible for the stations' technical standards, and for instrument calibration and maintenance. A National Meteorological Service supervisor should ensure that the personnel have proper training and that all relevant manuals and other documents are available at the stations.

(e) Identification

Island and coastal stations shall be identified by a station index number, as for land stations (see 3.2.1.2.6). Lightship stations are moored in fixed positions and may be also identified by a station index number.

(f) Communications

The stations shall be provided with appropriate telecommunication equipment that will guarantee a regular and reliable transmission of the coded reports. (See 3.2.1.2.7 dealing with telecommunications for land stations.)

(g) Personnel and training

The personnel required for surface synoptic observations at island and coastal stations are the same as for land stations for similar observations. If, however, both surface and upper-air observations are carried out, the staff must be large enough and properly trained for both types of observation. A supervisor must ensure that the operational personnel have the necessary qualifications for the service, including normal technical maintenance at the station and communication procedures (see also 3.2.1.2.4 and 3.2.1.2.5).

3.2.1.3.2.3 Fixed platform stations and anchored platform stations

(a) General

The offshore oil industry operates more or less permanently rigs and platforms on the continental shelf all over the globe. Platforms for oil drilling or

production may serve as excellent sites for observations of meteorological variables and Members should take advantage of them. Observations are needed by the platform operators to monitor weather conditions on and near the platforms during helicopter and supply ship operations. Operators of offshore platforms are generally required by the regulations laid down by individual countries to make reliable surface observations of at least some meteorological and oceanographic variables. Cooperative arrangements can readily be made with this industry.

(b) Station design

Meteorological instrument exposure is very important and the most difficult part of instrumentation on platforms, owing to the size and the structure of the platform, which may be more than 100 m above sea level.

(c) Operations

Care should be taken that the instrumentation and control of the observations remain the responsibility of the National Meteorological Service. It is essential that the standard practices defined by WMO be followed. Observers must be trained by the National Meteorological Service to make manual observations. Adequate technical expertise in automatic instruments should be available on board. The supervisor must ensure that all observational work is done according to WMO regulations and that relevant documentation is available.

(d) Identification

Fixed and anchored platform stations are identified as ships and included in the *International List of Selected, Supplementary and Auxiliary Ships* (WMO-No. 47) and contain appropriate explanatory notes.

(e) Communications

The types of equipment appropriate for timely transmission of observational data from platforms and rigs are:

- (i) Interface with public communication networks;
- (ii) Telegraphs;
- (iii) Telex typewriters;
- (iv) Radioteleprinters;
- (v) Radio facsimile broadcasts;
- (vi) Radios;
- (vii) Global system for mobile communication;
- (viii) Satellites.

There should be at least one alternative in case of failure of the primary link.

(f) Personnel and training

The number of personnel required depends on the degree of automation. A good general education, such as that for naval officers, is required. The observers should attend a theoretical and practical course administered by the National Meteorological Service. The course should comprise:

- (i) A general presentation of the relevant regulations and guidelines of WMO and of the National Meteorological Service;
- (ii) Instruments for use at sea;
- (iii) Visual observing techniques;
- (iv) Lectures on the weather and weather forecasting for the particular area of responsibility.

3.2.1.3.3 *Mobile sea stations*

3.2.1.3.3.1 Selected, supplementary and auxiliary ships

Mobile sea stations are composed of selected ship stations, supplementary ship stations, auxiliary ship stations and ice-floe stations (the latter is discussed in 3.2.1.3.4). Mobile ships are one of the main sources of surface observations over the oceans. The *Manual on the Global Observing System* (WMO-No. 544), Volume I, specifies that Members shall recruit as many mobile ships that traverse data-sparse areas and/or regularly follow routes through areas of particular interest as possible. The international scheme by which ships are recruited for making and transmitting meteorological information is called the WMO Voluntary Observing Ships Scheme. Relevant standards and recommended practices and procedures are contained in the *Guide to Marine Meteorological Services* (WMO-No. 471).

In accordance with the *Technical Regulations* (WMO-No. 49), each Member shall arrange for the recruitment of ships which are on the national register of that Member as mobile ship stations. By fulfilling this obligation, each Member contributes to the common objective of obtaining sufficient coverage of meteorological observations over the sea. Uniform coverage is desirable, albeit difficult to achieve, owing to large differences in the density of shipping traffic over the oceans that is comparatively greater in the northern hemisphere. Consequently, greater attention should be given to the recruitment of voluntary observing ships which operate in the tropics or in the southern hemisphere. To meet international meteorological requirements for data density over the oceans, successive plans under the World Weather Watch have shown the need for maintaining or increasing the number of voluntary observing ships.

The ships engaged in the WMO Voluntary Observing Ships Scheme are classified as follows:

- (a) Selected ship stations;
- (b) Supplementary ship stations;
- (c) Auxiliary ship stations.

For details, please refer to *International Meteorological Vocabulary* (WMO-No. 182), the *Manual on the Global Observing System* (WMO-No. 544), Part III, 2.3.3.12–2.3.3.14) and JCOMM Technical Report No. 4, *The Voluntary Observing Ships Scheme—A Framework Document* (WMO/TD-No. 1009).

A supplementary ship station is a mobile ship station with a limited number of certified meteorological instruments for making surface observations. It transmits weather reports in an abbreviated SHIP code form. (See 2.3.3.13 of the *Manual on the Global Observing System* (WMO-No. 544), Volume I, Part III.)

An auxiliary ship station is a mobile ship station, normally without certified meteorological instruments, which may transmit reports in a reduced code form in plain language as a routine or on request, in certain areas or under certain conditions. (See 2.3.3.14 of the *Manual on the Global Observing System* (WMO-No. 544), Volume I, Part III.)

Meteorological Services in many countries are generally required to provide more detailed information on the weather and sea conditions in coastal areas. Some Services have successfully recruited ships of local companies to make and transmit observations during their voyage from harbour to harbour along the coast. Such ships may be recruited as supplementary or auxiliary ships. Their observations have been found to be of great value everywhere.

3.2.1.3.3.2 Criteria for recruitment of voluntary observing ships

Several criteria can be used to decide whether a particular ship should be recruited as a selected, supplementary or auxiliary ship to meet national and international needs. The following points should be explored: whether all the necessary instruments can be installed, whether the ship's officers will have time to record and transmit the observations and whether the necessary regular contact can be established for the receipt of meteorological log-books. Generally, shipowners and masters are very cooperative in these matters; it is, however, advisable that these questions be thoroughly discussed at the recruiting stage. At the same time, the meteorological authorities must decide whether the standard duties of navigation and radio

officers would leave them sufficient time to conduct and transmit the observations.

Countries may also recruit ships of foreign registry with a view to obtaining a sufficient number of observations from the oceans. This is sometimes done by arrangement between the Meteorological Services of two countries in cases where the home port of certain ships is situated in other than the recruiting country. Selected or supplementary ships thus recruited should, however, visit the ports of the recruiting country often enough to permit regular contact. In order to avoid the entry of duplicate data into the international archiving system, meteorological log-books from ships registered in a foreign country should be produced and stored through appropriate arrangements with the Meteorological Service of the country of registry. When a ship of foreign registry is recruited, the Member in whose country the ship is registered should be notified, unless a port in the country of the Member that recruits the ship is considered to be its home port.

No prior arrangements are required with the Meteorological Service of the country of registry for the recruitment of an auxiliary ship.

The recruitment of voluntary observing ships is the responsibility of each Member participating in the scheme, and for this purpose Members should establish a suitable organizational unit. Shipping agencies should be contacted to enlist their cooperation. Appropriate measures should also be taken for the provision of instruments, instruction material and other necessary documents to ships, for the collection and examination of ships log-books for visits to ships and for the various financial questions involved. A special officer within this national unit should be made responsible for ship recruitment.

3.2.1.3.3.3 Information relating to ships participating in the WMO Voluntary Observing Ships Scheme

(a) International list of selected, supplementary and auxiliary ships

This list is an important source of marine data that is used for various purposes all over the world. In analysing these data, Meteorological Services should be aware of the type of instrumentation on board a given ship, or of a particular observing method when several methods are generally in use. For this purpose WMO issues the annual *International List of Selected, Supplementary and Auxiliary Ships* (WMO-No. 47) on the basis of information supplied by Members in accordance with 2.3.3.3 and 2.3.3.4 of the *Manual on the Global Observing System* (WMO-No. 544),

Volume I, Part III. This publication contains particulars for each ship such as:

- (i) Recruiting country;
- (ii) Metadata format version;
- (iii) Date of report preparation;
- (iv) Name of ship;
- (v) Country of registration;
- (vi) Call sign or WMO number;
- (vii) International Maritime Organization number;
- (viii) Vessel type;
- (ix) Vessel digital image;
- (x) Ship characteristics (length, moulded breadth, freeboard, draught, cargo height, distance of bridge from bow);
- (xi) Area or routes which the ship normally plies;
- (xii) Type of barometer;
- (xiii) Type of thermometer;
- (xiv) Thermometer exposure;
- (xv) Type and exposure of hygrometer or psychrometer;
- (xvi) Method of obtaining sea-surface temperature;
- (xvii) Various other meteorological instruments used aboard the ship;
- (xviii) Height, in metres, of the instruments above (or below, e.g. for sea-surface temperature) the maximum Summer load line;
- (ix) Height, in metres, of the anemometer above the maximum Summer load line and above the deck on which it is installed.

The International List of Selected, Supplementary and Auxiliary ships (WMO-No. 47) should be updated regularly, owing to the frequent changes in the international merchant shipping fleet and in the recruitment of auxiliary ships, in particular. As a rule, Members are required to provide on a quarterly basis, namely by 15 January, 15 April, 15 July and 15 October each year, to the WMO Secretariat a complete list of their selected, supplementary and auxiliary ships that were in operation at the end of the quarter in question. This information can also be given in the form of amendments to the list for the preceding year.

(b) Logistics

Some advice on how to handle the recruitment and operation of mobile ship observations through a national unit is given above. In addition, in larger ports, a port meteorological officer should be appointed to liaise directly with the ships' officers. This is often necessary in order to provide the latter with manuals and other documents, inspect the instruments on board, collect the log-books, or the data from the electronic log-books and to take any necessary corrective action. Port meteorological

officers play a very important role and the efficiency of the Voluntary Observing Ships Scheme is heavily dependent on them. Their duties are set out in detail in the *Guide to Marine Meteorological Services* (WMO-No. 471).

(c) Meteorological log-books

The recording of observations in a meteorological log-book or electronic log-book is obligatory for selected and supplementary ships and recommended for auxiliary ships. The layout of log-books is a national responsibility. An example of a log-book is given in Figure III.3. Log-books should contain clear instructions for entering observations. It is useful, for example, to indicate by shading those columns which are meant for entries to be transmitted as part of the weather report. To facilitate the supply of meteorological log-books to ships which do not regularly call on their home ports, port meteorological officers in various ports keep a stock of log-books of different National Meteorological Services. In addition, they may keep stocks of observing and coding instructions in different languages.

(d) Communications

Weather reports from mobile ship stations should be transmitted to a coastal radio station as soon as possible after the time of observation; hence the meteorological report, as soon as it is made on board ship, should be handed to the ship's radio officer without delay so that it can be cleared to shore as rapidly as possible. Regulations for the transmission of weather reports from mobile ship stations to designated coastal radio stations are given in the *Manual on the Global Telecommunication System* (WMO-No. 386), Volume I, Part I, Attachment I-1. The relevant procedures are reproduced below for ready reference. Weather reports from mobile ship stations should be transmitted without special request from the ship to the nearest coastal radio station situated in the zone in which the ship is navigating. If it is difficult to contact promptly the nearest radio station in the zone in which the ship is navigating owing to radio propagation conditions or other circumstances, the weather messages should be cleared by following the procedures in the order given below:

- (i) Transmission to any other coastal radio station in the zone in which the ship is navigating;
- (ii) Transmission to any coastal radio station in an adjacent zone within the same Region;
- (iii) Transmission to any coastal radio station in any other zone within the same Region;
- (iv) Transmission to a coastal radio station in an adjacent zone in a neighbouring

Region or, failing that, to any other station in a neighbouring Region;

- (v) Transmission to another ship or an ocean weather station with the function of or willing to act as a relay station. Maritime mobile radio systems used for ship-to-shore communications as above can cause problems, for various reasons of a technical nature, in the collection of ships' weather reports for subsequent distribution over the Global Telecommunication System. The use of new communication techniques, especially through satellites, offers a promising solution to these problems. Special mention may be made of the system known as INMARSAT, designed for full communication capability for public ship-to-shore communication. The use of this system has, however, important technical and financial implications for National Meteorological Services, and WMO has been studying them. Other satellite data telecommunication systems are now also being used in a cost-effective way.

(e) Personnel and training

An essential step in recruiting voluntary observers for ships' observations is to obtain the permission of the owner and the master of the ship. When this has been done and the observer(s) identified, the port meteorological officer provides instructions in the following areas:

- (i) General care of instruments;
- (ii) Exposure and reading of hygrometer and psychrometer;
- (iii) Obtaining sea-water temperatures;
- (iv) Cloud observations;
- (v) Use of WMO codes;
- (vi) Coding and transmission of observations.

Once a ship has been recruited, the port meteorological officer should endeavour to visit it at least every three months to check instrument accuracy and renew supplies of forms and documents, for example, codes and regulations. The officer should take the opportunity to foster an interest in meteorology in the crew members concerned and explain to them the mutual value of accurate weather information to seafarers and meteorologists.

3.2.1.3.4 *Ice-floe stations*

(a) General

An ice-floe station is generally a part of a scientific base on a large ice floe drifting in the polar regions. Such stations make an important contribution to the network in data-sparse polar regions.

Members, individually or jointly, should arrange for meteorological observations from large ice floes whenever possible, either as part of the programme of a scientific base or as an automatic station. In the case of a joint undertaking, one National Meteorological Service should have the responsibility for the station's scientific and technical standards.

(b) Identification

Identification of ice-floe stations shall be the same as for ships.

(c) Communications

Ice-floe stations should have two-way radio connections or automatic transmission via satellite. In the polar regions, only polar-orbiting satellites can be used. The ARGOS system operated with some of the US satellites offers this possibility, and the use of the Doppler effect in the receiver signals makes it possible to locate the station fairly accurately. Using polar-orbiting satellites as a means of communication may give asynoptic reporting times.

(d) Personnel and training

A sufficient number of the staff on the ice-floe base must have adequate training for taking all the required observations in accordance with WMO regulations. At least one trained technician should be available to operate and maintain the instruments and be responsible for the supply of expendables and back-up equipment. The staff must also include personnel to operate the communications system.

3.2.1.4 Automatic stations

3.2.1.4.1 General

An automatic weather station is defined in *International Meteorological Vocabulary* (WMO-No. 182) as a "meteorological station at which observations are made and transmitted automatically".

The following information in this section of the Guide deals with the planning and establishment of real-time networks of automatic stations that are part of the regional basic synoptic networks and other synoptic station networks where the emphasis is on quick and direct access to the data.

Complementary information can be found in Chapter 1, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.2.1.4.2 Purposes of automatic stations

Automatic stations are used for many purposes. These include:

- (a) Providing data from sites that are difficult to access or are inhospitable;
- (b) Providing observations at manned stations outside the normal working hours of the observing staff, for instance during the night or on weekends;
- (c) Increasing the reliability of the data and standardizing observing methods and timing for all network stations;
- (d) Cutting costs by reducing the number of manned stations;
- (e) Placing sensors in meteorologically favourable sites apart from the places of residence and work of the observer.

3.2.1.4.3 Types of automatic synoptic networks and stations

3.2.1.4.3.1 Network configuration

Automatic synoptic networks need real-time operation for data collection, transmission and processing. Stations can be organized within a network in different ways. Data collection is directly controlled by a single data processor at a central data collection point or by several data processors at sub-central data collection points which periodically collect the data from the stations and distribute them (see Figure III.4). Sub-central data acquisition processors are suited to large networks when a regionalization of the control and processing functions seems to be an advantage. The use of a single processor to service a network makes the entire automatic observing system vulnerable to a failure of this processor.

The data-transmission facilities offered by automatic synoptic networks can also be used, if necessary, by manned or partially automated stations, provided the observers have adequate terminals for manual observation input. These terminals may be used to enter synoptic data, coded or in parameter form, or climatological information. The network central processor collects the observations directly or together with the automatic measurements via the automatic stations (Figure III.5).

3.2.1.4.3.2 Data processing

The major part of data processing or coding is accomplished either at the station site or at a sub-central or single central processor site.

The main advantage of a central data processing facility is that quality control, real-time computation and data conversion are performed at a single place. Furthermore, synoptic code changes can be

For office use only	Sea temperature		Wind waves		Swell waves		Ice accretion				Ice		Remarks							
	15	16	18	19	20	21	22	23	22	23	22	23								
Section indicator	D _s	T _w T _w T _w	P _w P _w P _w	d _{w1} d _{w2}	P _{w1} P _{w1} P _{w1}	P _{w2} P _{w2} P _{w2}	Is	E _s E _s E _s	ICE	C _i S _i D _i	ICE	C _i S _i D _i	Shifts of wind, times of start and finish of rainfall, etc. Special phenomena should be entered briefly. Space for additional remarks is provided at the end of this log-book. The Beaufort notation shown in Table III.2 may be used in this column. Call sign to which sent, frequency (kHz) used and time sent (GMT)							
222	00	0	2	3	4	5	6		ICE		ICE									
06	222	0	2	3	4	5	6		ICE		ICE									
12	222	0	2	3	4	5	6		ICE		ICE									
18	222	0	2	3	4	5	6		ICE		ICE									
00	222	0	2	3	4	5	6		ICE		ICE									
06	222	0	2	3	4	5	6		ICE		ICE									
12	222	0	2	3	4	5	6		ICE		ICE									
18	222	0	2	3	4	5	6		ICE		ICE									
00	222	0	2	3	4	5	6		ICE		ICE									
06	222	0	2	3	4	5	6		ICE		ICE									
12	222	0	2	3	4	5	6		ICE		ICE									
18	222	0	2	3	4	5	6		ICE		ICE									
34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54

Figure III.3. Example of a meteorological log-book for ships (continued)

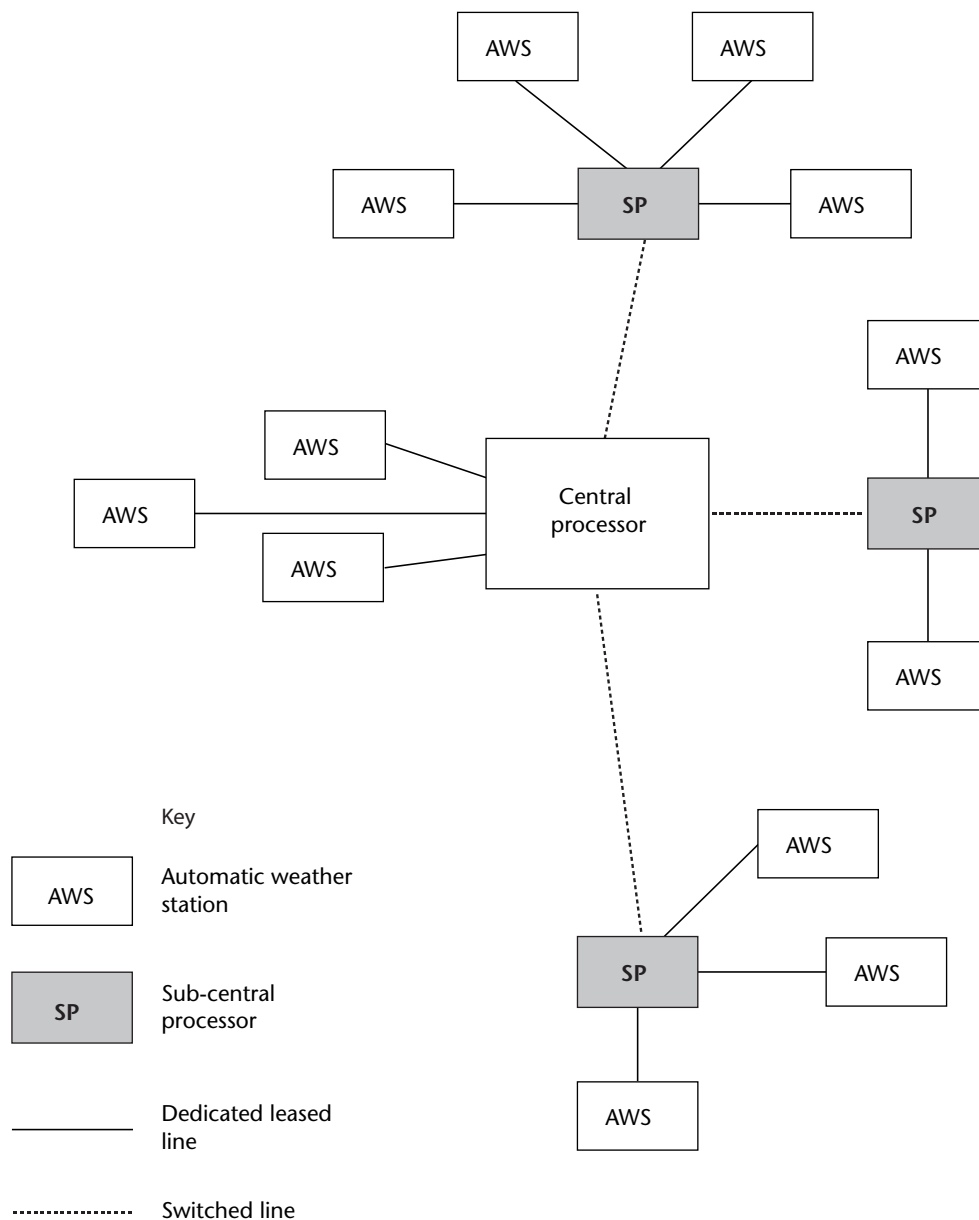


Figure III.4. Network configuration

Source: Branke, W., 1978: System technology for networks, Technical Seminar for Measuring Techniques, Automation and Data Processing for Water Control, May 1978, Bayerisches Landesamt für Wasserwirtschaft

implemented for all stations at once with only one modification; a single station can be modified and maintained without altering the standard codes. Moreover, this concept offers an important advantage to the data user, who can analyse the instrumental problems with the raw sensor data directly from the central site and can plan repair work more efficiently. Data transmission is a vital function for real-time synoptic stations. For more details see the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part II, Chapter 1, 1.3.2.10.

3.2.1.4.3.3 Multi-purpose stations

Since the costs of automatic synoptic stations are very high, it seems judicious to use the station facilities for other purposes as well, for instance, to meet the needs of climatology, aeronautical meteorology, storm warnings, nuclear power safety, air and water quality surveys and flood warnings.

For such multi-purpose stations, the data may be stored continuously on local storage units. Thus, the data can be retransmitted to the network

central processor after an interruption or processed at a later date on a separate computer system.

3.2.1.4.3.4 Sensors

The sensors for use with automatic weather stations for the measurement of the different variables and their performance are described in 1.2.1, Chapter 1, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.2.1.4.4 Planning guidance

3.2.1.4.4.1 Determination of requirements

All disciplines involved with meteorological observations—synoptic meteorology, climatology, aeronautical meteorology, agricultural meteorology,

and hydrology—have formulated their own functional requirements for observations to satisfy their specific service needs. All disciplines, however, agreed that it was beneficial to apply universal rules or standard methods of observation in order to avoid unnecessary confusion and achieve data compatibility. In line with this policy, standardization of automatic weather stations will be beneficial if designed to fulfil the requirements of the various disciplines.

To support present and future automatic weather station applications, functional specifications—a list of required meteorological variables and their characteristics—for automatic weather stations were developed (see Appendix III.1). They show current users' requirements for data reported by automatic weather stations, and may be used by

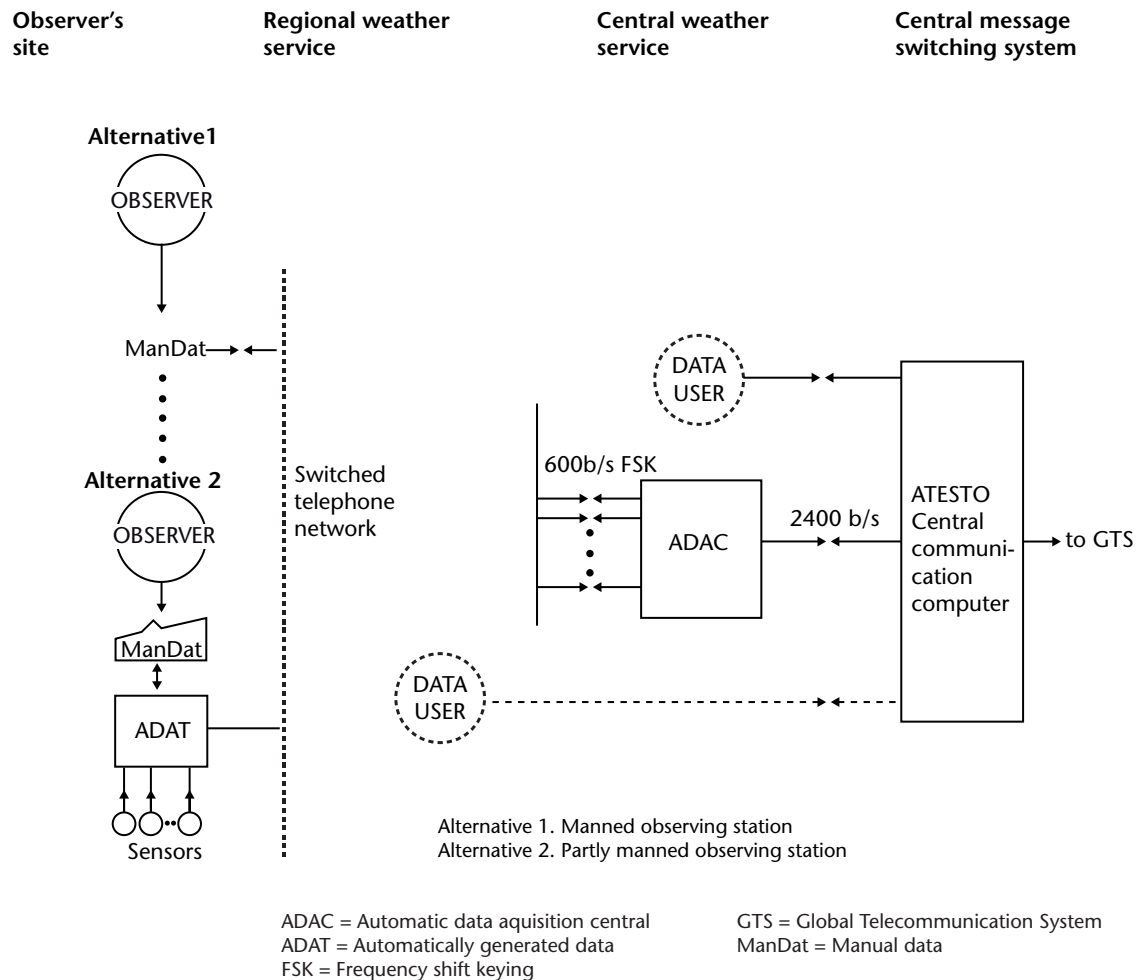


Figure III.5. Automatic data collection system for conventional stations and partially or fully automatic weather stations

Source: Hovberg, T. and Udin, I., 1984: Papers presented at the WMO Technical Conference on Instruments and Cost-effective Meteorological Observations (TECEMO), Nordwijkerhout, September 1984; *WMO Instruments and Observing Methods*, Report No. 15

manufacturers in designing automatic stations and sensors. These specifications are expressed in terms of variable name, maximum effective range, minimum reported resolution, mode of observation and present ability to represent variables by BUFR/CREX codes. Future requirements will be incorporated in the functional specifications upon proposal of the users.

Some of the variables listed in the functional specifications should be mandatory. A standard automatic weather station should consist of an observing system that provides observational data from a standard set of variables, for example, pressure, temperature, wind and humidity. Apart from this standard set, a set of optional variables may be considered. The basic set of variables to be measured by automatic weather stations, compiled from the *Manual on the Global Observing System* (WMO-No. 544), is provided in Appendix III.2.

The first step in planning an automatic network is to set up a list of requirements of known and potential data users. At the outset, purely meteorological aspects are to be considered, for example, which station distribution, measuring cycle and observing programme are necessary to meet the requirements of the weather predictions made in the country and which are necessary to fulfil international weather information requirements. The answer could be found by using a table similar to the one developed for Scandinavia in Table III.1). Interdependency with other data acquisition systems, such as radar, upper-air stations or satellites, should also be considered.

Results obtained from manned stations are often regarded as standards by opponents of automation, who compare the performance of automatic equipment with the performance of ideal conventional stations. This way of thinking is often unfounded. In some cases it is indispensable that new methods be adopted if meteorological observation is to be successfully automated. Replacing manual observing methods by automatic means frequently leads to a complex, expensive and unreliable outcome. In view of this problem, an automatic system should be designed to work according to a predetermined specification rather than in terms of "measurements" taken by an observer. Sensors whose output is consistent with automatic data handling should be adopted.

Because of the diversity of meteorological problems, network planning should not be the concern solely of automatic measuring system engineers or manufacturers who are often unaware of the real problems faced by users. During the planning phase future users

must devote their time and bring their experience to bear on the issue in order to avoid disappointments caused by an unsuitable system. Member countries without experience in that field should seek advice from those who have been running automatic observational networks for a number of years.

It is essential to establish detailed specifications that take into account local requirements and the environment. These specifications should mention technical parameters such as measuring range, uncertainty, resolution, reproducibility, response time, stability, reliability, power consumption, exchangeability, critical dimensions (distance between sensors and transmitters/receiver, space or weight limitations) and spare parts and maintenance requirements. Other factors to be included are long-term compatibility requirements with attached or neighbouring equipment, if the equipment is intended to replace a part or to be a complementary part of another system, and possible interferences with other systems, in particular at airports.

3.2.1.4.4.2 System selection criteria

(a) Future station environment

Automatic weather stations must be able to withstand the most severe meteorological extremes. It is essential, therefore, to analyse the station's future environment before specifying or designing a system. The major influences are high humidity, low or high temperature, dust, high-frequency fields, lightning and corrosive environments. Nuclear-electromagnetic pulses should also be taken into account. Protective measures against these influences should be planned at the outset.

(b) Reliability

The mean time between failures of an automatic synoptic station should be more than 10 000 hours without taking into account individual sensor failures.

The reliability of automatic weather stations can be enhanced by making a partial or full duplication of the station, in other words, by providing a backup system. Partial duplication is defined as the duplication of critical variables by using redundant subsystems such as power supplies, and wind and temperature sensors. Full duplication, where the second station is a less expensive type with a lower capability which will report only basic variables such as atmospheric pressure, wind speed, wind direction or air temperature, would require different power supplies and communication channels, at least at the station, if all risks are to be avoided. A feature of the duplication approach is that both the primary and the secondary

Table III.1. Meteorological data user requirements in Scandinavia

<i>Time and space scales</i>	<i>Observations</i>
0–2 h 0–100 km Nowcasting	<ul style="list-style-type: none"> • Complete regional radar coverage; continuous operations • Automatic stations, including buoys; regional network for wind, humidity with density approximately 40 km; wind measurements in narrow channels with density less than 20 km; wind and temperature along popular mountain tracks; temperature, wind, humidity and radiation along highway sections prone to icing; all values in real time • 1–2 vertical sounding systems for wind, temperature and humidity; measurements every hour • Reports from civilian and military aircraft in the Region • Airport observations, hourly synoptic observations and METAR • In southern Sweden, METEOSTAT digital information every half hour
2–6 h 20–300 km	<ul style="list-style-type: none"> • Complete radar coverage • Complete synoptic observations every third hour; density 80 km • Automatic stations, including buoys; pressure measurements with density approximately 50 km; wind, temperature and humidity with density approximately 40 km once an hour • Digital satellite pictures with a period of 3–6 hours • 1–2 vertical sounding systems at least every sixth hour • Scandinavian synoptic observations every third hour • Acoustic sounders, instrumented masts and the like
6–18 h 20–300 km	<ul style="list-style-type: none"> • Synoptic observations every third hour; density approximately 80 km • Automatic stations with pressure sensor every third hour; density approximately 50 km • Digital satellite pictures with period 3–6 hours • Satellite vertical soundings, for example, TOVS, every sixth hour or more frequently • 1–2 vertical sounding systems every sixth hour • Foreign observations (SYNOP, TEMP, PILOT, AIREP) every third or sixth hour • Ship observations • Acoustic sounders, masts and the like
12–26 h 150–4 000 km	<ul style="list-style-type: none"> • As above

Source: Ag., L., 1981: Papers presented at the second WMO Technical Conference on Instruments and Methods of Observation (TECIMO-II), Mexico City, October 1981; *WMO Instruments and Observing Methods*, Report No. 9.

systems will be working continuously except, of course, when one of them is out of order.

Generally, partial or full equipment duplication tends to be expensive and is only worthwhile in the absence of a suitable maintenance organization that guarantees corrective action within acceptable time limits.

The percentage of synoptic observations that may reach the user in time to be of value is a critical quality factor in the assessment of an operational automatic system. The point at which a decline from 100 per cent becomes sufficient to render the system no longer cost-effective might depend somewhat upon the circumstances of its use; in general, however, the aim is to achieve a data availability of more than 90 per cent for successful operational systems. For Regional Basic Synoptic Stations, a data availability of at least 95 per cent appears to be indispensable for daily routine work.

The most important losses of reliability are generally connected with data transmission interruptions. The safety of data transmission can be improved by overlapping star-type network designs and rerouting communications along different communication lines. (See Figure III.6.)

(c) System architecture

The system should be flexible and modular in order to suit the most varying applications. Special attention should be paid to expanding capability. It should be possible to connect additional stations, new sensors and peripherals to the system at a later stage. The conception of a network should leave the choice of data routing and diverse communication devices open, so that they can be adapted to the latest technological developments.

The basic structure of an automatic station and its data handling should also be kept as modular as possible. As much signal conditioning as possible should be carried out by each sensor interface, preferably at, or very close to, the sensor.

Synoptic stations designed to be used unattended over a long period of time should be kept as simple as possible. More elaborate solutions, including sophisticated data processing, can be envisaged for synoptic stations which can be visited more often or which are used semi-automatically, however.

(d) Life-length considerations

Life length is considered by manufacturers to be the time a piece of equipment remains in active production; the user, however, is more likely to think in

terms of useful life in the field. It is well known that electronic products tend to have a short production life cycle. For the user, the useful life of a system tends to be much longer.

In some cases, the life length of a system is limited by the rapid progress of technology. Availability of spare parts or human know-how becomes a serious problem. It is possible that by the time a system is designed, tested and accepted, it has already become obsolete.

It is, therefore, better to choose sensors which have already been successfully used in other countries and are readily available instead of undertaking expensive research and development in one's own country. This is especially true with respect to the acquisition of smaller series. The contract with the manufacturer should contain guarantees concerning spare parts maintenance and the availability. If a system manufacturer cannot guarantee the required life length under acceptable conditions, a commitment from the network operator is indispensable. The latter must participate in development and maintenance work to acquire the necessary know-how and obtain enough materials for an adequate period.

3.2.1.4.4.3 Logistics

(a) Site selection

As automatic stations are expensive, it is necessary to study site facilities carefully before making significant installation investments. The considerations in choosing a site for a surface synoptic station (see 3.1.2) also apply to automatic stations.

Since there should not be any difference between the performance and quality of the observational data from manned and automatic stations, 3.2.1.2.1 and 3.2.1.2.2 outlining siting and exposure requirements also apply to any automatic weather stations and sensors installed.

(b) Resources required

The establishment of an automatic observational network calls for considerable material resources. If the quality and quantity of the data acquired by automation is disregarded, establishment of an automatic synoptic network can be financially advantageous only if it replaces many manned stations making round-the-clock observations by totally unmanned stations or by partially manned stations with a reduced observer presence.

The total cost of an automatic synoptic network is composed of the initial costs and the operating costs. Initial costs include costs for development, acquisition, installation, efficiency tests, documentation

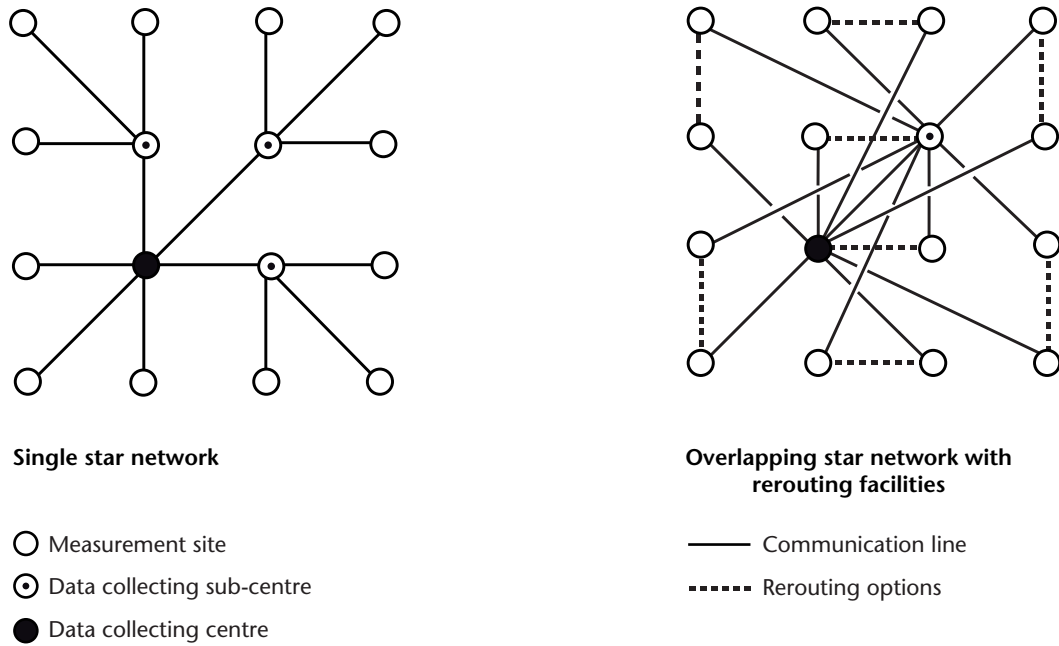


Figure III.6. Single star network and overlapping star network with rerouting facilities

Source: Van den Enden, I.F.H.C.C., 1984: Papers presented at the WMO Technical Conference on Instruments and Cost-effective Meteorological Observations (TECEMO), Noordwijkerhout, September 1984; *WMO Instruments and Observing Methods*, Report No. 15.

and software programmes. Operating costs are staff costs, maintenance, transmission, modification and replacement of parts, electricity consumption, land rental, training, measurement control and processing. The costs of modifying and replacing system parts should be estimated on the basis of the initial costs, as these can be distributed over the years in relation to the life length of each system.

The annual operating costs of a well-maintained network are about 10 to 20 per cent of the initial costs. Operating costs are rarely included in a realistic manner in the offers made by the manufacturers, and are therefore often underestimated. The staff component of the initial costs is relatively small; as for the operating costs, the corresponding parts for the staff and the material are of similar size. It is generally more important to spend the available resources for the infrastructure needed to maintain a small automatic network than to enlarge the network without such support.

3.2.1.4.4.4 Time needed for the establishment of an automatic observational network

(a) Time for development

When National Meteorological Services participate in the development of new sensors or complete automatic stations, they must ensure, through the

use of prototypes and pilot series, that the technical specifications of the instruments have been fully respected; they must undertake compatibility tests in the field. Since complete field intercomparison of existing and new instruments should cover all four seasons, the minimum test duration is one year. After completing the evaluation of obtained data sets, the test results may require the redesign of the product. It may take years to successfully develop a product for use in the field. If it takes too long, the rapid progress of technology may overtake developments and the finished equipment may be obsolete by the time routine operations can start.

(b) Test operations

Setting up a system as complex as an automatic measuring network requires a good working team. The time needed for completing test operations depends on the complexity and scale of the network, and available means. Depending upon the level of experience, it takes about six months to one year for the team to become familiar with the system. This period becomes much longer if the network operators have not participated in the development and construction of the system. After the completion of an automatic network and before routine operation and dissemination of synoptic information at the international level, a learning and testing

period should take place. Testing should also be carried out for any network station established subsequently, especially those belonging to the regional basic synoptic networks.

(c) Parallel operation with conventional stations

If previous long-standing climatological data series have to be extended in time by data provided by automatic synoptic stations, parallel measurements by conventional and automatic observing methods are indispensable to ensure continuity of the records. One year of parallel measurements does not suffice; preference is given to at least two years, depending on the climatic region.

Once stations become fully or partially automated, it is often difficult to stimulate observers to make parallel observations, or financial pressures may demand a reduction in the number of operating stations. In that case, sufficiently long parallel observations should be carried out at least at a selected number of automatic stations.

3.2.1.4.5 Operations

3.2.1.4.5.1 Time and frequency of observation

For most meteorological variables measured by automatic weather stations and for their applications, a measuring interval of one to ten minutes is possible; in many countries a measuring interval of 10 minutes has become usual. See the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part III, Chapter 2, 2.4.2.

If there is an intention to use data from automatic stations for real-time monitoring, warning and forecasting, or even nowcasting, an interval of a few minutes—one to five—is indispensable, making it possible to follow weather developments continuously and offers some possibilities for interpolation after a short system failure.

3.2.1.4.5.2 Surface synoptic meteorological observation variables

When partially automated stations are used along with an observer providing complementary observations of variables which are not measured automatically, human observations can be conducted at a separate location, for example, if the observer lives far away from the station site. If so, the observer can be equipped with a remote data entry device allowing him or her to contact the automatic stations at any time by telephone or high-frequency transmission. Thus, human observations are independent of those made

automatically. However, the distance between the remote data entry device and the automatic station should not be more than 10 km, especially in mountainous regions, in order to ensure the consistency of the observations.

3.2.1.4.5.3 Safeguards against breakdown

Failures at the network central processors can paralyse a whole network or large parts of it. For safety reasons, it is recommended that a double central processor system should be provided. Even for failures of a completely double system, procedures should be planned that will ensure the continuation of some minimal real-time network functions.

At major surface synoptic stations, at least for those in the regional basic synoptic network, failures of the automatic data acquisition from the stations must be compensated by an adequate emergency system. Observers, with the help of some alternative instrumentation, should be able to take the measurements themselves and code and transmit the synoptic messages until the fault is repaired.

3.2.1.4.5.4 Monitoring and processing

To increase user confidence in the reliability of information derived from an automatic network, it is necessary to institute a continuously operational real-time and near-real-time monitoring programme and thereby validate the quality of the data generated by the network.

The quality requirements for pre-processing and processing control at automatic stations are set out in a general manner and for each variable in the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part II, Chapter 1, and Part III, Chapters 1, 2, and 3. Further information about quality control at the observing site and at data collection centres can be found in Parts V and VI of the present Guide.

Data quality control and correction should be carried out as quickly as possible after data collection. Timely data processing is only possible if the site and instrument characteristics of the parameters are permanently known. This intensive work should already be considered when planning the network.

3.2.1.4.5.5 Maintenance

Important considerations in setting up a maintenance organization for automatic stations and the principles to be followed in carrying out a

maintenance programme are described in 1.6, Chapter 1, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), and in a more general way in Part III, Chapters 4, 5 and 7, of the aforementioned Guide.

Maintenance work should be carried out primarily by specially trained technical personnel. This staff, however, cannot always solve the problems encountered by the observer with the non-automatic observations or notice possible deficiencies in station performance. It is, therefore, useful for partially automated synoptic stations to be inspected by specially trained staff, independently of the technical maintenance work.

In a well-established system, modifications should generally be kept to a minimum. As far as possible inspections and the bulk of preventive maintenance work should be done by a small—and always the same—team, in order to improve the homogeneity and the continuity of an automatic network.

3.2.1.4.5.6 Training

The more complex the equipment, the more technical knowledge is required from the people who will maintain and use the system. Rapid strides in technical developments make regular training courses indispensable. The staff's technical knowledge needs to be kept up by refresher courses from time to time, especially when the duties and responsibilities of staff members have changed.

The *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) outlines the general requirements for the training of observers in 1.8, Chapter 1, Part II.

At many partially automated synoptic stations, observers will no longer have the same close relationship with their work as they formerly had with conventional measurements. In such cases, it is recommended that they be given instructions as to the necessity, importance and purpose of their new work along with practical examples of the value and use of the data their station provides.

3.2.1.4.5.7 Documentation

Detailed documentation is the basis for the international exchange of experiences with automatic weather observation networks and should therefore be available at the time the network is established. The documentation should be obtained from the competent authorities or the manufacturer, together with the equipment specifications.

The actions and conditions that influence measurements at a weather station should be featured in standardized documentation. Writing down all changes in measuring conditions provides a complementary source of meteorological information and permits the data user to interpret the measurements correctly. With automatic measurements made over a long period of time, the events which should be recorded become so numerous that subsequent reconstruction is almost impossible. Therefore, the role and importance of station metadata cannot be disputed.

Data producers are responsible for providing adequate and sufficiently detailed metadata. For more information, see the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part I, Chapter 1, 1.1.3 and 1.3.4, and Part III, Chapter 1, 1.6.

Two sets of metadata for automatic weather stations were developed with respect to real time, near-real time, and non-real-time; taking into account the significance of each entry for operational data. They are reproduced as possible guidelines for network managers in Appendix III.3.

Real-time automatic networks that permit dialogue between stations and the network's central processor can also be used to provide documentation of all kinds. Observers or maintenance staff equipped with fixed or mobile data terminals for interactive communication can, inter alia, achieve the following:

- (a) Obtain guidance for complex maintenance procedures at the station using information called up from the central station;
- (b) Record maintenance work that has been done or comments of the inspector. This information can be transmitted to the network's central processor for storage;
- (c) Update automatically system tables containing the basic characteristics of the individual stations or update stock management files after installation, exchange removal or sensor calibrations;
- (d) Interrogate the observer handbook. If the handbook is centrally modified it is easier to keep up to date.

3.2.1.4.5.8 Quality standards

Reference should be made to the following publications: The *Guide on the Global Data-processing System* (WMO-No. 305), Chapter 6; the *Manual on the Global Data-processing and Forecasting System* (WMO-No. 485), Part II, Volume I, section 2; and Guidelines for Quality Control Procedures Applying to Data from Automatic Weather Stations which appear in Part VI, Appendix VI.2, of the Guide.

3.2.1.4.6 *Automatic sea stations*

(a) General

Automatic stations for provision of meteorological data from the oceans are an important and reliable tool for collecting data, especially from such remote areas as the polar regions. General considerations applicable to automatic land stations are also largely valid for automatic sea stations. Station reliability problems are also generally similar.

Moored and drifting buoys are used with automatic stations to provide data from sea areas where few or no mobile ships operate. A striking example is the low-cost Lagrangian drifting-buoy system operated in the global oceans. In line with the framework of the former Surface Velocity Programme (SVP) of the World Ocean Circulation Experiment 1995–2005, standard Lagrangian drifters are referred to as SVPs; SVPBs are Lagrangian drifters equipped with barometers. A mobile ship observing programme may also be fully automatic, but it is advisable to provide for manual insertion of data in the system at least for the visual observations that cannot be made automatically. In general, automatic sea stations supervised and supplemented by human observers, when possible, are recommended for several reasons: overall reliability is improved, time resolution is increased, sensors and other vital parts can be replaced quickly and efficiently and costs of manned stations are reduced, owing to smaller staff.

