SPACE WEATHER AND HELIOPHYSICS MODELLING WORKSHOP

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SPACE SAFETY

REGIONAL ADAPTIVE AND ASSIMILATIVE 3D IONOSPHERIC MODELING OVER ITALY

Carlo Scotto, Dario Sabbagh
INGV
carlo.scotto@ingv.it

ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

Climatology vs. Nowcasting: Traditional empirical models like IRI (International Reference Ionosphere) represent monthly median values.
Need for Real-Time Data: There is a growing requirement for models that use assimilative techniques to react to short-term events like geomagnetic storms.
Approach: This model extends the "Adaptive Ionospheric Profiler“ (AIP) approach to represent an entire ionospheric volume rather than just a vertical profile above a single location.

The Electron Density N(h) Model

Foundation: Based on the AIP software used by *Autoscala* for automatic ionogram inversion.

Input: Uses 12 free parameters to define the shape of the ionosphere (e.g., NmF2, hmF2, B0).

Approach: Horizontal extension of AIP.

(Fig. 1): Illustrates the N(h) profile divided into the bottomside F-layer profile (A to C) and the E region/valley (C to F).

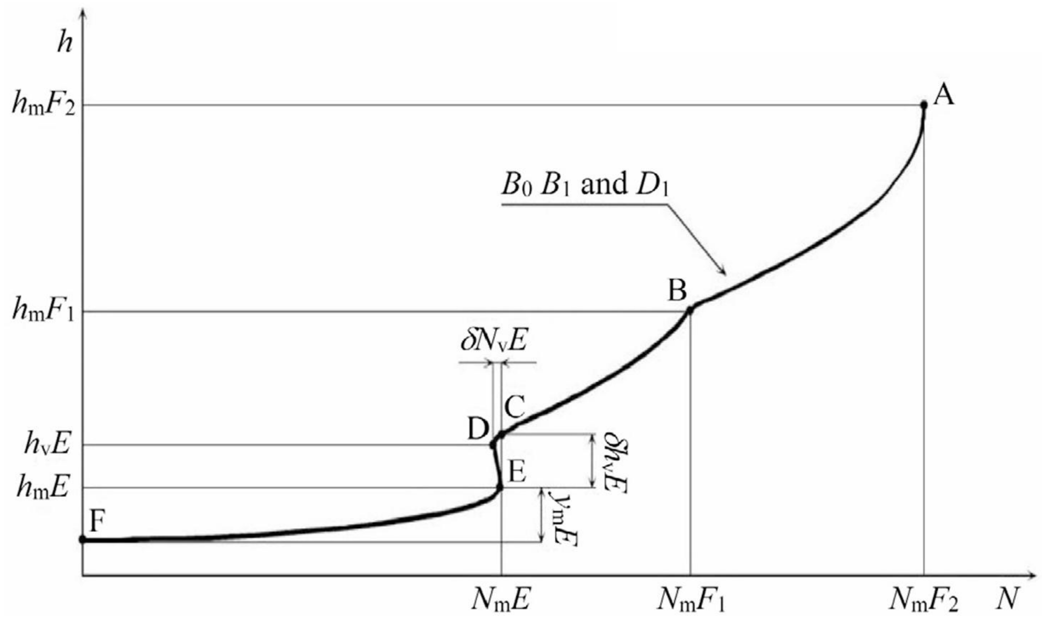

Fig. 1. The $N(h)$ model used in this work. It is divided into the following two regions: (1) the bottomside F_2 profile, through the F_1 layer down to the top of the E valley (from A to C); (2) the E valley, and the E bottomside (from C to F).

Input data: from Rome and Gibilmanna (Now also La Spezia is in operation).

Validation: San Vito dei Normanni.

3D Visualization and Cross-Sections

Multi-altitude Analysis: Provides plasma frequency maps at different fixed heights (e.g., 110 km, 180 km, and 300 km).

(Fig. 4): Maps of fp at different heights.

