WAAS Ionospheric Research at Stanford

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Abstract

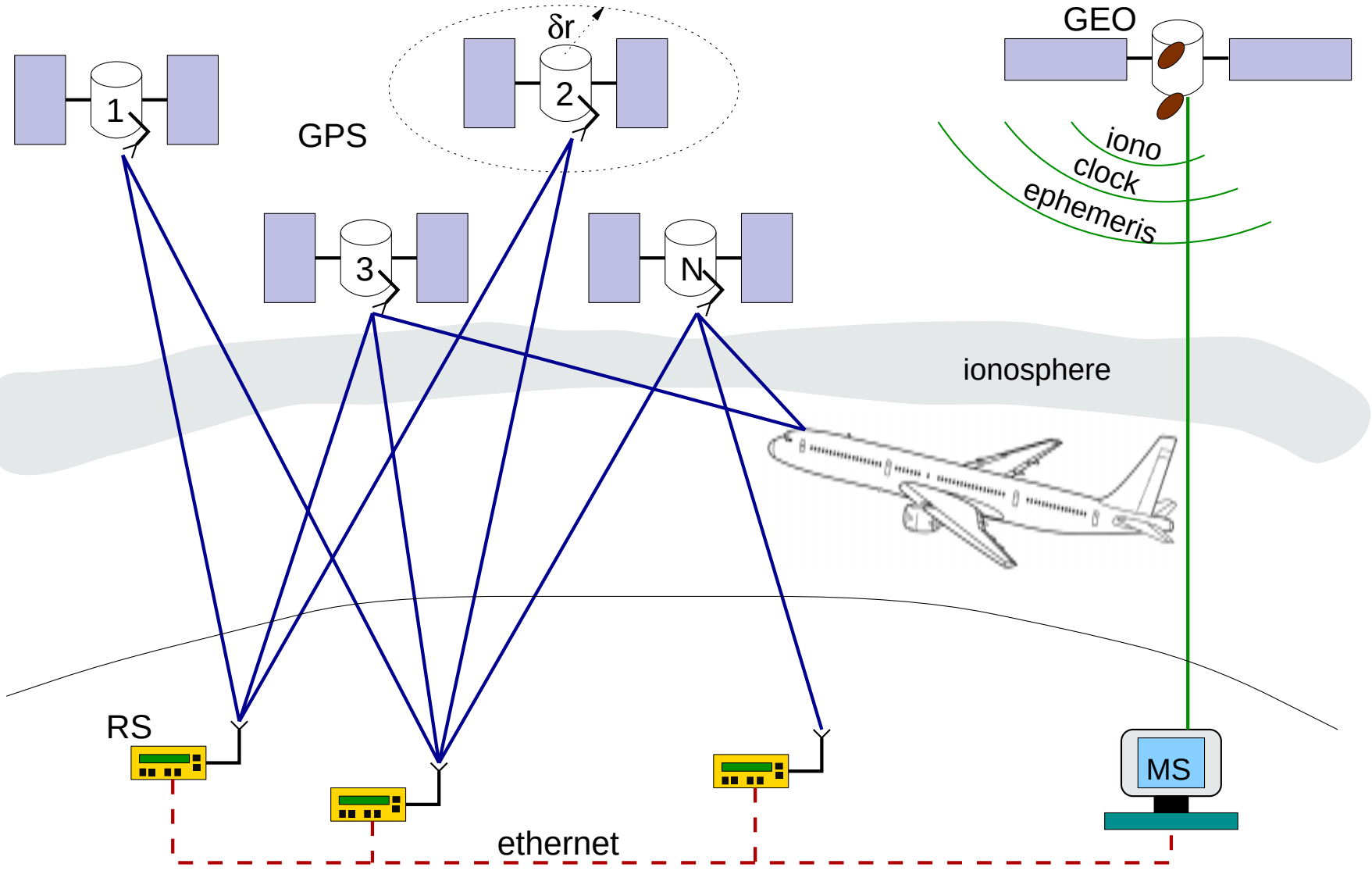
This presentation summarizes the WAAS ionospheric research conducted by the WADGPS Laboratory at Stanford University including primarily tomographic estimation, ionospheric data collection, and high fidelity WAAS simulation. The fundamental physical resource for the work is the National Satellite Test Bed (NSTB) reference network. The coupling of live data from the NSTB and the theoretical algorithms developed at Stanford has realized a working WAAS prototype with the capability of exploring operational difficulties and the sensitivities to natural variations such as the ionosphere. We present performance results for both live and synthetically disturbed conditions.

Electronic copy is available under "Presentations" at `http://www.stanford.edu/~ahansen/` on the Web.

Purview

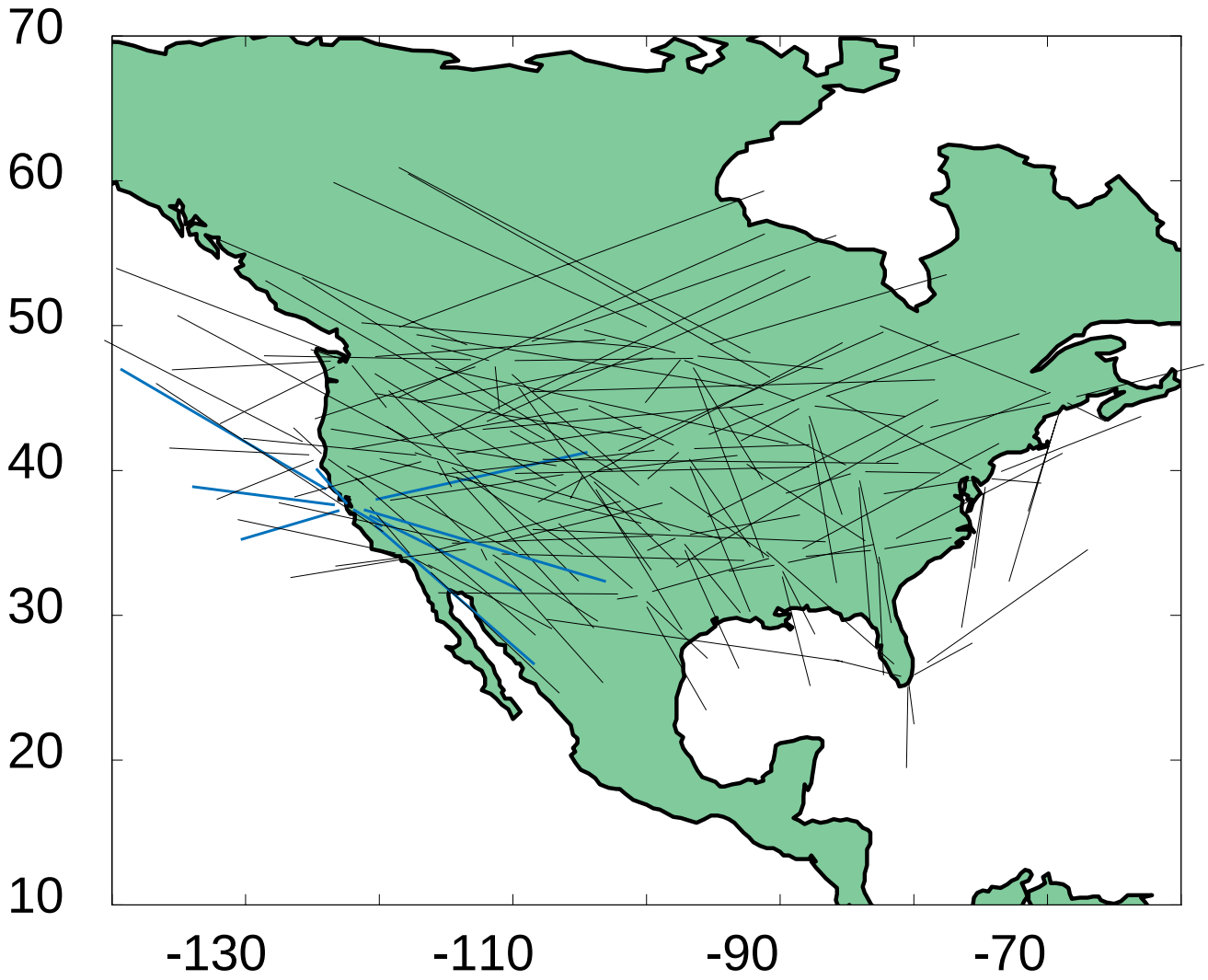
- Real-time tomographic estimation
  - real-time estimation algorithm
  - ionospheric reconstructions
  - hardware bias calibration
  - navigation performance
- Ionospheric data collection
  - continuous real-time ionospheric parameters (DDai)
  - post processing of 1Hz NSTB data (Nusawardhana)
- High-fidelity WAAS simulation facility (EPeterson)
  - ionospheric disturbances
  - clock/SA modelling
  - orbit disturbances
  - measurement noise

