GRAZING ANGLE GNSS REFLECTOMETRY WITH PRETTY: AN OPPORTUNITY TO RESOLVE THE STRUCTURE OF IONOSPHERIC LAYERS

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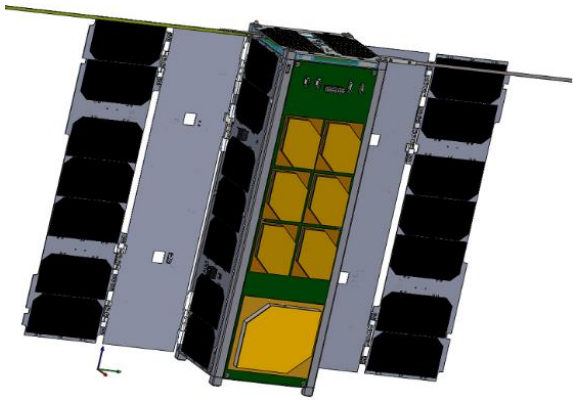


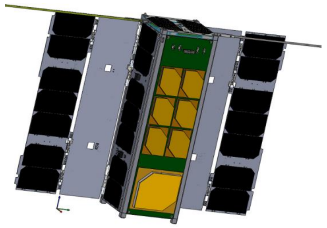
EGU General Assembly, 2025/04/28

Why and how to use GNSS Reflectometry?

Motivation GNSS Remote Sensing

- A: Low Earth Orbiter

  Wickert et al. 2016
  Semmling et al. 2016
  Cardellach et al. 2020
  Moreno et al. 2023



- B: Aircraft

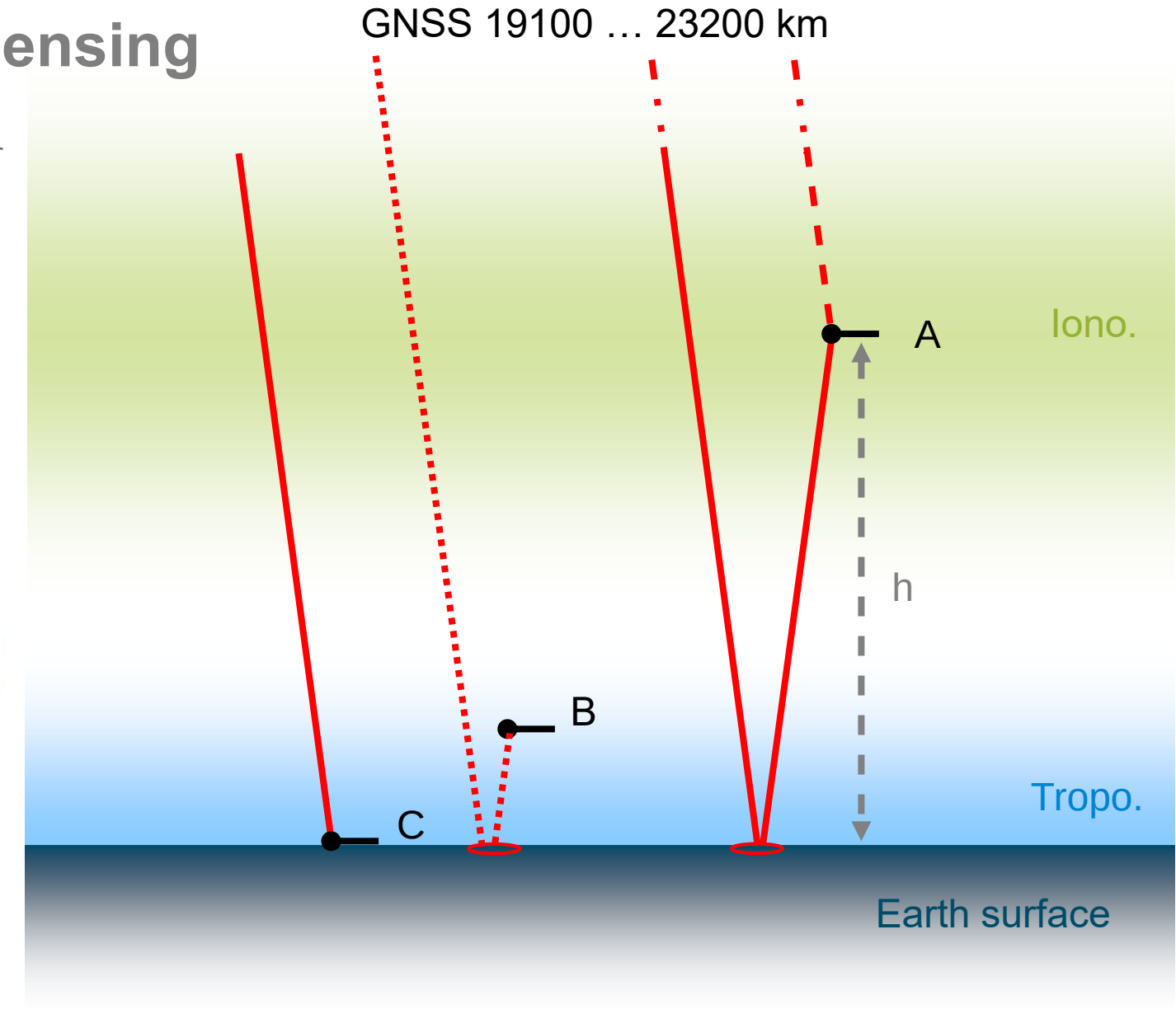
  Semmling et al. 2014
  Moreno et al. 2022

- 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 ~ 560 km
B: e.g. HALO, h ~ 3500 m
C: e.g. Polarstern, h ~ 25 m

