Mean winds and tides over Collm (51.3°N, 13°E) as measured with meteor radar and the LF D1 method in 2007

Ch. Jacobi, G. Stober, P. Hoffmann

Abstract

Results of mesosphere/lower thermosphere wind measurements over Collm in 2007, carried out with a meteor radar (MR) and the LF D1 method in 2007 are presented. The seasonal cycles of wind parameters are in qualitative agreement with other years, but strong southward winds are noted in the first half of the year. The tidal amplitudes are lower than on a long-term average. Trend analyses of the LF winds show an increase of the zonal prevailing wind throughout the year, a decrease of the meridional Brewer-Dobson-circulation, and a tendency of the semidiurnal tidal phases towards later times, possible in connection with middle atmosphere cooling. However, these trends seem to decrease in recent years. The LF winds are in good agreement with modern empirical models, partly owing to the fact that these models base on LF and similar wind measurements. MR winds are usually stronger, which is especially the case with the semidiurnal tide.

Zusammenfassung

Es werden die Ergebnisse von Meteorradar- und LF D1-Windmessungen im Mesopausenbereich über Collm im Jahre 2007 vorgestellt. Der Jahresgang der Windparameter ist in qualitativer Übereinstimmung mit denjenigen anderer Jahre, aber deutliche nach Süden gerichtete Winde werden in der ersten Hälfte des Jahres festgestellt. Trendanalysen der Windparameter zeigen eine Zunahme des Zonalwindes, eine Abnahme des Meridionalwindes, und eine Tendenz zur Verschiebung der halbtägigen Gezeiten zu späteren Zeitpunkten, was in Übereinstimmung mit einer Abkühlung der Atmosphäre ist. Diese Trends weisen in den letzten Jahren jedoch eine Tendenz zur Verringerung auf. Die mit der LF D1-Methode gemessenen Winde sind in guter Übereinstimmung mit empirischen Modellen, was jedoch zum Teil darauf zurück zu führen ist, dass diese Modelle auch auf Collmer Daten beruhen. Meteorradars messen im Allgemeinen stärkere Winde, dies zeigt sich vor allem bei den halbtägigen Gezeiten.

Introduction

As background information for linear models, for validation purposes, and for estimation of further derived parameters there is a need for empirical models of the wind parameters in the middle atmosphere, as well as information on the variability of winds and tides. Particularly interesting in this connection is the mesosphere/lower thermosphere (MLT) region, because its structure is mainly dynamically driven and represents to a certain degree the boundary between middle and upper atmosphere.

Well-established models such as CIRA (Fleming et al., 1990) or HWM93 (Hedin et al., 1996) have been constructed that include the MLT, but it has been found that these models do not reflect the wind systems in this height region very well. Therefore updated models mainly based upon radar data (but also including satellite information at 95 km) such as the GEWM (Portnyagin et al., 2004) have been developed very recently, accompanied by models of the semidiurnal tidal (SDT) and diurnal tidal (DT) parameters. However, since the majority of radars deliver continuous and reliable measurements essentially since the 1990s and only since then UARS satellite measurements are available, such models necessarily have to rely upon a relatively short time interval of not much more than one decade. In fact, it is well known that the MLT region dynamics varies at time scales of years to decades (e.g., Namboothiri et al., 1994, 1999), and also long-term trends have been recognised (e.g., Bremer et al., 1997, Jacobi and Kürschner, 2006). Therefore, to accomplish global empirical models there is a need to construct models also at single stations, where the database is significantly extended compared to that taken within the usually available time interval. These long-term mean climatologies or single station models will be more representative than global empirical models when real background information is required, while, of course, they only describe the MLT region at one specific geographic site. The extended database also provides information about the variability of MLT winds at time scales of years to decades. Continuous surveys allow the update of such climatologies, and permit us insight into peculiarities of the dynamics during single years.

Operational radars used for MLT wind measurements in general either use the Doppler shift of the reflected radio wave, or apply the spaced receiver (D1) method. While the former is the usual method for meteor radars (MR), the latter has been used for the conventional analysis of medium frequency (MF) radars as well as for the low-frequency (LF) method. Indeed, during recent years MR and D1 wind comparisons have provided hints to systematic differences between the results of the two methods. Hocking and Thayaparan (1997) discovered that there are such systematic differences in some wind parameters. Portnyagin et al. (2004) have found a small mean difference of 2 m/s between MR and MF prevailing winds. Manson et al. (2004) used 3 radars in Scandinavia and reported that MR winds are larger than MF radar ones by a factor of 1.6 at 97 km, but this factor being close to unity at lower heights. This would mean that the comparatively small prevailing winds even at higher altitudes are not as much affected than tidal amplitudes and this is thus not in contradiction to Portnyagin et al. (2004). Direct comparisons between LF and MR measurements, although both without height finding, have been performed by Lysenko et al. (1972). They concluded that the resulting winds and tides show general agreement on average, but may differ when shown in detail. Literature results in all cases indicate that generally winds measured using MF and LF are smaller than those from MR, while the reasons and details of these differences are still under discussion. Therefore, comparisons of winds measured by the Doppler and D1 method are still required. This also allows more accurately evaluating and interpreting empirical model predictions, which partly base upon D1 radar measurements.

In the following we present results of wind measurements of 2007 using the Collm SKiYMET meteor radar together with LF winds. We compare these measurements with the long-term climatology (1979-2007) of LF winds available at 52°N, 15°E.

Collm meteor radar and LF D1 wind measurements

At Collm Observatory (51.3°N, 13°E), a SKiYMET meteor radar is operated on 36.2 MHz since summer 2004 (Jacobi et al., 2005). The wind measurement principle is the detection of the Doppler shift of the reflected VHF radio waves from ionised meteor trails, which delivers radial wind velocity along the line of sight of the radio wave. An interferometer is used to detect azimuth and elevation angle from phase comparisons of individual receiver antenna pairs. Together with range measurements the meteor trail position is detected. The raw data collected consists of azimuth and elevation angle, wind velocity along the line of sight, meteor height, and additionally in the decay time for each single meteor trail. The data collection procedure is also described in detail by Hocking et al. (2001).

