Using GNSS Tracking Networks to Map Global Ionospheric Irregularities and Scintillation

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Ionospheric Scintillation Indices

$$S_4(f) = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}} \propto f^{-1.5}$$

$$\sigma_\phi(f) = \sqrt{\langle \phi^2 \rangle - \langle \phi \rangle^2} \propto f^{-1}$$

$$\mathrm{ROTI} = \sqrt{\langle \mathrm{ROT}^2 \rangle - \langle \mathrm{ROT} \rangle^2}$$

$$\mathrm{ROT} = C \frac{\Phi_I(t + \Delta t) - \Phi_I(t)}{\Delta t}$$

- **S_4 and σ_ϕ indices – amplitude and phase scintillation, respectively**
  - I – detrended signal intensity
  - ϕ – detrended signal phase
  - I & ϕ data sampled at 20 ms (50 Hz)
  - Frequency dependent
  - Measurements of phase scintillation susceptible to Trn & Rcv oscillator noise
- **ROTI – Rate of TEC index**
  - A measure of ionospheric TEC fluctuations - irregularities
  - ROT – detrended rate of TEC derived from dual-frequency phase data
  - ROT data typically sampled at 30 sec
  - In principle independent of frequency and not susceptible to local oscillator quality

Examples of Ionospheric Irregularities Measured Using GPS Signals

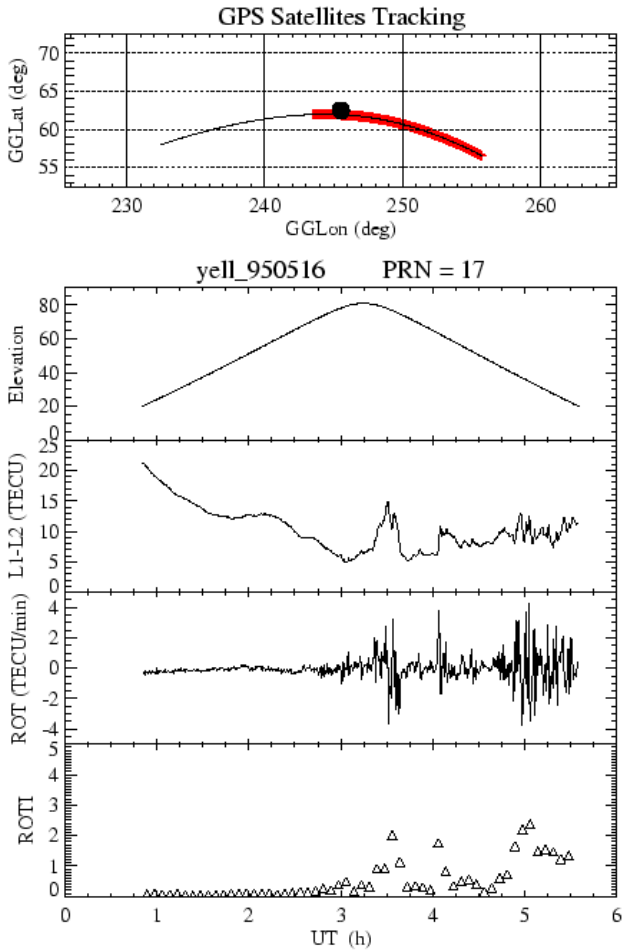
IPP Grnd Track

ELV

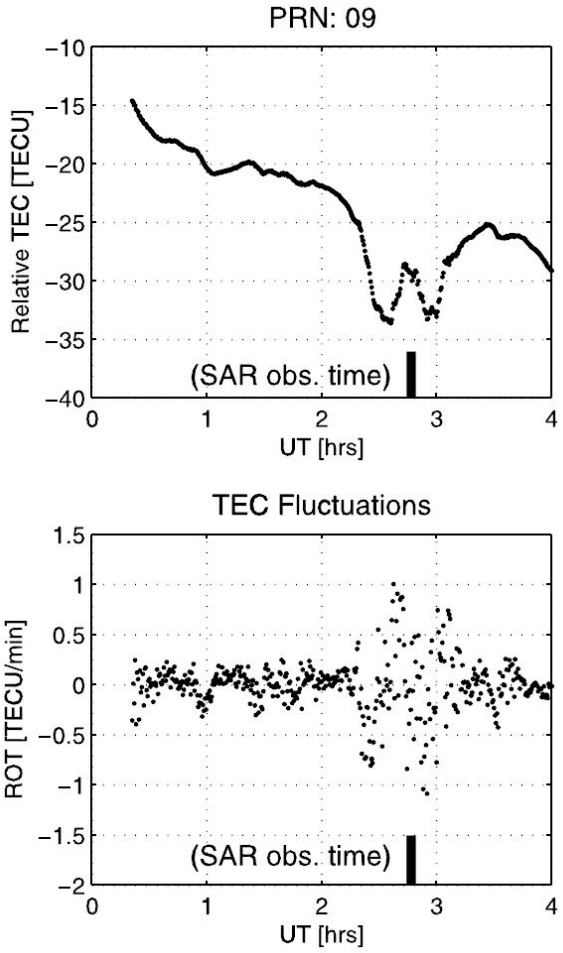
LOS TEC

ROT

ROTI



TEC perturbations, and ROT fluctuations as well as ROTI derived from dual-frequency GPS data collected from an IGS site in Yellowknife, Canada, on 16 May 1995. [Ref#1, 1997]

