GNSS+R observations from MAPHEUS sub-orbital flight: testing ionospheric E-layer resolution

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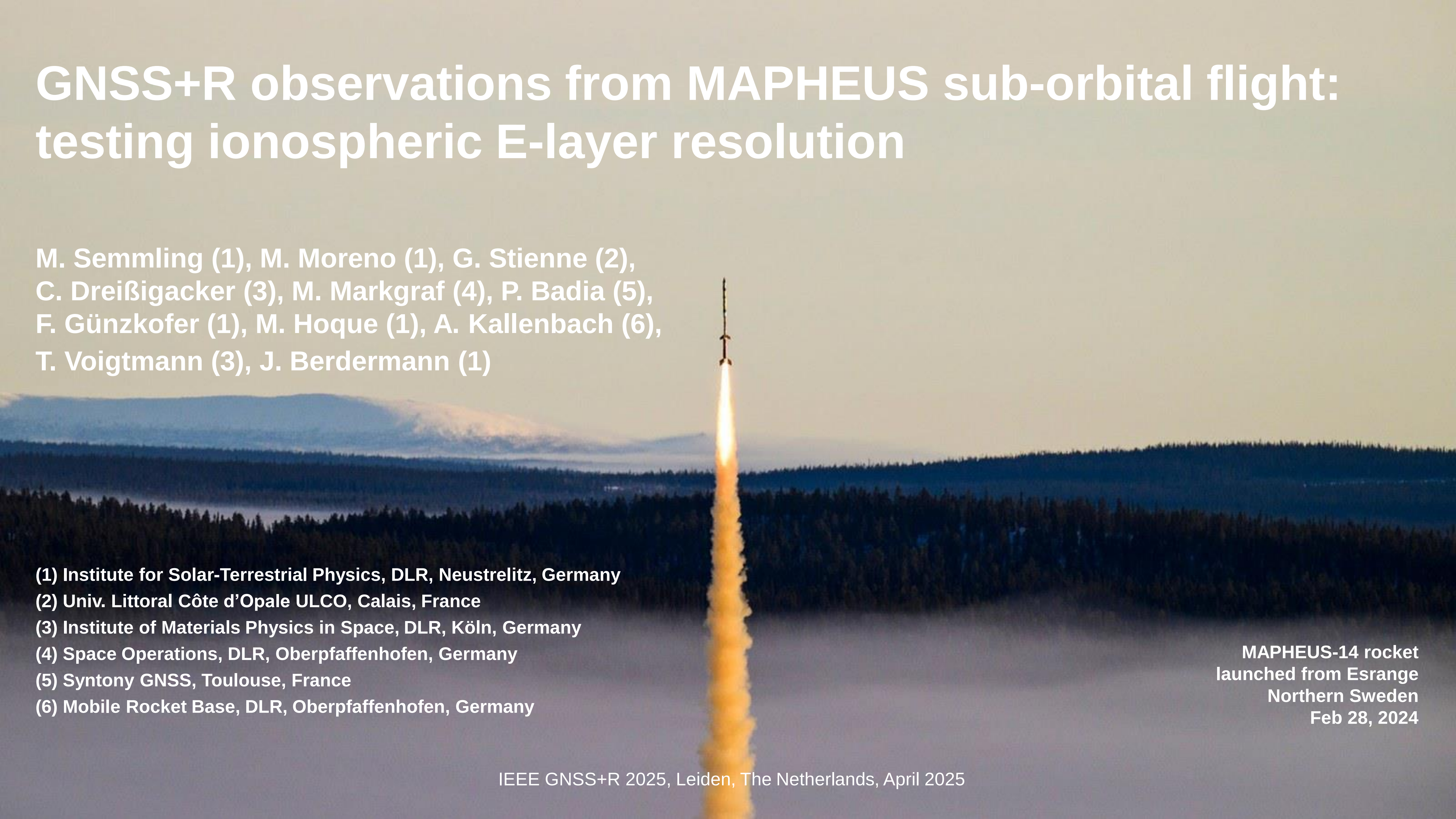


MAPHEUS-14 rocket launched from Esrange Northern Sweden Feb 28, 2024

IEEE GNSS+R 2025, Leiden, The Netherlands, April 2025

Outline

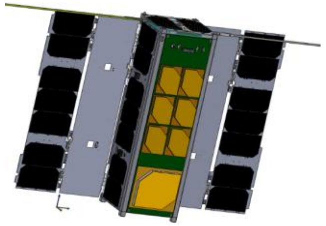
- Background and Motivation
- MAPHEUS-8: GNSS+R Simulation
- MAPHEUS-15: GNSS+R Setup and Preliminary Results
- Conclusions

Background and Motivation

Motivation GNSS Remote Sensing

- A: Low Earth Orbiter

  Wickert et al. 2016
  Semmling et al. 2016
  Cardellach et al. 2019
  Moreno et al. 2023



