THE ESPRIT ROCKET PAYLOAD LAUNCH: INITIAL COMPARISON WITH GROUND BASED ATMOSPHERIC MEASUREMENTS

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ABSTRACT

The ESPRIT (Engineering/Scientific Projects for Research and International Teamwork) rocket payload was launched from Andøya Rocket Range (ARR), Norway on 1 July 2006 at 0639 UT. Reaching an apogee of 169 km, the rocket payload was designed to investigate plasma interaction in the high latitude ionosphere, and the physical characteristics of mesospheric noctilucent cloud (NLC) particles and polar mesospheric summer echo (PMSE) conditions. Students from the Pennsylvania State University and three Norwegian universities (Oslo, Bergen and Narvik) worked along with faculty advisors to outfit the payload with multiple atmospheric measuring experiments suitable for the science investigations of ESPRIT.

1. INTRODUCTION

Measurements of the high latitude D- and E-region plasma environment and aerosols in the polar summer mesopause region were performed on the rocket-borne payload using instruments prepared by students at Pennsylvania State University and three Norwegian Universities; Oslo, Bergen and Narvik. Students and faculty representatives from these universities conducted the campaign of ESPRIT, with ARR and NASA personnel carrying out the launch activities. The campaign included collaborations with researchers from several laboratories operating ground based instruments at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) and the European Incoherent Scatter Radar (EISCAT) in Ramfjordmoen near Tromsø, Norway. This paper reports the initial efforts to compare data obtained from the rocket payload with the local ground based measurements.

The ESPRIT rocket payload launch was conducted at Andøya Rocket Range, Norway on 1 July 2006 at 0639 UT (0839 LT) using a Terrier Improved-Orion sounding rocket configuration, provided by NASA's Wallops Flight Facility, which launched the scientific payload to an apogee of 169 km. At the time of the launch, remote-sensing ground based LIDAR measured an intense NLC layer centered at 83 km altitude, and the ALWIN MST radar detected PMSE layers below the NLC layer, and at 83.5 and 88 km above the NLC. At the same time, the EISCAT UHF and VHF radars detected a sporadic-E layer at 107-109 km.

Four ionospheric instruments (including a solid-state energy detector, bremsstrahlung X-ray radiation detector, a Langmuir probe and a plasma frequency probe) and two mesospheric aerosol instruments (a multi-channel photometer and aerosol particle dust collector) collected data during the flight. The principle ground based instruments contributing to the operation included the ALOMAR RMR and Na Lidar, ALWIN (ALOMAR wind) Radar, EISCAT (UHF and VHF) at Tromsø, Andenes MF Radar, and the University of Tromsø Digisonde.

This paper provides a background for the science mission, introduces the rocket-borne instruments, and describes measurements of the ground based and rocket-borne instruments used to investigate the characteristics of the plasma environment and mesospheric particles present during the ESPRIT launch.

2. SCIENCE BACKGROUND

The ionospheric investigations for ESPRIT focused on studies of the D- and E-regions of the ionosphere from 70 – 170 km altitude. The At high latitudes the ionosphere is interesting because of the many sources contributing to the ionization, and the electromagnetic fields that act upon this conducting region of the upper atmosphere. Ionization of this region is characterized by photo ionization by solar ultraviolet radiation, X-rays, and by energetic particles entering from the plasmasphere or through the cusp region of the magnetosphere. In fact, the plasma density in this high latitude region is frequently enhanced by the drizzle of particles with sufficient energy to ionize the molecular and atomic species of the atmosphere at D- and E-region heights. The typical daytime E-region electron number densities are about 1.5×10^{11} m^{-3} and peak near 110 km. Fig. 1 shows the electron density profiles from EISCAT UHF and VHF at the time of the rocket-borne Langmuir probe.

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Thin layers with several times the typical number densities of E-region ions often develop at nulls in the zonal wind shears. These wind shears force ions into *v x B* layers, which are principally composed of meteoric ions because of their low ionization potential and longer ion lifetime. They are referred to as sporadic-E due to their thin and irregular appearance and they are often in layers (about one kilometer thick) between 90 and 120 km [1].