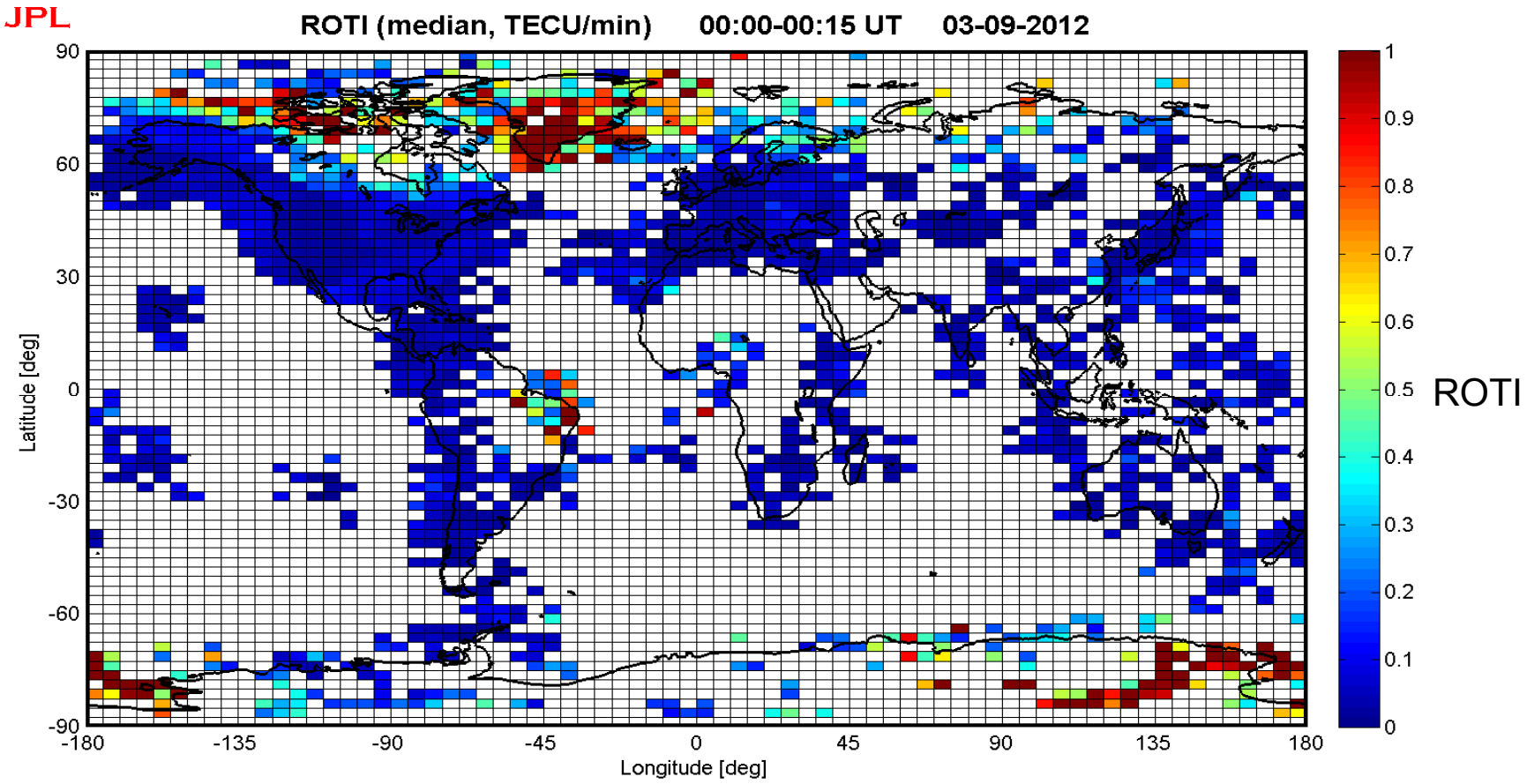


Relative LOS TEC

ROT

Plasma or TEC bubbles and ROT fluctuations observed from Brazil during 18 November 2007. [Ref#2, 2011]

Global Map of Ionospheric Irregularities



A global map of ionospheric irregularities measured using ROTI.

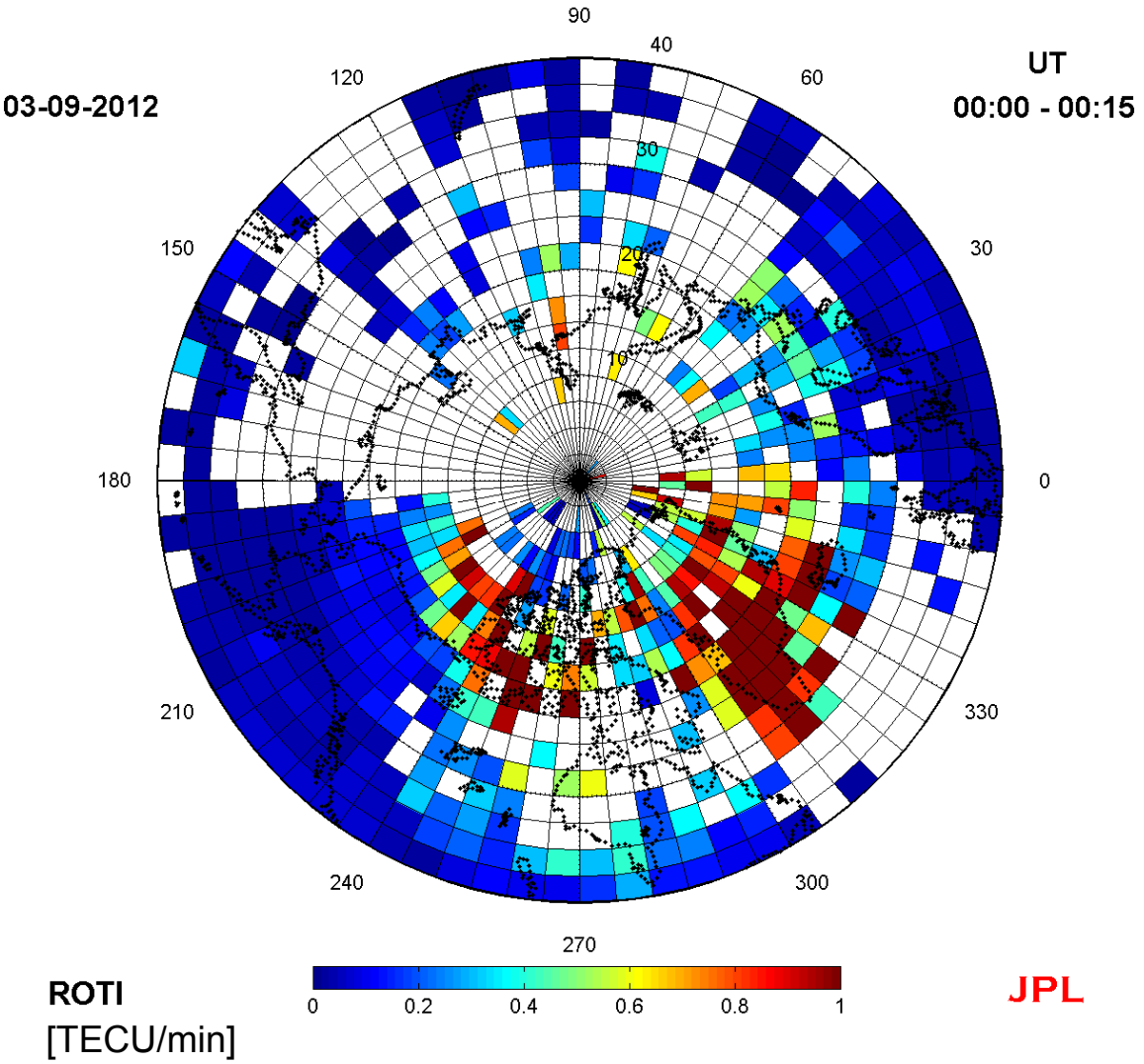
- Global grid: $\Delta LON \times \Delta LAT = 5° \times 2.5°$
- Temporal resolution: 15 minutes

