IONOSPHERIC DELAY IN GRAZING ANGLES GNSS-R: INSIGHTS FROM THE ESA PRETTY MISSION OBSERVATIONS

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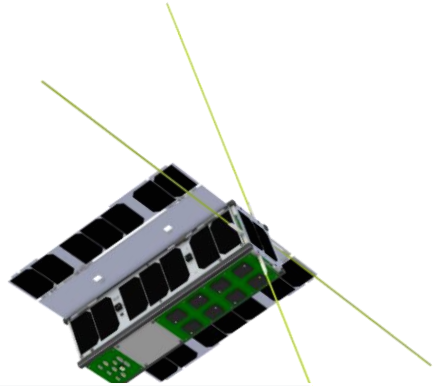
Content

- Background
- PRETTY preparation - Ionospheric Delay Simulation
- PRETTY Observations - Ionospheric Delay Estimation
- Conclusions

Background – PRETTY Mission



Platform	3U CubeSat
Orbit Height / Incl.	560 km / 98°
GNSS-R Modes	cGNSS-R / iGNSS-R
Main Objective	Altimetry / Sea Ice
Band	E5 / L5
Elevation Range	0 - 30
Duty Cycle	30 min

Launched: 09.10.2023

Simulation:

Characterizing Ionospheric Effects on GNSS Reflectometry at Grazing Angles from Space

Mario Moreno, Maximilian Semmling, Georges Stienne,
Mainul Hoque, Jens Wickert.

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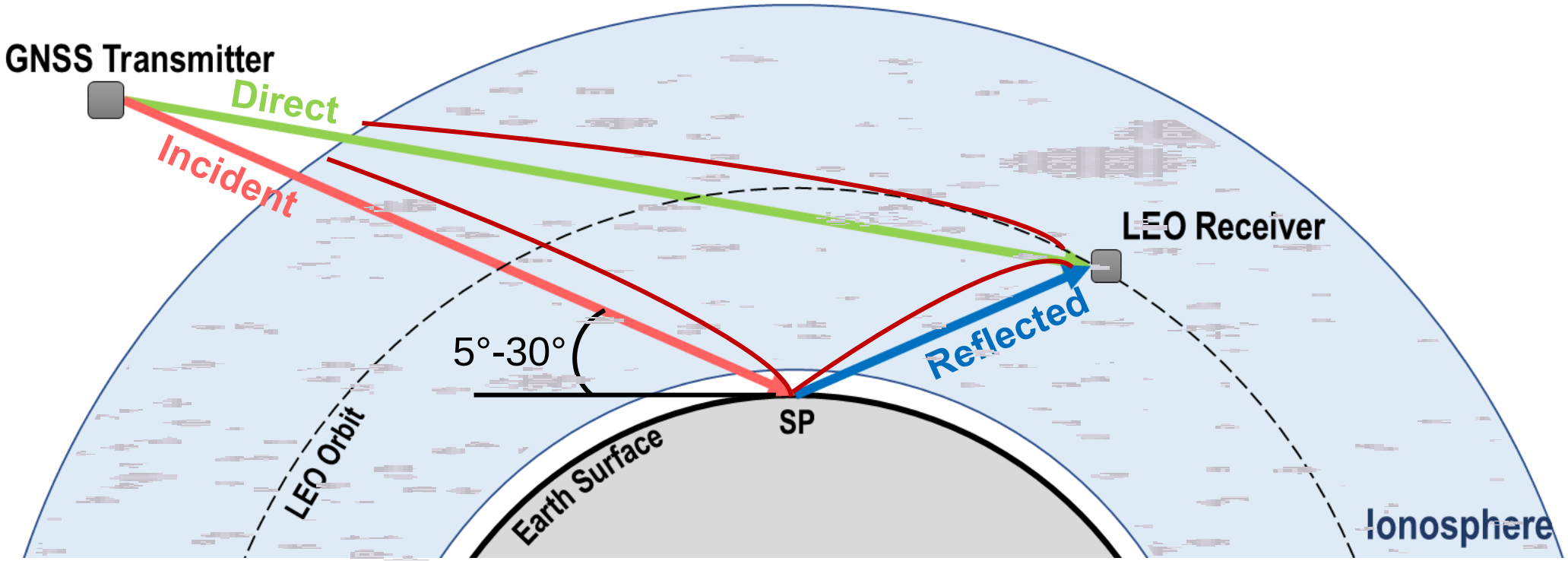
Ionospheric Parameters

