Ionospheric prediction tools in IPS EU-Project

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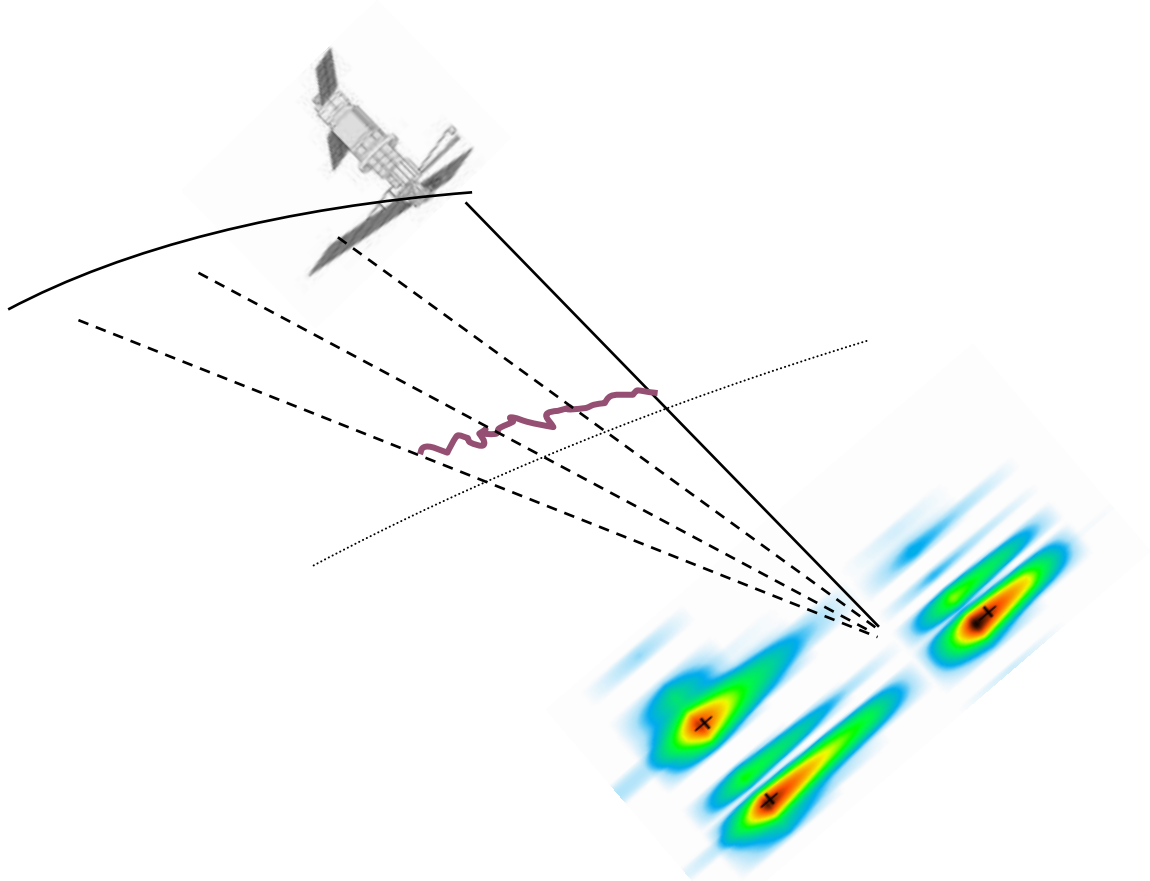
UN/USA Workshop on the ISWI 2017: The Decade after the International Heliophysical Year 2007

Boston, 31 July - 04 August 2017

Outline

- IPS project
- Ionospheric nowcasting and forecasting tools
- Validation
- Tools in operation
- Final remarks

IPS Project



- "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.

Team Member	Type	Roles
Telespazio	Industry	Prime Contractor. In charge of IPS design, development and testing activities.
Telespazio VEGA Germany	Industry	Involved in T5 (IPS Service Requirements), support to T6 and T9
NSL (Nottingham Scientific Ltd)	Industry	Involved in T2 (User Req analysis), T6 (warning message generation) and T9 (feedback from aviation UC).
University of Tor Vergata	University	Monitoring and forecast of Flares and Coronal Mass Ejections. Measurements of SEP and GCR.
INGV	Research Institute	Forecast and nowcast of VTEC, spatial and temporal gradients, Proxy Scintillation Indices (PSI), S4, σ_{Φ}
University of Nottingham	University	Prediction of GNSS tracking errors, loss of signal lock and expected levels of positioning errors. Detection of Travelling Ionospheric Disturbances (TIDs).

Istituto Nazionale di Geofisica e Vulcanologia

Ionospheric Prediction Tools EU Project

INGV

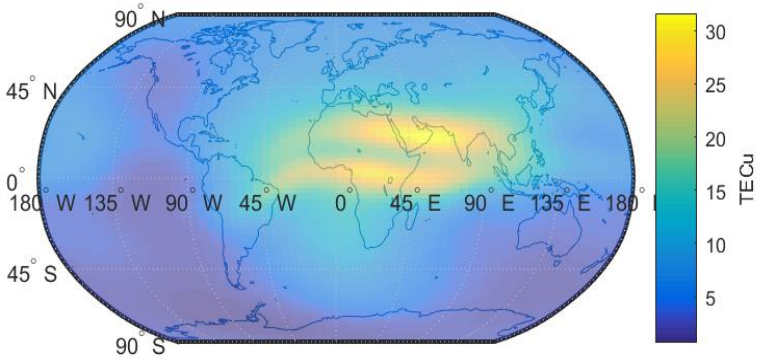
TELESPAZIO a LEONARDO and THALES company

INGV

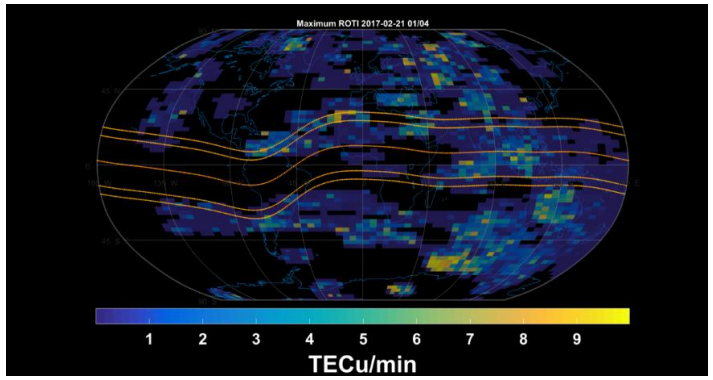
The University of Nottingham UNITED KINGDOM - CHINA - MALAYSIA

NSL

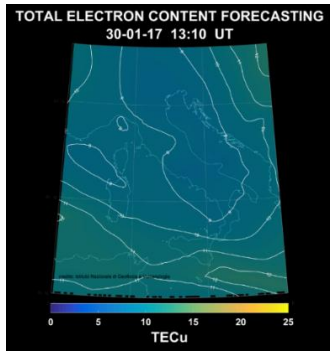
Università di Roma Tor Vergata



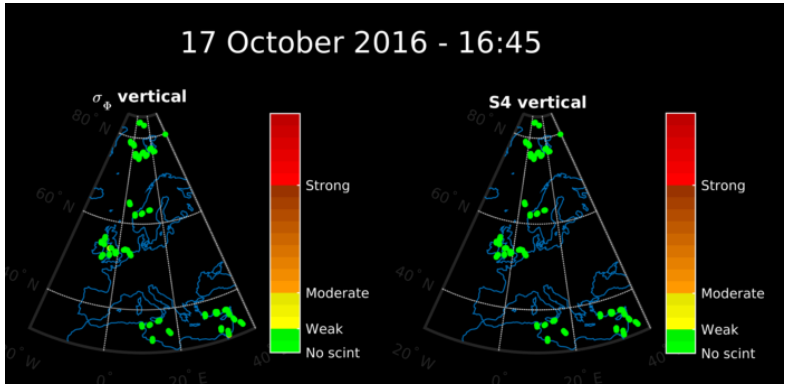
Long term forecasting TEC at global level



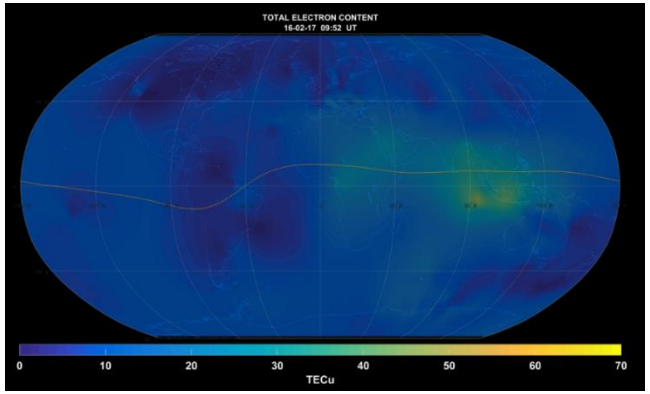
Long term forecasting Proxy Scintillation Index at global level



