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TomoScand

Ionospheric imaging

26.10.2023 **Johannes Norberg**

Contents

- Ionospheric electron density measurements
- Ionospheric imaging with TomoScand
- Recent developments

Ionospheric electron density measurements

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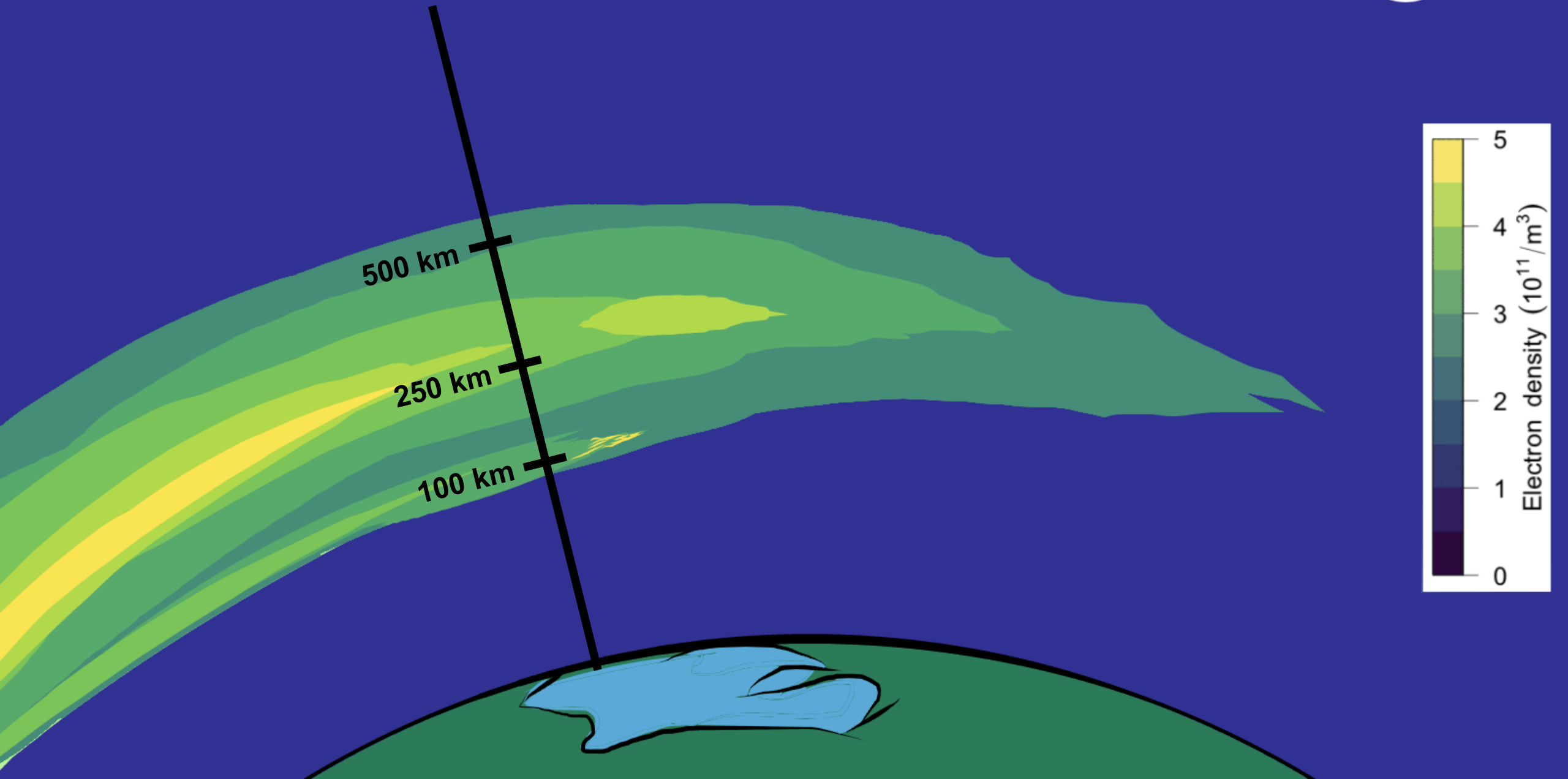
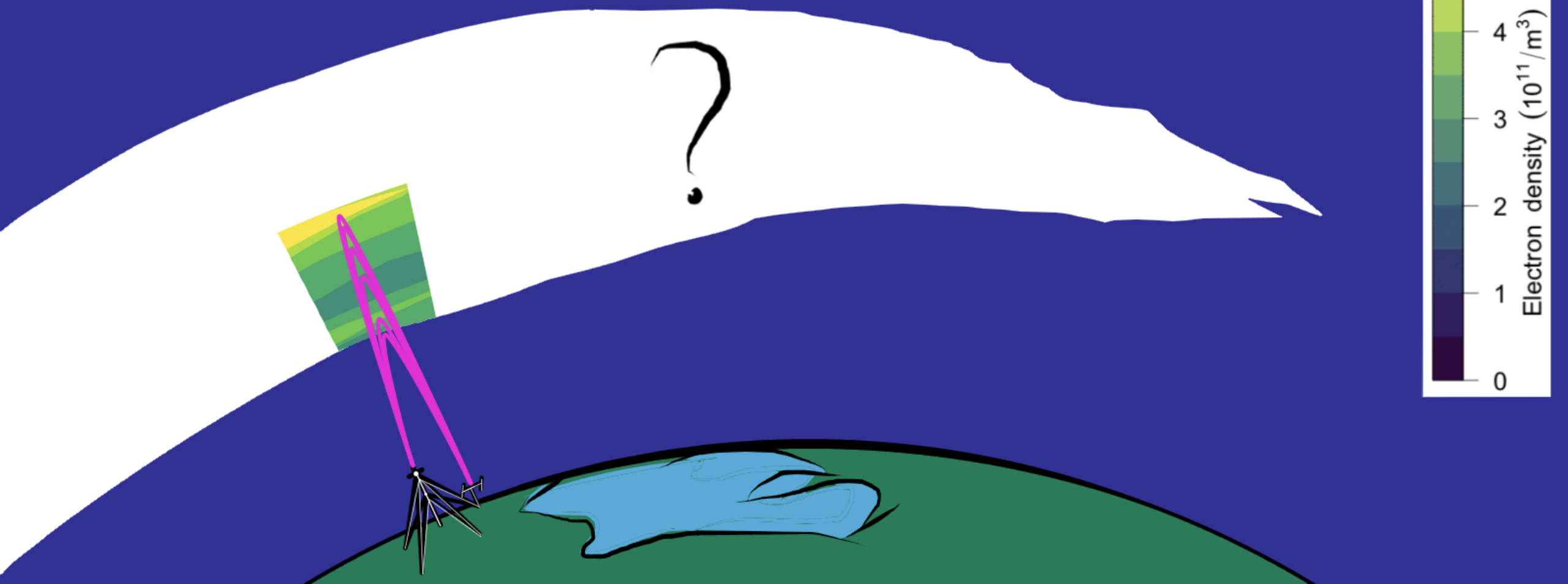
Ionosphere