More Detailed Model View …

F-layer

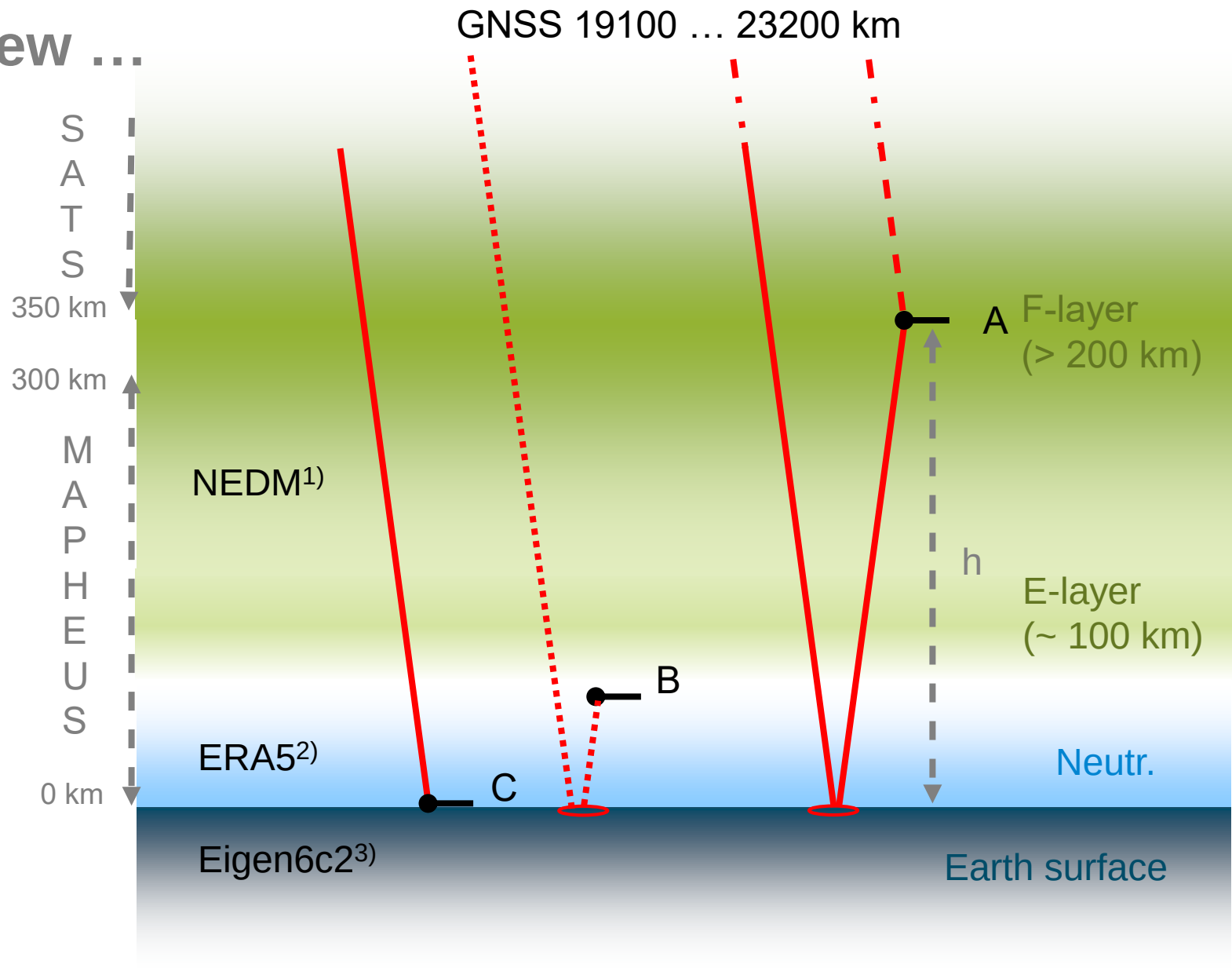
- permanent, usually highest density
- max. elec. density at 250 … 400 km
- regular daily cycle
- dependent on sun incidence

E-layer

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

Required Model Data

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

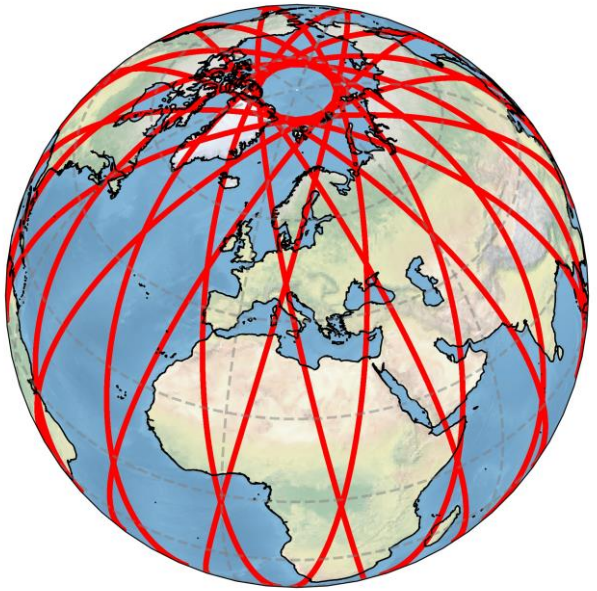


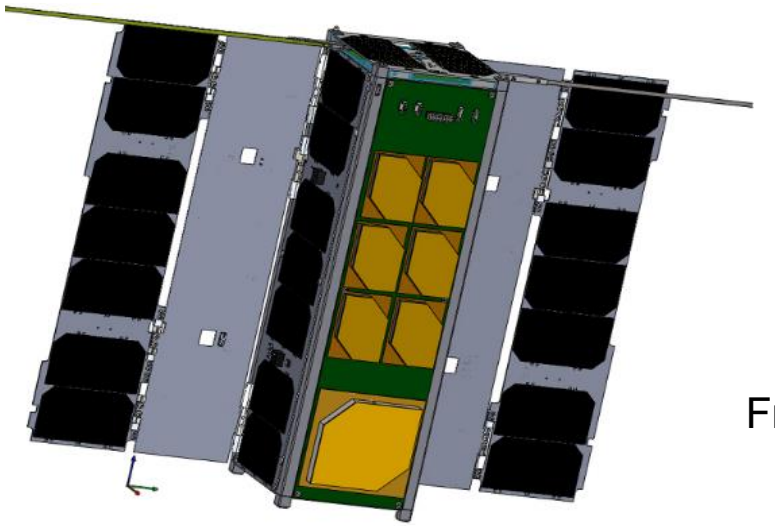
1) Hoque et al. 2022 ; 2) Hersbach et al. 2020 ; 3) Förste et al. 2013

Satellite Mission Parameters

PRETTY (**P**assive **RE**flec**T**ometry and dosime**T**r**Y**)

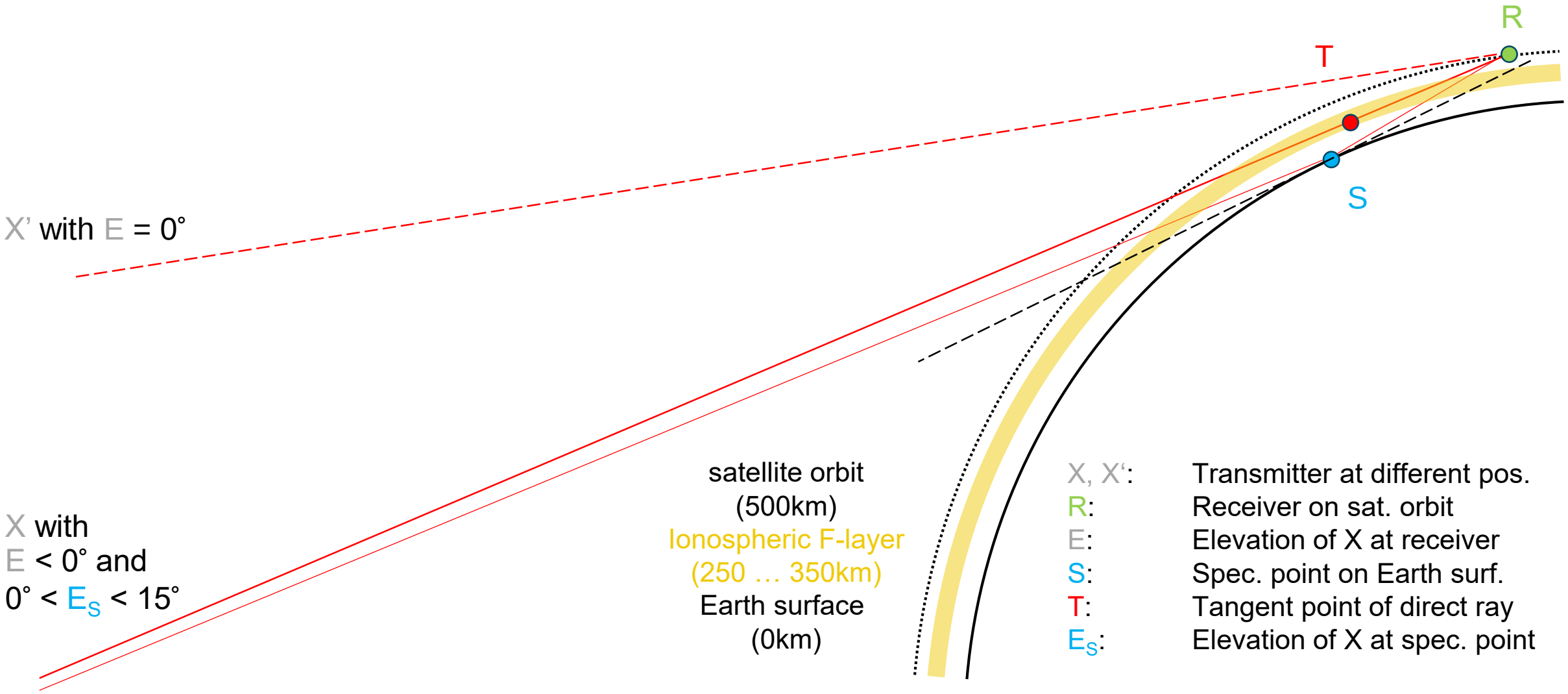
- ESA CubeSat mission, developed by an Austrian consortium led by Beyond Gravity Austria
- Size: 30 x 10 x 10 cm³
- Orbit: polar SSO, altitude 560 km
- GNSS-R antenna: RHCP, limb pointing
- GNSS-R grazing elevations: 0° to 15°
- GNSS-R signal carrier: L5





