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High Latitude Ionospheric Gradient Observation Results from a Multi-Scale Network

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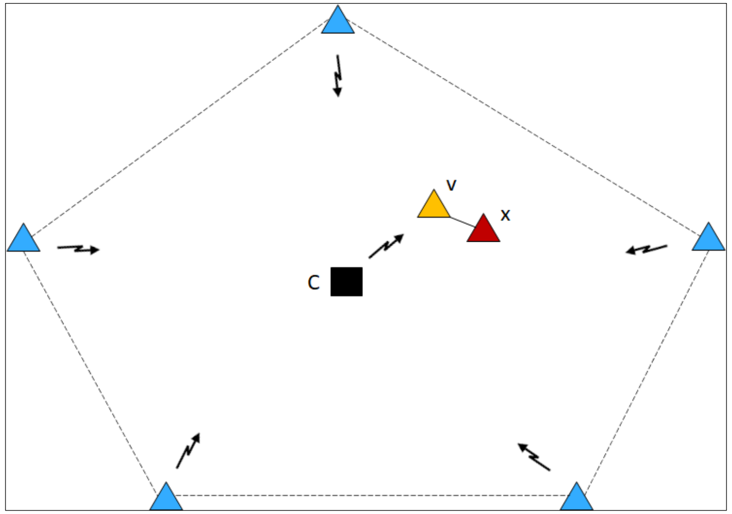
Background

High latitude regions are known to frequently have increased ionospheric activity and observe smaller size of high-density irregularities.

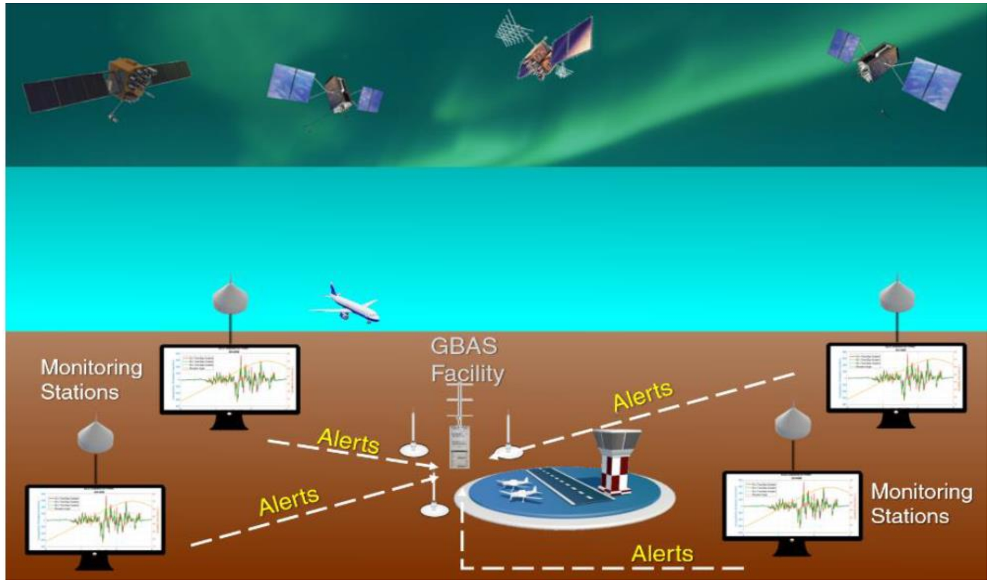
Observation of small spatial-scale ionospheric delay features is a challenge for sparse CORS networks. E.g.:

- NRTK, VRS approach - the inability to observe an ionospheric spatial gradient can lead to a residual error on the user side impacting the ambiguity fixing time and success rate. Can potentially pose an integrity risk (if system/network supports integrity).
- GBAS, use of external network for real-time ionospheric gradient monitoring.

NRTK, VRS approach.

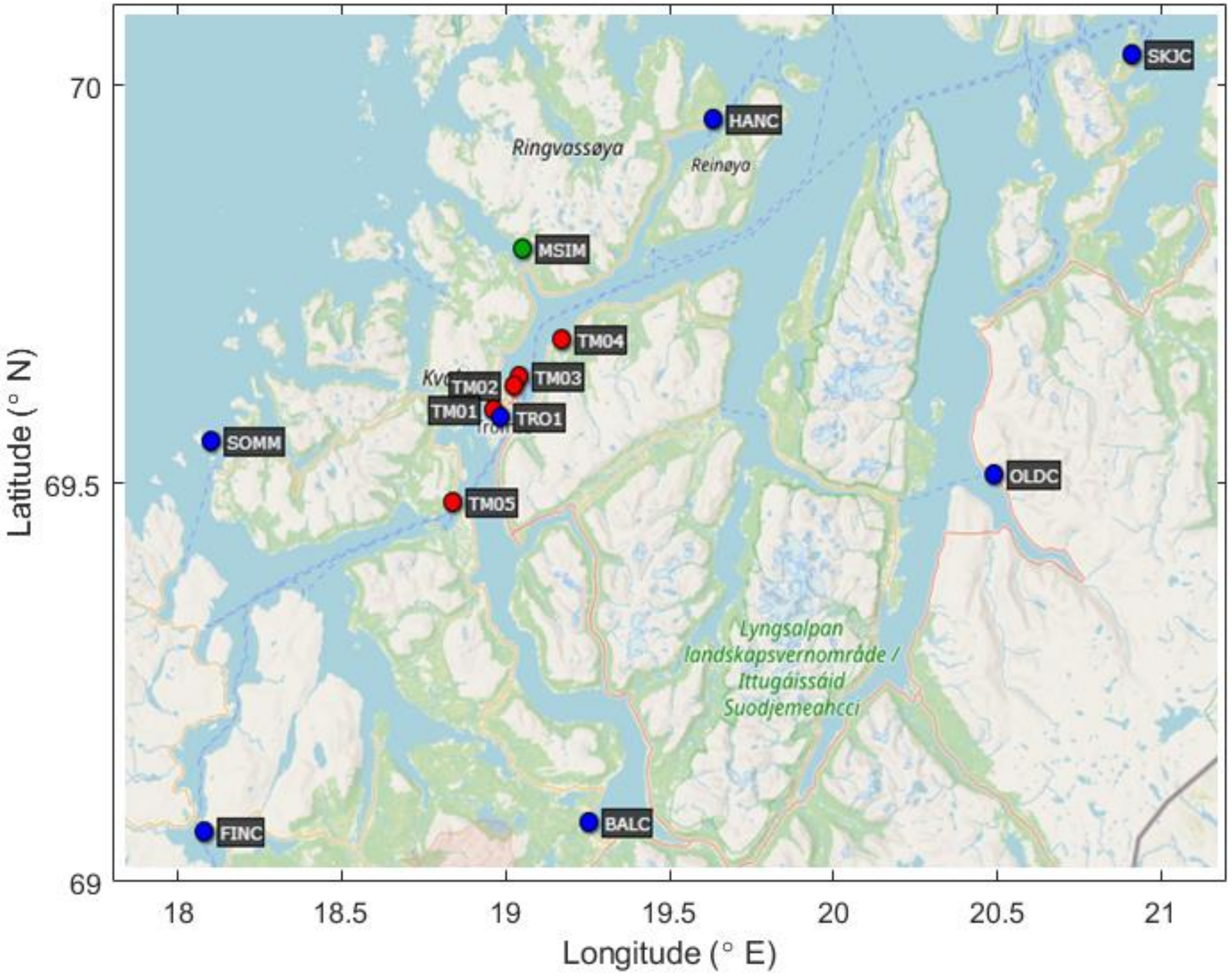


GBAS, use of external network for iono gradient monitoring (image source [1]).



