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Report on the Scientific Activities under the 'Optical Aeronomy' Programme carried out during the XIV Scientific Expedition (summer component)

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Objective of the Programme

To conduct an exploratory study of—(1) monitoring the auroral emissions during sunlit conditions from Maitri, which is classified as a subauroral station; (2) studying the spatial variations of the different auroral emissions excited by high energy and low energy electrons and protons by scanning the region of emission; and (3) establishing the relative contributions under varying geophysical conditions, with a view to eventually study the fundamental auroral processes during daytime conditions from the solar terrestrial physics point of view.

Introduction

The above exploratory study is the first of its kind in the world and has been successfully carried out using a unique, indigenously built multiwavelength daytime photometer. The development of an instrument of this type itself is a technological breakthrough and the details were provided during the XIII expedition report.

Interesting results indicating significant particle precipitation activities in a narrow latitudinal region over and around Maitri were discovered and it was conjuetured that as the field lines passing through Maitri, when get mapped to the equatorial plane cut across the plasma pause region, these measurements indirectly give us clues to the complex processes that occur in the boundary between the plasmasphere and magnetosphere.

The strategies for the XIV expedition were worked out based on the initial results and it was decided to include northward looking scans to separate out the regions of enhanced activity. Only five full days of clear sky conditions prevailed during the total period of 2 months and even then only on one day northward scans were possible.

Very interesting results revealed that the actual region of auroral activity lies around 57-59° invariant latitude which is ~ 3°- 5° north of Maitri. The activities noticed during the XIII expedition were corresponding to only one wing of the precipitation pattern. The region of deposition extended to >4° in latitude. Incidentally the field lines get mapped exactly to the plasmapause region at the times of enhanced activity. There must be certain acceleration mechanism which manifests itself as enhanced particle precipitation and the eventual auroral emissions, A brief account of the results from the XIV expedition with due comparison with the XIII expedition is provided as under:

Mode of Operation

The results obtained for the months of January-February 1994 and 1995 are presented here. The emissions at which observations were made are OI 557.7 nm, N^+_2**lNG** band emission at 391.4,427.8 and 470,9 nm and Hβ 486.1 nm. OI 557.7 nm emissions ($O(^1s)$ state) requires 4.17 eV of energy if excited from $O(^3P)$ state or 9.29 eV if excited from $O_2(X^3 \Sigma g)$ (dissociation energy for O_2 being 5.12 eV) while on the other hand, N^+_2lNG state ($B^2\Sigma^+_g$) requires 18.7 eV if excited from $N_2(X^1 \Sigma g)$. The excitation in auroral region is mostly by the incident energetic particles, in this case the solar wind electrons and protons. Hence, we treat the $O(^1S)$ emission as low-energy electron induced and N^+_2lNG emissions as (relatively) high-energy electron induced ones. Maitri (70°45'S; 11° 38'E) is generally considered to be a sub-auroral station. However the region is sunlit for most part of the day with Sun reaching a maximum angle of elevation of ~ 45° during the months of December and January.

Observations were carried out in meridional scanning mode covering a region towards south of Maitri (62.8° I- geomag. lat.) during the XIII expedition. The mirror elevation angle was changed in a programmed manner, starting from sky elevation angle of 10 to 50 degrees in steps of 10 degrees and later the photometer was pointed towards zenith. Data were collected from all the three filters at a given elevation angle within a duration of half a minute. With a knowledge of the altitude of these emissions and also the coordinates of the station, these elevation angles were translated into magnetic latitudes. Round-the-clock observations have been made for more than eleven clear cloudless days in 1994 and live days in 1995 during a onc-and-a-half month campaign each. The results are presented below:

Low-energy Electron Induced Emission

$O(^1S)$ 557.7 urn emission is known to be one of the strongest features of the nighttime aurora (Chamberlain, 1961). In the high-latitude region dissociative recombination of O^+_2 with electrons is treated to be the mechanism of production of $O(^1S)$.

$$O^+_2\ (X^2\pi g) + e \rightarrow O(^1S) + \qquad O(^3P) \qquad ...(1)$$

It is known that this emission originates at an altitude of ~ 100 km (Berg *et al.,* 1956). For this height the maximum latitude range that can be covered for 10° elevation angle turns out to be 5.15°. Hence, these observations correspond from 62.8°S to 67.95°S I-geomagnetic latitude. Figure la shows these emission intensities after taking into account the excess contribution due to Van Rhijn advantage for various elevation angles other than zenith. The x-axis shows the time in UT (LT = UT + 40 min.), y-axis shows the geomagnetic latitude and z-axis shows the intensity in photon counts. For this location, UT leads Magnetic Local Time (MLT) by ~ 2 hrs. One can notice very large variabilities in intensities with respect to time on a given day as well as on different days with different geophysical conditions. One of the most prominent features which is seen on all days is the peak 'pillar- like' structure standing above the weak intensities of other locations at all other times. This rise is seen between 63°-66° geomag. latitude close to zenith. Another interesting feature that can be noticed is the rise in intensity at 0400 UT on 1 February 1994 at all latitudes unlike the noon peak which is confined to only a few degrees.

This enhancement at 4 UT seems to move towards mid-day and merges with the central peak as can be seen by 6 and 9 February data (Fig. lb). The overall intensities do not seem to show any significant variation with magnetic activity (e.g. 9 and 18 February). But, the width (in time) of the central pillar near its base is larger on 6 February ($\Sigma K_p = 43^+$) when compared with other days. The 18 February data shows a very narrow width ($\Sigma K_p = 13^-$). The observations on 29 January and 2 February 1995 do not show such strong enhancements. Fourth February measurements, on the other hand show enhancements in intensities at 0600 UT in all the latitudes while 31 January reveals a large oscillatory feature.

High-energy Electron Induced Emissions

As mentioned earlier, $N^+_2$1NG band emissions at 391.4,427.8 and 470.9 nm are considered to have been induced by high energy electrons. The average height for these emissions has been taken to be at 150 km and hence the spatial extent covered is ~7.3° in latitude from 62.8° to 70.1 °S geomag. latitude.

