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COMBINED GROUND AND *IN-SITU* MEASUREMENTS NEEDED IN SOLAR-TERRESTRIAL RESEARCH

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Abstract: Although much progress has recently been made in our understanding of the terrestrial space environment, many questions remain. Our efforts have uncovered new questions that need to be addressed. In this paper I will mainly discuss why ground-based observations are needed in addition to *in-situ* measurements in the study of dayside magnetosphere-ionosphere coupling processes and boundary layer phenomena.

The mapping of boundary layers based on optical measurements will be compared by the statistical data of particle precipitation regions developed from satellite observations. Satellites can never acquire data which are not ambiguous in time and space. The resolution in space and time for important plasma processes are often not adequate. Thus, without coordinated ground-based observations *in-situ* measurements will be severely limited.

The future emphasis should be on the dynamic nature of magnetospheric processes and their ionospheric signatures. Three-dimensional maps of the space environment are needed. Because of the global extent of these phenomena, international cooperation's will be more and more important in years to come.

1. Introduction

The cornerstones in any realistic solar-terrestrial physics studies are: 1) the solar wind, 2) the magnetospheric generator, 3) the Earth's magnetic field structures, 4) interactions of energetic charged particles with electric and magnetic fields, and 5) the ionospheric signatures and their electrodynamics.

Today most of the solar-terrestrial research is carried out using rockets and satellites that enables measurements in regions of special interests. These in-situ data have resulted in an explosive growth of our knowledge and understanding of physical and chemical processes in the near Earth space (SISCOE *et al.*, 1991).

Ground-based observations of the upper atmosphere using cameras, photometers, spectrometers, magnetometers, radio-tools and sensitive devises have been reduced and often neglected in recent solar-terrestrial programs. This is very unfortunately, because satellite measurements can never acquire data which are not ambiguous in time and space. Furthermore, the satellite data seldom have adequate resolution for many important plasma processes. Thus continuous observations at different sites are needed. However, there are limitations inherent in the ground observations too. Therefore, combined ground-based and *in-situ* measurements are needed to solve the central problems in solar-terrestrial physics.

2. The Ionosphere and Magnetosphere Exploration

As these Proceedings include contributions from different scientific disciplines, a short background of our present picture of the upper atmosphere, the ionosphere and magnetosphere will be given.

The electrically conducting region between altitudes of about 100 and 500 km is called the ionosphere. The most spectacular of all naturally occurring heavenly phenomena -the aurora- occurs in this high region. Today we know that the causes of aurora are more complicated than Kr. BIRKELAND'S (1913) original theory from the end of the last century (ALFVÉN and EGELAND, 1987).

The region outside the ionosphere, linked to the Earth by the Earth's magnetic field, is called the magnetosphere. Rockets and satellites provided the best tools for exploring the magnetosphere.

The trapped radiation belts were discovered more than 30 years ago. About the same time both American and Soviet space probes clearly identified the solar wind and its entrained magnetic field, and clearly demonstrated its controlling role in producing aurora and geomagnetic activities.

An important next step was the mapping of the boundary -the magnetopause- between the flowing solar wind and the Earths magnetic field. Figures 1 and 2 illustrate the significant change in our picture of the near Earth space -the magnetosphere- from the pre- to the post-space age.

Many different diagrams of the magnetosphere and its different regions have been published during the last 20 years. Figure 2 is derived from several earlier schematic diagrams (SISCOE *et al.*, 1991). The various regions depicted in this figure have almost exclusively been identified from characteristics of hot plasma measurements on low- and

