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FIRST HEIGHT COMPARISON OF NOCTILUCENT CLOUDS AND SIMULTANEOUS PMSE

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Abstract. On the night of August 9-10, 1991, two rocket payloads were launched into simultaneously occurring noctilucent clouds (NLC) and polar mesospheric summer echoes (PMSE) above Esrange, a third rocket payload was launched into a NLC where a PMSE was detected 5 minutes later above Esrange, in Sweden as part of the NLC-91 campaign. An aim of this experiment was to compare the vertical structures and locations of the NLC and PMSE events. To this end, in situ optical photometers and particle impact sensors were used to measure the altitude and vertical structure of the NLC layer, while the Cornell University portable radar interferometer (CUPRI) was used to probe the PMSE. Although this comparison is complicated by the horizontal separations between the in situ measurements and the radar volume, and low electron densities which reduced the overall radar reflectivity, we conclude that the PMSE layer in the CUPRI radar volume remained above the NLC layer detected by the in situ instruments by 300 to 2000 m throughout the experiment. We interpret this result as supporting the view that PMSE are more likely to result from the presence of aerosols smaller than the ones optically detectable as NLCs.

Introduction

During the arctic summer, the extremely cold temperatures present at mesospheric altitudes lead to the formation of aerosol or particle layers visible from the ground as noctilucent clouds (NLC) and from space as polar mesospheric clouds (PMC). The cloud displays are observed within the twilight arc when aerosol particles grow to sufficient size and are numerous enough to scatter incoming sunlight above the background scattering (Rayleigh scattering) of the atmosphere at this height. They have been studied with ground and aircraft based cameras and photometers, rocket payloads, and satellites (see overviews by Gadsden and Schröder [1989] and Thomas [1991]). Also peculiar to the arctic summer mesopause are radar observations of polar mesospheric summer echoes (PMSE) at altitudes similar to NLC displays [Ecklund and Balsley, 1981].

Whether NLC and PMSE events are related phenomena (as Jensen et al. [1988] suggest) or not (as Taylor et al. [1989] conclude) remains a contested issue. The aim of this work is to present new data on NLC profiles compared with simultaneous PMSE measurements and thus contribute new ammunition for this ongoing discussion.

The NLC-91 campaign is described in recent articles by Kopp et al. [1991] and Goldberg et al. [1993]. Within Salvo A, the DECIMALS-A and B (Dynamical Electrodynamical and Chemical Interactions at the Mesopause at Arctic Latitudes in Summer), and PEP-A (Pennsylvania State Electrodynamics Payload) were equipped with SLIPS (Scattered Light Intensity Profile Sensor) type photometers [Wilhelm and Witt, 1988]. In addition to the SLIPS photometers, the DECIMALS payloads carried PAT (Particle and Aerosol Trap) electrical impact sensors to measure secondary electron releases from the impact of NLC particulates on the sensor. The launch dates, the equipment and the code names of the three payloads are given in Table 1. All three payloads were launched from Esrange, Sweden on the night of August 9-10. During the NLC-91 campaign, the Cornell University portable radar interferometer (CUPRI) [Swartz et al., 1993] was operated in a special PMSE detection mode from its location approximately two kilometers from the Esrange launch pad.

Observations

The observer on board of an aircraft (one of us J.S.) documented a complete NLC cover above Esrange beginning on August 9, 1991 at 22:30 UT and continuing until August 10, 1991 at 00:30 UT when the cloud's contrast to the background atmosphere became too low as dawn approached. The presence of NLC above Esrange was confirmed by the SLIPS and PAT instruments on the NAD-14, NAP-17 and NAD-20 payload.

During the same night as these NLC launches, a well defined PMSE event was observed in real-time displays above

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Table 1: Payloads of the noctilucent cloud experiment carrying instruments for the detection of the NLC layer. The DECIMALS payloads carried a SLIPS and a PAT, the PEP payload carried a SLIPS instrument.

