# High-Accuracy Subdaily ERPs from the IGS

- IGS ERP product streams serve various latencies
  - Ultra-rapids for real-time & near real-time applications
  - compare with other IGS products
- Performance of Ultra-rapid observed ERPs
  - compare with Final & Rapid ERPs
  - assess random & systematic errors
- Performance of Ultra-rapid predicted ERPs
  - compare with Final ERPs & prediction services
  - assess random & systematic errors

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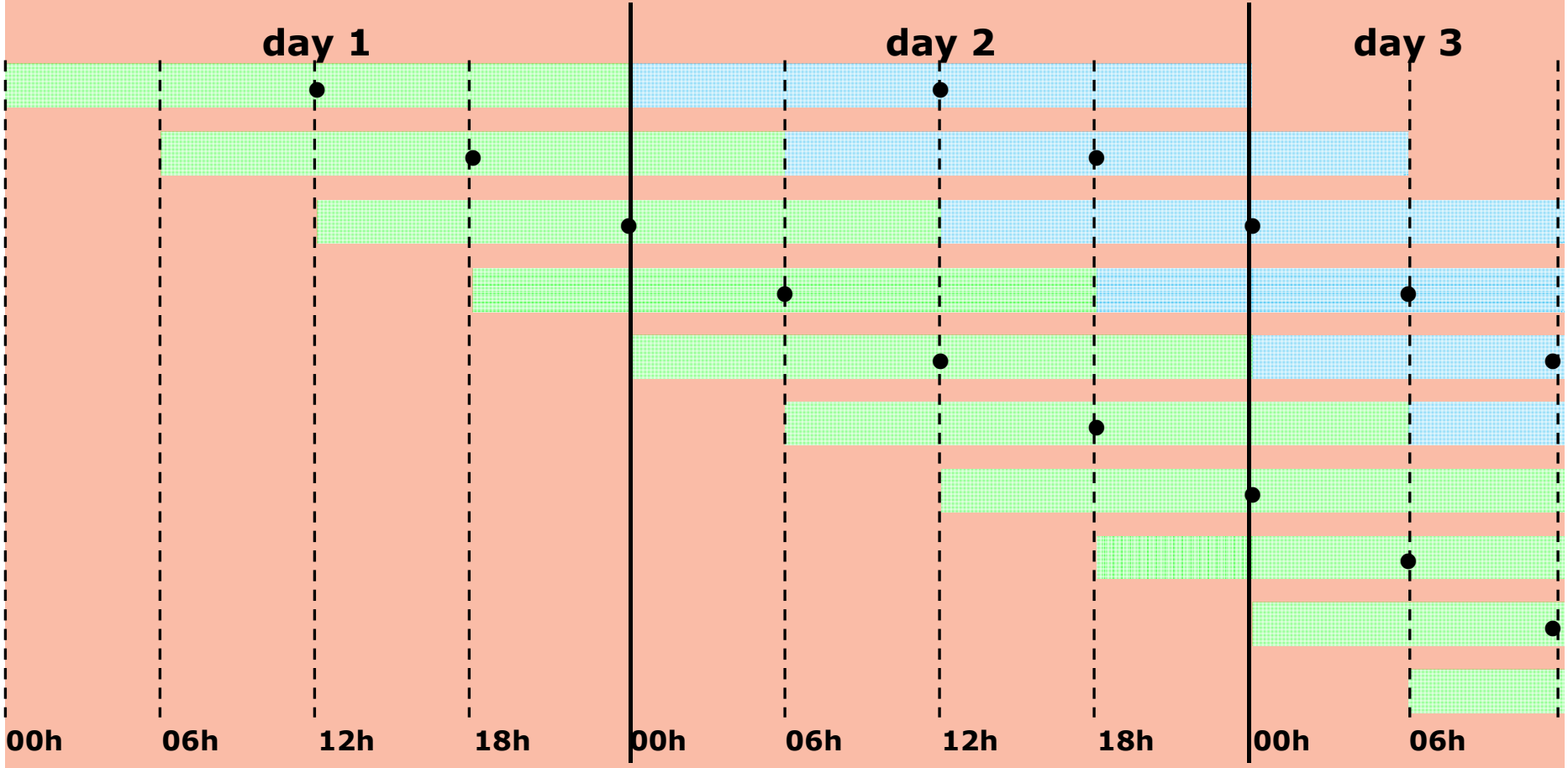
# IGS Ultra-Rapid (IGU) Products

- Intended for real-time & near real-time applications
  - started officially 3 Nov 2000, updated every 12 hr originally
  - update cycle reduced to 6 hr starting 19 Apr 2004
  - products span 48 hr, including: GPS + GLONASS orbits, GPS clocks, ERPs
  - ERPs = polar motion (PM) & length of day (dLOD)
  - PM-rates reported too but suffer from errors in IERS subdaily tide model
  - up to 9 Analysis Centers (AC) contribute (but normally just 5 used)

- IGU observed products (IGA) provided for 1st 24 hr
  - for near real-time applications
  - initial latency is 3 hr
  - products only slightly less accurate than IGS Rapids

- IGU predicted products (IGU) provided for 2nd 24 hr
  - for true real-time GNSS applications; but not an EOP prediction service
  - based on AC projections of their observed results

# IGS Ultra-Rapid Update Cycle




= 24 hr of **Observations**

= 24 hr of **Predictions**

= **Observed ERPs**

= **Predicted ERPs**

IGU updates every 6 hr are always 3 hr after the beginning of each prediction interval

