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LOCALIZED PRECIPITATION OF ENERGETIC PROTONS AT SUBAURORAL LATITUDES

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Introduction

Particle observations onboard the low-altitude satellites, e.g. OV1-15 [*Cornwall et al.*, 1971], OV1-17 and OV1-19 [*Mizera*, 1974], ESRO-1A [*Hauge and Söraas*, 1975; *Söraas et al.*, 1977], Intercosmos-5 [*Kudela et al.*, 1977], Kosmos-900 [*Altyntseva et al.*, 1982], TIROS/NOAA [*Gvozdevsky et al*, 1997; *Yahnina et al.*, 1998], showed the existence of different types of energetic (>30 keV) proton precipitation in the polar regions. Precipitation at relatively high latitudes is characterized by isotropic pitch-angle distribution, which is, likely, due to the pitch-angle scattering on the magnetotail current sheet [e.g., *Sergeev et al.*, 1983]. Several precipitation zones can be distinguished equatorward of the isotropy boundary. One of such zones – anisotropic band of energetic proton precipitation just equatorward of the isotropic boundary, has been recently investigated by *Gvozdevsky et al.* [1997] and *Yahnina et al.* [1998]. In particular, it has been found that this precipitation zone is mapped to the equatorial plane to the narrow region in the vicinity of the plasmapause. In this paper we will present preliminary results of the study of another type of anisotropic proton precipitation which is observed further to equator (i.e. closer to the Earth) than above mentioned one. Thus, it is expected that the precipitation occur inside the plasmapause. Precipitation of protons inside the plasmasphere have been predicted [*Cornwall et al.*, 1970] and interpreted in many previous studies as a result of ion-cyclotron instability [e.g., *Williams and Lyons*, 1974]. Precipitation considered here is characterised by narrow (1-2 degrees in latitude) spikes of quasi-trapped (trapped at the satellite altitude) particles. According to our data, the spikes are observed at L=3.5-5.2 and spatially separated from other precipitation zones. This type of the proton precipitation has been already described in literature [e.g. *Hauge and Söraas*, 1975; *Kudela et al.*, 1977], but not studied in detail. In addition to statistical consideration we will compare morphological features of this precipitation with the observed characteristics of ion-cyclotron waves (pulsation Pc1). Also, we will present the results of the comparison of proton spike observations with the satellite measurements of waves and some ionospheric parameters.

Observations

We have used the data obtained from TIROS/NOAA satellites. These low-altitude (800-850 km), polar-orbiting satellites have onboard the instrument MEPED, which measures particles with energy more than 30 keV [*Hill et al.*, 1985]. An example of the phenomena of interest is presented in Fig.1. The data have been obtained on August 31, 1979 during just simultaneous passes of TIROS-N (orbit 4543) and NOAA-6 (orbit 923) in the southern hemisphere. The data show the existence of energetic proton spikes at different local times (the spikes are marked in figures 1-4; the thin and thick lines mark the precipitating and quasi-trapped fluxes, respectively). The spikes are observed at the same latitudes in different local time sectors. The intensities of the proton fluxes don't differ significantly. Another example (Fig.2) illustrates how long the precipitation may exist. On August 16, 1979 the first signatures of the proton precipitation spike were detected by TIROS-N (orbit 4328) at 0838 UT. The data from successive orbits showed that the duration of the phenomenon was more than 10 hours. It is interesting to note that sometimes, for a short time at the beginning of the observation interval, both quasi-trapped and precipitating particles were detected. An example of such event is plotted on the top panel of Fig.2.

