Ionospheric Research for WAAS

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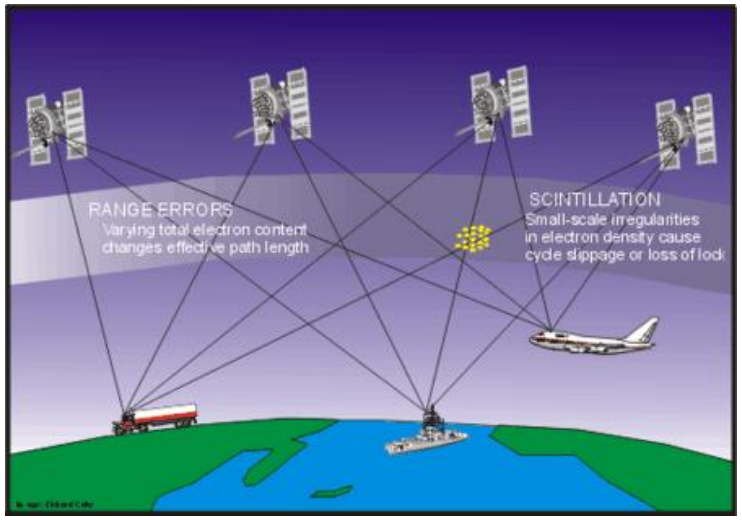
FEDERAL AVIATION ADMINISTRATION

ICAO

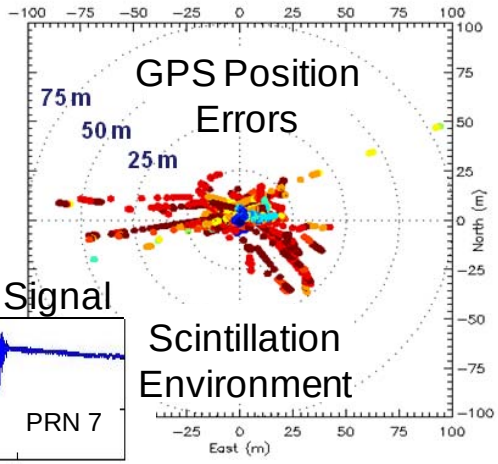
Tokyo, Japan

27 Feb 2012

Outline



- The Worldwide Ionosphere
- Past Research for WAAS
  - Geomagnetic Storms
  - Solar Radio Bursts
  - Scintillation
  - Equatorial Bubbles
- Current Research Efforts
  - Feasibility Studies of SBAS at Low-latitudes
  - Capabilities of Next Generation GNSS to Mitigate the Ionosphere
  - Monitoring Storm Effects on Upgraded WAAS
  - International Outreach
- SBAS Ionospheric Working Group
- Summary

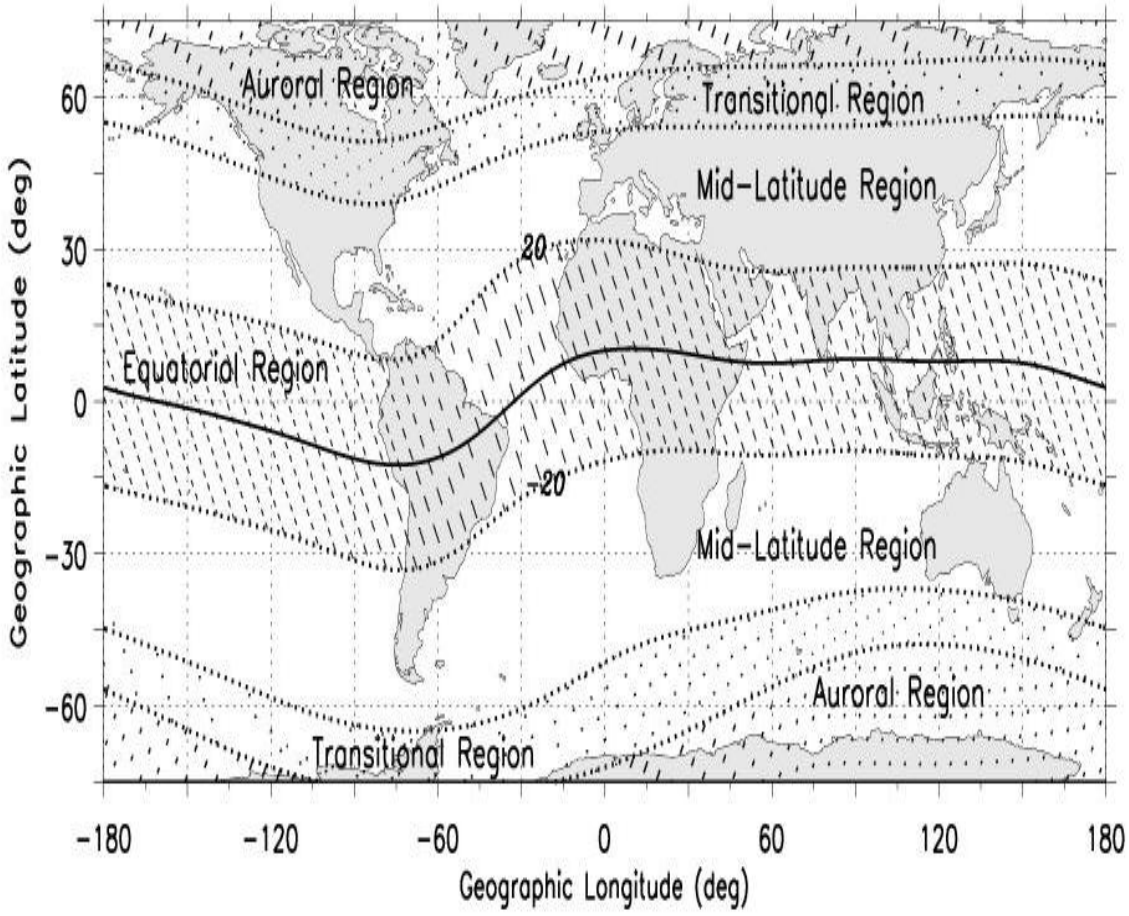


The Worldwide Ionosphere

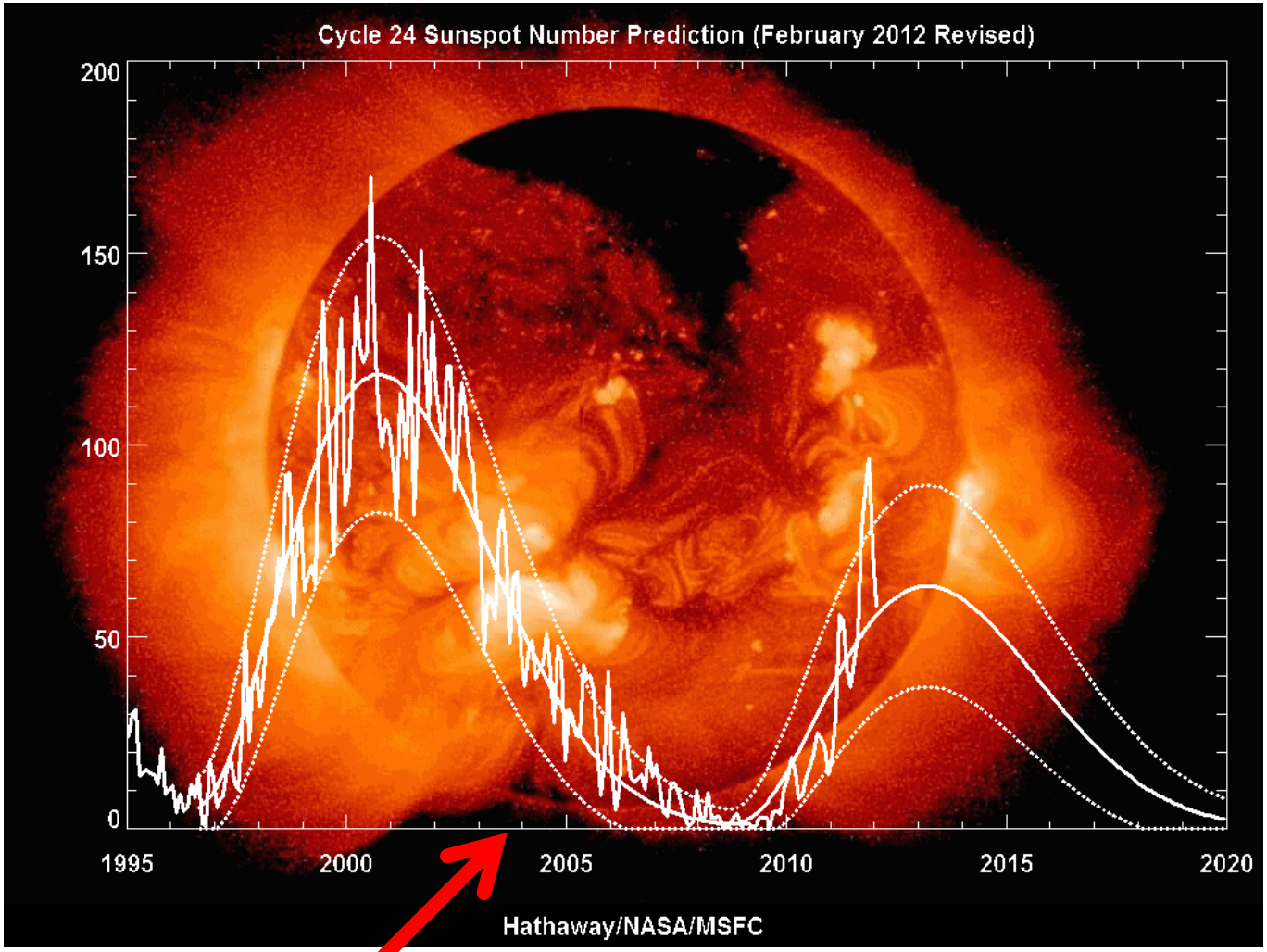
Equatorial Region: strongest effects; highest range errors and TEC; strongest TEC gradients; frequent scintillation and bubbles. Irregularities not correlated with magnetic activity

Mid-Latitude Region: normally quiescent but with strong gradients and evidence of scintillation during extreme levels of geomagnetic activity

Auroral Region: aurora and structures (blobs) are frequent but don't have a major effect on GPS signals. Phase scintillation can be problematic.



