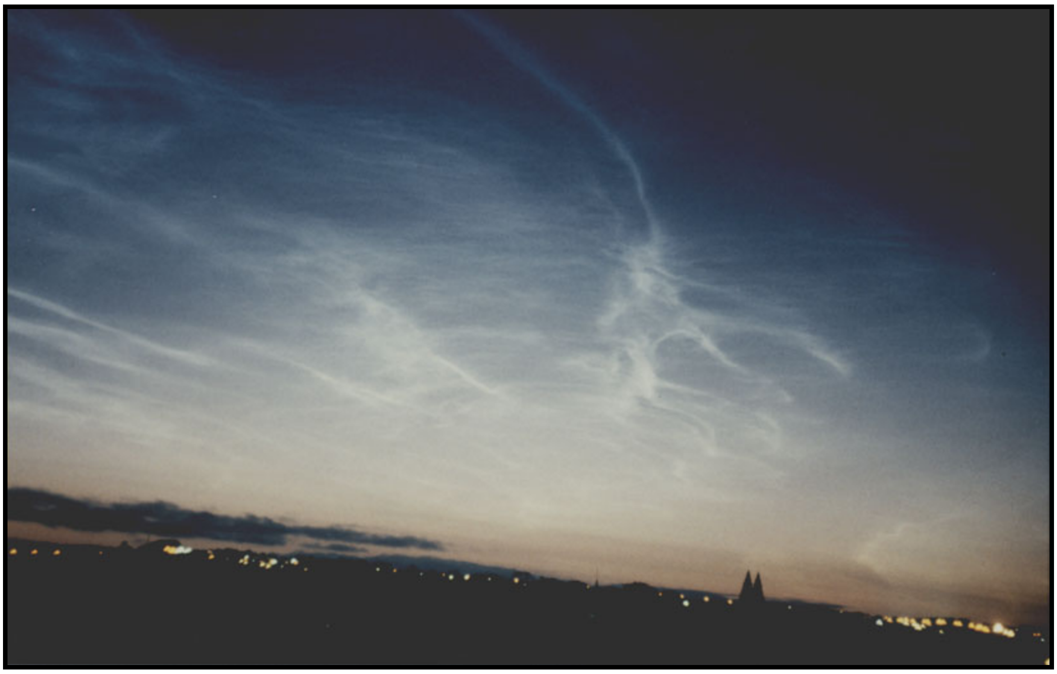
OBSERVING NOCTILUCENT CLOUDS

Michael Gadsden and Pekka Parviainen



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The picture on the front cover was taken at Aberdeen, Scotland, on the night of 23/24 July 1986. The exposure at 22.30 UT was 4 seconds at aperture f/2 on Ektachrome 400 film.

FOREWORD

‘Observing Notilucent Clouds’ was first published in 1995. Michael Gadsden compiled the book, soliciting contributions from the authors named at the beginning of their respective chapters, and Pekka Parviainen provided the beautiful photographs. Michael published the book under the auspices of the International Association of Geomagnetism and Aeronomy (IAGA), the first in the ‘IAGA Guide’ series, and produced hard copies by hand, inserting prints made from the original slides taken by Pekka Parviainen.

Sadly, Michael died in April 2003 at his home in Perth, Scotland. The stock of ‘Observing Notilucent Clouds’ held by IAGA has run out, but there is still a demand for the book. To satisfy this demand, the original has been scanned, reformatted and converted to electronic form. As part of this process some minor corrections have been made to the text, but there has been no attempt to update the content, other than the list of of national collators of observations. The quality of reproduction of the photographs in this electronic edition cannot match that of the prints included in the original. However, copies can be obtained from Pekka Parviainen, and details of his website where the images in this guide, along with many others, can be viewed, are given in Appendix A.

The book can be downloaded in *pdf* format, free of charge, at the IAGA web site:

http://www.iugg.org/IAGA/

It is possible that in converting the book into digital form some errors have been introduced and not detected. If you find any such errors then please inform the IAGA Secretary General, whose email address can be found at the IAGA web site.

I am grateful to Mavis Gadsden and Pekka Parviainen who have given their approval for the publication of this version of ‘Observing Notilucent Clouds’.

David Kerridge
Edinburgh
September 2006

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1. INTRODUCTION

In 1970, the World Meteorological Organization published a manual for observations of noctilucent clouds. That publication has been out of print for a number of years and the techniques of observation have developed in the twenty-five years since the publication. At the insistance of Professors O , (Tartu, Estonia) and O B Vasilyev (St Petersburg, Russia), a group of people active in noctilucent cloud observation and research has come together to produce this new manual for observation of noctilucent clouds.

The group has individually contributed sections dealing with particular aspects and interests of observation. The principal effort in bringing together this collection was made by Professor O Avaste, who died in 1991.

There is a widespread professional interest in the study of noctilucent clouds, which largely has to be satisfied by amateurs' observations. Discussion of secular change in the upper atmosphere and of the morphology of waves and turbulence at great heights depends on continuing amateur observations. This manual is published in the hope that it will stimulate and maintain interest among the amateur observers living at latitudes suitable for noctilucent cloud observation.

1.1 Appearance in the sky

The clouds, usually pale blue in colour, may be seen on a clear night in summer by an observer at 50 to 60 degrees latitude. A typical example is shown in Photograph 7 in Appendix A; clouds looking like these in daytime would be classified as cirrostratus. What sets noctilucent clouds apart is their occurrence in the middle of the night, their very obvious pale blue colour and their disappearance into the dawn close to the onset of Civil Twilight, when the Sun is 6 degrees below the horizon.

Noctilucent clouds were first recognised as being set apart from ordinary clouds in 1885 by Leslie, who called them ‘luminous silvery-white clouds’. In Germany, the name given them was the rather terser ‘leuchtende nachtwolken’ (luminous nightclouds).

The very distinctive patterns that appear in noctilucent clouds were commented on right from the start. Leslie remarks on ‘….. weird small cloud forms, at times very regular, like ripple marks in sand, or the bones of some great fish or saurian embedded on a slab of stone.’

At midnight, noctilucent clouds are seen rather low in the northern (or southern, south of the equator) sky and may lose their characteristic blue colour through reddening by atmospheric absorption. As sunrise approaches, noctilucent clouds can appear in more and more of the sky. They are seen in the zenith quite often but with a low contrast because the Sun is then no more than 7 to 8 degrees below the horizon. Such occasions, though infrequent, are of particular interest because they offer the chance of seeing patterns in the cloud relatively undistorted by oblique viewing.

Noctilucent clouds are high in the atmosphere and remain visible throughout nautical twilight because they are still, at their great height, in direct sunlight. The blue colour of the clouds comes about through the effect of absorption by atmospheric ozone in the Chappuis bands, which are prominent in the yellow part of the spectrum. The sunlight shining on noctilucent clouds has passed obliquely through the ozone layer. As a result, a path length equivalent to several centimetres of ozone at atmospheric pressure is experienced by the light rays.

