A Fresh View of Global Atmosphere and Ionosphere from the Combined GNSS-RO (Radio Occultation) Constellations

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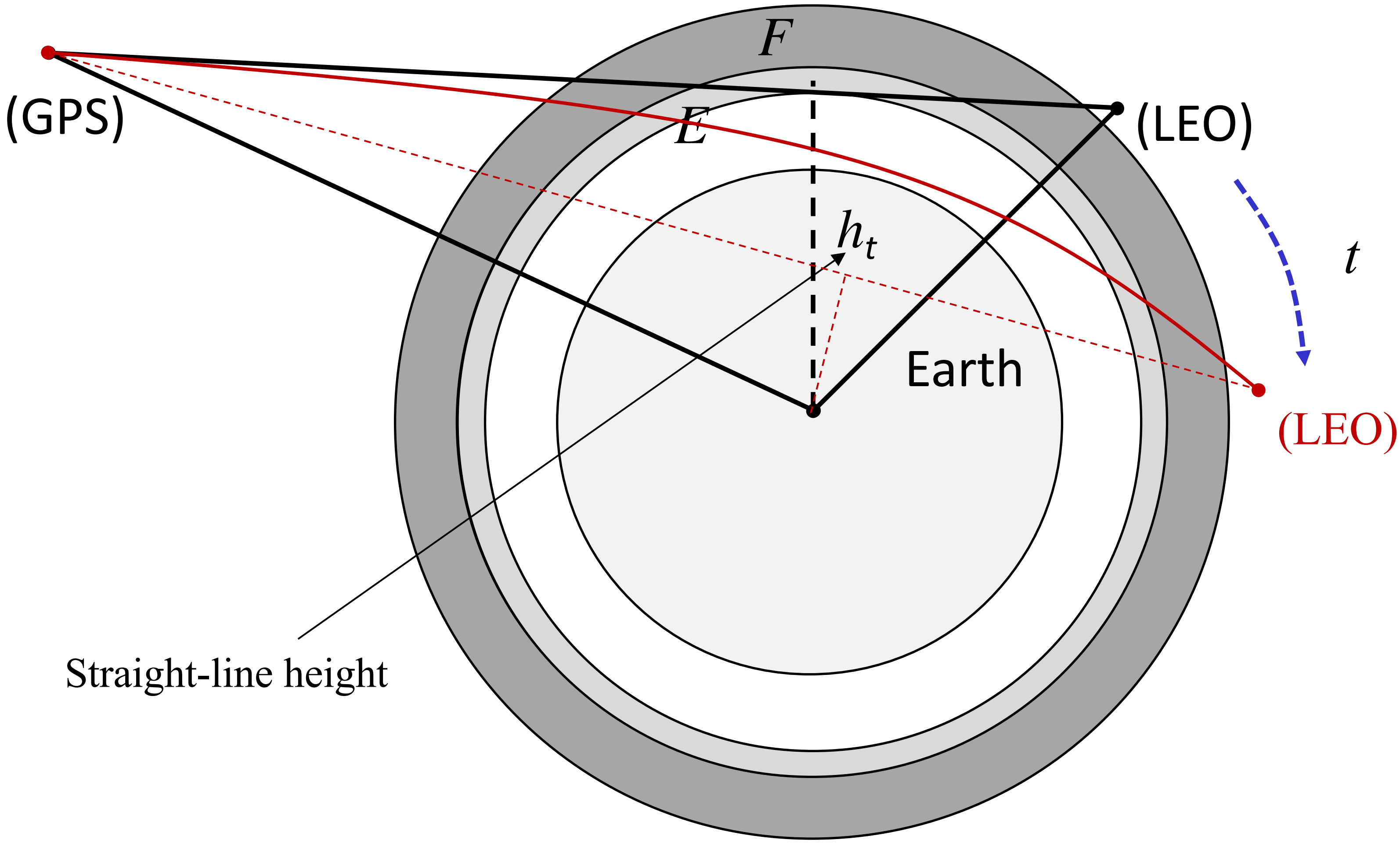
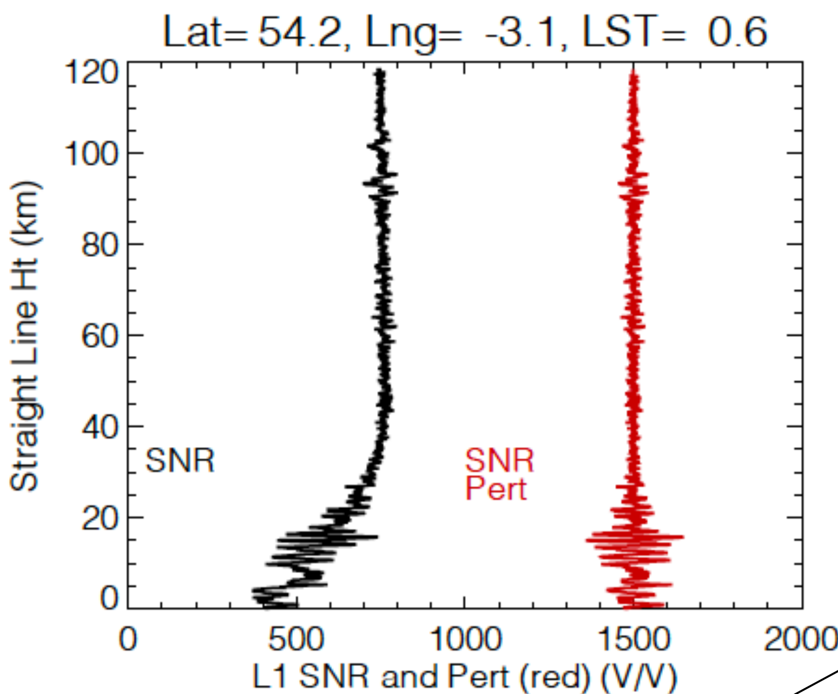
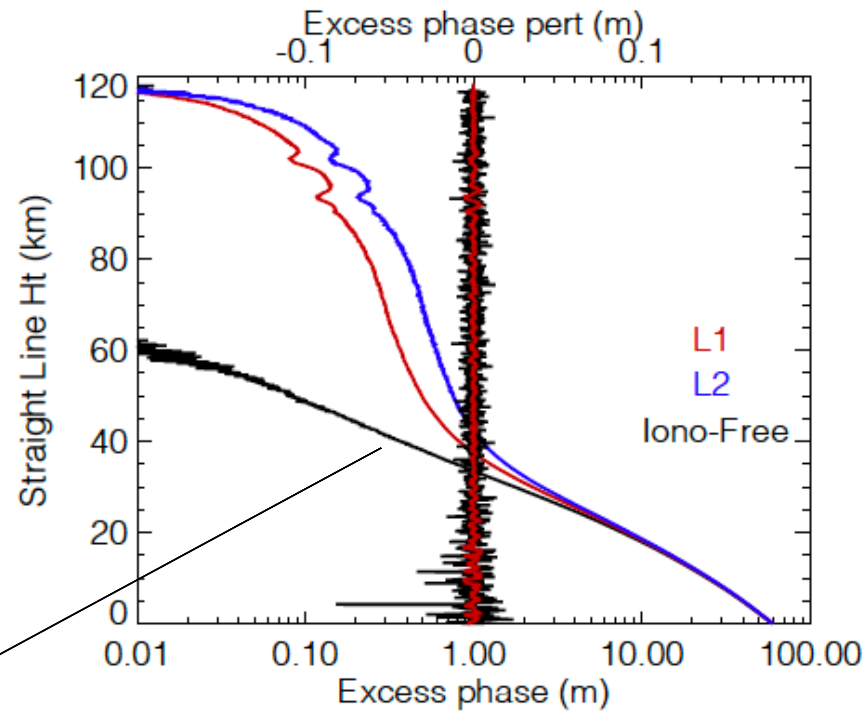
Global Navigation Satellite Systems (GNSS)
Radio Occultation (RO)



