ABSTRACT

During recent years, special attention has been paid to the background circulation of the middle atmosphere and, including a variety of new measurements particularly using radar especially in the mesosphere/lower thermosphere (MLT) region, to the comparison of existing empirical middle atmosphere wind models as CIRA-86 and HWM with new data. This leads to the construction of empirical models of MLT winds as the Global Empirical Wind Model (GEWM). Further investigations aim at the construction of new empirical and semi-empirical wind models of the whole middle atmosphere including the new experimental results. Results of a new wind climatology (0-100 km) are presented based upon the GEWM, stratospheric reanalysis data, and a numerical model to fill the gap between stratospheric and MLT data.

1. Introduction

Many attempts have been undertaken to construct empirical wind models of the middle and upper atmosphere that include the stratosphere, the mesosphere and the upper mesosphere/lower thermosphere region. The most widely used models are the COSPAR International Reference Atmosphere 72 (CIRA-72, 1972) and the Fleming et al. (1990) model, which is a part of CIRA-86 model. Since the CIRA model concerns areas far above the greatest heights for standard radiosondes the CIRA-72 model was mainly based on rocket data, including only sparse meteor radar and ionospheric drift data. In the CIRA-86 model the zonal wind was calculated from the zonally averaged momentum balance equation. The related temperatures...
for the stratosphere/mesosphere were determined from satellite radiance measurements (Barnett and Corney, 1985), and from the mass spectrometer and incoherent scatter (MSIS-83) empirical model temperatures (Hedin et al., 1991). This method is not a direct way of wind determination. In addition the reliability of the gradient winds is also questionable due to the low accuracy of the satellite temperature measurements in the upper mesosphere, and the absence of direct temperature data between 85 and 100 km in the MSIS model.

The Fleming et al. (1988, 1990) model does not contain information about meridional winds, although the CIRA-86 includes tabulations of radar winds at several locations (Manson et al., 1990). However, unlike in the stratosphere, the prevailing meridional winds in the upper mesosphere/lower thermosphere are at times of the same order of magnitude than the zonal winds. A meridional wind model for this region has been developed by Groves (1969) using sporadic rocket wind data obtained at few sites in the Northern Hemisphere (NH). As a result, his model presented a schematic picture of the height-latitudinal structure of the zonal mean meridional wind field at 60-110 km. Nastrom et al. (1982) have also developed an empirical model of the meridional circulation at 95 km for NH summer. Their analysis has shown that at all measurement sites the prevailing meridional wind was predominantly southward independent of longitude. The analytic empirical horizontal wind model (HWM93) has been developed by Hedin et al. (1996). The model is based on the CIRA-86 tabulations in the stratosphere and lower mesosphere, but also on satellite data, historical rocket data, previous rocket data based tabulations, meteor radar and MF radar data, and lower thermosphere incoherent scatter data used for a former version (Hedin et al., 1991) of a thermospheric wind model.

For prevailing winds in the mesosphere/lower thermosphere (MLT) region, the radar-based Global Empirical Wind Model (GEWMI) for the height region 70-110 km, was constructed by Portnyagin (1984) and updated in the following years (e.g., Portnyagin et al., 1995; Portnyagin and Solovjova, 2000), most recently by Portnyagin et al. (2004). The last version of the model, basically referring to the 1990-2000 period, also includes data from the HRDI experiment on board the UARS satellite.

Recently direct wind observations from the wind imaging interferometer (WINDII, Wang et al., 1997) and the high-resolution Doppler imager (HRDI, Fleming et al., 1996) on board the Upper Atmosphere Research Satellite (UARS) have provided a new global wind data set for the upper mesosphere/lower thermosphere region. From these data, also a vertical wind model (Fauliot et al., 1997) has been constructed. Fleming et al. (1996) and Portnyagin et al. (1999) concluded that, in general, the space-based zonal wind models exhibited significant differences relative to the ground-based models. In contrast, however, Fauliot et al. (1997) have stated that the WINDII-based prevailing meridional model winds have cellular structure, similar to those from the ground-based Portnyagin et al. (1995) model. HRDI winds, together with winds from the Met Office assimilation system (Swinbank and O’Neill, 1994) and balanced winds from the UARS Reference Atmosphere Project (URAP) project have been used to construct a reference wind model (Swinbank and Ortland, 2003) for one year (Apr 1992 - Mar 1993), but an extended data set is also available. However, the balanced URAP winds are only available for one year.
Below the stratopause, analyses data (Met Office, ECMWF, NCAR/NCEP) are available that, although the winds derived from these data are not purely empirical, give good estimates of the mean circulation there. The wind models for the mesosphere, however, still need to be improved. In addition, only little information is available for non-zonal structures in the middle atmosphere, namely stationary planetary waves, and the variability in the time scale of planetary waves. Only recently, Fahrutdinova et al. (2003) accomplished a comparison for some midlatitude sites (Kazan, Collm, Saskatoon) using Met Office and radar data. They showed significant longitudinal distinctions in the altitudinal and seasonal structure of the circulation, thus indicating their non-zonal character.

