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Observations and Simulations of Atmospheric Mean Winds in the Mesosphere and Lower Thermosphere over Langfang, China (39°N, 117°E): A Postprint

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Abstract

Using horizontal wind field observations from the meteor radar at Langfang station (39°N, 117°E) in China during the period from April 1, 2012 to March 31, 2013, we analyzed the variation patterns of mean zonal and meridional winds in the mesosphere and lower thermosphere (MLT, 80-100 km) over Langfang. The results indicate that both mean zonal and meridional winds exhibit pronounced seasonal variations. The mean zonal wind prevails as west wind in the MLT during winter, with its maximum located in the mesosphere, weakening with increasing altitude; in summer, the mesosphere features east wind while the lower thermosphere exhibits strong west wind, with the wind direction transition height at approximately 82 km; spring and autumn represent transitional phases between winter and summer characteristics. The mean meridional wind is dominated by south wind in winter and north wind in summer. Both mean zonal and meridional winds primarily display transitional characteristics during spring and autumn. The meteor radar observations are generally consistent with the climatic variation features simulated by the WACCM4 and HWM93 models. The WACCM4 model wind field is relatively large, whereas the HWM93 model wind field is relatively small.

Full Text

Observations and Simulations of the Mean Winds in the Mesosphere and Lower Thermosphere over Langfang, China (39°N, 117°E)

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Abstract

Using horizontal wind field observations from the meteor radar at Langfang Station (39°N, 117°E) in China between April 1, 2012 and March 31, 2013, this study analyzes the variation characteristics of mean zonal and meridional winds in the mesosphere and lower thermosphere (MLT, 80–100 km) over Langfang. The results reveal pronounced seasonal variations in both mean zonal and meridional winds. During winter, westward winds prevail throughout the MLT, with maximum values in the mesosphere that weaken with increasing altitude. In summer, eastward winds dominate the mesosphere while strong westward winds appear in the lower thermosphere, with the wind reversal occurring at approximately 82 km. Spring and autumn represent transitional phases between winter and summer characteristics. The mean meridional winds are primarily southward in winter and northward in summer. Both spring and autumn exhibit transitional features between seasons. The meteor radar observations are largely consistent with the climate variation characteristics simulated by the WACCM4 and HWM93 models, though WACCM4 overestimates wind speeds while HWM93 underestimates them.

Keywords: Meteor radar, Atmospheric mean wind field, Mesosphere and Lower Thermosphere (MLT), WACCM, HWM

1 Introduction

The mesosphere and lower thermosphere (MLT) region at 80–100 km altitude represents a transitional zone between the middle atmosphere and thermosphere, characterized by complex chemical and dynamical phenomena and processes. Atmospheric tides, gravity waves, and planetary waves play crucial roles in momentum and energy transport in the upper middle atmosphere, making this a key region for scientific research [1]–[3]. As a background field, the mean wind field significantly modulates the behavior of gravity waves, tides, and planetary waves, rendering the study of atmospheric wind structures and variation characteristics in the MLT region scientifically important for upper atmosphere research [4]–[6].

Current methods for detecting atmospheric winds in the MLT region include radio radar, lidar, sounding rockets, and satellites [7]–[11]. All-sky coherent radar has developed rapidly in recent years alongside advances in computational technology and meteor detection techniques [7], [8]. The National Space Science Center of the Chinese Academy of Sciences established the Langfang Station (39°N, 117°E) as China's first comprehensive near-space environment observation and research station. Among its key instruments is an all-sky meteor radar, which operates continuously regardless of weather conditions or diurnal cycles, providing extensive observational data for the near-space atmosphere and enabling in-depth investigation of MLT variation characteristics [9]. In addition to remote sensing observations, model simulation represents another important approach for studying wind field variations in the MLT region [5], [11]–[14]. The Whole Atmosphere Community Climate Model (WACCM) is a fully self-coupled numerical model covering the entire atmosphere, used to investigate tides, planetary waves, and gravity waves in the MLT region [5], [15], [16]. The Horizontal Wind Model (HWM) is an empirical atmospheric model for horizontal wind fields [17]. Together, observational data, WACCM, and HWM provide complementary perspectives for analyzing the seasonal variation characteristics of mean winds in the MLT.

