Ionospheric prediction tools in IPS EU-Project

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\textsuperscript{3}SpacEarth Technology, Italy

UN/USA Workshop on the ISWI 2017: The Decade after the International Heliophysical Year 2007
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Outline

• IPS project
• Ionospheric nowcasting and forecasting tools
• Validation
• Tools in operation
• Final remarks
“Ionosphere Prediction Service” (IPS) is a project funded by European Commission through the Tender contract No:434/PP/GRO/RCH/15/8381.

The objective of IPS project is to design and develop a prototypal service platform with the aim to translate the current status and forecast of the ionosphere into tangible results and user-devoted metrics.

The pillar of this service are:

- characterization of ionospheric effects that influence the GNSS performance and improvement of current solutions to monitor and predict the ionospheric Space Weather effects;
- generate, archive and distribute performance and prediction reports, analysis results, disseminate alert and early-warning messages, sensor data, etc., customized to the relevant user communities on the basis of the requirements defined for each of them;
- Implementation of a front-end platform to interface the user communities providing dedicated services and presenting relevant monitoring and forecast data results.
<table>
<thead>
<tr>
<th>Team Member</th>
<th>Type</th>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telespazio</td>
<td>Industry</td>
<td>Prime Contractor. In charge of IPS design, development and testing activities.</td>
</tr>
<tr>
<td>Telespazio VEGA Germany</td>
<td>Industry</td>
<td>Involved in T5 (IPS Service Requirements), support to T6 and T9</td>
</tr>
<tr>
<td>NSL (Nottingham Scientific Ltd)</td>
<td>Industry</td>
<td>Involved in T2 (User Req analysis), T6 (warning message generation) and T9 (feedback from aviation UC).</td>
</tr>
<tr>
<td>University of Tor Vergata</td>
<td>University</td>
<td>Monitoring and forecast of Flares and Coronal Mass Ejections. Measurements of SEP and GCR.</td>
</tr>
<tr>
<td>INGV</td>
<td>Research Institute</td>
<td>Forecast and nowcast of VTEC, spatial and temporal gradients, Proxy Scintillation Indices (PSI), S4, σ₀</td>
</tr>
<tr>
<td>University of Nottingham</td>
<td>University</td>
<td>Prediction of GNSS tracking errors, loss of signal lock and expected levels of positioning errors. Detection of Travelling Ionospheric Disturbances (TIDs).</td>
</tr>
</tbody>
</table>
Ionospheric Prediction Tools EU Project

Long term forecasting TEC at global level

Long term forecasting Proxy Scintillation Index at global level

Short term forecasting TEC over Italy

Nowcasting scintillation indices over Europe

Nowcasting TEC at global level

Nowcasting Ionospheric Range Error over Europe
Ionospheric tools
# Ionospheric TEC and Scintillation tools

<table>
<thead>
<tr>
<th>Parameter(s)</th>
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<tr>
<td>TEC, IRE, TEC_gradNS, TEC_gradEW</td>
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<td>Scintillation indices (S4, $\sigma_\Phi$)</td>
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### Ionospheric TEC nowcasting and short-term forecasting

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# Ionospheric Scintillation Nowcasting

Scintillation nowcasting over Europe

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</tbody>
</table>
## TEC nowcasting over Europe

### Parameter(s)
- TEC, IRE, TEC\_gradNS, TEC\_gradEW

### Type of casting
- Nowcasting

### Refresh rate
- 15 min

### Coverage
- Europe

### Spatial Resolution
- 0.5° x 0.5° (lat x long)

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### Diagrams

- **TOTAL ELECTRON CONTENT**
  - 31-01-17 13:15 UT
  - Total Electron Content (TECu)

- **IONOSPHERIC RANGE ERROR on L1**
  - 31-01-17 13:15 UT
  - Ionospheric Range Error (m)

- **TEC N-S Gradient**
  - 31-01-17 13:15 UT
  - TEC N-S Gradient (TECu/m)

- **TEC E-W Gradient**
  - 31-01-17 13:15 UT
  - TEC E-W Gradient (TECu/m)

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**Around 60 stations from IGS/EUREF**
Nowcasting TEC at global level

21 December 2016 at 14:00 UT
Around 120 IGS stations

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Long term forecasting TEC at global level

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Nowcasting PSI at global level

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$$sDPR = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\bar{\psi} - \psi_i)^2}$$

$$\psi_i = \frac{\Phi_g^{t_i} - \Phi_g^{t_{i-1}}}{t_i - t_{i-1}}$$

$sDPR = \text{sigma delta phase rate}$

$\Phi_g$ is the carrier phase at the $i-th$ epoch
Long-term prediction of scintillation (24 hours)

\[
ROT = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}
\]
Validation
Validation of TEC nowcasting over Italy

Validation (offline) of the TEC measurement:
Comparison against Ciraolo calibration technique

Ciraolo et al., 2007

Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 0.7873 (0.7765, 0.7981)
p2 = 1.212 (1.114, 1.31)

Goodness of fit:
SSE: 1.926e+04
R-square: 0.7772
Adjusted R-square: 0.7771
RMSE: 1.809

1 day of data
Validation of TEC nowcasting over Europe

Validation of the TEC measurement: Comparison against ROB TEC maps

INGV TEC–ROB TEC
Mean

INGV TEC–ROB TEC
Std

1 month of data (May 2017)
Validation of TEC forecasting products

Global
Mean = 0.3546
RMSE = 2.2846

Europe
Mean = 0.4679
RMSE = 1.3306

Italy
Mean = 0.4979
RMSE = 0.76021

15-16 February 2017
Tools in operation
IONORING - Real-time Total Electron Content over Italy