RO Amplitude



RO Excess Phase

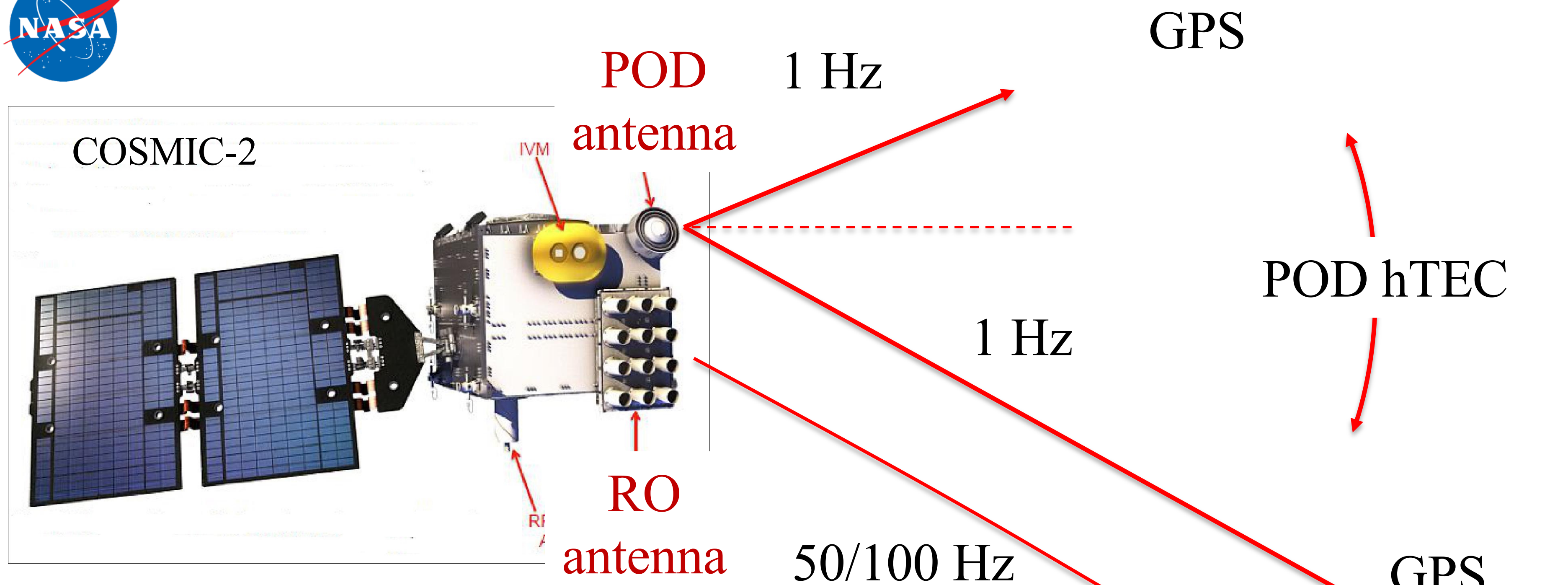


$$N = (n-1)\times 10^6 = \underbrace{76.6\frac{P}{T}}_{\text{Operation}} + \underbrace{3.73\times 10^5\frac{P_w}{T^2} - 4.03\times 10^7\frac{n_e}{f^2} + o(IWP, f^3, f^4)}_{\text{Research}}$$

Operation

Research

Wu (Remote Sensing, 2020)

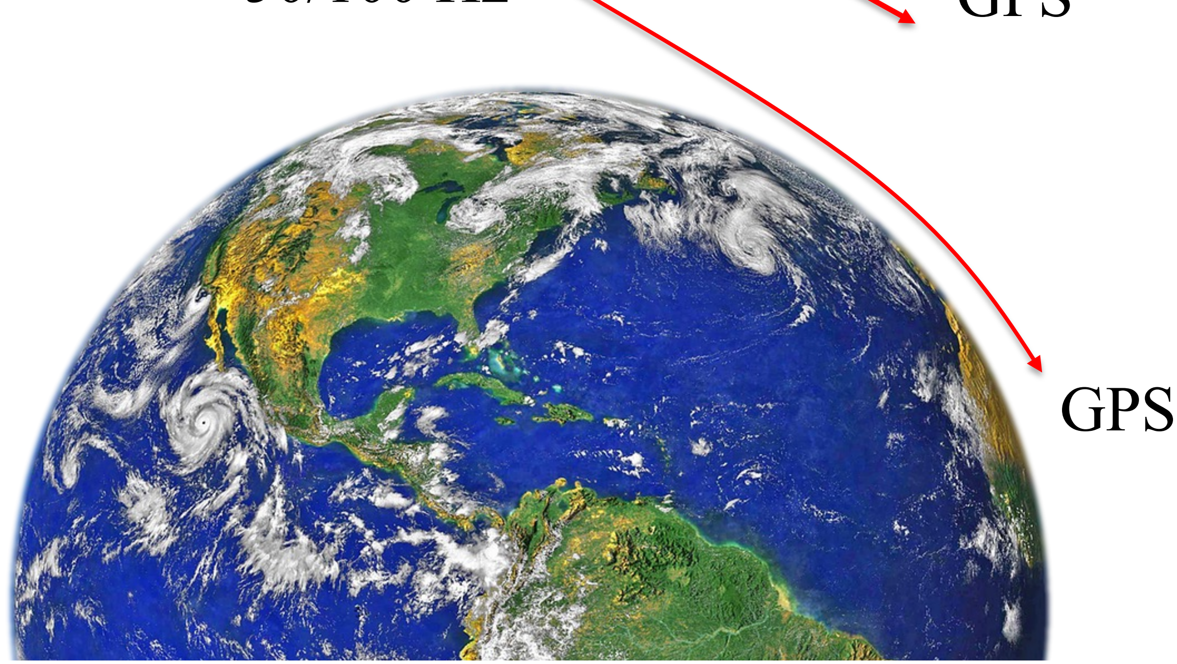


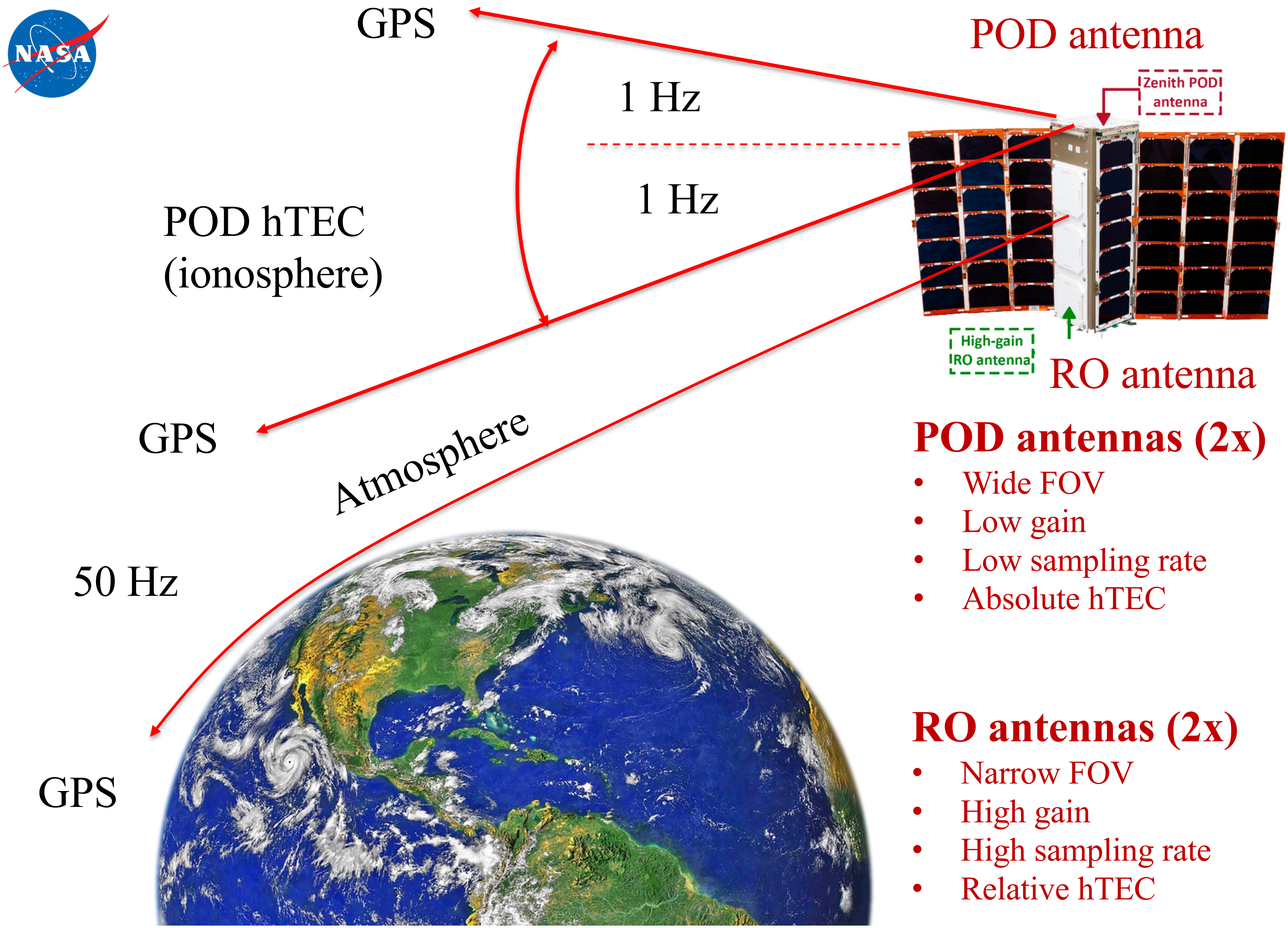
POD antennas (2x)

