



Observing the Ionosphere Remotely



U.S. Department of Transportation
Research and Innovative Technology Administration

**GNSS Network Observation of
Ionospheric Structure and
Disturbances**

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**ICAO GNSS Atmospheric Effects
Seminar
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Overview

- ❑ Ionospheric Study Groups
- ❑ Overview of the Ionosphere
- ❑ Effects of Ionosphere on L-band Signals
- ❑ GNSS Ionospheric Observables
- ❑ Ionospheric Structure and Detail
- ❑ Low Latitude Ionospheric Networks
- ❑ Detecting, Correcting, Bounding
- ❑ Summary & Very Recent Developments

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Ionospheric Research Community

- ❑ URSI International Beacon Satellite Working Group
 - Triennial symposia academia, industry, and government (<http://www.bc.edu/sites/beacon/>)
 - 35+ year history of ionospheric data collection & analysis
- ❑ International SBAS Ionospheric Working Group
 - International cooperation from Europe, Japan, India, US
 - Extensive analysis from GNSS—GPS, WAAS, MSAS, GAGAN, and EGNOS—systems including solar max 2000
- ❑ Ionospheric Effects Symposium (www.ies2008.com)
- ❑ Instituto Nacional de Pesquisas Espaciais (INPE)
 - South American contributors to ionospheric community
 - Coordination with both organizations above since 2002

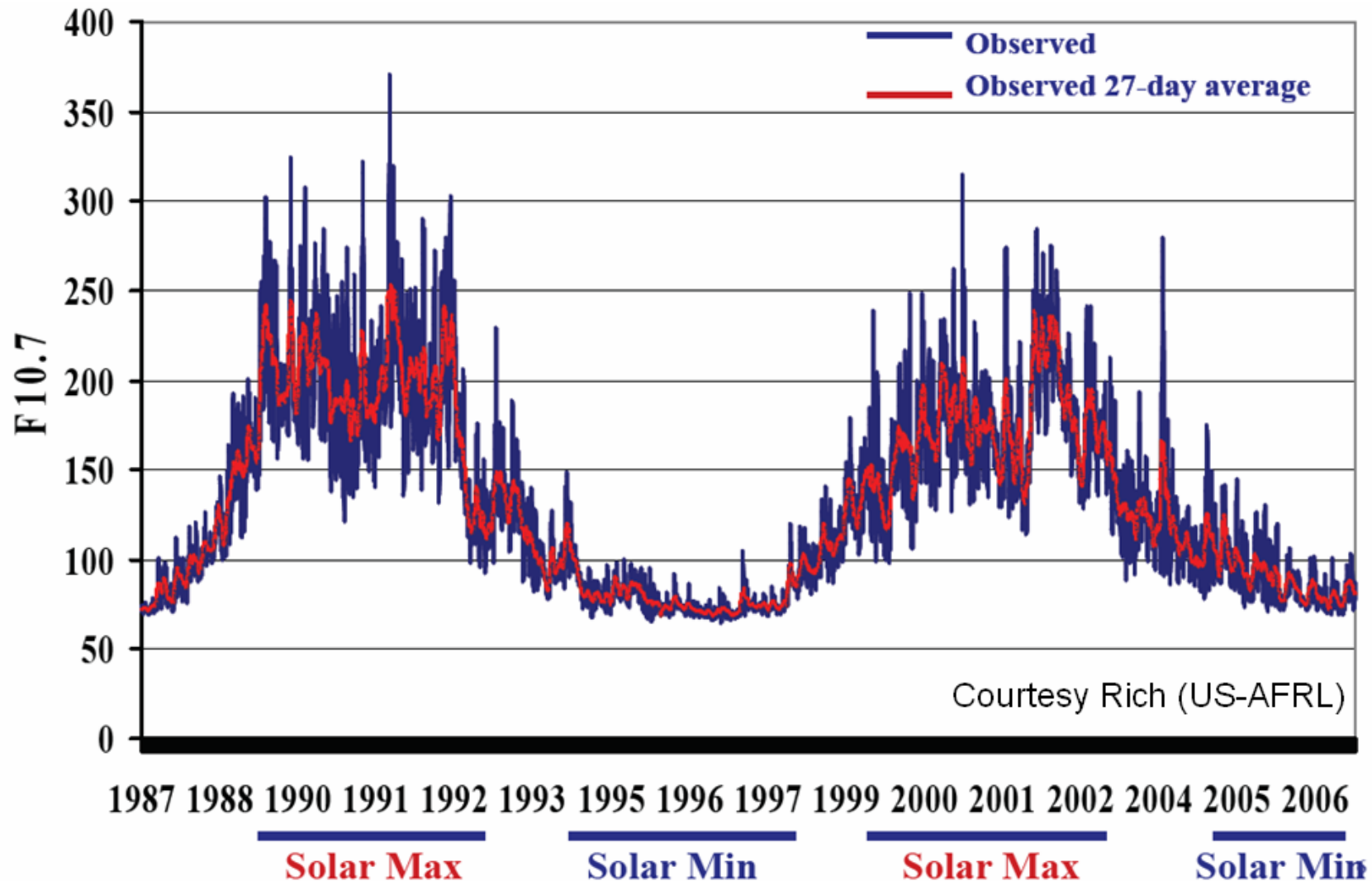
CAR/SAM Ionospheric Efforts

- ❑ Ionospheric Working Group Under ICAO RLA/00/009
 - Initial focus on Brazil Test Bed (BTB) reference network
 - ✓ CAR/SAM analog of the US National Satellite Test Bed
 - ✓ Remote GPS reference stations (5) connected to a central storage and processing facility
 - ✓ Membership primarily DECEA, US-FAA-Tech Center, INPE
 - Objectives defined with respect to ionospheric challenges
 - ✓ Ionospheric irregularities and features
 - ✓ Equatorial anomaly
 - ✓ Scintillation in L-band
 - Operational scenarios were split across levels of service
 - ✓ SBAS, GBAS, second civil frequency for aviation
 - ✓ Initial priorities established in 2002
- ❑ Underlying goal was to collect ionospheric observations

