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# OCCURRENCE OF THE MAIN IONOSPHERIC TROUGH IN GPS/GLONASS TEC MEASUREMENTS

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**Abstract.** For analyses of the trough occurrence in TEC the latitudinal profiles formed from TEC maps over Europe have been used. GPS/GLONASS observations collected by International European Permanent Network (EPN) were used to create TEC maps. More than 180 stations from Europe were included in the analysis. The large number of GPS stations in Europe provides good coverage for GPS data and enable high-accuracy TEC maps with a temporal resolution of 5 min. The profiles were created with resolution of 1° at fixed longitude of 20°E in latitudinal range 40-74°N. We analyzed the dynamics of trough minima location for winter (December 2015), equinox (March 2015) and summer (June, 2015) and accordingly storm days December 20, March 17 and June 22, 2015. During winter and equinox storms the trough is registered at latitudes of 47-52° N.

**Introduction.** The middle-latitude ionospheric trough is the main and dominant scale structure, which is identified in F region of the ionosphere [*Muldrew*, 1965]. The spatial structure of the trough is presented as the latitudinal narrow and longitudinal extended depletion in the electron distribution. A theory and mechanisms of the trough formation were discussed in *Moffett and Quegan* [1983] and *Rodger et al.* [1992]. The trough dominates in winter conditions and is regularly detected in evening and night hours. The occurrence of the trough is essentially differ in varied longitudinal sectors [*Deminov et al*., 1992; *Karpachev et al.*, 1996]. The trough was studied by employing different methods using satellite and ground observations [*Tulunay and Grebowsky*, 1978; *Grebowsky et al*., 1983; *Whalen*, 1989; *Werner and Prolss*, 1997]. The numerous investigations concerned the occurrence of the trough in F2 region of the ionosphere. The occurrence of the trough in TEC has been studied in details and for northern hemisphere by *Ciraolo and Spalla* [1998] and *Pryse et al.* [1993]. Recently the studies of structures and dynamics of the TEC trough were undertaken by *Pryse et al*. [2006], using radio transmission from new satellites of the Navy Ionospheric Monitoring System. The trough influences HF as well as the transionospheric radio wave propagation [*Chernouss et al*., 2015]. Strong latitudinal gradients were already associated with the trough by *Wielgosz et al.* [2004]. As known, the severe horizontal TEC gradients can hamper the ambiguity resolution and influence on the accuracy of the GPS positioning [*Wanninger*, 1993; *Wielgosz et al*., 2005]. In these studies we present the analysis of the structure and dynamics of the TEC trough over Europe for winter, equinox and summer conditions including strong storms of December 20, March 17 and June 22, 2015.

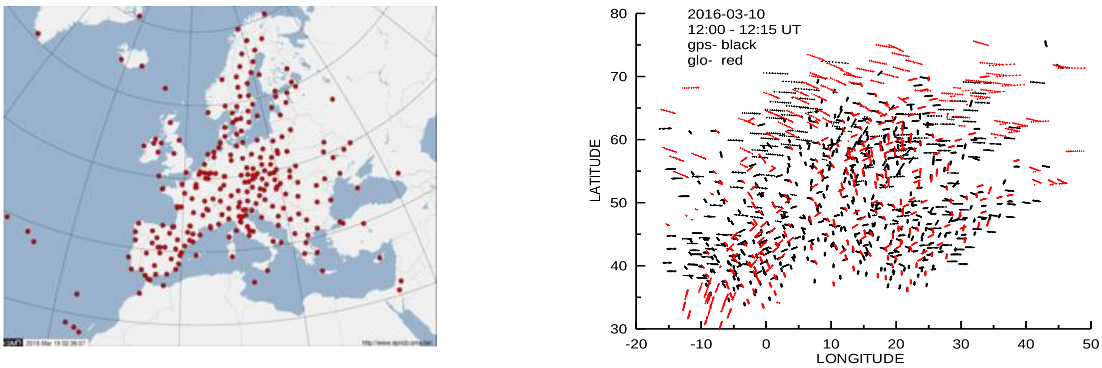


**Figure 1.** Map of GPS/GLONASS stations, which are used in map generation over Europe (*left panel*). Spatial distribution of GPS/GLONASS measurements over European region with 15 minutes interval (*right panel*).

