

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.

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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” General comments

A topic of this manuscript, study of correlation between a length of a day and zonal mean winds, is very interesting. However, I concern about three points.

General reply: We thank the Referee for this constructive suggestions and comments that help to improve the paper. We attached in the supplements a corrected version of the manuscript.

C1

Although data analysis results are presented in 6 figures in the manuscript, all of them are about mean zonal winds from meteor radars. Among them, only 3 figures overplot lengths of a day. Trends of lengths of a day and zonal mean winds look somehow correlated in the figures, but correlations are not presented numerically. Because mean winds are presented in terms of seasonal and interannual variations. I would like to have seen them for lengths of a day, too.

Reply: We added numerical correlation values between the parameters for different heights and different locations, whereby we want to mention that these values corresponds to the whole data set and not for short time series (below one/half year). With our current methods we do not find a connection between the LOD and the zonal MLT wind on time scales less than a year.

We added to the text:

Additionally, we show in Table 1 correlation coefficients for the 4 locations for the altitudes between 80 and 98 km. Positive correlation values correspond to the occurrence of an eastward directed wind together with an increased LOD. The values of the NH follow a similar pattern, with positive coefficients below the vertical transition height and negative above. Davis shows a different pattern, with overall negative correlation coefficients. This relies in the opposite zonal wind pattern compared to the NH. Theoretical, a time shift of \sim half a year would lead to a similar correlation pattern as the NH.

According to Abarca-del Rio et al. (2003) an accurate estimation of the impact of the solar radiation is quite complicated, due to the point that internal oscillations in the climate system show variations within the same frequency as the 11 year solar cycle. Further, Gray et al. (2010) supports this statement and mention that the problem is further caused due to the small influence of the solar forcing on the climate. Nevertheless, Chapanov and Gambis (2008) showed that based on a decomposition of the LOD, the solar activity (10.47 years) is included.

Abarca-del Rio, R., Gambis, D., Salstein, D., Nelson, P., and Dai, A.: So-

C2

lar activity and earth rotation variability, *Journal of geodynamics*, 36, 423–443, [https://doi.org/doi:10.1016/S0264-3707\(03\)00060-7](https://doi.org/doi:10.1016/S0264-3707(03)00060-7), 2003.

Gray, L. J., Beer, J., Geller, M., Haigh, J. D., Lockwood, M., Matthes, K., Cubasch, U., Fleitmann, D., Harrison, G., Hood, L., Luterbacher, J., Meehl, G. A., Shindell, D., van Geel, B., and White, W.: Solar influence on climate, *Reviews of Geophysics*, 48, <https://doi.org/10.1029/2009RG000282>, <http://dx.doi.org/10.1029/2009RG000282>, 2010.

Chapanov, Y. and Gambis, D.: Correlation between the solar activity cycles and the Earth rotation, *Proc. Journées 2007 “Systèmes de référence Spatio-Temporels”*, edited by: Capitaine, N., *Obs. de Paris*, 206–207, 2008.

Zonal mean winds are presented using meteor radar measurements at 3 sites in the northern hemisphere and the high latitude southern hemisphere, and Aura/MLS. I expected that Aura/MLS data results are compared with radar results for a validation and then would present any global variations. However, Aura/MLS results are used only for comparisons of radar results in the northern hemisphere. Because authors conclude zonal mean winds agree between MLS/Aura and radar measurements, I do not understand motivation of presenting trends of lengths of a day and zonal mean winds from both meteor radars (Figure 6) and Aura/MLS (Figure 7).

Reply: Based on MLS data we added a Figure where is shown the zonal mean winds at ~ 80 km geometric height together with the LOD at the fixed longitude 0° - 20° E between northern high latitudes and southern high latitudes. With this Figure we show the development of the global variations between both parameters. As result can be seen that the correlation between the LOD and the mean zonal wind increase towards the northern high latitude. The same would be seen if half a time shift of \sim half a year would be added to the time series.

FIGURE 9

C3

Caption Figure9 : Zonal MLS wind (red) and LOD (black) at ~ 80 km geometric height for 0° - 20° E. The left part show the values for the southern hemisphere, the right for the northern hemisphere, for every 10° latitude.