# IGS Core Product Series (2011)

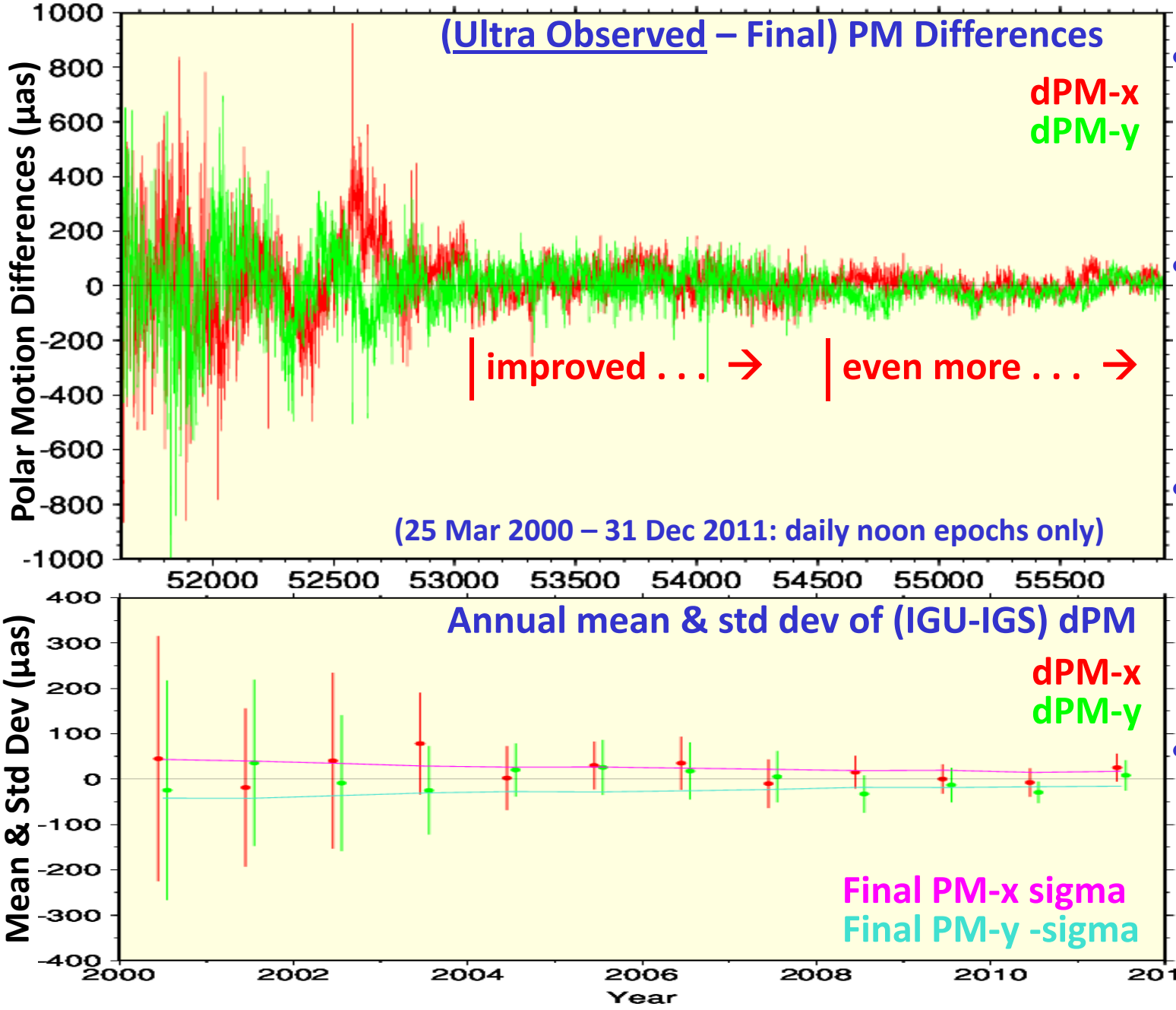
| Series | ID | Latency | Issue times (UTC) | Data spans (UTC) | Remarks |
|---|---|---|---|---|---|
| **Ultra-Rapid (predicted half)** | IGU | real-time | @ 03:00, 09:00, 15:00, 21:00 | +24 hr @ 00:00, 06:00, 12:00, 18:00 | • for real-time apps<br>• GPS & GLONASS<br>• issued with prior IGA |
| **Ultra-Rapid (observed half)** | IGA | 3 - 9 hr | @ 03:00, 09:00, 15:00, 21:00 | -24 hr @ 00:00, 06:00, 12:00, 18:00 | • for near real-time apps<br>• GPS & GLONASS<br>• issued with following IGU |
| **Rapid** | IGR | 17 - 41 hr | @ 17:00 daily | ±12 hr @ 12:00 | • for near-definitive, rapid apps<br>• GPS only |
| **Final** | IGS | 11 - 17 d | weekly each Thursday | ±12 hr @ 12:00 for 7 d | • for definitive apps<br>• GPS & GLONASS |

# IGS Core Product Accuracies (2011)

| Series | ID | Product Types | Accuracies | Output Intervals |
|---|---|---|---|---|
| **Ultra-Rapid (predicted half)** | IGU | • **GPS orbits** | ~ 5 cm (1D) | 15 min |
| | | • **GLONASS orbits** | ~10 cm (1D) | 15 min |
| | | • **GPS SV clocks** | ~3 ns RMS / ~1.5 ns Sdev | 15 min |
| | | • **EOPs: PM + dLOD** | ~250 µas / ~50 µs | 6 hr |
| **Ultra-Rapid (observed half)** | IGA | • **GPS orbits** | ~ 3 cm (1D) | 15 min |
| | | • **GLONASS orbits** | ~5 cm (1D) | 15 min |
| | | • **GPS SV clocks** | ~150 ps RMS / ~50 ps Sdev | 15 min |
| | | • **EOPs: PM + dLOD** | <50 µas / ~10 µs | 6 hr |
| **Rapid** | IGR | • **GPS orbits** | ~2.5 cm (1D) | 15 min |
| | | • **GPS SV & station clocks** | ~75 ps RMS / ~25 ps Sdev | 5 min |
| | | • **EOPs: PM + dLOD** | <40 µas / ~10 µs | daily |
| **Final** | IGS | • **GPS orbits** | <2.5 cm (1D) | 15 min |
| | | • **GLONASS orbits** | <5 cm (1D) | 15 min |
| | | • **GPS SV & station clocks** | ~75 ps RMS / ~20 ps SDev | 30 s (SVs) + 5 min |
| | | • **EOPs: PM + dLOD** | <30 µas / ~10 µs | daily |
| | | • **Terrestrial frames** | ~2 mm N&E / ~5 mm U | weekly |