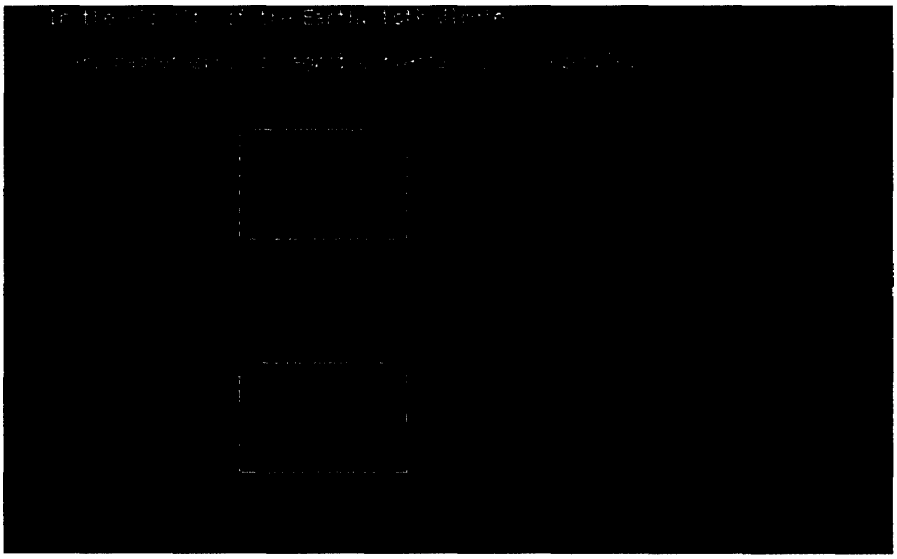

Fig. 1. This figure of the Earth's magnetic field -in a plane- clearly demonstrate the significant change in topology of the near Earth Space -the magnetosphere- from before and after the space age. Notice the solar wind coming in from the left - drastically change the form of the geomagnetic field.

medium-altitude satellites and geomagnetic field models.

The most comprehensive statistical summary of magnetospheric particle characteristics has been conducted by NEWELL and MENG (1992) and the results are shown in Fig. 3. It is based on several thousands DMSP particle observations. Figures 2 and 3 are very frequently quoted in recent papers.

The boundaries in Fig. 3 have a latitude accuracy of less than ±50 km. Using ground measurements, the latitude of any regions can be determined ten times or more accurate.

As one purpose of this paper is to test and compare ground observations *versus* satellite recordings, the characteristics of the map in Fig. 3 will be further explained. LLBL is short for the low-latitude boundary layer. The other boundary layers are

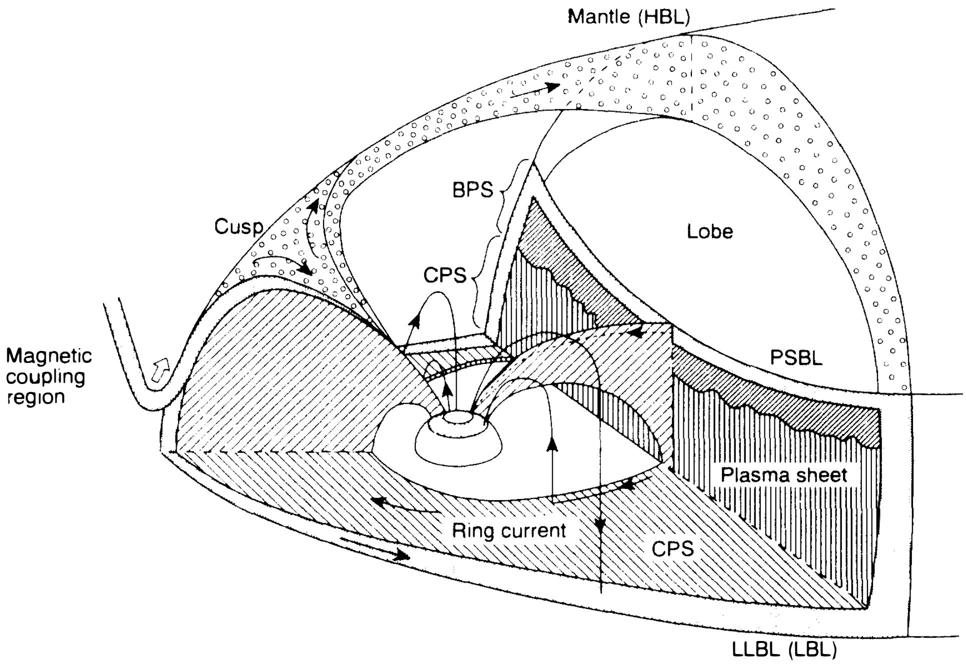

Fig. 2. This three dimensional diagram of the magnetosphere and its different plasma regions is based on many earlier pictures and the most comprehensive in-situ measurements. The various regions depicted are mainly based on in-situ plasma measurements (SISCOE, 1991). Notice specially the following regions LLBL, Cusp, Mantle, BPS and Lobe which will be further discussed in the text.