Fragner et al. 2020

Ray Geometry at Grazing Angles



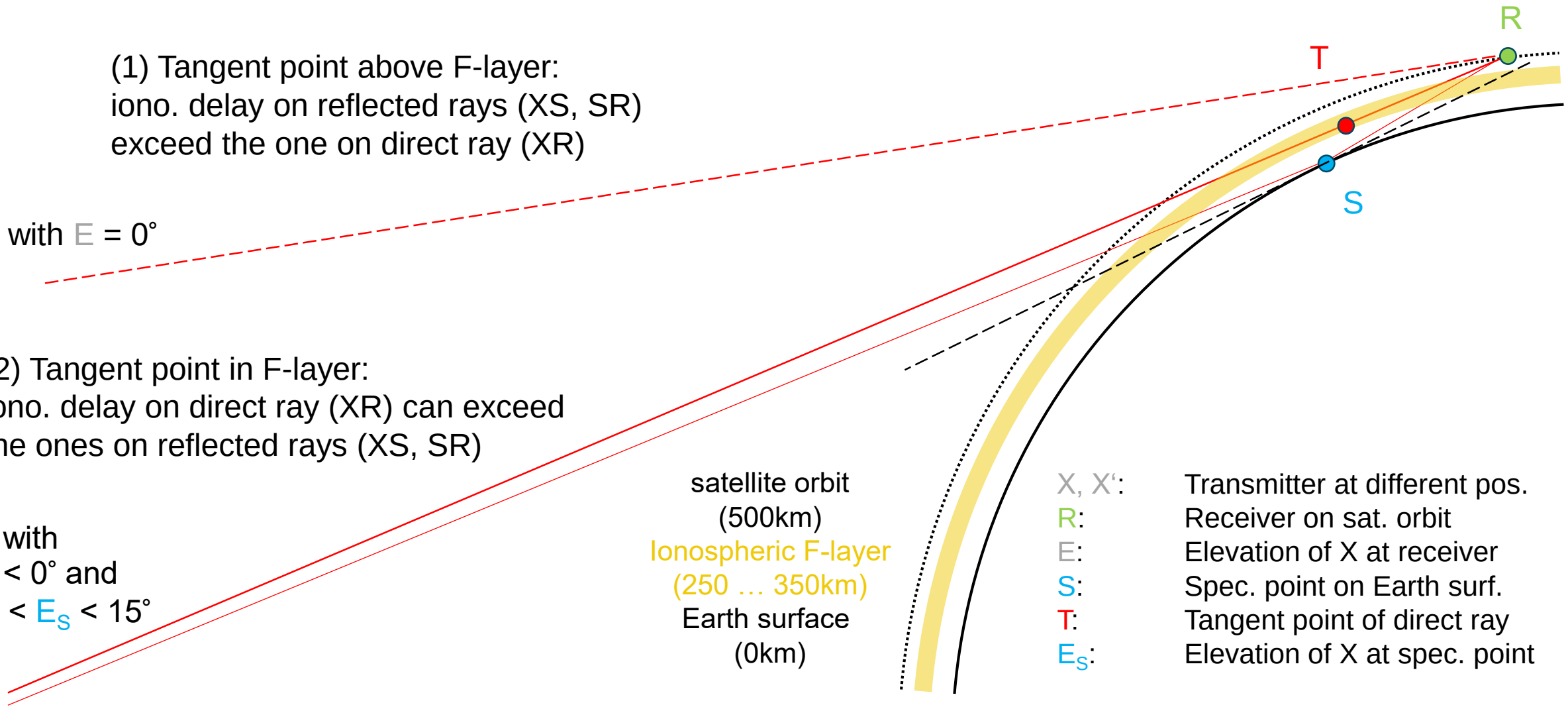
Scenarios of Ionospheric Delay

(1) Tangent point above F-layer:
iono. delay on reflected rays (XS, SR)
exceed the one on direct ray (XR)

X' with E = 0°

(2) Tangent point in F-layer:
iono. delay on direct ray (XR) can exceed
the ones on reflected rays (XS, SR)

