

## ***Interactive comment on “Statistical study of ULF waves in the magnetotail by THEMIS observations” by Shuai Zhang et al.***

**Shuai Zhang et al.**

tamin@sdu.edu.cn

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First of all, we would like to thank the reviewer for the helpful comments and suggestions. We are very appreciative of that. Our responses to the comments are in **blue** font. In the revised manuscript, the modifications are highlighted in **red** font.

### **General comments**

This paper presents results from a statistical study of ULF waves in the Pc5-Pc6 frequency range in the magnetotail using magnetic field and plasma data from instruments onboard the THEMIS satellite during 2008-2015. Azimuthally oscillating waves and radially oscillating waves are studied separately. The authors found that in the near-Earth magnetotail the dawn-dusk asymmetry of wave occurrence is observed only

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in the case of radially oscillating waves. In the far magnetotail, they reveal a higher occurrence rate during post-midnight magnetic local times than during pre-midnight, and that the peak frequency of waves decreases with increasing radial distance from Earth. A majority of events in the near-Earth magnetotail are standing waves, while these represent very small percentage of the events in the far magnetotail. No dawn-dusk asymmetry could be found in the wave frequencies. Finally, the authors studied the effects of solar wind parameters and geomagnetic activity, and found that ULF wave occurrence is favoured by high solar wind speed, high solar wind pressure variability, but quiet to moderately active geomagnetic activity. Overall, the paper is well-written, the reasoning is clearly exposed, and it reaches substantial conclusions. Below are a few specific comments which could be considered to improve the manuscript before final publication.

### **Specific comments (major)**

l) It would be good to have a figure in the same format as Figure 3 showing the number of events in each bin, both for azimuthal and radial oscillating events. Indeed, the text mentions on several occasions that a given bin should be considered with caution due to the small number of events it contains. In particular, such an additional figure could help in analysing Figure 4, as one might want to be cautious in drawing conclusions with so many blank bins in this figure.

**We have added the distribution of event numbers in Fig. 3 in the revised manuscript. Two sentences have been added in lines 173-175: “Figure 3a and 3b shows the spatial distribution of the number of events in the GSM\* X-Y plane, both for azimuthal (left panel) and radial (right panel) oscillating wave events. The blank bins inside the magnetopause indicate that there are no events.”.**

l. 327: “solar wind dynamic pressure (Pd) and the IMF Bz values were also examined (not shown).” ! If the results on the dynamic pressure are mentioned in the conclusion (see l. 386), I would recommend to show the analysis of these parameters in the paper.

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Thanks for your suggestions. The relationship between the occurrence of ULF waves and the relative variation of solar wind dynamic pressure (Pd) and the IMF Bz values have been added in Fig. 8 (Fig. 8c and 8d) in the revised manuscript. And the calculation formula of the relative variation of Pd have been added in lines 347-349 in the revised manuscript.

#### Specific comments (minor)

I. 42: I suggest to give the frequency range for ULF waves from the very beginning of the introduction.

The frequency range for ULF waves have been added in line 42 in the revised manuscript.

I. 69: The full name of THEMIS should be given when mentioned for the first time after the abstract (see AnGeo guidelines: [https://www.annaes-geophysicae.net/for\\_authors/manuscript\\_preparation.html](https://www.annaes-geophysicae.net/for_authors/manuscript_preparation.html)).

Ok. The full name of THEMIS has been added in lines 69-70 in the revised manuscript.

I. 75: Please define MLT.

The definition of MLT have been added in line 75 in the revised manuscript.

I. 77 and 79: "Susumu Kokubun (2013)" ! please check the reference. I think it should be "Kokubun (2013)", and in the reference list it should appear as "Kokubun, S. (2013). ULF waves in the outer magnetosphere...".

Yes, revised.

I. 82: Pi2 should be defined.

Ok. The definition of Pi2 have been added in line 83 in the revised manuscript.

I. 108: It could be worth briefly defining the GSM coordinate system here.

Ok. The definition of GSM coordinate system has been added in lines 115-119 in the

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revised manuscript.

I. 120: I assume Dp stands for "dynamic pressure"; perhaps it would be better to make it fully clear to the reader.

Yes, it stands for "dynamic pressure". The full name of Dp has been added in line 112 in the revised manuscript.

Figure 2: I would suggest that, for a given event (A/B), the three components of the velocity, magnetic field, electric field should have the same y-axis limits. This would better emphasise the azimuthal or radial nature of the oscillations. This could also be done for the components of the PSD of the velocity, as the relative importance of the peaks would be immediately visible, without needing to look at the scale for comparison. An exception should obviously be made for panel (d2), as the Bz range for event B is very large.

Ok. We re-plotted Fig. 2 using the same y-axis limits for the components of each vector quantity (except Bz) in the revised manuscript.

I. 174: "calculated by dividing the total event times by the total observation times" ! do you mean the total number of events/observations? Or the total duration of events/observations? This wording may be ambiguous; please rephrase.

Ok. The sentence has been rephrased as "calculated by dividing the total duration of all events by the total duration of observations in each bin" in line 183 in the revised manuscript.