FMI

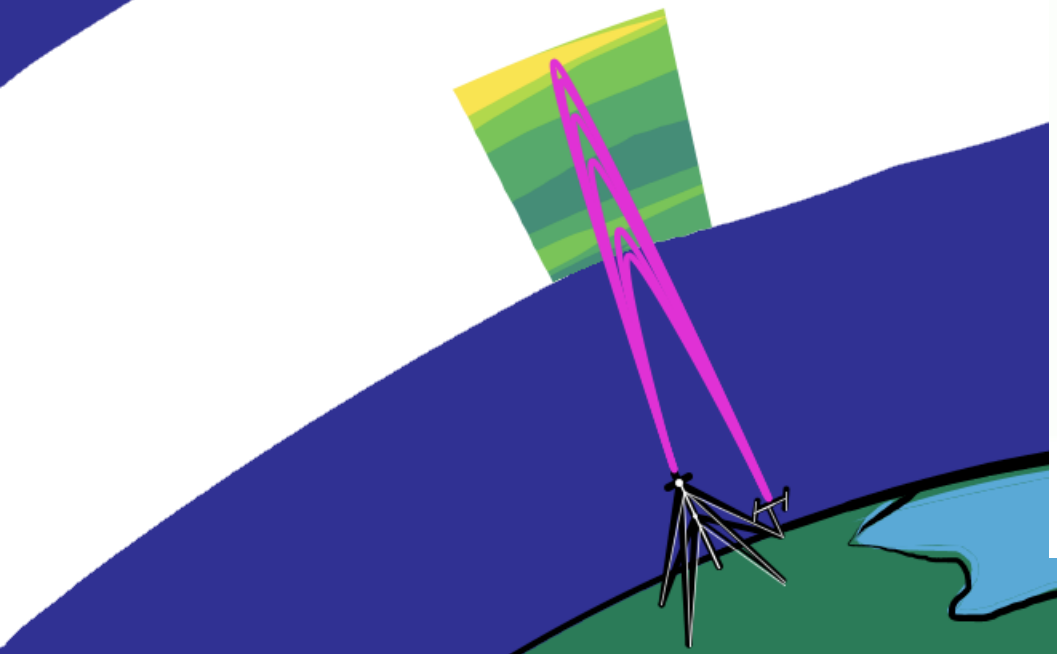


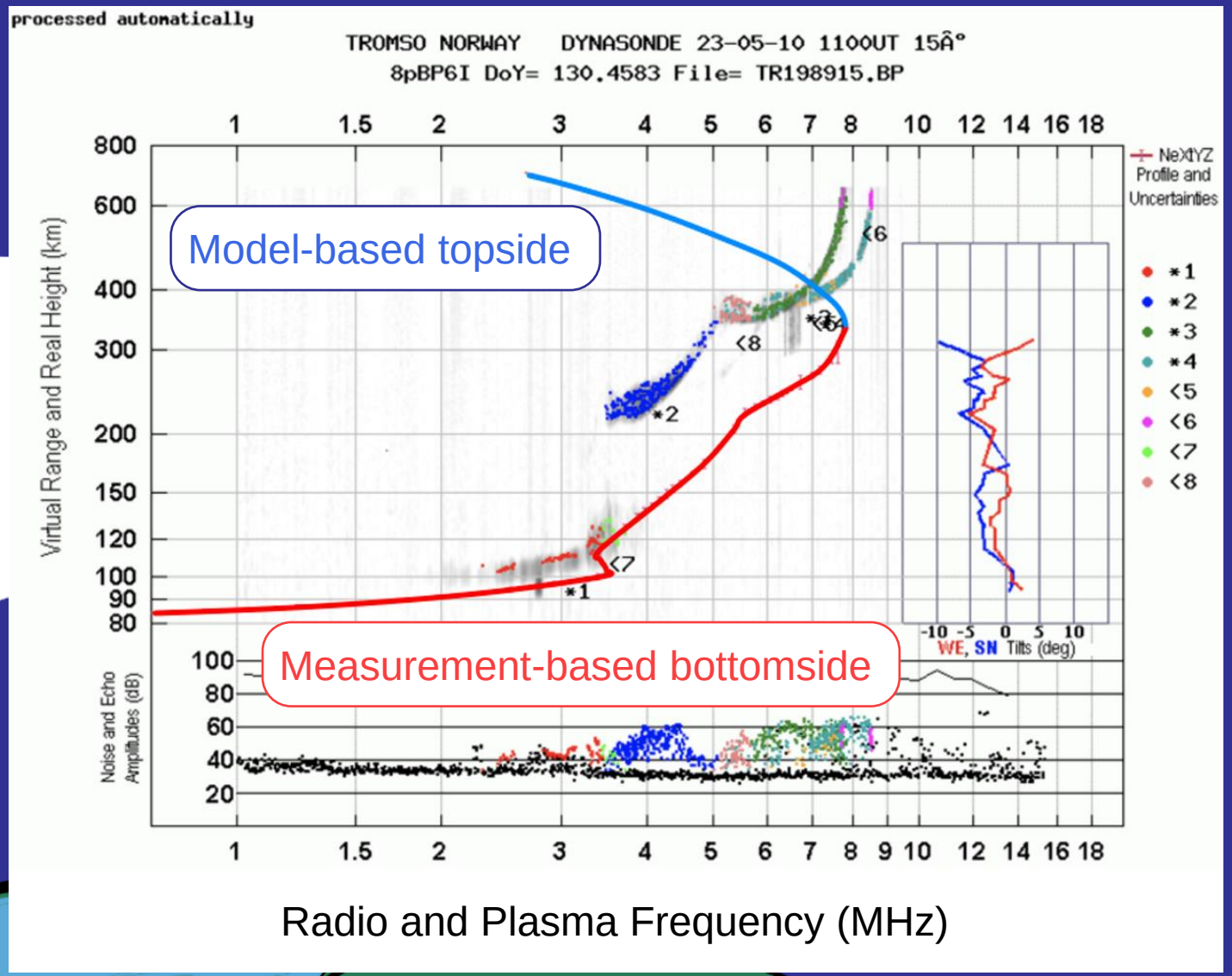
Ionosonde measurements

FMI

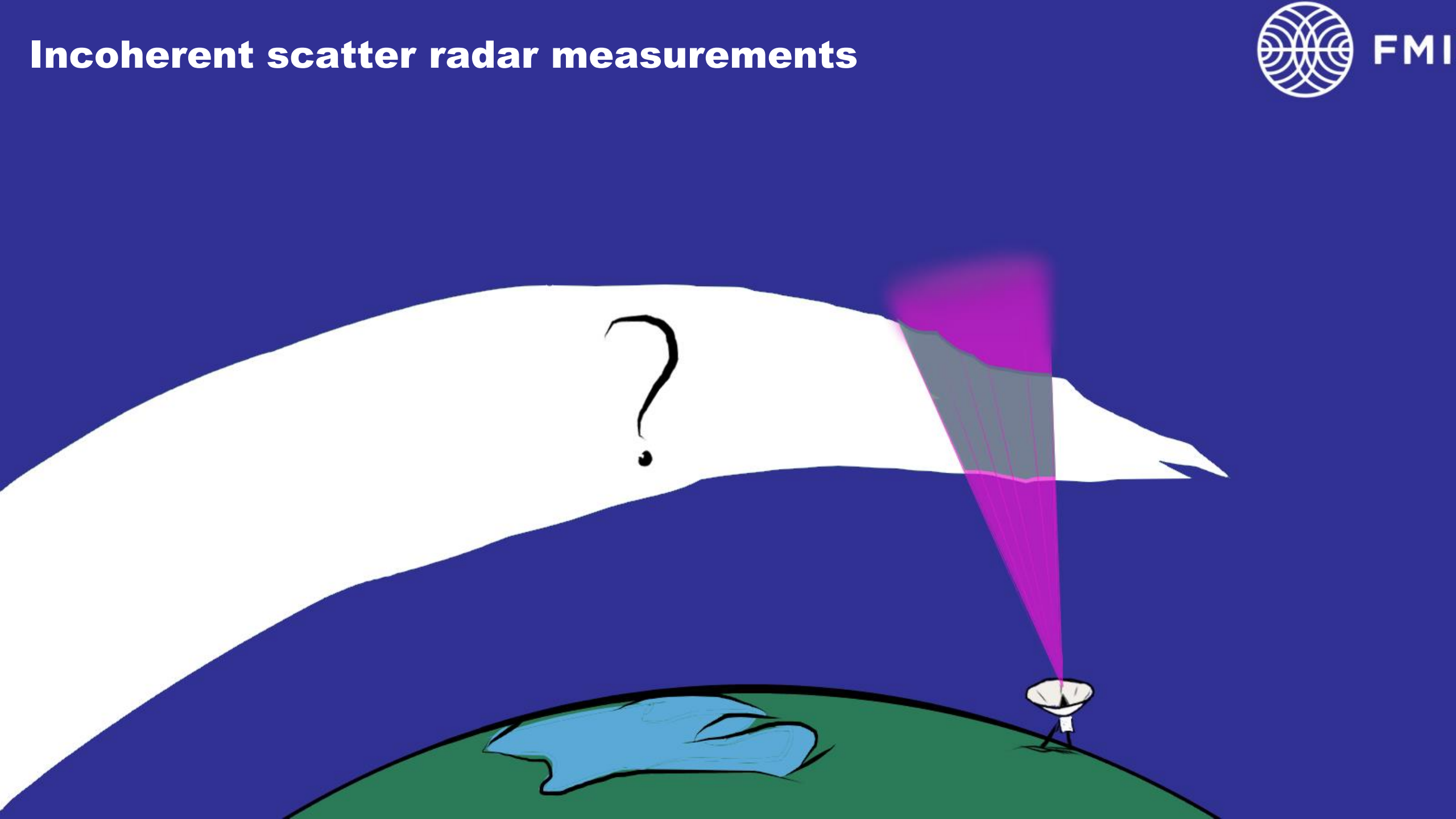


Ionosonde measurements

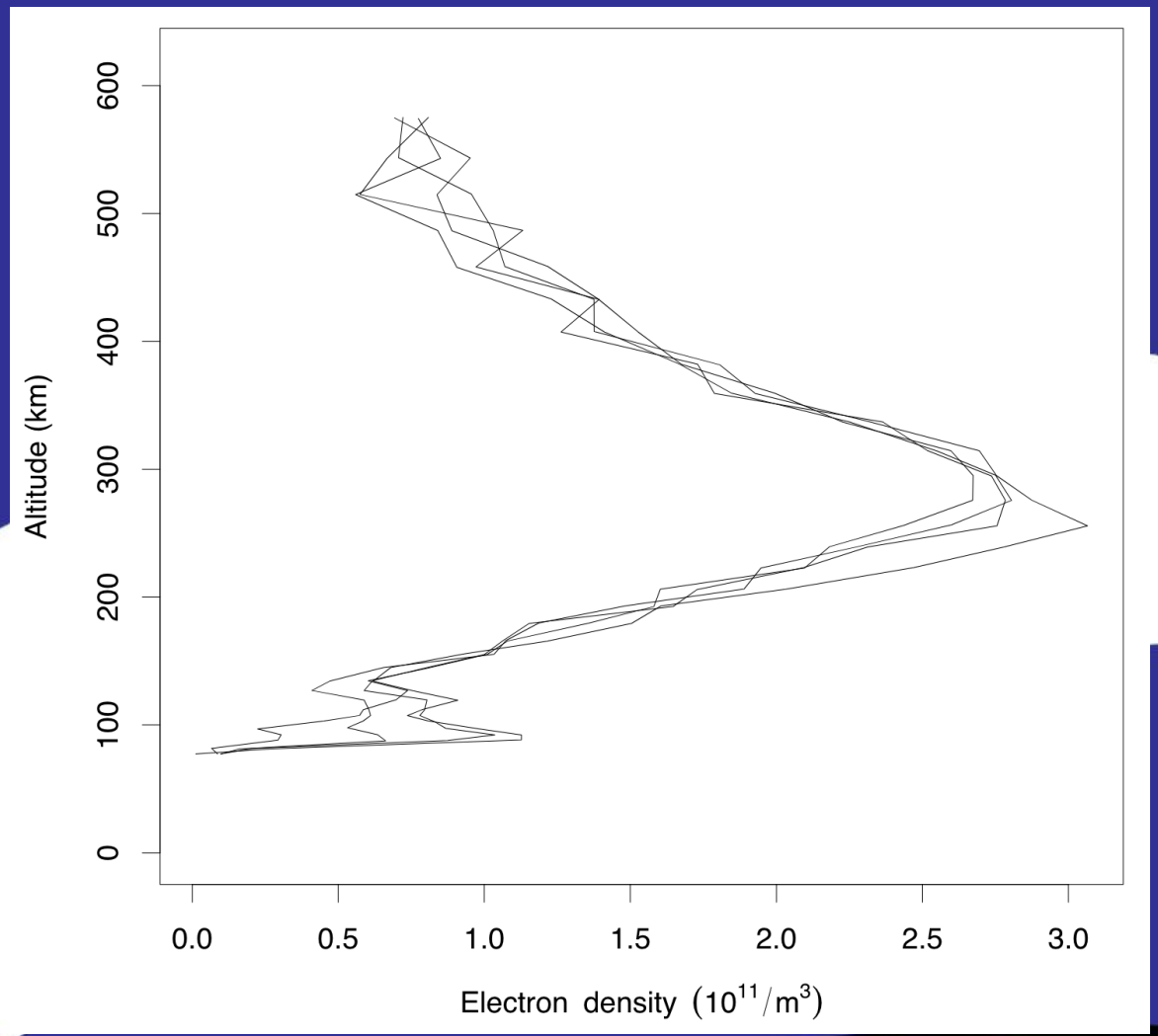




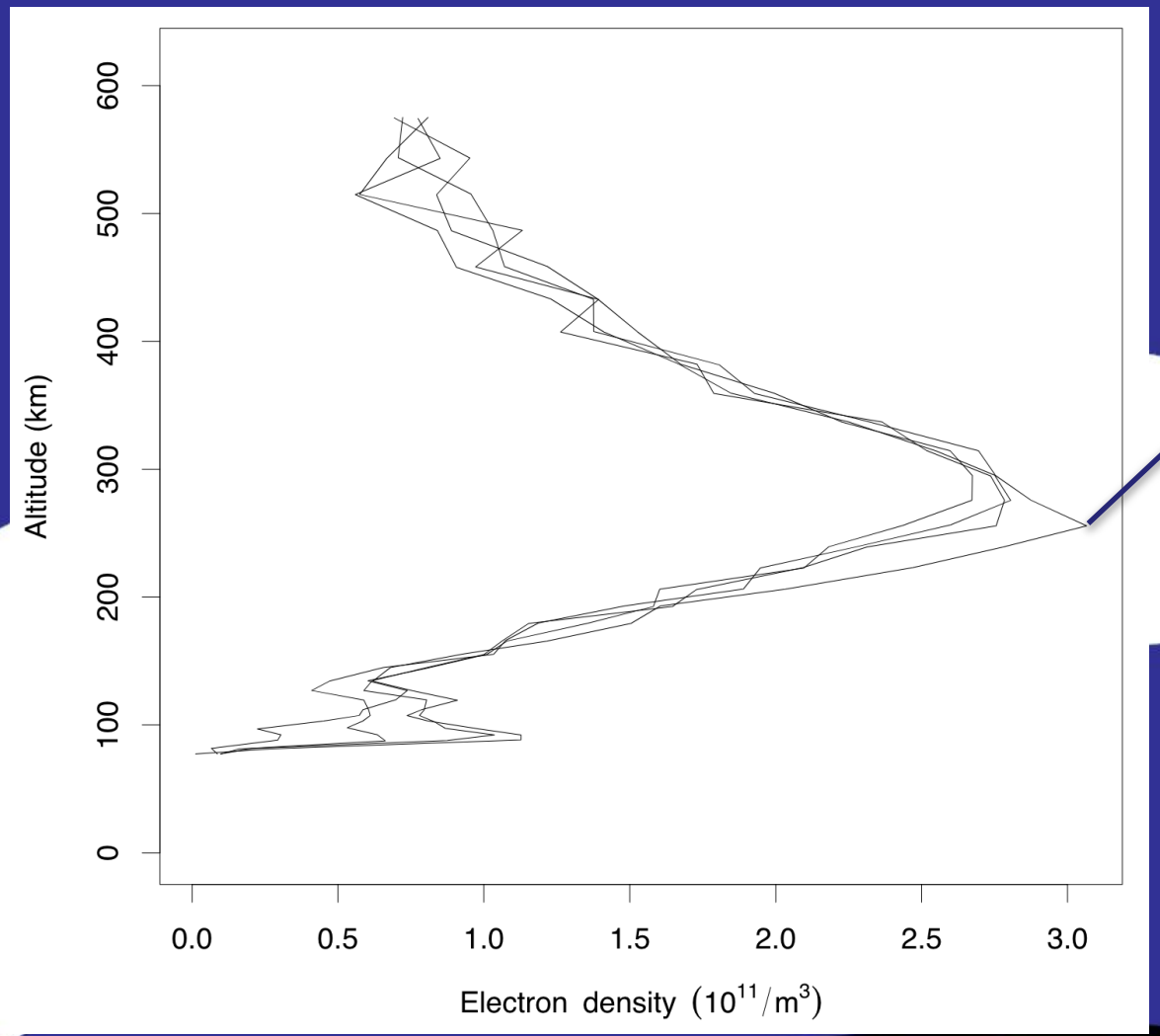
Incoherent scatter radar measurements

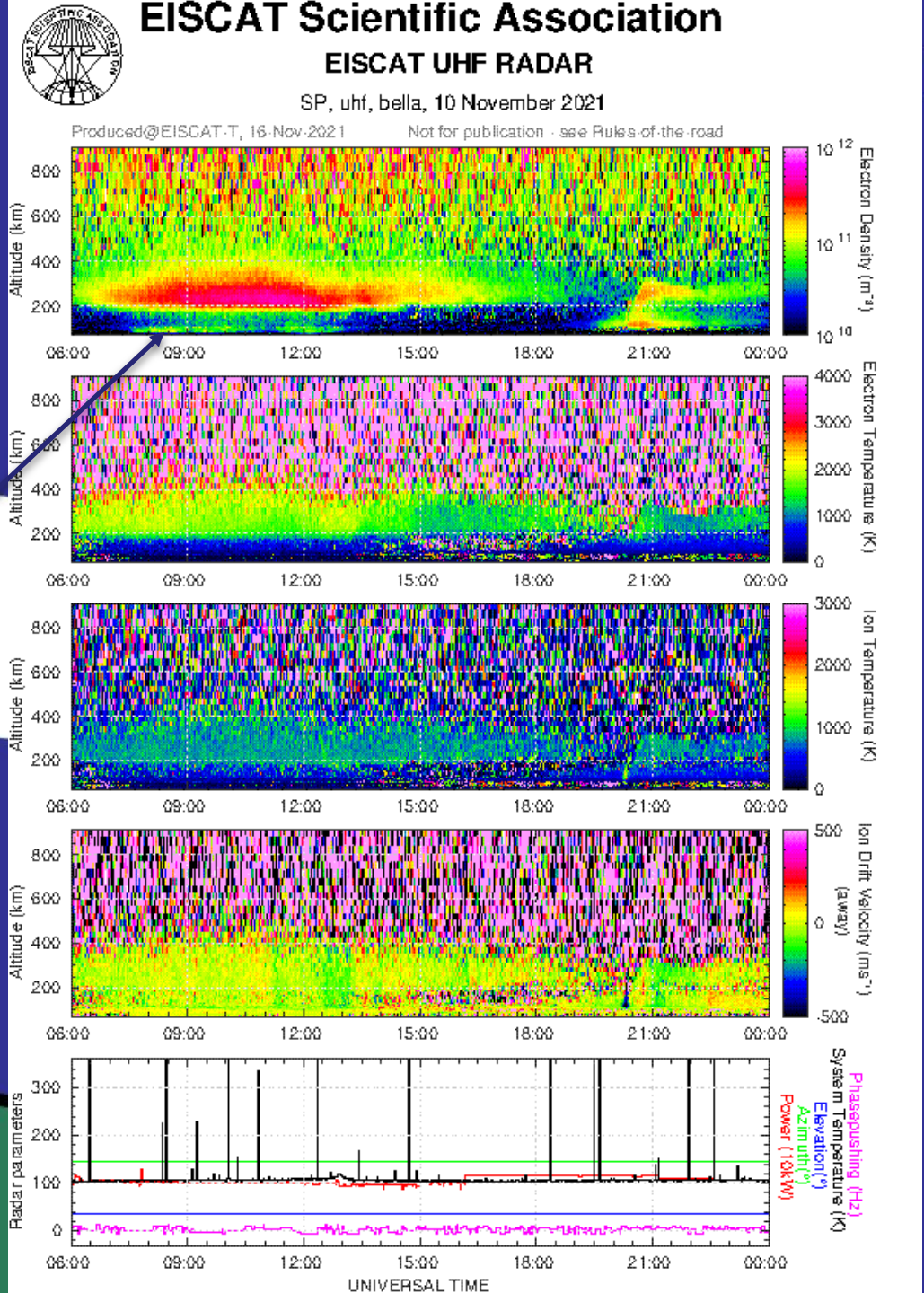


Incoherent scatter radar measurements

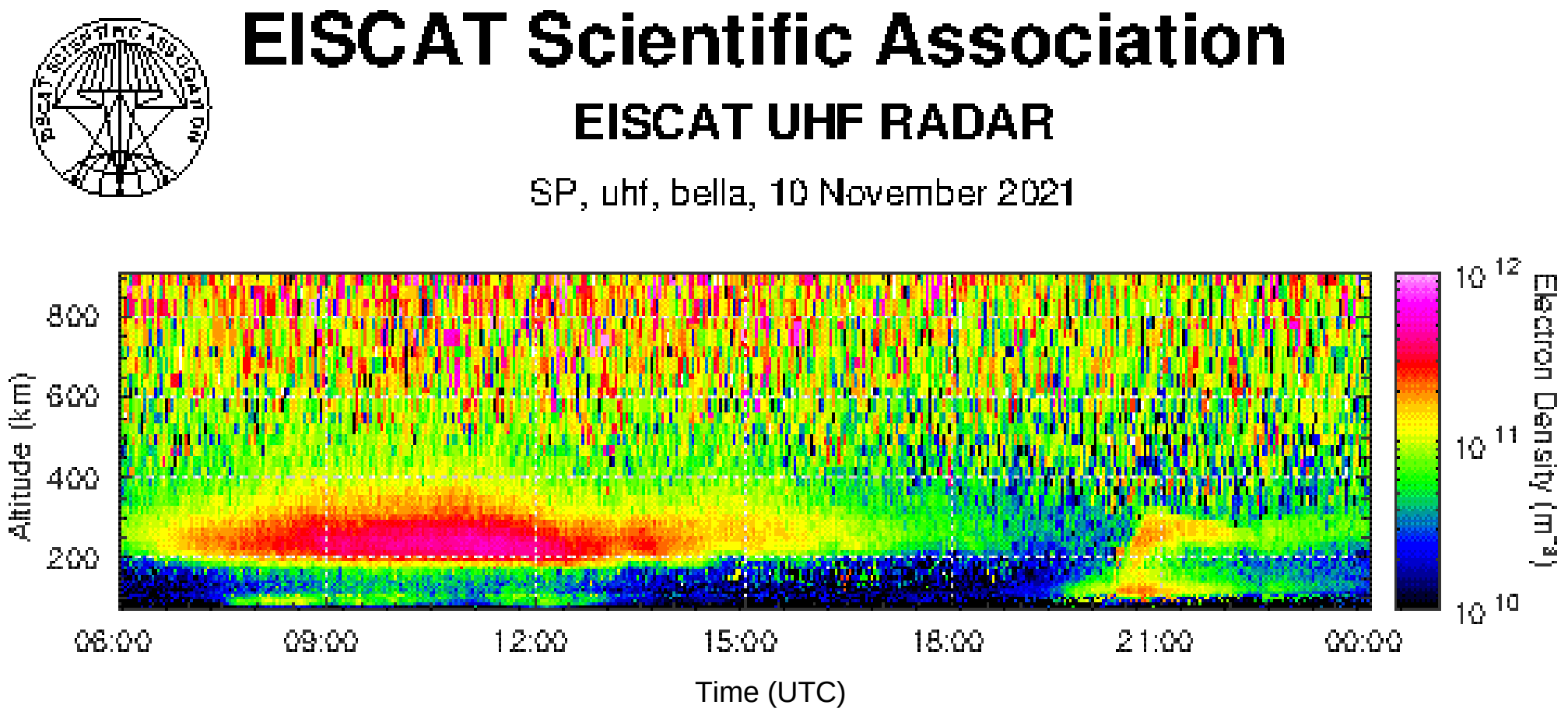