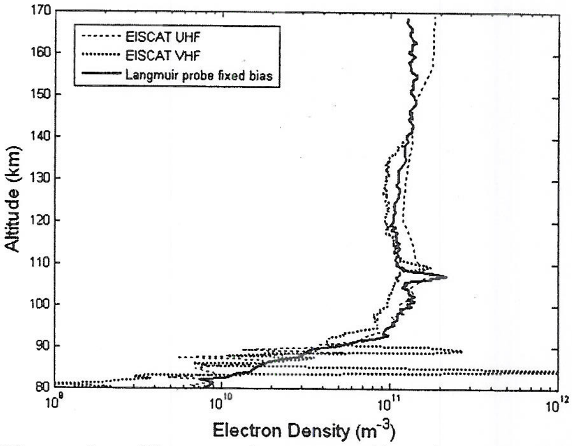

Figure 1. Electron density profiles from the LP instrument, and the EISCAT VHF and UHF radar.

The D-region of the ionosphere forms in the upper mesosphere between 60 and 90 km, and exists, with any significance, only during the daytime or during periods of energetic particle ionization. D-region electron number densities are typically about one to two orders of magnitude below E-region densities at 10^3 to 10^4 cm^{-3}. X-rays, EUV radiation, and energetic electron and proton ionization are the primary sources of electrons, which most often attach to molecules forming negative ions at altitudes below 80 to 85 km. The loss of ions is by recombination, associative detachment and mutual neutralization [1].

During the summer months, aerosol particles form in the upper mesosphere by freezing water vapor into small ice particles; these accumulate and coalesce at the extremely cold mesopause region. The calculations of Garcia and Soloman [2] combine the effects of a global model of atmospheric chemistry and a parameterized model of gravity waves to show the primary processes involved. Temperatures range below 140 K from adiabatic cooling from circulation; the region is cold enough to freeze water vapor at the vapor pressure in mesospheric altitudes. A high-resolution rocket borne accelerometer instrument was able to provide the first accurate profiles of the temperature and dynamics of the region during an NLC event in 1982 [3]. The ice particles nucleate on meteoric dust or large water cluster ions at altitudes with the largest degree of super saturation in the mesopause region, and grow by condensation of additional water vapor [4]. The particles settle down due to gravity and grow further until they reach visible sizes, between about 20 - 50 nm radius [5]. These now visible particles are the basis for formation of NLCs, which usually occur near 84 km in local temperature minima occurring at those altitudes during the summer months [3].

PMSEs are associated with sub-visual particles 0.1 - 20 nm radii in size existing in the regions of formation and dissipation of NLC between 80 and 95 km. The small ice particles are immersed in the D-region plasma, and evidence suggests that when the water ice is distributed as many small ice particles, which is the case in the regions of formation or dissipation above or below and NLC, the VHF radar scatter signal is observed.

3. ESPRIT INSTRUMENTS

3.1. Langmuir probes

A Langmuir probe (LP) instrument developed at Penn State University provided ionospheric plasma measurements in the high latitude E-region. The LP measured electron density, electron temperature, ion density, and small-scale charge density fluctuations. The instrument included two cylindrical probes. One probe was swept from -10 to +10 V to detect the plasma potential, and make temperature measurements of the plasma. The other probe was fixed at a bias, and provided the high spatial resolution necessary for measurements of variations in plasma density [1].

The Langmuir probes were extended on booms far enough from the payload to measure the ambient ion or electron currents collected on the probes outside of the vehicle shock. During periods of positive biasing, electron attraction delivers a negative current to the probe. Negative biasing works in the reverse way, repelling electrons and attracting the positive ions. Monitoring of the applied biases and resulting currents during the ESPRIT launch provides the data required for determining plasma characteristics.

3.2. Plasma Frequency Probe

The Plasma Frequency Probe (PFP) developed at Penn State was also flown on the ESPRIT payload as a step in developing this technique (see the right-hand side of Fig. 2). Plasma density is obtained from the plasma resonance measurements of the PFP. The PFP instrument was positioned in the wake of the separated payload during up-leg and was pointed into the ram during down-leg. The PFP obtains plasma density by measuring the oscillations excited in the plasma surrounding the probe. The electric field of an RF signal is radiated into the plasma by the upper section of the probe using frequencies in the low MHz range. The lower band on the probe emitted the same signal to minimize discontinuities in the electric field. [6]

Reactance and resistive measurements of the probe's coupling with the plasma are used to determine the plasma frequency. It is found by scanning the RF until the load becomes purely resistive. At the moment when plasma frequency detection is achieved, the probes radiated frequency matches the upper hybrid frequency and the reactance goes to zero. Instrument data will allow calculations of the phase and gain as a function of frequency. For each frequency step, the return current from the probe is compared to the emitted voltage to find the resonance frequency. The instrument appears to have worked normally, however these results are not shown here, as the analysis is not yet completed and the vertical resolution of data from this developmental flight is rather low (~1 km).

