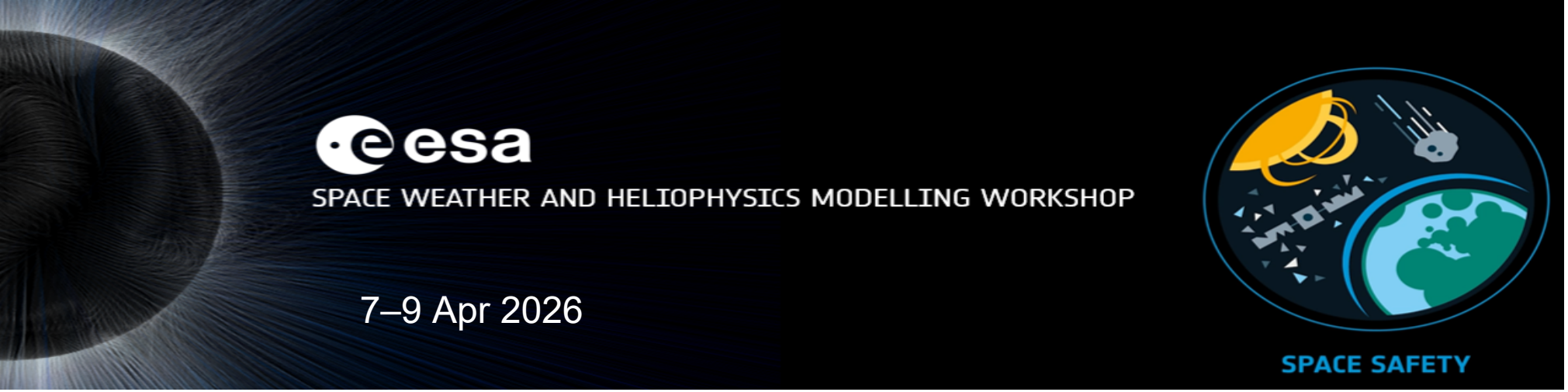


# Forecasting of foF2 over Europe

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esa

# OUTLINE

- EUROMAP model overview
- Operational implementation (ESA & PECASUS)
- Model performance and validation
- Storm case
- IONONET infrastructure
- Future developments
- Conclusions

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# EUROMAP model overview

EUROMAP is  based on:

1. Available hourly foF2 observations (both historical and real time) over European stations

2. 3-hour forecasted ap indices as driving input parameter

3. Effective ionospheric monthly T indices to specify the background level

**Local  Models have been created for European Ionospheric Stations**
**This allows to Monitor foF2 over the whole European Region**

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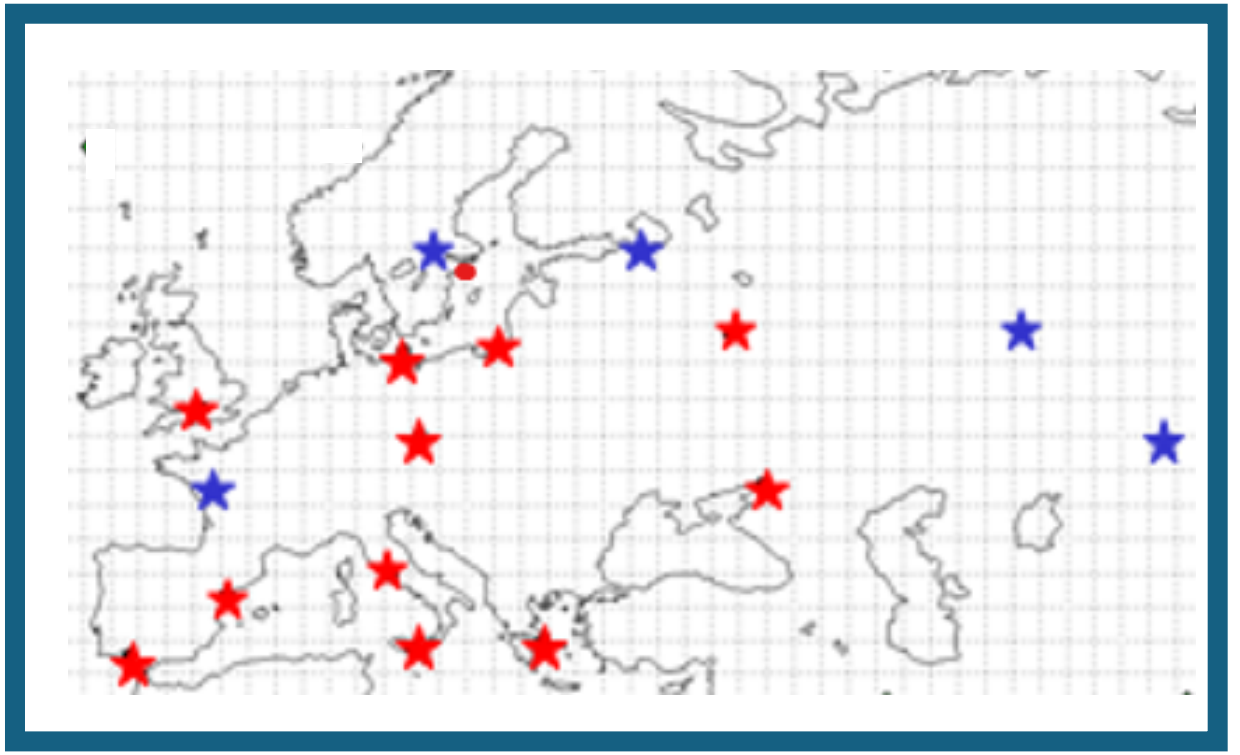
# LOCAL MODELS developed for European ionosonde stations