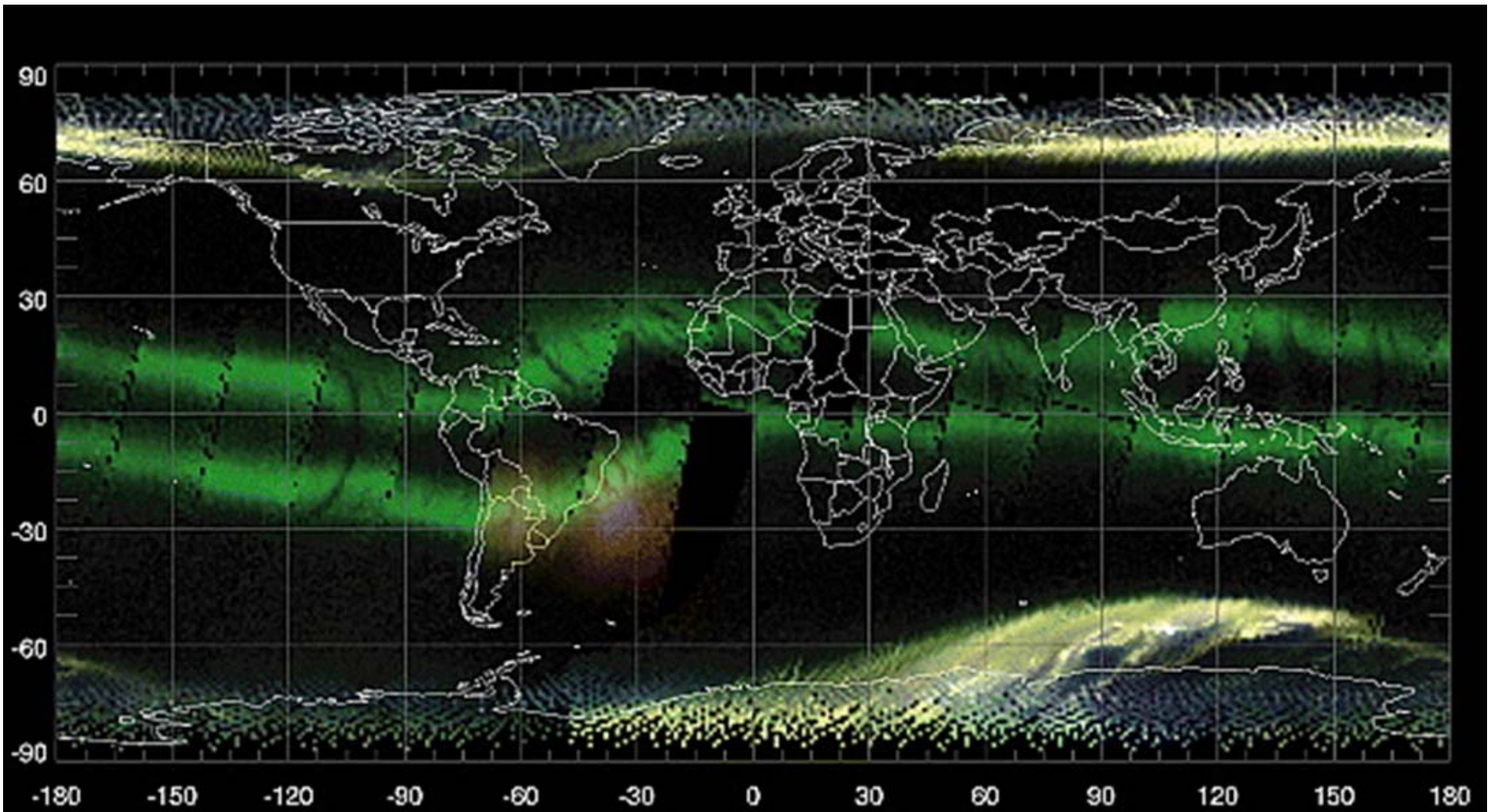
CAR/SAM Ionospheric Efforts (Cont.)

- ❑ Determination made in 2005 that SBAS operational goals were not feasible in CAR/SAM region
 - BTB data collection continued (sporadic)
 - Operation focus shifted to A/GBAS solutions for aviation
- ❑ ABAS navigation in CAR/SAM region (ICAO Annex 10)
 - GPMS program to meet Annex 10 GPS monitoring requirement for En route and NPA levels of service
 - Development phase delivered in May 2006 extending BTB reference network with 4 additional reference stations
- ❑ GBAS ionospheric effort in CAR/SAM region
 - LAAS Test Prototype (LTP) single frequency systems were installed at Rio de Janeiro and surrounding areas
 - CAR/SAM effort in parallel with US FAA LAAS/GBAS development, primarily gradients, secondarily scintillation

