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Interactive comment on "Connection between the length of day and wind measurements in the mesosphere and lower thermosphere at mid and high latitudes" *by* Sven Wilhelm et al.

Sven Wilhelm et al.

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Review of: "Connection between the length of day and wind measurements in the mesosphere and lower thermosphere at mid and high latitudes." by Sven Wilhelm et al. [AnGeo 2018-15, rcvd June 2018]

Relation between zonal wind and length of day variations is a very ambitious topic. The discussion is very interesting, but I can't find any proof that LOD affects the measured winds.

General reply: We thank the Referee for this constructive suggestions and comments

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that help to improve the paper. In the supplement you can find the corrected version of the manuscript.

Aim of this study is to show that, according to previous work by Stober et al. (2012), the mesospheric/lower thermospheric zonal wind is connected to changes in the neutral density. Due to a lack of global density observations these concern are hard to proof. Therefore we took the LOD for comparison to the zonal wind, because the LOD is related to changes in the global Earth rotation speed. These changes can be influenced by large scale atmospheric processes and we further state that within the MLT the atmospheric rotation speed is also affected by changes in the neutral density. We figured out that the connection occurs on annual or longer time scales, and further follows the influence of solar radiation (on 11-year solar cycle scale, as well as differences in the Earth-Sun-distance). On shorter time scales, only based on wind measurements, a connection between the LOD and MLT winds, with respect to the impact of the Sun are quite complicated to find. We will leave a true understanding of the effect, which implies exact velocity values, for future work.

There are a few points which should be addressed in the introduction.

1. If the earth-atmosphere system were rigid, and the atmosphere expands, the whole system would slow down (become less eastward or more westward) to maintain conservation of angular momentum, But it is not rigid, and since atmospheric drag is the proposed cause of the earth seasonal LOD change, it is important to estimate the time constant. If longer than a season, then maybe no effect on wind would be noticeable. Pg. 8 L 23 mentions the matter, but there is no estimate.

Reply: We agree that a calculation of a time constant is important to estimate a direct LOD effect on higher located winds, but only based on our available radar measurements we are not able to estimate the lag. We will mention this for future work. Nevertheless, we added the following part to the paper:

According to e.g., Dickey et al. (1994) a direct effect exists between the stratospheric and tropospheric zonal wind and the LOD on annual time scales due to long term geophysical effects, as e.g., QBO and El Nino. They found that the stratosphere cannot be neglected in the Earth's angular momentum. Around 20 % of the LOD relative to the atmosphere below 100 mbar, belongs to the impact of the stratosphere. Furthermore, they mentioned a small lag (10 - 20 days) between the LOD and variations in the angular momentum, but the lag do not appear to be statistically significant.

Dickey, J., O., Marcus, S., L., Hide, R., Eubanks, T., M., and Boggs, D., H.: Angular momentum exchange among the solid Earth, atmosphere, and oceans: A case study of the 1982 - 1983 El Nino event., Journal of geophysical research, 99, 23, 921– 23,937, 1994.

2. If the atmosphere is heated why would expansion be simple and not lead to a different climatology, including winds. Reply: We assume that the expansion/shrinking of the atmosphere also influence the climatology, but the effect is relatively small compared to the atmospheric drivers, as gravity waves and chemistry. In a model simulation Marsh et al. (2007) showed for the whole atmosphere a response to changes in the 11-year solar cycle, with e.g., the result of temperature changes in the lower thermosphere by over 100 K at solar maximum relative to solar minimum. Further they showed the occurrence of tropospheric wind and temperature changes due to changes in the solar radiation. But they also mention that changes in the climatology due to solar radiation are too complex to lead to simplified results. Furthermore, there are other factors as e.g., the composition of chemical components and the occurrence and propagation of gravity waves which lead to the state of the climatology.

