GNSS Reflectometry For Ionospheric Observation

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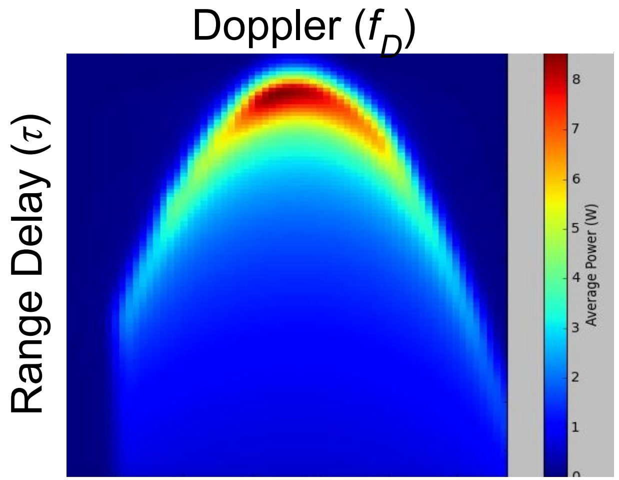
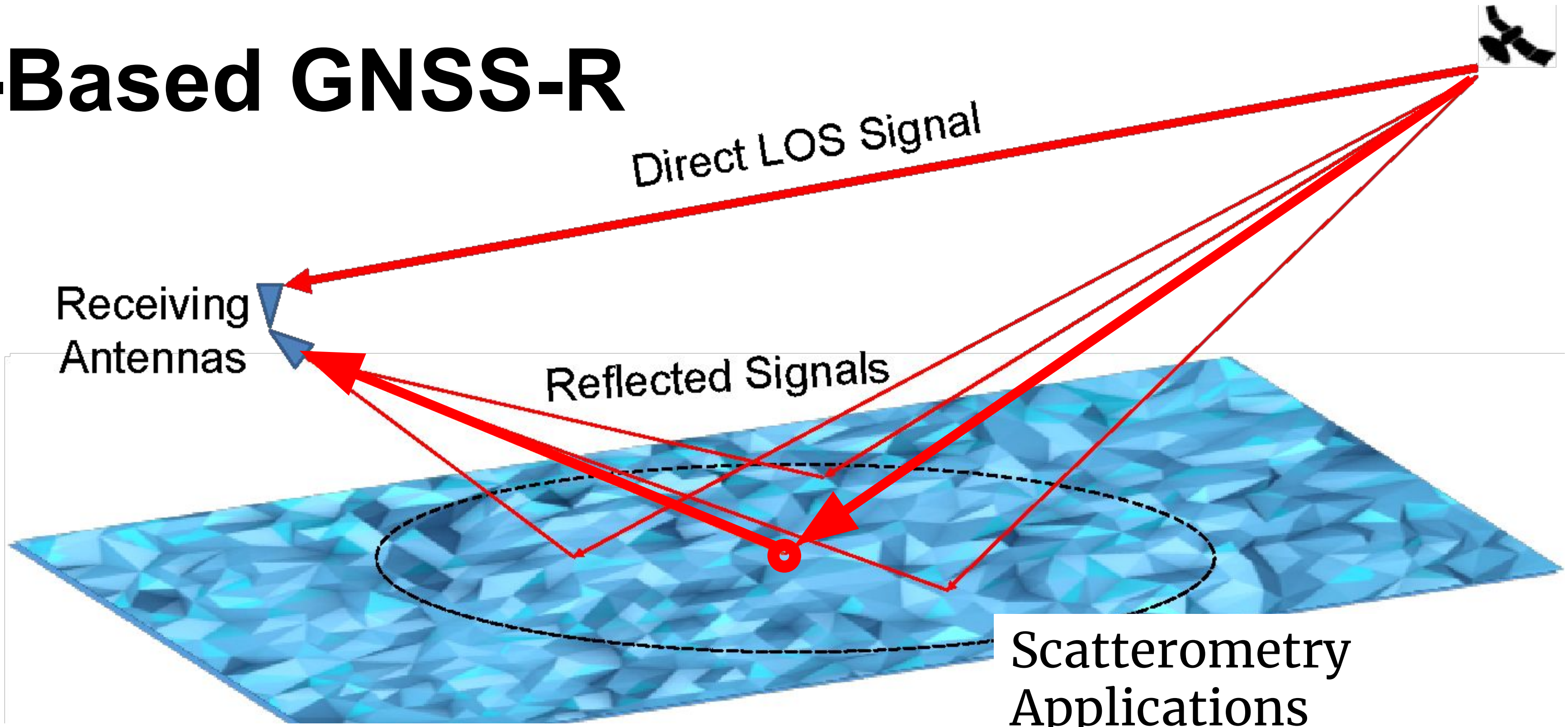
JRO 60th Anniversary Workshop

