Response to anonymous referee #2

"Semidiurnal solar tide differences between fall and spring transition times in the Northern Hemisphere2

By J. Federico Conte et al. submitted to Ann. Geophys.

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The current paper focuses on differences in variability of semidiurnal solar tide (S2) between autumn and spring in the Northern Hemisphere. The differences were first described using wind data observed by meteor radars at three stations: one at high latitude (Andenes) and two at mid-latitudes (Juliusruh and Tavistock). In brief, S2 was found to decrease suddenly at all observed altitudes in autumn, while in spring S2 decreases more gradually and the decrease occurs earlier at lower altitudes than at higher altitudes. In order to explain these differences, the authors considered contributions from dominant semidiurnal tidal components (SW1 and SW2) provided by HAMMONIA simulation. The authors found that differences in variabilities of both SW1 and SW2 mostly lead to different variabilities of S2 during autumn and spring. In addition, gravity wave (GW) activity observed by meteor radars is stronger in autumn than in spring. This, as suggested by the authors, may also contribute to differences in S2 behavior via GW-tide interaction.

The paper is scientifically interesting. It is generally well written and clearly structured. It also has an adequate length and pertinent title and abstract.

We would like to thank this anonymous referee for taking the time to read and review our paper. The response to each comment can be found below. Also, we have attached a new version of the manuscript so the referee can see the applied changes.

General comments:

1. The introduction mentions only one possible reason, which could lead to S2 differences between autumn and spring (tide-tide interaction). Another possible reason, as you discussed later in your manuscript, could be GW-tide interaction. Although it is not the main topic of the current paper, I think GW-tide interaction should be briefly mentioned in the introduction.

R: thank you for this comment. We have added a sentence with a proper reference on this matter.

2. To estimate the tidal information from meteor radar measurements, a running window of 21 days was used. For HAMMONIA simulation, a 30-day window was used. Can you please explain: (1) the reason why 21 days and 30 days were chosen? and (2) why is the window for wind observations different from the window for simulated wind?

R: thank you for this comment. Now, we explain in the manuscript the reason for selecting 21-day and 30-day windows. Briefly, the number of daily unknowns to be determined in HAMMONIA simulations, at each pressure level, is 111. Squared, this is 12,321. A fitting window of 21 days would be large enough (and would coincide with the window selected for the observations) to obtain a solution after applying least squares (21 [days] x 8 [time points] x 96 [longitude points] = 16,128). However, in order to reduce the error of the fitting process and avoid some numerical artifacts, we had to use a window of 30 days. On the other hand, using a 30-day window for the observations would significantly smooth the tidal behavior (from previous studies of the authors of this

manuscript and other researchers, we know that a 21-day window is still good enough for climatological studies such as the one presented here).

Further, extracting tides from HAMMONIA simulation took into account PWs, but extracting tides from radar measurements did not consider PWs. This difference should be explained in the manuscript.
R: thank you very much for this comment. We also fitted HAMMONIA wind simulations without explicitly considering the PWs (as in the case of meteor radar measurements). The mean winds and tides determined in this second case were very similar to those obtained with the explicit inclusion of PWs, and hence we decided not to consider the results of this second fitting. We now explain this in the manuscript.

3. For all figures in the manuscript, please add a vertical grid or at least 2 vertical lines for each spring and autumn. This will help the readers very much to follow the variability (decrease) of tidal components that you described in the text.
R: thank you for this comment. We have added vertical white dashed lines in all our figures for days of the year 90 and 275, so the readers can better understand our results.

4. The fall decrease occurs earlier in HAMMONIA simulation than in the observations. This can be seen for all 3 locations and very clearly for Juliusruh and Tavistock. Please describe and explain this fact in your paper.
R: thanks. This is mentioned in the manuscript. Nevertheless, we have modified a few sentences and added new ones so this is clearer for the readers.

Specific comments:
Below, the first number is the page number and the second number is the line number or line numbers, separated by a forward slash. For example, 2/5 refers to page 2, line 5; 3/10-12 means page 3 lines 10 to 12.

1. 1/19: PW → PWs
R: thanks. We have made this correction.

2. 1/20: GW → GWs
R: thanks. We have corrected this.

