Model-Based Analysis of Ionospheric Effects in Grazing Angle Reflectometry from Space

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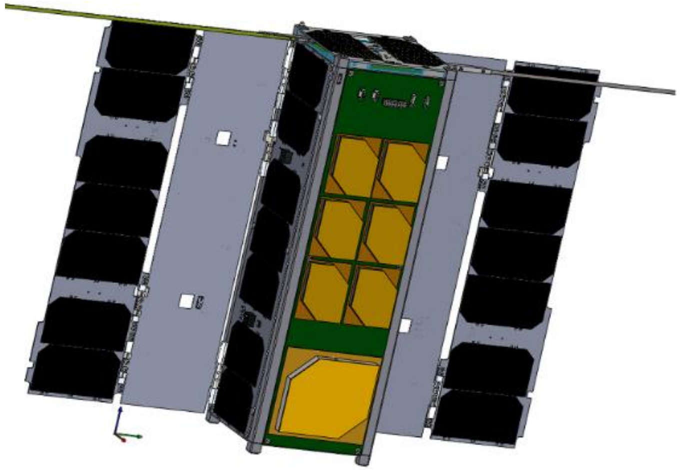


LISIC Laboratoire d'Informatique Signal & Image de la Côte d'Opale

GFZ Helmholtz Centre POTSDAM

TU berlin

Outline

- Airborne GNSS-R. Tropospheric study.
- Spaceborne GNSS-R. Ionospheric study.
- Grazing Angle Reflectometry: Ionospheric Effects Analysis
- Results
- Summary & Conclusions

Atmospheric Parameters (Troposphere)

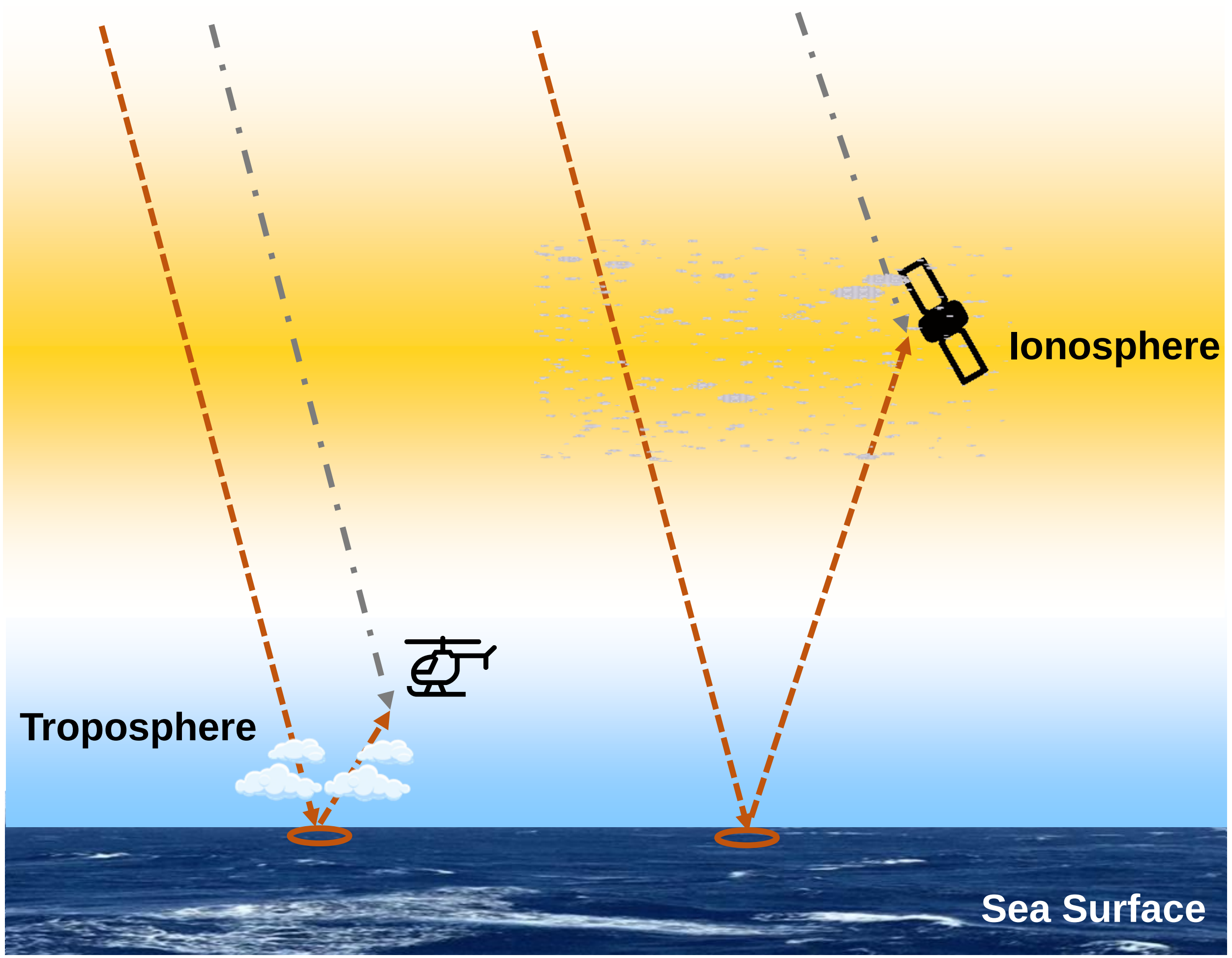
Airborne GNSS-R

Motivation: Impact Factors

1. Transmitter – Receiver Position
   Moving Platform
   Signal Re-tracking

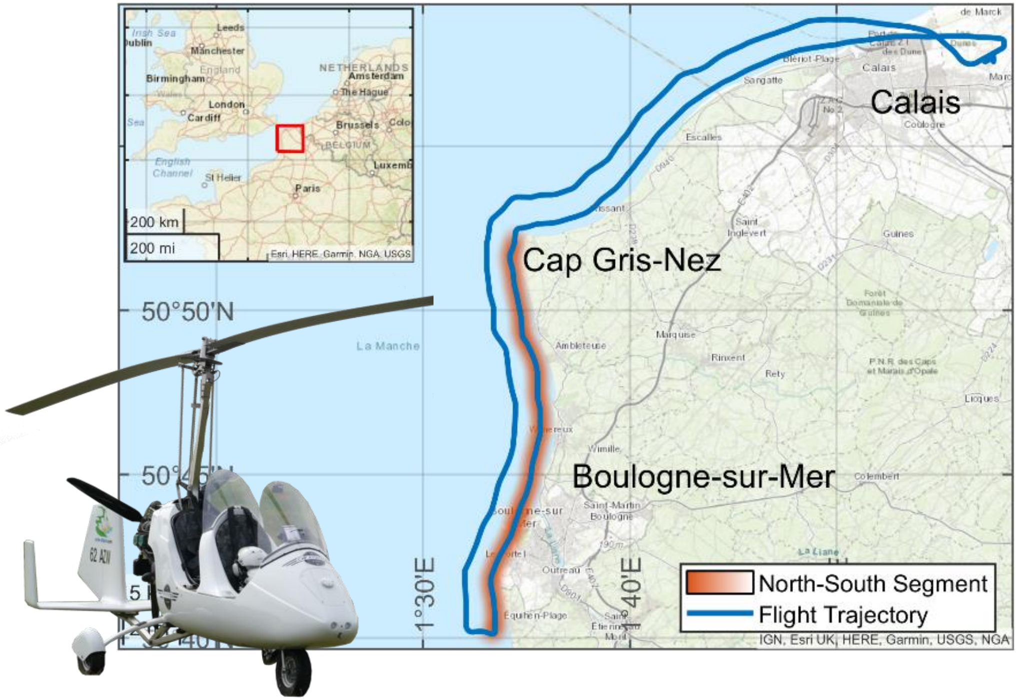
3. Tropospheric Parameter Inversion
   Zenith Total Delay
   Coherent Phase

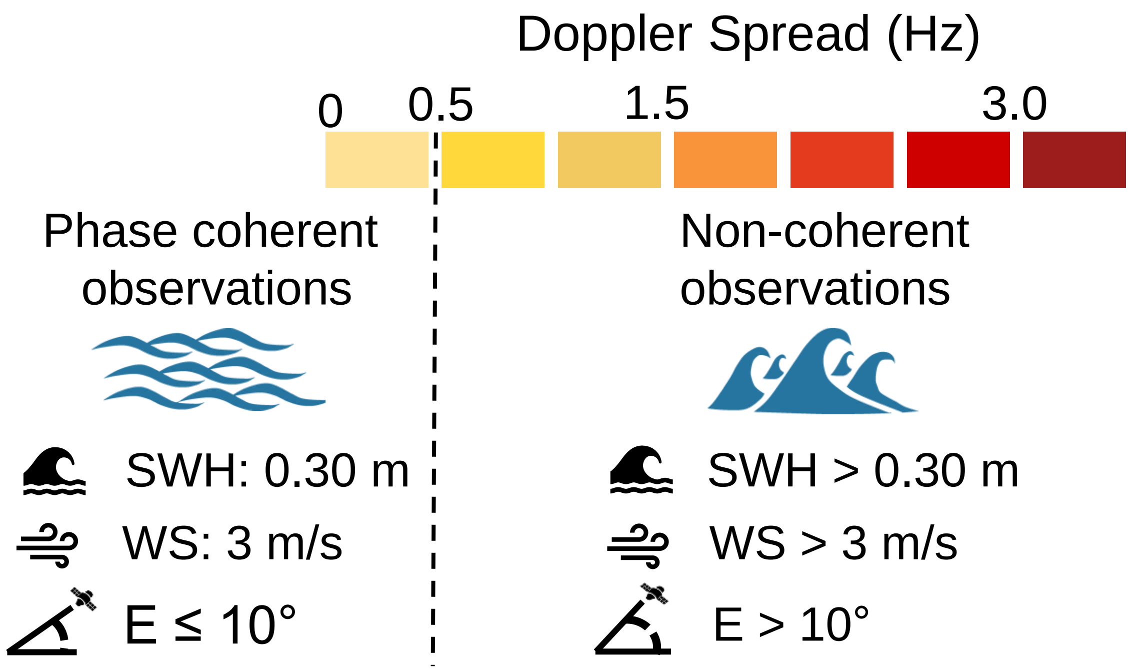
2. Surface Roughness – Sea State
   Doppler Spread