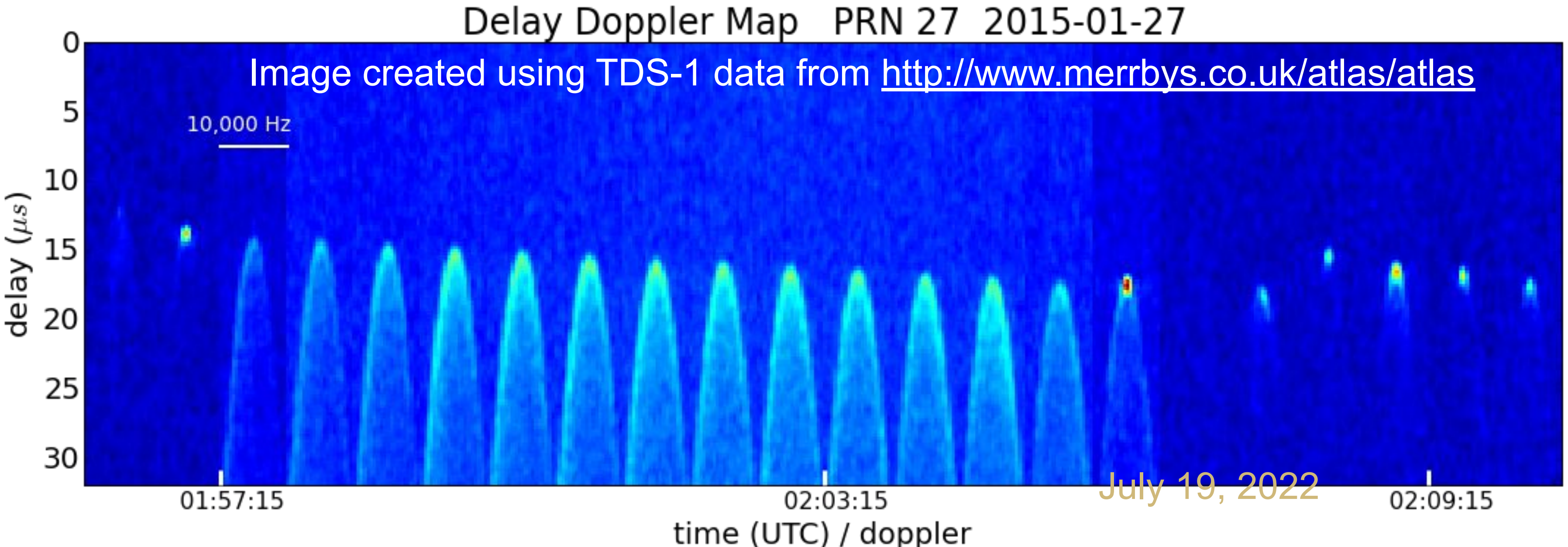
Outline

1. Background and Motivation
2. GNSS-R for Ionospheric Monitoring
3. Challenges and Opportunities

LEO Satellite-Based GNSS-R







Scatterometry Applications

- Ocean wind speed
- Land surface water content
- Soil moisture

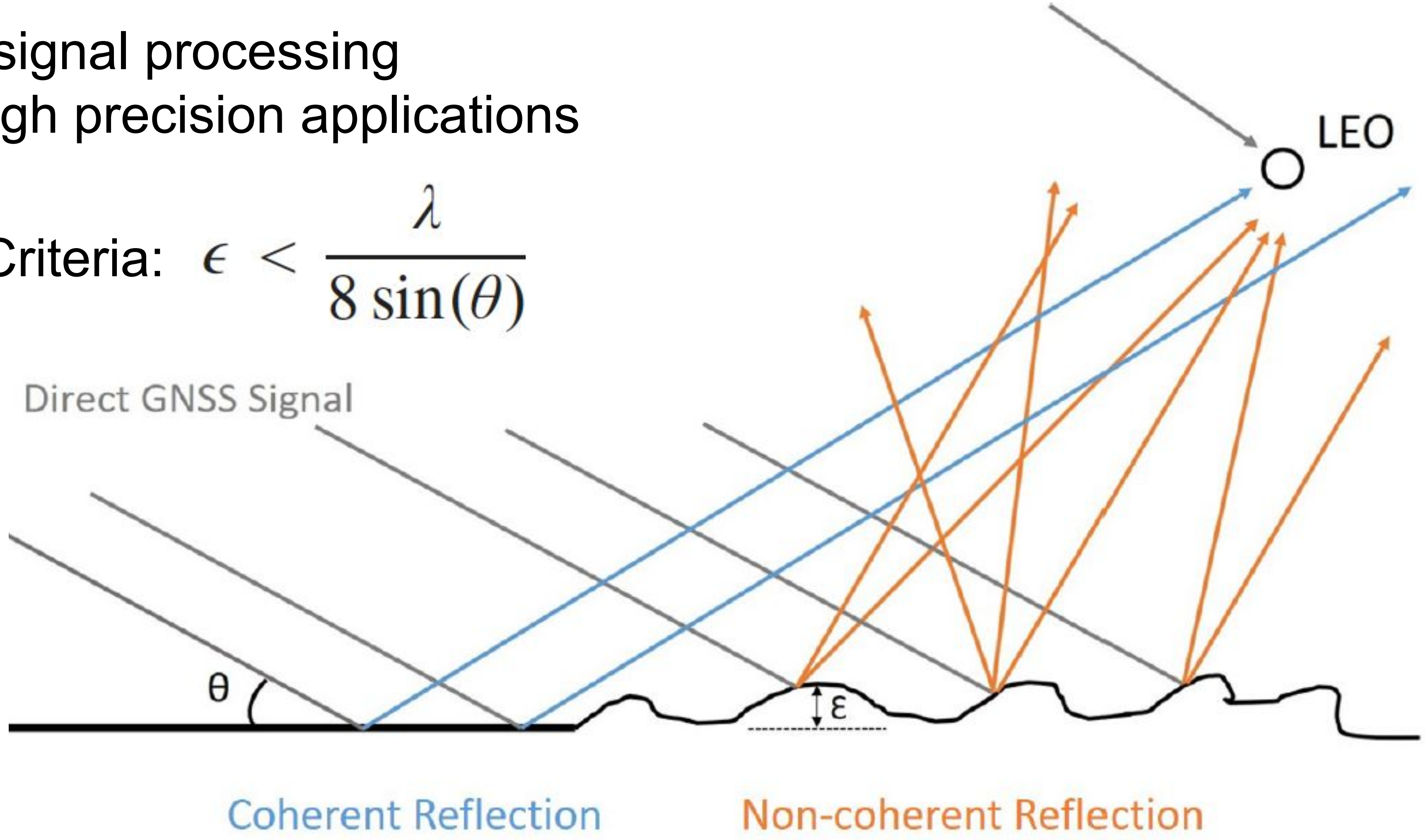
Altimetry Applications

- Sea surface height
- Sea ice topography
- Inland water body
- Ionosphere TEC,

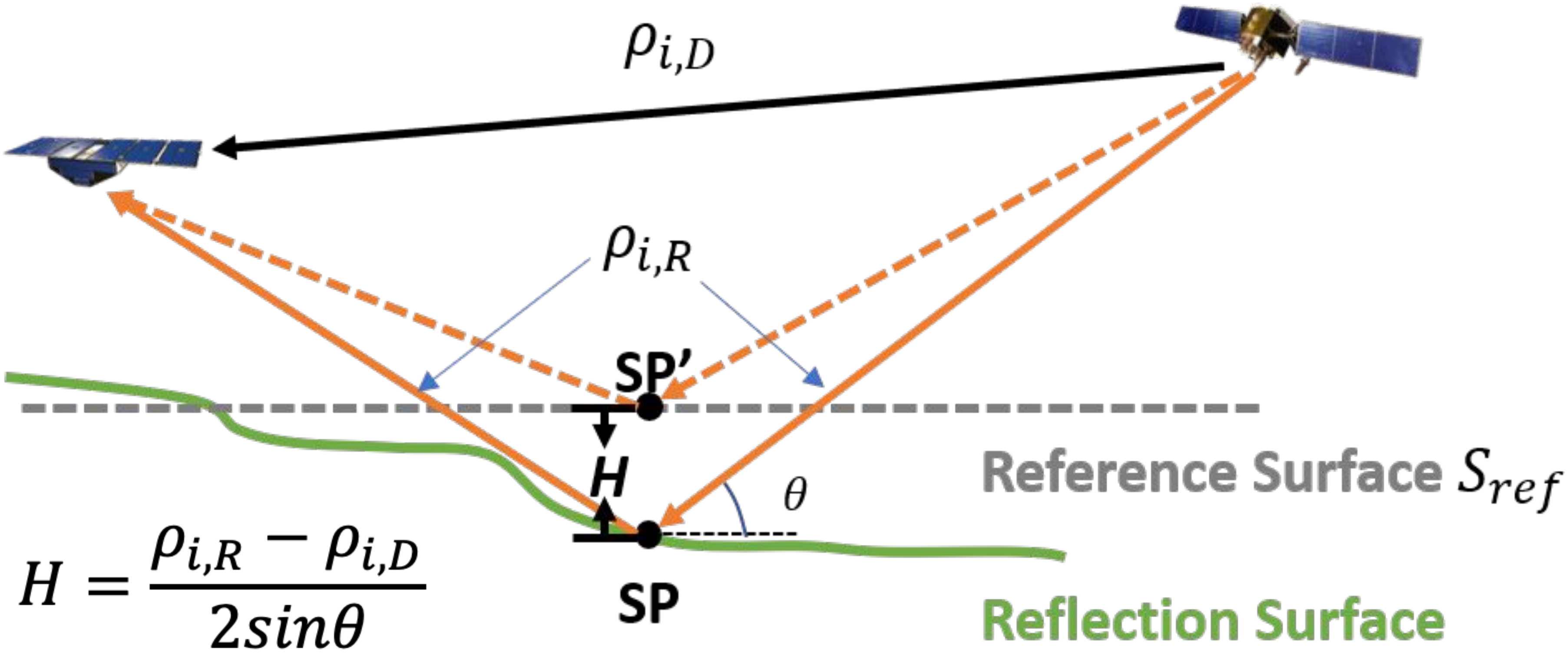
Coherent GNSS Reflections

Coherent signal processing enables high precision applications

Rayleigh Criteria: $\epsilon < \dfrac{\lambda}{8\sin(\theta)}$



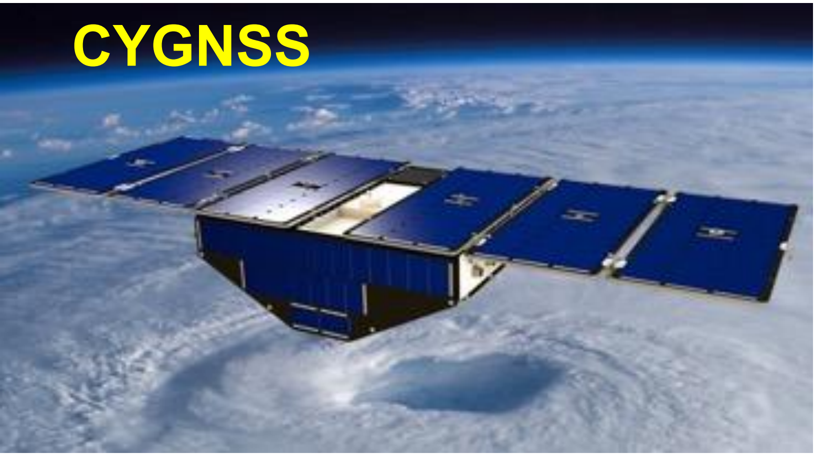
Space-borne GNSS-R Altimetry



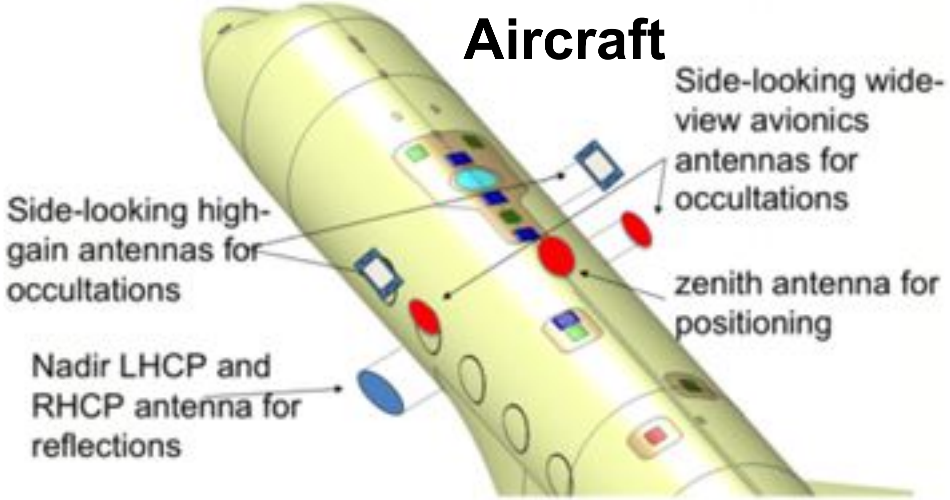
Wang, Y., Y. Morton, "Coherent GNSS reflection signal processing for high-precision and high-resolution spaceborne applications," *IEEE Trans. Geosci. Remote Sensing,* DOI:10.1109/TGRS.2020.2993804*,* 2021.

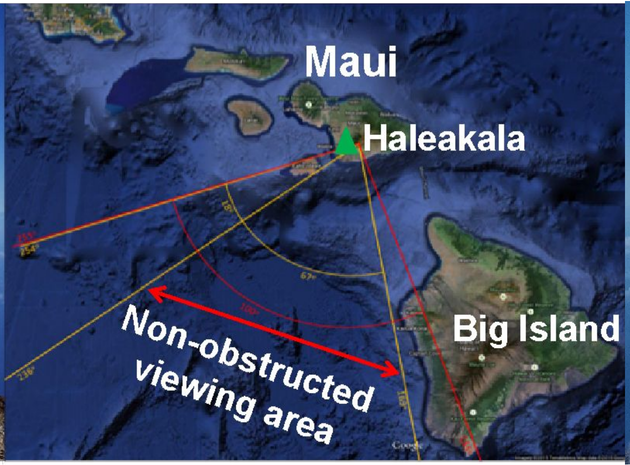
GNSS-R Data Sources

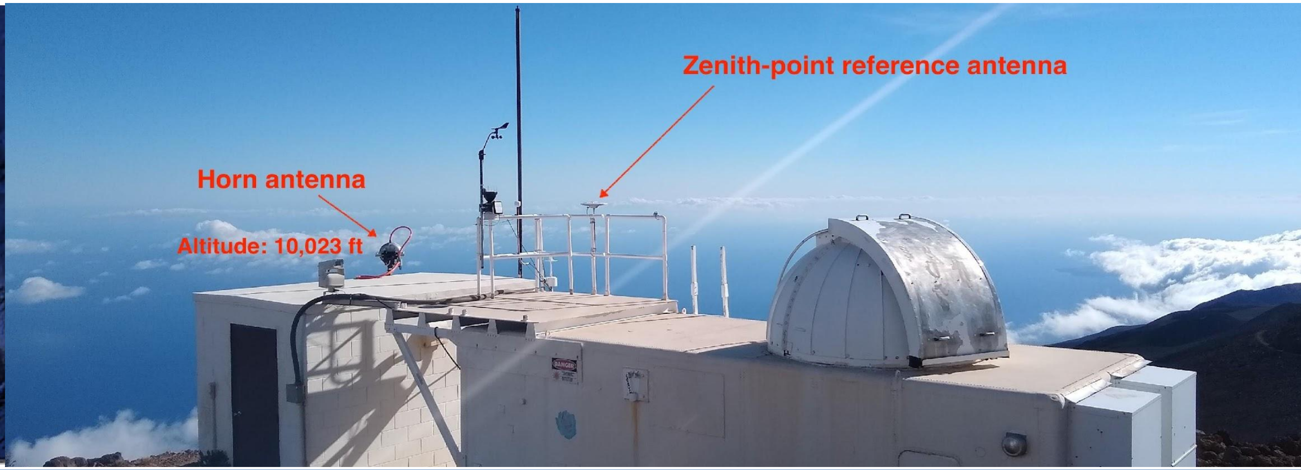
UA
V



Aircraft





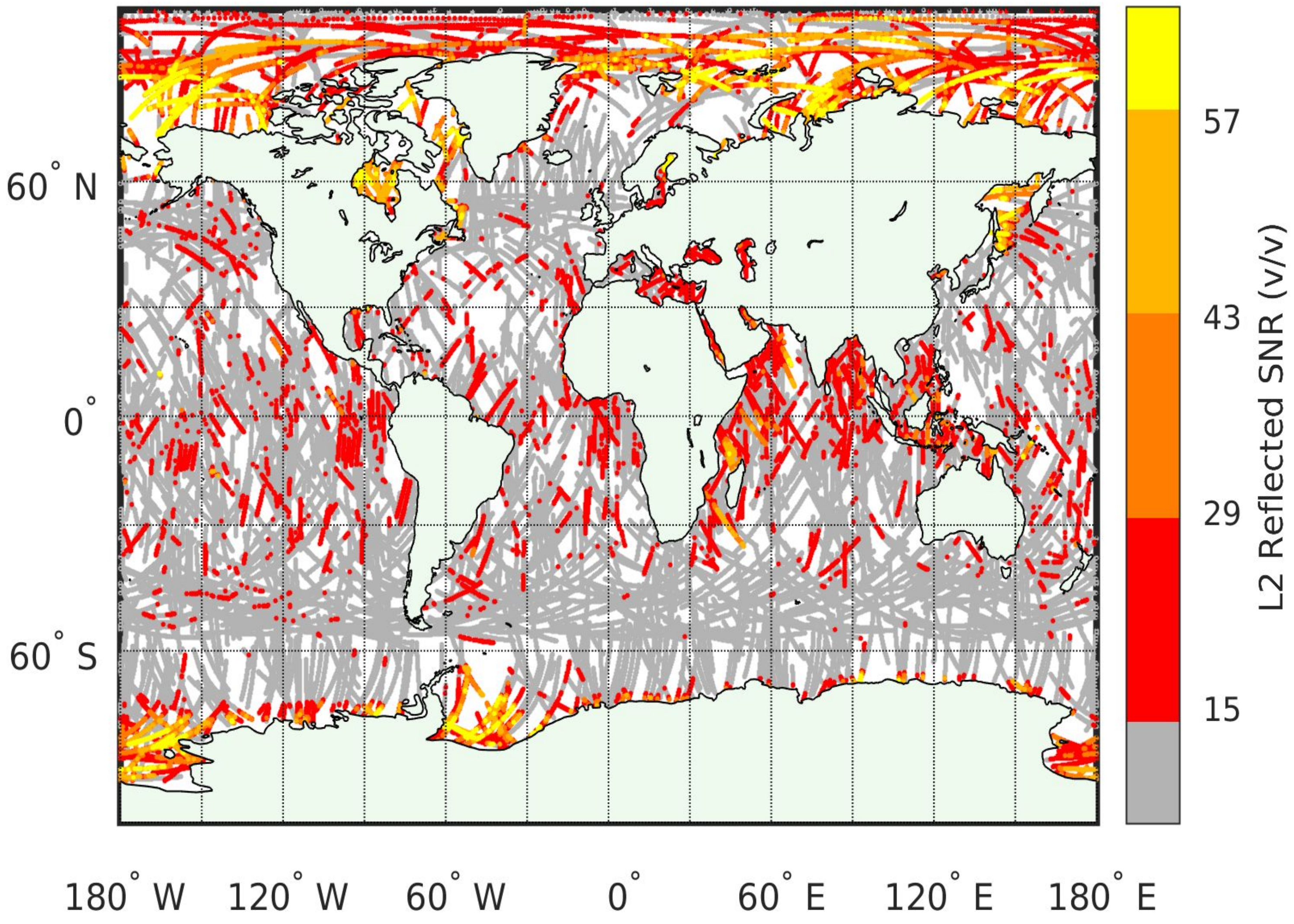


Coherent Reflection Statistics: Spire Global CubeSat

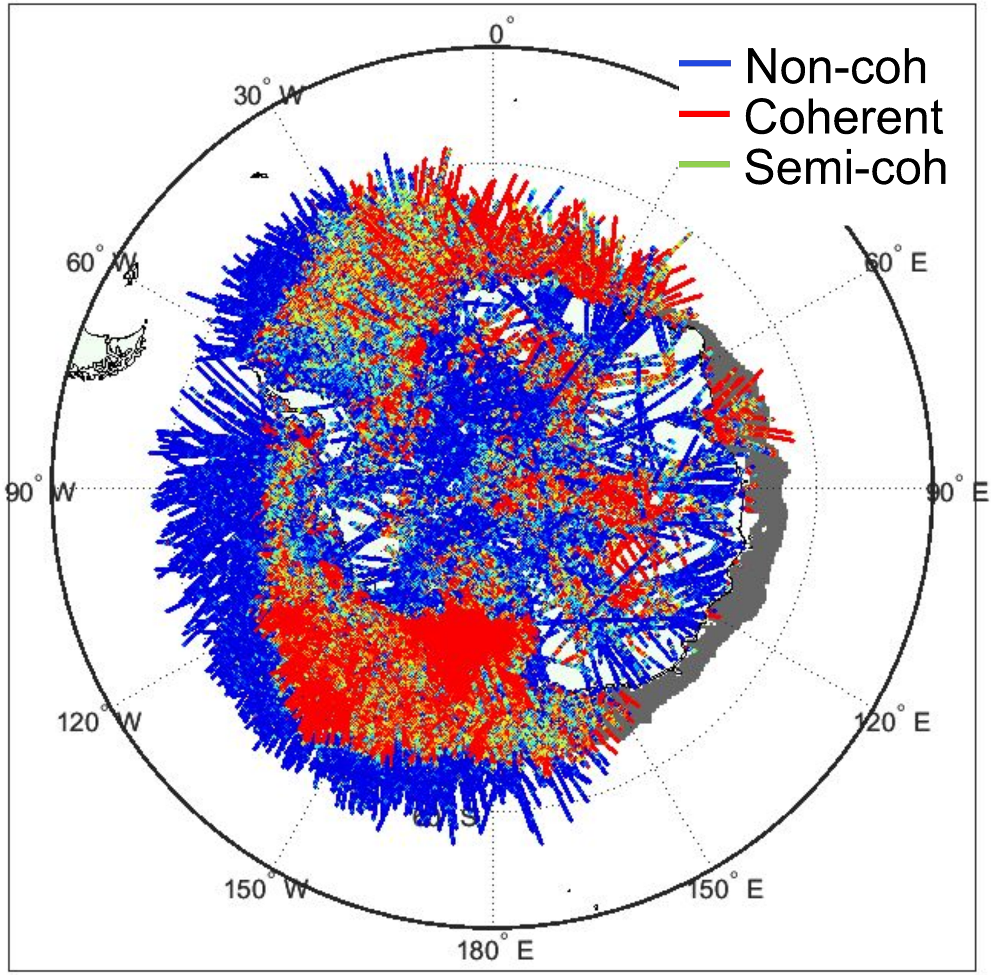
Surface type		% coherent reflections
Ocean	Global average	1%
	Wind speed < 5m/s	15%
	Within 200km of coast lines	5.5%
	Indonesia Archipelago	23%
Sea Ice	Global average	44.3%
	Multi-year ice	32%
	First year ice	75%

Roesler, C., Y. J. Morton, Y. Wang, R. S. Nerem, "Coherent GNSS-reflections characterization over ocean and sea ice based on Spire Global CubeSat data," IEEE Trans. Geosci. Remote Sensing, DOI: 10.1109/TGRS.2021.3129999, 2021.