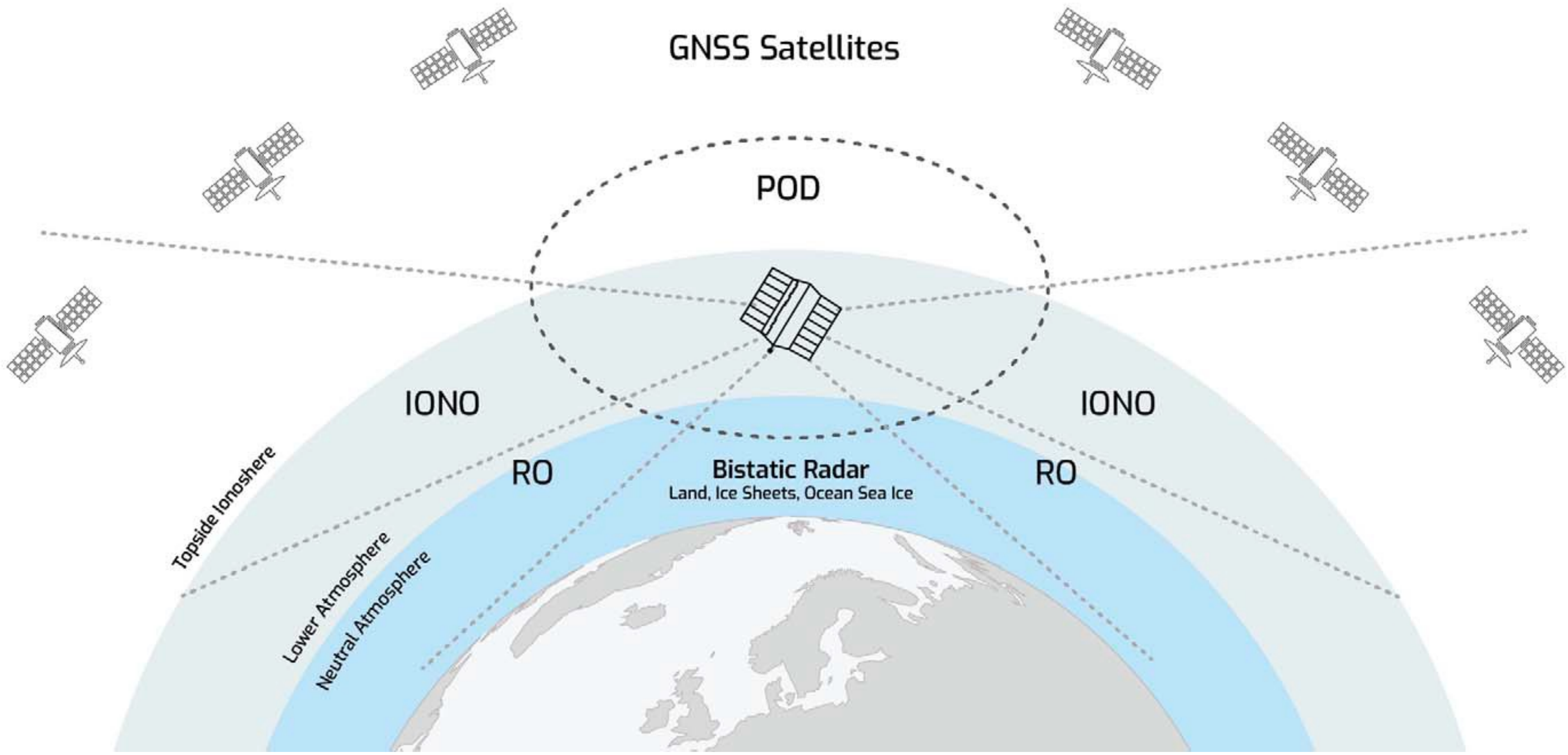
- Wide FOV
- Low gain
- Low sampling rate
- Absolute hTEC

RO antennas (2x)

- Narrow FOV
- High gain
- High sampling rate
- Relative hTEC



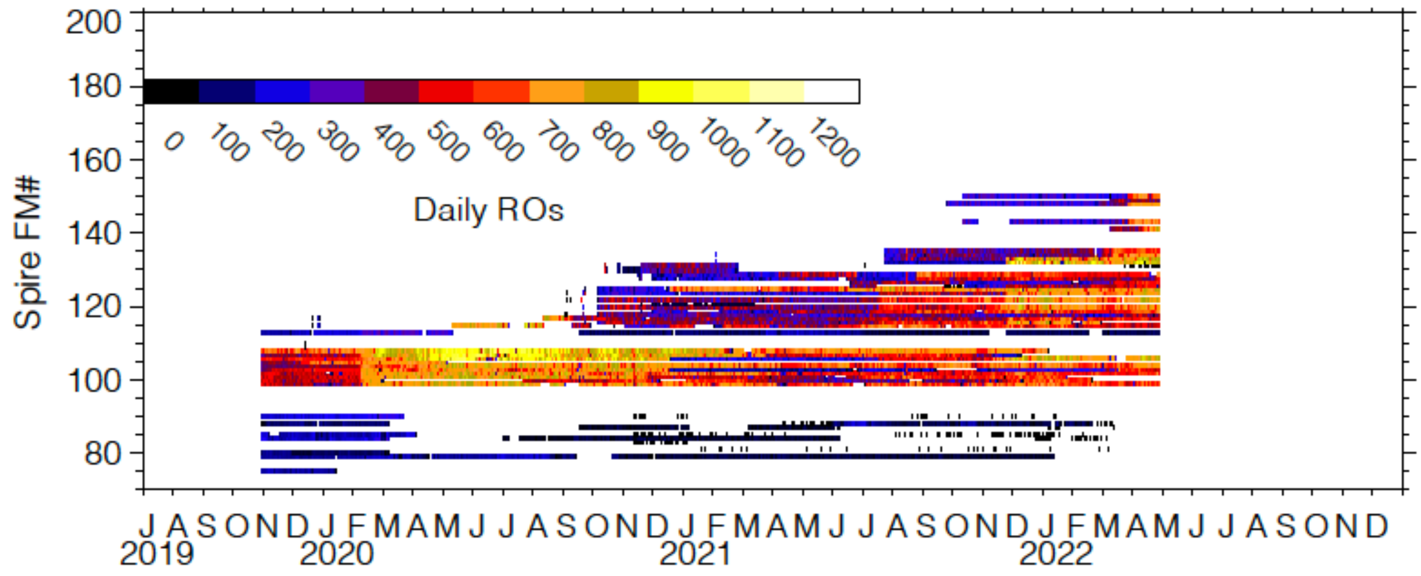

GPS
1 Hz
1 Hz
POD hTEC
(ionosphere)
GPS
Atmosphere
50 Hz
GPS
POD antenna
Zenith POD antenna
High-gain RO antenna
RO antenna
POD antennas (2x)
Wide FOV
Low gain
Low sampling rate
Absolute hTEC
RO antennas (2x)
Narrow FOV
High gain
High sampling rate
Relative hTEC



