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NOCTILUCENT CLOUDS

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NOCTILUCENT CLOUDS

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The clear, bright twilight of the northern summer night offers to a keen observer a number of beautiful natural phenomena. Occasionally, about an hour after sunset, a delicate veil of clear bluish-white colour appears over the northern horizon, so tenuous that only a trained observer would be aware of its presence. Sometimes, however, this so-called noctilucent cloud exhibits much brighter billows, bands and other features reminiscent of common cirrus cloud formations. Noctilucent clouds consist of a layer of particulate matter, concentrated by some mechanism in the vicinity of the mesopause (the temperature minimum) at an altitude of 80 to 85 km. Because of their great height they are illuminated by the sun's rays when lower layers of the atmosphere at normal cloud heights lie in the earth's shadow; they can be seen when there is sufficient contrast between the light scattered by the cloud particles and the light scattered by the air molecules in the line of sight. These conditions are fulfilled when the sun is between about 4° and 12° below the horizon.

The first reported scientific observations of these clouds were made during the 1880's in Germany and Russia (Jesse, 1896). The discovery was made shortly after the eruption of the volcano Krakatoa in the Indonesian archipelago. The dust from the explosion remained in the stratosphere for several years, causing various optical effects, and it is understandable that noctilucent clouds were assumed to be associated with this explosion. The height of the clouds was established soon afterwards from pairs of photographs taken simultaneously from the end points of long baselines. Spectra of the clouds, obtained by Helmholtz, showed the presence of the Fraunhofer lines of the solar spectrum, thus indicating that the light from the clouds was scattered sunlight.

In time, the Krakatoa debris settled but the noctilucent clouds were observed regularly, summer after summer. Particularly intense displays were seen during the summer of 1908, after the impact of the great Siberian meteorite in June of that year. The hypothesis of a volcanic origin of the cloud particles was now abandoned and a new theory was put forward according to which the clouds consisted of meteoric debris—remains of disintegrated meteors or interplanetary dust particles. Continued observations during the following years in Russia, Norway and Scotland indicated a remarkable constancy of the altitude of these clouds and the outstanding problem was to find a mechanism for the concentration of the particles at this particular level of the upper atmosphere.

The possibility that the clouds could be formed by condensation or sublima-

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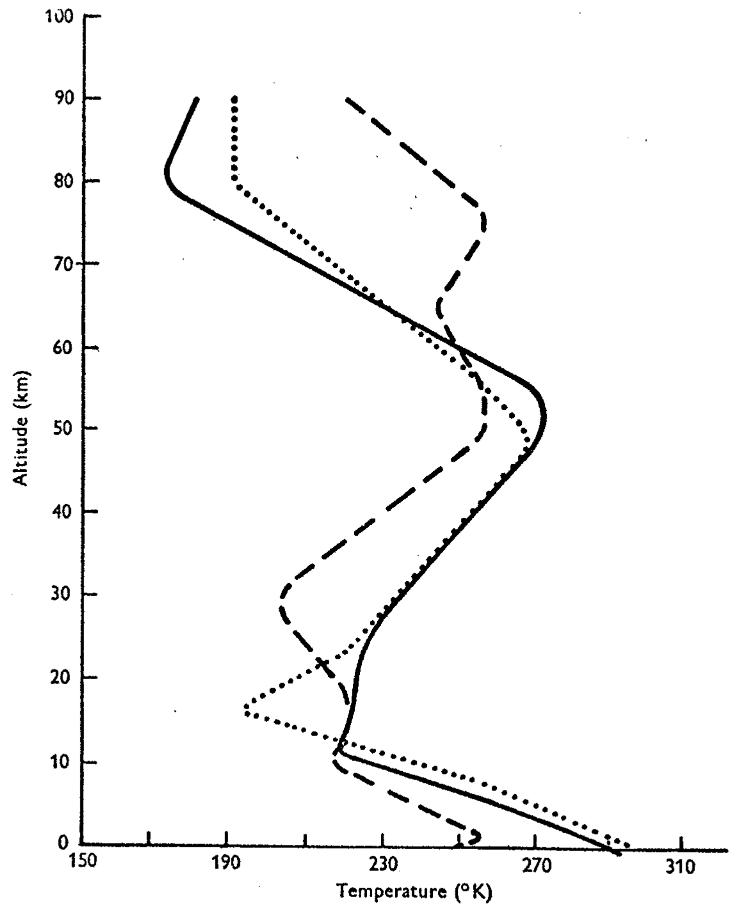
tion of water vapour has been considered by several authors (Khvostikov, 1952). This hypothesis received much support when it became evident that a sharp temperature minimum exists at about 80 km altitude, and that the minimum is deepest during the summer months at high latitudes—whereas in winter time the inversion is weak or may even be absent (Fig.). With the