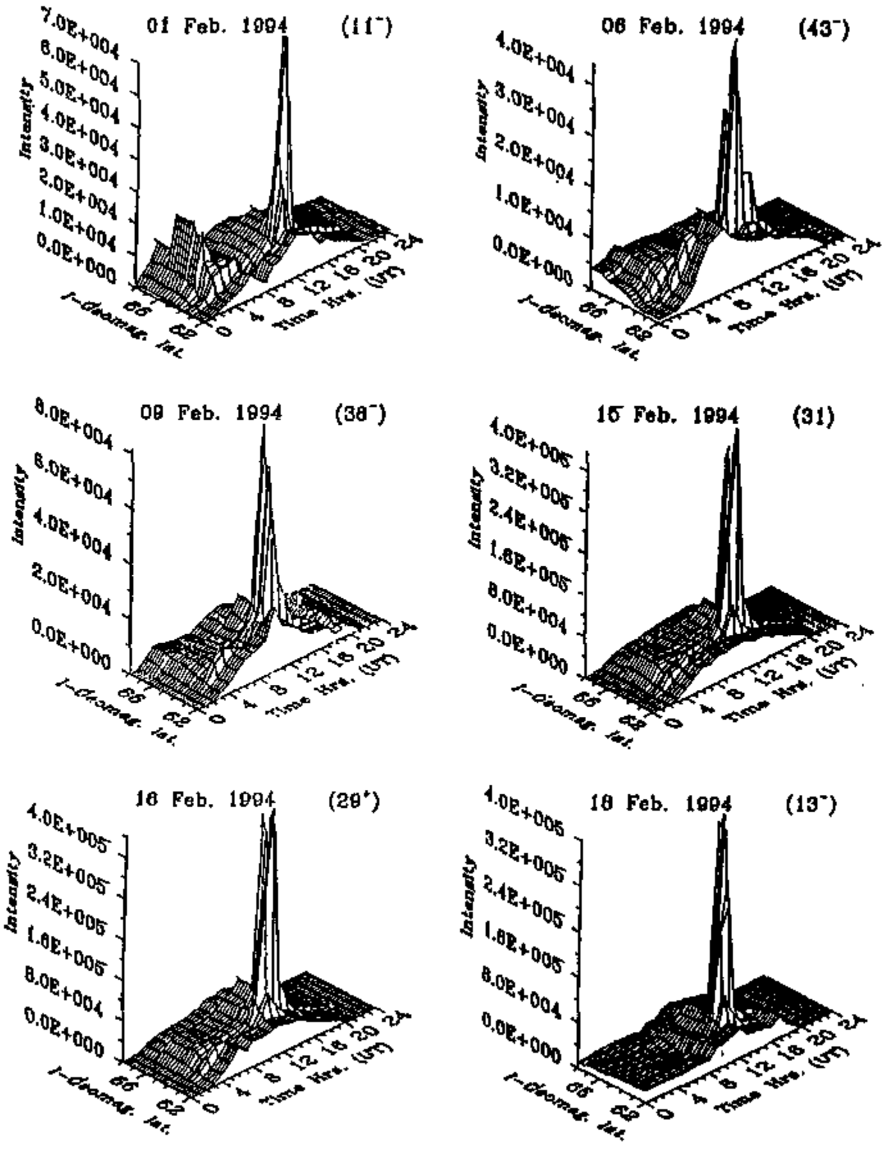


Fig. 1a: Surface plots of 5577 Å emission intensities as observed from Maitri during February 1994. The X, Y and Z axis represent the universal time. I—geomagnetic latitude and the relative intensities in photon counts respectively.

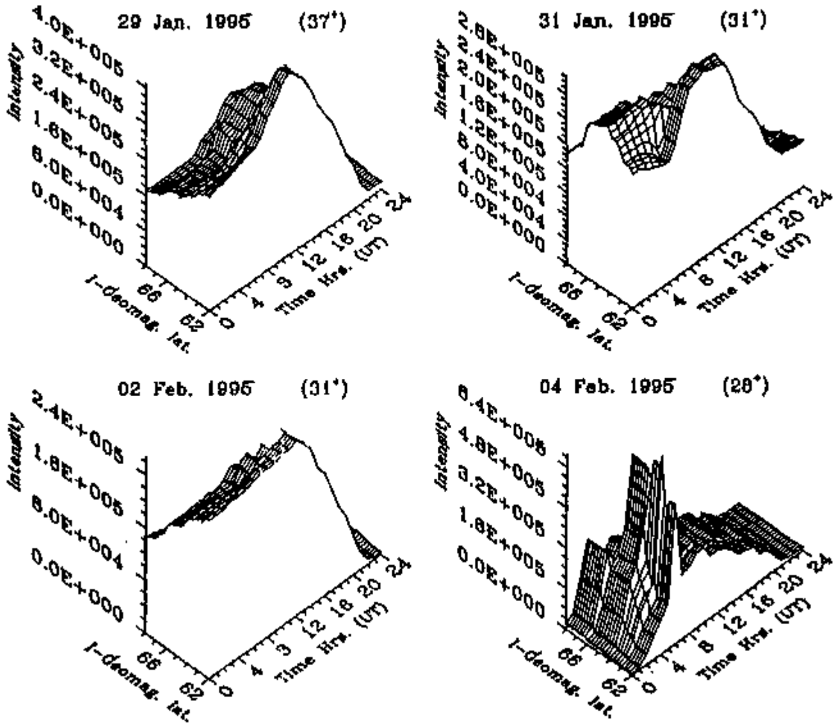


Fig.1b: Same as fig. 1a but representing 1995 January/February. The absence of the prominent noontime peak during 1995 in the south pointing scans to be noted.

(a) 391.4 nm emission:

Figures 2 a,b show the intensities of 391.4 nm emission for different days. Except for 1 February 1994 and 2 February 1995, each and every day is different in its own way. The above mentioned days show nearly identical behaviour with a noontime maximum over zenith (62.8°S geomag. lat.) 2 February 1994 shows a double-humped structure over zenith intensity indicating the propagation of large-scale wave-like disturbances. 11 February too shows a double-hump sort of intensity pattern with early morning intensities rising to quite a large value. 4 February 1995 data shows overall similarity with 2 February 1995 in peak intensities, but there is a steep increase in the intensity of the former by 0600 UT from zenith to at least upto 67°S geomag. latitude.

(b) 427.8 nm emission:

Figure 3 shows five days of intensity of 427.8 nm emission. Each of the 3-D plots for this emission shows variations in the shapes of the noontime peaks.

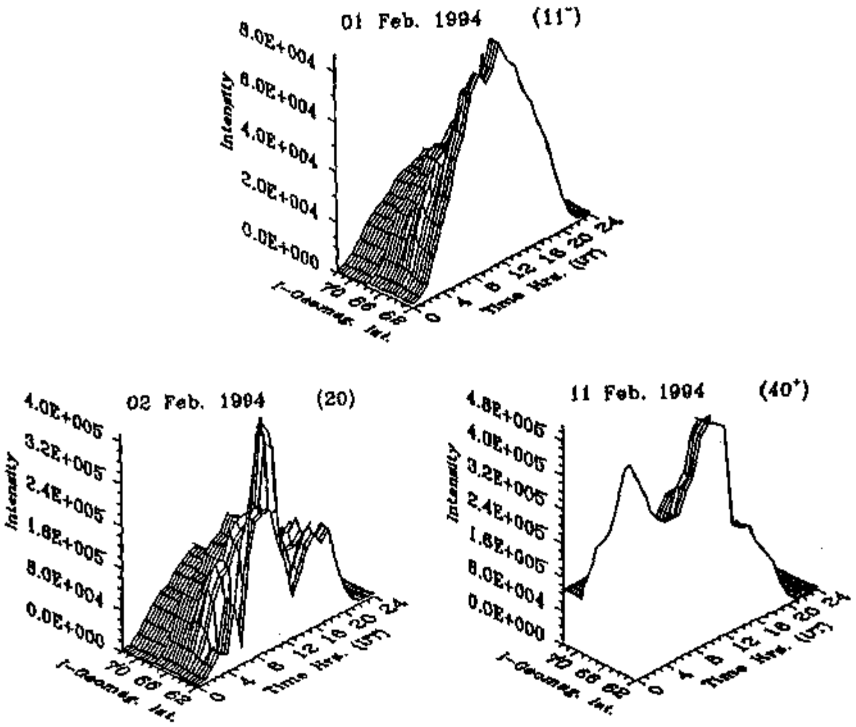


Fig.2a: Surface plots for 3914 Å emission depicting the large day-to-day variability and oscillatory features during February 1994.

