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IONOLAB GROUP ACTIVIES USING CORS-TR GPS NETWORK

Feza Arikan[*], Orhan Arikan[o], Umut Sezen[*], Cenk Toker[*], Onur Lenk[†], Ali Kilicoglu[†], Bahadir Aktug[†], Melih Sukru Aysezen[†], Isiltan Sayin[*] and Ozan Koroglu[/]

[*] Department of Electrical and Electronics Engineering Hacettepe University
06800, Beytepe, Ankara, Turkey
e-mail: arikan@hacettepe.edu.tr, U.Sezen; cenk.toker; isiltan@ee.hacettepe.edu.tr
[o] Department of Electrical and Electronics Engineering Bilkent University
06800, Bilkent, Ankara, Turkey
e-mail: oarikan@ee.bilkent.edu.tr
[†] General Command of Mapping Cebeci
Ankara, Turkey
e-mail: onur.lenk; ali.kilicoglu; bahadir.aktug; melihsukru.aysezen@hgk.mil.tr
[/] Roketsan Inc.
Ankara, Turkey
e-mail: koroglu.ozan@gmail.com

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Summary: Monitoring of the ionospheric variability is necessary for improving the performance of communication, navigation and positioning systems. In this study, we introduce the activities of the IONOLAB group in statistical modelling and characterization of the ionosphere over Turkey using the new CORS-TR GPS network.

1 INTRODUCTION

IONOLAB group is formed by researchers from various disciplines gathered together to handle the challenges of the ionosphere using state-of-the-art signal processing techniques over a GPS network. The group currently has researchers from Hacettepe University, Bilkent University and General Command of Mapping of Turkish Army. Constantly Operating Reference Station-Turkey (CORS-TR) Network is a recently installed system of 147 GPS stations homogeneously distributed over Turkey and North Cyprus Turkish Republic as shown in Figure 1. The CORS-TR network is in operation since May 2009 and it provides a wide variety of possibilities for active research not only in geodetics but also in areas from geology to tropospheric and ionospheric characterization. Ionosphere is the main source of

error for navigation and positioning systems and it can also cause major disturbance for satellite communication. Therefore, characterization and constant monitoring of variability of the ionosphere is of utmost importance for the performance improvement of these aforementioned systems. IONOLAB group has been active in estimation of Total Electron Content (TEC) using single station GPS recordings in IGS network, regional spatial interpolation (mapping) of TEC, global Computerized Ionospheric Tomography (CIT), statistical analysis of TEC, and investigation of lithosphere- ionosphere coupling through seismic activity[1-15]. The techniques that have been developed for various purposes are applied to randomly distributed GPS stations in IGS network. With the new CORS-TR, it is observed that there are various prospective areas in processing GPS recordings for higher accuracy and reliability in characterization of the regional ionosphere. In this study, we will introduce these possible sectors for performance improvement in monitoring the regional ionosphere and possible impacts on navigation, positioning and communication systems.

