A SURVEY OF SOME SYSTEMATIC ERRORS IN IGS PRODUCTS

- Clock jumps at day boundaries & near-field multipath
- Position time series show N * 1.04 cpy harmonics
- N/S distortions in IGS frames
- Earth rotation parameters smoothed & filtered
- Spurious tidal lines in EOPs
- Orbit discontinuities have fortnightly variations

Jim Ray, NOAA/National Geodetic Survey

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Context

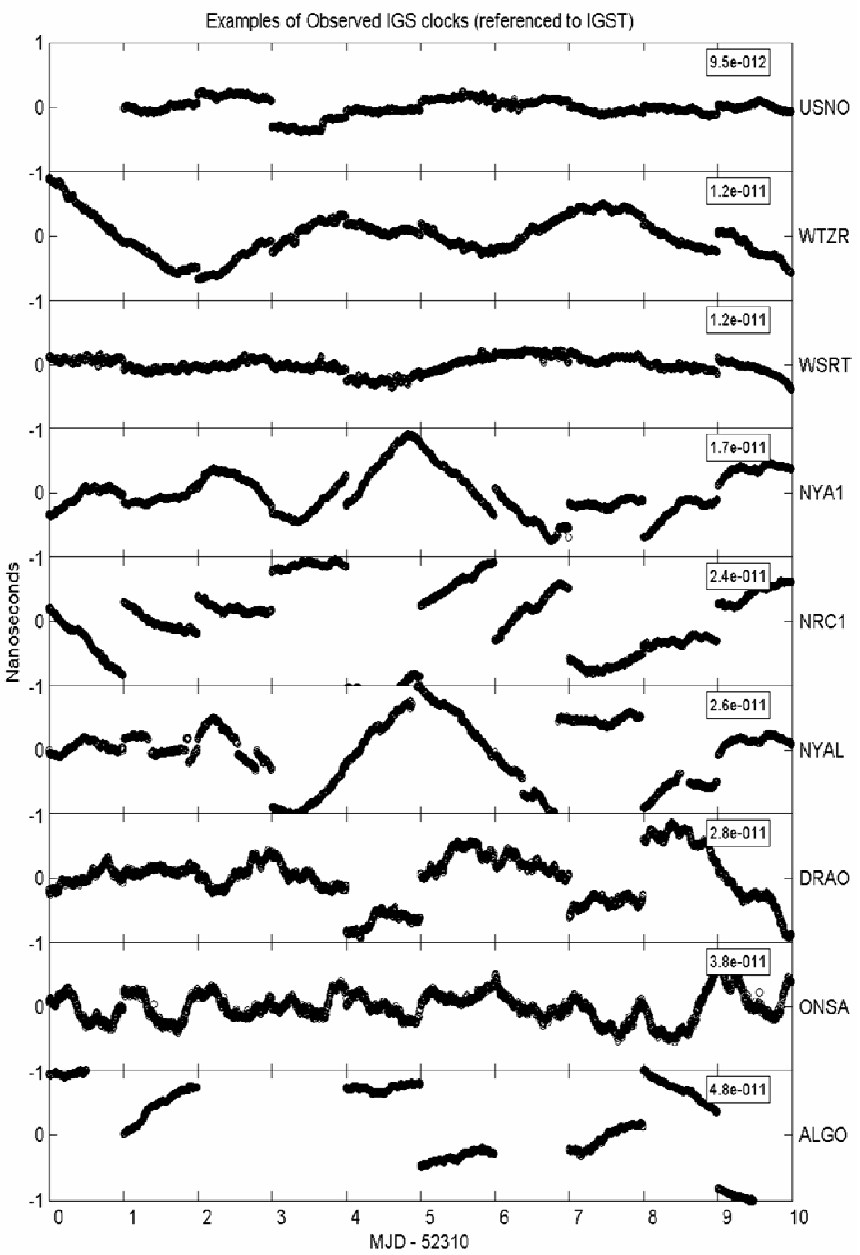
- **GPS errors are propagated formally but true data noise is unknown**
  - **highly site-dependent & not white noise**
  - **e.g., variances of AC frame solutions differ by > x 100**
    - **dealt with by empirical rescaling of covariance matrix**

- **Evidence for systematic effects in IGS product covariances is well known**
  - **e.g., user velocity errors are routinely inflated to account for temporal correlation of position errors**
    - **but methods are purely empirical**

- **Objective: Survey systematic errors in some IGS product *values***
  - **underlying causes mostly unknown or not confirmed**

