High-frequency signals of oceans and atmosphere in Earth rotation

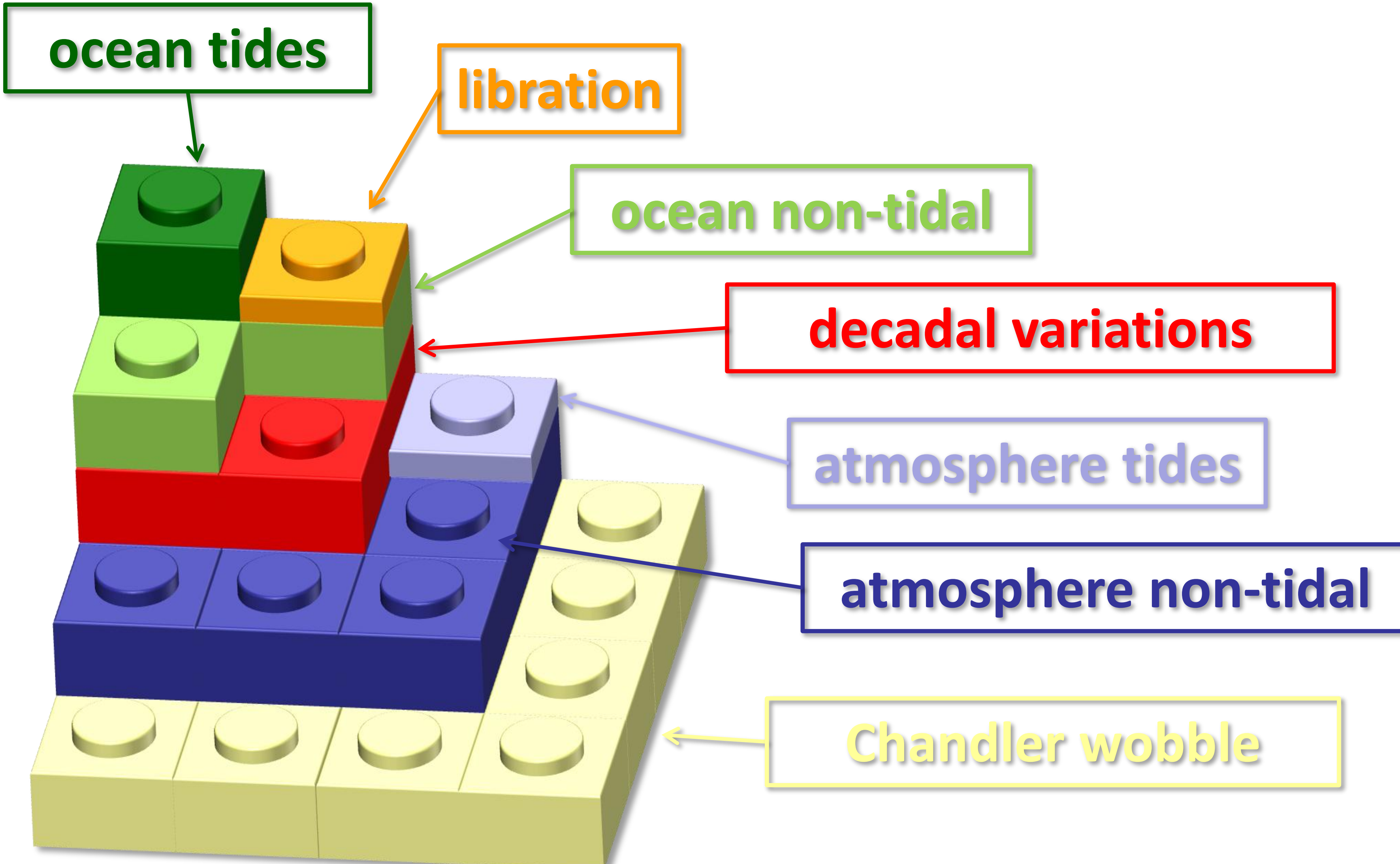
Sigrid Böhm

Tobias Nilsson

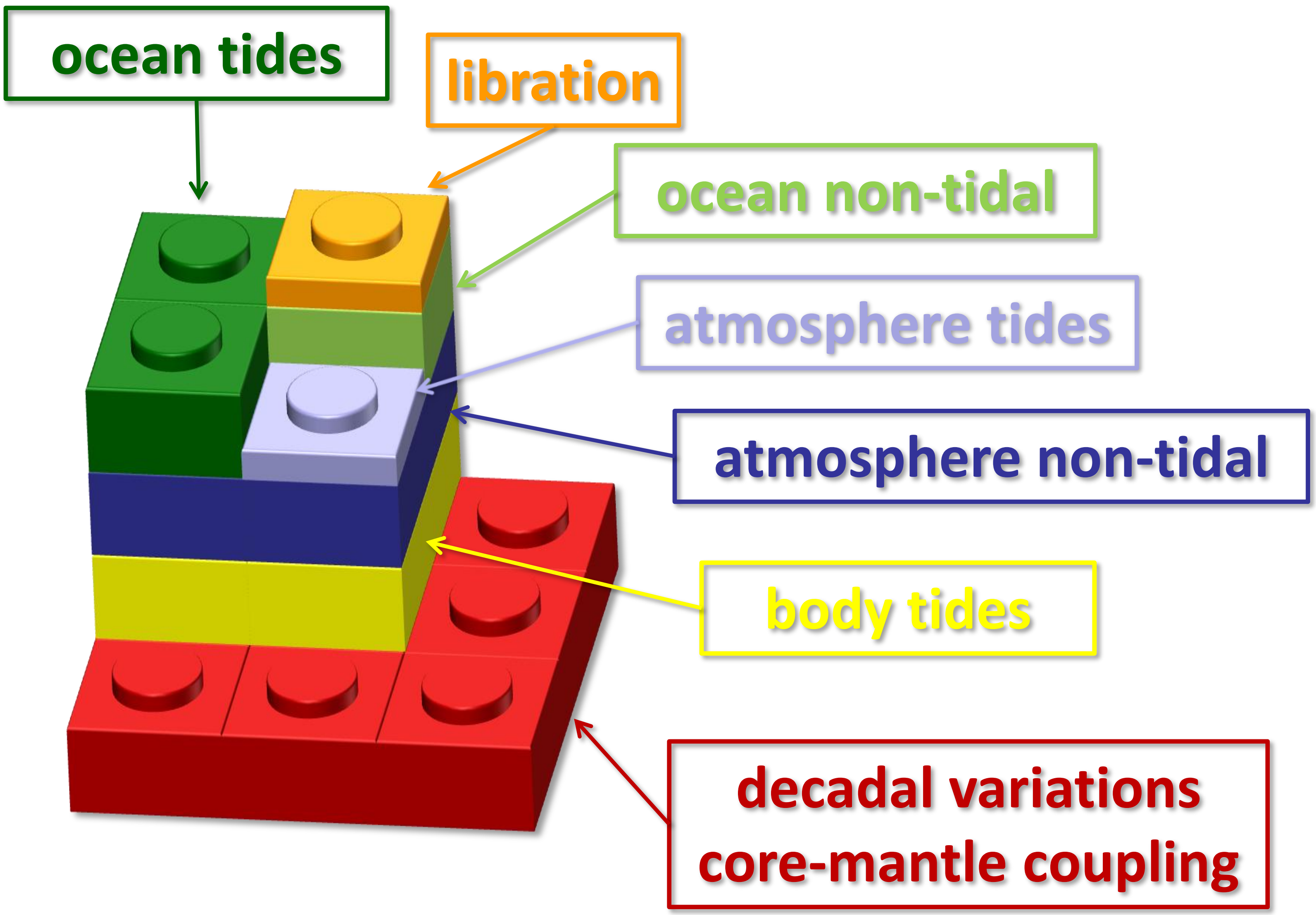
Michael Schindelegger

Harald Schuh