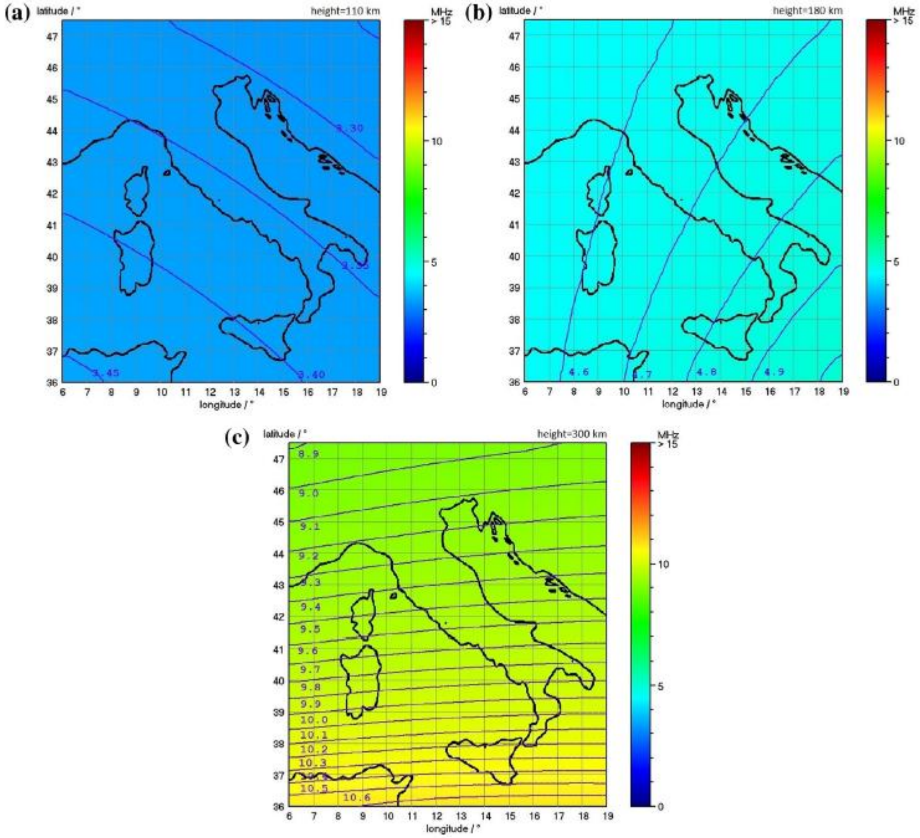

Fig. 4. (a–c) Maps of $f_p(\lambda, \varphi)$, for different values of h calculated for the day of March 27, 2015 at 12:45 UT, on the basis of the $f_p(h)$ obtained from the ionogram of the DPS-4 digisonde in Rome (41.8N, 12.5E), interpreted by ARTIST, and the $f_p(h)$ obtained from the ionogram of the AIS-INGV ionosonde in Gibilmanna (37.9N, 14.0E), interpreted by Autoscala.

(Fig. 5): Displays vertical cross-sections (e.g. latitude vs. height) at different longitudes.

