Augmentation of EGNOS Ionospheric Data with Locally Adapted Ionospheric Model

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Ionospheric Influence on GNSS

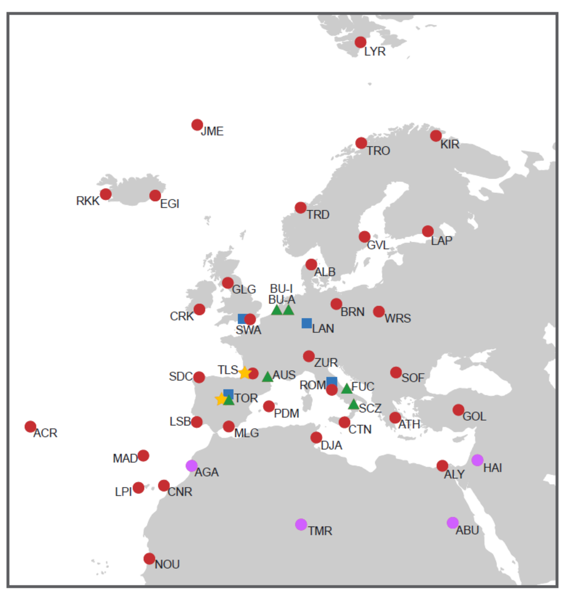
Performance of Global Navigation Satellite Systems (GNSS) is affected by several error sources and the ionosphere is recognized as the major one. Ionospheric error varies depending on the time of day, season, position of the receiver, solar activity and the Earth's geomagnetic field. The ionospheric error is quantified by the amount of Total Electron Content (TEC) on the path between satellite and receiver. This error is frequency dependent so it can be estimated using two frequencies in the satellite-receiver communication.

$$TEC = \int N_e \mathrm{d}s_0 = \frac{f_{L1}^2 \cdot f_{L2}^2}{40.3 \cdot (f_{L1}^2 - f_{L2}^2)} \cdot (\rho_{L2} - \rho_{L1}) \qquad I_{err} = \frac{40.3}{f^2} TEC$$

Vast majority of GNSS receivers still uses only one frequency and they rely on global ionospheric models to calculate and mitigate ionospheric error. Such models can perform well in non-disturbed ionospheric conditions, but in the time of high solar activity and sudden ionospheric changes, single frequency GNSS receivers' performance degrades severely.

Satellite-Based GNSS Augmentation

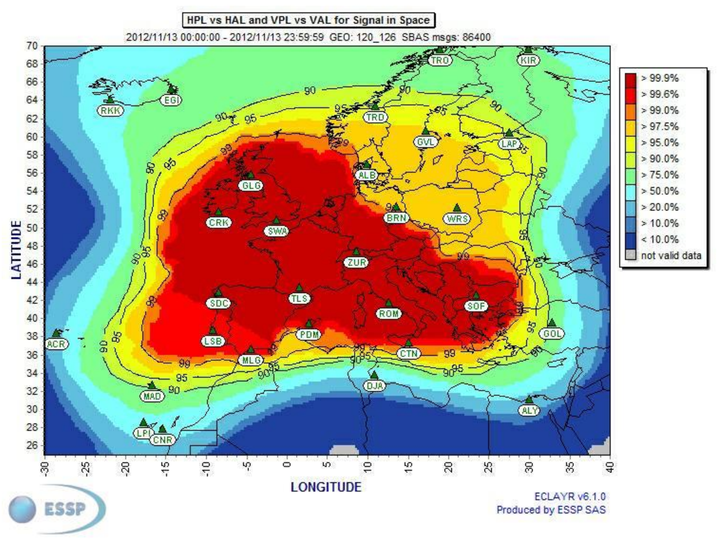
To overcome this problem, Satellite-Based Augmentation Systems (SBAS) can be used. Using networks of dual-frequency GNSS receivers, current ionospheric error over some region is estimated. The calculated correction parameters are transmitted to the receivers by geostationary satellites. European Geostationary Navigation Overlay Service (EGNOS) provides Safety-of-Life (SoL) service with emphasis on integrity, primarily for usage in aviation, and Open Service (OS) with emphasis on accuracy, intended for non-SoL usage. EGNOS OS coverage area extends over most of the European Civil Aviation Conference (ECAC) region, but the eastern border area remains uncovered. In case of ionospheric disturbances, coverage is additionally disrupted because of lack of Ranging and Integrity Monitoring Stations (RIMS) in that area. However, many GNSS stations placed in the Eastern Europe continuously provide publicly available data.



