Extraction of the Atmospheric Excess Phase for RO processing

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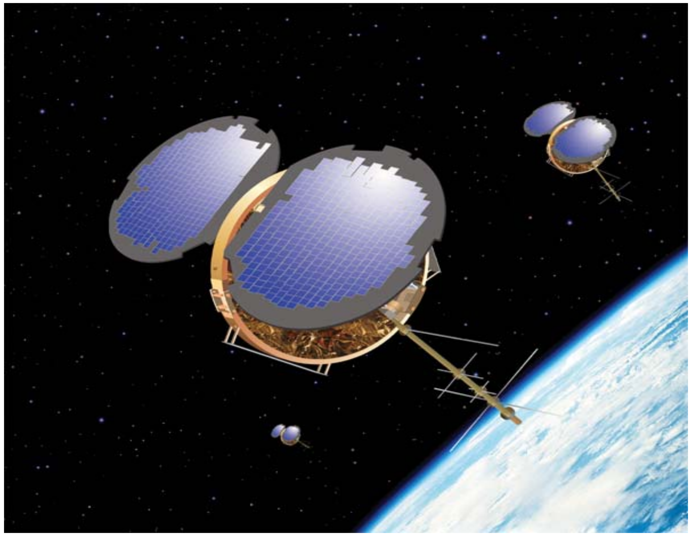
COSMIC at a Glance

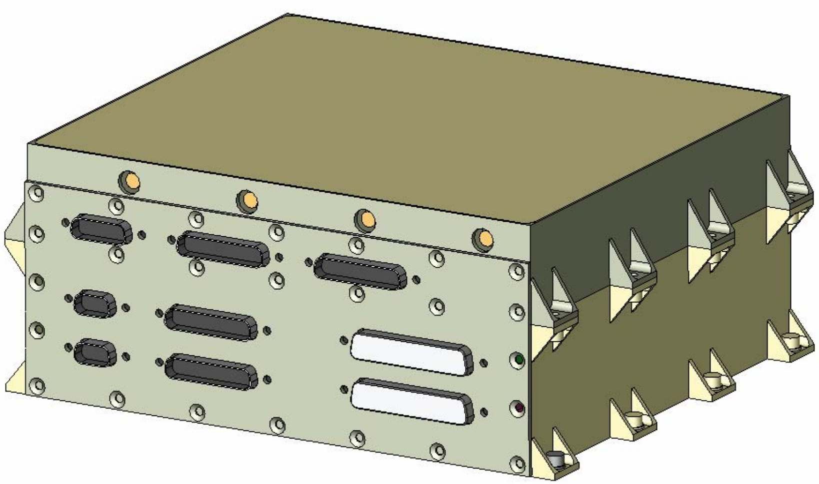
- **C**onstellation **O**bserving **S**ystem for **M**eteorology **I**onosphere and **C**limate (ROCSAT-3)
- 6 Satellites launched in late 2005
- Orbits: alt=800km, Inc=72deg, ecc=0
- Weather + Space Weather data
- Global observations of:
  - Pressure, Temperature, Humidity
  - Refractivity
  - TEC, Ionospheric Electron Density
  - Ionospheric Scintillation



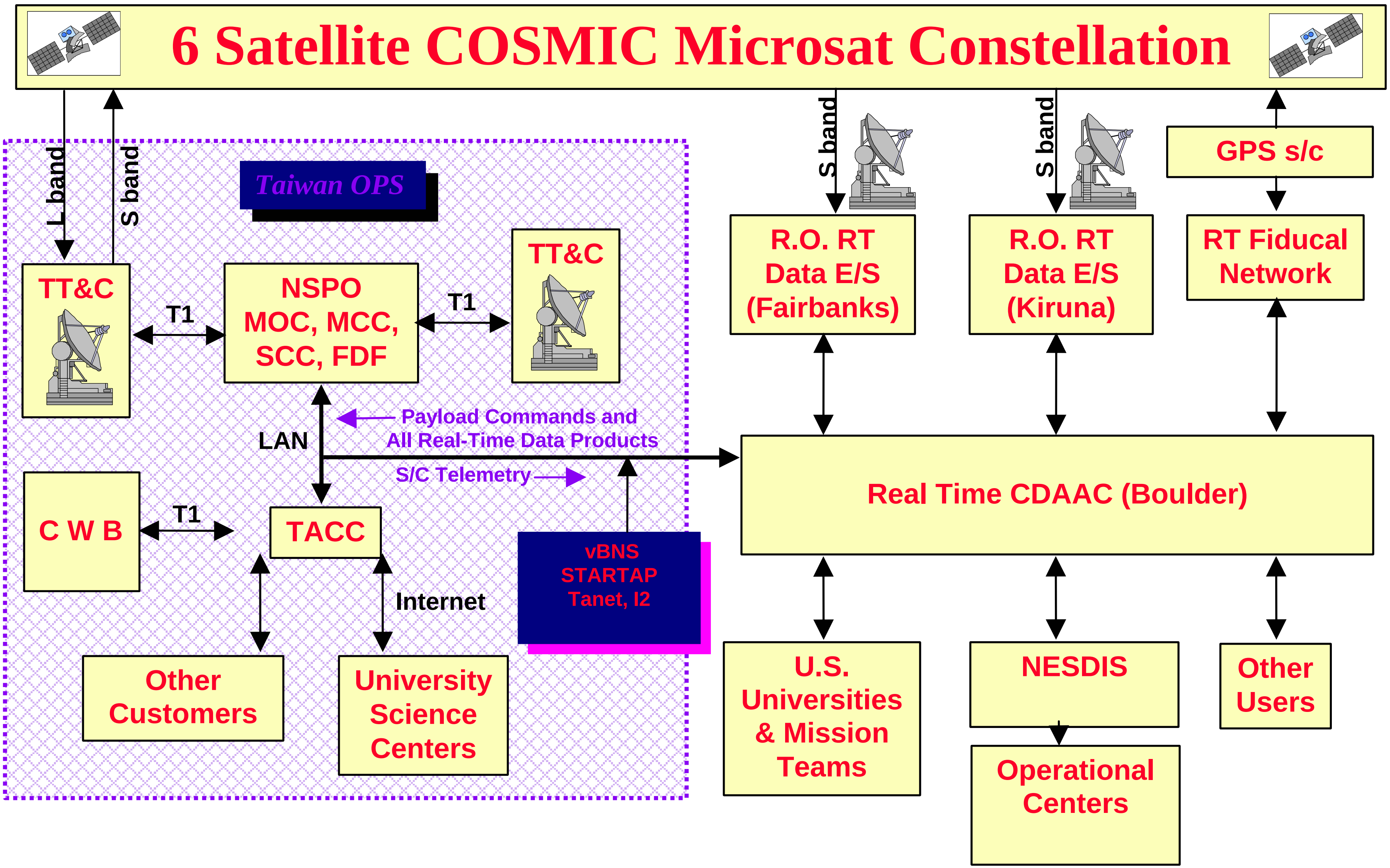
- Demonstrate quasi-operational GPS limb sounding with global coverage in near-real time
- Climate Monitoring
- Geodetic Research

COSMIC GPS Receiver: ARGO

JPL Design, ARGO is based on CHAMP BlackJack Receiver
Technology transfer JPL -> Broad Reach Engineering
4 antennas: 2 occultation + 2 POD antennas
Receiver + Data Recorder/PC: 3.5 kg
Power ~16W GPS + 10 W Data Recorder/PC
New “open loop” tracking and software for rising occultations under development at JPL