Receiver Cluster and Data

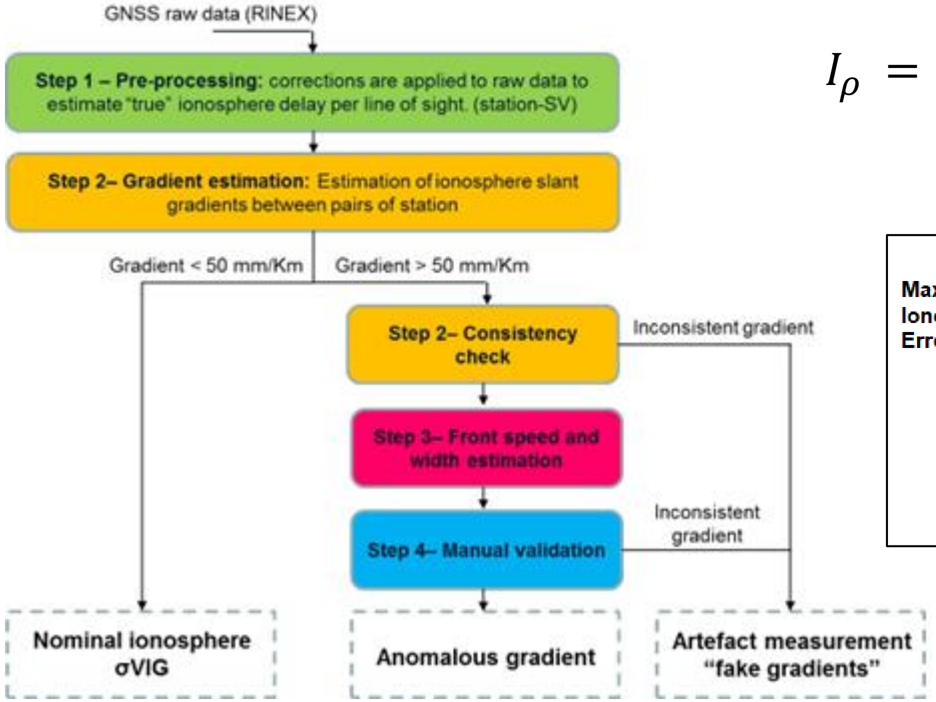
Map of the receiver locations (blue: CPOS reference receivers, green: CPOS monitoring receiver, red: test receivers).



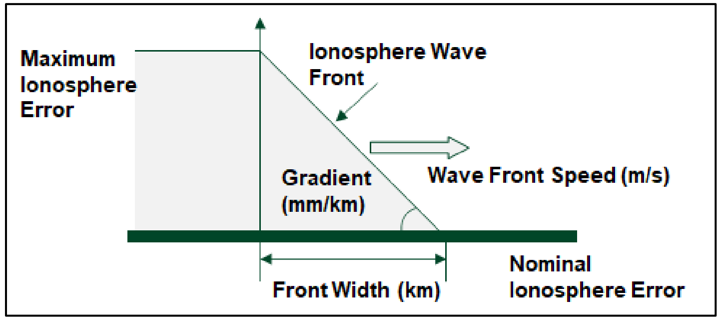
- **Receiver cluster:** 13 CORS receivers (7 reference receivers, 1 monitoring receiver, 5 test receivers) covering the area around Tromsø (69.6^0 N , 18.9^0 E).
- Baselines from 1.37 km to 146 km.
- Cluster location is in the Auroral zone at night-time.
- **Data:** period between 1 April 2021–31 December 2022.

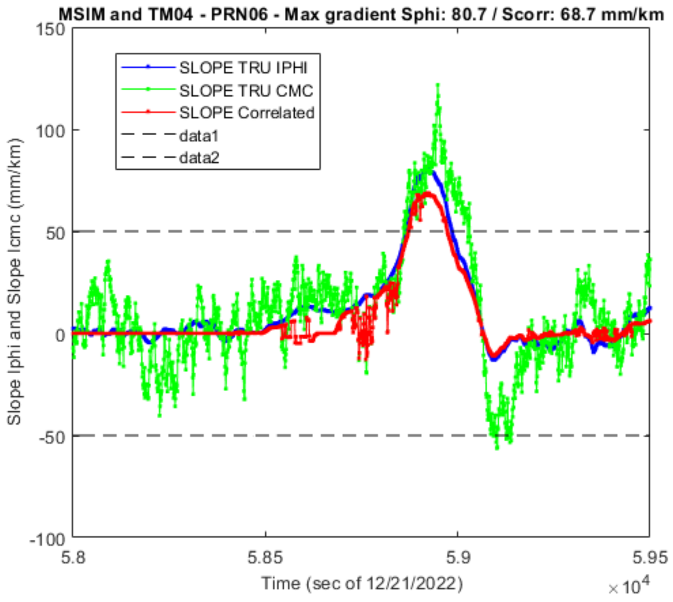
Data Processing (1/2)

To study the spatial decorrelation of the ionospheric delay for the considered cluster of receivers, the data recorded by each of the receivers was analyzed using a MATLAB-based GBAS Ionosphere Monitoring Assessment (GIMA) tool developed by EUROCONTROL [2].



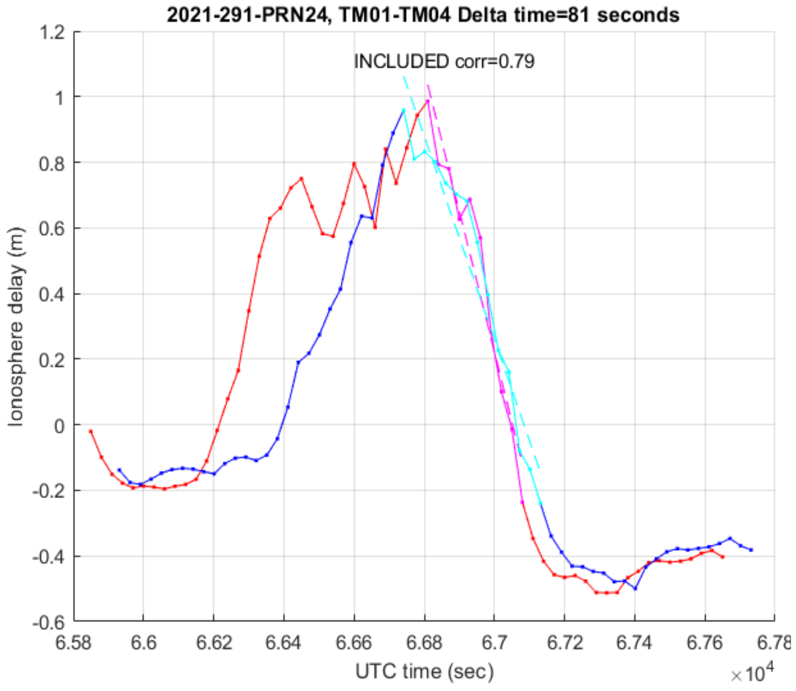
$$I_\rho = \frac{\rho_2 - \rho_1}{\gamma - 1}, \qquad I_\phi = \frac{\phi_2 - \phi_1}{\gamma - 1}, \qquad I_{CMC} = \frac{\rho_1 - \phi_1}{2}.$$