Periodic polar motion – composition

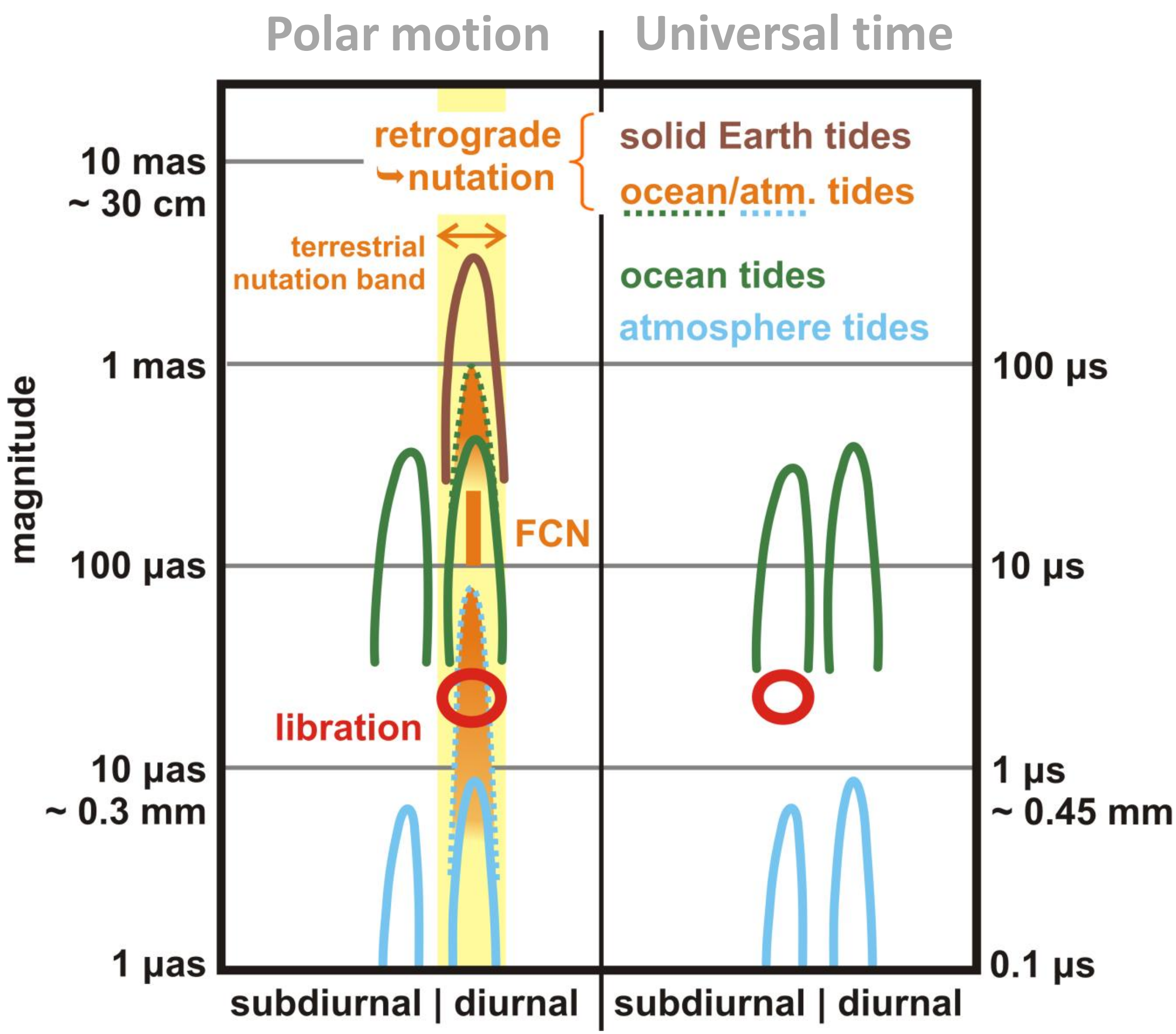


Periodic UT1/LOD – composition

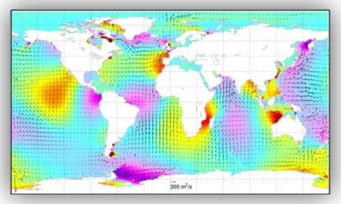


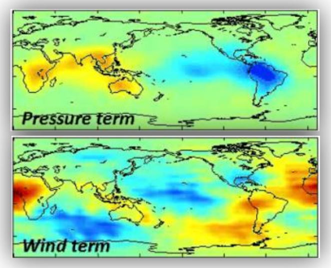
Diurnal and subdiurnal signals in Earth rotation

- 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

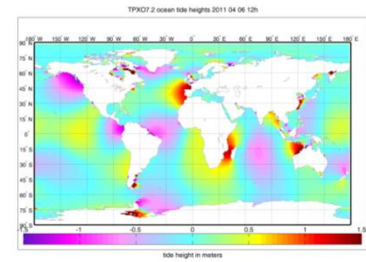
theory tidal potential

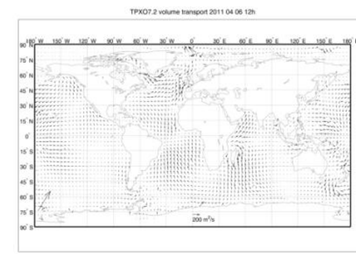
measured by ...