3.3. X-ray Imager and Solid State Detector

An imaging X-ray detector was developed at the University of Bergen. The detector measures the production of bremsstrahlung X-ray radiation caused by energetic electron scattering from molecules present in the lower thermosphere and upper mesosphere. This interaction occurs as an energetic electron passes close to a molecule's nucleus, where it is deflected in the Coulomb field of that nucleus. During the scattering process the electron experiences deceleration, losing energy, which is radiated away as X-ray bremsstrahlung radiation. The radiation pattern and flux of the X-rays depend on the energy of the incoming electrons and the altitude distribution of the atmospheric gas [7].

The X-ray detector design has a one-dimensional array of four spectroscopy-grade cadmium–zinc–telluride (CdZnTe) detectors. This array creates a two-dimensional image of the X-ray sources in the upper atmosphere by making use of the payload's spin. The X-ray detector was mounted on the aft bulkhead with a field of view between 120 and 180 degrees with respect to the payload spin axis. Two solid-state detectors (SSD) were used to measure the spectrum of energetic electrons. They were mounted on the forward bulkhead (facing 85°, and 30° to spin axis) and provided local energetic electron measurements to correlate with the level of radiation measured by the X-ray detector. These results are discussed in Section 4.

3.4. NLC Photometer

An NLC Photometer (see Fig. 2, left side), was developed at Penn State to study the size and number density of mesospheric aerosol particles. The photometer design was based upon using the polarization ratio of the scattering phase function to measure size distribution and number density of optical scattering particles [8]. This is done by measuring the orthogonally polarized directional intensities of light scattered from the aerosols. Measurements of the angle of the scattering with respect to the sun, allows the size and number density of the NLCs particles to be determined [10, 11].

Ten separate channels, eight of which used narrow band filters at 340, 420 and 550 nm with polarizers made up the array of the photometer. The channels were paired, based on the filters and polarization angles relative to the payload axis.

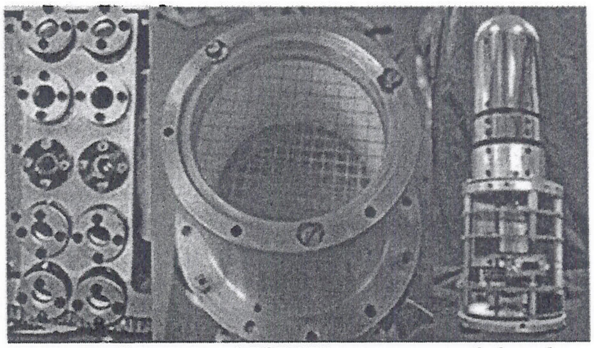

Figure 2. Selection of ESPRIT instruments (left-right): NLC photometer, Aerosol detector, PFP plasma probe.

3.5. Aerosol Detector

The Aerosol Detector is a bucket collector (see Fig. 2, middle section), which is covered at the top by a grid (G1) biased at +6.2 V, followed by another grid (G2) biased at -6.2 V located 20 mm above the bottom that is biased at +2.0 V. The inner diameter of the probe was 80 mm. The grid, G1, is made with a square profile. G2 has the same shape and intergrain distance. The currents from G1, G2 and the gold-plated bottom plate are all measured. The aerosol probe is a modified version of the original DUSTY probe [11], but the configuration of the grids has been altered to change the production of secondary charges from impacting dust particles.

The absolute values of the raw currents recorded during the flight in the NLC and PMSE regions are shown in Fig 3. The currents measured on G2 and the cup collector record the impact of NLC particles and PMSE particles. The G1 grid shows unplanned collection of ion current each second, when the payload potential is swung negative by the +10 volt sweep of the Langmuir probe combined with the +6.2 volt collection here.

