Possible signal of tropospheric circulation patterns in middle atmosphere dynamics, Collm (51.3°N, 13°E) mesosphere lower thermosphere winds 1979-2008

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Abstract

Time series of monthly mean Collm mesosphere/lower thermosphere winds 1979-2008 are analyses with respect to a possible correlation with North Atlantic Oscillation (NAO) and Southern Oscillation (SO) indices. There is a positive correlation with both indices until the middle 1990s, but later the correlation decreases or even reverses. Owing to the coupling of the SO with the NAO the change of correlation occurs broadly at the same time. The change of correlation is probably connected with changes of the middle atmosphere mean dynamics.

Zusammenfassung

Zeitreihen von Monatsmittelwerten des Windes in der Mesosphäre/unteren Thermosphäre über Collm werden auf mögliche Korrelationen mit der Nordatlantischen Oszillation (NAO) und der Südlichen Oszillation (SO) hin untersucht. Während eine positive Korrelation bis in die 1990er Jahre existiert, schwächt sich diese in der Folge ab und kehrt sich teilweise um. Da NAO und SO gekoppelt sind, erfolgen diese Änderungen etwa zur selben Zeit. Die Änderung der Kopplung steht wahrscheinlich in Verbindung mit einer generellen Änderung der Dynamik der mittleren Atmosphäre.

1. Introduction

The middle atmosphere is dynamically coupled to the troposphere mainly through gravity and planetary wave propagation and in this connection through wave-wave and wave-mean flow interaction. Therefore, since many years possible coupling mechanisms between the lower and middle atmosphere have been investigated. Since considerable part of the tropospheric circulation is described by teleconnection patterns like the North Atlantic Oscillation (NAO) or the Southern Oscillation (SO), signals of those (and other) patterns has been sought in middle atmosphere time series.

The NAO is the primary circulation pattern in the northern Atlantic and European sector. Broadly, the NAO may be described by a pressure difference between the Azores high and the Icelandic low pressure system. Thus, NAO influences the climate of the North Atlantic, but also of Europe. One possibility to describe the NAO through an index is using the difference between Ponta Delgada (alternatively Gibraltar or Lisbon) and Stykkisholmur, Iceland. Another frequently used method is to define the NAO is to use the Rotated Principal Component Analysis (RPCA) used by Barnston and Livezey (1987), and define time series of the primary pattern. Generally, high NAO index winters – the NAO describes larger part of the total circulation variance in winter than in summer - are connected with more northward storm tracks, higher European temperatures, less/more precipitation in southern/northern Europe, and generally a stronger polar vortex. This is also seen in the stratosphere (e.g., Baldwin et al., 1994), i.e. the stratospheric polar vortex is deeper and more stable during high NAO index winters. Jacobi and Beckmann (1999) showed that for the time interval 1979-1996 high NAO index winters were connected with stronger westerly winds even in the mesosphere/lower thermosphere (MLT) over Collm, Germany, around 90 km.

The SO may be considered as the atmospheric counterpart of the El Nino/La Nina oscillation, so that both phenomena usually are summarised as El Nino/Southern Oscillation (ENSO). A SO index (SOI) is defined as the difference of Tahiti and Darwin pressure anomalies. Since during El Nino the Pacific region is warmer with negative pressure anomalies there, the SOI is negatively correlated with Pacific Ocean surface water temperatures, so that high positive values of SOI correspond to La Nina and large negative SOI values correspond to El Nino events.

ENSO is one of the primary circulation patterns at equatorial latitudes and affects climate worldwide. Since strong El Nino events (warm events) are connected with more clouds over the tropical pacific, this also leads to cooling of the tropopause region and lowermost stratosphere. This in turn during winter reduces the temperature gradient between lower latitudes and the polar vortex, weakens the latter, and enhances the probability of major stratospheric warmings (van Loon and Labitzke, 1987). Stratospheric major warmings are strong disturbances of the stratospheric polar vortex with a reversal of the zonal mean flow. Thus, on average the polar stratospheric vortex is weaker during El Nino years than it is during La Nina years. Jacobi and Kürschner (2002) showed that a weak connection between ENSO and the middle atmosphere can also be seen in MLT winds over Collm such that a positive correlation of SOI and MLT zonal wind was found in winter, which means that during warm events (positive SOI), when there is enhanced probability of disturbed polar stratospheric vortex, on average the MLT zonal winds were weaker.

