Monitoring Ionospheric Scintillation Effects on Precise Positioning in the North America Region

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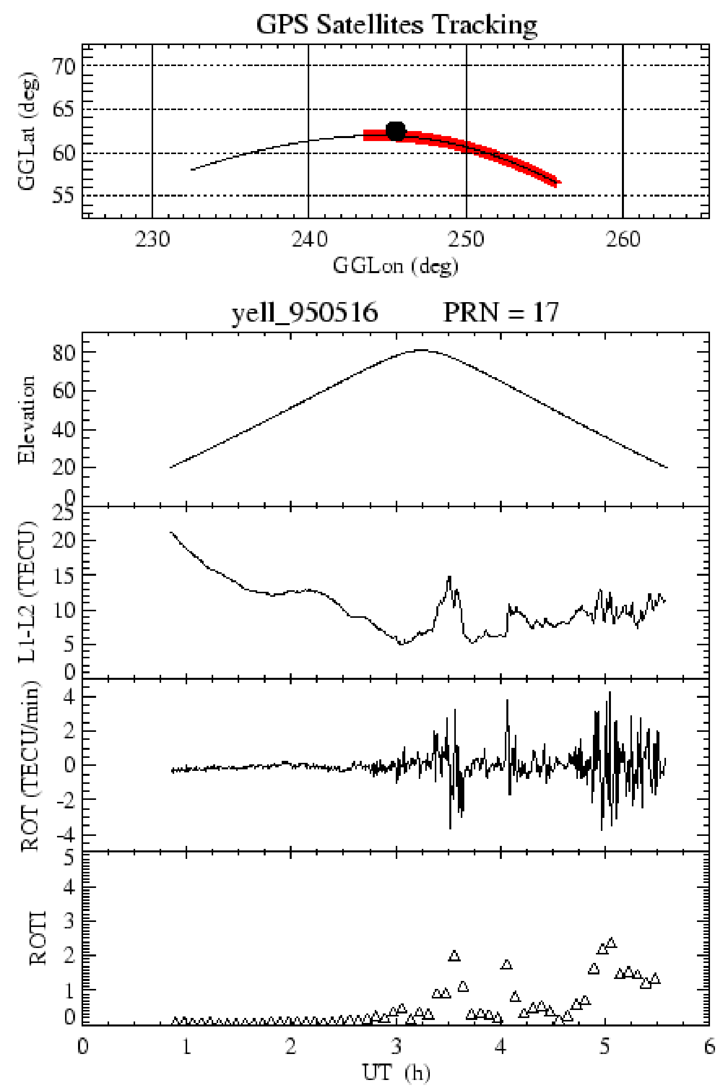
Introduction

- NOAA 2012 SBIR topic to develop SWPC product for ionosphere-induced denial of service for GPS customers
- Phase I work (six months):
  - Survey of user community/potential customers (poster)
  - Feasibility study of scintillation effects nowcast
  - Focused on continental US

Nowcast based on ROTI

- Total Electron Content (TEC) measured using phase difference between L1 and L2 GPS signals
- Rate of TEC (ROT): $$ROT = \frac{\Delta TEC}{\Delta t}$$
- ROT measurements indicate small-scale variations on top of a slower, larger scale trend
- Rate of TEC Index: $$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$
- Use ROTI to determine presence of amplitude and phase scintillation



Advantages of ROTI over S_4 and σ_ϕ

- Can be measured using thousands of standard GNSS receivers already deployed around the globe
- Not susceptible to receiver clock/oscillator error
- Directly measures ionospheric TEC irregularities

ROTI at High Latitudes

- Published work has established correlation between ROTI and both phase and amplitude scintillation at low latitudes
- At high latitudes, amplitude scintillation is suppressed, so need to study relationship
- We examined GPS L1 scintillation data from Yellowknife, Canada (62.3^{o}N)
- Data courtesy of Susan Skone, University of Calgary