Concerning tides, which become a prominent feature of middle atmosphere circulation above 70 km, only few climatologies are available. The probably first attempt to construct a global picture of the diurnal and semidiurnal tide has been undertaken by Manson et al. (1989). More recently, updated measurements from MF radars at different latitudes have been presented (Manson et al., 1999, 2002a), while Jacobi et al. (1999) presented semidiurnal tides from a narrow (middle) latitude band, but for different longitudes. An empirical model, as the GEWM I based upon radar winds, have been presented by Portnyagin and Solovjova (1998) and recently updated, now also including satellite data (Portnyagin et al., 2006a), while Forbes et al. (1994) presented tides calculated from an assimilative approach. Global pictures of tides were also derived from UARS measurements (Burrage et al., 1995; Khattatov et al., 1997a,b; Manson et al., 2002b). Generally, these models refer to heights around the mesopause, including radar and UARS satellite data. The HWM93 (Hedin et al., 1996) also contains information about tides, for a larger vertical extent.

It may be concluded that there is still need for a comprehensive reference model that contains mean winds, planetary waves, tidal amplitudes and phases, and information about the variability of the winds, including trends and long-period variations. Since the database in several regions is sparse (mesosphere, thermosphere), pure empirical models constructed using only one method are only possible for selected regions. Therefore, a combined approach may be taken into account, that includes empirical models for the regions well covered with data, but an assimilative approach for the mesosphere and the lower thermosphere region.

2. A new semiempirical model of the middle atmosphere

The basis of the new semiempirical model of the middle atmosphere consists in three climatologies of wind data that has been constructed for different height regions. Monthly mean tables of zonally averaged Met Office zonal and meridional winds have been constructed for each latitude belt. The data had been averaged over the period 1992-2002. These data range from the ground to about 56 km or above. At height between 70 and 100 km, GEWM I data are used. GEWM data are also available on a latitude-height grid. The construction of the GEWM I has been described by Portnyagin et al. (2004). The gap between the Met Office and GEWM data, roughly corresponding to the lower and middle mesosphere, has been filled by data from the COMMA-LIM numerical circulation model of the middle atmosphere. COMMA-LIM is a three-
dimensional, primitive equation model from the ground to about 150 km. The model contains an updated Lindzen-type gravity wave parameterisation, and a detailed radiation routine for self-consistent maintaining of the mean circulation depending on season. Planetary waves can be included through forcing of a temperature disturbance near the lower boundary, however, in the present version used here only long-term averaged stationary waves taken from Met Office reanalysis data has been included. The model has been described by Fröhlich et al. (2005) and Jacobi et al. (2006a), while results of a background climatology calculation using the model has been presented by Jacobi et al. (2006b).

To construct the new background wind model, GEWM data were used between 100 and 70 km, and numerical model results have been included between 80 and 50 km. This means an overlap of the purely empirical GEWM data and the numerical model wind, which is necessary to smooth the latitudinally more structured GEWM radar data, towards the larger horizontal scales preferred in a numerical model at the GEWM lower boundary.