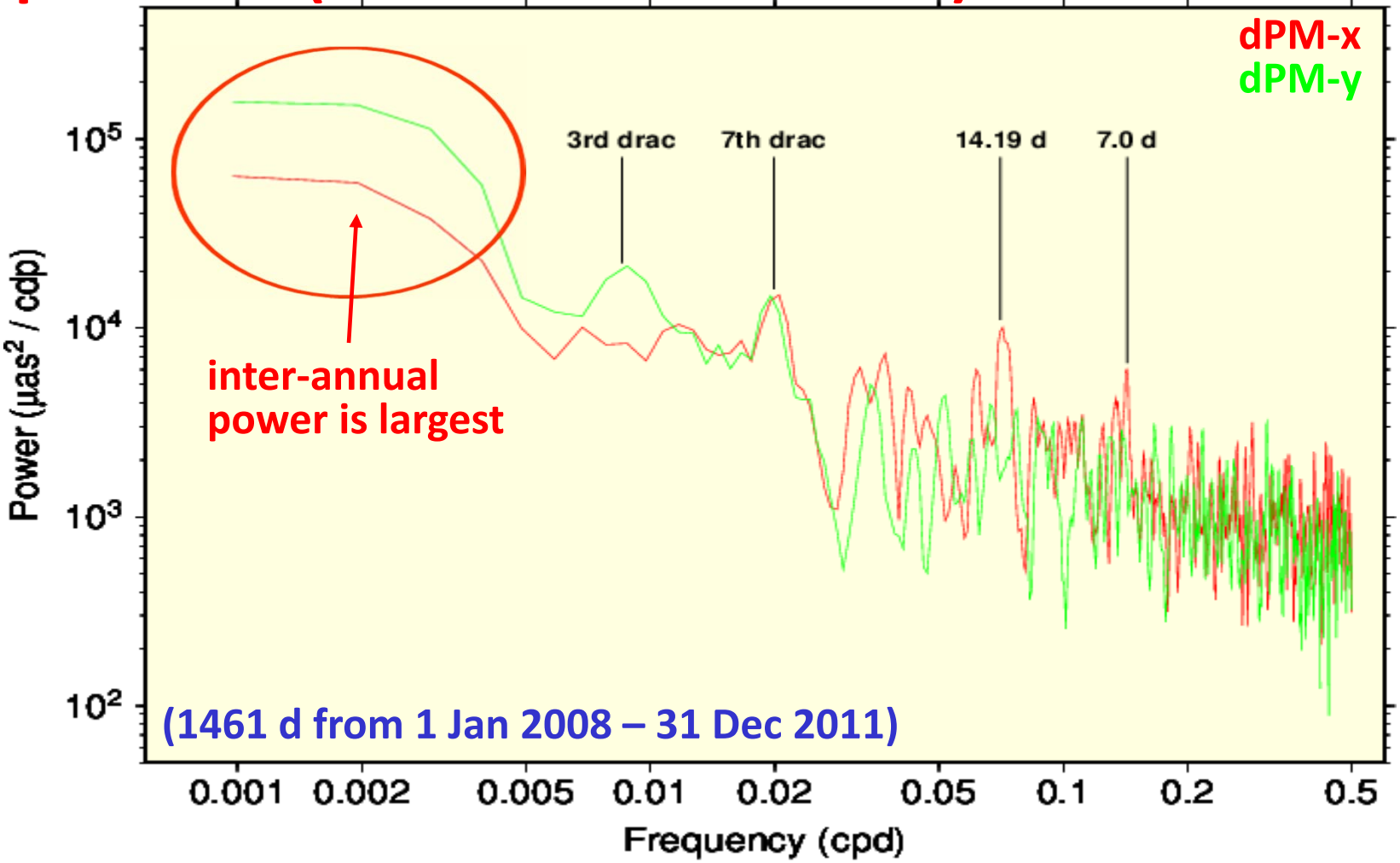
- **IGS aims for ~1 cm orbit & ~1 mm terrestrial accuracies**
  - **to satisfy most demanding mm-level user application requirements**