I. 177: "For azimuthal oscillating events, there is no clear dawn-dusk asymmetry in the occurrence rates" ! based on Figure 3, this statement seems a bit too strong, since high occurrence rates (red colour) span within 18–20 MLT on the duskside vs 5–6 MLT on the dawnside. Perhaps rephrasing this statement into something like "For azimuthal oscillating events, the dawn-dusk asymmetry in the occurrence rates is less clear than for radial oscillating events" would be better. Similarly, this statement should also be

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made less strong in the conclusion and abstract.

Thank you, the sentence has been rephrased as "For radial oscillating events, the occurrence rates of waves are higher on the duskside than dawnside. For azimuthal oscillating events, the dawn-dusk asymmetry in the occurrence rates is less clear than that for radial oscillating events." in lines 187-189 in the revised manuscript. Similarly, the sentence has also been rephrased in lines 281-283 and 397-399 in the revised manuscript.

I. 202: "the frequency can be as low as 0.55 mHz" which is the lower frequency in the Pc6 band retained in this study. Could there be waves with even lower frequency observed? To my knowledge, there is no upper limit in the period of Pc6 oscillation (see Saito, T. (1978), Long-period irregular magnetic pulsation, Pi3, Space Sci. Rev., 21(4), 427–467, doi:10.1007/BF00173068), so it could be interesting to check whether pulsations of even lower frequency can be identified.

The field aligned coordinates used in this work are obtained by subtracting the 30min sliding average background magnetic field. So, we only focus on waves with frequencies above 0.55mHz. However, in the preliminary screening stage, we did notice two wave events with frequencies as low as 0.49 mHz and 0.51mHz, which can be studied in the future work. Besides, the words "Pc6 (>600s)" were revised in line 57 in the revised manuscript. The paper of Saito (1978) was quoted in the lines 58 and 496-497 in the revised manuscript.

I. 226: "The second row shows the 1.26-3.26 mHz (Fig. 6a) and 2.03-4.03 mHz (Fig. 6b) band-pass filtered Ba and Er components"!how were those frequency bands selected?

The lower (upper) limit of the frequency bands is obtained by subtracting (adding) 1 mHz from the peak frequency in Fig. 2(l-n). We added one sentence in lines 237-238.

I. 319-320: The calculation of the normalised event number does not seem fully clear

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to me. Is it so that the number of events is divided by the proportion of solar wind speed within a given bin to the total duration of solar wind measurements? Or are events binned according to the mean/median solar wind speed at the time when they were observed? Please rephrase this explanation.

Yes, the detailed calculation formula for the normalized event number is as follows (take that dividing by the duration proportion of solar wind  $V_x$  as an example):

$$\begin{aligned} \text{Normalized event number} &= \frac{\text{the number of events in a given bin}}{\text{the duration proportion of solar wind } V_x \text{ in a given bin}} \\ &= \frac{\text{the number of events in a given bin}}{\frac{\text{duration of background } V_x \text{ in a given bin}}{\text{total duration of background } V_x}} \end{aligned}$$

Taking into account the suggestion of another reviewer, we re-plotted Figure 8. The new vertical axis shows the probability of detecting a wave event instead of the normalized number of events in each bin. The probability is calculated by dividing the normalized event number in a given bin by the total normalized event number of all bins (take the solar wind  $V_x$  as an example). The sentence has been rephrased to "The Y-axis indicates the probability of detecting one wave event in each bin. The background solar wind data is obtained from OMNI from 2008 to 2015." in lines 338-339 in the revised manuscript.

#### Copyediting and typesetting

All the following problems have been corrected in the revised manuscript accordingly.

I. 57: "primarily" being an adverb, it cannot be used in this context. Instead, one could write, for instance, "Pc5 and Pc6 waves are the most common waves observed at high latitudes and in the magnetotail."

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- l. 60: "nightside" is generally written in a single word (same for dawnside, dayside, duskside...)
- l. 67: "the both occurrence and frequency distributions..." -> "both the occurrence and frequency distributions..."
- l. 102, l. 201: earth ! Earth
- l. 106: sub-solar ! subsolar
- l. 108: "whose X axis **is** rotated"
- l. 145: "to satisfy **the** criteria mentioned above"
- l. 154: "of **the** three components"
- l. 260: "the magnetic field lines in the nightside **are** very stretched"
- l. 276: "K-H instabilities are **more** inclined to occur in the dawnside than in the dusk-side"
- l. 278: "more events are needed **to** further study the definite reasons" l. 286: Alfvén ! Alfvén
- l. 321: "the ULF waves occurrences increase with" ! "the ULF wave occurrence increases with"
- l. 322: a sources ! a source
- l. 324: "the waves occurrences are higher" ! "the wave occurrence is higher"
- l. 327: occurrence
- l. 336: (Forsyth et al., 2015) ! Forsyth et al. (2015)
- l. 379: "the peak frequency decreases **with increasing** radial distance"
- l. 383: "the frequencies for all the events in this paper do not show obvious dawndusk"

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asymmetry **contrary to results from** previous studies for waves in the inner magnetosphere" (the original phrasing can be ambiguous and interpreted the other way round)

- l. 387: maybe ! may be
- l. 389: "that the ULF waves **are** most likely to occur"

Please also note the supplement to this comment:  
<https://www.ann-geophys-discuss.net/angeo-2018-39/angeo-2018-39-AC1-supplement.pdf>

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Interactive comment on Ann. Geophys. Discuss., <https://doi.org/10.5194/angeo-2018-39>, 2018.

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