Analysis of Seasonal Ionospheric Gradients Over Turkey For Year 2011

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Abstract

Ground Based Augmentation Systems (GBAS) monitor the ionosphere locally for giving measurement integrity information to nearby users. Monitoring systems use ionospheric threat models to calculate the integrity information and contain ionospheric gradients estimated from the ionospheric slant delays through the maximum gradient observed days. These models show only maximum gradient estimates according to the elevation angles of the satellites. In this study, ionospheric gradients are analyzed seasonally in order to give input information to the threat modeling process over Turkey. In the analysis process, developed method also shows the effects of the geomagnetic storms and earthquakes on the ionospheric gradients. As a result, for the first time, by using the developed tool, a detailed seasonal threat modeling is obtained over Turkey for year 2011. According to the analysis results, maximum gradient observed as 20 mm/km and variability of the gradients are highly dependent on to geomagnetic storms and earthquakes over Turkey in 2011. The seasons with more earthquakes and geomagnetic storms have more high gradients.

1. Introduction

GBAS provides integrity information to users for correction of Global Positioning System (GPS) receiver solutions [7]. To give true corrections, ionosphere should be monitored locally through the GPS receiver networks in the GBAS systems. The monitoring process has to be done in real time and with the recent measurements. Ionosphere is a layer of the atmosphere that affects the radio signals due to its ionization level. When the ionization levels are getting higher, scintillations occur on the radio signals and cause performance degradation for GPS receivers. Electron density levels of ionosphere are varies with diurnal, seasonal, solar variations and geomagnetic activities [2]. Master station within the GPS receiver network computes an integrity level from the local ionospheric threat models for the users within the local region. Threat models are established by computing the gradient of the slant delays for each receiver and satellite and by choosing the maximums of the computed gradients. In literature, an ionospheric disturbance is be defined by its gradient, width and constant velocity that shown as Figure 1 [1].

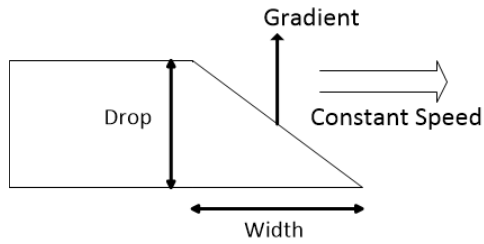

Figure 1. Ionospheric Disturbance Model [1].

Ionospheric gradients are estimated by dividing the differential slant delays of the receiver pairs to the distance between the receivers [1]. Slant delays are estimated by using IONOLAB-STEC values that include IONOLAB-BIAS as receiver Differential Code Bias (DCB), satellite DCB and ephemeris data (www.ionolab.org) [4].

In this study, accurate estimates of ionospheric delays for L1 band are obtained by using dual-frequency GPS measurements from the stations of the Turkish National Permanent GNSS Network (TNPGN-Active) for year 2011. In the measurement fault detection process, faulty measurements are eliminated by using K-means algorithm as given in [7]. As a result, measurement faults can be classified as satellite borne errors, receiver based errors and general errors.

All computed and validated gradients are analyzed according to the statistical properties and grouped into seasons. The variability of the gradients according to the seasons depends on geomagnetic storms and earthquakes. Finally, the upper bounds for the threat model over Turkey are determined by processing annual TNPGN-Active measurements. According to the developed seasonal threat model, maximum gradient obtained as 20 mm/km over Turkey for the year 2011. In addition, autumn and winter seasons earthquake and geomagnetic storms occurrences are more than other seasons. These seasons have higher gradients in the high elevations. The ionospheric slant delay and gradient estimation algorithms are presented in the following section.

2. Ionosphere Slant Delay and Gradient Estimation

The TNPGN-Active stations are divided and grouped into subregions 2° in latitude and 3° in longitude. For each subregion, a base station is selected and its neighbouring stations that are within 150 km range are paired with the base station as given in Figure 2. Ionospheric Pierce Points (IPP) define intersection points of thin shell model of ionosphere and ray path from receiver to satellite. Ionosphere thin shell model defines the ionosphere as a thin layer at the Chapman height. Chapman height is defined as 428.8 km that is the height with the maximum electron density level of the ionosphere. After the station pairing process, for each station, each day and each satellite STEC values and slant delays are estimated with IONOLAB-STEC method from stations RINEX, Differential Code Bias and IONEX files. By using the station-pair method, two receivers that receive signals from the same satellite are paired.

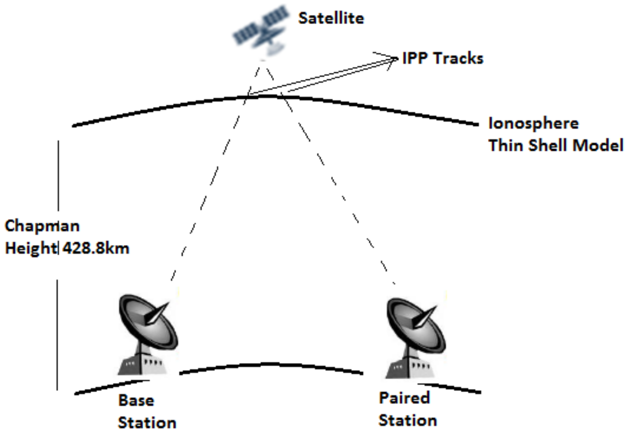

Figure 2. Configuration of Station-pair method.