Wide Area Differential GPS Navigation (WAAS)



Wide area Ionospheric Corrections

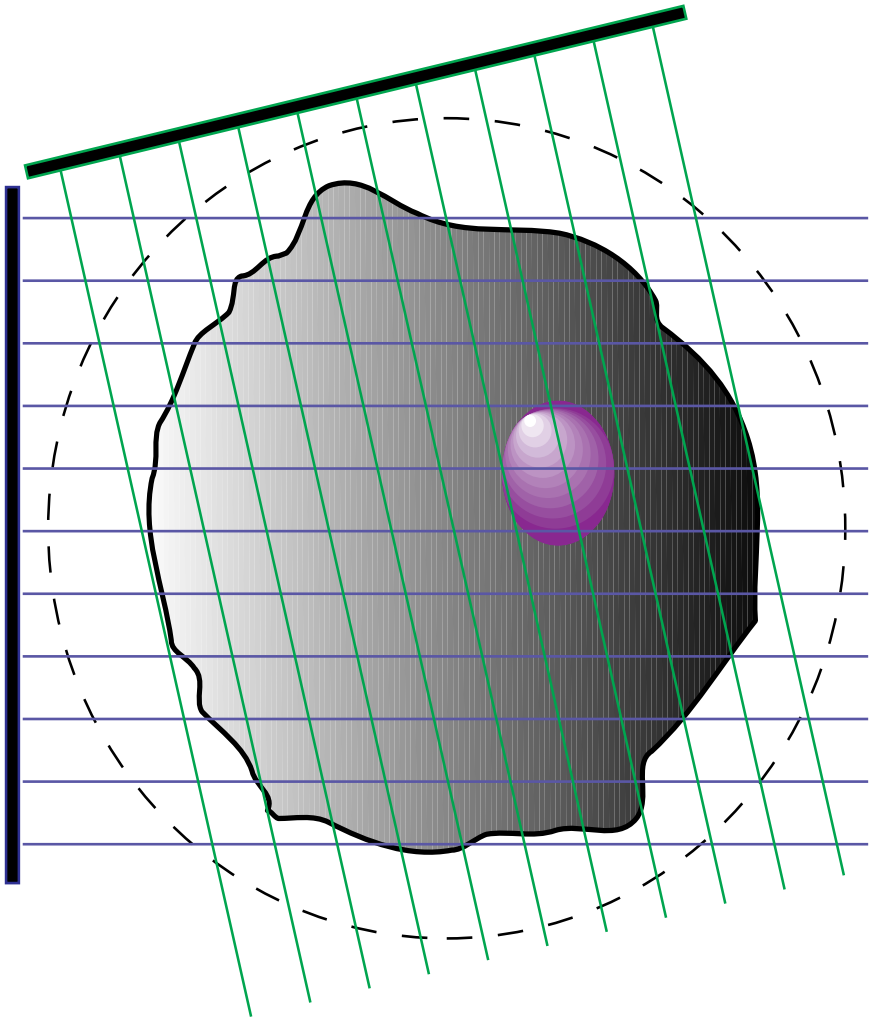
Reference observations spatially correlated by the ionosphere are assembled into continental scale estimates



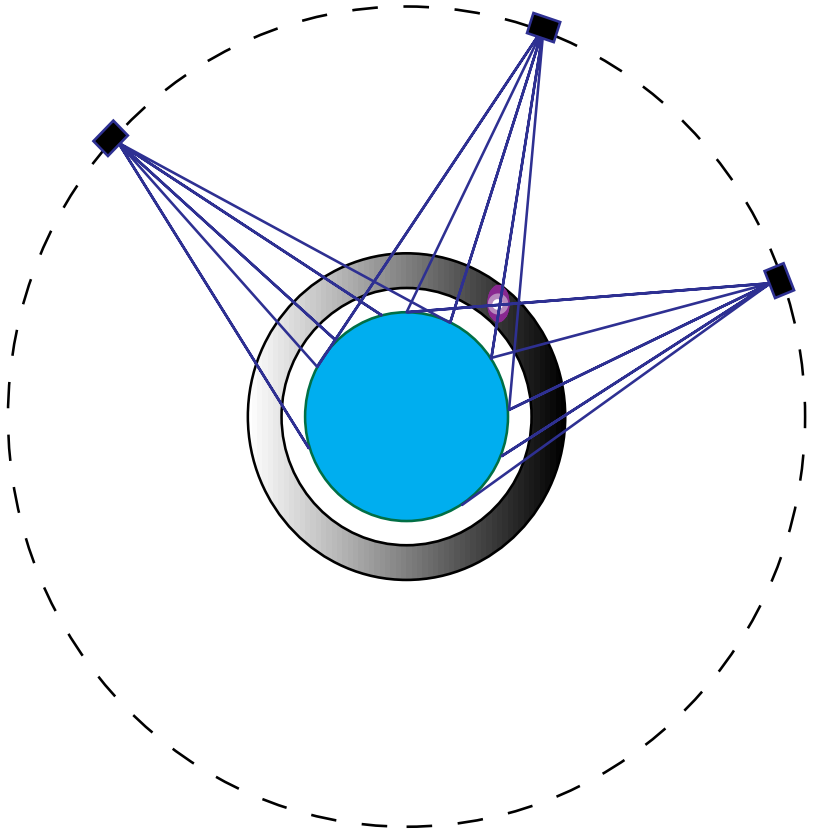
Correlated user ranging errors are corrected by projecting the estimate onto the local SV geometry

Tomography, Solution to an Inverse Problem

Medical Imaging (CAT scan)



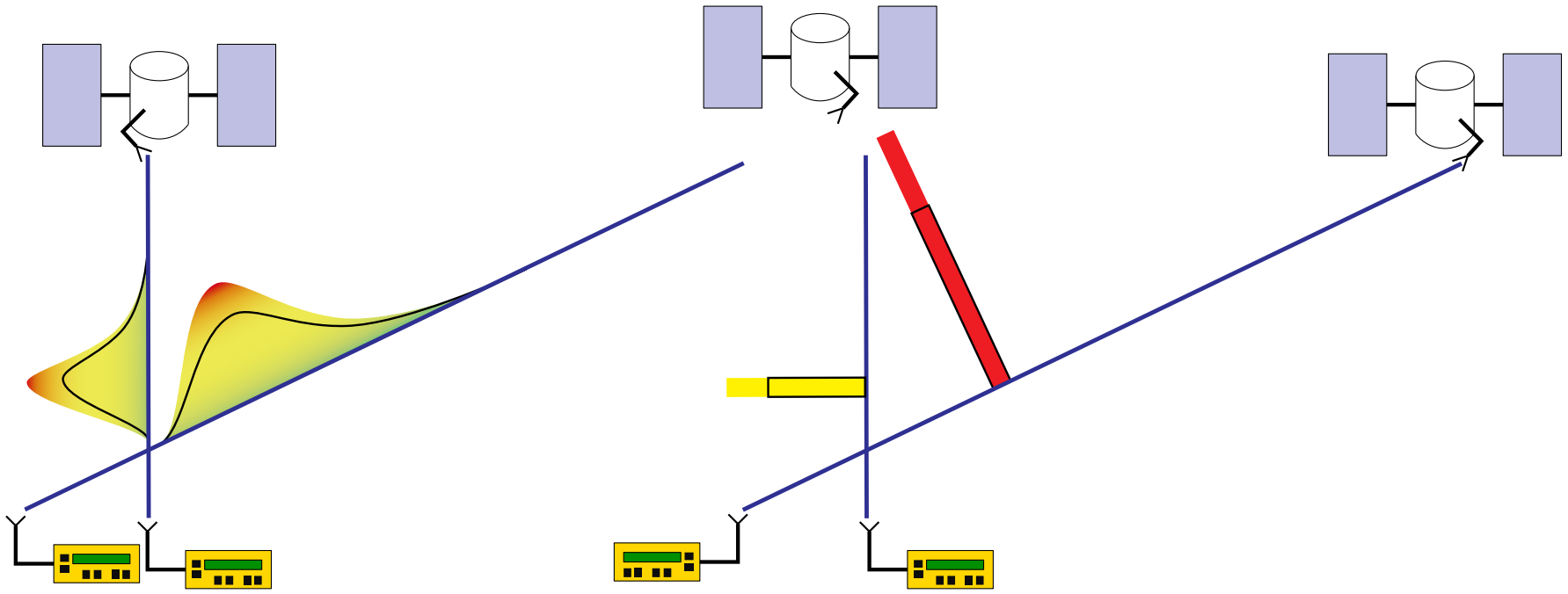
Ionospheric Imaging (GPS)



