Ionospheric impact on space-borne GNSS reflectometry: studying satellite and sounding rocket scenarios

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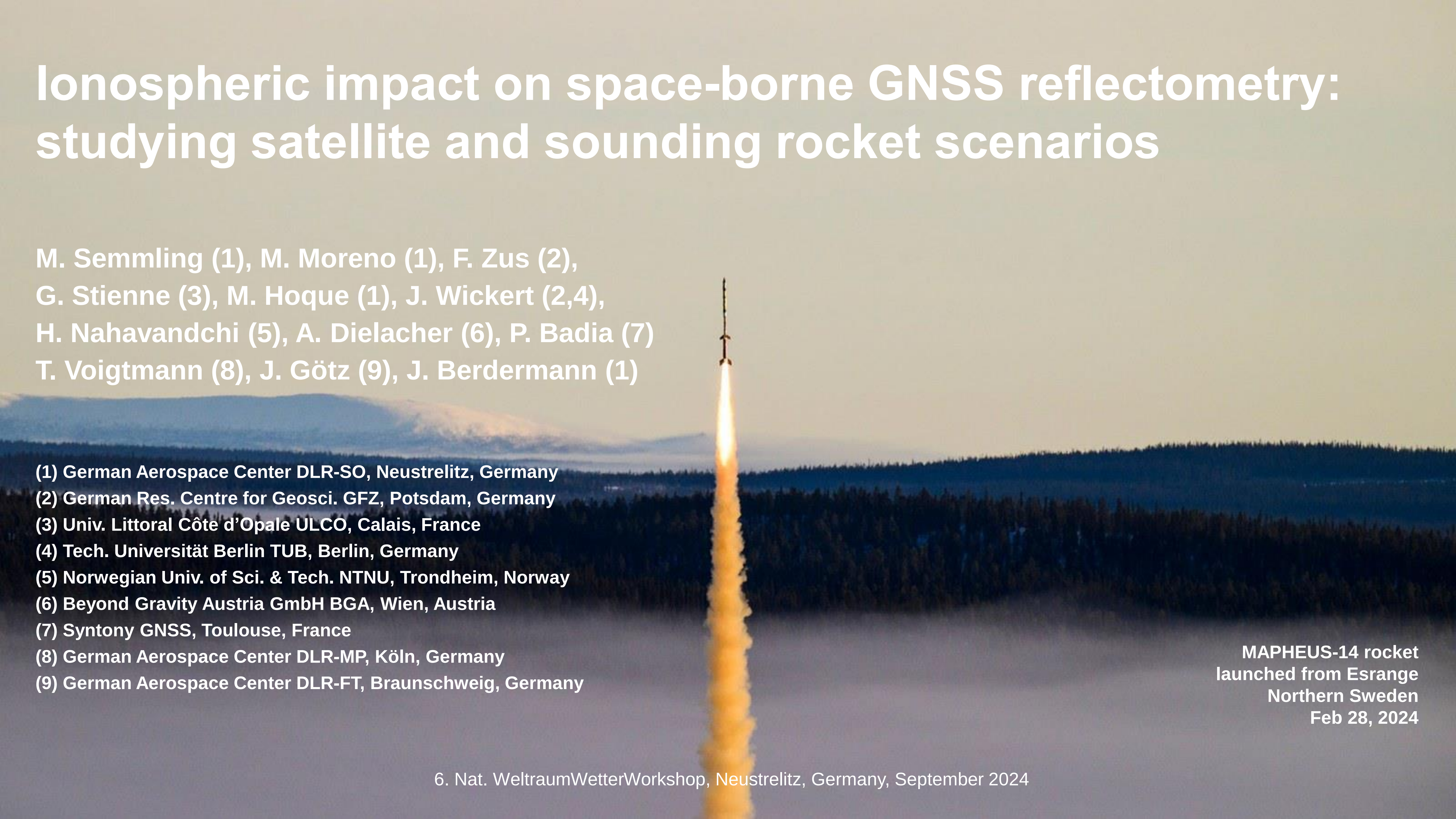


MAPHEUS-14 rocket
launched from Esrange
Northern Sweden
Feb 28, 2024

6. Nat. WeltraumWetterWorkshop, Neustrelitz, Germany, September 2024

Outline

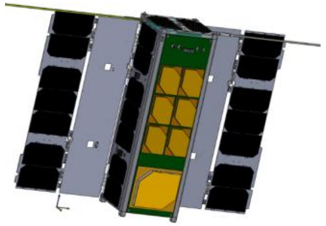
- Background and Motivation
- Prelim. Results from Satellites
- Preparation and Simulation of Rocket Obs.
- Summary & Outlook

Background and Motivation

Motivation GNSS Reflectometry

- A: Low Earth Orbiter

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



- B: Aircraft

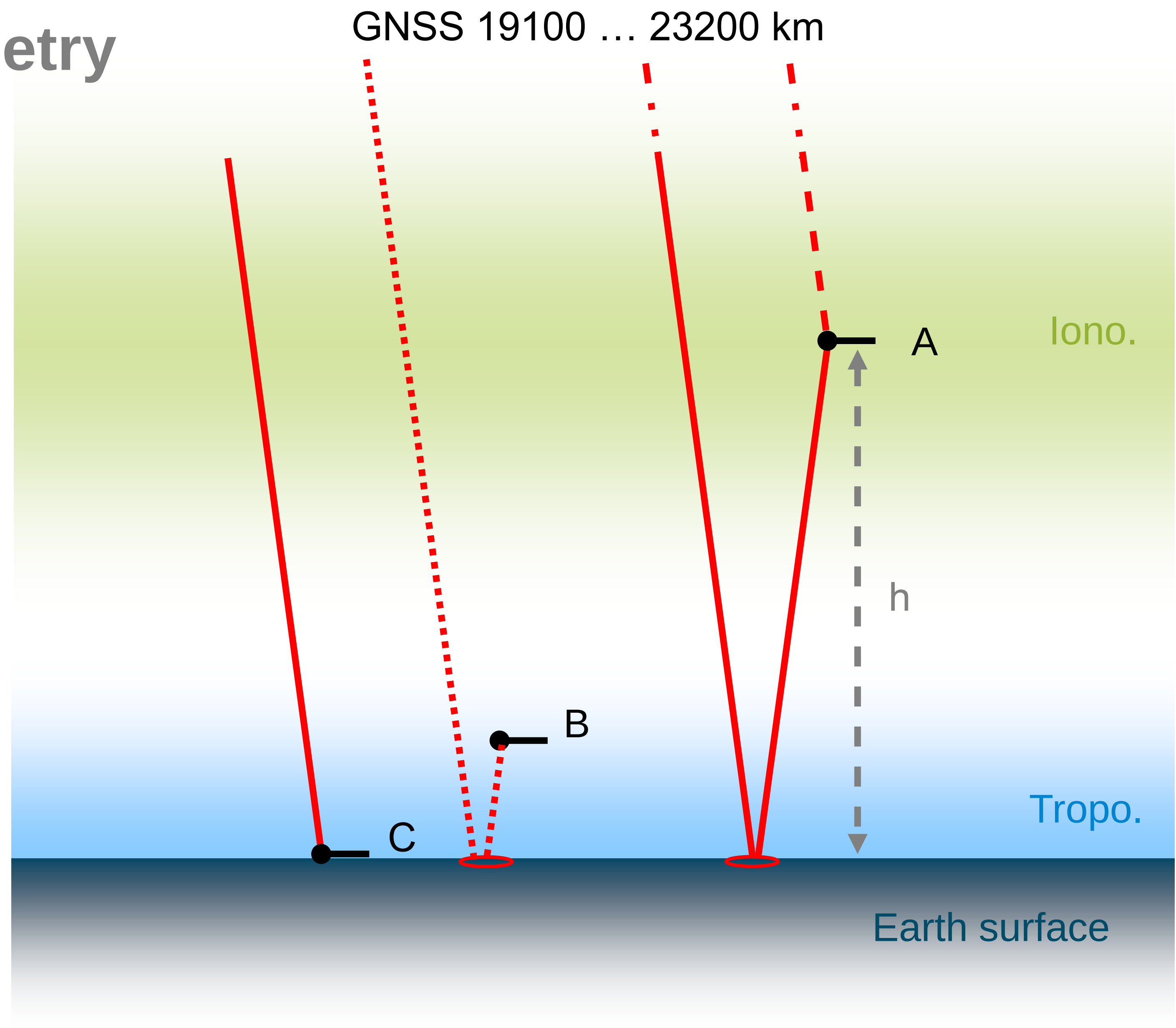
  Semmling et al. 2014
  Moreno et al. 2022