Further we added some text:

Figure 9 shows, based on MLS data, the zonal mean wind at ~ 80 km geometric height and the LOD. These zonal mean winds include wind values within the longitude grid between 0° E and 20° E, which is comparable to the NH stations. The Figure is divided in 10° latitude steps from 80° to 10° S/N. Each latitude grid includes values for $\pm 6^\circ$. For the MLS observations the comparison between the wind and the LOD are similar to the 80 km meteor results at the respective latitudes. Further can be seen the occurrence of half a year time shift, between both high hemispheres. A 180° phase shift would lead to the wind-LOD pattern of the opposite hemisphere. Furthermore, the strongest correlation can be seen between both parameters at northern polar latitudes. Due to an increase in the difference between the geometric and geopotential heights, we do not show comparison for higher altitudes. Further we added correlation coefficient between the zonal mean wind and the LOD for each latitude. As result occurs a correlation increase towards the northern high latitude. The same could be seen if a 180° phase shift is added to the time series.

Lastly, authors compare zonal mean winds using Andenes and Davis in the northern and southern hemisphere in a same season and conclude that a difference is caused only by lengths of a day between northern hemisphere summer and winter. However, I believe that mean winds from ground measurement only one site include zonal mean wind and stationary planetary waves and difference of stationary planetary wave amplitudes largely results to a difference of mean winds of ground measurements. I also believe that main reason of interhemispheric differences in atmospheric dynamics is a difference of topography. It makes a difference of atmospheric waves with interact with mean winds. The difference of topography makes an interhemispheric difference of chemical composition in the atmosphere, such as water vapour, ozone, and carbon

C4

dioxide, which makes an interhemispheric difference of viscosity and then winds.

Reply: We totally agree with that point. Our aim is not to state that the differences in the mesospheric zonal mean winds are only a result of the LOD. As we already wrote, we only want to point out, that beside other factors, which have a way stronger influence on the differences of the wind, the LOD has an influence on the winds on both hemispheres. As example for other influencing factors can be called the topography, chemical components and the occurrence and propagation of gravity waves. These waves are the main drivers of the atmospheric wind circulation and therefore also influences the local wind differences at both hemispheres. 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 the LOD.

We added/reformulated some text in the manuscript to clarify the point in the manuscript.

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 (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. 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.

Lübken, F.-J., Höffner, J., Kaifler, B., and Morris, R., J.: Winter/summer mesopause

C5

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 mesospheric carbon monoxide, *Journal of atmospheric and solar-terrestrial physics*, 170, 21–34, <https://doi.org/https://doi.org/10.1016/j.jastp.2018.02.001>, 2018.

I report that this manuscript needs further consideration and discussion.

Specific comments

Line 24 on page 4: What is d ? Because equation (7) shows $d(t)$, it must be a variable parameter depending on time (I expect that t stands for time). Can authors change “ d ” to another symbol or acronym because it is very confusing with integral and differential symbols?

Reply: d which we changed now to D 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.

Lines 21 to 24 on page 5: I am suspicious if you can estimate winds at 78 (or below ~85 km) and 100 km by meteor radars. What is an altitude resolution, and every how much in km did authors determine hourly mean winds? Is there any threshold for a determination, such as elevation angle, range, minimum and maximum radial velocities, and minimum number of sampling meteor echoes? Although authors mention uncertainties as “between 2 and 6 m/s”, weightings of uncertainties are very different between 50 m/s wind with 6 m/s uncertainty and 5 m/s with 6 m/s uncertainty.

Reply: Some literature to show results for the wind estimation based on specular me-

C6

teor trails:

Hall, C., Aso, T., Tsutsumi, M., Nozawa, S., Meek, C., and Manson, A.: Comparison of meteor and medium frequency radar kilometer scale MLT dynamics at 70° N, *J. Atmos. Sol.-Terr. Phys.*, 68, 309–316, <https://doi.org/10.1016/j.jastp.2005.03.025>, 2006.

