Longitudinal difference in total electron content over the East Asian region: feature and explanation

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Abstract

The mechanism of the longitudinal difference of ionospheric electron density is in general attributed to the thermospheric wind effect modulated by the local geomagnetic declination. Although this mechanism is tested in many case studies, there are other possible factors such as solar activity and so on which still need further investigations. In this paper, TEC data from two Chinese GPS stations located at almost same geographic latitudes but with a wide longitude span ($\sim 38^\circ$) are used to study the morphological features of longitudinal differences under various geophysical conditions. A parameter R_{ew} is defined as a normalized measure of the TEC difference between the two stations. All the observed temporal variations of R_{ew} are analyzed statistically, with the results showing that negative east-west differences (Western TEC > Eastern TEC) in the noontime are pronounced during Day of Year (DoY) 90-270, while nighttime positive differences (Western TEC < Eastern TEC) are around DoY 60-90, and 270-300. All above observed features are examined by the dynamic effect of thermospheric wind using the HWM07 model. The results show that although the zonal wind does play an important role on average, it is not sufficient to explain all the observed features, the longitude dependence of the meridian wind must be considered. Finally, we observed a new feature characterized by the summer nighttime positive value in R_{ew} which could be related to a Midlatitude Summer Night Anomaly (MSNA) phenomenon. So, it is also concluded that besides the thermospheric wind effect, other mechanisms such as the longitudinal dependence of the plasmaspheric downward flux should also be taken into consideration in explaining the longitudinal differences in the ionosphere.

Keywords: Ionospheric longitudinal difference; TEC; Thermospheric wind effect

1. Introduction

32 Over the last few decades, longitudinal variations in the ionosphere and thermosphere have
33 received extensive attentions in the aeronomy community. In the low latitude and equatorial regions,
34 the well-known wavenumber 4 (WN4) structure (Immel et al., 2006; Hagan et al., 2007) in the
35 longitudinal variations of a number of ionospheric and thermospheric parameters, has been attributed
36 to be mainly associated with upward propagation of the nonmigrating atmospheric tides, which
37 modify the electric fields to produce longitudinal variations in the equatorial fountain effect. At
38 midlatitudes, another notable longitude variation in the ionosphere was named the Weddell Sea
39 anomaly (WSA). The WSA is an unusual nighttime enhancement of electron density in summer
40 which was found in the region around the Weddell Sea and Antarctic Peninsula (Penndorf, 1965;
41 Horvath and Essex, 2003; He et al., 2009; Jee et al., 2009). Later, this nighttime electron density
42 enhancement was also observed in the middle latitude of the northern hemisphere named the
43 Midlatitude Summer Nighttime Anomaly (MSNA) or Summer Evening Anomalies (SEAs) (Lin et al.,
44 2009; Thampi et al., 2009; Liu et al., 2010; Burns et al., 2011).

45 More recently, Zhang et al. (2011) reported a new finding of pronounced longitudinal variations
46 in midlatitude total electron content (TEC) over the continental US manifested as an east-west coast
47 difference with distinct diurnal and seasonal dependencies characterized by a higher east coast TEC
48 in the evening and vice versa in the morning. It has been suggested that these longitudinal variations
49 in ionospheric TEC at midlatitudes are dominated by the longitudinal differences in geomagnetic
50 declination combined with the effect of thermospheric zonal wind, which is analogous to the
51 physical mechanisms proposed for the Weddell Sea Anomaly (WSA) (Luan et al., 2008; Jee et al.,
52 2009; He et al., 2009; Ren et al., 2012). This declination-zonal wind mechanism was further tested
53 by a comprehensive investigation of both electron density longitudinal variations and the nighttime

thermospheric zonal winds retrieved from the Fabry-Perot interferometer measurements database in the eastern US, and the results successfully show that the observed zonal wind climatology is consistent with the east-west electron density variations in terms of local time, season, and solar cycle dependency (Zhang et al., 2012a). In fact, the east-west electron density difference differs from the MSNA features as follows: (1) The MSNA is primarily an evening enhancement in plasma density, while the newly found longitudinal variation shows a daily variation. (2) The MSNA occurs more evidently in summer; the longitudinal differences occur persistently in all seasons (Zhang et al., 2012b).