Stations in some parts of the globe such as the Arctic and Antarctic, isolated islands and drifting buoys on ice and sea are difficult to visit for repair and replacement in case of failure. Reliability is therefore even more essential than for land stations. Full duplication is the best solution, but a rather expensive one. For drifting buoys, duplication means simply deploying two buoys instead of one. By making the buoy very simple, with only a few sensors, such as pressure and temperature sensors, the risk of malfunction is kept low.

(b) Site selection

Isolated unpopulated islands and relatively inaccessible coastal regions are natural sites for automatic stations. Members can improve their national network in an efficient and inexpensive way by establishing such stations which might also make an important contribution to the regional and global network.

Moored buoys in fixed positions in ocean or coastal areas may also be sites for meteorological observations and for surface flux and oceanographic sub-surface measurements. Members should be aware and take advantage of the planning and deployment

of such buoys by others, such as oceanographic institutes; reciprocally, when such buoys are operated by a Meteorological Service, the latter should offer to carry oceanographic sensors on board. This may also apply to some extent to drifting buoys.

Fixed platforms may also be selected for fully automatic stations.

Coastal stations may also be automatic or semi-automatic if personnel are available for manual observations of additional variables.

Lightship stations can be automated in the same way if they are unmanned or inadequately manned.

Relatively large ice floes provide excellent sites for automatic stations, and ice-buoy networks should be operated in the polar regions individually or jointly by Members.

Drifting buoys with automatic stations provide an efficient way of obtaining meteorological information from the high seas. Members should plan deployments jointly to obtain a desirable network.

(c) Design

An automatic sea station should consist of the following components:

- (i) A number of sensors for measuring or observing the variables;
- (ii) An electronic package with a microprocessor or microcontroller to sample, process and record sensor output;
- (iii) A source of electric power such as battery packs, solar panels or external sources to provide sufficient electric power for the station to operate without interruption during its life-time; some safety prevention measures must be taken, as dangerous explosions have been reported and recommendations subsequently made;
- (iv) A transmitter for communication purposes.

If possible, meteorological sensor exposure should be the same for automatic lightship, island and coastal stations as for manned stations.

The exposure of instruments (sensors) on fixed-platform stations is discussed in 3.2.1.3.2.3. Exposure should be taken into account in the planning/construction phase of a platform. It should be negotiated between the platform owner and the National Meteorological Service. An offshore drilling or production platform is a state-of-the-art structure with sophisticated equipment on board, including computers. It would be wise to connect the

meteorological sensors to an on-board computer with the necessary software to handle the raw data and convert them to meteorological variables, and to code the information in the relevant WMO codes or transmission to a coastal collection centre.

Drifting buoys for the oceans or for deployment on ice floes (ice buoys) can have different designs; for most meteorological purposes a simple version is sufficient. A sketch of a typical simple drifting buoy is given in Figure III.7. Like the buoys which were developed during the first Global Experiment of the Global Atmospheric Research Programme, i.e. FGGE drifters, these have sensors for two variables only. A drogue is generally used to minimize the drift of the buoy and the slip with regard to the moving water parcel (Lagrangian drifters).

More sophisticated buoys may have a number of sensors, for example, to take wind measurements. In that case, the hull must be much larger—taller—and consequently much more expensive. Ice buoys generally resemble drifting buoys except for the hull, which in the former is designed to rest on an ice surface.

(d) Observing programme

In accordance with 2.3.3.16, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544), a surface synoptic observation from a fixed automatic sea station shall cover atmospheric pressure; wind direction and speed; air temperature and sea-surface temperature.

If possible sea-state observations (waves) and information on precipitation (yes or no; especially in tropical areas) should be included.

Observing programmes for a typical simple drifting buoy consist of observing two variables: atmospheric pressure and sea temperature. Generally, surface synoptic observations should be conducted in accordance with stipulations set out in 2.3.3.17, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544).

The observing programmes presented above for automatic sea stations must be regarded as minimum requirements. Large automatic stations, especially those that are supervised daily, should also, if possible, provide cloud base height, visibility, computed pressure tendency and characteristic, and amount of precipitation.

The larger drifting and moored—often combined oceanographic-meteorological—buoys may have a more extensive observing programme including, for instance, wind measurements.

(e) Network organization

It is advantageous to use automatic means when setting up a sea-station network; in many cases automatic observing stations are the only solution. In a number of cases, and especially with regard to automatic weather stations onboard voluntary observing ships, it is preferable to employ “hybrid” stations where manual observations are used together with automatic sensor output to obtain a complete set of observations, as for some ships. A network will in general consist of both manual and automatic stations.

Fixed platforms, lightships and coastal stations may be isolated automatic stations in an otherwise conventional network and be an integrated part of national, regional and global networks.

Automatic ice-floe stations, composed of ice buoys, and drifting buoys are specialized and fully automated networks that provide data from remote and otherwise data-empty areas.

By introducing automatic means for new stations or for automating conventional stations, Members could contribute to maintaining and/or improving the total network for national, regional and global purposes.

Members should, through suitable joint organizations or arrangements, try to establish a network of drifting buoys in critical sea areas. When planning such a network, knowledge of the wind systems in the sea areas in question is essential. Outside the tropical areas, it is generally sufficient to compute the mean geostrophic wind for each month. The drift paths of free-drifting buoys can then be determined with sufficient accuracy for planning deployments. This is accomplished successfully by the WMO-IOC Data Buoy Cooperation Panel.

(f) Logistics

- (i) Electrical power must be available, preferably by power-generating equipment like solar cells. If batteries are used, they should last at least one year (two years for drifting buoys and three for ice buoys); security measures aimed at preventing possible explosions must be taken when using batteries in non-vented compartments;
- (ii) Telecommunication facilities must be available. For automatic sea stations this generally means an automatic transmitter with suitable antennae for direct communication with land stations or via satellites;
- (iii) Service, maintenance and supplies must be provided by the operating agency;
- (iv) Specially trained staff must be available to plan maintenance and monitor operations properly.

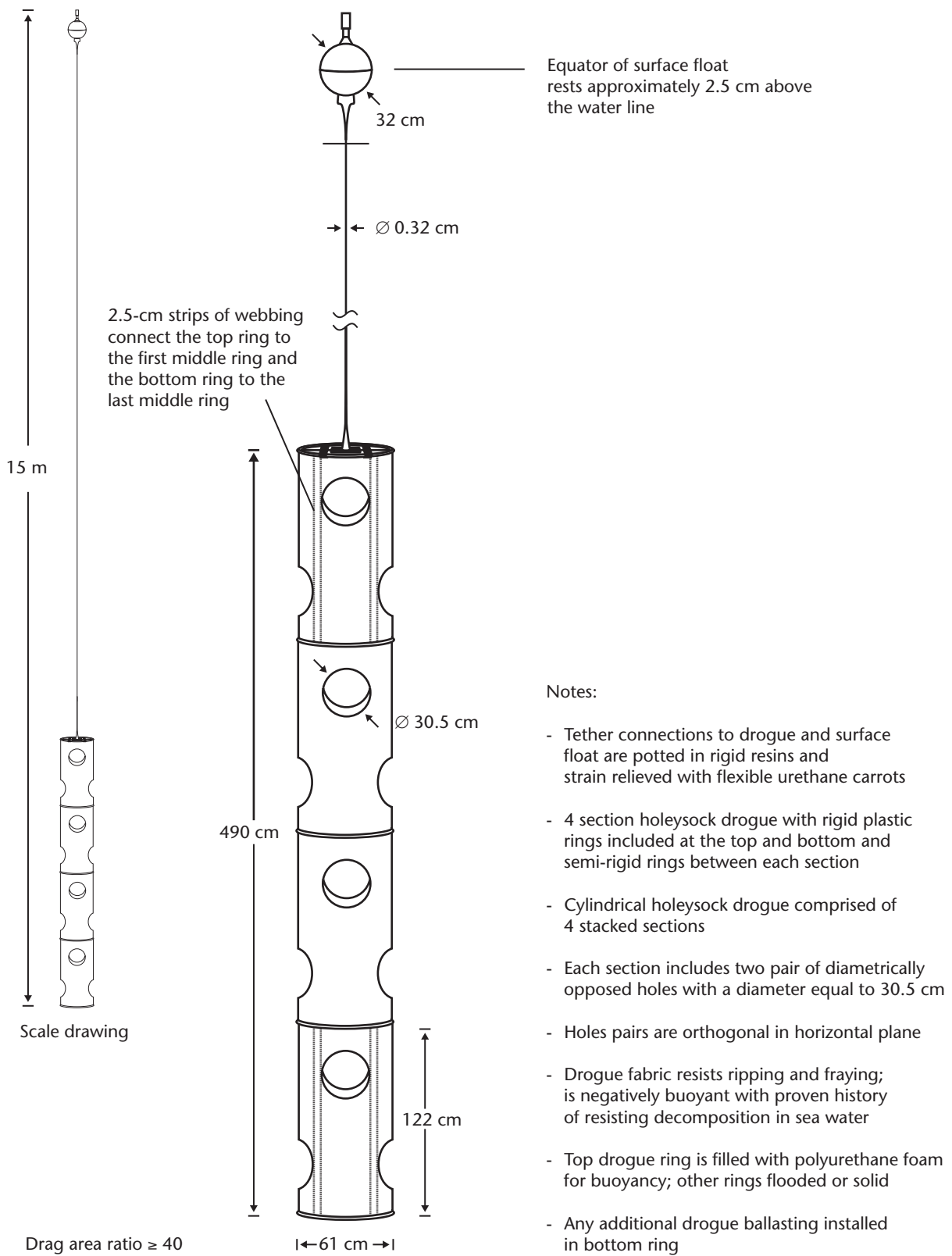


Figure III.7. Typical simple drifting buoy

To maintain a certain number of buoys (ice buoys and drifting buoys) within a specified area, it is necessary to make successive deployments. The effective operation of a buoy network is, therefore, dependent on available ships, or aircraft in the case of ice buoys. Ships of opportunity can be used for drifting buoys; drifting buoys can be deployed from low-level aircraft.

Certain types of drifting buoys floating out of a desired area or no longer functioning properly can be recovered and re-used. However, modern versions of Lagrangian drifters are not meant for recovery or refurbishment. An advantage of simple buoys, however, is that, owing to their relatively low cost, they may be regarded as expendables.

(g) Coding and communications

Data processing and coding can be carried out at the automatic station itself by a microprocessor, or at a central receiving station and processing centre. The latter method is recommended because the automatic station can then be made very simple.

The pressure tendency, three hours, and the tendency characteristic can be provided for the simple drifting buoys in addition to the pressure. This requires a microprocessor to do some handling, including storage of the sensor output.

The communications for automatic coastal stations may be achieved by land line, very high frequency (VHF) and ultra-high frequency (UHF) radio or direct satellite link, for example, geostationary or polar orbiting. The data can be retransmitted via satellite to local users with a receiving station, or disseminated over the Global Telecommunication System from the large main satellite ground stations. The drifting- and ice-buoy communication link is chiefly accomplished via polar-orbiting satellites because this makes it possible to determine the transmitting buoy's position at the same time. A platform telemetry transmitter is preset for dissemination at fixed intervals, usually every 90 seconds. The satellite must have at least four different contacts with the buoy's platform telemetry transmitter at each pass to obtain sufficient data for proper location. Because the Doppler shift in the frequency is transmitted together with the sensor data, platform telemetry transmitter circuit stability must be ensured. Data obtained in this way are essentially asynoptic in case only the most recent data are being transmitted. New buoy systems also record past observations at synoptic and round hour times on board and transmit them asynoptically through the satellite system.

The ARGOS system for determining the location of drifting buoys and for collecting data via satellites provides a very effective means of taking full

advantage of drifting buoys. A special tariff is negotiated by user Countries, under the auspices of WMO and the Intergovernmental Oceanographic Commission with the agency responsible for administering the ARGOS system for the benefit of interested Members, permitting a reduction in the cost of acquisition of data from buoys and other automatic stations.

(h) Personnel

The implementation of an automated network requires a considerable number of well-qualified personnel to keep the systems operating properly. This is sometimes overlooked, with the unfortunate result that expensive equipment becomes useless. This is the most important advice to Members planning a network of automatic sea stations.

(i) Quality standards

In addition to the resources mentioned in 3.2.1.3.2.1, please refer to the following publications:

- (a) *Handbook of Automated Data Quality Control Checks and Procedures of the National Data Buoy Center*, NDBC Technical Document 03-02;
- (b) *Reference Guide to the GTS-Sub-system of the ARGOS Processing System*, DBCP Technical Document No. 2;
- (c) *Guide to Data Collection and Localization Services Using Services Argos*, DBCP Technical Document No. 3;
- (d) *Global Drifter Programme Barometer Drifter Design Reference*, DBCP Report No. 4.

3.2.2 Observations/measurements

3.2.2.1 General

3.2.2.1.1 Time and frequency of observations

Sections 2.3.1.3 and 2.3.1.4 contained in Part III, Volume I of the *Manual on the Global Observing System* (WMO-No. 544) specify the main standard times for surface synoptic observations—0000, 0600, 1200 and 1800 Coordinated Universal Time (UTC)—and the intermediate standard times for these observations, 0300, 0900, 1500 and 2100 UTC. The mandatory and/or recommended times of observation at different types of surface synoptic stations such as land stations, fixed sea stations, mobile sea stations and automatic stations, are given in 2.3.2 and 2.3.3, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544).

3.2.2.1.2 Observing programme

The variables comprising surface synoptic observations required to be made at different types of stations, for example, land stations, ocean weather

stations, mobile ship stations and automatic stations on land and at sea, are given in 2.3.2.9, 2.3.2.10 and 2.3.3.11 to 2.3.3.16 contained in Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544). Additional guidance material for the observation or measurement of each of these variables is given below. For convenience, the information is provided separately for land stations and sea stations, although for some variables the rules to be followed are the same in both cases.

3.2.2.2 Observations at land stations

Meteorological variables that shall be observed and recorded at a manned synoptic land station are defined in the *Manual on the Global Observing System* (WMO-No. 544), Volume I, Part III, 2.3.2.9. They are described below.

3.2.2.2.1 Present and past weather

The specifications used for present and past weather shall be those given in the *Manual on Codes* (WMO-No. 306, Volume I.1, Part A, code form FM 12-XII SYNOP). The specifications used for atmospheric phenomena shall be those provided in the same publication under the description of "weather". Additional specifications and descriptions of all types of weather phenomena given in the *International Cloud Atlas* (WMO-No. 407) should also be adhered to, namely hydrometeors (precipitation), lithometeors, electrometeors (electrical phenomena) and photometeors (optical phenomena). See the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part I, Chapter 14, for further information.

Observations of weather and atmospheric phenomena are mainly conducted visually.

Land stations shall make round-the-clock observations of the weather, including atmospheric phenomena. Other surface stations should do so to the extent possible. The frequency of atmospheric phenomena observations (in between the standard observation times) should be such as to cover even short duration and non-intensive phenomena.

During observations, the following steps must be taken:

- Note the type and intensity of atmospheric phenomena (light, moderate, heavy);
- Record the time of the beginning, change in intensity and end of the phenomena in hours and minutes;
- Observe the station's closest surroundings.

- The following steps are optional, but recommended:
- Monitor the changing state of the atmosphere as a composite whole (development of clouds, wind changes, rapid changes in atmospheric pressure, visibility and the like);
 - Correlate the type of precipitation and electrometeors with the cloud types, phenomena-reducing visibility with the visibility value, type of snowstorm phenomenon with wind speed and snowfall intensity, etc.

The weather phenomena observations are recorded in the appropriate part of the log-book for surface meteorological observations. When the observations are recorded, it is recommended that the conventional symbols given in the *Technical Regulations* (WMO-No. 49) be used.

3.2.2.2.2 Wind direction and speed

The following parameters should be measured:

- Mean wind speed at the time of observation;
- Mean wind direction at the time of observation;
- Maximum wind speed at the time of observation;
- Maximum wind speed in between standard observation times.

The wind instruments to be used, their height, the averaging period for the observation and the estimation method in the absence of instruments are given in 3.3.5, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544) and in 12.2.2.3, Part A, Volume I.1, of the *Manual on Codes* (WMO-No. 306).

Land stations shall read the mean wind direction clockwise from the geographical (true) meridian as the direction from which the wind is blowing. For this purpose, the instruments shall be oriented exactly along the geographical meridian. This orientation should be systematically checked, as should the verticality of the equipment's mast and instruments, and corrected where necessary.

During observations, the following shall be strictly adhered to:

- Prescribed measurement times;
- Averaging period for wind characteristics;
- Uncertainty for the readings:
 - speed: $\pm 0.5 \text{ m s}^{-1}$ for $\leq 5 \text{ m s}^{-1}$ and $\pm 10\%$ for $> 5 \text{ m s}^{-1}$;
 - direction: $\leq 5^\circ$.

All wind measurements should be recorded in the surface meteorological observations log-book.

All wind equipment should be installed on special masts allowing access to the equipment. It must be possible either to lower the upper part of the mast, or the mast must be fitted with metal crossbars or rungs.

A preventive check should be carried out once a year on the wind vane: the vane should be removed from its spindle and cleaned, the weight of the fin checked (permissible error ± 1 per cent) and the vane recoated with black lacquer. If the pivot bearing (the upper part of the spindle, screwed into the mast) is worn, it should be unscrewed and remachined.

See the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part I, Chapter 5, for further information.

Note: The averaging of wind direction is straightforward in principle, but a difficulty arises in that a 0–360° scale has a discontinuity at 0°. As an extreme example, the average of 1° and 359° is 180°. This presents no difficulty to an observer making a continuous recording of wind direction, but automatic computation devices must be provided with some means to resolve the ambiguity.

3.2.2.2.3 *Cloud amount, cloud types and cloud base height*

Cloud amount should be determined according to the degree of cloud over the visible celestial dome in tenths or octas with an uncertainty of one unit.

For visual observations of cloud types, the classification tables, definitions and descriptions of types, species and varieties of clouds as given in the *International Cloud Atlas* (WMO-No. 407), Volume I, shall be used. See the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part I, Chapter 15, for further information.

Cloud base height should be determined by measurement. The technical means for measuring can be based on several methods, such as light-pulse location and lasers. Pilot-balloons launched from the ground can also be used.

The following recommendations shall apply to cloud observations:

- (a) The observation sites should be as unobstructed as possible to enable observers to see the maximum amount of the celestial concave;
- (b) In order to determine the cloud species and types correctly, their evolution should be monitored systematically at and between the observation times;
- (c) Cloud amount should be determined globally for all layers (total cloud amount) and individually for each significant cloud layer in order to meet the requirements of code form FM 12-XII SYNOP set out in Volume I.1, Part A, of the *Manual on Codes* (WMO-No. 306);

- (d) At night, the determination of cloud species should be correlated with the nature of precipitation and optical and other phenomena.

Cloud observations should be recorded in sufficient detail in the surface observations log-book to permit the observations to be reported in code form FM 12-XII SYNOP (see the *Manual on Codes* (WMO-No. 306), Volume I.1, Part A).

3.2.2.2.4 *Visibility*

For definitions of visibility during the day and at night, see Part I, Chapter 9, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Surface synoptic stations shall measure or determine the meteorological optical range. Other visibility characteristics such as runway visual range and slant visual range can be measured at aerodromes and from aircraft.

Visual estimation and instrumental measurement of the meteorological optical range are described in detail in Part I, Chapter 9, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

The objects used to estimate the meteorological optical range during the day should be spaced at standard distances enabling determination of the visibility value in accordance with code table 4377, Horizontal visibility at surface, Part A, Volume I.1, of the *Manual on Codes* (WMO-No. 306). The distances up to the objects (L) should be measured instrumentally.

Visibility observations (meteorological optical range) should be recorded in the surface meteorological observations log-book in three steps as specified in code table 4377, Part A, Volume I.1, of the *Manual on Codes* (WMO-No. 306).

3.2.2.2.5 *Air temperature and extreme temperature*

See 3.3.3, Part III of the *Manual on the Global Observing System* (WMO-No. 544) for the basic regulations relating to this point.

The methods and instruments involved in measuring air temperature at surface stations are described in Chapter 2, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Surface stations shall measure the following air temperature characteristics:

- (a) Temperature at the time of observation;
- (b) Maximum temperature (highest temperature over a prescribed period of time, for example, 12 or 24 hours);
- (c) Minimum temperature (lowest temperature over a prescribed period of time, for example, 12 or 24 hours).

Extreme (maximum and minimum) temperatures, when required by Regional Associations, shall be measured at a minimum of two of the standard times (main or intermediate) with a 12-hour interval between each; these roughly correspond to the morning and evening local time at the observing site or station.

The measurement results and corrections, shall be recorded in the surface meteorological observations log-book.

3.2.2.2.6 *Humidity*

See 3.3.4, Part III of the *Manual on the Global Observing System* (WMO-No. 544) for basic regulations relating to this point.

The methods and instruments used to measure the atmospheric humidity at surface stations are described in Part I, Chapter 4, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Land stations shall measure or calculate the following parameters:

- (a) Vapour pressure;
- (b) Relative humidity;
- (c) Dew-point temperature.

Psychrometers and hair hygrometers are the most commonly used instruments for measuring humidity at land stations.

Instrument readings shall be recorded at the specified time of observation in the surface meteorological observations log-book. Calculated atmospheric humidity characteristics shall also be recorded there.

3.2.2.2.7 *Atmospheric pressure, pressure tendency and characteristic of pressure tendency*

The methods and instruments for measuring atmospheric pressure at surface stations are described in Chapter 3, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Requirements for measuring atmospheric pressure, procedures to be followed for reducing the pressure to mean sea level and requirements and procedures

for reporting the geopotential height of an agreed standard isobaric surface at high-level stations in accordance with the relevant resolution adopted by the Regional Association are outlined in 3.3.2, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No.544), and in 12.2.3.4.2 and code table 0264, Part A, Volume I.1, of the *Manual on Codes* (WMO-No. 306). Furthermore, atmospheric pressure observations should be made exactly at the standard time for surface synoptic observations defined in 3.2.2.1 above.

The direct reading of atmospheric pressure from a barometer should be recorded in the surface meteorological observations log-book. The following parameters should also be recorded in the log-book: corrected station-level atmospheric pressure, calculated sea-level pressure or isobaric surface height, calculated pressure tendency and pressure tendency characteristic.

Atmospheric pressure can be recorded continuously by using electronic barometers or barographs.

The pressure tendency shall be determined from the atmospheric pressure values measured from a barometer and expressed as the difference between these values during the three hours preceding the observation time. The pressure tendency can be calculated from the barograph readings as the difference between the readings taken from the recorded curve (plotted around the clock) at corresponding observing times, that is, every three hours.

Characteristic of pressure tendency shall be determined by using the appropriate sign (rise = "+" or fall = "-") when taken from a barometer, and with the type of curve when taken from a barograph.

Characteristic of pressure tendency shall be designated according to code table 0200 found in Volume I.1, Part A, of the *Manual on Codes* (WMO-No. 306).

Observation of the following variables are determined by the relevant resolutions of regional associations:

3.2.2.2.8 *Amount of precipitation*

See 3.3.8, Part III, of the *Manual on the Global Observing System* (WMO-No. 544).

The methods and instruments for measuring precipitation at surface stations are described in Part I, Chapter 6, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Surface stations shall, when required by regional associations, measure amounts of precipitation and determine other precipitation characteristics such as duration and intensity. The amount of precipitation shall be measured at a minimum of two standard times (main or intermediate), 12 hours apart and roughly corresponding to the morning and evening local time at the observing site or station.

Note: In addition, Members may establish other times for measuring precipitation and carry out continuous recording of liquid and solid precipitation.

Rain gauges are used for measuring the amount of precipitation. The type and exposure of the rain-gauges and the material of which they are made should be chosen in such a way as to reduce to a minimum the influence of wind, evaporation, wetting of the glass and splashing.

The measurements and corrections shall be recorded in the surface meteorological observations log-book.

3.2.2.2.9 *State of ground*

The methods of observing the state of the ground at surface stations are described in Chapter 14, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Land stations shall, when required by regional associations, determine the following parameters at the morning observation time when the minimum temperature is measured, provided that in winter there is enough light:

- (a) State of ground without snow or measurable ice cover;
- (b) State of ground with snow or measurable ice cover.

The state of the ground with or without snow, or measurable ice cover, should be determined visually in accordance with the specifications given in code tables 0901 and 0975, Volume I.1, Part A, of the *Manual on Codes* (WMO-No. 306), which are self-explanatory.

The observations should meet the following requirements:

- (a) In the absence of snow or measurable ice cover, the state of the ground is determined in the meteorological instrument area at the spot where the thermometers are installed for measuring the temperature of the surface and the ground is free of plant cover (bare ground);
- (b) The state of the ground and the snow or ice cover shall be determined in such a way as

to characterize the station's environment, an open, representative area. Consequently, the observations must always be made from the same, preferably raised place through a visual survey of the area surrounding the station, or meteorological instrument area.

The observations shall be recorded in the surface meteorological observations log-book. The recording can be in words, abbreviated conventional signs and in code form FM 12-XII SYNOP found in Volume I.1, Part A of the *Manual on Codes* (WMO-No. 306).

3.2.2.2.10 *Direction of cloud movement*

Surface stations shall, when required by Regional Associations or national decisions, determine cloud movement direction. This can be estimated visually and can also be determined, together with its angular velocity by using a nephoscope.

3.2.2.2.11 *Special phenomena*

Surface stations should observe special weather phenomena that are generally called dangerous or extremely dangerous—catastrophic, hazardous or severe—on an uninterrupted, round-the-clock basis whenever possible.

These special phenomena hamper industrial and other daily activities and frequently cause significant losses to industry and the population. In order to prevent or reduce losses, appropriate observations should be made at the stations.

Special phenomena may comprise the following variables:

- (a) Large values of the usual meteorological variables, for example, strong wind, considerable rainfall and drop in air temperature during the transitional periods below 0—frosts;
- (b) Unfavourable combinations of variables, for example, high temperatures and low air humidity leading to droughts;
- (c) Exceptionally long-lasting atmospheric phenomena such as fog or snowstorms;
- (d) Individual rare phenomena, for example, hail tornadoes and others.

In practice, lists of special phenomena that are dangerous or extreme in nature and relevant criteria such as threshold values are established by the Members.

Land stations shall ensure measurement or observation of the phenomena given in the *Manual on Codes* (WMO-No. 306), Volume I.1, Part A, code

form FM 12-XII SYNOP, section 3, as specified in code table 3778.

Other special phenomena are determined by Members, depending on local conditions.

The following recommendations are made for observing special phenomena:

- (a) Measurements should be made using instruments which have a sufficient range or scale capable of pinpointing a rarely occurring value;
- (b) Observers should be extremely attentive and flexible when there are signs of a special phenomenon;
- (c) Observations may be made at the station and in its vicinity, whilst data on the consequences of a special phenomenon may also be collected through a survey of local inhabitants.

Observations should be recorded in the log-book for surface meteorological observations in expanded form, preferably including a brief descriptive text written in a section specially reserved for this purpose.

Special phenomena of a catastrophic nature should be described in detail and their sequences should, as far as possible, be photographed and mapped. It is recommended that special instructions for the stations be prepared by Members for this purpose.

3.2.2.2.12 *Automatic measurements*

The content of a surface synoptic observation at an automatic land station is described in 2.3.2.10, Volume I, Part III, of the *Manual on the Global Observing System* (WMO-No. 544).

Sensors and uncertainty requirements for automatic weather stations are outlined in Part II, Chapter 1, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8). Information on sampling and reduction methods can be found in Part V of the present Guide and in Part III, Chapters 2 and 3, respectively, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

In general, classic visual observations are difficult to replace by automated means, although in some cases new observing technology, such as satellites or remote-sounding techniques, can supply better information than those obtained by classic means. It is possible, however, to approach classic visual information by combining some automatically measured variables at land stations. Examples are provided below.

- (a) Present weather and past weather
 - (i) Of the possible 99 code variations, some of the most significant present weather and past weather types may, with the development of suitable algorithms, be automatically reported by using the combination of outputs of different common automatic sensors such as precipitation sensors, thermometers, lightning counters and anemometers, for example, ww: 17, 18, 21, 22, 29, 51, 61, 63, 71, 73, 75, 91, 92, 95, 97;
 - (ii) Distinction between solid and liquid precipitation with the help of melting power used in precipitation gauges;
- (b) Cloud information
 - (i) Interpretation of the gradient of air temperature near the ground (for example, difference of temperature between 2 m and 5 cm above ground) to estimate the total clouds amount;
 - (ii) Evaluation of radiation and illumination measurements to derive information about the development of cloud cover.

3.2.2.3 *Observations at sea stations*

Meteorological variables that shall be observed and recorded at ocean weather stations are defined in 2.3.3.1, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544) and described in 3.2.2.3.1 to 3.2.2.3.11 below.

3.2.2.3.1 *Present and past weather*

The rules to be followed at sea stations also apply to land stations.

3.2.2.3.2 *Wind direction and speed*

The methods and instruments for observing the wind at sea stations are outlined in 4.2.5, Chapter 4, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Wind speed and direction may be observed by making visual estimates or using anemometers or anemographs.

Visual estimates are generally based on the appearance of the sea surface. Observers should be aware that wave height in itself is not always a reliable criterion since it also depends on wind fetch and duration, and swell presence.

The Beaufort wind scale in Table III.2 provides the criteria for the visual estimation of wind speed.

Wind direction is determined by observing the crest orientation of the wind-driven sea waves.

Wind measurements using anemometers and anemographs are made in the same way as for land stations, but it may be difficult to avoid local effects, for instance those produced by a ship's superstructure. Therefore, the instrument should be sited on board of the mobile ship as far forward and as high as possible.

When measurements are made on a moving ship, it is necessary to distinguish between the wind relative to the ship and the true wind. For meteorological purposes, the true wind should always be reported. It may be obtained from the apparent wind by using the velocity parallelogram as shown in Figure III.8.

The apparent wind speed measured on board a moving ship is to be corrected for the ship's course and speed in order to obtain the speed of the true wind, which be reported. The correction can be made by using the velocity parallelogram or special tables (see 12.2.2.3.3, Part A, Volume I.1, of the *Manual on Codes* (WMO-No. 306)).

Special rules must be applied for determining the wind on fixed and anchored platform stations because their heights may be more than 100 m above sea level, whereas surface wind is defined as the horizontal component of the wind vector that is measured 10 m above the ground or the sea surface. If the wind sensor is exposed at a higher elevation, the readings must be corrected. The following scale should be applied for reporting mean wind speed over 10 minutes:

Elevation (height in meters)	Coefficient (<i>r</i>)
20	1.10
30	1.15
40	1.20
50	1.23
60	1.26
70	1.29
80	1.31
90	1.33
100	1.35

Example:

Sensor at 75 m, observed speed 50 kt

Coefficient 1.30 (interpolated)

Wind reduced to a standard 10 m height = $50/1.30$
= 38.46 or 38 kt

3.2.2.3.3 *Cloud amount, cloud type and cloud base height*

The rules for land stations are generally followed for sea stations as well, but estimating the cloud base without landmarks such as mountains may be difficult. Ordinary methods using a searchlight are of limited value because of the short baseline available on a ship. The best solution is probably a pulse-light cloud searchlight which does not require a baseline and which electronically measures the reflection time from the cloud base. This instrument, however, is rather sophisticated and expensive and therefore not widely used. Observers should

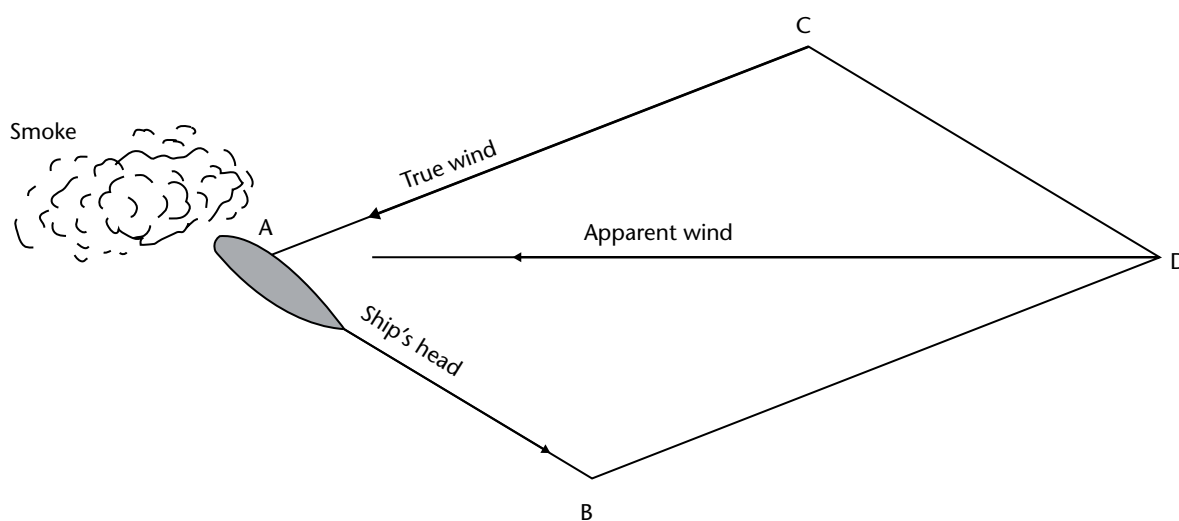


Figure III.8. Velocity parallelogram

Table III.2. Beaufort wind scale
(for a standard height of 10 metres above flat open ground)

Beaufort number (force)	Descriptive term	Estimated mean speed (range)			Specifications for use		On the coast	Probable wave height ^a (metres)	Probable wave height ^a (feet)
		Knots	m s ⁻¹	km/h	mph	On land			
0	Calm	<1	0-0.2	<1	<1	Calm; smoke rises vertically	Calm	-	-
1	Light air	1-3	0.3-1.6	1-5	1-3	Direction of wind shown by smoke drift but not by wind vanes	Fishing smack just has steerage way	0.1 (0.1)	¼ (¼)
2	Light breeze	4-6	1.6-3.3	6-11	4-7	Wind felt on face; leaves rustle; ordinary vanes moved by wind	Wind fills the sails of smacks which then travel at about 1-2 knots	0.2 (0.3)	½ (1)
3	Gentle breeze	7-10	3.4-5.4	12-19	8-12	Leaves and small twigs in constant motion; wind extends light flag	Good working breeze, smacks carry all canvas with good list	0.6 (1)	2 (3)
4	Moderate breeze	11-16	5.5-7.9	20-28	13-18	Raises dust and loose paper; small branches are moved	Smacks shorten sail	1 (1.5)	3½ (5)
5	Fresh breeze	17-21	8.0-10.7	29-38	19-24	Small trees in leaf begin to sway; created wavelets form on inland waters	Smacks shorten sails	2 (2.5)	6 (8½)
6	Strong breeze	22-27	10.8-13.8	39-49	25-31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	Smacks have double reef in mainsail; care required when fishing	3 (4)	9½ (13)
7	Near gale	28-33	13.9-17.1	50-61	32-38	Whole trees in motion; inconvenience felt when walking against wind	Smacks remain in harbour and those at sea lie to	4 (5.5)	13½ (19)
8	Gale	34-40	17.2-20.7	62-74	39-46	Breaks twigs off trees; generally impedes progress	All smacks make for harbour, if near	5.5 (7.5)	18 (25)

Beaufort number (force)	Descriptive term	Estimated mean speed (range)			Specifications for use		On the coast	Probable wave height ^a (metres)	Probable wave height ^a (feet)
		Knots	m s ⁻¹	km/h	mph	On land			
9	Strong gale	41-47	20.8-24.4	75-88	47-54	Slight structural damage occurs (chimney pots and slates removed)		7 (10)	23 (32)
10	Storm	48-55	24.5-28.4	89-102	55-63	Seldom experienced inland; trees uprooted; considerable structural damage occurs		9 (12.5)	29 (41)
11	Violent storm	56-63	28.5-32.6	103-117	64-72	Very rarely experienced; accompanied by widespread damage		11.5 (16)	37 (52)
12	Hurricane	64 and over	32.7 and over	118 and over	73 and over			14 (-)	45 (-)

^aThis table is intended to serve as a guide to provide a rough indication of what may be expected in the open sea, remote from land. It should never be used to log or report the state of the sea. In enclosed waters, or when near land, with an off-shore waves, wave heights will be smaller and the waves steeper. Figures in brackets indicate the probable maximum height of waves.

take every opportunity to check their cloud height estimates against known heights, for example, mountains near the coast.

3.2.2.3.4 *Visibility*

In the absence of suitable landmarks, it is not possible for visibility observations at sea stations to attain the same uncertainty as those made at land stations. The requirements for accurate visibility observations at sea stations are therefore set low, as shown in decade 90–99 of code table 4377, Volume I.1, Part A, of the *Manual on Codes* (WMO-No. 306).

When not uniform in all directions, visibility should be estimated or measured in the direction of least visibility. A suitable entry should be made in the log-book, except in situations of reduced visibility due to the ship's exhaust.

Methods of observing visibility at sea stations are described in 4.2.8, Part II, Chapter 4, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.2.2.3.5 *Air temperature and humidity*

Temperature and humidity observation requirements for use at sea stations are described in 4.2.9, Part II, Chapter 4, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

When reporting air temperature and humidity observations made at fixed and anchored platform stations higher than 100 m above sea level, it is not necessary to take into account variations of temperature and humidity with height.

3.2.2.3.6 *Atmospheric pressure, pressure tendency and characteristic of pressure tendency*

Requirements and instruments used for observing atmospheric pressure at sea stations are described in 4.2.6, Part II, Chapter 4, of the *Guide*

to Meteorological Instruments and Methods of Observation (WMO-No. 8).

3.2.2.3.7 *Ship's course and speed*

A ship's position, course and speed is taken from its navigation system or computed independently using a satellite navigator, for example, a global positioning system.

The mean speed shall be reported. (See group 10 in the code form FM 13-XI SHIP contained in Volume I.1, Part A, of the *Manual on Codes*, WMO-No. 306).

3.2.2.3.8 *Sea-surface temperature*

The measurement of sea-surface temperature is described in 4.2.11, Part II, Chapter 4, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

The method used for measuring sea-surface temperature at manned sea stations shall be recorded in the relevant meteorological log-book.

3.2.2.3.9 *Ocean waves and swell*

The observation of waves and swell is described in 4.2.12, Part II, Chapter 4, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

The characteristics of a simple wave are shown in Figure III.9.

Observations of waves made from island and coastal stations are not representative owing to shallow water, effects of shelter by the shore and other factors.

3.2.2.3.9.1 Use of wave measurement instruments

In recent years suitable sea-wave recorders have been developed for measuring the height and period of waves. The following instruments are used:

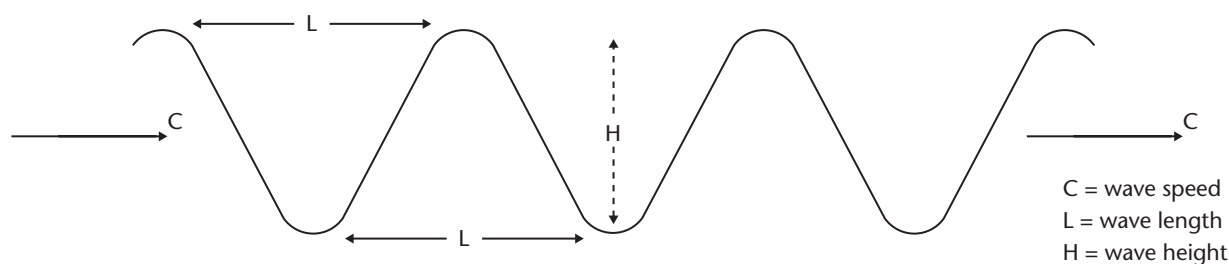


Figure III.9. Characteristics of a simple wave

- (a) Surface-following buoys that measure acceleration;
- (b) Ship-borne wave recorders that measure pressure and acceleration;
- (c) Wave staffs that measure electrical resistance or capacity;
- (d) Radar measurement instruments mounted on a platform or on land. It is strongly recommended that such recording instruments be used at ocean weather stations, research ships and fixed platforms.

Further information on wave observations is given in the *Handbook on Wave Analysis and Forecasting* (WMO-No. 446).

3.2.2.3.10 *Sea ice*

The observation of ice is described in 4.2.13, Chapter 4, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

The following four features of sea ice should be observed:

- (a) Ice thickness;
- (b) Amount—concentration (estimates expressed in eighths of sea surface covered by ice);
- (c) Types of sea ice, such as fast ice or pack ice;
- (d) Ice movement.

Reports on ice accretion at sea may be made in plain language or in code form (FM 13-XI SHIP) as indicated in Volume I.1, Part A, of the *Manual on Codes* (WMO-No. 306).

3.2.2.3.11 *Special phenomena*

WMO has been requested to provide observations of a special nature through its Voluntary Observing Ships Scheme. Examples of these are as follows:

- (a) Observations of locust swarms in sea areas around Africa, the Middle East, Pakistan and India;
- (b) Observations of freak waves which present a great danger to shipping;
- (c) Sea-surface currents, which can be determined from measurements of a ship's set and drift, and are of value to research and climate studies.

Further details on the reporting of these observations can be found in 6.4.5, Chapter 6, of the *Guide to Marine Meteorological Services* (WMO-No. 471) and its Annexes.

Waterspouts should be reported as a special observation. When describing a waterspout, the direction of rotation should always be given as if seen from above.

3.3 **UPPER-AIR STATIONS**

3.3.1 **Organizational aspects**

An upper-air observation is a direct or indirect meteorological observation made in the free atmosphere. Pilot-balloons, radiosondes, radiowinds, combined radiosondes and radiowinds, or rawinsondes are used for in situ direct measurements. Sodars, wind profilers, radio-acoustic sounding systems, lidars and other observing technologies can be used for remote sensing of the troposphere. See measured and calculated variables listed in 3.3.2.6.

3.3.1.1 **Site selection**

Once the general area for siting a station has been chosen, it is necessary to select a specific site for the facility. It is recommended that the following criteria be applied:

- (a) Government-owned land should be considered as the first choice, since there is less chance of having to relocate, and future encroachment would be minimized;
- (b) The optimum site area should be approximately 40 000 m²;
- (c) The site must be accessible by an all-weather road to facilitate delivery of supplies and proper station maintenance;
- (d) The site should not be located in a flood plain; it should have good drainage;
- (e) The site should be free from natural or man-made obstructions that would interfere with the launch, path or tracking of balloons;
- (f) Utilities such as electric power, water, sewerage and communications should be available;
- (g) The site must be surveyed to ensure that electronic equipment or telecommunications are free from any interference.

See overleaf for an example of a site survey questionnaire.

Part I, Chapters 12 and 13, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) provides further details.

3.3.1.2 **Planning of facilities**

The basic buildings on the site are the station office (Figure III.10) and the balloon inflation shelter (Figure III.11). In many cases, the radar or radiotheodolite are located above the main station building.

Design considerations for the station office are as follows:

- (a) Operational functions;
- (b) Area limitations;

Upper-air site survey questionnaire

Location: _____ Date: _____

1. (a) Describe the proposed upper-air site and enter latitude and longitude coordinates.

- (b) Attach an obstruction diagram plotted from data obtained by theodolite measurements showing direction, distance and angular elevation of all obstructions to tracking equipment above zero elevation. Attach a copy of photos arranged to form a 360° panoramic view of the horizon. If this report is being prepared for co-location with radar, panoramic photos prepared for the radar can serve the purpose.

2. (a) Where will tracking set be located? Describe location: on roof of building, on top of inflation shelter, on tower, on ground and with respect to office and inflation shelter.

- (b) Height in feet or metres: _____

- (c) Elevation in feet or metres above mean sea level: _____

3. Length of the cable run between the tracking set and the recorder: _____

4. Estimated costs. The estimates prepared in the Meteorological Department show the following:

- (a) Land – purchase or rental costs: _____

- (b) Site preparation (roads, walks, utilities): _____

- (c) Building construction or modification: _____

- (d) Communications: _____

- (e) Inflation shelter or support: _____

- (f) Conduits and cables: _____

- (g) Other: _____

TOTAL: _____

5. Remarks:

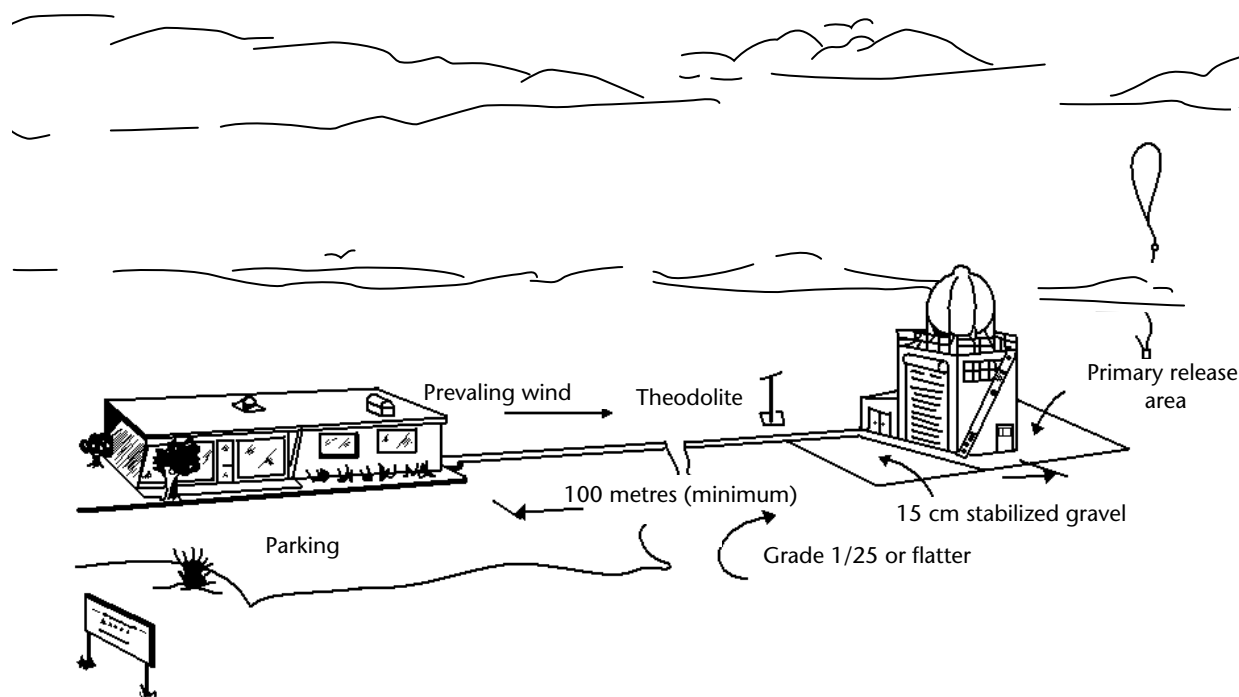


Figure III.10. Upper-air facility with station office

- (c) Severe weather protection;
- (d) Heating and cooling equipment;
- (e) Emergency electric power;
- (f) Fire protection;
- (g) Lightning protection;
- (h) Communications;
- (i) Safety techniques.

