Status & Prospects for Combined GPS LOD & VLBI UT1 Measurements

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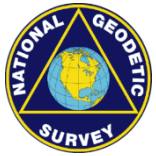

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- Kalman filter combination model (EGU 2008)
- VLBI data editing tests & optimal KF inputs (AGU 2008)
- spurious GPS LOD signals
- compare our KF to other combination series
- IGS Rapid & Ultra-rapid LOD results & UT1 prediction

Kalman Filter Combination Model

- UT1 is integral of –(LOD) + random walk process
- + Gauss-Markov process used to model GPS LOD biases wrt VLBI UT1 (assumed unbiased)
- + 14.19 d harmonic captures effect of mismodeled tides in GPS LOD biases *(Kouba, 2003)*
- Input data series:
  - **UT1 from 24-hr multi-baseline VLBI sessions** (GSFC solution "2008a")
  - if $\sigma <= 5$ μs, then $\sigma_{KF} = 2 * \sigma$
  - if $\sigma > 5$ μs, then reject data point (~17% of all 24-hr data)
  - **reject UT1 from all 1-hr single-baseline VLBI "Intensives" sessions**
  - due to systematic biases that cannot be compensated by rescaling of formal errors
  - **daily IGS Final LOD** (multi-AC combination "igs00p03.erp")
  - some bias corrections applied already by IGS using IERS Bulletin A
  - if $\sigma <= 9.25$ μs, then $\sigma_{KF} = 3.90$ μs
  - if $\sigma > 9.25$ μs, then $\sigma_{KF} = 3.90$ μs $* (\sigma/9.25)$
  - Correct all series for zonal tides before combination

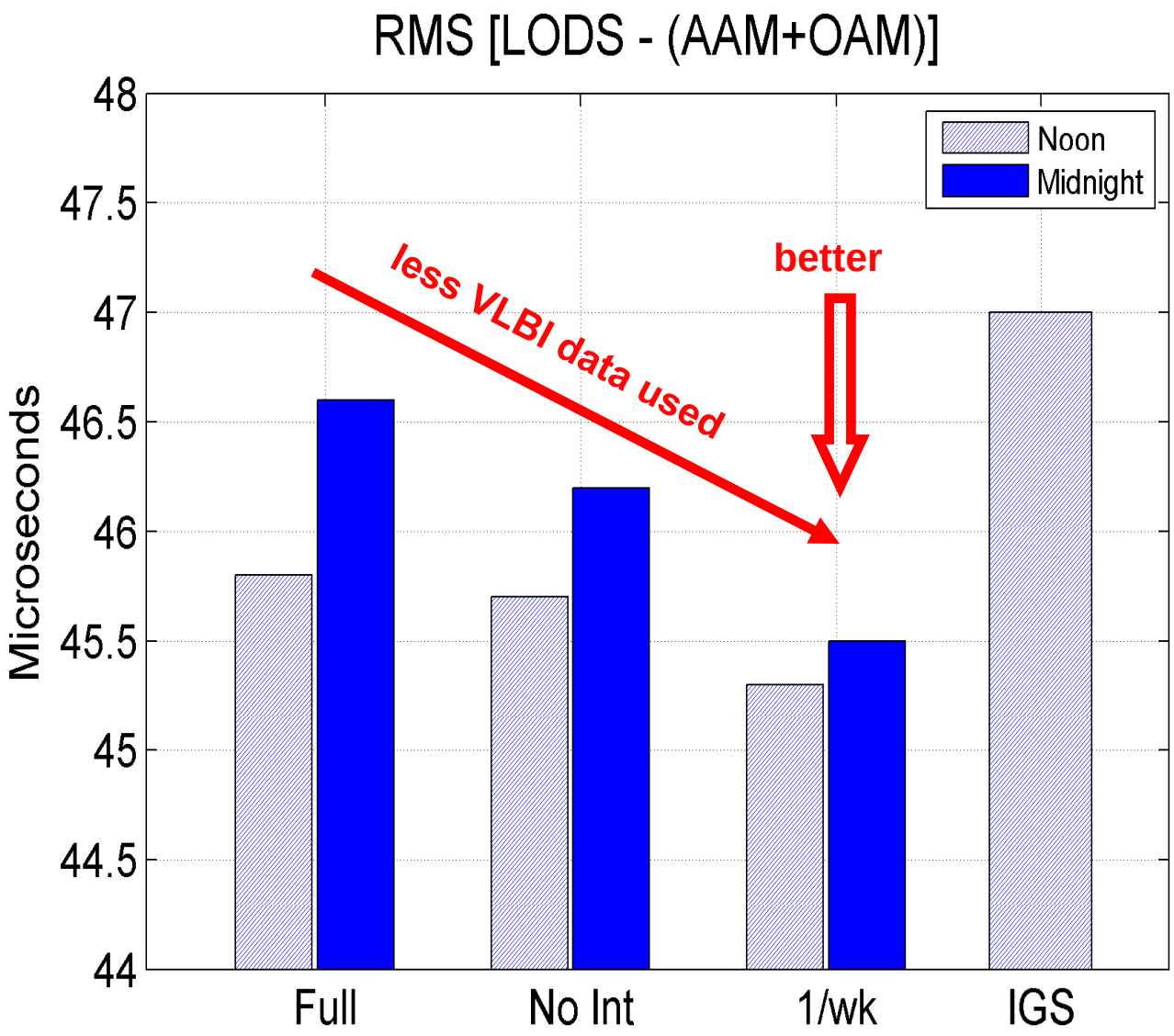
Tests of Edited VLBI UT1 Inputs

- Tests requested by U.S. NRC Committee on Geodetic Infrastructure
- Compare tests of reduced VLBI UT1 data with full VLBI UT1 & IGS LOD combination
  - examine changes in combined UT1/LOD values
  - examine changes in residuals & correlations with (AAM+OAM) excitations
  - Run #1 – **Control: UT1/LOD combination using all data**
    - all 24-hr multi-baseline VLBI UT1 data from NASA/GSFC
    - 1-hr single-baseline VLBI "Intensive" UT1 data from NASA/GSFC
    - daily combined IGS Final LOD series
    - all formal errors scaled by 2
  - Run #2 – **Test no Intensives**
    - all 24-hr multi-baseline VLBI UT1 data from NASA/GSFC
    - daily combined IGS Final LOD series
    - all formal errors scaled by 2
  - Run #3 – **Test only once-weekly VLBI**
    - weekly "R1" series of 24-hr multi-baseline VLBI UT1 from NASA/GSFC
    - daily combined IGS Final LOD series

    all formal errors scaled by 2
- Use same Kalman filter combination method for each test