Incoherent scatter radar measurements

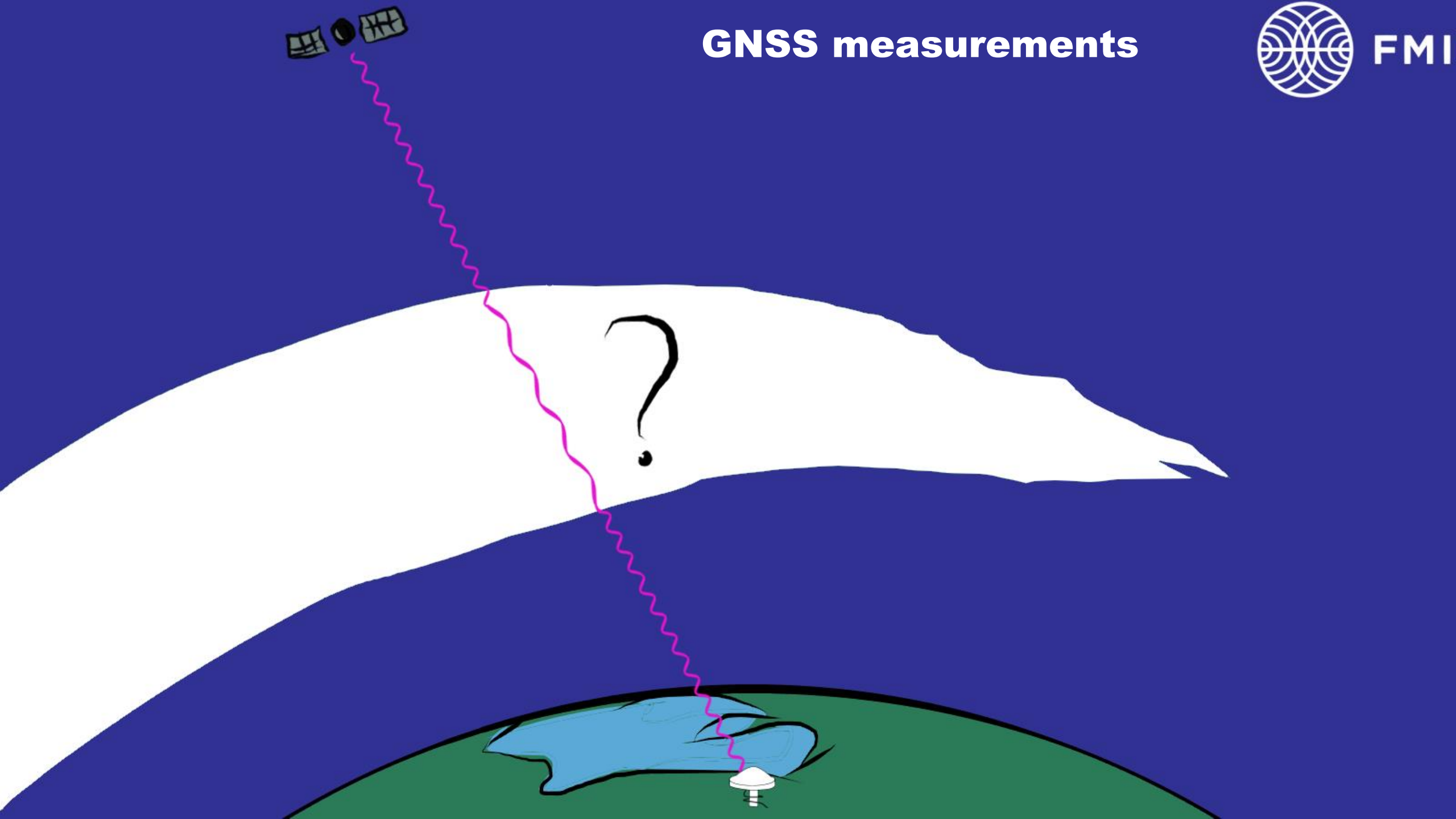




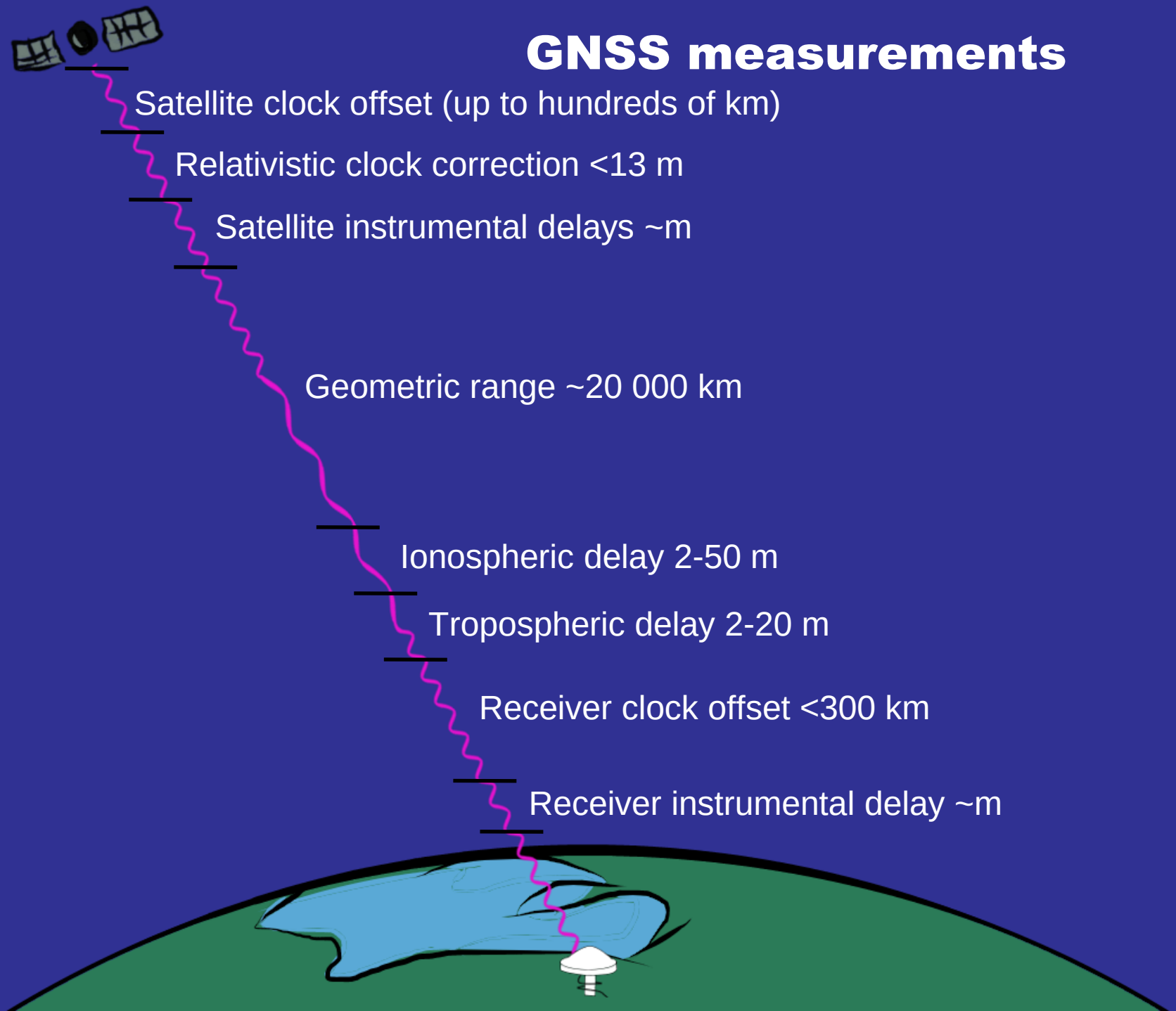
Incoherent scatter radar measurements



GNSS measurements

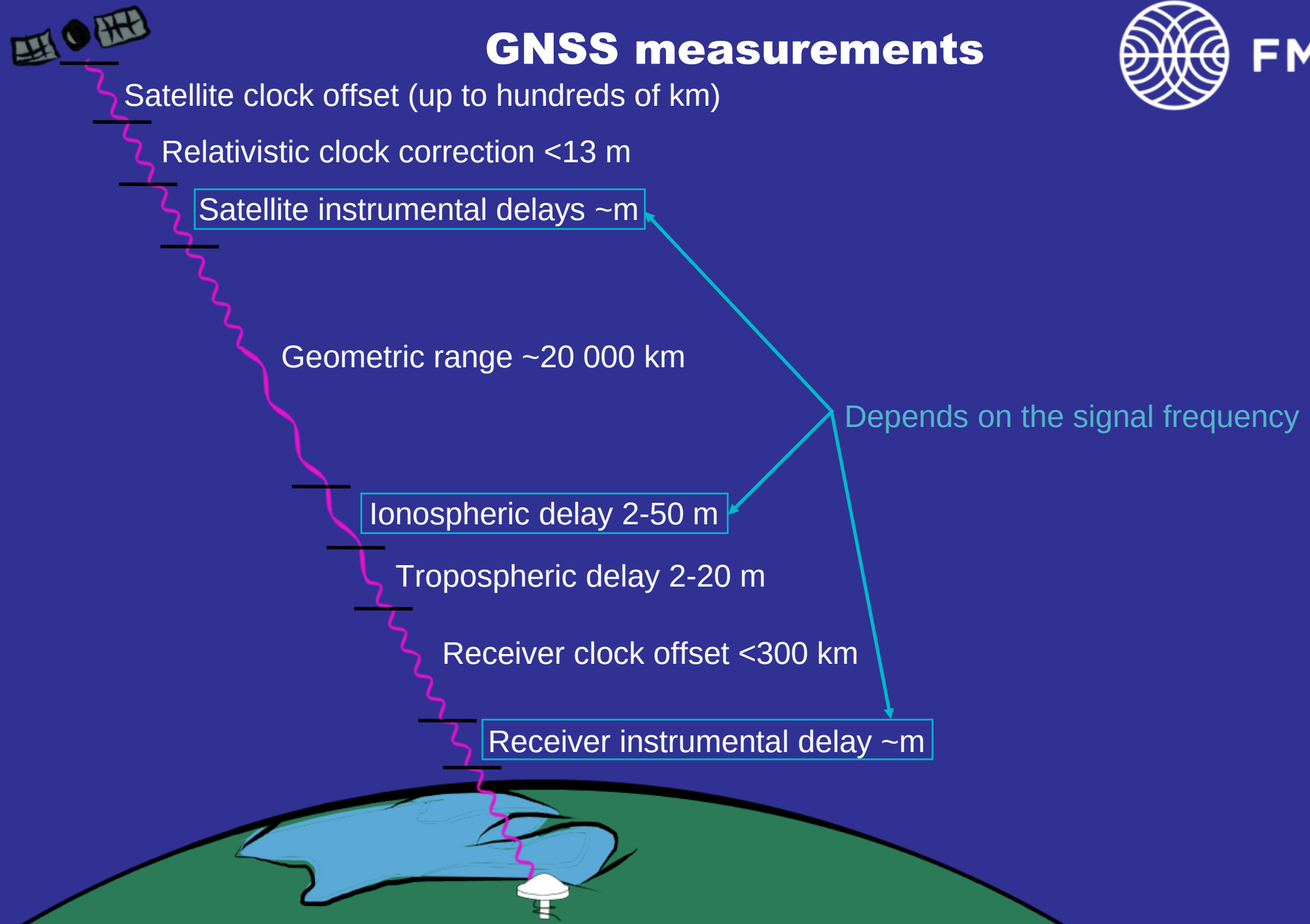


GNSS measurements



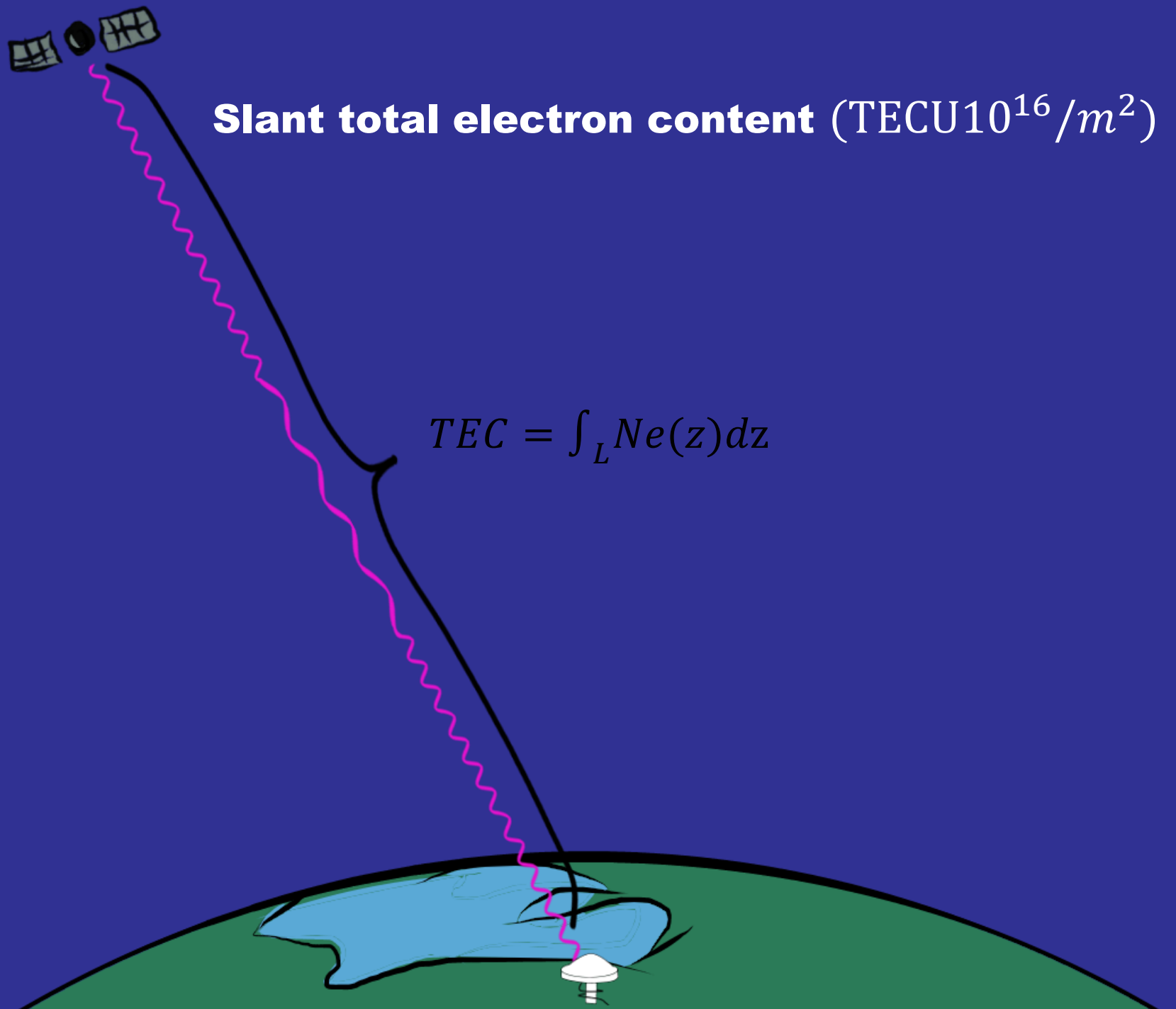
(Navipedia)

GNSS measurements



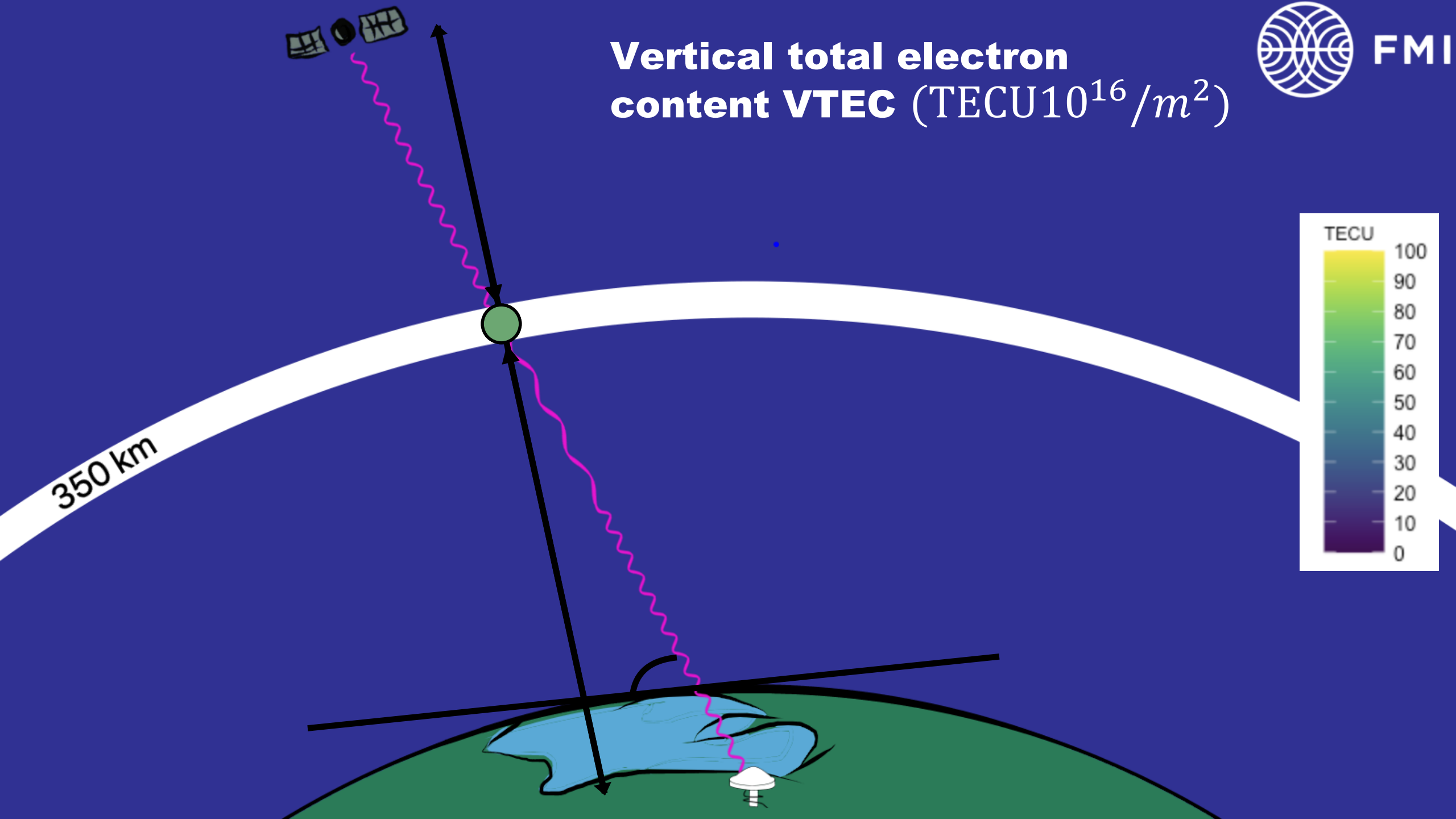
Slant total electron content $(\mathrm{TECU}10^{16}/m^2)$