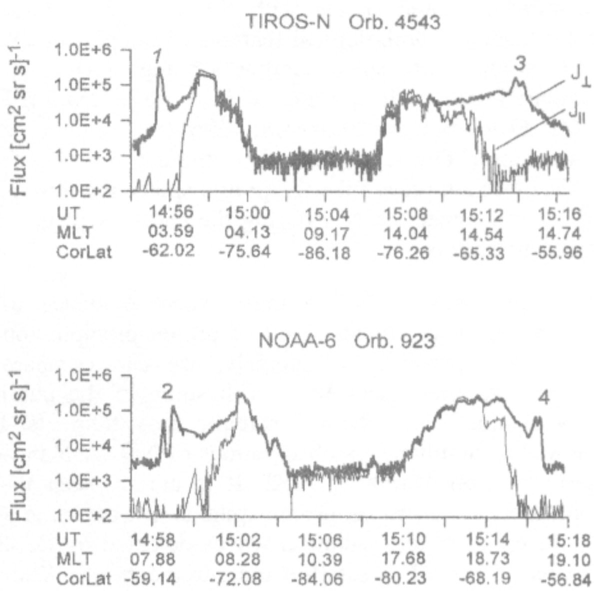

Fig. 1

To make a statistical study we have used the data obtained during the period of August 11-31, 1979. During this time there were four geomagnetic storms: August 13-16 (minimal D_{st} = -71 nT), August 18-20 (D_{st} = -56 nT), August 20-22 (D_{st} = -60 nT), and August 29-31 (D_{st} = -140 nT). For the statistics only the spikes with intensity exceeding the background level by at least an order of magnitude have been considered. The use of two satellites allowed us to have the observations at all local times except the 10-12 MLT sector. This is because the satellites did not cross the invariant latitudes 58-64° at this MLTs.

Let us list some statistical results we have obtained and presented in Figs. 3 and 4:

1) Maximum occurrence of the spikes has been observed at the end of the recovery phase of magnetic storms.

2) Probability of spike observations for considered interval is minimum in the night sector and maximum in the day-morning sector.

3) Quasi-trapped proton spikes are observed at Inv.Lat. = 58-64° with maximum of the occurrence at 60-62°.

We have noticed some dependence of the considered phenomenon on the energy of protons. The spikes of more energetic particles have higher probability (Fig.4a) and are observed at slightly lower latitudes (Fig.4b). The latter is in a good agreement with observations by *Kudela et al.* [1977] of isolated >440 keV proton spikes at L=3-3.5.

Statistics for the spikes inspired by both quasi-trapped and precipitating particles shows that they occur only in 7% of all spike events. Maximum of the observation probability is in the day sector. Most of such events are observed when geomagnetic activity is very low (AE<200 nT).

Comparison with the ion-cyclotron waves and ionospheric plasma observations

Keeping in mind that the most probable mechanism of the energetic proton precipitation is the ion-cyclotron wave interaction we have compared the features of the anisotropic proton spikes with those of pulsations Pc1. Indeed, some morphological features of the phenomena are very similar. Statistical studies of the pulsations Pc1 measured both on the ground and in space [*Fukunishi et al.*, 1981; *Erlandson and Anderson*, 1996] have shown that the maximum of their occurrence is in the day-morning sector, at the close latitudes. Like the proton spikes the ionospheric Pc1 waves appear mainly during the recovery phase of the magnetic storms.

It is important to find a more direct evidence of the relationship between this kind of proton precipitation and ion-cyclotron waves. Fortunately, we can compare the NOAA satellite observations with some of the published data obtained from the DE satellite measurements. Fig.5 shows the simultaneous observations of NOAA-6 and DE-2 performed on March 5, 1982. It is clearly seen that the latitude of the energetic proton spike is just the same as that of the spike of ion-cyclotron waves detected by DE-2 (for details of the DE-2 satellite measurements see *Erlandson and Anderson* [1996]). The satellites were in the day-morning sector at different MLTs, but, as we have noted (see, Fig. 1), the simultaneous proton spikes are typically seen at close latitudes in a wide longitudinal extent.

It is known that the electron temperature enhancements are associated with ion-cyclotron waves [*Erlandson et al.*, 1993]. On the other hand, Fig.6 shows an example of comparison of the proton spikes with ionospheric electron temperature enhancements. The DE satellite data for this case (October 16, 1981) have been published by *Horwitz et*