Hocking, W. K., Fuller, B., and Vandeppeer, B.: Realtime determination of meteor-related parameters utilizing modern digital technology, *J. Atmos. Sol.-Terr. Phys.*, 69, 155–169, [https://doi.org/10.1016/S1364-6826\(00\)00138-3](https://doi.org/10.1016/S1364-6826(00)00138-3), 2001a.

Jacobi, C., Arras, C., Kürschner, D., Singer, W., Hoffmann, P., and Keuer, D.: Comparison of mesopause region meteor radar winds, medium frequency radar winds and low frequency drifts over Germany, *Adv. Space Res.*, 43, 247–252, <https://doi.org/10.1016/j.asr.2008.05.009>, 2009.

McCormack, J., Hoppel, K., Kuhl, D., de Wit, R., Stober, G., Espy, P., Baker, N., Brown, P., Fritts, D., Jacobi, C., Janches, D., Mitchell, N., Ruston, B., Swadley, S., Viner, K., Whitcomb, T., and Hibbins, R.: Comparison of mesospheric winds from a high-altitude meteorological analysis system and meteor radar observations during the boreal winters of 2009/2010 and 2012/2013, *J. Atmos. Sol.-Terr. Phys.*, <https://doi.org/10.1016/j.jastp.2016.12.007>, 2016.

Stober, G., Matthias, V., Jacobi, C., Wilhelm, S., Höffner, J., and Chau, J. L.: Exceptionally strong summer-like zonal wind reversal in the upper mesosphere during winter 2015/16, *Ann. Geophys.*, 35, 711–720, <https://doi.org/10.5194/angeo-35-711-2017>, 2017.

Wilhelm, S., Stober, G., and Chau, J. L.: A comparison of 11-year mesospheric and lower thermospheric winds determined by meteor and MF radar at 69° N, *Annales Geophysicae*, 35, 893–906, <https://doi.org/10.5194/angeo-35-893-2017>, <https://www.ann-geophys.net/35/893/2017/>, 2017.

The monostatic meteor radars cover an altitude range between 75 and 110 km and

C7

the obtained winds have an hourly temporal resolution and a vertical altitude resolution of 2 km in the applied analysis. Within these altitudes, we are able to detect meteors whereby qualitative good wind measurements are reached between 78 and 100 km. Below 75 km we are limited due atmospheric conditions and above 110 km due to technical limitations.

In these time and height window each meteor is weighted by its statistical uncertainty and by its temporal distance from the centre of the window by using a Gaussian kernel. Further regularization is implemented in the wind estimation, which allows estimating the wind within the windows by having at least 3 meteors. As example in December 2015 we detected ~90.000 meteors between 78 and 100 km for the location of Andenes. These meteors follow a Gaussian height distribution, which leads to detections of ~300 meteors at 90±1 km altitude window per hour. At 90 km these meteors are detected within an observational diameter of 425 km and all detected meteors within the diameter are taken for the wind analysis. Of course there are thresholds for the determination, as e.g. elevation angle of zenith < 65°. Further details can be found in then mentioned literature.

Depending on the amount of available detected meteors within the window, the statistical uncertainties of the meteor wind measurements vary between 2 and 6 m/s, whereby values larger than 4 m/s nearly only be reached at the edges of the observation range. In Wilhelm et al. (2017) is shown in Figure 1 an altitude/time distribution of the uncertainties. There its shown that based on the meteor altitude distribution, which includes daily as well as seasonal variations, the statistical uncertainties vary between 2 and 4 m/s between 84 and 94 km.

We don't want to describe the complete wind analysis within this manuscript, therefore we linked to Stober et al. (2017) as well as to Hocking et al. (1999) where the analysis are described in detail.

Line 31 on page 5: Please check a vertical resolution. In my knowledge, Aura/MLS

C8

data are every 1.3 km up to 50 km, 2.7 km up to 62 km and 5.4 km above.

Reply: The vertical resolution which we use in this study is ~ 4 km in the stratosphere and ~ 14 km in the mesosphere. We added a reference.

