Measuring Ionospheric Irregularities Globally by the Rate of TEC Index and GNSS Networks

Xiaoqing Pi

Jet Propulsion Laboratory, California Institute of Technology

Copyright 2012 California Institute of Technology.
United States Government Sponsorship acknowledged.

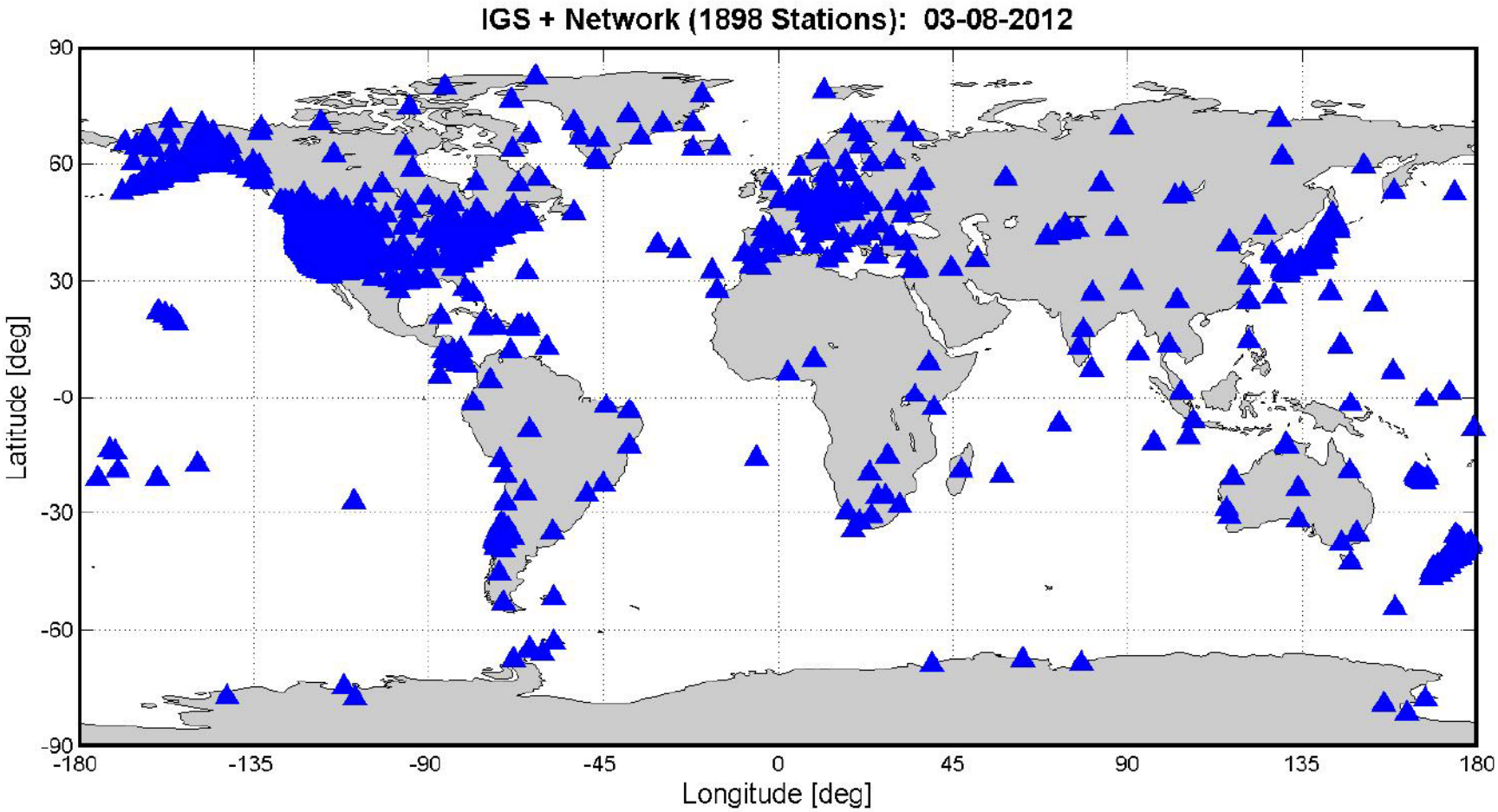
Space Weather Workshop, Boulder, CO, April 27, 2012

Outline

- Why do we use the rate of TEC index (ROTI) instead of the standard S_4 and σ_ϕ indices?
- What are the differences between S_4, σ_ϕ and ROTI?
- Examples of ROTI measurements
- Development status and plan

Why do we use ROTI instead of the standard scintillation indices (S_4 and σ_ϕ)?

IGS + Network (~1900 Stations)