[Ref#3, 2012; Ref#4, 2013]

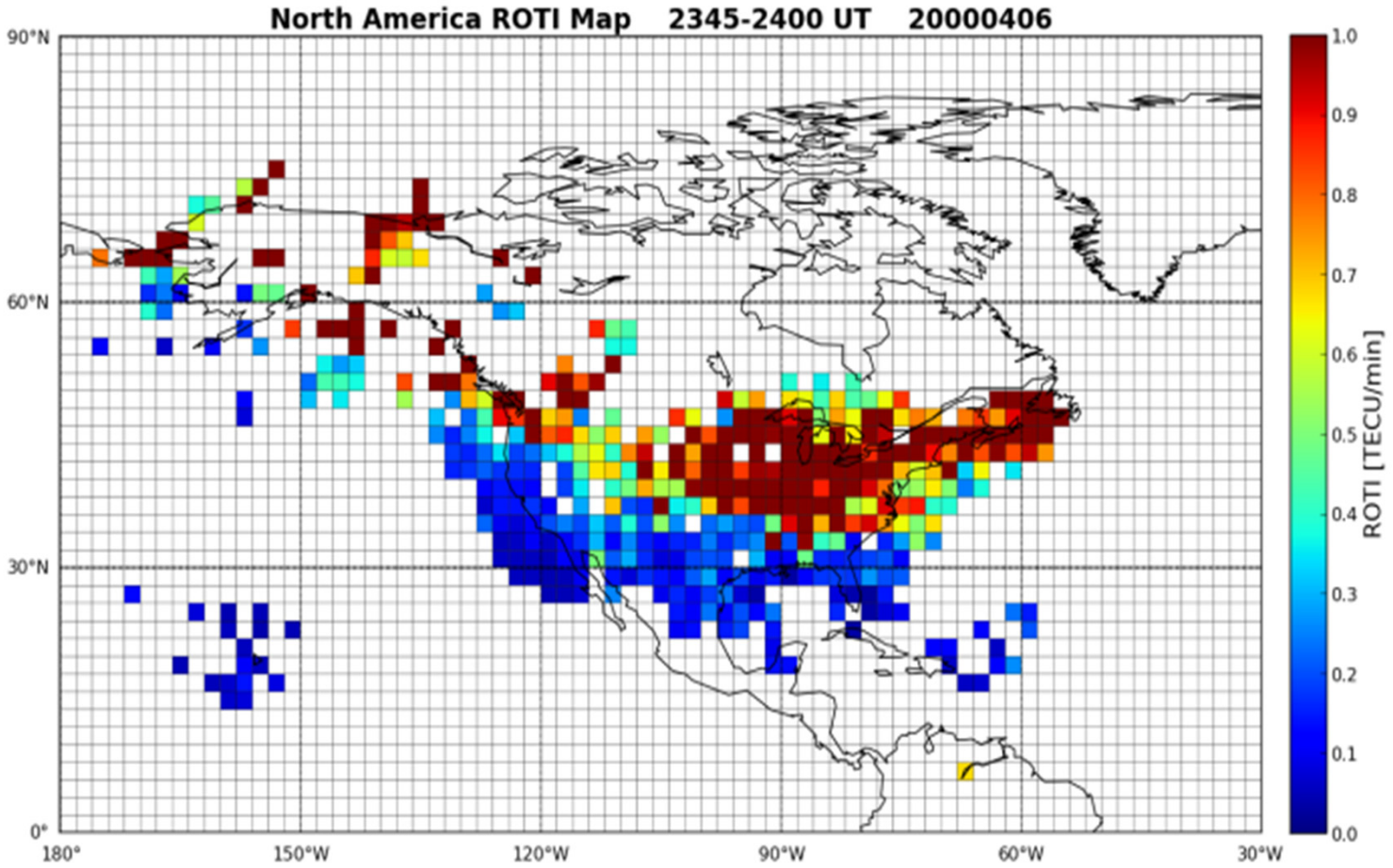
Polar Map of Ionospheric Irregularities and Scintillation