East-west longitude differences in the F-region ionospheric electron density not only appear in the North America region, but also exist in other areas with similar geomagnetic configurations. Then it is important to determine the similarities and differences among various regions, which will benefit from the clarification of the dominant factor controlling the regional ionospheric variability. Zhao et al. (2013) examined the climatology of the F2-region peak electron density (N_mF_2), electron density (N_e) of different altitudes with longitudinal separation in the Far East region based on 3 pairs of ground ionosondes and satellite measurements. The results showed that the east-west differences over the Far East region display clear diurnal variation features, as seen in the US, but they differ in seasonal and solar activity dependence. By analyzing differences of the midlatitude ionospheric TEC in the east and west sides of North America, South America and Oceania based on a ground GPS receiver network, Xu et al. (2013) revealed that the east-west differences mainly depend on local time and less depend on season and the level of solar activity.

Empirical Orthogonal Functions (EOF) analysis from the contribution of the variance shows that the variation of the east-west difference is a significant ionospheric variability feature, which is

76 more prominent than the well-known midlatitude phenomena, winter anomaly. This is instructive for
77 regional ionospheric modeling (Zhang et al., 2013; Chen et al., 2015). Therefore, in this study, we
78 carry out an analysis on the east-west ionospheric difference in the East Asian region based on the
79 TEC data over northern China, which is different from the peak value of F2-region (NmF2) that has
80 been used by Zhao et al. (2013). Furthermore, we will focus on the possible causes of the
81 climatology variation of the east-west difference in northern China to understand the mechanism that
82 could be responsible for the east-west difference seen in ionospheric TEC.

83 **2. Observation**

84 The data used for deriving TEC are the raw GPS data in the receiver-independent exchange
85 format with 30s sampling rate. To examine the effects of solar activity, data are taken for high
86 activity years of 2001-2002 and low activity years of 2007-2008 from two Chinese GPS stations
87 located in northern China. These two stations are the east one at Changchun (geographic latitude
88 43.8°; geographic longitude 125.3°; magnetic inclination 60.1°; magnetic declination -7.9°) and the
89 west one at Urumqi (43.7°; 87.6°; 62.3°; 2.3°), which locates in the same latitudes and are separated
90 by a longitudinal span of about 40°. The data are collected by GPS receivers affiliated with the
91 Crustal Movement Observation Network of China (CMONOC). The type of the receiver at
92 Changchun (Chan) is ASHTECH Z-XII3 (2002), ASHTECH UZ-12 (2007), and the type of the
93 receiver at Urumqi (Urum) is AOA SNR 800 ACT (2002, 2007). All the receivers are operated in the
94 semi-codeless tracking mode. The GPS measurements from these receivers are consistent, including
95 the carrier phases and pseudorange measurements of GPS L1 and L2 frequencies.

96 Dual frequency GPS observation provides a relative time delay of electromagnetic wave at the
97 two frequencies traveling through the dispersive ionosphere. The TEC along the line of sight can be

98 derived from this delay (Lanyi and Roth, 1988). Based upon the derived TEC data, the studies of the
99 ionospheric disturbances have been reported frequently (Calais and Minster, 1995; Ho et al., 1996;
100 Saito et al., 1998; Zhang and Xiao, 2005; Huang and Yuan, 2014; Shuai et al., 2014; Jia et al., 2015;
101 Shi et al., 2015). The vertical TEC derivation method in this study was developed by the Peking
102 University. The characteristics of this method are described as follows: Firstly, this method is for
103 calculating the vertical TEC from single GPS site observations. Secondly, the absolute TEC data are
104 calculated by combining the carrier phase and pseudorange measurements of GPS dual-frequency
105 according to the method by Mannucci et al. (1998). Thirdly, the instrumental bias of satellites and
106 receiver are estimated by combining the SCORE (Lunt et al., 1999), and Ma and Maruyama (2003)
107 methods. The ionospheric shell height is assumed to be 400 km, and the cutoff elevation is 25
108 degrees (e.g. Zhang et al., 2010).