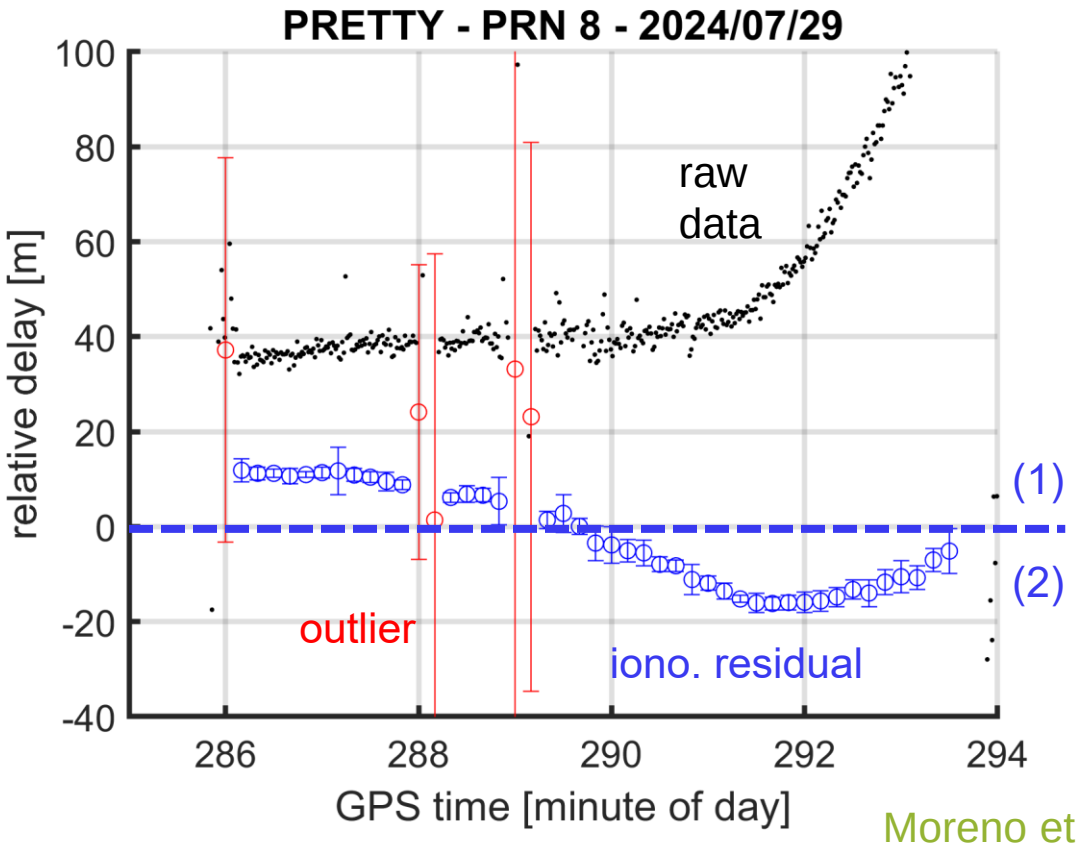
X with
E < 0° and
0° < E_S < 15°



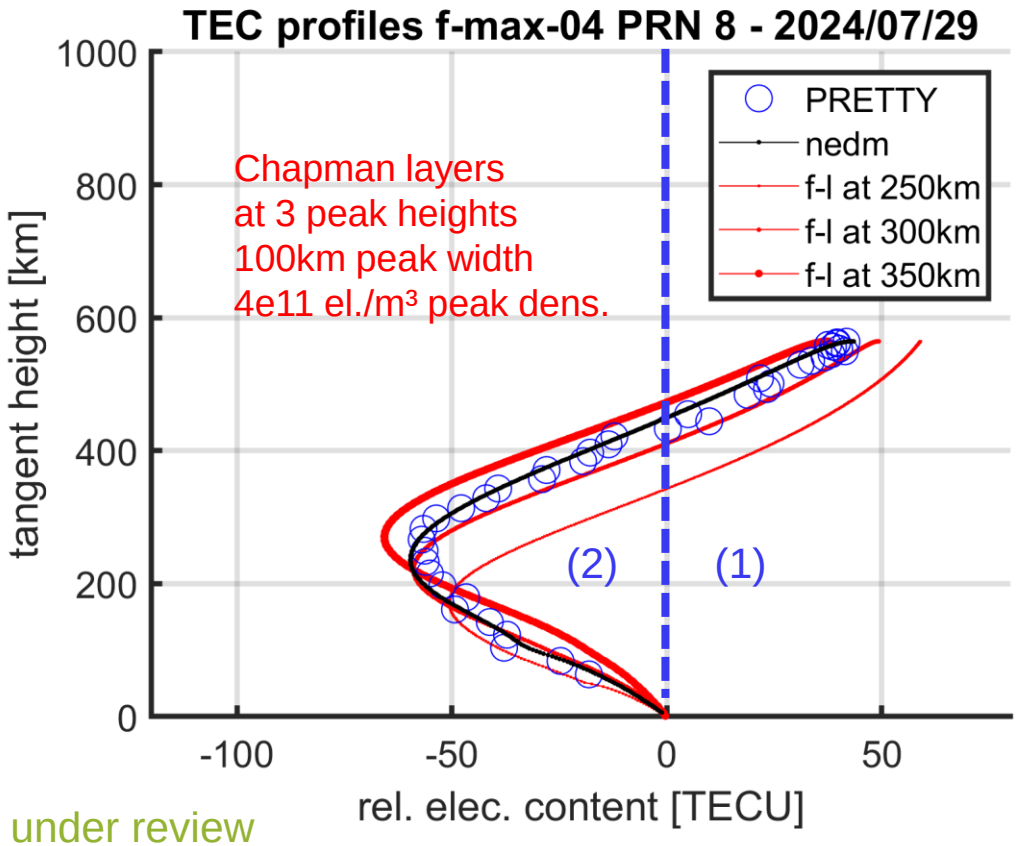
Preliminary Results of Ionospheric Analysis

Observation Example GPS PRN 8 – 2024/07/29

Satellite Obs. Data



Comparison with model profiles



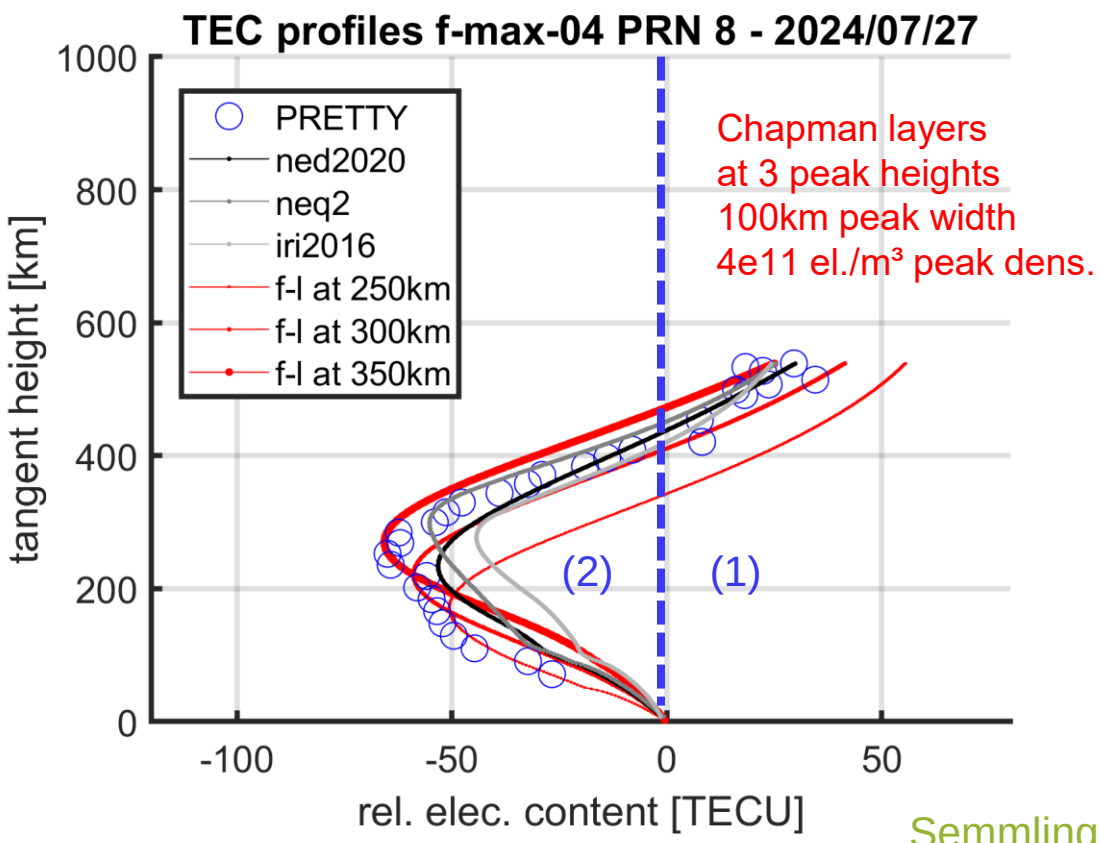
Moreno et al. under review

Ionospheric residual is retrieved after correction of tropospheric delay. Residual below zero belong to scenario (2), tangent point in F-layer

Iono. Residual is converted to relative electron content and compared to predictions with NEDM and chapman layers

