

Intermittency of the turbulent processes in the Earth's magnetosphere detected from the ground-based measurements

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Abstract. Turbulent processes in the Earth's magnetosphere are reflected in the dynamical behavior of the geomagnetic indices and other parameters determined from ground based observations. Intermittent properties of one minute Polar Cap (PC) index and auroral radio wave absorption are studied using 1995-2000 data sets. It was found that the probability distribution functions (PDFs) of both PC-index and absorption fluctuations display a strong non-Gaussian shape. This indicates that they are not characterized by a global time self-similarity but rather exhibit intermittency, as previously reported for solar wind velocity and auroral electrojet index values. In the case of the auroral absorption it was also found that intermittency strongly depends on the magnetic local time, being largest in the nighttime sector. This shows that the acceleration of precipitating particles is intermittent, especially near the substorm eye, where the level of turbulence increases. Application of the Local Intermittency Measure (LIM) technique confirms the aforementioned results to a better precision.

1. Introduction

The study of intermittency of space plasmas turbulence has been the subject of intensive discussions in the last few years. It is well established that for any fluctuation energy at a given scale is not evenly distributed in space and time. In other words, the behaviour of multiscale complex phenomena represents an interplay between periods of relative quiescence and short localized bursts of activity, observed in a variety systems including the Earth magnetosphere.

Here, values of the Polar Cap (PC) index (Troshichev, 2000) and of auroral radio wave absorption (Hargreaves, 1969), based observations are considered. PC as a measure of the variations of the large-scale dawn-dusk electric field, and auroral absorption as a proxy for energetic electrons precipitating along the geomagnetic field lines, reflecting the presence of induction electric fields.

The study of intermittency of time series for both quantities was done using the method proposed by Castaing et al. (1990) to describe the intermittent turbulent flow. To confirm previous results and to

make a more precise determination of intermittency the Local Intermittency Measure (LIM) technique is applied to auroral absorption values.

2. Data analysis

In our first analysis, we use the 1 min resolution PC-index data obtained at the Vostok station in 1992, 1995, January 1996, and 1997-2000, provided by the Arctic and Antarctic Research Institute (Stepanova et. al., 2006a).

To quantify the turbulent behaviour of the magnetosphere, we perform a statistical study of the PC index increments $\delta PC(t, \tau) \equiv PC(t + \tau) - PC(t)$ (see Figure 1), using the method proposed by Castaing et. al., (1990). They showed that turbulent behaviour can be represented, in the framework of a multiplicative cascade model, by a convolution of Gaussian variances σ distributed according to a log-normal distribution. This allows one to calculate a parameter λ depending on the scale τ , which represent the width of the log-normal distribution of the variances of the Gaussians the following PDF functional form:

$$P(x) = \frac{A}{2\pi\lambda} \int_0^\infty \exp\left[-\frac{x^2}{2\sigma^2} \left(1 + a \frac{x/\sigma}{\sqrt{1+(x/\sigma)^2}}\right)\right] x \exp\left[-\frac{\ln^2(\sigma/\sigma_0)}{2\lambda^2}\right] \frac{d\sigma}{\sigma^2} \quad (1)$$