1 “Relative” Ionospheric Delay

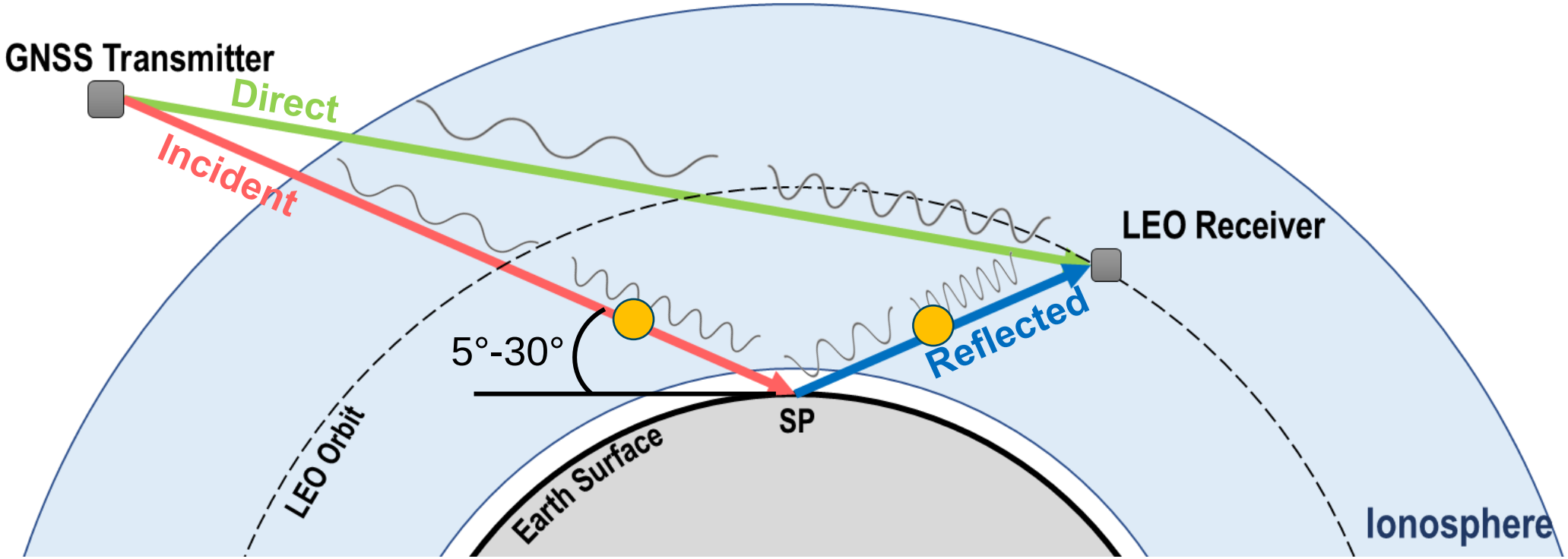


Ionospheric Parameters

1 “Relative” Ionospheric Delay

2 Doppler Shift

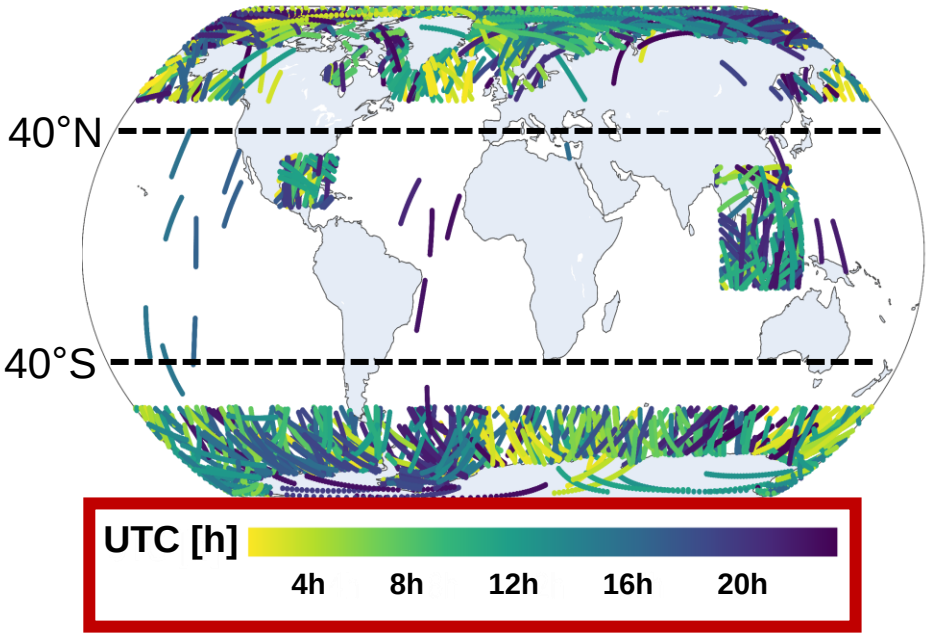
3 Peak Ne Height



GNSS-R Iono. Simulations at Grazing Angles

PRETTY-like scenario…

1200 Specular Points Tracks



GNSS Constellation: GPS.

LEO Orbit data: Spire Global CubeSat LEMUR-2.

Earth Model: Osculation sphere.

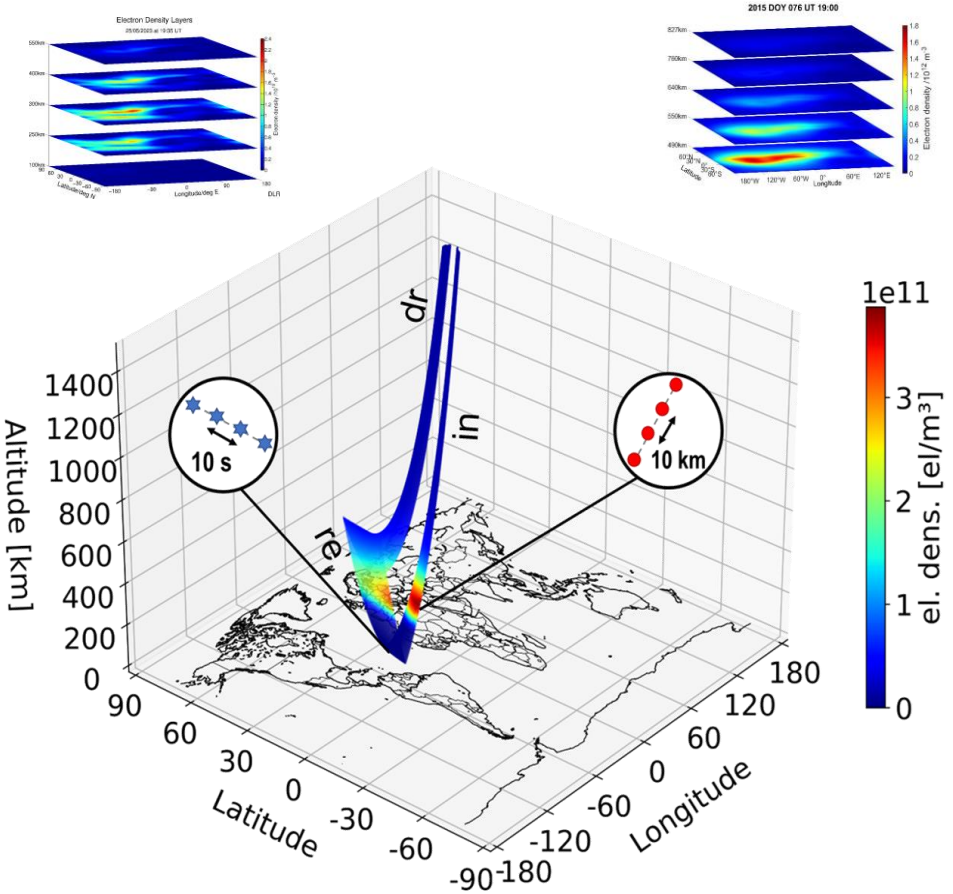
Date: 01.03.2021

Neustrelitz Electron Density Model (NEDM2020) DLR-SO.

(Hoque et al. 2022)