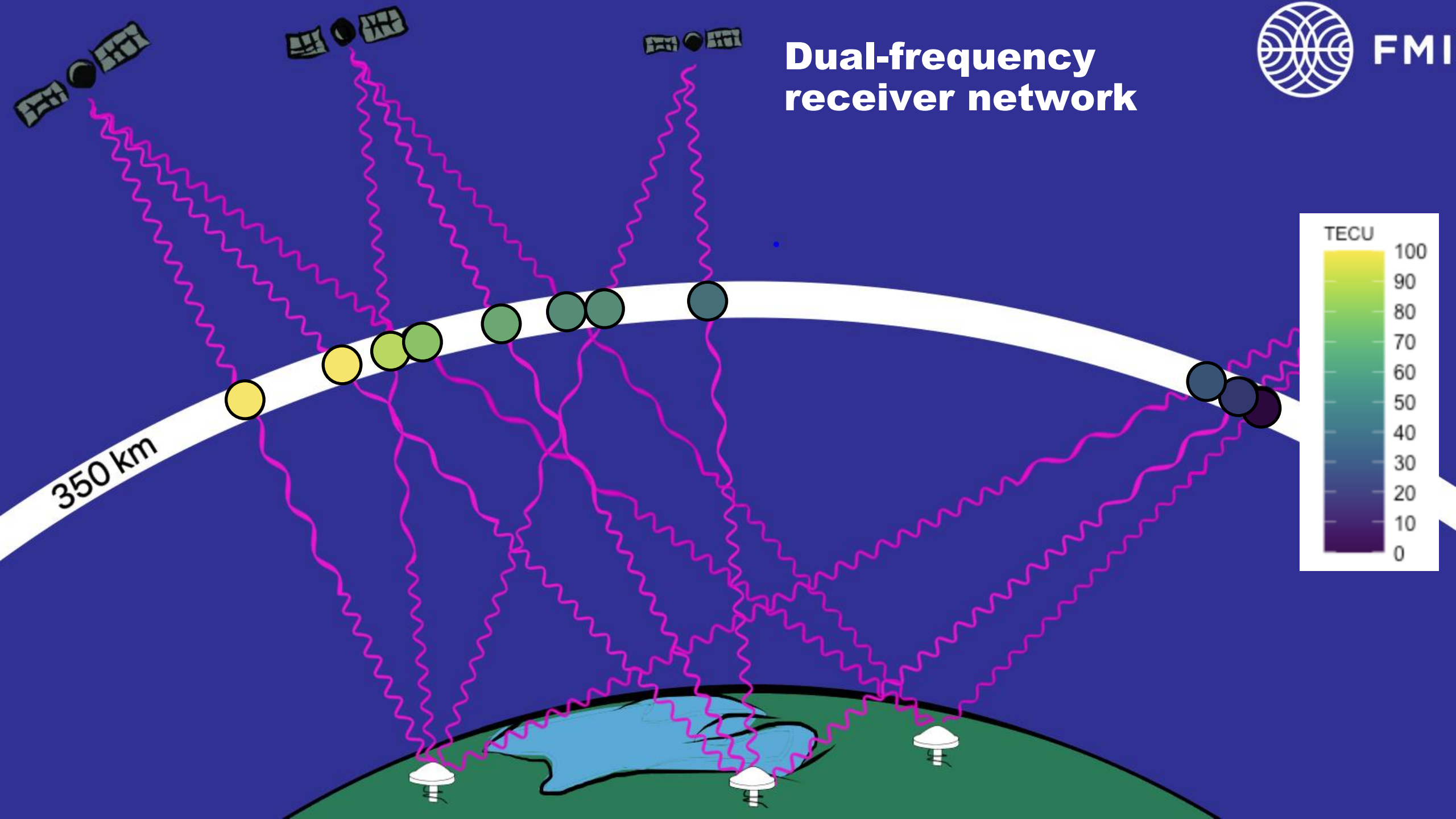
$$TEC = \int_L Ne(z)dz$$

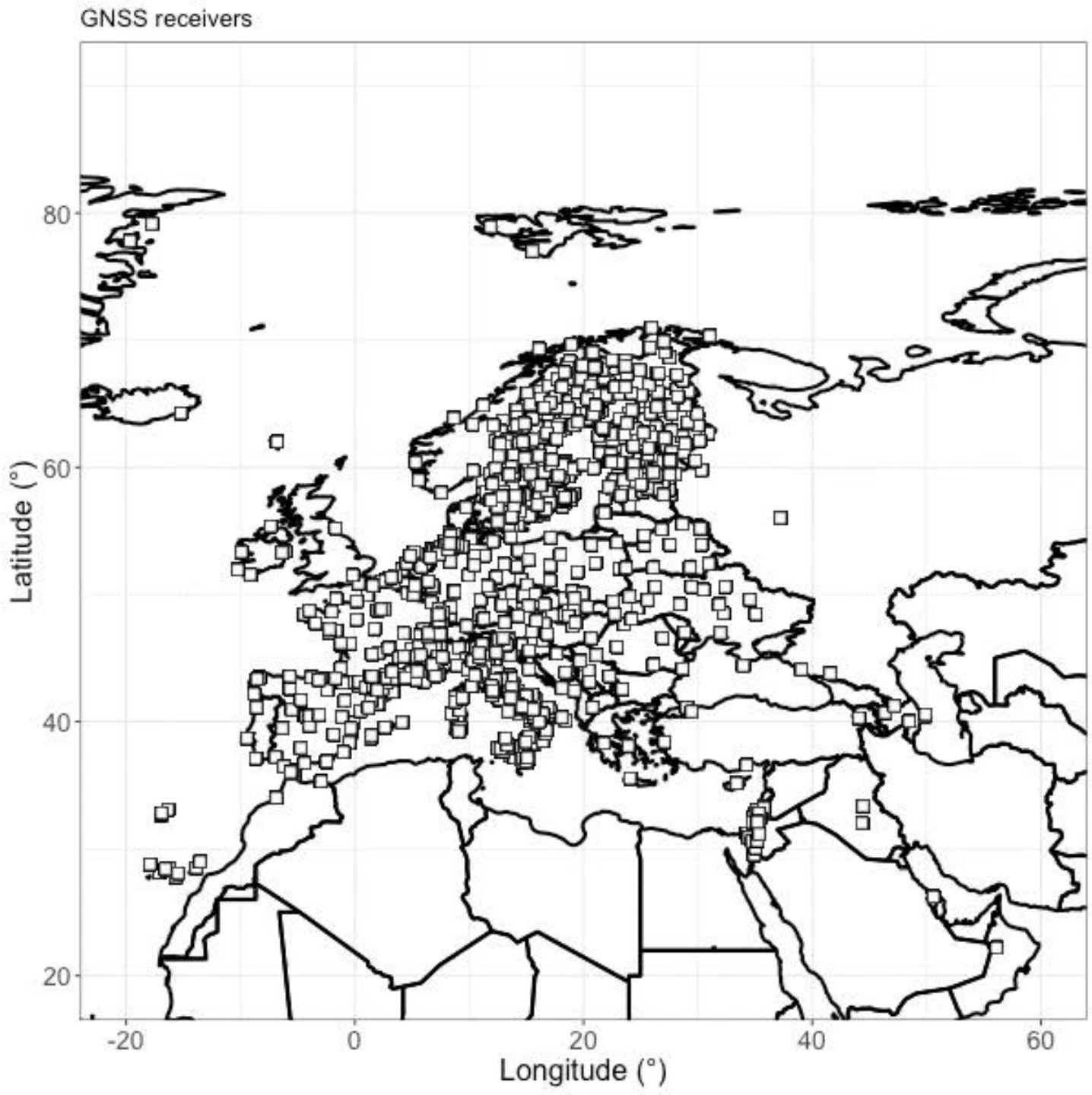


Vertical total electron content VTEC $(\mathrm{TECU}10^{16}/m^2)$

FMI




Dual-frequency
receiver network
FMI
350 km
TECU
100
90
80
70
60
50
40
30
20
10
0



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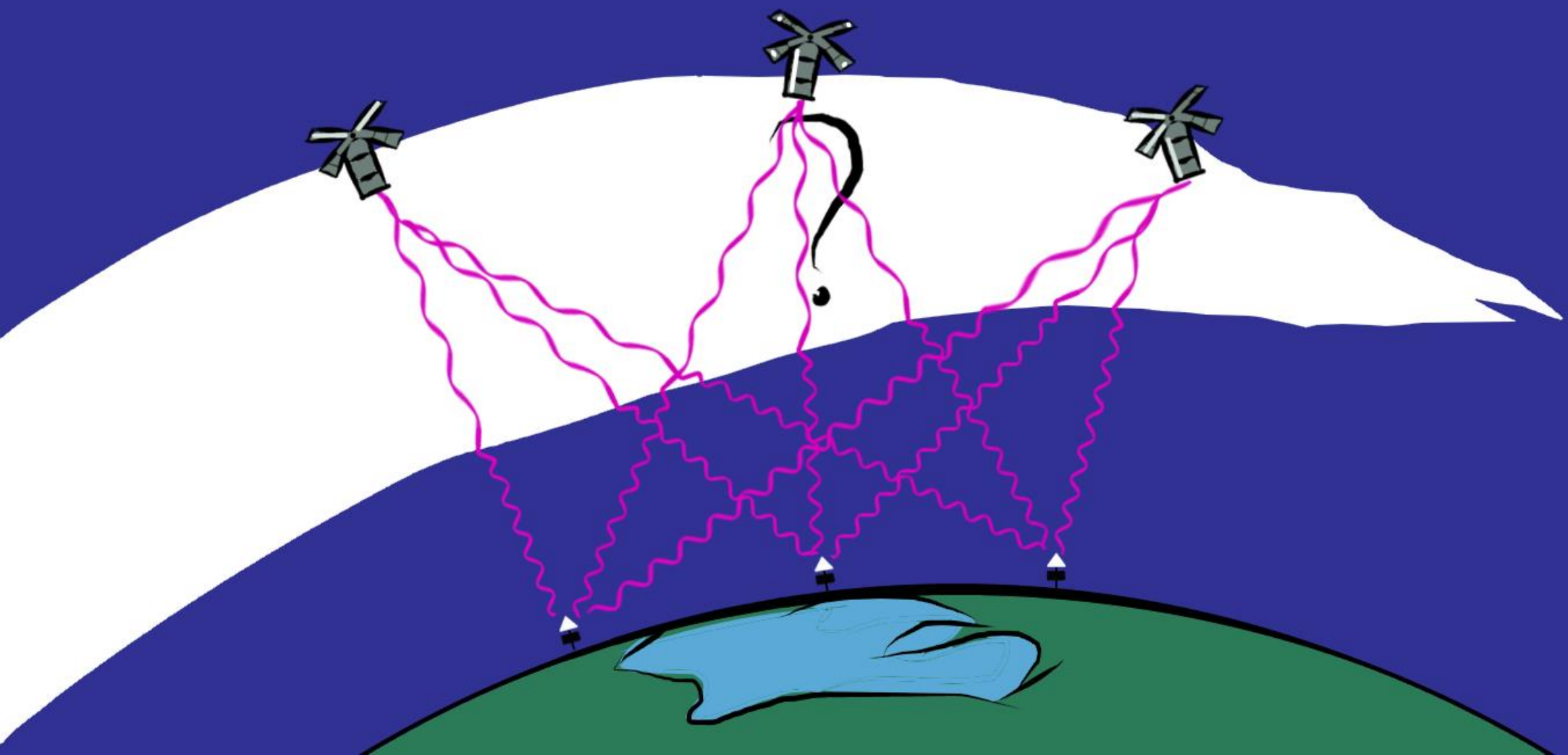
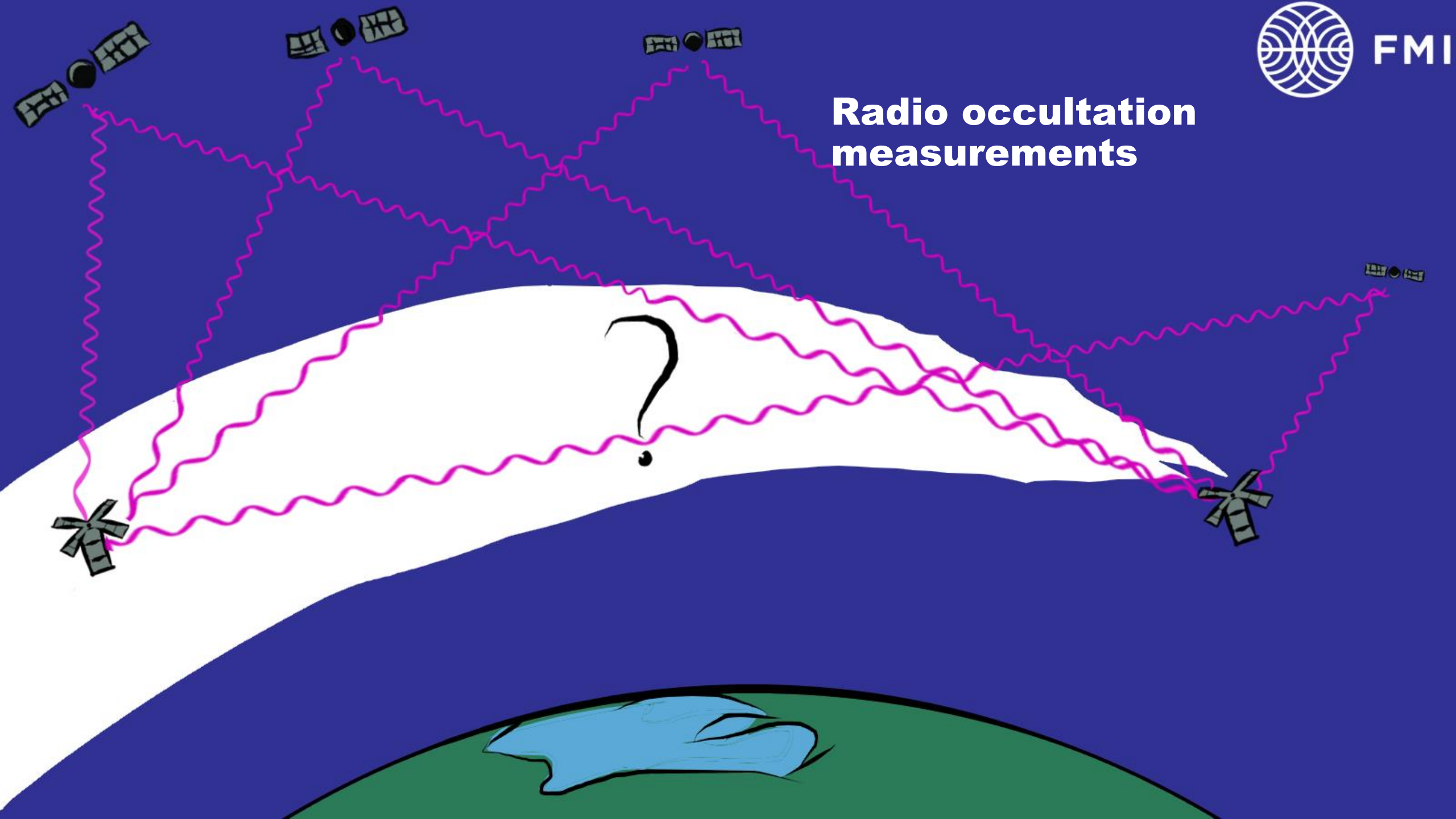
Low Earth orbit (LEO) beacon satellite measurements



Radio occultation measurements



Ionospheric imaging

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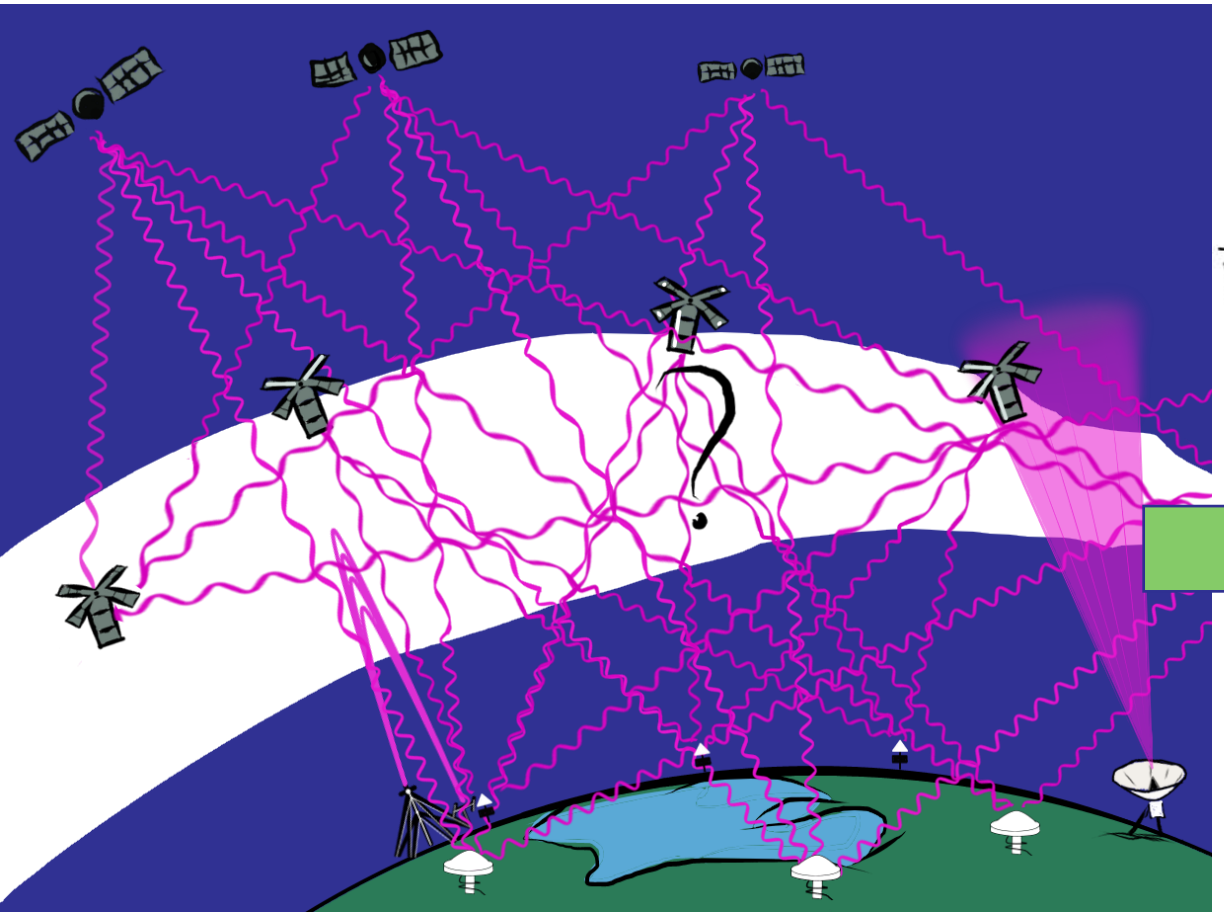
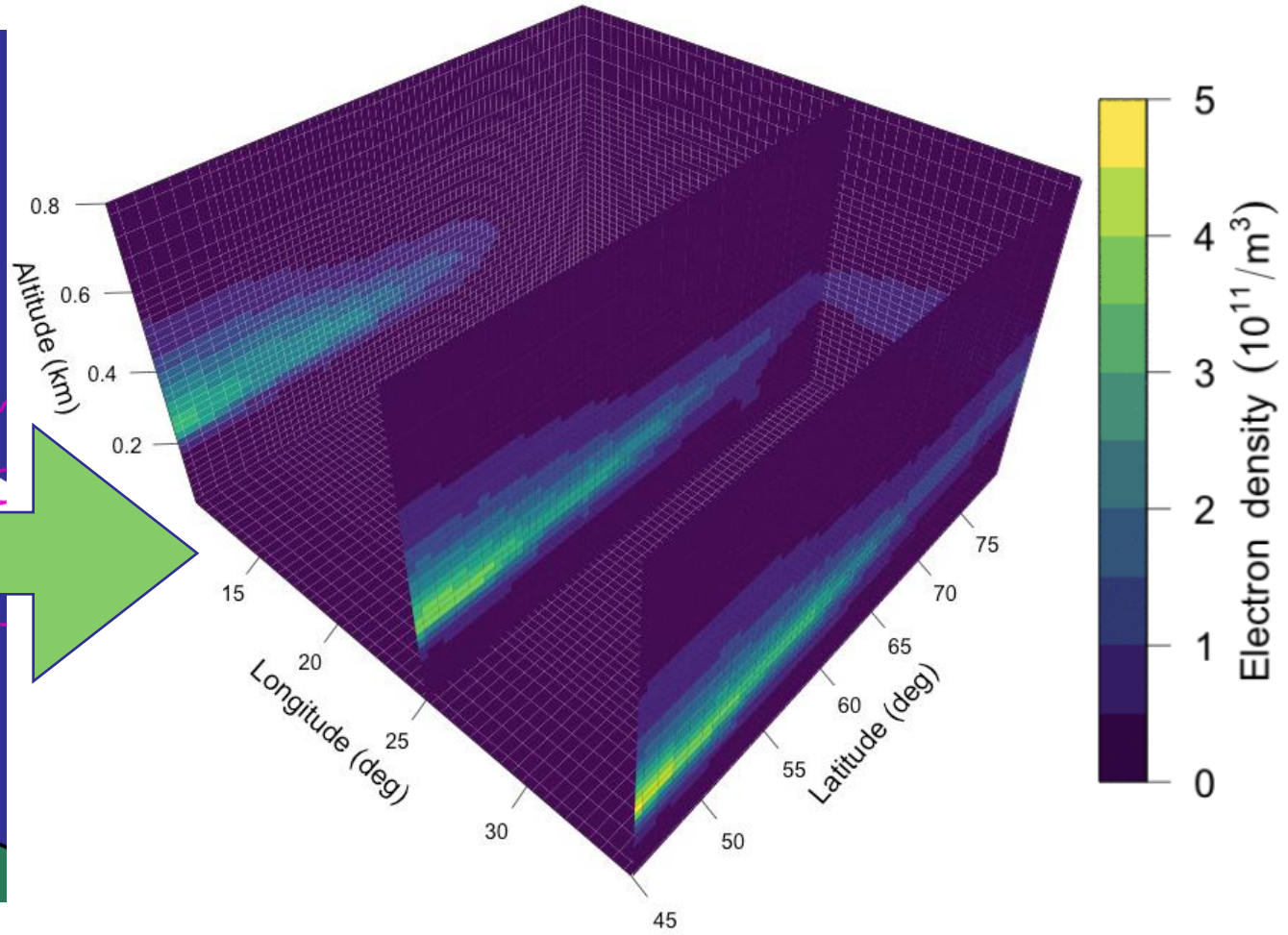
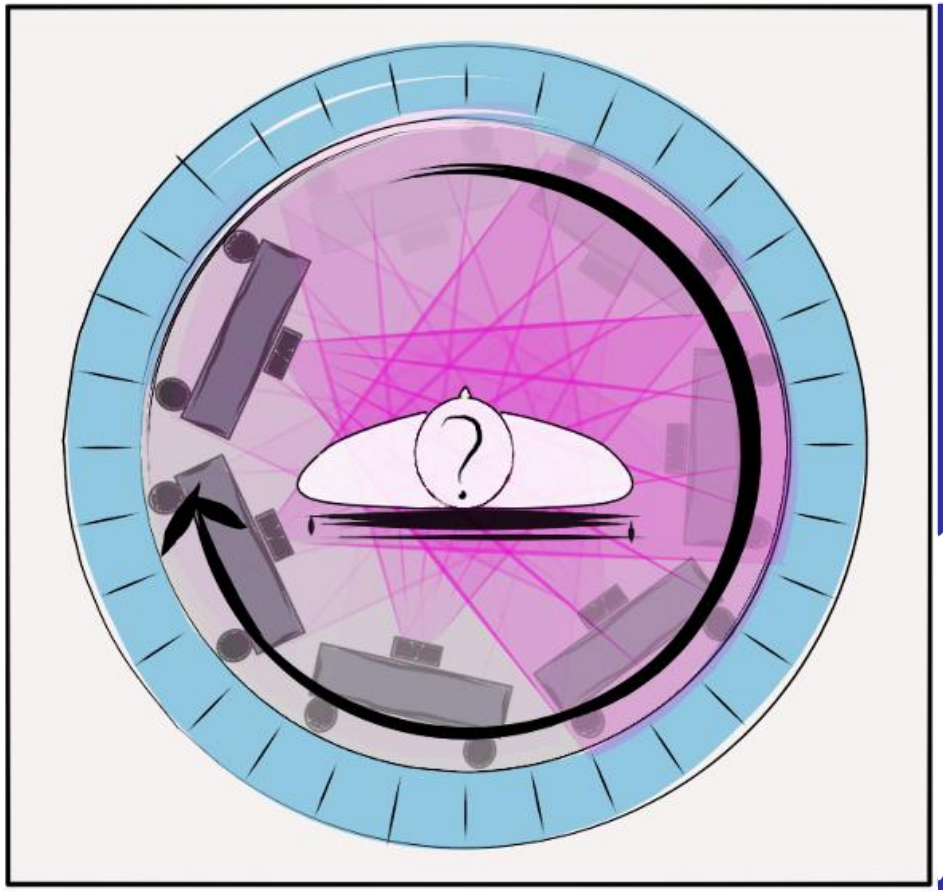
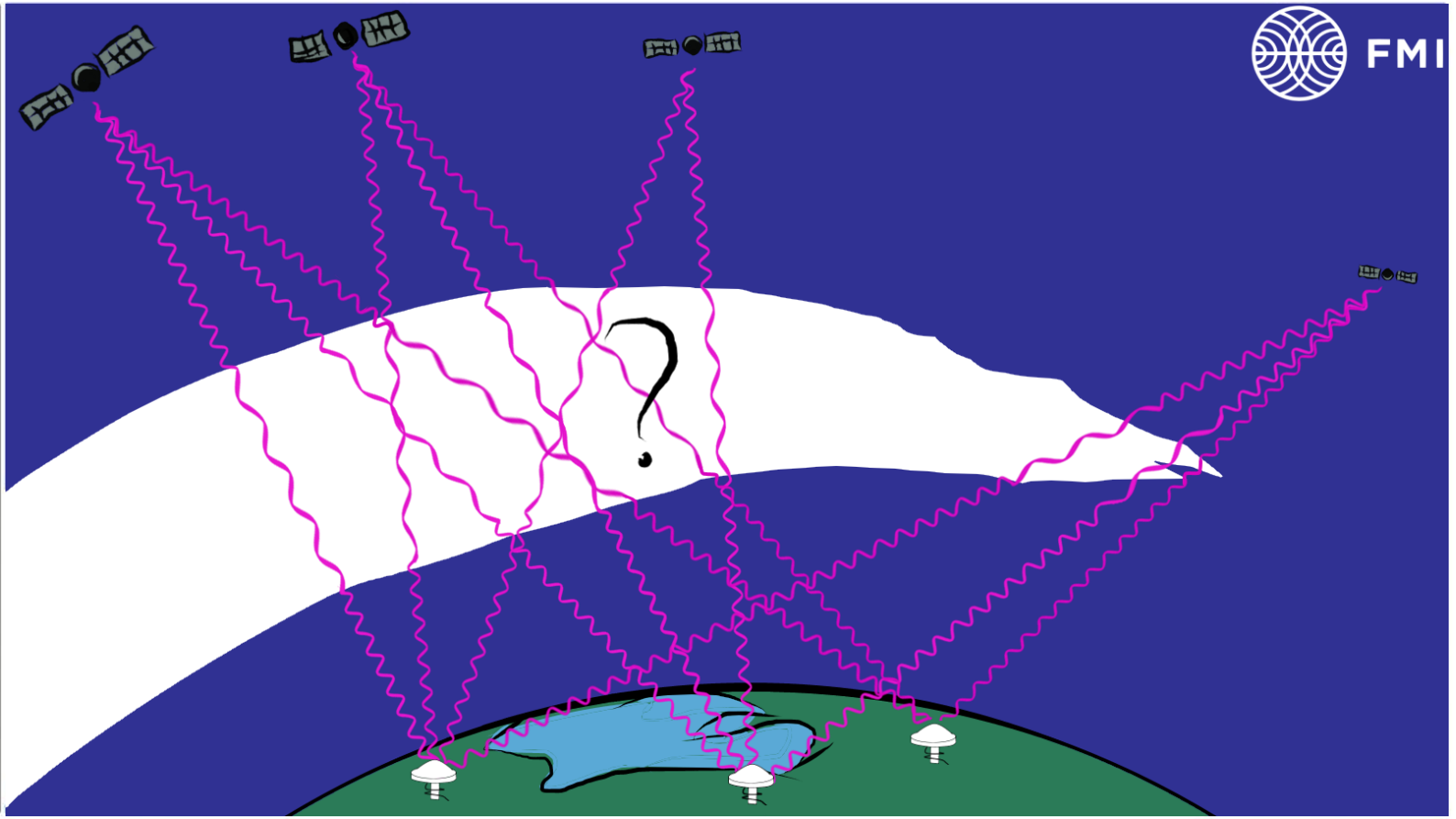
Ionospheric imaging





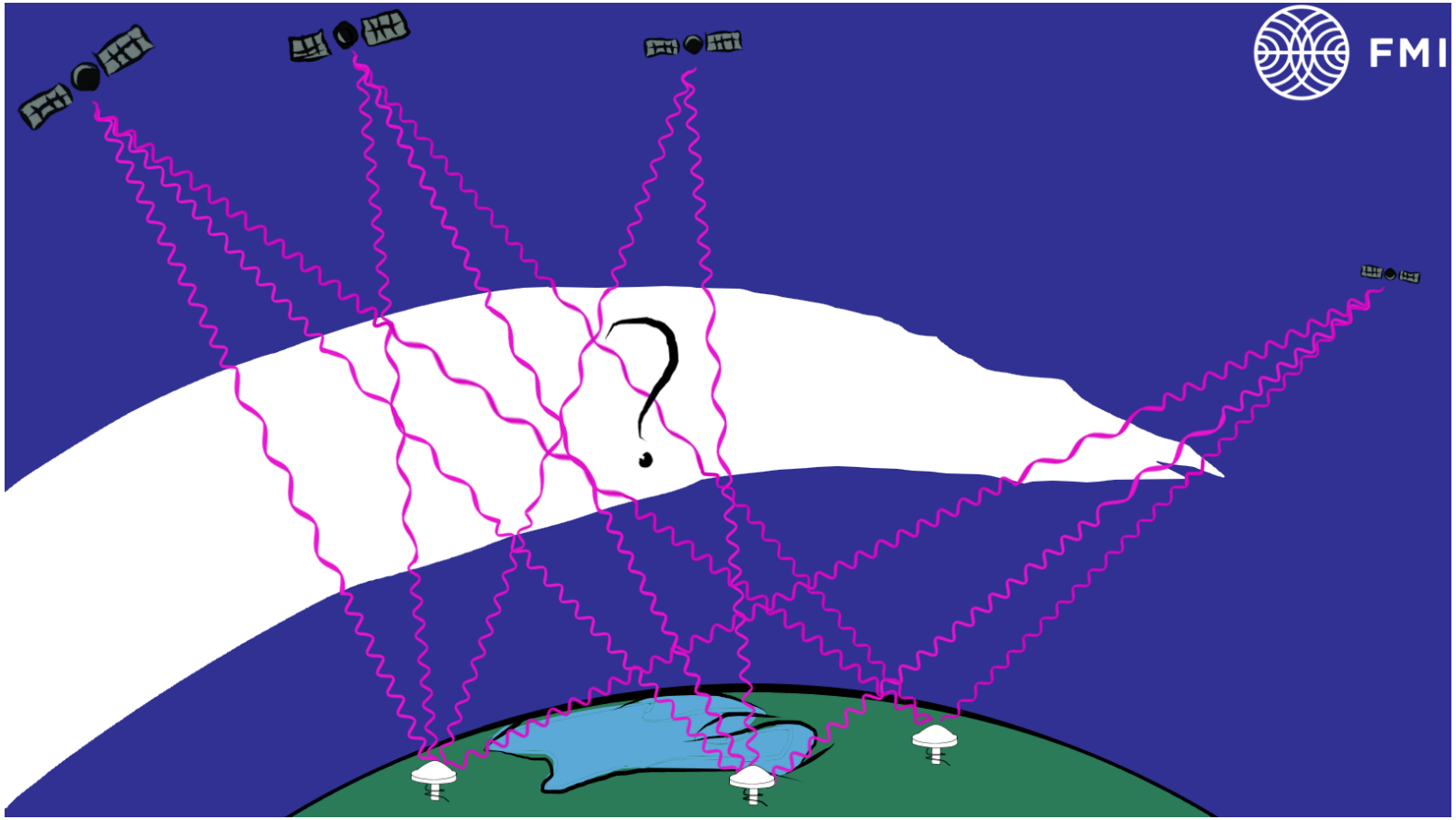
Tomography





Tomography

- Little information on the vertical structure
- Additional regularising information is needed
- Ionospheric model?