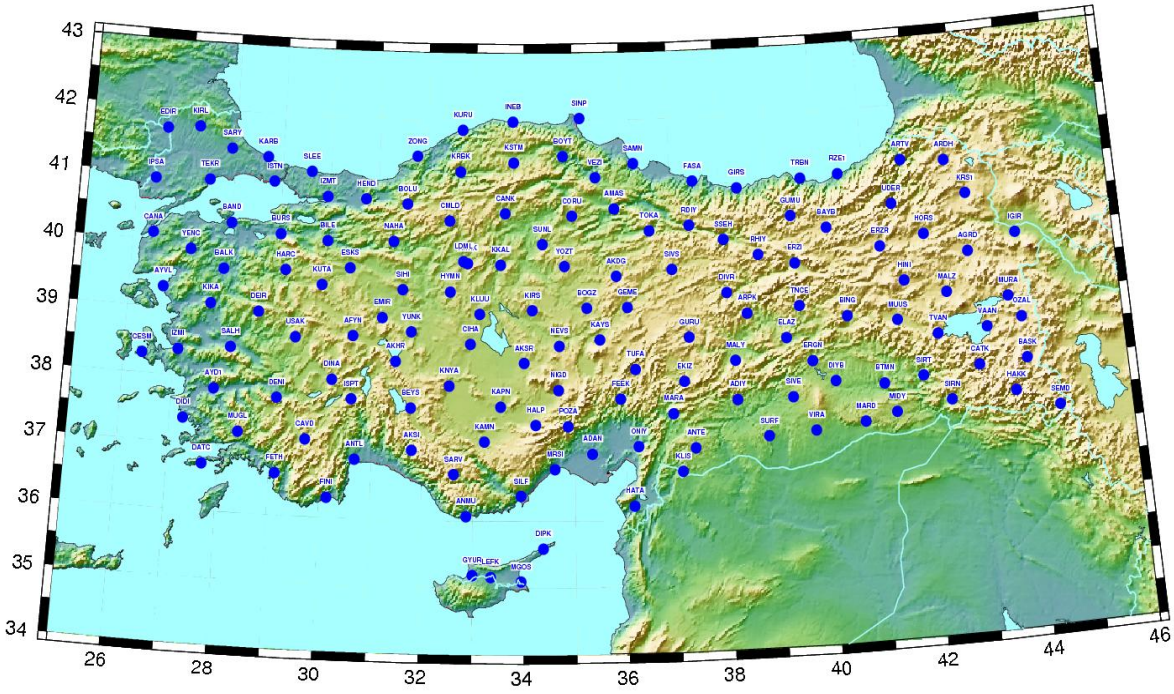

Figure 1: 147 GPS stations in CORS-TR Network.

2 ESTIMATION OF TEC THROUGH 4-D REGIONAL COMPUTERIZED IONOSPHERIC TOMOGRAPHY (CIT)

Ionosphere is a temporally and spatially varying, dispersive, anisotropic and inhomogeneous medium that is characterized primarily by its electron density distribution. Electron density is a complex function of spatial and temporal variations of solar, geomagnetic, and seismic activities. Unfortunately, a complete physical model of this important quantity is not available universally. Ionospheric electron density distribution can not be obtained by direct measurements either. Due to these inconveniences, an important derivable quantity about the electron density, the Total Electron Content (TEC) is used widely in attempts to characterize the ionosphere. TEC is proportional to the total number of electrons on a line crossing the atmosphere. TEC can be computed using the measurements and recordings of the vertical ionosondes both bottom-side and top-side, Faraday Rotation of satellite signals such as GLONASS and EISCAT, TOPEX/POSEIDON and JASON satellites with double frequency altimeters, GPS phase and delay recordings and incoherent backscatter radar signals. In recent years, Global Positioning System (GPS) dual frequency signals are widely used to estimate both regional and global TEC values over a significant proportion of global land mass. IONOLAB group has developed an important tool in estimation of TEC with a single GPS station, IONOLAB-TEC[1,2,4,7,11,15]. IONOLAB-TEC provides reliable and robust estimates for all latitudes and both calm and disturbed days by using RINEX, IONEX and satellite ephemeris data provided from the IGS centers. IONOLAB-TEC consists of a regularized signal estimation algorithm which combines signals from all GPS satellites for a given instant and a given receiver, for a desired time period or for 24 hours, with 30 s time resolution. IONOLAB-TEC values also include the receiver differential code bias (DCB) for each GPS station estimated uniquely by the IONOLAB-BIAS algorithm. The web based computation program is written in JAVA and it is provided both in Turkish and English at www.ionolab.org. The estimated IONOLAB-TEC values are used in a novel Singular Value Decomposition (SVD) based CIT reconstruction technique for the imaging of electron density in both space (latitude, longitude, altitude) and time[5,6,10]. The underlying model is obtained from International Reference Ionosphere (IRI). Based on the IRI-2007 model, a basis is formed by SVD for the required location and the time of interest.

Selecting the first few basis vectors corresponding to the most significant singular values, the 3-D CIT is formulated as a weighted least squares estimation problem of the basis coefficients. By providing significant regularization to the tomographic inversion problem with limited projections, the proposed technique provides robust and reliable 3-D reconstructions of global ionospheric electron density.

The CORS-TR opens up new possibilities in estimation of TEC and CIT with its homogeneously distributed, dense GPS Reference Station network. Turkey extends between 26º-45ºE and 36º-42ºN. It has a midlatitude, respectively quiet ionosphere. A parametric (empirical) electron density model can be tried in a linearized tomographic inversion algorithm where GPS recordings can be directly used in the measurement model. IONOLAB group is investigating possibilities in the choice of the parametric electron density model and devising a novel GPS measurement model. The estimated electron density over Turkish ionosphere will be integrated in the local zenith directions for computation of TEC.