* Not to Scale

Zenith Total Delay – Airborne GNSS-R Results





Location: North Sea (Calais, France)
Flights Altitude: 750 m.a.s.l.
Date: July 2019

Expected ZTD: 2.3 m

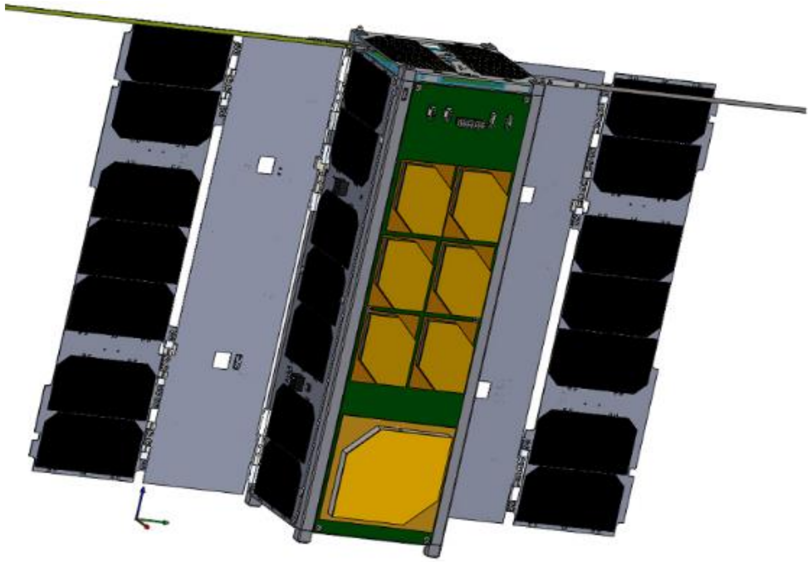
GNSS-R ZTD: 2.4 and 2.8 m

Atmospheric Parameters (Ionosphere)

Spaceborne GNSS-R

Background – PRETTY Mission

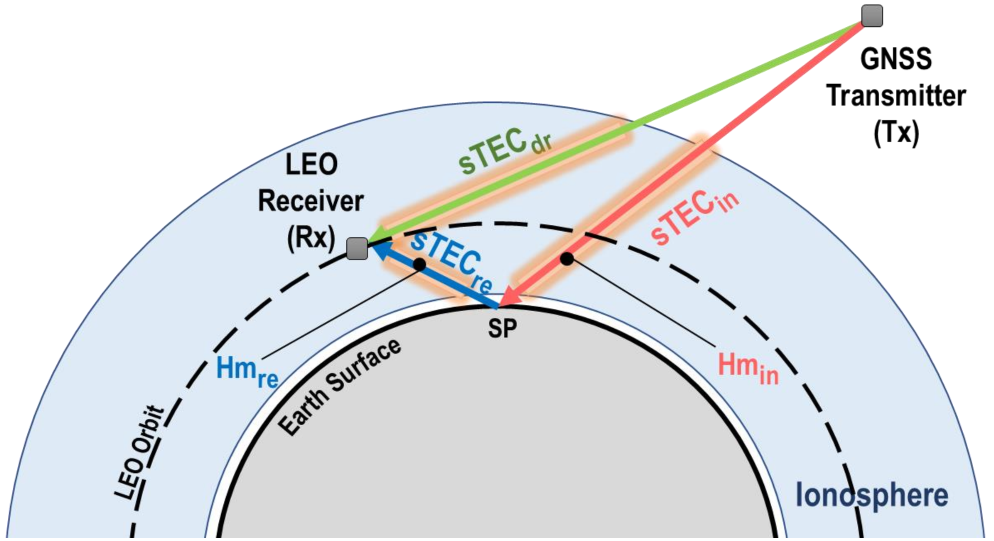
(**P**assive **RE**flec**T**ometry and dosime**T**r**Y**)
Launch: 09 Oct 2023

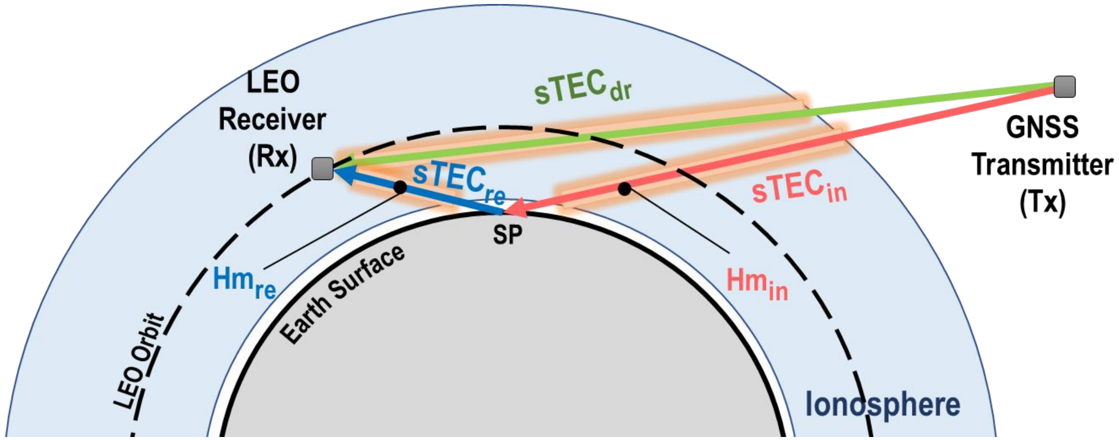


CubeSat mission
Orbit: SSO, altitude 560 km
Size: 30cm x 10cm x 10cm

Background – PRETTY Mission

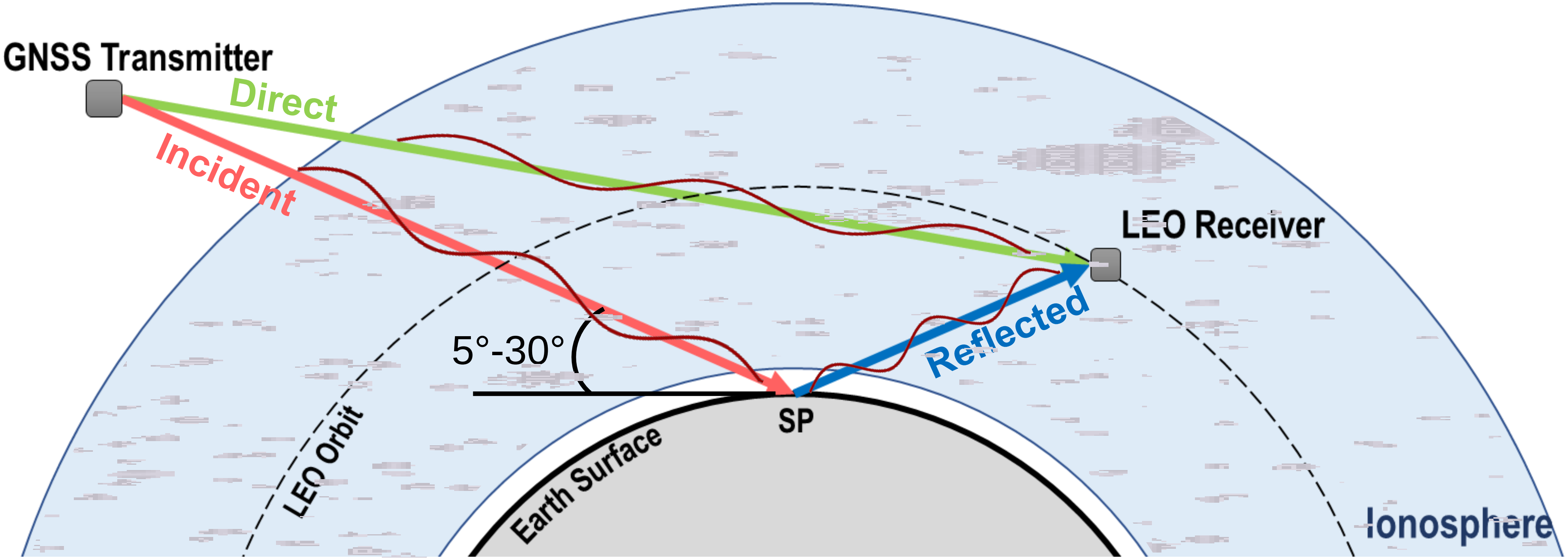
- **Grazing angles** observations for global altimetric concept.
- Precise **phase observations** are expected at low elevation angles.
- At low elevation angles, the **effects of the atmosphere increases** due to the longer propagation path.