1.2 Morphology of the clouds

Observations over the last one hundred years have shown that noctilucent clouds appear almost invariably in the summertime and only at mid- to high-latitudes (50-65 degrees). They have not been seen from ground level at polar latitudes (greater than 75 degrees) because of daylight or bright twilight there during the summer; they are rarely, if ever, seen from latitudes less than about 45 degrees. There are only differences in detail between the northern and the southern hemispheres; observation in the southern hemisphere is hampered by the poorer summer weather there and the relative absence of land (and population) in the observing zones. The clouds are truly a summer phenomenon: in the Northern hemisphere, the observing season is the months of May, June, July and August. In the Southern hemisphere, the season is November, December, January and February.

Satellites have extended the study of noctilucent clouds right to the pole in each hemisphere; visual observation by cosmonauts and astronauts and photometric detection of a scattering layer have both been reported. Cosmonauts in the Salyut spacecraft have photographed noctilucent clouds seen edge on, at the horizon (the Earth's limb). They appear in the pictures as a thin layer, well separated from the underlying intense forward-scattering of the lower atmosphere.

1.3 Height of the clouds

Modern height measurements, both by ground-based parallactic photography and by *in situ* penetration of a cloud with rocket-borne photometers, show that noctilucent clouds lie at 80 to 85 kilometres height. This is below the pronounced minimum in atmospheric temperature of the mesopause. Nucleation of the cloud particles undoubtedly occurs at the mesopause; subsequent growth to an observable size takes some time (probably hours) during which time the particles fall an appreciable distance. The developed cloud layer is therefore seen a few kilometres below the level at which nucleation takes place.

1.4 Layering

The developed cloud particles are falling through a region of the atmosphere whose temperature decreases with increasing height. That is, the particles experience a ***rising*** temperature as they fall and at some point they fall out of the region, which is saturated with respect to water vapour over ice. They then begin to sublime, their fall speed decreases rapidly, and they turn fully into the vapour phase within a short distance (perhaps 200 to 400 metres).

The particles are almost certainly submicron in size, even at their greatest development, and their light-scattering cross-section decreases very quickly as their radius decreases. The clouds appear, therefore, to have a sharp lower level, a distinct cloud base.

1.5 Observations from ground level

Observing noctilucent clouds can be an activity enjoyed in a number of ways:

Simple aesthetic enjoyment of a beautiful natural phenomenon: the observer should make a report to his or her national collator, giving place, date, time and a concise verbal description.

The next stage is to make regular observations of the twilight sky and to make simple measurements of the azimuth and altitude of noctilucent clouds.

A photograph is worth a hundred words: a regular colour slide photographed with an ordinary camera is valuable. Note the exact time of each picture (and the date!), roughly in what direction the picture was taken, and tell your collator what has been done. Be prepared to lend your slide for measurement.

Two or more observers can very profitably take simultaneous photographs with their cameras fixed to observe a common area of noctilucent clouds. Exact heights and position can be fixed in this way.

1.6 Classification of noctilucent cloud forms

In the original International Noctilucent Cloud Manual (Fogle, 1970), five types of noctilucent clouds were distinguished: Veils, Bands, Billows, Whirls and Amorphous. In the recommended classification given below, these categories have been retained with the exception of ‘Amorphous’. To take account of the often very varied patterns seen in noctilucent clouds, ‘Bands’, ‘Billows’ and ‘Whirls’ have been subdivided and, in addition, four types of ‘Complex’ noctilucent clouds are now recognized. It should be mentioned here that the capital letters used to distinguish the different types of ‘Complex’ noctilucent clouds are the first letters of the key words in Finnish. This has been done in recognition of the great contributions made to noctilucent cloud observational technique by the Finns.

Type I: Veils
These are very tenuous, they lack well-defined structure and are often present as a background to other forms. They resemble cirrus clouds, occasionally containing a faintly fibrous structure, and often are said to exhibit a flickering luminosity. Veils are the simplest form of noctilucent cloud and often precede (by about half an hour) the appearance of noctilucent cloud with well-defined structure.

Type II: Bands
These are long streaks, often occurring in groups arranged roughly parallel to each other or interwoven at small angles but occasionally an isolated band is observed. Bands show little change in location at low elevation angles, but changes in brightness can occur in periods of 20 to 60 minutes. Within the general structure, blurred bands with little mobility are often the predominant structure in the noctilucent cloud field, particularly when the brightness is low. Smaller streaks with twists or bends branch out from them. There are two types of bands to be distinguished:

IIa Streaks with diffuse, blurred edges.
IIb Streaks with sharply defined edges.

Type III: Billows
These are arrangements of closely spaced, roughly parallel short streaks. Billows sometimes lie across the long bands, giving the appearance of a comb or feather. At other times they appear alone against the veil background. The billows may change their form and arrangement, or appear and disappear within several minutes or tens of minutes which is much more rapidly and frequently than the long bands This noctilucent cloud type also can divided into two subgroups:

IIIa Short, straight and narrow streaks.
IIIb The billows exhibit a wave-like structure with undulations.

Type IV: Whirls
These are partial or, on rare occasions, complete rings of cloud with dark centres. They are sometimes seen in veil, band and billow forms.

Whirls in three identifiable subgroups may be seen:

IVa Whirls of small angular radius of curvature (0.1 to 0.5 degrees). They may appear as small bright crests looking somewhat like light ripples on a water surface.
IVb A simple curve consisting of one or more bands with angular radius of curvature of 3 - 5 degrees.
IVc Large-scale ring structure.

1.7 Complex structure

In some displays, two or more forms may be seen simultaneously. It is not unusual for two intersecting groups of long bands to occur and these give rise to bright knots where the waves cross. These complex structures are categorised as follows:

O A form which does not fit into the types I-IV above.
S A noctilucent cloud with bright 'knots' in the structure.
P Billows crossing a band.
V A net-like structure.

1.8 Amorphous noctilucent cloud:

In the manual published in 1970 (Fogle, 1970) the use of a fifth type, namely amorphous noctilucent cloud, was recommended. This was similar to a veil, Type I, in that it has no well-defined structure but is brighter and more readily visible than the veil type. In practice, it has proved to be extremely difficult, or impossible, to make a distinction of 'amorphous' noctilucent clouds from 'veil' noctilucent clouds. Amorphous noctilucent clouds are not included in many recent manuals (e.g. Romeyko, 1990).

2. VISUAL OBSERVATIONS

For one person to carry noctilucent cloud observations out even for one season is a quite difficult task, as he or she must be alert for 4-5 hours continuous observation on several successive nights. It is best to arrange for coordinated observations carried out by several persons. If the observers do not have experience of noctilucent cloud observation then it is recommended that they start in the period when the occurrence of bright noctilucent cloud is most probable, that is, in the latitudinal belt of 50-60°N from the middle of June to the end of July. If the observation site is further north then because of 'white nights' no noctilucent cloud are seen in June and in the first weeks of July.

