Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2018-51
Manuscript under review for journal Ann. Geophys.
Discussion started: 20 June 2018

Connection between the length of day and wind measurements in the mesosphere and lower thermosphere at mid and high latitudes.

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Abstract.

This work presents a connection between the density variation within the mesosphere and lower thermosphere (MLT) and changes in the intensity of the solar radiation. On a seasonal time scale, these changes take place due to the revolution of the Earth around the Sun. While the Earth, during the northern hemispheric winter, is closer to the Sun, the upper mesosphere expands due to an increased radiation intensity, which results in changes in density at these heights. Theses density variations, i.e. a vertical redistribution of atmospheric mass, have an effect on the rotation rate of Earth's upper atmosphere owing to angular momentum conservation. In order to test this effect we applied a theoretical model, which shows a decrease of the atmospheric rotation speed of about $\sim$ 4 m/s in the case of a density change of 1% between 70 and 100 km. To support this statement, we compare the wind variability obtained from meteor radar (MR) and MLS satellite observations with fluctuations in the length of a day (LOD). The LOD is defined as the difference between the astronomical determined time the Earth needs for a full turnaround and a standard day length of 86.400 seconds. Changes in the LOD on time scales of a year and less are primarily driven by tropospheric large scale geophysical processes. A global increase of eastward directed winds leads, due to friction with the Earth's surface, to an acceleration of the Earth's rotation by up to a few milliseconds per rotation. The LOD shows an increase during northern winter and decrease during summer, which corresponds to changes in the MLT density due to the Earth - Sun movement. Further, we show that, even after removing the seasonal and solar cycle variations, the wind and the LOD are connected, by analyzing trends for the years 2005 - 2016.

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1 Introduction

According to the first Kepler's law the Earth travels, in a good approximation, on an elliptic trajectory around the Sun. Within a year the distance between both celestial bodies changes. During the northern hemispheric winter the range is approximately 3.29% shorter than in the northern hemispheric summer. Due to the inverse square law, where the intensity I of the radiation is inverse proportional to the Earth-Sun distance squared. This shorter distance between the Sun and the Earth during boreal winter leads to an increased heating of the mesosphere and lower thermosphere (MLT) resulting in an expansion of the MLT and thermosphere, compared to the annual mean. Another effect on the expansion/shrinking of the MLT is given by the variability of solar radiation due to the solar cycle effect. Figure 1 shows a scheme of the Earth Sun constellation and the resulting effects, which will be explained in the following. Keckhut et al. (1995) showed the occurrence of a pronounced shrinking of the middle atmosphere between solar minimum and solar maximum as well as changes in the temperature by 2 K. Stober et al. (2014) showed that a solar cycle effect between 2002 and 2013 led to changes in the neutral density within the MLT region by up to 2.5%. Furthermore, satellite measurements showed a neutral density decrease by up to $\sim$ 30% between solar maximum and solar minimum at about 400 km (Emmert et al., 2010). For the winter season 2009/2010 Stober et al. (2012) showed a connection between the neutral density and the expansion/shrinking of the atmosphere by using meteor radar (MR), Lidar and Microwave Limb Sounder (MLS) satellite wind and temperature measurements. Further, they show a strong anti-correlation of neutral density and prevailing zonal wind. This indicates that an increase/decrease of the neutral density occurs simultaneously with a decrease/increase in zonal wind speed, respectively.

Changes in the thickness of the atmosphere resulting from differences in the distance between Earth and Sun as well as from solar cycle effects go along with changes of the Earth‘s rotation speed. Based on the conversation of angular momentum L, the angular velocity ω for an altitude defined atmospheric layer a, with the thickness $a_o - a_i$, can be estimated by:

$$L = J\omega = \frac{2}{5}\, m\, \frac{{a_o}^5 - {a_i}^5}{{a_o}^3 - {a_i}^3}\, \omega, \tag{1}$$

where J is the moment of inertia for a spherical shell, which rotates about an axis through the center, $a_{o,i}$ are the inner and outer radius of the spherical shell, and m is the atmospheric mass. On this occasion the atmospheric mass is calculated according Trenberth and Guillemot (1994) by

$$m = \int_{r_0}^{\infty}\int_{0}^{2\pi}\int_{-\pi/2}^{\pi/2} \rho r^2 cos\phi \, d\phi \, d\lambda \, dr, \tag{2}$$

where $\rho = \rho(\lambda, \phi, r)$ is the density of air at longitude λ and latitude ϕ, and r is the distance from the Earth's center, while $r = r_0$ at the surface of the Earth. In a good approximation the Earth's surface can be described as an ellipsoid $r_0^2 = a^2(1 - 2\alpha sin^2\phi)$, where a is the equatorial radius, $\alpha = (a^2 - b^2)/2a^2$ is related to the flattening and b is the polar radius. With respect to the height above the surface z, this results in $r^2 = (a+z)^2(1-2\alpha sin^2\phi)$ and $dr = (1-2\alpha sin^2\phi)^{\frac{1}{2}}dz$. Further, under the assumption that $\rho = \rho_1(r)\rho_2(\lambda,\phi)$, the atmospheric mass can be derived by

$$m = \int_0^{2\pi}\int_{-\pi/2}^{\pi/2}\left[\int_0^{\infty}\rho_1(z)(a+z)^2dz\right]\rho_2(\lambda,\phi)(1-2\alpha sin^2\phi)^{\frac{3}{2}}cos\phi\, d\phi\, d\lambda \quad (3)$$

The integral with respect to z and the relation to the measurements of the surface pressure p_s can be estimated by solving

$$p_s = \int_0^{\infty}\rho_1(z)g(z)\,dr, \quad (4)$$

where g is the acceleration due to gravity. Considering that g is a function of height and latitude the total atmospheric mass can be written in numerical terms as $m = 5.22371$ x 10^{15} $\bar{p}_s$, where m is in kilograms, and $\bar{p}_s$ is in hectopascal, for standard gravity at 45° latitude. More detailed information about the estimation of the total mass of the atmosphere can be found in Trenberth and Guillemot (1994). According to Trenberth and Smith (2004) the total mean mass of the atmosphere is 5.148 $\times 10^{18}$ kg and varies slightly on annual scales mainly due to the amount of available water vapor.