Introduction – Motivation

① Relative Ionospheric Delay

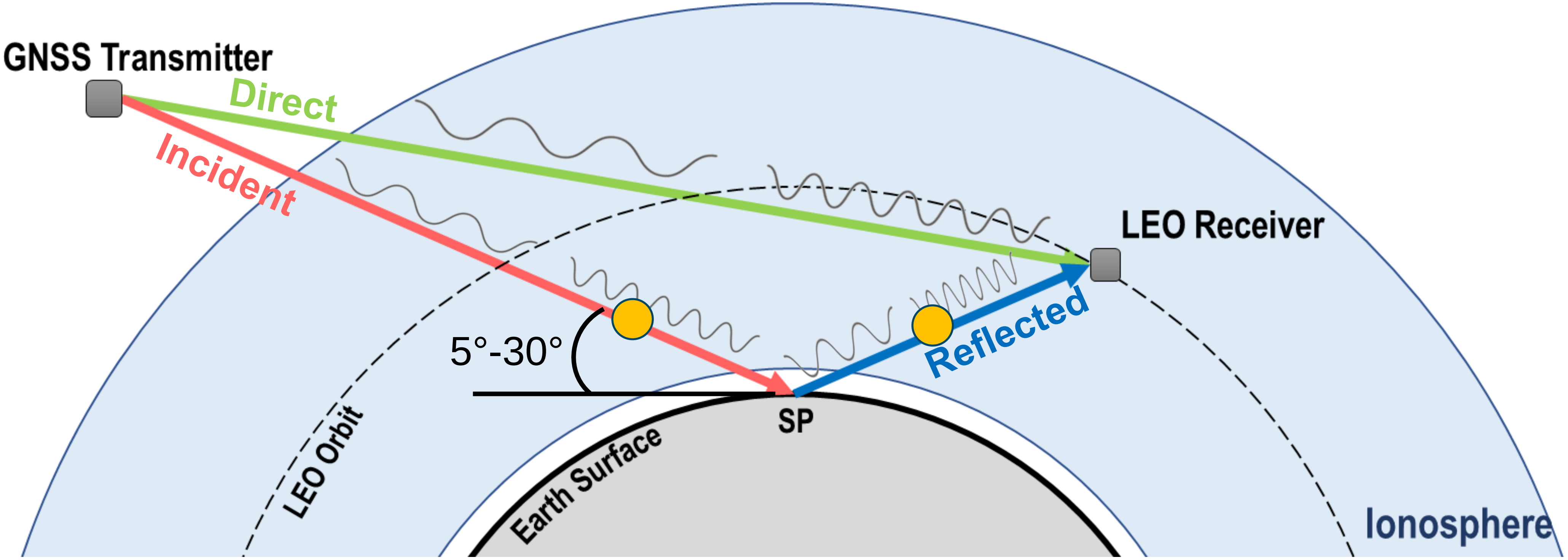


Introduction – Motivation

1 Relative Ionospheric Delay

2 Doppler Shift

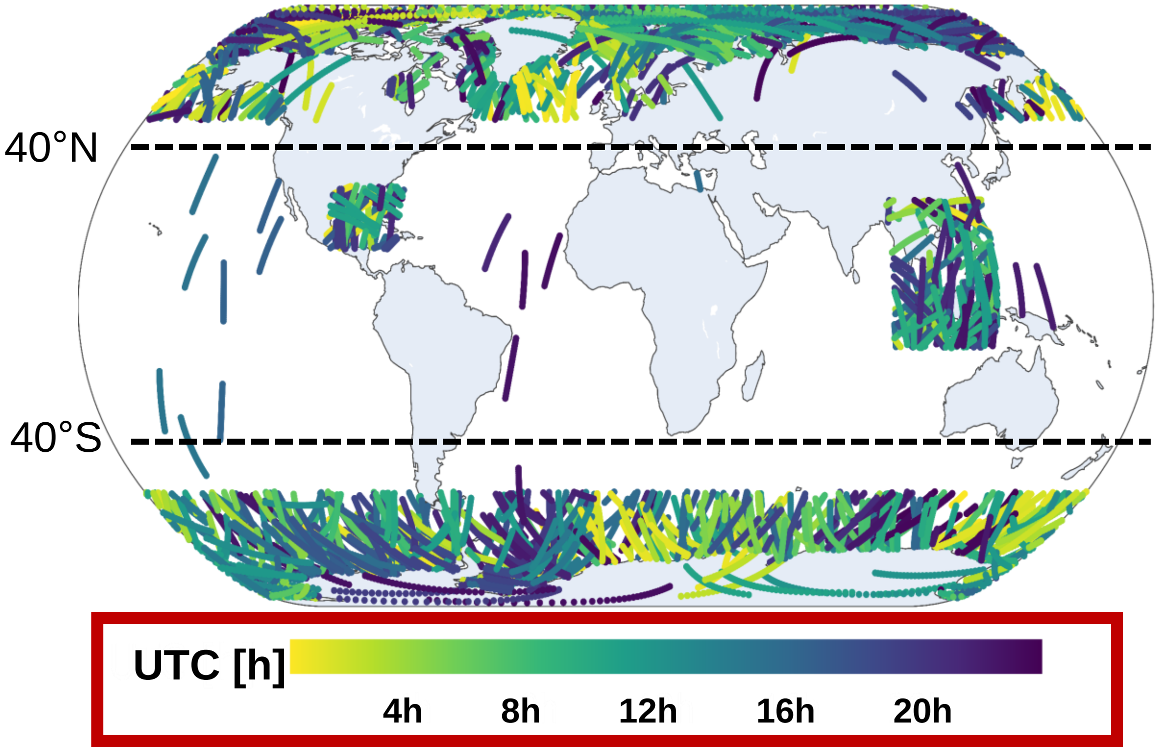
3 Peak Ne Height



Grazing Angle Reflectometry:
Ionospheric Effects Analysis

Orbit Data

Specular Points Tracks

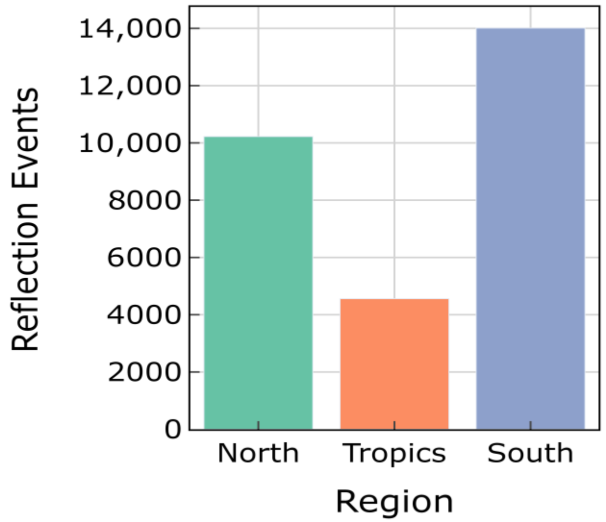


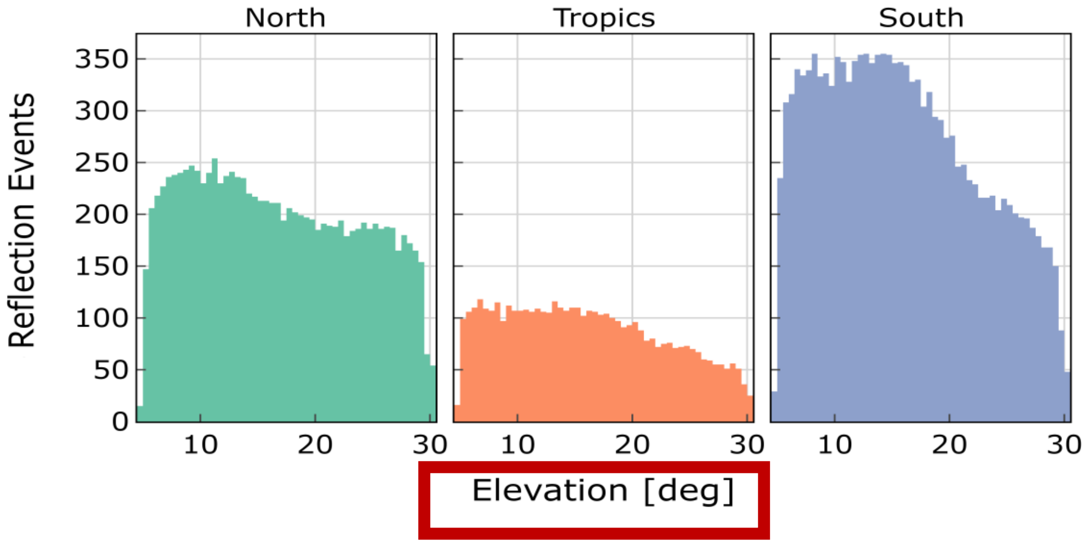
GNSS Constellation: GPS.

LEO Orbit data: Spire Global CubeSat LEMUR-2.

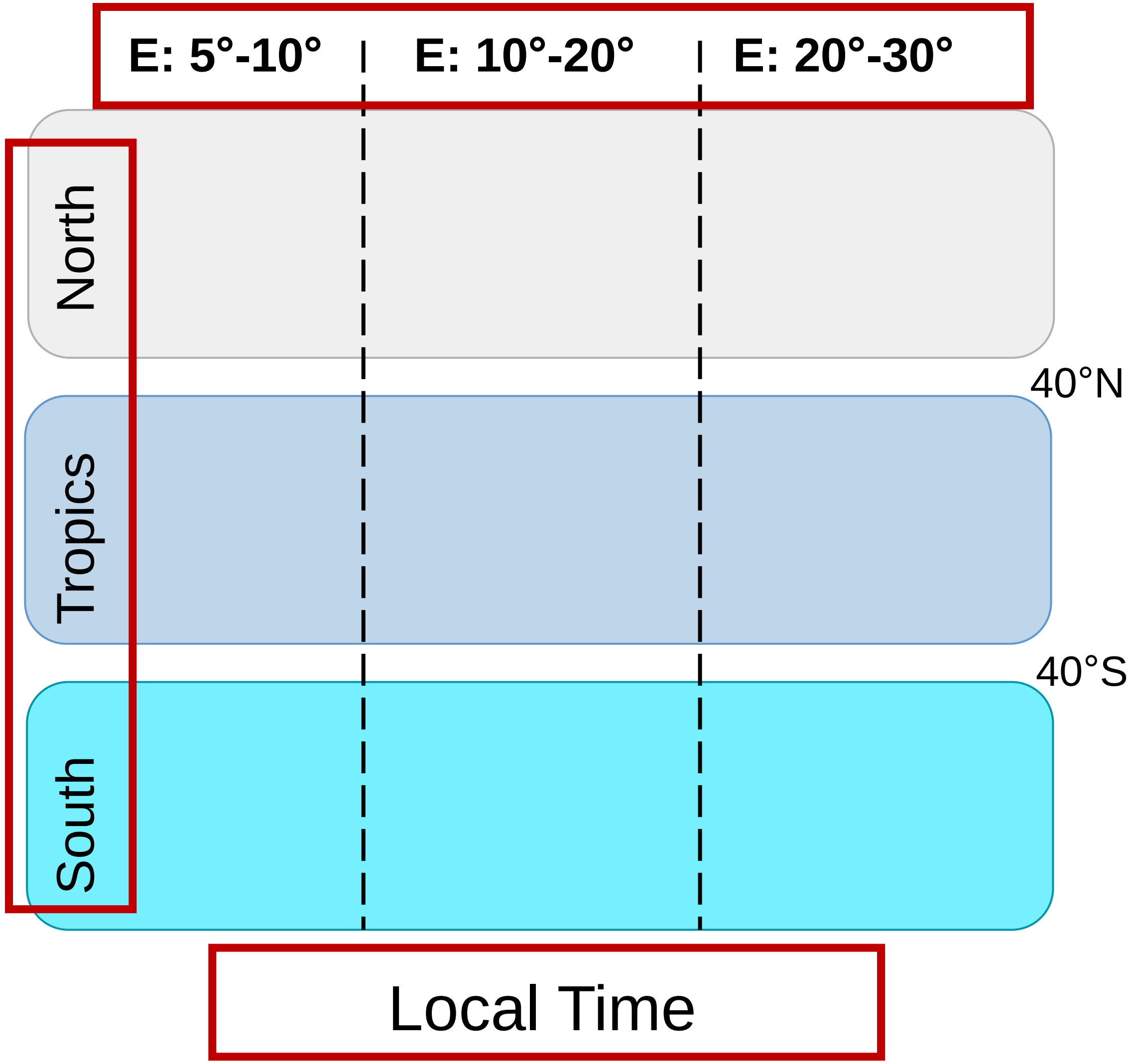
Earth Model: Osculation sphere.