Payload	Code name	Launch time [UT]
DECIMALS-A	NAD-14	09-08-1992, 23.15.15
PEP-A	NAP-17	09-08-1992, 23.40.00
DECIMALS-B	NAD-20	10-08-1992, 01.37.00

the Esrange site by the CUPRI radar beginning on August 9, 1991 at 21:50 and disappearing the same day at approximately 23:50 UT. The NAD-14 and the NAP-17 payloads were launched into this simultaneous NLC/PMSE event. When the NAD-20 payload was launched on August 10, 1991 at 01:37 UT, the on-line display of CUPRI data did not indicate an obvious PMSE signal. However, subsequent analysis of the data has clearly revealed the presence of a PMSE layer between 01:44 UT and 02:05 UT.

The data from the SLIPS and PAT instruments on board the NAD-14 payload are shown for both the upleg and the downleg in Figure 1. As can be seen the two instruments measured the presence of NLC between 82.5 and 83.5 km on the upleg and between 83.0 and 84.0 km on the downleg. Complete agreement between the two instruments in the height and vertical extension of the cloud is not expected due to the different sensitivities as a function of aerosol particle size between the two instruments. The response of the optical instrument follows the sixth power of the radius of particles as long as they are small and then Mie scattering describes its behaviour. The impact sensor's sensitivity depends of the mass of the particles. As a consequence of this a certain particle size distribution on a certain height does give the same relative signals on both sensors. Therefore the maximum signal of the NLC can be on different heights for both instruments. As we see such small height diffenences in the signals of the instruments we have a direct evidence that the particle size distribution in the NLC is not uniform as a function of its vertical extension.

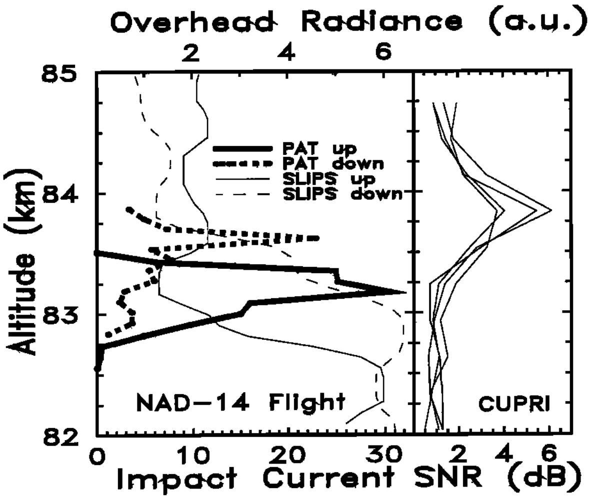

Fig 1. Data from the NAD-14 payload launched at 23:15:15 UT on August 9, 1991 (left). The SLIPS photometer and the PAT sensor indicate the height of the NLC layer. The small differences in height result from different instrument sensitivities as a function of the NLC particle size. Note that the units are arbitrary. Also shown are profiles of post-processing signal-to-noise ratio recorded by CUPRI (right). The successive profiles are from 23:15:07 to 23:16:49 UT with an integration time of 34 s.

The NLC structure recorded on the upleg by the PAT instrument is similar to published structures measured with optical instruments (e.g., Witt el al. [1974]). The downleg data, however, show a large mass concentration in the cloud near the top of the layer followed by a roughly linear decrease in the cloud mass concentration on the bottomside. To our knowledge, no such structure has been reported previously.

The vertical extent of the cloud can also be clearly seen in the plot of scattered light intensity from the SLIPS photometer on the NAD-14 payload shown in Figure 1. As the payload passed through the cloud layer, the intensity of the light scattered from the aerosol particles into the photometer decreased until the payload passed out of the layer. The total reduction in signal strength in this case is approximately a factor of three. Unfortunately, high levels of noise in this data required extra numerical filtering which made it impossible to calculate the derivative of the overhead radiance to obtain volume emission rate from the cloud, and thus high resolution information on the vertical structure of the cloud was lost.

Also shown in Figure 1 are the successive altitude profiles of PMSE signals observed by the CUPRI during the time of the NAD-14 flight. The echo powers were decreasing at this time and the height of the intensity peak was descending with time (see Swartz et al. [1993] for an overview of the PMSE morphology and radar parameters).

Figure 2 shows the SLIPS optical data from the NAP-17 payload and the corresponding CUPRI echo profiles.

