Excess Path Model for Space-based GNSS Reflectometry: Preparing for the PRETTY satellite mission

M. Semmling (1), M. Moreno (1), M. Hoque (1),
F. Zus (2), J. Wickert (2,3)

(1) German Aerospace Center DLR-SO, Neustrelitz, Germany
(2) German Research Centre for Geosciences GFZ, Potsdam, Germany
(3) Technische Universität Berlin, Germany

Photo: GEOHALO mission, over Mediterranean Sea

Outline

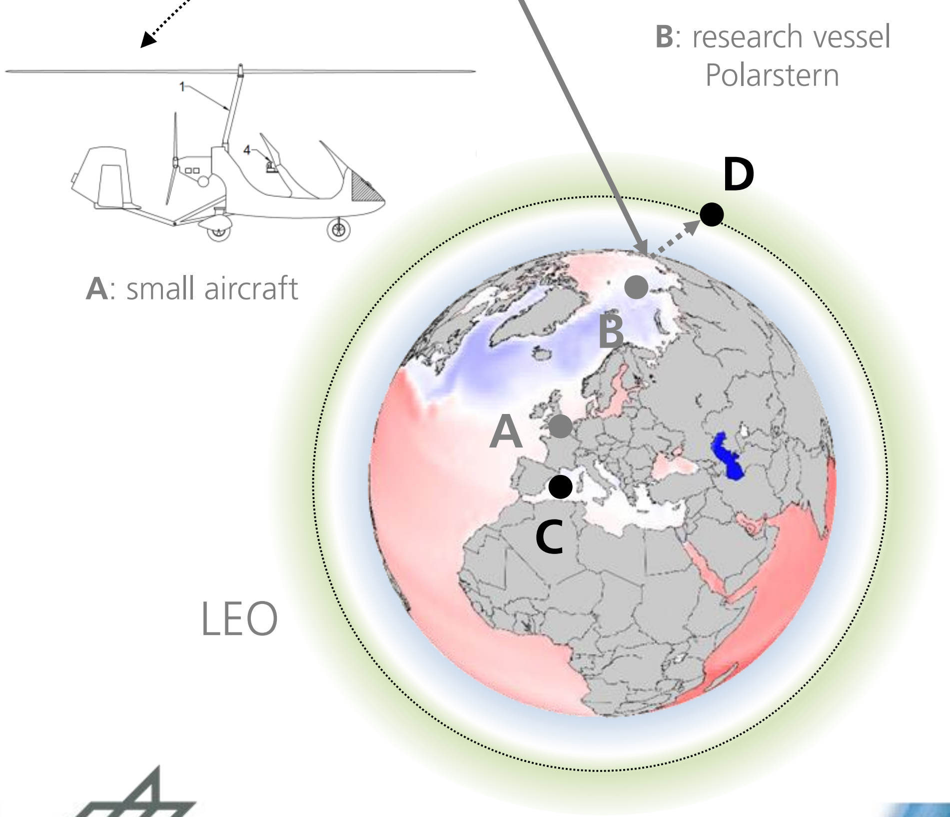
- Motivation for Coherent Reflectometry
- Model of Atmospheric Excess Path
- Neutral Atmosphere Results
- Ionosphere Results
- Outlook & Conclusions

DLR GFZ Helmholtz Centre Potsdam TU berlin

Motivation for Coherent Reflectometry

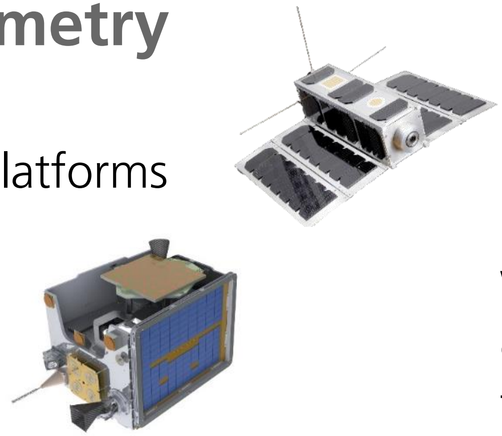
Scenarios of Coherent Reflectometry

Receiver platforms

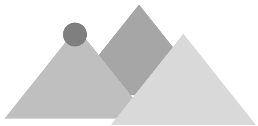


A: small aircraft

B: research vessel Polarstern



D: small satellites

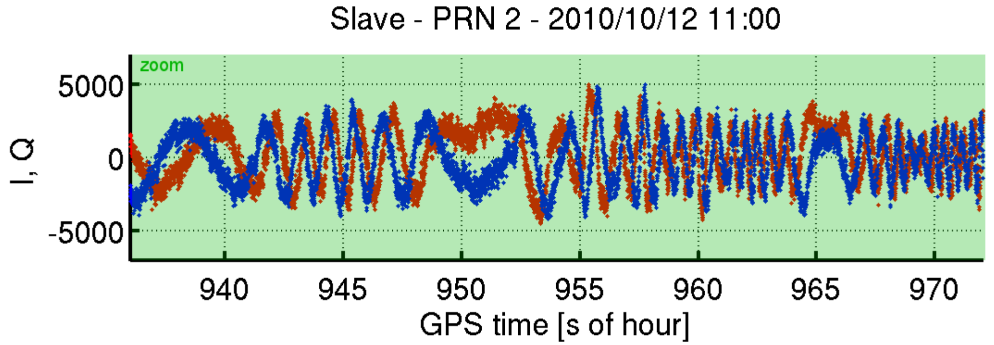


C: mountain station

A: small aircraft,	h ~ 700 m
B: research vessel,	h ~ 20 m
C: mountain station,	h ~ 1430 m
D: small satellite,	h ~ 650 km

Coherent Reflectometry:

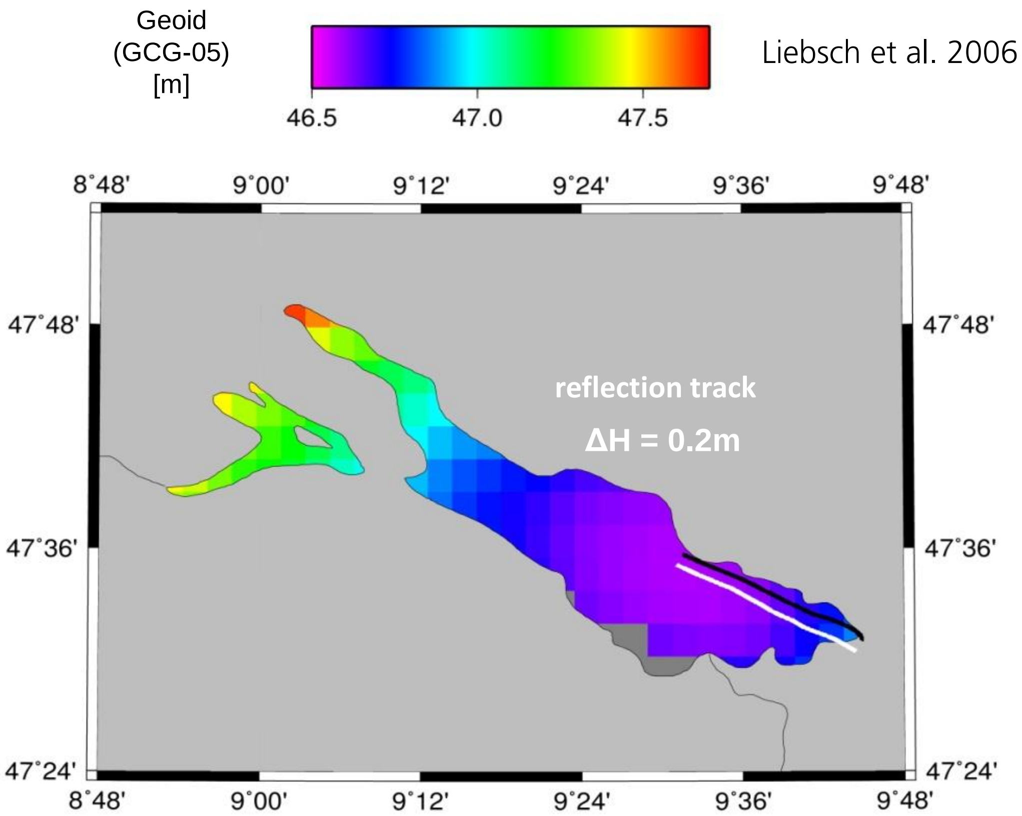
We have samples of the reflected signal that contain phase information over a reasonable time scale …



Coherent reflection event over lake Constance, airborne record (Zeppelin NT airship)