For the Langfang MLT region, previous research utilized medium-frequency radar data to investigate mean wind and tidal variations during the summer of 2009 [11]. This paper employs one full year of meteor radar observations from April 1, 2012 to March 31, 2013 to examine the seasonal variation characteristics of mean atmospheric winds over Langfang, focusing on how the mean wind field varies with season and altitude to reveal the wind patterns over Langfang and enhance understanding of near-space atmospheric parameters in China' s mid-latitude region. Both WACCM4 and HWM93 models—numerical and empirical respectively—are widely used in scientific research. This study compares monthly mean wind fields from meteor radar observations with WACCM4 and HWM93 simulations.

2.1 Meteor Radar Observations and Data Analysis

The Langfang meteor radar is an all-sky interferometric meteor radar system. Its operational principle involves determining atmospheric wind speed and direction at meteor trail altitudes using Doppler shifts of very high frequency echo signals [18]. The system features a small footprint, compact control equipment, and high mobility, enabling redeployment for multi-site, all-weather ground-based observations. The main system parameters are listed in Table 1 .

The meteor radar has conducted routine observations in Langfang since July 2010, except under special circumstances. To ensure good data continuity, this study uses observations from April 1, 2012 to March 31, 2013, within the altitude range of 80–100 km. The data analysis procedure involves: first, averaging 24-hour wind field data to obtain daily mean winds, requiring at least 18 hours of hourly observations per day; then averaging daily means by month to obtain monthly mean winds, requiring at least 5 days of daily mean data per month. During the 365-day observation period, daily mean data were available for 279 days after processing. Missing data occurred primarily in summer; except for June, July, and August, all other months had more than 20 valid observation days.

2.2.1 WACCM Model

The Whole Atmosphere Community Climate Model (WACCM) is a fully coupled chemistry-climate numerical model developed by the National Center for Atmospheric Research (NCAR) [15]. WACCM4 extends the Community Atmosphere Model (CAM4) from the surface to the lower thermosphere at 145 km altitude (~4.5×10   hPa). The model provides horizontal resolutions of 4°×5° and 1.9°×2.5° (latitude × longitude). Vertically, it comprises 66 layers with variable resolution: approximately 1.1 km in the troposphere above the surface, 1.1–1.4 km in the lower stratosphere, 1.75 km at the stratopause, and about 3.5 km above 65 km. WACCM4 can simulate planetary waves and other large-scale disturbances, while small-scale perturbations such as orographic gravity waves, non-orographic gravity waves, and turbulence-like effects are parameterized [19]–[21].

WACCM4 is nested within the Community Earth System Model (CESM) framework, allowing configuration of relevant parameters for specific research questions. This study ran version CESM1.0.4 in F_2000_WACCM mode at 1.9°×2.5° horizontal resolution to simulate one year of atmospheric variations and obtain climatological wind field patterns.

2.2.2 HWM Model

The Horizontal Wind Model (HWM) is an empirical model series providing horizontal neutral wind fields. The first version, released in 1987 [22], provided wind data above 220 km. HWM90 subsequently incorporated ground-based incoherent scatter radar and Fabry-Perot interferometer observations, extending the altitude range to above 100 km [23]. HWM93 further expanded the wind data downward to the surface by incorporating medium-frequency and meteor radar observations [24]. Studies comparing HWM93 with medium-frequency and meteor radar data indicate that the model' s mean zonal winds are generally consistent with observations, though some differences exist in meridional winds [14], [17].

