The Ionosphere Prediction Service for GNSS users

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The Ionosphere Prediction Service (IPS) project has the aim to design, implement and operate a prototype for the monitoring and the prediction of ionosphere-related disturbances affecting GNSS user communities.
The project is developed in the framework of the Galileo Programme, with the view to offer to GNSS users a prediction service of potential degradation of service performance. It is funded by the European Union's R&D programme Horizon 2020. The project team is composed of Telespazio (coordinator), Nottingham Scientific Ltd, Telespazio Vega DE, The University of Nottingham, The University of Rome Tor Vergata and the National Institute of Geophysics and Volcanology.
The IPS development is composed of two concurrent activities: the design and development of the prototype service, and the research activity that will run along the whole project. The final part of the project are dedicated to operations.
The design and development of the service is organized in four phases: the collection of user requirements, the architecture specification, the implementation and validation of the prototype. A sub-activity analyses also the integration feasibility in the Galileo Service Center, located in Madrid.
The prediction models of IPS are based on the results of the research activity carried out during the project. It represents the scientific backbone of IPS.
The IPS service prototype is conceived with a 4-layer architecture:

- The external sensors which provide the input to the processors that run the algorithms;
- The processors, called RPFs, Remote Processing Facilities, that are in charge to run the forecasting and nowcasting algorithms;
- The Central Storage and Processing Facility (CSPF), that manages the output of the chain of processors;
- The Web Portal that is the final user interface

The IPS products are thought to monitor and forecast the solar and ionospheric activity and its well-known effect on GNSS signals and on the final performances of user applications; a whole class of products translates the observation of the atmospheric behavior and perturbations into predictions of GNSS performance figures at user level.
The four RPFs are in charge to generate the several products.

- The RPF 1 is dedicated to the monitoring and prediction of the Solar events like Coronal Mass Ejections (CME), Flares and Solar Energetic Particles (SEP). The input data are provided by several sensors and scientific payloads like among the others, GOES X, SOHO, MOTH telescope etc.
- The RPF 2 is dedicated to the Ionosphere monitoring where TEC and scintillation estimation are nowcasted and forecasted at Regional and Global level. It takes as input several GNSS reference station data (e.g. IGS) and scintillation data (e.g. the Ionosphere Scintillation Monitor Receiver (ISMR) network).
  For Regional and global products scintillation is provided through the ROTI (rate of TEC index) parameter, but direct output of scintillation values are monitored in specific stations.

- The RPF 3 and the RPF 4 take as input the ionosphere estimation provided by the RPF 2 and they are able to monitor and predict of the GNSS related performance at local and global level. In particular the RPF 3 is dedicated to high accuracy users while RPF 4, developed by Telespazio, provides, among the others, nowcasting and forecasting of aviation related performance figures at regional and global level.

The user can select his own products of interest and display them on the IPS Web Site by using widgets. Products are then refreshed in real-time, thereby allowing regular checks without having to reload the computation. In this sense, the web page is conceived as an operator's console.
An alert system has been put in place applicable to those products for which is possible to configure an alarm. For such products, the user can generate an alert with a specific threshold; the user can also set directly the geographical area of interest, by setting in lat/lon values of interest. The result of the configuration is the appearance of a gauge widget associated to the alarm in the user page. Warnings will be notified via mail after the alarm generation. The IPS service is able to promptly provide different warnings related to the same product for different users. The procedure is thought to demonstrate how the IPS service is capable of diversifying the alarm generation for its subscribers.
All the available products are also downloadable through an archive specific page of the portal in the form of internal IPS raw data format. Specific instructions are provided to decode this format with a simple pseudocode.

An important part of the paper is dedicated to the evidence of the goodness of the products that was achieved through an extensive validation campaign.
The validation was carried out through two different strategies. The first provided a statistical characterization of the behavior of the service using the "retro-validation" IPS products, measuring the discrepancy between the prediction and the actual value of the specific event.
A sufficient number of retro-validation realizations can be used to derive a statistic of the specific product. The historical data of IPS will be retained in order to enrich such statistics in benefit of the users.
The second method was based on the direct comparison of the IPS forecasting and nowcasting products against external ones (i.e. coming from other services). Typical external sources are IGS real time products, against which the IPS predictions are compared.
Since IPS development was carried out in a period of quiet Solar activity, historical analysis is needed in order to provide evidence of the behavior of the service in presence of events of different magnitude.
The performance of the developed algorithms to generate the RPF-1 forecast products have been assessed using historical data, where available. Differences between the observed events recorded in the catalogues and the produced forecast was analyzed and characterized to assess the goodness of the IPS products.
In the case of the RPF 2, 3 and 4 products five events of recent geomagnetic storms with different geomagnetic values (from G1 to G4, https://www.swpc.noaa.gov/noaa-scales-explanation) were selected to run the forecasting algorithms and compare the forecast to the actual monitored values from the external data sources .
In all the cases the IPS generated products demonstrate a high correspondence with the actual measured values, confirming the goodness of the service.

The IPS will be freely accessible, upon registration, through its web portal and from June 2018 the project team will operate the prototype for a 6-month period. User feedback will be collected during the period.