GPS Observations

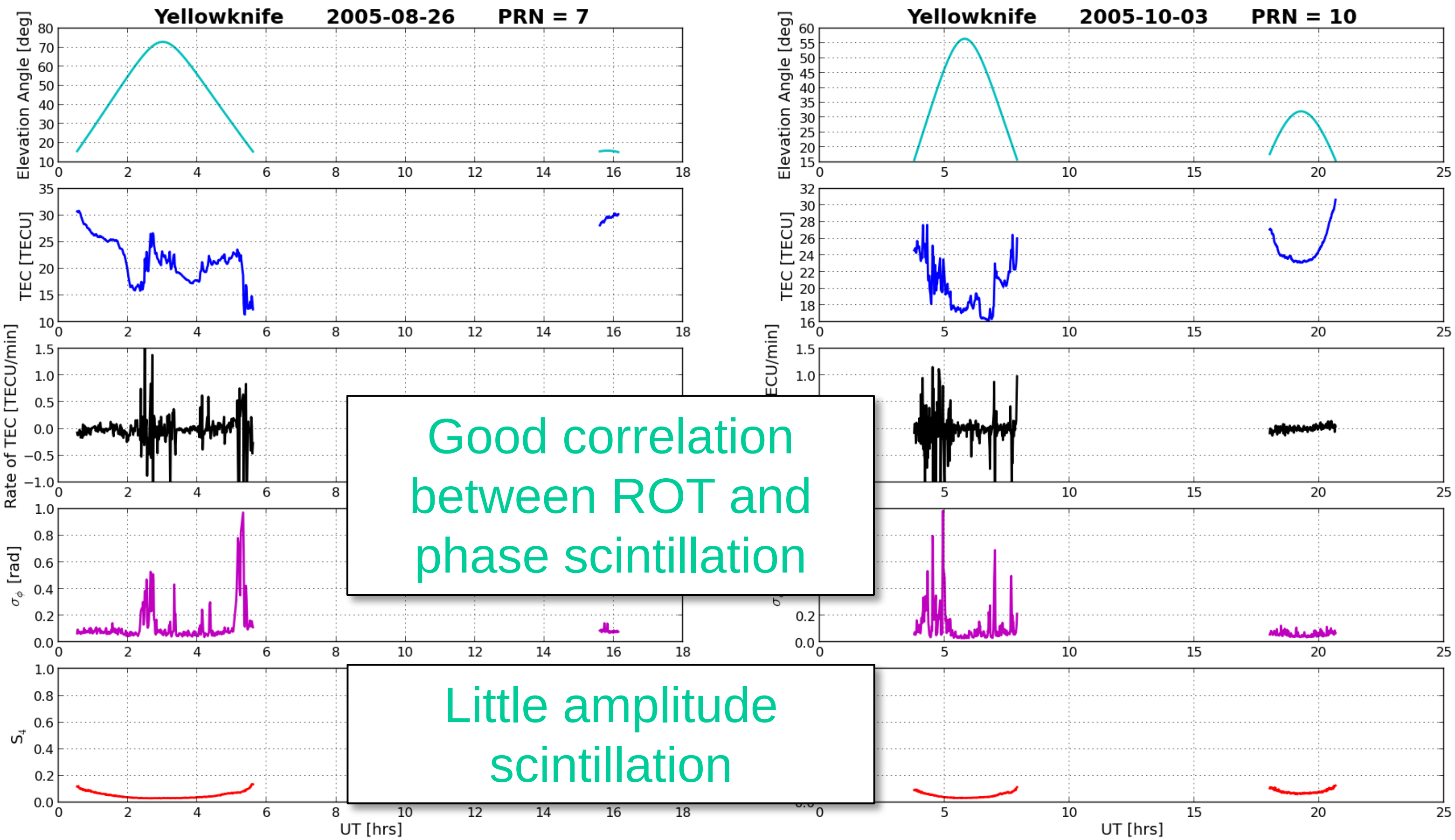
EL

TEC

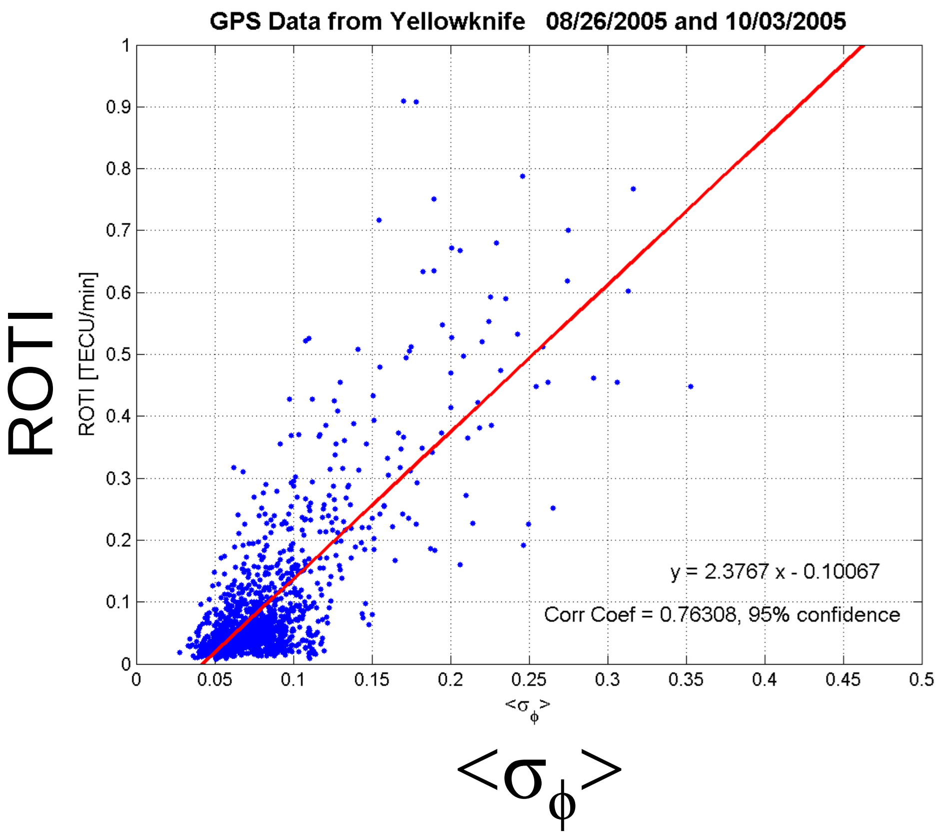
ROT

σ_φ

S_4



ROTI and σ_ϕ



- Difference in data rate affects comparison
- Magnitude of single-frequency signal scintillation is also affected by
  - irregularity spectrum
  - observation geometry
  - radio wavelength
  - speed of plasma
  - etc.

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ROTI Map

- Using standard GPS data collected from the CORS network, regional snapshot ROTI maps can be produced for every 5- to 15-minute intervals
- ROTI measurements with corresponding coordinates of 400-km ionospheric piercing points assigned to 2 by 2 degree cells
- Feasibility study performed using archived data