A method to measure variations in the rotation speed of the solid Earth is estimating the time the Earth needs for a full rotation. In the following we define the crust, mantle and core of the Earth as solid Earth. To estimate the percentage of the atmospheric rotation velocity from the solid Earth rotation velocity, their rotation speed and their variations are necessary. The time the Earth needs for a full rotation is not constant. The rate of rotation and the orientation of the Earth's axis varies in time and space. Perturbations in the Earth's rotation rate are caused either by external forces, as e.g., the influence of celestial bodies, or by internal torques, which are, e.g., large scale geophysical processes (Brzezinski et al., 2001). These internal torques are a combination of relative movements and mass reallocation of Earth's core, mantle, crust, oceans tides, and the atmosphere. Geographical differences in wind pattern and oceans cause shifts in the air and in the water masses. Earthquakes displacing the Earth's mantle might also influence the Earth's rotation on longer time scales (Carter and Robertson, 1986).

On time scales less than a year the dominant geophysical process to influence the duration of the Earth's rotation is the atmosphere (Volland, 1988). Every large scale momentum exchange of the Earth's atmosphere on the Earth's surface increases or decreases their rotation, due to the law of conservation of total angular momentum within a system. The total angular momentum of the Earth's atmosphere M can be approximately written as

$$M = \int_v \rho_{apc}L_{apc}\,dV = \int_v \rho_{apc} r\times(u_{rel}+\omega\times r)\,dV, \quad (5)$$

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where L_{apc} is the angular momentum of an air parcel of unit mass, ρ_{apc} the density of the air parcel, u_{rel} the relative velocity, and $\omega \times r$ is the velocity due to the rotation of the Earth (Madden and Speth, 1995).

The total angular momentum and the velocities can be split into two parts. The mass part M_ω represents the value the angular momentum would take if the atmosphere would be vertically and horizontally stationary relative to the ground, and the relative part M_r describes the part of the atmosphere angular momentum that is due to the motion of the atmosphere relative to the Earth's rotation. Following Madden and Speth (1995), Egger et al. (2007), and Driscoll (2010) these parts of angular momentum can be written as

$$M = M_\omega + M_r = \frac{r^4\omega}{g}\int_0^{2\pi}\int_{-\pi/2}^{\pi/2} p_{sfc}cos^3\theta \, d\theta \, d\lambda + \frac{r^3}{g}\int_0^{1000}\int_0^{2\pi}\int_{-\pi/2}^{\pi/2} ucos^2\theta \, d\theta \, d\lambda \, dp. \quad (6)$$

Thus, changes in the atmospheric angular momentum depend on the sum of different torques $dM/dt = T_F + T_M + others$. Here T_F is the friction torque, T_M is the mountain torque, and others torques include for example, the gravity wave torque. However, the gravity wave torque is small compared to the other two mentioned. The friction torque is exerted on the Earth's surface mainly due to frictional forces between the wind and the surface. If eastward directed surface winds are prevailing on a global scale, this torque leads to an increase of the rotation rate due to angular momentum transfer from the atmosphere to the Earth's surface. The mountain torque is based on the surface pressure and orography, and it is the torque which is exerted on the Earth's surface due to a difference of pressure on two sides of a mountain. Both torques vary according to their global location and reach values in the range of 10^{19} Nm (Egger et al. (2007), Driscoll (2010), de Viron and Dickey (2014)). The dominant exchange of the angular momentum between atmosphere and Earth takes place in the atmospheric boundary layer, which, depending on the orography and latitude, has a typical thickness of about 1 km at mid-latitudes (Volland, 1988).

Already in the 1960's and 70's scientists showed that fluctuations in the orientation of the Earth's rotation axis, on seasonal time scales, are associated with changes in the east-west tropospheric wind on a global scale and therefore accompanied with a transfer of angular momentum between the Earth's crust and the atmosphere (Munk and MacDonald (1961), Lambeck (1978)). Changes in the speed of the Earth's rotation axis can be seen in fluctuations in the duration of a day. These fluctuations have been measured since the 60's using the Very Long Baseline Interferometry (VLBI) technique. They are connected with the length of day (LOD), which is the difference between the astronomical determined duration of a full day $2\pi/d$ and the standard 86400 SI seconds (Aoki et al., 1981). The LOD can be written as

$$LOD(t) = \frac{2\pi}{d(t)} - 86400s. \quad (7)$$

Carter and Robertson (1986) studied the influence of geophysical processes of the atmosphere on the duration of a day. They showed that when the globally averaged mean winds from east to west increase, the rotation rate of the Earth decreases and the day gets longer. Rosen and Salstein (1991) showed that the effect of the wind on the LOD decreases with heights, by showing that winds in the atmospheric layer between 1000 and 10 mbar contributes 0.5 ms, from 10 to 1 mbar contributes 0.03 ms, and winds above 1 mbar contributes less than 4 μs to the inter-annual LOD budget. The impact of large scale geophysical processes like, e.g., El Niño (e.g., Dickey et al., 1994) and the stratospheric quasi-biennial oscillation (QBO) can also be seen in the LOD (e.g., Volland (1988), Eubanks et al. (1988)).

Within this study we focus on heights between 60 and 100 km. These heights are sensitive enough to density changes due to the changes in the intensity of the solar radiation. After we described the data we used in this study in Section 2, we show results and discuss the theoretical change of the rotation speed due to an expanding/shrinking atmosphere in Section 3. We will show that due to the expansion/shrinking effect even under the assumption on an in average, equal density distribution between the northern and southern hemisphere, differences in the prevailing wind occur. Furthermore we will show a connection between the LOD and the prevailing wind by showing correlations in the MLT region by using MR and MLS data for one polar and two mid latitude locations. We use the LOD data to show how deep is the influence of the solar radiation on the atmospheric rotation speed. The conclusions are found in section 4.

2 Data

The wind data we use in this study are derived from MR and MLS satellite measurements. The MRs are located at the northern high latitude station Andenes (32.5 MHz, 69.3°N, 16°E, Norway), the northern mid latitude stations Juliusruh (32.5 MHz, 54.6°N, 13.4°E, Germany), and Collm (36.2 MHz, 51.3°N, 13°E, Germany) and the southern high latitude station Davis (33.2 MHz, 68.6°S, 78.0°E, Antarctic). The radars cover an altitude range between 75 and 110 km and the obtained winds have an hourly temporal resolution and a vertical altitude resolution of 2 km in the applied analysis. At 90 km altitude the observed volume of each radar has a diameter of $\sim$ 400 km, and the mean wind above each station is a weighted average over this volume. In the case of the Andenes, Davis and Collm MR data are available since 2005 and for Juliusruh since 2008. We focus on an altitude range between 78 and 100 km where we obtain continuous measurements. The statistical uncertainties of winds are obtained from a fitting procedure by taking the number of detected meteors per bin into account, as well as a full error propagation of the radial wind errors. Therefore the resulting uncertainties for the hourly winds vary in a range between 2 and 6 m/s with larger errors at the edges of the meteor layer. More information about the all-sky meteor radars and the used wind estimation method can be found in Hocking et al. (2001), Holdsworth et al. (2004) and Stober et al. (2017). For this research, we focus primarily on the zonal wind component, because a connection between winds and changes in LOD will be mainly seen in the main rotation direction of the Earth.