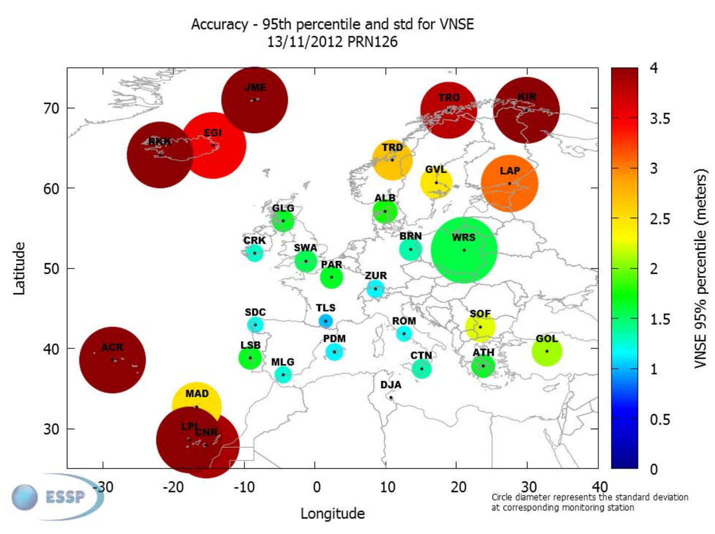
EGNOS RIMS stations

Other GNSS stations

Augmenting the Augmentation System



EGNOS APV-1 availability on November 13 2012



Positioning accuracy (color) and standard deviation (diameter) on November 13 2012

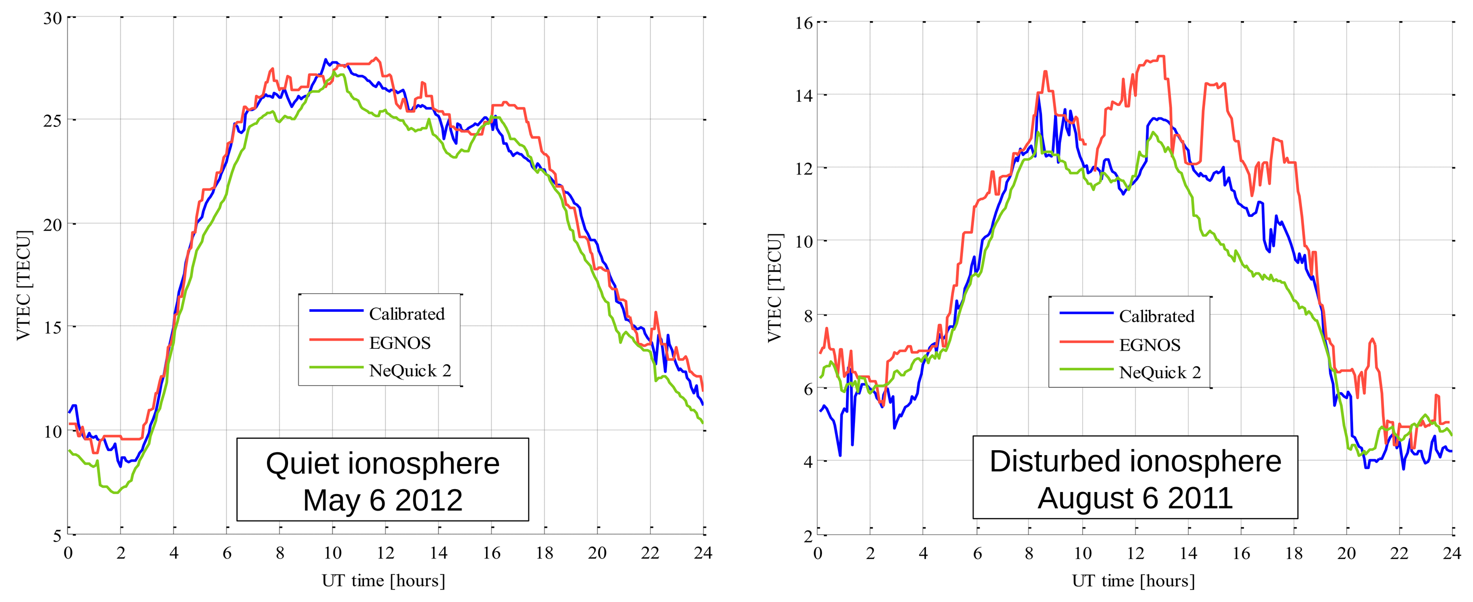
Images shown above demonstrate an example of shrinkage of the coverage area caused by a geomagnetic storm. In the areas temporarily or continuously affected by the lack of EGNOS Ionospheric Grid Point (IGP) data, positioning accuracy can be improved by providing substitute ionospheric corrections with the accuracy level similar to the one that EGNOS provides in well covered areas. Local reference TEC, calculated using data from GNSS stations situated in the observed areas, can be used to modify a global ionospheric model in a way to adapt it to the local ionospheric conditions.

The model of choice is NeQuick 2, a global model able to compute ionospheric density between any two given points, designed for simple and fast execution. It can be locally adapted using local ionization level derived from local TEC as a model input instead of solar flux index.

Ionospheric Error Domain Results

Receiver Independent Exchange Format (RINEX) observation data from a GNSS station chosen as a local adaptation location were calibrated using Ciraolo method, which resulted in slant TEC (STEC) and vertical TEC (VTEC) not affected by inter-frequency biases. NeQuick 2 model output for the same geographic coordinates was fitted to differ from calibrated VTEC by maximally 0.3 TEC units (TECU). Such locally fitted model was tested and compared with EGNOS ionospheric corrections on several locations and for multiple periods of different ionospheric conditions.