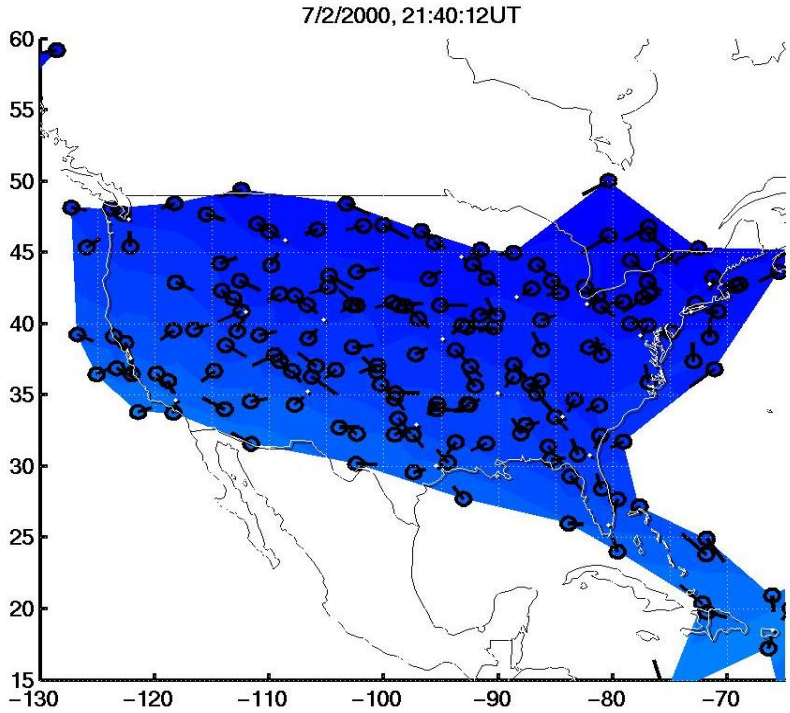
Solar Cycle 24

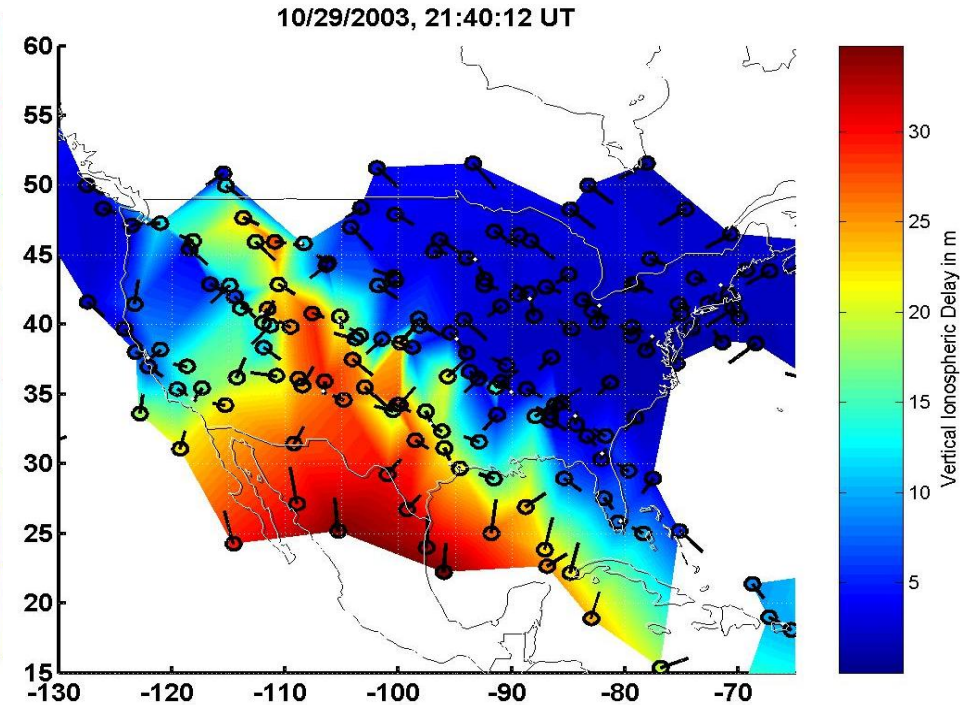


WAAS deemed operational in July 2003, 3 months before largest geomagnetic storms of SC23.