# Ultra-rapid Observed Polar Motion Accuracy



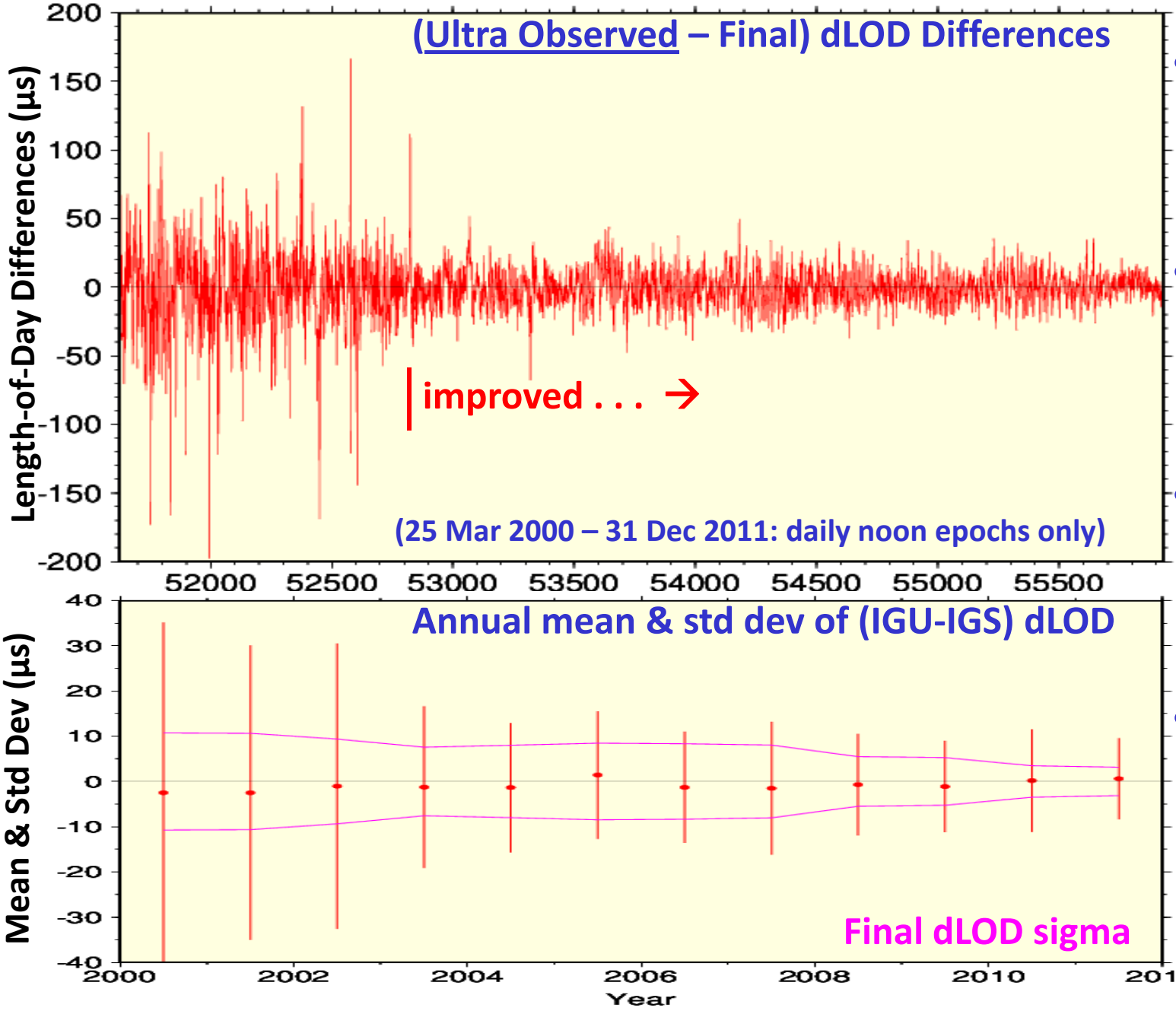

- IGU accuracy improved greatly after ~2003
- IGU dPM RMS errors <40 µas in most recent years
- errors in IGS Final PM reference no longer negligible
- IGS PM errors have low-frequency systematic components