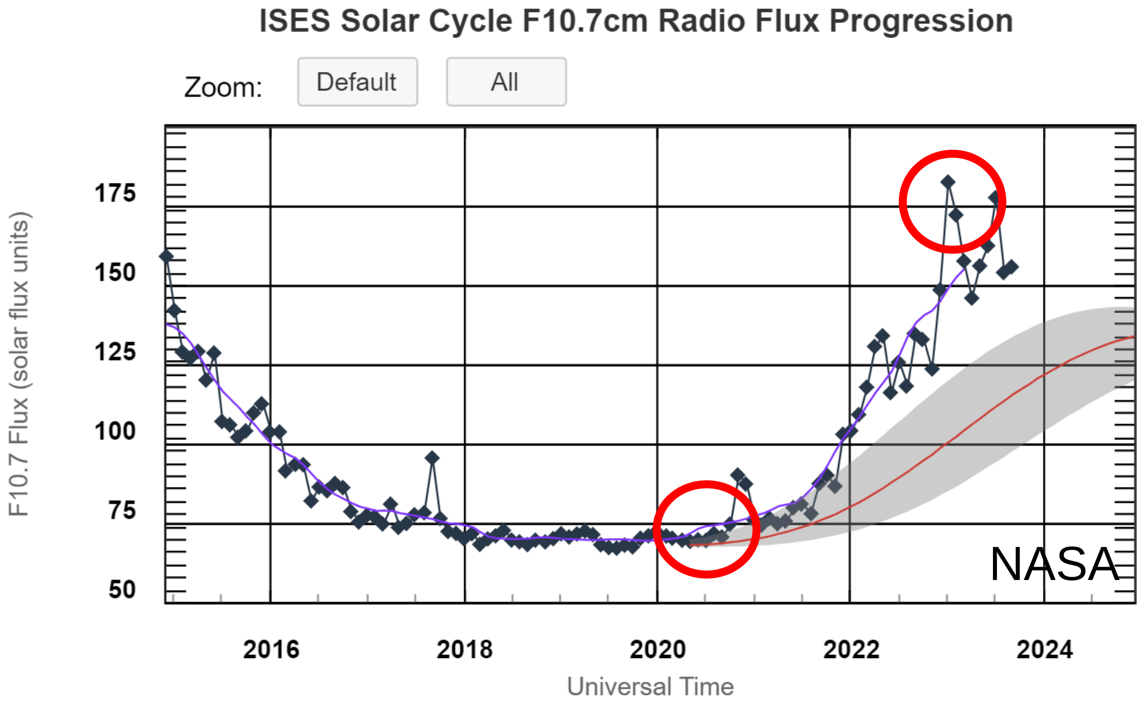
Date: 01.03.2021





Objective





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

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

Electron Density Models

Neustrelitz Electron Density Model (NEDM2020) DLR-SO.

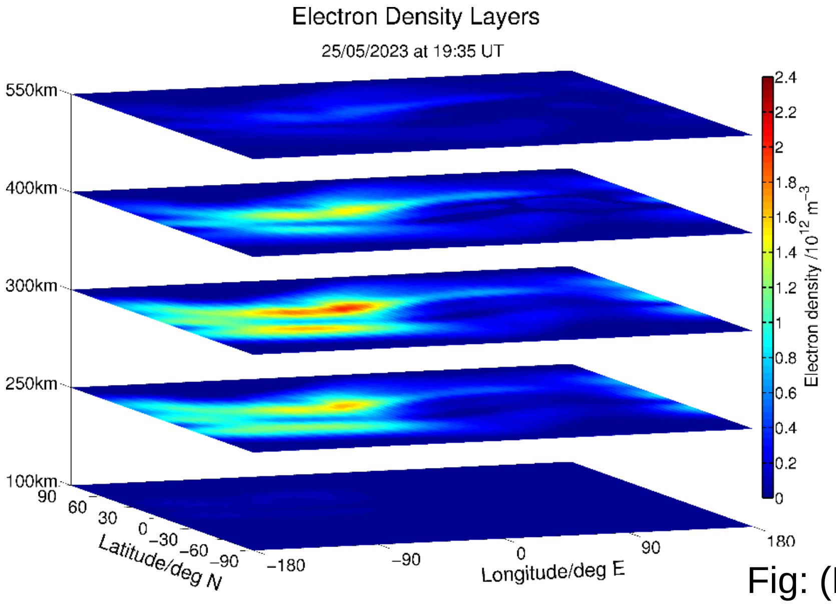


Fig: (DLR – IMPC)

(Hoque, M. et al., 2022)

NeQuick Model T/ICT4D Laboratory

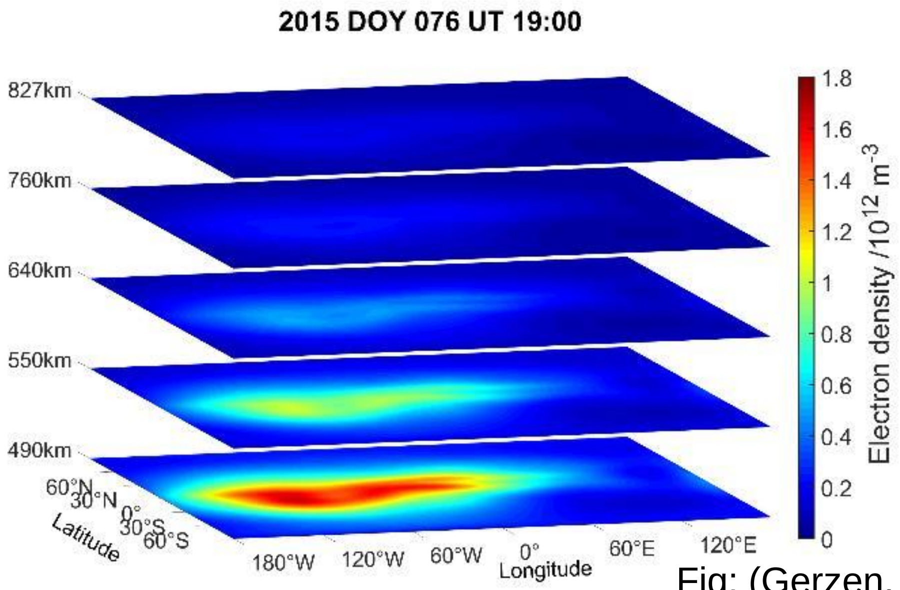


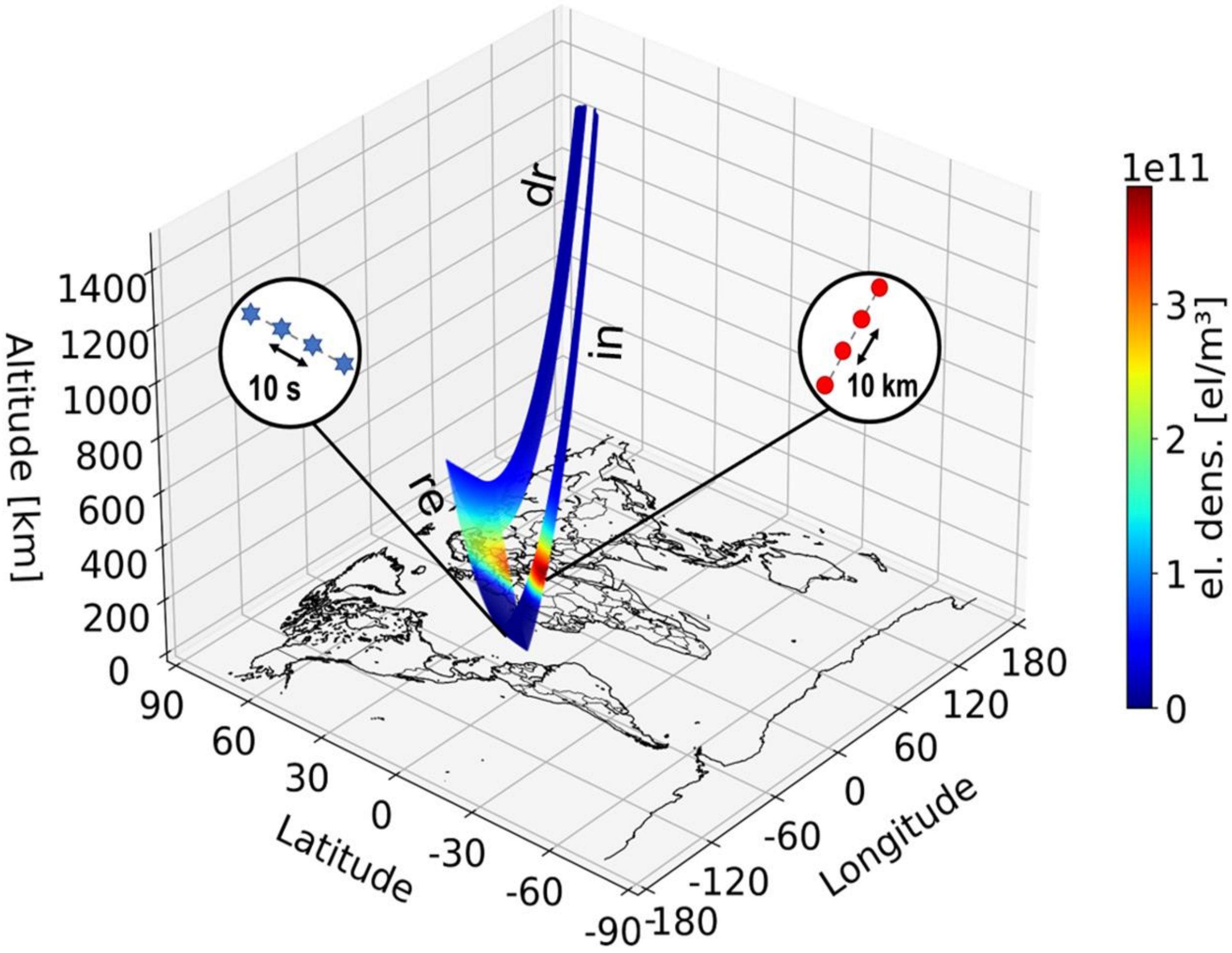
Fig: (Gerzen, T. et al., 2020)