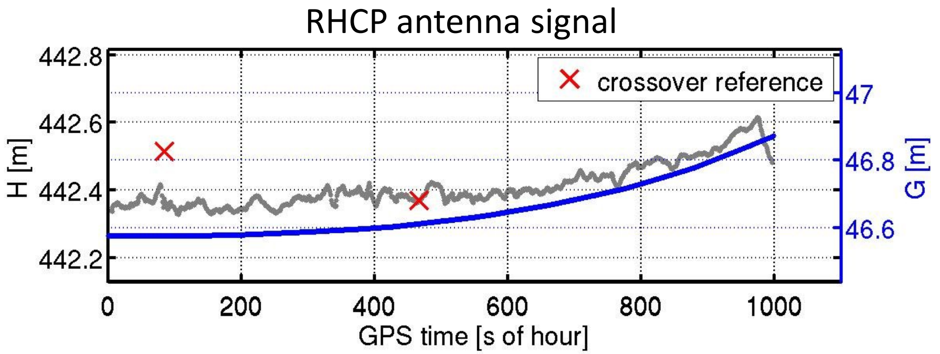
Semmling et al. 2013

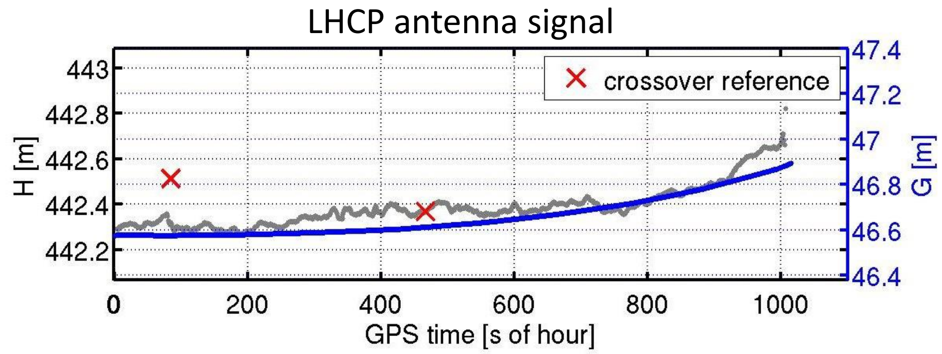
Altimetric Features from Reflectometry



Liebsch et al. 2006

Coherent phase obs. allow to retrieve water level variation e.g. geoid undulations with cm-precision.





	mean bias	precision
H to G (RHCP)	7 cm	3 cm
H to G (LHCP)	5 cm	4 cm

Semmling et al. 2013, 2014

Dependent on Impact Factors

Sea Surface

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

Semmling et al. 2022

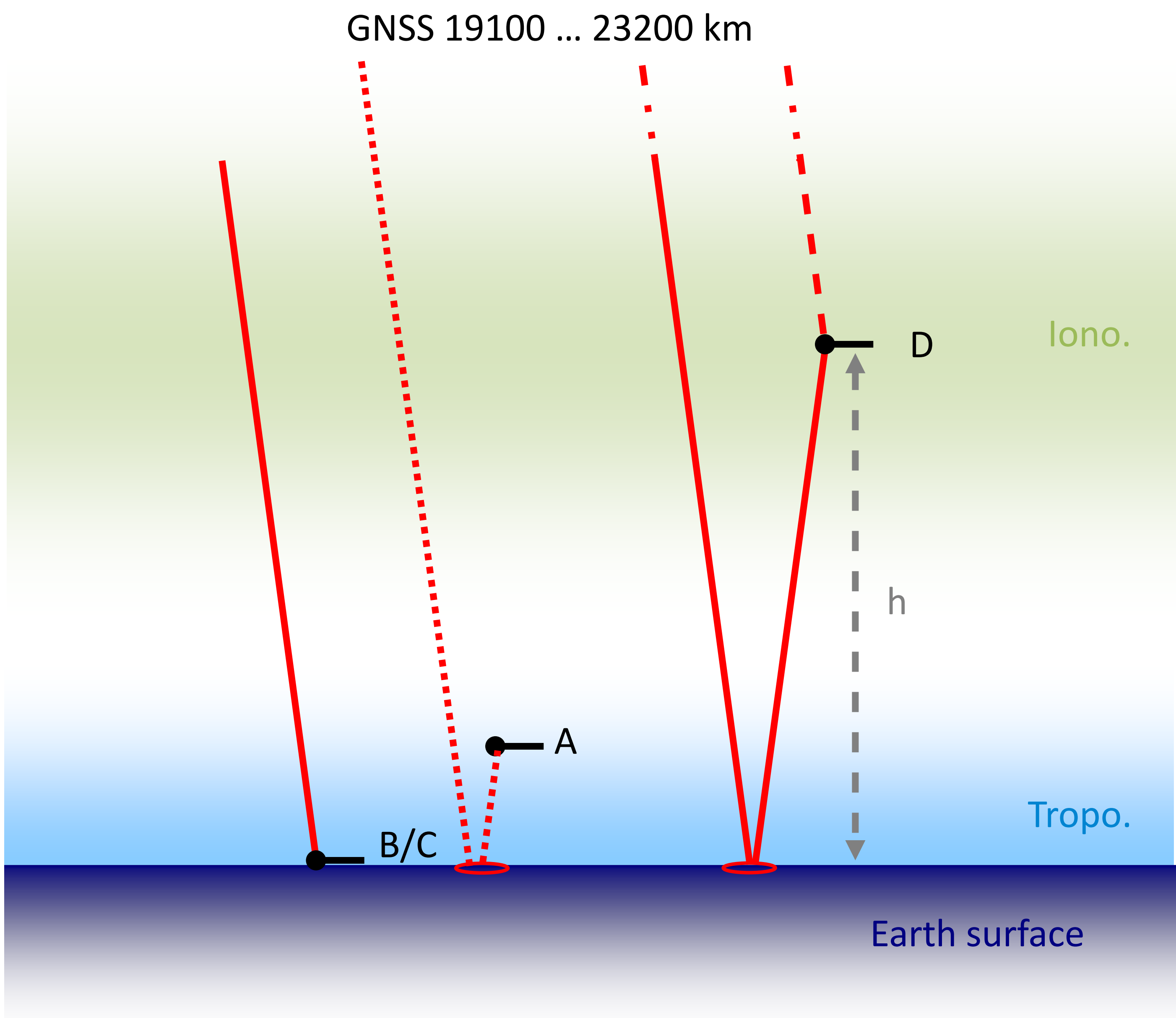
Atmosphere

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

Receiver & Transmitter

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

coherence effect



A: small aircraft
B: research vessel
C: mountain station
D: small satellite

Model for Atmospheric Excess Path

Scales of Atmospheric Impact

Direct ray
Incident ray
Reflected ray

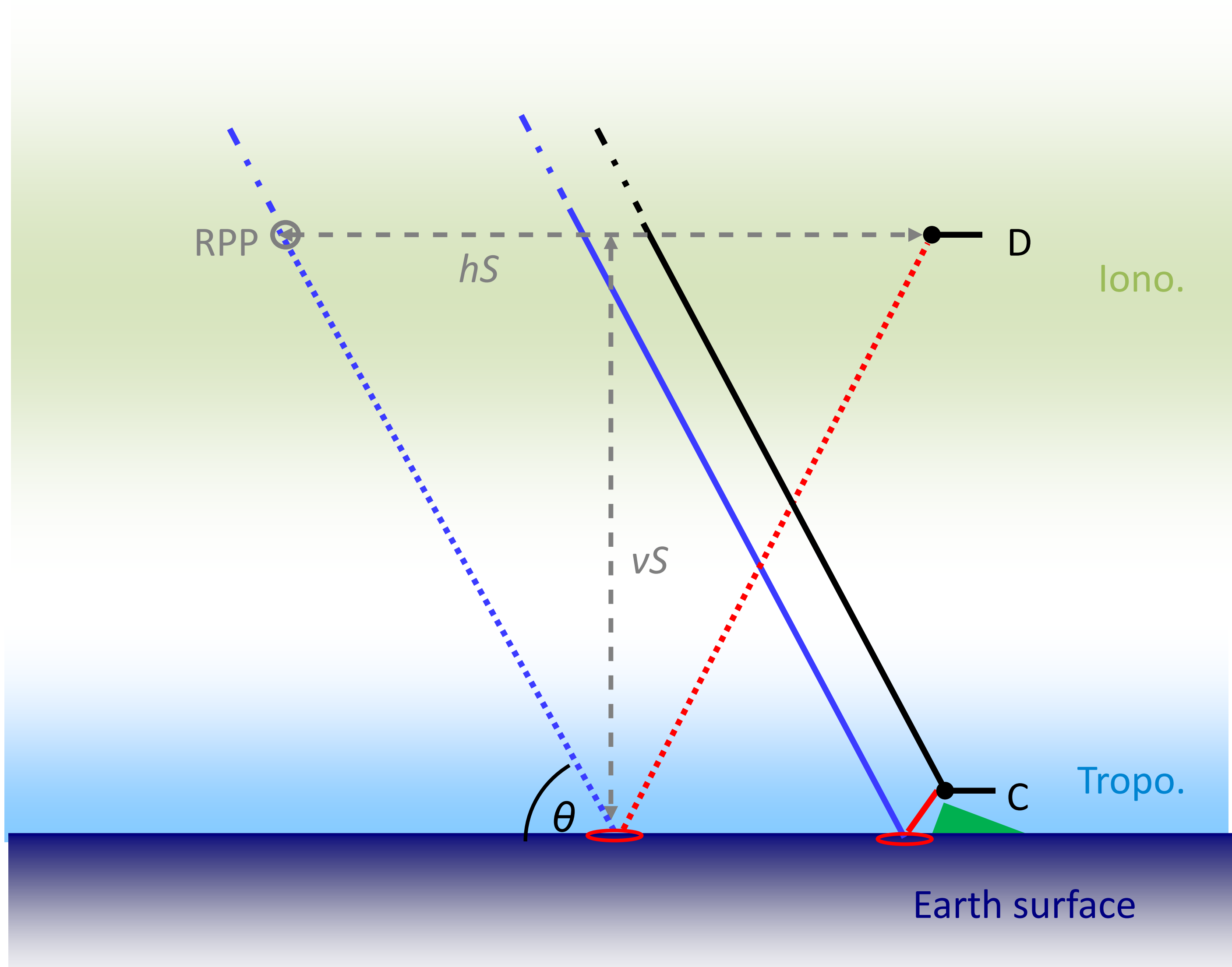
Elevation angle θ
Receiver-level Piercing Point RPP

Vertical Scale *vS*
(excess-atmo-penetration)

Horizontal Scale *hS*
(inter-ray-distance)

C: *vS* ~ 1430 m, *hS* elev. depend.
D: *vS* ~ 640 km, *hS* elev. depend.

