Observations of the upper atmosphere by optical radar in Alaska and Sweden during the summer 1964

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ABSTRACT

Optical radar observations were carried out at high latitudes simultaneously from two stations at widely separated longitudes. Some measurements related to the optical thickness of noctilucent clouds are reported.

Previous exploratory work has demonstrated the use of a pulsed optical radar technique for the detection and ranging of scattering layers in the upper atmosphere (FIOCCO & SMULLIN, 1963; FIOCCO & GRAMS, 1964; FIOCCO & COLOMBO, 1964; FIOCCO, 1965). By integrating a relatively large amount of data, statistical evidence was achieved that, on occasions, optically thin layers were present at altitudes of about 20 km, 60–90 km and 110–140 km. These early observations were carried out at a station near Lexington, Massachusetts (geographical coordinates 42° 25′ N, 71° 15′ W).

At the invitation of the Geophysical Institute of the University of Alaska, and of the Institute of Meteorology of the University of Stockholm, two optical radar devices were taken to Alaska and Sweden during the summer of 1964 to perform observations of the upper atmosphere at latitudes where noctilucent clouds might be visible.

The unit in Alaska was installed at the Ester Dome observatory of the Geophysical Institute of the University of Alaska, College (64° 53′ N, 148° 3′ W) and in operation from July 24 to August 31. The unit in Sweden was mounted in a trailer made available by the National Aeronautics and Space Administration and was stationed at Ölands Skogsby (56° 38′ N, 16° 31′ E) from July 15 to July 31 and at Torsta, Ås, Jämtland (63° 15′ N, 14° 33′ E), from August 5 to August 27. The longitude coordinates of the stations in Alaska and Sweden differ by about 165°.

Because optical radar observations require a dark sky background in order to maximize the signal-to-noise ratio, the unit in Sweden was mobile so that observations could be started at lower latitudes where longer periods of darkness are obtained. It was also of special interest to make observations during those nights when rocket experiments were carried out at Kronogård, Sweden.

These experiments, designed to measure temperature and wind velocity at the mesopause and to sample the particulate content of the noctilucent clouds, were carried out jointly by scientists of the Swedish Space Committee, the National Aeronautics and Space Administration, and the Air Force Cambridge Research Laboratories.

Visibility conditions were less than satisfactory much of the time in Alaska as well as in Sweden. Precipitation was not uncommon and cirrus clouds or lower clouds were often present. On July 15, in Sweden, a very strong noctilucent cloud display was visible overhead and to the South, when the apparatus was not yet operational. On some other occasions noctilucent clouds were seen low on the horizon, i.e., at a distance of several hundred kilometers; thus all of our measurements were obtained when noctilucent clouds were not visible overhead. At our locations, during that period of time, we visually observed noctilucent clouds on the following nights (observations are reported in Universal Time):

5–6 August, Torsta
6–7 August, Torsta (Strong display)
7 August, College
7–8 August, Torsta (Strong display)
9–10 August, Torsta
10–11 August, Torsta
15–16 August, Torsta
16–17 August, Torsta

It is possible that on other occasions noctilucent clouds may have been present, but not observable from our location because of local visibility conditions.

The apparatus used in Alaska utilized a Q-switched ruby laser head built by the Radio Corp. of America which emitted pulses of approximately ½ joule with a wavelength of 6943 Å and duration shorter than 1 μsec at a p.r.f. of 0.1 sec^{-1}. The 3″ ruby rod and the elliptical cavity were cooled by dry nitrogen which had passed through a coil immersed in liquid nitrogen. The Edgerton, Germeshausen and Grier FX 47 A (3″ arc length) flashtube used in the laser was modified by us for cooling with distilled water. A refracting telescope with a focal length of 1 meter and aperture of 10 cm was used to collimate the outgoing radiation; a synchronized rotating shutter was incorporated into the transmitting unit to prevent the emission of fluorescent light and residual flashlamp light after the pulse had been emitted. The receiving unit utilized a 30 cm aperture telescope of the Newtonian type, a 3 Å bandwidth interference filter, and an EMI 9558 A photomultiplier tube cooled by the same nitrogen used to cool the laser cavity. A synchronized rotating shutter was included to prevent exposing the photometer to the intense return obtained from scattering at short distances.