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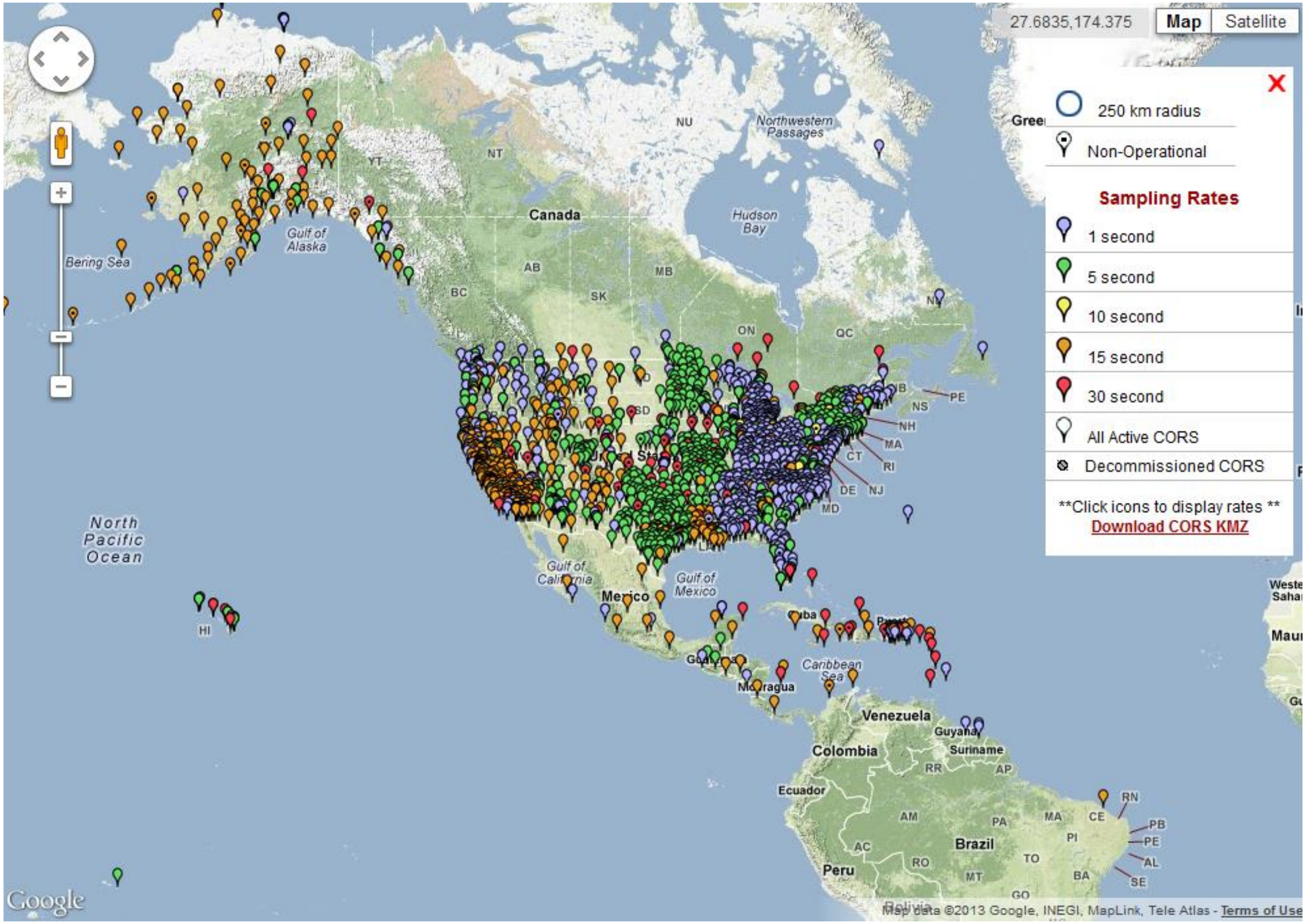