In Europe INGV manages three vertical ionosondes stations in Italy: Lerici, Rome, Gibilmanna



Ionosonde for which we have done local models
Ionosondes: operative (red stars), ionosondes worked in the past (blue stars).

EUROMAP provides foF2 forecasted from1 to 24 hour ahead also without foF2 real-time observations

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# EUROMAP in ESA and PECASUS services

**EUROMAP was originally designed to forecast foF2. The MUF capability was later implemented using the foF2 forecast as a core input**

MUF(3000) maps forecasted by EUROMAP are inserted in **PECASUS** one of the 4 Global centers appointed since November 2019 by ICAO to provide real-time SWx advisories for aviation user (Kauristi et al, *Remote Sens.* **2021**

https://pecasus.eu/


**SWESNET**: Space Weather Service Network Development and Pre-Operation
https://swe.ssa.esa.int/swesnet-project

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Testing Results for Juliusruh (~ 40 days for each Season)
Relative Mean Deviation in % are given Red – Proposed Method; Blue – IRI (STORM)
Significance of the difference in % between two models according to t-criterion is given

| Equinox | Summer | Winter |
|---|---|---|
| *Strong Positive Disturbances* | | |
| 13.8 / 20.6<br>99.9% | 9.9 / 16.7<br>99.9% | 16.0 / 26.1<br>99.9% |
| *Strong Negative Disturbances* | | |
| 19.2 / 28.6<br>99.5% | 15.3 / 18.0<br>Insign | 20.5 / 33.3<br>99.7% |

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Testing Results for Rome (~ 40 days for each Season)
Relative Mean Deviation in % are given
Red – Proposed Method; Blue – IRI (STORM)
Significance of the difference in % between two models according to t-criterion is given

| Equinox | Summer | Winter |
|---|---|---|
| *Strong Positive Disturbances* | | |
| 14.5 / 12.9<br>Insign | 14.0 / 13.4<br>Insign | 16.8 / 14.8<br>Insign |
| *Strong Negative Disturbances* | | |
| 14.5 / 27.4<br>99.9% | 11.7 / 16.8<br>99.0% | 14.7 / 26.7<br>99.9% |

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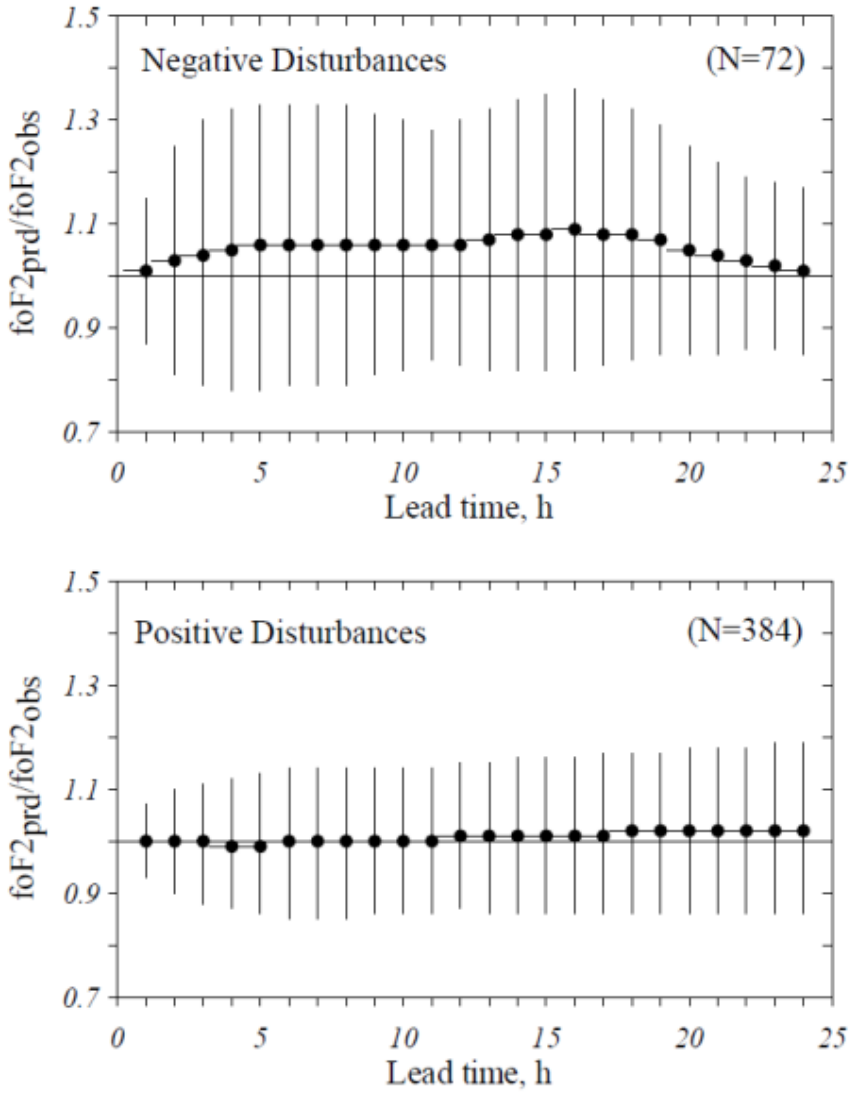
# Stable performance up to 24h lead time