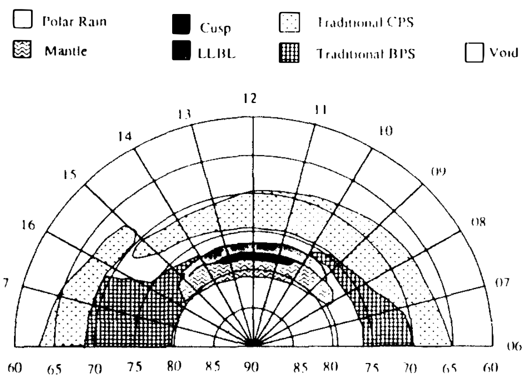

Fig. 3. The statistical particle precipitation regions developed from the polar satellites DMSP by NEWELL and MENG (1992). Notice the different hatches for the mantle, the cusp, the low-latitude boundary (LLBL), the boundary plasma sheet (BPS), and the central plasma sheet region (PS) between ≫ 68° and 82° MLAT in the 09–15 MLT sector.

defined in the label. We will limit ourselves to 09 to 15 magnetic local time (MLT) sector. The ionospheric projection of the LLBL -sometimes called the cleft- can comprise one half of the auroral ring, with the plasma-sheet projection filling in the rest.

Notice that the LLBL projection joins smoothly with the traditional boundary plasma sheet (BPS). The cusp is continuous with the LLBL on the poleward edge and extends for about 3 hours in local time centered around magnetic noon. The mantle fills in a position of the polar region above the cusp and LLBL. The projection of the central plasma sheet (CPS) extends around at all local times equatorward of the regions mentioned above. The ring of Region 1 Birkeland currents coinside with the projection of the LLBL (the cleft), cusp, and a portion of the BPS. For further details, *cf.* NEWELL and MENG (1992) and POTEMRA (1994).

The main drawbacks with the cartoon shown in Fig. 3 is that it does not distinguish between intensities and directions of the interplanetary magnetic field (IMF), and even between south- and northward IMF. There is no separation between open and closed geomagnetic field times. Spatial and temporal variations are neglected. Thus, all fine structures and dynamics in the boundary layers have been averaged out.

3. The Need for Comprehensive Ground Observations in Order to Understand the Physics of the Dayside Boundary Layers and *their Ionospheric Signatures*

3.1. Background

During the last decades we have seen an enormous amount of qualitatively new data. Many of the questions connected with this complex solar-terrestrial phenomenon have been solved partly and/or fully, but new problems have risen. Still several of the old fundamental questions remain unanswered. Thus, there is a clear need for further quantifying research in years to come (AKASOFU, 1992; HOLTET and EGELAND, 1994; SANDHOLT *et al.*, 1990).

Because the aurora is an unambiguous signature of particle precipitation and it is the most spectacular of all naturally occurring heavenly phenomena, the discussion will be limited to dayside aurora; *i.e.* between $\approx$09 and 15 MLT (SANDHOLT *et al.*, 1990).

As these phenomena and their mapping are complex, the following will naturally reflect my personal point of view.

3.2. Why ground observations

The great advantages with continuous, ground auroral observations are that one can get temporal resolutions better than one second and spatial resolution £ 1 km. Furthermore, discrimination between spatial and temporal variations is not a problem. In addition, we can distinguish between processes which are stable, quasi-stable or pulsed.

From triangulation's, we can get auroral heights, while relative changes in the spectral ratios contain information or the particle spectra. The heights decrease as the auroras change from blood-red to yellow-green and to magenta.

From accurate calibrated auroral measurements, the total net downward particle energy flux can be estimated.

From a well planned net of stations one can get reliable two-dimensional information of auroral structure -both large and small scales- intensities, direction of movements and speeds. It is important to know if the auroral structures move parallel or perpendicular to a specific plasma population, and their relationship with local ionospheric convection. Such networks should be extended for more detailed studies of polar cap and dayside auroras.

Another advantage of using ionospheric signatures as compared to any conceivable septum of *in-situ* measurements is the scale factor. The auroral oval differs in scale with the magnetosphere by perhaps as much as 10^6.

The size and shape of the auroral form reflect all forces acting on the auroral particles. By studying the occurrence of aurora in space and time, it is possible to describe the origin of the auroral particles and the forces acting upon them.

The temporal and/or spatial variations of individual auroral forms are important. The energy of the auroral primaries is reflected in the emission spectrum due to various production and loss mechanisms associated with electron impact on the atmospheric constituents. Only by continuous observations at nets of ground stations is it possible to follow the electrodynamics of individual events, even in global terms.

By careful studies of the auroral spectrum it is also possible to discriminate between electron and proton precipitation.

