Extraction of the Atmospheric Excess Phase for RO processing

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COSMIC at a Glance

- Constellation Observing System for Meteorology Ionosphere and Climate (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

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

6 Satellite COSMIC Microsat Constellation

TT&C
NSPO MOC, MCC, SCC, FDF
C W B
TACC
Payload Commands and All Real-Time Data Products
S/C Telemetry
Internet
Other Customers
University Science Centers

Taiwan OPS

TT&C

R.O. RT Data E/S (Fairbanks)
R.O. RT Data E/S (Kiruna)
Real Time CDAAC (Boulder)
U.S. Universities & Mission Teams

GPS s/c
RT Fiducial Network

NESDIS
Operational Centers
Other Users

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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

Time [minutes]

0 100 115 155

On-Orbit Data Collection 100-minute period

Start of Orbit

End of Orbit Download

Profiles Sent to users

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

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Getting COSMIC Results to Weather Centers

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

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

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The GPS Observation Equation

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

- \( \rho_r^s \): Geometrical distance between satellite and receiver
- \( c \): Speed of light in vacuum
- \( \delta t_r \): Station clock correction: receiver clocks (time and frequency transfer)
- \( \delta t_{r,sys} \): Delays in receiver and its antenna (cables, electronics, ...)
- \( \delta t^s \): 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
- \( \lambda \): Wavelength of the GPS signal (\( L_1 \) or \( L_2 \))
- \( N_r^s \): Phase ambiguity: ambiguity parameters (ambiguity resolution)
- \( \epsilon \): Measurement error
There are several ways to obtain $\delta \rho_{trp}$ from the GPS observations

$$L^s_r = \rho^s_r + c \cdot \mathbf{X}_{tr} + c \cdot \delta \mathbf{X}_{r,sys} - c \cdot \mathbf{X}^s_t - c \cdot \mathbf{X}^s_{sys} + \delta \rho_{trp} + \delta \rho_{ion} + \delta \rho_{rel} + \delta \rho_{mul} + \lambda \cdot \mathbf{X}_r^s + \ldots + \epsilon$$

(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

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CHAMP Clock Distribution Problem

Clock ‘Spikes’ in Raw L1 and L2 phase

Spikes appear to be Eliminated in Single-Diff

CHAMP Occultation, 2002.213, #571
Forward Difference of L1 and L2 vs. time

CHAMP Occultation, 2002.213, #571
Forward Difference of SDL1, SDL2 vs. time
Residual clock signal remains on L2 after single-difference
Effect of L4 smoothing

Aug 1, 2002, 012939
Lat = 79S, Lon = 49W
PRN 18

Temperature: (champtst - champ), 2002.213-243

Meteorology Colloquium, June 20 - July 2, 2004, Boulder, CO
Calibration of excess phase delay

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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.
Global 1-sec sampling rate IGS GPS network

- Planned COSMIC augmentation sites

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Occultation antennas boresight to ~ Earth limb at nominal orbit

- POD antenna boresight +15 deg
- COSMIC satellite
- GPS antenna mount schematic
Characterization of antenna phase pattern
Using satellite size model in anechoic chamber
Strategy for Post-Processed and Near Real-Time POD

- **IGS Final** or **IGU Orbits/EOP** → **Fiducial Troposphere** → **High Rate GPS clocks** → **GPSEST Zero-Diff Reduced-Dynamic** → **LEO Orbits**

- **1-s LEO GPS**
  - **Clean LEO Data**
  - **RNXSMT or MAUPRP (ZD)**

- **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**

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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.

![Graph showing Fractional Refractivity Error due to LEO Velocity Error](attachment:image.png)

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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)
- Process LEO dumps every hour
  - Currently, LEO arcs must start at 00:00 UTC

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External Orbit Overlaps with JPL(Quick), Velocity, CHAMP, 2002.214

Radial RMS = 0.08 mm/s
Transverse RMS = 0.12 mm/s
Normal RMS = 0.09 mm/s