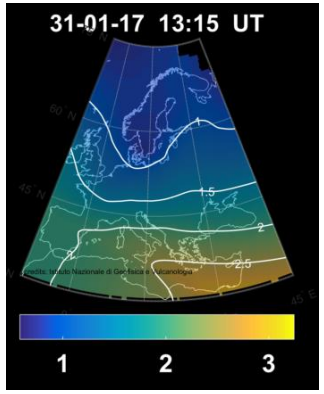
Short term forecasting TEC over Italy



Nowcasting scintillation indices over Europe

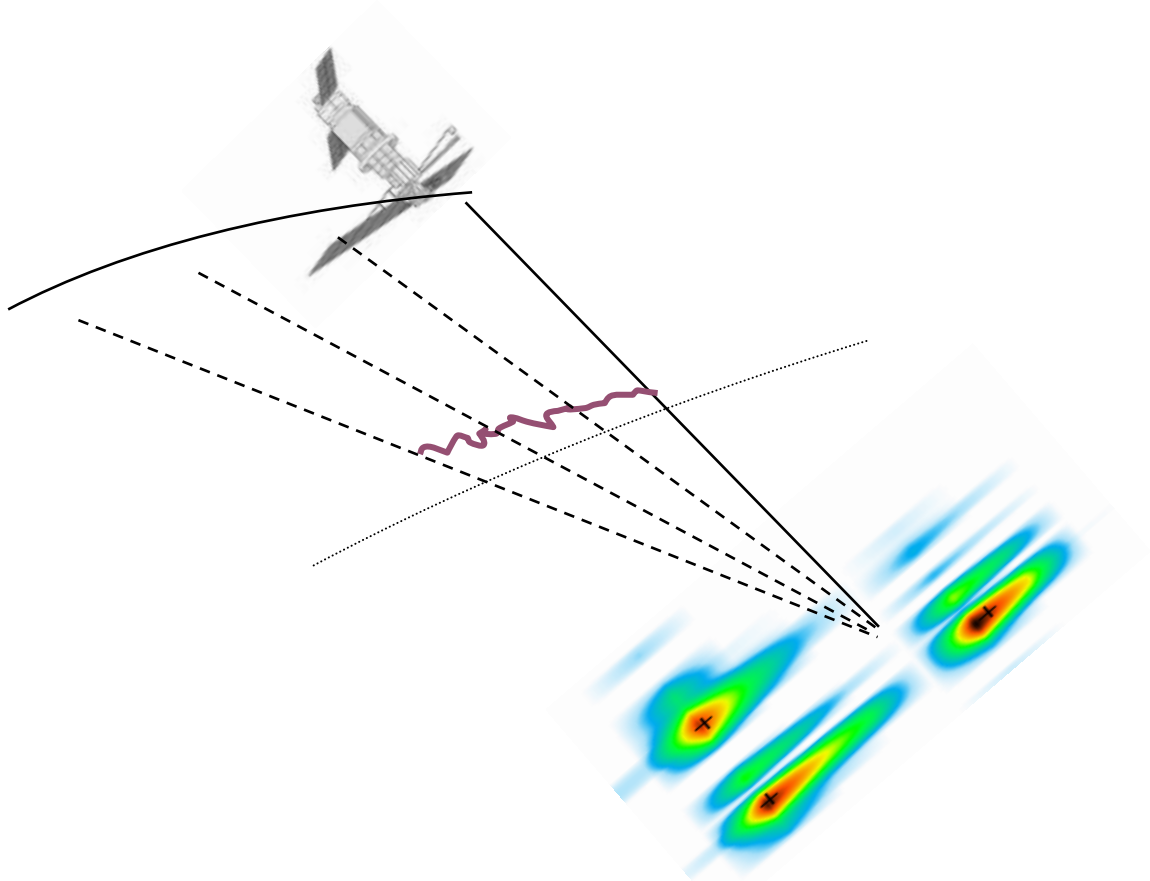


Nowcasting TEC at global level



Nowcasting Ionospheric Range Error over Europe

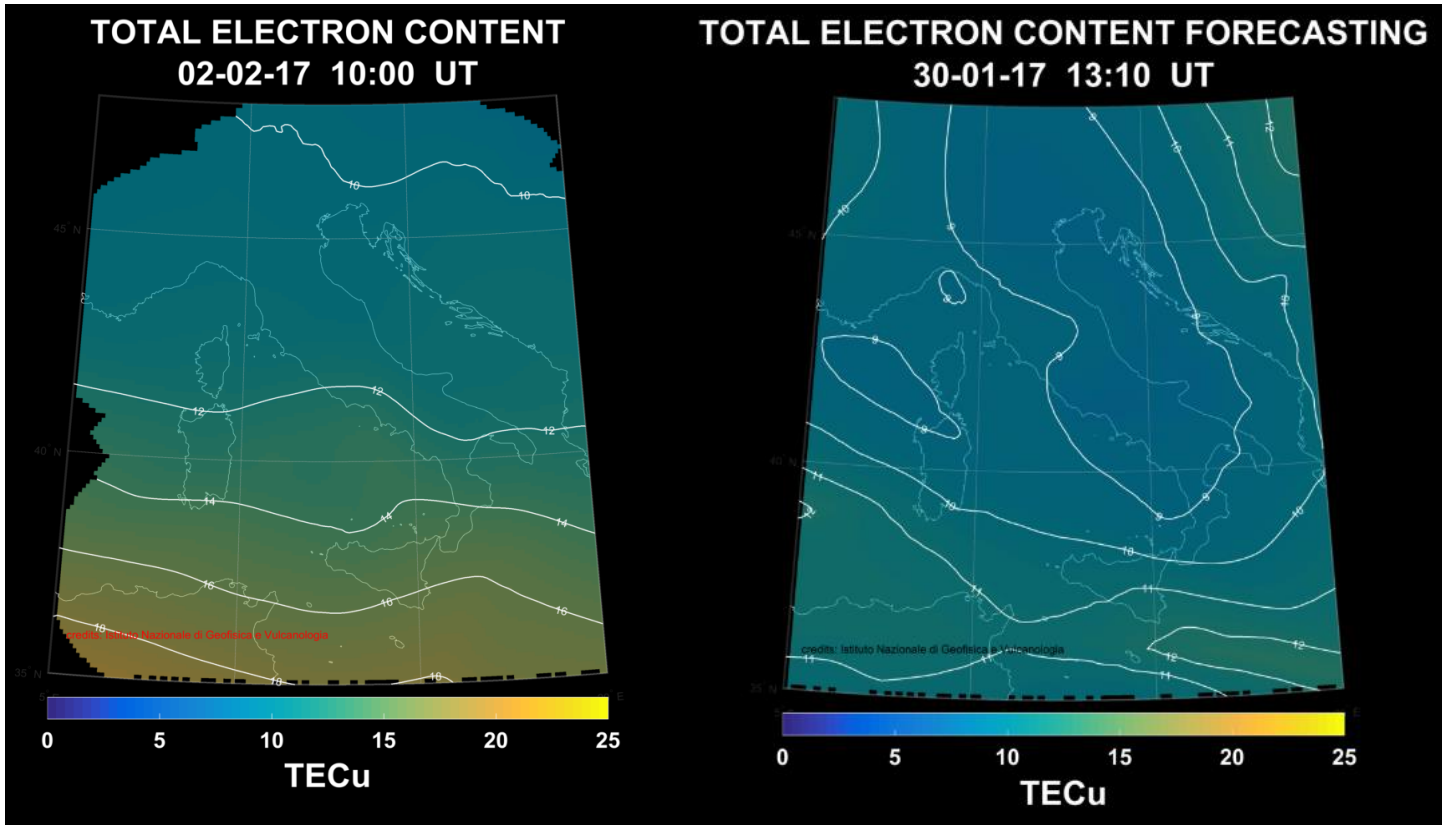
Ionospheric tools



Ionospheric TEC and Scintillation tools

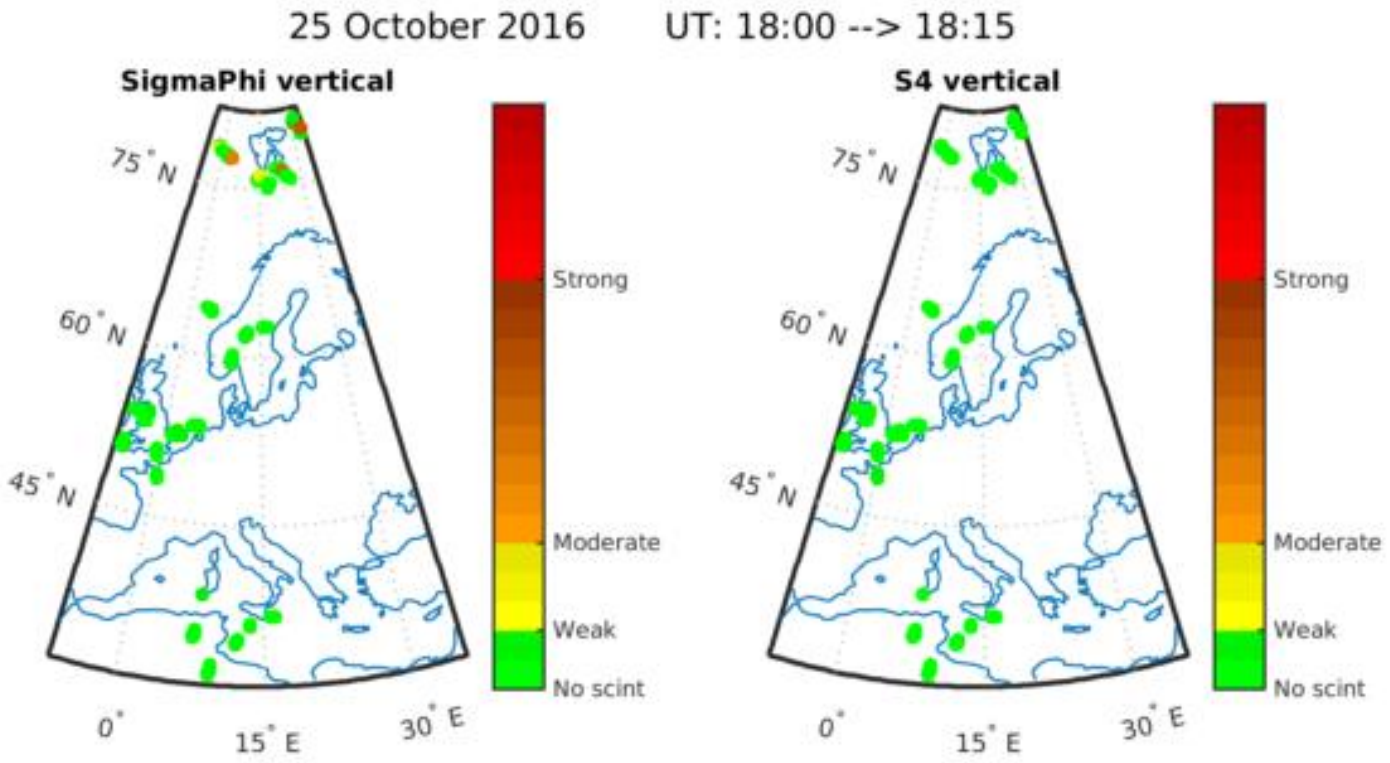
Parameter(s)	Type of casting	Refresh rate (min's)	Coverage	Spatial Resolution (lat x long)
TEC, IRE, TEC_gradNS, TEC_gradEW	Nowcasting	10	Italy	0.1° x 0.1°
TEC, IRE, TEC_gradNS, TEC_gradEW	Nowcasting	15	Europe	0.5° x 0.5°
TEC, IRE, TEC_gradNS, TEC_gradEW	Nowcasting	15	Global	2.5° x 5°
TEC, IRE	Short term (30 minutes)	10	Italy	0.1° x 0.1°
TEC, IRE	Short term (30 minutes)	15	Europe	0.5° x 0.5°
TEC, IRE	Short term (30 minutes)	15	Global	2.5° x 5°
TEC, IRE	Long term (24 hours)	120	Global	2.5° x 5°
Scintillation indices (S4, σ_Φ)	Nowcasting	15	Europe	Values at the IPP
Proxy scintillation indices (PSI)	Nowcasting	15	Global	2.5° x 5°
Proxy scintillation indices (PSI)	Long term (24 hours)	180	Global	2.5° x 5°

Ionospheric TEC nowcasting and short-term forecasting



Parameter(s)	Type of casting	Refresh rate (min's)	Coverage	Spatial Resolution (lat x long)
TEC, IRE, TEC_gradNS, TEC_gradEW	Nowcasting	10	Italy	0.1° x 0.1°
TEC, IRE	Short term (30 minutes)	10	Italy	0.1° x 0.1°