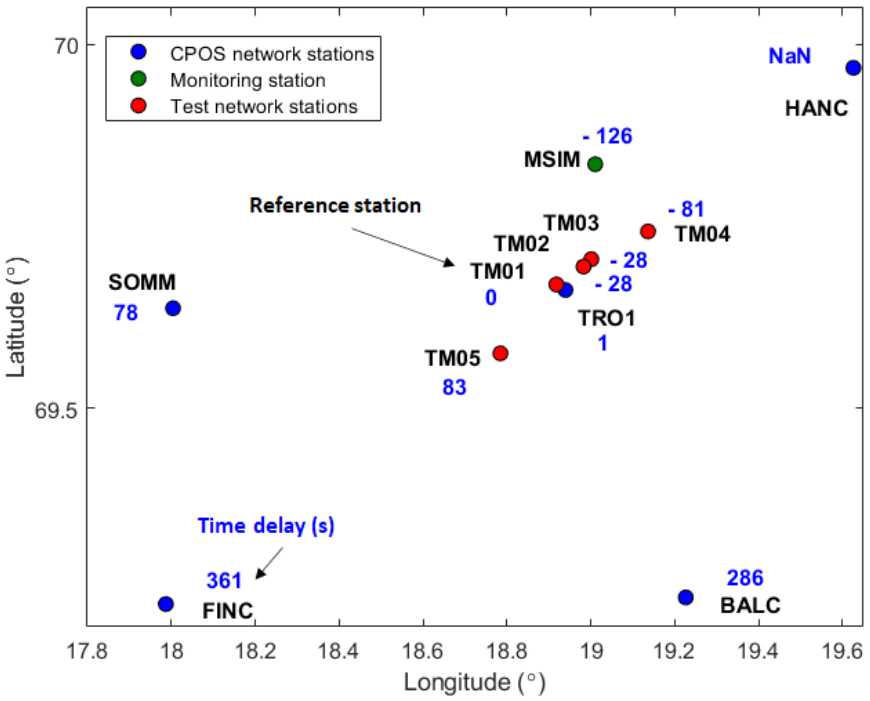


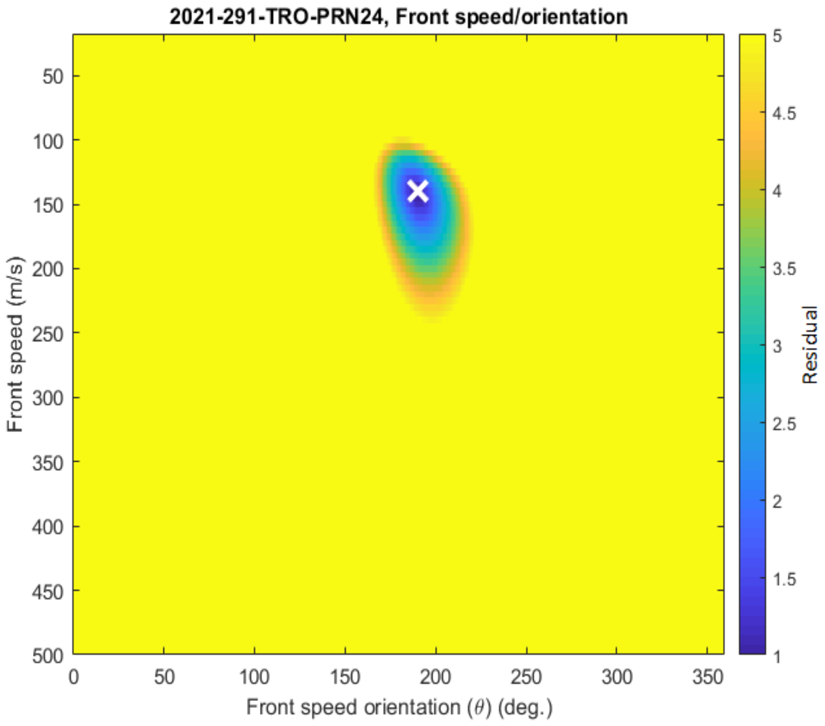


Data Processing (2/2)

Ionosphere front speed and direction estimation:



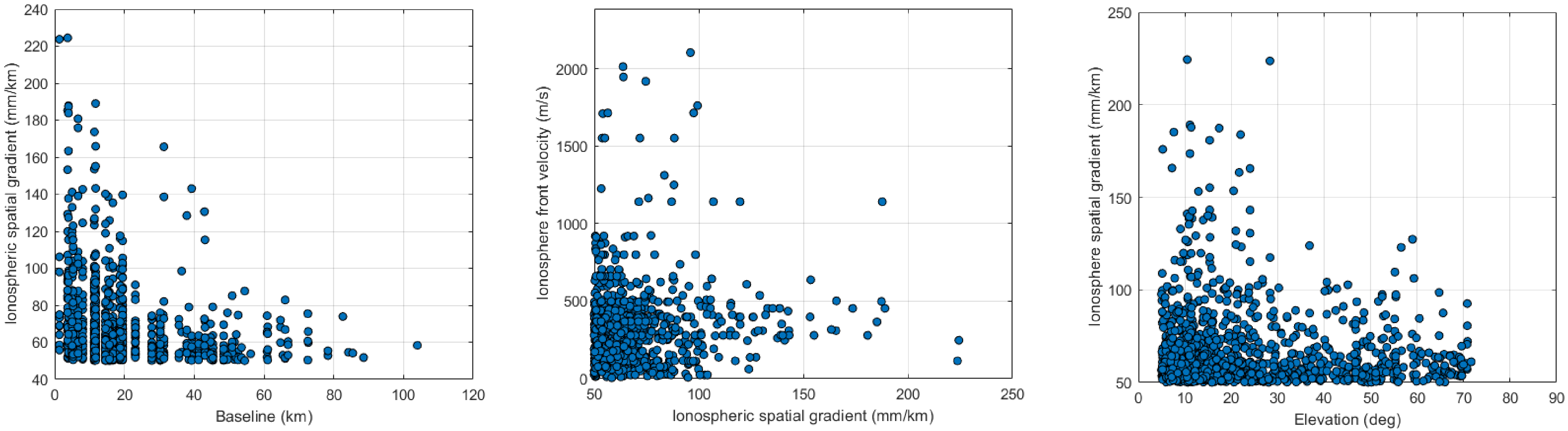




- At least 3 receivers have to be observing the gradient for this process.

