High-frequency signals of oceans and atmosphere in Earth rotation

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Periodic polar motion – composition

- Ocean tides
- Libration
- Ocean non-tidal
- Decadal variations
- Atmosphere tides
- Atmosphere non-tidal
- Chandler wobble
Periodic UT1/LOD – composition

- ocean tides
- libration
- ocean non-tidal
- atmosphere tides
- atmosphere non-tidal
- body tides
- decadal variations
- core-mantle coupling

core-mantle coupling
Diurnal and subdiurnal signals in Earth rotation

- **Ocean tides**
  - Q1, O1, P1, K1, N2, M2, S2, K2

- **Atmosphere tides**
  - S1, S2

- **Effect of lunisolar torque on triaxial Earth**
  - PM: O1, P1, K1
  - UT1: M2, S2
Determination of HF Earth rotation variations

predicted from ...

- ocean tide models
- numerical weather model data
- theory tidal potential

measured by ...

VLBI, GNSS, SLR, ringlaser ...
Ocean tidal excitation from ocean tide models

- Global grids of complex amplitudes of tidal heights and current velocities
  - **TPXO7.2**: Oregon state university (2010)
  - **HAMTIDE11a**: University of Hamburg (2011)

Data-assimilative hydrodynamic models
- **IERS2010:**
  based primarily on the ocean tide model TPXO.2 (1994)
Earth rotation excitation at daily and subdaily periods, investigated with different sets of AAM functions (from different ECMWF data classes)

- Polar motion: amplitudes of S1 and S2 \( \sim 1 \, \mu\text{as} \)
- UT1: amplitudes of S1 and S2 \(< 0.5 \, \mu\text{s}\)

Models of S1 and S2 are strongly dependent on the atmospheric model and the considered data time interval

Amplitudes are small: pressure and wind effects, decisive for Earth rotation variations counterbalance each other.

Poster XL121: Schindelegger et al.
High-frequency Earth rotation from VLBI

- Option 1: from highly resolved (1-2 h) ERP time series
  - 1\textsuperscript{st} step: estimate celestial pole offsets (cpo) for all sessions
  - 2\textsuperscript{nd} step: re-introduce cpo, fix nutation, estimate ERP with hourly resolution
  - 3\textsuperscript{rd} step: remove low-frequency signal from the ERP time series, estimate amplitudes of selected periods in a least squares adjustment

\[
\delta x_p(t) = \sum_{i=1}^{77} (-A_i^+ - A_i^-)\cos(\xi_i(t)) + (B_i^+ - B_i^-)\sin(\xi_i(t))
\]

\[
\delta y_p(t) = \sum_{i=1}^{77} (B_i^+ + B_i^-)\cos(\xi_i(t)) + (A_i^+ - A_i^-)\sin(\xi_i(t))
\]

\[
\delta UT1(t) = \sum_{i=1}^{77} U_i^c \cos(\xi_i(t)) + U_i^s \sin(\xi_i(t))
\]

\[
\xi_i(t) = \sum_{j=1}^{6} a_{ij} \alpha_j(t)
\]

\[a_{ij} \ldots 6 \text{ integer multipliers for each tide } i\]

\[\alpha_j \ldots 5 \text{ Delaunay variables } I, I', F, D, \Omega + (\text{GMST} + \pi)\]

as used in the IERS Conventions
Option 2: from demodulated ERP (complex demodulation technique, Herring & Dong (1994), Brzezinski (2012))

- celestial pole offsets (nutation) can be estimated!
- alternative ERP parameterisation:

\[
\begin{bmatrix}
 x_p(t) \\
 y_p(t)
\end{bmatrix}
= \sum_{k=-N}^{N} \begin{bmatrix}
 x_k(t) \\
 y_k(t)
\end{bmatrix} \cos(k\phi(t)) + \begin{bmatrix}
 y_k(t) \\
 -x_k(t)
\end{bmatrix} \sin(k\phi(t))
\]

\[
UT1(t) = \sum_{k=0}^{N} u^c_k(t) \cos(k\phi(t)) + u^s_k(t) \sin(k\phi(t))
\]

\[
\phi = GMST + \pi
\]

\[
k = 0 \Rightarrow \begin{bmatrix}
 x_0(t) \\
 y_0(t)
\end{bmatrix} \cos(0) + \begin{bmatrix}
 y_0(t) \\
 -x_0(t)
\end{bmatrix} \sin(0)
\]

- low frequency variations

\[
k = 1...4 \text{ (diurnal, semidiurnal, terdiurnal, quarterdiurnal band)}
\]
Option 2: from demodulated ERP (complex demodulation technique)

- preserves the amplitudes of periodic signals but shifts the frequencies
- E.g. diurnal frequency band:

\[
\begin{align*}
\xi_i &\quad \phi \\
\text{original} &\quad \text{frequency} &\quad \text{demodulation} &\quad \text{frequency}
\end{align*}
\]

- Tidal coefficients

\[
\delta UT1(t) = \cos \phi \cdot \sum_{i=1}^{n} \left[ U_i^s \sin(\xi_i - \phi) + U_i^c \cos(\xi_i - \phi) \right] + \sin \phi \cdot \sum_{i=1}^{n} \left[ U_i^s \cos(\xi_i - \phi) - U_i^c \sin(\xi_i - \phi) \right]
\]

- Demodulated UT1 time series

<table>
<thead>
<tr>
<th>Tidal Coefficient</th>
<th>Frequency Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1 23.93h</td>
<td>\rightarrow \infty</td>
</tr>
<tr>
<td>O1 25.82h</td>
<td>\rightarrow 13.66 days</td>
</tr>
<tr>
<td>S1 24.00h</td>
<td>\rightarrow 365.25 days</td>
</tr>
</tbody>
</table>
High-frequency Earth rotation from VLBI

Option 3: within a global solution
- Accumulate single session normal equations
- Estimate tidal terms directly together with other parameters such as station positions

3 sets of tidal amplitudes
- Vienna VLBI Software VieVS: VLBI data 1984-2010
- Polar and spin libration considered a priori
- 40+3 diurnal, 30+3 semidiurnal, 1 terdiurnal (M3) tide/s

Option 1: highly resolved ERP time series
Option 2: demodulated ERP time series
Option 3: global solution
Polar motion w.r.t. IERS2010
VLBI estimates show better mutual agreement than ocean tide models.

ERP variations based on TPXO7.2 fit best to the VLBI values, for polar motion as well as for UT1.
Conclusions

- More recent ocean tide models do not necessarily agree better to empirical tidal ERP terms.
- There is room for improvement – on the part of the modeling procedure?
- Extension with S1 tide from ocean tide models could help.
- S1 and S2 from atmospheric models should be interpreted with caution as they are strongly dependent on the used model and the considered data time interval.
- Combined analysis of VLBI and ring laser data
  - Poster XL 119, Nilsson et al.

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