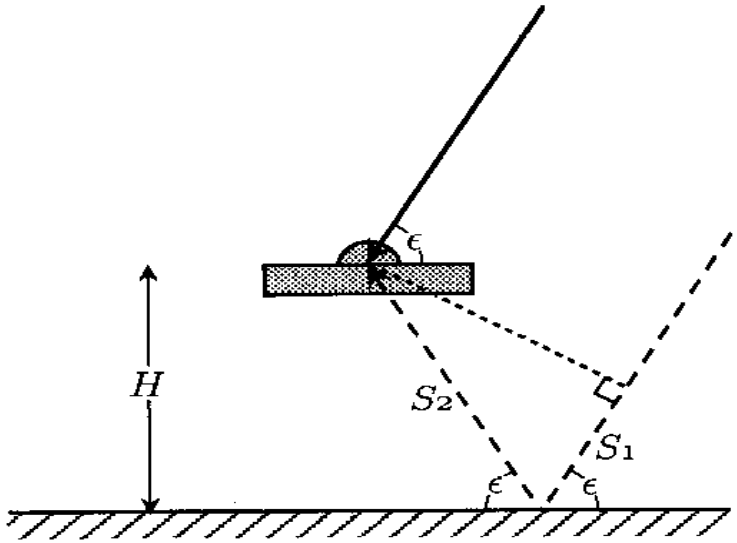
1) Day-boundary Clock Jumps

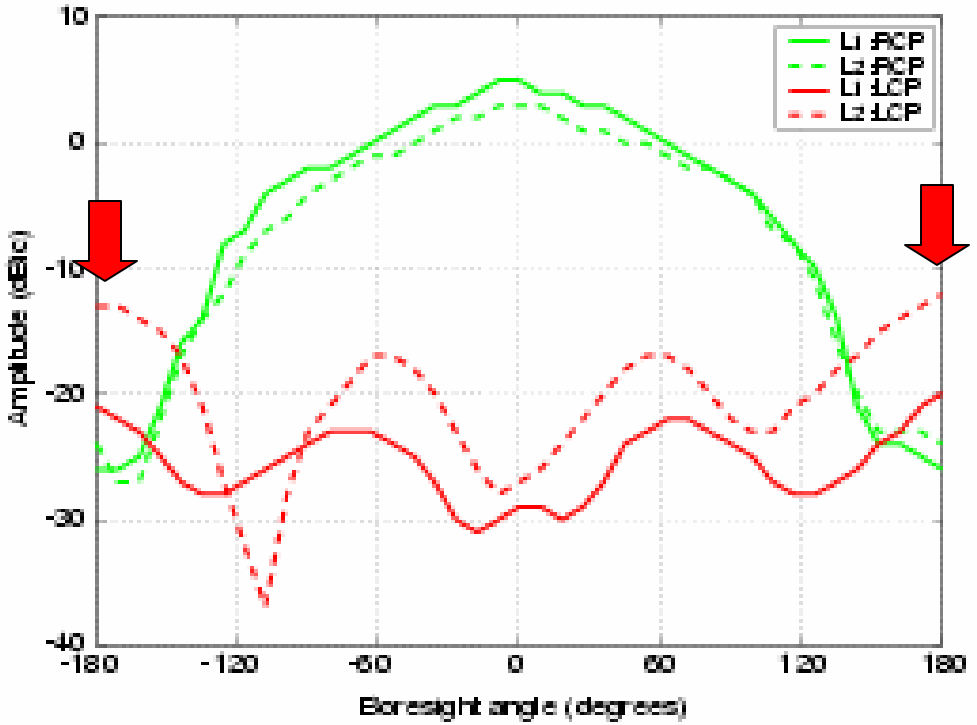
- clock bias accuracy is based on mean of code data per arc
- for 24-hr arc with code σ = 1 m, clock accuracy should be ~120 ps
- can study local code biases via clock jumps at day boundaries (H-maser stations only)
- **observed clock jumps vary hugely among stations:**
  110 ps to >1500 ps
- presumably caused mainly by local code multipath conditions, ***esp. in near-field of antenna***