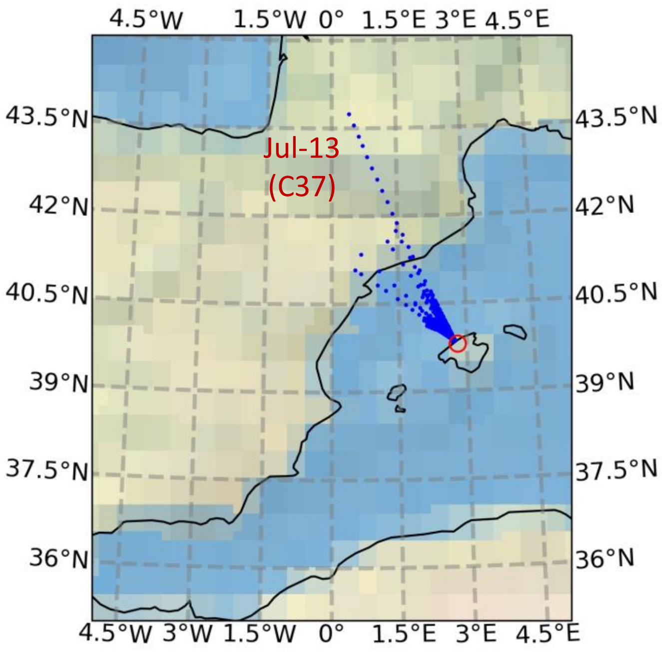
GNSS 19100 … 23200 km



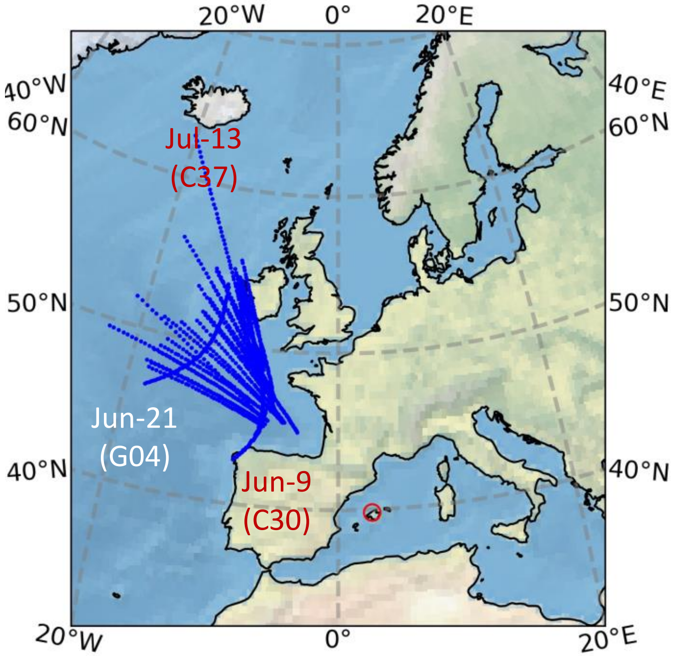
C: Puig Major, h ~ 1430 m
D: PRETTY and TDS-1 h ~ 640 km

Mountain Station Scenario

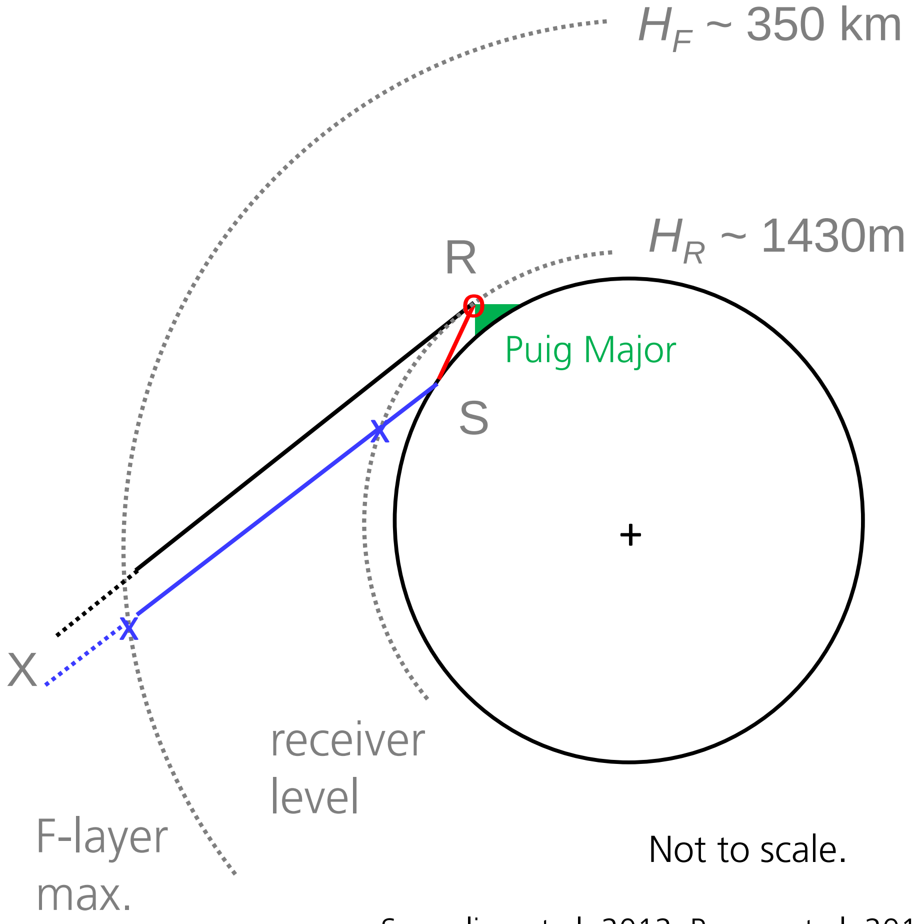
Receiver-level Piercing Point



F-layer Piercing Point



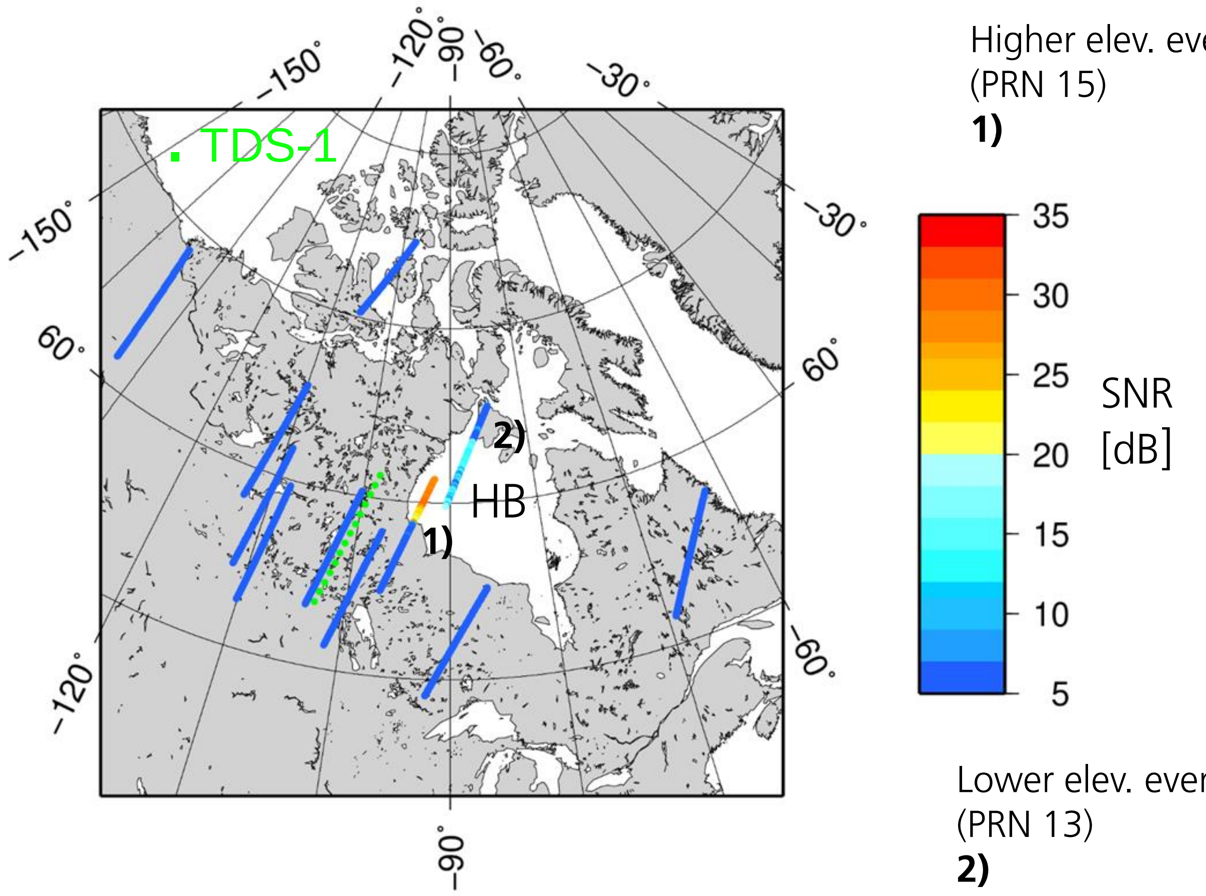
Even in mountain scenario at **grazing angle** geometry receiver-level piercing point (in troposphere) and F-layer piercing point (in ionosphere) extend over **great distances**.



