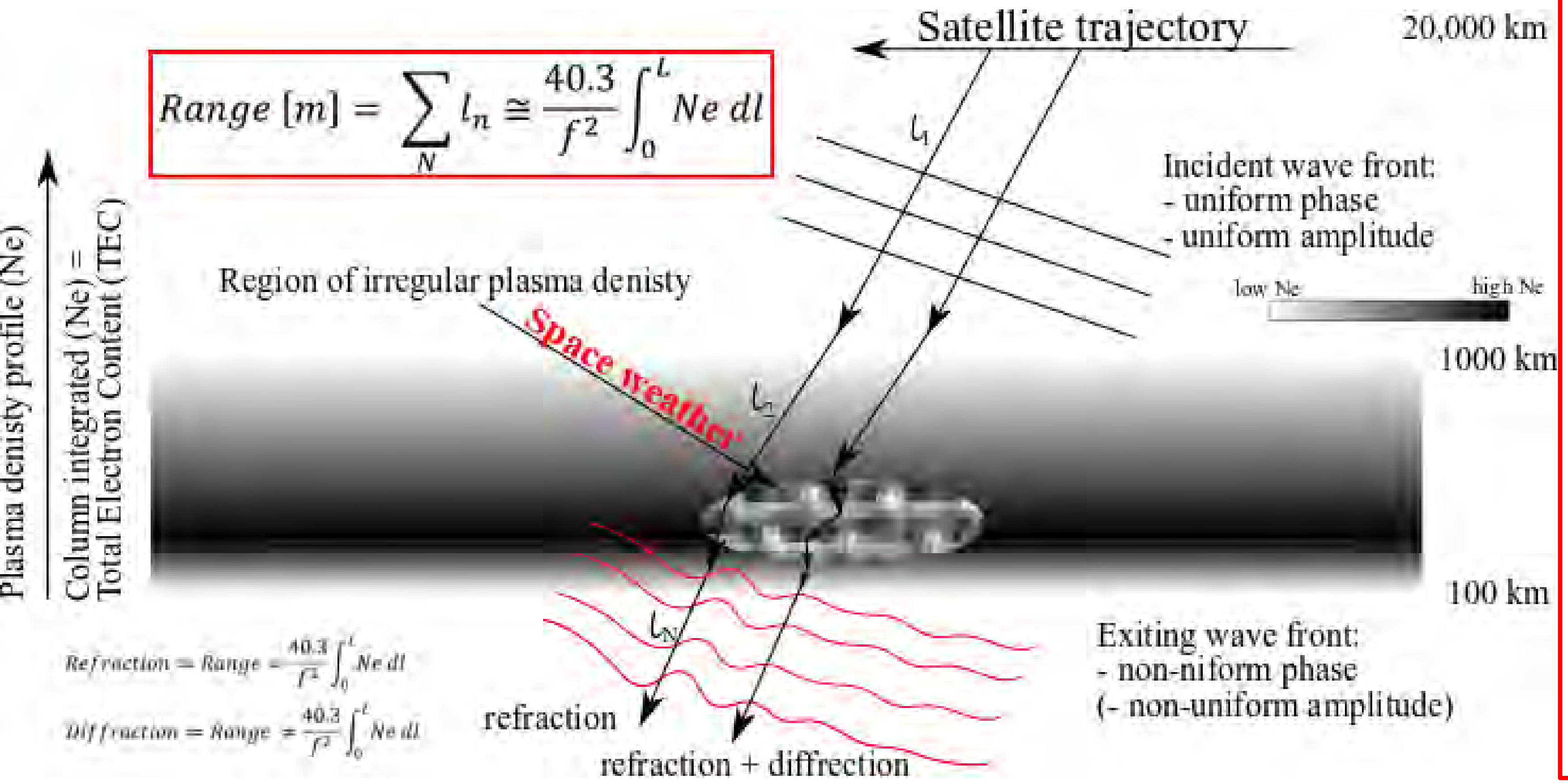
Space weather impacts to GPS at mid latitudes: Signal scintillation and positioning errors

Sebastijan Mrak, Joshua Semeter, Toshi Nishimura, Carlos Martinis; Boston University

Zhe (Jenny) Yang, Jade Morton; CU Boulder

Contact: smrak@bu.edu

Space weather effects on the GPS (GNSS)



Refraction: **effects phase**
- Incorrect range estimate
- Deterministically scale with frequency
- Fast fluctuations => lock of locks
- (Multi frequency mitigation)

Diffraction: **effects amplitude**
- Signal fading effects signal tracking
- Signal multipath: stochastic
- Deep fading => signal lost
- No straight forward mitigation

Both effect GNSS purpose:

P Position
V Velocity
T Time

Measuring ionospheric scintillation via scintillation indices

Phase Scintillation [rad, degree, cycles]

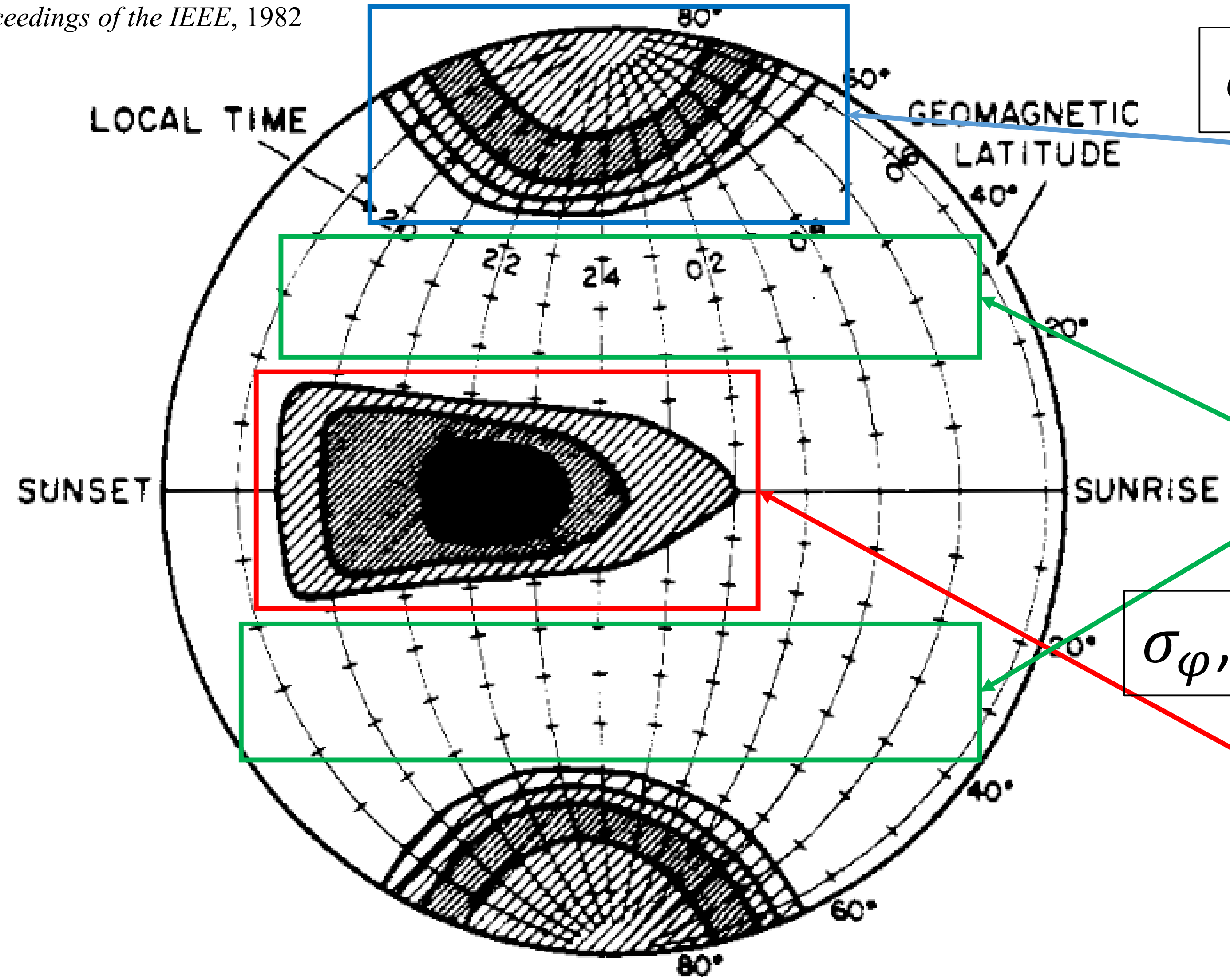
$$\sigma_\varphi = \sqrt{< \varphi^2 > - < \varphi >^2}_{\,60s}$$