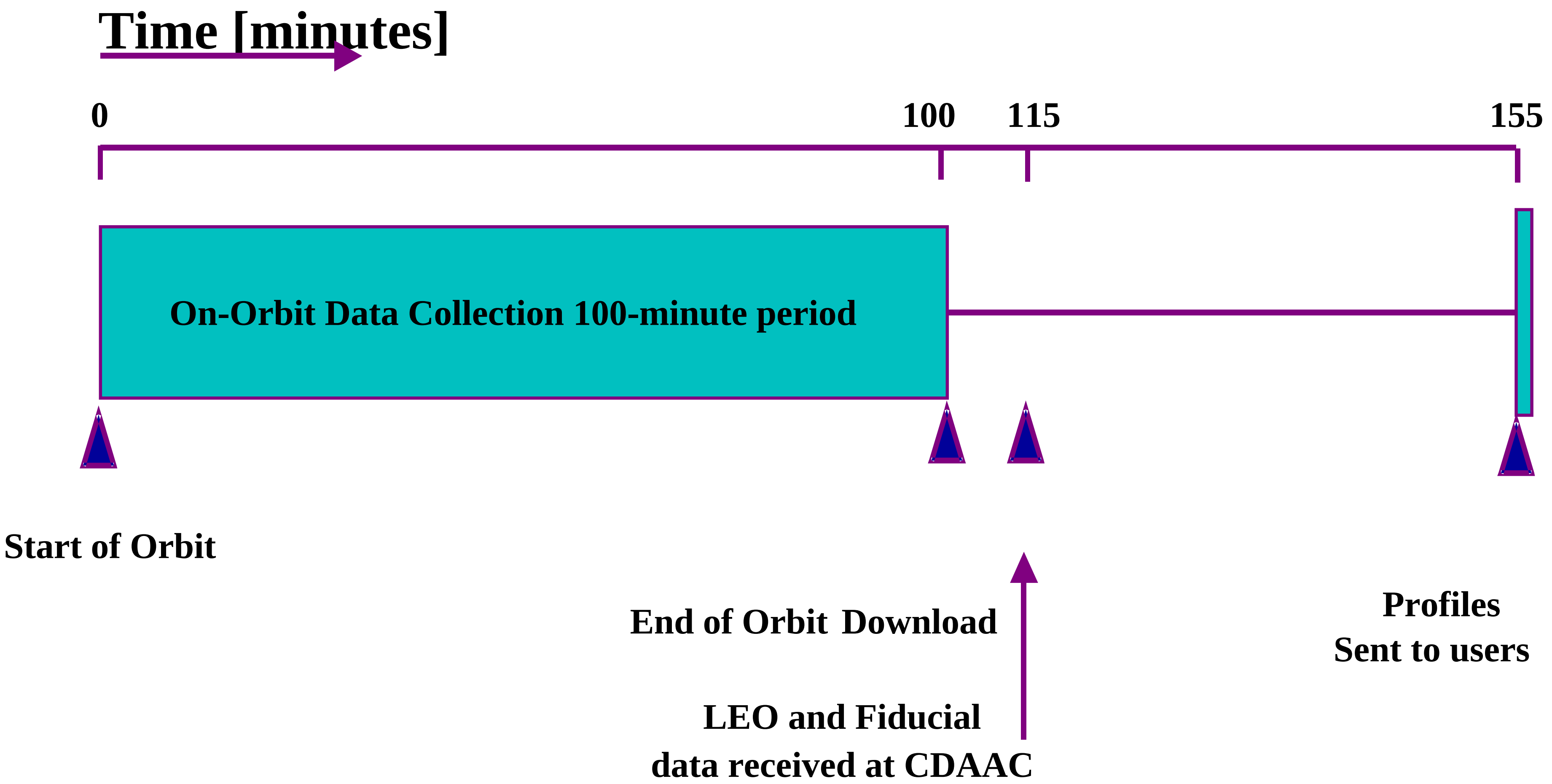
COSMIC System



CDAAC Responsibilities

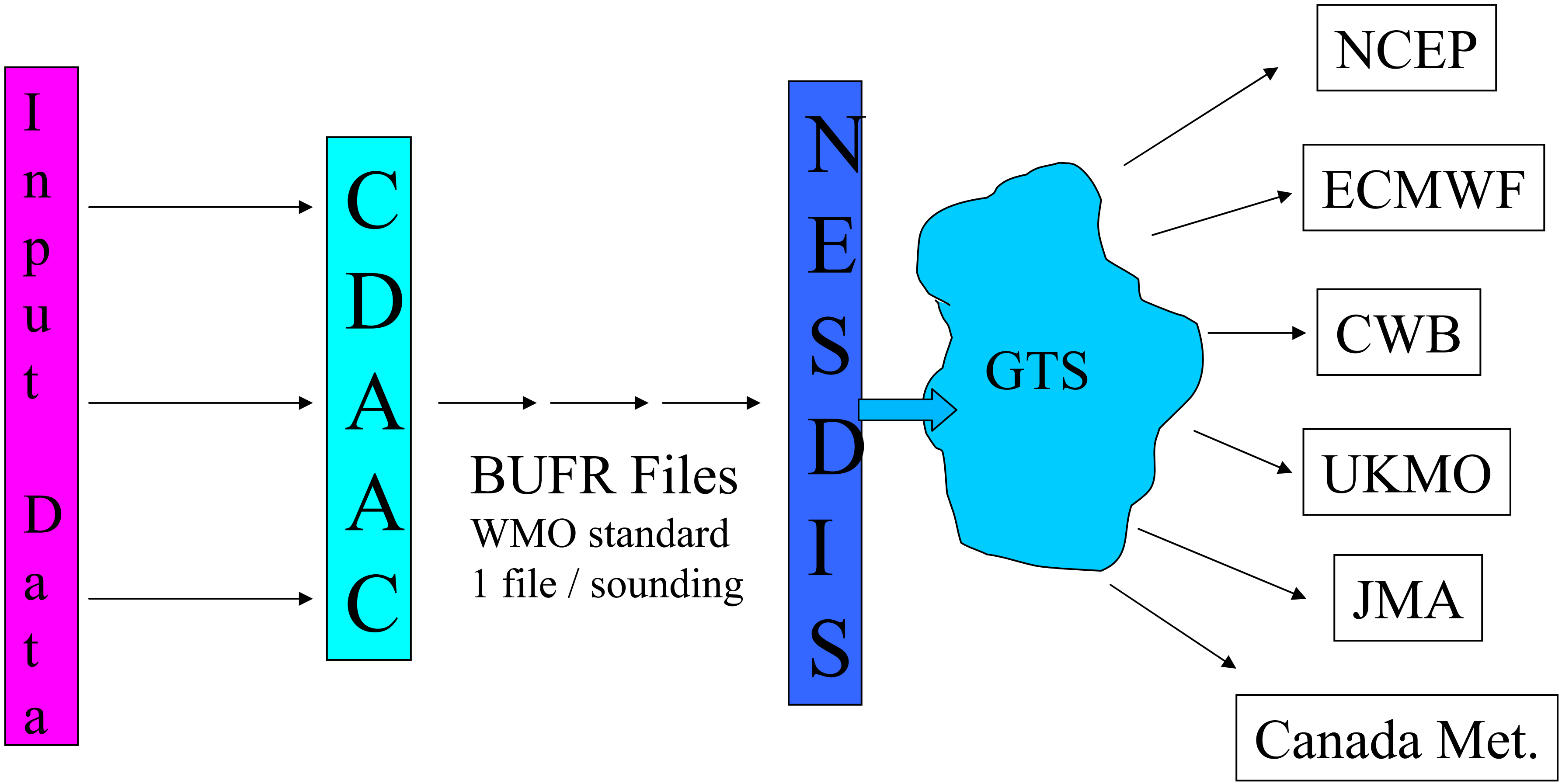
- Process all COSMIC observations
  - » LEO/GPS orbit determination
  - » Atmospheric & Ionospheric profiles
  - » Rapid analysis for operational demonstration
  - » Post-processed analysis for climate and other research
- Provide data to universities and research laboratories
- Provide data feeds (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