Semmling et al. 2012, Peraza et al. 2017

Small Satellite Scenario

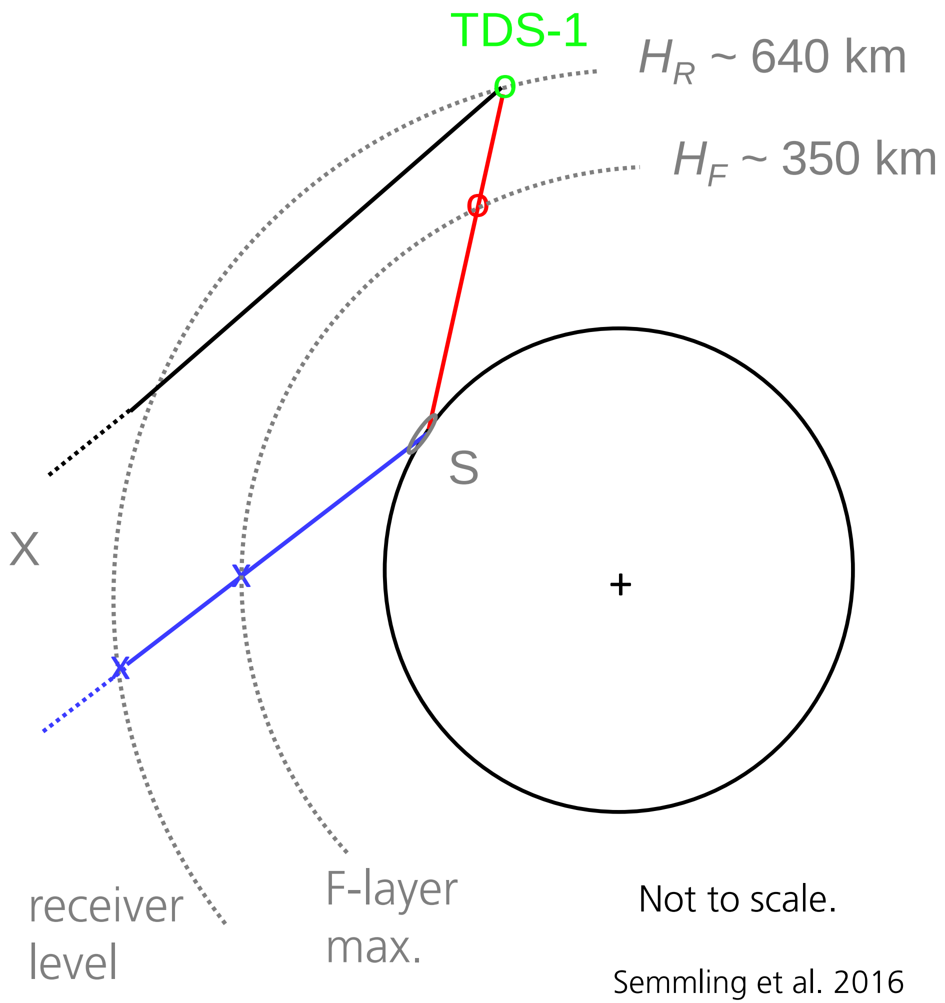
Specular Reflection points



Higher elev. event
(PRN 15)
1)

Lower elev. event
(PRN 13)
2)

Two events over Hudson Bay (HB) with rather high SNR selected for analysis.



Semmling et al. 2016

DLR

Model Input Data for Neutral Gas and Ionosphere

ERA5 model

- global, obs.-driven
- horizontal grid (res.: 30km)
- vertical levels (res.: 10m … ~6km)
- temporal scale (res.: 1h)
- provider ECMWF*
- Meteorological parameter of interest:

  air pressure *p*
  air temperature *T*
  specific humidity *q*

* European Centre of Medium-range Weather Forecast

Hersbach et al. 2020

NEDM model

- global, empirical climatology
- continuous in time and space
- smallest features 2.5° (TEC map based)
- temporal scale (down to semidiurnal)
- provider DLR-SO**
- Ionosphere parameter of interest:

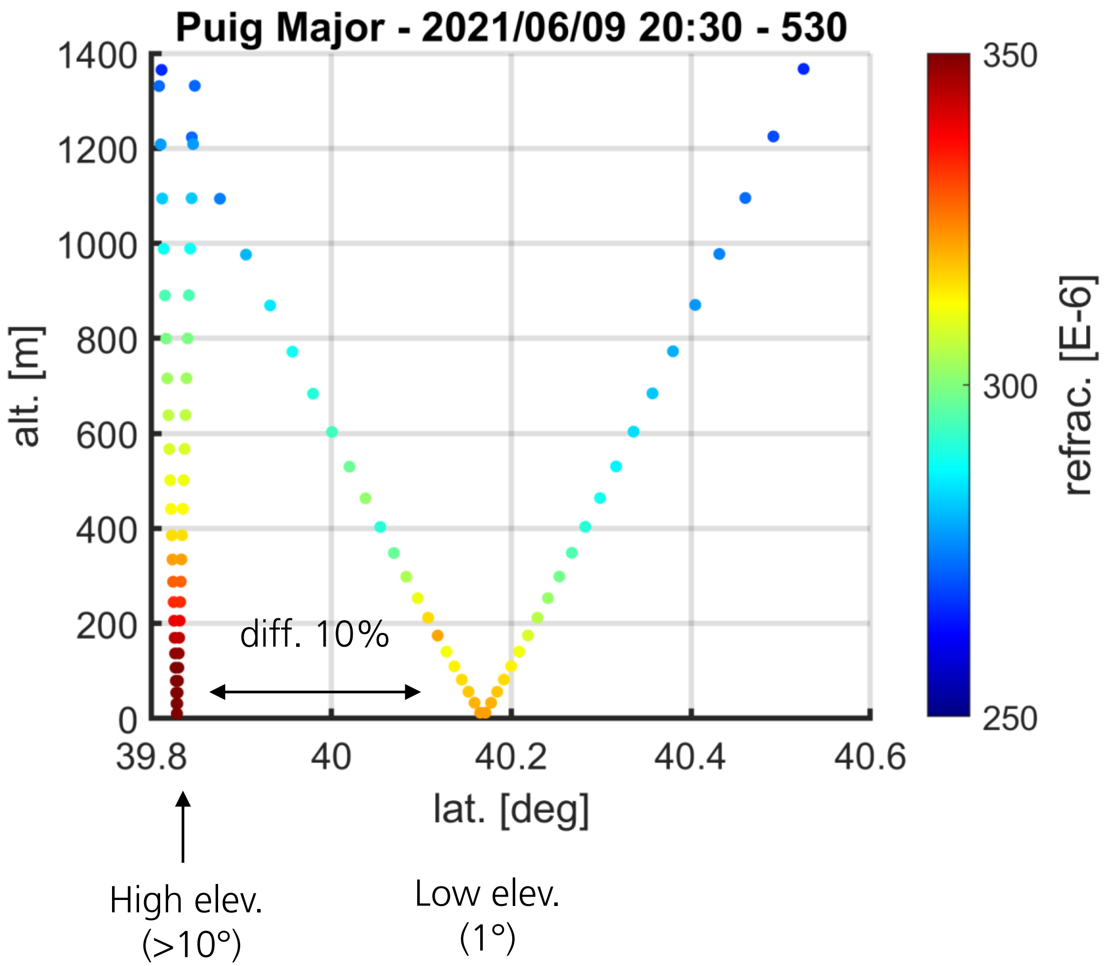
  electron density *ne*

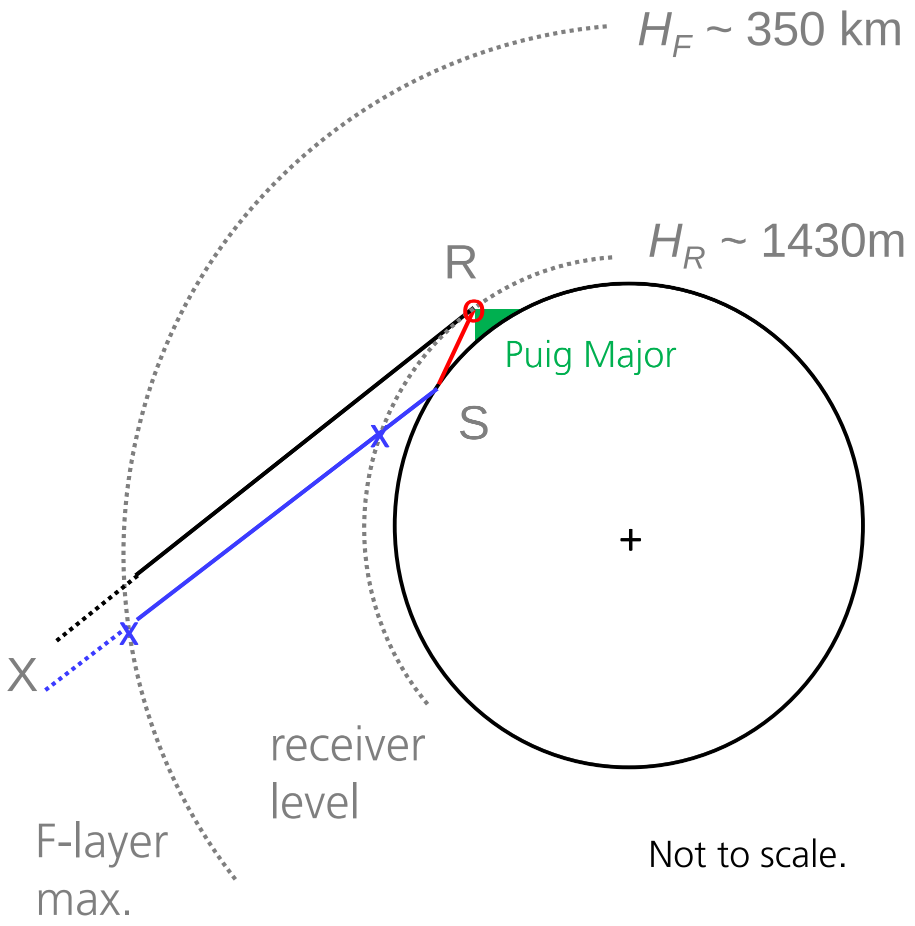
** German Aerospace Center, Institute for Solar-Terrestrial Physics