## Data and estimation technique

The GPS and GLONASS observations of 150-200 European Permanent Network (EPN) stations were used to create TEC maps (Fig. 1). The dense GPS/GLONASS stations provided high TEC resolution over Europe. In Fig. 1 (right panel) the spatial distribution of TEC measurements over Europe are presented. In order to obtain the spatial and temporal variation of TEC and to create TEC maps, the measurements were fitted to a spherical harmonic expansion in a geographic latitude (Φ) and longitude (Θ). The TEC maps provide a spatial resolution of 100-300 km and a time resolution of 5 min [*Shagimuratov et al*., 2015, 2016]. The trough structure was recognized from latitudinal profiles which were obtained from TEC maps. The profiles were created with resolution of 1° at fixed longitude of 20° E. An automatic procedure was developed to identify the trough signatures.

## Occurrence of trough during December 2015

Fig. 1 presents geophysical condition (Dst index) for December 2015. The storm started after 17 UT of 19 December. The strong storm with values of Kp and Dst peaks of up to 7 and 155nT was observed.

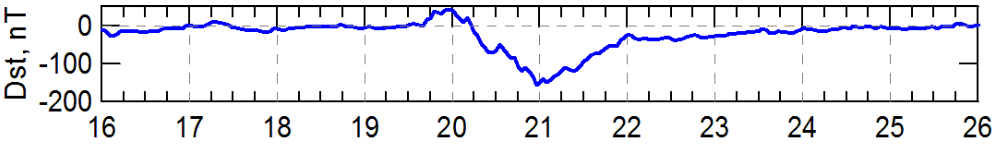


**Figure 2.** Dst variation for 16-26 December 2015.

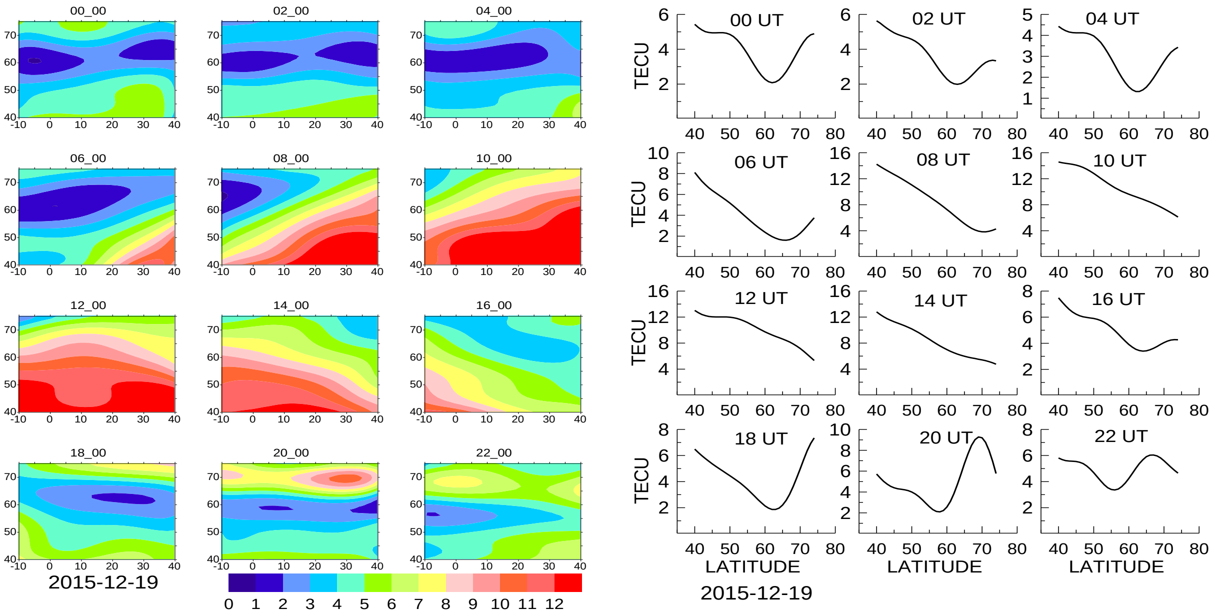


**Figure 3.** The TEC maps over Europe and latitudinal profiles at 20° E for 19 December 2015.

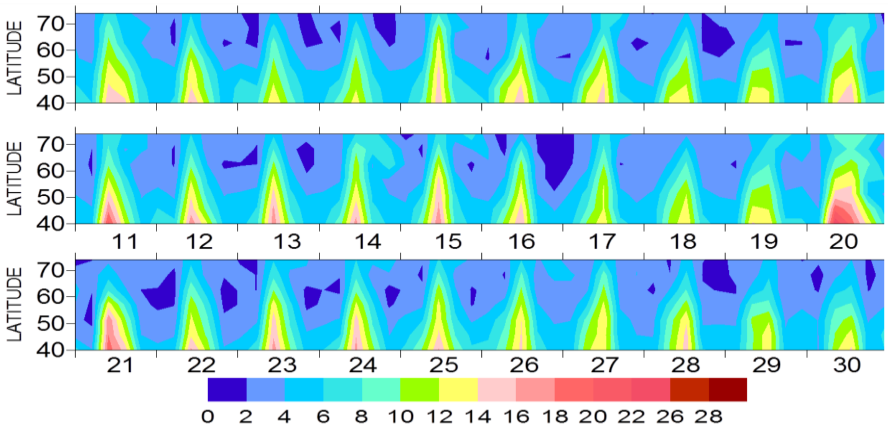


**Figure 4.** Day by day dynamics of latitudinal profiles over Europe during December 2015.

As shown in Fig. 3, the trough structure is very well recognized on TEC maps in morning and evening hours. The trough signatures are demonstrated on latitudinal profiles as the minimum values of TEC with well defined equatorial and polar walls. The deepest of trough minima is observed during time interval of 00-06 UT. The time develop of