Quiet versus Disturbed Ionosphere

from WAAS Reference Station Measurements

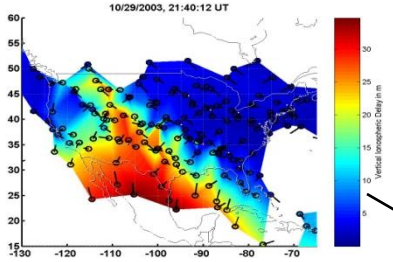


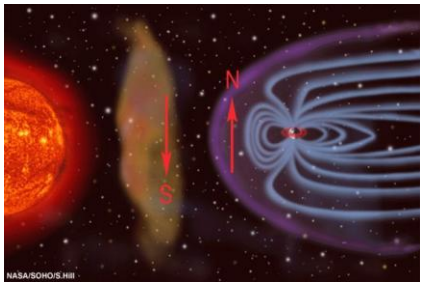


Results in loss of vertical guidance availability

Figures courtesy of Seebany Datta-Barua

WAAS LPV Availability Versus Magnetic Activity

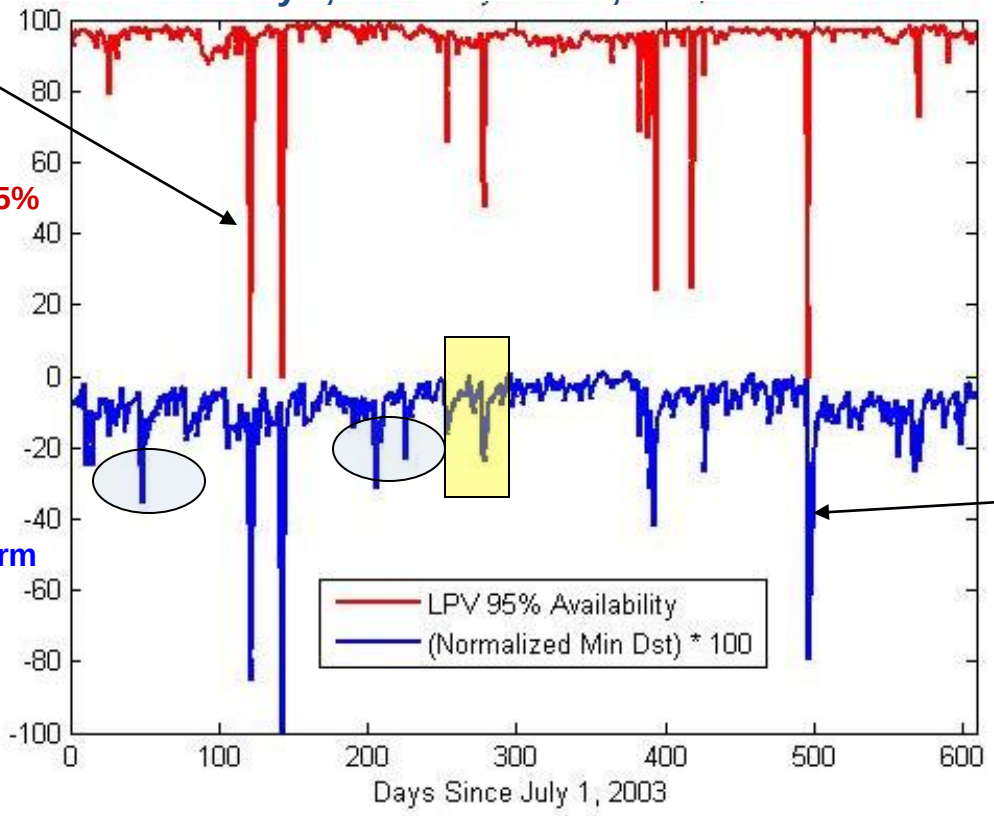




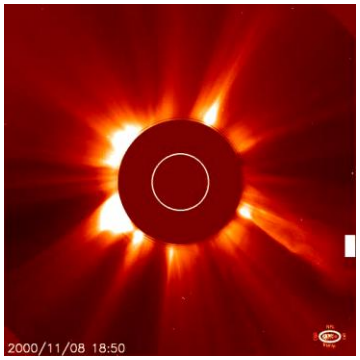
July 1, 2003 – March 1, 2005

% CONUS at 95% Availability

Magnetic Storm Index



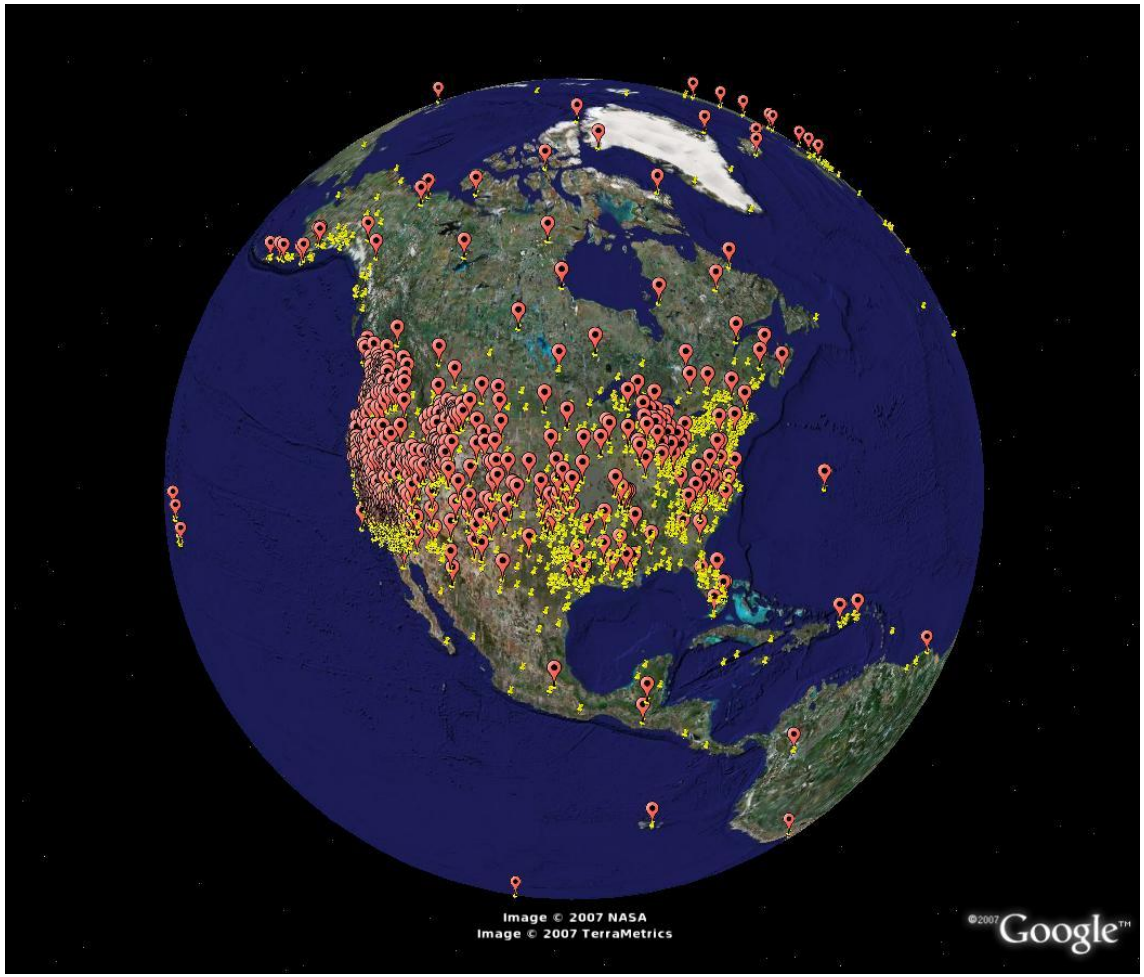
(Nov 8, 2004)



SOLAR RADIO BURSTS

December 6, 2006 – unprecedented solar radio burst caused large numbers of GPS receivers to fail.

- **All IGS and CORS Receivers**
- **Receivers impacted by the solar radio burst *(tracking fewer than 4 satellites for 6-10 minutes)***



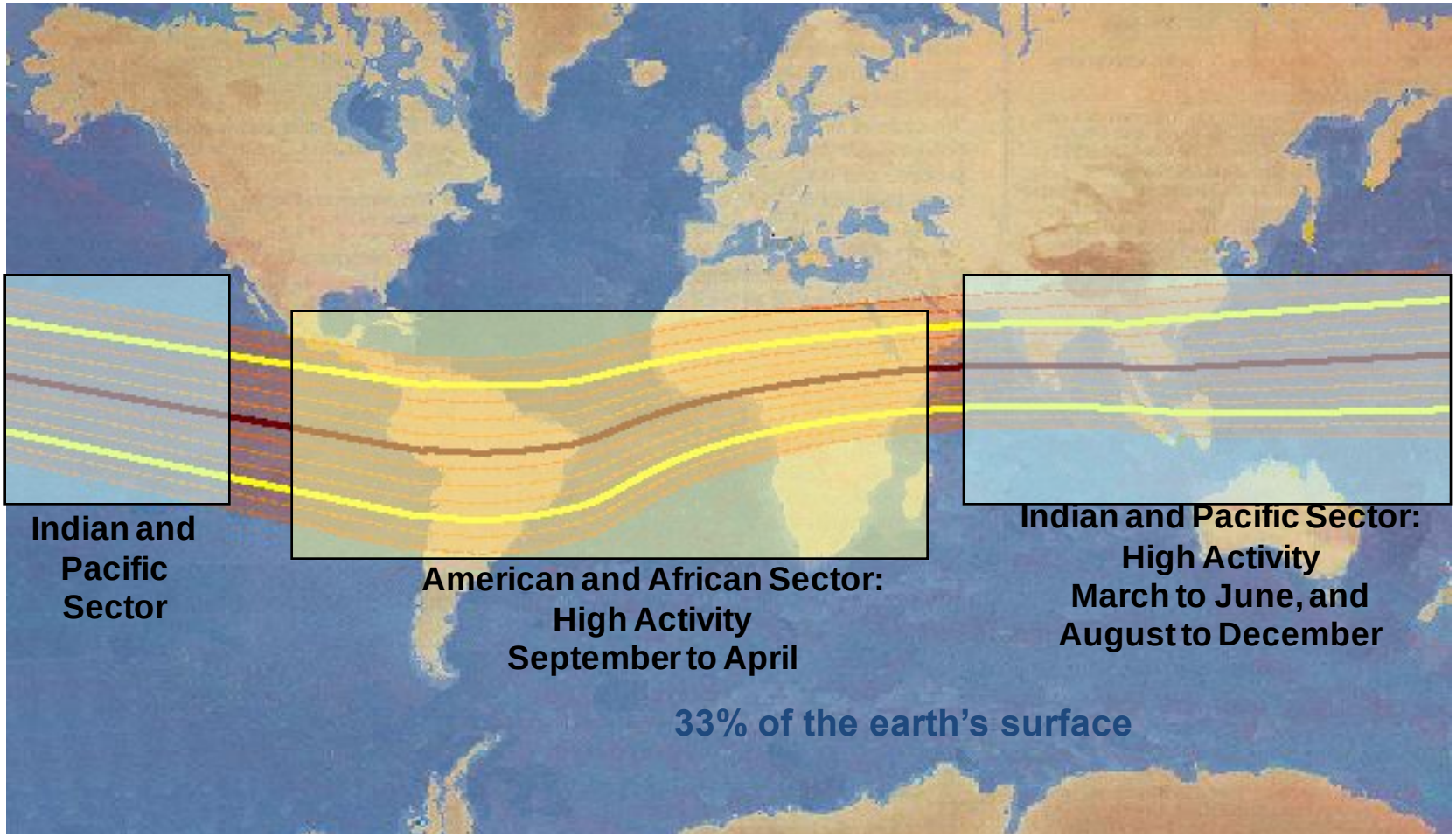
(Figure Courtesy of Anthea Coster)

Much to learn from this event:

- **Effects more profound than expected**
- **Solar Minimum Event**
- **Some Receivers minimally affected (WAAS)**

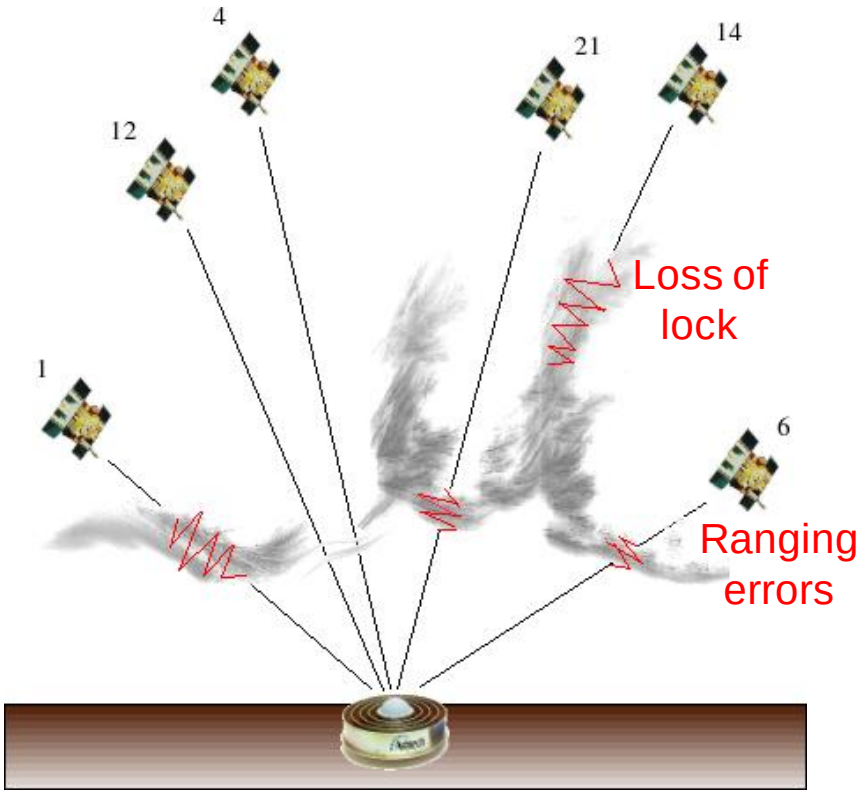
When & Where Scintillation Occurs

- Night time only (Mainly from 2000 to 0300 LT)
- During certain seasons
- Activity occurs frequently, even in the absence of magnetic storms

