Explanatory note on detection of statistical significance in long-term trends

Meteorological observation data, including those relating to temperature and precipitation, are subject to large amplitude fluctuations due to the influence of atmospheric and oceanic dynamics on a broad spectrum of spatial and temporal scales. To examine the possible presence of long-term climate system trends associated with global warming in consideration of natural variability, raw climate data need to be converted into suitable statistical time-series representations and subjected to statistical testing in order to highlight the likelihood of systematic temporal trends that cannot be explained by random variability alone. When the results of such testing allow reasonable conclusion that random variability is unlikely to be the sole factor at work, a change is described as statistically significant.

In this report, the likelihood of a systematic long-term change existing in a time-series representation is based on the results of statistical significance testing performed at confidence levels of 99, 95 and 90%. The following terminology summary describes each level:

Level of confidence	Term
≥ 99%	**Virtually certain** to have increased/decreased (statistically significant at a confidence level of 99%)
≥ 95%	**Extremely likely** to have increased/decreased (statistically significant at a confidence level of 95%)
≥ 90%	**Very likely** to have increased/decreased (statistically significant at a confidence level of 90%)
< 90%	No discernible trend

The following statistical methods are applied for the data used in this report:

i) For statistical variables whose annual fluctuation component can be assumed to follow normal distribution

For temperature anomalies, trend-removed annual variability data are expected to approximately follow normal distribution. T-testing is performed for statistical variables assumed to be normally distributed using a coefficient of correlation between years and values.

ii) For statistical variables whose annual fluctuation component cannot be assumed to follow normal distribution

The assumption of normality may not be applicable to frequency statistics regarding weather conditions, including those for extremely warm days, tropical nights and hourly precipitation amounts exceeding 50 mm. Accordingly, non-parametric testing, which does not depend on underlying assumptions about distribution, is applied to such variables.

It should be noted that statistical tests are in theory inevitably susceptible to the establishment of false conclusions even if the results indicate a statistically significant trend. Even outcomes indicating statistical significance at confidence levels of 90, 95 or 99% imply that there are small inherent probabilities of up to 10, 5 and 1%, respectively, of the significance being erroneously detected when in fact the observed long-term change occurred by mere random chance. Conversely, when a systematic long-term change actually exists, statistical testing may fail to detect the significance correctly. In general, test results are not considered highly stable if they are based on observation records that are temporally limited, influenced by large annual fluctuations/rare events or subject to change when new observations are added to a data sequence. Readers are encouraged to interpret the analytical results presented in the report appropriately with due note of these considerations.

Glossary

Aerosols

Aerosols are airborne solids or liquids in fine particle form. Their many types include particles of natural origin blown up from land/sea surfaces, anthropogenic particles and secondary aerosols formed from anthropogenic and biogenic precursors. In addition to absorbing and scattering sunlight, they also provide condensation nuclei for clouds. Particulate matter 2.5 (PM2.5) is the name given to aerosol particles measuring 2.5 micrometers or less in diameter (about 30 times thinner than a human hair), and is considered to have possible adverse effects on human health when inhaled.

Anthropogenic

Resulting from or produced by human activity.

Arctic Oscillation

The Arctic Oscillation (AO) is a major atmospheric circulation variation exhibiting an annular pattern of sea-level pressure anomalies in a seesaw fashion with one sign over the Arctic region and the opposite sign over the mid-latitudes. Its negative phase, which is characterized by positive and negative sea-level pressure anomalies over the Arctic region and the mid-latitudes, respectively, helps cold Arctic air move into the mid-latitudes. The positive phase, whose sea-level pressure anomaly pattern is reversed, keeps Arctic air over the Arctic region.

Erythemal UV radiation

Erythema is sunburn – a reddening of the skin resulting from continuous exposure to ultraviolet (UV) rays present in solar radiation. It is known that excessive erythema and long-term exposure to the sun can cause human health problems such as a high incidence of skin cancer and cataracts. Erythemal UV radiation is widely used as a scale of UV radiation for evaluation of its effects on the human body, and is calculated in consideration of various influences depending on wavelength.