The main goal of the IONORING (IONospheric RING) project is to exploit data from the RING (Rete Integrata Nazionale ODISI) network to obtain ionospheric Total Electron Content (TEC) maps with very fine spatial resolution in latitude, longitude. These maps will be useful to support ionospheric event mitigation in precise positioning and to study the ionosphere microphysics and dynamics during strong solar and geomagnetic storms affecting the mid-latitude ionosphere. This page reports the TEC maps generated in real-time every 10 minutes collecting data from about 90 stations.

http://ionos.ingv.it/Ionoring/ionoring.htm

TOTAL ELECTRON CONTENT
15-07-17 00:10 UT
Quiet day

TOTAL ELECTRON CONTENT
16-07-17 00:10 UT
Disturbed day
Final Remarks

• INGV has a large community involved in investigation of ionosphere and Space Weather
• INGV and Italy have a consolidated international role in several Space Weather projects and initiatives
• Several scientific results became innovative tools and services to operation
• INGV is happy to start the collaboration with ISWI and to reinforce the Italian contribution to the community
Thank you!

vincenzo.romano@ingv.it
Backup slides
Potential users

- GNSS service providers
  - Aviation
  - Maritime
  - Agriculture
  - High precision
- Space weather centres
- Research centres
Most relevant on-going projects/initiatives

- **DemoGRAPE**: Demonstrator of GNSS Research and Application for Polar Environment, PNRA
- **GRAPE**: GNSS Research and Application for Polar Environment, SCAR
- **TREASURE**: Training, REsearch and Applications network to Support the Ultimate Real time high accuracy EGNSS solution, H2020-ITN Marie Curie
- **IRIS**: Ionospheric Research for Biomass in South America, ESA
- **IBISCO**: Ionospheric environment characterization for Biomass Calibration over South East Asia, ESA
- **IPS**: Ionospheric Prediction Service, EC
- **Arctic Table at the Italian Ministry of Foreign Affairs**: Task Force on Telecommunication Infrastructures in the Arctic (TFTIA) within the Arctic Council
- **PNRA"Geomagnetic Observatory at Mario Zucchelli station"**.
- **PNRA"Geomagnetic Observatory at Concordia station - Dome C, Antarctica"**.
- **PNRA"Italian magnetometer network for longitudinal and latitudinal monitoring in Antarctica"**.
- **PNRA “Upper atmosphere observations and Space Weather”**
- **PNRA “Bipolar Ionospheric Scintillation and TEC”**
- **COPUOS - Committee on the Peaceful Uses of Outer Space – SW expert group**
- **ISWI – International Space Weather Initiative**
Recent and main publications

- Belehaki A. et al., The ESPAS e-infrastructure: Access to data from near-Earth space., ASR, 2016
- Cesaroni C. et al., L-band scintillations and calibrated total electron content gradients over Brazil during the last solar maximum. JSWSC, 2015.
- Cesaroni C. et al., The Ionosphere Prediction Service Project. 32 nd URSI GASS, Montreal, 19-26 August 2017
- D'Angelo G. et al. GNSS data filtering optimization for ionospheric observation. ASR, 2013
- Grzesiak M et al., Regional short-term forecasting of ionospheric TEC and scintillation, submitted to RS, 2017
- Lepidi S. et al., A study of geomagnetic field variations along the 80°S geomagnetic parallel, AG, 2017.
- Moen J. Et al., Space weather challenges of the polar cap ionosphere, JSWSC, 2013.
- Olwendo O. J. and Cesaroni C., Validation of NeQuick 2 model over the Kenyan region through data ingestion and the model application in ionospheric studies, JASTP, 2016.
- Prikryl P. et al., An interhemispheric comparison of GPS phase scintillation with auroral emission observed at the South Pole and from the DMSP satellite, AoG, 2013.
- Romano V. et al., eSWua: a tool to manage and access GNSS ionospheric data from mid-to-high latitudes. AoG, 2013.
- Romano, V. et al., The IDIPOS project: is a multidisciplinary data infrastructure for weather and space weather feasible? AoG, 2013.
- Spogli L. et al., GPS scintillations and total electron content climatology in the southern low, middle and high latitude regions, AoG, 2013.
Ionospheric observations
Ionospheric Observatories

Gibilmanna (Italy)
- Rhombic Antennas (TX and RX)
- AIS - INGV

S. Miguel de Tucumán and Bahia Blanca (Argentina)
- Delta Antennas (TX and RX)
- AIS – INGV with AUTOSCALING

Rome (Italy)
- AIS - INGV

Mario Zucchelli Station (Antarctica)
- AIS - INGV

Space Weather forecast
Achievement of forecasting and nowcasting three dimensional (3-D) electron density mapping of the ionosphere.

Real-Time Alert of Ionospheric Storm based on HF methods

Real-time autoscaling
GNSS receivers network for ionospheric scintillation and TEC (including Galileo)

- First receiver installed at Ny-Alesund (Svalbard) on 2003
- Polar ionosphere
  - Svalbard islands (4)
  - Antarctica (5)
- Mid latitude ionosphere
  - Chania (Crete)
  - Huelva (Spain) – stopped
  - Huelva station moved to Lampedusa (Sicily, Italy)
- Equatorial Ionosphere
  - Tucuman (Argentina)

Data are accessible at the electronic Space Weather upper atmosphere website

[www.eSWua.ingv.it](http://www.eSWua.ingv.it)
[www.spaceweather.it](http://www.spaceweather.it)