Results (1/5)

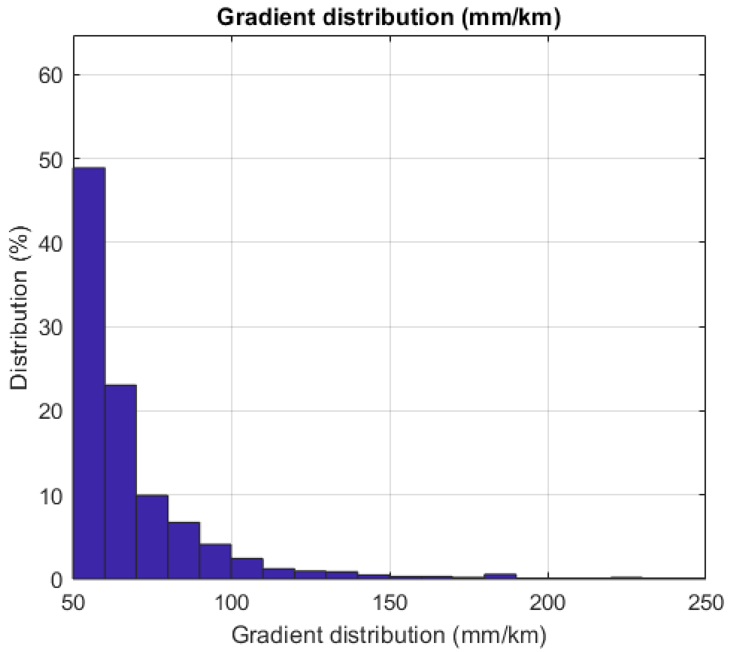
- Results shown are for a gradient threshold value of 50 mm/km. In total 23588 events were identified for the considered period, of which 1076 passed the manual validation process.

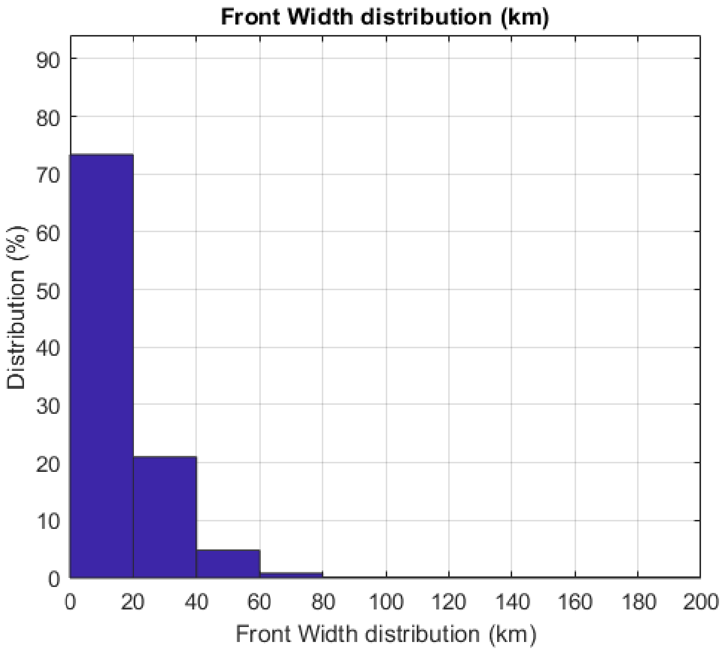


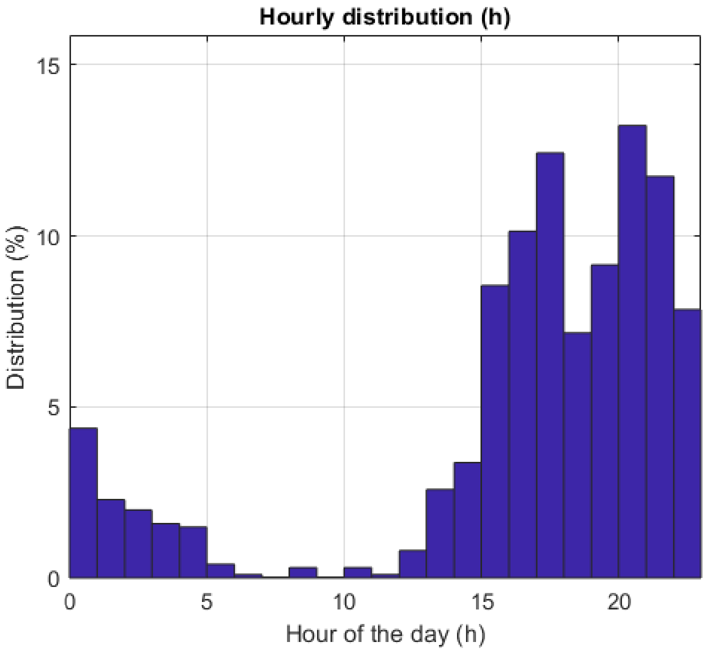
- The majority of events as well as the highest magnitude events have been observed at the baselines ranging from 1.36–41 km.
- The observed events appear to range from quasi static to moving at velocities of nearly 2000 m/s.
- More than 40% of the events were observed on elevation angles below 15.

Results (2/5)

- The vast majority of the events are under 100 mm/km. (highest observed gradient: 224 mm/km, TM01 - TM02 station pair separated by 3.71 km).
- The vast majority of the gradient width (or the scale size) estimates are below 20 km, indicating that most of the observations are small spatial scale events.
- Most of the events occurred during evening and nighttime.