The meteor trail reflection heights are varying roughly between 75 and 110 km, with a maximum around 90 km. In standard configuration, the data are binned in 6 different not overlapping height gates centred at 82, 85, 88, 91, 94, and 98 km. Individual winds calculated from the meteors are collected to form hourly mean values using a least-squares fit of the horizontal wind components to the raw data under the assumption that vertical winds are small (Hocking et al., 2001). An outlier rejection is added. Mean prevailing winds and tidal amplitudes and phases can be calculated with a least-squares fit (Jacobi et al., 2007).

Collm LF D1 wind measurements at 80 to 100 km altitude have been carried out for more than 4 decades now. Commercial radio transmitters in the LF range (177 kHz, 225 kHz and 270 kHz) are used, and an automatic algorithmic variant of the similar fade analysis is used for interpretation of the measurements. The reference height has not been measured before September 1982, so that the results from the earlier measurements have been attributed to the mean nighttime height near 90 km. From late 1972 the analysis is performed automatically, and since 1979 half-hourly winds from three measuring paths are constructed. To avoid artefacts owing to changes in measurement strategy, we here consider only the time interval starting in 1979.

The measurements are investigated by calculating monthly median winds at each time (with a resolution of 30 minutes) of the daily measuring intervals and applying a multiple regression analysis to the monthly medians of the half-hourly mean winds. This procedure has also been applied to a shorter time interval by Jacobi et al. (1997) and Jacobi and Kürschner (2006), so that the results presented here are an extension of their work. Jacobi et al. (1997) have presented data since 1972 and showed that apparent trends may vary before and after the early 1980s, which is not considered here.

Prevailing winds and tides measured with MR in 2007

Height-time cross-sections of the zonal and meridional prevailing winds are shown in Figure 1. The data consists of daily least-squares fit analyses of the prevailing winds and the 8-, 12- and 24-hour tidal components, each based on 15 days of hourly winds for each height gate. The zonal prevailing winds are generally positive (eastward) in winter, and during summer in the lower thermosphere. Westward winds are seen during spring, during a short time interval in autumn, and at lower altitudes in summer. The meridional winds are negative (southward) in summer, and generally positive (northward) in winter. This represents the signature of the mesospheric Brewer-Dobson circulation that is forced through gravity wave mean flow interaction. During January and February the winter circulation is disturbed; this behaviour is typical for stratospheric warmings, which occurred in January and February 2007.

The zonal amplitudes of the DT, SDT and terdiurnal tide (TDT) are shown in Figure 2. The respective phases for each month are presented in Figure 3. The strongest signal is given by the SDT in winter, which reaches amplitudes of more than 60 ms^{-1}. The DT and TDT are weaker, and both tides disclose a less regular behaviour. This is, for the DT, owing to the more variable forcing mechanism through tropospheric water vapour and the short vertical wavelength. Nevertheless, a tendency towards a seasonal cycle with maximum amplitudes during spring and early summer is visible at the upper levels considered. The TDT is thought to be mainly forced through non-linear interaction between the DT and SDT (Teitelbaum et al., 1989), so that its behaviour is even more irregular. But there is a tendency towards larger amplitudes in autumn, which is in good coincidence with results presented by Younger et al. (2002) from Esrange (68°N). Note that from the phase change with height in Figure 3 it can be inferred that the TDT becomes evanescent during this time interval. This characteristic is also visible for the DT, which shows relative large phase gradients (short wavelengths) in the lower region considered, but weak phase changes with height in the upper part, where the amplitudes are larger.

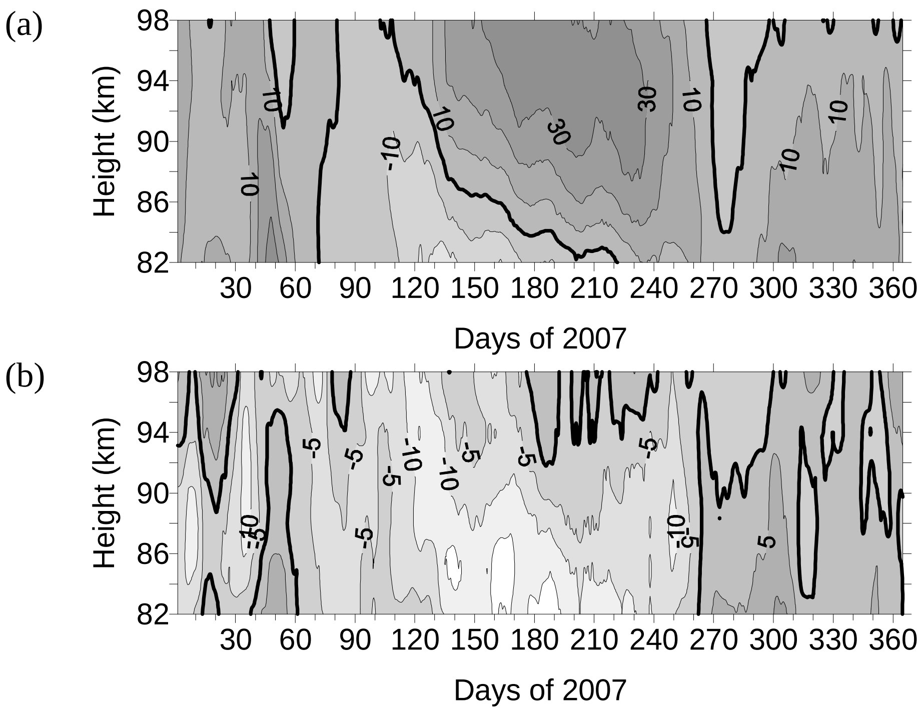

Figure 1: *Height-time cross-sections of the (a) zonal and (b) meridional prevailing winds as measured by the Collm meteor radar. Data base on multiple regression analyses including 15 days of hourly winds each.*