Test locations were the locations of other GNSS stations that could provide a referent TEC for comparison with the model output and EGNOS data. Stations placed in the area well covered by EGNOS ionospheric data were chosen in order to enable performance comparison between the model and EGNOS. It was determined that the level of ionospheric correction similar to that provided by EGNOS can be achieved at distance of several hundred kilometers from the point of local adaptation, i.e. in that area locally adapted model could augment the EGNOS OS. As expected, ionospheric disturbances degrade the model performance, but it remains comparable to EGNOS.

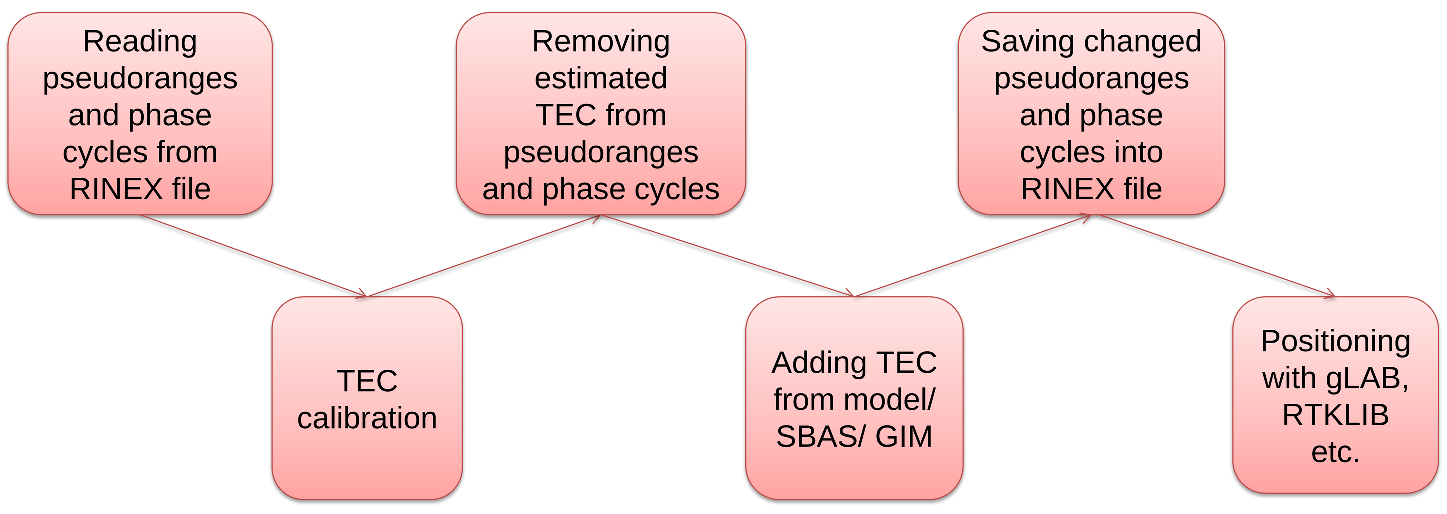


Daily results for GANP station, situated 300 km from the reference SULP station for days with quiet and disturbed ionospheric conditions

GNSS Station	Ionospheric Condition	NeQuick 2 VTEC Error			EGNOS VTEC Error		
		Mean(Abs)		Mean [TECU]	Mean(Abs)		Mean [TECU]
		TECU	%		[TECU]	%	
SULP - Local Adaptation 49.8356° N 24.0145° E	Disturbed (August 3-8 2011)	0.019	0.2	0	1.312	13.2	0.722
	Quiet (May 2-7 2012)	0.019	0.1	-0.001	1.374	9.7	1.04
GANP – Test Site 49.0344° N 20.3228° E	Disturbed (August 3-8 2011)	0.737	7.6	-0.119	1.339	13.8	0.645
	Quiet (May 2-7 2012)	1.171	7.2	-1.098	0.798	5	-0.068

Positioning Domain

To compare the performance of single-frequency GNSS positioning augmented by the locally adapted NeQuick 2 model with results achieved by EGNOS augmentation, a test method was developed. Pseudoranges and phase cycles from observation RINEX data of some GNSS station can be changed to contain amount of TEC calculated by the adapted model. Steps necessary to change a file are shown below. Such a file can be read by positioning software to determine positioning performance of the developed model.



RINEX file modification procedure for testing ionospheric model performance in positioning domain

Conclusion

This research compared ionospheric correction performance of EGNOS and locally adapted NeQuick 2 model on eastern border of EGNOS coverage area in different solar and geomagnetic conditions. For all the observed cases mean absolute error was lower than 1.5 TECU. Procedure for positioning domain tests was prepared and its results will determine usable area for the proposed method of supplementing EGNOS ionospheric data with locally adapted ionospheric model.

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