- B: Aircraft

  Semmling et al. 2014
  Moreno et al. 2022

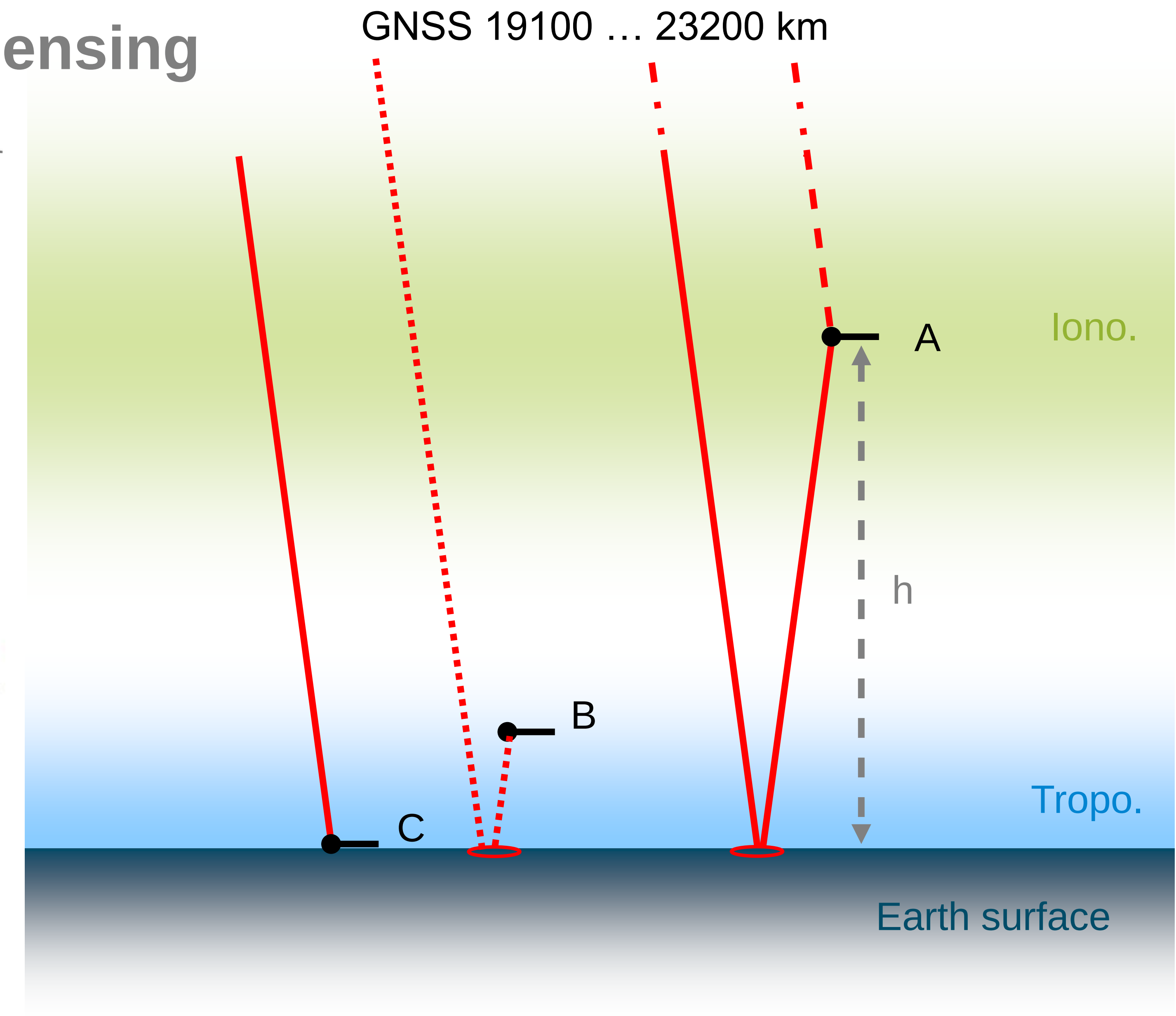
- C: Research Vessels

  Wang et al. 2019
  Semmling et al. 2019, 2022
  Semmling et al. 2023

- Application

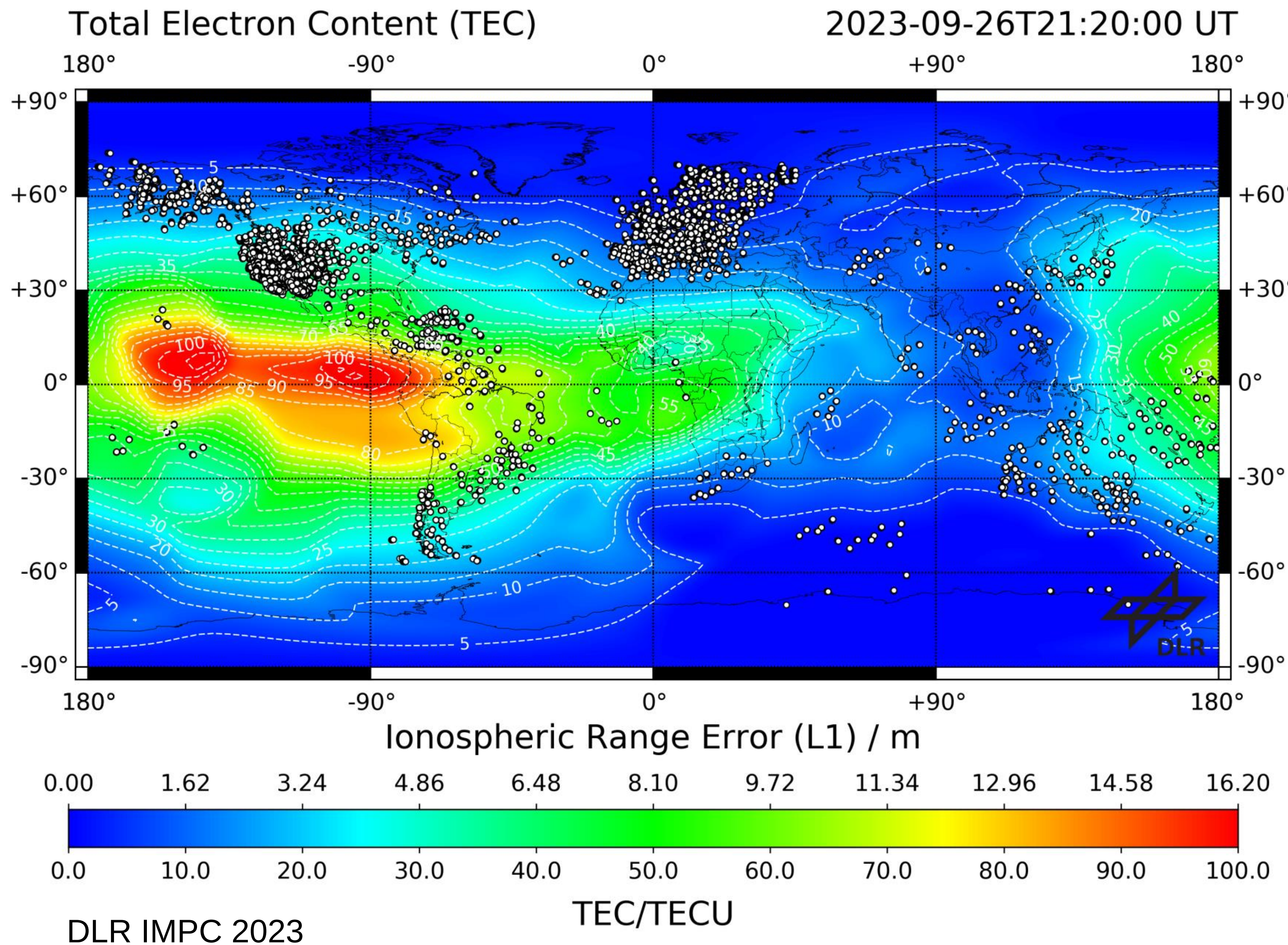
sea surface altimetry
sea state estimation
sea-ice detection

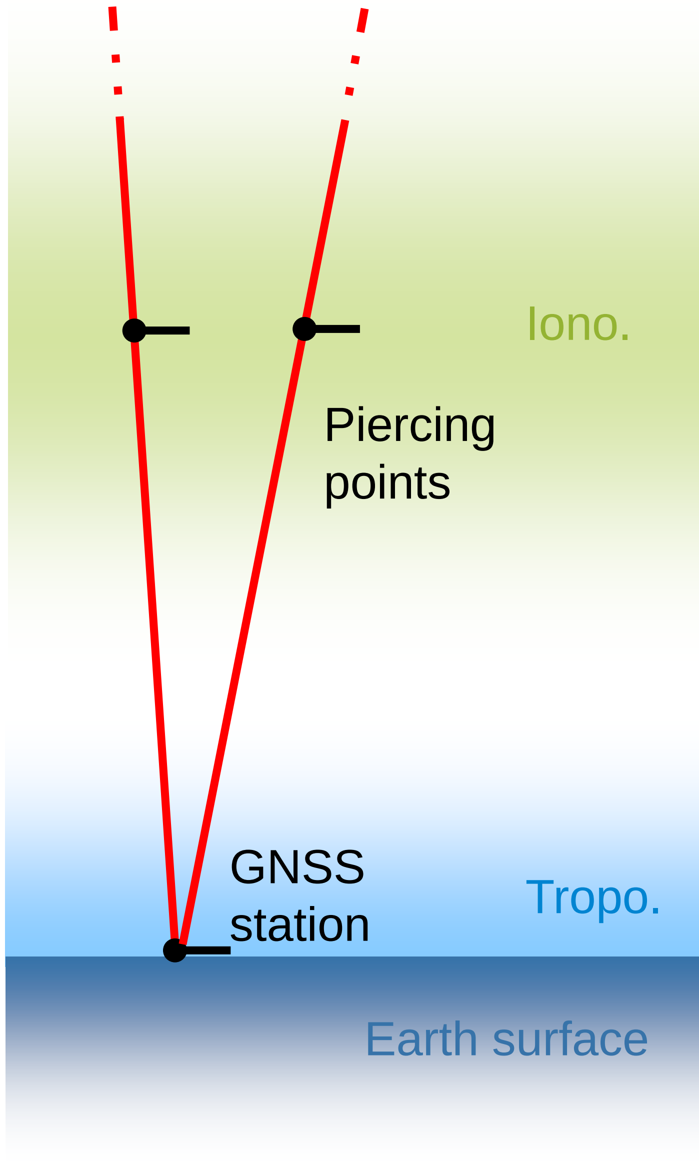
water vapor estimation
ionosphere monitoring



A: e.g. PRETTY, h ~ 540 km
B: e.g. HALO, h ~ 3500 m
C: e.g. Polarstern, h ~ 25 m

Ionospheric TEC Monitoring with GNSS





DLR IMPC 2023

More Detailed View …

F-layer

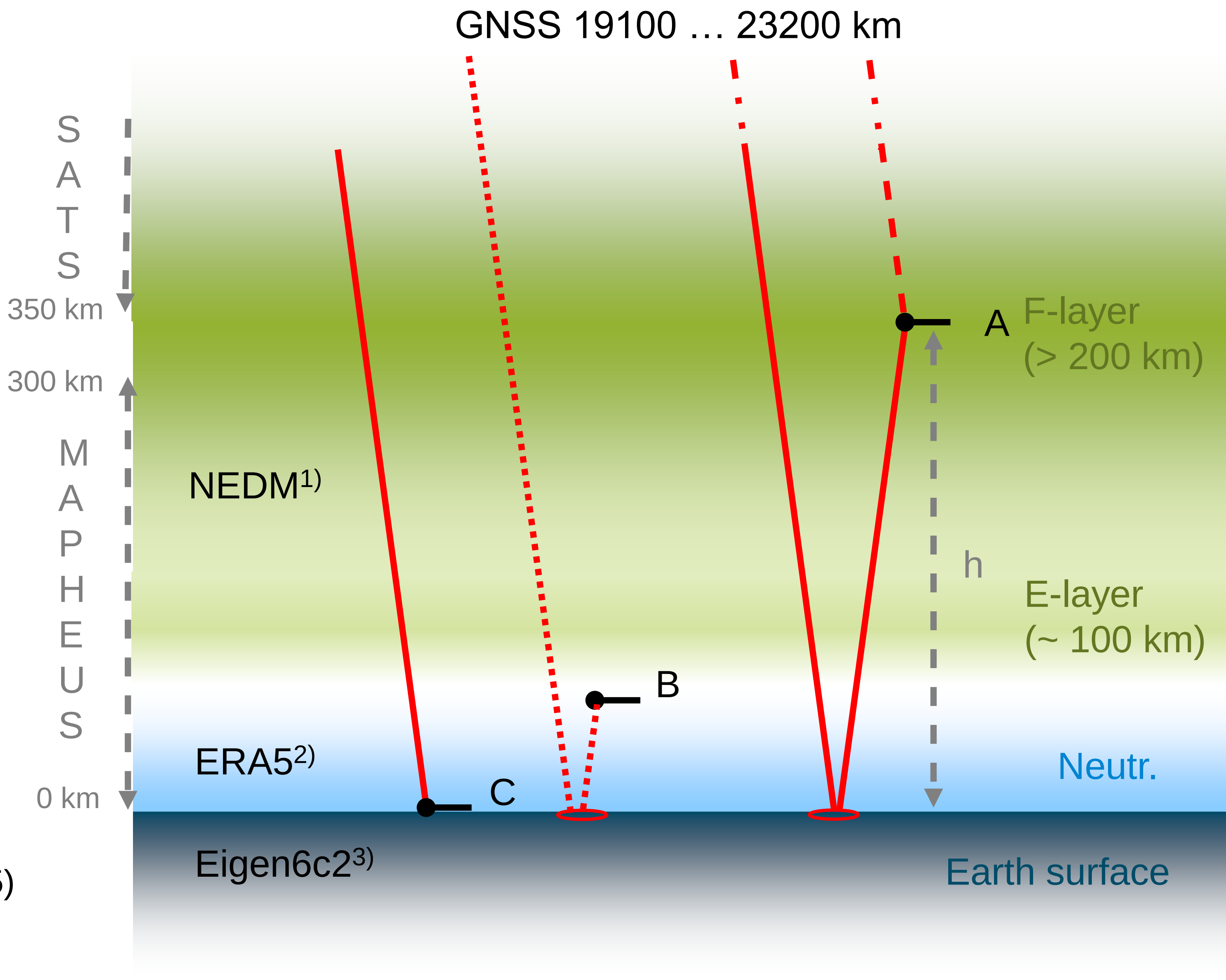
- permanent, usually highest density
- max. elec. density at 250 … 400 km
- regular daily cycle
- dependent on sun incidence

