Development of GBAS Ionosphere Anomaly Monitor Standards to Support Category III Operations

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Presentation for ENRI International Workshop on ATM / CNS
Tokyo, Japan

November 11, 2010

Presentation Schedule

- Background
- Previous Results
- Simulation Details
  - High Fidelity Plasma Bubble vs. GBAS Simulations
- Latest Results
- Conclusions

Background

Motivation

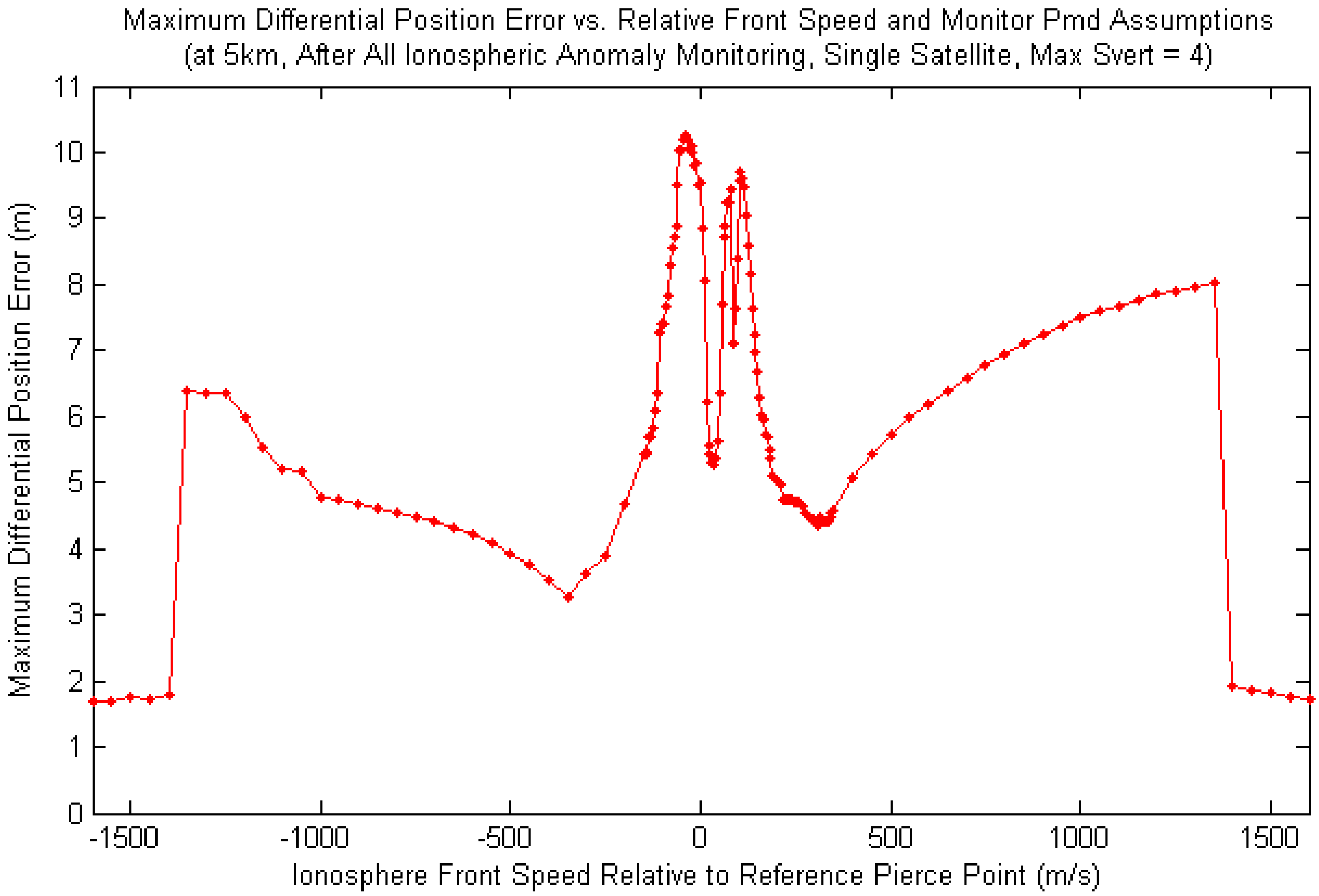
- **Ionospheric Anomalies Affect GBAS**
  - Travelling ionosphere disturbances & equatorial plasma bubbles
- **New Methodology for GBAS to Support Cat III Airworthiness**
  - Primarily due to ionospheric anomalies
  - Additional airborne and reference iono monitors standardized
  - Airworthiness based on set of Air and Ground functional requirements
- **Are the latest GBAS standards sufficient to protect a GBAS user from position errors due to ionospheric anomalies in Category III weather conditions?**
  - This extension of previous work aims to assist in validation of the baseline GBAS standards (ICAO SARPS, Annex 10, and RTCA DOs)
    - Is a maximum vertical error ~10m feasible?
    - What are worst case range errors for GBAS signal model use?
    - Is the worst multiple satellite impact bounded by worst two satellites?

Background

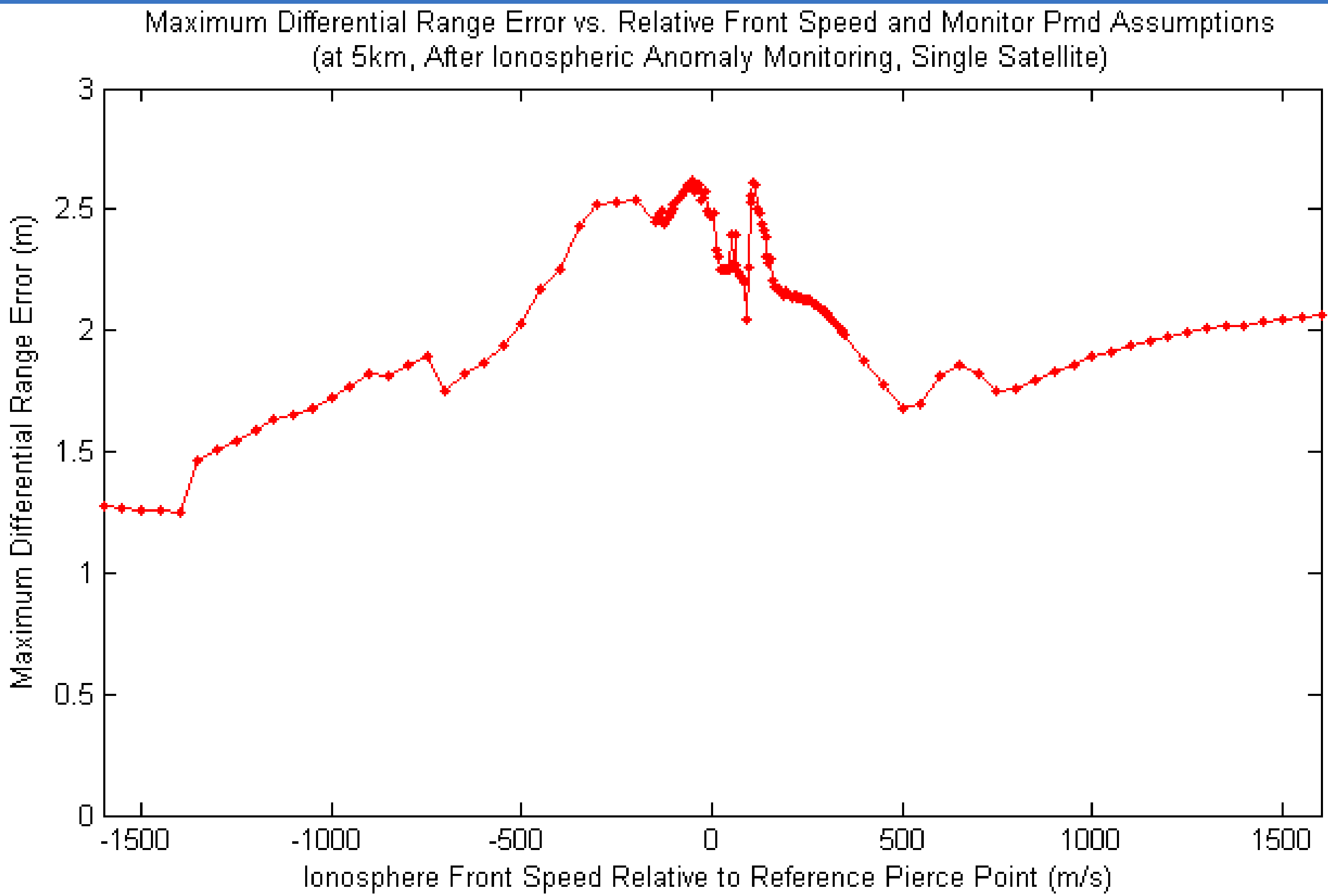
- **Industry Ionospheric Anomaly Threat Models**
  - Wedge gradient models North American anomalies
  - Plasma bubble models equatorial anomalies
- **Simulation Methodology**
  - Range domain wedge simulation
  - Three dimensional plasma bubble simulation
  - Search exhaustively for worst case phasing / timing / error
- **Air and Ground Monitors Simulated**
  - RTCA DO-253C and Draft Changes to ICAO SARPs Annex 10
  - Airborne: CCD, RAIM, dual position solution monitor, geometry screens
  - Reference: CCD, absolute gradient (VPL, LPL, S_{vert}, S_{vert2}, S_{lat}, S_{lat2})
- **Assumptions**
  - 10^{-9} missed detection probability simulated
  - Plasma bubbles are a relatively regular occurrence

