The First Results from the Scintillation and Ionospheric TEC Receiver in Space (CITRIS) Instrument on STPSat1

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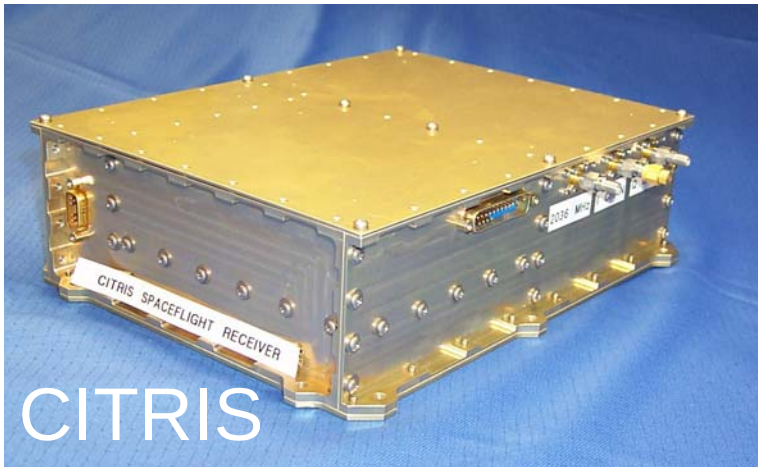
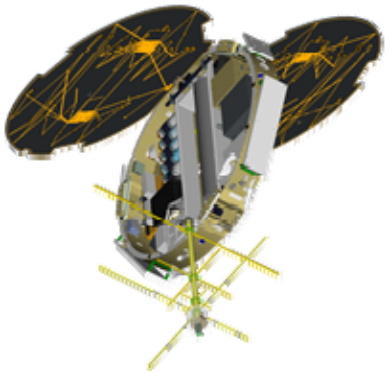
XXIX URSI General Assembly
Chicago, Illinois, USA
August 13, 2008



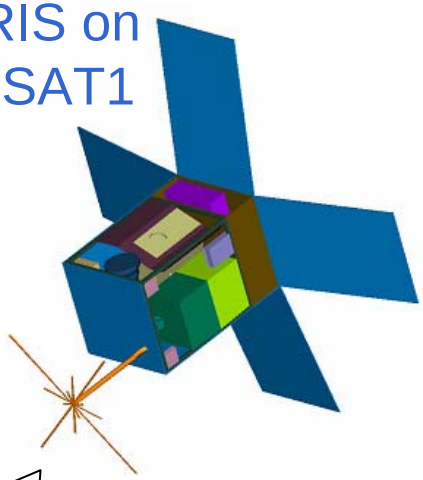
CITRIS A Proof of Concept Mission
Space Based Monitor of DORIS Ground Beacons or Satellite Based Beacons



CERTO on COSMIC
(or other Beacons)

RF Link

CITRIS on
STPSAT1



RF Link

DORIS
Station in
Australia

CITRIS Operations

- Satellite to Satellite Links
  - Simultaneous VHF/UHF/L-Band
  - 150 MHz, 400 MHz, 1067 MHz
- DORIS to Satellite Links
  - 401 MHz and 2036 MHz
- Global TEC Inputs to Space Weather Models
- Global Scintillation Monitor

Two Frequency Differential Phase Measurements of TEC

- Phase Path (Wavelengths)

$$P = (S - \int \frac{\varepsilon N}{f^2} ds)\ \frac{f}{c} \text{ or } S = P\frac{c}{f} - \frac{\varepsilon}{f^2}\int N\, ds$$

- Two Frequency Differential Phase Removes Path Length

$$P_{ab} = P_a - P_b \frac{f_a}{f_b} = \frac{(f_a - f_b)(f_a + f_b)\,\varepsilon}{c f_a f_b^2}\int N\, ds$$

- Integer Derived Frequencies: $f_a = n_a f_0$, $f_b = n_b f_0$, etc.

$$P_{ab} = \frac{(n_a^2 - n_b^2)\,\varepsilon}{n_a\, n_b^2\, c\, f_0}\int N\, ds$$

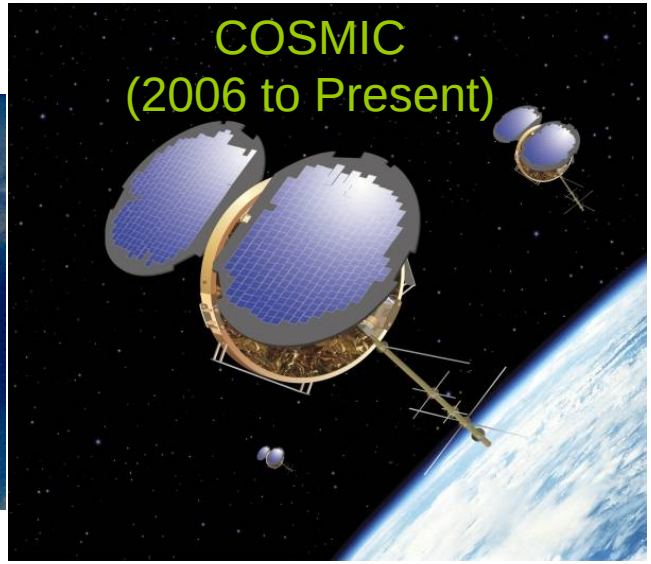
- Total Electron Content from 2 Frequency Differential Phase

$$\int N\, ds = \frac{n_a n_b^2\, c\, f_0}{(n_a^2 - n_b^2)\,\varepsilon} P_{ab} = 7.44\,10^6\, f_0 \frac{n_a n_b^2}{n_a^2 - n_b^2} P_{ab} m^{-2}$$

Radio Beacon Satellites Available for CITRIS

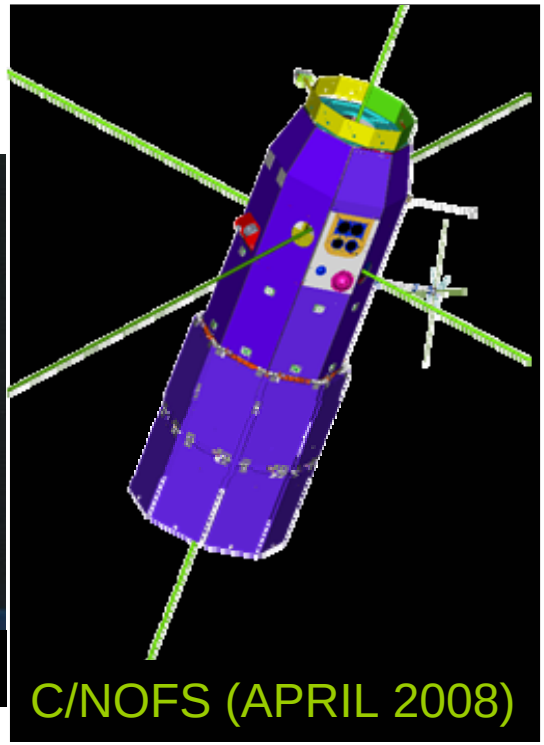
RADCAL (1993 to Present)

GFO (1998 to Present)



COSMIC
(2006 to Present)

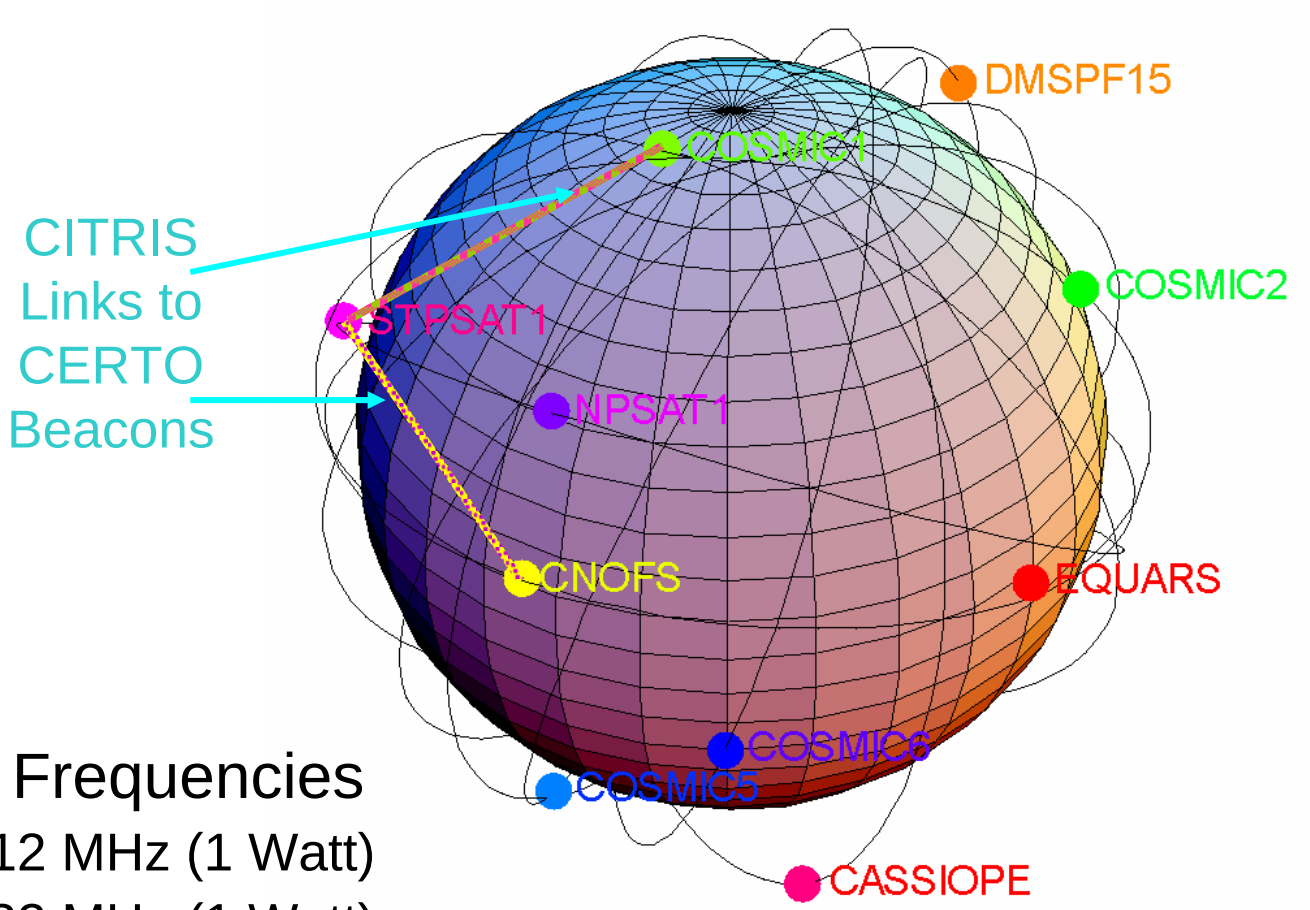
NIMS (1991 to Present)



C/NOFS (APRIL 2008)

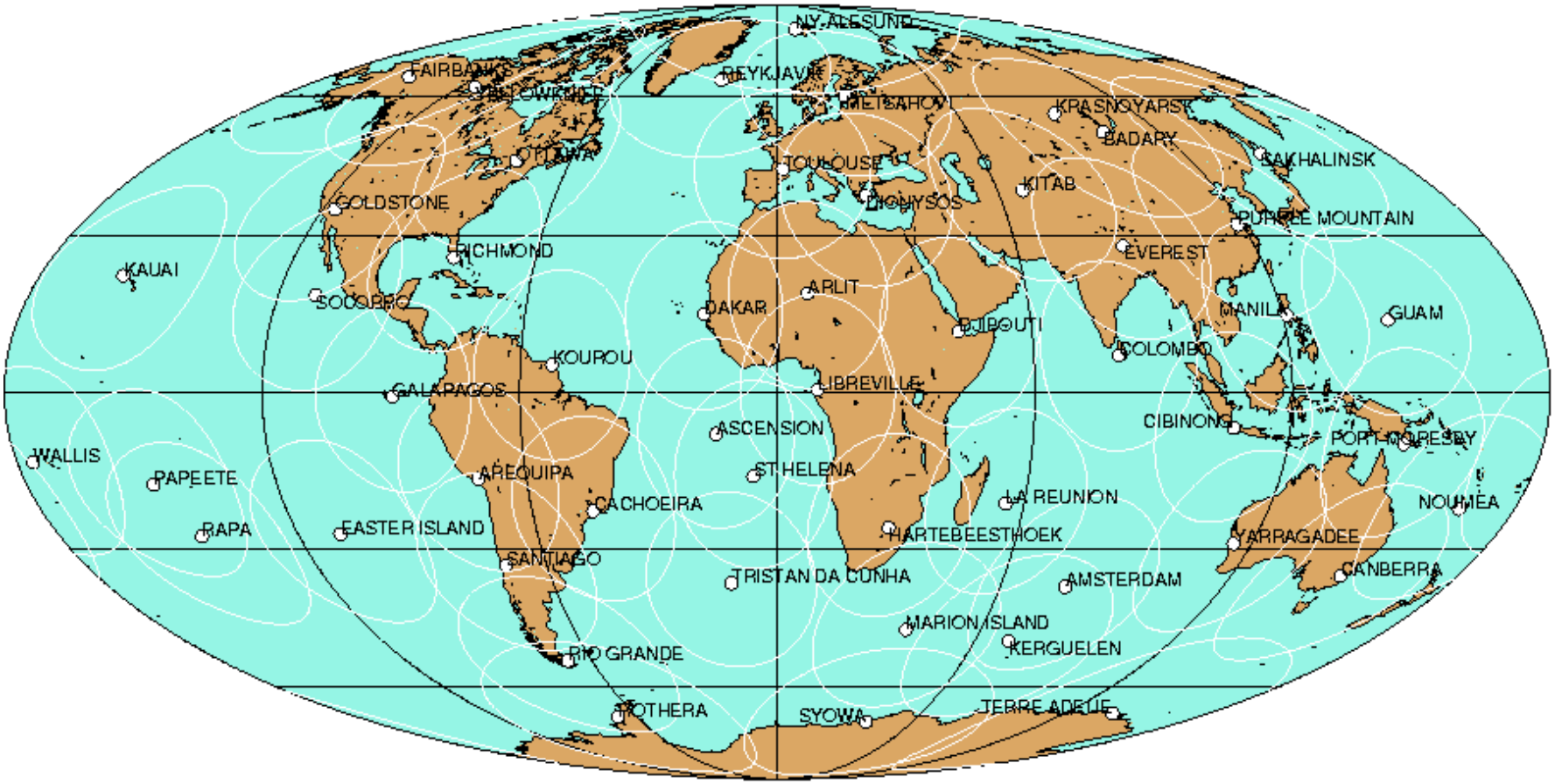
RADCAL on DMSP/F15
(Aug 2006 to Present)

NRL CERTO Beacons and CITRIS



- CERTO Frequencies
  - 150.012 MHz (1 Watt)
  - 400.032 MHz (1 Watt)
  - 1066.752 MHz (2 Watts)
- R-H Circular Polarization
- No Modulation

DORIS UHF/S-Band Beacon Ground Sites



Global Map of 56 DORIS Transmitters at 401 $^1/_4$ and 2036 $^1/_4$ MHz

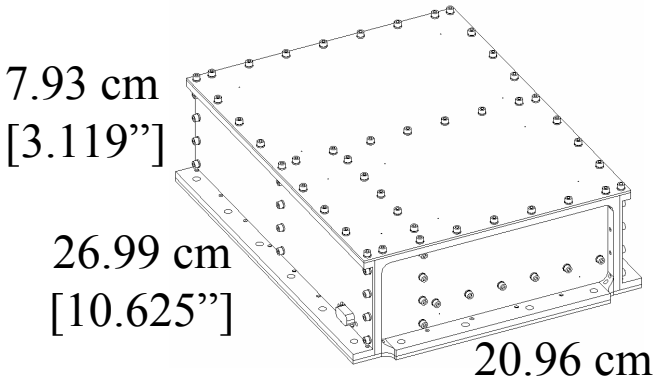
CW Transmissions with 0.8 s Modulation Every 10 s.

