Comparative Analysis of Geomagnetic Field and GPS-TEC Variations for Middle-latitude and Arctic Regions

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Abstract— We present the results of comparative analysis of geomagnetic field and total electron content (TEC) variations. The analysis is based on the long series of data from the Siberian GPS network of the Institute of solar-terrestrial physics (ISTP) of Siberian Brunch of Russian Academy of Science (SB RAS) and Norilsk GPS station operated by the Geophysics Service of RAS (GS RAS.) ISTP SB RAS Siberian network makes continuous TEC measurements since 2012 and provides TEC-variation data with time resolution of 1 sec. The calculation of TEC is based on two-frequency phase measurements of GPS receivers. We analyzed TEC variations in two period ranges (0–10 min and 10–40 min), which are correspond to different types of ionospheric disturbances. Magnetic intensity data were obtained from ISTP SB RAS observatories and INTERMAGNET sites. The common level of TEC disturbance is estimated by the index of the TEC-variation intensity Wtec. The index is calculated for all available GPS satellites with the highest elevation angle at every moment. This method allows to investigate continuous variations of TEC disturbances intensity. The Wtec was calculated for all the GPS data 2013. The Wtec dynamics features are revealed for different times of day, seasons and levels of geomagnetic activity for middle-latitude and Arctic regions. The response of the Wtec to sudden storm commencements (SSC) was also investigated.

1. INTRODUCTION

Modern global navigation satellite systems (GNSS) GPS and GLONASS with wide networks of ground receivers is a unique instrument for monitoring the Earth's upper atmosphere. Space distribution of "receiver-satellite" rays during a day for only one GNSS receiver provide ionosphere observation in radius of 500–1000 km. However length of GNSS-provided continuous total electron content (TEC) series is restricted by satellite observation time (2–6 h). Such limitation obstructs investigation of long-term TEC variations connected with processes in Earth's magnetosphere and caused by solar wind via magnetic storms and sub-storms [1–3]. But in Arctic region such type of processes exactly influence ionospheric plasma dynamics. The method permitting calculation continuous TEC variations intensity investigation by single GNSS-station measurements is worked out in the Institute of solar-terrestrial physics of Siberian Brunch of Russian Academy of Science (ISTP SB RAS) [4]. Moreover, ISTP SB RAS actively develop Siberian network of GPS/GLONASS stations which should increase ionospheric monitoring potential in Siberia.

Abilities of Siberian GNSS network and new data processing method allow us to carry out comparative analysis of geomagnetic field and total electron content variations for middle-latitude and Arctic regions.

2. DATA AND PROCESSING METHODS

Analysis of the common level of TEC disturbance in 2013 is made for high- and middle-latitudes. Data in middle-latitudes are obtained from the Siberian GPS/GLONASS network of ISTP SB RAS. This network makes continuous TEC measurements since 2012 and provides TEC-variation data with time resolution of 1 sec. We used data from GPS/GLONASS stations ORDA (ISTP SB RAS observatory in Usolie-Sibirskoe city), LIST (ISTP SB RAS observatory in Listvyanka village), MOND (ISTP SB RAS observatory in Mondy village), UZUR (ISTP SB RAS observatory in Uzur village). Data in high latitudes are obtained from GNSS station NRIL operated by the Geophysics Service of RAS (GS RAS) and located in Norilsk Integrated Magnetic-Ionospheric Station (69.4°N, 88.2°E) of ISTP SB RAS.

The TEC calculation is based on two-frequency phase measurements of GPS receivers. We analyzed TEC variations in two period ranges (01–10 min and 01–40 min), which are correspond to medium (MS) and large scale (LS) traveling ionospheric disturbances (TIDs). MS TIDs and LS TIDs should be associated with acoustic and gravity modes of atmospheric oscillations, respectively.

The common level of TEC disturbance was estimated by the index Wtec(t) of the TEC variation intensity. We calculated Wtec(t) index for all available GPS satellites with elevation angles $> 5°$. First of all we filtered initial TEC series I(t) in period ranges 01-10 min and 01-40 min, using a moving average method. Then for each filtered TEC series dI(t) the module A(t) of amplitude of TEC oscillations was computed. At a final stage we defined the intensity Wtec(t) of TEC variations as averaged A(t) over all "satellite-receiver" lines of sight (LOS). Since GPS satellites are observed in various intervals of time, sharp leaps may occur in averaged data on borders of time series from different satellites when simple averaging of data is used. So we utilized the procedure of A(t) weighed averaging for all observed satellites. The described procedure of Wtec(t) calculation allows us to obtain a continuous averaged series of TEC variation intensity filtered in the chosen period range, with any duration. The sampling rate of averaged TEC series is determined by sampling rate of GPS observations.