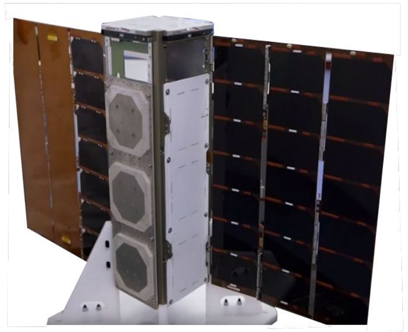
Spire GNSS-R Data:Jan-Apr 2019

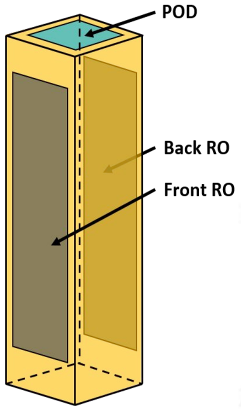


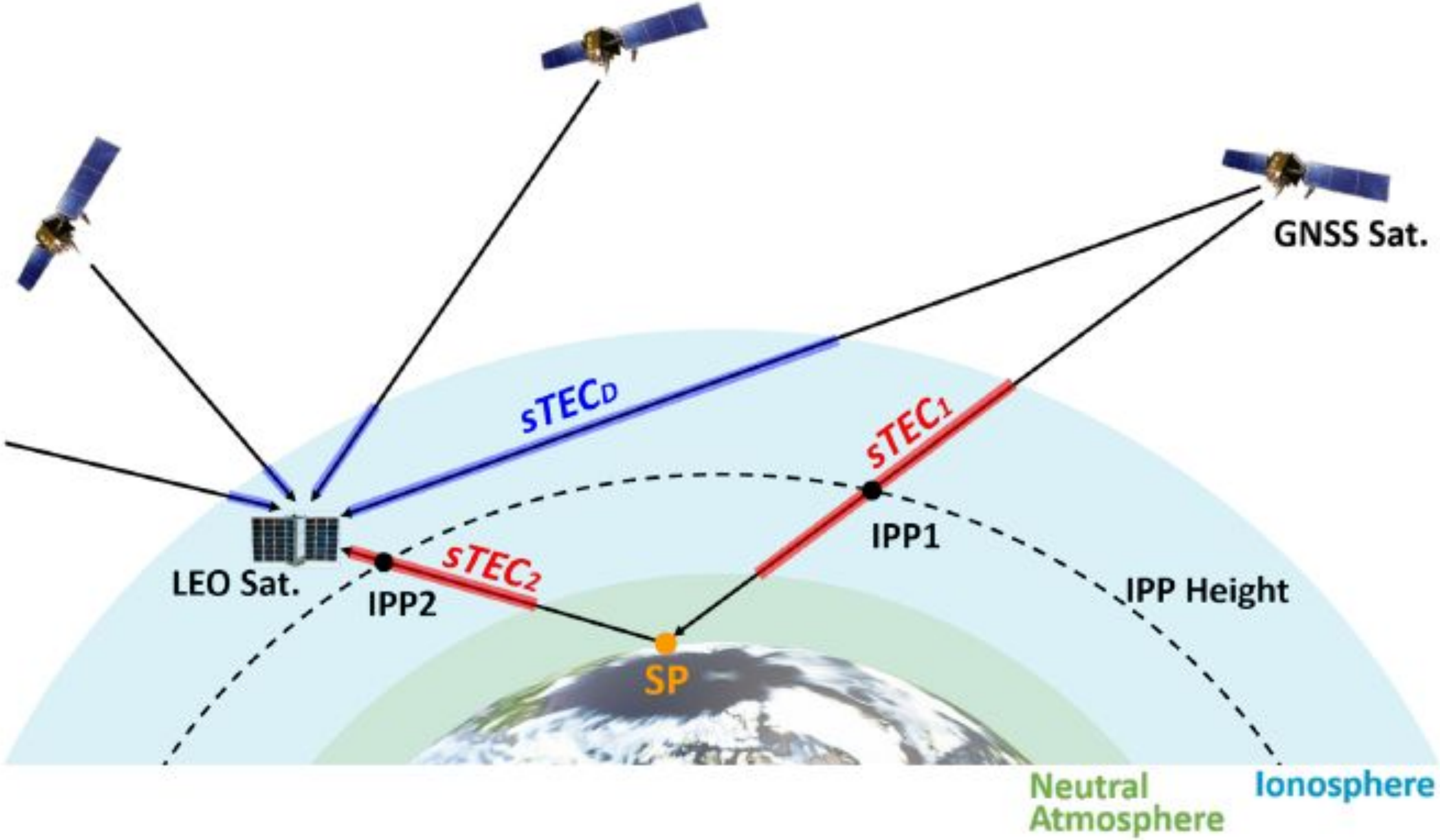
Oct. 2021



Spire Global CubeSat Dual-Frequency Measurements for Ionosphere Monitoring



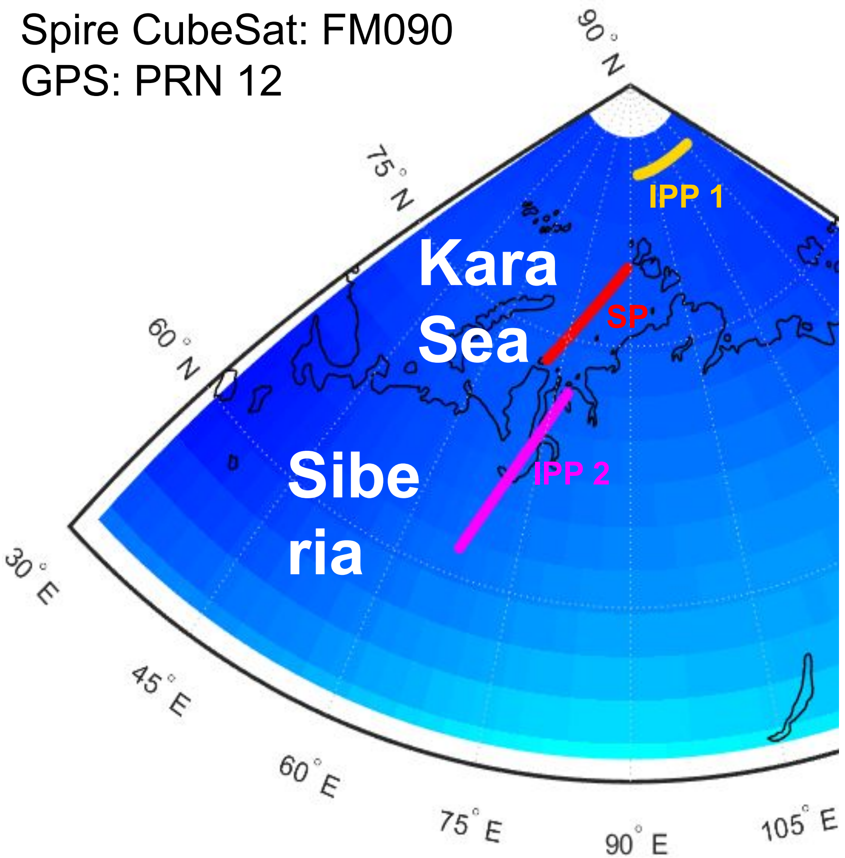


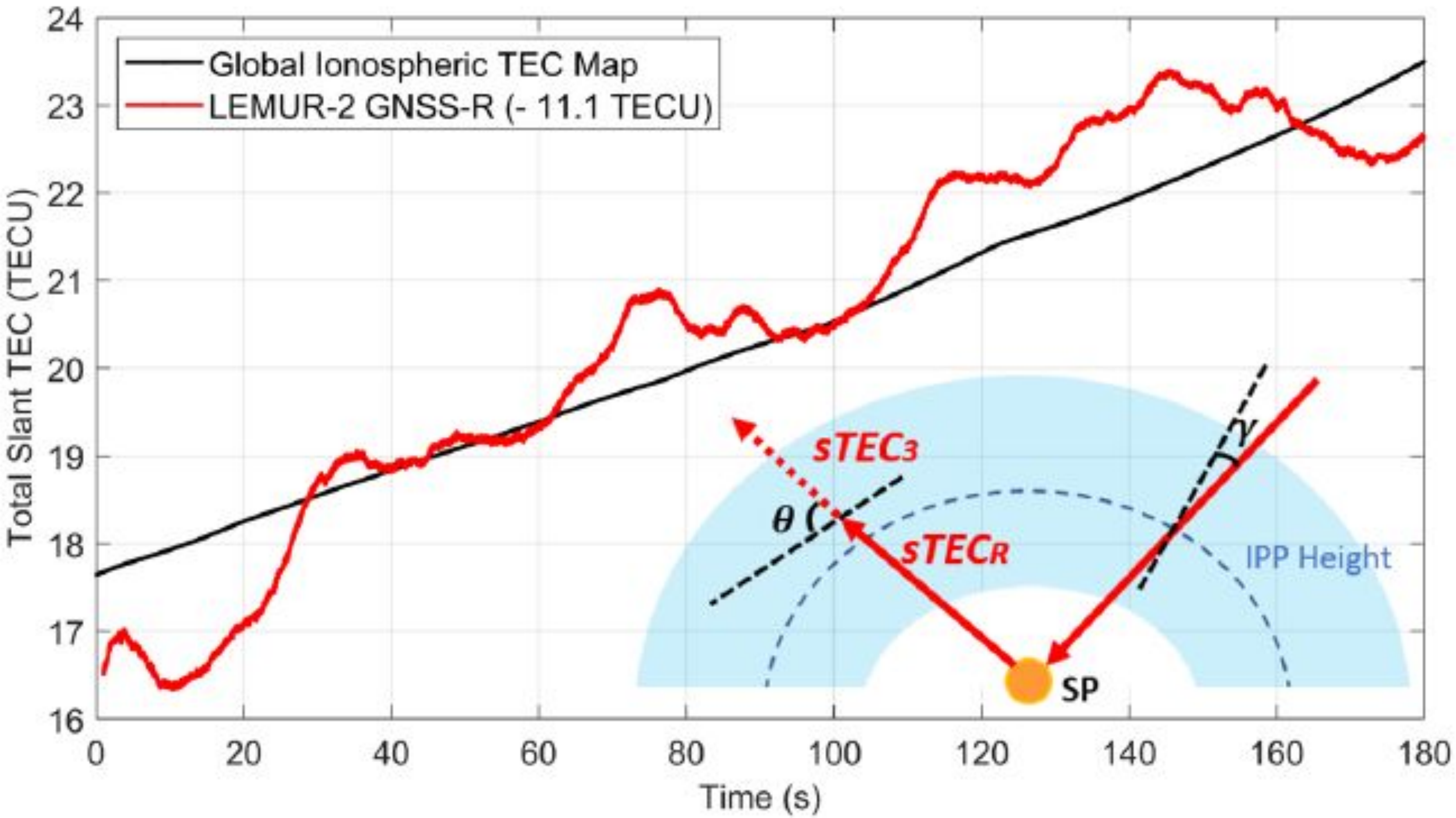


Wang, Y., Y. J. Morton, "Ionospheric total electron content and disturbance observations from space borne coherent GNSS-R measurements," *IEEE Trans. Geosci. Remote Sensing,* DOI: 10.1109/TGRS.2021.3093328, 2021.

TEC Retrieval

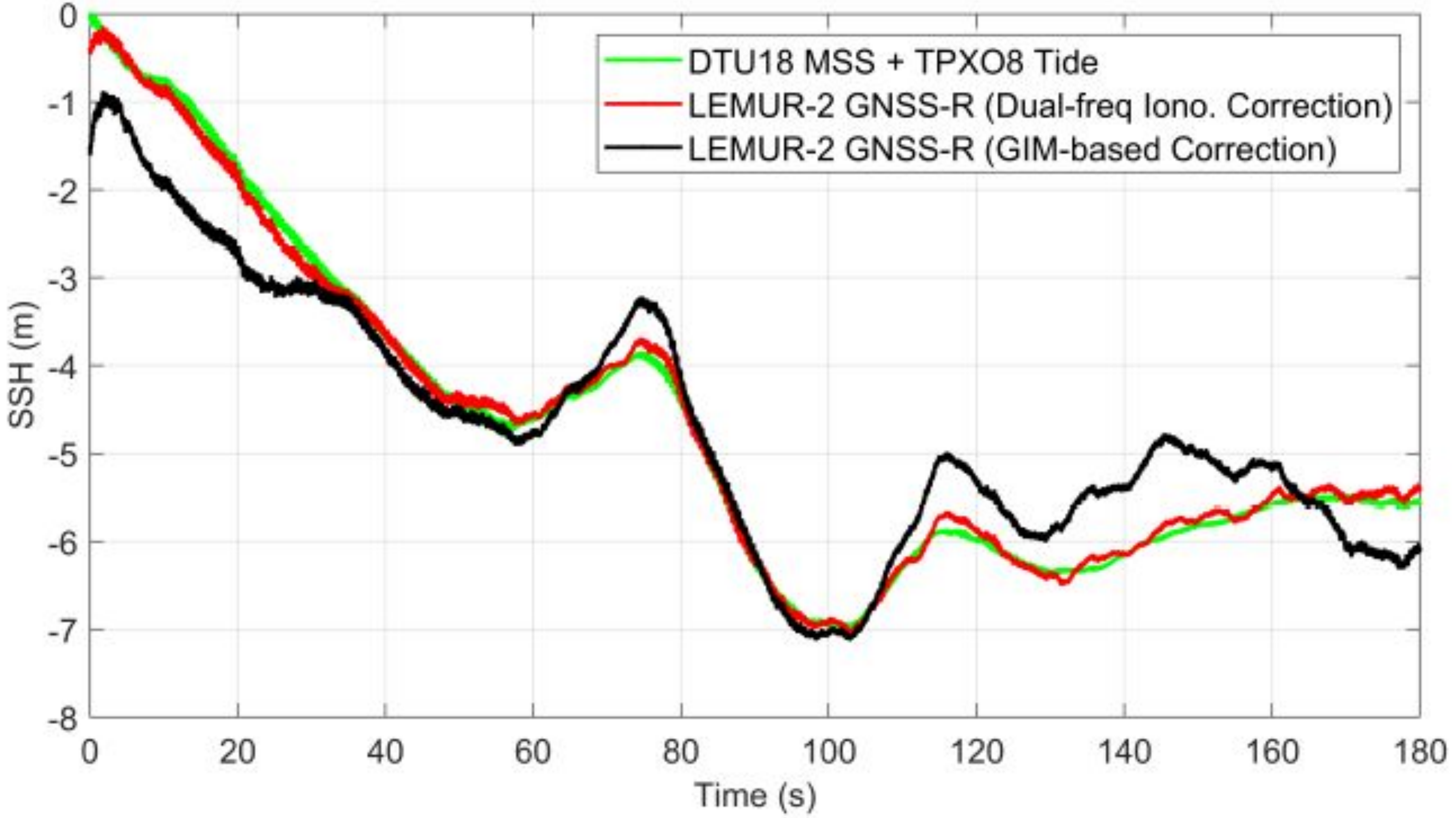
2/2/2019, 06:24:16 UTC
Spire CubeSat: FM090
GPS: PRN 12