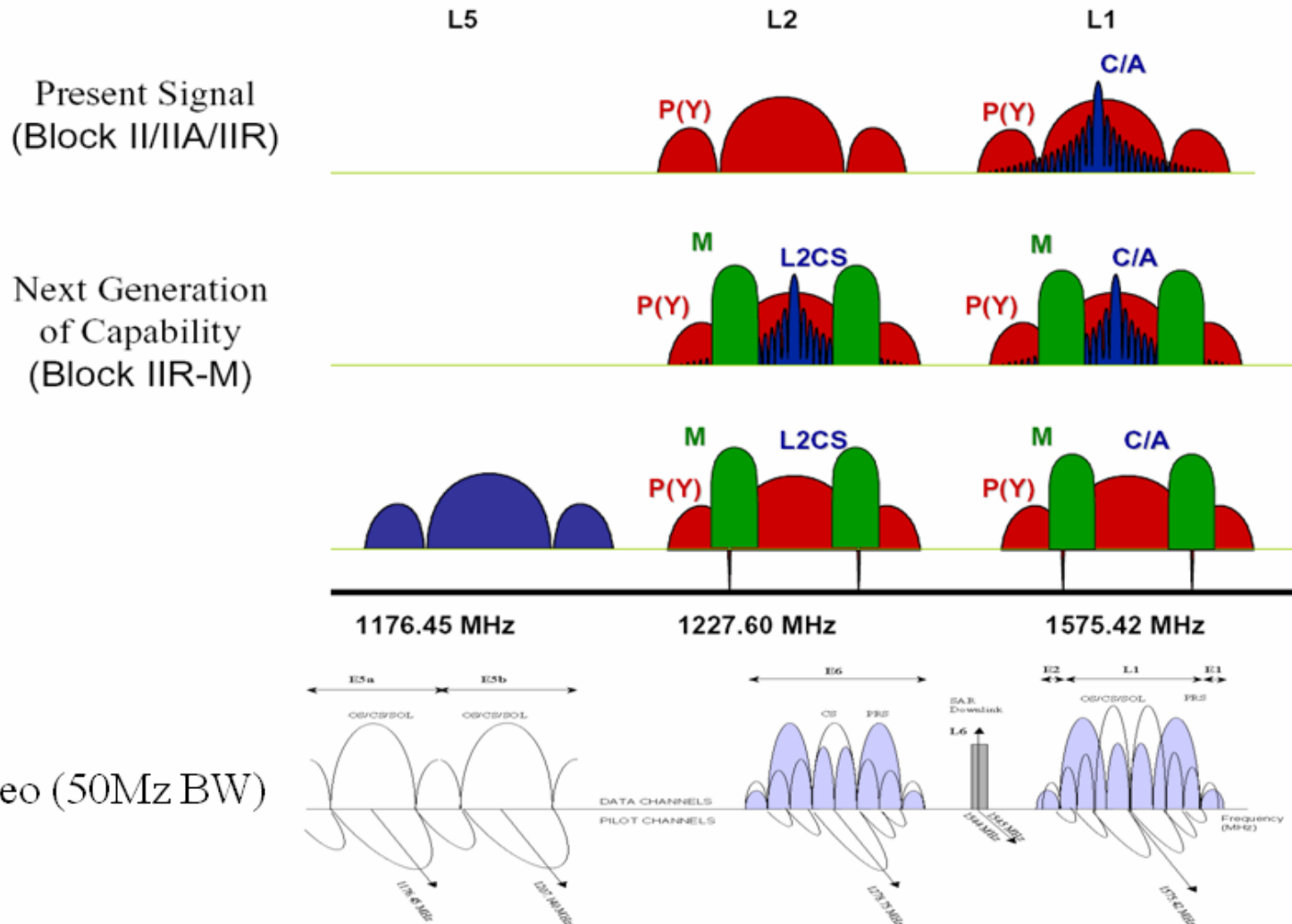
Two Most Recent Solar Cycles



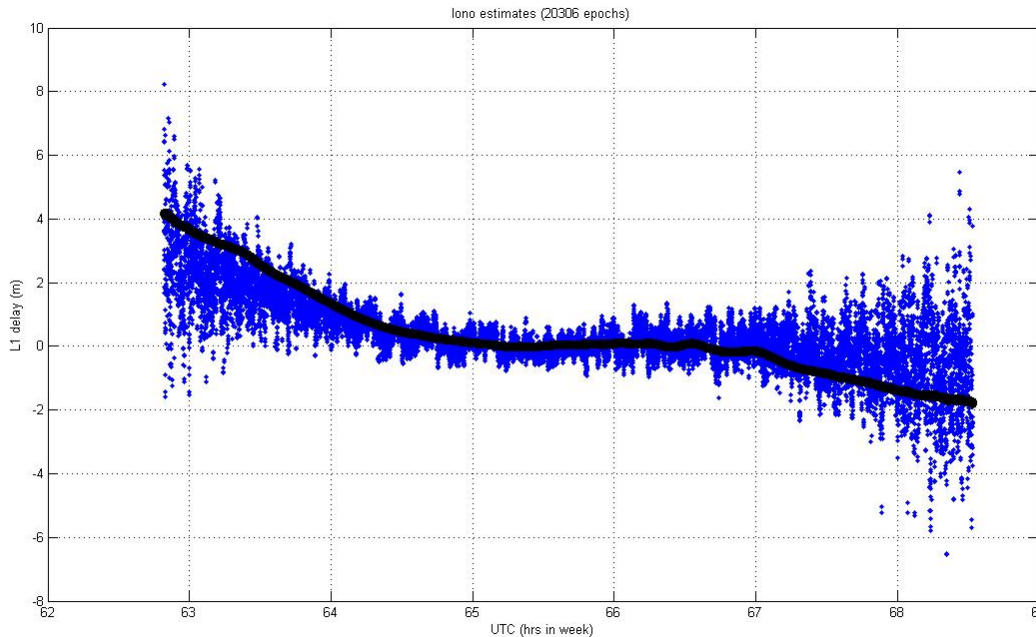
Macroscopic View of Ionosphere (GUVI)



L-Band GNSS Signal Structure



Carrier-phase Ionospheric Observations

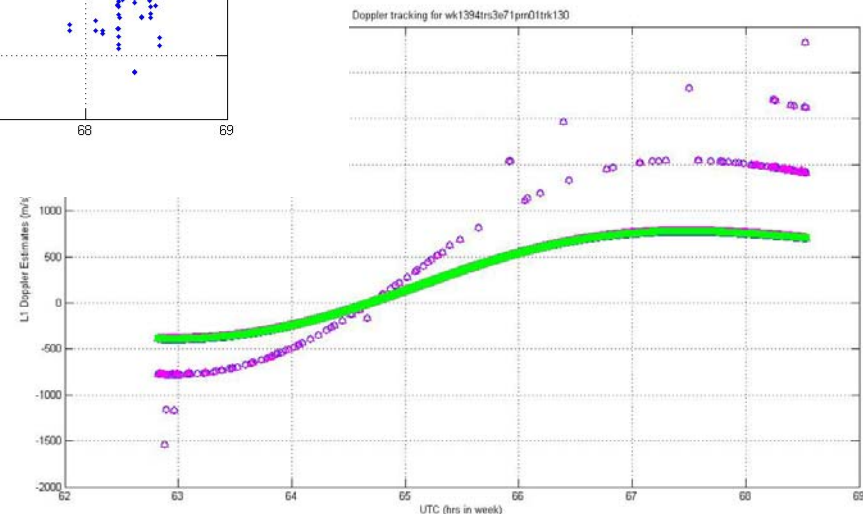


Cycle slips and other bias breaks identified and patched (where possible) with Doppler measurements:

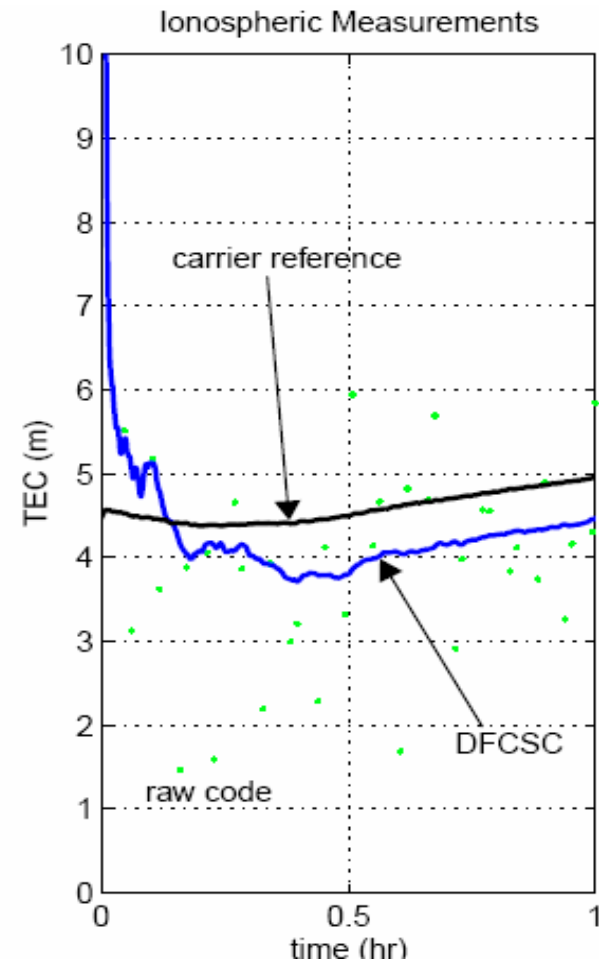
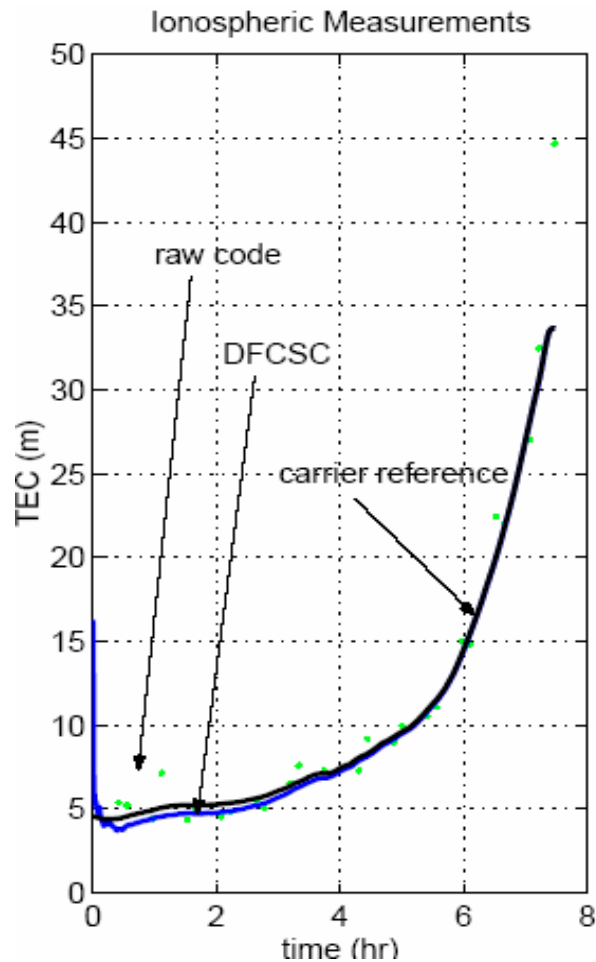
$$|I_{t+dt} - I_t + \text{Dopp}(dt)| < \text{Lambda}/2$$