A possible, and probably oversimplified, explanation of the described correlations may be that simply the MLT region defines the uppermost part of the middle atmosphere, and a disturbed stratospheric vortex with weaker zonal mean winds is reflected in reduced zonal mean winds in the MLT, too. However, coupling processes between stratosphere and the MLT circulation during stratospheric warming events is not straightforward, but owing to wave-mean flow interaction processes. Stratospheric warmings (e.g., according to the early model by Matsuno, 1971) are connected with poleward residual circulation in the upper stratosphere, downward motion in the polar stratosphere and therefore warming in the middle and lower stratosphere. This leads to decrease of the stratospheric zonal mean zonal flow, but at the same time the residual circulation pattern includes upward motion in the mesosphere and southward residual circulation in the MLT. This is connected with eastward acceleration of the mean flow in the upper mesosphere. As a consequence, depending on the strength of this upper branch of the residual circulation anomaly, the MLT zonal winds may be weaker than average (if the stratospheric zonal wind decrease/reversal is not yet compensated) or stronger than average. Jacobi et al. (1997) have shown both cases when analysing several major stratospheric warming events and their effect on the MLT.

To summarise, while in the past correlation between tropospheric circulation patterns and MLT winds have been detected, the underlying coupling mechanisms are complicated, and it is not clear whether such correlations will remain stable under changing middle atmosphere circulation conditions. In view of the fact that considerable change of the middle atmosphere temperature, composition and dynamics (in particular change in trends) has occurred during the 1990s and early 2000s (e.g., Lastovicka and Krizan, 2006; Bremer and Peters, 2008; Jacobi, 2008), it may be worth reconsidering the correlation between MLT and tropospheric indices including roughly a decade of additional data. Therefore, after describing the used datasets in section 2, in section 3 a running correlation analysis after Kodera (1993) is applied to investigate possible changes of coupling between MLT and troposphere. Section 4 concludes the paper.

2. Data

Collm MLT winds

Collm LF D1 wind measurements at 80 to 100 km altitude have been carried out for more than 4 decades until late 2008. Commercial radio transmitters in the LF range (177 kHz, 225 kHz and 270 kHz) were used, and an automatic algorithmic variant of the similar fade analysis was 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. Since 1979 half-hourly winds from three measuring paths were constructed. To avoid artefacts owing to changes in measurement strategy, we here consider only the time interval starting in 1979.

The measurements were 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 and Beckmann (1999) and Jacobi and Kürschner (2002), so that the results presented here are, to a certain degree, updated from their work.

Time series of monthly mean zonal and meridional prevailing winds for each month of the year are shown as contour plots in Figure 1. Note that the scaling of the y-axis ranges from November through February to present the winter season months together. This means that November and December data refer to the year before the one indicated on the x-axis. Both the zonal and the meridional prevailing winds show, in addition to considerable interannual variability, long-term trends, in particular a positive trend of the zonal as well as the meridional prevailing wind in summer. This has already been shown, e.g., by Jacobi and Kürschner (2006). A positive trend is also visible in the winter prevailing zonal winds. Note, however, that during recent years the trend has weakened or even reversed, which has been shown by Jacobi (2008).

This trend and structural change is also shown in Figure 2, which displays January and February winds out of Figure 1 as time series. Solid symbols denote months with major stratospheric warmings according to the FU Berlin analyses (Labitzke and Naujokat, 2000). A clear connection between mesospheric winds and major stratospheric warming events is not visible. This substantiates earlier results from Jacobi et al (1997) who found that, although in some cases the prevailing winds are reduced during the warmings (as is the case with the stratospheric winds), this is not the case for every warming. Sometimes the MLT zonal winds are particularly strong, which had been called compensation effect. In brief, this is simply the effect of the upward mesospheric drift during the warming, first described by the model of Matsuno (1971), which lead to cooling in the mesosphere and subsequently eastward acceleration of the zonal flow.

