The MONITOR project: architecture, data and products.

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Abstract

Ionospheric effects may degrade the performance of GNSS systems. Recognising the importance of continuous ionospheric monitoring and in order to consolidate the knowledge related to the impact of ionospheric effects on the performance of GNSS (EGNOS and Galileo) systems, in particular those effects happening during extreme events during and around solar maximum, the European Space Agency has started the MONITOR project.

MONITOR includes a set of stations distributed around the globe (European mid-latitudes, Polar and Equatorial locations), a central archiving and processing facility and a number of external processors providing near real-time products. Furthermore, apart from continues monitoring, ad-hoc experimental campaigns are being coordinated with specific instruments and during specific periods.

Some of the regular data and products to be provided are: daily ionospheric scintillation indices, dual-frequency observables and high-frequency raw data from MONITOR stations, Slant TEC from a large set of ground stations (for model verification/assimilation), ultra-rapid European and Global VTEC maps, Global Electron Content index, rapid and ultra-rapid 3D electron density grid data, sidereal day, TID and solar flare indices, solar flare variability index and higher-order errors from IONEX.

Eventually, the analysis of the observations will support the understanding of abnormal events, characterisation of disturbed periods and the synthesis into new or updated models, recommendations and conclusions useful for characterisation of GNSS performance and development of mitigation techniques.

1. Introduction

The performance of Global Navigation Satellite Systems (GNSS) is impacted by signal propagation impairments due to the ionosphere. The understanding of nominal ionospheric propagation behaviour is well established. Ionospheric effects follow variations depending on time-of-day, season, location and solar condition. The Sun activity exhibits a long-term variation following approximately an 11-year cycle, and after a long solar minimum it is expected that the coming years will be active, increasing the likelihood to see abnormal effects affect GNSS systems.

Ionospheric modelling is a challenging domain, depending on solar activity and its interactions with geomagnetic field; the ionosphere may deviate from its nominal behaviour. This happens, for instance, during severe geomagnetic storms. In those cases, it is essential for a safety of life system to confirm that the integrity of the computed ionospheric corrections is still maintained while minimising the impact on availability and continuity of service. For this reason, accurate models or realistic synthetic/measured data of a disturbed ionosphere is needed for a complete system qualification.

Ionospheric amplitude and phase scintillations are important ionospheric impairments on GNSS signals affecting system performance for user receivers, but also for Sensor Stations in the ground segment of the GNSS system. Strong scintillations can induce cycle slips and loss-of-lock in GNSS receivers. Scintillations depend on location, time-of-day and solar activity. Also large spatial and temporal gradients of electron density are observed in low latitude regions and they may impact the performance of safety-of-life carrier smoothing receivers.

Specific developments of semi-codeless tracking GPS receivers for ionospheric scintillation monitoring have been done in the past, which can provide very useful information for nominal scintillation levels, however they are far from robust under strong scintillation activity, not being able to derive enough statistics under extreme cases, which is needed for stringent Integrity and Continuity GNSS requirements. Those receivers have very specific characteristics regarding sampling rate and loops filter bandwidth in order to cope with scintillation without altering the results. The possibility to use codes on signals at various frequencies in Galileo, together with other signal characteristics (C/No, bandwidth, code length, pilot signals ...) will allow designing a robust receiver for ionospheric monitoring.

Solar activity has increased in 2011 and strong events are expected in the coming years.

2. Objectives

Monitor is a project dedicated to understand the impact of ionospheric effects on GNSS systems such as EGNOS and Galileo. Those systems include certain requirements on availability, continuity of service. Some of those requirements are driven by safety-of-life applications such as civil aviation, requiring a complete knowledge of the effects of strong ionospheric events in the performance of the system.

The Total electron content (TEC) is the most important quantity for correcting first and higher order ionospheric range errors. Global and regional TEC products are required for verification of ionospheric error correction capabilities for single and double-frequency services. TEC gradients may also impact the performance of smoothing filters in single-frequency systems, therefore, proper characterisation of gradients is required. The measurements of ionospheric gradients may be used to derive probability density functions of horizontal gradients of ionospheric ionization under different geophysical conditions.