Amplitude Scintillation [dB]

$$S_4 = \sqrt{\frac{< I^2 > - < I >^2}{< I >^2}}_{\,60s}$$

Scintillation occurrence - Climatology

J. Aarons, **Global Morphology of Ionospheric Scintillations**, *Proceedings of the IEEE*, 1982



σ_φ

High Latitudes: Sub-auroral and auroral zone, polar cap: **Phase scintillation**

- TEC fluctuations at scales they don't facilitate diffraction.
- All longitudes, most pronounced near magnetic local midnight (substorms, enhanced sub-auroral drifts)

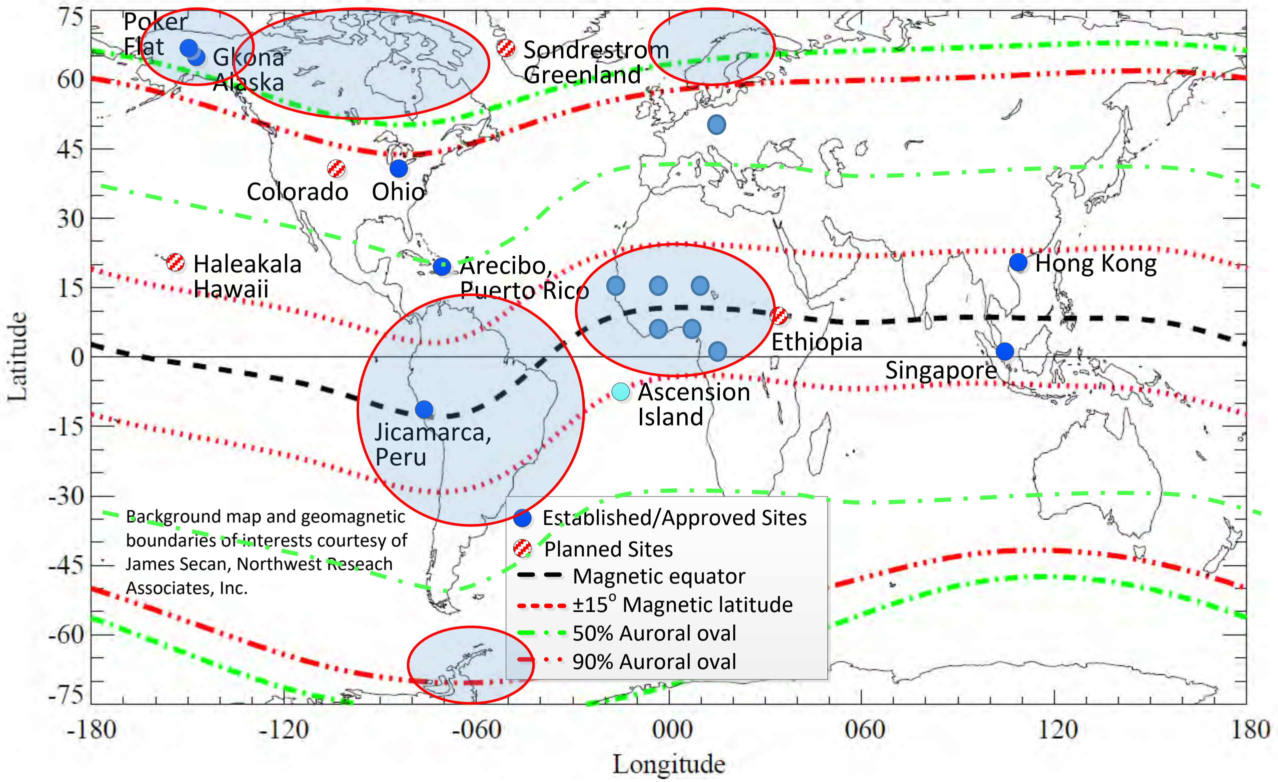
A whole lot of nothing?
Majority of population lives here.