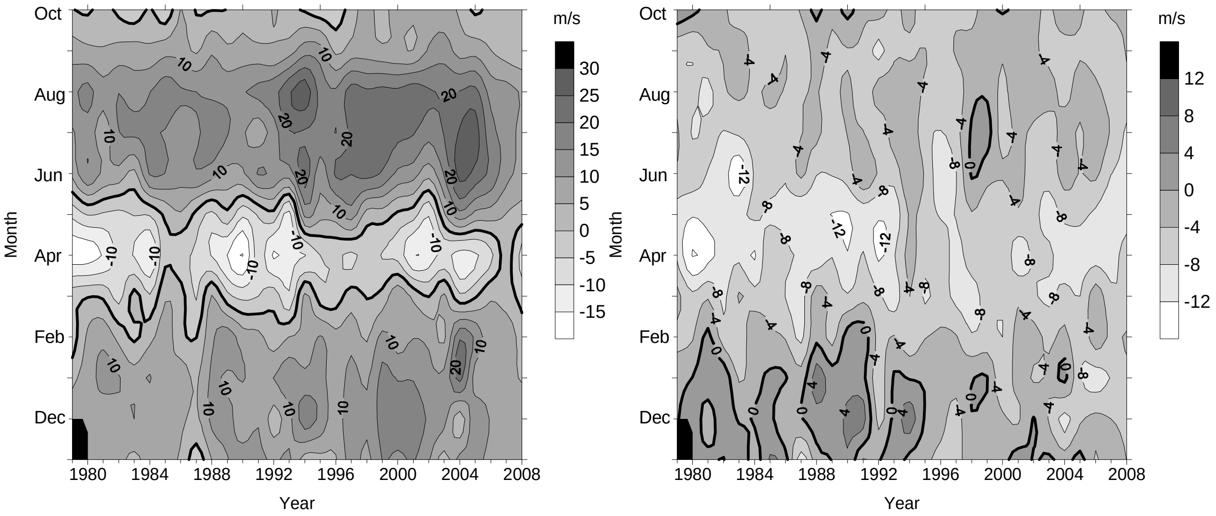

Figure 1*: Zonal (left panel) and meridional (right panel) prevailing MLT winds over Collm.*

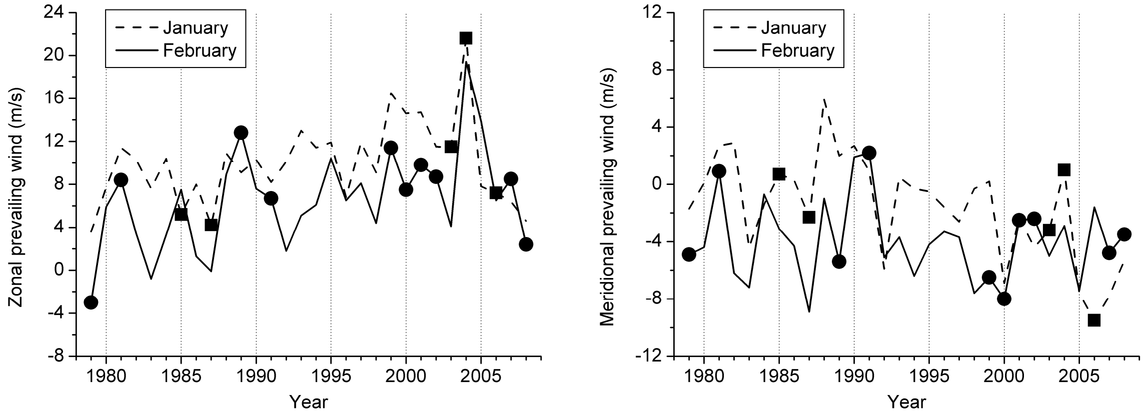

Figure 2: *Time series of January and February zonal (left panel) and meridional (right panel) mean prevailing MLT winds over Collm.*

The meridional prevailing wind is weakly correlated with the zonal wind, since mesospheric gravity wave forcing, which is responsible for the mesospheric/lower thermospheric wind reversal also leads to the meridional wind jet as part of the residual circulation. Therefore, at time scales of several years, positive zonal wind anomalies are connected with more northward meridional winds. This is visible, e.g., through comparing the February wind anomalies in the 1980s and early 1990s.

