GEOPHYSICAL RESEARCH LETTERS, VOL. 20, NO. 20, PAGES 2299-2302, OCTOBER 22, 1993

ELECTRIC FIELD MEASUREMENTS IN THE VICINITY OF NOCTILUCENT CLOUDS AND PMSE

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Abstract. We report mesospheric electric field structure in the vicinity of noctilucent clouds (NLC) and polar mesospheric summer echoes (PMSEs) measured on the DECIMALS-B rocket payload launched during the international rocket-radar campaign NLC-91 from Esrange, Sweden on August 10, 1991. Unusually large vertical E- fields, E_z, about 100-300 mV/m on ascent and greater than 1 V/m on descent were detected at 82.5-84.5 km. The region of the large E_z was clearly limited by the NLC layer on the bottom and by the distinctly separated PMSE layer on the top. A narrow negative peak in the E_z height profile observed on ascent in the lower part of the NLC layer was apparently caused by the interaction of the field mill with impacting NLC particles possibly carrying negative charge. If the impact signature is due to single particles, their size is estimated to at least 0.5 μm and their concentration about 10^{-4} cm^{-3} locally. Based on the light-scattering properties of NLC such massive particles can only be a minor part of the NLC population.

Introduction

The only E-field measurement made hitherto in the vicinity of noctilucent clouds (NLC) was made during the Middle Atmosphere Electrodynamics (MAED) rocket campaign in Kiruna, Sweden in July 1986. The MAED experiment gave a clear indication that aerosol particles may be involved in the modification of the E-field structure at the summertime polar mesopause [Goldberg, 1989]. Recent measurements in the lower mesosphere have also indicated a connection between the mesospheric E-fields and aerosols [Zadorozhny et al., 1993]. The study of the electrodynamic properties of the middle atmosphere in the vicinity of noctilucent clouds was continued as part of the international rocket-radar campaign NLC-91 [Kopp et al., 1991; Goldberg et al., 1993]. In particular, several rocket measurements of the electric field strength were carried out over Esrange, Sweden, and Heiss Island, Russia. A further goal of this campaign was to clarify the relationship between the occurrences of NLC and PMSE. In this paper we present preliminary results of the E-field measurement in the vicinity of NLC carried out on the DECIMALS-B payload which was launched during this campaign from Esrange a few minutes before PMSEs were detected by Cornell University portable 50 MHz radar interferometer (CUPRI).

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Paper number 93GL02626
0094-8534/93/93GL-02626$03.00

Instrument description

The measurements described here were done with an improved version of the field mill used earlier for measuring the vertical E-field in the stratosphere and the mesosphere on Russian meteorological rockets M-100B [Bragin et al., 1974; Tyutin, 1976; Zadorozhny et al., 1989, 1993]. The electric field mill operates on the basis of the principle of a rotating capacitor. An external E-field will induce a charge on the plates of the capacitor. If the capacitor is loaded by a resistor, an alternating current is produced in the circuit with a frequency equal to that of rotation rate of the capacitor. The current amplitude is proportional to the component of the external E-field perpendicular to the rotation axis of the capacitor. Our instrument consisted of a cylindrical capacitor cut through, and rotating about its axis of symmetry. The angle between the capacitor rotation axis and the payload spin axis was 85°, the distance between the capacitor and the payload axis was about 40 cm, and the rotation frequency was about 20 Hz. Since the orientation of the probe changed with the rotation of the spinning rocket, we were able to obtain all three components of the atmospheric E-field strength. A more detailed description of the field mill is found in the paper by Zadorozhny et al. [1993].

Experimental conditions

The DECIMALS-B payload was launched to an apogee of 117.2 km from Esrange during Salvo A on August 10, 1991 at 01:37 UT. An NLC display over the rocket range was visually and photographically recorded earlier that night. By the time DECIMALS-B was launched the background sky had become too bright for optical confirmation of the presence of NLCs. However, the NLC layer was detected by the combined electrostatic-optical particle sensor on board the rocket both on ascent and on descent [Wälchli et al., 1993]. The CUPRI radar recorded PMSE during the early phase of Salvo A, up to about 23:40 UT, August 9. After this time the echoes gradually faded and eventually vanished except for two brief periods: around 00:45 and shortly before 02:00 UT, August 10. The latter period began about 7 minutes after DECIMALS-B was launched. The geomagnetic conditions were unusually quiet during this part of the night, with very low ionisation at mesopause heights. We refer the reader to Swartz et al. [1993] for description of the CUPRI system and the PMSE characteristics during Salvo A.

