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GNSS CONTRIBUTION TO NEXT GENERATION GLOBAL IONOSPHERIC MONITORING

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Key words: GNSS and non-GNSS based methods, ionospheric models analysis and testing, optimal modelling methods, recommendations for a New European Ionosphere Monitoring System.

Summary: This abstract provides a short overview about the ESA TRP study “GNSS Contribution to Next Generation Global Ionospheric Monitoring” performed by a study team of Hewlett-Packard (HP), QinetiQ Ltd., DLR and gAGE/UPC.

1 INTRODUCTION

Within a study team of four partners recommendations for a new ionosphere monitoring system were identified and formulated, meeting the requirements of different types of potential users, e.g. for operational now/forecasting but on the other hand also for scientific applications. The study was performed in three steps: 1) Description of the main physical processes driving the ionosphere; overview of GNSS and non-GNSS ground- and space-based methods to monitor the ionosphere. 2) Description of different methods within and outside the study team to model ionospheric Total Electron Content (TEC), their concepts and philosophy; selection of reference models; definition and establishment of a test dataset to validate the different methods. 3) Performance of the tests defined in step two in order to identify the strengths and weaknesses of the tested methods and, based on the outcome of these tests, recommendations for a new ionosphere model meeting the requirements of many different potential users (practically orientated, science orientated).

2 THE IONOSPHERE, WHY IS ESA INTERESTED IN IT, HOW CAN IT BE OBSERVED?

In the first part of the study the typical features and characteristics of the ionosphere were described: its layered structure, its main geographical regions, its dependency on solar activity, season and latitude. In addition, the ionization processes, the disturbed ionosphere, its close coupling with magnetosphere and thermosphere and the physical processes standing behind these phenomena were explained.

Since 1998 ESOC is active as Analysis Centre in the International GNSS Service (IGS) Ionosphere Working Group (http://igscb.jpl.nasa.gov/projects/iono/index.html): Daily TEC maps showing the global ionosphere with a 2-hours time resolution are delivered to the IGS. Currently investigations are undertaken at ESOC to establish a prediction tool for the IGS service. Another important future task will be to increase of time resolution to e.g. 15 minutes. Also the establishment of 3-dimensional reconstructions will be a very important task of future ESOC activities, and this aspect played also a major role in this study.

There are several ways to monitor the ionosphere:

- TEC derived from ground-based GNSS tracking networks (e.g. IGS and EUREF), currently about 400 sites, in future about 1000 sites and about 90 GNSS spacecraft.
- TEC derived from DORIS measurements, currently about 60 sites.
- Electron density profiles (derived from radio occultation) and TEC (Fig. 1 left hand side) recorded with GNSS receivers onboard LEOs, currently CHAMP, GRACE and COSMIC, in future SWARM and others.

- Ground-based ionosondes, data access to about 30 ionosondes worldwide.
- Vertical TEC from dual-frequency altimeters, e.g. JASON; provide VTEC values over the oceans where no GNSS sites can be placed.
- TEC from LEO beacons transmitting phase coherent signals at 150 and 400 MHz, about a dozen satellites. Receiver chains along beacon spacecraft pass are well suited for ionospheric tomography, Fig. 1 right hand side.