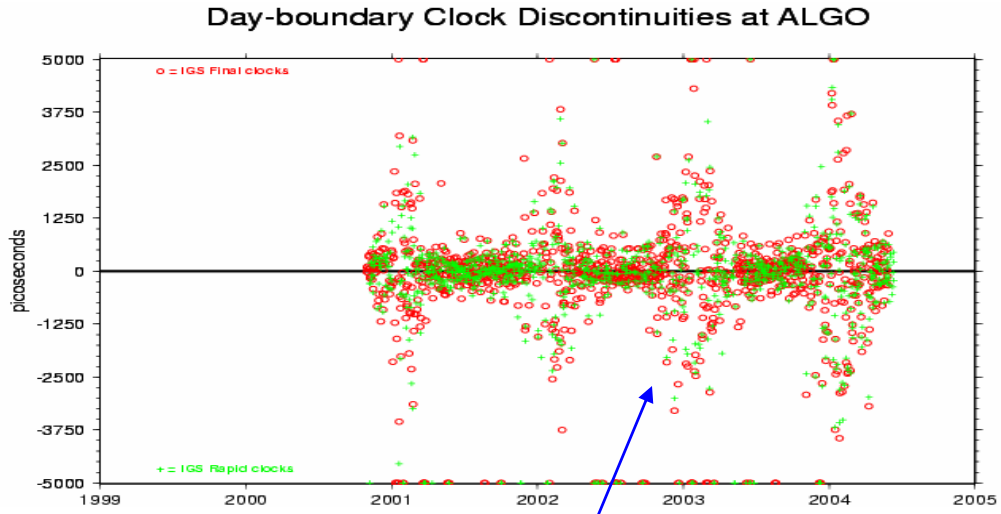
Near-field Multipath Mechanism

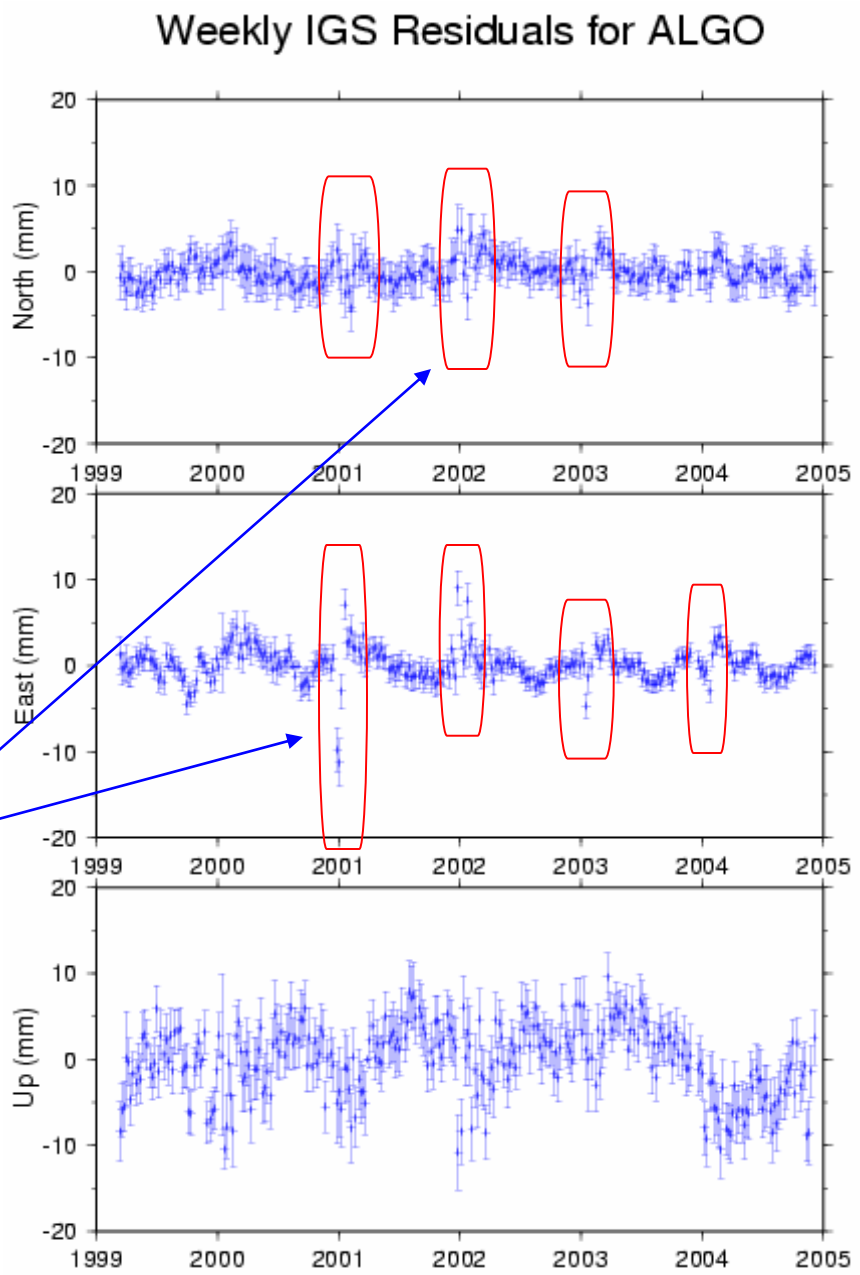
- expect largest & longest-period MP errors when height H of antenna is small [Elósegui et al., 1995]
- may have special problems when H is near multiples of λ/4
- reflected RCP GPS signals enter from behind as LCP
- choke-ring design esp sensitive to L2 reflections from below [Byun et al. 2002]
- most IGS RF antennas mounted over flat surfaces!





Correlated Clock & Position Effects: ALGO





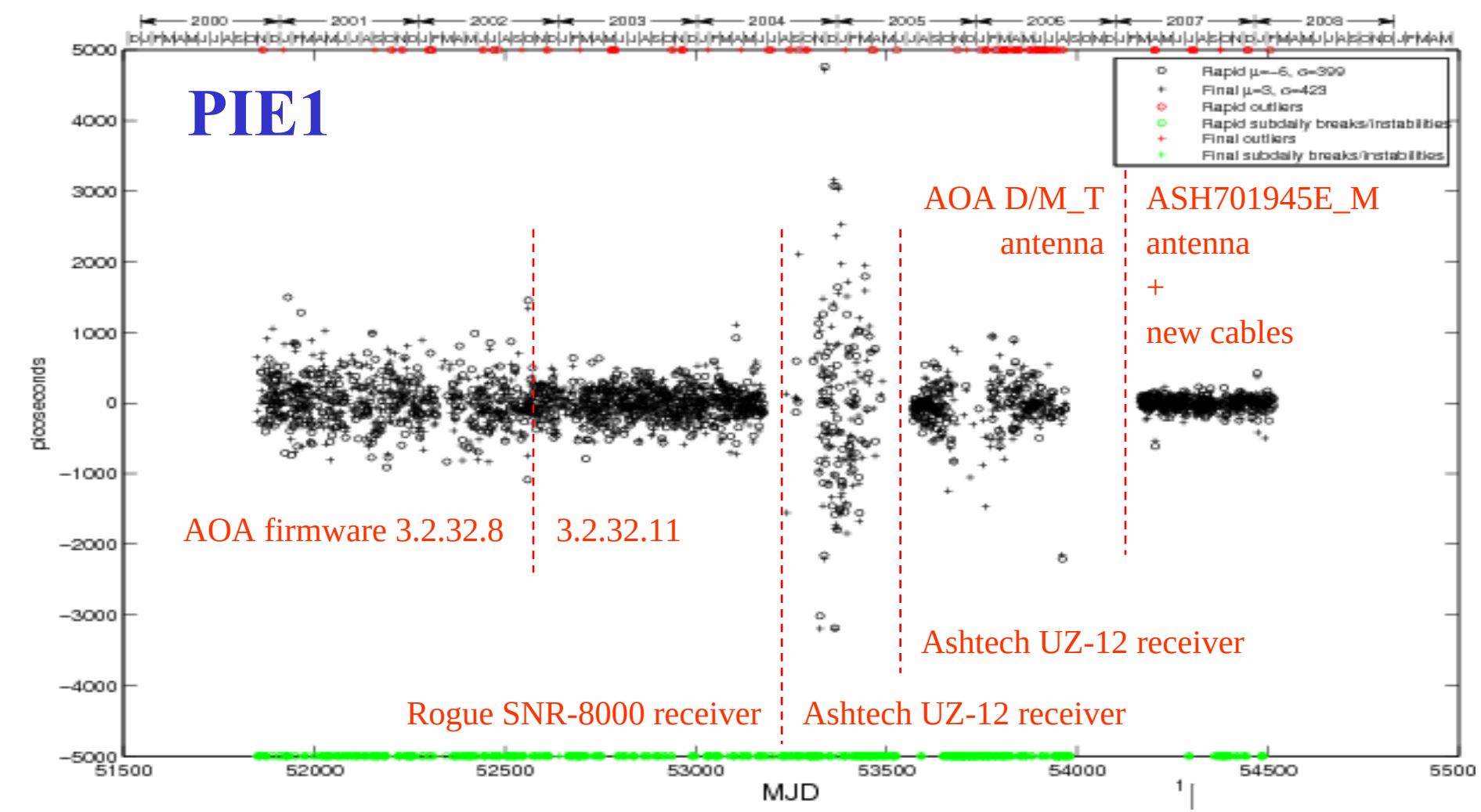
- **ALGO day-boundary clock jumps increase in winters**
- **every winter ALGO also has large position anomalies**
  - **IGS deletes outliers >5 σ**
- **implies common near-field multipath effect is likely (phase & code)**

