Responses to Anonymous Referee #1

- **Reviewer's comment:**

This paper presents tidal proxies in MIPAS temperatures inferred as global ascending-descending node differences. The authors explain how these differences highlight diurnal and terdiurnal ("odd") harmonics, and present longitudinal spectral decompositions asa fnction of latitude, altitude and month. The novelty of the work lies in the presentations of MIPAS thermospheric temperatures, the first such results presented above 100 km. This paper is very pertinent to thermospheric dynamics and energetics, and should inform tidal modeling and studies of vertical coupling. I recommend publication after the comments below are addressed, and after a more thorough editing for English grammar.

Author's response:

We thank the Reviewer for his/her comments. We think we addressed them all and they certainly improved the manuscript. A native English speaker has checked the grammar of the reviewed version.

Main changes of the manuscript are: update of the version of retrieved thermospheric temperatures (results barely change); inclusion of new figures with lower altitude of 40 km; old Sect. 3 has been moved to an Appendix; the discussion on thermospheric tides has been extended.

- **Reviewer's comment:**

1. Abstract, line 9-10: The data do not inform you of the QBO transmission process; only the facts should be reported. Change to " ...4) a quasi-biennial oscillation of the migrating tide in the stratosphere and the MLT."

Author's response:

Done.

- **Reviewer's comment:**

2. Lines 35-36: "Tidal inter-annual variability is thought to be correlated with the El Nino-Southern Oscillation (ENSO)"

The following paper demonstrated clearly how ENSO causes tidal variability.

Lieberman, R. S., D. M. Riggin, D. A. Ortland, S. W. Nesbitt, and R. A. Vincent (2007), Variability of mesospheric diurnal tides and tropospheric diurnal heating during 1997–1998, J. Geophys. Res., 112, D20110, doi:10.1029/2007JD008578.

Author's response:

We deleted 'thought to be' and included the reference.

- **Reviewer's comment:**

3. Lines 47-48: "The extent to which tides propagate from the lower atmosphere to the thermosphere or to which changes in lower altitude regions are transmitted by tides to the upper atmosphere or to other latitudes is not completely known."

The following papers should be cited in this section:

Talaat, E. R., and R. S. Lieberman (2010), Direct observations of nonmigrating diurnal tides in the equatorial thermosphere, Geophys. Res. Lett., 37, L04803, doi:10.1029/2009GL041845.

Lieberman, R. S., J. Oberheide, and E. R. Talaat (2013), Nonmigrating diurnal tides observed in global thermospheric winds, J. Geophys. Res. Space Physics, 118, 7384– 7397, doi:10.1002/2013JA018975.

Lieberman, R. S., D. M. Riggin, D. A. Ortland, J. Oberheide, and D. E. Siskind (2015), Global observations and modeling of nonmigrating diurnal tides generated by tide-planetary wave interactions, J. Geophys. Res. Atmos., 120, doi:10.1002/2015JD023739.

Author's response:

Done. They are now included in the next paragraph of the manuscript.

- **Reviewer's comment:**

4. Lines 58-70. This paragraph is extremely confusing, and should be deleted. The authors discuss sun-synchronous sampling before the MIPAS satellite and its orbit are even mentioned. Non-sun-synchronous sampling is not relevant here.

Author's response:

An unavoidable caveat in sun-synchronous measurements is aliasing of certain tidal modes. Slowly precessing satellites eventually provide a complete local time coverage that overcomes that problem but at the expense of the temporal resolution. We did not delete the whole paragraph in the text but we significantly shorten and clarify it. We have also exchanged the order of this paragraph and the (old) next one.

- **Reviewer's comment:**

5. Lines 74-76: "Therefore, they provide a wealth of information on the tidal excitation mechanisms, the processes inducing tidal variability and the lower and upper atmosphere coupling through tides". Delete this statement. The data cannot accomplish all of that on their own, only in combination with models.

Author's response:

We think that the study of correlations among measured longitudinal oscillations and also with external sources help to understand excitation mechanisms (Immel et al., 2006; Xu et al., 2014), atmospheric coupling (Oberheide and Forbes, 2008; Forbes et al., 2009) and variability processes (Zhang and Shepherd, 2005; Forbes et al, 2008).
Nevertheless, we agree that this information must be demonstrated in combination with models. Therefore, we softened the sentence by substituting 'provide a wealth of information' by 'may reveal indications'.

- **Reviewer's comment:**

6. Section 3, beginning. I suggest preceeding line 134 with a BRIEF qualitative discussion of the consequences of sun-synchronous sampling. E. g., "Because MIPAS observations occur at 2 fixed local times, migrating tides (that depend only on local time) are seen as invariant features over the course of a day... We explore this and other ramifications of MIPAS sampling in the following discussion..."