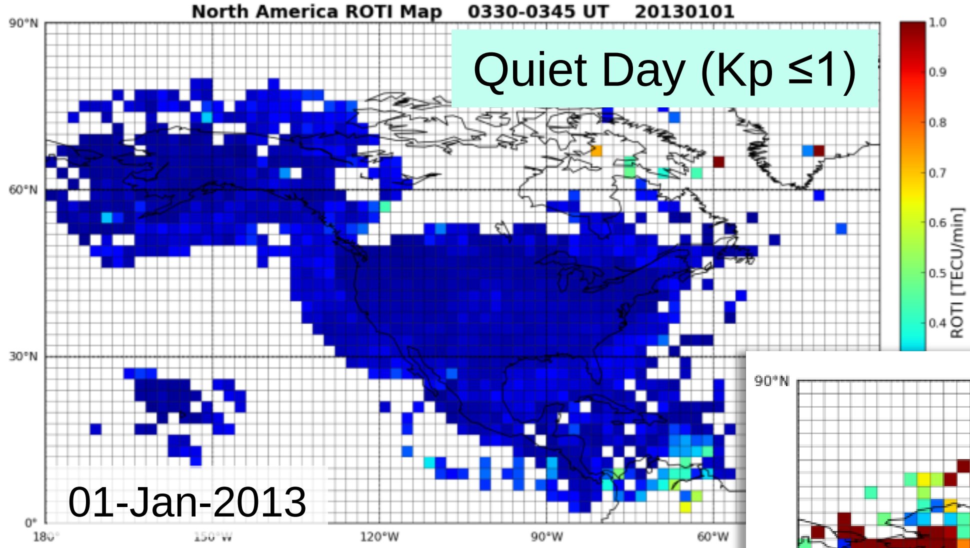
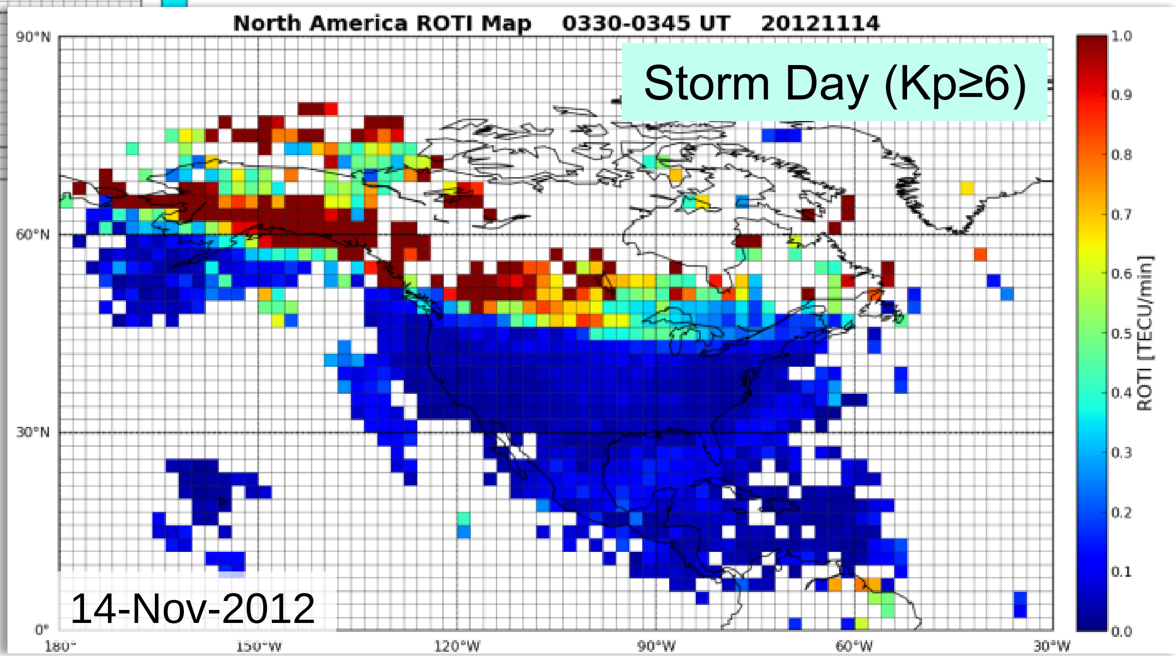
CORS Network