3 INTERPOLATION OF TEC SAMPLES WITH ANISOTROPIC KRIGING: TEC MAPPING

IONOLAB group employed Multiquadrics, Inverse Distance Weighting (IDW), Cubic Splines, Ordinary and Universal Kriging, Random Field Priors (RFP), Multi-Layer Perceptron Neural Network (MLP-NN), and Radial Basis Function Neural Network (RBF-NN) as the spatial interpolation algorithms for TEC Mapping8,9,12. These mapping techniques are initially tried on synthetic TEC surfaces for parameter and coefficient optimization and determination of error bounds. Interpolation performance of these methods are compared on synthetic TEC surfaces over the parameters of sampling pattern, number of samples, the variability of the surface and the trend type in the TEC surfaces. By examining the performance of the interpolation methods, it is observed that both Kriging, RFP and NN have important advantages and possible disadvantages depending on the given constraints. It is also observed that the determining parameter in the error performance is the trend in the Ionosphere. Optimization of the algorithms in terms of their performance parameters (like the choice of the semivariogram function for Kriging algorithms and the hidden layer and neuron numbers for MLP-NN) mostly depend on the behavior of the ionosphere at that given time instant for the desired region. The sampling pattern and number of samples are the other important parameters that may contribute to the higher errors in reconstruction. The east-west extend of Turkey indicates a major anisotropy in TEC distribution during sunrise and sunset hours. A north-south anisotropy is also observed for hours with full sun exposure and during night hours. IONOLAB group is currently investigating a novel method in introducing anisotropicity into Ordinary Kriging for TEC mapping and an accurate temporal model for the semivariogram function for CORS-TR Network. TEC maps will be generated automatically according to a specialized, optimum temporal update period (TUP). This way, the ionospheric variability will be monitored and characterized accurately with low computational complexity and data storage. A random space-time model of ionosphere over Turkey can be developed using the TEC maps with optimum TUP.

4 CONCLUSION

Monitoring of ionosphere with a dense, homogeneous GPS network provides important possibilities in characterization and modeling of electron density and TEC. In this study, activities of IONOLAB group are introduced for CIT, TEC Mapping and development of a random space-time model using the new CORS-TR GPS network.

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REFERENCES

[1] Arikan, F., Erol, C.B. and Arikan, O., "Regularized estimation of vertical total electron content from Global Positioning System data", *Journal of Geophysical Research-Space Physics*, 108(A12), 1469-1480, (2003).

[2] Arikan, F., Erol, C.B. and Arikan, O., "Regularized estimation of VTEC from GPS data for a desired time period", *Radio Science*, 39(6), RS6012, (2004).

[3] Erol, C.B. and Arikan, F., "Statistical analysis of the ionosphere using GPS signals", *Journal of Electromagnetic Waves and Applications*, 19(3), 373-387, (2005).

[4] Nayir, H., Arikan, F., Arikan, O. and Erol, C.B., "Total electron content estimation with Reg-Est", *Journal of Geophysical Research-Space Physics*, 122, A11313, (2007).

[5] Arikan, O., Arikan, F., and Erol, C.B., "Computerized ionospheric tomography with the IRI model", *Advances in Space Research*, 39, 859-866, (2007).

[6] Arikan, O., Arikan, F., and Erol, C.B., "3-D Ionospheric Tomography with Random Field Priors", in *Mathematical Methods in Engineering*, K. Tas, J.A. Tenreiro Machado and D. Baleanu (Eds), Springer, Netherlands, 335-334, (2007).

[7] Arikan, F., Nayir, H., Sezen, U., Arikan, O., "Estimation of single station interfrequency receiver bias using GPS-TEC", *Radio Science.*, 43, RS4004, 1-13, (2008).

[8] Sayin, I, Arikan, F., and Arikan, O., "Regional TEC mapping with Random Field Priors and Kriging", *Radio Science*, 43, (2008).

[9] Yilmaz, A., Akdogan, K.E., and Gurun, M., "Regional TEC Mapping Using Neural Networks", *Radio Science*, 44, RS3007, (2009).

[10] Erturk, O., Arikan, O., and Arikan, F., "Tomographic reconstruction of the ionospheric electron density as a function of space and time", *Advances in Space Research*, 43, 1702-1710, (2009).

[11] Arikan, F., Sezen, U., Arikan, O., Ugurlu, O., and Nayir, H., "Space weather activities of IONOLAB group; IONOLAB-TEC", *Geophysical Research Abstracts*, 11, EGU2009-5188, *EGU-General Assembly*, Vienna, Austria, 19- 24 April (2009).

[12] Arikan, F., Yilmaz, A., Arikan, O., Sayin, I, Gurun, M., Akdogan, K.E., and Yildirim, S.A., "Space weather activities of IONOLAB group; TEC mapping", *Geophysical Research Abstracts*, 11, EGU2009-6962, *EGU-General Assembly*, Vienna, Austria, 19-24 April (2009).

[13] Arikan, F., Karatay, S. and Arikan, O., "Investigation of ionospheric disturbance due to strong earthquakes using total electron content", *Geophysical Research Abstracts*, 11, EGU2009-8440, *EGU-General Assembly*, Vienna, Austria, 19-24 April (2009).

[14] Karatay, S., Arikan, F. And Arikan, O., "Investigation of hourly and daily patterns for Lithosphere- Ionosphere coupling before strong earthquakes", *Proceedings of RAST-2009*, Istanbul, Turkey, 11-13 June (2009).

[15] www.ionolab.org