Latitude Range: - 70^o to + 80^o

Data Records: **Absolute TEC (Differential Phase +Group Delay)**

UHF and L-Band Scintillations

CITRIS Receiver Block Diagram



Inputs from Antenna

CERTO

150 MHz

400 MHz

1067 MHz

2036 MHz

DORIS

Control

RF

IF

ADC

12-bits

IF

ADC

12-bits

IF

ADC

12-bits

GC4014

Link Port

ADSP-21060

Clock

Serial Out

Serial In

ACK

SYNC

Spacecraft Interface

28 Volts

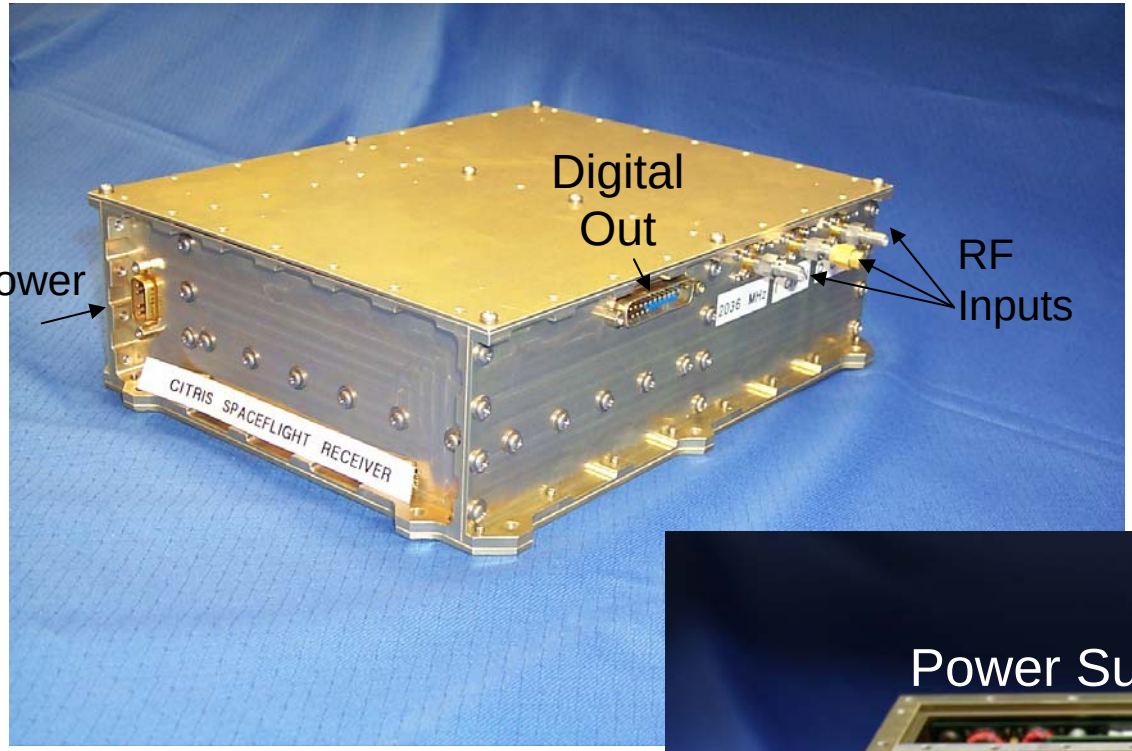
Power Supply

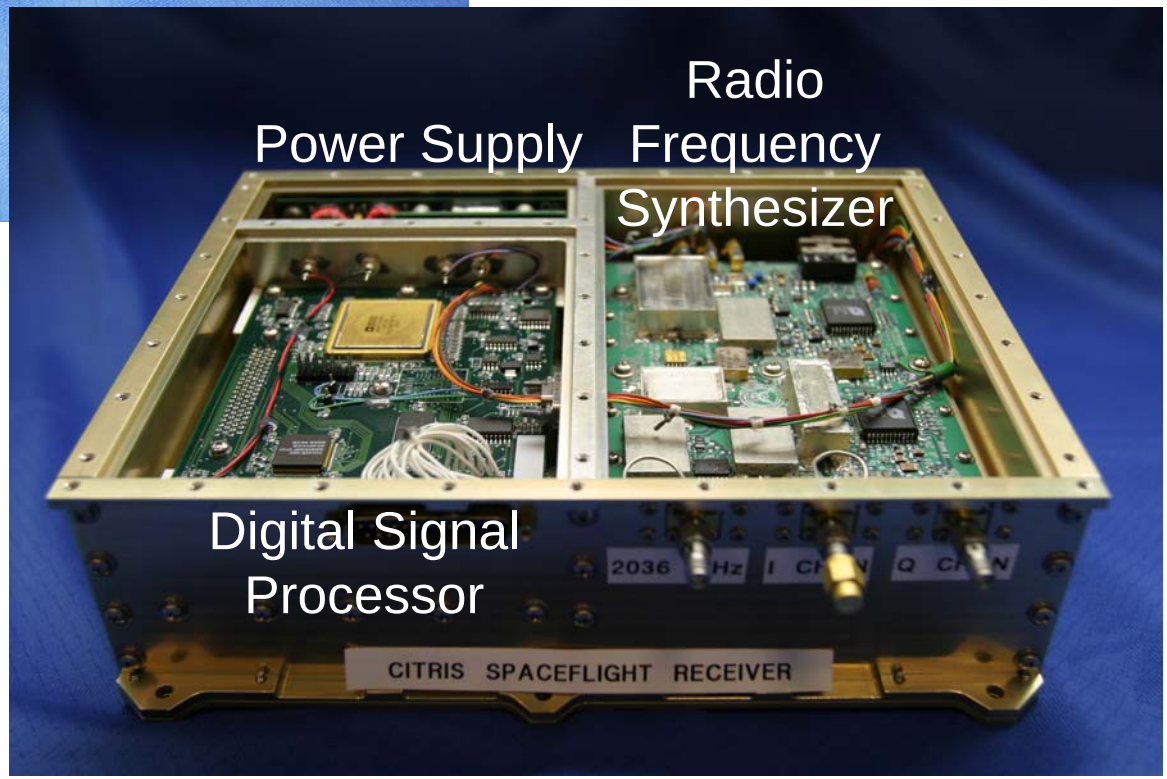
5V DSP

5V ADC

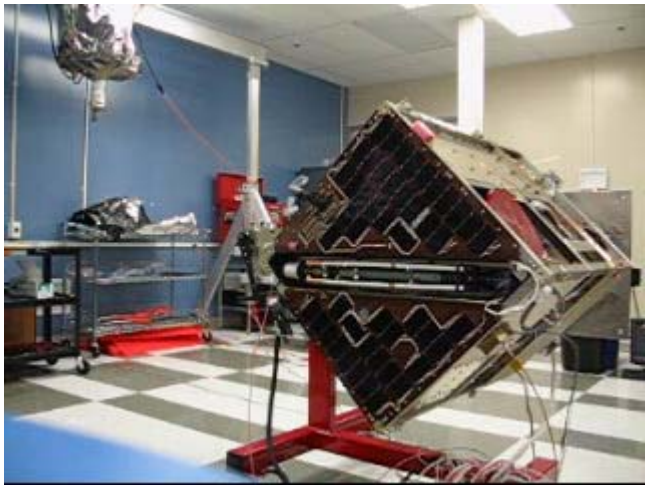
5V RF

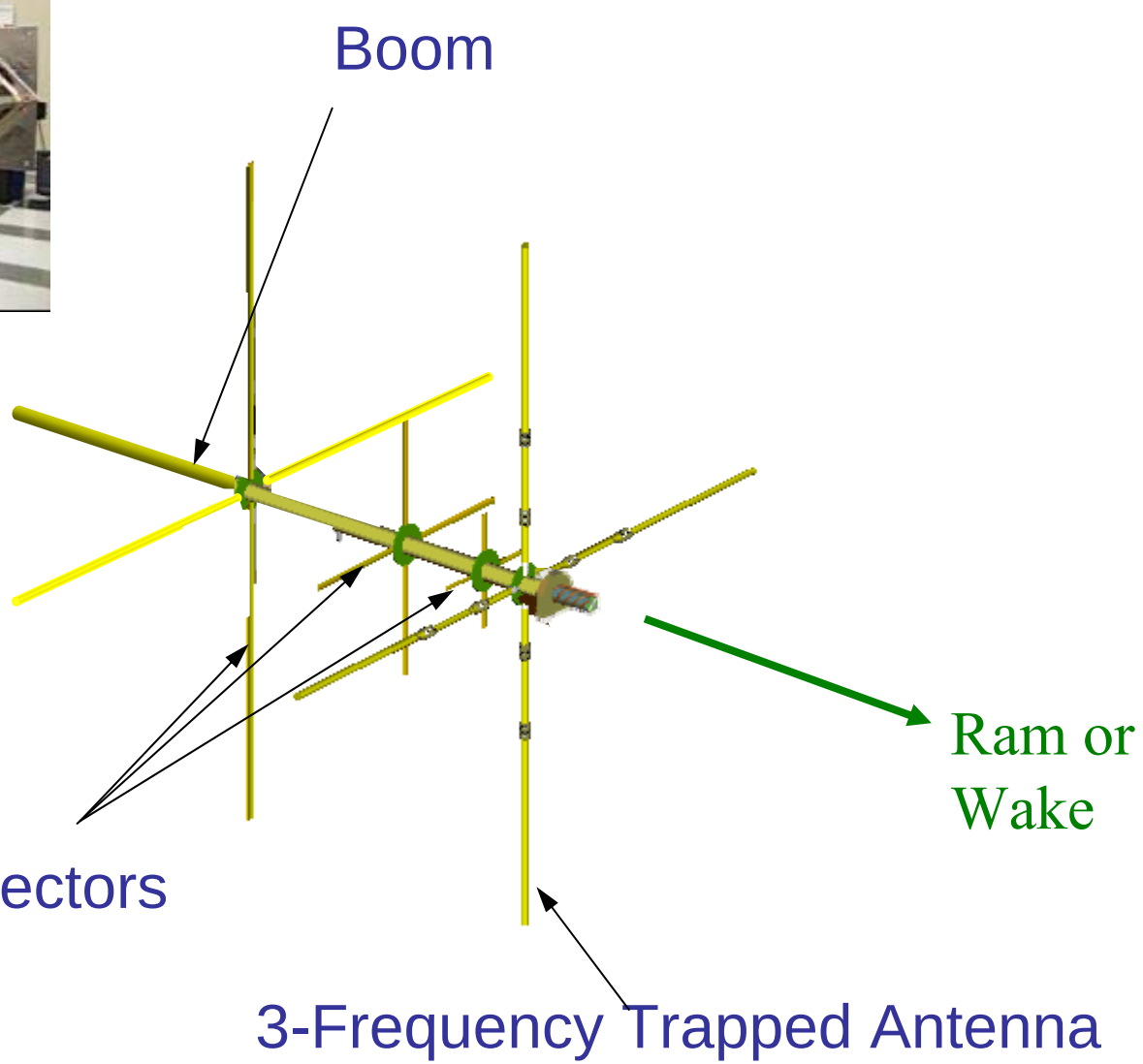
