

**Ionospheric Equatorial Depletion Overview  
and the Equatorial Ionospheric Working Group  
Presentation to  
Third PLA/00/009 Project Coordination Meeting**

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FAATC ACB-430  
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# Outline

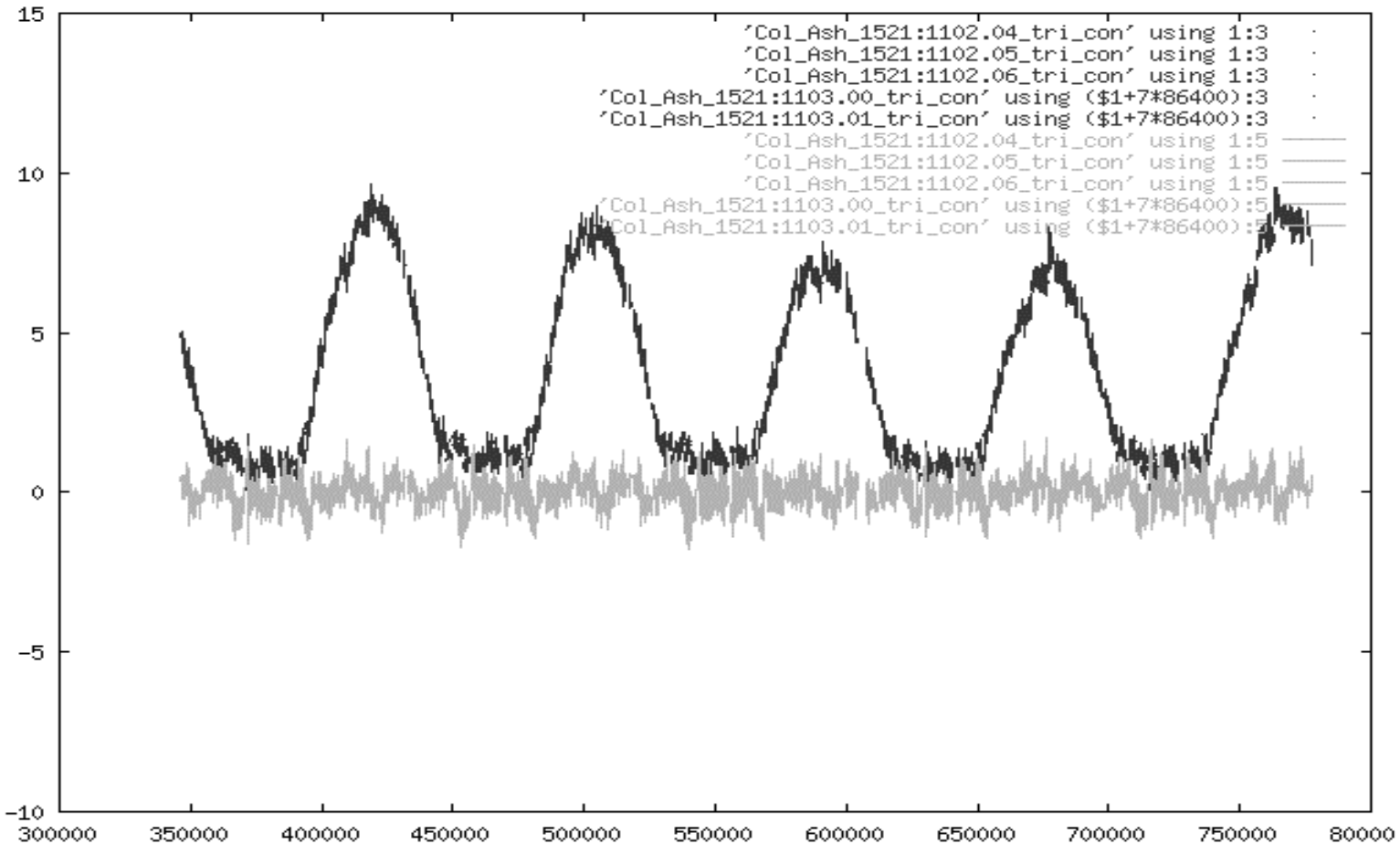
- Review of the ionospheric threats to GNSS
- Overview of the Equatorial Ionospheric Working Group and the SBAS Ionospheric Working Group
- Progress of the EIWG
- Plans of the EIWG
- Data Examples
- Conclusions

# Example Data – US – Non-storm

(Columbus, Nebraska TRS, 5 days over Weeks 1102-1103)

x axis shows seconds of week

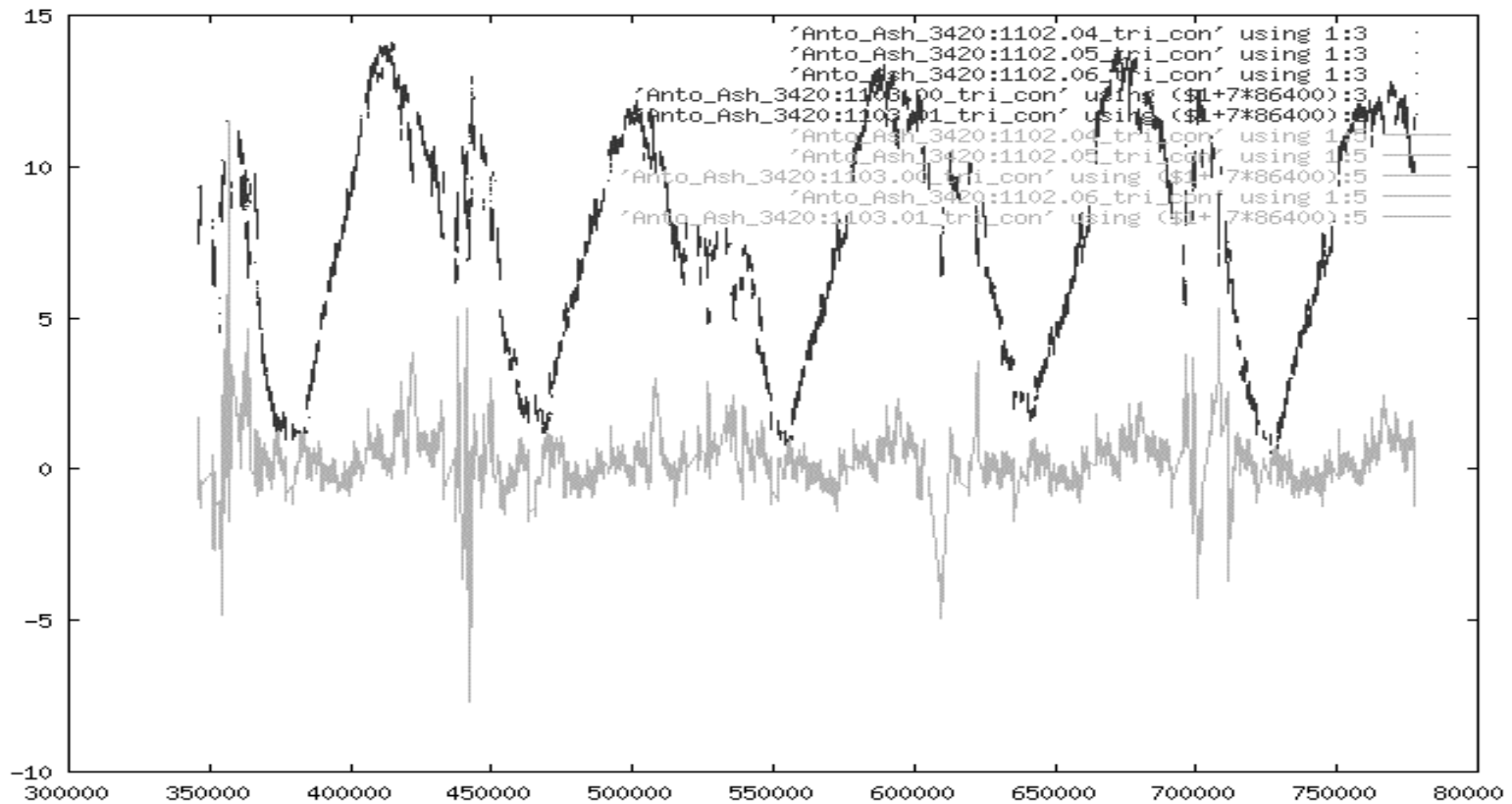
y axis shows vertical iono delay (red) and irregularity (green) in meters