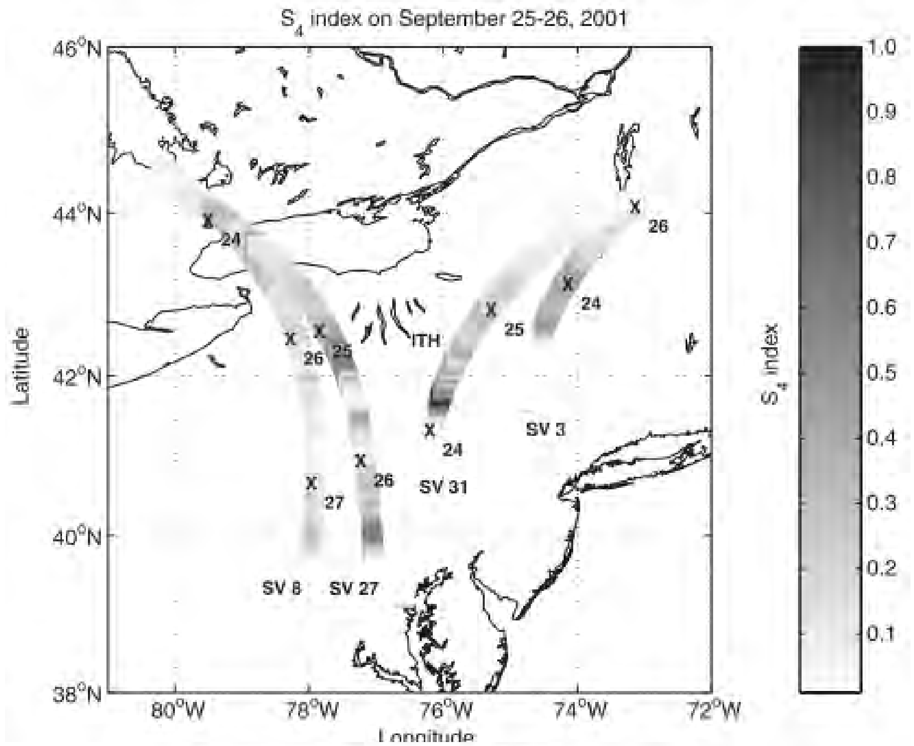
σ_φ, S_4

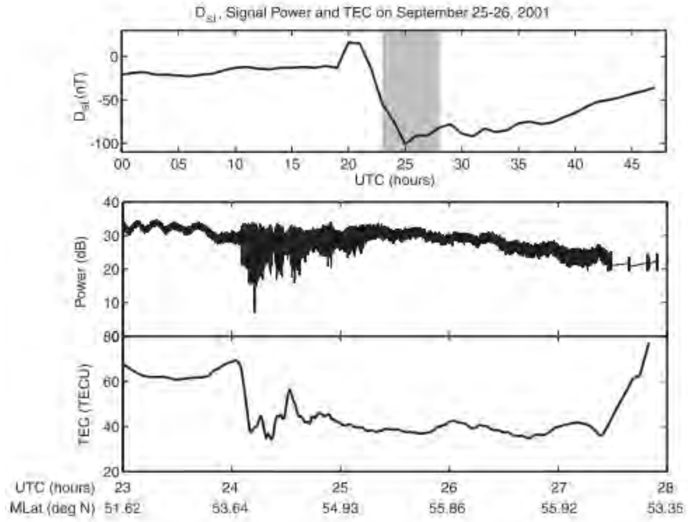
Equatorial region – Low latitudes: **Phase and amplitude scintillation**

- Plasma density irregularities due to internal plasma instability (Reyligh-Taylor).
- All longitudes, most pronounced near magnetic local midnight (substorms, enhanced sub-auroral drifts)

Global morphology of GNSS scintillation?



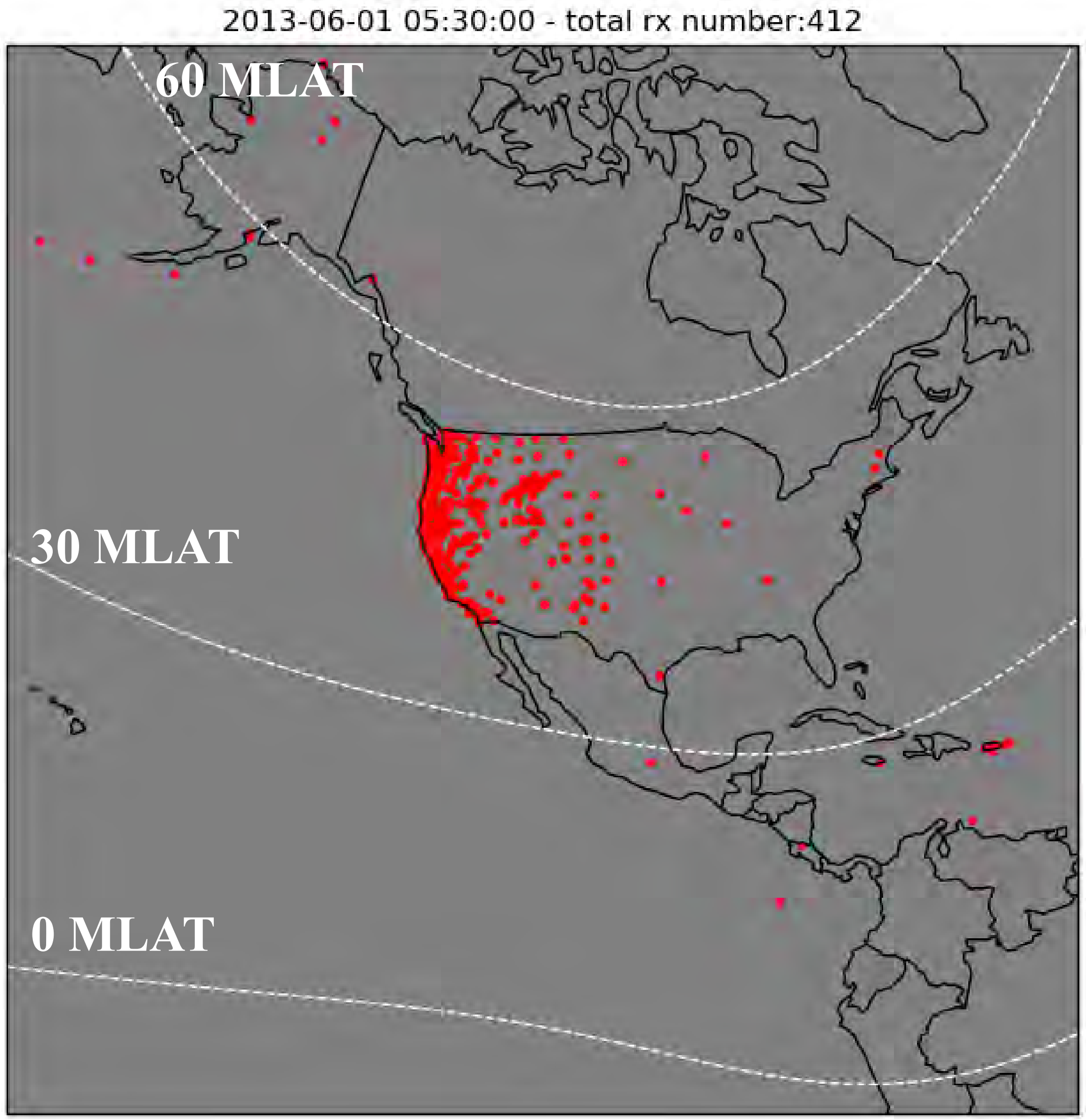




Ledvina et al..
First observations of intense GPS L1 amplitude scintillations at midlatitude.
Geophysical Research Letters, 2002

- What is scintillation occurrence at middle latitudes?
- How does space weather affects the PVT?
- There is only one prominent example available in the literature, recorded by at Cornell.
- **But there is no permanent GNSS scintillation receivers deployed at the (CONUS, Europe) territory to comprehensively characterize the space weather effects.**

Utilizing geodetic GPS receivers by UNAVCO



UNAVCO GPS receivers:

- Diverse hardware selection;
- Data availability at 1s resolution (scintillation receivers usually operate at 50-100 Hz);

Missing reliable measurements of signals phase and amplitude

- **Phase → TEC (Phase combination)**
- **Amplitude → Signal-Noise-Ratio (SNR)**

Scintillation index substitutes:

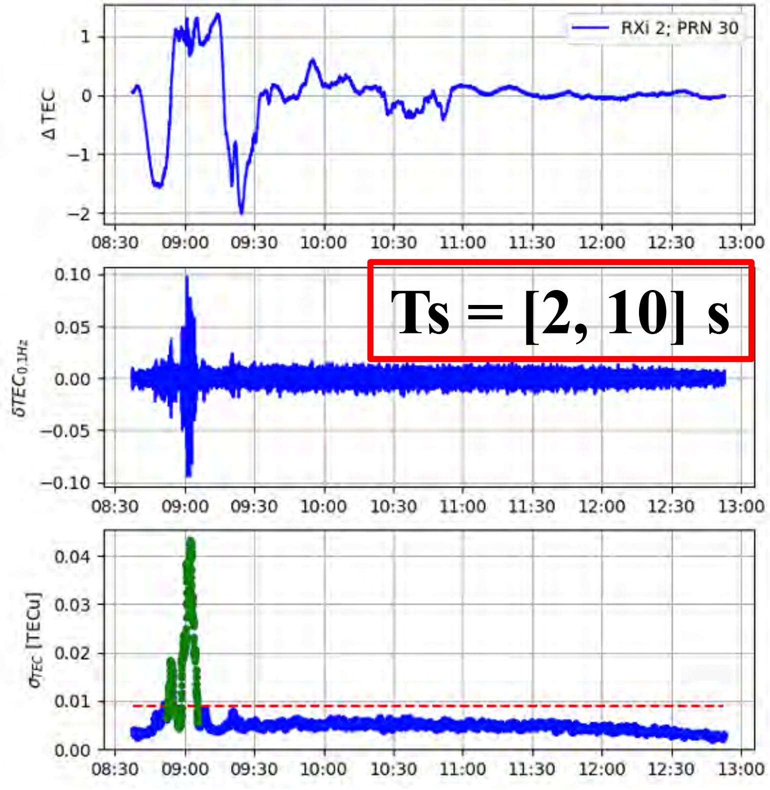
$$\sigma_{TEC} = \sqrt{< TEC^2 > - < TEC >^2}\Big|_{60s}$$

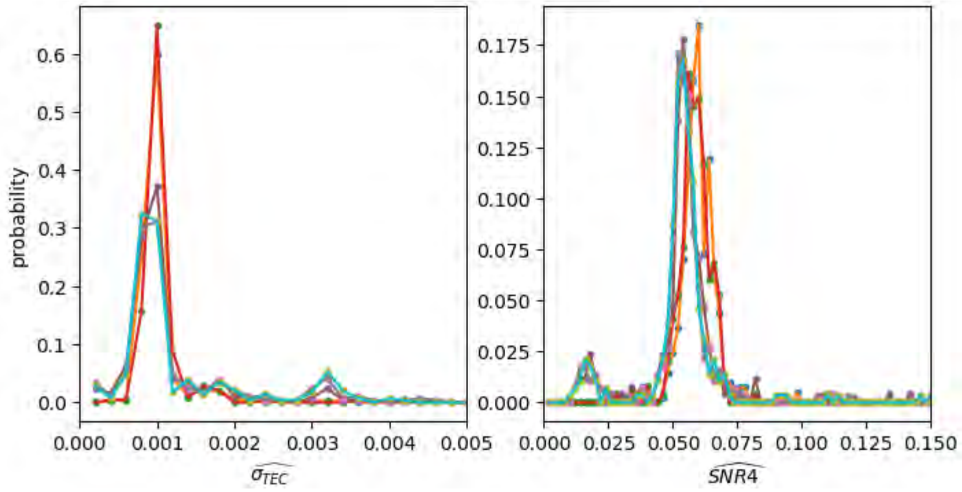
$$SNR_4 = \sqrt{< SNR^2 > - < SNR >^2}\Big|_{60s}$$

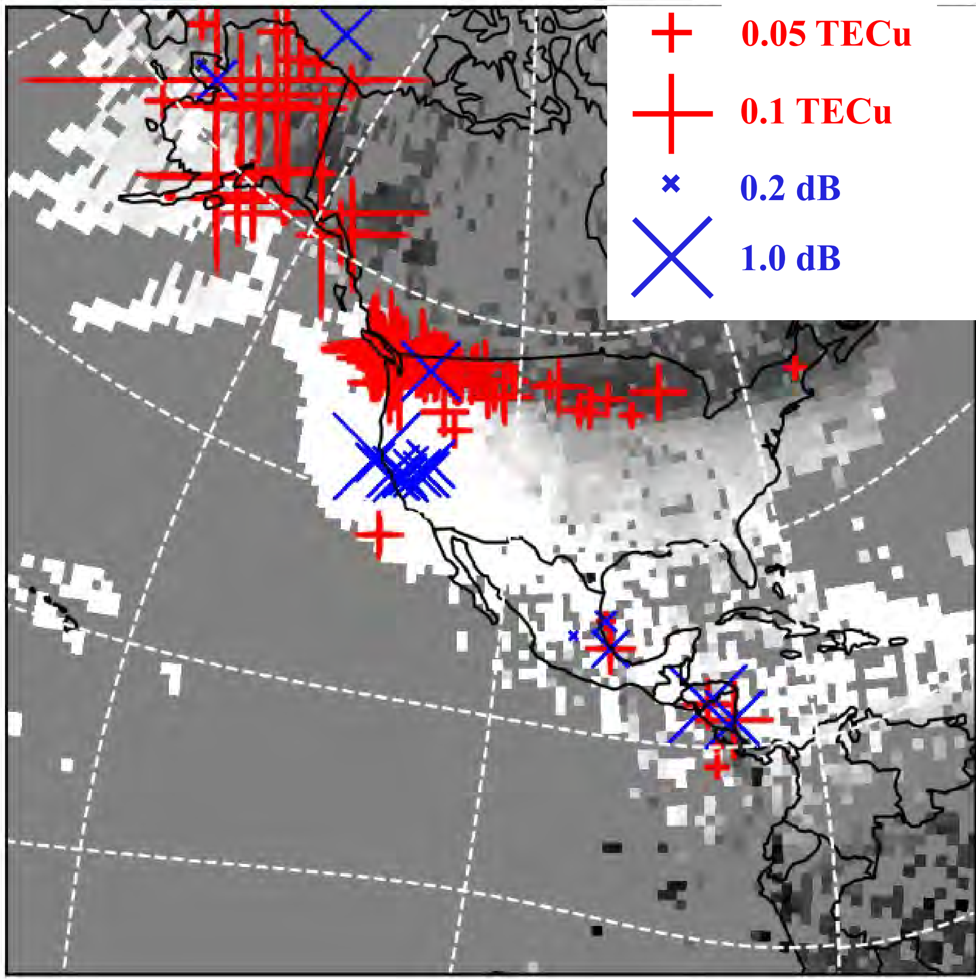
The UNAVCO dataset enables a unique opportunity to study GPS scintillation and space weather impacts at mid latitudes.

- Bias in spatial sampling! (Rocky mountains)
- 400 receivers available in 2013 → 750 in 2018!