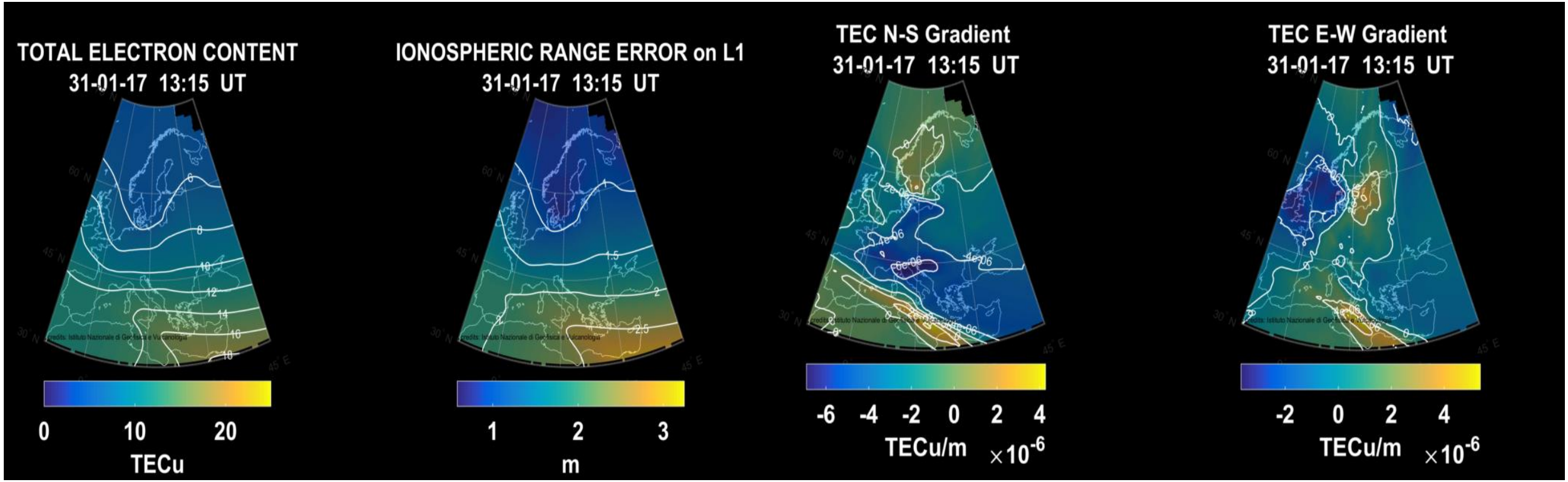
Ionospheric Scintillation nowcasting



Scintillation nowcasting over europe

Parameter(s)	Type of casting	Refresh rate (min's)	Coverage	Spatial Resolution (lat x long)
Scintillation indices (S4, σ_Φ)	Nowcasting	15	Europe	Values at the IPP

TEC nowcasting over Europe

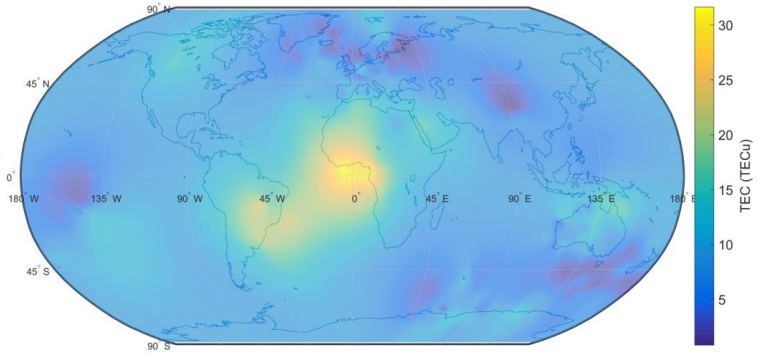


Around 60 stations from IGS/EUREF

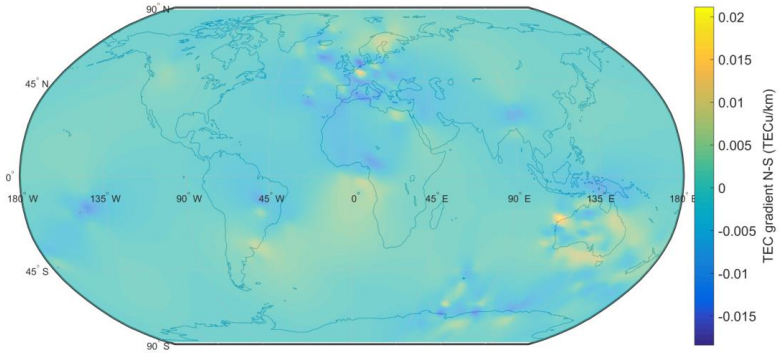
Parameter(s)	Type of casting	Refresh rate	Coverage	Spatial Resolution
TEC, IRE, TEC_gradNS, TEC_gradEW	Nowcasting	15 min	Europe	0.5° x 0.5° (lat x long)

Nowcasting TEC at global level

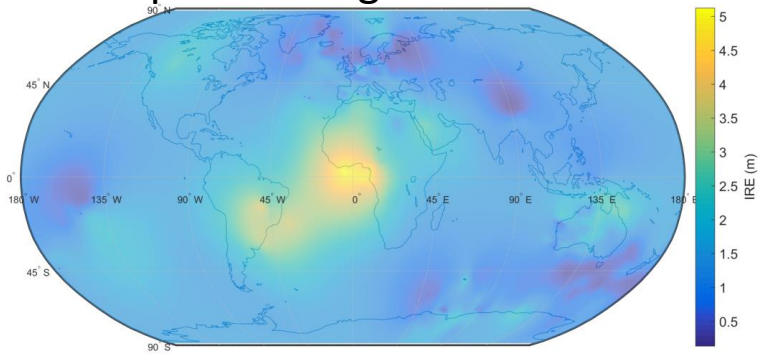
Total Electron Content



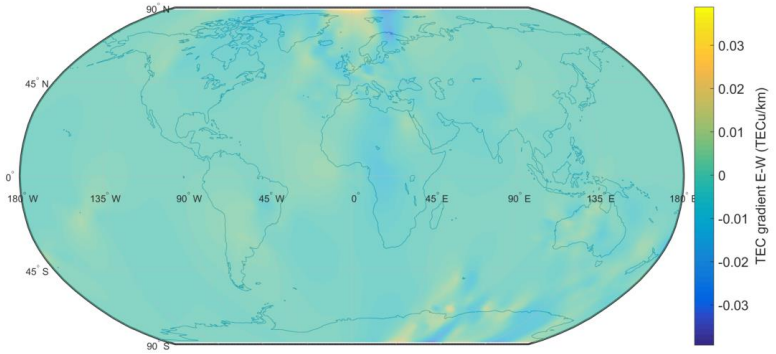
TEC gradient N-S



Ionospheric Range Error on L1



TEC gradient E-W

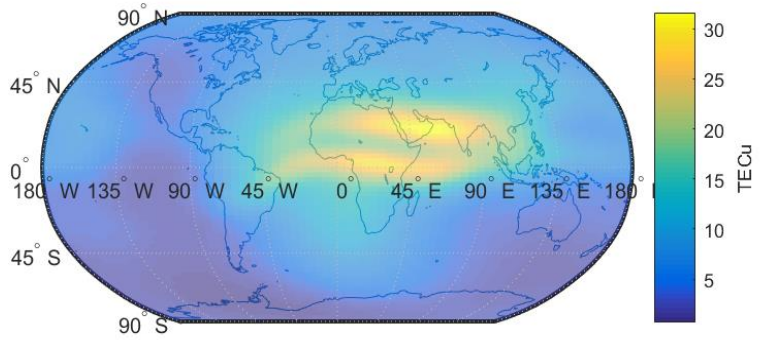


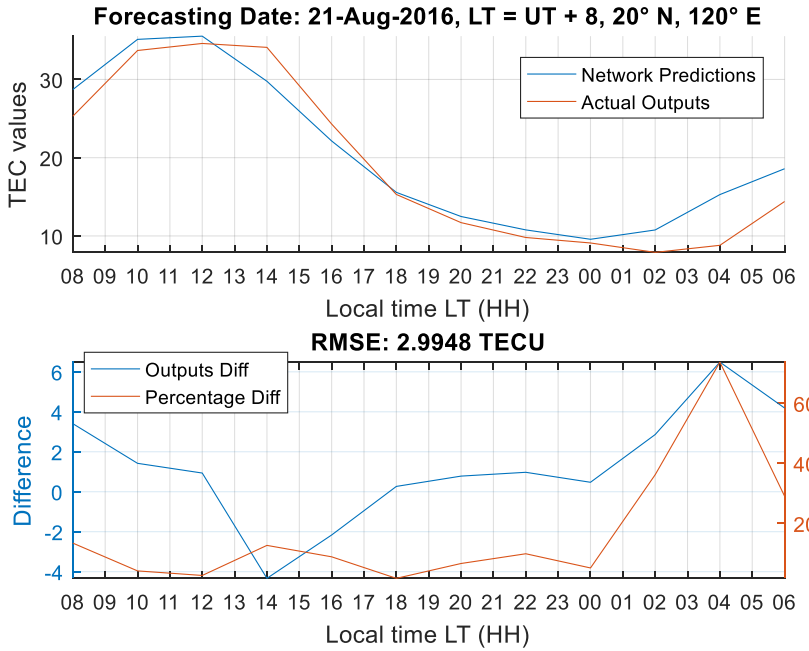
21 December 2016 at 14:00 UT

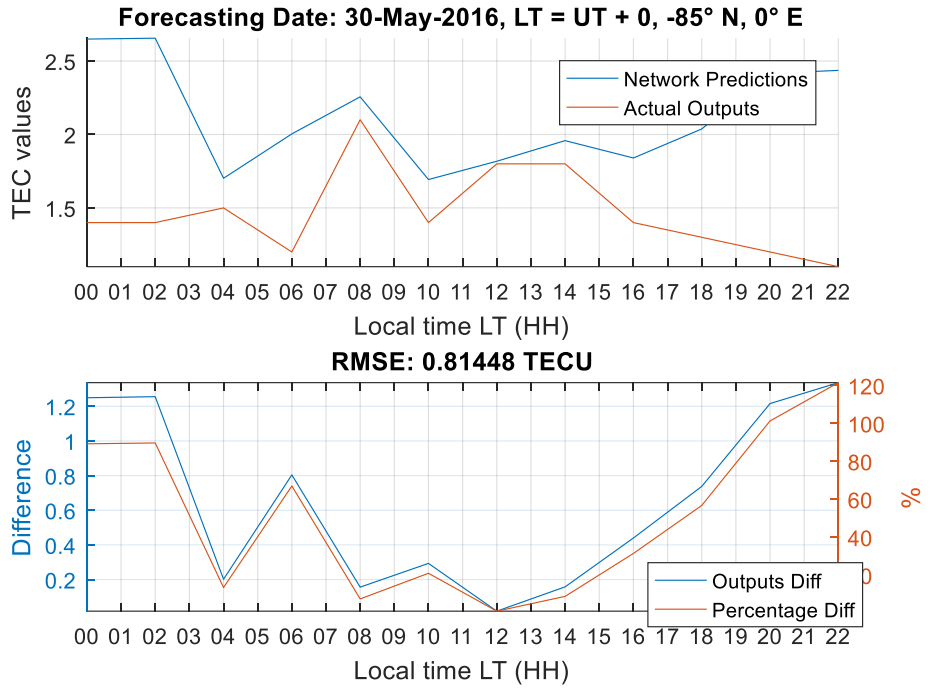
Around 120 IGS stations

Parameter(s)	Type of casting	Refresh rate (min's)	Coverage	Spatial Resolution (lat x long)
TEC, IRE, TEC_gradNS, TEC_gradEW	Nowcasting	15	Global	2.5° x 5°