Southern Oscillation index

The SOI is defined as the difference of the standardised Tahiti and Darwin pressure anomalies, divided through the mean standard deviation of this difference. The index is normalised with respect to the 1951-1980 base period. The SO is the atmospheric counterpart of El Nino. The SOI is negatively correlated with Pacific Ocean surface water temperatures, so that high positive values of SOI correspond to La Nina and large negative values correspond to El Nino events. Time series of SOI data for each month are shown in the left panel of Figure 3. Most striking patterns are the El Nino events 1982/83 and 1997/98. On the right panel the January and February time series are shown. Years with major stratospheric warmings are marked by squares (January) and solid dots (February). For February there is a tendency that years with major stratospheric warmings are more frequently found during years of positive SOI, which has already been described in the literature (van Loon and Labitzke, 1987).

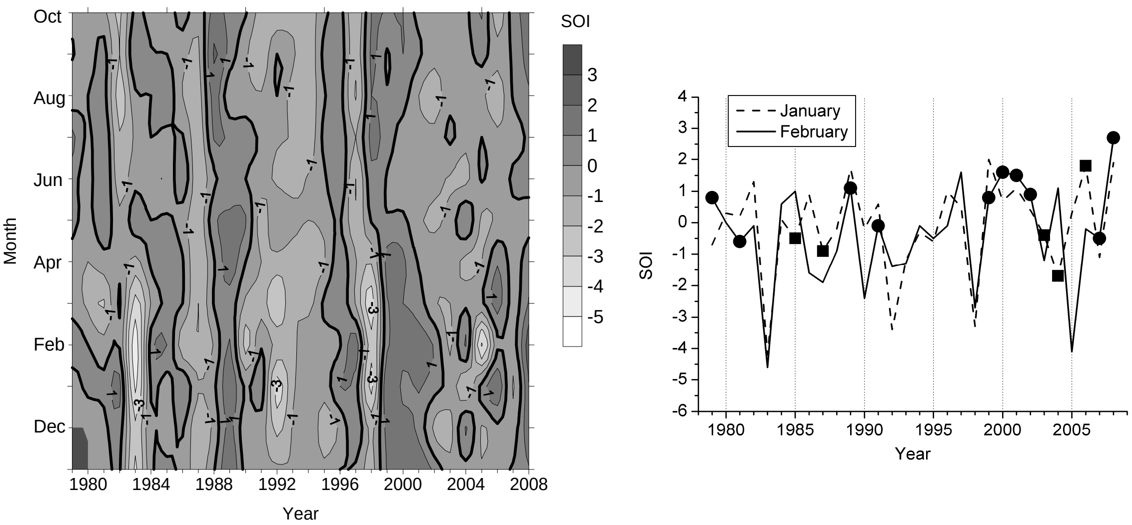

Figure 3: *Left panel: Monthly mean SOI values from 1979-2008. Right panel: Time series of the January and February SOI. Years with major stratospheric warmings are marked by squares (January) and solid dots (February).*

NAO index

NAO teleconnection indices used here has been provided by NOAA/NCEP Climate Prediction Center (CPC). The procedure used by CPC to calculate NAO indices is based on the RPCA used by Barnston and Livezey (1987). This procedure isolates the primary patterns for all months and allows time series of the patterns to be constructed. To obtain the teleconnection patterns, CPC applies the RPCA technique to monthly standardized 500-mb height anomalies in the analysis region 20°N-90°N between January 1950 and December 2000. Monthly mean NAO indices are potted in the left panel of Figure 4. There is a tendency for an increase of the NAO index after the middle 1980s, and a gradual decrease in the 1990s and 2000s. Since the NAO is known to be the primary circulation pattern of the Atlantic-European region, and since from earlier studies it was found that coupling between NAO and the upper middle atmosphere is strongest in winter (Jacobi and Beckmann, 1999), in the right panel of Figure 4 the January and February means are presented. As in Figure 3, months with major stratospheric warmings are highlighted.