- C: Research Vessels

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

- Application

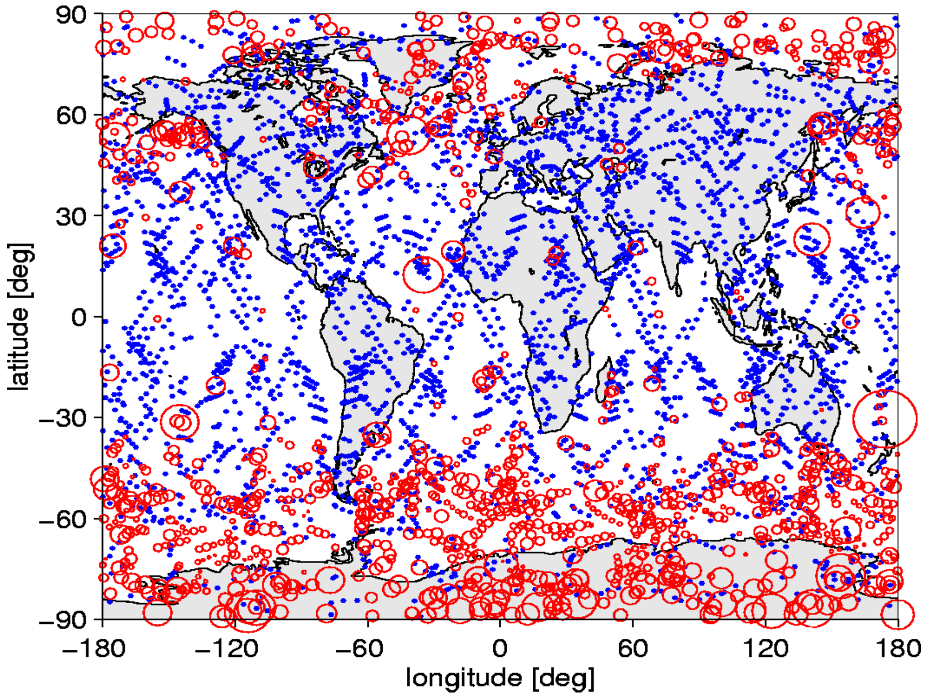
sea surface altimetry
sea state estimation
sea-ice detection
water vapor estimation
ionosphere monitoring



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

Opportunities and Challenges

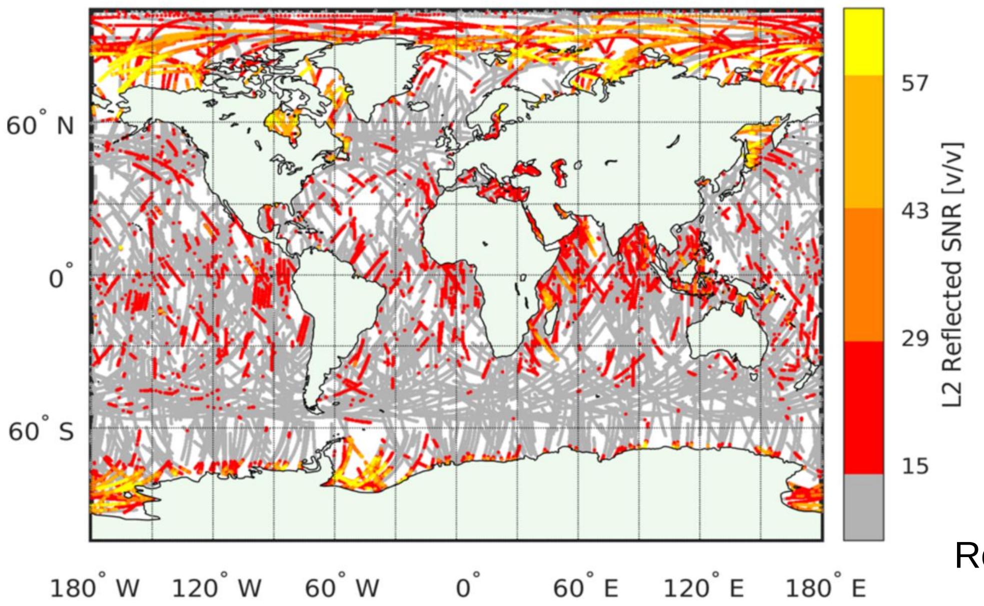
- **GNSS signal** are **freely available** with global coverage
- Coherent signature have been observed in various scenarios also from space
- **Main goal**: understand & correct **ionospheric effects**, exploit them **for earth observation**
- **Disturbances** to be considered
  - Irregularities on Earth surface (land, ocean roughness)
  - Irregularities in Earth‘s atmosphere (ionosphere, troposphere)
- Best **Opportunities** for coherent reflectometry
  - Over **sea ice**, **calm ocean** and in coastal areas
  - At **grazing elevation** angles
- **New points** in this study
  - Sat. obs. down to **grazing elevation** -> increased atmo. effect
  - **Rocket** obs. focusing on **E-layer** detection



Radio Occultation events recorded with CHAMP mission (one month)

red with reflection
blue w/o reflection

Beyerle et al. 2002



Reflectometry events recorded by Spire constell. (four months)