The Wtec(t) behavior was compared with geomagnetic field variations, obtained from ISTP SB RAS magnetic station IRKT included in the INTERMAGNET network, and with behavior of geomagnetic Dst, Kp, AE indexes (http://wdc.kugi.kyoto-u.ac.jp/wdc/Sec3.html). The Dst, Kp indexes are estimated from equatorial and middle-latitude magnetic observatories data, respectively. As a first approximation the DST is supposed to be a variation of a ring current field. Perturbation in Earth's magnetic field is considered as a magnetic storm when the Dst index falls lower than -50 nT, and Kp exceeds 4. For calculation of the high-latitude AE index, magnetograms from the observatories located on auroral and sub-auroral latitudes are used. The AE index characterizes fluctuations of a magnetic field connected with auroral zone currents (the auroral electrojet) and is the indicator of sub-storm activity.

3. RESULTS AND DISCUSSION

We calculated Wtec(t) for both high- and middle-latitude regions and analysed correlation between them and magnetic AE, Dst, Kp indexes for every month of 2013. Variations of Wtec(t), AE(t), Dst(t), Kp(t) in March, June, September and December of 2013 are presented in Fig. 1. Fig. 2 shows diurnal-seasonal Wtec(t) variations in high- and middle-latitude regions for two period ranges: 01–10 min and 01–40 min. TEC data are presented on Figs. 1 and 2 obtained on NRIL, ORDA and MOND GNSS stations.

The intensity of LS variations (periods $\sim$ 40 min) is higher than of MS ones ($\sim$ 10 min). In high-latitude region LS and MS TID minimal intensities are about 0.12 TECU and 0.02 TECU, respectively. Minimal intensity level does not depend on season. Most pronounced diurnal variations are in March-April and September-October. Diurnal variations are more intense for MS disturbances (Figs. 1, 2). Diurnal Wtec variations are connected with NRIL Arctic circle location. Polar day and polar night last there about several weeks: from 30 November till 13 January and from 19 May till 25 July, respectively.

In middle-latitude region disturbance minimal intensity has certain seasonal variations. In winter, it is about 0.006 TECU for MS TIDs and 0.03 TECU for LS TIDs, in summer, it rises to 0.01 TECU and 0.07 TECU, respectively. Diurnal variations of Wtec(t) intensity have also some seasonal features. In the summer, the disturbances are more intense at the beginning and the end of the day, whereas in all the other seasons it is higher in the middle of the day. It is also interesting that daytime Wtec(t) level increases in the end of 2013 in both period ranges (Figs. 1(d), 2(d)). In October intensity increases and high values (0.05–0.06 TECU for MS TIDs; 0.2–0.3 TECU for LS TIDs) persist till the end of the year.

Black lines in Fig. 2(d) mark the sunrise moments at 100 km and 300 km over the station MOND. One can see that solar terminator (ST) generates intense LS disturbances. MS TIDs caused by terminator are not observed (Fig. 2(d)). Presented in Figs. 2(c), (d) Wtec(t) variations are obtained using MOND data, but all the other middle-latitudinal stations demonstrates the same picture. Our results is in a good agreement with [5], where it was shown that in middle-latitudes ST generates ionospheric disturbances with periods T more than 15 min, and disturbances with $T < 10$ min are not presented. These allow us to conclude that solar terminator generates gravity waves ($T > 10$ min [3]) and does not generate acoustic ones ($T < 10$ min [3]). In Arctic region (NRIL station, Figs. 2(a), (b) ST-caused disturbances are absent in Wtec(t) variations of both period ranges.

Magnetic storm influence on disturbances intensity is different for high- and middle-latitude regions. High-latitude ionosphere is naturally more sensitive to magnetic field disturbances.

TEC disturbances intensity on NRIL station is significantly increases (up to 10-15 times) during