Dual frequency carrier phase ionosphere tracks. Cycle (wide-lane) ambiguity resolved with C/A code averaging:

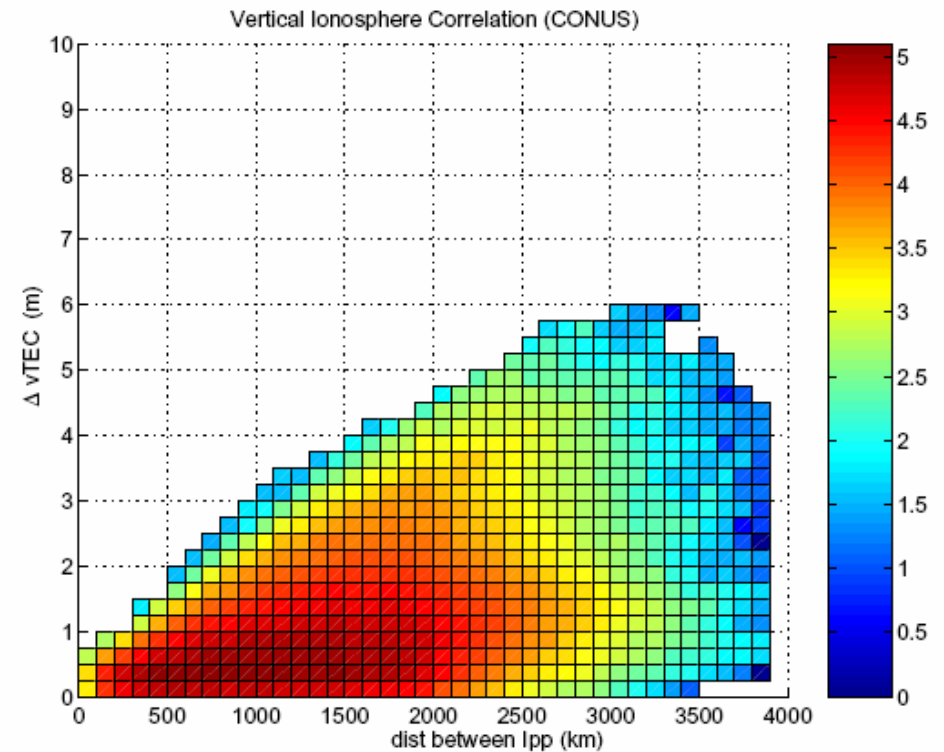
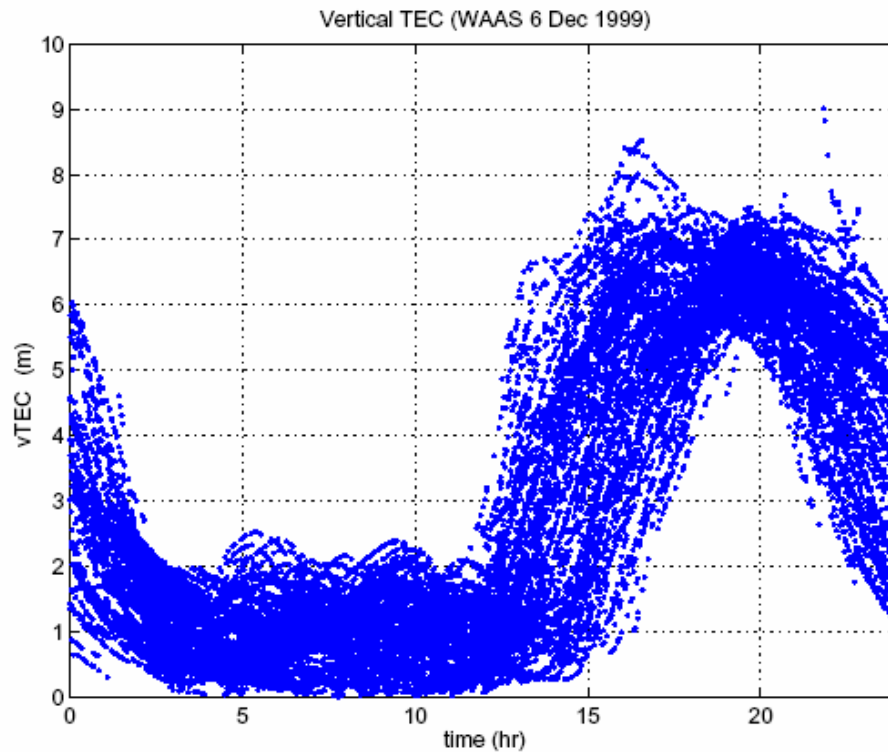
$$I_{\text{phi}} = (L1 - L2)/(\text{gamma}-1) + \text{bias}$$