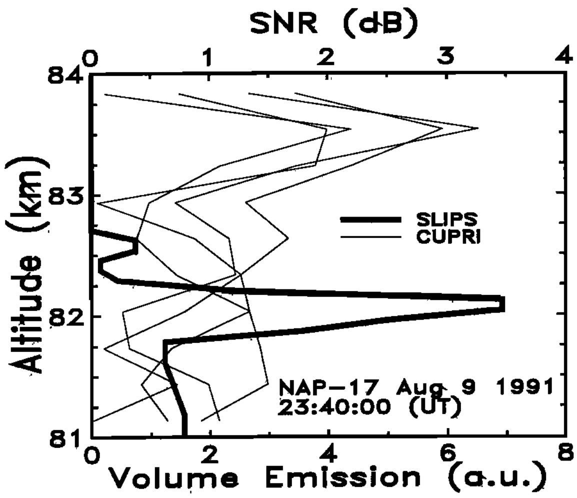

Fig 2. Comparison of the SLIPS photometer data from the NAP-17 payload launched at 23:40:00 UT on August 9, 1991 (converted to volume emission rate in arbitrary units) and CUPRI SNR profiles. The successive profiles are from 23:40:26 to 23:42:07 UT with an integration time of 34 s.

From this SLIPS data set, we were able to determine the volume emission rate as a function of altitude for the lower part of the NLC layer. Unfortunately also this photometer suffered from technical problems – this time a reduced sensitivity which made it impossible to determine the upper edge of the scattering layer. These sensitivity problems resulted in both the secondary maximum (at 82.5 km) and subsequent drop to zero in the volume emission rate above this height. Neither of these results have a physical meaning.

Finally, Figure 3 displays the SLIPS and the PAT data from the NAD-20 payload, launched on August 10, 1991 at 01:37 UT. By this time the foreground sky radiance had become too intense for visual confirmation of NLCs by the aircraft observer but the in situ measurements clearly indicate the existence of an aerosol layer. Also in Figure 3, backscattered power profiles recorded by the CUPRI clearly reveal a PMSE layer. Note, however, that the profiles are from the period 01:44-01:48 UT. There was no obvious PMSE layer in the radar volume at the exact time of the NAD-20 flight.

Comparison

An aim of this experiment was to compare the altitudes of the measured NLC and PMSE layers to determine if the layers were co-located at the same height. Such a comparison is complicated by several factors: The different physical locations of the measurements, the sensitivity of the radar to absolute electron density, the inherent errors involved in rocket and radar measurements, and the sensitivity problems of the photometer on board of the NAP-17 payload.

First, the CUPRI radar beam was directed vertically during the NLC-91 campaign with a full-width-half-maximum of approximately five degrees. This resulted in a scattering volume approximately 7 km in diameter at PMSE heights, located above the Esrange launch site. The rocket payloads were launched northeast from the launch site and were approximately 20 km down-range when they reached 83 km of altitude on the upleg. On the downleg, they passed through 83 km approximately 40 km down-range. Thus both regions of in situ measurements were outside of the radar beam. NLC displays often show wave structures in the height of the cloud layer as a function of the horizontal coordinates (e.g., Witt [1962]). The horizontal extent and structure of PMSE layers are not very well known at the present, although it is usually assumed that the time evolution of the PMSE layer in the radar beam is due primarily to the horizontal advection of air masses carrying the layer through the radar beam. Under this assumption, wavelike structures in the height of the PMSE layer are often seen in the CUPRI radar data. However, no such structure was visible during the PMSE event of August 9, 1991, making it conceivable that this particular layer was not vertically "wavy" over a considerable extent. Second, the data of Friedrich et al., [1992] show that the electron density was decreasing with decreasing altitude and was approximately 10^9 m^{-3} at 83 km (as measured by instruments on both the NAD-14 and the NAD-20 payloads). Such an electron density may have been too low for the system to detect even if 3-m radar Bragg scattering structures were present. Third, the altitude measurements from the rocket and radar data contain uncertainties. For the rocket payloads, the altitude can be measured to a certainty of ±200 m, while for the radar the uncertainty is within the range resolution of 300 m. Fourth, the NAP-17 payload was only able to detect the bottom boundary and