coherent obs. coincide with higher SNR

Roesler et al. 2021

Considerable Factors

Sea Surface

- Roughness (Sea State)
- Penetration (e.g. Sea Ice)
- …

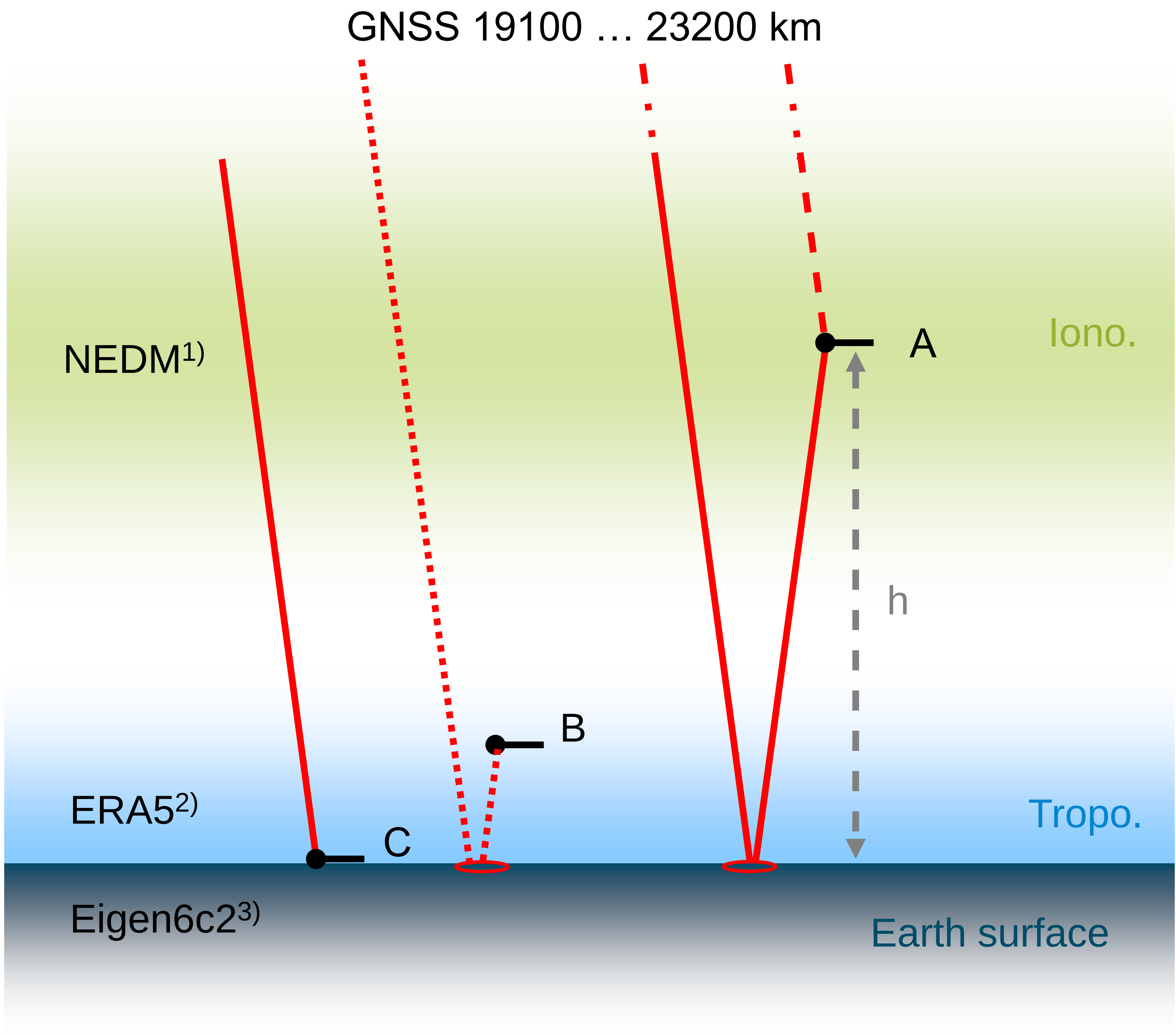
Atmosphere

- Refraction
  (neutral gas and ionosphere)
- Scintillation
  (Plasma Depletion, Space Weather)
- …

Receiver & Transmitter

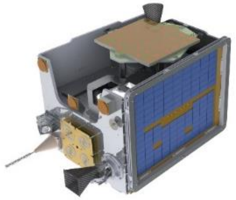
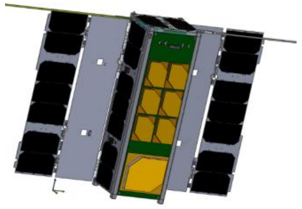
- Position & Attitude uncertainty
  (of vessel, aircraft or satellite)
- Antenna & Instrumental parameter
  (e.g. gain pattern)
- …

degree of disturbance



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

Data for space-borne reflectometry

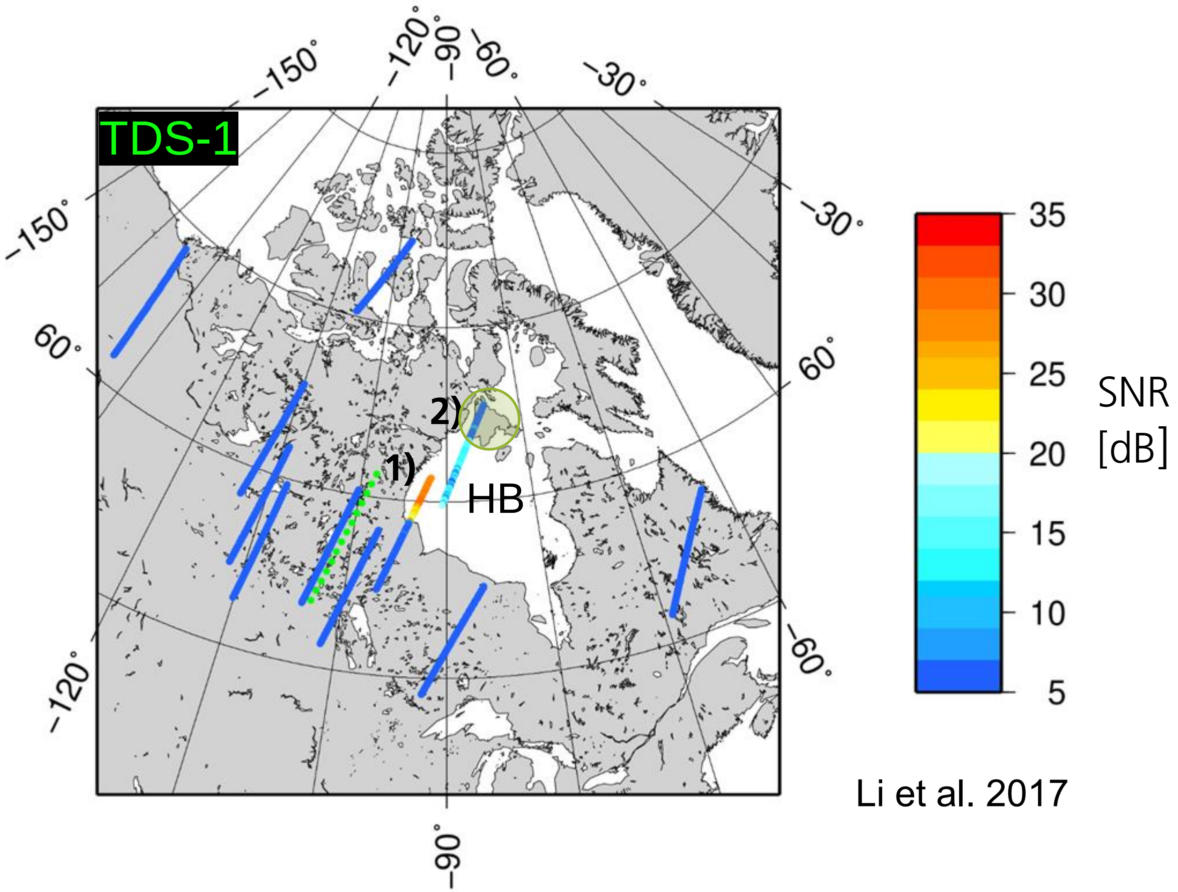
			
Mission:	TDS-1	PRETTY	MAPHEUS-15
Platform type:	small sat	cube sat	sounding rocket
Observation alt.:	~ 650 km	~ 560 km	80 … 240 km
Major field of view:	near-nadir	grazing	grazing
Supported signals:	GPS L1 C/A	GPS L5C & GAL E5	GNSS L1 & L5
Observation area:	Hudson Bay, Canada	Arctic Ocean	Northern Europe
Time period:	Jan 2015	May – July 2024	Nov 2024 (planned)

Prelim. Results from Satellites

Altimetric Scenario with TDS-1

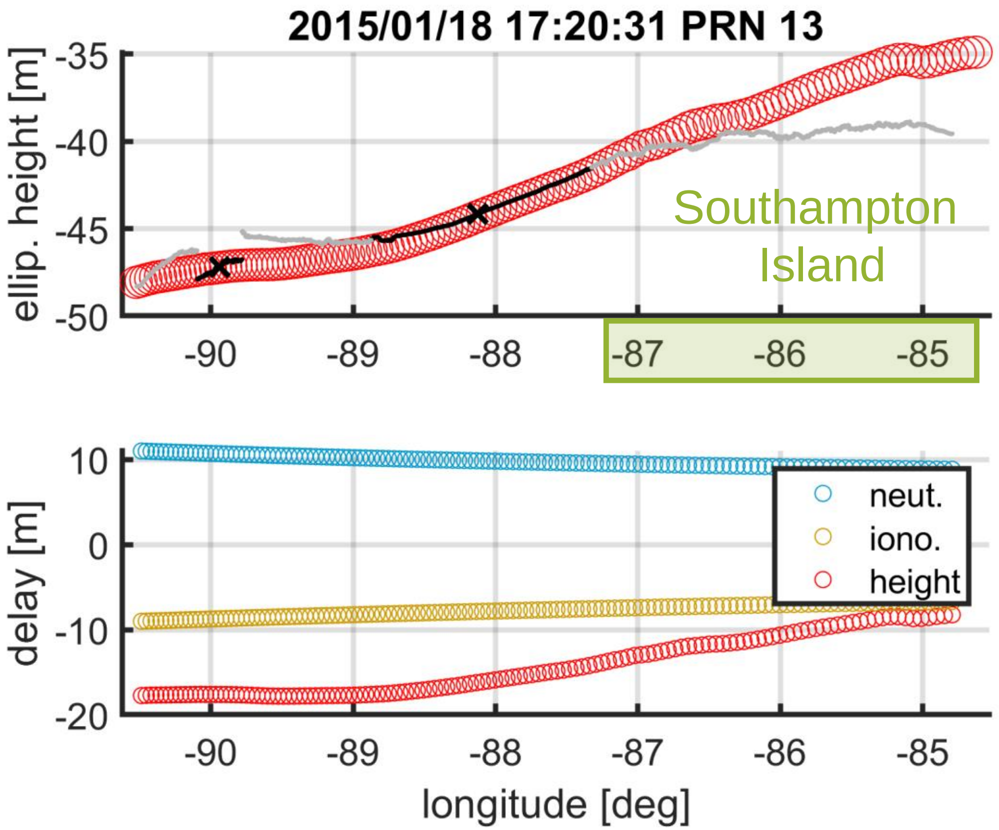
DLR

Coherent Phase Tracks of TDS-1 Mission



- Two tracks over Hudson Bay (HB) with rather high SNR selected for analysis, they run over sea ice
- Reflection at **spec. Point with high and mid elevations**:
  1) western HB track ~ 58°
  2) eastern HB track ~ 30°