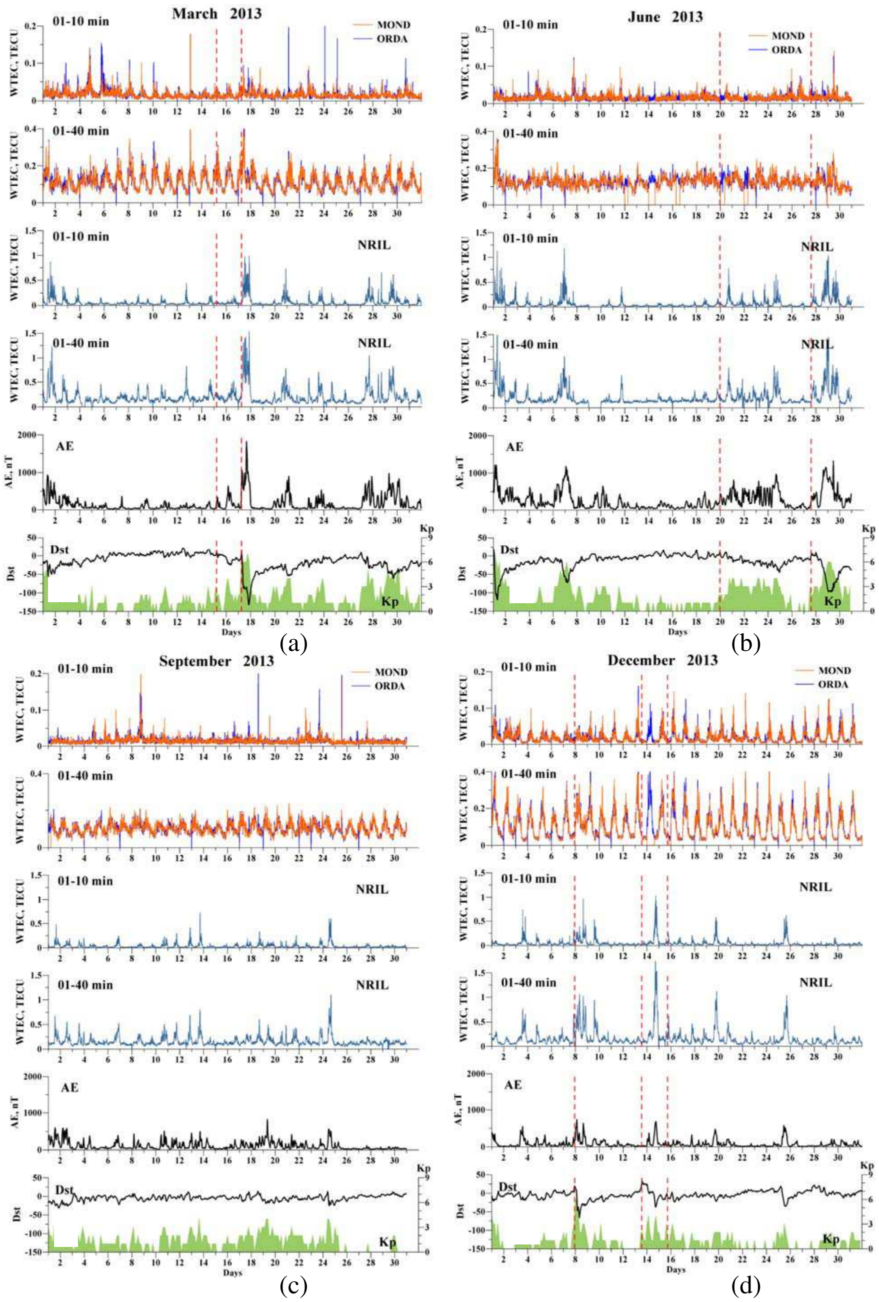

Figure 1: The TEC disturbance variations Wtec(t) in two period ranges (01–10 min, 01–40 min) at NRIL, MOND, ORDA stations and behavior of Dst, Kp, AE geomagnetic indexes in March (a), June (b), September (c), December (d), 2013. The vertical dashed lines indicate sudden storm commencements (SSC).

geomagnetic storms (Fig. 1). Consistency between variations of Wtec(t) and magnetic indexes Dst and Kp in this periods is also quite clear. In other periods correlation is much lower because Kp and Dst represent magnetic field dynamics in equatorial- and middle-latitudes. At the same time there is high correlation between Wtec(t) and high-latitude AE index (correlation coefficient is 0.6–0.8). Wtec(t) dependence on magnetic field fluctuations is prevailing in high-latitudes; it overrides diurnal Wtec(t) variations (Figs. 1, 2).

Wtec(t) response to magnetic field variations is less pronounced in middle latitudes. Some correlation is observed during strong magnetic storms with big falls of Dst index values. Diurnal LS TID intensity in such periods increases approximately twice. Most pronounced response is