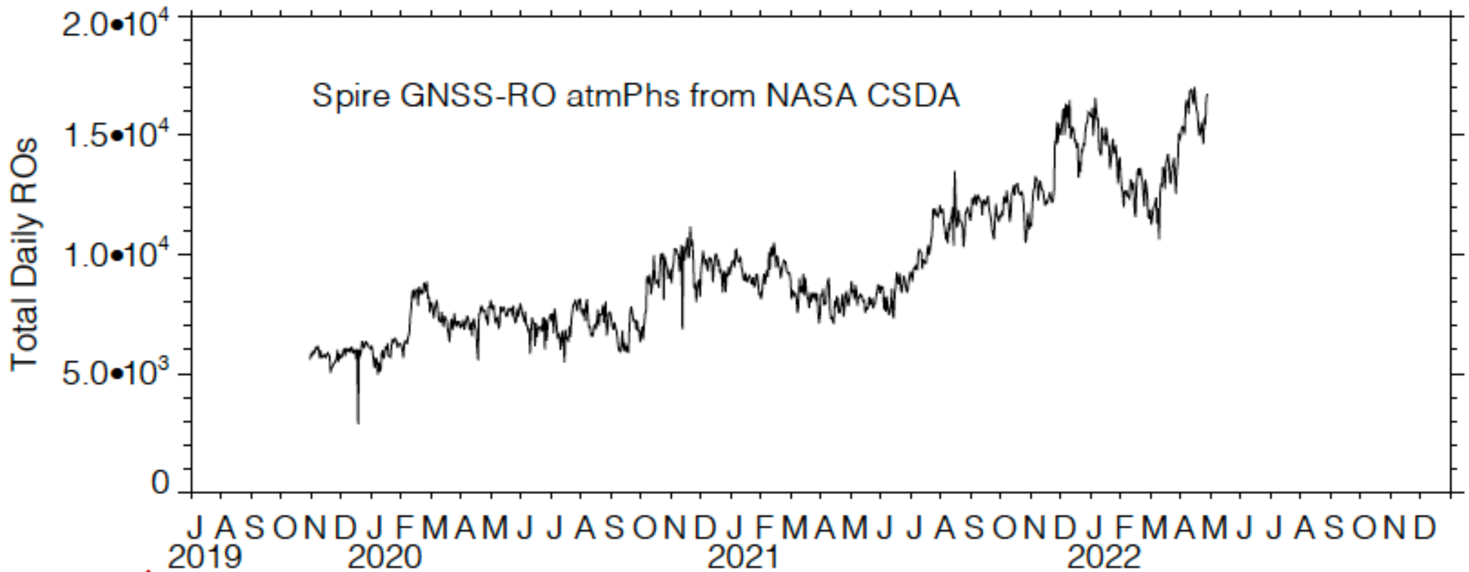
Angling et al. (2021)

Spire Daily GNSS-RO Statistics (L1B: atmPhs)

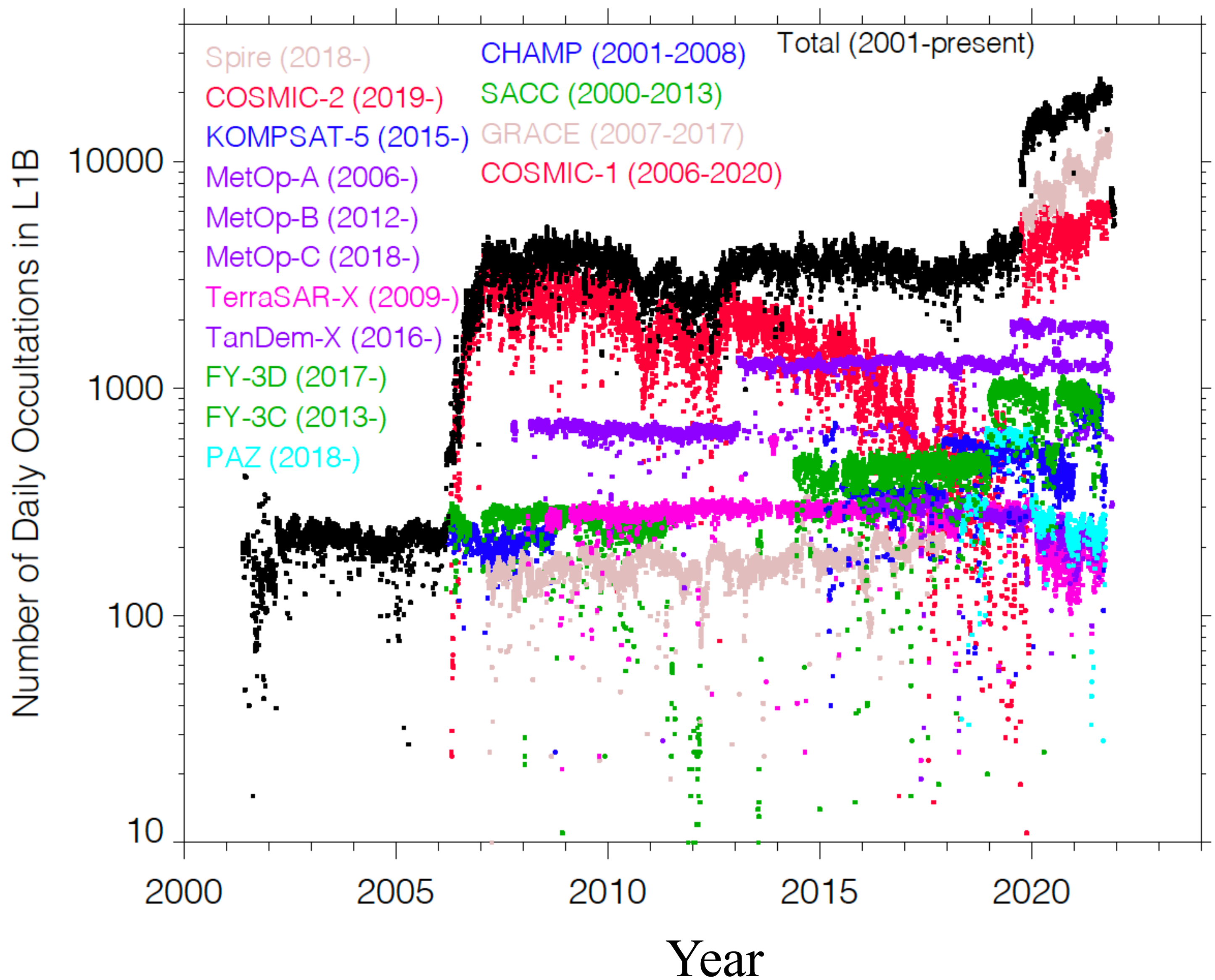
By flight model (FM)