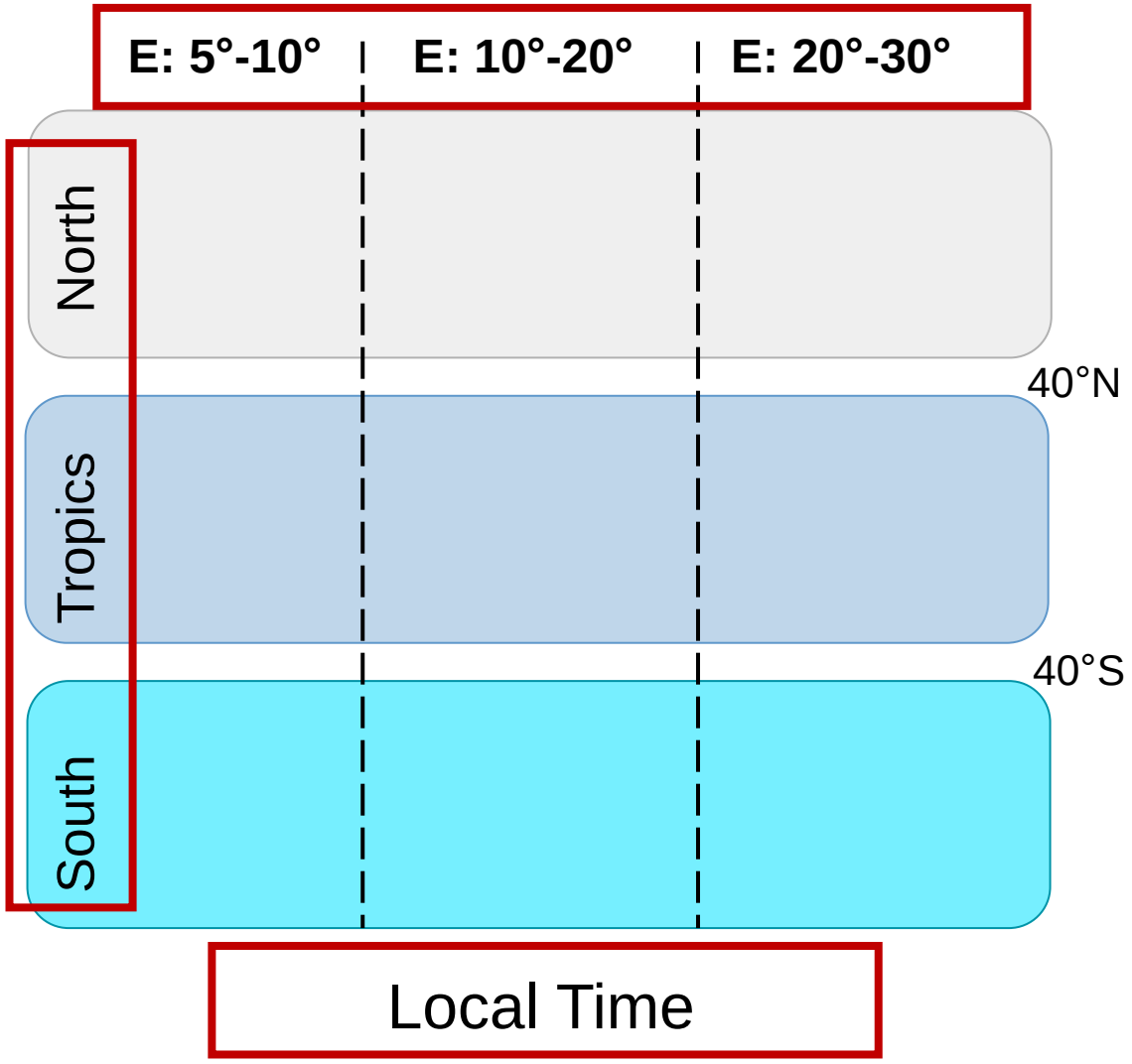
NeQuick Model T/ICT4D Laboratory

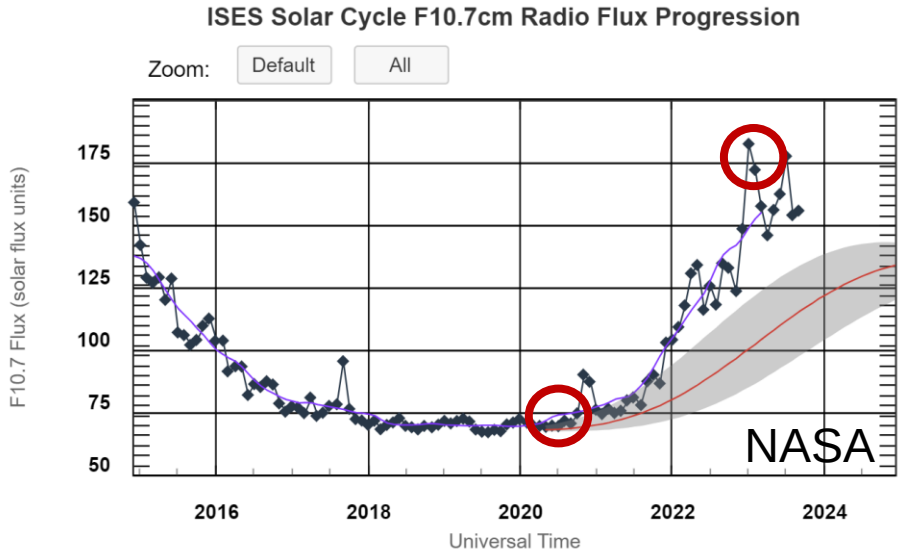
(Nava, B. et al., 2008)



$$sTEC_x = \int N_e dl \Rightarrow \Delta sTEC \Rightarrow \Delta_r = \frac{40.3}{f^2} \Delta sTEC$$