CDAAC Real-time Processing



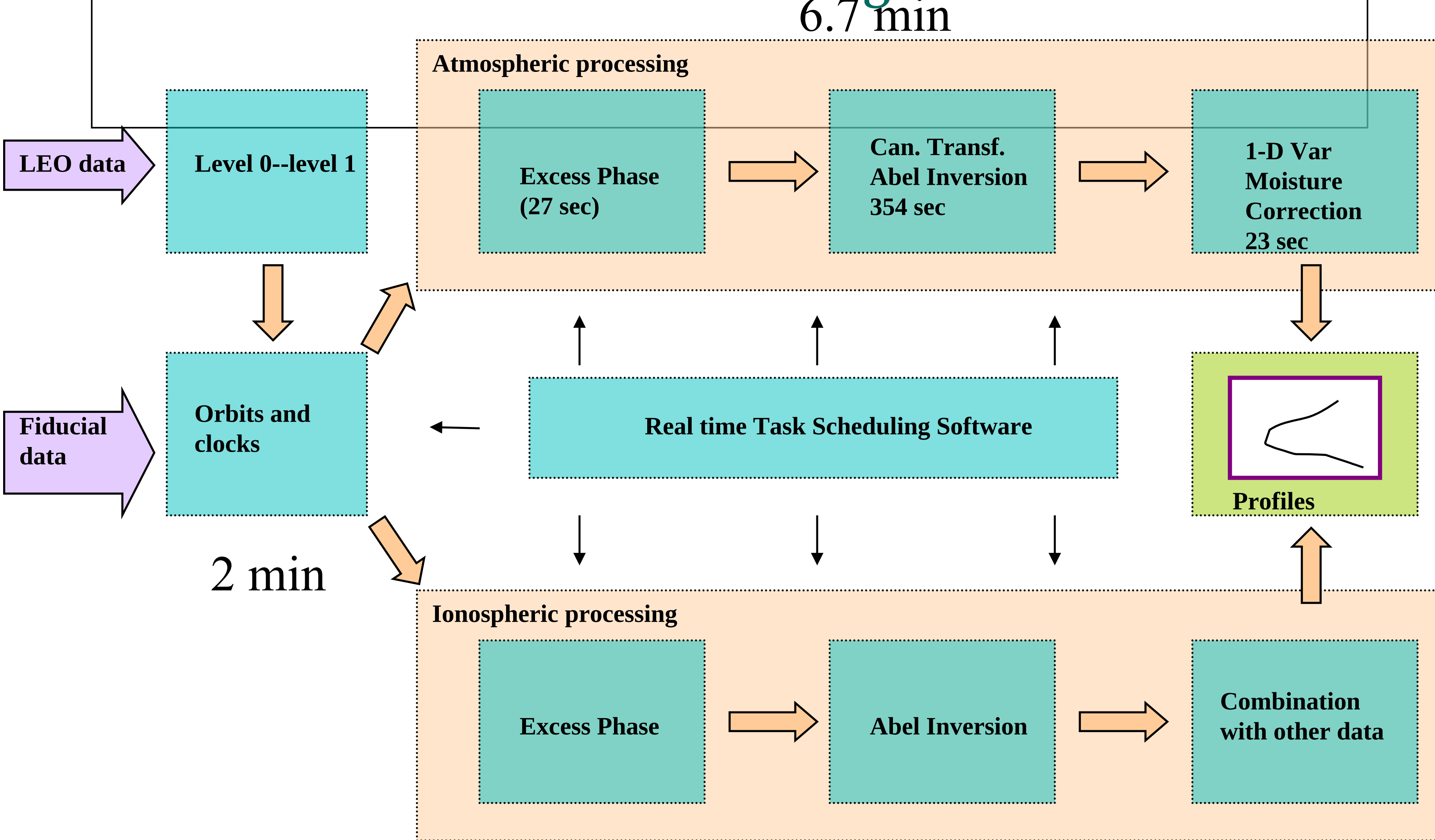
Average age of profiles is ~100 minutes - UCAR now processes ~35 profiles in 9 minutes

Getting COSMIC Results to Weather Centers



This system is currently under development by UCAR, NESDIS, + UKMO

CDAAC Processing Flow



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

The GPS Observation Equation

$$L_r^s = \rho_r^s + c \cdot \delta t_r + c \cdot \delta t_{r,sys} - c \cdot \delta t^s - c \cdot \delta t_{sys}^s + \delta \rho_{trp} + \delta \rho_{ion}$$
$$+ \delta \rho_{rel} + \delta \rho_{mul} + \lambda \cdot N_r^s + \ldots + \epsilon$$

ρ_r^s	Geometrical distance between satellite and receiver
c	Speed of light in vacuum
δt_r	Station clock correction: *receiver clocks* (time and frequency transfer)
$\delta t_{r,sys}$	Delays in receiver and its antenna (cables, electronics, . . .)
δt^s	Satellite clock correction: *satellite clocks*
$\delta t_{s,sys}$	Delays in satellite and its antenna (cables, electronics, . . .)
$\delta \rho_{trp}$	Tropospheric delay: *troposphere parameters* (meteorology, climatology)
$\delta \rho_{ion}$	Ionospheric delay: *ionosphere parameters* (atmosphere physics)
$\delta \rho_{rel}$	Relativistic corrections (Special and General Relativity)
$\delta \rho_{mul}$	Multipath, scattering, bending effects
λ	Wavelength of the GPS signal (L_1 or L_2)
N_r^s	Phase ambiguity: *ambiguity parameters* (ambiguity resolution)
ϵ	Measurement error

C Rocken "Ground based GPS Meteorology" NCAR GPS Meteorology Colloquium, June 20 - July 2, 2004, Boulder, CO

There are several ways to obtain $\delta\rho_{trp}$ from the GPS observations

$$L_r^s = \rho_r^s + c \cdot \delta t_r + c \cdot \delta t_{r,sys} - c \cdot \delta t^s - c \cdot \delta t^s_{sys} + \delta\rho_{trp} + \delta\rho_{ion} + \delta\rho_{rel} + \delta\rho_{mul} + \lambda \cdot N_r^s + \ldots + \epsilon$$

(1) Remove all other components from $L^s{}_r$
This is done for estimating the "atmospheric delay for radio occultation observations where all other components must be known from separate processing steps

(2) Model it and estimate as a parameter
This is done for ground based GPS and will be explained in more detail in this lecture

Ionospheric free linear combination

Form double difference

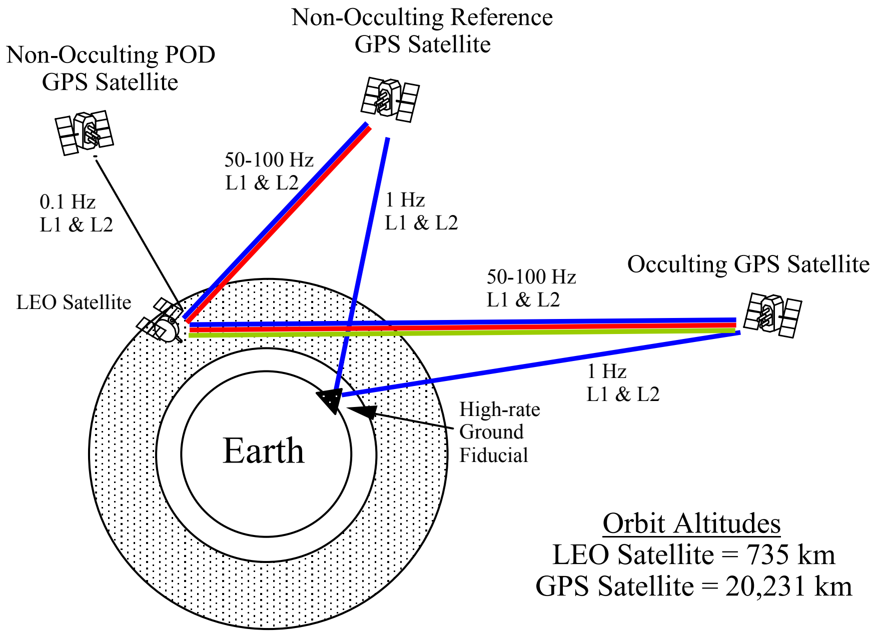
$$\frac{d(\delta_{trp})}{dt}$$

Radio occultation is only sensitive to rate of change

Calibration of excess 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
  - » 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