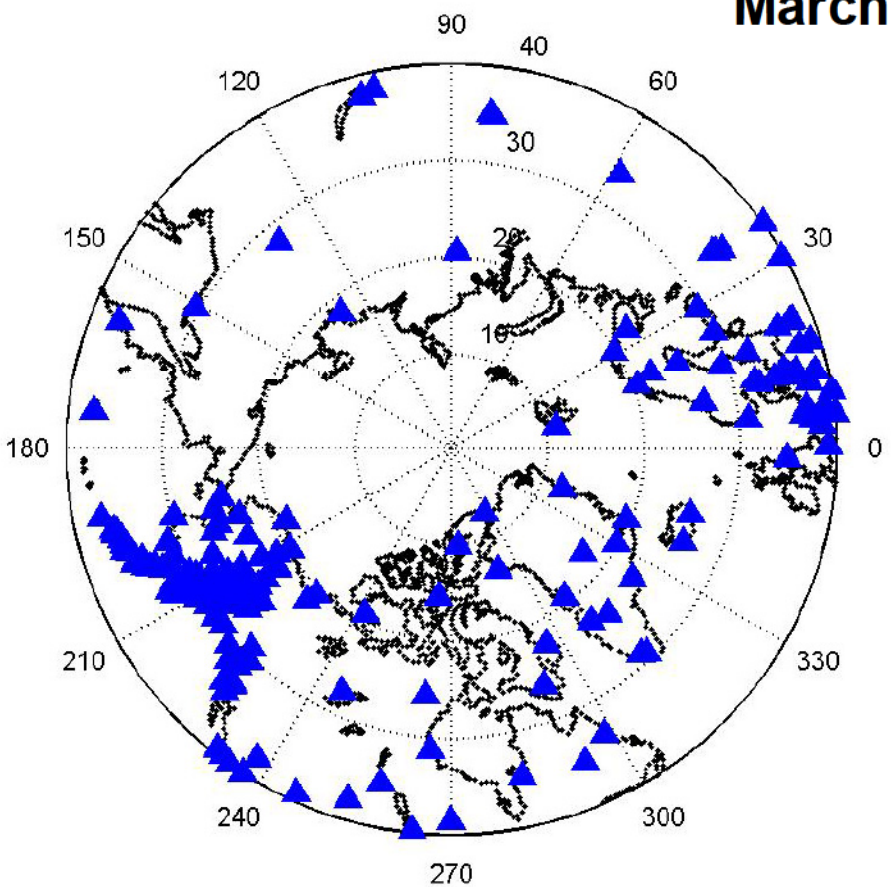


Registered IGS stations: 441

Polar View of IGS + Network

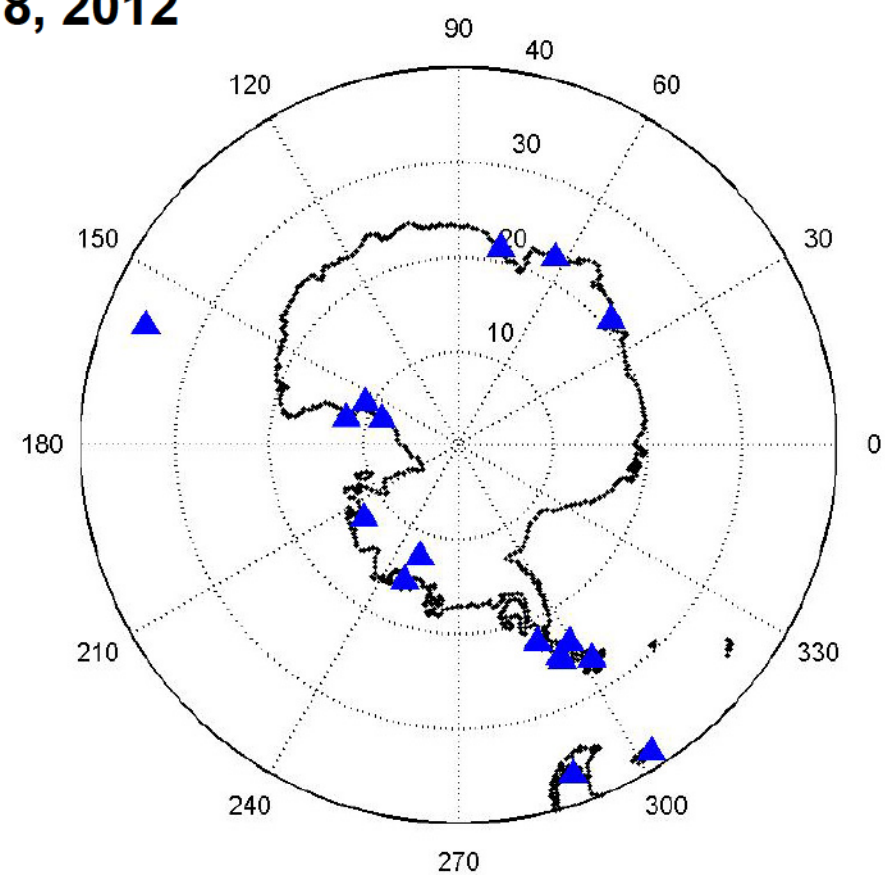
March 8, 2012

Northern



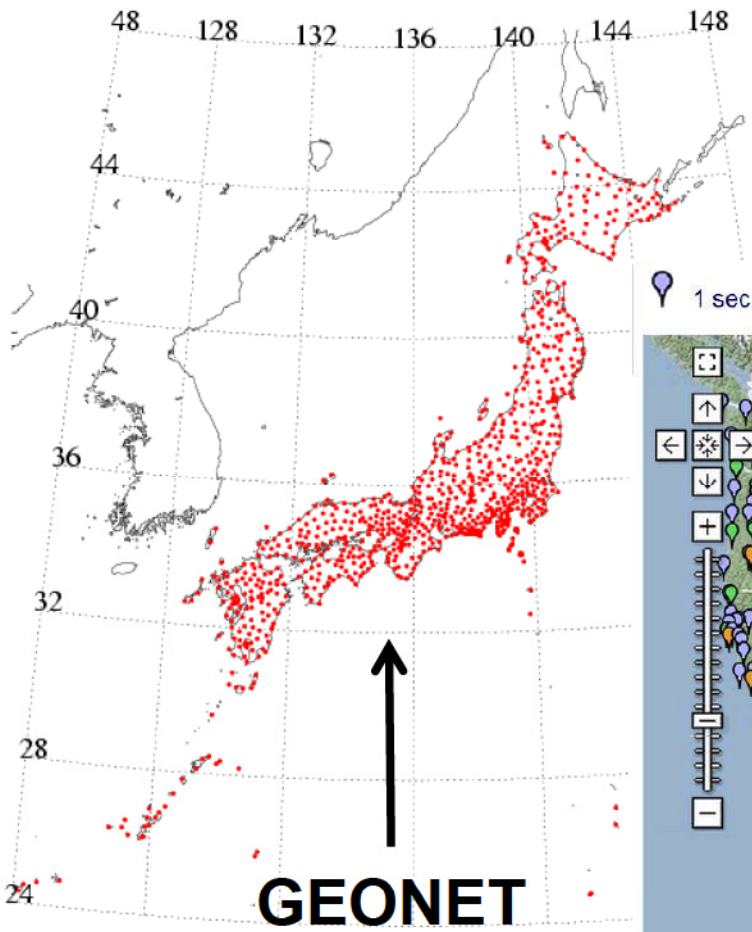
221 Stations

Southern



18 Stations

Ground-Based Regional GPS Networks



GEONET

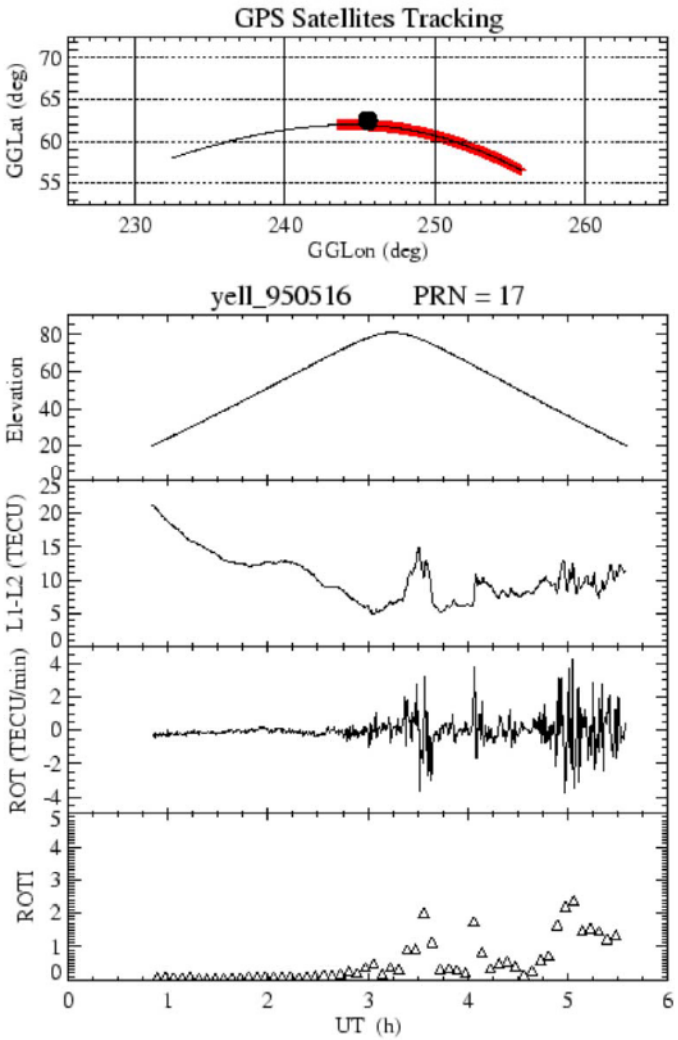
GPS Earth Observation Network

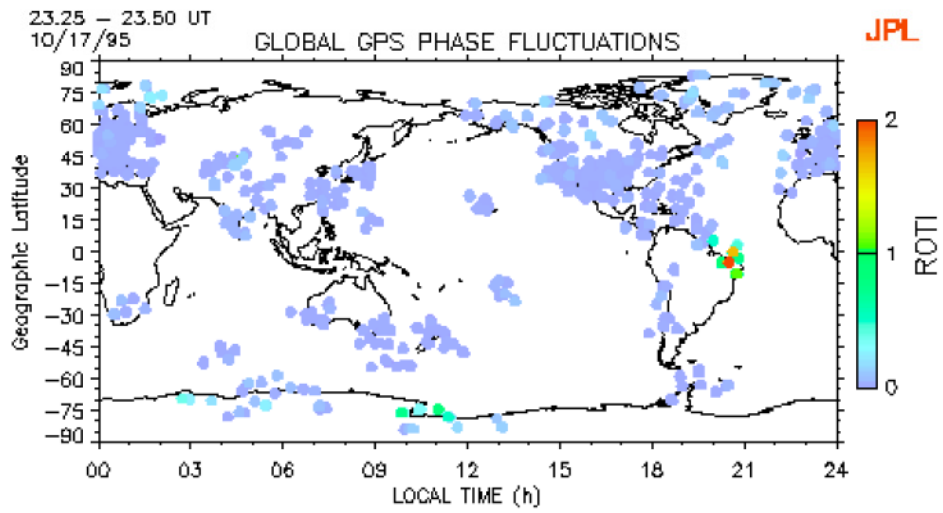
~1200 stations