Long term forecasting TEC at global level

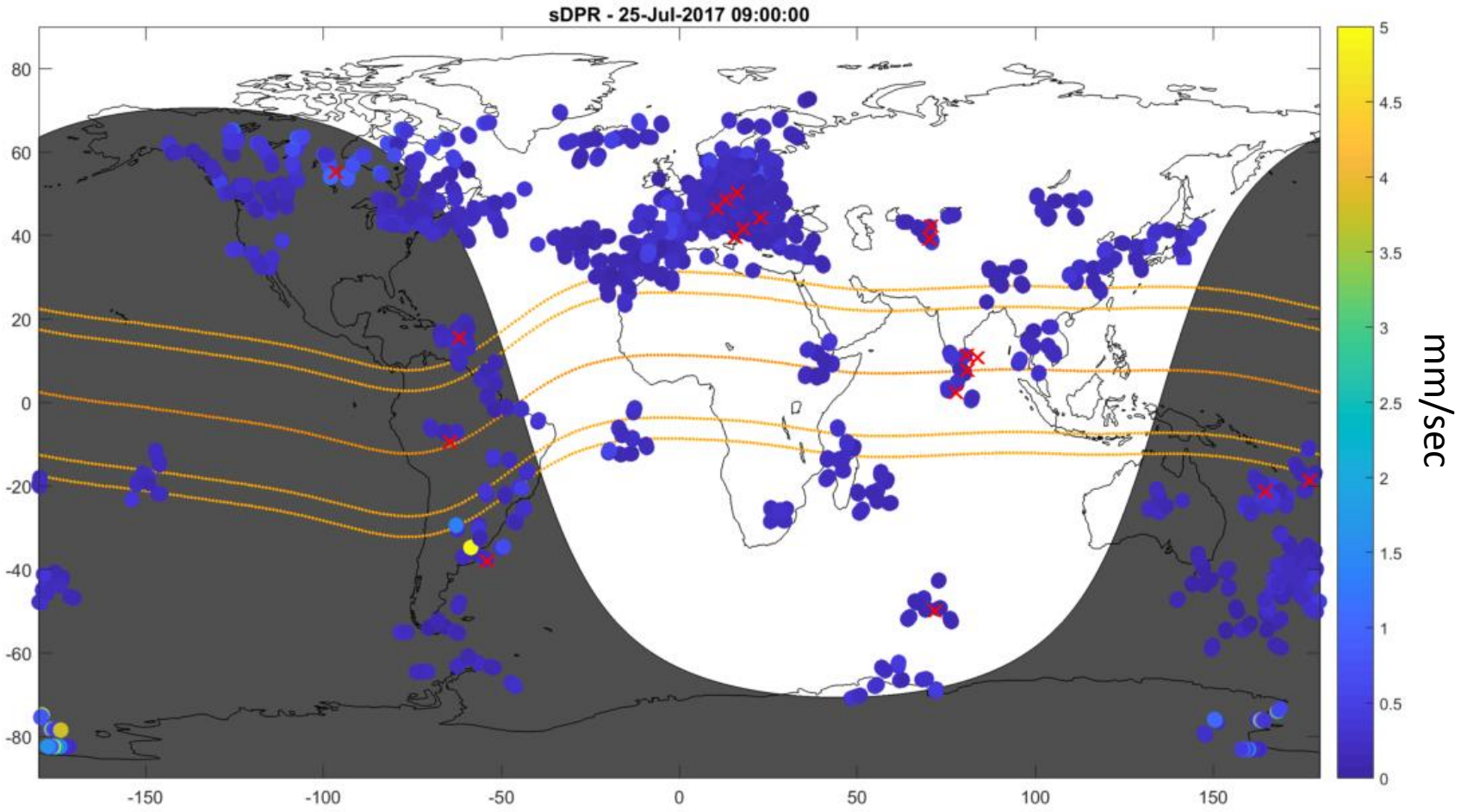






Parameter(s)	Type of casting	Refresh rate (min's)	Coverage	Spatial Resolution (lat x long)
TEC, IRE	Long term (24 hours)	120	Global	2.5° x 5°

Nowcasting PSI at global level



X cycle slip detected

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

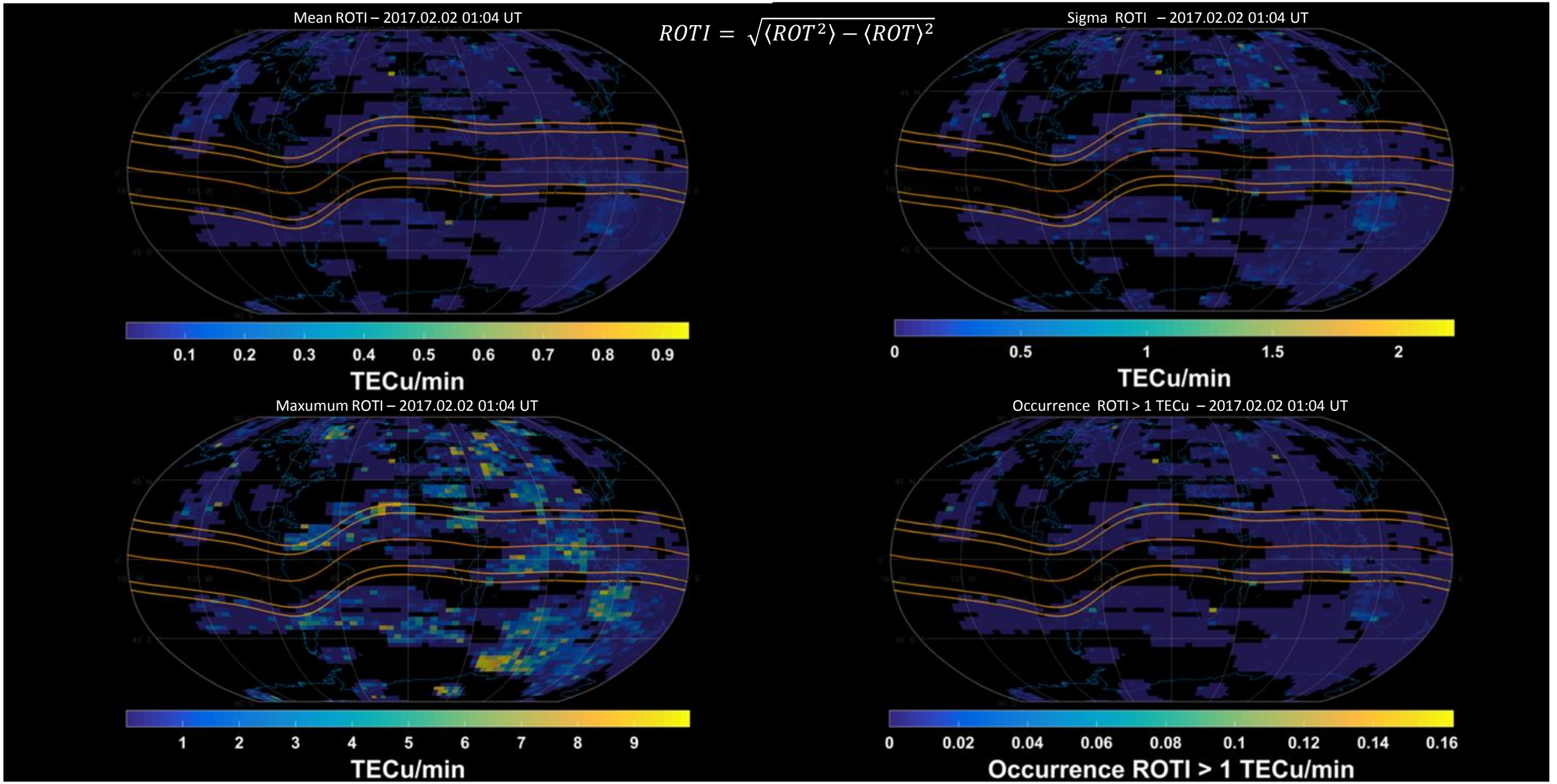
$$\psi_i = \frac{\Phi_g^{t_i} - \Phi_g^{t_{i-1}}}{t_i - t_{i-1}}$$

sDPR = sigma delta phase rate

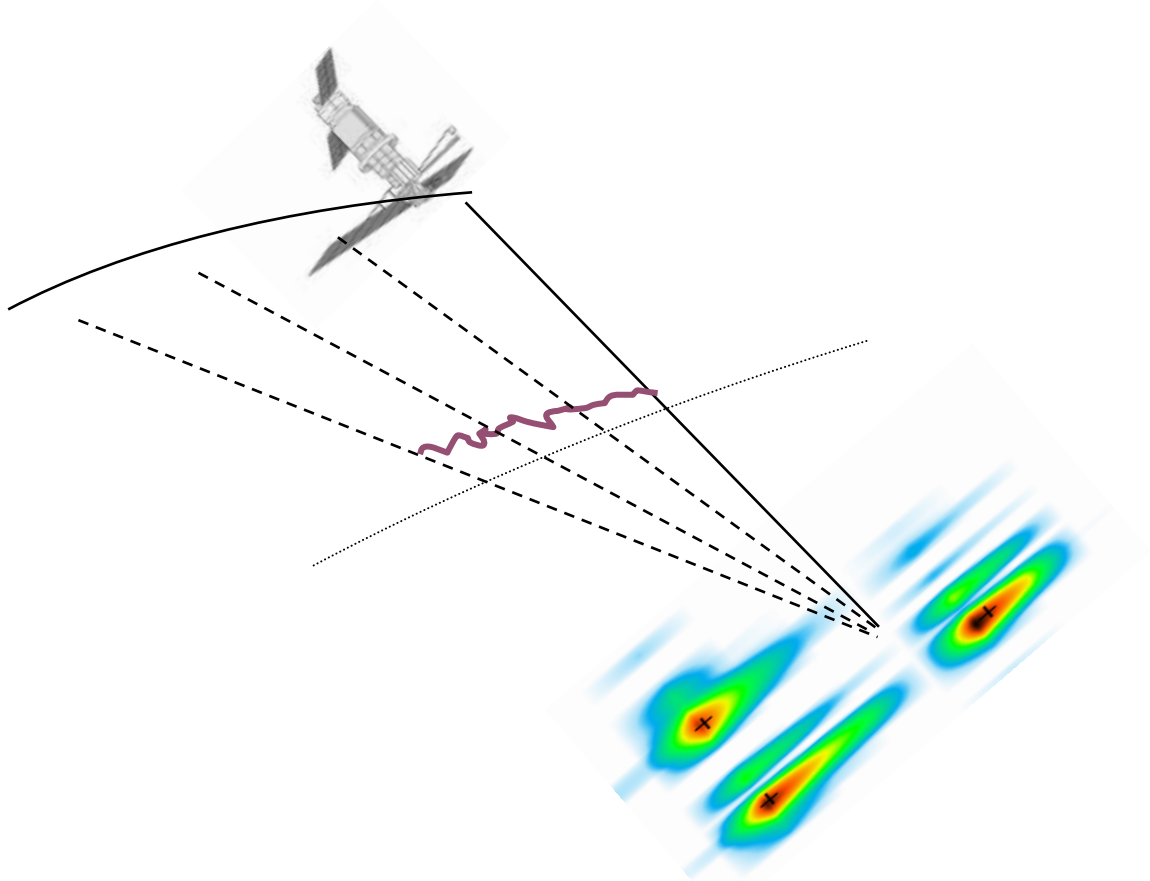
Φ_g Is the carrier phase at the *i-th* epoch