L-Band Dual Frequency Ionosphere Measurement

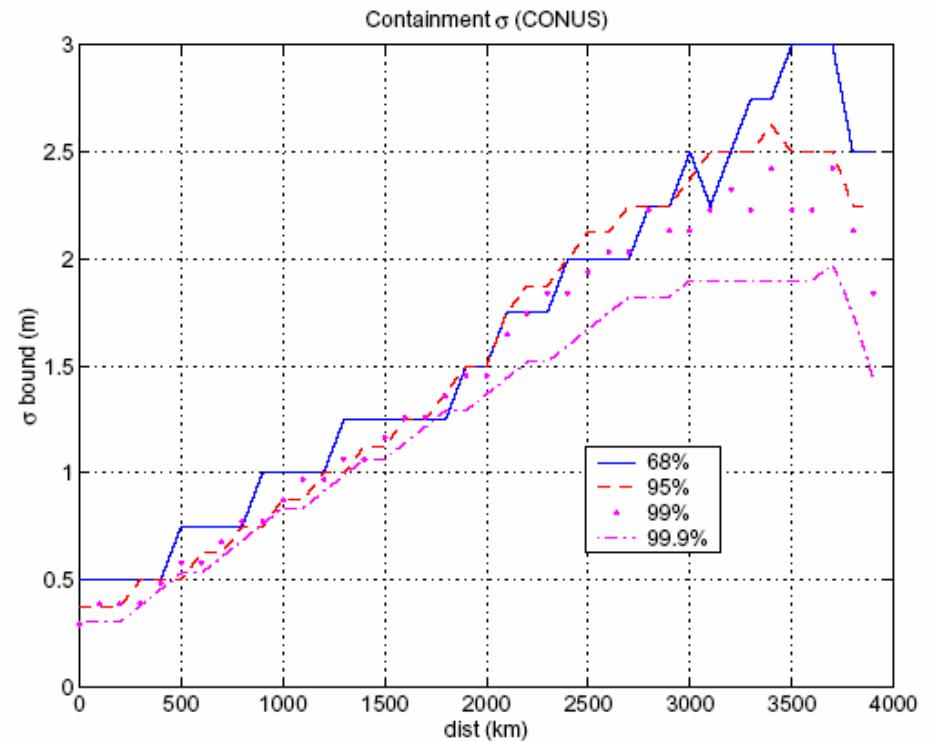
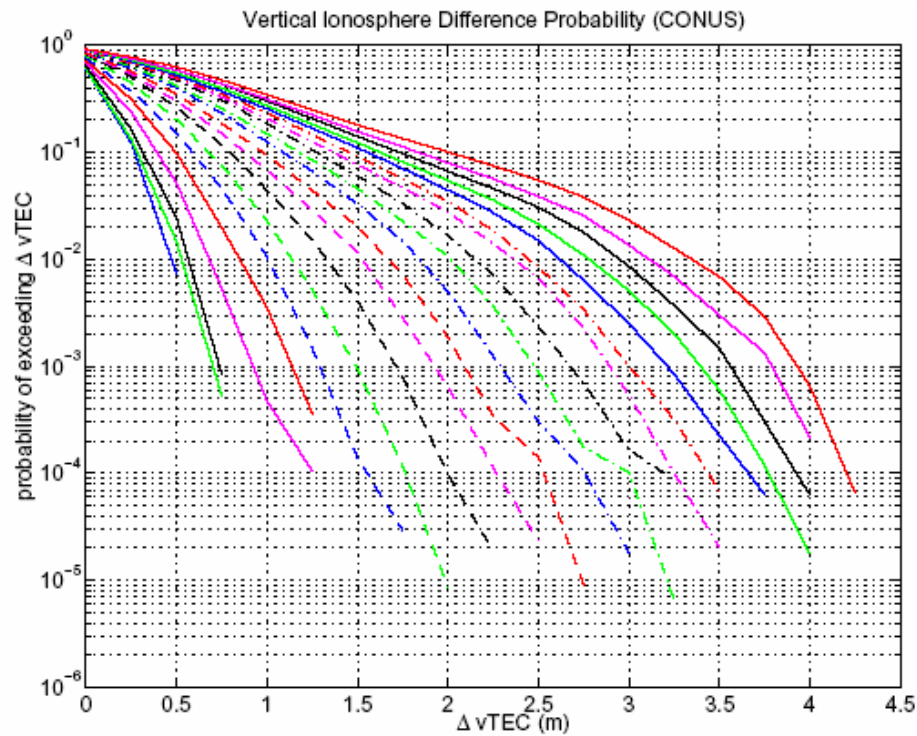


Quiet Ionosphere Correlation Distance



Single difference of observations from distributed reference network

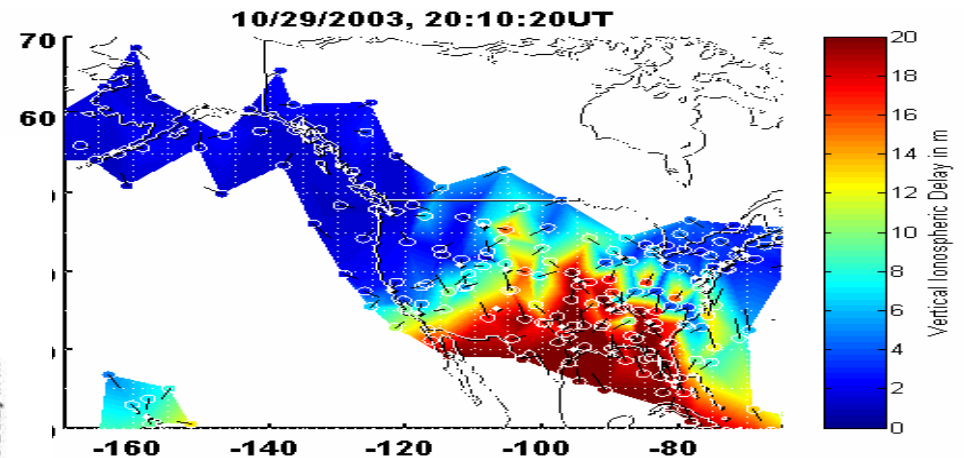
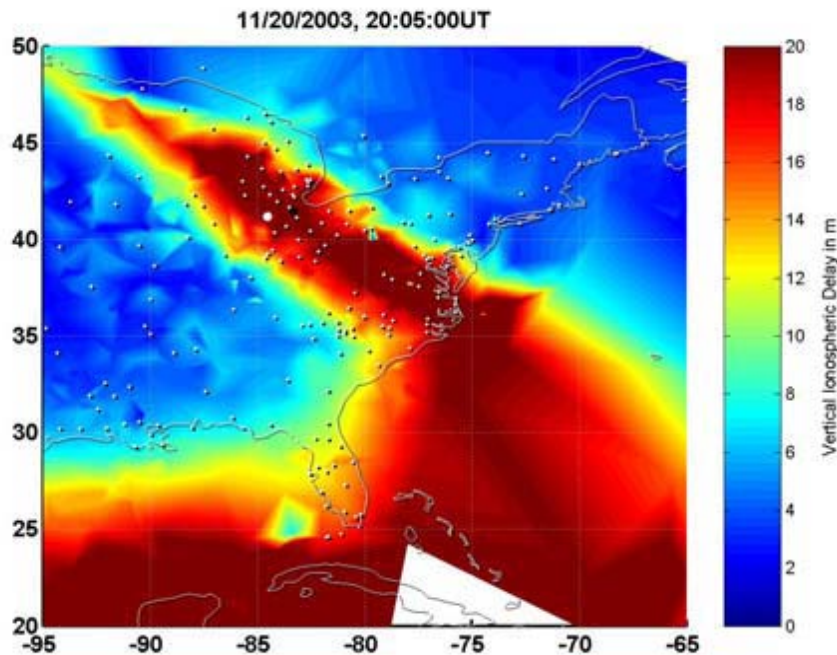
Bounding Quiet Ionospheric Decorrelation