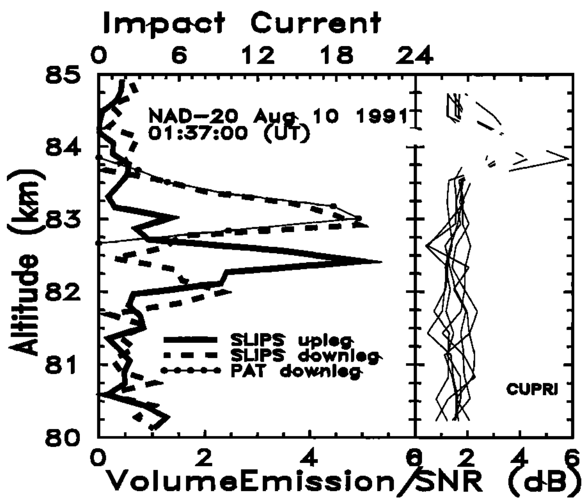

Fig 3. Data from the NAD-20 payload launched at 01:37:00 UT on August 10, 1991 (left). The SLIPS photometer and the PAT sensor indicate the height of the NLC layer. The units are arbitrary. Also shown are profiles of post-processing signal-to-noise ratio recorded by CUPRI (right). Note that the successive profiles from 01:44:09 to 01:48:05 UT with an integration time of 34 s. There was no PMSE layer in the radar volume at 01:37 UT.

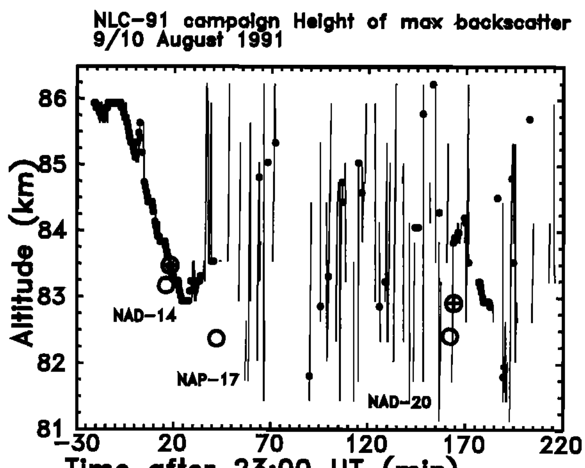

Fig 4. Comparison of the altitude of the maximum PMSE (radar) and NLC (in situ) signal strengths as a function of time. The heights of all the echoes were connected by a fine line. Whenever a sequence of four echoes was within ± 500 m around the average value at that time it is marked with a •. The NLC data are given as ○ for the upleg and as ⊕ for the downleg.

not the upper boundary of the NLC cloud (as mentioned above).

Finally, we compare the altitude of the maximum signal from the NLC layer with the altitude of the maximum radar backscatter signal as a function of time in Figure 4. Some explanation of the various measurements is necessary. The altitude chosen for the NAD-14 payload corresponds to the maximum impact current strength measured by the PAT instrument on upleg and downleg. For the NAP-17 payload the center height was determined assuming a total layer thickness of 1 km vertically since the SLIPS instrument on that flight only observed the bottom side of the NLC layer. The altitudes measured by the NAD-20 payload were determined from SLIPS optical data.

From these data, we conclude that the NLC layer observed August 9-10, 1991 was below the simultaneous PMSE layer by a distance on the order of 300 to 1000 m. This does not, of course, imply that the two phenomena are unrelated. According to the theory of Cho et al. [1992], PMSE occur because the electron density inhomogenities at the radar Bragg scales are maintained against diffusive dissipation due to the presence of charged aerosols which have very low diffusion speeds. The optical detection of NLCs has its principal limitations in the Rayleigh scattering background of the atmosphere which makes it impossible for optical instruments to detect small concentrations of particles that do not enhance the volume emission by more than $\approx$ 5% above and below the NLC layers. A possible candidate for an instrument which does not have such principle detection limits would be an improved version of a particle impact sensor which we are planning to fly in a future NLC/PMSE campaign as an attempt to unambiguously establish the presence or absence of aerosols in the regions of the PMSE.

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