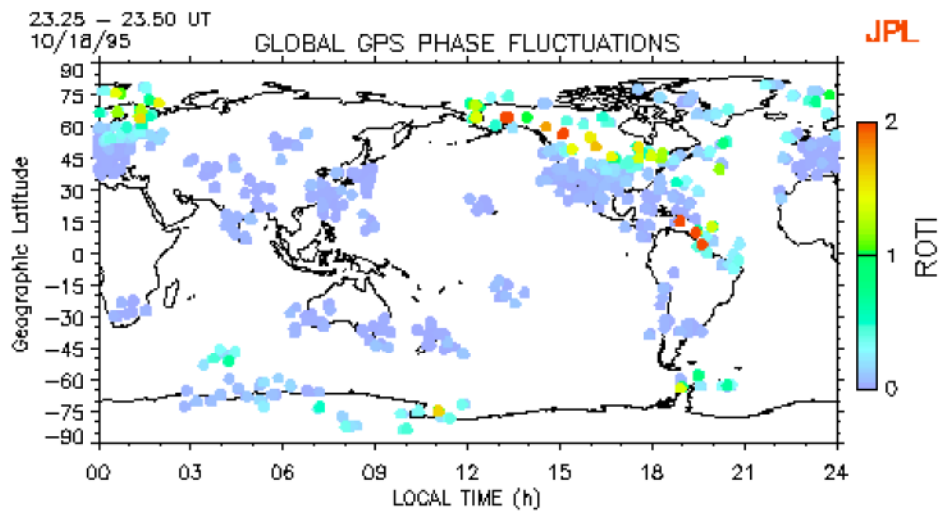
CORS

Continuous Operating Reference Stations

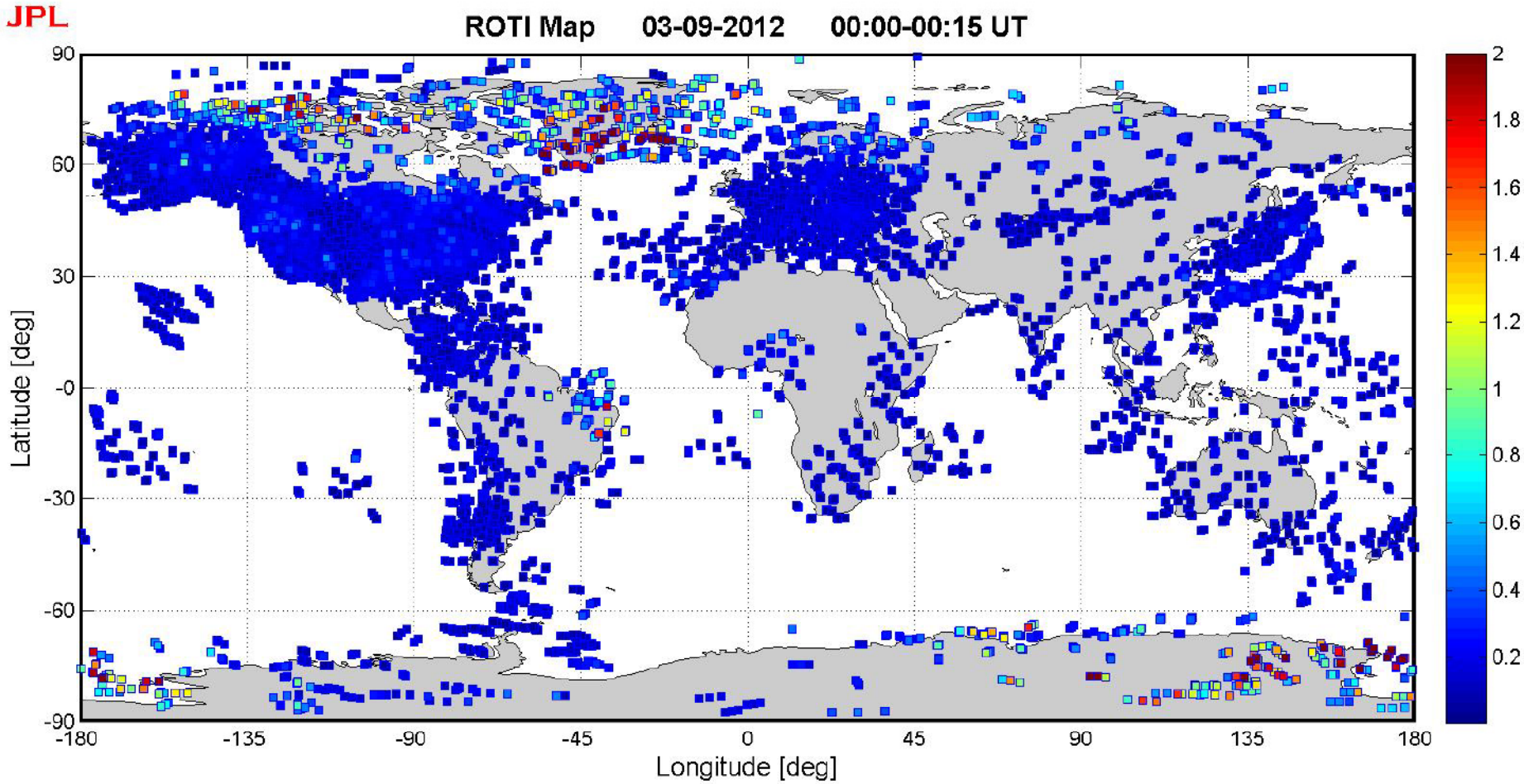
ROTI: Measurement of Ionospheric Irregularities





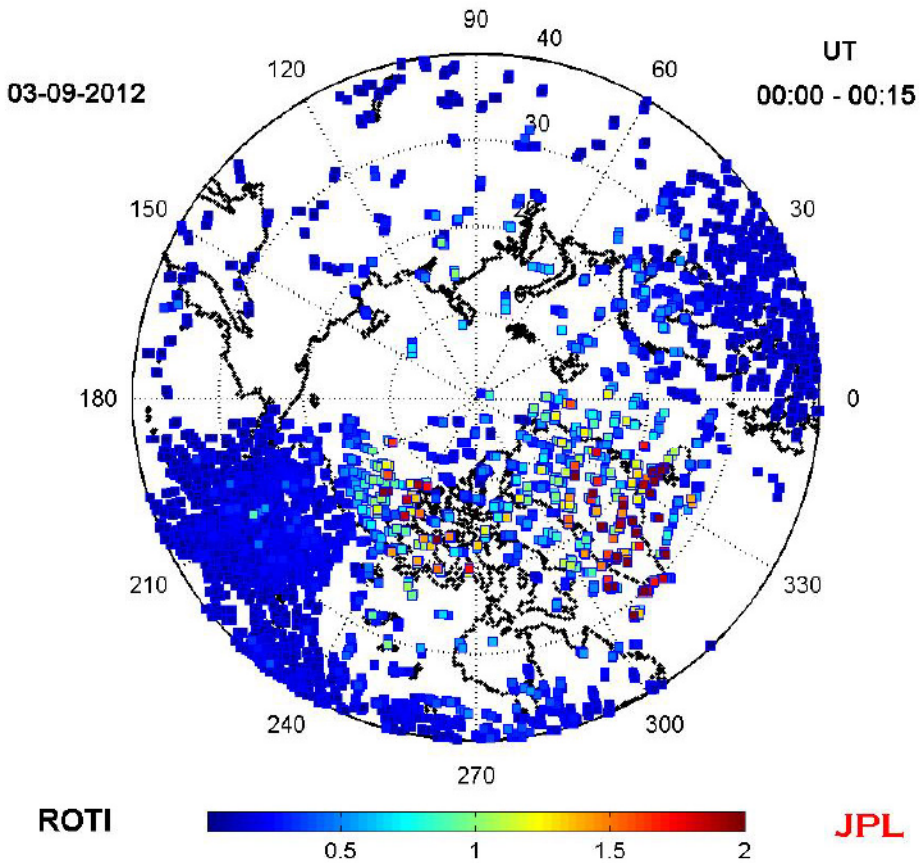


Global ROTI Map

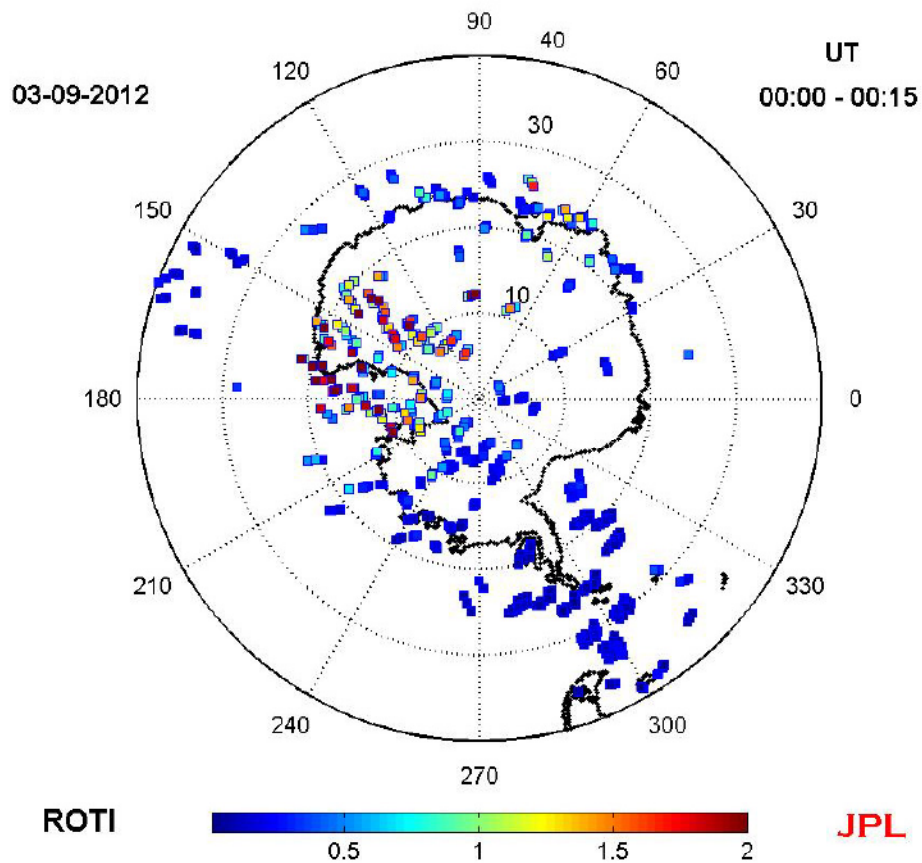


- **IGS + networks**

ROTI Polar Maps



North



South

What are differences between the standard scintillation indices and ROTI?