2.1 Selection of the observing site

The observing site should: (1) have an unobstructed view of the horizon toward the twilight sector of the sky (that is, SE through N to SW in the northern hemisphere and NE through S to NW in the southern hemisphere); (2) be away from bright lights, and (3) be the same for the entire period of observation.

It is recommended that the horizon is clear of trees and mountains. To avoid ground mists, it is preferable to have the observing site situated higher than the surrounding area. If possible, an observing site away from lakes, rivers and factories should be chosen.

The minimal equipment for carrying out visual noctilucent cloud observations consists of an accurate clock, binoculars (8x40 or 7x50), an electric torch with a blue or green filter, and a logbook for observations. It is recommended to use also a voice recorder. A polarizing filter can be used to increase the contrast of faint noctilucent clouds and thereby make them the more easily detectable. For estimating elevation angles either transparent coordinate grids or an alidade will be needed.

Observations are made either in local standard time (LST) or in universal time (UT: the standard meridian time for 0° longitude). Beginning at the quarter-hour directly preceding the 6° solar depression angle (SDA) time for the particular station and date, the observer should carefully scan the twilight sector to determine the presence or absence of noctilucent cloud, and to estimate the amount of tropospheric clouds obscuring the twilight sector.

Thereafter, the noctilucent cloud observations should be made at 15-minute intervals throughout twilight when the sun is 6° to 16° below the horizon before midnight, and 16° to 4° after midnight. The times when solar depression angle (SDA) is within the limits of 6° to 16° varies markedly with time of year and station latitude.

It must be realised that visual observations of noctilucent cloud are always subjective in some sense. Nevertheless the morphological classification described in Chapter 1, and illustrated in the photographs reproduced in Appendix A, allows reliable data on noctilucent cloud genesis to be recorded.

A typical programme of visual observation is as follows:

- **Every 15 minutes**, patrol observations of the twilight sector are carried out. The meteorological situation is noted. The time of appearance and disappearance of noctilucent cloud is recorded.
- **Morphological structure** is noted, using the classification given in Chapter 1. A note is made of the speed of changes in the noctilucent cloud shapes and sizes.
- **The brightness** of the noctilucent cloud is estimated.
- **Measurements of the borders** of the noctilucent cloud field are made.

2.2 Detection and identification of noctilucent cloud

When bright, well-developed noctilucent cloud displays are observed under clear-sky conditions, identification is easy, even by an inexperienced observer. Difficulties arise in identifying noctilucent cloud when they are faint and lack structural detail. The identification problem is made more difficult if much of the sky is obscured by tropospheric clouds.

The following comments will serve as useful aids in identifying noctilucent cloud:

- **noctilucent clouds are always brighter** than the twilight sky, therefore clouds which stand out as dark silhouette against the sky background cannot be noctilucent cloud.
- **tropospheric clouds when illuminated** by the moon, city lights, or light scattered from bright parts of the sky may appear brighter than the sky background when the latter is fairly dark. These clouds can usually be distinguished from noctilucent cloud by their colour and form. The moonlit clouds will be milky-white whereas noctilucent clouds are bluish white. Unlike noctilucent cloud, these low clouds will continue to be visible during civil twilight and after sunrise.
- **cirrus clouds illuminated by the sun** when it is below the horizon are usually coloured yellow, orange and pink. Clouds having these colours are unlikely to be noctilucent cloud (but see the comment on page 12 concerning man-made noctilucent clouds).

To gain familiarity with the colour and form of noctilucent cloud, the observers should study carefully the photographs reproduced in Appendix A. If the station personnel includes a person who has seen noctilucent cloud and he or she happens to see them, it is important that all the other observers are shown the noctilucent cloud under natural conditions.

2.3 Airborne observations

Ground-based observations of noctilucent cloud are often hampered by considerable tropospheric cloud cover but observers in high-flying aircraft do not have this problem. Thus, airborne observations of noctilucent cloud are of great value, and pilots flying during the twilight hours are strongly urged to keep watch for these clouds and to write down their observations at the time. At the end of the flight, the report should to be sent to one of the noctilucent cloud data centres or given to the aviation meteorological officer for forwarding to one of the centres.

2.4 Noctilucent cloud and aurorae

The simultaneous occurrence of noctilucent cloud and aurorae is unusual and it is of great interest because it is not known if there is a connection between the two phenomena. Therefore it is recommended to describe changes in both phenomena in detail when they are seen together.

2.5 Systematic observations

We give below the instructions that the late Professor Avaste suggested for use by his network of observers in Estonia. Each group of observers has its own way of doing things; the following notes are given as an example of a procedure that has been tried and given satisfaction.

Essential information

At the start of an observing session, always note down the date and time before doing anything else!

If EST is used, always use the double-date, e.g. June 23/24, meaning the night of the 23rd and the early morning of the 24th, to make clear on what night the observations were made even if the observations are entirely before midnight or entirely after midnight. In other continents, particularly in Australasia where the date in Universal Time does not change during the night, a single date is used but ONLY if time is recorded in U.T.

On an observations form, it helps to describe in a column of 'Notes' the observing conditions briefly, e.g. misty, patchy cloud, bright moon etc. It is important to record also the fact of absence of noctilucent cloud, when the observing conditions are good. (For theoretical interpretation, it is almost as important to know when there were NO clouds as the occasions when there were noctilucent clouds.)

Classification of forms

The type of the noctilucent cloud should be recorded (perhaps by making a tick mark or a cross in a pre-printed list) according to the classification given in Chapter 1.

Brightness

Noctilucent clouds are visible behind the foreground of the twilight sector and their illuminance varies with azimuth and elevation angle. It is reasonable to estimate average brightness of the total visible noctilucent cloud field, and this should done every fifteen minutes. (The brightness of the noctilucent cloud field is actually a sum of the twilight sky brightness and the noctilucent cloud brightness. The contrast of the noctilucent clouds, which can be calculated, is (Noctilucent cloud brightness - Sky brightness)/Sky brightness). Bright noctilucent clouds have contrast values from 0.5 to 0.7 and only rarely does the contrast exceed this.) Enter the value indicating the brightness of the noctilucent cloud (see photographs in the centrefold for examples) according to the following 5-point scale:

1. **Very weak noctilucent clouds**, which are barely visible against the twilight sky, detectable only through very careful examination of the sky.
2. **Noctilucent cloud clearly detected**, but having low brightness.
3. **Noctilucent cloud clearly visible**, standing out sharply against the twilight sky.
4. **Noctilucent cloud very bright** and attracting the attention of casual observers.
5. **Noctilucent cloud extremely bright** and noticeably illuminating objects facing it.

