Ionospheric Effects on Satellite Based Augmentation Systems (SBAS)

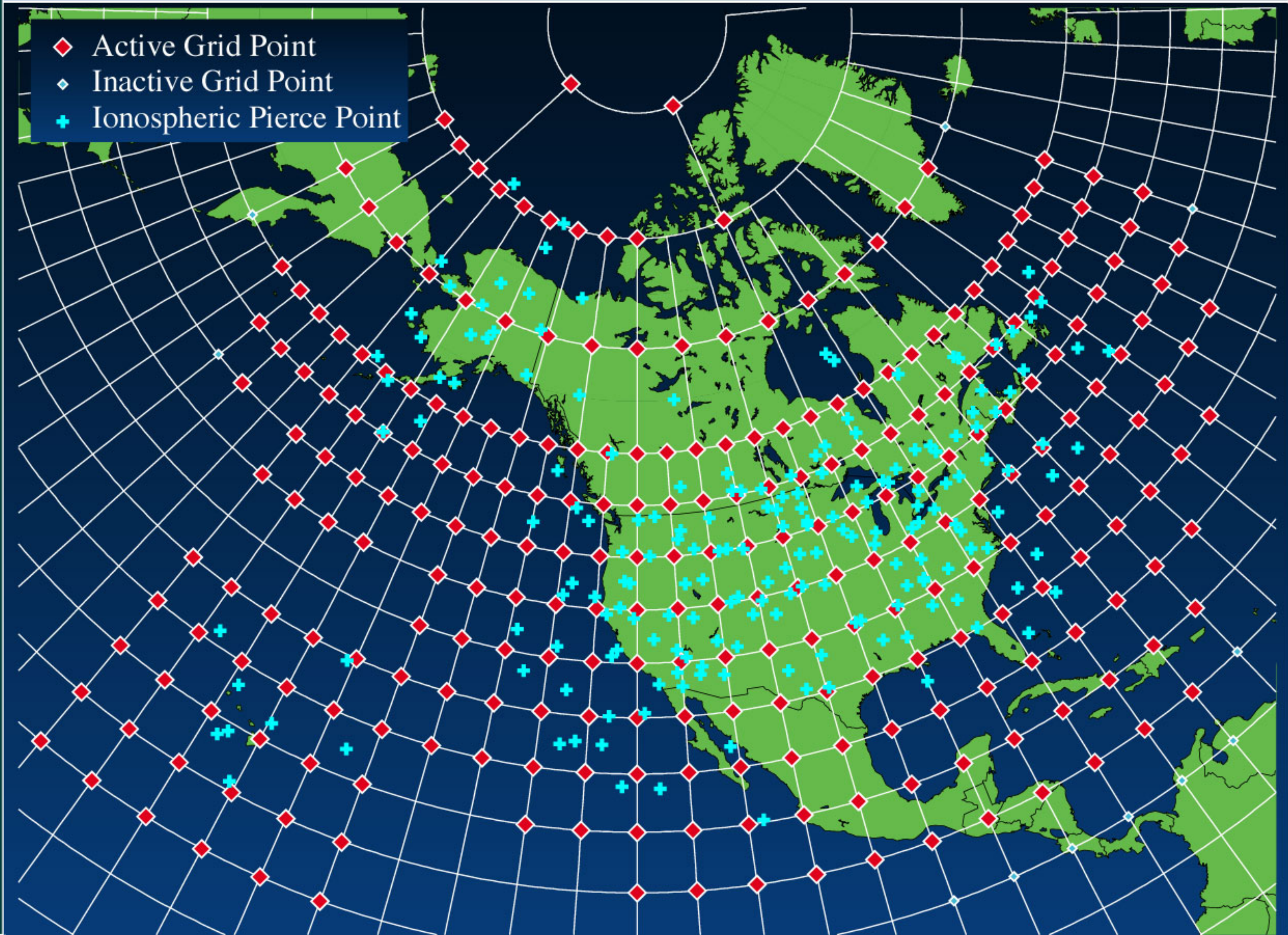
Todd Walter
Stanford University

http://waas.stanford.edu

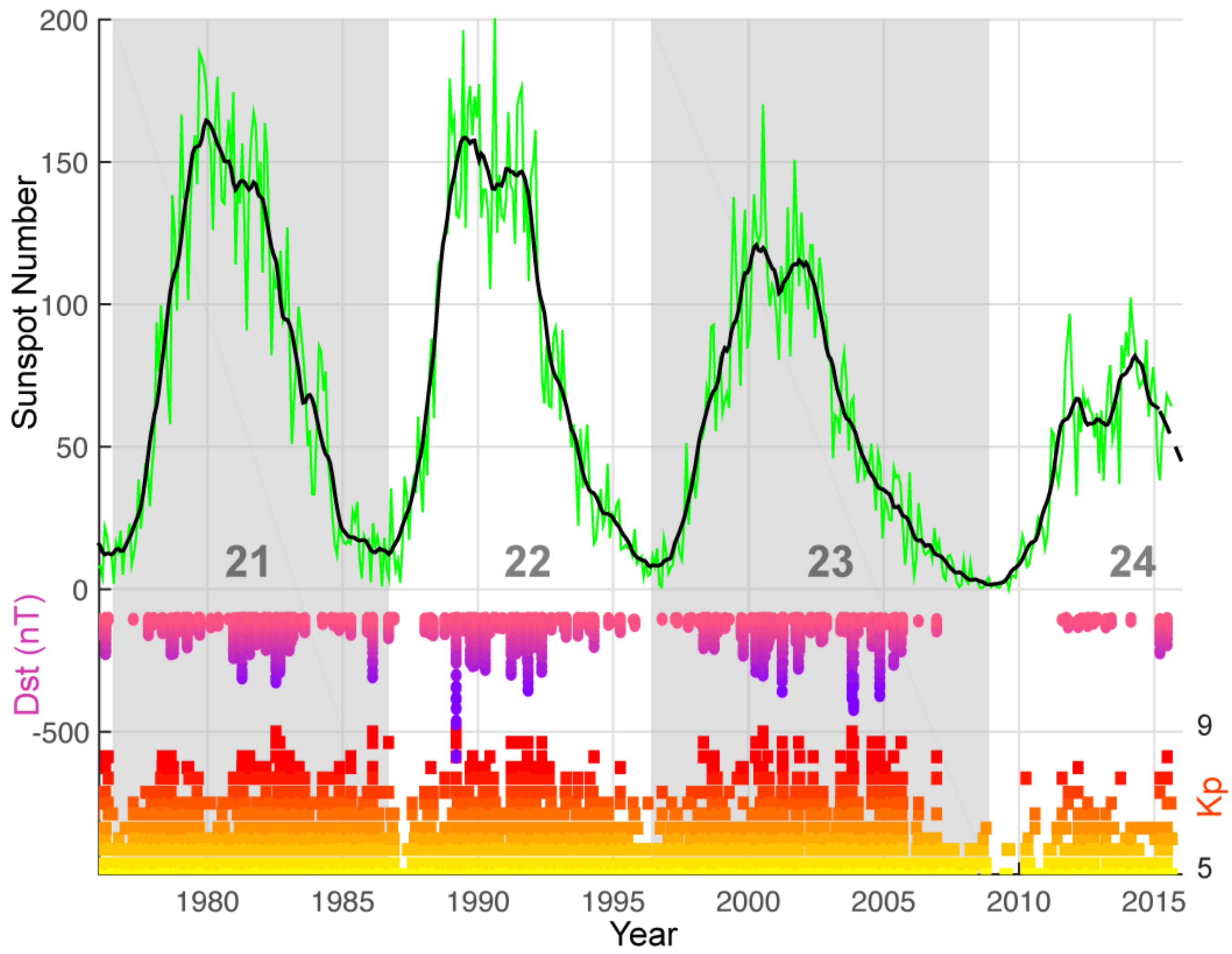
Introduction

- SBASs are high-integrity, high-accuracy, navigation systems
- The ionosphere presents the largest limitation to precise navigation
  - *Major ionospheric storms have had an impact on SBAS vertical guidance*
- Lateral guidance remains available even during disturbed ionosphere
  - *Scintillation affects continuity*