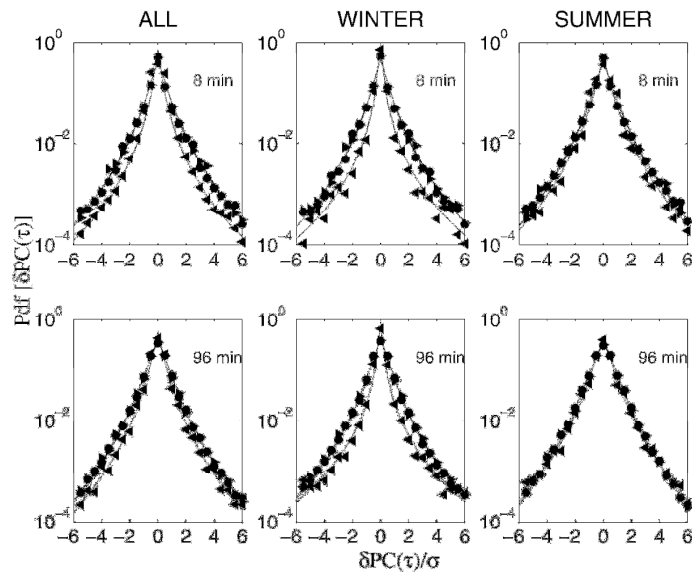


Figure 1. Probability density function $Pdf[\delta PC(\tau)]$ for two different time scales ($\tau = 8$ min, and $\tau = 96$ min) for total (\bullet), positive (\blacktriangleright), and negative (\blacktriangleleft) PC-index data sets, $\delta PC(\tau)$ is a standart deviation of $\delta PC(\tau)$.

where A is the normalization factor, a is the skewness factor, which describes the asymmetry of the PDF tails, and σ_0 the most probable variance fitted by (1), using a non-linear Nelder-Mead algorithm. As seen, PC-index has strong non-Gaussian character for all seasons and scales τ , which is more pronounced for negative values of the PC. This means, that the obtained PDFs are scale-dependent.

In order to study the evolution of the PDFs with the time-scale, we analyze the behaviour of $\lambda(\tau)$, which is the quantitative measure of intermittency. The adjust of data, result in a power law fit $\lambda(\tau) = \mu\tau^\alpha$. The best agreement between the obtained μ and α values for PC-index fluctuations and the

ones observed for the magnetic field fluctuations is between those for the summer PC index and the slow solar wind. Physical reasons for the observed relationships between of PC, AE, and solar wind parameter are discussed elsewhere (Stepanova et. al., 2006a).

Similar study was made for the AE-index intermittency (Consolini and De Michelis, 1998). In this case, the observed and fitted power-law dependence of λ^2 on τ , show that indeed λ^2 tends to decrease slowly with τ for all MLT hours, the absolute value of $\lambda^2(\tau)$ is higher for 18-24 MLT (Figure 2). This confirms the dependence of intermittency on MLT, the intermittency being significant only during night time.

In a second analysis (Stepanova et. al., 2006b), we have used the radio-wave absorption values from South Pole station (magnetic latitude of -74.2°).

Auroral absorption events at South Pole were first selected by visual inspection of one day plots, giving one-minute absorption values, covering the 1995 – 1997 intervals. The selection criteria used were event time structure and maximum absorption value. Although this clearly precludes the inclusion of any PCA events in the data base, it must be conceded also that some spiky events may be lost. To confirm that the selected events correspond to times for which South Pole lies within the auroral oval, Newell model images of the oval (Newell et al. 2002) corresponding to times nearest to each event were inspected whenever model images were available.

In total there were selected 535 events of more than one hour of duration. They were distributed according to the MLT in 8 sectors. Each event was analysed separately by applying the LIM technique. This method makes it possible to single out intermittent events from the time series by applying the wavelet transform (Farge et. al., 1990). The wavelet coefficients $w(\tau, t)$ are obtained through a convolution between the analysed function $f(t)$ and a shifted and scaled version of a given wavelet basis (ψ) as:

$$w(\tau, t) = \int f(t') \frac{1}{\sqrt{\tau}} \psi\left(\frac{t'-t}{\tau}\right) dt' \quad (2)$$

According to Parseval's theorem, $|w(\tau, t)|^2$ represents the energy content of fluctuations at the scale τ and the time t . The LIM is defined as

$$LIM(\tau, t) = \frac{|w(\tau, t)|^2}{\langle |w(\tau, t)|^2 \rangle_t} \quad (3)$$

When the *LIM* is equal to one for any time and scale, the time series does not exhibit an intermittent behaviour. On contrary, when it is greater than one, this means that a given time t and scale τ contribute more than the average over t to the Fourier energy spectrum at scale τ , and the series is intermittent.

