Possible climate change response of the mesosphere/lower thermosphere region

Christoph Jacobi, Dierk Kürschner
University of Leipzig, Faculty of Physics and Earth Sciences

1. Introduction

Anthropogenic increase of greenhouse gases like CO_2 results in a cooling of the middle atmosphere (Lastovicka et al., 2006) owing to increased cooling due to infrared emission. Cooling of the stratosphere has been reviewed by Ramaswamy et al. (2001), while Beig et al. (2003, 2006) have summarized the current knowledge on mesospheric cooling. They showed that the mesosphere cooling amounts to about 2K/decade obtained from datasets from the 1960s to date. However, at that time no clear cooling trend is present in the mesopause region (mesosphere/lower thermosphere, MLT). The dynamics and variability of the MLT is of particular interest in this connection, since it is steered both by the general radiatively driven middle atmosphere circulation and dynamical influences through wave propagation from below.

Recent analyses using results of long-term low-frequency (LF) measurements have shown that mesospheric cooling is not linear. In particular, a correlation is found between mesospheric temperatures and stratospheric ozone (Bremer et al., 2005), which plays a major role in the middle atmosphere energetics. Changes in temperature affect the wind field. Recent results on long-term changes in MLT winds have been published by Jacobi et at. (2006) and Portnyagin et al. (2006). They showed that MLT wind parameters have significantly changed since the beginning of the early 1960s. The sign of the linear trends, however, seem to change in the early 1990s, which qualitatively agrees with the behavior of mesospheric temperatures.

To summarize, there are still open questions on the nature of MLT trends and its possible connection with climate change. In the following, measurements of winds and reflection heights using low frequency (LF) radio waves are presented to contribute to the database available for mesospheric trend analysis.

2. Measurements at Collm Observatory

At Collm Observatory (51.3°N, 13.0°E), MLT winds are measured by D1 LF radio wind measurements, using the ionospherically reflected sky wave of three commercial radio transmitters. The data are combined to half-hourly zonal and meridional mean wind values. A multiple regression analysis is used to determine the monthly prevailing wind and the semidiurnal tidal wind components assuming clockwise circularly polarized tidal wind components (Kürschner, 1991). The data are attributed to the mean reflection height at about 90 km. We use results of wind measurements since 1979 to avoid inhomogeneity of the time series due to modifications in the data analysis procedure in 1978.

The virtual reflection heights h´, referring to the reflection point at 52.1°N, 13.2°E, are estimated since late 1982 using measured travel time differences between the separately received ionospherically reflected sky wave and the ground wave using phase comparisons between both components on sporadic oscillation bursts of LF radio waves in a small modulation frequency range around 1.8 kHz (Kürschner et al., 1987). Half-hourly virtual reflection heights range between h´ = 80 km during daytime and h´ ≥ 100 km during nighttime. Owing to the effect of electromagnetic waves group retardation the measured virtual heights h´ are larger than h, the difference amounts to several km, increasing with altitude.

3. The signal of mesospheric temperature in the LF reflection heights

The change of the daily mean reflection heights on time scales of years to decades can be interpreted as an effect of temperature changes of the middle atmosphere below (Kürschner and Jacobi, 2003; Bremer et al., 2005). Since cooling of the middle atmosphere leads to a shrinking of atmospheric layers, this is connected with a decrease of the height of constant electron density and this causes a decrease of the reflection heights of LF radio waves. However, Bremer et al. (2005) showed that in the course of the 1990s the mesospheric cooling trend vanishes (and even reverses), which they attributed to the influence of ozone recovery during the last decade.

Reflection heights measured at Collm are presented in Figure 1. The data have been corrected for group retardation. In the lower part of the upper panel the long-term trends are shown, each calculated to the respective year. One can see that the negative trend, which is present until the mid 1990 decreases, so that on the whole no trend between 1983 and 2007 is visible. Kürschner and Jacobi (2003) have reported a negative trend between 1983 and 2001, so that this shows the increasing reflection heights since 2001, which have also been reported by Bremer et al. (2005). Calculating trends using an 11-year window shows that after 1990 on average no negative, but rather a weakly positive trend is observed.

