Response of the Earth system to zonal tidal forcing examined by VLBI based dUT1 variations

Sigrid Böhm
Harald Schuh
Outline

- The “zonal response coefficient” - basic concept
- Observed dUT1
  - The Vienna VLBI Software VieVS
  - Parameterization
- Estimation of the zonal response coefficient
  - Time series pre-processing
  - Functional model
- Preliminary results
- Summary and conclusions
Zonal tidal forcing

- V20 - latitude dependent part of the tide generating potential (TGP)
  - varies with the declination of the celestial body
  - causes long period tidal deformations (5 days – 18.6 years)
Deformation ↔ speed of rotation

Conservation of angular momentum

- Deformation of the Earth gravity field / tensor of inertia is proportional to TGP
- Change in rotational velocity is also proportional to TGP
Proportionality factor

- Love number $k_2$
  \[ \delta V_{20} = k_2 V_{20} \]
  \[ V_{20} = a_{20} P_{20} (\cos \theta) \]

- Induced change in $\delta LOD$ in an elastic spherically symmetric Earth:
  \[ \frac{\delta LOD}{LOD_0} = -k_2 \frac{2 R^3}{3 \ GC} a_{20} \]

  - $C$ ... axial moment of inertia
  - $G$ ... grav. Const.
  - $R$ ... mean Earth radius
  - $LOD_0$ ... 86400 s
Zonal response coefficient of the Earth-ocean system $\kappa$ (Agnew & Farrell, 1978)

- frequency dependent, complex-valued
- Transfer function – also includes effects of the oceans, anelasticity of the mantle and fluid core

\[
\frac{\delta \text{LOD}(\omega)}{\text{LOD}_0} = -\kappa(\omega) \frac{2}{3} \frac{R^3}{\text{GC}} a_{20}(\omega)
\]
Extension of the Love number concept

- Zonal response coefficient of the Earth-ocean system \( \kappa \) (Agnew & Farrell, 1978)
  - frequency dependent, complex-valued
  - Transfer function – also includes effects of the oceans, anelasticity of the mantle and fluid core

\[
\delta UT1(\omega) = -\kappa(\omega) \frac{1}{i\omega} \frac{2}{3} \frac{R^3}{GC} a_{20}(\omega)
\]
Vienna VLBI Software

- Developed at the Institute of Geodesy and Geophysics of the Vienna University of Technology
- Available for registered users: new users are welcome!

**Processing Flow**

- **VIE_SETUP**
  - Processing setup, graphical user interface

- **VIE_INIT**
  - Data reading

- **VIE_MOD**
  - Theoretical delay, partial derivatives

- **VIE_LSM**
  - Least squares adjustment

- **VIE_GLOB**
  - Global solution

- **VIE_SIM**
  - Simulation tool
Special parameterization: piecewise linear offsets at integer hours:

\[ x = x_1 + \frac{(t-t_1)}{(t_2-t_1)}(x_2 - x_1) \]

- \( dUT1 \)
  - 6h interval
  - \( \sim 3600 \) sessions (1984-2010.5)
Estimation of $\kappa$

- **dUT1 time series pre-processing $\rightarrow$ $\delta$UT1**
  - “clean” time series from other than tidal signal
  - only tides with periods from 5-35 days are considered for the estimation of $\kappa$

**Atmospheric excitation:**
Effective Atmospheric Angular Momentum Functions from NCEP
Estimation of $\kappa$

- Functional model

Unknown parameters: magnitude and phase for each frequency

$$\delta UT1(\omega) = -\kappa(\omega) \frac{1}{i\omega} \frac{2}{3} \frac{R^3}{GC} a_{20}(\omega)$$

Pseudo-observations “measured” by VLBI

Amplitudes and frequencies from HW95 tidal potential catalogue
Theoretical values for $\kappa$

- For a spherically symmetric Earth without oceans:
  $$\kappa = \left( \text{static} \right) k_2 = 0.300$$

- + equilibrium ocean (+ 16%)
  + completely decoupled fluid core (-11%)
  $$\kappa = 0.315$$

- Dynamic oceans, time dependent core-mantle coupling and mantle anelasticity introduce frequency dependence and phase lag:
  $$\kappa(\omega \pm \varphi)$$

Values from Chao et al. (1995)
Preliminary results

<table>
<thead>
<tr>
<th>Tidal wave Period (d)</th>
<th>6.86</th>
<th>7.10</th>
<th>9.13</th>
<th>9.56</th>
<th>13.63</th>
<th>13.66</th>
<th>14.77</th>
<th>27.56</th>
<th>31.81</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mqm</td>
<td>Msqm</td>
<td>Mtm</td>
<td>Mstm</td>
<td>Mf*</td>
<td>Mf</td>
<td>Mtm</td>
<td>Mm</td>
<td>Msm</td>
</tr>
<tr>
<td>Magnitude</td>
<td>0.315</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary and conclusions

- We re-processed VLBI sessions from 1984-2010.5 using the Vienna VLBI Software VieVS to generate a long dUT1 time series.
- dUT1 variations from 5-35 days were used to derive the zonal response coefficient $\kappa$ for various tidal frequencies.
- First results for the longer periods (> 14d) agree well with the findings of older studies, e.g. Chao et al. (1995). Most of the $\kappa$ of terms with periods <10 days seem to have smaller magnitudes with bigger phase lags, but this has to be confirmed by further investigations (because these terms also show larger formal errors).
- More detailed examination is needed, e.g. in terms of pre-processing and reliability of AAM data at short periods, before real statements about the geophysical meaning of the $\kappa$ magnitudes and phases can be made.
Thank you!
sigrid.boehm@tuwien.ac.at
Preliminary results

### Main tidal periods

<table>
<thead>
<tr>
<th>Tide</th>
<th>Period [d]</th>
<th>$\kappa$ (magn.) ± $\sigma$</th>
<th>$\kappa$ (phase) ± $\sigma$ [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mqm</td>
<td>6.86</td>
<td>0.1798 ±0.0382</td>
<td>18.77 ±12.06</td>
</tr>
<tr>
<td>Msqm</td>
<td>7.10</td>
<td>0.2857 ±0.0305</td>
<td>34.21 ±6.16</td>
</tr>
<tr>
<td>Mtm</td>
<td>9.13</td>
<td>0.3476 ±0.0039</td>
<td>8.31 ±0.63</td>
</tr>
<tr>
<td>Mstm</td>
<td>9.56</td>
<td>0.2264 ±0.0190</td>
<td>-20.65 ±4.95</td>
</tr>
<tr>
<td>Mfp</td>
<td>13.63</td>
<td>0.3049 ±0.0013</td>
<td>3.13 ±0.24</td>
</tr>
<tr>
<td>Mf</td>
<td>13.66</td>
<td>0.3147 ±0.0005</td>
<td>3.71 ±0.09</td>
</tr>
<tr>
<td>Msf</td>
<td>14.77</td>
<td>0.3297 ±0.0055</td>
<td>2.78 ±0.99</td>
</tr>
<tr>
<td>Mm</td>
<td>27.56</td>
<td>0.3073 ±0.0005</td>
<td>1.68 ±0.09</td>
</tr>
<tr>
<td>Msm</td>
<td>31.81</td>
<td>0.3373 ±0.0022</td>
<td>-0.78 ±0.38</td>
</tr>
</tbody>
</table>