Probably better to mount antennas away from close reflecting surfaces!

worse

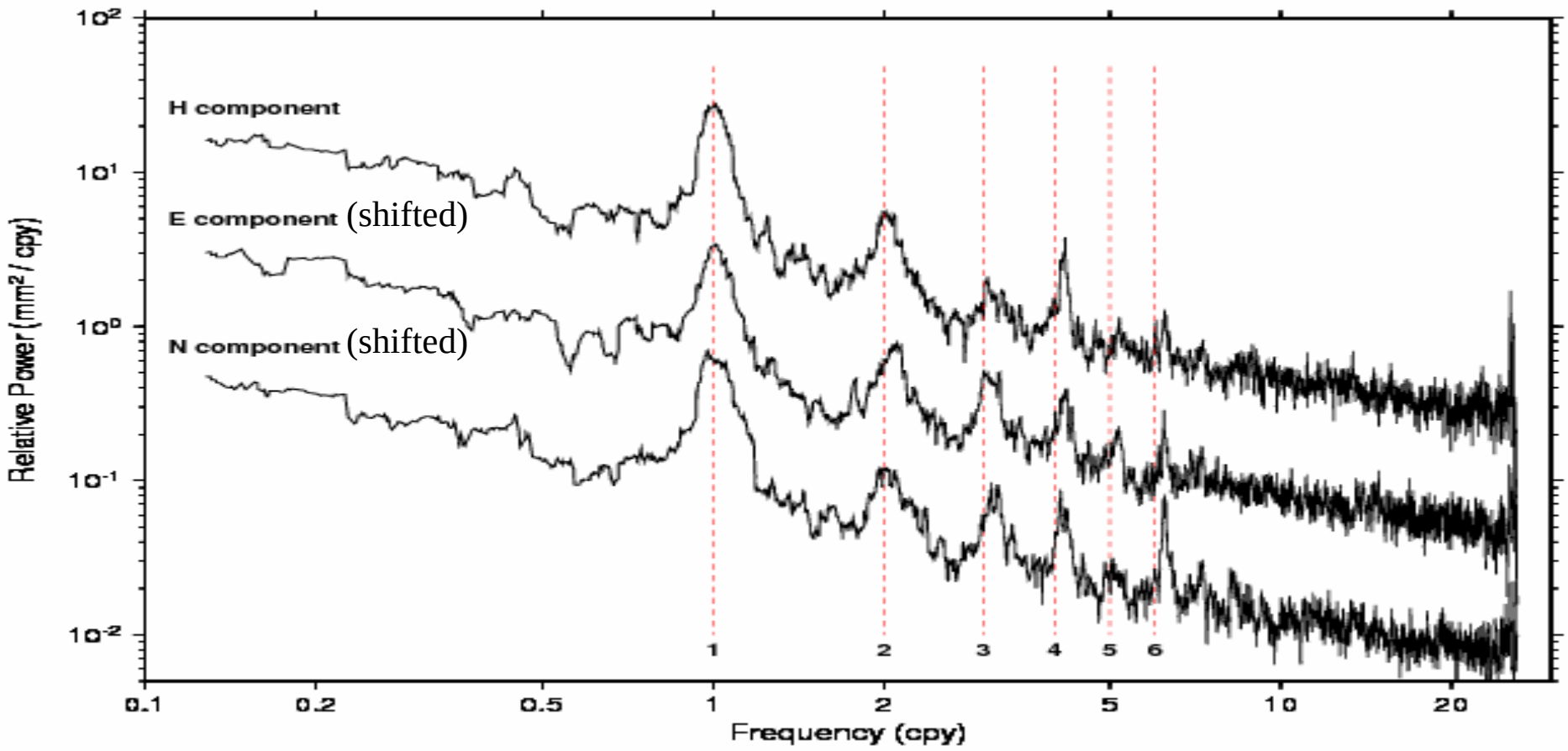
better

Other Hardware Choices Also Important



- **receiver health, firmware, antenna model, & cables also affect day-boundary clock jumps**