In addition to local radar observations, we use satellite data from the Microwave Limb Sounder (MLS) to extend the vertical coverage. MLS onboard the Aura satellite (Waters et al. (2006), Livesey et al. (2015)) has a global coverage from 82°N to 82°S and an useful height range from approximately 11 to 97 km (261 to 0.001 hPa). The vertical resolution varies between $\sim$ 4 km in the stratosphere and $\sim$ 14 km at the mesopause. In this work we focus on the height range between 60 and 80 km (if not otherwise specified) to investigate a connection between the LOD and the density depending zonal wind within the northern MLT. Daily quasi geostrophic winds for the years between 2005 and 2016 are derived from MLS geopotential height observations. For this study we use two different horizontal grids cells, which are located around Andenes (67-71°N and 0-30°E) and around Juliusruh/Collm (49-53°N, 0-30°E), which are further referred to as high and mid latitude station, respectively.

Further we use in this study Combined 04 data (IERS) from the International Earth Rotation and Reference Systems Service. The use of interferometry between several stations, which observe radio sources, leads to fundamental geodetic information as changes in the Earth's spinning or in the Earth orientation (Rothacher (2002), Altamimi et al. (2007), Boeckmann (2010)). Based on these information the mean rotation rate and the astronomical duration of the day were computed (Aoki et al., 1981). The IERS provides uncertainties for the LOD measurements which most of the time vary in a range of $\sim 5\%$. More information about the LOD data provided by IERS and their algorithm to estimate the LOD can be found in Bizouard et al. (2017).

3 Results and Discussion

3.1 LOD and neutral air density at the MLT

Figure 2 shows composites of zonal winds from MR measurements at Andenes, Juliusruh, and Collm. These data are estimated by using a mean wind adaptive spectral filter (Stober et al., 2017), which uses a 1 day sliding window, which mainly suppresses the impact of short-term variations, as atmospheric tides and gravity waves. All three stations show similar wind patterns, with typical mesospheric eastward directed winds during the winter, with values of up to 10 m/s, and a wind reversal during spring. The spring wind reversal occurs earlier at mid latitudes than at polar latitudes. During the summer a vertical wind shear is present with westward directed winds below 90 km for Andenes, below 88 km for Juliusruh, and below 85 km for Collm. Above these heights a strong eastward jet occurs. The westward and the eastward jets reach wind values of up to 40 m/s at all three locations. These annual wind climatologies are consistent with previous studies e.g., Manson et al. (2004), Hoffmann et al. (2010), and Jacobi (2012).

Besides the radar data we additionally use MLS data within this study to extend the vertical coverage down to 60 km. In Figure 3 the zonal wind is shown for the high latitude location of Andenes and for middle latitudes at Collm. In both cases the altitude ranges between ~ 60 and ~ 97 km geopotential heights. A comparison of the MLS composite winds with MR composite winds results, below 90 km, in a qualitativ good agreement of the seasonal amplitudes and phases. Above that height differences occur, which are based on the use of the geopotential height, as well as on the higher resolution of the meteor radar. Nevertheless, both Figures show eastward directed wind between September and April for nearly all altitudes, with values of up to 40 m/s for the high latitude area and up to 60 m/s for the midlatitudes. During summer westward directed wind dominates below 95 km and reaches values of up to 30 m/s for the high latitudes. For the middle latitude, below 90 km, the wind reaches values of up to 50 m/s. A similar pattern of an eastward directed wind occurs in both cases during summer above 90 km geometric height. In the following discussion we will focus on the MLS altitude range 60-80 km and use the MR data for the altitudes between 80 and 100 km.

According to previous studies as e.g., by Emmert et al. (2004) and Stober et al. (2012) a connection exists between the thickness of an atmospheric layer and the density fluctuation within that layer. Stober et al. (2012) explained the occurrence of

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this connection by showing variations in the neutral density, based on MLS and MR observations, together with changes in the MLT geometric height. Furthermore they showed a strong anti-correlation between the simultaneous occurrence of the zonal wind and the density change within the mesosphere. Therefore within the following part we investigate a potential connection between the expanding MLT and the atmospheric rotation speed. Figure 4 shows, as an example, the theoretical variation in the atmospheric rotation velocity with height due to a density increase up to 1% between 70 and 100 km. The calculation is done in 2 km height layers. The density increase in the MLT should correspond to the impact of fluctuations in the solar intensity between summer and winter, or between a solar minimum and solar maximum, which influences the temperature within this atmospheric layer as well as their expansion compared to the annual mean. According to equations 1 - 4, we estimated for three different cases (linear (red), exponential (green) and a gaussian shape (blue) density increase) the resulting theoretical change in the rotation speed within these heights, with the solid Earth rotation speed (black) as background flow. Based on the conserved quantity of the angular momentum within a narrow atmospheric layer (2 km vertical) this sums up, according to each case, to a decrease of the rotation speed by up to $\sim$ 2-4 m/s, with the strongest variation within the gaussian shape curve. These results fit to the observations from Stober et al. (2012) and show the dependence of the rotation speed within an atmospheric layer due to changes in the neutral density.

Based on ERA40 data (Trenberth and Smith, 2004) showed that the global mean of the surface pressure is nearly constant, and surface pressure anomalies at the northern and the southern hemisphere are nearly identical, but opposite, fluctuations. These anomalies are mainly derived due to the changing amount of available water vapor in the atmosphere. Under the assumption of opposite surface pressure anomalies within both hemispheres and therefore by neglecting other factors as e.g., different gravity wave forcing between the hemispheres, we assume, on annual scales, similar pressure values within the MLT region. Therefore the prevailing wind within the MLT region should be similar in magnitude between two locations on the same latitude. To underline the influence of the intensity of the solar radiation on the density and also on the amplitude of the zonal wind, we compare the temporal development of the seasonal mean wind measurements from the northern hemispheric station Andenes (69.3°N) and southern hemispheric station Davis (68.3°S). Figure 5 shows for both stations the winter and summer mean wind for the altitudes 88 and 96 km. The northern winter includes the mean of the months December, January and February, and the southern winter the months June, July and August. The northern winter period comes along with the perihelion, which is the point where the Earth comes nearest to the Sun. While during the winter season the wind values are higher in Davis for both altitudes, they are higher in Andenes during summer season, especially at 96 km, with values of up to 10 - 20 m/s. Both seasonal wind differences are consistent with the change in the average density within the upper mesosphere, resulting from the different distance between Earth and Sun and leading to the variation of the averaged zonal wind, as shown in Stober et al. (2012). We have to note that beside many others factors, this is only one reason for the wind differences between both locations at theses altitudes. For a closer understanding of this phenomena global density observations are required and therefore we can not say how strong the effect is.