While 2 February data shows a broad-peak, the data for 1, 10 and 11 February show a 'thorn-like' sharp peak. 31 January shows broad enhancement in intensities around noontime.

(c) 470.9 nm emission:

Similar to the variations in the above mentioned emission intensities, this N^{+}_{2} emission too shows large day-to-day variability. The variations of these intensities for six days are shown in Fig. 4. These emissions show different shapes in their overall intensities as well as the noontime peaks. Sixth February shows a symmetric 'dome-shaped' intensity distribution with respect to the broad noontime peak at the center. The data of 9,11 and 18 February and 15 and 16 February show asymmetries in opposite sense, viz., the former set shows enhancements in intensity in the afternoon with weak intensities in prenoon hours, while those of the latter show enhancement in the prenoon and a decrease in afternoon hours. The central peaks too show large variabilities.

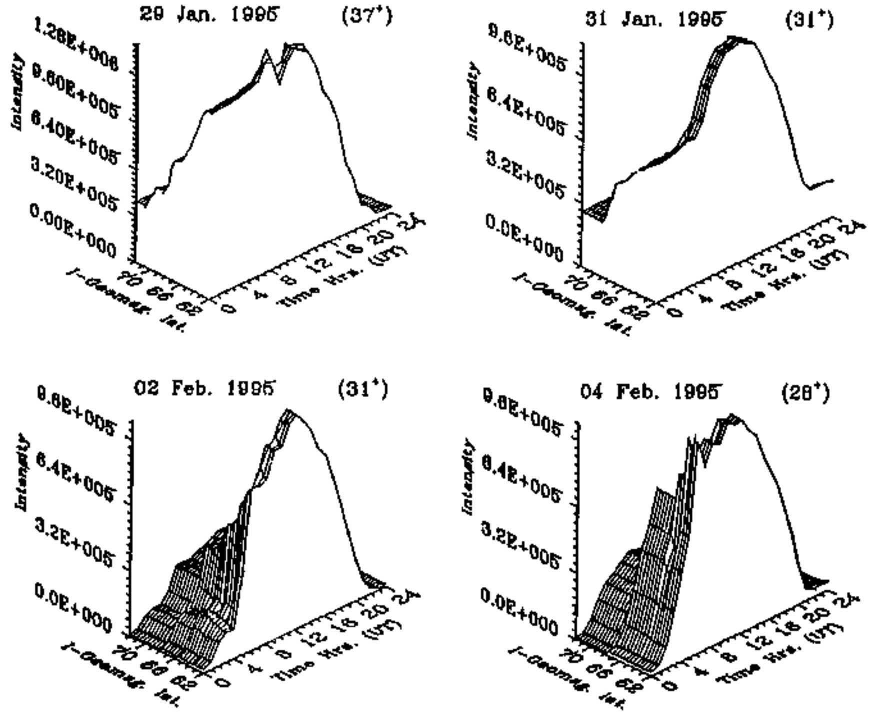


Fig.2b: Same as fig, 2a but during January/February 1995.

Proton-induced Emission

As mentioned earlier, energetic protons undergo charge exchange reactions and get transformed to neutral hydrogen atoms in their exited states.

$H^+ + O_2 \rightarrow O^+{}_2 + H^*$ ... (2)

$H^+ + N_2 \rightarrow N^+2 + H^*$ ... (3)

$H^+ + O \rightarrow O^+ + H^*$ ....(4)

Such excited hydrogen atoms give out photons as they reach their ground state.

$\mathbf{H^* \rightarrow H + h\upsilon}$ ...(5)

These emissions can be from H_α(3-2) 656.3 nm or Hβ (4-12) 486.1 nm.

The intensities Hβ for 9 days are shown in Figs. 5a,b. The proton induced emissions show a large variation in intensities, sometimes more than a factor

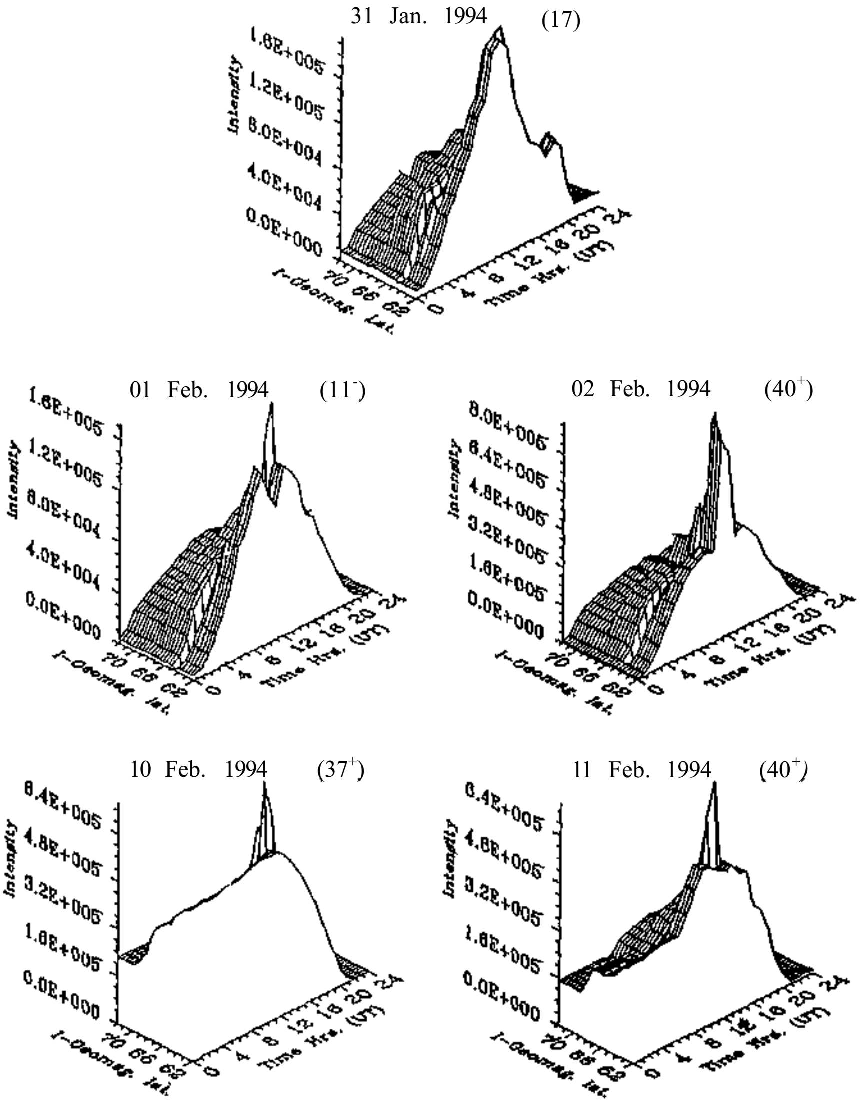


Fig.3: The variability of 4278 Å emission intensities during 1994 with time and latitude.

of six in peak intensities during the course of the observational period. The location of the peak is highly varying. Again, while 6,9,15,16 and 19 February 1994 show a fairly symmetric distribution in intensities, the variation on 2, 10 and 18 February 1994 show an asymmetric behaviour.