Parameter(s)	Type of casting	Refresh rate (min's)	Coverage	Spatial Resolution (lat x long)
Proxy scintillation indices (PSI)	Nowcasting	15	Global	2.5° x 5°

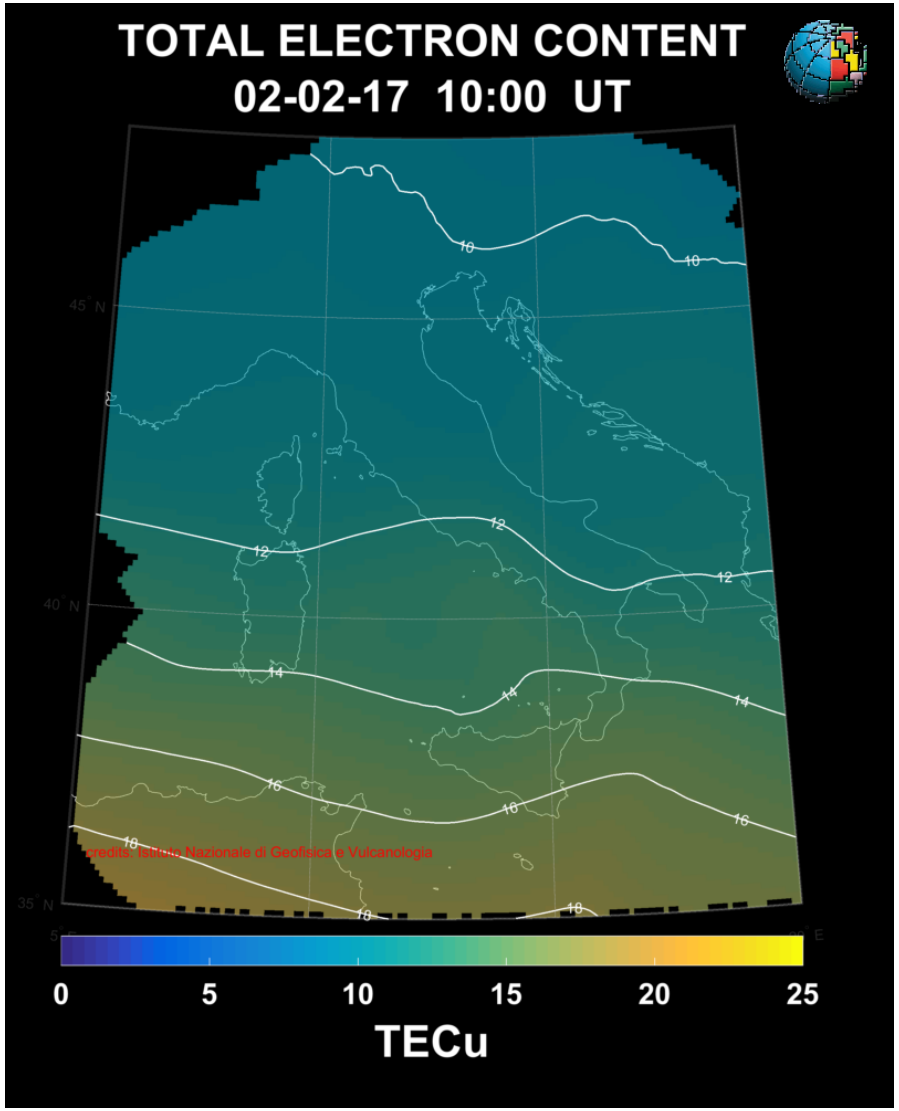
Long-term prediction of scintillation (24 hours)