Total daily number

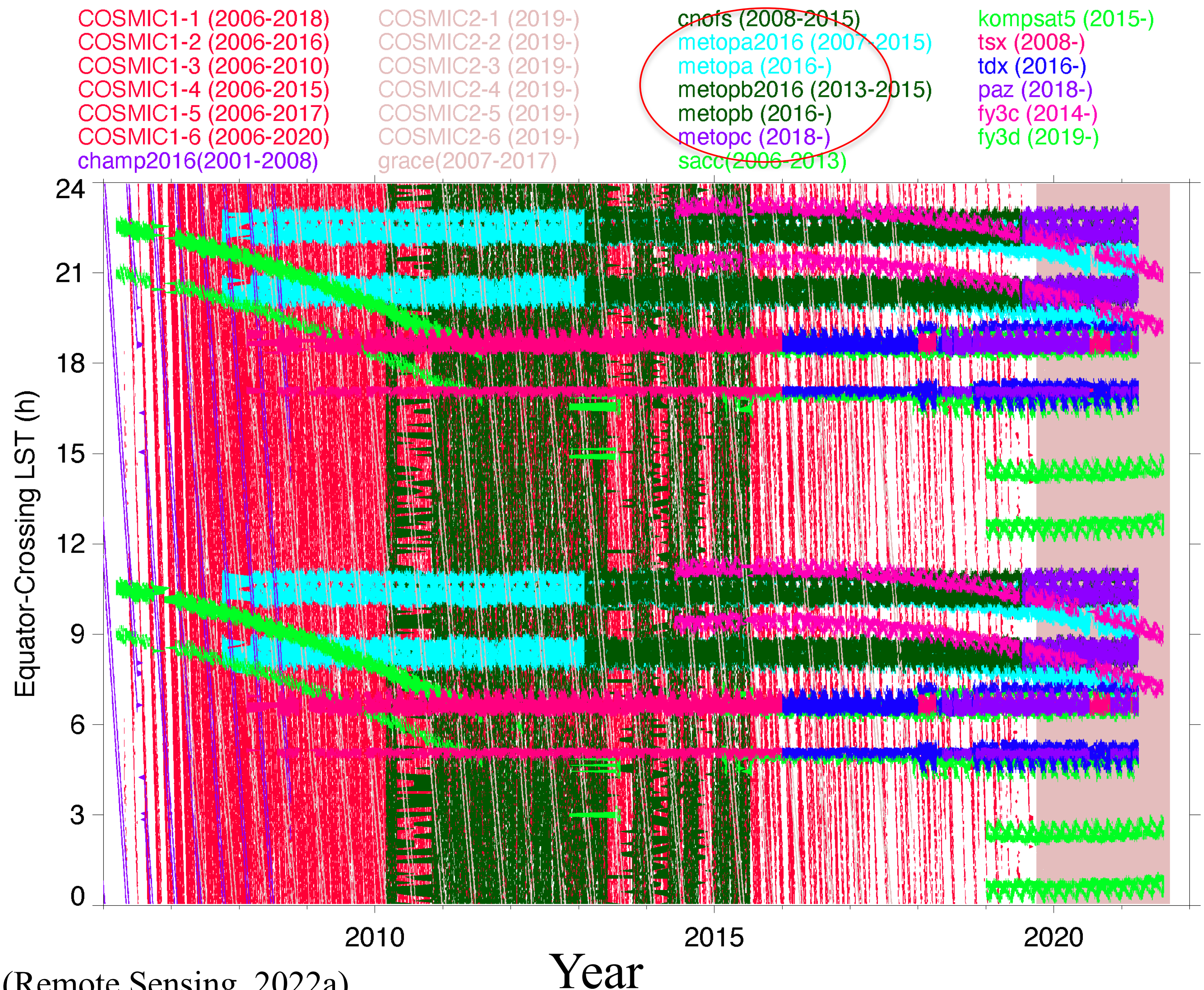


Daily RO Observations Since CHAMP (NASA-DLR)



Wu et al. (Remote Sensing, 2022a)

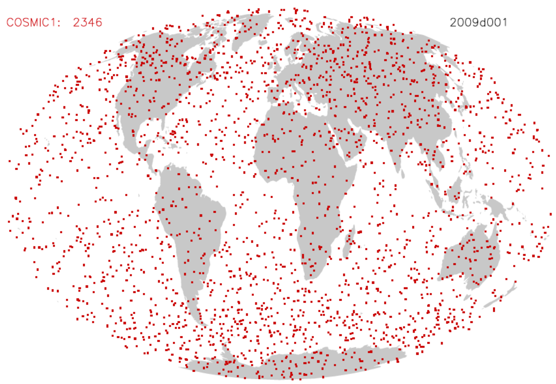
Local Time Sampling



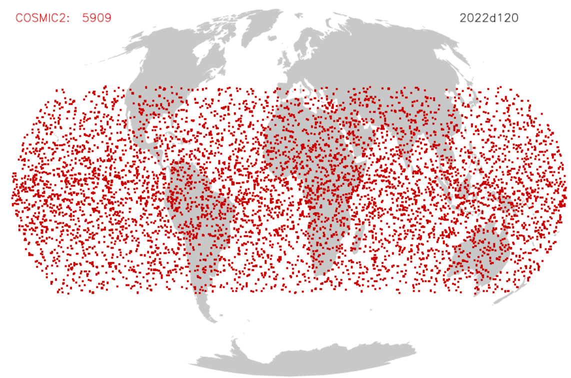
Wu et al. (Remote Sensing, 2022a)

Daily Sampling Maps from GNSS RO

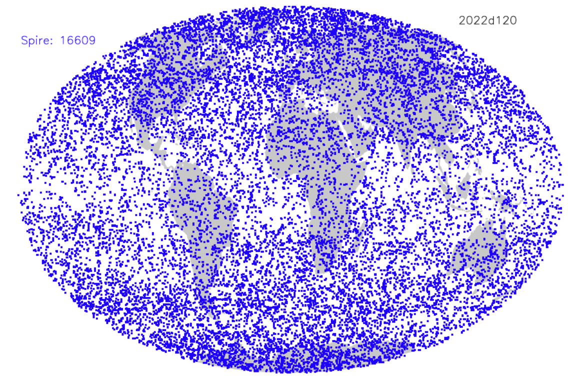
COSMIC-1
(2006-2020)



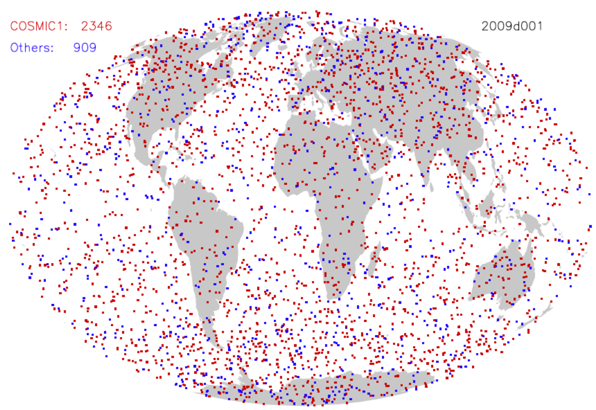
COSMIC-2
(2020-)



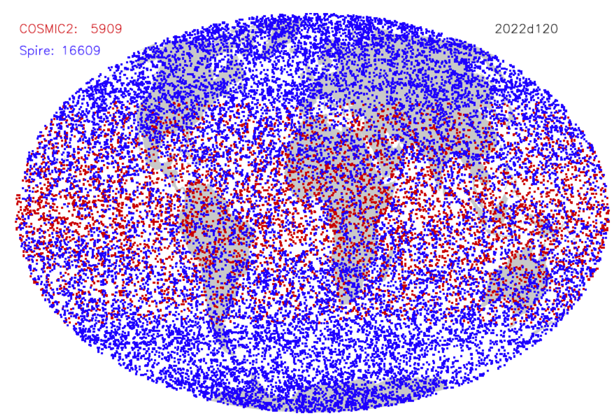
Spire
(2019-)



COSMIC-1 + Others (2009d001)

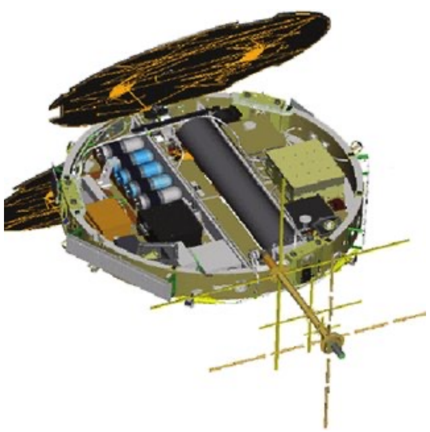


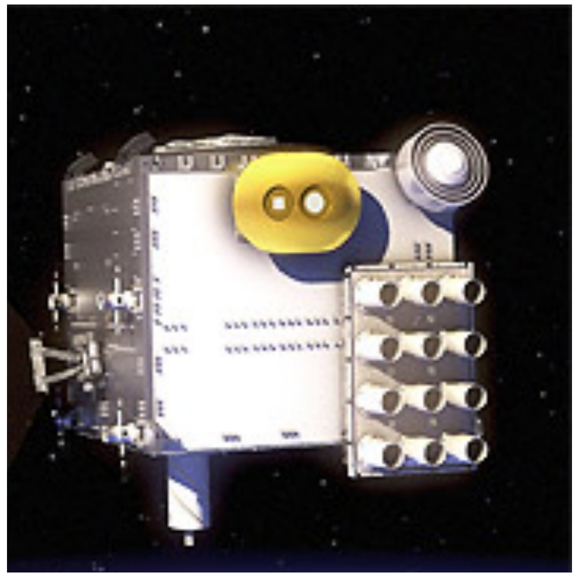
COSMIC-2 + Spire (2022d120)



Comparisons of LEO Satellite Dimension and GNSS Tracking

COSMIC-1	COSMIC-2	Spire
D = 100 cm H = 18 cm	(L × W × H) 125 × 100 × 125 cm	(L × W × H) 10 × 10 × 30 cm





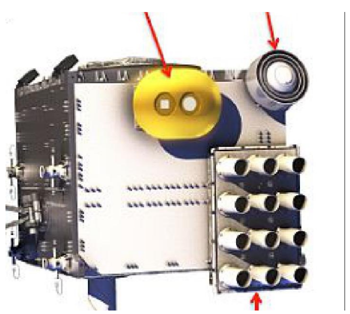
U.S. NavstarGlobal Positioning System (GPS)
Russia's GLObal NAvigation Satellite System (GLONASS) constellations
European Navigation Satellite System Galileo (Galileo)
Japanese Quasi Zenith Satellite System (QZSS).