We added/reformulated some text in the manuscript to clarify the point of the study:

We have to note that beside many others factors, this is only one reason, and by far not the dominant factor, for the wind differences between both locations at theses altitudes. Other physical processes have also a strong effect on the hemispheric wind differences e.g., the topography, chemical composition of the atmosphere (Marsh (2007),

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Lee (2018)), and the occurrence and propagation of gravity waves. These waves are the main drivers of the atmospheric wind circulation and therefore also influence the local wind differences at both hemispheres. Furthermore gravity waves lead, compared to the annual mean, to a colder summer mesosphere and a warmer winter mesosphere e.g., Luebken (2014). These temperature differences also fit well to the atmospheric expansion/shrinking. Unfortunately, based only on wind measurements we are not able to estimate a precise value on how strong the connection is between zonal mean wind with the LOD. For a more detailed understanding of these phenomena global density observations would be required.

and

In a model simulation Marsh et al. (2007) showed for the whole atmosphere a responds to changes in the 11-year solar cycle, with e.g., the result of temperature changes in the lower thermosphere by over 100 K at solar maximum relative to solar minimum. Further they showed the occurrence of tropospheric wind and temperature changes due to changes in the solar radiation. But they also mention that changes in the climatology due to solar radiation are too complex to lead to simplified results.

Lübken, F.-J., Höffner, J., Kaifler, B., and Morris, R., J.: Winter/summer mesopause temperature transition at Davis (69°S) in 2011/2012, Geophys. Res. Lett., 41, 5233–5238, https://doi.org/10.1002/2014GL060777, 2014.

Marsh, D., R., Garcia, R., R., Kinnison, D., E., Boville, B., A., Sassi, F., Solomon, S., C., and Matthes, K.: Modeling the whole atmosphere response to solar cycle changes in radiative and geomagnetic forcing, Journal of geophysical research, 112, https://doi.org/doi:10.1029/2006JD008306, 2007.

Lee, J., N., Wu, D., L. R. A., and Fontenla, J.: Solar cycle variations in mesopheric carbon monoxide, Journal of atmospheric and solarterrestial physics, 170, 21–34, https://doi.org/https://doi.org/10.1016/j.jastp.2018.02.001, 2018.

3. The proposed LOD effect depends on heating: the solar cycle radiation variation is surely bigger than the earth-sun distance effect. Does zonal mean wind show a solar cycle variation?

Reply: Yes, the zonal mean wind shows a solar cycle variation. We added a Figure, where for the location of Andenes the zonal mean wind between 84 and 94 km is displayed together with the F10.7 solar cycle index. As result is shown that for a low F10.7 index an enhanced westward wind appears, while for stronger a F10.7 index the eastward directed wind gets enhanced. Further also a shift in the summer vertical wind shear occurs, which is also correlated to the solar cycle. There occurs a shift onto higher altitudes together with a decrease of the solar radiation, due to a change in the neutral density. This pattern can also be seen for the other locations.

We added the text: To underline this statement, Figure 4 shows, for the location of Andenes, the zonal mean wind between 84 and 94 km together with the F10.7 11-year solar cycle index (black line). An enhancement of the eastward directed wind occurs together with a stronger F10.7 index and more clearly an increase of the westward directed wind together with a smaller F10.7. Furthermore a shift occurs in the summer vertical wind shear, which is also correlated with the solar cycle, whereby a shift to higher altitudes takes place together with a decrease of the solar radiation, due to a change in the neutral density.

FIGURE 4

Caption (Figure 4.. see attachment): Zonal mean wind for Andenes for the heights between 84 and 94 km, together with the F10.7 11 year solar cycle index in black.

4. It appears that heating to the winter atmosphere should be smaller, even with a closer sun-earth distance, else why is it winter. Why is not atmospheric expansion smaller than in summer?

Reply: Propagation of gravity waves which breaks in the mesosphere leads, compared to the annual mean/radiative equilibrium, to a cold mesosphere during the summer and a warm mesosphere during the winter. This temperature difference fits well with the atmospheric shrinking/expansion.

We added a comment in the text: (see point 2.)

Other physical processes have also a strong effect on the hemispheric wind differences e.g., the topography, chemical composition of the atmosphere (Marsh (2007), Lee (2018), and the occurrence and propagation of gravity waves. These waves are the main drivers of the atmospheric wind circulation and therefore also influence the local wind differences at both hemispheres. Furthermore gravity waves lead, compared to the annual mean, to a colder summer mesosphere and a warmer winter mesosphere e.g., Luebken (2014). These temperature differences also fit well to the atmospheric expansion/shrinking.