The foF2prd/foF2obs dependence versus lead time (1-24) h for 3 negative and 16 positive disturbances observed at Juliusruh in 2000-2002. Average foF2prd/foF2obs (dots) along with ±SD values are given. Each lead time includes N cases.

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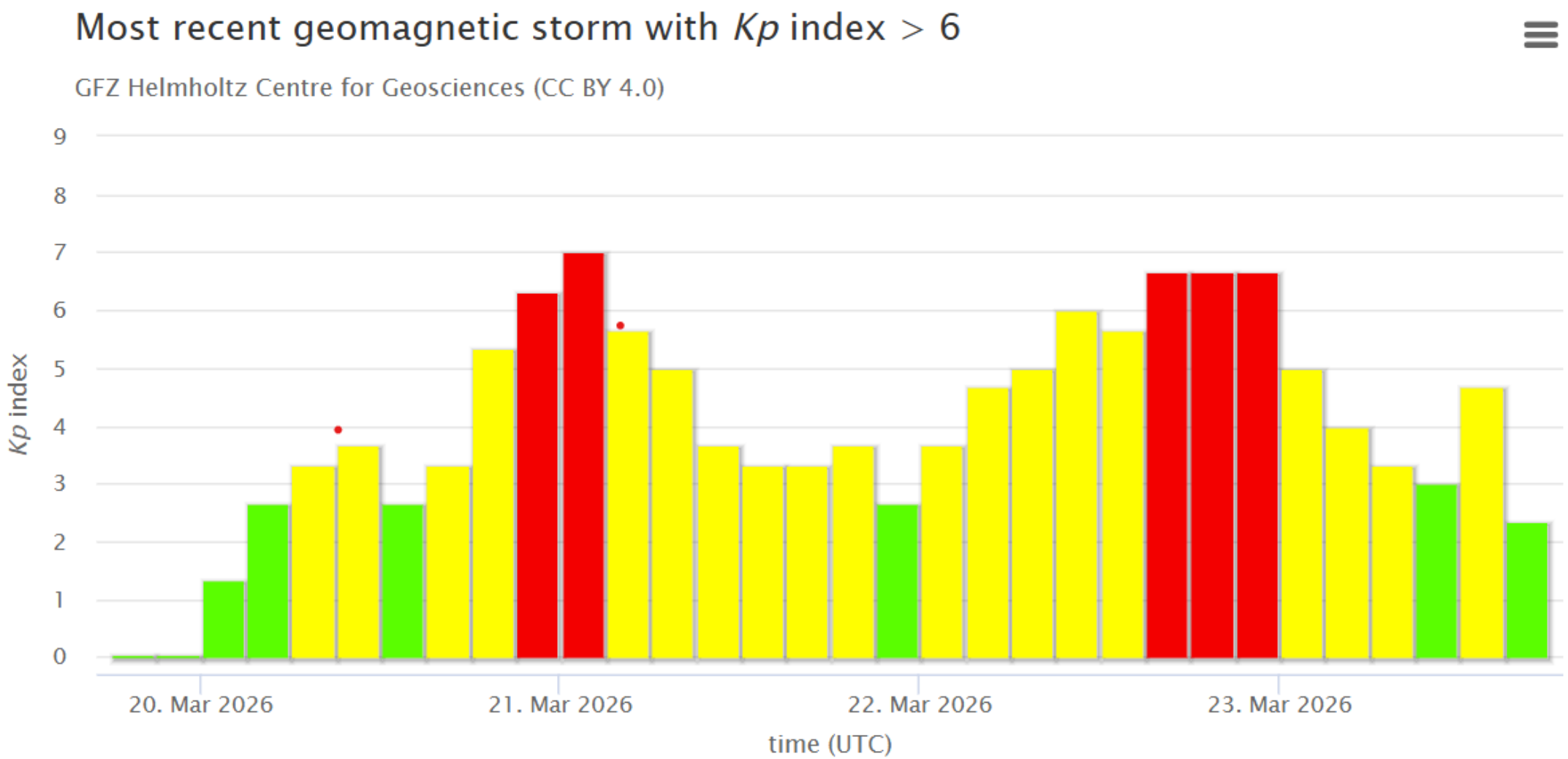
