Reply to the Review Comments #2

The manuscript addresses the interesting scientific problem of understanding the properties of large scale travelling ionospheric disturbances (LSTIDs), which are frequently observed during geomagnetic storms. This manuscript discusses the properties of LSTIDs during 17th March 2015 with focus on the Chinese and Japanese sector. Although, descriptions of LSTID occurrence during this event have been published before, this manuscript adds new aspects on the longitudinal dependence of the LSTID properties in the Chinese/ Japanese sector based on GNSS, HF and ionosonde data. The manuscript is well structured, well written and presents analysis of high quality in a well understandable way. Thus, my overall evaluation is publishing after solving minor remarks. The manuscript in its current form has three weak points.

Thank you for your substantial and detailed comments here and in the supplement material! According to these comments and corresponding annotations in the supplement material, we revised the manuscripts on the basis of the last revised draft based on reviewer 1 comments. And gave our replies point by point. The red colors mark the revised parts and the new references.

Since this revision is based on the revised manuscript according to Review Comments #1. The revised part related to reviewer 1 comments is marked with yellow highlights.

Reply to Major Comment:

Major Comment I.

I. First, already in the abstract the authors are referring to negative and positive LSTIDs and seem to treat them in the course of the manuscript like separate phenomenon. Since these LSTIDs are the signature of atmospheric gravity waves, both signatures belong to the same wave. Therefore, I would recommend to avoid discussing positive and negative amplitudes separately.

Related Annotation: measuring wave trough and crest should be rather the same, since they belong to one phenomenon, which is the gravity wave. However, the wave properties might change with time dependent on the forcing. This might explain the differences of both measurements. Looking at the error margins, both Vt and Vc indeed overlap (although only marginally). This is good.

Reply I.

Thank you very much for these suggestions!

Firstly, we misused phrases of “negative and positive LSTIDs”. They should be “the trough and crest of the LSTID”. This has also been pointed out by the Review Comments #1. We have revised those misleading statements accordingly. Besides, because the scale of this LSTID (period and wavelength) is very large and cover large spatial region, the wavefront of the LSTID maybe deformed due to different background condition during its propagation from higher to lower latitude, we discussed the trough and crest of the LSTID separately since they behave differently, which can be seen in our results. This may be attributed to, as the reviewer suggest, that the wave properties change with time dependent on the forcing. Meanwhile, Vt and Vc show certain

consistency. We have revised our manuscript accordingly to make these clear. To be specific:

The statement

"Besides, it is interesting to note that the mean Vc is slightly larger than the mean Vt, which seems like the wave behind is pushing that ahead."

is revised to

Page 8, Lines 28-33: "Vt and Vc overlap, although only marginally, considering the error ranges. Meanwhile, the mean Vc is slightly larger than the mean Vt, which seems like the wave behind is pushing that ahead. In general, the speed of trough and crest of the LSTID should be rather the same since they are induced by the same gravity wave. However, the wave properties might change with time dependent on the forcing from background condition, especially for LSTID covering large spatial region. This might explain the differences."

Major Comment II.

II. Second, the key point of the manuscript is the discussion of longitudinal dependence of LSTID properties. But, this is impacted by the data coverage. The data coverage is lower in the east and west boundaries of the investigated region. I argue that this impacts the accuracy of the estimation of the LSTID properties. The discussion of the LSTID properties (wavelength, period and speed) should be treated with more care concerning reliability of the results.

Related Annotation. Please elaborate on the impact of data coverage and size of the regions of investigation on the accuracy of the results. The regions used for the Time-Latitude Plots cover about 20 °in latitude. This is roughly one wavelength. If the data coverage is reduced (what is the case in the East and West regions), this introduces certainly an error on the results.

Related Annotation. Nice figure and good illustration. Again, I am requesting to elaborate on the accuracy of the results. The deviation between geomagnetic declination and wave propagation direction is largest in the East and West, where you have lower data coverage.

Related Annotation. I see it critical to highlight this fact, on the one hand because there is no clear dependence and explanation for the longitudinal tendency and on the other hand, it might be impacted by the measurement properties.

Reply II.

Thank you very much!

Indeed, the data coverage in the East and West boundaries of the studied region is relatively lower comparing to that between 100 ℃-120 ℃. Such difference in data coverage is resulted from both GPS-receivers and land-sea distributions. Besides, the studied latitudinal range is ~ 20 °, which is roughly one wavelength as the reviewer pointed out.