(Nava, B. et al., 2008)

Three-dimensional and time dependent **Ionospheric Electron Density** models

Both are used to determine Galileo **single-frequency ionospheric corrections**

Simulation Setup



$$sTEC_x = \int_{alongray} N_e dl$$

⇩

$$\frac{sTEC_{in} + sTEC_{re} - sTEC_{dr}}{\Delta sTEC}$$

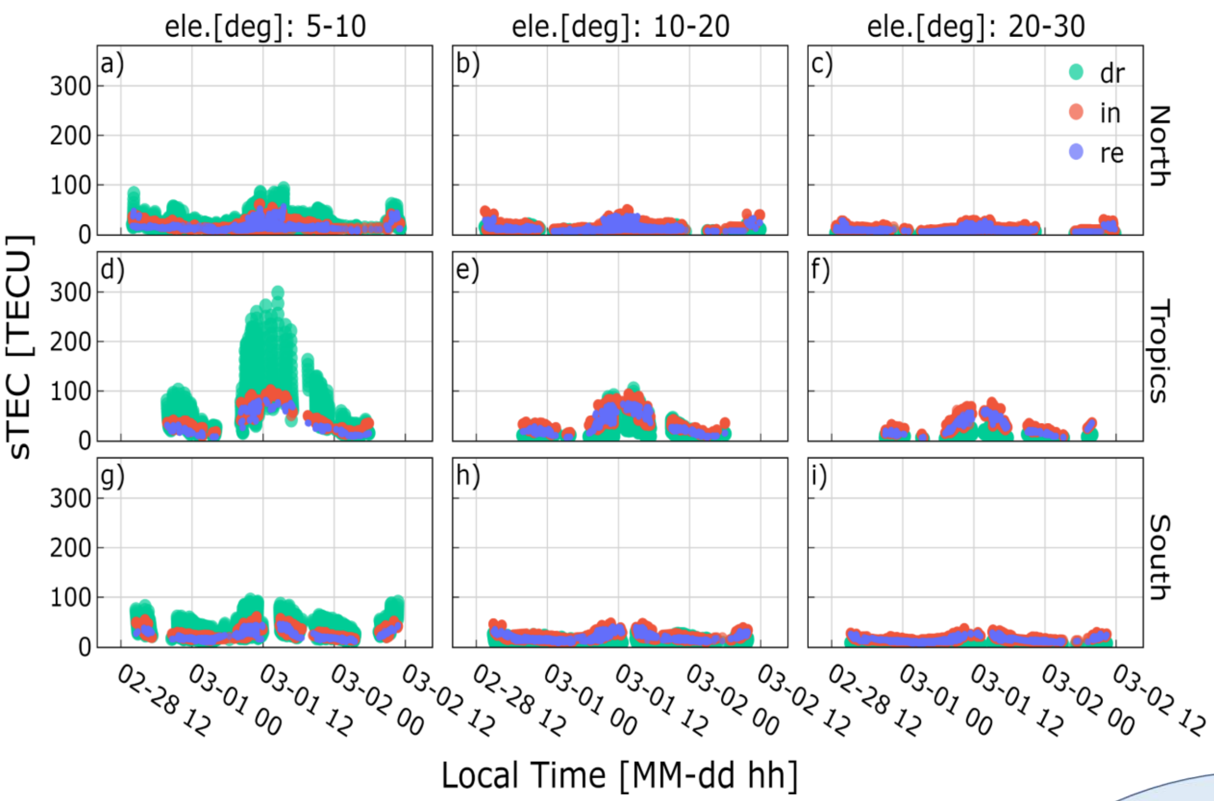
⇩

$$I_r = \frac{40.3}{f^2} \Delta sTEC \text{ with } f = GPS\ L1$$

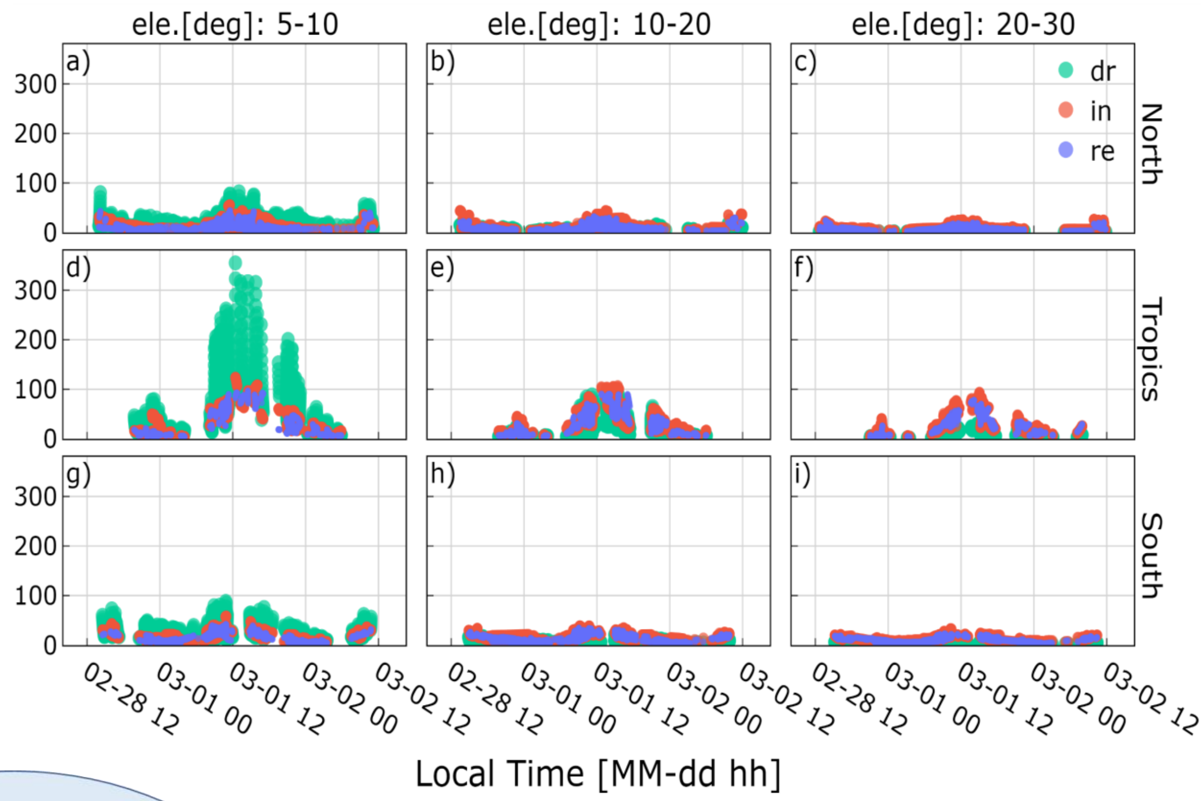
Ionospheric Effects Analysis: Results

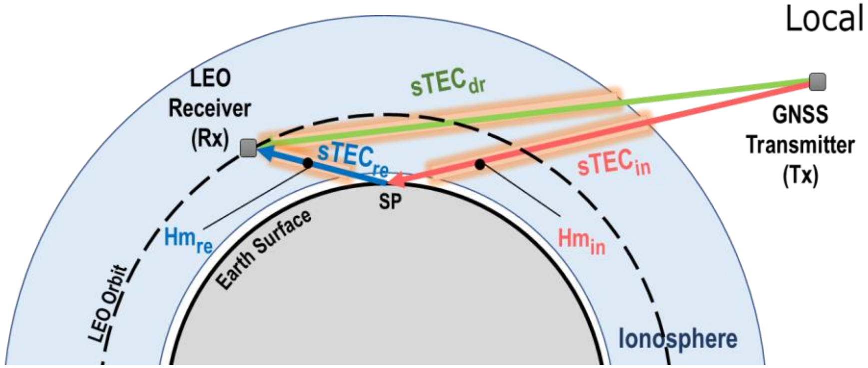
Results - slant Total Electron Content (sTEC)