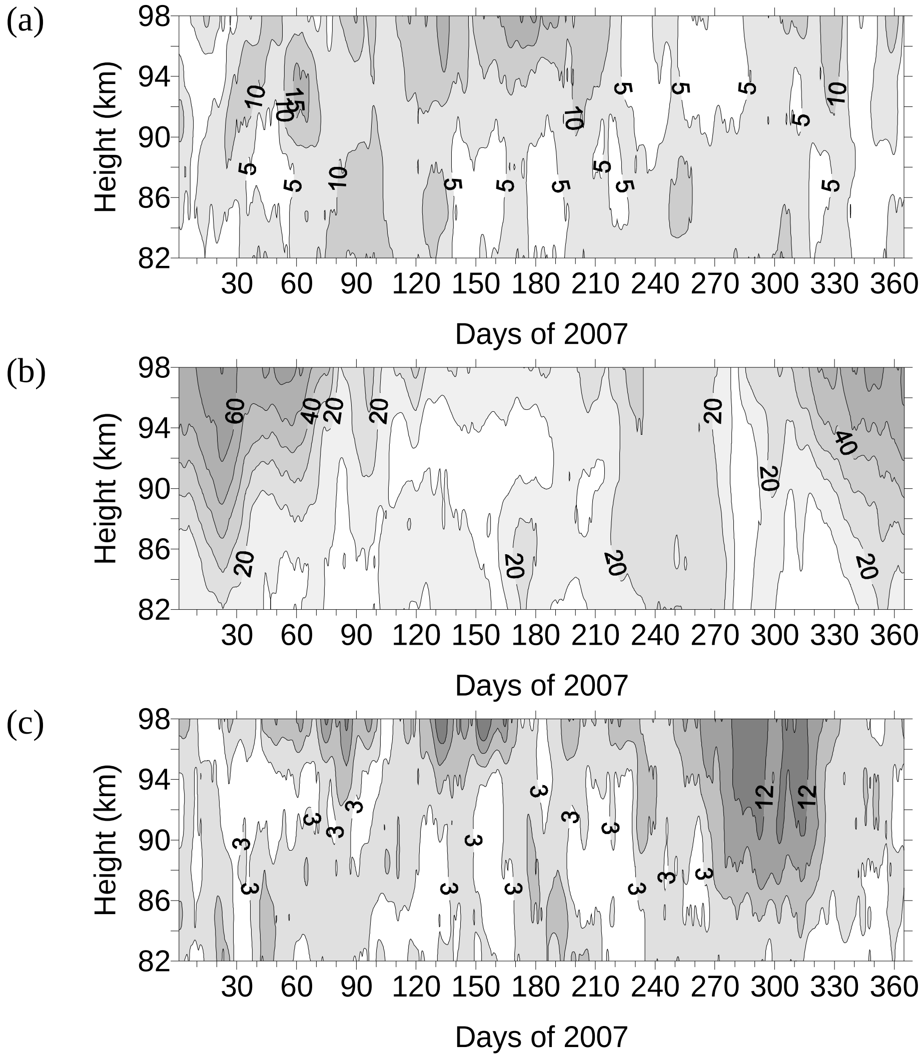

Figure 2: Height-time cross-sections of the zonal (a) diurnal, (b) semidiurnal, (c) terdiurnal tidal amplitudes as measured by the Collm meteor radar. Data base on multiple regression analyses including 15 days of hourly winds each.

In Figures 2 and 3 only the zonal component is plotted. According to linear theory the zonal and meridional components are generally nearly circularly polarized. This is well justified for the SDT (e.g. Jacobi et al., 1999). For the analyses of the DT from LF measurements, the assumption of circular polarization is necessary to overcome the problem of the regular daytime data gaps (Kürschner, 1991). To test this assumption, in the left panel of Figure 4 the normalized amplitude differences

$$\Delta A = 2 \cdot \frac{a_z - a_m}{a_z + a_m} \,, \tag{1}$$

with a_z and a_m as the zonal and meridional amplitudes, for the TDT, SDT and DT are shown as cumulative frequencies, while in the right panel the respective phase differences are shown. The mean amplitude differences amount to 0.21±0.65, -0.04±0.23 and -0.09±0.58 for the TDT, SDT and DT, while the mean phase differences are 104±60°, 92±21° and 81±45°. As expected, for the SDT only small deviations from the circular polarization appear, while the largest differences are found for the TDT. In any case, however, the phases tend to cluster around a phase difference of 90°.