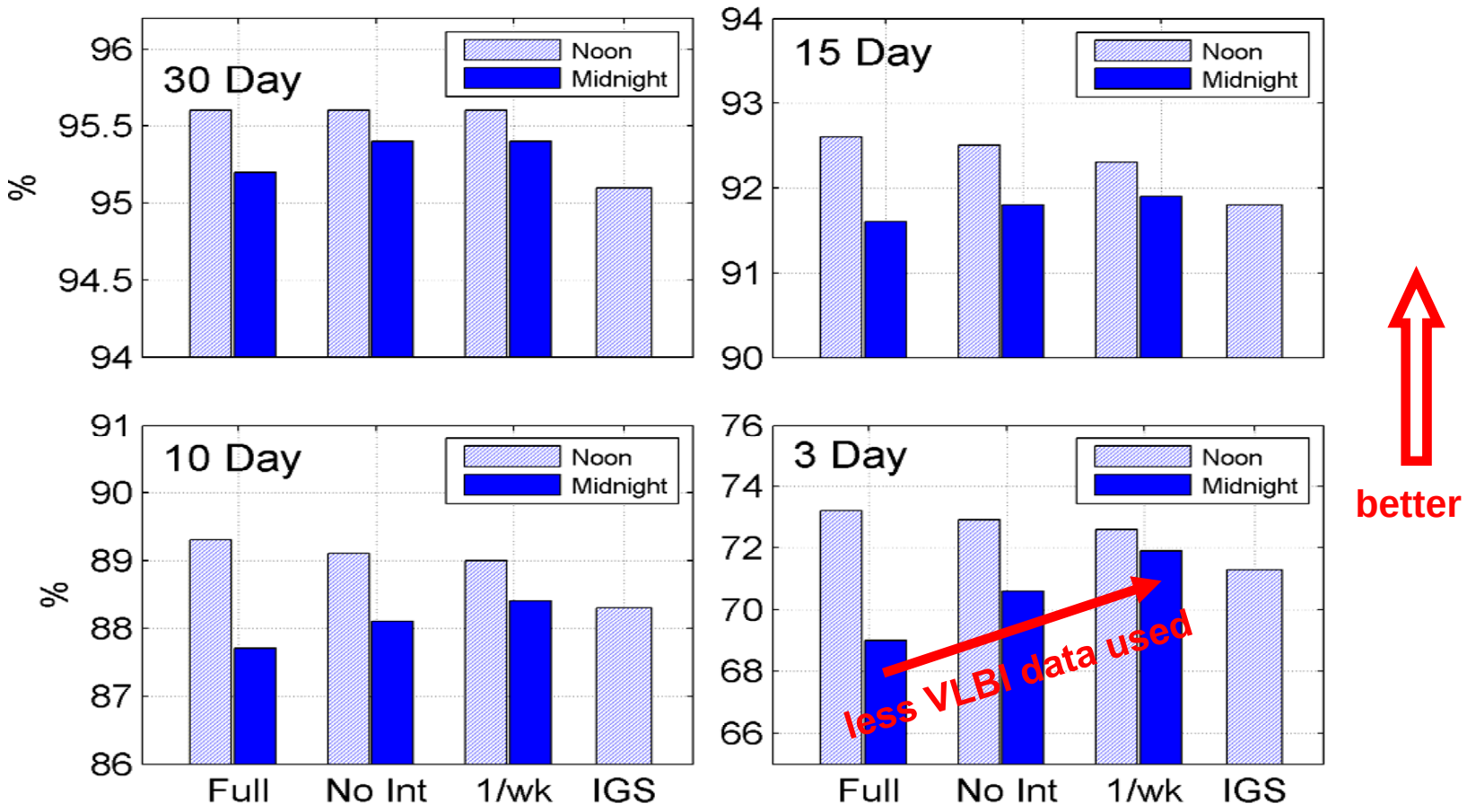
[LODS – (AAM+OAM)] RMS Residuals

- LOD test series (epochs)
  - full data (00:00,12:00)
  - no Intensive VLBI (00:00,12:00)
  - once-weekly VLBI (00:00,12:00)
  - IGS LOD only (12:00)
- compare with (AAM + OAM) over 8 Jan 2002 to 31 Mar 2006
- surprisingly, residuals decrease as more VLBI data excluded
- but using some VLBI data better than IGS alone
- implies excess UT1 noise in non-R1 VLBI sessions



LODS/(AAM+OAM) Correlation Coefficients

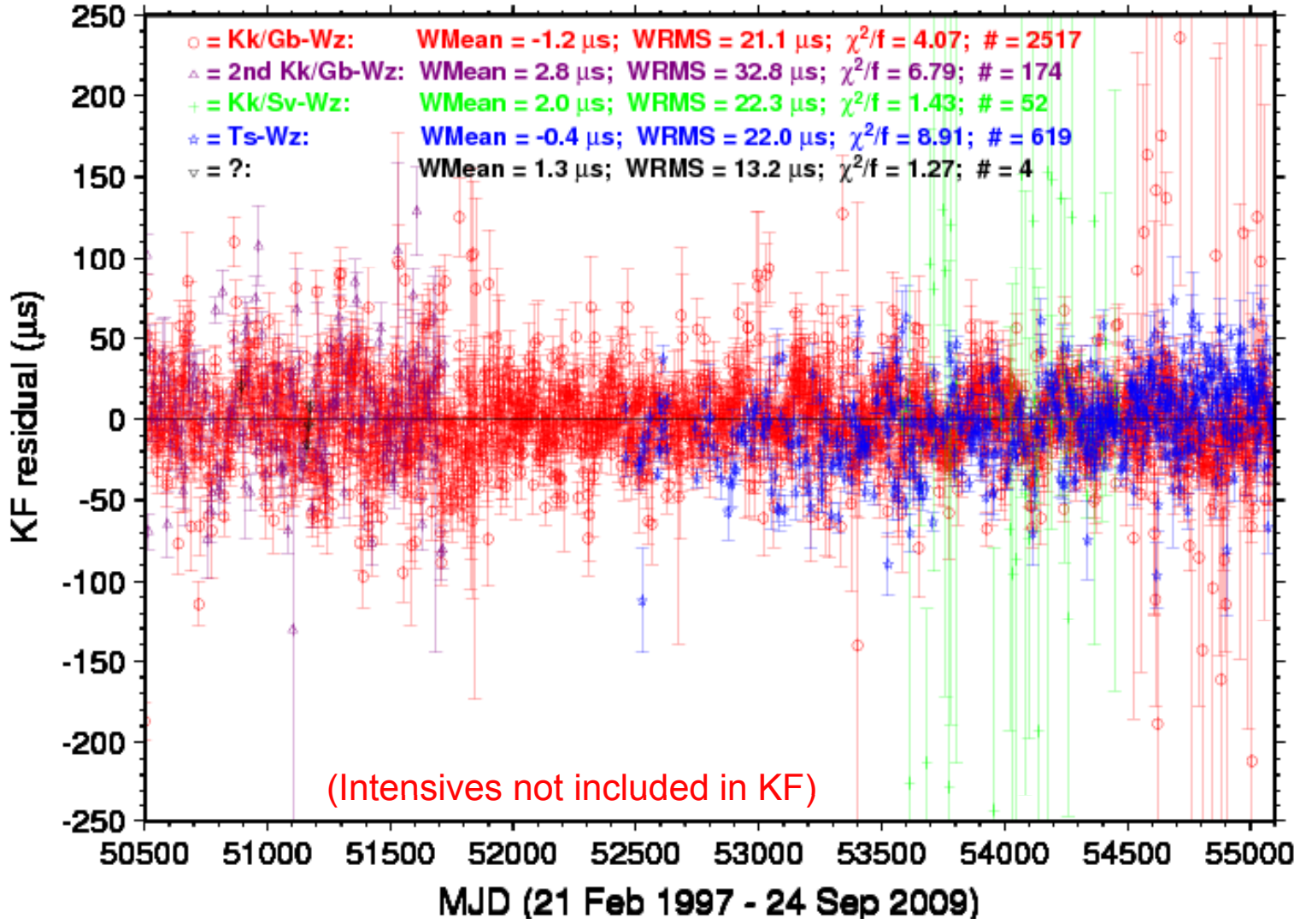
- computed over sliding windows from 3 d to 4.2 yr
  - correlation over full range = 99.2% for all series



- 12:00 correlations drop slightly as VLBI data rejected (IGS LODs at 12:00), but 00:00 correlations increase much more as VLBI data rejected