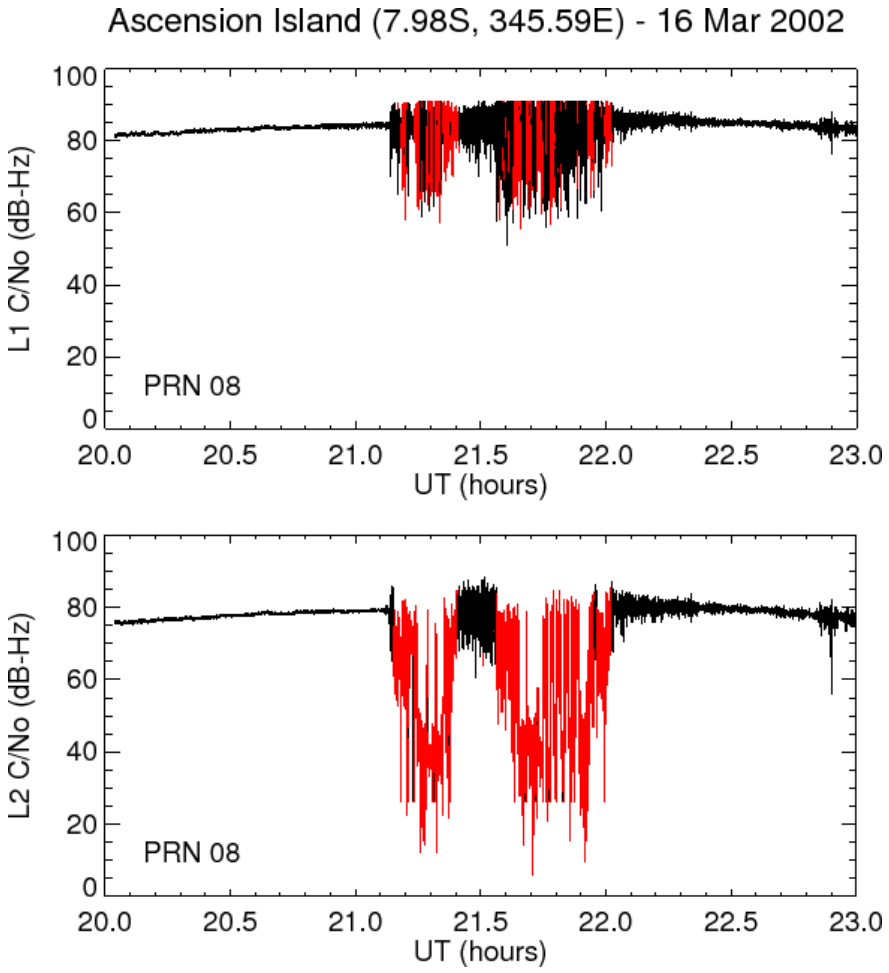


Scintillation and Impacts on GPS

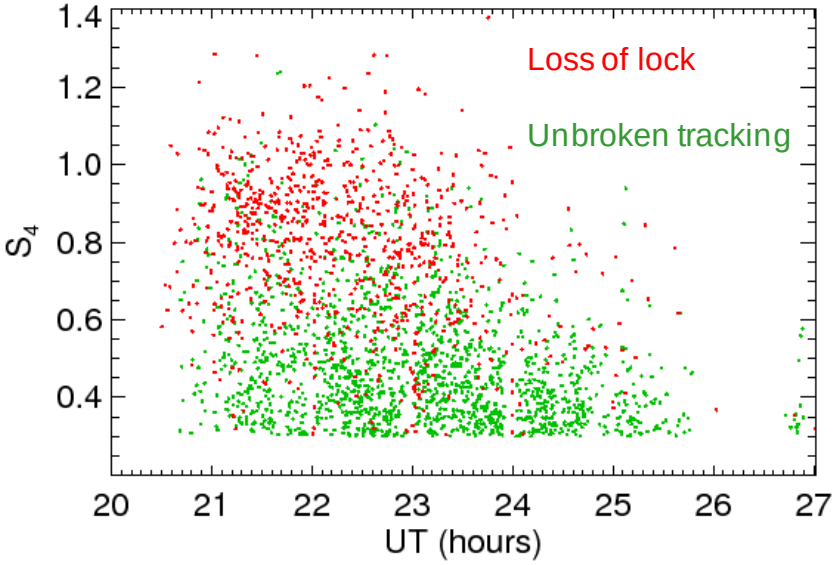
Schematic of impacts on GPS

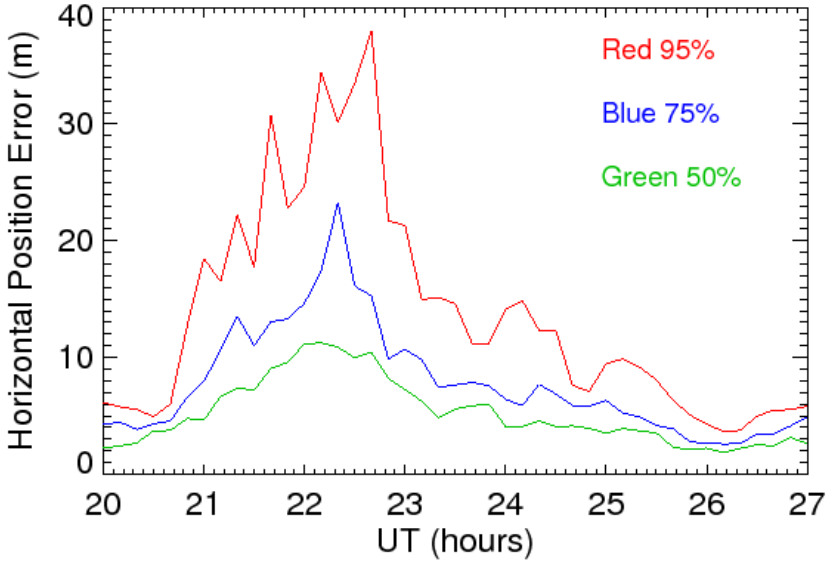


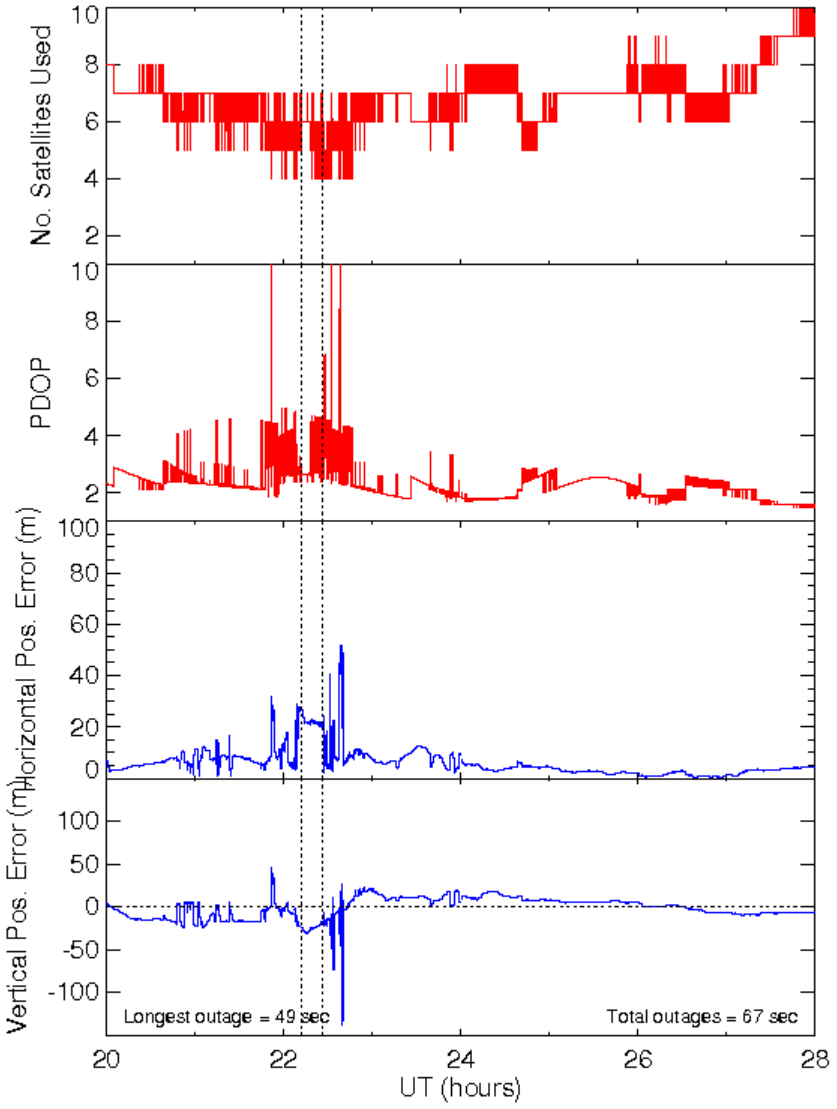
Scintillation during previous Solar Max



Positioning Accuracy during Scintillation







Plasma Depletions (Bubbles)