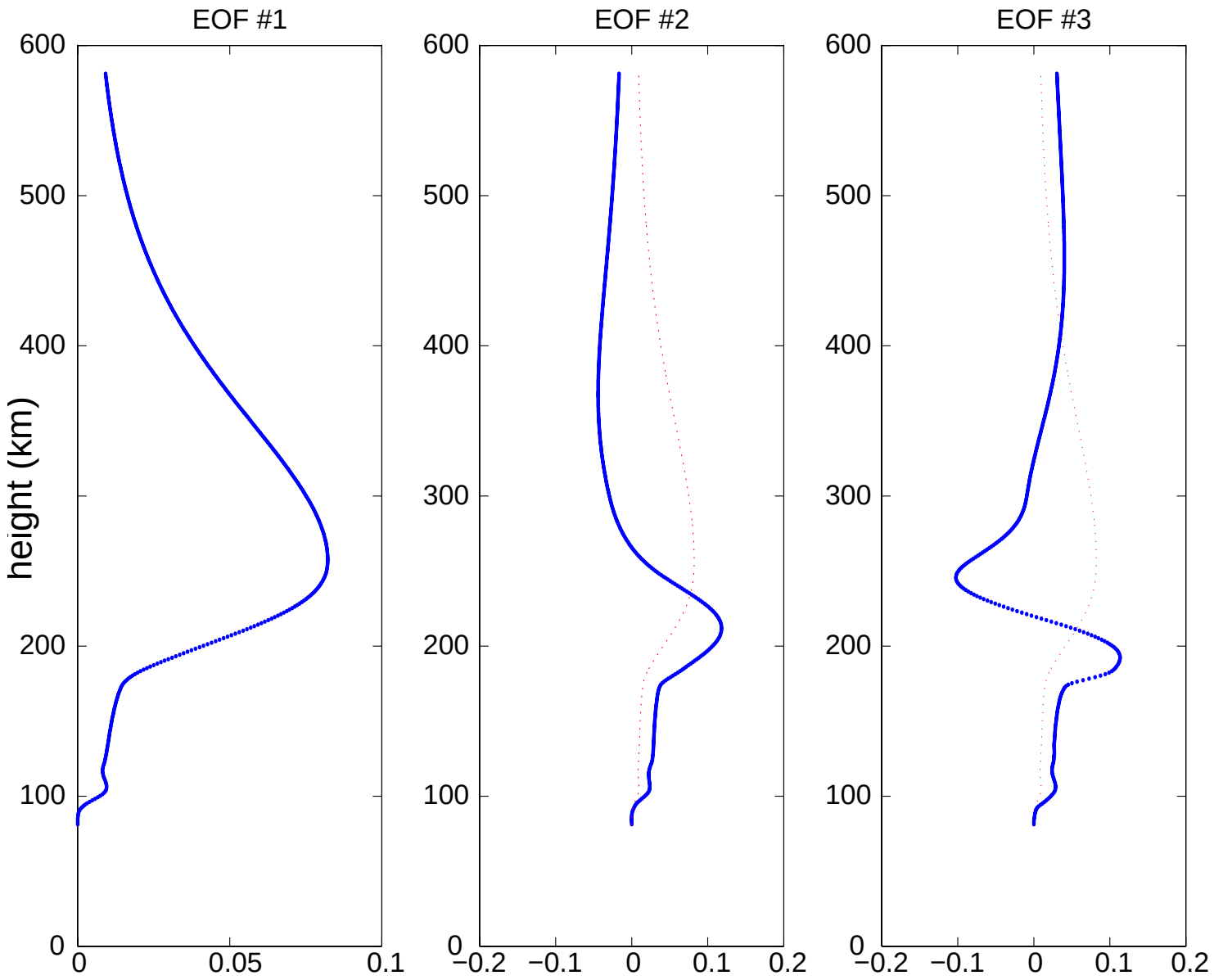
Real-time Ionosphere Estimation Methodologies

