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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Statistical similarity between high energy charged particle fluxes in near-earth space and earthquakes" *by* P. Wang et al.

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We appreciate for appropriate and constructive suggestions to improve the manuscript and the point-by-point responsed to comments are listed as below.

Responses to referee 2

Major comments

Q1. The method applied to analyze the statistical properties of PBs is partially described. In Section 3, it is not clear how the PBs frequency fluctuation is applied in the context of the probability density function (PDF).

Answer1: The PBs frequency fluctuation is defined as Z_∆n = k_{n+∆n} – k_n, where n is an integer corresponding to the nth seismic event. kn is the total number of PBs counted in a time window centered around the nth seismic event. Here seismic events are arranged in order of time from n = 0 to 384 (See figure 1 (b)). ∆n is interval scale between two seismic events, they have different geographic location and date generally. It is in this sense that interval ∆n is both time and space scale between two seismic events.

During period 2005 – 2010, the total numbers of global seismic events are 385 with the magnitude greater than or equal to 5.0 and the McIlwain parameter $1.3 \leq L \leq 1.4$. For Z_1 = k_{n+1} - k_n (n = 0, 1, ...384), the successive fluctuation with time window $\pm$ 0.5 day is shown in figure 1 (c). The probability distribution function (the PDF) of P(z_1) (with ∆n=1) is illustrated by red circle in figure 2 (a), which is nearly symmetric and non-Gaussian. We also investigated fluctuation for larger intervals (with $2 \leq \Delta n \leq 100$). For different ∆n,P(z_∆n) collapse nearly on the same curve, which show that this behavior does not depend on scale intervals (see figure 2 (c)). More interestingly, this behavior is consistent with the fluctuation of energy released by the corresponding earthquakes.

Q2. The authors did explain why they excluded more than 50% of the DEMETER/IDP observations.

Answer2: Presently, we focus on statistical properties of particles from higher energy band of IDP. Both seismic events and particle fluxes are selected from the same L range $1.3 \leq L \leq 1.4$. Furthermore, very high counting rates region of satellite orbits (lat : $-90°$- 0°, lon : $-100°$- 45°) were excluded from consideration, which include the core region of SAA where the magnitude of particle fluxes across several orders. Similar method was adopted by Aleksandrin et al., (2003) and Sgrigna et al., (2005).

Specific points

1 Introduction

The works of Anagnostopoulos et al. (2012), Caruso et al. (2007) and Corral (2004) should be detailed in this Section. Page 1- Line 16-27: Authors cited several references in this paragraph. However it is not clear if the seismic activity is related to all electron precipitations. Other effects like the man-made transmitters (e.g. Sauvaud et al., Geophys. Res. Lett., 35, L09101, 2008) should be cited in this paragraph.

Answer: Anagnostopoulos et al. (2012) investigated the PBs time evolution over epicenter and revealed its profiles under various geomagnetic conditions for some strong earthquakes. They observed these PBs appeared several days before a large earthquake and accompanied by wide band VLF waves which could result in radiation belt electron precipitation by means of cyclotron-resonant interactions.

Sauvaud et at. (2008) examined inner radiation belt electrons enhancement caused by ground-based VLF transmitter NWC. They combined VLF wave and particle observations from the DEMETER satellite to demonstrate that cyclotron resonance is responsible for this process.

Sidiropoulos et al. (2011) compared the effects of radiation belt electron precipitation at middle latitudes induced by earthquake and ground-based man–made VLF transmitter. They found seismic events most probably dominate the process of electron precipitation which accounts for the presence of PBs.

As an alternative perspective, Corral (2004) suggested that the system should be regard as a whole and he found that the PDF of the earthquake recurrence times can be described by a unique universal distribution after time is rescaled, which is irrelevant of earthquake geographic location and magnitude ranges.

Caruso et al. (2007) analyzed the PDF of energy fluctuation released by earthquake at different times which exhibit q-Gaussian shape. Remarkably, this behavior does not depend on the time interval and consistent with the hypothesis that earthquake is a phenomena of dissipative self-organized criticality.

Page 1- Line 22-24: What are the other types of precursors?

Answer: The observation on high energy charged particle fluxes in near earth space has the advantage of global remote detection for particles fast eastward drifting. This research suggests a new possible precursor of strong earthquakes and shows potential advantage over other precursors, such as mechanical deformation, geochemical and hydrological precursors which are mainly based on local observations.

Page 1- Line 28: Is the ‘spatio-temporal’ related to the occurrence time and the location of the earthquakes.

Answer: Yes, spatio-temporal is relate to the occurrence time and the location of the earthquakes.

More explication should be given Page 1- Line 45: What means ‘universal’ statistical properties?