Ionospheric Scintillation Indices

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

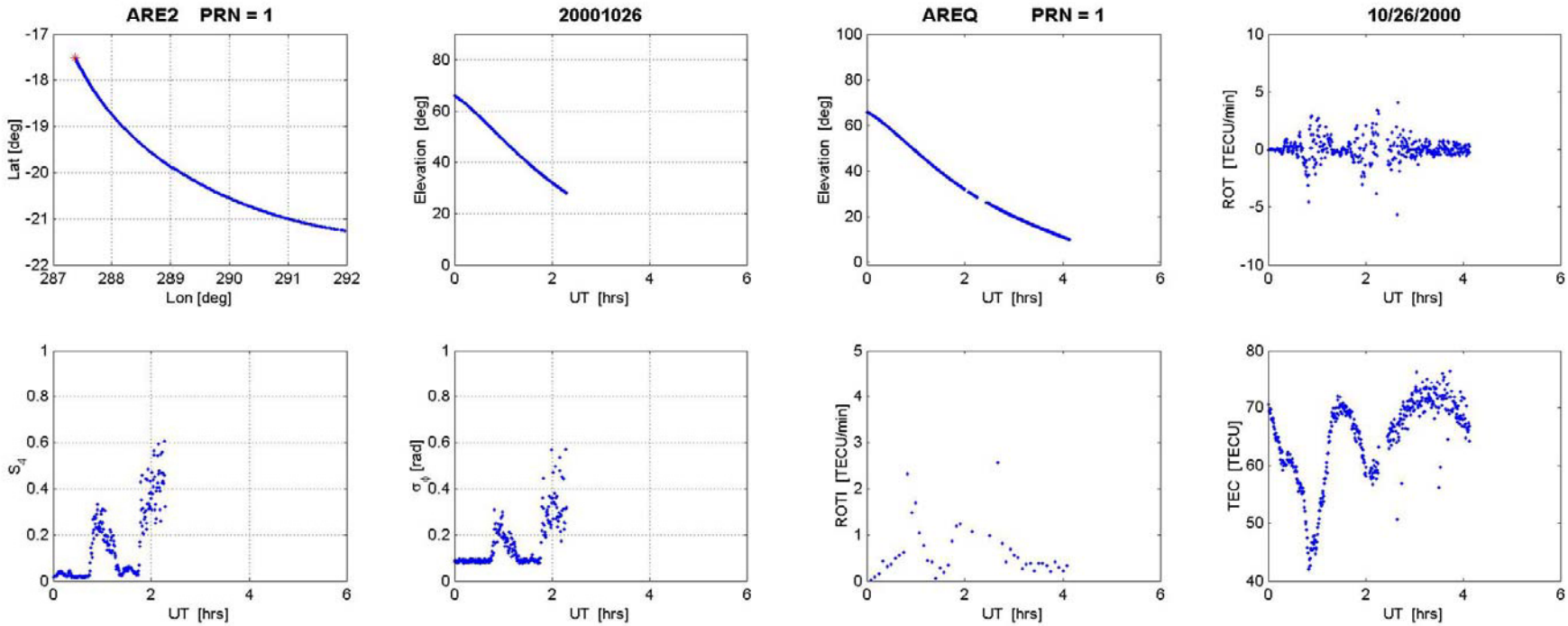
$$\sigma_\phi(f) = \sqrt{\langle \phi^2 \rangle - \langle \phi \rangle^2} \propto f^{-1}$$

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

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

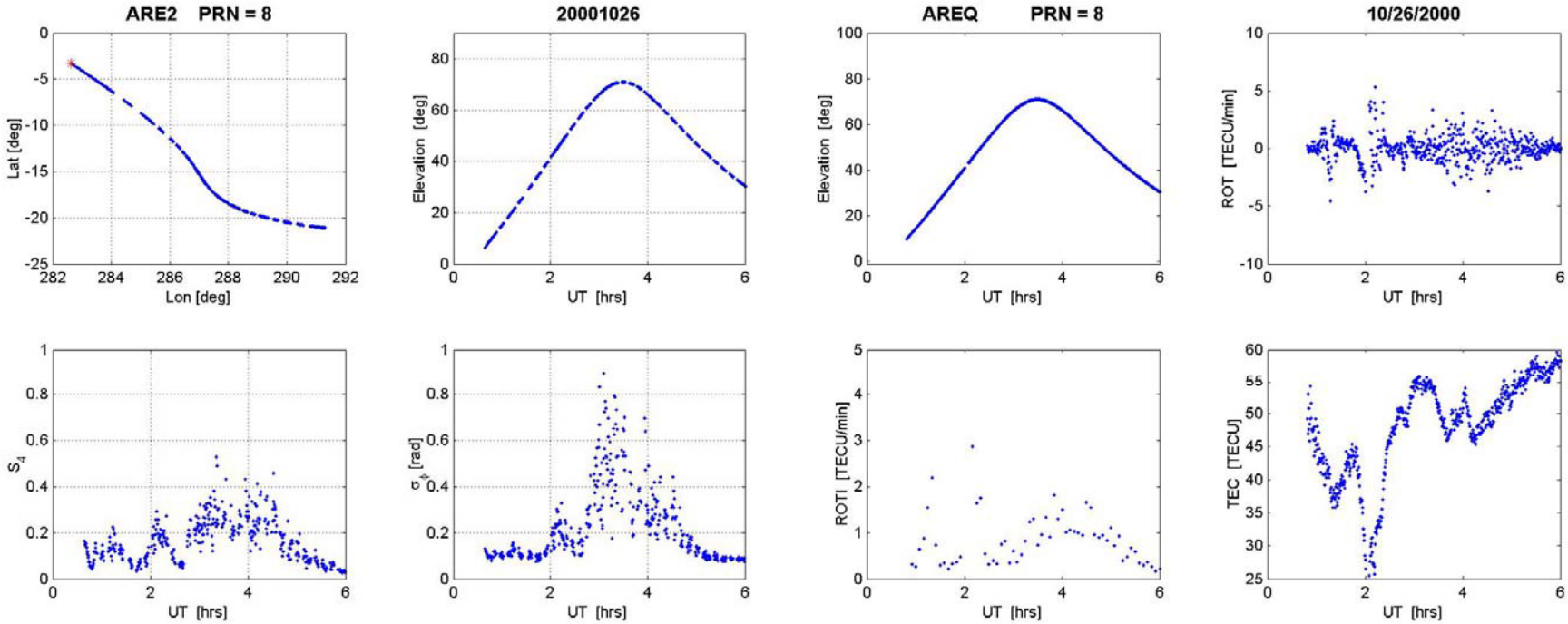
- **S_4 and σ_ϕ indices – amplitude and phase scintillation, respectively**
  - I – detrended signal intensity
  - ϕ – detrended signal phase
  - raw data is sampled at 20 or 10 ms (50 Hz or 100 Hz)
  - frequency dependent
  - Measurements of phase scintillation susceptible to local oscillator errors of transmitter and receiver
- **ROTI – Rate of TEC index**
  - ROT – detrended rate of TEC derived from dual-frequency phase data
  - ROT data sampled at 30 sec (or 1 s)
  - Not susceptible to local oscillator errors, in principle