Probability bounds on a quiet ionosphere provide containment of the decorrelation distance

Ionospheric Disturbances Drive Gradients

WAAS and NGS/CORS observations



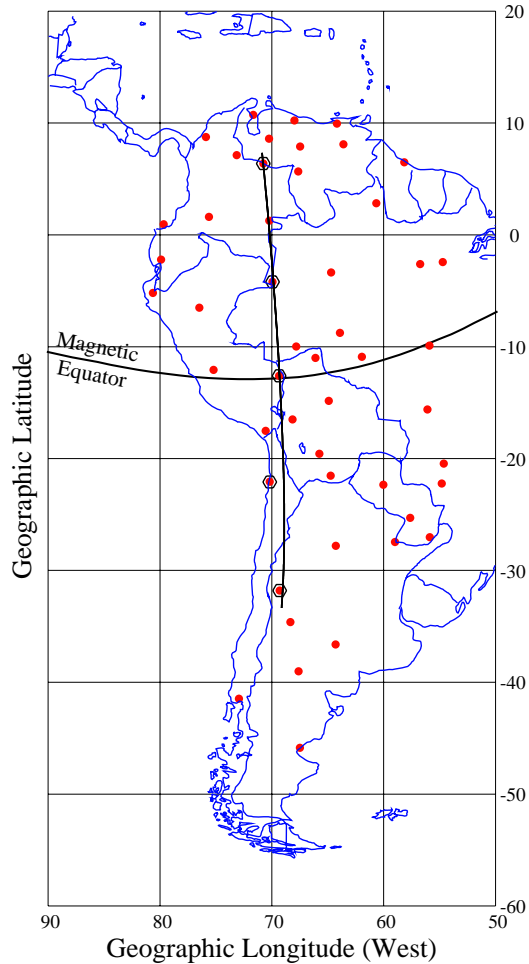
Spatial and temporal gradients observed by a GPS reference network and aircraft procedures establish envelopes for the threat model parameters (slope, velocity, width).

Graphics Courtesy Stanford University

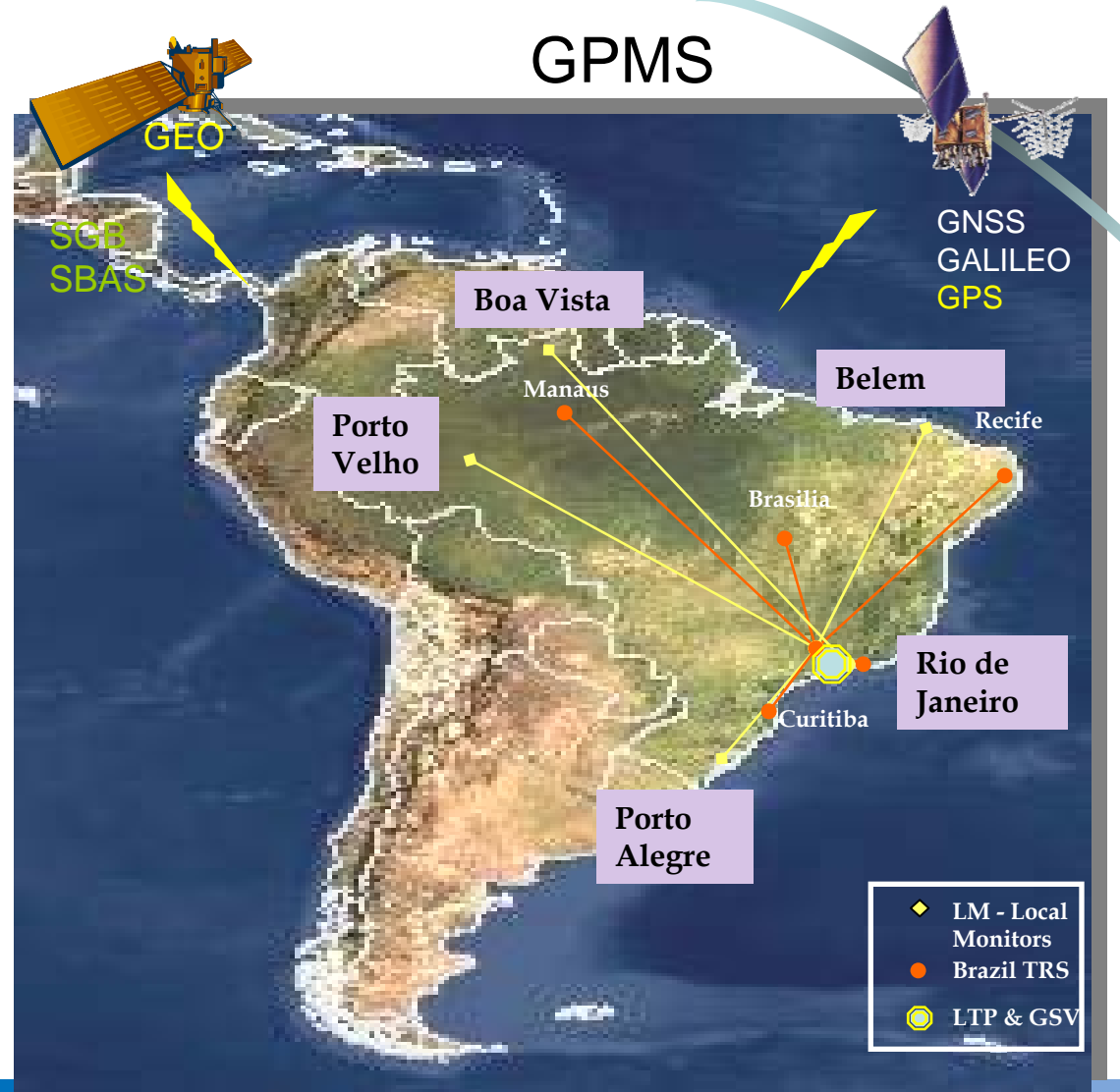
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Low Latitude Reference Networks