2) Stacked/Smoothed Spectra of Site Residuals



- for 167 IGS sites with >200 weekly points in 1996.0 – 2006.0
- large annual + semi-annual variations
- plus harmonics in all components at N * (1.040 ± 0.008) cpy
- flicker noise spectra down to periods of ~few months

Position Harmonics Linked to GPS Year

- **1.040 ± 0.008 cpy fundamental does not match any expected alias or geophysical frequency**
  - **also not seen in VLBI, SLR, or fluid load spectra**

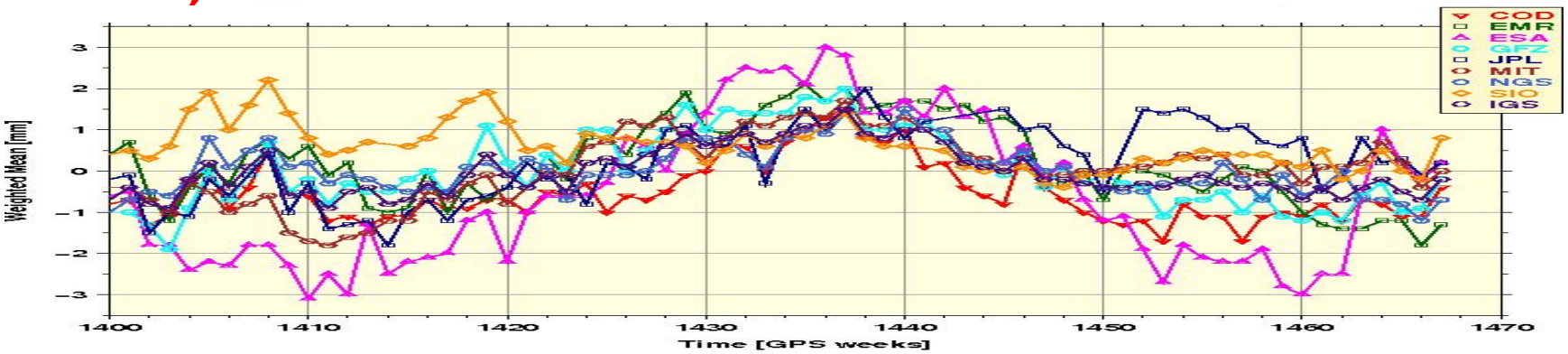
- **Closely matches GPS "draconitic" year**
  - **rotation period of Sun w.r.t. GPS nodes (viewed from Earth)**
  - **GPS nodal drift is -14.16° per year (due to Earth's oblateness)**
  - **period = 351.4 day or frequency = 1.039 cpy**

- **Two possible coupling mechanisms suggested:**
  1) **direct orbit modeling errors (e.g., related to eclipse periods & planes)**
  2) **alias of site position biases (e.g., near-field phase multipath) due to beating of 24-hr processing arc against 23.93-hr GPS repeat period**

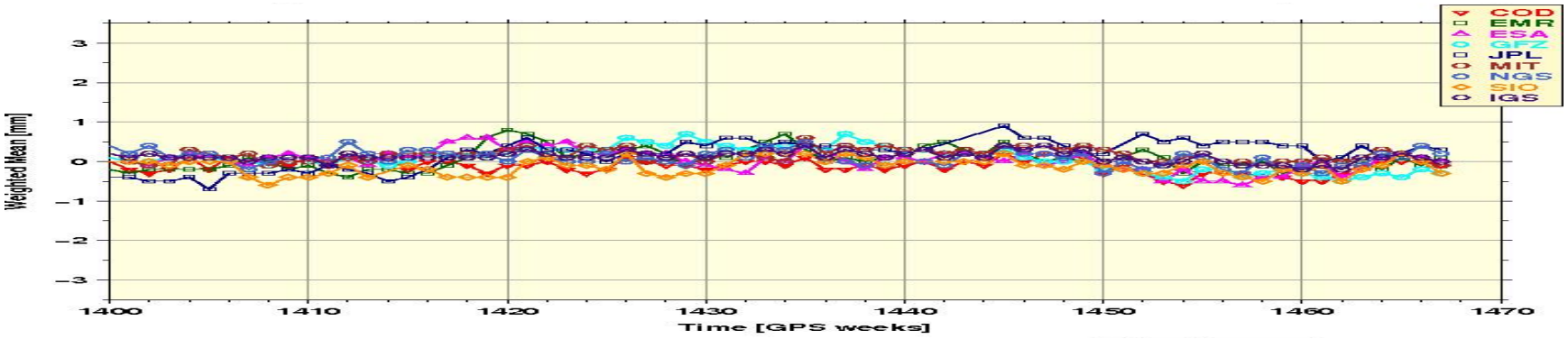
  - **useful distinguishing tests not yet made**