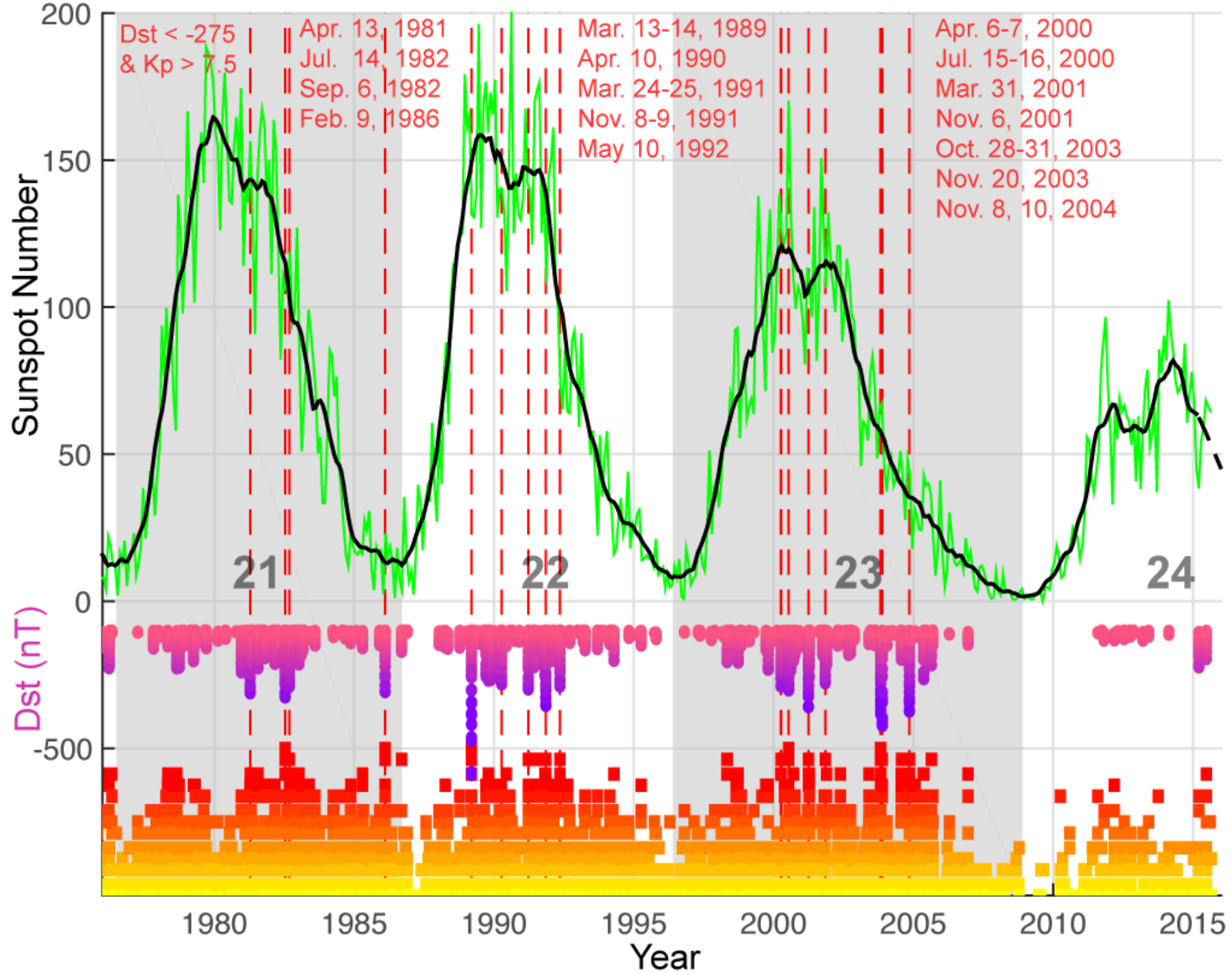
SBAS Ionospheric Grid



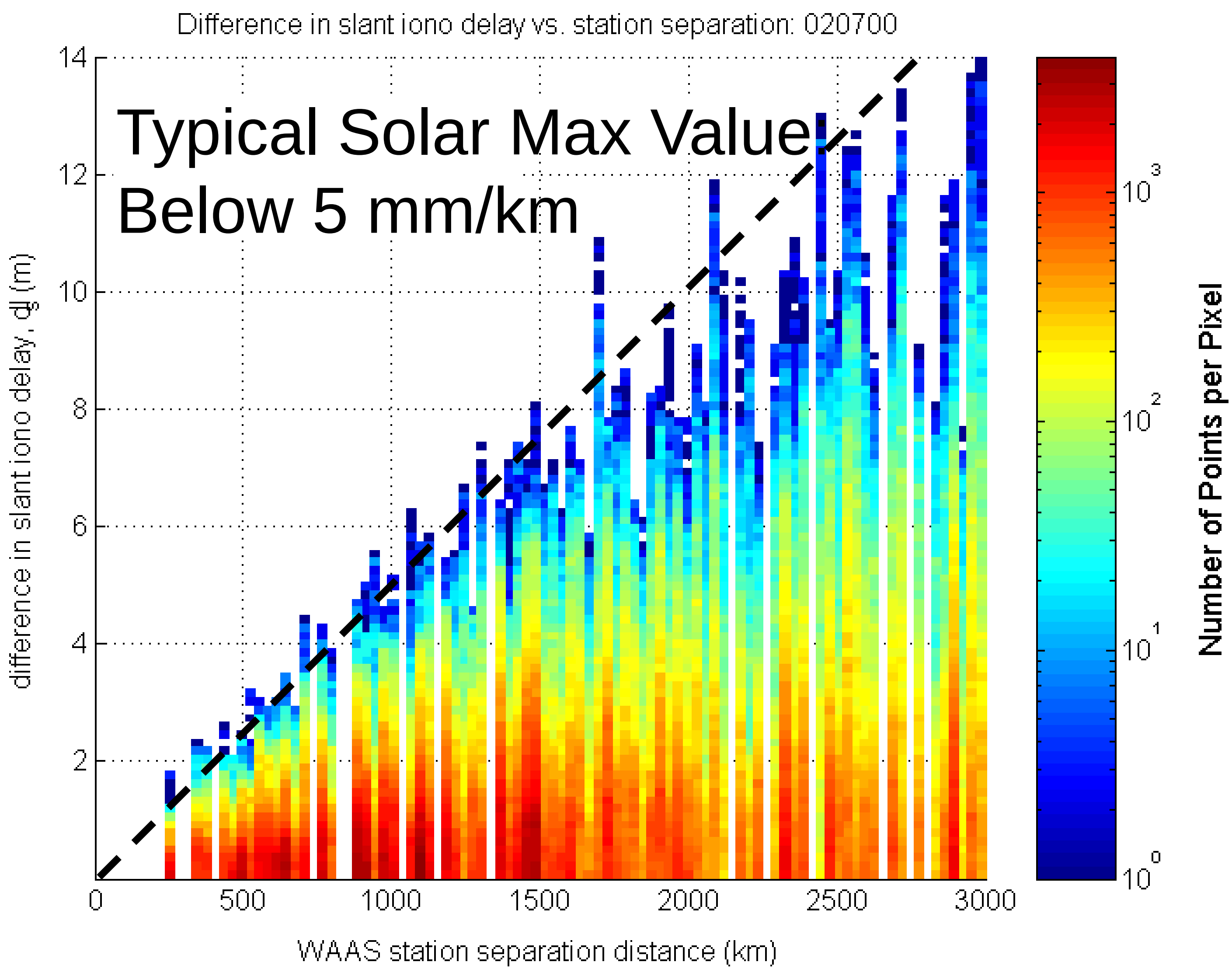
11 Year Solar Cycle



Major Iono Storms

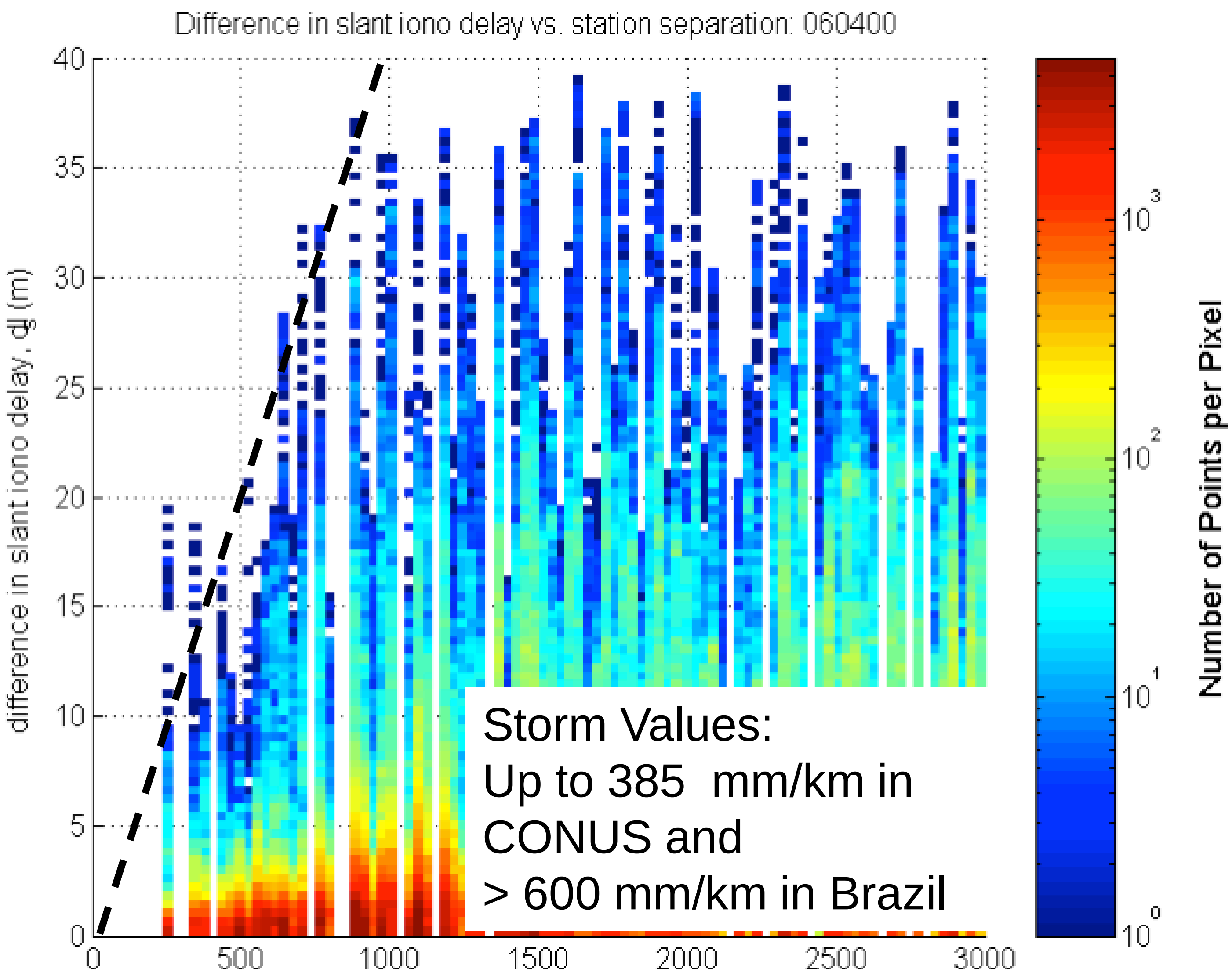


Nominal Day Spatial Gradients Between WAAS Stations