Answer: Here ‘universal’ statistical properties means that the PDF of PBs fluctuation is nearly spatio-temporal scale invariant, which does not depend on interval Δn (1 $\leq$ Δn $\leq$100). This is true only in the case of time window is $\pm$ 0.5 day.

Page 1- Line 46/475: Why the PBs plays the same role as the energy dissipated in earthquakes?

Answer: This is a topic is worth of more discussion. Here we just investigated this from statistical similarity. Both the PDFs of PBs fluctuation and corresponding energy fluctuation dissipated in earthquakes share similar q-Gaussian distribution. They both are independent on interval Δn (1 $\leq$ Δn $\leq$100). This is true only in the case of time window is $\pm$ 0.5 day.

2 DEMETER data

Page 1- Line 58/64: This paragraph should be moved to the end of the Section.

Answer: This paragraph contains the definition of PBs fluctuation, so we moved this paragraph to the location ahead of the illustration of figure 1b and 1c.

Page1- Line 58: The word ‘analogy’ refers to what? I suggest writing: ‘We analyze the PBs frequency fluctuations which are defined as ...’ instead of ‘To study this analogy, we analyze the PBs frequency fluctuations. The PBs frequency fluctuation is defined ...’.

Answer: We have corrected this sentence as referee suggested.

Page 2- Line 69/72: The authors should indicate the magnitude ($M > 2$) of the investigated earthquakes. In a Table, the authors may list (date, time, geographical latitude and longitude, magnitude) the strongest investigated earthquakes in the time interval 2005-2010.

Answer: We investigated the strong earthquake ($M \geq 5.0$) with data supplied by the IPGP. The total number of earthquakes are 385 with $M \geq 5.0$ and McIlwain L-parameter $1.3 \leq L <\leq 1.4$. We enclosed the table list for reference.

Page 2- Line 77: Why the southern hemisphere (lat: -90_ to 0_) and the geographical longitude range (-100_ to 45_) are excluded from this analysis?

Answer: The explanation is the same as the response to the Q2 of Major comments.

Page 2- Line 82/84: It is not clear from Fig.1a how ‘one PB will be regarded as two or more PBs’?

Answer: Our statement in this sentence may cause misunderstanding. We have changed it as ‘one PB is defined within 28 seconds.’

Page 2 – Line 84/92: Fig.1a refers to DEMETER observations of Feb. 2005. Is it the case of Fig.1b and Fig.1c? The selected areas and the time intervals are not given for Fig.1. A paragraph should be added to explain: (a) selected areas, (b) time intervals and (c) the gap origins (in Fig.1b and Fig.1c).

Answer: Figure 1a is a typical case for definition of PB date from 15 to 30, Feb, 2005.

Earthquakes and PBs are located at McIlwain L-parameter $1.3 \leq L <\leq 1.4$. Here time window is $\pm$ 1 day. Figure 1b and 1c are cases for total data set (2005 - 2010), they have the same area range as figure 1a but different time window ($\pm$ 0.5 day) which used to analyze the statistical properties exhibited in figure 3a and 3c.

The gap in the middle of Figure 1b means that there are no PBs satisfy the condition that PBs take place within time window $\pm$ 0.5 day for corresponding nth earthquake where both PBs and earthquakes have the same McIlwain L-parameter $1.3 \leq L <\leq 1.4$. It should be noted that this gap does not mean that there are no particle fluxes on the contrary there are particle fluxes appear but they do not satisfy the condition mentioned above. Figure 1c is the result of successive fluctuation of figure 1b.

Furthermore, the absent of PBs for those EQs are also considered in later analysis of the PDF of PBs fluctuation, where they take the value of $k = 0$. However, the reason for the cluster of $k = 0$ is still not clear for us until now.

Page 2 – Line 87: The successive frequency fluctuations are found positive and negative, according to Fig.1c. How the sign of z1 can be interpreted? Is this related to PB precursors when the z1 is negative?

Answer: The successive fluctuation is defined as Z_1 = k_{n+1}-k_n, where n is the nth earthquake and 1 means successive fluctuation. If k_{n+1} < k_n then Z_1 is negative. However there is no relation of PBs precursors with the sign of Z_1.

3 Statistical similarity

Page 2 – Line 94/109: In the two paragraphs, the authors estimated the PDF of PBs frequency fluctuations. They did not give clear interpretations of their results (shown in Fig.2). Why the maximum of PDF is around the center (i.e. z(delta n) equal zero)? Are the increase and the decrease of the PDF related to the PBs precursors? What is the physical interpretation of the no symmetric distribution? Is this related to the PB precursor on the Earthquakes’ preparation zone?