Validation

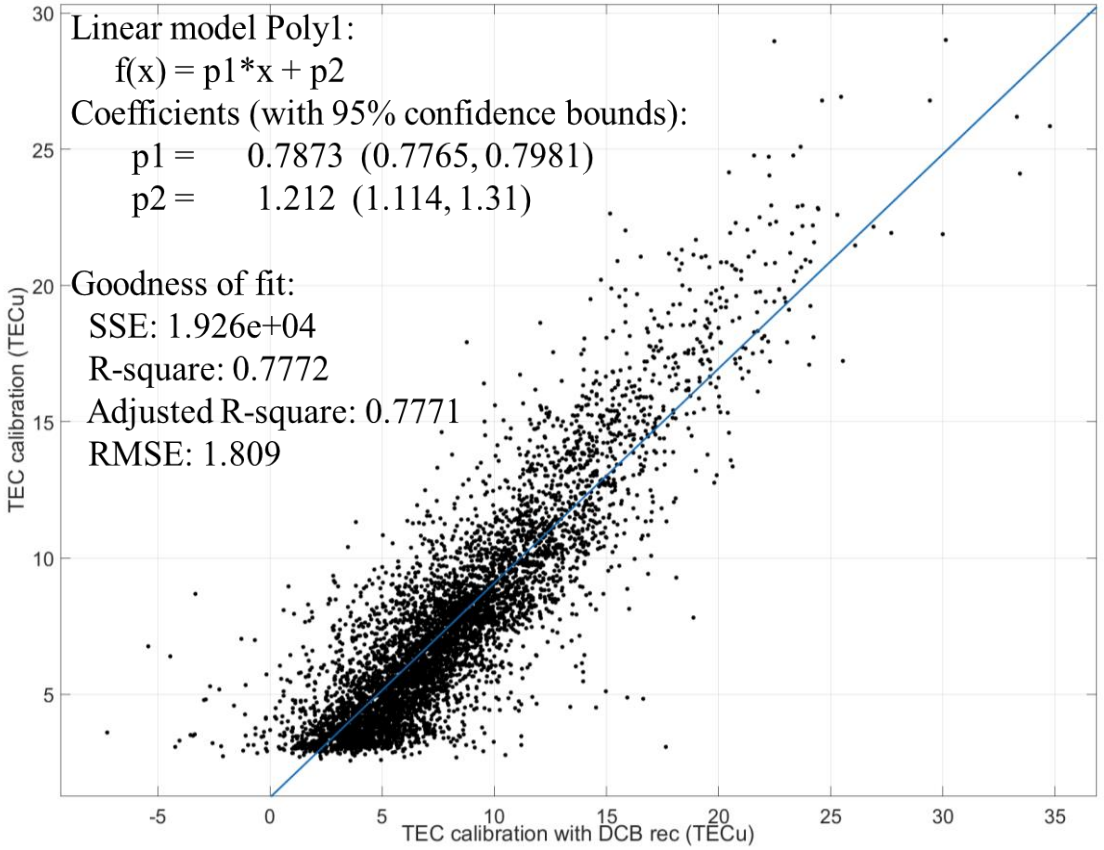


Validation of TEC nowcasting over Italy



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

Ciraolo et al., 2007

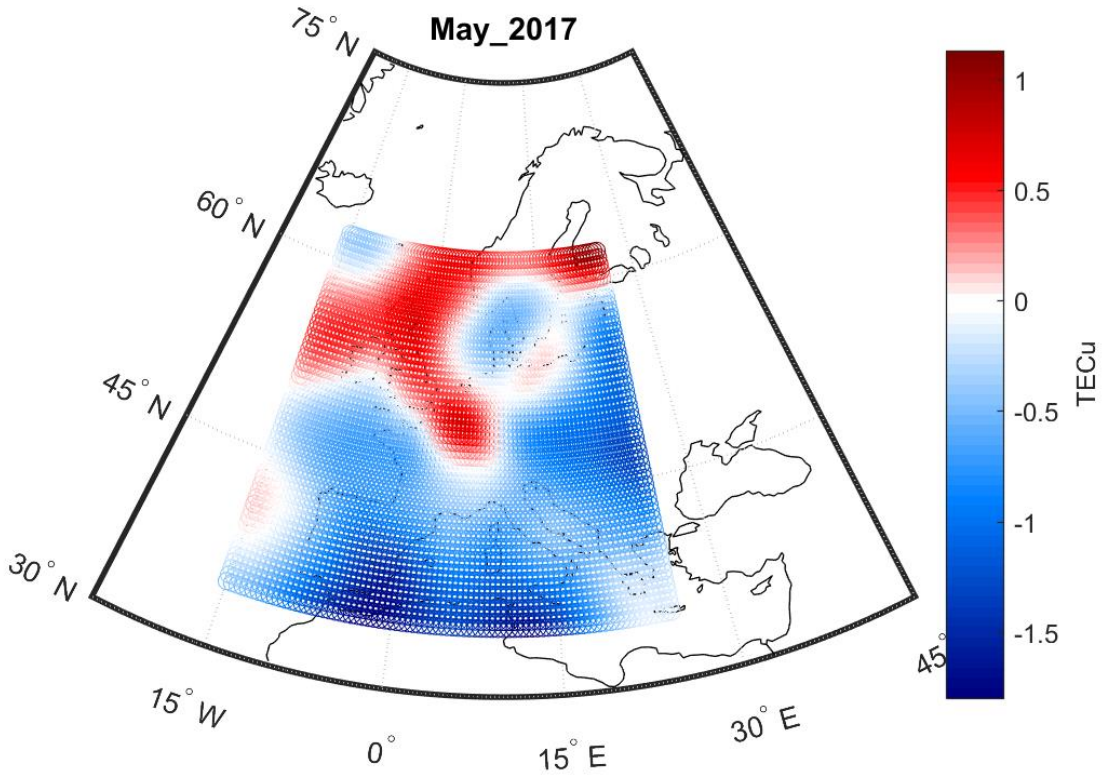


1 day of data

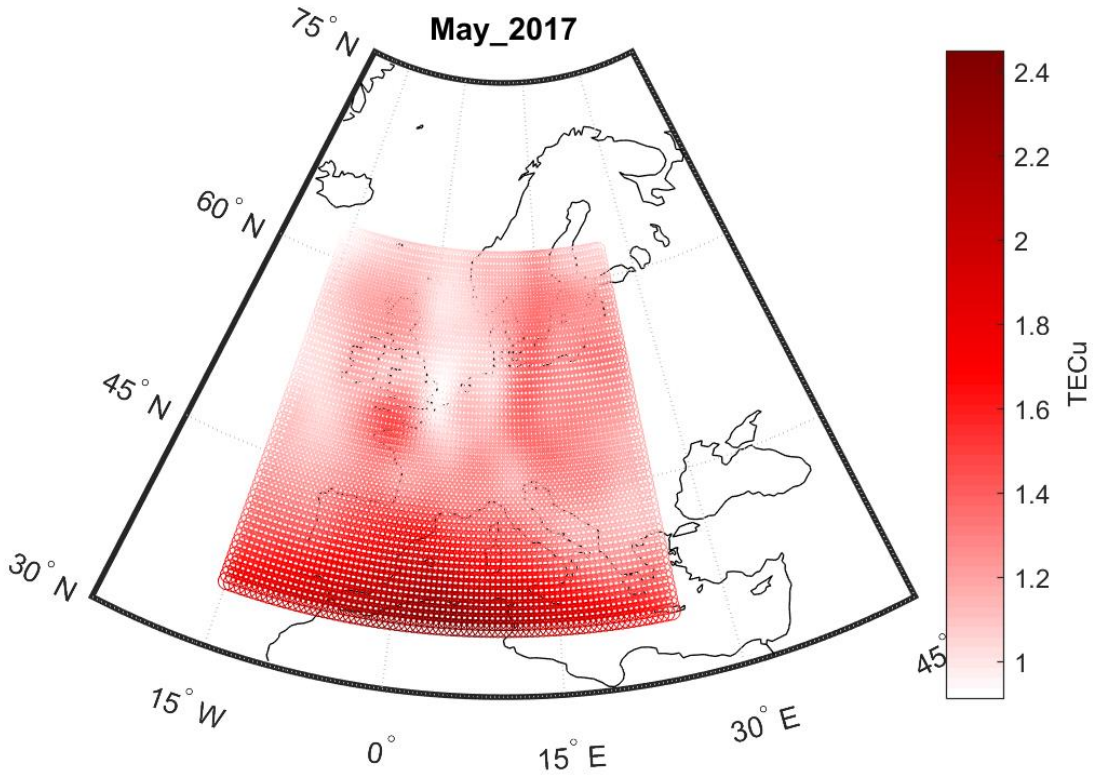
Validation of TEC nowcasting over Europe

Validation of the TEC measurement: Comparison against ROB TEC maps

INGV TEC– ROB TEC
Mean

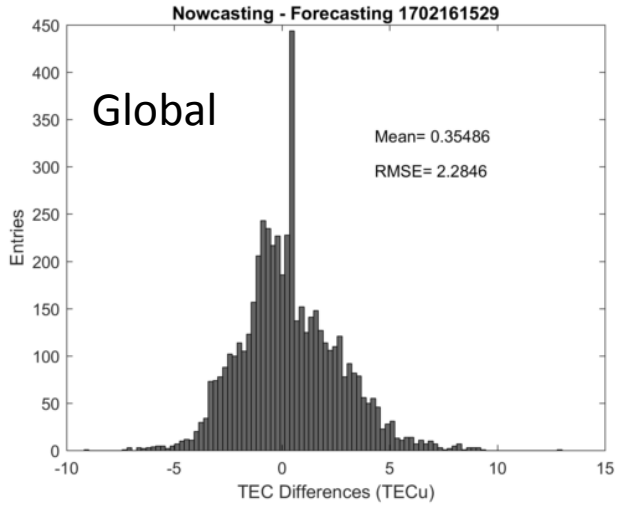


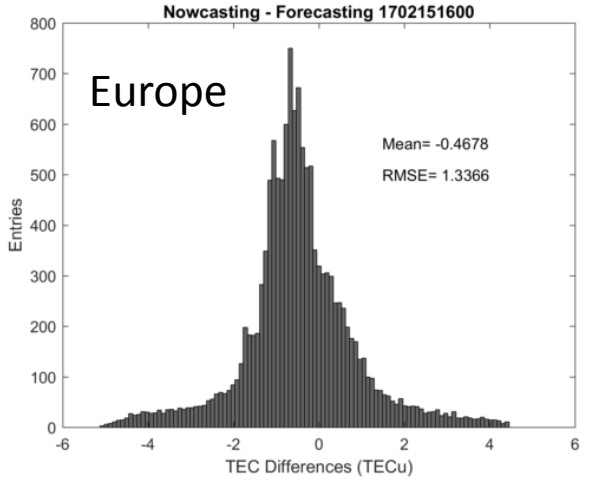
INGV TEC– ROB TEC
Std

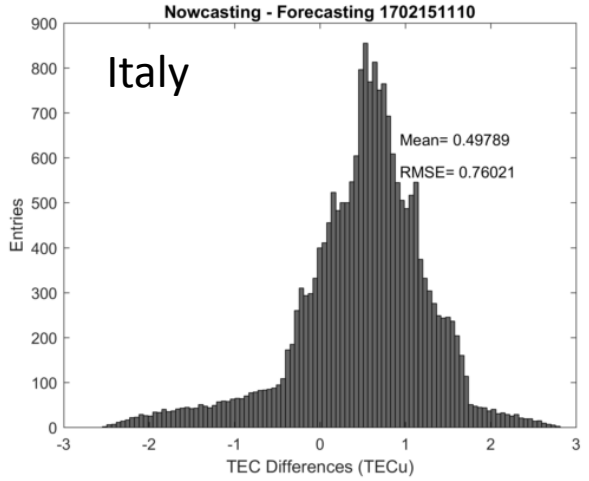


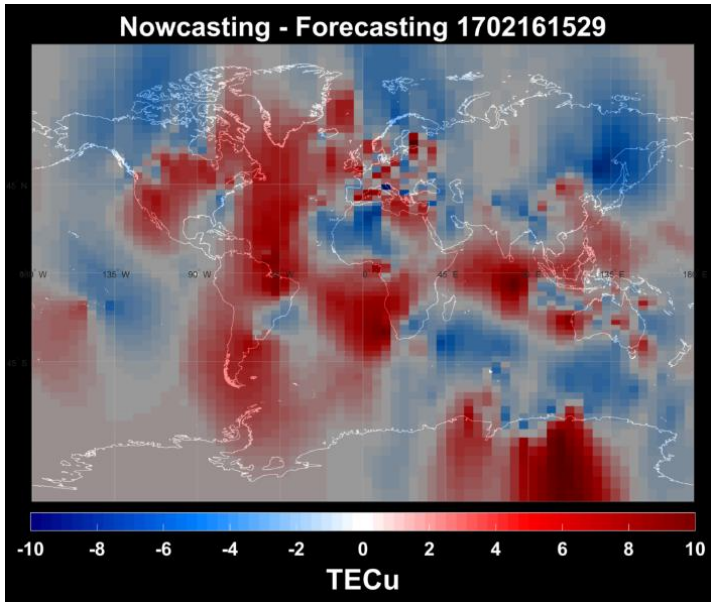
1 month of data (May 2017)