Slant Delay from Rio and Rio-West (~90km apart)/PRN 11

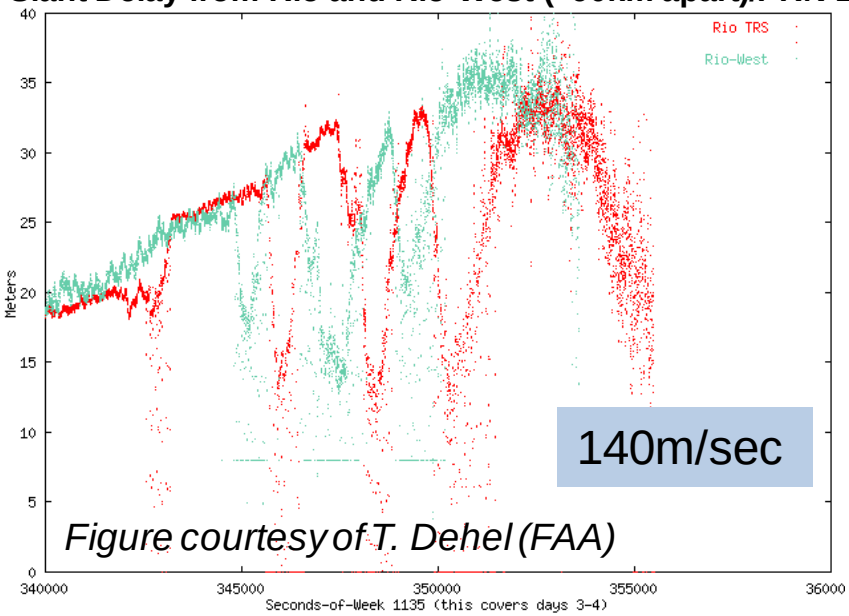


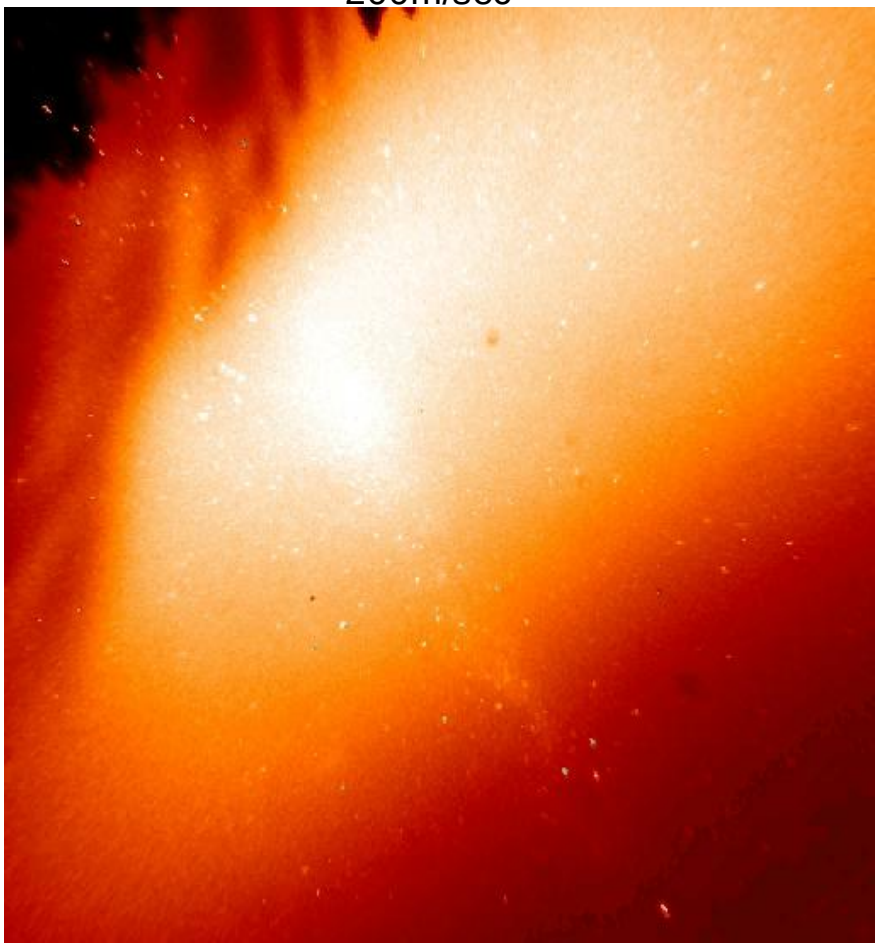
Figure courtesy of T. Dehel (FAA)

- Post-sunset feature
- Drifts east to west
- Size and frequency vary by season, location and solar activity levels
- Irregularities within a bubble induce scintillation

All-Sky Imager at Cachoeira Paulista

~ 21:00 TO 01:00 LT MARCH 18, 1999

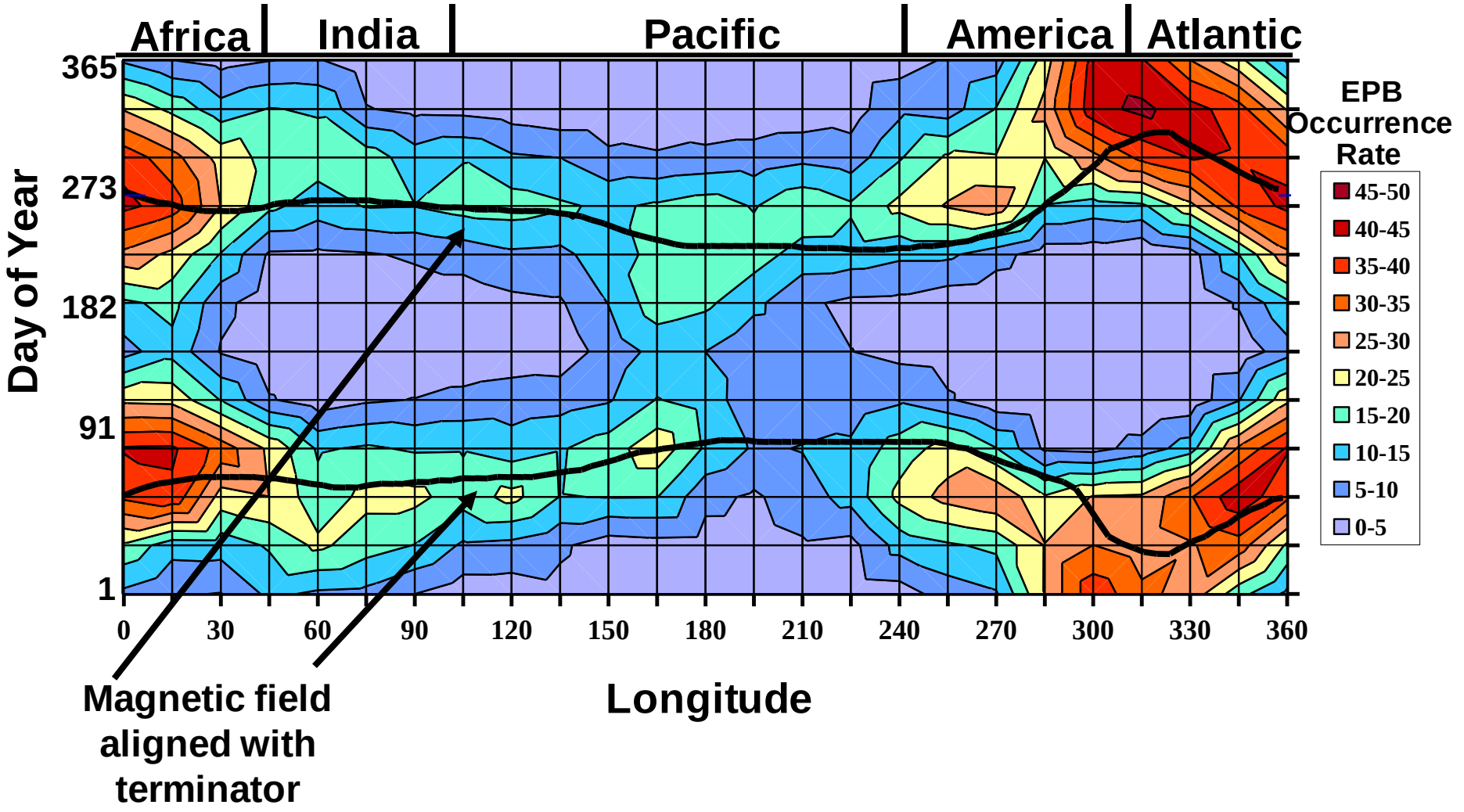
200m/sec



1200km x 1200km, at 250 km altitude over Cachoeira Paulista (-17.32 dip latitude)