Livesey, N.J., Read, W.G., Lambert, A., Cofield, R.E., Cuddy, D.T., Froidevaux, L., Fuller, R.A., Jarnot, R.F., Jiang, J.H., Jiang, Y.B., Knosp, B.W., Kovalenko, L.J., Pickett, H.M., Pumphrey, H.C., Santee, M.L., Schwartz, M.J., Stek, P.C., Wagner, P.A., Waters, J.W., Wu, D.L., 2007. EOS MLS Version 2.2 Level 2 Data Quality and Description Document. Technical Report, Version 2.2 D-33509, Jet Propulsion Lab., California Institute of Technology, Pasadena, California 91198-8099.

Matthias, V., Hoffmann, P., Rapp, M., and Baumgarten, G.: Composite analysis of the temporal development of waves in the polar {MLT} region during stratospheric warmings, *J. Atmos. Sol.-Terr. Phy.*, 90–91, 86–96, <https://doi.org/10.1016/j.jastp.2012.04.004>, 2012.

Line 18 on page 6: Juliusruh and Collm are at nearly same location in a global sense. What causes a difference of reversal altitudes by 3 km? Are they systematic difference?

Reply: Even if, on a global sense, Collm and Juliusruh are nearly located on the same latitude, small changes at mid and especially lower latitudes can show strong differences in the transition height. Even if it is not included in this paper, we further compared the mid latitude data with meteor radar data from a Canadian location (43.3 °N), with the result of an even deeper (80 km and blow) vertical wind shear.

Lines 9 to 10 on page 8: How was “the fluctuation in the LOD” obtained? Was it by equation (7)? If so, what is $d(t)$, as asked above? Was $d(t)$ obtained from measurements or some simulation models?

Reply: The LOD data are the result from a combination of several intra-technique services, each associated with a given space geodetic technique. One of them is the VLBI technique, which is able to determine the celestial pole and the Earth rotation

C9

angle and therefore observes changes in the day lengths. Measurements derived by VLBI consist of simultaneous observations of extra-galactic radio sources by two or more radio telescopes. During a standard VLBI observation of 24 hours, three to eight globally distributed telescopes observe up to 60 extra-galactic radio sources. These sources are located in a distance of 2-12 billion light-years and emit broadband microwave signals which can be assumed as a plane wave front when they arrive at the Earth. These radio sources are e.g., quasars which are active galactic nuclei of very high brightness, and which are so far away that no proper motion of them has ever been observed. Therefore they serve as best available fixed position to a fixed reference. Any change in the Earth's spinning or in the Earth orientation, measured by extra-galactic signals can be determined within a fraction of a millisecond of arc. The use of interferometry between several stations leads to the fundamental geodetic VLBI information. Therefore the LOD can be defined by equation (7).

Thomas, J.: An Analysis of Long Baseline Interferometry. DSN Progress Report, JPL Technical Report, 8, 32–1526, 1972.

Campbell, J.: Very long baseline interferometry., pp. 67–87, Berlin Springer Verlag, <https://doi.org/doi:10.1007/BFb0010105>, 1987.

Boeckmann, S.: Robust determination of station positions and Earth orientation parameters by VLBI intra-technique combination, Ph.D. thesis, Friedrich-Wilhelms-University, http://hss.ulb.uni-bonn.de/diss_online, 2010.

Line 22 on page 8: What is “the F10.7 solar cycle”? Is it the 11-year cycle, the 27-day cycle, or both cycles?

Reply: The F10.7 solar cycle is the 11 –year solar cycle. We further tried to estimate the 27-day-cycle within the zonal winds, but didn't found any correlation. We changed in the manuscript F10.7 solar cycle to F10.7 11-year solar cycle.

Line 29 on page 8: LOD (either length of a day or fluctuation in a length of a day)

C10

must have unit of time (probably second from Figures 6 to 8). Why is an LOD unit ms (millisecond or meter times second)?

Reply: ms = milliseconds, we added this in the text.

Line 33 on page 8: Again, please make sure what “the solar cycle” is, 11 year, 27 day, both, or some other cycle? Also, how much does “the solar cycle” influence on a fluctuation of a length of a day? It means how much important to remove a solar cycle influence.