Slide Courtesy Seebany Datta-Barua

Spatial Gradients Between WAAS Stations During Anomaly



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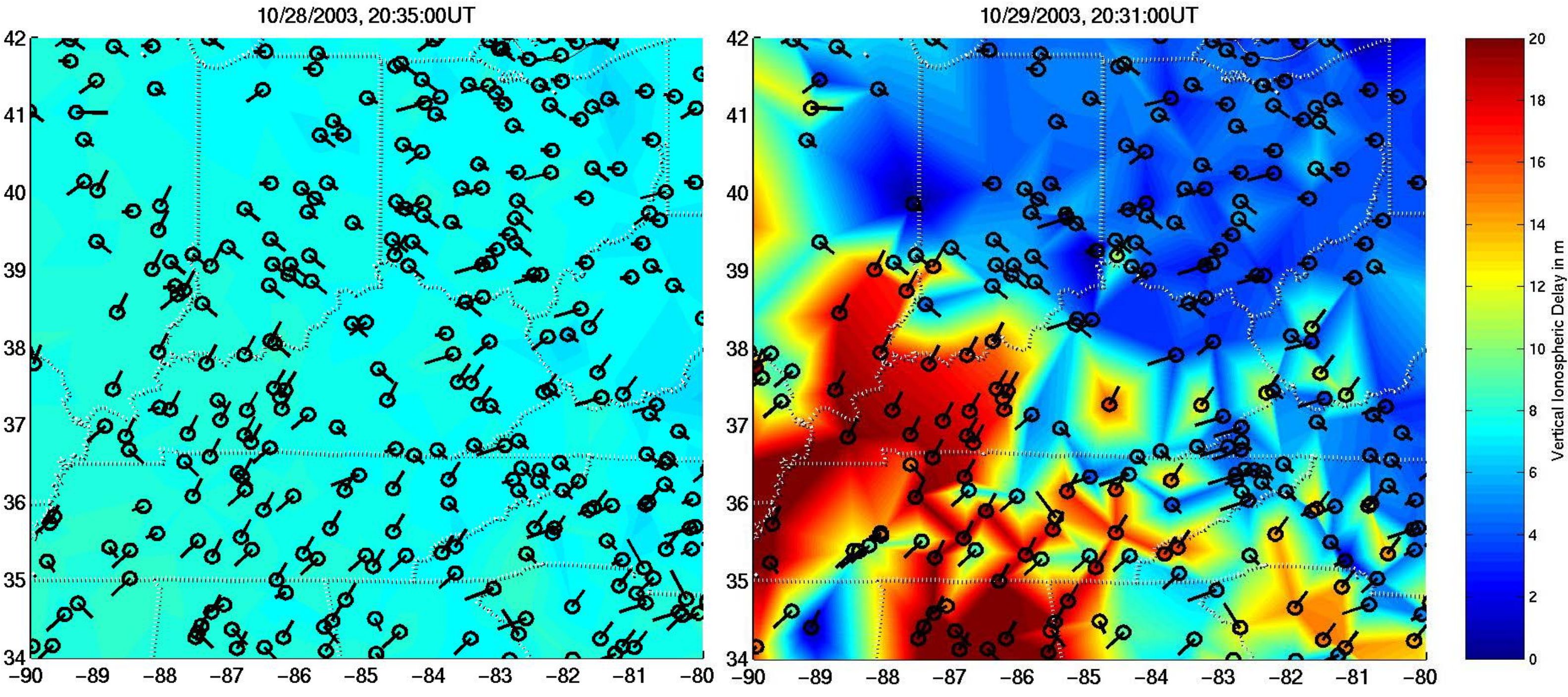
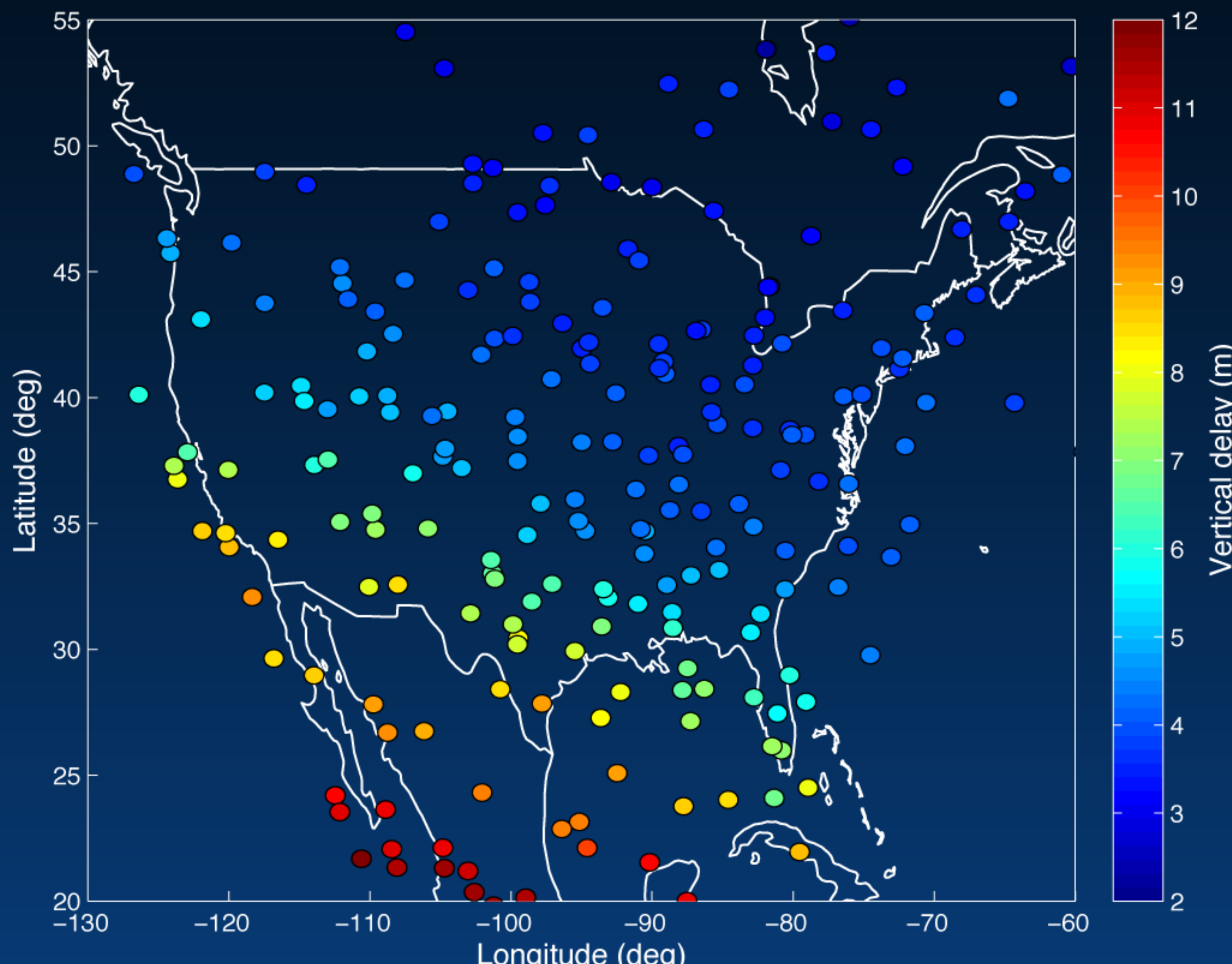
Thin Shell Model