3. 1/22: "they have typical periods ...". Some rewording may be needed. My suggestion: "The most dominant tide components have periods .."
R: thanks. We have re-written this sentence in a different way.

4. 2/14: It is helpful for the readers to introduce again the abbreviations (SW2 and SW1) here in parentheses
R: thanks. We have included the acronyms again.

5. 3/13: "The mean winds .." → "The zonal mean winds .."
R: thanks for this. We have corrected the sentence.

6. 4/14: Which part of GW spectrum can be seen by your measurements? Please specify the observed GW spectrum.
R: thanks. Now we have specified that the meteor radar observations allow us to see GWs with periods larger than 2 hours.

7. 4/23-26: Do you have any explanation for the earlier decrease during the years 2009, 2012, 2013 and the lower amplitude during 2013?

R: sadly, no. We have investigated some possible agents that might be causing these differences (e.g., solar activity levels, proximity to strong warmings the following winter, etc.) but found nothing convincing. We plan to further investigate the year-to-year variability of S2.

8. 4/28: What is the reason of more variability during the spring?
R: again, sadly we do not have a convincing answer to this question. We believe that the observed variability during the spring could be connected, e.g., to late warmings. Late stratospheric warmings have been observed during March/April of, e.g., 2005 and 2015. We think this late warmings might be partially introducing more variability in the MLT region. But, again we need to further investigate this.

9. 4/30: Can you please explain why the duration is longer at high latitudes than at middle latitudes?
R: as in the case of point 7., we still cannot explain this. That is one of the reasons why we want to estimate the impact of SW1 directly from the observations (mentioned in the manuscript) in order to see if this longer duration at high latitudes has some connection with the planetary wave activity.

10. 5/10: Is it possible to turn off the GW parameterizations and see how much GW-tide interaction influences S2 variability?
R: in theory, it could be done. However, we have used HAMMONIA simulations that were already stored in Hamburg MPI servers. To run new simulations would be time consuming and sadly, H. Schmidt is extremely busy with other projects right now. Nonetheless, in future studies we plan to "play" with different GW parameterizations using other models (such as WACCM-X and CMAT-2).

11. 7/14: Do you also see the annual variability in HAMMONIA simulation?
R: No. We see very similar behaviors during all the 20 years used in the study.

12. 7/14: Please mention that the fall decrease in simulation occurs earlier than in observations. Further, the simulated S2 amplitude is higher than observed S2 amplitude. Can you please also comment on that?
R: These features are already mentioned in the manuscript. However, we have added new mentions of these facts in other parts of the manuscript in order to make it more clear.

13. 7/28: "These differences are reproduced .. model" → "These differences are reproduced .. model to a certain extent"
R: thanks. We have applied the suggested change.

14. 8/0: Title of Fig. 4: CMOR → Tavistock?
R: thanks. We have changed the title accordingly.

15. 9/8: For observations, you showed the phase analysis for S2 (Fig. 4). For simulation, why don't you show the phase analysis for the same S2? why did you choose SW2 instead?
R: well, for two main reasons. Firstly, because we fitted each tidal component separately. Hence, mixing the phases of all tidal components contributing to S2 would be misleading. Secondly, because after realizing that SW2 strongly dominates the behavior of S2 during the fall, we mainly focused our study on this component (in the simulations).

16. 9/25: I agree with the authors that GW-tide interaction requires a thorough analysis, given that not only the simulation, but also your observations contain only a certain part of the GW spectrum, and different parts of the GW spectrum can interact differently with tides. The interaction of other parts of the GW spectrum with S2 cannot be estimated here and may also influence the S2 variability. Maybe you should add one sentence here to clarify that fact.

R: thanks. We have added a sentence on this matter.

17. 9/27: “the GW activity" → “the long-wave GW activity"
R: thanks for this comment. We believe that in the context of the sentence it is clear we are talking about long-wave GWs. Hence, we did not apply this change.

18. 9/30: Would you conclude that long-wave GWs suppress the migrating semidiurnal tide SW2 amplitude?
R: we think that the GW-tide interaction could be one of the causes of the fall decrease of SW2. However, we don’t have sufficient evidence yet to firmly conclude this, and that is why we are only suggesting that GWs could be involved.