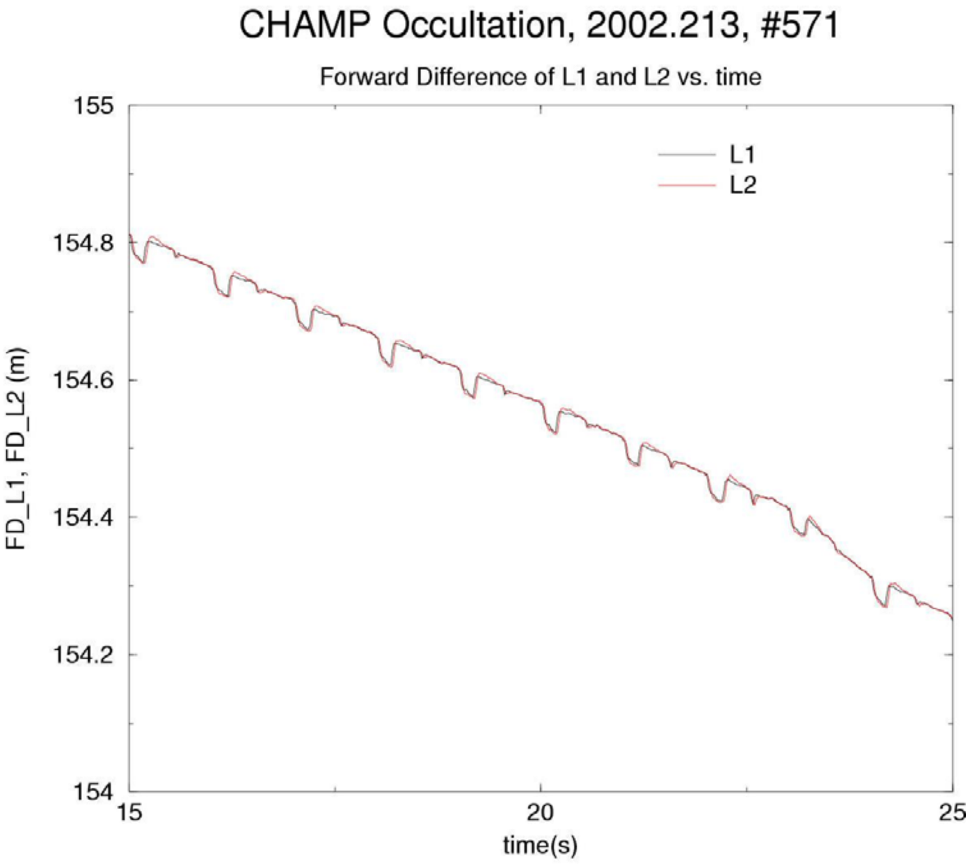
* L4 (L1-L2) smoothing required to minimize CHAMP/SAC-C clock distribution problem

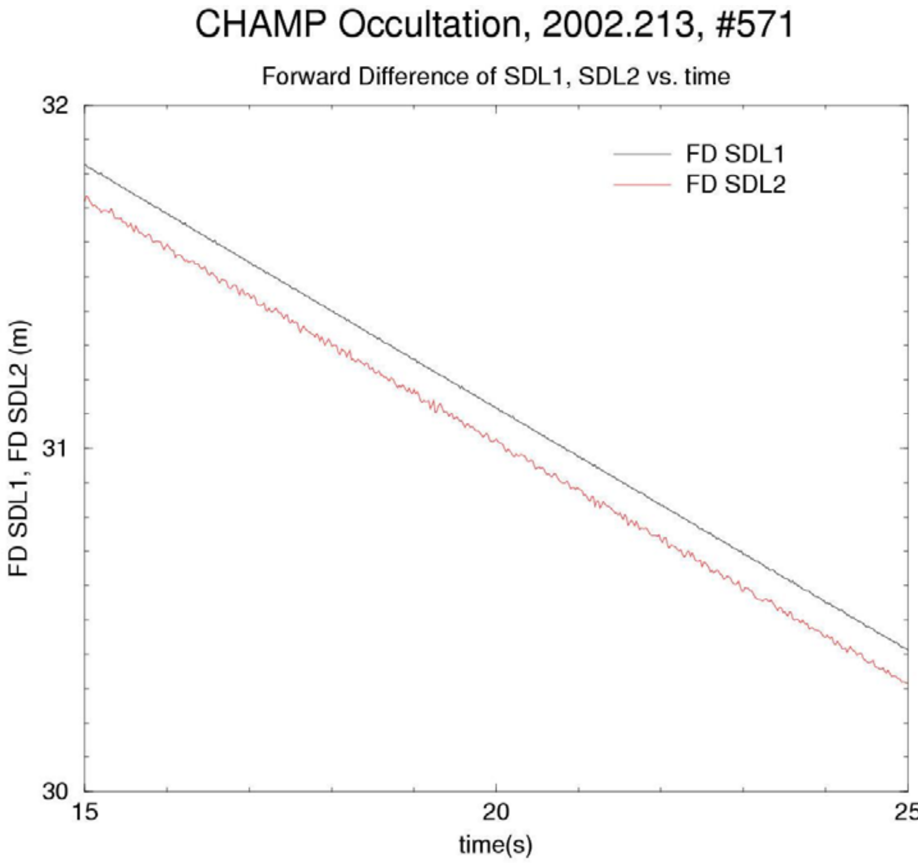


CHAMP Clock Distribution Problem

Clock ‘Spikes’ in
Raw L1 and L2 phase

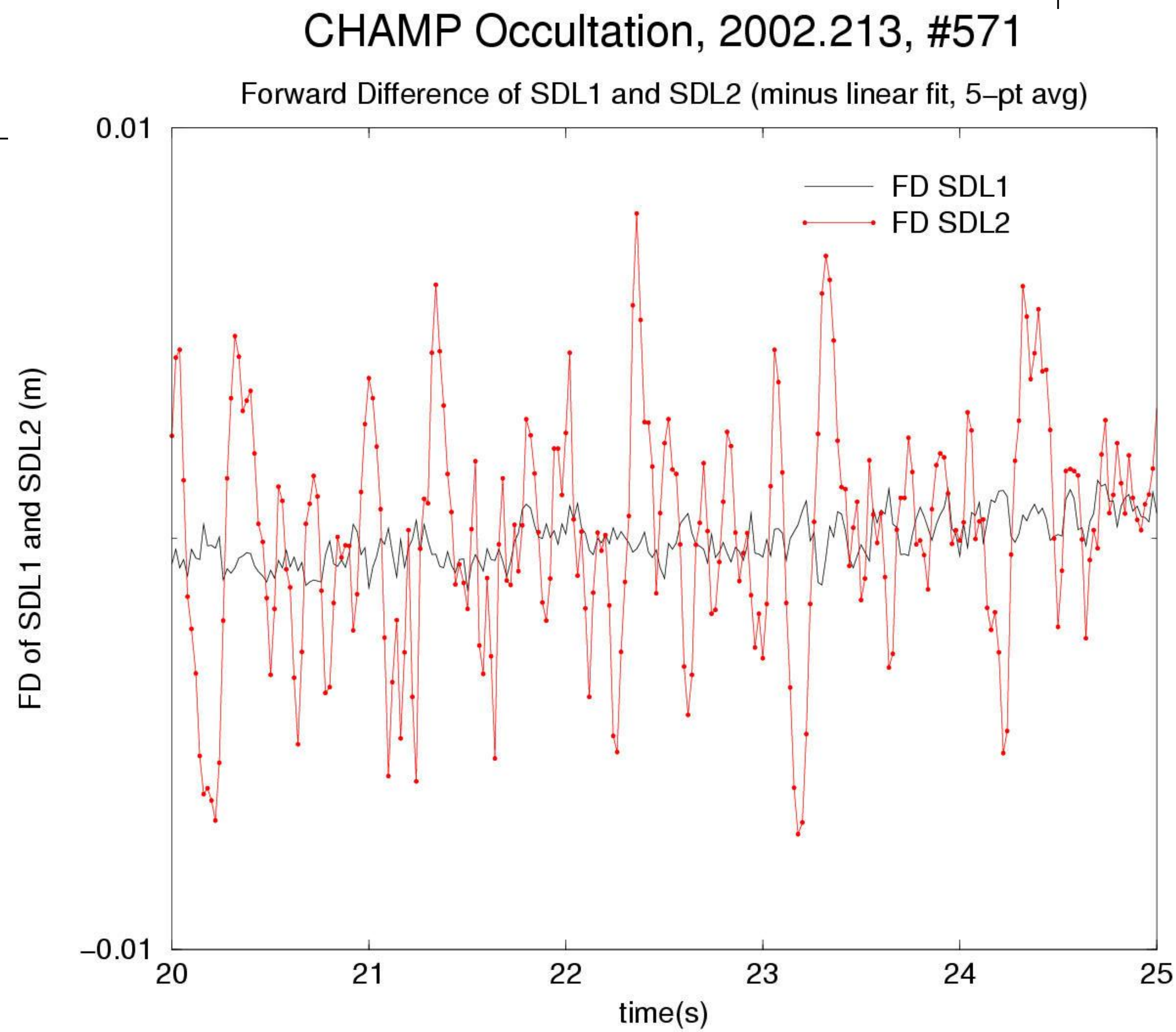
Spikes appear to be
Eliminated in Single-Diff