3.1 Variations of the Mean Atmospheric Wind Field

Figure 1 [Figure 1: see original paper] presents the temporal and altitudinal variations of daily mean zonal and meridional winds over Langfang in the MLT region. To analyze seasonal variation patterns in spring, summer, autumn, and winter, we examined one full year of wind observations from April 1, 2012 to March 31, 2013. In Figure 1, wind speeds are in m/s, with zonal winds representing east-west flow (westward positive, eastward negative) and meridional winds representing north-south flow (southward positive, northward negative). The solid black line denotes zero wind speed, and blank areas indicate missing data.

Figure 1(a) shows that during summer, eastward winds prevail in the mesosphere, decreasing with altitude before reversing to westward winds at approximately 82 km. The westward winds increase then gradually decrease with height, reaching a maximum of ~69 m/s near 94 km. These summer zonal wind characteristics are consistent with previous analyses using medium-frequency radar at the same station [11]. During autumn (September–November), westward winds dominate the mesosphere, first strengthening then weakening with altitude, with eastward winds appearing in the lower thermosphere. In winter (December–February), westward winds prevail in the mesosphere, reaching a maximum of ~71 m/s at 80 km, then weakening with altitude and showing alternating eastward and westward flows at upper levels. Spring (March–May) can be analyzed using data from March 2013 and April–May 2012. In March 2013, distinct eastward winds appear in the lower thermosphere, transitioning to strong westward winds by April 2012, while the strong winter westward winds in the mesosphere shift to eastward. Although March and April–May are from different years, the zero wind speed line shows a gradual downward shift, indicating continuous evolution. These analyses demonstrate that mean winds exhibit distinct winter and summer characteristics, with spring and autumn serving as transitional phases.

Figure 1(b) shows that meridional wind speeds are generally smaller than zonal wind speeds, with strong diurnal variations and significant seasonal patterns. During the winter half-year (October–March), southward winds dominate, peaking in the mesosphere and decreasing or even reversing with altitude. During the summer half-year (April–September), northward winds prevail.

Both zonal and meridional winds in Figure 1 exhibit pronounced diurnal variations, particularly the meridional wind with its prominent alternation between northward and southward flows, indicating significant wind field disturbances throughout the seasons over Langfang. These disturbances are widely believed to be associated with atmospheric transient planetary wave activities with periods of 6.5 and 16 days [11], [25].

Figure 1 Variations of daily mean winds observed by meteor radar at Langfang Station from April 1, 2012 to March 31, 2013. (a) Zonal winds, contour interval 5 m/s; (b) Meridional winds, contour interval 2.5 m/s. The solid black line denotes zero wind speed.

3.2 Comparison Between Observations and Models

To better compare observational data with model simulations and extract seasonal variation characteristics, monthly mean zonal and meridional winds were calculated from the daily mean data in Figure 1, as shown in Figure 2 Figure 2: see original paper and Figure 2(a).

Figure 2(b) presents the seasonal variation of monthly mean zonal winds over Langfang simulated by WACCM4. The simulation shows westward winds prevailing in winter throughout the 80–100 km range, eastward winds below 82 km in summer transitioning to westward winds above 82 km, and weaker winds in spring and autumn representing transitional seasons. The variations exhibit primarily annual and semi-annual cycles. Compared with meteor radar observations in Figure 2(a), WACCM4 captures the main seasonal variation characteristics, though simulated zonal wind speeds are relatively larger with some differences in local details. The most significant discrepancies occur in spring and autumn. The numerical simulation shows weak westward winds during these transitional seasons, representing annual minima. In contrast, observed zonal winds exhibit a tongue-like eastward structure in spring, with eastward winds above 95 km in March and below ~85 km in April–May. During autumn, observed westward winds are stronger, with a secondary annual maximum in October exceeding winds in November and December. Extracting semi-annual cycles would thus reveal substantial differences between model and observations. Additionally, the simulated strong winter westward winds in the mesosphere are ~10 m/s higher than observed, with the simulated westward maximum at ~82 km versus the observed maximum below 80 km. In summer, the simulated westward maximum in the lower thermosphere is ~10 m/s higher than observed, occurring at ~98 km compared to ~92 km in the observations.