Meanwhile, it should be noted that we do had considered these issues in the manuscript and tried our best to reduce such influences. For example, we selected areas for every l0 longitudinal degrees with varying latitudinal ranges (Figure 7) to include as many data points as possible. Data in longitudinal bands of 70 ℃-80 ℃ and 140 ℃-150 ℃ were not used considering the bad data coverage. Besides, data in every 0.1-hours bin in TLPs (Figure 8) was obtained by latitudinal average for every 10 °longitudinal band. We find that data in 130 ℃-140 ℃ is hugely influenced by

data coverage, so it has not been used when deriving LSTID parameters. In addition, since the studied latitudinal range is roughly one wavelength, it is hard to estimate the wavelength directly from the 2D VTECP map. Instead, the wavelength is estimate with the velocity and period from TLPs.

Of course, these cannot totally eliminate the data-coverage influence to the estimation accuracy of the LSTID parameters. Our results should be examined by further studies with better data coverage in a wider longitudinal range.

The statement

"Finally, with the period and speed, the wavelength can be easily determined."

is revised to

Page 8, Lines 17-20: "As for the estimation of wavelength, note that the studied area is ~ 20 ° in latitude, which is roughly one wavelength and thus make it difficult to estimate the wavelength directly from the 2D VTECP′ map. So, the wavelength is derived from the multiplication of speed and period."

The statement

"The longitudinal dependence of these parameters can be seen clearly."

is revised to

Page 8, Lines 23-26: "It can be seen that these parameters show certain longitudinal dependence. It should be noted that the data coverage is relatively lower in the east and west boundaries of the investigated region. This may impact the accuracy of the estimation of the LSTID properties in these areas."

The statement

"It should be noted that our speculation needs to be verified with more observational data and numerical simulation to reduce uncertainty in our propagation estimation and to figure out the detailed physical processes."

is revised to

Page 10, Lines 34-35: "Besides, considering the relatively low data coverage in the East/West side of the studied region, it should be noted that our speculation needs to be verified with more observational data and numerical simulation to reduce uncertainty in our propagation estimation and to figure out the detailed physical processes."

The statement

"(3) Other propagation parameters are also longitudinal dependent (see Table 1), and the mean values and standard deviations of the period, Vt, Vc, and wavelength are 74.8±1.4 minutes, 578±16 m/s, 617±23 m/s, and 2691±80 km, respectively.".

is revised to

Page 11, Lines 40-Page 12, Lines 6: "(3) The propagation parameters in different longitudinal bands are estimated. These parameters show certain longitudinal dependence. Besides, the mean values and standard deviations of the period, Vt, Vc, and wavelength are 74.8±1.4 minutes, 578±16 m/s, 617±23 m/s, and 2691±80 km, respectively.

It should be noted that our results show certain consistency with previous works focusing on the

Chinese or Japanese sector for different LSTID events. Nevertheless, the longitudinal dependence shown in our results should be examined further with more case studies based on large longitudinal and high-resolution coverage of GPS data."

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Major Comment III.

III. Third, the authors present also the result of the LSTID occurrence in Europe. This has been extensively discussed in Borries et al. (2016, https://doi.org/10.1002/2016JA023178). Specifically, the LSTID occurring between 11 and 12 UT has been discussed to be "special" because it is impacted by winds and prompt penetration electric fields at the same time. This fact should be included in the discussion of this manuscript. It supports the finding of the authors that the LSTID properties in Europe differ from the LSTID properties in the Chinese/ Japanese sector.

Related Annotation: Borries et al. (2016) shows and discusses some more details about the LSTIDs. The LSTID between 11 and 12 UT is specifically large and a combination of wind and electric field effects.

Related Annotation: The reason for the difference are the different physical processes that compete over Europe (as described in Borries et al., 2016).

Related Annotation: It is not clear why these LSTIDs can be only driven by winds. Please elaborate what would be the difference in case these TEC perturbations would be driven by electric fields.

Reply III.

Thank you very much for recommending this reference!

Actually, after the manuscript submission, we noticed that we missed this reference. This paper has also been recommended by the Review Comments #1. We have already added it into the revision.

According to this comment and related annotation, the statements about the difference between East-Asian and European sectors focusing on PPEF are added accordingly.