Jakowski & Hoque 2018

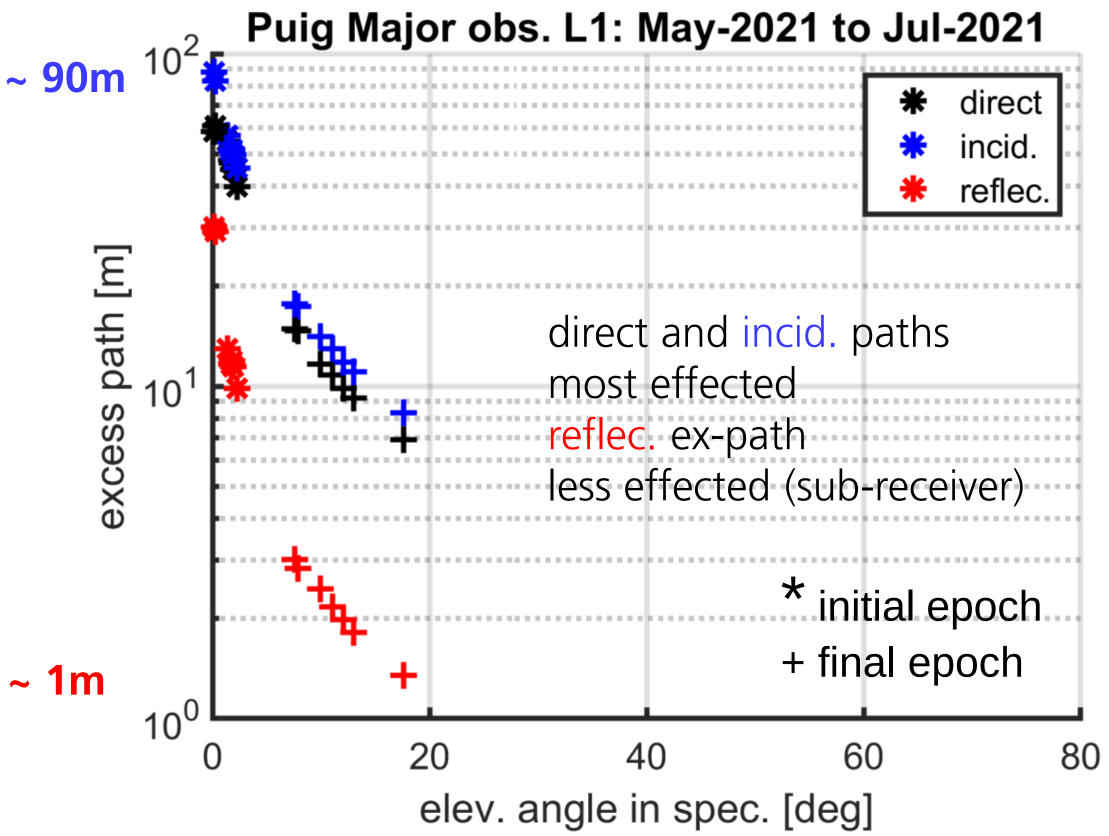
Neutral Atmosphere Results

Variation of Refractivity in Montain Station Scenario

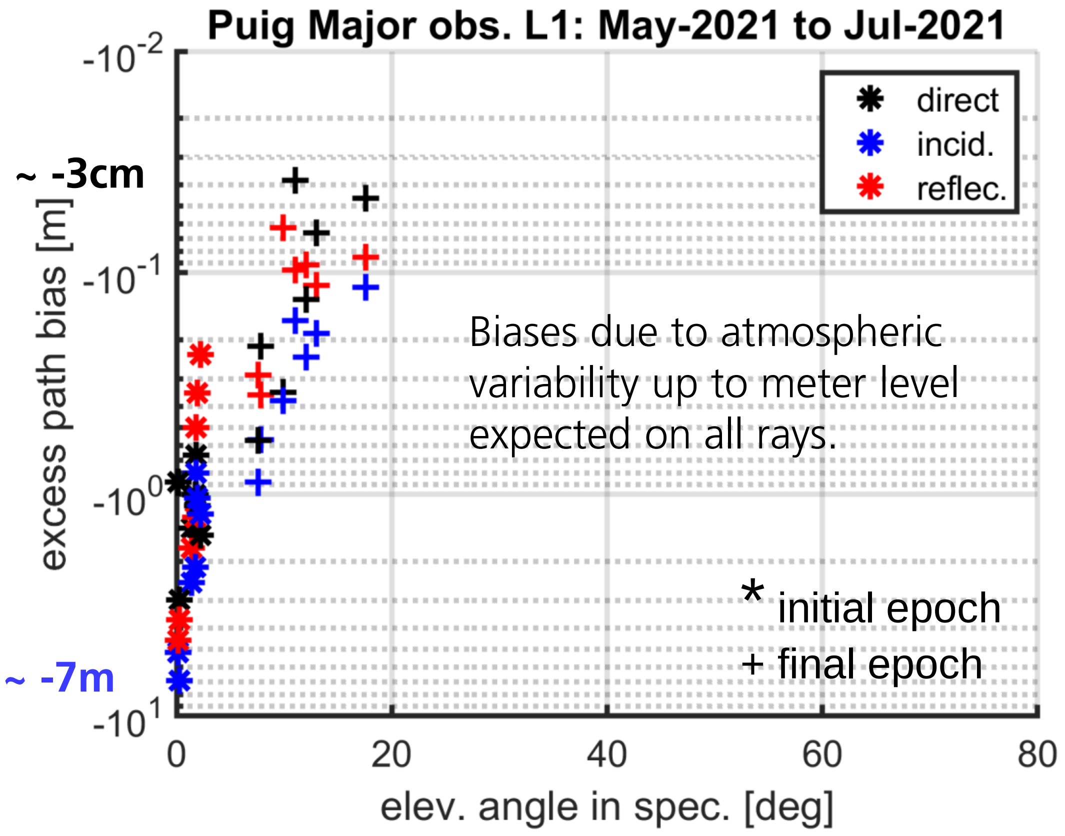




Excess Path Results



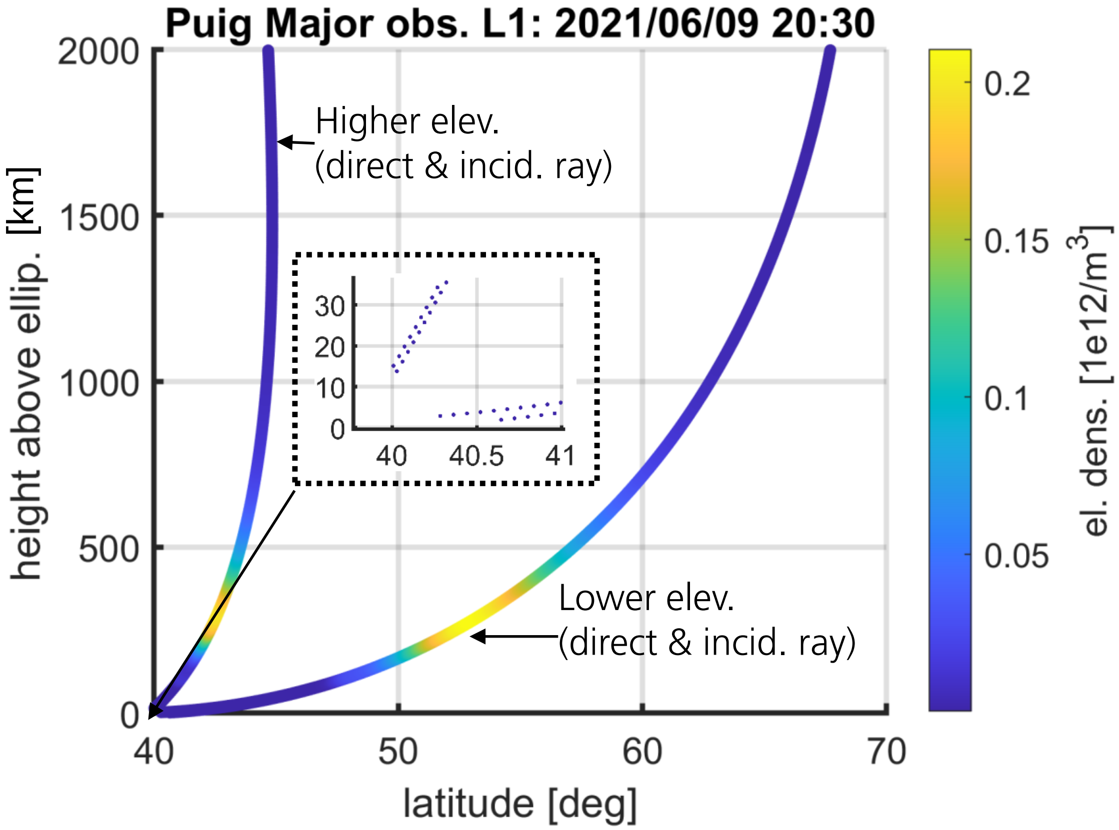
Refractivity integrated over geom. slant path (ray bending disregarded)