Notes

It will be useful for the observer to record

- if the twilight sector was completely covered with tropospheric clouds; or
- if the twilight sector contains scattered clouds or thin, high transparent clouds such as cirrostratus; or
- if only part of the twilight sector was visible through breaks in tropospheric clouds; or
- if the twilight sector was completely overcast or obscured by fog; and
- the presence of aurora; and
- the presence of moonlight.

Particularly make a note if the noctilucent cloud identification is not a reliable one.

Colour

Noctilucent clouds shine brightly with a typical pearly-white or electric-blue radiance but sometimes golden or greenish tints are observable when these clouds are near the horizon. On occasion, there is a red upper edge to the noctilucent cloud field, which is caused by the effects of refraction and absorption in the troposphere of the illuminating solar rays (Avaste, Gadsden and Grechko, 1988). Sometimes, a rich set of colours from red to yellow and green is seen within the noctilucent cloud field. These colours may occur when clouds in the mesopause are caused by the exhaust of hydrogen-boosted rockets.

Movement of noctilucent clouds

The direction of drift of the noctilucent cloud field is very difficult to estimate by eye: reliable observations demand time-lapse imaging, either photographically or electronically. Usually noctilucent clouds in the northern hemisphere drift from NE to SW; sometimes they are seen to drift in other directions but this is not frequent.

Recommended procedures

Every 15 minutes observers check left, right, upper and lower borders of visible noctilucent cloud areas, visible noctilucent cloud structures, colours, brightness (scale 1 to 5), and weather conditions. The azimuth of the left and right borders of noctilucent cloud field are measured in true bearings (not magnetic), using the convention

000° = north; 090° = east; 180° = south; and 270° = west.

Every half an hour, observers make a drawing of the noctilucent cloud field. This sketch can be schematic or can be more detailed, depending on the observer's skill. When noctilucent clouds are covering a large amount of the sky it is appropriate to use a circular plan view of the sky. Observers are recommended to make some kind of verbal description of the whole display, classifying the display (eg. band type, billows type, whirls etc.) and noting major changes or areas and structure etc.

The wavelength of bands and billows should be estimated in angular measure, and a record made of changes as time goes by, the direction of their drift, and also how large is the area covered with waves and billows.

3. PHOTOGRAPHING NOCTILUCENT CLOUDS

Photographing noctilucent cloud with ordinary equipment and using standard routines does not automatically result in photographs which are of scientific value. If pictures are not calibrated in a very strict way they cannot be used for brightness or polarization measurements. However, amateur pictures can be used in measuring accurate spatial coordinates in noctilucent cloud structures, they can provide stereo views of noctilucent cloud and, occasionally, possible anomalies are easier find in photos than to detect visually. Sometimes wide-angle views give a nicely compressed and clear picture of the display structure. It is also worth remembering the purely aesthetic values when photographing these light summer nights' ‘sailors’.

3.1 Equipment and exposure

Noctilucent cloud photography is easiest to do with normal 35mm SLR-cameras because of the camera's versatility and fast lenses available. Automatic exposure control will be of great help. Depending on the brightness of display and the sky, exposure parameters will vary several f-stops. There are no universal figures which can be be used as a starting point. However, exposure determination in modern cameras usually extends far enough to solve the problem. Practice has shown that in several camera brands automatic exposure (or exposure time indicated by light meter) with exposure correction of -1/3 to -3/3 f-stops will yield very- satisfactory results. Usually exposure bracketing is an essential part of noctilucent cloud photography.

It is worth considering maximum exposure times in noctilucent cloud-photography. The rule of thumb is to use as short times as possible. Normally noctilucent cloud do drift and usually this movement restricts excessively long exposures. An upper limit can be found from stars' diurnal drift. Due to bright northern horizon and the latitudes where noctilucent cloud are usually visible, stars with declinations of +50 or more are practically the only ones one can find on the photographs of noctilucent cloud. These stars will remain point-like in case of exposures up to 15 seconds long if we use standard lenses with focal length of 50 mm. This gives us an upper limit to the exposure time, i.e. it must be less than 15x50/F seconds, where F means focal length of the lens used. Following this guarantees that stars can be used to fix an accurate coordinate grid to the picture and this grid can be used in measuring the spatial coordinates of noctilucent cloud.

The extent of noctilucent cloud displays varies considerably. All-sky displays are very common when the Sun is only a few degrees below the horizon. When the solar depression angle is 12°, though, the display will be confined to within a few degrees of the horizon. This implies that all different focal length lenses from 8mm ‘Fisheye’ say to a 135mm teleobjective are useful in noctilucent cloud photography. There are a couple of things to remember in using wide-angle lenses: first, these lenses cause serious spatial distortion, so that fixing coordinates for measuring purposes is not usually possible. Secondly, great contrast differences between the upper and the lower part of the picture are hard to master. However if aesthetics, or print cropping, needs wide-angle there is no reason to avoid using it!

Practice has shown that focal lengths from 35mm to 85mm are best suited to most displays. When thinking of fixing a coordinate grid it is advisable to use lenses with focal lengths of 50mm or longer. In some cases this causes a new problem: where to find stars in the narrower picture angle?

Choosing film for noctilucent cloud-photography is not a problem. In practice all films (speed >= 50 ASA) work pretty well if the lens aperture is 2.8 or better. Making prints allows control of contrast by dodging and burning; using colour results in more beautiful pictures. Choice between colour negative and slide film follows the usual argument: negative film has broader exposure latitude (and so produces better prints in a professional's hands); slide film is safer in the sense that risk of scratches on film is less and that slide is already a picture and does not suffer from commercial laboratories' mishandling and automatic printing. Because it is easy to have paper prints made from slides (if necessary), any 100 ASA slide film (or one used in your normal photography) will be a good choice.

3.2 General considerations

As already said, photographs of noctilucent cloud do not automatically have scientific interest. The main motive must be in recording displays and getting aesthetically beautiful pictures of a natural phenomenon. In spite of this it is strongly recommended to use the following routine: Take one or two pictures of the brightest, most interesting part of the noctilucent cloud display. Try to include at least three stars (or use stars, moon and possible bright planets) in these pictures. Start the exposure accurately (within the accuracy of 15 seconds) at every hour, half hour and quarter or threequarter hour. (Doing all this precisely means that one has to know the correct time.) If pictures were not taken precisely at these times, it must be logged properly and later transferred honestly to picture files. It is not a sin to have pictures taken ‘at wrong moments’, the sin is to lie about the time. Make sure that you can identify these pictures later when your film has been processed.

The idea of the above-described routine is to get systematic, evenly spaced pictures of the display development. If two or more photographers at appropriate distances use this same routine, it will result in double station pictures without cumbersome agreements and planning beforehand.

These simultaneous photographs can be used for precise and accurate determination of the height of noctilucent clouds by the method of parallax. With access to a microcomputer, the analysis of photographs can be done satisfactorily at home with the methods outlined by Taylor, Hapgood and (1984); see also Gadsden and Taylor (1993). No exposure times or f-stops are required, only accurate timing is essential. During all photography it is essential to make notes of the times when photos were taken. To make sure that these ‘official’ pictures can be distinguished correctly from other noctilucent cloud-patrol pictures it is advisable to expose one black frame each time before starting them. This is a fast and a reliable method of marking.