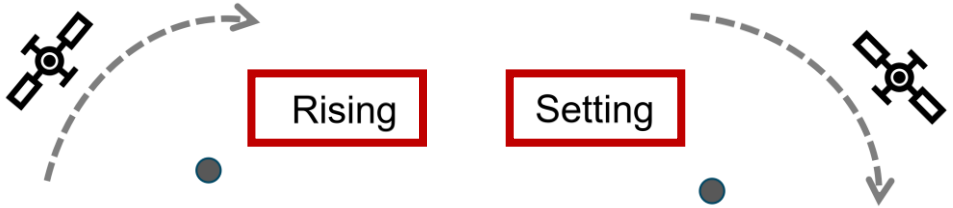
Results



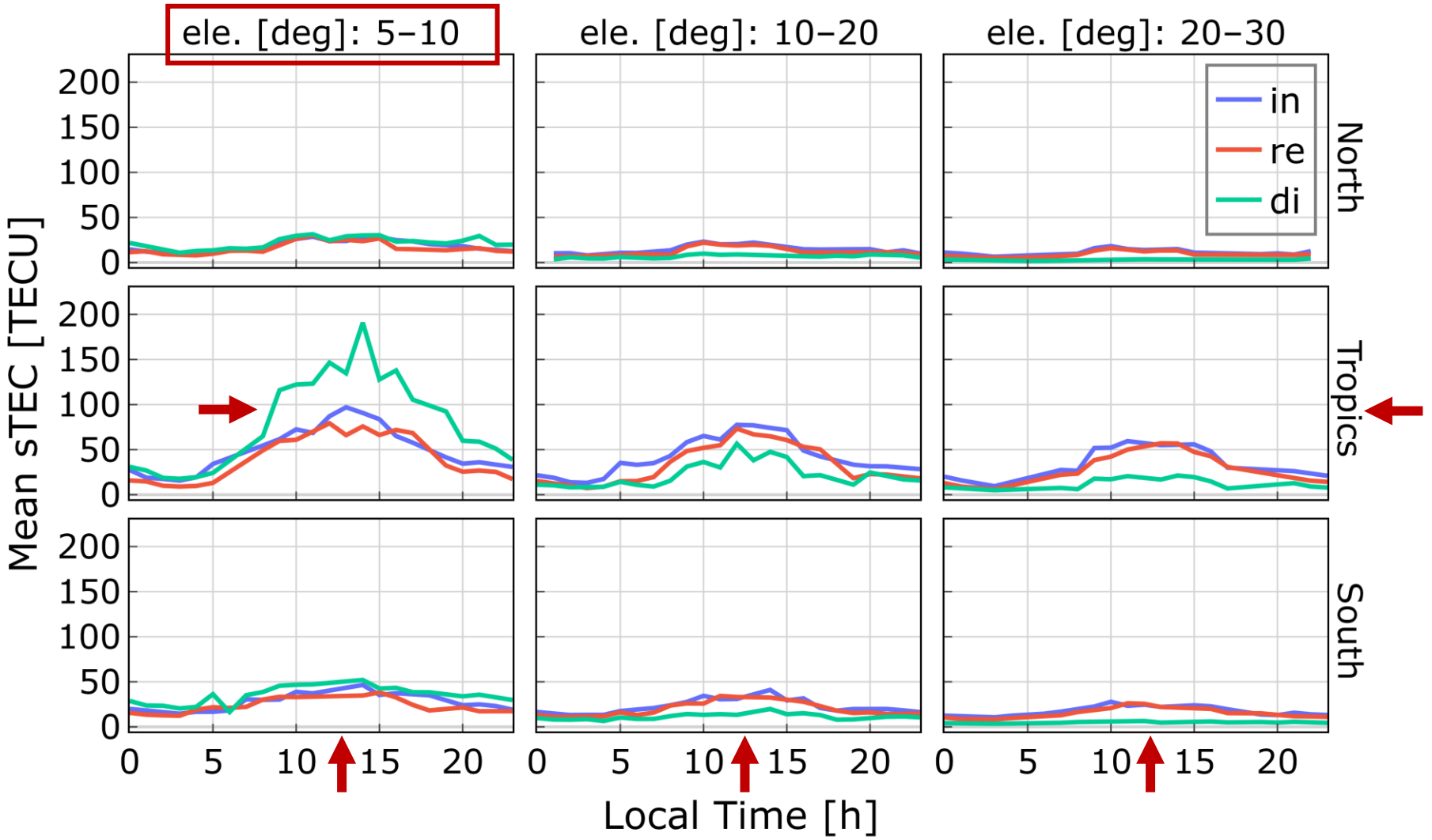


$$LSA \rightarrow F10.7 = 75$$

$$HSA \rightarrow F10.7 = 180$$

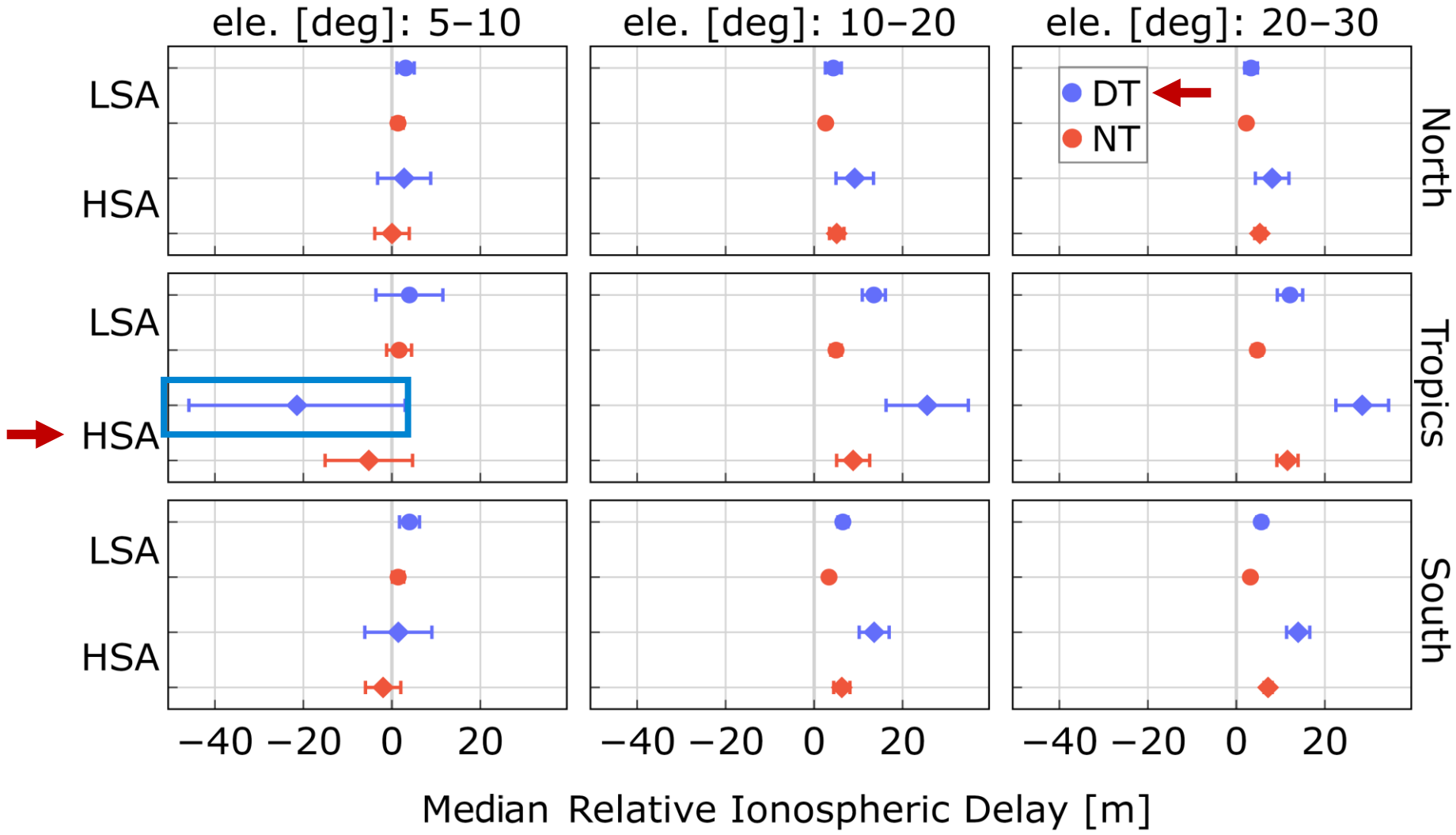


Results - slant Total Electron Content (sTEC)