E-layer

- usually weaker, sporadic peaks
- max. elec. density at 110 … 130 km
- less predictable
- important for radio communication

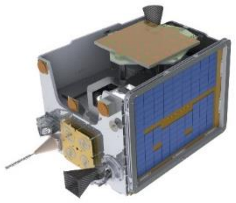
Required Model Data

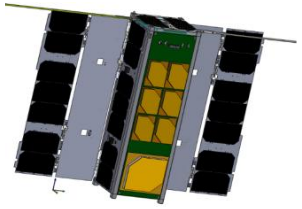
- empirical model for iono. electron dens. distribution (NEDM)
- numerical weather model for neutral gas based on data reanalysis (ERA5)
- geoid model for Ocean surface heights (Eigen6c2)



1) Jakowski & Hoque 2018 ; 2) Hersbach et al. 2020 ; 3) Förste et al. 2013

Data for space-borne reflectometry

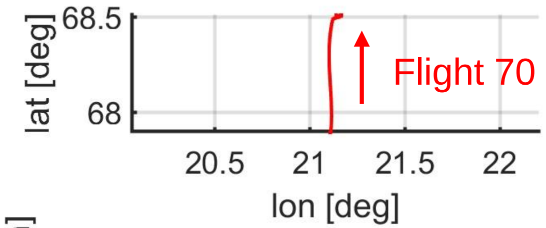


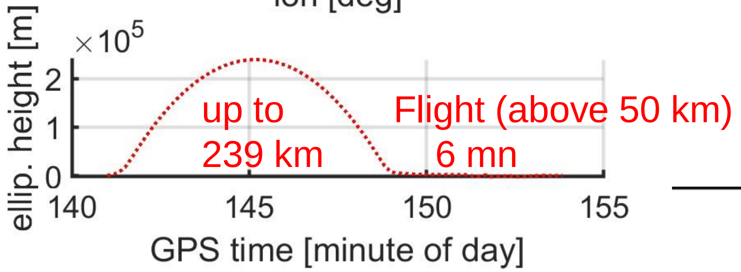


Mission:	TDS-1	PRETTY	MAPHEUS-15
Platform type:	small sat	cube sat	sounding rocket
Observation alt.:	~ 650 km	~ 560 km	80 … 310 km
Major field of view:	near-nadir	grazing	grazing
Supported signals:	GPS L1 C/A	GPS L5C & GAL E5	GNSS L1 & L5
Observation area:	Hudson Bay, Canada	Arctic Ocean	Northern Europe
Time period:	Jan 2015	May – July 2024	Nov 2024