Extreme climate event

In general, an extreme climate event is recognized as an unusually severe or rare climate event creating disaster conditions or exerting significant socio-economic influence. The definition includes severe weather conditions covering periods ranging from only a few hours (such as heavy rain or strong wind) to several months (such as drought or cold summer conditions). JMA defines extreme climate events as those occurring once every 30 years or longer.

IPCC (Intergovernmental Panel on Climate Change)

The Intergovernmental Panel on Climate Change (IPCC) is an international organization established by the United Nations Environment Programme (UNEP) and the World

Meteorological Organization (WMO) in 1988. It reviews and assesses scientific, technical and socio-economic information on climate change, the potential impacts of such change and related vulnerability, and options for adaptation and mitigation, in collaboration with scientists and experts on an international basis. The Panel's reports highlight common understanding of such information to support political matters such as treaty negotiations on global warming.

Kosa (Aeolian dust)

Kosa (Aeolian dust) is a meteorological phenomenon in which fine dust is blown up to an altitude of several thousand meters by cyclonic or other wind systems from deserts or cropland in semi-arid areas of the Asian continent, and is transported over long distances by westerly winds, resulting in haze or dustfall in downstream areas. It is often observed between March and June in Japan and makes the sky yellow and hazy. Heavy Kosa can affect transportation by obstructing visibility.

Monsoon

The term *monsoon* primarily refers to seasonally reversing winds, and by extension includes related seasonal rainfall change with wet and dry phases. Monsoon climate regions where seasonal winds prevail are found in numerous places around the world, with a major one located over a broad area from the Asian continent to northern Australia.

Normals

Normals represent climatic conditions at meteorological stations, and are used as a base to evaluate meteorological variables (e.g., temperature, precipitation and sunshine duration) and produce generalizations (e.g., cool summer, warm winter and dry/wet months) for particular periods. JMA uses averages for the most recent three decades (currently 1981 – 2010) as normals, which are updated every decade in line with WMO Technical Regulations.

Terms relating to surface temperature variations

El Niño/La Niña events: In an El Niño event, sea surface temperatures (SSTs) are higher than normal across a wide region from near the date line to the area off the coast of South America in the equatorial Pacific for about a year. In a La Niña event, SSTs are lower than normal in the same area. Both occur every few years, and are associated with frequent extreme climate conditions worldwide.

JMA recognizes the occurrence of an El Niño event when the five-month running mean of SST deviations from the climatological means (based on a sliding 30-year period averaged over the NINO.3 El Niño Monitoring Region (5ºN – 5ºS, 150ºW – 90ºW; Figure A)) remains +0.5°C or above for a period of six months or more. Similarly, a La Niña event is recognized when the corresponding figure is −0.5°C or below for the same area/period.

Figure B shows typical SST deviations from the normal during El Niño and La Niña events. The dark red and blue shading seen from the date line to the coast of South America indicates large deviations.

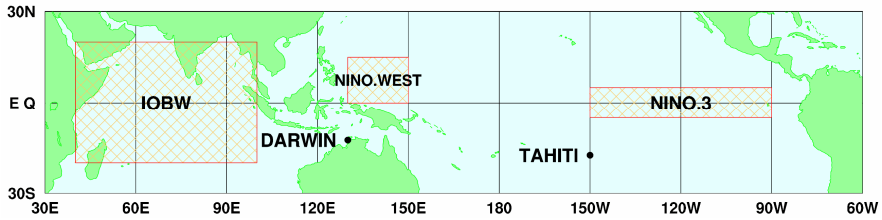


Figure A El Niño monitoring regions

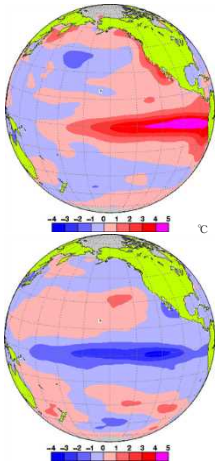


Figure B Left: monthly mean SST anomalies for El Niño (November 1997); right: for La Niña (December 1998)

Red and blue shading represents positive and negative SST deviations, respectively. Darker shading indicates larger deviations. The unit of temperature is degrees Celsius.