CITRIS Flight Receiver



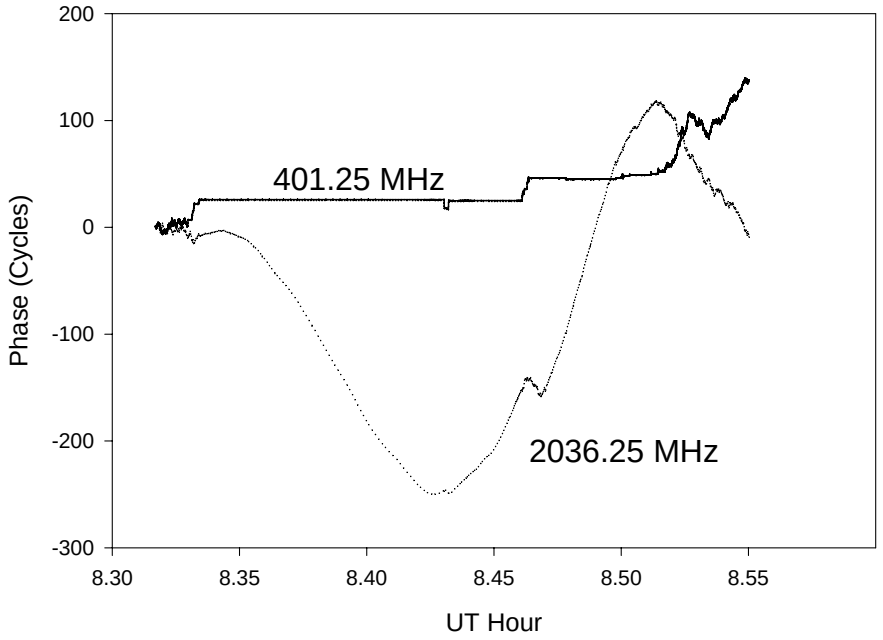


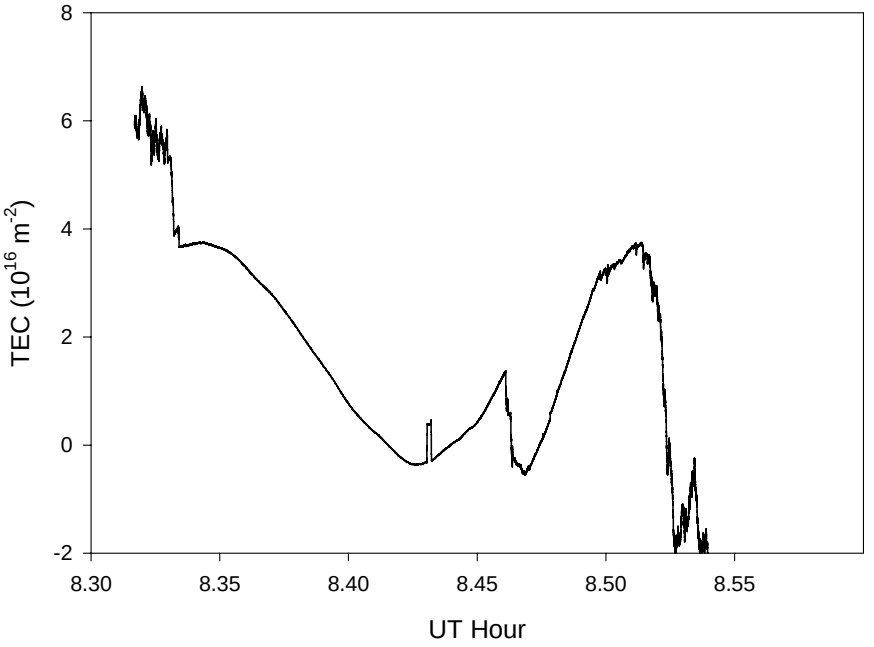
CITRIS Antenna



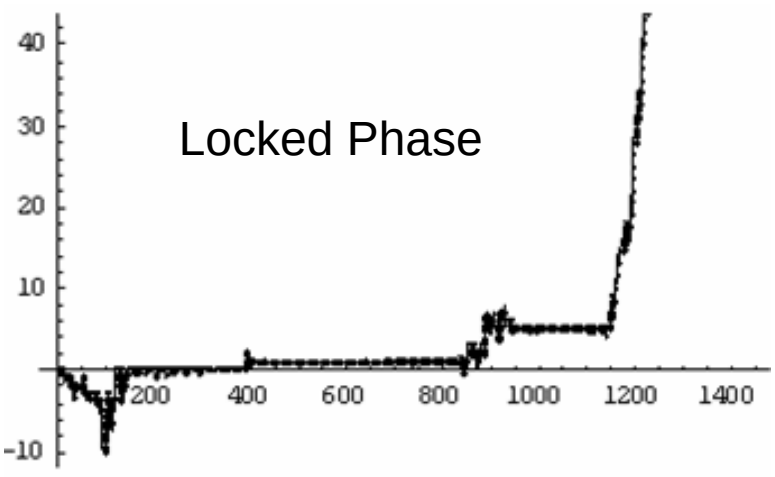


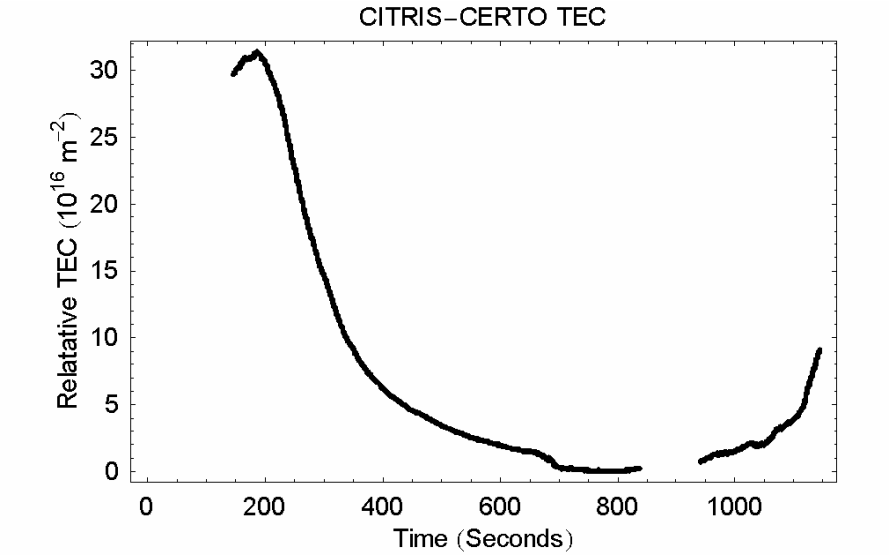
CITRIS Data Processing



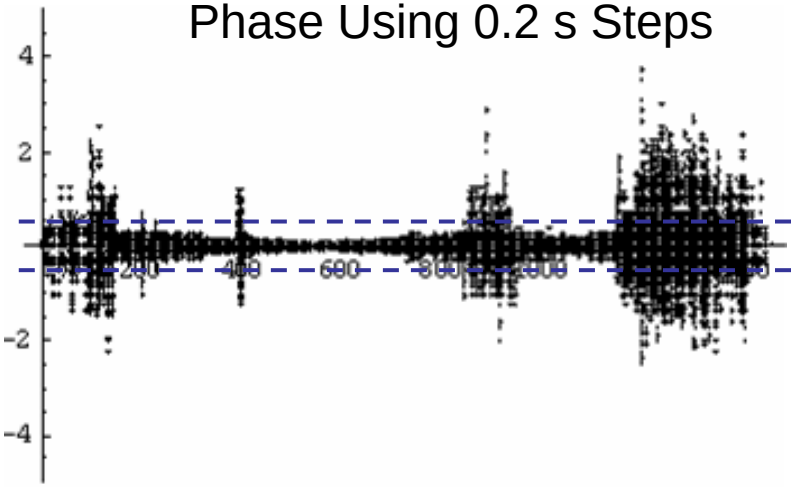


CITRIS-CERTO Data



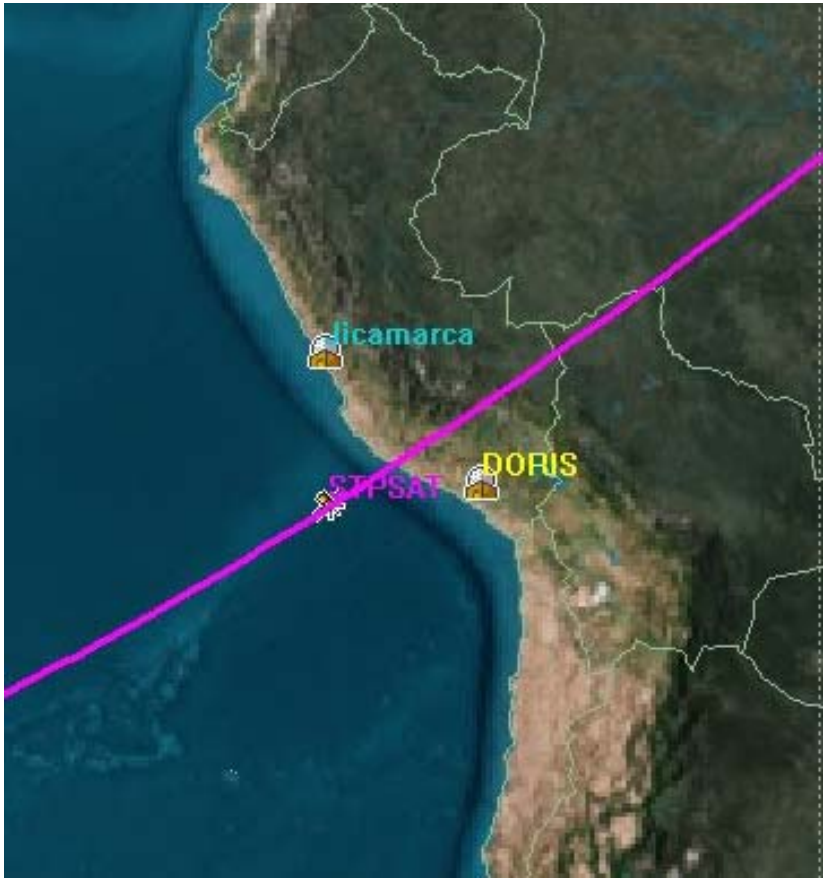


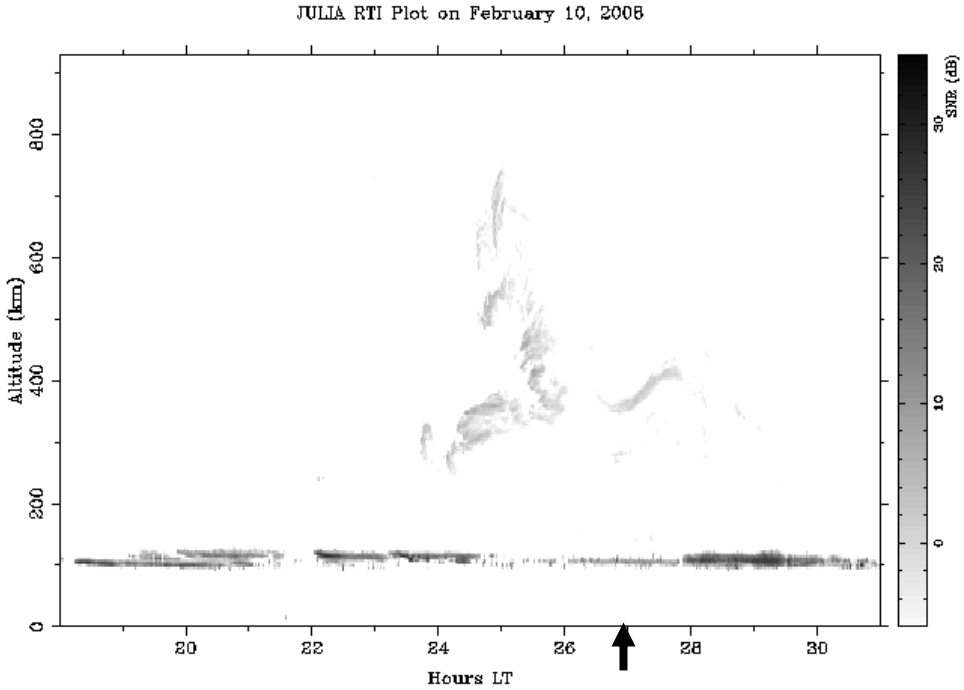
Numerical Derivative of Locked Phase Using 0.2 s Steps

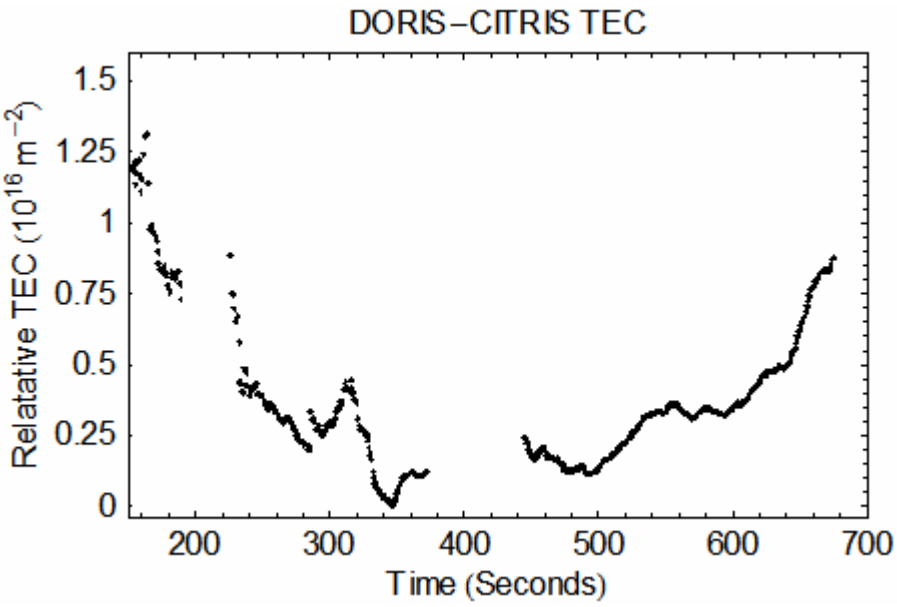


Acceptance Bounds

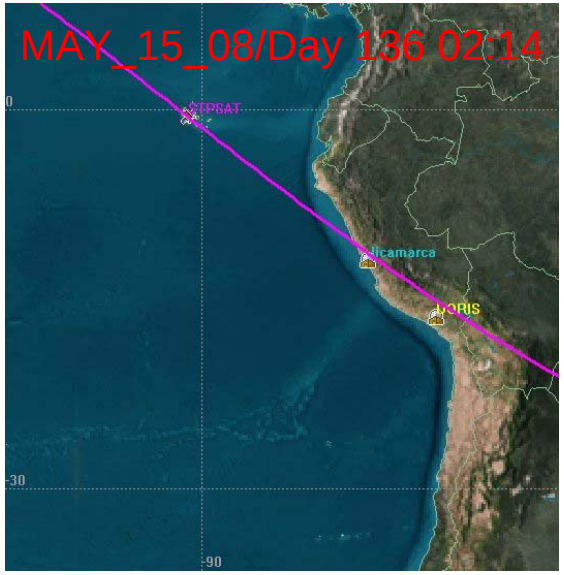
CITRIS-DORIS Pass During Spread-F Event 02/10/08