For reference, Figure 2(c) shows the seasonal variation of monthly mean zonal winds simulated by HWM93. The overall structural features are similar to observations and WACCM4 simulations, but wind speeds are generally smaller, underestimating observations by 10–20 m/s in extreme regions. The spring structure resembles observations more closely, while the autumn pattern is more similar to WACCM4 results. The smaller wind speeds in HWM93 primarily reflect its nature as a climatological model based on multi-year statistical data [24].

Comprehensive comparison of Figures 2(a), (b), and (c) reveals that the largest differences among meteor radar observations, WACCM4 simulations, and HWM93 results occur in autumn, where observations show a westward maximum in October unlike the simulations. This discrepancy may result from data gaps in the first 10 days of October during the transition from eastward to westward winds, or may represent local characteristics of the Langfang region in 2012.

Compared with observations at other latitudes [14], [25], [26], Langfang' s mean zonal winds show similar seasonal and altitudinal variation patterns with slight local differences. The summer mesopause wind reversal from eastward to westward occurs at ~80 km near 30°N [14], [25] and ~90 km at high latitudes [26]. For Langfang (39°N), the reversal height is ~82 km, consistent with URAP (UARS Reference Atmosphere Project) and WACCM4 results showing the summer zonal wind reversal height tilting poleward with increasing altitude [15].

Figure 2 Seasonal variations of monthly mean zonal winds over Langfang from April 1, 2012 to March 31, 2013. (a) Meteor radar, (b) WACCM4 model, (c) HWM93 model, contour interval 5 m/s. The thick black line denotes zero wind speed.

For meridional winds, Figure 2(a) similarly presents the seasonal and altitudinal variations of monthly mean meridional winds from meteor radar, with WACCM4 and HWM93 results shown in Figures 2(b) and 2(c), respectively. The comparison reveals significant seasonal variations in MLT meridional winds, with northward winds in summer, southward winds in winter, and transitional wind direction changes in spring and autumn. Monthly mean meridional wind speeds from meteor radar are ~5 m/s smaller than WACCM4 simulations but ~5 m/s larger than HWM93 values. Local detail differences appear mainly in April and November–December. In April, observations show northward winds while WACCM4 shows southward winds. In November, observations show northward winds at ~88 km while WACCM4 shows southward winds. In December, observations show southward winds at ~90 km while WACCM4 shows northward winds. Differences with HWM93 also exist, primarily in the 94–100 km range where structural features are essentially reversed in winter and summer.

The comparison demonstrates that WACCM4 and HWM93 capture the main seasonal variation characteristics of monthly mean winds, though WACCM4 overestimates wind speeds while HWM93 underestimates them. It should be noted that the meteor radar observations cover only slightly more than one year, with relatively small statistical samples in some months, particularly June-August. Long-term accumulated data would better characterize climatological features. WACCM4 could potentially achieve better agreement with observations by adjusting gravity wave parameterization processes and lower boundary forcing to alter circulation structures and analyze underlying dynamical mechanisms. As HWM93 represents multi-year climatological features, incorporating more observational data from China could improve the model results.

Figure 3 Seasonal variations of monthly mean meridional winds over Langfang from April 1, 2012 to March 31, 2013. (a) Meteor radar, (b) WACCM4 model, (c) HWM93 model, contour interval 2.5 m/s. The thick black line denotes zero wind speed.

4 Conclusions

Using observational data from the meteor radar at Langfang Station (39°N, 117°E), this study analyzed variations of mean zonal and meridional winds in the mesosphere and lower thermosphere over Langfang, revealing seasonal variation characteristics and comparing them with WACCM4 numerical simulations and HWM93 model results. The main findings are:

1. The mean wind field over Langfang exhibits significant seasonal variation. Zonal winds are westward throughout the MLT in winter, weakening and even reversing with increasing altitude. In summer, eastward winds dominate the mesosphere while westward winds prevail in the lower thermosphere, with a reversal height at ~82 km. Spring and autumn are transitional seasons, with a tongue-like eastward structure in spring. Meridional winds are primarily northward in summer and southward in winter.