Southern Oscillation: El Niño and La Niña events are closely related to trade winds (easterlies blowing around the tropical Pacific), which tend to be weak during the former and strong during the latter. The strength of such winds is closely related to the sea level pressure difference between eastern and western parts of the Pacific. This pressure difference varies in a phenomenon known as the Southern Oscillation. El Niño/La Niña events and the Southern Oscillation are not independent of each other; they are different manifestations of the same phenomenon involving atmospheric and oceanic interaction, and are referred to as ENSO (El Niño – Southern Oscillation) for short.

Pacific Decadal Oscillation (PDO): A phenomenon in which variables in the atmosphere and oceans tend to co-vary with a period of more than ten years in the North Pacific. When sea surface temperatures are lower (higher) than their normals in the central part of the North Pacific, those in its part along the coast of North America are likely to be higher (lower) than their normals, and sea level pressures in the high latitudes of the North Pacific are likely to be lower (higher) than their normals. These atmospheric variations affect meteorological conditions in North America and elsewhere.

Terms relating to the greenhouse effect

Greenhouse effect: The earth's atmosphere contains small amounts of greenhouse gases, which absorb a large part of the infrared radiation emitted from the earth's surface and re-emit it back, thereby warming the surface. This process is known as the greenhouse effect. Without it, the earth's average surface temperature of around 14°C would be approximately −19°C. Increased concentrations of greenhouse gases enhance the greenhouse effect, thereby producing higher surface temperatures. Major greenhouse gases include carbon dioxide, methane and nitrous oxide. Although water vapor has the strongest greenhouse effect, it is not

usually regarded as a greenhouse gas in the context of global warming because the amount of water vapor on a global scale is not directly affected by human activity.

Carbon dioxide: Of all greenhouse gases, carbon dioxide (CO_2) is the most significant contributor to global warming. Since the start of the industrial era in the mid-18th century, its atmospheric concentration has increased as a result of emissions associated with human activity, such as fossil fuel combustion, cement production and deforestation. Around half of all cumulative anthropogenic CO_2 emissions have remained in the atmosphere. The rest was removed from the atmosphere and stored in natural terrestrial ecosystems and oceans (IPCC, 2013).

Methane: Methane (CH_4) is the second most significant greenhouse gas after CO_2, and is emitted into the atmosphere from various sources including wetlands, rice paddy fields, ruminant animals, natural gas production and biomass combustion (WMO, 2018b). It is primarily removed from the atmosphere via photochemical reaction with reactive and unstable hydroxyl (OH) radicals.

Nitrous oxide: Nitrous oxide (N_2O) is a significant greenhouse gas because of its large radiative effect per unit mass (about 300 times greater than that of CO_2) and its long lifetime (about 121 years) in the atmosphere. It is emitted into the atmosphere by elements of nature such as soil and the ocean, and as a result of human activity such as the use of nitrate fertilizers and various industrial processes. It is photo-dissociated in the stratosphere by ultraviolet radiation.

ppm, ppb, ppt: In this report, greenhouse gas concentrations are described in terms of mole fractions in units of ppm/ppb/ppt, representing the numbers of molecules of the gas per million/billion/trillion molecules of dry air, respectively.