# Example Data – Antofagasta, Chile

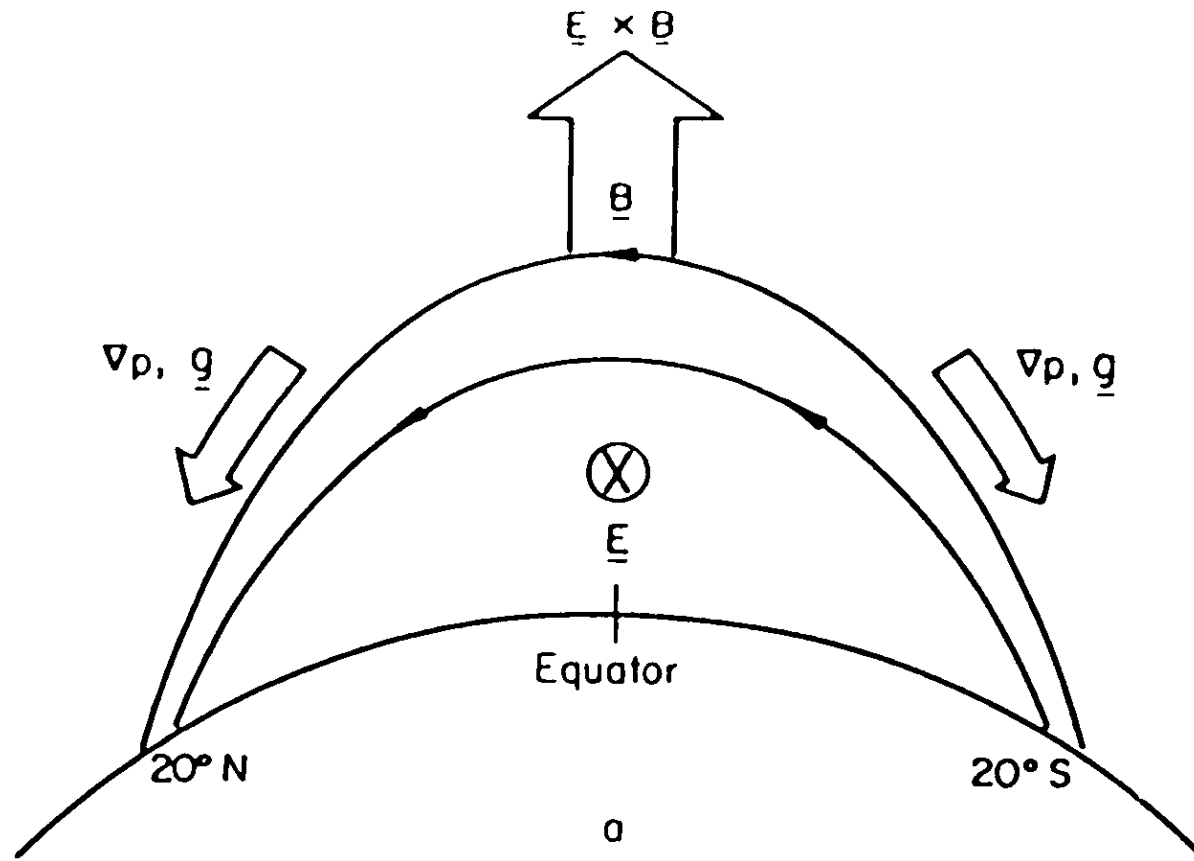
Non-storm but affected by equatorial anomaly

~5 days showing vertical iono delay (red) and irregularity (green) with simple planar method  
x axis shows seconds of week 1102 into 1103 and y axis shows meters



# What causes the equatorial anomaly effect?

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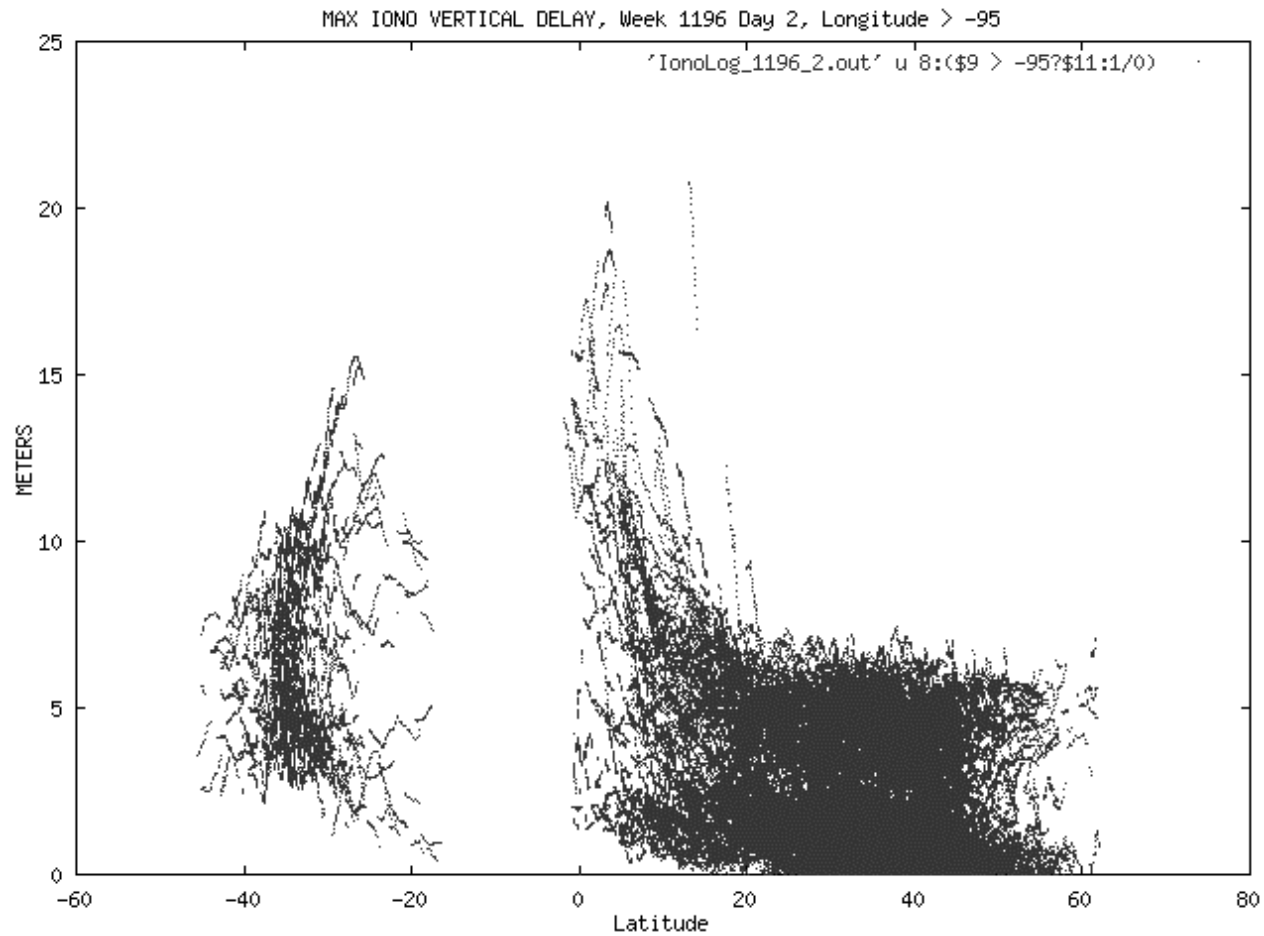
From "The Earth's Ionosphere", M.C. Kelley, 1989.