3D Tomography

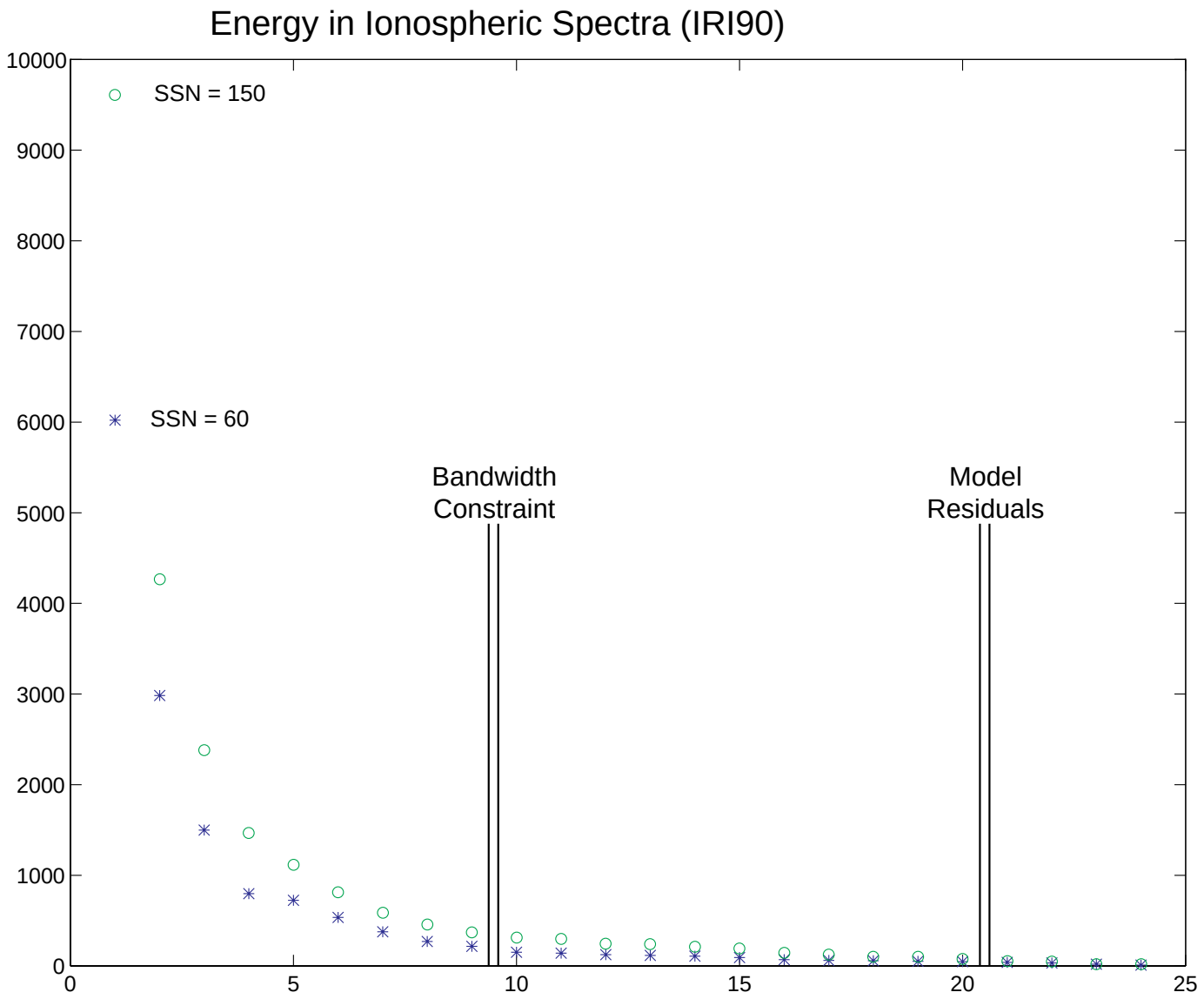
2D Thin Shell



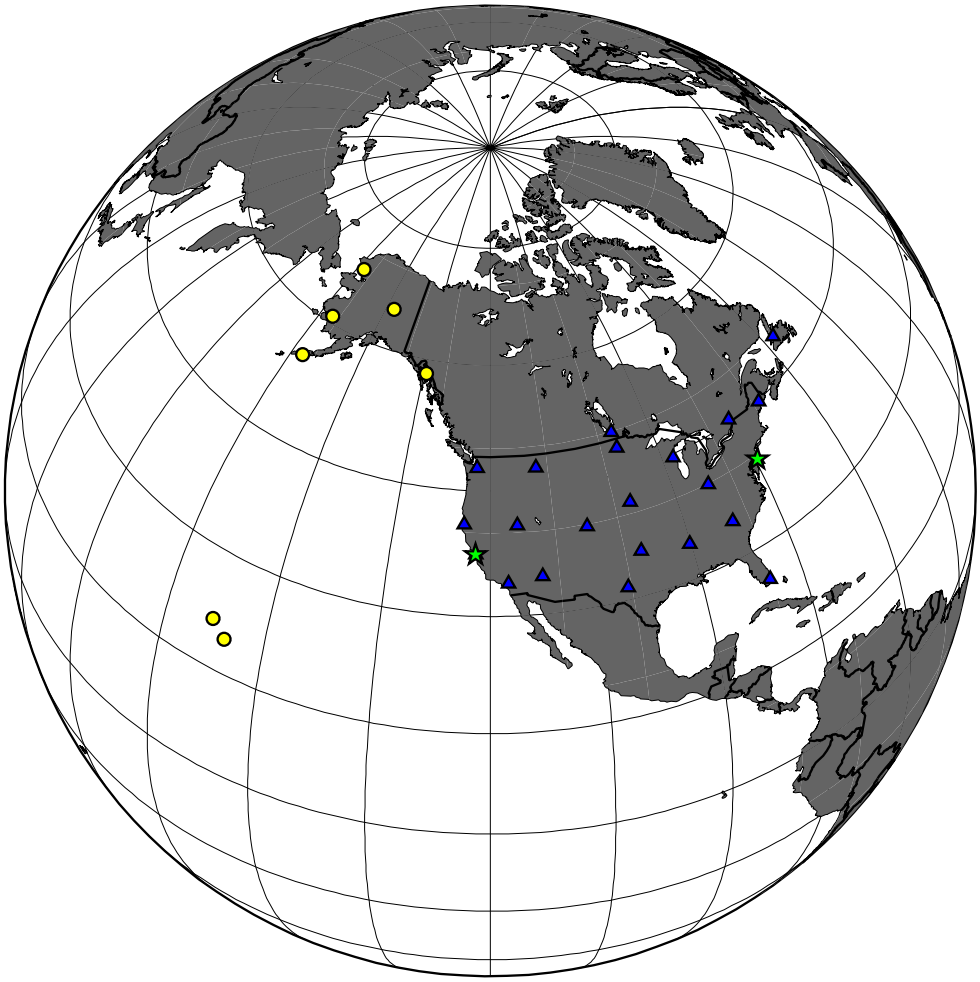
Vertical Basis of EOF's



Energy Spectrum of Electron Density Distribution



National Satellite Test Bed (NSTB)

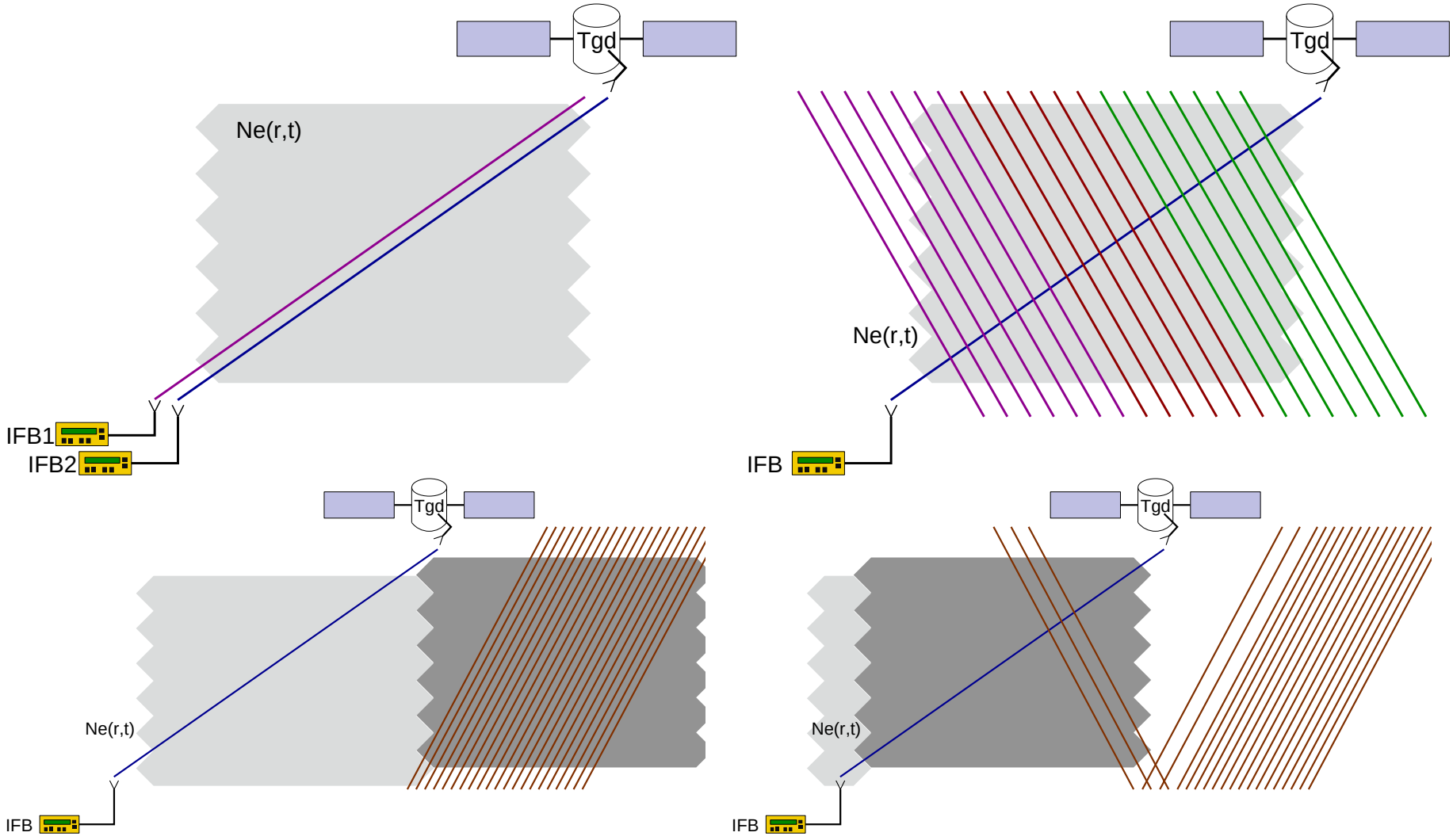


Network of dual-freq receivers (Trimble, Ashtech, NovAtel) connected in real-time via multicast UDP to central server platform (DEC Alpha 4100s).