Experimental results

The scattered light intensity profile sensor (SLIPS) [Wilhelm and Witt, 1989] also on board DECIMALS-B, indicated a passage of the payload through the NLC layer at about 86 sec on ascent and at 256-257 sec on descent. Figure 1, trace (a) shows the raw DECIMALS-B field mill data at the moment of passage through the NLC layer on ascent , while trace(b) displays a segment of data from an undisturbed region at a lower height. The difference between the two figures is clearly seen. Along with the sinusoidal variation at the field mill rotation frequency, short-period fluctuations with about 10-20 msec duration are observed at 86 sec. However, the field mill signal amplifier had a high-frequency filter with a 200-Hz cut-off. Thus the actual disturbances may have been much shorter. Note that these short-term fluctuations were seen only between about 85.9 and 86.5 sec on ascent. The disturbance in the field mill signal was observed also on descent when the payload passed through the NLC during 256-257 sec, but the disturbance in this case was so large that the field mill went off-scale. The field mill signal was processed in the following manner. The vertical, E_z, and horizontal, E_{xy}, components of the field mill signal were extracted from the raw data by using the reference signal from the capacitor position sensor. Subsequently, the E_{xy} vector was decomposed into two components, E_x and E_y, using the reference signal from a sun sensor to obtain the frequency of the payload rotation. The phase of the sun sensor signal was chosen so that the x-axis would be directed along the solar azimuth. In this way the largest photoelectric interference was in the E_x component, and the smallest in E_y. Because of its asymmetrical position relative to the payload axis, the field mill also measured the E-field E_p due to the payload surface charge. This field was the dc component in the E_{xy} signal while the atmospheric E-fields and photoelectric interference were the ac components with the frequency of payload rotation. Thus we were able to subtract E_p from E_{xy}. All the components, E_x, E_y, E_z, and E_p were averaged over each payload revolution. The results are shown in Figure 2 for ascent and descent. All three components, E_x, E_y, and E_z, increased sharply above about 85 km because of the photoelectric charging of the sensor. This is clearly seen in the data before averaging and appears to be related to Lyman-alpha radiation. For the sake of clarity the contaminated data are not shown in the figures. The E_x component is more sensitive to the photoelectric effect, therefore a weak increase in E_x up to about -150 mV/m near 80 km appears to be the result of solar illumination, too, but at longer wavelengths. A similar behavior of the E_z component indicates that the E_z signal at 75-80 km was also probably caused by photoelectric charging. On the other hand, E_z values of about 200 mV/m below 70 km on ascent

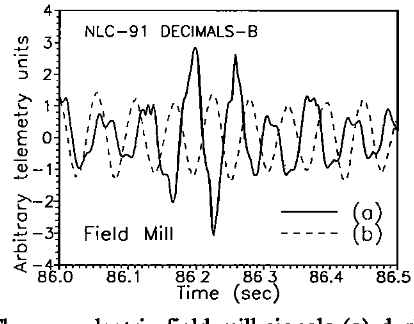

Fig. 1. The raw electric field mill signals (a) during the passage of the DECIMALS-B payload through noctilucent clouds and (b) 10 seconds earlier on ascent.

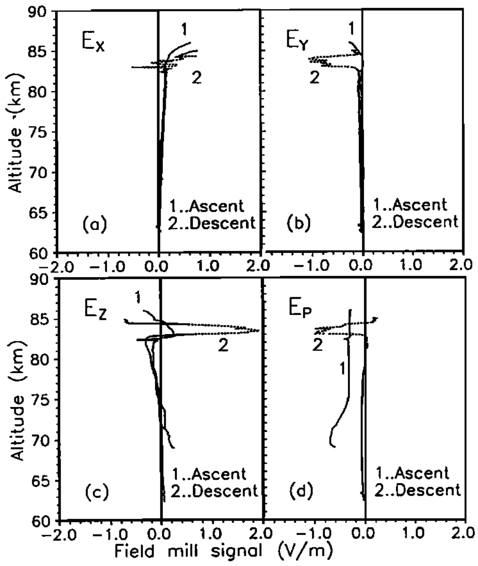

Fig. 2. The electric field components derived from the field mill signal. Panels (a) to (c) show the horizontal X- and Y-, and the vertical components as indicated. Panel (d) shows the field caused by the payload surface charge. The data on descent where the field mill was off-scale are shown by dashed lines.