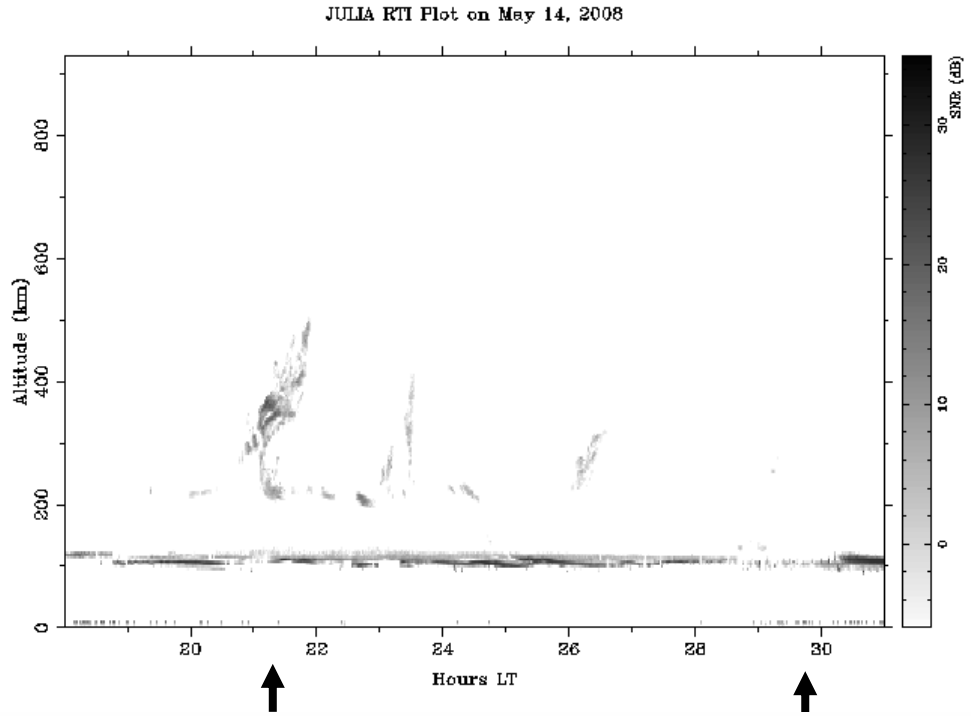


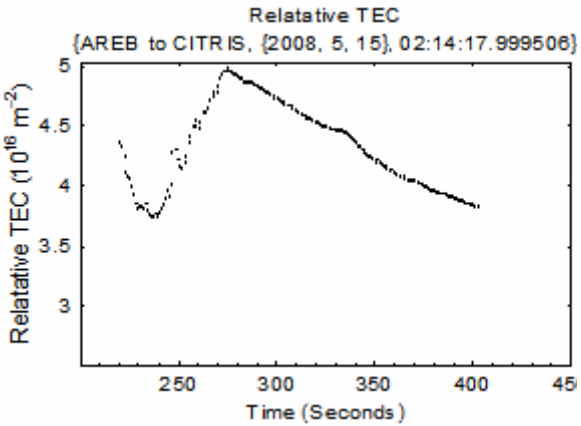


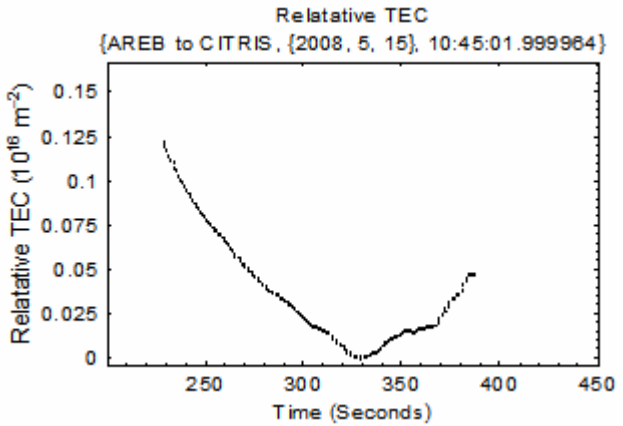


Jicamarca Overpasses CITRIS/DORIS

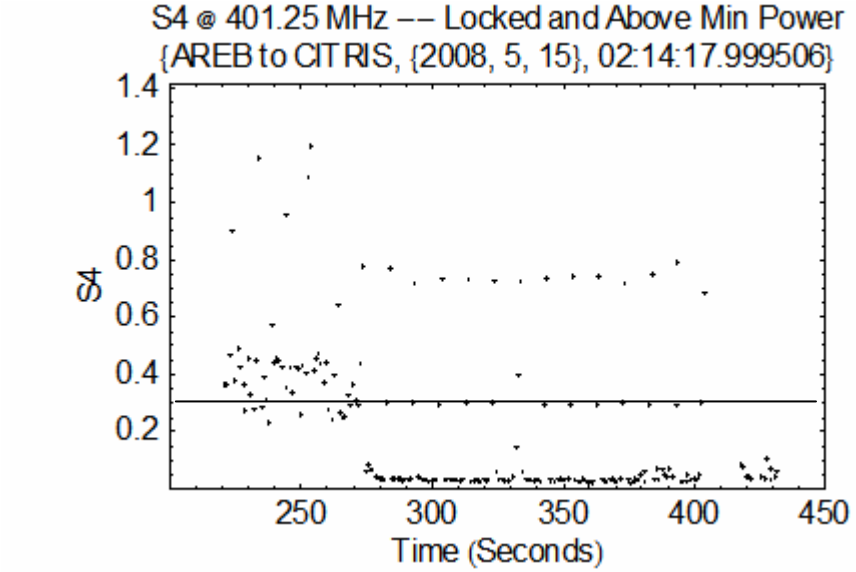


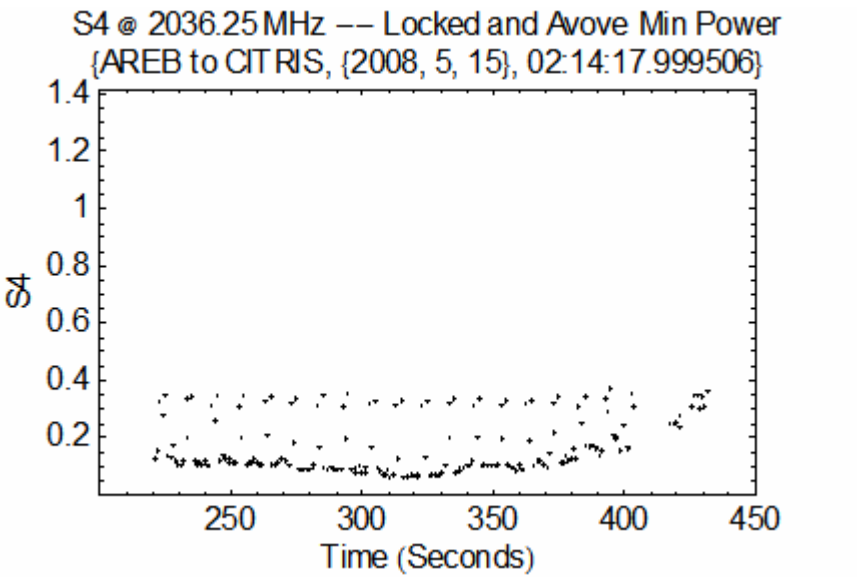


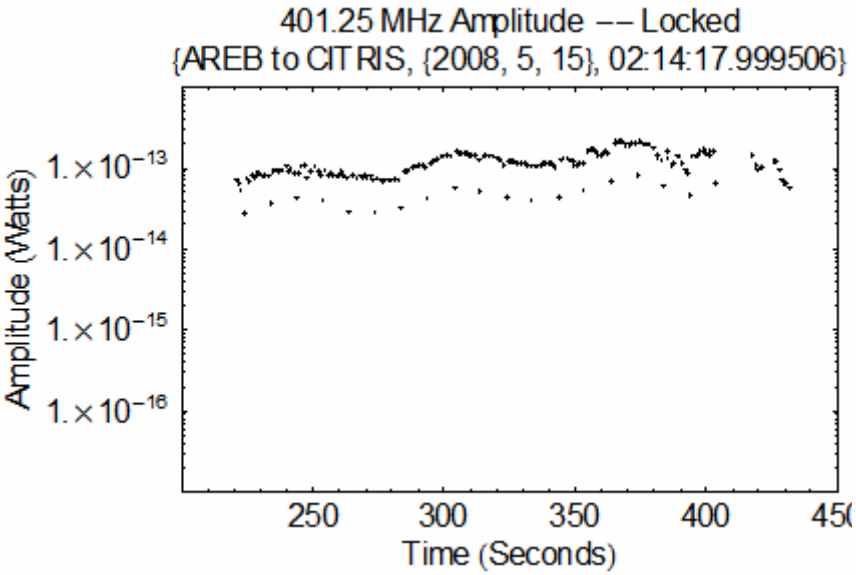


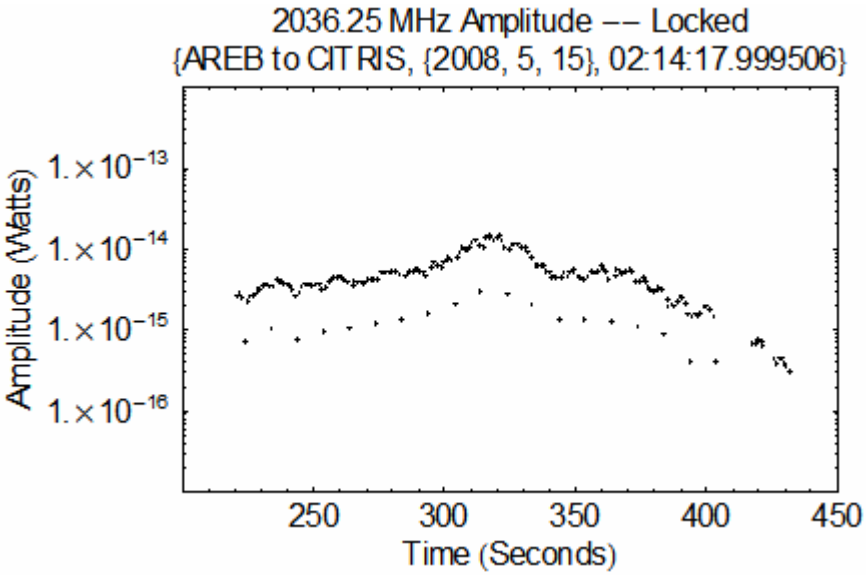


401 MHz Scintillations

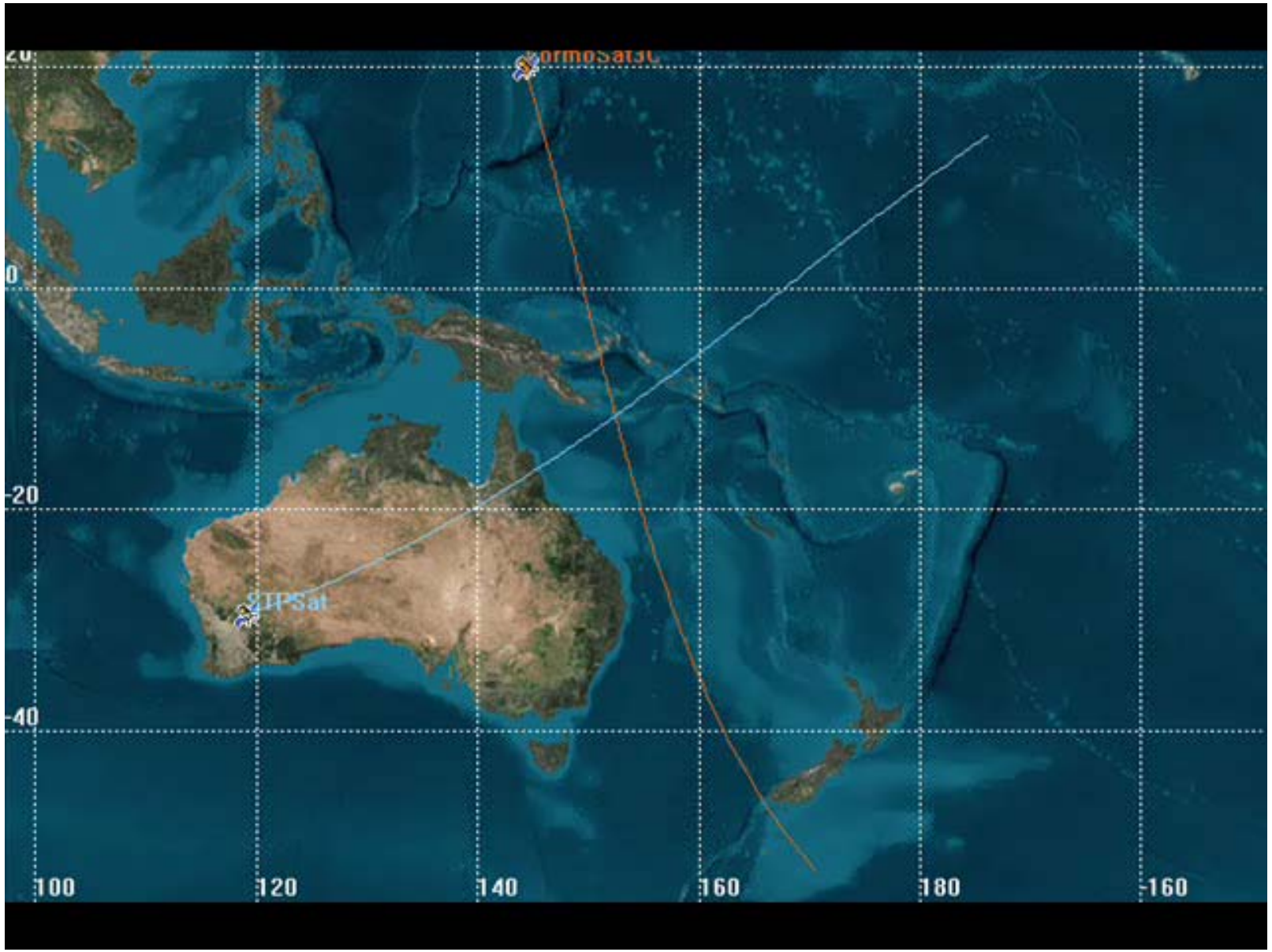




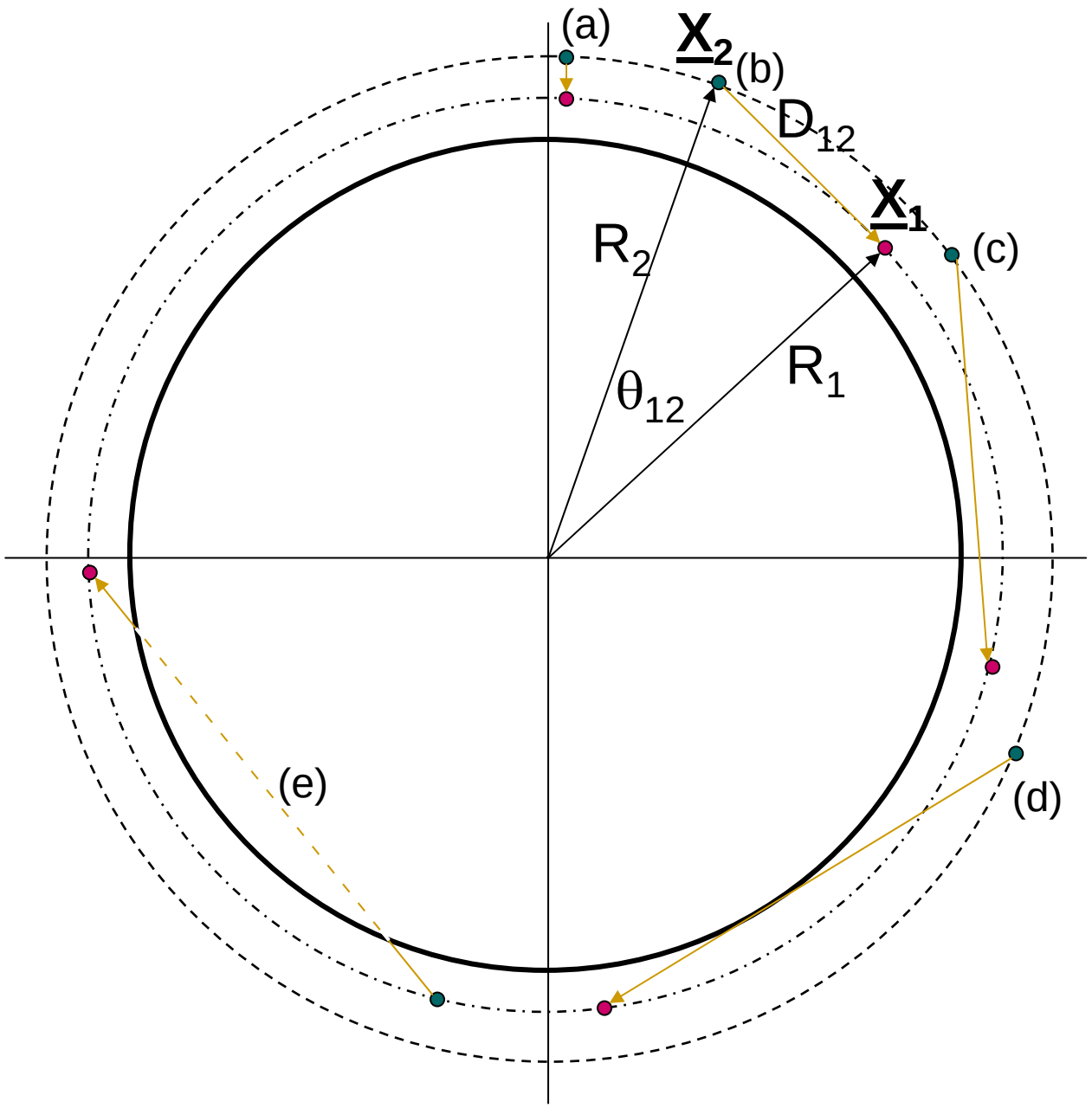




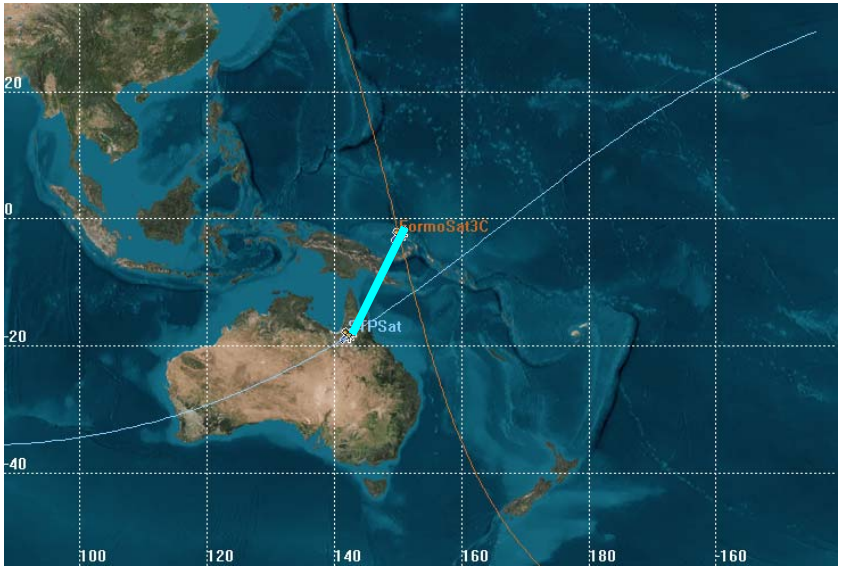
COSMIC to CITRIS Pass

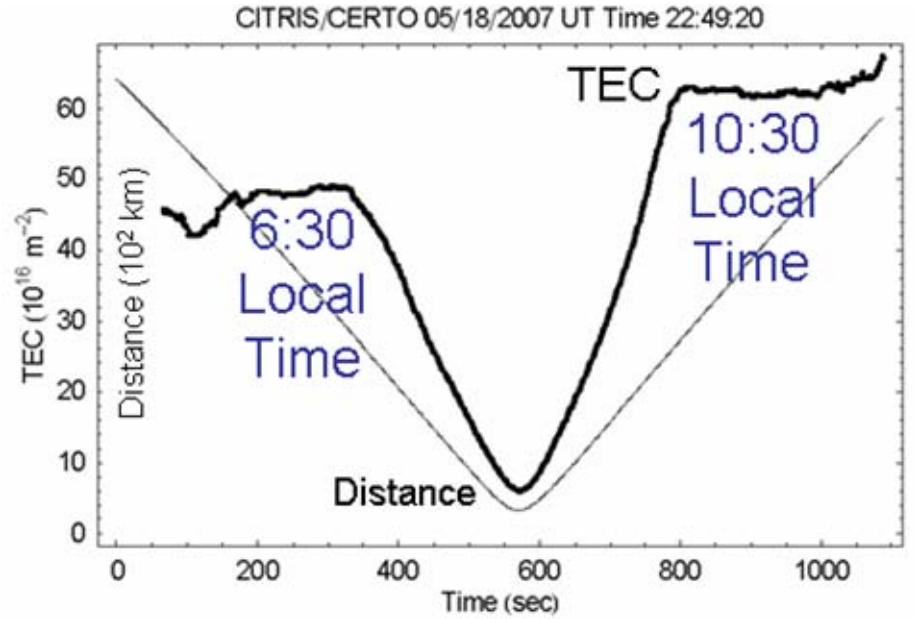


LEO-LEO Satellite Measurement Geometry

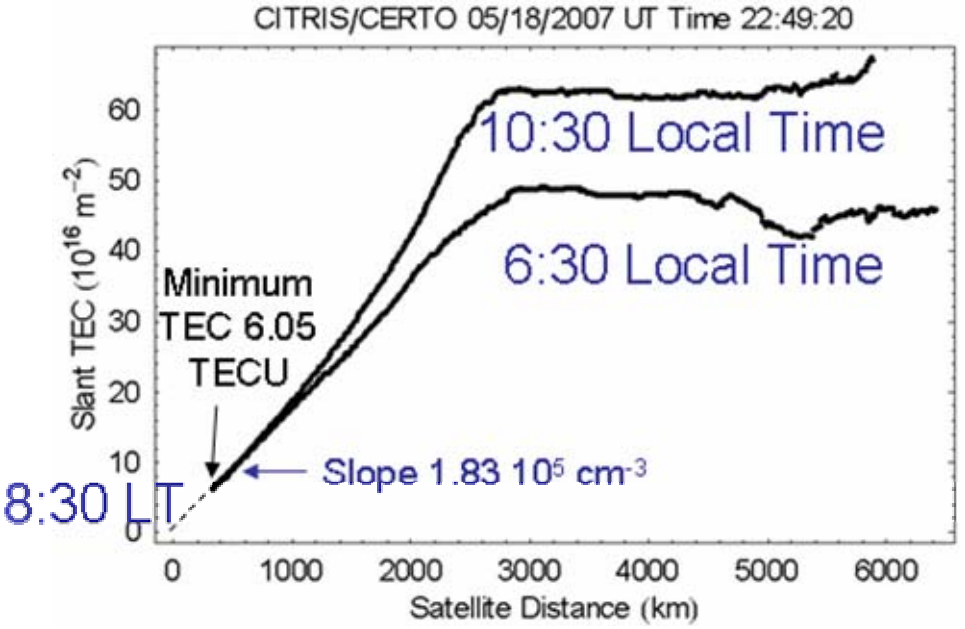


CERTO-CITRIS Measurements of Satellite-to-Satellite TEC 18 May 2007