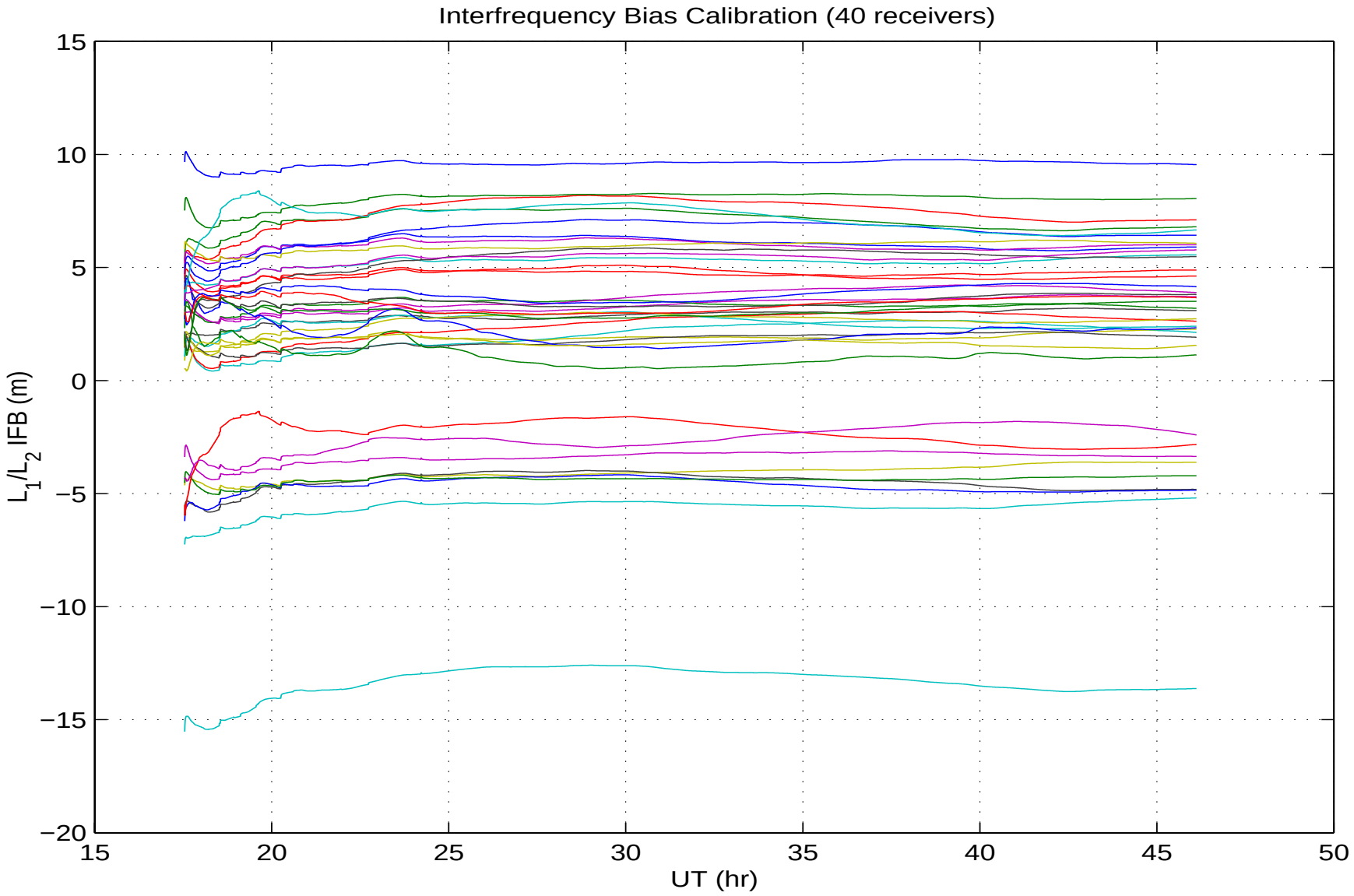
Software IFB Calibration

- Relative IFBs simple if receivers collocated
- Single network wide bias is tolerable in position domain ($\sim$clock)
- Remote IFB calibration necessarily relies on a model ionosphere
- IFB must pass through a non-linearity to be observed
- One such transformation is obliquity factor (2D iono model)
- Using a 3D model, receiver IFB is addressed directly