Finding stars on the pictures may prove to be a rather tough task. Sometimes only Alpha Aurigae (Capella) is easily recognizable. In the eastern direction, Gamma Andromedae will provide a starting point; in the western direction Alpha Bootes (Arcturus) is a good starting point. Occasionally it may prove to be useful to have at least one overexposed picture in the noctilucent cloud direction just to help in finding reference stars.

3.3 Storing the photographs

As in all photography, it is worth spending some time with the films when they are done. The first task is to file pictures in a sensible way. In the case of noctilucent cloud this means chronological order in files. All slides should have their double dates and exposure times either on their mountings or on file pages. Visual inspection may reveal some anomalies which can be examined more carefully with other observers. Pictures should be compared to what was seen and reported during the night. One interesting thing is also to try to see noctilucent cloud in three dimensions (pseudo-stereoscopy). This could be achieved with pictures taken a few minutes apart, as appropriate movement of clouds against stars gives the same impression as real double station pictures do.

4. VIDEO IMAGING

(Dr M J Taylor, Utah State University, USA)

Photography of noctilucent clouds provides an excellent medium for recording the morphology of the clouds and their colour. To study the motions of individual features in the display it is necessary to take a series of pictures. These should be obtained at a fixed azimuth and preferably at regular intervals. For normal noctilucent cloud observing it is recommended to take pictures at an interval of 15 minutes centered on the hour (see Chapter 3) . However, the wave forms seen during many displays, in particular the small scale billows, can change significantly over this time interval. Thus, depending upon the features of interest, many more photographs (as often as one every few minutes) may be necessary to document accurately the motion.

4.1 Cine photography & video recording

Time-lapse cine photography has been successfully used to study the motions of noctilucent clouds. Each frame is exposed for an interval of typically a few seconds (set by the film speed and the observing conditions) and, by introducing a suitable time delay between exposures, the movements of the noctilucent cloud appear speeded up when the film is replayed. This technique enables the relative motions of different features to be studied as well as the bulk motion of the display.

In recent years the cine camera has been superseded by the video camera. An obvious advantage of video measurements over cine or photographic observations is the potential to obtain good quality images of the display in real time (one picture every 1/25 s). Using modern video cassette recorders, these data can then be viewed speeded up or slowed down to reveal the motions of the wave forms in detail. Unfortunately, the sensitivity of most home video cameras (camcorders) is insufficient for most noctilucent cloud studies, exceptions being the Canon EX-1and LX-1.

Real time and time lapse video measurements of noctilucent clouds have been made using more sensitive ‘low light’ TV cameras such as Silicon Intensified Target (SIT) and Image Isocon cameras (Gadsden et al., 1979; Taylor et al., 1984). Measurements should also be possible using charged coupled devices (CCD) type imagers with exposure times of a few seconds (depending upon the detector sensitivity). However, these are specialist instruments and are much more expensive than photographic or cine cameras. At best, a home video camera will register the twilight sky containing a bright noctilucent cloud display but the contrast of the individual wave forms will be very low.

4.2 Filters

The contrast of the clouds may be enhanced by placing a filter in front of the camera lens at the expense of signal level. The filter can be used to either limit the polarization of the transmitted light or the spectral bandwidth of the observations. For example, because noctilucent clouds exhibit significant linear polarization at large viewing angles from the sun-earth-observer plane the contrast of the waves can be considerably improved by using a linear polarizing filter. Similarly, most video cameras have a large bandwidth stretching from deep blue to near infrared wavelengths (typically 400-800 nm) . By limiting the bandwidth of the observations the amount of scattered sunlight can be significantly reduced without major loss of noctilucent cloud signal. As the response of many types of cameras peak around 500 nm and the noctilucent clouds are relatively bright over this spectral range a blue-green filter is usually chosen. However, for a CCD camera, which exhibits considerable near infrared sensitivity, measurements can be made at much longer wavelengths (up to 1000 nm) if desired.

4.3 Polarization measurement

With low light TV cameras fitted with a complex polarimetric device, the polarization of the noctilucent cloud display can be measured (Taylor, 1981). As the video data can be replayed many times over this technique permits changes in polarization to be investigated for various cloud features at any point in the image. Observations of this type have been used to investigate the presence of circular polarization in the light scattered from the clouds (Gadsden et al., 1979).

4.4 Film versus video

The dynamic range of a video image is somewhat lower than that of most photographic films and due to the finite size of the image elements (pixels) compared with the very small grain size of the film the spatial resolution is considerably lower. Film is therefore capable of registering fainter stars than the TV camera can resolve against the twilight foreground. The summertime sky to the north around local midnight (2 hours) contains relatively few bright stars and calibration of film data (itself quite difficult) is usually easier than that of video data. On the other hand video data are readily digitised and therefore become more amenable to processing by computer than do photographic images.

4.5 Summary

Low light video observations of noctilucent clouds are extremely useful for accurately determining movement of the cloud features characterising the display and for measuring changes in their polarization as a function of time and space. Compared with photographic film, low light video images are generally of lower quality and are not easily observed in colour.OBSERVATIONS FROM ORBIT

(Prof. Ch I Willmann, Institute of Astrophysics and Atmospheric Physics, Estonia)

It has been proved (Willmann et al., 1977) that for space observations the above described classification of noctilucent clouds is usable. In addition, visual observations from space allow detection of multilayered structure of the noctilucent cloud field.

Noctilucent clouds are seen at an essentially constant height (corresponding to 2 degrees above the horizon) when the orbital station is at a height of 350 km. They are visible with the Sun both above and below the horizon (limb of the Earth). Their distance from the orbital station can be calculated from the geometry, therefore it is recommended to carry out continuous recording of the orbital station coordinates together with the noctilucent cloud display coordinates at successive orbits when noctilucent clouds are observable.

4.6 Visual observations from space

It is recommended to record following data in the onboard logbook with an accuracy of one minute:

- **The height** of the noctilucent cloud above the horizon, with an accuracy of at least one minute of arc.
- **The position** of the noctilucent cloud according to the solar vertical, i.e. to record the angular extent of the noctilucent cloud field along the horizon.
- **The brightness** of noctilucent clouds according to a 5-step scale similar to the classification presented in Chapter 2.
- **The morphological structure** (using Roman numbers from I to IV according to the classification Chapter 2) but this may be difficult because of the extremely slanted viewing angle and great distance of the limb. It is of particular interest to note if there is a multilayered structure present; this is one aspect of the morphology, which is easier to observe from space than from the ground.
- **The drift** of the noctilucent cloud field as a whole and also the drift of separate details of the noctilucent cloud field, if possible.
- **Other interesting characteristics** of the noctilucent cloud field, i.e. their colour, comments on the observation conditions: e.g. if planets or the Moon are observable in the close neighbourhood of the noctilucent cloud or even through the noctilucent cloud. If possible, it is recommended to draw a sketch of the noctilucent cloud field, pointing out the most interesting details and the position of planets or the Moon.