UT1 Residuals for VLBI Intensives

- significant baseline- & time-dependent systematic errors evident

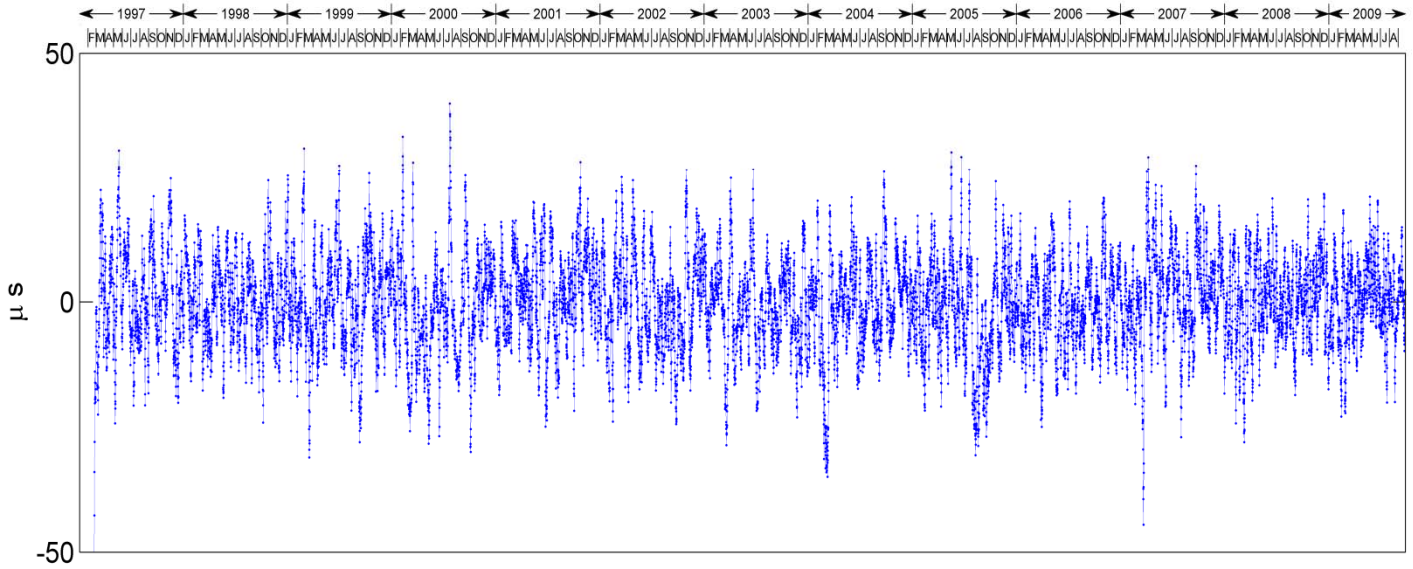


"Optimal" VLBI UT1 + GPS LOD Combination

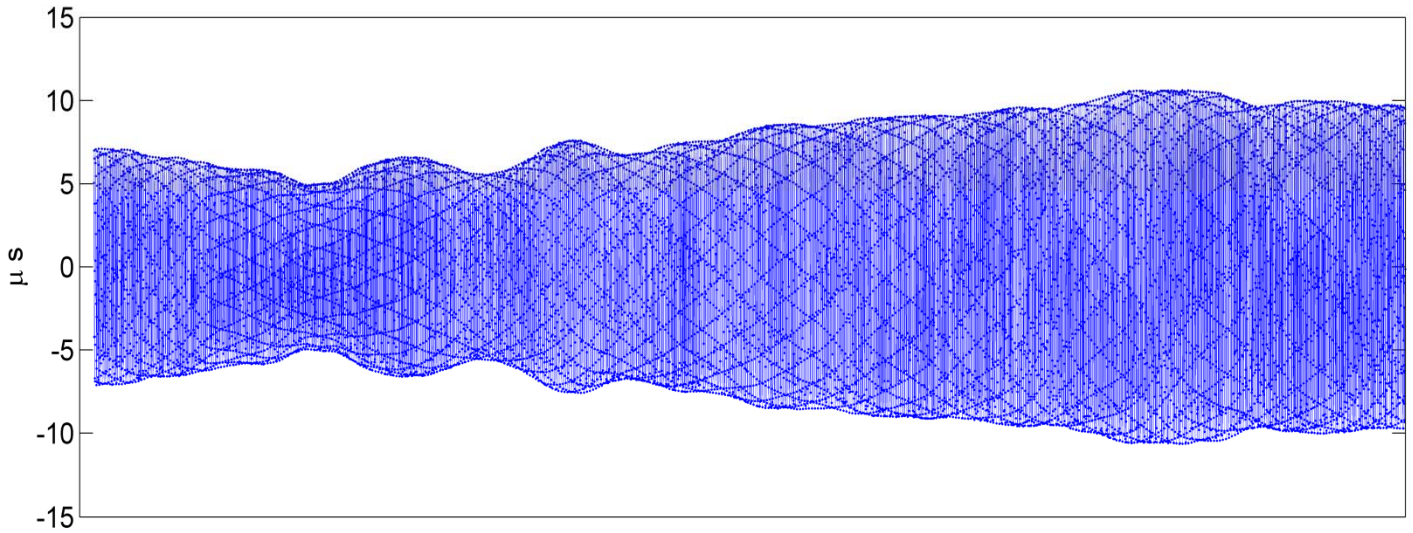
- further tests of VLBI data editing & reweighting tried
- average VLBI UT1 formal errors since 2002:
  - weekly R1 EOP sessions = 2.2 μs
  - weekly R4 EOP sessions = 2.8 μs
  - all other 24-hr sessions = 10.1 μs
    (max UT1 σ = 127.3 μs)
  - 1-hr Intensive sessions = 13.0 μs
- *best* overall agreement with AAM+OAM found using:
  - **reject all 1-hr Intensive UT1 data**
  - **for 24-hr VLBI UT1 – reject weak determinations:**
    - if σ <= 5 us, then $\sigma_{KF} = 2*\sigma$
    - if σ > 5 us, then reject data point (17% of all 24-hr data)
  - **for GPS LOD – increase weights** (mean LOD formal error = 9.25 μs):
    - if σ <= 9.25 us, then $\sigma_{KF} = 3.90$ us
    - if σ > 9.25 us, then $\sigma_{KF} = 3.90$ us * (σ/9.25)

Kalman Filter Estimates for LOD Biases

- **Gauss-Markov model estimates for GPS LOD biases**
  - peak-to-peak range = ± 40 μs
  - RMS = 9.35 μs



- **14.19-d periodic**
  - treated as GPS artifact
  - amplitude varies between 5 & 11 μs
  - phase varies linearly w/ time due to changing period

