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A review of mesospheric and lower thermosphere models

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Abstract

The empirical mesosphere/lower thermosphere (MLT) models, in particular Fleming et al. [Fleming, E.L., Chandra, S., Schoeberl, M.R., Barnett, J.J. Monthly mean global climatology of temperature, wind, geopotential height and pressure for 0–120 km. NASA Technical Memorandum 100697, 1988; Fleming, E.L., Chandra, S., Barnett, J.J., Corney, M. Zonal mean temperature, pressure, zonal wind and geopotential height as function of latitude. Adv. Space Res., 10 (12), 11–59, 1990.], HWM-93 [Hedin, A.E., Fleming, E.L., Manson, A.H., Schmidlin, F.J., Avery, S.K., Clark, R.R., Franke, S.J., Fraser, G.J., Tsuda, T., Vial, F., Vincent, R.A. Empirical wind model for the middle and lower atmosphere. J. Atmos.Terr. Phys., 58, 1421–1447, 1996] and GEWM [Portnyagin, Yu.I, Solovjova, T., Merzlyakov, E., et al., Mesosphere/lower thermosphere prevailing wind model. Adv. Space Res., 34, 1755–1762, 2004] models, are compared. The main reasons of the differences between the models are discussed. These reasons are mainly connected with the differences between the used ground- and space-based datasets, including the systematic biases between the ground-based and space-based measurements, and with the different methods of the data assimilation. The effects of year-to-year wind variations and the longitudinal prevailing wind variability, as well as the effects of non-migrating tides in construction of the climatic empirical models is not so strong. The recommendation to construct a new and updated CIRA wind model for the MLT region has been followed.

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1. Historical review

Empirical wind models of the mesosphere/lower thermosphere (MLT) region play an important role in our understanding of governing mechanisms of general circulation in the MLT region, for study of the corresponding heat and momentum sinks and for analysis of the coupling of this regions with the above and below regions. From the first glance the problem of constructing of the MLT empirical wind models looks rather simple: the more data you accumulate, the more comprehensive the model should become. However diversity of the measurement techniques, temporal and spatial variability of the dynamical processes, non-uniform distribution of observational sites and difficulties in assimilation of the corresponding experimental data make this problem rather complex.

The first serious attempt to construct a global empirical MLT wind model was made by Groves (1969) by assimilation of the all available rocket and ground-based wind data for this height region. The used rocket wind data for technology reasons were almost entirely limited by night-time. The ground based meteor radar and ionospheric drift data (mainly meteor radar wind data) were collected from the 11 observational sites, 8 of which were located in the rather narrow NH latitudinal belt (50–56°N). The CIRA-72 (1972) prevailing (daily mean) wind model for height interval from 60 to 130 km were constructed by updating of the Groves (1969) model. Only minor changes were introduced as a result of an additional two years of data. When developing the CIRA-72 model the circulation structures in the Southern hemisphere (SH) were believed to be a mirror image of the NH wind systems for the corresponding season. The model was the first serious step in constructing

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wind models for the MLT (we will not discuss here some attempts to construct similar models, which were called Standard Atmospheres in the former USSR and USA, and which were not so widely distributed).

The CIRA-72 model was adopted by COSPAR and URSI, and accepted as providing the first impression concerning the MLT circulation and its seasonal variations. Moreover, it was shown that in many applications, this model gave reasonable and sufficient information about the global structure of the prevailing winds in the Northern hemisphere. It did show, correctly, the poleward/equatorward flows at mesopause heights for winter/summer months in the Northern hemisphere.

