FUTURE IMPROVEMENTS IN DETERMINATIONS OF EARTH ORIENTATION PARAMETERS

• Present polar motion accuracy
  – about 30 µas, mostly from GPS

• Present UT1 accuracy
  – usually from 4 to 20 µs, but sometimes worse
  – mostly from VLBI, but GPS LOD could add more

• Improvements possible from better networks, new GNSSs, reduced systematic errors

Jim Ray, NOAA/NGS
Recent Polar Motion Accuracy

- **ITRF2005 multi-technique combination experience**
  - scaled formal errors $\sim 30 \mu$as for daily PM-x & PM-y
  - equivalent to net equatorial rotation errors of $\sim 1 \text{ mm}$

- **IGS GPS heavily dominates modern combinations**
  - due to robust global network & continuous, high-accuracy data
  - SLR & VLBI networks are sparse, non-uniform, & irregularly observed
  - SLR & VLBI PM contribute to rotational frame alignments, less for EOPs
  - DORIS PM noisy due to limited satellite constellation

- **GPS PM errors difficult to quantify precisely**
  - since increase in IGS RF to 99+ sites (Jan. 2004), PM errors $<\sim 30 \mu$as
  - recent PM errors due to: orbit mismodeling, subdaily EOP tide model errors, & AC solution constraints
  - can compare Rapid & Final series for some insights
  - current Rapids about 25 to 50% poorer than Finals
  - IGS reprocessing campaign will improve old PM results
### IGS Polar Motion Accuracy

**IGS Rapid Pole Differences with IGS Final ERP**

![Graph showing the comparison between IGS and IGR poles with weekly and daily means.]

- **<55 RF sites**
- **>98 RF sites**

#### Table: Years vs. Rapid vs. Final vs. Δ(Rapid-Final)

<table>
<thead>
<tr>
<th>Years (units = μas)</th>
<th>Rapid</th>
<th>Final</th>
<th>Δ(Rapid-Final)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$&lt;\sigma_x&gt;$</td>
<td>$&lt;\sigma_y&gt;$</td>
<td>$&lt;\sigma_x&gt;$</td>
</tr>
<tr>
<td>1999-2001.5</td>
<td>77.3</td>
<td>85.9</td>
<td>44.1</td>
</tr>
<tr>
<td>2001.5-2003</td>
<td>47.5</td>
<td>47.3</td>
<td>33.3</td>
</tr>
<tr>
<td>2004-2006</td>
<td>34.0</td>
<td>39.5</td>
<td>25.6</td>
</tr>
<tr>
<td>2007-2009.5</td>
<td>24.3</td>
<td>27.7</td>
<td>20.1</td>
</tr>
</tbody>
</table>
Spectra of (Rapid-Final) PM Differences

- High-frequency noise consistent with ~30 μas accuracy
  - but longer period errors might be significant
  - fortnightly feature near 14.2 d may signify tide model errors
PM Differences among IGS ACs

- Differences among ACs reflect mostly analysis variations
  - networks, geophysical models, & parameterizations quite similar
  - main analysis differences relate to orbit dynamics & solution constraints
Recent PM-Rate Accuracy

- ITRF2005 multi-technique combination experience
  - scaled formal errors \( \sim 90 \mu \text{as/d} \) for PM-xrate & PM-yrate
  - but these estimates are probably optimistic

- IGS GPS also dominates PM-rate combinations

- GPS PM-rate errors can be assessed by examining day-boundary discontinuities

- PM-rates very sensitive to subdaily EOP tide model errors
  - imply IERS2003 errors for K1, O1, Q1/N2, & probably other lines
  - odd numbered harmonics of 1.04 cpy point to orbit errors
  - estimated IGS PM-rate errors: \( \sim 140 \mu \text{as/d} \) for xrate; \( \sim 180 \mu \text{as/d} \) for yrate
  - PM-yrate error larger due to greater 1.04 cpy orbit harmonics

- For excitation studies, probably best to use PM time differences, not directly observed PM-rates
Compute Polar Motion Discontinuities

- Examine PM day-boundary discontinuities for IGS time series
  - should be non-zero due to PM excitation & measurement errors
Power Spectra of IGS PM Discontinuities