Reply: We added some text to clarify this part: (see 1st point) According to Abarca-del Rio et al. (2003) an accurate estimation of the impact of the solar radiation is quite complicated, due to the point that internal oscillations in the climate system show variations within the same frequency as the 11 year solar cycle. Further, Gray et al. (2010) supports this statement and mention that the problem is further caused due to the small influence of the solar forcing on the climate. Nevertheless, Chapanov and Gambis (2008) showed that based on a decomposition of the LOD, the solar activity (10.47 years) is included.

Abarca del Rio, R., Gambis, D., Salstein, D., Nelson, P., and Dai, A.: Solar activity and earth rotation variability, *J. Geodyn.*, 36, 423–443, 2003.

Gray, L. J., Beer, J., Geller, M., Haigh, J. D., Lockwood, M., Matthes, K., Cubasch, U., Fleitmann, D., Harrison, G., Hood, L., Luterbacher, J., Meehl, G. A., Shindell, D., van Geel, B., and White, W.: Solar influences on climate, *Rev. Geophys.*, 48, RG4001, doi:10.1029/2009RG000282, 2010.

Chapanov, Y. and Gambis, D.: Correlation between the solar activity cycles and the Earth rotation, *Proc. Journées 2007 “Systèmes de Référence Spatio-Temporels”*, edited by: Capitaine, N., *Obs. De Paris*, 206–207, 2008. (https://syrtte.obspm.fr/jsr/journees2007/pdf/s4_18_Chapanov.pdf)

Line 12 on page 9: What is “the size range”?

C11

Reply: we corrected the sentence.

Line 25 on page 9: I do not see that the authors showed effects on mesospheric winds by expansion/shrinking of the upper atmosphere in this work.

I saw that the authors showed correlations between zonal winds in the mesosphere and fluctuations in a length of a day. Stober et al. inferred that fluctuations in a length of a day are correlated with a variation of a thickness of the upper atmosphere. It is possible to expect that zonal winds in the mesosphere are related to a thickness of the upper atmosphere. Please revise it.

Reply: We added Figure 4 to show a direct connection between fluctuation in the solar radiation and the zonal wind. Based on this and on the results of Emmert et al. (2004) and Stober et al. (2012) we show the relation between the thickness of the upper atmosphere and the prevailing zonal wind.

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.

FIGURE4

Caption Figure4: 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.

Emmert, J., T., Picone, J., M., Lean, J., L., and Knowles, S., H.: Global change in the thermosphere: Compelling evidence of a secular decrease in density, *Journal of*

C12

geophysical research, 109, doi:doi:10.1029/2003JA010176, 2004.

Stober, G., Jacobi, C., Matthias, V., Hoffmann, P., and Gerding, M.: Neutral air density variations during strong planetary wave activity in the mesopause region derived from meteor radar observations, *Journal of Atmospheric and Solar-Terrestrial Physics*, 74, 55–63, doi:10.1016/j.jastp.2011.10.007, 2012.

Figure 2 and 3: Why do they exclude Davis in Figure 2 and southern hemisphere?

Reply: We will add Davis, as well as the southern hemisphere (MLS) in Figure 2 / 3. Further we will add for both locations a description in the text.

Figure 2 and 3 captions: Correct to “positive”. Reply: corrected

Figure 6: Please describe what black and blue dashed lines are in a caption. Reply: description is added in the caption.

Technical corrections

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

Line 10 on page 1: Do authors use LOD as “length of a day” or “fluctuations in a length of a day” in this manuscript? Line 24 on page 4 says “length of day (LOD)”. However, “LOD” is used in a subsection 3.2 and a caption of Figure 6 although most of them must imply “fluctuation of LOD”, except for lines from 9 to 10 on page 8 say “fluctuation in the LOD”. Please make it consistent.

Reply: LOD is the acronym for the “fluctuation in a length of a day”, which is also used as this in the area of geodesy. We added and corrected parts to make this more clear.

Lines 9 to 10 on page 2: “shrinking of the middle atmosphere between solar minimum and solar maximum” is very confusing. Does the middle atmosphere shrink at the solar minimum, the solar maximum, or both at the solar minimum and maximum?

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

C13

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.

Later on we wrote that Emmert et al. (2010) showed compared to an average over some solar cycles a decrease in the neutral density during a solar minimum.