4. DETECTION IN THE IONOSPHERE

The ionosphere was monitored during the launch by incoherent scatter radars along with a Mesosphere, Stratosphere, Troposphere MST Radar, magnetometers, an ionosonde, and Imaging Riometer to determine launch conditions that would satisfy the science mission. ESPRIT launched during relatively quiet conditions with local magnetic K values of 1 to 2,

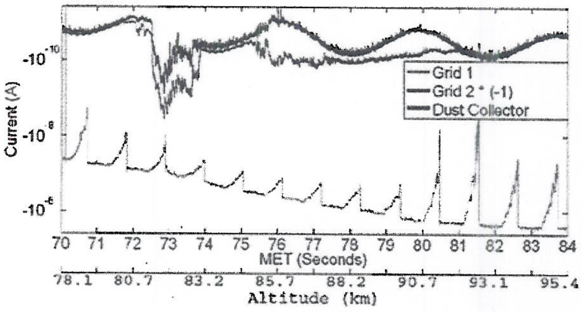

Figure 3. Data showing detection by the Aerosol Detector at altitudes corresponding to PMSE and NLC layers observed by radar and lidar [13].

and little activity (<0.5 dB) detected from the ALOMAR imaging Riometer. Low energy levels were also indicated by the SSD, shown in Fig. 4. Signal counts were well below levels desired for studying the development of bremsstrahlung radiation, and make analysis of the X-ray detector data difficult. Thus far, initial results shown in Fig. 4 indicate SSD response to the PMSE and sporadic-E layers, and response to low energy particle flux at altitudes above 150 km. The X-ray sensor appears to respond to signals below about 140 km from the low energy particle drizzle. Despite non-ideal conditions for the X-ray detector, launch conditions satisfied all other payload instrument requirements. In the D- and E-regions of the ionosphere, electron density levels were typical for quiet conditions at this location. The electron density profile is shown in Fig. 1 from EISCAT UHF and VHF radars and the ESPRIT rocket probe.

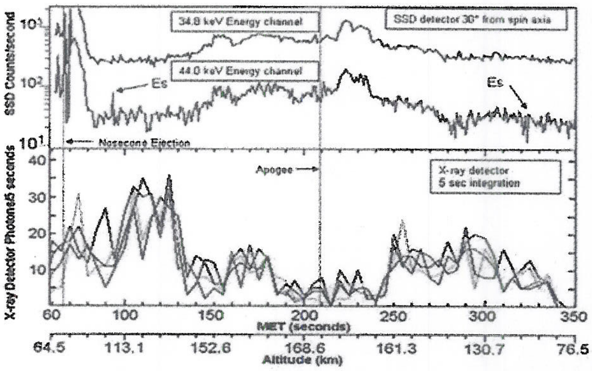

Figure 4. X-ray and Solid State detection for ESPRIT flight [7].

4.1. Sporadic-E Measurements

A thin sporadic-E (E_s) layer was measured by both ground based and *in situ* rocket instruments near 107 - 109 km altitude. The Es layer was present on both up-leg and down-leg portions of the ESPRIT rocket flight. The EISCAT UHF incoherent scatter radar (928.4 MHz), located outside of Tromsø, Norway (about 130 km east of Andøya), had its beam directed over the launch site. The UHF radar's orientation provided a useful comparison with the rocket *in situ* measurements; however the vertical resolution is reduced making it difficult to compare altitudes of the thin layer. The UHF radar measurements of electron density, for a 10-minute interval centered at the time of launch, are shown in Fig. 5. From about 106 - 109 km altitude, the presence of the Es layer is indicated, and its peak is 1.75 x 10^{11} m^{-3} at 107.4 km (see Fig. 1, 5, and 7). The EISCAT VHF (224 MHz) vertical profile also recorded the Es layer with integrated E-region peak electron density of 1.77 x 10^{11} m^{-3} at a higher altitude of 109.3 km. Fig. 5 shows the comparison of the sporadic-E layer detected by the rocket payload, UHF radar (looking toward the launch area), and the vertical VHF radar (130 km away).

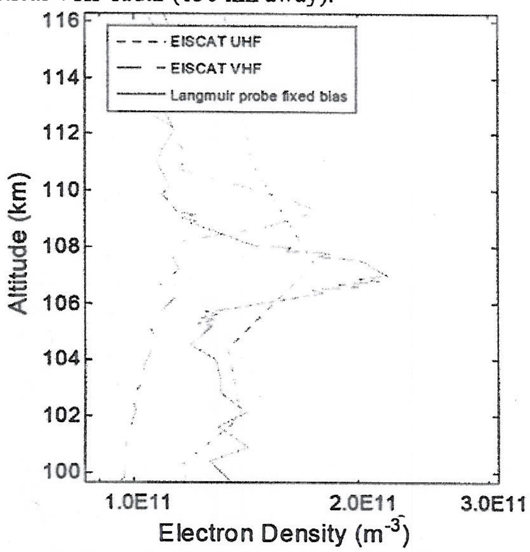

Figure 5. Sporadic-E layer measured by EISCAT VHF, UHF radar and ESPRIT Langmuir probe.