3.3. Ionospheric signatures of the boundary layers

Complementary, multi-point and multi-instrument ground-based measurements should always be included. Table 1 lists different observation techniques and the corresponding physical parameters observed.

The auroral occurrence is directly related to the particle precipitation and auroral intensity should be proportional to the net downward energy flux (EGELAND *et al.*, 1992). As pointed out by SERGEEV (1990) and SANDHOLT *et al.* (1993) aurora is perhaps the most unambiguous ionospheric signature of the open/closed field lines separatrix in the dayside magnetosphere. Another important factor is the dynamics of

Table 1. Observation technique - physical parameter.

Observation techniques	Physical parameters
Meridian scanning photometry All-sky TV cameras Spectrometers	Optical aurora
Interferometer	Neutral winds/compositions
Magnetometer networks	Earth magnetic fields and its variations
RADARS (EISCAT, CUTLASS, etc.)	Ionospheric densities Ionospheric ion drift Ionospheric temperature
Passive radio receivers (Riometers, ELF/VLF receivers, etc.)	Absorptions Wave/particle interactions

dayside aurora in relation to both IMF B_Z and B_Y (SANDHOLT *et al.*, 1994; SANDHOLT, 1998).

The dayside auroral occurrence will be discussed in relation to the boundary layers as mapped by DMSP satellites; *cf.* Fig. 3. Mainly meridian scanning photometer data (MSP) at 630.0 and 557.7 nm of auroral luminosity recorded at Ny-Ålesund, Svalbard (75.4° MLAT) will be shown. However, the conclusions drawn are based on simultaneous all-sky camera observations at different wavelengths as well as integrated light from 390 to 650 nm. Identical observations have been made at Danmarkshavn, East Greenland at approximatey the same magnetic latitude, but separated roughly 2 hours in magnetic time. (For an overview of the different stations in the Dayside Cusp program at Svalbard as well as the instrumentation at the various stations including Danmarkshavn, *cf.* EGELAND, 1994).

The red line emission at [01] 630 nm dominate the dayside aurora during quiet conditions. The intensity ratio between the red and the green line is typical larger than two and often >10, while at night, in the auroral oval this ratio is 0.1. Because the lifetime of this excited oxygen atom is long (100 s or more), quiet dayside aurora appears to be diffuse in form and often spread over wide areas. Its average height is 2.5 times higher than typical for nightside aurora. Thus, the particles responsible for aurora during daytime have a relatively low energy.

However, dramatic changes often occur in the dayside aurora, as illustrated in Fig. 4 recorded at 630 nm in the prenoon period. The line-of-sight intensity is plotted *vs.* zenith angles (0 to 180 degrees) and time. Up to ~0510 UT small scale auroral structures over the main part of the sky move poleward with a speed of more than 1 km/s. After 0515 UT we record a narrow, persistent arc on the equatorward side. By one or even several satellites crossing the sky once every 90 min it is not possible to obtain a realistic picture of such an event as shown in the figure.

Figure 5 shows the auroral situation over the northern hemisphere during the SCIFER rocket launch over Svalbard, in January 1996 (DEEHR, priv. commun.). The regions of both diffuse and discrete auroras have been plotted together with stable and unstable trapping boundary. Furthermore, the regions of pulsating aurora as well as proton rich auroras are illustrated. For such a detailed mapping continuous ground measurements are needed.

We will now show three more examples of boundary layer mapping based on ground observations. The conclusion is that during disturbed conditions, dayside aurora is a very dynamical phenomenon.

Example 1

Auroral observations obtained by MSP at Ny-Ålesund on 23 January 1985 at wavelengths 630.0 and 557.7 nm as function of zenith angle are shown in Fig. 6. The start time of each scan in UT is given. MLT is approximately three hours ahead of UT. Thus, this event is recorded roughly 1 hr before magnetic noon. Intensity scales are given in the upper left corner. By assuming an altitude of 250 km -which is reasonable for this event- zenith angles are converted to magnetic latitudes in the bottom scale.

The region south of zenith is characterize by I(630 nm)$\gg$I (557.7 nm); *i.e.* the red line is much more intense than the green line. The cusp region -located to the south of 75° MLAT- cover a broad region of $\approx$400 km.