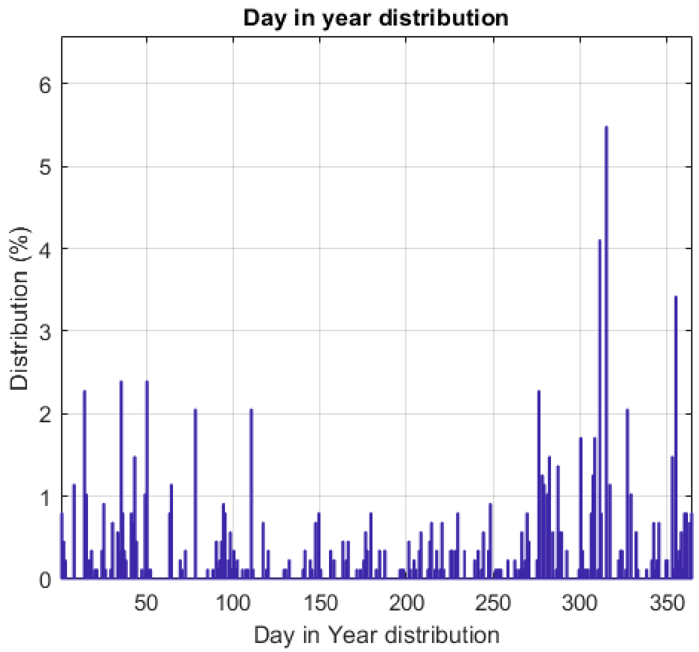


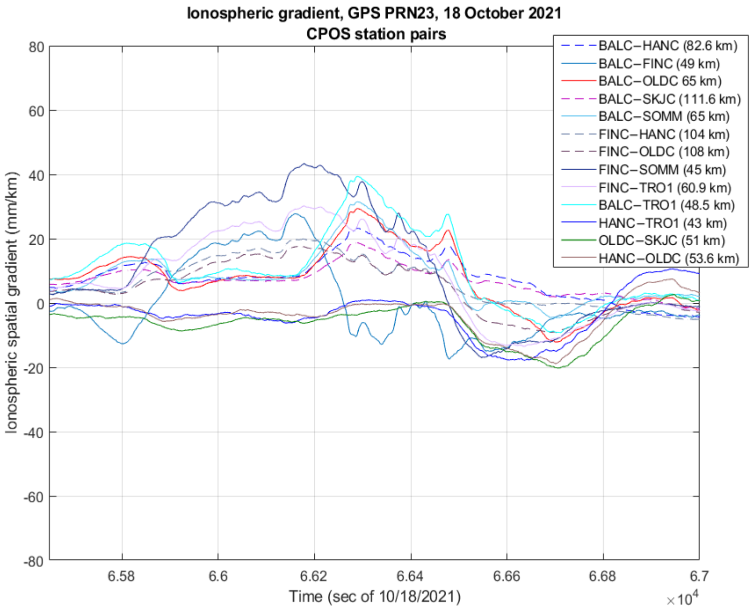


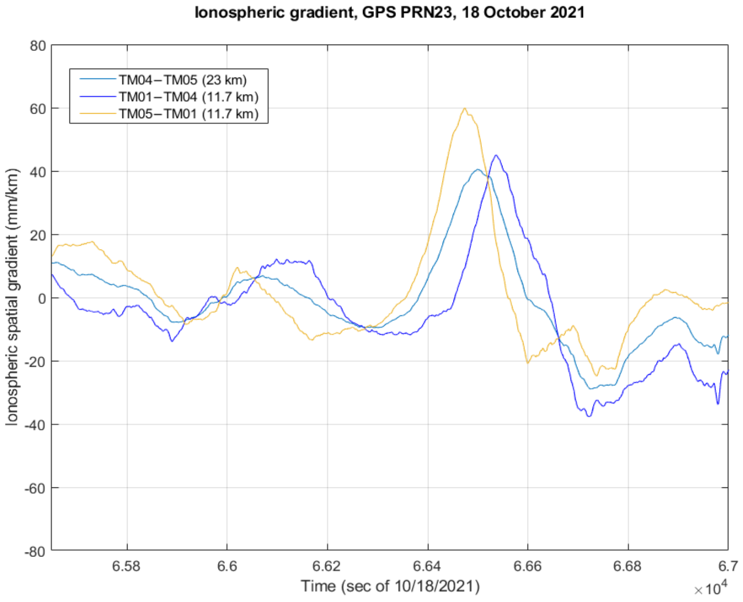


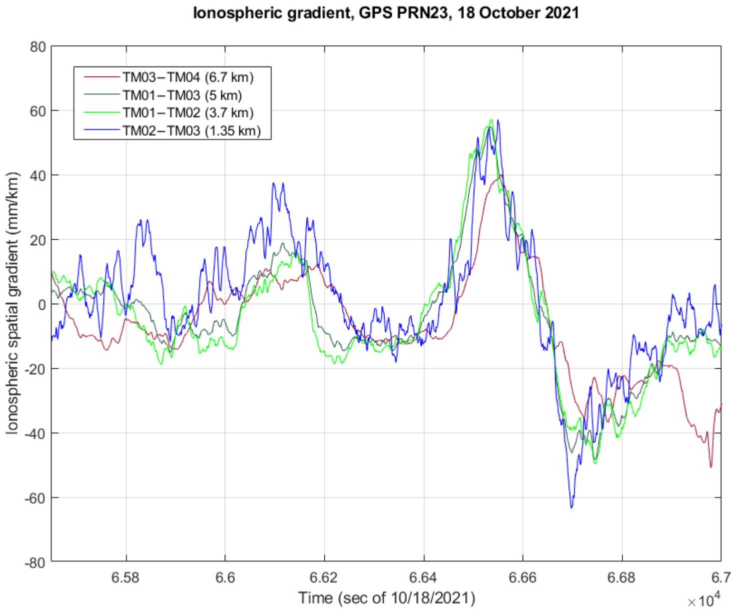
Results (3/5)