109 **3. Results**

110 **3.1 Seasonal variation of diurnal TEC at Changchun and Urumqi**

111 The vertical TEC at each site is obtained by averaging the vertical TEC data from all GPS
112 satellites with an elevation angle larger than 45 degrees for each observing epoch (30 seconds). Then,
113 the hourly TEC is obtained by averaging the TEC in one hour. Considering possible effects of any
114 sudden disturbances localized at one region could bias one receiver over another (like mid-latitude
115 tongues of ionization observed by Foster et al., (2005)), only the periods of daily mean $K_p < 3$ are
116 used, which removes the effect of geomagnetic activity while ensuring sufficient sample numbers for
117 statistics. Fig. 1a illustrates the diurnal variations of the monthly mean TEC in equinoctial and
118 solstitial months at Changchun(CC) and Urumqi(WM) during the high solar activity year of 2002.
119 From March equinox to December solstics, there are 26, 29, 24 and 22 days of data counted. The

120 variation range of 10.7 cm solar flux index (f107) of the counted days for each month is labeled in
121 each subplot. It can be seen that f107 varies with considerable magnitude during these months. This
122 to a large extent can explain day-to-day variability of ionospheric TEC as illustrated in the standard
123 deviation (σ) plotted as error bars above and below the diurnal average.

124 For convenience, an index R_{ew} is defined to represent the east-west difference based on the
125 procedure of Zhang et al. (2011) as $R_{ew} = (TEC_{CC} - TEC_{WM}) / (0.5 \times (TEC_{CC} + TEC_{WM}))$. The blue empty
126 circle expresses the absolute TEC difference $\Delta TEC = TEC_{CC} - TEC_{WM}$ while the red dot denotes the
127 east-west difference index R_{ew} . The corresponding range of f107 and monthly mean Kp is also
128 labeled in the bracket beside the month. Fig. 1a shows that during the daytime (08:00-18:00 LT) the
129 TEC at WM is higher than that at CC, which is most obvious in June and September, less in March
130 and least in December. Daytime minimum ΔTEC values are -7.68, -11.21, -6.55 and -1.95 TECU
131 respectively, and minimum R_{ew} values are -0.24, -0.28, -0.09 and -0.07. At night, TEC is obviously
132 higher at CC than at WM in March, while less in the other seasons. Nighttime maximum ΔTEC
133 values are 6.08, 0.86, 1.89 and 1.78 TECU respectively, and maximum R_{ew} approach 0.29, 0.04,
134 0.12 and 0.14.

135 Fig. 1b presents the diurnal variations of the monthly mean TEC in equinoctial and solstitial
136 months at CC and WM during the low solar activity year of 2007. For each month, f107 varies with a
137 much smaller magnitude than during 2002. From March equinox to December solstice the day
138 numbers with daily mean $Kp < 3$ are 28, 29, 27 and 28. The overall geomagnetic activity is quiet as
139 most of the daily mean Kp is around 1.0. It is shown from the figure that during the daytime TEC at
140 WM is higher than that at CC, this phenomenon is also obvious in June and September, but the
141 magnitude is much smaller compared to the year with high solar activity. Daytime minimum ΔTEC

values are -1.87 and -2.34 TECU, and minimum R_{ew} approach -0.11 and -0.18. There is no east-west difference in March and December during the daytime. At night, TEC is also higher at CC than at WM. This is most evident in March and June, with nighttime maximum Δ TEC being 1.89 and 2.53 TECU, and maximum R_{ew} approaching 0.18 and 0.25. Comparison between the results of year 2002 and 2007 indicates that the daytime magnitude of R_{ew} has a clear positive correlation with solar activity, while the nighttime R_{ew} in March and September does not show such a clear dependence. Also in December 2007, R_{ew} shows a totally negative value during the entire nighttime with the minimum approaching -0.2, which indicates that the nighttime TEC at WM is higher than that at CC.

