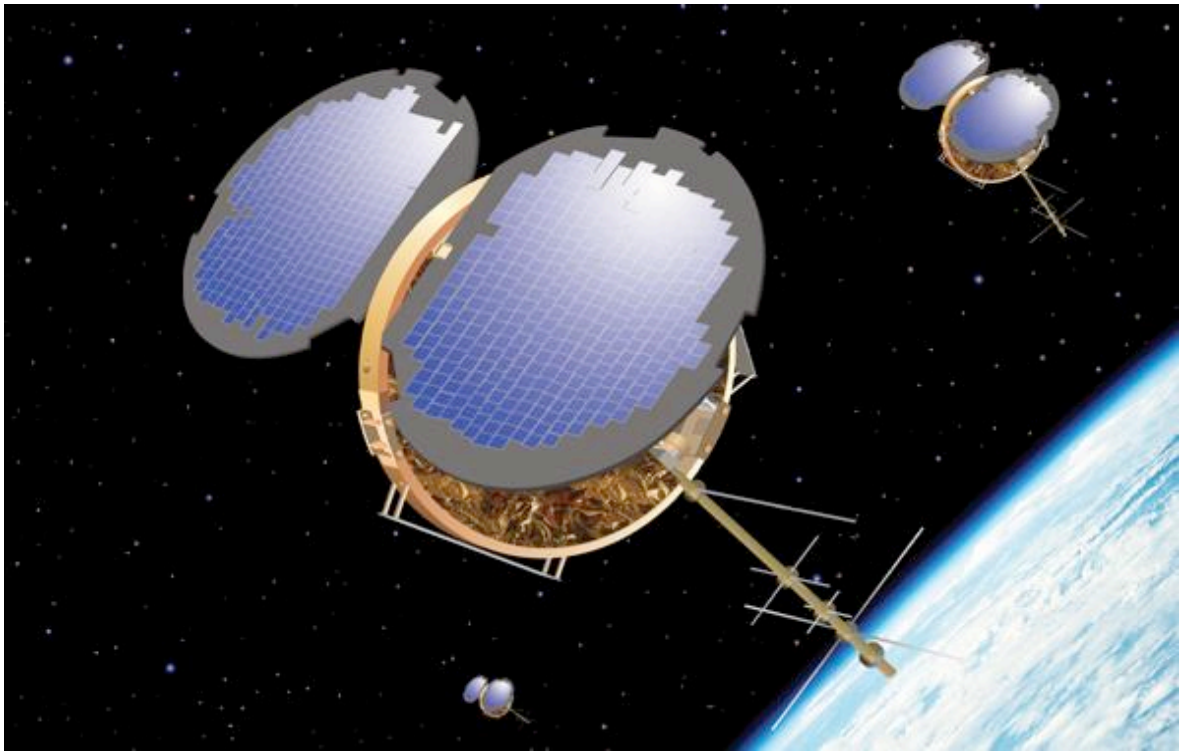
COSMIC / FormoSat 3

Status and real time data use

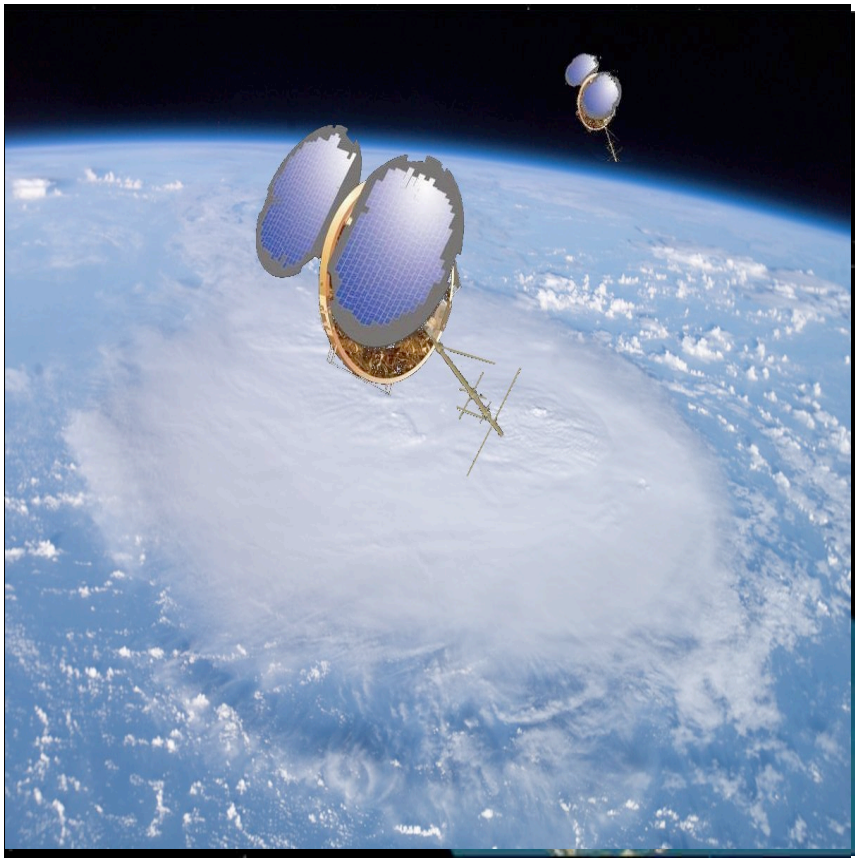


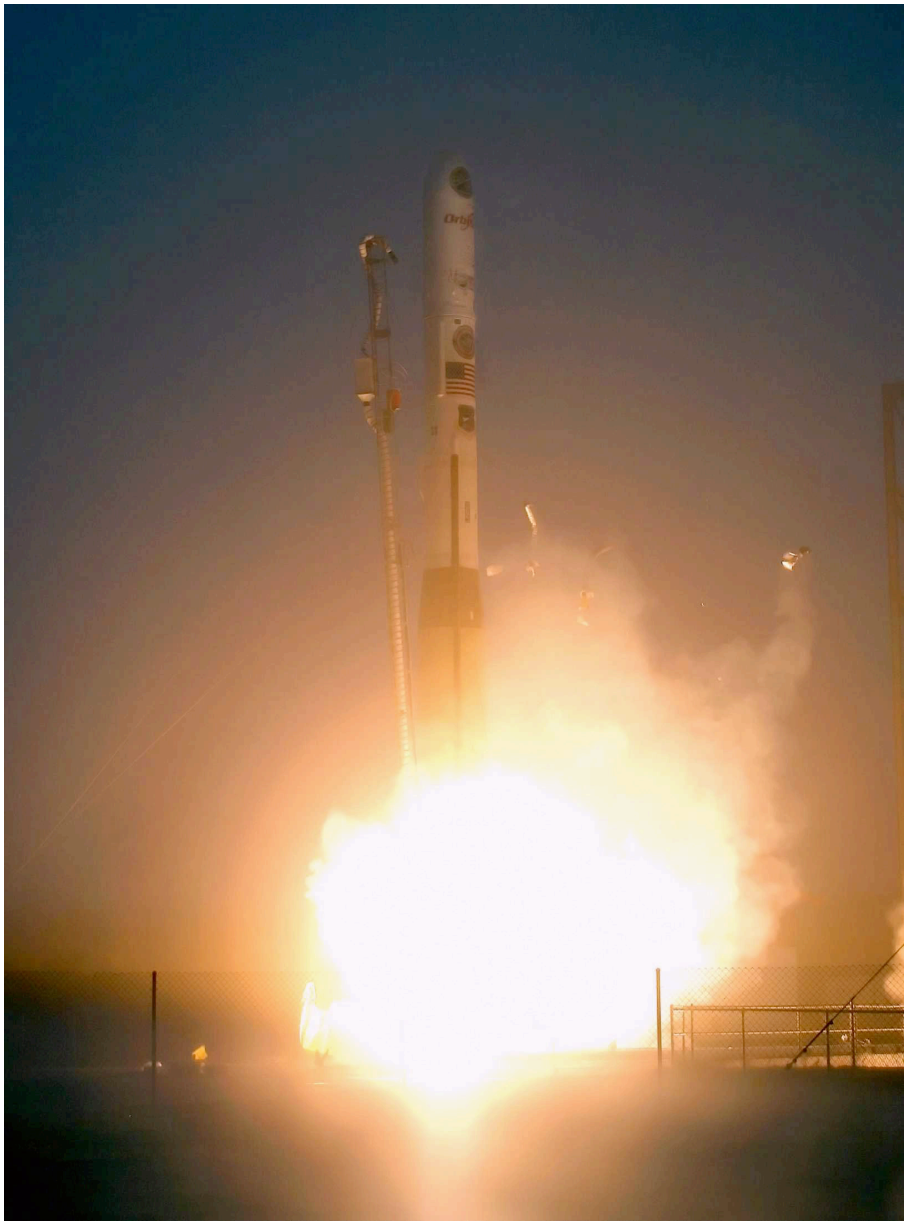
Outline

- COSMIC Introduction / Status
- Data Analysis - Use of IGS products
  - Real time orbits
  - Occultation Processing
  - 50-Hz Navigation data bits
- Preliminary results from COSMIC
- Data needs and data availability
- Summary

COSMIC/Formosat 3 at a Glance

- **C**onstellation **O**bserving **S**ystem for **M**eteorology **I**onosphere and **C**limate (Formosat-3)
- 6 Satellites launched in April 2006
- Orbits: alt=800km, Inc=72deg, ecc=0
- Weather + Space Weather data
- Global observations of:
  - Refractivity
  - Pressure, Temperature, Humidity
  - TEC, Ionospheric Electron Density
  - Ionospheric Scintillation
- Demonstrate quasi-operational GPS limb sounding with global coverage in near-real time
- Climate Monitoring
- Geodetic Research





COSMIC launch picture provided by Orbital Sciences Corporation

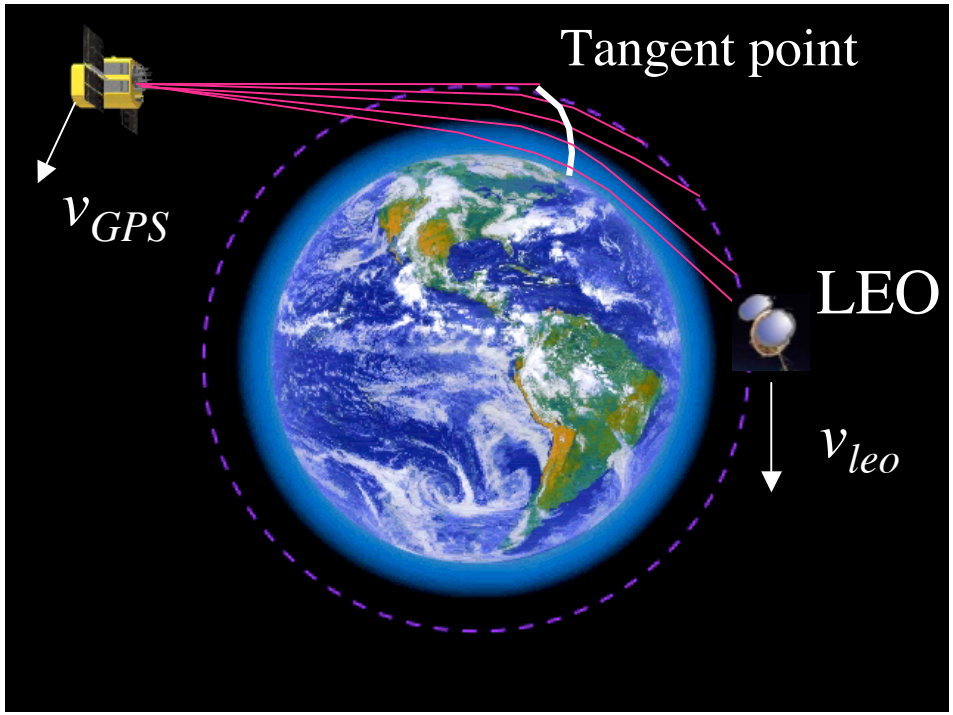
Launch on April 14, 2006
Vandenberg AFB, CA

- All six satellites stacked and launched on a Minotaur rocket

- Initial orbit altitude ~500 km; inclination ~72°

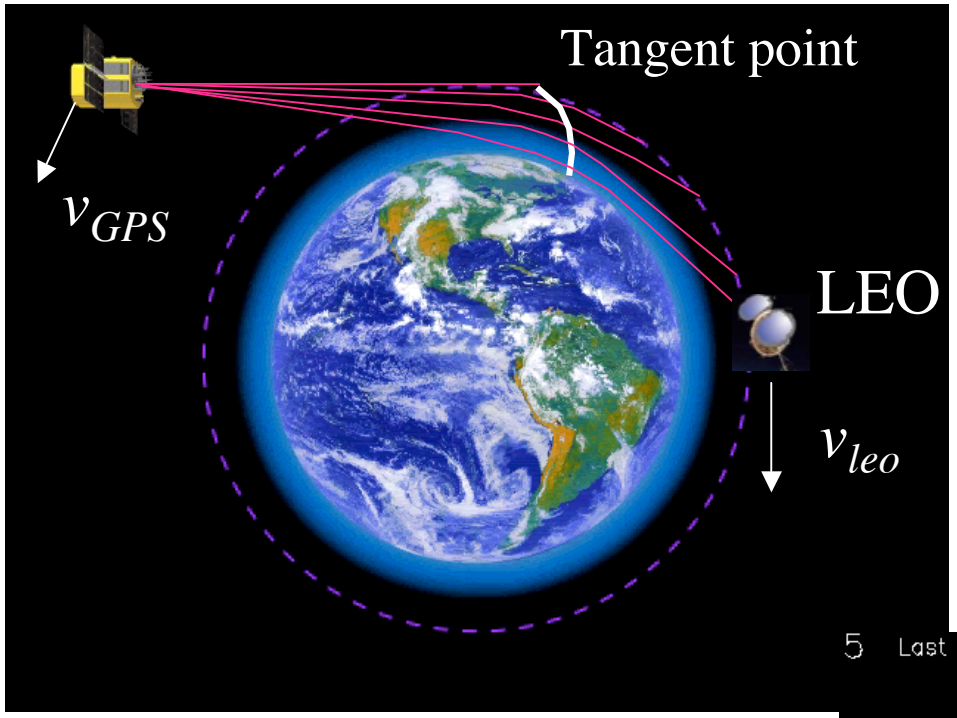
- Will be maneuvered into six different orbital planes for optimal global coverage (at ~800 km altitude)