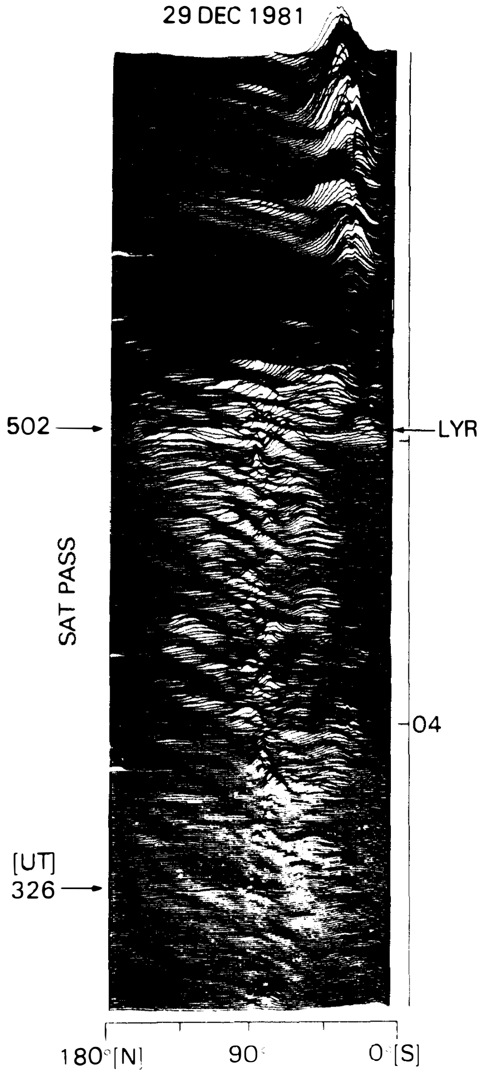

Fig. 4. North-south meridian photometer scans at Svalbard - at 630.0 nm wavelength. The line-of-sight intensity is plotted vs. time (UT) and zenith angle. This event clearly illustrates that both small and large scale structures and dynamics are characteristics for dayside aurora during disturbed events.

The spectral composition for the mantle region north of the cusp - is quite different from the cusp because often intense, short lived 557.7 nm auroras occur (*cf.* Fig. 6). Notice that in this case the mantle region is narrow in latitude. During this event IMF $B_Z > 0$. The average electron energy (E_{av}) recorded by DMSP F 7 just overhead the cusp (73-75° MLAT) was ≈ 100 eV, while over the mantle arc, near 76° MLAT, $E_{av} \approx$ 1 keV. This explain the optical signatures in Fig. 6. Near the southern horizon, *i.e.* 70-72° MLAT—1-10 keV electrons were observed, indicating precipitation from the BPS region (*cf.* Fig. 6).

Example 2

Figure 7 shows MSP records (line-of-sight intensities) -between 1140 and 12 MLT- of emission profiles plotted *vs.* time and zenith angle. A persistent cusp aurora -marked by the straight line in the left panel- is observed. Notice that between 0810 and 0813 UT, only the cusp region [*i.e.* I (630 nm)$\gg$I (557.7 nm] is observed, and that the equatorward border of the cusp -near 72° MLAT- is stable. Thus, in the time period 0810 to 0812.30 UT, the particle precipitation only cover a very narrow region in latitude. Both regular and irregular transient auroral forms occur frequently. For