- A polar ROTI map measuring ionospheric irregularities and scintillation during a major geomagnetic storm
- Temporal resolution: 15-minute interval
- Grid resolution: $\Delta LON \times \Delta LAT$ = $5° \times 2.5°$
- IGS and CORS networks

[Ref#5, 2012]

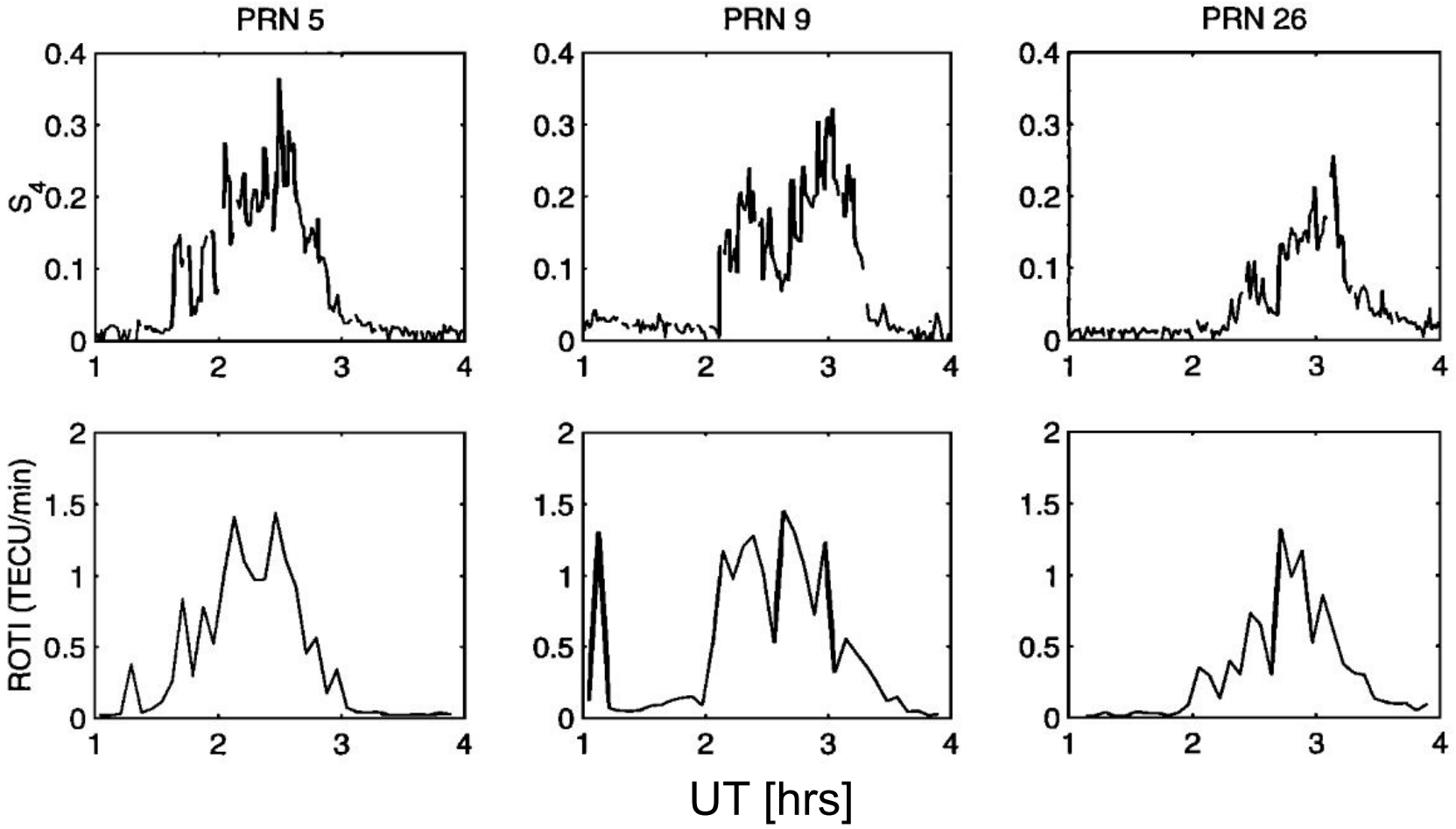


A Major Event of Mid-Latitude Ionospheric Scintillation during a Storm



Mid-latitude Ionospheric phase scintillation occurred in most of the United States during a major geomagnetic storm on 4/6/2000, observed using ROTI derived from the CORS GPS data. [Ref#4, 2013]