The apparatus taken to Sweden utilized a 40 cm aperture Cassegrainian receiving telescope and a laser unit built by Applied Lasers, Inc. This laser unit was ordinarily used to deliver approximately 1.5 joule pulses of duration shorter than 1 μsec at a p.r.f. of 0.2 sec^{-1}. It utilized a 90° orientation ruby rod 6 ⅝″ long and ⅜″ in diameter. The ruby, flashlamp (EG & G FX 67 A), and elliptical cavity were cooled by closed loop circulation of distilled water. The Q-switching was achieved by a rotating prism and the output of the laser was collimated by a telescope with the same characteristics as the one used in Alaska. The receiver included a 6 Å bandwidth interference filter and a EMI 9558 QA photomultiplier cooled by methanol and dry ice. Synchronized rotating shutters were part of both the transmitter and the receiver.

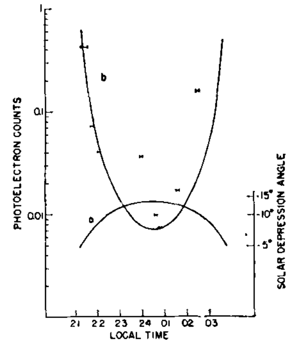

FIG. 1. Time variation of (*a*) solar depression angle and (*b*) intensity of sky background for 16–17 August 1964 at Torsta.

The optical radar systems were zenith-oriented during operation. The recording and analysis of the data as well as much of the experimental set-up was as described in earlier work by FIOCCO & SMULLIN (1963).

The intensity of the echoes for a thin layer of homogeneously distributed scatterers, expressed as n_R, the expected number of photoelectrons per transmitted pulse emitted at the photodetector cathode, can be computed with the aid of the following expression:

$$n_R = \frac{\eta\lambda}{hc} W_t A_r k_r k_t k_a^2 \frac{HN\sigma}{4\pi R^2},$$

where W_t is the transmitted energy per pulse, A_r is the collecting area of the receiving telescope and k_r and k_t are the efficiencies of the receiving and transmitting systems, k_a is the atmospheric transmission, H is the geometrical depth of the layer, $N\sigma$ is the average radar cross section of the scatterers per unit volume, R is the distance, λ is the wavelength, η is the quantum efficiency of the photocathode, h is Planck's constant and c is the speed of light. The product $HN\sigma$ is defined as the optical thickness of the layer. Because of the difficulty in measuring some of the parameters in the equation we have calibrated the sensitivity of the apparatus by assuming that the echoes from heights of 40–60 km were produced by a