TomoScand approach

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING

Gaussian Markov Random Field Priors in Ionospheric 3-D Multi-Instrument Tomography

Johannes Norberg, Juha Vierinen, Lassi Roininen, Mikko Orispää, Kirsti Kauristie, William C. Rideout, Anthea J. Coster, and Markku S. Lehtinen

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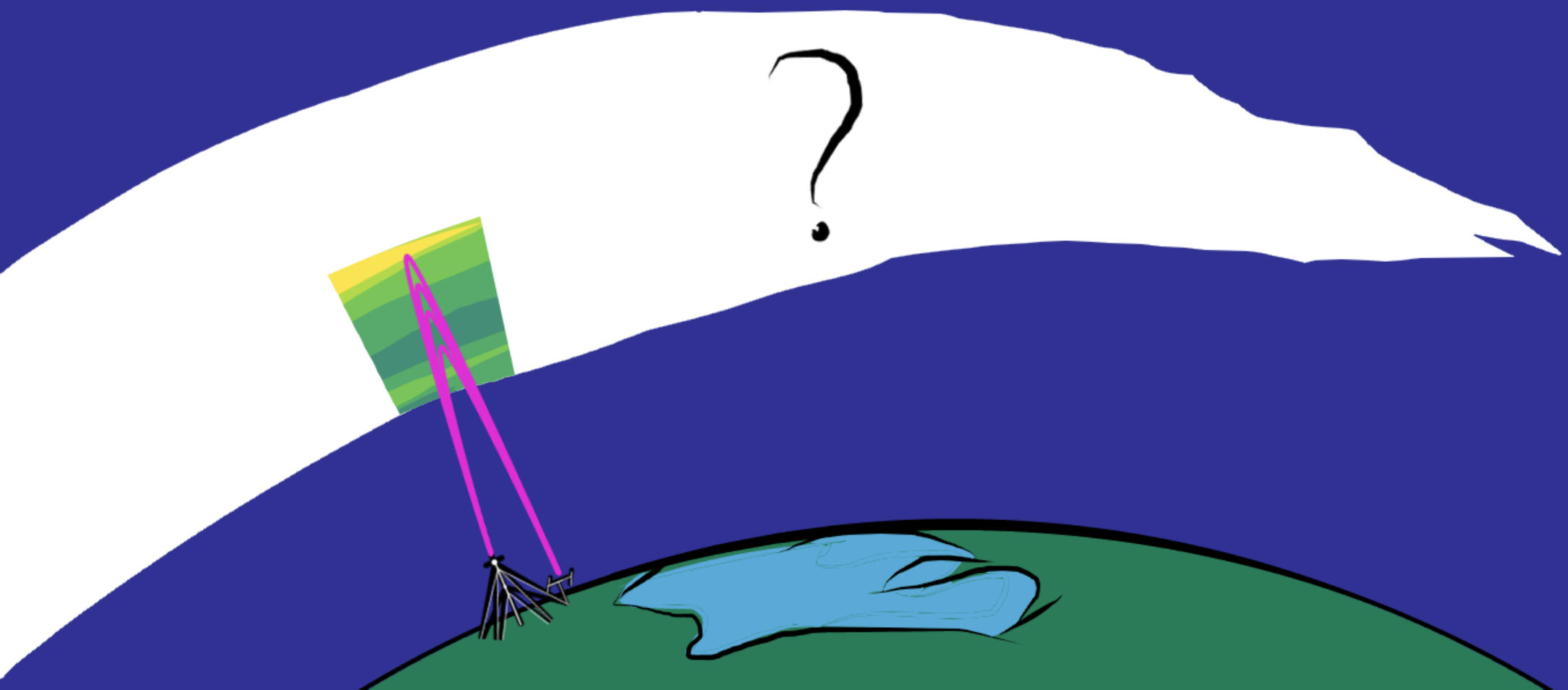
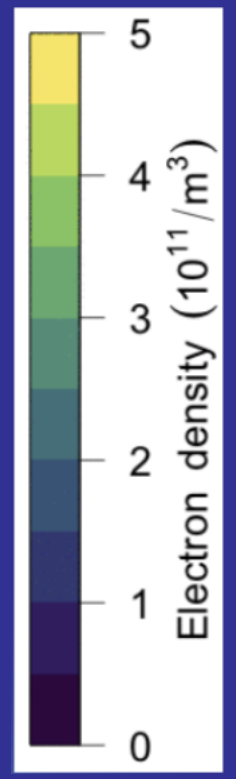
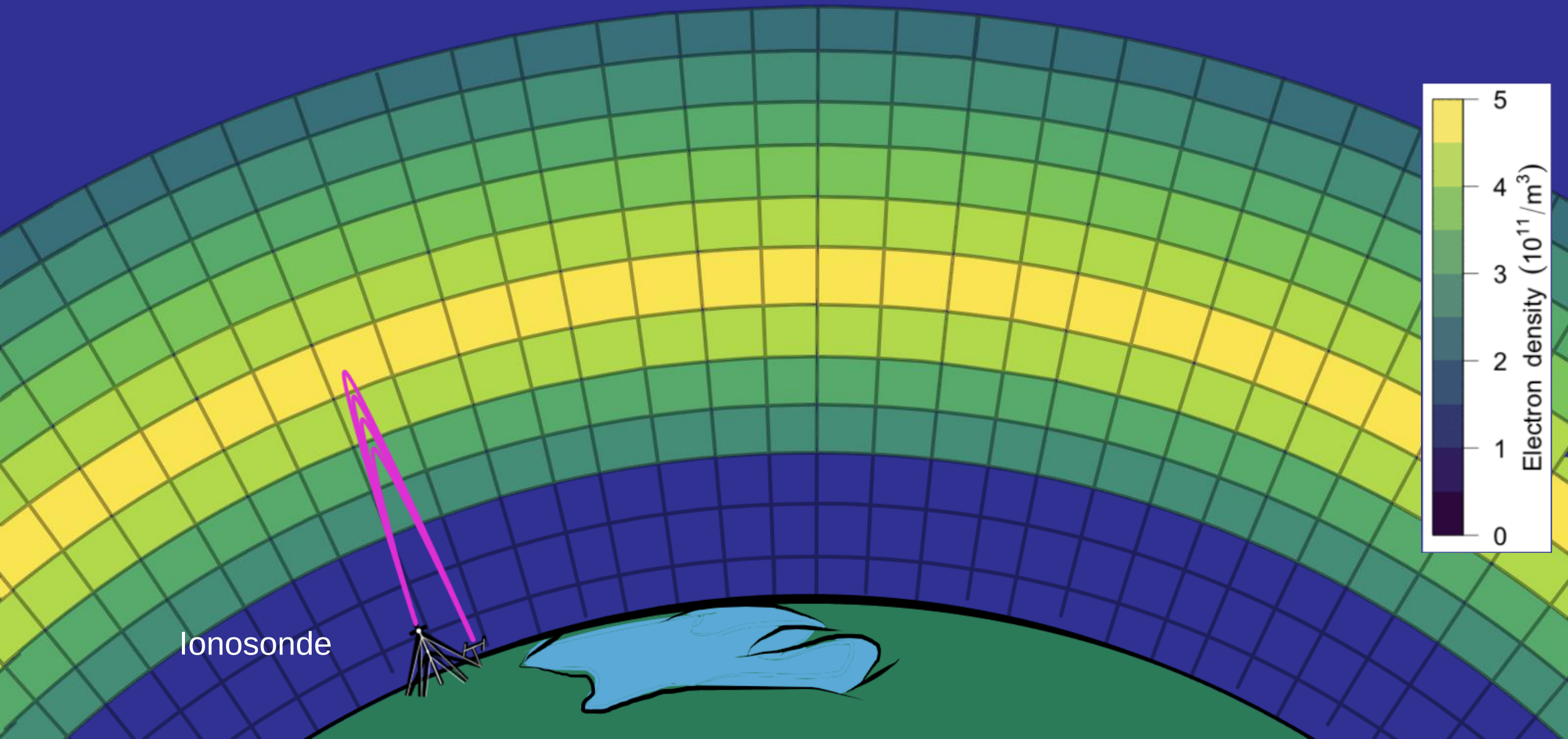
ionososonde measurements