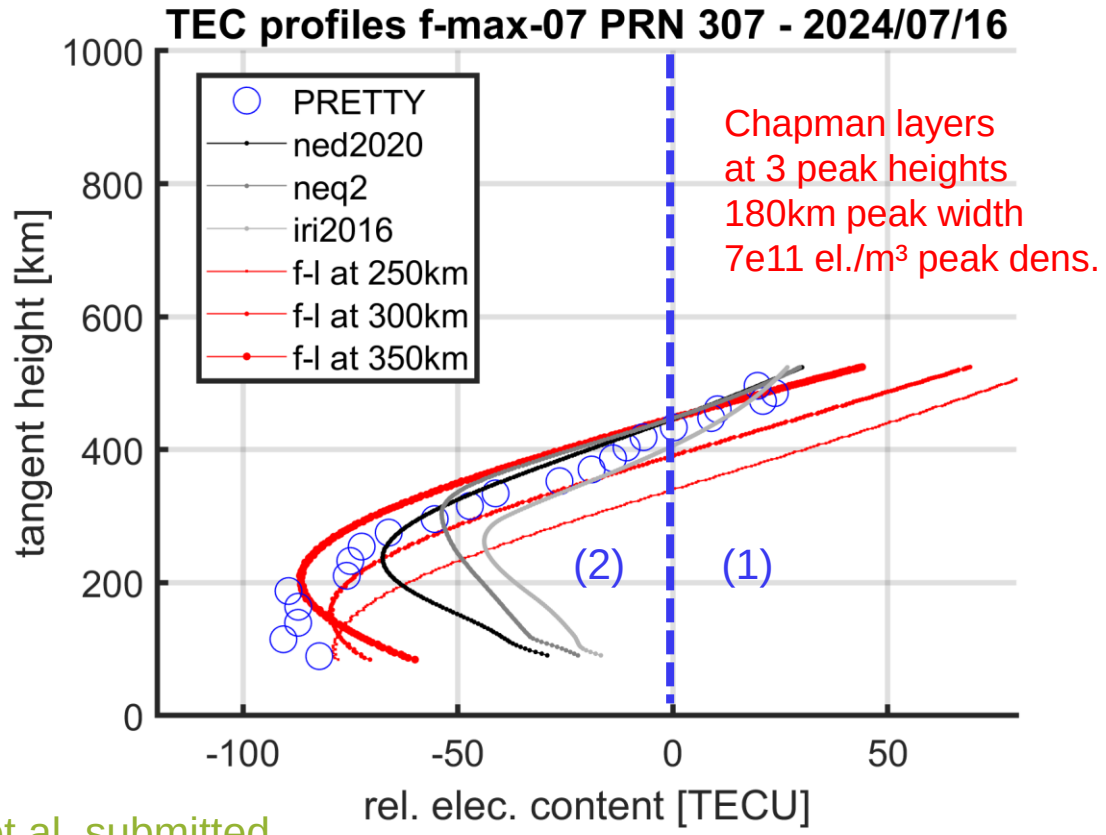
More Examples for GPS and Galileo

Comparison with model profiles



Very similiar to previous example,
two days earlier same ground track

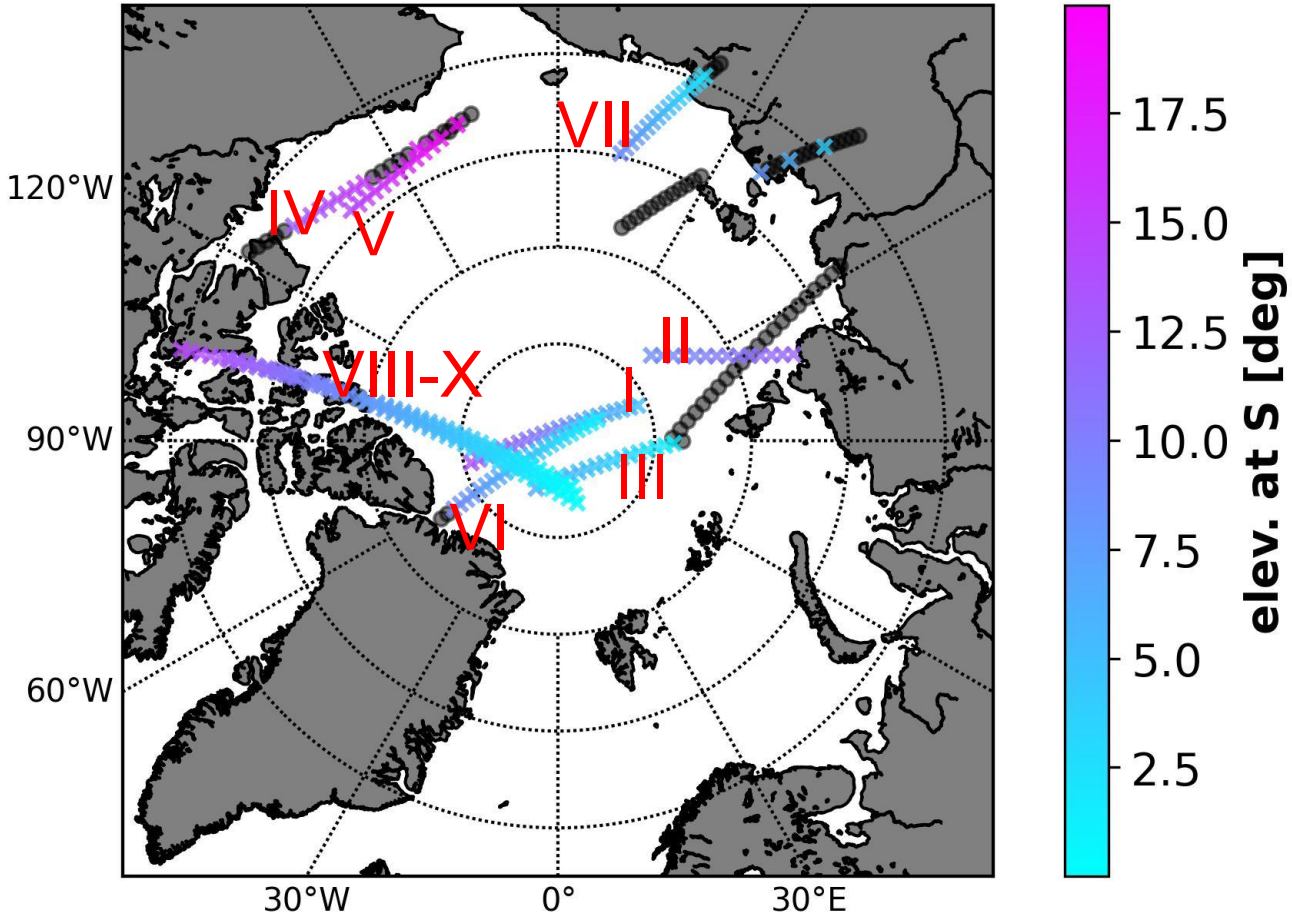
Comparison with model profiles



Semmling et al. submitted

Significantly different example,
about 2 weeks earlier, different track
larger peak width and peak density

Geo-Reference and Uncertainties



I	GPS PRN 11	2024/03/11
II	GPS PRN 25	2024/05/15
III	GAL PRN 7	2024/07/06
IV	GPS PRN 4	2024/07/08
V	GPS PRN 4	2024/07/15
VI	GAL PRN 7	2024/07/16
VII	GAL PRN 8	2024/07/20
VIII	GPS PRN 8	2024/07/27
IX	GPS PRN 8	2024/07/28
X	GPS PRN 8	2024/07/29

Tropo. Unc.: ~60cm (2 TECU) *
Surface Unc.: ~10cm (< 1 TECU) *
Bending Effect: ~10% of tang. Height *

* Ray geometry at E_S = 3°

Conclusions & Outlook

- **PRETTY** mission gathered code delay obs. in **grazing-angle reflectometry**
- **Ionospheric delay profiles** retrieved after tropo. and surface correction
- **Rel. Electron Content** reaches **min.** when **tangent point crosses F-layer**
- Some retrieved profiles show **excellent agreement with model** (NEDM)
- Others indicate **persisting biases**
- **Chapman layers fitted** to estimate peak height and scale height
- Expected **delay uncertainties** (troposphere, surface) are **not significant**
- **Bending has an effect** (on tangent height) to be considered in future

Acknowledgements

This work was partly funded by ESA.