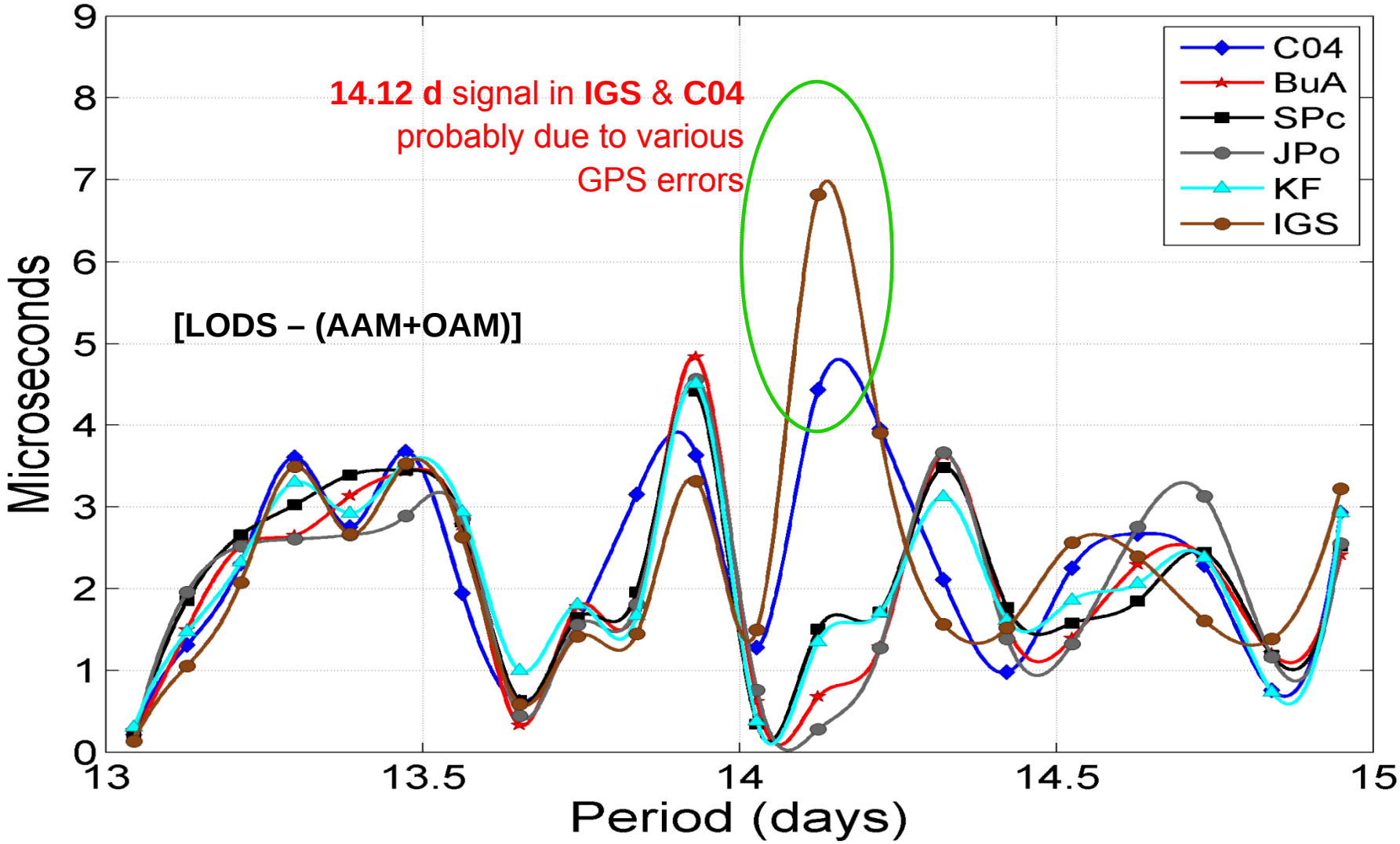


Closer Look at 3 Tidal Bands

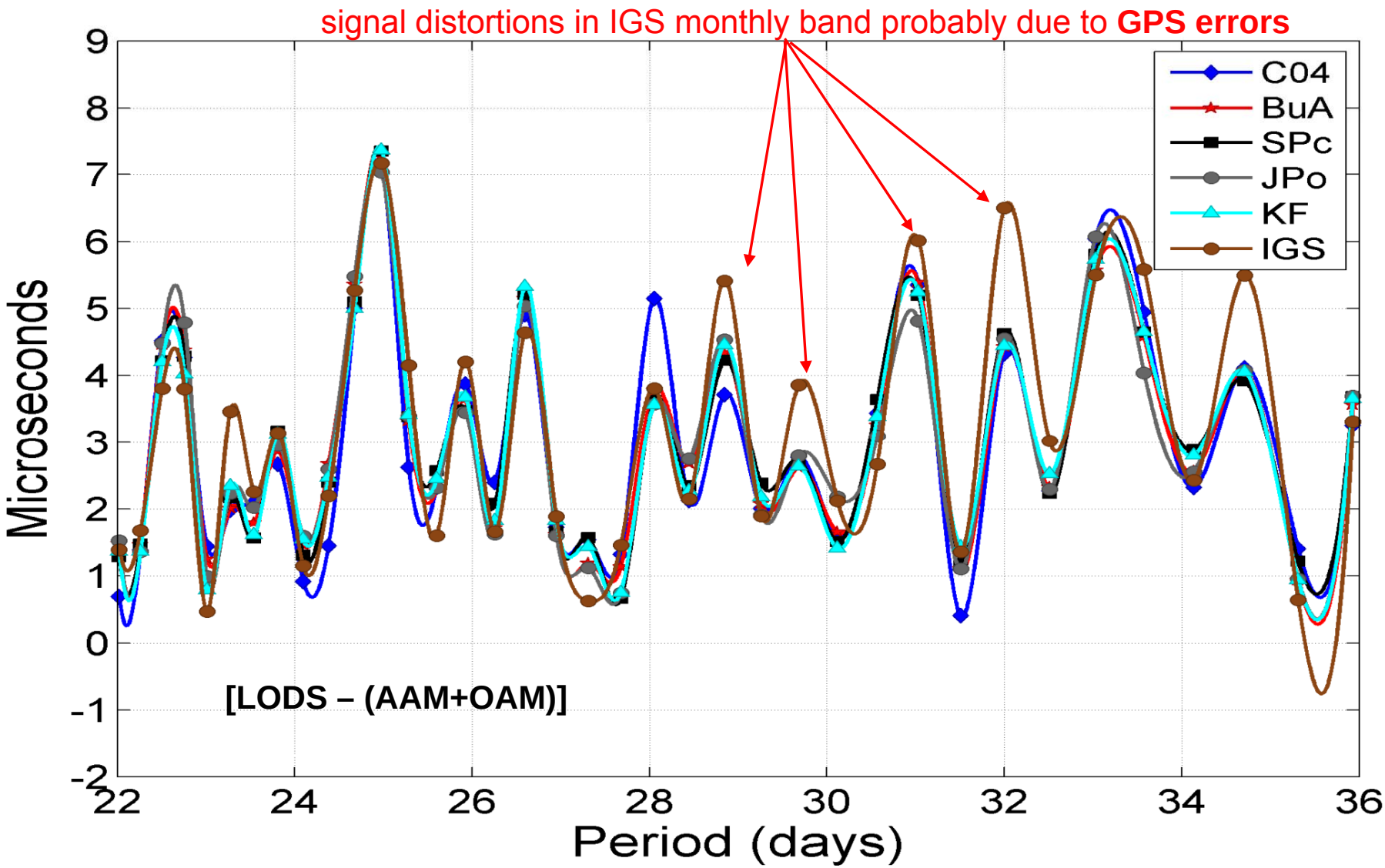
- fortnightly: evidence for spurious IGS LOD tidal errors
- monthly: probably more GPS errors
- 9 d: probably unmodeled ocean tidal effect