FMI

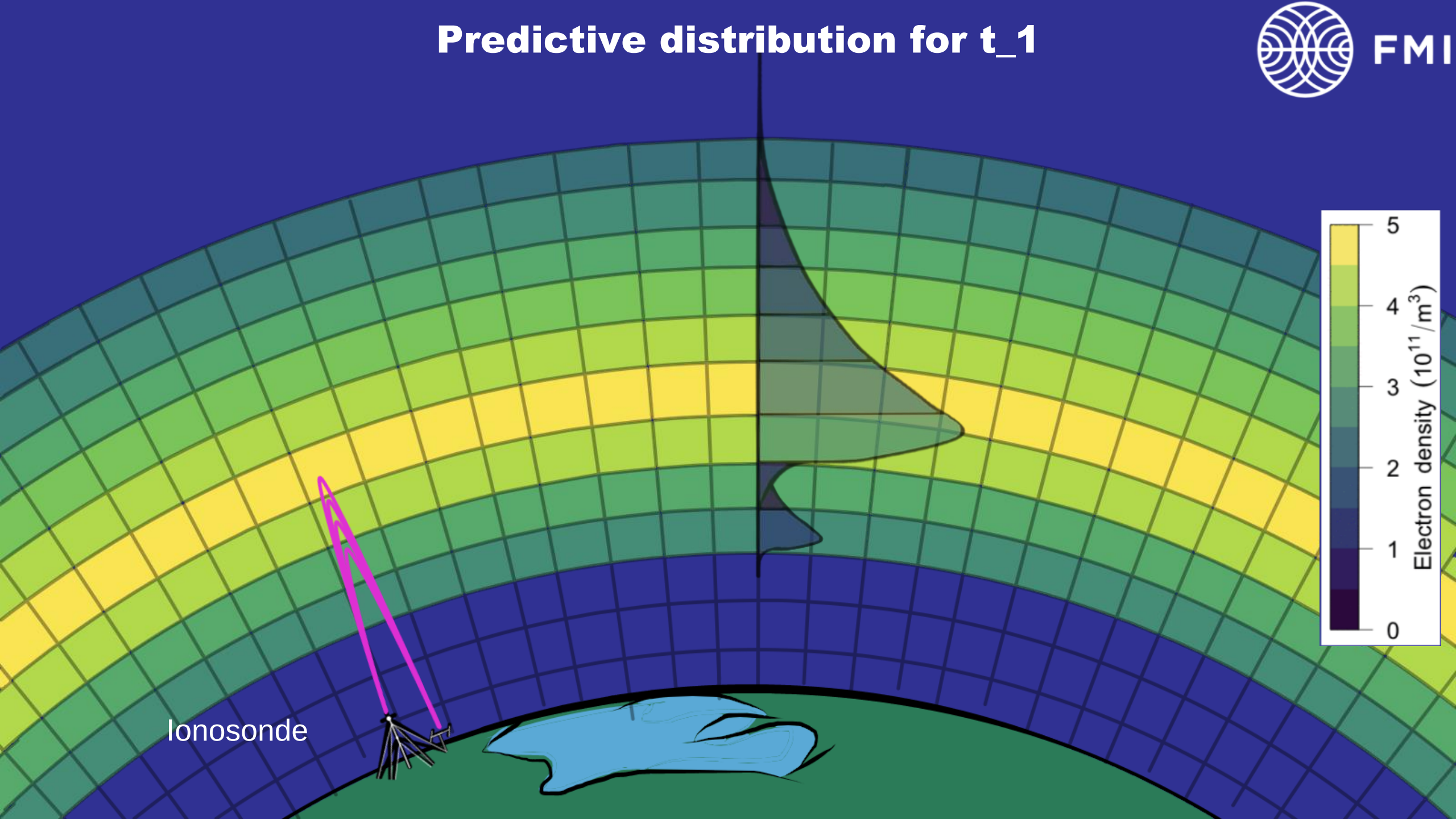


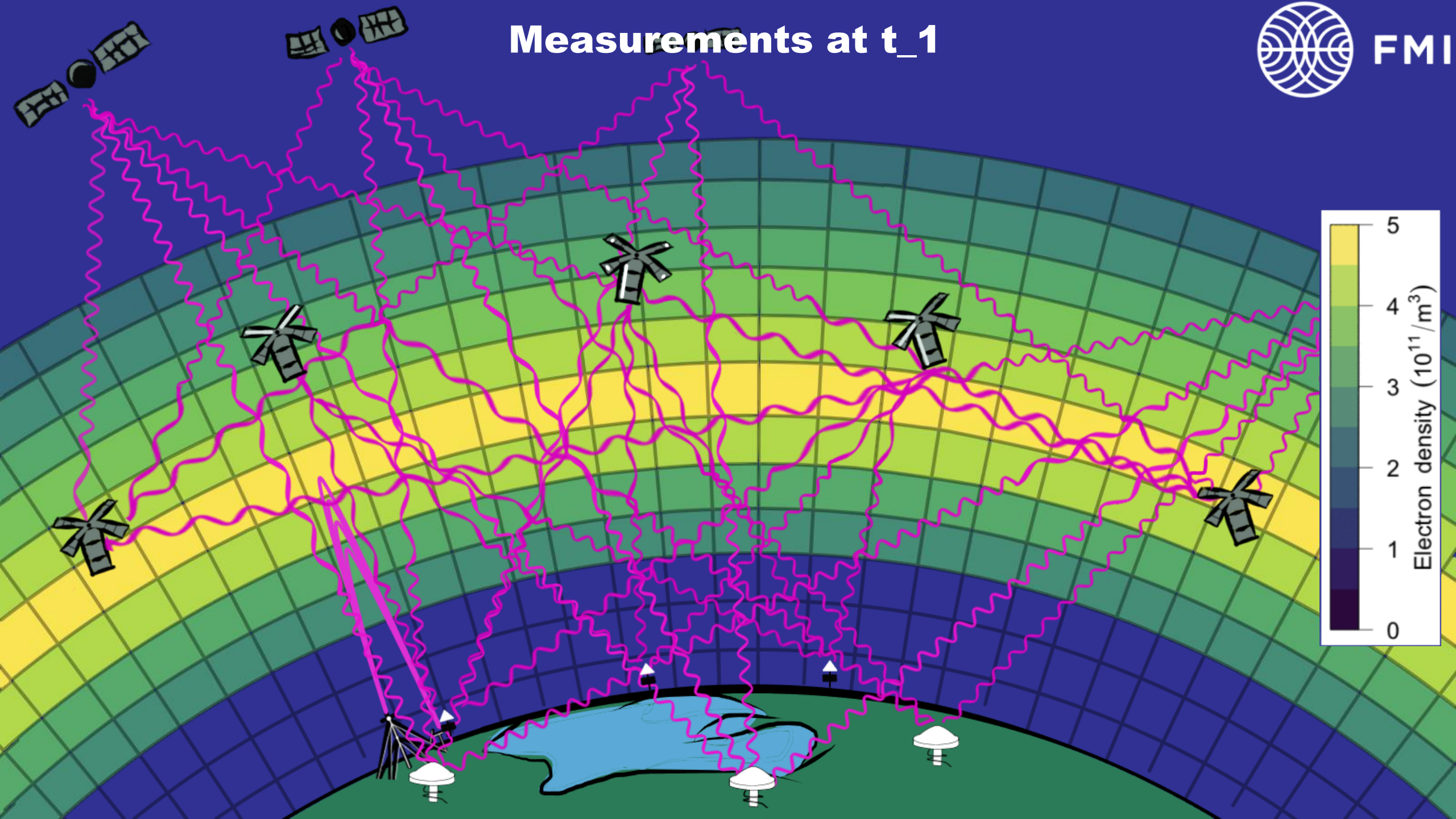


Initial mean

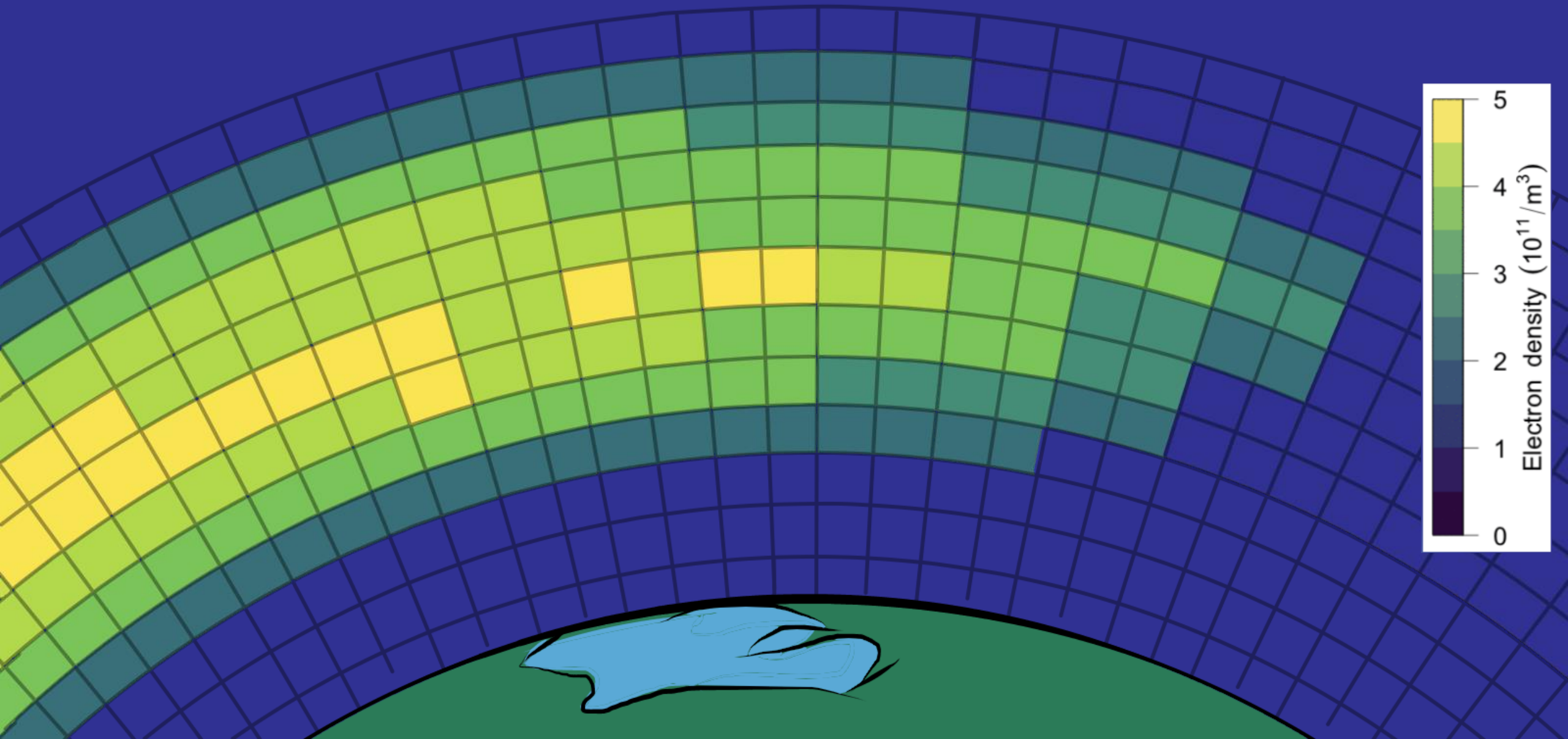


Predictive distribution for t_1

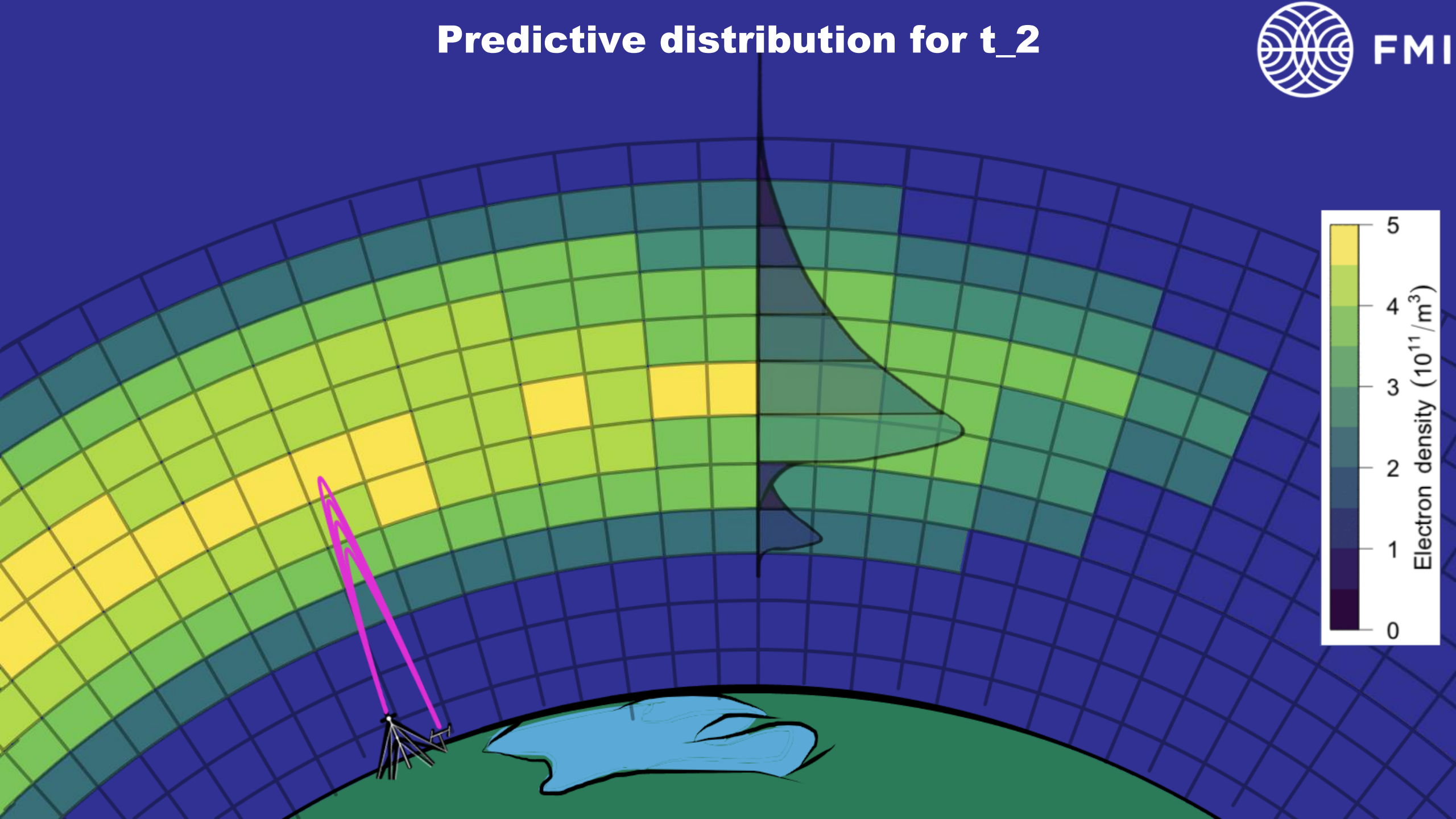



Measurements at t_1
FMI
5
4
3
2
1
0
Electron density (10^{11}/m^3)

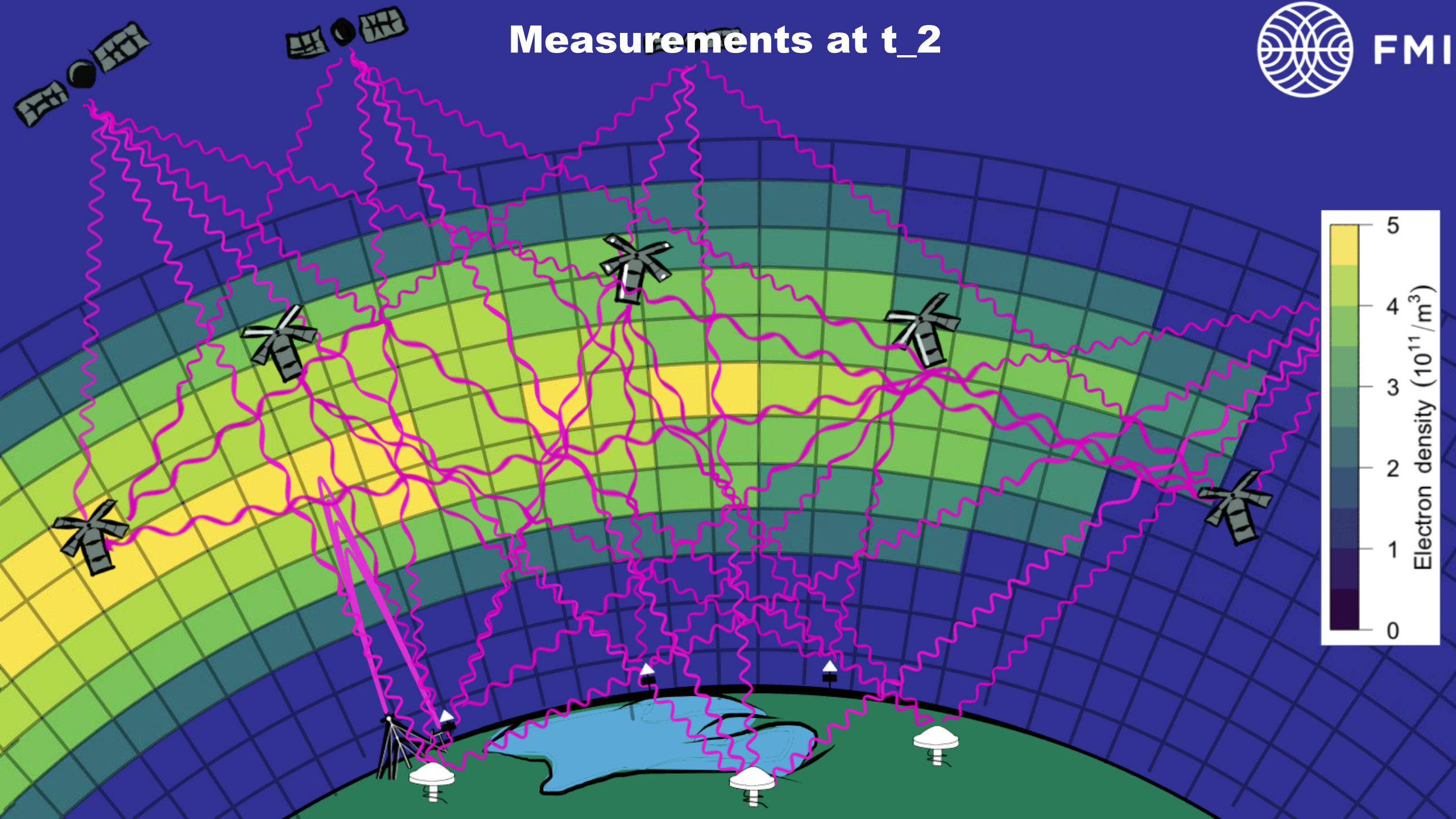
Reconstruction t_1



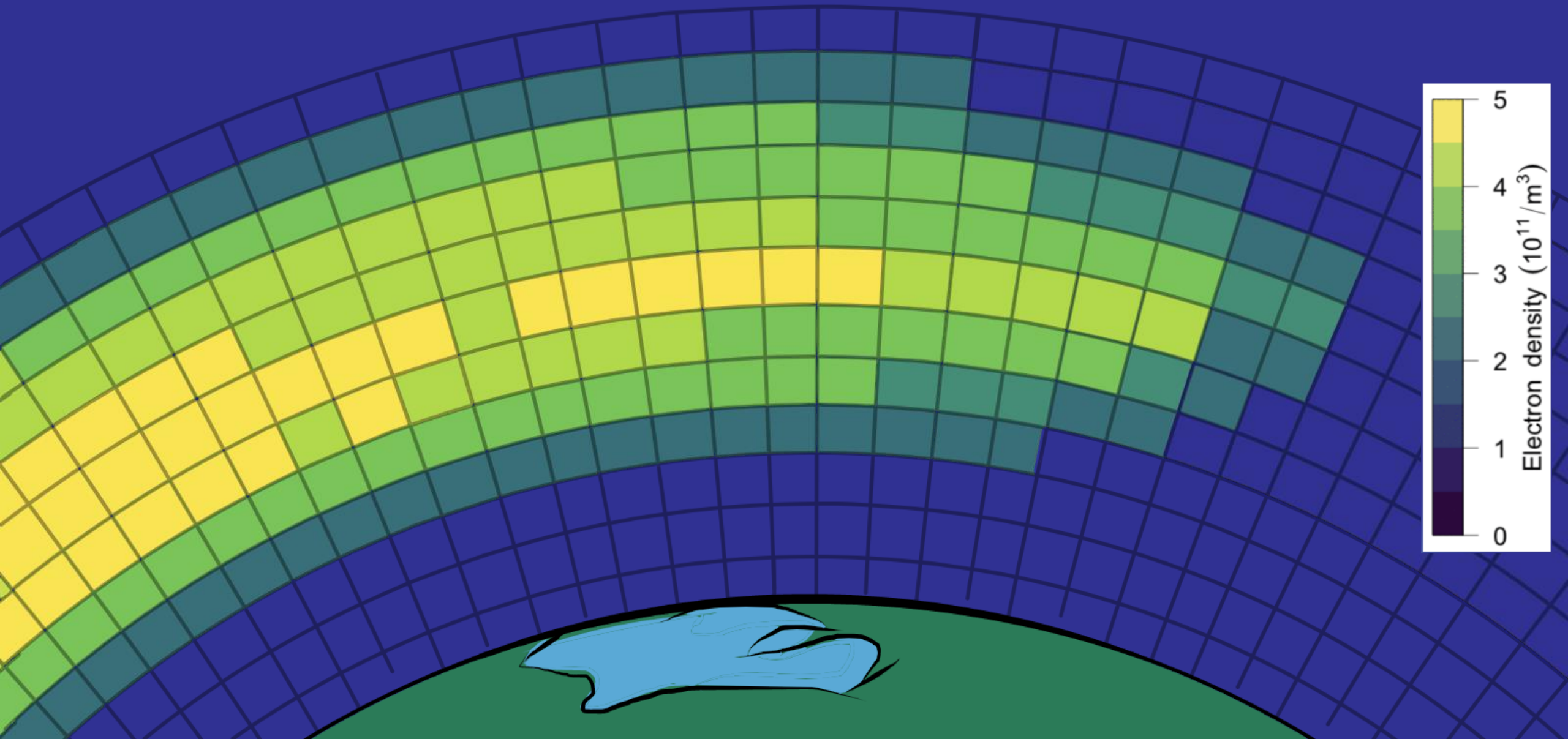
Predictive distribution for t_2



Measurements at t_2



Reconstruction t_2



Validation results

JGR Space Physics

RESEARCH ARTICLE

10.1029/2022JA030794

Key Points:

- A Kalman filter application with Gaussian Markov random field priors enabling fast computation
- No external ionospheric electron

Model-Free Approach for Regional Ionospheric Multi-Instrument Imaging

J. Norberg[1], S. Käki[1], L. Roininen[2], J. Mielich[3], and I. I. Virtanen[4]

[1]Finnish Meteorological Institute, Helsinki, Finland, [2]Lappeenranta-Lahti University of Technology, Lappeenranta, Finland, [3]Leibniz Institute of Atmospheric Physics at the University of Rostock, Rostock, Germany, [4]University of Oulu, Oulu, Finland

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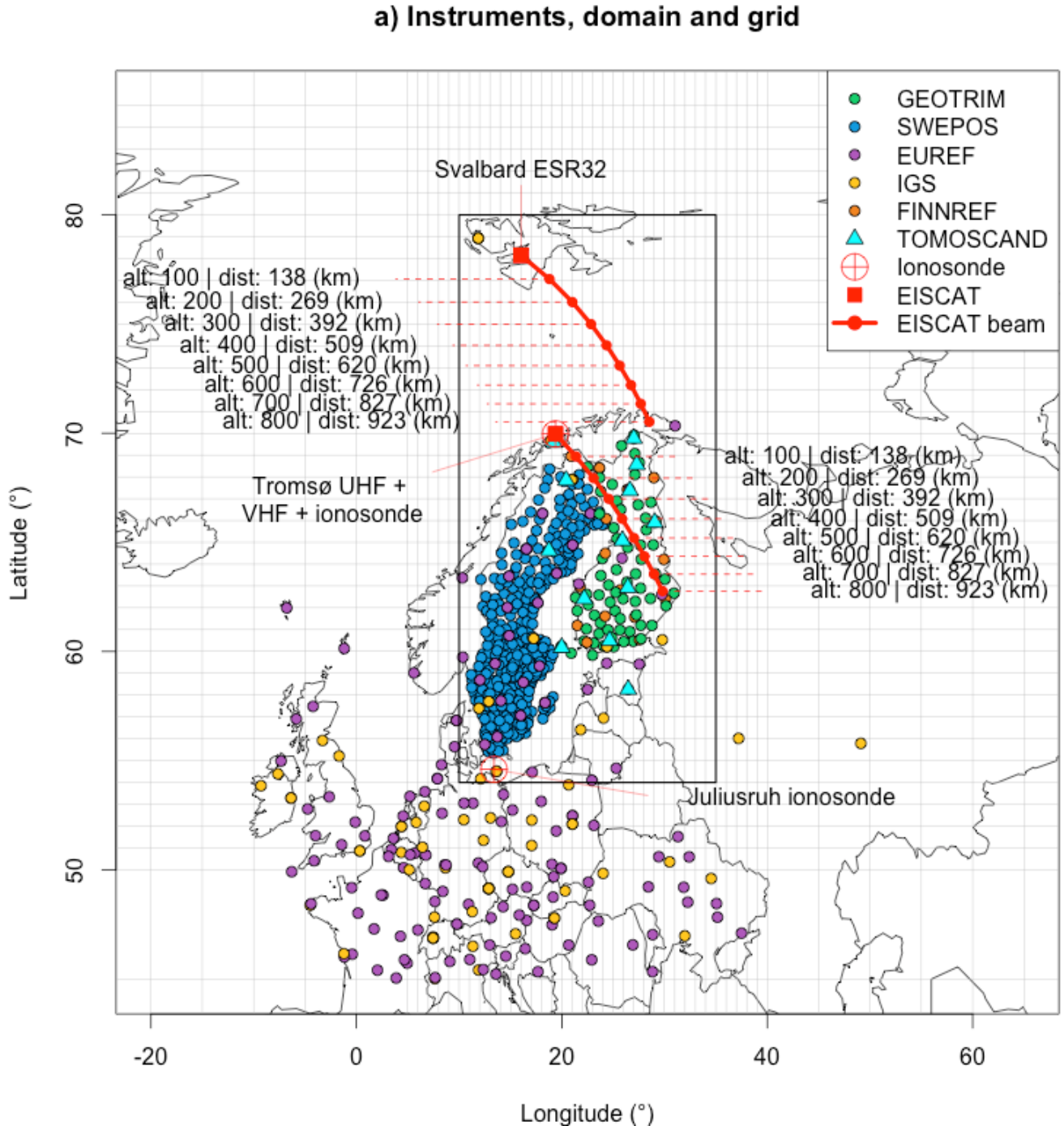

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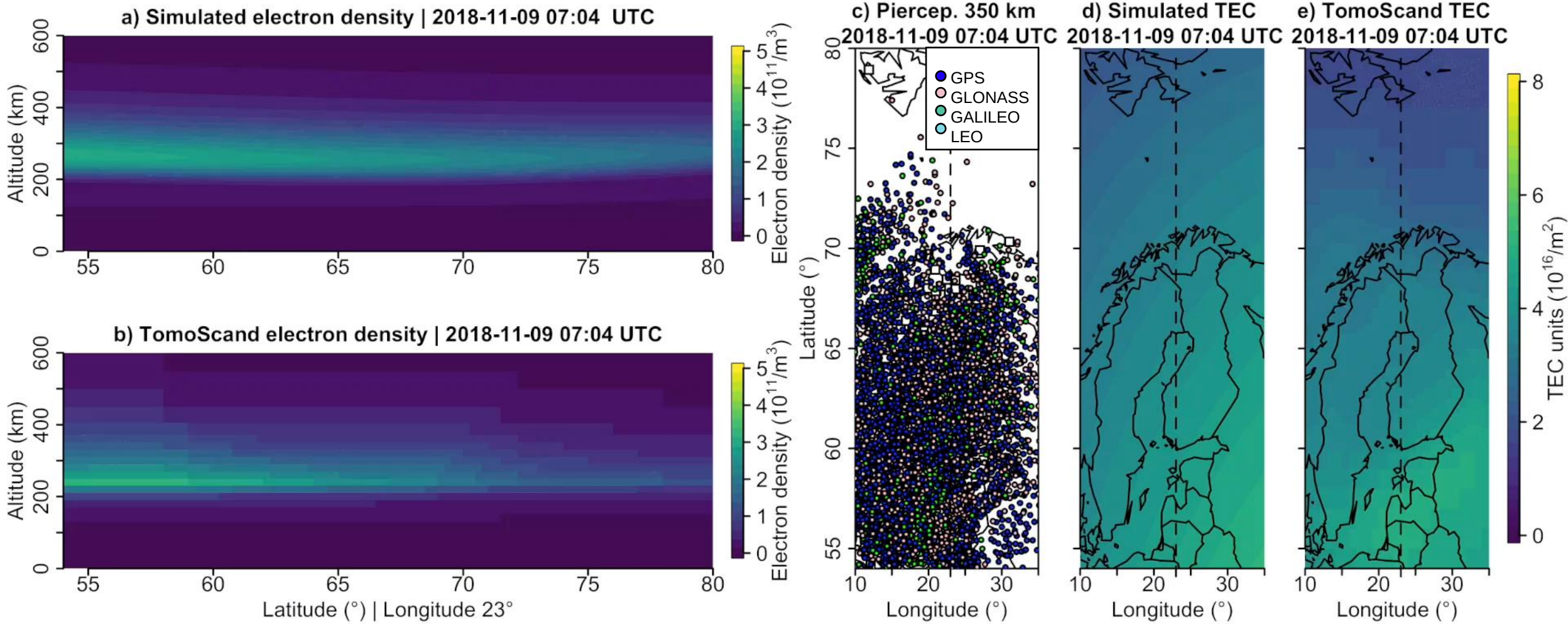
Simulation study