Thank you for your attention

References

- Förste et al. 2013: EIGEN-6C2 - A new combined global gravity field model including GOCE data up to degree and order 1949
  Geophysical Research Abstracts
- Semmling et al. 2014: Sea surface topography retrieved from GNSS reflectometry phase data of the GEOHALO flight mission.
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  Q J R Meteorol. Soc.
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  IEEE Selected Topics in Applied Earth Observations and Remote Sensing
- Hoque et al. 2022: A new climatological electron density model for supporting space weather services
  J. Space Weather Space Clim.
- Moreno et al. 2022: Airborne Coherent GNSS Reflectometry and Zenith Total Delay Estimation over Coastal Waters.
  Remote Sens.
- Moreno et al. 2023: Characterizing Ionospheric Effects on GNSS Reflectometry at Grazing Angles from Space
  Remote Sens.
- Semmling et al. 2023: Ionosphere Sounding in the Central Arctic: Preliminary Results of the MOSAiC Expedition.
  URSI Radio Science Letters

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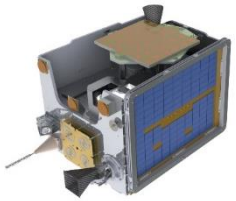
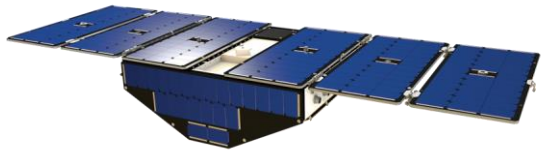
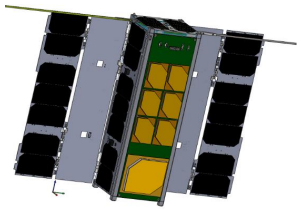
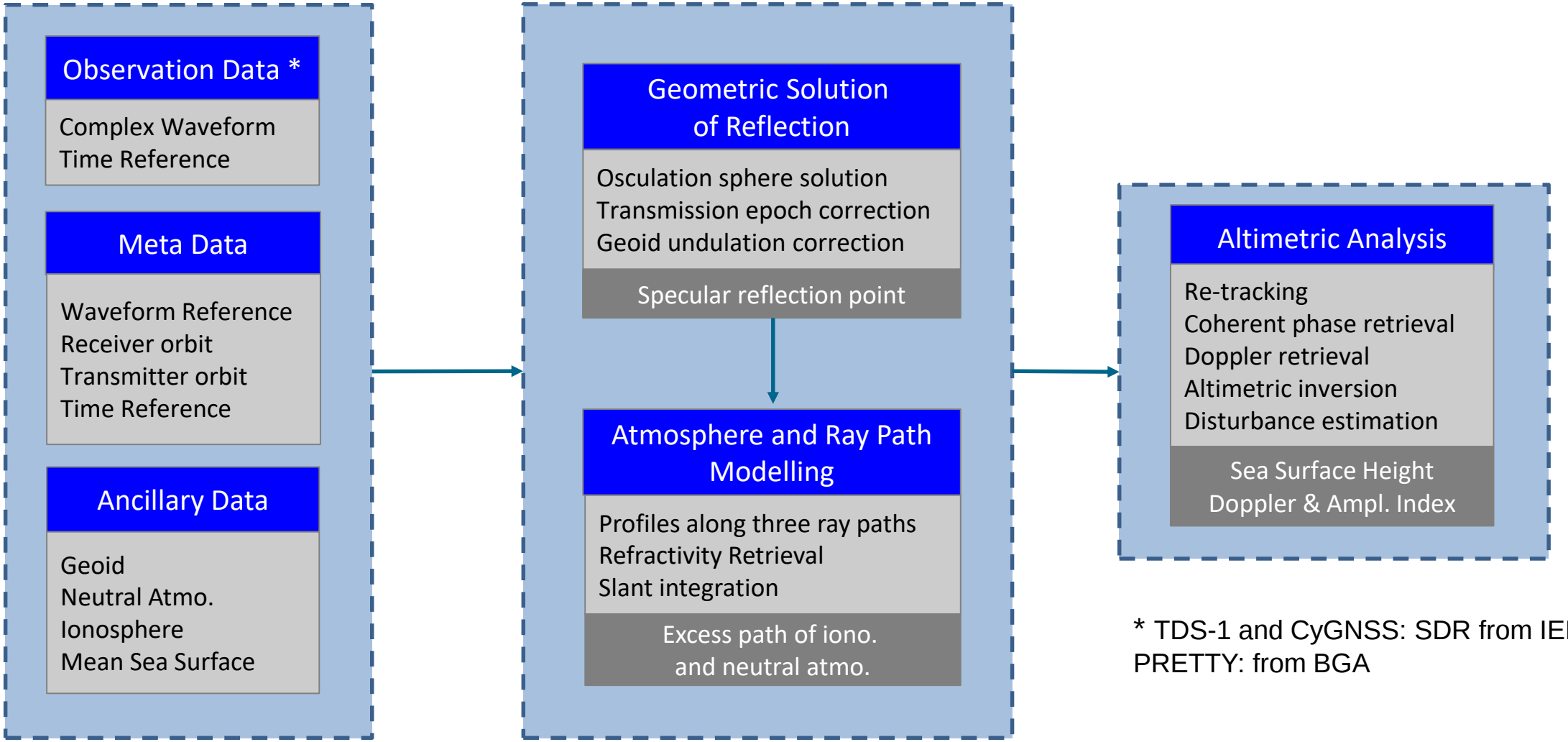
- Moreno et al. 2024: Grazing-angle ionospheric delays observed during the GNSS-R PRETTY mission. (under review)
- Semmling et al. 2025: Ionospheric Delays in PRETTY Mission Data: An Opportunity to study Ionospheric F-layer Structure (submitted)

Appendix

Some Satellite Missions with different settings

			
Mission:	TDS-1	CyGNSS	PRETTY
# of sats:	1 small sat	8 small sats	1 cube sat
Orbit height:	~ 650 km	~ 520 km	~ 570 km
Orbit inclination:	98.8°	35.0°	97.6°
Major field of view:	near-nadir	near-nadir	grazing
Supported signals:	GPS L1 C/A	GPS L1 C/A	GPS L5C & GAL E5
Select. area:	Hudson Bay, Canada	Caribbean Sea	Arctic Ocean
Time period:	Jan 2015	Sep 2017, Sep 2018	May – Sep 2024

