SI Traceability Applied To GPS Radio Occultation

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Overview of Today’s Talk

- The Radio Occultation Measurement
- Applied SI-traceability
- Instrumentation
- Results
- Summary
The Radio Occultation Measurement

Geometry of an acquisition

- Tied to atomic clock standards
- Relative motion, GPS-LEO, Doppler shift
- Local spherical symmetry
- Doppler -> refractive index vs altitude

\[ N = a_1 \frac{P}{T} + a_2 \frac{P_W}{T^2} \]
Role Of Geodetic Modeling

- Geodetic modeling software systems solve directly for clocks
  - GIPSY (JPL), Bernese (U. Berne), etc.
- Satellite and ground locations assumed known
  - Orbits to ~cm level are demonstrated
- GPS time synchronized to atomic time via reference receivers (e.g. USNO)
Retrieval Products From WRF Model

\[ N = a_1 \frac{P}{T} + a_2 \frac{P_W}{T^2} \]

Ducting criterion
\( \text{d}N/\text{dr} \leq -157 \text{ N-units per km} \)

Negligible occurrence above 4 km (Ao, Radio Sci, 2007)
Advantages Of Self-Calibration

• Systematic error cancellation
Instrumentation: Measuring Phase

Analog Electronics

- Radio Frequency Downconverter
- Osc
- Analog-to-digital conversion

Digital Electronics

- Phase model
- Range model
- Lag_{-1}, Lag_{0}, Lag_{+1}

Digital Signal Processor

Poor clock is acceptable (e.g. CHAMP clock is compromised)
Stability required over times ~50 msec (differential light times)
Research Issues

• Ionospheric residual at high altitudes
  – Imperfect cancellation from dual frequency
  – In situ mesosphere residual
  – Improve algorithm and characterization

• Multipath
  – Proper design
  – Monitor in-situ

• Antenna phase center variation
  – Monitor in-situ

Retrieval systems must be carefully analyzed and vetted by the community
Results

• Compare collocated soundings from different RO satellites
• CHAMP-SAC-C
• COSMIC/FORMOSAT-3 six satellite
• No bias (no drift) is confirmed
• Does not directly assess all possible sources of systematic error
Coincident Soundings From CHAMP and SAC-C

Coincident Observations Within 1/2 hour 100-300 km
Jul ‘01-Mar’03 N = 212


Careful accounting for decorrelation with distance

Differences: Median and standard deviation versus separation
Soundings From COSMIC – JPL

COSMIC3 - COSMIC2

Window:
30 km
10 minutes
June 4-16, ’06
224 pairs

Inter-quartile Range
Contains central 50% of differences

Median

ds < 30 km, dt < 10 min (June 4-16, 2006, cosmic3–cosmic2, 224 pairs)
UCAR COSMIC Results

FM3-FM4 (2006.111-300)

Number of pairs

< 0.2 % between 10 and 20 km

Difference (%) Refractivity

MSL Altitude (km)
Other Results

• RO Trends study: analysis of inter-center differences in monthly mean refractivities
  – JPL, UCAR, GFZ, Wegener Center (Austria)
  – CHAMP 2002-2007
  – 8-25 km altitude
  – Independent implementations
  – Differing geodetic software, orbit determination
  – Varying quality control criteria

• Trends determined much better than absolute differences
  – Different center retrievals have small but fixed offsets that do not vary in time
RO Trends: Four Processing Centers Compared

JPL, UCAR, GFZ, Wegener Center

Deseasonalized fractional refractivity anomalies
monthly mean climatologies (profile set not common)

CHAMP 2002-2007

Uncertainty of the trend for fractional refractivity anomalies among centers is within ±0.04%/5 yrs globally.
Summary

• Radio occultation is a geodetic technique for measuring climate trends
  – Physics of the measurement is highly advantageous
• Self-calibrating time delay measurements yield high quality SI-traceable accuracy
  – Accuracy implies stability
  – Negligible inter-satellite biases

  “Climate index tied to atomic clock standards”

• CLARREO provides data we urgently need for the long term climate record
• Research is ongoing to fully quantify all sources of systematic error that do not completely difference out