3.2 Local time and Day of Year (DoY) variation in R_{ew}

To understand more details in how R_{ew} changes with local time, season and solar activity, we calculate R_{ew} for every single day for the year of 2001, 2002, 2007 and 2008. Since R_{ew} has large day-to-day variability and data gaps occur (~40 days a year), data smoothing has been employed to suppress the fluctuations and discontinuity. First, we perform a 31-day smooth mean for R_{ew} of each local time independently and then for each day a 3-hour smooth mean is employed. After the processes above, the climatology characteristics of R_{ew} are well illustrated as shown in Figs. 2a and 2b for periods of 2001-2002, 2007-2008. The upper panel of Fig. 2a shows that the negative R_{ew} in 2001 is most significant (~-0.45) during DoY 120-150 and lasts for nearly the entire daytime. Another daytime minimum appears around DoY 210 but is much smaller and appears only around 09:00-12:00 LT. The negative R_{ew} in 2002 is relatively pronounced around DoY 170-190 and 240-270, which shows a different pattern from that in 2001. Furthermore, we have noticed that in the nighttime during the periods of DoY 0-30 and 330-360 R_{ew} show a notable negative value, which indicates that the west TEC is higher than the east one during the winter nighttime for the high solar

164 activity year.

165 The positive R_{ew} in 2001 mainly appears around DoY 80-110 and 270-300 during the nighttime
166 at 21:00-06:00 LT. This equinoctial pattern also occurs in year 2002 but less significantly.
167 Furthermore, there is another maximum around DoY 30, which can also be identified in the year
168 2002. During summer seasons of DoY 150-240 at night, R_{ew} has a small positive value of 0.1
169 compared to the equinoctial value for both 2001 and 2002.

170 As shown in Fig. 2b, for the low solar activity years of 2007 and 2008, the distribution patterns
171 of both the positive and negative R_{ew} are largely resemble that shown in the years of 2001 and 2002,
172 but the magnitude is smaller. One different feature is that the nighttime positive R_{ew} during the
173 period of DoY 120-210 is larger for 2007 and comparable for 2008 to the equinoctial value of R_{ew} .
174 Furthermore, the winter nighttime negative value for the low solar activity year is also seen in Fig.
175 1b.

176 **4. Possible explanation for the climatology feature of R_{ew}**

177 It has been reported that the midlatitude east-west difference in NmF2 over East Asia is mainly
178 due to the difference of local magnetic declination that leads to the plasma drifting upward and
179 downward across the zero declination longitude under the effect of thermospheric zonal wind (Zhang
180 et al., 2012; Zhao et al., 2013). The upward/downward field aligned drifts move the ions to
181 higher/lower altitudes where their recombination rates are smaller/larger and thus increase/decrease
182 the F-region plasma density (Rishbeth, 1998). This mechanism well captures the diurnal variation of
183 the reverse R_{ew} observed during the daytime and nighttime in the month of June as an example (Zhao
184 et al., 2013). However, the LT and DoY distribution in R_{ew} for a whole year has not yet been
185 understood. Here we investigate whether the zonal wind effect can explain the yearly and seasonal

186 variation in R_{ew} described in the above section or other additional contributing factors should be
187 introduced.

188 It has been pointed out that the altitude distribution of the pronounced daytime (12:00 LT)
189 negative R_{ew} mainly concentrates at 270–450 km and nighttime (20:00 LT) positive R_{ew} at 270-400
190 km (Zhao et al., 2013). We therefore use the geomagnetic field and neutral wind parameters at
191 300km over the year of 2002 to calculate the ion drift caused by neutral winds. Here we define V_{dz}
192 (positive for upward drift), the vertical component of the field aligned ion drift caused by the
193 thermospheric zonal wind. It is obtained by $-U_e \sin D \cos I \sin I$, where D and I are the geomagnetic
194 declination and inclination derived from the 11th generation of International Geomagnetic Reference
195 Field (IGRF) and U_e is the zonal wind (positive for eastward). Thus the difference in V_{dz} between
196 CC and WM can be expressed as ΔV_{dz} defined as $V_{\text{dz}_{\text{cc}}} - V_{\text{dz}_{\text{wm}}}$. The vertical component of the field
197 aligned ion drift caused by the thermospheric meridional wind, V_{dm} , is defined by $-U_n \cos D \cos I \sin I$
198 with U_n the meridional wind (positive for northward). Hence, the difference in V_{dm} between CC and
199 WM can be expressed as ΔV_{dm} . The combined effect is ΔV_{d} defined as $\Delta V_{\text{dz}} + \Delta V_{\text{dm}}$.