TEC trough is coordinated with another observations and it demonstrate local time dependence. As seen, latitudinal profiles shown the lowest location of trough was near 55°N.

Fig. 4 shows the behavior of dynamics of latitudinal profiles during 20 December. During storm day of 20 December the positive effect is observed. The picture shows that profiles are very variable in night time. In winter conditions the trough structure can see every day.

For quiet days the average location of trough minima was obtained. The location of the trough minima in the storm day of 20 December is lower than during the quiet period (Fig. 5, left). During storm day, the sharp decrease of TEC, which was associated with the trough, was observed in daytime. In evening hours the trough was recognized at the latitudes lower than 50° N. It is known that the trough location is essentially depending on geomagnetic activity. The variation of the trough location with Kp is shown in Fig. 5 (right)

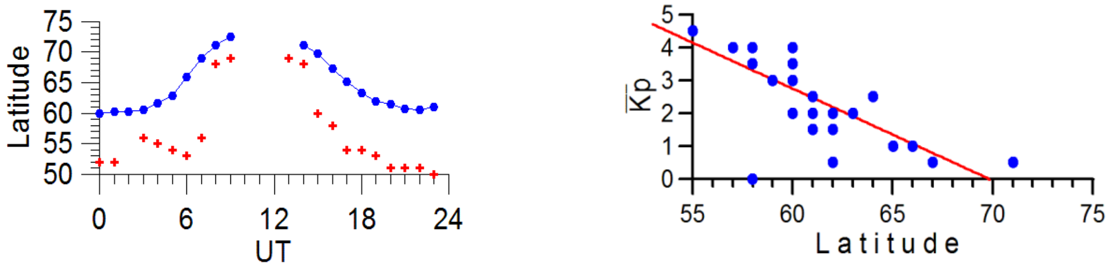


**Figure 5.** Latitudinal location of trough over Europe at 20° E for storm day of 20 December (*dots*) and the average(*cross*) for December 2015(*right*), Scatter plot of latitudinal location of trough vs Kp for 19 UT December 2015. The red line shows a linear fit to the data.

## Occurrence of trough during March 2015

In fig.6 the behavior dynamics of latitudinal profiles for March is presented. Similarly, December the profiles demonstrated the trough structure. During quiet conditions location trough minima is occurred in latitudinal range 60-68° N. The trough is regularly detected in night hours. During strong storm of 17 March, as well the December storm, positive effect took place. On recovery phase of storm (18-20 March) negative effect is prevailed. In storm days the trough is observed even day time hours (Fig. 7) Storm period the trough cuts down until 47° N.