Design considerations for the balloon inflation shelter and release area are the following:

- (a) Storage of expendable supplies;
- (b) Orientation;
- (c) Area lighting;
- (d) Ventilation;
- (e) Explosion-proof electrical system;
- (f) Door openings;
- (g) Fire protection;
- (h) Pit equipped for waste;
- (i) Safety techniques.

Design considerations should also include a location for the following equipment:

- (a) Observing equipment;
- (b) Inflation equipment;
- (c) Power-generation equipment;
- (d) Communication equipment;
- (e) Hydrogen-generation equipment or helium supply;
- (f) Balloon-preparation equipment.

Station design should be in the hands of qualified architects or engineers who are familiar with the functional requirements of the activity programme

at the station, and in close collaboration with the Meteorological Service.

Several sites should be considered, site surveys should be conducted and the results submitted to the relevant authorities for official approval. Plans including specifications and other contract documents should also be prepared. Procurement of necessary equipment, design of buildings or rental of new or existing property should be undertaken.

Provisions necessary for the day-to-day operation of the station must include the following:

- (a) Procurement and storage of expendable supplies:
 - (i) Inflation gas and supplies;
 - (ii) Radiosondes, targets and balloons;
 - (iii) Engine generator fuel;
 - (iv) Office materials;
- (b) Adequate documentation such as the *Technical Regulations* (WMO-No. 49), Manuals and Guides;
- (c) Complement of spare parts;
- (d) Maintenance and supplies for buildings and grounds;
- (e) Space for electronic technician for on-site or on-call equipment maintenance.

3.3.1.3 Organization of the upper-air unit

The upper-air unit consists of those components required to carry out upper-air observations. It includes all aspects of facilities, personnel, equipment and maintenance for any upper-air observations made at the station: pilot-balloon, radiosonde,

radiowind, rawinsonde, combined radiosonde and radiowind observations.

The upper-air unit may or may not be in the same location as other weather services. It may also provide the only type of observation made by a participating Member at a particular station. Co-location of weather services and observations is often a cost-effective approach. Usually, the unit is merely a part of another observational office. Observers usually perform other functions in addition to upper-air observations. However, in some cases it may be necessary to maintain the unit apart from the other weather services. Observers may staff the upper-air unit alone, or

perform duties at both locations. If upper-air observations are the only service provided at a station, observers would require upper-air training only.

Regardless of the unit's location, certain organizational relationships must be developed to ensure its efficiency. When the upper-air unit is co-located with other weather services, upper-air observations become an integral part of the organization. Personnel skills, work schedules, training and the like must be expanded or modified to meet upper-air observational requirements. When the unit is not co-located with the main weather office, it may or may not be an integral part of the latter. With few exceptions, the

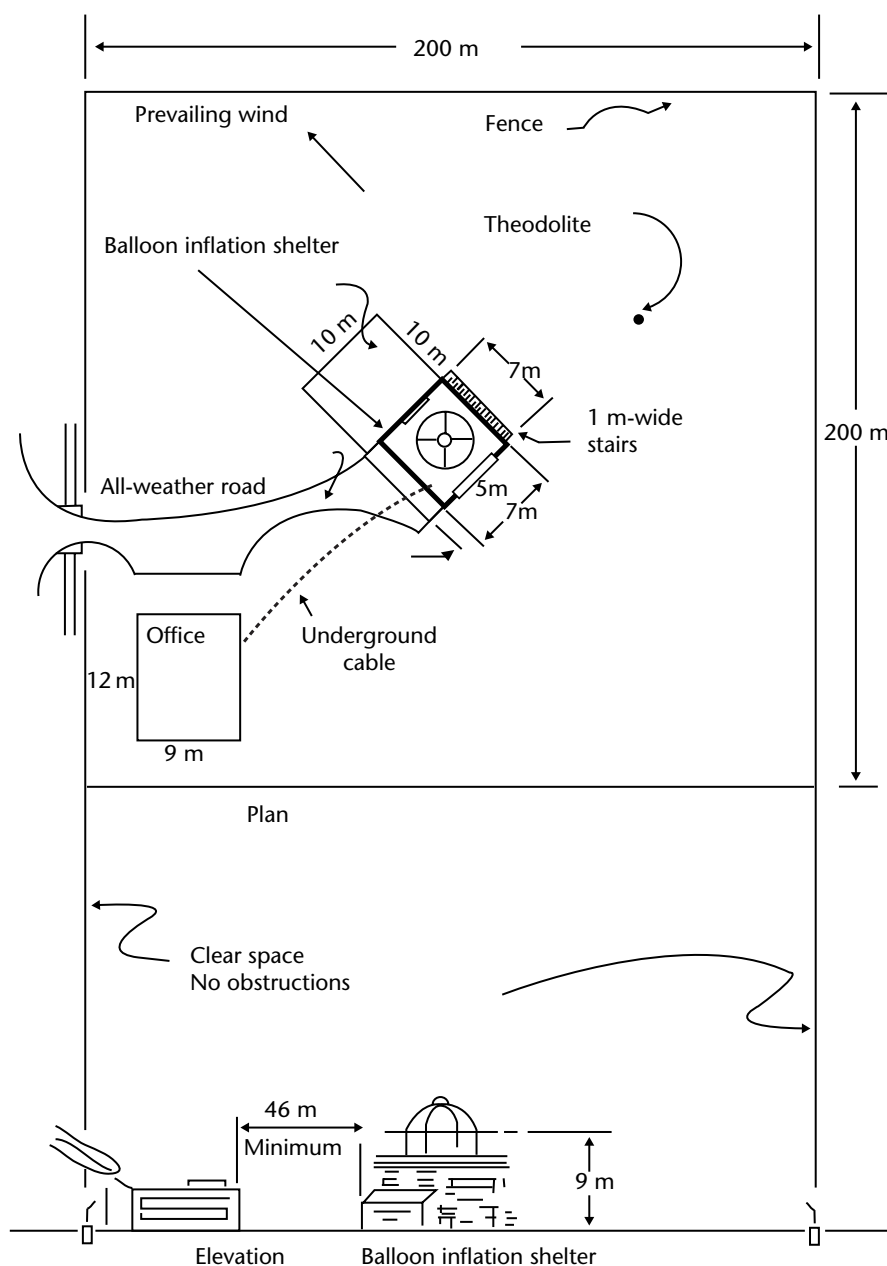


Figure III.11. Upper-air site

upper-air unit should ideally have an organizational relationship with another weather office.

If applicable, the upper-air unit should have a close working relationship with a central headquarters whose function may consist of establishing policies and regulations, ordering materials and supplies and providing training.

3.3.1.4 Archiving data and maintenance of records

Archiving upper-air data after completing an observation is very important to the World Weather Watch and the World Climate Programme. A complete set of records containing pertinent observational data must be kept by the station or the central headquarters, or in another location. In addition, the data may be stored on a medium such as magnetic tape or disk. Countries that can do so are advised to make provisions to supply the data upon request.

Further details can be found in 12.10.2, Part I, Chapter 12 of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

In addition to the data archives mentioned above, the upper-air unit should keep the following records to monitor operations:

- (a) Various types of information relating to the observation, for example, bursting height, reason for termination, problems encountered during the flight and type of radiosonde used;
- (b) A complete list of instruments and other office equipment used to obtain and transmit the data.

3.3.1.5 Communications

The unit responsible for transferring the data from the upper-air unit to national communications circuits and the Global Telecommunication System may vary from Member to Member.

Some countries may employ communicators or communications specialists who ensure that the data are disseminated over the Global Telecommunication System network in a timely fashion. In other countries the observer, or even personnel not associated with the upper-air unit, may be given this responsibility. Some Members use trained private-sector individuals under contract with National Meteorological Services.

For the data to be of any value, they must be entered into the distribution network at the required times. Alternative means to communicate information should be available when the primary communications link has been disrupted.

The following communications equipment is needed to disseminate data, depending, inter alia, on the quality of communications circuits, remoteness of the upper-air unit and availability of satellite ground stations:

- (a) Interface to public communication networks;
- (b) Telegraphs;
- (c) Telex typewriters;
- (d) Radioteleprinters;
- (e) Radio facsimile broadcasts;
- (f) Radios;
- (g) Satellite-based communication equipment.

The data may be transmitted to the central headquarters, which sends them to the Global Telecommunication System network. In some cases, another weather office or agency may be responsible for transmitting the data to the Global Telecommunication System network.

3.3.1.6 Personnel

The type and number of upper-air unit personnel depend on the equipment used, and the level of expertise and number of observations required. The type and degree of training depend on the role and responsibilities of the staff members.

Personnel requirements by category are outlined below; examples of the recommended number of personnel are provided in Tables III.3 and III.4.

- (a) Station supervisor (WMO classification: Meteorologist; designated as "S" in Tables III.3 and III.4)

When more than one person is employed in the upper-air unit, a supervisor should be designated. The relationship between the supervisor and the other staff is crucial to a well-run office. The supervisor should be one of the most experienced people in the upper-air unit, preferably with expertise in areas other than upper-air observations, such as hydrogen safety and other upper-air instruments and equipment. Good communications and management skills are also important. A supervisor's main duty is to manage the upper-air unit so that it functions efficiently. Another is to serve as the unit's spokesman when communication with other weather offices or agencies is required. In particular, this responsibility should include the following duties:

- (i) Seeking guidance from the central headquarters when a higher authority is required;
- (ii) Establishing work schedules for station personnel;
- (iii) Keeping inventories of all supplies and expendables and ordering them in time;
- (iv) Ensuring that all relevant policies and regulations are carried out by the station personnel and that the WMO *Technical*

Regulations, Manuals and Guides and other such documentation are kept up to date and available to the station personnel;

- (v) Ensuring that all safety precautions are observed with respect to hydrogen gas, upper-air instruments and equipment, power installations and other equipment.

(b) Shift supervisor (WMO classification: Meteorological Technician) (SS)

The designation of shift supervisors is desirable at a station performing manual upper-air observations and is optional for all other methods of observation. Shift supervisors, who are amongst the most experienced observers assigned to each shift, should have a broad operational background. The minimum requirements can be fulfilled with on-the-job training.

(c) Observer (WMO classification – Meteorological Technician) (O)

The number of observers required to carry out an observation depends on the methods used (automatic, semi-automatic, manual) and the observers’ level of experience. Although previous experience in upper-air observations is not required, formal and on-the-job training are necessary.

(d) Maintenance staff/technicians (WMO classification: Meteorological Technician) (M)

Minimum requirements for maintenance personnel/technicians are a high school or technical school diploma. They must also have specialized training in the maintenance and operation of some types of equipment, some knowledge of station equipment, a basic understanding of the physical atmosphere and a minimum of two years’ recent experience.

(e) Communicator (C)

The role of communicators will depend on the volume of information transmitted and the diversity of responsibility. Their basic training should include course work; further experience will be

gained through on-the-job training. In some cases, a licence for operating the appropriate communications equipment may be required.

Notes:

1. The tables should be used as a staffing guide, not to establish minimum requirements.
2. For a description of the classification of meteorological personnel and their duties, see *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology* (WMO-No. 258).

3.3.1.7 Training

The purpose of a training programme is to ensure that the personnel in the upper-air facility are able to meet all the demands made of them. These include the administration and management of the station and the effective operation of the observing programme as well as the implementation of new requirements or modifications to operating procedures that may be requested. Training of a recurring nature is therefore important.

Technical training should cover operational and maintenance aspects. Operational training is required for the meteorological technician who selects the pertinent meteorological data from the equipment. Observers are key members of the team in this category since they are responsible for data acquisition, sounding reduction and preparation of the data for local use and transmission over the telecommunications systems. Training is essential, whether acquired on-the-job or through formal course work.

Maintenance training is required for personnel responsible for preventive and corrective maintenance of the system. In order to understand adequately the operation of electronic and electro-mechanical devices, and to maintain them, it is necessary to understand the theory on which they are based. The theory provides the foundation for understanding the operation of present-day and proposed operational meteorological equipment.

Table III.3. Example of recommended observational personnel requirements – number per observation

Observing method	Pilot balloons						Radiosondes						Rawinsondes						Radiowinds					
	S	SS	O	C	M	T ^a	S	SS	O	C	M	T ^a	S	SS	O	C	M	T ^a	S	SS	O	C	M	T ^a
Automatic	-	-	-	-	-	-	1	-	1	1 ^b	1 ^b	2	1	-	1	1 ^b	1 ^b	2	1	-	1	1 ^b	1 ^b	2
Semi-automatic	1	-	1	1 ^b	-	2	1	-	1	1 ^b	1 ^b	2	1	-	1	1 ^b	1 ^b	2	1	-	1	1 ^b	1 ^b	2
Manual	1	1 ^b	1	1 ^b	-	2	1	1	1	1 ^b	1 ^b	3	1	1	2	1 ^b	1 ^b	4	1	2	1	1 ^b	1 ^b	4

^a Minimum number of personnel needed to carry out observation; optional staff not included
^b Optional positions for observing programme; supervisors considered part of observing programme

Table III.4. Example of recommended observational personnel requirements – number per week

Observations/ day	Observing method	Pilot balloons					Radiosondes					Rawinsondes					Radiowinds								
		S	SS	O	C	M	T ^a	S	SS	O	C	M	T ^a	S	SS	O	C	M	T ^a	S	SS	O	C	M	T ^a
1	Automatic	-	-	-	-	-	-	1	-	2	2 ^b	1 ^b	3	1	-	2	2 ^b	1 ^b	3	1	-	2	3 ^b	1 ^b	3
	Semi-automatic	1	-	2	2 ^b	-	3	1	-	2	2 ^b	1 ^b	3	1	-	2	2 ^b	1 ^b	3	1	-	2	3 ^b	1 ^b	3
	Manual	1	2 ^b	4	2 ^b	-	5	1	2	2	2 ^b	1 ^b	5	1	2	4	2 ^b	1 ^b	7	1	2	4	3 ^b	1 ^b	7
2 or 3	Automatic	-	-	-	-	-	-	1	-	3	3 ^b	1 ^b	4	1	-	3	3 ^b	1 ^b	4	1	-	3	3 ^b	1 ^b	4
	Semi-automatic	1	-	3	3 ^b	-	4	1	-	3	3 ^b	1 ^b	4	1	-	3	3 ^b	1 ^b	4	1	-	3	3 ^b	1 ^b	4
	Manual	1	3	6	3 ^b	-	7	1	3	3	3 ^b	1 ^b	7	1	3	6	3 ^b	1 ^b	10	1	3	6	3 ^b	1 ^b	10
4	Automatic	-	-	-	-	-	-	1	-	4	4 ^b	1 ^b	5	1	-	4	4 ^b	1 ^b	5	1	-	4	4 ^b	1 ^b	5
	Semi-automatic	1	-	4	4 ^b	-	5	1	-	4	4 ^b	1 ^b	5	1	-	4	4 ^b	1 ^b	5	1	-	4	4 ^b	1 ^b	5
	Manual	1	4 ^b	8	4 ^b	-	9	1	4	4	4 ^b	1 ^b	9	1	4	8	4 ^b	1 ^b	13	1	4	8	4 ^b	1 ^b	13

^a Optional positions for observing programme; supervisors considered part of observing programme

^b Minimum number of personnel required to carry out observing programme; optional staff not included

Instructions in theory should therefore have priority in the training of a maintenance technician. Appropriate practical training should also be provided to the staff before they attempt to maintain sophisticated and equipment at their facilities.

A variety of training opportunities are often available at local or regional universities, technical schools, or factories producing specialized meteorological equipment. On-the-job training should be arranged either at the local facility or at another which performs the same function. On-the-job-training in the use of complex equipment is sometimes provided upon the successful conclusion of formal schooling instead of classroom study. Non-technical training is as important as technical training as a basis for achieving operational efficiency of the facilities.

3.3.1.8 Quality standards

Reference should be made to:

- Manual on the Global Data-processing and Forecasting System* (WMO-No. 485), Part II, 2.1.3, Minimum standards;
- Guide on the Global Data-processing System* (WMO-No. 305), Chapter 6.

3.3.2 Observations/measurements

3.3.2.1 General

The basic regulations are contained in 2.4, Part III, of the *Manual on the Global Observing System* (WMO-No. 544).

Upper-air soundings are taken with a number of different types of instruments on land and at sea, at permanently established stations and on moving platforms, including research vessels. For further information on applicable measurements, see Chapters 12 and 13, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.3.2.2 Pilot-balloon observations

Pilot-balloon observations are one of the oldest and simplest methods of upper-air observation in use today. They involve the visual tracking of a pilot balloon as it rises by means of an optical theodolite. An assumed ascension rate according to the balloon weight and the lifting gas provides the height needed to calculate the wind speeds and direction. Observers read the elevation and azimuth angles for a designated time period for as long as the balloon can be tracked visually. The data may be plotted to derive the necessary wind data or entered into a calculator or computer for semi-automatic data reduction.

Although this type of upper-air observation is primitive in comparison to other methods, it is still used by some Members. It can be an inexpensive, simple-to-operate sounding procedure, especially in climates which enjoy many cloud-free days. The major disadvantages of this technique are that the observations are limited, even by small amounts of cloud cover. Moreover, measurement uncertainty is directly proportional to the validity of the assumed ascension rate.

Further information can be found in 13.3.2, Chapter 13, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.3.2.3 Radiosonde observations

Of all the upper-air observations which use telemetry signals to collect data, radiosonde observations continue to be the basic observation. Generally speaking, most radiosondes in use today measure the basic variables of temperature, pressure and relative humidity (or dew point). These measurements are carried out by sensors mounted in an instrument package which also contains a radio-frequency transmitter. The transmitter communicates these data to the ground-receiving equipment which may be converted into a strip chart recording or go directly into a computer for further analysis. Regardless of the method employed, these data must be converted into an easily recognizable, standardized form in accordance with the *Technical Regulations* (WMO-No. 49).

The radiosonde design and the exposure of its sensors should be such as to minimize adverse effects of solar and terrestrial radiation, precipitation, evaporation or freezing on a sensor. Suitable radiation corrections should be made if necessary. A control or check reading for each sensor should be performed a few minutes before the radiosonde is released.

At synoptic upper-air stations, the vertical distances of an ascending radiosonde shall be determined by means of hydrostatic computation or precision radar tracking. Variables measured by a radiosonde and the desirable ranges and uncertainty requirements are given in Annex 12.A, Chapter 12, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

A properly made radiosonde observation gives a two-dimensional picture of the atmosphere and a three-dimensional picture when used in an upper-air network. For those Members not having the use of a wind-finding apparatus, pilot-balloon observations can be made in conjunction with radiosonde observations. The heights can be accurately derived from the radiosonde data which, in turn, will produce accurate wind data.

Further information can be found in Chapter 12, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.3.2.4 Radiowind observations

A common radiowind observing method uses a windfinding radar that tracks a reflective surface attached below the balloon. In practice, most operational windfinding radars have difficulty in measuring height with sufficient accuracy to satisfy user requirements for pressure and height measurements in the troposphere.

The major advantage of this observing method is that the necessary equipment for this type of upper-air observation is generally small and can be mounted almost anywhere. This system works best in climates which are not influenced by upper-air jets since the radar range is usually limited to under 100 km. The disadvantage is that it may be influenced by passing high-altitude aeroplanes causing the radar to lose track of its target.

Further information can be found in 13.2.2, Chapter 13, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.3.2.5 Rawinsonde observations

The most widely used type of upper-air observation in the world today is that of the rawinsonde, which stands for radio-sounding wind. Rawinsonde and radiowind observations differ in their observing method. Rawinsonde observations keep track of the radiosonde position and use that information to make wind calculations. It uses the radiosonde as the active target. Another difference is that the methods of collecting the positional data may vary. Two types of wind-finding methods are used in most of today's rawinsonde observations and include the use of radio direction finding (RDF) systems and navigation aid (NAVAID) signals such as GPS and long-range navigation (LORAN-C).

These systems vary in complexity, ranging from the use of strip chart recorders to highly sophisticated computers which automatically analyse the data. In general, RDF involves the use of large wind-finding equipment and NAVAIID, relatively small wind-finding equipment. The pros and cons of the various systems are discussed in 3.3.2.8.

3.3.2.6 Combined radiosonde and radiowind observations

Upper-air observations involve the use of the radiosondes in conjunction with radar. The radiosondes are equipped with sensors for measuring

meteorological variables. They have a transmitter which communicates meteorological data and at the same time serves as an active target for radar determination of the radiosonde position. This type of upper-air observation provides the highest number of measured variables, such as temperature, humidity, pressure, height of ascent and wind speed and direction.

The variables listed below can be measured or derived from the basic measurements described in the previous sections:

- Wind speed and direction
- Constant pressure/height levels
- Analysed tropopause data
- Dew point/dew-point depression
- Stability index (optional)
- Mean winds (two levels)
- Wind shear
- Observation clouds (optional)
- Maximum wind
- Freezing level (optional)
- Minimum/maximum temperature and relative humidity for the observation
- Observation explanations (optional)
- Superadiabats and inversions (climate)
- Other data

3.3.2.7 Aerological soundings using automated shipboard or land-based upper-air systems

The development and successful trials of a highly automated system known as the automated shipboard aerological programme (ASAP) offers additional possibilities for obtaining upper-air observations from ocean areas as well as isolated land areas.

ASAP involves the generation of upper-air profile data from data-sparse ocean areas using automated sounding systems carried on board merchant ships plying regular ocean routes. The profile data are available in real time on the Global Telecommunication System, for use by operational centres. ASAP is of vital importance to both the World Weather Watch and the Global Climate Observing System. Several National Meteorological Services operate ASAP units, and the programme is coordinated through the ASAP Panel, a component of the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology Ship Observations Team. Most of the soundings are presently made from the North Atlantic and North-West Pacific Oceans. The Ship Observations

Team publishes an annual report, giving ASAP programme status and statistics on data return and data quality.

The main components of the ASAP system are the launcher, automatic upper-air and communication systems and the land-based ground station, which receives the data via satellite and inserts them into the Global Telecommunication System. The release of the balloon is automatic and its position as it ascends is determined by using the global positioning system to calculate the winds aloft. All of the data processing is done automatically by computer, which converts the sounding data to standard coded message form for relay via a geostationary meteorological satellite using its data-collection system. The high degree of automation allows the ASAP system to be operated by one person.

Figure III.12 provides an example of the system. The example is taken from a ship crossing the Pacific between Japan and Canada. A sketch of the container is given in Figure III.13.

3.3.2.8 Upper-air systems

An upper-air sounding system consists of two primary components that are needed to make one or more of the upper-air observations mentioned in 3.3.2.2 to 3.3.2.6: a radiosonde that measures and transmits meteorological data and a ground station that receives the telemetry and processes it into meteorological data products. Those systems in turn are composed of five main parts:

- (a) Radiosonde/transmitter;
- (b) Antenna(s)/receiver(s);
- (c) Signal processing system (decoder);
- (d) System computer;
- (e) Meteorological operating system (software).

An upper-air system can also contain peripheral equipment specific to certain manufactures such as radiosonde ground check devices.

Figure III.14 contains a simplified system diagram of the RDF (a) and GPS (b) type system.

An important difference between the two formats is that the 1680 MHz receiver is located in the antenna for RDF systems. The 403 MHz global positioning systems require two receivers (UHF and differential GPS), both of which are located in the meteorological processor. This makes it a much more complex and costly device than the corresponding signal processor used in RDF systems.

3.3.2.8.1 *Plug-and-play systems or interoperability*

There are several reasons why upper-air systems have become closed rather than open, plug-and-play type systems:

- (a) Manufacturers use proprietary methods to decode, correct and process the pressure, temperature and humidity data collected by their radiosondes. These methods cannot be disclosed without putting trade secrets at risk;
- (b) Plug-and-play compatibility is expensive to develop and there is no incentive for manufacturers to provide it;
- (c) Manufacturers have an incentive to control all parts of the system in order to maintain quality and provide seamless integration. If one manufacturer does not control the complete system, it becomes difficult to determine who is responsible if there is a system malfunction;
- (d) Users generally do not require it.

3.3.2.8.2 *RDF systems interoperability*

The 1680 MHz RDF systems have demonstrated the technical feasibility of interoperability. For an RDF system to use a new radiosonde, two conditions must be met by the sonde manufacturer:

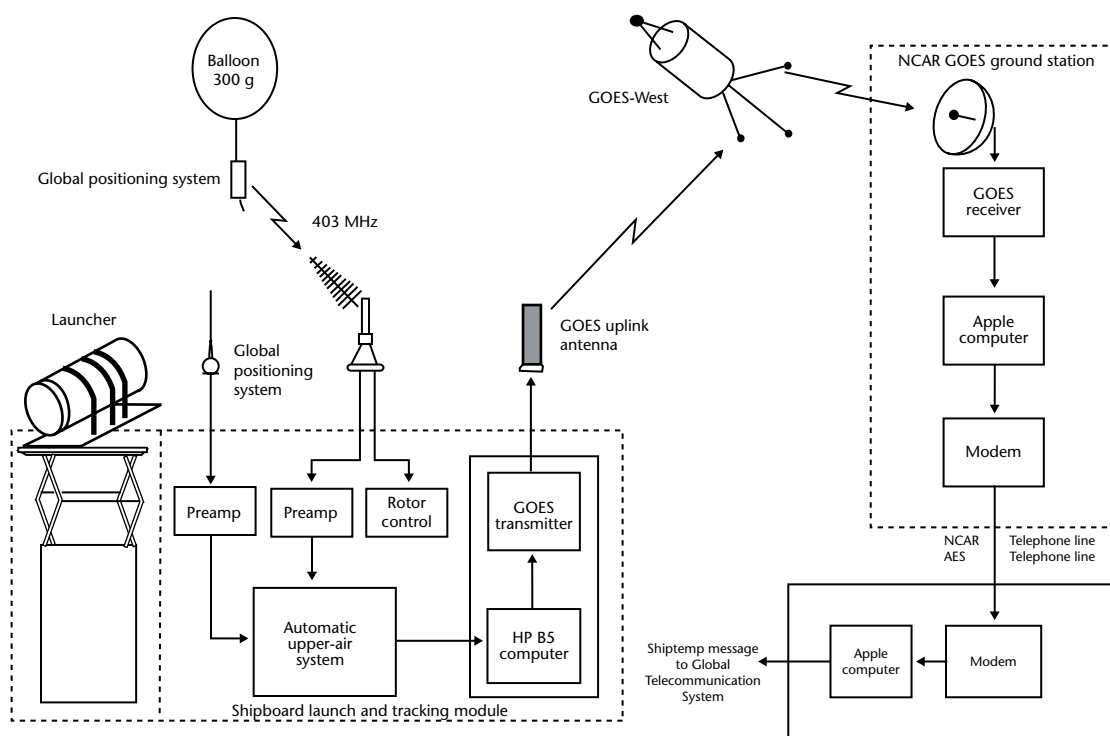
- (a) A sonde-specific signal processing system must be supplied that is compatible with the antenna and system computer;
- (b) Certain algorithms have to be provided to the antenna supplier so the Meteorological Operating System can apply sonde-specific calibration and data corrections.

After a new sonde has been integrated into the operating system, it should be possible to change over from one sonde to another in a matter of minutes.

3.3.2.8.3 *GPS systems interoperability*

Although it is theoretically possible, operational interoperability has not been demonstrated in 403 MHz GPS systems. There are three main reasons for this:

- (a) The signal processing system that is swapped out for compatibility in RDF systems (Figure III.14 (a)) is a relatively simple and low-cost device. The meteorological processor used in GPS systems (Figure III.14 (b)) is significantly more expensive since it includes the system's receivers as well as the sonde decoder;
- (b) The UHF antennas and low-noise amplifiers included with 403 MHz GPS systems are not



NCAR = National Center for Atmospheric Research, USA

Figure III.12. Example of an automated shipboard aerological programme system

standardized and need to be carefully integrated with the corresponding receivers in the meteorological processor;

- (c) Algorithms required for the meteorological operating system are more extensive than merely calibration and solar correction. Since most sonde manufacturers use proprietary GPS wind-finding schemes, this code would also have to be integrated.

For further details on present systems, see Part I, Chapters 12 and 13, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.3.2.8.4 Optical theodolites

Optical theodolites, derivatives of the surveyor's instrument, were one of the first upper-air devices developed. They use a telescope-type apparatus which the observer uses to track a balloon. For a specific time interval selected—usually one minute—the elevation and azimuth angles are recorded according to the height, which has been estimated. Section 13.2.1, Chapter 13, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) gives a more complete description of this technique.

3.3.2.8.5 Radio direction-finding (RDF)

One of the most widely used methods of deriving wind information is through the use of RDF. The basic design of an RDF system consists of a parabolic disk antenna, a radio receiver and either a strip chart recorder or a direct link to a computer. To obtain wind information, the elevation and azimuth angles and slant ranges of the antenna are sampled with respect to a given time increment, usually at one-minute intervals. The antenna range for receiving the radiosonde signal depends on the power and antenna gain.

RDF offers Members the ability to track accurately the radiosondes to an uncertainty of $\pm 0.5^\circ$ for the elevation and azimuth angles and ± 20 m for slant ranges. Wind calculations are derived from spherical geometry techniques which make them easily accessible to computer reduction algorithms.

The antennas may measure from 2 to 3 metres up to 5 to 6 metres in diameter. They usually require shelter from the elements, and older versions require a fair degree of maintenance due to the myriad moving parts. The antenna's ability to collect accurate angular/slant-range data may be

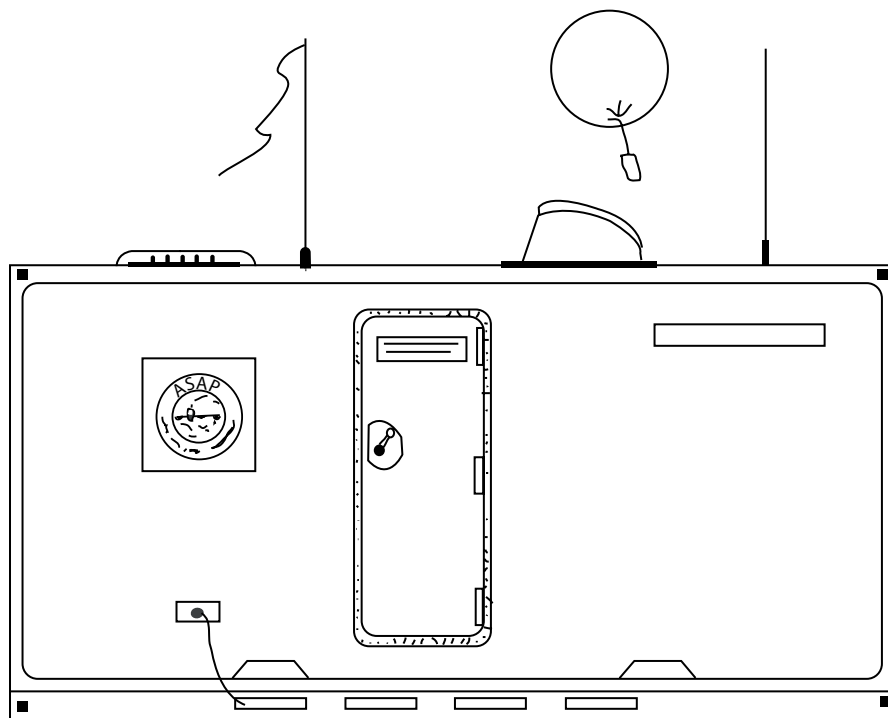


Figure III.13. Marine module for the shipboard installation of an ASAP launching and tracking module

affected by obstacles such as buildings and trees lying between the antenna and the radiosonde.

3.3.2.8.6 *Wind-finding radar*

The derivation of winds is achievable through translation with the use of a tracking station. Wind-finding radars, as the name implies, can derive wind information without having to use a radiosonde to calculate heights. Although similar to radio theodolites in many ways, they acquire data somewhat differently. Instead of homing in on a radio signal like a radio theodolite, the radar emits pulses that are reflected from a target suspended below the balloon. These reflected pulses measure the distance between the station and balloon which, when combined with the elevation and azimuth angles, produce highly accurate wind data. Section 13.2.4, Chapter 13, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) provides a more complete description of this technique.

3.3.2.8.7 *NAVAID systems*

The principle of wind finding with the use of NAVAIDs is simple. A balloon or parachute, equipped with a NAVAID receiver, retransmits the NAVAID signals to a base station. They are transmitted from a number of fixed stations through the sonde to the

base station. The difference in the signals' time of arrival is used to determine the range difference between pairs of stations. Since the path from the sonde to the base station is identical for each transmitter, the measurement of range differences eliminates the common path from the sonde to the base station. The base station can, therefore, be in motion without introducing error to the wind computation. The technique is ideally suited for measuring winds from a moving ship with a balloon sonde. See 13.2.5, Chapter 13, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) for a more complete description of this technique.

LORAN-C is a navigation system used to provide accurate ship navigation. A number of chains cover the Pacific, Atlantic and Gulf Coasts, and the Aleutians. Global coverage, however, is not available. Only a few LORAN-C NAVAID systems have been built, but they provide excellent wind accuracy if located in areas of good coverage.

3.3.2.8.8 *Other upper-air systems*

3.3.2.8.8.1 *Safesondes*

The safesonde system consists of a base station, a reference transmitter and three translator stations located 3 to 5 km from the base station. Signals are

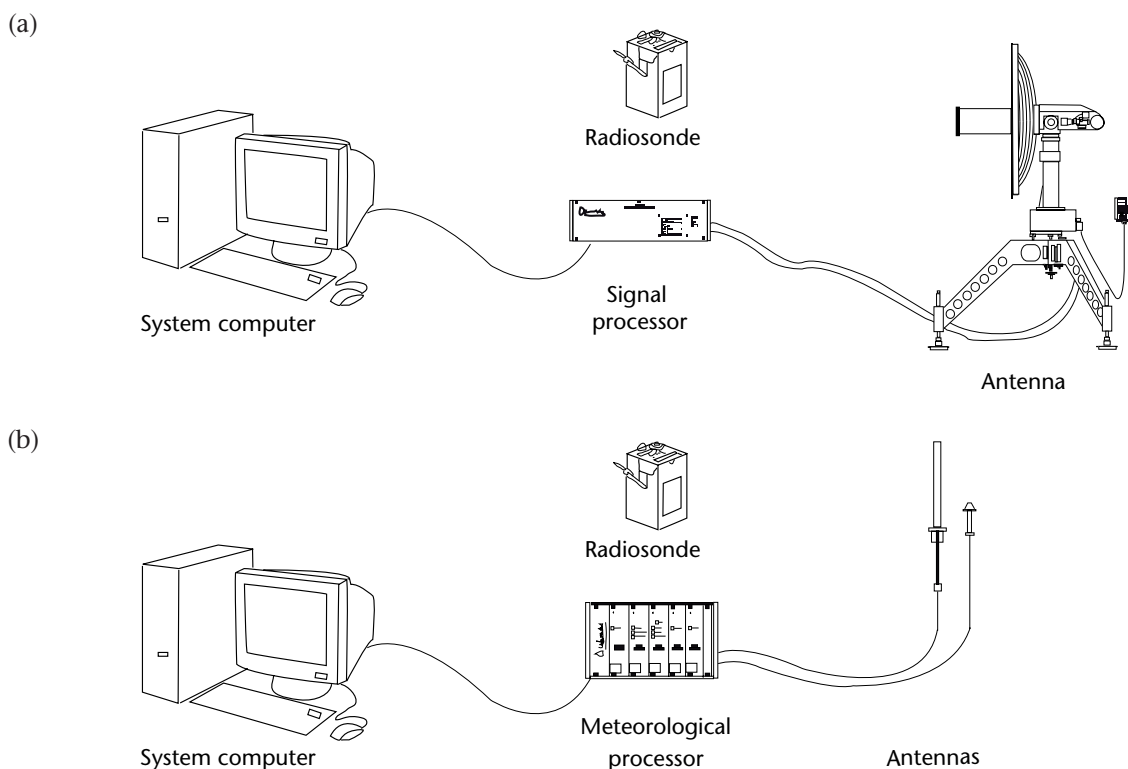


Figure III.14. RDF (a) and GPS (b) upper-air sounding systems

retransmitted from a radiosonde at 403 MHz and retransmitted at 1 680 MHz from the translator stations to the base station. Phase comparison of the received signals permits the computation of the radiosonde location in three dimensions. Temperature, humidity and pressure data are transmitted to the base station. These data are then used to compute altitude independently as a check on the measured altitude. The computations for all parameters are performed by a small computer with no need for an operator after the balloon has been released.

Within the network, balloon motion is measured to an uncertainty of a few centimetres per second. At large distances from the network, errors increase markedly. Network dimensions can be increased to provide precise data at extended ranges. Typical errors for the system are 0.5 m s^{-1} for 10-s averages up to 5 km altitude. At higher altitudes, uncertainty depends on system baseline dimensions and balloon distance from the network. Uncertainty better than 1 m s^{-1} should be achieved for 1-m averages over all altitudes.

3.3.2.8.8.2 Aircraft dropwindsondes

Dropwindsondes operate in the same fashion as radiosondes, telemetering data on pressure, temperature and humidity. A parachute is used rather than a balloon and the sondes must be designed to take high shock loadings on release. Current dropwindsondes may pose a danger to populated areas because of their rugged design.

Until the development of the navigation-aid sonde, a number of expensive and abortive attempts were made to develop a dropsonde which could measure winds. With the NAVAID sonde, the problem was resolved. Measurements are made of the difference in phase of the signals received by the sonde from the several transmitting stations.

3.3.2.9 Observational requirements

3.3.2.9.1 Time and frequency of observations

According to 2.4.2, Volume I, Part III, of the *Manual on the Global Observing System* (WMO-No. 544), the standard times of upper-air synoptic observations shall be 0000, 0600, 1200 and 1800 UTC. The actual time of observation in relation to the standard time of observation is outlined in 2.4.10, Volume I, Part III, of the *Manual on the Global Observing System* (WMO-No. 544). The number and time of observations are specified in 2.4.8, 2.4.9 and 2.4.11 of the aforementioned reference.

3.3.2.9.2 Type of observation

The central headquarters will decide whether upper-air synoptic observations, low-level observations, or a combination of the two should be made, meeting the requirements set out in 2.4.6, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544).

3.3.2.9.3 Observer functions

Observers should follow the pre-release, data evaluation and verification procedures in accordance with the standard operating procedures and other instructions given to the station.

The pre-release procedures include checking the radiosonde and ground equipment to ensure that they are working properly, inflation of the balloon and preparations for entering the observational records.

Data evaluation procedures may consist of automatic, semi-automatic or manual computations. Some pilot-balloon calculations are now semi-automatic or automatic.

Data validation procedures are limited to some extent in automatic upper-air systems. Data validation procedures for semi-automatic systems are carried out partly by the computer and partly by the observer.

Observers may be required to carry out periodic equipment checks separately from the actual observation and to regulate or adjust the equipment in accordance with the standard procedures for the equipment in use. (Certain types of equipment such as radiotheodolites and barometers require comparison with standards to verify accuracy of the data). When the equipment is inoperative or malfunctioning, observers are advised to make an entry to this effect in an equipment log. The upper-air unit must have back-up procedures or back-up equipment when the primary equipment is inoperative. Manual computation may be necessary when a computer becomes inoperative.

3.3.3 Special management considerations

3.3.3.1 General

Upper-air observation is a complicated and costly activity which is undertaken to obtain data for a three-dimensional analysis of the atmosphere. There is, therefore, a need for rigorous working standards at each station which should be ensured by proper arrangements for station management and operation.

A Member operating a network of upper-air stations should establish an appropriate organizational unit within the National Meteorological Service having responsibility for all aspects of network management, such as station operation, maintenance and supervision; logistics; procurement and supply of equipment and other necessary material to ensure the efficient and uninterrupted functioning of the stations.

The basic principles to be followed in organizing management unit activities for an upper-air station network are the same as those for a similar unit responsible for a surface synoptic network (see 3.1.3 and 3.2.1). Therefore, only those aspects which are applicable to upper-air stations are discussed in the present section.

3.3.3.2 Procurement of instruments and equipment

For further information on instruments and equipment, please refer to Chapters 12 and 13, Part I, and Chapter 10, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8). The WMO Secretariat can also provide additional advice.

Useful information on currently used radiosondes and systems can be found in the *WMO Catalogue of Radiosondes and Upper-air Wind Systems in Use by Members in 2002 and Compatibility of Radiosonde Geopotential Measurements for Period from 1998 to 2001*, Instruments and Observing Methods Report No. 80 (WMO/TD-No. 1197).

3.3.3.3 Maintenance

The purpose of a maintenance programme is to keep equipment in good operating condition and obtain desirable performance from the system. The maintenance programme should include preventive maintenance, equipment calibration, periodic cleaning and lubrication, performance testing, corrective and adaptive maintenance and equipment modification, as necessary. Section 12.9, Chapter 12, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) discusses this topic.

Preventive maintenance is important and must be conducted extensively on all equipment. It is more efficient and effective to keep equipment running than to correct a breakdown. Scheduling preventive maintenance is an absolute necessity for the successful continued operation of an upper-air system. Original equipment manufacturers,

usually through testing and evaluation programmes, have determined a preventive maintenance programme to be followed by users, which must be followed carefully during the entire period of use of the equipment to ensure correct functioning. Where local guidelines regarding the maintenance programme do not conflict with the manufacturer's standards, they may be followed. Where conflict in guidelines exists, clarification should be sought from the manufacturer.

The purpose of periodic equipment inspections and/or calibration is to ensure the continuous operation of the equipment with a minimum of outage time. The inspection should include a detailed visual examination to detect any physical deterioration, corrective action as necessary, checking of the mechanical functions of the equipment to ensure their operation within specifications and applicable tolerances and checking of all electrical functions to ensure that the inputs and outputs meet the manufacturer's specifications.

Periodic performance testing provides information on what can be expected when the equipment is under operating conditions. It is also an effective way to discover and correct malfunctioning equipment prior to use. Regularly scheduled performance testing is advised to maintain the equipment in a satisfactory operating mode. Simulated operations should be performed to check the equipment and ensure that all facets of the operation are within specifications and provide the required data.

An effective corrective maintenance programme involves ensuring the availability of adequate supplies, spares, and trained electronic and other maintenance personnel.

Original equipment manufacturers usually prescribe procedures and techniques to be followed in determining and correcting equipment malfunctioning. These techniques and procedures are based on laboratory testing and experience gained from field operations and must be followed first in attempting to correct equipment failures and maintain the quality standards of the operation. There are times when a disruption in the operation of a facility can arise from a local and unusual occurrence which may not have occurred elsewhere. Such malfunctions should be documented for future reference and forwarded to Members having similar equipment.

Trouble-shooting procedures are closely integrated with corrective maintenance and can be viewed as a combined technique for correcting any malfunctions.

The design of equipment may feature one or more components whose mean time between failures is below what is expected. These components must be given special attention in a maintenance programme and if they deteriorate rapidly, the original equipment manufacturer must be informed for possible redesign. Care must be exercised in making locally initiated equipment modifications to ensure that the change is within the manufacturer's specifications and that no change occurs in the uncertainty and temporal resolution of the data.

3.3.3.4 **Budgetary requirements**

The purpose of determining budgetary needs is to ensure that resources are available for the efficient and effective operation of the upper-air facility. Standards should be developed to determine the number of people needed at a facility for the type of operation contemplated. (See 3.3.1.6 and Tables III.3 and III.4.) Budgetary needs should be established on that basis. Budgetary requirements for maintenance, supplies and other support activities should also be prepared in a similar fashion. Resources must be made available for all personnel involved in the station operations.

3.4 **AIRCRAFT METEOROLOGICAL STATIONS**

3.4.1 **General**

An aircraft meteorological station is an aircraft in flight from which meteorological data are obtained by utilizing instruments and equipment installed for navigational purposes. The measured data can be supplemented by the observation of visual, weather phenomena and by subjective or objective assessments of turbulence and icing. When compiled into reports, they constitute a vital part of the global data base. The reports are of particular value over areas where other upper-air data are scanty or lacking. They can provide information on atmospheric phenomena such as wind, temperature and turbulence along horizontal and vertical profiles on a much smaller scale than do other routine observing systems. Thus, they also constitute a valuable source of information for the issuing of reports on significant weather phenomena and for special investigations and research. The collection and evaluation of post-flight reports is also an invaluable data source. Subject to timely receipt, processing and dissemination, they can be of use for forecasting purposes.

Over recent years it has become evident that valuable meteorological data can be obtained from large areas of the world by collecting data from aircraft fitted with appropriate software packages. To date the predominant sources of automated aviation data have been from aircraft-to-satellite data relay (ASDAR), and more recently, from aircraft equipped with aircraft communication addressing and reporting systems (ACARS).

Aircraft communication and reporting systems route data back via general-purpose information processing and transmitting systems now fitted to many commercial aircraft. Such systems offer the potential for a vast increase in the provision of aircraft observations of wind and temperature.

The various systems—ASDAR, ACARS—are collectively named AMDAR, which stands for aircraft meteorological data relay. They are making an increasingly important contribution to the observational data base of the World Weather Watch of the World Meteorological Organization. It is envisaged that AMDAR data will inevitably supersede manual air reports (AIREP).

AMDAR systems operate on aircraft which are equipped with sophisticated navigation and other sensing systems. There are sensors for measuring air speed, air temperature and air pressure. Other data relating to aircraft position, acceleration and orientation are available from the aircraft navigation system. The aircraft also carry airborne computers for the flight management and navigation systems, by which navigation and meteorological data are computed continuously and made available to the aircrew at the flight deck.

In AMDAR systems, the data are further processed and fed automatically to the aircraft communication system for transmission to the ground, or alternatively, a dedicated processing package can be used on the aircraft to access raw data from the aircraft systems and independently derive the meteorological variables. In addition, these facilities are used to compile and transmit meteorological reports in real time. The messages contain wind speed and direction, air temperature, altitude, a measure of turbulence and the aircraft position.

The source data for meteorological observations require significant correction and complex processing to yield meteorological measurements representative of the free airstream in the vicinity of the aircraft. Although the data processing involved is complex, errors in reported wind and temperatures are comparable with those of radiosonde systems. AMDAR observations can thus provide high-quality single-level data in cruise and detailed profile data up to cruise levels.

AMDAR observations where made can meet the resolution and accuracy requirements for global numerical weather prediction. Observations are restricted from commercial aircraft to specific air routes at cruise level and profile data are only available on climb or descent in the terminal areas. AMDAR observations are not made at standard times, and significant gaps in observations arise owing to the normal flight scheduling.

AMDAR profiles can be very useful for local airfield forecasting and are available during flight operations. This can be especially important during severe storm events.

For further details concerning AMDAR, please refer to the *Aircraft Meteorological Data Relay (AMDAR) Reference Manual* (WMO-No. 958).