200 To obtain U_e , the Horizontal Wind Model (HWM), a well-known empirical global wind model
201 of the upper thermosphere, is used. HWM has undergone several upgrades incorporating
202 Atmospheric Explorer (AE-E), Dynamics Explorer (DE2), Wind Imaging Interferometer (WINDII)
203 satellite observation, ground-based FPI, ISR observation, MF Radar/Meteor Radar, radiosonde data,
204 and gradient wind derived from International Reference Atmosphere (CIRA-86) tabulations and
205 becomes the present version HWM07 (Hedin et al., 1988, 1991, 1996; Drob et al., 2008). HWM has
206 been extensively utilized in atmosphere and space sciences researches for explaining the climatology
207 phenomena or space weather prediction as it provides a balance between pre-computed pattern and a

208 full coupled theoretical calculation (Drob et al., 2008). Here, we use the U.S. Naval Research
209 Laboratory HWM routine to calculate the meridional and zonal components of the wind under
210 magnetically quiet conditions.

211 Fig. 3 from top to bottom illustrates the LT and DoY variation of ΔV_{dz} , ΔV_{dm} , and their
212 combined effect with thermospheric wind derived from HWM07. It is shown that large negative
213 ΔV_{dz} , $\leq -6\text{m/s}$, occurs during DoY 60-270 and 06:00-10:00 LT. This pattern matches well with the
214 distribution of a large negative value of R_{ew} appearing in Figs. 2a and 2b in the years of 2001-2002
215 and 2007-2008. The minimum R_{ew} lags the minimum ΔV_{dz} by about 1-2 hours which mainly appears
216 during 08:00-12:00 LT. The delay is due to the time that is needed for the ionosphere to drift for
217 several tens of kilometers and the recombination process due to the elevation of the F-layer to take
218 effect. However, the pattern fails to reproduce the minimum R_{ew} during DoY 120-150 and 240-270.
219 The pattern predicts $\geq 4\text{m/s}$ and $\geq 2\text{m/s}$ nighttime enhancement in ΔV_{dz} at DoY 240-365 and 0-90
220 during 18:00-24:00 LT and 00:00-03:00 LT. The distribution of nighttime positive ΔV_{dz} shows
221 equinoctial asymmetry represented by large values of $\geq 6\text{m/s}$ for 19:00-23:00 LT and $\geq 4\text{m/s}$ for
222 00:00-02:00 LT appearing in DoY 250-300. The distribution of nighttime positive ΔV_{dz} generally
223 agrees with the distribution of nighttime positive R_{ew} (≥ 0.1) appearing in DoY 30-120 and DoY
224 240-330. However, the nighttime positive R_{ew} during some days and local time has a larger value
225 than that in the other periods. This is illustrated in Fig 2a around DoY 80-100 and DoY 270-300
226 during 00:00-06:00 LT for 2001 and 2002. Similar feature appears during 2007 and 2008 although
227 the nighttime enhancement of R_{ew} is not as large as that for the high solar activity year shown in Fig
228 2b. This feature also exists in the NmF2 changes as illustrated in Fig. 3 of Zhao et al. (2013). This
229 local time enhancement pattern in R_{ew} is well reproduced in the distribution of ΔV_{dm} showing larger

230 positive values of 5 m/s and 10 m/s around DoY 90 and DoY 270-300 during 00:00-03:00 LT as seen
231 in the second panel of Fig. 3. The superimposed ΔV_{dz} and ΔV_{dm} effect ΔV_d shown in the bottom
232 panel of Fig. 3 maximizes the summer daytime negative value and equinoctial nighttime positive
233 value, which captures the seasonal variation of positive R_{ew} fairly well as illustrated in Figs. 2a and
234 2b. The daytime negative value generally varies from -10 m/s to -25 m/s and nighttime positive value
235 can be from 5 m/s to 15 m/s.