MAPHEUS-8: GNSS+R Simulation

MAPHEUS-8: Rocket Flight

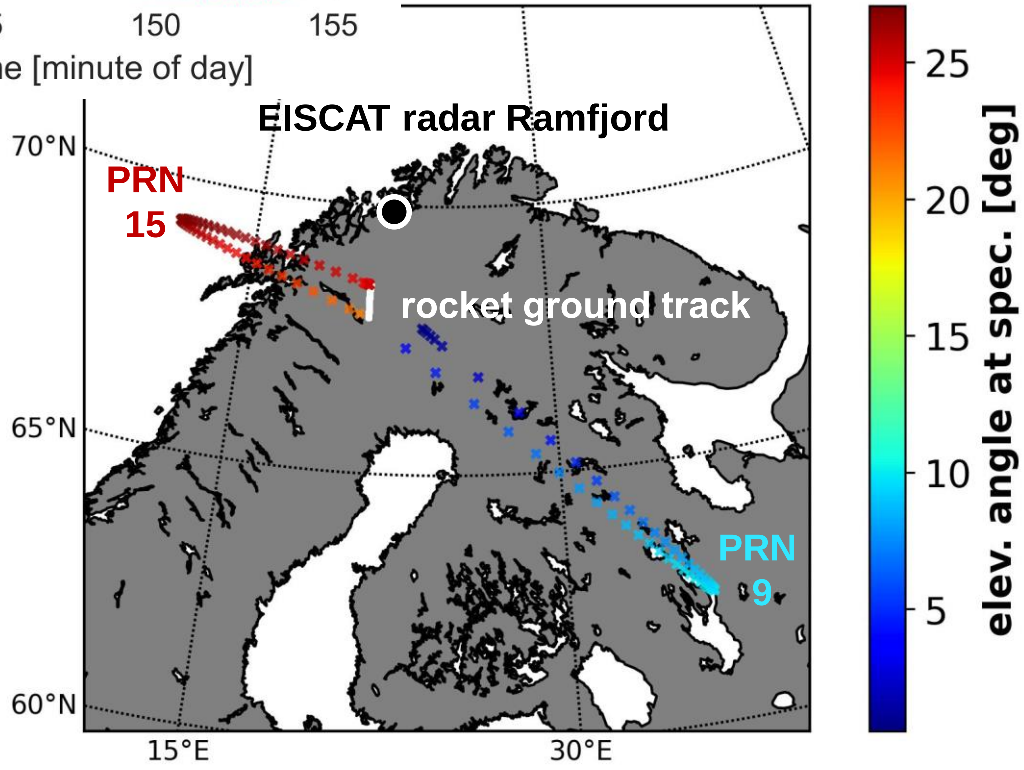


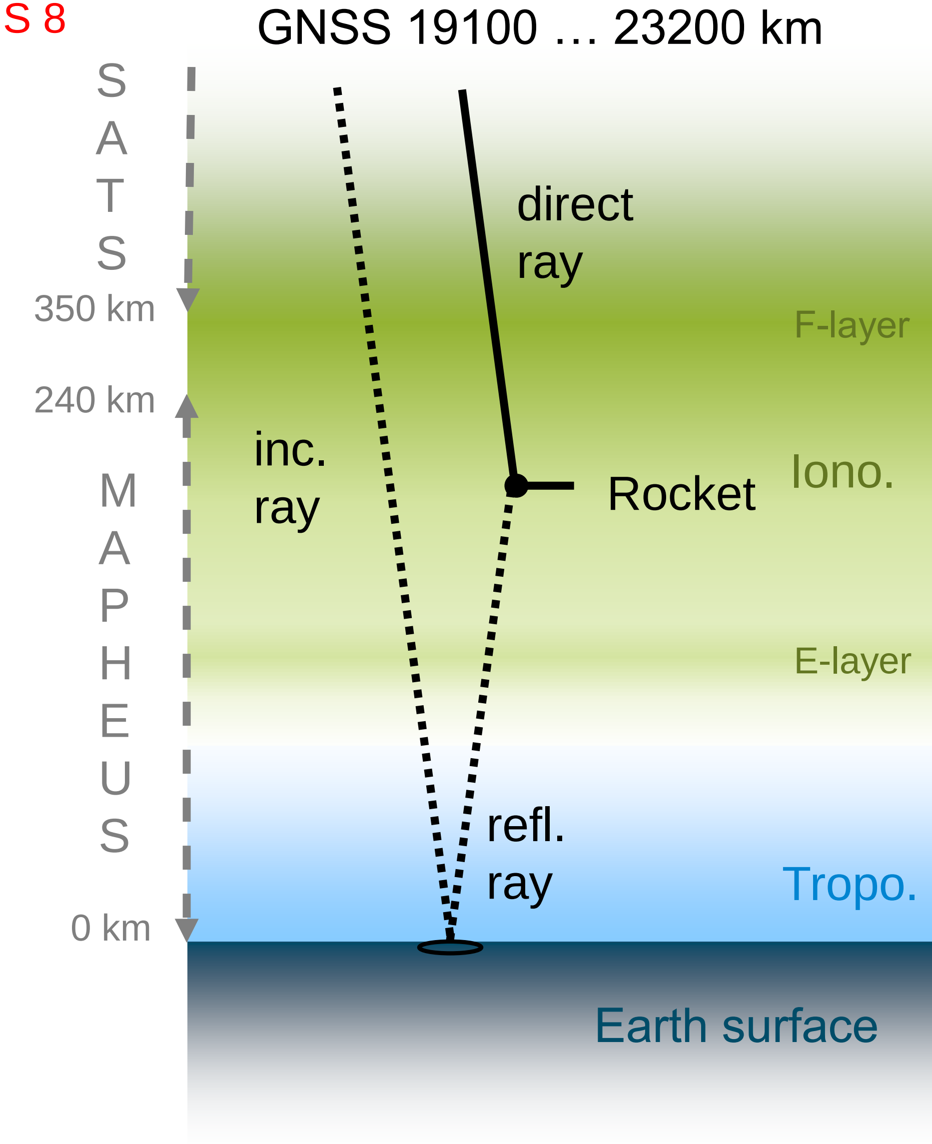


Previous flight data of MAPHEUS 8
Jun 13th, 2019

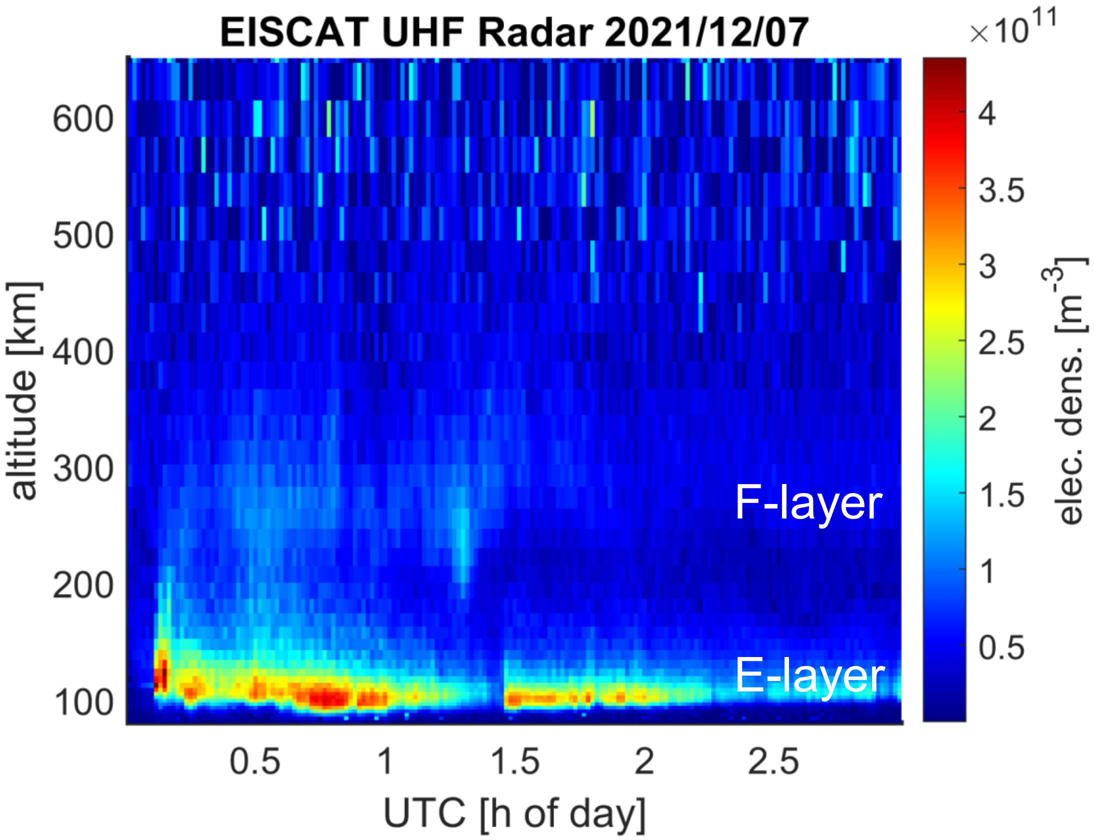
Starting point to simulate GNSS remote sensing obervations from a rocket

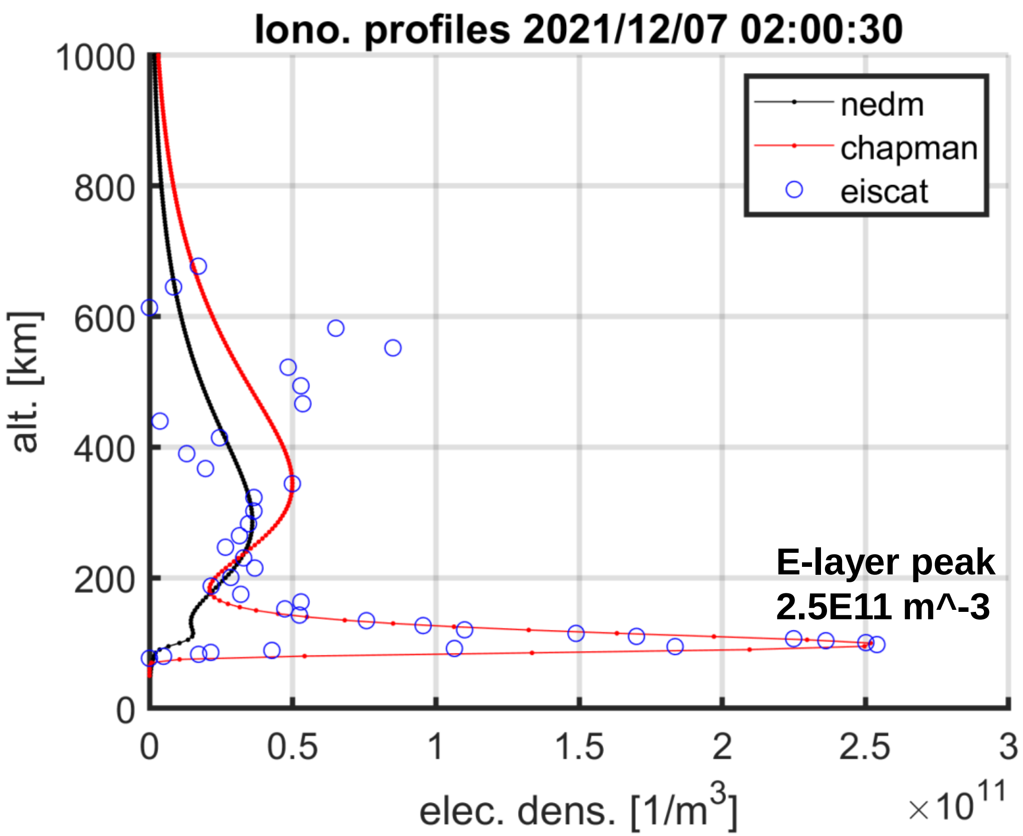
Specular reflection ground tracks of a **mid elevation** and a **grazing elevation** event.





EISCAT: Ionosphere Scenario

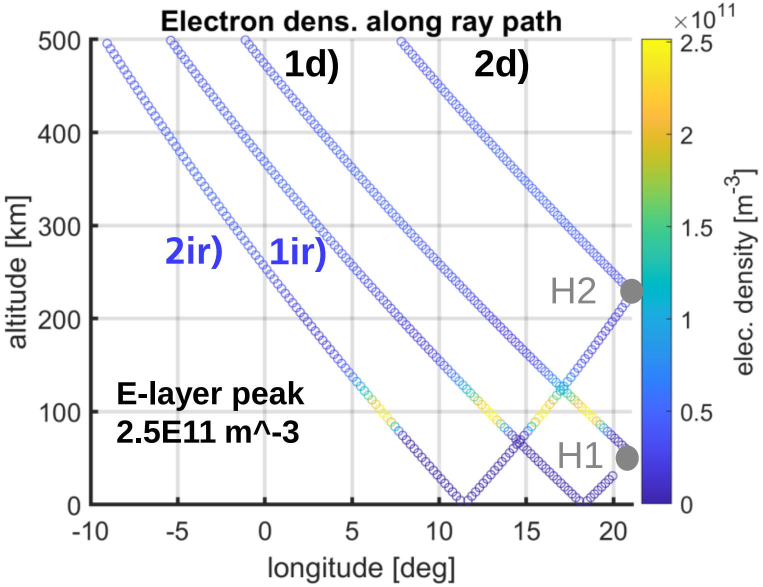




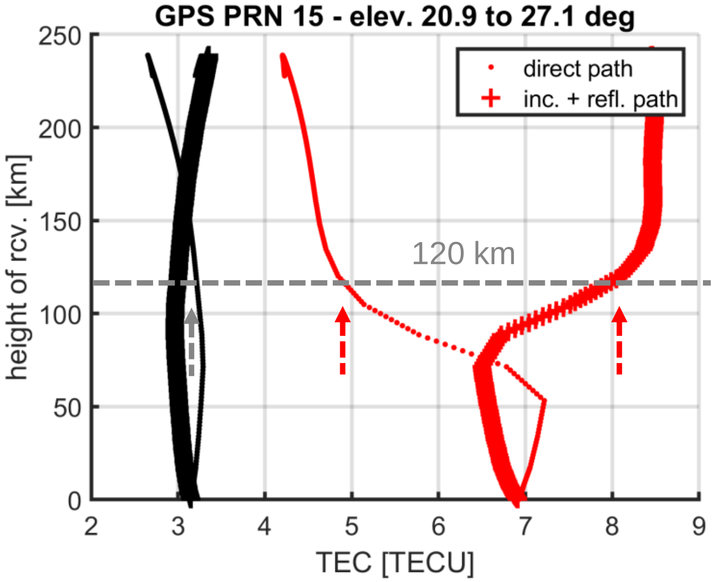
- 3h of elec. density data from EISCAT (European Incoherent Scatter) radar site near Ramfjord, Northern Norway
- **Polar night** period with **E-layer dominated ionosphere**