Comparison of S_4, σ_ϕ, and ROTI



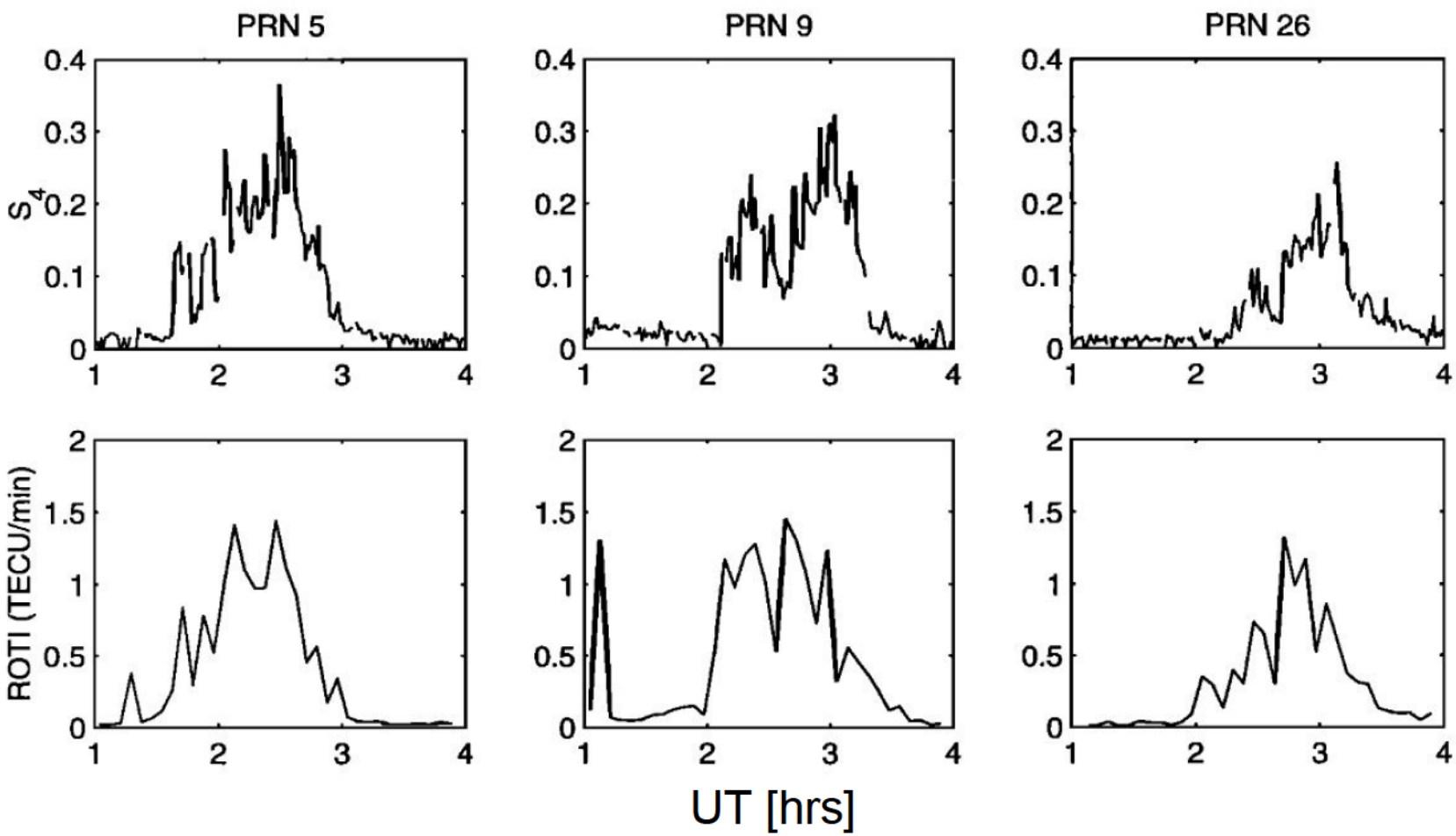
S_4 **σ_ϕ** **ROTI** **ROT, TEC**

Comparison of S_4, σ_ϕ, and ROTI



S_4 **σ_ϕ** **ROTI** **ROT, TEC**

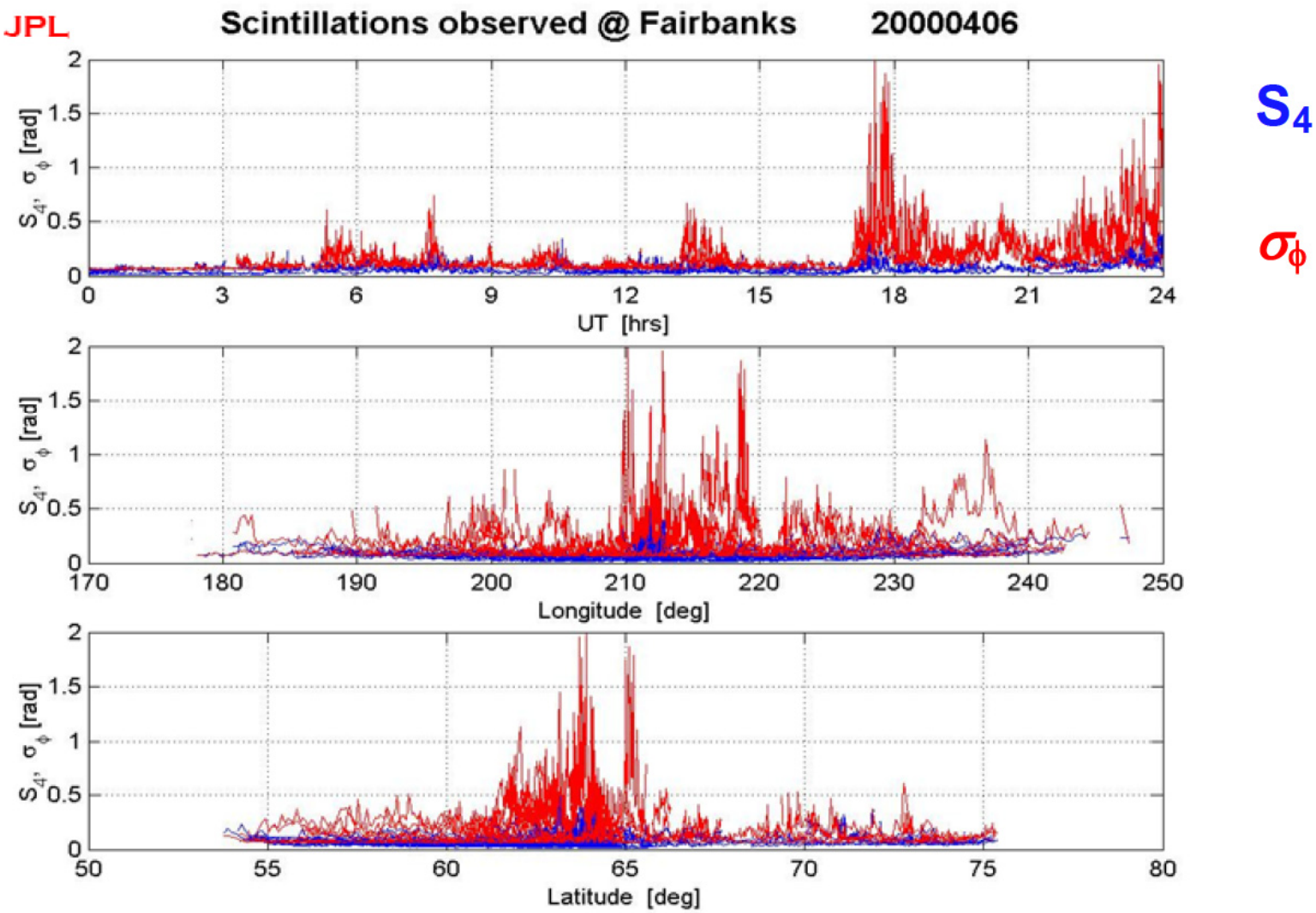
Comparison of S_4 and ROTI



Measurements made in Acon, Peru, April 1997.

