Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 56 (2015) 1354–1365

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

# Climatological modeling of horizontal winds in the mesosphere and lower thermosphere over a mid-latitude station in China

Xin Yao [a,b,e], Tao Yu [c,d], Biqiang Zhao [a,b,*], You Yu [a,b], Libo Liu [a,b], Baiqi Ning [a,b], Weixing Wan [a,b]

[a] Key Laboratory of Earth and Planetary Physics, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China
[b] Beijing National Observatory of Space Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China
[c] Institute of Geophysics and Geomatics, China University of Geosciences, Wuhan, China
[d] National Center for Space Weather, China Meteorological Administration, Beijing, China
[e] University of Chinese Academy of Sciences, China

Received 20 February 2015; received in revised form 30 May 2015; accepted 22 June 2015
Available online 27 June 2015

**Abstract**

In this study, we employed the non-uniform rational B-splines surface technique to develop a provisional horizontal wind model of the mesosphere and lower thermosphere at altitudes of 87, 97, and 250 km over Kelan (38.7°N, 111.6°E) in China using Fabry–Perot interferometer (FPI) observations for the period between January 2012 and May 2014. We compared the meridional and zonal winds derived from the Kelan FPI wind model with those based on Meteor Radar wind observations at Beijing (39.92°N, 116.39°E), and those calculated from horizontal wind models, i.e., HWM93 and HWM07, at Kelan. Our analysis showed the following. (1) At 87 and 97 km, the Kelan FPI wind patterns exhibited strong annual variation in the meridional wind and semiannual variation in the zonal wind, as well as diurnal variation, which was dominated by a semidiurnal tidal variation in the meridional and zonal winds during May and September with a diurnal phase difference. The Kelan FPI wind patterns agreed well with the Meteor Radar winds and the HWM07 model results, but less well with the HWM93 model. (2) At 250 km, the FPI wind patterns agreed fairly well with the HWM93 results, where both indicated annual/diurnal variation in the meridional and zonal winds, and weak semidiurnal tidal variation. There were large discrepancies between the Kelan FPI winds and the HWM07 model results, which were mainly due to differences in the annual variation in the nighttime meridional wind. (3) The magnitude of the FPI winds was comparable to the HWM93 results but they were nearly 40–50% lower than the other winds, which is attributable to the inherent limitations of airglow measurement. Thus, this local empirical wind model could be used to investigate the climatological features of local ionospheric spatial–temporal variations.


*Keywords:* Fabry–Perot interferometer; Horizontal wind model; Thermosphere

## 1. Introduction

The features of the ionosphere and upper atmosphere depend mainly on dynamic processes in the thermosphere–ionosphere coupling system. Experimental and theoretical evidence suggests that neutral winds play a very important role in controlling the behavior of the ionospheric F-layer (e.g., Rishbeth (1972) and Titheridge (1995)), i.e., the movements of the ionospheric plasma are mainly influenced by the ion drag effects of neutral winds and the electrodynamic drift effect, due to the large scale electric field originating from the ionospheric wind dynamo in both the E and F regions, as well as the dissipation of gravity and pressure gradients.

* Corresponding author at: Key Laboratory of Earth and Planetary Physics, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China. Tel.: +86 010 82998310; fax: +86 010 62010846.
*E-mail address:* zbqjz@mail.iggcas.ac.cn (B. Zhao).

http://dx.doi.org/10.1016/j.asr.2015.06.026

To obtain neutral wind information, various ground-based and satellite-based instruments, such as the Incoherent Scatter Radar (ISR), Fabry–Perot interferometer (FPI), Medium-Frequency (MF) Radar/Meteor Radar, sounding rocket, and lidar, are used to make neutral wind observations of the middle and upper atmosphere, including the stratosphere and the mesosphere and lower thermosphere (MLT) regions (e.g., Salah and Holt (1974), Hays et al. (1981), Sipler et al. (1982, 1991), Meriwether et al. (1986), Hernandez et al. (1991), Shepherd (1993), Lilensten and Lathuillere (1995), Swinbank and Ortland (2003), and She et al. (2004)). These instruments can provide reliable measurements of in-situ neutral winds, but the measurements obtained are restricted to limited locations and periods due to the high costs of instruments and other reasons. Wind measurements can also be calculated from theoretical models, such as the horizontal wind model (HWM) and the NCAR/TIE-GCM model (e.g., Hedin et al. (1996), Drob et al. (2008), and Richmond et al. (1992)), where these models have no limitations in terms of locations and periods, but their results generally represent the average state.