## **WBMOD Model**

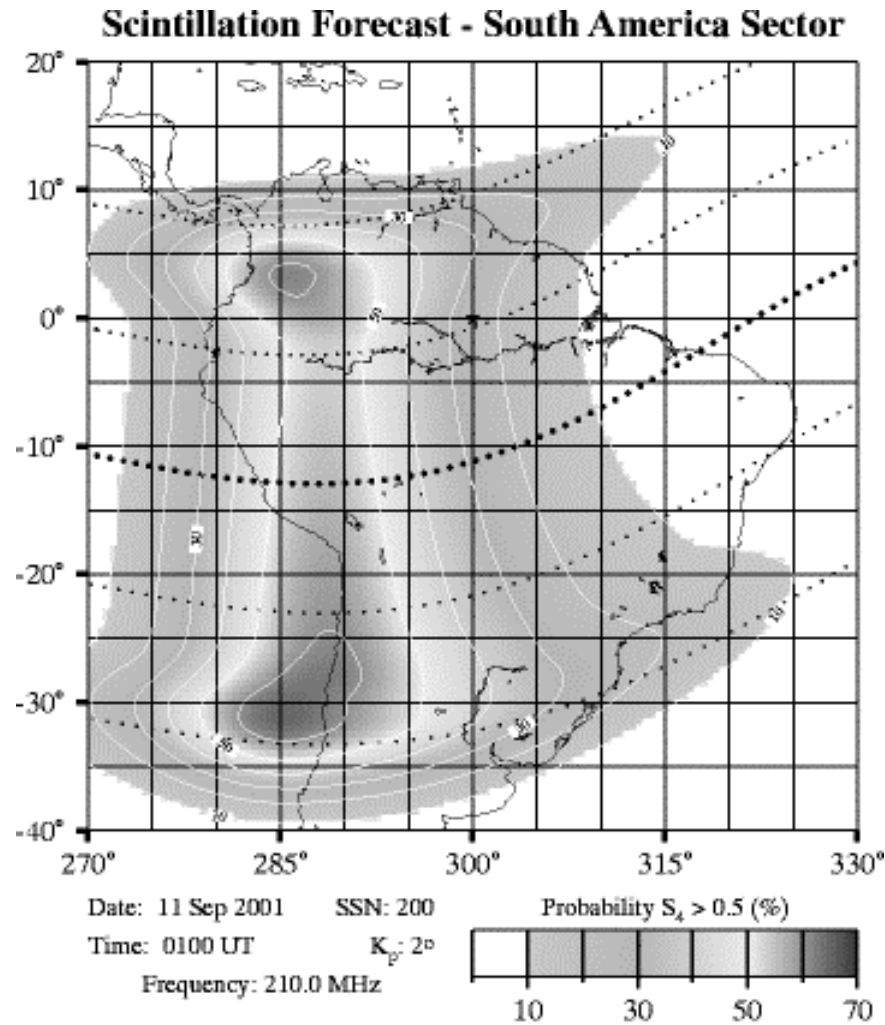
**S4, September 15, SSN = 150, Kp =1, Local Time = 2100**

# Appleton Anomaly – Week 1195 Day 2

Peak at  $\sim 5^\circ$  N and  $\sim 25^\circ$  S Geographic  
(24 hours of vertical delay data shown)



# Equatorial Risks to Planar Ionosphere - III



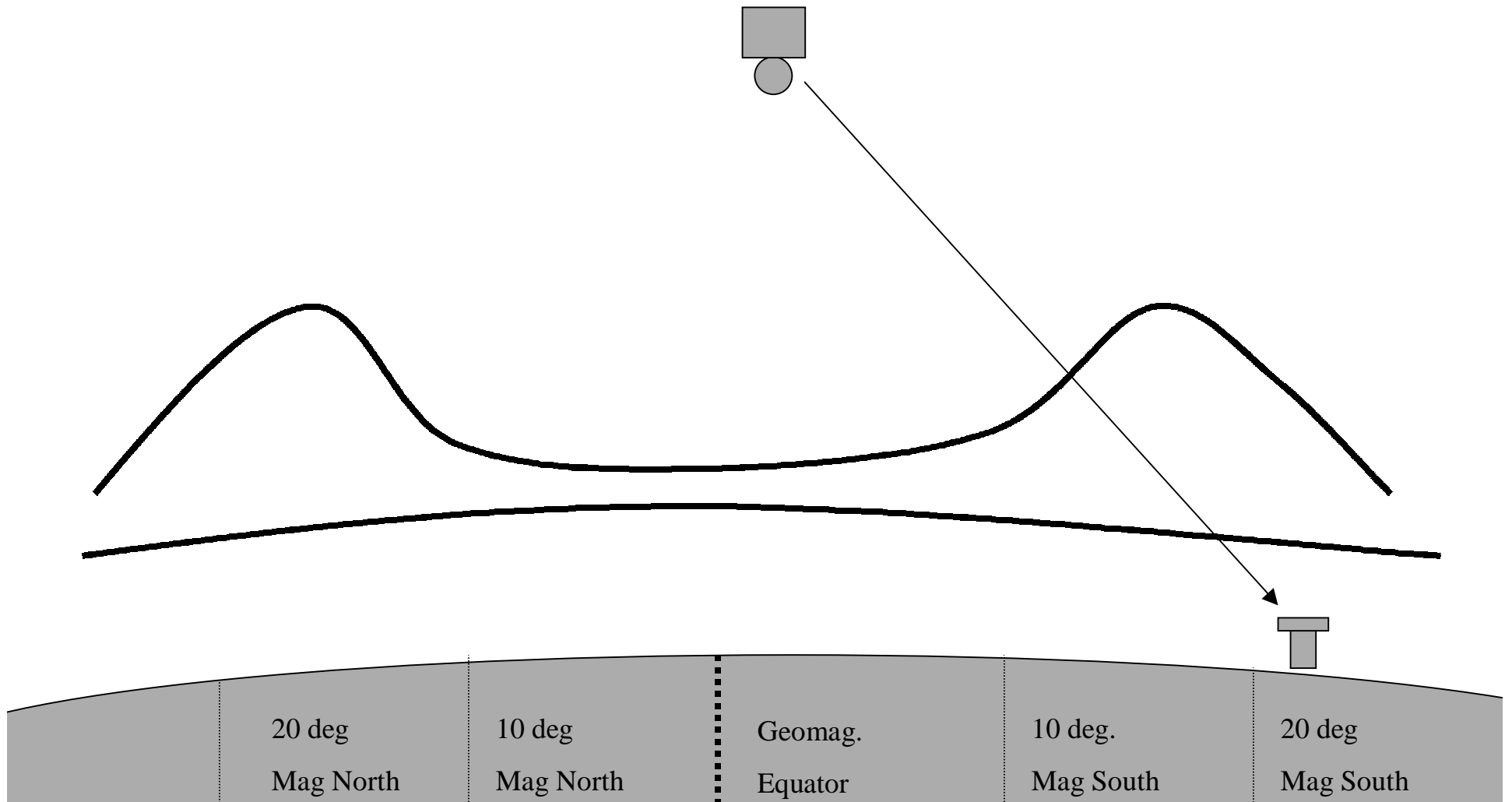
Copyright 2001, Northwest Research Associates, Inc.