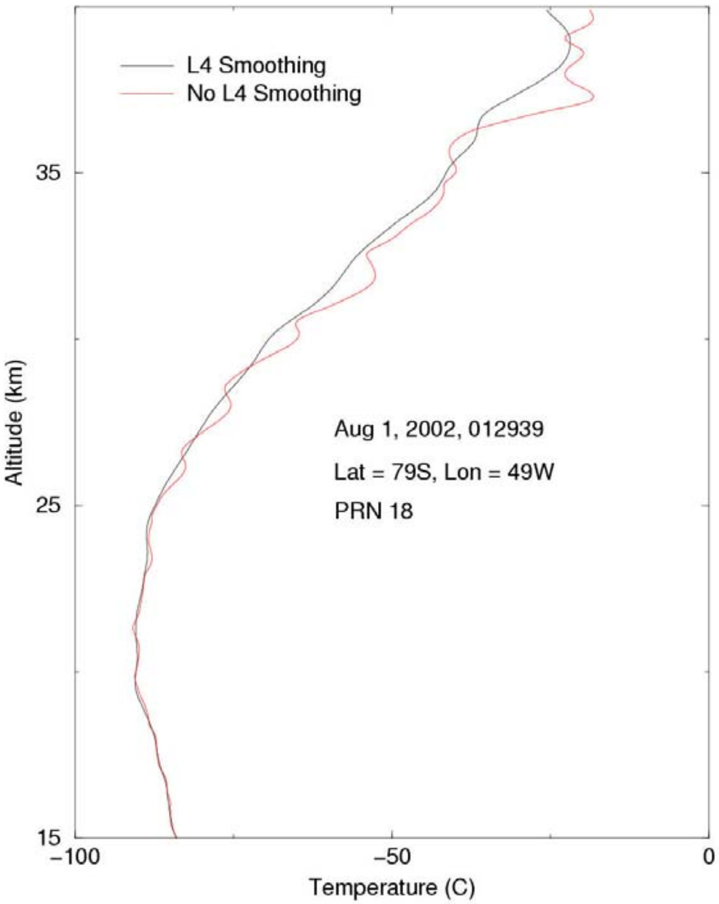


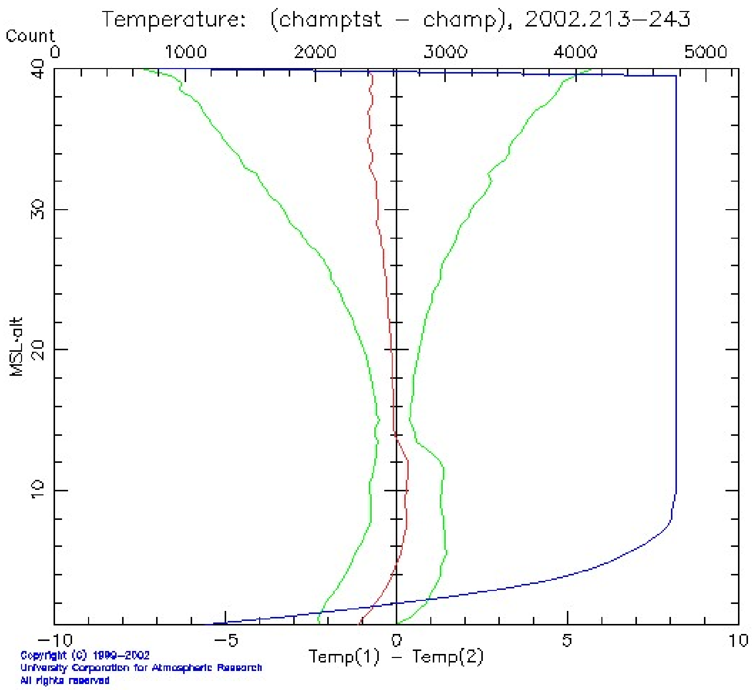
CHAMP Clock Distribution Problem

Residual clock signal remains on L2 after single-difference

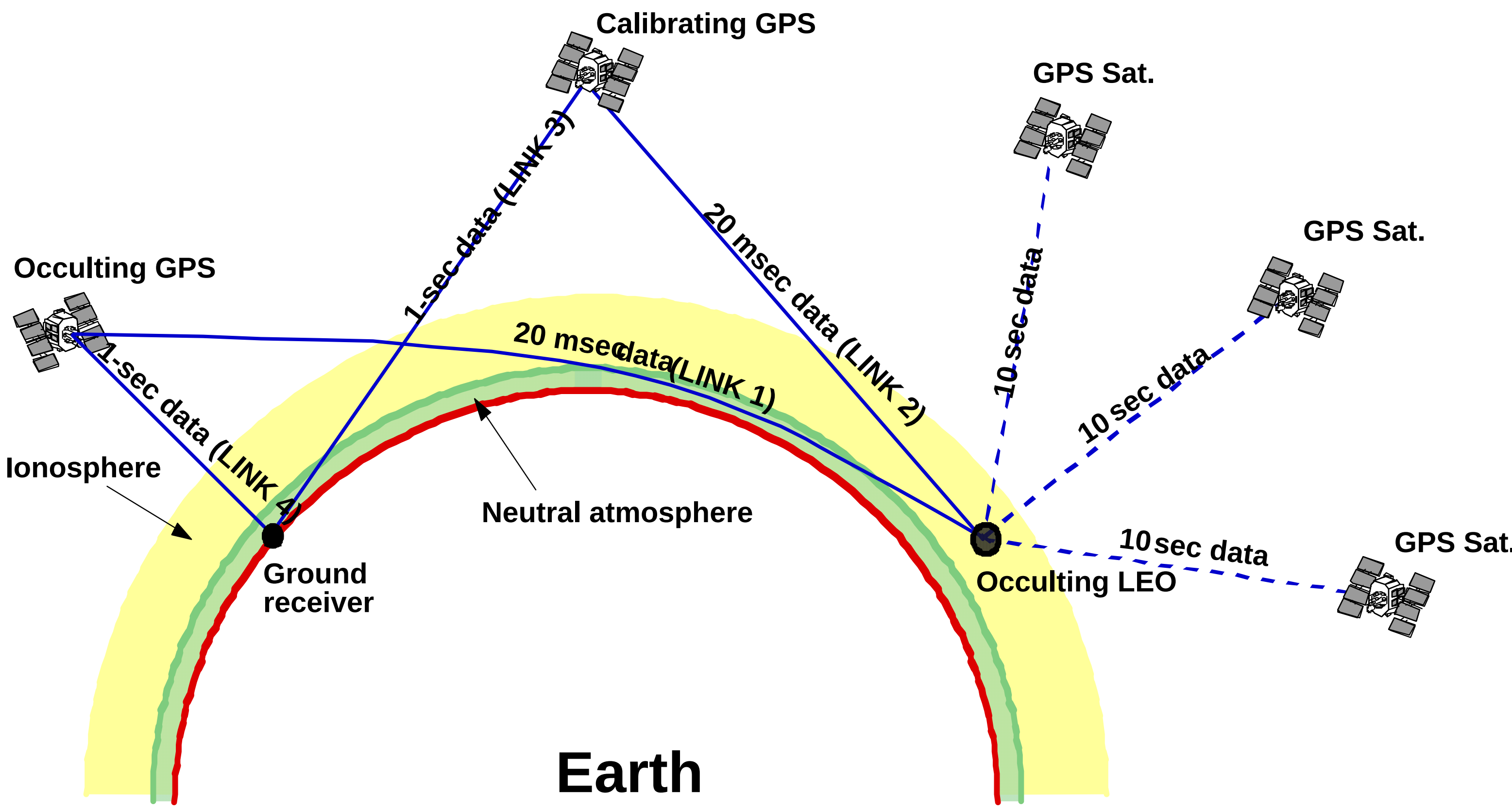


Effect of L4 smoothing





Calibration of excess phase delay



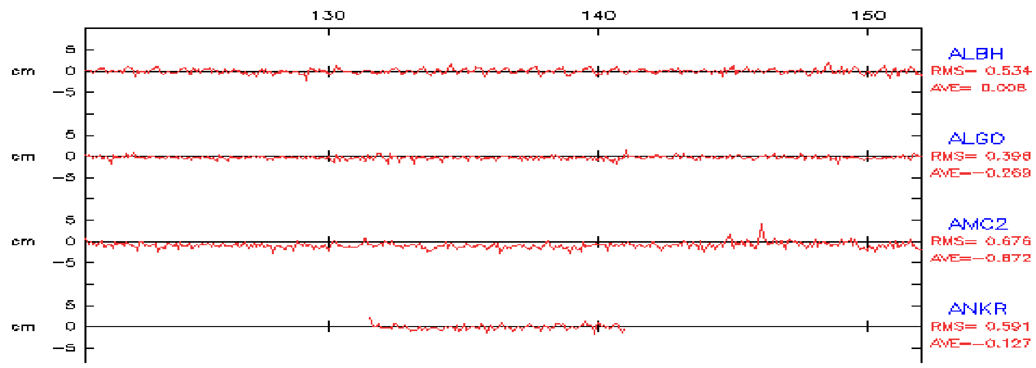
- Double Difference
  - » Advantage: Clock errors removed
  - » Problem: Fid. site MP, atmos. Noise, thermal noise

- Single Difference
  - –LEO clock errors removed
  - –use solved-for GPS clocks