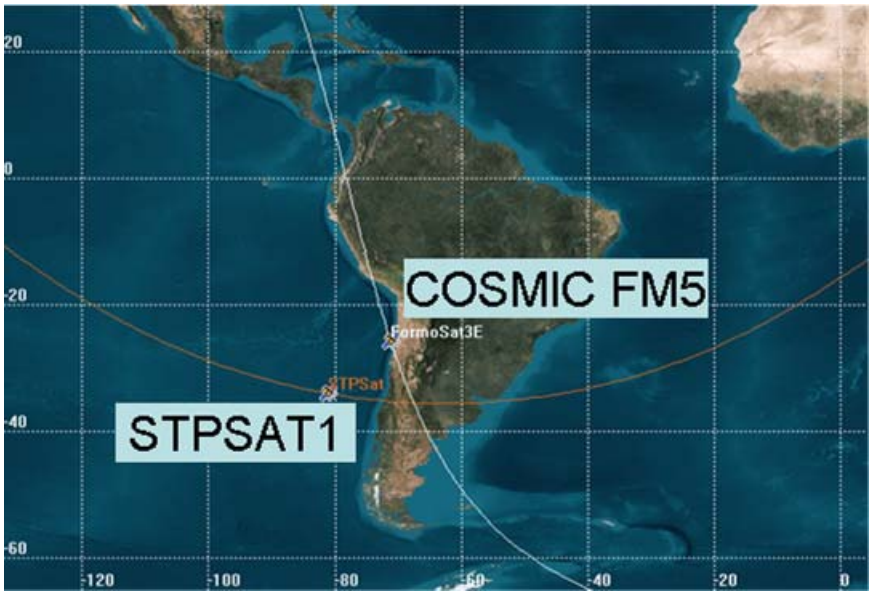


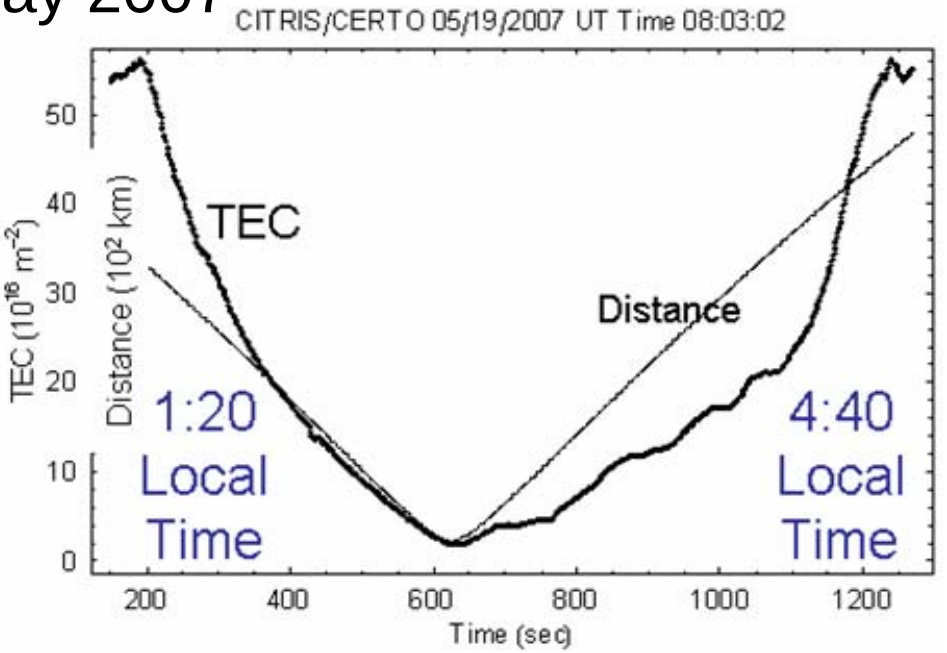


- Low Earth Orbit Occultation
  - COSMIC FM5 CERTO at 830 km Altitude
  - STPSAT1 CITRIS at 560 km Altitude
  - Ionospheric TEC Profile at Low Inclinations
  - Average Density Near Crossing
  - Absolute TEC by Extrapolation to Zero Distance

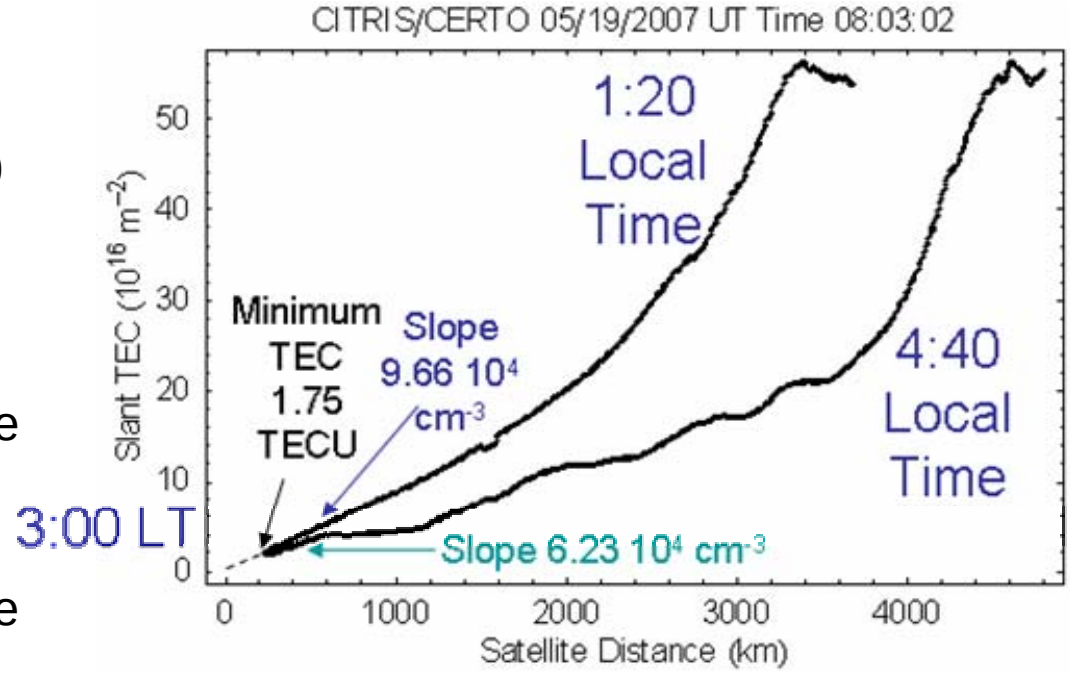


CERTO-CITRIS Measurements of Satellite-to-Satellite TEC 19 May 2007

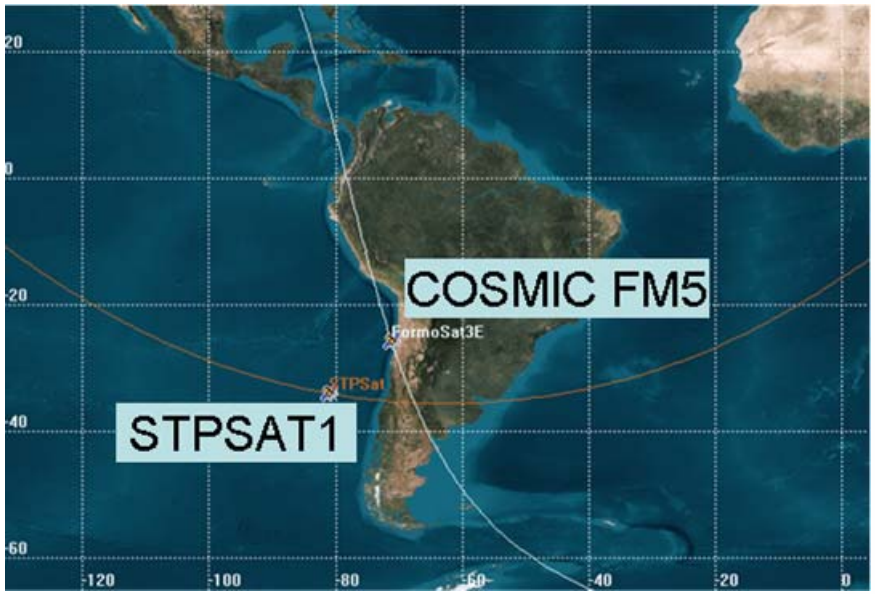


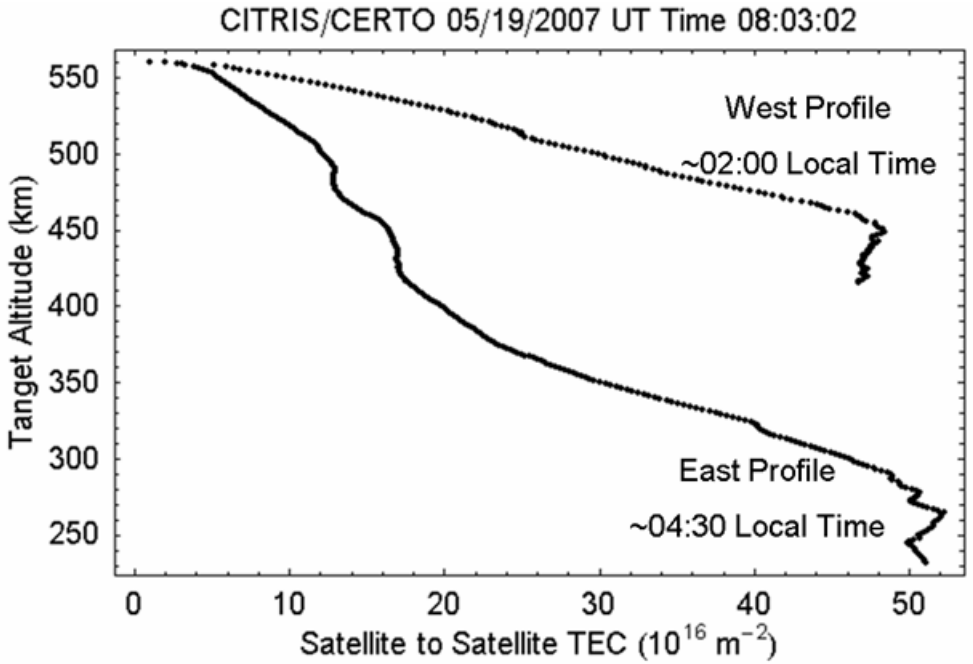


- Low Earth Orbit Occultation
  - COSMIC FM5 CERTO at 830 km Altitude
  - STPSAT1 CITRIS at 560 km Altitude
  - Relative TEC Versus Distance Between Satellites
  - Absolute TEC From Extrapolation to Zero Distance