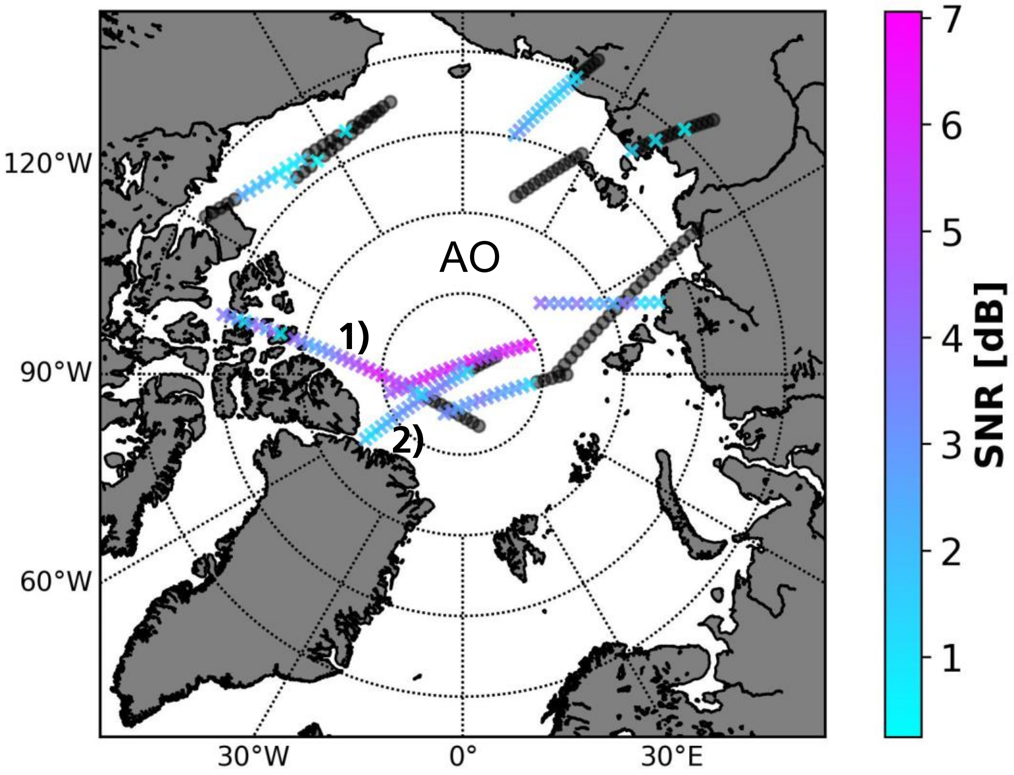
Retrievals for Eastern HB Track 2)



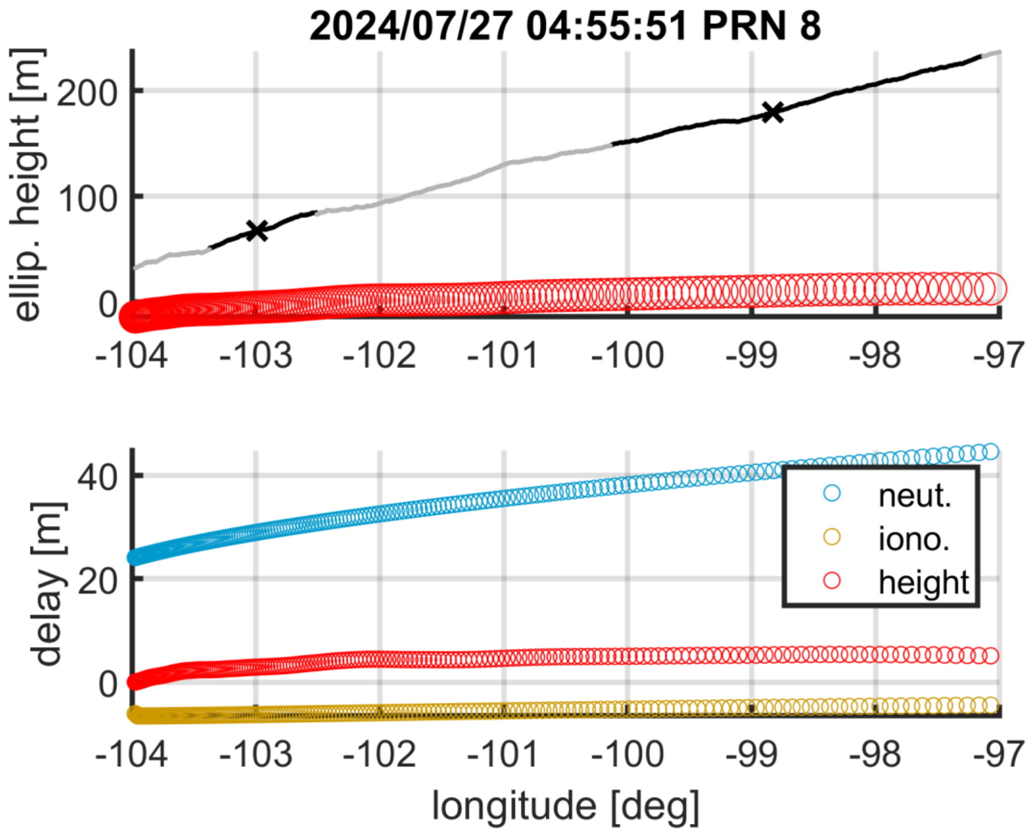
- Surface **height retrievals** (black marker) **follow the sea surface** height model (red marker)
- Altimetric scenario because expected delay (based on model) is **dominated by sea surface height** effect

Atmospheric Scenario with PRETTY

Coherent Phase Tracks of PRETTY Mission



Retrievals for Western AO Track 1)