Marsh, D., R., Garcia, R., R., Kinnison, D., E., Boville, B., A., Sassi, F., Solomon, S., C., and Matthes, K.: Modeling the whole atmosphere response to solar cycle changes in radiative and geomagnetic forcing, Journal of geophysical research, 112, https://doi.org/doi:10.1029/2006JD008306, 2007.

Lee, J., N., Wu, D., L. R. A., and Fontenla, J.: Solar cycle variations in mesopheric carbon monoxide, Journal of atmospheric and solarterrestial physics, 170, 21–34, https://doi.org/https://doi.org/10.1016/j.jastp.2018.02.001, 2018.

Lübken, F.-J., J. Höffner, T. P. Viehl, B. Kaifler, and R. J. Morris (2014), Winter/ summer mesopause temperature transition at Davis (69âŮęS) in 2011/2012, Geophys. Res. Lett., 41, 5233–5238, doi:10.1002/2014GL060777.

Fig. 6,7 seem to be showing the full zonal wind vs. LOD. According to an earlier statement, 4 m/s is the estimated contribution from LOD (e.g. Fig. 4), both having annual variations. How does this figure show the LOD-only contribution?

Reply: A precise estimation of the impact of the LOD on the wind is difficult. Based on the wind observations only we are not able to estimate a correct value for the LOD contribution. According to the equations 1-4 estimations could be done, but due to a lack of density measurements we are not able to determine correct values. This point is added as an outlook for future work.

Fig. 8 The long term effect of tides and earth deformation are usually taken to be the cause of slowing the earth's rotation, not atmosphere. How does that physically create a trend in the zonal wind.

Reply: We added this text to the introduction:

On short time scales a change in the Earth rotation can lead to an uneven heating of the Earth's surface, which results to temperature differences between the surface and the atmosphere above. This can further cause convection currents, which leads to pressure differences in the atmosphere and results in a different wind formation, which can influence the LOD. On longer time scale and especially on higher altitudes increases the importance of the solar influence. An increase of the solar radiation, which can be caused due to a slowing of the Earth's rotation, leads to an expansion of the higher atmosphere, which further results, due to the conversation of angular momentum, in a slower rotation of the atmosphere. What further needs to be considered is e.g., the influence of volcanic eruptions, which influence the Earth's rotation as well as the atmospheric chemistry/temperature (e.g., She et al. (2015)). Changes in these parameters can further lead to changes in the neutral density.

She, C., Krueger, D., A., and Yuan, T.: Long-term midlatitude mesopause region temperature trend deduced from quarter century (1990- 2014) NA lidar observations, Annales Geophysicae, 33, 363–369, https://doi.org/doi:10.5194/angeocom-33-363-2015, 2015.

Minor typos, grammatical, etc.

General Reply: Thanks for the advices. We will correct the mentioned points, and added here for some points few comments for the Referee.

Pg 1 L 10 siderial time L 11 full rotation , "86400" to make it international. But 86400s is a mean solar day, not a mean siderial day, and LOD was said to based on siderial time; the difference is $\sim$ 4 minutes. Some text changes are necessary.

Reply : we added some text : Within the estimation of the LOD the sidereal time gets converted into solar time, by taking into account the Earth's position and motion with respect to the stars (Aoki, 1981).

Aoki, S., Guinot, B., Kaplan, G., Kinoshita, H., McCarthy, D., and Seidelmann, P.: The new Definition of Universal Time, Astronomy and Astrophysics, 105, 359–361, 1981.

L 13 deceleration ? – no, eastward directed wind (or westerly) leads to an acceleration of the Earth's rotation.

Pg 2 L 10 at solar minimum as well as decrease in the temperature ... ?