GNSS Tracking

COSMIC-1	**COSMIC2**	**Spire**
GPS	GPS, GLONASS	GPS, GLONASS, Galileo, QZSS

Sampling Comparisons of GNSS-RO and GNSS-POD

	RO Antennas (Atmos & D/E-Region)		POD Antennas (F-Region)	
	Total L1B	Ne	Total L1B	Ne
COSMIC-1 (Jan 1, 2008)	1,690	1,419	1,832	1,175
COSMIC-2 (Jan 1, 2022)	6,199	6,068	9,366	6,661
Spire (Jan 1, 2022)	15,900	15,756	18,433	5,960



TEC

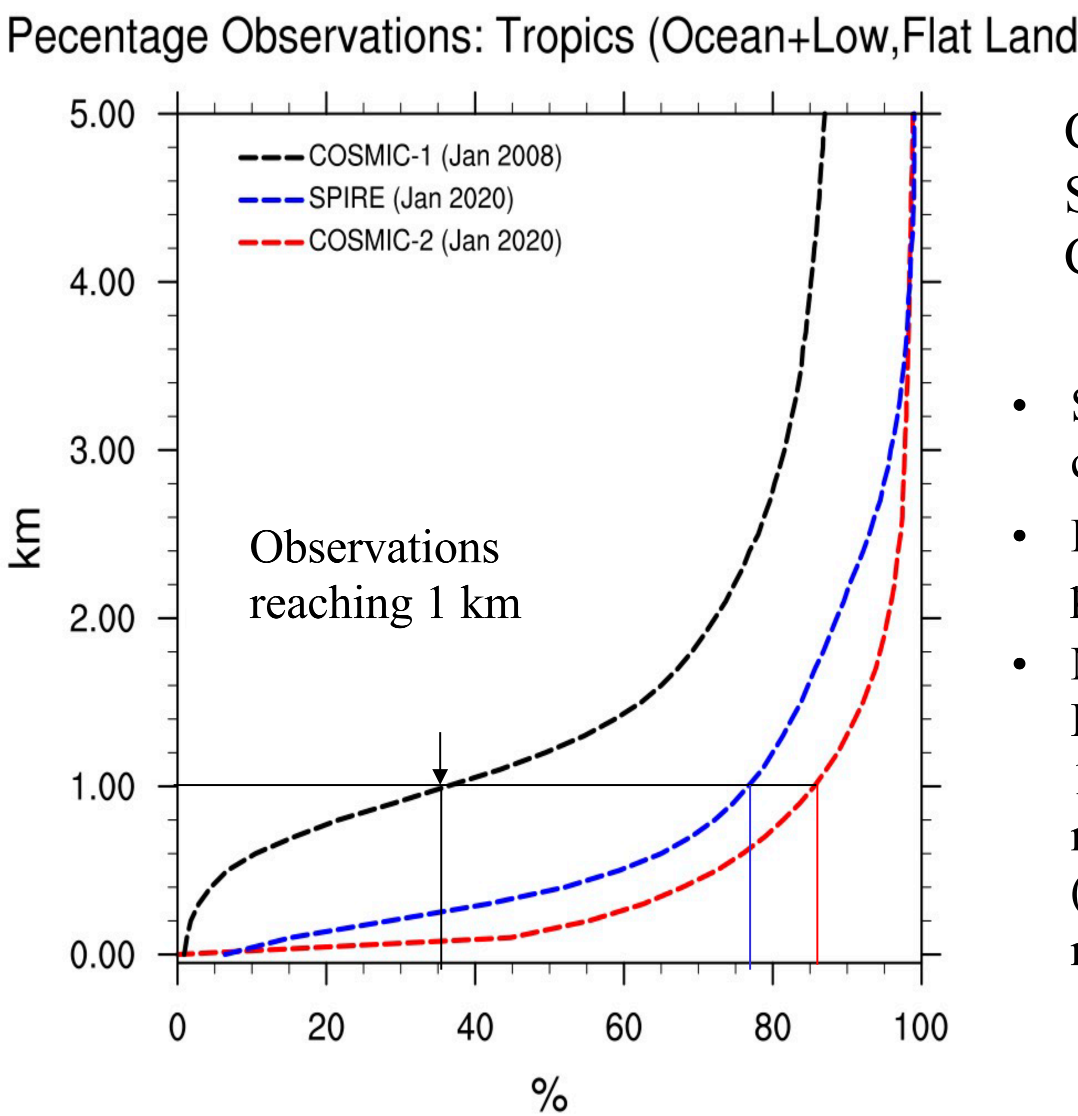
RO data

TEC

POD data

Atmospheric Sciences

Fraction of SPIRE RO observations reaching PBL (ocean & low, flat land only)

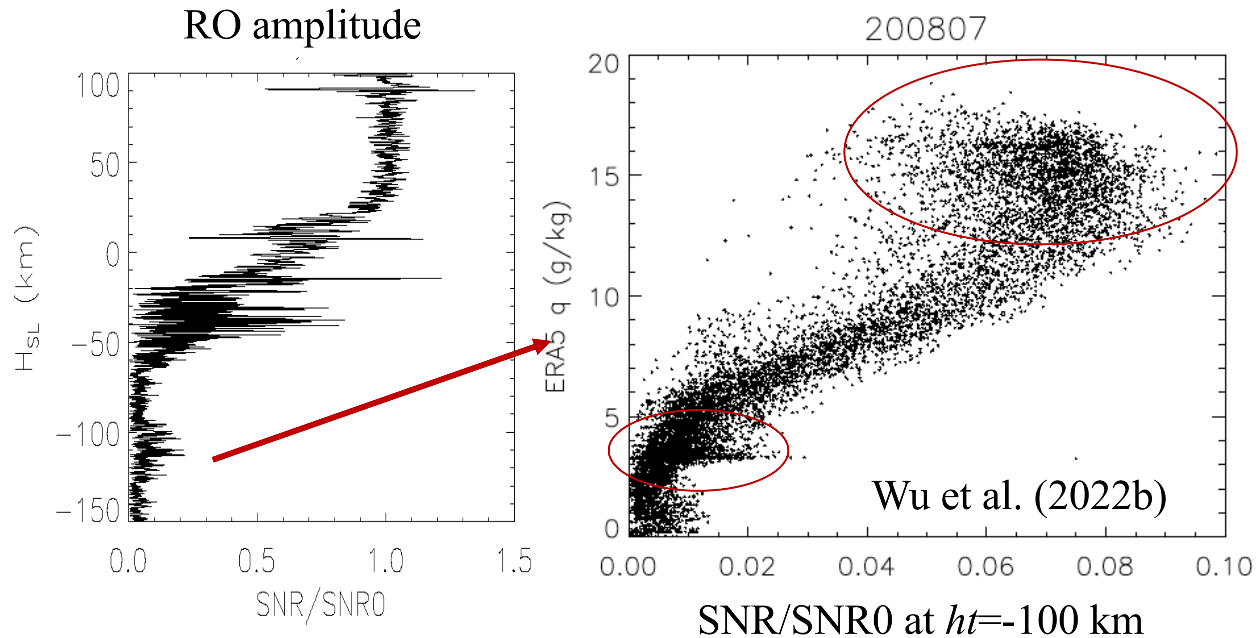


Comparison of **Level-2 atmPrf** Sampling Statistics from Spire, COSMIC-1 and COSMIC-2:

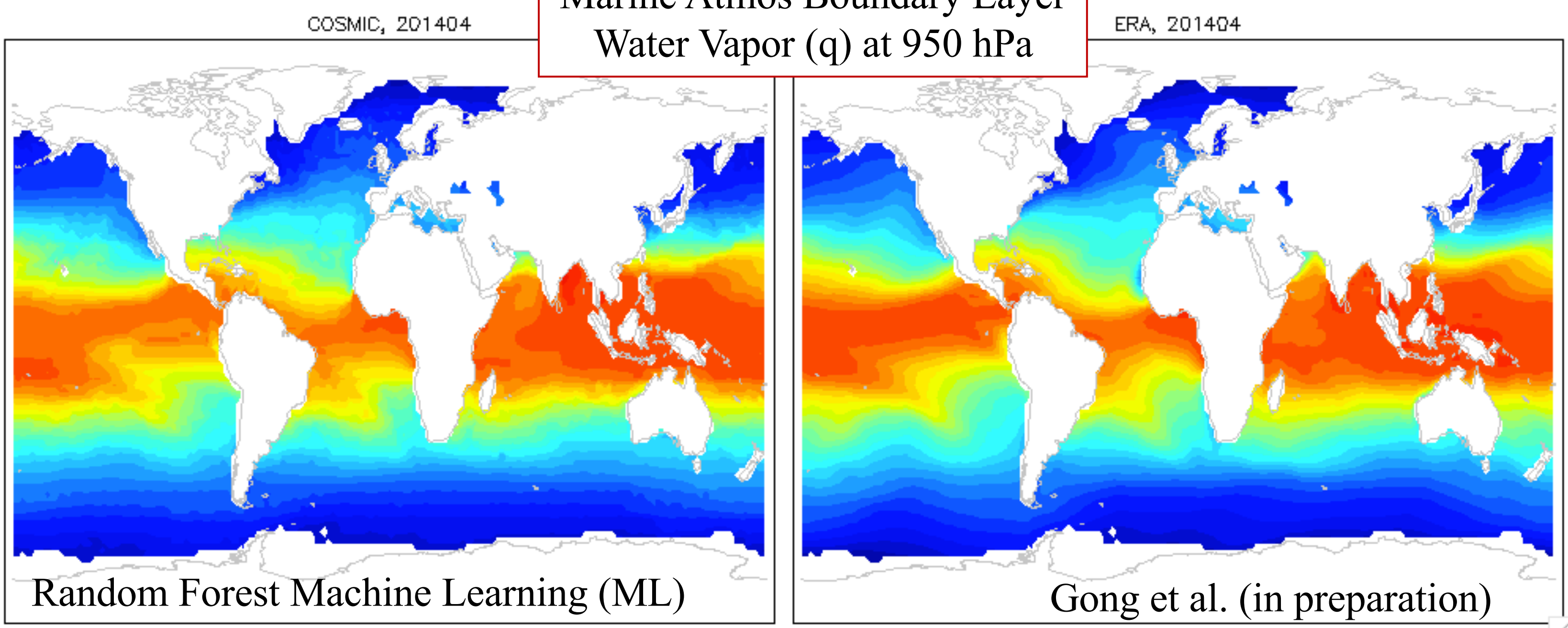
- Spire has generally lower but comparable sampling in PBL;
- Large fraction of SPIRE RO profiles reach 1km level;
- Monthly variability in SPIRE RO penetration (%) evident at 1km level (tropics and NH midlatitude) and 200m level (NH midlatitude and NH polar regions).

(Courtesy of M. Ganeshan)

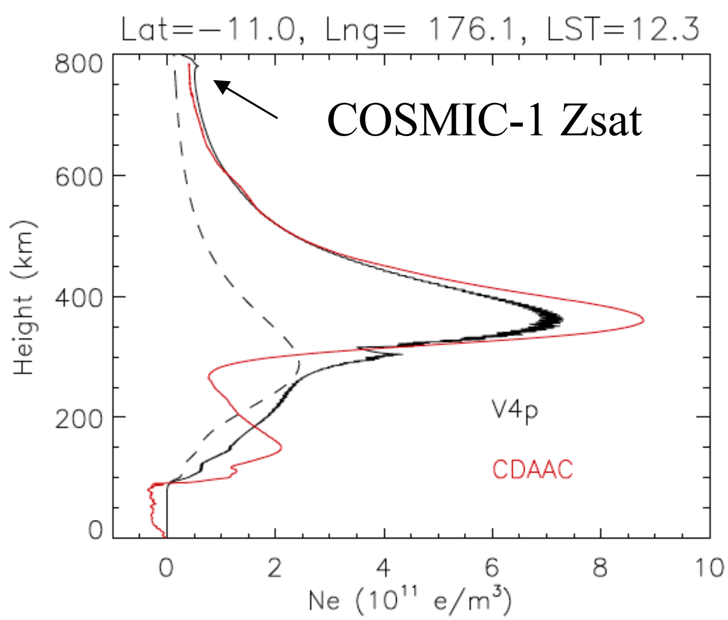
- Novel method to infer PBL water vapor (q) from GNSS-RO amplitude
- Benefit of global GNSS-RO sampling to study diurnal variations and polar regions

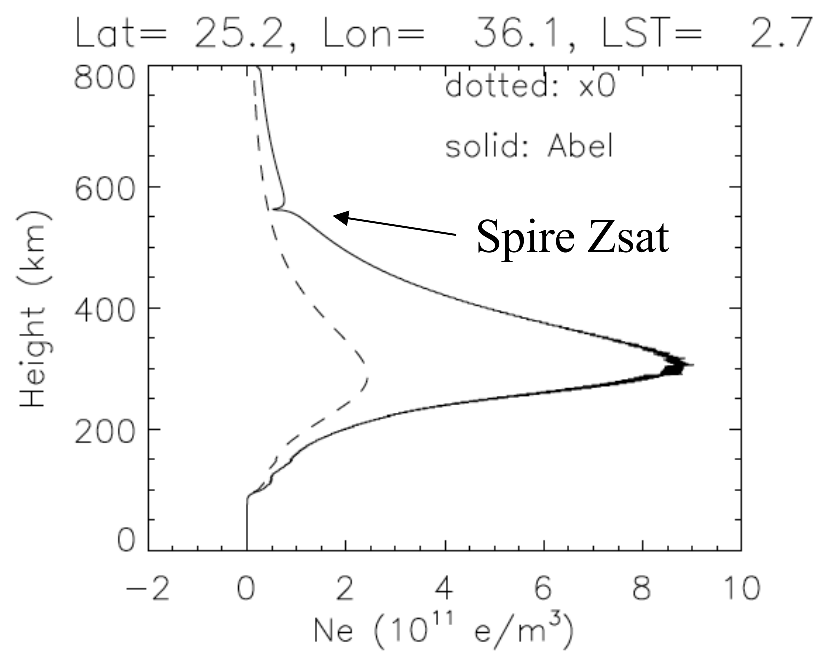


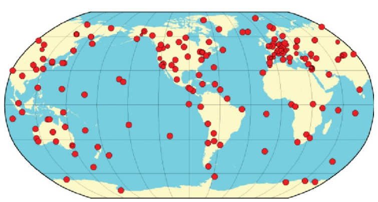
Marine Atmos Boundary Layer Water Vapor (q) at 950 hPa