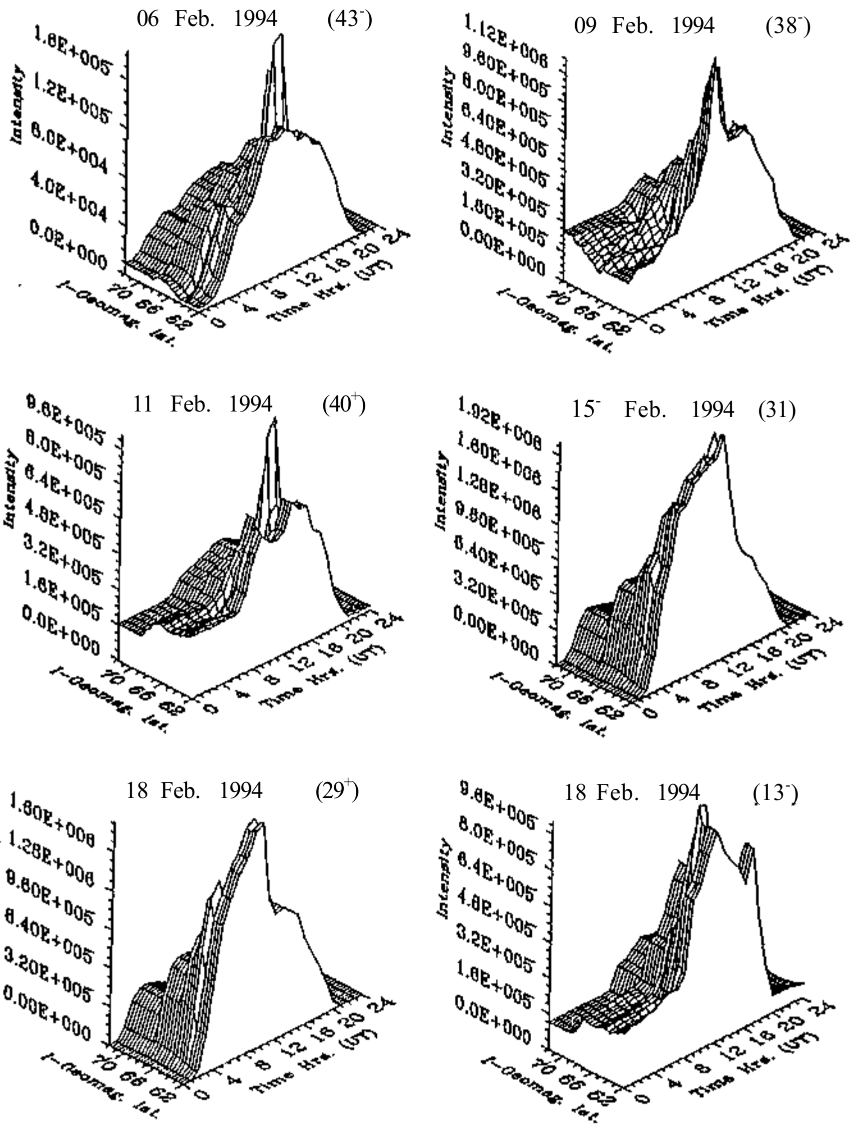


Fig.4: 4709 Å intensity variations during February 1994.

Figure 5b shows distinct variations of Hβ emission intensities on 31st January, 2nd and 4th February, 1995, while 31st January shows a dip in intensities with a width of ~ 3° in latitude similar to OI 557.7 ran emission, 2nd and 4th February data show peaks in intensities at different times. The former shows an increase around 0600 UT southward from the observing location.

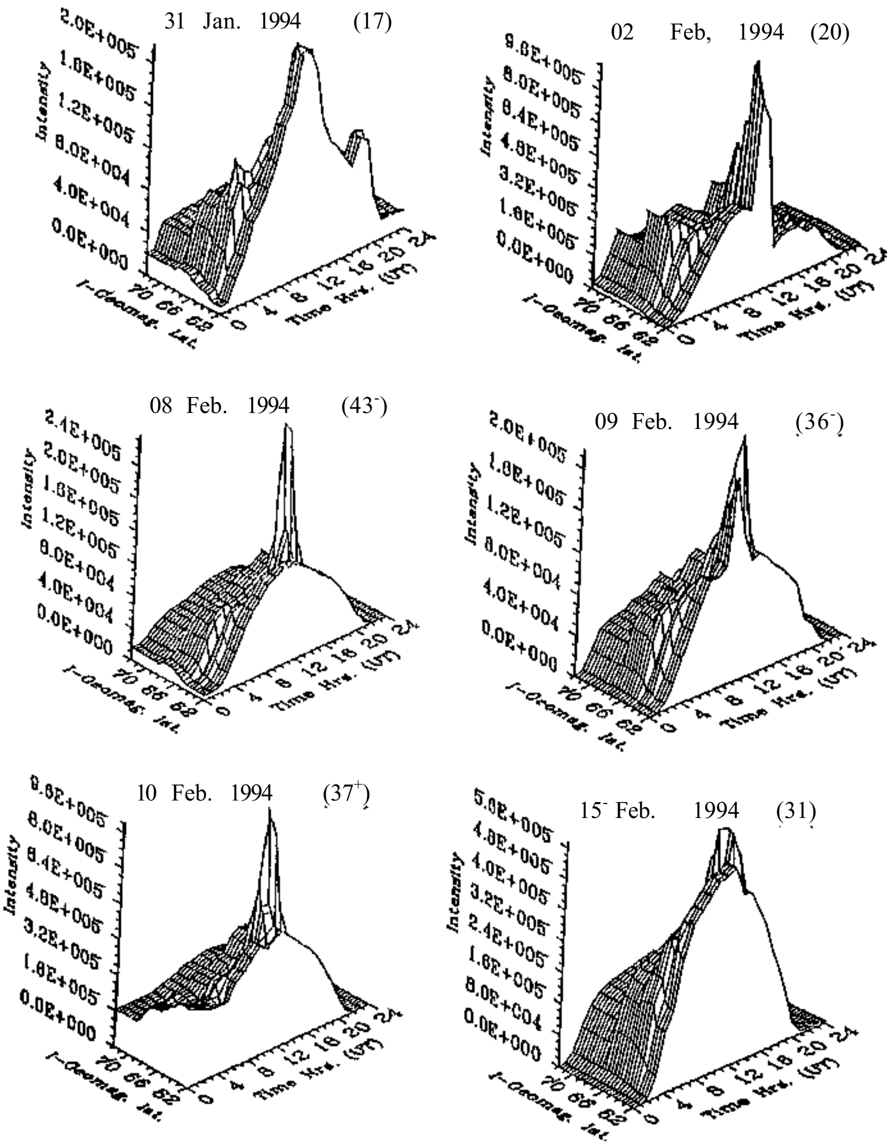


Fig.5a: 4861 Å intensities during January/February 1994. (Contd.)

The intensity profile goes through a shallow dip before reaching its maximum ~ 1200 -1400 UT. In the case of 4th February '95 data the intensity shoots up to its maximum ~ 0700 - 0800 UT itself. Prominent wave features are recorded.

Figures 6a,b show the ground-projection of these intensities along with the $\sum$Kp value on each day. It can be seen that on a moderately disturbed day i.e.