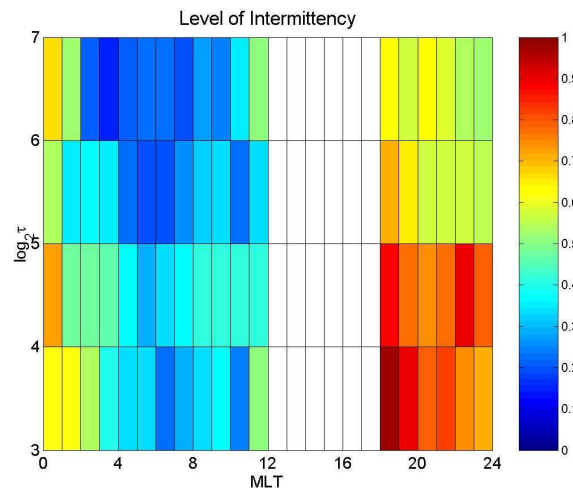


Figure 2: Magnetic local time dependence of Number of auroral absorption events analysed for each of λ^2 , a quantitative measure of intermittency of auroral absorption fluctuations, on τ , the time scale parameter.

Meneveau and Sreenivasan (1991) introduced the Flatness Factor of the wavelet coefficients distribution as:

$$FF(\tau) = \langle LIM^2(\tau, t) \rangle_t \quad (4)$$

Values of $FF(\tau) > 3$ allow localisation of events which lie outside the Gaussian statistics and cause intermittency.

We apply the *LIM* procedure to auroral absorption events measured at South Pole inside the 21-24 MLT interval, using a Mexican Hat basis (Stepanova et. al., 2006):

$$\psi(t) = \left(\frac{2}{\sqrt{3}} \pi^{-1/4} \right) (1-t^2) e^{-t^2/2} \quad (5)$$

for calculate the *FF* by equation (4). The *FF* decreases quickly with τ , and can be fitted by the power function $FF = \mu\tau^{-\alpha}$. We obtain the mean flatness factor value, averaged over all events inside each bin as a function of MLT and τ (Figure 3). As can be seen, the small scle fluctuations have larger values of *FF*. For $\tau < 8$ min the *FF* values lie outside the Gaussian statistic, indicating the presence of intermittency in these time scales. A clear maximum is observed between 20 and 24 MLT.

3. Results and conclusions

The PDF analysis of power spectrum of the PC-index, show a good agreement in their values of μ and α parameter with similar parameter observed for the same fitting parameters of the solar wind and AE-index. (Stepanova et. al., 2005). This indicates that PC-index adequately describes the energy transfer process from the solar wind to the polar ionosphere at different times scales, that is, the least perturbed nature of the information about the solar wind energy input to the magnetosphere contained in the PC index, makes itt useful for space weather forecast.

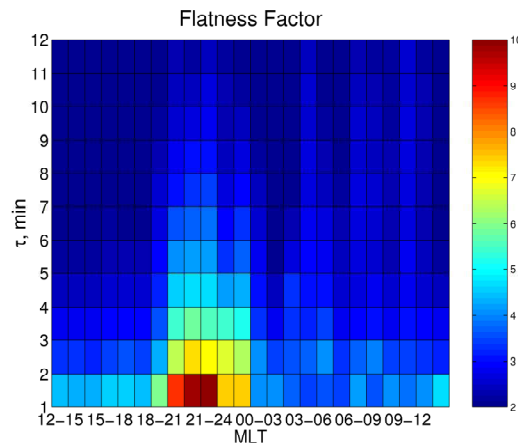


Figure 3: Mean flatness factor as a function of MLT and scale.

The LIM technique is a powerful tool for analysing time series for the presence of intermittency (Stepanova et. al., 2006). The intermittency can be treated as localised in time intervals of the time series for which a correlation exists. Applications of those techniques to auroral absorption values, confirms the intermittent behaviour of these ground based observations.

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