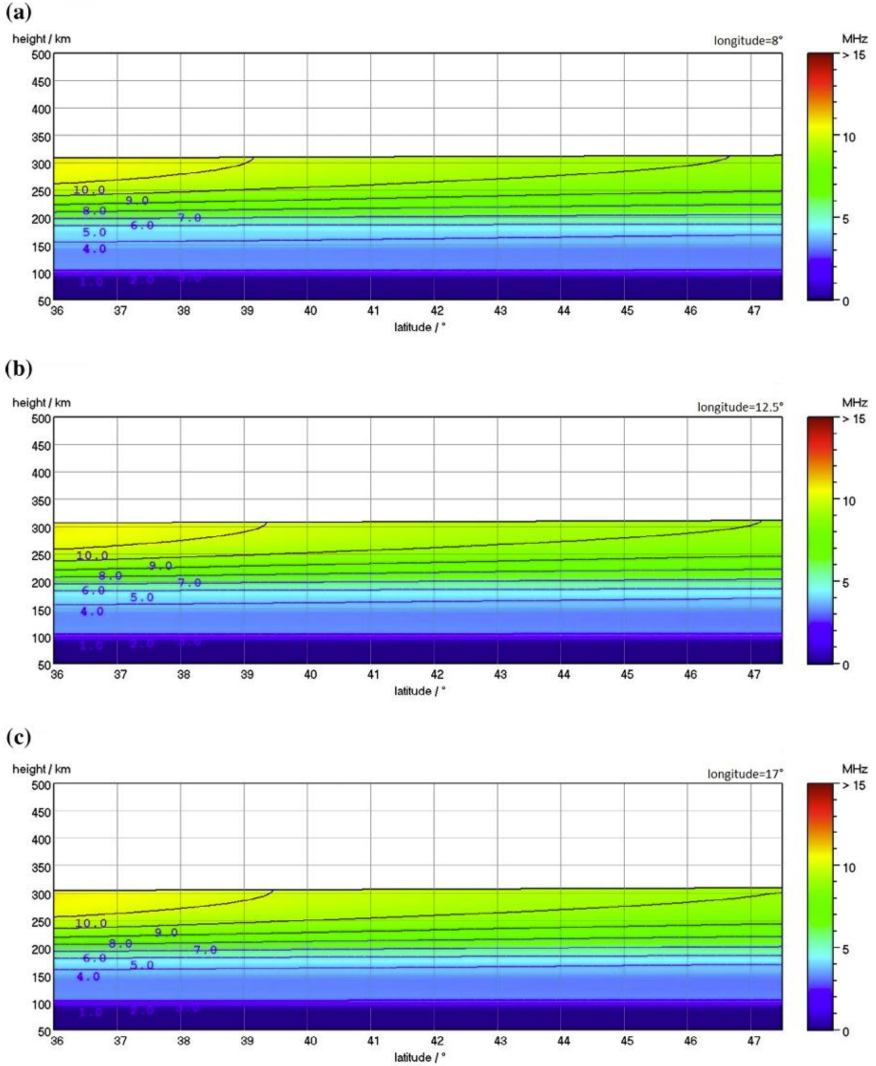

Fig. 5. (a–c) $f_p(h, \varphi)$, for different values of λ, calculated for the day of March 27, 2015 at 12:45 UT, on the basis of the $f_p(h)$ obtained from the ionogram of the DPS-4 digisonde in Rome (41.8N, 12.5E), interpreted by ARTIST, and the $f_p(h)$ obtained from the ionogram of the AIS-INGV ionosonde in Gibilmanna (37.9N, 14.0E), interpreted by Autoscala.