Answer: The maximum of PDF (See figure 2a and 2c) is around the center located at the place $z\_\Delta n = 0$. From the definition of $z_{\Delta n}$, $z_{\Delta n} = Z_{\Delta N}/\sigma$, we know that $k_{n+\Delta n}$ has the most probability with value equal to k_n. This behavior is nearly irrelevant of the interval Δn and it is similar to the energy fluctuation of corresponding EQs (See figure 3b). However we do not think that the increase or decrease of the PDFs are related to the PBs precursors.

The difference between the symmetry (See figure 2a and 2c) and asymmetry (See figure 2b and 2d) PDF is the different selection of the time window, $\pm$ 0.5 and $\pm$ 4 days respectively. Because of the statistical similarity among figure 2a, 2c and figure 3b, we suggest that PBs within time window $\pm$ 0.5 day are correlated with EQs. The asymmetry of the PDF in figure 2(b) and 2(d) maybe introduced by PBs which obey different statistical property after time window is extended to $\pm$ 4 days. The physical mechanism behind this asymmetry is still not clear for us.

Page 2 – Line 110/116: How the energy distribution of earthquakes is defined? Which seismic event data are used to find the power law of Fig.3a? Why the power law is not fitting the earthquakes data when the fluctuation distribution is smaller than 10 and 'S' bigger than 300 (magnitude around 5.7)? What is the magnitude of the earthquakes considered in Fig3a? Is the maximum (of magnitude) of about 7.0?

Answer: The energy S dissipated in an earthquake relates with the magnitude M, $S \equiv \exp(M)$. Similar to the definition for PBs fluctuations, the energy fluctuations for earthquakes are defined as $Z\_\Delta n = S_{n+\Delta n} - S_n$, where n is the nth seismic event. The PDFs for different Δn = 1, 10, 100 are plotted in figure 3b (Solid symbols).

Seismic event data, which is used to fit power law (See figure 3a), is also used in figure 1b, 1c, 2a, 2b, 2c, 2d and 3b. The total number of seismic events are 385, which are global distributed with McIlwain L-parameter $1.3 \leq L \leq 1.4$ and magnitude greater than or equal to 5.0 during the period 2005 – 2010.

We fitted the earthquake (Mentioned above) frequency distribution with power law that

y is proportional to $S^{-3.0}$ instead of earthquake fluctuation distribution in figure 3a. Relatively fewer strong earthquakes may cause deviation from power law as M increasing.

The magnitude of earthquakes considered in figure 3a is greater than or equal to 5.0.

The maximum of magnitude is 7.2, occurred at 16, Aug, 2005 with L = 1.32.

Page 2 – Line 125: The agreement (in Fig.3b) only concerns the earthquakes with magnitude smaller than 5.7. What about the strongest earthquakes, above 6 M?

Answer: As mentioned above, figure 3a is a power law fitting with earthquake frequency distribution.

The number of earthquakes greater than or equal to 6.0 M are 42 in our consideration. It is hard to do statistical analysis for this data set.

4 Conclusions

Page 2 – Line 138/139: What means the 'spatio' correlation? Page 2 – Line 139: The authors come to the conclusion that the occurrence of earthquakes is 'spatiotemporal'correlated. In the paper, may be, only the 'temporal correlation' was analyzed but not the spatial one. Is it possible to compare their results to the work of Corral (2004)?

Answer: Seismic events are arranged in order of time from n = 0 to 384 (See figure 1 (b)). Δn is interval scale between two seismic events. They distribute globally with different geographic location and occurrence time. It is in this sense that different intervals Δn are both time and space scale between two seismic events.

For different Δn, the PDFs of $P(z\_\Delta n)$ collapse nearly on the same curve (See figure 2(a) and 2(c)), which show that this behavior does not depend on various scale intervals (see figure 2 (c)). The results show fat tails and non-Gaussian behavior, which was explained with a dissipative Olami-Feder-Christensen model (OFC) when long-range interaction is considered (Caruso et at., 2007).

Corral (2004) investigated the PDF of the earthquake recurrence times and found it can be described by a unique universal distribution after time is rescaled, which is irrelevant of earthquake geographic location and magnitude ranges. Our work analyzed the PDF of fluctuation of PBs and EQs at various intervals. They both focused on the universal behavior of EQs.

Page 2 – Line 148: Are DEMETER/IDP measurements associated to the particle counting rates or to the charged particle fluxes?

Answer: Different detectors may have different geometric factors, but environment counting rates or particle fluxes should be independent of the detector, including DEMETER/IDP.

Page 2 – Line 147/150: Is it possible to estimate the time delay (in hours or days) between the PB events and the earthquakes occurrences?

Answer: According to the results exhibited in figure 2(a) , 2(c) and 3(b), together with the definition of time window, T = T_PBs - T_EQs, we estimate time delay or advance between the PBs events and the earthquakes occurrences time may be within $\pm$ 0.5 day.

References It will be useful to consider alphabetic names in the reference list.

Answer: We have changed the reference list in an alphabetic order.

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