3) N/S Distortions of IGS Frames

N



E



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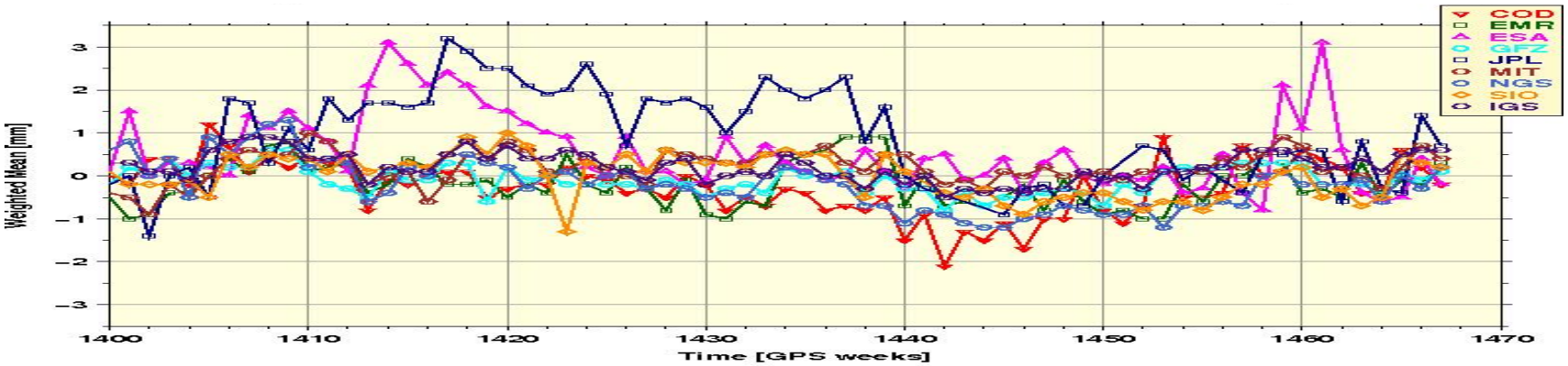
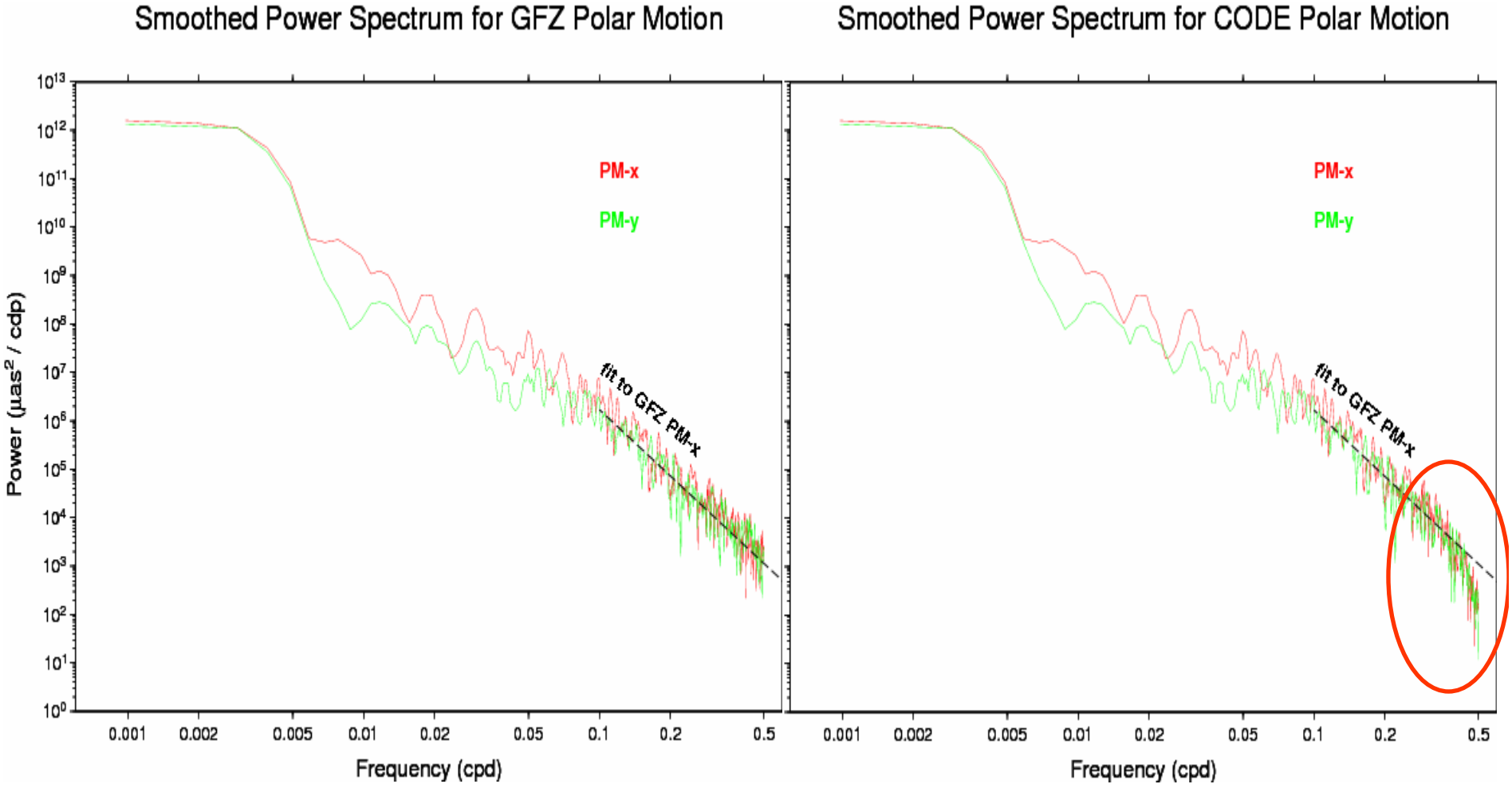


- **Weekly mean biases of IGS frames compared to long-term frame**

IGS Frame Distortions

- N/S mean component of IGS weekly frames shows largest annual variation
  - after weekly 7-parameter Helmert alignment
  - also largest dispersion among ACs in N/S direction
- Not likely to be caused by annual inter-hemisphere fluid load cycle
  - load signal should be largest in heights, not N/S
- Could possibly be related to along-track GPS orbit errors
  - but no mechanism identified
- Likelier explanation: possible neglected 2^{nd} order ionospheric effect