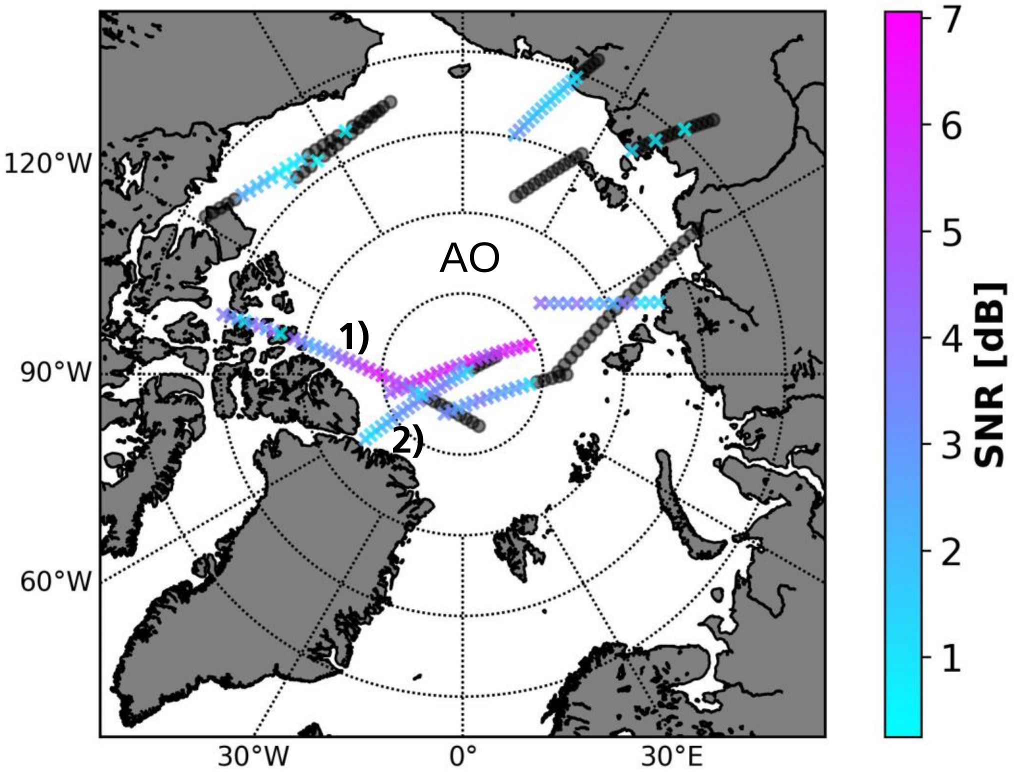


- Nine sea-ice tracks over Arctic Ocean (AO) with reflection signature (rather low SNR), segments without reflection (grey)
- Reflection at **spec. Point with grazing elevation**:
  1) western AO track 0 … 11°
  2) Greenland track 0 … 10°

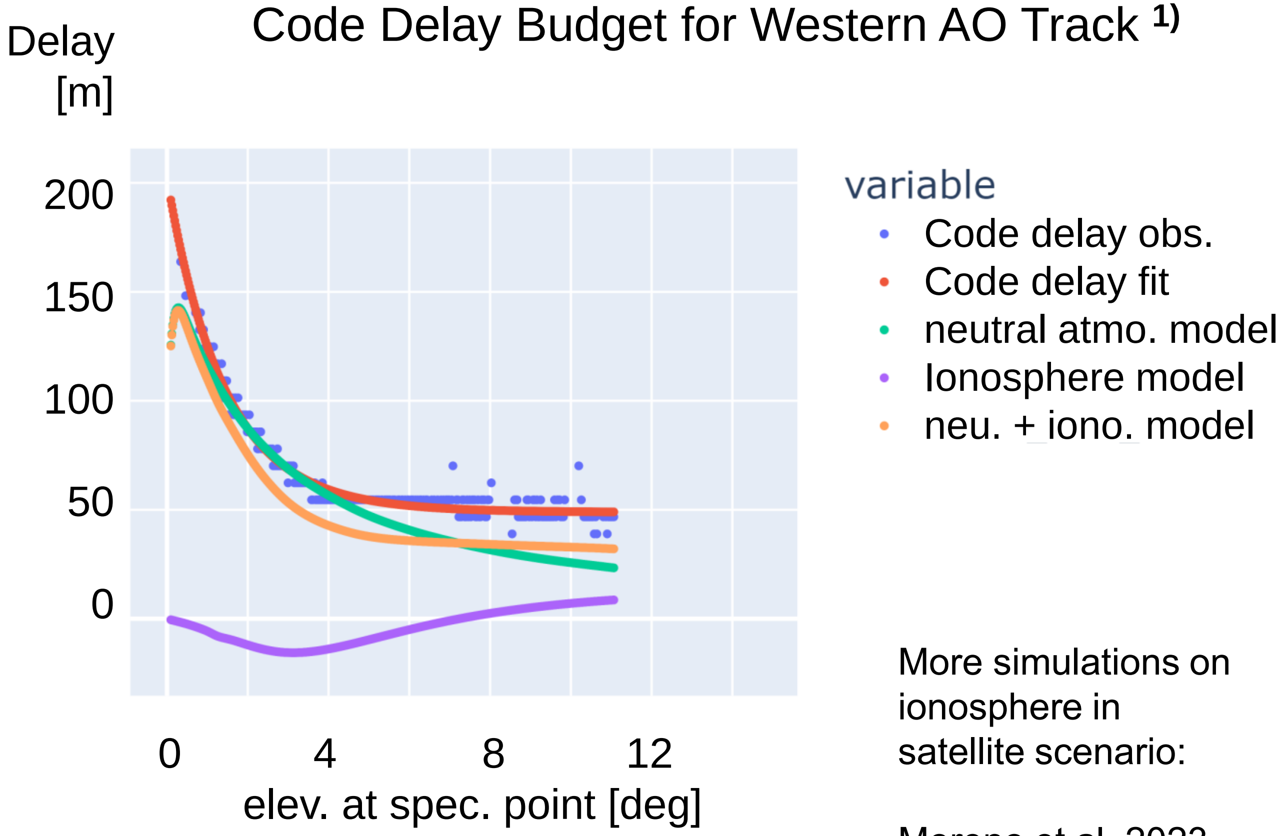
- Surface **height retrievals** (black marker) **follow not the sea surface** height model (red marker)
- Atmospheric scenario because expected delay (based on model) is **dominated by neutral atmo.** effect

Atmospheric Scenario with PRETTY

Example Tracks of PRETTY Mission



Code Delay Budget for Western AO Track 1)



More simulations on ionosphere in satellite scenario:

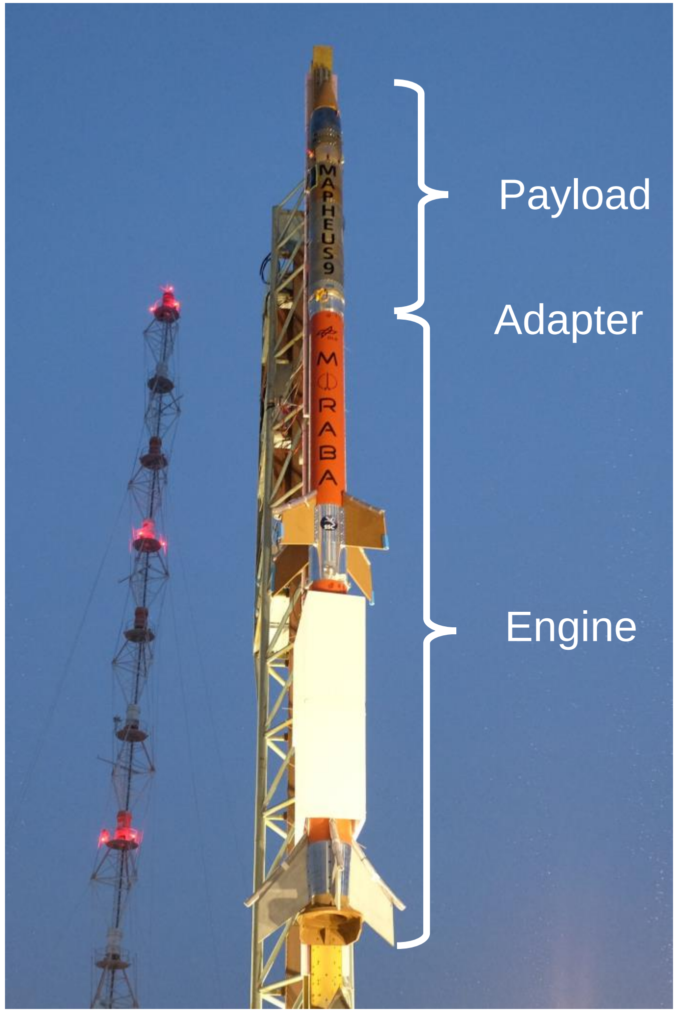
Moreno et al. 2023

- Nine sea-ice tracks over Arctic Ocean (AO) with reflection signature (rather low SNR), segments without reflection (grey)
- Reflection at **spec. Point with grazing elevation**:
  1) western AO track 0 … 11°
  2) Greenland track 0 … 10°

- In grazing reflection geometry (elev. < 15°) atmo. delay increases exponentially
- **retrieved delay and model agree** in this **trend**, bias remains (10m range underestimation)

Preparation and Simulation of Rocket Obs.