# Spectra of (Ultra Observed-Final) PM Differences



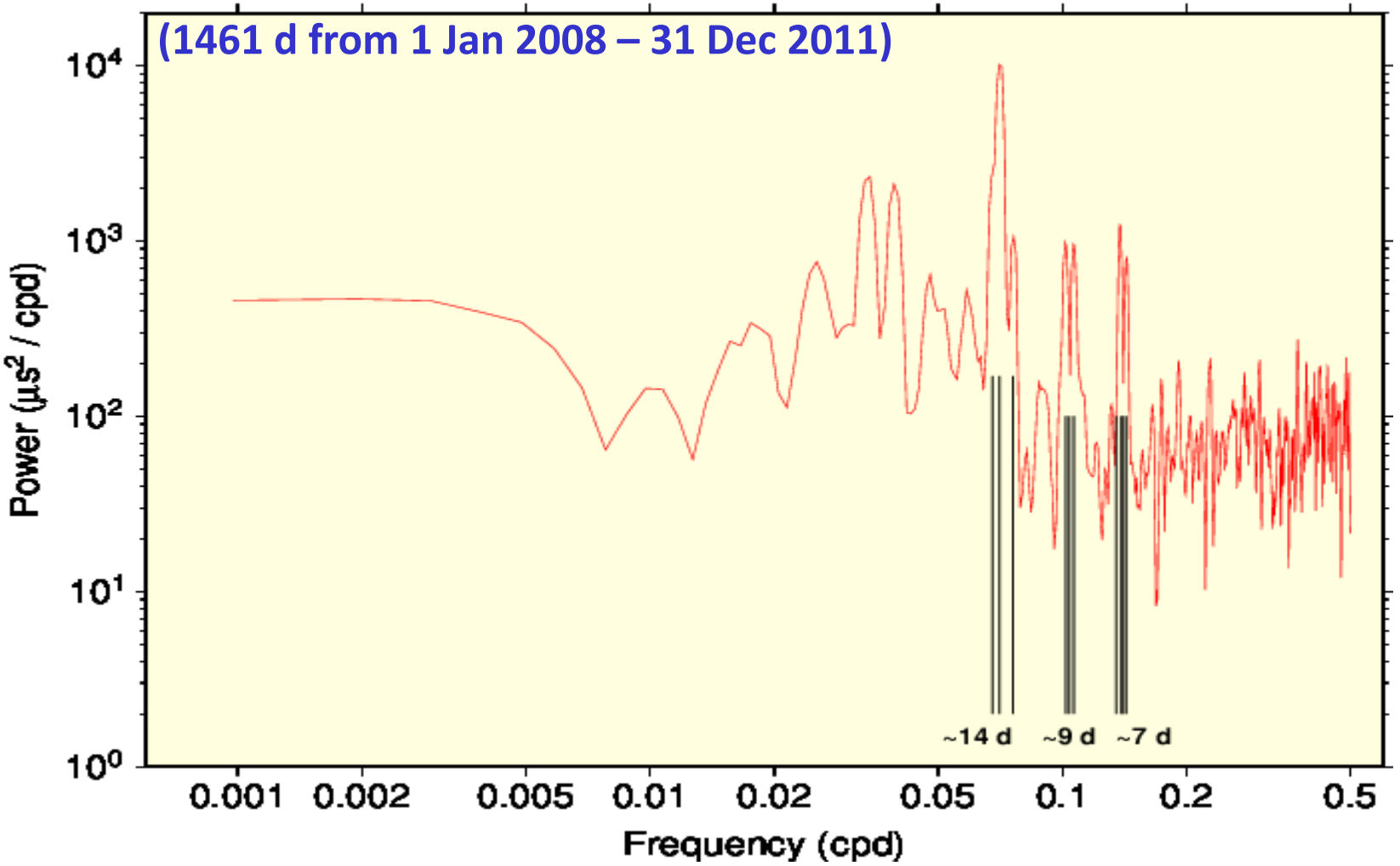

- Subdaily tide model alias errors seen at 7.0 & 14.19 d periods
  - 7th GPS draconitic peak also strong in polar motion rates
  - 3rd GPS draconitic peak also prominent in IGS orbit discontinuities
  - note that differencing should remove common-mode errors!

# Ultra-rapid Observed dLOD Accuracy




- IGU accuracy improved steadily after ~2002
- IGU dLOD RMS errors <12 µs in most recent years
- errors in IGS Final dLOD reference not negligible
- IGS dLOD errors have high-frequency systematic components

# Spectra of (Ultra Observed-Final) dLOD Differences




- Subdaily tide model alias errors seen at ~7, ~9, & ~14 d bands
  - long-period errors muted by "calibration" of AC LOD biases via comparison with IERS Bulletin A over sliding window of recent past results

# 3 Cornered Hat Decomposition of ERP Errors

- 3 cornered hat method is sensitive to uncorrelated, random errors
  - for time series {i, j, k} form time series of differences (i-j), (j-k), (i-k)
  - then Var(i-j) = Var (i) + Var(j) (assuming $R_{ij} = 0$ for $i \neq j$)
  - and Var(i) = [Var(i-j) + Var(i-k) – Var(j-k)] / 2
  - but true errors also include common-mode effects removed in differencing

- Apply to IGS Ultra (observed), Rapid, & Final PM & dLOD
  - consider recent 1461 d from 1 Jan 2008 to 31 Dec 2011

- <u>Surprising results</u>:
  - apparently, Rapids give best polar motion & Ultras give best dLOD
  - Ultras give similar quality polar motion as Finals
  - perhaps Finals affected by simultaneously solving for weekly TRFs

| IGS Product Series | σ(PM-x) (μas) | σ(PM-y) (μas) | σ(dLOD) (μs) |
|---|---|---|---|
| Ultra (Obs) | 25.8 | 27.6 | 4.99 |
| Rapid | 16.0 | 15.4 | 5.69 |
| Final | 25.3 | 31.3 | 9.19 |

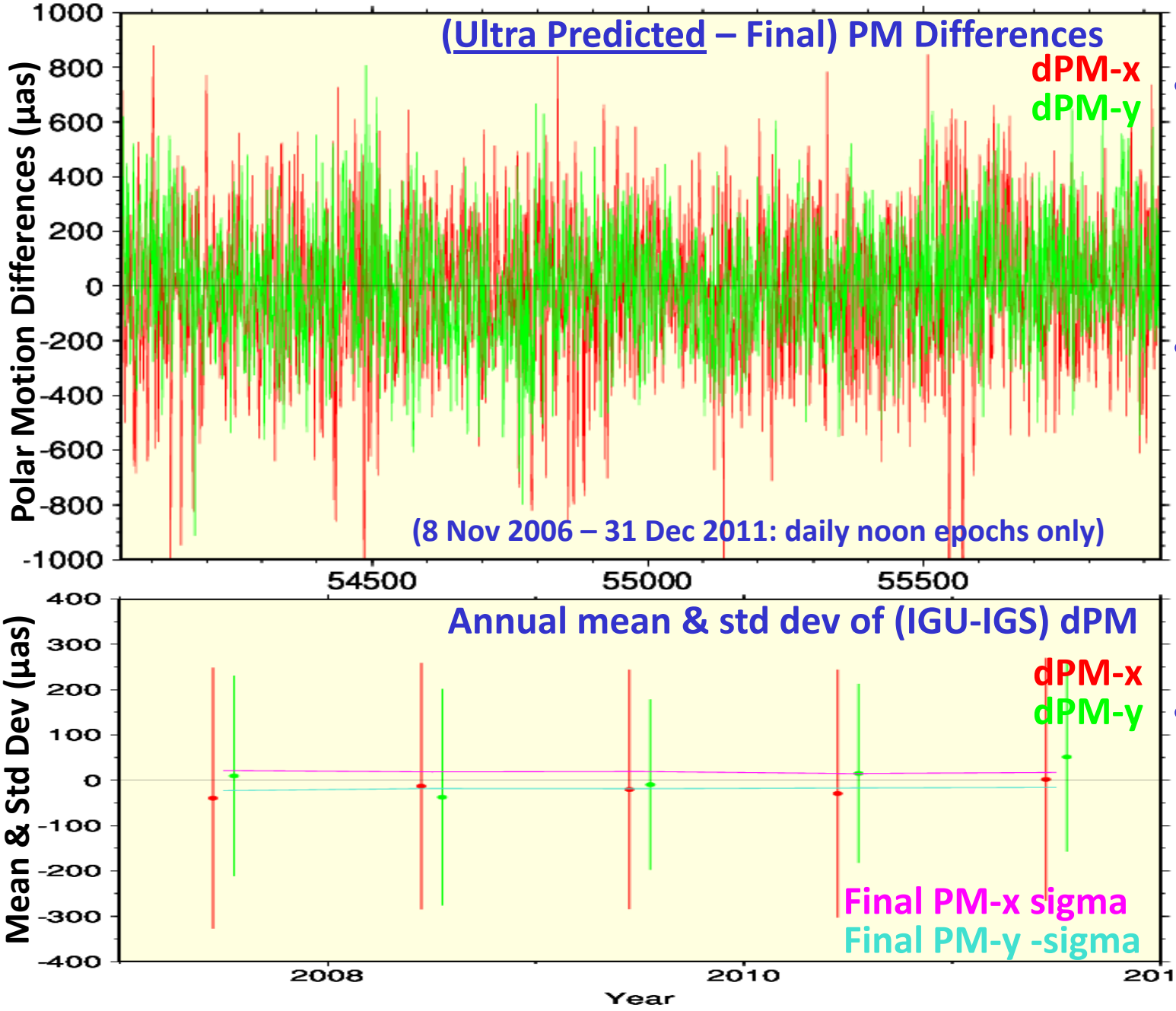
# 3 Cornered Hat PM Results with High-Pass Filtering