Ionospheric Sciences

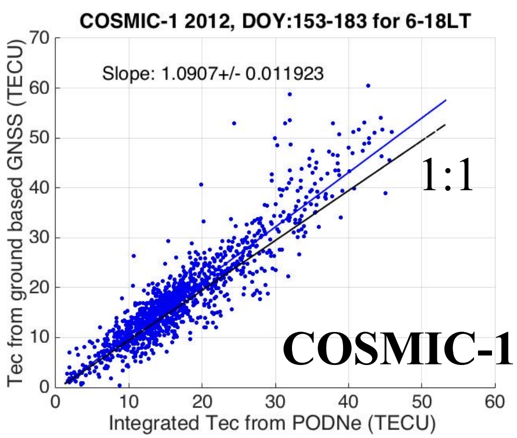


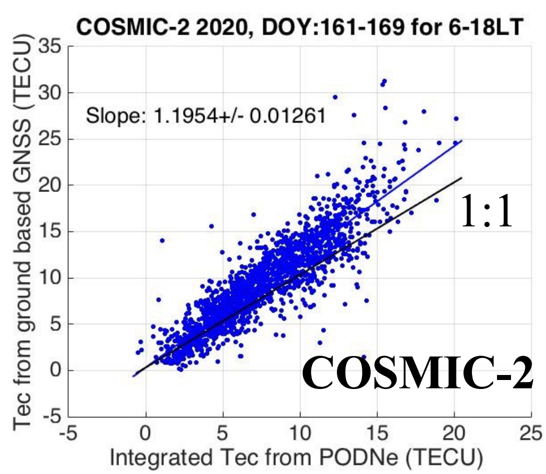


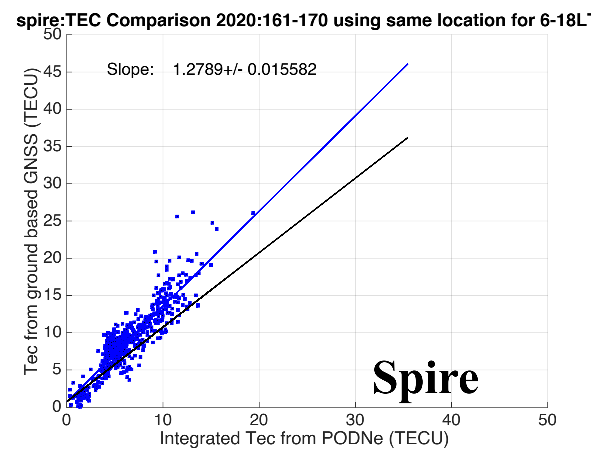


Comparisons with TEC from IGS Network

Under evaluation

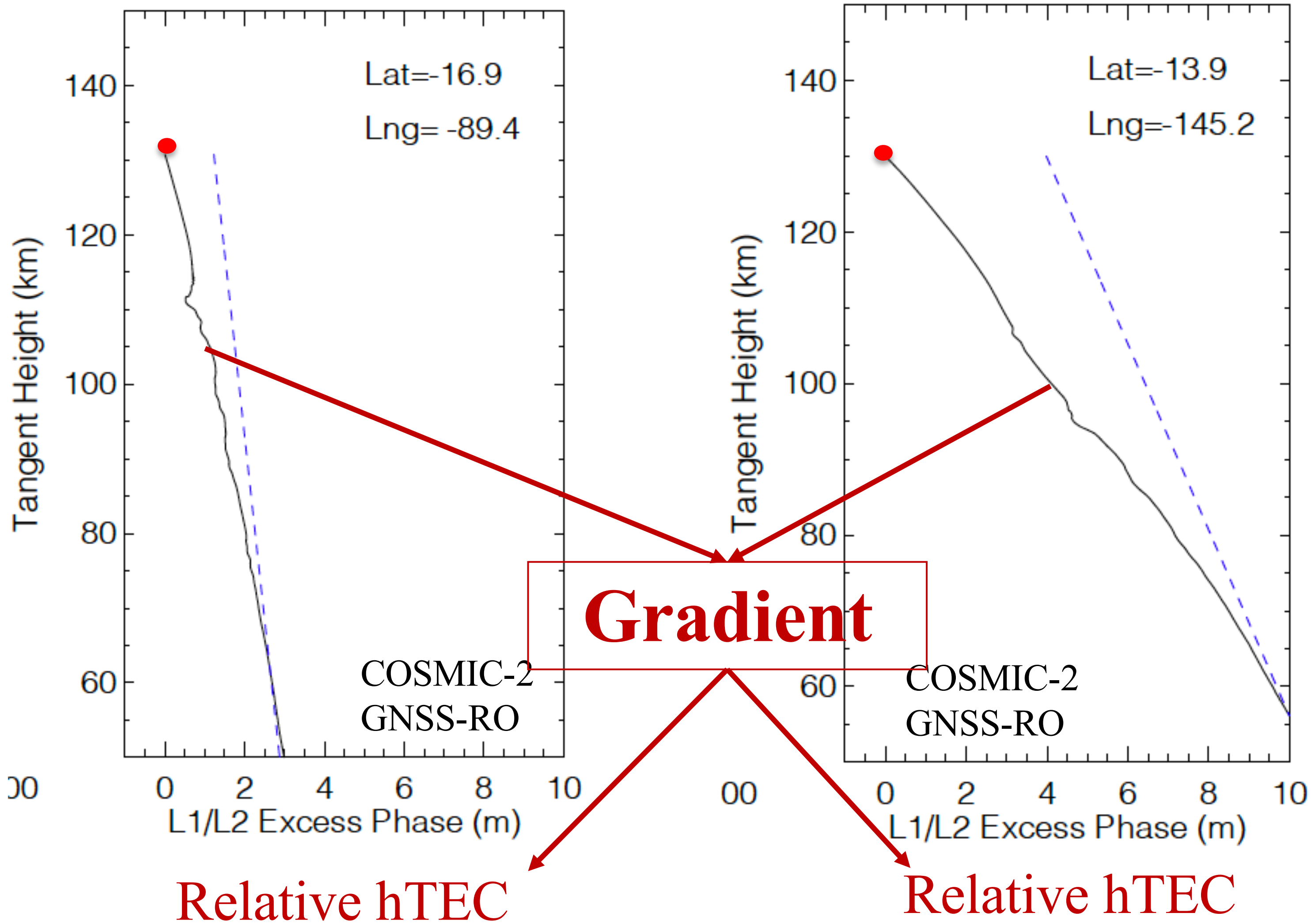




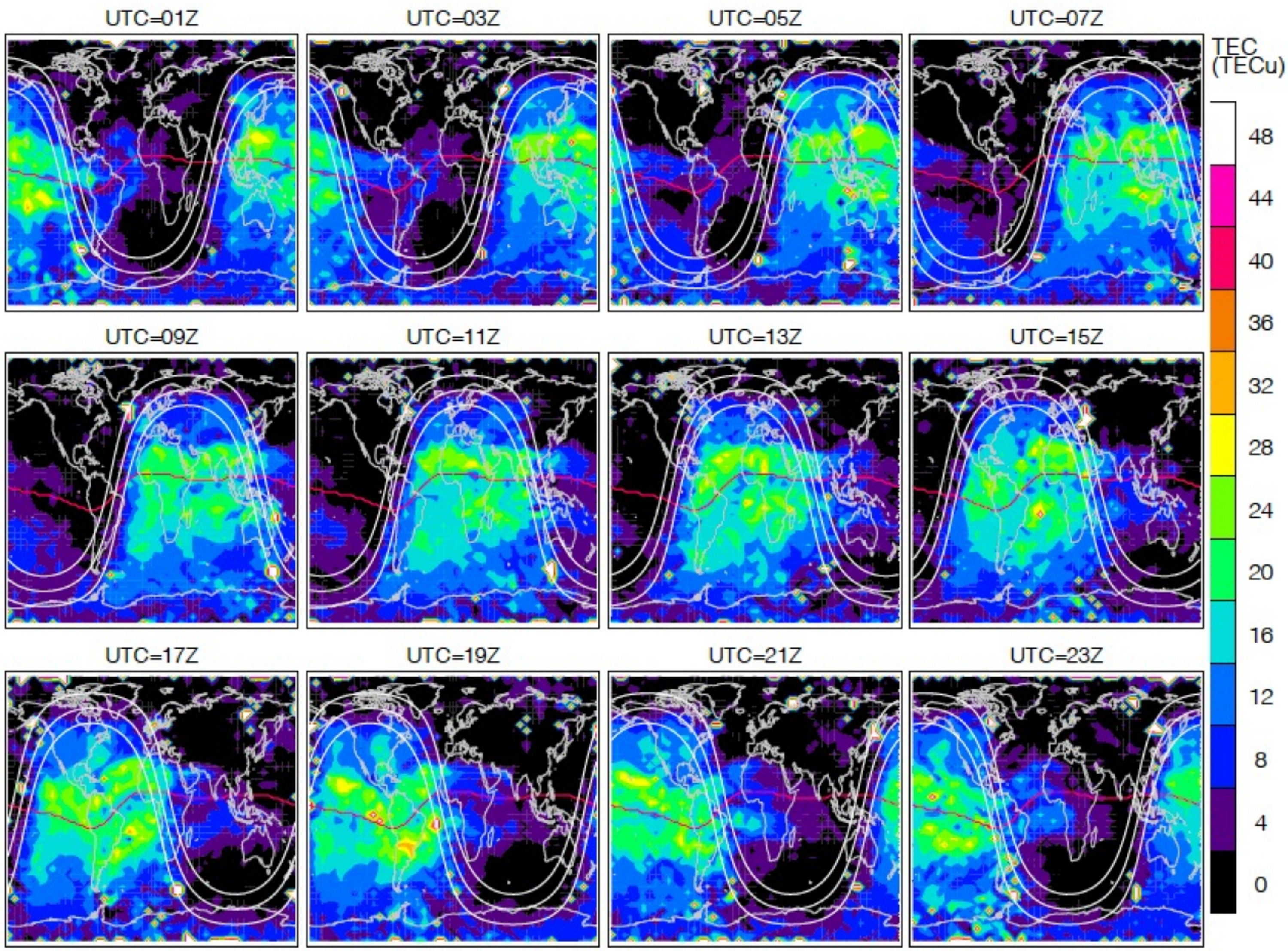


TEC Derived from GNSS-RO Gradient

Low TEC High TEC



Spire 2-Hourly TEC Maps from Jan 2022



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