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Observation of low frequency electromagnetic activity at 1000 km altitude

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Abstract. We present a statistical study of low frequency fluctuations of electric and magnetic fields, commonly interpreted as Alfvénic activity. The data base consists of six months of electric and magnetic field measurements by the Astrid-2 microsatellite. The occurrence of the events is studied with respect to the location and general activity. Large regions of broadband Alfvénic activity are persistently observed in the cusp/cleft and, during the periods of high geomagnetic activity, also in the pre-midnight sector of the auroral oval.

Key words. Ionosphere (auroral ionosphere) – Space plasma physics (waves and instabilities) – Magnetospheric physics (magnetosphere-ionosphere interactions)

1 Introduction

Fluctuations of electric and magnetic fields with frequencies below the local ion cyclotron frequency represent a common feature of the auroral zone plasma and have been observed by sounding rockets (e.g. Gelpi and Bering, 1984; Ivchenko et al., 1999) and satellites (e.g. Berthelier et al., 1988; Dubinin et al., 1990; Louarn et al., 1994; Chaston et al., 1999) over almost three decades. The fluctuations in the transverse components of δE and δB are often correlated. This fact can be explained either in terms of stationary magnetic field aligned current structures closing by Pedersen currents in the inonosphere, or as a signature of Alfvén waves. The ratio of $\delta E/\delta B$ is used to distinguish between the two possibilities. For conductivity-controlled structures it is $1/\mu_0\Sigma_P$, where Σ_P is the height-integrated Pedersen conductivity, while for propagating Alfvén waves, the ratio is roughly a measure of the Alfvén speed, V_A (Aikio et al., 1996). Interfering Alfvén waves may produce other values for the ratio and complicate the phase relations between δE and δB.

The Alfvénic nature of the low frequency electromagnetic fluctuations in the auroral ionosphere has been established in a number of studies, and several classes of models have been developed to account for generation and propagation of the waves and their interaction with the ionosphere (see a comprehensive review of observations and theories by Stasiewicz et al., 2000). Despite the effort, there is still no general consensus as to the spatial and temporal structure of the events. Furthermore, it seems that several regimes of the waves may exist in different parts of the auroral region.

This paper reports on the low frequency fluctuations of electric and magnetic fields observed in the auroral ionosphere by the Swedish Astrid-2 microsatellite at 1000 km altitude during the first half of 1999.

2 Data

The Astrid-2 microsatellite was launched on 11 December 1998 into a circular 1000 km altitude orbit with 83° inclination. Scientific data collection was carried out between 11 January and 24 July 1999, when the contact with the satellite was lost. Among other instruments onboard Astrid-2 was the EMMA electric and magnetic field instrument. The instrument provided simultaneous measurements of three components of the magnetic field and two components (in the spin plane) of the electric field. Three modes with different time resolution were available: 16, 256 and 2048 samples per second. The latter mode was memory extensive, and thus, could be used only occasionally.

The electric and magnetic field data were despun and converted into geophysical coordinates. Two coordinate systems are used in this study: the "magnetic field spin plane" system (msp) and the "magnetic field - east - equatorward" system (mee). In the former, the $\boldsymbol{e}_{3msp}$ axis is in the direction of the spin axis, $\boldsymbol{e}_{1msp}$ is in the spin plane along the projection of the magnetic field in the spin plane, and $\boldsymbol{e}_{2msp}$ completes the right-handed set, being perpendicular to $\boldsymbol{B}$. In the mee coordinate, $\boldsymbol{e}_{1mee}$ is along the model magnetic field, $\boldsymbol{e}_{2mee}$ is in the eastward direction, defined as the direction of $\boldsymbol{r} \times \boldsymbol{B}$, where $\boldsymbol{r}$ is the radius-vector of the satellite