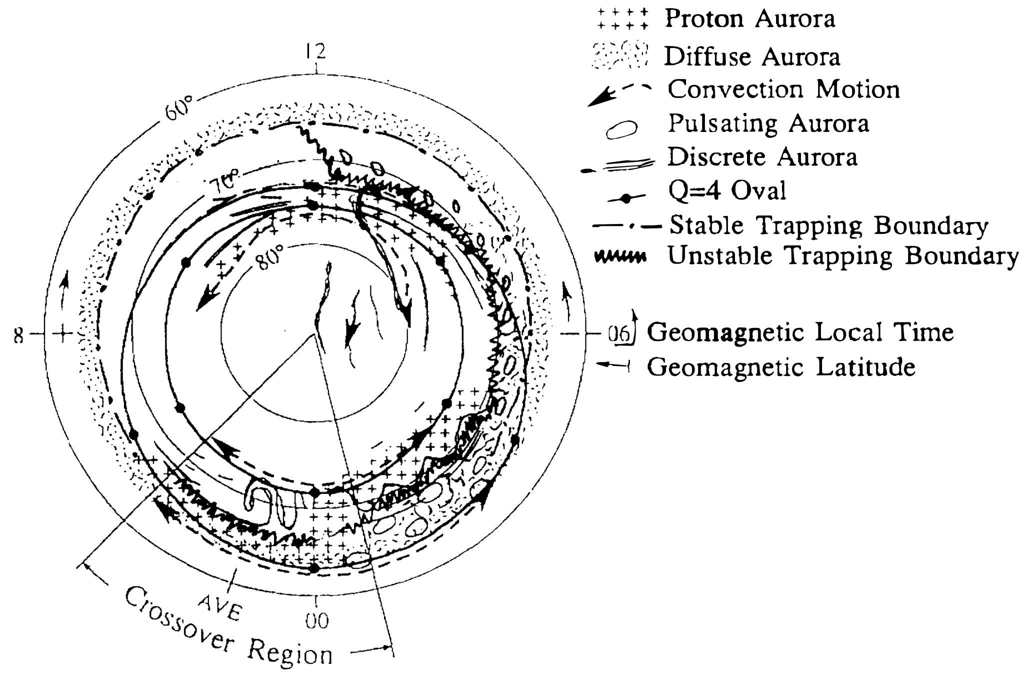

Fig. 5. This map of the northern hemisphere - in magnetic time and latitude - is based on extensive ground and rocket observations during the SCIFER rocket launch. The locations, widths and large scale changes are indicated. Such a detailed map could never be obtained without a net of advanced ground measurements.

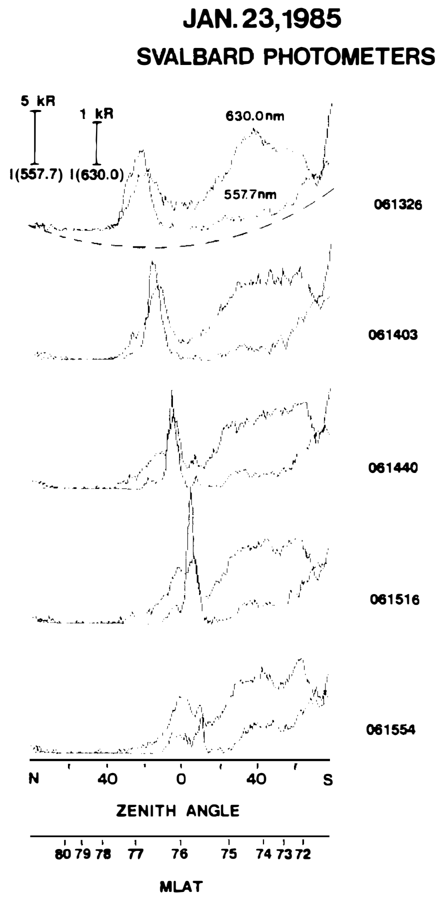

Fig. 6. North-south meridian photometer scans at Ny-Ålesund, Svalbard (75.4° MLAT) at wavelengths 630.0 and 557.7 nm plotted as function of time (UT) and zenith angle. Intensity scales are given in the upper left corner. MLT is approximately three hours ahead of UT. Thus, the recordings shown are close to 0920 MLT. By assuming an altitude of 250 km the zenith angles are converted to MLAT in the lowest scale. During this event, both the cusp and the mantle regions are observed.