- All satellites are in good health and providing initial data



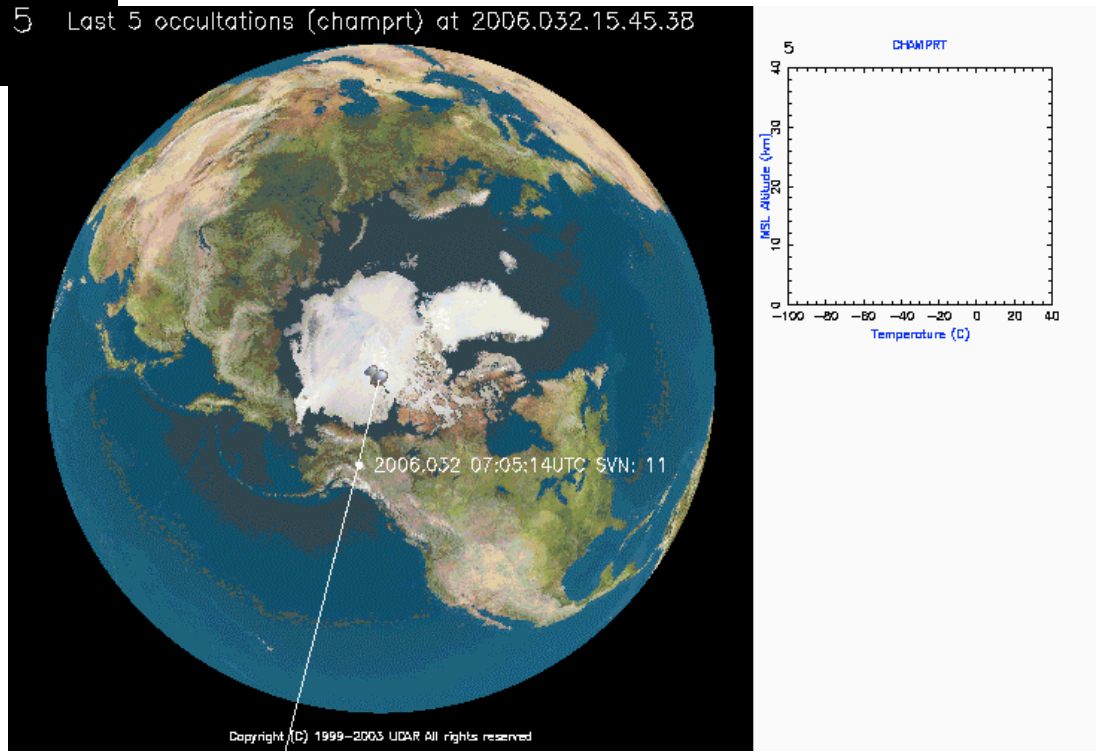
The LEO tracks the GPS phase while the signal is occulted to determine the Doppler

The velocity of GPS relative to LEO must be estimated to **~0.2 mm/sec** (velocity of GPS is ~3 km/sec and velocity of LEO is ~7 km/sec) to determine precise temperature profiles



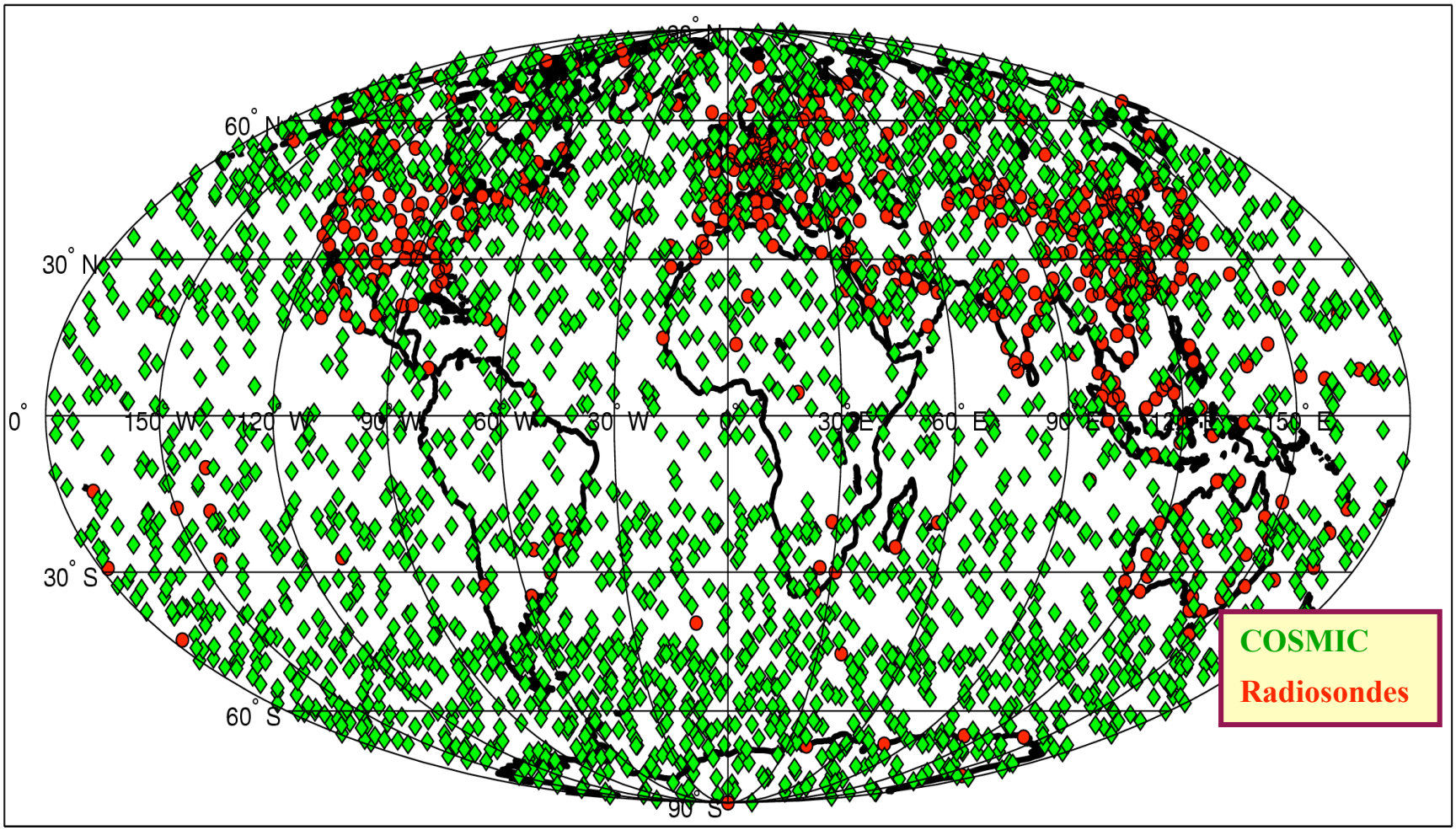
The LEO tracks the GPS phase while the signal is occulted to determine the Doppler

The velocity of GPS relative to LEO must be estimated to **~0.2 mm/sec** (20 ppb) to determine precise temperature profiles

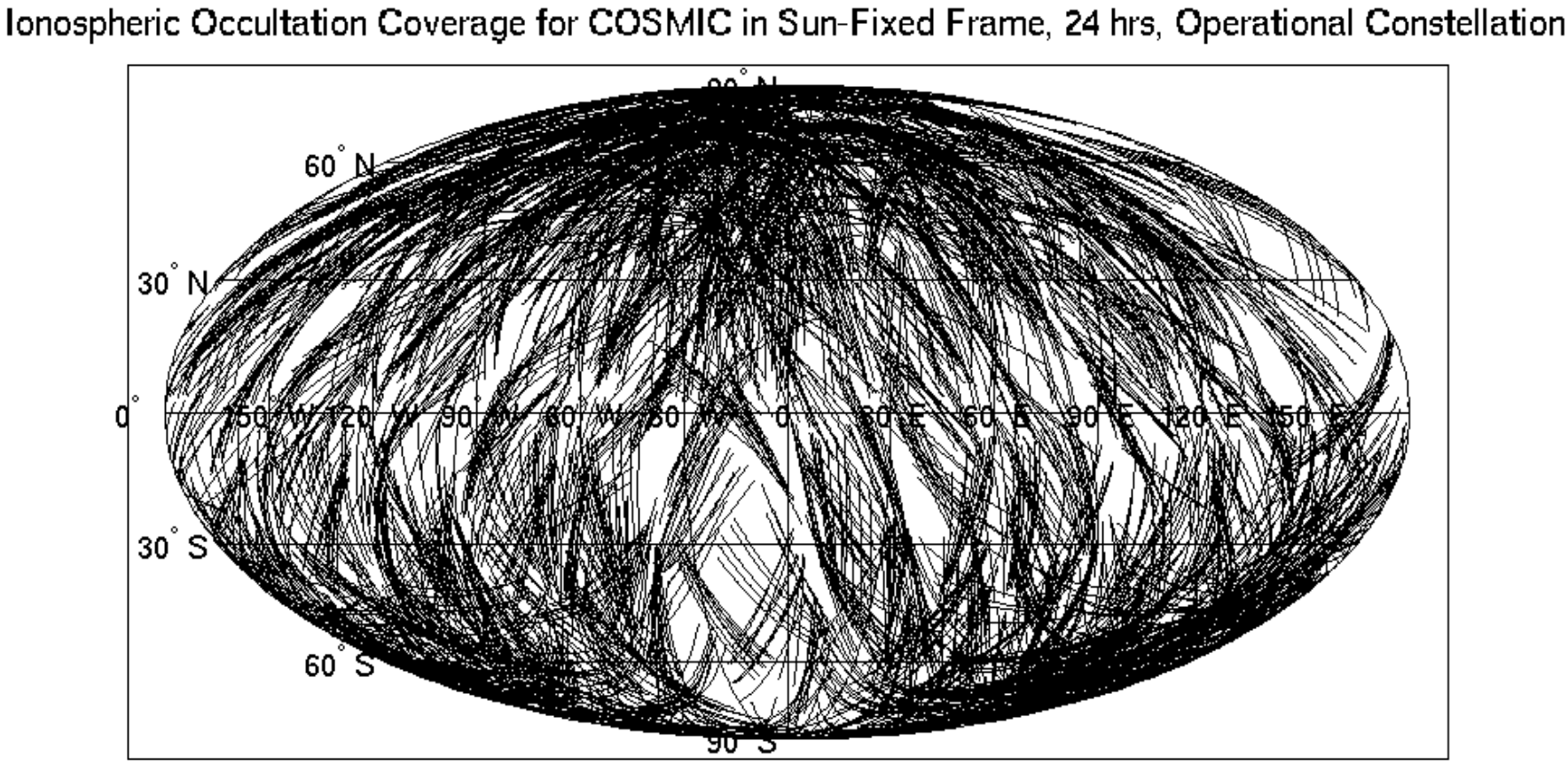


COSMIC Soundings in 1 Day

Occultation Locations for COSMIC, 6 S/C, 6 Planes, 24 Hrs

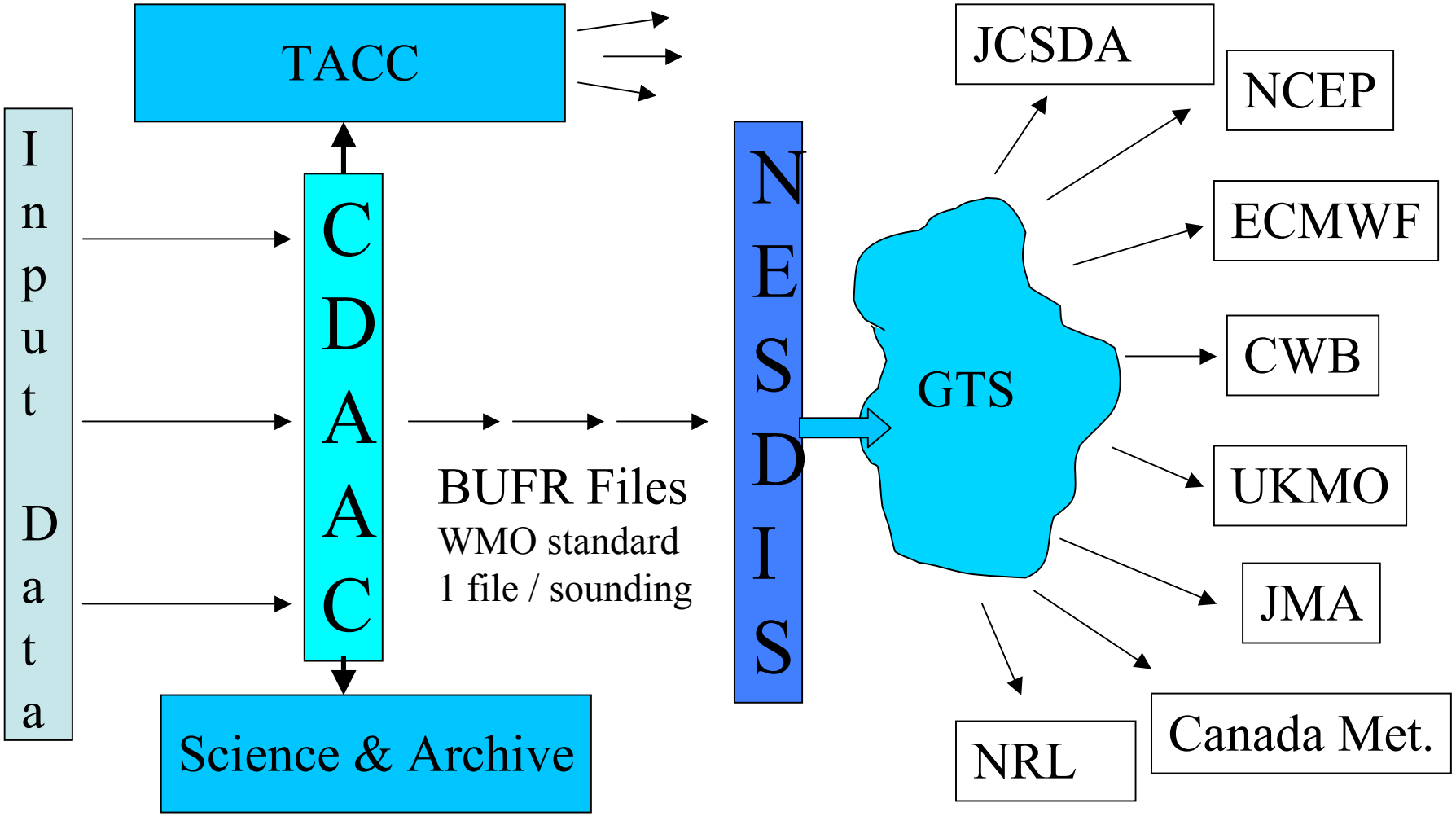


Ionospheric Occultation Global Coverage



- About 2500 ionospheric occultations per day
- Profiles of electron density between 100 and 800 km
- Total Electron Content to all GPS satellites in view