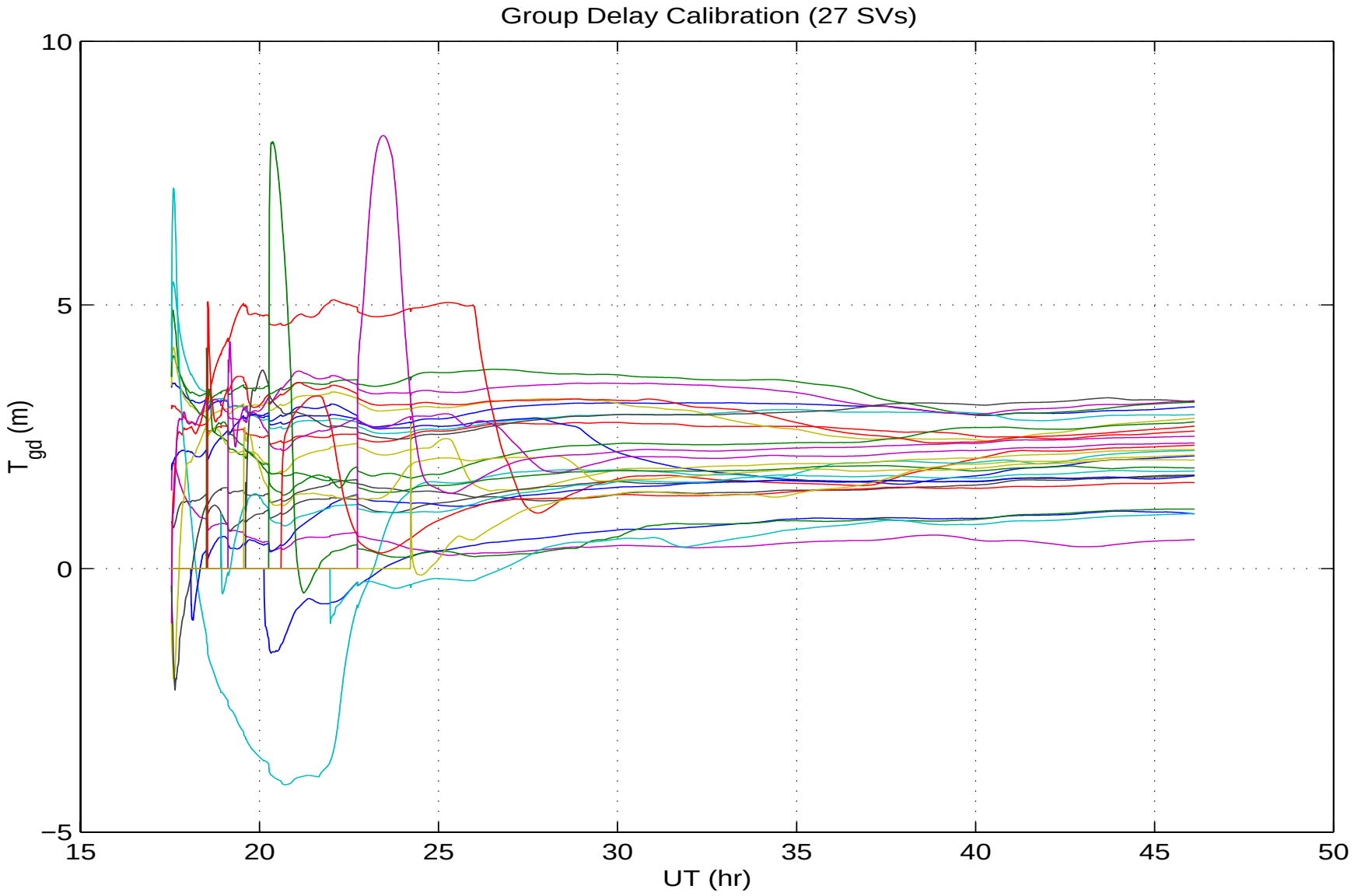
Interfrequency Bias Calibration



Tomographic IFB Calibration

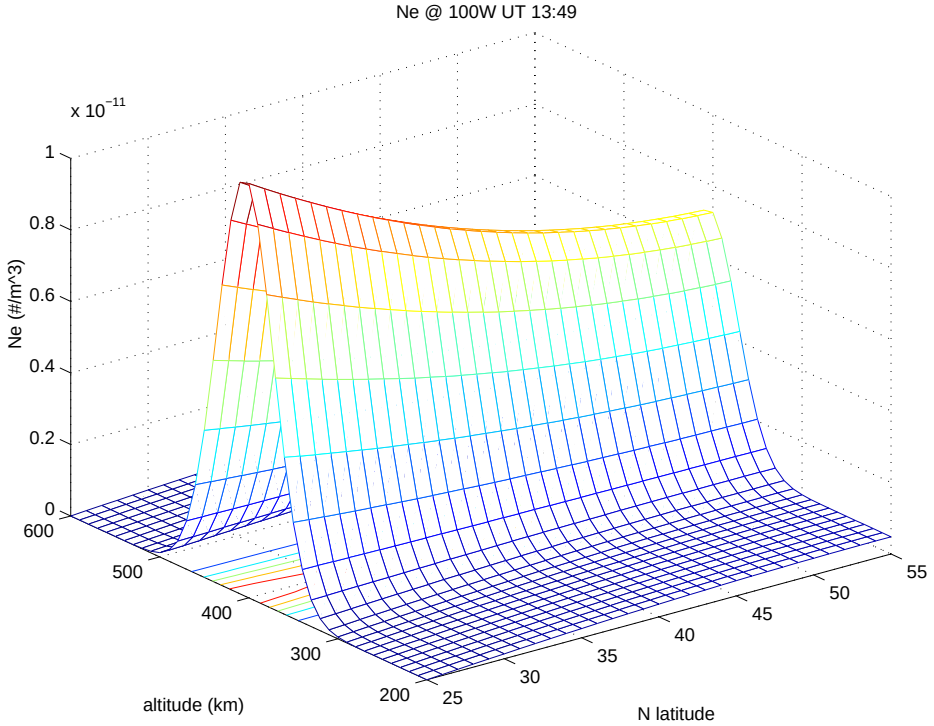


Tomographic T_{gd} Calibration

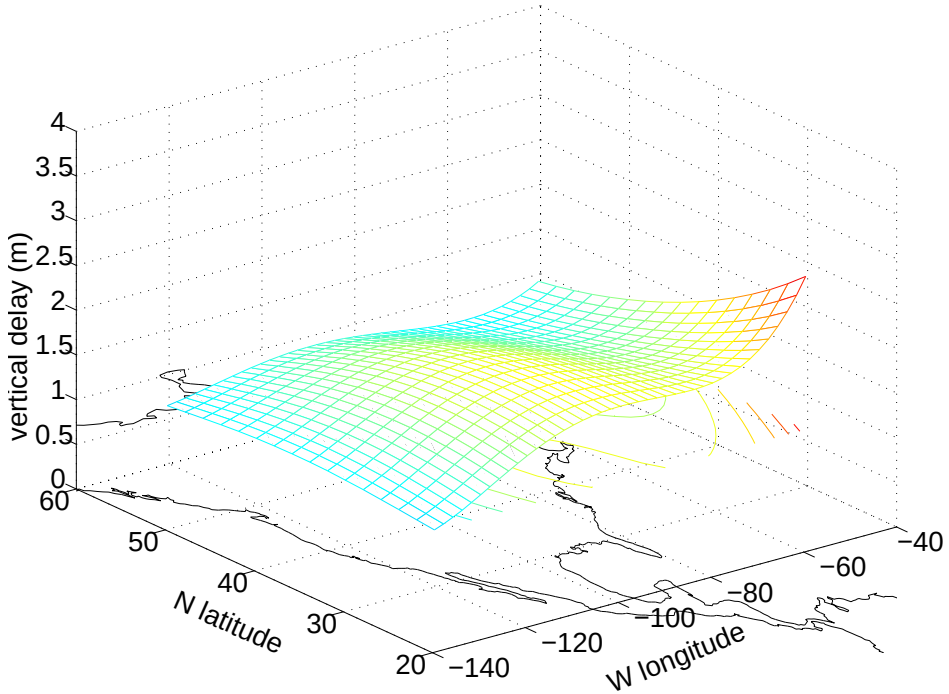


Real-time Tomographic Reconstructions

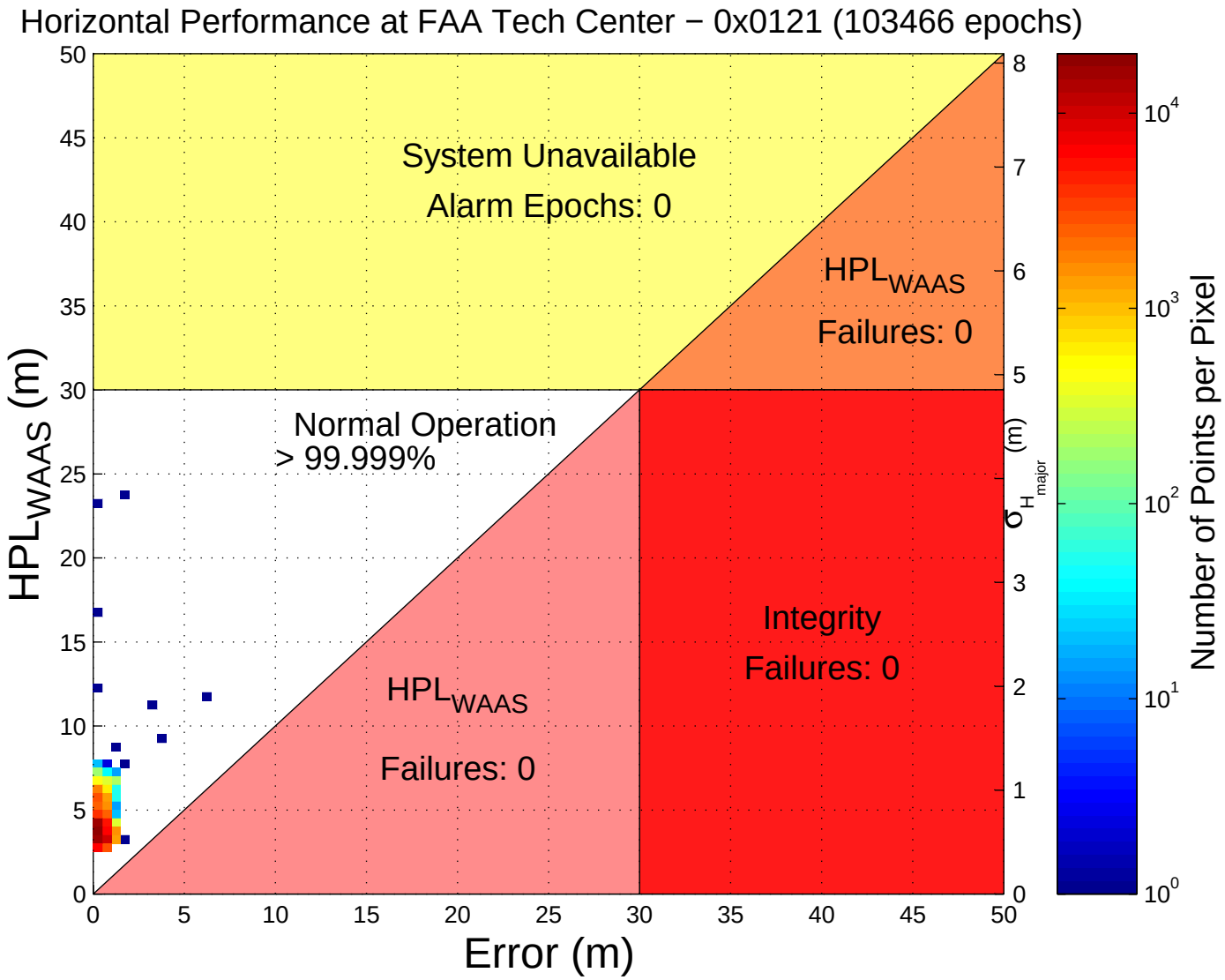
Electron Density @ 100W