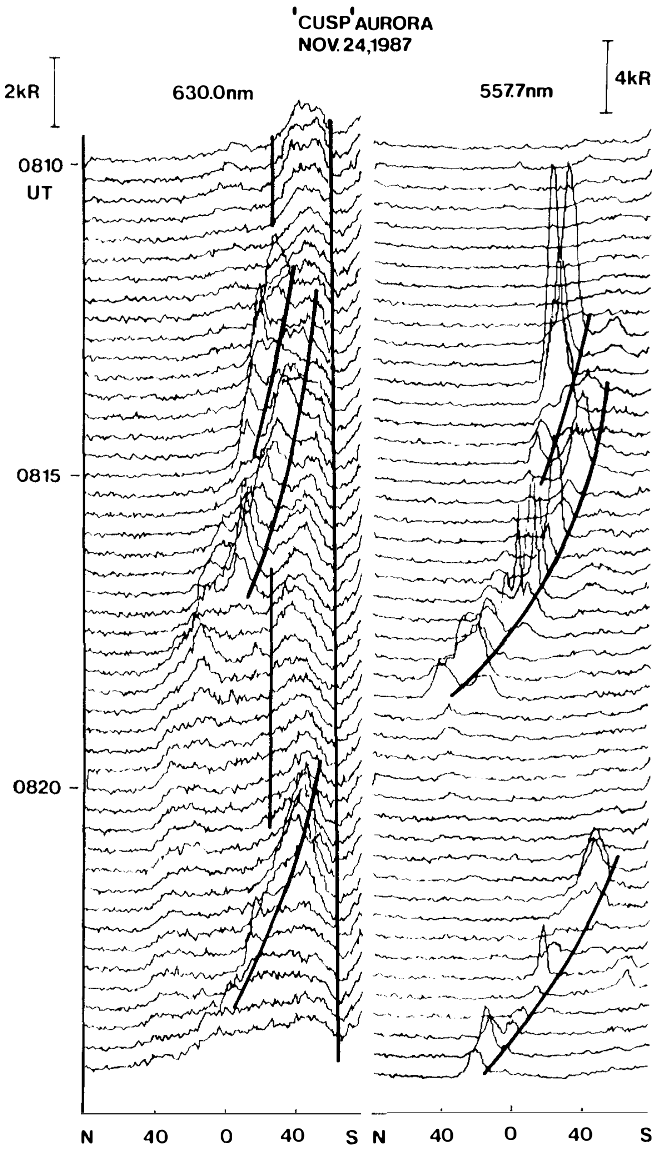

Fig. 7. Meridian scanning photometer records of auroral emission profiles (line-of-sight intensity) plotted in the same way as in Fig. 6. A persistent cup aurora [i.e. I (630 nm)≫I (557.7 nm)] marked by a straight vertical line in the left panel - is observed between 0810 and 082.30 UT and from 0818 to 0821 UT. During the first period, we only observed one boundary layer. From about 0815 UT mantle aurora -poleward of the cusp- is also clearly seen.

further details of such auroral structures, *cf.* SANDHOLT *et al.* (1993). From 0816 UT to the end of the record shown, we notice again the mantle zone just poleward of zenith. However, in this case, the green line intensity is weaker.

Example 3

During the MSP event from 22 November 1995, several intensity maxima at different zenith angles were observed in the interval from 70 to 80 MLAT. The different forms have been given labels A, B, C, and D in Fig. 8.

The southernmost emission (D) is a diffuse aurora covering a relatively large range of zenith angles. In this aurora the green line emission is significantly stronger than the red line, in contrast to the aurora in the north. The latter consists of multiple rayed bands (A-B-C) aligned in the east-west-direction. Form B is characterized by a very high red to green line intensity ratio. The green line is almost absent in this form, which appeared as a prominent feature around 0700 UT (10 MLT) and perished until the end of the observation period at 1000 UT (13 MLT).

An enhancement of the green line is seen in the northernmost aurora (form A)

