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Interactive comment on "Temperature decadal trends, and their relation to diurnal variations in the lower thermosphere, stratosphere, and mesosphere, based on measurements from SABER on TIMED" *by* Frank T. Huang and Hans G. Mayr

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Response to anonymous reviewer #2 interactive comment concerning manuscript titled "Temperature decadal trends, and their relation to diurnal variations in the lower thermosphere, stratosphere, and mesosphere, based on measurements from SABER on TIMED" by Frank T. Huang and Hans G. Mayr

Anonymous Referee #2 Received and published: 1 December 2020 A) Referee #2: The authors have used temperatures obtained from SABER data to extend study about the local time variations of temperature trends from 2002 to 2014, 20 to 100 km, and 48_S to 48_N latitude. The trends found have been compared with those published and after some discussion the authors found that temperature decadal trends for a fixed local time were different from trends at another fixed local time. In addition, the authors also found that the amplitudes and phases of the tides also revealed decadal trends, and they inferred that thermal tides likely count to contribute to the local time variations of temperature trends.

Based on my evaluation, this is an important scientific contribution which can help to clarify differences and achieve more consistent trend results. However, there are some concerns that need to be addressed.

1) Referee #2: comment 1): The introduction can be improved in order to clarify the findings in previous works and the difference from present investigation. The authors have discussed this issue, however the way it is written has become confused.

Authors' response to comment 1: We are also a bit confused. In the introduction, there is one reference which we have moved. Otherwise, we do not mention previous works. We have now added sentences that refer to our previous works, and to Section 2, which contains the details of our descriptions of previous work.

2) Referee #2: comment 2): One of the main results found by the authors concerns the contribution of thermal tides to the local time variations of temperature trends, since their amplitudes and phases also display decadal trends. In this sense, Figure 2b should be further explored in order to show readers how the variation in thermal tides contributes to the local time variations of temperature trends. The same can be considered in sections 4.1 (Stratosphere) and 4.2 (Lower Thermosphere), where the relationship between the thermal tides and the trends should be emphasized.

Authors' response to comment 2: We have added an Appendix to the manuscript, which contain additional plots of tidal trends, corresponding to Figure 2b of the manuscript. The Appendix is included below here also. The narrative of the Appendix is as follows: "We present additional figures, corresponding to Figure 2 (b), of temperature diurnal amplitudes and phases over more altitudes (20, 40, 60, 80, 90 km) and latitudes (0âĄř, 40âĄř). The left panels (a) of each Figure show temperature tidal diurnal amplitudes and phases at different altitudes and the Equator, while the right panels (b) correspond to the left panels but at 40âĄřN latitude. In each panel, the left axis scale and black line denote tidal diurnal amplitudes (K), while the right axis scale and red line show the diurnal phases (hr of maximum value). The displayed trend values are obtained from a simple least squares straight line fit. The larger variations generally reflect modulation of the tides by the quasi biennial oscillation (QBO). This has been discussed in models (Mayr and Mengel, 2005) and other SABER data (Forbes et al., 2008). Although the figures may give additional insight to the nature of the trends, there are caveats to be considered. We note that the semidiurnal amplitudes and phases can also be significant. We have derived a total of five Fourier components, and our numerical results reflect all 5 Fourier terms. Because both amplitudes and phases exhibit trends, they need to be considered in parallel, in tandem, and this is difficult to discern, qualitatively. In addition, because the trends are generally small, it would be difficult to arrive at conclusions."

3) Referee #2: comment 3): The diurnal tide on temperature in stratosphere (_ 40-50 km) has its strongest amplitudes at latitudes 40_N, S, while in the MLT region (_ 85-95 km) they are strongest around the equator, where the phases are best resolved. Therefore, I would like to suggest adding the analysis of trends in the amplitudes and phases of the diurnal tide for these regions, which may provide enrichment in the discussion of results.

Authors' response to comment 3: The plots at 90 km and the Equator, and at 40 km at 40deg, are shown below in the Appendix, as described in the response to C) earlier. Although the plots can provide valuable insight, we believe that numerical analyses are

needed, and some sort of modeling. Currently we are not aware of 3D models focusing on trends related to local times. If there are, a simple test would be to constrain zero trends on the tides, and see if there are effects on the trends of the temperature.