Assuming equilibrium between ionisation and recombination, a one gas and isothermal atmosphere, monochromatic radiation, and with that resulting a Chapman profile of the electron density, the diurnal plasma scale height H (Lauter et al., 1984), which can be considered as a proxy for the MLT temperature, is given by the rate of change Δh´ of the measured reflection height h´. Note that the variability of this MLT temperature not necessarily coincides with the reflection height changes in Figure 1, since the former is the temperature in situ, while the latter is an integrated measure for middle atmosphere density. In Figure 2 winter monthly H values are given. A decrease of H or T, respectively, is visible. However, the trend is not significant, and seems to vanish towards the end of the time series.

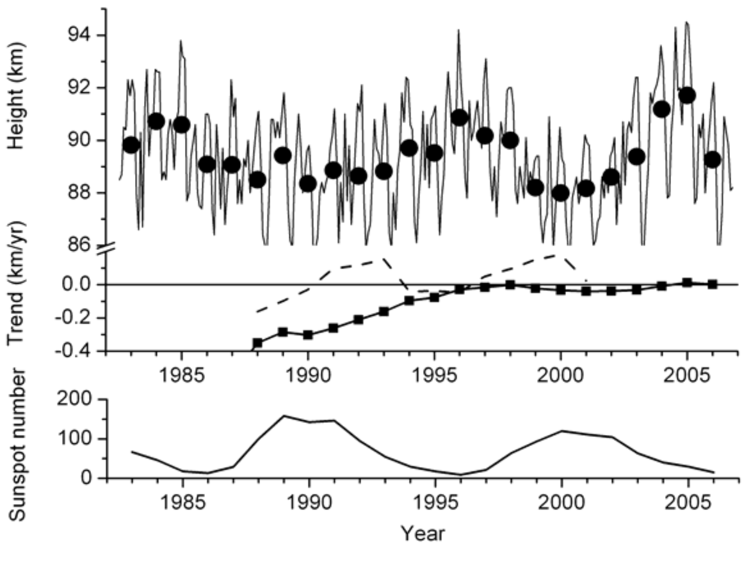

Figure 1*: Long-term analysis of monthly mean nighttime (21-1 UT) measured reflection heights. Upper panel: Time series of reflection heights (solid line), together with annual mean values (solid dots). In the lower part the trend coefficients are added a) for different analyses covering the time interval from 1983 to the respective year (line + symbols), and b) for a 11-year window centered at the respective year. In the lower panel the annual mean sunspot number is shown.*

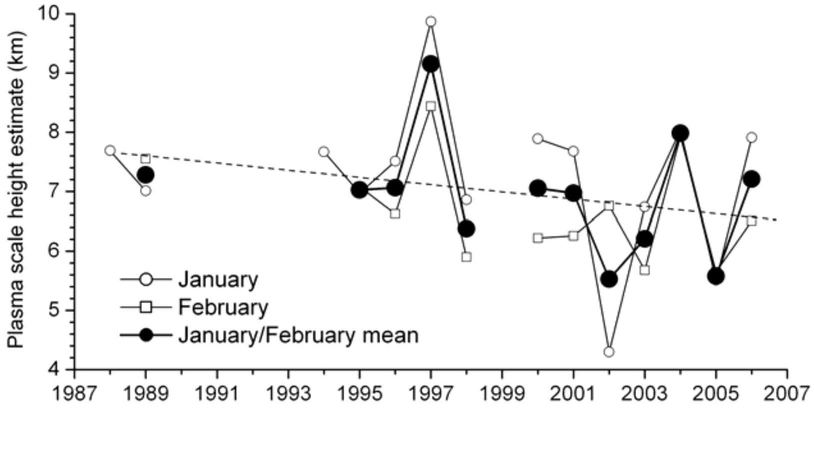

Figure 2: *Scale height estimates, calculated from monthly median half-hourly virtual heights. Only those data are shown which have been calculated from at least 9 height data points. The straight line represents a linear fit curve with a trend of -0.61 ± 0.61 km/decade.*