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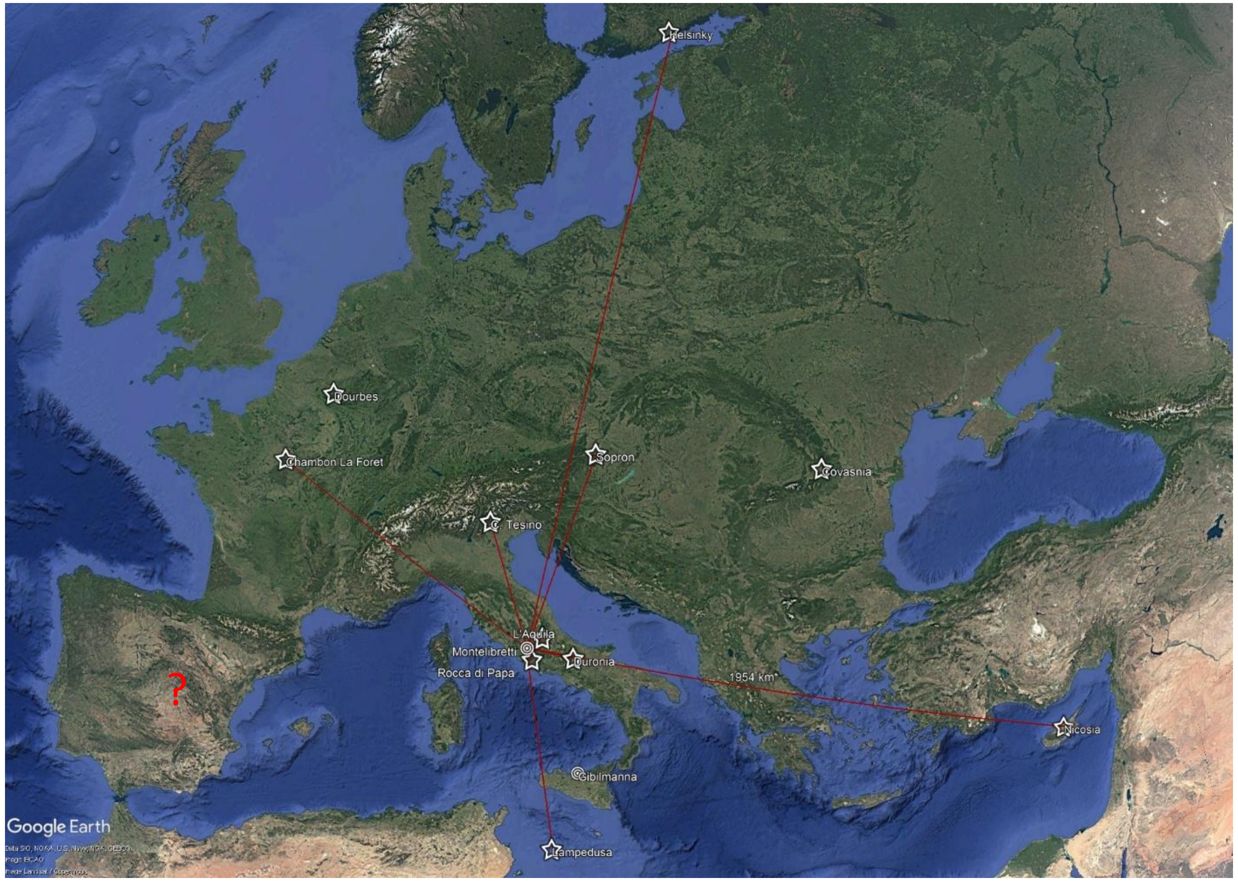
IonoNet ITALY and EUROPE

(Zirizzotti et al., ASR, 2026a, 2026b)

Further data can be assimilated into the 3D model through the Iononet network of oblique ionosondes

Transmitters: Montelibretti (center), Gibilmanna (south), La Spezia (north).
Italian Receivers: Rocca di Papa, Preturo, Duronia, Lampedusa, C. Tesino
European Receivers: Dourbes, **Sopron**, **Paris**, **Nicosia**, **Vithi**, Covasnia, Spain (somewhere).