Figure courtesy of E. De Paula (INPE)

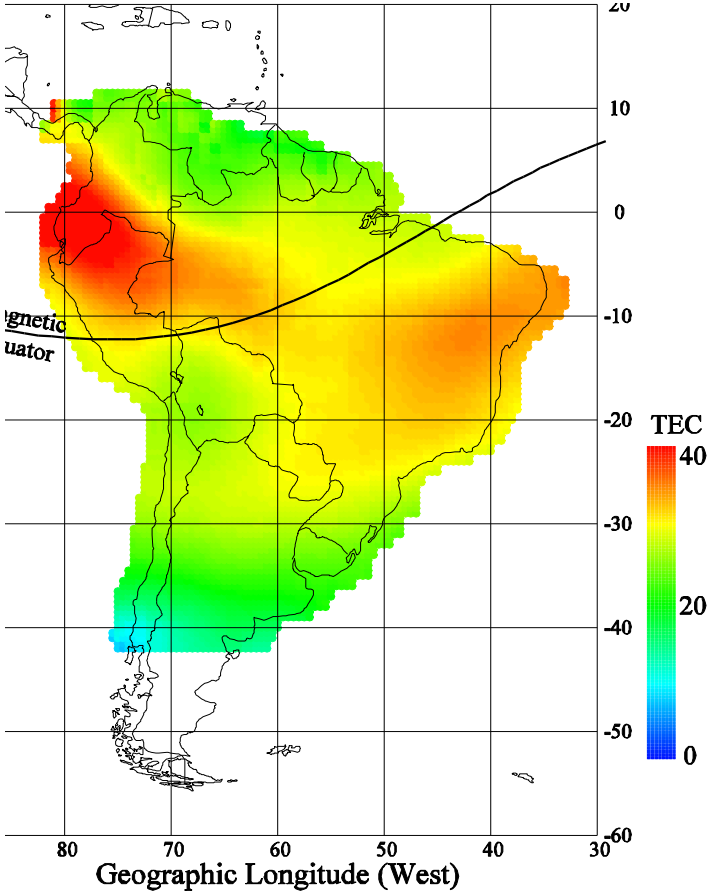
DMSP Bubbles 1989 - 2002



From Burke & Huang, 2004

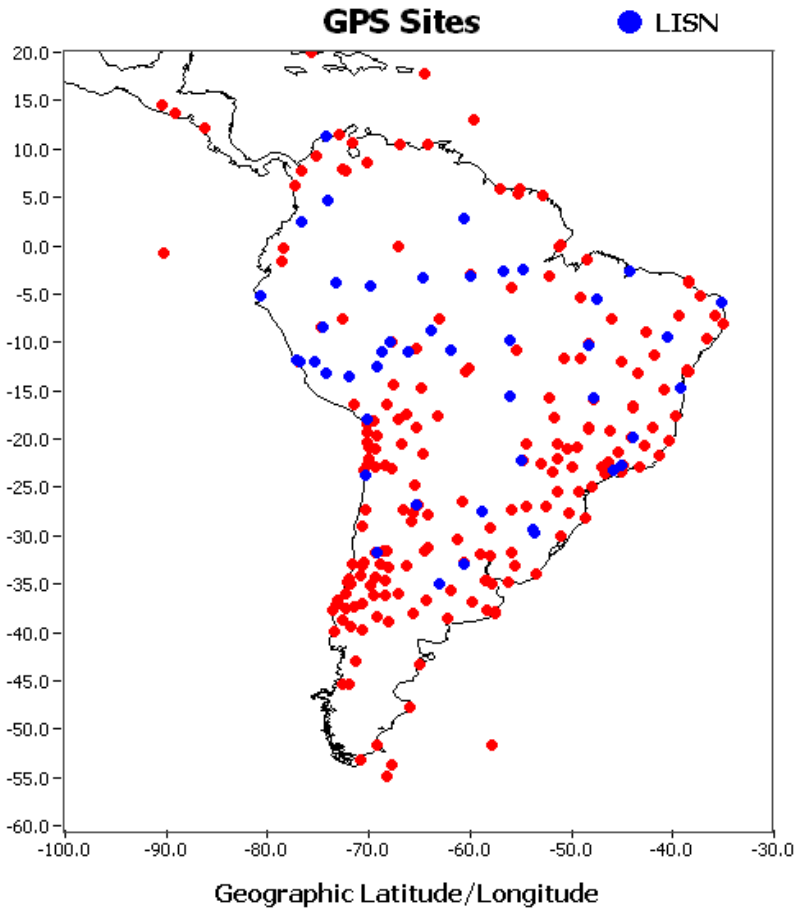
Current and Planned Studies

- Focus is on Next Generation of GNSS, Modernized signals and multiple systems will help mitigate ionospheric effects
  - Deploying numerous receivers to Brazil for 6 months – fall 2012
  - Estimating correlation of scintillation on multiple frequencies
  - Considering benefits of multiple GNSS systems
- Range Delay
  - Continuing to monitor geomagnetic storm effects on WAAS
- International Outreach
  - South America and Africa



Current Studies at Low-Latitudes
The Low Latitude Ionospheric Sensor Network (LISN)

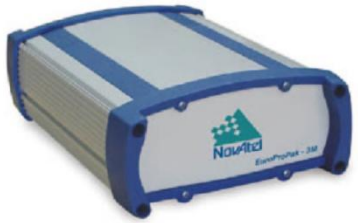
LISN GPS Network
& 3 more Networks



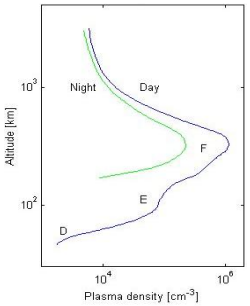
•To address key questions about the physics of the equatorial ionosphere

•Develop nowcast/forecasts capabilities on the onset of Spread F

- **200 GPS Receivers**
  - TEC, TIDs
  - Scintillation (~50)

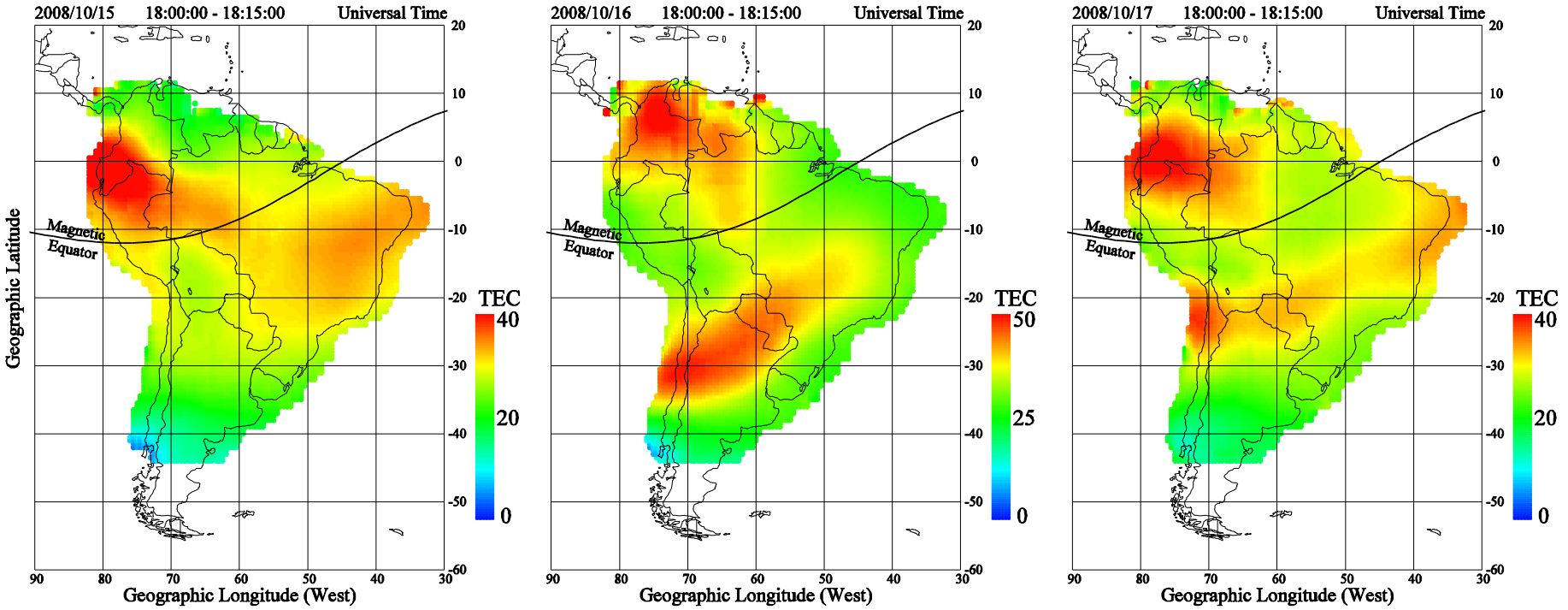


- **5 Ionosondes**
  - Virtual height
  - Bottomside density profiles
  - Meridional winds
  - Nighttime capability