3.4.2 **Instrumentation and data processing**

The type of sensors used and their siting on board the aircraft are determined by the manufacturers and depend on the type of aircraft. For details concerning instruments, measurement and data processing on board aircraft, reference should be made to Chapter 3, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.4.3 **Site selection**

The selection of observing sites is prescribed by the reporting procedures promulgated by the International Civil Aviation Organization and national aviation authorities. See [C.3.1.] 5, Volume II, *Technical Regulations* (WMO-No. 49). These generally lead to an accumulation of data at reporting points fixed at intervals of 10° longitude or latitude along major air routes, with most altitudes being between the upper standard pressure levels, 300 hPa and 150 hPa.

Observations related to specified weather phenomena should be made wherever these phenomena are encountered.

Data obtained automatically during ascent or descent are related to the predetermined pressure increments and refer to the vicinity of the aerodrome of departure or arrival. However, owing to the geographical separation of sectors used for approach and take-off and to the differences in descent and climb rates, systematic differences are to be expected.

3.4.4 **Observing and reporting procedures**

The observational data requirements to support international air navigation are contained in Volume II of the *Technical Regulations* (WMO-No. 49). Details on the frequency and time of observations are given in 2.5.5 and 2.5.11, Volume I, Part III of the *Manual on the Global Observing System* (WMO-No. 544).

3.4.5 **Communications**

ASDAR data are transmitted from the host aircraft via the International Data Collection System on board the Meteorological Geosynchronous Satellite System (METEOSAT, GOES-E, GOES-W, GMS). Ground stations are located in the USA, Japan and Europe where the received data are encoded into WMO AMDAR code and injected into the Global Telecommunication System.

The standards for aircraft VHF data-links have been established for ACARS and adopted by SITA (AIRCOM), ARINC, Air Canada (ACARS) and Japan (AVICOM). These five compatible systems provide coverage over most of the land areas of the globe through a network of remote ground stations.

Airlines operating international routes have contacts with appropriate service providers; for instance transatlantic operations require contracts with SITA, ARINC and ACARS. ACARS/AIRCOM is used mainly for automation of key airline applications such as maintenance, engine monitoring, flight operations and logistics support. Meteorological data are readily attached to down-linked messages and can be controlled by ground command or on-board programming. The data formats for down-linking meteorological reports through ACARS/AIRCOM are not standardized globally.

3.4.6 **Personnel and training**

Making meteorological measurements and observations on board the aircraft is a part of pilots' training in which National Meteorological Services should cooperate as far as possible.

3.4.7 **Quality standards**

For safety reasons, operators generally apply very high quality standards for measurements and reports. The quality of air reports has been found to be comparable with radiosonde data. For a single level, the reports are much more accurate than satellite wind and temperature data.

Systematic errors noticed during the evaluation of observations received at meteorological offices need to be identified; the malfunctioning unit should be located if possible, and the operator notified.

Procedures should be developed by the National Meteorological Services together with national airlines for continuously monitoring adherence to established reporting procedures, the quality of the reports and the adequacy of dissemination methods.

3.5 AERONAUTICAL METEOROLOGICAL STATIONS

3.5.1 General

Although the aim of commercial aviation is to be independent of meteorological conditions and modern aviation has made considerable progress in all-weather operations, flight safety is still weather related and atmospheric conditions continue to have a significant influence on the economy and regularity of commercial aviation. Moreover, the introduction of lower aircraft-operating minima and the increasing scale of operations have enhanced the requirement for reliable and complete aerodrome information. It is the task of aeronautical meteorological stations established at aerodromes and other points of significance to air navigation to provide this information. The observations and reports made by aeronautical meteorological stations are disseminated locally and to other aerodromes in accordance with regional air navigation agreements. The procedures for observation and reporting services are developed and promulgated jointly by WMO and the International Civil Aviation Organization (ICAO) on the basis of operational requirements stated by the latter. The responsibility for providing the means to satisfy these requirements rests with WMO (see the *Guide to Practices for Meteorological Offices Serving Aviation* (WMO-No. 732)).

The basic reference document to be used in making meteorological observations and reports at aeronautical meteorological stations is the *Technical Regulations* (WMO-No. 49), Volume II – Meteorological Service for International Air Navigation, Part I, [C.3.1.],⁵ section 4.

⁵ Except for a few minor editorial differences, Part C.3.1 of the *Technical Regulations* (WMO-No. 49), Volume II, is identical to Annex 3 (International Standards and Recommended Practices – Meteorological Service for International Air Navigation) to the Convention on International Civil Aviation, commonly referred to as “Annex 3” in the context of ICAO documents.

The day-to-day activities for the provision of meteorological information for aeronautical purposes call for close cooperation between the meteorological staff on the one hand and the users, such as air traffic services and airport management units, airline flight planning centres and aircrew, on the other. In particular, the type and accuracy of the data provided, the form and speed of their transmission to the users, the methods and duration of their documentation and the cost-effectiveness of the system should be regularly reviewed.

3.5.2 Instrumentation

The types of instruments used at an aeronautical meteorological station are, in general, the same as those of a synoptic station. Certain instruments such as ceilometers and transmissometers are, however, commonly used at aeronautical meteorological stations.

To be able to meet the demands for specific information for the approach and take-off areas, the touchdown zone or portions of the runways, particularly at aerodromes with all-weather operations, it is necessary to install multiple instruments. In these cases, it must be decided which of the measurements is to be used on a routine basis for reports disseminated beyond the aerodrome or in appropriate broadcasts for aviation.

Where only one instrument is used to measure a variable essential for take-off or landing, such as surface wind, cloud base and atmospheric pressure, a back-up instrument should be available in case of failure.

Instruments requiring electric power should be connected to an emergency power supply available at the aerodrome. In view of the importance of individual weather variables for the safety of take-off and landing operations and of the technical specifications of the instruments used, it must be determined whether uninterrupted availability of electric power is required or whether switching-over periods are acceptable and how they are to be limited.

At some aerodromes the installation of anemometers at distant sites or of other remote-sensing devices suitable for the measurement of vertical wind shear or of gusts at the surface may be advisable.

3.5.3 Location of meteorological stations and instruments

Special care is necessary in selecting sites for making observations or for the installation of instruments to ensure that the values are representative of the

conditions at or near the aerodrome. It is particularly important that, while the siting and exposure of the instruments meet operational requirements, the instruments or their operation do not pose hazards to air navigation, and that the jet-blast or movement of aircraft on the aerodrome, such as taxiing, take-off, runs, landing and parking, and the various aerodrome installations, do not unduly influence the measured values. Relevant instructions are contained in the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part II, Chapter 2, and in the *Manual of Aeronautical Meteorological Practice* (ICAO Doc 8896), Appendix C.

An important distinction should be made between observations at aeronautical meteorological stations and synoptic observations. The latter aim at determining at one location a value of a meteorological variable representative of a large area. Meteorological observations for aeronautical purposes are often made at several locations and need to be representative of more limited areas and times. As conditions vary from aerodrome to aerodrome and the exact locations for which the data are needed are not always available for the installation of instruments, owing to obstruction limits, universally applicable guidance cannot be given. Detailed information on the representativeness of measurements and observations at aeronautical meteorological stations can be found in the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), Part II, Chapter 2, in the following sections: 2.2 Surface wind; 2.3 Visibility; 2.4 Runway visual range; 2.5 Present weather; 2.6 Cloud; 2.7 Air temperature; 2.8 Dew point; and 2.9 Atmospheric pressure.

3.5.4 **Observing and reporting programme**

There are several types of observations as follows:

(a) Routine observations

At aerodromes, routine observations are normally made at hourly or half-hourly intervals depending on regional air navigation agreements. At other aeronautical meteorological stations, observations are made as required by air traffic services units and aircraft operations.

(b) Special and other non-routine observations

At aerodromes, routine observations are supplemented by special observations which are made during the intervals between routine observations. Special observations refer to specified conditions involving the deterioration or improvement of one or more meteorological variables.

Other non-routine observations, such as observations for take-off and landing, are made as agreed between the meteorological authority and the appropriate air traffic services authorities.

(c) Continuous real-time observations

Information about certain meteorological parameters is required by air traffic services units and operators almost continuously and in real time. These include information on surface wind for take-off and landing and on cloud base or vertical visibility and runway visual range for all weather operations.

As these requirements can generally not be met by a human observer, it is preferable to use, as far as possible, integrated automatic systems for data acquisition, processing and dissemination/display.

(d) Synoptic observations

The regulations for surface synoptic stations in 3.2 generally apply to aeronautical observations. However, as aeronautical meteorological observations have high priority, they must be completed first, in the event of competing interests. The observations needed for the preparation of meteorological reports by aeronautical meteorological stations are specified in 2.6.6, Volume I, Part III, of the *Manual on the Global Observing System* (WMO-No. 544).

Some of the variables will require different procedures for reports disseminated within and beyond the aerodrome.

Detailed instructions on observing and reporting surface wind, visibility, runway visual range, present weather, clouds, air temperature, dew-point temperature and atmospheric pressure, and on the inclusion of supplementary information are contained in [C.3.1.] 4.6, Volume II, of the *Technical Regulations* (WMO-No. 49).

Observing methods and commonly used instruments are discussed in Chapter 2, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.5.5 **Communications**

The aim of communications with respect to aeronautical meteorological data and reports should be to achieve the best possible response time of the system observer-forecaster-traffic controller-pilot.

Plain language meteorological reports required for take-off and landing should be disseminated by the quickest means available to the air traffic controller, the relevant airline operators and the

meteorological forecaster, if not co-located with the observer. The same applies to the dissemination of meteorological reports which are to be included in the local automatic terminal information service or the routine broadcast of meteorological information for aircraft in flight broadcasts. An automatic dissemination/display system should be employed for measured data required on a real-time basis.

Standard meteorological or aeronautical telecommunication systems, such as the GTS, MOTNE, which stands for Meteorological Telecommunications Network Europe, or AFTN, the Aeronautical Fixed Telecommunications Network, are generally sufficient for the preparation of coded meteorological reports.

3.5.6 Personnel and training

In addition to being fully trained in making meteorological observations, personnel at aeronautical meteorological stations should be thoroughly familiar with the relevant regulatory material, in particular the *Technical Regulations* (WMO-No. 49, Volume II, [C.3.1.] 4) and the *Manual on Codes* (WMO-No. 306, Volume I.1, Part A). Information on the training of meteorological technicians in the field of aeronautical meteorology is provided in the *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology* (WMO-No. 258).

In view of the requirements of making observations at hourly and even half-hourly intervals, a full understanding of observing, coding and reporting procedures is needed if reports are to be prepared promptly. Additional observations may be needed at any time if the weather deteriorates or improves with reference to established criteria for this purpose, or at the request of the air traffic services units. Observers must be alert to such circumstances and prepared to make the observations called for. The importance to being alert to aviation safety should be reflected in appropriate duty rosters and the application of standards governing the maximum acceptable number of uninterrupted working hours for the observers.

3.5.7 Quality standards

As aviation safety is involved, quality standards must be set very high and applied to essential variables on a real-time basis. In order to initiate prompt corrective action, observers should monitor all data whose acquisition, processing and display are carried out automatically. A continuous record of the data should be provided to the users during the periods specified by local agreements or requirements.

Instrument readings should be frequently checked, instruments recalibrated and, where necessary, duplicated or provided with an emergency power supply. Contacts with pilots after landing should be maintained in order to provide for a non-real-time feedback on the representativeness of surface wind, visibility, runway visual range and cloud observations.

Further details can be found in the *Guide to Practices for Meteorological Offices Serving Aviation* (WMO-No. 732).

3.6 RESEARCH AND SPECIAL-PURPOSE VESSEL STATIONS

Many research and special-purpose vessels carry out a variety of activities during oceanic expeditions but they are not always included in the Voluntary Observing Ships Scheme. Members with such vessels should do their utmost to ensure that all such vessels make surface and upper-air meteorological observations in accordance with the observing programme for sea stations (see 3.2.2.3). Upper-air wind observations in particular are extremely important in the tropics and in data-sparse areas.

Research and special-purpose vessels may also be equipped to make bathythermograph observations during ocean crossings. The use of an expendable bathythermograph require does not the ship to reduce speed or make course alterations. All arrangements for this type of observation are made within the framework of the joint WMO/IOC Integrated Global Ocean Services System. Procedures for the collection and exchange of BATHY and TESAC observations are specified in the *Guide to Operational Procedures for the Collection and Exchange of Oceanographic Data*.⁶ The preferred times for BATHY and TESAC observations are 0000, 0600, 1200 and 1800 UTC. However, observations made at any time are useful and should be transmitted.

3.7 CLIMATOLOGICAL STATIONS

3.7.1 Organization

Each Member shall establish a network of climatological stations in the national territory. A climatological station network should give a

⁶ *IOC Manuals and Guides No. 3, 1999, UNESCO, or the Manual on the Global Telecommunication System* (WMO-No. 386), Volume I, Part I.

satisfactory representation of the climate characteristics of all types of land in the territory of the Member concerned, for example, plains, hills, mountainous regions, plateaux, coasts, inland areas and valleys.

Each Member should maintain an up-to-date directory of the climatological stations in its territory similar to the synoptic station directory, as described in 3.2.1.2.6.

The *Guide to Climatological Practices* (WMO-No. 100) and the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) provide complementary information on the subject. Chapter 2 of the former, covering climatological observations, is particularly relevant.

3.7.2 Climatological station networks

Spacing of the climatological stations should not exceed 100 km where feasible—the manned station network should be supplemented when necessary by automatic stations—if possible, maintaining this density in deserts and other sparsely populated areas. Observations from more widely separated stations are also very valuable but stations of the network should not be further apart than 500 km.

Climatological stations for measuring precipitation in the network should be more closely spaced but the density depends on geographical features and economic considerations.

3.7.3 Station classification

According to the Appendix in Volume I of the *Manual on the Global Observing System* (WMO-No. 544), a climatological station network is composed of the following types of station:

- (a) Reference climatological stations;
- (b) Principal climatological stations;
- (c) Ordinary climatological stations;
- (d) Climatological stations for specific purposes.

Observing programmes of individual categories of climatological stations are described in 2.8, Part III, of the *Manual on the Global Observing System* (WMO-No. 544).

3.7.3.1 Reference climatological stations

Each Member should maintain at least one reference climatological station for different climatic regions. A reference climatological station should be sited with an adequate and unchanged exposure where the observations can be made in

representative conditions. The station's surroundings should not be altered over time to such an extent as to affect the homogeneity of the series of observations.

3.7.3.2 Principal climatological stations

Each Member should arrange for its principal climatological stations to be inspected at least once a year and preferably twice a year, in summer and in winter. Special attention should be paid to noting any possible changes in the siting of the station. To this effect, it is recommended that every five years four pictures be taken from the thermometer screen, in the main compass directions: north, east, south and west.

Each principal station should be located at a place and under an arrangement that will provide for the continued operation of the station for at least 10 years, and for the exposure to remain unchanged over a long period.

3.7.3.3 Ordinary climatological stations

The considerations for establishing ordinary climatological stations are similar to those for principal climatological stations.

The operation of this type of station may be restricted to a much shorter period, but not less than three years. Inspection should be carried out occasionally, preferably during the winter season, to ensure a high standard of observation and the correct functioning of instruments.

3.7.3.4 Special-purpose stations

These stations are established by the Member for special observing programmes that are limited by the number of variables involved and require appropriate instrumentation. The special-purpose observing programme will determine its own frequency, spacing and timeliness on an irregular basis.

3.7.3.4.1 Precipitation stations

The operation and observing programme of these special-purpose stations are confined to the precipitation element only. The instrumentation consists of a standard rain gauge operated by the Member or, in desert areas, of a mechanical or automatic storage rain gauge. These may be supplemented by recording rain gauges. In the winter, a snow gauge and the measurement of snow depth are required in many areas.

Each Member should arrange for its precipitation stations to be inspected at least every three years, or more frequently if necessary, to ensure the maintenance of high observation standards and the correct setting and operation of instruments. It is important that any changes in the surroundings of the site be noted. Proper action should be taken to ensure the correct functioning of the station.

3.7.4 **Operation of stations**

The observational requirements of a typical climatological station are described in 1.3, Chapter 1, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Each Member should arrange for observations at climatological stations to be made at fixed hours, according to a standard time, UTC or other. These times should remain unchanged throughout the year, regardless of the introduction of daylight-saving time by the authorities, namely in summer and winter.

When two or more observations are made at a climatological station, they should be arranged at times that reflect significant diurnal variations of climatic variables.

When changes are made at a station, including the replacement of a station or any changes in surrounding observing sites, simultaneous observations should be carried out for an overlapping period of at least one year to determine the effects of changed instruments or sites on climatological data and to ensure the correct observational values.

When climatological observation times have been changed, simultaneous observations should also be carried out on a skeleton network of representative stations for a period covering the main climatic seasons of the area at former and new observation times.

3.7.5 **Quality standards**

Reference should be made to the following publications:

- (a) *Guide to Climatological Practices* (WMO-No. 100), Chapter II, 2.6, Station and network operations, and Chapter III, 3.4, Quality control, (draft third edition, 2007);
- (b) *Guidelines on Climate Metadata and Homogenization* (WMO/TD-No. 1186), 2.5, Data processing.

3.7.6 **Archiving**

Efforts must be made to safeguard and preserve climatological data for future use.

3.8 **AGRICULTURAL METEOROLOGICAL STATIONS**

3.8.1 **Organization**

Each Member should establish within its territory a network of agricultural meteorological stations. Such a network should give a true representation of the existing agricultural areas, which are defined by biological and meteorological factors, to provide the required data. Therefore, each station network should be sufficiently dense to delineate weather parameters on the scale and magnitude required for agricultural meteorological planning, operation and research, taking into account the agricultural potential and features of the country in question.

Each Member should maintain an up-to-date directory of agricultural meteorological networks, as required for synoptic stations. In addition, the following information about each station should be provided:

- (a) Natural biomass, main agrosystem and crops of the area;
- (b) Types of soil, physical constants and types of soil profiles.

The *Guide to Agricultural Meteorological Practices* (WMO-No. 134) describes the basic requirements of agricultural meteorology in detail. Chapter 2, Agricultural elements and their observation, is particularly relevant.

The *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) also provides essential information on the subject. Reference is made mainly to sections dealing with measurements of meteorological variables in relation to agricultural meteorological stations: Chapters 1, 2, 4, 5, 7, 10 and 11, Part I; and Chapter 1, Part II.

3.8.2 **Station classification**

According to the Appendix in Volume I of the *Manual on the Global Observing System* (WMO-No. 544), agricultural meteorological stations are classified as follows:

- (a) Principal agricultural meteorological station;
- (b) Ordinary agricultural meteorological station;
- (c) Auxiliary agricultural meteorological station;
- (d) Agricultural meteorological station for specific purposes.

Observing programmes of agricultural meteorological stations are described in 2.11.5 and 2.11.6, Volume I, Part III, of the *Manual on the Global Observing System* (WMO-No. 544).

An example of the layout of instruments at an agricultural meteorological station is given in Figure III.15.

According to the *Manual on the Global Observing System* (WMO-No. 544), Volume I, Part III, 3.1.8, agricultural meteorological stations should be inspected at least once a year.

3.8.3 Operation of stations

The information given under 3.7.4 applies in a general sense to agrometeorological stations.

3.9 SPECIAL STATIONS

3.9.1 General tasks and purposes of special stations

A wide range of special stations is used to measure or record meteorological variables of special interest. These stations provide specialized information which is important to the overall purpose of the World Weather Watch, although their main purpose is to meet national requirements relating to toposcales, mesoscales and meteorological phenomena.

Some types of special stations, such as radars and reconnaissance aircraft, can cover large areas in cost-effective ways. This may create some redundancy, which is unavoidable if routinely available data are to be verified or reinforced efforts are made to ensure protection against system failure.

3.9.2 Types of special stations

3.9.2.1 Weather radar stations

3.9.2.1.1 General

Weather radar stations are in many cases co-located with surface or upper-air stations of the basic synoptic network. Such stations should be established and equipped to carry out radar observations in order to obtain information about areas of precipitation and associated phenomena, and the vertical structure of cloud systems. The information obtained from radar stations is used for operational purposes in synoptic meteorology—forecasting and warning of dangerous weather phenomena such as tropical cyclones, the generation of numerical analyses and guidance, aeronautical meteorology and hydrology, and research.

WMO Technical Note No. 181, *Use of Radar in Meteorology* (WMO-No. 625), contains useful guidance on the types of radar available, their possible usage, methods of operation and the practical aspects of siting and maintenance.

Chapter 9, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) provides further information.

3.9.2.1.2 Site selection

Several principles to be considered when selecting a site for a radar station are as follows:

- (a) The location should be free of natural or man-made obstructions interfering with the radar beam. Local construction plans should be examined to identify future potential interference. Fixed targets should be as few as possible or at least not higher than 0.50 above the level of the radar aerial;
- (b) Many national regulations require a survey to ensure that people living in the area surrounding the station site are not influenced by the microwave energy emitted;
- (c) A licence for operating the radar at the planned site must be obtained from the radio-telecommunication authorities concerned in order to avoid interference with any other installation.

See 9.7.1, Chapter 9, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) for more details.

3.9.2.1.3 Observing programme

Radar observations have been found most useful for the following tasks:

- (a) Severe weather detection, tracking and warning;
- (b) Surveillance of synoptic and mesoscale weather systems;
- (c) Estimation of precipitation amounts;
- (d) Wind shear detection.

Further information can be found in 9.1.3, Chapter 9, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.9.2.1.4 Organization

A radar meteorological observation is a manual or automated “evaluation” of the radar echoes received from meteorological targets, coded as a message and transmitted to various meteorological centres and other users at regular intervals.

The distance between two stations in an operational weather radar network should be a function of the effective radar range. In the case of a radar network intended primarily for synoptic applications, radars in mid-latitudes should be located at a distance of approximately 150 to 200 km from each another. The distance may be increased in latitudes closer to the Equator, if the radar echoes of interest frequently reach high altitudes. Narrow-beam radars yield the best accuracy for precipitation measurements.

Radar networks have a routine observing schedule. Each radar station may, however, increase its observation times or take continuous observations according to the current weather situation. A list of measurements and products can be found in 9.1.4, Chapter 9, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

There should be at least one principal weather radar station or a national weather radar centre which is responsible for receiving radar observational data from local stations and synthesizing

this data into a large-scale echo pattern for the entire network. The national weather radar centre should also be responsible for regular inspection and quality control of network data.

3.9.2.1.5 Operations

An up-to-date directory of weather radar stations should be maintained by each Member within its territory, giving the following information for each station:

- Name, geographical coordinates and elevation;
- Type of radar and some characteristics of the equipment used, such as wave length or maximum transmitting power;
- Routine observing schedule.

A minimum radar network should consist of at least two radars together covering most of the service area. Where necessary, individual radar can operate in conjunction with others in neighbouring countries to form a network. Ground-level precipitation estimates from typical radar systems are made for areas of typically 2 km², successively for 5–10 minute periods.

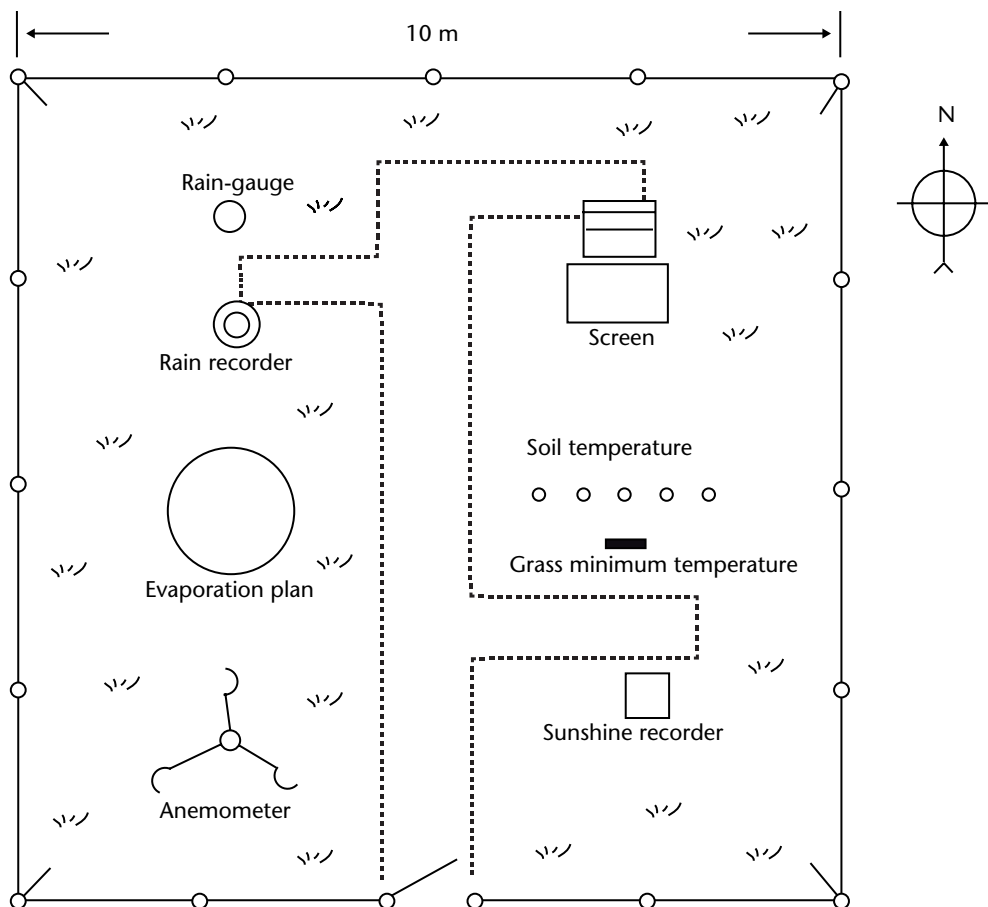


Figure III.15. Instrument layout at an agricultural meteorological station in the northern hemisphere

A growing number of meteorological offices, governmental agencies, commercial users and water authorities receive either the composite images or graphics produced at the weather radar centre or single radar images directly from the radar sites.

3.9.2.1.6 *Communications*

Regular radar data are coded in code forms FM 20-VIII RADOB, found in the *Manual on Codes* (WMO-No. 306, Part A, Volume I.1) or FM 94 BUFR, in the *Manual on Codes* (WMO-No. 306, Parts B and C, Volume I.2) and disseminated in a timely fashion through the national or regional telecommunication network. The type of communications equipment needed for disseminating data depends on the temporal resolution of the data, the processing level and the quality of communications available (telephone lines and the like).

3.9.2.1.7 *Personnel*

Weather radar personnel requirements with regard to category and number depend on the type of equipment used, the level of automation and the number of observations required.

Maintenance and technical personnel responsible for the weather radar station or the entire network must have specialized training in the maintenance and operation of equipment used and a basic understanding of electronics and radar techniques.

A station supervisor is needed to carry out periodic checks of the calibration and the interpretation methods used in manual or semi-automatic observations.

3.9.2.1.8 *Quality standards*

The relationship between surface rainfall and radar echo strength is unfortunately not fixed or geographically universal. In addition, there are often significant echoes caused by ground clutter and anomalous propagation that are not due to rainfall. The difficulty of correcting the calculation of surface rainfall estimates objectively in real time is one factor that should be taken into account when designing an interactive display system and interpreting radar images.

In addition to the quality control of radar observations, a combined digital satellite and radar interactive system may enable its operators to use geostationary satellite data to extend the surface rainfall analyses beyond the radar coverage area. This involves

subjective judgement and the use of algorithms that relate surface rainfall to cloud brightness and temperature. Alternatively, real-time calibration of radar echoes with rainfall data from rain-gauges can also be carried out when analysing rainfall data and estimating rainfall from radar echoes.

3.9.2.2 *Radiation stations*

3.9.2.2.1 *General*

It is recommended that Members should establish at least one principal radiation station in each climatic zone of their territory and maintain a network of stations of sufficient density to permit the study of radiation climatology. (See 2.12.3, Volume I, Part III, of the *Manual on the Global Observing System* (WMO-No. 544).)

The terminology of radiation qualities and measuring instruments, and the classification and calibration of pyranometers are given in Chapter 7, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.9.2.2.2 *Site selection*

Every effort should be made at site radiation stations so as to allow adequate instrument exposure and permit representative observations to be made. The location should have a free horizon, undisturbed by obstructions. The station's exposure and surroundings should not alter over time to such an extent as to affect the homogeneity of the observation series.

3.9.2.2.3 *Instrument selection*

For details concerning radiation instruments and measurements, reference should be made to Chapters 7 and 8, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.9.2.2.4 *Observing programme*

The various observing programmes at principal and ordinary radiation stations are set out in 2.12.3.5 and 2.12.3.6, Volume I, Part III, of the *Manual on the Global Observing System* (WMO-No. 544).

It is important that the data generated in a world-wide radiation measurement network be homogeneous with respect not only to calibration, but to observation times as well.

3.9.2.2.5 **Organization**

The special requirements of all potential users should be considered in planning a radiation station network. The answers to the following questions are therefore needed:

- (a) How many stations are necessary to satisfy the requirements with respect to the spatial resolution of the different kinds of meteorological radiation quantities?
- (b) Which observing programme for each of the radiation quantities has to be set up for real-time and non-real-time purposes?

The principal radiation station should be closely connected to or co-located with the National Radiation Centre which is responsible for the calibration and checking of all radiometric instruments used within the whole national radiation station network.

Detailed specifications for a National Radiation Centre are provided in Annex 7 C, Chapter 7, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.9.2.2.6 **Operations**

The comprehensive fulfilment of the tasks of a National Radiation Centre is a prerequisite of an adequately equipped and smoothly operating national radiation network.

The radiation measurements as specified in Chapter 7, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) can be organized within the framework of meteorological stations. An up-to-date directory of radiation stations should be maintained by each Member in its territory, giving the following information for each station, as well as the information requested in 2.12.3.3, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544).

The National Radiation Centre should be responsible for preparing and keeping up to date all necessary technical information for the operation and maintenance of the national network of radiation stations.

The results of all radiation measurements made at a radiation station should be collected and/or transmitted to a designated centre according to arrangements which guarantee a timely utilization of the data for operational and scientific research purposes. The collection of data may be accomplished either through telecommunication channels or by mail.

3.9.2.2.7 **Communications**

Some of the regularly measured radiation data, such as diffuse solar radiation, sky radiation and sunshine duration, are coded and then disseminated in a timely fashion to the National Meteorological Centre for further data processing.

Data on sunshine duration is coded in tenths of hours and included once a day in section 3 of code form FM 12-XI SYNOP (see the *Manual on Codes* (WMO-No. 306), Volume I.1, Part A, for regional exchange of meteorological data). In contrast, data on global and sky radiation data may be coded and distributed nationally in connection with other synoptic observations using the same data collection procedures and telecommunication channels.

3.9.2.2.8 **Personnel**

National Radiation Centre staff should ensure continuity and include at least one qualified scientist with experience in radiation. The staff is also responsible for giving instructions to the staff of any other stations in the network and for maintaining close liaisons with them.

Observers at radiation stations must be trained in order to ensure accurate and reliable radiation data. They may require special training in the use of sophisticated equipment and instruments.

3.9.2.2.9 **Quality standards**

All radiation data intended for permanent storage or non-real-time investigations should be subjected to either manual or automatic quality control. Errors and obscurities should be resolved as soon as possible.

3.9.2.3 **Atmospherics detection stations**

3.9.2.3.1 **General**

Atmospherics or sferics may be defined as electromagnetic waves resulting from electric discharges, for example, from lightning in the atmosphere.

The main purposes of this type of special station are to deduce the presence of atmospherics from observations and classify their activities. Technical progress now offers the prospect of locating distant thunderstorms by means of automated atmospherics detection systems.

Certain characteristics of atmospheric, when determined by special techniques, can usefully be employed in combination with other observations, especially for mesometeorological purposes, to analyse severe storms in order to determine their characteristics, forecast their severity and improve early warning to the community. In particular, lightning detection networks have proven useful in augmenting radar detection of storms, especially in mountainous terrain where radar interference may occur.

For details on how to locate the sources of atmospheric, reference should be made to Chapter 7, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.9.2.3.2 *Site selection*

For reasons of cost-effectiveness, lightning location systems are generally installed at the site of manned or automatic synoptic stations or at the site of weather radar stations. If a lightning or thunderstorm sensor is to be used for automatic detection and reporting of the presence or absence, direction, range, intensity and movement of such phenomena within an operational network of atmospheric detection stations, the distance between two stations should be not more than 150 to 250 km.

The area covered by a system of at least three atmospheric detection stations can be extended to several tens of kilometres in a local warning system and to 200 to 400 km in a regional warning system.

Before making significant installation investments, it is necessary to study site facilities, especially the availability of electrical power, telecommunication facilities and staff. Considerations for the site selection of automatic weather stations largely apply in this case as well.

3.9.2.3.3 *Capital equipment*

The type of equipment to be used depends on the purpose for which the observations are planned and the technology or technique to be used.

3.9.2.3.4 *Observing programme*

Real-time collection, transmission and processing are necessary to derive the full use of lightning location data. The observing programme should take into account the requirements of different users and should be employed in conjunction with other.

The observing programme depends on the following factors:

- (a) type of equipment used at the observing site, for example:
 - (i) Direction finders (an optimum distance of 500 to 1 000 km between the stations is required);
 - (ii) Time-of-arrival receivers (the number of stations for an effective service is five);
 - (iii) Local lightning detectors (effective lightning counters are useful only within a radius of 20 to 50 km);
- (b) type of measuring system employed, for example:
 - (i) Manual systems (for instance, only for sampling periods H-10 to H; continuous observation is not practicable);
 - (ii) Semi-automatic systems (computational facilities are needed);
 - (iii) Automatic systems (a sampling process with time provided for communications and data processing).

3.9.2.3.5 *Organization*

Strong organizational principles must be followed in an operational network of atmospheric detection stations, and a control station is necessary. Automatic systems are preferred where the prerequisites for a fully automatic network are given.

3.9.2.3.6 *Operations*

Lightning location systems are used not only for operational purposes, often along with weather radar observations, but also for non-real-time or research activities.

In general, the events must be plotted manually or automatically onto charts during one-day or one-month periods, depending on requirements. The events should be recorded in a cumulative manner only, for example, for making decisions on planning electric power lines.

3.9.2.3.7 *Communications*

Relevant information can be found in Chapter 7, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.9.2.3.8 *Personnel*

At least one observer per station is needed for the operation of a network of manned atmospheric detection stations. Observers must be qualified to carry out this job effectively, including equipment calibration and testing and careful reading of the

different measuring scales. In some countries, lightning information may be purchased from companies that maintain their own networks.

In an automatic system, the task of supervising the error-free operation of a lightning location sensor may be carried out by an ordinary observer with special training.

In modern equipment, a built-in microprocessor controls the data collection, derives an estimate of thunderstorm movement and intensity and formats the processed thunderstorm data for transmission to the automatic weather station and/or to the meteorological office concerned. In this case, an electronics expert should be available for routine maintenance and repair.

3.9.2.3.9 *Quality standards*

Relevant information can be found in Chapter 7, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.9.2.4 **Meteorological reconnaissance aircraft stations**

3.9.2.4.1 *General*

A meteorological reconnaissance aircraft station is defined as a station situated in a meteorological reconnaissance aircraft. Observations by aircraft can provide a valuable addition to the meteorological information acquired by more conventional methods. As a result of the latest developments in the techniques and instruments for automatic meteorological observations and reporting by aircraft using space-based telecommunication facilities, modern equipment installed in wide-bodied commercial aircraft on long-distance routes can provide valuable upper-air temperature, humidity and wind data. The information obtained in this way, particularly from remote and inaccessible areas of the world where routine surface-based observations are sparse or non-existent, is of great value.

Since commercial aircraft are bound to their flight routes and timetables, there is a continuing need to organize routine or special aircraft weather reconnaissance flights, for example, in the event of hurricanes. Such meteorological reconnaissance aircraft should be devoted exclusively to the task of meteorological observing, and therefore adequately equipped with meteorological instrumentation, conducting the required flight patterns without regard to any other commitment.

The instructions in 2.12.6, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544), should be followed.

3.9.2.4.2 *Site selection*

The site selection for the air base of meteorological reconnaissance aircraft and the type of reconnaissance flight plan vary according to the purpose of the mission and depend on other conditions as well. In some cases, where modern instrumented aircraft with satellite data links to the National Meteorological Centre or the relevant meteorological offices are available, the aircraft range must be taken into account when planning the flight track as triangles or polygons in order to cover as vast a synoptic area as possible.

If, for example, reconnaissance flights are planned for research activities in tropical cyclones in order to determine the position of vortex centre, maximum wind and minimum sea-level pressure, or isobaric height, a variety of meteorological variables within 150 km of the storm centre are necessary to produce analysed fields and detailed storm tracks in real time.

3.9.2.4.3 *Capital equipment*

Depending on the reconnaissance task, the aircraft should be equipped with remote-sensing technology, a video-recording device and, if possible, meteorological instruments providing pressure, temperature and humidity observations.

3.9.2.4.4 *Observing programme*

The observing programme may be determined in advance or varied on a flight-to-flight basis. In general, a fixed programme in which the aircraft makes flights at the same time daily, along identical tracks and with altitude variations at the same geographical points, is most suitable for synoptic or area reconnaissance. The aircraft usually reports location, pressure, temperature, winds and altitude, and some are specially fitted with meteorological radar.

3.9.2.4.5 *Organization*

The type of aircraft selected for meteorological reconnaissance flights is best determined by the task to be performed.

3.9.2.4.6 *Operations*

Operationally, three types of flights are available to the National Meteorological Centre or the meteorological office, differing according to the purpose for

which the information is required, and hence the type of observation to be obtained:

- (a) Low-level flight, in which the aircraft simulates as closely as possible a series of normal synoptic surface observations;
- (b) Vertical flight, providing a vertical cross-section of the atmosphere at or near a fixed point;
- (c) High-altitude flight, in which a horizontal cross-section of the observable parameters is given at a chosen level.

In practice, a single flight may be devoted to one or a combination of these conditions. The flight plan may consist solely of a vertical ascent over base, or of level flights at one or more altitudes, with or without measurements taken as vertical soundings during the ascents and descents between levels.

3.9.2.4.7 *Communications*

Adequate means of communication, related to the range of the meteorological reconnaissance flight and the amount of data to be transmitted, are required.

If limited computing capacity prevents extensive data processing aboard the aircraft, the unanalysed observations must be sampled at short intervals—a few minutes—and transmitted at high speed to the National Meteorological Centre or the meteorological office concerned where they can be processed with other available meteorological data.

3.9.2.4.8 *Personnel*

Personnel requirements depend on the type of aircraft, the quantity and nature of the special instrumentation and the exact purpose of the meteorological reconnaissance aircraft station.

To derive full benefits from the flight, at least one crew member should be a meteorologist who is specially trained in aircraft measurements and observations. Certain circumstances may necessitate accepting a regular crew member for this task.

Ground personnel to support the meteorological reconnaissance flights should be highly qualified to perform aircraft and instrument maintenance.

3.9.2.4.9 *Quality standards*

Accurate height and airspeed measurements are essential, and the necessary corrections to the instruments should be readily available.

Special meteorological instrumentation is required and should be chosen and installed to provide adequate accuracy for the purpose.

3.9.2.5 *Meteorological rocket stations*

3.9.2.5.1 *General*

Meteorological rocket sondes are used to obtain information on atmospheric variables from the stratosphere and mesosphere, generally between 20 and 90 km above the Earth's surface.

Data obtained by rocket sonde systems are mainly used for the calibration and verification of vertical temperature profiles derived from satellite infra-red radiometers.

See Chapter 6, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), for more information.

3.9.2.5.2 *Site selection*

The main principles to be considered when selecting a site for a meteorological rocket station are as follows:

- (a) A survey should be conducted to ensure a high level of security for the people living in the vicinity of the planned launching site;
- (b) A licence for the launching site, which must not be located within air traffic zones, shall be applied for and obtained from the authorities concerned, including those responsible for air traffic control;
- (c) The launching schedule must be checked and approved by the authorities.

Problems in connection with safety and high costs tend to limit the number of stations and frequency of launching.

Two worldwide sounding cross-section networks located approximately along the meridians 60°E and 70°W have been formed with close international cooperation.

3.9.2.5.3 *Observing programme*

The variables observed or computed include temperature, wind direction and speed. By setting dates and times for launching, it has been possible to prepare meridional cross-sections of the upper atmosphere.

3.9.2.5.4 *Organization*

A central body, World Data Centre A, undertakes collection of the data and the various exchanges of data between participating Members. These data are

used to conduct systematic studies on topics such as the general circulation, solar high-atmosphere relationships, the correlation between geomagnetism and meteorological parameters, the composition of standard atmospheres, verification of satellite data and stratospheric warming.

3.9.2.5.5 *Operations*

Where altitudes higher than 20 km are concerned, meteorological variables such as temperature, wind and air density should be determined for mandatory and significant levels.

The launching programme should be based on international agreements. Many different types of rockets and sensors are in use and various data reduction techniques are employed.

3.9.2.5.6 *Communications*

For each launching, a report known as FM 39-VI ROCOB is compiled and disseminated over the Global Telecommunication System.

3.9.2.5.7 *Personnel*

Personnel requirements (categories and number) at a meteorological rocket station depend on the equipment used, the level of automation and expertise and the number of rocket launches per week.

One person should be responsible for all facets of station operation and should be one of the most experienced members in this field. Qualified scientists and engineers are required for the preparation, execution and interpretation of the rocket launch.

3.9.2.5.8 *Quality standards*

International intercomparisons have been conducted to ensure uniformity of the results obtained by the existing systems.

Modifications to certain measuring systems and laboratory experiments should be carried out after each intercomparison in order to make the various systems and the evaluation of corrections more uniform.

3.9.2.6 **Global Atmosphere Watch (GAW) stations**

3.9.2.6.1 *General*

The WMO Global Atmosphere Watch is designed to meet the need for monitoring the chemical composition and related characteristics of the atmosphere

on global and regional scales. Such information is required to improve understanding of the behaviour of the atmosphere and its interactions with the oceans and the biosphere and to enable prediction of the future states of the Earth system. The GAW integrates many monitoring and research activities involving high-quality measurement of atmospheric composition. Some GAW components have been in operation since the 1950s.

Atmospheric chemical observations should be carried out at GAW stations with the same attention as is given to the measurements of other meteorological variables. National meteorological and/or environmental protection services are encouraged to ensure that chemical composition observations become an integral part of atmospheric observations in general.

The network of GAW stations comprises the following two main categories of stations:

- (a) Global, or baseline stations are established to provide measurements needed to address atmospheric environmental issues of global scale and importance, for example, climate change and depletion of the ozone layer.

The required number of global stations should be such that a minimum of one per principal climatic and ecological zone is achieved. Towards this goal, Members are being encouraged to establish and/or cooperate in establishing some 30 stations of this category at selected sites. At the time of writing there are 24 GAW global stations.

- (b) Regional stations are established to provide measurements primarily to help assess regional aspects of global atmospheric environmental issues and atmospheric problems in various regions or countries, for example, acid rain, near-surface ozone, deterioration of ecosystems and materials and air pollution in rural areas.

The number of regional stations should allow regional aspects of global environmental issues and environmental problems of interest to the Region or country) concerned to be adequately addressed. To this end, Members are being encouraged to establish at least 400 stations of this category.

For further information, see the *Global Atmosphere Watch Measurement Guide* (WMO/TD-No. 1073), the *Updated Guidelines for Atmospheric Trace Gas Data Management* (WMO/TD-No. 1149), the *WMO/GAW Aerosol Measurement Procedure: Guidelines and*

Recommendations (WMO/TD-No. 1178), the *Manual for the GAW Precipitation Chemistry Programme: Guidelines, Data Quality Objectives and Standard Operating Procedures* (WMO/TD-No. 125) and the *Baseline Surface Radiation Network (BSRN): Operations Manual* (WMO/TD-No. 879). See <http://www.wmo.ch/web/arep/gaw/gawreports.html> for a complete list of GAW reports.

3.9.2.6.2 Site selection

Global Atmosphere Watch stations should be established only at sites where direct pollution effects can be avoided. Therefore, strict siting criteria have been established and listed in the WMO Global Atmospheric Watch (GAW) Strategic Plan: 2008–2015 for the two main categories of station. The following criteria should be met for regional stations:

- (a) The station location should be regionally representative of the variables measured and free of the influence of significant local pollution sources;
- (b) Adequate power, air conditioning, communication and building facilities to sustain long-term observations with greater than 90 per cent data capture (i.e. <10 per cent missing data) should be available;
- (c) Technical staff should be trained to operate the equipment;
- (d) The agency in charge should be committed to long-term observations of at least one of the GAW variables in the GAW focal areas;
- (e) GAW observations should be of high quality and linked to the GAW Primary Standard;
- (f) Data and associated metadata should be submitted to one of the GAW World Data Centres no later than one year after the observations are made. Metadata changes, including instrumentation, traceability and observation procedures, should be reported to the relevant World Data Centre;
- (g) If required, data should be submitted to a designated data distribution system in near-real time;
- (h) Standard meteorological in situ observations necessary for the accurate determination and interpretation of GAW variables should be accurate and precise;
- (i) The station's characteristics and observational programme should be updated in the GAW Station Information System on a regular basis;
- (j) A station log-book, namely a record of observations made and activities that may affect observations, should be maintained and used in the data validation process.

In addition to the above-mentioned requirements, GAW global stations should meet the following criteria:

- (k) Variables should be measured in at least three of the six GAW focal areas (see (d));
- (l) Global stations should boast a strong scientific supporting programme with appropriate data analysis and interpretation within the country and, if possible, the support of more than one agency;
- (m) Measurements of other atmospheric variables important to weather and climate, including upper air radio sondes at the site or in the region, should be taken;
- (n) A facility where intensive campaign research can augment long-term routine GAW observations, and testing and development of new GAW methods can be undertaken should be provided.

Siting requirements may also differ, depending on the measurement programmes and the specialities of variables to be monitored.

3.9.2.6.3 Capital equipment

The capital equipment needed for Global Atmosphere Watch stations depends on the purpose of the station and differs mainly in terms of scientific objectives and technical feasibility with regard to the monitoring programme concerned.

Further information on equipment requirements can be found in 3.9.2.6.4, Observing programme, of the *Global Atmosphere Watch Guide* (WMO/TD-No. 1073) and the GAW publications mentioned in 3.9.2.6.1.

The observing programmes may differ according to the recommended priority to be given to the measurement of atmospheric composition at global and regional stations as laid down in 2.12.8.4, 2.12.8.5 and 2.12.8.6, Part III, Volume I, of the *Manual on the Global Observing System* (WMO-No. 544) and in Chapter B.2, Volume I, of the *Technical Regulations*, (WMO-No. 49). For further information, see Chapter 17, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.9.2.6.4 Organization and operation

The basic responsibilities for monitoring the operation of the Global Atmospheric Watch shall rest with participating Members.

All GAW stations are operated by Members in accordance with the *Global Atmosphere Watch Measurements Guide* (WMO/TD-No. 1073). Data collection and preparation for WMO data publication are undertaken by the GAW Data Centres.