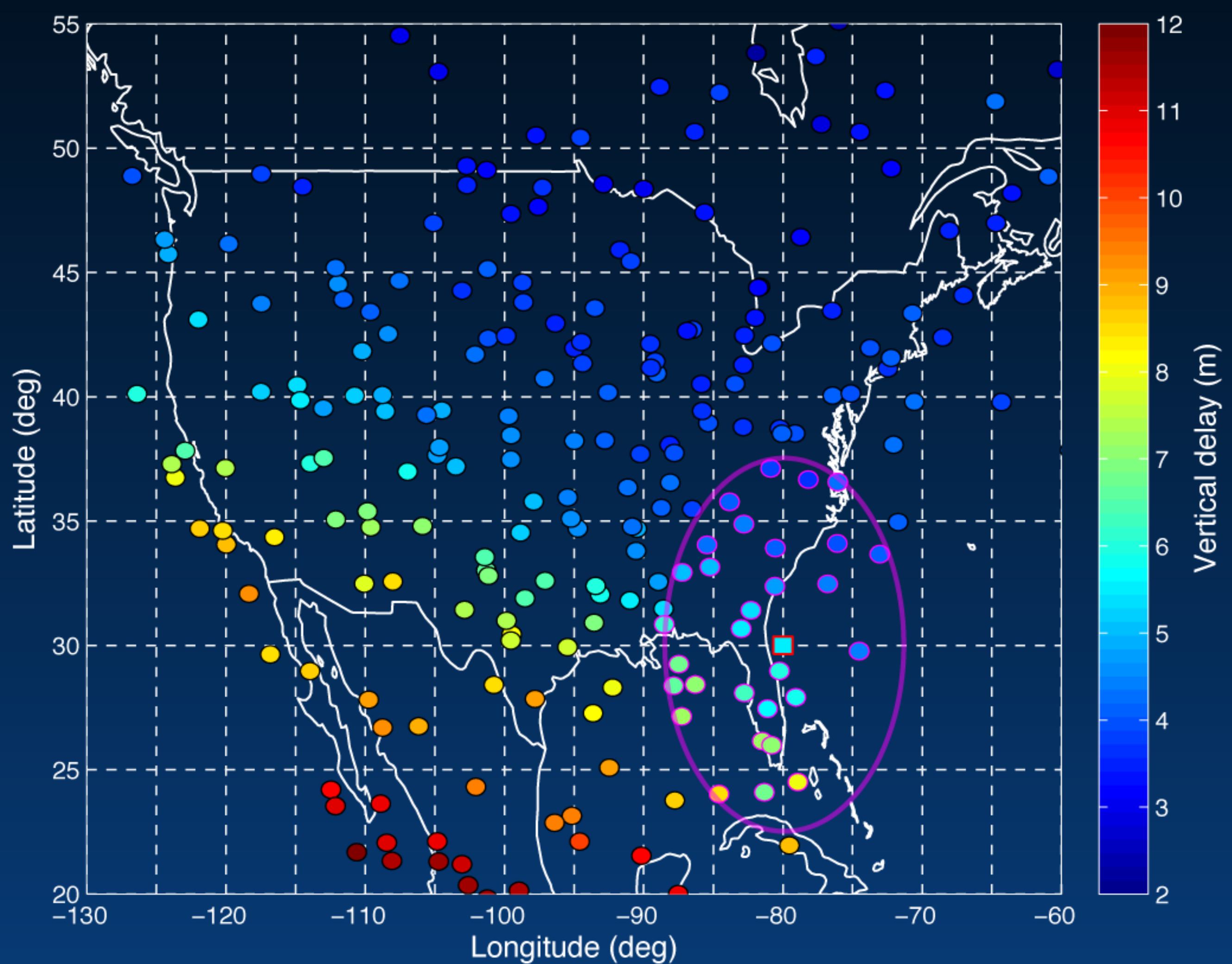
Quiet Day

Disturbed Day

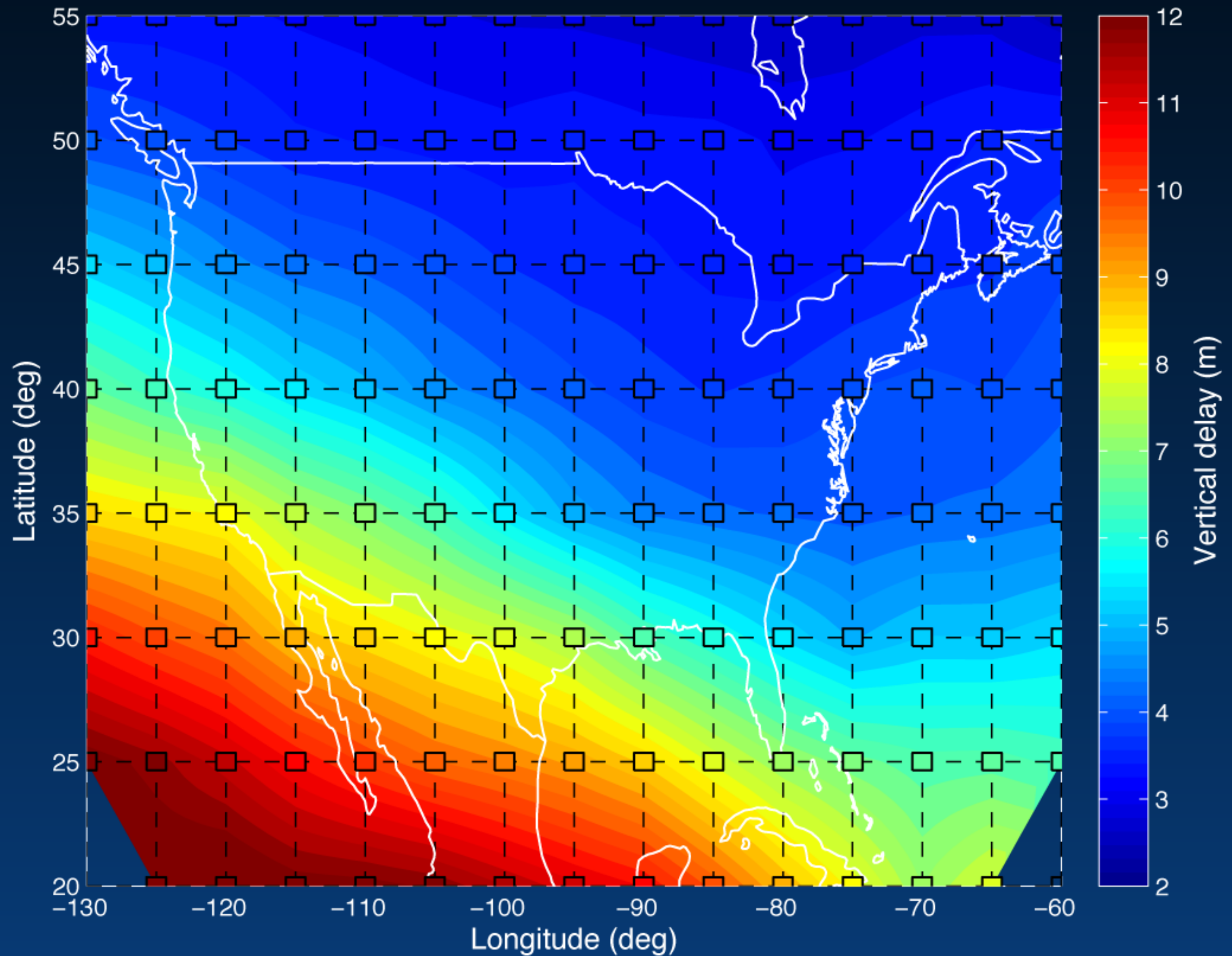
Nominal Ionosphere - IPPs



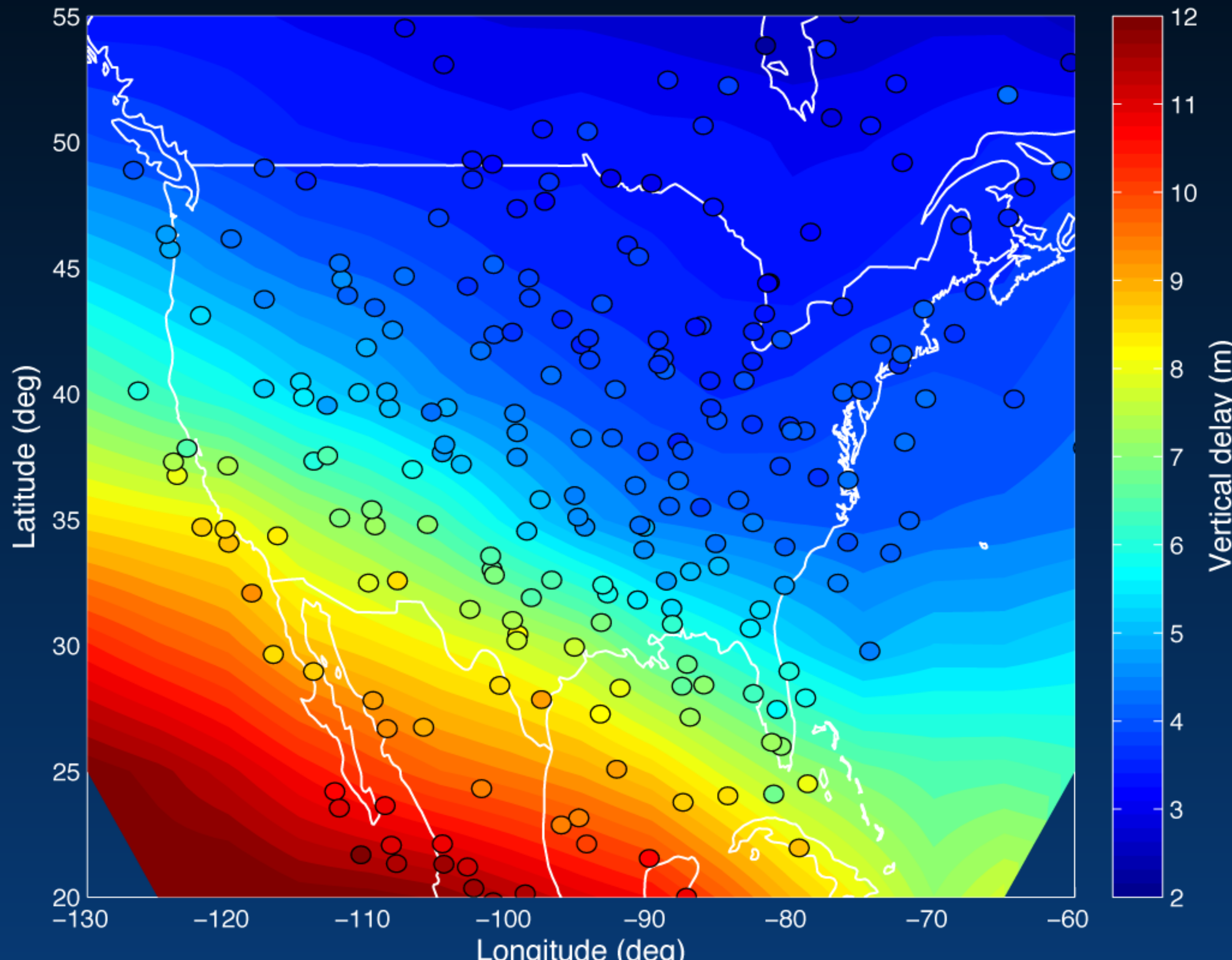
Fit to Local IPPs



Nominal ionosphere – Grid Delays



Nominal ionosphere – Grid Comparison to IPPs



Bounding the Estimation Error

- The GIVE contains many elements
  - *Formal error term*
    - Measurement noise
    - Ionospheric modeling error
      - *Accounts for sampled iono disturbance state*
      - *Error across full grid square*
    - Antenna bias contribution
  - *Undersampled threat term*
    - Spatial & temporal threats
  - *Floor term*
  - *Storm detector*

