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Annual and semiannual harmonics of wind in the Northern stratosphere, mesosphere, and lower thermosphere

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Abstract

Based on the UK MetOffice gridded analysis in the altitudes from the tropopause to the mesopause of the Northern Hemisphere and the meteor radar observations in the mesosphere/lower thermosphere over Kazan (56°*N* 49°*E*) and Collm (51°*N* 13°*E*), the annual and semiannual harmonics of the horizontal wind components in the stratosphere, mesosphere, and lower thermosphere are studied for the period 2004–2013. The maxima of the amplitude of the annual harmonics of zonal wind are much more pronounced than the respective maxima for meridional wind. In contrast, the magnitudes of the maxima of the semiannual harmonics are comparable between zonal and meridional wind. The annual harmonics of horizontal wind in the studied layer typically reaches maximum in January–February. The semiannual harmonics of the components of horizontal wind in the stratosphere–lower thermosphere layer basically attains it first maximum in spring or in early summer. The results, included in the present paper, may be used for climate models validation.

Keywords: Stratosphere; Mesosphere; Lower thermosphere; Horizontal wind; Annual harmonics; Semiannual harmonics

1. Introduction

One of the most prominent feature of the Earth's climate is an annual cycle (AC) exhibited by all climatic variables. Its cause is the orbital movement of the Earth around the Sun. However, the annual cycle also includes a variety of feedbacks. Most of those feedbacks operate at the interannual and longer time scales as well. Despite a possible dependence of the efficiency of these feedbacks on the time scale of climate variations, an accurate simulation of AC might be considered as a prerequisite for realistic simulations of climate change at the decadal and longer time scales. Assessments of the annual cycle of surface air temperature as simulated by global climate models were performed earlier (Covey et al., 2000; Eliseev et al., 2004; Eliseev et al., 2004).

Recently, the so called CMIP5 (Coupled Models Intercomparison Project, phase 5) ensemble of climate models became available. In comparison to the earlier–generation models, the upper boundary is located at larger altitudes (up to 0.01 hPa in pressure coordinates, e.g., Manzini et al., 2014). Moreover, contemporary climate models start to include modules representing atmospheric chemistry. All this poses the necessity to extend the previous analysis for additional variables and for higher levels of the atmosphere.

A prerequisite for such an analysis is an assessment of the AC characteristics based on observations. Previous

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papers on this topic were published earlier (Webb, 1966; van Loon, 1967; van Loon and Jenne, 1970; van Loon et al., 1972; Groves, 1972; Hirota, 1980; Hedin et al., 1996). In these papers, horizontal wind variations were decomposed into annual and semiannual harmonics. However, in comparison to the present day, a much smaller amount of data was available during when the listed papers were in preparation, either with a much coarser spatial resolution, or with a smaller vertical coverage.

We note that even the feedbacks involved in the formation of the annual and, especially, the semiannual variations of horizontal wind in the stratosphere and the mesosphere are understood incompletely. For instance, there are multiple origins of west and east accelerations of zonal flow in these layers. First, east acceleration may be caused by the cross-equatorial advection of east flow from the summer hemisphere (Meyer, 1970; Holton and Wehrbein, 1980). This phenomenon occurs twice per year and is most intensive shortly after the solstices. Second, semiannual variations could arise from the eddy momentum originating from the waveguide–trapped breaking planetary waves (Hitchman and Leovy, 1988; Hamilton et al., 1995). Another mechanism of the semiannual variations in the tropical stratosphere and mesosphere may be due to the fast Kelvin waves and gravity waves which transport momentum upward (Hitchman and Leovy, 1988; Hamilton et al., 1995; Sassi and Garcia, 1997).

In the mesosphere, semiannual variations are determined by a range of the vertically propagating gravity waves and the fast Kelvin waves. These waves are forced from below and are filtered by the zonal flow in the stratosphere. In turn, this flow experiences semiannual variations. Such a filtering may be the reason the approximate anti–phase relationships between the stratospheric and the mesospheric semiannual oscillations of wind in the tropics (Dunkerton, 1982; Hitchman and Leovy, 1986).

The goal of the present paper is to study annual and semiannual harmonics of zonal and meridional wind at different altitudes in the stratosphere, mesosphere, and lower thermosphere based on observations. We are able to identify the specific structures, which are formed by these harmonics in these layers, and attribute such structures to different sources. Further, we found the phase relations between the stratospheric and mesospheric semiannual variations which differ from those obtained earlier. In addition, we suggest one more mechanism for the formation of the semiannual variations of horizontal wind related to the thermally forced vertically propagating extratropical quasi–stationary planetary waves.

2. Methods

We use the monthly mean fields of zonal u and meridional v wind in the Northern Hemisphere as supplied by the UK Meteorological Office (MetOffice) operational analysis (Swinbank and O'Neill, 1994, and updates) for years 2004–2013 from the pressure level 215 hPa (which corresponds roughly to the tropopause) to the pressure level 0.01 hPa (approximately at altitude 79 km). We extend the height range with respect to the earlier analyses, which only covered the atmosphere up to 10 hPa, to higher levels covering not only the lower stratosphere, but the upper stratosphere and the mesosphere as well.

In addition, we use the mesosphere/lower thermosphere meteor radar data over Kazan ($56^\circ N$, $49^\circ E$) and Collm ($51^\circ N$, $13^\circ E$). For Kazan, the measurements are performed during campaigns arranged during the years 2003, 2004, and 2007, and are representative to the layer from $\approx$ 78 km to $\approx$ 110 km (Fahrutdinova, 2004, and update). As a result, in the presented plots, the Kazan meteor radar data are attributed to the centre of this layer, about $\approx$ 94 km. The long–term means for Kazan is constructed by averaging the data for the indicated years. At Collm, the measurements performed at a regular basis since 2004. The retrieved horizontal winds are arranged in height gates of 3 km width. The Collm radar data are described elsewhere (Jacobi, 2012; Placke et al., 2010). While an analysis of the fields just in two geographic locations is very limited with respect to the analysis of the total field, it allows one to extend the data to larger altitudes, into the lower thermosphere. This is the reason why we include it in the present paper as well.

Both components of horizontal wind are compactly represented as sums of sinusoidal annual and semiannual harmonics with amplitudes Y_j and initial phases $\phi_{Y,j}$ ($Y = u, v; j = 1, 2$). However, for the purpose of interpretation, we use the month of the year $M_{Y,j}$, when the respective harmonics attains its maximum, as a characteristics of the phase of this harmonics. This month in the year is unique for the annual harmonics. We use the first such a month within the calendar year as a phase characteristics for the semiannual harmonics.

In addition, we performed a test to study whether our results are robust with respect to the choice of the observational period. For this, we repeated our processing of the MetOffice data for the shorter time period, from 2010 to 2013. No marked changes of the results compared to those of the period 2004–2013 were found. So, our results are rather insensitive to the choice of the period of observations. In particular, it allows one to extend the gridded MetOffice data by the meteor radar point measurements.

Finally, we studied the impact of the interannual variability on our results. In particular, one may construct a monthly long–term mean based on the available data and then calculate Y_j and $M_{Y,j}$ based on this climatology. Alternatively, these characteristics may be calculated for each year and then averaged over all available years. We found that the way of calculation does not affect the results for the annual harmonics but markedly changes the results for the semiannual one. The latter is due to larger interannual variability of the semiannual harmonics than for the annual one. Similar dependence on the use of either climatological