2022







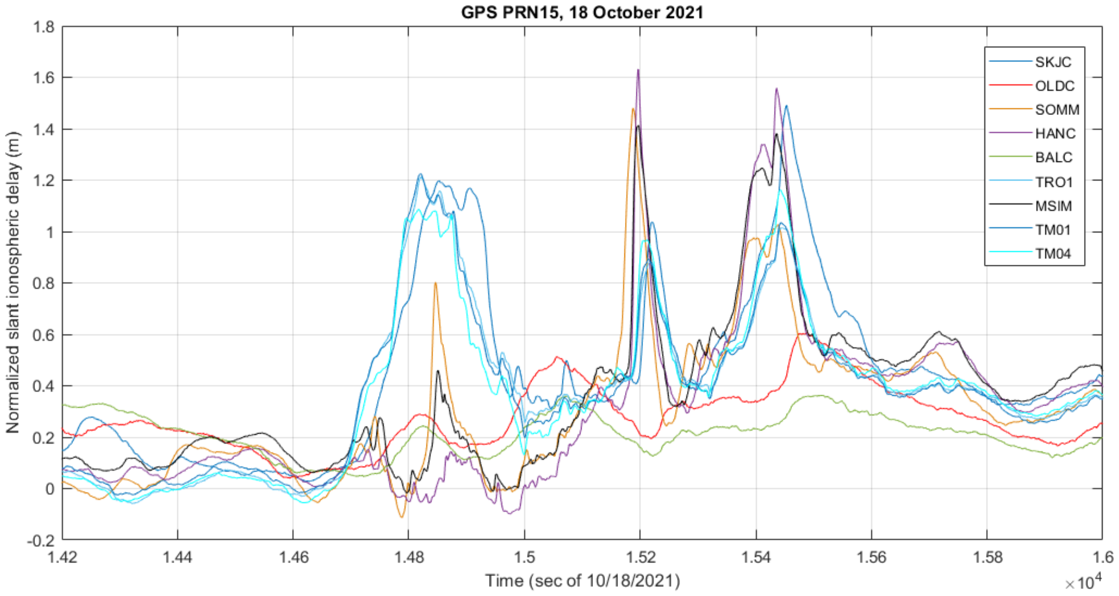


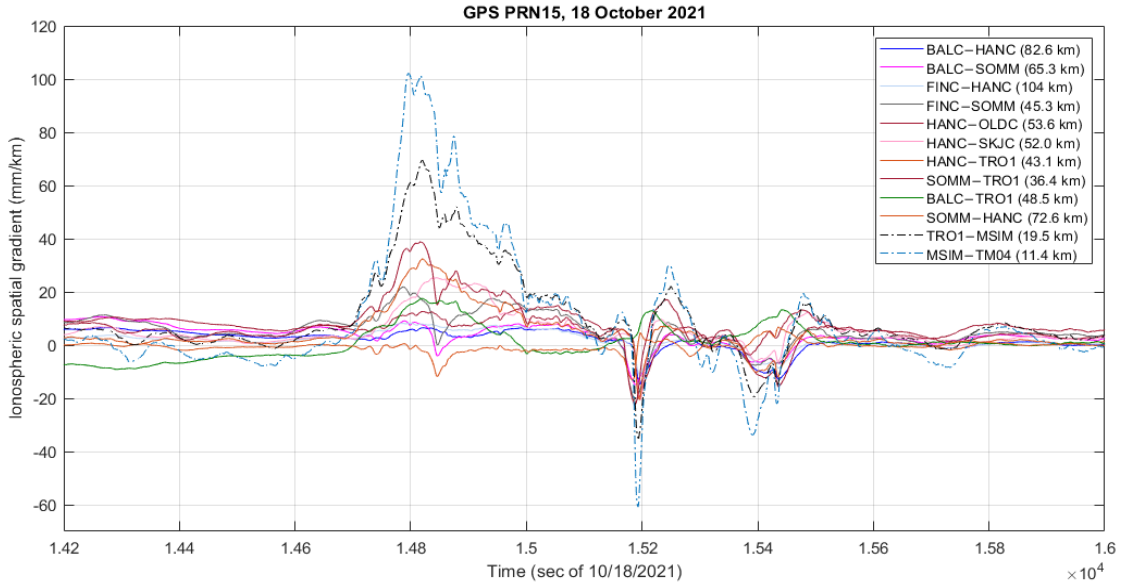
- Maximum observed peak-to-peak ionospheric spatial delay gradient value considering only the CPOS stations was about 56 mm/km.
- Noticeably higher peak-to-peak variation in the case of the test stations.

Results (4/5)

Example of a relatively steep but small scale and spatially isolated event:

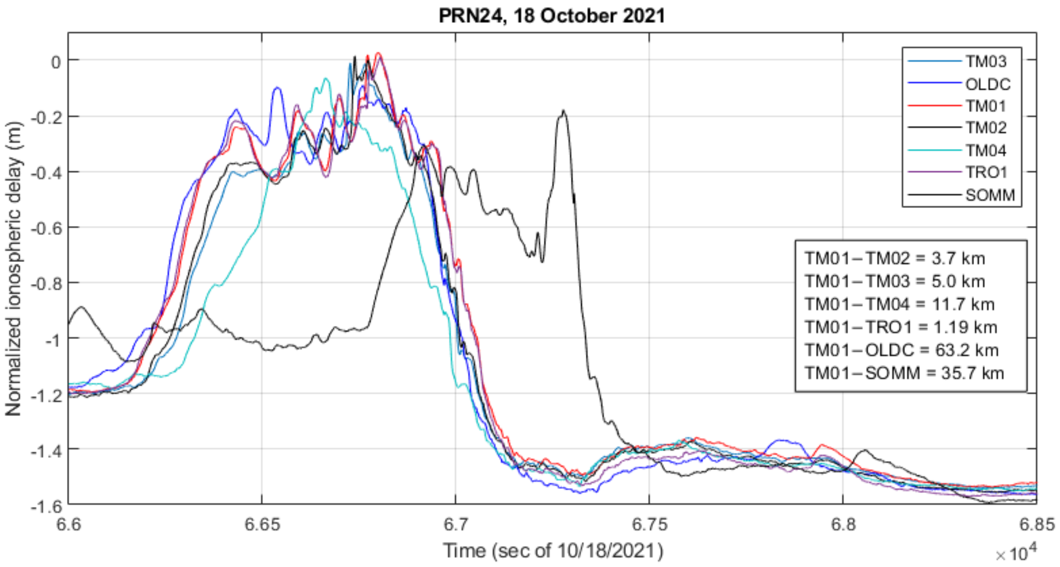
- Ionospheric front was detected to be approaching the receiver cluster from the South-East.
- Some stations (SKJC, TRO1, TM01, and TM04) observed the entirety of the event, (OLDC and BALC) observed almost no activity, (SOMM, HANC, and MSIM) observed a much smaller and shorter duration though still notable increase in the ionospheric delay.
- Result - larger spatial gradient observed by the MSIM-TRO1 and MSIM-TM04 station pairs, small or no gradient between the rest of station pairs.

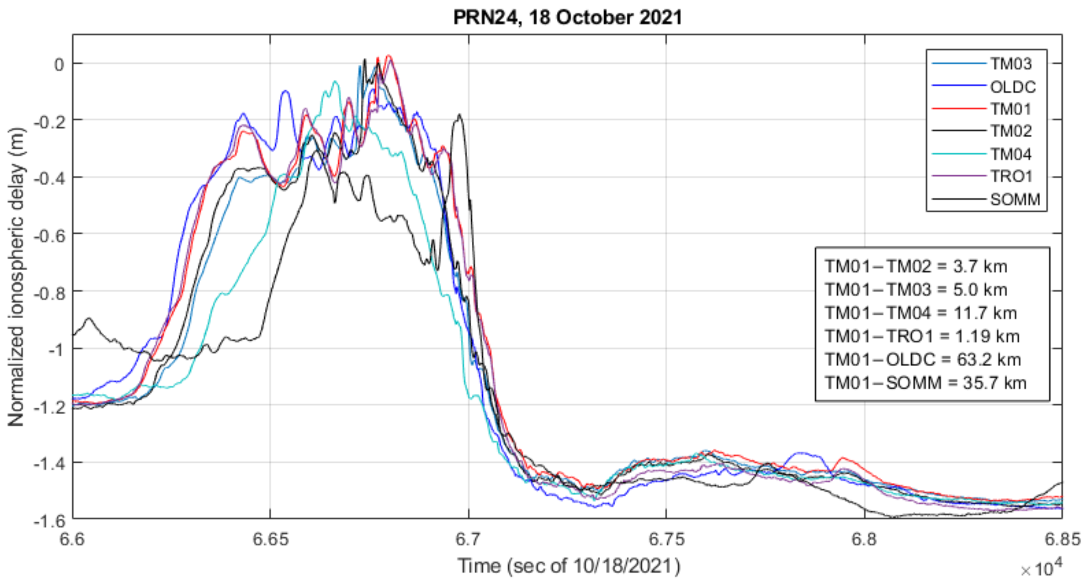




Results (5/5)

Variation in the slant ionospheric delay as observed on GPS PRN24 by a subset of monitoring stations (elevation angle of 48 - 60° across stations during the plotted time period):





- Falling edge of the feature - the decrease of about 1.2 m took 3.7 min. Observation of such spatially small-scale structures can be a challenge for larger scale networks.
- Slope/magnitude/duration signature variation can make mitigation relying on feature matching/correlation challenging.