- **Chapman layer profile** fitted to EISCAT data, **dominant E-layer peak** and moderate F-layer peak
- Profile from empirical **NEDM** (Neustrelitz Elec. Density Model) for comparison, **E-layer underestimated**

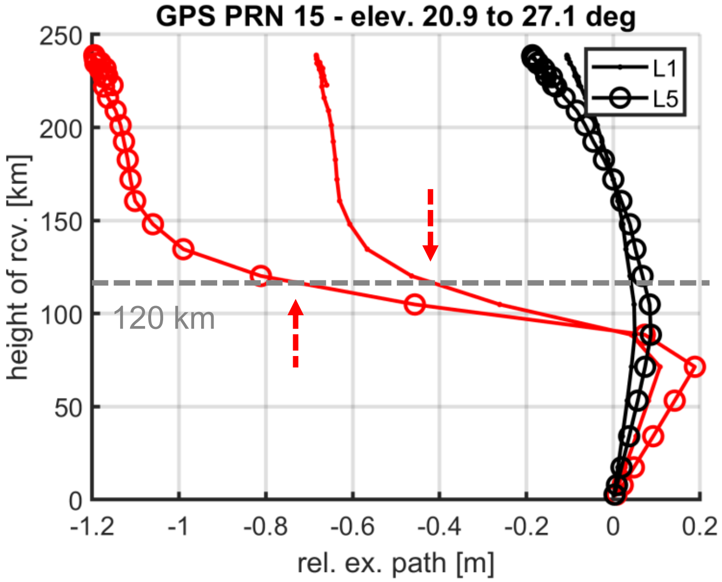
Results for mid elevation event: GPS PRN 15



- Rays path for two receiver heights (H1 ~ 50km, H2 ~ 240km)
- For **H1**: **incident-reflected** (ir) and **direct** (d) signals **hit E-layer**
- For **H2**: **only incident-reflected** signal hits E-layer (even twice)

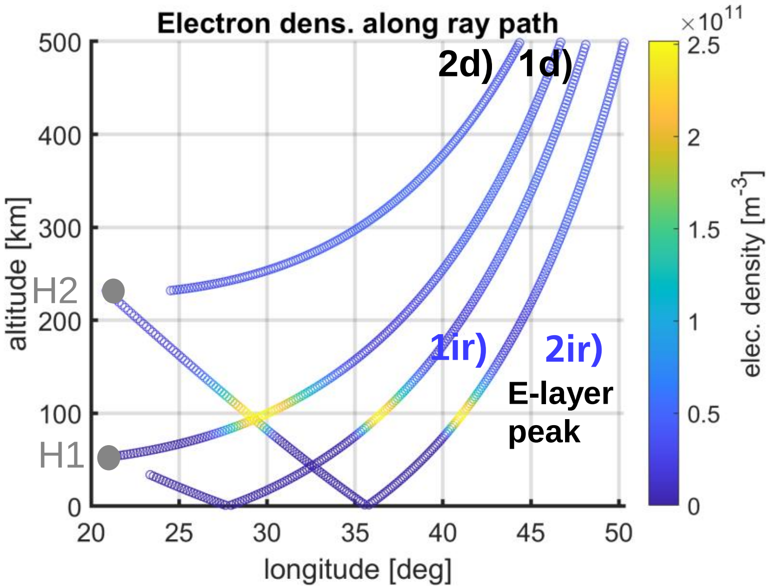


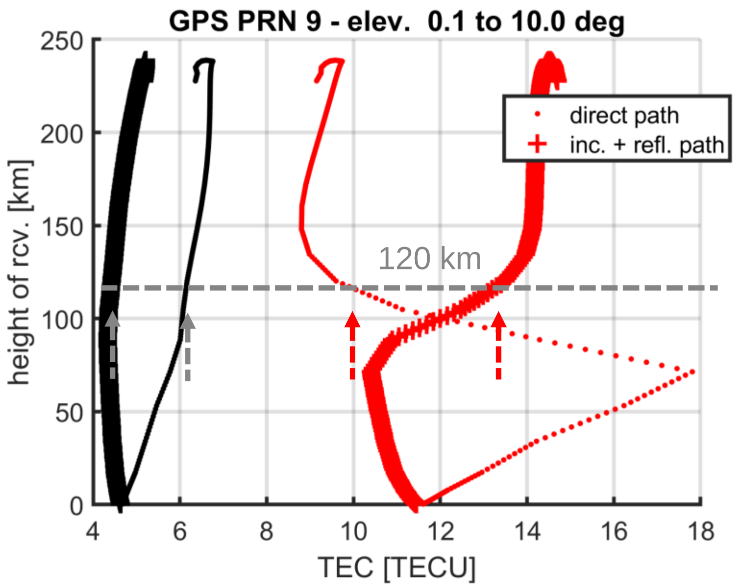
- Comparison of TEC along direct and incident-reflected paths dependent on height of receiver (rocket)
- NEDM scenario (black), E-layer-domin. scenario (red)
- TEC at 120km (above E-layer) differs significantly between scenarios:
  ~ 5 TECU on ir path
  ~ 2 TECU on d path

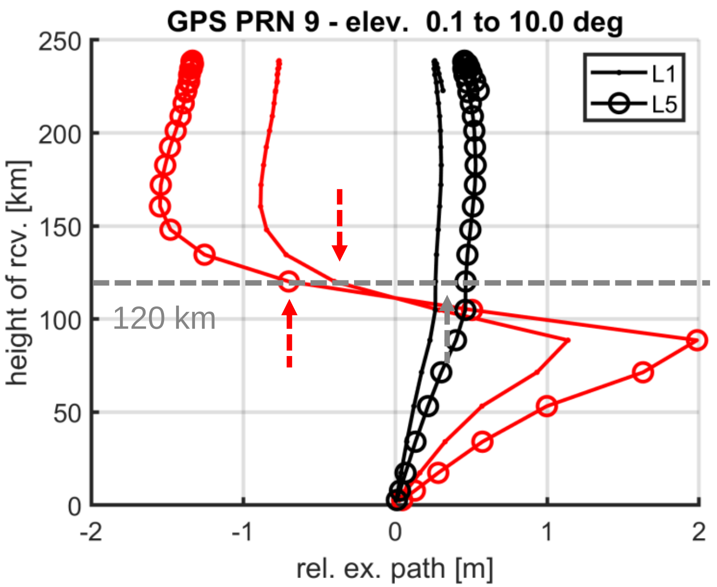


- Comparison of relative ionosphere excess path (between ir and d path)
- NEDM scenario (black) and E-layer domin. scenario (red) for L1 and L5
- ex. path at 120km (above E-layer) differs in dm range between scenarios:
  ~ 4 dm for L1
  ~ 8 dm for L5

Results for grazing elevation event: GPS PRN 9







- Rays path for two receiver heights (H1 ~ 50km, H2 ~ 240km)
- For **H1**: **incident-reflected** (ir) and **direct** (d) signals **hit E-layer**
- For **H2**: **only incident-reflected** signal hits E-layer (even twice)

- Comparison of TEC along direct and incident-reflected paths dependent on height of receiver (rocket)
- NEDM scenario (black), E-layer-domin. scenario (red)
- TEC at 120km (above E-layer) differs significantly between scenarios:
  ~ 8 TECU on ir path
  ~ 4 TECU on d path

- Comparison of relative ionosphere excess path (between ir and d path)
- NEDM scenario (black) and E-layer domin. scenario (red) for L1 and L5
- ex. path at 120km (above E-layer) differs in dm to m range between scenarios:
  ~ 7 dm for L1
  ~ 10 dm for L5