Fortnightly Band – Spurious IGS LOD Peak

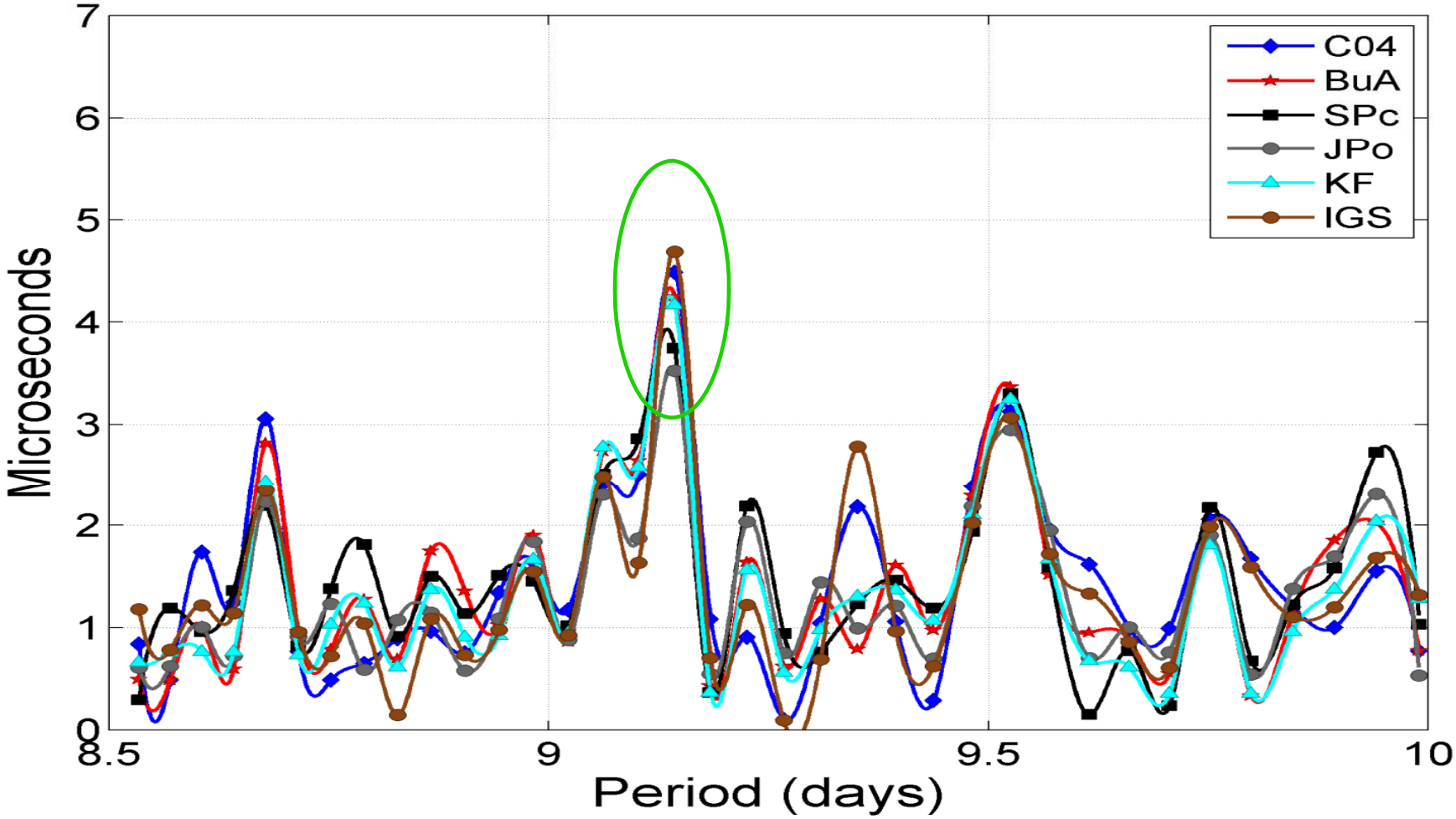
- combinations must model spurious fortnightly IGS signals !



Monthly Band – Probably GPS Errors



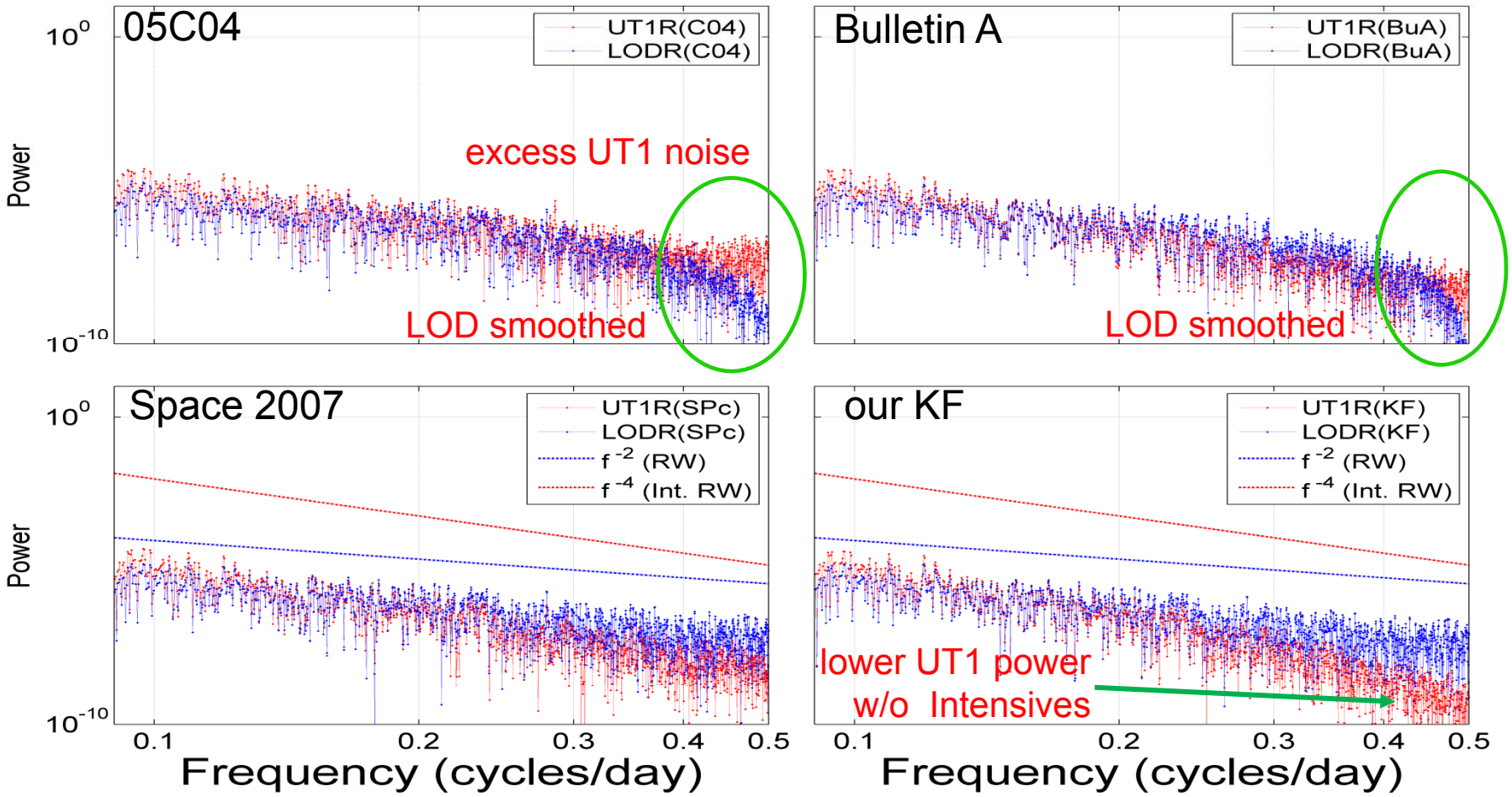
9-d Band – Unmodeled Geophysical Effect?



- small 9.14 d peak seen in all LODS series – likely caused by residual ocean tides
- needs further investigation – could be included in [LODS-(AAM+OAM)] fit