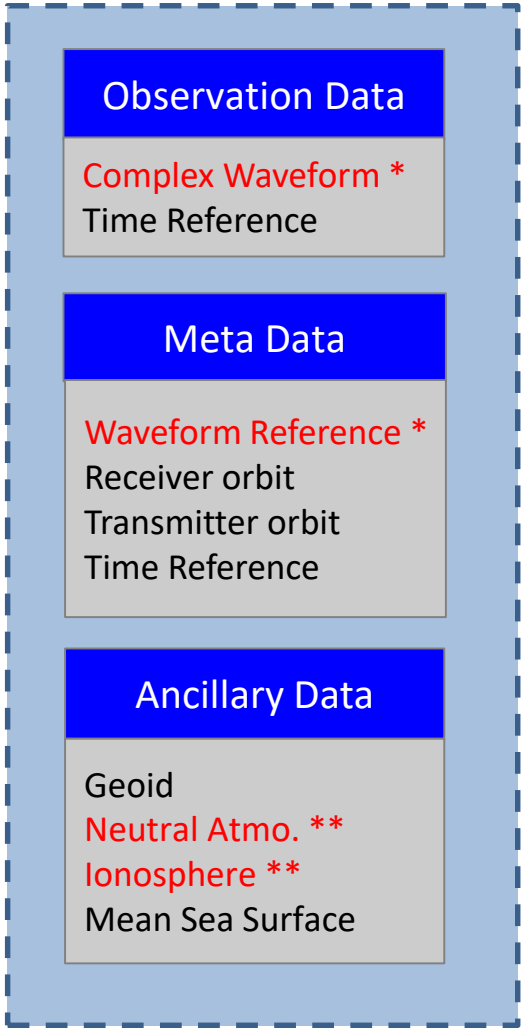
Algorithm Theoretical Baseline Document for PRETTY



* TDS-1 and CyGNSS: SDR from IEEC
PRETTY: from BGA

Semmling et al. 2022

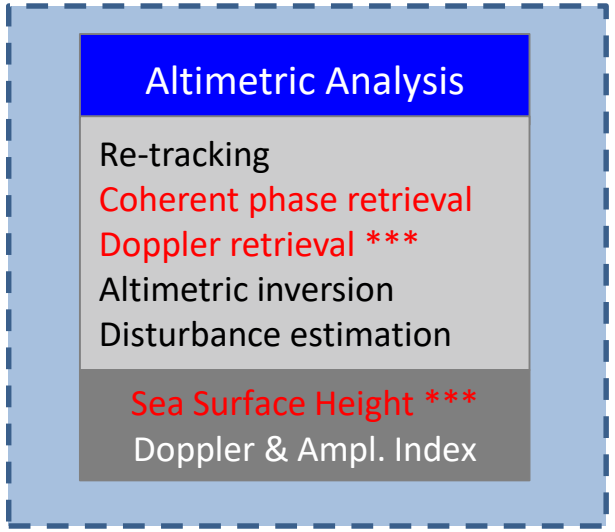
Important Points of ATBD for PRETTY



* Reference to Direct Signal
with Interferometric & Conventional
Approach different than for other missions, leads to biases

** Two different models for neu. atmo
International Stand. Atmosphere (ISA)
ECMWF Re-Analysis (ERA5)
** In-house model for ionosphere
Neustrelitz Electron Density Model (NEDM)

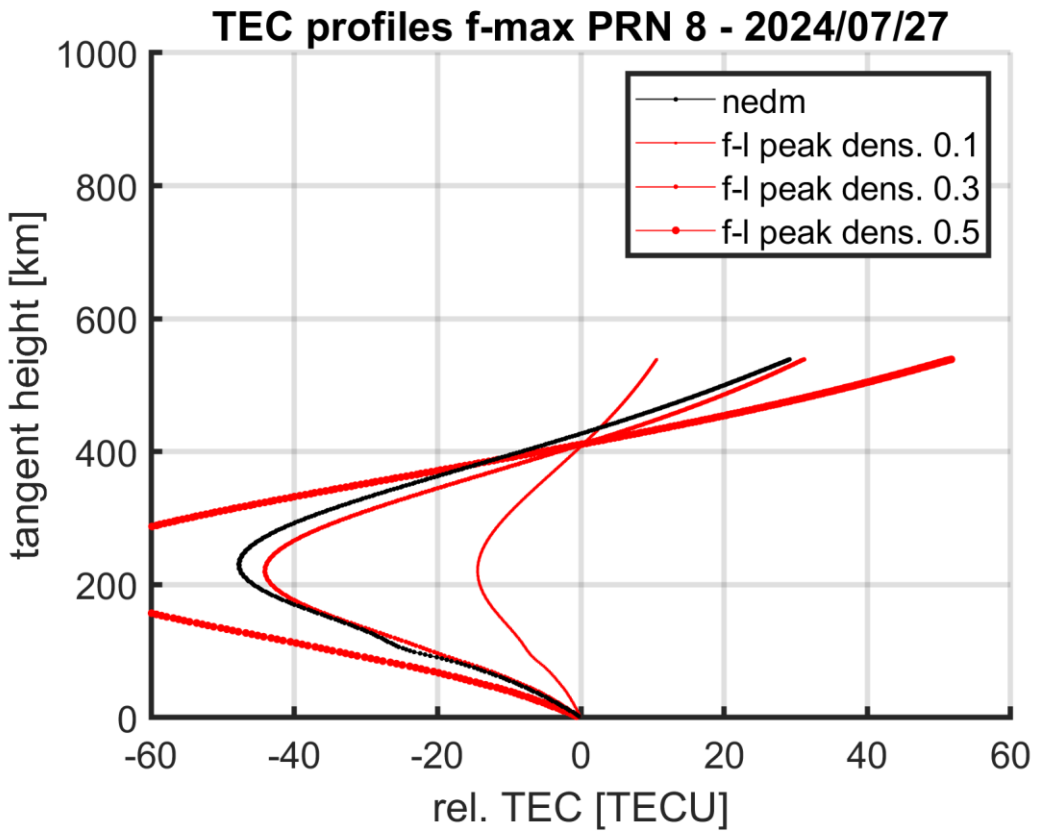
*** Focus on code delay retrievals
Delay waveforms from conventional approach best agreement with atmosphere model
*** investigate additionally ionosphere



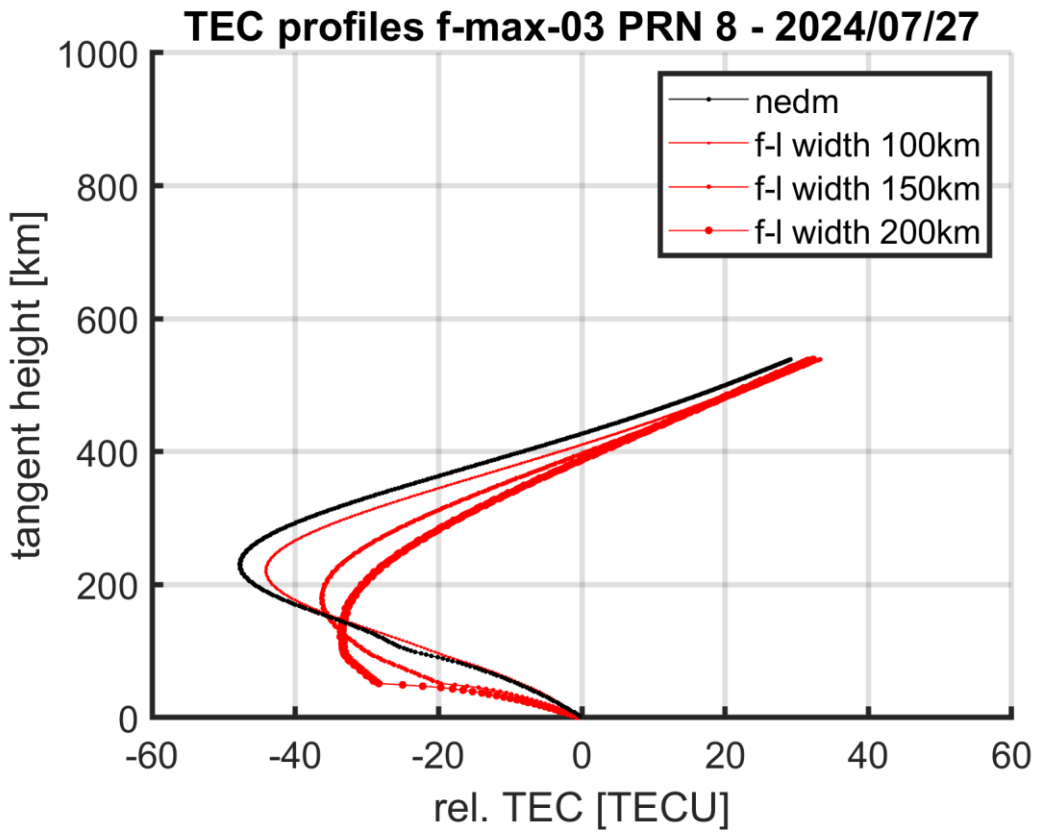
** Zus et al. 2015
** Semmling et al. 2016
** Jakowski et al. 2018
*** Li et al. 2018
*** Moreno et al. 2024 (in prep.)