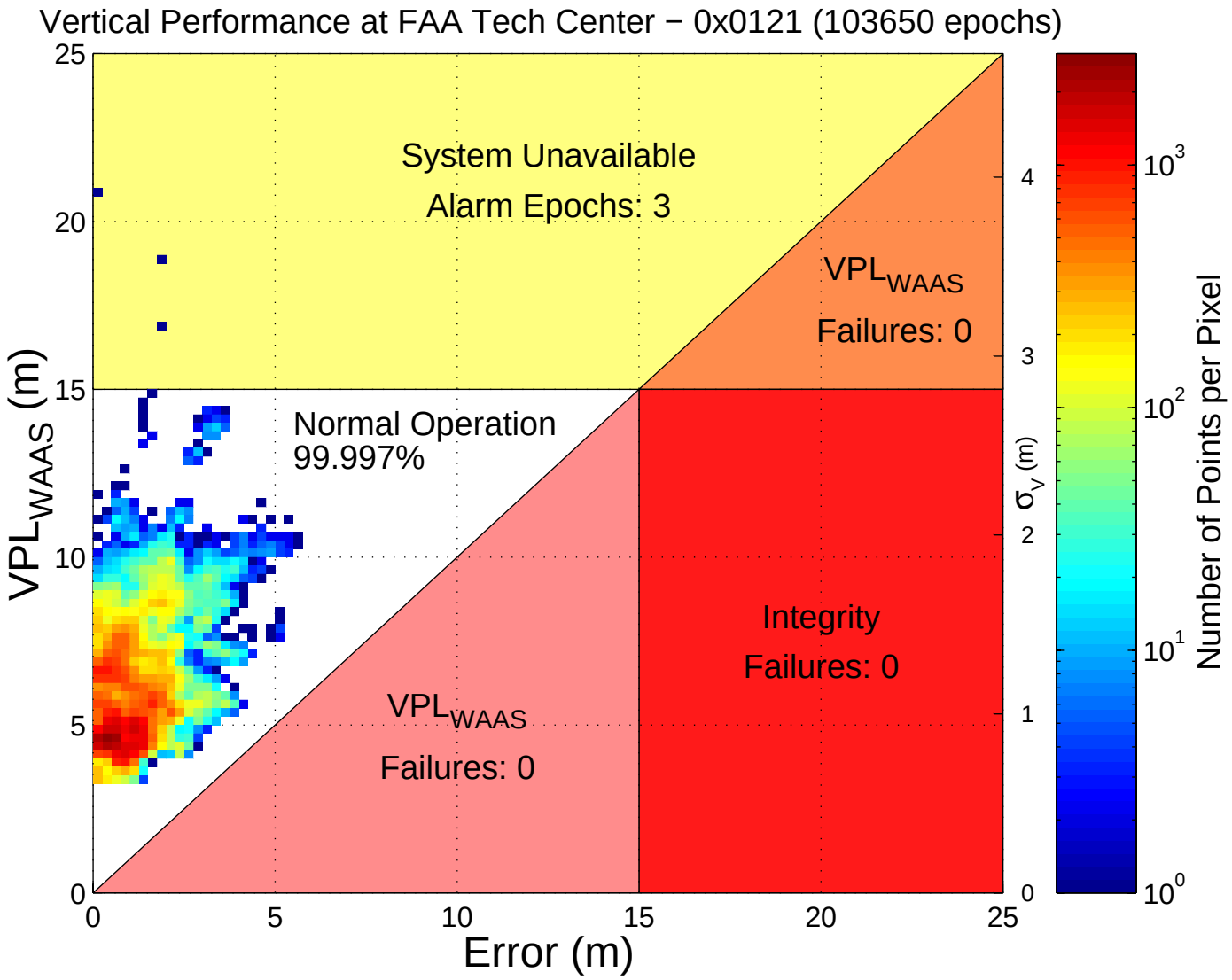
Vertical Reduction @ 350km



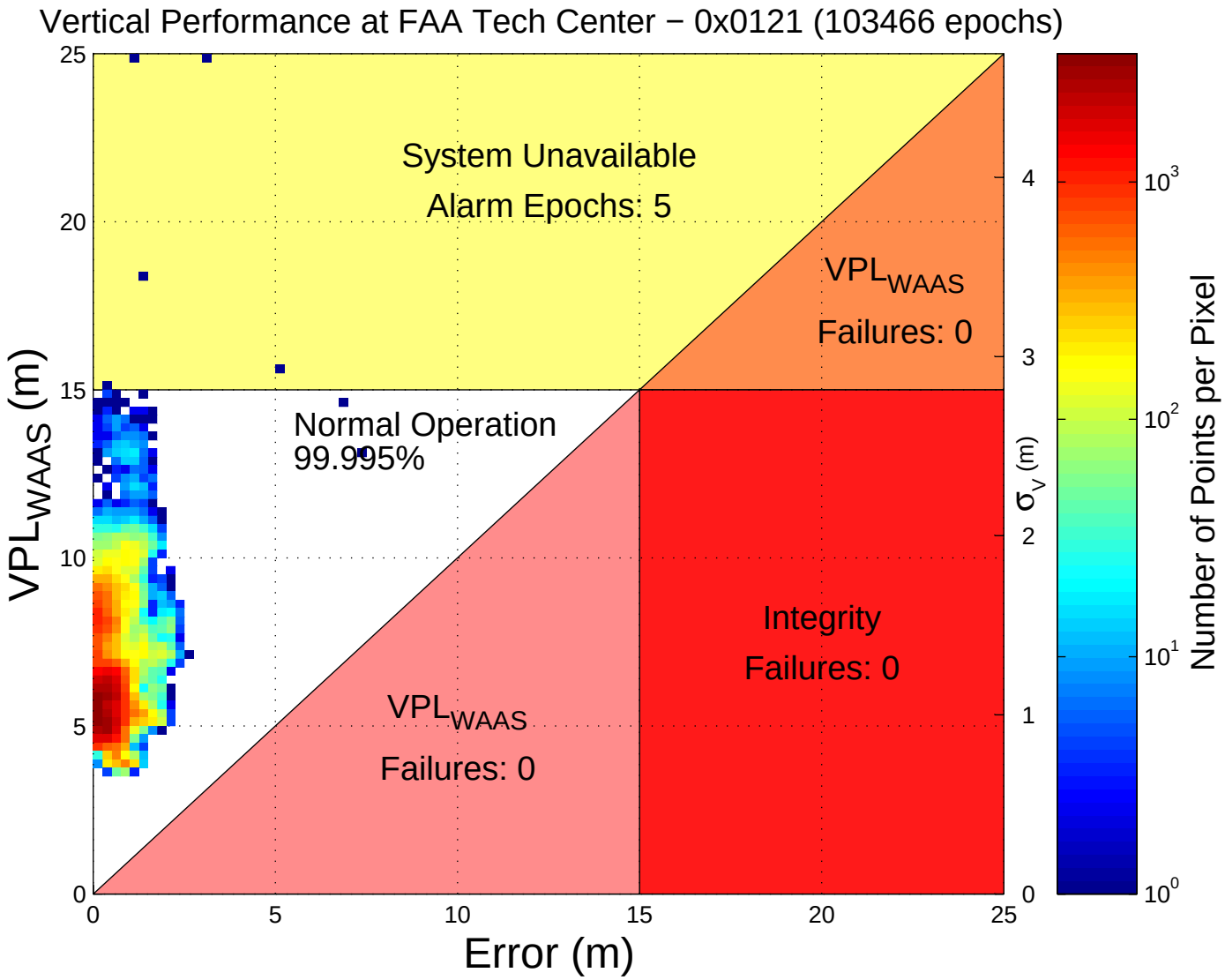
Horizontal System Performance (25 March 1998)



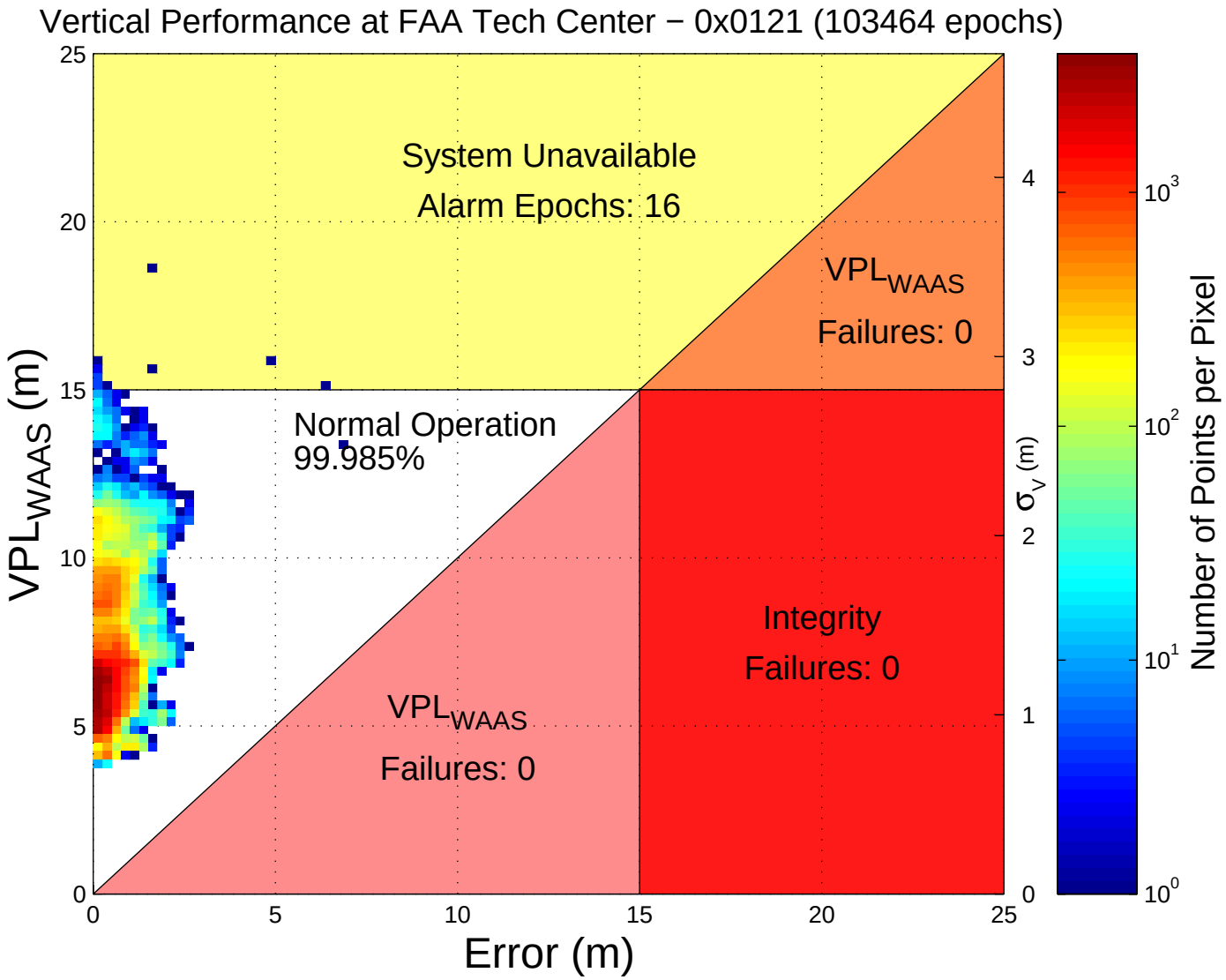
Vertical System Performance (25 March 1998)



Vertical System Performance, Tomo IFBs (25 March 1998)



Vertical System Performance, Dual freq (25 March 1998)