## **Features that are related to Equatorial Anomaly**

- **Ionospheric Depletions**
- **Scintillation**

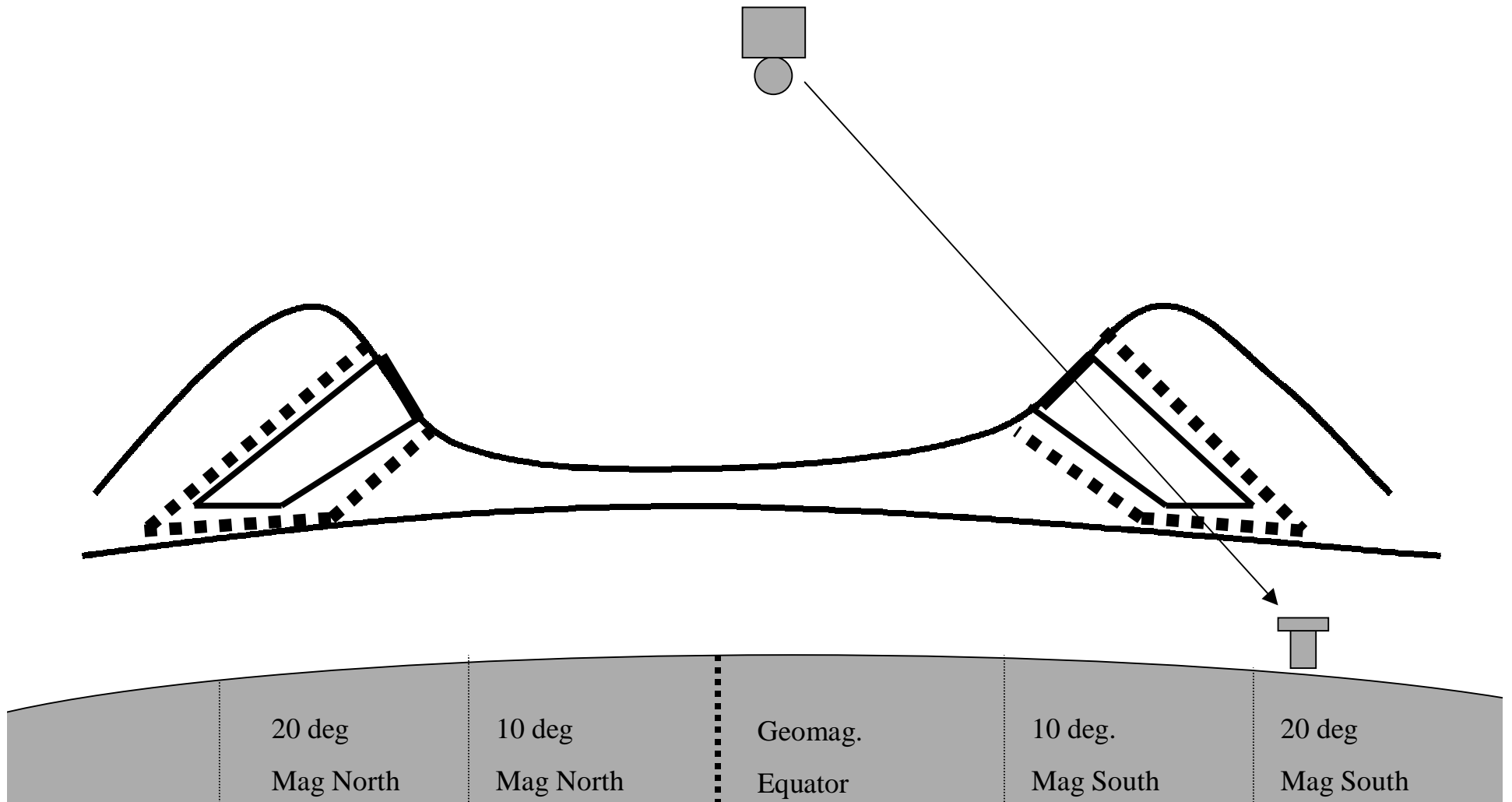
# Data Collection Example

(time 0, no bubble is line-of-sight)



# Data Collection Example

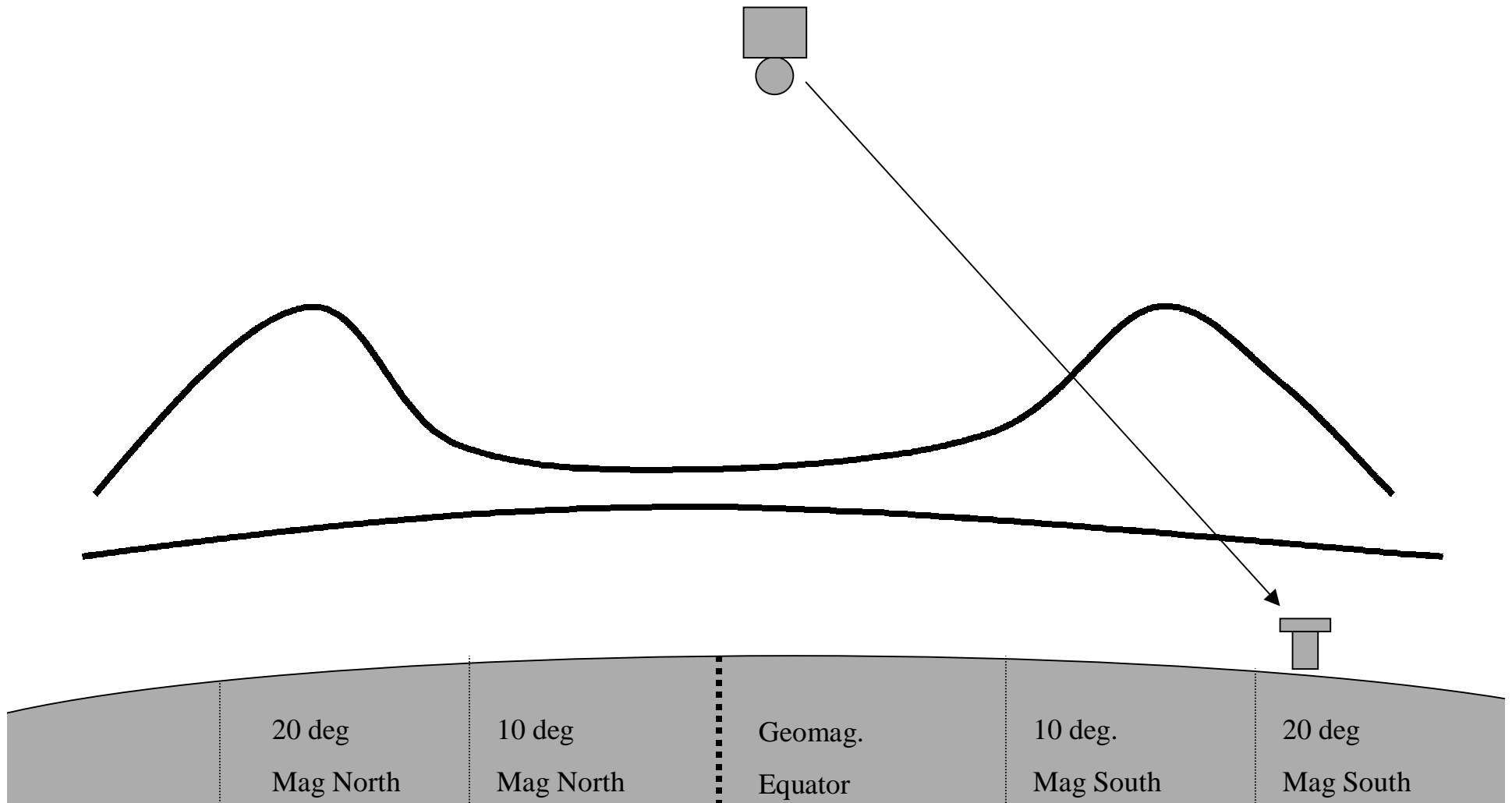
(time 1, with Bubbles/Scintillation in LOS)