- Apply Vondrak high-pass filter before 3 cornered hat for PM
  - test 4 cutoff frequencies: pass all, >0.5 cpy, >1 cpy, >2 cpy
  - results below from Paul Rebischung (IGN)
- IGU & IGR PM errors nearly insensitive to frequency filtering
- IGS Final PM appears to improve when high-pass filtered
  - implies low-frequency errors are in IGS Finals or common to IGU & IGR
  - tests underway to compare all series with AAM+OAM
  - source of low-frequency error (orbits?, frame?) not yet identified

| Freq Cutoff: | none | | 0.5 cpy | | 1 cpy | | 2 cpy | |
|---|---|---|---|---|---|---|---|---|
| (μas) | $\sigma_x$ | $\sigma_y$ | $\sigma_x$ | $\sigma_y$ | $\sigma_x$ | $\sigma_y$ | $\sigma_x$ | $\sigma_y$ |
| Ultra (Obs) | 25.8 | 27.6 | 24.2 | 25.5 | 24.1 | 23.7 | 23.7 | 22.5 |
| Rapid | 16.0 | 15.4 | 16.2 | 14.6 | 15.6 | 16.1 | 15.2 | 16.8 |
| Final | 25.3 | 31.3 | 20.2 | 23.1 | 19.4 | 19.7 | 18.5 | 17.3 |

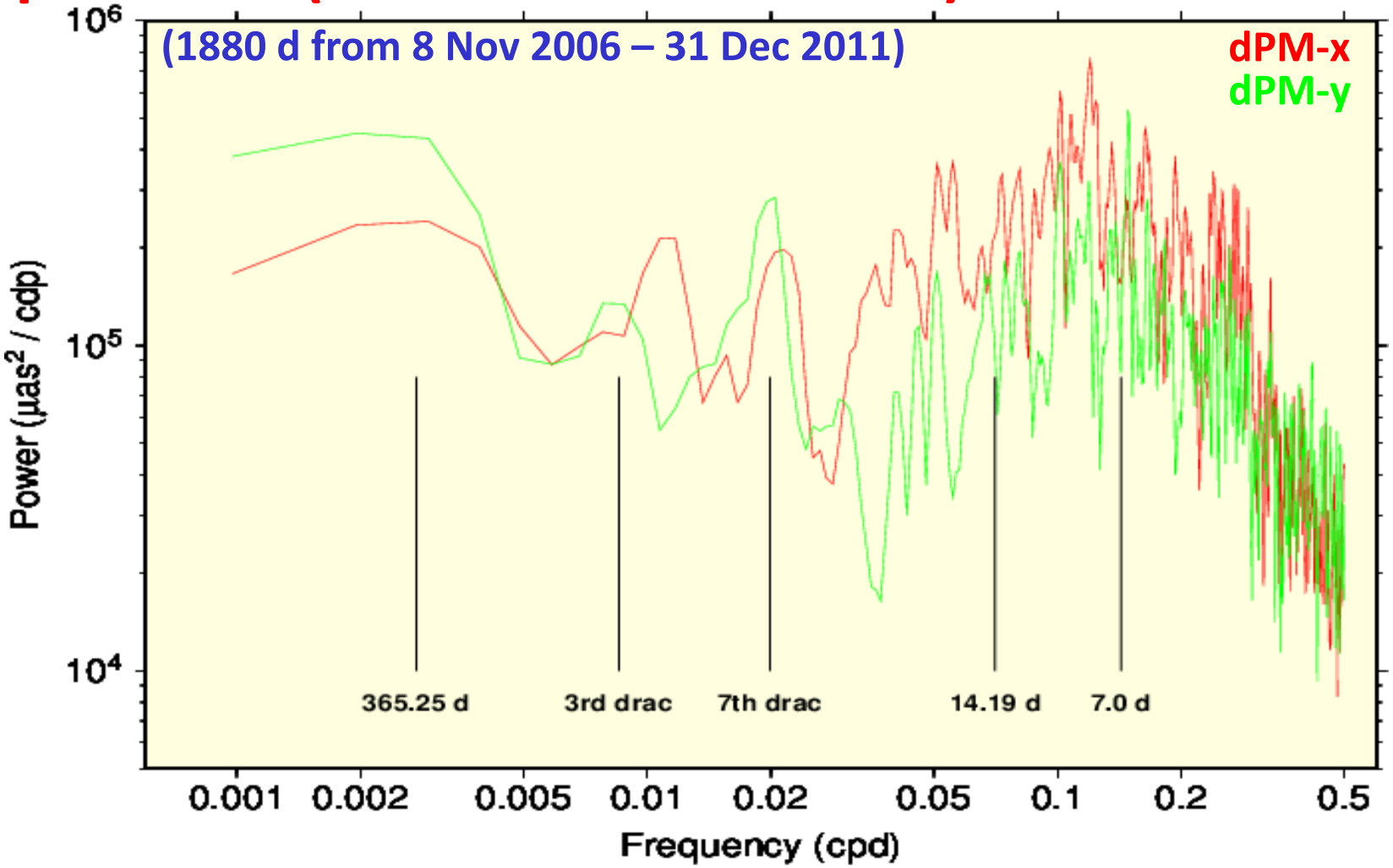
(filtered results from Paul Rebischung, IGN)