Some parameterized semi-empirical and empirical wind models have been constructed based on various wind measurements to develop applications using advanced modeling techniques. In particular, HWMs are well-known parameterized global wind models of the lower and middle atmosphere, as well as comprehensive global empirical wind models of the thermosphere (Hedin et al., 1988, 1991, 1996; Drob et al., 2008). The HWM87 model is used for describing thermospheric winds above 220 km and it was derived from Atmospheric Explorer (AE-E) and Dynamics Explorer (DE 2) satellite observations without altitude dependency, although the data coverage was insufficient to parameterize solar cycle effects (Hedin et al., 1988). The HWM90 model incorporated ground-based FPI (~250 km), ISR (90–400 km) observations, and early MF Radar/Meteor Radar and rocketsonde data to extend HWM downward to 100 km, where the HWM90 includes height-dependent and solar cycle effects (Hedin et al., 1991). By including MF/Meteor Radar data (75–110 km), rocket and radiosonde database (20–100 km), and gradient winds derived from Committee on Space Research (COSPAR) International Reference Atmosphere (CIRA-86) tabulations, the HWM93 extended the HWM model to the ground (Hedin et al., 1996). For HWM07, the provisional successor of the HWM series mentioned above, Drob et al. (2008) revised and incorporated numerous ground- and satellite-based observational data sets in the HWM database, including an extensive thermospheric dataset from the Wind Imaging Interferometer (WINDII) onboard the Upper Atmosphere Research Satellite (UARS), the 557.7 nm O1S green line (90–300 km altitude during the day, 90–110 km at night) and the 630.0 nm O1D red line (daytime 125–300 km, nighttime 225–300 km), the UARS High Resolution Doppler Imager (HRDI) measurements (50–115 km), as well as some other ground-based MLT datasets. The HWM series has been utilized extensively in various atmospheric and space science research projects to explain climatological phenomena or for space weather prediction because it allows a trade-off between the use of pre-computed patterns and fully-coupled theoretical calculations (Drob et al., 2008). HWMs also have several limitations, the most obvious of which is the sparsity of the ground data used in the construction process, where most of the FPI and ISR observations included in the HWM database are relatively focused on American and European longitudes (Meriwether, 2006; Drob et al., 2008).

Neutral wind measurements of the middle and upper atmosphere have been carried out over China for a decade. A Meteor Radar chain of four stations was gradually established over several years along the 120°E meridian in the northern hemisphere by the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS). These radars are used for studying tidal structures in the upper atmospheric wind at altitudes of 80–100 km (Xiong et al. 2004; Zhao et al., 2005a,b; Yu et al., 2013). For the F-region wind, Liu et al. (2003a) developed a new approach to derive the vertical component equivalent wind (VEW) from ionosonde measurements, before investigating the climatology of VEW over Wuhan (114.4°E, 30.6°N) and then expanding it to global change (Liu et al., 2003b,c, 2004; Luan et al., 2004). Direct wind observations over China using a FPI system were first reported by Yuan et al. (2010). The Xinglong (40.2°N, 117.4°E) FPI is manufactured by the National Center for Atmospheric Research (NCAR) based on the design of the FPI at Resolute, Canada (Wu et al., 2004, 2005; Won et al., 2007). Yuan et al. (2013) studied the annual, semiannual, and terannual variations in the midnight winds based on the Xinglong FPI between April 2010 and July 2012, and found that the Xinglong FPI winds were much more consistent with HWM07 at heights of 87 km and 98 km than at 250 km.

Under the support of the China Meteorology Administration, another FPI system with a similar design to that at Resolute (Canada) was deployed at Kelan (38.7°N, 111.6°E, Fig. 1), which is about 400 km southwest from Beijing (Yu et al., 2014). Kelan is located in a semi-arid and cold region of the north central part of China at an altitude of 3 km. There are few rainy days throughout the year in this area, which makes it highly suitable for optical measurements. Since January 2011, the FPI has observed the nightglow continuously in the upper atmosphere under a clear sky and over 600 nights of data have been pooled. Yu et al. (2014) introduced the FPI operational mode and data process, and provided preliminary results based on the measurements, including comparisons with the HWM93 model. In this study, we performed a detailed quantitative investigation of the wind pattern by developing a climatological model over Kelan. The remainder of this paper is organized as follows. We describe the measurements database and mathematical formulations