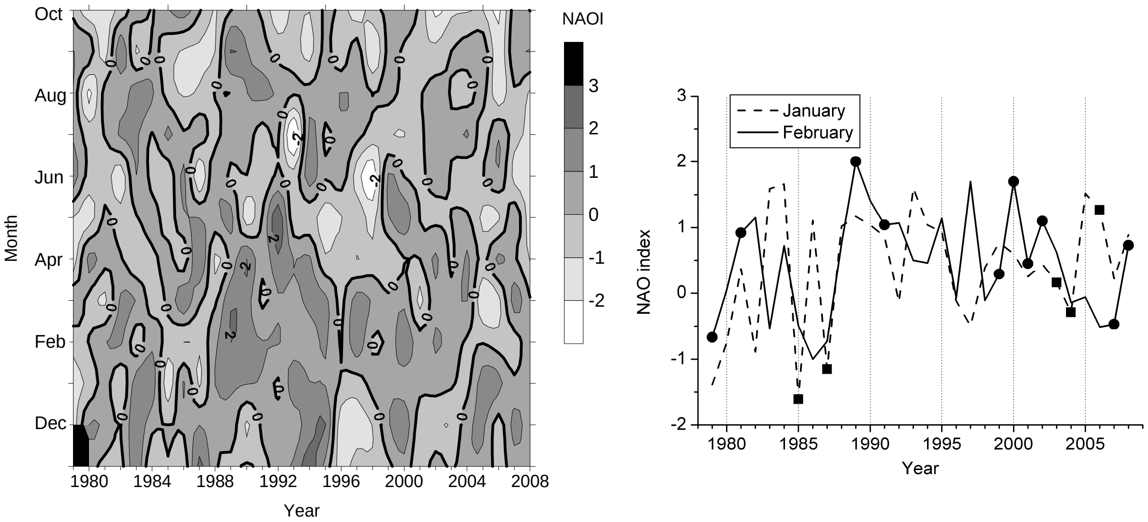

Figure 4: *Left panel: Monthly mean NAO index values from 1979-2008. Right panel: Time series of the January and February NAO index. Years with major stratospheric warmings are marked by squares (January) and solid dots (February).*

3. Running correlation analysis

Earlier studies have shown that there is a possible correlation of MLT prevailing winds with the NAO index during winter (Jacobi and Beckmann, 1999) and the SOI both in summer and winter (Jacobi and Kürschner, 2002). However, more recent analyses including about an additional decade of measurements indicate that these correlations decrease. To investigate the possible coupling processes and their changes therefore requires the analysis of correlation during different time intervals. Here the running correlation analysis (Kodera, 1993) is applied, which essentially consists of the calculation of correlation coefficients within time intervals of defined length (11 years is used here) and shifting this window through the time series under investigation.