3.2 Correlation of mean winds and LOD

In the following we want to show that the LOD correlates with the prevailing wind from the three northern hemispheric stations. If the Earth‘s rotation is constant the LOD should be zero, however small wobbles of the Earth rotation between the days causes tiny deviation in the day length. These have to be compensated by a momentum transfer between the different parts of the Earth to the atmosphere. As the atmosphere is slaved to the Earth crust, because the atmospheric momentum and mass are much smaller than of the Earth core, the atmosphere has to respond to changes in the rotation velocity and at least the troposphere can trigger an own feedback on the LOD. So far we use the LOD just as reference for the changes in the rotation speed, which can be seen in the zonal wind, as well as to verify up to which height the solar driven density effect is dominant. Therefore the next two Figures 6 and 7 show wind values for Andenes and Collm at different altitudes and the fluctuation in the LOD by using the same smoothing method as done for the winds. Two different altitudes in the MLT are considered from the MR winds: (1) 80 km, where within a year a change between eastward and westward directed wind occurs and (2) 96 km for both locations, the altitude where the wind, during the summer shows the opposite direction as at 80 km (see Figure 2). Positive wind values corresponds to eastward directed winds and positive LOD values corresponds to a longer duration of the day. If not explicit mentioned the results of the two mid latitude stations are nearly identical. Therefore we only show the results for the location around Collm.

At the altitude of 80 km (Figure 6) the oscillation pattern of the smoothed zonal wind (blue) and the smoothed LOD (black) are similar for Andenes. According to previous studies the LOD consists of superpositions of serval periods, as 0.5 years, 1 year (see also Vondrák and Burša, 1977), 2-3 years (Buffet, 1996), 5.9 years (Abraca del Rio et al., 1999) and other (e.g., Munk and MacDonald (1961), Holme and de Viron (2013)). Although, the zonal wind includes a superposition of several periods as the solar cycle, diurnal and semidiurnal tides and more (e.g., Emmert et al. (2010), Hoffmann et al. (2010)). Therefore, we additional show with the red line a smoothed zonal wind after removing variations due to the F10.7 solar cycle. The influence of the solar cycle on the daily zonal wind is relativ small, therefore the smoothness of the red line is stronger for the visualization. Changes in the LOD are sluggish compared to variations in the wind, due to the amount of momentum which is needed to influence the Earth’s rotation speed. Therefore only comparisons on seasonal and longer time scales are useful to be considered. All parameters which are displayed in Figure 6 show a seasonal pattern, with decreasing values during summer and increasing values during winter. Beside the striking seasonality, short time fluctuations within a year are observable during the winter in the zonal wind for some years. During the winter of 2010 and 2011, and on even shorter time scales as few months during the winter 2006, 2014 and 2015 decreases in the LOD together with decreases in the zonal wind are visible. The LOD varies between -1 and 4 ms. The LOD oscillation shows seasonal fluctuations with shorter day lengths during NH summer and longer day lengths during winter, which fits to the density increase and decrease of the MLT as described above. For the mid latitude station the oscillation pattern in the LOD and the wind are qualitatively similar, but shifted in time. The wind peaks occur earlier in the year than the LOD peaks, which goes along with the earlier wind transition at the mid latitude, which can be seen in Figure 2. Removing variations of the solar cycle shows a similar pattern as result as with the impact of the solar cycle. For the MLS observations the comparison between the wind and the LOD are similar to the 80 km meteor results. Beside the dominant seasonal cycle in the wind regime as well as in the LOD, also short time fluctuations occur at both locations (not shown here), but with lower heights the influence of the density variation due to the solar radiation is decreasing. In the summer wind transition altitude, which is in the case of Andenes roughly at 88 km, for Juliusruh at 86 km and for Collm at 84 km (see Figure 2) a time shift occurs between both parameters. The altitude of the wind transition in these cases is defined as the height between the above located eastward and the below located westward wind during summer. At these heights the wind and the LOD seems almost not to be correlated. Above the summer wind transition altitude the oscillation pattern between the LOD and the winds are quite the opposite than for 80 km altitude, with a 180° shift between both parameters, which can be seen in Figure 7. The phase shift, which is pronounced during the summer, obviously results from the opposite wind regime compared to the 80 km altitude. Nevertheless, above the transition height, changes in the density, due to the intensity of the solar radiation, are more sensitive than at lower heights. Therefore the existing seasonal wind pattern fits well to the atmospheric density increase and decrease at these layers.

According to Figure 4, we showed that already a density change of 1 % results in wind changes in the size range of a few m/s. Though to prove this, it is necessary to distinguish between further natural factors and density variations and we are also not able to estimate the influence of the radius on the velocity due to lack of global density measurements. Nevertheless, we show in Figure 8 the development of the LOD, and therefore indirect of the density, together with the zonal wind. We show here for Collm, annual mean values for the zonal wind (red) and the LOD (black), after removing the seasonal and solar cycle variations, for the heights between 80 and 96 km. Further we added tendency lines, which show for the LOD an increase between the years 2005 and 2015, while the wind trend shows up to 94 km a decrease. Above 94 km the trend turns into a slightly positive wind incline. This reversal can be explain can be explain by stronger influence due to gravity wave filtering, which we can not exclude this consideration. Furthermore, the same effect can be seen at the polar and the second midlatitude station for all observed altitudes, with the result of and overall negative wind trend for all altitudes. The results show that the connection between the LOD and the wind are more pronounced at lower latitudes, which can be explained by the influence of the radius on the rotation velocity, which is much higher at the middle latitude stations than at Andenes.