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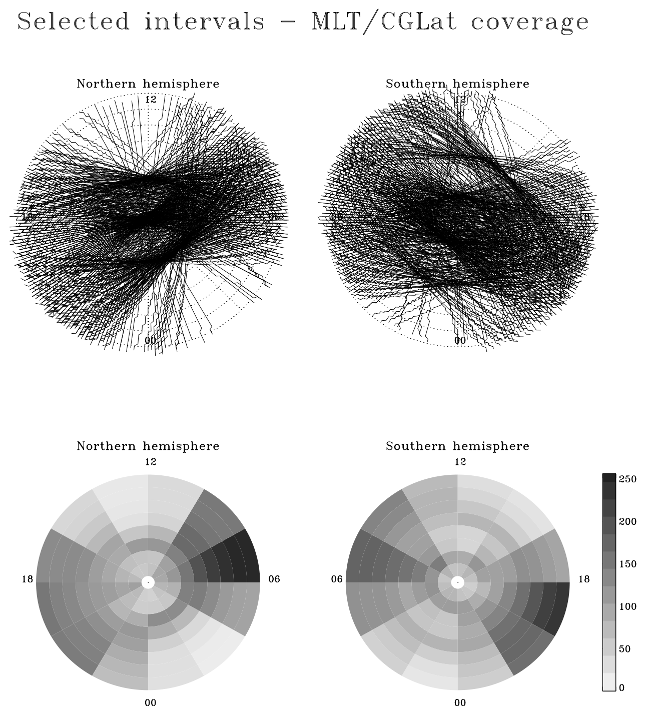

Fig. 1. Orbit intervals selected for the study.

and $\boldsymbol{B}$ is the model magnetic field, and $\boldsymbol{e}_{3mee}$ completes the right-handed set. Using two systems is necessary because the electric field is measured only in the spin plane. Two components, E_{1msp} and E_{2msp} are measured and some assumption has to be made concerning the third component. Since it is known that the electric field normally has a much larger component in the direction perpendicular to the magnetic field than along it, a natural assumption to make is that $\boldsymbol{E} \cdot \boldsymbol{B} = 0$. The component of $\boldsymbol{E}$ perpendicular to $\boldsymbol{B}$ and E_{2msp} can thus be calculated as $\boldsymbol{E}_{1\perp} = E_{1msp} / \sin\alpha$, where α is the angle between the spin plane and $\boldsymbol{B}$. This poses a natural problem when $\alpha \approx 0$. In addition, for small values of α, disturbances related to the satellite influence on the measurements are seen in E_{1msp}, so only one component of the electric field can be measured reliably (Ivchenko et al., 2001). It should be kept in mind that the reliable transformation of $\boldsymbol{E}$ into the mee coordinates is only possible for α being far from zero.

For this study we selected 1035 passages of the satellite at high latitudes (over 50° corrected geomagnetic latitude) from January to June 1999. Figure 1 shows the orbit tracks of the selected intervals in magnetic local time and corrected geomagnetic latitude, and the coverage of various MLT-CGL at regions in both hemispheres. In six month the orbital plane of the satellite made almost one complete rotation in local time, so we have a rather complete coverage of all local time sectors in both hemispheres. Due to technical problems on the satellite, the data collection was not continous in January and March 1999, which resulted in a smaller number of selected passages near the noon-midnight meridian.

To identify the events, a windowed Fourier transform (window length 4 seconds) was performed on the data downsampled to 16 samples/second resolution for uniformity. An example of the data, together with the spectra, is presented in Fig. 2. Intervals with enhanced power between 0.5 Hz and 8 Hz in the spectrum of E_{2msp} were selected. The E_{2msp} component of the electric field was used as it has the same quality independent of the angle between $\boldsymbol{B}$ and the spin plane. The events where the enhanced spectral power was caused by outliers were excluded from the data base.

3 Occurrence of the low frequency electromagnetic activity

Over 7000 intervals with E_{2msp} fluctuations with frequencies between 0.5 Hz and 8 Hz have been identified. The enhanced spectral power in the electric field was continually associated with magnetic field fluctuations. The fluctuations of the magnetic field were perpendicular to the background magnetic field. Estimates of the $\delta E / \delta B$ ratio were made considering the ratios of the spectral powers of the perpendicular components of δE and δB. This is a coarse estimate, providing no phase information. The ratios generally range between $5 \cdot 10^5$ and $5 \cdot 10^6$ m/s, which is consistent with the expected values of Alfvén velocity for the altitude of the observations. Corresponding Pedersen conductivities would be between 0.1 and 1 S, thus lower than the values expected for the ionospheric conductivities. The ratio is higher in the winter hemisphere than in the sunlit one, as would be expected considering the seasonal density fluctuations (see Fig. 3). Altogether this indicates the fluctuations are of Alfvénic nature, rather than stationary field-aligned currents.