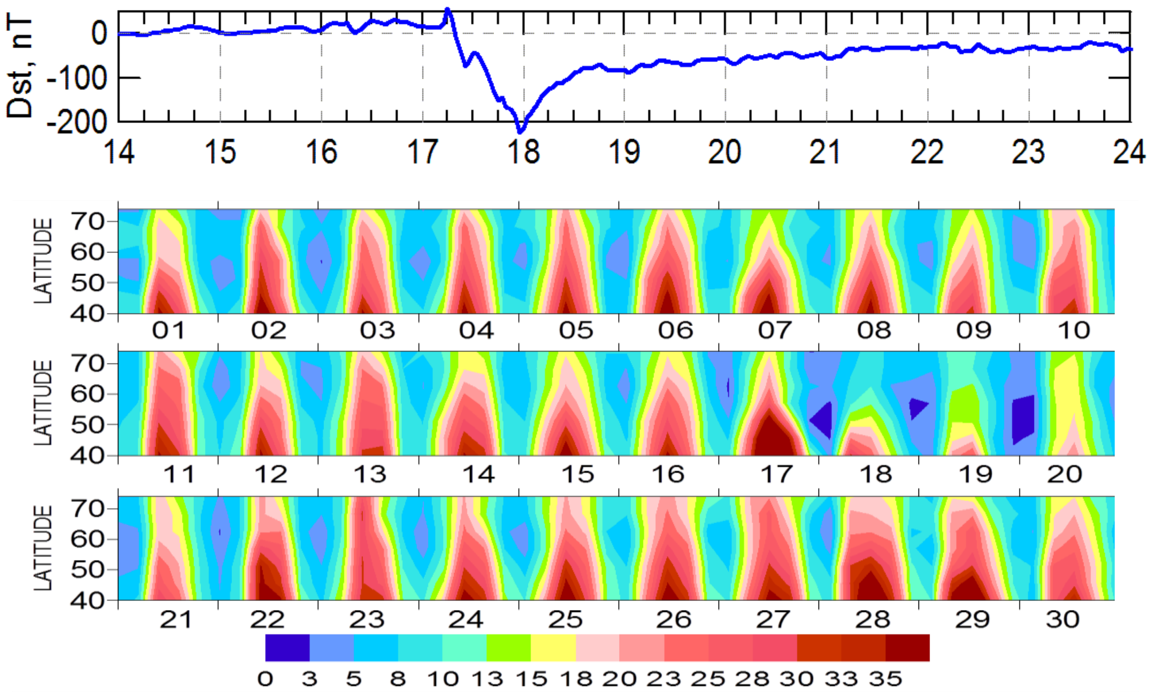


**Figure 6.** Day by day dynamics of latitudinal profiles over Europe during March 2015.

## Remark to occurrence of trough during June 2015

During summer trough do not registered on under consideration latitudes. The trough was observed only during strong storm day of 22-23 June 2015 (ΣKp~42, Dst~ -200nT). The trough structure was weakly pronounced. The relation of

TEC in the trough minimum to the equator and polar walls amounted to a factor 1.5-2.0. The lowest location of trough was near 55-70°N in night hours.

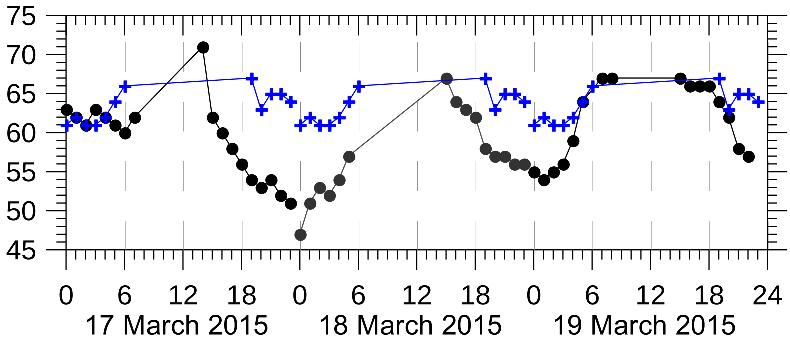


**Figure 7.** Latitudinal location of trough during storm 17 March 2015 (*dotes*). Trough location for quiet day of 15 March (*cross*).

## Summary

For analyses of the ionospheric trough the TEC latitudinal profiles were formed from TEC maps. More than 180 GPS/GLONASS European stations were included in the analysis.

We analyzed the dynamics of trough minima location for winter (December 2015), equinox (March, 2015) and accordingly storm days of 20 December, 17 March. In winter the trough was regularity registered during quiet as well as disturbed days. In quiet geomagnetic condition, on average, the low location the trough was occurred at 60°N of geographic latitude in night time. In day time the trough was raised higher than 73°N. The relation of TEC in the trough minimum to the equator and polar walls amounted to a factor more than of two. During storms 20 December 2015 trough shifted to equator, the lowest location of trough was near 50-51°N. During 15 March 2015 the trough in whole was located at latitudes higher than in December 2015. During strong storm of 17 March 2015 (ΣKp~48, Dst~ -223nT) the lowest location of trough was low than 50°N.

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