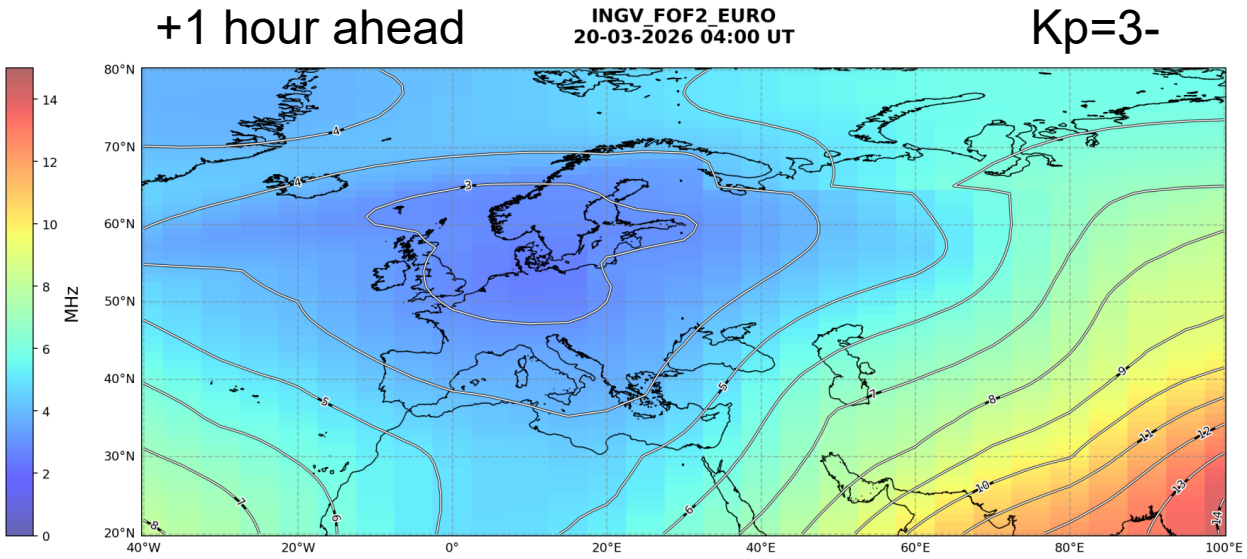
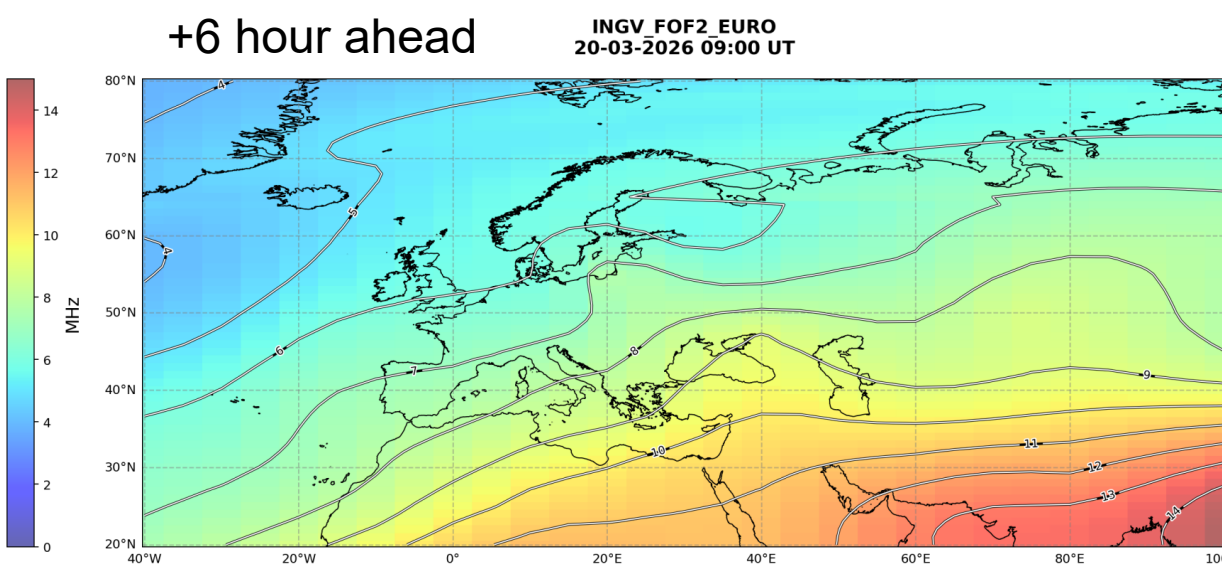

Most recent geomagnetic storm with Kp index > 6
GFZ Helmholtz Centre for Geosciences (CC BY 4.0)
Kp index
9
8
7
6
5
4
3
2
1
0
20. Mar 2026
21. Mar 2026
22. Mar 2026
23. Mar 2026
time (UTC)