Profiles of atmospheric temperature. The solid curve shows high-latitude summer conditions and the dotted line refers to the low-latitude summer. High-latitude winter temperature is shown by the broken line. The high temperature at about 50 km is due to the absorption of solar radiation by ozone.

advent of more refined measuring techniques, particularly high-altitude sounding rockets, it was found that the mesopause temperature could be as low as 160 °K at high latitudes.

Making an assumption about the moisture content in the upper stratosphere, one could find a mechanism which would explain the constant height of the clouds as well as the fact that noctilucent clouds are only observed during the summer. Unfortunately, nothing is known so far about the abundance of water near the altitude of the mesopause, and all assumptions have to be made on the basis of humidity measurements at altitudes less than 40 km.

The possibility of sublimation processes at the mesopause was investigated by Hesstvedt (1962) who concluded that, even if such a process were involved in the formation of noctilucent clouds, solid particles would still be required to act as sublimation nuclei, one particle for every cloud crystal. Thus we are left with the same question of whether these particles are of terrestrial or extra-terrestrial origin, and if they are really absent when no clouds are observed. An important clue to the solution of these problems is to be found in a statistical analysis of the geographical distribution and seasonal distribution of occurrence of the clouds. However, lack of observations from some parts of the world can easily lead to premature conclusions. Until recently it was considered that the lack of observations from Arctic America was significant, but systematic observations now started at College, Alaska (Fogle, 1962) show that the clouds may be as frequent in occurrence there as in Scandinavia and Siberia—from where all our observations have come until recently. The latitudes from which the clouds are most frequently seen are characterized by poor visibility conditions during the critical weeks of summer, and experience in Sweden has shown how useful high-flying aircraft would be as an observational aid.

Between 1955 and 1961 work in Sweden has been conducted by Meteorologiska Institutionen of Stockholm University at Torsta (lat 63·3° N, long 14·6° E) (Ludlam, 1957; Witt, 1957, 1962). The programme included study of the height and structure of cloud systems by means of photogrammetry and time-lapse films, as well as determination of the size distribution of the cloud particles by measurement of the polarization of the light. The photograph facing p 710 shows one of the pictures used in the photogrammetric analysis. It was taken during a particularly bright display on 10–11 August 1958 when the features were so distinct that a time sequence of contour maps of the cloud system could be prepared. The bulk movement of the clouds and the billows was directed from north-east to south-west (as is usual) with a speed near 100 m/s. However, a system of parallel bright bands was found to move in the opposite direction with a speed of 10 to 20 m/s. The contour maps show that both these features are associated with wave motions in the cloud system, the brightest parts being where the line of sight lies in the cloud surface. For the billows a wavelength of 5 to 10 km and an amplitude of about 500 m was found; the longer waves had a wavelength of the order of 500 km and amplitudes between 1 and 4 km.

The size of the individual cloud particles has been studied in Sweden by taking photographs to determine the degree of polarization of the scattered sunlight. Theoretical values of the polarization can be derived for particles, assumed to be spherical, and of various radii and refractive indices. In this way, the particles which scatter most of the light were found to have radii of about 10^{-5} cm (Witt, 1960); this result is similar to that obtained in the USSR (Villmann, 1962). The density of the cloud was estimated to be about 1 particle per cubic cm at 80 km.

In August 1961, a small "Arcas" rocket was fired from a range in northern Lapland. The rocket nose was loaded with about 300 g of magnesium oxide to be released at the mesopause by an explosive charge. The aim was to study the scattering properties of a cloud of a known amount of dust in order to obtain information about the particle density in natural noctilucent clouds. This first firing was unsuccessful, the next firing with the same type of rocket and an improved version of the same payload was made on 7 August 1962, this time with complete success. At an altitude of about 60 km a small cloud was released and remained visible for about 30 min, illuminated by the sun's rays (see Plate II facing p 710).