GNSS setup on MAPHEUS rocket



rocket of MAPHEUS programme
at launcher (previous campaign)

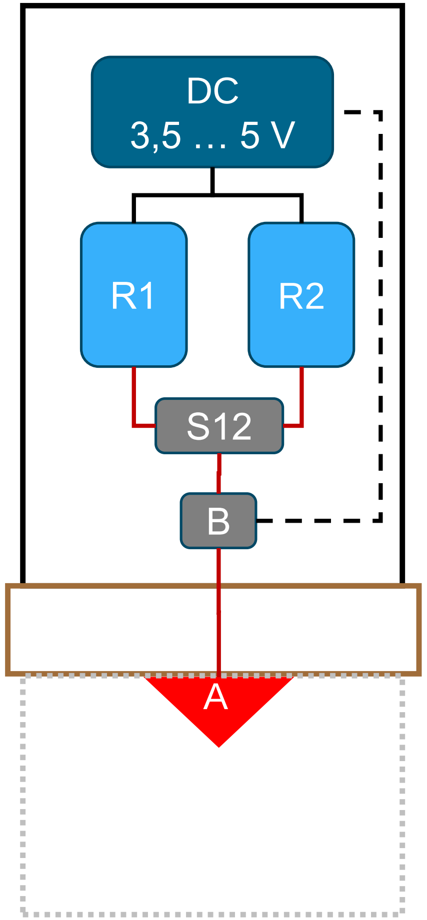
Receiver unit
in payload module

GNSS Bitgrabber
(redundant)

Payload Adapter

GNSS Antenna

Clear view to Earth
once engine is
thrown off



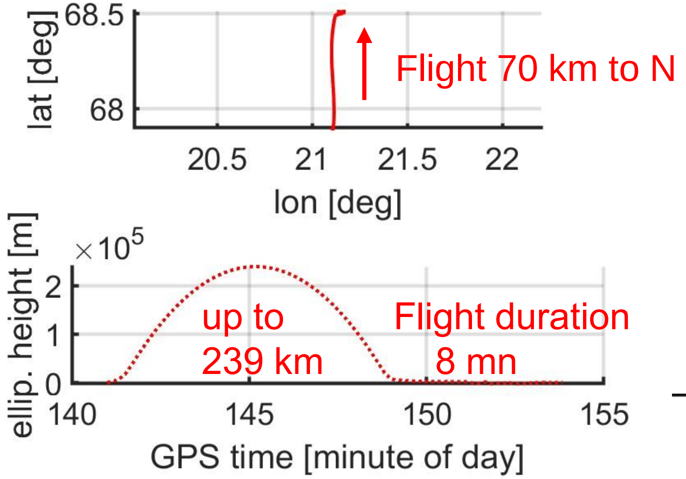
Design & layout for
GNSS remote sensing

Components:

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

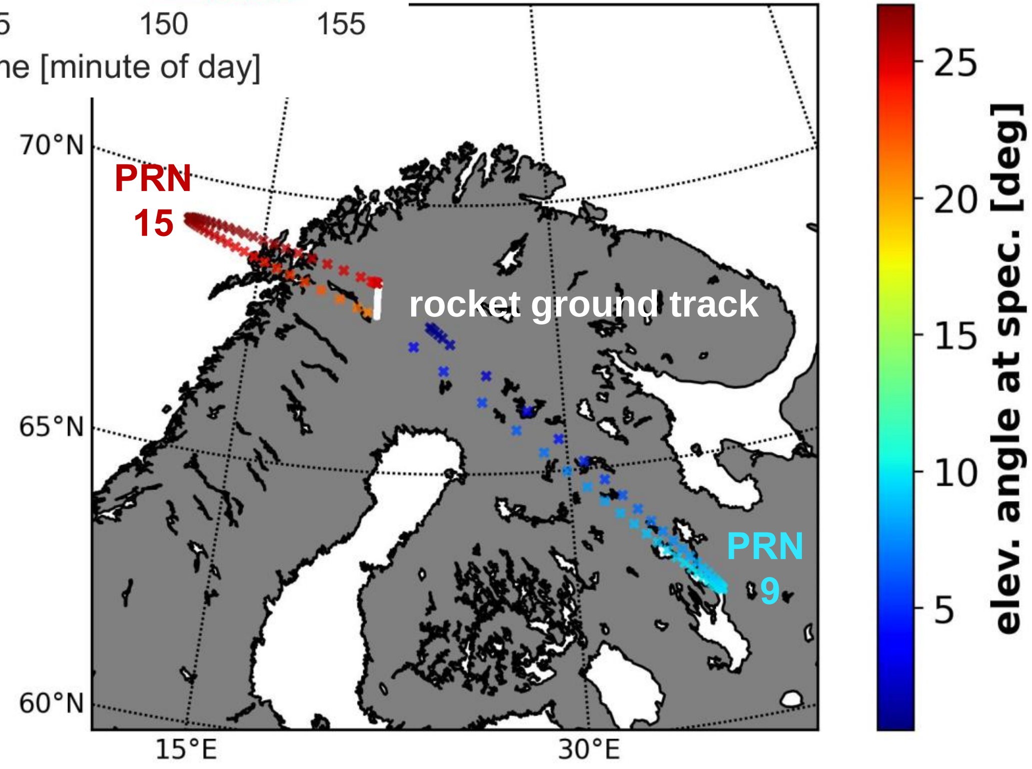
GNSS setup components

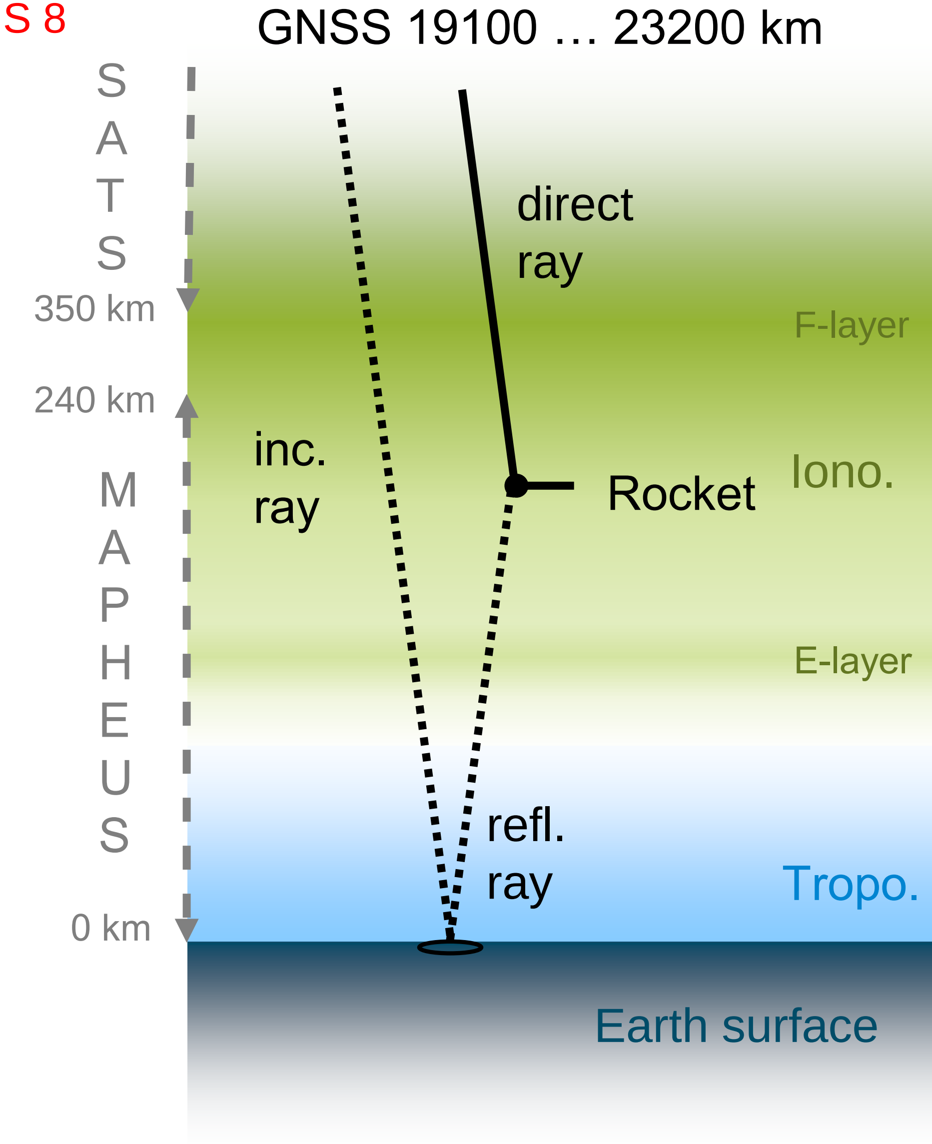
GNSS remote sensing simulation



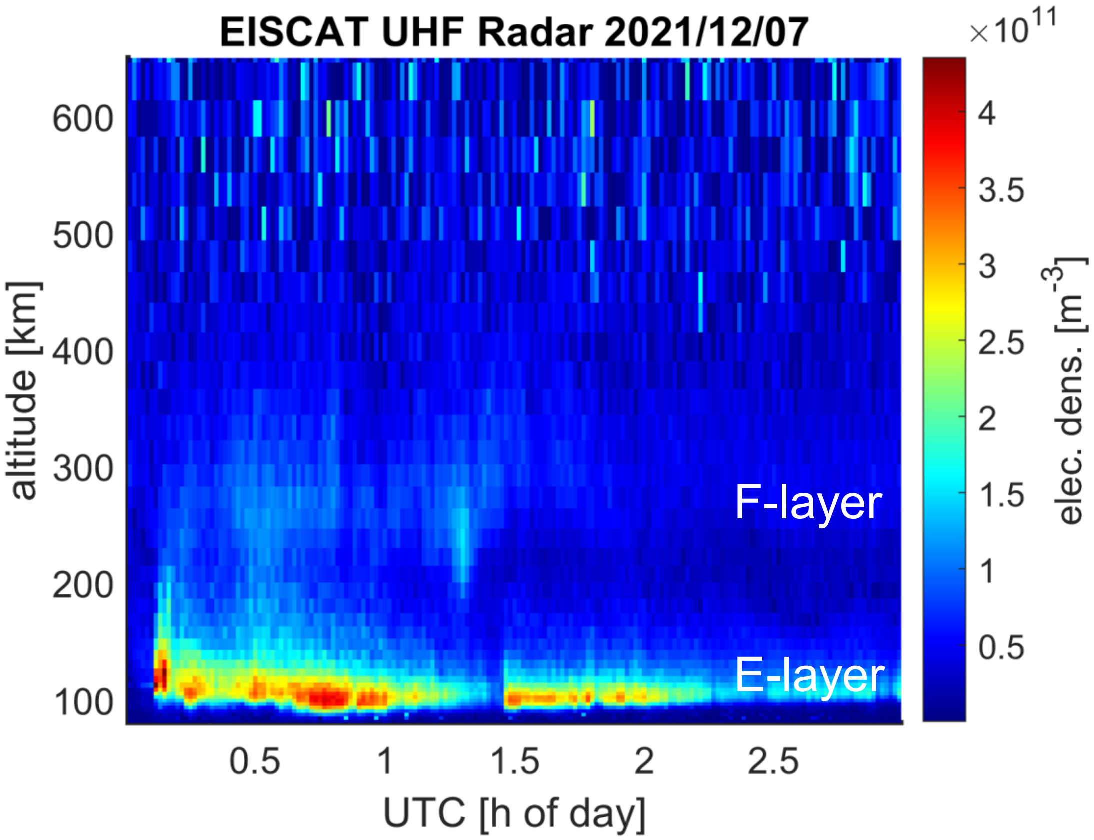
Previous flight data of MAPHEUS 8
Jun 13th, 2019
Starting point to simulate GNSS remote sensing obervations from a rocket

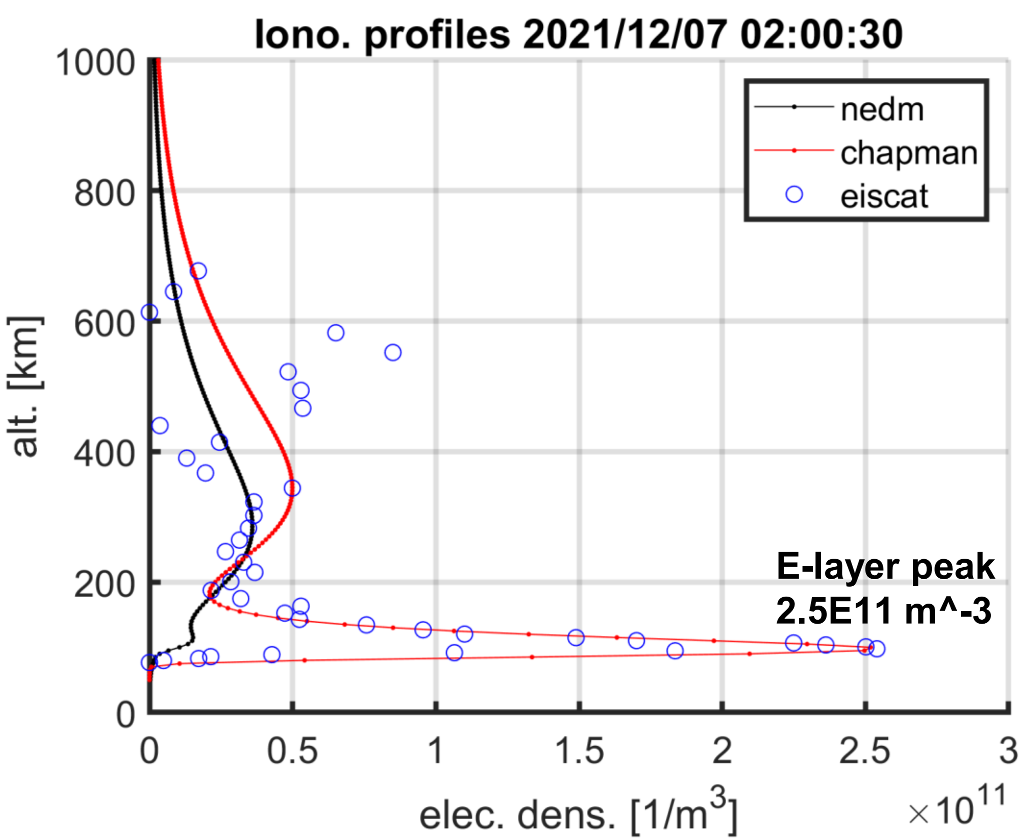
Specular reflection ground tracks of a **mid elevation** and a **grazing elevation** event.