In addition to TEC and TEC gradients is the problem of amplitude and phase scintillations. Indeed, most of the time and in particular at the present time, low-level ionospheric behaviour is observed (and in particular no or few scintillations). This prevents direct experimentation of GNSS performance and robustness, whereas it is well known that significant disruption of service can be induced especially by ionosphere amplitude and phase scintillations. Besides, past observations (e.g. for the last peak around year 2000) do not allow to fill the gap, because of the lack of observations. The few GPS receivers monitoring the scintillation did not allow a full characterisation of the phenomenon, and obviously, no Galileo receiver was present. Also the boreal area was scarcely covered.

These facts have led to base GNSS performance assessment on synthetic state-of-the-art models, such as GISM, with known limitations in the modelling, in particular:

- scintillation conditions during high solar activity (namely when solar flux is higher than 193),
- behaviour in boreal area
- correlation effects (time, space and frequency for amplitude and phase)

One additional purpose of Monitor is to focus the analysis, on the occurrence of abnormal events, on the receiver transfer function and to illustrate the impact on GNSS of some extreme events through dedicated system simulations. This analysis will greatly benefit from the processing various data and products from the same event.

3. Monitor architecture

Monitor is composed by the following elements:

- Central Archiving and Processing Facility (CAPF), which includes the following features:
  - Internal processors.
  - Interface for public and private users (web based).
  - Interface with external processors and external data providers.
  - Interface with Ionospheric Experimental Stations.
  - Archiving and backup system
- Ionospheric Experimental Network including several Ionospheric Experimental Stations (IES)
- External Processors
- External Data Providers

These modules are depicted in Figure 1.

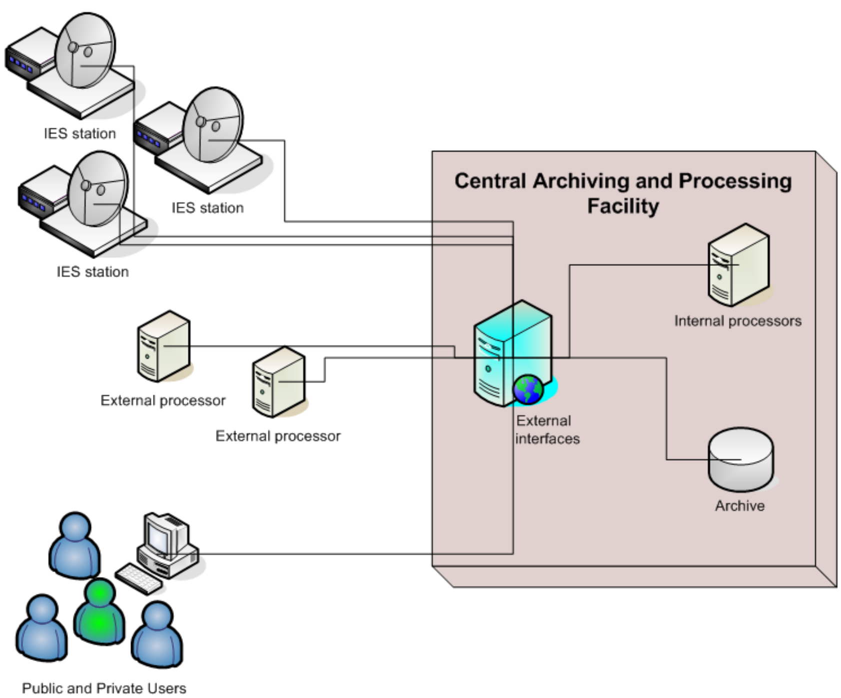

Figure 1. High level architecture of Monitor

For the IES stations, existing stations from a previous project (PRIS) will be incorporated to Monitor. Additionally, new stations will be installed. The selection of stations is shown in Figure 2,. The final list may vary slightly with the possibility to include some of the backup or additional stations as part of the baseline.