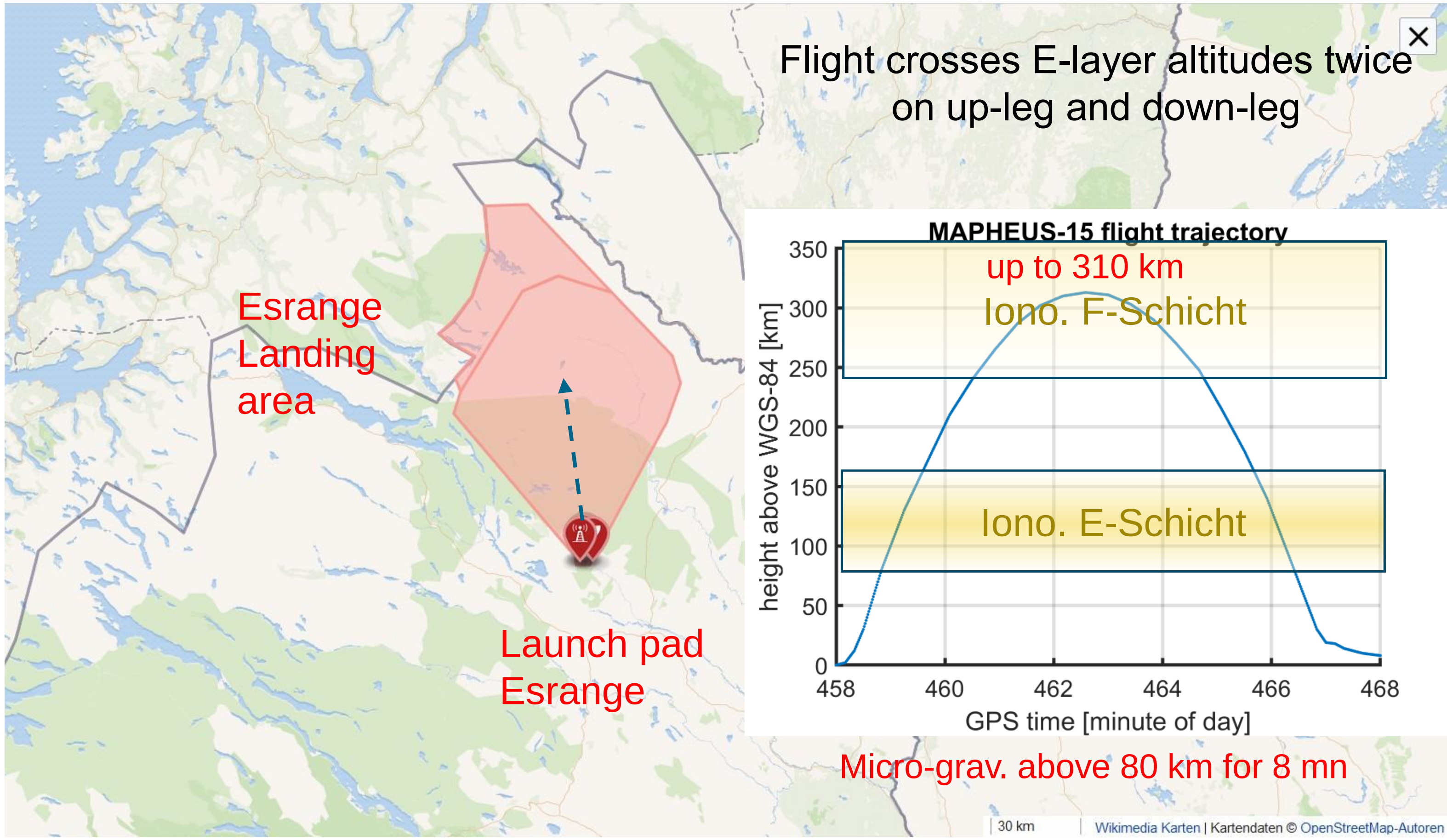
MAPHEUS-15: GNSS+R Setup and Preliminary Results

MAPHEUS-15: GNSS Payload and Flight

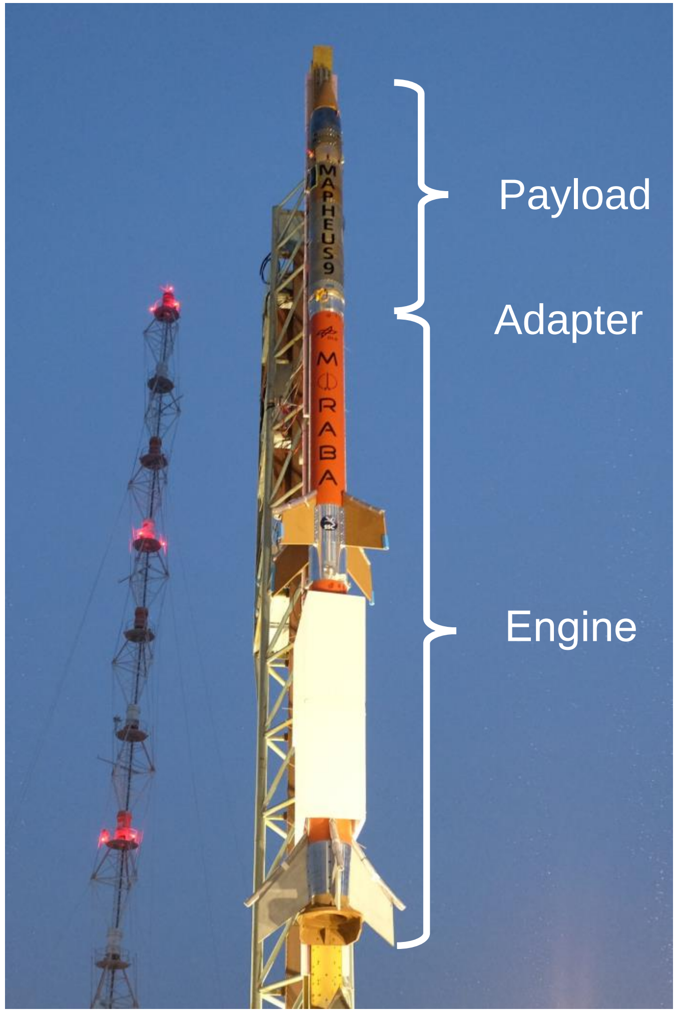
Nose GNSS (Septentrio) for Navigation

Tail GNSS (Syntony) for Reflectometry

Sucessful sub-orbital flight on Nov 11 2024



MAPHEUS-15: GNSS+R Tail Setup



rocket of MAPHEUS programme
at launcher (previous campaign)

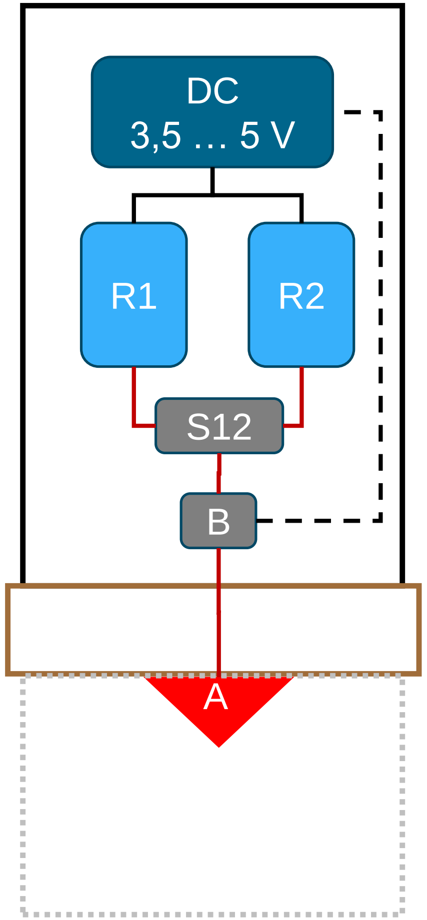
Receiver unit
in payload module

GNSS Bitgrabber
(redundant)