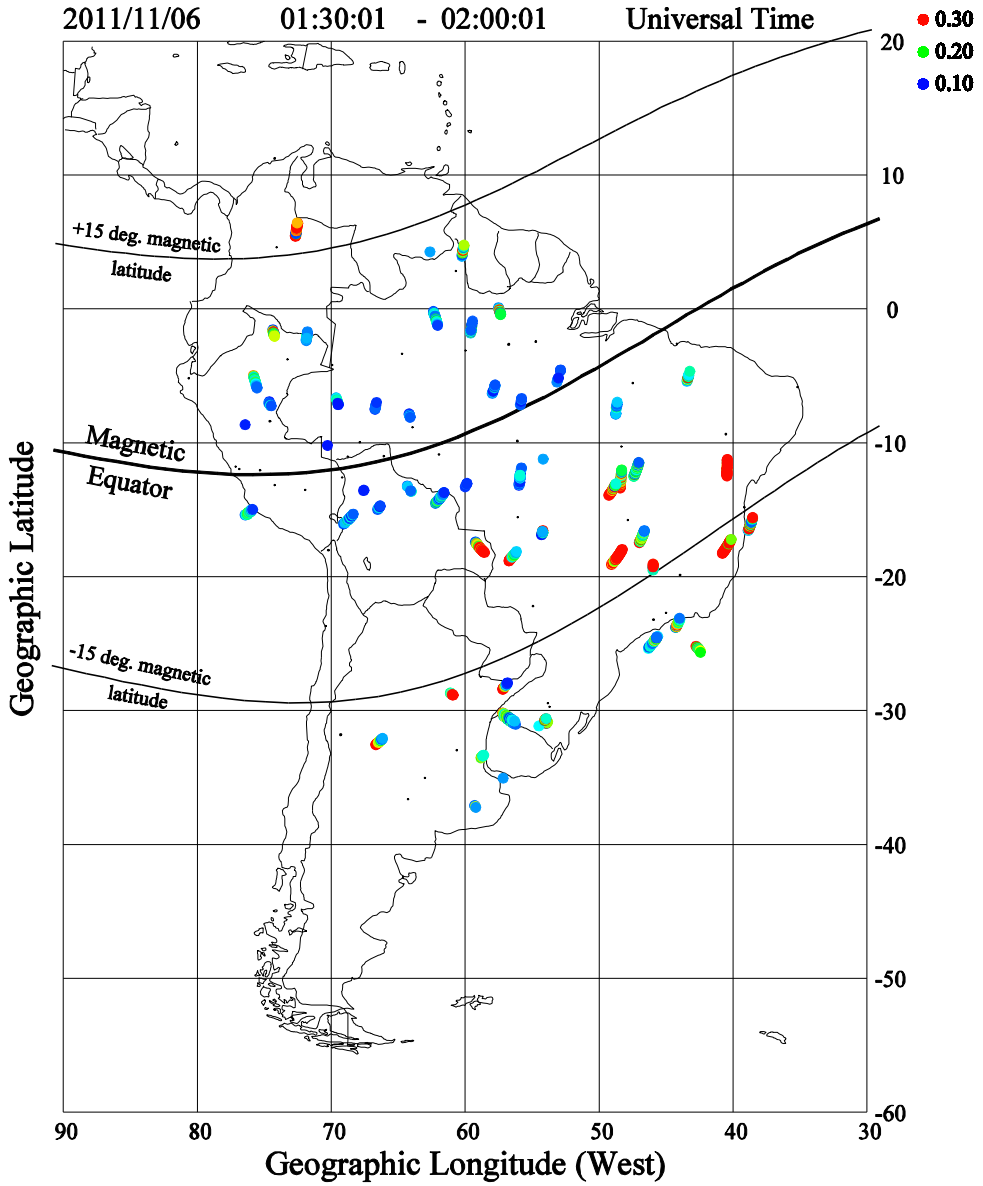


- **5 Magnetometers**
  - Monitor ionospheric currents
  - Measure Vertical plasma drifts

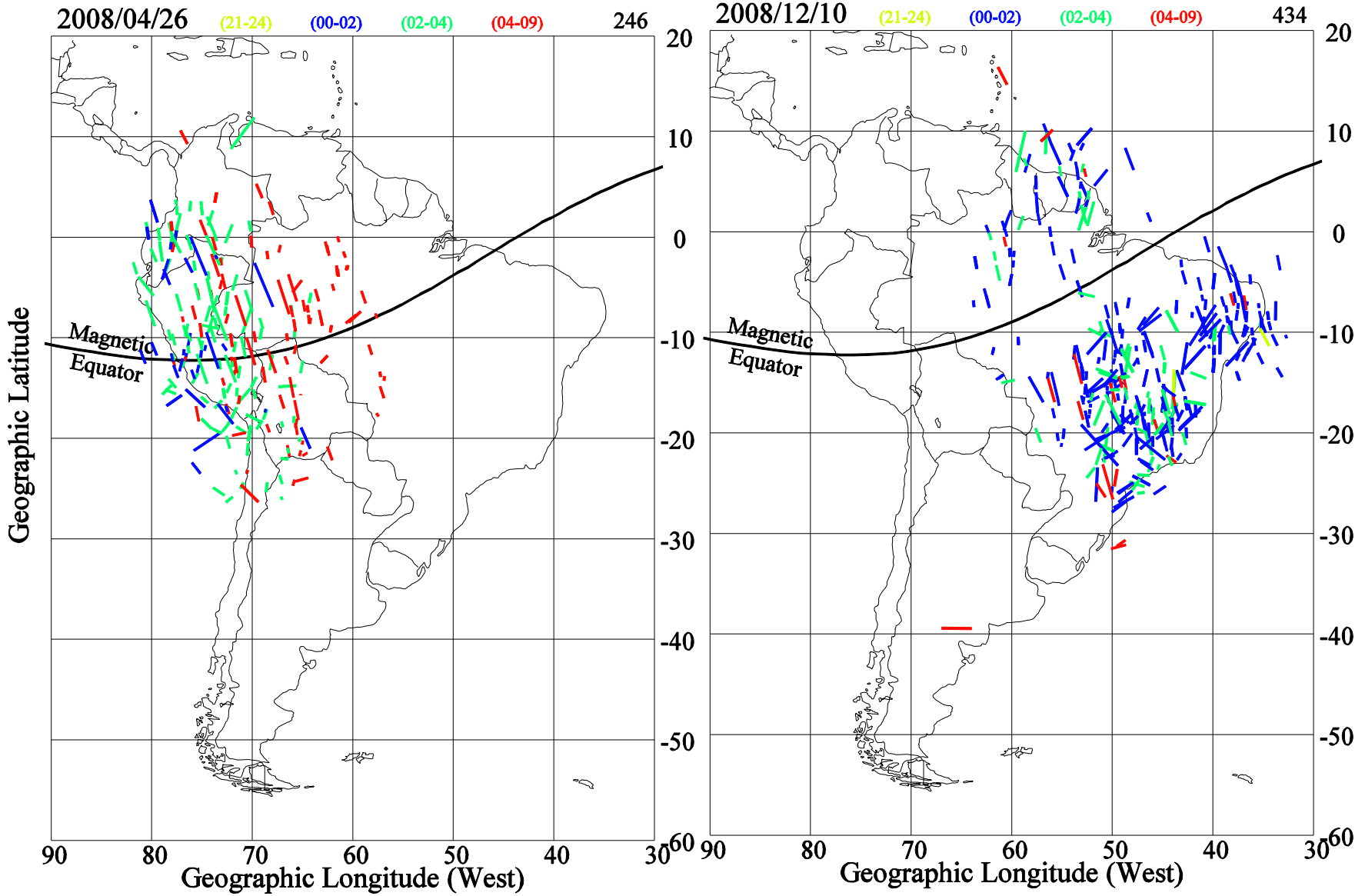
Current Studies with LISN
TEC values observed on 3 consecutive days
Oct 15-17, 2008 at same local time (2 PM at 60 W)