Met Office data were used between the ground to 56 km for the meridional and zonal component, respectively. As with the GEWM (Portnyagin et al., 2004) the merging of the data was performed using the method proposed by McLain (1974). In Figure 1 height-time cross-sections of the available input data are displayed for January. Generally the GEWM data are more structured than the other data; this is particularly the case with the meridional wind at the lower GEWM altitudes. The Met Office meridional winds show comparatively large values (more than 2 m/s in this case) near the upper boundary, so that the uppermost meridional Met Office winds were disregarded. It can, however, be seen that the summer zonal wind jets predicted by the model are smaller than the Met Office winds, so that the upper layer zonal Met Office winds are necessary to predict realistic winds in the combined model.

Height-time cross-sections of the new model are shown in Figure 2 for the zonal mean wind, and in Figure 3 for the meridional mean wind. The lower layers (below 50 km) are purely determined by the Met Office analyses. GEWM data dominate in the uppermost layers (compare, e.g., the right panel of Figure 1 with the upper left panels of Figure 2 and Figure 3). The strong structures of the lowermost GEWM heights have been smoothed through the numerical model. On the other hand, the meridional wind jet, which extends over the entire globe in the numerical model (lower left panel of Figure 1) is, except for Northern summer, now separated into more isolated regions.

Examples of comparisons of the new model with existing models (CIRA and HWM93) are shown in Figure 4. The panels show monthly means at 70 km altitude for 4 different Northern Hemisphere latitudes. The height chosen here represents the zone where the new model is mostly determined by the numerical model, but with some influence of the GEWM I. The merging of the two models results in a slightly weaker zonal wind jet, most strongly expressed at 50°N. The annual amplitudes of the meridional wind predicted by the new model are generally stronger than the HWM93 ones. This is more realistic compared with experimental data, and represents the meridional wind jet from the summer to the winter hemisphere. The model data at 50 km, shown in Figure 5, represents Met Office data merged with numerical model winds. Here, the zonal prevailing winds predicted by all models are relatively close to each other. the HWM93 and
the new model meridional winds disagree, however, generally the meridional winds at 50 km are weak and differences are smaller than 3 m/s.

3. Conclusions

The new semiempirical model does not contain information about wind variability, except for the seasonal cycle. The major part of the GEWM data set has been measured during the last decade of the 20th century, while the Met Office analyses apply to a very similar time interval. The COMMA-LIM model does not include information about the year, except for the stationary planetary waves included, and these again have been calculated using data from the same time interval. Therefore, it may be concluded that the new semiempirical model refers to the late 20th century. There have been several papers on long-term trends in middle atmosphere, especially MLT, winds. However, recent analyses showed that at least concerning the MLT region there has been structural changes in long-term trends of winds (Portnyagin et al., 2006b), which, however, are not well known so far, so that it is not possible to include information on interannual or decadal changes into the model.

The model does not contain information about longitudinal variability. Fahrutdinova et al. (2003) had presented a comparison of mean winds over different stations of similar latitude and found some longitudinal differences. However, this analysis, while it can be performed using global Met Office data, near the MLT is only possible for selected latitudes with good coverage of radars. Thus, since the model does not contain many oscillations it does not reproduce important features needed for current applications, e.g. maximum strength of wind jets, maximum wind gradients, and others. In conclusion, the model can only present the main circulation patterns and seasonal variability, i.e. serve as a background climatology.

The combined model data, as well as the data from the three input models have been constructed in the frame of an INTAS project. The data are available on the internet on http://www.uni-leipzig.de/~jacobi/intas03/data.htm. The model may be used as background data set for linearised numerical models, and as a reference for measurements.

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References


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**Figure captions**

Figure 1: Example of input data (January). Left panels: COMMA_LIM numerical results. Data from the region marked with filled contours is used. Middle panels: GEWM data (upper part of the panels) and Met Office data (lower part of the panels). Right panels: Merged model. Upper panels show zonal mean winds, lower panels show meridional mean winds. Note that the meridional zero wind isoline is not displayed.

Figure 2: Height-latitude cross-sections of monthly mean zonal mean winds, combined from Met Office, COMMA-LIM, and GEWM I monthly wind tables, for each month of the year.

Figure 3: As in Figure 2, but for the meridional monthly mean wind. Note that the zero wind isoline is not displayed.

Figure 4: Comparison of monthly CIRA zonal winds, HWM93 zonal and meridional winds, and new model data for 70 km altitude, for 4 different Northern hemisphere latitudes.

Figure 5: As in Figure 4, but for 50 km altitude.
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