While this experiment was being planned, contact was established between Meteorologiska Institutionen and Dr R. Soberman, Air Force Cambridge Research Laboratories, in the United States, who had previously used rockets in order to collect micrometeorites at high altitudes. A joint Swedish–American project was started to collect samples of noctilucent clouds. The experiment was carried out in co-operation with the National Aeronautics and Space Administration in the United States and the Swedish Committee on Space Research, with Dr Soberman and the writer as project scientists. Altogether, four Nike–Cajun rockets were fired from the Lapland range at Kronogård (lat 66° N, long 19° E) during August 1962 (Plate III). In order to detect changes in the particle concentration, two of these were fired when noctilucent clouds were observed and two when the clouds were absent. One pair of payloads was not recovered, but the other pair worked successfully and the results are being analysed in laboratories in Sweden and in the United States.

The principle of the sampling technique is simple. The rocket nose was fitted with a pair of small cylindrical cans containing certain prepared impact surfaces, which were exposed as the rocket passed between the altitudes 75 to 92 km. Then the containers were hermetically sealed, the rocket nose separated from the vehicle and returned with the aid of a parachute, finally located by acoustical and radio-ranging systems. Thanks to the efficient acoustical and radio-locator systems, the precious payloads could be recovered within an hour after firing in spite of poor twilight illumination in the middle of the Lapland wilderness. During the flight only part of the sampling surfaces was exposed to the particles; the other part remained covered by a lid as a control against possible post-flight contamination of the sample by handling.

The samples are examined by electron microscope for the number, density and size distribution of the particles. Three different techniques are used to obtain information about the composition of the particles. A possible crystal structure of the particles is investigated by electron diffraction analysis. The second method is known as electron microsonde analysis; if a particle is illuminated by a fine-focused electron beam, it emits X-rays with wavelengths characteristic of the elements of which the particle is composed, and by measuring these wavelengths the chemical composition of the sample can be determined. The third method consists of activation of the sample by neutrons in a nuclear reactor. In this way radioactive isotopes are formed and the radiation from these is again characteristic for the elements composing the

Plate I. Noctilucent cloud display with wave structure on 11 August 1958, photographed from Torsta at 00.20 local time. The camera, which had a focal length of 379 mm and f/5, was directed due north and elevated 5°. The exposure was about 10 s on Kodak P 1200 plates. Due to some peculiar physiological reason a better perspective view is obtained if the picture is viewed upside down.

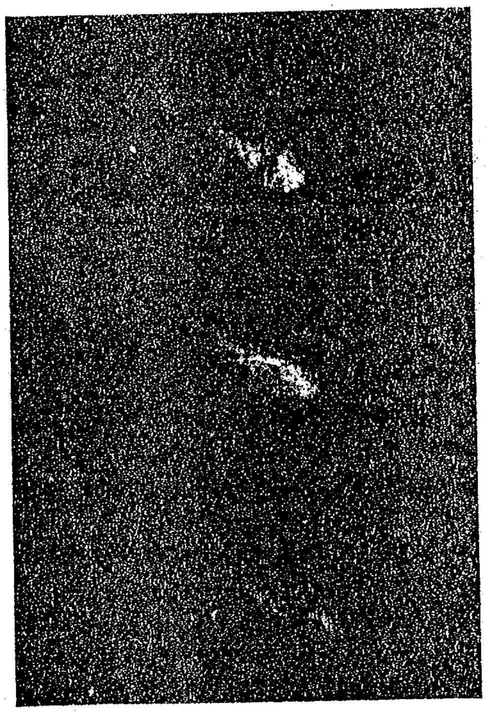


Plate II. Artificial dust cloud released about 60 km above the Kronogård launching site on 7 August 1962 at 23.00 hr local time. The pictures show different stages of the development of the cloud, which remained visible for about 30 min. The length of the cloud was several kilometres and the amount of magnesium oxide powder released was 300 g.