Disturbance intervals of different lengths were found, ranging from seconds to tens and even hundreds of seconds. The longest interval for which electromagnetic field fluctuations of varying strength were continuously observed was 414 seconds (which corresponds to about 3000 km along the orbit). This event was detected in the dayside auroral zone at 02:52–59 UT on 18 February 1999, shortly after a solar wind discontinuity reached the magnetosphere. The discontinuity was associated with a solar wind velocity increase from 400 km/s to over 600 km/s and the interplanetary magnetic field B_z component reaching below -25 nT. The cases where electromagnetic field disturbances were observed during long time intervals along the orbit have all been found to have a similar appearance; an example of which is shown in Fig. 2. Irregular fluctuations in both electric and magnetic fields are present with a falling frequency spectrum. The amplitudes of the electric field fluctuations occasionally reach 200–300 mV/m, but a more typical value is below 100 mV/m. The electric field waveform often shows a finer structure than that of the magnetic field, which results in the steeper fall of the δB frequency spectrum than that of the δE. It is rather difficult to single out separate events in the turbulence.

On the other hand, the short intervals of the δE spectral power enhancement show a broad variety of the fluctuations. The spectra are often structured, having one or several peaks

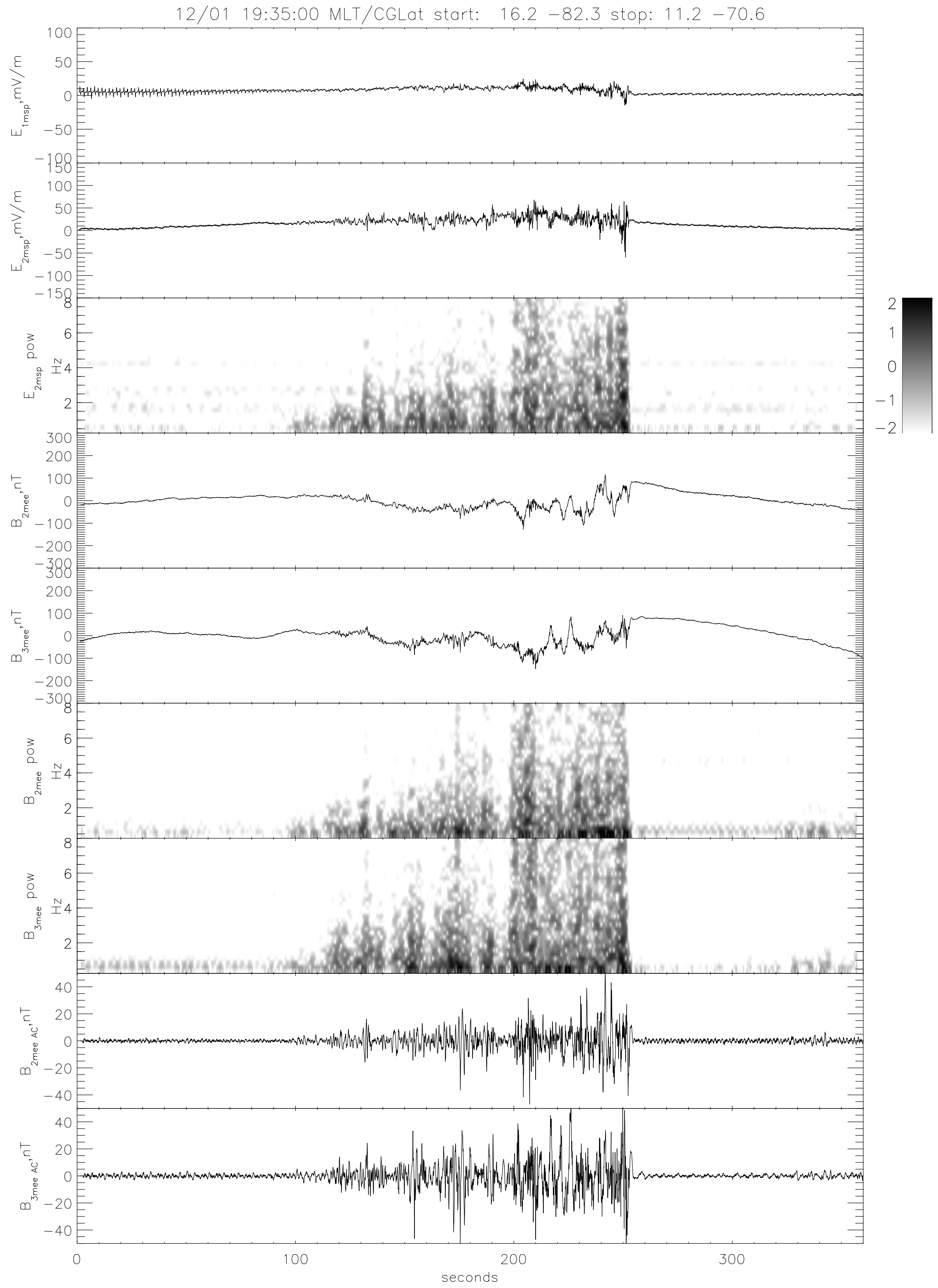

Fig. 2. An example of an extended period of low frequency electromagnetic turbulence. Panels from top to bottom present two components of E in the msp coordinates, spectrum of E_{1msp}, two components of B perpendicular to the backgound magnetic field in the mee coordinates with spectra of the signals, and high pass filtered B_{2mee} and B_{3mee}.

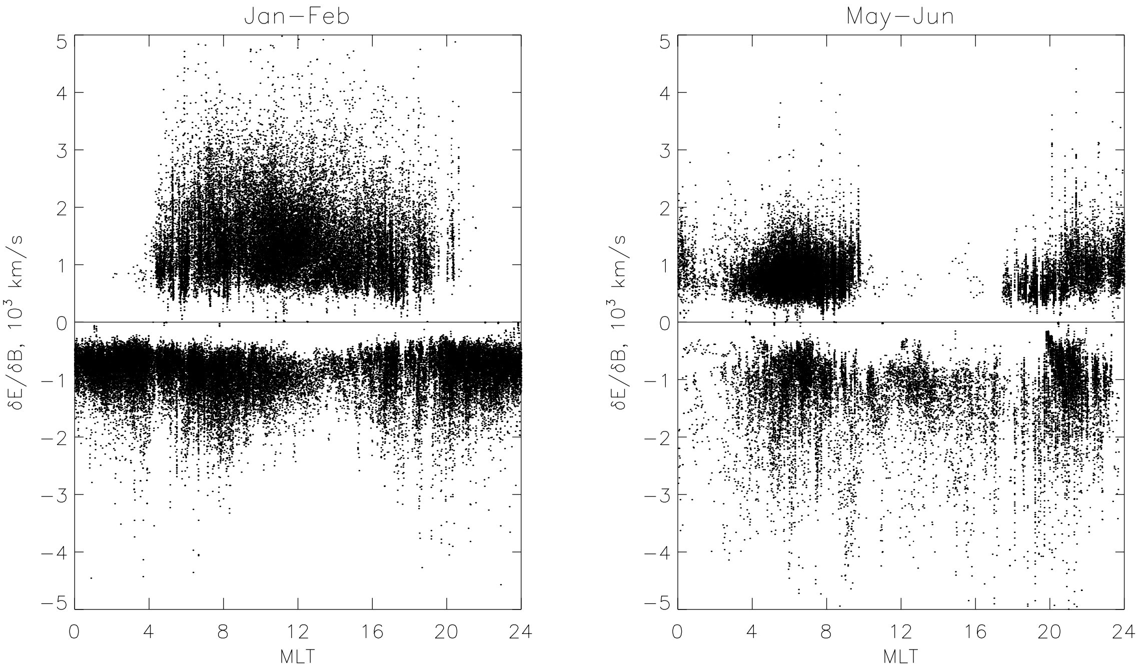

Fig. 3. Estimates of $\delta E/\delta B$ ratio vs magnetic local time for selected events. Each point corresponds to a ratio of spectral powers above 0.5 Hz in perpendicular components (for $|\alpha| > 20$ $\delta E_{2mee}/\delta B_{3mee}$ and $\delta E_{3mee}/\delta B_{2mee}$, and for $|\alpha| < 20$ $\delta E_{2msp}/\delta B_{3msp}$). Left panel presents cases from January and February, and the right panel cases from May and June. The points from the southern hemisphere are plotted with a negative sign. Larger and more scattered values are observed in the winter hemisphere as compared to the summer one, and in at MLTs around midnight as compared to midday. The different and incomplete MLT coverage in the hemispheres is due to the orbital characteristics of the spacecraft.