# Ultra-rapid Predicted Polar Motion Accuracy



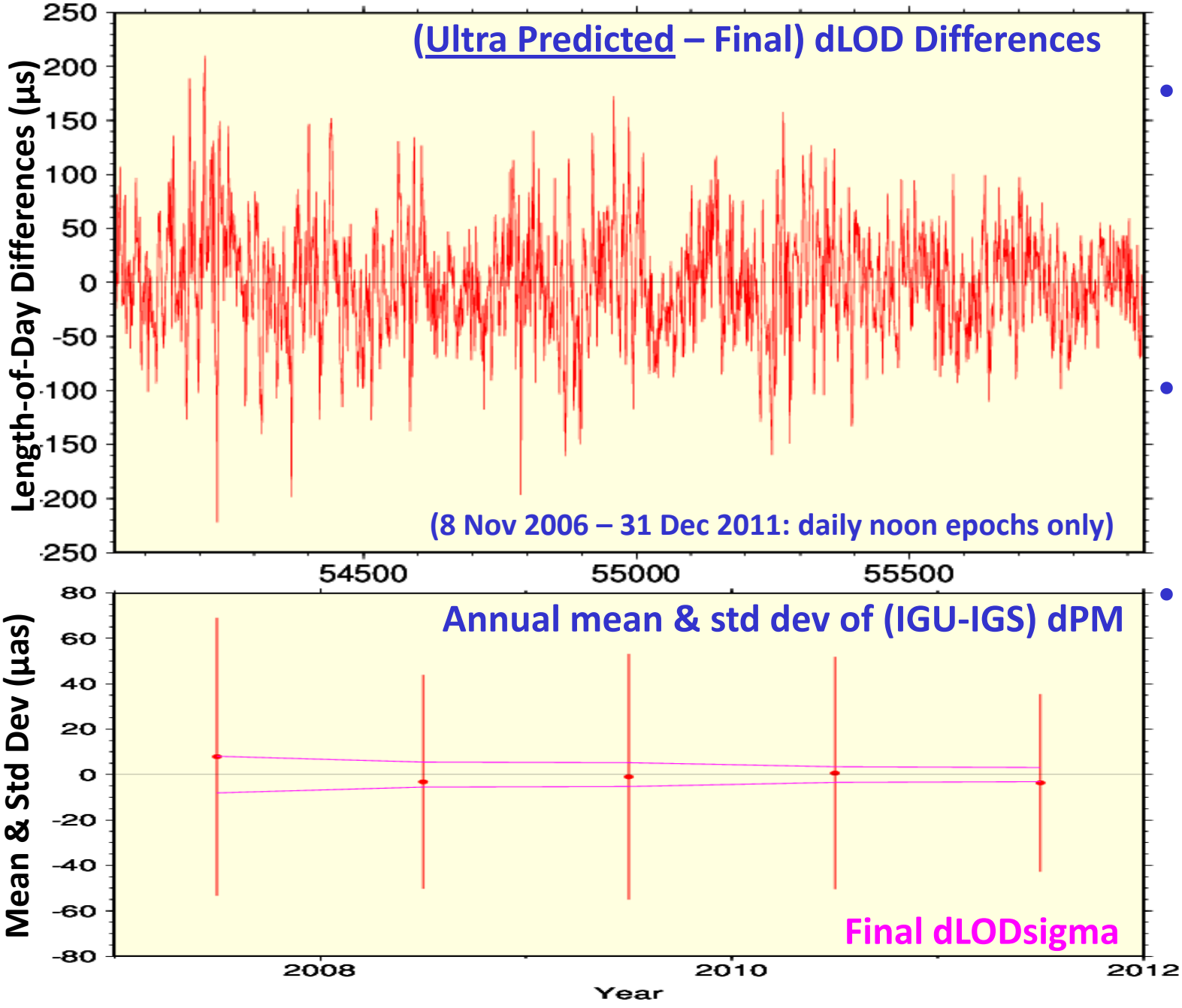

- IGU PM prediction accuracy unchanged since ~2006
- recent IGU 1-d RMS prediction errors:
  ~270 µas for PM-x
  ~210 µas for PM-y
- PM prediction errors appear more random than systematic