- Synthetic ionospheric model
- Chapman profiles
- Ionospheric trough
- Night-time E-region
- Measurement geometries from real measurements
- Errors and instrument biases added to simulated measurements



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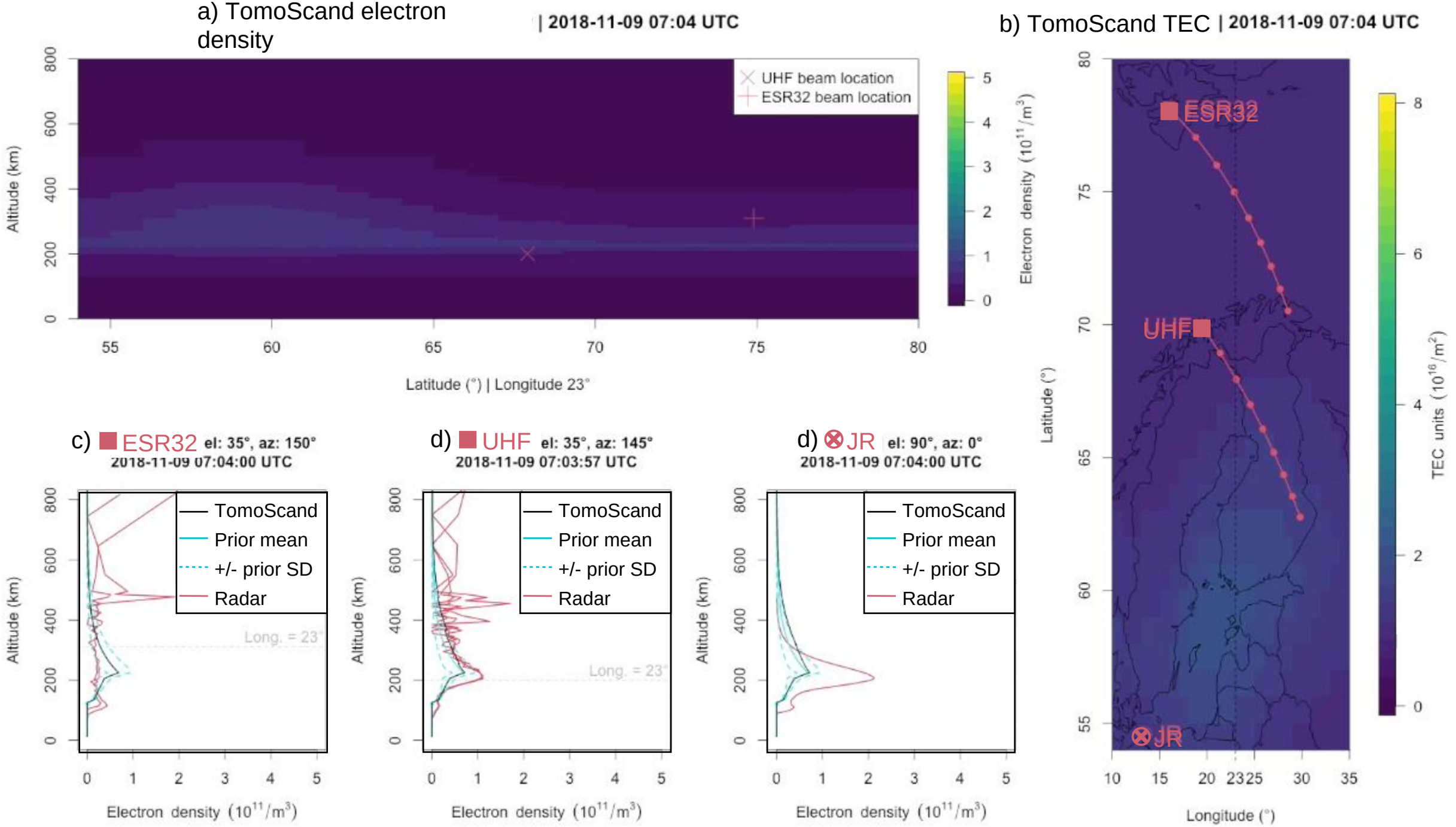
Real data validation

- EISCAT UHF incoherent scatter radar in Tromsø, Norway
- ESR 32m incoherent scatter radar in Svalbard
- Juliusruh ionosonde in north Germany


a) TomoScand electron density
| 2018-11-09 07:04 UTC
UHF beam location
ESR32 beam location
Altitude (km)
Latitude (°) | Longitude 23°
Electron density (10^{11}/m^3)
b) TomoScand TEC | 2018-11-09 07:04 UTC
ESR32
UHF
JR
Latitude (°)
Longitude (°)
TEC units (10^{16}/m^2)
c) ESR32 el: 35°, az: 150°
2018-11-09 07:04:00 UTC
d) UHF el: 35°, az: 145°
2018-11-09 07:03:57 UTC
d) JR el: 90°, az: 0°
2018-11-09 07:04:00 UTC
TomoScand
Prior mean
+/- prior SD
Radar
Long. = 23°
Electron density (10^{11}/m^3)

Journal of Geophysical Research: Space Physics 10.1029/2022JA030794

Measurement

TomoScand

IRI 2012

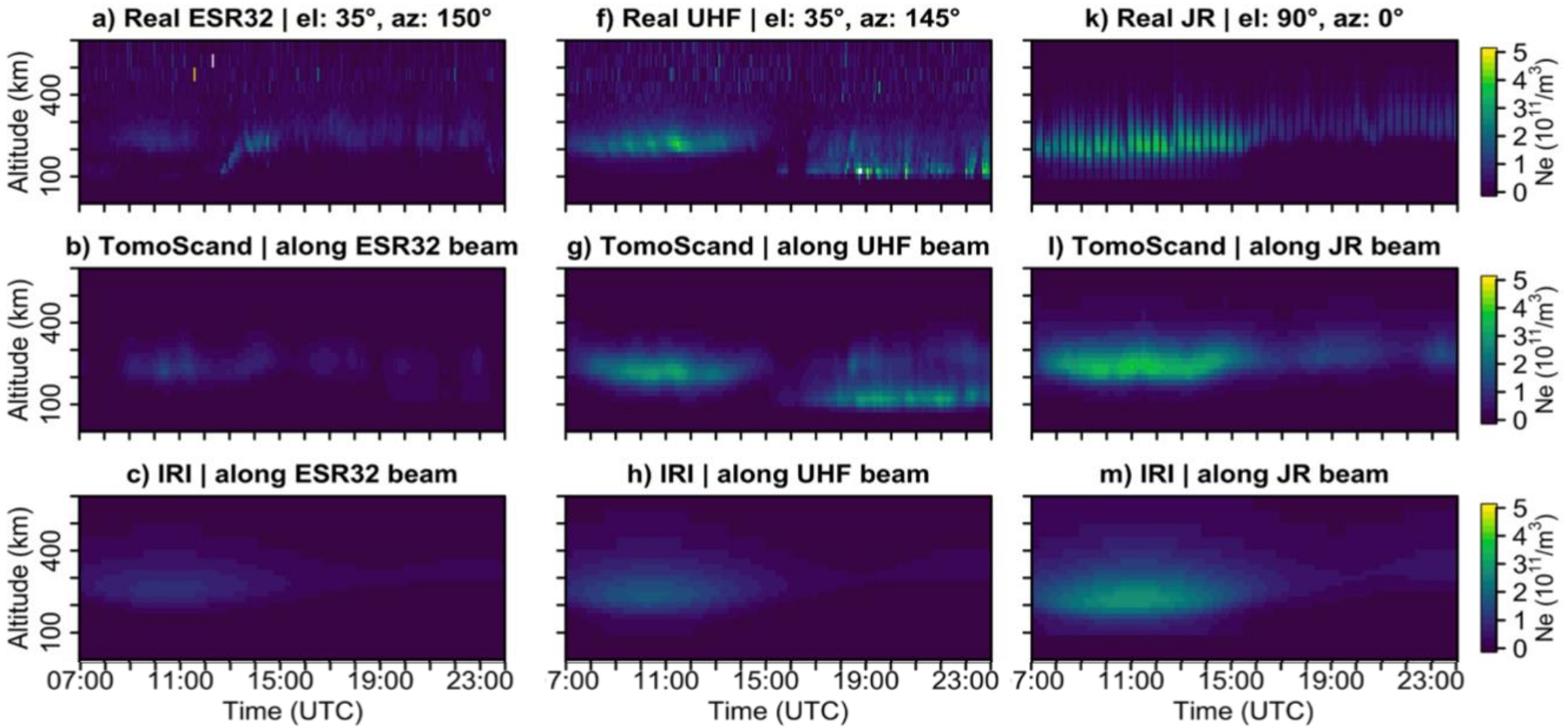
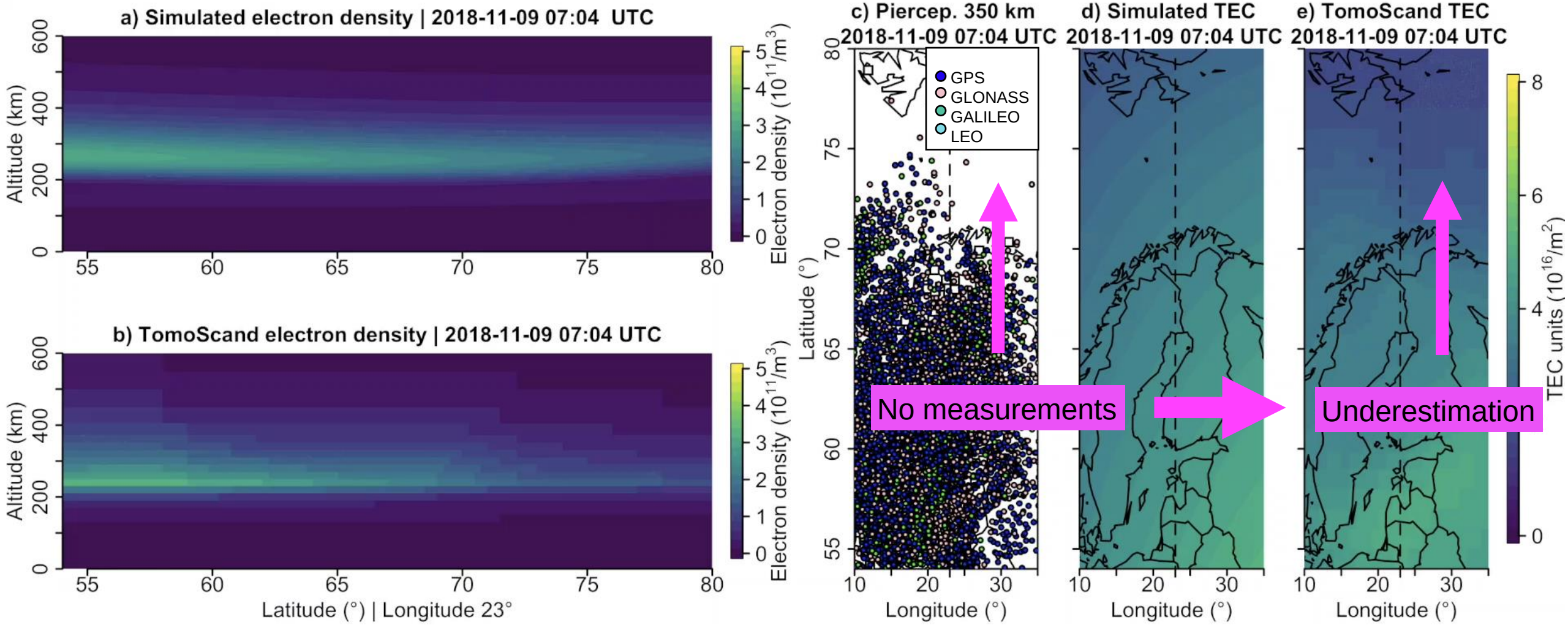


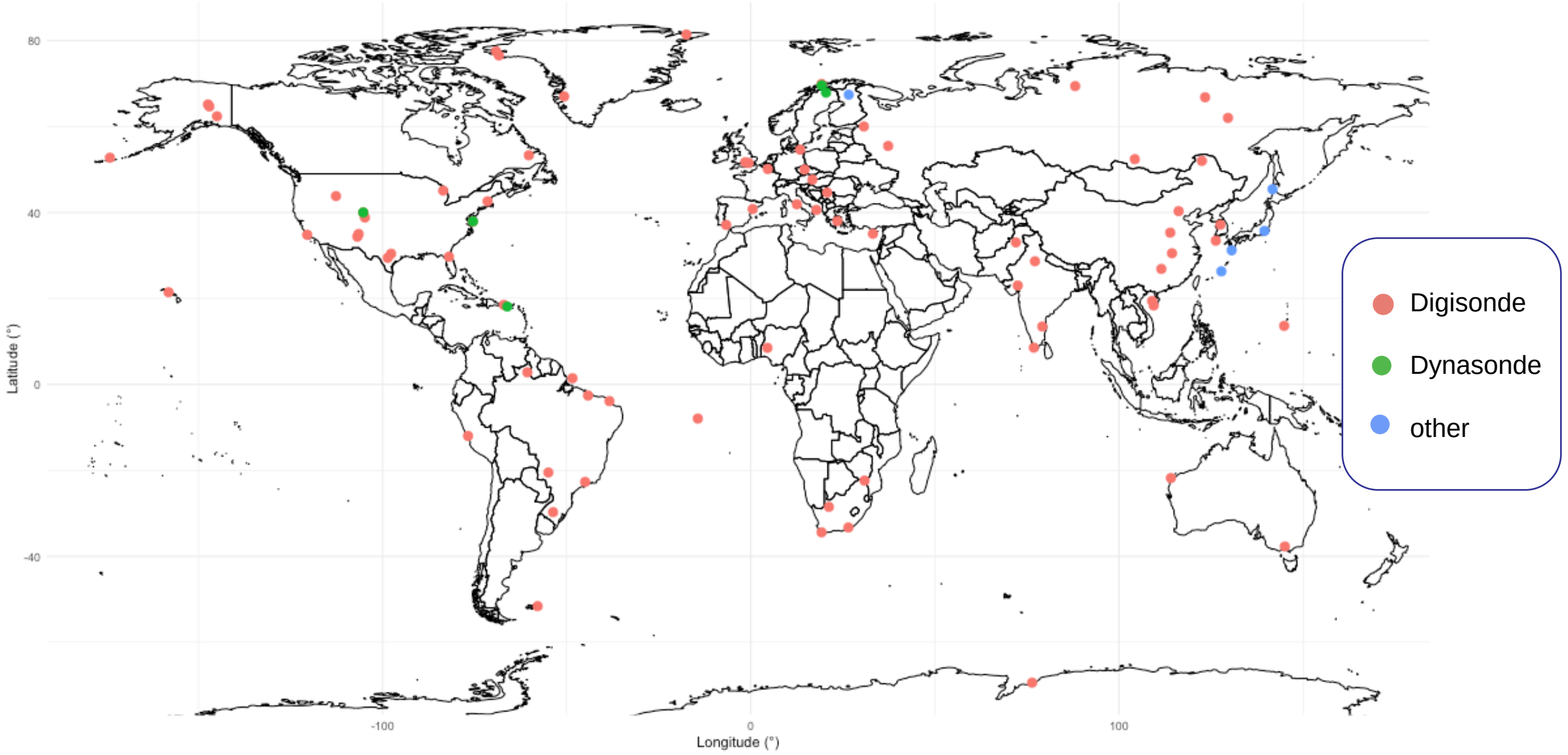
Figure 5. Comparison of measured real validation profiles, corresponding profiles from TomoScand reconstruction and IRI 2012 model from 9 November 2018. EISCAT ESR32 incoherent scatter radar is located in Longyearbyen, Norway (78.2°N, 16.1°E), UHF incoherent scatter radar in Tromsø, Norway (69.6°N, 19.3°E) and JR ionosonde in Juliusruh, Germany (54.6°N, 13.4°E).