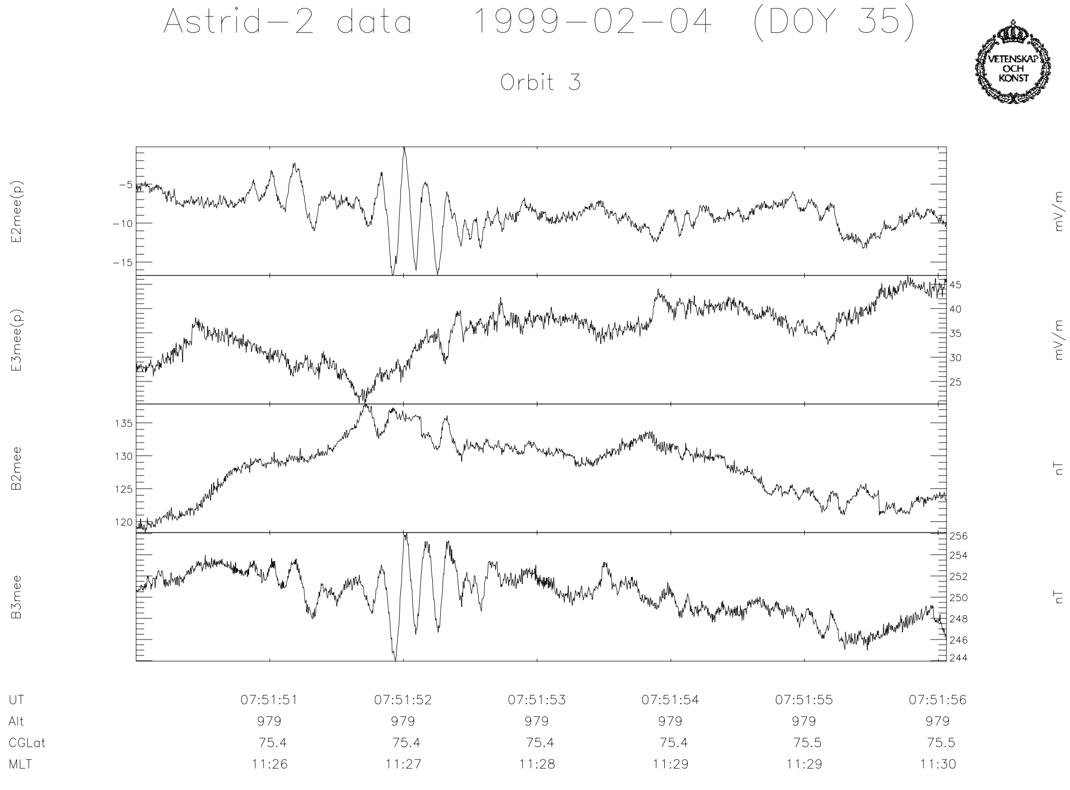

Fig. 4. An example of a localized period of quasiperiodic oscillations. The panels from top to bottom show eastward and southward components of E and B perpendicular to the model magnetic field direction.

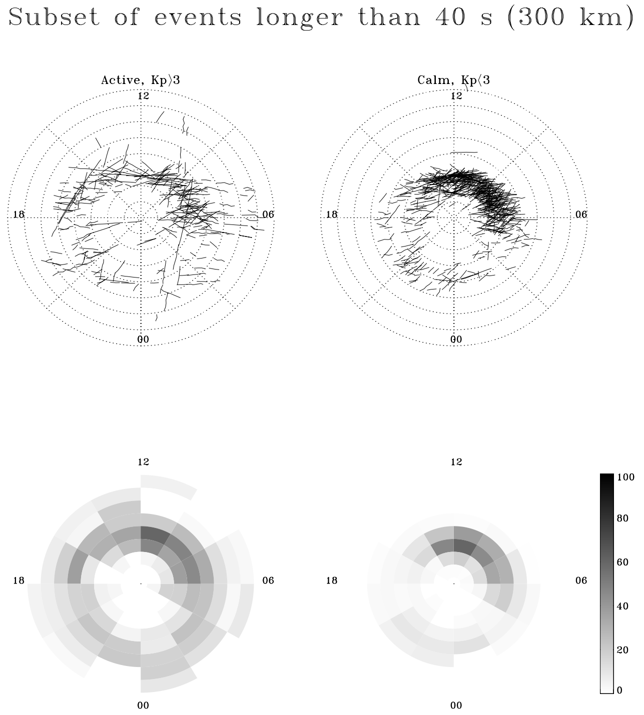

Fig. 5. Occurrence pattern of extended regions of Alfvénic activity. The upper panels show the location of the regions as traversed by the satellite, the lower panels the normalized observation probability. The panels on the left are for periods of high geomagnetic activity, the panels on the right are for periods of low activity.