4) High-frequency Smoothing of EOPs

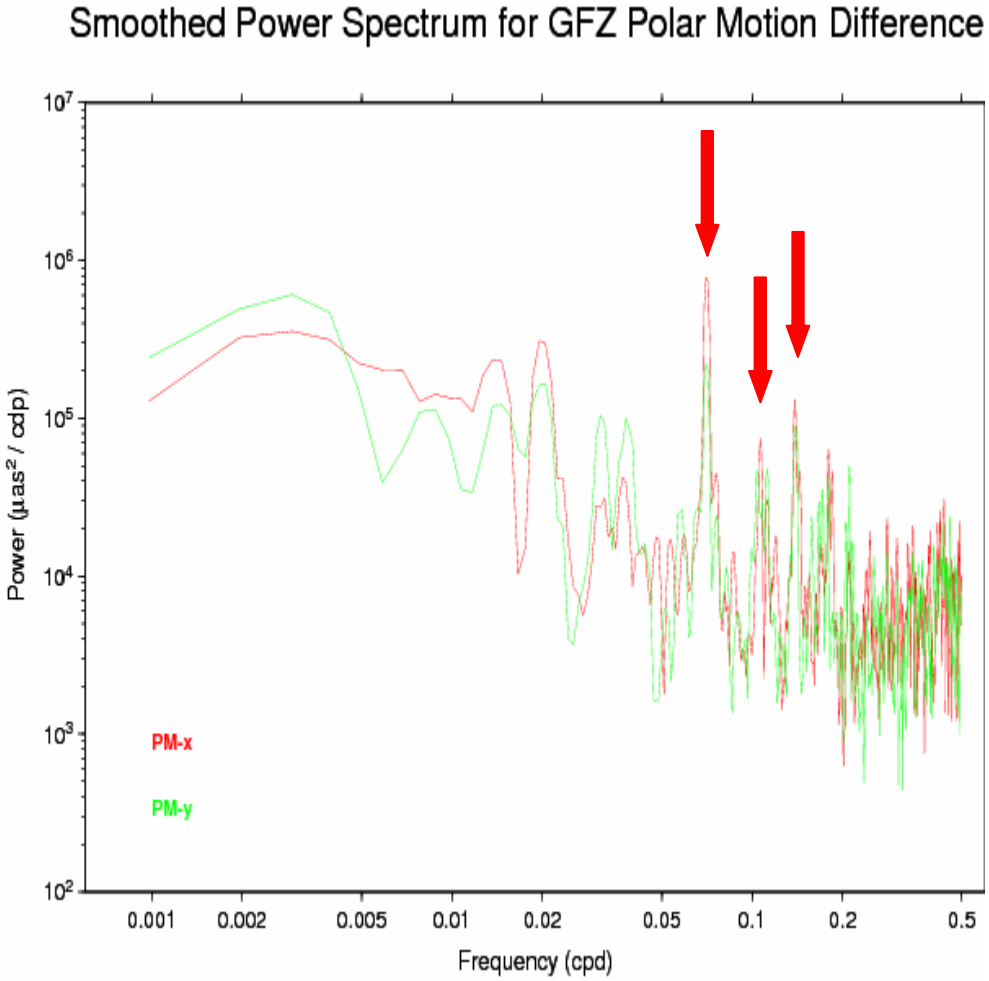


- **Day-boundary continuity constraint by some ACs smoothes & filters EOP estimates near Nyquist limit**

Filter/Smoother by Continuity Constraints

- **Some ACs estimate EOPs (& others) by *continuous* linear segments**
  - **attenuates power by factor 4 at Nyquist limit**
  - **smoothes estimates**
  - **filters certain phase components**
- **To avoid contaminating IGS combination, such EOP solutions rejected since January 2008 (wk 1460)**
  - **but effects on other parameters probably still present**
- **Past high-frequency studies should be reconsidered**
- **Can use GFZ polar motion to estimate background, non-tidal, sub-daily variance: 13.6 to 20.7 μas^2**