Previous Results

Example Results: Worst Position Error



Example Results: Worst Range Errors



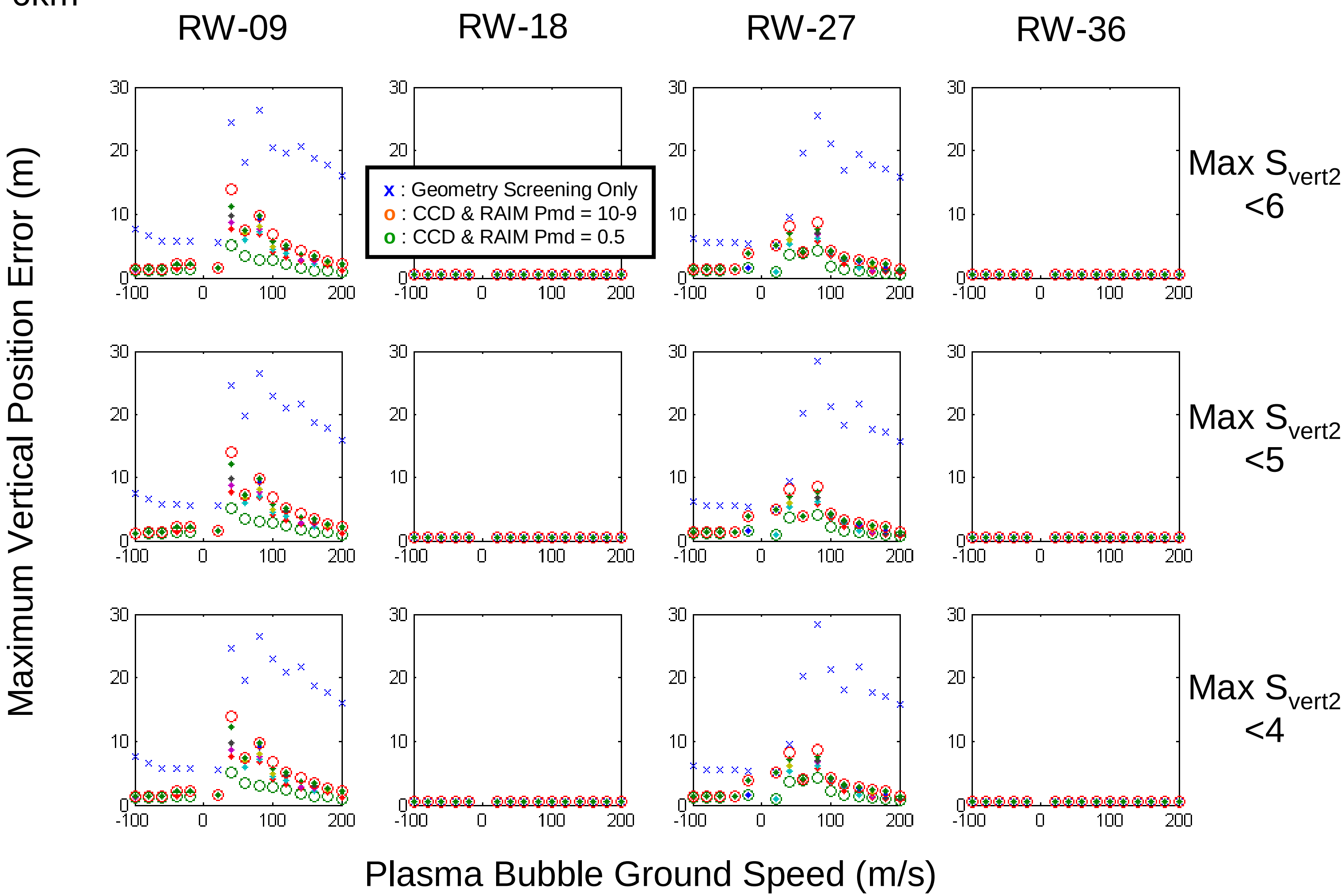
Initial Bubble Results: Worst Vertical Error

Maximum Vertical Error vs. Dist from Reference, Approach Direction, Max Svert2, Pmd