A Digisonde located near Tromsø, operated by the University of Tromsø Geophysics Observatory, provided additional local ground based measurements. Two plots, one nine minutes before the launch (6:30 UT) and six minutes into the launch (6:45 UT, down-leg portion) are shown in Fig. 6. The detected maximum frequency of the Es, f_oE_s (ordinary frequency), was 4.5 MHz at 0630. However, it is shown in Fig. 6 to extend over 5 MHz at UT 0645, indicating a dense Es-layer.

4.2. Charged Particle Detection

Several instruments were able to make measurements of the Es-layer during ESPRIT. The LP detected the layer at 107 km altitude with electron density of 2.35 x 10^{11} m^{-3}. Figs. 1 and 5 show that the peak of the E-layer from the up-leg of the LP compared with that of the EISCAT UHF and VHF integrated data. Even

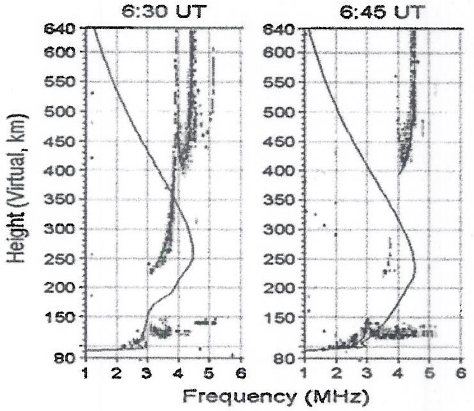

Figure 6. Tromsø Digisonde data from 6:30 and 6:45 UT, 1 July 2006.

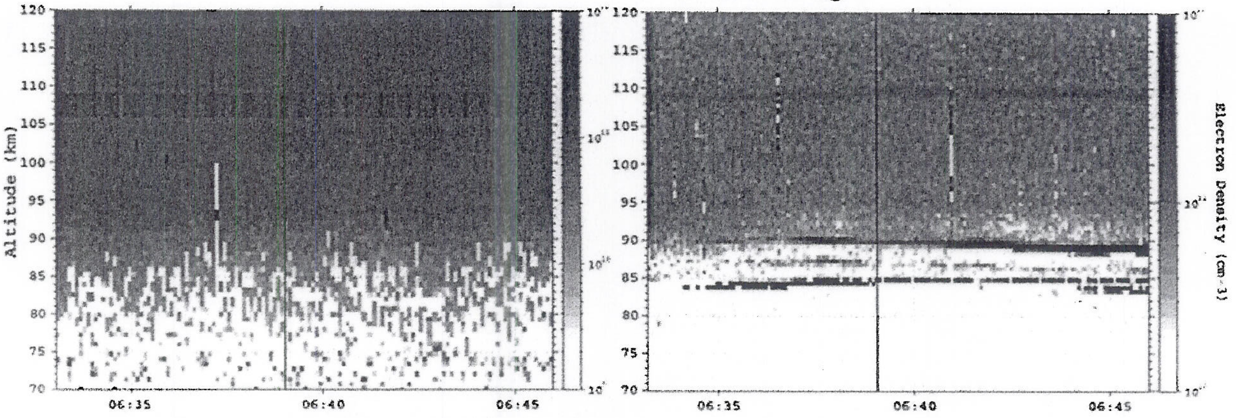

Figure 7. EISCAT UHF (left) and VHF (right) electron density profiles for 70 - 120 km altitude, 1 July 2006.

though, there are significant horizontal spatial separations between the different observations by radars, digital ionosonde, and the up-leg and down-leg portions of the flight; we find the sporadic-E layer present over a large area. Limited comparisons are made because of the spatial and temporal variation of Es layers. Wind data is unavailable at the time of this paper. Normally, the East-West winds from tidal and/or gravity wave propagation force the ions in the E-region into an Es-layer. These processes have been observed many times at high latitude [cf. 14].

The data from ground based radars provide valuable results for additional comparisons of charged particle layers. In Fig. 7 the EISCAT VHF profile from 80 - 90 km exhibits a structure corresponding to the PMSE layers detected by the ALWIN VHF radar, shown in Fig. 8. The density levels shown represent the added backscatter from the PMSE layers and are not due to electron density enhancements. The integrated peak values for the two detected layers occur at 84.2 km and 89.2 km and are shown at the corresponding altitudes in Figs. 1 and 7. The LP profile also shows (Fig. 1) the presence of the NLC layer at 84.5 km indicated by a drop in electron density due to the increase in electron loss from attachment collisions with ice particles.