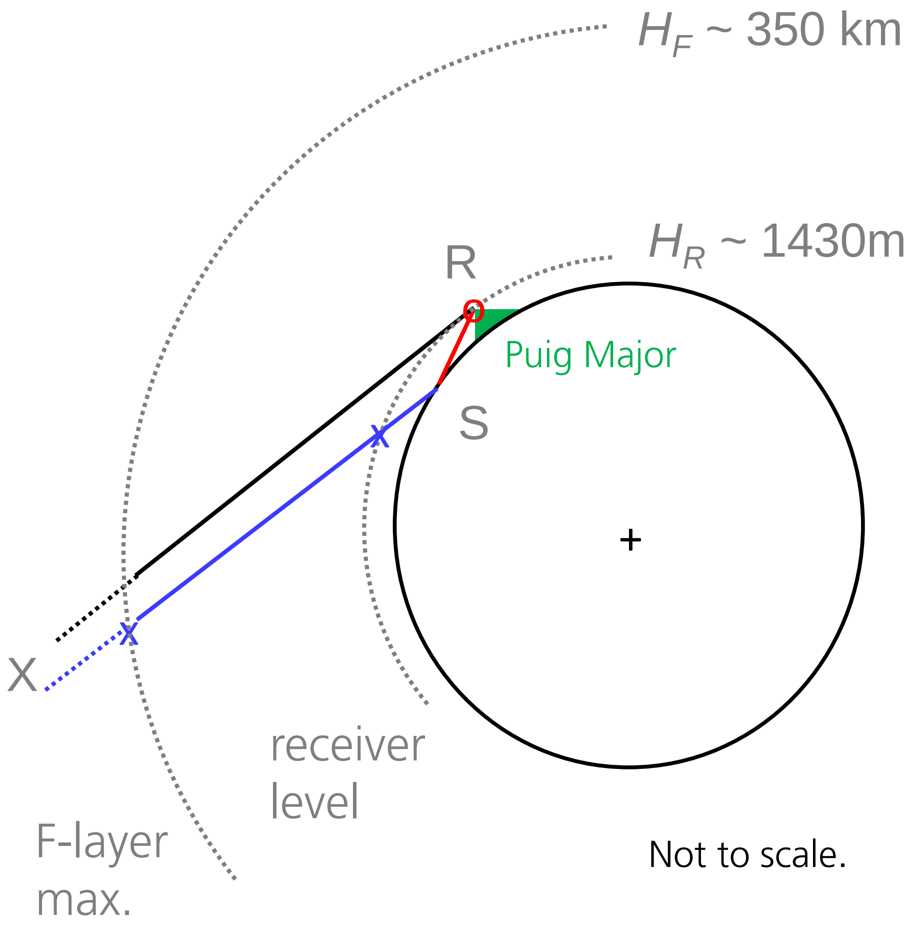


Difference between excess path from ERA-5 and international standard atmosphere

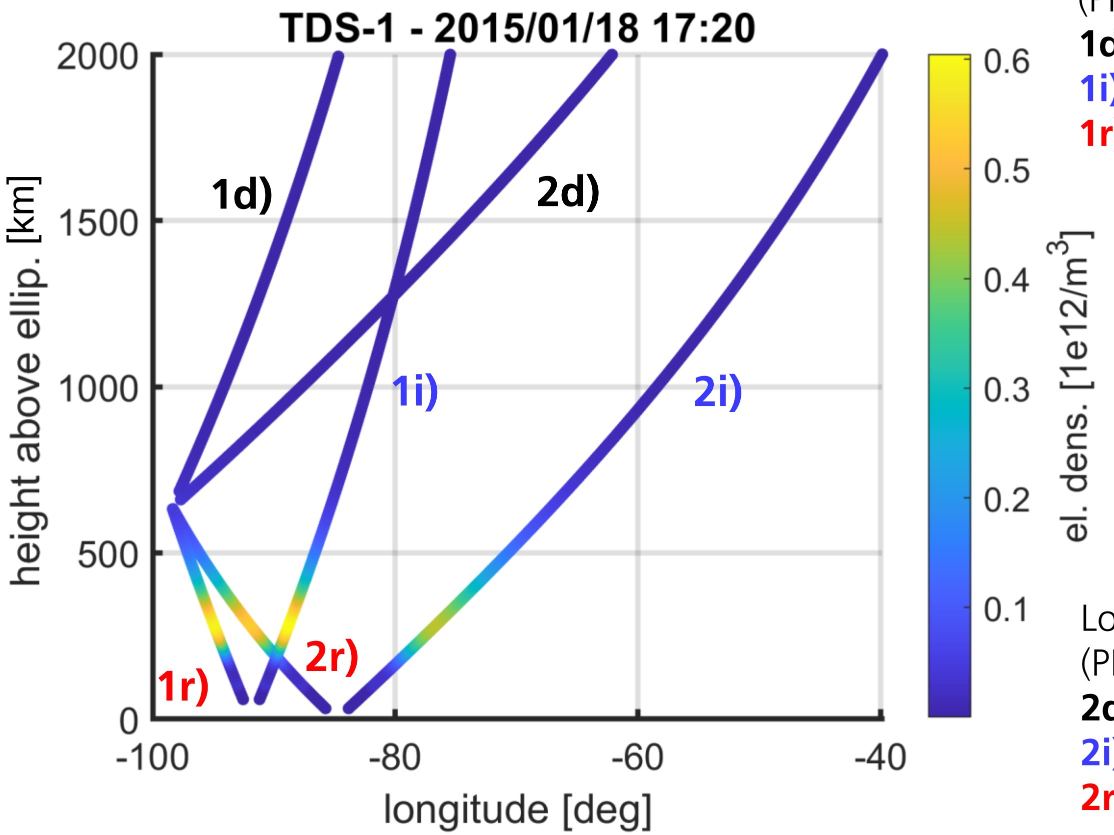
Ionosphere Results

Variation of Electron Density in Mountain Scenario



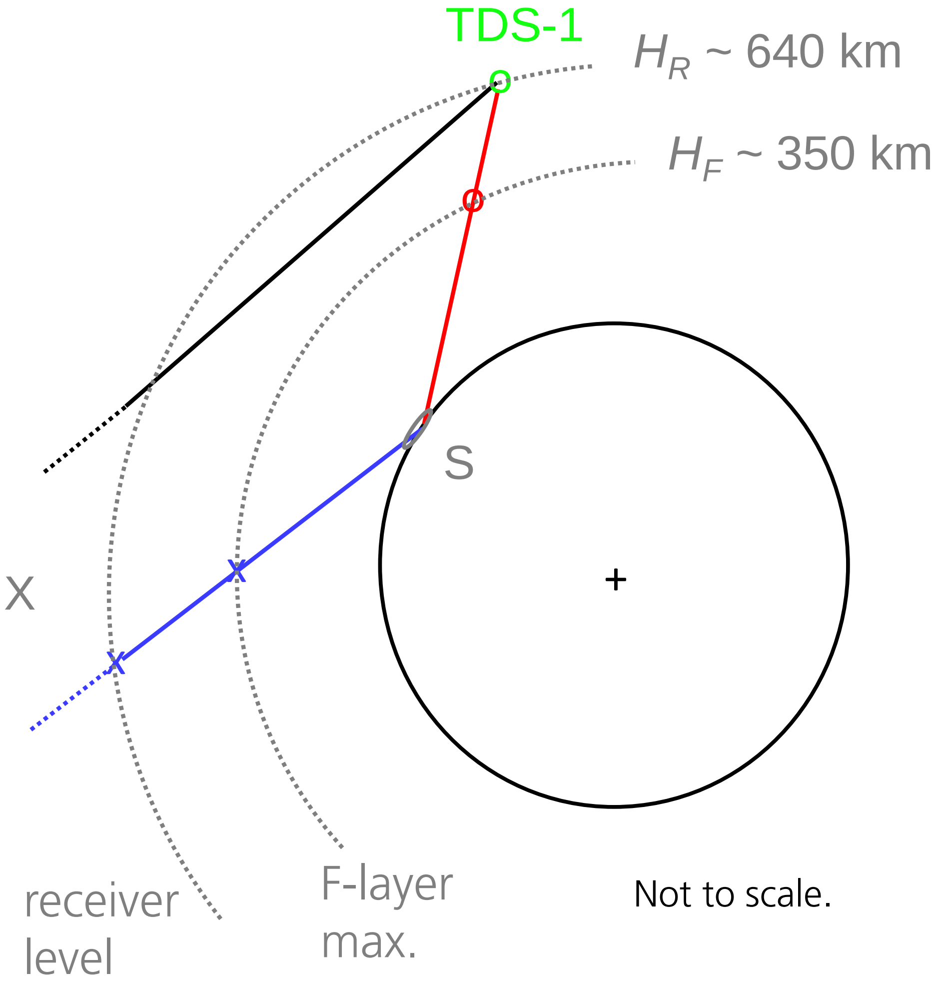


Variation of Electron Density in LEO Satellite Scenario

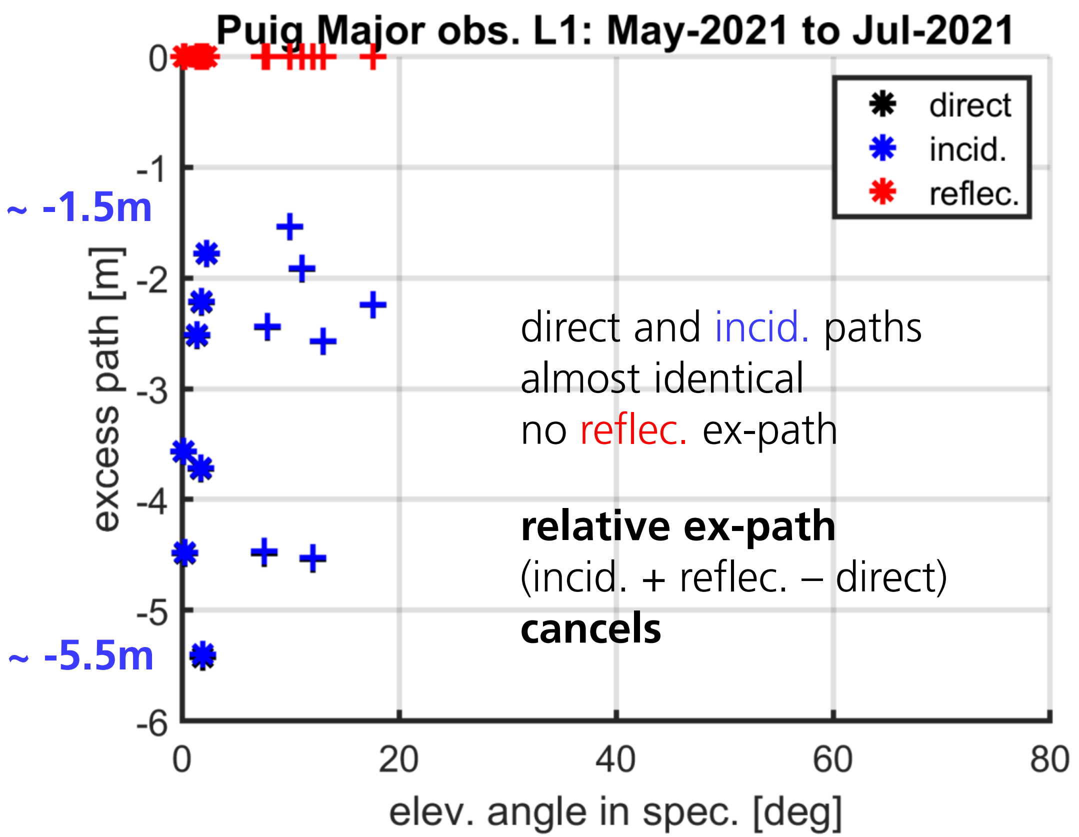


Higher elev. event (PRN 15)
1d) direct ray
1i) incident ray
1r) reflected ray

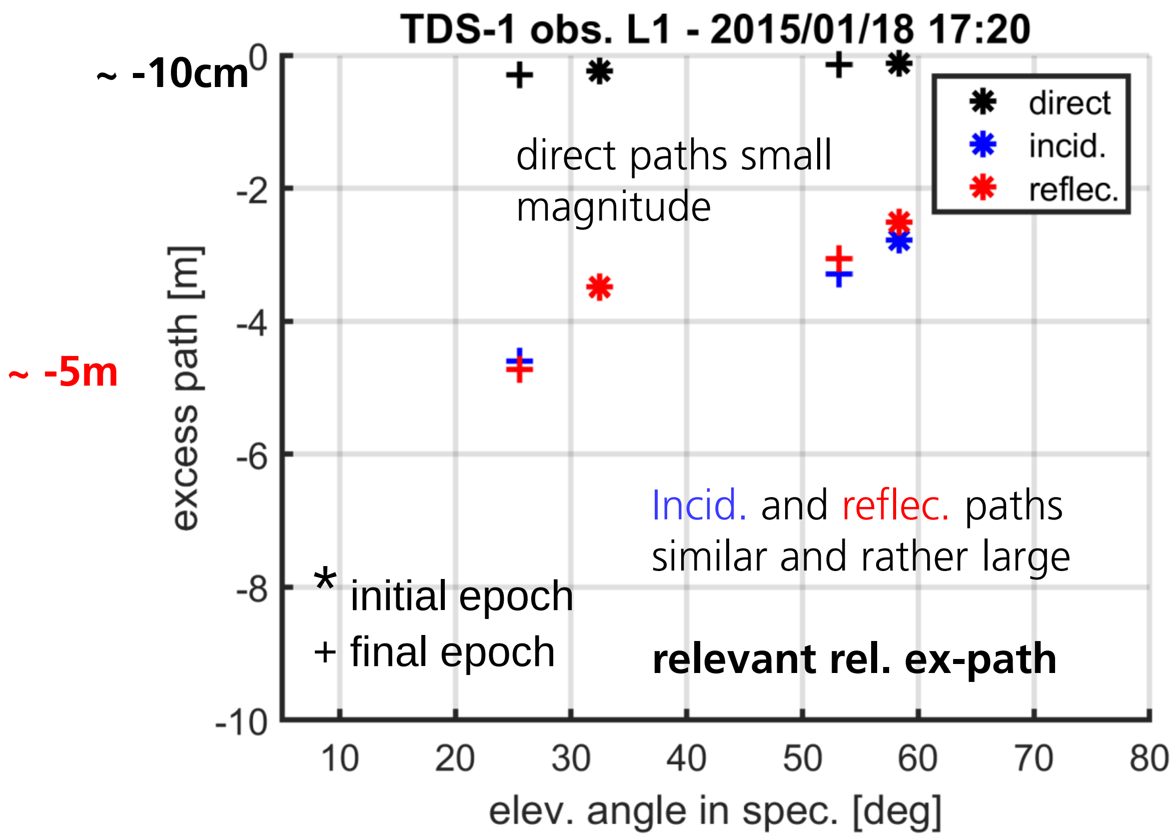
Lower elev. event (PRN 13)
2d) direct ray
2i) incident ray
2r) reflected ray



Excess Path Results both Scenarios



Refractivity integrated over geom. slant path (ray bending disregarded) – 7 events over 3 months



Refractivity integrated over geom. slant path (ray bending disregarded) – 2 events at same time

Outlook & Conclusions

Conclusions

Motivation

- exploit coherent reflectometry for altimetry and atmospheric sounding
- modelling of excess paths for reflectometry on upcoming satellite missions

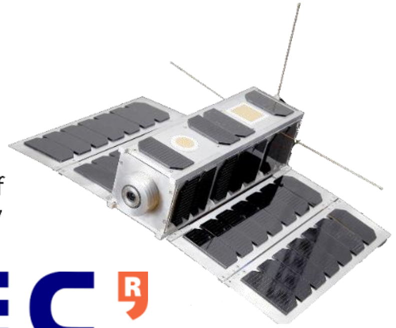
Excess Path Results

- lower troposphere variability impact on decimetre level
- relative ionosphere path cancels ground-based scenario
- it adds meter-scale contributions in satellite scenarios

Outlook: Atmospheric Parameter Retrieval

- define observation types for potential retrievals (TEC, ZTD)
- first achievements using airborne data (ZTD estimates)
  next talk: Mario Moreno

NTNU
Norwegian University of Science and Technology



IEEC

esa
European Space Agency

Thank you for your Attention.