AirCCD + RefCCD + RAIM, Max S_{vert1}=4, FASVAL=10m, AirSpeed=80m/s

NO RAIM for ADDITION, NO GROUND GRADIENT MONITOR

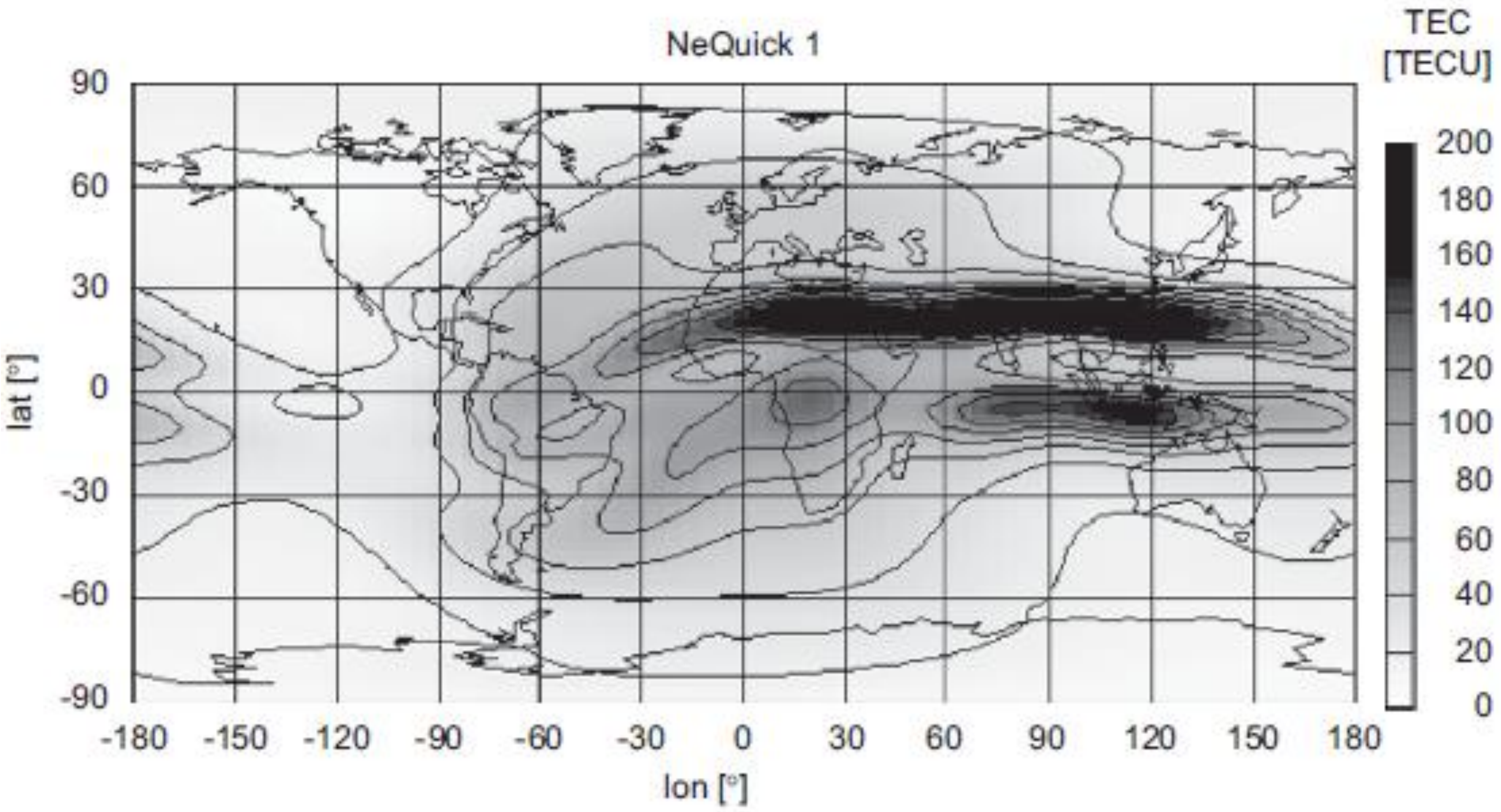
D=6km



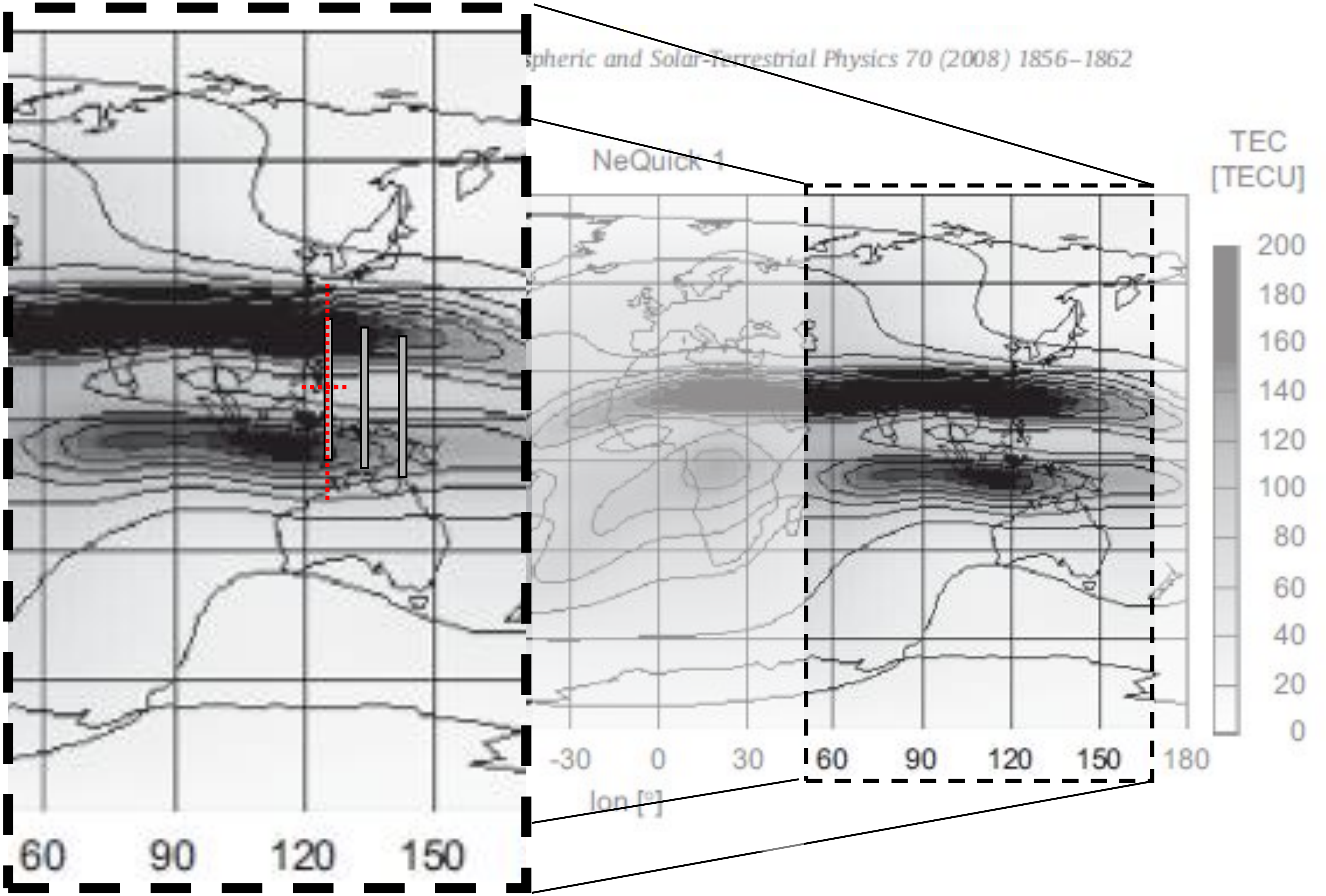
Simulation Details

Background Ionosphere Simulation

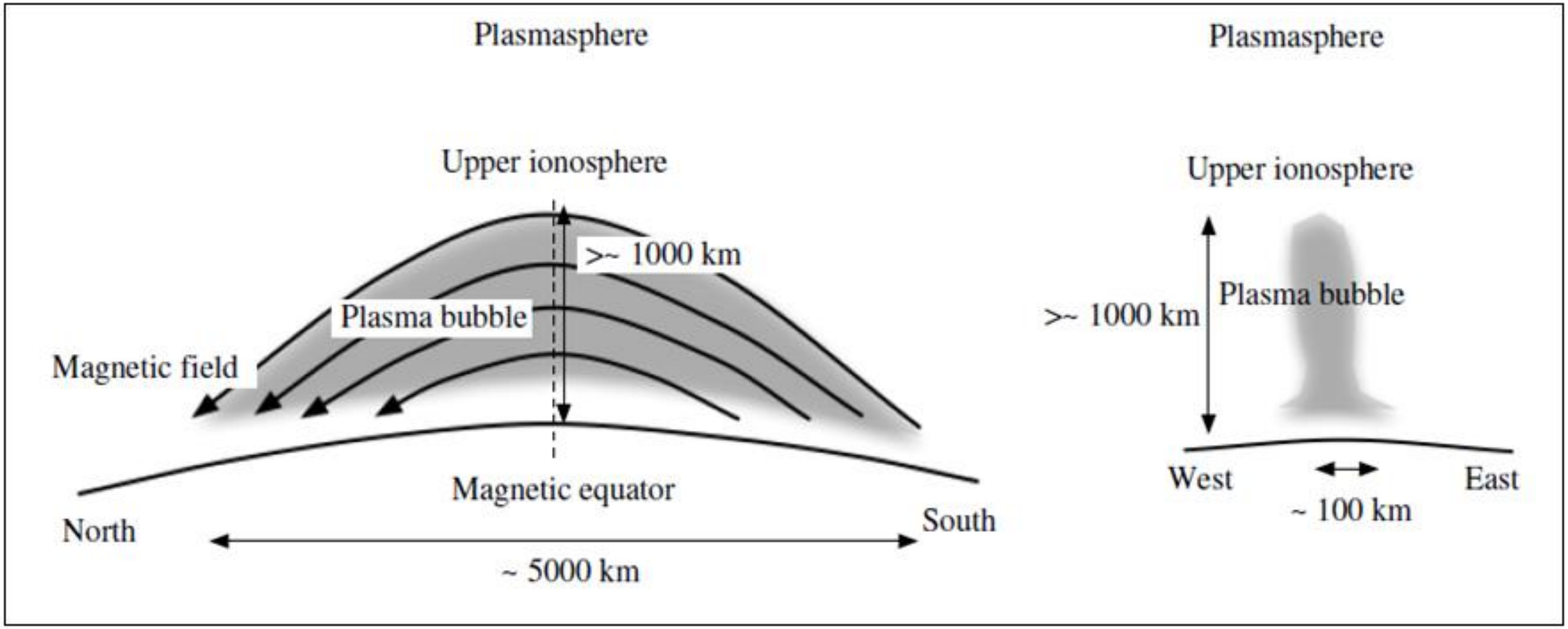
B. Nava et al. / Journal of Atmospheric and Solar-Terrestrial Physics 70 (2008) 1856–1862



Background Ionosphere Simulation



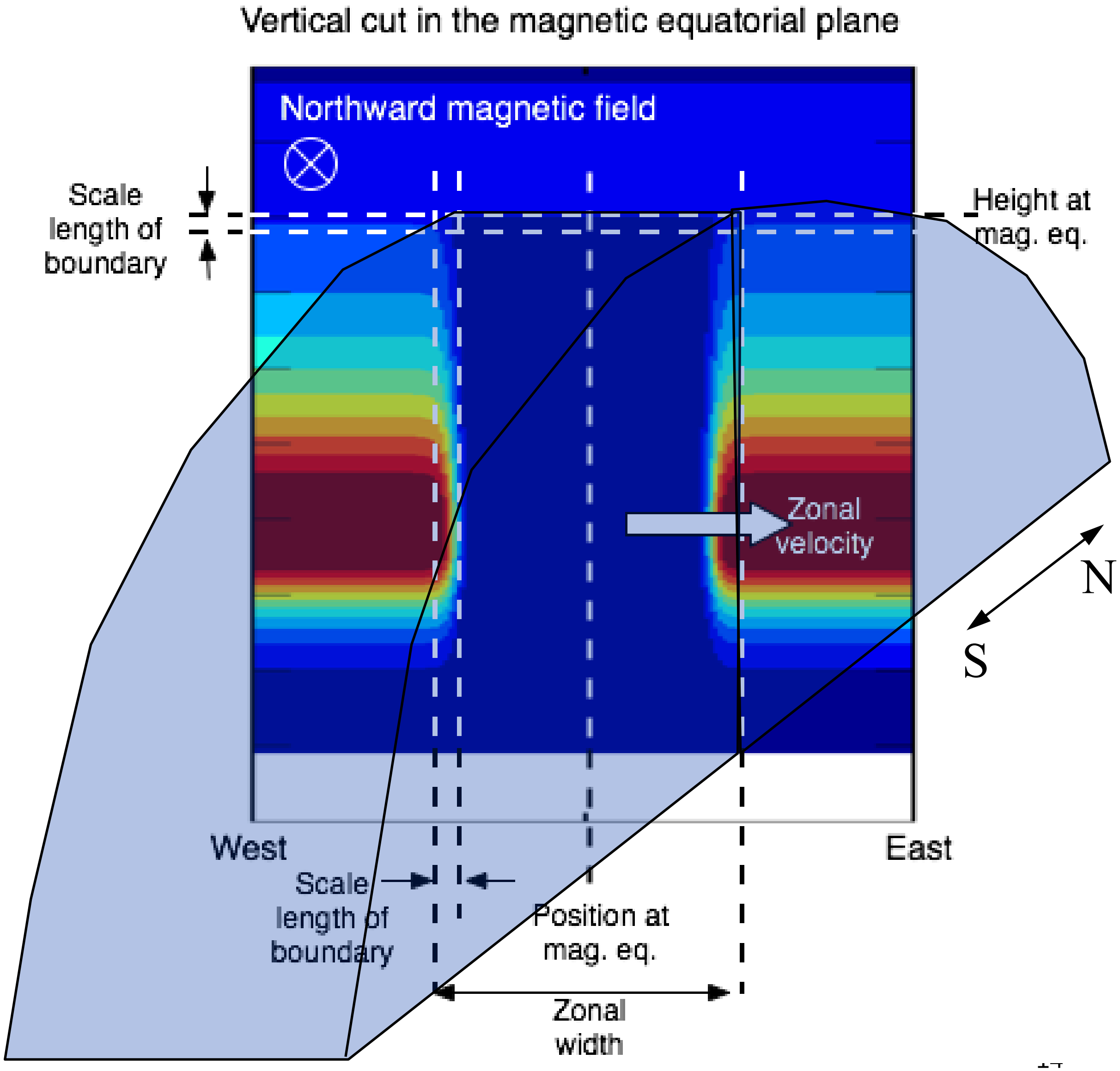
Typical Plasma Bubble



- Fan shaped N-S depletion region with contours that follow magnetic field
- Finger shaped W-E cross section
- Maximum height at magnetic equator
- Irregular transition regions