4) Referee #2: comment 4) The theme of the section 4.3 (Orbital drift and generic) needs to be improved and explored. It could be moved to section 2 without prejudice to the manuscript.

Authors' response to comment 4: We realize that Sections 4.3 and 4.4 are not only brief, but even skimpy. For the general dependence of trends on local time, because the results are new, our motive was only to provide more information on a wider altitude and latitude range. Because trends depend on the time span considered, the tidal trends may well also be different for another time span, and their behavior relative the mean temperature trend may also be different. As noted in replies to comments 2 and 3, we believe that further studies would need to entail numerical aspects, and some sort of modeling. Again, if there are 3D models which focus on trends and local times, a simple test would be to constrain zero trends on the tides, and see if there are effects on the trends of the temperature For orbital drifts, there have been no previous similar results on this subject. Our motive is only meant to provide an indication of what may result when local times at which measurements are made are not controlled. Specifics would depend on the drift of the particular satellite and the particular study. Due also to other comments, we have merged Sections 4.3 and 4.4, and added a bit more information.

5) Referee #2: comment 5: Discussion should be made more rigorous. The basis for the statements needs to expand further.

Authors' response: We have added to the discussion, describing the basis of our calculation

The discussion is now as follows: "Using SABER data, we have investigated the local time variations of temperature trends (K/decade) from 2002 to 2014, 20 to 100 km, and

48°S to 48°N latitude. SABER provides global temperature measurements over the 24 hrs of local time, and from 20 to 100 km in altitude, that are not available from other satellites and sources. From our past studies based on SABER data, we had estimated diurnal variations of the temperature (thermal tides) for each day, expressed in the form of five Fourier series components (Huang et al., 2010a). We had also derived zonal means of temperature that are averages over both longitude and local time for a latitude circle (Huang et al., 2006). These 'synoptic' zonal means are important because it can then be compared directly with 3D models (Austin et. al., 2008). As explained earlier, zonal means from sun-synchronous satellites are tied to one or two local times. To our knowledge, comparable zonal means of temperature that are averages over longitude and the 24 hours of local time are just not available elsewhere. In this current study, we have combined the past results to estimate the zonal mean trends corresponding to specific local times. These results at local times have not been available previously. They show that the values of temperature decadal trends for a fixed local time are different from trends at another fixed local time. We find that the amplitudes and phases of the tides themselves also display decadal trends and are then likely contributors to the local time variations of temperature trends. Our results of trend variations with local time are supported by comparisons with corresponding nighttime lidar measurements in the stratosphere and lower thermosphere. They are also supported by comparisons with corresponding satellite measurements made at specific local times in the stratosphere. The dependence of trends on local time is significant throughout the region of analysis, and can be significant even from hour to hour, as can be seen in Figures 3, 4, 5, and 6. In the lower thermosphere, this agrees with corresponding trend results by She et al.,[2019], based on lidar night-time measurements. She et al., [2019] found that trends based on a two-hour average near midnight show systematic differences from the average over other hours. Our comparisons with the overnight results of She et al., [2019] are seen in Figure 5, where our trends at 19, 20, and 21 hours compare favorably, while our day time trends at 15, 16, and 17 hours compare less favorably. In the stratosphere, our comparison with trends found by Funatsu et al.,[2016], based