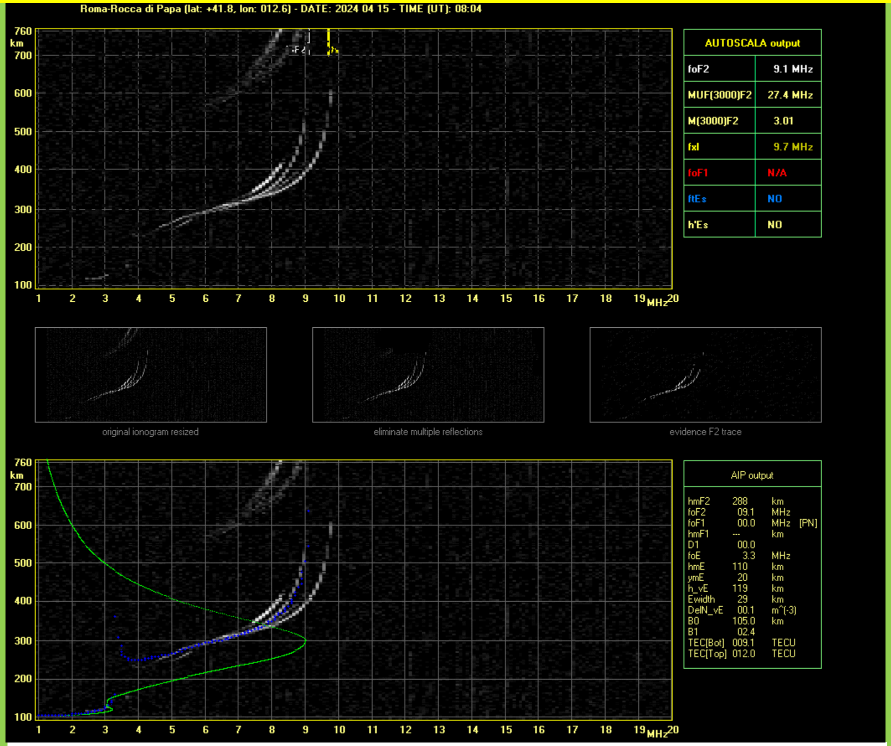
Vihti (Finland) Finnish Meteorological Institute (FMI) **Nicosia (Cyprus)** Frederick University (FIT), Nicosia, **Paris (France)** Université Paris Cité, Institut de physique du globe de Paris (IPGP), Paris **Hungary/Romania** Institute of Earth Physics and Space Science (EPSS), Sopron(Hungary)



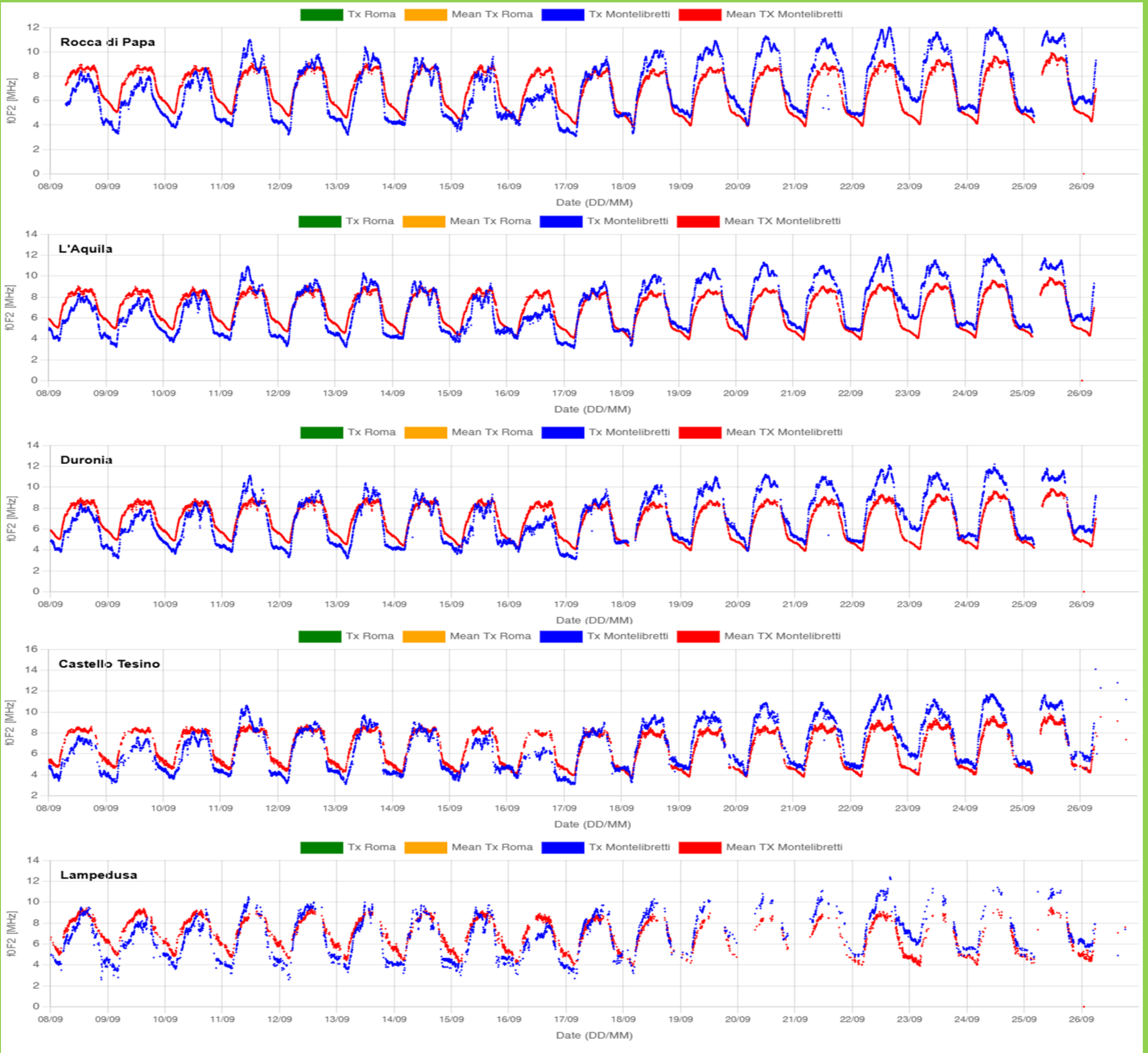
POTENTIAL OF SHORT-DISTANCE OBLIQUE SOUNDINGS (IONONET ITALY)