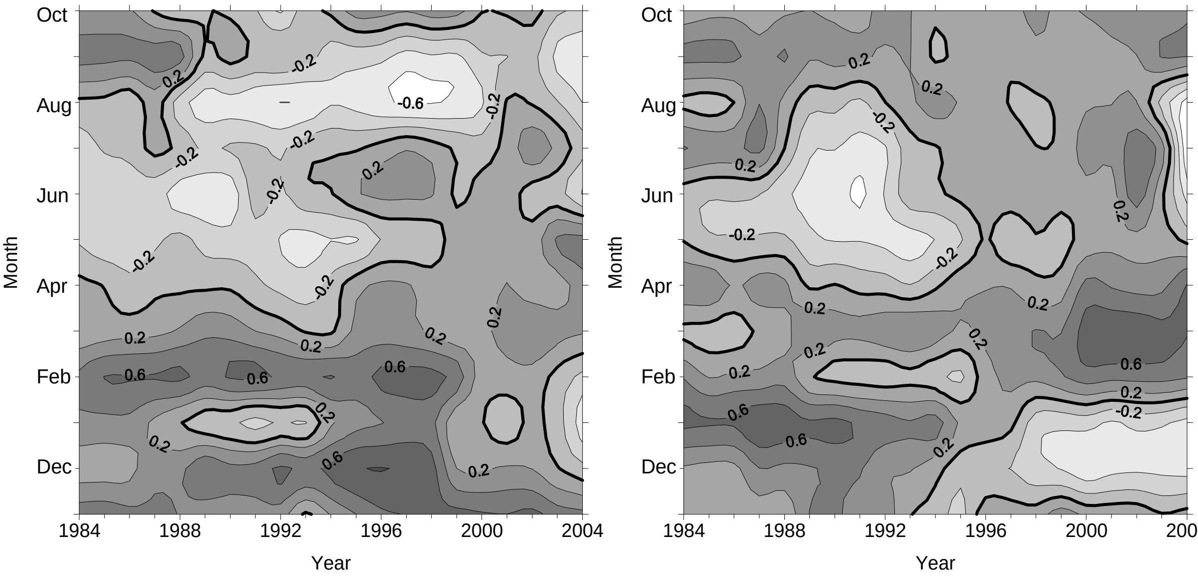

Figure 5: *Running correlation between SOI and Collm MLT zonal (left panel) and meridional (right panel) prevailing winds for each month of the year. Analysis is based upon 11 year data windows.*

Figure 5 displays results of running correlation analysis between the zonal (left panel) and meridional (right panel) prevailing MLT winds and the SOI. As has already been shown by Jacobi and Kürschner (2002), the correlation between SOI and zonal wind is mainly positive in winter, but - weakly - negative in summer, which both means a stronger mesospheric wind jet for positive SOI. However, after the late 1990s the correlation decreases and even reverses. While for this time interval there is no significant correlation in summer any more, in the 2000s the winter wind/SOI correlation is negative. The correlation patterns between meridional MLT wind and SOI are broadly similar to the ones in the left panel of Figure 5, which reflects the correlation between zonal and meridional MLT winds.

The correlation between winter NAO index and MLT zonal prevailing wind is positive in the first half of the time interval under consideration (Figure 6). As has been shown by Jacobi and Beckmann (1999), the correlation is only significant during winter. Again, the correlation between NAO index and meridional winds show similar features. As is the case with the SOI/MLT wind correlation in Figure 5, the NAO/MLT wind correlation decreases during the late 1990s and reverses in the 2000s.

The similar behaviour of the correlation between MLT and SOI as well as NAO index may be explained by a possible coupling between SOI and NAO. As has been shown in the literature (van Loon and Labitzke, 1987), the stratospheric polar vortex is weaker during ENSO warm events (negative SOI) than during cold events (positive SOI). On the other hand the NAO is correlated with stratospheric circulation such that during positive NAO index winters the stratospheric vortex is deeper than during negative NAO index winters (e.g., Baldwin et al., 1994).