Compare UT1 & LOD Power Spectra

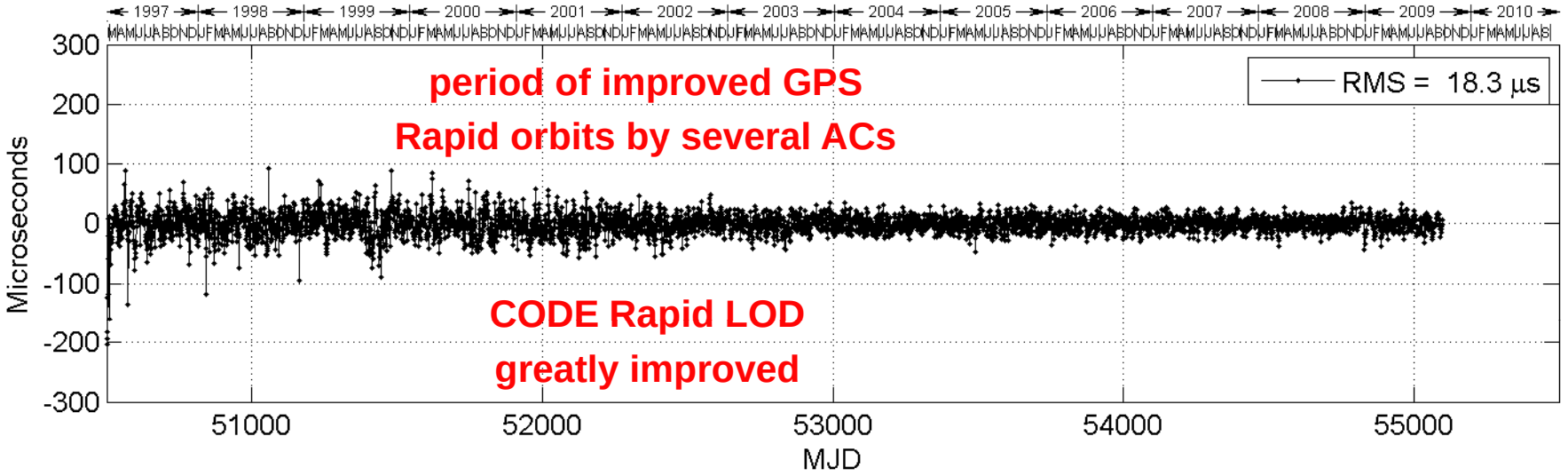
- seasonally detrended & tidally corrected
- IERS LOD series are smoothed; C04 has excess high-frequency UT1 noise

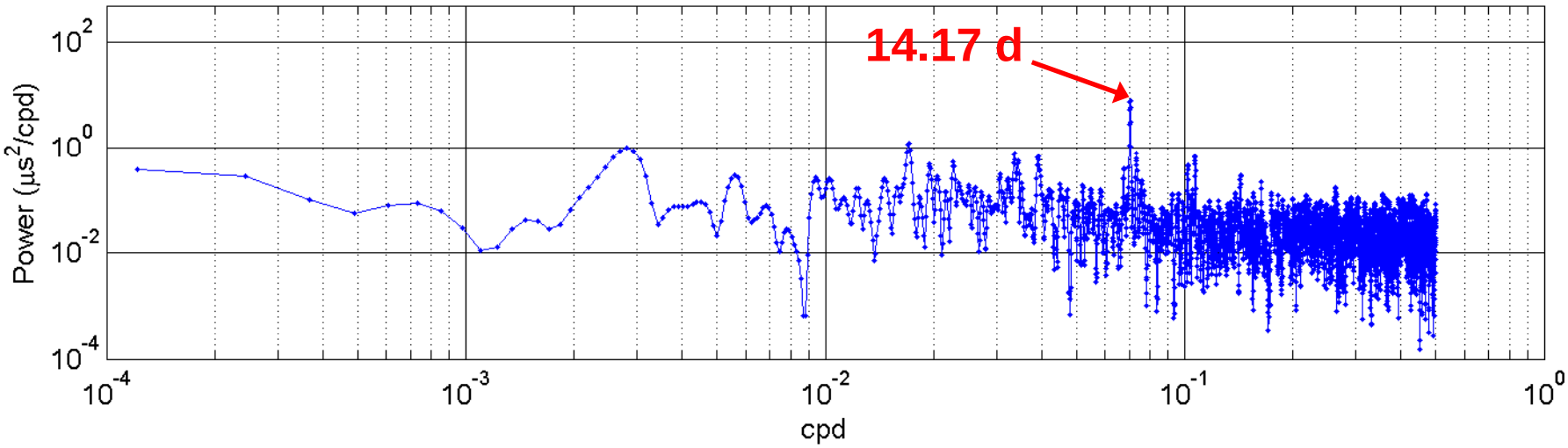


UT1/LOD KF Combination Conclusions

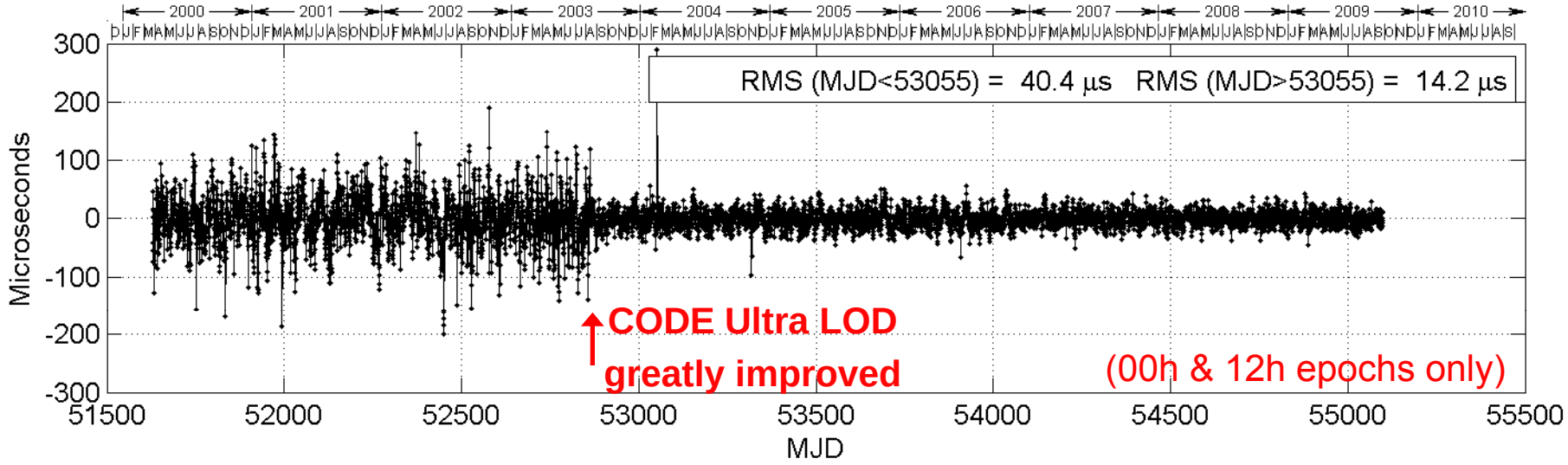
- IGS LOD series adds critical high-frequency information
  - but must handle time-correlated biases & spurious signals
- IERS 05C04 LOD correlates well with (AAM+OAM) – but is simply smoothed IGS LOD
  - so inherits spurious fortnightly signal from IGS LODs
  - UT1 & LOD values are not consistent
  - strong high-frequency smoothing for LODs & excess noise for UT1
- IERS Bulletin A LODs derived from UT1 values
  - sharp high-frequency smoothing for LODs due to differentiation of UT1 values
- SPACE 2007 performs very similarly as our KF
  - slightly more high-frequency UT1 power, probably due to using VLBI Intensives
- our KF UT1/LOD combination (with VLBI data editing) performs best by nearly all measures