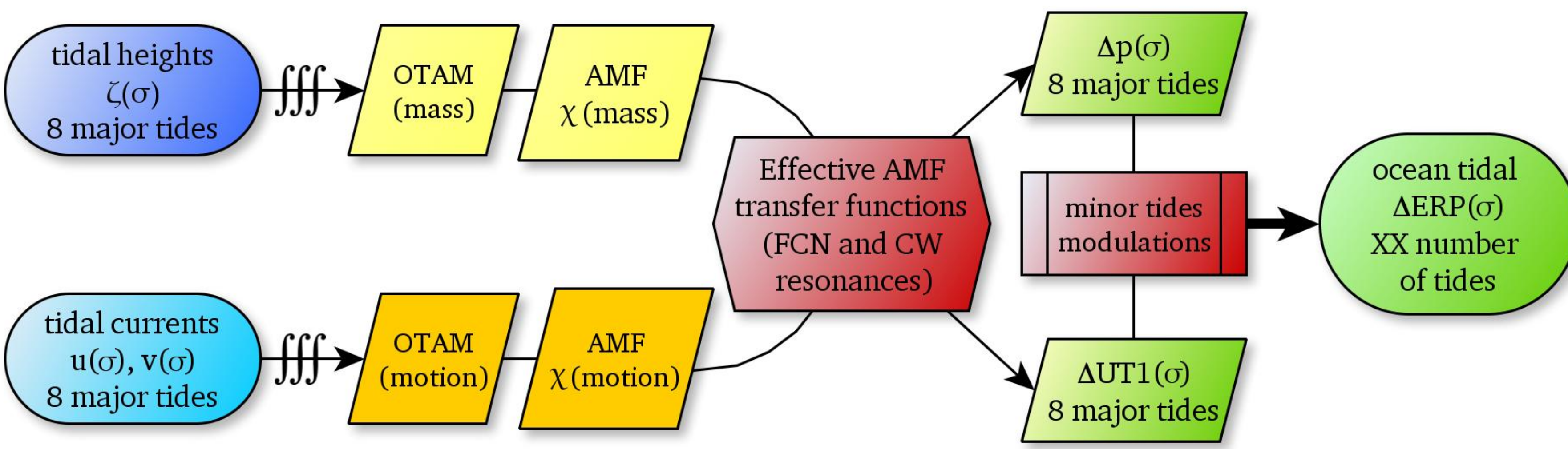
VLBI, GNSS, SLR, ringlaser ...