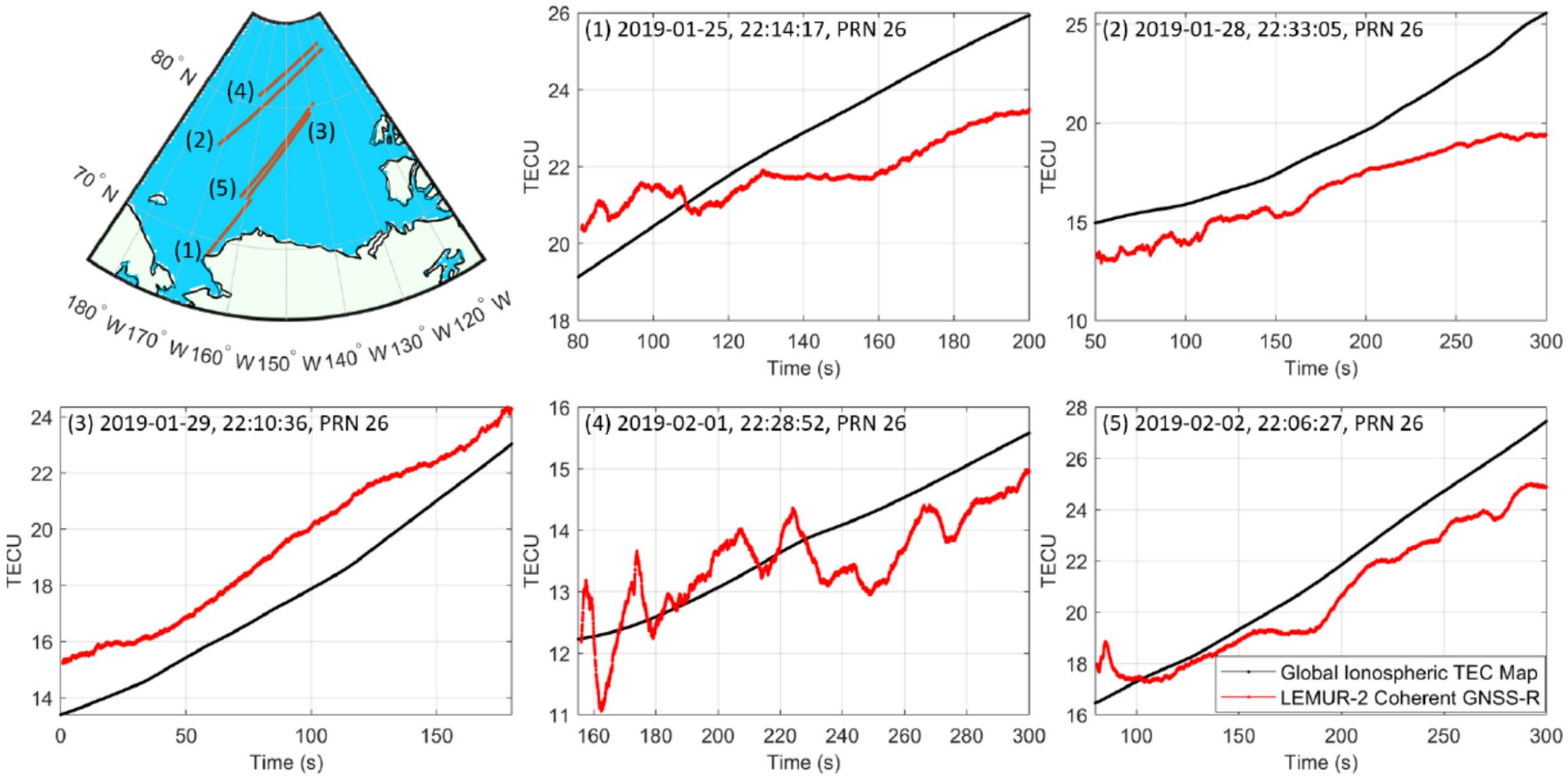
Wang, Y., Y. J. Morton, "Ionospheric total electron content and disturbance observations from space borne coherent GNSS-R measurements," *IEEE Trans. Geosci. Remote Sensing,* DOI: 10.1109/TGRS.2021.3093328, 2021.

Validation Based on Sea Surface Model: GNSS-R TEC vs. IGS GIM

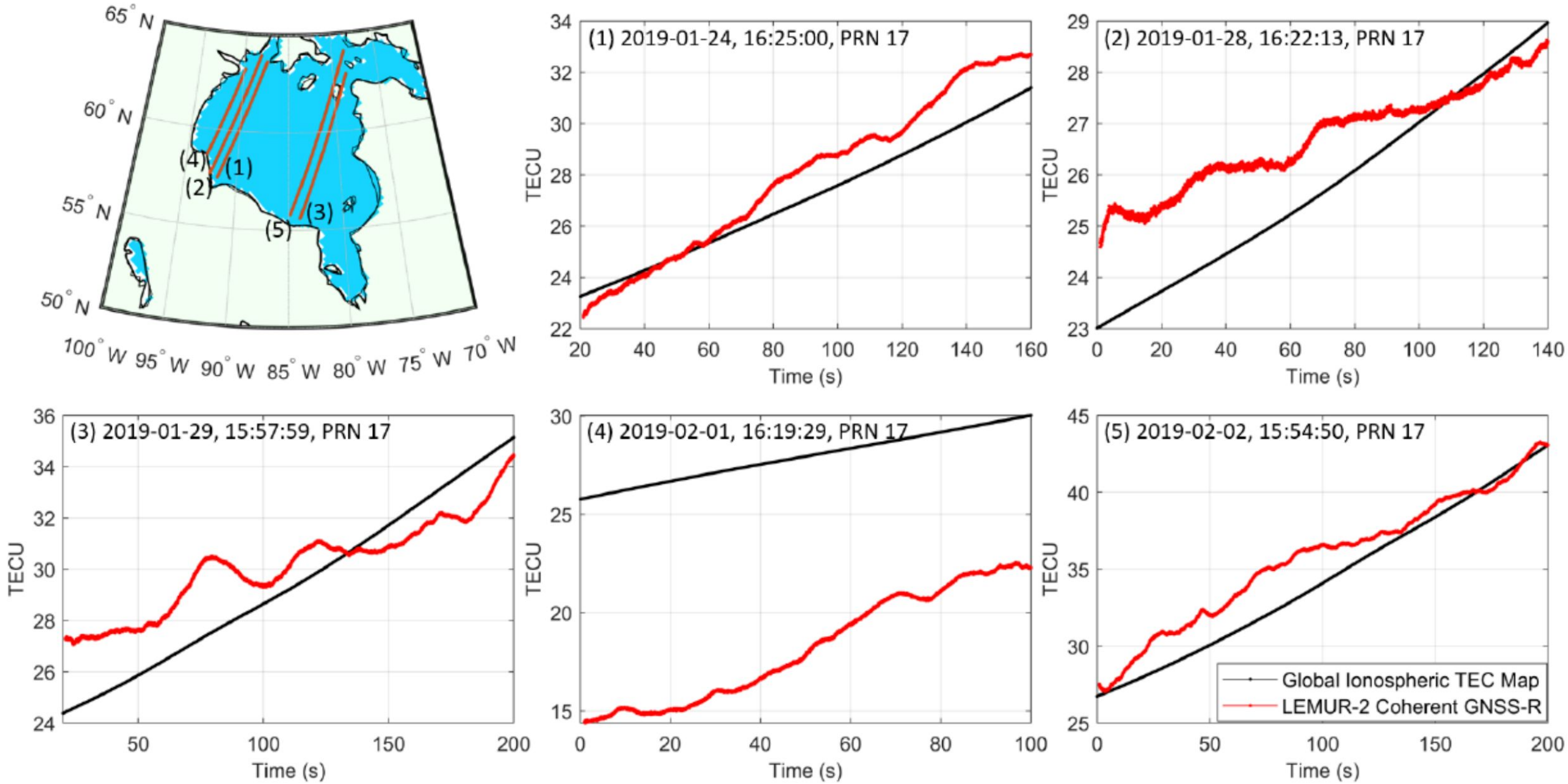


Wang, Y., Y. J. Morton, "Ionospheric total electron content and disturbance observations from space borne coherent GNSS-R measurements," *IEEE Trans. Geosci. Remote Sensing,* DOI: 10.1109/TGRS.2021.3093328, 2021.