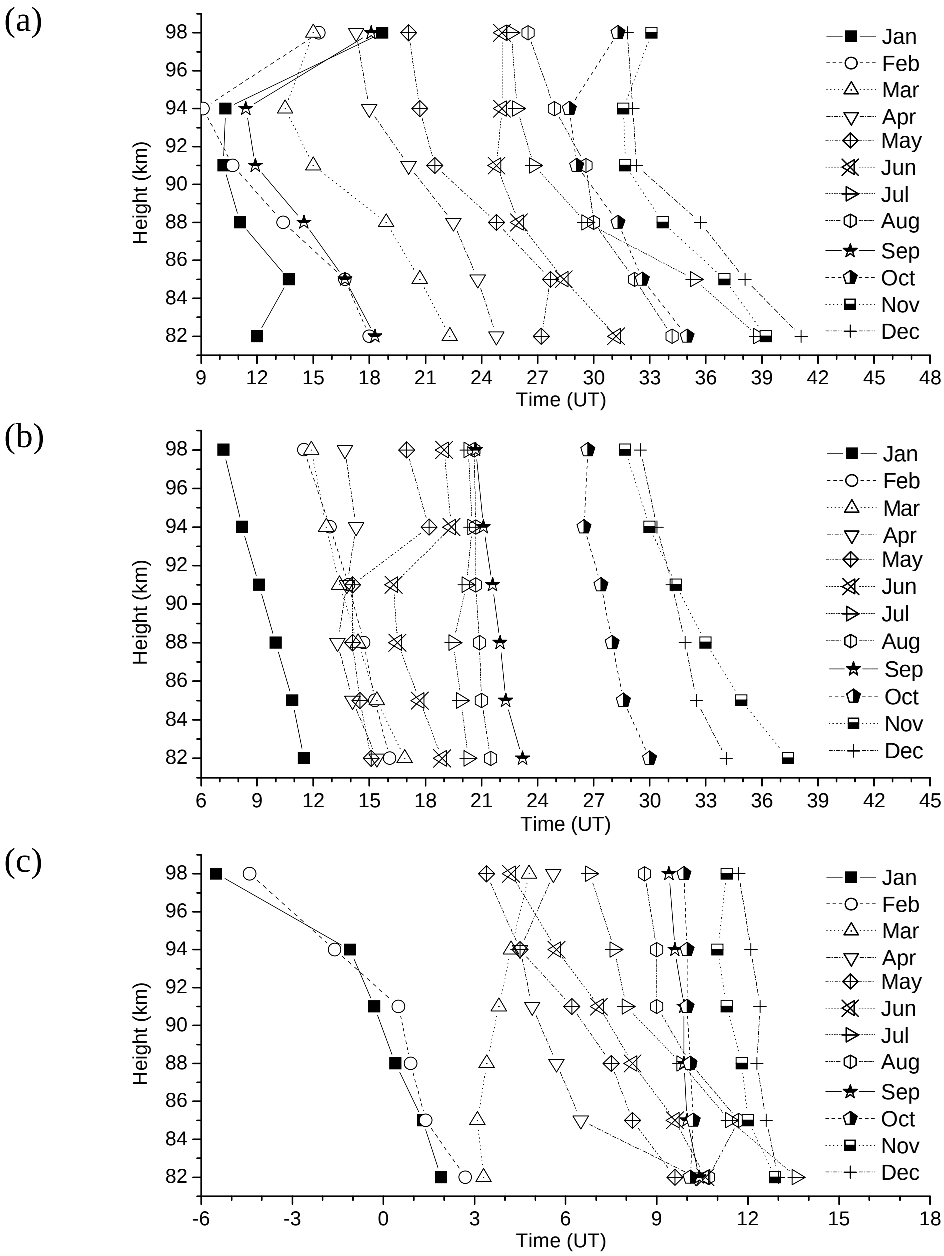

Figure 3: Monthly mean zonal phases, defined as the time of maximum eastward wind, for the (a) DT, (b) SDT, (c) TDT. Phases of successive months have been shifted by 2 ms^{-1} (DT and SDT) or 1 ms^{-1} (TDT), respectively.

Comparison of LF and MR winds and semidiurnal tides

Literature results (e.g. Manson et al., 2004) and previous analyses from Collm winds (Jacobi et al., 2005, 2006) indicate that the hourly winds measured by Doppler methods as with the MR measurements are substantially larger than those measured by the D1 method. Furthermore, without explicit height finding the LF reference height is not known, while the measured reference heights are virtual owing to group retardation in the presence of the D region plasma, so that these heights are too large by an unknown factor. However, comparison of the SDT phases has led to the conclusion that the MR and LF phases agree best when the 91 km height gate of the MR is considered, so that we conclude that, on an average, the LF D1 method delivers winds at a real height around 90 km.

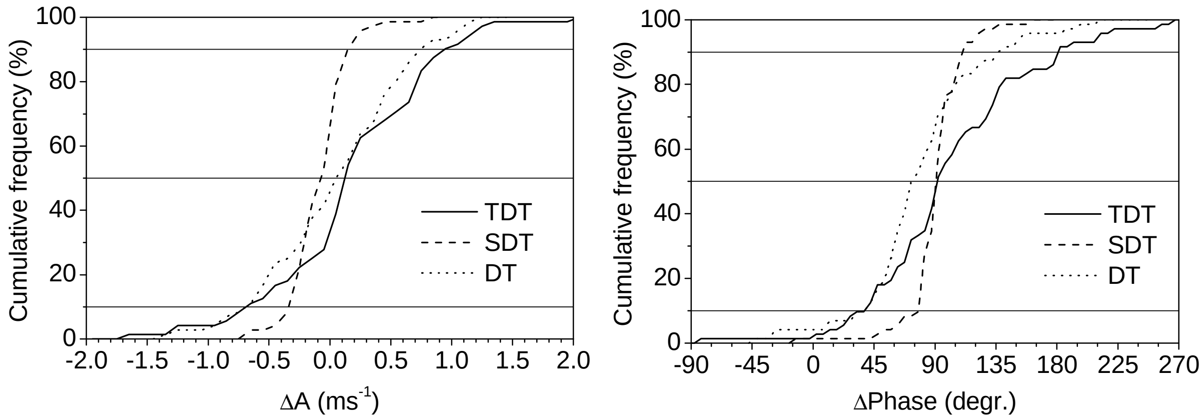

Figure 4: Cumulative frequencies of relative amplitude differences ΔA after Eq. 1 (left panel) and phase differences (right panel) for the TDT, SDT and DT. Median, upper and lower percentiles are also added. Data includes monthly mean values for each season of 2007 and for each height gate.