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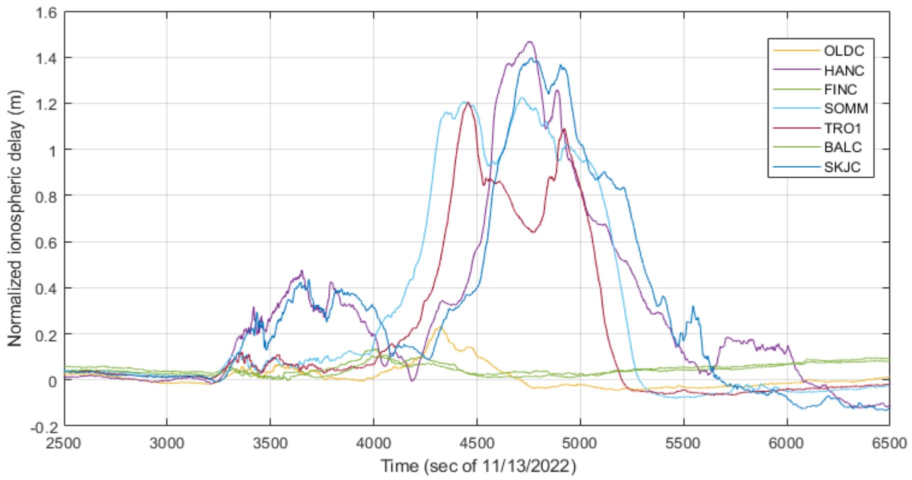
References

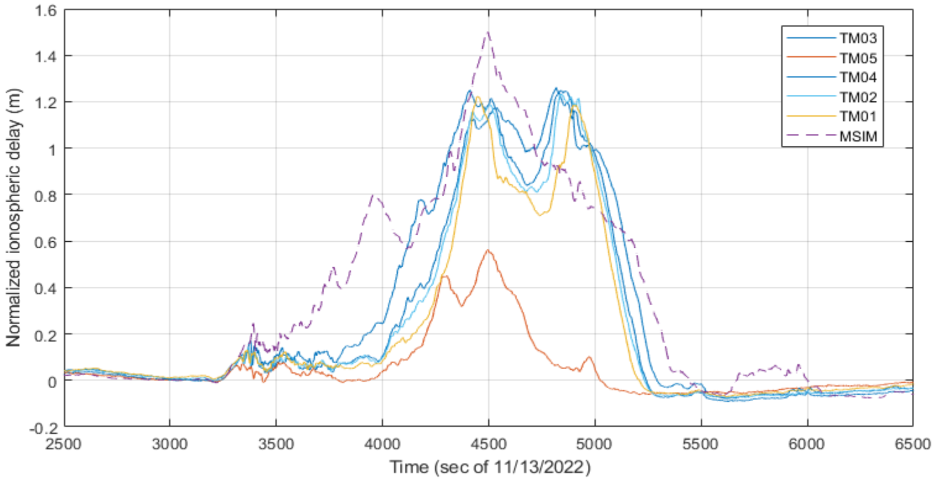
1. Marini-Pereira, L.; de Oliveira Moraes, A.; Pullen, S. A Simple and Effective Approach to Real-Time Ionospheric Monitoring for GBAS in Low Latitudes. In Proceedings of the 35th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2022), Denver, CO, USA, 19–23 September 2022; pp. 2954–2969.

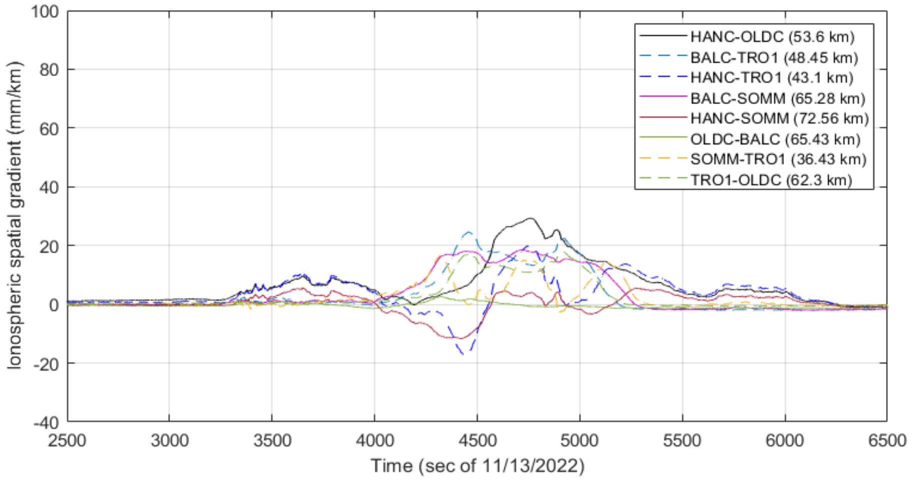
2. Robert, E.; Jonas, P.; Vuillaume, J.; et al. Development of a European ionosphere threat model in support of GBAS deployment. In Proceedings of 2018 IEEE/ION Position, Location and Navigation Symposium (IEEE/ION PLANS 2018), Monterey, CA, USA, 23–26 April 2018; pp. 1181–1190.