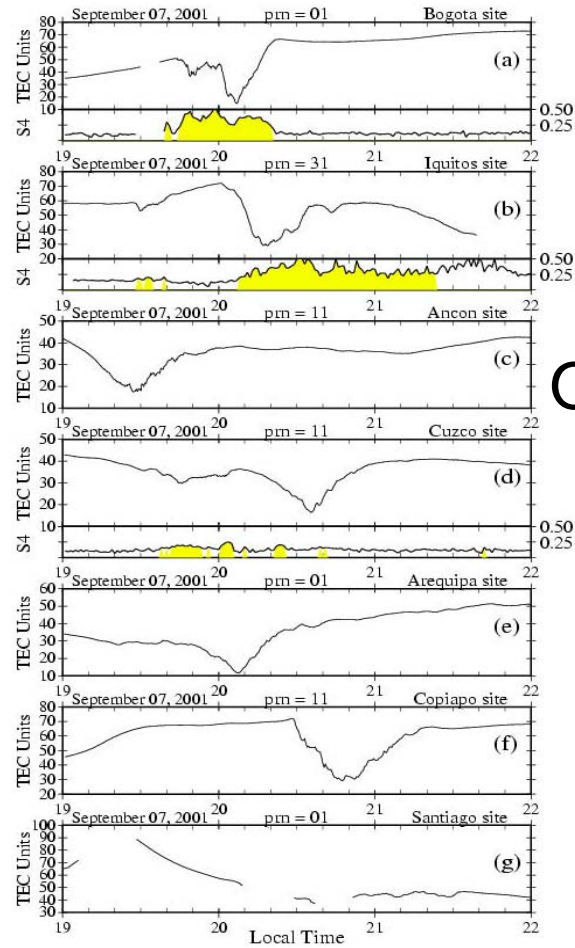
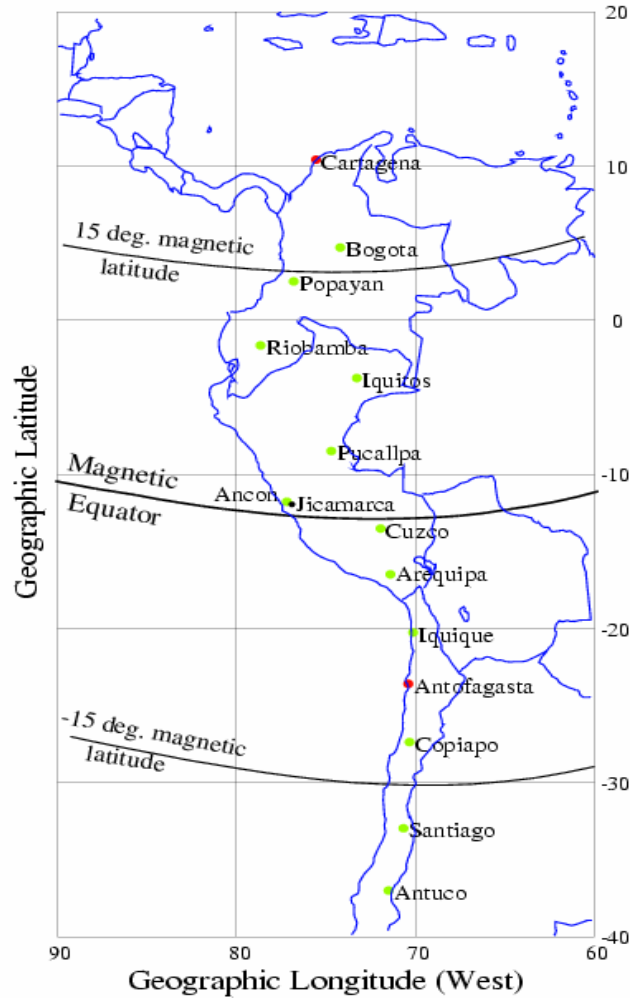
LISN



GPMS



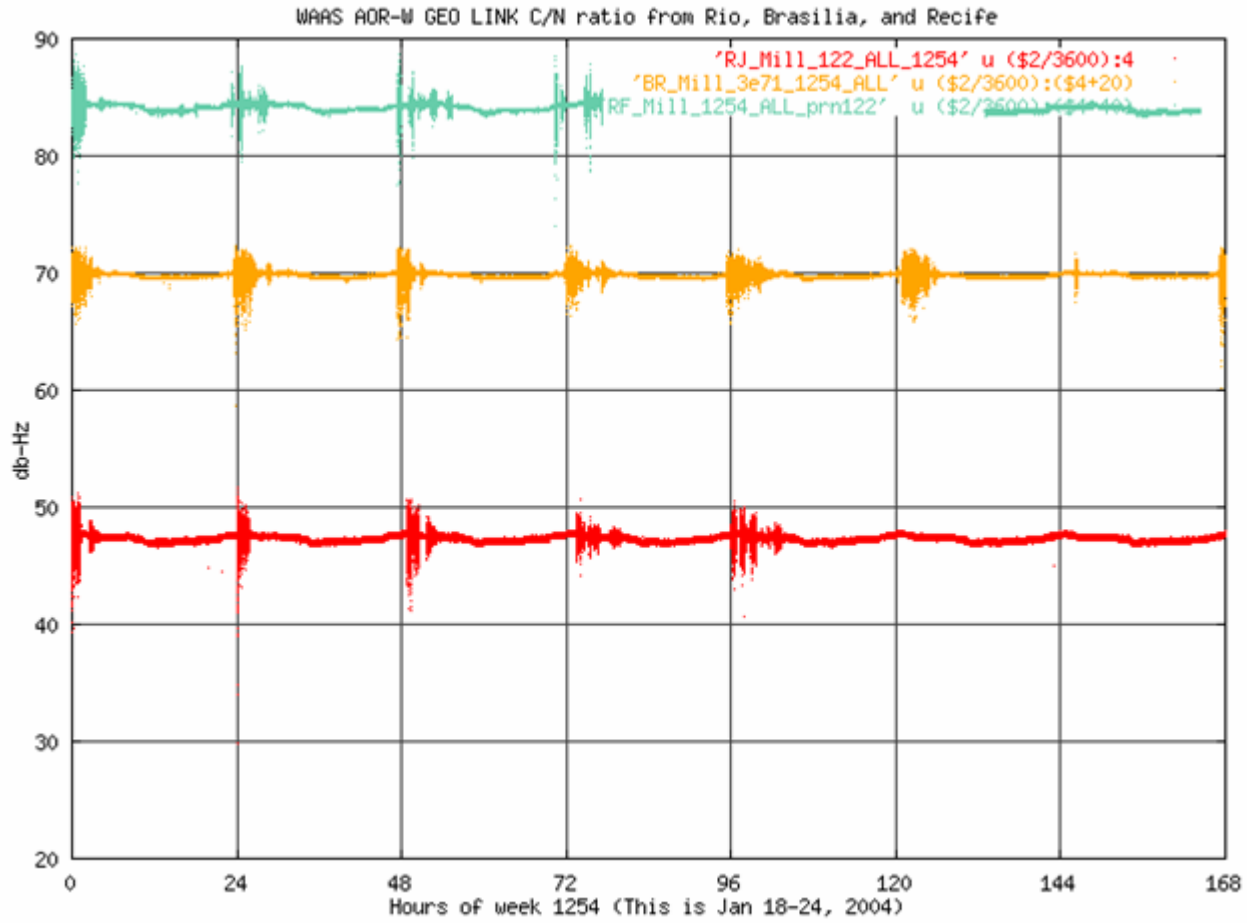
Low Latitude Depletions



Observed Velocity of 140 m/s

Graphics Courtesy Stanford University and SBAS IWG

Scintillation Observation Via GEO Link



Courtesy Dehel (ION GPS 2004)