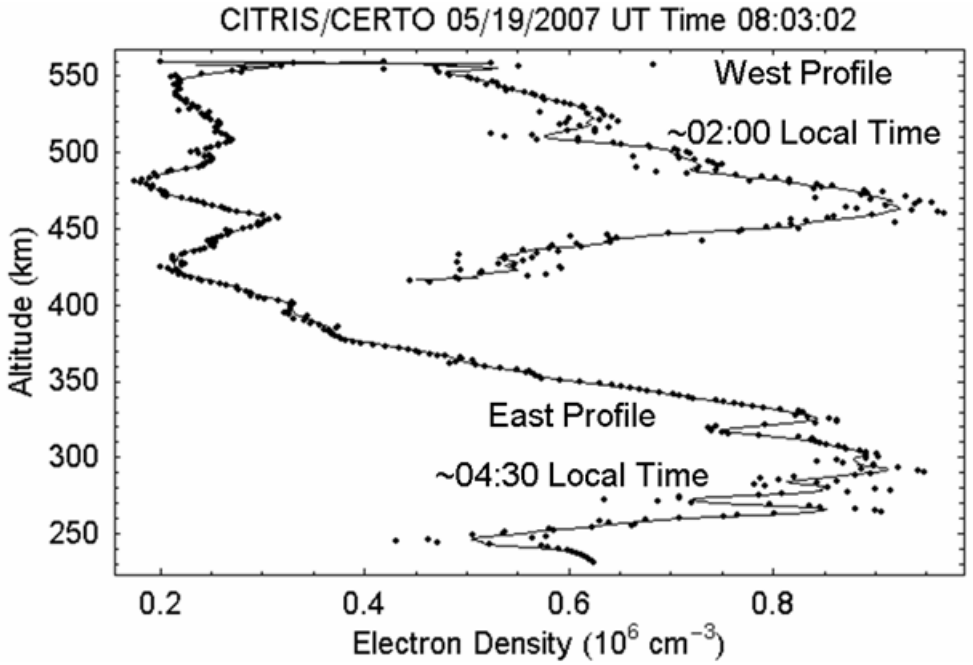


CITRIS Occultation TEC and Electron Density Profiles



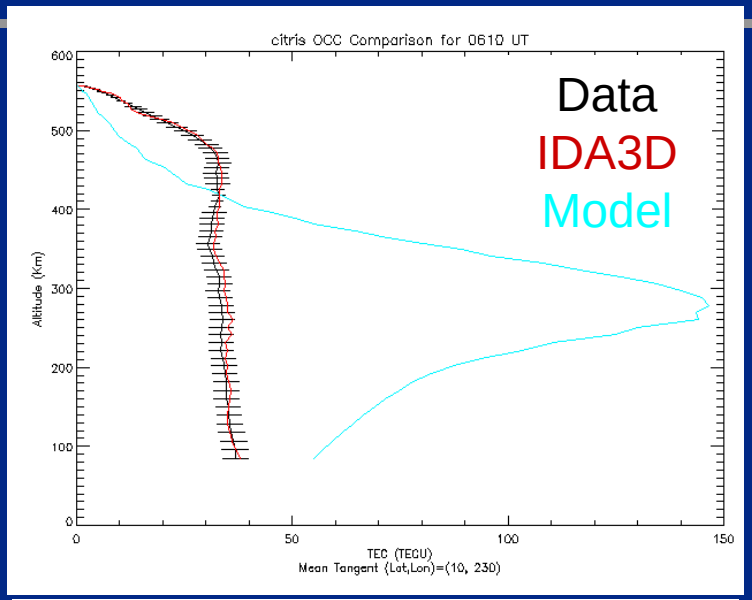


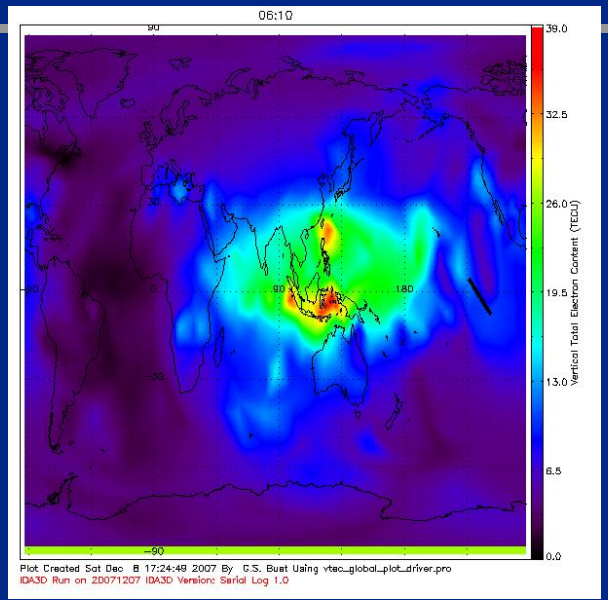
- Low Earth Orbit Occultation Analysis
  - STPSAT1 CITRIS at 560 km Altitude
  - COSMIC FM5 at 791 km Altitude
  - Abel Inversion of TEC Between Lower Altitude Orbits
  - About 2 x 10^5 Peak Electron Density

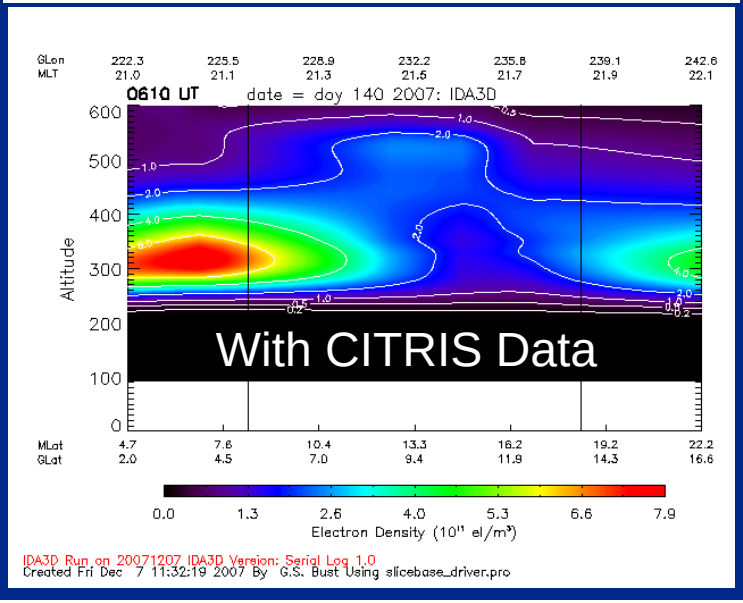


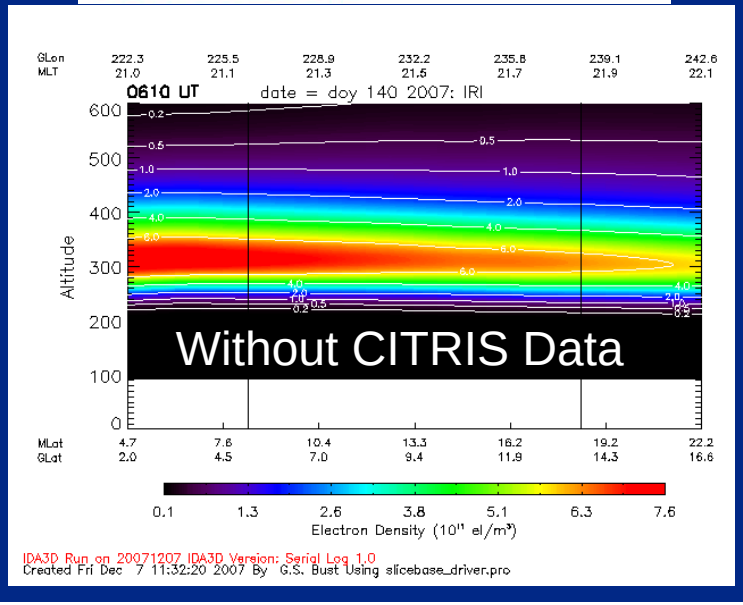
CITRIS LEO-to-LEO Occultation Example - Equatorial Pacific

(Bust et al, AGU 2007 SA11B-06)



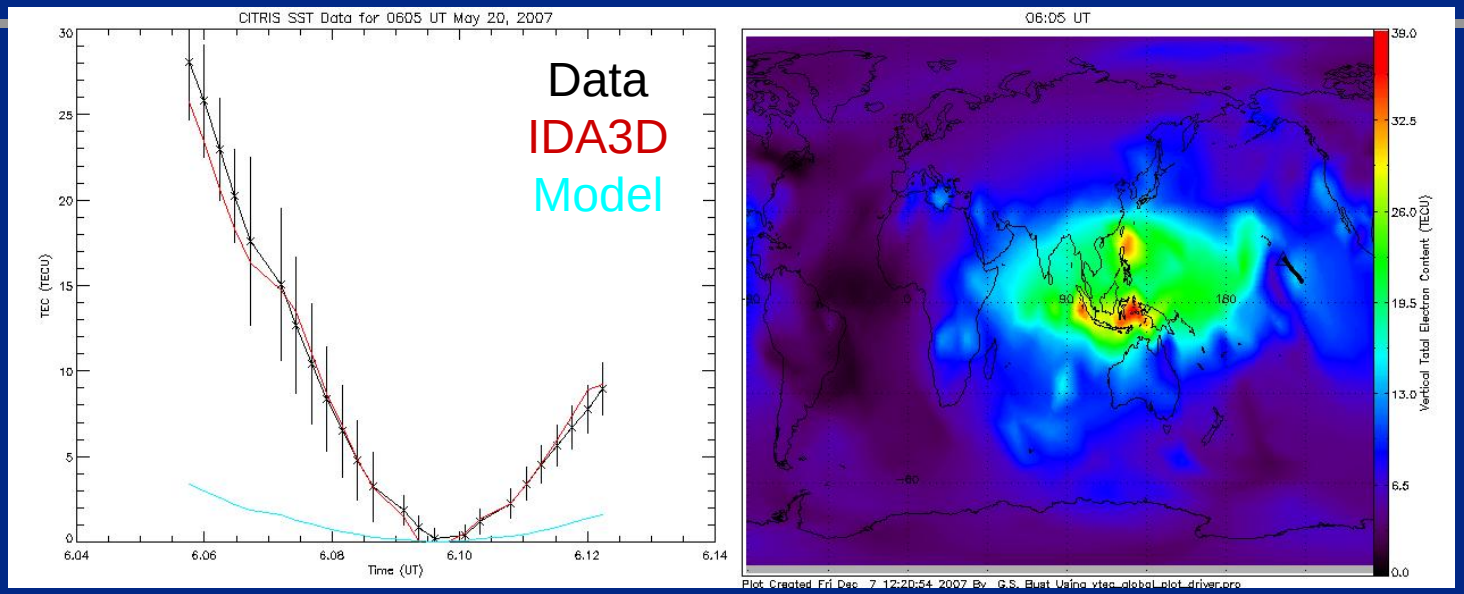


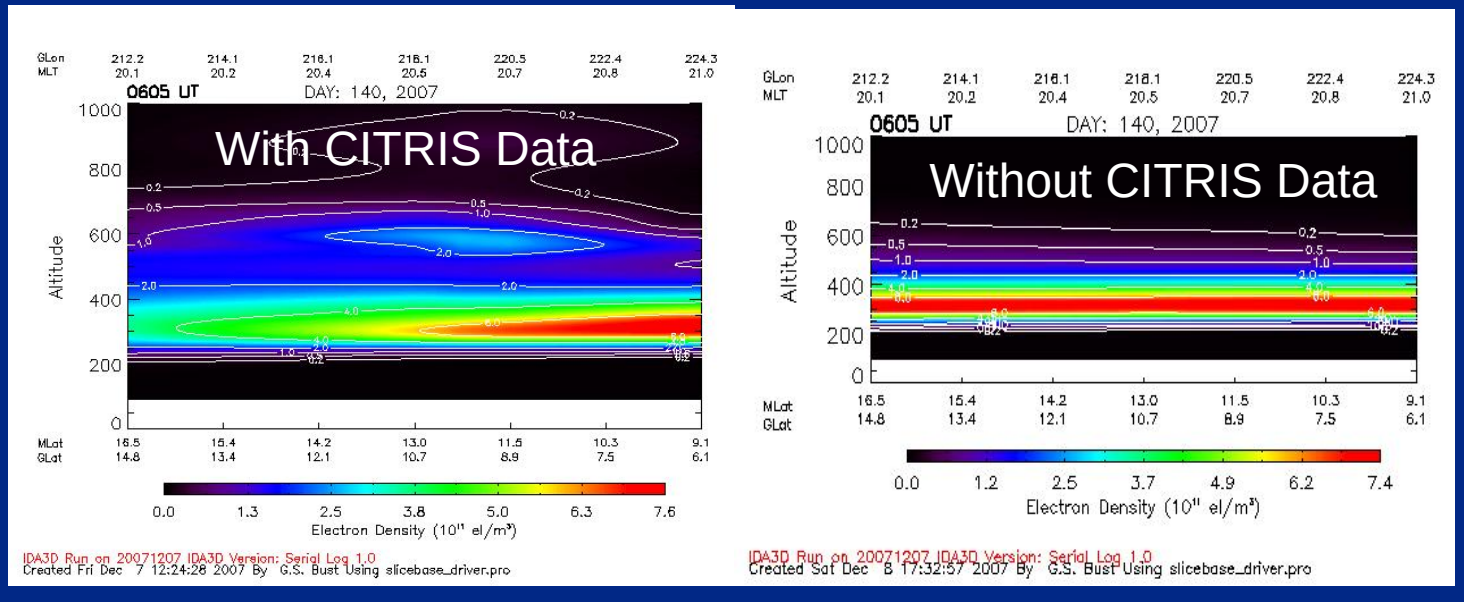




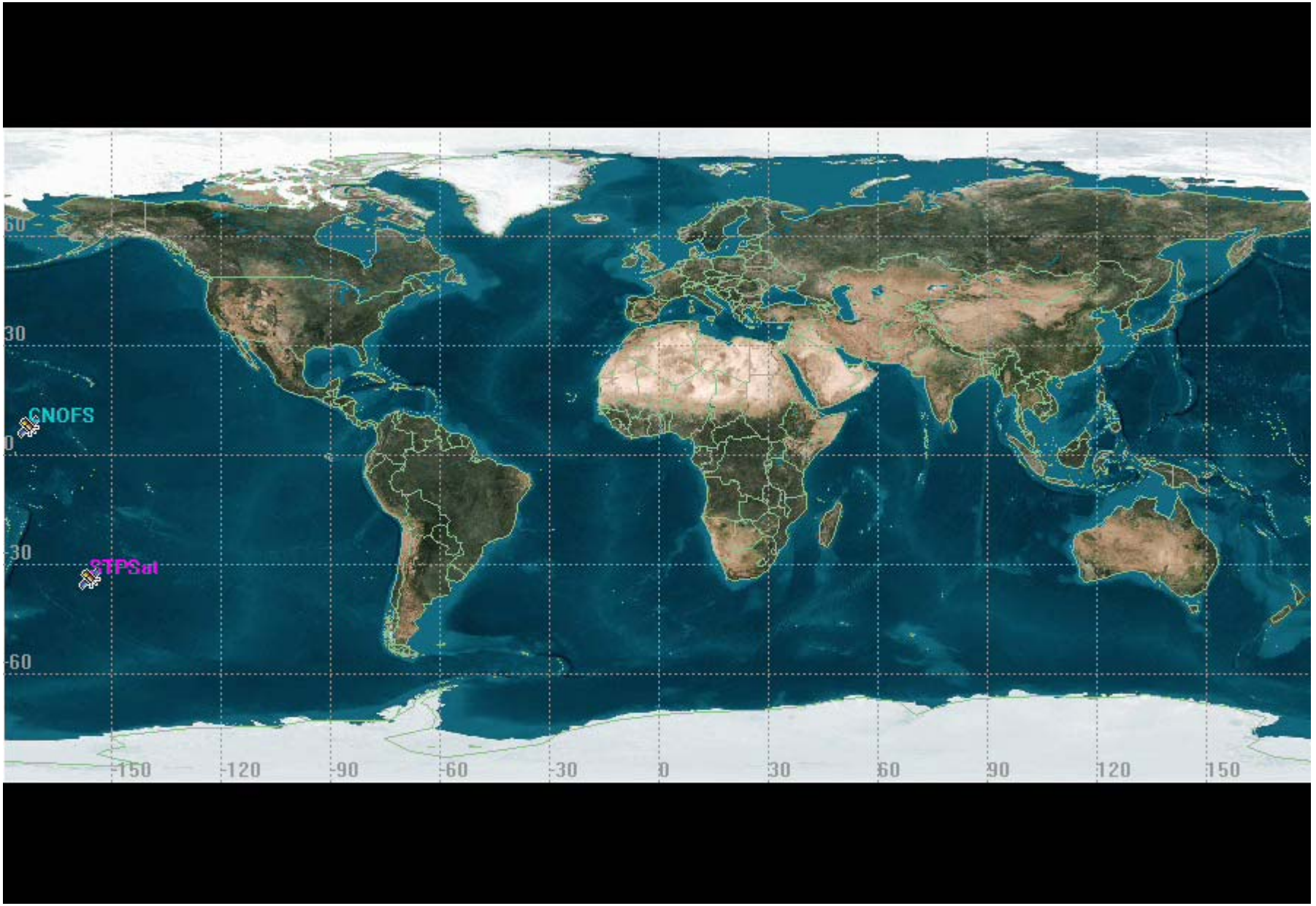
CITRIS LEO-to-LEO SST Example - Equatorial Pacific