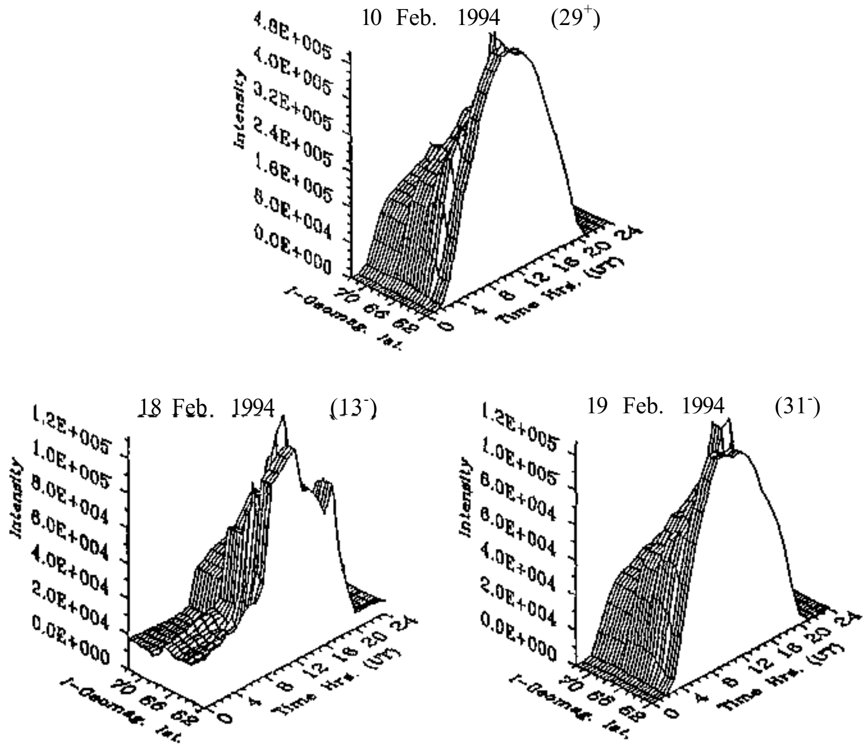


Fig.5a: 4861 Å intensities during January/February 1994.

6 February 1994, there are 'wave-like' features that seem to be getting generated in and around the central peak regions. Similar plots for OI 630.0 nm and 557.7 nm are presented in Figure 6b showing the respective peak zone of precipitation. These plots also bring to light the existence of a boundary at ~68°S geomag. latitude beyond which the wavy features cease to permeate.

Similarities among Various Emissions

Though the results presented above have been classified into different categories, there are many instances when the different emissions tend to show similarities. Few such examples are presented here. Figure 7 shows the intensities of 470.9, 557.7 and 486.1 nm emissions as obtained on 6 February 1994. It can be seen that there is an enhancement in all these intensities in the morning time, 470.9 and 486.1 nm showed a steep gradient in intensities upto 0500 UT, while 557.7 nm emission showing a gradient upto ~ 0730 UT. The noontime peaks in intensities in 470.9 and 486.1 nm emissions occur at 68°

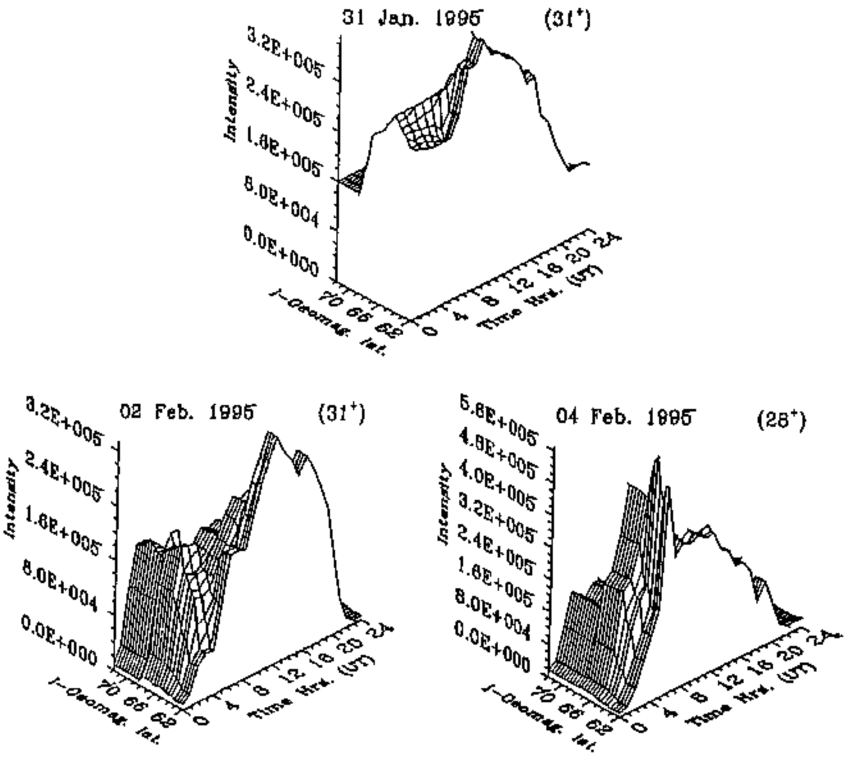


Fig.5b: Same as 5a but during 1995. The distinct differences to be noted

latitude. In another example on 18 February 1994, these two emissions show strikingly similar variations (Fig. 7).

Another classical event which reveals such similar behaviour can be on 4 February 1995 data. Figure 7 shows the variations of 486.1 and 557.7 nm emissions on this day. Such similarities in the variabilities of electron-induced and proton-induced emission on some occasions indicate that the source region of these particles can be the same under certain geophysical conditions. These occasions also bring forth complex and intriguing nature of the polar upper atmospheric phenomena.

Discussion

The results presented above can be understood with the basic knowledge on the behaviour of the plasmapause under varying geophysical and solar input conditions, as this seems to be the main cause which gives rise to noontime enhancements via some possible acceleration mechanisms. Both *in situ* and

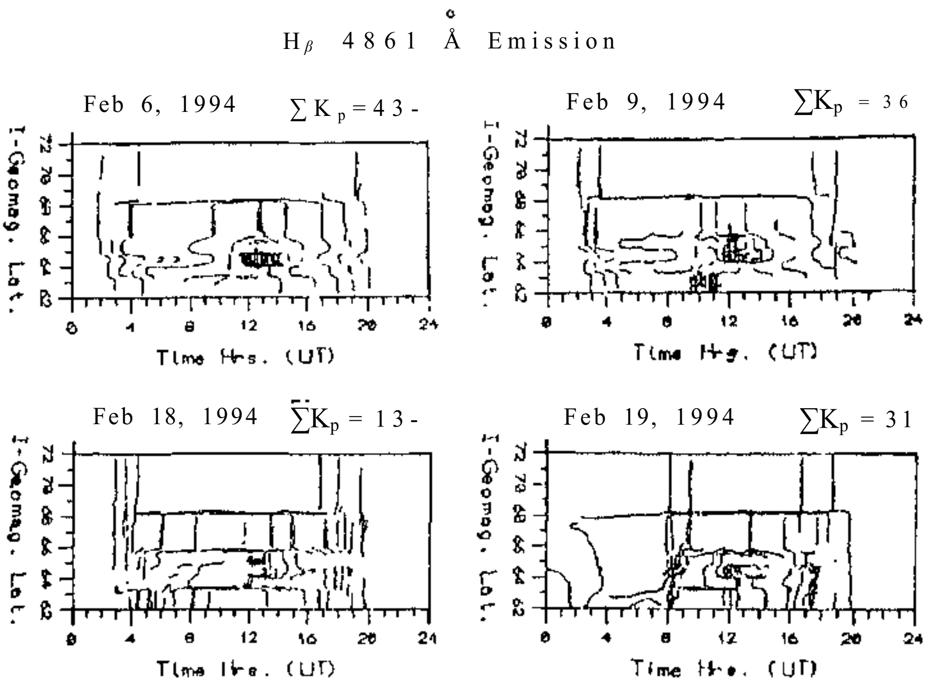


Fig. 6a: Ground projections of H_β-4861 emission during February 1994 under different magnetic activity levels.