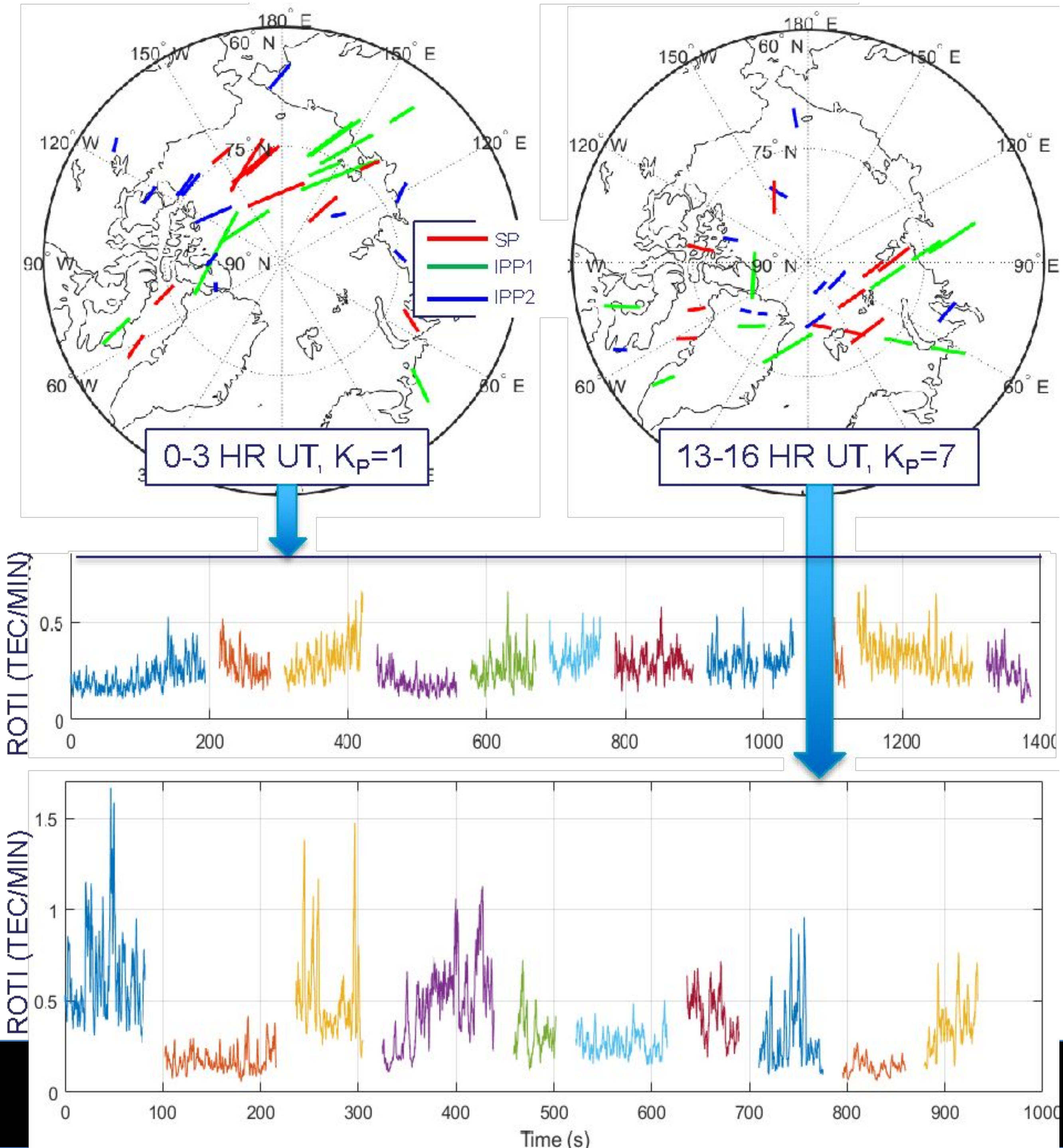
More Results Over Arctic Ocean



More Results Over Hudson Bay

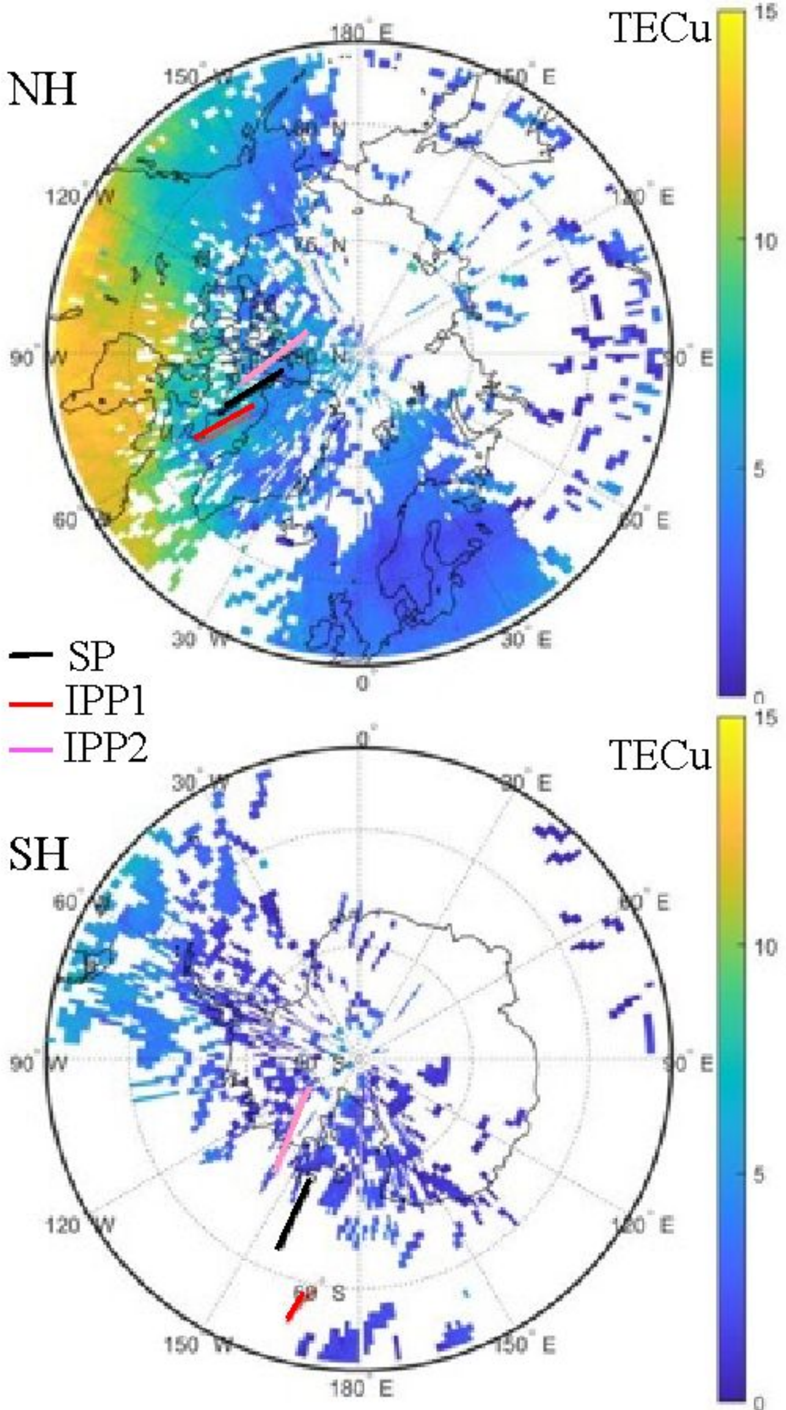


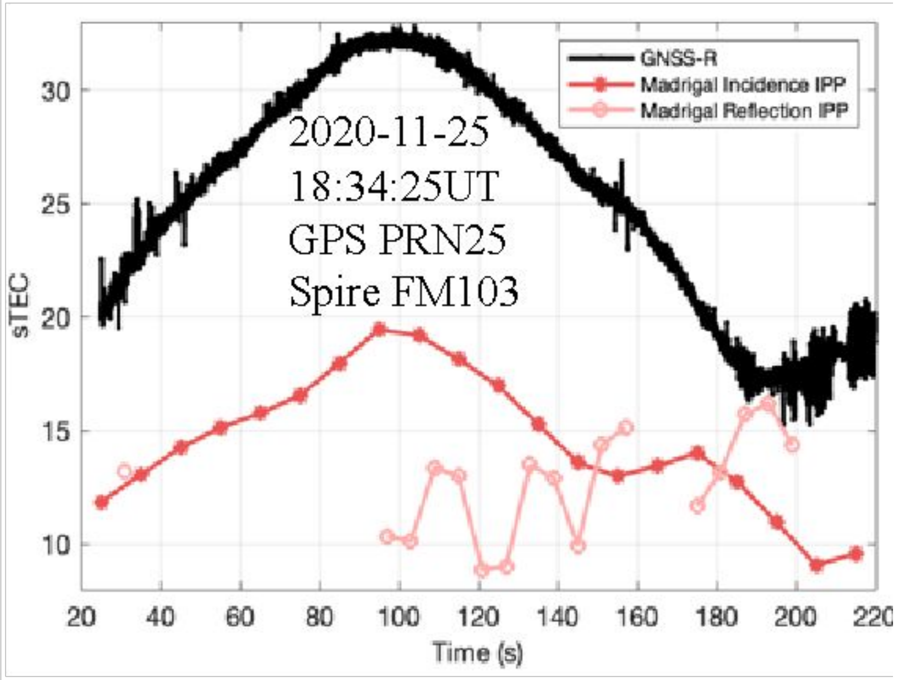
Ionospheric Disturbances Observation

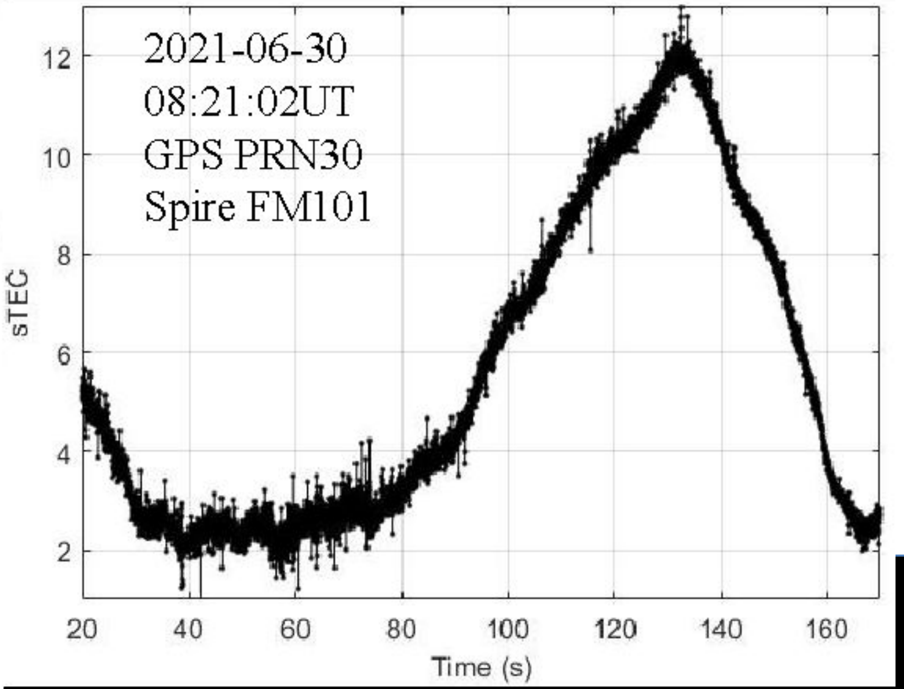


TEC Enhancement

Arctic 11/25/2011

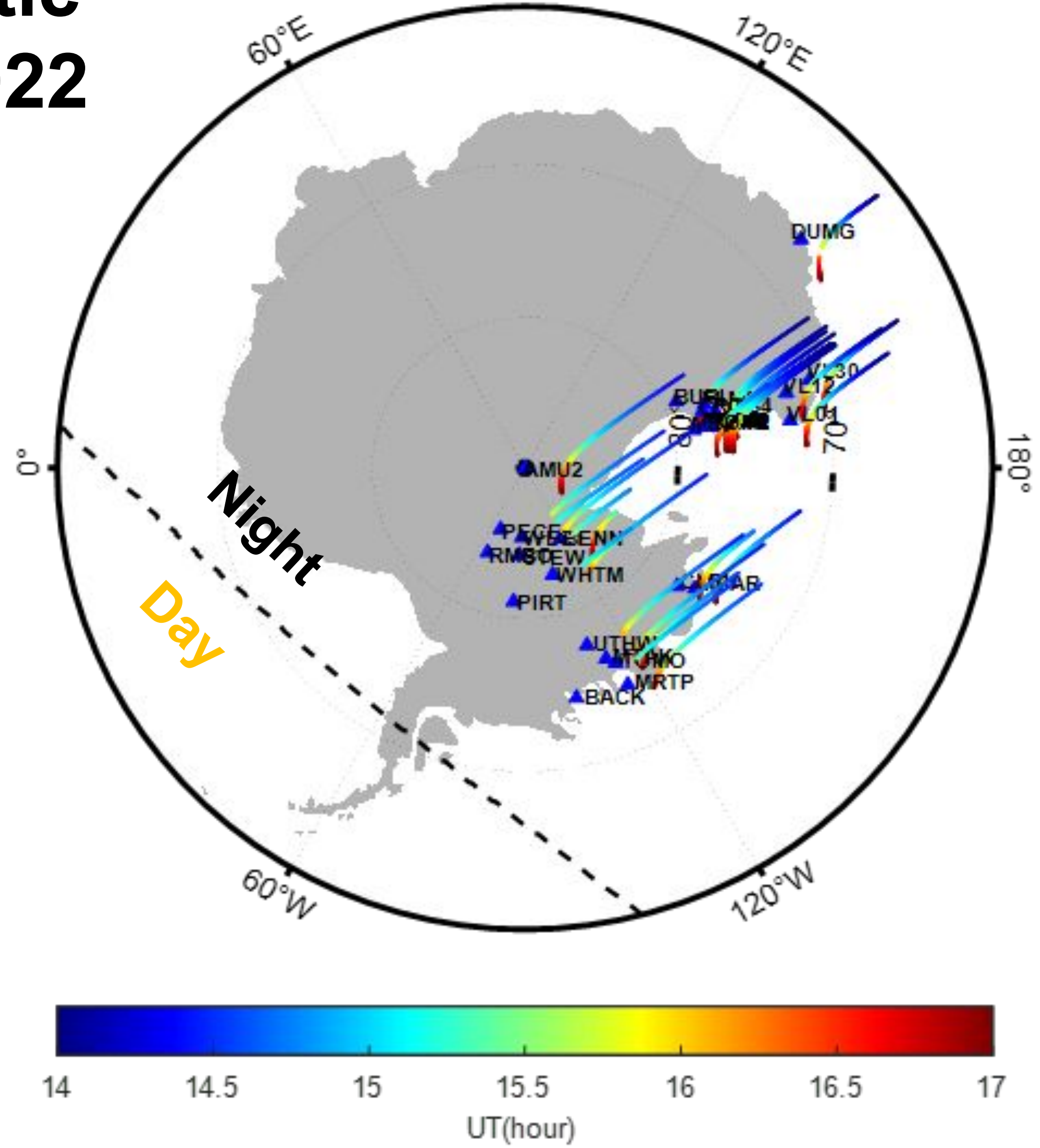


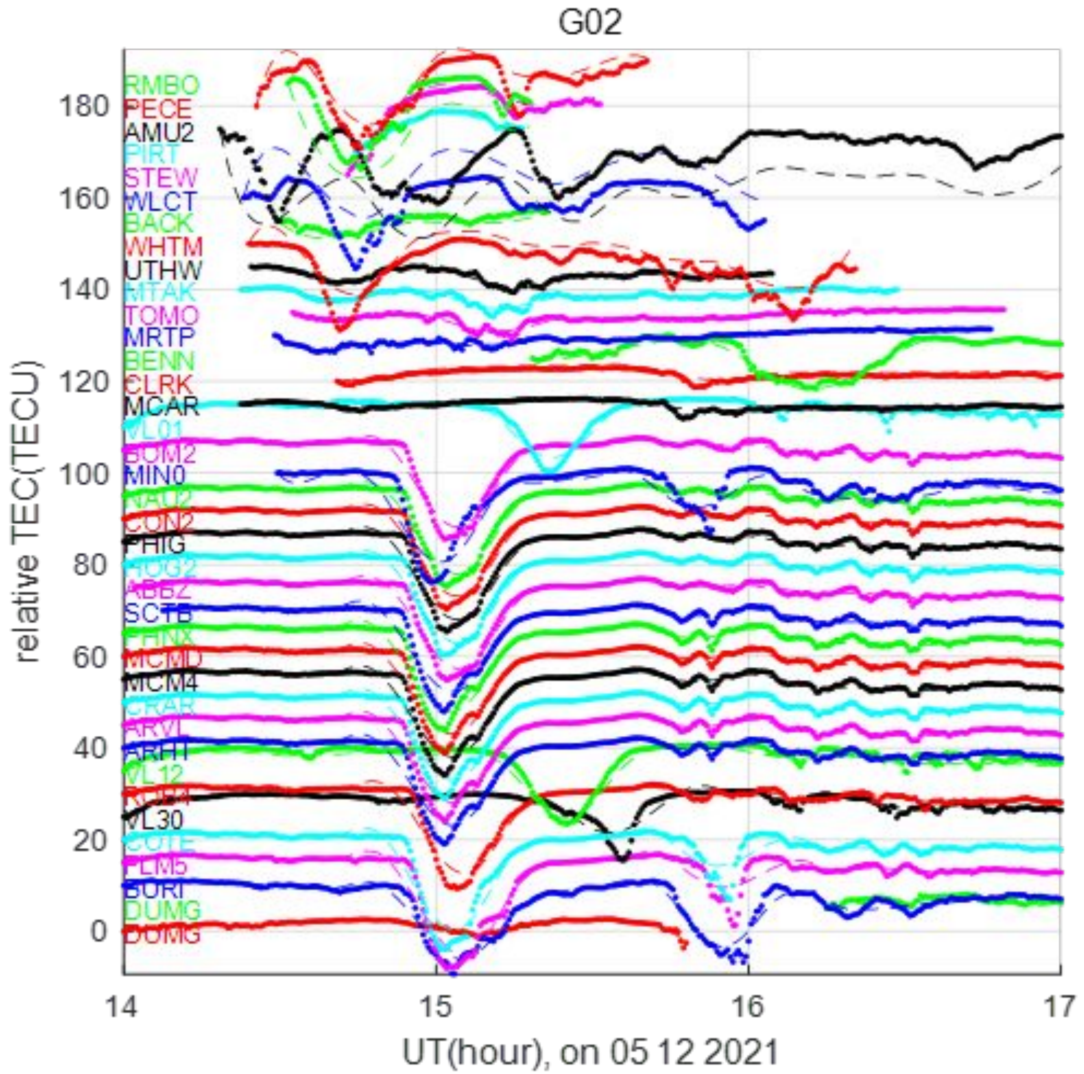