3.9.2.6.5 *Central collection, publication and availability of data*

Global Atmospheric Watch data are centralized and published as follows:

- (a) The agency operating the station(s) in each participating country submits all data from the station(s) on data forms or agreed formats to the following centres according to their areas of specialization:
 - (i) Total ozone, profile ozone, solar ultraviolet radiation:
World Ozone and Ultraviolet Radiation Data Centre
c/o Experimental Studies Section
Environment Canada
4905 Dufferin Street
Toronto, Ontario
Canada M3H 5T4
<http://www.woudc.org>
 - (ii) Carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, surface ozone:
World Data Centre for Greenhouse Gases
c/o Japan Meteorological Agency
1-3-4, Otemachi, Chiyoda-ku
Tokyo 100-8122, Japan
<http://gaw.kishou.go.jp/wdcgg.html>
 - (iii) Solar radiation, radiation balance, sunshine duration:
World Radiation Data Centre
Voeikov Main Geophysical Observatory
7, Karbyshev Street
194021 St Petersburg, Russian Federation
<http://wrdc.mgo.rssi.ru/>
 - (iv) Aerosol optical depth, aerosol light scattering and backscattering, aerosol chemistry, aerosol light absorption, condensation nuclei concentration, aerosol size distributions:
World Data Centre for Aerosols
Joint Research Centre, European Commission
Ispra, Italy
<http://wdca.jrc.it/>
 - (v) Precipitation chemistry:
World Data Centre for Precipitation Chemistry
Atmospheric Sciences Research Centre,
State University of New York
Albany, New York, USA
<http://www.wdcpc.org>
 - (vi) Atmospheric composition as measured from space with emphasis on ozone and aerosols:

World Data Center for Remote Sensing of the Atmosphere
DLR-DFD-KA
Oberpfaffenhofen
D-82234 Wessling, Germany
<http://www.wdc.d/r.de>

- (b) The World Ozone and Ultraviolet Radiation Data Centre at Environment Canada processes all ozone data (surface, total column, vertical distribution) and publishes the *Ozone Data for the World (ODW)* annually. The Centre also issues an index which contains the list of stations, a station catalogue with information on stations (names, organizations operating the stations, types of observation, types of instrument used, observing programmes) and a catalogue of available ozone data (stations, period, data type, *ODW* volume numbers in which the data are contained);
- (c) Every six months the WMO World Data Centre for Greenhouse Gases at the Japan Meteorological Agency processes and publishes the data for which it is responsible. Every year, in October/November the World Data Centre for Greenhouse Gases assists the WMO Secretariat with the preparation of the *WMO Greenhouse Gas Bulletin*.

Details on GAW data availability, including conditions and procedures for ordering, can be obtained directly from the Centres listed in (i) through (vi).

3.9.2.6.6 *Communications*

Each Global Atmosphere Watch station should retain its own complete original data record and documentation of station operations. The operating agencies will make whatever use of these data as suits their needs. However, accessibility to the entire data reservoir is essential, which should be accomplished through centralized archiving. All data from GAW stations should be sent every two months to the relevant GAW Data Centre (see 3.9.2.6.5).

3.9.2.6.7 *GAW-ozone-observing stations*

3.9.2.6.7.1 General

In view of the radiation properties of ozone as a minor atmospheric constituent, this gas is a significant contributor to the atmosphere's radiation energy. In addition to its radiation properties, ozone reacts photochemically with many other trace species, some of which are anthropogenic in

origin. The meridional and vertical distributions of ozone in the atmosphere are determined by a complex interaction of atmospheric dynamics and photochemistry.

Ozone-observing stations have been promoted by WMO since the mid-1950s and are now a part of the Global Atmosphere Watch. These stations regularly measure total column ozone and the vertical distribution of the ozone in the troposphere and the stratosphere. Surface ozone near the ground has generally been measured at selected GAW background pollution stations.

The available observational data have documented the geographic and seasonal average ozone distributions and have indicated the presence of variations on many time and space scales. These variations are, in part, associated with meteorological processes and may also be affected by anthropogenic and solar influences. An improved representation of the global ozone distribution is essential to provide a definitive pattern of the space and time variations of ozone over the globe and for periods up to a decade or longer. The GAW Ozone Network has played a crucial role in the discovery of the Antarctic ozone hole and in the quantification of the effect of chlorofluorocarbons and halons on the ozone layer all over the globe. Data from the total ozone and ozonesonde stations, stored at the World Ozone and Ultraviolet Radiation Data Centre, have played a central role in the quadrennial WMO/United Nations Environment Programme Scientific Assessments of Ozone Depletion. These data will also be important in the quest for eventual ozone recovery, which is expected to happen around 2050–2070, depending on the region.

The following three characteristics of atmospheric ozone should be routinely measured and reported from ozone-observing stations:

- (a) Surface ozone;
- (b) Total ozone;
- (c) Vertical profile of ozone.

Members who establish ozone-observing stations should follow the *Global Atmosphere Watch Measurements Guide* (WMO/TD-No. 1073).

3.9.2.6.7.2 Network considerations

The site selection for an ozone-observing station depends mainly on the types of routine atmospheric ozone observations intended to be made and available facilities. Observing sites should be

selected so as to minimize effects of pollution and cloudiness as much as possible. Total ozone is determined from ground-based and satellite-borne instruments, and vertical ozone profiles are derived from ground-based, balloon-sonde and satellite techniques.

The GAW ozone system reflects the concern for the quality control and cross-validation of all components of the system. In addition, the observations must be part of a network sufficiently representative in space and time to allow for the documentation of all geophysically significant ozone variations. This requires guarantees of long-term network maintenance and observing system stability. The derived data need to be made readily available to the user community in a timely manner and in an appropriate form; this is achieved through the services offered by the World Ozone and Ultraviolet Radiation Data Centre in Toronto under the auspices of WMO.

The existing network of surface-based observing stations for the total ozone field is very irregular, with a high density of stations in Europe, North America, and parts of Asia, and low density over the tropics and the oceans, and in the southern hemisphere in general. Results of field examinations suggest that total ozone should be sampled with the spatial resolution of mid-scale waves, or at intervals of 30° longitude or less, implying the need for about 100 well-distributed total ozone stations throughout the world. Information about the spatial statistical structure of the total ozone field may be derived for the optimal location of new stations by means of iterative procedures based on optimization criteria and internal network redundancy. Through the efforts of international and national organizations, substantial progress has been made in improving the consistency of the Dobson ozone network and extending the spatial coverage. However, there is a clear need for further progress in these directions.

Balloon-borne ozone soundings play an important role in furthering knowledge of the global vertical ozone distribution. However, three quarters of this kind of sounding have been made in the latitude belt between 35°N and 55°N.

The following requirements should be noted:

- (a) Additional ozone-observing stations representative of “unpolluted” areas—preferably connected with a meteorological observatory—should be established, especially in the tropical region and in the southern hemisphere;

- (b) The current ground-based ozone network should be expanded by the addition of about 10 suitably sited Dobson and/or Brewer stations;
- (c) A subset of Dobson and Brewer stations should be maintained and calibrated in such a way that they can assist in the validation of satellite measurements.

Adequate answers to ozone questions can be provided only if there is a continuous flow of reliable total and vertical profile ozone data sufficient to form a coherent data set. This goal can be achieved effectively only by coordinating the diverse existing and planned ozone-measuring programmes by Members concerned. They are urged to cooperate closely with the World Ozone and Ultraviolet Radiation Data Centre in Toronto by providing the data in a timely manner.

3.9.2.6.7.3 Capital equipment

The capital equipment needed for a surface-based ozone-observing station comprises at least one of the following main components:

(a) Total ozone

Total ozone may be measured by one of the following types of equipment:

- (i) Dobson ozone spectrophotometer;
- (ii) Brewer ozone spectrophotometer;
- (iii) Filter ozonometer (type M-83, M-124);
- (iv) System of Analysis of Observations at Zenith (SAOZ) spectrophotometer;
- (v) Other ultraviolet-visible spectrometers using the differential optical absorption spectroscopy technique.

(b) Vertical ozone profile

Vertical ozone profile may be measured by the following techniques and equipment:

- (i) Surface-based (Dobson/Brewer) stations where the vertical profile of ozone is measured remotely from the ground by the Umkehr inversion method;
- (ii) Balloon ozonesonde stations employing the electrochemical concentration cell sondes;
- (iii) Lidar, or optical radar systems, which are usually limited to operation at night and when there are no appreciable clouds;
- (iv) Microwave instruments;
- (v) Ozonesonde and laser radar.

See Chapter 16, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) for more details.

3.9.2.6.7.4 Observing programme

Total ozone should be observed daily, because the frequency of observations is as important as the spatial density of observation. Data acquisition depends on the local weather conditions encountered. Difficulties arising from cloudy sky and/or haze should be noted in order to reduce their bias in the data acquisition.

A balloon-borne ozone measurement network has been built up within GAW. It features routine soundings carried out according to an agreed launching schedule of at least one per week at some 60 stations using one of five versions of electrochemical ozonesondes.

3.9.2.6.7.5 Organization

Findings of the WMO Global Ozone Research and Monitoring Project have shown the need for a network of ozone soundings and total ozone stations as an integrated part of the GAW network.

Each Member with more than one station taking part in ozone measurements should select one to become the national focal point or national ozone centre of the relevant country. This special station or observatory should be responsible for regular inspection, quality control, sampling, archiving and distributing ozone data. Common efforts should be directed towards instrument calibration and data intercomparisons to be carried out within the Global Atmosphere Watch in order to improve the ozone database. The data from calibrations and intercomparisons should be routinely deposited at the WMO World Ozone and Ultraviolet Radiation Data Centre in Toronto.

Regional Associations may designate a Regional Ozone Centre that could take an active role in implementing related activities, namely:

- (a) To organize intercomparisons of instruments for measuring total ozone and/or the vertical profile of ozone;
- (b) To carry out instrument checks;
- (c) To offer training courses for various ozone measurement methods;
- (d) To assist in analysis and evaluation of ozone data in close cooperation with the WMO World Ozone and Ultraviolet Radiation Data Centre.

The World Ozone and Ultraviolet Radiation Data Centre plays an important role in publishing and archiving all available ozone data, relevant calibrations and documentation provided by Members.

3.9.2.6.7.6 Operations

An ozone-observing station network should focus on the following points:

- (a) Calibration of instruments used, documentation of major changes and the like;
- (b) Cross-validation of the ozone-measurement system used in order to detect possible sources of errors;
- (c) Commitment to long-term continuous operation of ozone stations.

For many applications of ozone measurements, and particularly for the detection of long-term trends, a long record is necessary. Thus, stations and systems with long histories should be given priority in future programmes.

While the implementation of specialized techniques is encouraged, they should be carefully assessed to determine their likely long-term operation in a network setting.

The operational validation of an ozone measurement system should consist of the following four parts or steps:

- (a) Complete calibration and a thorough understanding of the performance characteristics of the measuring instruments, including their errors;
- (b) Identification of error sources due to mathematical modelling and external inputs to the evaluation algorithm;
- (c) Thorough understanding of the evaluation algorithm and the propagation of the above-mentioned errors by the algorithm;
- (d) Intercomparison or cross-validation with independent observations.

Neglect of any of these four steps will lead to an incorrect assessment of the performance of the measuring system and the validity of the derived data products.

For all measuring systems, the problem of long-term stability of the instruments must be considered. Ozone measuring systems also have to take into account changes in atmospheric composition such as aerosols that may affect the retrieval schemes. Lastly, in connection with instruments operating at ultraviolet wavelengths, the stability of the primary source of their radiation, the Sun, is a critical matter of concern. Solar ultraviolet variability as related to ozone measurement should be assessed by means of continuous satellite monitoring.

3.9.2.6.7.7 Communications

Ozone-observing stations should maintain a complete original data record and documentation of station operations. In most cases, the data will have to be scrutinized

by ozone experts. Special precautions are also necessary before the exchange of ozone data as agreed between the relevant Members. In connection with the Antarctic and Arctic ozone decline, a need for data transmission in near-real time has appeared. Data centres have been established to collect ozone, ultraviolet and meteorological data in near-real time and make them available to the scientific community. There is a need to standardize delivery routines, data formats and metadata reporting. The use of the WMO Information System should be considered for the exchange of ozone and other atmospheric composition data. Some stations already transmit their ozone data to the GTS. The number of stations submitting data in this manner should be increased and eventually involve all ozone stations in the GAW network. Satellite data exchange should take place expeditiously.

To ensure an adequate inventory of ozone data, it is recommended that a summary regarding data availability be included in the *Ozone Data for the World* and updated about once every year. This should include information on satellite data, surface-based total ozone measurements and ozonesondes. Graphs should show the availability of data from particular stations and satellites.

The exchange of total ozone data and/or validated ozone profiles will normally take place by electronic mail or ftp within two months of the measurement.

3.9.2.6.7.8 Personnel

The availability of specially trained observers and technicians is fundamentally important in the implementation of the GAW ozone system. At least two or three persons should be employed at an ozone-observing station. The station supervisor must be highly qualified, with preference given to experts with a university-level education. Advanced training in ozone-measuring techniques is indispensable for effective participation in the GAW, especially at ozone observatories and laboratories.

3.9.2.6.7.9 Quality standards

The responsibility for observational data quality rests with the agency providing the data. With regard to ozone-observing stations, strong emphasis should be placed on instrument maintenance and calibration, strict adherence to proper observing techniques and careful rechecking of all clerical steps.

Like all measuring instruments, the accuracy of ozonesondes is also limited by sources of error. More detailed information on this point, in particular a

discussion of comparison, calibration and maintenance of diverse instruments, can be obtained in *JOSIE-2000, Jülich Ozone Sonde Intercomparison Experiment 2000* (WMO/TD-No. 1225).

3.9.2.6.7.10 Archiving

Ozone soundings must be scrutinized carefully by the agency in charge of the station before results are submitted to the World Ozone and Ultraviolet Radiation Data Centre.

Regarding surface-based total ozone station networks, the raw data should be recorded on standard forms which should be archived at the station with due care to include all relevant information, or by the agency responsible for the station. Preservation of the raw data is necessary if retrospective corrections are to be made. A directory of all archived raw data should be published by the World Ozone and Ultraviolet Radiation Data Centre at regular intervals. In addition, information required for reduction of the raw data, such as calibration tables, standards, sensor corrections, atmospheric corrections, zenith charts and cloud corrections should be archived at the national ozone centres.

3.9.2.7 Planetary boundary-layer stations

3.9.2.7.1 General

Some Members have operated planetary boundary-layer stations on a regular or experimental basis. The following guidance based on their experience will be useful if the need for a fully operational network is established.

3.9.2.7.2 Site selection

Measurements of the planetary boundary-layer may be carried out on a regular basis at a permanent site, at special observatories, for example, or on special occasions at particular sites by mobile teams.

Wind-profiling and Doppler radars are proving to be extremely valuable in providing high-resolution data in space and time for these measurements. Wind profilers are especially useful in making observations at times between balloon-borne soundings, and have great potential as a part of integrated networks. Doppler radars are used extensively as part of national and, increasingly, regional networks, mainly for short-range forecasting of severe weather phenomena. The Doppler radar capability of making wind measurements and estimates of rainfall amounts is particularly useful.

Current ground-based systems that can be used for these purposes are described in more detail in Chapter 5, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

3.9.2.7.3 Capital equipment

The capital equipment varies depending on the measuring techniques used.

3.9.2.7.4 Operational observing programmes

Over the past few decades there have been a number of boundary-layer observing programmes. In some cases these have been organized specifically for boundary-layer studies, while in other cases the boundary-layer studies have formed a component of larger experiments, for example, those established within the Global Atmospheric Research Programme. Each of these observing programmes has increased the understanding of boundary-layer processes and provided data sets invaluable to research in this field.

Most of the observing methods and techniques are described in Chapter 5, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8). Further background information can be found in WMO Technical Note No. 165, *The Planetary Boundary Layer* (WMO-No. 530).

3.9.2.7.5 Personnel

The personnel engaged in supervising planetary boundary-layer stations should have a university or equivalent degree in electronics or mechanical engineering combined with a good knowledge of meteorology.

3.9.2.7.6 Quality standards

Procedures should be developed to meet a minimum standard level in quality control of data derived from the sophisticated instruments or equipment used for special investigations—sodars, lidars and wind profilers, for example. Owing to the very high resolution in time and space for data acquisition at planetary boundary-layer stations, accuracy requirements can be more stringent than in most other cases. For this reason, quality control becomes a difficult task for variables with very short time constants.

3.9.2.8 Tide-gauge stations

3.9.2.8.1 General

Tide-gauge stations should be established along coasts subject to storm surges. They provide sea-level measurements which must be filtered to

remove high-frequency fluctuations such as wind waves, in order to provide time-series data from which tides and tidal predictions can be determined.

These stations provide the basic tidal datums for coastal and marine boundaries and for chart datums as required by the tsunami, seiche, and storm-surge warning services. Global sea-level measurements are necessary to monitor possible increases due to global warming. Coastal sea-level measurements are vital for hydrographic surveys and give indications of ocean circulation patterns and climate change. Likewise, the archived data of sea-level heights may be very important for making decisions on vessel navigation, coastal processes and tectonic studies, and for numerous other engineering and scientific purposes and investigations.

An international network of sea-level measuring stations including tide-gauge stations forms the basis of the Global Sea Level Observing System (GLOSS), coordinated by the Intergovernmental Oceanographic Commission of UNESCO. For further information, reference should be made to the *Manual on Sea-Level Measurement and Interpretation*, IOC Manuals and Guides No. 14, UNESCO.

3.9.2.8.2 *Site selection*

Location of tide-gauge stations should be selected for their open ocean characteristics, routinely avoiding or accounting for such influences as overflow, salinity, hydraulics, density, stratification, stability, and wave and storm resistance.

Some locations may be selected to provide bay, estuary, or river information for marine boundary datum determinations or similar studies. A selected set of tide-gauge benchmarks must be accurately connected to a global geodetic reference system.

The following points should be considered when selecting and setting up a tide-gauge station:

- (a) Stable support structure such as a pier, or bulkhead, for the installation of water-level measurement sensors. The support structure must be above the highest expected water level, and water depths must be below the lowest expected water level;
- (b) Space for a small shelter (typically 1.5 m × 1.5 m) to house the instrumentation (or 2 m × 2 m clear wall space to mount the equipment in an existing building);

- (c) If satellite data transmission of an automatic tide-gauge station is conducted, the antenna must have a clear line of sight to the satellite that serves as data collection platform;
- (d) Locations near geodetic first- or second-order vertical control networks, if existent, are highly desirable;
- (e) Utility services are highly advisable but not critical. The site should have AC power available nearby; however, many measuring systems can operate solely on solar panel power if necessary. Telephone lines are desirable at tide-gauge sites to allow direct communication with the instrumentation.

3.9.2.8.3 *Capital equipment*

Each station consists of a stable structure from which the measurements can be made, of water-level measurement equipment, and of a suite of fixed physical objects, or benchmarks, used to reference the vertical datums.

If continuous data collection is of vital importance, the primary data collection platform (DCP) (see 3.9.2.8.7) should have a backup DCP with another water-level measurement sensor. In these cases, further auxiliary data, such as wind speed and direction, atmospheric pressure, air temperature, relative humidity and water conductivity may also be accommodated by the DCPs.

A telephone line should be available to allow access to pre-quality-controlled data by selected real-time users.

3.9.2.8.4 *Observing programme*

Visual readings by human observers should be made at the following times, listed in descending order of preference:

- (a) Hourly, particularly in coastal storm situations;
- (b) Times of high and low water;
- (c) Main synoptic hours of 0000, 0600, 1200 and 1800 UTC.

Where the installation of automatic sea-level measurement equipment combined with the data collection platform is feasible, the system may be programmed to average a series of measurements. Data should be stored temporarily at the station site in the DCP memory and periodically transmitted via satellite or land-line to a central collection station for further processing and long-term storage. For further information, reference should be made to the *Manual on Sea-Level Measurement and Interpretation*, IOC Manuals and Guides No. 14, UNESCO.

3.9.2.8.5 *Organization*

Owing to the vital impact of the deviation of tidal heights which might be generated by tsunamis or storm surges on coastal community activities, real-time information on water-level deviations is sorely needed. Although many tide-gauge stations are still equipped with simple water-level gauges where visual readings have to be made by human observers, there are already fully automatic water-level observational networks in operation. Where feasible and necessary, preference should be given to creating a network that utilizes automatic data-acquisition and recording equipment to measure water levels along the coastline.

To protect life and property from flood situations resulting from storm surges, the meteorological hydrological warning system should be closely linked with public alert and coastal defence systems. Where the warning time required exceeds the capability of meteorological forecasting, an alert system composed of several phases of increased alert should be introduced, resulting in a higher frequency of observations at manned tide-gauge stations.

The tide-producing forces are distributed in a regular manner over the Earth, varying with latitude. However, the response of the oceans and seas to these forces differs, depending on the hydrographic features of each basin. As a result, the tides as they actually occur differ significantly along the coast and in bays and estuaries. An attempt should be made to space the stations so that the changes in the tidal characteristics are represented. Among the numerous tidal features which vary at different places, those relating to the time of tide, range of tide, and type of tide are the principal features reviewed to form the network.

3.9.2.8.6 *Operations*

An up-to-date directory of tide-gauge stations where water-level measurements are taken should be maintained, providing the following information for each station:

- (a) Name of station and geographical coordinates;
- (b) List and description of equipment and measuring techniques;
- (c) Description of support structure;
- (d) Description of benchmarks;
- (e) Dates of stability and calibration checks of water-level measurement equipment;
- (f) Station or data collection platform access information, such as:
 - (i) Telephone number;
 - (ii) Satellite platform ID and channel;

- (g) Corrections to reference data to chart datum or description of "zero" reference.

IOC Member States agreeing to participate in the Global Sea Level Observing System are requested to perform the following tasks:

- (a) Ensure that all operating GLOSS stations report monthly mean sea-level data values to the International Council for Science Permanent Service for Mean Sea Level within one year of acquisition;
- (b) Make hourly values of sea-level data available for international exchange;
- (c) Upgrade existing stations which are below GLOSS standards;
- (d) Install new stations in consultation with the Intergovernmental Oceanographic Commission.

In order to standardize the procedures for sea-level measurements, national instructions should be in accordance with the *Manual on Sea-Level Measurement and Interpretation*, IOC Manuals and Guides No. 14.

3.9.2.8.7 *Communications*

Tide-gauge stations must have access at least to a public telecommunication network with the aim of making data available after timely quality control checks at manned stations. Data from automated stations accommodated by data collection platforms can be transmitted via satellite to the main computer of the relevant service centre for quality control and further analysis and dissemination of water-level information. Even data which have not been subject to quality control should be made available immediately from the downlink through a decode programme on a personal computer for public information services.

Selected users can be authorized to access the water-level data directly from the measurement equipment if tide-gauge stations have a telephone line.

3.9.2.8.8 *Personnel*

Tide-gauge station personnel should be familiar with national observing instructions and guidance material. The operation and maintenance personnel responsible for these stations, especially when automated water-level measuring systems are used, must have specialized training in the following areas: structure maintenance, electronic equipment installation and repair, scuba (self-contained underwater breathing apparatus) diving for inspecting and cleaning the underwater components, and surveying for running differential levels to monitor stability of the equipment and benchmarks.

3.9.2.8.9 *Quality standards*

Owing to the various locations of tide-gauge stations, there are no preset quantified confidence or uncertainty limits that state datum variability in a generic sense, for example, +/- 0.1 feet. Such accuracies are site-specific, relating to physical environment, vertical stability, signal-to-noise ratios, gauge operation, length of series, closeness of control stations and the like. Users should be provided with estimated confidence limits for data on a case-by-case basis.

The readings of individual sea levels should be made with a target resolution of 0.1 m. Connections between the benchmark and the gauge zero should be made to an uncertainty of a few millimetres every six months.

Members participating in the Global Sea Level Observing System should send their monthly and annual sea-level mean values to the Permanent Service for Mean Sea Level at Bidston Observatory, Merseyside, UK, together with details of gauge location, missing days and a definition of the datum to which the measurements are referred. Received data are checked for consistency. If possible, values are reduced to revised local reference; this involves the identification of a stable, permanent benchmark close to the tide-gauge station and the reduction of all data to a single datum level which is referred to this benchmark, ensuring continuity with subsequent data.

References

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Global Atmosphere Watch Guide (WMO/TD-No. 553)

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Guide to Data Collection and Location Services Using Service
ARGOS, WMO Marine Meteorology and Related
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Guide to Marine Meteorological Services (WMO-No. 471)
Guide to Meteorological Instruments and Methods of
Observation (WMO-No. 8)
Guide to Practices for Meteorological Offices Serving Aviation
(WMO-No. 732)
International List of Selected, Supplementary and Auxiliary
Ships (WMO-No. 47)
Location and Data Collection Satellite System, ARGOS User's
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1982-1988

APPENDIX III.1

FUNCTIONAL SPECIFICATIONS FOR AUTOMATIC WEATHER STATIONS

<i>Variable^a</i>	<i>Maximum effective range^b</i>	<i>Minimum reported resolution^c</i>	<i>Observing method^d</i>	<i>BUFR/CREX^e</i>
Atmospheric pressure				
Pressure	500–1080 hPa	10 Pa	I, V	0 10 004
Temperature				
Ambient air temperature (over specified surface)	-80°C – +60°C	0.1 K	I, V	0 12 101
Dew-point temperature	-80°C – +60°C	0.1 K	I, V	0 12 103
Ground (surface) temperature (over specified surface)	-80°C – +80°C	0.1 K	I, V	0 12 113
Soil temperature	-50°C – +50°C	0.1 K	I, V	0 12 130
Snow temperature	-80°C – 0°C	0.1 K	I, V	N
Water temperature – river, lake, sea, well	-2°C – +100°C	0.1 K	I, V	0 13 082
Humidity				
Relative humidity	0–100%	1%	I, V	0 13 003
Mass mixing ratio	0–100%	1%	I, V	N
Soil moisture, volumetric or water potential	0–103 g kg ⁻¹	1 g kg ⁻¹	I, V	N
Water vapour pressure	0–100 hPa	10 Pa	I, V	N
Evaporation/evapotranspiration	0–0.1 m	0.1 kg m ⁻² , 0.0001 m	T	0 13 033
Object wetness duration	0–86 400 s	1 s	T	N
Wind				
Direction	0–360 degrees	1 degree	I, V	0 11 001
Speed	0–75 m s ⁻¹	0.1 m s ⁻¹	I, V	0 11 002
Gust speed	0–150 m s ⁻¹	0.1 m s ⁻¹	I, V	0 11 041
X, Y, Z component of wind vector (horizontal and vertical profile)	0–150 m s ⁻¹	0.1 m s ⁻¹	I, V	N
Turbulence type (low levels and wake vortex)	up to 15 types	BUFR table	I, V	N
Turbulence intensity	up to 15 types	BUFR table	I, V	N
Radiation^f				
Sunshine duration	0–86 400 s	60 s	T	0 14 031
Background luminance	1·10 ⁻⁶ –2·104 Cd m ⁻²	1·10 ⁻⁶ Cd m ⁻²	I, V	N
Global downward solar radiation	0–6·106 J m ⁻²	1 J m ⁻²	I, T, V	N
Global upward solar radiation	0–4·106 J m ⁻²	1 J m ⁻²	I, T, V	N
Diffuse solar radiation	0–4·106 J m ⁻²	1 J m ⁻²	I, T, V	0 14 023
Direct solar radiation	0–5·106 J m ⁻²	1 J m ⁻²	I, T, V	0 14 025
Downward long-wave radiation	0–3·106 J m ⁻²	1 J m ⁻²	I, T, V	0 14 002
Upward long-wave radiation	0–3·106 J m ⁻²	1 J m ⁻²	I, T, V	0 14 002
Net radiation	0–6·106 J m ⁻²	1 J m ⁻²	I, T, V	0 14 016

<i>Variable^a</i>	<i>Maximum effective range^b</i>	<i>Minimum reported resolution^c</i>	<i>Observing method^d</i>	<i>BUFR/CREX^e</i>
UV-B radiation	0–1.2·10 ³ J m ⁻²	1 J m ⁻²	I, T, V	N
Photosynthetically active radiation	0–3·10 ⁶ J m ⁻²	1 J m ⁻²	I, T, V	N
Surface albedo	1–100%	1%	I, V	0 14 019
Clouds				
Cloud base height	0–30 km	10 m	I, V	0 20 013
Cloud top height	0–30 km	10 m	I, V	0 20 014
Cloud type, convective vs. other types	up to 30 classes	BUFR table	I	0 20 012
Cloud hydrometeor concentration	1–700 hydrometeors dm ⁻³	1 hydrometeor dm ⁻³	I, V	N
Effective radius of cloud hydrometeors	2·10 ⁻⁵ –32·10 ⁻⁵ m	2·10 ⁻⁵ m	I, V	N
Cloud liquid water content	1·10 ⁻⁵ –1.4·10 ⁻² kg m ⁻³	1·10 ⁻⁵ kg m ⁻³	I, V	N
Optical depth within each layer	To be determined	To be determined	I, V	N
Optical fog depth	To be determined	To be determined	I, V	N
Inversion height	0–1 000 m	10 m	I, V	N
Cloud cover	0–100%	1%	I, V	0 20 010
Cloud amount	0–8/8	1/8	I, V	0 20 011
Precipitation				
Accumulation	0–500 mm	0.1 kg m ⁻² , 0.0001 m	T	0 13 011
Duration	up to 86 400 s	60 s	T	0 26 020
Precipitating element size	1·10 ⁻³ –0.5 m	1·10 ⁻³ m	I, V	N
Quantitative intensity	0–2000 mm h ⁻¹	0.1 kg m ⁻² s ⁻¹ , 0.1 mm h ⁻¹	I, V	0 13 055
Type	up to 30 types	BUFR table	I, V	0 20 021
Ice accretion rate	0–1 kg dm ⁻² h ⁻¹	1·10 ⁻³ kg dm ⁻² h ⁻¹	I, V	N
Obscurations				
Obscuration type	up to 30 types	BUFR table	I, V	0 20 025
Hydrometeor type	up to 30 types	BUFR table	I, V	0 20 025
Lithometeor type	up to 30 types	BUFR table	I, V	0 20 025
Hydrometeor radius	2·10 ⁻⁵ –32·10 ⁻⁵ m	2·10 ⁻⁵ m	I, V	N
Horizontal extinction coefficient	0–1 m ⁻¹	0.001 m ⁻¹	I, V	N
Slant extinction coefficient	0–1 m ⁻¹	0.001 m ⁻¹	I, V	N
Meteorological optical range	1–100 000 m	1 m	I, V	N
Runway visual range	1–4 000 m	1 m	I, V	0 20 061
Other weather type	up to 18 types	BUFR table	I, V	0 20 023
Lightning				
Lightning discharge rates	0–100 000	Number h ⁻¹	I, V	0 13 059
Lightning discharge type (cloud to cloud, cloud to surface)	up to 10 types	BUFR table	I, V	N
Lightning discharge polarity	2 types	BUFR table	I, V	N
Lightning discharge energy	To be determined	To be determined	I, V	N
Lightning distance from station	0–3·10 ⁴ m	103 m	I, V	N
Lightning direction from station	1–360 degrees	1 degree	I, V	N

<i>Variable^a</i>	<i>Maximum effective range^b</i>	<i>Minimum reported resolution^c</i>	<i>Observing method^d</i>	<i>BUFR/CREX^e</i>
Hydrologic observations				
Flow discharge – rivers	0–2.5·10 ⁵ m ³ s ⁻¹	0.1 m ³ s ⁻¹	I, V	0 23 017
Flow discharge – wells	0–50 m ³ s ⁻¹	0.001 m ³ s ⁻¹	I, V	0 23 017
Ground water level	0–1 800 m	0.01 m	I, V	N
Ice surface temperature	-80°C – +0°C	0.5 K	I, V	N
Ice thickness – rivers, lakes	0–50 m	0.01 m	I, V	N
Ice thickness – glaciers, seas	0–4 270 m	1 m	I, V	0 20 031
Water level	0–100 m	0.01 m	I, V	0 13 071 0 13 072
Wave height	0–50 m	0.1 m	I, V	0 22 021
Wave period	0–100 s	1 s	I, V	0 22 011
Wave direction	0–360 degrees	1 degree	I, V	0 22 001
Sea salinity	0–50·10 ⁻³ ‰	10 ⁻³ ‰	I, V	0 22 062
Ice thickness	0–3 m	0.015 m	T	0 20 031
Ice mass	0–50 kg m ⁻¹	0.5 kg m ⁻¹ (on 32 mm rod)	T	N
Snow density (liquid water content)	100–700 kg m ⁻³	1 kg m ⁻³	T	N
Other surface variables				
Runway conditions	up to 10 types	BUFR table	I, V	N
Braking action/friction coefficient	up to 7 types	BUFR table	I, V	N
State of ground	up to 30 types	BUFR table	I, V	0 20 062
Type of surface specified	up to 15 types	BUFR table	I, V	0 08 010
Snow depth	0–25 m	0.01 m	T	0 13 013
Sea salinity	0–50·10 ⁻³ ‰	10 ⁻³ ‰	I, V	0 22 062
Ice thickness	0–3 m	0.015 m	T	0 20 031
Ice mass	0–50 kg m ⁻¹	0.5 kg m ⁻¹ (on 32 mm rod)	T	N
Snow density (liquid water content)	100–700 kg m ⁻³	1 kg m ⁻³	T	N
Runway conditions	up to 10 types	BUFR table	I, V	N
Braking action/friction coefficient	up to 7 types	BUFR table	I, V	N
State of ground	up to 30 types	BUFR table	I, V	0 20 062
Type of surface specified	up to 15 types	BUFR table	I, V	0 08 010
Snow depth	0–25 m	0.01 m	T	0 13 013
Other				
Gamma radiation dose	1–10 nSv h ⁻¹	1 nSv h ⁻¹	I, T	N
Stability categories	9 types	BUFR table	I, V	0 13 041

^a Name of variable

^b Maximum range of measuring capability

^c Lower resolution of reporting is not permissible

^d Type of data being reported:

I Instantaneous – 1-minute value; instantaneous as defined in 1.3.2.4, Part II, *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8)

V Variability – average (mean), standard deviation, maximum, minimum, range, median, of samples; those reported depend on meteorological variable

T Total – integrated value during defined period (over a fixed period(s)); maximum 24 hours for all parameters except radiation, which requires a maximum of one hour

^e BUFR/CREX – present ability to represent variable by BUFR tables

N Does not exist

^f Radiation energy amounts given over a 24-hour period

APPENDIX III.2

BASIC SET OF VARIABLES TO BE REPORTED BY STANDARD AUTOMATIC WEATHER STATIONS FOR MULTIPLE USERS

<i>Variables</i>	<i>SYNOP land stations</i>	<i>Fixed ocean weather stations</i>	<i>Aeronautical meteorological station</i>	<i>Principle climatological station</i>	<i>Standard</i>
Atmospheric pressure	M A	M A	X ^a	X	A
Pressure tendency and characteristic	[M]	M			[A]
Air temperature	M ^b A	M A	X	X ^c	A
Humidity ^d	M A	M	X ^e	X	A
Surface wind ^f	M A	M A	X	X	A
Cloud amount and type	M	M	X	X	A
Extinction profile/ cloud-base	M [A]	M	X	X	A
Cloud direction, cloud movement	[M]				
Weather, present and past	M	M	X	X	A
State of the ground	[M]	not applicable		X ^g	[A]
Special phenomena	[M] [A]				
Visibility	M [A]	M	X	X	A
Amount of precipitation	[M] [A]	[A]		X	A
Precipitation, yes/no	A	[A]		X	A
Precipitation, intensity	[A]				
Soil temperature				X	A
Sunshine and/or solar radiation				X	A
Waves		M [A]			A ^h
Sea temperature		M A			A ^h

^a Also QNH and QFE (See key, Appendix III.3)

^b Optional: extreme temperatures

^c Inclusive extreme temperatures

^d Dew-point temperature and/or relative humidity and air temperature

^e Dew-point temperature

^f Wind speed and direction

^g Snow cover

^h Sea and coastal stations only

M Required for manned stations

[M] Based on a regional resolution

A Required for automatic stations

[A] Optional for automatic stations

X Required

APPENDIX III.3

AUTOMATIC WEATHER STATION METADATA

Metadata—which refers to station and data history as applied to measurement and observation—describe the location, instrument and method of observation, quality and other data characteristics. Metadata are important for data users in understanding the origins of meteorological values, and most importantly, in understanding elements that are particularly sensitive to exposure, such as precipitation, wind and temperature.

Metadata are an extension of the station administrative record, containing all possible information related to station siting, instrument installation, instrument type, maintenance schedule and scheduled and

unscheduled system changes that occur during the history of an observing system. Expanded metadata information should also include digital images.

Metadata are dynamic. Station location, ground cover, instruments, observation measurement and reporting practices, algorithm processing, data formats and the like change over time. As computer data management systems gradually become an important component of the data delivery systems, metadata should be available in near-real time since a computer database allows for computerized composition, updating and delivery.

Key
 BUFR Binary universal form for the representation of meteorological data
 MSL Mean sea level
 QFE Pressure at the station or aerodrome level

QNH Pressure at mean sea level, reduced from QFE by applying corrections according to the International Civil Aviation Organization's standard atmosphere
 UTC Coordinated universal time
 WGS 84 World Geodetic System 1984

1. WEATHER STATION METADATA REQUIRED FOR OPERATIONAL PURPOSES

1.1 Station information

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Station name	Official station name	Bratislava-Koliba
Station index number or identifier	Number used by the National Meteorological Service to identify a station	11813, A59172
WMO block and station numbers	BUFR descriptors 0 01 001 and 0 01 002 ^a	11 and 813
Geographical coordinates	Latitude and longitude of the station reference point with respect to WGS 84 ^b	18.7697 degrees 18.5939 degrees
Reference time	Actual time of observations in UTC	0655
Elevation above mean sea level	Vertical distance of a reference point of the station measured from mean sea level with respect to EGM 96	260.25 m
Surface qualifier	BUFR descriptor 0 08 010	Land grass cover
Roughness classification	Davenport classification of effective terrain roughness	2
Datum level to which station's atmospheric pressure data refer; elevation data used for QFE/QNH	Datum levels to which the atmospheric pressure is reduced	Pressure sensor: 123.45 m MSL; Station: 125.67 m MSL Aerodrome reference point: 124.56 m MSL

^a The current limitation of WMO station number to 999, also limited by BUFR descriptor 0 01 002, which has a data width of 10 bits, is a problem for a wide exchange of observations. More than 999 stations often exist in the area covered by a given WMO block number. Not all the observations available are currently disseminated on the Global Telecommunications System. To disseminate the observations from all potentially available stations, the WMO station number should be expanded, that is, a new descriptor is defined and used.

^b To add a note for the relevant descriptor denoting latitude and longitude with reference to WGS 84.

1.2 Individual instrument information

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Principle of operation	Description of method or system used	
<ul style="list-style-type: none"> • Method of measurement/observation^a • Type of detection system 	Type of operation principle describing measurement/observing method used BUFR descriptors 0 02 175–0 02 189	Direct current principal, polymer capacitance
Siting and exposure	Complete set of measuring instruments and other equipment assembled to carry out specified measurements BUFR descriptors 0 02 175–0 02 189	Optical scatter system combined with precipitation occurrence sensing system
<ul style="list-style-type: none"> • Height above ground (or level of depth) • Representative height of sensor above ground 	Siting classification ^b	1.75 m, -0.1 m
Expected instrument performance	Standard height for the measurement	1.25 m
	A performance classification (to be defined) should include instrument uncertainty and periodicity of preventive maintenance and calibration. All these elements determine the expected instrument performance	Class A: for an instrument following WMO instrument and maintenance recommendations Class D: for an instrument with unknown characteristics and/or unknown maintenance
Adjustment procedures in relation to the nominal value	Adjustment applied to the data	Class B and C: intermediate; BUFR descriptor 0 08 083

^a To add a note for the existence of shielding and type of shielding applied and whether artificially ventilated or not.

^b To be standardized. France has defined a classification using values from 1 to 5. The National Oceanic and Atmospheric Administration (NOAA)/National Climatic Data Center (NCDC) uses a similar classification system. It is recommended that the Commission for Instruments and Methods of Observation develop guidelines for such classification, possibly in collaboration with ISO/TC146/SC5 meteorology.

1.3 Data-processing information

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Measuring/observing programme		
<ul style="list-style-type: none"> • Data output • Processing interval 	Quantity that is delivered by an instrument or system Time interval from which the samples are taken	2-m average value 2, 10 m (wind)

1.4 Data-handling information

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Quality control flag for each parameter	Description of quality control flags	1 = good, 2 = inconsistent, 3 = doubtful, 4 = erroneous, 5 = not checked, 6 = changed

2. **AUTOMATIC WEATHER STATION METADATA REQUIRED FOR NEAR-REAL TIME AND NON-REAL TIME PURPOSES**

2.1 **Station information**

There is a great deal of information relating to a station's location, local topography and others. Basic station metadata include the following:

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Station name	Official station name	Bratislava–Koliba
Station index number or identifier	Number used by National Meteorological Service to identify station	11813, A59172
WMO block and station numbers	BUFR descriptors 0 01 001 and 0 01 002	11 and 813
Geographical coordinates	Latitude and longitude station reference point with respect to WGS 84	18.7697 degrees 18.5939 degrees
Reference time	Actual time of observations in UTC	0655
Elevation above mean sea level	Vertical distance of station reference point of the station measured from mean sea level with respect to EGM 96	260.25 m
Surface qualifier	BUFR descriptor 0 08 010	Land grass cover
Types of soil, physical constants and soil profile	Description of soil type below station, soil characteristics	Clay
Types of vegetation and condition, date of entry	Description of station's environment, land	Natural; grass, 7 December 2004
Local topography description	Description of station's surroundings, with emphasis on topographic features that may influence weather at station	Valley station
Roughness classification	Davenport classification of effective terrain roughness	2
Type of automatic weather station, manufacturer, hardware and software versions, model details, (model, serial number, software version)	Basic information on the automatic weather station installation	Automatic Weather Stations: Model Vaisala MILOS 500 Hardware v1.2 Operating system v1.2.3, application program v1.0.2 Modem model ABCD, hardware v2.3, software v3.4.5, power supply model XYZ, hardware v4.5
Station's observing programme	Information on types of observation made, variables measured	1-hour synoptic observations
• Parameters measured	List of variables measured	Temperature, pressure, humidity, wind speed and direction
• Reference time	Reference time of observations	UTC
• Message codes and reporting times (offset and interval)	Actual time of observations	METAR: Start 0000 UTC 1-hour intervals; SYNOP: Start 0000 UTC 3-hour intervals Automatic weather stations: Start 0000, 1-minute intervals
Datum level to which atmospheric pressure data of the station refer; elevation data used for QFE/QNH	Datum levels to which the atmospheric pressure is reduced	Pressure sensor: 123.45 m MSL; station: 125.67 m MSL; aerodrome reference point: 124.56 m MSL

2.2 Individual instrument information

Relevant metadata should include the following:

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Sensor type	Technical information on the sensor used to measure the variable	Temperature, humidity, pressure
<ul style="list-style-type: none"> • Manufacturer • Model • Serial number • Hardware version • Software version 		Vaisala, Campbell HMP45C, pressure, temperature, humidity-2000 12345... V1.2.3 V2.3.4
Principle of operation	Description of method or system used	
<ul style="list-style-type: none"> • Measurement/observing method 	Type of operation principle describing method of measurement/observation used	Direct current principle, polymer capacitance
<ul style="list-style-type: none"> • Type of detection system 	BUFR descriptors 0 02 175–0 02 189 Complete set of measuring instruments and other equipment assembled to carry out specified measurements	Optical scatter system combined with precipitation occurrence sensing system
Performance characteristics	BUFR descriptors 0 02 175–0 02 189 Operating range of sensors	-50 – +60°C, 0–100%
Unit of measurement	SI unit in which the variable is measured	K, Pa, m s ⁻¹
Measuring range	Interval between upper and lower value limits for which variable reported	-50 – +60°C, 0–75 m s ⁻¹
Resolution	Smallest change in a physical variable which will cause variation in measurement system response	0.01 K
Uncertainty	Variable associated with result of measurement that characterizes the dispersion of values that could be reasonably attributed to measurement; interval in which the “value” of the variable at the time of measurement is expected	±0.1 K
Instrument time constant	Time required for instrument to indicate given percentage (63.2%) of final reading resulting from input signal	20 s
Interface time constant	Time required for interface electronics to indicate given percentage (63.2%) of final reading resulting from input signal	5 s
Time resolution	Sampling frequency	3 s, 10 s

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Output averaging time	Time period to determine reported value	1 m; 2 m; 10 m
Siting and exposure	Siting classification	
<ul style="list-style-type: none"> • Location • Degree of interference from other instruments or objects • Shielding • Shielding time constant 		Screen, mast, tower
	Time required for instrument exposure method (solar radiation screen, or vent) to indicate a given percentage (63.2%) of final reading resulting from input signal	Screen, naturally aspirated 10 seconds
<ul style="list-style-type: none"> • Height above ground (or level of depth) • Representative height of sensor above ground 		1.75 m, -0.1 m
	Standard height for measurement	1.25 m
Expected instrument performance	Performance classification (to be defined) should include: uncertainty of instrument and periodicity of preventive maintenance and calibration; these factors determine expected performance of instrument	Class A: instrument following WMO instrument and maintenance recommendations; Class D: instrument with unknown characteristics and/or unknown maintenance; Classes B and C: intermediate
Data acquisition		
<ul style="list-style-type: none"> • Sampling interval • Averaging interval • Type of averaging 	Time between successive observations	3 s, 10 s, 30 s
	Time interval from which samples are used	1, 2, 10, 30 m
Adjustment procedures for nominal value	Method used to calculate average Adjustment applied to data	Arithmetic; exponential; harmonic BUFR descriptor 0 08 083
Calibration data		
<ul style="list-style-type: none"> • Correction • Calibration time 	Value to be added to or subtracted from instrument reading to obtain correct value	$C = R(1+0.6R)$
	Date of latest calibration	12 December 2003
Preventive and corrective maintenance		
<ul style="list-style-type: none"> • Recommended/scheduled maintenance • Calibration procedures • Calibration frequency • Procedure description 	Frequency of preventive maintenance	Once every 3 months
	Type of method/procedure used	Static/dynamic calibration
	Recommended frequency	12 months
Results of comparison with travelling standard	Sensor field test results immediately after installation	98%
Results of comparison with travelling standard	Sensor field test results immediately prior to removal	103%

2.3 Data processing information

Metadata related to processing procedures should include the following information for each individual meteorological parameter:

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Measuring/observing programme		
• Observation time		10th, ..., 60th m
• Reporting frequency		10 m
• Data output	Quantity delivered by instrument or system	2-m average value
• Processing interval	Time interval from which samples taken	2, 10 m (wind)
• Reported resolution	Resolution of variable reported	0.1 m s ⁻¹
Data-processing method, procedure, algorithm	Method used	A running 10-m average
Formula used to calculate the element		$VIS=N/(1/V1+1/V2+ \dots +1/Vn)$
Observing/measuring method	Type of data being reported	Instantaneous, total, mean value, variability
Input source (instrument, element and the like)	Measured or derived variable	WAA 151
Constants and parameter values	Constants, parameters used to compute derived parameter	$g = 9.806\ 65\text{ms}^{-2}$

2.4 Data-handling information

Important metadata components include the following:

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Quality control procedures, algorithms	Type of quality control procedures	Plausible value check; time consistency check, internal consistency check
Quality control flag for each parameter	Description of quality control flags	1 = good, 2 = inconsistent, 3 = doubtful, 4 = erroneous, 5 = not checked, 6 = changed
Processing and storage procedures	Different procedures used in data reduction and data conversion	A computation of visibility derived from extinction coefficient
Constants and parameter values		

2.5 Data transmission information

The transmission-related metadata of interest are as follows:

<i>Type of metadata</i>	<i>Description</i>	<i>Example</i>
Transmission method	Means of transmission	Global System for Mobile Communication/General Packet Radio Service, OrbComm; radio
Data format	Type of message used for data transmission	BUFR; SYNOP
Transmission time	Time of regular transmission of data	11th m; 60th m
Transmission frequency	Frequency of data transmission	10 m; 1 h

PART IV

THE SPACE-BASED SUBSYSTEM

4.1 GENERAL

4.1.1 History of the space-based subsystem

The first experimental meteorological satellite was launched by the United States of America on 1 April 1960. It provided basic, albeit very useful, cloud imagery and was such an effective proof of concept that the decision was rapidly made to implement a series of operational polar satellites. The automatic picture transmission (APT) system was flown for the first time in 1963 and improved access to image data. APT systems have been flown on many satellites since then to provide images several times a day to relatively inexpensive user stations around the world. By 1966, the United States had launched its first experimental geostationary meteorological satellite demonstrating the value of a fixed viewing point relative to the Earth, enabling frequent images to be taken and used to generate animated views of the world's weather. In 1969 the then Union of Soviet Socialist Republics launched the first of a series of polar-orbiting satellites. In 1974, the United States launched the first operational geostationary satellite. Similar geostationary meteorological satellites were launched and operated by Japan and by the European Space Agency (ESA) in 1977. Thus, within 18 years of a first practical demonstration, a fully operational meteorological satellite system was in place, giving routine data coverage of most of the planet. The network stabilized in terms of sensor data and services during the 1980s but there was a resurgence of experimental environmental satellites and an upgrading of the operational subsystem during the 1990s with the contribution of new operators such as India and China. Further significant improvements in sensor performance and additional spacecraft are being implemented during the first decade of the new century, contributing to a more robust constellation of operational and research and development (R&D) satellites around the Earth. The rapid development of a new inter-national observing system, entailing major investments, has been unprecedented and indicates the enormous value of these satellites to meteorology and society when allied to massive improvements in the ability to communicate process and display information.