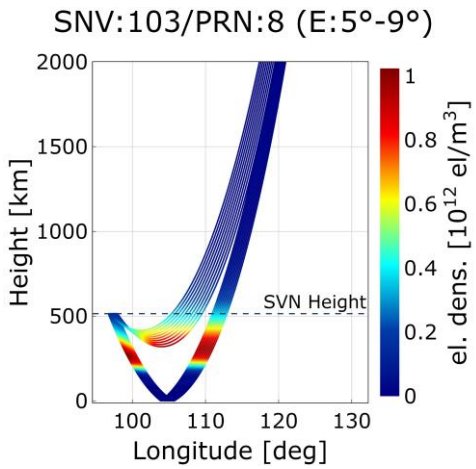


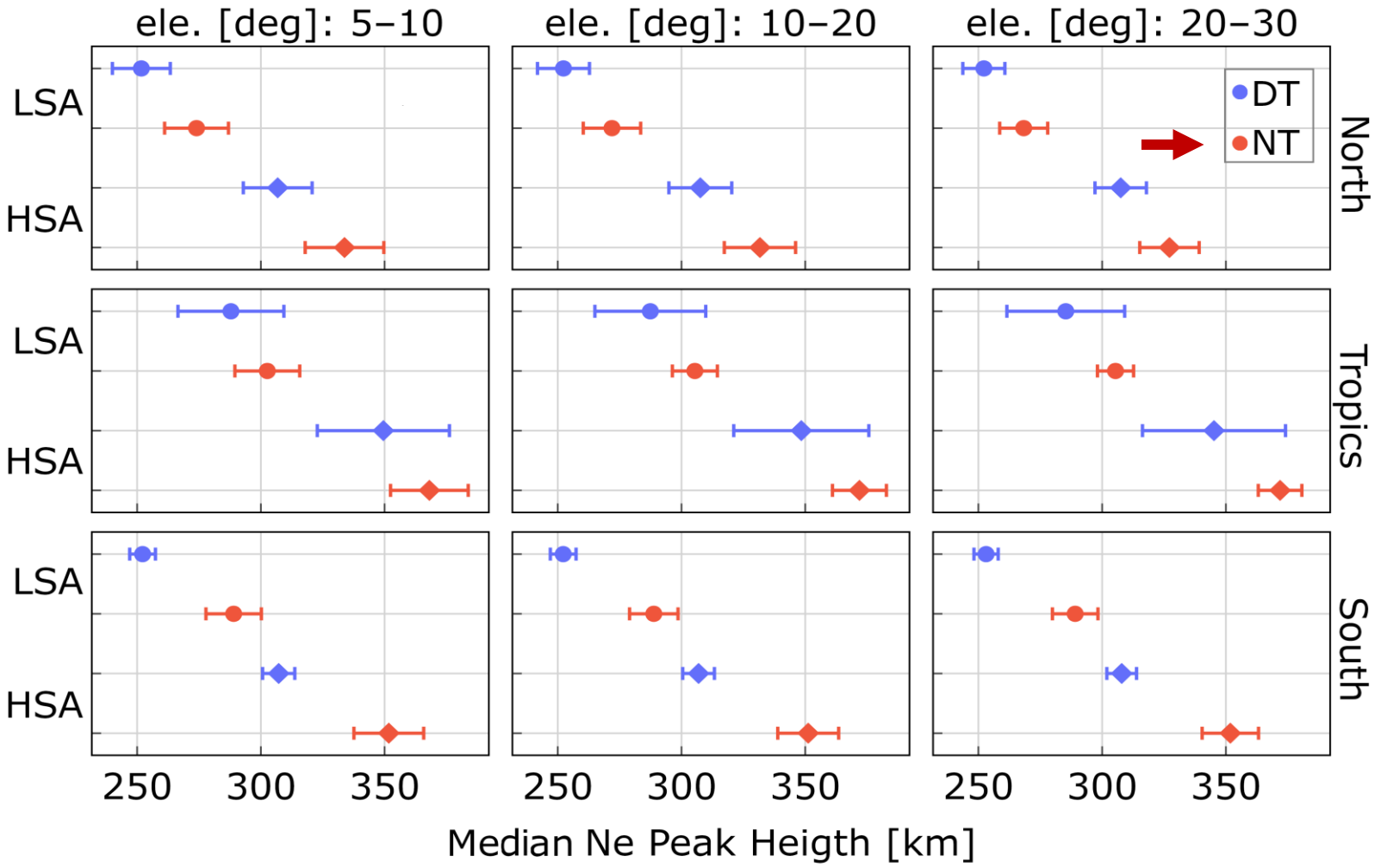
Results - Relative Ionospheric Delay

$$I_r = \mathrm{I_{in}} + \mathrm{I_{re}} - \mathrm{I_{dr}}$$



Results - Peak Electron Density Height





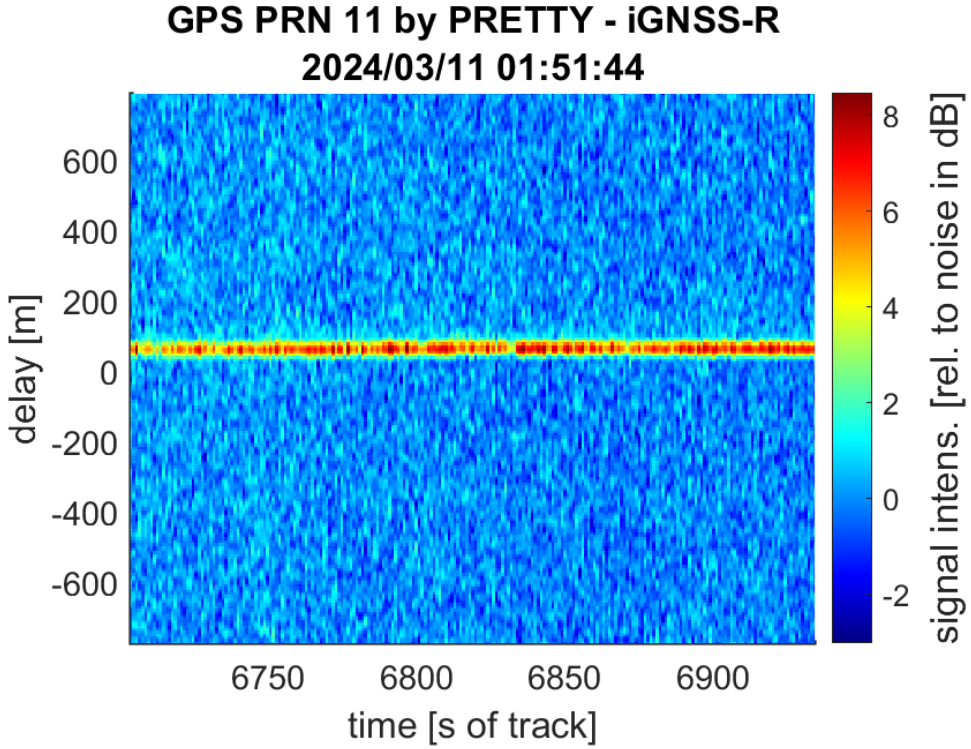
PRETTY Observations:

Grazing-angle ionospheric delays observed during the GNSS-R PRETTY mission

Mario Moreno, Maximilian Semmling, Florian Zus, Georges Stienne, Andreas Dielacher, Mainul Hoque, Jens Wickert, Hossein Nahavandchi.

Journal of Geodesy: Under Review

PRETTY – Delay Maps



Ele.: 14° ..... 5°

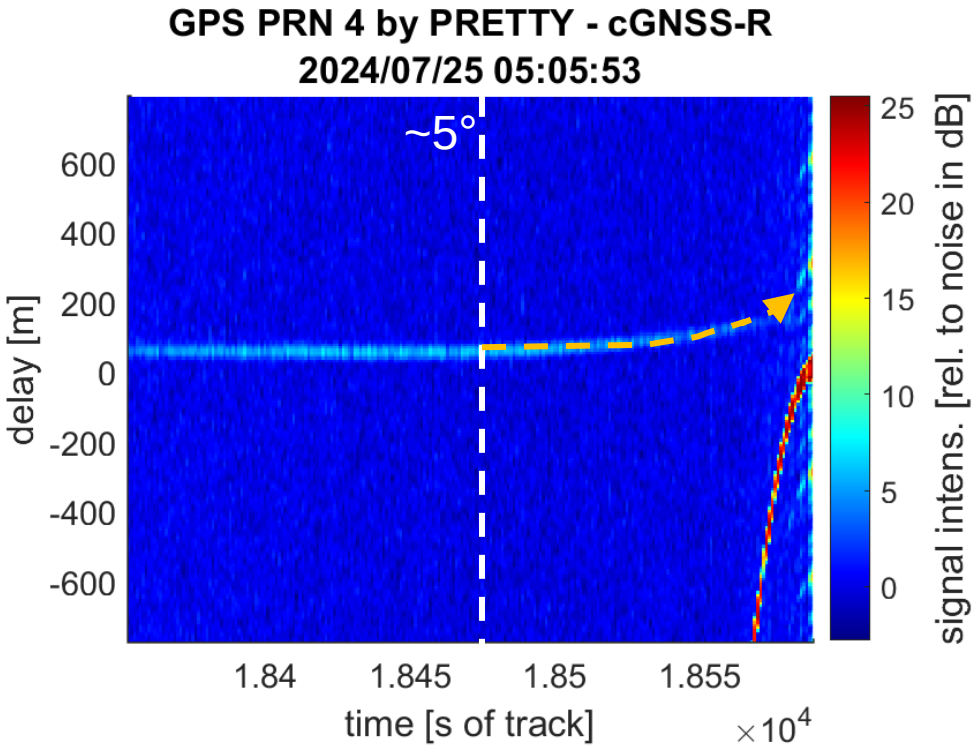
+ PRETTY Capabilities

Mode:

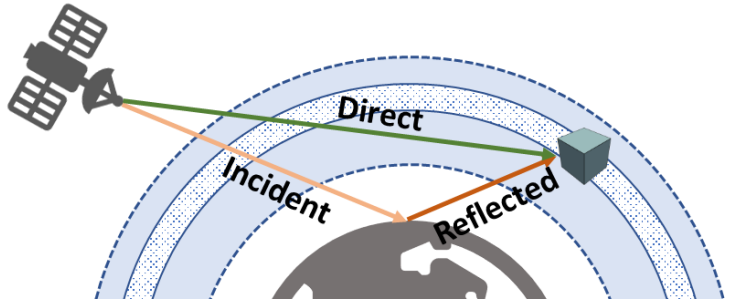
Clean Replica

Elevation Range:

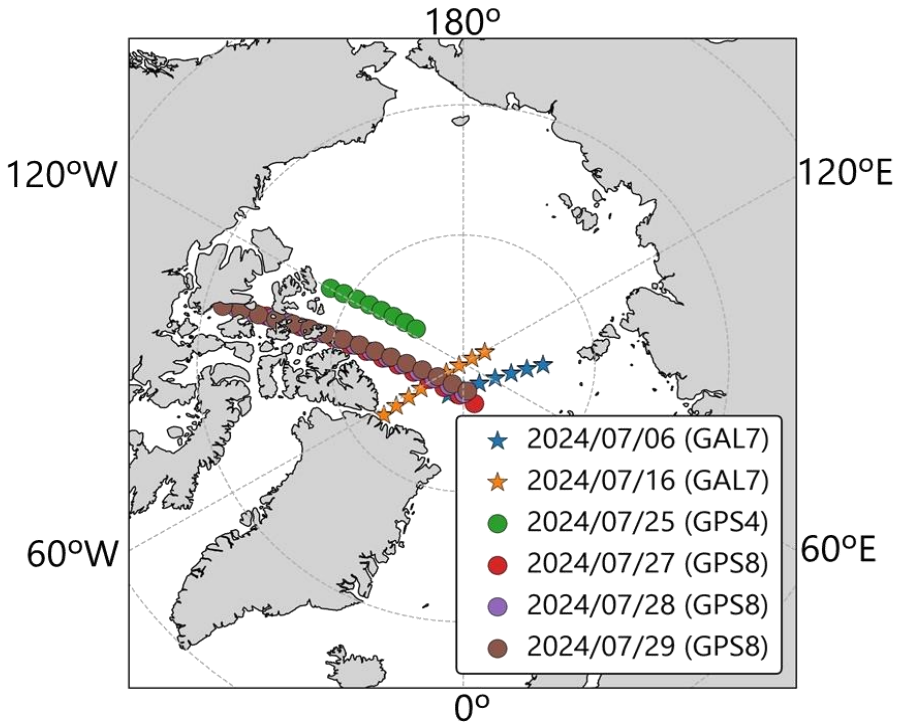
20° - 0.01°

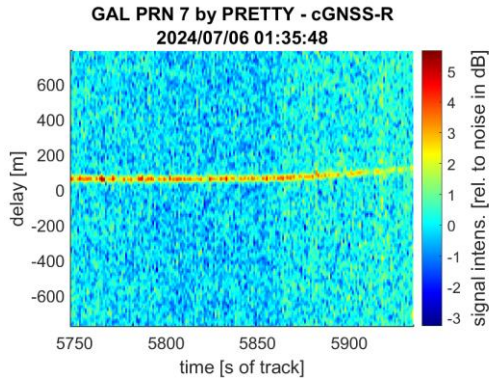


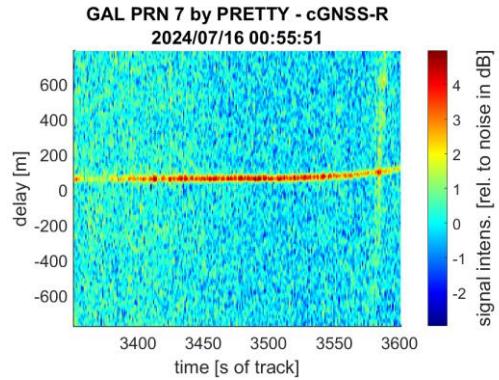
Ele.: 9° ..... 0°

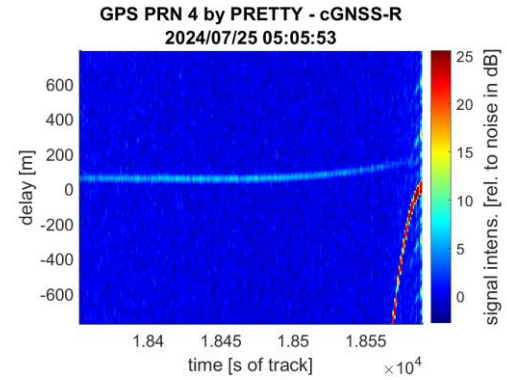


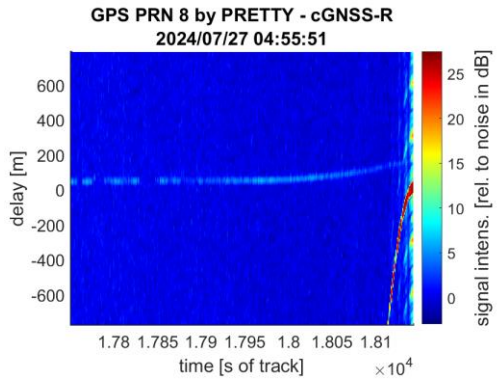
PRETTY - Code Delay Events

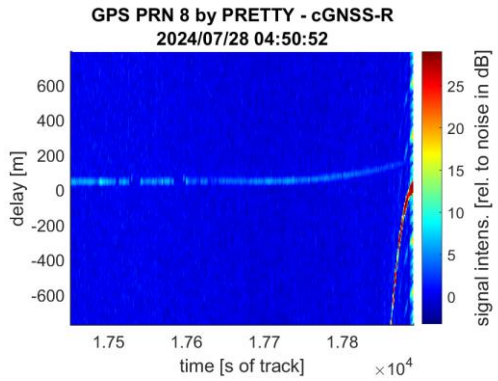


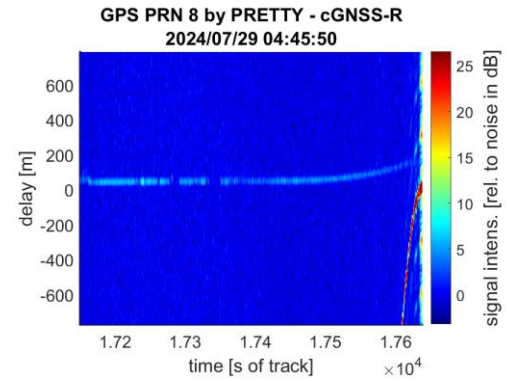








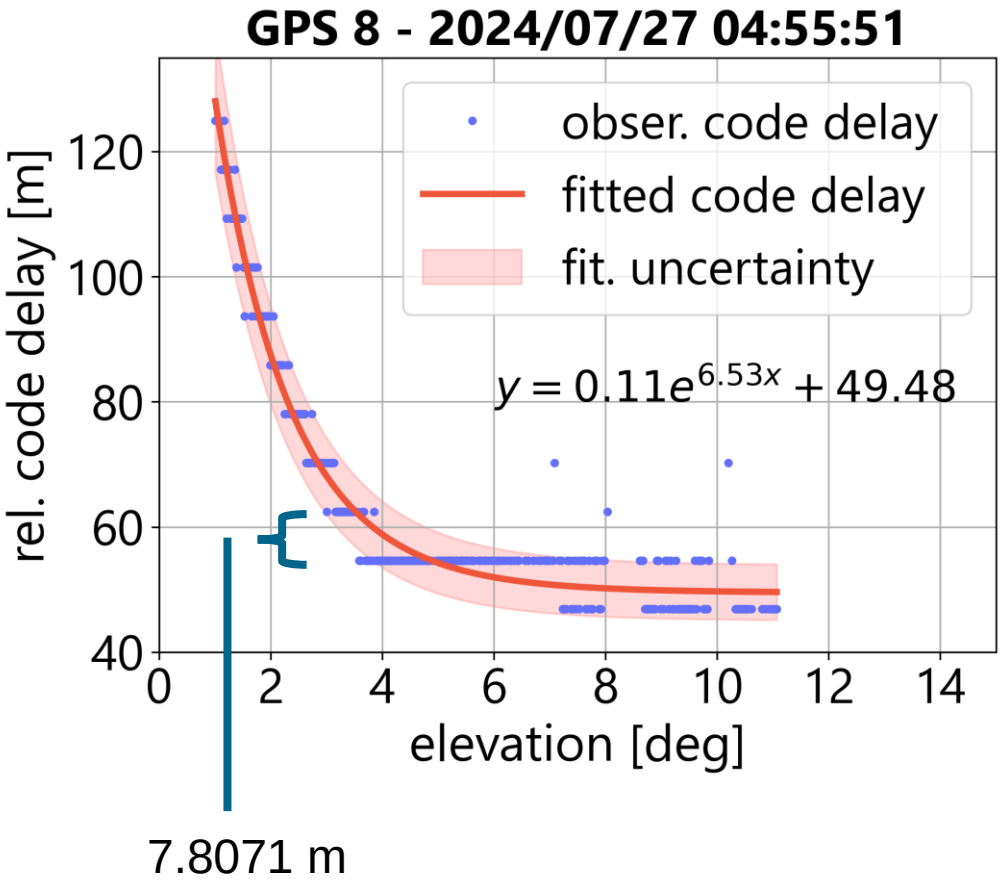




Date	GNSS – PRN	UTC	Ele. Range [deg]	Duration [mm:ss]	F10.7
2024/07/06	GAL – 7	01:35:48	7 – 1	03:09	169.9
2024/07/16	GAL – 7	00:55:51	10 – 1	04:12	242.4
2024/07/25	GPS – 4	05:05:53	9 – 0.01	03:58	172.0
2024/07/27	GPS – 8	04:55:51	11 – 0.01	06:34	186.7
2024/07/28	GPS – 8	04:50:52	13 – 0.01	07:21	216.6
2024/07/29	GPS – 8	04:45:50	15 – 0.01	08:10	224.2