The statement

"In addition, the tendency of field-aligned propagation of the LSTID indicates that it is driven by the neutral winds rather than by electric fields since the winds push the plasma up and down along the magnetic field lines."

is revised to

Page 10, Lines 29-34: "In addition, the tendency of field-aligned propagation of the LSTID indicates that it is driven by the neutral winds since the winds push the plasma up and down along the magnetic field lines. There is no evidence, such as simultaneous perturbations at all latitudes in other cases [Borries et al., 2016; Zakharenkova et al., 2016], to show that the LSTID in the Chinese/Japanese sector is affected by prompt penetration electric field (PPEF) during the same period."

Statements below are added.

Page 11, Lines 15-19: "Borries et al. [2016] present a detailed study on the LSTID in Europe during this storm. It is suggested that the perturbation occurring around 11:00 UT is special since it is impacted by PPEF and wind at the same time. Comparatively, the LSTID in the Chinese/Japanese sector seems only driven by winds. This may partly account for the longitudinal difference in our results."

Technical Recommendations/Corrections:

Comment 1

Jakowski et al. (2008) did not discuss LSTIDs but large scale gradients (no discussion of wave properties)

Reply 1

Thank you very much! This reference has been deleted in the revised article.

Comment 2

URLs of the data sources are usually provided in the acknowledgements, not in the text.

Reply 2

Thank you very much! URLs of the data sources have been moved into the acknowledgements.

Comment 3

Presenting the LSTID results with VTECP' has the advantage of better illustrating most wave properties, but it does not represent the true wave amplitude anymore. On a quick view, the figures might be misinterpreted. Therefore, I recommend to make it very clear that this is an "artificial" amplitude.

Related Annotation: This is certainly nice to better visualize the positive and negative amplitude of the TEC perturbation. But the authors should take care, that the readers do not misinterprete the amplitude of the TEC perturbation. It looks like the Amplitude is about 2 TECU, but is that the true amplitude?

Reply 3

Thank you very much for this suggestion! We have revised the manuscript accordingly.

The statement

"Note that the raw value of VTECP is converted into VTECP′ with

$$VTECP' = sign(VTECP) * log_{10}(abs(VTECP) + 1)$$

to make it easier to distinguish the regions with positive and negative perturbations."

has been revised to:

Page 6, Lines 2-9: "The raw value of VTECP has already been converted into VTECP′ with the equation

$$\mathrm{VTECP'} = \mathrm{sgn(VTECP)} * \log_{10}(\mathrm{abs(VTECP)} + 1) \quad (3)$$

The raw amplitude of VTECP above 30 ℃N is ~ 2 TECu while the raw amplitude of VTECP below 30 ℃N (dip latitude) reaches ~ 10 TECu. So, transform (3) provides a better colormap for 2D

VTECP plots by sharpening the edges between positive and negative values and reduce the differences of VTECP in middle and low latitudes. Consequently, it should be noted that the amplitude of the wavelike variation does not represent the true wave amplitude but an "artificial" one."

The Figure 4 caption

"**Figure 4.** A series of 2D VTECP′ maps over the East Asian sector from the period of 09:40-09:50 UT to 11:30-11:40 UT on 17 March 2015. The grey areas represent the nightside. The colorbar represents the VTECP′ (units: TECu). The lime and yellow lines illustrate the least square fittings (order 2) for wavefronts."

is revised as

Page 17, Lines 13-17: "**Figure 4.** A series of 2D VTECP′ maps over the East Asian sector from the period of 09:40-09:50 UT to 11:30-11:40 UT on 17 March 2015. The grey areas represent the nightside. The colorbar represents the VTECP′ (units: TECu), which is transformed from the original VTECP value with equation (3) for a more viewer-friendly colormap. The green and yellow lines illustrate the least square fittings (order 2) for wavefronts."

Comment 4

Figures 3 and 5 do not have much content. But they are supposed to be compared with each other. Therefore, I recommend to join the content of both figures into one figure. This will increase the information density and allow better comparability.

Related Annotation: I think, it would be nice to join Fig3 and Fig 5 to one plot, to have a more direct comparison of peaks in both plots and better visualize the similarities.

Reply 4

Thank you very much!

It is a good idea to combine Figure 3 and 5 together to have a more direct comparison. However, combining them together will change the logical frame of the manuscript and a lot of places need to be rewritten considering the context. So, we plot the variation of doppler shifts into Figure 5.