Payload Adapter

GNSS Antenna

Clear view to Earth
once engine is
thrown off



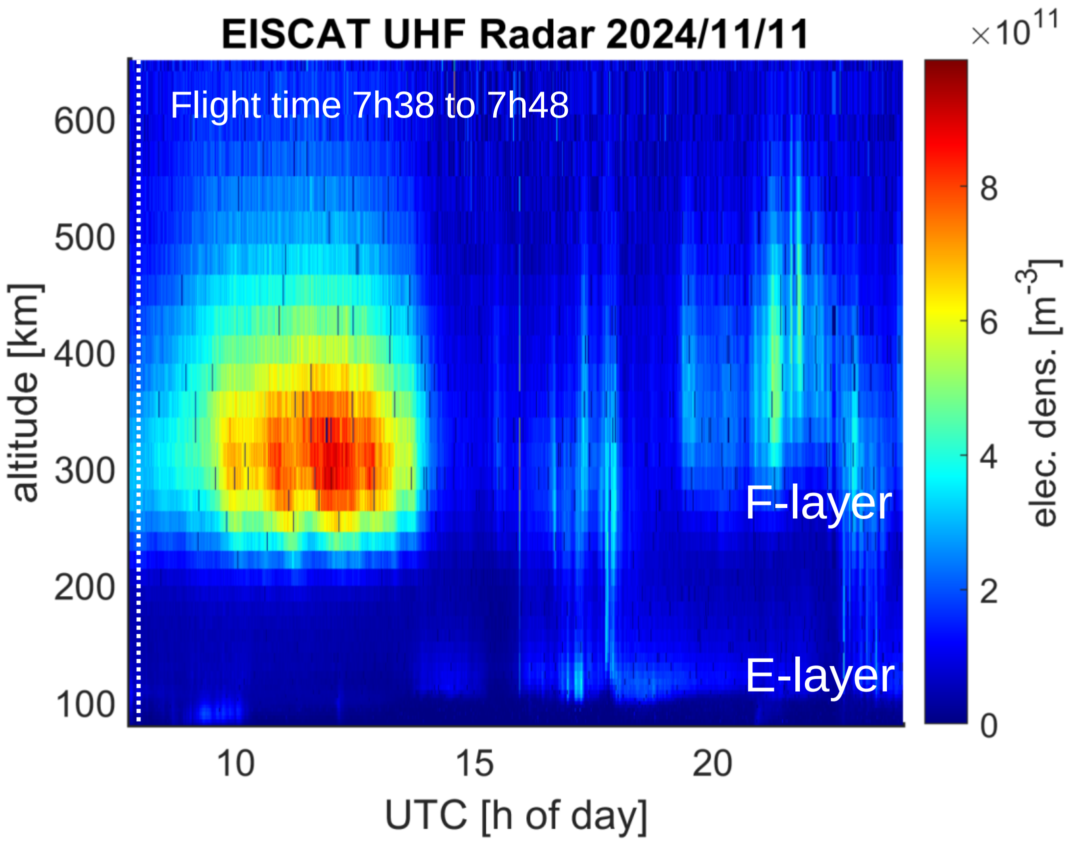
Design & layout for
GNSS remote sensing

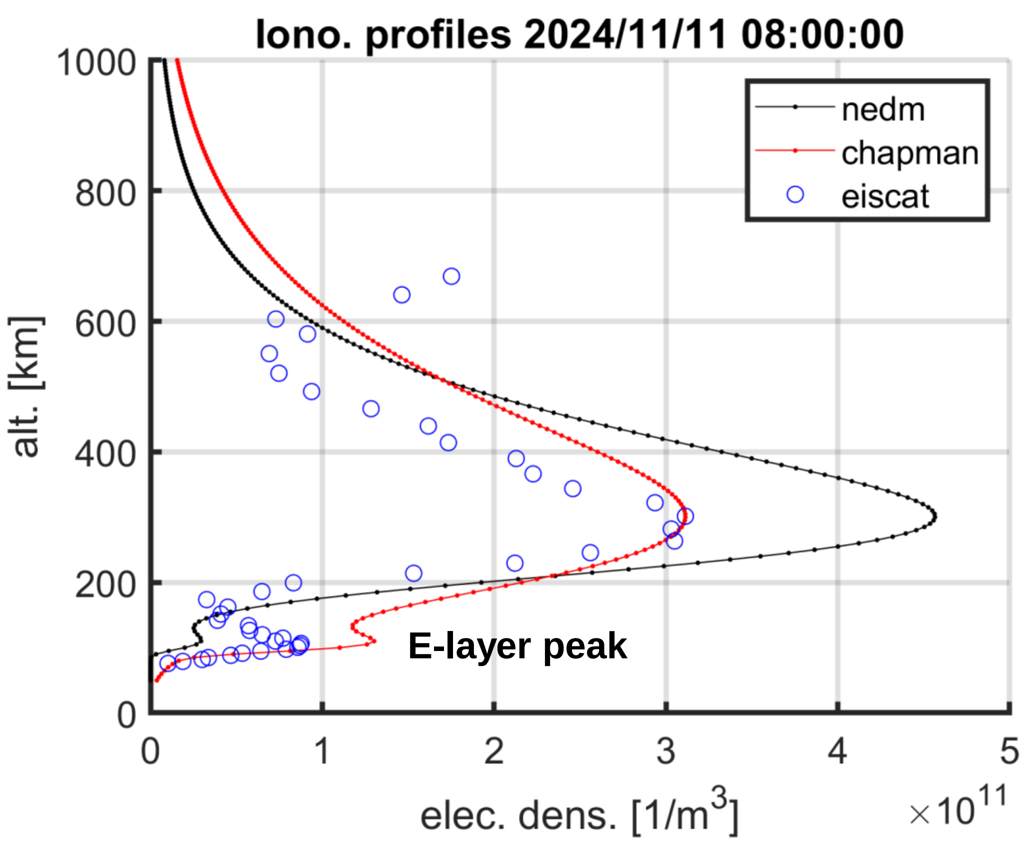
Components:

- Bitgrabber (R1,2) Syntony GNSS
- Antenna (A) matterwaves
- Bias-tee (B)
- Splitter (S12)
- Powercontrol (DC)

GNSS setup components

EISCAT: Ionosphere Conditions

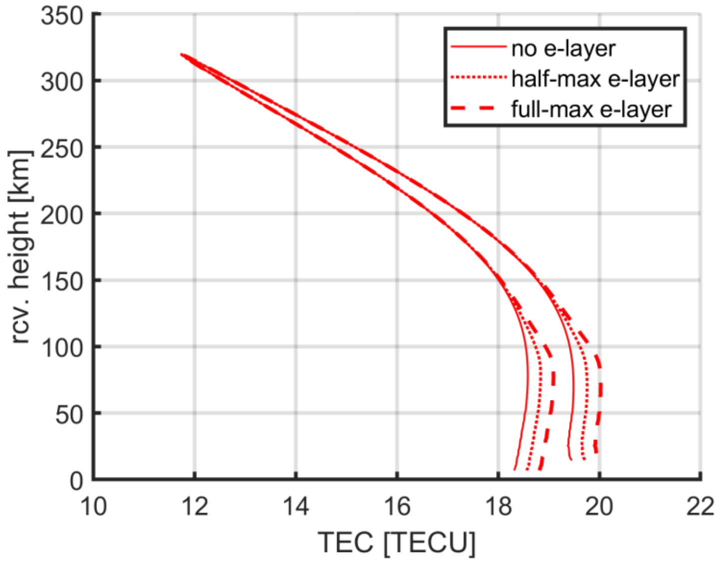




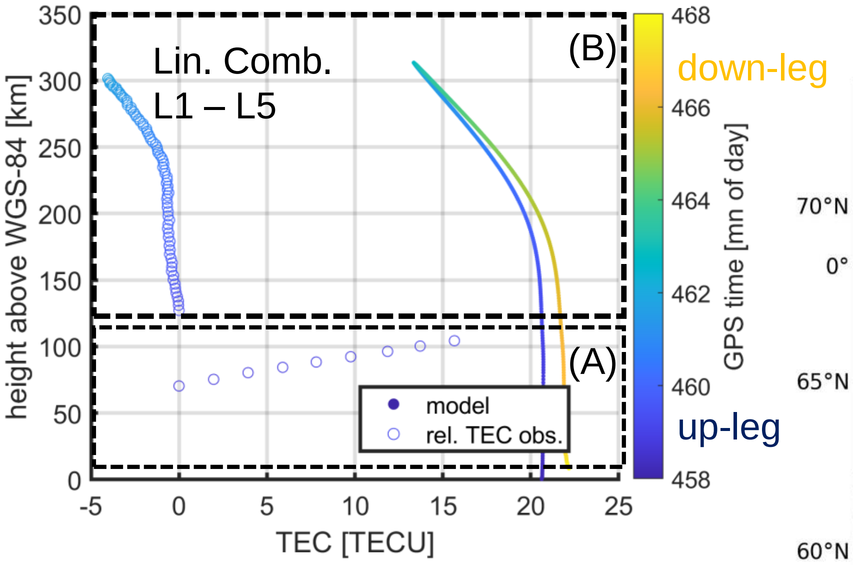
- 17h of elec. density data from EISCAT (European Incoherent Scatter) radar site near Tromsø, Norway
- **Dawn condition** period with **F-layer dominated ionosphere**
- **Chapman layer profile** fitted to EISCAT data, **dominant F-layer peak** and small E-layer peak
- Deviation between **NEDM** (Neustrelitz Elec. Density Model) and **EISCAT** obs.

Preliminary Results: Nose GNSS – GAL PRN 3

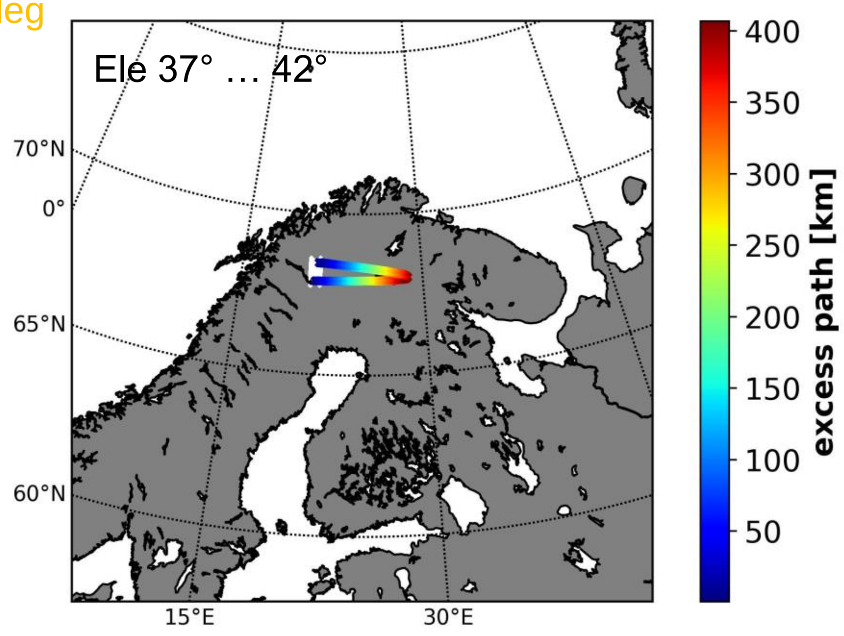
Chapman layer sims.: direct



Obs. vs. NEDM model: direct



Refl. Point sims.