IONOLAB-STEC algorithm gives two different STEC values which are computed from code and phase measurements of the dual frequency receivers. The algorithm takes difference of L1 code measurements and L2 code measurements to compute STEC and do the same process for the phase measurements of the L1 and L2. Since code measurements are noisier than phase measurements, STEC values computed from phase measurements are used in the slant delay estimations [2]. According to the long observations of code and phase differences, a constant bias that occurs from ambiguity term is observed between code and phase measurements. To resolve the bias term IONOLAB-BIAS method is used [4].

After having STEC estimates, slant delays are computed for each station and satellite by using Equation (1). In Equation (1), A is a constant with value $40.308193\ m^3/s^{-2}$, n denotes the epoch, m denotes the satellite and u denotes the receiver. As a result, $STEC_u^m(n)$ defines the STEC values belong to satellite m and receiver u in epoch n. In addition $\hat{I}_u^m(n)$ defines the slant ionospheric delay of the receiver u that visible for satellite m in epoch n (mm).

$$\hat{I}_u^m(n) = \frac{A}{f^2} STEC_u^m(n) \tag{1}$$

According to the station-pair method, ionospheric gradients are estimated by Equation (2). Gradients are computed by taking the difference of slant delays and divide it by the distance between the receivers [1,5].The general formula given in Equation (2).

$$Gs^m(n) = \frac{\left|\widehat{I_u^m}(n) - \widehat{I_v^m}(n)\right|}{D_{uv}} \tag{2}$$

$Gs^m(n)$ denotes the gradient estimation that belongs satellite m in epoch n (mm/km). $I_v^m(n)$ denotes slant ionospheric delay of the receiver u that matches with receiver u and visible for the satellite m in epoch n (mm) and D_{uv} defines the distance between the receivers u and v (paired stations) (km).

3. Turkish National Permanent GPS Network (TNPGN-Active)

TNPGN-Active GPS Network is a mid-latitude network ([26° E – 45° E] and [36° N – 45° N]) and contains 146 stations. The receivers within the network provide daily continuous raw data. By using IONOLAB-STEC method, these raw data are converted to STEC that have 30 second time resolution. Distances between receivers are around 50-150 km range. 40° masking angle in elevation, 19 subregions are used in the analysis to observe local and regional disturbances [6]. Receivers are selected according to the distance between them and are paired with the receivers that are in within the area which radius is 150 km. The receiver network is given in Figure 3.

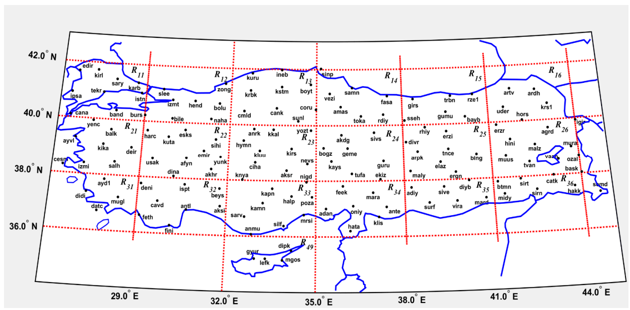

Figure 3. TNPGN-Active Network

4. Analysis Process

The first step of the analysis process is the validation of the gradient estimates for each region, each satellite and receiver pair. So, fault measurement elimination method is carried out for the computed slant delays. The method detects faulty measurements and classifies them by using K-means algorithm. K-means algorithm is a non-parametric technique which is used for the classification in pattern recognition. K-means algorithm is used on the slant delays of the receivers [7]. If faulty measurement is only on one satellite for all receivers, it is classified as satellite-borned error. Similarly, if faulty measurement is only on a receiver for all satellites, the fault measurement is classified as receiver based error. The faulty measurements on all satellites and receivers are classified as general errors.

After the validation process, the gradients are computed by using the validated slant delays of all receivers and all satellites. Then, all statistical properties of gradients (minimum, maximum, mean, median, standard deviation) are computed. To extract the variability of the gradients according to the seasons, all gradients grouped into the seasons. To extract the nominal seasonal behavior of gradients, for each day in a month, median value of maximum gradients observed from each station-pair and each satellite is computed. A standard deviation value is computed as a similar process with the median value for each day. As a result, a nominal behavior band is computed as median of daily median gradient values plus standard deviation of daily gradients.

5. Results

Daily, seasonal, annual maximum, minimum, median and standard deviations of gradients are observed for year 2011. According to the results, the maximum gradients are observed on 2011 as 20 mm/km. Annual gradient map of maximum gradients for year 2011 is given in Figure 4. Maximum gradients are observed in the southwest area of Turkey where it receives more solar radiation.