may have been caused by a charging of the rocket, judging from the increase in E_p at these heights. Thus we can conclude that all three components of the atmospheric E-field vector remained below a few tens mV/m during the DECIMALS-B flight in the mesosphere above about 65 km with the exception of in the disturbed region between about 82 and 84.5 km. On ascent, pronounced disturbances were observed only in the E_z component. There is a very narrow negative peak in the profile of E_z at 82.3 km with $E_z \sim -480$ mV/m. Another more extended positive maximum with values of E_z varying from 100 to 300 mV/m is seen at 82.5-84.5 km. The negative peak is exactly co-located with the NLC layer while the positive disturbance in E_z occurs above the NLC heights where the PMSE layer was found (Figure 3). Figure 4 shows the E_z-component and the SLIPS photometer data obtained on descent along with the CUPRI data. This figure also shows a striking height correlation: the NLC layer is co-located with the lower boundary, and the PMSE layer occurs just at the upper boundary of the increased E_z region. This is an analog to a charged capacitor with the negative charge on the lower plate (NLC) and the positive charge on the upper plate (PMSE).

Discussion and Conclusions

The disturbances in the field mill signal at 82-84.5 km could not have been caused by rocket charging (as can be seen from the E_p data on ascent) nor by the photoelectric effect. Another possible source of interference is the interaction of the field mill electrodes with the flux of aerosol particles in three possible ways: (a) currents caused by space charges, (b) direct impact of charged particles, and (c) emission of charged particles from the surface. The latter can either be electron emission from the surface itself or charge separation

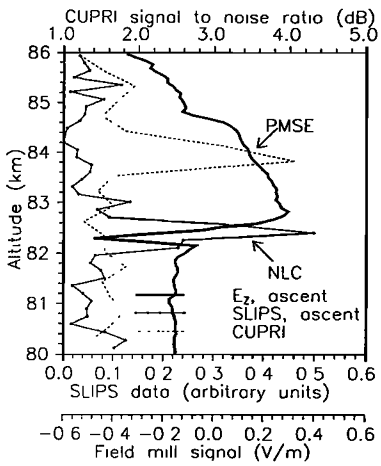

Fig. 3. The vertical electric field E_z, and the light-scattering profile measured by the SLIPS obtained on ascent alongside with the CUPRI radar signal: The peak scattering seen at 82.4 km indicates the maximum of the NLC layer. The CUPRI profile shown is the average of several radar scans between 01:44 UT and 01:48 UT just after the rocket flight. The PMSE layer is clearly seen near 84 km.

by the break-up of ice aerosols as observed in laboratory experiments by Vostrikov et al. [1988]. It is easily shown that the electric field disturbances we observed were not due to (a), since the space charge density can be estimated from the field mill data. As for (b) and (c), we can compare the sign of the field disturbances during ascent and descent to test their origin. If the disturbances were caused by atmospheric E-field variations their would be of the same sign during ascent and descent, which would not be the case for an interaction of the sensor with sub-micron NLC particles. It should be mentioned that the electric disturbances cause by particle impact are utilised by the electrostatic NLC-detector on board of the DECIMALS-B payload [Wälchli, 1993]. The possible effects of a charged rocket wake observed by Kelley et al (1983) also would have different signs on ascent and descent.

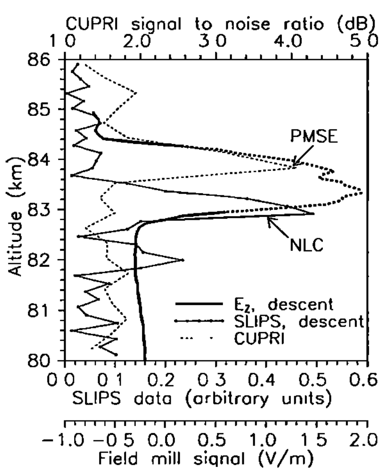

Fig. 4. The same as Figure 3 but for descent. The field mill data are shown by broken lines where the field mill was off-scale.

The signal disturbances were observed on descent for all four components of the field mill signal (Figure 2). Still, to be borne in mind, the sensor on descent was off-scale at 83-84 km heights, so that the signal was non-linearly distorted. In this case, one can not decompose the signal into its original components. This means that even if the source signal only contained one single component the computation with such an off-scale signal would produce other components as well. Therefore, we cannot unambiguously state, for example, whether the E_p component resulted from payload charging or it was due to the non-linear mixing of the other components of the source signal. Nevertheless, since the decomposition of the signal is very sensitive to the phase which does not change appreciably as long as the signal is limited symmetrically, one should expect that the component least affected would be the one with the largest magnitude, which is the E_z component, as seen in Figure 2. Since the sign of the E_z disturbance at 82.5-84.5 km on ascent and descent were the same, we have good reason to believe that these disturbances resulted from genuine atmospheric E-field variations. As for the negative disturbance in the E_z component detected on ascent only, the only plausible explanation appears to be an interaction of the field mill with the NLC particles.

