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Real-time mapping of VTEC and slab thickness in cooperation of IGS' GNSS and GIRO sensor networks

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Abstract

This work presents early results from a near-real-time ionosphere mapping system combining ionospheric data from two separate sensor networks: IGS permanent GNSS receivers providing VTEC measurements and GIRO high-frequency ionosonde sounders providing data for 3D mapping of the bottomside ionospheric plasma density.

Near-real-time mapping systems can be considered as a step towards real-time systems, at the moment an extremely important and difficult to solve problem, not only considering mapping process itself, but also data gathering from all over the world, data delivery to the computational center, quality control, validation, mapping and releasing of final product in possibly unnoticeable amount of time.

VTEC values gathered from IGS GNSS receivers and peak density of F2 layer NmF2 from GIRO ionosondes allows computation of an equivalent slab thickness, a derived descriptor of the near-Earth plasma layer up to the GNSS spacecraft altitudes that characterizes the skewness of its shape.

The combination of IGS and GIRO real-time capabilities brings an intriguing possibility of evaluating dynamics of the topside ionosphere and plasmasphere, even though crudely, using only ground-based resources whose real-time performance can be engineered to accomplish below one minute latency of nowcast.

1. Introduction

Mapping is a computational process that synthesizes, using fragmentary data available from a sparse network of sensors, the underlying 2D continuous map of the observed physical quantity. Real-time mapping system must perform sensor data collection and associated mapping computations with sufficiently low latency from the real-time. It is a difficult problem, found frequently in various scientific and engineering domains, that becomes an extremely difficult one when available sensors are few and remote, such as in the plasma physics applications that monitor space weather conditions.

In order to build, for example, a real-time global map of the vertical total electron content (VTEC), the required procedural steps (observe GNSS signal, extract the plasma density content information from it, deliver data from the GNSS receivers around the world to the computation center, perform data quality control and cross-validation to then produce and publish maps) require an extremely well designed system which computing performances are adequate, communication networks are fast and reliable, latencies are subject to strict timing rules, and all potential real-life issues are accounted for and provided with prompt mitigation protocols.

2. Data acquisition

We will present early results from a system for the ionospheric weather nowcast based on near real-time data products from two separate sensor networks: an International GNSS Service (IGS) fleet of 505 permanent GNSS receivers that provides vertical total electron content measurements for the global ionospheric maps [Hernández-Pajares et al. 2009; http://www.igs.org/network] and a Global Ionosphere Radio Observatory (GIRO) [Reinisch and Galkin, 2011; http://giro.uml.edu] with 60 online high-frequency (HF) ionosonde sounders that provide data for 3D mapping of the bottomside ionospheric plasma density by the IRI-based Real-Time Assimilative Model (IRTAM) [Galkin et al., 2012].

Combination of the VTEC from IGS and peak density of F2 layer NmF2 from GIRO allows computation of an equivalent slab thickness τ = VTEC/NmF2, a derived descriptor of the near-Earth plasma layer up to the GNSS spacecraft altitudes that characterizes the skewness of its shape.

3. Methodology

A significant effort has been invested in transitioning the participating sensor networks to unattended real-time operations without human in the loop. STEC acquisition at each IGS permanent GNSS station is based on geometry free (P4 and Φ4) GPS combination. Corresponding VTEC value is then projected on single thin layer basing on the point angle of GPS signal piercing that ionosphere layer. The projection is performed with formula (1):

$$VTEC = STEC * \sqrt{1 - \left(\frac{R_e}{R_e + h_{ion}} \cos \varepsilon\right)^2} \quad (1).$$

where $VTEC$ and $STEC$ are vertical and slant total electron content values respectively, R_e is the radius of the Earth, h_{ion} is the height of single thin ionospheric layer (assuming 450km) and ε is the elevation angle between the receiver and a satellite.

Although 50- and 100Hz GPS receivers are used at each site, due to great importance put on data consistency and its quality control, the state of the ionosphere for official global IGS' Ionospheric Working Group products is a result of numerous recomputations and validations. For more details please refer to Hernández-Pajares et al. (2009).

Resulting Global Ionospheric Maps (GIMs) created by IGS are typically delivered on daily basis in 2h (time) x 2.5 deg (lat) x 5 deg (lon) resolution in IONEX (IONosphere map EXchange) format with rapid product released with under 24h latency and final product with about 11 days latency [http://www.igs.org/products]. Despite worldwide usage of IGS global ionospheric product its extremely strict validation rules and resulting latency of final product release means it cannot be considered as a source of data for near-real-time and real-time applications and different VTEC source had to be established.

For real-time mapping of VTEC and slab thickness cooperative IGS and GIRO project a newly developed internal ionospheric product has been used with improved 15 min time resolution, 45x46 points NASA WorldWind grid for GIRO compatibility and near-real-time product delivery latency capability. For improved reliability, internal data quality control and validation and faster delivery of a prefinal VTEC product a methodology developed under SRRC UWM cooperation with UPC Ion-SAT was used. For more details please refer to Kotulak et al. (2017).

4. Future work

Future work will be mainly concentrated on improving each link of a chain between data acquisition and final product delivery in order to lower latencies as much as possible at as many chain links as possible. Constant improvement of available computational power and optimization of data acquisition, data control, validation and mapping algorithms is necessary to establish an autonomous computation routine that meets the strict criteria of real-time mapping system.

5. Summary

The combination of IGS and GIRO current near-real-time and future real-time capabilities brings, for the first time, an intriguing possibility of evaluating dynamics of the topside ionosphere and plasmasphere, even though crudely, using only ground-based resources which real-time performance can be engineered to accomplish below one minute latency of nowcast. Figure 1 places deviation maps of VTEC, NmF2, and records side by side for comparison.

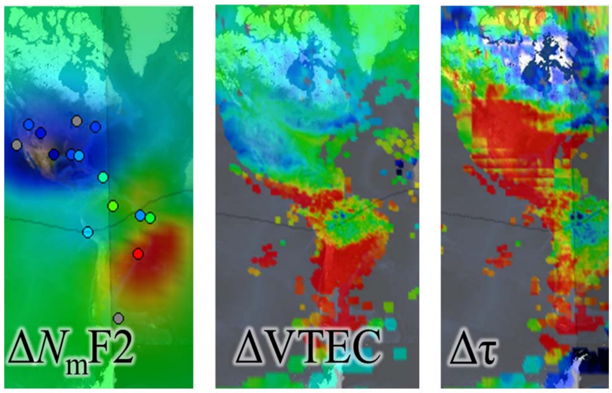

Figure 1. Deviation maps of NmF2, VTEC, and computed during a substorm of March 17, 2015 at 23:22 UT using combination of IGS and GIRO data products

6. References

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