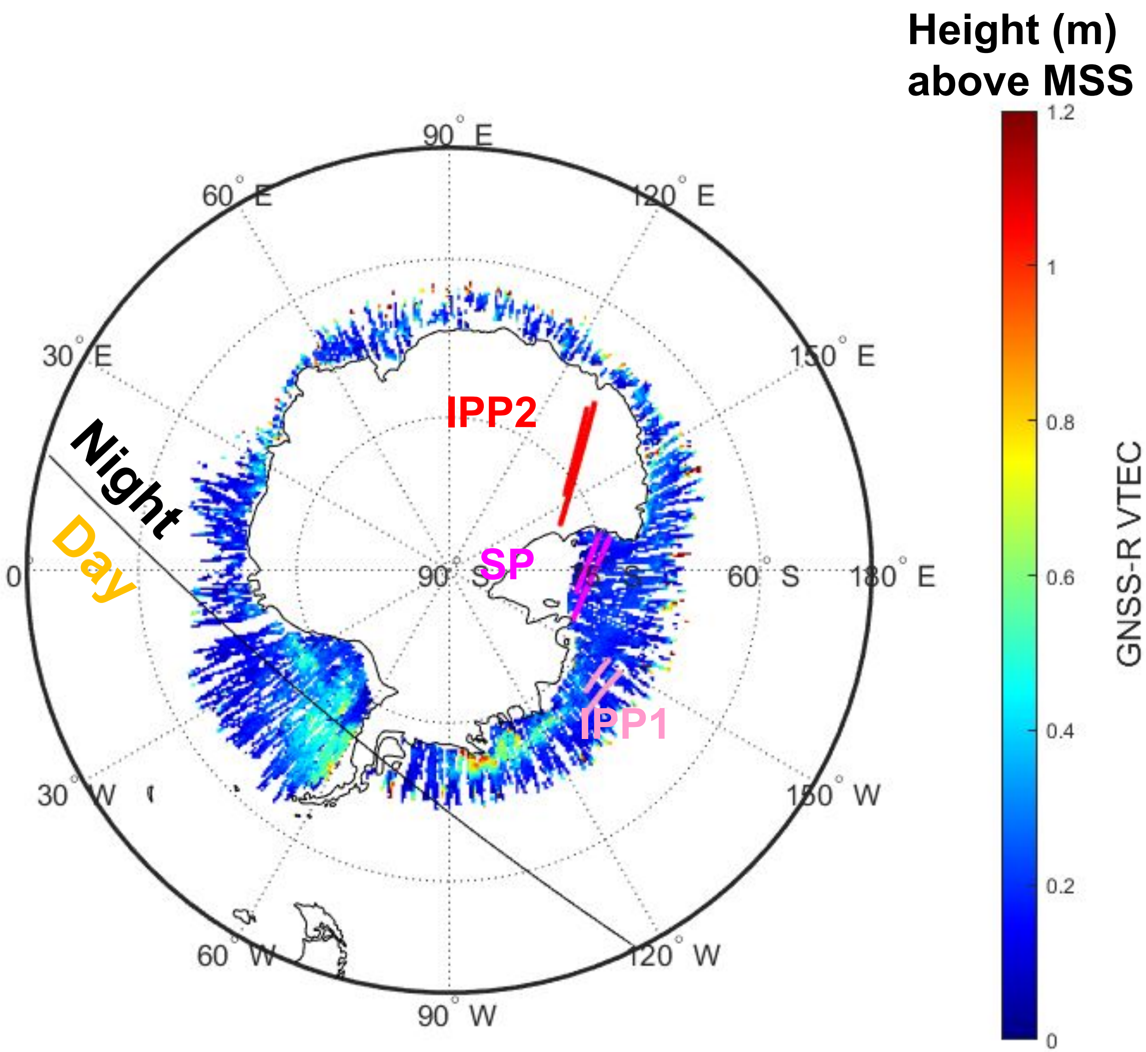
TEC Depletion
Madrigal TEC
Antarctic
5/12/2022

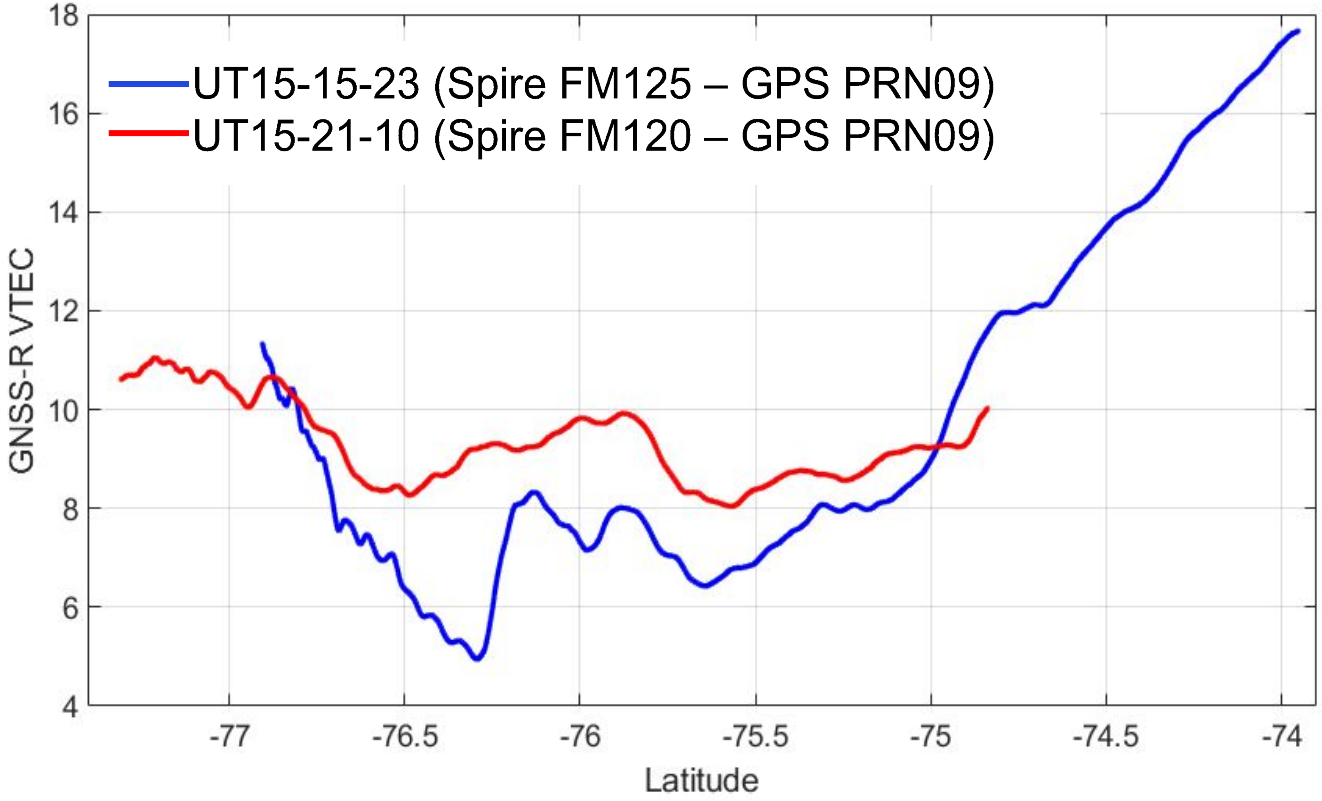
	Ap	00-03h	03-06h	06-09h	09-12h	12-15h	15-18h	18-21h	21-00h
2021/05/12	42	1	1	4	4+	7	7-	2	3



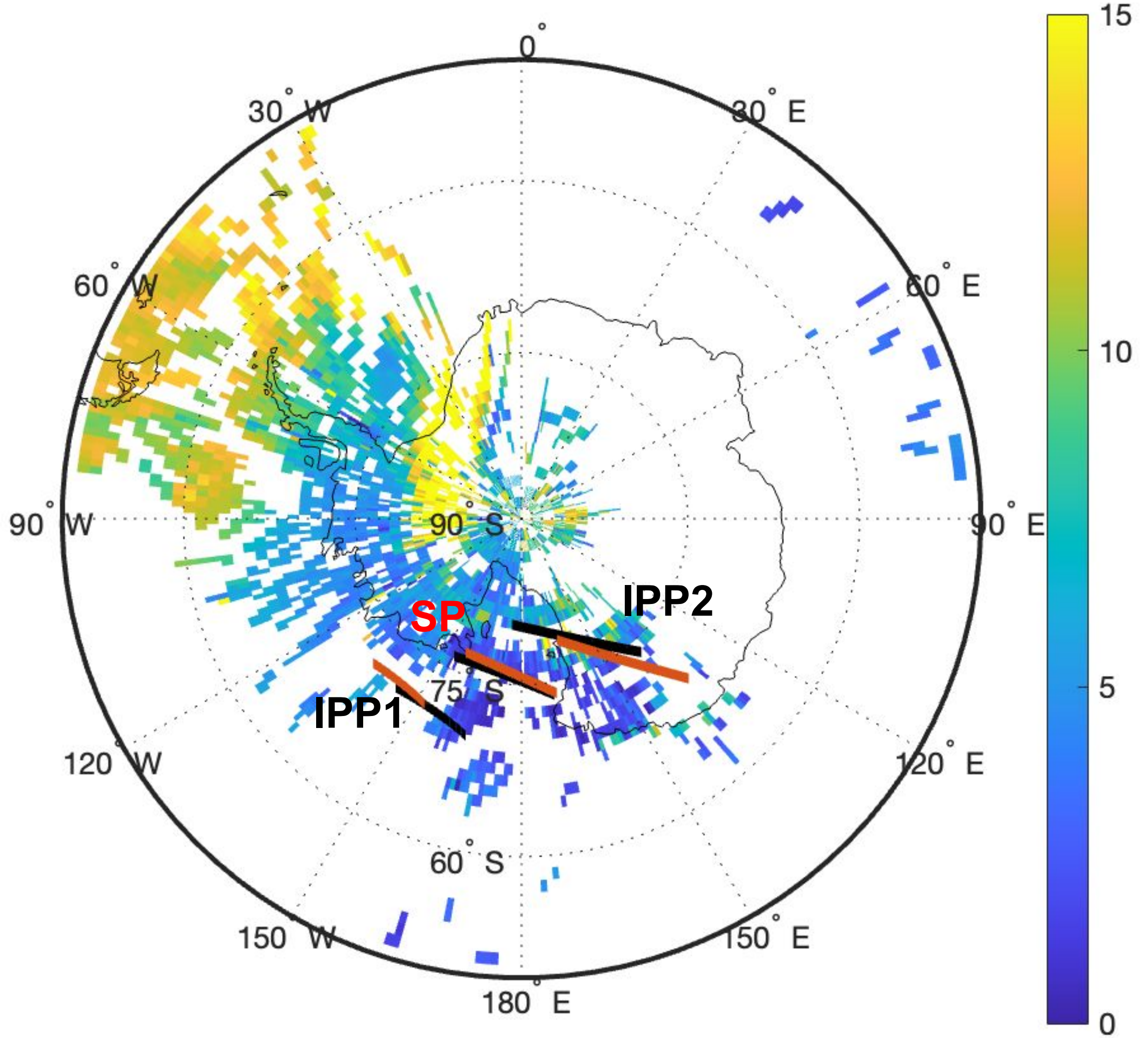


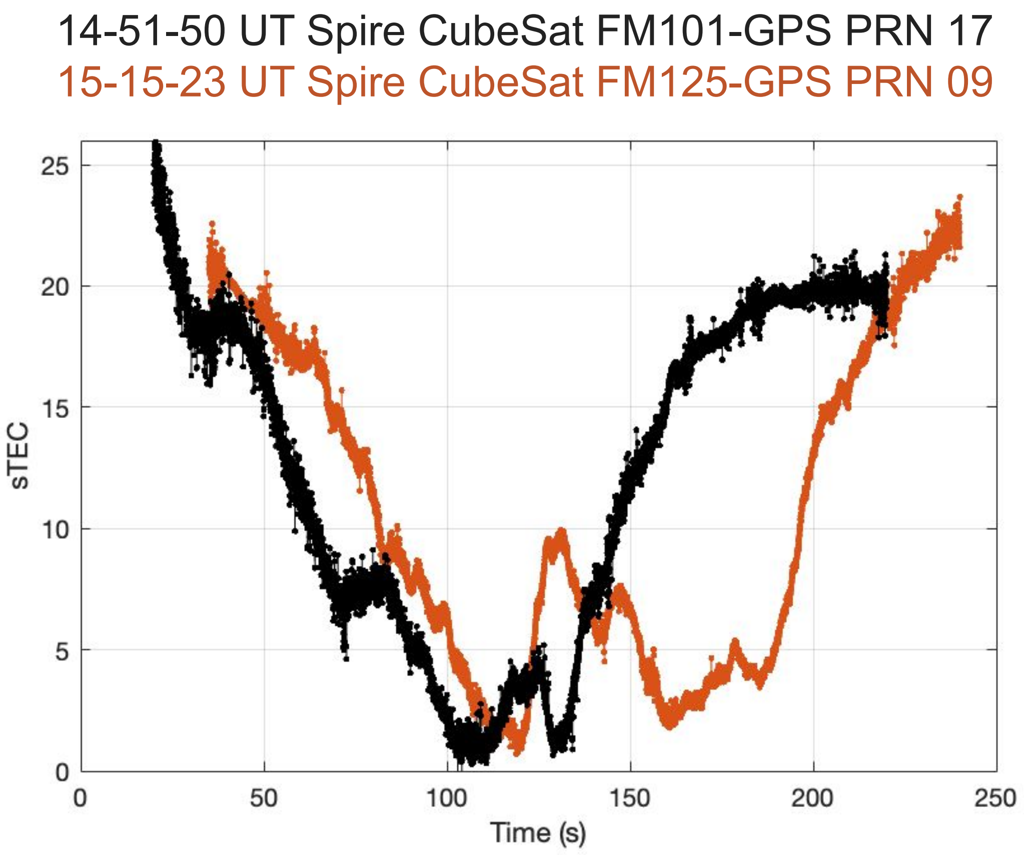
Spire CubeSat GNSS-R VTEC Observation: 5/12/2022