Next Steps For Scintillation Monitoring

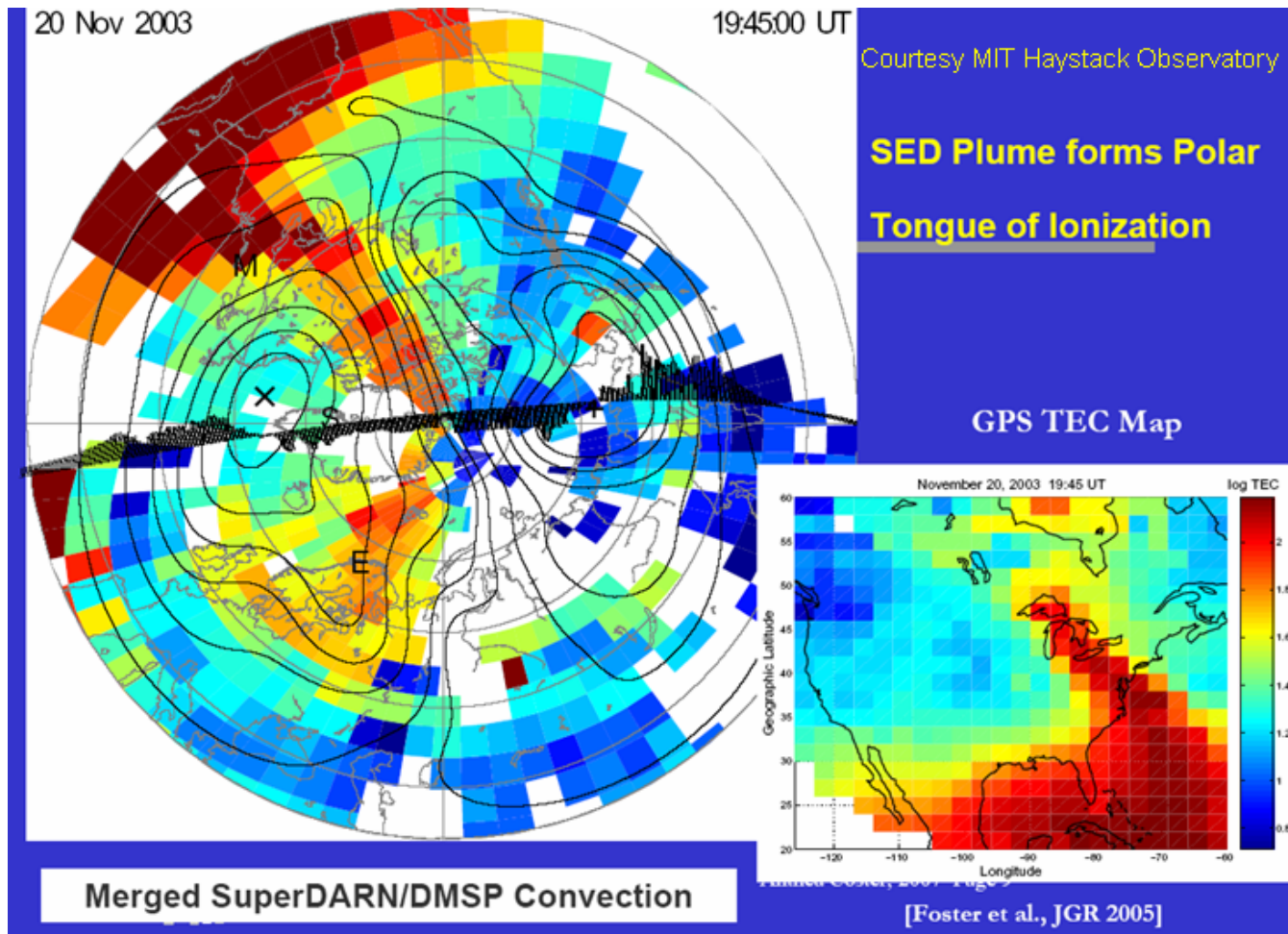
- ❑ Improved Signal Tracking and Performance on L5
- ❑ Applied on Geostationary Links Scintillation Motion is Identified
- ❑ Combining Nearly Co-located Receivers Yields Correlation Distance (VanDierendonck)
 - Co-location < 200km, ionospheric pierce points are nearly the same separation
 - Assume decorrelation function is gaussian with distance in the near field
 - Correlate co-located scintillation measurements and invert gaussian to derive correlation distance

Ionospheric Delay: Detect, Correct, or Bound

- ❑ Variety of Approaches for GNSS
 - ABAS primary approach is to bound (conservative approach)
 - SBAS primary approach is to correct nominal ionosphere and detect disturbed ionosphere
 - GBAS primary approach is to bound (tightly) against threats
 - GBAS partitioning and detection being studied to reduce bounding penalty under quiet conditions
- ❑ Dual-frequency Service Will Eliminate Correction
 - Potential need for SV signal calibration (Tgd)
 - Scintillation susceptibility increases as both links necessary
 - Graceful degradation algorithms under study

Magnetosphere Drainage Plume

Courtesy Coster (BSS 2007)



Recent Ionospheric Advances

- ❑ Ionospheric Storm Enhanced Density Plume Mechanism
 - Coster/MIT Haystack (2007) identified plume features
 - Repeatable observation and detection of SED plumes
 - Captures largest gradients observed in mid-latitude sector
 - Foster/MIT Haystack (2007) identified magnetic conjugacy
- ❑ Amplitude Scintillation and Ionospheric Bubbles
 - Bhattacharyya/IIG (2007) showed scale lengths shorten with stronger dynamo effect
 - Likewise, scale lengths decreased with larger solar flux
 - Krishna & Rao/Andhra Univ. (2007) proposed depletion detection algorithm from dense Indian reference network
- ❑ Scintillation Observations With Multiple Frequencies
 - GPS, Geostationary, & Galileo open codes on L1 and L5
 - Nearly co-locate receivers to measure correlation distance

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