Confidence Computation

$$\hat{I}_{IGP} = \mathbf{w}^{\mathrm{T}} \cdot \mathbf{I}_{IPP}$$

Formal error due to ionospheric uncertainty

Undersampled threat term

$$\sigma_{IGP}^2 = R_{irreg}^2 \left[\mathbf{w}^{\mathrm{T}} \cdot \mathbf{C} \cdot \mathbf{w} - 2\mathbf{w}^{\mathrm{T}} \cdot \mathbf{c} + \left(\sigma_{decorr}^{total} \right)^2 \right] + \mathbf{w}^{\mathrm{T}} \cdot \mathbf{M} \cdot \mathbf{w} + \left(\sigma_{decorr}^{undersamp} \right)^2$$

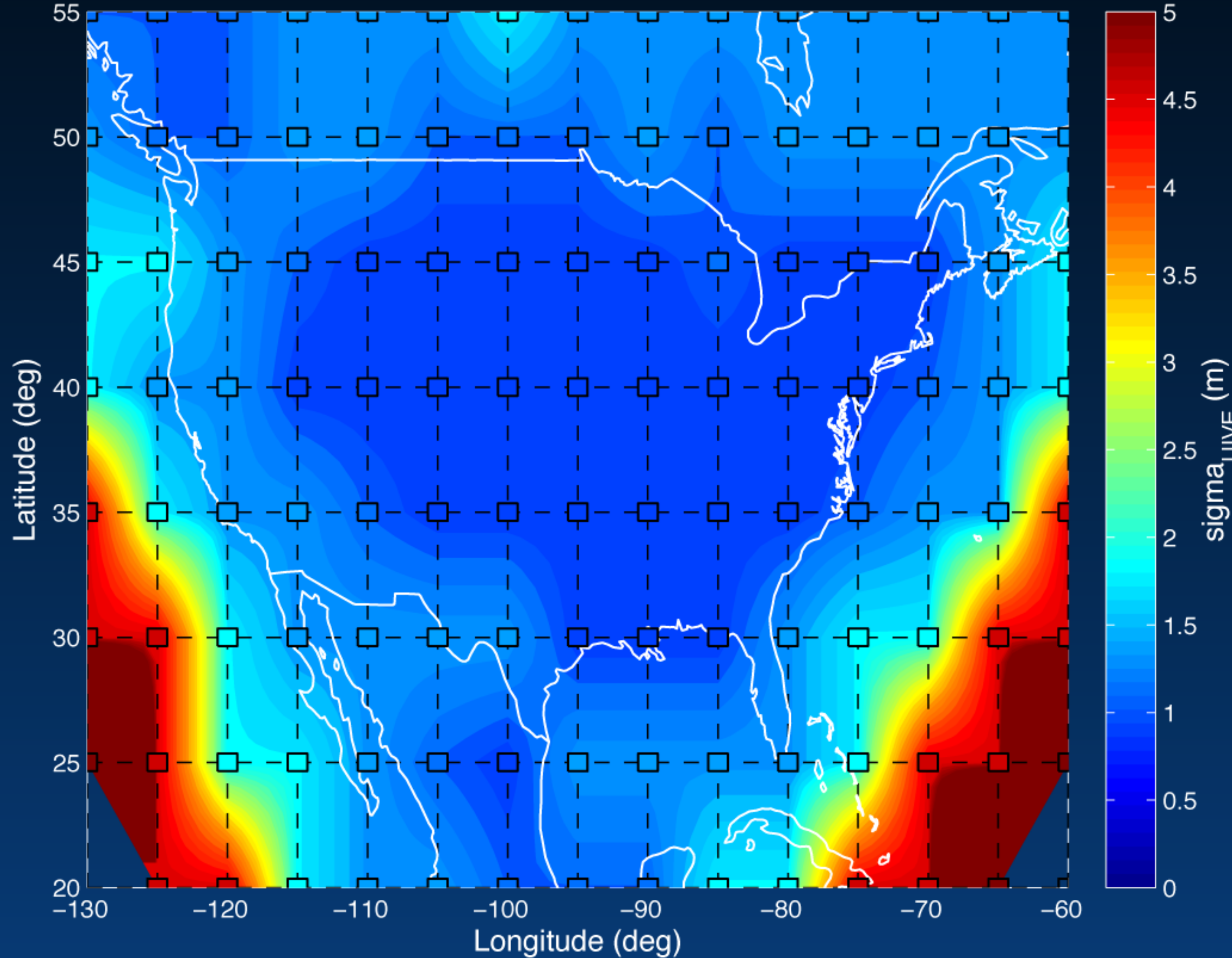
Measure of ionospheric state

Formal error due to measurement noise

$$R_{irreg}^2 = \frac{R_{noise} \chi^2}{\chi_{lowerbound}^2}$$

Sparks, L., Blanch, J., Pandya, N., "Kriging as a Means of Improving WAAS Availability," *Proceedings of the 23rd International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2010)*, Portland, OR, September 2010, pp. 2013-2020.