# Data Collection Example

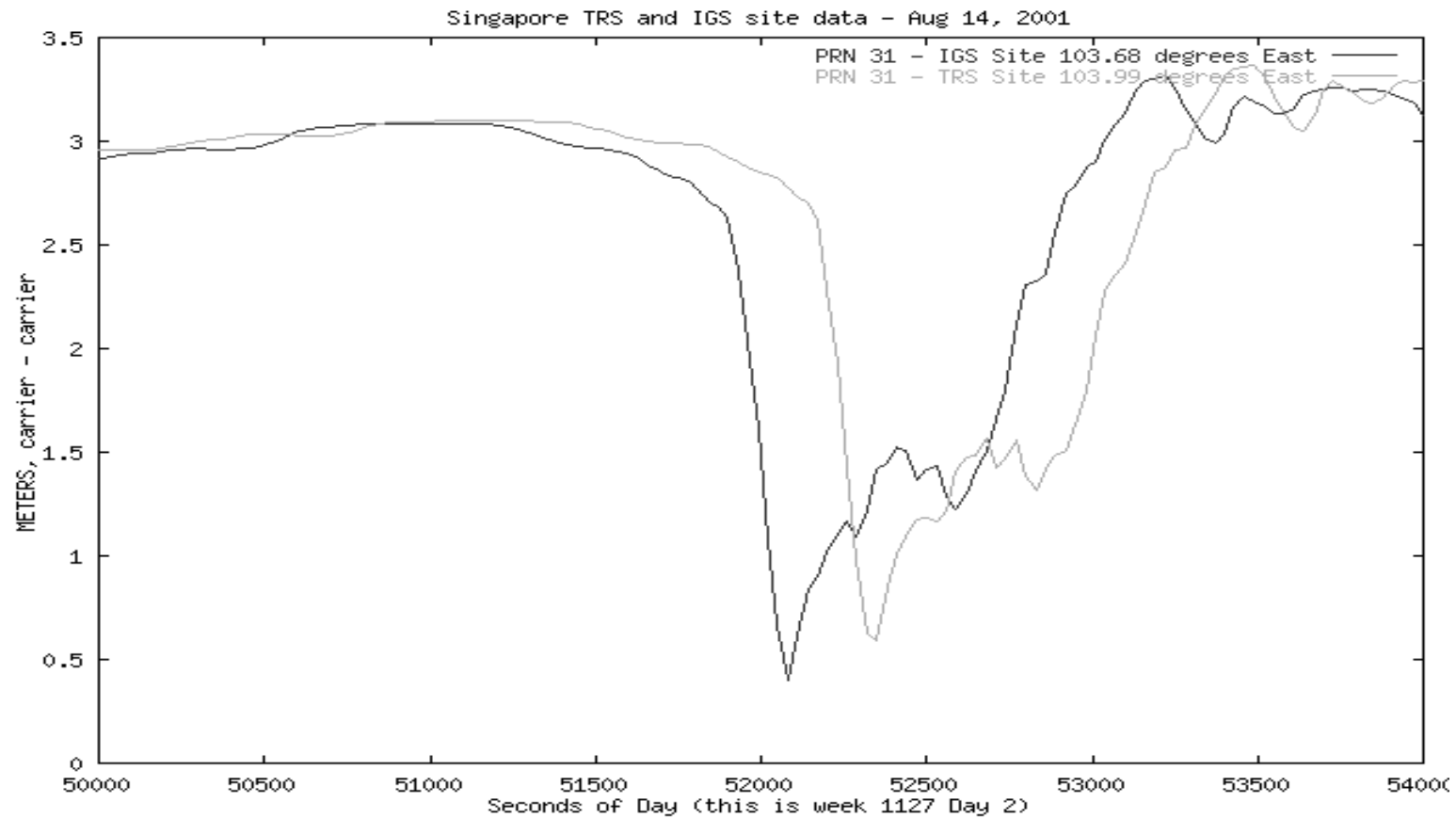
(time 3, bubble gone from line-of-sight)

(Bubble moving east  $> 100$  meters/sec)



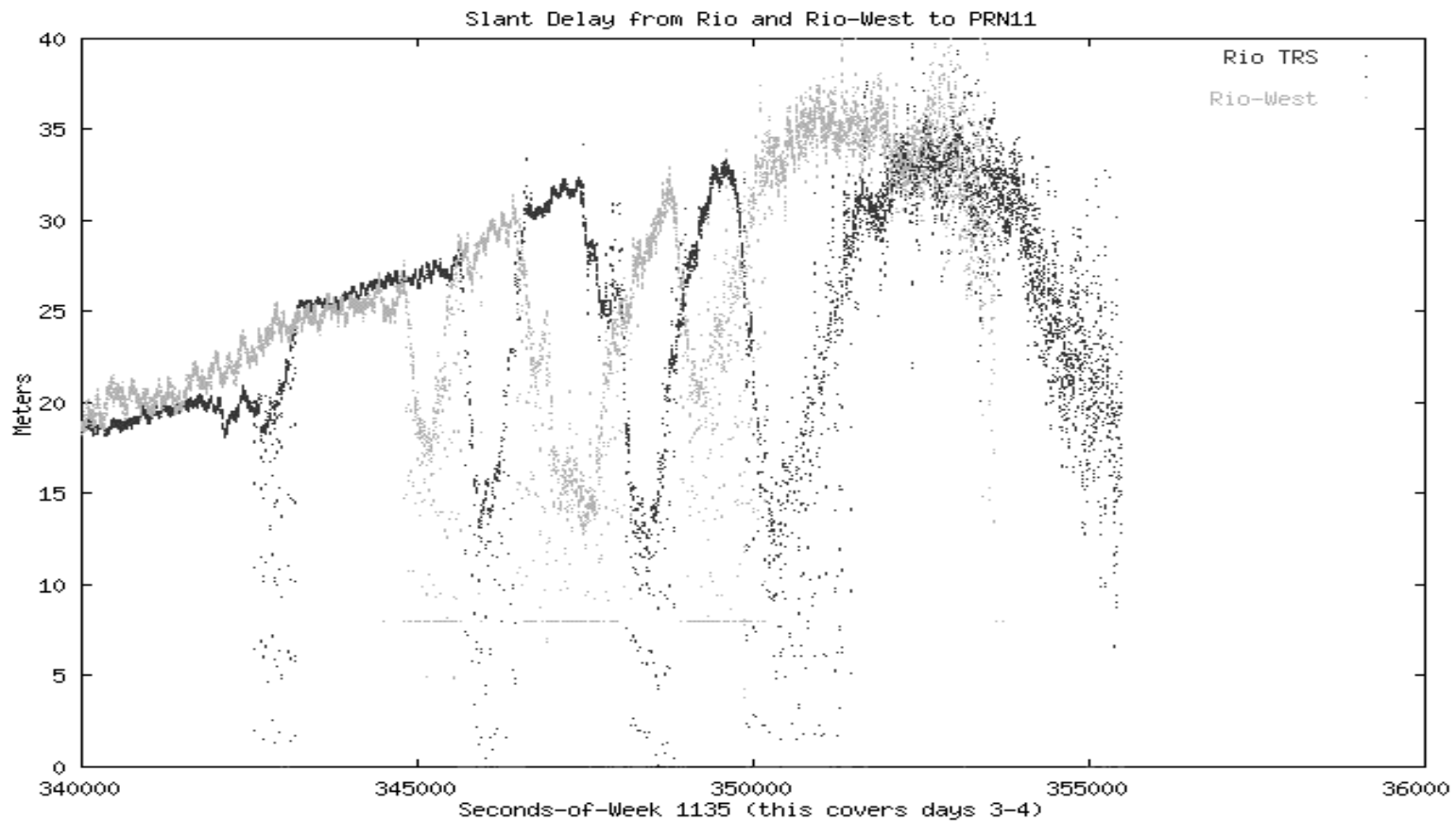
# Equatorial Risks to Planar Ionosphere

Data from Singapore showing motion in “bubbles”