4. MLT winds

Seasonal mean values of MLT wind parameters over Collm are presented in Figure 3, representing an update from Jacobi and Kürschner (2006). One can see that most of the parameters change significantly in the course of the time interval considered. Linear trend coefficients are provided in Table 1. A closer look, however, shows that most of these trends are obviously not linear, and have changed during the 1990s. As an example, in

Figure 4 we present linear trends for the zonal prevailing wind that have been calculated from a running 13-year windows. While in the 1980s there is no trend, the zonal prevailing wind increases since the late 1980s/early 1990s, and remains at a quasi constant level since the late 1990s. This means that there was a more stepwise change of MLT winds around 1990, but no large trends before or after that time.

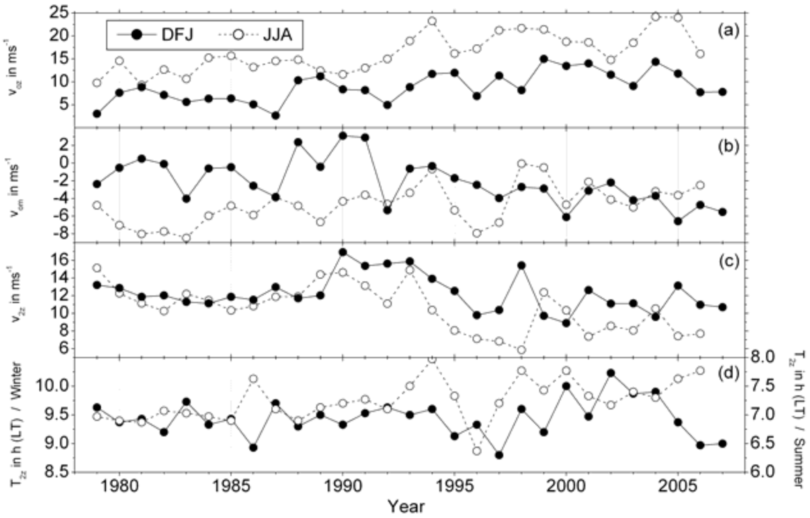

Figure 3: *Time series of December-February (solid symbols) and June-August (open symbols) mean wind parameters over Collm (a) zonal prevailing wind, positive eastward, (b) meridional prevailing wind, positive northward, (c) semidiurnal tidal amplitude and (d) semidiurnal tidal phase, defined as the time of eastward wind maximum. Updated from Jacobi and Kürschner (2006).*

Table 1: *Long-term linear trend parameters for circulation parameters over Collm. Statistical significant trends (99% level) are highlighted by shading.*

Parameter	Trend/DJF (1979-2007)	Correlation coefficient	Trend/JJA (1979-2006)	Correlation coefficient
v_{oz}	+0.23 ms^{-1}/yr	0.59	+0.38 ms^{-1}/yr	0.74
v_{om}	-0.17 ms^{-1}/yr	0.56	+0.15 ms^{-1}/yr	0.56
v_{2z}	-0.06 ms^{-1}/yr	0.25	-0.19 ms^{-1}/yr	0.60
T_{2z}	+0.003 h/yr	0.07	+0.023 h/yr	0.54

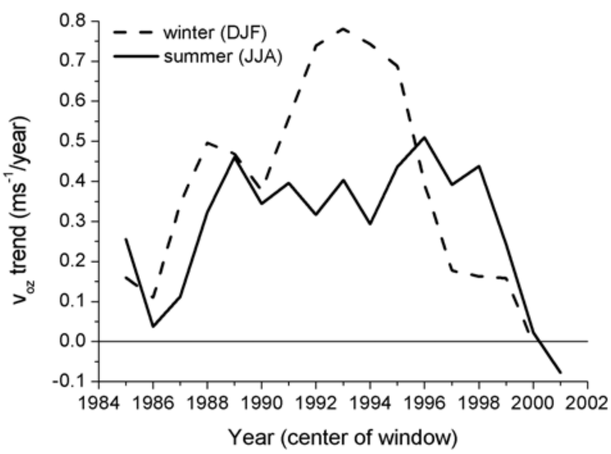

Figure 4: *Linear trends for DJF and JJA mean zonal prevailing winds from Figure 3, calculated using 13-year running windows centered at the respective years.*