4 Conclusion

Within this work we show that the mesospheric winds are affected by an expansion/shrinking of the upper atmosphere takes place due to changes in the intensity of the solar radiation, which effects the density within the atmosphere. A reason, besides the solar cycle effect, is the annual movement of the Earth around the Sun, which leads to a smaller distance between both celestial bodies during the northern hemispheric winter, and a longer distance during summer. This leads to a shrinking/expansion of the atmosphere during the northern hemispheric summer/winter. This shrinking effect takes mainly place in the upper atmosphere, where the amount of mass is small to be sensitive enough to changes to the intensity of solar radiation, as well as temperature changes. We showed that a theoretical density increase by 1% between 70 and 100 km leads to a decrease in the atmospheric rotation speed, within a defined layer, by up to 4 m/s. The influence of the Earth-Sun distance on the wind speed was further investigated using winds from in total four station, whereby two stations are located at similar latitudes for the northern and southern hemisphere. Based on summer and winter mean wind, we found that during the perihelion, where the MLT expands, a decrease in the zonal wind speed for the respective location occurs together with an increase in the LOD. During the opposite aphelion, an increase in the zonal wind occurs beside an decrease in the day length.

Further we showed that even after removing the seasonal and the solar cycle (F10.7) variations these parameters are connected. We showed the annual tendency development over the whole time period, with the result of an increasing LOD trend together with and more pronounced westward directed wind tendency for the middle latitude stations. This effect weakens at the polar station, which is on the one hand due to a smaller radius, which effects the rotation speed of the atmospheric layer. On the other hand, there are further natural factors, as e.g., the gravity wave drag, who strongly influence these tendencies. Further, we were only able to investigate the connection between theses parameters on time scales which are at least one year. On shorter time scales a connection between the LOD and the winds can not figured out, the LOD consists of oscillations with at least half a year period and with the current available data we are not able to fully resolve the superpositions of both parameters. Future work remains to fully understand these effects when global density data measurements are available.

Additionally, we do not want to state that the tropospheric wind LOD drives the mesospheric zonal wind, neither that the wind drives the LOD. We want to mention that based on our findings a connection between both parameters occurs, which we explain by the variation of the available atmospheric density. Further we only compare on the one side global LOD data with local measurements, and on the other side there are way stronger geophysical effects which drives the wind regime in theses altitudes. Within this work we only want to point on this effect, and for closer investigations we need global longtime density data.

Data availability.

The Andenes/Juliusruh radar data are available upon request from Gunter Stober (stober@iap-kborn.de).
The Collm radar data are available upon request from Christoph Jacobi (jacobi@rz.uni-leipzig.de)
The Davis radar data are available upon request from Damian Murphy (Damian.Murphy@aad.gov.au)

Competing interests.

The authors declare that they have no conflict of interest.

Acknowledgements. This work was supported by the WATILA Project (SAW-2015-IAP-1 383). The Operation of the Davis Meteor radar was supported through Australian Antarctic Science projects 2668 and 4025. We thank IERS for providing the used LOD data, which can be found under https://datacenter.iers.org., Furthermore we acknowledge the IAP technicians for the technical support.

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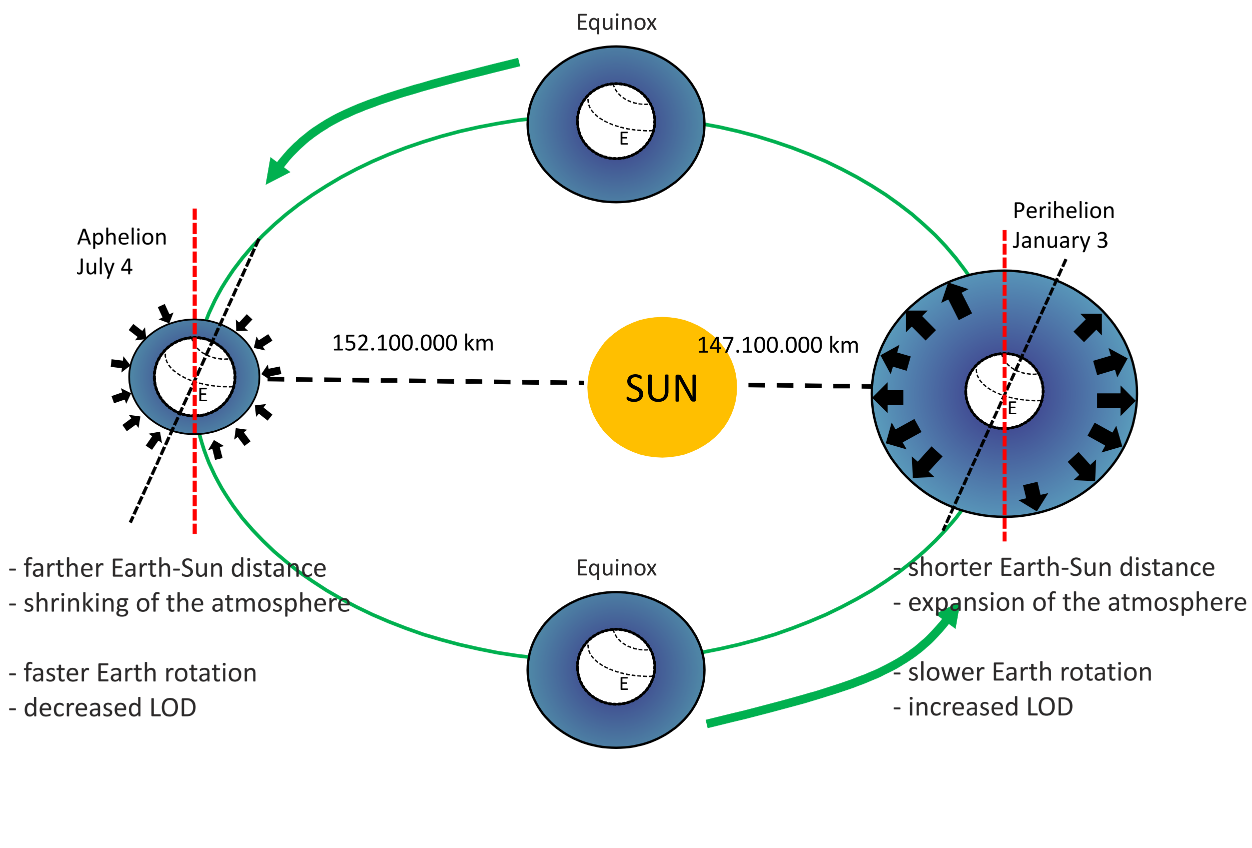

Figure 1. Schema of Earth and Sun correlation and the resulting effects on the thickness of the atmosphere and the Earth's rotation velocity.