- Common peaks seen in most AC spectra are:
  - annual + 5th & 7th harmonics of GPS year (351 d or 1.040 cpy)
  - probably aliased errors of subdaily EOP tide model (IERS2003)
Spectra of Subdaily EOP Tide Model Differences

- Compare TPXO7.1 & IERS2003 (used by IGS) EOP models
  - TPXO7.1 & GOT4.7 test models kindly provided by Richard Ray
  - assume subdaily EOP model differences expressed fully in IGS PM results
Spectra of PM Discontinuities & Subdaily EOPs

- Aliasing of subdaily EOP tide model errors probably explains:
  - annual (K1, P1, T2), 14.2 d (O1), 9.4 d (Q1, N2), & 7.2 d (σ1, 2Q1, 2N2, μ2)
- Orbit errors presumably responsible for odd 1.04 cpy harmonics
Recent UT1 Accuracy

- **ITRF2005 multi-technique combination experience**
  - mean scaled formal errors \( \sim 8.0 \mu s \) since 2002.0 (at irregular epochs)
  - equivalent to net equatorial rotation errors of \( \sim 3.7 \text{ mm} \)

- **UT1-UTC only measured by VLBI, but irregular quality & epochs**

- **For VLBI data since 2002:**
  - 24-hr EOP sessions give UT1 formal errors of 2.2 to 2.8 \( \mu s \) (twice weekly)
  - accuracy is about twice formal errors: \( \sim 5 \mu s \) (= 2.3 mm rotation)
  - other 24-hr sessions have estimated mean accuracy \( \sim 20 \mu s \) (irregular)
  - 1-hr Intensive sessions have mean formal errors \( \sim 13 \mu s \) (nearly daily)
  - but Intensives show clear systematic effects that are difficult to handle

- **Daily GPS LOD (= -UT1-rate) generally not used optimally**
  - must model time-correlated biases – easy in Kalman filter, difficult otherwise
  - LOD residuals from such a Kalman filter are \( \sim 4 \mu s \)
  - combinations with VLBI UT1 yield best UT1/LOD time series
Some Kalman Filter Combination Outputs

- **VLBI 1-hr UT1 residuals**
  - show systematic patterns
  - RMS = 20 μs

- **GPS LOD residuals**
  - approx. white, RMS = 4 μs
  - small peak at 13.7 d
  - possible difference in a priori tidal models wrt VLBI

- **Gauss-Markov values for GPS LOD biases**
  - peak-to-peak range = ± 40 μs
  - RMS = 9 μs

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

- note systematic patterns in residuals

- EMR analysis upgrade
UT1 KF Residuals for VLBI 1-hr Intensives

Note systematic baseline- & time-dependent patterns
(series “int21” from NASA/GSFC)
**EOP Error Sources**

**Station-related measurements:**
- thermal noise
- instrumentation
- propagation delays
- multipath, etc

\[ \sigma_{\text{Station}} \approx \frac{1}{\sqrt{N_{\text{Station}}}} \]

**Geophysical & parameter models:**
- esp near S1, K1, K2 tidal periods

**Source-related errors:**
- orbit dynamics (GPS, SLR, DORIS)
- quasar structures (VLBI)

\[ \sigma_{\text{Source}} \approx \frac{1}{\sqrt{N_{\text{Source}}}} \]

**Possible improvements:**
- more robust SLR, VLBI networks?
- more stable site installations?
- near asymptotic limit for GPS already
- new subdaily EOP tide model?
- better handling of parameter constraints?
- modern theory of Earth rotation?
- new GNSS constellations?
- better GNSS orbit models?
- quasar structure models (VLBI)?

\[ \rightarrow \text{Multi-technique EOP combinations mostly sub-optimal!} \]
Conclusions

- Stronger VLBI & SLR contributions will depend mostly on larger, more robust networks & continuous operation
  - GPS will probably continue to dominate PM for indefinite future

- GPS PM nearing asymptotic limit for random errors (~20 μas)
  - smaller systematic errors possible with new GNSSs, better orbit modeling, & better handling of solution constraints
  - better PM-rates require new subdaily EOP tide model & reduced orbit effects – prospects currently unclear

- VLBI UT1 improvements require attention to station- & network-dependent errors
  - new GNSSs & orbit models will improve GPS LOD by unknown amount
  - combination methods generally do not match observation accuracy & require better approaches

- Exploration of subdaily non-tidal EOPs remains distant, but a challenging possibility for UT1