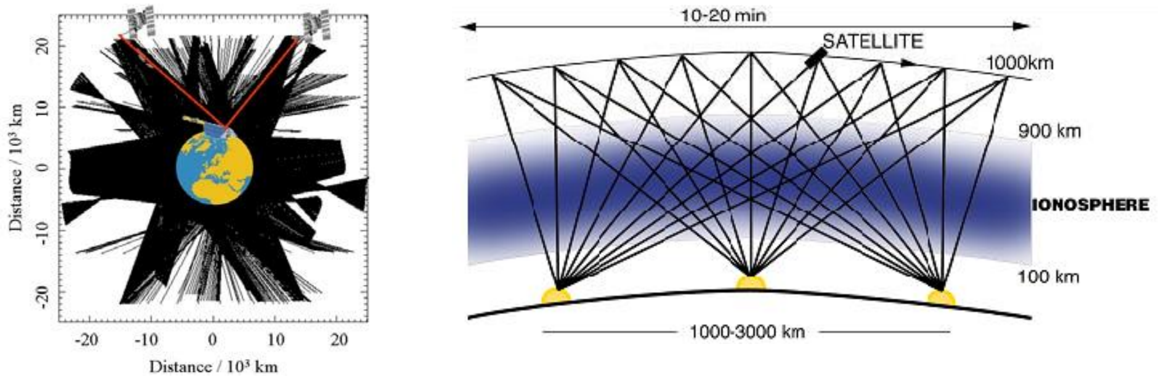

Figure 1: About 4000 TEC measurements recorded onboard CHAMP during one orbital revolution (left); receiver chain to follow a LEO beacon pass (right)

3 SELECTION OF REFERENCE MODELS AND ANALYSIS OF EXISTING MODELLING METHODS

In order to identify optimal modelling methods for a New European Ionosphere Monitoring System, the different ionosphere modelling techniques of the study team were validated against an agreed test dataset and against NeQuick und the IGS TEC Maps, which served as 3D resp. 2D reference.

The study team models are:

- Electron Density Assimilative Model (EDAM), QinetiQ – different types of ionospheric observation data are assimilated into a background model. Currently IRI2007 is used as background.
- IONosphere MONintoring Facility (IONMON) Version 2, HP – Closed function approach describing ionospheric structures by vertical profiles combined with horizontal surface functions, no background, TEC and electron density data are processed.
- TOMographic IONosphere model (TOMION), UPC – The ionosphere is represented by two or more layers of voxels. In each voxel, electron density is

assumed to be constant, no background, fed with different types of ionospheric observation data.

- Neustrelitz TEC Model (NTCM), DLR – This is a family of empirical TEC models developed for European and Polar cap regions so far. The TEC reconstructions used in this study are obtained by assimilating ground based TEC measurements into the European TEC model NTCM-EU. A global TEC model is planned to be developed.

The study team models and NeQuick and the IGS TEC Maps were validated against:

- Differential slant TEC (dSTEC) data.
- Vertical TEC (VTEC) from TOPEX and JASON.
- Ionosonde data (only EDAM, TOMION and NeQuick).
- Electron density measured along the CHAMP orbit (only EDAM, TOMION and NeQuick).

Two test periods: May 2002, Solar maximum, and December 2006, Solar minimum. The models performance can be summarized briefly as follows:

- Generally the models display similar performance, having RMS values between 1.5 – 3.5 TECU for all stations (apart from some isolated equatorial sites).
- IONMON Version 2 showed a worse performance (model is still experimental, and could not be properly evaluated during the study).

4 IDENTIFICATION OF OPTIMAL MODELLING TECHNIQUES, RECOMMENDATIONS FOR A FUTURE SYSTEM

A new system should combine the advantages of different methods. Important appears to be a background model to create a median ionosphere. This median ionosphere will then be upgraded by an assimilation technique with actual observation data, where available. The new system should describe the ionosphere 3-dimensionally and inhere to a certain extent some physics and allow for future extensions into the direction of a real physics-based model. The new system should be able to run in real-time and allow for ionospheric predictions.

The new system should be suitable for the following two major groups of potential users:

1) Practically oriented users: GNSS users, oil industry, airlines, transport companies, ...

2) Scientific users: In order to earn more knowledge about the physics of the ionosphere, its coupling with the magnetosphere and the Sun-Earth system, the availability of a real physics- based first-principles ionosphere model would be desirable.

The new system should use all observation data types listed at the end of Section 2 and new sources of observation data types that may arise in the future.

5 CONCLUSIONS

Based on an analysis of current ionosphere modelling and observation techniques and on tests and validations of existing ionosphere modelling methods, recommendations were formulated on how a future ionosphere monitoring system could be realized. Principally, the development of a New European Ionosphere Monitoring System should follow two strategic lines:

I) Development of a pragmatic solution for near-real-time data provision based on current near-real-time GNSS measurements.

II) Preparation of future oriented physics-based modelling techniques.

Both activities should be established and supported by ESA and European Commission simultaneously.

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