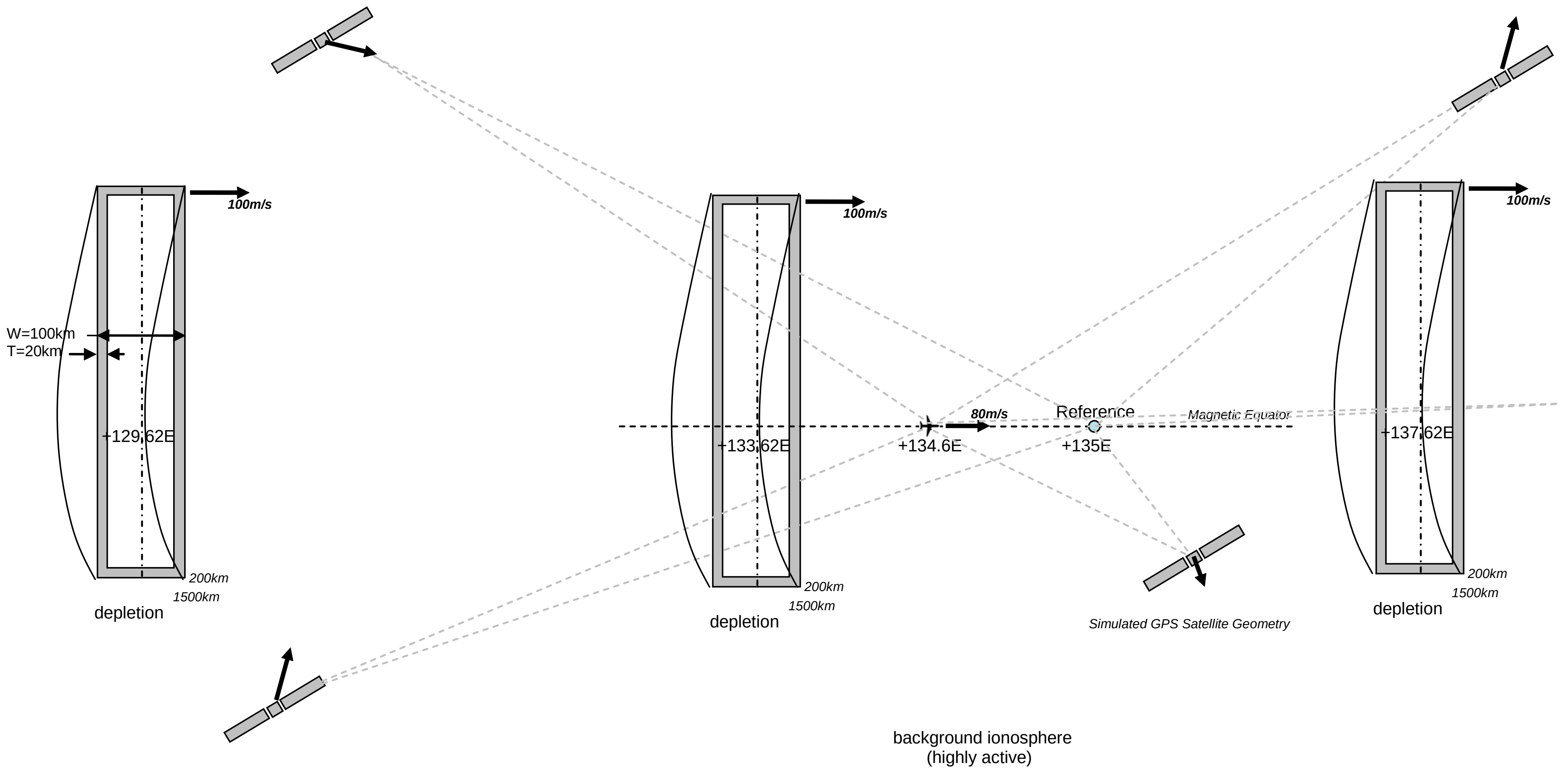
Plasma Bubble Simulation Model

- Modeled as rectangular depletion in W-E direction
- Dipole magnetic field model used for N-S shape
- Constant, linear boundary length
- Constant depletion region shape moves zonally