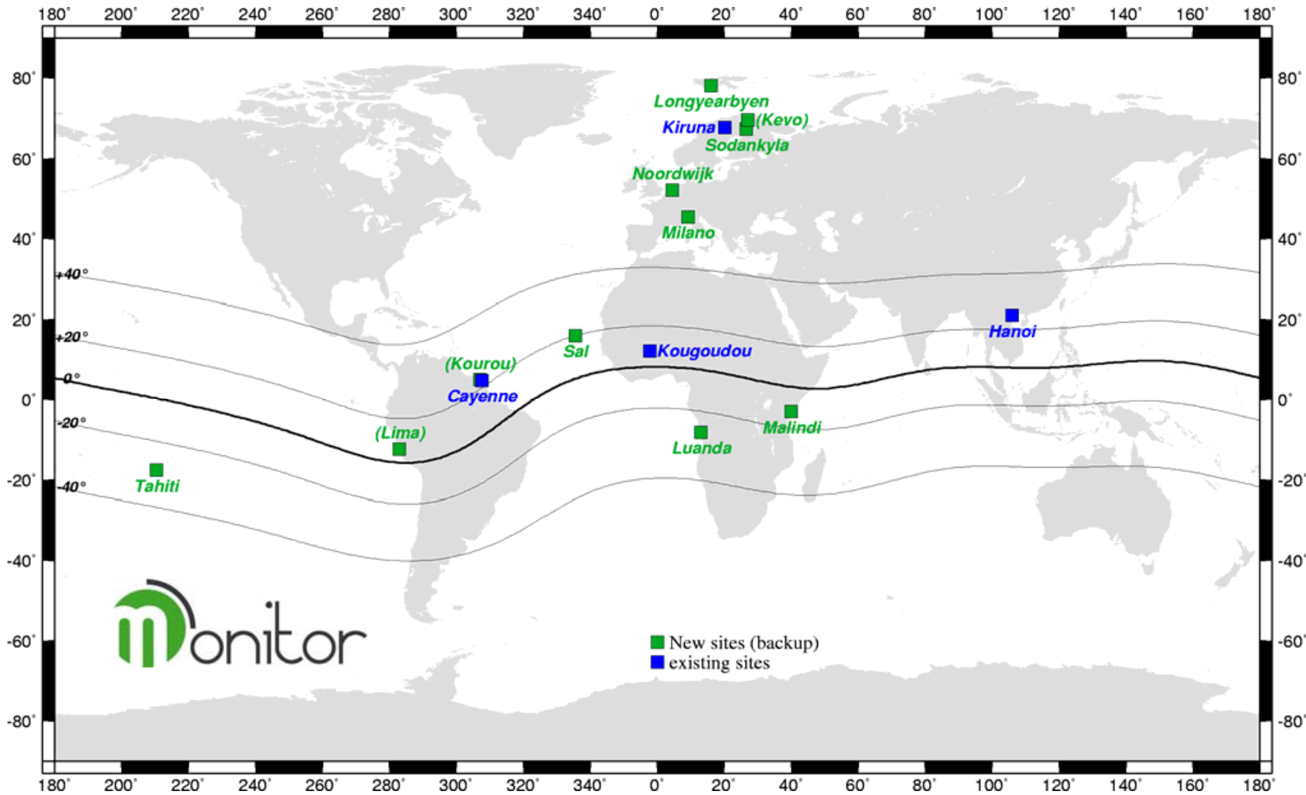

Figure 2 Monitor Ionospheric Experimental Stations (in blue existing stations, in green planned stations)

Four different types of ionospheric scintillation receivers will be installed in the stations. Existing sites include Novatel GSV4004 or Javad receivers. The new stations will include Novatel GSV4004, or Septentrio PolarxS. Two of those stations (Longyearbyen in Svalbard, Norway and Sal in Cap Verde) will include additionally one GISMO receiver and a bitgrabber. The GISMO is a receiver based on previous developments in Thales Alenia Space Italy but adapted for ionospheric scintillation monitoring during the Monitor project. In those two stations, together with the GISMO, a bitgrabber output will be made available to record the I & Q samples in case of strong scintillations (a special interface and configurable scintillation detector has been developed to trigger the bitgrabber when medium to strong scintillation is detected by GISMO).