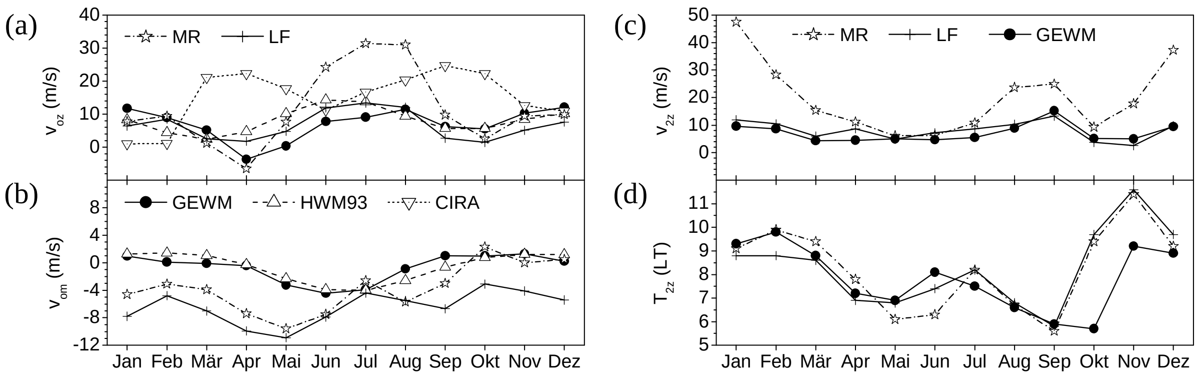

Figure 5: Zonal (a) and meridional (b) prevailing winds, semidiurnal tidal zonal amplitudes (c) and phases (d), as measured with the Collm meteor radar (MR) at 91 km and with the LF method. Added are mean winds taken from three different empirical climatologies: GEWM I (Portnyagin et al., 2004), HWM93 (Hedin et al, 1996), CIRA86 (Fleming et al., 1990, only zonal winds), and GEWM II SDT amplitudes and phases.

Figure 5 compares the MR and LF wind parameters together with predictions from the CIRA (Fleming et al., 1990), HWM93 (Hedin et al., 1996), and GEWM (Portnyagin et al., 2004) empirical models. Considering the zonal prevailing wind (Figure 5a) it can be seen that the LF winds agree well with both the HWM93 and GEWM predictions. This is not surprising, since both of these models partly base of D1 radar winds. The CIRA predictions do not agree with the measurements, which is due to the known uncertainties of the CIRA approach especially at mesopause heights.

Empirical models for the meridional wind (Figure 5b) predict the mesospheric Brewer-Dobson-circulation, i.e. southward winds in summer and northward winds in winter. The measurements both with LF and MR in the first half of the year display negative (southward) winds. This is partly due to the winter stratospheric warmings (see Figure 1), but shows an overall deviation of the meridional circulation from the long-term mean.

The SDT amplitudes derived from the LF measurements are in excellent agreement with the GEWM model (Figure 5c). Again, as is the case with the zonal prevailing wind, the MR winds and thus amplitudes are much larger, which is mainly the case in winter. The measured SDT phases agree well with the GEWM model predictions, except for autumn. This can partly be explained by the large variability of the SDT during the autumn transition, with small amplitudes, which at times makes the phase unstable.

Long-term trends derived from LF measurements

Figure 6 again presents the seasonal cycle of LF derived wind parameters as already given in Figure 5, but together with the long-term mean to illustrate peculiarities of the year 2007. It may be noted that the semiannual cycle of the zonal prevailing wind is weaker than on an average, with weaker eastward winds in winter and summer. At the same time the meridional southward winds are stronger during nearly each month of the year. Long-term trend analyses (Jacobi and Kürschner, 2006) had shown positive trends for the zonal prevailing winds, so that the zonal winds in 2007 do not fit into this picture. The SDT amplitudes are smaller than on an average in most months, which is owing to a tendency for amplitude decrease since the 1990s. The tidal phases do not show any special behaviour, compared to other years.

Time series prevailing winds are presented in Figure 7, while in Figure 8 for the SDT amplitudes and phases are shown. Results from a regression analysis

$$v = v_0 + \Delta_t \cdot yr + \Delta_R \cdot R \ , \qquad (2)$$

with R as the Zurich sunspot number, which is a proxy for solar activity are shown in Figure 9 and Figure 10. These results are an update of results presented by Jacobi and Kürschner (2006).

Considering the zonal prevailing wind, there is a clear tendency that the overall increase (upper left panel of Figure 9) is not continued during recent years. The meridional wind shows a negative trend for winter months (lower left panel of Figure 9), but a positive one for summer. While the 2007 winter winds fit into this picture, the summer meridional circulation gives rise to a change of the long-term trends. This, together with the peculiarities of the zonal circulation in recent years, indicates a change in wind regime and its trends during the time interval considered (Jacobi and Kürschner, 2007).

The SDT amplitude trend is weak in each month except for August. Comparing the upper right panel of Figure 9 with the time series in Figure 8 it becomes obvious that the weak trends are superposed by decadal variations and, especially during equinoxes, interannual variability. The latter is owing to the strong sensitivity of the tidal amplitudes and phases during the spring and autumn transitions. The SDT phases generally show a positive trend, i.e. they exhibit a shift towards later times of westward wind maximum. Such a shift in times would be consistent with an increase towards longer vertical SDT wavelength, which may be owing to a cooling of the middle atmosphere and therefore to reduced scale height. Note again that this trend, at least for winter, is not continued in recent years, which is in accordance with changes in mesospheric temperature trends reported by Bremer et al. (2005).