Author's response:

Following the suggestion from the other referee, we have moved Section 3 to an Appendix. The new Appendix has been also modified. Nevertheless, we included the sentence suggested by the referee in Sect. 3.1.

- **Reviewer's comment:**

7. Line 134: Sentence needs clarification: "An atmospheric variable X consisting only of tides and a background state at altitude z, latitude, longitude and Universal Time (UT) tâA˘š can be expressed as the sum of the background zonal mean value and the sum of all individual tidal components Xn,s with zonal wavenumber s and wave frequency n at that position and time.."

Author's response:

We have slightly changed the sentence and shortened the paragraph.

- **Reviewer's comment:**
8. Line 168: Delete "solution".
Author's response:
Done.

- **Reviewer's comment:**
9. Lines 183-188: Delete.
Author's response:
We have almost deleted the complete paragraph but have left the reference.

- **Reviewer's comment:**
10. Line 204-205. Change to "an oscillation tilting eastward with height..."
Author's response:
Done.

- **Reviewer's comment:**
11. Lines 208-209: Change to "Fig. 1 exhibits wave features tilting westward with height (18 km vertical wavelength)..."
Author's response:
Done.

- **Reviewer's comment:**
12. Lines 211-212: "This feature is difficult to notice..." Delete. In general, do not dwell on things that are not in the data.
Author's response:
It is true that this is not a striking feature in Fig. 1 in October but, as it is shown later (Fig.10), it certainly is in the data. It is weak and masked by other oscillations in Fig. 1. We substituted 'difficult to notice' by 'perceived (...) but it is not as evident as at lower altitudes or in August,'.

- **Reviewer's comment:**
13. Line 237: Delete "mainly".
Author's response:
Done.

- **Reviewer's comment:**
14. Lines 239-240: "including the information of the local time phase." This will confuse the reader, suggest deleting.
Author's response:
Done. (We moved the sentence suggested by the reviewer some comments above to this paragraph).

- **Reviewer's comment:**
15. Line 254: Chapman and Lindzen predicted a vertical wavelength of 27 km for (1,1). Please specify where the observed vertical wavelength of "20-30 km" is smaller or larger than C & L's predictions.
Author's response:

Done.

- **Reviewer's comment:**

16. Line 305: Change to "...and the zonal winds in the middle atmosphere.."

Author's response:

Done.

- **Reviewer's comment:**

17. Line 330: Change to "They may originate..." and reference previously mentioned Lieberman et al., 2015. paper.

Author's response:

Done.

- **Reviewer's comment:**

18. Lines 334-335: "The monotonical change in phase with altitude..." I suggest selecting 3 key latitudes -equatorial, and midlatitude nothern and southern hemisphere - and generating line plots of the phase with altitude. That would make it much easier to see the phase tilt.

Author's response:

This is a great suggestion. We now include two new figures: new Figs. 7 and 10.

- **Reviewer's comment:**

19. Lines 340-344: "Those features probably belong..." Delete.

Author's response:

Done.

- **Reviewer's comment:**

20. Line 372: "MIPAS |nodd −s|=2 longitudinal oscillation embeds the diurnal DE1 and DW3 and the terdiurnal TW1 and TW2 components..."

No mention of TW2 is made in Table 1 for MIPAS wave 2, and the math I use (based on Salby's formulas) yields an alias of 1 for TW2.

Author's response:

As correctly pointed out by the referee, TW2 yields 1, as shown in Table 1. TW2 deleted in the text.

- **Reviewer's comment:**

21. Lines 373-374: "...both are most likely originated by non-linear interactions between their migrating counterpart (DW1 and TW3, respectively) and the s = 1 stationary planetary wave (SPW1)."

The verbiage here is very muddy. What do you mean by "both"? DE1 and DW3?

What are you proposing for the interactions? DW1 + SPW1, and TW3 + SPW1? Neither one of these produces DE1, DW3, TW1 or TW2.

Author's response:

That sentence was definitely wrong. These non-migrating tides could originate from non-linear interactions between their migrating counterparts (DW1 and TW3) and s=2 stationary planetary waves (SPW2). Changed.

- **Reviewer's comment:**

22. Lines 375-376 ("Not many tidal analyses..."): Delete.

Author's response:
Re-written.

- **Reviewer's comment:**
23. Lines 406-407: "The phase dependence with altitude indicates contribution from an eastward propagating wave..." Again, show line plots at representative latitudes. It is actually quite difficult to determine phase tilt in contour plots. Also, the phase appears to be increasing with height in the southern hemisphere, and decreasing with height in the northern hemisphere.

Author's response:
Thank you again for this suggestion. As mentioned above, we now include Fig. 10 showing the phase tilt with height.