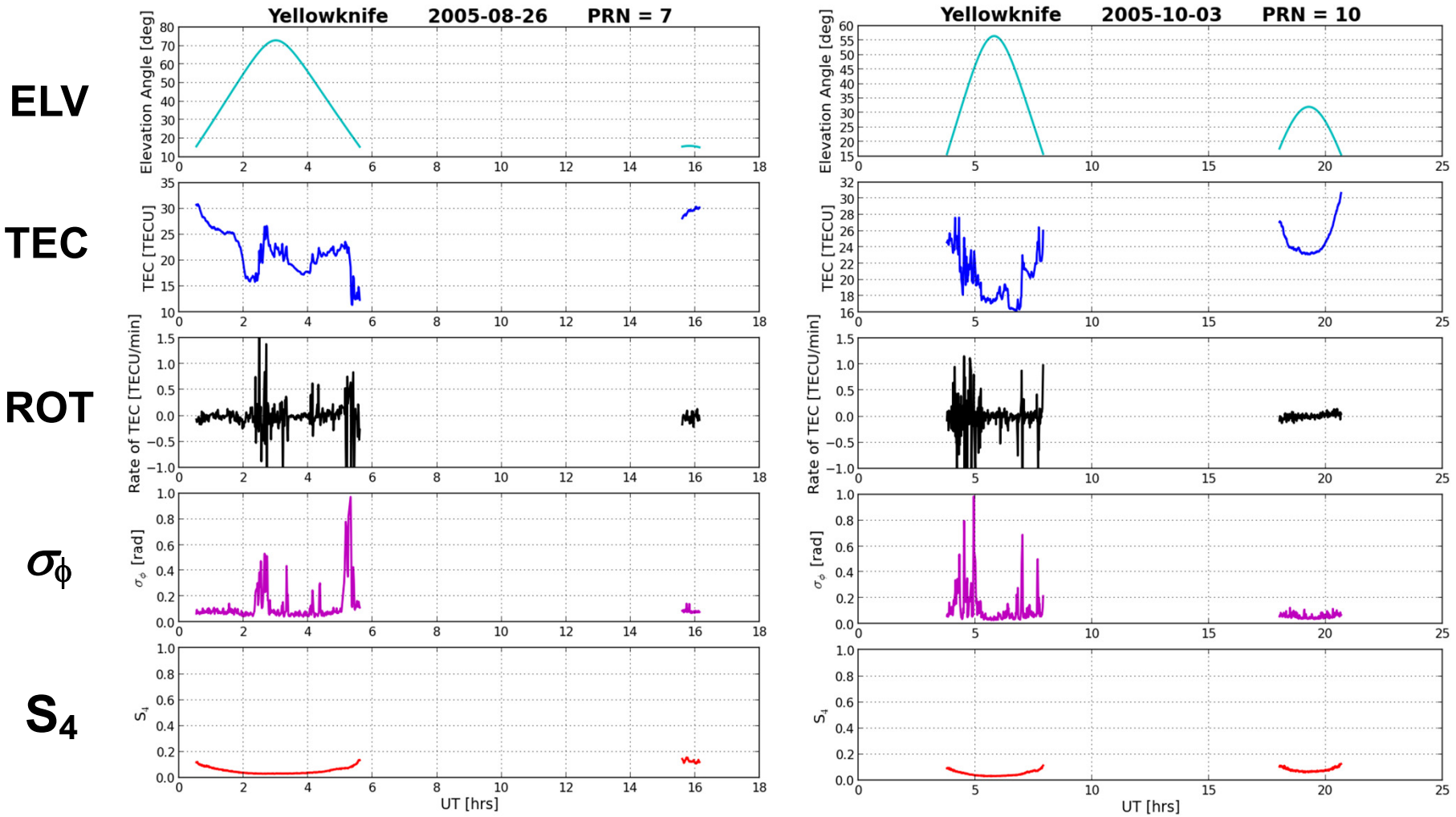
Comparison of S_4(L1) and ROTI (Equatorial)



Measurements made in Ancon, Peru, April 1997.

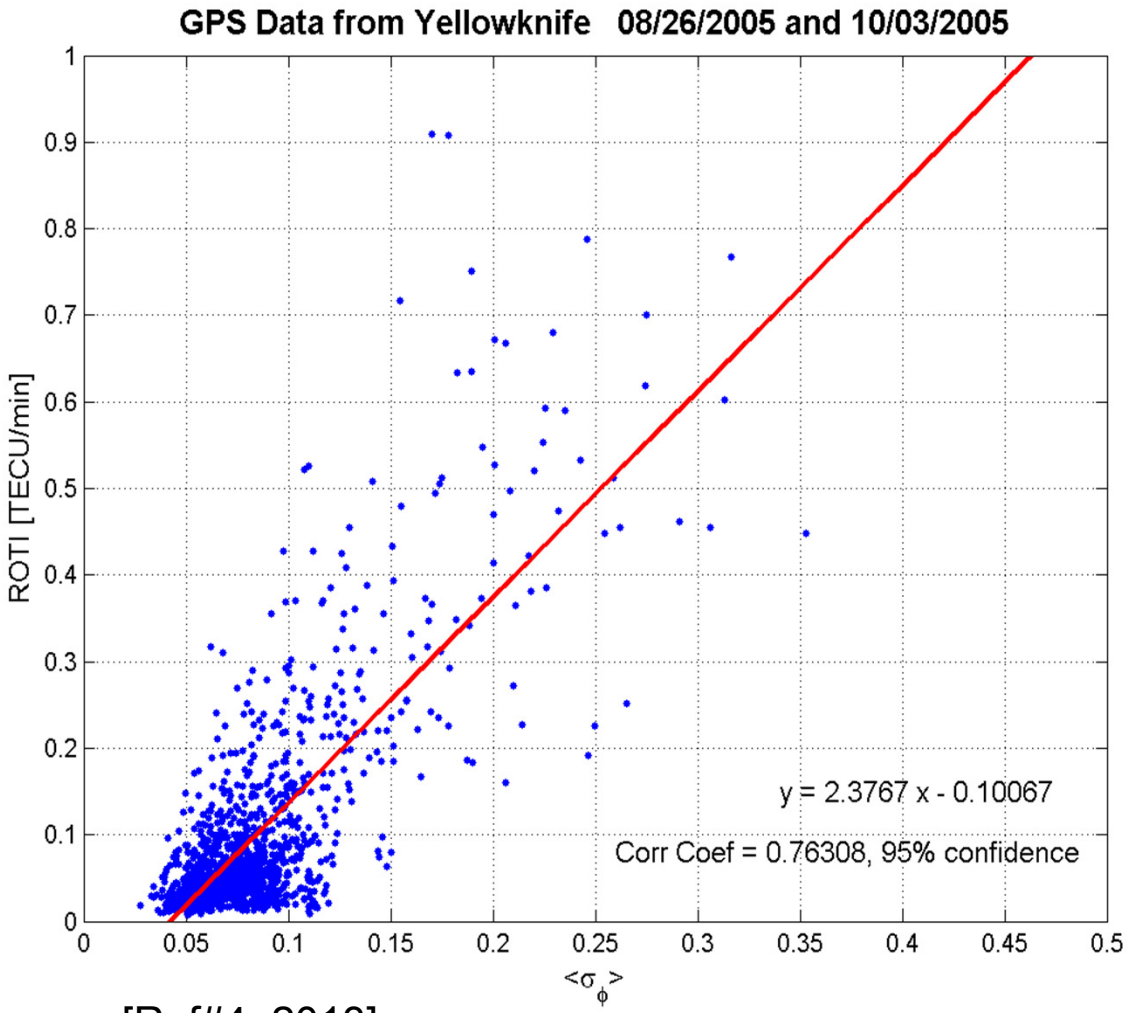
Beach and Kintner [Ref#6, 1999]