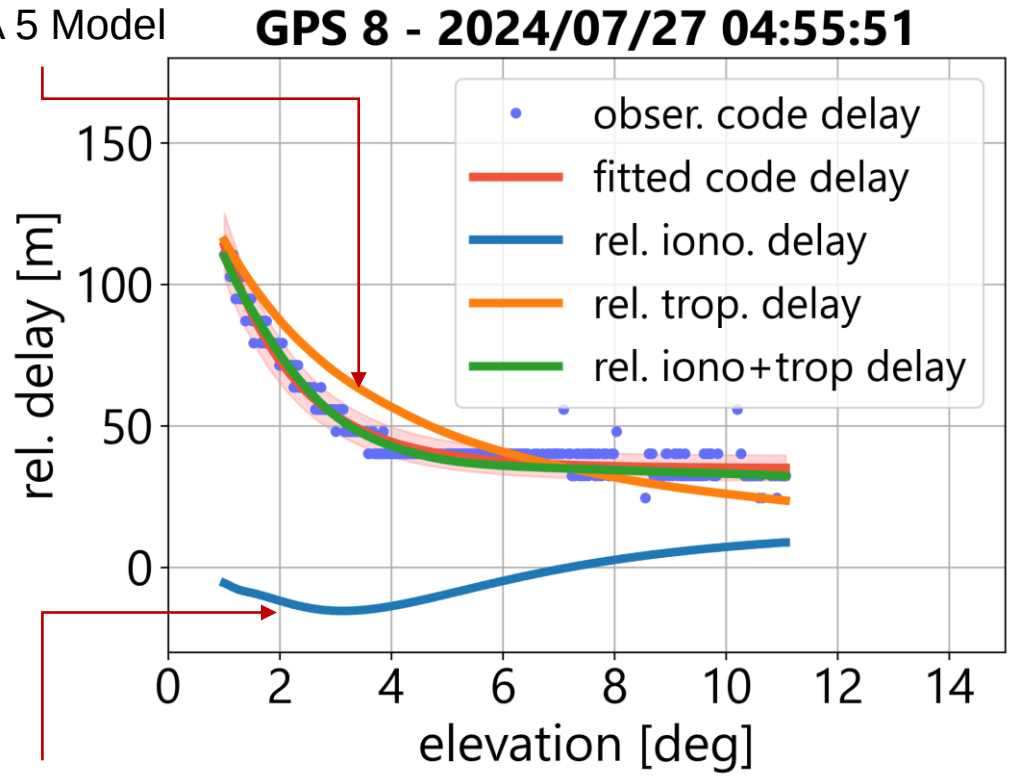
Obs. Fitting and Model-Based Atmospheric Corrections

Exponential Fitting



Zus et. al., 2012
GFZ
ERA 5 Model

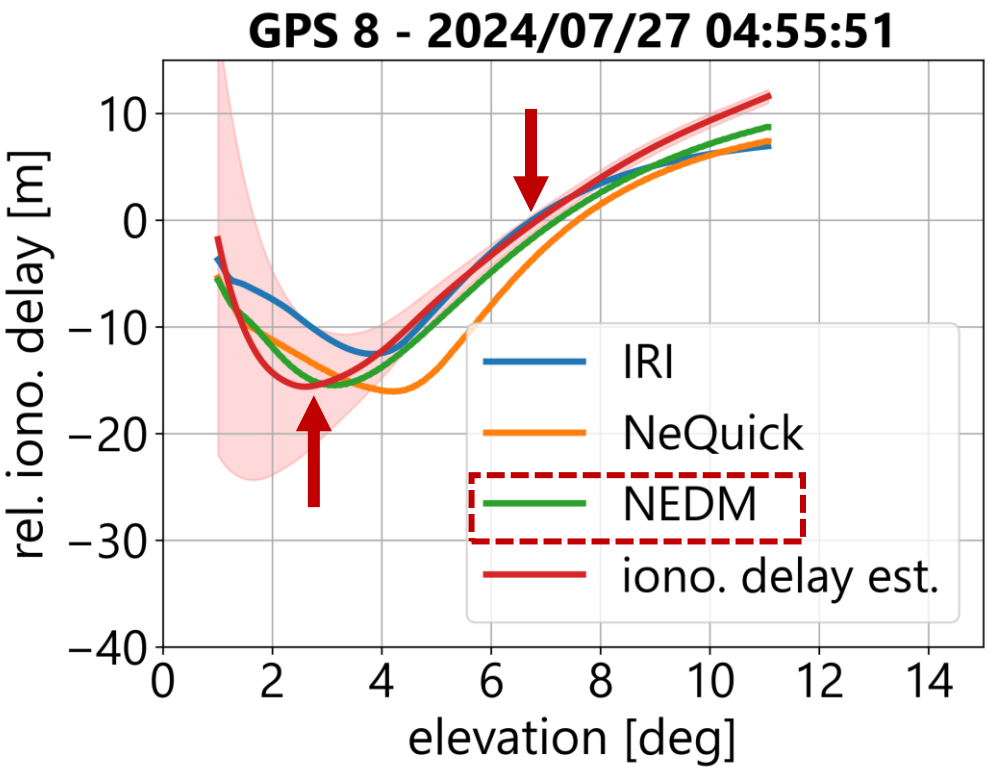
Model-based Atmospheric Corrections

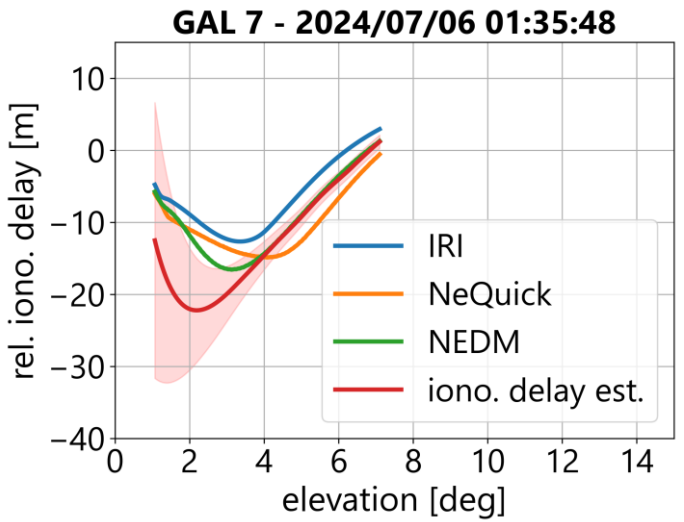


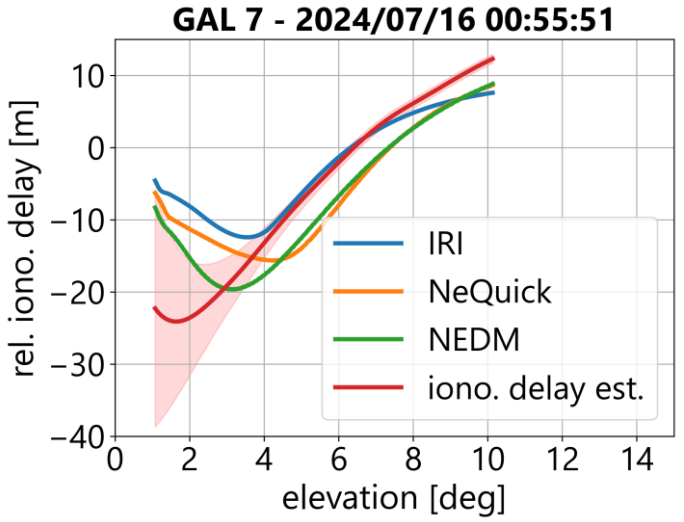
Moreno et. al., 2023
DLR
NEDM2020 Model
(Hoque et al, 2022)