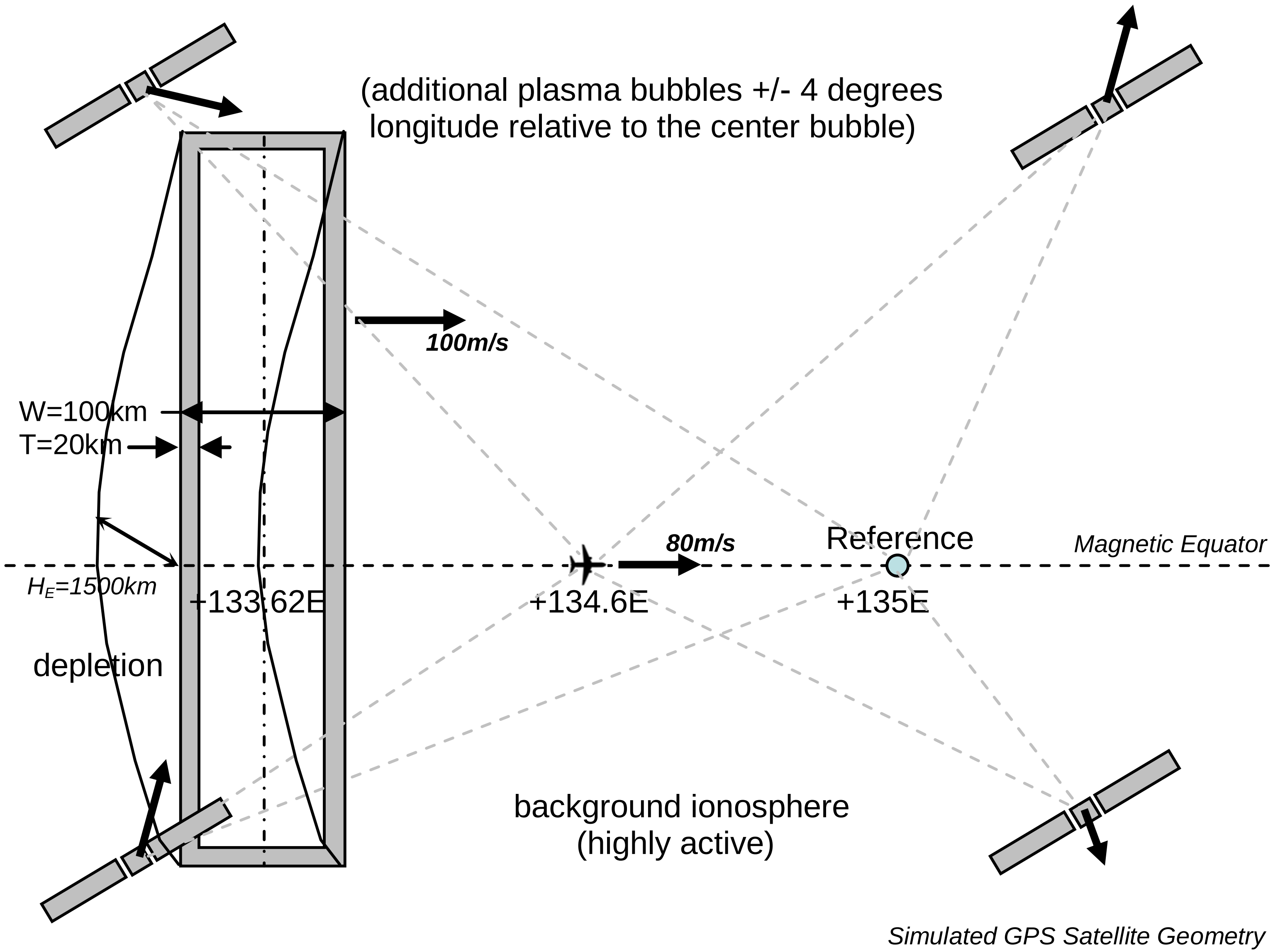


Bubble Scenario Visualization

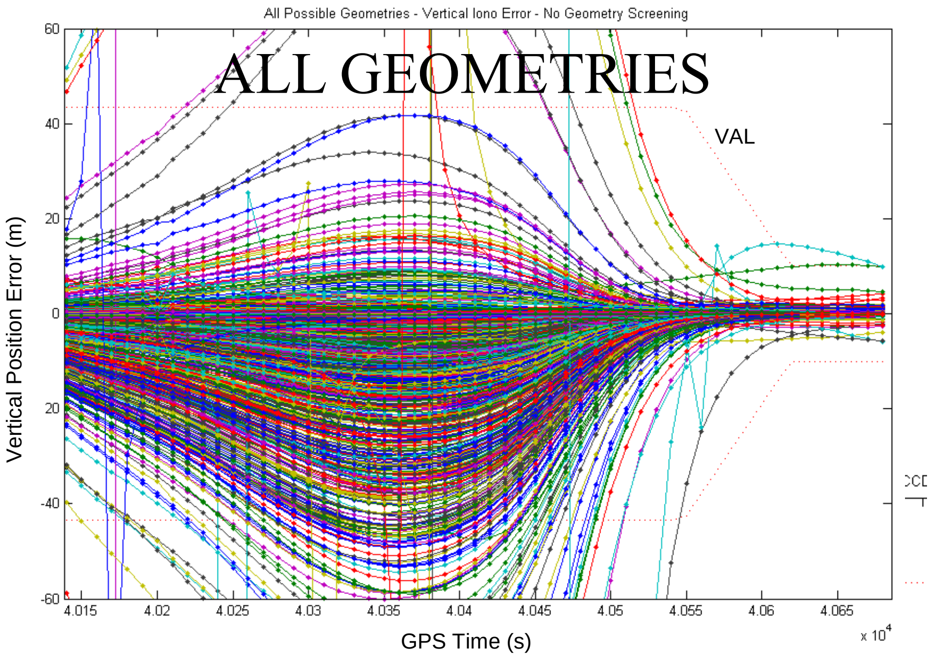
- **Three identical bubbles in each simulation, at fixed intervals**