  - –Main advantage: Minimizes double difference errors

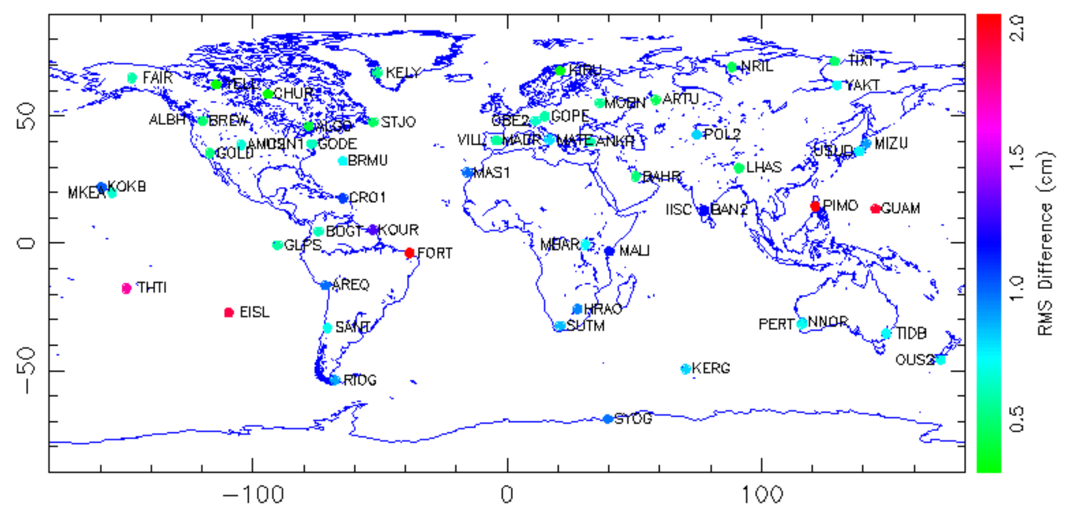
Global Fiducial network processing has been implemented

- •Comparisons of CDAAC post-processed zenith delays with IGS final values
- •CDAAC software in place to automatically fetch files, populate database with comparison values and display reports, including global summary maps.
- •Most sites show monthly average RMS differences with IGS of < 1cm with little bias

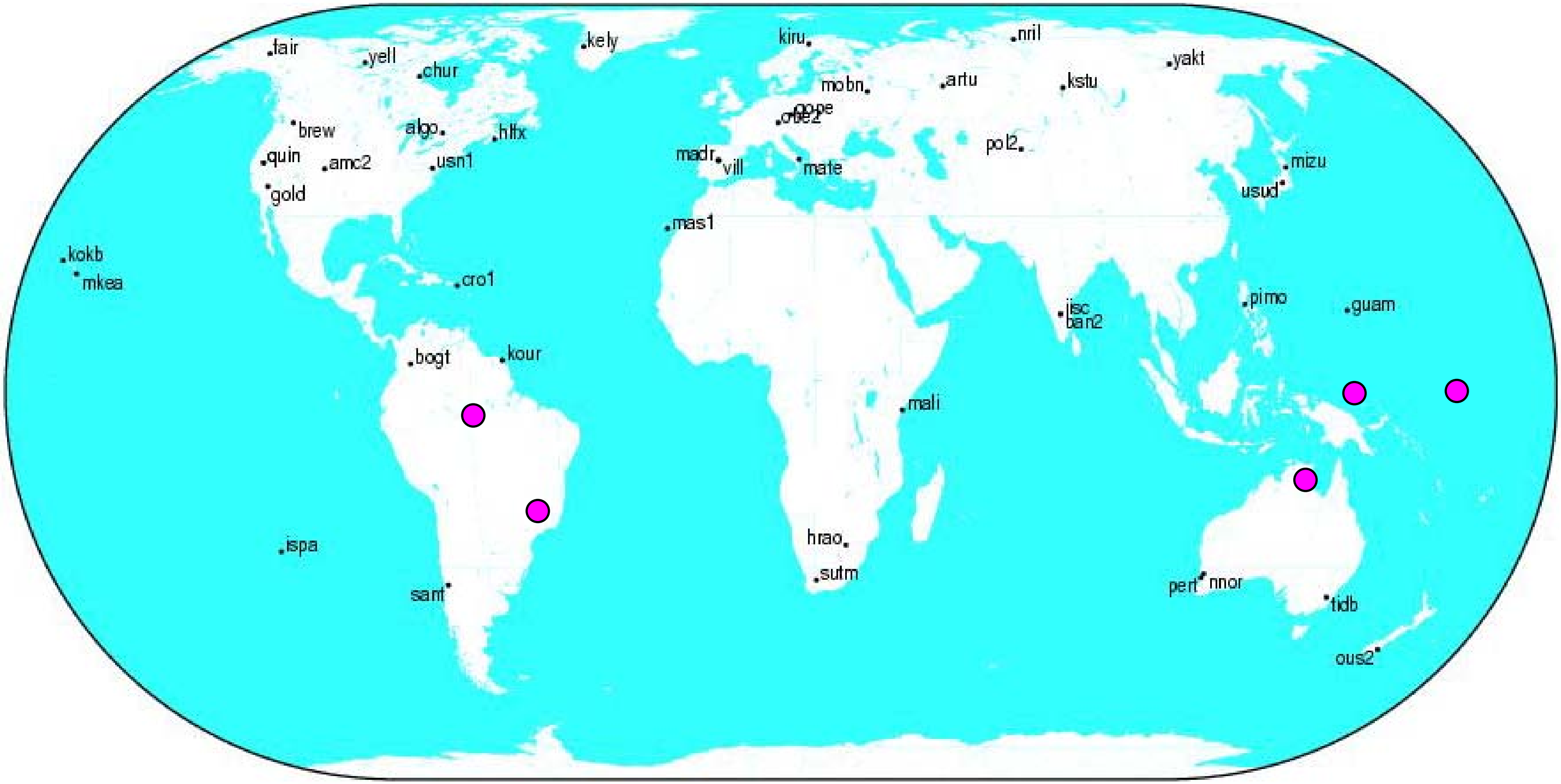
fidtrp – igstrp, 2003.121–151 (page 1/10)