NEDM2020



NeQuick

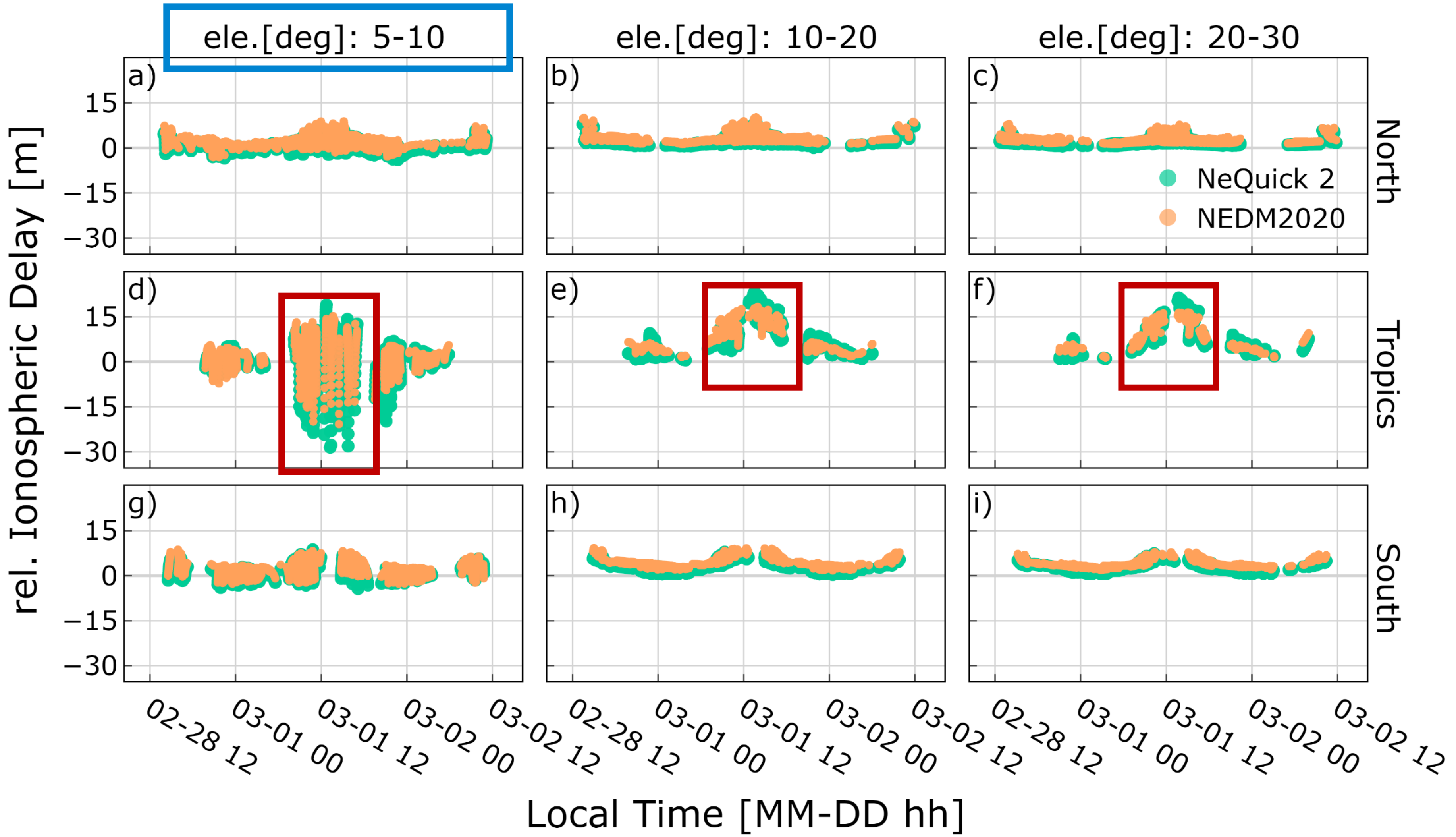




Results - Relative Ionospheric Delay

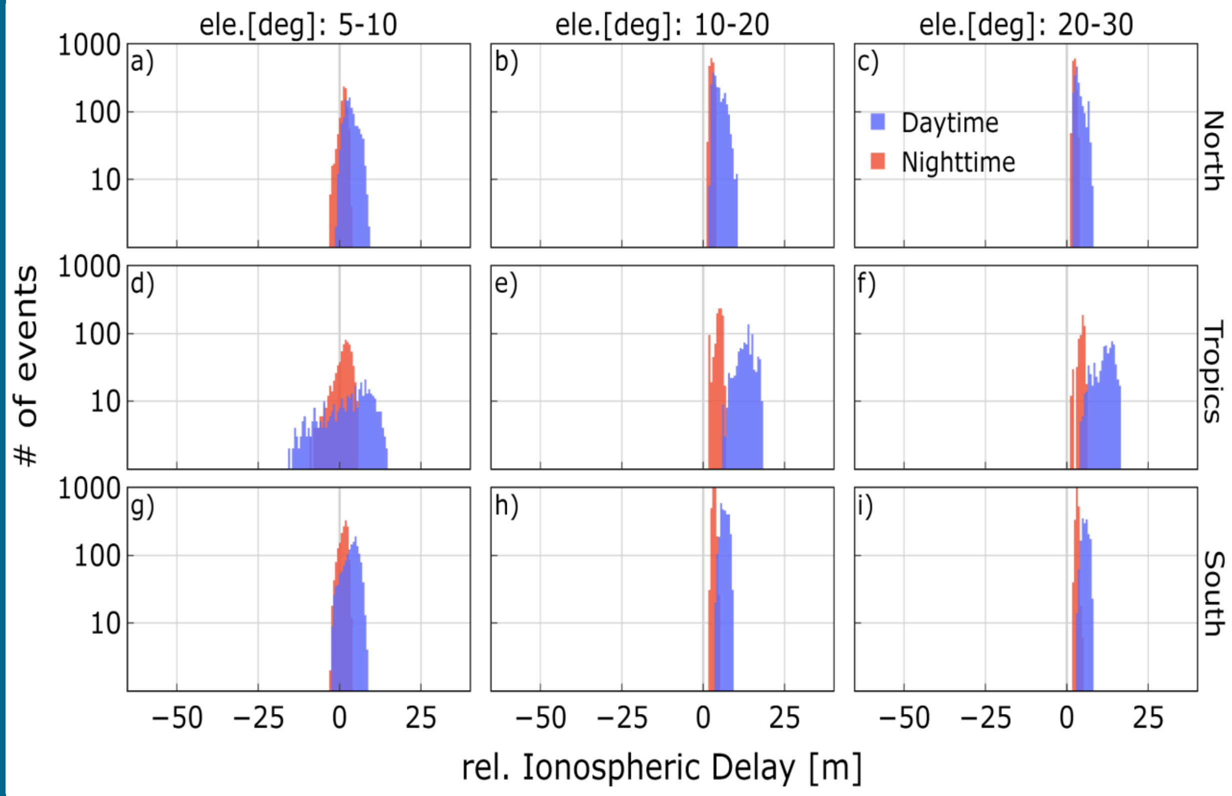
①

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

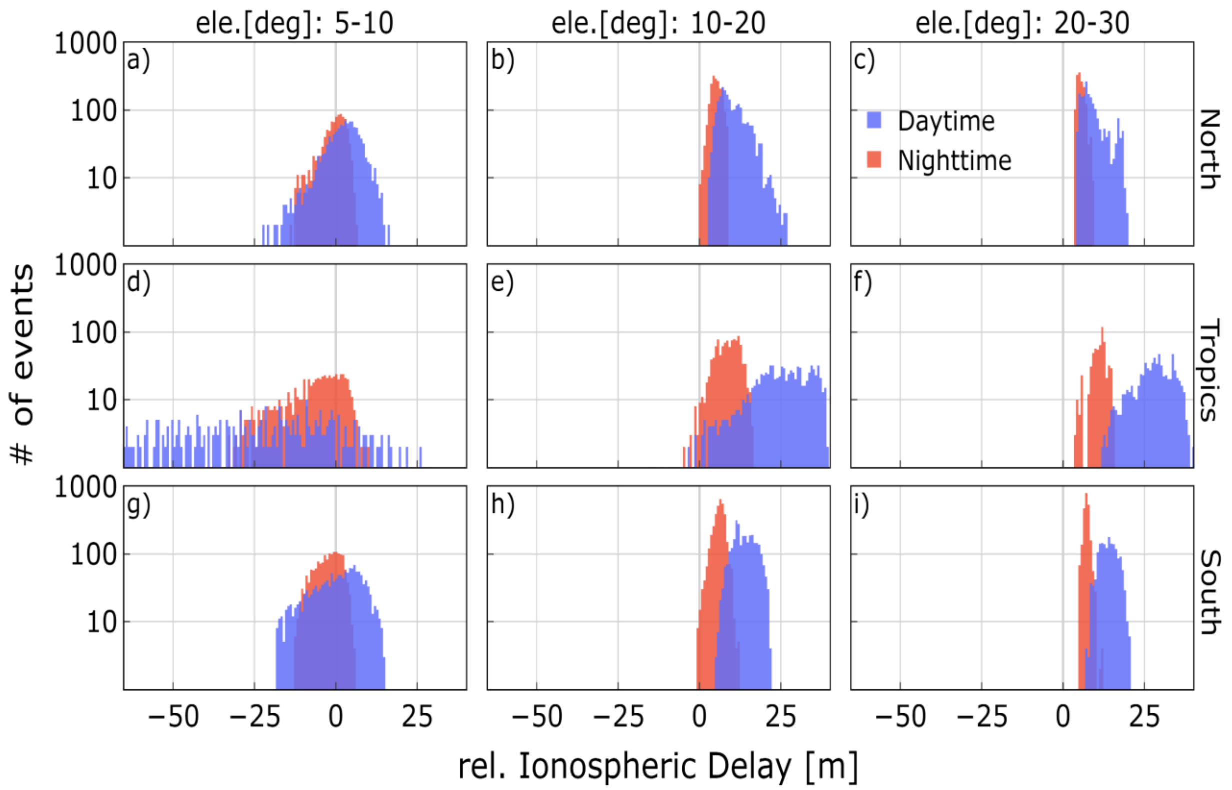


Results - Relative Ionospheric Delay ①

NEDM
F10.7 = 75

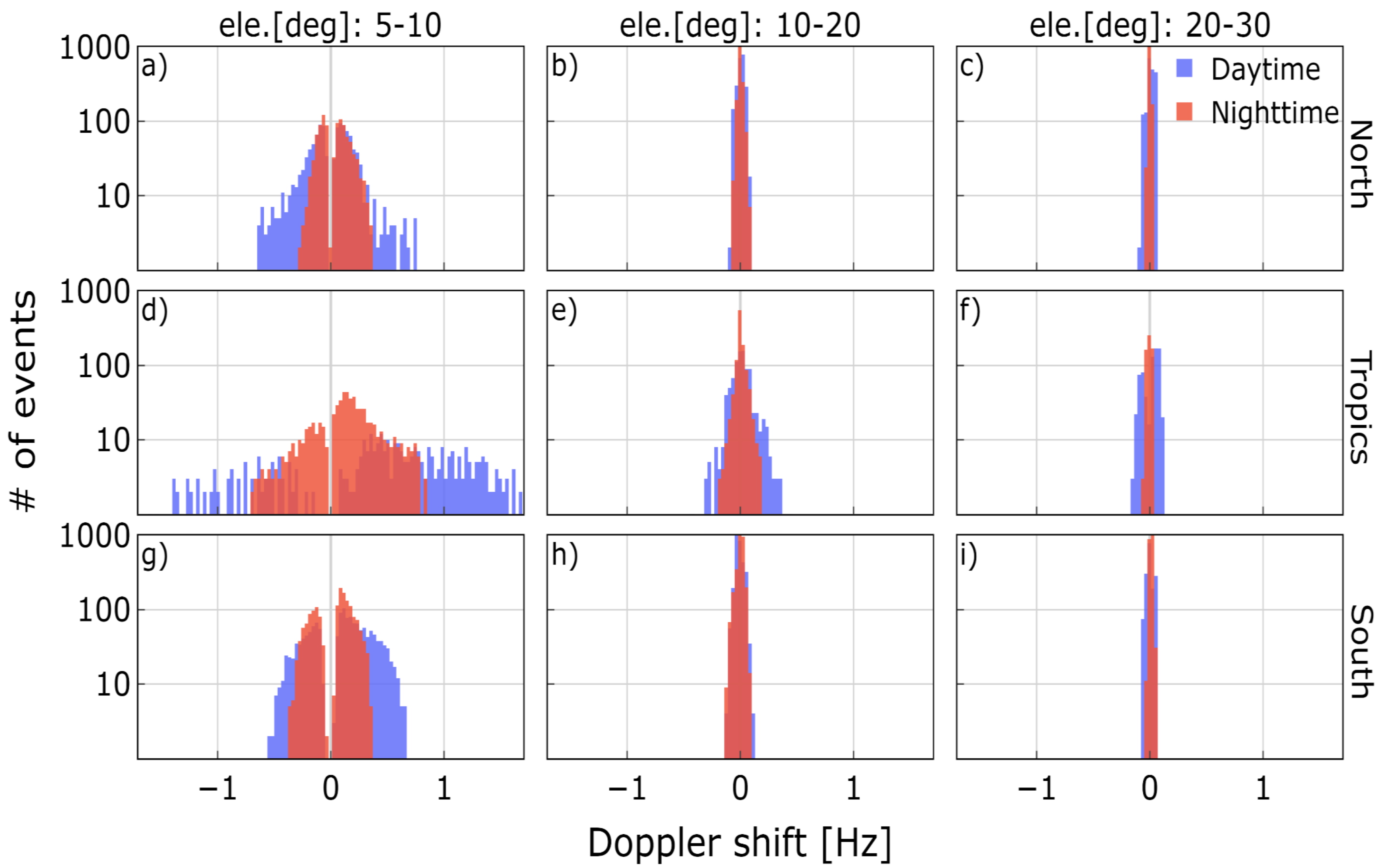


NEDM
F10.7 = 180



Results - Doppler Shift ②

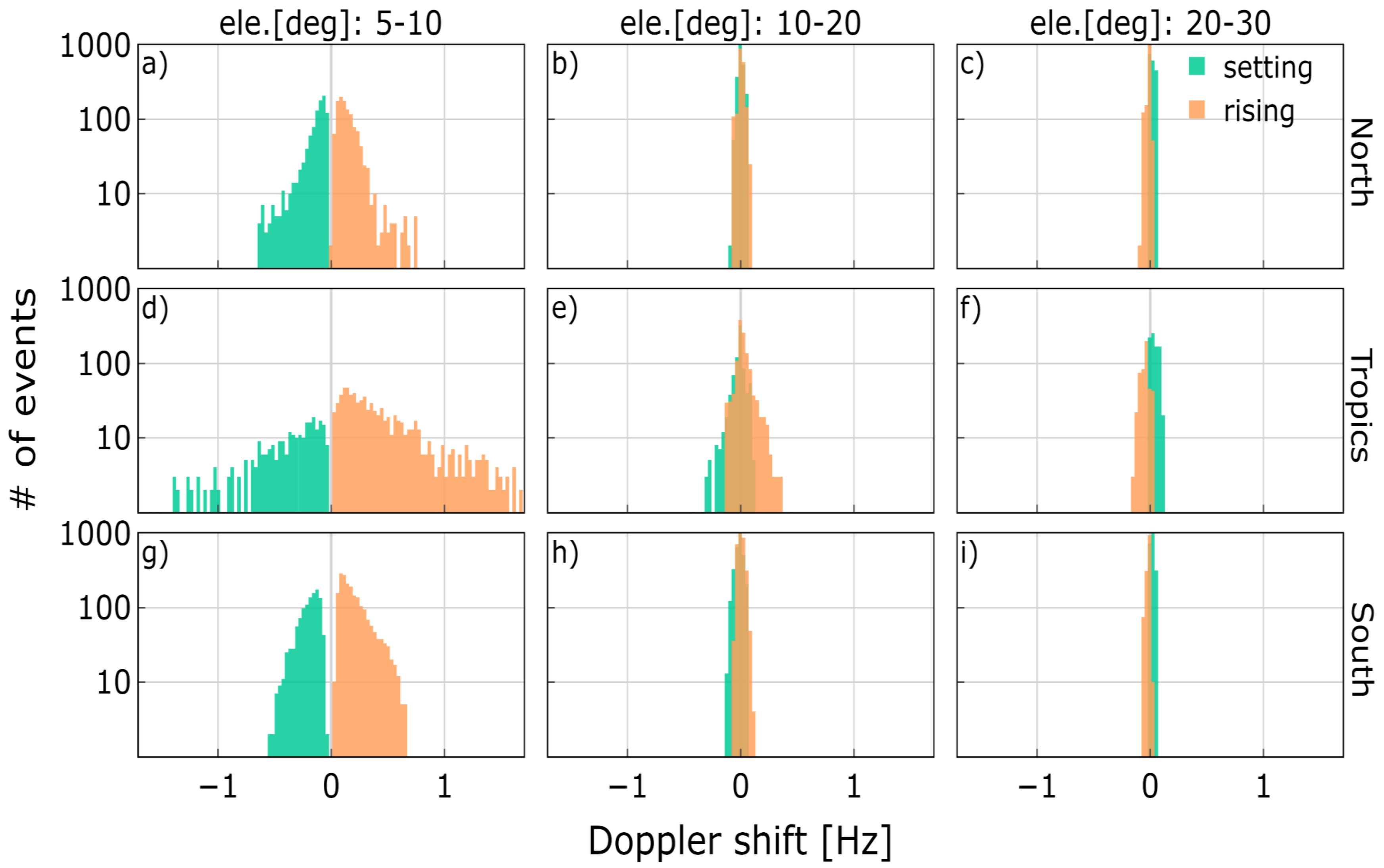
$$f_d = d\phi/dt$$

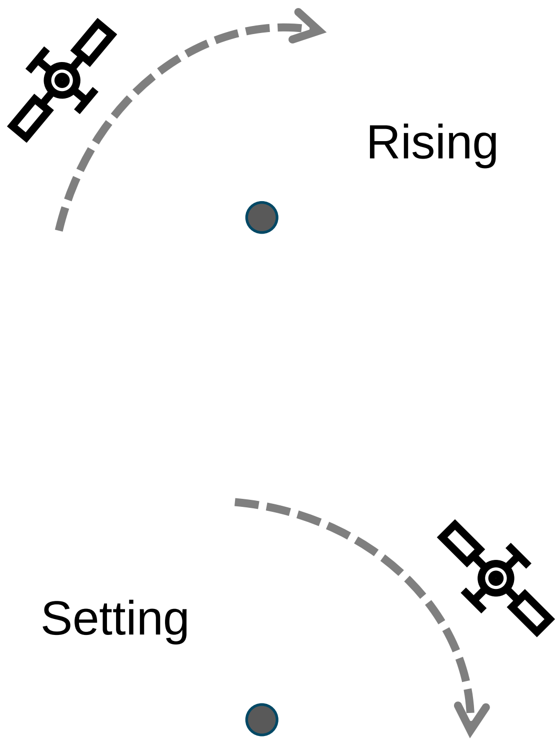


For F10.7 = 180
$f_d = \pm 4\ Hz$

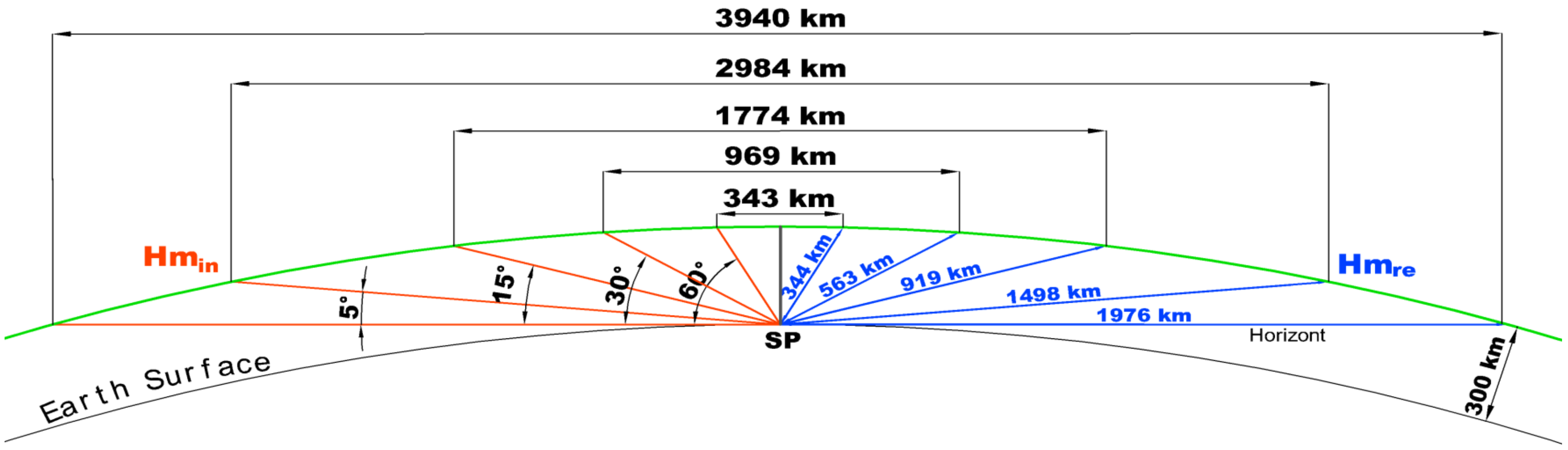
Results - Doppler Shift ②

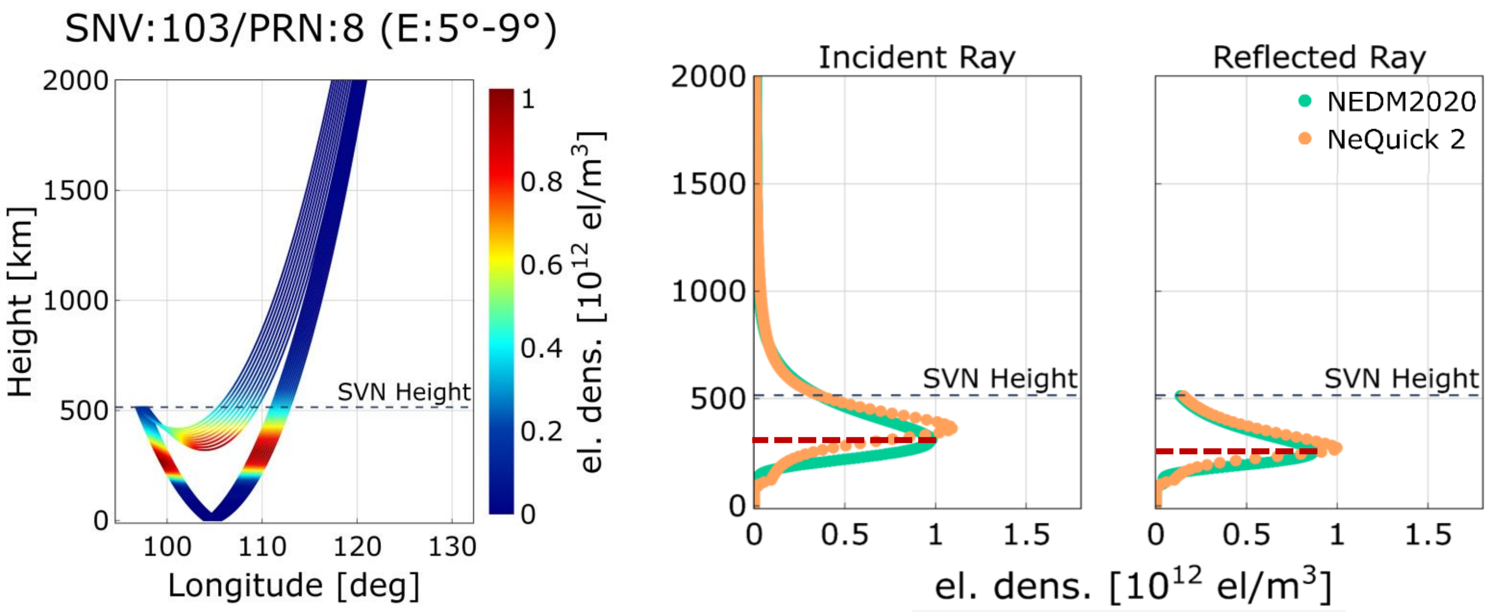
$$f_d = d\phi/dt$$



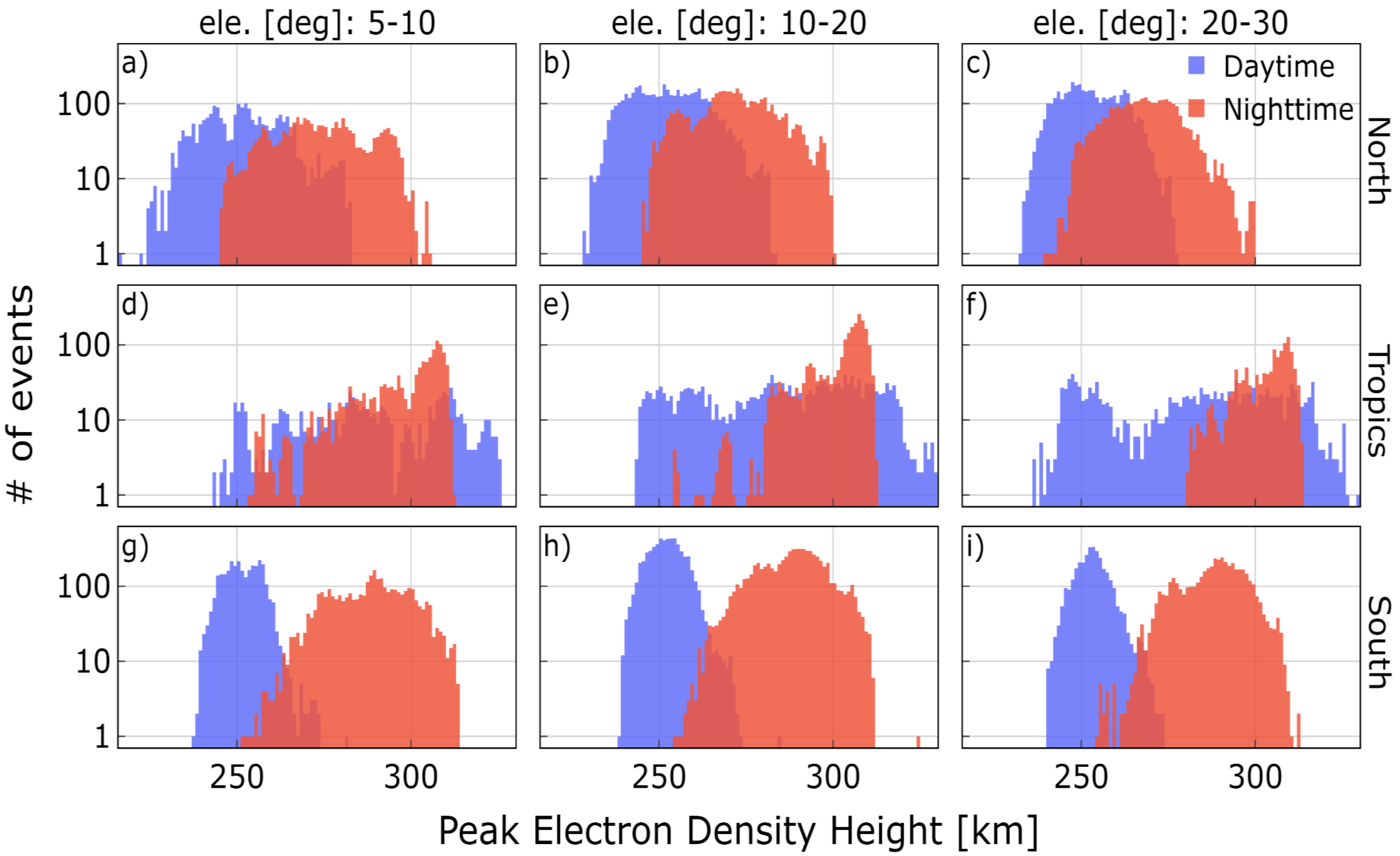


Results - Peak Electron Density Height ③

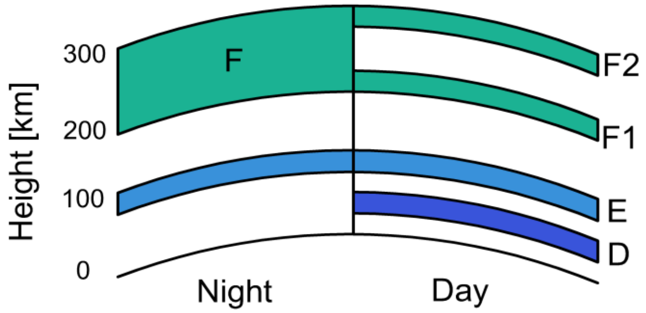