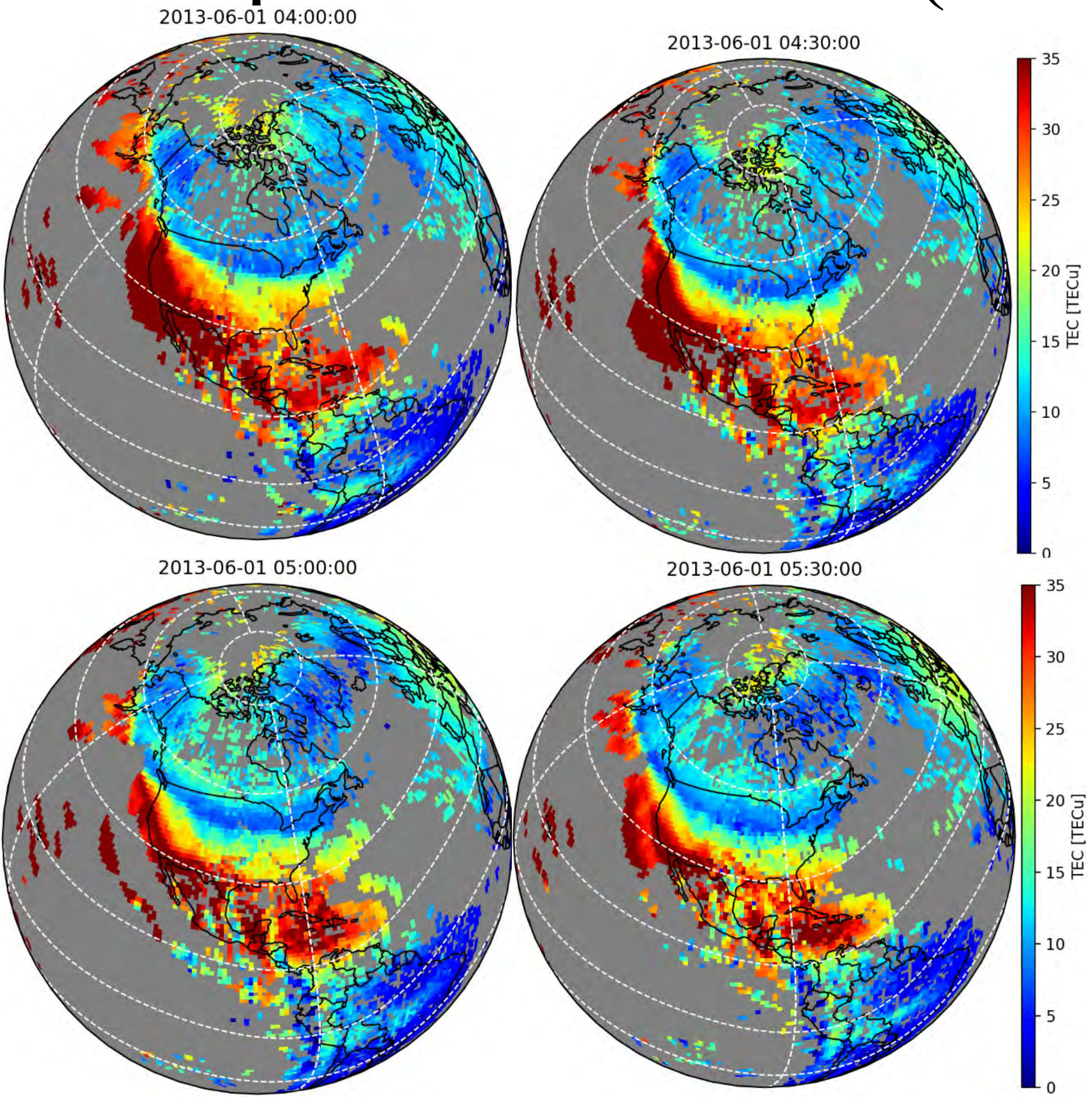
Data and processing and presentation



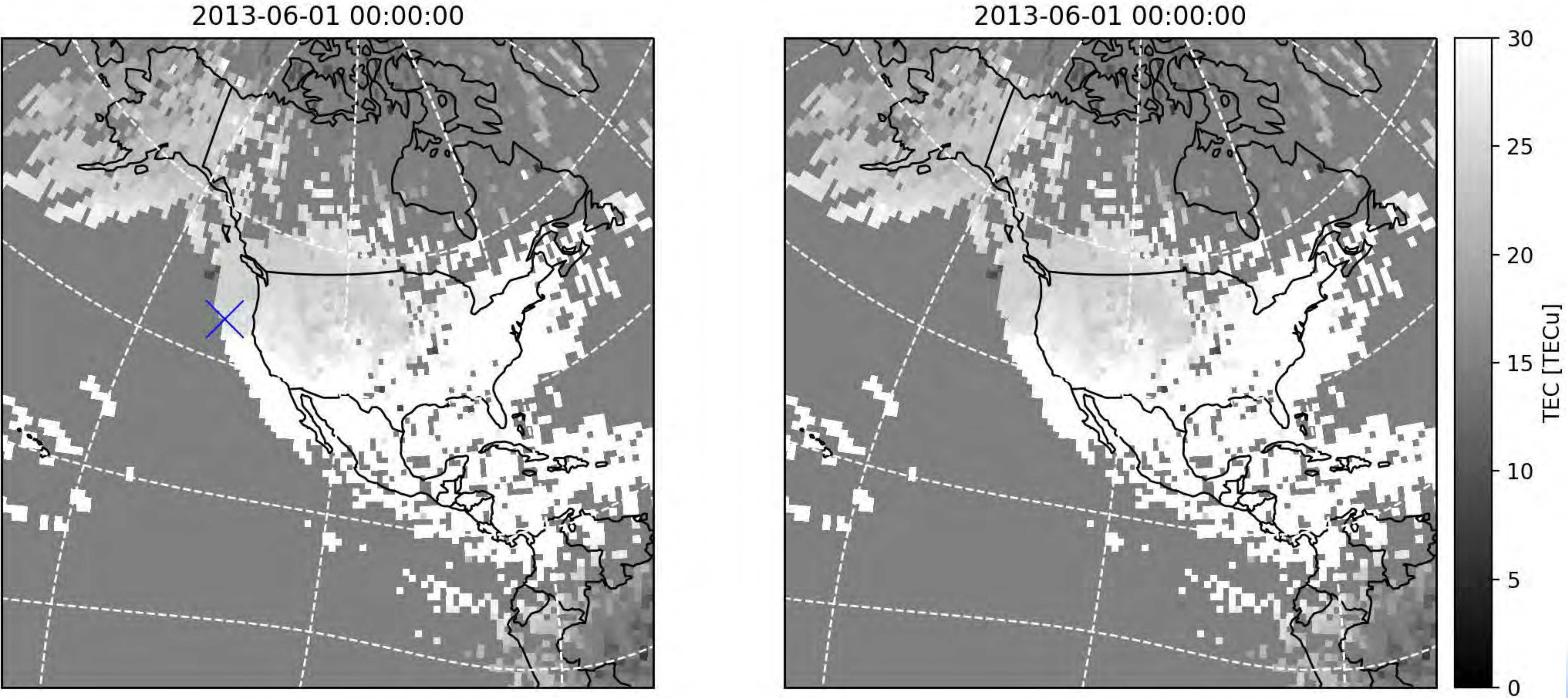




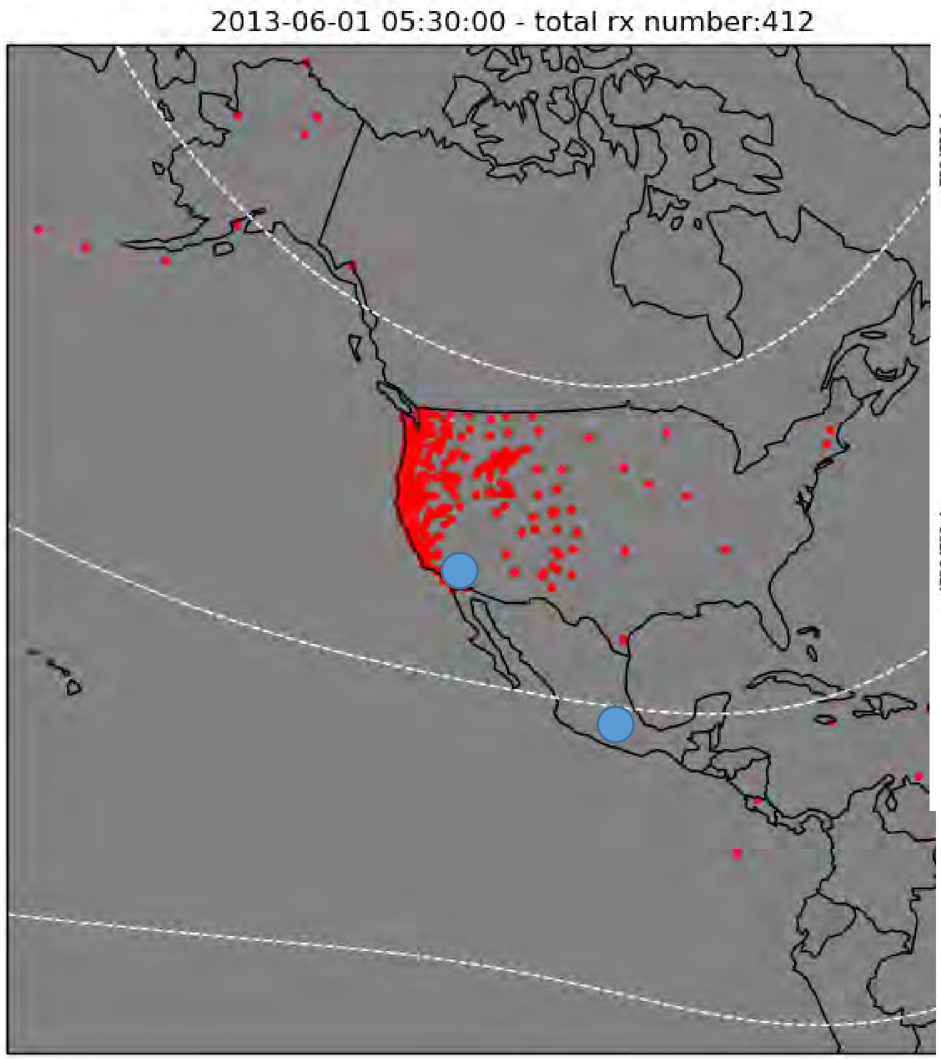
Example: 1 June 2013 (a moderate geomagnetic storm)