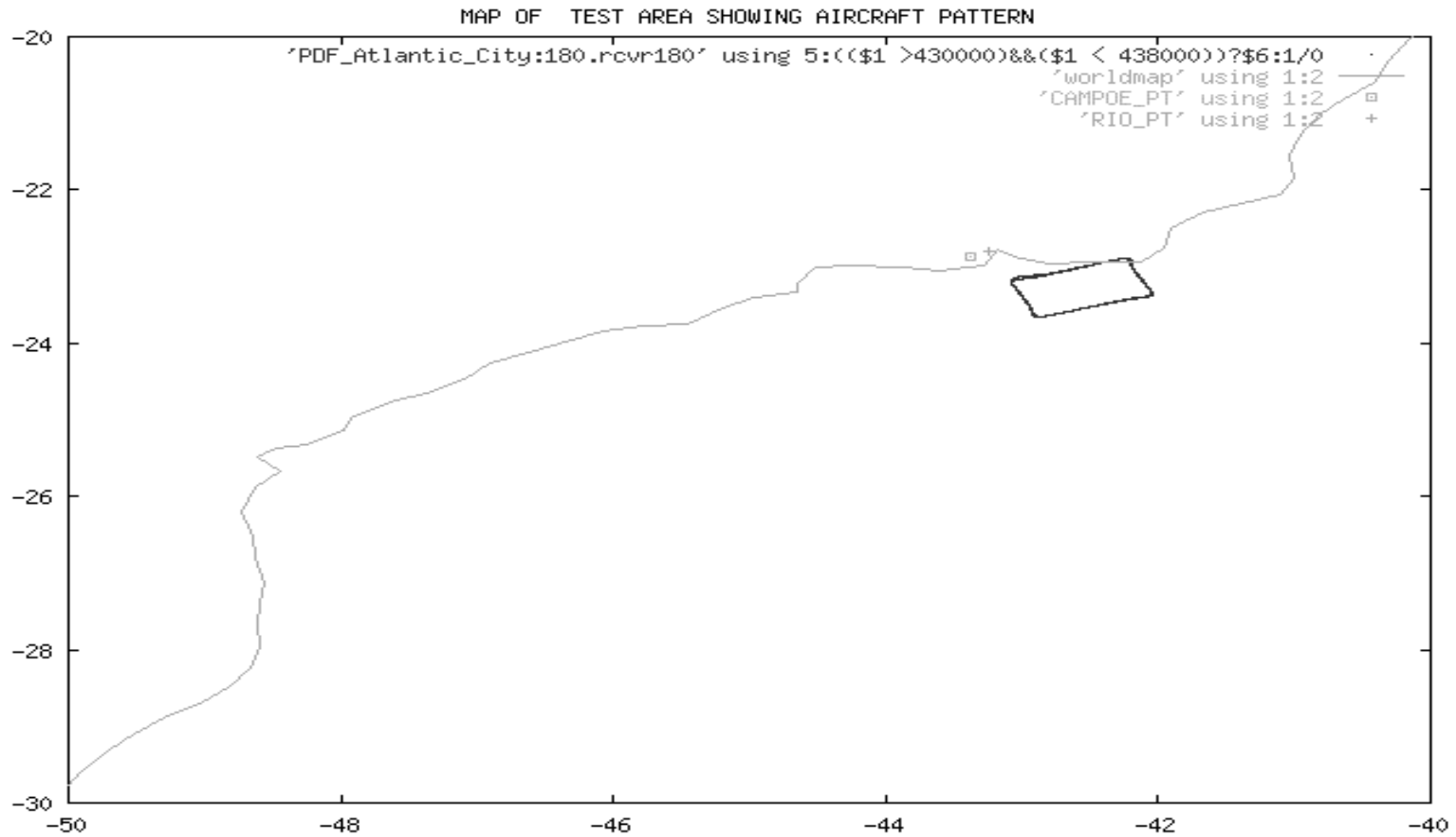
# Equatorial Risks to Planar Ionosphere

Data from Brazil showing motion in “bubbles”  
(Rio-west was a temporary site ~95 km west of Rio TRS)



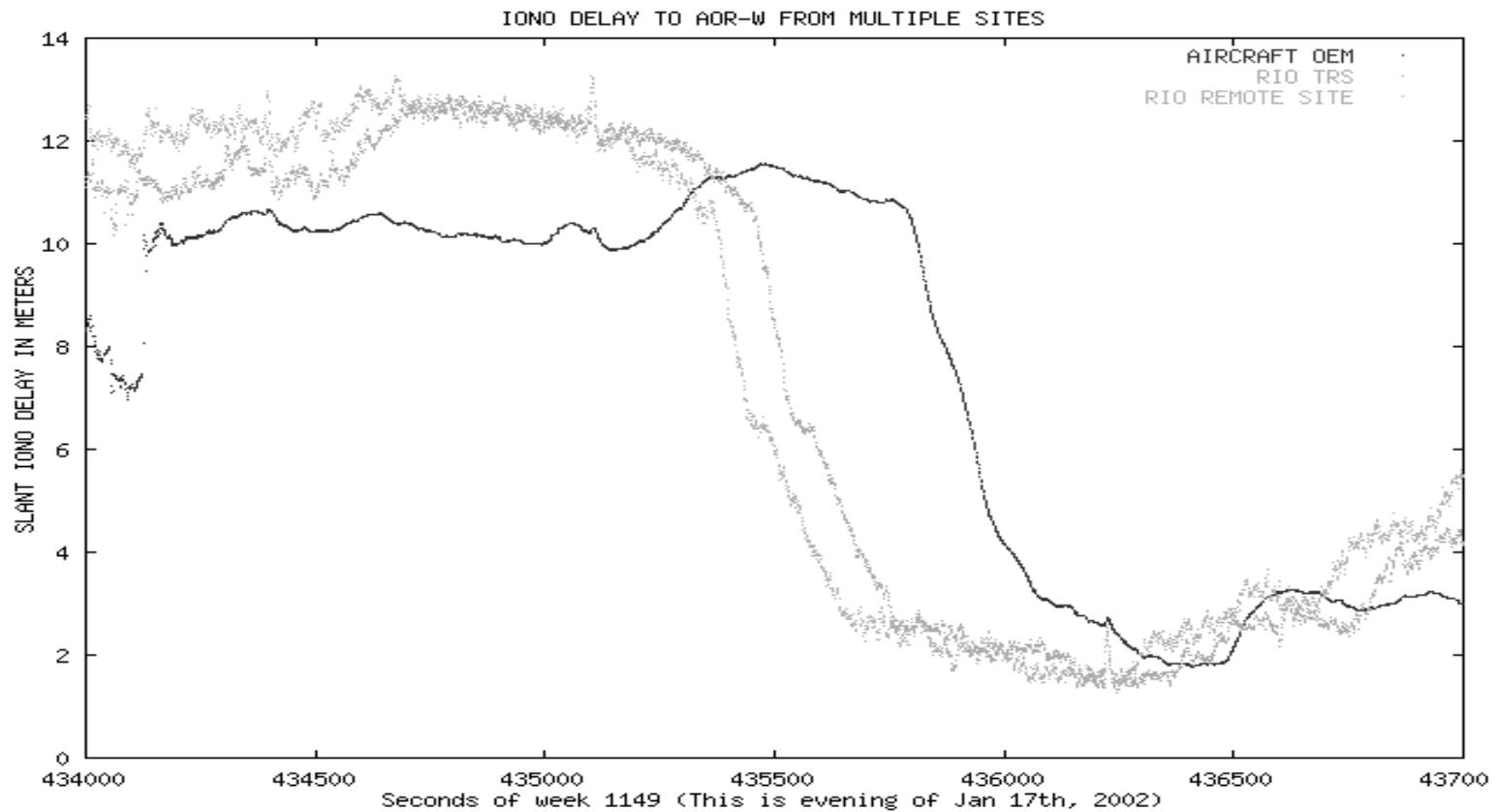
# Equatorial Risks to Planar Ionosphere

(Plots shows location of 2 ground receivers 15 km apart in Rio de Janeiro area, ,  
and aircraft receiver)