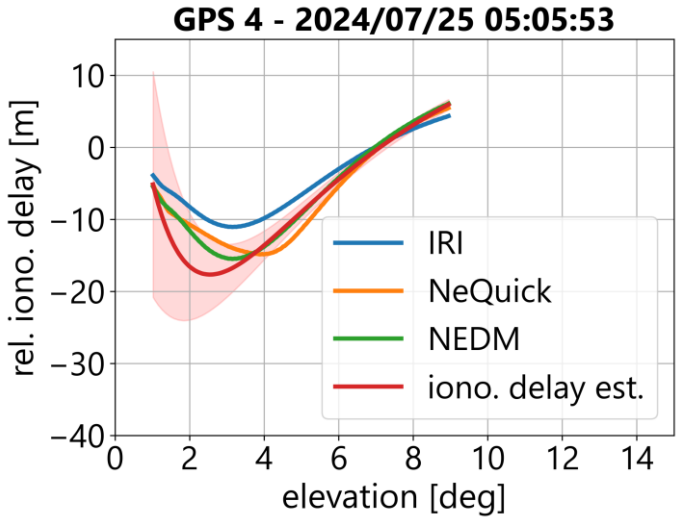
Ionospheric Delay Estimations

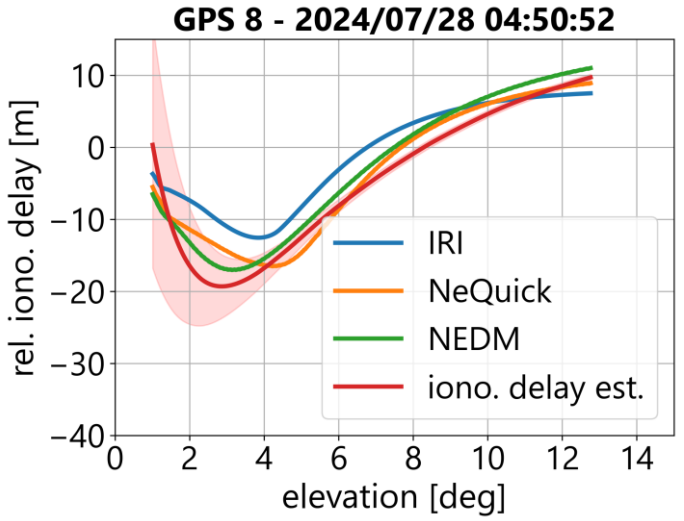
Removing tropospheric contribution → Isolate the ionospheric delay component







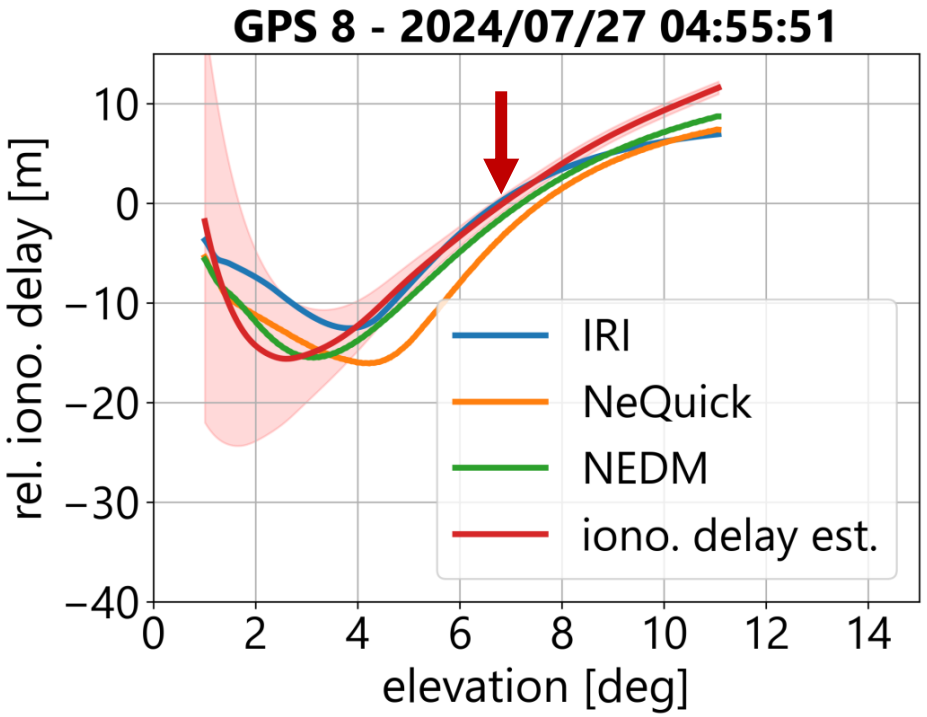


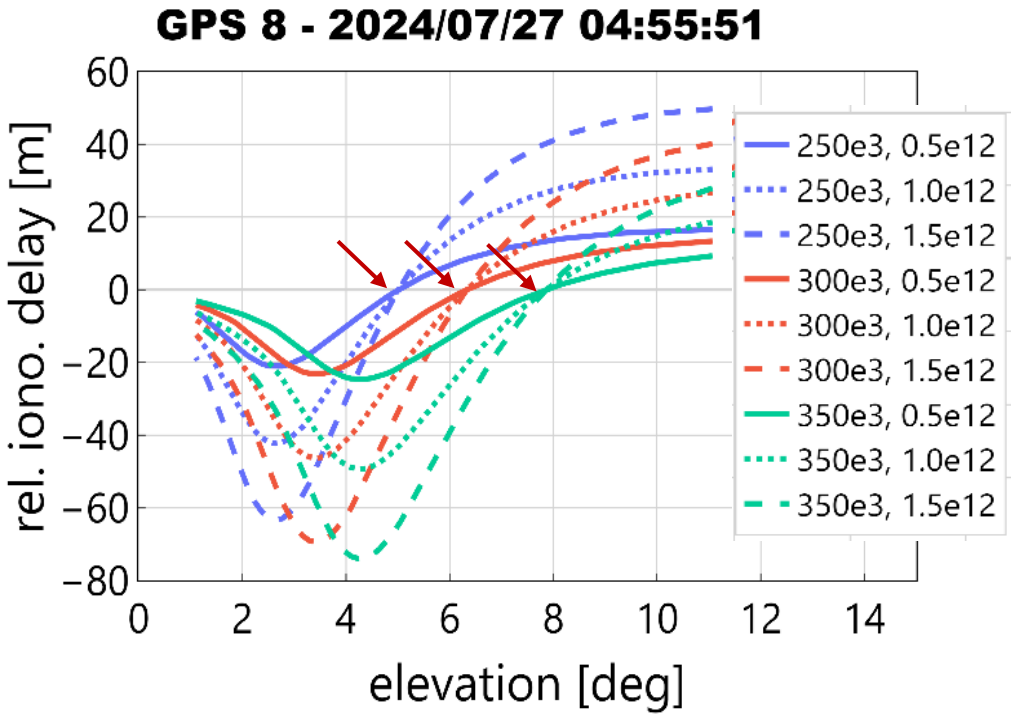


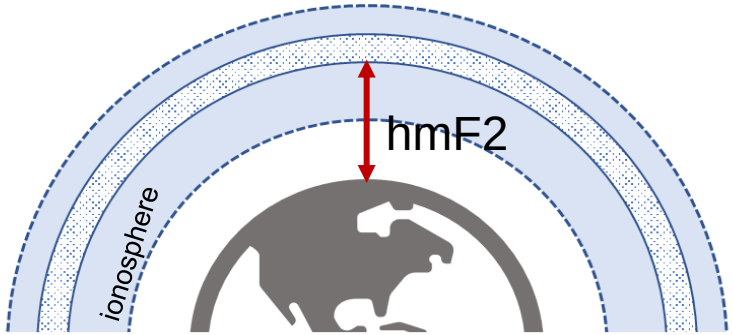
Ionospheric Peak Ne Height

Chapman Layer Simulation

$$N_e(h) = N_0 \cdot \exp\left(\frac{1}{2} * \left(1 - \left(\frac{h - h_m}{H}\right) - \exp\left(-\frac{h - h_m}{H}\right)\right)\right)$$







Date	GNSS – PRN	Elevation. [deg]	h_m [km]
2024/07/06	GAL – 7	6.83	317
2024/07/16	GAL – 7	6.41	303
2024/07/25	GPS – 4	7.20	330
2024/07/27	GPS – 8	6.85	318
2024/07/28	GPS – 8	8.29	367
2024/07/29	GPS – 8	7.44	338

Conclusions

From simulations:

- Making ionospheric corrections in GNSS reflectometry is challenging at grazing angles below 20° due to the increasing σ_{I_r}.
- Higher influence from Direct signal below 10° elevation.
- *Peak Ne Height:* Nighttime Hm is 10% ↑ than daytime Hm. Tropics most dynamic.

From Observations:

- Models accurately capture the atmospheric delay dynamics in the North Pole Region
- The direct signal contributes approximately 60% to the Relative Ionospheric Delay (E<10°)
- The cancellation point could provide valuable information about the height of the F-layer peak using GNSS-R code delay observations at grazing angles

Thank you!

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