Operational Processing

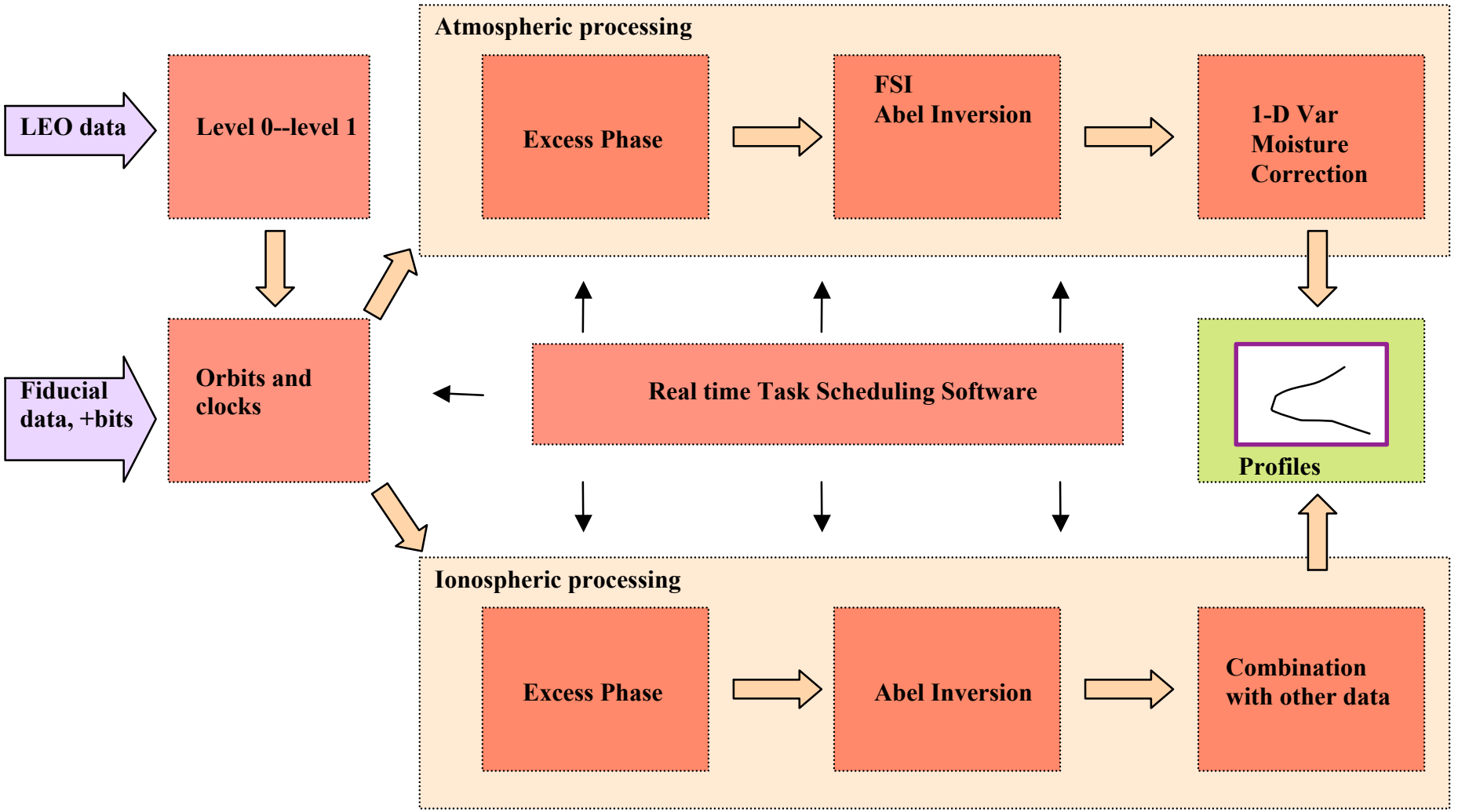


Data available to weather centers within < 180 minutes of on-orbit collection

CDAAC responsibilities

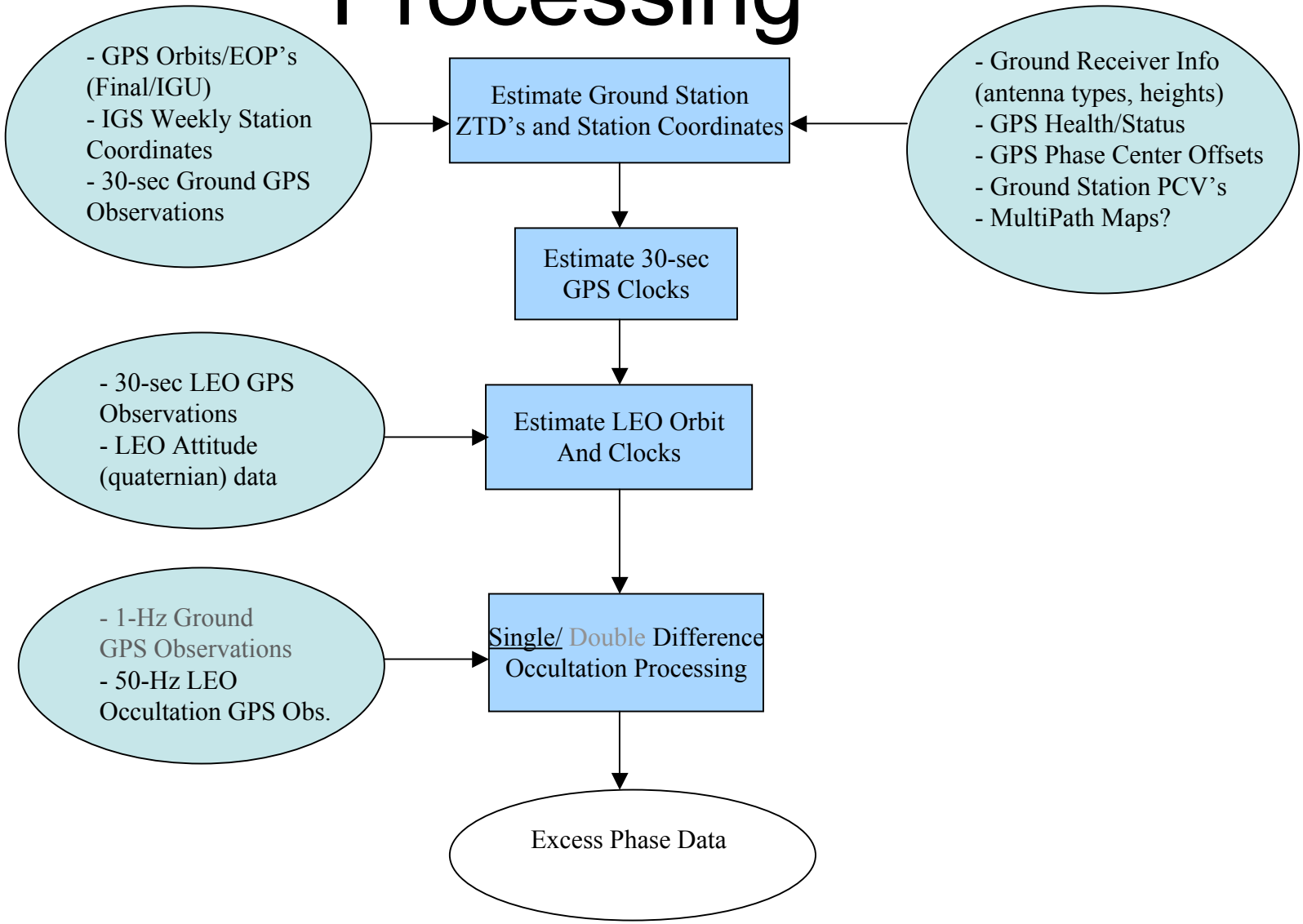
- Process all COSMIC observations
  - LEO/GPS orbit determination
  - Atmospheric & Ionospheric profiles
  - Rapid analysis for operational demonstration
  - Post-processed analysis for climate and other research
- Provide data to universities and research laboratories
- Provide data feeds (< 3hr) to operational centers
- Archive data & provide web interface
- Provide and support installation at TACC (including source code)

CDAAC overview



Current processing time for 35 occultations + 100 minutes of fid data: ~ 9min

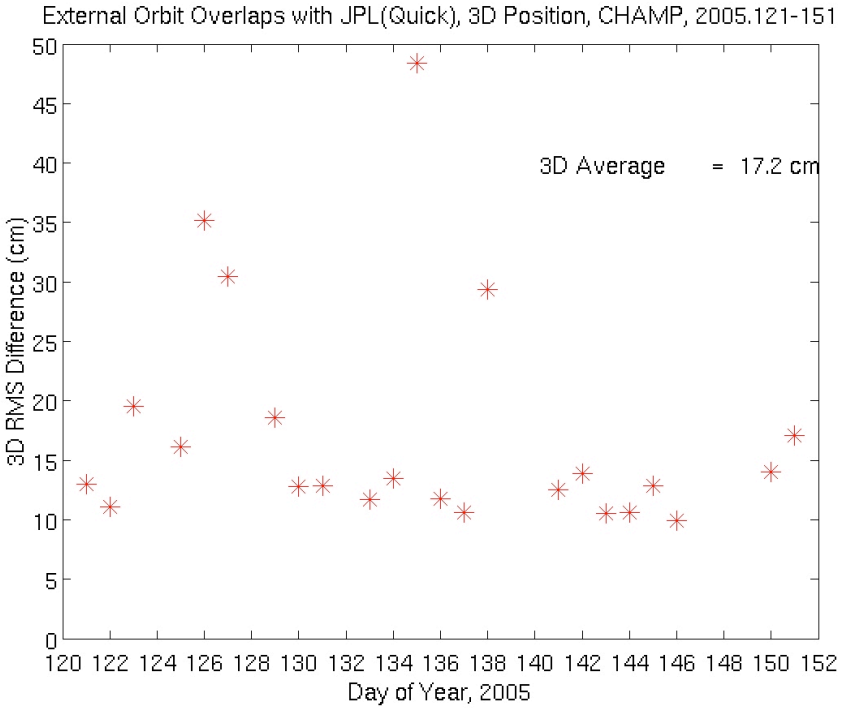
CDAAC Excess Phase Processing



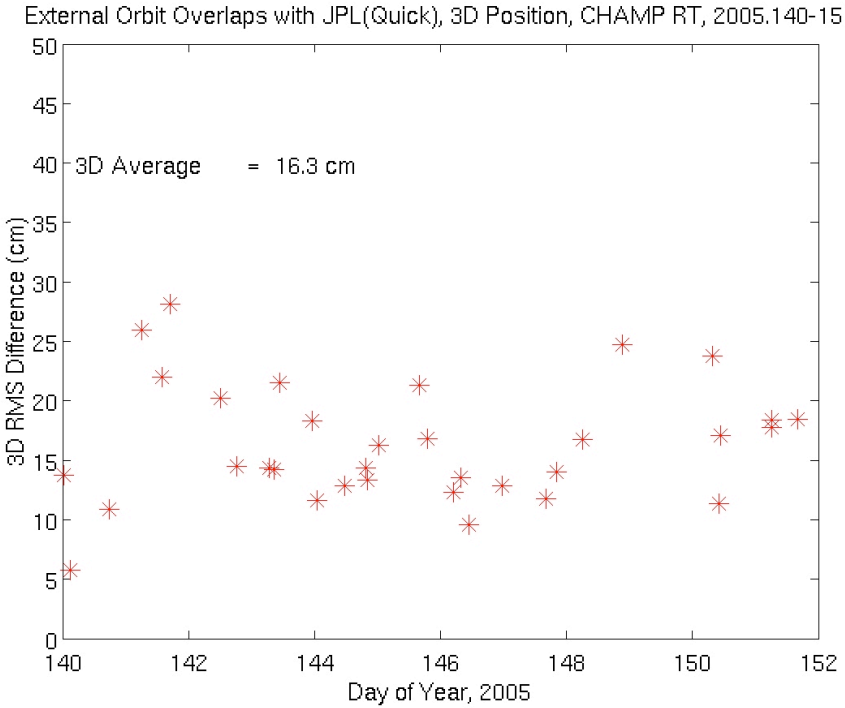
Excess phase Doppler error must be < 0.2 mm/sec

Post-Processed and NRT CHAMP Orbit Position Overlap Results (vs. JPL)

Post-Processing
(Daily 24 hour arcs)

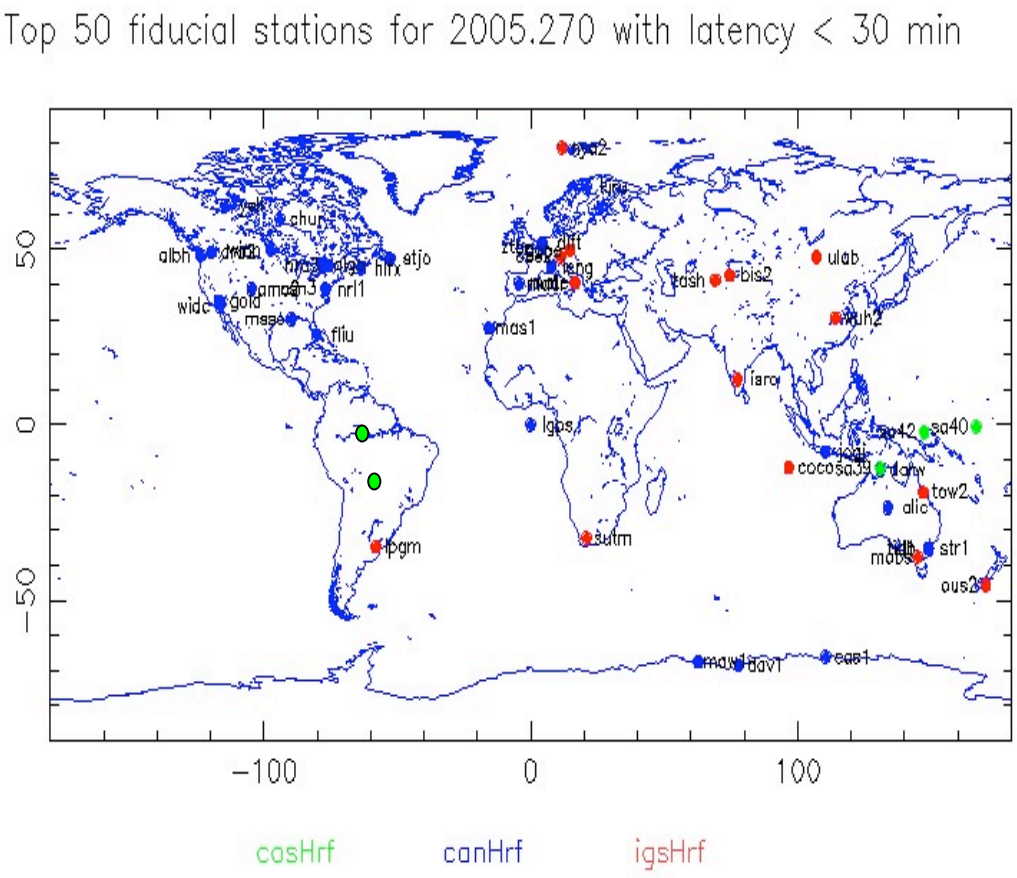


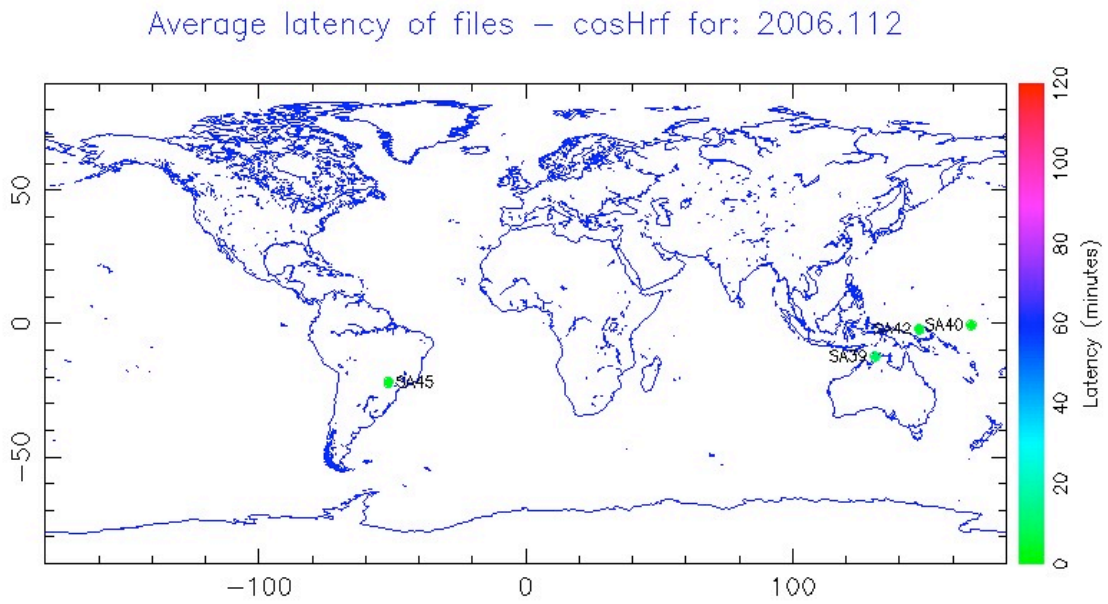
Near Real-Time
(Arcs for every CHAMP dump)



FIDUCIAL SITE STATUS

- Real time processing
  - ~30 stations in a real time stream from NR Canada (canHrf)
  - Three netRS receivers in South Pacific + 2 in Brazil (cosHrf)
  - The balance of stations we use for real time (total = 50) are fetched from the IGS (CDDIS) based on latency and coverage
  - Script rateIgsHrf.pl determines which igsHrf sites to fetch. This list will be updated monthly.