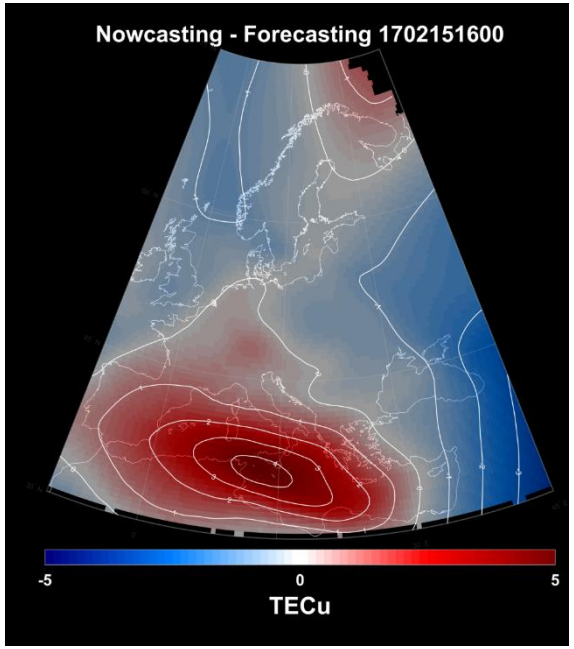
Validation of TEC forecasting products

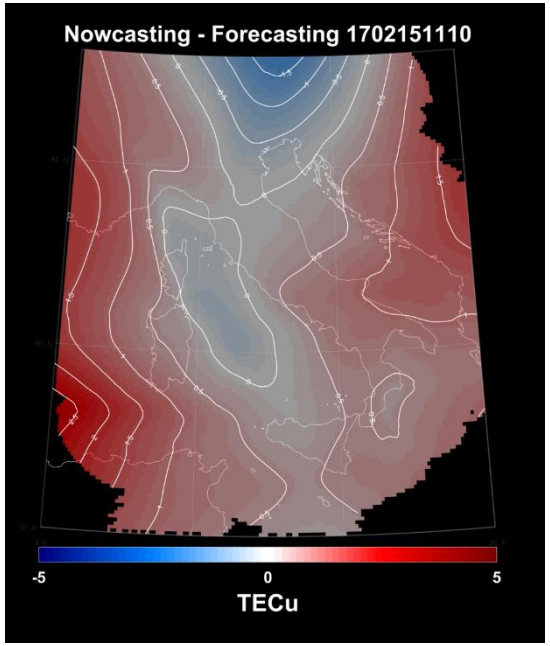






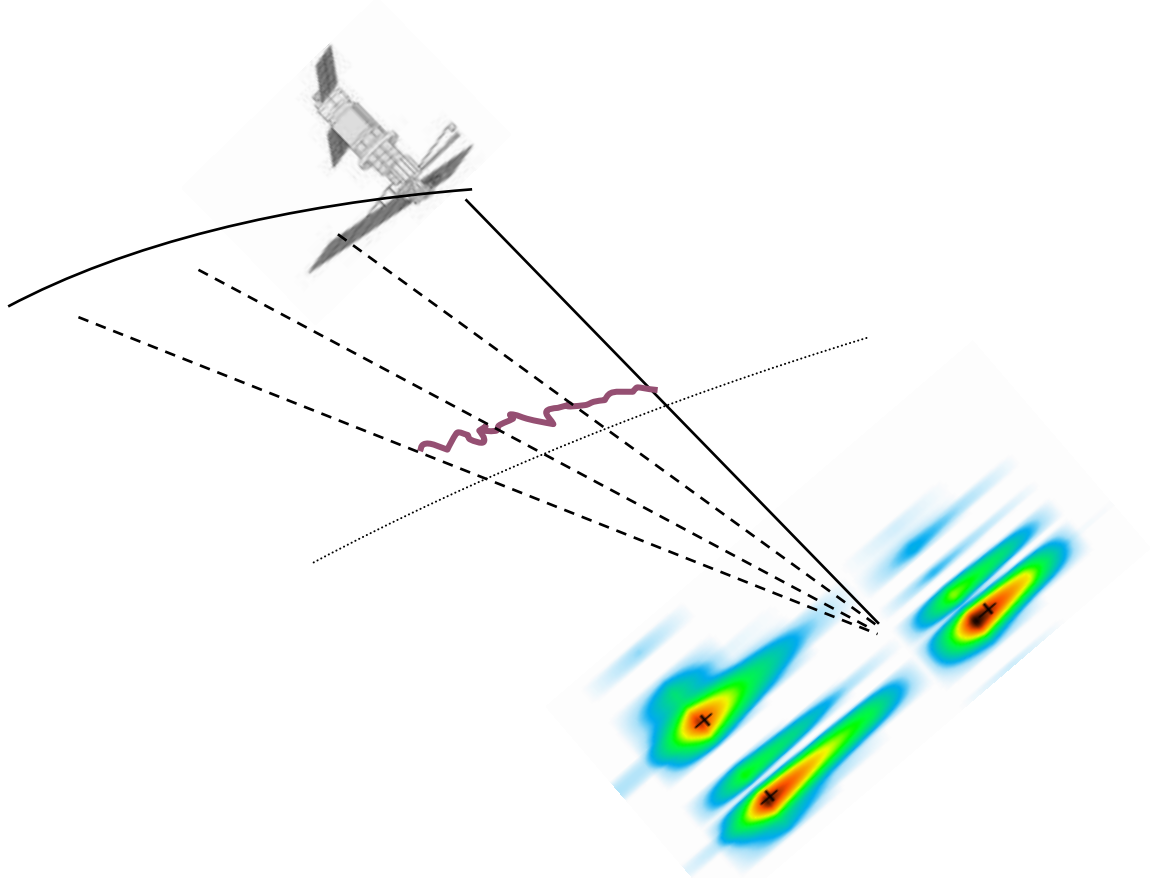






15-16 Febbruary 2017

Tools in operation



Istituto Nazionale di Geofisica e Vulcanologia

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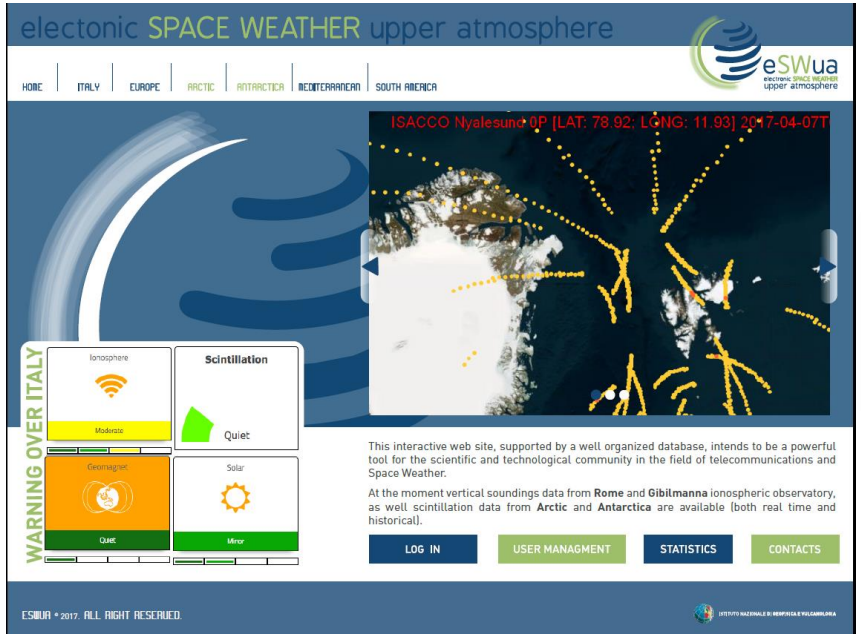
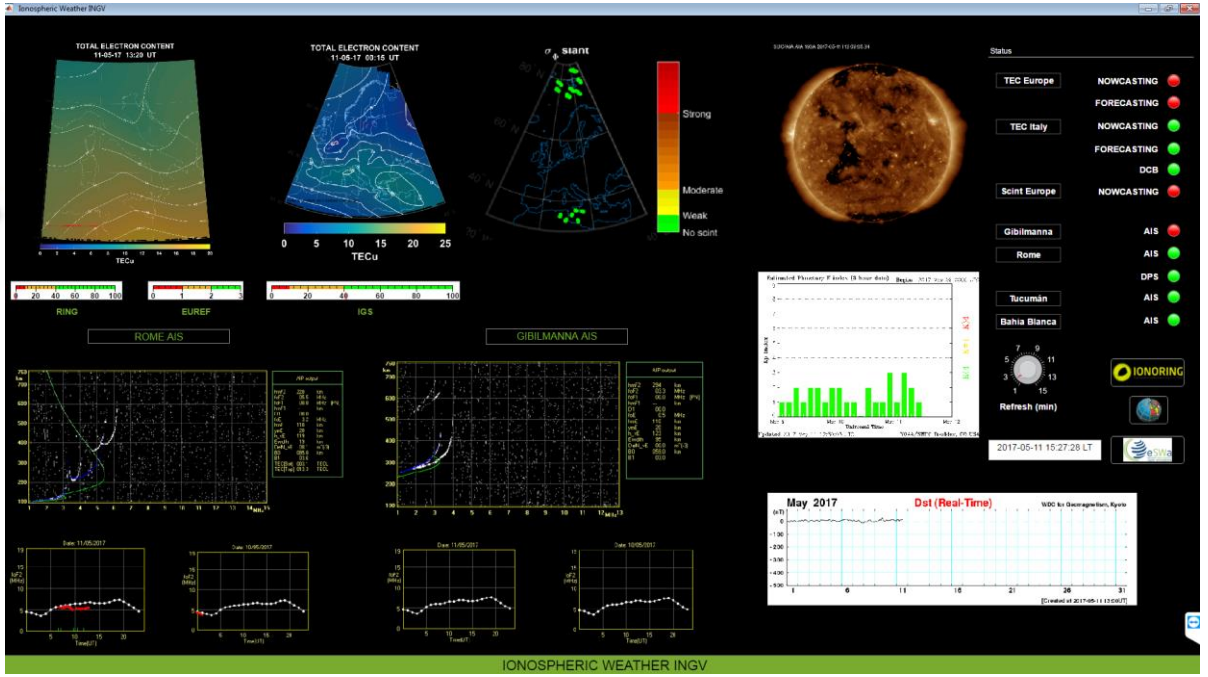
IONOSPHERIC WEATHER SERVICE





www.eswua.ingv.it
www.spaceweather.it

The ionospheric weather service at ionolab at INGV

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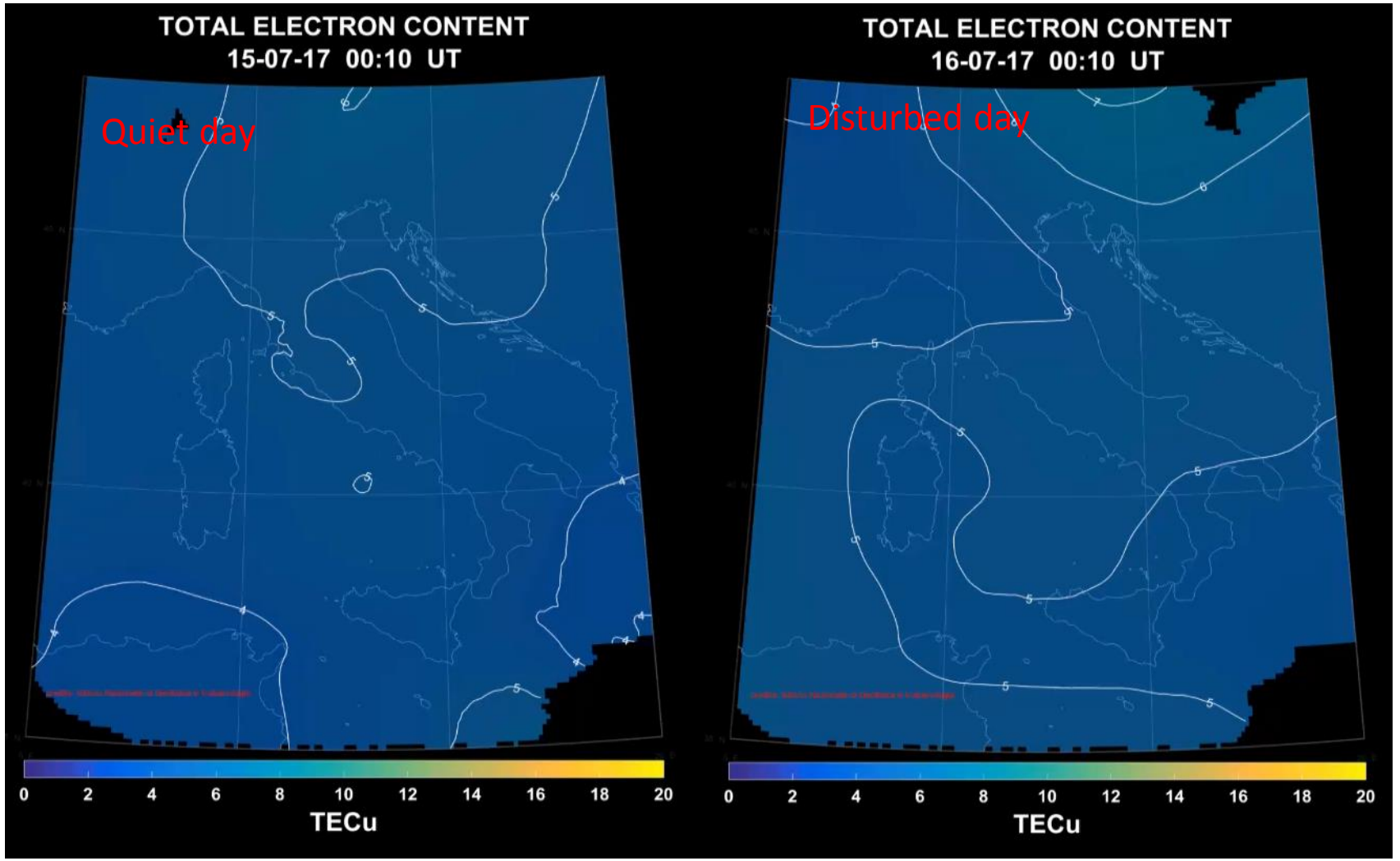
IONORING - Real-time Total Electron Content over Italy

by Upper Atmosphere Physics research group

The main goal of the IONORING (IONOspheric RING) project is to exploit data from the RING (Rete Integrata Nazionale GPS) network to obtain ionospheric Total Electron Content (TEC) maps with very fine spatial resolution (0.1°x0.1°, lat x long). These maps will be useful to support ionospheric error mitigation in precise positioning and to study the ionosphere morphology 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 40 RING stations.