4.7 Photography from space

It is important to record the time of taking photographs at least with an accuracy of 5 seconds. The exposure time (or exposure corrections of f-stops when using automatic cameras) should be recorded in logbook. Also the lens aperture number, number of the frame on the film, filter characteristics (if used), the azimuth of the optical axis of the camera (with accuracy better than 5 degrees).

Exposure time depends on the speed of the film used. Onboard ‘Salyut 6’, Soviet cosmonauts used film Aviaphot pan30 (Agfa Gavaert). The normal exposure time was 1/30 second, and the lens aperture was chosen according to the brightness of visible noctilucent clouds and the twilight sector in the range from 4 to 22. Usually the best results were reached when focal apertures of 11 and 16 were used.

It is recommended to take the frame so that the horizon is also seen, or so that some bright objects such as the Moon or planets are present. This is important for determination of the spatial scale of the noctilucent cloud field. Planets and the Moon will be especially useful when the horizon brightness is so high that the bright background interferes.

When photometric processing of the noctilucent cloud films is planned, it is important to fix on every frame the image of a photometric wedge.

4.8 Observations of pseudo-noctilucent clouds in equatorial latitudes

During the 5th expedition on the Orbital Station ‘Salyut 6’, V.V.Kovalyonok and V.P.Savynykh detected, in the period from 22 March 1981 to 14 May 1981, bright formations at heights of 86-95 km in the equatorial belt and at low latitudes, which resembled noctilucent clouds. The orbital station was flying on a so-called ‘solar orbit’ in which the station was in the dark but the cosmonauts could see the twilit limb for a considerable period of time.

Considering the classical prerequisites for noctilucent cloud occurrence these clouds could not be ordinary noctilucent clouds, therefore they were called pseudo- noctilucent clouds. It is of primary importance to carry out further investigations of these clouds, as they give information of the processes which are present in equatorial mesopause. The main aim of such observations is to record these occurrences and to determine their spatial coordinates and height above sea level. If it is possible, they should be photographed.

4.9 Instrumental investigations

It is recommended to carry out measurements of spectral radiance of these clouds using telephotometers. Such measurements should be accompanied by photographs using telephoto cameras.

Vertical photometric profiles of the atmosphere taken near the horizon (so called limb profiles) can be easily carried out when the orbital station is flying on ‘rolling wheel’, ‘saw-teeth’ or ‘spinning’ regimes.

4.10 Research from above the southern hemisphere

The period of most frequent occurrence of noctilucent clouds above the southern hemisphere lasts from January to March. The observations carried out onboard ‘Salyut 6’ by Y.V.Romanenko and G.M.Grechko in the period from 23 December 1977 to 2 February 1978 showed that noctilucent clouds were recorded during 164 orbits. The observation of noctilucent clouds over the southern hemisphere from space is especially useful as there are only a few surface stations monitoring noctilucent cloud occurrence in the southern hemisphere. Tropospheric clouds screen them for most of the time.

It is hoped that future space observations of noctilucent clouds above the southern hemisphere will give a good database for analysing the physical processes in the southern mesopause.

It is recommended that patrol automatic scans of the horizon for seeking noctilucent cloud should be carried out at 5-day intervals. If noctilucent clouds are detected, the scanning must be carried out in every following orbit during the whole period when noctilucent clouds exist.

Ch. I. Willmann
1923-1992

Charles Willmann died suddenly on 25 March 1992 during a meeting at the Institute of Astrophysics and Atmospheric Physics in Tõravere in Estonia. A figure of enormous vitality and intellectual life, he was a survivor of the Leningrad blockade and a WWII artillery man. He organized the international Information Centre of Noctilucent Clouds and for the last two decades of his life was closely involved in the scientific direction of atmospheric research aboard the Soviet orbiting stations.

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5. POLAR MESOSPHERIC CLOUDS

(Dr G Thomas, Colorado University, USA)

When mesospheric clouds are viewed above the atmosphere, the geometrical limitations of observing from the ground are significantly reduced. They may be observed 'edge-on' against the comparatively dark sky background, even in full daylight. The photometer field of view must be well baffled to avoid interference from the very bright Earth about a degree beneath the cloud layer. It is a much more difficult task to observe the clouds against the bright background of the illuminated Earth, although this has been achieved in the ultraviolet in the 200 to 300 nm spectral region, because of the very small albedo of the earth in this part of spectrum.

American and Soviet astronauts observed the phenomenon from space as early as 1970. Most observations are reported from the night side of the orbit and the observer is looking towards the twilight sector. At this time the observer's eye is dark-adapted and polar mesospheric clouds would appear with maximum contrast against a comparatively dark background. Soviet astronauts have reported sightings of mesospheric clouds even when the Sun is above the horizon.

Satellite observations allow the very coldest parts of the polar mesosphere to be observed, all the way to the geographic pole. In the early 1970's, visible airglow photometers first scanned the atmospheric horizon throughout the summer polar mesospause region (Donahue et al, 1972). This experiment, which flew on the OGO-6 satellite, was the first to trace noctilucent-like cloud layers across the polar cap. The very bright scattering layer was seen in full daylight conditions, and was identified as the poleward extension of noctilucent clouds. In the early 1980's, the layer was observed again from a satellite, the Solar Mesospheric Explorer (SME) . On board this satellite was an ultraviolet spectrometer, which mapped the distributions of clouds over the time period 1981 to 1986. The experiment measured the altitude profile of scattering from clouds at two spectral channels (primarily) 265 nm and 296 nm (Thomas and MacKay, 1985). This phenomenon is now known as Polar Mesospheric Clouds.

5.1 Morphology

The general seasonal characteristics of polar mesospheric clouds are well established from the five years of continuous SME data. Over that period, data for four cloud 'seasons' in the north, and five 'seasons' in the south were recorded. In both hemispheres, the season begins about one month before summer solstice and ends about two months afterwards. Since there are no biases due to such factors as changing number of hours of visibility, weather conditions, etc. this is a 'true' behaviour. It is believed to be a result of the fact that summertime mesopause region becomes ***coldest*** during this period causing water-ice to form, in contrast to most other regions of the atmosphere which are ***warmest*** in summer. Temperatures at latitudes equatorward of the boundary of detection never get low enough for water-ice to form.