Recent development

Problems with the current approach

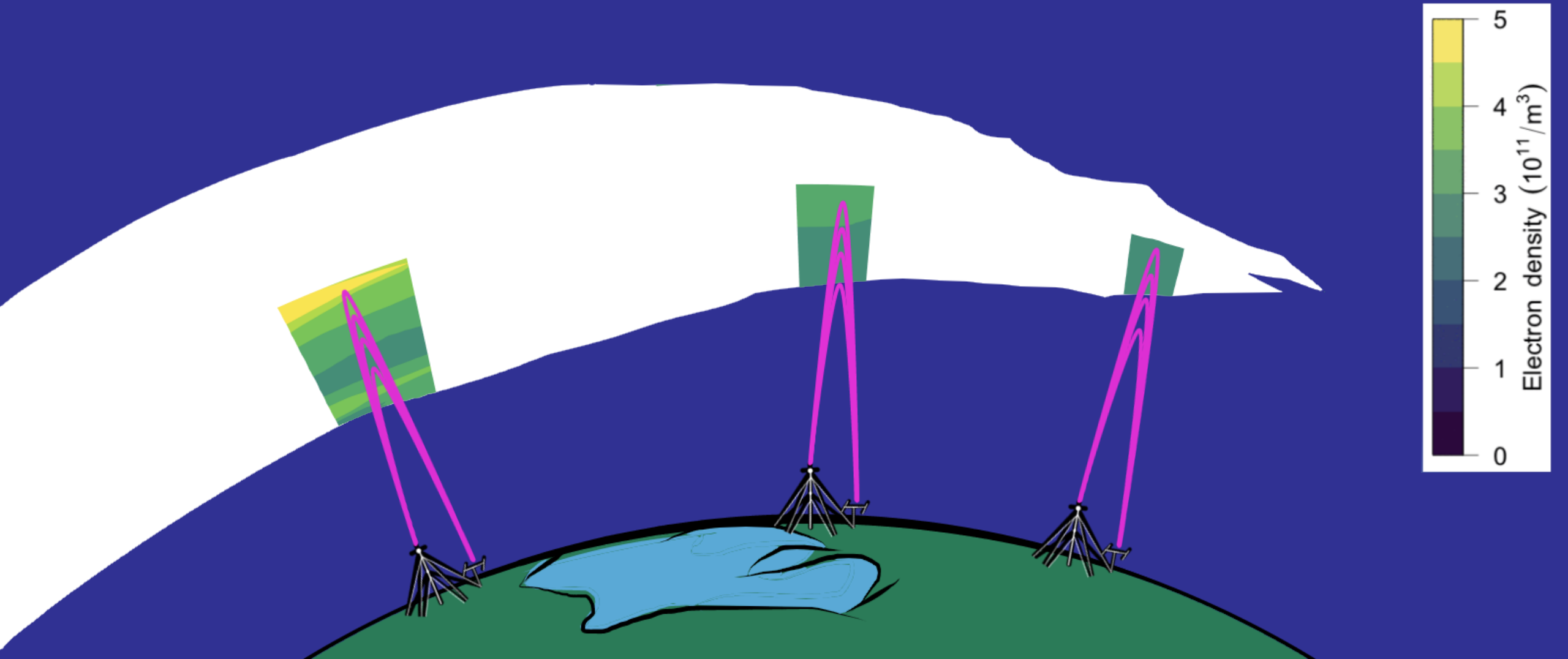


Ionosonde locations

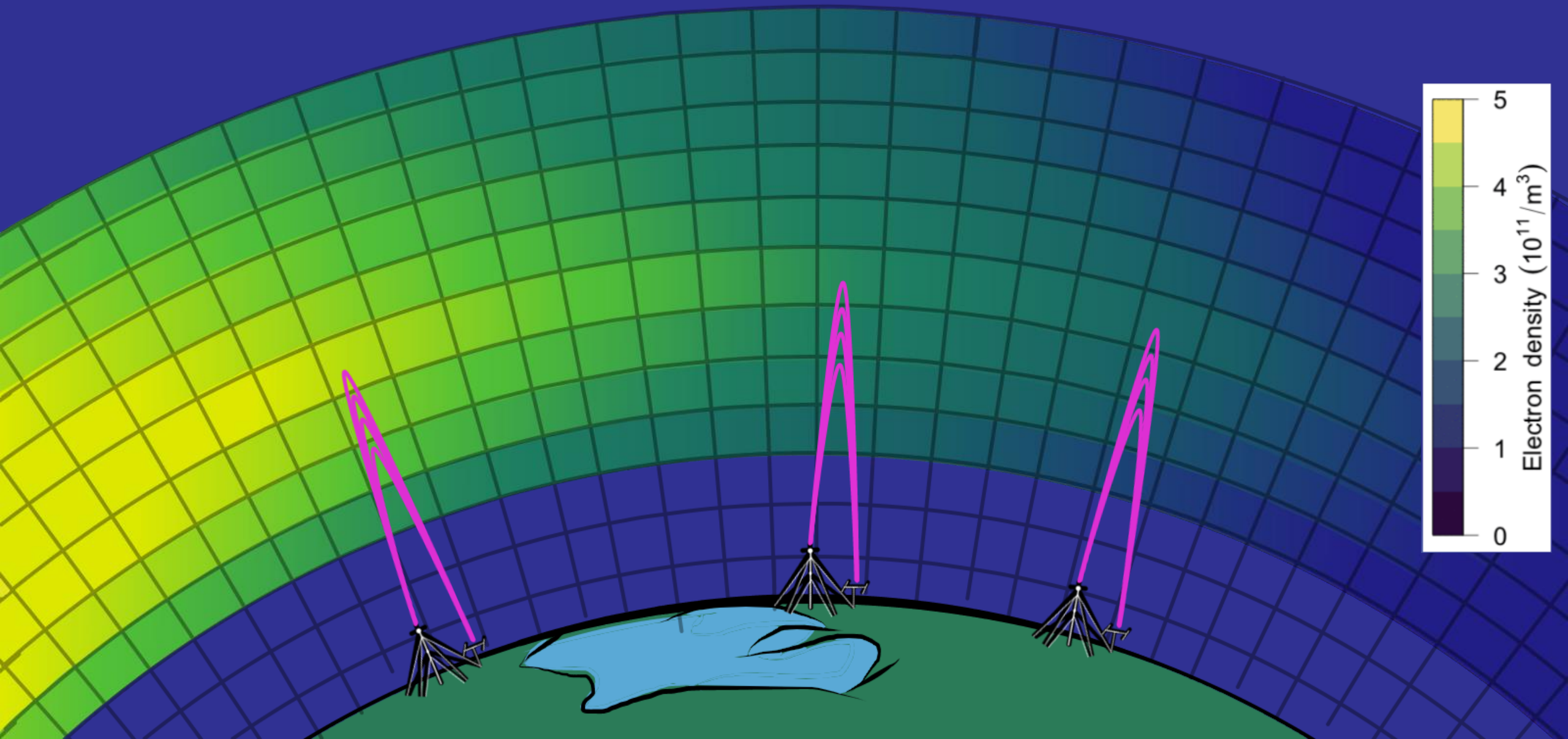


Ionosonde measurements

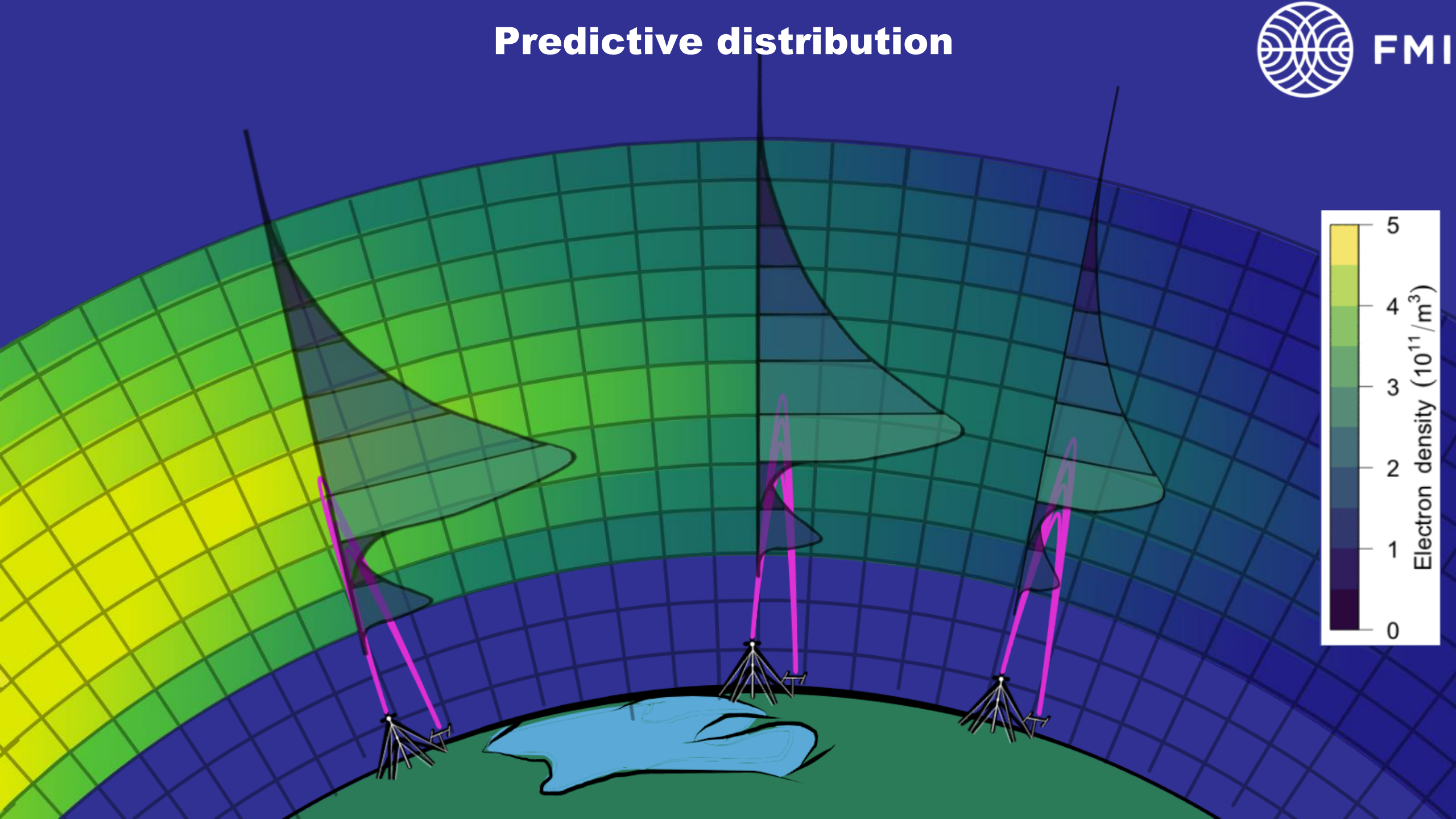
FMI



Ionosonde-based smooth non-uniform background



Predictive distribution



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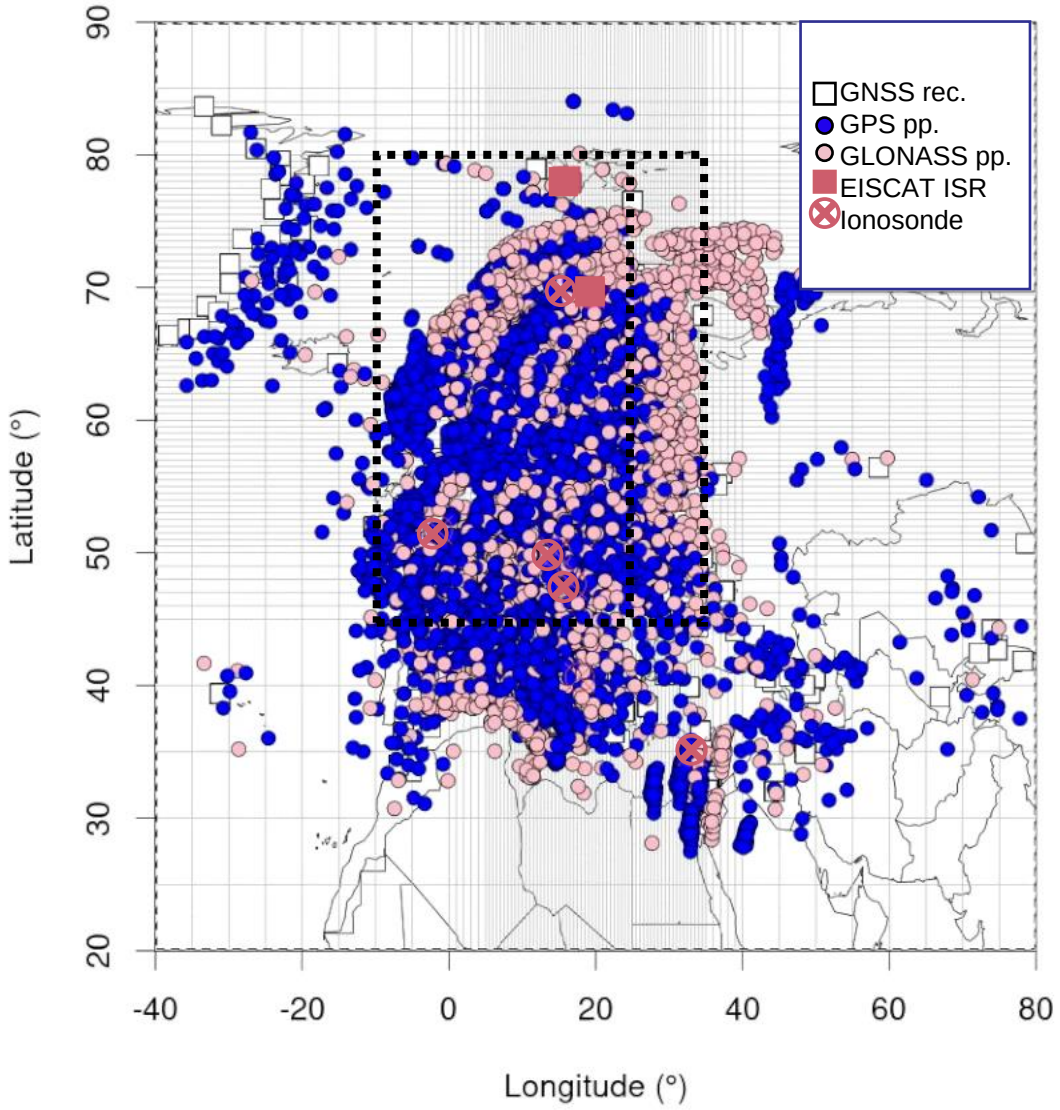

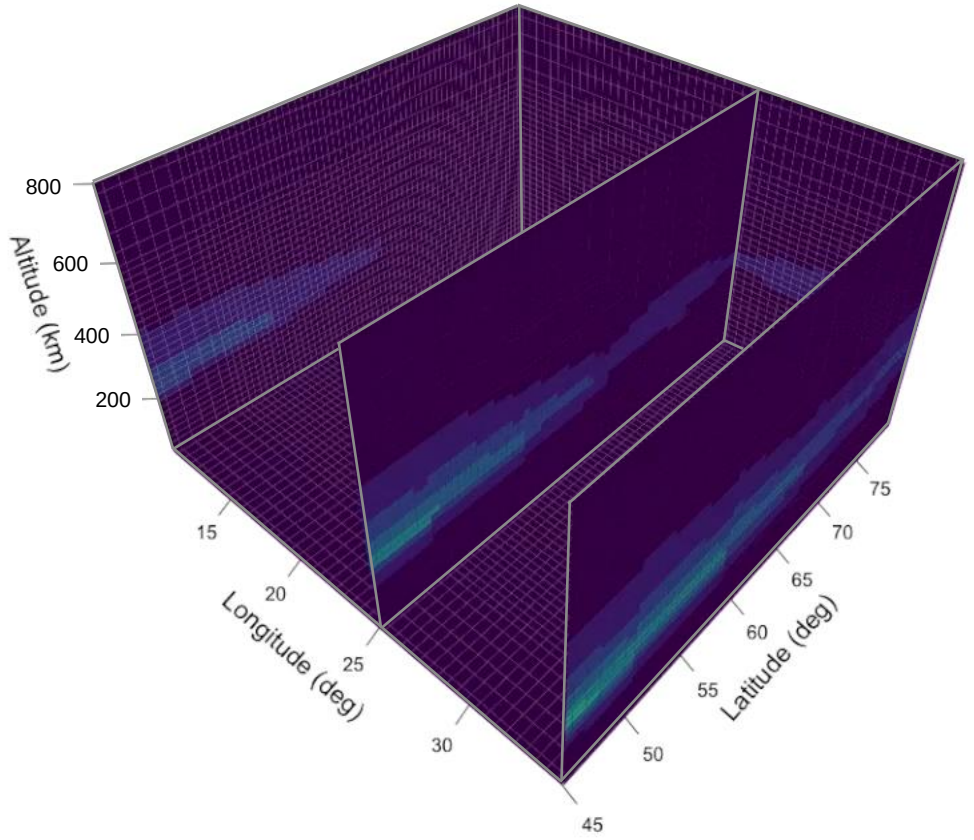

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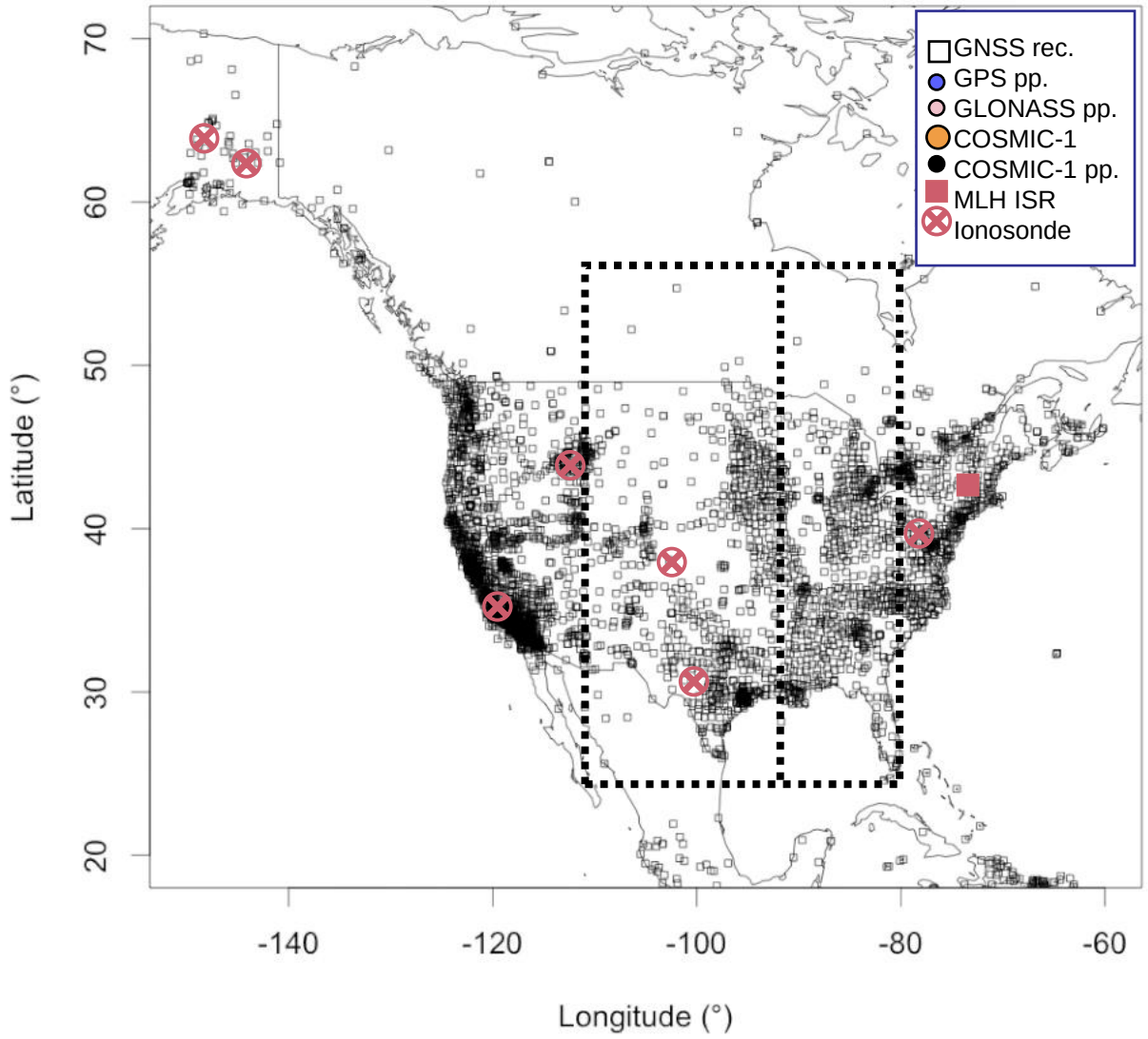

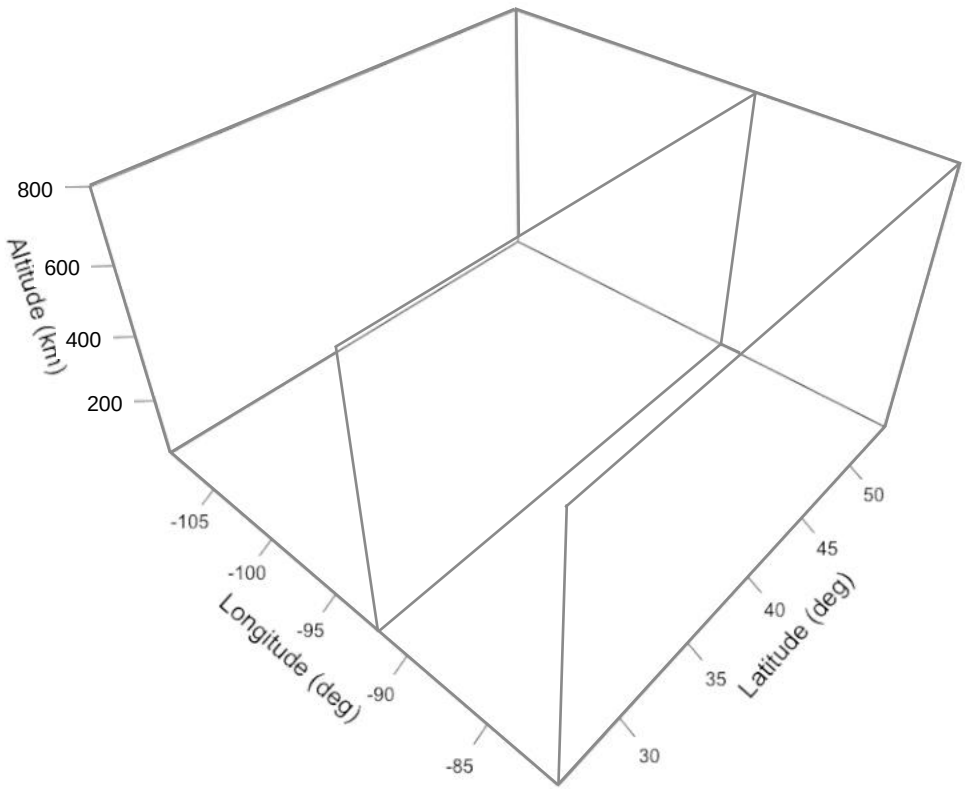

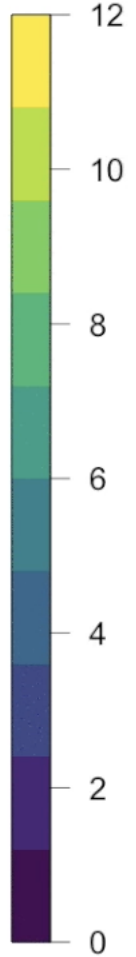

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Norberg, J., Vierinen, J., Roininen, L., Orispää, M., Kauristie, K., Rideout, W. C., Coster, A. J., & Lehtinen, M. S. (2018). Gaussian Markov Random Field Priors in Ionospheric 3-D Multi-Instrument Tomography. *IEEE Transactions on Geoscience and Remote Sensing*, 1–13. https://doi.org/10.1109/TGRS.2018.2847026

Norberg, J., Käki, S., Roininen, L., Mielich, J., & Virtanen, I. I. (2023). Model-Free Approach for Regional Ionospheric Multi-Instrument Imaging. Journal of Geophysical Research: Space Physics, 128(1). https://doi.org/10.1029/2022JA030794

johannes.norberg@fmi.fi

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