5) Aliased Tidal Peaks in EOP Discontinuities

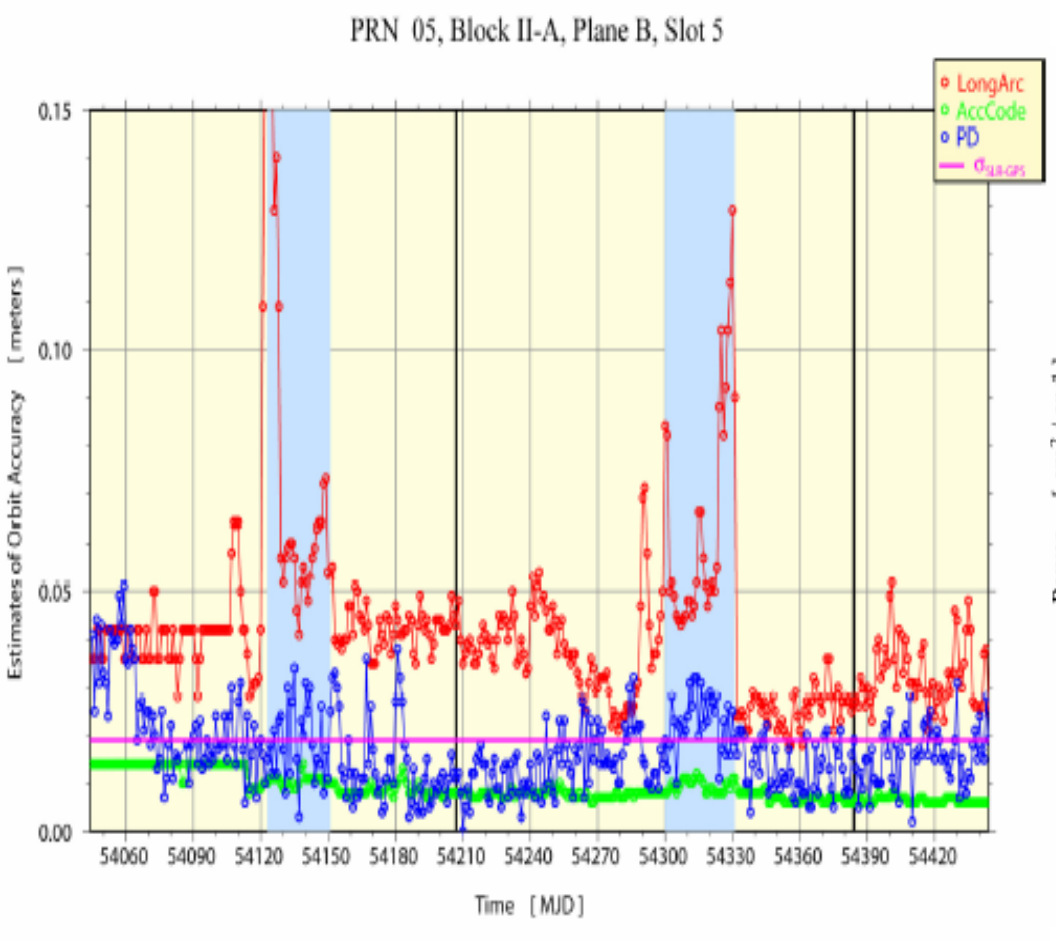


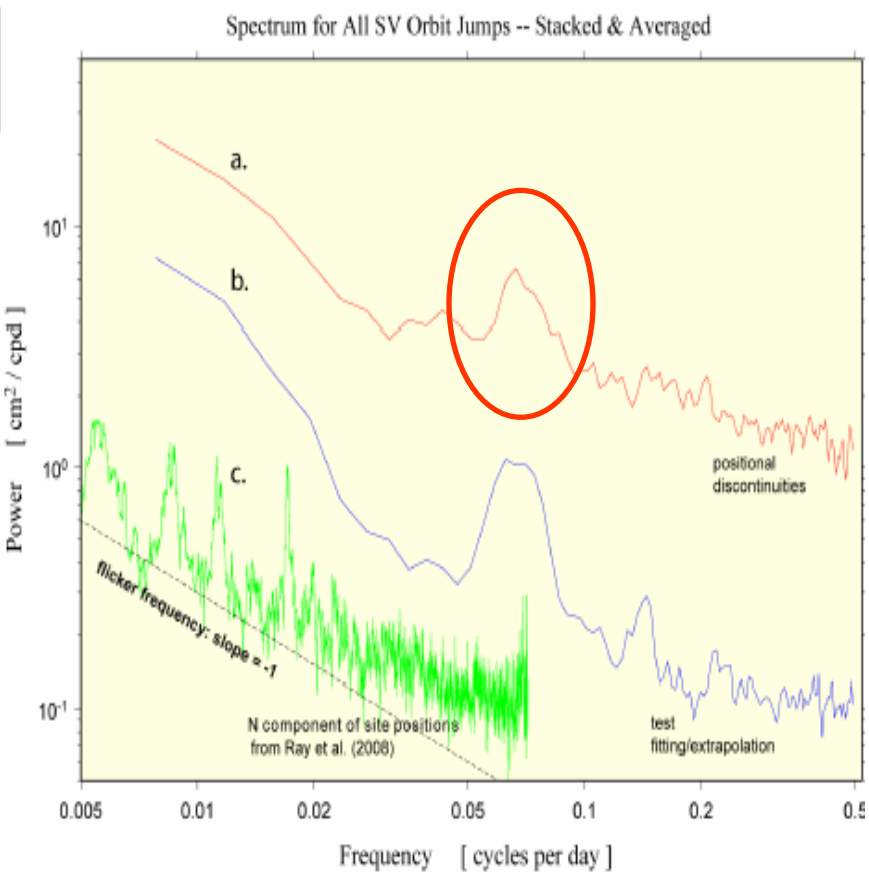
Peaks in PM Differences

AC	14 d	9 d	7 d
EMR PM-x	14.2	9.35	7.18
±	0.2	0.09	0.05
EMR PM-y	14.1	9.6 & 9.0	7.16
±	0.2	0.1	0.05
GFZ PM-x	14.2	9.4	7.21
±	0.2	0.1	0.05
GFZ PM-y	14.2	9.6 & 8.9	7.14
±	0.2	0.1	0.05
JPL PM-x	14.2	9.4	7.23
±	0.2	0.1	0.05
JPL PM-y	14.2	9.2	7.26
±	0.2	0.1	0.05

- **Spectra of polar motion day-boundary discontinuities show signatures of aliased O1, Q1, & N2 tides + unknown 7.2 d line**

6) Day-boundary Orbit Discontinuities





- **Orbit discontinuities between days show temporally correlated errors & broad fortnightly spectral peak**

Conclusions

- **Despite huge progress by IGS since 1994, numerous small systematic errors remain in products**

- **Applications to cutting-edge science must recognize limitations**
  - **need to focus on identifying, understanding, & mitigating errors**
  - **must renew basic GNSS research efforts, not just in geophysical applications**
  - **should avoid rush to premature science conclusions**

- **Improvements will probably require better station installations (to reduce near-field multipath) & analysis upgrades**
  - **more research into field configuration effects badly needed**
  - **need better leadership to popularize lessons learned**
  - **need better cooperation & coordination between analysts & network**