Polar mesospheric clouds generally increase in brightness and occurrence frequency with increasing latitude, from about 60 degrees to the highest latitudes observed (85 degrees). So far, no apparent dependence on longitude has been found, nor is there any evidence of a dependence on auroral activity (Thomas and Olivero, 1989). This indicates that control of polar mesospheric clouds is determined by geographical rather than geomagnetic factors. The brightness of polar mesospheric clouds and noctilucent clouds appears to be consistent at the latitudes where both are observed, but polar mesospheric clouds near the pole are much brighter than noctilucent clouds, even taking into account the lower sky background seen from space. Polar mesospheric cloud observations have revealed that the well-known phenomenon of the northward shifting with latitude of date of peak noctilucent cloud occurrence is partly due to the increased number of hours of noctilucent cloud visibility with latitude and partly due to an actual northward retreat of the boundary towards the end of the season.

5.2 Relationship between noctilucent clouds and polar mesospheric clouds

An unsolved problem is the discrepancy between the equatorward boundaries of polar mesospheric clouds and noctilucent clouds. Polar mesospheric clouds merge into the sky background at about 60 to 65 degrees in latitude, whereas noctilucent clouds have been sighted from as far south as 47 degrees. Taking into account the 4 to 7 degree latitudinal distance of noctilucent clouds from the observer, this indicates a difference in the boundary location of 5 to 10 degrees. Two suggestions for this discrepancy are: (1) the contrast of polar mesospheric clouds against the background sky is lower for the satellite ultraviolet measurements than for ground-based visible observations; or (2) there is a diurnal variation (perhaps due to atmospheric tides) of mesospheric cloud properties such that the boundary moves equatorward between daytime hours (the local time at which the satellites observe them) and nighttime hours, when they are seen from the ground. There is much variability of polar mesospheric cloud occurrence from day to day, which apparently is controlled mainly by atmospheric conditions at lower heights. The long- term behaviour of polar mesospheric cloud frequency has been found to vary inversely with solar activity, in the same general way that noctilucent clouds vary.

The available evidence suggests that polar mesospheric clouds and noctilucent clouds are the same phenomenon. Noctilucent clouds appear to be the ‘ragged- edge’ of a much brighter and more pervasive polar cloud layer. It has been suggested that the very cold polar regions are the birthplace, or ‘nursery’, for ice particles that subsequently move equatorward into warmer regions where they sublimate. However there is very little evidence for this kind of association. In fact this is a research area in which ground-based observers can contribute significantly. New opportunities for coordination with satellite observations have occurred with the launch of the NASA Upper Atmospheric Research Satellite (UARS) in 1992 and with future missions such as MSX (1996) and Odin (1998).

6. POLARIZATION MEASUREMENTS

NLCs are seen by sunlight being scattered from an assembly of small (micron-sized) particles; the particles may be pure ice, or ice deposited on a solid core, and they can be in one of several crystal habits or amorphous. The state of polarization of the light scattered from the particles in principle contains unique information about the nature of the particles. In practice, the deduction of the particles' nature from observations of the polarization of the scattered light is neither straightforward nor unambiguous.

6.1 Correction for twilight foreground

As with all photometric observations in the twilight sky, it is necessary to correct the observations for the presence of the foreground light scattered from low in the atmosphere. This subtraction is most easily carried out if the polarization measurements are expressed in terms of the Stokes vector of the scattered light. When two incoherent beams of light are added together, the Stokes vector of the resulting light has the four components equal to the individual sums of the components of the two original Stokes vectors (see, for example, Shurcliff, 1962).

The correction for the presence of foregound (twilight sky) light is done by measuring the components of the Stokes vector of a part of the twilight sky in the immediate neighbourhood of the NLC feature. The reference area of sky is chosen to be as close to, and as far as possible at the same elevation angle as, the area of NLC being measured. Also, the reference area should not have NLC in it. In favourable cases, the NLC measurement is taken from a field of view perhaps 30 x 10 minutes of arc in size, with a portion of non-NLC sky located within a few minutes of arc.

Often though, this ideal cannot be achieved because NLCs are extensive and have few ‘dark spaces’ within the display. In such cases, it is difficult to separate and so to allow for the contribution of the foreground light to the polarization measurement

6.2 Measurement

The four components of a Stokes vector are not separately measurable by real physical photometers. Measurement of the light is done by passing it through polarizing elements using four configurations to give four independent measurements of the transmitted light. The assembly of polarizing elements and photodetector are called a ***polarimeter***. The polarizing elements consist of a linear polarizer and a retarder. There are a number of arrangements of the polarizing elements to perform the measurements; two that have been used on NLCs are either a quarter-wave retarder in front of a linear polarizer, each rotating at a set angular speed but in opposite directions or a rotating quarter-wave retarder is placed in front of a fixed linear polarizer.

In both cases, the intensity of the transmitted light contains a mixture of steady (dc), 2f and 4f signals (where f is the frequency of rotation of the polarizing elements). The steady component is largely the intensity of the unpolarized component of the incident light, the 4f component (and its phase) gives the amount and direction of the plane-polarized component and the 2f component gives the amount of circular polarization in the incident light.

For simple estimation of degree of polarization and whether circular polarization is present in the signal (such as has been done for video recording of the degree of polarization; see Gadsden, Rothwell and Taylor, 1979), it can be enough to write out the signal continuously on a chart recorder.

The depth of modulation of the signal indicates the amount of linear polarization in the NLCs, and alternation of the heights of the maxima or minima in the signal shows the presence of circular polarization.

While it is quite feasible to have electronic band-pass filters on the output to separate out these three signals (which, with the phase of the 4f signal gives the requisite four independent measures), with low-light measurements such as are involved in NLC observing it has proved to be useful to integrate the output signal over successive 22.5° rotations of the polarizers. The observer then has groups of four successive observations of intensity which can be solved in a set of four simultaneous linear equations to give the four components of the Stokes vector. Calibration of such a system can be done by pointing the polarimeter at a uniform, white screen and placing a linear polarizer (usually a large sheet of polaroid) and a quarter-wave retarder over the entrance pupil of the polarimeter. The intensities observed for four distinct states of polarization of the light entering the polarimeter may then be used to set up coefficients for the four simultaneous linear equations that yield the components of the Stokes vector in an observation of NLCs. The procedure is described fully in Gadsden and Schröder (1989: pages 62-65).

APPENDIX A. PHOTOGRAPHS

The images, which were selected by Professor Olev Avaste, can be viewed, after following the link to ‘Noctilucent clouds’, at Pekka Parviainen’s web site:

http://www.polarimage.fi

The table below lists the images as numbered here together with their reference numbers on the web site.

Numbering in this Appendix	Numbering at http://www.polarimage.fi
Photograph 1	vy03251
Photograph 2	vy00731
Photograph 3	vy00621
Photograph 4	vy01312
Photograph 5	vy04753
Photograph 6	vy03641
Photograph 7	vy03623
Photograph 8	vy04722
Photograph 9	vy03713
Photograph 10	ra00334 (Rocket exhaust section)
Photograph 11	vy00111
Photograph 12	vy02142
Photograph 13	vy02224
Photograph 14	vy01834
Photograph 15	vy08053
Photograph 16	vy08053 (combined with 15)

Photograph 1 1988 Jul 8/9, 22.45
Type I: Veil. At the upper border, diffuse bands and billows are present. (Upper left: diffuse bands, IIa. Upper centre: diffuse billows, IIIb.)