Event GPS PRN 7 – 2024/07/29

Slant model - Standard Neutral Atmo.



Ray-tracing model - ERA5

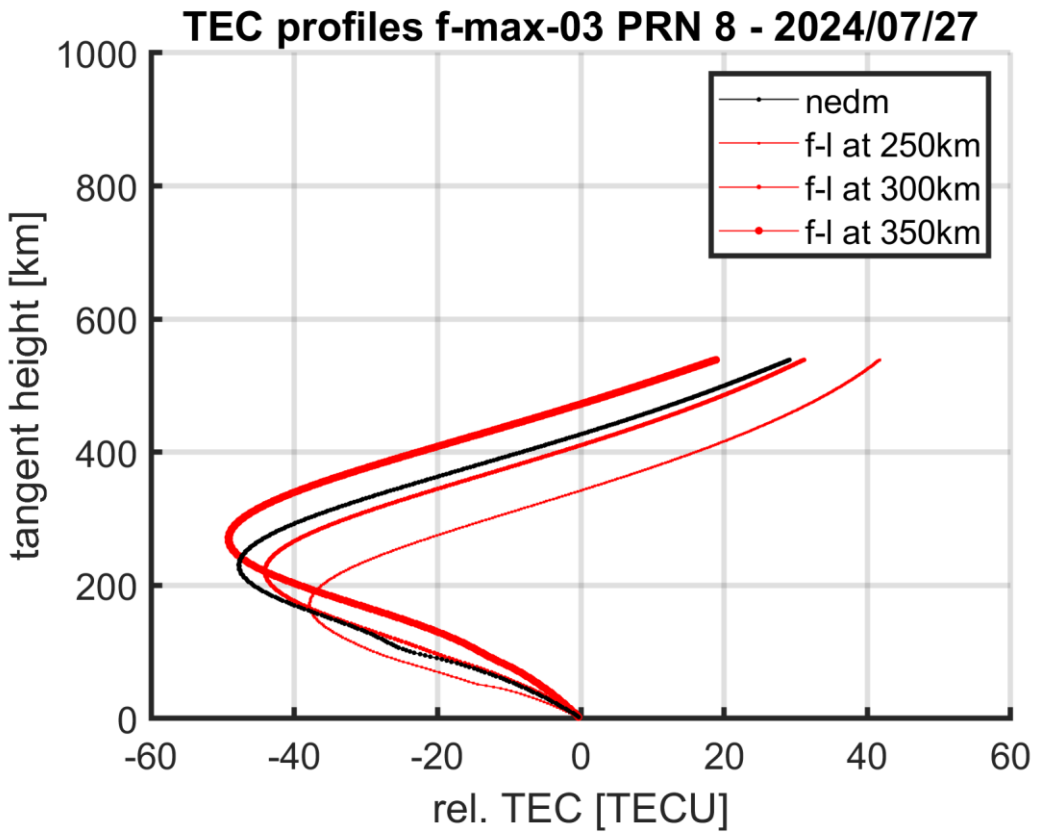


★ Retrievals locked on model at first epoch
- Altimetric drift due to bias below 5deg

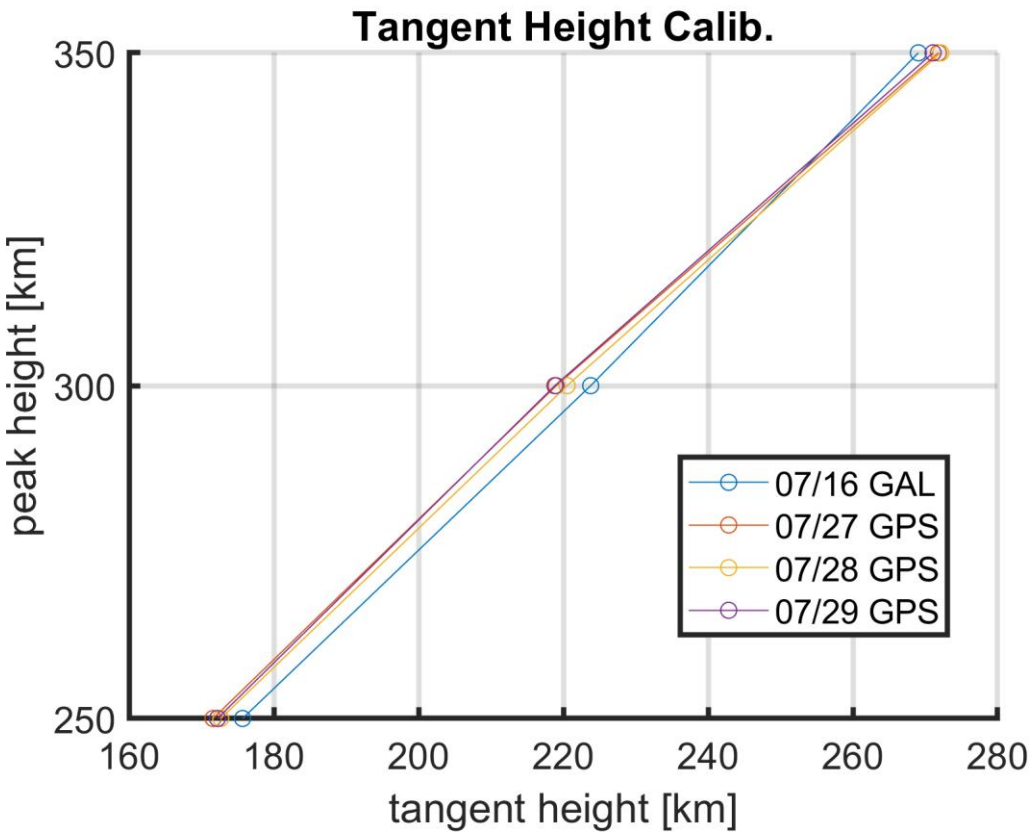
- Ray tracing little improvement
- Precision limits: > 10 m for height, > 5 m for delay

Event GPS PRN 7 – 2024/07/29

Slant model - Standard Neutral Atmo.



Ray-tracing model - ERA5



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- 77166.2497+-1548.1122, 76988.2182+-2322.0991