236 So far we have compared the distribution of R_{ew} in TEC with the difference of the vertical
237 component of the field aligned ion drift caused by the thermospheric wind. They have very positive
238 correlation which is understandable that loss of ions due to recombination into neutral species occurs
239 most rapidly at the lower altitudes. Since the parameter TEC is an integration of the height profile of
240 the electron density, it is necessary to give a quantitative explanation on how much TEC could be
241 affected by the change of vertical drift. This process was recently done by David et al. (2016) by
242 investigating the influence of the neutral wind variability on the accuracy of ionospheric modeling
243 and forecasting. Using the three-dimensional physics-based Time Dependent Ionospheric Model
244 (TDIM) of Utah State University (Sojka et al., 2013), they give a quantitative relationship between
245 the uncertainty in the meridional component of the horizontal neutral wind ($\Delta Wind$) and the
246 uncertainty in the simulated TEC values (ΔTEC). In their test at the location of Millstone Hill (42°N,
247 288°E), an enhancement of poleward meridional wind of 38.4 m/s for 3 hours would cause a 26%
248 reduction in TEC during the daytime at 11:00-14:00 LT, while a 40 m/s equatorward wind produces a
249 27% enhancement in TEC during 23:00-02:00 LT. Their results are relevant to our study as the 38 to
250 40 m/s meridional wind corresponds to 16 m/s upward drift at latitude where Changchun and Urumqi
251 stations are. Compared the above values with the ΔV_d shown in the Fig.3 and R_{ew} of TEC shown in

252 Fig. 2, we can find a reasonable quantitative relationship between the distribution of R_{ew} in TEC and
253 the difference of the vertical component of the field aligned ion drift caused by the thermospheric
254 wind. For example ΔV_d is -20m/s during DoY 150~210 while R_{ew} is ~ -0.25 in 2002, and 10m/s
255 during DoY 270~300 while R_{ew} is ~ 0.18 in 2001.

256 From the above results, we can see that the climatology features of R_{ew} are well described by the
257 thermospheric wind from HWM07. Thus, there are two main potential causes of the excess or
258 reduced TEC at one station vs. the other. One is the variation in thermospheric neutral winds due to
259 climatological effects that can force vertical motion and therefore a change in recombination rate
260 resulting in a change in TEC. The other is the change in the magnetic field configuration for the two
261 stations due to the tilted dipole, which affects the vertical speed. The analysis in Fig. 3 includes both
262 of the causes, the thermospheric wind variation and the different magnetic field configuration.
263 However, both zonal and meridional effects are considered in the above analysis, we are still
264 interested in distinguishing the individual effects of these two components of the thermospheric wind.
265 The thermospheric zonal wind and geomagnetic declination effects have been used to explain the
266 east-west differences of American east and west coast areas (Zhang et al., 2011). Is it also the main
267 factor to cause the east-west differences in the East Asian region? Furthermore, it is also interesting
268 to check the potential role of longitudinal difference of local thermospheric wind between these two
269 stations. For this purpose, we calculated the LT and DoY variation of ΔV_{dz} , ΔV_{dm} , and their
270 combined effect with thermospheric wind derived from HWM07 but with the same diurnal
271 thermospheric wind at CC and WM. The results are shown in Fig. 4. The pattern of negative ΔV_{dz}
272 still resembles that of Fig. 3. However, the nighttime equinoctial enhancement is significantly
273 reduced as illustrated in both the distributions of ΔV_{dm} and ΔV_d shown in the middle and bottom

panels of Fig. 4. Furthermore, the magnitudes of both the positive and negative values of ΔV_d are largely reduced compared with those shown in the bottom panel of Fig. 3. This indicates that when modeling the R_{ew} in the Asia sector, both zonal and meridian components play an important role and an accurate local wind model must be used.