Comparison of S_4(L1), σ_ϕ(L1), and ROTI
Observation Site: Yellowknife, Canada (Polar)



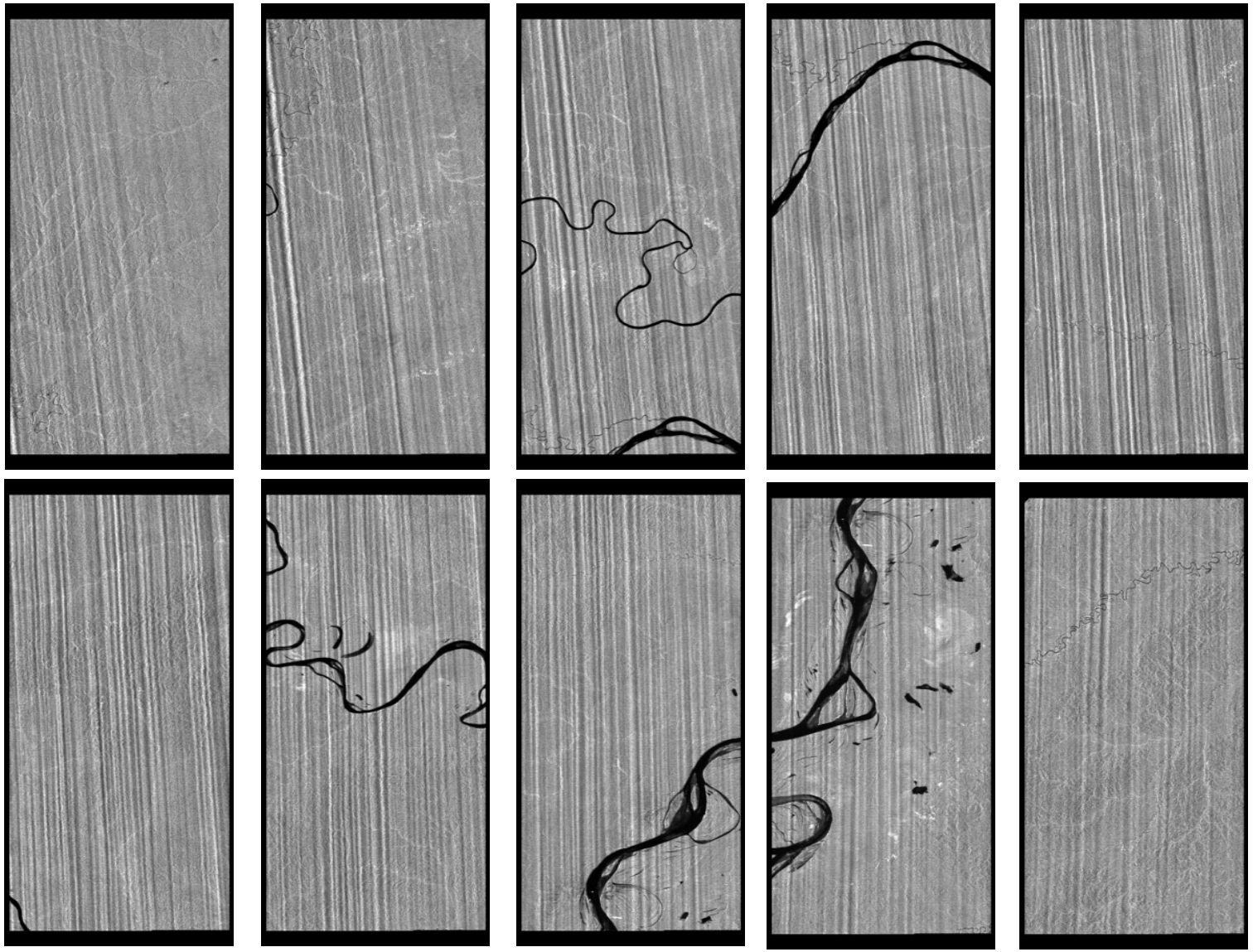
Correlation Analysis (High-Lat): ROTI vs. σ_ϕ

- **σ_ϕ(L1)**
  Derived from 50-Hz phase (ϕ) data;1-minute cadence
- **$<\sigma_\phi>$**
  Averaged over 15 minutes
- **ROT & ROTI**
  ROT: 1-minute cadence;
  ROTI values are computed for the same time intervals as $<\sigma_\phi>$.
- **Results**
  - ROT and ROTI capture phase scintillation period very well
  - Magnitude of ROTI (TEC fluctuations), σ_ϕ (phase scint.) and S_4 (amplitude scint.) can be different



[Ref#4, 2013]