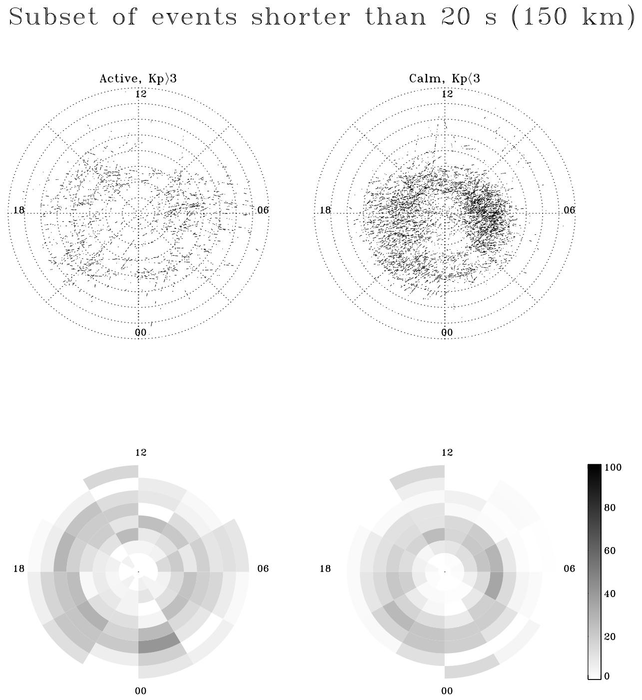

Fig. 6. Occurrence pattern of short intervals of Alfvénic activity. The upper panels show the location of the regions as traversed by the satellite, the lower panels the normalized observation probability. The panels on the left are for periods of high geomagnetic activity, the panels on the right are for periods of low activity.

in the covered spectral range. While examples of remarkable δE and δB correlations are seen occasionally, as in the train of linearly polarized oscillations seen in the dayside auroral oval shown in Fig. 4, the fluctuations are often less regular. The correlation between the electric and magnetic fields is generally better than in the extended turbulent regions. The amplitudes of the disturbances are lower than those in the extended regions of turbulence, typically of the order of 10–50 mV/m in the electric field.

To study the occurrence of the electromagnetic fluctuations, we binned all the data into two subdatabases corresponding to high and low geomagnetic activity ($K_P > 3$ and $K_P < 3$, respectively). The occurrence of the extended intervals of Alfvénic activity is shown in Fig. 5 and the occurrence of the short periods of electromagnetic fluctuations is shown in Fig. 6. It is seen that for both low and high activity the extended periods of Alfvénic turbulence are observed with a high probability (maximum over 70%) in the dayside cusp/cleft region, with the maximum occurrence lying shifted somewhat to the prenoon sector. For low activities the maximum occurrence shifts to higher geomagnetic latitudes, as expected for the cusp/cleft location. Another area of the extended turbulent regions is located in the nightside auroral oval. Here the fluctuations are less common, and are observed only for high activity levels. The occurrence of the short intervals of fluctuations is lower, and follows the statistical auroral oval for both low and high activity levels, coming to lower geomagnetic latitudes in the latter case. No clear locations of maxima can be seen.

4 Summary

Electric field fluctuations with frequencies between 0.5 and 8 Hz are commonly observed by the Astrid-2 microsatellite at 1000 km altitude. The associated magnetic field disturbances suggest that the fluctuations are of the Alfvénic nature. A variety of different waveforms are seen, with different degrees of correlation between the electric and magnetic fields. The events characterized by extended intervals of turbulence longer than tens of seconds have certain similarities. They show irregular fluctuations in both δE and δB, sometimes rather poorly correlated. The amplitudes of the electric field reach up to 200–300 mV/m. The extended regions with fluctuations have a high occurrence in the dayside cusp/cleft region (in agreement with findings of Berthelier et al. (1988) based on a smaller database), suggesting the electromagnetic activity is present in large spatial areas, at least hundreds of kilometers across. During periods of high geomagnetic activity, they are also observed in the nightside auroral oval, though with a somewhat lower probability. Both the cusp and the nightside oval during disturbed periods are the regions of large energy and plasma influx into the ionosphere. Similarities in the fluctuations seen in both regions suggest that it stems from this energy, even though the sources of plasma and physical mechanisms at play are essentially different at the dayside and at the nigthside. The short intervals of electromagnetic fluctuation, corresponding to more localized regions, are less uniform in appearance, and probably represent a number of different classes of phenomena. Having smaller amplitudes, they typically show a better correlation of δE and δB. The short bursts or localized regions of Alfvénic activity are rather uniformly spread along the auroral oval.

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