ROTI Map





~450 stations

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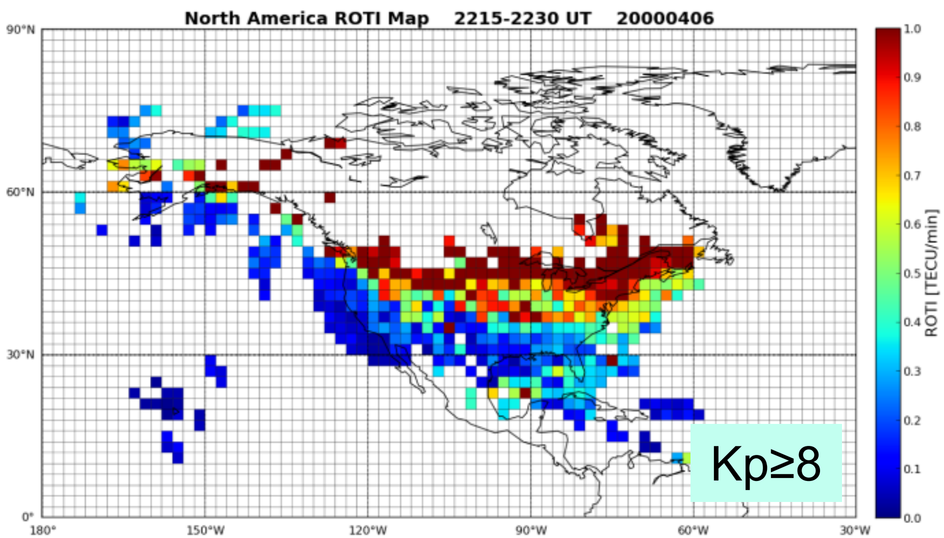
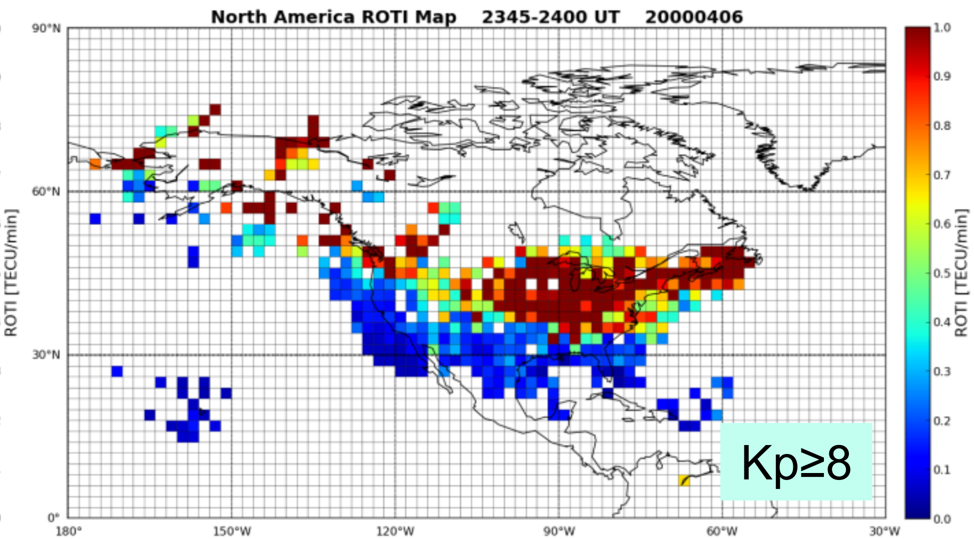
Storm Effects in CONUS