5. Discussion and Conclusions

Both temperature proxies and winds measured over Collm indicate that a substantial change has occurred in the MLT around 1990. This coincides with results by Bremer et al. (2005) who measured nearly no reflection height trend after the early 1990s. They attributed this trend change to the recovery of the ozone layer taking place since the early 1990s. In contrast, Remsberg and Deaver (2005) reported negative trends for the subtropical mesosphere from HALOE data 1991-2004. However, satellite mesospheric data (their Figure 1) also show an increase of temperature after 1990, which, however, may as well be due to the 11-year solar cycle .

Our measurements show that, coinciding with the long-term behavior of temperatures, the MLT winds have substantially changed around 1990. This substantiates the hypothesis, that the upper middle atmosphere long-term trends are not only due to greenhouse gas changes, but rather are the result of several influences. It seems that the ozone change possibly plays a major role. Other possible mechanisms influencing the MLT circulation involve tropospheric circulation changes, e.g. expressed through variations of the North Atlantic Oscillation, which also exhibited an increase in the 1990s.

6. References

Beig, G.: Trends in the mesopause region temperature and our present understanding - an update, Phys. Chem. Earth, 30 (3), doi: 10.1016/j.pce.2005.03.007, 2006.

Beig, G., Keckhut, P., Lowe, R. P., Roble, R. G., Mlynczak, M. G., Scheer, J., Fomichev, V. I., Offermann, D., French, W .J. R., Shepherd, M. G., Semenov, A. I., Remsberg, E. E., She, C. Y., Lübken, F.-J., Bremer, J., Clemesha, B. R., Stegman, J., Sigernes, F., Fadnavis, S.: Review of mesospheric temperature trends, Rev. Geophys., 41, 1015, doi:10.1029/2002RG000121, 2003.

Bremer, J., J. Schacht, and Th. Barth, 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.

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

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

Kürschner, D., Schminder, R., Singer, W., Bremer, J. Ein neues Verfahren zur Realisierung absoluter Reflexionshöhenmessungen an Raumwellen amplitudenmodulierter Rundfunksender bei Schrägeinfall im Langwellenbereich als Hilfsmittel zur Ableitung von Windprofilen in der oberen Mesopausenregion. Z. Meteorol., 37, 322-332, 1987.

Kürschner, D., and Ch. Jacobi, 2003: Quasi-biennial and decadal variability obtained from long-term measurements of nighttime radio wave reflection heights over central Europe. Adv. Space Res., 32, 1701-1706, doi: 10.1016/S0273-1177(03)00773-2.

Lauter, E.A., Taubenheim, J., von Cossart, G. Monitoring middle atmosphere processes by means of ground-based low-frequency radio wave sounding of the D-region. J. Atmos. Terr. Phys., 46, 775-780, 1984.

Lastovicka, J., R.A. Akmaev, G. Beig, J. Bremer, and J.T. Emmert, 2006: Global change in the upper atmosphere. Science, 314, 1253-1254.

Portnyagin, Yu.I., E.G. Merzlyakov, T.V. Solovjova, Ch. Jacobi, D. Kürschner, A. Manson, and C. Meek, 2006: Long-term trends and year-to-year variability of mid-latitude mesosphere/lower thermosphere winds. J. Atmos. Solar-Terr. Phys., 68, 1890-1901.

Ramaswamy, V., M.-L. Chanin, J. Angell, J. Barnett, D. Gaffen, M. Gelman, P. Keckhut, Y. Koshelkov, K. Labitzke, J.-J.R. Lin, A. O'Neill, J. Nash, W. Randel, R. Rood, K. Shine, M. Shiotani, and R. Swinbank, 2001: Stratospheric temperature trends: Observations and model simulations. Rev. Geophys., 39, 71-122.

Remsberg, E.E., and L.E. Deaver, 2005: Interannual, solar cycle, and trend terms in middle atmospheric temperature time series from HALOE. J. Geophys. Res., 110, D06106, doi:10.1029/2004JD004905