Terms relating to the ozone layer

Total ozone: Total ozone at any location on the globe is defined as the sum of all ozone in the atmosphere directly above that location, and is often reported in m atm-cm or Dobson units. The unit of m atm-cm (read as “milli-atmosphere centimeters”) indicates the columnar density of a trace gas (ozone) in the earth’s atmosphere. A value of 1 m atm-cm represents a layer of gas that would be 10 μm thick under standard temperature and pressure conditions. For example, 300 m atm-cm of ozone brought down to the earth’s surface at 0°C would occupy a layer 3 mm thick. Typical values of total ozone vary between 200 and 500 m atm-cm over the globe, and the global mean is about 300 m atm-cm.

Ozone-depleting substances: Ozone-depleting substances (ODSs) are those that deplete the ozone layer as listed in the Montreal Protocol, which bans their production. Major ODS species include chlorofluorocarbons (CFC-11, CFC-12 and CFC-113 among others), carbon tetrachloride, hydrochlorofluorocarbons (HCFCs), 1,1,1-trichloroethane, chloromethane, halons and bromomethane. These are also powerful greenhouse gases that trap heat in the atmosphere and contribute to global warming.

Ozone hole: The phenomenon referred to as the ozone hole is a reduction in the concentration of ozone high above the earth in the stratosphere over the Antarctica. For simplicity, it is often regarded as the area in which the total ozone amount is equal to or less than 220 m atm-cm to the south of the southern latitude of 45 degrees. The hole has steadily

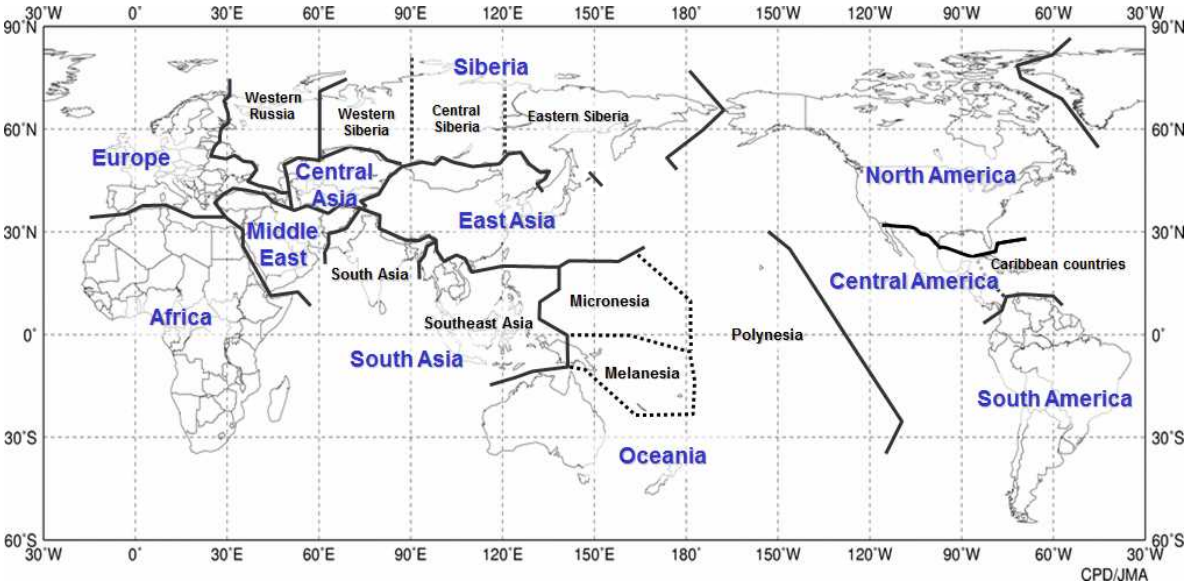
grown in size and annual length of presence (from August to December) over the last two decades of the last century.

Montreal Protocol: The Montreal Protocol on Substances that Deplete the Ozone Layer (a protocol to the Vienna Convention for the Protection of the Ozone Layer) is an international treaty designed to protect the ozone layer by phasing out the production of numerous substances believed to be responsible for ozone depletion. The treaty was opened for signatures in 1987 and came into force in 1989. Since then, it has undergone several revisions. Japan ratified the protocol in 1988.