A further attempt to construct a global MLT wind model was made by Fleming et al. (1988). In that model, the zonal winds were calculated by applying the thermal (gradient) wind equation (which assume geostrophic motion) to the pressure field derived from temperature and density data. For the MLT region these data were derived by interpolation between the satellite remote sensing data by Barnett and Corney (1985) for the middle atmosphere and the mass-spectrometer and incoherent scatter data MSIS-83 empirical model (Hedin, 1987) for the thermosphere. The Fleming et al. (1990) model was extended to both hemispheres and covered the height interval from the ground to the thermosphere (0–120 km). However, the validity of the gradient wind approximation in the MLT region is questionable, and in practice the used by Fleming et al. temperature and pressure data sets contains virtually no direct temperature data from between 85 and 100 km. Nevertheless, this modeling activity (Fleming et al., 1990) was incorporated in the CIRA-86 volume as a supplementary model to the temperature, density and pressure CIRA-86 models. At that time the Fleming et al. (1990) model was considered as the most reliable and comprehensive upper atmosphere wind model available. The Fleming et al. (1988, 1990) model cannot been considered as a complete empirical model, because it was based on the thermal wind relationship and did not use a lot of empirical (radar meteor and MF) ground-based (GB) wind data. In addition, this model describes global-monthly distributions of zonal prevailing winds, but not meridional winds.

A set of observations known as an "interim new CIRA" contained a set of radar-derived direct wind measurements for 14 sites (Manson et al., 1985). These were extensively discussed (Manson et al., 1985), and much useful information about global wind structures in the MLT region was obtained. These corresponding data were also included in the CIRA-86 volume of Advances in Space Research, but formed no part of the formal CIRA-86 global wind model.

In Manson et al. (1991) comparisons between the gradient winds of the CIRA-86 and radar-derived winds were made. It was found that overall the agreement for the zonal winds at the particular observational sites was rather good, but only below 80 km. The comparison of meridional winds revealed significant ageostrophy, associated with poleward/equatorward flow at mesospheric height in winter/summer months.

An interesting attempt to develop a global height-latitude model of meridional winds was undertaken by Manson et al. (1987). However, due to insufficient data (the data obtained at nine sites were used) the authors only succeeded in constructing the height-latitude cross-sections of meridional wind fields for two months and for a limited range of observations in the both hemispheres.

For many years it was well recognized (since the first meteor radar measurements by Greenhow (1952)) that in the MLT region the amplitudes of the wind vary significantly on a diurnal basis and as a result the amplitudes of the diurnal and semidiurnal variations were comparable with that of the prevailing wind. So, a comprehensive MLT wind model would predict not only daily mean wind values, but also provide these tidal variations as a function of time within the day, and preferably for a comprehensive range of latitudes and for each month of the year. The only widely recognized model of this kind was the HWM-93 model (Hedin et al., 1996), which included the height interval 70–110 km. This analytical empirical horizontal wind model is based not only on a reworking of data included in the CIRA-86 tabulations, but also on selected rocket data, meteor radar and MF radar data. The spherical harmonic-Fourier expansion has been used to decompose the observed winds into mean winds, solar diurnal and semidiurnal tides and stationary planetary wave components, as well as annual and semi-annual variations in these fields. However, the data used for the construction of this model for the upper mesosphere/lower thermosphere region (80–110 km) were obtained at a limited number of stations.

The global prevailing zonal wind model, which was constructed by use of the UARS (WINDII) wind measurements (Wang et al., 1997) is very interesting. The model was constructed by using the nearly global wind data obtained from Doppler-shifts of the oxygen green-line airglow emission observed by WINDII (on the UARS satellite) between 90 and 120 km altitude. The model formulation is similar to that of HWM-93, as is discussed by Hedin et al. (1996).

An empirical climatic 2-D zonal and meridional prevailing wind model for the upper mesosphere/lower thermosphere (70–110 km), extending from 80°N to 80°S, was developed by Portnyagin and Solovjova (2000). The model was constructed from the fitting of monthly mean winds from meteor radar and MF radar measurements at more than 40 stations, well distributed over the globe.

Ground-based (GB) instruments have the obvious advantage of good time resolution, but are distributed sporadically over the globe. Space-based (SB) measurements offer global coverage, but poor time resolution at various points fixed on the earth. In order to deconvolve unambiguously the spatial and temporal characteristics of the dynamically evolving MLT circulation, it is becoming increasingly evident that the SB and GB measurements need to be assimilated together in some way. Recently,

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