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

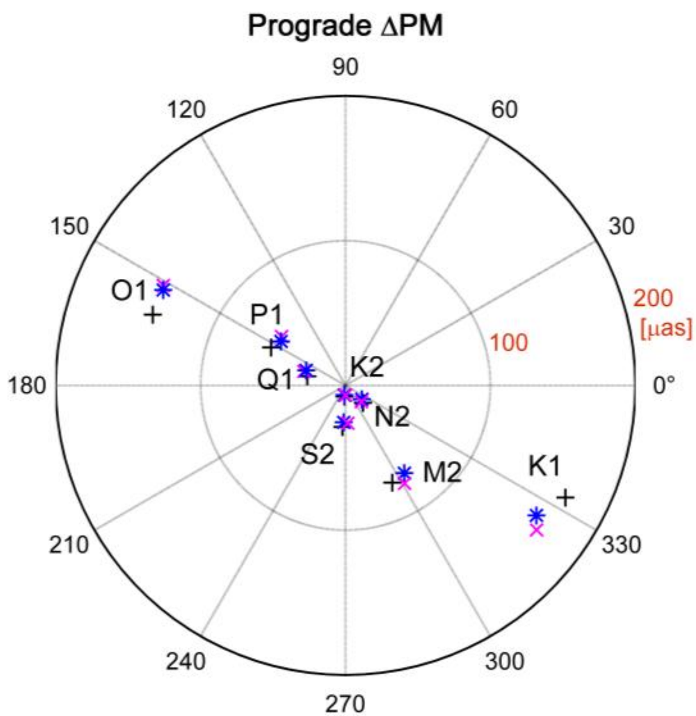
data-assimilative hydrodynamic models

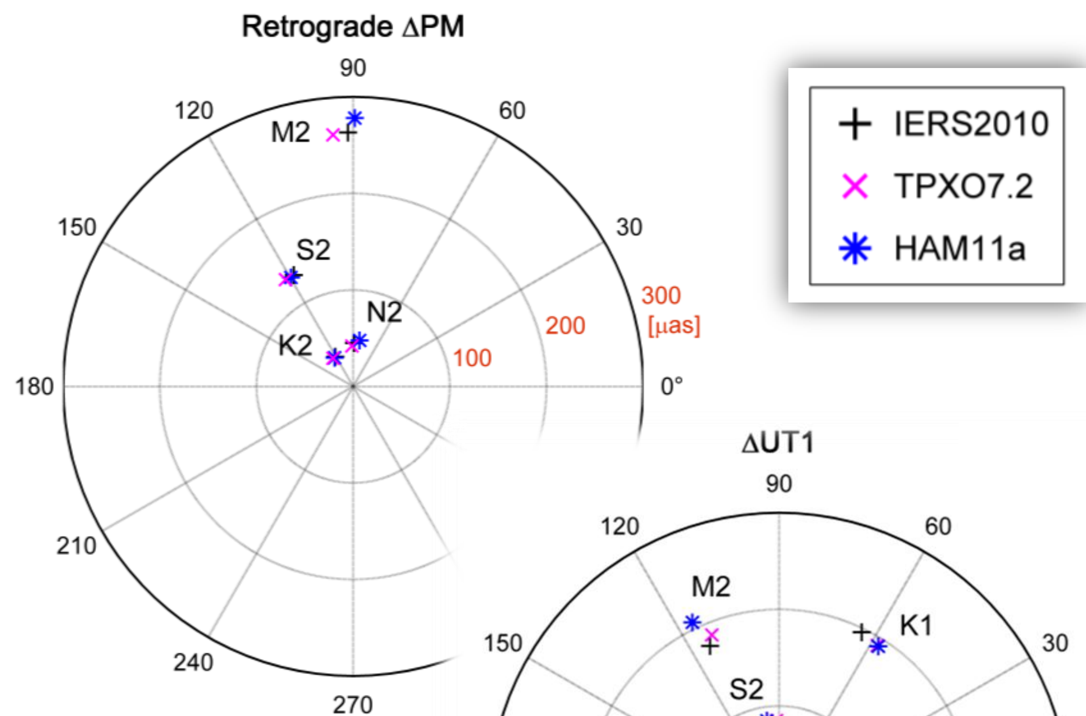


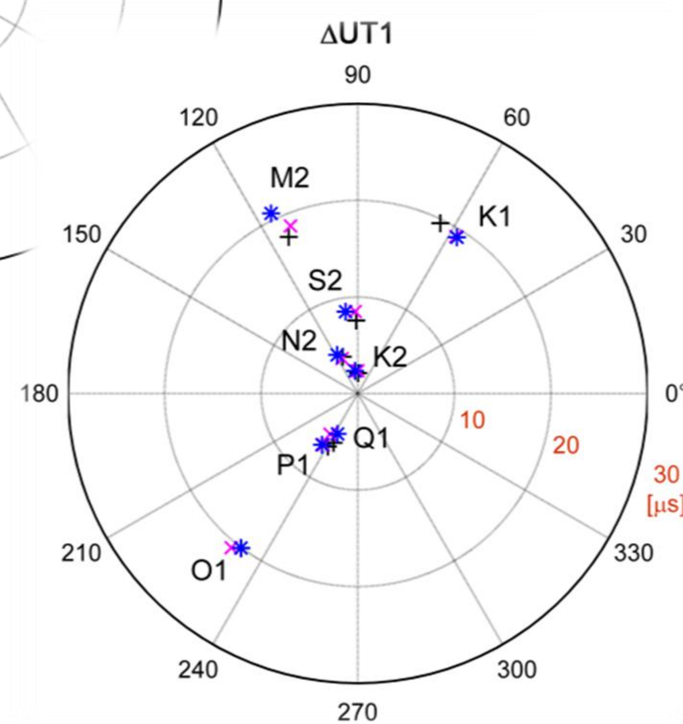




Ocean tidal Earth rotation variations major terms



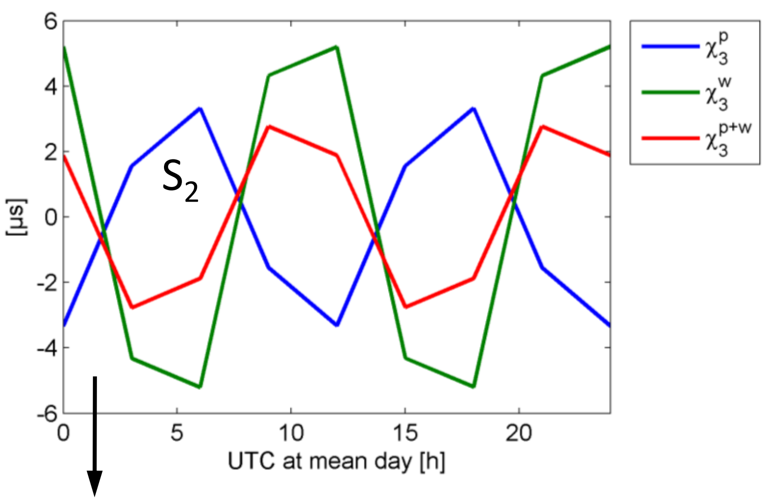




- **IERS2010**:
  based primarily on the ocean tide model TPXO.2 (1994)

Atmospheric excitation

- 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 ~ 1 µas
  - UT1: amplitudes of S1 and S2 < 0.5 µs



Pressure and wind terms partly balance each other, total net effect small

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

ERP time series

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

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

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

Tidal coefficients

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

a_{ij} ... 6 integer multipliers for each tide i

α_j ... 5 Delaunay variables *l, l′ , F, D, Ω* + (GMST+π)

as used in the IERS Conventions

High-frequency Earth rotation from VLBI

- Option 2: from demodulated ERP (complex demodulation technique, Herring & Dong (1994), Brzezinski (2012))