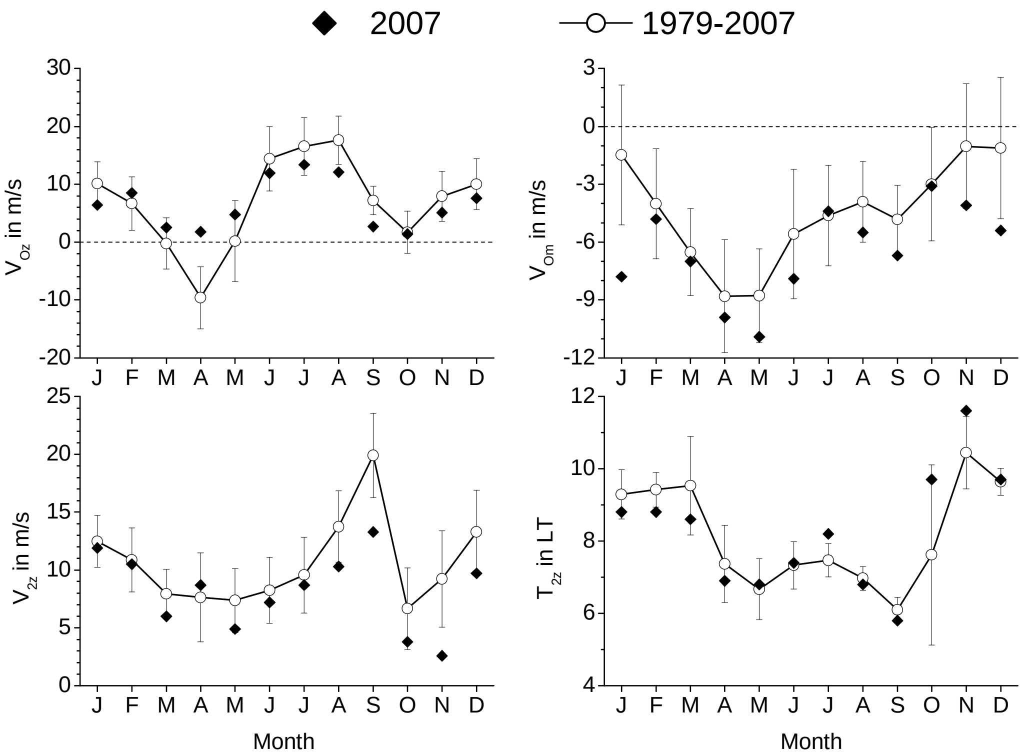

Figure 6: Monthly mean LF winds and tides near 90 km in 2007, and comparison with the 29-year mean values 1979-2007. Panels show zonal prevailing wind (upper left panel), meridional prevailing wind (upper right panel), zonal semidiurnal amplitude (lower left panel), and semidiurnal tidal phase (lower right panel).

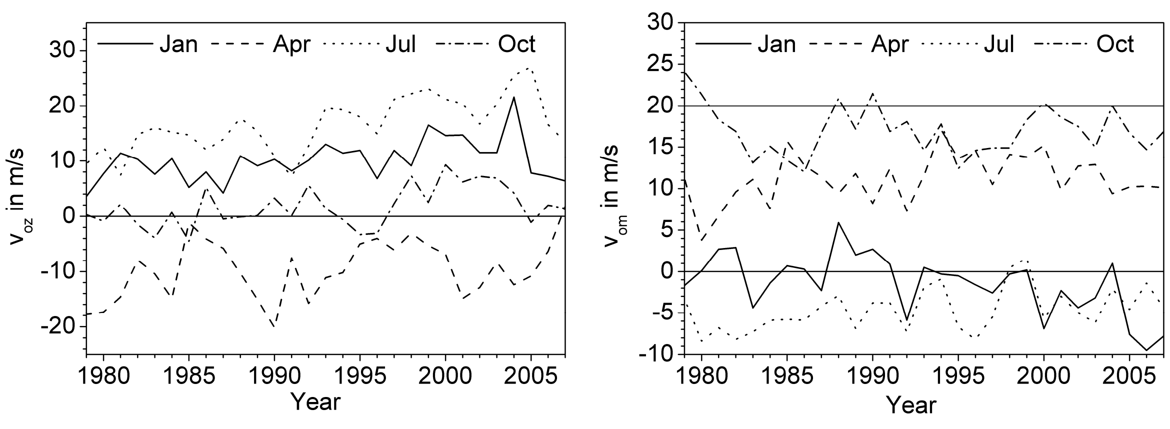

Figure 7: Monthly mean zonal (left panel) and meridional (right panel) prevailing winds from 1979 to 2007, for 4 different months. April and October meridional winds are shifted by 20 ms^{-1}.

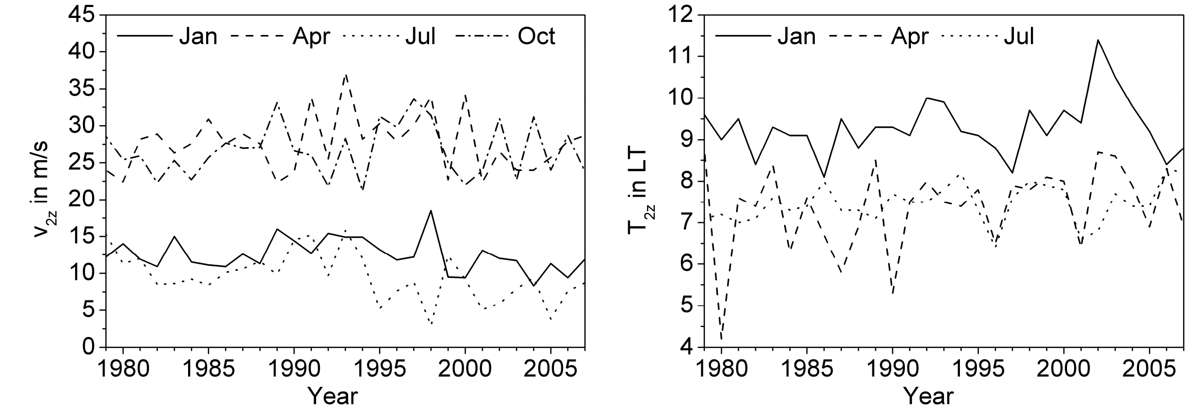

Figure 8: Monthly mean zonal amplitudes v_{2z} (left panel) and phases T_{2z} (right panel) of the SDT from 1979 to 2007, for 4 different months. October T_{2z} values are not shown. April and October amplitudes are shifted by 20 ms^{-1}.