(Bust et al, AGU 2007 SA11B-06)

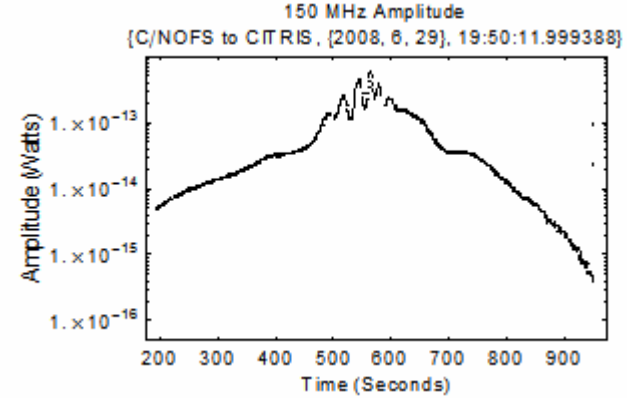


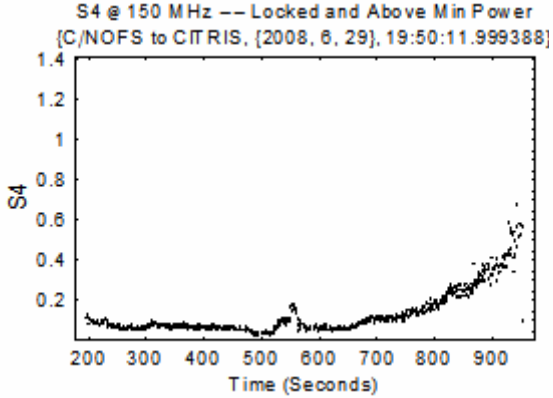


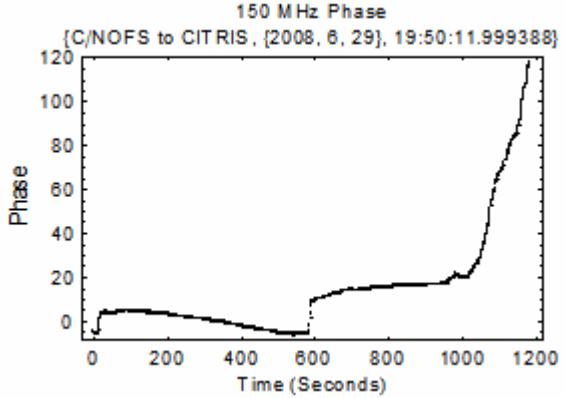
CNOFS and CITRIS Tandem Operation

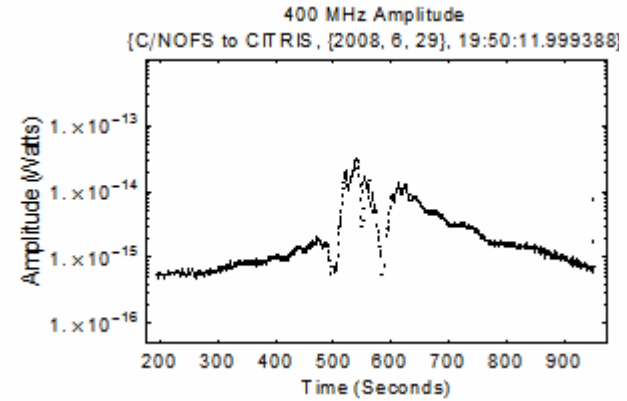


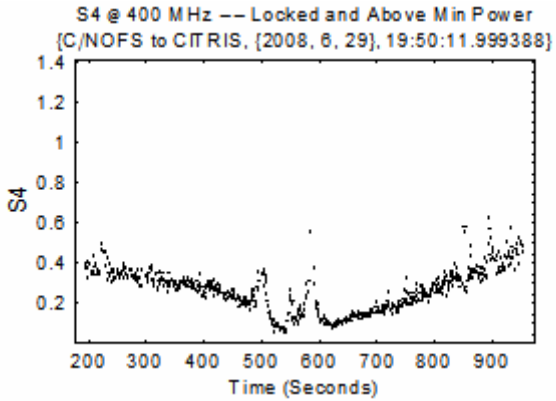
C/NOFS has Three Frequency CERTO Beacon Allowing Three Different Measurements of TEC

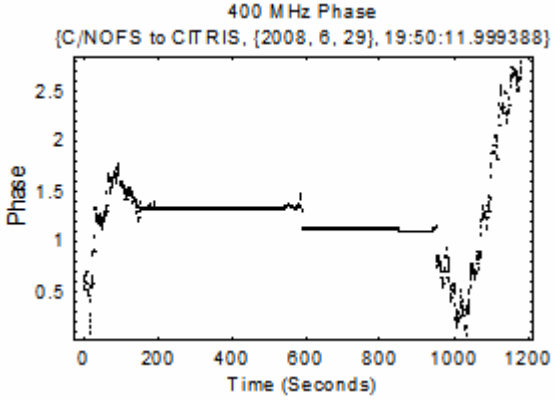


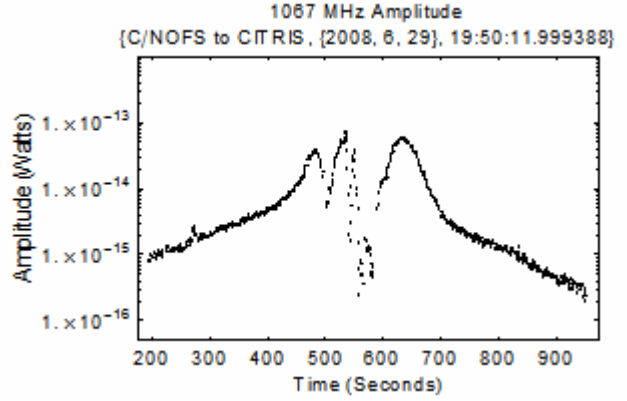


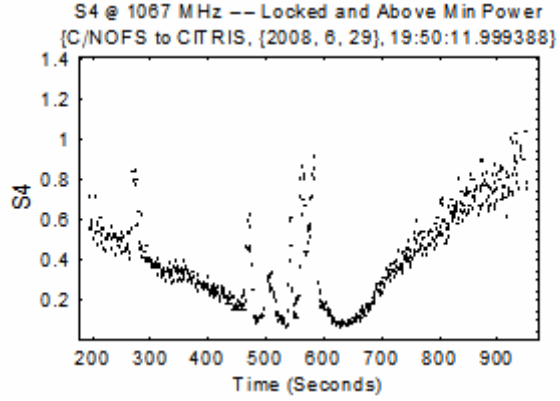


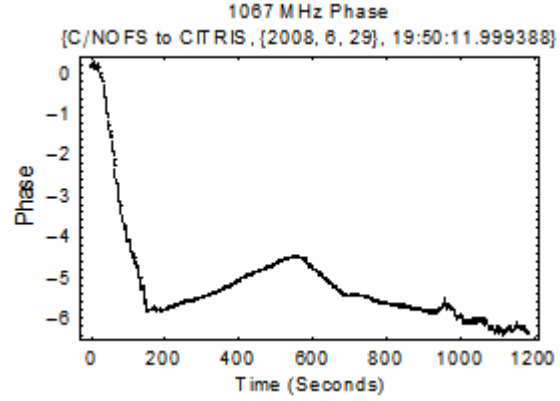




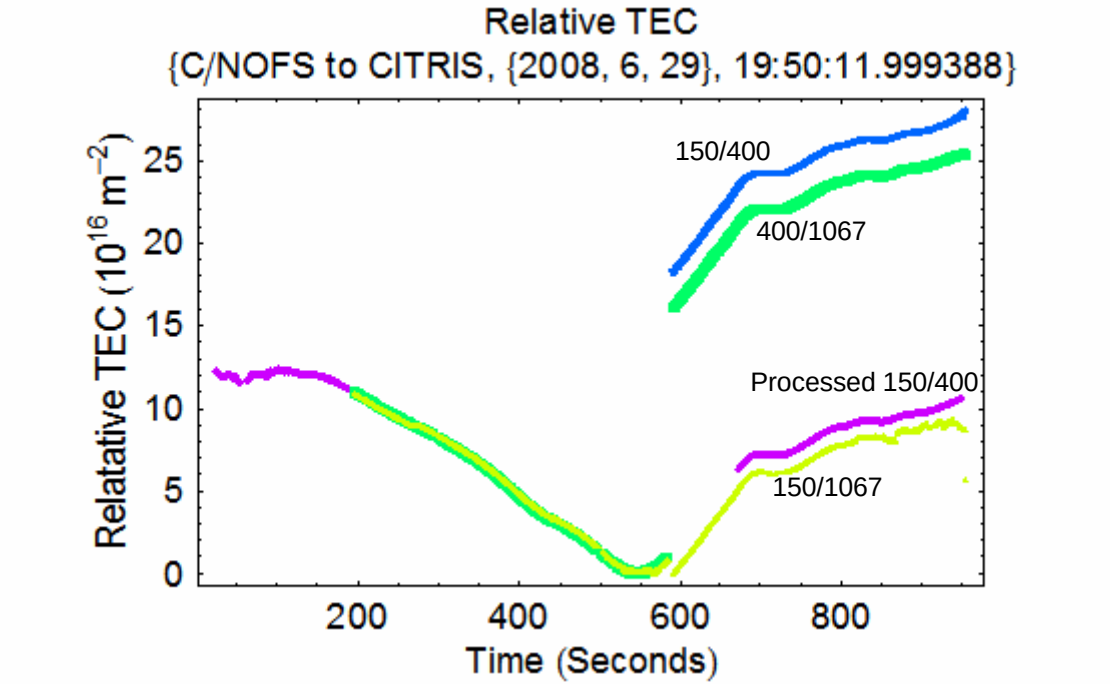




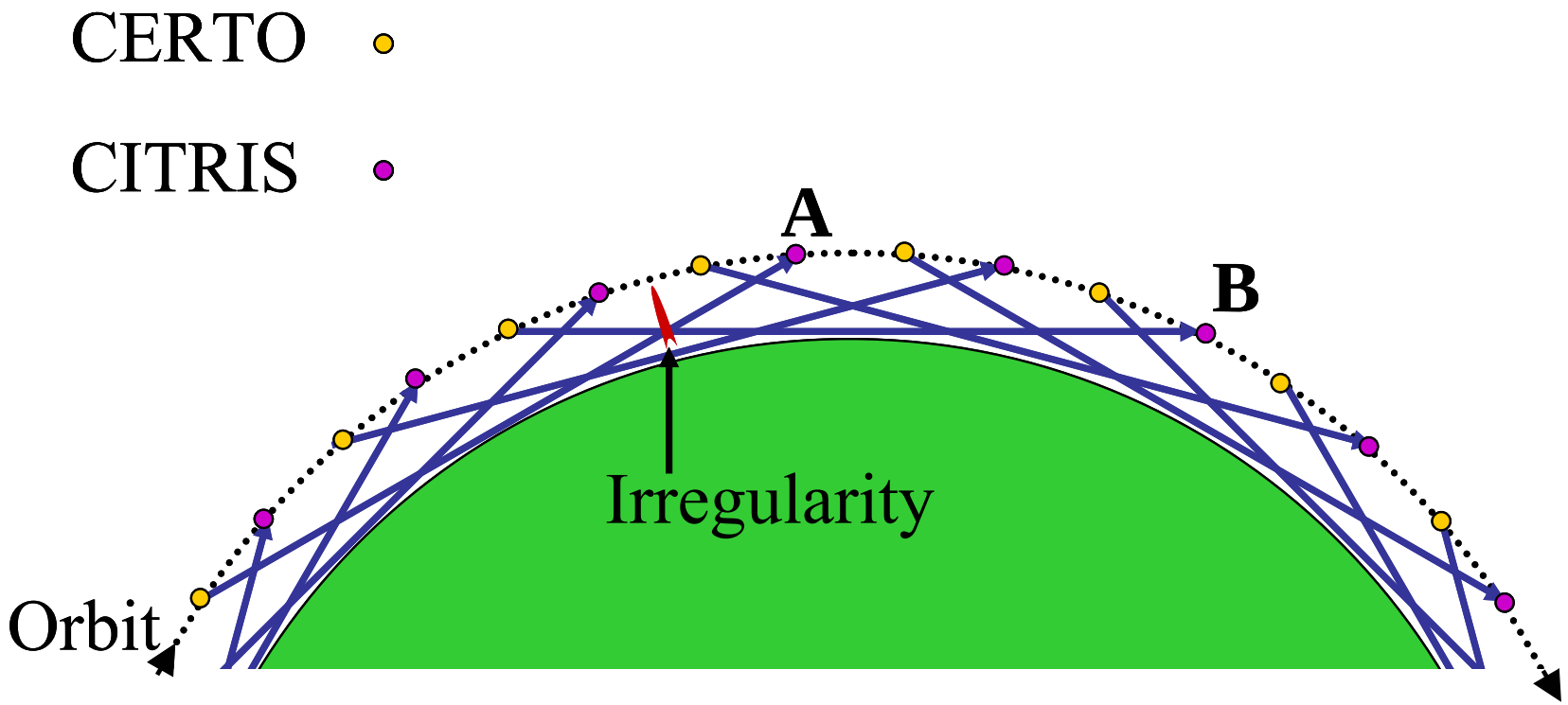




C/NOFS has Three Frequency CERTO Beacon Allowing Three Different Measurements of TEC



Tandem Satellite Observations of Ionospheric Irregularities



CITRIS Status

- Major Milestones
  - Integration and Test of CITRIS Finished March 2006
  - STPSAT1 Launched March 9, 2007
  - On Orbit CITRIS Check-Out Completed March 15, 2007
  - Normal Operations Started March 27, 2007
  - First Satellite-to-Satellite TEC Measurements May 2007
  - Preliminary Data Presentation June 2007
  - Integration of CITRIS Data in Ionospheric Model Dec 2007 (Bust et al, SA11B-06)
  - STPSat1 Turned over to NRL Blossom Point for Operations May 2008
    - NASA Funding obtained for ~ one year of operations
  - Coordinated measurements with C/NOFS June/Aug 2008

- Current Operational Status
  - Data Acquisition for Twenty (20) Contacts per Day of 20-40 Minutes
  - Receiver Processed TEC and Scintillation Statistics (1 sample/sec)
  - Raw Data Available at up to 200 sample/sec
    - With 6 MByte Data Restriction before Download

- Things to Do

  -Comparison of C/NOFS and CITRIS Data

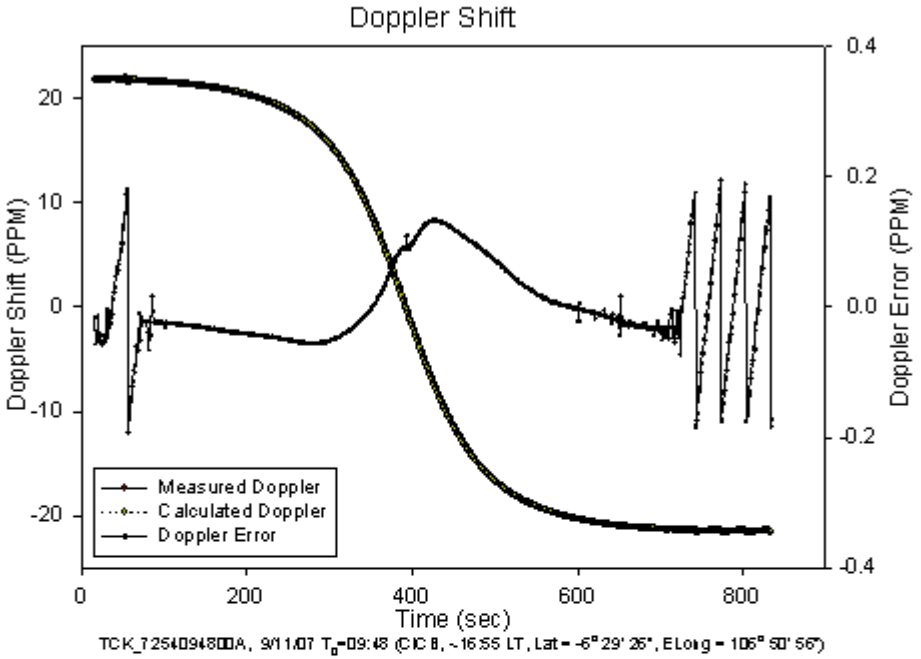
  -Detailed Comparison of Passes near Jicamarca Incoherent Scatter Radar During September 2007 Ionospheric World Days