on lidar and AMSU measurements, are even better, as seen in Figures 3 and 4. At 44°N (AMSU and OHP lidar), Funatsu et al., [2016] provide AMSU trend results only from 30 to 40 km, but they match our results almost exactly. Their results from 20 to 40 km, representing mid latitudes (30° to 60°N) also match our results almost exactly from 20 to 30 km, but are larger from 30 to 40km. Between $\sim$ 30 to 40 km, the night-time lidar trends are significantly smaller (more negative) than both our and that of Funatsu et al.,[2016]. However, when the comparison is between night time lidar and our night-time results (21, 22, and 23 hours, see Figures 3a, 3b), the agreements are better. At 20°N (AMSU and MLO lidar), similar comments apply. These examples all suggest that at least some of the differences between night time lidar trends and those based on other measurements that are not made at night, can be explained at least partly, through variations of trends with local time. However, we emphasize that our three examples of course do not a pattern make, and more direct comparisons are needed. Our current comparisons are limited because the various results should be based on the similar time spans, and also not based on merged data from various sources, as the identity in local time would not be clear for merged data. Although there have been previous studies related to variations with local time, they focused on mitigating differences when merging data from different sources, and on accounting for temperature variations with local time due to orbital drifts. Because our results show that the data sets representing measurements at different fixed local times can result in varying trends, merging those data can result in trends that cannot be tied to specific local times, or to averages over the 24 hours of local time, as in 3D models, and can result in biases.“

Referee #2: Technical revision Please check the citations through the text considering the rules required by the journal. Authors: Will do.

Referee #2: Page 2, line 82: change “Advanced Microwave Sounder...” by “Advanced Microwave Sounder Unit” Authors: The paragraph containing the sentence has been removed because the other referee believed that conclusions such as that expressed there do not belong in the introduction.

Referee #2: Page 7, Figure 3b,c,d: legend overlap with plots Page 11, Figure 7: legend overlap with plots

Authors: We have re-plotted the figures.

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Appendix

Please see supplement file for figures.

We present additional figures, corresponding to Figure 2 (b), of temperature diurnal amplitudes and phases over more altitudes (20, 40, 60, 80, 90 km) and latitudes (0âĄř, 40âĄř). The left panels (a) of each figure show temperature tidal diurnal amplitudes and phases at various altitudes and the Equator, while the right panels (b) correspond to the left panels but at 40âĄřN latitude. In each panel, the left axis scale and black line denote tidal diurnal amplitudes (K), while the right axis scale and red line show the diurnal phases (hr of maximum value). The displayed trend values are obtained from a simple least squares straight line fit. The larger variations generally reflect modulation of the tides by the quasi biennial oscillation (QBO). This has been discussed in models (Mayr and Mengel, 2005) and other SABER data (Forbes et al., 2008). Although the figures may give additional insight to the nature of the trends, there are caveats to be considered. We note that the semidiurnal amplitudes and phases can also be significant. We have derived a total of five Fourier components, and our numerical results reflect all 5 Fourier terms. Because both amplitudes and phases exhibit trends, they need to be considered in parallel, in tandem, and this is difficult to discern, qualitatively. In addition, because the trends are generally small, it would be difficult to arrive at conclusions.

Figure A1. Left panel (a): Temperature tidal diurnal amplitudes and phases at 20 km,

equator; left axis scale: black line: tidal diurnal amplitude (K); right axis scale: red line: diurnal phase (hr of maximum value). Right panel (b): as in left panel but at 40âĄřN latitude.

Figure A2. Left panel (a): Temperature tidal diurnal amplitudes and phases at 40 km, equator; left axis scale: black line: tidal diurnal amplitude (K); right axis scale: red line: diurnal phase (hr of maximum value). Right panel (b): as in left panel but at 40âĄřN latitude.

Figure A3. Left panel (a): Temperature tidal diurnal amplitudes and phases at 60 km, equator; left axis scale: black line: tidal diurnal amplitude (K); right axis scale: red line: diurnal phase (hr of maximum value). Right panel (b): as in left panel but at 40âĄřN latitude.

Figure A4. Left panel (a): Temperature tidal diurnal amplitudes and phases at 80 km, equator; left axis scale: black line: tidal diurnal amplitude (K); right axis scale: red line: diurnal phase (hr of maximum value). Right panel (b): as in left panel but at 40âĄřN latitude.

Figure A5. Left panel (a): Temperature tidal diurnal amplitudes and phases at 90 km, equator; left axis scale: black line: tidal diurnal amplitude (K); right axis scale: red line: diurnal phase (hr of maximum value). Right panel (b): as in left panel but at 40âĄřN latitude.

Please also note the supplement to this comment:
https://angeo.copernicus.org/preprints/angeo-2020-63/angeo-2020-63-AC2-supplement.pdf

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