# Spectra of (Ultra Predicted-Final) PM Differences



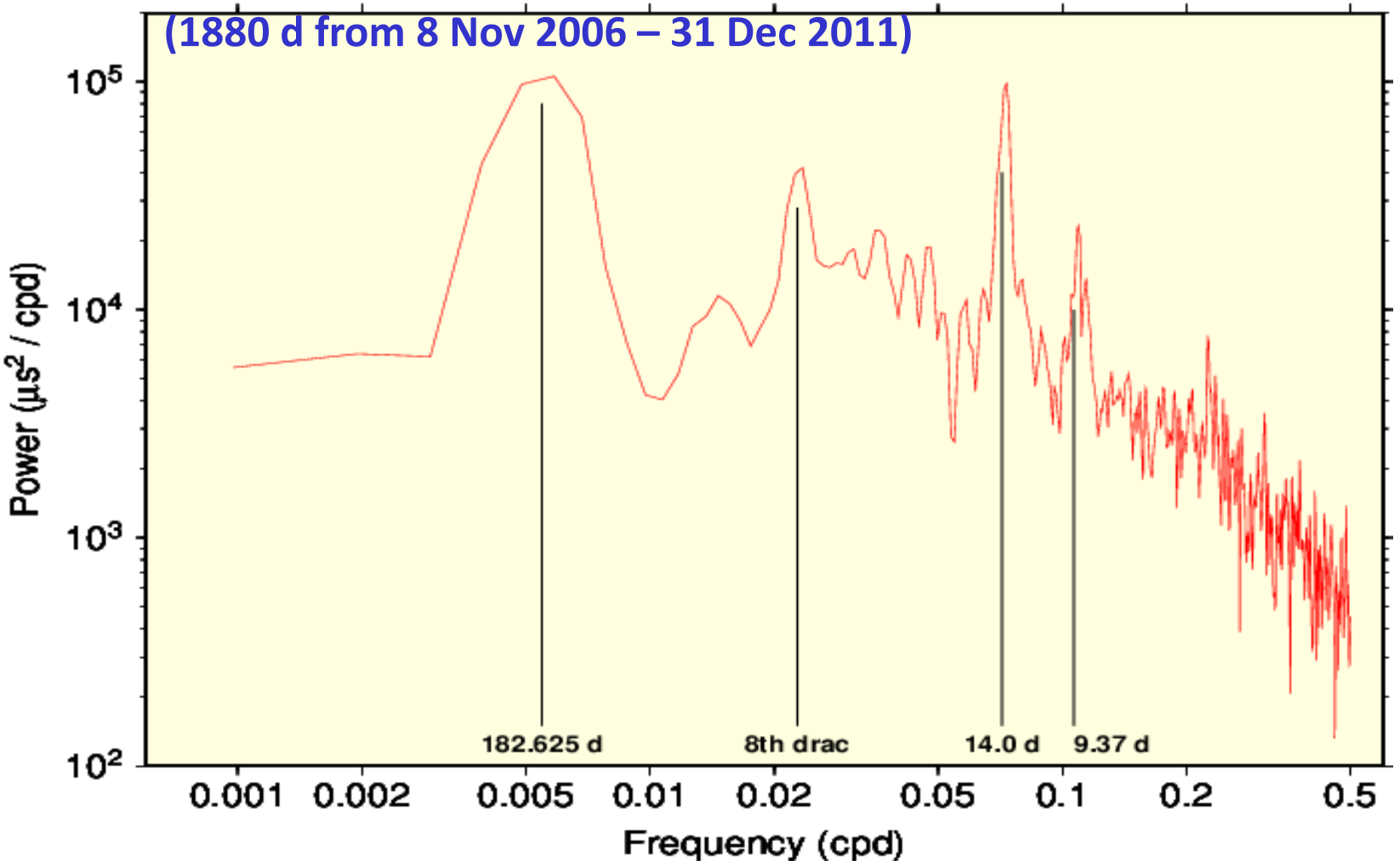

- Subdaily tide model alias errors probably dominate sub-monthly band & perhaps annual, but no distinct lines
  - draconitic errors probably important in between

# Ultra-rapid Predicted dLOD Accuracy




- IGU dLOD prediction accuracy slightly improved since ~2006
- recent IGU 1-d dLOD prediction error ~50 µs
- dLOD prediction errors have evident systematic signatures

# Spectra of (Ultra Predicted-Final) dLOD Differences




- Subdaily tide model alias errors seen at ~9 & ~14 d bands
  - plus strong 8th GPS draconitic & semi-annual peaks

# IGS ERP Predictions Compared to Other Services

- IGS Ultra ERP predictions for 1 d after last observations compared to operational EOP services
  - IGU ERPs issued 9 hr before prediction epoch
  - predictions benefit from access to latest high-accuracy observations
- Compare to IERS (USNO & Paris Obs) & JPL EOP services
  - results from IERS EOP Combination of Predictions Pilot Project (18.03.2012)
  - IGU PM predictions better than any others
  - IGU comparable to UT1/dLOD services due to their use of AAM predictions
- EOP prediction services should consider assimilating IGU predictions, as well as most recent IGU observations

| Prediction Service | RMS(PM-x) (μas) | RMS(PM-y) (μas) | RMS(dLOD) (μs) |
|---|---|---|---|
| **Ultra (Pred)** | **270** | **211** | **48** (dLOD) |
| **USNO/Bull A** | **442** | **290** | **55** (UT1) |
| **Paris Obs** | **522 - 609** | **337 - 438** | **334 – 414** (UT1) |
| **JPL** | **562** | **423** | **55** (UT1) |

# Conclusions

- IGS produces Ultra-rapid ERPs with subdaily resolution & high accuracy
  - observed ERPs updated every 6 hr with 15 hr latency
  - PM accuracy roughly similar to IGS Finals: 25 to 30 µas
  - IGS Rapid PM accuracy may be even better: 15 to 16 µas
  - IGU dLOD accuracy may be better than IGS Finals: ~5 µs
  - further study needed to assess accuracy of IGS ERPs

- Main (systematic) error components are probably:
  - errors in IERS subdaily EOP tide model
  - orbit mis-modeling (draconitic signals)
  - instabilities in terrestrial reference frame (though none detected directly)

- IGS Ultra-rapid PM predictions better than operational services
  - IGU dLOD predictions similar to operational service

- IGS Ultra-rapid ERP observations & predictions should be assimilated by operational EOP prediction services !