Figure 5 is revised to

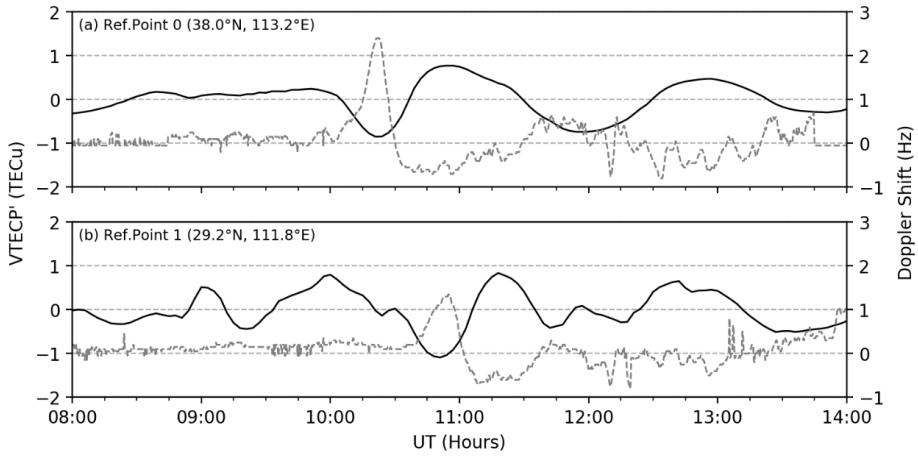

Figure 5 description is expanded to

Page 17, Lines 18-20: "**Figure 5.** Temporal variations of mean VTECP′ near the Doppler

reflection points between 08:00 UT and 14:00 UT, 17 March 2015. Doppler shift recordings in Figure 3 are plotted with dashed lines for comparison."

The statement below is added.

Page 6, lines 38-39: "Doppler shift recordings in Figure 3 are also plotted with dashed lines for comparison."

Comment 5

In figure 8, the impact of EIA is addressed. I assume, the dashed black lines indicate the boundary of EIA. This should be made clear in the text and figure description

Related Annotation: Please include a sentence describing, how the reader is going to identify the EIA region. I assume, the black dashed lines are encapsulating this region.

Reply 5

Thank you very much! The manuscript has been revised accordingly.

The statements

"As mentioned before, the variation of VTECP′ in the EIA region is rather complex, so only the values over 30°N (marked with dashed lines) are used to estimate the speed."

is revised to

Page 8, Lines 2-5: "As mentioned before, the VTECP′ variation related to EIA is rather complex. Considering that EIA is mainly a low-latitudinal phenomenon, the 30 ℃N is marked with black dashed lines in Figure 8 which indicate the boundary of EIA. Only values over 30 ℃N are used to estimate the speed."

Figure 8 caption

"**Figure 8.** TLPs of VTECP′ for different longitudinal bands between 07:00-14:00 UT. White dots give the data points for linear fitting, and the fitting results are marked with white lines. Black dashed lines depict 30 ℃N in (b-d, f) and 40 ℃N in (f)."

is revised as

Page 17, Lines 29-31: "**Figure 8.** TLPs of VTECP′ for different longitudinal bands between 07:00-14:00 UT. White dots give the data points for linear fitting, and the fitting results are marked with white lines. 30 ℃N in (b-d, f) is marked with black dashed lines which indicate the boundary of EIA. 40 ℃N is marked in (f)."

Comment 6

In the discussion section, the authors exclude the impact of electric fields on the LSTID propagation and favour the impact of winds, driving the LSTID propagation because of field-aligned propagation. For a better understanding, the authors should explain, what would be different in case of electric field impact. In fact, since Borries et al. (2016) describe prompt penetration electric field impact in Europe at that time, more emphasis should be given to discuss electric field impact in the Chinese/Japanese sector at the same time.

Reply 6

Thank you very much for this suggestion! This Comment is related to the Major Comment III. Please refer to replies to in that section in page 2.

Comment 7

I detected a few spelling errors and grammar issues (indicated in the supplementary material). I expect, there are more than I found and recommend professional editing.

Reply 7

Thank you very much!

We have revised all the spelling errors and grammar issues that indicated in the supplementary material. We have further checked throughout the article and found several other errors and they have also been revised in the revision. All of them are marked with red color in the supplement material.