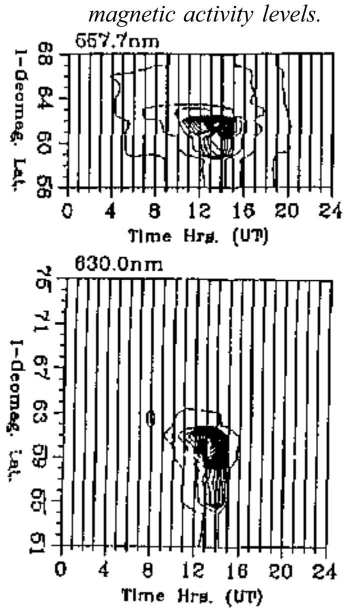


Fig.6b: Ground projections of both 5577 and 6300 Å during 1995. The highly localized deposition region is seen to he north of Maitri during 1995.

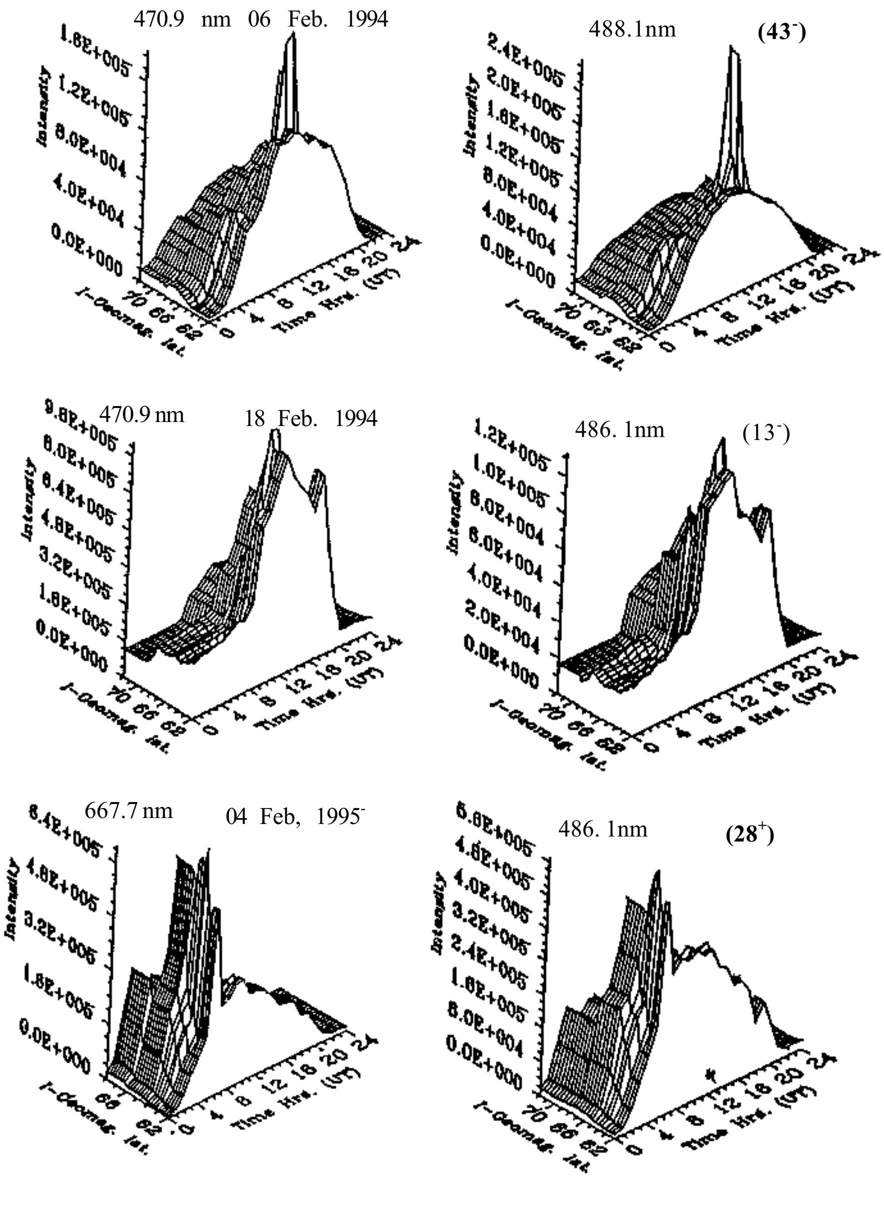
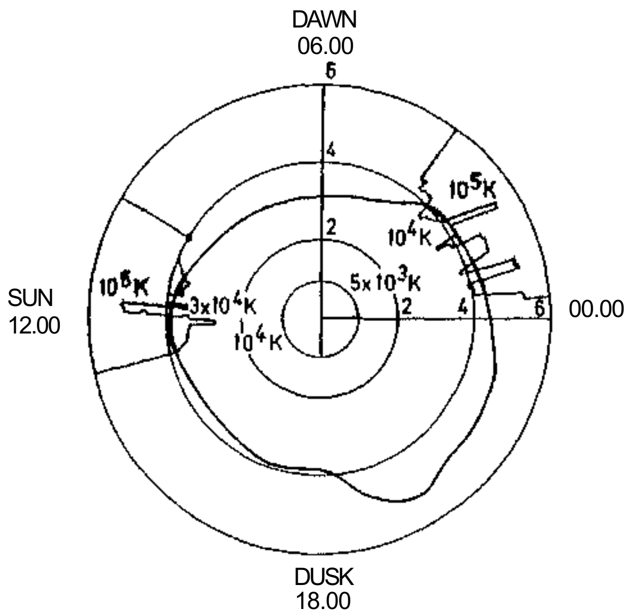


Fig. 7: Similarities in the deposition and emission pattern between the high energy electron excited, low energy electron excited and proton excited emissions on a given day.



Fig, 8: The diurnal variation of the plasmapause location depicting the highly asymmetrical nature of the same.