Reply: We reformulated the sentence and added some more references:

Previous studies as, e.g., Walterscheid (1989), Marsh et al (2007), Emmert (2015), and Lee et al. (2018) showed that solar cycle variations affects the atmospheric density, temperature, chemical composition and winds over the whole atmosphere, but in particular, in the MTI (Mesosphere-Thermosphere-Ionosphere) system.

Walterscheid, R., L.: Solar Cycle effects on the upper atmosphere: Implications for Satellite Drag, Journal of spacecraft and rockets, 26, 439–444, https://doi.org/DOI: 10.2514/3.26089, 1989.

Marsh, D., R., Garcia, R., R., Kinnison, D., E., Boville, B., A., Sassi, F., Solomon, S., C., and Matthes, K.: Modeling the whole atmosphere response to solar cycle changes in radiative and geomagnetic forcing, Journal of geophysical research, 112, https://doi.org/doi:10.1029/2006JD008306, 2007.

Emmert, J. T.: Altitude and solar activity dependence of 1967-2005 thermospheric den-

sity trends derived from obrital drag, Journal of geophysical research: space physics, 120, 2940–2950, https://doi.org/doi:10.1002/2015JA021047., 2015.

Lee, J., N., Wu, D., L. R. A., and Fontenla, J.: Solar cycle variations in mesopheric carbon monoxide, Journal of atmospheric and solar terrestial physics, 170, 21–34, https://doi.org/https://doi.org/10.1016/j.jastp.2018.02.001, 2018.

Pg 3 L 22 its? –corrected-

Pg 4 L 4 "... atmosphere were vertically ..." –corrected- L 19 1960s and 70s –corrected- L 23 60s –corrected- L 24 What is "d" ? We changed d to D, which is the angular velocity of the Earth. To avoid misunderstandings we didn't choose ω, because it is already used in the equations 1,5 and 6 as angular velocity for an altitude defined atmospheric layer.

Pg 5 L 6 describe –corrected- L 8 " ... under the assumption of equal density ..." –corrected- L 30 The Aura MLS GPH at 0.001 hPa is virtually always $\sim$90 km Reply: We converted the geopotential height into geometric height, as e.g., done in Matthias et al (2013). We added some text to clarify this.

Added text: The geometric heights are approximately estimated from pressure levels as described in Matthias (2013): h = -7 ln(9/1000), where h is the altitude in km and p the pressure in hPa. Furthermore, we are aware about a difference between the geometric and geopotential heights, which increase especially above 80 km. Therefore, we focus in this work on the height range between 60 to 80 km. . .

Matthias, V., Hoffmann, P., Manson, A., Meek, C., Stober, G., Brown, P., and Rapp, M.: The impact of planetary waves on the latitudinal displacement of sudden stratospheric warmings, Ann. Geophys., 31, 1397-1415, https://doi.org/10.5194/angeo-31-1397-2013, 2013.

L 32 " density-dependent " ? –see above

Pg 6 L 1 "height and temperature ..", "horizontal grids which are ..." –corrected- L 23 $\sim$

90 km again –corrected- L 24 "... in qualitatively good agreement ..." –corrected-

Pg 7 L 2 Geopotential? or is geometric calculated from geopotential ? – we added some more words to clarify this.

L 9,12 " Gaussian" –corrected-

L 13 " these results agree with the observations ..." ? Only based on wind measurements we are not able to extract a specific value.

L 15 misplaced "(" -corrected- L 31 these , this phenomenon or these phenomena –corrected-

Pg 8 L 8 explicitly –corrected- L 22 relatively –corrected- L 34 "solar cycle variation " (there is only one cycle here) –corrected-

Pg 9 L 14-20 need to be re-written. Reply: we reformulated the part:

In the Figures 10 and 11 are shown long term changes of annual LOD (black) and annual zonal mean winds (red) for Collm and for Davis. At this point, we have to mention that a tendency over a long time series is not linear in time. Parameter which influence the tendency of the wind and the LOD also vary over time and therefore be observed in long time series should be limited within a specific period. Such changes are often be approximated by a piecewise linear trend model (e.g., Tomé and Miranda (2004), Merzlyakov et al. (2009) and Jacobi et al. (2011)), where different linear fit tendencies are estimated for different time periods. Nevertheless, due to the length of the available data series we decide to use no piecewise linear trend model. The wind values exclude seasonal and solar cycle variations and the LOD excludes the seasonal variations. Exemplary for the locations of Collm (Figure 10) the altitudes between 80 and 96 km are displayed. The errorbars corresponds to the annual variance for each height and the dotted lines show the long term tendency for each parameter. The result is that a long term increase of the LOD occurs together with a long term decrease of the zonal wind. Above 94 km the tendency reverses for the mid latitude locations into

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a slightly positive wind. This reversal can be explain by the stronger influence due to gravity wave filtering, which has to be considered and cannot be excluded by filtering the data. The tendencies of an increased value for the LOD and a decreased value for the zonal mean wind can be seen for all mid latitude locations and also for Davis (see Figure 11). Andenes shows for all altitudes increase tendency in the zonal wind. The results indicates that the connection between the LOD and the wind are more pronounced at lower latitudes, which simply explainable by the rotation velocity, which is higher at the middle latitude stations than at the polar latitudes like Andenes and Davis. The results of an increase of the LOD and a decrease of zonal wind fits to the relation between fluctuations in the neutral density and the zonal wind, as shown Stober et al. (2012).

Tomé, A., R. and Miranda, P., M. A.: Piecewise linear fitting and trend changing points of climate parameters, Geophys. Res. Lett., 31, https://doi.org/doi:10.1029/2003GL019100, 2004.

Merzlyakov, E., G., Jacobi, C., Portnyagin, Yu., I., and Solovjova, T., V.: Structural changes in trend parameters of the MLT winds based on wind measurements at Obninsk (55°N, 37°E) and Collm (52°N, 15°E), Journal of atmospheric and solar-terrestial physics, 71, 1547–1557, https://doi.org/doi:10.1016/j.jastp.2009.05.013, 2009.

Jacobi, C., Hoffmann, P., Liu, R., Q., Merzlyakov, E., G., Portnyagin, Yu., I., Manson, A., H., and Meek, C., E.: Long-term trends, their changes, and interannual variability of Northern Hemisphere midlatitude MLT winds, Journal of Atmospheric and Solar-Terrestrial Physics, 75-76, 81–91, https://doi.org/doi:10.1016/j.jastp.2011.03.016, 2011.

L 21 "an overall ..." –corrected- L 22 " is more ..." –corrected-

L 33 "stations" –corrected-

Pg 10 L 10 "can not be figured ..." –corrected- L 16 "... at these altitudes. " –corrected-

Pg 11 L35 "using" –corrected- Caption Figure 2, 3: "positive" –corrected-

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2018-51/angeo-2018-51-AC1-supplement.zip

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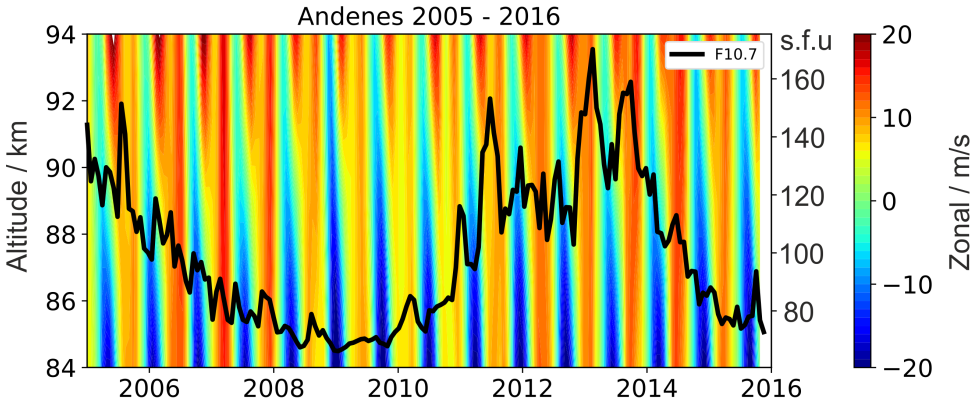

Fig. 1.

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