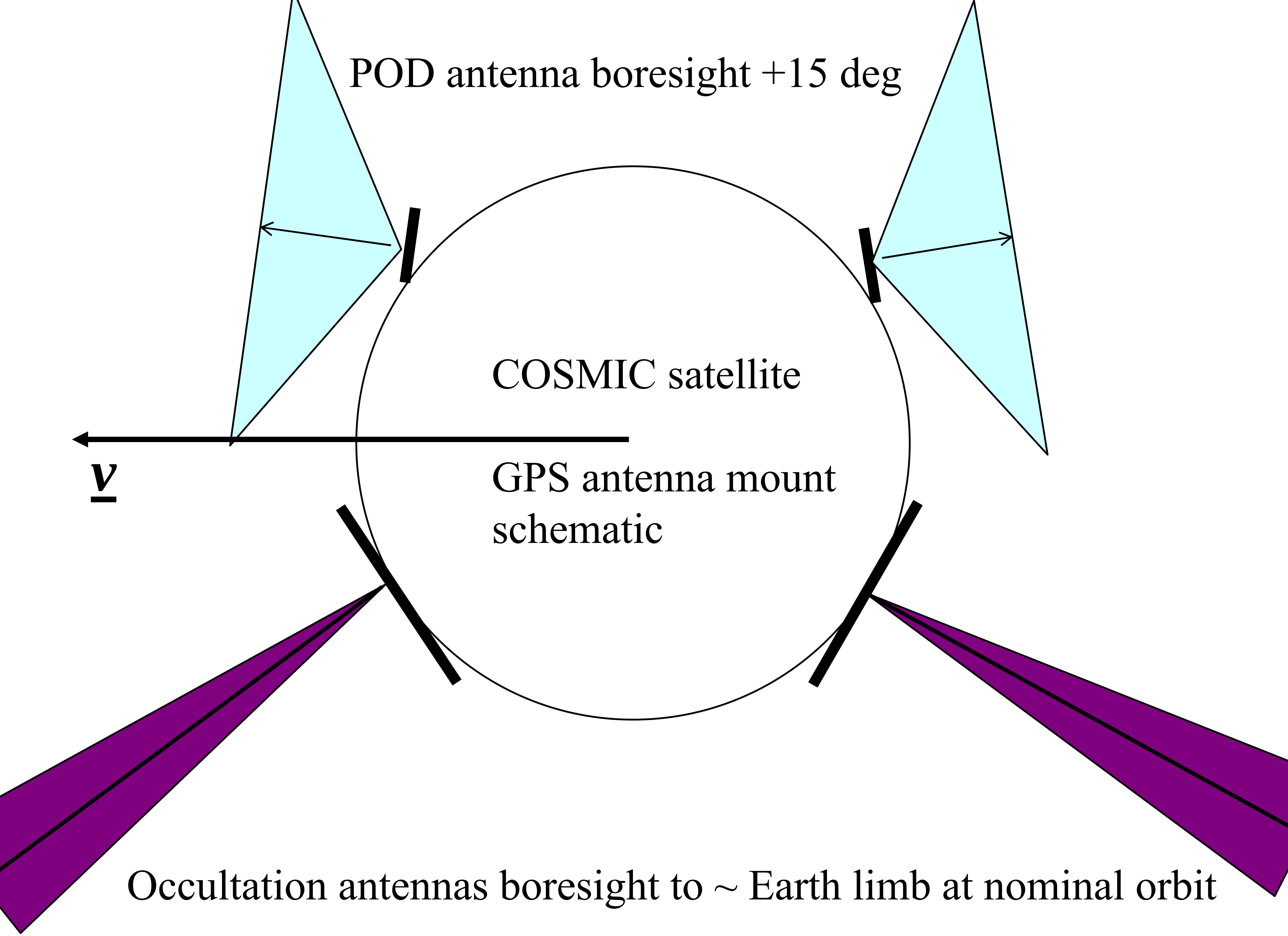
fidtrp – igstrp, Average RMS (2003.121–151)