- **Reviewer's comment:**
Line 409: "Amplitudes from 115-150 km during December also exhibit eastward propagation."
Do you mean to say here that the phases increase with altitude???

Author's response:
Yes, we did mean that phases increase with altitude. Re-written.

- **Reviewer's comment:**
24. Line 432: Replace monotonically with "increasing".

Author's response:
Done. Sentence re-written.

- **Reviewer's comment:**
25. Lines 437-438: "..phase moves westward as latitude increases... phase moves eastward..." Use phrases such as "phase increases/ decreases with latitude".

Author's response:
Done.

- **Reviewer's comment:**
26. Lines 487-488: "The DE3 component should also present a QBO (Li et al., 2015) but small and it is not surprising that we could no detect it in MIPAS data." Delete.

Author's response:
We re-phrased the sentence.

- **Reviewer's comment:**
27. Lines 520-524: "That suggest then that the effect on tides..." Delete these lines.

Author's response:
We think that, assuming the argument from Ekanayake et al., (1997) (stronger tides when direction of propagation is opposite to the wind), if the QBO effect on the migrating tide (westward propagation) were produced locally in the mesosphere, the tide amplitude would strengthen when the zonal wind mesospheric QBO were in its westerly phase (wind towards the east). That is *not* the case in MIPAS data. The tide, on the contrary, strengthens during the westerly phase of the stratospheric QBO. Therefore, it is *more likely* that the tide QBO originates in the stratosphere. The later is however not necessarily true and that is why we leave a door open and write in Sect. 4 (old Sect. 5) that other mechanisms cannot be ruled out.

We think this reasoning is not a speculation but suggests that the mesospheric tide QBO is not a local effect.
Nevertheless, we re-wrote the paragraph and say that MIPAS suggests that a stratospheric effect is more likely than a mesospheric effect. We hope that the argument is clearer now and eludes speculations.

- **Reviewer's comment:**
28. Figure 13: Convert to a line only at altitude of amplitude maximum.
Author's response:
We think that substituting this color map by a 1D plot with amplitude vs. latitude at only one selected altitude would eliminate a lot of information. We believe the figure is simple and clear enough. We think that all information on the dependence of the amplitude on altitude and latitude can easily be shown with this map. Additionally, Fig. 14 (old Fig.12) gives some more information at the latitude where the QBO peaks.

- **Reviewer's comment:**
29. Line 549: Delete "as expected".
Author's response:
Done

- **Reviewer's comment:**
30. Lines 576-577: "Comparison of tidal QBO and zonal wind stratospheric..." Delete.
Author's response:
Changed to: ' the effect on tides does not mainly occur in the mesosphere' (see argument in response to comment 27).

- **Reviewer's comment:**
In general the figures were much too small for a review copy.
Author's response:
We re-did all figures. We hope they meet the standards of ACP.

- **Reviewer's comment:**
1. Figure 1: Use monthname-day-year format rather than yyyymmdd in the Figure titles.
Author's response:
Done.

- **Reviewer's comment:**
2. I suggest either enlarging the latitude-altitude plots, or starting them at z = 60 km. Since the amplitudes are very weak below 60 km, most of these ploots are empty space,and they squish the more interesting behavior at high altitudes into too small of a space.
Author's response:
We moved the Figures up to 40 km. We note that Zeng et al. (2008) detected DW1 activity (although with very small amplitudes 1K) already in the lower stratosphere.

References (used in this document but not included in the manuscript)

Forbes, J.; M.; Zhang, X.; Palo, S.; Russell, J.; Mertens, C.; J. & Mlynczak, M. Tidal variability in the ionospheric dynamo region, *Journal of Geophysical Research,* **2008**, *113*, A02310 .

Oberheide, J.; Forbes, J.M. Tidal propagation of deep tropical cloud signatures into the thermosphere from TIMED observations, *Geophys. Res. Lett.,* **2008***, 35*, L04816.

Xu, J.; Smith, A. K.; Liu, M.; Liu, X.; Gao, H.; Jiang, G.; Yuan, W. Evidence for nonmigrating tides produced by the interaction between tides and stationary planetary waves in the stratosphere and lower mesosphere, *J. Geophys. Res.,* **2014***, 119*, 471-489.

Zhang, S.; P.; Shepherd, G. G. Variations of the mean winds and diurnal tides in the mesosphere and lower thermosphere observed by WINDII from 1992 to 1996 *Geophys. Res. Lett.,* **2005***, 32*, L14111.

Zeng, Z., W. Randel, S. Sokolovskiy, C. Deser, Y.-H. Kuo, M. Hagan, J. Du, and W. Ward (2008), Detection of migrating diurnal tide in the tropical upper troposphere and lower stratosphere using the Challenging Minisatellite Payload radio occultation data, J. Geophys. Res., 113, D03102, doi:10.1029/2007JD008725.