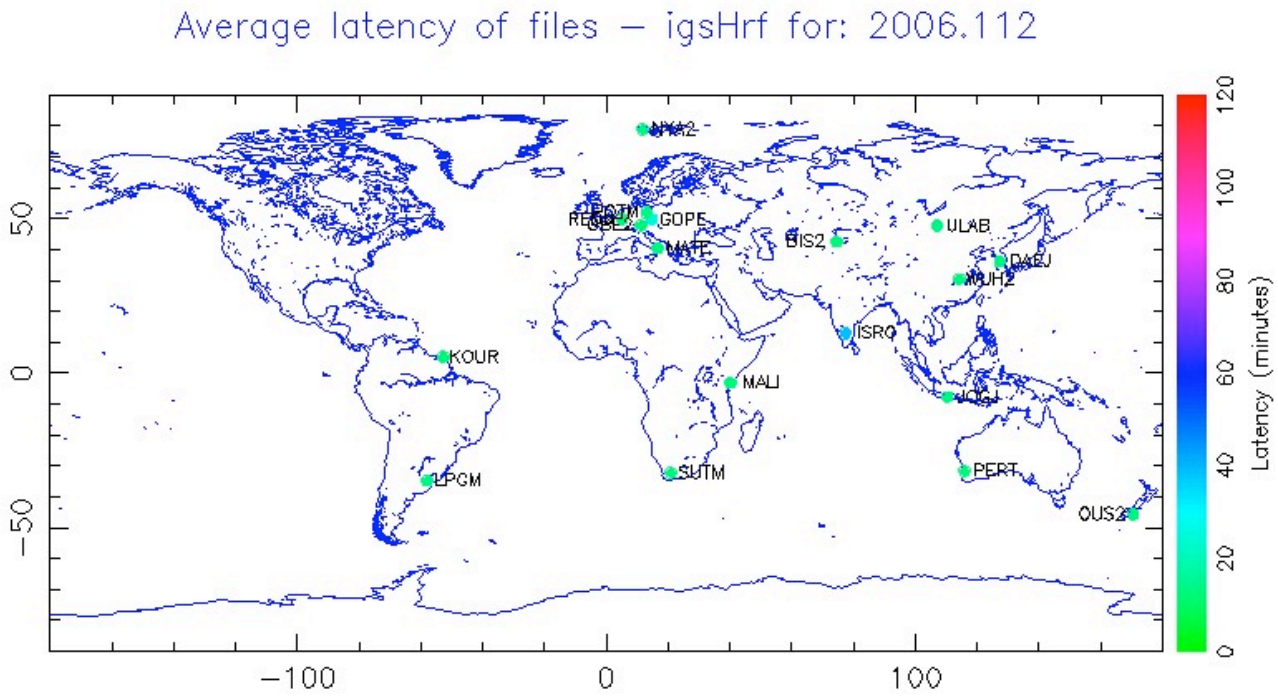




Recent latencies

~ 30 nrCan real-time sites not shown because latency is zero minutes

Latency of IGS site in India delayed processing ~20 minutes



Improved IGS Services

- Add new low latency stations in the oceans around S. America, in Africa and in Asia.(30-sec is sufficient in real-time)
- Improve the uptime for CDDIS (cddis.gsfc.nasa.gov). We have had several one or two day outages over the last year, the most recent being over the first COSMIC weekend
- Improve the latency of one second data (found at ftp://cddis.gsfc.nasa.gov/pub/gps/data/highrate)
- IGU orbit quality improvements (nice to have)
- IGU predicted clock (average over all satellites) needs to be better than 100 ns

Global “Bit Grabber” network

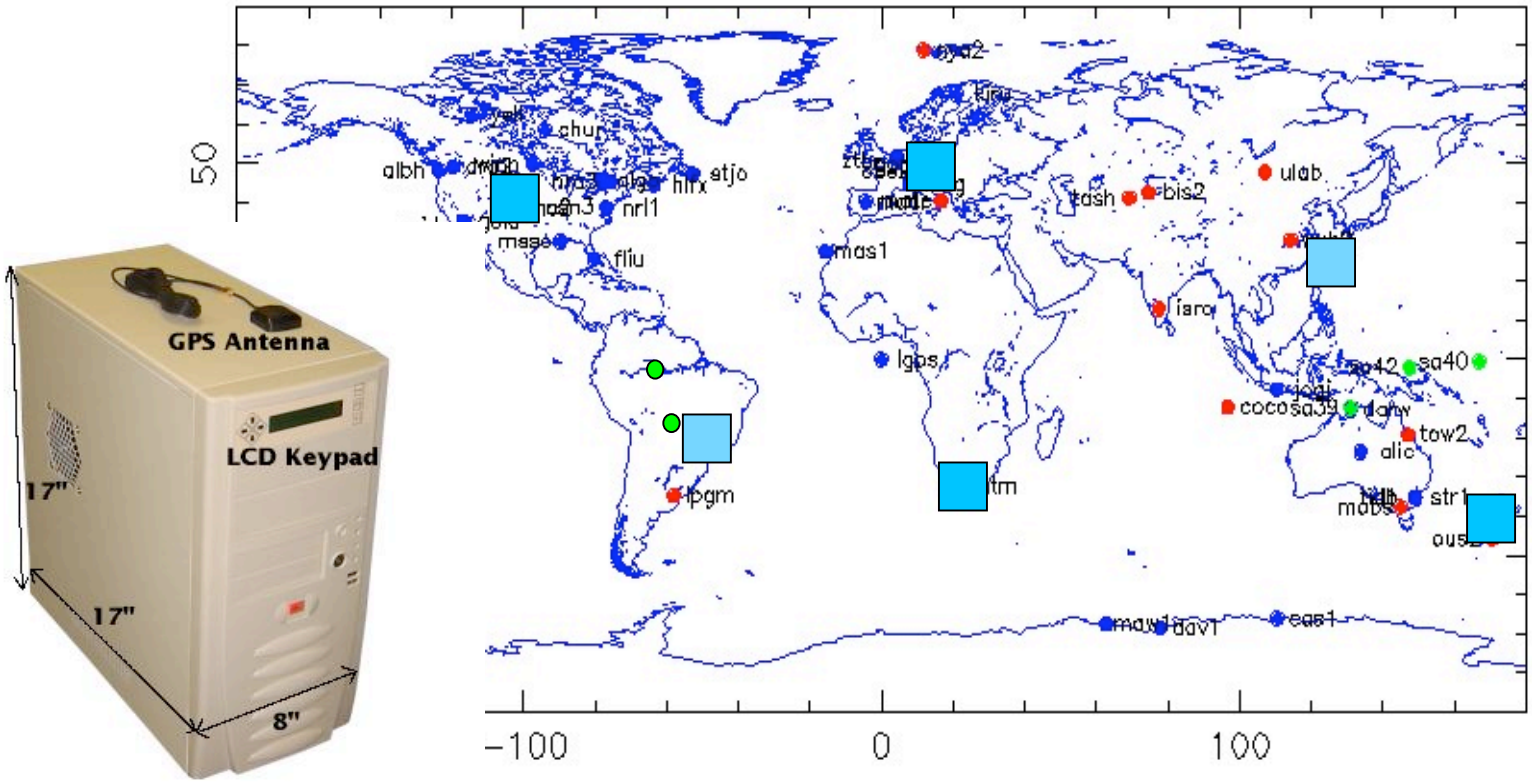


Figure 1: Front view of the BitGrabber PC.

Delivered + installed

COSMIC Data Availability

after ~2-month checkout phase

- All Data (including raw data) available at the end of each day
- Real-time products (profiles of bending, refractivity, …) in WMO standard format available via the GTS
- Post-processed data for climate research will be updated every few months
- Data use agreement with NSPO required for use of all data and data products (via TACC or CDAAC website)

COSMIC Data Policy

- Real-time data (raw data, excess phase data, etc.) available upon approval of letter request to NSPO director and UCAR president
- All requests so far have been approved
- Next slide shows how to sign up (or go directly to:)

  http://tacc.cwb.gov.tw/service/policy.htm

COSMIC Data Access

http://www.cosmic.ucar.edu

* Select the 'Sign Up ' link under COSMIC

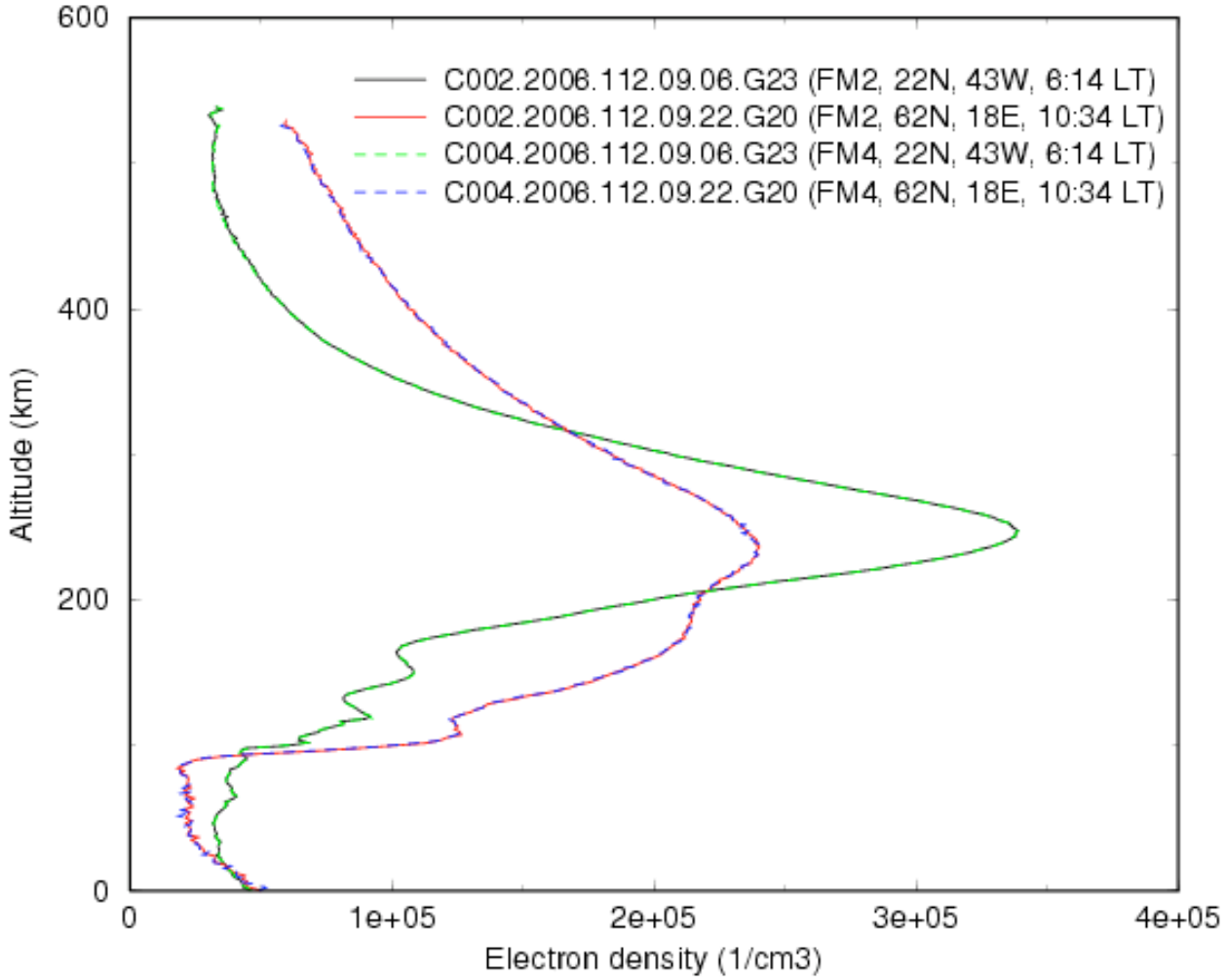
•Accept data use agreement

* Enter information:
Name, Address, email, user_id, Password, planned use of data

• An email will be sent within 2-3 business days to indicate access has been granted.

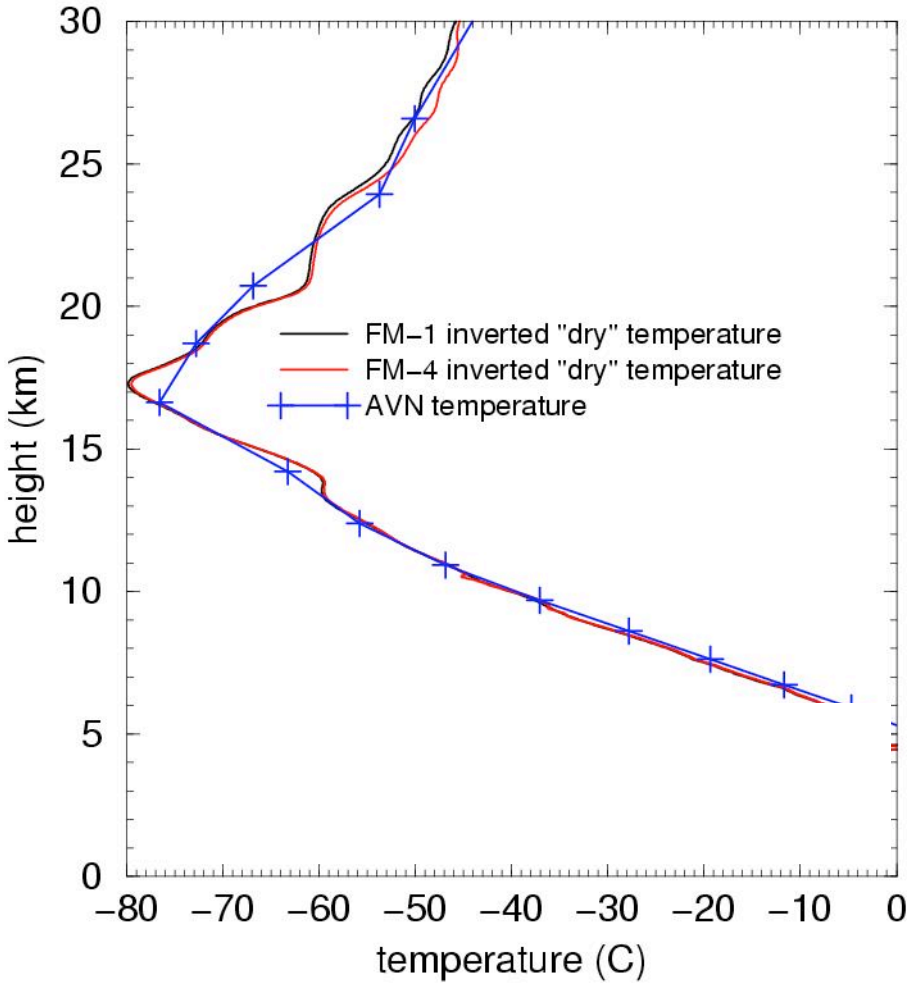
Some Amazing First Ionosphere Profile Comparisons…