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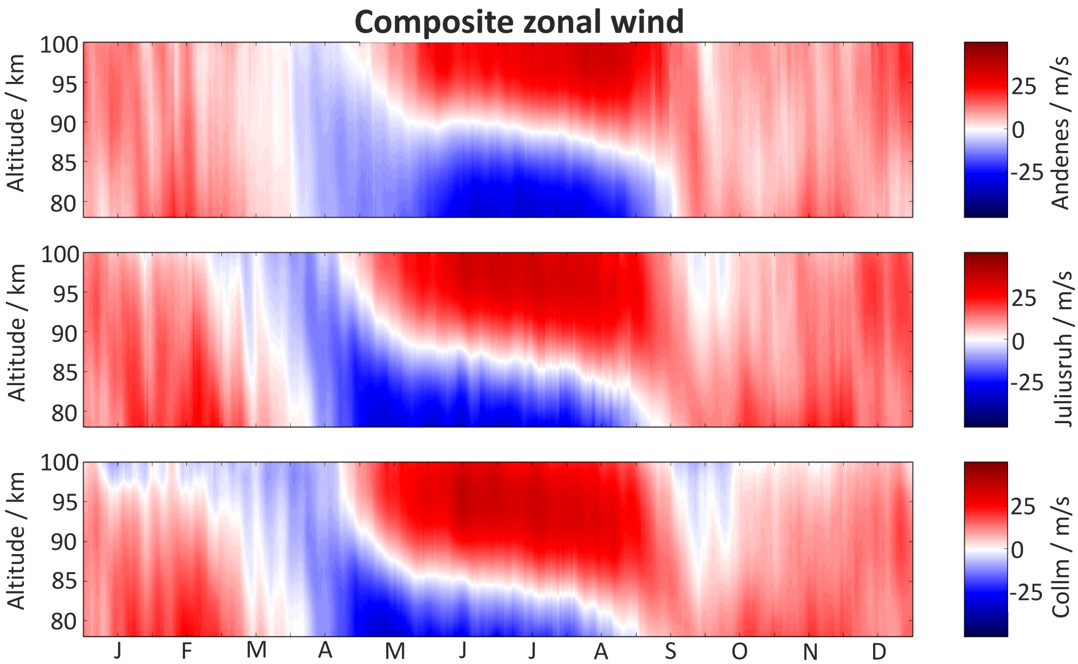

Figure 2. Composites of zonal wind for Andenes (top), Juliusruh (mid), and Collm (bottom). The composite for Andenes and Collm include 12 years of meteor radar data and that of Juliusruh 9 years. Positiv values correspond to eastward directed winds and negative to westward directed winds.

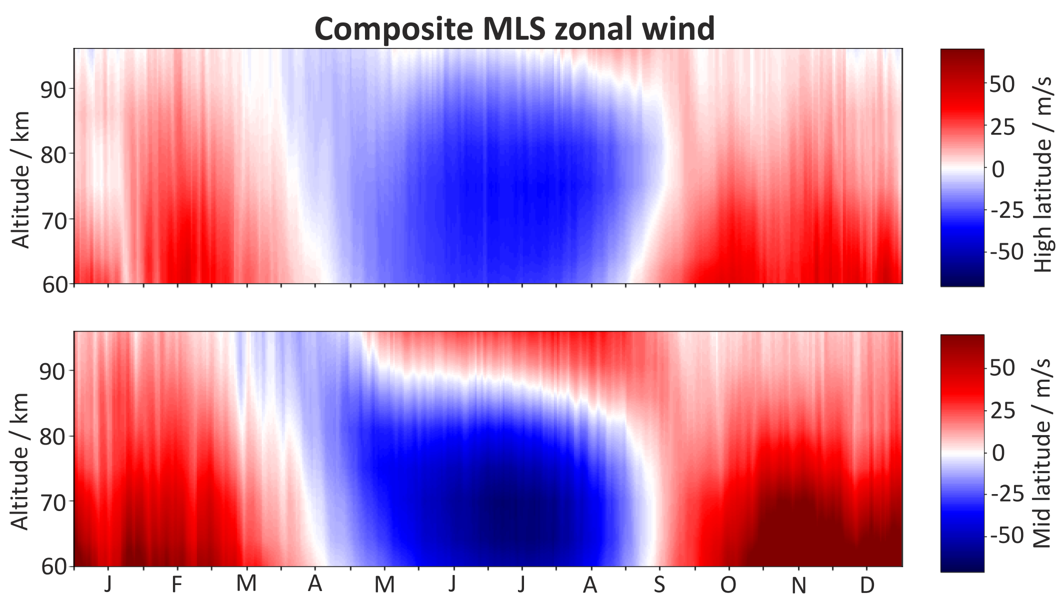

Figure 3. Composite of zonal wind for high latitude location (top), and mid latitude location (bottom). The composite of both figures includes 12 years of data wind data derived from MLS geopotential height data. Positiv values corresponds to eastward directed winds and negative to westward directed winds. The altitude is given in geopotential height.

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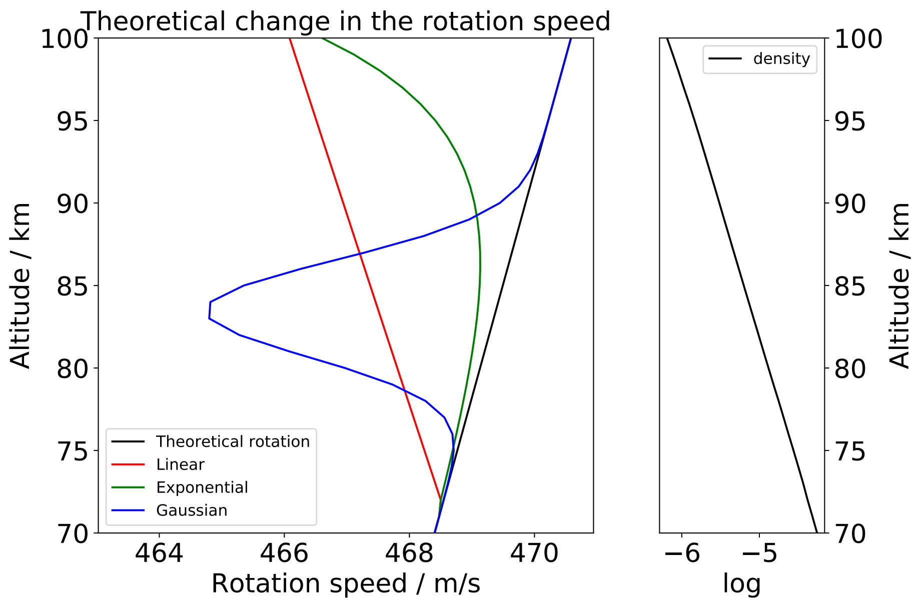

Figure 4. Theoretical change of the rotation speed (left side) for a rigid atmospheric layer. In black the theoretical rotation speed of the Earth's atmosphere and in colors the change due to density increase of 1% according the legend. On the right side the density progress is shown for specific altitudes.