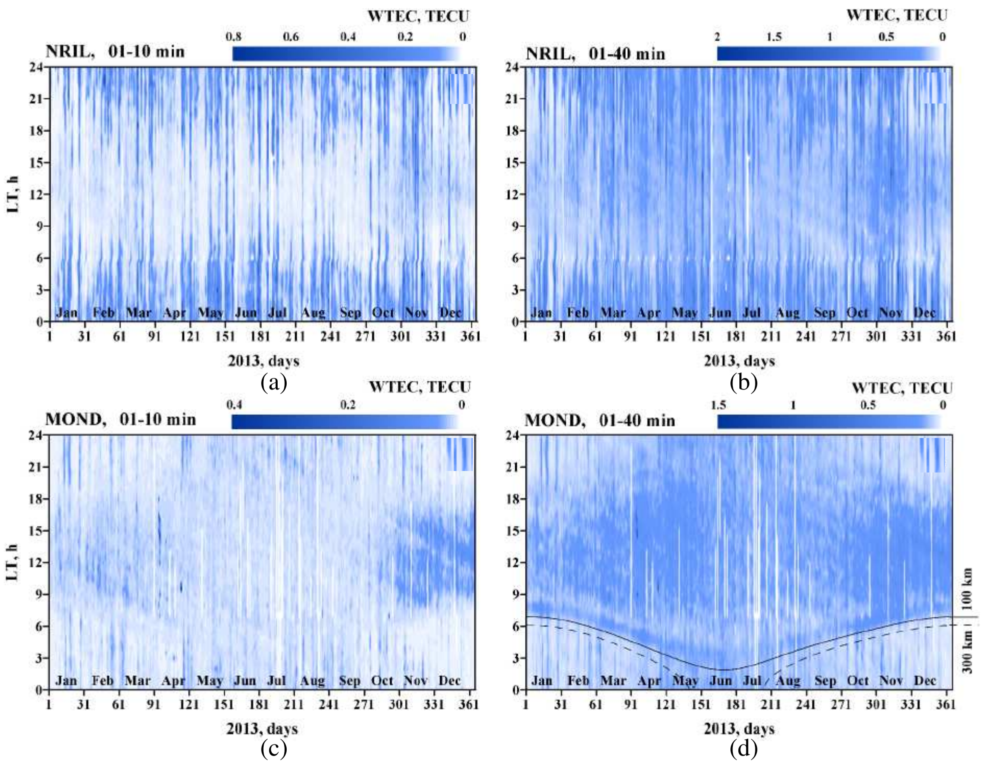

Figure 2: Diurnal-seasonal Wtec(t) variations in period ranges of 01–10 min (a), (c) and 01–40 min (b), (d) at NRIL (a), (b) and MOND (c), (d) stations. Vertical axes are given in local time LT. For NRIL station $LT = UT + 6\,\text{h}$. For MOND station $LT = UT + 7\,\text{h}$. Black lines mark sunrise time at 100 km (solid line) and 300 km (dashed line).

observed in the middle of March and in the beginning of June. Apparently it is because of GNSS stations were on a illuminated side of Earth in these cases. MS TID intensity does not have any significant response to geomagnetic variations.

4. CONCLUSIONS

Analysis of the common level of TEC disturbance in two period ranges (01–10 min and 01–40 min) during 2013 was made using data from middle-latitude Siberian GPS/GLONASS network of ISTP SB RAS and high-latitude NRIL GNSS station located near Norilsk city. The common level of TEC disturbance is estimated by the index Wtec(t) of the TEC-variation intensity.

In Arctic region (NRIL station) minimal intensity level is not depend on season. Minimal intensity is about 0.12 TECU and 0.02 TECU for LS TIDs (periods ~ 40 min) and MS TIDs (periods ~ 10 min), respectively. In the middle-latitude region minimal disturbance intensity changes over year. In winter it is about 0.006 TECU for MS disturbances and 0.03 TECU for LS ones, in summer it rises up to 0.01 TECU and 0.07 TECU, respectively. Diurnal variations are more intense for MS disturbances. In high latitudes strong Wtec(t) dependence on magnetic field fluctuations (which is represented by the AE index) overrides diurnal variations of TEC perturbation. Wtec(t) correlation with the Dst and Kp indexes is evident only during the magnetic storms having planetary character. TEC disturbances intensity on NRIL station rises up to 10–15 times during geomagnetic storms.

In middle latitudes diurnal Wtec(t) variations are strongly pronounced over the year and have also some seasonal features. In the summer the disturbances are more intense at the beginning and the end of the day, whereas in all the other seasons its are higher in the middle of the day. Intensity of LS and MS disturbances increase in October and high values persist till the end of the year. During strong magnetic storms, the average daily level of LS TID intensity increases and correlates with the Kp index changes.

It is revealed that in middle latitudes solar terminator generates intense LS TIDs and doesn't cause MS TIDs, which is in a good agreement with [5]. Obtained results allow us to conclude that ST generates gravity waves ($T > 10$ min) and does not generate acoustic ones ($T < 10$ min). In

Arctic region ST-caused disturbances are absent.

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