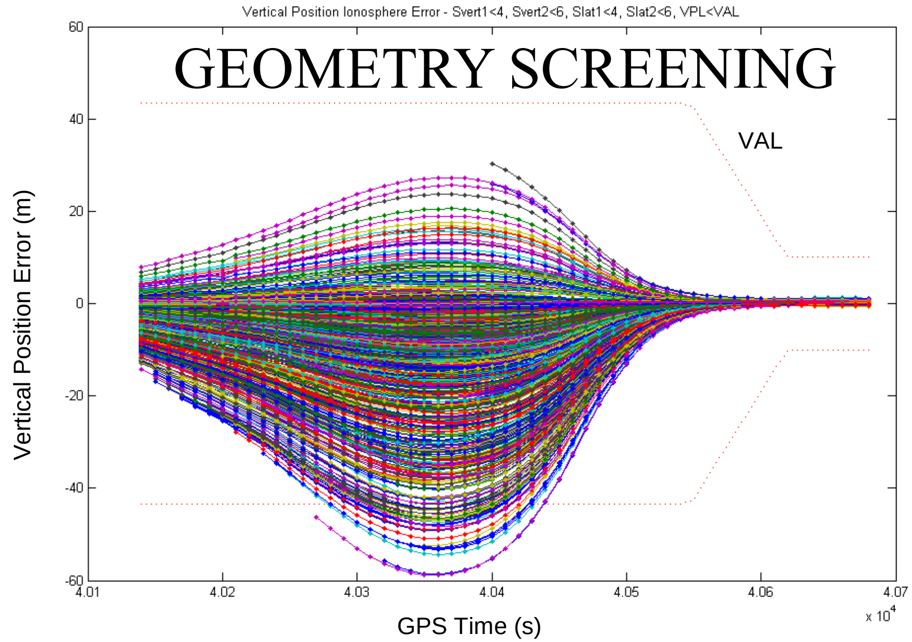


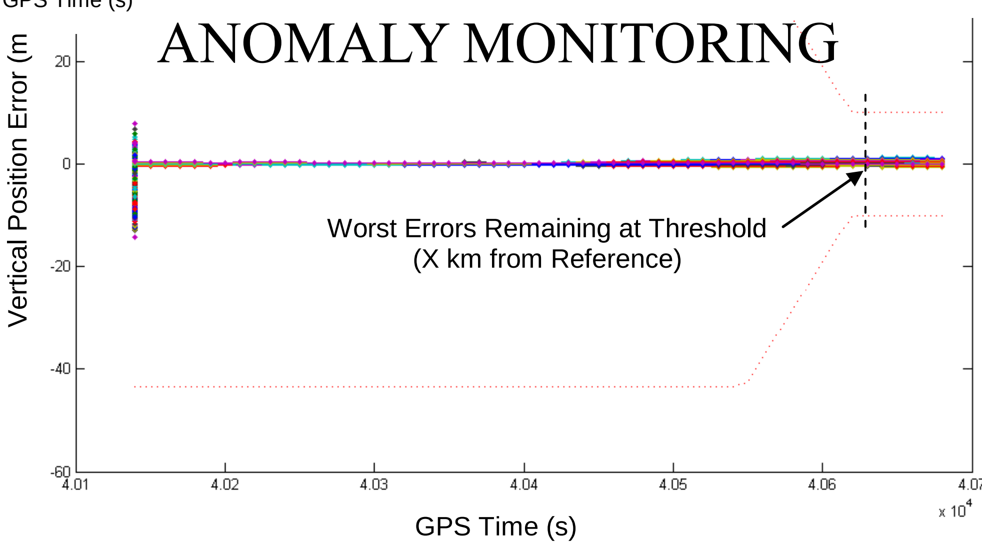
Bubble Scenario Visualization, RWY 09



Example Results for a Single Scenario



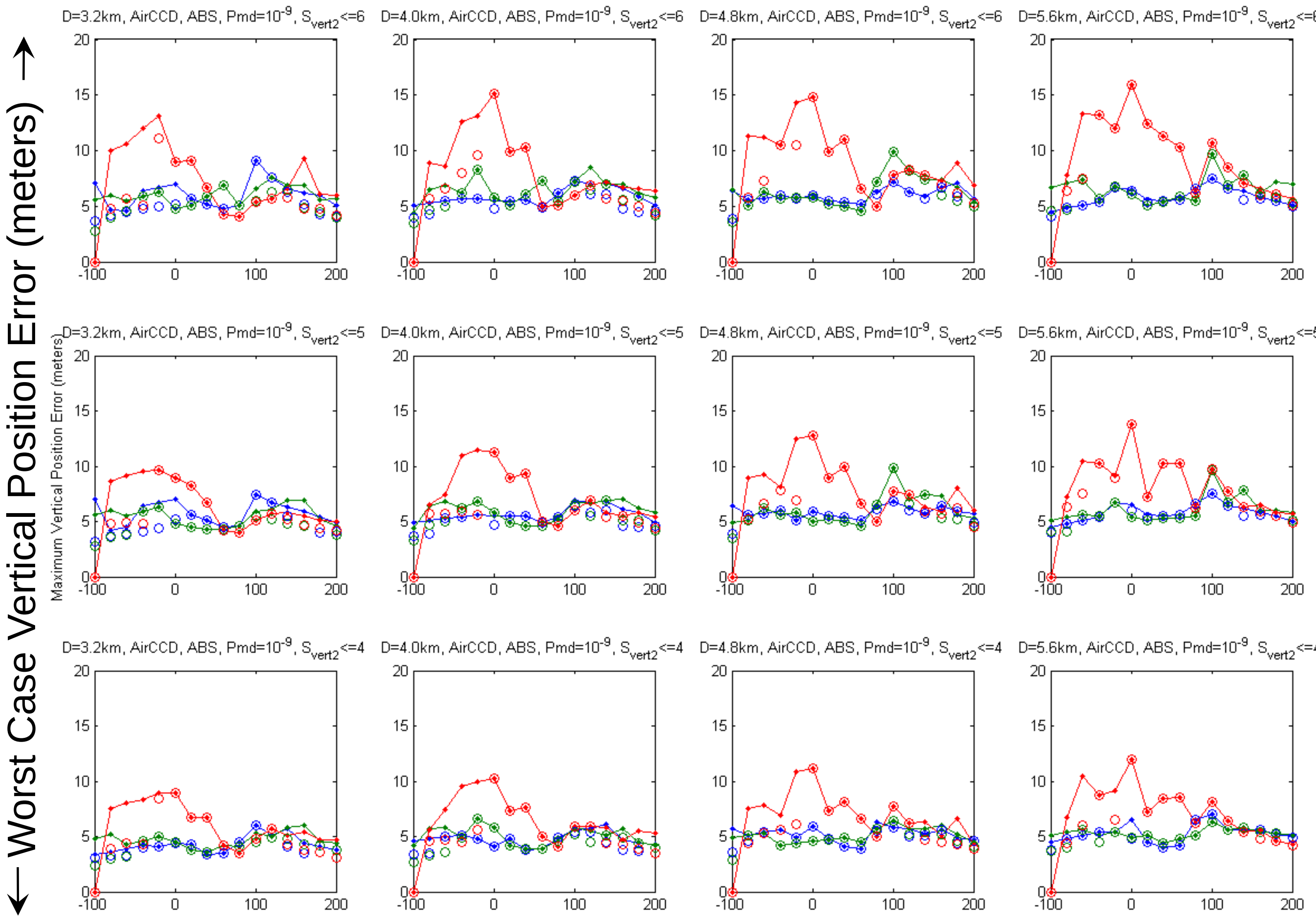




Results

Latest Results, RWY 09

Maximum Vertical Position Error at 5.6km from Reference (meters) at Three