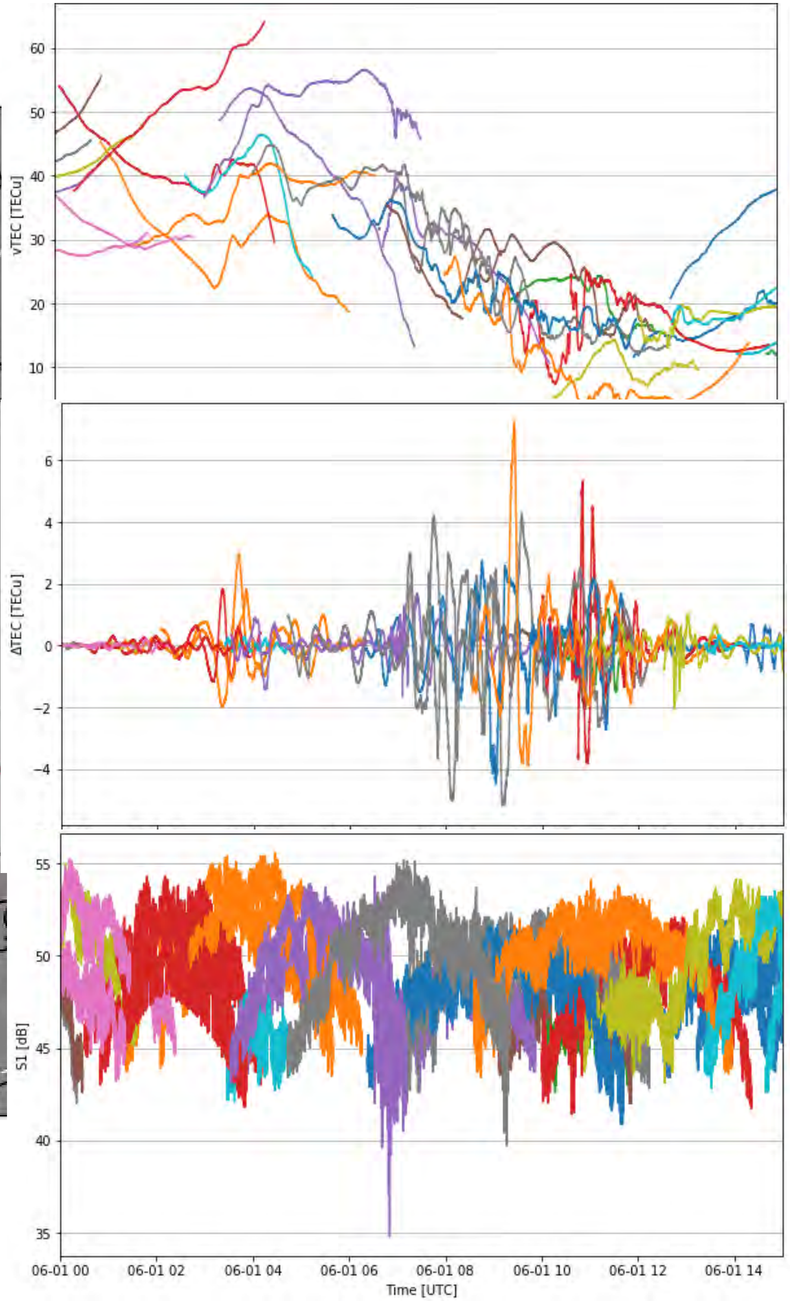


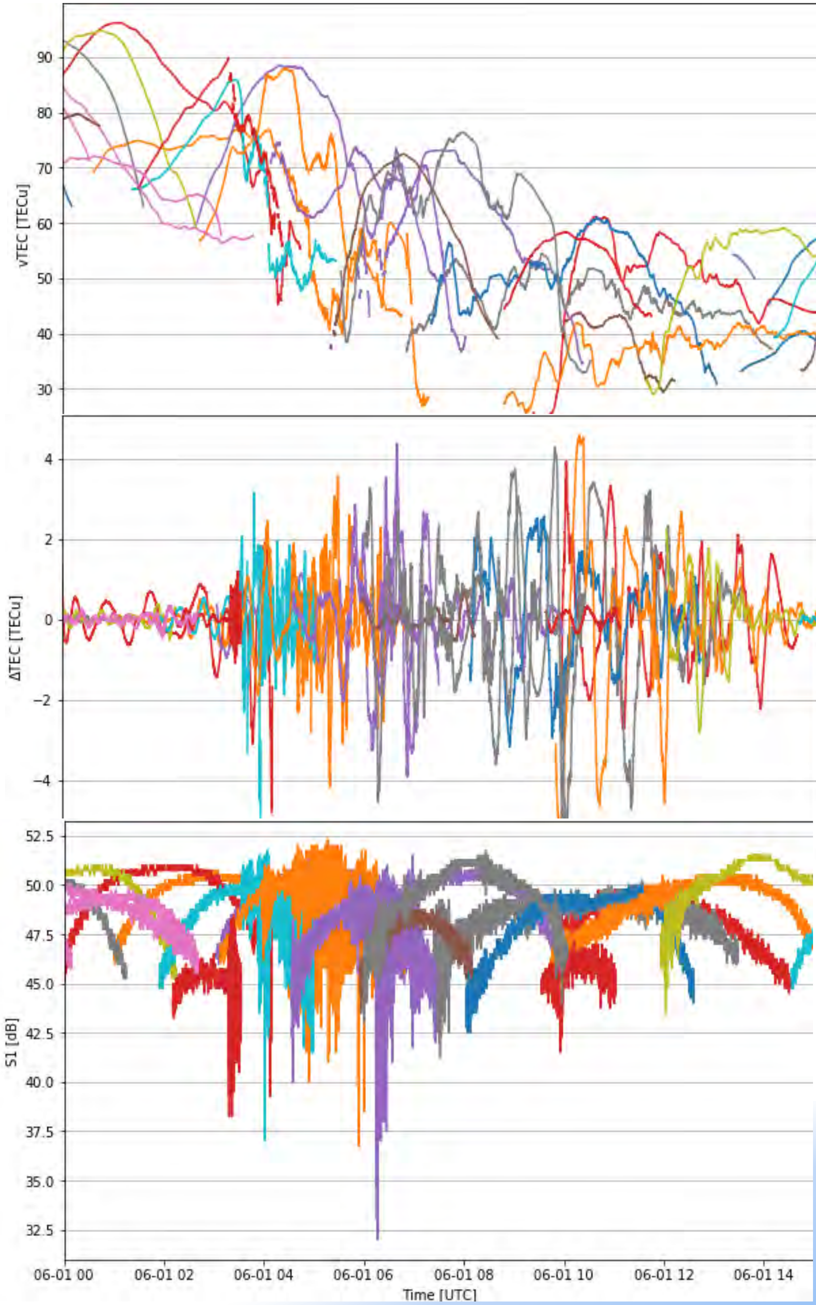
Scintillation development



High-rate (1 Hz): GPS receiver array by UNAVCO





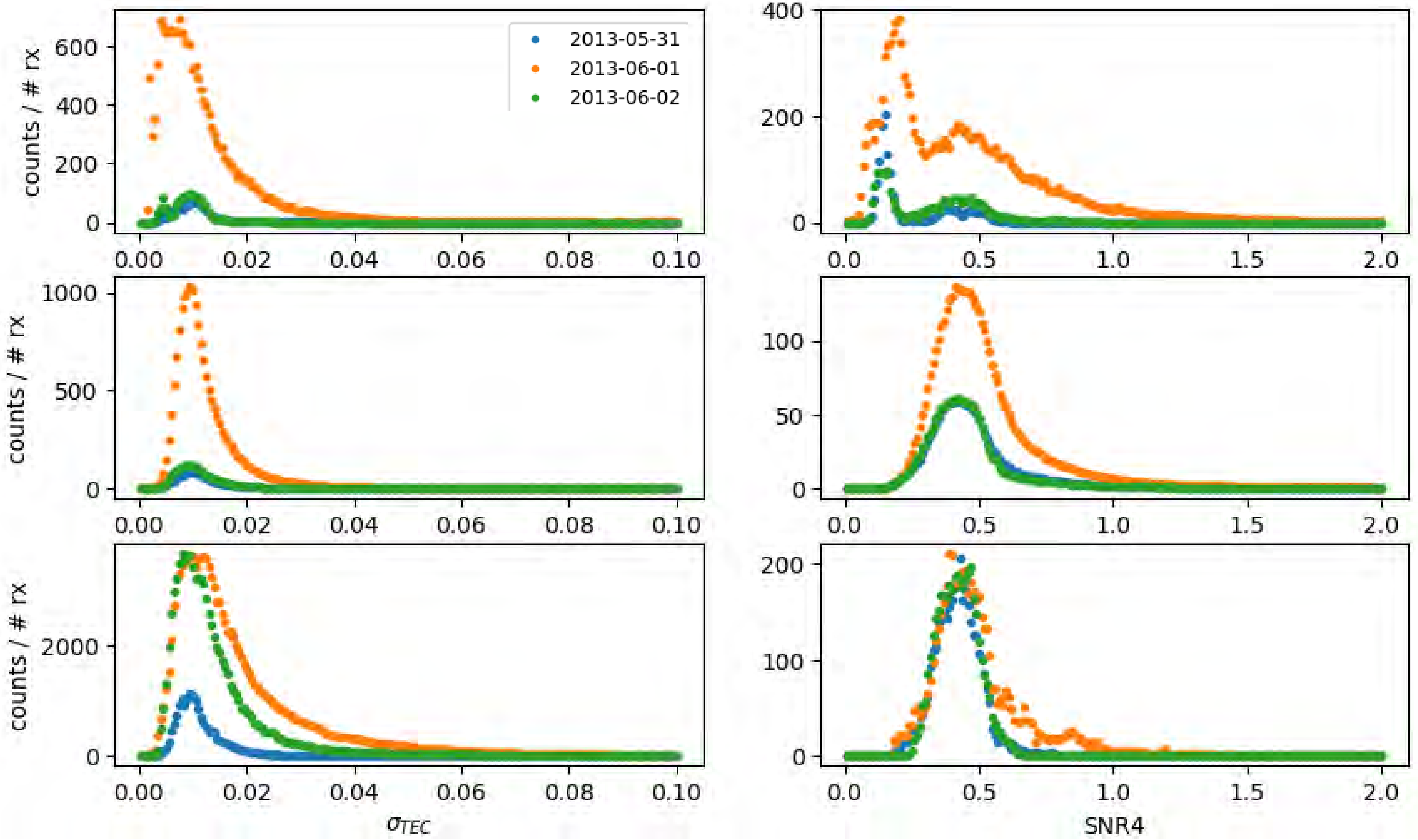


Scintillation statistics. Normalized to # of receivers

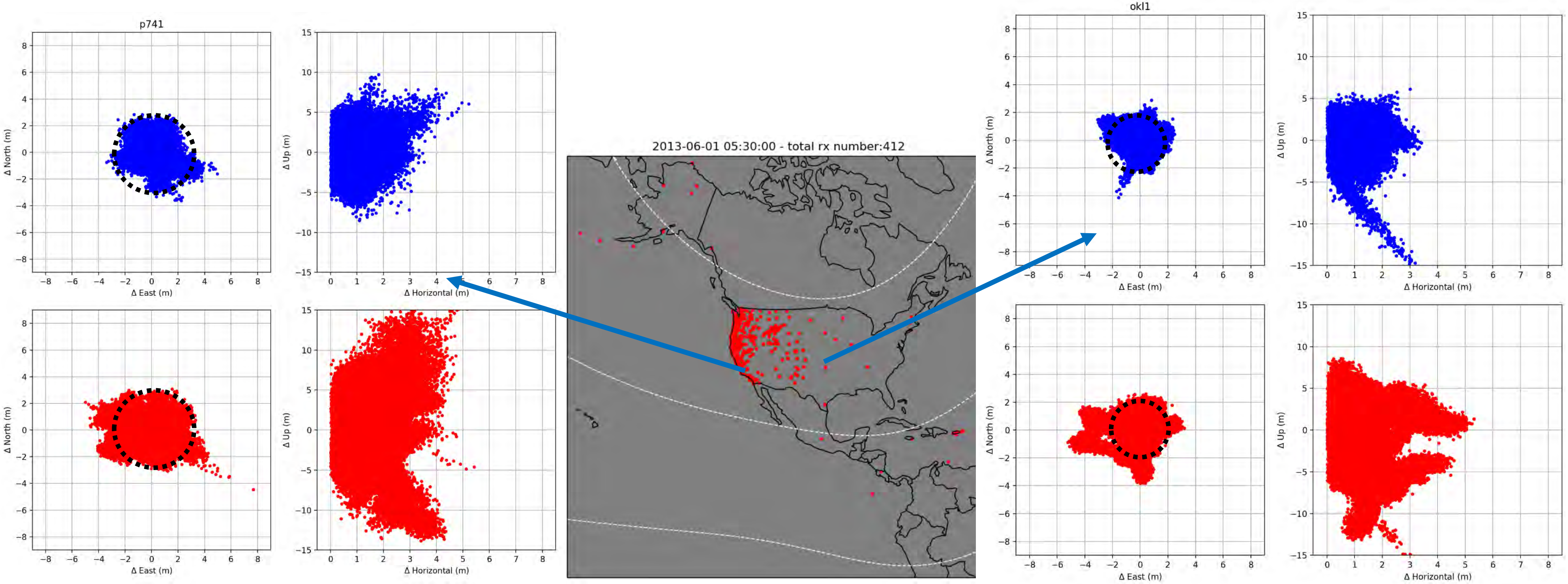
Low latitudes:
|MLAT| < 30

Mid latitudes:
30 < |MLAT| < 60

High latitudes:
60 < |MLAT|



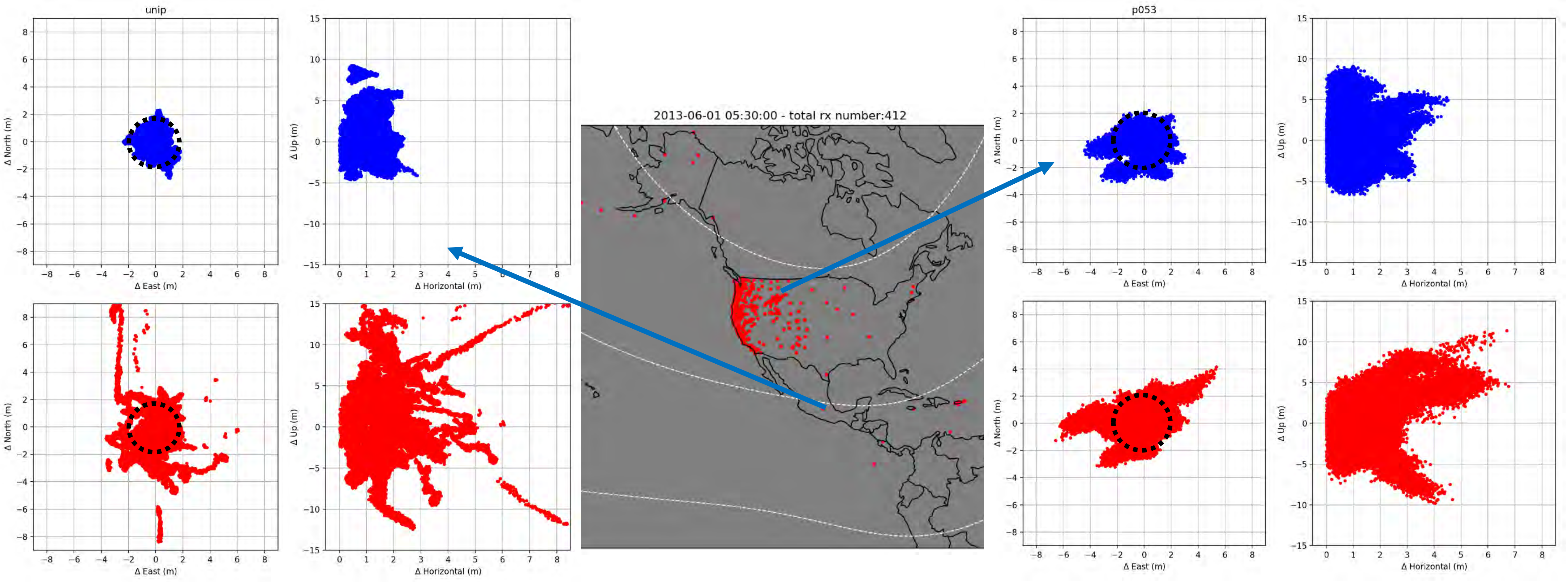
Positioning errors: Dual frequency, static estimate



Receivers from California and Oklahoma:
Increased error:

- Horizontal positioning ~ 2m
- Vertical positioning ~>5m

Positioning errors: Dual frequency, static estimate



Receivers from central Mexico:
Increased errors:
- Horizontal positioning ~ 5m
- Vertical positioning ~>10m

Receivers from Montana:
Increased errors:
- Horizontal positioning ~ 2m
- Vertical positioning ~>2m

Summary

- We discussed utilization of geodetic GNSS receivers for scintillation studies at middle latitudes.
- We introduce alternative signal processing as a proxy we the established scintillation indices
- A case study of a moderate storm is presented, where low- and high- latitude ionospheric disturbances converged over the continental United States
- Long lasting GPS scintillation is observed, causing increased positioning errors. Horizontal errors exceeded 2m, whereas vertical error increased for >5m at all (US) latitudes.
- The presented space weather effects on the GPS took place during a moderate storm, at moderate solar and geomagnetic activity.
- Climatology and thorough analysis of scintillation characteristics at mid latitudes is underway.