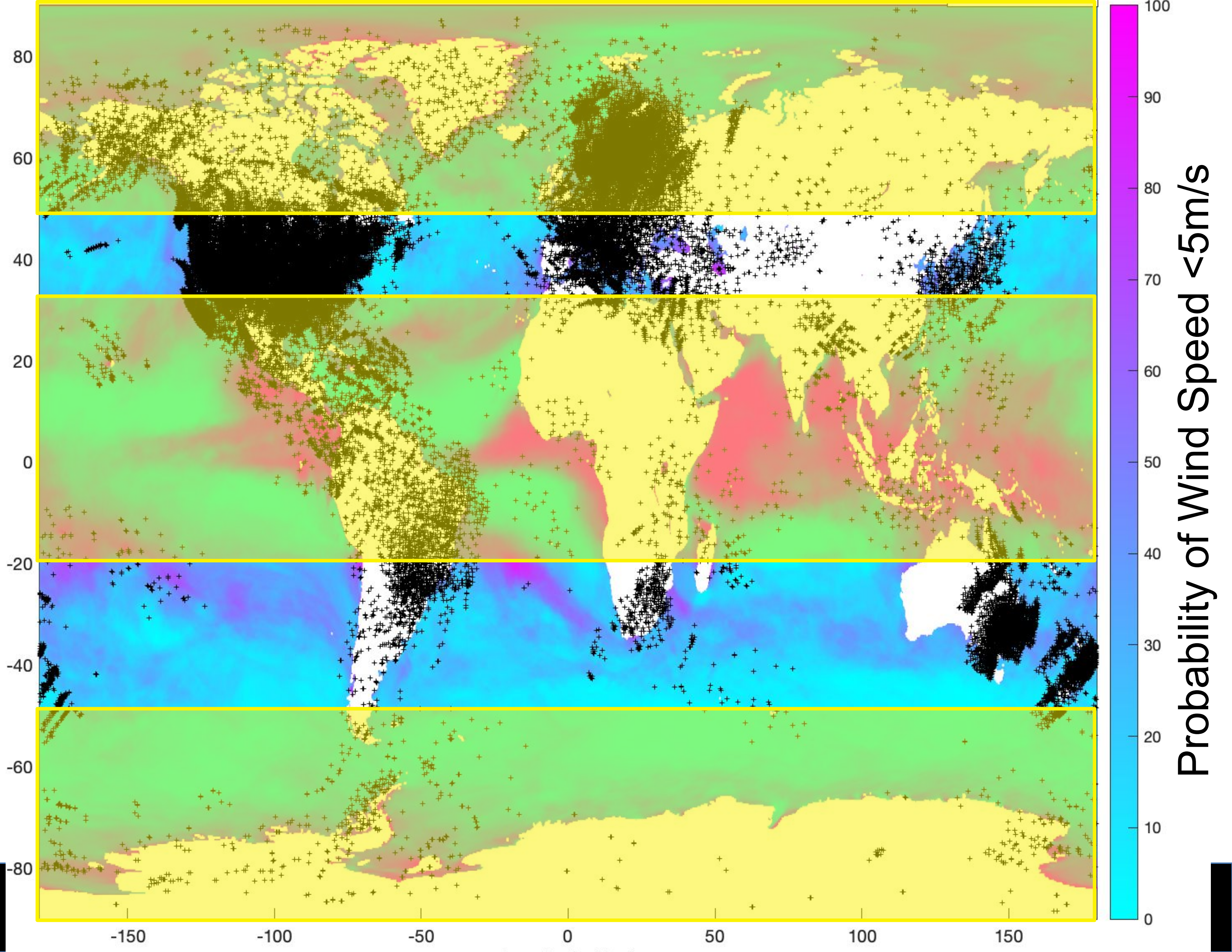


Spire CubeSat GNSS-R STEC Observation: 5/12/2022





Regions with High Probability of Coherent Reflections + Above Inland Water Bodies



GNSS-R Ionosphere Monitoring Challenges

- Coherent reflection signal carrier tracking and cycle slip mitigation
- GNSS-R receiver hardware bias calibration
- Incidence and reflection ray contribution separation

Conclusions

- GNSS-R has the potential to fill data gaps at critical regions (equatorial and high latitudes)
- GNSS-R offers nearly frozen-in time view of the ionosphere due to its rapid scan velocity
- There are challenges that need to be addressed. Potential methods under implementation.

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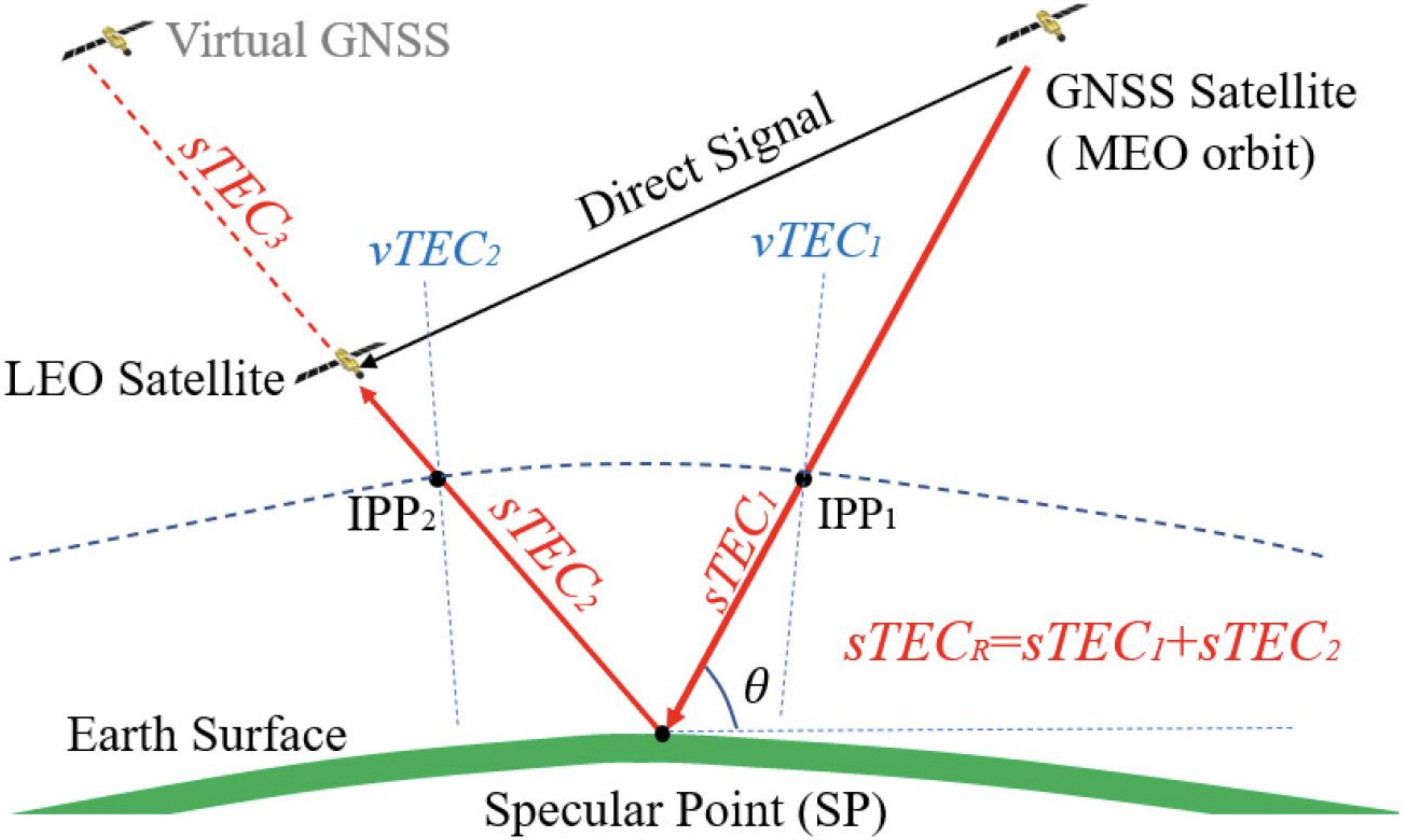
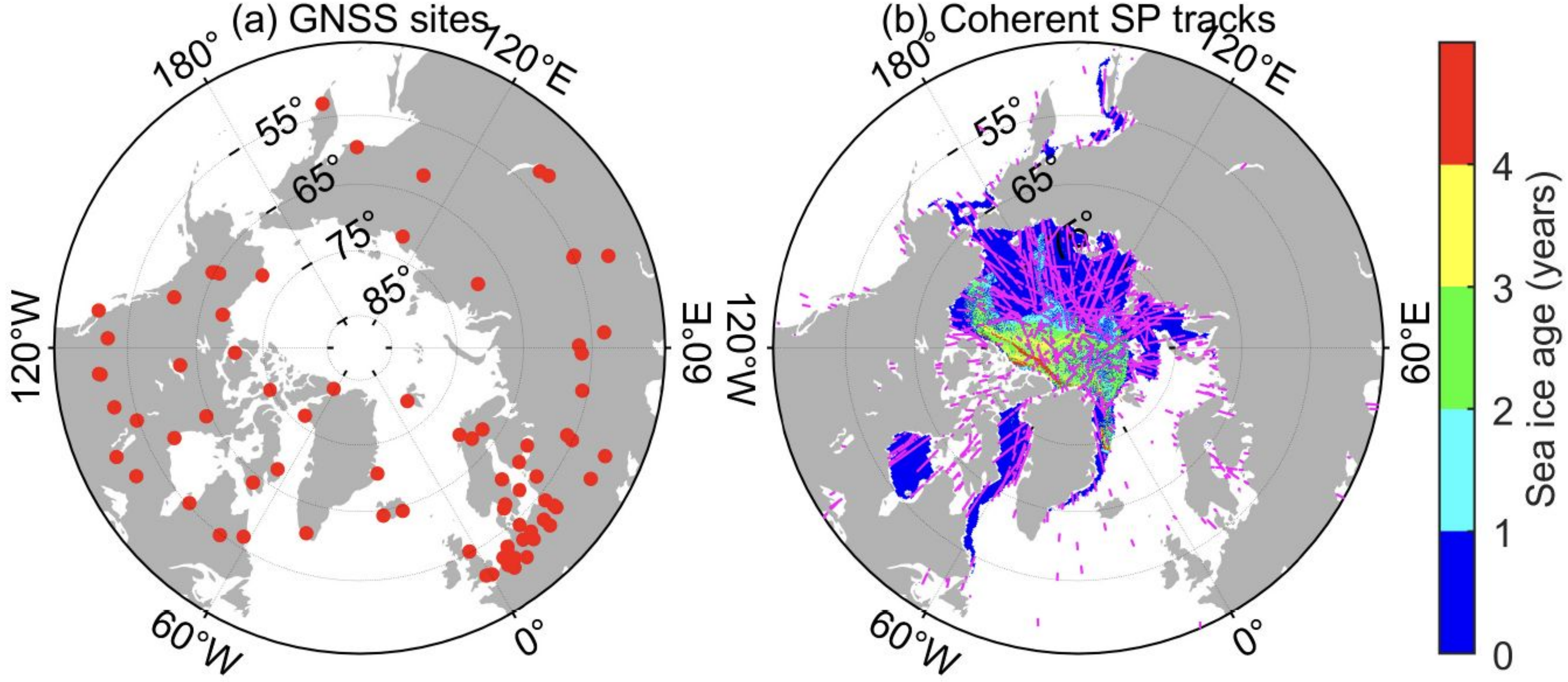
NASA 80NSSC21K1553, 80NSSC20K1738, DARAP AWD-102938-G3

$$(\mathrm{sTEC}_R + \mathrm{sTEC}_3) \cdot \mathrm{MF}(\theta) = \sum_{i=i_1}^{i_2} \sum_{n=0}^{n_{\max}} \sum_{m=0}^{n} \widetilde{P}_{nm}(\sin\phi_i) \cdot (a_{nm}\cos m\lambda_i + b_{nm}\sin m\lambda_i).$$