+1 hour ahead



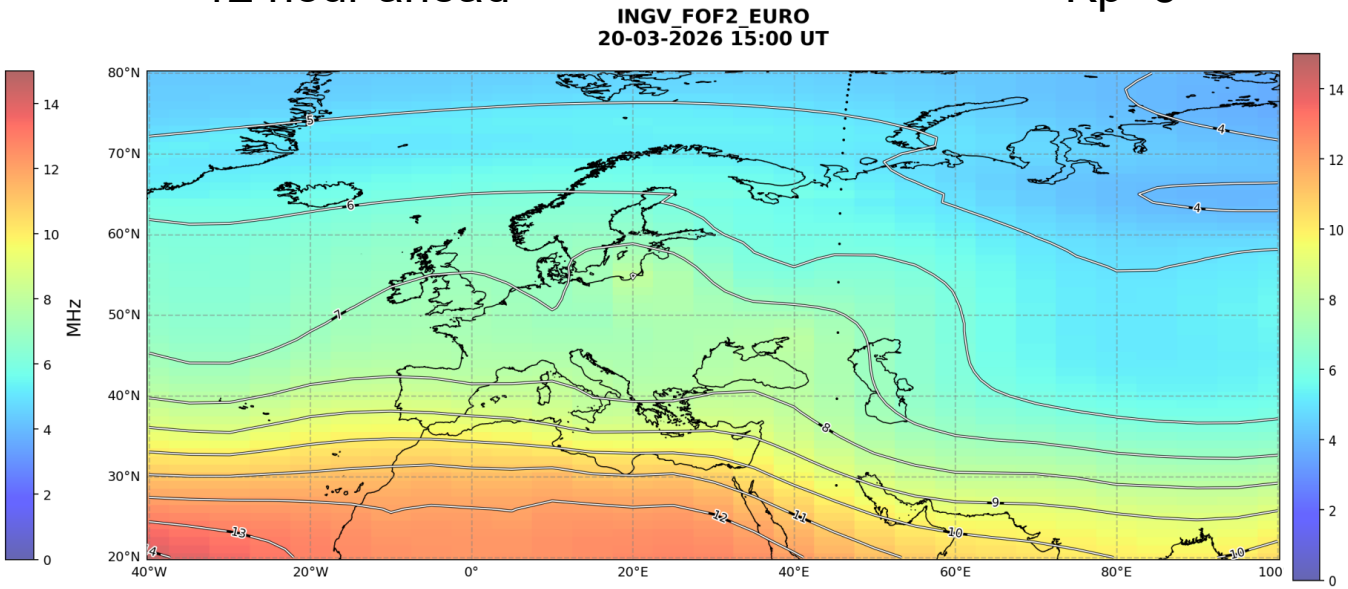

Kp=3-

+6 hour ahead

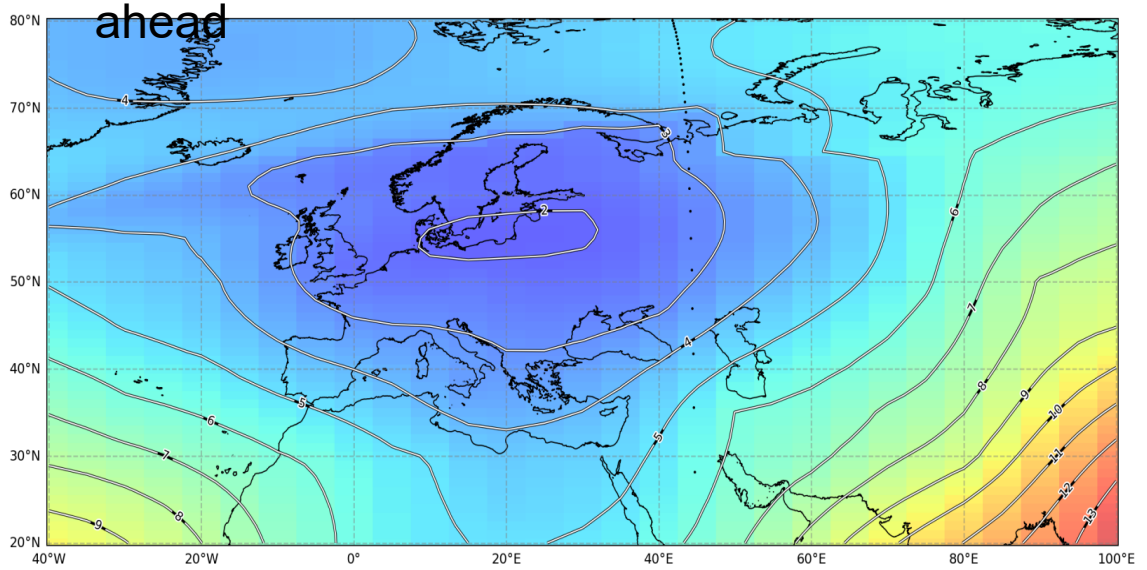



+12 hour ahead

Kp=5

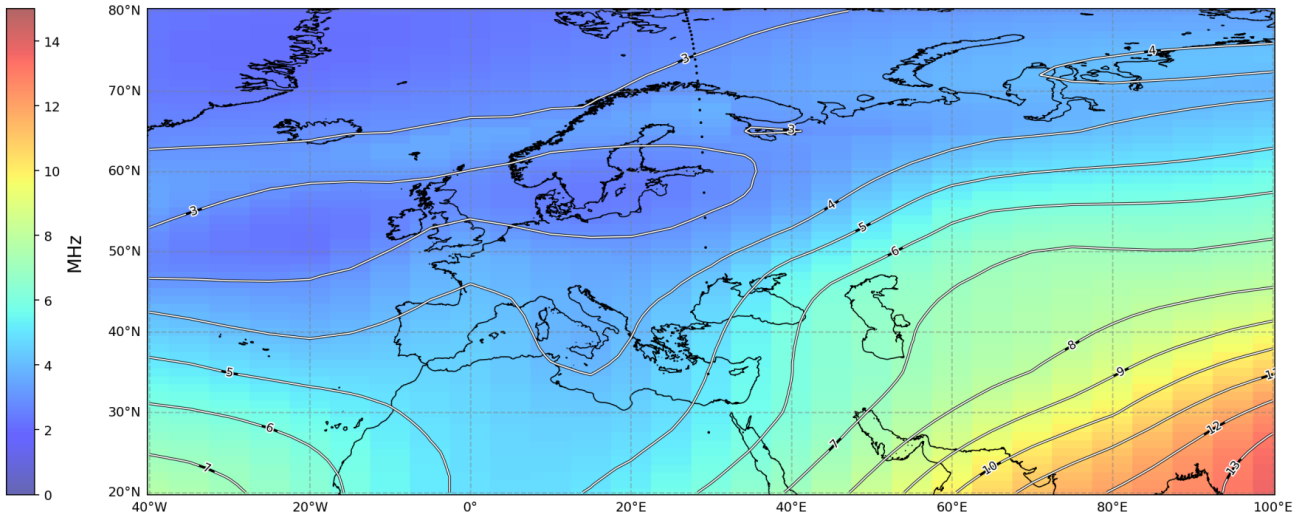



+24 hour ahead



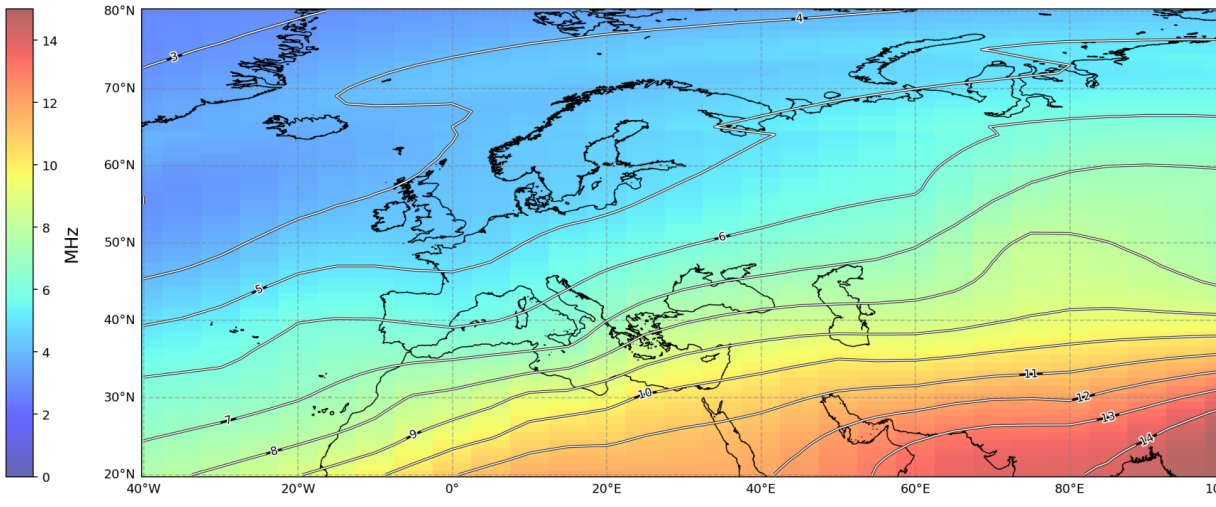

Kp=7

+1 hour ahead



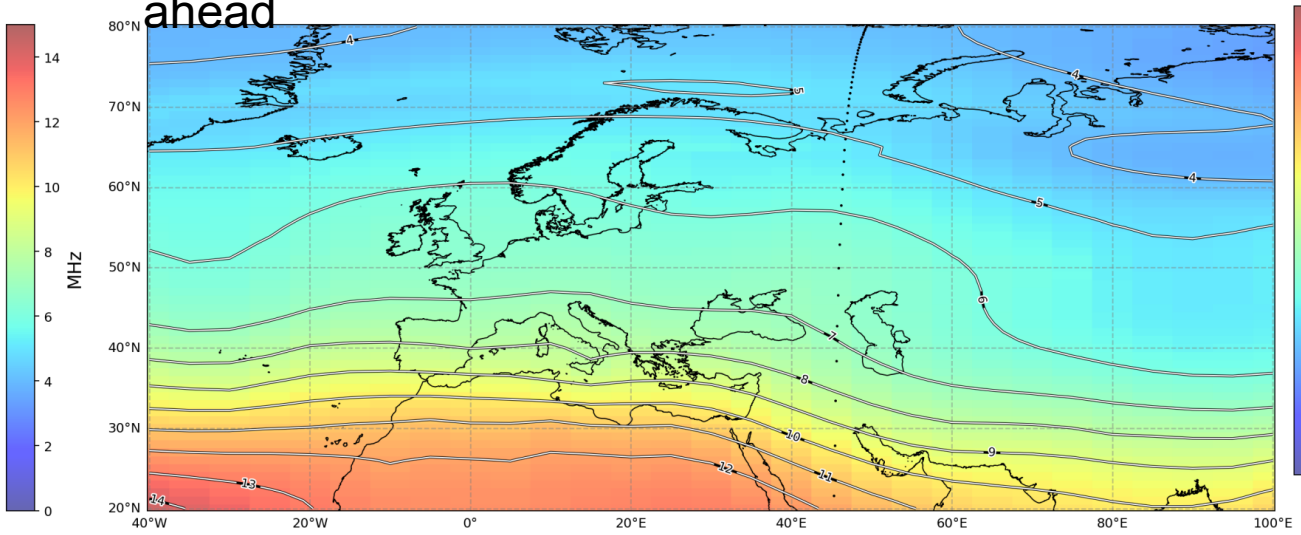

Kp=7

+6 hour ahead



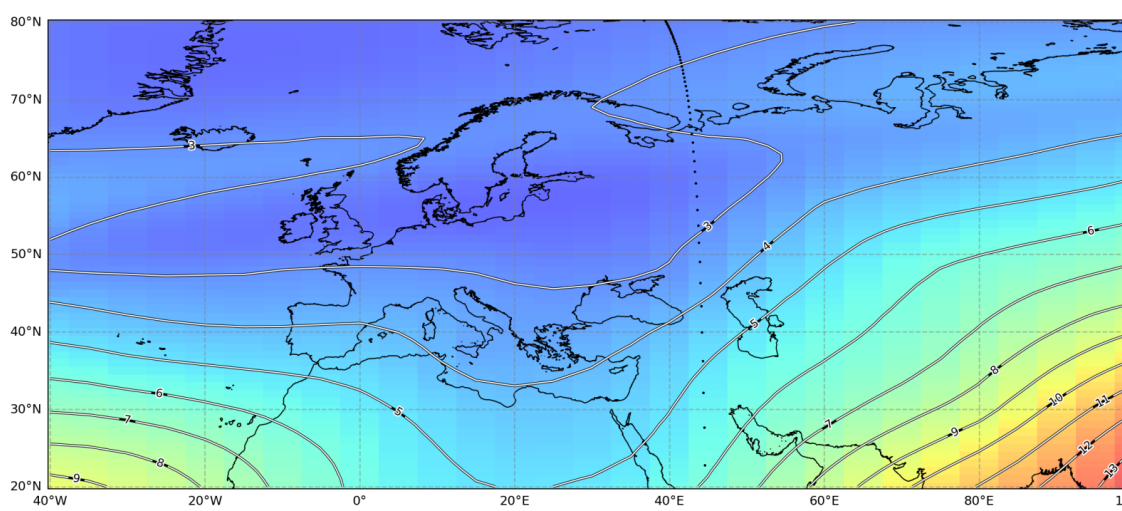

Kp=5

+12 hour ahead



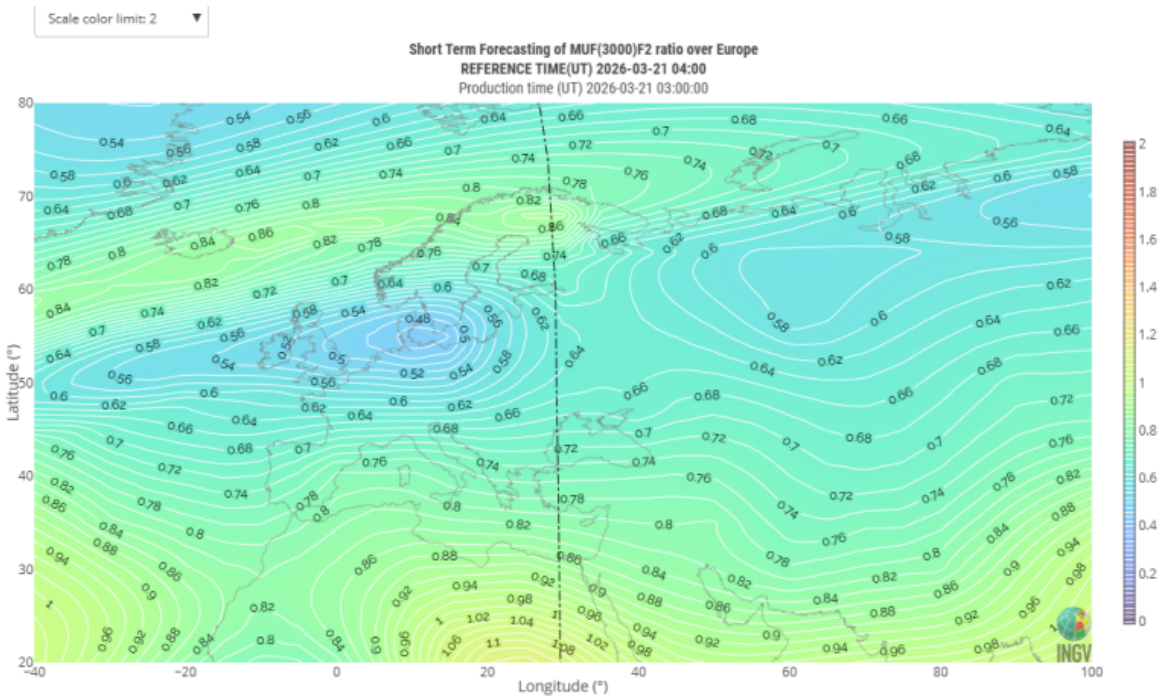