5. DETECTION IN THE MESOSPHERE

5.1. NLC and PMSE Detection

The ESPRIT campaign observed high particle densities in the NLC/PMSE layers, which were detected by the ground-based ALWIN VHF (53.5 MHz), the ALOMAR RMR lidar, EISCAT VHF radar, the rocket-borne Aerosol Detector and NLC photometer instruments. The PMSE layers are observed in the VHF radar profiles from backscatter of large numbers of small charged particles. The ALWIN radar is typically used to observe PMSEs, which were detected at 82.5 – 84.4 km and 86.3 – 90.0 km altitude as shown in Fig.6.

The radar detected PMSE layers correspond to the Aerosol Detector profile, which indicates particle presence from 82 - 84 km and 85 - 88.2, see Figs. 3, 7, and 8. ALOMAR RMR lidar is used to observe the development of the NLC, which was located within the lower PMSE layer and lasted for several hours around the launch window. Fig. 9 shows the ALOMAR RMR lidar detection of the NLC layer between 81.8 and 84.0 km. The NLC began to intensify at the time of launch, and roughly one hour after launch the lidar detected a decrease in altitude and greatly increased brightness.

5.2 Particle Size Distribution

Fig. 9 shows the scattering intensity detected from the NLC. Preliminary results from the RMR lidar show particles of average radius of 46.0 ± 6.4 nm, distribution of 12.69 ± 2.06 nm and a number density of 84 ± 33 cm^{-3}. These measurements will be useful for comparison with the *in situ* measurements of the NLC photometer. This comparison is planned for future publications.

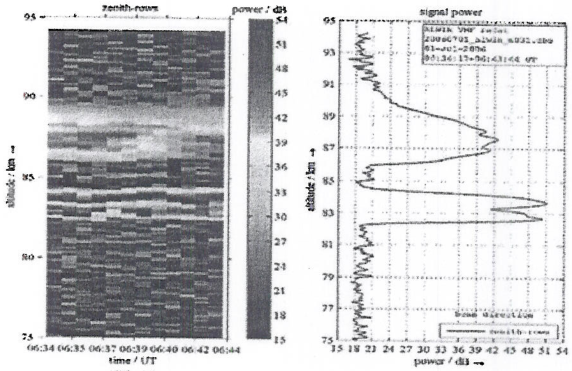

Figure 8. ALWIN VHF Radar Power Plot (left) and integrated averages (right) for 75-95 km altitude.

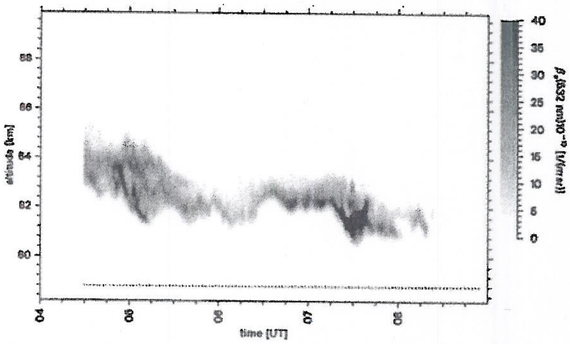

Figure 9. Brightness levels indicating NLC presence detected by ALOMAR RMR Lidar 4:00 - 9:00 UT, 1 July.

6. CONCLUSIONS AND SUMMARY

This paper discusses the background for the science mission of ESPRIT and introduces the key payload instruments which obtained *in situ* data on the polar ionosphere and mesosphere. We find that two PMSE layers (centered near 83.5 km and 88 km) and one NLC layer (~83 km) have been measured by several of the scientific instruments on the ESPRIT payload and by ground based instruments. In addition, the data from instruments measuring plasma properties of the ionosphere are shown to correspond well with radar measurements of the D- and E-region, including detection of a sporadic-E layer near 107 km. Similarities and differences between the *in situ* and ground based measurements were described. Further analysis of the Langmuir probe and NLC photometer measurements are discussed by Escobar et al. [15] and McKeever et al. [16] in these proceedings.

Overall, this paper has described our initial efforts to analyze the data sets from the various instruments and experiments connected with the ESPRIT launch. The characteristics of the plasma environment and mesospheric particle have been examined. Future analyses of the data are expected to yield additional results from the ESPRIT rocket payload - a payload that was designed and built entirely by students.

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