# Equatorial Risks to Planar Ionosphere

(Plots shows motion of bubble wall passing 2 ground receivers 15 km apart, then aircraft receiver)



# Risks to Planar Ionosphere

## As indicated by initial observations

- Ionospheric Irregularities are common, at certain times and seasons, in area near geomagnetic equator
  - Depletions in the ionosphere can range in size smaller than 200 km across
  - Gradients in depletion walls can exceed 2 meters in 10 kms, to total ionospheric delay changes of 20 meters or more
  - Depletions could significantly contribute to GIVEs – and significantly reduce availability – the exact effect is still TBD

## Specific Issues to be considered

- Problems include:
  - Loss of lock (due to scintillation that is associated with large depletions) – true threats may filter themselves out
    - (see example next two slides)
  - Accepted (?) three-D shape of these features suggests that any measurement of a “depletion” from one line of sight may not capture iono change as measured from a different line of site, requiring (?) GIVE value protection to worst geometry thru which a user line-of-sight may pass
  - They occur too frequently (in certain places, years, and seasons) for an aviation precision landing system to simply deny service when they exist [this is just a personal point of view, but should be discussed] – so the service (with vertical guidance and some level of VPL within a TBD VAL) must be available during the depletions to be practical
    - (however, VALs greater than 50m *may* be considered)

# Overview of the SBAS Ionospheric Working Group

- Sub-group of the Interoperability Working Group, consisting primarily of iono experts of US, Canada, Europe, and Japan; now others (India, Brazil, are also invited)
  - countries already involved in fielding SBAS systems
  - Goal is to promote international interoperability
  - Standards are ultimately reflected in ICAO SARPS; some are non-SARPs considerations (i.e., proof of safety discussions, iono modelling, etc.)
  - Last meeting in Portland (Sept. 2003, prior to ION)
    - Included US, Brazil, Italy, Netherlands, Japan, others

# Equatorial Ionospheric Working Group (EIWG)

- Primarily, the EIWG is the initial US attempt to define and solve the difficulties presented by the ionosphere near the geomagnetic equator
- US membership consists of the US Iono experts
  - Stanford University – member and chair (Dr. Todd Walter)
  - Raytheon
  - JPL
  - MITRE
  - Boston College
  - FAA

# EIWG Identified Tasks

(example – not a complete list)

- What are the best models to represent the ionosphere for different regions (equatorial, near-equatorial or transitional, mid-latitude, auroral, polar)?
  - How much data do they require? How sensitive are they to loss of data?
  - **What GIVE values do they yield for reasonably sized reference station networks?**
  - Can algorithms based on the thin shell model approach be made to work sufficiently well in the equatorial region? What improvements will different forms of tomographic, or other solutions offer?
  - How far in latitude away from the magnetic equator does the influence of these large spatial gradients extend?

# EIWG Identified Tasks

(example – not a complete list)

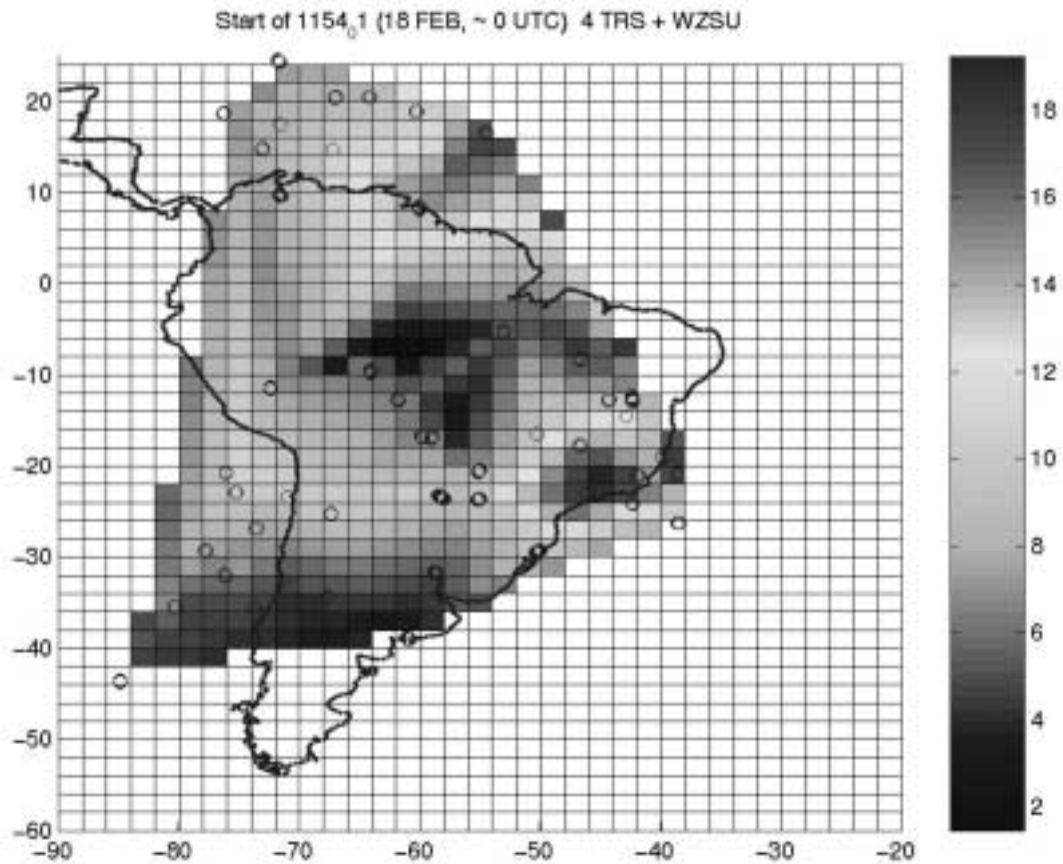
- **Tools and data available to answer the above questions:**
  - Three dimensional electron density models, (e.g. LowLat model, perhaps others).
  - TEC data from near-solar-maximum conditions, particularly during the years 2000-2002.
  - About 30 days of data recorded at 12 sites in Brazil in 2002 under various ionospheric conditions from quiet ionosphere to major storm (Note: these are not “Testbed” sites);
  - South American Testbed Data will be useful in several ways
    - augmenting other data where dropouts occur
    - comparing performance of different receiver types
    - ultimately investigation impact of data dropouts on WAAS algorithms