Artifacts in PALSAR Images along an ALOS Path over South America



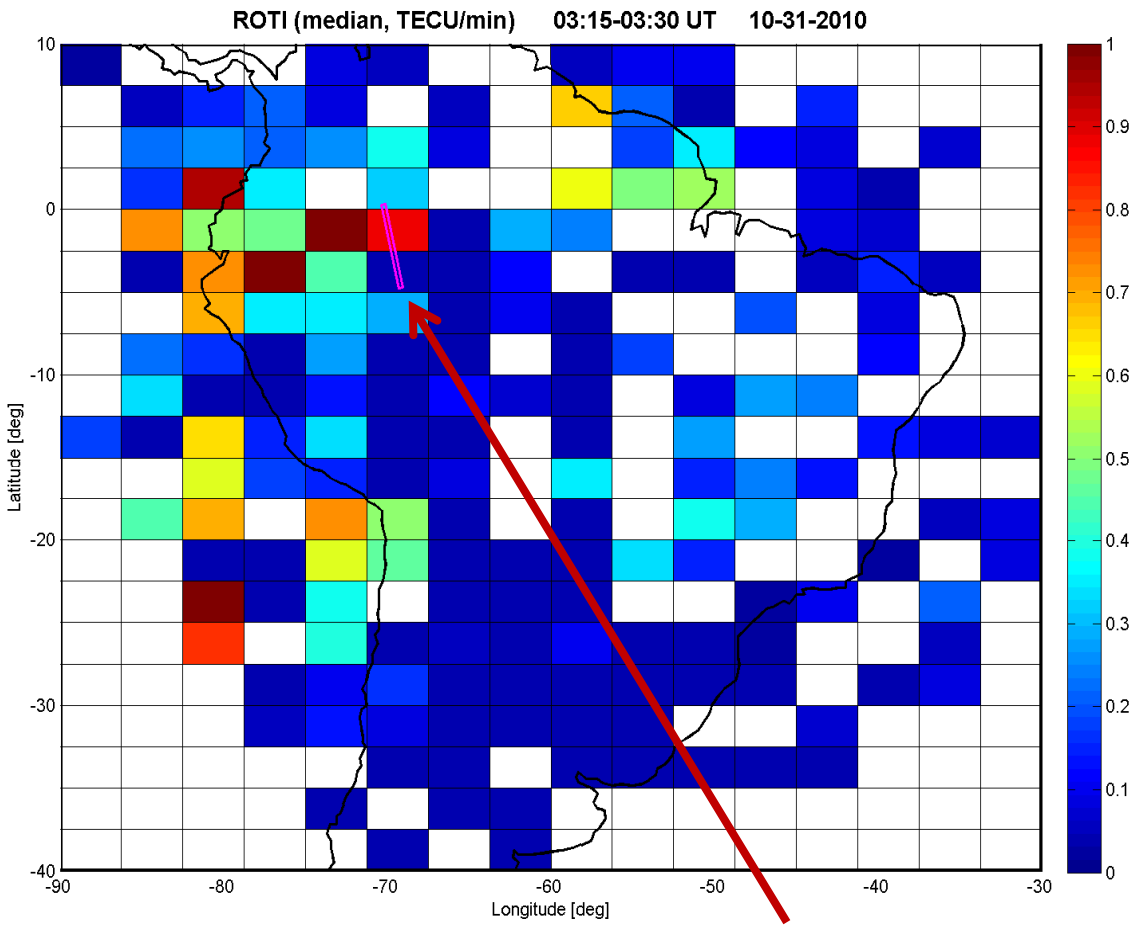
Supporting Studies of Ionospheric Impact on Spaceborne InSAR Imagery

PALSAR Imagery

- Phased Array type L-band Synthetic Aperture Radar
- InSAR images affected by ionospheric irregularities and scintillation, shown as artifacts in radar images

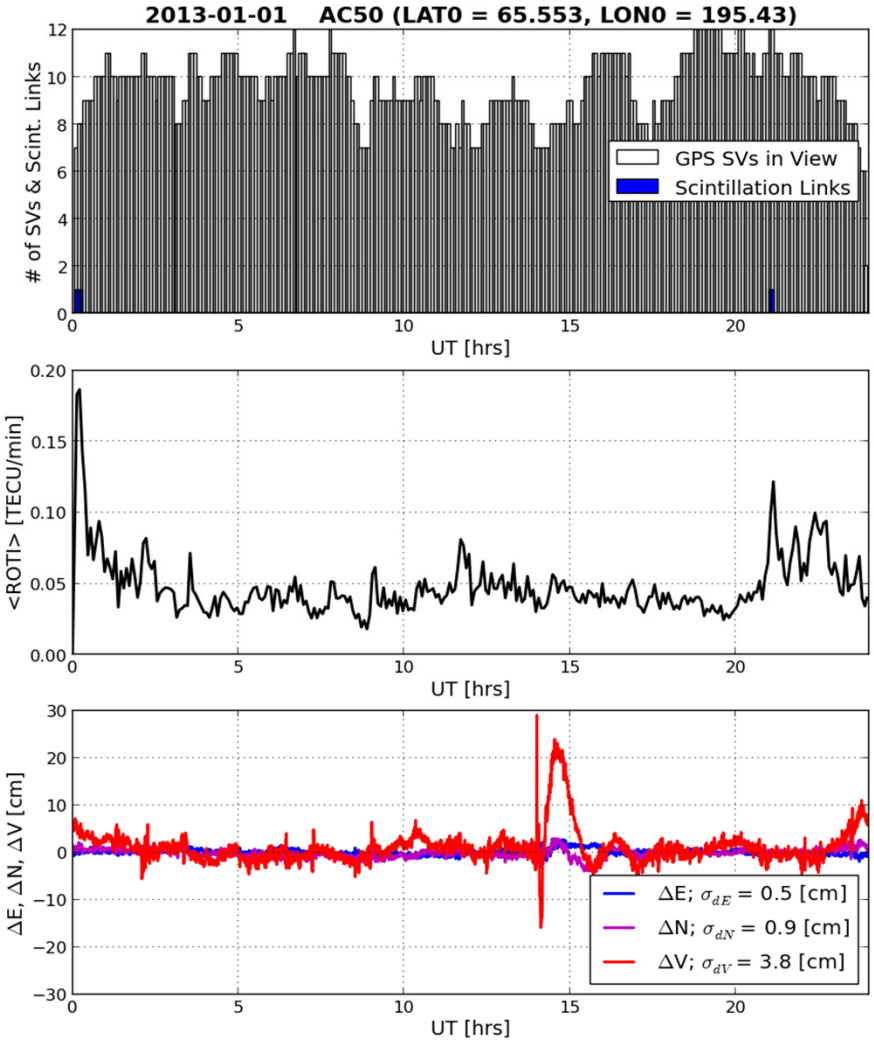
Regional Map of Ionospheric Irregularities and Scintillation (RMIIS)