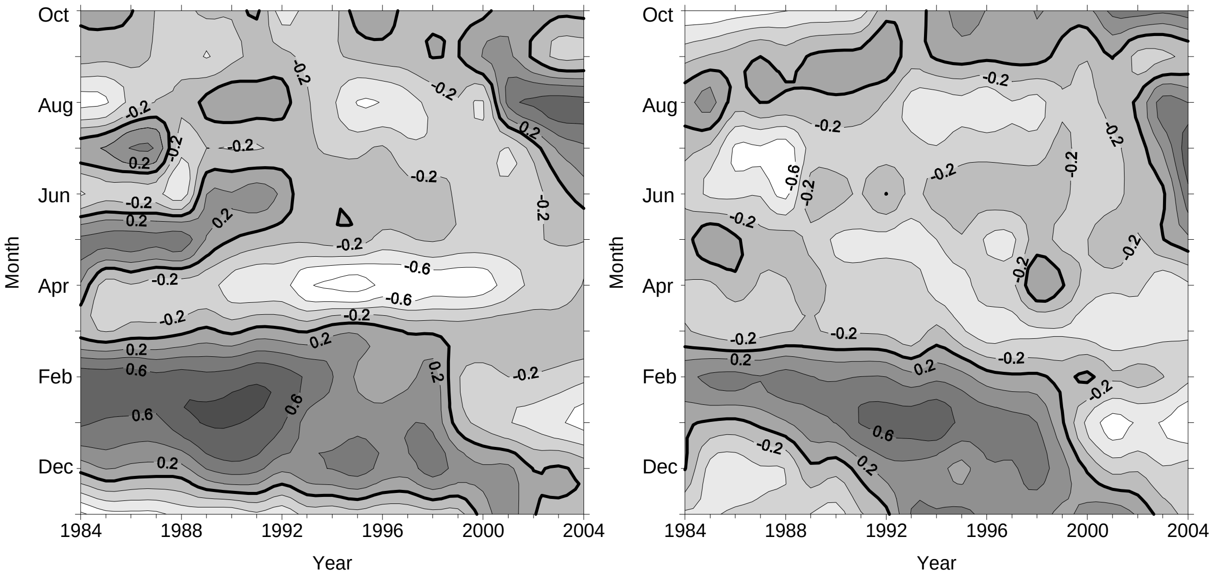

Figure 6: *Running correlation between NAO index and Collm MLT zonal (left panel) and meridional (right panel) prevailing winds for each month of the year. Analysis is based upon 11 year data windows.*

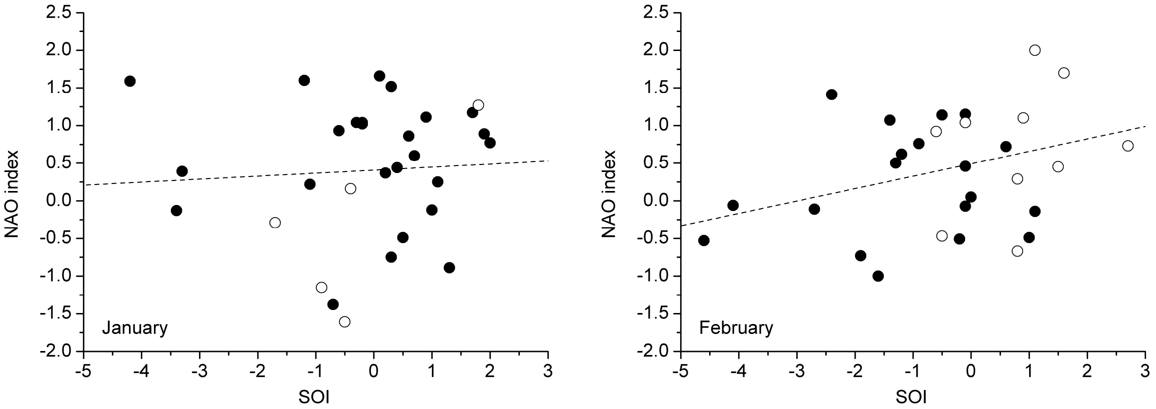

Figure 7: *Scatter plots of monthly NAO indices against SOI for January (left panel) and February (right panel). Months with major stratospheric warmings are indicated as open symbols.*

Correlation between the NAO index and the SOI shows that for January there is no correlation, while for February the correlation is, although weakly, positive (r = 0.34 for 1979-2008). As can be seen from the scatter plot in Figure 7 (see also the right panel of Figure 3), this weak positive correlation is connected with the appearance of major stratospheric warmings that are found more frequently for positive SOI in February.

4. Discussion and conclusion

From Figure 5 and Figure 6 one finds that obviously there is a change in the middle atmosphere circulation after the late 1990s that affects the coupling between the lower and middle atmosphere. This feature has also been found by Merzlyakov et al. (2008) using MLT winds over Obninsk (55°N, 37°E) which rules out an influence of possible inhomogeneity of the Collm wind time series. This change corresponds to the increased number of major stratospheric warmings since the late 1990s, after there has been none for several years since the warming in February 1991. There is also an indication for a change in long-term trends found in MLT winds such that the positive zonal prevailing wind trends seem to level out or even reverse in recent years (Jacobi, 2008).