2. Daily mean zonal and meridional winds show strong diurnal variations throughout all seasons, particularly the meridional wind with its prominent alternation between northward and southward flows, primarily resulting from disturbances by atmospheric transient planetary waves.
3. WACCM4 and HWM93 simulations of monthly mean zonal and meridional winds over Langfang are consistent with meteor radar observations in their main variation characteristics, though with some local detail differences. WACCM4 overestimates wind speeds by ~10 m/s for zonal winds and ~5 m/s for meridional winds, while HWM93 underestimates them by ~10 m/s for zonal winds and ~5 m/s for meridional winds.

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References

[1] Smith A K. Global dynamics of the MLT. Surveys in Geophysics, 2012, 33(6): 1177–1230.

[2] Wan Weixing, Xu Jiyao. Recent investigation on the coupling between the ionosphere and upper atmosphere. Science China: Earth Sciences, 44(9): 1863–1883, in Chinese (万卫星, 徐寄遥. 2014. 中国高层大气与电离层耦合研究进展. 中国科学: 地球科学, 44(9): 1863–1883).

[3] Zhao Lei, Chen Jinsong, Ding Zonghua, et al. First observations of tidal oscillations by an MF radar over Kunming (25.6°N, 103.8°E). J. Atmos. Sol. Terr. Phys., 2012, 78: 44–52.

[4] Lu Xian, Liu A Z, Swenson G R, et al. Gravity wave propagation and dissipation from the stratosphere to the lower thermosphere. J. Geophys. Res., 2009, 114, D11101.

[5] Lu Xian, Liu A Z, Oberheide J, et al. Seasonal variability of the diurnal tide in the mesosphere and lower thermosphere over Maui, Hawaii (20.7°N, 156.3°W). J. Geophys. Res., 2011, 116, D17103.

[6] Limpasuvan V, Richter J H, Orsolini Y J, et al. The roles of planetary and gravity waves during a major stratospheric sudden warming as characterized in WACCM. J. Atmos. Sol. Terr. Phys., 2012, 78: 84–98.

[7] Wen Yi, Chen Jinsong, Ma Chunbo, Li Na, Zhao Zhenwei. Observation of upper atmospheric temperature by Kunming all-sky meteor radar. Chinese J. Geophys., 2014, 57(8): 2433–2432, in Chinese (易稳, 陈金松, 马春波, 李娜, 赵振维. 昆明全天空流星雷达观测中高层大气温度. 地球物理学报, 2014, 57(8): 2433–2432).

[8] Xiong Jiangang, Wan Weixing, Ning Baiqi, Liu Libo. Meteor radar observation of circulation near mesopause over Wuhan. Chin. Sci. Bull., 2003, 48(10): 1102–1106, in Chinese (熊建刚, 万卫星, 宁百齐, 刘立波. 武汉上空中层顶附近大气环流的流星雷达观测. 科学通报, 2003, 48(10): 1102–1106).

[9] Xiao Cunying, Hu Xiong, Xu Qingchen. Response of mesosphere and lower thermosphere wind over mid-latitude to the 2013 major sudden stratospheric warming event. In General Assembly and Scientific Symposium (URSI GASS), 2014, XXXIth URSI (pp. 1-4).

[10] Chen Hongbin. An overview of the space-based observations for upper atmospheric research, 2009, 24(3): 229–241, in Chinese (陈洪滨. 中高层大气研究的空间探测. 地球科学进展, 2009, 24(3): 229–241).