Coincident occultations from two different COSMIC satellites



- FM2 and FM4 within 30 km of each other
- FM2 about 4 seconds behind FM4
- At any given time FM2 is within 1 km of where FM4 was 4 seconds earlier
- FM2 and FM4 orbit altitudes differ by a few hundred meters

Early atmospheric profile results - coincident profiles

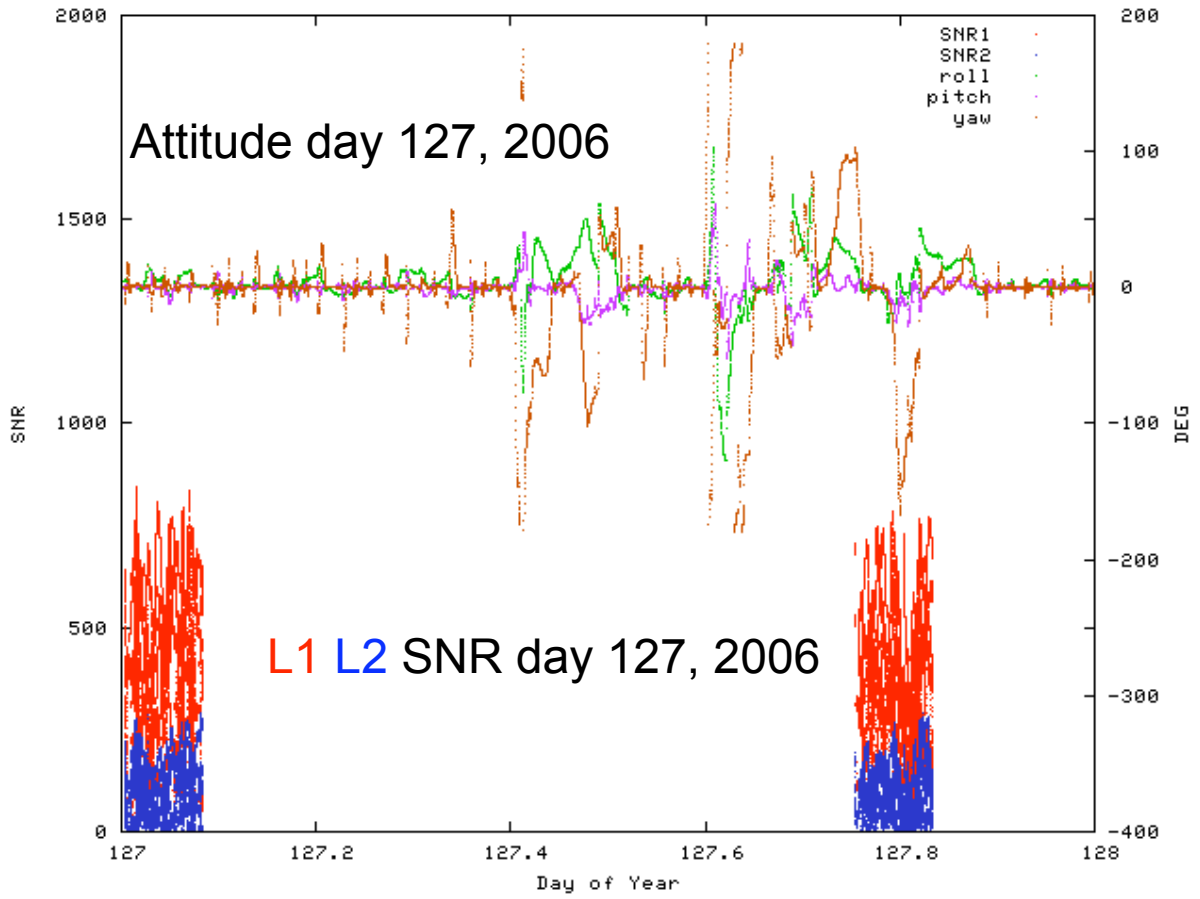


Summary

- All six satellites and GPS payloads appear to be working
- Early results promising even though there are issues with tracking firmware and attitude control
- Success of COSMIC depends on IGS products (IGU orbits) and fiducial data - thanks to NRCan and CDDIS
- All COSMIC data (LEO, fiducial, data bits) will be made available after checkout period

COSMIC attitude

Control / knowledge specification: pitch/roll/yaw 2/5/5 deg (1-sig)



http://www.cosmic.ucar.edu

* Select the 'Sign Up ' link under Other Missions

* Enter information:
Name, Address, email, user_id, Password

• An email will be sent within 2 business days to indicate access has been granted.

After validation of
Username/password
Login to data server
With ‘Data Access Login’

BitGrabber Locations
- USA
- South Africa
- Germany
- New Zealand
- Taiwan
- Brazil[2]

[1]Shipped but not online
[2]In shipping process

Additional Information
www.cosmic.ucar.edu/bitGrabber.html

Operator Interface - Fiducial Information

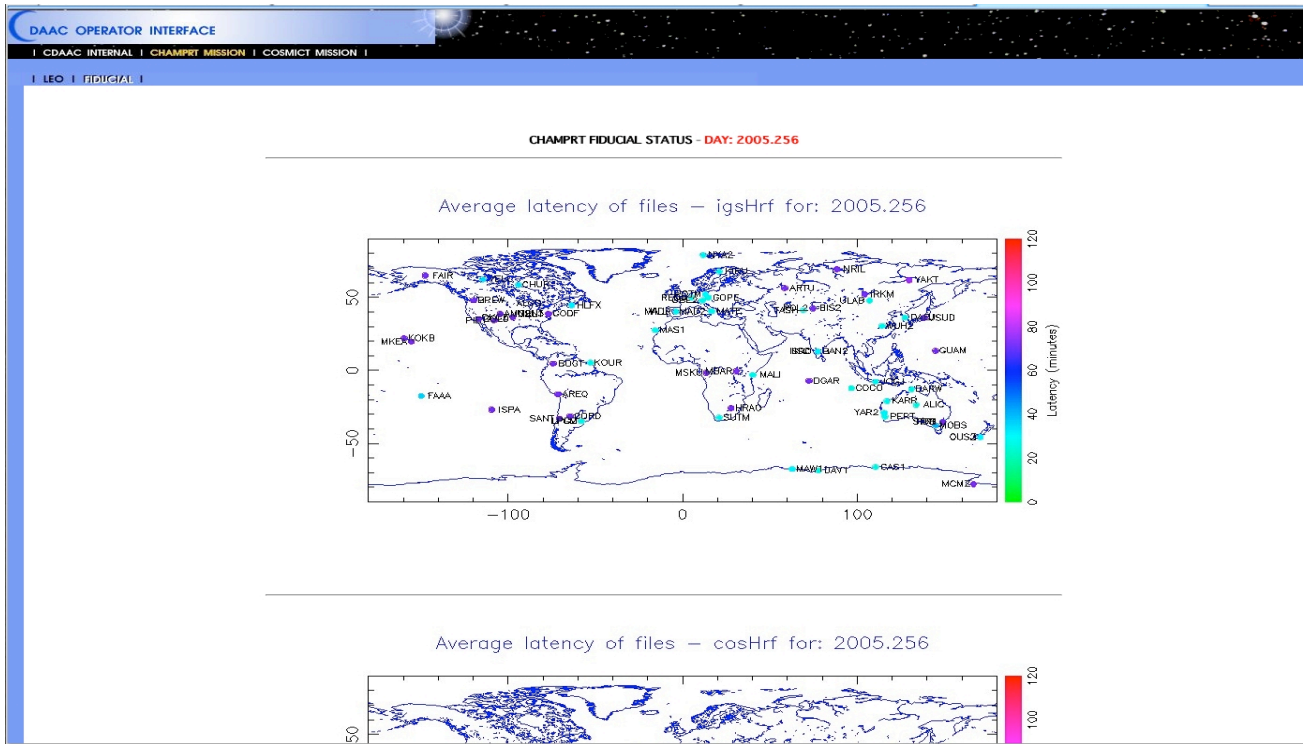
The main screen allows display for the current day, with the option to view up to ten days back. The display shows:

*** Average Latency Map for a given day for CosHrf and IgsHrf files (New)**

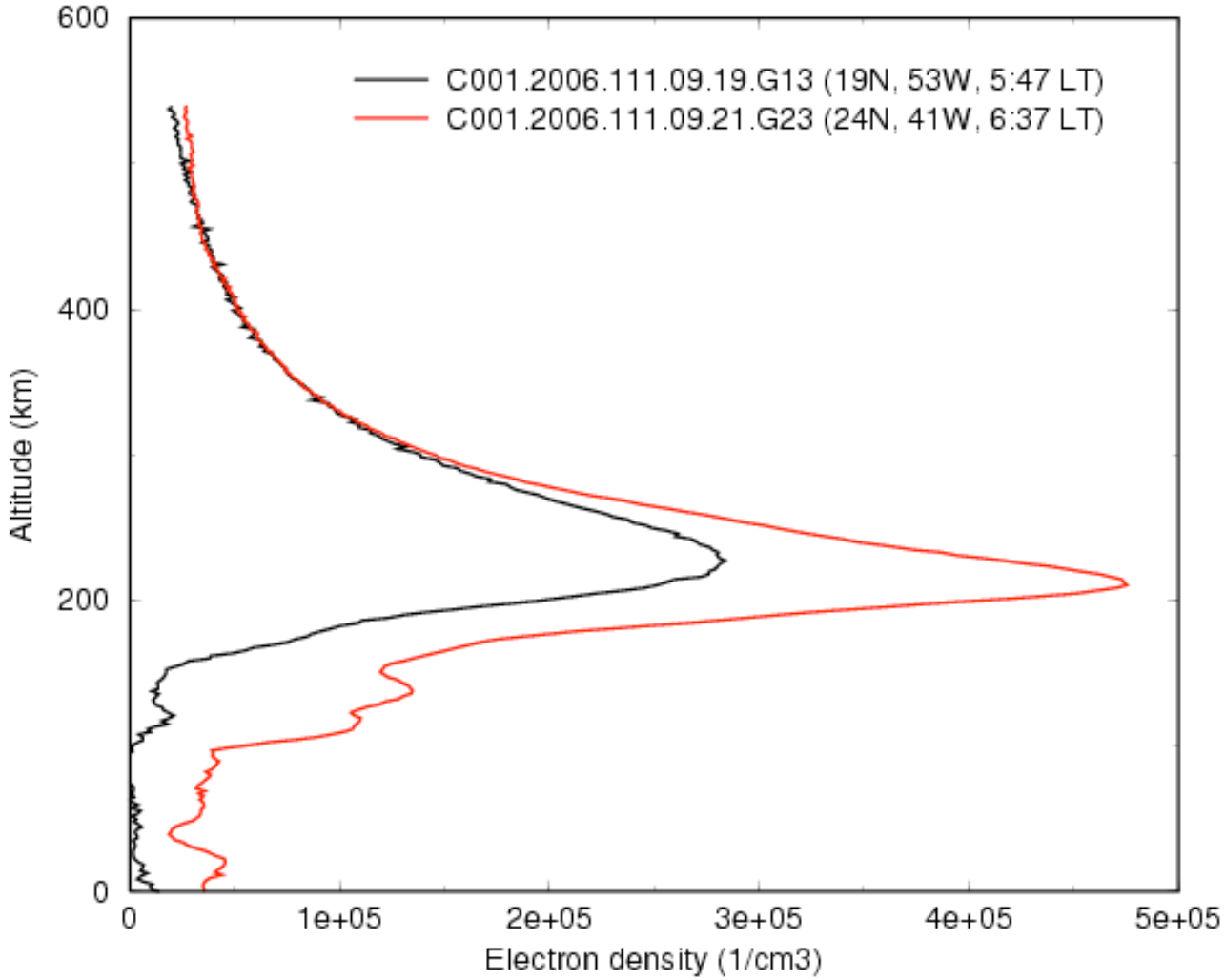
*** Fiducial RealTime Data Inventory (New)**

*** Hour count of CanHrf, CosHrf, and IgsHrf files for the present day (New)**

*** MP1_AVG and MP2_AVG (GPS data quality indicators), EPOCHS_SUM (the total number of epochs for this day) and NOBS_SUM (the total number of observations for this day) for each site.**