Nominal ionosphere – Confidence Values



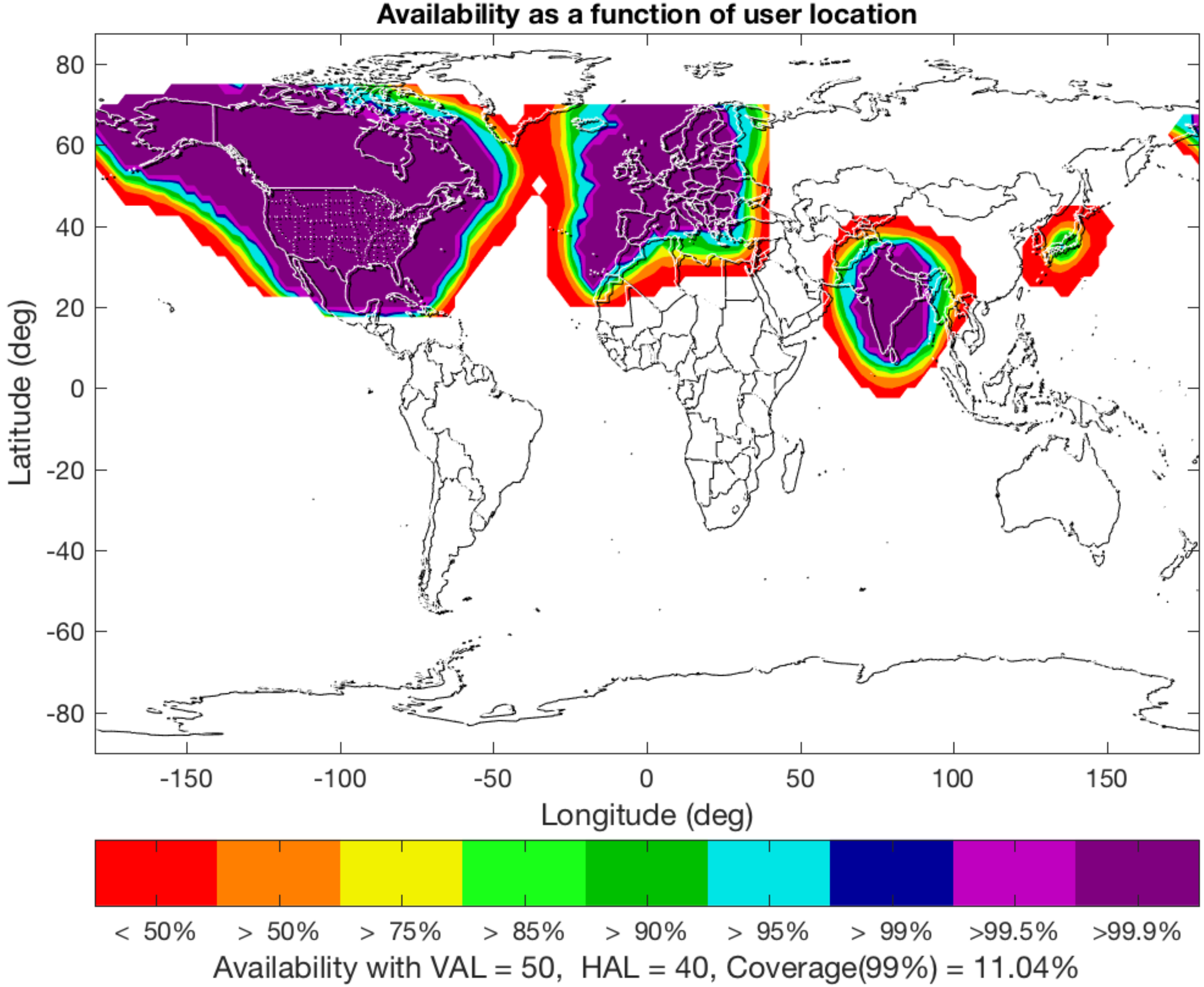
SBAS Precision Guidance Coverage

WAAS

EGNOS

MSAS

GAGAN



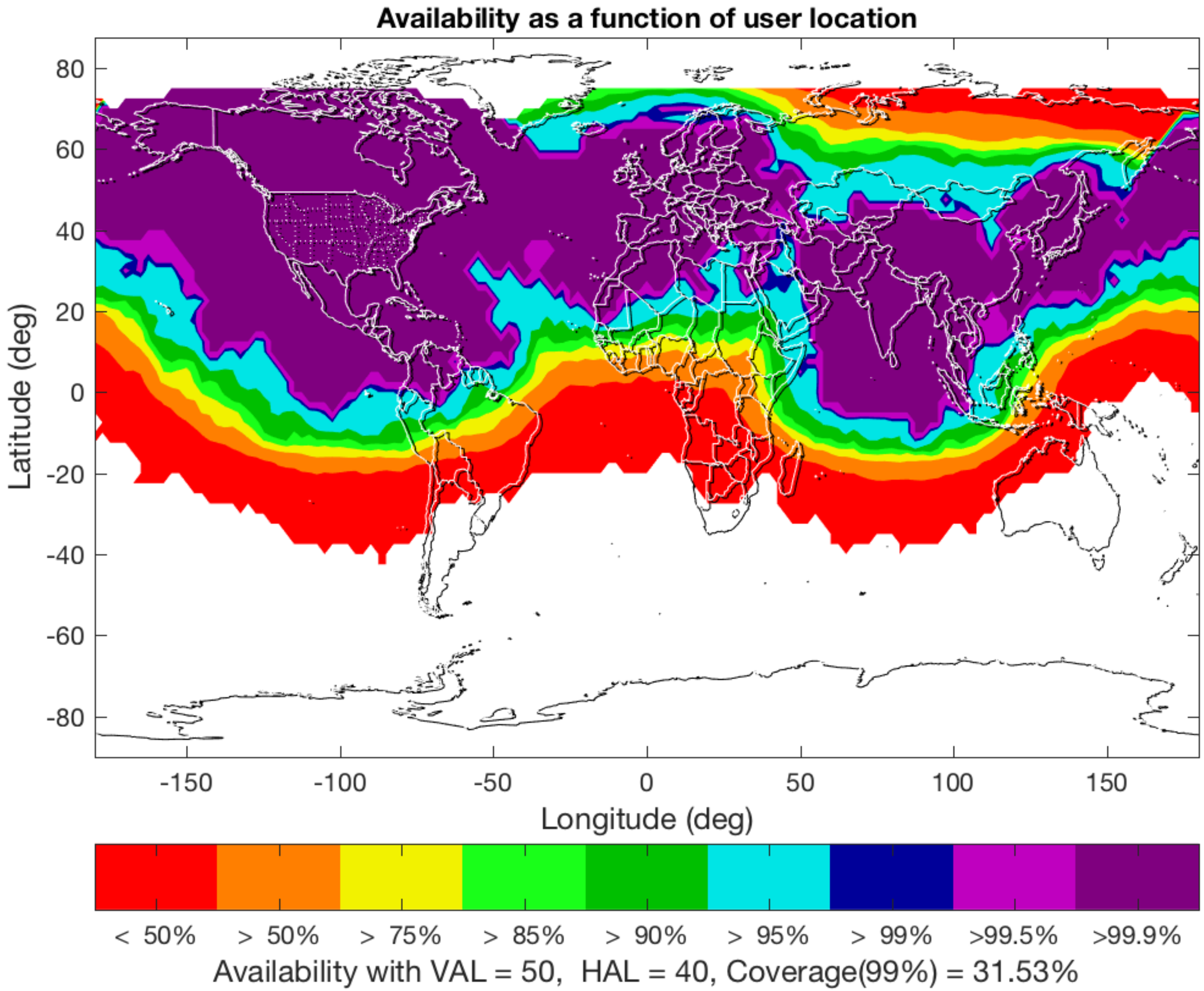
Dual Frequency SBAS Precision Guidance

WAAS

EGNOS

MSAS

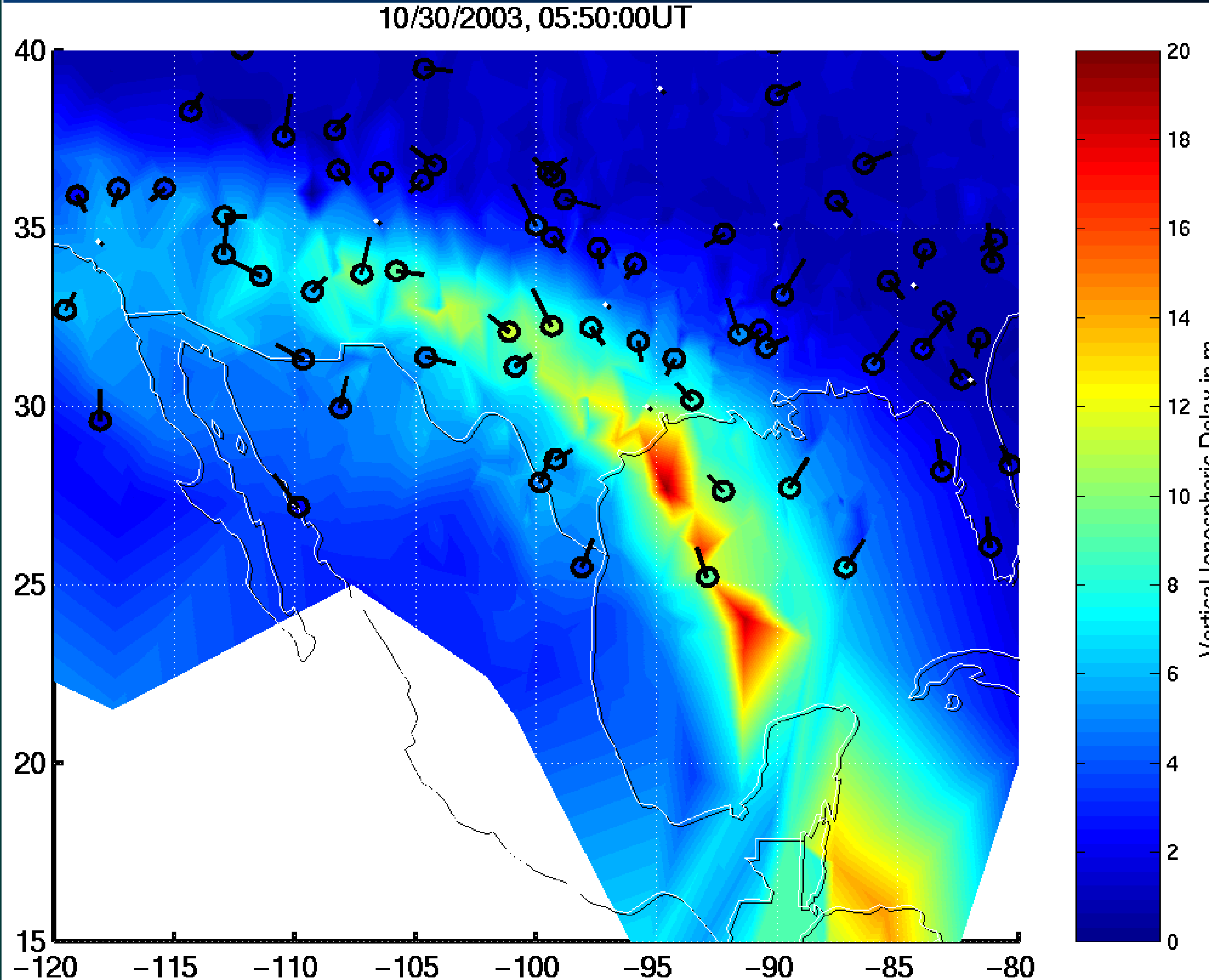
GAGAN



Conclusions

- The ionosphere presents the largest limitation to SBAS vertical guidance
  - *The GIVE protects user integrity*
    - Accounts for all ionospheric delay threats
  - *Delay effects can be eliminated with two frequencies at the user*
- Lateral guidance remains available even during disturbed ionosphere
- Scintillation affects continuity
  - *Dual frequency use is also vulnerable*

Undersampled Condition



Courtesy:
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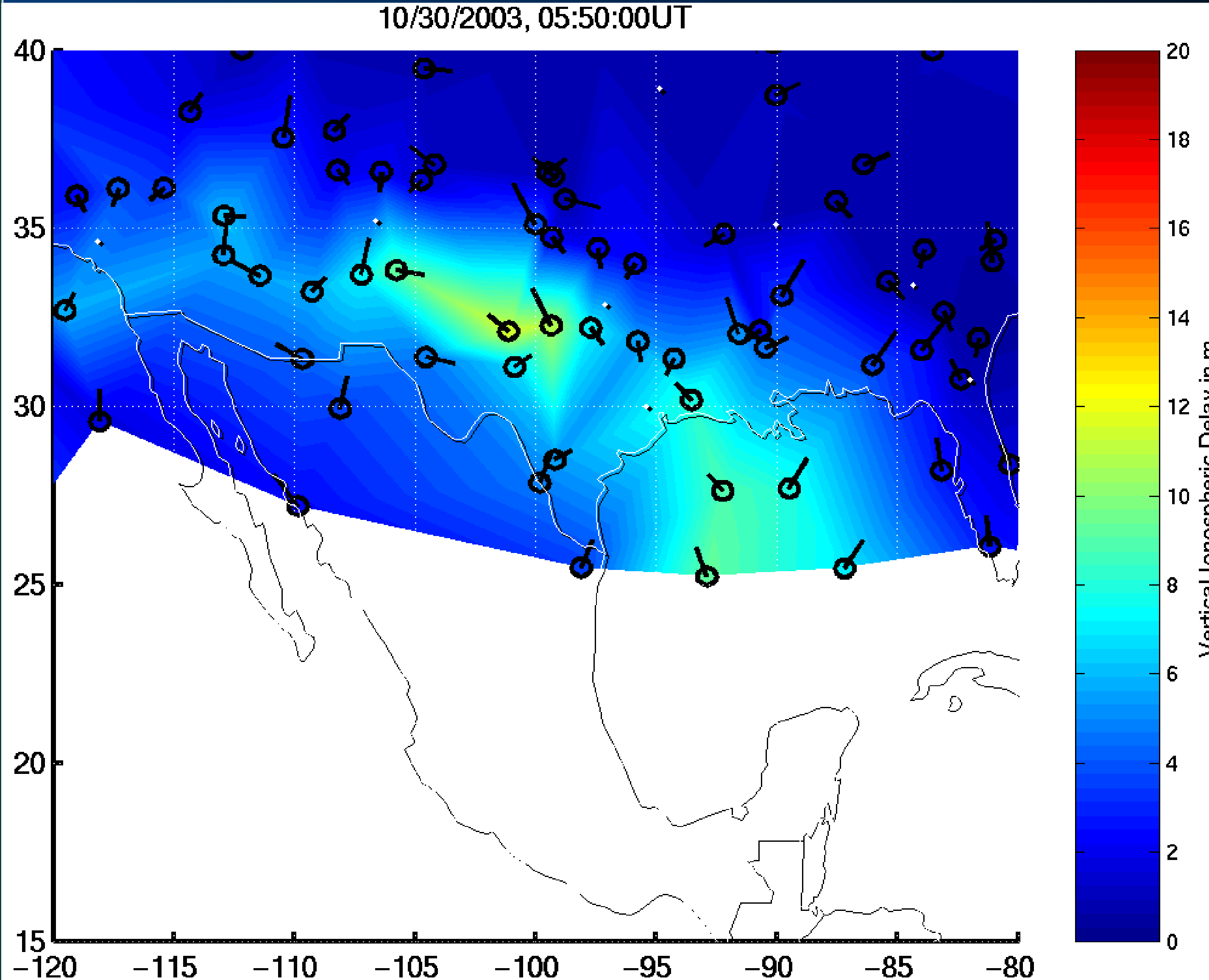
Datta-Barua

WAAS Measurements



Courtesy:
Seebany
Datta-Barua

GIVE Description

- Formal error term:
  - *"Using Kriging to bound Satellite Ranging Errors due to the Ionosphere," Ph.D. Dissertation, Stanford University, December 2003 by Juan Blanch*
  - *Sparks, L., Blanch, J., Pandya, N., "Kriging as a Means of Improving WAAS Availability," Proc. of ION GNSS 2010*
- Undersampled threat:
  - *Sparks, L., et al., "The WAAS Ionospheric Threat Model," in Proceedings of the Beacon Satellite Symposium, Boston, MA, June 2001*
  - *Walter, T., et al., "Protecting Against Unsampled Ionospheric Threats," in Proceedings of the Beacon Satellite Symposium, Trieste, Italy, October 2004*
- Storm Detector:
  - *Walter, T., et al., "Robust Detection Of Ionospheric Irregularities", NAVIGATION, Journal of The ION, Vol. 48, No. 2, Summer 2001*
  - *Sparks, L., et al., "Extreme Ionospheric Storms and Their Impact on WAAS", Proceedings of IES 2005, Alexandria, VA, May 2005*