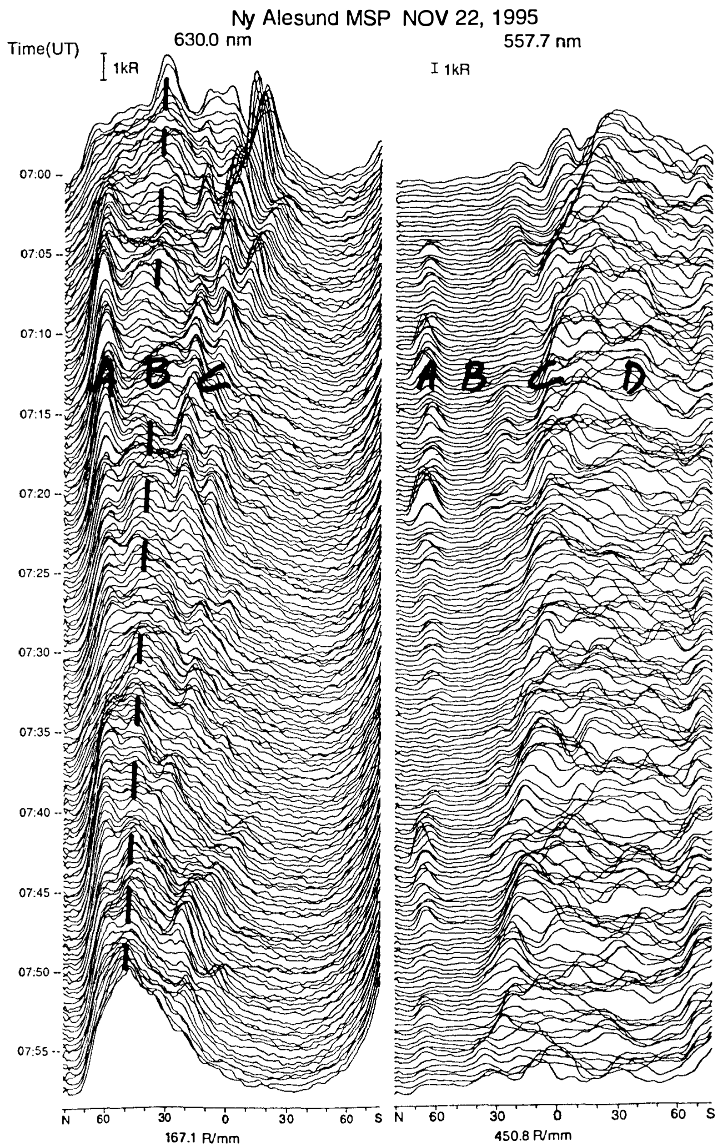

Fig. 8. Meridian scanning photometer records of auroral emissions from 22 November 1995 are plotted as in Figs. 6 and 7.
During this event several intensity maxima -labeled A, B, C and D- are observed. The different forms represents signatures of the different layers presented in Fig. 3. Notice the variations in first structure and dynamics. For further details, see the text.

during the interval 0700–0800 UT (10–11 MLT). The poleward boundary of the diffuse aurora in the south as well as form B (marked by dashed line) was moving poleward in this interval. The diffuse aurora disappeared from the Ny-Ålesund meridian at 0800 UT. More short-lived auroral events located at the equatorward boundary of the persistent red aurora, called form C, were observed in the period 0820–0840 UT.

It is possible to identify the ionospheric signatures of the layers presented in Fig. 3. However, notice that there are large variations both in widths and locations. This event was obtained during northward IMF conditions, but with large variations in IMF B_Y.

4. Summary and Conclusions Regarding

4.1. Coordinated observations

Periodic and quasi-periodic bright forms as well as a high degree of spatial variations in the ionospheric signatures of the boundary layers are observed. Thus, the latitude widths can vary from less than 50 km to more than 500 km. Due to the variations in occurrence, one often get the feelings that LLBL, Cusp, Mantle regions represent different stages of evolution or different time-dependent coupling processes at the magnetopause boundary. The low altitude satellite characteristics observed may reflects different processes between the magnetopause and the ionosphere. Some of the main findings and conclusions can be summarized as follow:

1) Even though much progress have been made during the last decades and we have begun to understand the generator process that powers the high latitude ionospheric activity, many fundamental problems remain unsolved. Thus, more information is needed to answer the question "What causes the ionospheric disturbances?". This knowledge is also essential in our studies of similar phenomena on the other planets.

2) The need for continuous, ground-based measurements at high latitudes has been documented.

3) A few, well-planned net of stations in the oval and polar cap regions to obtain reliable two-dimensional structures, intensities, direction of movements and speeds of ionospheric signatures should have high priority.

4) Measurements of the cusp and related phenomena in both the northern and southern hemispheres are important because they can provide information on hemispheric asymmetries or similarities, as the case may be. For example, the orientation of the interplanetary magnetic field as it sweeps past Earth may lead to hemispheric asymmetries in the boundary between open and closed field lines. Coordinated measurements between hemispheres thus, offer the possibility of investigating these various influences.

5) For further studies of boundary layers a consistent reference system should be defined.

6) Improved magnetic field models that accurately map the outer magnetosphere, particularly the boundary layers, and a new classification scheme should be worked out.

7) New instrumental developments as well as theoretical works are needed.

It should be possible based on ground-based, measurements -including pulsating auroras, proton rich auroras, discrete and diffuse auroras- to accurate locate the separatrix between open and closed geomagnetic field lines, as well as the cross-over from one boundary layer to the next.

Future progress in solar-terrestrial physics requires, more than before, thoughtful international cooperation and coordination of our research work. A general understanding of this medium will be important for studies of planetary atmospheres and the whole Universe.

The present instrumentation will be expanded in the next years. The EISCAT Svalbard Radar extends the range of incoherent scatter observations into the polar cap. New, more sensitive TV cameras will be placed at key locations.

With ISTP missions like GEOTAIL, Polar and Interball in place, ground-based observations from high-latitude stations will be more and more important for monitoring the evolution of magnetospheric processes and place spaceborne observations in a global context.

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