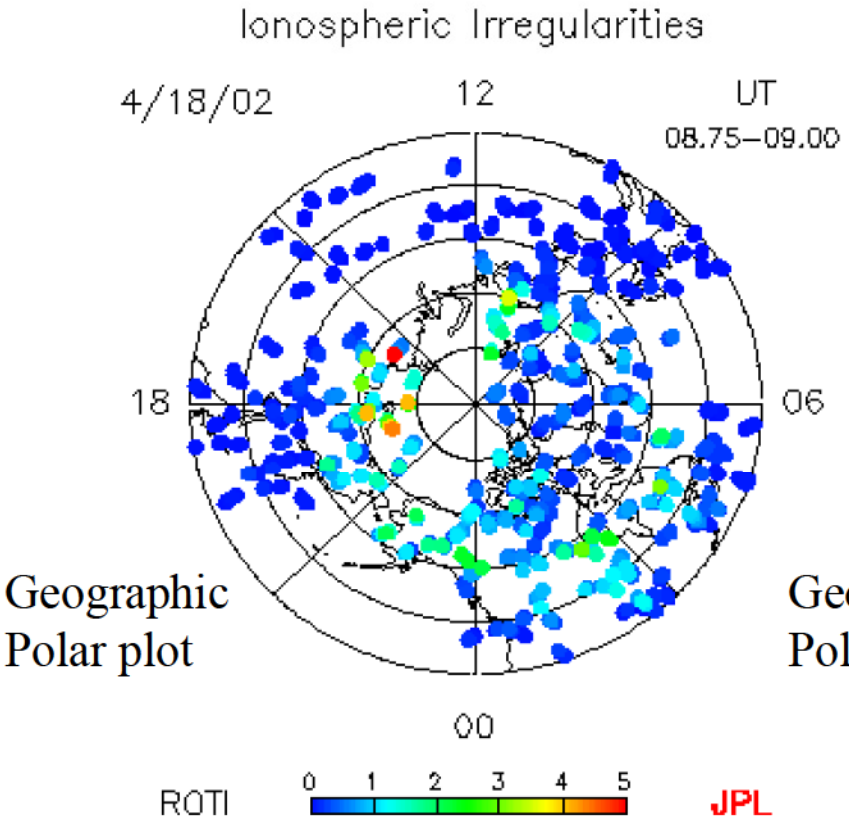
Beach and Kintner [1999]

An Example of Ionospheric Scintillation Measured at High Latitudes

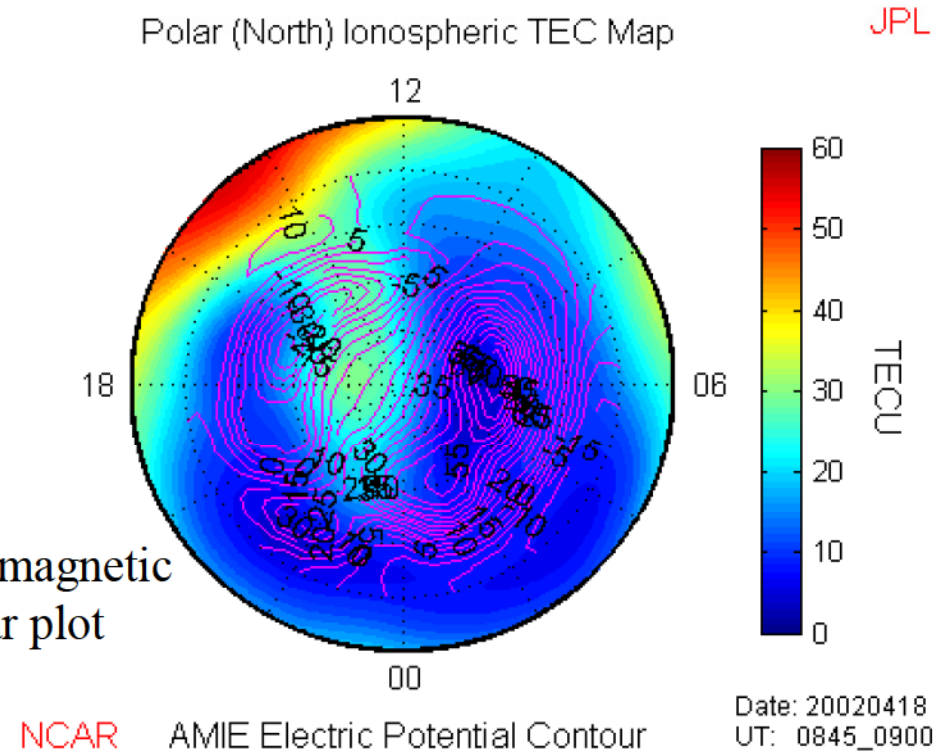


Examples of ROTI Measurements

Tongue of Ionization and Irregularities in the Polar Regions



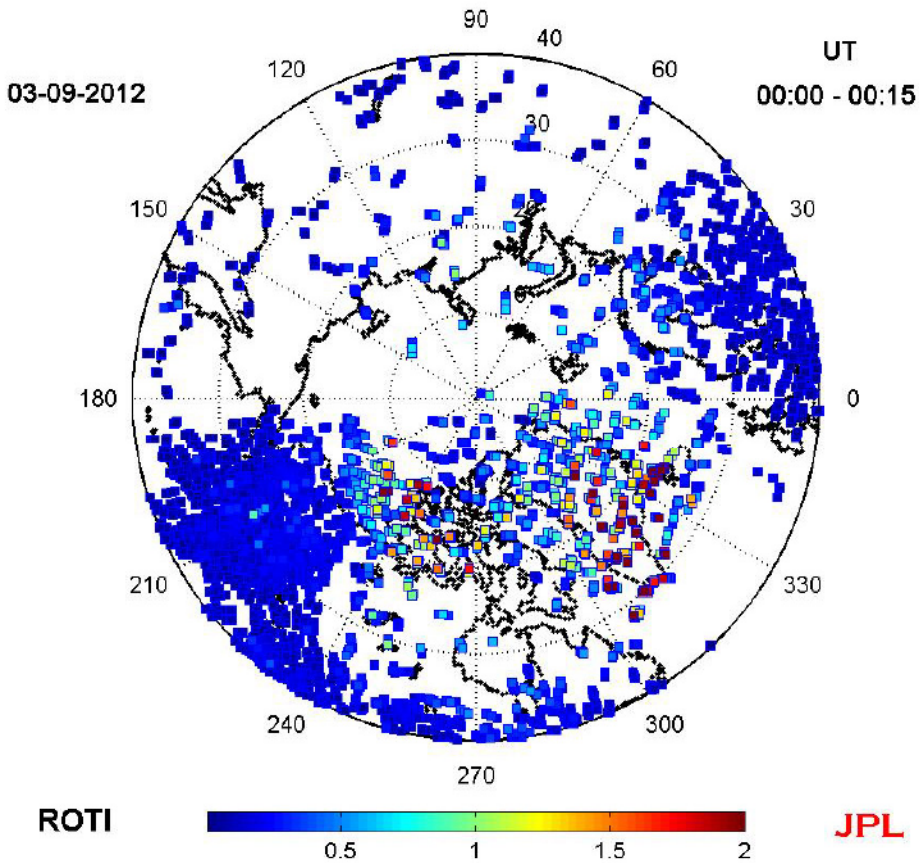
Geographic Polar plot



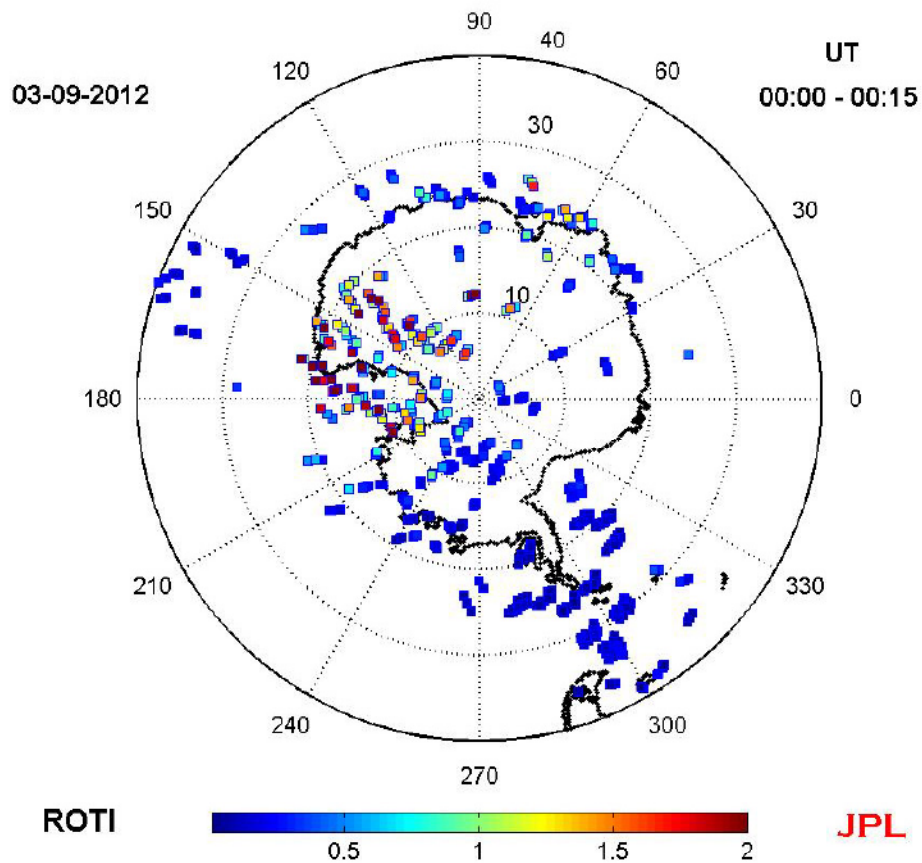
Geomagnetic Polar plot

- Tongue of ionization is formed due to high speed (~1 km/s) plasma convection.
- It pushes dayside plasma through the polar cap and into the nightside.
- High density plasma patches can be detached from the tongue, and scintillation can occur as a radio wave traverses the irregularities associated with the patches.