4.1.2 Relation to the surface-based subsystem

Several factors make meteorological satellite data unique compared with those from other sources; it is worthwhile noting a few of the most significant:

- (a) Because of its high vantage point and broad field of view, a satellite can provide a regular supply of data from those areas of the globe yielding very few observations from the surface-based subsystem.
- (b) The atmosphere is broadly scanned from satellite altitude which enables large-scale weather systems to be seen in a single view.
- (c) The ability of geostationary satellites to view a major portion of the atmosphere continually from space makes them particularly well suited for the monitoring and warning of short-lived storms.
- (d) Advanced communications systems initially developed as an integral part of satellite technology permit rapid data transmission from the satellite, or their relay from automatic stations on Earth and in the atmosphere, to operational users. This is still the case after four decades, although the current trend is towards carrying broadcasting and observing functions on separate spacecraft that are optimized for telecommunications or Earth observation.
- (e) Information about the atmosphere or surface is obtained indirectly by measuring properties of electromagnetic radiation reaching a satellite-borne sensor. The use of such data poses particular problems. These generally manifest themselves in the difficulty of obtaining the required vertical resolution in some measurements and long-term stability. Furthermore, errors tend to be spatially correlated, which makes it challenging to use the measurements in defining differential field properties. The underlying surface, whether it be the actual surface or cloud top, can make contributions to the upwelling radiation by inferring the properties of the overlying atmosphere.

On the other hand, in situ measurements can be directly interpreted but may be influenced by local factors, which raises an issue of representativeness. Furthermore, the density of observing networks is not homogeneous.

The density of conventional surface and upper-air soundings in some portions of the globe, such as North America or Western Europe, far exceeds the density of similar information over oceanic and less-developed regions. Reports from ships, aircraft, island stations and some buoys are often the only surface-based observations available from the oceans, and many of the data are concentrated in limited geographical areas covered by commercial transportation routes. Polar-orbiting and geostationary satellites provide the only other source of environmental data over these and other data-sparse areas. Winds inferred from cloud and atmospheric pattern motions monitored by the geostationary satellites, particularly over the otherwise data-sparse low latitudes, occupy a further important niche. The quality of forecasts and services is directly correlated to the information available on atmospheric conditions, regardless of what scale of motion is examined, although the effects of any deficiencies may not be co-located with them.

Forecasts from numerical models are the foundation for routine regional and local weather forecasts. The global temperature-sounding data from polar-orbiting weather satellites, first available in the late 1960s and used operationally since the mid-1970s, have encouraged numerical modelling activities. Computer power and model improvements have made it both necessary and possible to develop increasingly sophisticated methods for extracting the temperature and humidity profiles from the satellite radiances. Sounding data assimilation has a significantly positive impact for both hemispheres thanks to the improved vertical resolution allowed by advanced hyperspectral sounders.

Strengths and weaknesses from surface and space-based measurements are complementary, which why the Global Observing System should be considered a composite that builds upon the strengths of both components. Satellite observations are critical to the generation of warnings and forecasts of hazardous conditions such as storms, tropical cyclones, polar lows, high winds and waves. More than 90 per cent of the volume of data assimilated in global numerical weather prediction models comes from space systems. Nevertheless, direct measurements from surface, radiosondes and aircraft remain indispensable to provide geophysical variables that are not easily derived from remote sensing, to monitor small-scale phenomena and to provide independent validation and calibration data.

4.1.3 **Coordination**

The combination of operational environmental satellites making the space-based subsystem is a series of independent national or regional systems coordinated by mutual agreement among satellite operators and WMO through the Coordination Group for Meteorological Satellites (CGMS). The Group's membership involves the operators of meteorological satellites, including operational and R&D satellites, and WMO in its capacity as a major user organization. It currently includes meteorological and/or space agencies from China (CMA and CNSA), Europe (EUMETSAT and ESA), France (CNES), India (IMD), Japan (JMA and JAXA), the Republic of Korea (KMA), the Russian Federation (ROSHYDROMET and ROSKOSMOS) and the United States (NOAA and NASA). The Group had its first meeting in September 1972, when it was known as the Coordination of Geostationary Meteorological Satellites, and has met on an annual basis ever since. It deals with the coordination of a wide-ranging list of operational aspects of the satellite systems, such as contingency planning, optimization of the mutual locations of geostationary and polar-orbiting spacecraft and telecommunications standards. It has helped to ensure the standardization of key facilities across the entire global system and fosters cooperation on sensor calibration, product derivation and user training. More information on the Coordination Group for Meteorological Satellites can be found at http://www.wmo.int/pages/prog/sat/CGMS/CGMS_home.html.

As regards contingency planning, satellite operators within the Coordination Group for Meteorological Satellites have established a practice of mutual support among geostationary satellite systems, whenever necessary and feasible. Troubles experienced by a spacecraft generate a contingency situation over one region when continuity of critical missions can no longer be maintained and a replacement satellite cannot be launched before a long period of time. In such cases, if another satellite operator has a spare satellite in orbit with sufficient fuel capacity to allow for additional manoeuvres, it is possible to relocate this spare satellite from its original location to the part of the globe that needs temporary coverage support. Although all geostationary meteorological satellites have some common mission objectives and a core set of similar capabilities, they are not interchangeable. Owing to diverse regional and national standards and to the emergence of different technologies from the independent phasing of satellite procurements,

each satellite system needs its own central ground station and control centre. Relocating a satellite can thus require more or less complicated arrangements depending on whether it is within or beyond the visibility of its central ground station. Such a contingency support was successfully implemented on several occasions in the 1980s and 1990s between GOES, METEOSAT and GMS spacecraft.

4.2 THE BASELINE SPACE SEGMENT

The World Weather Watch's Global Observing System space component is comprised of two types of satellites: operational meteorological satellites and environmental R&D satellites.

Operational meteorological satellites are designed to be operated in either of the two following orbit classes: geostationary equatorial orbit or sun-synchronous polar orbits. Most of the environmental R&D satellites are also in sun-synchronous polar orbits, although not all.

Six evenly spaced geostationary satellites are required to provide permanent coverage of the globe up to at least 55° latitude. A fully global coverage including the polar regions can only be obtained with polar orbiting satellites; four of them on equally spaced sun-synchronous orbital planes can provide frequent enough observations to reflect the diurnal cycle.

Other types of orbits may be adopted for specific missions depending on the coverage requirement. For instance, a 35° inclination orbit was adopted for the tropical rainfall monitoring mission and a 66° inclination orbit is preferred for an optimized ocean surface topography mission. Highly elliptical orbits are also under consideration but are not planned to be used within the Global Observing System, in the near future.

4.2.1 Sun-synchronous polar-orbiting satellites

4.2.1.1 Principle

A sun-synchronous satellite's orbital plane keeps a constant angle with the sun throughout the year, in order to ensure that it always passes over a given latitude at the same local solar time. This is a clear advantage for many applications because it minimizes scene differences due to the time of day and amount of solar illumination and hence

simplifies operational utilization. Customarily such satellites are used for precise radiance measurements as needed for temperature and water vapour soundings, monitoring land or sea-surface temperature and radiation fluxes.

Sun-synchronism can be achieved with a low Earth orbit (LEO) inclined at about 99° to the plane of the Equator, that is, an angle around 81° in the retrograde direction. Since the orbit passes over both polar regions it is called a polar orbit. Meteorological sun-synchronous satellites are usually on quasi-circular orbits with an altitude in the range of 800 km to 1 000 km, which implies an orbital period around 101 minutes. The satellite thus circles the planet every 101 minutes, that is, about 14 times each day. Since the Earth spins on its axis while the plane of the orbit remains almost constant, the tracks of successive orbits are displaced further to the west of about 25.5° longitude. If the imaging swath width is at least 2 900 km, there is no gap at equatorial latitudes between the areas covered at each revolution, and there is significant overlap between consecutive passes at higher latitudes. Each satellite can then view the entire planet twice in any 24-hour period, once during daylight and once at night. A sun-synchronous satellite is classified as a morning or a.m. satellite if the daylight pass across the equator occurs in the morning. It is said to be an afternoon or p.m. satellite if the daylight pass occurs in the afternoon. In general the afternoon pass is an ascending orbit from South to North, and the morning pass is a descending orbit from North to South, although this is not a rule.

Figure IV.1 gives a North Pole view of the orbital planes of sun-synchronous satellites as planned for 2008. While the Earth is moving around the sun and rotating on itself, the orbital planes keep a constant angle with the sun's direction. The figures (0000, 0600, 1200, 1800) indicate particular values of the mean local solar time (MLST). The MLST is determined by the location with respect to the sun's direction. The MLST is 1200 at the point of the Earth that is facing the sun, and on the meridian of this point. Sun-synchronous orbits that have their daylight part between 0600 and 1200 MLST are called "morning orbits" while orbits that have their daylight part between 1200 and 1800 MLST are called "afternoon orbits".

4.2.1.2 Implementation

The United States and the Russian Federation have operated polar meteorological satellites since the 1960s, with current satellites of the

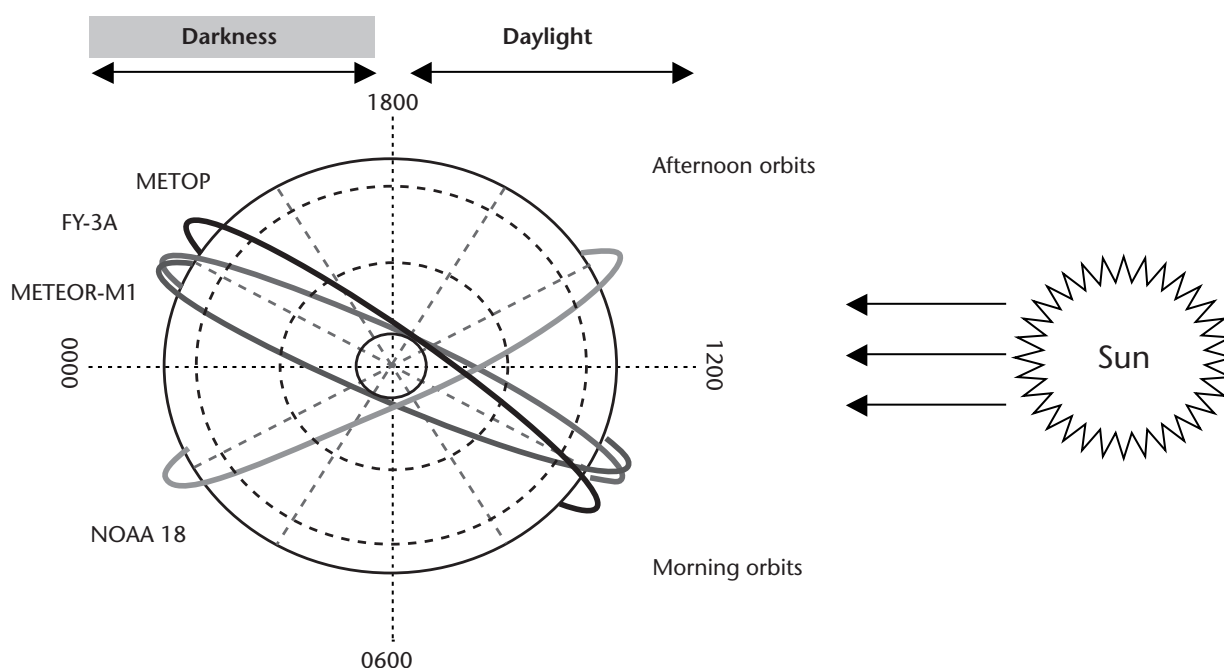


Figure IV.1. Orbital planes of sun-synchronous satellites as seen from the North Pole, 2008 configuration

NOAA-K, L, M and METEOR-3M design respectively. China launched polar meteorological satellites FY 1-C and FY I-D in 1999 and 2002. New generation spacecraft series are being implemented, with METOP (EUMETSAT) in 2006; METEOR-M1 (Russian Federation) and FY-3 (China) are planned for launch in 2007 and NPOESS (United States), at the beginning of the next decade. If these plans can be carried out without significant delay, continuity of observation from the polar orbit will be maintained and will benefit from greatly enhanced performance. The currently planned configuration for 2008 represented in Figure IV.1 is expected to include three morning satellites, METOP, FY-3 and METEOR-M1; and one afternoon satellite, NOAA-18.

4.2.1.3 Observing missions

The relatively low altitude of sun-synchronous polar satellites enables instruments to be flown that observe the atmosphere and the surface with high resolution. The core payload of meteorological polar-orbiting satellites includes in particular, imaging and sounding instruments (see Table IV.1). Imaging radiometers have a high horizontal resolution and monitor the surfaces of land, sea, ice or clouds, in spectral channels where the atmosphere is weakly absorbing (window channels). Sounding instruments have a high

spectral resolution and compare the radiation emitted by the atmosphere in series of narrow channels along atmospheric absorption bands (CO_2 and H_2O in infrared, O_2 and H_2O in microwaves). A variety of other instruments, passive or active, may be part of the payload, depending on the particular mission objectives and spacecraft design constraints.

4.2.1.4 Data dissemination missions

The data acquired by polar satellites are accessible either by direct broadcast or through retransmission by advanced dissemination systems (ADM). Satellite products are also distributed over the Global Telecommunication System and an increasing number of images or products can be found on the Internet.

Direct broadcast from the spacecraft provides the user with real-time data when the satellite is within the visibility area of its receiving station, which extends to about 2 500 km around the station if we assume a minimum antenna elevation angle of 5 degrees. Typical visibility areas of local receiving stations in different locations are indicated in Figure IV.2. The data accessed from direct broadcast are relevant to the portion of the globe that is scanned by the spacecraft at the moment of reception; they are thus referred to as local data. While the historical

Table IV.1. Description of the respective payloads of NOAA-N, -N' and METOP polar satellites

NOAA-N, N' (USA)	METOP (EUMETSAT)	Function
AMSU-A	AMSU-A	Atmospheric temperature sounding in the microwave spectral region; all-weather
HIRS/3	HIRS/4	Infra-red atmospheric temperature sounding (useful in clear sky conditions)
	IASI	New generation infra-red atmospheric sounding with improved spectral resolution; measures temperature and humidity profile with improved vertical resolution, and tropospheric chemical constituents
	GRAS	Atmospheric temperature sounding from the lower troposphere to the stratosphere, using radio occultation of a GPS-type signal
MHS	MHS	Atmospheric humidity sounding in the microwave spectral region; all-weather
AVHRR/3	AVHRR/3	Images and radiance/temperature of clouds and surface; vegetation monitoring; supports sounding by identifying cloud-free regions
SBUV/2	GOME	Profiles of atmospheric ozone and other constituents in the upper atmosphere
	ASCAT	Wind vectors at the ocean surface; active instrument

analogue dissemination service, automatic picture transmission, is still available on current NOAA spacecrafts, new generation satellite systems will include digital dissemination services only.

The standards agreed by the Coordination Group for Meteorological Satellites for digital dissemination in L-band from polar satellites are high-resolution picture transmission (HRPT) and low-resolution picture transmission (LRPT) for high-resolution and low-resolution data sets,

respectively. However, the latest planned satellite generations such as FY-3 and NPOESS will also make use of X-bands in order to cope with higher data rates. The current baseline for direct broadcast services in the 2006–2015 time frame is summarized in Table IV.2. Detailed information can be obtained directly from the respective satellite operators.

Direct broadcast services deliver raw data (see product level definition in Table IV.4). Several pre-processing software packages are available: the

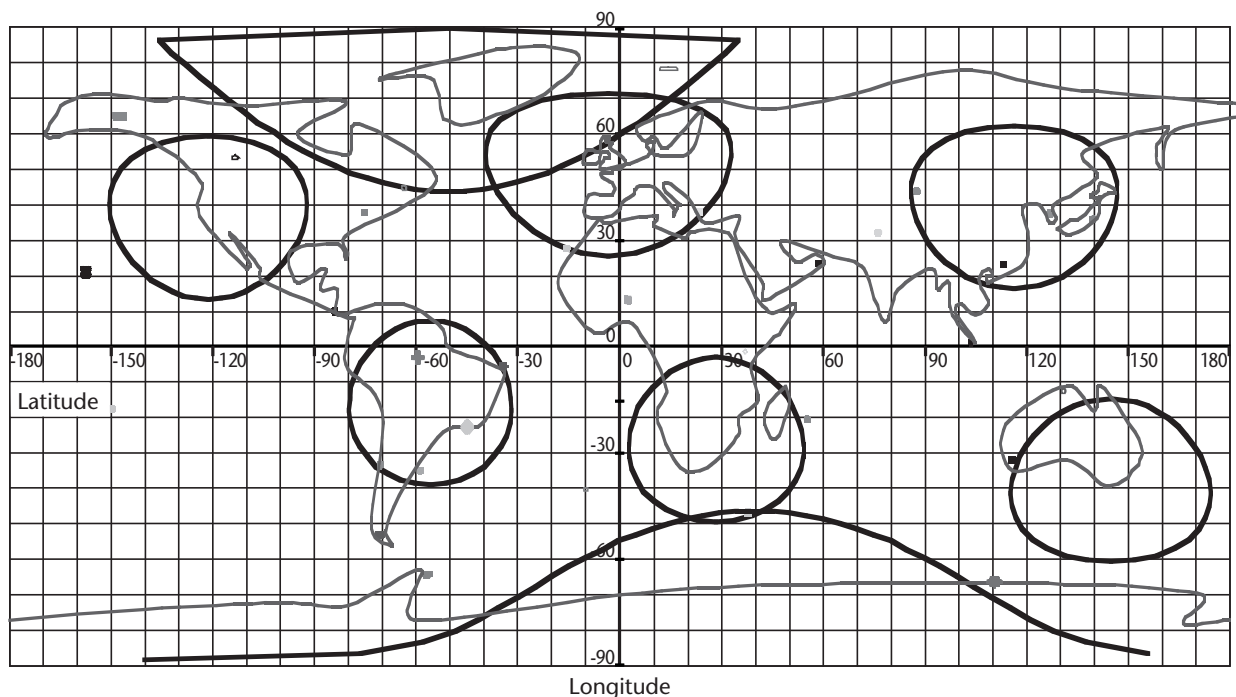
**Figure IV.2. Typical visibility areas of local receiving stations in various locations**

Table IV.2. Main direct broadcast services from operational polar-orbiting satellites in the 2006–2015 time frame

<i>Satellite series</i>	<i>Service</i>	<i>Frequency (MHz)</i>	<i>Data rate (Mb/s)</i>
METOP	LRPT	137.1 / 137.9	.072
METOP	AHRPT	1701	3.5
NPOESS	LRD	1706	3.88
NPOESS	HRD	7812 / 7830	20
NOAA-N,N'	APT (DSB)	137.1 / 137.9 (137.3 / 137.7)	.017 (0.008)
NOAA-N,N'	HRPT	1698 / 1707	.665
FY-1	CHRPT	1704.5	4.2
FY-3	AHRPT	1704.5	4.2
FY-3	MPT	7775	18.2
METEOR-M	LRPT	137.1 / 137.9	0.080
METEOR-M	HRPT	1700	0.665

International TOVS Processing Package software for NOAA satellites is provided by NOAA/NESDIS, the AVHRR and ATOVS pre-processing package (AAPP) that is suitable for NOAA and METOP satellite series is available from the EUMETSAT Satellite Applications Facility on numerical weather prediction (SAF NWP) led by the United Kingdom's Met Office.

A global data set cannot be received from a single local receiving station. Data recorded aboard the spacecraft are downloaded by the satellite operator at one or several ground stations and, after relevant pre-processing, made available through archive retrieval services or distributed in near-real-time through various means. As the amount of data acquired exceeds the recording capability of NOAA spacecraft, the global data set of AVHRR imagery is only available at reduced spatial resolution within the global area coverage service. Advanced TIROS operational vertical sounder (ATOVS) data are processed and distributed over the Global Telecommunication System. Taking into account the storage time aboard the spacecraft during up to one orbital period, and the time needed for data management, transmission and processing, the full global sounding data set cannot be available earlier than three hours after acquisition.

Regional retransmission services are being implemented to complement core ground segment functionalities and combine the advantage of direct broadcast (real-time availability) and of on-board recorded data services (global coverage). Since the coverage and timeliness requirements of regional and global numerical weather prediction became more demanding in 2001, the EUMETSAT ATOVS Retransmission Service (EARS) was initiated by

EUMETSAT. The principle of EARS is to implement a network of local HRPT stations, to concentrate ATOVS data sets received in real time by these stations and to re-distribute these data in a consistent format to the wider user community. Through the addition of acquisition areas of each HRPT station, the EARS network coverage extends to a large part of the northern hemisphere from Eastern Europe to North America, and from the polar cap to North Africa. Data are available within 30 minutes to end users. Implementation of similar regional ATOVS retransmission services (RARS) in the Asia-Pacific region and South America is being planned with a view to providing sounding data at full global coverage in a time frame adequate for assimilation in regional and global numerical weather prediction. Extension of these services to other instrument data beyond sounding is also being considered.

This near-real-time and global coverage functionality is part of the design of the ground segment of the National Polar-orbiting Operational Environmental Satellite System programme, since it is planned to reduce the latency time by implementing a network of 15 downlink stations all around the globe. The network would ensure that the spacecrafts are almost always in the range of a downlink station and can transmit their data with virtually no need for on-board storage.

Dissemination of data acquired through a RARS is performed either via the Global Telecommunication System or advanced dissemination methods. Increasing emphasis is put on the use of those methods for cost-efficient access to satellite data and products. Since this is not specific to polar-orbiting satellites, see 4.3 for further details.

4.2.1.5 Other communications missions

Polar-orbiting satellites are well suited to support data collection systems (DCS). The payload of NOAA and METOP includes the ARGOS DCS, which uses Doppler frequency-shift techniques aboard the satellite to determine the location of any ARGOS transmitter or beacon anywhere in the world with an accuracy of some 150 metres. ARGOS can also collect data from sensors on fixed or mobile data collection platforms (DCPs) and thousands of such DCPs are operating around the world. Although continuous satellite coverage is not available for the relay of DCP data except in the polar regions, the baseline subsystem provides a minimum of eight satellite over-flights each day for every point on Earth.

A search and rescue satellite-aided tracking (SARSAT) system uses polar-orbiting and other low-orbiting satellites to pick up distress signals from downed aircraft or ships in distress and relays the signals to rescue forces through ground stations in cooperating countries. Locating the signal geographically further supports the rescue operations. The polar-and low-orbiting satellites are equipped with transceivers operating at frequencies of 121.5, 243 and 406 MHz.

4.2.1.6 Space monitoring missions

In the baseline system, NOAA satellites include a space environment monitor instrument that measures solar proton flux, electron density and energy spectrum, and total particulate energy distribution at spacecraft altitude. The two detectors included within this instrument are the total energy detector and the medium-energy proton and electron detector. Meteor series also include detectors for solar wind particles. These data are used to monitor and predict solar events, such as sunspots and flares, and their effects on the magnetic field. Measurements of arriving energetic particles are used to map the boundaries of the polar aurora that affects ionospheric radio communications and electric power distribution systems.

4.2.2 Geostationary satellites

Geostationary satellites revolve about the Earth in the same direction and with the same period as the Earth's rotation, that is, they stay in almost fixed positions close to 36 000 km above one point on the Equator. Since the altitude of the geostationary Earth orbit (GEO) is 40 times higher than on a polar LEO, it is technically more difficult to perform measurements of the Earth's atmosphere and surface at high spatial resolution,

but the advantage of the GEO is to allow a continuous weather watch over a fixed extended part of the Earth's globe, or the Earth's disc. Frequent images, typically every 15 or 30 minutes, can be generated of the full Earth disc. Smaller areas can be scanned at even faster rate, namely rapid scanning. Full-disc and rapid scanning images are widely used to support nowcasting and severe weather warnings, to monitor mesoscale cloud growth, for verification of synoptic forecasts and to support TV weather reports. Analysing the displacement of clouds, water vapour patterns or other atmospheric features between consecutive scanning cycles makes it possible to derive wind vector fields. Atmospheric radiation fields observed by GEO satellites complement polar-orbiting satellite data with the effect to improve the temporal sampling of variables like sea-surface temperature or precipitation estimates either directly or indirectly through assimilation in numerical weather prediction models. Image quality is reduced with increasing distance from the sub-satellite point due to the Earth curvature. Data are considered useful for quantitative processing up to a zenith angle of around 70°, which corresponds to a great-circle arc of about 60° from the subsatellite point.

Some geostationary spacecraft such as METEOSAT or FY-2 are spin-stabilized platforms, using their own rotation to scan the Earth's disc line by line and to maintain a stable platform attitude. Other spacecraft designs like GOES, GOMS and MTSAT are 3-axis stabilized, which makes accurate attitude control more difficult but allows for greater flexibility in instrument operation. As a baseline, two geostationary meteorological satellites are maintained by the United States, at 75°W and 135°W, while one is operated by China (105°E), EUMETSAT (0°), Japan (140°E) and the Russian Federation (76°E). In addition, India operates satellites at 74°E and 93°E mainly for national use. The current baseline coverage is illustrated in Figure IV.3, although the actual coverage often differs from the baseline, for example over the Indian Ocean. The overall configuration is subject to regular review by the Coordination Group for Meteorological Satellites and WMO with the aim to optimize and consolidate the coverage, taking into account the participation of new satellite operators.

4.2.2.1 Observing missions

The core mission of operational geostationary satellites is to provide continuous imagery with a refreshment cycle of 30 minutes or less, in order to perform the following tasks:

- (a) Monitor mesoscale cloud features in support of nowcasting;
- (b) Allow the derivation of wind vector fields by tracking cloud or water vapour and other features in support of numerical weather prediction.

Several satellites provide more frequent images, either over the full Earth's disc or a selected area. All operational geostationary imagers include at least the following three core channels: visible, water vapour and infrared around 0.7, 6.7 and 11 μm respectively, with a typical horizontal resolution at the sub-satellite point of 1 or 2 km in the visible and 5 km in the infrared window bands. In addition, more recent satellites have a 3.9 μm channel and a "split-window" 12.0 μm and/or a 13 μm channel. The SEVIRI imager aboard METEOSAT Second Generation series includes 12 channels. A recommendation from the *Implementation Plan for Evolution of Space- and Surface-Based Subsystems of the GOS* is to improve the spatial and temporal resolution of geostationary earth orbit imagers in those spectral bands relevant for monitoring rapidly developing small-scale events and for wind retrieval. All geostationary satellite instruments are evolving towards more spectral coverage and faster imaging.

Some satellites have an extended payload to measure temperature and humidity profiles by infrared radiometry, or the Earth radiation budget. The more recent GOES satellites carry a dedicated atmospheric sounding instrument with 8 carbon dioxide channels, 4 water vapour channels, 4 infrared channels,

and ozone, nitrogen and visible channels. Soundings are produced hourly primarily over the United States and adjacent waters. The horizontal resolution of the sounding radiances is 10 km.

4.2.2.2 Data dissemination missions

Geostationary spacecraft also provide direct broadcast digital data dissemination services as described in Table IV.3. High-rate information transmission (HRIT) and low-rate information transmission (LRIT) are the agreed CGMS standards for direct broadcast from geostationary satellites in L-band, respectively for high and lower data rate, while analogue image dissemination services such as WEFAX, which stands for weather facsimile, are gradually being phased out. In addition, increasing emphasis is put on the use of advanced dissemination methods which complement or sometimes replace direct broadcast. Since the use of these methods is not specific to the geostationary satellites, it is described in more detail in 4.3. Derived products such as atmospheric motion vectors are distributed over the Global Telecommunication System for numerical weather prediction use.

4.2.2.3 Data collection and search and rescue missions

The continuity inherent to geostationary satellite operations provides the capability to collect data from fixed or moving data collection platforms according to a fixed schedule or in alert mode.

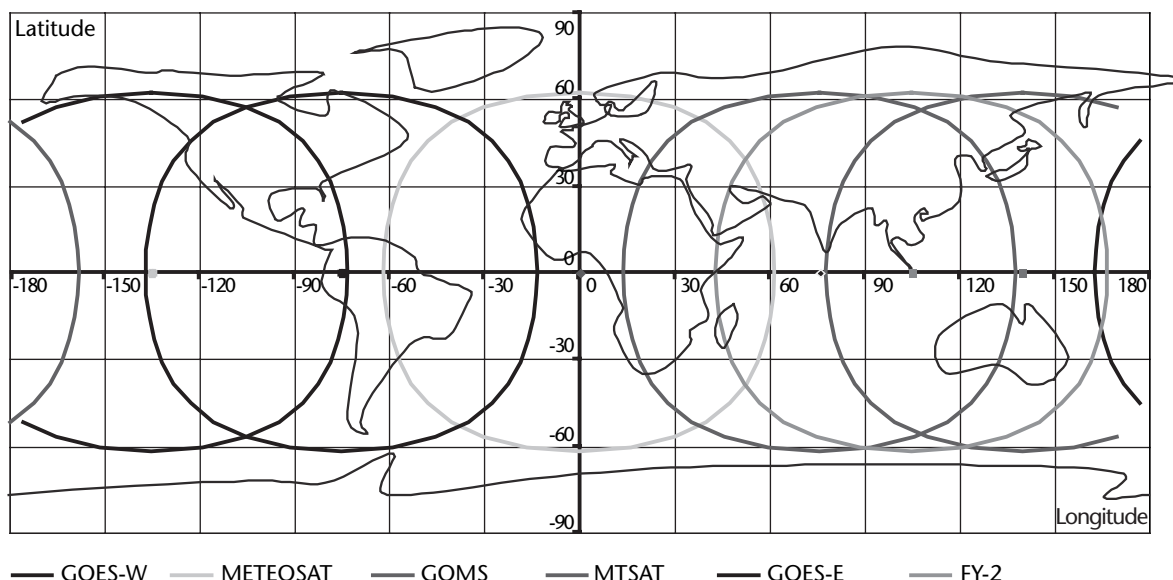


Figure IV.3. Nominal coverage by the current baseline geostationary satellites, with a maximum zenith angle of 70 degrees

Each operator of geostationary meteorological satellites supports a regional data collection system, for gathering data from data collection platforms at fixed locations within the field of view of their respective satellites. The service has proved valuable in relaying alert information pertaining to for example, tsunami, flash floods or radiation, over a large sector of the Earth.

The International Data Collection System was established by the Coordination Group for Meteorological Satellites to allow the collection of environmental data from mobile data collection platforms such as those mounted on ships, planes or free drifting buoys and balloons. Such international platforms are transmitting on a fixed frequency that is compatible with any of the geostationary meteorological satellites within communications range. The Automated Shipboard Aerological Programme (ASAP) uses the International Data Collection System to relay atmospheric sounding data obtained from moving vessels.

A COSPAS-SARSAT geostationary search and rescue (GEOSAR) transponder is aboard GOES, METEOSAT, INSAT, and is planned for ELEKTRO-L. Distress signals emitted by emergency beacons at 406 MHz are thus retransmitted in real time to dedicated ground stations. Unlike the search and rescue system on polar satellites, the geostationary satellite cannot provide the location of the beacon, but serves as an immediate indication of an emergency situation (see 4.2.1.5 for more information relating to search and rescue systems on polar-orbiting satellites).

4.2.2.4 Space environment monitoring missions

The GOES spacecraft carry a space environment monitor consisting of three major components: a magnetometer which measures the magnetic field at spacecraft altitude a solar X-ray sensor which provides data on solar X-ray activity to monitor and predict solar flares and an energetic particle sensor and high-energy proton and alpha detector designed to measure energetic particle flux at orbital altitude. X-ray data, monitored in real time from space environment monitor sensors, can disclose the onset of a solar flare that may seriously affect telephone and radio communications. High-energy particles may damage solar cells, cause sensor malfunctions and trigger spurious commands aboard spacecraft. For similar objectives, a heliogeophysical measurement system is planned aboard ELEKTRO-L.

4.2.3 Research and development (R&D) satellites

4.2.3.1 Primary purpose of R&D satellite missions

Weather and climate monitoring and prediction, knowledge of atmospheric processes and environmental resources monitoring require the observation of many geophysical variables beyond the mission objectives of core meteorological satellites described in 4.2.1 and 4.2.2. A number of environmental satellites have been launched or are being planned for that purpose in the framework of

Table IV.3. Main digital direct broadcast dissemination services from geostationary satellites in 2006–2010

<i>Satellite</i>	<i>Service</i>	<i>Frequency</i>	<i>Data rate</i>
GOES	GVAR	1685.7 MHz	2.1 Mbps
	LRIT	1691.0 MHz	128 kbps
METEOSAT (first generation)	HRI	1694.5 MHz	166 kbps
METEOSAT (second generation)	LRIT (primary dissemination is by ADM)	1691.0 MHz	128 kbps
MTSAT	HRIT	1687.1 MHz	3.5 Mbps
	LRIT	1691.0 MHz	75 kbps
ELEKTRO-L	HRIT	1691.0 MHz	0.665–1 Mbps
	LRIT	1691.0 MHz	64–128 kbps
FY-2	S-VISSR	1687.5 MHz	660 kbps
	LRIT	1691.0 MHz	150 kbps
COMS	HRIT	1691.0 MHz	
	LRIT		

experimental programmes of space agencies. They are referred to as “R&D satellites”. This category of satellite includes a wide range of missions with different status: technology demonstrator for new instrument concepts such as space-borne lidar, proof of concept for retrieving new variables from remote sensing, for example, soil moisture—or missions of already proven feasibility providing data that are required in support of process studies, for example, atmospheric chemistry missions. From a WMO standpoint, R&D satellite missions are especially valuable through the advances that they make possible in instrument technology, retrieving methods and process modelling that will ultimately benefit operational programmes and providing utilization opportunities for future operational polar-orbiting and geostationary satellites.

4.2.3.2 Relevance of R&D satellite missions to the Global Observing System

Since their primary purpose is to fulfil research and development objectives, R&D satellite data do not necessarily comply with operational requirements of long-term continuity and real-time data availability. Furthermore, there may be no guarantee that products will be derived from stable and validated algorithms. Nevertheless, research and development mission data are a valuable complement to operational data to improve the operational coverage, fill possible gaps and support calibration or validation activities. The early use of research and development data in an operational context is also essential as a learning process to adapt assimilation tools and anticipate as much as possible the operational availability of such data. The capability of numerical weather prediction models to assimilate new data streams is a key factor in reducing the gap between operational and research and development data and optimizing the benefit of research and development missions.

Research and development missions make a valuable contribution to the following areas:

- (a) Precipitation: This is an essential variable for environmental and climate monitoring, hydrology and weather prediction. Spatial and temporal rainfall variability and occurrence of extreme events at regional scales require high-density observations. Assimilation of precipitation data contributes to improving numerical weather prediction;
- (b) Cloud microphysics: Understanding the distribution of cloud water content, cloud properties and characteristics is important to parameterize and validate cloud/precipitation processes in numerical weather and global climate models and to determine the Earth’s radiation balance;

- (c) Aerosols and trace gases: Atmospheric chemistry variables affect the radiation budget for climate models and are important to monitor and forecast air quality and atmospheric pollution. Key products include aerosol total column and profile, particle size and optical properties;
- (d) Surface winds and atmospheric motion vectors: These are critical to weather predictions models, and wind is a key parameter for many areas of environmental monitoring and prediction such as coupled oceanic and atmospheric models, tropical weather analysis and hurricane warnings, aeronautical meteorology and fire watch;
- (e) Ocean surface variables such as temperature, topography, colour and sea-ice: Ocean surface characterization is essential for global coupled ocean-atmospheric climate models;
- (f) Land surface variables: Variables such as soil moisture or vegetation status are important in many applications such as agriculture, identification of potential famine areas, irrigation management, land use planning and environmental monitoring, for example, erosion and desertification. Land surface variables are essential to determine lower boundary conditions for numerical weather prediction models;
- (g) Disaster monitoring: Real-time disaster monitoring and management require high-resolution imagery across large areas, in all-weather conditions, day and night. Examples of disaster monitoring include flood, drought, fires, earthquake, landslide, sandstorms, duststorms tsunami, volcanoes, snow/ice cover and red tide.

A list of R&D satellite missions—actual or planned—that are of direct interest to the Global Observing System is available on the WMO Space Programme web page. Details on the respective spacecraft and missions can be found from individual satellite operators.

4.2.3.3 Transition to operational status

Atmospheric or other environmental variables that were initially monitored in support of process studies have proved to be essential in the long term for climate monitoring and modelling. The range of geophysical variables for which sustainable observation needs to be implemented is thus considerably extended beyond the original scope of the operational Global Observing System. Following a successful proof of concept, research and development instruments become candidates for being followed by an operational version and there is an expectation from the user community that continuity be achieved by an operational follow-on without any gap. Transition to an operational status may

require implementing first a transition or preparatory mission in partnership between research and development space agencies and operational agencies. Strong user involvement in data and products validation activities is also advisable. With regard to scheduling, a transition strategy may also require extending research and development missions beyond their initial objectives to fulfil operational needs, as was the case with ESA's European remote-sensing satellite mission and NASA-JAXA's tropical rainfall monitoring mission for instance, in order to bridge the gap between the original research and development mission and its follow-on.

Priorities for transition to operational status need to be regularly reviewed in the light of evolving requirements and of the outcome of research and development missions and impact evaluation of their data. For example, current priorities include:

- (a) Ocean surface topography (ongoing transition through NASA-NOAA-CNES-EUMETSAT agreement for JASON-2);
- (b) Cloud microphysics and atmospheric chemistry missions to monitor trace gases and aerosols playing a role in atmospheric radiation balance, including the greenhouse effect, and in precipitation processes;
- (c) Global precipitation monitoring (beyond the extension of the tropical rainfall monitoring mission and future global precipitation measurement).

Other missions addressing essential geophysical variables are still at the proof of concept stage, for instance 3D wind measurements by space-borne lidar or soil moisture monitoring.

4.3 DATA CIRCULATION AND USER SERVICES

4.3.1 General ground segment features

The ground segment consists of the facilities that are needed to operate the spacecraft, perform data acquisition, processing, archiving and distribution and to provide user support services.

Spacecraft control normally relies on the following facilities:

- (a) A command and data acquisition station capable of receiving the raw data stream transmitted by the spacecraft and house-keeping data, and of uplinking commands;
- (b) A ranging system to accurately check the location of the satellite;

- (c) A satellite and mission control centre in charge of monitoring the status of spacecraft and instruments, performing attitude control manoeuvres to maintain the spacecraft within its specified position and addressing any incident through appropriate measures to secure spacecraft operation.

Within a processing facility, data are pre-processed from level 0 (raw data) to Level I (calibrated and geo-located, or "navigated", radiances) and subsequently processed to derive geophysical products (Level II and beyond). Table IV.4 summarizes the terminology used for conventional data levels. Core product processing by satellite operators is often complemented by distributed processing centres having specialized skills in specific application areas, for example, EUMETSAT's network of Satellite Applications Facilities.

Links established among satellite operators or with other entities allow data exchange from different spacecraft and regions. Access to multi-satellite data sets can thus be facilitated.

Near real-time data dissemination of data and products relies on a range of communication means including direct broadcast, advanced dissemination methods and Global Telecommunication System distribution, as indicated in 4.2.1.4 and 4.2.2.4. Users should refer to the web pages of satellite operators and the WMO Space Programme to obtain the latest information on data access possibilities made available by satellite operators in specific regions with details on data policy and data formats (see References, Part IV).

4.3.2 Integrated Global Data Dissemination Service

Direct broadcast from meteorological satellites provides true real-time data access independently of any telecommunications infrastructure except the receiving station; however there are limitations to this approach. In the case of polar satellites, direct broadcast only delivers data related to the instantaneous field of view of the satellite (local data). Furthermore, low earth orbit or geostationary earth orbit direct broadcast users need appropriate software and computer facilities, which are often expensive, to perform pre-processing and product processing. In other cases such as the first generation of METEOSAT, data are not directly broadcast by the satellite but first downloaded to the central processing site and pre-processed up to Level I.5 before being retransmitted to the satellite and disseminated from there. This lessens the

Table IV.4. Usual terminology for data-processing levels

<i>Data level</i>	<i>Description</i>
0	Raw data
I	Data extracted by instrument, at full instrument pixel resolution, with Earth-location and calibration information
	Sub-levels for polar satellite data
	Sub-levels for GEO
	1a: instrument counts with ancillary information
	1.0 Instrument counts with Earth-location and calibration information
	1b: instrument counts with quality control and with Earth-location and calibration information appended but not applied
	1.5 Earth-located and calibrated instrument radiances
	1c: brightness temperatures (IR) or reflectance factor (VIS) of instrument pixels with Earth-location and calibration information
	1d: same as Level 1c, with cloud flag (for sounding data only)
II	Geophysical value (temperature, humidity, radiative flux) at instrument pixel resolution
III	Remapped (gridded) product based on geophysical value derived at instrument pixel resolution
IV	Composite product (multisource) or result of model analysis of lower-level data

Note: Products and Level I data are archived by satellite operators. Detailed information on archive data catalogue, formats and retrieval media can be found on the respective operators' websites (see References, Part IV).

difficulty of pre-processing by the user. However, another limitation remains: owing to the meteorological spacecraft data dissemination rate, it may not be possible to transmit the entire data set in full resolution.

Emphasis was put in recent years on the use of advanced dissemination methods whereby satellite data and products are distributed by state-of-the-art commercially available telecommunications means instead of being restricted to the on-board telecommunication function of the meteorological spacecraft. Data distribution can be optimized from a pure telecommunications point of view and evolve with time in order to meet new requirements and benefit from the most cost-efficient technology. Additionally, when the meteorological platform does not have to support dissemination functions, the position-keeping requirements can be relaxed, which facilitates extended lifetime operations. The most widespread type of advanced dissemination method is file transmission with Internet Protocol by digital video broadcasting satellite as available from various telecommunications operators around the

world. This allows data rates of tens of Mbps to be received with standard low-cost equipment. Dissemination is performed in Ku-Band or in C-band. C-band offers more robust signal strength in intertropical regions because of its lower absorption by water vapour and liquid water. It is however more sensitive to local interference with radars.

ADM services can offer unified access to various data sources including LEO, GEO or R&D satellites and multi-satellite composite products, high-level products and non-satellite information. Satellite data dissemination via ADM is not specific to the satellite world and is a component of the WMO Information System.

The Integrated Global Data Dissemination Service (see Figure IV.4) is the approach to satellite data and products circulation within the WMO Information System. In pursuing that vision, WMO supports cooperation among satellite operators towards establishing ADM in a coordinated way, organizing global data exchange, ensuring fulfilment of the needs of WMO Programmes and compatibility with overall WMO Information

System concepts. Satellite operators will act within the Service as Data Collection and Product Centres. The objective of the Service is to offer integrated access to the data of all satellites available over WMO Regions in a cost-efficient way for both users and satellite operators. The Integrated Global Data Dissemination Service relies on the expansion of ADM coverage, together with direct broadcast services as a complement, and the follow-on of the current Global Telecommunication System.

4.3.3 User services

Users should refer to the individual web pages of the respective satellite operators to benefit from the available user services (see References, Part IV). This normally includes updated information on the following points: Satellite status and operations (eclipse, manoeuvres); product catalogue and product algorithm description; archive catalogue, format description and retrieval modalities; technical issues for real-time data access, including specifications for receiving devices, software for data reception, decoding, decompression and/or pre-processing; administrative issues for real-time data access, including registration and subscription formalities and data policy; background information, publications, training opportunities and user conferences and user support.

4.3.4 Satellite meteorology user training

The WMO Strategy for Education and Training in Satellite Matters is based on cooperation between satellite operators and some Regional Meteorological Training Centres that take a particular responsibility as Centres of Excellence in satellite meteorology. The strategy emphasizes the “training of trainers”. The network of Centres of Excellence is expanding and currently covers practically all WMO Regions and provides training in five of six of the WMO official languages, as indicated in Table IV.5.