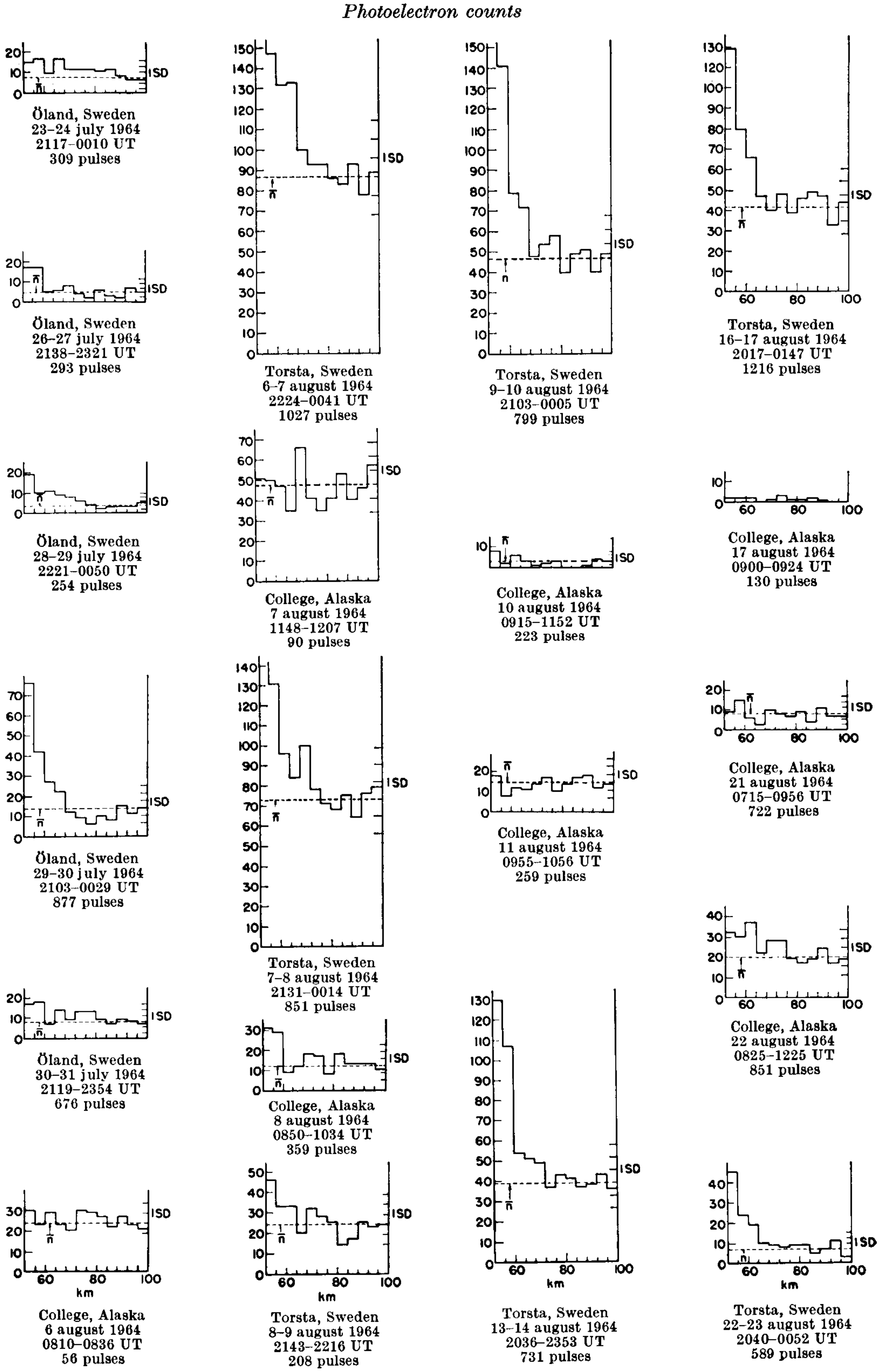

FIG. 2. Summary of observations for summer 1964.

model molecular atmosphere. This calibration was used to estimate the optical thickness of the layers above 60 km. It should be pointed out that the assumption of a dust-free atmosphere in the 40–60 km interval may lead to an underestimate of the optical thickness of these higher layers. On the other hand our photoelectron counting procedure may be subject to a reduced counting efficiency at lower heights which would result in an overestimate of the optical thickness of the upper layers. While these and other systematic instrumental uncertainties may modify the results to a certain extent, the system does provide us with the capability of obtaining a quantitative measure of the optical thickness of scattering layers in the upper atmosphere.

The important source of noise is the sky background which varies throughout the night and from night to night. In order to illustrate the nature of this variability, Fig. 1 shows, for the night of 16–17 August, (*a*) the solar depression angle and (*b*) the intensity of the sky background as a function of time. The intensity of the background is displayed as the average number of photoelectrons emitted in a 66 μsec interval (equivalent to a resolution in distance of 10 km). The scatter in the points is due to the occasional presence of thin clouds that increase the brightness of the background. Since the noise background increases very rapidly when the solar depression angle is less than 7–8 degrees, a very short interval of time is available for optical radar observations at high latitudes.