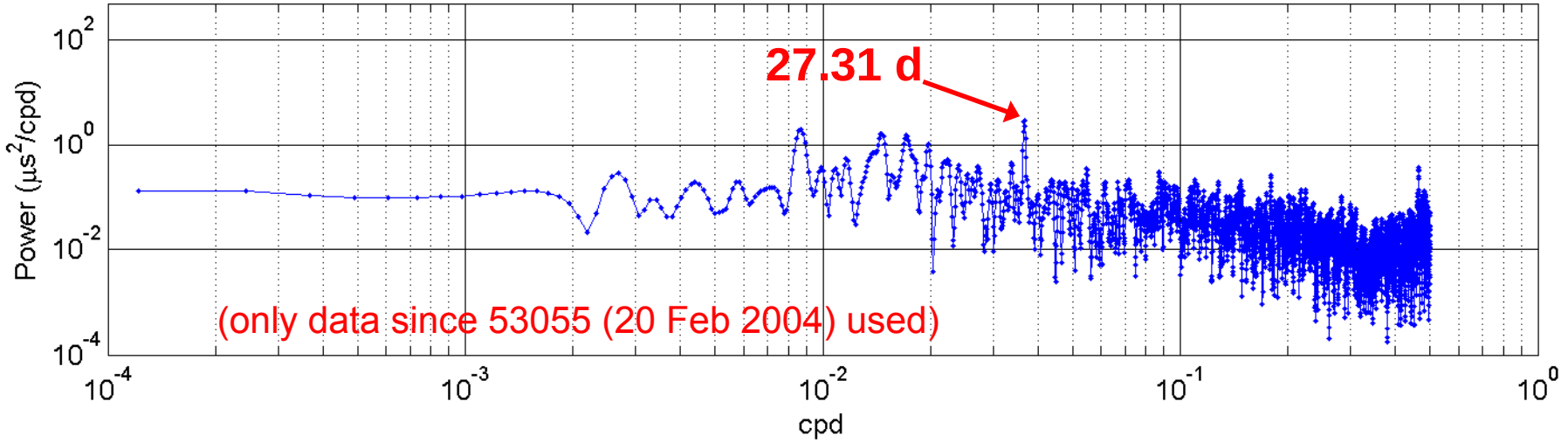
IGS Rapid LOD vs KF



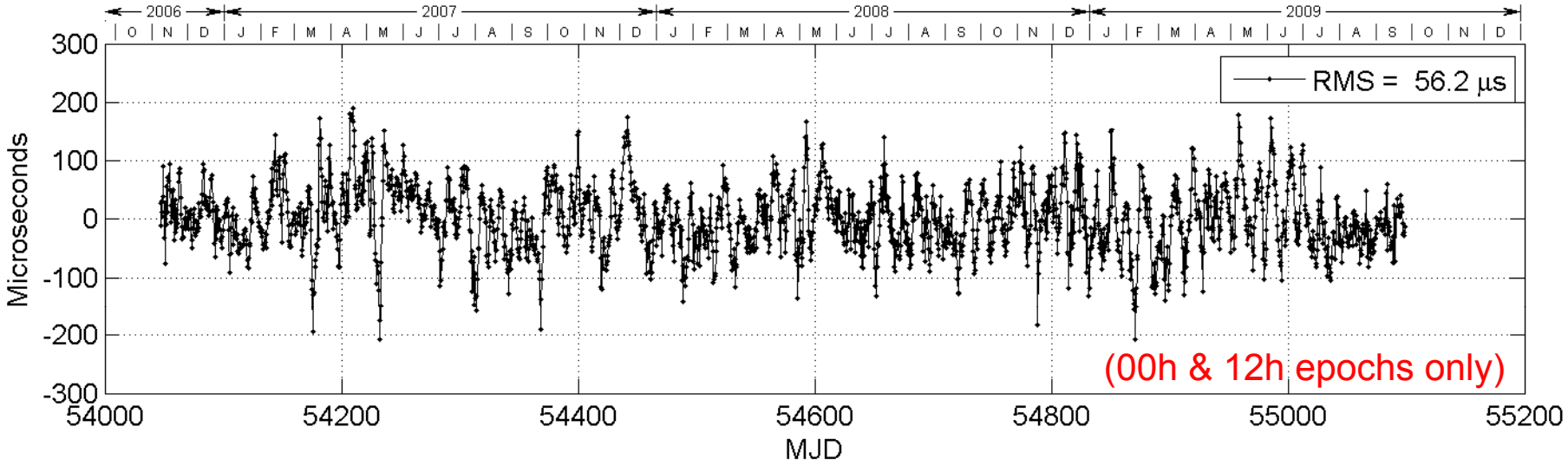


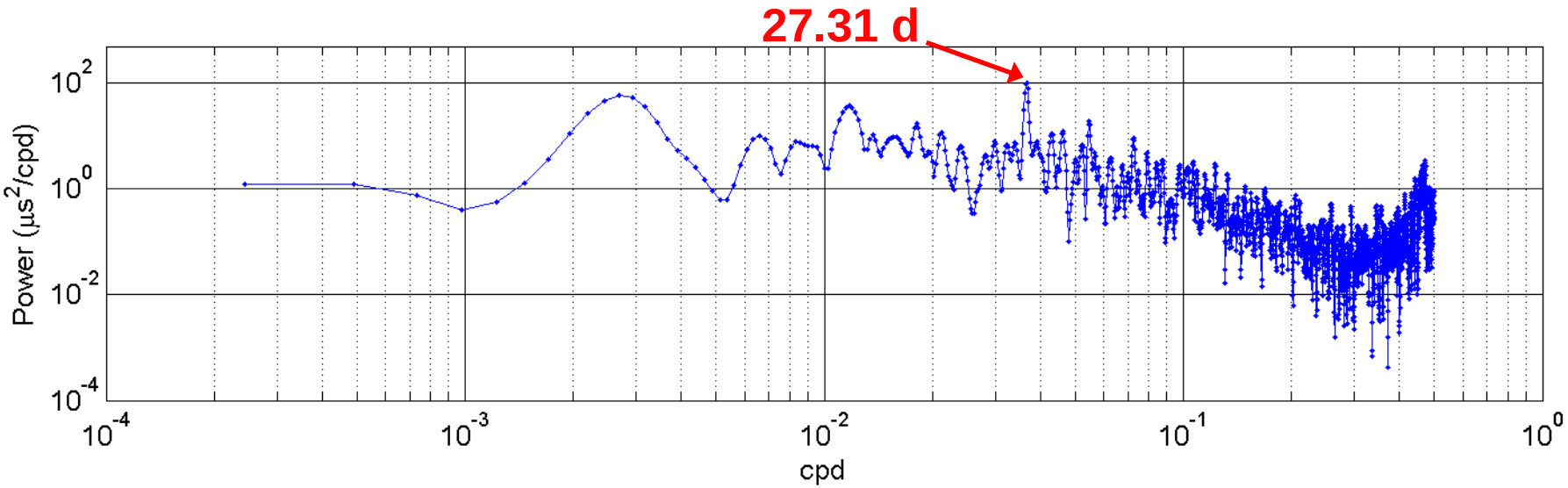
IGS Ultra-rapid *Observed* LOD vs KF





IGS Ultra-rapid *Predicted* LOD vs KF

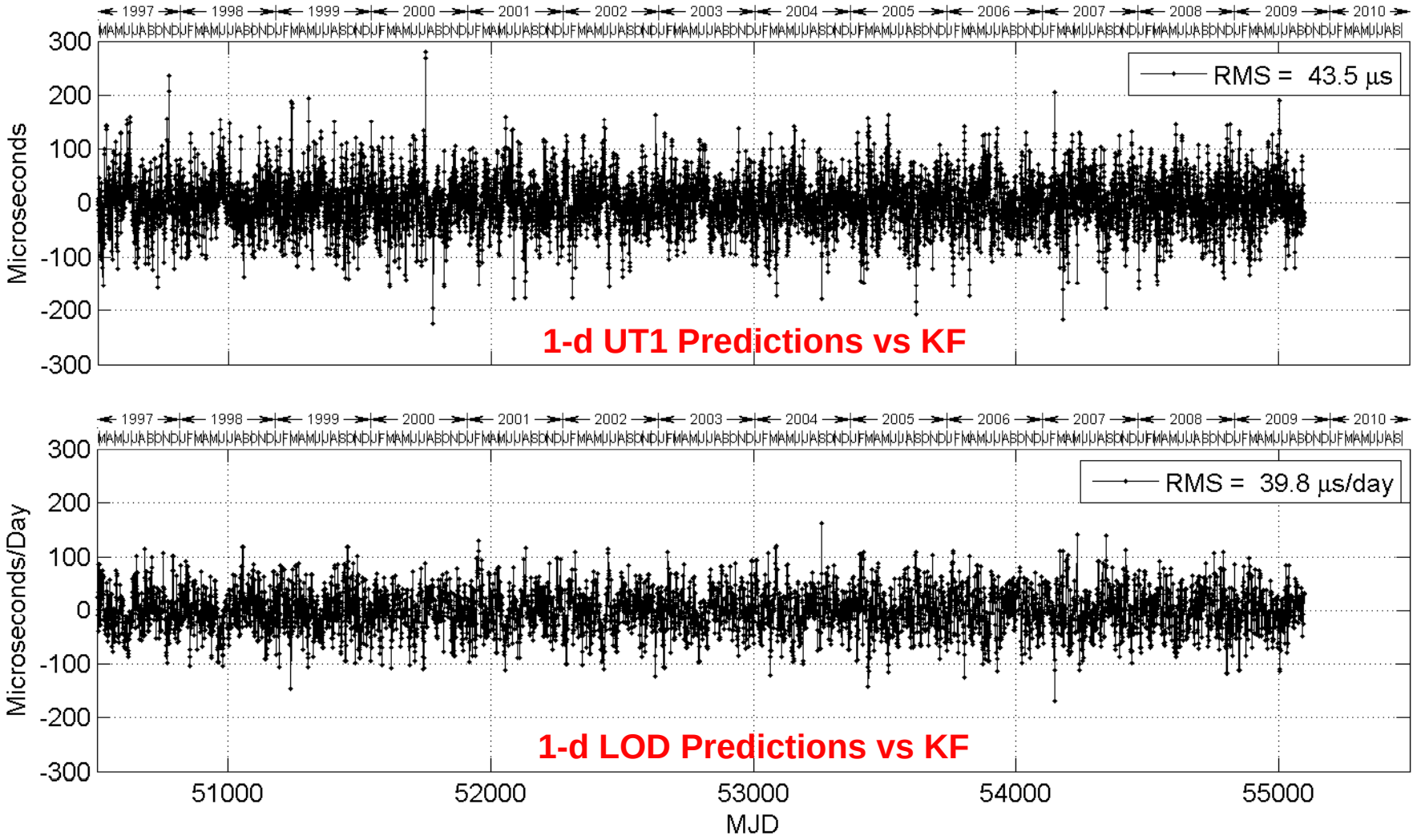




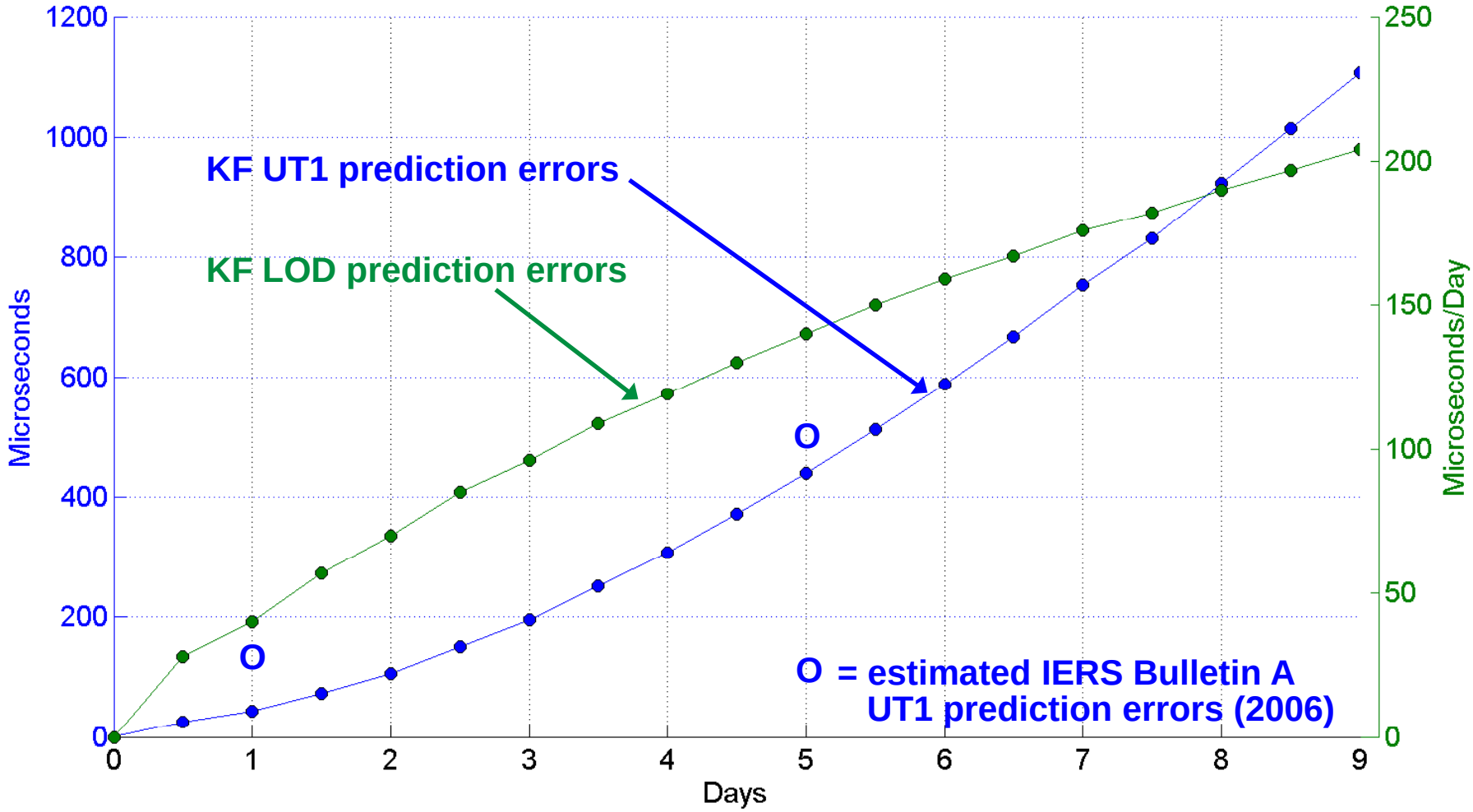
Simple KF UT1 Prediction Tests

- Use Kalman filter state prediction to simulate UT1 prediction ability
  - test performance over varying time intervals compared to KF combination
- Optimistic aspects:
  - all VLBI UT1 & GPS LOD values available with no latency
- Pessimistic aspects:
  - no IGS Rapid or Ultra-rapid LODs used
  - no other observational inputs used
  - no auto-regressive or other tuned models
- Test only near-term prediction capability of KF model
  - performance degrades quickly after a few days
  - but for IGS orbit predictions, only near-term EOP predictions are relevant

Best-Case Predictions (1-d projections)



Best-Case UT1/LOD Prediction Errors



Conclusions

- IERS combinations do not use VLBI UT1 & GPS LOD inputs optimally !
  - fidelity of high-frequency geodetic measurements is degraded
- JPL's SPACE2007 series performs similarly to our Kalman filter
  - JPL's operational prediction service also assimilates AAM excitation information
- VLBI UT1 & GPS LOD combinations must recognize & mitigate systematic errors
  - UT1 from VLBI Intensives has serious baseline- & time-dependent errors
  - UT1 from weak VLBI sessions should be rejected
  - GPS LODs have bias & harmonic errors that should be modeled
- Combination services should use IGS Final, Rapid, & Ultra-rapid (observed) LODs
  - to maximize accuracy (Finals & Rapids) & minimize latency (Ultra-rapids)
  - but must model biases
- IGS real-time orbit predictions require better EOP predictions
  - UT1 prediction errors (= RZ rotation errors) dominate real-time performance
  - polar motion prediction errors are also significant