06-Apr-2000 (~180 stations)





Ionospheric irregularities/scintillation seen at middle latitudes in the contiguous United States during a major geomagnetic storm.

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ROTI and Precise Positioning

- Analyzed GPS data from high-latitude CORS stations (~65^{o}N)
- Used JPL's GNSS Inferred Positioning System and Orbit Analysis Simulation Software (GIPSY-OASIS)
- Compared positioning results for storm day to quiet day
- Expect scintillation impact on real-time positioning applications would be worse than results from post-processing

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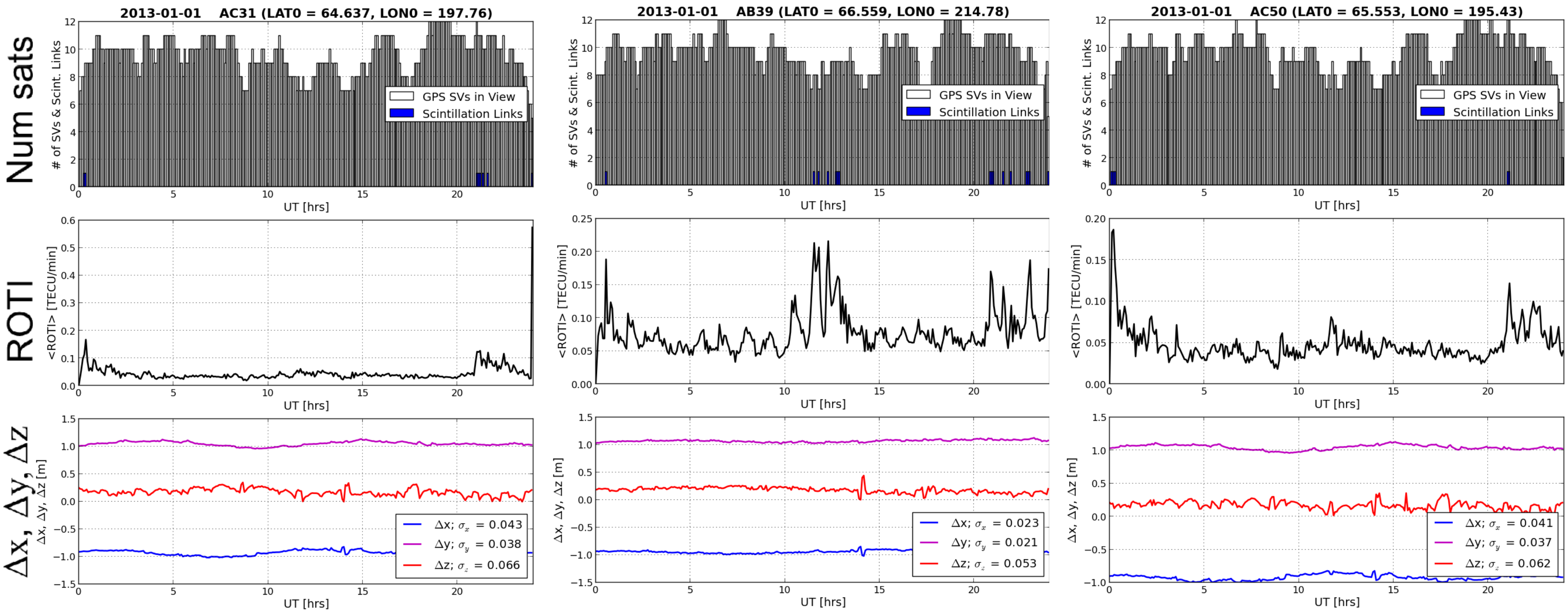
Quiet Day



On quiet day, the variation over the day is small (σ_{max} < 0.07m)