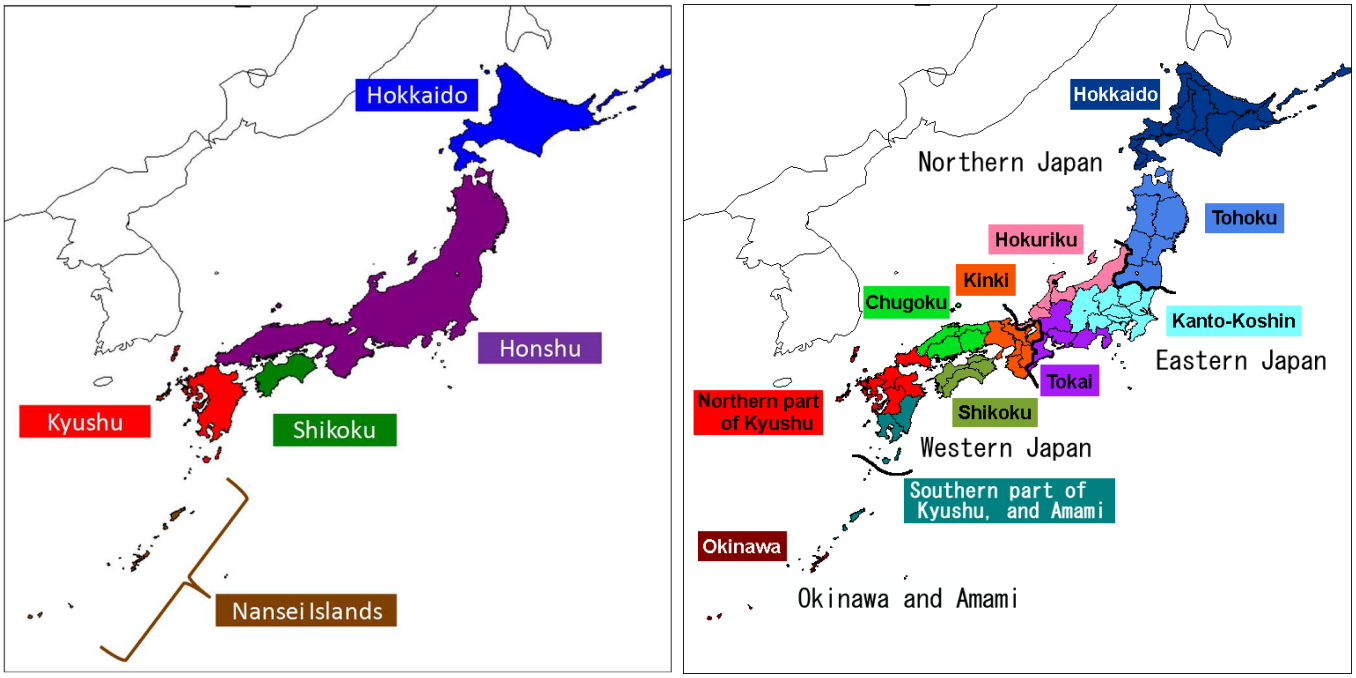
Terms relating to water masses

North Pacific Subtropical Mode Water (NPSTMW) area: A thermostad between the seasonal and main thermoclines. The NPSTMW area is considered to form in the surface mixed layer just south of the Kuroshio Extension as a result of huge heat loss in winter. It is defined as an area of 16 – 18-degree water at depths of 100 to 400 m at around 20 to 30°N along the 137°E line.