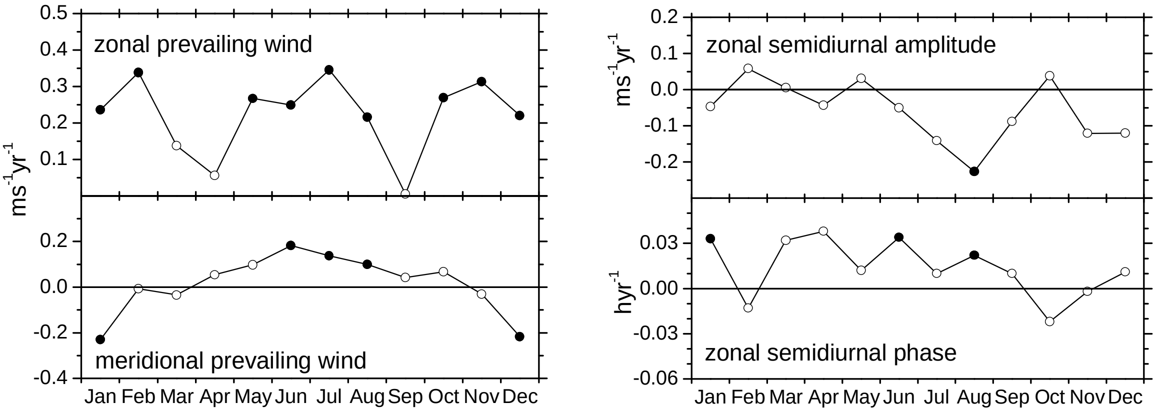

Figure 9: Trend coefficients Δ_t from Eq. 2, for each month of the year, and 4 different wind parameters. Database is 1979-2007. Solid symbols denote statistically significant trends on the 95% level according to a t-test.

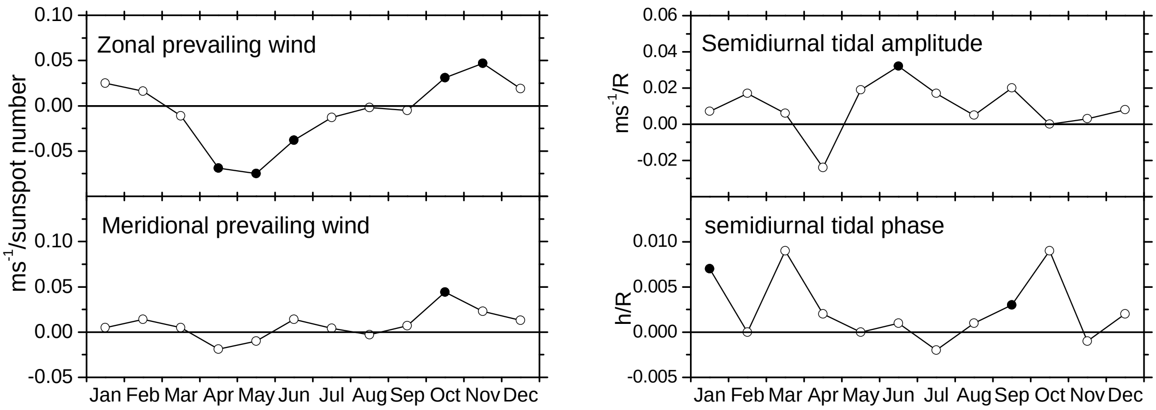

Figure 10: As in Figure 9, but for the solar cycle dependence Δ_R.

The solar cycle dependence of the prevailing wind is similar than the one that has been shown by Jacobi and Kürschner (2006). The zonal prevailing wind is more easterly in summer and more westerly in winter, which means that the mesospheric jets are stronger during solar maximum. Since the meridional wind is forced through gravity waves that carry the signature of the mean wind, the solar cycle signature of v_{om} is similar, although the signal is not so strong and in most months not significant. In addition, the exceptional meridional winds in recent years (see Figure 7) led to a decrease of the solar signal compared to Jacobi and Kürschner (2006).

The solar signal of the SDT is weak, however, Figure 8 indicates that, taking into account a delay of few years with respect to the solar cycle, a stronger correlation may be expected. But it is difficult to find a physical reason for such a delay, although von Zahn and Berger (2006) found a similar delay in noctilucent cloud variability in the summer mesopause region.

Conclusions

The seasonal variability of the midlatitude MLT wind field is qualitatively conserved from year to year, so that the main features of the 2007 seasonal variations are found in modern empirical models like the GEWM. Nevertheless, there is a year-to-year variability, which may lead to substantial deviations from the long-term mean or from reference models. In 2007 this is essentially represented by a more negative winter meridional wind, and a weak zonal semiannual oscillation.

Collm LF winds have been measured for nearly 3 decades now, and long-term trends may be analysed. It seems, however, that trends, which have been reported already in literature, are not completely stable, and may change. Several parameters show peculiarities during recent years, and the structure of MLT changes is still a question to be investigated.

The measurements in 2007 again confirm the differences in the results of D1 and Doppler wind measurements. Since empirical models, as the HWM93 and also the GEWM for a major part base on D1 (mostly medium frequency) radar winds in the MLT, this raises the question whether an update of these models is required.

Acknowledgements

This research has been partly supported by DFG under grant JA836/22-1. Sunspot numbers have been provided by NOAA/NGDC through their Internet Web site on http://www.ngdc.noaa.gov/stp/SOLAR/ftpsunspotnumber.html.

References

Bremer, J., Schminder, R., Greisiger, K.M., Hoffmann, P., Kürschner, D., Singer, W., 1997: Solar cycle dependence and long-term trends in the wind field of the mesosphere/lower thermosphere. J. Atmos. Solar-Terr. Phys. 59, 497-509.