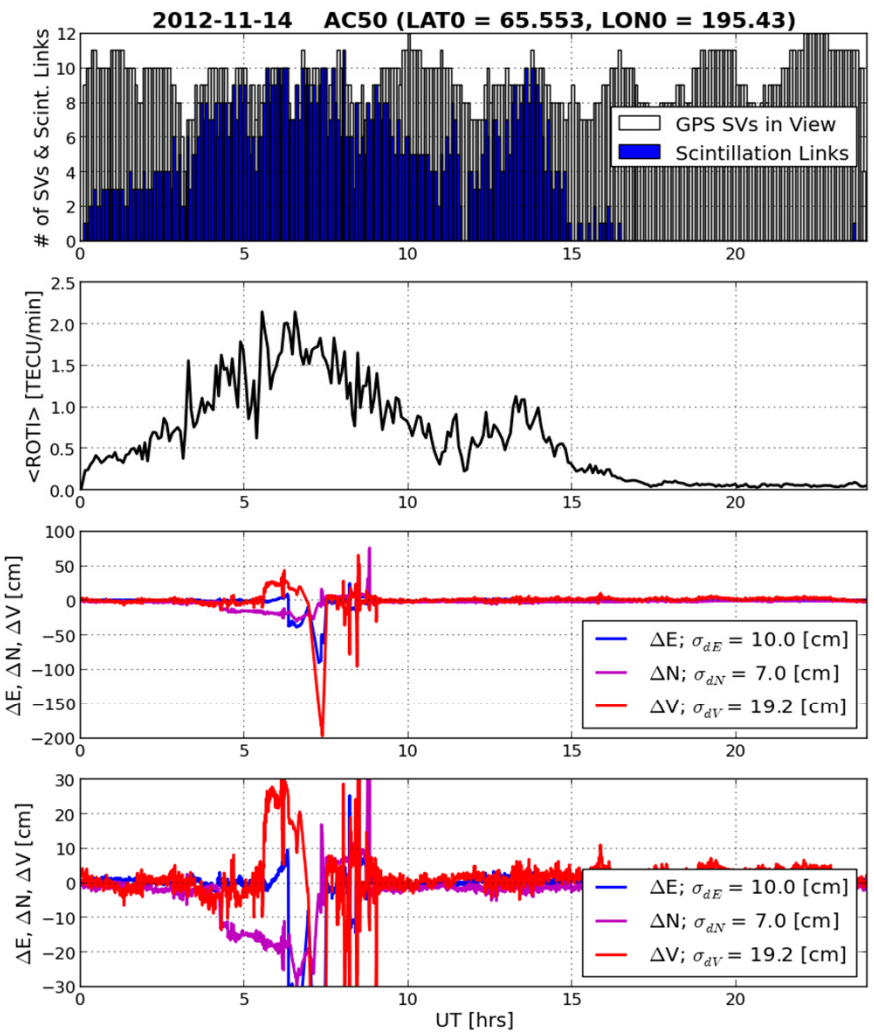
- Ground-based GPS receiver networks (31 stations)
- 15-min ROTI maps
- IPP at 400 km ALT
- Grid resolution: 3.75° x 2.5° (ΔLON x Δ LAT)



[Ref#3, 2012]

Impact of Scintillation on Positioning





Quiet [Ref#4, 2013] **Storm**

Summary

- Dual-frequency GPS phase data collected from existing GNSS networks have been used to derive ROT and ROTI measurements
- Analyses by various groups have shown that ROTI is a good occurrence indicator for L-band amplitude and phase scintillation, though their magnitudes can be different depending on plasma physics processes and radio propagation environment in different latitude regions
- ROTI maps have been applied to monitoring global and regional activities of ionospheric irregularities with a 15-min temporal resolution continuously
  - A significant event of irregularities and phase scintillation occurred in most of the contiguous United States and Alaska under space weather disturbances has been recorded using ROTI maps
- The GPS-based ionospheric irregularity measurements have been applied to various studies, including the impact of ionospheric scintillation on Earth science remote sensing imagery and GPS-based positioning
- Real-time ROTI maps have been tested at JPL, and U.S. regional real-time ROTI maps will soon be made available to the public to serve space weather monitoring and prediction

References

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2. Pi, X., A. Freeman, B. Chapman, P. Rosen, and Z. Li (2011), Imaging ionospheric inhomogeneities using spaceborne synthetic aperture radar, J. Geophys. Res., 116, A04303, doi:10.1029/2010JA016267.
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6. Beach, T.L. and Kintner, P.M. (1999). Simultaneous Global Positioning System observations of equatorial scintillations and total electron content fluctuations. *Journal of Geophysical Research 104: doi: 10.1029/1999JA900220. issn: 0148-0227.*