Kp=5

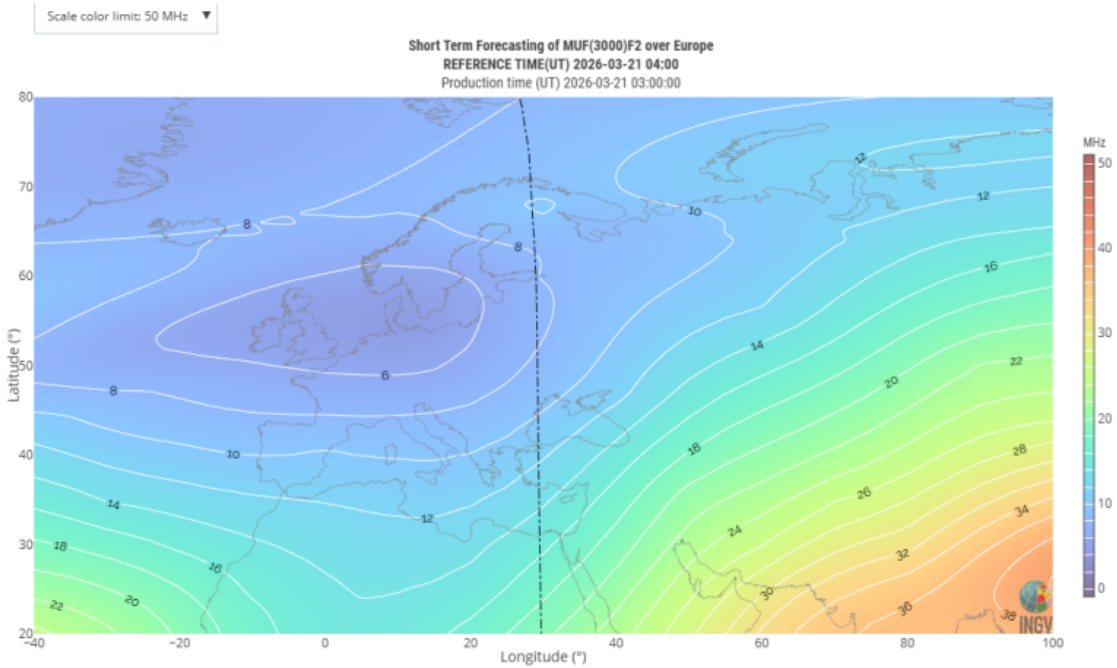
+24 hour ahead




Kp=4-

# MUF(3000) in the SWESNET project

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# IONONET:INGV EUROPEAN IONOSONDE OBLIQUE NETWORK

## ACTUAL IONOSONDE TRANSMITTER STATION Montelibretti


Zirizzotti et al., 2026,2025

***Helsinki (Finland)*** → *Finnish Meteorological Institute (FMI)*

***Nicosia(Cyprus)*** → *Frederick University,(FIT)*

***Dourbes(Belgium)****-Royal Meteorology Institute.*

***Paris (France)*** → *Institut de physique du globe de Paris (IPGP)-Universite Paris Cité*

***(Hungary/Romania)*** → *Institute of Earth Physics and Space Science (EPSS)*

***South Spain*** →*Universidad Computense dei Madrid(UCM)*

IonoNet.ingv.it

# Future Development of EUROMAP

- Develop local models for others ionosonde stations
- Progressive use of IONONET observations for validation and future model improvements
- Potential integration with THERION for thermospheric parameter prediction based on ionospheric forecasts

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# Conclusions

- EUROMAP is already operational in ESA services and PECASUS
- Provides robust and reliable forecasting, including disturbed conditions
- Supported by dedicated infrastructure and ready for future developments

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