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Semi-empirical model of middle atmosphere wind from the ground to the lower thermosphere

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Abstract

During recent years, special attention has been paid to understanding the background circulation of the middle atmosphere. Particularly in the mesosphere/lower thermosphere (MLT) region, this has involved including data from a range of new radar measurements. It has also involved the comparison of existing empirical middle atmosphere wind models, such as CIRA-86 and HWM-93 to the new data. This has led to the construction of empirical models of MLT winds such as the Global Empirical Wind Model (GEWM). Further investigations are aimed at the construction of new empirical and semi-empirical wind models of the entire middle atmosphere including these new experimental results. The results of a new wind climatology (0–100 km) are presented here, based upon the GEWM, a reanalysis of stratospheric data, and a numerical model which is used to fill the gap between data from the stratospheric and MLT regions.

Keywords: Winds; Middle atmosphere; Lower thermosphere; Semi-empirical model

1. Introduction

Many attempts have been made to construct empirical wind models of the middle and upper atmosphere including the stratosphere, the mesosphere and the upper mesosphere/lower thermosphere regions. 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 models have generally considered regions 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 regions were determined from satellite radiance measurements (Barnett and Corney, 1985), and from empirical models of temperature derived from mass spectrometer and incoherent scatter (MSIS-83, Hedin et al., 1991). This method is not, however, a direct technique of wind determination. In addition the reliability of the gradient wind technique for wind derivation is also highly questionable in the 85- to 110-km region, due to the absence of any direct tempera-

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ture data in the region between 85 and 100 km in the MSIS model, where only the "merging model" was used (Fleming et al., 1990), between the actual data-based model up to 85 km, and the MSIS-83 model above 120 km.

The Fleming et al. (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 region are, at least at times, of the same order of magnitude as the zonal winds. A meridional wind model for this region was developed by Groves (1969) using sporadic rocket wind data obtained at a 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 (HWM-93) was developed by Hedin et al. (1996). For the stratosphere and lower mesosphere, HWM-93 is based chiefly on the CIRA-86 tabulations. At greater altitudes, HWM-93 uses satellite data, historical rocket data, tabulations of previous rocket data-based, meteor radar and MF radar data, and lower thermosphere incoherent scatter data used for a former version (Hedin et al., 1991) of the HWM thermospheric wind model.

For prevailing winds in the mesosphere/lower thermosphere (MLT) region, the radar-based Global Empirical Wind Model (GEWM) 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 Upper Atmosphere Research Satellite (UARS).

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 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 1 year (April 1992–March 1993), but an extended data set is also available. However, the balanced URAP winds are only available for 1 year.

Below the stratopause, analyses of data provided by the Met Office, ECMWF and NCAR/NCEP are available and give good estimates of the mean circulation. However, the winds derived from these data are not purely empirical. Wind models for the mesosphere, however, still need to be improved considerably. In addition, rather little information is available concerning non-zonal structures in the middle atmosphere, namely stationary planetary waves, and the variability of winds within the region on the time scale of planetary waves. Only recently, Fahrutdinova et al. (2003) accomplished a comparison for some mid-latitude sites (Kazan, Collm, Saskatoon) using both Met Office and radar data. They showed significant longitudinal dependence in the altitudinal and seasonal structure of the wind circulation, thus indicating considerable non-zonal structure of the winds.

Tides become a prominent feature of middle atmosphere circulation above 70 km. However, only few climatological models are available. One of the first attempts to construct a global picture of the diurnal and semidiurnal tide in this altitude region was been undertaken by Manson et al. (1989). More recently, updated measurements from MF radars at different latitudes have been presented by Manson et al. (1999, 2002a), while Jacobi et al. (1999) presented an analysis of semidiurnal tides from a narrow (middle) latitude band and as a function of longitude. An empirical model, based upon radar winds, was presented by Portnyagin and Solovjova (1998). Forbes et al. (1994) presented tides calculated using an assimilative approach. Global pictures of tides have also been derived from measurements by UARS (Burrage et al., 1995; Khattatov et al., 1997a,b; Manson et al., 2002b). Generally, these models, including those using radar and UARS satellite data, refer to heights around the mesopause. The HWM-93 (Hedin et al., 1996) also contains tidal information, but over a larger vertical extent.

It may be concluded that there is an outstanding requirement for a comprehensive reference model containing mean winds, planetary waves, tidal amplitudes and phases, and information about the variability of the winds, including trends and long-period variations. The database for several altitude regions is sparse (in particular the mesosphere and thermosphere). Thus purely empirical models can be constructed using a single method only for selected altitude regions. To provide useful models covering the entire atmosphere, a combined or hybrid approach has to be used. Empirical or semi-empirical models can certainly be used for those altitude regions for which the observational data base is adequate. However, an assimilative approach should be used for the mesosphere and the lower thermosphere region, for which the data base (for wind measurements, in particular) is still very poor.