Separating TEC Contributions

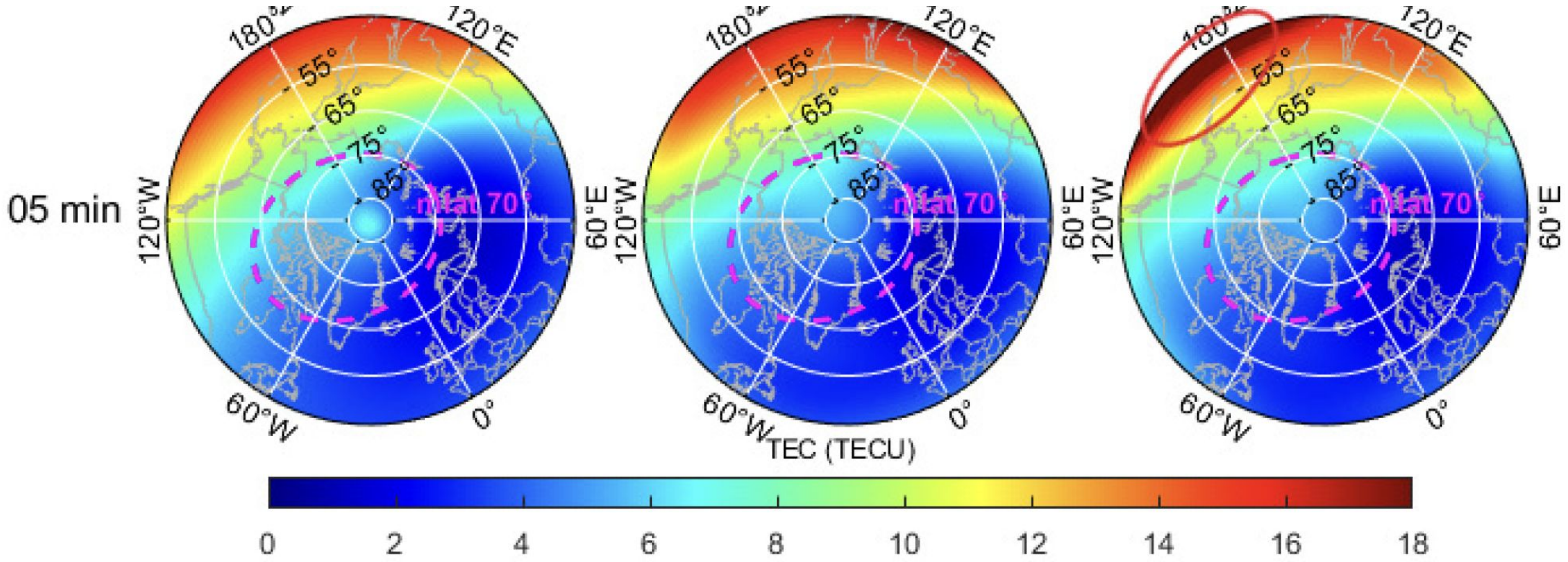


Simulation Studies



Liu, L., Y. J. Morton, *Y. Wang*, "Arctic TEC mapping using integrated LEO-based GNSS-R and ground-based GNSS observations: a simulation study," *IEEE Trans. Geosci. Remote Sensing,* DOI: 10.1109/TGRS.2021.3138692, 2021.

TEC Map Construction: Using 5 Minutes Data

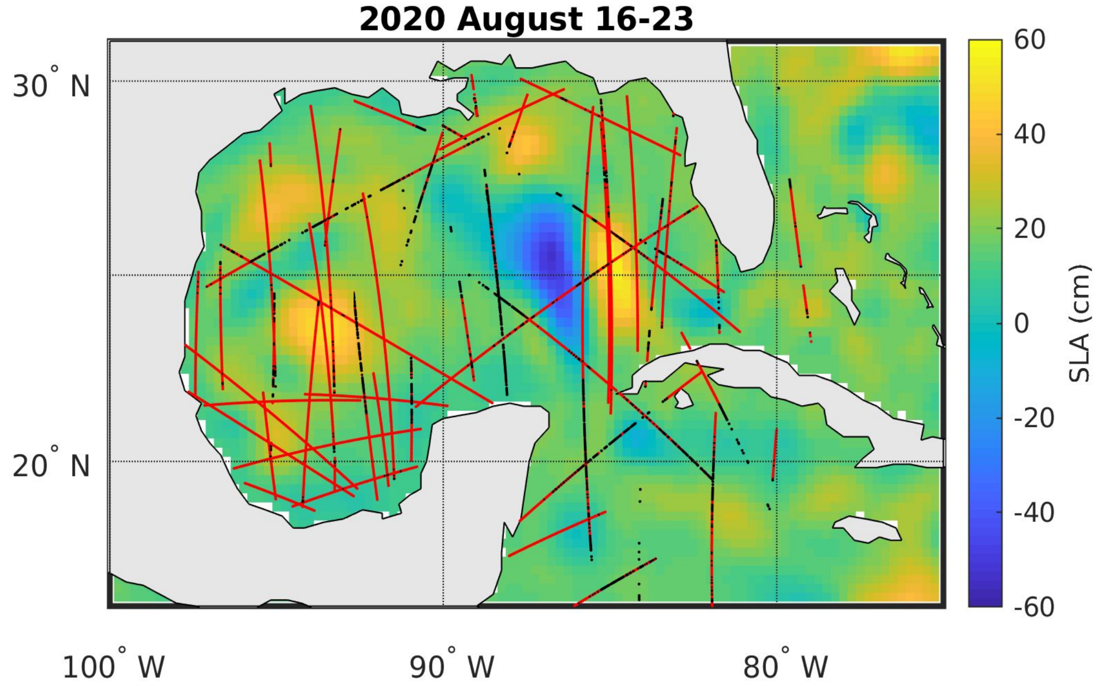


Liu, L., Y. J. Morton, *Y. Wang*, "Arctic TEC mapping using integrated LEO-based GNSS-R and ground-based GNSS observations: a simulation study," *IEEE Trans. Geosci. Remote Sensing,* DOI: 10.1109/TGRS.2021.3138692, 2021.

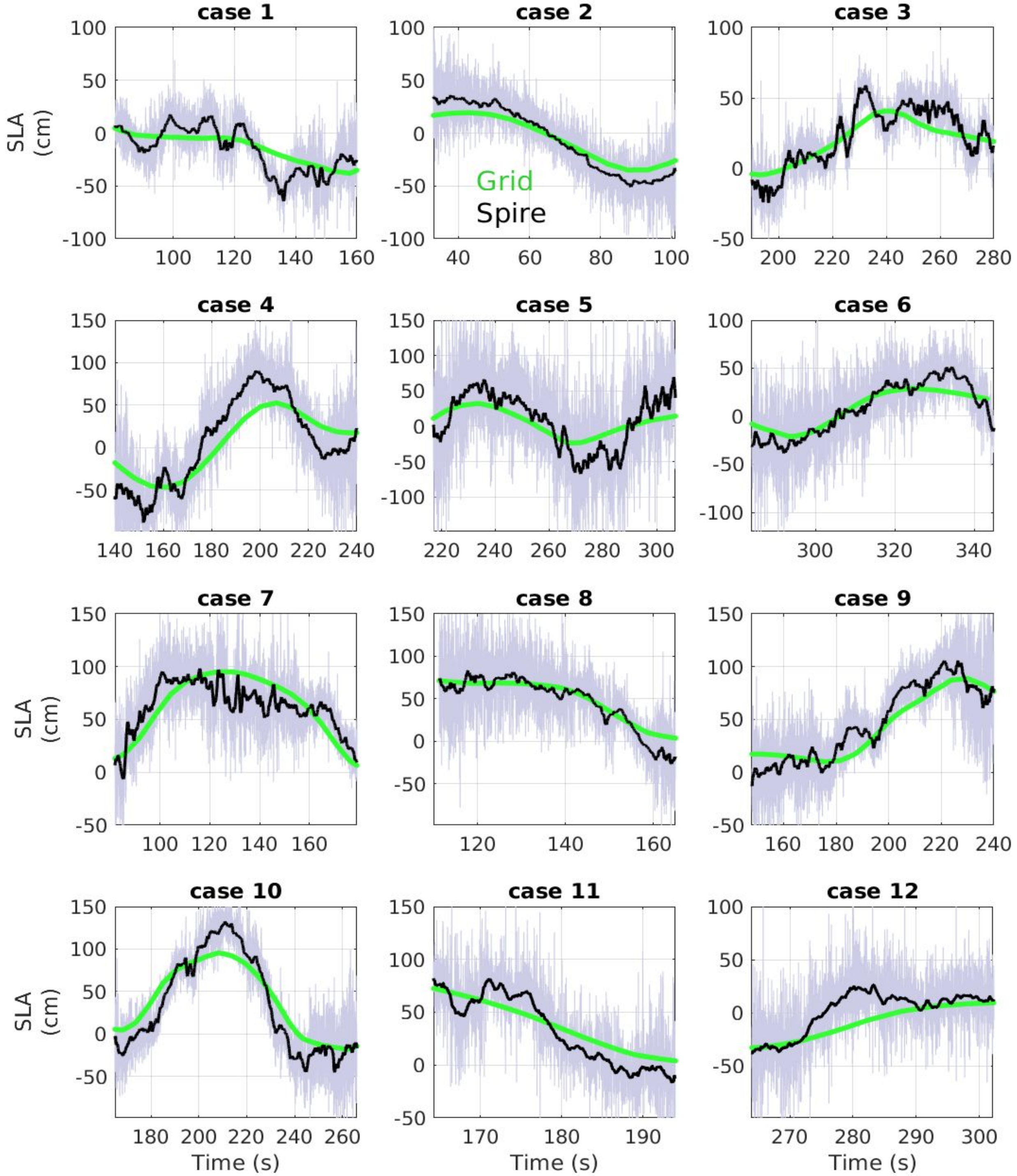
Backup Slides

Gulf of Mexico

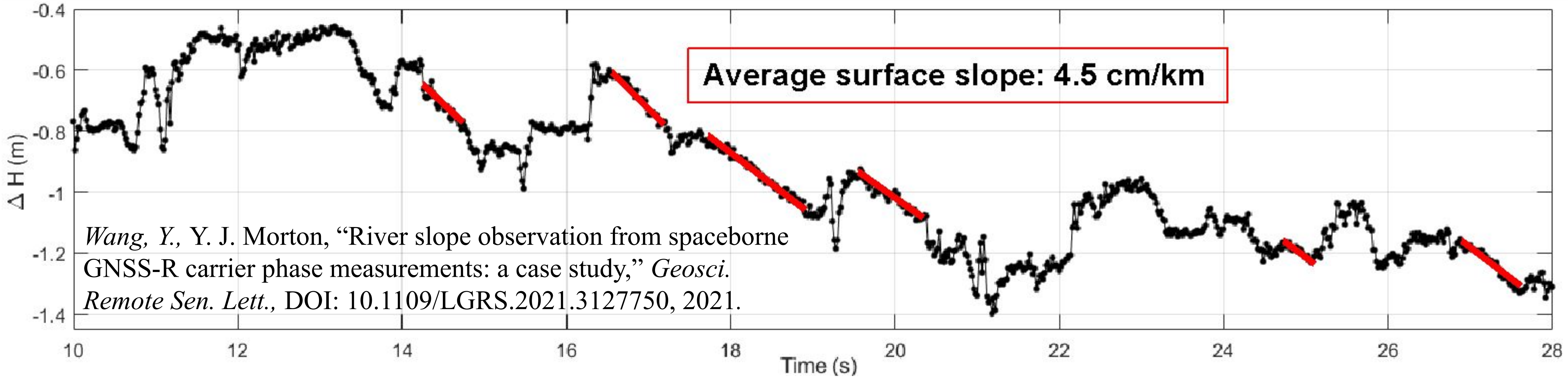
Sea Level Anomalies (SLA) at meter-level height and extending over 100km distance



Roesler, C., Y. J. Morton, *M. Scott,* R. S. Nerem, "GNSS altimetry in the Gulf of Mexico based on Spire CubeSat carrier-phase data," *Proc. IEEE GNSS+R Special Meeting on GNSS+R,* DOI: 10.1109/GNSSR53802.2021.9617729, 2021.

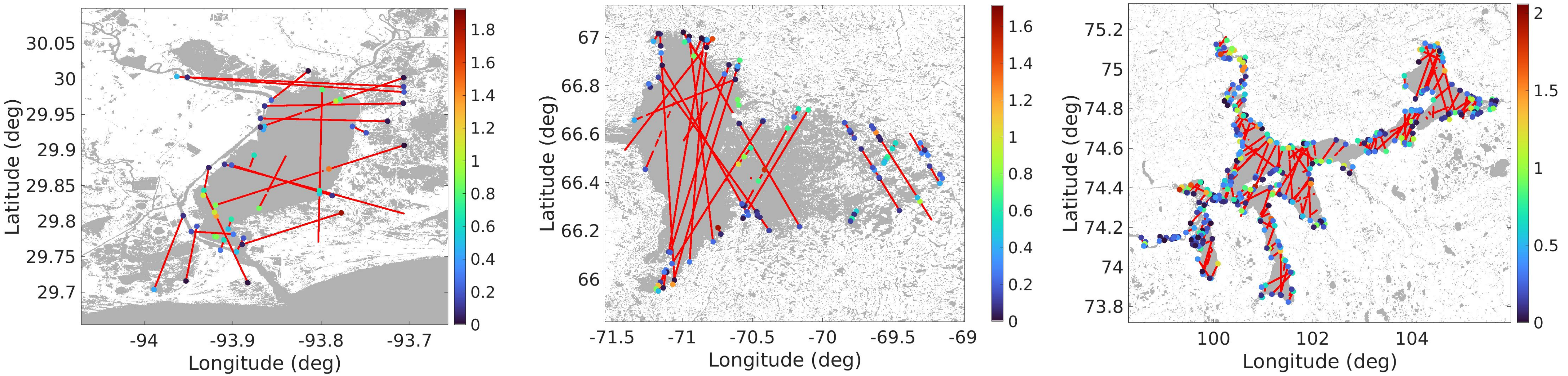


River Surface Slope Retrieval



Wang, Y., Y. J. Morton, "River slope observation from spaceborne GNSS-R carrier phase measurements: a case study," *Geosci. Remote Sen. Lett.,* DOI: 10.1109/LGRS.2021.3127750, 2021.

Masking Inland Water Body Boundary



Zhang, J., Y. J. Morton, Y. Wang, and C. Roesler, "Delineating lake boundaries by using raw GNSS-R measurements" Presented at the CYGNSS Science Team Meeting, March 9, 2022.

Comparison: Spire vs. NSIDC Sea Ice Age Data

4/8 – 4/14, 2020