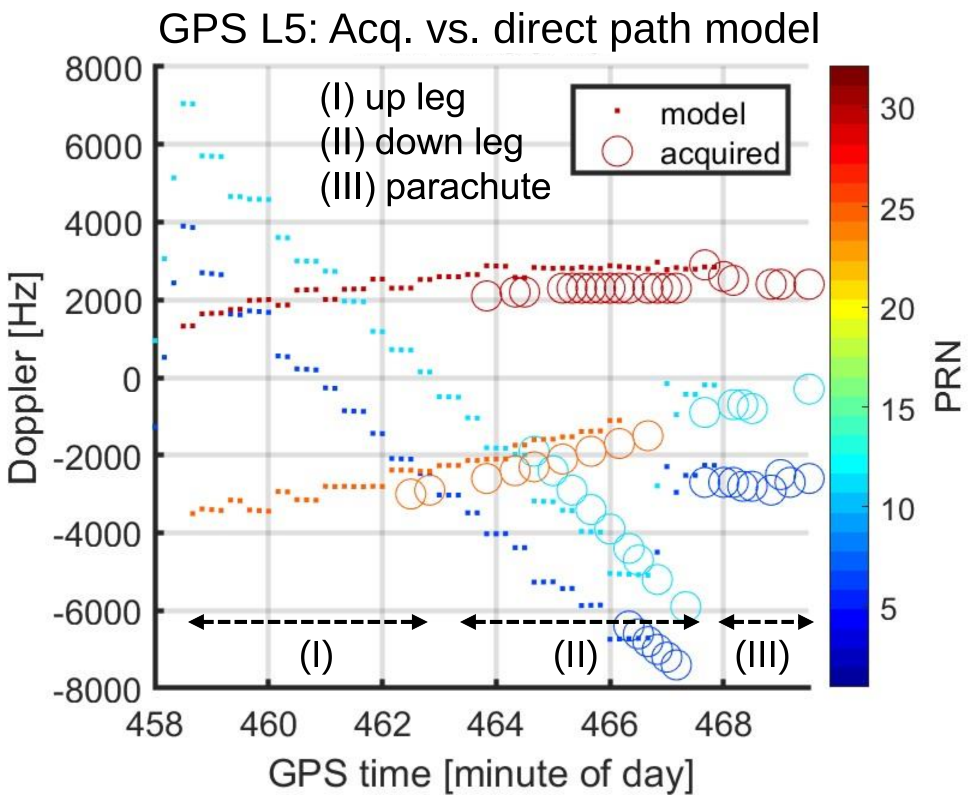


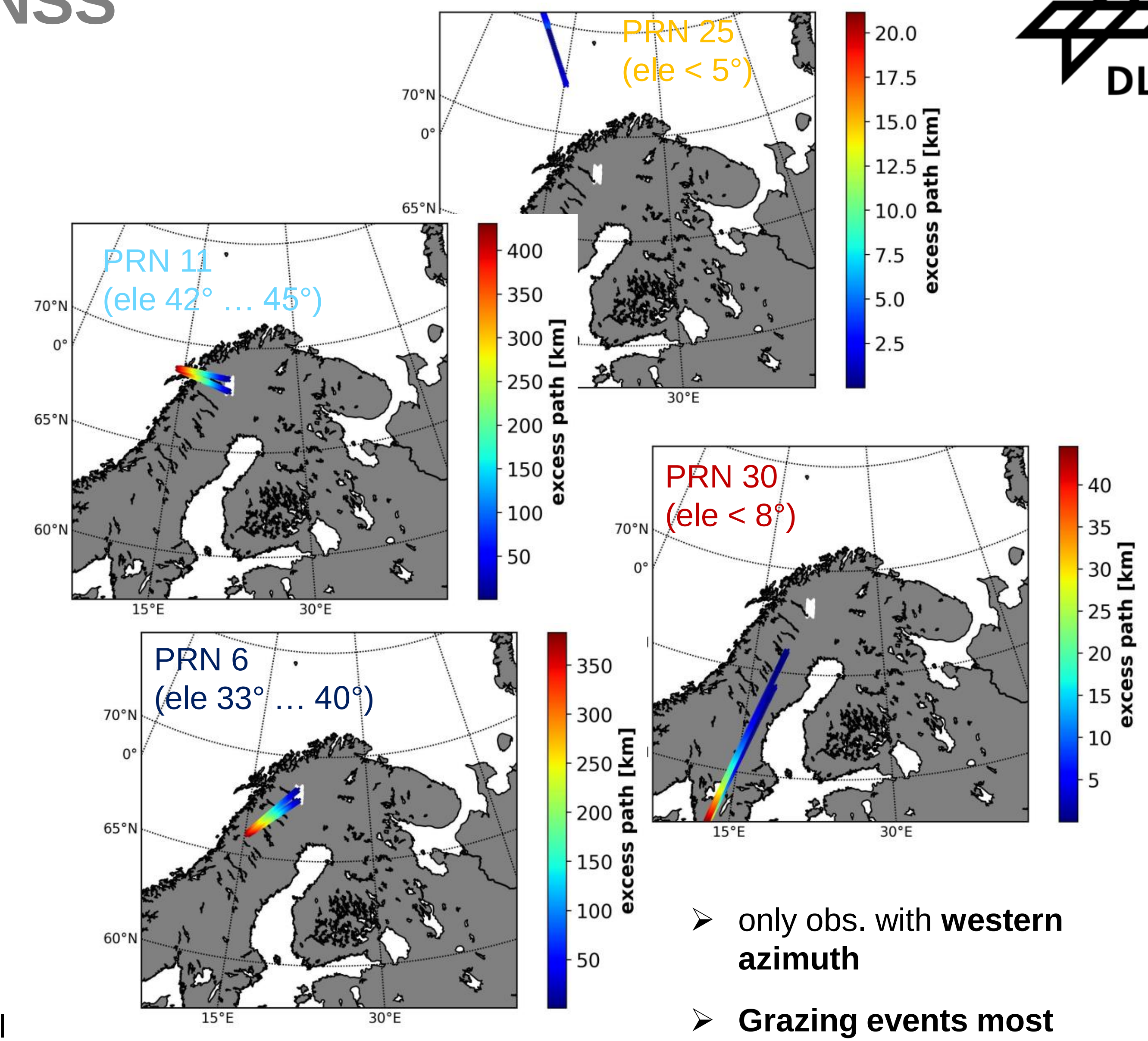
- **Similation** assuming Chapman layers with **variable E-layer config.** shows
- dominating F-layer leads **to overall TEC decrease** for direct link **above 100 km**
- In this scenario **E-layer** results small **shift** of TEC profile below 100 km **~1TECU**

- Model results assuming **NEDM** also **TEC decrease above 100 km** (F-layer effect)
- **TEC Obs. agree** with model in **micro-gravity Phase** (B)
- Observations show strong **bias** in **acceleration Phase** (A), residual spin?

- Event in **eastern direction**
- Simulated reflection points over vegetated land
- **Not promising reflection conditions**

Preliminary Results: Tail GNSS





- Signals are affected by **RFI**, more acquisitions on L5
- **four GPS sats** acquired during down-leg
- **Acquired Doppler obs. Agree direct signal model**
- Look for reflected signal using open-loop model model
- **Still open** signal **tracking for TEC retrieval**

- only obs. with **western azimuth**
- **Grazing events most promising for reflections**

Conclusion

- GNSS+R obs. **from satellite** very **significant ionospheric delay**
- Usually **F- and E-layer** will contribute
- Can we resolve **E-layer** contribution **with GNSS+R from rocket**?
- Simulations using **MAPHEUS-8** scenario and ionosphere from **NEDM & EISCAT**
- **E-layer dominated ionosphere** (ELDI) is **important uncertainty** in delay
- Simulated **delay bias** due to ELDI is in **dm range** (2-4 TECU)
- **GNSS+R data** recorded on **MAPHEUS-15** in F-layer dominated conditions
- **Direct signal** obs. give realistic **TEC** profile **above 120 km** - E-layer contribution is unclear
- Tracking of Reflected signals still ahead

Acknowledgements

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Thank you for your attention

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