A core component of this strategy is the Virtual Laboratory for Education and Training in Satellite Meteorology adopted by the Coordination Group for Meteorological Satellites and WMO. It develops and maintains a range of training materials and tools that are accessible on-line via the Virtual Laboratory Resource Library. It organizes conventional face-to-face training events (“training of trainers”) and on-line lectures with remote instructors. Cooperation among the Centres of Excellence and with sponsoring satellite operators is supported by regular on-line interactive sessions dealing with live meteorological situations. Up-to-date information on the Virtual Laboratory is found on its web page that is accessible

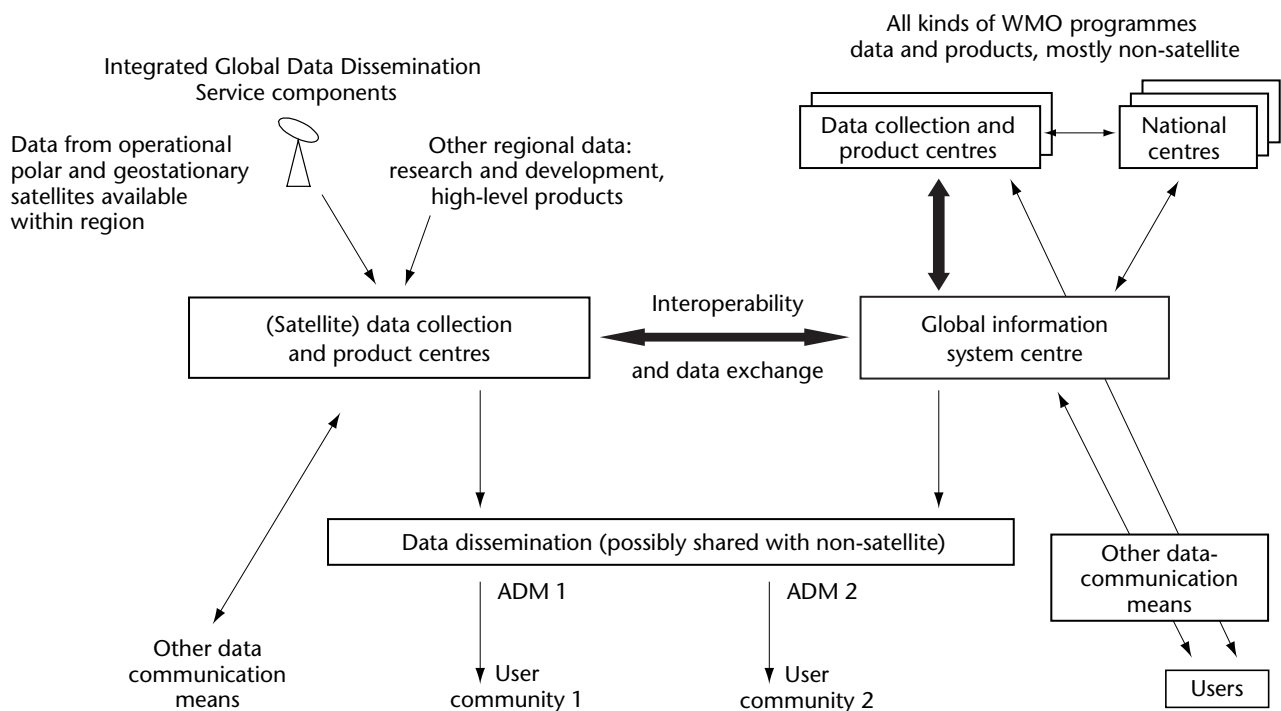


Figure IV.4. Schematic diagram of the Integrated Global Data Dissemination Service within the WMO Information System framework

Table IV.5. Network of Centres of Excellence and sponsoring satellite operators

<i>Centre of Excellence</i>	<i>Sponsoring satellite operator</i>	<i>Primary language</i>	<i>WMO region</i>
Niamey (Niger)	EUMETSAT	French	Regional Association I
Nairobi (Kenya)	EUMETSAT	English	Regional Association I
Muscat (Oman)	EUMETSAT and IMD	Arabic	Regional Association II
Bridgetown (Barbados)	NOAA/NESDIS	English	Regional Association IV
San José (Costa Rica)	NOAA/NESDIS	Spanish	Regional Associations III and IV
Nanjing (China)	CMA	Chinese and English	Regional Associations II and V
Melbourne (Australia)	JMA	English	Regional Association V
Buenos Aires (Argentina)	NOAA/NESDIS, ESA, NASA	Spanish	Regional Association III

from any of the sponsoring institutions' web pages, as well as those of WMO and the Coordination Group for Meteorological Satellites.

4.4 DERIVED PRODUCTS

4.4.1 Calibration issues

Instrument counts can only be converted to radiances with calibration coefficients that characterize the instrument's response as a result of its geometry and detector sensitivity. Industrial pre-launch measurements provide an initial model of the instrument's response and long-term behaviour, but only in-orbit commissioning and regular monitoring can provide accurate calibration coefficients as required for any quantitative product derivation. Some instrument designs include on-board calibration devices relying on a black body source for infrared sensors and moon, sun or deep space viewing. Each calibration cycle then allows updating the nominal calibration coefficients that are included in the disseminated data flow. When no on-board calibration system is available, or in order to check such on-board systems when available, retrospective calibration is achieved by atmosphere radiance measurements over stable and homogeneous targets such as deserts and cloud-free oceans. Results of this retrospective calibration process, known as vicarious calibration, are routinely published by satellite operators.

Monitoring climate change requires the detection of trends in terms of small variations, for example, a few tenths of a degree of temperature over a decade, which requires particularly accurate calibration ensuring consistency of global data sets from different sensors over a very long period. The

instrument's nominal calibration thus needs to be followed by an inter-calibration of different sensors that are simultaneously in orbit, comparing data series of carefully space-time co-located scenes with similar viewing angle, in order to provide normalized calibration coefficients.

The use of particularly accurate reference sensors, including airborne calibration campaigns, makes it possible to approach absolute calibration that is ultimately required for climate modelling. Provisions are being made within WMO and the Coordination Group for Meteorological Satellites towards establishing a global space-based intercalibration system that would enable to perform intercalibration on an operational basis rather than retrospectively.

4.4.2 Product categories

Some of the products derived from the satellite observations processed at major central facilities are exchanged internationally over the Global Telecommunication System. Some products are broadcast through ADM services together with Level I data. These products are also available on File Transfer Protocol servers hosted by the respective satellite operators. A consolidated list of operational products can be via through the web pages of satellite operators (see References, Part IV).

The CGMS Directory of Meteorological Satellite Applications describes the generation and use of a wide range of products that can be derived from satellite observations, including in particular the following categories:

- (a) Radiances and imagery products
Imagery products result from calibration, geolocation, remapping and dynamics adjustment of Level I data. Imagery and radiance products are a

necessary step for derivation of higher-level products. In particular, an accurate cloud mask product is a prerequisite for deriving meaningful quantitative surface and sounding products. Cloud detection can be performed through comparison with infrared brightness temperature thresholds or visible reflectance thresholds, with adjustments depending on the underlying surface (sea or land), the latitude and the season.

Imagery products are also used on a routine basis by direct interpretation either as single-channel images or after further processing such as multispectral compositing, temporal combination of animated sequences, or multisatellite mosaics.

(b) Cloud characteristics

Cloud characteristics products derived from satellite imagery provide essential support to nowcasting and regional short-term forecasting. Multispectral discrimination techniques applied to visible and infrared imagery allow identification of cloud types. Cloud top temperature or pressure level can be derived from infrared imagery.

(c) Atmospheric temperature and humidity soundings

Vertical temperature and humidity soundings by polar satellites are mainly derived from infrared sounder data, in clear-sky, and from microwave sounders in cloudy areas. Sounding data from the NOAA/ATOVS instrument package are operationally available from NESDIS on the Global Telecommunication System in SATEM code at reduced resolution. ATOVS data have been shown to have a significant positive impact on numerical weather prediction in both hemispheres. Advanced numerical weather prediction centres are increasingly assimilating radiance data directly, rather than the temperature and humidity soundings retrieved from them. Information on the error characteristics of retrieved products or radiances, including biases, is essential for their successful assimilation. Regional sets of locally received ATOVS radiance data are available through the regional ATOVS retransmission service as described in 4.2.1.4. Hyperspectral infrared sounders of the AIRS-IASI generation will allow considerable progress in accuracy and vertical resolution.

(d) Atmospheric motion winds

Such winds are generated automatically by applying a correlation algorithm to sequences of two or three images. They are extracted in the conventional manner by tracking the movement of cloud fields from a geostationary satellite. A similar

approach can be used in the absence of clouds, in particular with water vapour features detected in water vapour absorption channel images or ozone field patterns in ozone absorption channel images. Such geostationary winds are computed within 60° latitude and longitude of the subsatellite point, at least four times daily at 0000, 0600, 1200 and 1800 UTC, and distributed in SATOB and/or BUFR code by geostationary satellite operators. In general, operators are moving towards the production of higher-resolution products and the use of quality indicators to assist in their use. For polar regions, advantage can be taken of frequent overpasses by polar-orbiting satellites for the derivation of winds, as routinely demonstrated with water vapour radiances from the MODIS instruments aboard NASA's AQUA and TERRA satellites.

(e) Land and sea-surface temperature

Sea-surface temperature may be derived from infrared images of both polar and geostationary meteorological satellites in cloud-free areas. The primary advantages of the polar data are that they provide global coverage and have generally better spatial resolution. The advantage of the geostationary satellites is that their frequent data coverage gives a better chance to find cloud-free pixels. It also allows frequent temporal sampling necessary to monitor diurnal variations. Regional advanced very high-resolution radiometer (AVHRR)-based products are available at high resolution—typically 2 km—or global products at lower resolution, for example, 10 km. With METOP it should be possible to derive operationally high-resolution products on a global scale. High-accuracy sea-surface temperatures can be derived from AATSR (ENVISAT) and MODIS (AQUA and TERRA). Microwave passive imagery can also support measurements of that variable.

Infrared imagers also allow derivation of land surface temperature in combination with visible imagery to take into account the effect of vegetation.

(f) Snow and ice

Snow and ice areas are identified by visible, infrared and microwave imagery (AVHRR, MODIS, SSM/I). Active microwave sensors such as scatterometer or synthetic aperture radar imagers are useful to characterize the superficial snow or ice layer.

(g) Vegetation

Daylight AVHRR imagery provides an essential indicator of the overall vegetation status, the normalized difference vegetation index based on

the difference between reflectance of AVHRR channel 1 (0.6 μm) and channel 2 (0.9 μm). The index is used to assess fire risk and estimate vegetation growth and crop yields. More sophisticated products are the leaf area index and the fraction of absorbed photosynthetically active radiation. Vegetation products are also generated from more recent imagers like MODIS. Characterizing the land surface is important to determine lower boundary conditions for numerical weather prediction and is a major component of climate monitoring from space.

(h) Ocean surface

Active microwave sensors are essential to monitor the ocean surface: altimetry data provide sea-level information for ocean current monitoring and oceanographic modelling, but also provide information on sea state, such as significant wave height and wind intensity. Scatterometer data, for example, from SeaWinds on QuikSCAT and ASCAT on METOP, provide ocean surface wind vectors that are an essential input to numerical weather prediction and tropical cyclone monitoring.

4.5 TRENDS IN SPACE-BASED SUBSYSTEMS

Space-based observation capabilities are changing rapidly in many ways. One striking element is the increasing number of countries contributing to the space-based observing system, either by operational satellites or R&D satellites. When geostationary satellites from China, EUMETSAT, India, Japan, the Republic of Korea, the Russian Federation and the United States become operationally available at the same time, new possibilities will arise to optimize the global baseline configuration and ensure its robustness. For polar satellites, more operational spacecraft will allow a better time sampling from the low earth orbit. The growing capability of operational users to take advantage of R&D satellites and arrangements for real-time availability of selected R&D satellite data will also contribute to enhance the Global Observing System.

The performance of space-based instruments is dramatically improving, allowing higher temporal and horizontal resolution, and considerably higher spectral resolution. At some stage, geostationary satellites will all be equipped with hyper-spectral infrared sensors allowing frequent temperature and humidity sounding that so far can only be performed from the low earth orbit a

few times a day. Radio-occultation measurements of navigation satellites signals from the Global Navigation Satellite System will complement the observation of the stratosphere and upper troposphere. Active and passive infrared measurements from the polar orbit will improve observations of aerosols and atmospheric chemical components. Precipitation monitoring by radar and microwave imagery will be effective on the global scale. Doppler lidar on polar satellites will provide 3D global wind fields. Lightning detectors aboard geostationary satellites will improve the monitoring of active convective cells in areas not sufficiently covered by ground-based systems. Provided that the relevant frequency bands are kept free from man-made interferences, the potential of microwave passive radiometry will be further developed for monitoring soil moisture and ocean salinity and better monitoring of cloud microphysical properties.

The increased resolution and number of instruments will result in an explosion of the data rate acquired from satellites, requiring an updated and flexible dissemination infrastructure that the Integrated Global Data Dissemination Service is expected to facilitate. The data volume, together with the multiple numbers of data sources should lead users to focus their development efforts and strengthen their cooperation in order to be able to rely more on common products generated by regional specialized centres according to agreed requirements, rather than individually processing low-level data only. The need for accurate and consistent data series will also emphasize the importance of sensor calibration and inter-calibration in line with agreed standards.

Further details on the long-term vision of the space-based subsystem can be found in *The Role of Satellites in WMO Programmes in the 2010s* (WMO/TD-No. 1177).

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PART V

REDUCTION OF LEVEL I DATA

5.1 GENERAL

Various WMO manuals and guides define Level I data (primary data or instrument readings) and Level II data (meteorological parameters, that is, nominal values) and provide the appropriate recommendations concerning data reporting requirements.

Level I data, which comprise instrument readings and unprocessed measurements, are in general instrument readings or sensor signals expressed in appropriate physical units and referred to Earth coordinates. They require conversion to the meteorological variables specified in the data requirements given in the Weather Watch Plan. In general, the conversion of Level I data into the corresponding meteorological variables is achieved by applying the calibration functions and all systematic corrections. In some cases the process involves more complex procedures.

Level II data, which include meteorological variables and processed data, are data obtained directly from many types of simple instruments, or derived from Level I data.

Data exchanged internationally are supposed to be Level II data and Level III data (derived meteorological variables). If Level I data meet the data-reporting requirement as defined in WMO Manuals and Guides, no adjustment is needed. In such a situation both Level I and Level II data are have identical values.

In some cases, the WMO recommendations set out in the *Manual on the Global Observing System* (WMO-No. 544) and Part I of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8) require adjustment of Level I data into Level II data with regard to more than one aspect. The instrument value can be adjusted for the following reasons: representative height of sensor above local ground, surface roughness, wind speed, temperature, evaporation or wetting losses.

5.2 REDUCTION PROCESS

Meteorological stations installed by Members should meet the requirements for the variables most commonly used in synoptic, aviation, and marine

meteorology, and in climatology summarized in the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8). Chapter 1, Part I, Annex 1.B, and 1.7.1.2, Chapter 1, Part III, contains information on automatic weather stations; 1.3.2.6, Chapter 1, Part II, lists requirements and Chapter 3, Part III, provides general information on data reduction. Details concerning corrections and reductions of instrument values for meteorological variables can be found in Part I, whereas sampling meteorological variables is fully discussed in Chapter 2, Part III. Automatic weather stations are further discussed in 1.3.2, Chapter 1, Part II.

The introduction of new technology necessitates more than ever before a standardization of the conversion of raw data into Level I data or Level I data into Level II data. Owing to the lack of such approved standards and procedures, many commercial companies produce their own algorithms and consider these as firmware, with no access by the users. Situations in which instrument specialists lack necessary information, in particular in case of malfunction of microprocessors or black boxes, should be avoided.

5.3 AVERAGING OF MEASURED QUANTITIES

Although it is common practice to report observational data, averaged over a specified time, clear arguments in favour of averaging or a definition of the mathematical technique for averaging have not yet been provided. The averaging of some variables, however, is defined in Chapter 1, Part II, and in 3.6, Chapter 3, Part III, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Two typical reasons may exist for averaging:

- (a) To present a value that is more reliable in case of fluctuating, noisy measurements, whether natural or artificial;
- (b) To present a value with a higher measure of spatial representativeness.

In both cases, different mathematics may be chosen. For (a), a typical resistor-capacitor filtering method, not an arithmetical mean based on

a time window, reduces the noise. For (b), an arithmetical mean based on a time window might be favourable, although the use of a constant weighting factor is questionable. Moreover, the use of the median value for observations within a period is favourable in some cases; therefore, calculating the arithmetic mean should not be recommended in all cases. Averaging observational data to obtain Level II data is required in many circumstances.

In the absence of a clearly defined regulation, the averaging of each observed value for further reporting should be based on a well-defined method, to be substantiated with sound arguments. Mathematical calculus to be used should be described and explained in detail.

Reference

Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8)

PART VI

DATA QUALITY CONTROL

6.1 GENERAL

Meteorological observations are exchanged between countries on a worldwide basis. Users need to be confident that the observations they receive from other countries are made according to agreed standards set by WMO. The accuracy of the data is of primary importance to many kinds of analyses, computations and scientific investigations. Therefore, the need for quality control of observational data is linked with the fundamental importance of obtaining consistent and accurate data for their optimum use by all possible users, including the World Weather Watch Programme, and international research programmes.

Data quality is a measure of how well data serve the purpose for which they were produced. All data are produced for a purpose, and their quality is directly tied to whether they meet the requirements of that purpose. Although data quality addresses the appropriateness of the data for a specified use, there is no reason why the data cannot be put to a different use as long as the data user understands the original requirements and is confident that the data can meet current application requirements.

Data quality assessment is conducted during production against the producer's specifications. Data quality assessment is inherently complex and cannot be represented by a simple numeric value. Rather, it should be indicated by the sum of bits of information about the data that are captured during the data production process and made available to the data user as metadata.

There are two keys to the improvement of data quality: prevention and correction. Error prevention is closely related to the collection of the data and the entry of the data into a database. Although considerable effort can and should be given to error prevention, the fact remains that errors in large data sets will continue to exist, and data validation and correction cannot be ignored.

It is better to prevent errors than to have to rectify them later, and it is by far the cheaper option. Making corrections retrospectively can also mean that the incorrect data may have already been used in a number of analyses before being corrected. Preventing errors does not affect those errors

already in the database; however, data validation and cleaning remains an important part of the data quality process.

All means of automatic error monitoring should be used to recognize errors in advance before they affect the processed values.

The basic characteristics of quality control and general principles to be followed within the framework of the Global Observing System are described briefly in the *Manual on the Global Observing System* (WMO-No. 544).

The purpose of Part VI is to provide supplementary information and describe in more detail the practices, procedures and specifications which Members are invited to follow for quality control of observations made by their respective National Meteorological Services.

Recommendations provided below should be used in conjunction with the relevant WMO documentation dealing with data quality control.

Details of quality control procedures and methods to be applied to meteorological data intended for international exchange are described in Chapter 6 of the *Guide on the Global Data-processing System* (WMO-No. 305).

Minimum Global Data-processing and Forecasting System standards for data quality control are defined in section 2, Volume I, Part II, of the *Manual on the Global Data-processing and Forecasting System* (WMO-No. 485).

Basic steps for quality control of data relating to automatic weather stations are given in Chapter 1, Part II, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8); more general instructions are given in Part III of the aforementioned publication.

6.1.1 Levels of application of quality control procedures

Observational data must be quality controlled at different levels of data pre-processing and processing and transfer in real time and non-real time, using various procedures.

The levels of quality control procedures are as follows:

- (a) The observing site, starting with data acquisition by manual or automatic meteorological stations;
- (b) Data collection centres, prior to the transmission of observational data over the Global Telecommunication System;
- (c) GTS centres (standard telecommunication procedures, for example, control of timeliness and data format);
- (d) GDPFS centres and other available facilities.

Within the framework of the Global Observing System, quality control is restricted to items (a) and (b) above; therefore, the instructions and guidance provided in the Guide are concerned with observing sites and collection centres only.

Although the Global Observing System deals solely with Level I data and their reduction and conversion into Level II data, quality control should be performed at all stages until the data are transmitted over the Global Telecommunication System.

The reliability and accuracy of meteorological observations, the causes of observation errors and methods of preventing such errors are within the scope of the areas of quality control under discussion.

There are two levels involved in checking the quality of real-time observational data:

- (a) Quality control of raw data (Level I data)—basic quality control performed at the observing site. This quality control level is relevant during acquisition of Level I data and should eliminate errors of technical devices, including sensors, systematic or random measurement errors and errors inherent in measurement procedures and methods. Quality control at this stage includes the following tasks: a gross error checks, basic time checks and basic internal consistency checks. Application of these procedures is extremely important because some errors introduced during the measuring process cannot be eliminated later.
- (b) Quality control of processed data—extended quality control, partly performed at an observing site, but mainly at a National Meteorological Centre. This level is relevant during the reduction and conversion of Level I data into Level II data and Level II data themselves. It deals with comprehensive checking of temporal and internal consistency, evaluation of biases and long-term drifts of sensors and modules, malfunction of sensors and the like.

Quality control levels are outlined as follows:

- (a) Basic quality control procedures to be carried out at a station:
 - (i) Automatic quality control of raw data:
 - a. Plausible value check: gross error check on measured values;
 - b. Check on a plausible rate of change: time consistency check on measured values;
 - (ii) Automatic quality control of processed data:
 - a. Plausible value check;
 - b. Time consistency check:
 - i. Check on a maximum allowed variability of an instantaneous value, or step test;
 - ii. Check on a minimum required variability of instantaneous values or persistence test;
 - iii. Calculation of standard deviation;
 - c. Internal consistency check;
 - d. Technical monitoring of all crucial parts of a station;
- (b) Extended quality control procedures to be conducted at a National Meteorological Centre:
 - (i) Plausible value check;
 - (ii) Time consistency check:
 - a. Check on a maximum allowed variability of an instantaneous value or step test;
 - b. Check on a minimum required variability of instantaneous values or persistence test;
 - c. Calculation of standard deviation;
 - (iii) Internal consistency check.

Quality control procedures of Level II data and Level III data should be implemented at the National Meteorological Centre to check and validate the integrity of data, namely completeness, correctness and consistency of data. The checks performed at the observing station must be repeated at the Centre, but in a more elaborate, sophisticated form. This should include comprehensive checks against physical and climatological limits, time consistency checks for a longer measurement period, checks on logical relations among a number of variables, or internal consistency of data, and statistical methods for analysing data.

Quality control procedures and techniques, pre-processing checks, checks for surface data and upper-air data, flagging, computer program design and combined quality control for data Levels II

and III are described in detail in the *Guide on the Global Data-processing System* (WMO-No. 305).

Quality control can be carried out manually and automatically. In principle, all the necessary quality control procedures can be applied manually, but in general the time needed to do so is unacceptably long. No appreciable delay should be caused by quality control because the data must be transmitted in real time for operational use. The real-time quality control at the observing point is, however, of paramount importance since many of the errors introduced during the observation process cannot be eliminated later.

The real-time activity of quality control within the Global Observing System includes data up to one month old for land or sea stations. This applies particularly to the monthly CLIMAT and CLIMAT TEMP messages and BATHY/TESAC reports.

6.1.2 Observational errors

The entire range of observational errors can be divided into the following three main groups:

- (a) Errors of technical devices, including instruments;
- (b) Errors inherent in observing procedures and methods;
- (c) Subjective random or systematic errors on the part of observers and collecting operators.

Several types of errors involving measured data can arise:

- (a) Random errors are distributed more or less symmetrically around zero and do not depend on the measured value. They sometimes result in overestimation and underestimation of the actual value. On average, the errors cancel each other out.
- (b) Systematic errors on the other hand, are distributed asymmetrically around zero. On average these errors tend to bias the measured value above or below the actual value. Systematic errors can be caused by a long-term drift of sensors, or a sensor without valid calibration.
- (c) Gross or large errors are caused by malfunctioning of measurement devices or by mistakes made during data processing; errors are easily detected by checks.
- (d) Micrometeorological (representativeness) errors are the result of small-scale perturbations or weather systems, for example, turbulence, affecting a weather observation. These systems are not completely observable by the observing system owing to the temporal or spatial resolution of the observing system. Nevertheless when such a phenomenon occurs during

a routine observation, the results may appear strange compared to surrounding observations taking place at the same time.

- (e) Measurement errors in observations cannot be eliminated completely; the problem is reducing them to an acceptable level. A measurement error can be regarded as the sum of the above-mentioned types of errors. For further reference, see 1.6.1.2 and 1.6.2, Chapter 1, Part I, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

6.2 PROCEDURAL ASPECTS OF QUALITY CONTROL

6.2.1 Responsibility and standards

The primary responsibility for the quality control of observational data and the determination of their quality rests with the National Meteorological Service from which the data originate. Data producers should ensure that the following procedures are observed:

- (a) Quality control procedures are implemented and exercised during data acquisition;
- (b) Data and data quality are adequately and accurately documented;
- (c) Validation checks are routinely carried out on all observational data;
- (d) Validation checks are fully documented;
- (e) Data are available in a timely and accurate manner with documentation that allows users to determine fitness for use;
- (f) Feedback from users on the data quality is dealt with in a timely manner;
- (g) Data quality is maintained at the highest level at all times;
- (h) All known errors are fully documented and made known to users.

Therefore, it is crucial that Members make adequate provision for data quality control to ensure that they are as free from error as possible and the data quality is known at every level of the data-obtaining process.

According to the *Manual on the Global Observing System* (WMO-No. 544), Members must implement minimum standards of real-time quality control at all levels for which they are responsible, for example, observing stations and National, Regional and World Meteorological Centres. In addition, the *Manual on the Global Data-processing and Forecasting System* (WMO-No. 485) recommends that they do so before data received via telecommunication links are processed.

Recommended minimum standards of real-time quality control at the observing station and the National Meteorological Centre levels are similar to those provided in section 2, Volume I, Part II, of the *Manual on the Global Data-processing and Forecasting System* (WMO-No. 485).

6.2.2 Scope of quality control

The quality control system implemented by the National Meteorological Service should include data validation, data cleaning and quality control monitoring.

(a) Data validation

Validation is a process used to determine whether data are inaccurate, incomplete, inconsistent or unreasonable. The process may include completeness checks, plausible value checks and time and internal consistency checks. These processes usually result in flagging, documenting and subsequent checking of suspect records. Validation checks may also involve checking for compliance against applicable standards, rules and conventions. A key stage in data validation is identifying the causes of the errors detected and preventing those errors from re-occurring.

The quality of data should be known at any point of the validation process and can change with time as more information becomes available. Quality control flags should be used for that purpose.

(b) Data cleaning, or remedial actions

Data cleaning refers to the process of “fixing” data errors that have been identified during the validation process. The term is synonymous with “data cleansing”, although some use data cleansing to encompass both data validation and data cleaning. It is important that data is not inadvertently lost in the data cleaning process, and that changes to existing information be carried out with care. It is reasonable to retain both the original data and the corrected data side by side in the database so that if mistakes are made in the cleaning process, the original information can be recovered.

Data cleaning includes defining and determining error types, searching and identifying error instances, correcting errors, documenting error instances and error types and modifying data entry procedures to reduce future errors.

(c) Quality control monitoring

See 3.1.3.14, Part III, of the present Guide on network performance monitoring, which can be applied and implemented by National Meteorological Services for all types of observational data, and Appendix VI.1.

The procedures mentioned above should be partly applied at observing stations, but primarily at the relevant collection centres.

6.2.3 Implementation

Standardization of quality control procedures to be implemented at observing sites within the framework of the World Weather Watch is far from complete. The growing volume of international exchange of observational data calls for urgent measures to ensure that the meteorological information originating in different countries is of comparable quality. The practical steps to be taken for this purpose must aim at the maximum possible standardization.

See Appendix VI.2, Guidelines for quality control procedures applying to data from automatic weather stations.

To ensure that national obligations within the framework of the World Weather Watch system are met, regulatory material is required on tasks of meteorological stations and weather offices with regard to checking and correcting synoptic observational data. Both manual and automatic quality control methods may be used. Standard software modules are being developed to support computer-based quality control at observing sites or collection centres.

6.2.3.1 Manual methods

If manual quality control methods are used, a Member should include the following procedures in its national instructions or regulations on real-time monitoring of surface and upper-air observations before transmitting them over the Global Telecommunication System:

(a) Surface synoptic observations

Quality control and monitoring of the observing programme is to be carried out at the National Meteorological Centre for all stations concerned, at least those included in the regional basic synoptic network at main and intermediate standard times.

(b) Upper-air observations

Upper-air observations from stations of the regional basic synoptic network are processed and encoded either at the station itself or centrally. Quality control and monitoring should be carried out starting at the station and at the other centres responsible for processing or transmitting the data.

Data checking is applied to the following areas:

- (a) Occurrences of hyperadiabatic vertical gradients of temperature in the free atmosphere;

- (b) Comparison of some values in selected points against temporal change since the last observing time and against values obtained by interpolation from data of neighbouring stations;
- (c) Checking of the vertical wind profile against inhomogeneities.

Clearly, erroneous TEMP data should be fully or partially rejected from distribution, depending on where errors occur. Should minor errors be detected after checking, these TEMP data are corrected manually. In any case, corrections should be distributed nationally marked as corrected messages. Checked and controlled TEMP data are distributed internationally in accordance with transmission schedules and are therefore only marked as retard messages if data cannot be corrected and distributed in time.

After the data have been examined and checked at the station, quality control and correction—if necessary and possible—of all national meteorological data prior to their transmission over the Global Telecommunication System should be carried out manually at the relevant centres.

Monitoring the process of observations, timing, encoding and transmission is performed by the National Meteorological Centre in real time and non-real-time, the latter aiming at ensuring improved quality for non-real time data. Checks and appropriate remedial actions are conducted in the event of missing or delayed messages, observational errors and format errors.

6.2.3.2 Automated methods

Automated quality control of large quantities of meteorological data has become essential and is now possible via computer systems and quality control programmes.

The main advantages of automatic quality control procedures within the scope of their natural limits are as follows:

- (a) Objectivity and repeatability;
- (b) Uniformity;
- (c) Possibility of using complex control parameters and practically unlimited specifications;
- (d) Elimination of tedious checking of huge amounts of correct data;
- (e) Close supervision of the quality control results on display units by experts so that any possible errors can be rapidly analysed.

The principles of organizing automated quality control of meteorological data depend on the development stage of algorithm methods for quality

control and automatic data acquisition. The algorithms used by Members for quality control at an observing station are similar. In most cases they are based on physical and/or climatological interdependence and some statistical relations. There is, however, a requirement for further increasing the efficiency of the algorithms and programmes in use, and it is recommended that Members exchange information on their experience with the methods used in order to benefit others.

6.3 OTHER QUALITY CONTROL PROCEDURES

A number of minor improvements can be made in an observing station to help ensure that the observers carry out their duties correctly. The following is not intended to be an exhaustive list, but can serve as a guide to the many ways in which quality control can be expected, especially at single-observer stations.

6.3.1 Availability of statistics on variables

In practice, checking programmes are designed to reveal all gross and substantive errors which recur regularly. The detection of rare and irrelevant measurement errors is not worthwhile, as the reliability of tests varies in inverse proportion to the size of errors they are designed to detect. In other words, the degree of accuracy of the check tests varies—there is always the risk of missing an error or mistaking a correct value for a doubtful one. Most tests have been compiled on the basis of experience; they are the result of practical intuition or statistical analysis.

The statistics on variables must be made available at the observation site in order to enable the observer to compare the current observation with the statistics on past events at the station concerned. Such statistics may be essential in detecting equipment malfunctions. There will always be a need for a complete check of the overall results before the message is dispatched, even for a fully automatic observing system.

6.3.2 Use of accepted abbreviations

In order to reduce subjective errors during the recording of visual observations and instrument readings, the human observer should make use of accepted abbreviations. They should be standardized within a National Meteorological Service and laid down in national observing instructions.

6.3.3 Pictorial representations and diagrams

A plot of hourly values of the main variable can be used by the observer to detect gross errors. Variables subject to this type of error are pressure, temperature and dew point; however, the plotting of other variables may also be useful in this respect. Care should be taken to keep a certain number of plots of the different variables on the log sheet at any time and to use the same sheet the next day. Simultaneous plots of not less than six entries are required to maintain an adequate history.

A chart showing the average diurnal change in temperature representative of a recent period of several years and relevant to the observational data can also be useful to the observer as a safeguard against gross errors. In areas where large variations from such averages do not occur, the succession of hourly readings as indicated in the previous paragraph can provide an additional check. If the observed value appears incompatible with the average value, the observer should take a further independent reading. The existence of these averages can also stimulate additional interest in the observer, who will then be able to recognize those occasions which are not typical or are likely to be significant.

In tropical areas, a chart showing the average diurnal pressure change will provide a useful guide, familiarizing the observer with the magnitude of the changes to be expected.

In making cloud reports, the observer is confronted with a wide variety of cloud types and complicated regulations. The inexperienced observer should use flow diagrams to enable the correction of a report. These diagrams are comparatively simple to construct and are available in Volume I of the *International Cloud Atlas* (WMO-No. 407).

Observers should have access at all times to publications dealing with observing and coding procedures. Furthermore, the procedures should be displayed whenever possible as visual reminders of their responsibilities. Pictorial representations and diagrams are generally more effective, but when lists or tables are necessary they should be placed in a prominent position.

6.3.4 Simplified mathematical checks

Experience has shown that the greatest number of errors are detected at the pre-processing stage, which precedes the analysis. Mathematical checks

are made of upper-air and surface synoptic data received on an operational basis over communications channels by data-processing centres.

Simplified mathematical checks are used during the comparison of observed values with their approximated values. The comparison may be carried out both vertically over the observation site and in a horizontal plane between data for the same level.

The following are used as approximated values:

- (a) Values of the meteorological variables computed using the hydrostatic equation assuming polytropy of the atmosphere or linear variability within layers, and so forth (hydrostatic control);
- (b) The value and sign for temperature in adjacent layers, assuming a maximum gradient;
- (c) Interpolated values which may vary depending on how they were observed;
- (d) Forecast values for the actual period;
- (e) Approximated values, mainly polynomials of the second and third degree;
- (f) Average value for groups of adjacent stations;
- (g) Local statistical parameters of meteorological variables calculated on the basis of empirical relationships (regression equation).

Many control procedures make it possible not only to detect errors but to correct them or to reconstruct omitted observations.

References

- Guide to the Applications of Marine Climatology* (WMO-No. 781)
Guide to Climatological Practices (WMO-No. 100)
Guidelines on Climate Metadata and Homogenization (WCDMP-No. 53; WMO/TD-No. 1186)
Guide on the Global Data-processing System (WMO-No. 305)
Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8)
Guide to Marine Meteorological Services (WMO-No. 471)
Guide to Practices for Meteorological Offices Serving Aviation (WMO-No. 732)
International Cloud Atlas, Volume I (WMO-No. 407)
Manual on Codes (WMO-No. 306)
Manual on the Global Observing System (WMO-No. 544)
Manual on the Global Data-processing and Forecasting System (WMO-No. 485)
Manual on Marine Meteorological Services (WMO-No. 558)

DATA QUALITY CONTROL

1. QUALITY CONTROL OF DATA FROM THE SURFACE-BASED SUBSYSTEM

1.1 General

Various quality control methods are used for surface synoptic data, that is, data related to standard observational times. These include horizontal, vertical, three-dimensional, time and hydrostatic checks and a combination of these methods.

1.2 Tests using statistical structure parameters within an interpolation scheme

1.2.1 Horizontal checks

Horizontal checks can be performed with the aid of methods used for objective analysis by means of optimum interpolation for every station according to data from several—usually four to eight—surrounding stations and comparison of the interpolated value against the observed value. The interpolation is made according to the following formula:

$$\tilde{f}'_0 = \sum_{i=1}^n \rho_i f'_i \quad (1)$$

where f'_0 is the interpolated value of deviation f' of the element f from its normal value at the station in question; f'_i are the observed deviations of this element from its normal value at the surrounding stations; ρ_i are the weight multipliers found by solving the equation system.

$$\sum_{j=1}^n m_{ij} \rho_j + \delta^2 \rho_i = m_{io} \quad (2)$$

where m_{ij} are covariances describing statistic relation of the element f values at different points, namely:

$$m_{ij} = \overline{f'_i f'_j} \quad (3)$$

(the bar above indicates statistical averaging), δ is the mean square of the observational errors. It is rational to perform control by proceeding not from the absolute value of residue $\tilde{f}'_0 - f'_0$ between the interpolated and observed values, but from the ratio:

$$R = \frac{|\tilde{f}'_0 - f'_0|}{\Delta_0} \quad (4)$$

where Δ_0 is the mean square difference between \tilde{f}'_0 and f'_0 which can be computed according to the formula below:

$$\Delta_0 = \sqrt{m_{oo} - \sum_{i=1}^n \rho_i m_{oi} + \delta^2} \quad (5)$$

after weights ρ_i definition. If Δ_0 does not exceed some critical value K , the data are recognized to be correct; otherwise an error is assumed to exist. According to available data, $K = 4$ may be used; this ensures that the correct values are never called into question. In light of the above assumption, it is perhaps advisable to use smaller values.

The inequality $\Delta_0 > K$ indicates with a rather high probability that the presence of errors can arise not only from an erroneous value f'_0 at the checked station, but also from an erroneous value at the surrounding stations, especially in the case where the weight ρ_i for this value is large. Therefore, it is first necessary to perform a similar check for the surrounding stations to ensure that the erroneous value has been detected. In most cases this procedure ensures the indication of the erroneous value and its replacement by the interpolated value. When the values are erroneous at several surrounding stations, this method is not applicable.

1.2.2 Vertical checks

Vertical checks are also based on a comparison of the observed value with the interpolated one. However, this interpolation is not carried out with data from the neighbouring stations related to the same level, but rather with data from the same station related to

other levels. As the covariances in the vertical do not possess characteristics of homogeneity and isotropy, the values of m_{ij} (3) entering formulae (2) and (5) do not depend on the distance between levels, but rather on the height (pressure) of both levels.

Vertical checking and horizontal checking with respect to upper-air data is used mainly for the geopotential. However, with information on covariance matrices it is easy to tell how this method might be used for other meteorological elements as well.

1.2.3 Three-dimensional checks

Three-dimensional checks are performed by comparing the observed value with the value interpolated from data on several levels, both at the station in question and at neighbouring stations. Since the data on the three-dimensional statistical structure of a number of basic meteorological fields are available, the use of this procedure should pose no difficulty.

1.2.4 Time checks

Time checks involve data from the current and previous observational times. However, this control method requires time extrapolation instead of interpolation. It is therefore expedient to use e-data computed from previous observations as a reference for checking the results of the numerical prognosis for the time under consideration.

1.2.5 Hydrostatic checks

Hydrostatic checks are based on the use of the static equation or the geopotential barometric formula to show that the geopotential and temperature at different isobaric surfaces are internally consistent. The essence of this method is as follows:

Integrating the hydrostatic equation:

$$\frac{\partial H}{\partial r} = -\frac{R}{9.8} \frac{T}{r} \quad (6)$$

for the layer located between two adjacent isobaric surfaces ρ_n and ρ_{n+1} and turning from the absolute temperature T to the temperature in degrees Celsius, results in:

$$H_{n+1} - H_n = A_n + \frac{R}{9.8} \int_{\rho_n}^{\rho_{n+1}} t \, d \ln \rho \quad (7)$$

where R is the gas constant for air, A_n is the layer thickness at 0°C .

Assuming the mean temperature t in the layer is equal to the arithmetic mean of its boundary values, (7) can be reduced to the following form:

$$H_{n+1} - H_n = A_n + B_n (t_n + t_{n+1}) \quad (8)$$

The numerical values of coefficients A_n and B_n are listed in the table, Estimate of static check potentialities.

As the upper-air reports contain information on both the geopotential and temperature of isobaric surfaces, ratio (8) can be used to check this information. For this purpose the difference between the values of the left- and right-hand sides of relation (8) need to be computed for each layer located between adjacent mandatory isobaric surfaces.

$$\delta_n = H_{n+1} - H_n - A_n - B_n (t_n + t_{n+1}) \quad (9)$$

In addition, the values of δ_n need to be compared against its tolerable values Δ_n . The latter can be estimated empirically by handling a large number of observations and theoretically.

These estimates, as well as the estimates of the given method in general, depend to a large extent on the method used for defining the temperature and geopotential of the isobaric surfaces at each station.

A theoretical estimation of the tolerable discrepancies in the hydrostatic check is more difficult than for the methods described above, for these discrepancies have a variety of causes, namely: random errors of temperature measurement, random and systematic deviations of the vertical temperature profile $t(\ln p)$ from the linear one and rounding-off errors in the geopotential computation. The joint action of random observational errors and random deviations $t(\ln p)$ from the linear variation can be estimated with the aid of the formula:

$$\Delta_1 = \sqrt{\frac{m_{oo}}{2} \sqrt{1 + \frac{\delta^2}{m_{oo}} - \frac{1}{\ln^2 q} 4 - (2 - \ln q)^2} q} \quad (10)$$

Estimate of static check potentialities

p hPa	1000	850	700	500	400	300	200
A_n, m	1300	1553	2692	1786	2302	3244	5546
$B_n, m/degree$	2.38	2.84	4.03	3.27	4.21	5.94	10.15
$K\Delta_1, m$	20	24	35	9	19	70	64
$K\Delta, m$	1	1	6	10	10	10	10
$K\Delta_1 + \Delta_2, m$	20	25	41	19	29	80	74
Δ, m	30	30	40	30	40	100	120

where Δ_1 is the mean square of the corresponding discrepancy δ , q is the correlation coefficient between temperature values of the particular adjacent surfaces.

The values of $K\Delta_1$ cited in the above table are computed for the winter season; they are somewhat smaller for the summer season. The coefficient K is taken rather large ($K = 3.5$), because in addition to large-scale disturbances of the temperature vertical profile, taken into account in formula (10), mesoscale disturbances can take place.

The values Δ_2 given in the Table above represent maximum discrepancies resulting from rounding-off geopotential values, while Δ are the tolerable discrepancies of equation (8) defined empirically. In comparison with $K\Delta_1 + \Delta_2$, natural deviations of t ($\ln p$) from its linear form due to great curvature of the profile of t near the Earth's surface take place in the 1 000–850 hPa layer and in the 300–200 and 200–100 hPa layers due to the presence of the tropopause. This clearly explains the difference between Δ and $K\Delta_1 + \Delta_2$ for the indicated layers. As for the 500–400 and 400–300 hPa layers, the values of Δ can perhaps be smaller.

In addition to the detection of errors exceeding tolerable discrepancies, the static checking procedure makes it possible to determine the source of the error and consequently to correct it. This is true because errors from different causes result in diverse combinations of discrepancies. For example, an error in a geopotential value due to transmission garbling will result in discrepancies in equation (8) for the two adjacent layers, which are equal to this error and have opposite signs. Garbling of a temperature value will cause two discrepancies of the same sign proportional to the B_n coefficients. In addition, an error in computing the thickness of a layer results in a discrepancy for that layer only.

1.2.6 Combined checks

Combined quality control checks are carried out by means of various control methods not merely consecutively, but in close interrelation. This is necessary, first because no single control method is sufficient to detect and correct all the erroneous information and second, because different methods react to the errors in different ways, depending on the source.

The potential success of quality control increases significantly if several methods are used in combination, that is, if conclusions are drawn as to the character and the value of a certain error using results obtained from all the methods. This enables the detection of the source of the error; its localization, i.e. determining which of the suspected values is erroneous; definition of its numerical value and its correction. For example, the error localization obtained by the combined use of the horizontal and vertical checks is attained by the following means: the value of the tolerable discrepancy for a station changes during a horizontal check, based on the results of a previous, vertical check, for example. If the vertical check indicates an error, the tolerable discrepancy for the horizontal check must be diminished.

2. QUALITY CONTROL OF DATA FROM THE SPACE-BASED SUBSYSTEM

2.1 General

Indirect sounding data from satellites refer to a rapid succession of non-standard observational times, that is, the data are asynoptic. In order to check, take into account and assimilate asynoptic information for the objective analysis of meteorological fields, data should be used which refer to various points in space and time. In other words, a conversion from a space (three-dimensional)

analysis of meteorological fields to a four-dimensional space-time analysis is required.

At the same time, direct sounding data possess at least three more features that distinguish them from upper-air sounding data. First, the former give space-mean values, i.e. the scale of averaging is considerably larger than for values obtained by means of conventional upper-air sounding. Second, satellite-based instruments operate under more complicated conditions in comparison with upper-air sounding instruments, and conversion from spectral intensity to temperature and geopotential is approximate. Therefore, the errors of indirect-sounding data are greater than those of radiosondes. Third, all satellite measurements are performed by only one set of instruments during the satellite's lifetime; the errors of indirect sounding at various points should therefore be intercorrelated.

The above-mentioned properties of indirect sounding data allow the validity of the data to be estimated during—not before—the four-dimensional analysis and control.

2.2 Estimation of data reliability

The methods for estimating the reliability of the four-dimensional analysis for data-control purposes, taking into account both the asynoptic nature of the indirect sounding data and the value of sounding errors and degree of their correlation, are examined below. It is assumed that four-dimensional assimilation of the information is made with the aim of optimum time-space interpolation. If the observational errors are intercorrelated and do not correlate with the true values of the observed meteorological elements f , the equation of the optimum interpolation method for determining the weight multipliers ρ_i takes the following form:

$$\sum_{j=1}^n (\mu_{ij} + \eta_i \eta_j \nu_{ij}) \rho_j = \mu_{oi} \quad (i=1, 2, \dots, n) \quad (11)$$

where μ_{ij} is the correlation coefficient between the true values of f of two stations with indexes i and j ; μ_{oi} is the correlation coefficient between the true value of f of the station with index i and the unknown value of this element at the point o ; n is the quantity of data used for interpolation; η_i^2 is the mean square of the observational error of this meteorological element divided by its dispersion σ^2 ; ν_{ij} is the correlation coefficient between observational errors of two stations with indexes i and j .

Having computed the weights ρ_i by solving equation (11), it is easy to perform the interpolation according to the following formula:

$$\hat{f}_o' = \sum_{i=1}^n \rho_i \tilde{f}_i' \quad (12)$$

where the values with the prime sign imply deviations of f from its mean of climatological value (normal) f , the sign \sim refers to the observed values of the element, in contrast to the true values, and \wedge refers to the result of the interpolation, also in contrast to the true values.

Having solved system (11), the mean square interpolation error can be estimated by using the following formula:

$$\varepsilon^2 = 1 - \sum_{i=1}^n \mu_{oi} \rho_i \quad (13)$$

where ε^2 is the degree of interpolation error, i.e. the mean square of the interpolation error divided by σ^2 ; the value σ is supposed to be constant.

The spatial correlation functions of basic meteorological elements can be considered homogeneous and isotropic in the horizontal plane or along isobaric surfaces, i.e.

$$\mu_{ij} = \mu(r_{ij}) \quad (14)$$

may be assumed, where r_{ij} is the distance between two stations with indexes i and j ; $\mu(r)$ is the function of the given form.

Formula (14) is correct if both observations refer to the same isobaric surface and are performed at the same time. The more general hypothesis on time-space (horizontal-time) homogeneity and isotropy can therefore be implemented with sufficiently accurate results. If the distance between two stations is equal to r_{ij} and the time interval between observations is τ_{ij} , the following formula may be used:

$$\mu_{ij} = \mu\left(\sqrt{r_{ij}^2 + c^2 \tau_{ij}^2}\right) \quad (15)$$

where c is the constant denoting velocity. For the surface pressure $c \approx 35 \text{ km h}^{-1}$. This value of c will be used further on.