ROTI Polar Maps



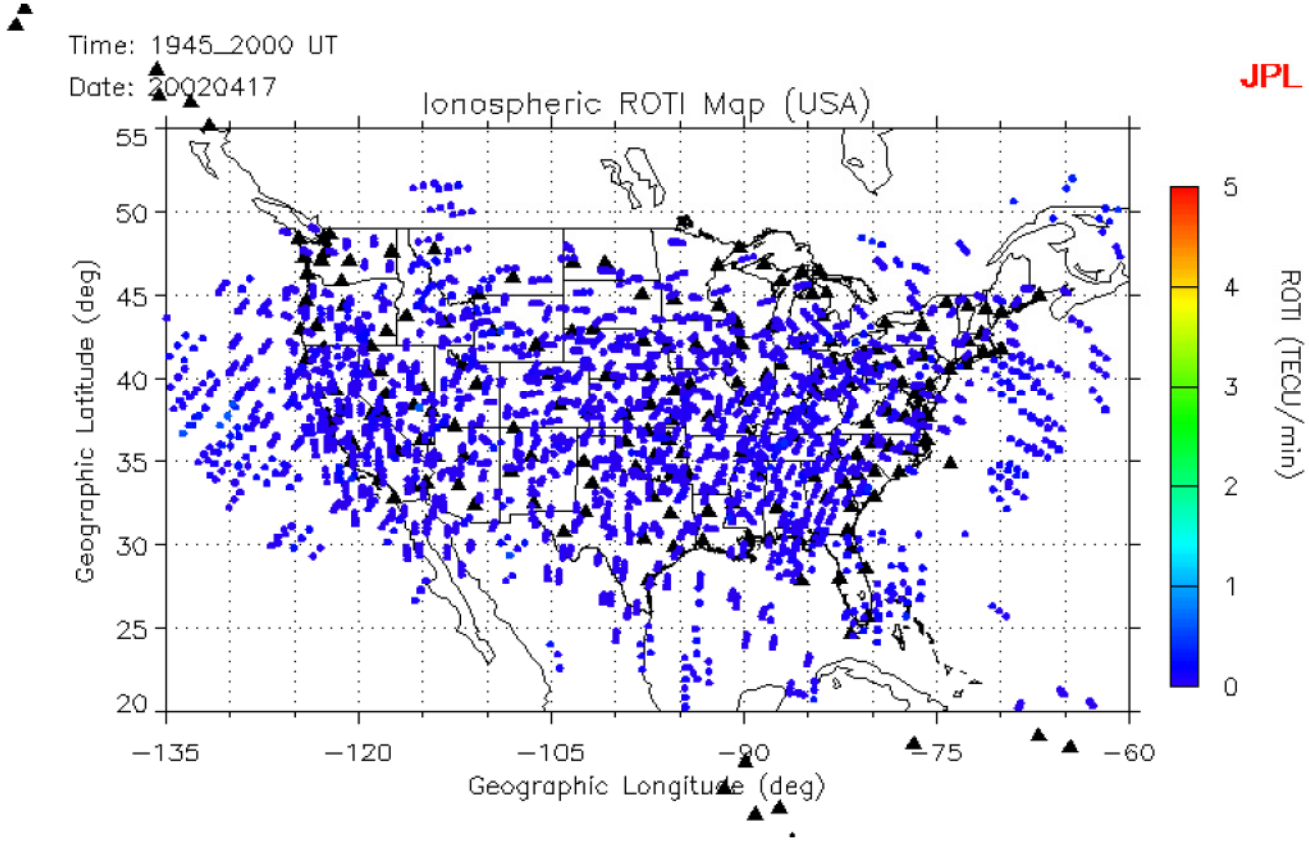
North



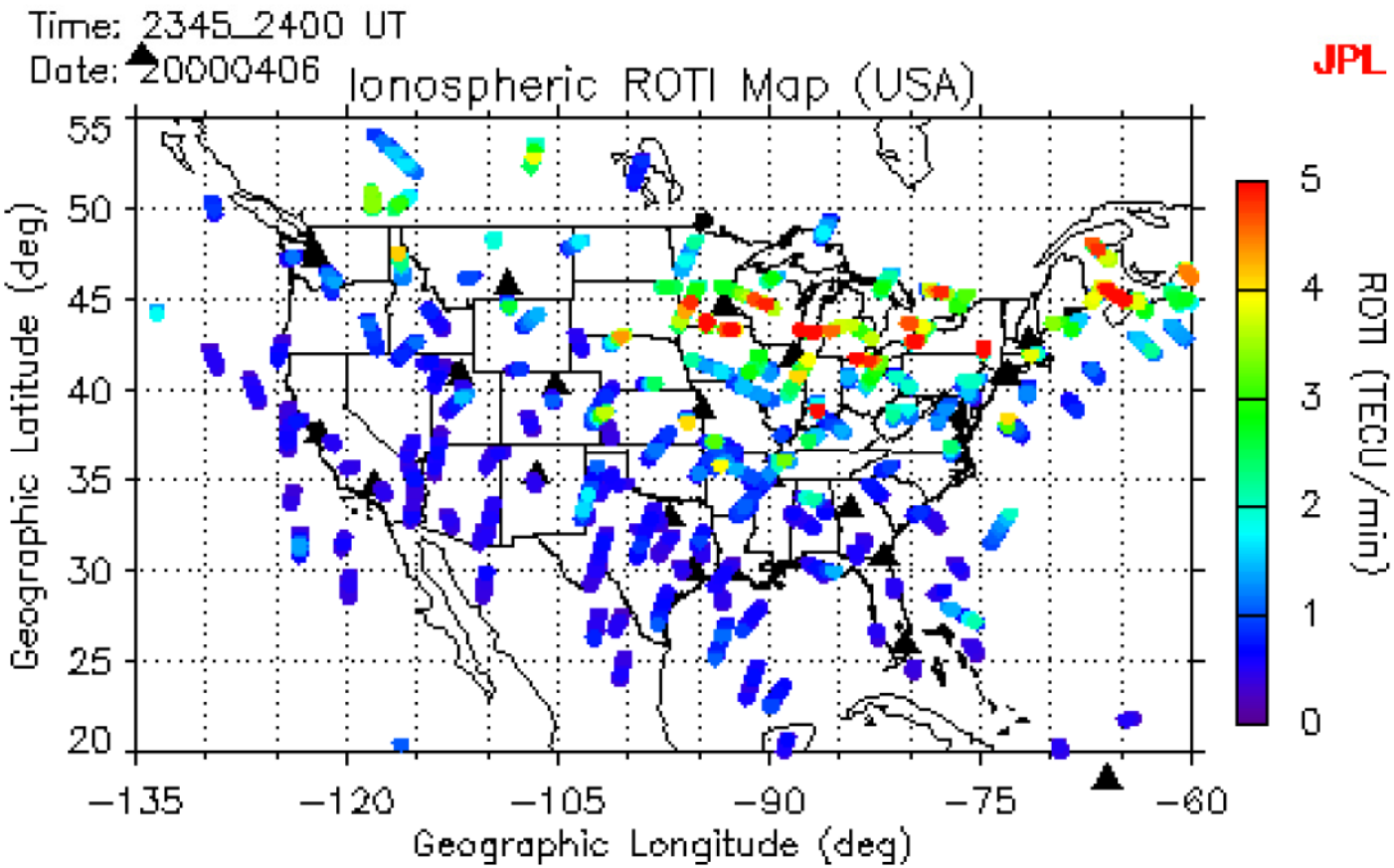
South

Measuring Ionospheric Irregularities Using the Ground-based CORS GPS Network

- Dual-frequency phase data enable the measurements of rate of TEC (ROT) and rate of TEC index (ROTI)
- Irregularity or ROTI maps can provide the needed information of space weather effects in the ionosphere



