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# The year-to-year variability of the autumn transition dates in the mesosphere/lower thermosphere wind regime and its coupling with the dynamics of the stratosphere and troposphere

E.G. Merzlyakov [a,*], Ch. Jacobi [b], T.V. Solovjova [a]

[a] *Institute for Experimental Meteorology, Pobedy Street, 4, Obninsk, 249030, Russia*
[b] *University of Leipzig, Institute for Meteorology, Stephanstrasse 3, 04103 Leipzig, Germany*

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ABSTRACT

The behaviour of the zonal prevailing wind in the autumn mesosphere/lower thermosphere (MLT) and its correlations with dynamical processes in the lower atmosphere is considered in terms of the autumn transition date (ATD) variability. The ATD is defined as the day when the rate of zonal wind decrease in the MLT region reaches its maximum in September–October. The method is applied to MLT radar wind data obtained at Collm (52°N, 15°E) and Obninsk (55°N, 37°E) during 1979–2007 and 1979–2011, respectively. The interannual variability of the ATDs depends on the direction of the stratospheric equatorial zonal winds at 30 hPa, i.e. the phase of the equatorial quasi-biennial oscillation (QBO). There is also a statistically significant correlation between the ATDs and the Northern Annular Mode (NAM) index taken at upper tropospheric/lower stratospheric heights during the westerly phase of the QBO. Numerical simulations with a mechanistic global circulation model demonstrate that high NAM indices correspond to later ATD and that the ATD, defined from the zonal wind characteristics, depends on the gravity wave flux.



## 1. Introduction

Dynamical coupling processes between the mesosphere/lower thermosphere (MLT) region and the stratosphere/troposphere is an ongoing field of research. Many recent works revealed vertical links between the dynamics of the MLT region and the lower atmospheric layers during specific events when significant changes in the circulation were observed, for instance, during sudden stratospheric warmings (e.g., Matthias et al., 2012) and during spring transition (Merzlyakov et al., 2012). Therefore, one may speculate whether the autumn transition is also a time period suitable to investigate possible vertical coupling processes between the dynamics of different atmospheric layers. Corresponding long time series of parameters of the MLT region covering a few decades are only available for horizontal winds obtained by radar at about 90 km. Therefore, it may be useful to study the specific characteristic of the zonal wind behaviour in autumn.

In order to analyse interannual and long-term changes in the middle atmosphere and its vertical coupling with the lower atmosphere, the dates of spring and autumn transition are useful parameters, since they do not necessarily depend on possible instrumental biases (for example, changes of instrument characteristics used for measurements) that may affect trend estimates. Even if an observation may suffer from some biases, the time of, e.g., minimum wind in autumn will be unaffected by these. A possible change of bias, e.g. after an upgrade or instrument change, will result in inhomogeneity of the time series of absolute values, but the date of a seasonal extreme value will be unaffected. Thus, instead of using absolute values, relative parameters may be more useful. Offermann et al. (2010) used the "equivalent summer length" as a measure for middle atmosphere trends, and they also presented time series of spring and autumn zonal wind turnaround dates in the stratosphere. In contrast to the stratospheric circulation, however, zonal winds in the mid-latitude MLT are eastward in both winter and summer (for example, Portnyagin et al., 2004; Jacobi et al., 2005a) above approximately 90 km, because the zero wind line is found at greater heights in winter than in summer. The planetary wave activity in the summer stratosphere is suppressed and as a consequence the autumn transition in the stratosphere is quite gradual compared to the spring one (Belmont et al., 1975). The autumn transition in the mid-latitude MLT is characterised by a weakening of zonal prevailing winds (e.g., Jacobi et al., 2005a), which do not regularly reach negative values (easterly winds) at heights of approximately 90 km. Instead,

* Corresponding author. Fax: +7 48439 40910.
*E-mail address:* eugmer@typhoon.obninsk.ru (E.G. Merzlyakov).

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a local minimum of the zonal prevailing wind is regularly observed in autumn. However, in some years this minimum is observed up to two months later than the wind transition in the stratosphere. During those time periods the circulation in the stratosphere and mesosphere is already a typical winter one. Therefore it does not seem to be useful to define the autumn beginning as the date when the local minimum is observed.

This problem was already noticed in early studies of the autumn wind transition (e.g., Minina et al., 1981). More recently, the problem with the definition of the autumn transition date (ATD) from MLT wind data was also noticed by Offermann et al. (2010), who consequently only showed MLT winter to summer transition dates in their study, and otherwise employed OH × temperature data for extracting information about the date of the autumn beginning in the MLT. In general, the literature about ATDs and its long-term and year-to-year variability in the MLT region is quite limited. The seasonal wind transition was also investigated by Kremp et al. (1999) using MF radar wind data and a numerical model, but for mesospheric heights where the zero line in the prevailing zonal wind field is clearly defined. The results by Offermann et al. (2010) showed that the interannual ATD variability and spring date variability in the MLT region are of the same order of magnitude. The situation is quite different in the stratosphere, where the ATD variability is not significant in comparison with the spring date variability.