Ionospheric test scenario

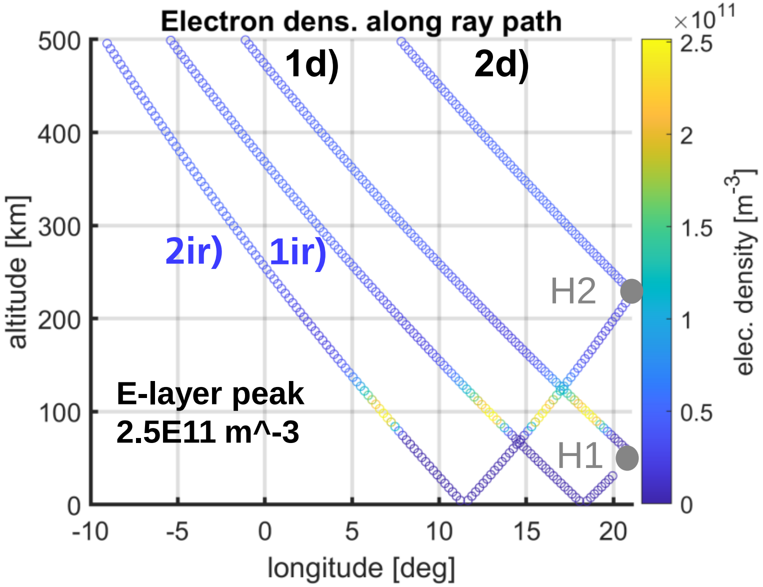




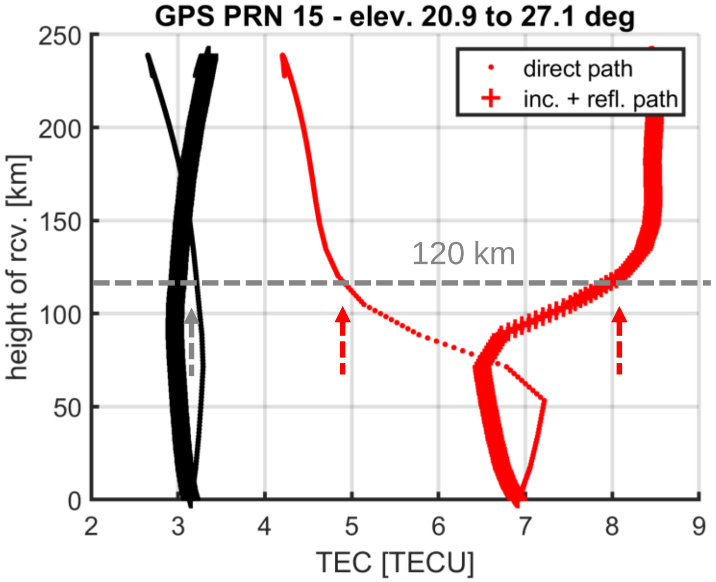
- 3h of elec. density data from EISCAT (European Incoherent Scatter) radar site near Tromsø, Norway
- **Polar night** period with **E-layer dominated ionosphere**

- **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**

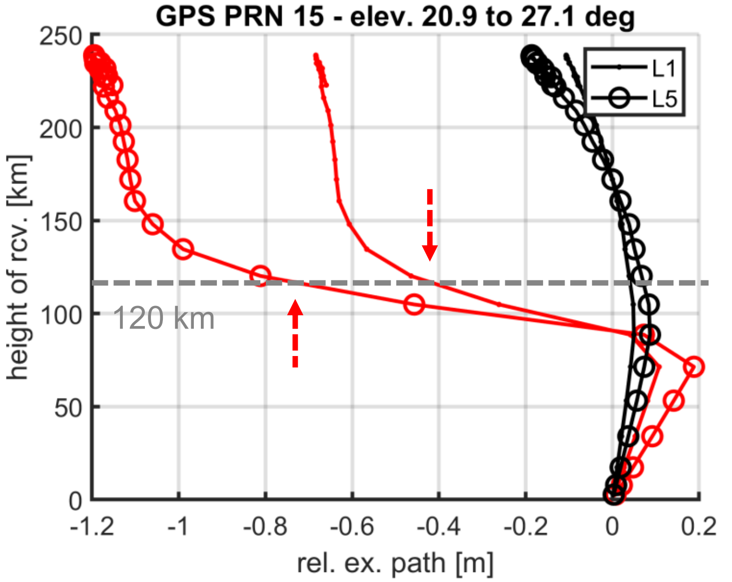
Results for mid elevation event



- 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)

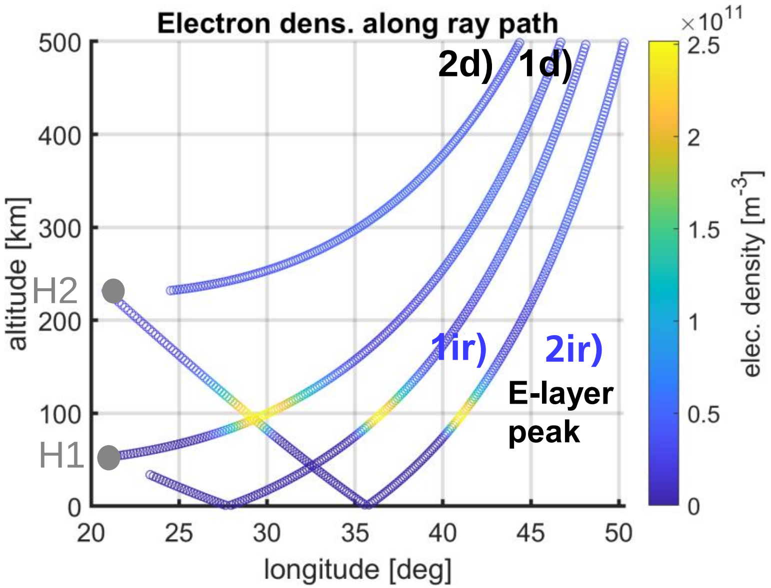


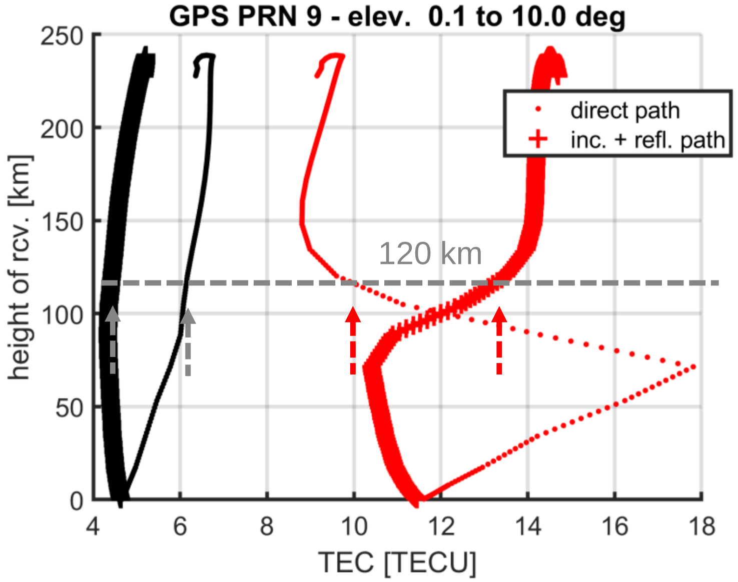
- Comparison of TEC along direct and incident-reflected paths dependent on height of receiver (rocket)
- NEDM scenario (black), E-layer-domin. scenario (red)
- TEC at 120km (above E-layer) differs significantly between scenarios:
  ~ 5 TECU on ir path
  ~ 2 TECU on d path

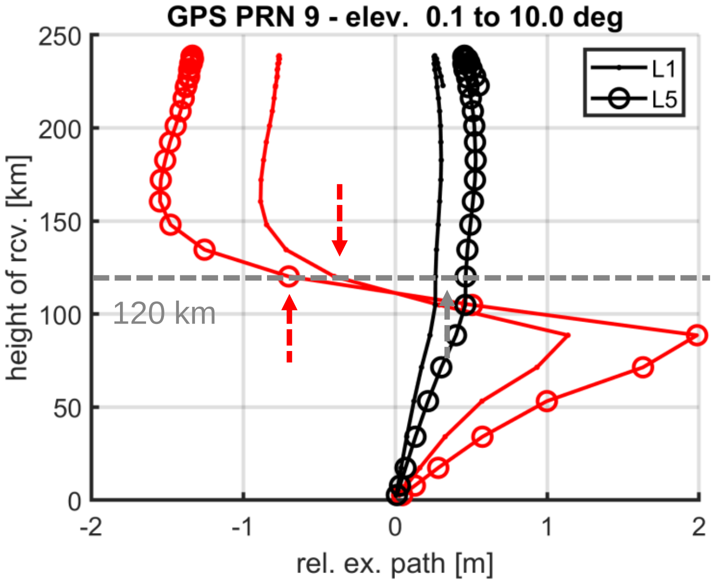


- Comparison of relative ionosphere excess path (between ir and d path)
- NEDM scenario (black) and E-layer domin. scenario (red) for L1 and L5
- ex. path at 120km (above E-layer) differs in dm range between scenarios:
  ~ 4 dm for L1
  ~ 8 dm for L5

Results for grazing elevation event







- 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

Summary & Conclusion

Conclusion

- **GNSS** signals offer opportunities **for atmospheric remote sensing** incl. **GNSS-R**
- **Coherent reflection** tracks often occur over **smooth surface** (e.g. sea ice)
- **Altimetry** or **atmosphere dominated** satellite obs., **elev. angle** plays major role
- Can we **detect E-layer** dominated ionosphere **with GNSS-R** ?
- Rocket experiment is currently prepared to answer
- **Delay** resolution in **dm range** (2-4 TECU) is required …

Acknowledgements

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(RESIliente TEchnologien für den Katastrophenschutz).

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Thank you for your attention

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