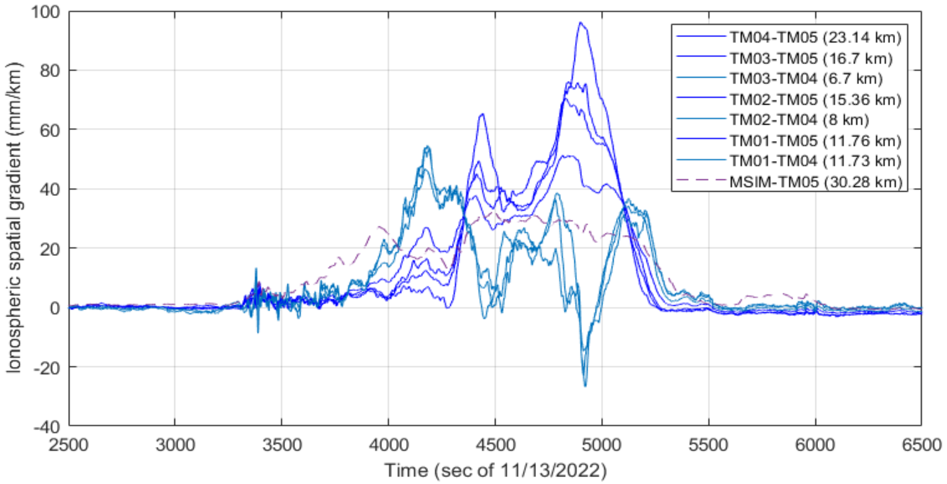
Additional Material

PRN27



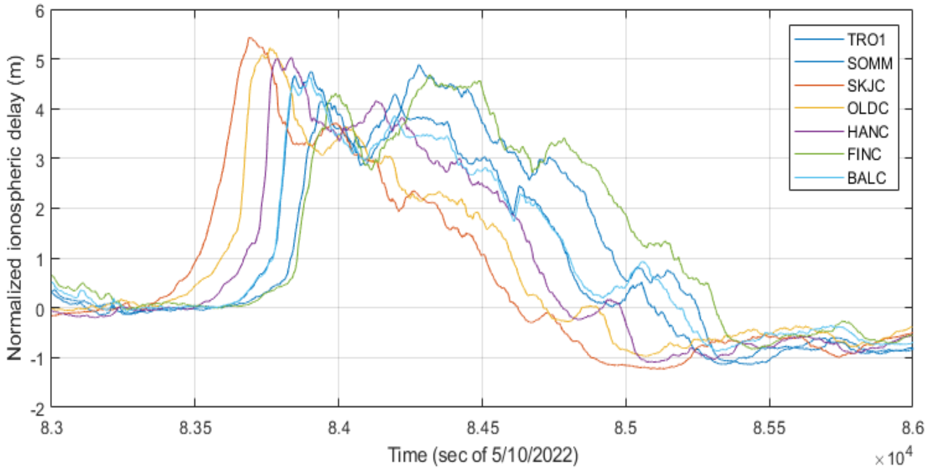


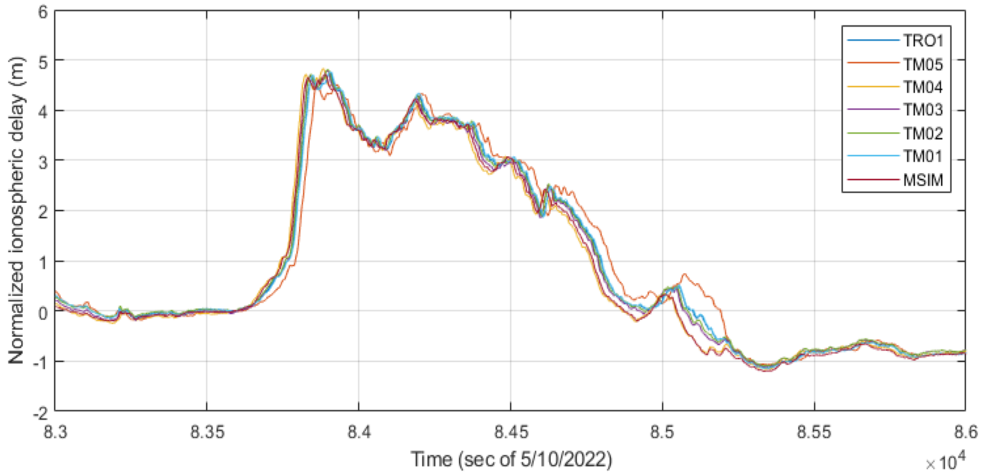


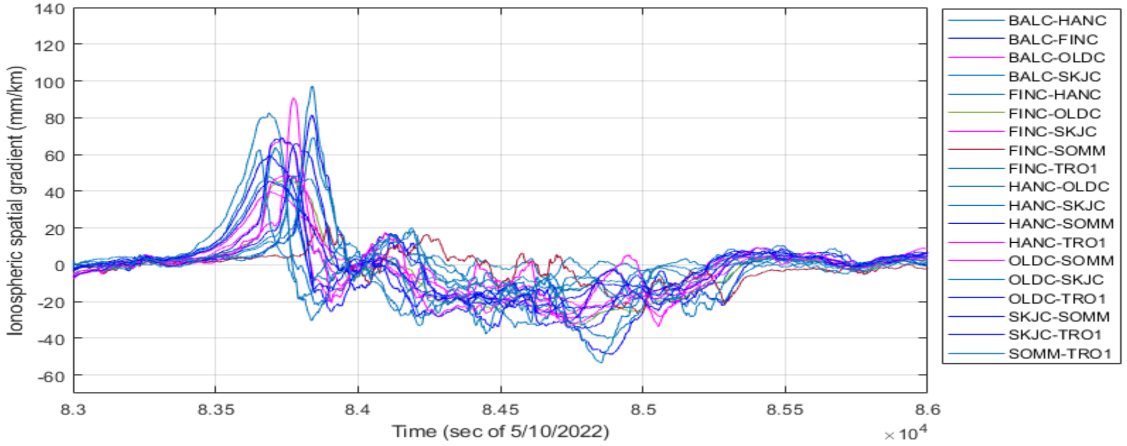


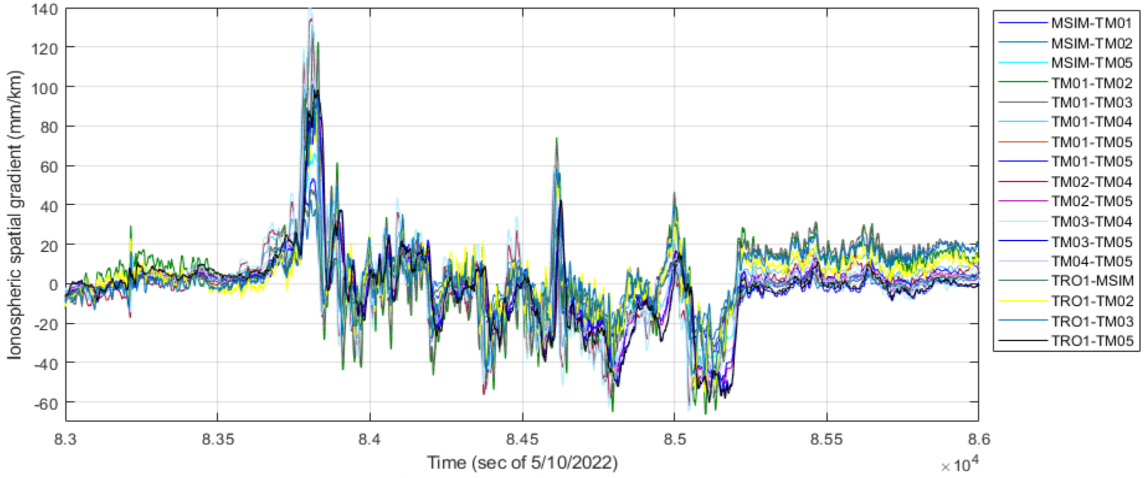
Additional Material

PRN4









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