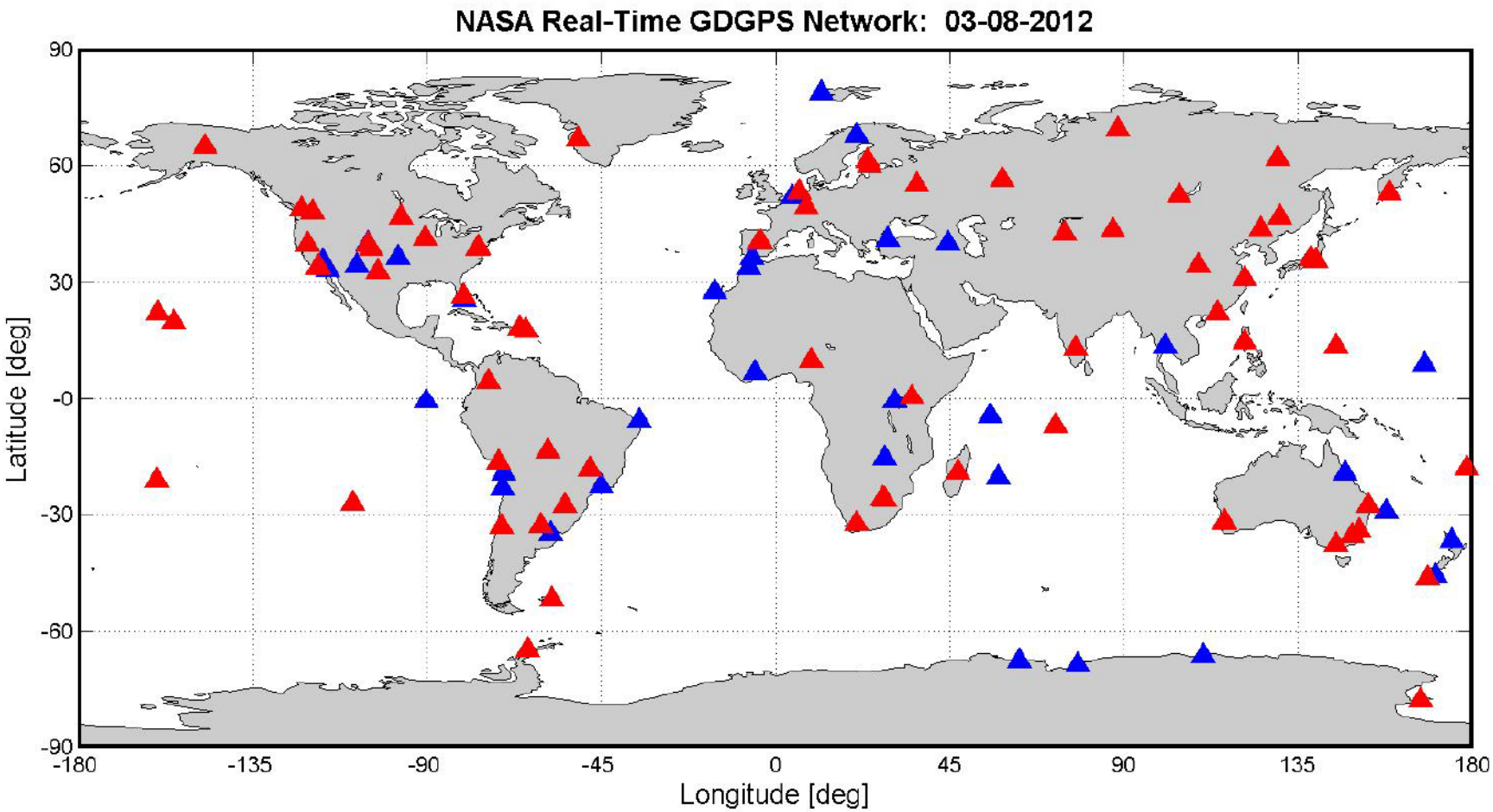
Ionospheric Irregularity Detectors



- **Rate of TEC Index –** A measure of ionospheric irregularities

Development Status and Plan

NASA Global Differential GPS Network



Δ NASA-JPL: 71 **Δ Contributed: 43** **(Total 114 stations)**

Global Differential GPS Network

www.gdgps.net

The largest global real-time tracking network

- 10 fold minimum redundancy
- 25 fold average redundancy
- All possible GPS observables
- 35 sites with atomic frequency standards (Rb, Cs, H-Maser)
- 4 National timing laboratories

Multiple data communications channels

- Redundant internet paths, frame relay

Triple redundant Operations Centers

- Geographic separation
- Fully independent
- Automatic fault detection and network rerouting

Multiple customer access options

- Internet, VPN
- Dedicated land lines
- Modem, Iridium
- TDRSS Augmentation Service (TASS) (S-Band)

Real-Time GDGPS System Augmentation and Applications

TDRSS Augmentation

- Space segment of GDGPS system
- Global S-band broadcast
- GDGPS differential corrections to enable precise autonomous positioning
- GPS integrity alarms

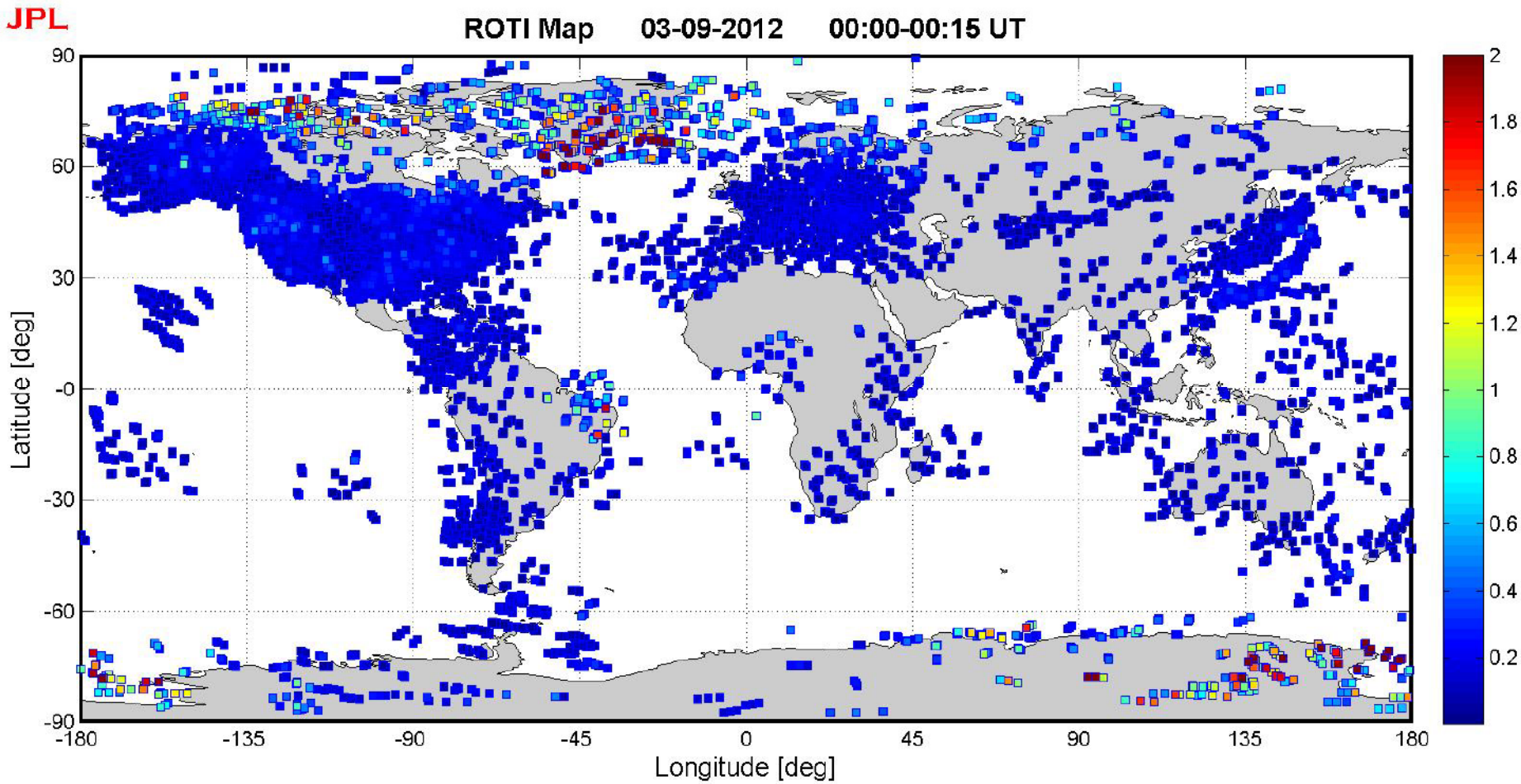
Navigation

- Orbit determination
- User positioning
- Timing

Ionospheric Specifications:

- Global ROTI maps (daily maps will be made available through the NASA Heliophysics Virtual Observatories and JPL web service)
- Global Assimilative Ionospheric Model (GAIM)
- Global TEC maps,

Will Be Available Soon



IGS + network