Results - Peak Electron Density Height ③



During Nighttime
H_m: 10% ↑



Summary & Conclusions

Summary Table Results

		Very-low: 5°-10°			Low: 10°-20°			Mid-low: 20°-30°		
		I_r [m]	$\|f_d\|$ [Hz]	Hm [km]	I_r [m]	$\|f_d\|$ [Hz]	Hm [km]	I_r [m]	$\|f_d\|$ [Hz]	Hm [km]
North										
DT	median	3.10	0.133	251.7	4.35	0.022	252.3	3.33	0.026	252.2
	std	1.96	0.142	11.7	1.81	0.019	10.5	1.44	0.021	8.5
NT	median	1.38	0.097	274.0	2.61	0.009	271.9	2.27	0.011	268.3
	std	1.19	0.067	12.9	0.60	0.014	11.6	0.47	0.006	9.7
Tropics										
DT	median	3.96	0.729	287.9	13.50	0.048	287.4	12.12	0.067	285.3
	std	7.57	0.415	21.4	2.61	0.070	22.4	2.87	0.028	23.8
NT	median	1.63	0.219	302.6	4.95	0.016	305.4	4.74	0.014	305.4
	std	2.82	0.195	13.1	1.18	0.033	9.1	1.05	0.013	7.3
South										
DT	median	3.98	0.220	252.2	6.49	0.030	252.2	5.63	0.014	253.1
	std	2.26	0.138	5.2	1.15	0.021	5.2	1.02	0.022	4.9
NT	median	1.41	0.145	289.0	3.36	0.012	288.8	3.17	0.015	289.1
	std	1.27	0.073	11.2	0.48	0.021	9.8	0.40	0.007	9.2

Conclusions

At grazing angle regime below 20°:

1. ***Relative Ionospheric Delay***: The median I_r ↓ but σ_{I_r} ↑
2. ***Doppler shift***: The median f_d ↑ and σ_{f_d} ↑

Challenging correction in GNSS reflectometry.

3. ***Peak Ne Height:*** Nighttime Hm is 10% ↑ than daytime Hm. Tropics most dynamic.

Even in the presence of ionospheric delay bias, precise relative **altimetry** at the **centimeter level** can be achieved by using **coherent phase observations**.

Thank you for your attention

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