Whistler observations (Fig. 8) show that the plasmapause is an asymmetric boundary with a minimum in the dawnside and a bulge in the duskside. Typically these values vary from ~ 3RE to 6.4RE from dawn-to-dusk. The location of this boundary is mainly affected by the magnetic activity denoted by the K_p value. *In situ* measurements of H^+ density profiles observed by Lockhead light ion mass spectrometer on-board OGO-5 with respect to varying magnetic activity at 02.00 ± 2 hrs LT are shown in Fig. 9. Here K_p index is an average value considered for 6 hours prior to observations. These values, as presented by Chappell *et al.* (1970), clearly show that for smaller K_p index the plasmapause can reach a value of ~ 6RE, while for large K_p index, it would get compressed to a value between 3-4 RE. The results of various independent measurements during different solar epochs show conclusively (Fig. 10) that the location of plasmapause varies only with the variation in magnetic activity (K_p).

Based on such large number of data sets an empirical relationship between the plasmapause location, L_{pp}, (in earth radii) and the instantaneous K_p index was shown (Rycroft and Thomas, 1970) to be

$$Lpp = 5.64 - (0.78 \pm 0.12)\ Kp \quad ...(6)$$

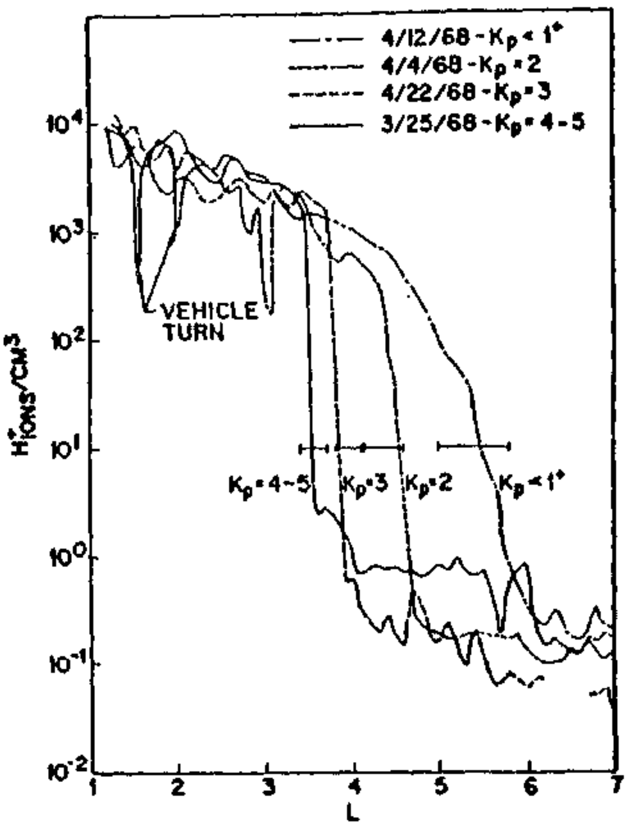


Fig.9: The level of the plasmapause as deduced from in situ measurements from OGO-V satellite.

Using this relation one can see that the probable plasmapause location can be anywhere between L ~ 5.0 - 3.84 for K_p values ranging from 1 to 4.

With this background if one looks into the daytime auroral measurements presented above, it can be seen that on most of the days the $\sum K_p$ was >~30. Hence by taking the average value for each three-hour duration to be ≅ 3.7 we can see by the relation (6) that the plasmapause location is always within 4.8 RE which incidentally is the L value of our observational location Maitri. This implies that the foot of the magnetic field lines passing through our station when mapped upto the equatorial plane, lies in the inner magnetosphere. Hence, one would expect that northward meridional scans of the optical emissions to give a better clue to the plasmapause associated processes. This experiment was done by monitoring OI 557.7 and 630.0 nm on 29 January 1995 (Figs 11 and 12). One can see that the peaks in them occur at 63° and 61° I-geomag. latitudes

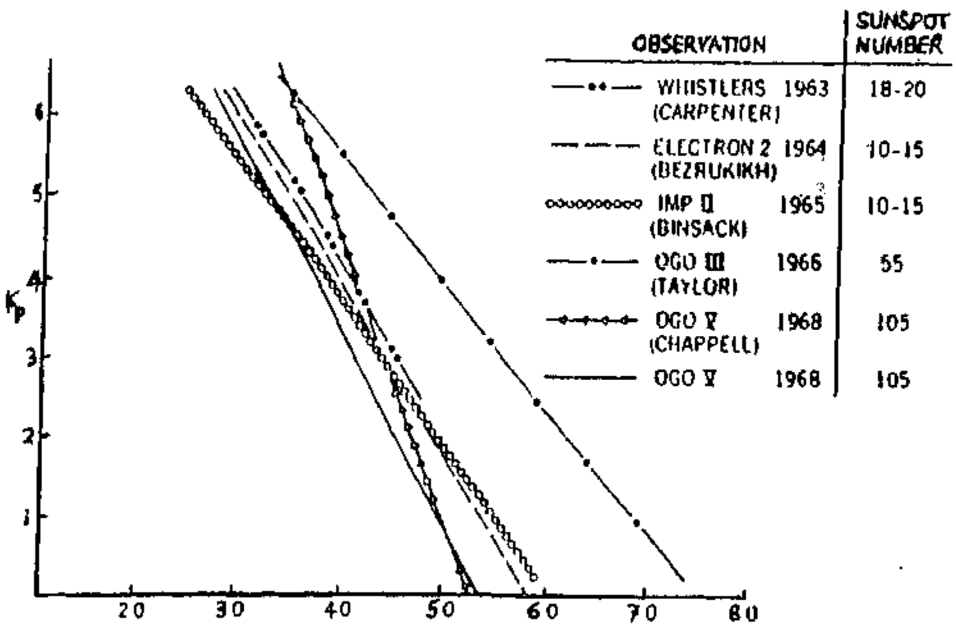


Fig. 10: Plasmapause location as inferred by different techniques for different geomagnetic activity levels.

respectively (L value ~ 4.3 for 62° latitude) and hence appears to agree well with the empirical relationship. Maitri, when mapped along the field lines comes closest to the plasmapause location only in the noontime and that is when these enhancements occur. The peak intensities obtained in the southward scans men correspond to the acceleration mechanisms outside the boundary of the plasmapause. That, similar enhancements in electron densities and electric fields exist, were shown experimentally as well as theoretically by many workers (Okada *et al.*, 1993; Oya *et al.*, 1990; Popecki *et al.*, 1993,etc.). Okada *et al.,* (1993) showed using EXOS-D satellite measurements that there were sharp peaks in the poleward electric fields during magnetically disturbed periods. Comparison of this with the electron density profile deduced from the wave measurements (Oya *et al,* 1990) showed that the peak was located in the low-density region just outside the plasmapause. The position of this peak moved towards higher latitudes during the recovery phase.