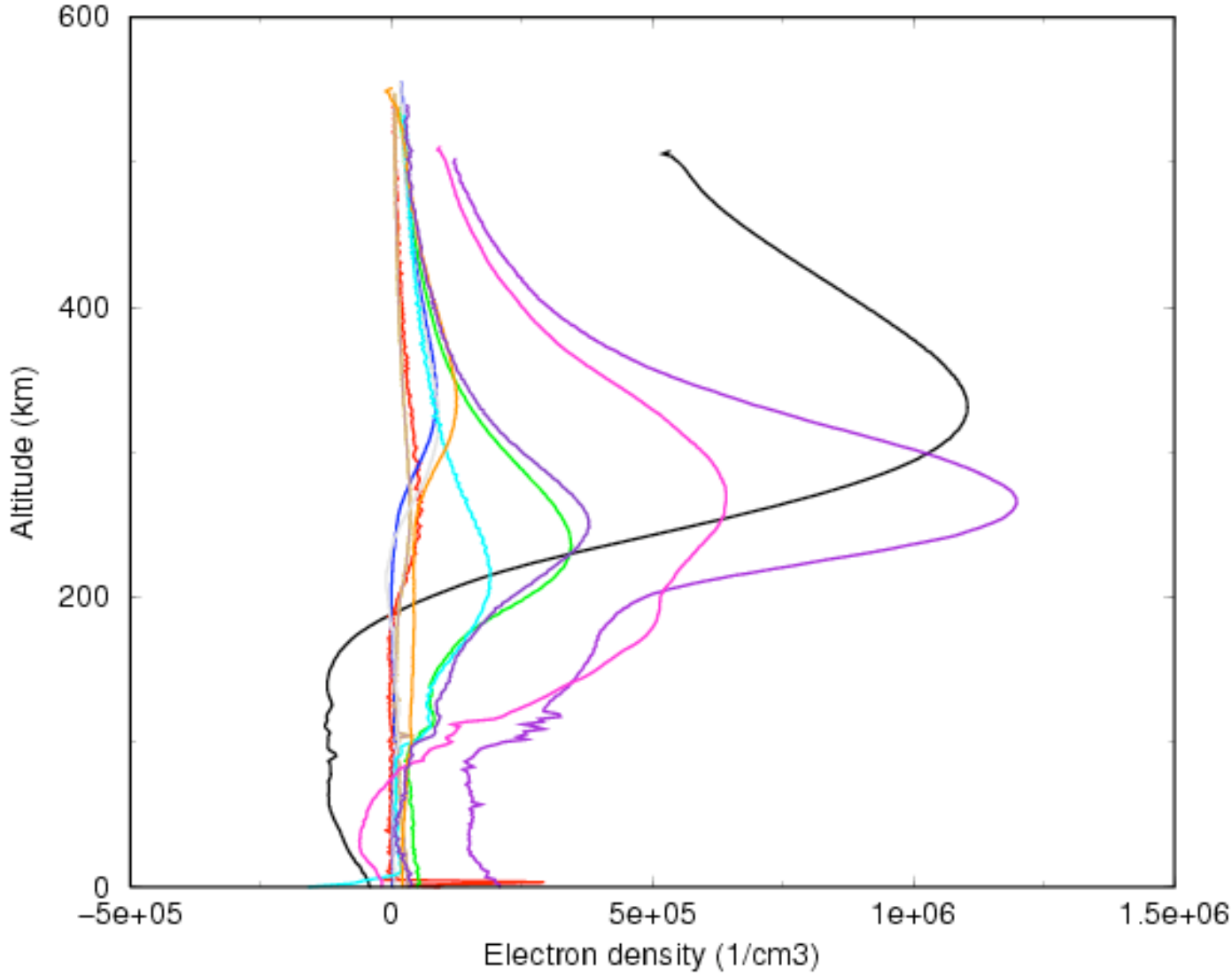


First Ionospheric Profiles

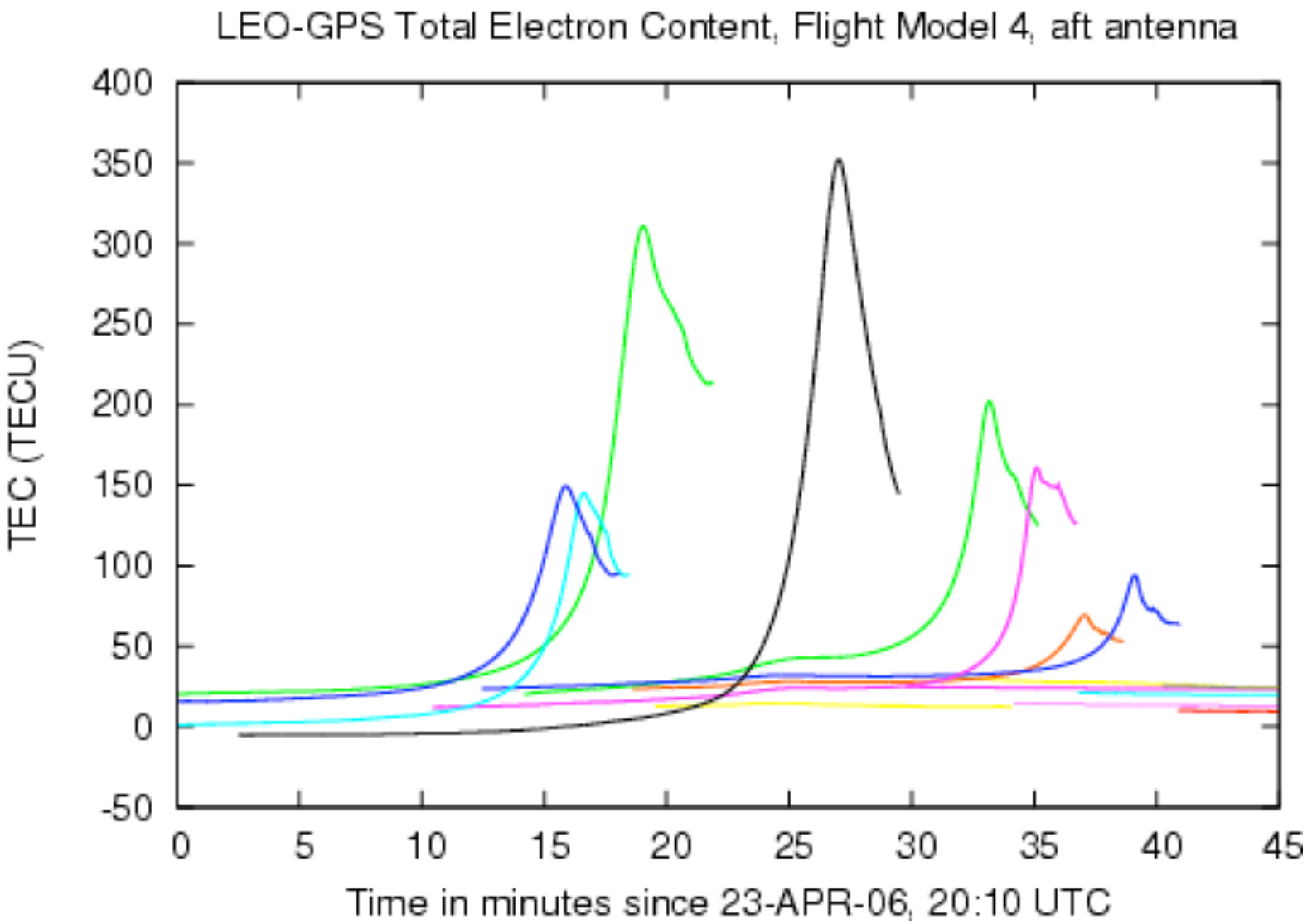


Collected on the morning of 21 April

More Ionospheric Profiles from 21-22 April

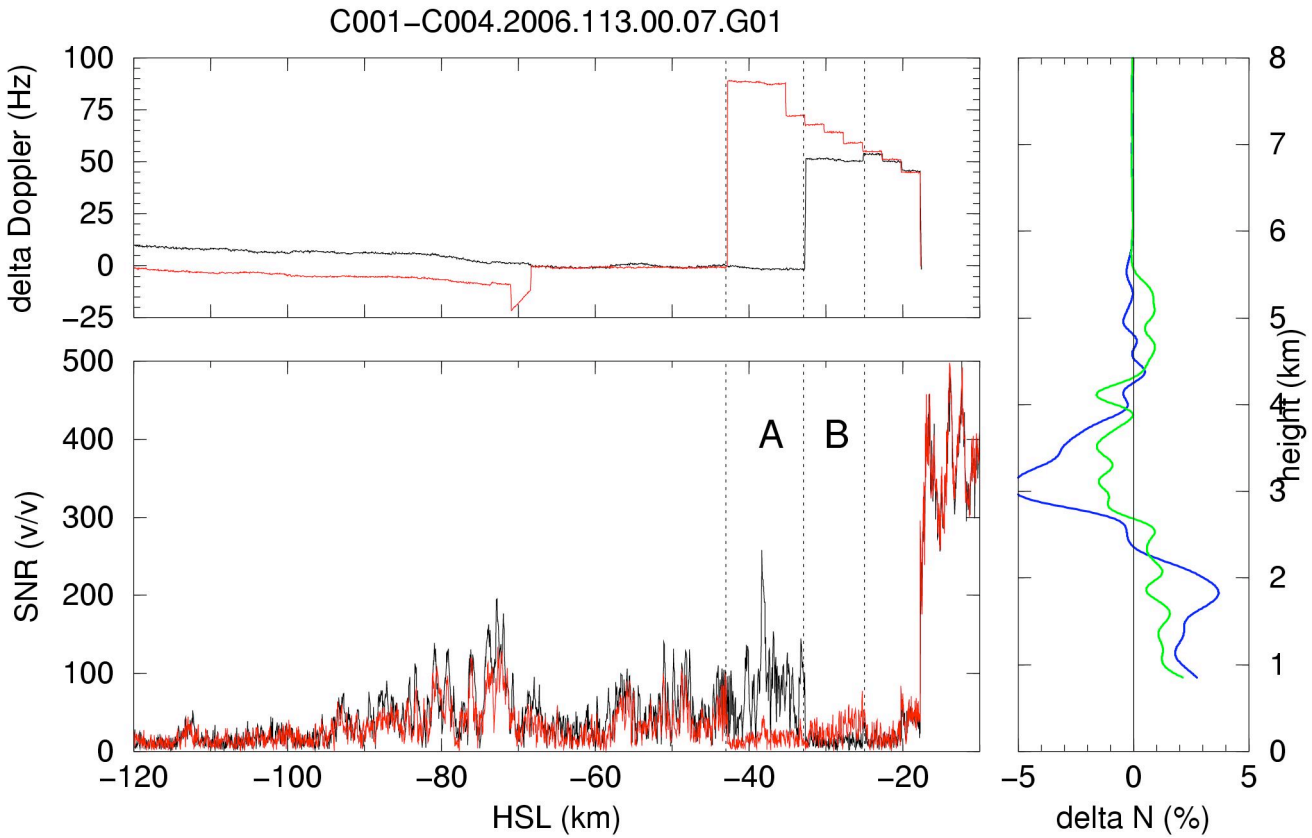


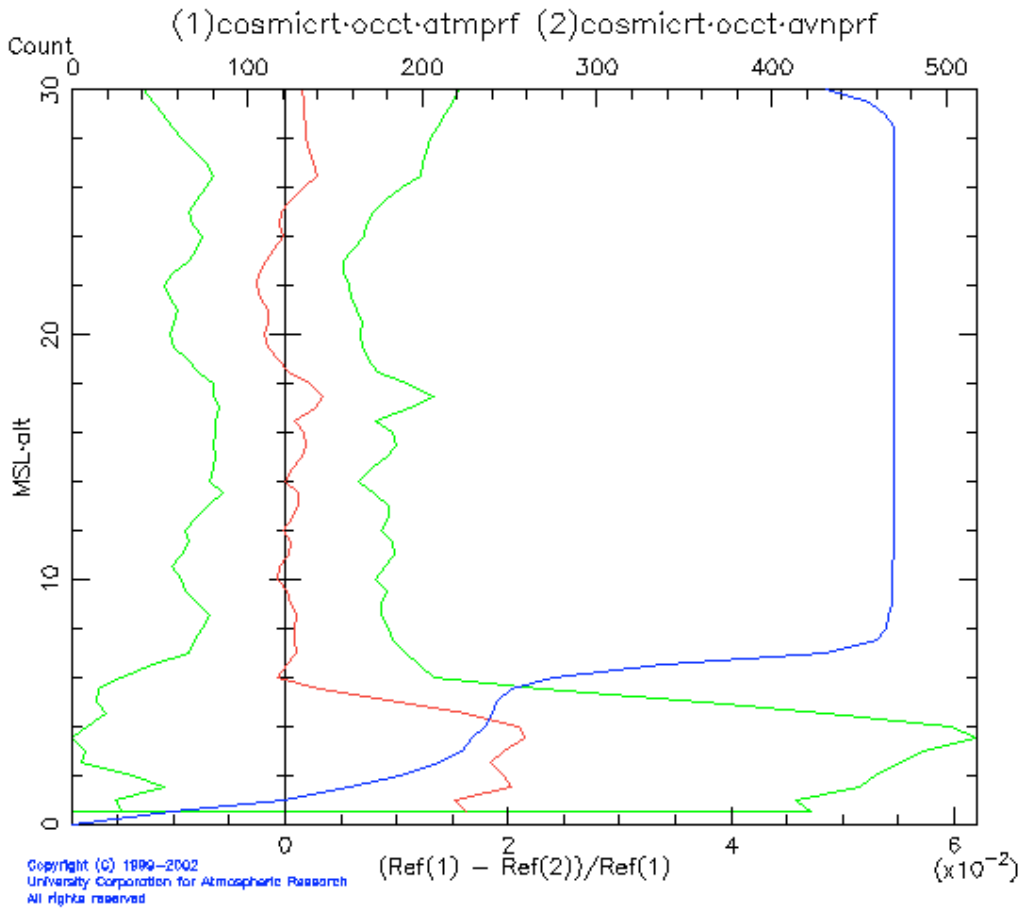
Total Electron Content



Summary

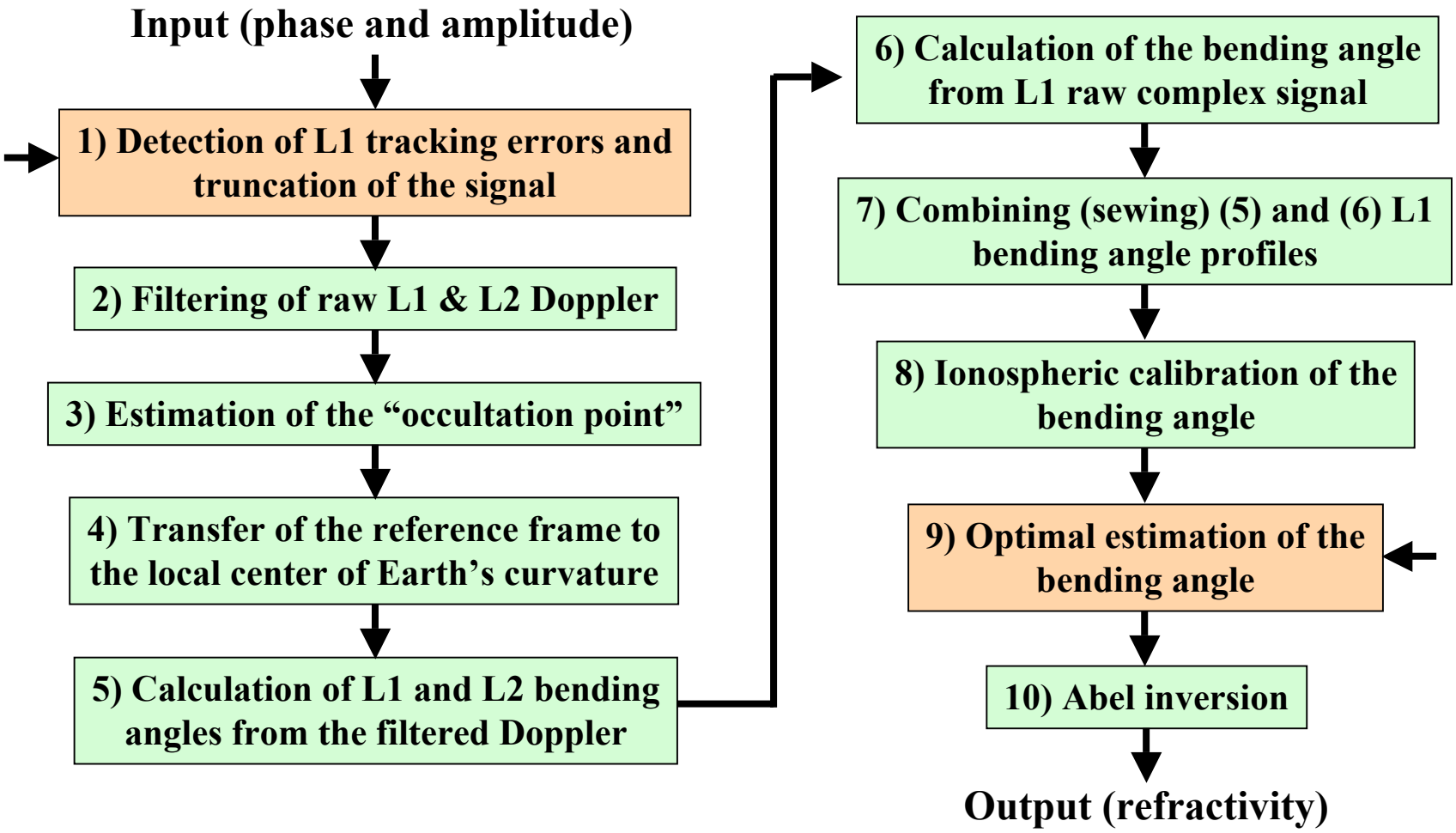
- CDAAC Software is ready for launch now
- TACC status previous presentation
- Tasks that we are still working on:
  - Open Loop Data
    - Need to tune QC process
    - Need to generate reliable statistics
  - Fiducial network
    - Combination of IGS, Canadian, COSMIC nets used
    - Bit grabber sites in US, Germany, SA, NZ installed, Brazil still needs to be installed, Taiwan needs to be shipped
  - CDAAC Data Processing
    - QC and data assimilation
    - Ionospheric EDP profiling using horizontal gradients
    - Real-time orbits - Combined use of fore + aft POD antennas
    - POD antenna phase center calibration
    - Operator interface improvement