[11] Xiao Cunying, Hu Xiong, Smith A K, et al. Short-term variability and summer-2009 averages of the mean wind and tides in the mesosphere and lower thermosphere over Langfang, China (39.4°N, 116.7°E). J. Atmos. Sol. Terr. Phys., 2013, 92: 65–77.

[12] Xu X, Manson A H, Meek C E, et al. Mesospheric wind semidiurnal tides within the Canadian Middle Atmosphere Model Data Assimilation System. J. Geophys. Res., 2011, 116(D17).

[13] Davis R N, Du J, Smith A K, Ward W E, Mitchell N J. The diurnal and semidiurnal tides over Ascension Island (8°S, 14°W) and their interaction with the stratospheric quasi-biennial oscillation: studies with meteor radar, eCMAM and WACCM. Atmos. Chem. Phys., 2013, 13: 9543–9564.

[14] Xiao Cunying, Hu Xiong, Zhang Xunxie, et al. Interpretation of the mesospheric and lower thermospheric mean winds observed by MF radar at about 30°N with the 2D-SOCRATES model. Advances in Space Research, 2007, 39(8): 1267–1277.

[15] Richter J H, Sassi F, Garcia R R, et al. Dynamics of the middle atmosphere as simulated by the Whole Atmosphere Community Climate Model, version 3 (WACCM3). J. Geophys. Res., 2008, 113(D8).

[16] Lu Xian, Liu Hanli, Liu A Z, et al. Momentum budget of the migrating diurnal tide in the Whole Atmosphere Community Climate Model at vernal equinox. J. Geophys. Res., 2012, 117(D7).

[17] Andrioli V F, Clemesha B R, Batista P P, Schuch N J. Atmospheric tides and mean winds in the meteor region over Santa Maria (29.71°S, 53.81°W). J. Atmos. Sol. Terr. Phys., 2009, 71: 1864–1876.

[18] Hocking W K, Fuller B, Vandepeer B. Real-time determination of meteor-related parameters utilizing modern digital technology. J. Atmos. Sol. Terr. Phys., 2001, 63(2–3): 155–169.

[19] Garcia R R, Marsh D R, Kinnison D E, Boville B A, Sassi F. Simulation of secular trends in the middle atmosphere. J. Geophys. Res., 2007, 112, D09301.

[20] Richter J H, Sassi F, Garcia R R. Towards a physically based gravity wave source parameterization. J. Atmos. Sci., 2010, 67: 136–156.

[21] Beres J H, Garcia R R, Boville B A, Sassi F. Implementation of a gravity wave source spectrum parameterization dependent on the properties of convection in the Whole Atmosphere Community Climate Model (WACCM). J. Geophys. Res., 2005, 110, D10108.

[22] Hedin A E, Spencer N W, Killeen T L. Empirical global model of upper thermosphere winds based on atmosphere and dynamics explorer satellite data. J. Geophys. Res., 1988, 93(A9): 9959–9978.

[23] Hedin A E, et al. Revised global model of thermosphere winds using satellite and ground-based observations. J. Geophys. Res., 1991, 96(A5): 7657–7688.

[24] 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 upper middle and lower atmosphere. J. Atmos. Sol. Terr. Phys., 1996, 58: 1421–1447.

[25] Zhang Dongya, Hu Xiong, Zhang Xunxie, Wu Xiaocheng, K. Igarashi. Observations of the mesospheric and lower thermospheric mean winds at 30°N with MF radars. Chin. J. Space Sci., 2005, 25(4): 267–272, in Chinese (张冬娅, 胡雄, 张训械, 吴小成, K. Igarashi. 北纬 30°N 中间层和低热层大气平均风中频雷达观测. 空间科学学报, 2005, 25(4): 267–272).

[26] Kishore P, Namboothiri S P, Igarashi K, Murayama Y, Watkins B J. MF radar observations of mean winds and tides over Poker Flat, Alaska (65.11°N, 147.51°W). Annals of Geophysics, 2002, 20: 679–690.

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