Global 1-sec sampling rate IGS GPS network

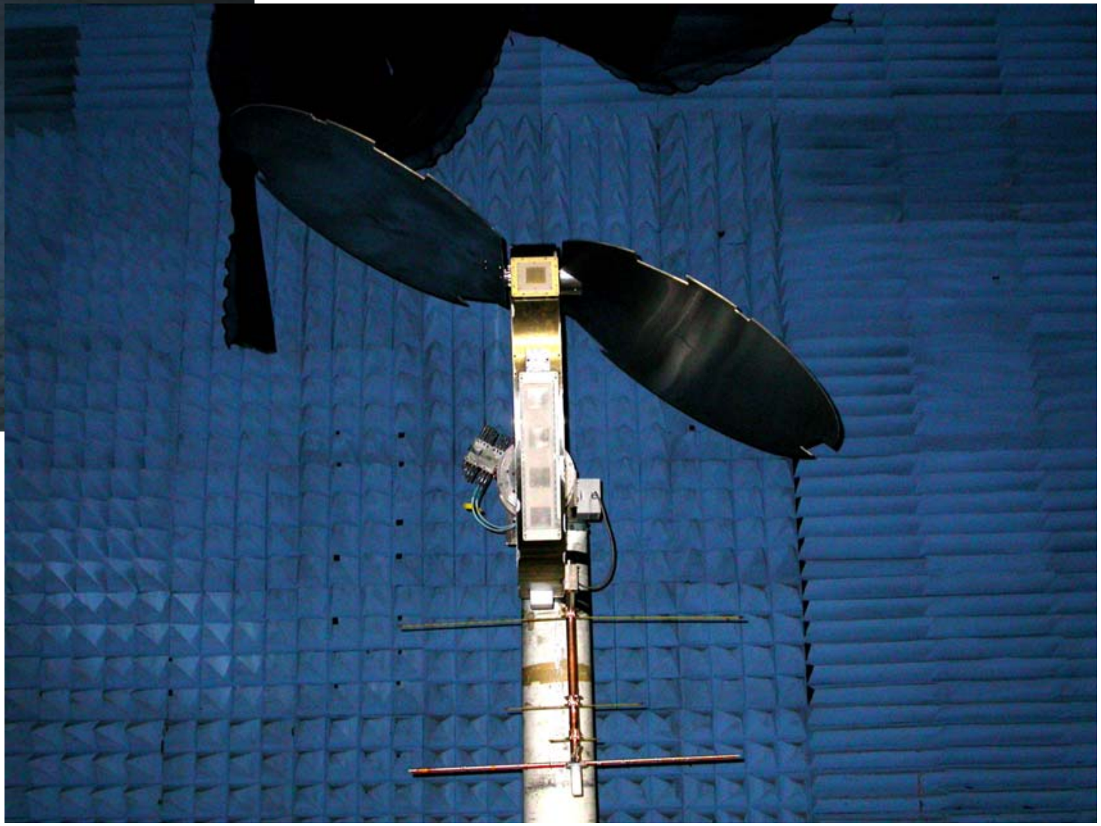


● Planned COSMIC augmentation sites

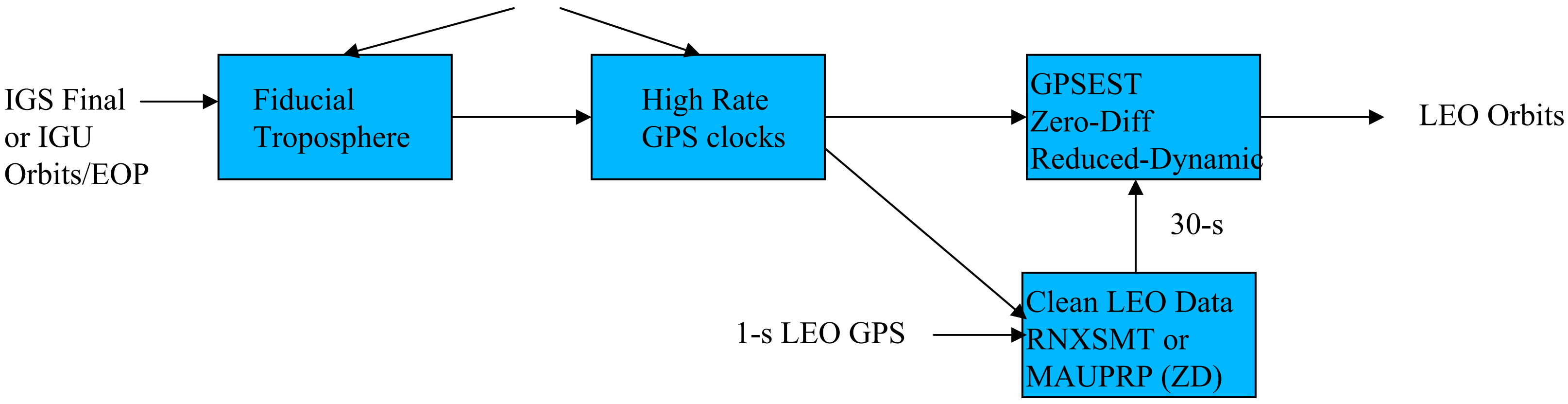

POD antenna boresight +15 deg
COSMIC satellite
v
GPS antenna mount
schematic
Occultation antennas boresight to ~ Earth limb at nominal orbit

Characterization of antenna phase pattern

Using satellite size model in anechoic chamber



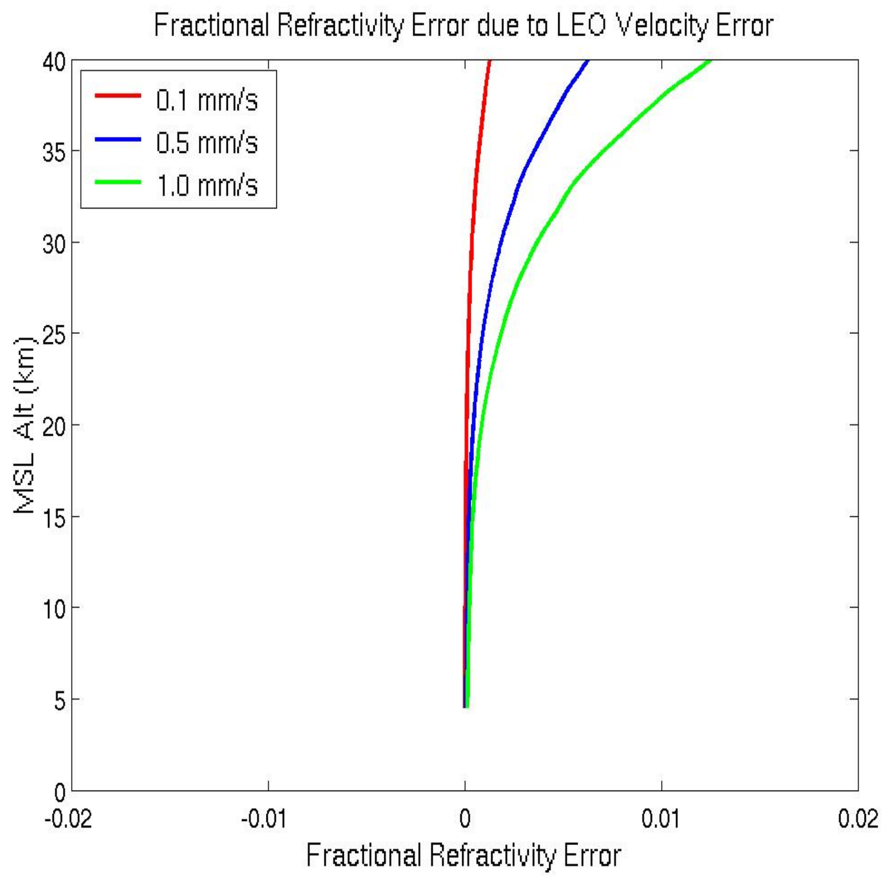
Strategy for Post-Processed and Near Real-Time POD



- Required Accuracy: < 10cm 3D, < 0.1 mm/sec 3D (Svehla and Rothacher, 2003, > 100 ground stations, 4cm 3D)
- LEO state vector: position,velocity, 9 SRP's, CD, Pseudo-stochastic velocity pulses every 10-15 min in along-track,cross-track,radial direction
- Potential Issues to be studied:
  - » Required number of ground stations
  - » Velocity jumps at pseudo-stochastic epochs
  - » Stacking of LEO NEQ's to be developed
  - » Inconsistent LEO clocks for POD1/POD2
- Arranging visit with Tech. Univ. of Munich to learn about LEO POD with Bernese v5.0

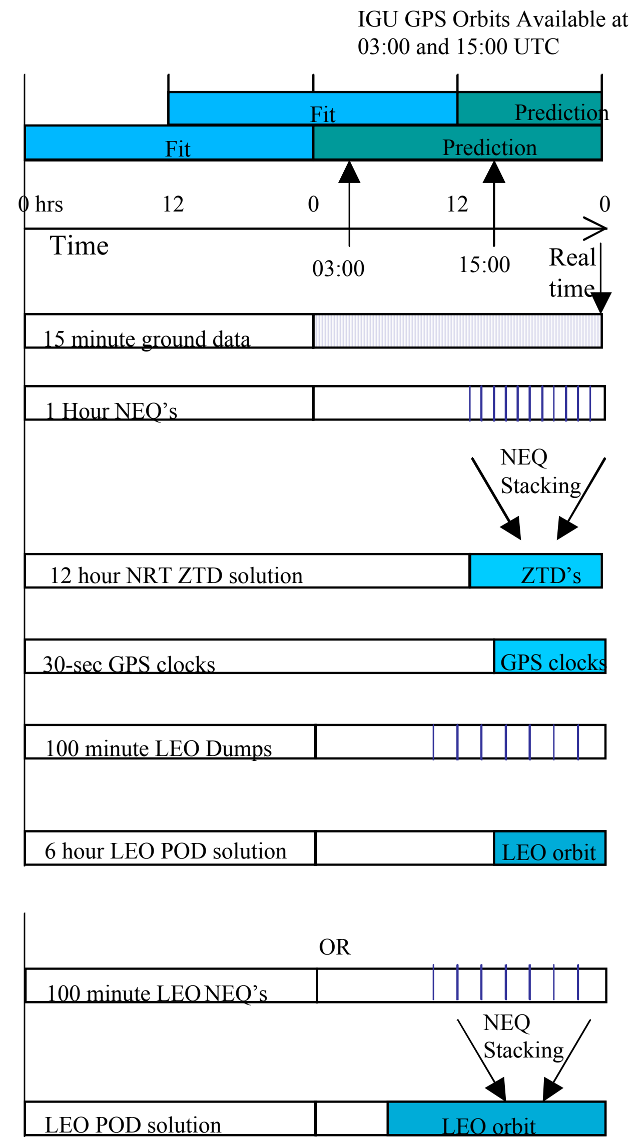
Orbit Error Impact on RO Retrieval Accuracy

- Velocity errors added to excess atmospheric phase delay of actual CHAMP occultation
- Perform RO inversions and compare with actual retrieval
- Retrievals used Statistical Optimization of bending angles which reduces impact of orbit error.



NRT Processing Flow / NRT Simulation

- Use IGU orbits/EOP's (current 6-hr update)
- Use station coordinate estimates from previous months post-processing
- Estimate troposphere ZTD's: pre-eliminate station coords before stacking 1-hr Neq's
- Estimate high-rate (30-sec) GPS clocks over LEO arc: Align phase derived clocks with IGU clocks
- Perform ZD RD processing for LEO arc



- NRT Simulation Assumptions
  - » No ground data latency, assume data arrives every hour
  - » Estimate ZTD's every hour, neglect processing time, no extrapolation (upto 1 hour)
  - » Processs LEO dumps every hour
  - \- Currently, LEO arcs must start at 00:00 UTC

UCAR-JPL(Quick) Orbit Overlap Results - 2002.214