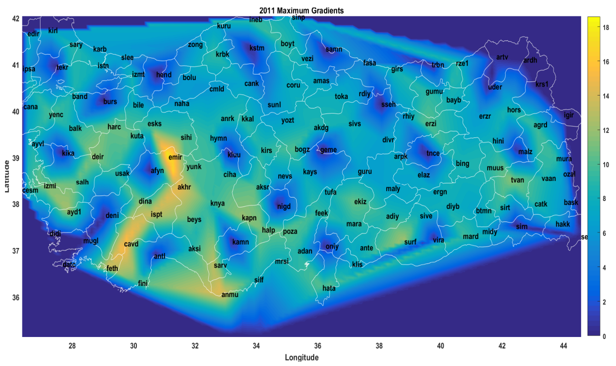

Figure 4. Annual Observation of Maximum Gradients on 2011.

Seasonal ionospheric threat models are given in Figure 5. All gradients have less value on the higher elevation angles of satellites. In year 2011, most of the strong earthquakes and solar storms are occurred in winter and autumn seasons.

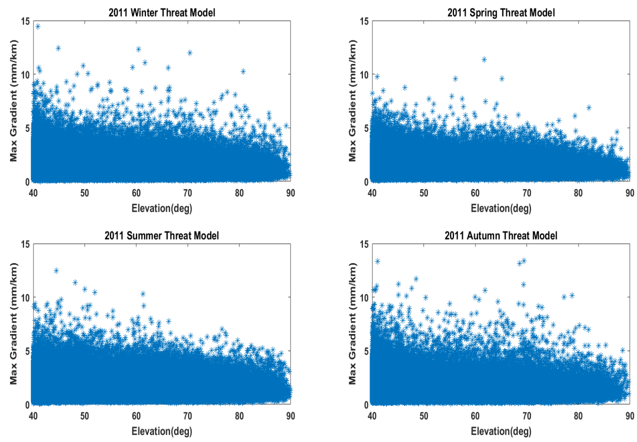

Figure 5. Seasonal Ionospheric Threat Models of 2011.

Strong earthquakes and solar storm statistics on 2011 are presented in Table 1. The geomagnetic storm dates are obtained from Ionosphere and Radio Wave Propagation of the Russian Academy of Sciences [10]. The earthquakes information is taken from United States Geological Survey (USGS) [11]. According to the Table 1, in winter and autumn seasons more earthquakes and geomagnetic storms occured. As a result, in these seasons gradient levels are observed higher than spring and summer seasons.

Table 1. Solar storm and Earthquake Statistics on 2011.

Seasons	Number of Earthquakes with higher magnitude 5.0	Number of Storms
Winter	11	1
Spring	3	1
Summer	4	-
Autumn	5	2

To give an detailed observation, monthly observations on the season autumn (September, October) gradients are given in Figure 6. According to the figure, maximum mean and standard deviation of gradients are observed. In calm days, median and standard deviation of daily gradients observed similar for both months. On the other hand, in the disturbed days, the trend variability of of daily gradients occurs between months..

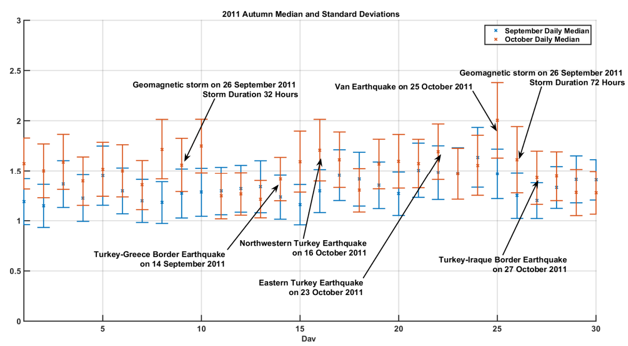

Figure 6. Monthly Observation of Gradients on October 2011.

The maximum median and standard value of the daily gradients are observed on 25 October 2011. The reason of the disturbance on 25 October 2011 is found as a strong earthquake with magnitude higher than 5.0. Another result from the Figure 6, before the earthquake days, the level of daily median values shifts up according to the calm days and standard deviations of the daily gradients are getting higher.

6. Conclusion

IONOLAB-STEC method is used on TNPGN-Active Receiver data of year the 2011, all slant delays of all satellite- receiver pairs are estimated. To observe the threat model of ionosphere over Turkey, all gradients are estimated. Measurement faults are detected and eliminated from the database. All statistical analysis is carried out for the gradients. The gradients ordered according to the seasons to observe the effect of the seasons on the gradients.

For the first time, local seasonal ionospheric gradients are calculated over Turkey in an automated process. One of the important results is reduction in the level of gradients for the high elevation angle of satellites. Maximum gradients are observed around 20 mm/km for year 2011 over Turkey. Geomagnetic storm and earthquake occurrences shift up the levels of the gradients.

Future work of this study is giving locally integrity information to users according to ionospheric gradient, width and velocity.

7. Acknowledgements

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8. References

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