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 density trends derived from orbital 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 mesospheric carbon monoxide, *Journal of atmospheric and solar terrestrial physics*, 170, 21–34, <https://doi.org/https://doi.org/10.1016/j.jastp.2018.02.001>, 2018.

Line 19 on page 2: Does “conversation” mean “conservation”? yes, it does. -corrected-

Line 8 on page 5: What does “on an in average” mean? – we modified the sentence -

Line 4 on page 6: I feel that “combined 04 data from the international Earth Rotation and Reference System Service (IERS)” is more appropriate. –corrected-, Thanks for the advice.

Line 24 on page 6: “qualitatively”? – corrected -

C14

Lines 24 to 25 on page 6: I do not understand the sentence and suggest revision. –
Reply: we deleted the sentence, because it causes confusion and were not needed.

Line 30 on page 6: Are MLS data shown in a geopotential height? If so, why “above 90 km” is suddenly described in geometric height?

Reply: The geometric altitudes are approximately estimated from the pressure levels as described in Matthias et al. (2013): $h = -7 * \ln(p/1000)$, where h is the altitude in km and p the pressure in hPa. We are aware that there is difference between the geometric and the geopotential heights especially in the MLT. Furthermore, we neglect altitudes above 85 km geometric height for closer investigations, because the obtained winds show larger discrepancies to the local radar measurements. We only used the upper heights for a general validation based on composites to show similarities.

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.

Added text: The geometric heights are approximately estimated from pressure levels as described in Matthias (2013): $h = -7 * \ln(p/1000)$, 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 and 80 km . . .

Lines 6 to 7 on page 7: It is very ambiguous. Does a density increase occur in summer OR winter, and at the solar minimum OR maximum?

Reply: Figure 4 is a theoretical approach to show changes in the rotation speed, for a defined atmospheric layer, based on changes in the density. For this approach it doesn't matter when the density increase/decrease occurs, it only show the results based on the theoretical change. Nevertheless, according to Emmert (2010) occurs a

C15

density decrease during the time of a solar minimum and a density increase during a solar maximum, respectively.

We reformulated the text: The density increase takes place for longer time scales during a solar maximum (e.g., Emmert et al, 2010) and on annual time scales during the winter, when the Earth-Sun distance is smaller. Both cases influence the temperature within this atmospheric layer as well as their expansion compared to the annual mean. Overall the density variation during an 11-year solar cycle are stronger than the variation causes due to Earth-Sun distance.

Emmert, J. T., Lean, J. L., and Picone, J. M.: Record-low thermospheric density during the 2008 solar minimum, *Geophysical Research Letters*, 37, n/a–n/a, <https://doi.org/10.1029/2010GL043671>, <http://dx.doi.org/10.1029/2010GL043671>, L12102, 2010.

Line 16 on page 7: Change “the northern and the southern hemisphere” to “the northern and southern hemispheres”. –corrected-

Line 16 on page 7: Remove comma between “opposite” and “fluctuations”. –corrected-

Lines 20 to 21 on page 7: What is “between two locations on the same latitude”? Does it mean “at the same latitude in the northern and southern hemispheres”?

Reply: we reformulated the sentence: Therefore the prevailing wind within the MLT region should be similar in magnitude between Andenes and Davis, which are located at the same latitude in the northern and southern hemispheres.

Line 21 on page 8: It should be “additionally”. –corrected-

Line 22 on page 8: It should be “relatively”. –corrected-

Line 29 on page 8: Please make sure if “seasonal fluctuation” means “seasonal variation of a fluctuation”, “seasonal means of fluctuation”, or something else. –corrected,
Thanks for the advice-

C16

Line 33 on page 8: What does “as result as” mean? –corrected-

Line 19 on page 9: “This reversal can be explain can be explain” must be “This reversal can be explained”. –corrected-

Lines 20 to 21 on page 9: First, “station” on line 21 must be “stations”? What are “the polar and the second midlatitude stations”? “the polar stations” include both Andenes and Davis? Is “the second milatitude station (I think not “stations” in this case)” Juliusruh or Collm? Did the authors define “first” and “second” stations previously?