Photograph 2 1982 Jul 24/25, 22 h (Approximate time only)
Type II: Bands. Sharp bands (IIa) and diffuse bands (IIb). There is an area of complex structure, Type S, in the centre of the cloud field.

Photograph 3 1982 Jul 18/19, 22 h (Approximate time only)
Type IIa: Bands. Streaks with blurred edges. Some billows, IIIa, in low centre and left.

Photograph 4 1983 Jul 31/Aug 1, 21.47
Type IIb: Bands. Streaks with sharply defined edges; diffuse billows, IIIb, are crossing the principal streaks.

Photograph 5 1989 Jul 21/22, 23.15
Type IIIa: Billows. Short, straight and narrow streaks, with bands, IIb, at the side. In the upper left corner there is complex structure, type 0.

Photograph 6 1988 Aug 8/9, 00.27
Type IIIb: Billows. Wave-like structure with undulations. Diffuse bands, IIa, and knots, Type S, in the centre.

Photograph 7 1988 Aug 8/9, 00.18
Type IVa: Whirls. Small angular radius of 0.1 to 0.5 degrees; a bright whirl in a highly-structured display.

Photograph 8 1989 Jul 21/22 22.48
Type IVb: Whirls. A simple curve consisting of one or more bands with angular radius of curvature of 3 to 5 degrees. Bands, IIb, showing diverging perspective.

Photograph 9 1988 Aug 8/9, 00.43
Type IVc: Whirls. Large scale ring structure with tropospheric clouds (altostratus) in the foreground. Upper left: diffuse billows, IIIb. Upper right: complex structure, type O.

Photograph 10 1988 Jul 27/28, 21.48
Man-made noctilucent cloud, no classification possible. The trail of a rocket created an artificial cloud showing irridescence. On this occasion, the height was estimated to be 80-90 km.

Photograph 11 1978 Jul 16/17, 21.25
Complex Type 0. A form which does not fit any of the types I to IV.

Photograph 12 1986 Aug 3/4, 22 h (Approximate time)
Complex Type V. A net-like structure consisting of billows. Possibly there are two distinct layers of cloud?

Photograph 13 1987 Jun 23/24, 22.45
Type IVb: Whirls. Veil, I, is present too.

Photograph 14 1985 Jul 25/26, 22.30
Type IIb: Bands. An example of brightness 3 noctilucent cloud.

Photograph 15 1993 Jul 8/9, 22.05
Fish-eye lens photograph.

Photograph 16 1993 Jul 8/9, 22.05
Fish-eye lens photograph, taken with a polarizing filter. Compare this with no.15, above, to see how the use of a linear polarizer (with the axis parallel to the northern horizon) can enhance the contrast of the cloud field.

APPENDIX B. CALCULATING SOLAR ELEVATIONS AND AZIMUTHS

The methods outlined by Duffet-Smith (‘Practical Astronomy with your Calculator’; Cambridge University Press, 2nd edition 1981) can be used to calculate the azimuth and elevation of the Sun at any given instant of time (in Universal Time, UT) for a particular observer. There is no input from tables: the position of the Sun in its orbit is calculated from iterative solution of Kepler's equation.

B.1 Calculation

The mean anomaly (M) of the Sun is given by

$$M = 0.017202791\ D - 0.0656742 \text{ radians.}$$

Subtract (or add) n times 2π to bring the angle M into the range 0-2π. D is the number of days, with UT being converted into decimal days, that have elapsed since epoch 1980.0. The number of whole days to the beginning (January 0.0) of years 1991 to 2000 are given in Table 1.

TABLE 1				
1991	4018		1996	5845
1992	4383		1997	6210
1993	4749		1998	6575
1994	5114		1999	6940
1995	5479		2000	7305

The number of days from January 0.0 to the ‘zeroth’ day of the month in each year is given in Table 2 (with the two columns for not Leap Year and Leap year):

TABLE 2					
January	0	0	July	181	182
February	31	31	August	212	213
March	59	60	September	243	244
April	90	91	October	273	274
May	120	121	November	304	305
June	151	152	December	334	335

To calculate the eccentric anomaly (E), set $E_i = M$, i=0, and proceed to calculate

$$\Delta = E_i - 0.016718 \sin E_i - M.$$

If the magnitude of Δ is less than 0.000001 radians, the iteration finishes. Otherwise, proceed to calculate

$$E_{i+1} = E_i - \Delta /(l - 0.016718 \cos E_i)$$

and calculate a new value of Δ with i incremented by one.

The true anomaly, v, is given by

$$\tan (v/2) = 1.0168601 \tan (E/2).$$

The ecliptic longitude of the Sun (λ_s) is

$$\lambda_s = v + 282.596403 \text{ degrees.}$$

The solar right ascension (α) and declination (δ) follow from

$$\tan \alpha = 0.9174821 \tan \lambda_s$$

$$\sin \delta = 0.3977769 \sin \lambda_s.$$

The observer's latitude (Φ) and longitude (λ; positive east) are used to find the solar azimuth (A) and elevation (h) . First, UT must be converted into local sidereal time (LST) as follows:

$$S = 0.7999589 + 0.000027378508\ D$$

$$R = 6.6460656 + 2400.051262\ S + 0.00002581\ S^2$$

$$B = 24 - R + 24\ (\text{year} - 1900)$$

$$LST = 0.0657098\ d - B + 1.002738\ UT + \lambda/l5.0$$

d is the whole number of days elapsed since January 0.0. (if LST is greater than 24 hours, subtract 24 hours. If LST is negative, add 24 hours.) The solar elevation (h) and solar azimuth (A) are found from

$$\sin h = \sin \delta \sin \Phi + \cos \delta \cos \Phi \cos (LST - \alpha)$$

$$\cos A = (\sin \delta - \sin \Phi \ \sin h)/(\cos \Phi \cos h)$$

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APPENDIX D. REFERENCES

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INDEX

CITATION INDEX

Noctilucent Clouds are seen in the summer months, shining in the northern sky at nighttime. Measurements show that the clouds are higher than any other clouds visible, by many tens of kilometres.

This manual and instruction book is a replacement for the International Noctilucent Cloud Observation Manual. Written by a group of active researchers, both professional and amateur, there are chapters giving practical advice for visual observations, photographing the clouds with film or with video recording, with a summary of observations from space and comments on the connection between noctilucent clouds and polar mesospheric clouds, so far measured only from orbit.

Lying at a height of 80-85 kilometres (60 miles), the clouds occur at the border of space and mark a boundary between meteorology and space physics. This book is to help everyone to recognize and appreciate these “sailors in the summer night”.

International Association of Geomagnetism and Aeronomy