# South American GPS receiver sites

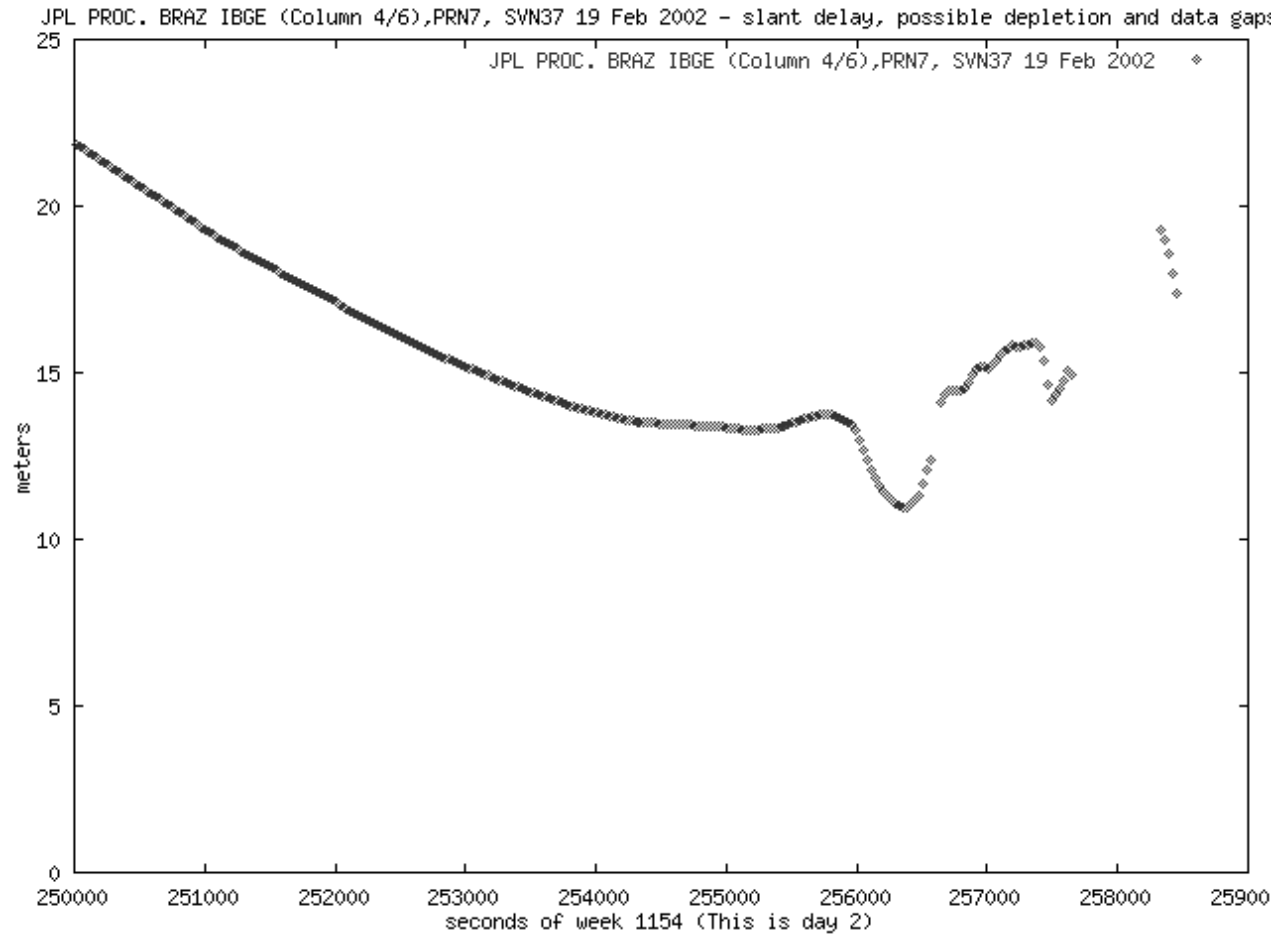
(used mostly for geological studies, surveying applications, etc.)  
(also, see video of JPL processed iono data)



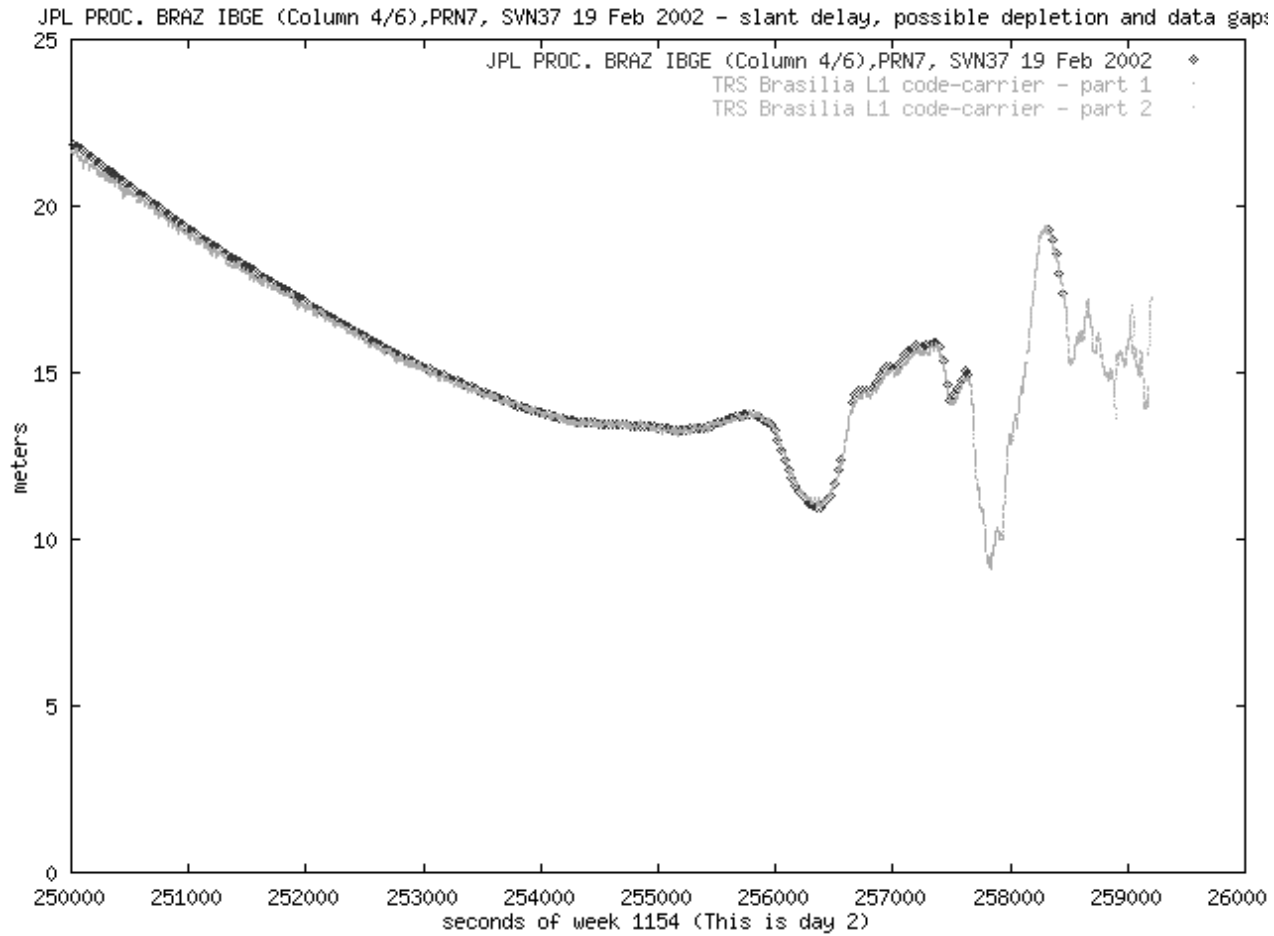
Testbed and WAAS estimate of South American Ionosphere during secondary peak of Equatorial Anomaly, 18 Feb 2002  
Santiago, Antofagasta, Rio De Janeiro, Brasilia, and Puerto Rico



# Example delay data from Brazil, JPL processed data (Non –testbed site showing data dropouts)



Previous data with Brazil testbed Millenium receiver data (code-carrier/2), offset (to remove cycle ambiguity) and overlaid – potential larger variation is now visible



## Conclusion

- Ionospheric research continues on the difficulties which have been found to exist in the equatorial regions
- Data collection during the *at least* the next 6 months will still give important data
- US and international ionospheric expert groups are working on the problems

Questions?

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