Reference Station Latitudes (0, 22, and 30 degrees - magnetic)



Vertical Projection:

S_{vert2}<6

S_{vert2}<5

S_{vert2}<4

Plasma Bubble Ground Speed (m/s)

Latest Results, RWY 09

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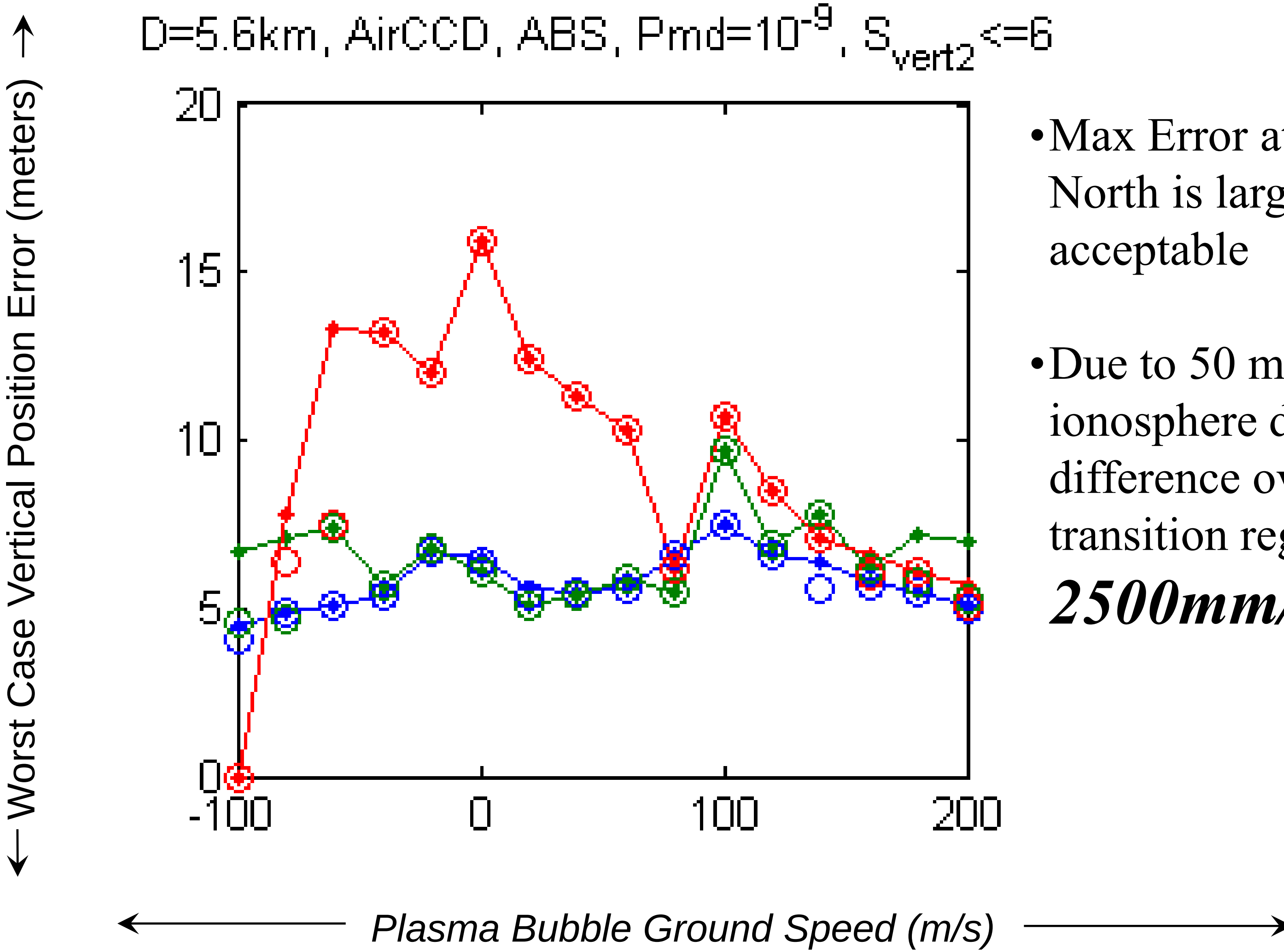
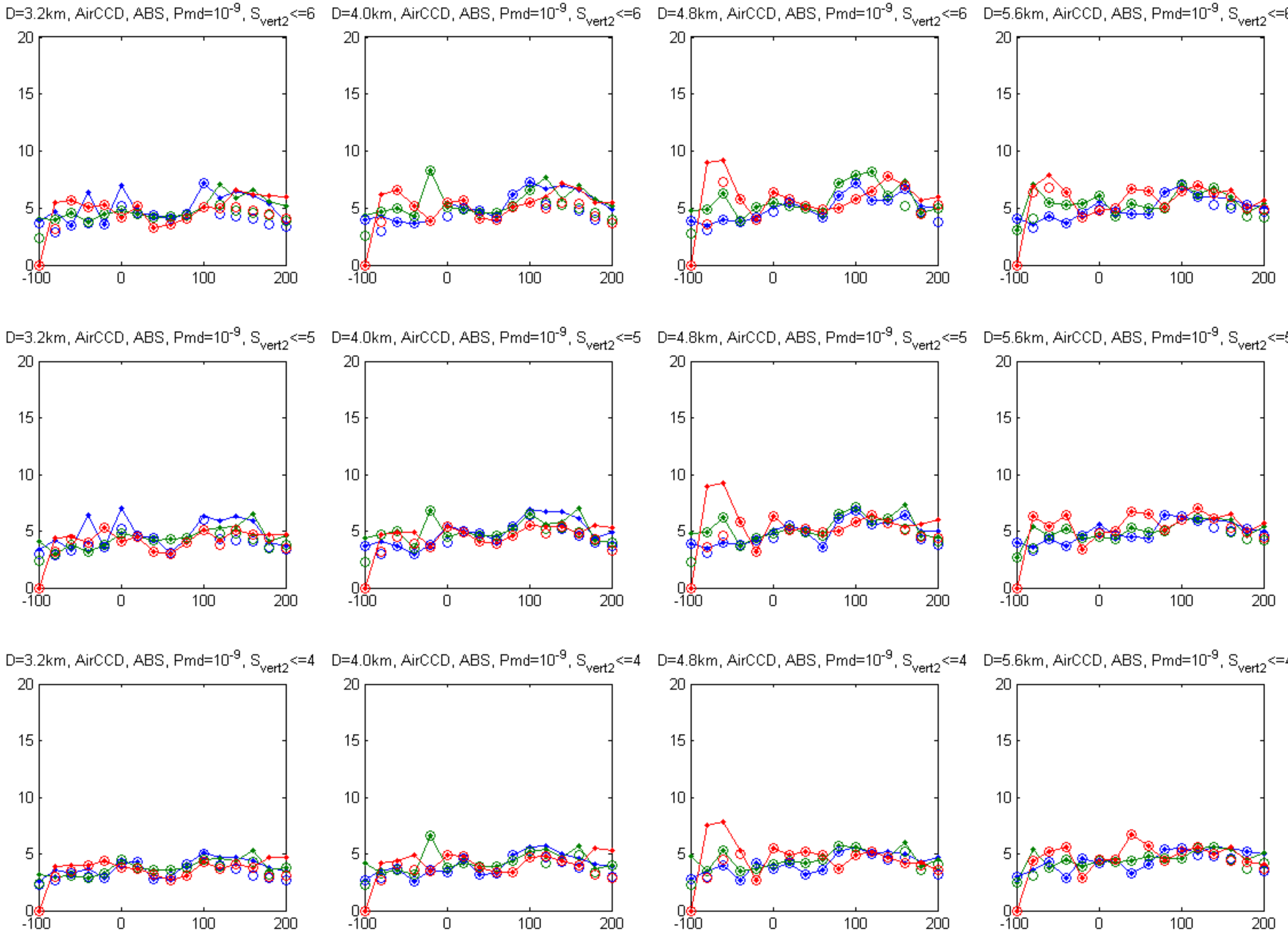