Using the AUTOSCALA program on the verticalized ionograms is possible to obtain ionospheric parameters.

This data can be integrated into the 3D model. The inclusion of this data in the ionospheric HF maps already is part of the feasibility study.



Example of verticalized ionogram from a short-distance oblique sounding



Example of the foF2 parameter at different stations

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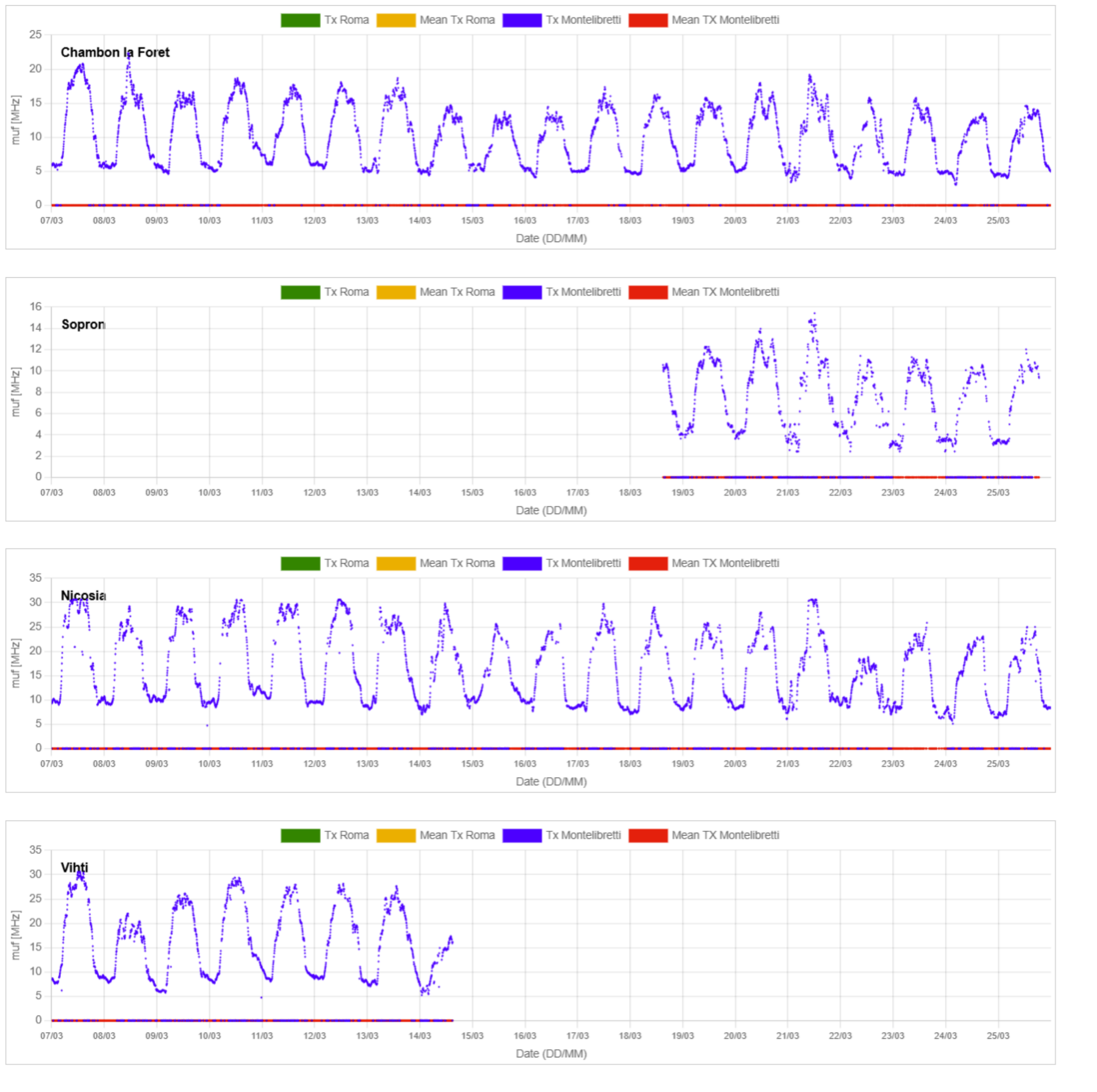
POTENTIAL OF LONG-DISTANCE OBLIQUE SOUNDINGS (IONONET EUROPE)