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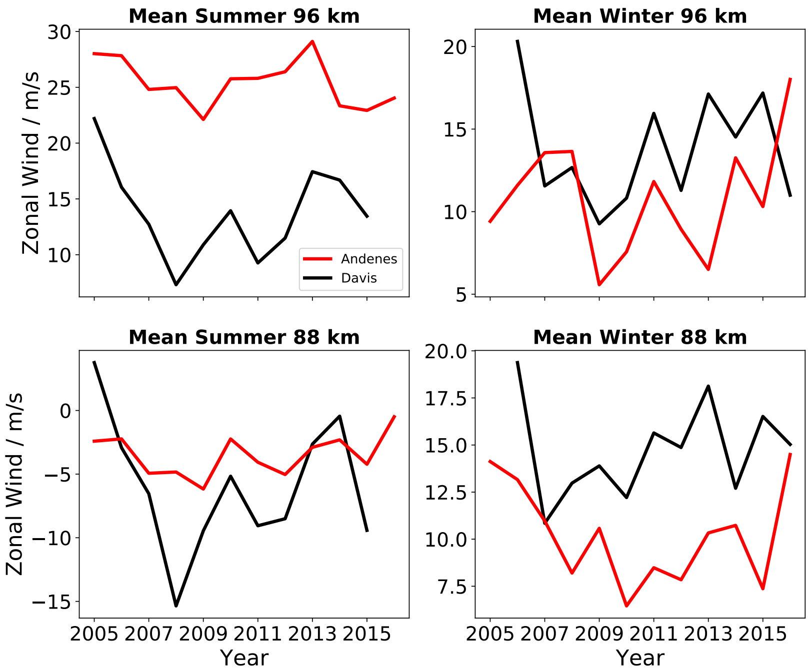

Figure 5. Zonal wind amplitudes for winter and summer season at 96 km and 88 km for Andenes and Davis.

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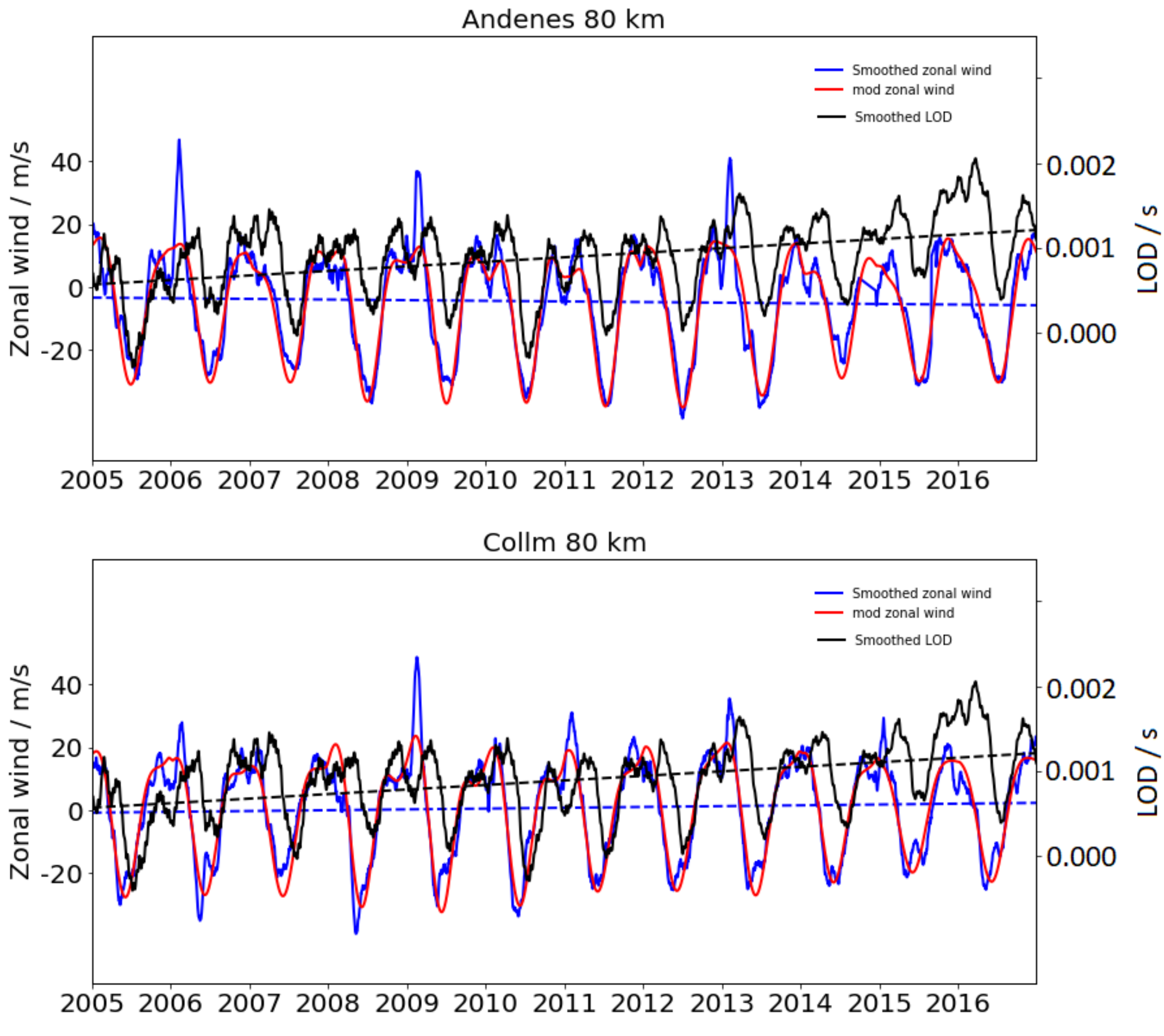

Figure 6. Smoothed zonal wind (blue) values based on meteor radar wind data at 80 km and smoothed LOD (black) values. The modulation of the smoothed zonal wind is displayed in red after removing the impact of the solar cycle, whereby the smoothing is stronger as in blue. All curves are done by a smooth over several days, without removing the day-to-day variations, to show the seasonal pattern of the parameters.