There are many studies of the vertical coupling of the stratosphere and troposphere in autumn (e.g., Mohanakumar et al., 2008; Inoue et al., 2011). However, there are only few results on coupling between the MLT region and the stratosphere and troposphere in autumn. For example, Taylor et al. (2001) and Liu and Roble (2001) observed significant influence of planetary waves from below, possibly from the troposphere, on the mesospheric temperature in late autumn. In this work we consider the time interval of late summer and early autumn, when planetary waves cannot easily propagate from the troposphere into the lower thermosphere. Nevertheless we found a strong vertical coupling of the MLT region and the troposphere.

First we propose a method for definition of the ATD based on the rate of the zonal wind decrease with time. The MLT wind data were obtained from meteor radar wind measurements at Obninsk (55°N, 37°E) and LF wind measurements at Collm (52°N, 15°E) since 1979. The approach directly links the ATD with the change of the gravity wave (GW) forcing during autumn, because seasonal changing of solar radiation during autumn leads to an increase of MLT winds from mesosphere summer easterlies to winter westerlies, but GW forcing changes its sign from positive (eastward directed) in summer to negative (westward directed) in winter and thus leads to a decrease of zonal winds in the MLT from summer to winter. Since the GW flux is modulated by the variability of the lower atmosphere (while interannual radiation variability is small compared to the GW one), we can anticipate an influence of possible GW interannual variability on the timing of the autumn transition in the MLT. Therefore one can expect correlations between the variability of the troposphere/lower stratosphere and the ATD. In this study we carry out a corresponding correlation analysis between the ATD and the Northern Annular Mode (NAM) index taken at different pressure levels. We also use the Cologne Model of the Middle Atmosphere – Leipzig Institute for Meteorology (COMMA-LIM) numerical model, which is a mechanistic global circulation model developed at Cologne University and further at the Institute for Meteorology of Leipzig University (Fröhlich et al., 2003a, 2003b). With the COMMA-LIM model we simulate the autumn transition in the MLT region for different lower atmosphere conditions.

To extend our analysis from a local approach to the entire Northern Hemisphere and to relate the local features of the autumn transition over Obninsk and Collm to the global scale circulation, we also use geopotential heights obtained from temperature measurements with the Microwave Limb Sounder (MLS) instrument aboard the NASA Earth Observing System satellite AURA during the period 2004–2011.

## 2. Transition date definition, measurements and data processing

There are several approaches to define the ATD in the stratosphere, e.g. using the date of the zonal wind reversal at a given pressure level. For example, Offermann et al. (2010) used the 30-hPa zonal wind. Gallego et al. (2006) defined the ATD using the averaged velocity of the vortex at 50 hPa. Langematz and Kunze (2006) defined spring transition dates and ATDs using a threshold value of 10 m/s for zonal winds at 50 hPa. The different approaches produce different ATDs, and the question about the best approach is still open.

The ATD is defined here in terms of daily mean values of the zonal winds during August–September. First, the daily winds are filtered with the classical 29-point Hamming filter. This filter was found to be adequate to remove long-period oscillations of the order of several days in the winds. Then, from the filtered time series we determine the day when the maximum rate of wind decrease is observed. This day is taken as the ATD. The procedure is illustrated in Fig. 1. In this figure the time series of the Obninsk prevailing zonal wind averaged over 1979–2011 years is shown, together with the filtered wind (top). One can see the seasonal wind behaviour in late summer–early autumn. The wind change with time is shown in the bottom panel of Fig. 1. Physical reasons of such an approach to define the ATD are that the MLT zonal wind decrease is mainly due to the change in GW forcing. Even assuming only small variations in GW sources, in autumn the GW flux is changing due to changes of the stratospheric and tropospheric circulation and corresponding wave filtering from the summer type to the winter one. We also compared the obtained time series of the ATD with the results of Offermann et al. (2010) obtained for the MLT region from temperature data. They were found to be in good qualitative agreement (not shown). Errors for a given ATD were estimated by using a Monte-Carlo approach. From the time series of daily zonal winds for a given year a smoothed wind change (using the 29-point Hamming filter) and the variance of the residuals were estimated. Then a set of 100 artificial time series of daily zonal winds with the same variance for each year were constructed and new ATDs were found. The ATD errors were calculated from the derived set of dates. The ATDs have been calculated from several data sources, namely Obninsk and Collm radar winds, and MLS gradient winds. The measurements are subsequently described.

### 2.1. Obninsk meteor wind data

Measurements of the horizontal winds in the MLT region over Obninsk (55°N, 37°E) have been carried out since 1964. The analysed wind data cover a time period from 1979 to 2011, during which daily prevailing winds are usually available from the measurements. The meteor radar data were described in several papers (e.g., Portnyagin et al., 2006) in detail. The meteor radar installed at Obninsk does not provide height information of the meteor echo, and the results of measurements are referred to an average height of 90 km. This is justified since the daily average height of the under dense sporadic meteors is quite stable for radars with frequencies from 30 to 50 MHz. An increasing number of MLT wind studies with SKiYMET radars distributed over several dozens of geographical sites demonstrate that. The Obninsk radar