Preliminary tests have been conducted at ESA / ESTEC (Prieto-Cerdeira, Orus, 2011) using a Spirent generator and a given scenario to assess the receivers performances on occasion of scintillation events. The Novatel and Septentrio receivers have been tested and provide comparable results. This experiment will be complemented with the other receivers.

All sites selected (except Koudougou & Hanoï) incorporate Internet connection allowing a quasi-real-time data processing of most recorded data.

The full deployment of the sites is expected to be completed by summer 2011.

4. Data, Processors and Products

In the IES stations, four types of data will be recorded and sent to CAPF: raw data at 50 Hz, 1 minute pre-processed scintillation data and dual-frequency geodetic Rinex at 1 Hz.

The CAPF external processors correspond to heritage services from some of the Monitor teams. They process data through existing or adapted services and make available products to CAPF. On the contrary the internal processors are implemented inside the CAPF and provide new functionality using data from IES stations, external processors or external data providers and provide processed data. Some of them are processed routinely and some others on demand.

External data will be used for routine or specific analysis such as; Solar Flux at 10.7cm, Ap/Kp and Dst indices, ionosonde data (foF2, M3000, slab thickness, vertical electron density) close to IES stations when available, EISCAT data during limited duration campaign.

From internal and external processors overall, the following products will be generated routinely:

- IES stations Slant TEC & Station Differential Code Biases
- Global VTEC maps from TOMION every 15 minutes
- Sidereal day variability index
- Travelling Ionospheric Disturbance (TID) variability index (able to detect TIDs with amplitudes higher than 0.5 TECU)
- Solar Flare variability index (able to detect most X-class Solar Flares)
- European VTEC maps every 15 minutes from SWACI
- Rapid (2 hours) and ultra-rapid (15 minutes) 3D electron density grid data from EDAM assimilative model
- GEC Global Electron Content index
- Higher-order ionospheric errors from IONEX files
- Optimised Az parameters for Galileo Single Frequency Correction algorithm using a Slant TEC from a large set of IGS-Real Time stations and derived every 6 hours
- Scintillation statistics and mapping
- A correlation of all TEC & scintillations data available (IES + EXT) with space weather parameters such as solar flux, Kp, Ap, DST and others...

5. Experimental campaigns

Apart from routine data archiving and product generation, a number of experimental campaigns are planned. In 2011, an active EISCAT heating campaign is planned in order to compare TEC changes and generation of scintillations.

Ionospheric Scintillation specific campaigns include high-latitude winter campaign to study the link of high-latitude scintillations to substorm phenomena, the comparison of 50 Hz scintillation data with standard data and products from existing co-located (or nearby) 1Hz receivers, coordination with Brazilian ionospheric scintillation network for retrieving the fluctuating medium properties, capture and analysis of medium to strong scintillation events with bitgrabber.

Other campaigns in the plan are related to determination of Medium Scale TIDs propagation parameters and its impact on precise GNSS positioning, the propagation of ionospheric perturbations from high to mid-latitudes and assessment of storm and threat models for Satellite and Ground Based Augmentation Systems.

6. Summary

The Monitor project architecture has been presented including the planned deployment of ionospheric experimental stations, plans for experimental campaign and the list of data and products to be derived routinely. The full deployment and start of operations is planned after Summer 2011 and it is expected to operate for a minimum 18 months.

7. Acknowledgements and disclaimer

The Monitor project federates several European experienced teams. It continues some work initiated in the ESA / ESTEC PRIS project (Béniguel, 2009). The PRIS group has been enlarged to include additional teams in order to fulfil the more demanding Monitor requirements.

The following teams are participating to the project (by alphabetical order): CLS (Toulouse, France), DLR (Neustrelitz, Germany), Finish Meteorological institute (Helsinki, Finland), gAGE-UPC (Barcelona, Spain), GMV (Madrid, Spain), ICTP (Trieste, Italy), IEEA (Paris, Fr), Jena-Optronik (Jena, Germany), QinetiQ (Malvern, UK), Télécom Bretagne (Brest, France), Thales Alenia Space France (Toulouse, France), Thales Alenia Space Italy (Milano, Italy).

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