There are other atmospheric parameters showing a change of trends in recent years. Randel et al. (2006) reported an increased Brewer-Dobson circulation and decreases of stratospheric water vapour beginning in 2001. Lastovicka and Krisan (2006) presented a change of trend in total ozone content (TOC) and ozone laminae, the latter being the signature of ozone streamers in the vertical and thus a possible indicator for PW (breaking) activity in the stratosphere. They found, that a decrease of TOC and ozone content within laminae before 1995 was followed by an increase after that time. It was assumed that this change was dynamically forced. Also reported is a change of stratospheric/mesospheric temperature trends in relation to an ozone trend change (Bremer and Peters, 2008), which appears in the middle 1990s and which is not a result of reduced anthropogenic chlorine loading, but has dynamical origin.

The reasons for such a structural change of the middle atmosphere are still under consideration. At present we may conclude that there is a possible change of the MLT and stratospheric circulation, and this change also affects coupling processes between the lower and the middle atmosphere.

Acknowledgements

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References

Baldwin, M.P., X. Cheng und T.J. Dunkerton, 1994: Observed correlations between winter-mean tropospheric and stratospheric circulation anomalies. Geophys. Res. Lett. 21, 1141-1144.

Barnston, A.G., and R.E. Livezey, 1987: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. Mon. Wea. Rev. 115, 1083-1126.

Bremer, J., and D. Peters, 2008: Influence of stratospheric ozone changes on long-term trends in the meso- and lower thermosphere. J. Atmos. Solar-Terr. Phys. 70, 1473-1481.

Jacobi, Ch., and B.-R. Beckmann, 1999: On the connection between upper atmospheric dynamics and tropospheric parameters: correlation between mesopause region winds and the North Atlantic Oscillation. Clim. Change 43, 629-643.

Jacobi, Ch., 2008: Low-frequency lower E region wind and reflection height measurements as sensor for climate variability. Adv. Radio Sci. 6, 331-335.

Jacobi, Ch., R. Schminder and D. Kürschner, 1997: The winter mesopause wind field over Central Europe and its response to stratospheric warmings as measured by D1 LF wind measurements at Collm, Germany. Adv. Space Res. 20, 1223-1226.

Jacobi, Ch., and D. Kürschner, 2002: A possible connection of midlatitude mesosphere/lower thermosphere zonal winds and the Southern Oscillation. Phys. Chem. Earth 27, 571-577.

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

Kodera, K., 1993: Quasi-decadal modulation of the influence of the equatorial quasi-biennial oscillation on the north polar stratospheric temperatures. J. Geophys. Res., 98, 7245-7250.

Labitzke, K. and B. Naujokat, 2000: The lower arctic stratosphere in winter since 1952. SPARC Newsletter No.15, 11-14.

Lastovicka, J., and Krizan, P.: Trends in laminae in ozone profiles in relation to trends in some other middle atmospheric parameters, Phys. Chem. Earth, 31, 46-53, 2006.

Matsuno, T. , 1971: A dynamical model of the stratospheric sudden warming, J. Atmos. Sci., 28, 1479-1494.

Merzlyakov, E., Ch. Jacobi, T.V. Solovjova, und Yu.I. Portnyagin, 2008: Structural changes in trends of the MLT winds at middle and high latitudes. 5th IAGA/ICMA/CAWSES Workshop "Long-Term Changes and Trends in the Atmosphere", St. Petersburg, 9.-13. September 2008, submitted to J. Atmos. Solar-Ter. Phys.

Randel, W. J., Wu, F., Vömel, H., Nedoluha, G.E., and Forster, P., Decreases in stratospheric water vapor after 2001: Links to changes in the tropical tropopause and the Brewer-Dobson circulation, J. Geophys. Res., 111, D12312, doi:10.1029/2005JD006744, 2006.

van Loon, H., and K. Labitzke, 1987: The Southern Oscillation. Part V: The anomalies in the lower stratosphere of the northern hemisphere in winter and a comparison with the quasi-biennial oscillation. Mon. Wea. Rev. 115, 357 -369.