The magnitude of the positive E_z disturbance on descent was a few times that on ascent. The upper boundary of the disturbance on descent was exactly colocated with the PMSE layer, while on ascent this correlation was less good. These two facts may be ascribed to the PMSE variations. The measurements on descent were taken about three minutes later than the ascent data, i.e. closer to the moment of appearance of PMSE echoes in the CUPRI data. The payload horizontal motion may also have contributed to this difference. In this event, it is also necessary to consider the wind at PMSE altitudes as well as the horisontal displacement between the radar scattering volume and the rocket apogee, about 30 km The visual NLC observations throughout the night indicated that there was a significant NE-to-SW drift in the NLC. The height correlation of the E_z disturbance with the NLC and PMSE positions indicates the importance of the aerosol particles in the generation of the vertical E-fields under NLC/PMSE conditions. This permits the following qualitative picture of the physical processes occurring in the region. In the low temperature environment, the generation of particles may be initiated by heterogeneous nucleation, or ion hydration. The sedimenting particles grow through accretion of water molecules attaining a maximum size, limited by the thickness of the supersaturated region and the available H_2O supply. Near the mesopause the lifetime of the particles is long but when the downward increasing temperature attains about 150 to 160 K evaporation is rapid compared with the fall speed and the particles evaporate within a narrow altitude range. Particles that are large enough can be distinguished optically from the background molecular scattering. The particles also acquire an electric charge which should be negative, in the statistical sense, so as to account for observed positive E-field.

The short-term fluctuations in the field mill signal detected between 82 and 82.5 km on ascent were also unexpected (Figure 1). This is in good agreement with the SLIPS observation of NLC particles at 82 to 82.7 km (Figure 3). The negative peak in E_z component lies in a somewhat narrower height interval between about 82.2 and 82.5 km. We interpret the short-term fluctuations to be a result of the impact of NLC particles on the field mill electrodes. The sign of these fluctuations was positive, i.e., the charge of the plate was positive after impact. This means that either the NLC particles carried a very large positive charge or negative charge was ejected from the surface of the electrodes. The amplitudes of the measured signatures from particles bombarding the field mill suggest that the charge acquired by the electrode in an individual event was about 10^7 elementary charges. It is unlikely that an NLC particle has a charge that high. The charge emission mechanism seems to be more realistic and has been observed in field experiments and in the laboratory [Wälchli et al., 1993; Vostrikov et al., 1988]. Assuming each emitted electron required 10 eV for emission, the total energy released in the impact could have exceeded 100 MeV. Should the observed effects arise from a single-particle impact then with an 800 m/s rocket velocity and a particle density of 1 g/cm^3, energy considerations lead to a dimension of at least 0.5 μm. From the short-term fluctuation frequency the concentration of these particles can be evaluated to be about 10^{-4} cm^{-3}. The size of these particles is much greater than the optically determined size of NLC particles [Heintzenberg et al., 1978; Thomas and Mc Kay, 1985]. While there is no a priori reason to preclude the sporadic occurrence of such large particles at the mesopause, optical considerations show that their total number must remain very small. Particles in this size range would have a substantial effect on the wavelength dependence of NLC scattering and the polarisation would be smaller than observed. The possibility of more than one particle hitting the probe surface within the response time of the instrument needs to be considered, needs to be further explored.

In conclusion we argue that at least the strong positive disturbances in the field mill signal measured in the vicinity of the NLC and PMSE layers portray real variations in the atmospheric fields. The disturbances of about 1 V/m in the vertical E-field are much greater than those observed previously in the vicinity of NLC [Goldberg, 1989] and are too large to be explained by current theories. Similar V/m vertical E-fields observed in the lower mesosphere, where the conductivity is smaller, are still not well understood [see e.g. Goldberg, 1989; Zadorozhny et al., 1993]. The higher conductivity at the sunlit mesopause only aggravates this problem. The height correlation of the E_z disturbance with NLC/PMSE emphasizes the importance of aerosol particles in the generation of E-fields under NLC/PMSE conditions.

Acknowledgments. The NLC-91 campaign and this work was supported by the Swedish National Space Board and the Swiss National Science Foundation. The Cornell group was supported under NASA Grant NAG5-666 and NSF Grants ATM-9021915 and ATM-9217007. The Novosibirsk Stae University group was supported by the Central Aerological Observatory, Dolgoprudny, Russia.

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(Received: August 11, 1993;
Accepted: August 30, 1993.)