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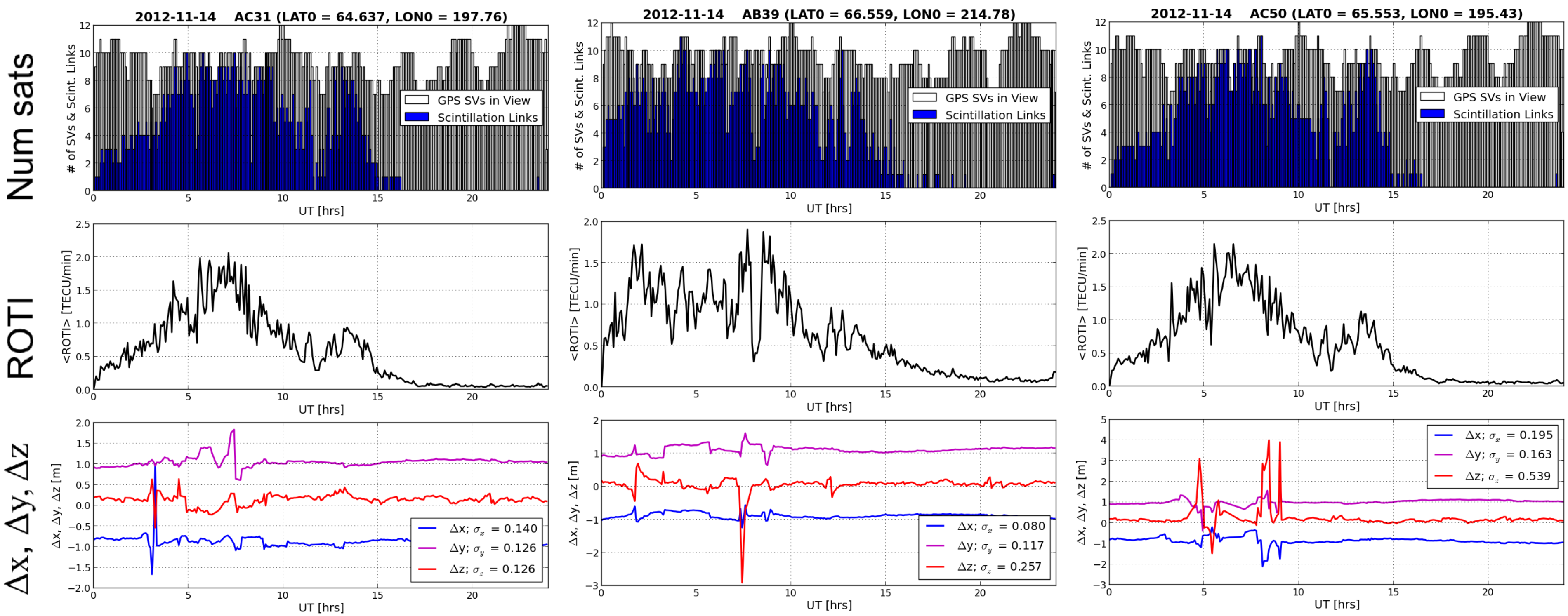
Storm Day

Blue = ROTI>0.5



On storm day, the variation grows substantially (Δ up to 3m)

User Experience Modeling

- To translate ROTI map to user experience, three more steps must be taken:
  - Calculate current location of GPS satellites and IPP location relative to user
  - Get ROTI value for link from ROTI map
  - Translate ROTI values to user impact
- In Phase I, notional receiver model developed for translating ROTI to measurement impact