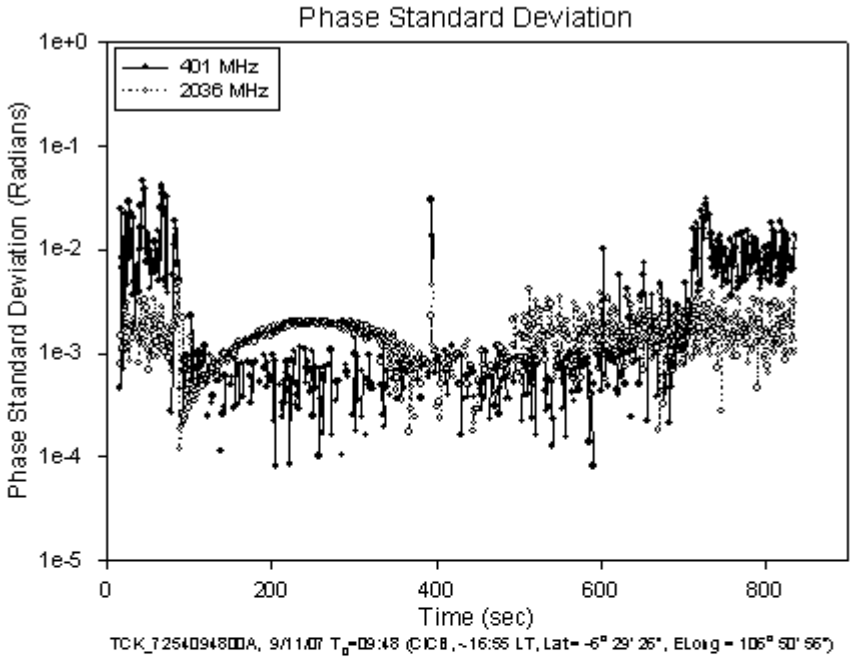
The Future of CITRIS

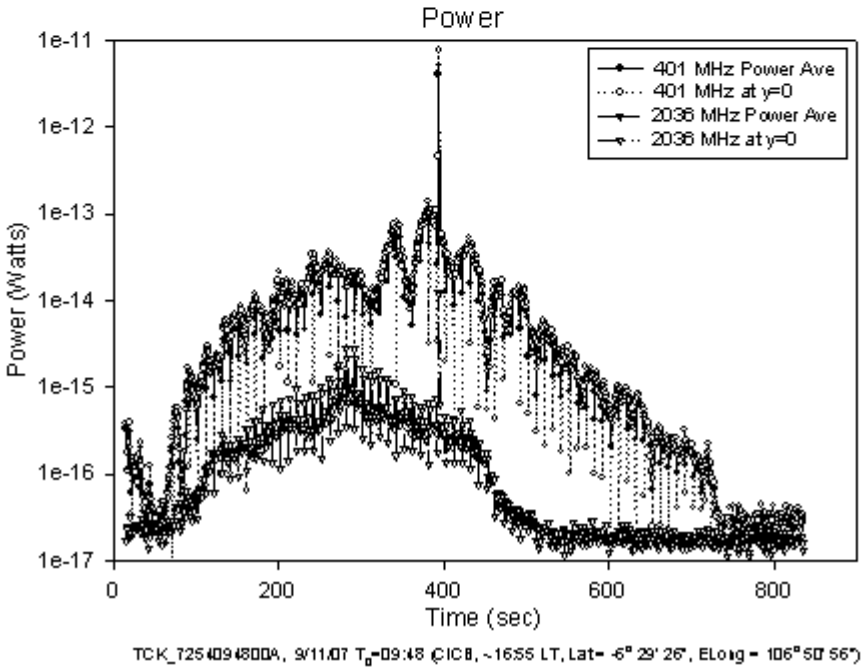
- Assimilation of CITRIS Data into Space Weather Models
  - Data Distributed to GAIM and IAD3D Models
- Continued Tandem Operations with C/NOFS
  - C/NOFS Launched April 2008
  - CITRIS Link to CERTO Beacon on C/NOFS
- New “SpaceBuoy” Satellite Under Design to Host CITRIS
  - Satellite Fabrication
    - Space Science and Engineering Lab, Montana State University
    - Professor David Klumpar, PI
  - Payload
    - CITRIS Receiver from NRL
    - Planar Langmuir Probe (PLP) from AFRL
  - Demonstration of Low Cost Space Weather Monitor

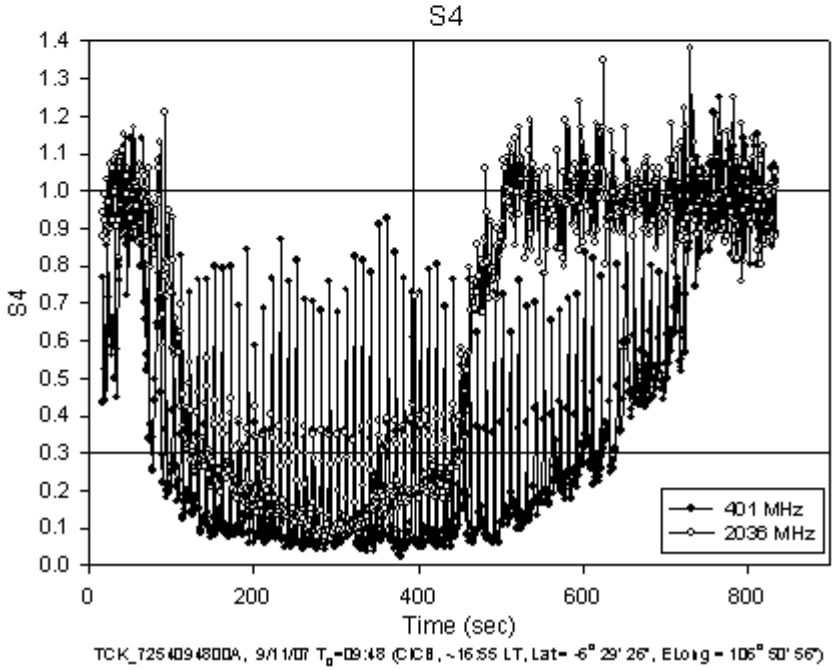
Extras

CITRIS Measurements for Scintillations

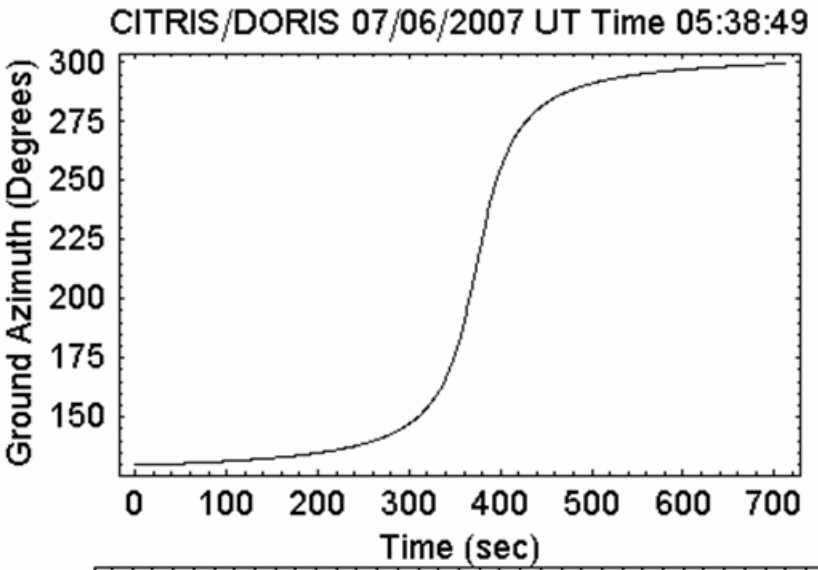


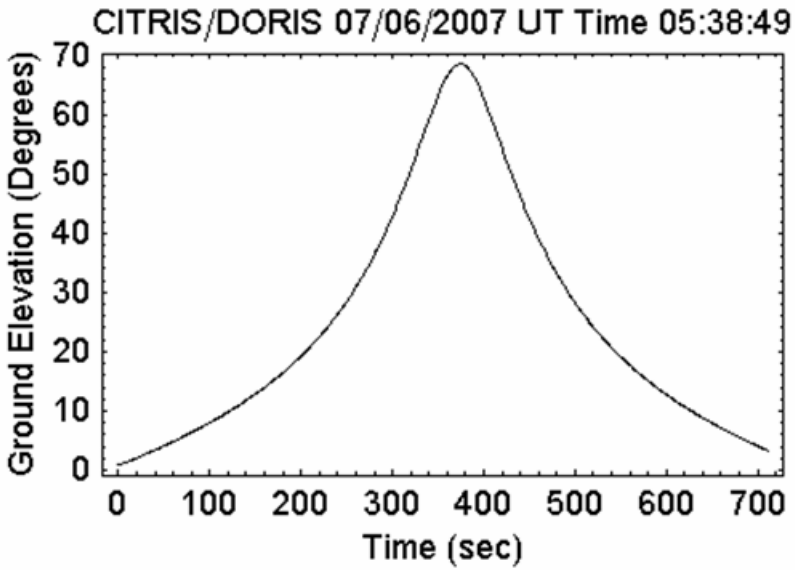


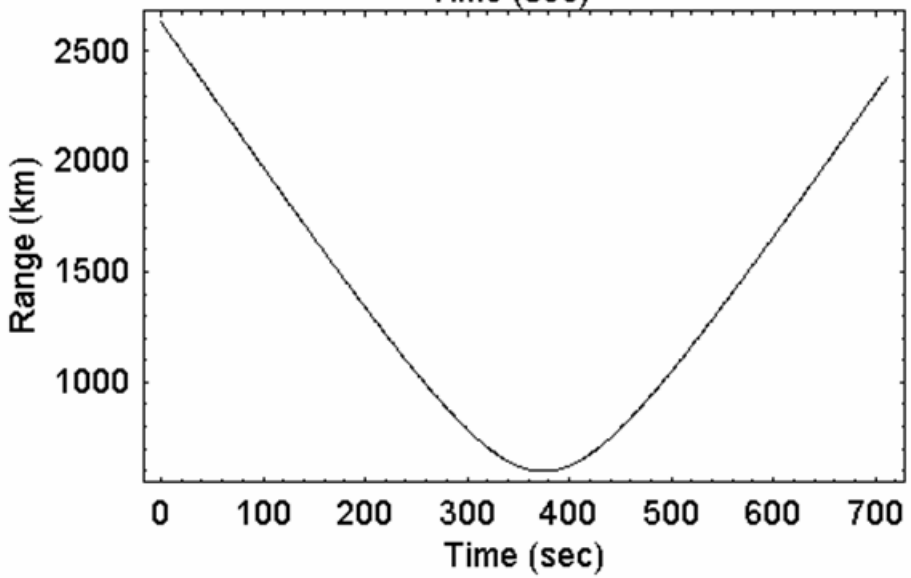


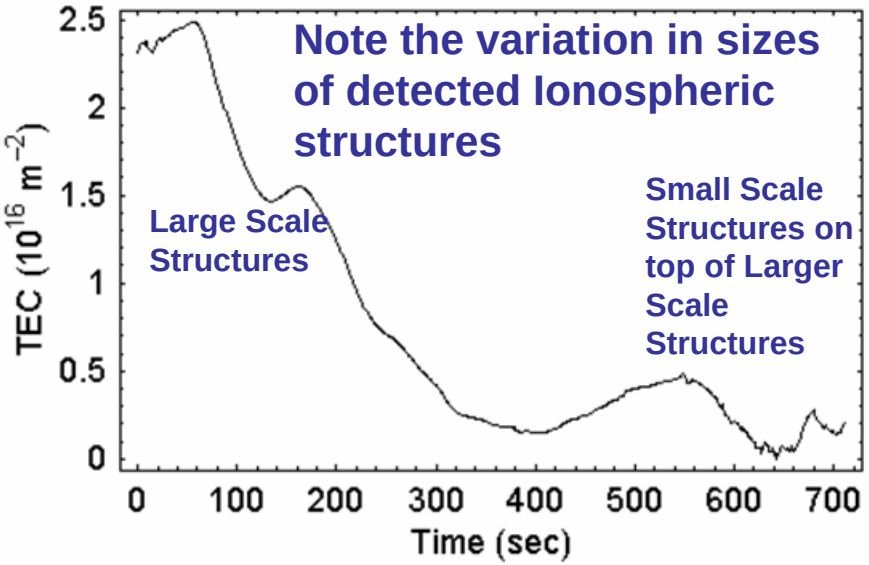


TEC From the DORIS Beacon at Arequipa Peru (-16.467 N Lat, -71.5 E Long)

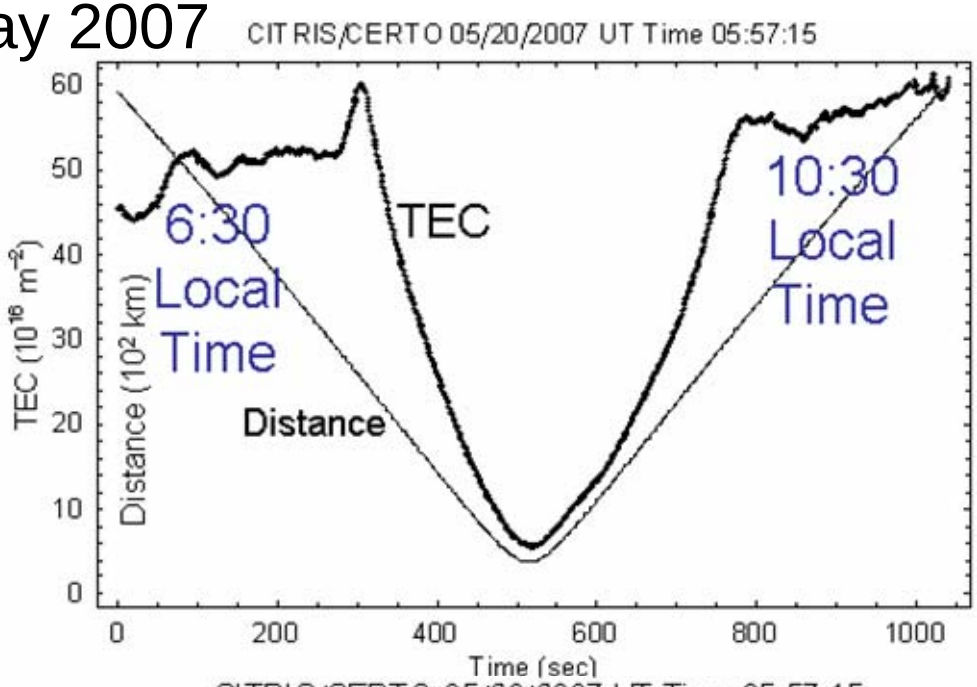








CERTO-CITRIS Measurements of Satellite-to-Satellite TEC
20 May 2007



- Low Earth Orbit Occultation
  - COSMIC FM5 CERTO at 830 km Altitude
  - STPSAT1 CITRIS at 560 km Altitude
  - Ionospheric TEC Profile at Low Inclinations