C001–C004.2006.113.00.07.G01
delta Doppler (Hz)
100
75
50
25
0
–25
SNR (v/v)
500
400
300
200
100
0
A
B
–120
–100
–80
–60
–40
–20
HSL (km)
–5
0
5
delta N (%)
8
7
6
5
4
3
2
1
0
height (km)


(1)cosmicrt·occt·atmprf (2)cosmicrt·occt·avnprf
Count
0
100
200
300
400
500
30
20
10
0
MSL-alt
0
2
4
6
(Ref(1) − Ref(2))/Ref(1)
(x10^{-2})
Copyright (C) 1999–2002
University Corporation for Atmospheric Research
All rights reserved

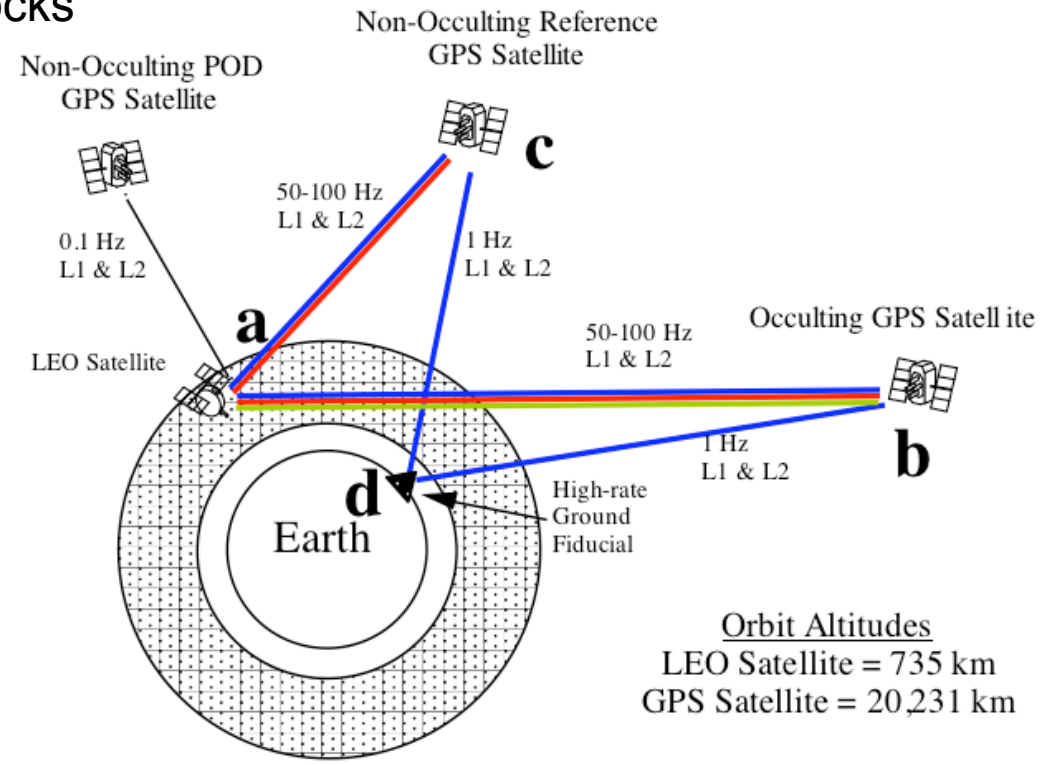
Lay-out of radio occultation data processing at CDAAC

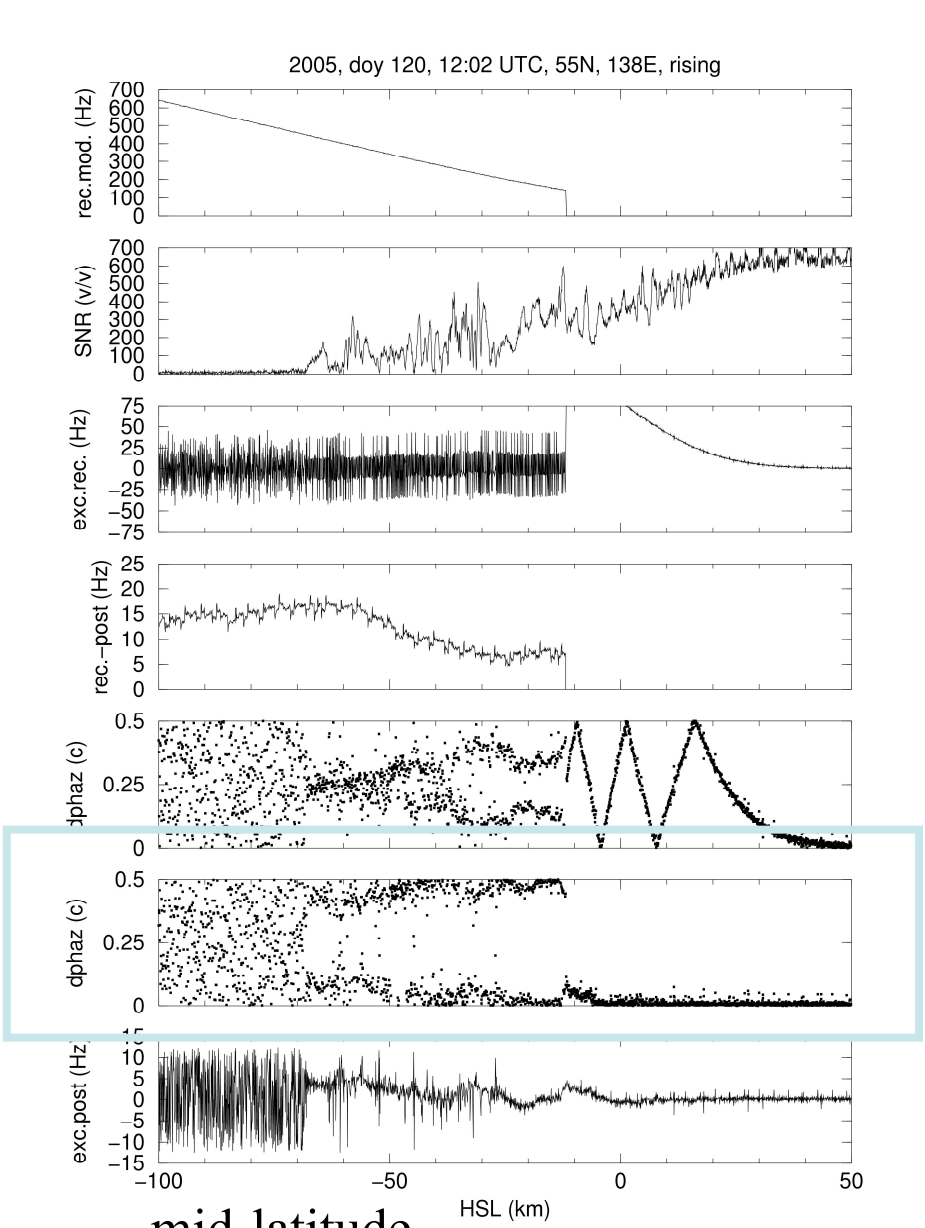
indicates the use of ancillary data (climatology)



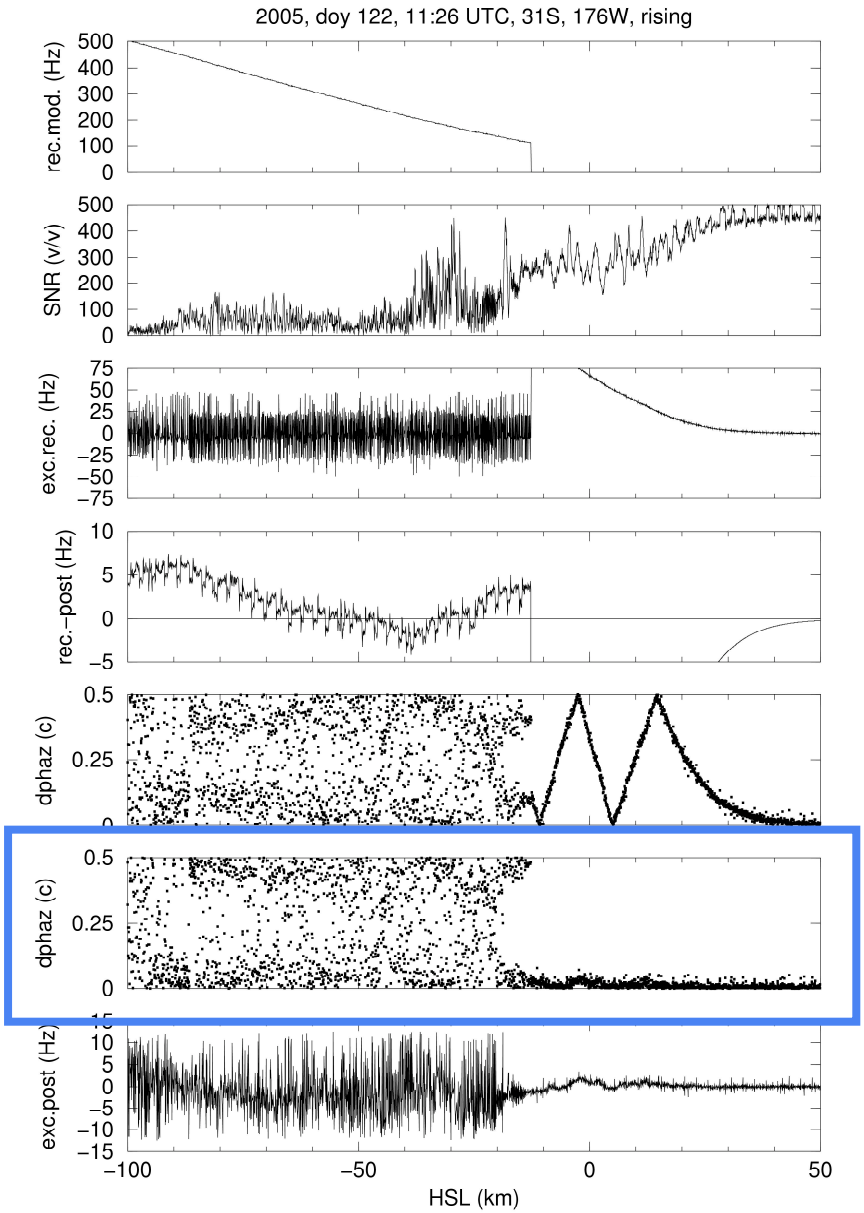
Computation of excess atmospheric delay

- Double Difference
  - Advantage: Station clock errors removed, satellite clock errors mostly removed (differential light time creates different transmit times), general and special relativistic effects removed, direct link to stable clocks
  - Problem: Fid. site MP, atmos. noise, thermal noise
- Single Difference
  - LEO clock errors removed
  - use solved-for GPS clocks
  - Main advantage: Minimizes double difference errors
- Zero Difference
  - Not feasible for COSMIC