- Max Error at 30deg North is larger than acceptable
- Due to 50 meter ionosphere delay difference over 20 km transition region = ***2500mm/km***

Latest Results, RWY 09, Grad < 500mm/km

Maximum Vertical Position Error at 5.6km from Reference (meters) at Three Reference Station Latitudes (0, 22, and 30 degrees - magnetic)

Worst Case Vertical Position Error (meters)



Vertical Projection:

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Plasma Bubble Ground Speed (m/s)

Latest Results, RWY 09, Grad < 500mm/km

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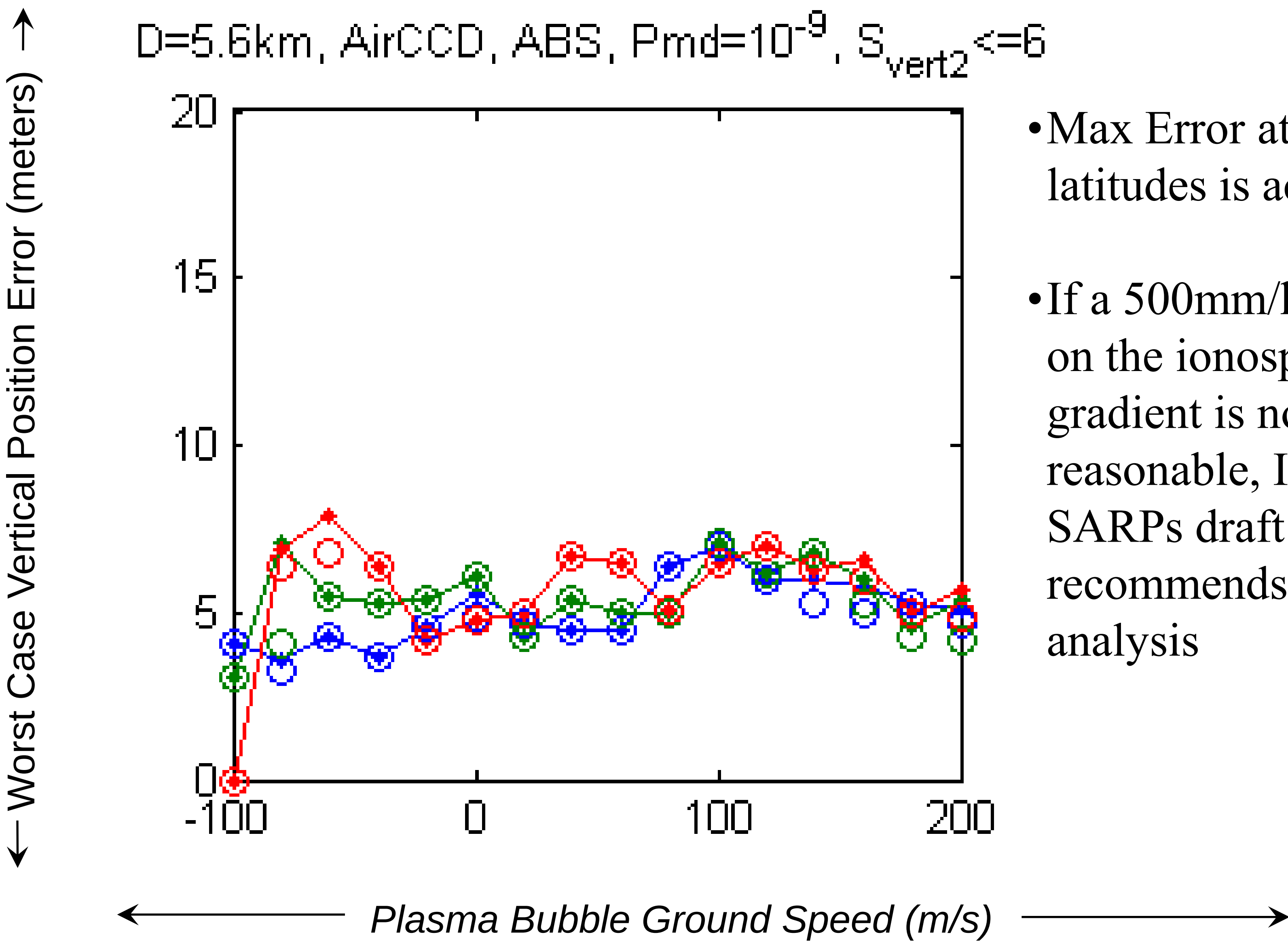

- Max Error at all latitudes is acceptable
- If a 500mm/km limit on the ionosphere gradient is not reasonable, ICAO SARPs draft change recommends further analysis

Conclusions

Conclusions

- **The maximum vertical or horizontal position errors induced by an ionospheric anomaly that will persist (with a probability of greater than 10-9) after all the ionospheric anomaly mitigations have been applied can be limited to less than 10 meters.**
  - Errors on the order of 10 meters or less have been shown to result in an airplane still landing in the safe landing box [1]. The maximum error can be reduced somewhat by using more aggressive geometry screening.
- **A 5 km baseline siting restriction appears to provide adequate performance.**
  - Although some possibility to relax this restraint still exists, it is recommended that 5 km be adopted as the baseline and that future work be undertaken during the operational validation phase to determine if this siting restriction can be relaxed or if additional siting flexibility can be achieved in some other way.

Conclusions, Continued

- **The general rule that the maximum error in the pseudorange domain of 2.75 meters (postulated in [9]) appears to hold for plasma bubbles as well as the wedge model. This maximum error characterization can be used in the formulation of a fault model for use in airworthiness assessments.**
- **The conservative approach of accounting for multiple satellites by geometry limiting based on S_{vert2} or S_{lat2} appears valid since no more severe effects have been found using the high fidelity 3-D plasma bubble in conjunction with a satellite geometry simulation than were found with the pseudorange domain wedge model as scaled by S_{vert2} limits.**