Reply: We reformulated the part according comments of Ref #1: 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 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

C17

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-terrestrial 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.

Line 1 on page 10: “hemisphere” must be “hemispheres”. –corrected-

Lines 6 to 7 on page 10: Why do authors specify “the middle latitude stations” as Collm and Juliusruh? Is “the polar station” only Andenes? How about Davis? Reply: We added to location of Davis, and corrected the sentence if needed

Line 10 on page 10: “not figured out” must be “not be figured out”. –corrected-

Line 13 to 14: I do not understand this sentence. Please revise it. Reply: For a better understanding we partly reformulated the conclusion.

Line 1 on page 11: “ssignal” must be “signal”. –corrected-

C18

Line 20 on page 11: "datadata" must be "data". -corrected-

Please also note the supplement to this comment:

<https://www.ann-geophys-discuss.net/angeo-2018-51/angeo-2018-51-AC2-supplement.zip>

Interactive comment on Ann. Geophys. Discuss., <https://doi.org/10.5194/angeo-2018-51>, 2018.

C19

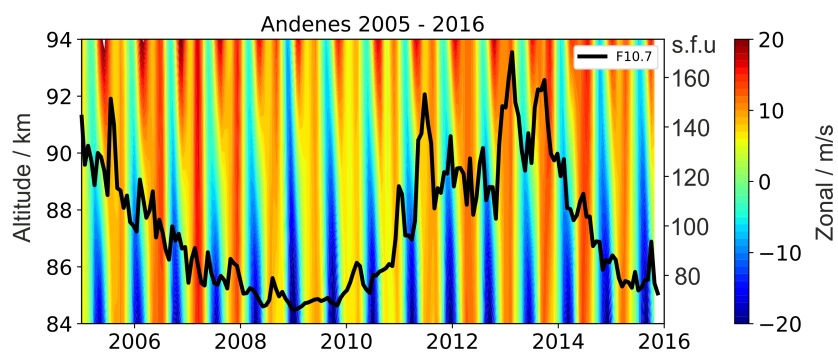


Fig. 1.

C20

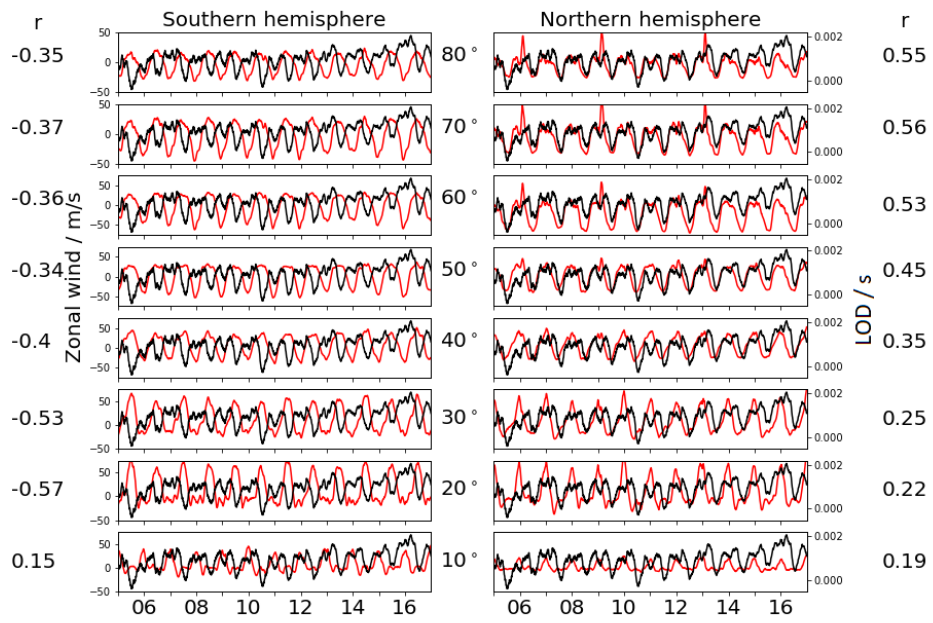


Fig. 2.