Bremer, J., Schacht, J., Barth, Th., 2005: Einfluss von Ozonvariationen auf Trends in der Mesosphäre mittlerer Breiten. Leibnitz-Institut für Atmosphärenphysik e.V. an der Universität Rostock, Institute Report 2004/2005, 94-95.

Fleming, E.L., Chandra, S., Barnett, J.J., Corney, M., 1990: Zonal mean temperature, pressure, zonal wind and geopotential height as function of latitude. Adv. Space. Res. 10(12), 11-59.

Hedin, A.E., Biondi, M.A., Burnside, R.G., Hernandez, G., Johnson, R.M., Killeen, T.L., Mazaudier, C., Meriwether, J.W., Salah, J.E., Sica, R.J., Smith, R.W., Spencer, N.W., Wickwar, V.B., Virdi, T.S., 1991: Revised global-model of thermosphere winds using satellite and ground-based observations, J. Geophys. Res. 96, 7657-7688.

Hocking, W.K., Fuller, B., Vandepeer, B., 2001: Real-time determination of meteor-related parameters utilizing modern digital technology. J. Atmos. Solar-Terr. Phys. 63, 155-169.

Jacobi, Ch., Schminder, R., Kürschner, D., Bremer, J., Greisiger, K.M., Hoffmann, P., Singer, W., 1997: Long-term trends in the mesopause wind field obtained from D1 LF wind measurements at Collm, Germany, Adv. Space Res. 20, 2085-2088.

Jacobi, Ch., Portnyagin, Yu.I., Solovjova, T.V., Hoffmann, P., Singer, W., Fahrutdinova, A.N., Ishmuratov, R.A., Beard, A.G., Mitchell, N.J., Muller, H.G., Schminder, R., Kürschner, D., Manson, A.H., Meek, C.E., 1999: Climatology of the semidiurnal tide at 52°N-56°N from ground-based radar wind measurements 1985-1995. J. Atmos. Solar-Terr. Phys. 61, 975-991.

Jacobi, Ch., Kürschner, D., Fröhlich, K., Arnold, K., Tetzlaff, G., 2005: Meteor radar wind and temperature measurements over Collm (51.3°N, 13°E) and comparison with co-located LF drift measurements during autumn 2004. Rep. Inst. Meteorol. Univ. Leipzig 36, 98-112.

Jacobi, Ch., Kürschner, D., 2006: Long-term trends of MLT region winds over Central Europe. Phys. Chem. Earth 31, 16-21.

Jacobi, Ch., Viehweg, C., Kürschner, D., Singer, W., Hoffmann, P., Keuer, D., 2006: Comparison of meteor radar, medium frequency radar winds and low frequency drifts over Germany. COSPAR 36th Scientific Assembly, Beijing, 16.-23.7.2006.

Jacobi, Ch., Fröhlich, K., Viehweg, C., Stober, G., Kürschner, D., 2007: Midlatitude mesosphere/lower thermosphere meridional winds and temperatures measured with meteor radar. Adv. Space Res. 39, 1278–1283.

Jacobi, Ch., Kürschner, D., 2007; Possible climate change response of the mesosphere/lower thermosphere region. Proceedings of the International Symposium “Atmospheric Physics: Science and Education”, St. Petersburg, 11.-13.9.2007, 33-37.

Kürschner, D., 1991: Ein Beitrag zur statistischen Analyse hochatmosphärischer Winddaten aus bodengebundenen Messungen. Z. Meteorol. 41, 262-266.

Kürschner, D., Jacobi, Ch., 2005: The mesopause region wind field over Central Europe in 2003 and comparison with a long-term climatology. Adv. Space Res. 35, 1981-1986.

Namboothiri, S.P., Meek, C.E., Manson, A.H., 1994: Variations of mean winds and solar tides in the mesosphere and lower thermosphere over scales ranging from 6 months to 11a: Saskatoon 52°N, 107°W. J. Atmos. Terr. Phys. 56, 1313-1325.

Namboothiri, S.P., Tsuda, T., Nakamura, T., 1999: Interannual variability of mesospheric mean winds observed with the MU radar. J. Atmos. Solar-Terr. Phys. 62, 1111-1122.

Portnyagin, Yu., Solovjova, T., Merzlyakov, E., Forbes, J., Palo, S., Ortland, D., Hocking, W., MacDougall, J., Thayaparan, T., Manson, A., Meek, C., Hoffmann, P., Singer, W., Mitchell, N., Pancheva, D., Igarashi, K., Murayama, Y., Jacobi, Ch., Kürschner, D., Fahrutdinova, A., Korotyshkin, D., Clark, R., Tailor, M., Franke, S., Fritts, D., Tsuda, T., Nakamura, T., Gurubaran, S., Rajaram, R., Vincent, R., Kovalam, S., Batista, P., Poole, G., Malinga, S., Fraser, G., Murphy, D., Riggin, D., Aso T., Tsutsumi, M., 2004: Mesosphere/lower thermosphere prevailing wind model. Adv. Space Res. 34, 1755-1762.

Teitelbaum, H., Vial, F., Manson, A.H., Giraldez, R., Massebeuf, M., 1989: Non-linear interactions between the diurnal and semidiurnal tides: terdiurnal and diurnal secondary waves. J. Atmos. Terr. Phys. 51, 627-634.

Von Zahn, U., Berger, U., 2006: The decadal-scale variation of solar Lyman-a and its effects on NLC occurrence rate, NLC brightness and the mesospheric water vapor. Meteorol. Z. 15, 379-384.

Younger, P.T., Pancheva, D., Middleton, H.R., Mitchell, N.J., 2002: The 8-hour tide in the Arctic mesosphere and lower thermosphere. J. Geophys. Res. 107, 1420, doi:10.1029/2001JA005086.

Addresses of Authors:

Christoph Jacobi, Peter Hoffmann, Gunter Stober, Institute for Meteorology, University of Leipzig, Stephanstr. 3, 04103 Leipzig, jacobi@uni-leipzig.de