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

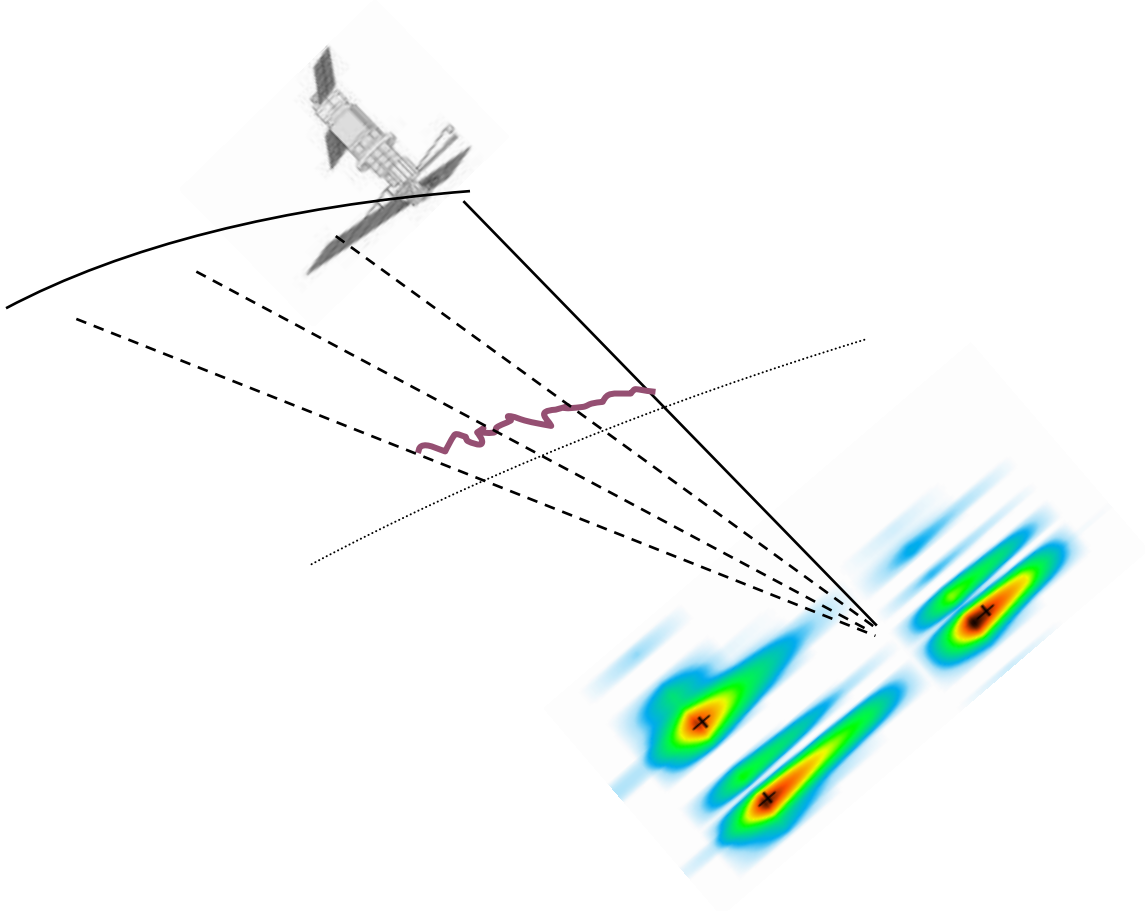
IONORING
real-timetotalelectroncontentoveritaly



Final Remarks

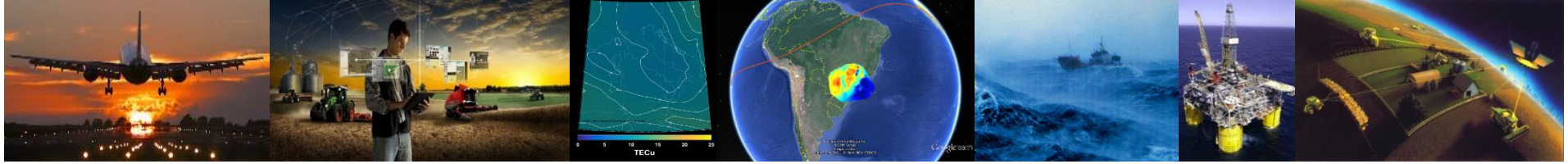
- INGV has a large community involved in investigation of ionosphere and Space Weather
- INGV and Italy have a consolidated international role in several Space Weather projects and initiatives
- Several scientific results became innovative tools and services to operation
- INGV is happy to start the 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

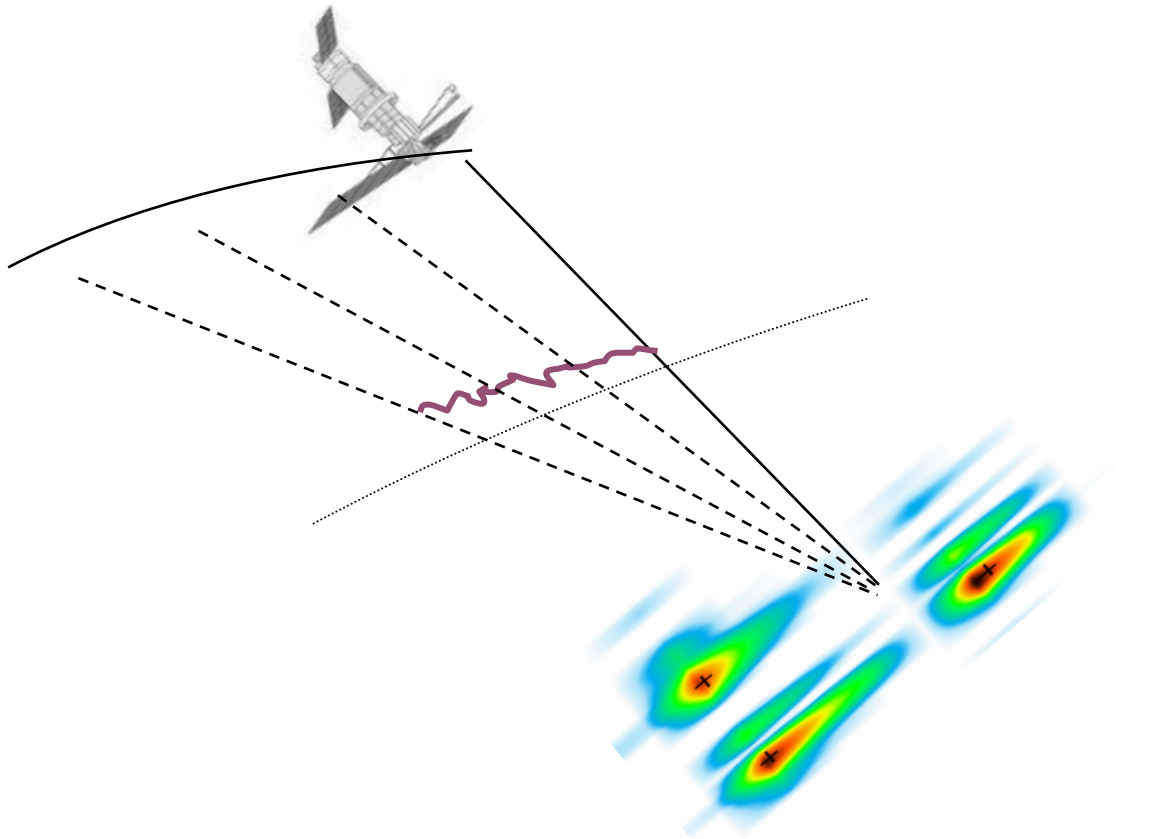
Most relevant on-going projects/initiatives

- **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

- Alfonsi L. et al., First Observations of GNSS Ionospheric Scintillations from DemoGRAPE Project. Space Weather, 2016.
- 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.
- Piersanti M. et al. Does TEC react to a sudden impulse as a whole? The 2015 Saint Patrick's day storm event, ASR, 2017.
- Prikryl P et al., GPS phase scintillation at high latitudes during geomagnetic storms of 7–17 March 2012–Part 2: Interhemispheric comparison, AG, 2015.
- 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. Formation of ionospheric irregularities over Southeast Asia during the 2015 St. Patrick's Day storm. JGR, 2016.
- Spogli L. et al., GPS scintillations and total electron content climatology in the southern low, middle and high latitude regions, AoG, 2013.
- Spogli L. et al., Regional short-term forecasting of ionospheric TEC and scintillation, International Beacon Satellite Symposium BSS-2016, 2016
- Zolesi,B and L. R. Cander. Ionospheric Prediction and Forecasting, Springer , Geophysics,DOI:101007/978-3-642-38430-1Springer Verlag Berlin Heidelberg, 2014 pp240

Ionospheric observations



Ionospheric Observatories

Gibilmanna (Italy)

Rhombic Antennas (TX and RX)

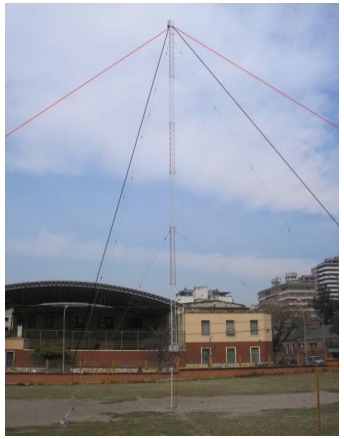
AIS - INGV

Rome (Italy)

AIS - INGV

Antennas (TX and RX)

S. Miguel de Tucumán and Bahia Blanca (Argentina)



Delta Antennas (TX and RX)

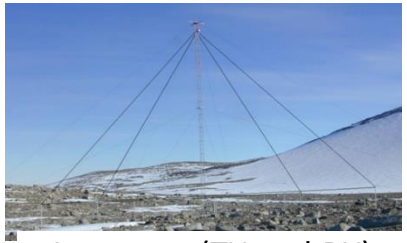
AIS – INGV

with

AUTOSCALING

Mario Zucchelli Station (Antarctica)

AIS - INGV

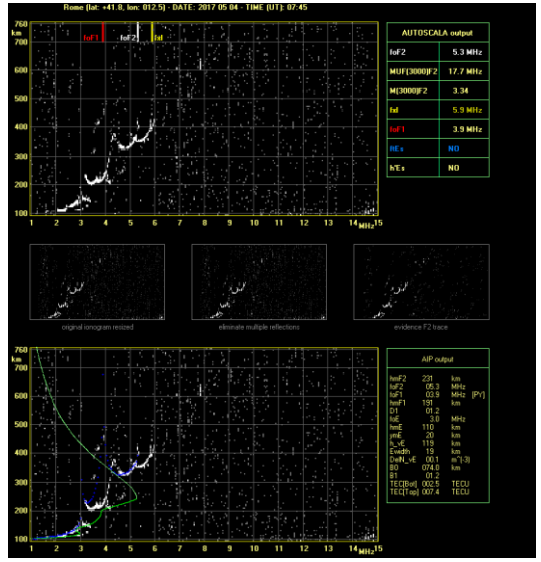


Antennas (TX and RX)

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 (Svalba
- 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

eSWua

www.eSWua.ingv.it

www.spaceweather.it