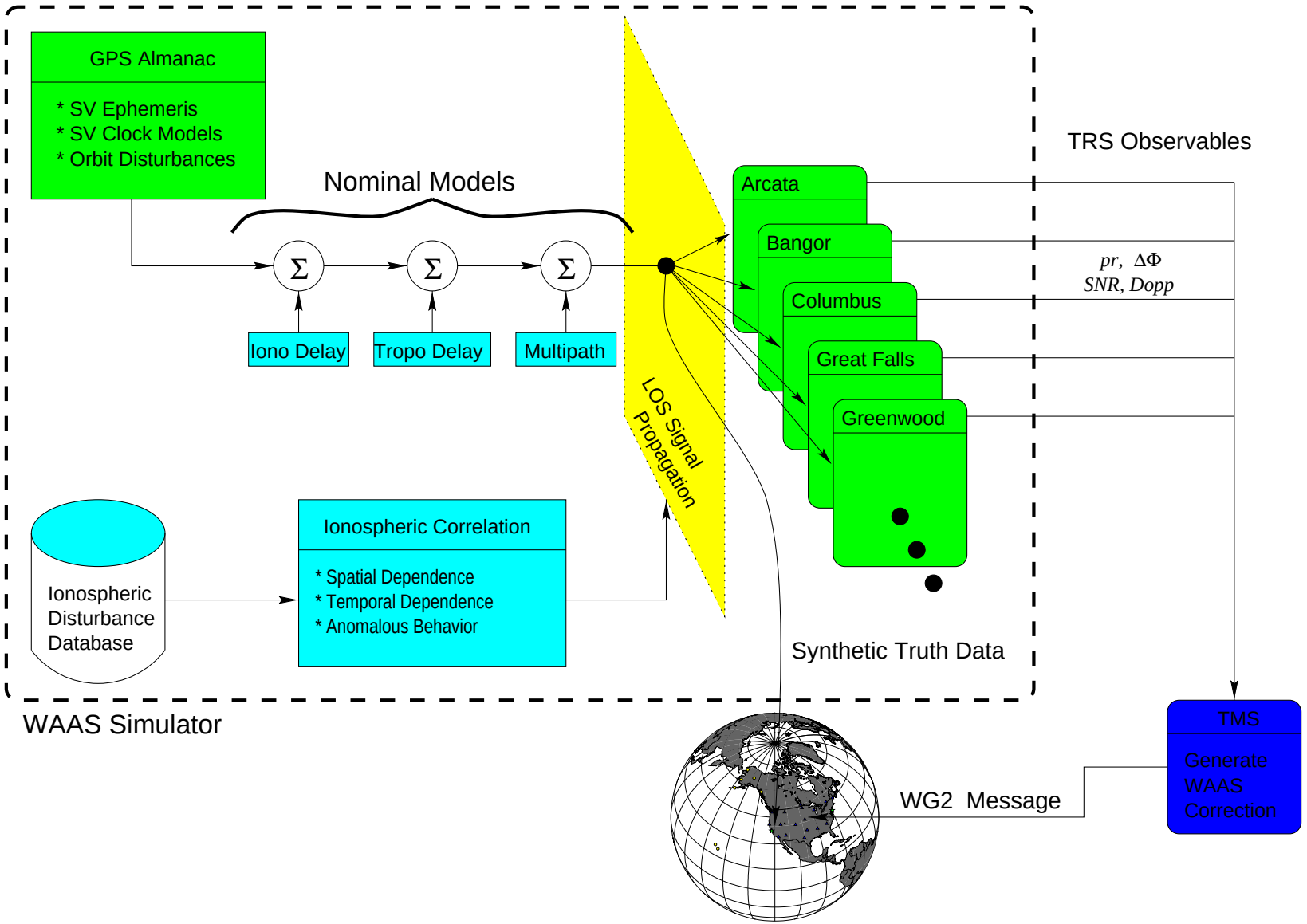
Ionospheric Data Collection (NSTB)

- 40+ calibrated (IFB,SNR) receivers at 29 locations
- Dual-frequency carrier smoothed code (multipath free)
- Multi-resolution (10/300/1800 sec) filter bank for data reduction
- Receiver archive data format
  - time history per SV pass
  - entries are

time	PRN	El	Az	I_{L_1}	$N\lambda$	σ	slip

  - $1 - 1\frac{1}{2}$MB per day ($\sim$ $\frac{1}{2}$GB per year)
  - slip index denotes detected bias break not a receiver flag
- High level (`Matlab`) archive interrogation

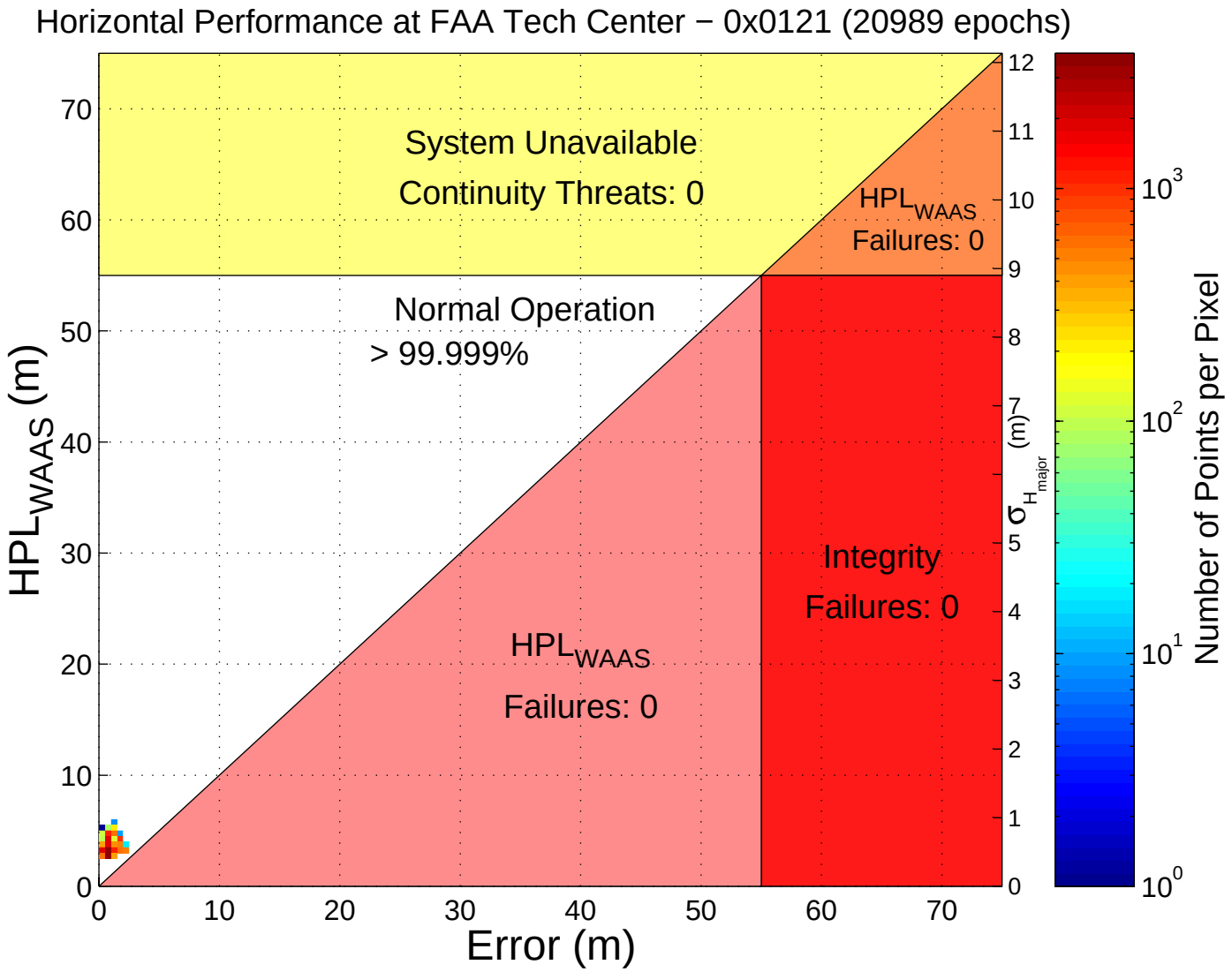
Software Simulator for WAAS



Ionospheric Disturbance Scenario

- Nominal models
  - 26 SV Constellation (no GEOs)
  - background iono model based on PIM
  - SNR receiver model with live data, Dai (IEEE PLANS, 1998)
  - tropo model from WAAS MOPS
  - multipath model, Enge, et.al (*Proc.* IEEE, 1995)
  - 27 reference receivers, 2 monitors
- Injected electron density enhancement
  - Gaussian bubble layer at 300(km)
  - 500 (km) 1-σ centered at 35N, 100W
  - amplitude is 25% of nominal
  - fixed in solar-magnetic coordinates
- Truth available in both pseudo-range and position domain

Horizontal System Performance (Simulated Iono)



Vertical System Performance (Simulated Iono)