Fig. 2 is a summary of all the observations performed. For each night, the total number of photoelectrons accumulated in 4 km wide intervals from 52 to 100 km is indicated, as well as the total number of pulses radiated and the Universal Time when the observations were made. The average noise level, $\bar{n}$, is taken as the average of the measurements between 88 and 100 km. A measure of the statistical fluctuations, $\sqrt{\bar{n}}$, is also indicated and is taken to be equivalent to the standard deviation of the measurement. Although we have a great number of traces with records from 100 to 200 km, these will not be presented at this time. We point out, however, that these records do not show echoes of intensity comparable to those obtained in the previous summer at those heights. The data presented in Fig. 2 indicate

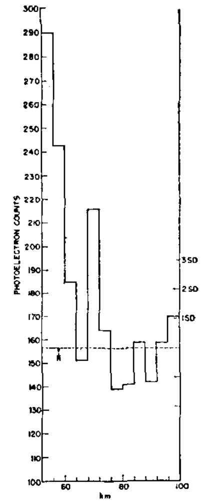

FIG. 3. Sum of observations obtained on 7, 7–8, 8, and 8–9 August 1964.

the presence of echoes on the nights of 6–7, 7, 7–8, 8, 8–9 August in the altitude range 64–72 km at the Swedish and Alaskan locations. Note that we visually observed noctilucent clouds on the horizon at both locations on the nights of 7 and 7–8 August. Noctilucent clouds were also reported from locations in the Soviet Union on 6–7 August (Willmann, 1965). In order to gain statistical evidence that a scattering layer was present at altitudes between 68 km and 72 km the observations for four consecutive nights (7, 7–8, 8, 89 August) were summed and the average optical cross section computed. The result is presented in Fig. 3; the average optical thickness of this layer is estimated at $1.0 \times 10^{-5} \pm 2 \times 10^{-6}$: This value is substantially larger than the optical thickness for the noctilucent clouds reported by LUDLAM (1957) and closer to the value suggested by DEIRMENDJIAN (1963) although different assumptions concerning the scattering phase functions may be involved.

Measurements were also obtained on the night of 16–17 August in Torsta during a noctilucent cloud display that may indicate the presence of scattering layers, but the statistical evidence is not conclusive. The partial count obtained from 0057 to 0147 UT suggests the presence of layers at altitudes of 60–64 km and 80–88 km. No comparable echoes were received during the earlier part of the night. The thickness of these layers is estimated to be 2×10^{-5} for the 60–64 km layer and 4×10^{-5} for the 80–88 km layer, although the peaks only exceed the noise by about $2\sqrt{\bar{n}}$ thus limiting the reliability of the measurements. This is the only occasion, however, when echoes were detected from an altitude of approximately 80 km, which is regarded as the level where noctilucent clouds are most frequently observed visually. In this respect, we point out that our measurements were carried out at night, well after twilight when noctilucent clouds cannot be observed overhead. The low value (68–72 km) measured for the height of the scattering layer may indicate that changes in the conditions of illumination in the nighttime mesosphere may have led to local thermal effects that caused the cloud to descend. For instance, the removal of a possible updraft, which might be responsible for the formation of the clouds, or a modification of it, could cause the particles suspended by the updraft to fall to lower altitudes.

In conclusion, we point out that, while throughout the period of our observations the noctilucent cloud activity was moderate, surprisingly no definite echoes (apart from those, relatively uncertain, of the 16–17 August) were ever received from the levels around 80 km while on occasions strong echoes were received from a level around 70 km. These measurements, admittedly of a preliminary type, have provided a quantitative measure of the optical thickness of mesospheric layers at high latitudes. The technique can be improved by increasing the rate at which the data are gathered thus reducing the length of time required to obtain statistical evidence. This will enhance the probability of detecting noctilucent clouds and would make it possible to study transient features of the clouds that are lost or smoothed out by averaging over long periods of time.

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