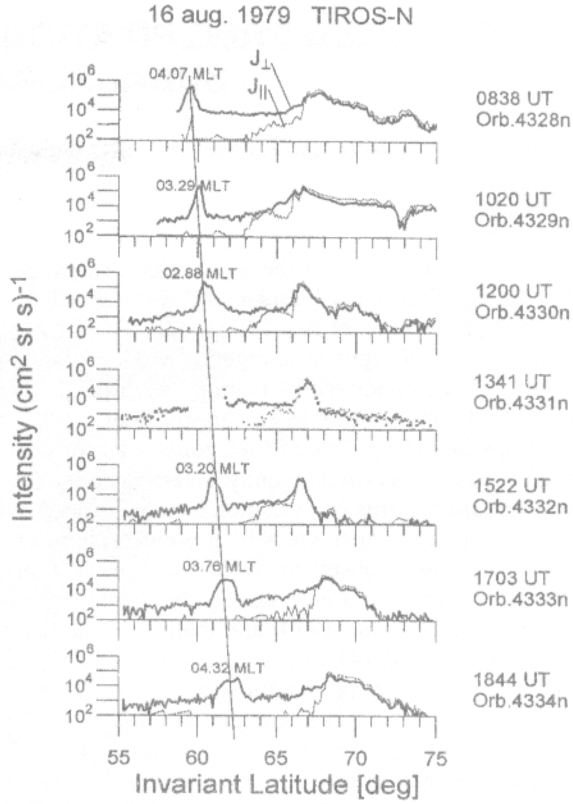

Fig. 2

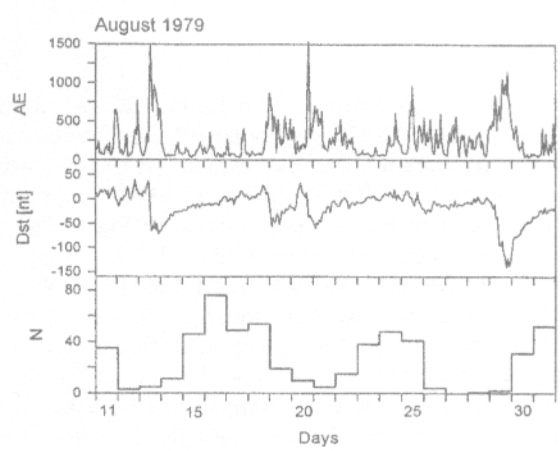

Fig. 3

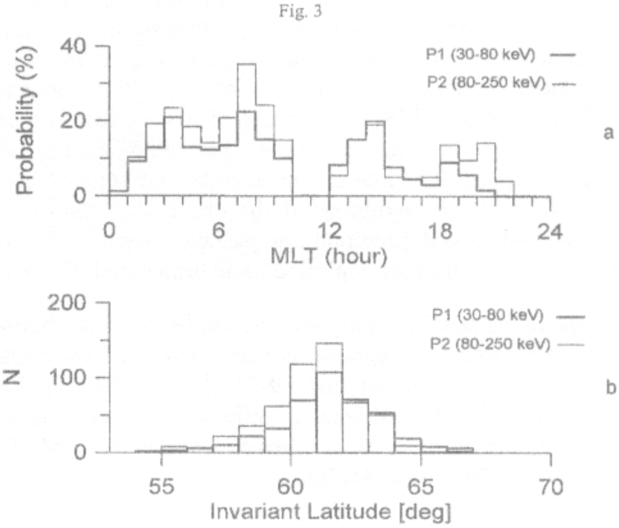

Fig. 4

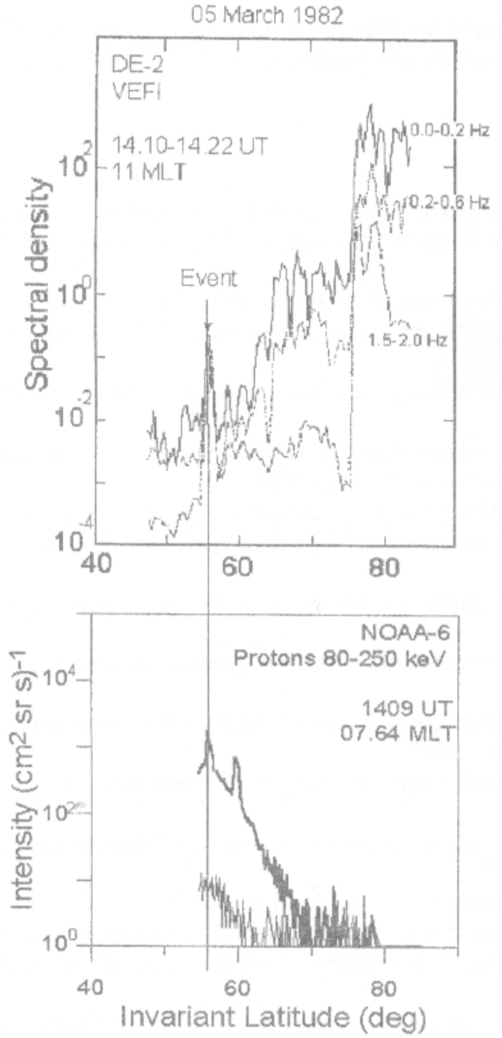

Fig. 5

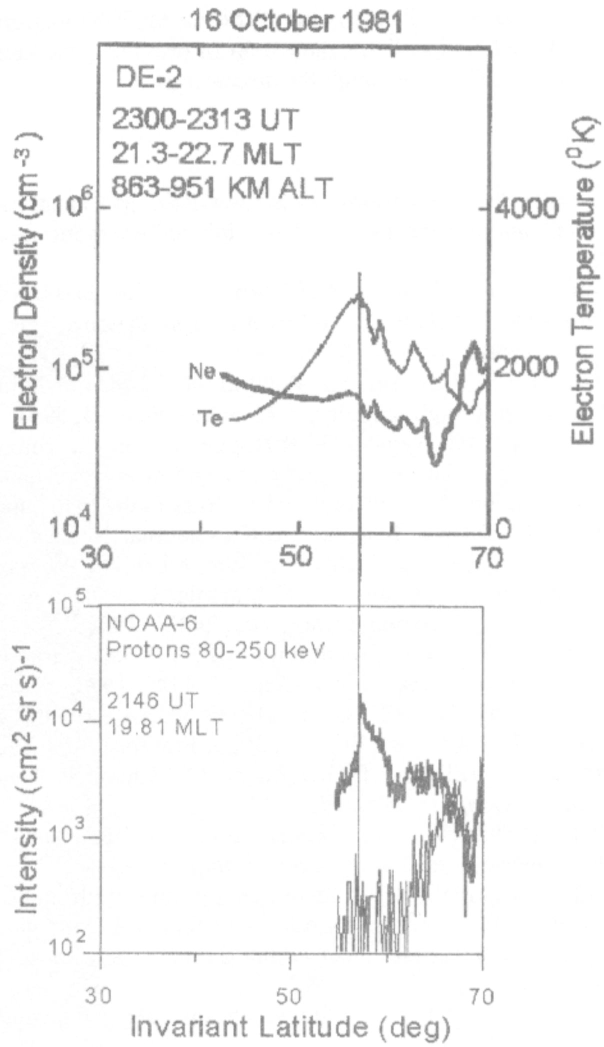

Fig. 6

al. [1986]. These data as well as a similar comparison for a case of November 23, 1981 (not shown here) also described in the above-mentioned paper provide us with the evidence of the close relationship between the temperature peaks and localised proton precipitation. In their paper *Horwitz et al.* [1986] presented simultaneous observations from both DE-1 and DE-2. From the comparison of the cold ion observations onboard the DE-1 satellite and ionospheric parameters obtained from DE-2 one can see that the temperature peaks are typically observed inside the plasmashphere. It is interesting to note that *Erlandson et al.* [1990] using the Viking Langmuir probe observations also found the narrow region of ion-cyclotron waves (Pc1) inside the plasmasphere.

Discussion and Conclusion

In this paper we have briefly described the morphological features of a specific type of energetic proton precipitation. Both the statistical and case considerations exhibit the relation of this precipitation to the ion-cyclotron waves. The ion-cyclotron mechanism has been also suggested for other proton precipitation types. However, the peculiarities of the wave-particle interaction seems to be different for different types of precipitation. For example, the mechanism of precipitation which have been observed just equatorward of the isotropic boundary [*Yahnina et al.,* 1998] seems to be more effective in the night-evening sector. Since this mechanism operates in the vicinity of the plasmapause, one can expect that the cold plasma gradients play an important role in generation of the ion-cyclotron waves here. As to the localised precipitation described in this paper, unlike the above-mentioned precipitation type, it is mainly observed in the day-morning sector and inside the plasmasphere. Thus, the mechanism of this precipitation should include the dependence on the high density of the cold plasma, and take into account the different conditions for the cyclotron wave generation in the day and night sectors. The further analysis of the experimental data and theoretical modelling has to be performed to complete the study of this phenomenon.

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