It can now be assumed that part of the basic data, for example, data from stations with indexes $i = 1, 2, \dots, k$, is obtained by means of conventional radiosondes, while the rest ($i = k+1, k+2, \dots, n$) is obtained indirectly. The errors of radiosondes are considered to be white noise, that is, they do not correlate between each other or with indirect sounding errors:

$$v_{ij} = \begin{cases} 1 & \text{at } j = 1; \\ 0 & \text{at } i = 1, 2, \dots, k; j \neq 1, 2, \dots, n; j \neq i; \\ 0 & \text{at } j = 1, 2, \dots, k; i = 1, 2, \dots, n; i \neq j; \end{cases} \quad (16)$$

The mean square, and consequently the degree of radiosonde error, is taken to be equal for all the radiosonde points:

$$\eta_1 = \eta_2 = \dots = \eta_R = \eta \quad (17)$$

The degree of indirect sounding error is also identical to (17), but different from direct-sounding errors:

$$\eta_{R+1} = \eta_{R+2} = \dots = \eta_n = \eta' \quad (18)$$

System (11) then becomes:

$$\begin{aligned} \sum_{j=1}^n \mu_{ij} \rho_j + \eta^2 \rho_i &= \mu_{oi} \quad (i = 1, 2, \dots, R) \\ \sum_{j=1}^k \mu_{ij} \rho_j + \sum_{j=k+1}^n (\mu_{ij} + \eta^2 v_{ij}) \rho_j &= \mu_{ij} \\ &\quad (i = k+1, k+2, \dots, n) \end{aligned} \quad (19)$$

For example, if $k = 2$ and $n = 5$, the matrix of coefficients of system (19) (taking into account that $\mu_{ji} = \mu_{ij}$ and $v_{ji} = v_{ij}$) is of the form:

$$\begin{pmatrix} 1 + \eta^2 & \mu_{12} & \mu_{13} & \mu_{14} & \mu_{15} \\ \mu_{12} & 1 + \eta^2 & \mu_{23} & \mu_{24} & \mu_{25} \\ \mu_{13} & \mu_{23} & 1 + \eta^{12} & \mu_{34} + \eta^{12} v_{34} & \mu_{35} + \eta^{12} v_{35} \\ \mu_{14} & \mu_{24} & \mu_{34} + \eta^{12} v_{34} & 1 + \eta^{12} & \mu_{45} + \eta^{12} v_{45} \\ \mu_{15} & \mu_{25} & \mu_{35} + \eta^{12} v_{35} & \mu_{45} + \eta^{12} v_{45} & 1 + \eta^{12} \end{pmatrix}$$

As regards the correlation coefficients v_{ij} between indirect sounding errors, the latter are accepted as being dependent only on the distance between points. Here the limiting case is of interest when these errors are of the "black noise" character, i.e. when for all i and j exceeding k :

$$v_{ij} = 1 \quad (i, j = k+1, k+2, \dots, n) \quad (20)$$

Therefore, the criteria of the quality control performed during the four-dimensional analysis or assimilation of information do not, for all practical purposes, differ from those stated in 1.2.1 of this Appendix, based on the application of the optimum interpolation. The essence of the quality control itself consists, as previously, in the comparison of the residue between the interpolated and reported values against the tolerable discrepancy and—depending on their relation—the determination of the validity or erroneousess of the checked data.

GUIDELINES FOR QUALITY CONTROL PROCEDURES APPLYING TO DATA FROM AUTOMATIC WEATHER STATIONS

INTRODUCTION

Quality control of data is the best known component of quality management systems. It consists of the examination of data at stations and at data centres with the aim to detect errors. Data quality control must be applied as real-time quality control performed at automatic weather stations (AWSs) and data processing centres (DPCs). In addition, it must be performed as near real-time and non real-time quality control at DPCs.

There are two levels of real-time quality control of AWS data:

- (a) Quality control of raw data (signal measurements), which is basic quality control performed at an automatic weather station site. This level is relevant during acquisition of Level I data and should eliminate errors of technical devices, including sensors; systematic or random measurement errors and errors inherent in measurement procedures and methods. Quality control at this stage includes gross error checks, basic time checks and basic internal consistency checks. Application of these procedures is extremely important because some errors introduced during the measuring process cannot be eliminated later.
- (b) Quality control of processed data, which is extended quality control, partly performed at an automatic weather station site, but mainly at a data processing centre. This level is relevant during the reduction and conversion of Level I data into Level II data, and Level II data. It deals with comprehensive checking of temporal and internal consistency, evaluation of biases and long-term drifts of sensors and modules, and malfunction of sensors, among others.

Quality control levels are outlined below:

- (a) Basic quality control procedures (automatic weather stations)
 - (i) Automatic quality control of raw data
 - a. Plausible value check, or gross error check on measured values
 - b. Check on a plausible rate of change, or time consistency check on measured values
 - (ii) Automatic quality control of processed data
 - a. Plausible value check
 - b. Time consistency check
 - i. Check on maximum allowed variability of an instantaneous value, or step test
 - ii. Check on minimum required variability of instantaneous values, or persistence test
 - iii. Calculation of standard deviation
- (b) Extended quality control procedures (data processing centres)
 - (i) Plausible value check
 - (ii) Time consistency check:
 - a. Check on a maximum allowed variability of instantaneous value, or a step test
 - b. Check on minimum required variability of instantaneous values, or persistence test
 - c. Calculation of standard deviation
 - (iii) Internal consistency check.

When quality control procedures are applied to AWS data, the data are validated and flagged, and if necessary, estimated or corrected. If original value is changed as a result of quality control practices, it is strongly advisable that it be preserved with the new value. A quality control system should include procedures for returning to the source of data, or original data, to verify them and prevent recurrence of errors. All possibilities for automatic monitoring of error sources should be used to recognize errors in advance before they affect the measured values.

The quality of data should be known at any point of the validation process, and the quality control flag can be changed throughout the process as more information becomes available.

Comprehensive documentation on quality control procedures applied, including the specification of basic data processing procedures for a calculation of instantaneous—one minute—data and sums, should be a part of standard documentation at automatic weather stations.

The guidelines deal only with quality control of data from a single automatic weather station; therefore spatial quality control is beyond the scope of this publication. The same also applies to checks against analysed or predicted fields. Furthermore, quality control of formatting, transmission and decoding errors is beyond the scope of this publication owing to a specific character of

these procedures, as they are dependent on the type of message and transmission method used.

Notes:

1. Recommendations provided in the guidelines should be used in conjunction with the relevant WMO documentation dealing with data quality control:
2. Basic characteristics of quality control and general principles to be followed within the framework of the Global Observing System are briefly described in the *Manual on the Global Observing System* (WMO-No. 544). Quality control levels, aspects, stages and methods are described in the Guide.
3. Basic steps of quality control of AWS data are given in the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8), especially in Chapter 1, Part II.
4. Details of quality control procedures and methods that have to be applied to meteorological data intended for international exchange are described in Chapter 6 of the *Guide on the Global Data-processing System* (WMO-No. 305).
5. The Global Data-processing System's minimum standards for quality control of data are defined in Volume I of the *Manual on the Global Data-processing and Forecasting System* (WMO-No. 485).

1. DEFINITIONS

Quality assurance, quality control

Quality assurance and quality control are two terms that have many interpretations because of the multiple definitions of the words "assurance" and "control".

Quality assurance: All planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an establishment will meet quality requirements.

The primary objective of the quality assurance system is to ensure that data are consistent, meet data quality objectives and are supported by comprehensive description of methodology.

Quality control: The operational techniques and activities that are used to fulfil requirements for quality.

The primary purpose of quality control of observational data is missing data detection, error detection and possible error corrections.

Quality control of observational data consists of examination of data at stations and data centres to detect missing data and errors; data are validated and flagged and if necessary, estimated or corrected, in order to eliminate the main sources of errors and ensure the highest possible standard of quality for the optimum use of these data by all users.

To ensure the high quality of AWS data, a well-designed quality control system is vital. Efforts shall be made to correct all erroneous data and validate suspicious data detected through quality control procedures. The quality of AWS data shall be known.

Types of errors

Several types of errors, described below, can occur with regard to measured data. They shall be detected by implementing quality control procedures.

Random errors are distributed more or less symmetrically around zero and do not depend on the measured value. Random errors sometimes result in overestimation or underestimation of the actual value. On average, the errors cancel each other out.

Systematic errors are distributed asymmetrically around zero. On average these errors tend to bias the measured value either above or below the actual value. Systematic errors can be caused by a long-term drift of sensors or sensor without valid calibration.

Gross errors are caused by malfunctioning of measurement devices or by mistakes made during data processing; errors are easily detected by checks.

Micrometeorological (representativeness) errors are the result of small-scale perturbations or weather systems affecting a weather observation. These systems are not fully observable by the observing system owing to its temporal or spatial resolution. Nevertheless when such a phenomenon occurs during a routine observation, the results may appear strange compared with surrounding observations taking place at the same time.

2. BASIC QUALITY CONTROL PROCEDURES

Automatic data validity checking (basic quality control procedures) shall be applied at automatic weather stations to monitor the quality of sensors' data prior to their use in computation of

weather parameter values. This basic quality control is designed to remove erroneous sensor information while retaining valid sensor data. In modern automatic data acquisition systems, the high sampling rate of measurements and the possible generation of noise necessitate checking of data at the levels of samples and of instantaneous data, generally one-minute data. Basic quality control procedures shall be applied at each stage of the conversion of raw sensor outputs into meteorological parameters. The range of basic quality control procedures strongly depends on the capacity of AWS processing units. The basic quality control outputs should be included in every AWS message.

Types of basic quality control procedures are as follows:

- (a) Automatic quality control of raw data (sensor samples) intended primarily to indicate sensor malfunction, instability and interference in order to reduce potential corruption of processed data; the values that do not pass this quality control level are not used in further data processing;
- (b) Automatic quality control of processed data intended to identify erroneous or anomalous data; the range of this control depends on the sensors used.

All AWS data should be flagged using appropriate quality control flags. These are used as qualitative indicators representing the level of confidence of the data. At the basic quality control level, a simple flagging scheme of five data quality control categories suffices. The quality control flags are as follows:

- (a) Good – accurate; data with errors less than or equal to a specified value;
- (b) Inconsistent – one or more parameters are inconsistent; the relationship between different elements does not meet defined criteria;
- (c) Doubtful – suspect;
- (d) Erroneous – wrong; data with errors exceeding a specified value;
- (e) Missing data.

It is essential that data quality be known and demonstrable; data must pass all basic quality control checks. In case of inconsistent, doubtful and erroneous data, additional information should be provided; in case of missing data, the reason of missing should be transmitted. In case of BUFR messages for AWS data, BUFR descriptors 0 33 005 (quality information AWS data) and 0 33 020 (quality control indication of following value) can be used.

- (a) Automatic quality control of raw data
 - (i) Plausible value check – gross error check on measured values
The aim of the check is to verify whether the values are within the acceptable range limits. Each sample shall be examined if its value lies within the measurement range of a pertinent sensor. If the value does not pass the check, it is rejected and is not used in further computations of relevant parameters.
 - (ii) Check on a plausible rate of change – time consistency check on measured values
The aim of the check is to verify the rate of change (unrealistic jumps in values). The check is best applicable to data of high temporal resolution (a high sampling rate), as the correlation between the adjacent samples increases with the sampling rate.

After each signal measurement, the current sample shall be compared to the preceding one. If the difference between these two samples is more than the specified limit, the current sample is identified as suspect and is not used for the computation of an average. However, it is still used to check the temporal consistency of samples, and the new sample is still checked with the suspect one. The result of this procedure is that in case of large noise, one or two successive samples are not used to compute the average. In case of sampling frequency of five to ten samples per minute (sampling intervals, 6–12 seconds), the limits of time variance of successive samples (the absolute value of the difference) implemented at automatic weather stations can be as follows:

- a. Air temperature: 2°C;
- b. Dew-point temperature: 2°C;
- c. Ground (surface) and soil temperature: 2°C;
- d. Relative humidity: 5 per cent;
- e. Atmospheric pressure: 0.3 hPa;
- f. Wind speed: 20 m s⁻¹;
- g. Solar radiation (irradiance): 800 Wm⁻².

At least 66 per cent or two thirds of the samples should be available to compute an instantaneous (one-minute) value; for wind direction and speed, at least 75 per cent of the samples are necessary to compute a 2- or 10-minute average. If less

than 66 per cent of the samples are available in one minute, the current value does not meet the quality control criterion and is not used in further computations of relevant parameters; the value should be flagged as missing.

(b) Automatic quality control of processed data

(i) Plausible value check

The aim of the check is to verify whether the values of instantaneous data (one-minute average or sum; where wind is concerned, 2- and 10-minute averages) are within acceptable range limits. Limits of different meteorological parameters depend on the climatic conditions of an AWS site and the season. At this stage, they can be independent of them and they can be set as broad and general. The following fixed-limit values implemented at automatic weather stations are possible:

- a. Air temperature: $-90^{\circ}\text{C} - +70^{\circ}\text{C}$;
- b. Dew-point temperature: $-80^{\circ}\text{C} - 50^{\circ}\text{C}$;
- c. Ground (surface) temperature: $-80^{\circ}\text{C} - +80^{\circ}\text{C}$;
- d. Soil temperature: $-50^{\circ}\text{C} - +50^{\circ}\text{C}$;
- e. Relative humidity: 0–100 per cent;
- f. Atmospheric pressure at the station level: 500–1100 hPa;
- g. Wind direction: 0–360 degrees;
- h. Wind speed: $0 - 75 \text{ m s}^{-1}$ (2-minute, 10-minute average);
- i. Wind gust: $0 - 150 \text{ m s}^{-1}$
- j. Solar radiation (irradiance): $0 - 1600 \text{ Wm}^{-2}$;
- k. Precipitation amount (1-minute interval): 0–40 mm.

Note: The fixed-limit values listed above can be adjusted to reflect climatic conditions of the region more precisely, if necessary. If the value is outside the acceptable range limit, it should be flagged as erroneous.

(ii) Time consistency check

The aim of the check is to verify the rate of change of instantaneous data (detection of unrealistic spikes or jumps in values or dead band caused by blocked sensors).

- a. Check on a maximum allowed variability of an instantaneous value, or a step test: if the current instantaneous value differs from the prior one by more than a specific limit or step, the current instantaneous value does not pass the check and it should be

flagged as doubtful or suspect. The possible limits of a maximum variability, the absolute value of the difference between the successive values, are provided below:

<i>Parameter</i>	<i>Limit for suspect</i>	<i>Limit for erroneous</i>
Air temperature	3°C	10°C
Dew-point temperature	2–3°C; 4–5°C ^a	4°C
Ground (surface) temperature	5°C	10°C
Soil temperature 5 cm	0.5°C	1°C
Soil temperature 10 cm	0.5°C	1°C
Soil temperature 20 cm	0.5°C	1°C
Soil temperature 50 cm	0.3°C	0.5°C
Soil temperature 100 cm	0.1°C	0.2°C
Relative humidity	10%	15%
Atmospheric pressure	0.5 hPa	2 hPa
Wind speed (2-minute average)	10 m s ⁻¹	20 m s ⁻¹
Solar radiation (irradiance)	800 Wm ⁻²	1000 Wm ⁻²

^a If dew-point temperature is directly measured by a sensor, the lower limit is to be used. If dew point is calculated from measurements of air temperature and relative humidity, a larger limit is recommended, taking into account the influence of the screen protecting the thermometer and hygrometer. A screen usually has different system response times for air temperature and water vapour, and the combination of these two parameters may generate fast variations of dew point temperature, which are representative of the influence of the screen during fast variations of air temperature and relative humidity, not of a sensor default.

In case of extreme meteorological conditions, an unusual variability of the parameter(s) may occur. In such circumstances, data may be flagged as suspect, although correct. They are not rejected and are further validated during extended quality control implemented at data processing centres regardless of whether they are correct or incorrect.

- b. Check on a minimum required variability of instantaneous values during a certain period (persistence test), once the measurement of the

parameter has been taken for at least 60 minutes. If the one-minute values do not vary over the past 60 minutes at least by more than the specified limit or threshold value, the current one-minute value does not pass the check. Possible limits of minimum required variability are as follows:

- i. Air temperature: 0.1°C over the past 60 minutes;
- ii. Dew-point temperature: 0.1°C over the past 60 minutes;
- iii. Ground (surface) temperature: 0.1°C over the past 60 minutes;¹
- iv. Soil temperature may be very stable, so there is no minimum required variability;
- v. Relative humidity: 1 per cent over the past 60 minutes;²
- vi. Atmospheric pressure: 0.1 hPa over the past 60 minutes;
- vii. Wind direction: 10 degrees over the past 60 minutes;³
- viii. Wind speed: 0.5 m s⁻¹ over the past 60 minutes;³

If the value fails the time consistency checks it should be flagged as doubtful (suspect).

A calculation of a standard deviation of basic variables such as temperature, pressure, humidity and wind at least for the last one-hour period is highly recommended. If the standard deviation of the parameter is below an acceptable minimum, all data from the period should be flagged as suspect. In combination with the persistence test, the standard deviation is a very good tool for detecting a blocked sensor or a long-term sensor drift.

(iii) Internal consistency check

The basic algorithms used for checking internal data consistency are based on the relation between two parameters. The following conditions shall apply:

- a. Dew-point temperature ≤ air temperature;
- b. Wind speed = 00 and wind direction = 00;
- c. Wind speed ≠ 00 and wind direction ≠ 00;
- d. Wind gust (speed) ≥ wind speed;
- e. Both elements are suspect⁴ if total cloud cover = 0 and amount of precipitation > 0;⁵

- f. Both elements are suspect⁴ if total cloud cover = 0 and precipitation duration > 0;⁶
- g. Both elements are suspect⁴ if total cloud cover = 100 per cent and sunshine duration > 0;
- h. Both elements are suspect⁴ if sunshine duration > 0 and solar radiation = 0;
- i. Both elements are suspect⁴ if solar radiation > 500 Wm⁻² and sunshine duration = 0;
- j. Both elements are suspect⁴ if amount of precipitation > 0 and precipitation duration = 0;
- k. Both elements are suspect⁴ if precipitation duration > 0 and weather phenomenon is different from type of precipitation.

If the value does not pass the internal consistency checks, it should be flagged as inconsistent.

Technical monitoring of all crucial AWS components, including sensors, is an intrinsic part of the quality assurance system. It provides information on data quality through the technical status of the instrument and information on the internal measurement status. Corresponding information should be exchanged together with measured data; in case of BUFR messages for AWS data, technical monitoring can be carried out by using BUFR descriptor 0 33 006 – internal measurement status (AWS).

¹ For ground temperature outside the interval (-0.2°C +0.2°C). Melting snow can generate isothermy, during which the limit should be 0°C (to take into account the measurement uncertainty).

² For relative humidity < 95 per cent (to take into account the measurement uncertainty).

³ For 10-minute average wind speed during the period > 0.1 m s⁻¹.

⁴ Possibly used only for data from a period not longer than 10–15 minutes.

⁵ Or greater than the minimum resolution of the rain-gauge, to take into account the deposition of water by dew or other factors.

⁶ With the exception of snow pellets, which can occur with cloud cover = 0.

3. EXTENDED QUALITY CONTROL PROCEDURES

Extended quality control procedures should be applied at the national data processing centre to check and validate the integrity of data: completeness of data, correctness of data and consistency of data. Checks that are performed at AWS sites should be repeated at data processing centres, but in a more elaborate form. This should include, inter alia, comprehensive checks against physical and climatological limits, time consistency checks for a longer measurement period, checks on logical relations among a number of variables (internal consistency of data) and statistical methods to analyse data.

Suggested limit values (gross-error limit checks) for surface wind speed, air temperature, dew-point temperature and station pressure are outlined in, Chapter 6, Quality control procedures, of the *Guide on the Global Data-processing System* (WMO-No. 305). The limits can be adjusted on the basis of improved climatological statistics and experience. In addition, the aforementioned publication also describes internal consistency checks for surface data, where different parameters in a SYNOP report are checked against each other. Where other types of report containing AWS data, such as BUFR, are involved, the relevant checking algorithms must be redefined; in case of BUFR, corresponding BUFR descriptors and code/flag tables should also be redefined.

Internal data consistency checks

An internal consistency check on data can result in corresponding values being flagged as inconsistent, doubtful or erroneous when only one of them is suspect or incorrect. Therefore further checking by other means should be performed so that only the suspect or incorrect value is correspondingly flagged and the other value is flagged as correct.

In comparison with basic quality control performed at automatic weather stations, extended quality control procedures will require more quality control categories, for example: data verified (at basic quality control: data flagged as suspect, incorrect or inconsistent; at extended quality control: validated as correct using other checking procedures) and data corrected (at basic quality control: data flagged as incorrect or suspect data; at extended quality control: corrected using appropriate procedures).

The different parameters in the AWS N-minute data report ($N \leq 10-15$ minutes) are checked against each other. In the description below, the suggested checking algorithms have been divided into areas where the physical parameters are closely connected. The symbolic names of parameters with the corresponding BUFR descriptors used in the algorithms are explained below.

- (a) Wind direction and wind speed
Wind information is considered to be erroneous in the following cases:
 - (i) Wind direction without any change and wind speed $\neq 0$;
 - (ii) Wind direction is changing and wind speed = 0;
 - (iii) Wind gust (speed) \leq wind speed.
- (b) Air temperature and dew-point temperature
Temperature information is considered to be erroneous in the following cases:
 - (i) Dew-point temperature $>$ air temperature;
 - (ii) Air temperature $>$ dew point temperature $> 5^{\circ}\text{C}$ and obscuration is from {1, 2, 3} (BUFR descriptor 0 20 025).
- (c) Air temperature and present weather
Both elements are considered suspect when:
 - (i) Air temperature $> +5^{\circ}\text{C}$ and type of precipitation is from {6, ..., 12};
 - (ii) Air temperature $< -2^{\circ}\text{C}$ and type of precipitation is from {2};
 - (iii) Air temperature $> +3^{\circ}\text{C}$ and type of precipitation is from {3};
 - (iv) Air temperature $< -10^{\circ}\text{C}$ and type of precipitation is from {3};
 - (v) Air temperature $> +3^{\circ}\text{C}$ and obscuration is from {2} or (obscuration is from {1} and character of obscuration is from {4}) (BUFR descriptors 0 20 021, 0 20 025, 0 20 026).
- (d) Visibility and present weather
The values for visibility and weather are considered suspect when:
 - (i) Obscuration is from {1, 2, 3} and visibility $> 1\ 000$ m;
 - (ii) Obscuration is from {7, 8, 9, 11, 12, 13} and visibility $> 10\ 000$ m;
 - (iii) Visibility $< 1\ 000$ m and obscuration is not from {1, 2, 3, 8, 9, 10, 11, 12, 13} and type of precipitation is not from {1, ..., 14};
 - (iv) Obscuration = 7 and visibility $< 1\ 000$ m;
 - (v) Visibility $> 10\ 000$ m and type of precipitation is missing and obscuration is missing and weather phenomenon is missing (BUFR descriptors 0 20 021, 0 20 023, 0 20 025).

- (e) Present weather and cloud information
Clouds and weather are considered suspect when total cloud cover = 0 and type of precipitation is from {1, ..., 11, 13, 14} or weather phenomenon is from {2, 5, ..., 10} (BUFR descriptors 0 20 021, 0 20 023).
- (f) Present weather and duration of precipitation
Present weather and duration of precipitation are considered suspect when type of precipitation is from {1, ..., 10, 13, 14} and precipitation duration = 0 and type of precipitation is not from {1, ..., 10, 13, 14} and precipitation duration > 0 (BUFR descriptor 0 20 021).
- (g) Cloud information and precipitation information
Clouds and precipitation are considered suspect when total cloud cover = 0 and amount of precipitation > 0.⁷
- (h) Cloud information and duration of precipitation
Clouds and duration of precipitation are considered suspect when total cloud cover = 0 and precipitation duration > 0.
- (i) Duration of precipitation and other precipitation data
Precipitation data are considered suspect when amount of precipitation > 0 and precipitation duration = 0.
- (j) Cloud information and sunshine duration
Clouds and sunshine duration are considered suspect when total cloud cover = 100 per cent and sunshine duration > 0.

For each check, if the checked values do not pass the internal consistency check, they should be flagged as erroneous or suspect depending on the type of the check and inconsistent. Further checking by other means should be performed so that only the suspect or incorrect value is correspondingly flagged and the other value is flagged as correct.

The symbolic name and the corresponding BUFR descriptor (as reference) used in quality control algorithms (a) – (j) are as follows:

<i>Symbolic name</i>	<i>BUFR descriptor</i>
Wind direction	0 11 001
Wind speed	0 11 002
Wind gust (speed)	0 11 041
Air temperature	0 12 101
Dew-point temperature	0 12 103
Total cloud cover	0 20 010
Visibility	0 20 001
Type of precipitation	0 20 021
Precipitation character	0 20 022
Precipitation duration	0 26 020
Weather phenomenon	0 20 023
Obscuration	0 20 025
Character of obscuration	0 20 026

For further treatment of data, it is necessary to keep the results of the extended quality control data quality control and the information on how suspect or incorrect data were treated, using sophisticated system of flags. The output of the quality control system should include quality control flags that indicate whether the measurement passed or failed, as well as a set of summary statements regarding the sensors.

Every effort should be made to fill data gaps, correct all erroneous values and validate doubtful data detected by quality control procedures at the data processing centre.

4. QUALITY CONTROL MONITORING

Real-time quality control procedures have their limitations and errors, such as sensor drift or bias, and errors in data transmission can go undetected. Therefore, performance monitoring at the network level is required at meteorological data processing centres and by network managers.

Effective real-time quality control monitoring as an integral part of a quality control system should include checks of the following items: completeness of observations at the meteorological station, data quality, and completeness and timeliness of the collection of observational data at the centre concerned.

Quality control monitoring is intended to identify deficiencies and errors, monitor them and activate appropriate remedial procedures. Some assessment

⁷ Or greater than the minimum resolution of the rain-gauge, to take into account the deposition of water by dew, etc.

can be and should be performed in real time, whereas other evaluations can only be accomplished after sufficient data has been gathered over a longer period of time.

Quality control monitoring requires the preparation of summaries and statistics. Therefore, it is necessary to build a quality control monitoring system to collect statistics on observational errors of individual meteorological variables through a series of flags indicating the results of each check, and generate hourly, daily, weekly, monthly and yearly summaries of the following data:

- (a) The total number of observations scheduled and available for each variable (completeness of data);
- (b) The total number of observations which failed the quality control checks for each variable (quality of data) in case of:
 - (i) Plausible value check;
 - (ii) Time consistency check;
 - (iii) Check on a maximum allowed variability of an instantaneous value;
 - (iv) Check on a minimum required variability of instantaneous values;
 - (v) Internal consistency check;
 - (vi) Percentage of failed observations (quality of data);
 - (vii) Error and threshold values for each failed observation (reason for failure);
 - (viii) Root mean square error/mean error/percentage failure for failed observations for each station (daily/weekly/monthly/yearly) (quality statistics).

Large percentages of failed observations at stations are most likely due to hardware or software failures or inappropriate maintenance. These should be referred back to the network manager.

The quality control monitoring system must keep station monitoring statistics on the frequency and magnitude of observation errors encountered at each station. The statistics provide information with a view to monitoring quality of station performance, locating persistent biases or failures in observations, evaluating improvement of quality of observation data and performance and maintenance of station/network.

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PART VII

MONITORING THE OPERATION OF THE GLOBAL OBSERVING SYSTEM

7.1 GENERAL

The World Weather Watch Programme comprises monitoring of the operational performance of its components in order to evaluate their efficiency, identify deficiencies and take corrective action. The main objective of WWW Monitoring is to maintain the overall efficiency and effectiveness of the Programme on a global, regional and national level.

Since the operations of the three core components of the World Weather Watch—the Global Observing System, Global Data-processing and Forecasting System and Global Telecommunication System—are closely interrelated, they cannot be monitored independently. Therefore, in order to monitor the World Weather Watch as an integrated system, identify deficiencies and take quick corrective action, close coordination between all centres concerned and the WMO Secretariat is essential.

The Plan for Monitoring the Operation of the World Weather Watch is reproduced in the *Manual on the Global Data-processing and Forecasting System* (WMO-No. 485) and in the *Manual on the Global Telecommunication System* (WMO-No. 386). According to this Plan, monitoring is performed on a real-time and non-real-time basis. Explanations of these terms and the procedure for follow-up actions are given in the Plan.

7.2 IMPLEMENTATION OF THE MONITORING PROCEDURES

7.2.1 Quantity monitoring of the operation of the World Weather Watch

The periodic status report on implementation of the World Weather Watch, issued by the WMO Secretariat at two-year intervals, is designed to inform the management of the National Meteorological and Hydrological Services of the operational status of the World Weather Watch. It provides information concerning the structure, status and trends of the implementation and performance of the core components of the World

Weather Watch, including availability statistics of observational reports and data. The current version of the Status Report can be downloaded from www.wmo.int/web/www/StatusReport.html.

Three types of quantity monitoring are coordinated by the WMO Secretariat within the framework of the World Weather Watch Programme: Annual Global Monitoring, special main telecommunication network monitoring and data quality monitoring.

7.2.1.1 Annual Global Monitoring

Annual Global Monitoring is carried out in October each year. World Weather Watch centres are invited to monitor SYNOP, TEMP, PILOT, CLIMAT and CLIMAT reports from the regional basic synoptic network stations in accordance with the responsibility taken for the exchange of data on the Global Telecommunication System:

- (a) National Meteorological Centres should monitor data from their own territory;
- (b) Regional Telecommunication Hubs should monitor data from their associated National Meteorological Centres at least, and possibly from their own Region;
- (c) World Meteorological Centres and Regional Telecommunication Hubs located on the Main Telecommunication Network should monitor the complete global data set.

Each year about 100 World Weather Watch centres send their monitoring results to the WMO Secretariat through the Internet, on diskette or on paper.

The results of the Annual Global Monitoring make it possible to compare the availability of the reports received from regional basic synoptic network stations at the National Meteorological Centre responsible for inserting the data in the Regional Meteorological Telecommunication Network, at the associated Regional Telecommunication Hubs and at Main Telecommunication Network centres. The differences in the availability of data between centres are due to the following main reasons: differing requirements in data reception, shortcomings in the relay of the data on the Global Telecommunication System, data not monitored and differences in the implementation of the monitoring procedures at centres.

Annual Global Monitoring has the following limitations:

- (a) It provides monitoring information over a limited period each year;
- (b) It delivers information at the report level but no information at the bulletin level for regional basic synoptic network Stations;
- (c) Differences in the implementation of the monitoring procedures at centres lead to differences in the availability of reports between centres.

7.2.1.2 Special main telecommunication network monitoring

Special main telecommunication network monitoring was implemented with a view to complementing Annual Global Monitoring. Taking into account the limited resources available at World Weather Watch centres to carry out the monitoring activities, it was agreed to share the workload of special main telecommunication network monitoring between the main telecommunication network centres.

One of the main features of special main telecommunication network monitoring is that the sets of messages, also called raw data, provided by the various main telecommunication network monitoring centres are processed by a pre-analysis centre, unique for each type of data. This feature aims to eliminate the discrepancies in the availability of data reported by monitoring centres caused by differences in the implementation of monitoring procedures, similarly to Annual Global Monitoring, primarily due to different methods of counting the reports. The purpose of pre-analysis is to prepare files that have a data-base structure and contain the information extracted from all the sets of messages provided by the monitoring

centres. The pre-analysis files represent a unique reference for each type of data for further analysis. One advantage of special main telecommunication network monitoring is that it is always possible to access the raw data and read the complete text of the bulletins as received by the monitoring centres. Special main telecommunication network monitoring provides complete monitoring information at the report and bulletin levels for further analysis.

Special main telecommunication network monitoring is carried out four times each year: 1–15 January, April, July and October. The responsibilities taken by the Main Telecommunication Network centres are given in Tables VII.1 and VII.2.

After receiving the background information, Toulouse Regional Telecommunication Hub and the Secretariat make an analysis of the monitoring results.

The analysis of the latest Annual Global Monitoring and special main telecommunication network monitoring exercises can be accessed from www.wmo.int/web/www/ois/monitor/monitor-home.htm, where more information about quantity monitoring of the operation of the World Weather Watch can also be found.

A project on integrated World Weather Watch monitoring is under development and will be available for use in the near future.

With regard to monitoring, the Plan for Monitoring the Operation of the World Weather Watch states that the Global Observing System is responsible for ensuring that the observations are made according to prescribed standards, encoded correctly and presented for transmission at the stipulated times. Monitoring

Table VII.1. Responsibilities of special main telecommunication network monitoring centres

<i>Data set</i>	<i>Centres providing raw data</i>	<i>Centres preparing pre-analysis of raw data</i>
Surface data from fixed stations: SYNOP reports	Algiers, Melbourne, Offenbach, Toulouse, Tokyo	Tokyo
Upper-air data from fixed stations: Parts A of TEMP, PILOT reports; proposed extension: BUFR wind profiler	Melbourne, Nairobi Toulouse, Tokyo	Tokyo
Climate data: CLIMAT and CLIMAT TEMP reports	Cairo, Melbourne, New Delhi, Toulouse	Cairo
Data from marine stations: SHIP, TEMP SHIP, PILOT SHIP, BUOY, BATHY/TESAC/ TRACKOB reports	Cairo, Melbourne, Offenbach, Toulouse	Offenbach
Data from aircraft: AIREP and AMDAR reports, Proposed extension: BUFR aircraft reports	Melbourne, Nairobi, Toulouse, Tokyo	Toulouse

Table VII.2. Data monitored by the main telecommunication network centres

<i>Type of data</i>	<i>T1T2</i>	<i>GGgg</i>
SYNOP	SM	0000, 0600, 1200, 1800
TEMP, PILOT	US	0000, 0600, 1200, 1800
CLIMAT	CS	Report of the previous month
CLIMAT TEMP	CU	Report of the previous month
SHIP	SM	0000, 0600, 1200, 1800
TEMP SHIP, PILOT SHIP	US	0000, 0600, 1200, 1800
BUOY	SS	All bulletins
BATHY/TESAC/TRACKOB	SO	All bulletins
AIREP	UA	All bulletins
AMDAR	UD	All bulletins

of the Global Observing System is thus essentially a question of quality control of the observations. The basic rules of quality control within the framework of the Global Observing System are contained in Volume I, Part V, of the *Manual on the Global Observing System* (WMO-No. 544). Detailed instructions about the quality control procedures which Members are invited to follow are given in Part VI (Appendix VI.2) of the present publication. Additional information can also be found in Chapter 1, Part III, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

7.2.2 Data quality monitoring

7.2.2.1 Monitoring centres

To assess data quality, a number of data processing centres compare the information received from each of the different types of observations with

the first-guess numerical short-term forecast. The participating centres produce monthly reports of the various observational data that are of consistently low quality (Table VII.3). These lists of suspect data are exchanged between participating centres, and communicated to the originating country for remedial action. National focal points have been designated to assist in this action. This feedback leads to improvements in the quality of observational data and ultimately to improved initial analysis and model forecasts.

Lead centres have been established by the Commission for Basic Systems to coordinate the monitoring results of specific types of observation. They produce six-monthly consolidated reports of the observations with data of consistently low quality. These reports are also known as suspect lists. The lead centres are listed in Table VII.4.

Table VII.3. Data quality monitoring centres

European Centre for Medium-Range Weather Forecasts	Monthly report containing monthly suspect lists of marine observations, radiosonde, aircraft and satellite observations
Regional Specialized Meteorological Centre, Bracknell	Monthly report containing monthly suspect lists of land, marine, radiosonde, aircraft and satellite observations
Regional Specialized Meteorological Centre, Montreal	
Regional Specialized Meteorological Centre, Tokyo	
World Meteorological Centre Melbourne	Monthly report containing monthly suspect lists of land, marine and radiosonde observations
Regional Specialized Meteorological Centre, Offenbach	Monthly report containing monthly suspect lists of land observations
Regional Specialized Meteorological Centre, Toulouse	Monthly report containing monthly suspect lists of land, marine radiosonde, aircraft observations and satellite observations

Table VII.4. Lead centres in charge of coordinating monitoring results

<i>Centre</i>	<i>Data type</i>	<i>Area of responsibility</i>
World Meteorological Centre, Washington	Aircraft and satellite data	Global
Regional Specialized Meteorological Centre, European Centre for Medium-Range Weather Forecasts	Upper-air data	Global
Regional Specialized Meteorological Centre, Bracknell	Surface marine data	Global
Regional Specialized Meteorological Centre, Nairobi	Land surface observations	Regional Association I
Regional Specialized Meteorological Centre, Tokyo	Land surface observations	Regional Association II
Regional Specialized Meteorological Centre, Buenos Aires	Land surface observations	Regional Association III
Regional Specialized Meteorological Centre, Montreal	Land surface observations	Regional Association IV
World Meteorological Centre, Melbourne	Land surface observations	Regional Association V
Regional Specialized Meteorological Centre, Offenbach	Land surface observations	Regional Association VI

7.2.2.2 Procedures and formats for exchange of monitoring results

Quality monitoring procedures and formats for the exchange of the monitoring results for surface and upper-air data including marine, aircraft and satellite data have been developed, periodically updated, and published in Attachment II.9 of the *Manual on the Global Data-processing and Forecasting System* (WMO-No. 485). The six-monthly consolidated suspect reports are distributed to Members so that they can take remedial action as required. These Members/agencies then report to lead centres and the WMO Secretariat on their remedial efforts.

More information on data quality monitoring, monitoring procedures and report types can be found at www.wmo.int/web/www/DPS/Monitoring-home/mon-index.htm, and, for example, at: <http://www.metoffice.gov.uk/research/nwp/observations/monitoring/marine/index.html>.

References

- Manual on the Global Data-processing and Forecasting System* (WMO-No. 485)
Manual on the Global Observing System (WMO-No. 544)
Manual on the Global Telecommunication System (WMO-No. 386)

PART VIII

QUALITY MANAGEMENT

8.1 GENERAL

The key aim in modern quality management is not only to check the final product, but the entire process as well. A fundamental approach to quality is the quality improvement circle, which features four steps: preparation and planning, product implementation, checking the results with, in addition, user satisfaction in mind, and reacting to that information in order to improve further action.

The quality of observing systems can be assessed by comparing user requirements with the capability of the systems to fulfil them. More details are given in Part II of the present Guide.

8.2 QUALITY MANAGEMENT FRAMEWORK

Fourteenth Congress decided, by adopting Resolution 27 (Cg-XIV) – Quality management, that WMO should work toward a Quality Management Framework for National Meteorological Services that would eventually include and develop the following distinct, albeit related elements: WMO technical standards; quality management system(s), including quality control; and certification procedure(s).

The structure of the existing Quality Management Framework corresponds to the following aims of WMO:

- (a) To ensure adequate uniformity and standardization in the practices and procedures used by National Meteorological Services;
- (b) To ensure quality of observational data, since the effectiveness of any National Meteorological Service depends on the quality of data and products exchanged through the WMO Systems;
- (c) To ensure overall availability of observational data for all purposes, especially for the numerical weather prediction.

As regards the Global Observing System, these aims are achieved by the following means:

- (a) Extensive system of documented standards and recommended practices and procedures

which shall, or should, be followed by Members. These are described in the *Manual on the Global Observing System* (WMO-No. 544), in the present Guide and other publications;

- (b) Different levels of quality control procedures of meteorological observations (the observing site, collecting centres, prior to transmission over Global Telecommunication System centres and Global Data-processing and Forecasting System centres);
- (c) Variety of systems for monitoring of the availability of observational data (statistics concerning the availability of observational reports on a non real-time basis, real-time monitoring on a global basis in leading centres);
- (d) Activities for training of staff operating different components of the Global Observing System (training courses, regional meteorological training centres).

The WMO Quality Management Framework should enable the provision of early and continuing relevant advice to Members on developing their quality management system. The WMO Quality Management Framework, in accordance with the statement issued by the Executive Council at its fifty-sixth session, should focus on technical aspects of the operation of the National Meteorological Services.

8.3 WMO TECHNICAL STANDARDS AS REFERENCE DOCUMENTATION

The procedures and practices described in the *Technical Regulations* (WMO-No. 49) provide the basic material for use as the reference material in national quality management systems. The publication also contains some quality requirements and quality control and quality assurance practices and procedures.

8.4 QUALITY MANAGEMENT SYSTEM

According to ISO 9001 terms and definitions, a quality management system is designed to manage and control an organization with regard to quality.

The idea of the ISO quality management system is based on the precept that the quality of an organization's final product depends on how well each link of the chain of processes functions.

A quality management system defines the specific procedures, processes and resources required to meet a specified standard. The ISO 9001 Standard defines the requirements for such a system.

The ultimate goal of a quality management system is to encourage and support the continual improvement of the quality of services and products delivered.

A quality management system consists of a set of rules, procedures and practices that an organization decides to follow in order to achieve objectives related to the quality of its products. To do so, it is essential that clear and unambiguous procedures be used for each specific task.

In the Global Observing System, it is necessary to specify clearly and precisely the separate processes of the quality management system for basic observational networks, and criteria for the control of their quality, including the monitoring procedure and, where applicable, the quality of processes or different functions of observing systems. More attention should be paid to guidance on how to manage observational networks of stations and observing subsystems.

Good quality observational data cannot be provided without a quality management system. The appropriate quality management system shall operate continuously at all points of the whole observing system, from planning and installation, operations, maintenance and inspection, test and calibration, quality and performance monitoring, training and education, to data pre-processing, dissemination, processing and archiving; feedback and follow-up actions are inseparable parts of this chain.

General ISO 9001 requirements applicable to the Global Observing System are as follows:

- (a) Identification of the processes needed for the quality management system;
- (b) Determination of the sequence and interactions of these processes;
- (c) Determination of the criteria and methods to ensure the operation and control of the processes;

- (d) Provision of resources and information necessary to support the management and operation of the processes;
- (e) Monitoring, measurement and analysis of the processes;
- (f) Implementation of actions necessary to achieve planned results and continual improvement of the processes.

Further discussion on quality management can be found in Chapter 1, Part III, of the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

Definitions

Quality assurance: Part of quality management focused on providing confidence that quality requirements will be fulfilled; includes all the planned and systematic activities implemented in a quality system so that quality requirements for a product or service will be fulfilled.

Quality control: Part of quality management focused on fulfilling quality requirements; includes all the operational techniques and activities used to fulfil quality requirements.

Quality: Degree to which a set of inherent characteristics fulfils requirements.

Quality management: Coordinated activities to direct and control an organization with regard to quality.

Quality management system: Management tool designed to direct and control an organization with regard to quality.

Quality policy: Overall intentions and direction of an organization related to quality, as formally expressed by management.

References

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- Explanatory circular on the WMO Quality Management Framework: http://www.wmo.int/web/www/QMF-Web/Documentation/Other/QMF-circ_en.pdf
Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8)
 Quality Management Framework: <http://www.wmo.int/web/www/QMF-Web/home.html>

ANNEX

ACRONYMS

AAPP	AVHRR and ATOVS pre-processing package
AATSR	Advanced along-track scanning radiometer
ACARS	Aircraft communication addressing and reporting system
ADM	Advanced dissemination systems
ADSDAR	Aircraft-to-satellite data relay
AHRPT	Advanced HRPT
AIREP	Manual air reports
AIRS	Atmospheric infrared sounder
AMDAR	Aircraft meteorological data relay
AMSU	Advanced microwave sounder unit
APT	Automatic picture transmission
AQUA	NASA Earth observation satellite in afternoon orbit
ARGOS	Data relay collection and platform location system on NOAA satellites
ASAP	Automated shipboard aerological programme
ASCAT	Advanced scatterometer
ATOVS	Advanced TIROS operational vertical sounder
AVHRR	Advanced very high resolution radiometer
AWS	Automatic weather station
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group for Meteorological Satellites
CHRPT	Chinese HRPT
CMA	China Meteorological Administration
CNES	Centre national d'études spatiales (France)
CNSA	China National Space Administration
CoE	Centre of Excellence
COSPAS	<i>Cosmicheskaya sistyema poiska avariynich sudov</i> (space system for the search of vessels in distress)
DCP	Data collection platform
DCS	Data collection system
DSB	Direct sounder broadcast
EARS	EUMETSAT ATOVS Retransmission Service
ENVISAT	Environmental satellite
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FY-1, 2, 3	Geostationary meteorological satellite (China)
GAW	Global Atmosphere Watch
GDPFS	Global Data-processing and Forecasting System
GEO	Geostationary Earth orbit
GEOSAR	Geographic synthetic aperture radar
GLOSS	Global Sea Level Observing System
GMS	Geostationary meteorological satellite
GNSS	Global navigation satellite system
GOES	Geostationary operational environmental satellite
GOMS	Geostationary operational meteorological satellite
GOS	Global Observing System
GPS	Global positioning system
GRAS	GNSS receiver atmospheric sounder
GTS	Global Telecommunication System
GVAR	GOES variable
HRD	High-rate data
HIRS	High-resolution infrared sounder

HRI	High-resolution image
HRIT	High-rate information transmission
HRPT	High-resolution picture transmission
IASI	Infrared atmospheric sounding interferometer
ICAO	International Civil Aviation Organization
IMD	India Meteorological Department
INSAT	Indian National Satellite
IOC	Intergovernmental Oceanographic Commission
JMA	Japan Meteorological Agency
JASON	TOPEX/POSEIDON follow-on ocean topography satellite
JAXA	Japan Aerospace Exploration Agency
KMA	Korea Meteorological Administration
LORAN-C	Long-range navigation
LEO	Low Earth orbit
LRD	Low-rate data (NPOESS satellites)
LRIT	Low-rate information transmission (standard for geostationary satellites)
LRPT	Low-resolution picture transmission
METEOR	Series of polar satellites (Russian Federation)
METEOSAT	Geostationary meteorological satellite series
METOP	Meteorological operational satellite
MHS	Microwave humidity sounder
MLST	Mean local solar time
MODIS	Moderate-resolution imaging spectroradiometer
MPT	Medium-resolution picture transmission
MTSAT	Multi-functional transport satellite
NASA	National Aeronautics and Space Administration (United States)
NAVAID	Navigation aid
NESDIS	National Environmental Satellite, Data and Information Service
NOAA	National Oceanic and Atmospheric Administration (United States)
NPOESS	National Polar-orbiting Operational Environmental Satellite System
R&D	Research and development
RARS	Regional ATOVS retransmission service
RDF	Radio direction finding
ROSHYDROMET	Federal Service for Hydrometeorology and Environmental Monitoring (Russian Federation)
ROSKOSMOS	Federal Space Agency (Russian Federation)
SARSAT	Search and rescue satellite-aided tracking
SBUV	Solar backscatter ultra violet instrument
SEVIRI	Spinning enhanced visible and infrared imager
S-VISSR	S-visible and infrared spin scan radiometer
SSM/I	Special sensor microwave/imager
TERRA	NASA Earth observation satellite in morning orbit
TIROS	Television infrared operational satellite
TOPEX/POSEIDON	Oceanic topography experiment
TOVS	TIROS operational vertical sounder
UTC	Coordinated universal time
UHF	Ultra-high frequency
UNESCO	United Nations Educational, Scientific and Cultural Organization
VHF	Very high frequency
VIS	Visible
WEFAX	Weather facsimile
WMO	World Meteorological Organization
WWW	World Weather Watch