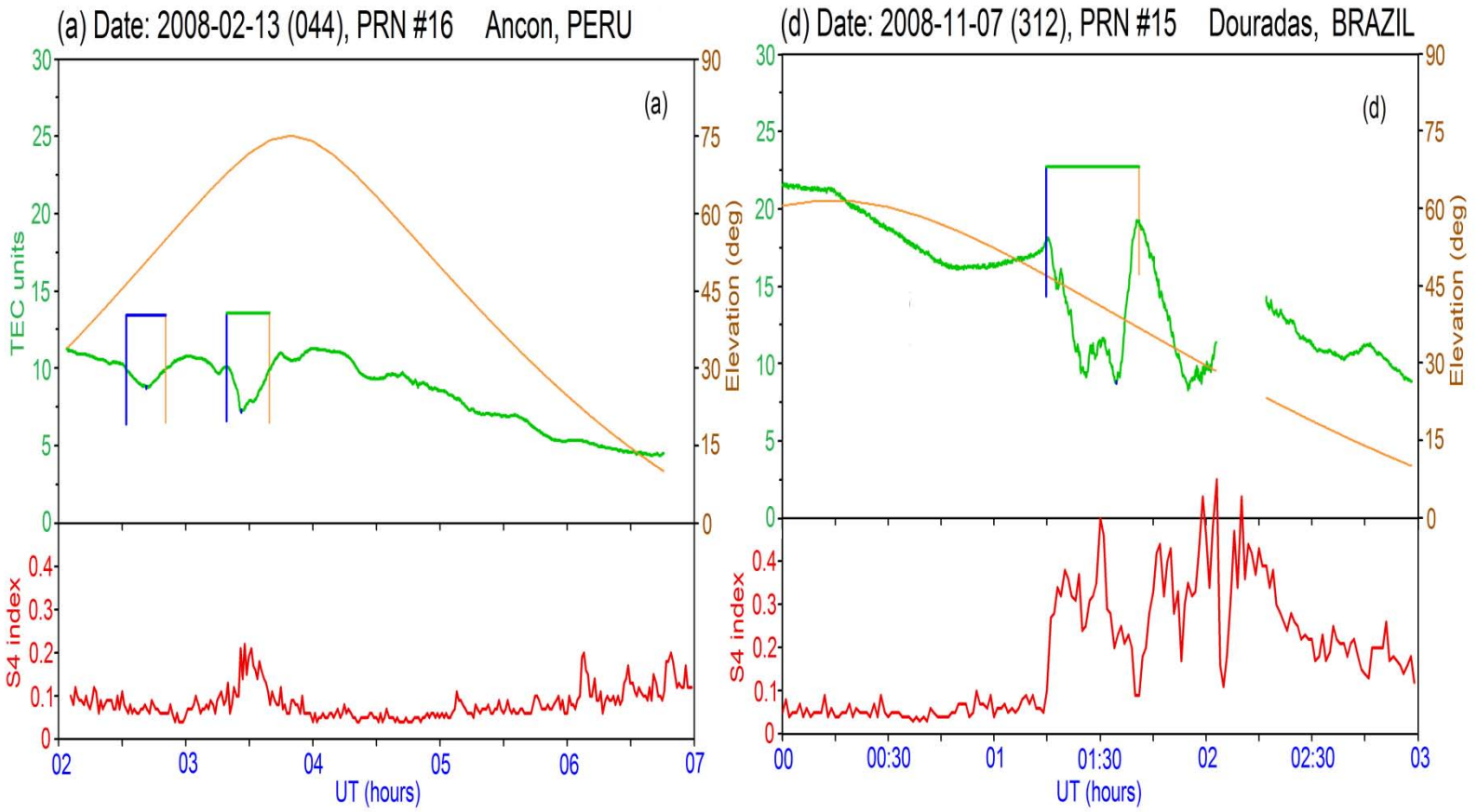
Current Measurements from LISN
Real-Time Scintillations Nov 6, 2011



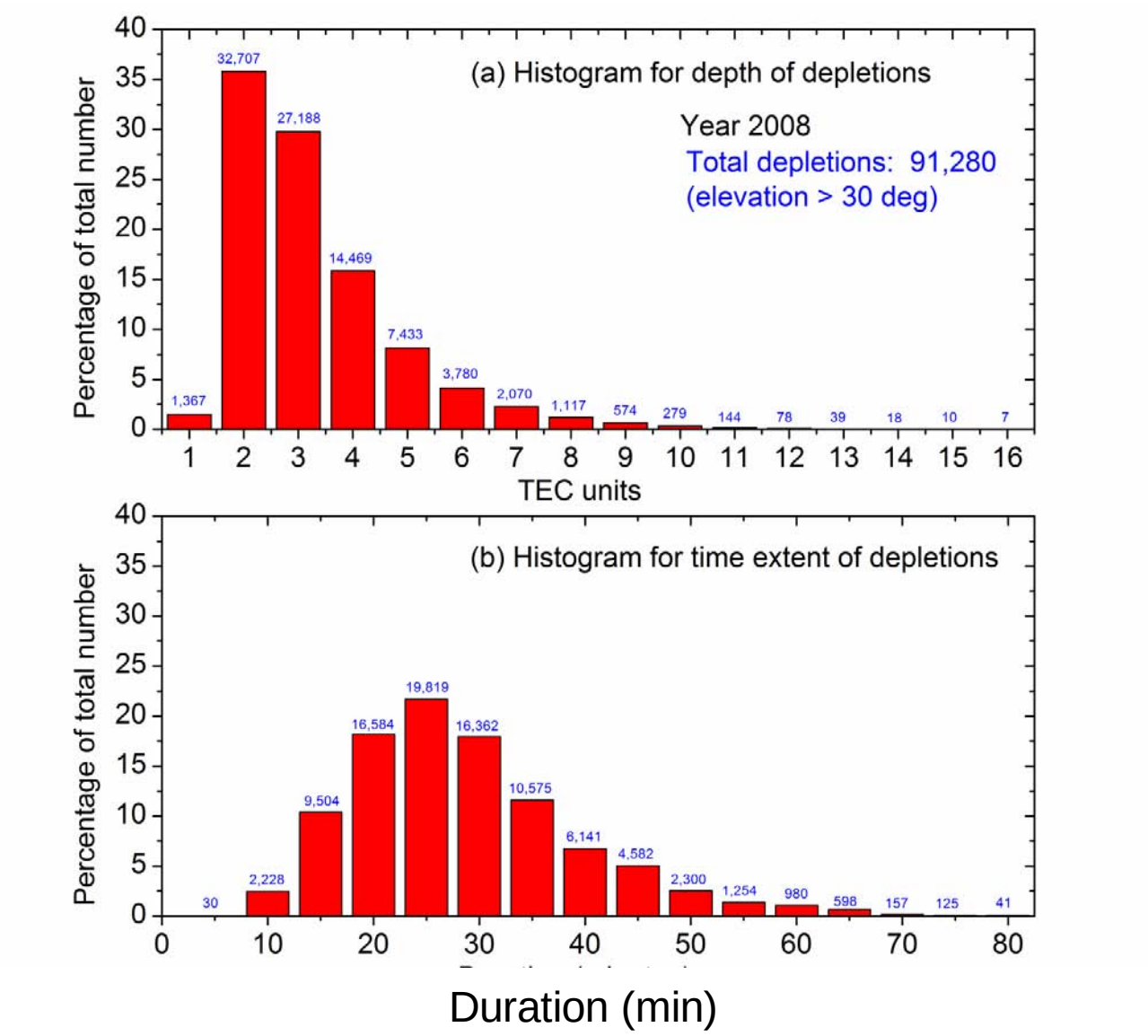
Current Studies with LISN
Seasonal Variability of TEC Depletions



Current Studies with LISN
TEC Depletions and Scintillation



Depth and Duration of Depletions (2008)



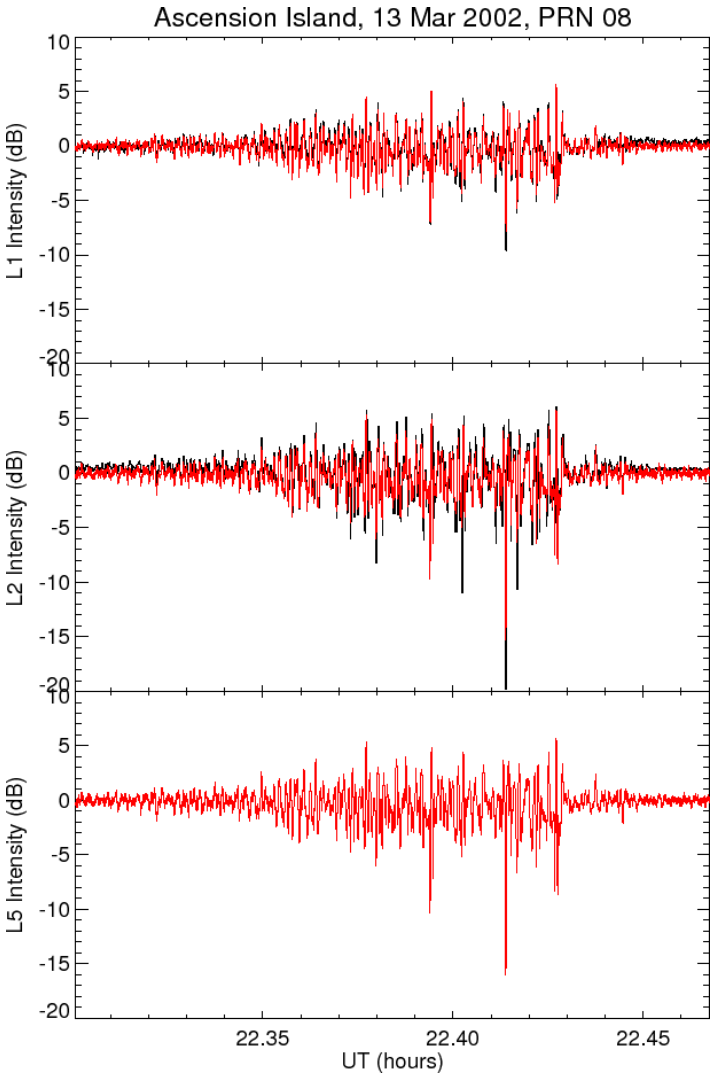
Current Scintillation Efforts

(*correlation of effects on L1, L2 and L5)*

Simulating scintillation effects on L5 using measurements from last solar peak at Ascension Island.

Early results indicate that weak scintillation is highly correlated between L1, L2 and L5. More intense effects appear to be less correlated.

More to come…



(C. Carrano and K. Groves, BC)

The SBAS Ionospheric Working Group

PURPOSE OF THE GROUP

- Open a direct channel of communication between the ionospheric experts involved in SBAS systems
- Transfer knowledge to other SBASs to ensure their rapid and safe development
- Exchange data
- Define the ionospheric threats in various regions of the world
- Define methods to mitigate the ionospheric threats
- Report to the IWG

- Please consider participating in the next meeting!
- Next meeting in April 20-21, 2012 in Trieste, Italy

Thanks for your attention.

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