

The Ionosphere Prediction Service

Carlo Albanese¹, Filippo Rodriguez¹, Roberto Ronchini¹,
Stefano Di Rollo¹, Francesco Berrilli², Alice Cristaldi²,
Dario Del Moro², Roberta Forte², Giorgiana De Franceschi³,
Claudio Cesaroni³, Luca Spogli³, Vincenzo Romano³,
Marcio Aquino⁴, Sreeja Vadakke Veetil⁴, Osman Kalden⁵,
Michael Hutchinson⁶ and Eric Guyader⁷

¹Telespazio, Rome, Italy

²University of Rome “Tor Vergata”, Rome, Italy

³Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy

⁴University of Nottingham, Nottingham, UK

⁵Telespazio Vega DE, Darmstadt, Germany

⁶Nottingham Scientific Ltd, Nottingham, UK

⁷European Commission, Bruxelles, Belgium

Abstract. The aim of the Ionosphere Prediction Service (IPS) project is to design and develop a prototype platform to translate the prediction and forecast of the ionosphere effects into a service customized for specific GNSS user communities. The project team is composed by Telespazio (coordinator), Nottingham Scientific Ltd, Telespazio Vega Deutschland, the University of Nottingham, the University of Rome “Tor Vergata” and the Italian Istituto Nazionale di Geofisica e Vulcanologia (INGV). The IPS development is conceived of two concurrent activities: prototype service design and development & research activity that will run along the whole project. Service design and development is conceived into four phases: user requirements collection, architecture specification, implementation and validation of the prototype. A sub-activity analyses also the integration feasibility in the Galileo Service center, located in Madrid. The research activity is the scientific backbone of IPS that will provide the models and algorithms for the forecasting products.

Keywords. Sun: CMEs, Sun: activity

1. Introduction

Changes of the environmental conditions in the near-Earth space (space weather) due to solar transient events, such as flares or Coronal Mass Ejections (CMEs), can affect the performance and longevity of space-borne and ground-based technological systems. Space weather monitoring and forecasting is thus of crucial importance to prevent harmful effects on the technological society. Within this context, the Ionosphere Prediction Service (IPS) aims to develop specific methodologies and techniques in order to monitor and predict changes in the physics of the ionosphere that can affect the Global Navigation Satellite System (GNSS) performance.

2. User Requirements

IPS is designed on the basis of GNSS users requirements. Indeed, representatives of the user communities (Aviation, High Accuracy, Mass Market and the Emerging Applications) have been contacted to fill a questionnaire about IPS objectives, and provided a collection of requirements used to define the service components, based on the evaluation and prediction of ionospheric effects on GNSS receivers. Specifically, the Aviation

community highlighted the importance of an ionospheric prediction service since GNSS is critical to performance-based navigation operations, including both en-route and run-way approach operations. High Accuracy GNSS service providers expressed their need to account for ionospheric effects in order to achieve the levels of positioning accuracy required by their customers. Liability Critical Applications users stressed the consequences on navigation of undetected GNSS miss-performances, which can generate significant legal or economic consequences. Furthermore, Smart grids and Micro grids, where timing accuracy and continuity is more challenging, are particularly threatened by GNSS service outages. Finally, it is worth mentioning the impact of space weather on the financial services. Some operations in this sector depend on accurate timing, provided by GNSS and commonly used to generate time stamps for financial transactions. All those infrastructures can be affected by ionospheric events.

3. Sensor Networks

High-quality data recorded from both ground-based and satellite-based instruments allow to monitor and forecast the ionospheric changes and solar eruptive events. We provide here a list of the sensor networks employed to monitor the ionospheric and near-Earth environment:

- The Ionospheric Scintillation Monitor Receivers (ISMR) network, composed by 12 GNSS stations with standard dual frequency receivers (NovAtel GSV4004) or with special scintillation high rate receivers (50 Hz Septentrio PolaRxS).
- The RING geodetic network, composed by $\simeq 180$ GPS dual-frequency receivers distributed over Italy. L1 and L2 signals from GPS satellites are acquired by RING receivers at 30 s sampling period and sent to 2 main servers located at INGV premises in Rome and Grottaminarda (in Southern Italy).
- GONG (Global Oscillation Network Group), managed by the National Solar Observatory (NSO), H-Alpha worldwide Network composed by 6 sites equipped with a Fourier tachometer.
- MOTH (Magneto-Optical filters at Two Heights), a 20 cm telescope equipped with 2K x 2K CMOS cameras providing magnetogram, intensity and velocity maps at two different layers of the solar atmosphere.
- HMI (Helioseismic and Magnetic Imager, Schou *et al.* 2012), an instrument designed to study oscillations and the magnetic field at the solar surface, aboard the SDO (Solar Dynamic Observatory, Pesnell *et al.* 2012) satellite.
- AIA (Atmospheric Imaging Assembly, Lemen *et al.* 2012), aboard the SDO, which observes the solar corona by taking images that span at least 1.3 solar diameters in multiple wavelengths, at a resolution of about 1 arcsec.
- LASCO (Large Angle and Spectrometric Coronagraph, Brueckner *et al.* 1995), one of the instruments aboard the Solar and Heliospheric Observatory satellite, which consists of three solar coronagraphs with three nested fields of view.
- PAMELA (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) satellite-borne experiment, which has been measuring particle (100 MeV - 100 GeV) fluxes in polar orbit. Due to the unavailability of PAMELA data since the beginning of 2017, the project will continue using the GOES-13 satellite proton fluxes.

4. Research Activities

Current studies related to flares and CMEs predictions, ionospheric changes and disturbances are carried out by the University of Rome "Tor Vergata" (flare, CME and energetic

particles now- and fore-casting; see, e.g. Berrilli *et al.* 2014, Di Fino *et al.* 2014, Romano *et al.* 2015), the INGV (ionospheric plasma morphology and dynamics, scintillation mapping and modelling on global and/or regional scale; see, e.g., Spogli *et al.* 2013, Spogli *et al.* 2016, Cesaroni *et al.* 2017), and the University of Nottingham (modelling and prediction of GNSS errors, detection of travelling ionospheric disturbances in collaboration with INGV; see, e.g., Sreeja *et al.* 2011, Sreeja *et al.* 2012, Aquino *et al.* 2013).

5. IPS Architecture

The IPS architecture is based on the following elements:

- Sensors: this layer collects all the elements used to gather raw data for the space weather and ionospheric products generation.
- Remote Processing Facilities (RPFs): these processing elements generate space weather and ionospheric products starting by collected raw data or intermediate products generated by other RPFs. They interact with both the remote sensors for the collection of the needed input data and the central storage to save the generated products, retrieve and process data from other RPFs or trigger one or more processes implemented in the central unit. In particular, each RPF deals with:
 - RPF-1: Sun activity, such as sunspots, solar flares, CMEs, solar energetic particles.
 - RPF-2: ionosphere activity, such as Total Electron Content variation, scintillation and travelling ionospheric disturbances (RPF-2 products are input to both RPF-3 and RPF-4).
 - RPF-3: forecast of disturbance at receiver level: loss of lock, position error, tracking error.
 - RPF-4: monitor and forecast of the ionospheric effects on the performance of GNSS systems at service level for several classes of users. It also provides ABAS (Aircraft-based Augmentation System) and SBAS (Satellite-based Augmentation System) forecast services to civil aviation users, including integrity, accuracy, availability and continuity.
- Central Storage and Processing Facility (CSPF): this is the IPS central facility that implements all the functionalities related to the collection and distribution of the products and the interactions with the GNSS user communities.

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