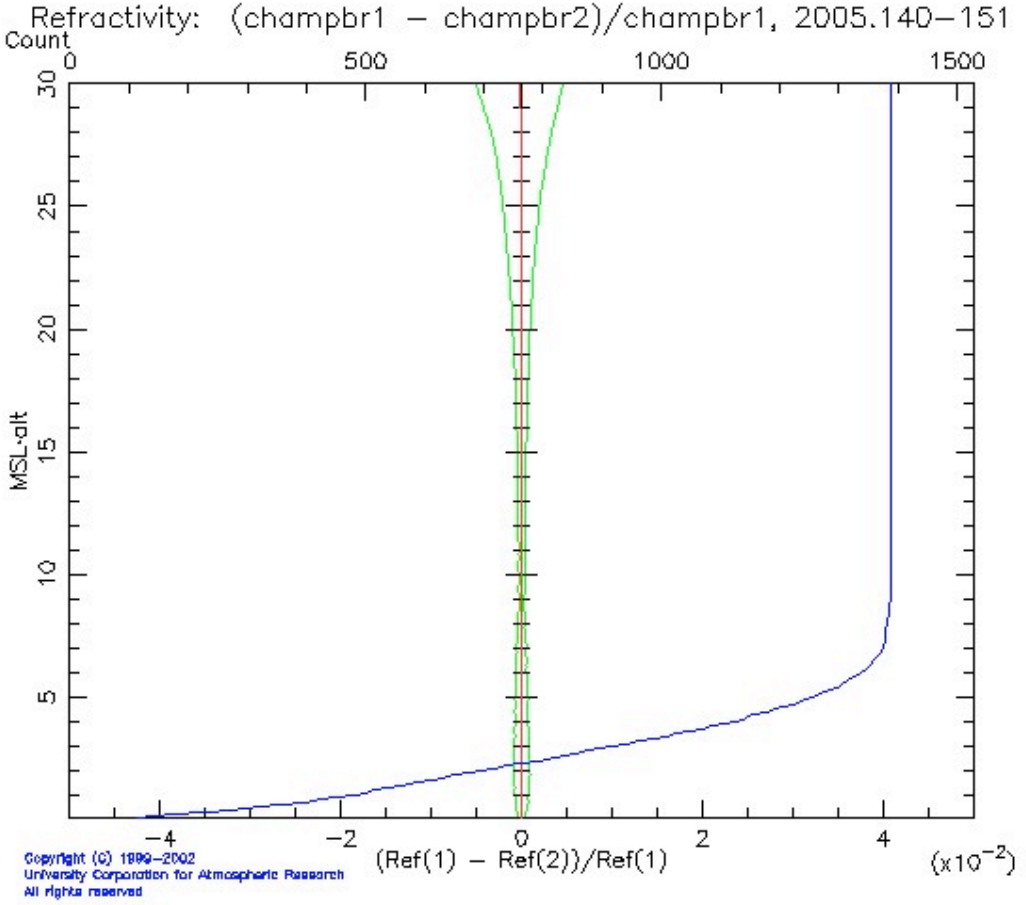


mid-latitude

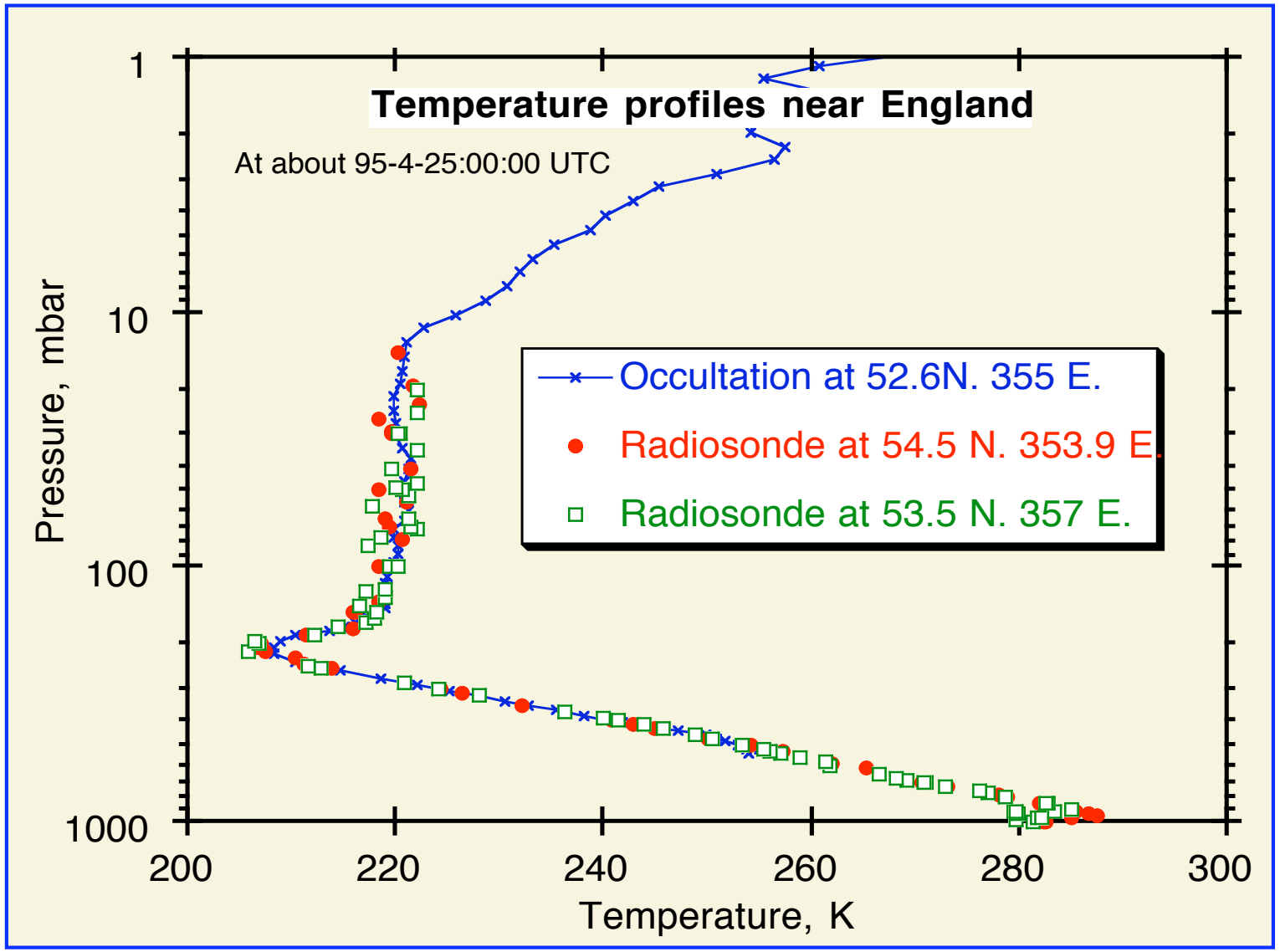


tropics

Single Difference vs. Double Difference

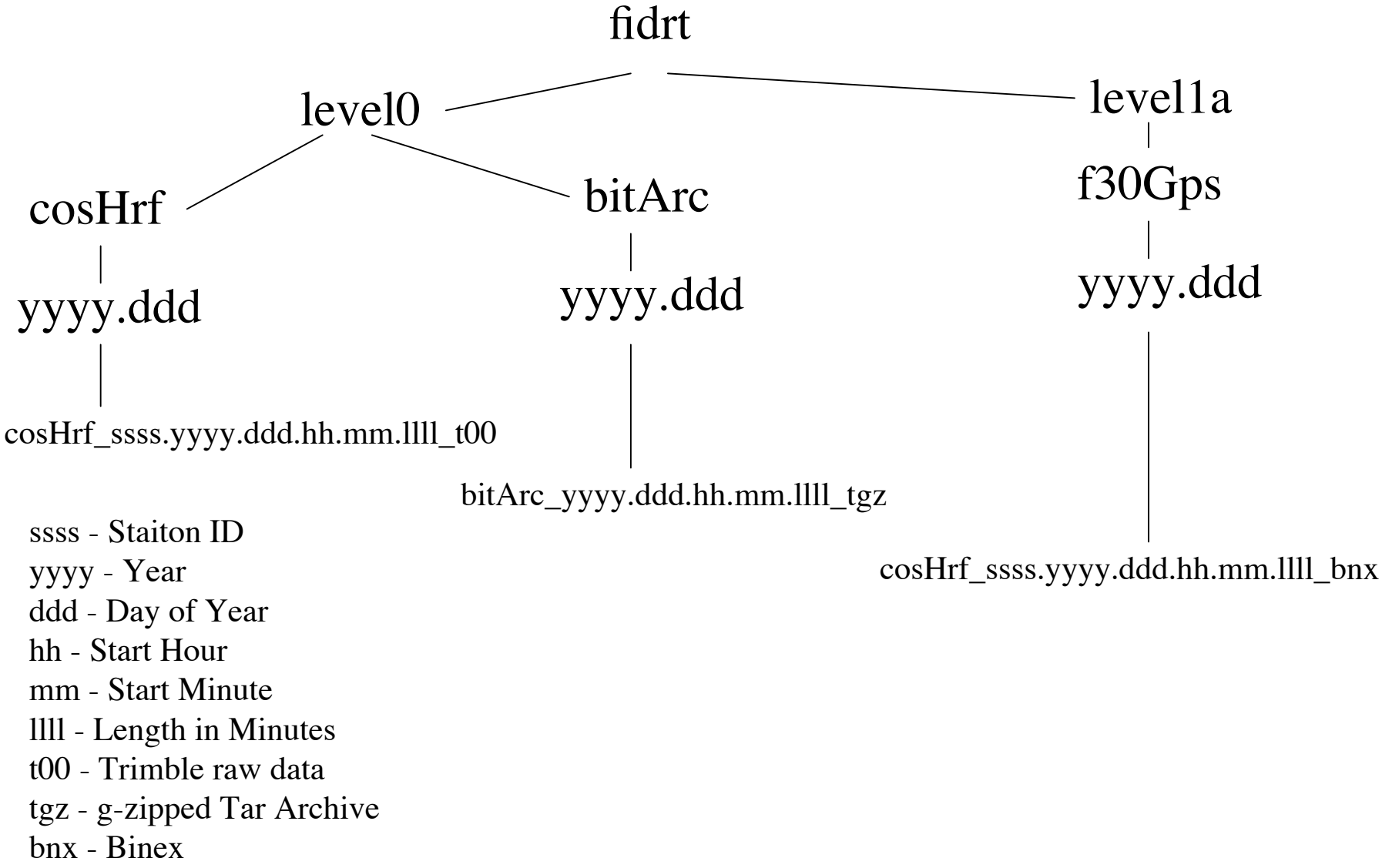


No significant difference - therefore CDAAC will generate excess phases based on single difference processing


Temperature profiles near England
At about 95-4-25:00:00 UTC
Occultation at 52.6N. 355 E.
Radiosonde at 54.5 N. 353.9 E.
Radiosonde at 53.5 N. 357 E.
Pressure, mbar
1
10
100
1000
200
220
240
260
280
300
Temperature, K

Data Access On Cosmic

http://cosmic-io.cosmic.ucar.edu/cdaac/login/

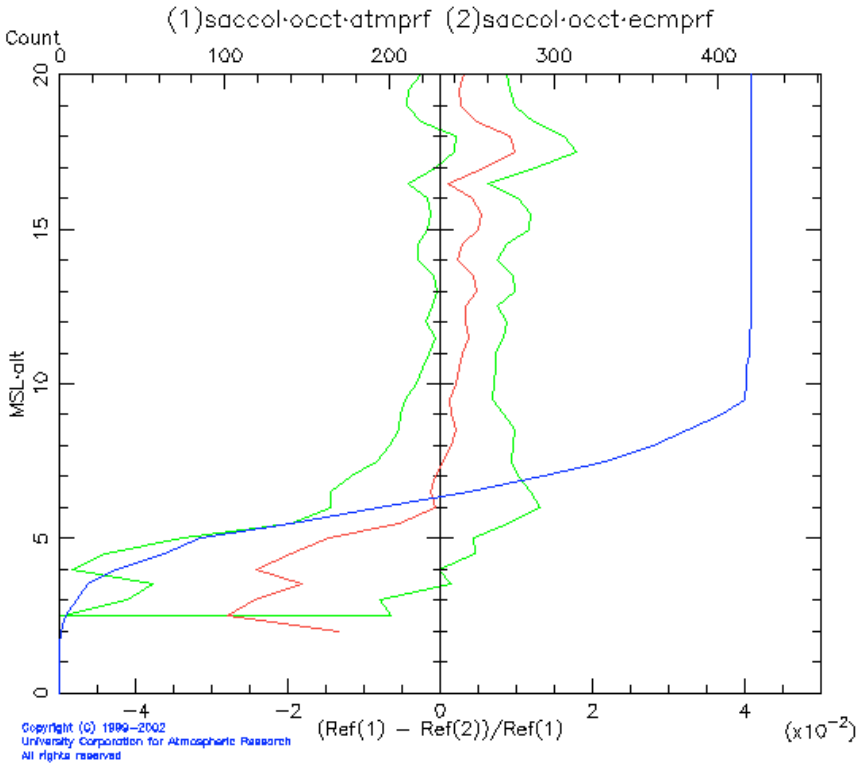


ssss - Staiton ID
yyyy - Year
ddd - Day of Year
hh - Start Hour
mm - Start Minute
llll - Length in Minutes
t00 - Trimble raw data
tgz - g-zipped Tar Archive
bnx - Binex

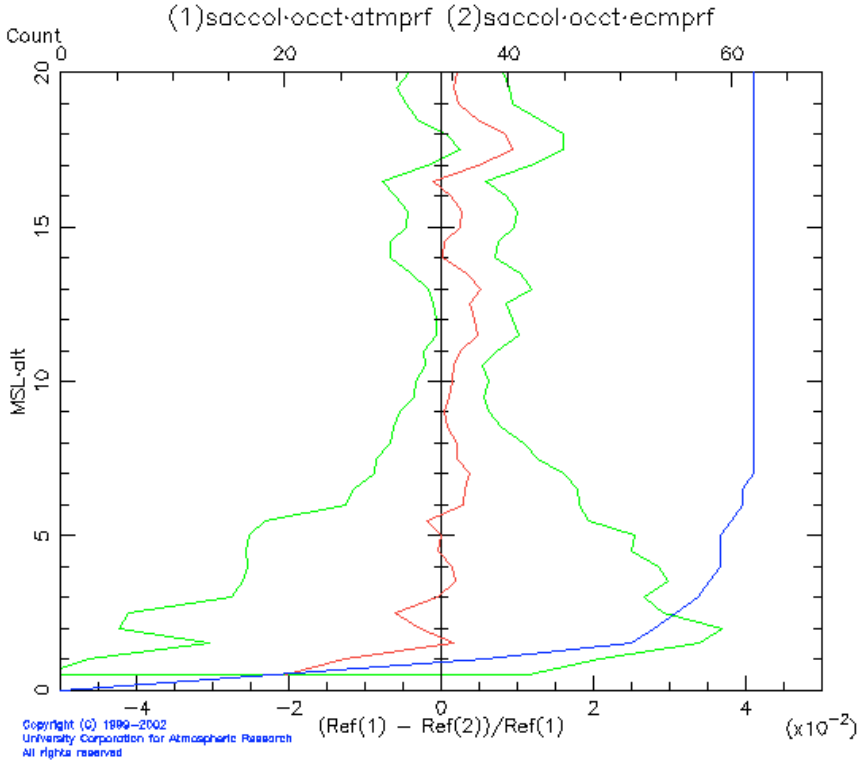
Statistics of comparison of the RO inverted N to ECMWF analysis.

tropics

Phase-locked loop tracking



Open-loop tracking



- better penetration;
- larger standard deviation
- smaller negative N-bias

Open Loop tracking

- Developed at COSMIC and JPL - Implemented first by JPL for SAC-C satellite
- In Open Loop tracking is required to obtain good atmospheric profiles in the lowest 4 km of the tropical atmosphere
- The receiver uses a software model instead of past measurements to down convert the measured GPS signal (no feedback from receiver)
- The receiver cannot (in general) remove the 50 Hz GPS data bit stream (half cycle phase jumps on L1)
- These “half cycle slips” have to be removed in post-processing
- External observations of data bits required when atmospheric phase change between epochs > 1/4-cycle

Figure 1 below shows the front view of the BitGrabber system with a small magnetic mount patch antenna on top. The system measures 17 inches tall, 8 inches wide and 17 deep.

Figure 1: Front view of the BitGrabber PC.

Figure 2 shows a close up view of the LCD Keypad. In the figure shown, the standard display is shown -- the top line shows the system name (`cdbs09`) followed by the date (`20050510-2244` or 2005/05/10 22:44) and the bottom line shows the IP address of the PC (`128.117.29.123`), the number of SVs currently being tracked (`07`) and a status character (`*`) that will flash once per second. The arrow keys on the left and Enter/Function keys on right can be used to display different outputs and also perform the initial network setup for the system. For information on this can be found at the CCAR OpenGPS site.

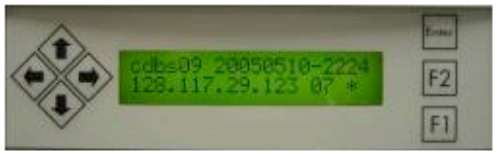
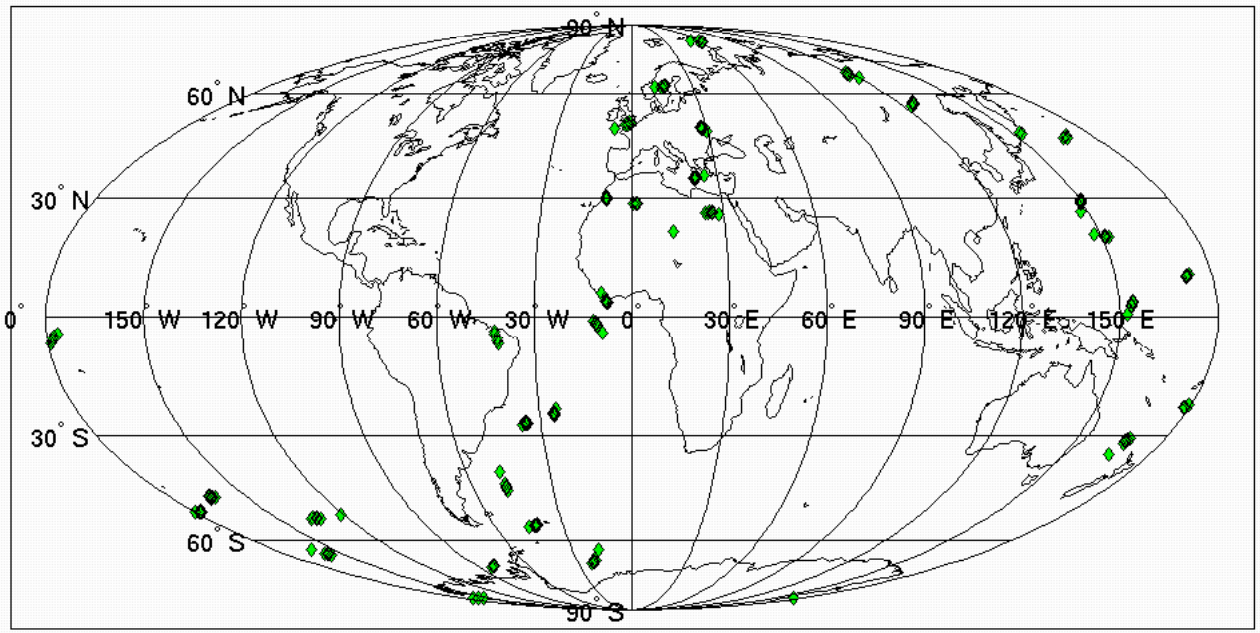


Figure 2: Close up view of LCD Keypad.

- Bit Grabber System
- 10 systems built
- Six deployed
- User guide on web
- Data already proven beneficial for tropical occultations

Earth-Fixed RO Locations for COSMIC, 6 S/C, 6 Planes, Orbit = 01, Launch+1.5months



Early atmospheric profile results - coincident profiles