In another study using the ground-based observations of PC 1/2 (0.1 - 0.4 Hz) and PC_1 micropulsations during 1986, Popecki *et al* (1993) identified the location of the source region of PC 1/2 micropulsations to be between the

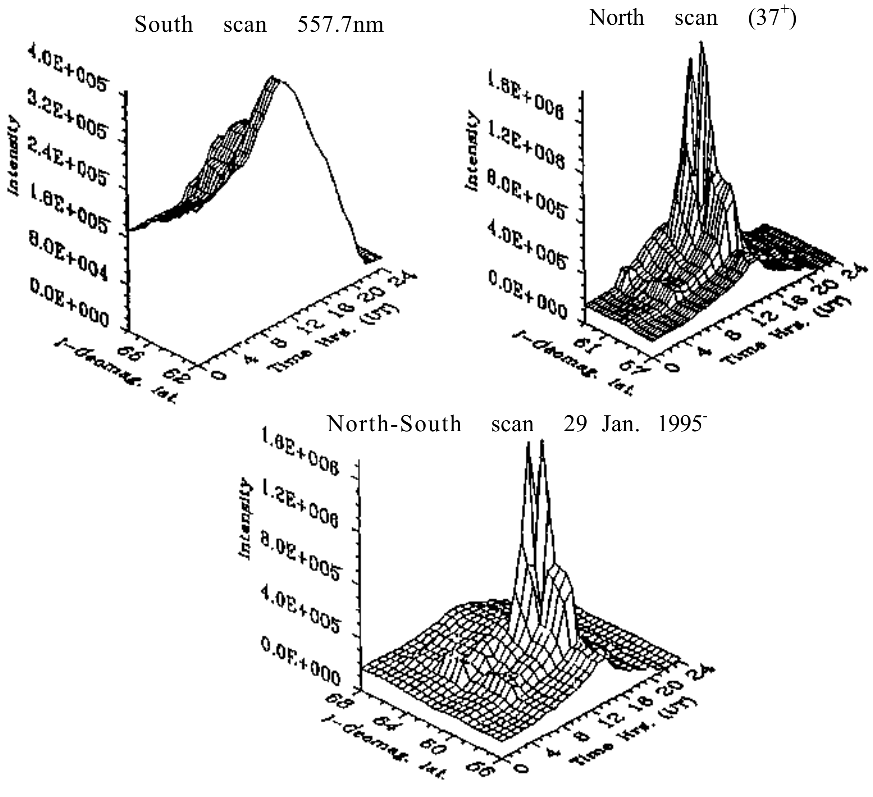


Fig.11: Top left—South scan 5577 Å; Top right—North scan of 5577 Å; Bottom—Combined representation. The change in intensity levels between the south and north pointing observations is to be noted.

plasmapause and magnetopause. Using the data from three high-latitude stations, located at south pole (-75° geomag. lat., 1330 UT LN) Sondre Stromford(+ 74° geomag. lat., 1330 UT LN) and Siple (-61° geomag. lat., 1700 UT LN), they showed that the diurnal occurrence pattern of these waves in the 0.01 - 0.4 Hz band was not due to the effects of sunlight on the ionosphere but instead from a postnoon magnetospheric source region. On the basis of the latitudinal occurrence patterns of the waves above and below 0.4 Hz, it was concluded that the waves observed on the ground above 0.4 Hz come primarily from plasmapause latitudes, while the source of the PC 1/2 lies between the plasmapause and the magnetopause.

As the variations discussed above are some of the manifestations of auroral phenomena, it is expected that the daytime auroral emissions too would show such enhancements in the vicinity and beyond the plasmapause. It is believed

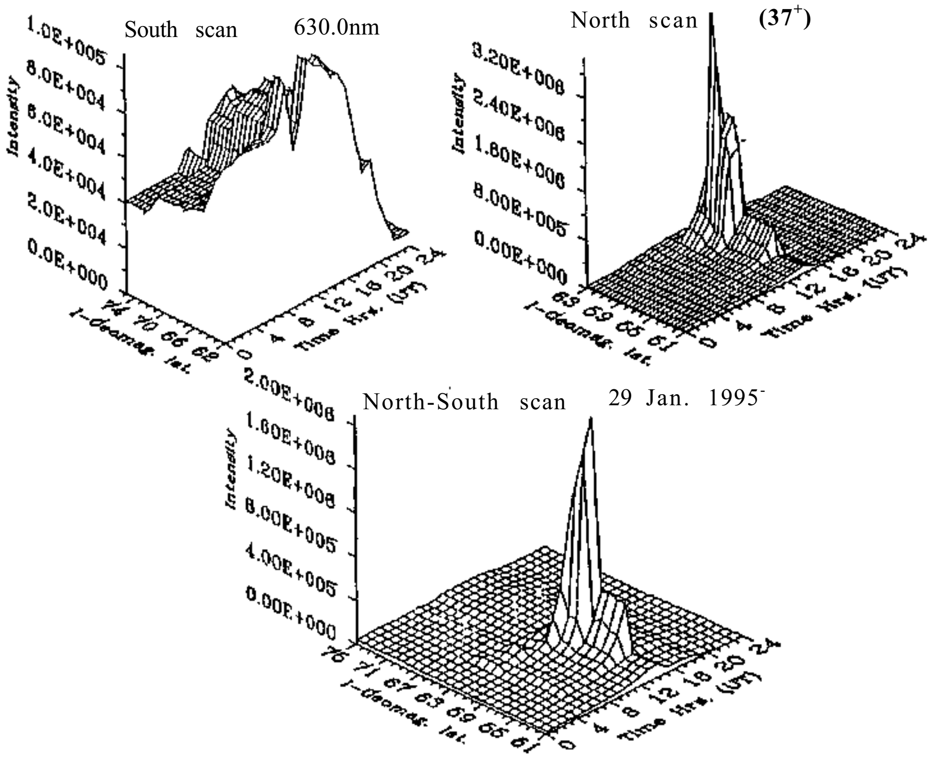


Fig. 12: Same as in Fig. 11 but for 6300 Å

that the variabilities of daytime auroral emissions presented in this report, corroborate above results, thus highlighting the complex interactive processes pertaining to the dayside region. This calls for a concerted multi-technique approach both by ground-based and space-borne methods.

Future Scope

As could be seen, the first ever systematic monitoring of the daytime auroral emissions has been highly successful. In order to have a comprehensive understanding of the energetic processes, their impact on the atmospheric system, the ways and means the excess energy is transported to lower latitudes strongly coupling the high and low latitude regions, a systematic round the year coordinated measurements using multiple techniques are needed. The present results have indeed opened up a new aspect to the high latitude processes. With the successful launching of the PSLV and with the availability of satellite platforms, enabling mapping and *in situ* measurements, absolute new information would become available on the upper atmospheric system. The complementary experiments should be judiciously chosen and a detailed proposal has already been made to DOD to this effect, for the setting up of a Geomagnetism and Optical Aeronomy Laboratory (GOAL) at Maitri.

Acknowledgements

The Department of Ocean Development had provided the necessary logistic support for carrying out the campaigns successfully. Our thanks are due to Professors R.K. Varma, B.H. Subbaraya and R. Raghavarao for their constant encouragement. The team members of both the XIII and XIV expeditions had been a source of inspiration and their cooperation during the campaigns is duly acknowledged.

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Publications Resulting out of the Expedition:

1.	**R. Sridharan** D. Pallam Raju R. Narayanan N.K. Modi B.H. Subbaraya & R. Raghavarao	Daytime measurements of optical auroral emissions from Antarctica.	*Current Science* 68, **8**, 830, 1995.
2.	D. Pallam Raju **R. Sridharan** R. Narayanan N.K. Modi R. Raghavarao & B.H. Subbaraya	Ground-based optical observations of daytime auroral emissions from Antarctica	*J. Atmos. Terr. Phys.,* **57**, 1591-1597, 1995.

Manpower trained : : Total - 5
(including two Ph.D.Students)

The outcome of this exploratory study has formed a part of the Ph.D. Thesis of Mr. Pallam Raju being submitted to Indore University during February 1996.