(*Facing p* 710)

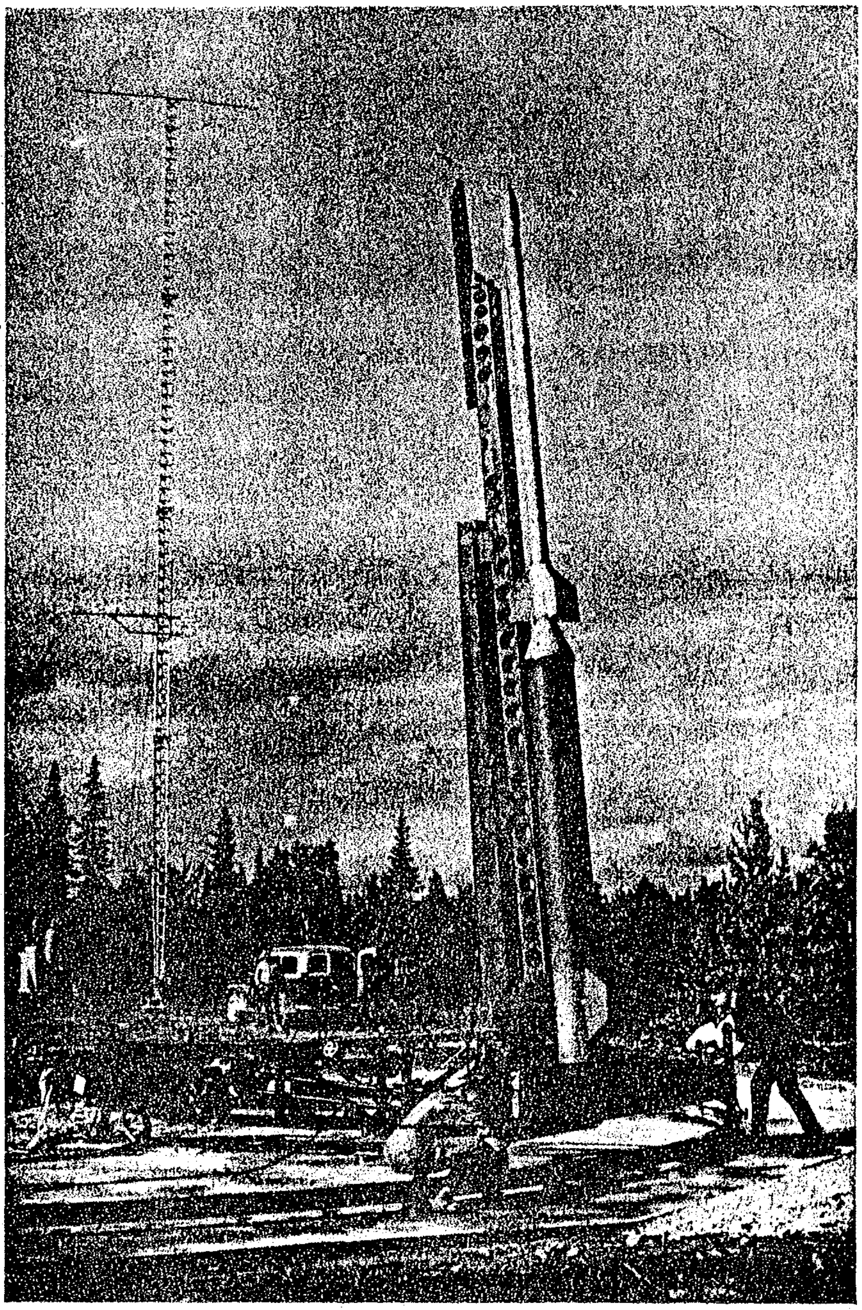


Plate III. Nike–Cajun rocket ready for firing at the Kronogård launching site. The complete vehicle weighs about 800 kg and has a length of 8 m. The rocket carried a 40 kg payload to an altitude of 110 km. Part of the nose cone contained instrumentation for measurement of electron flux in aurorae as well as emulsion packages for detection of cosmic ray particles. (This part of the experiment was carried out by the Kiruna Geophysical Observatory and the University of Lund.)

particles. Scarcity of particles and the requirement of extreme cleanliness introduce in our case a number of technical problems which must be solved before the analysis can be completed. The preliminary results of the electron microscopic analysis, however, indicate that the clouds consisted of solid particles with sizes from about 10^{-4} cm radius and less, the number of these particles being at least one hundred times larger when noctilucent clouds were present than when they were absent. So far nothing is known about whether the particles possessed a coating of ice when they were sampled.

The successful outcome of this rocket activity has encouraged us to plan further experiments for the study of the mesopause in high latitudes, and temperature measurements by the sound-grenade technique are planned for 1963. Better knowledge of the temperature structure of the high atmosphere should shed more light on the enigma of noctilucent clouds.

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