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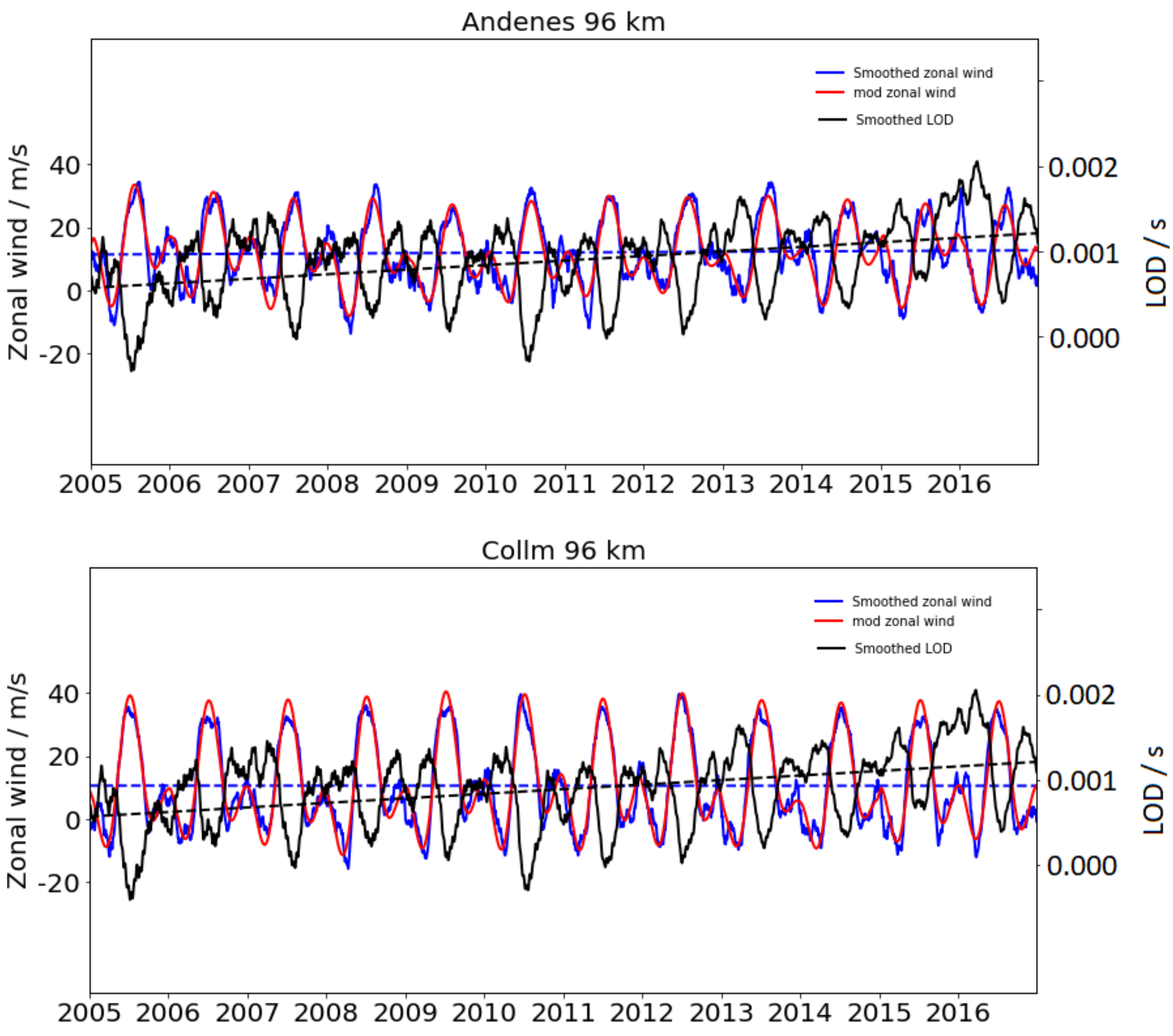

Figure 7. Same as Figure 6, but for 96 km.

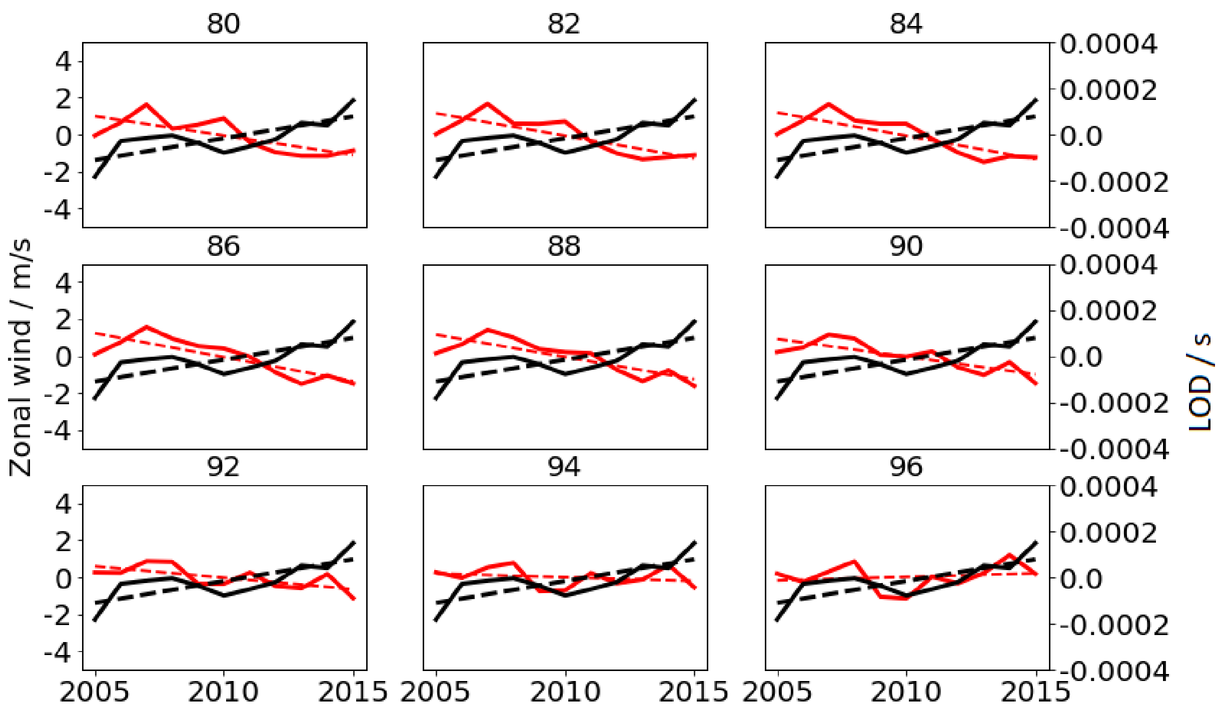

Figure 8. Annual mean values for the LOD (black) and the zonal wind (red), for the station Collm, after removing seasonal variations and the solar cycle for the altitudes between 80 and 100 km. The dashed lines represents the trend over the years 2005 - 2016.