Real-time MUF is obtained through **new techniques based on ML**. While verticalization is a promising approach for shorter-distance radio links (IonoNet–Italy), **further study is needed on how oblique sounding data can be integrated into the 3D model.**

However, the long-distance oblique sounding data (IonoNet –Europe) can be used in SWESNET to: **a)** improve MUF maps; **b)** validate all HF products (potentially after manually validating restricted sets of oblique sounding data).



Example of the MUF parameter for different soundings

SUMMARY

- **Real-Time 3D Modeling:** Development of a new 3D model providing ionospheric bottomside plasma frequency over Italy. The system extends the "Adaptive Ionospheric Profiler" (AIP) from a single-location vertical profile to an entire ionospheric volume. It uses 12 free parameters to define the ionosphere's shape.

- **Data Assimilation:** The model ingests real-time data from ionosondes in Rome, Gibilmanna.

- **Possible expansion** to a wider geographic area assimilating data from the IonoNet network of oblique ionosondes across Italy and Europe.

- **Integrating IonoNet data** serves a dual purpose: expanding the reach of the 3D ionospheric model and providing a robust framework for validating SWESNET HF products.

THANK YOU !

Sabbagh D., Scotto C., Sgrigna V. (2016). A regional adaptive and assimilative three-dimensional ionospheric model. Adv. Space Res. 57(5): 1241-1257, https://doi.org/10.1016/j.asr.2015.12.038.

Zirizzotti A., Scotto C. Sabbagh D. Ippolito A. (2026a). Ionosphere parameters from verticalized oblique ionograms across Italy. Adv. Space Res. 77(5): 6171-6183, https://doi.org/10.1016/j.asr.2026.01.015.

Zirizzotti A., Sciacca U., Zuccheretti E., Scotto C., Perrone L., Baskaradas, J.A. (2026b). IonoNet: a European network of oblique ionosondes. Adv. Space Res. 77(3): 3351-3366, https://doi.org/10.1016/j.asr.2025.12.019.