DLR

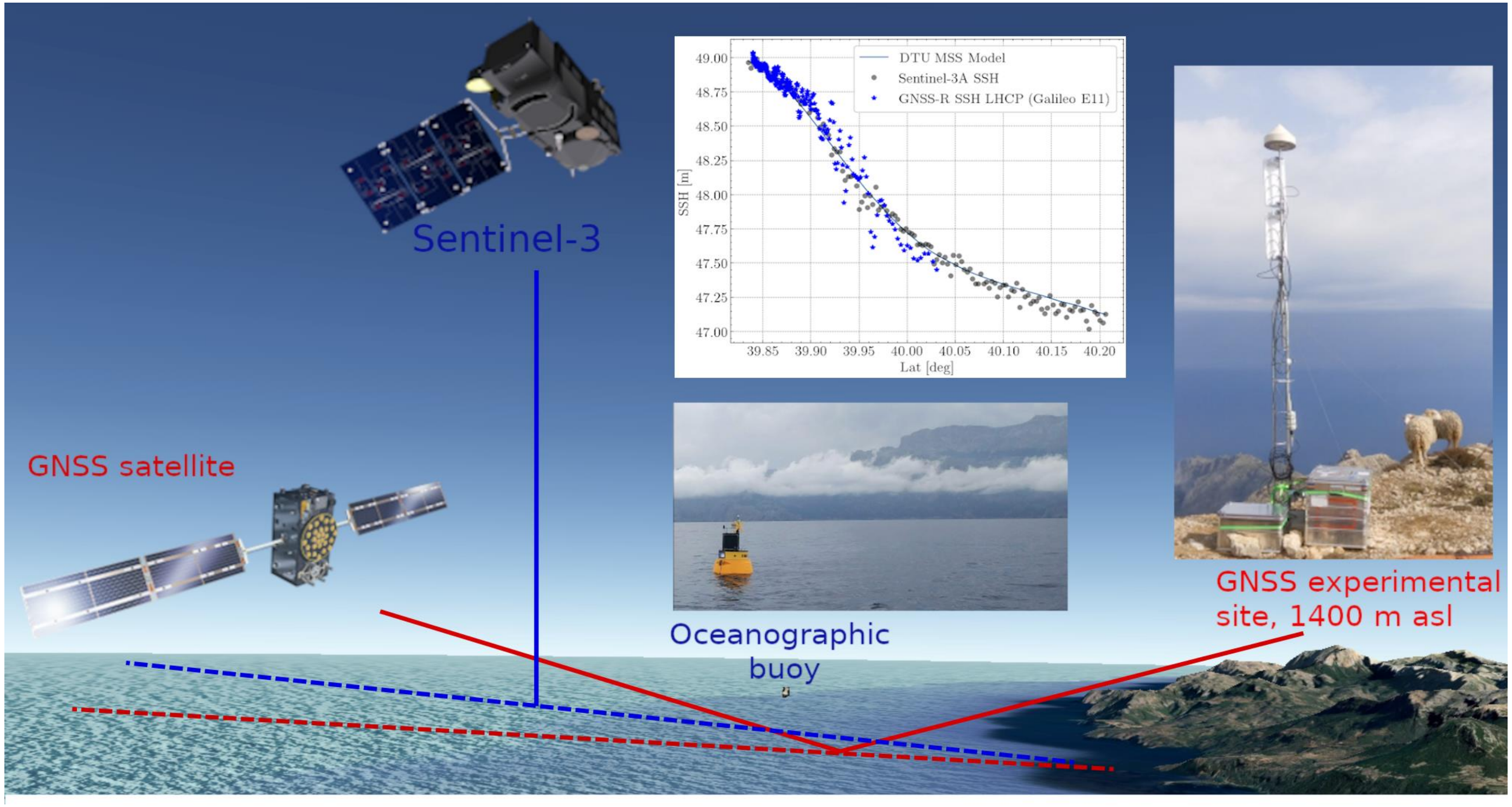
GFZ
Helmholtz Centre
Potsdam

TU berlin

References

- Liebsch et al. 2006: Quasigeoidbestimmung für Deutschland.
  DVW-Schriftenreihe
- Helm et al. 2007: GORS - A GNSS Occultation, Reflectometry and Scatterometry Space Receiver.
  ION GNSS
- Semmling et al. 2012: On the Retrieval of the Specular Reflection in GNSS Carrier Observations for Ocean Altimetry
  Radio Science
- Semmling et al. 2013: A zeppelin experiment to study airborne altimetry using specular Global Navigation Satellite System reflections.
  Radio Science
- Semmling et al. 2014: Airborne GNSS reflectometry using crossover reference points for carrier phase altimetry.
  in Proc. IEEE IGARSS
- Semmling et al. 2016: A Phase-Altimetric Simulator: Studying the Sensitivity of Earth-Reflected GNSS Signals to Ocean Topography.
  IEEE Trans. Geosci. Remote Sens.
- Peraza et al. 2017: Analysis of Grazing GNSS Reflections Observed at the Zeppelin Mountain Station, Spitsbergen
  Radio Science
- Jakowski & Hoque 2018: A new electron density model of the plasmasphere for operational applications and services.
  J. *Space Weather Space Clim.*
- ECMWF: ERA-5 reanalysis data, available via https://cds.climate.copernicus.eu
- Hersbach et al. 2020: The ERA5 global reanalysis.
  Q J R Meteorol. Soc.
- Semmling et al. 2022: Sea-ice permittivity derived from GNSS reflection profiles: Results of the MOSAiC expedition.
  IEEE Transaction on Geoscience and Remote Sensing

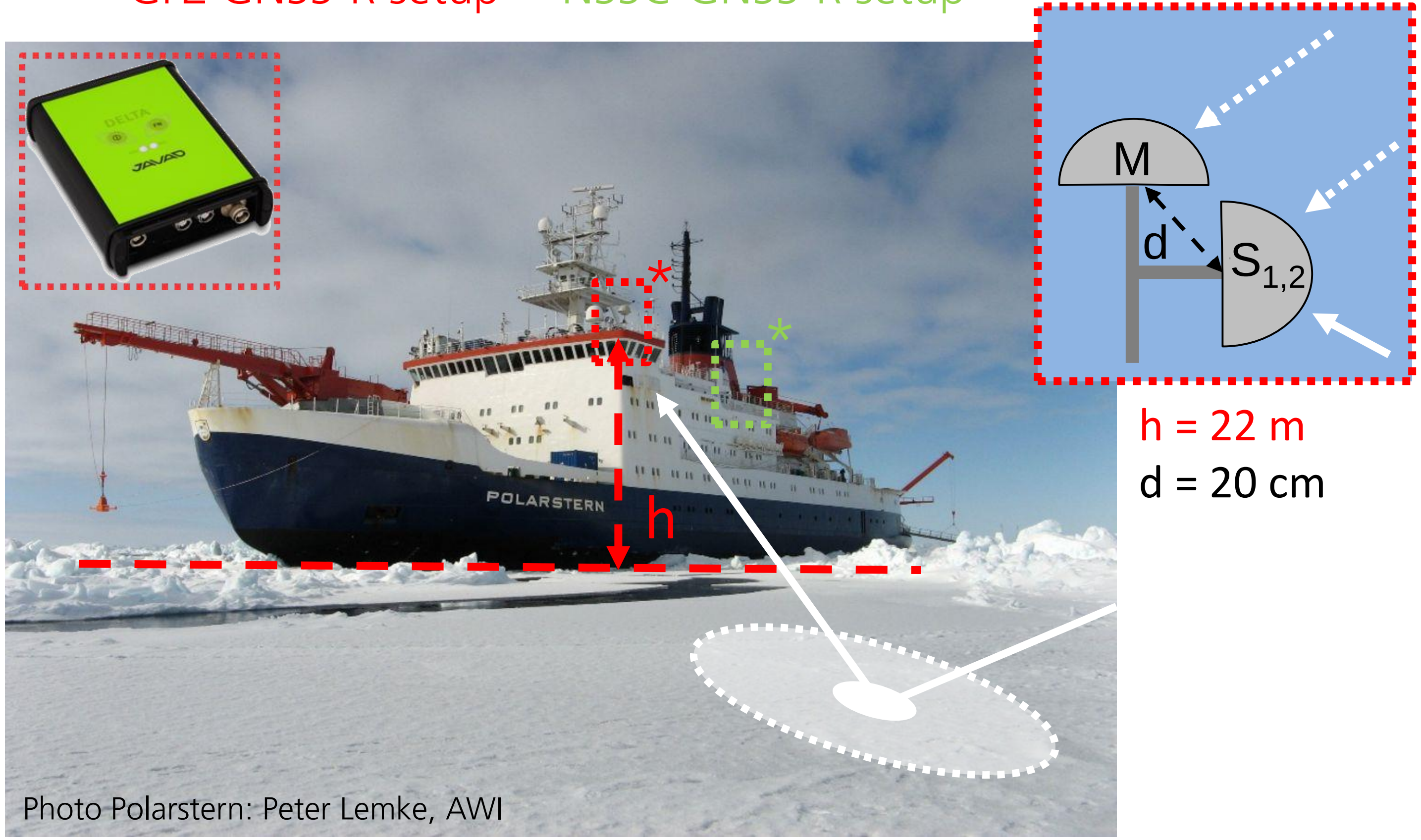
DLR



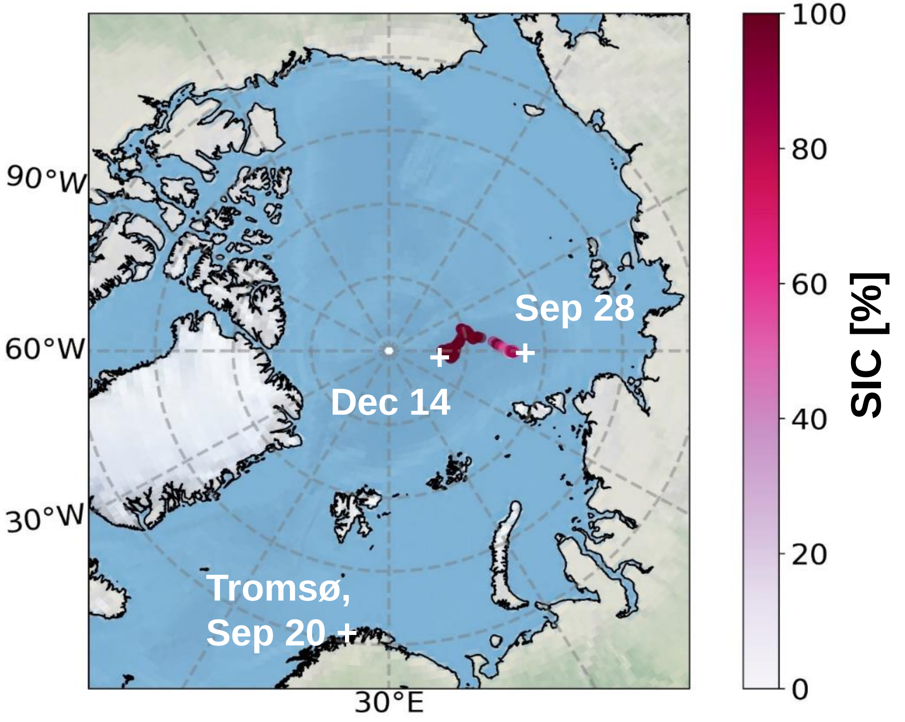
Can GNSS signals reflected off the sea surface at grazing geometry provide precise altimetry measurements?
Under which atmospheric and sea state conditions?

Setup & Measurements

* GFZ GNSS-R setup * NSSC GNSS-R setup



MOSAiC first leg: Sep - Dec 2019



Marginal Ice Zone (MIZ): first three days, low SIC
Central Arctic (CA): last fourteen days, high SIC

Setup cf.: Helm et al. 2007; Semmling et al. 2019

Master link (M): up-looking ant. RHCP
Slave links ($S_{1,2}$): side-looking ant. LHCP, RHCP

Semmling et al. 2021