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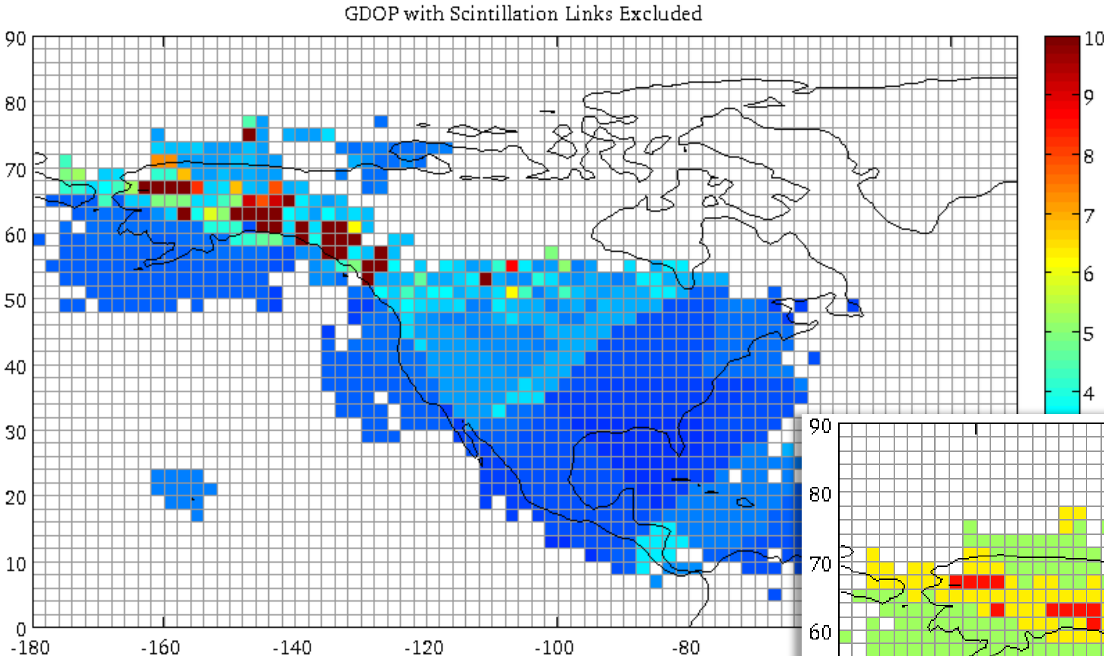
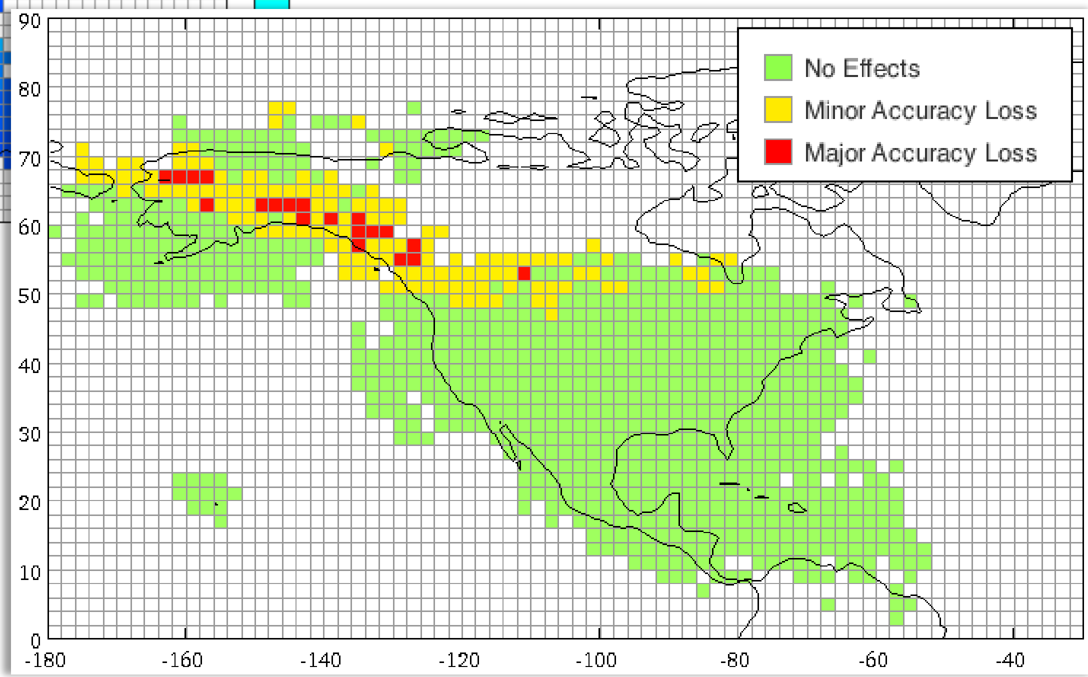
Example GDOP-based Product





GDOP as defined in Parkinson, B.W. and J.J. Spilker, 1996. ***Global Positioning System: Theory and Applications (Volume One)*** (Progress in Astronautics and Aeronautics). 1st Edn., American Institute of Aeronautics and Astronautics, Washington, DC, pp: 793.

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Conclusion

- We have produced:
  - ROTI maps to observe scintillation activities in the North America region
  - User impact nowcast for GPS precise positioning
- Showed correlation between:
  - ROTI and L1 phase scintillation in the polar region.
  - ROTI and precise positioning errors
- Phase II work (if awarded):
  - Develop real-time processing using streaming CORS data
  - Further develop user impact algorithm