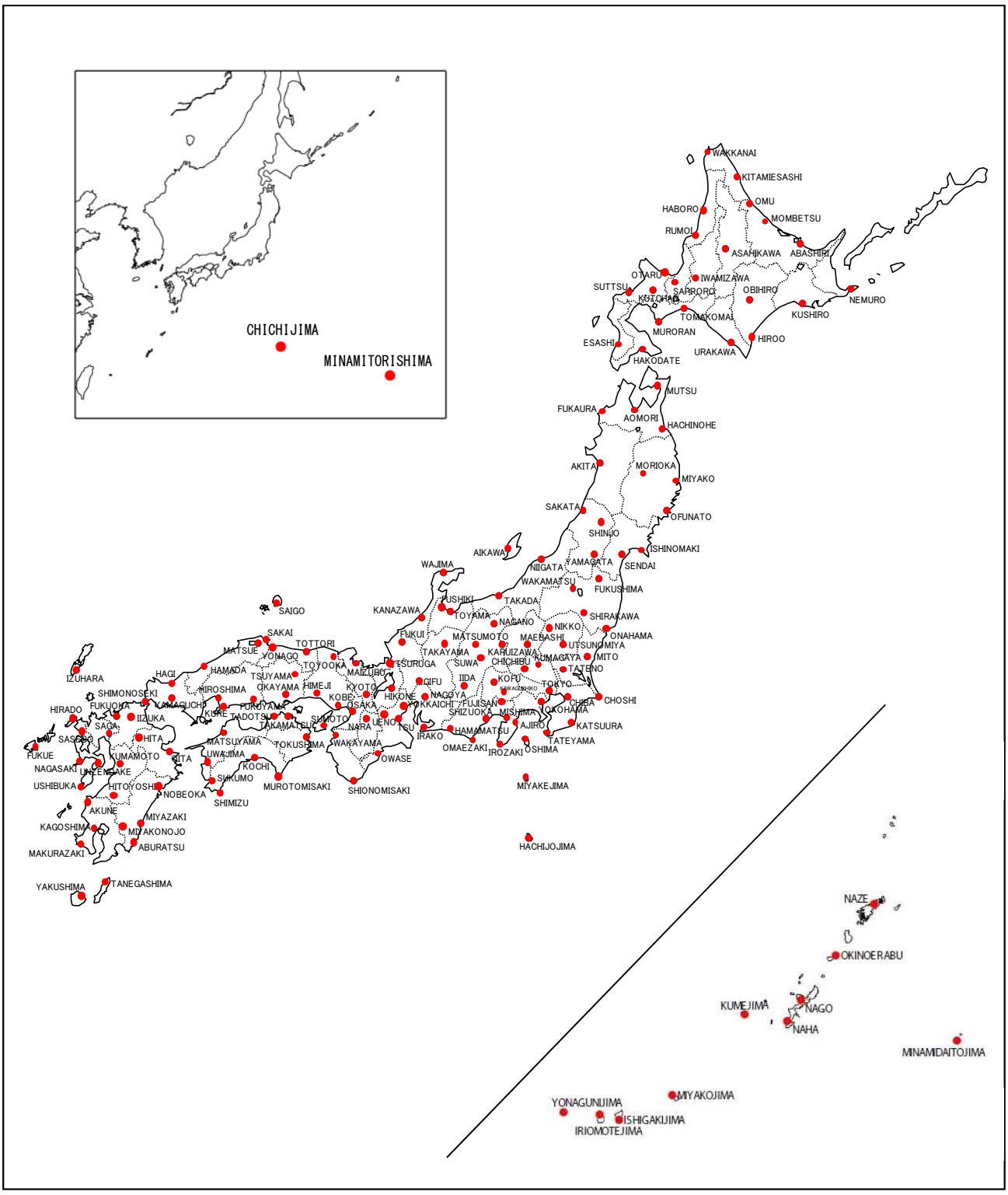
North Pacific Intermediate Water (NPIW) area: The NPIW area forms in the mixed region between the Kuroshio Extension and the Oyashio front. It is defined as water with a salinity level of 34.0 or less at a depth of around 800 m at around 20 to 30°N along the 137°E line.



Map 1 Names of world regions



Map 2 Names of Japan's island areas (left figure) and Names of Japanese regions used in this report (right figure)



Map 3 Distribution of surface meteorological observation stations in Japan

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