The above results also show that the thermospheric wind mechanism alone can not entirely explain the summer nighttime enhancement in R_{ew} shown in the year of 2007 around DoY 150-180. The summer nighttime positive value in R_{ew} is due to the WSA or MSNA appearing at $\sim 135^\circ\text{E}$ geographic longitude at 18:00-24:00 LT over the Northeast Asia (Lin et al., 2010). Chen et al. (2011) theoretically investigated the formation of the MSNA, and pointed out that although the equatorward neutral wind is the critical driver for the formation of WSA, the plasmaspheric downward flux provides the plasma source after 22:00 LT which maintains the intensity of the WSA density structure. Thus the east-west difference here could also be related to the longitude difference in the plasmaspheric downward flux. It is shown that the summer nighttime positive value in R_{ew} is more significant during the low solar activity year of 2007 than in high solar activity years. This agrees well with the fact that the MSNA index is negatively correlated with solar activity in Chen et al. (2012). It is proposed that the solar activity variation of the MSNA index is caused by the combined effect of the vertical plasma drift induced by the neutral wind and photoionization at night (Chen et al., 2012). The ionization-uplift effect has a negative solar activity dependence. This is because the neutral wind velocity during the nighttime at midlatitude is higher for the low solar activity period but lower for the high solar activity period (Kawamura et al., 2000). Faster equatorward neutral wind could produce stronger vertical plasma drift and then result in higher electron density in the ionosphere at midlatitudes. Finally, we noticed that the winter nighttime negative R_{ew} distributed

around DoY 330-30 which is evident for the year 2001, 2007 and weak in 2002 and 2008 (also appear in NmF2). This feature cannot be fully explained by the current distribution of ΔV_{dz} and ΔV_{dm} .

5. Summary

The present study focuses on the longitudinal east-west differences in ionospheric TEC observed over northern China, specifically the climatology of the east-west difference index, R_{ew} . The patterns of east-west asymmetry in TEC basically resemble those of NmF2 reported before (Zhao et al., 2013), based on the comprehensive analysis of 4 years of GPS data. The results indicate that the negative east-west differences (Western TEC > Eastern TEC) at noon are pronounced during DoY 90-270, while the nighttime positive differences (Western TEC < Eastern TEC) are around DoY 60-90, 270-300. The observed climatological variations of R_{ew} are examined by the dynamic effects of the thermospheric winds using HWM07. The results show that thermospheric zonal winds alone cannot explain the DoY variations of all the R_{ew} features. The longitude dependence of the meridional winds should also be taken into account, especially in explaining the nighttime equinoctial enhancement of R_{ew} . Besides, HWM07 cannot describe the daytime pronounced negative R_{ew} around DoY 120-150 and 240-270 and winter nighttime negative R_{ew} . This is understood that HWM has several limitations, in which the most evident one is the sparse ground-based data used. Most FPI and ISR observations are relatively concentrated in American and European longitudes while extremely limited at other longitudes (Meriwether et al., 2006). Recent local wind model from FPI wind measurement over northern China has shown that there exists considerable difference in the nighttime climatology of the thermospheric wind between the local observations and HWM (Yao

et al., 2015). The summer nighttime positive R_{ew} could possibly be explained by other mechanisms, such as the longitude dependence of the plasmaspheric downward flux. At the same time some new issues arise, for example, the winter nighttime negative value appearing in R_{ew} , the day-to-day variability and magnetic storm effect between WM and CC, all of which needs a detailed study in the future.

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Fig. 1a. Local time (LT) variation of the monthly mean TEC at Changchun (CC) (green) and Urumqi (WM) (magenta) in March, June, September and December during year 2002. The standard deviation (σ) plotted as error bar around average. The blue empty circle denotes Δ TEC (CC-WM) while the red dot refers to the east-west differential index R_{ew} . The minimum and maximum 10.7 cm solar radio fluxes of each month are labeled on the top of each panel. The numbers 0.4 and -0.4 on the right side of the right two plots denote the scale of R_{ew} .

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Fig. 1b. Same as Fig. 1a but for year 2007.

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Fig. 2a. 31-day smooth mean R_{ew} for TEC as a function of DoY vs. LT during high solar activity years of 2001-2002.

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Fig. 2b. Same as Fig. 2a but during low solar activity years of 2007-2008.

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Fig. 3. The upper panel illustrates the DoY< variation of ΔV_{dz} , difference in the vertical component of the field-aligned ion drift produced by the thermospheric zonal wind between Changchun and Urumqi. The middle panel presents the similar variation in ΔV_{dm} produced by the meridional wind, and bottom panel shows their combined effect (ΔV_d). Thermospheric wind is derived from HWM07.

Fig. 4. Same as Fig. 3 but with the same diurnal thermospheric wind variation calculated at Changchun and Urumqi. Thermospheric wind is derived from HWM07.