  - celestial pole offsets (nutation) can be estimated!
  - alternative ERP parameterisation:

$$\begin{bmatrix} x_p(t) \\ y_p(t) \end{bmatrix} = \sum_{\substack{k=-N \\ k\neq -1}}^{N} \begin{bmatrix} x_k(t) \\ y_k(t) \end{bmatrix} \cos(k\phi(t)) + \begin{bmatrix} y_k(t) \\ -x_k(t) \end{bmatrix} \sin(k\phi(t))$$

$$UT1(t) = \sum_{k=0}^{N} u_k^c(t)\cos(k\phi(t)) + u_k^s(t)\sin(k\phi(t)) \qquad \phi = GMST + \pi$$

$$k = 0 \Rightarrow \begin{bmatrix} x_0(t) \\ y_0(t) \end{bmatrix} \underbrace{\cos(0)}_{1} + \cancel{\begin{bmatrix} y_0(t) \\ -x_0(t) \end{bmatrix} \underbrace{\sin(0)}_{0}}$$

low frequency variations

k = 1...4 (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:

original frequency

$$\xi_i - \phi$$

demodulation frequency

demodulated frequency

K1 23.93h	**→**	**infinity**
O1 25.82h	→	13.66 days
S1 24.00h	→	365.25 days

Tidal coefficients

$$\underbrace{\delta UT1(t)}_{\text{diurnal}} = \cos\phi \cdot \sum_{i=1}^{n} \underbrace{\left[U_i^s \sin(\xi_i - \phi) + U_i^c \cos(\xi_i - \phi)\right]}_{u_1^c(t)} + \sin\phi \cdot \sum_{i=1}^{n} \underbrace{\left[U_i^s \cos(\xi_i - \phi) - U_i^c \sin(\xi_i - \phi)\right]}_{u_1^s(t)}$$

demodulated UT1 time series

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

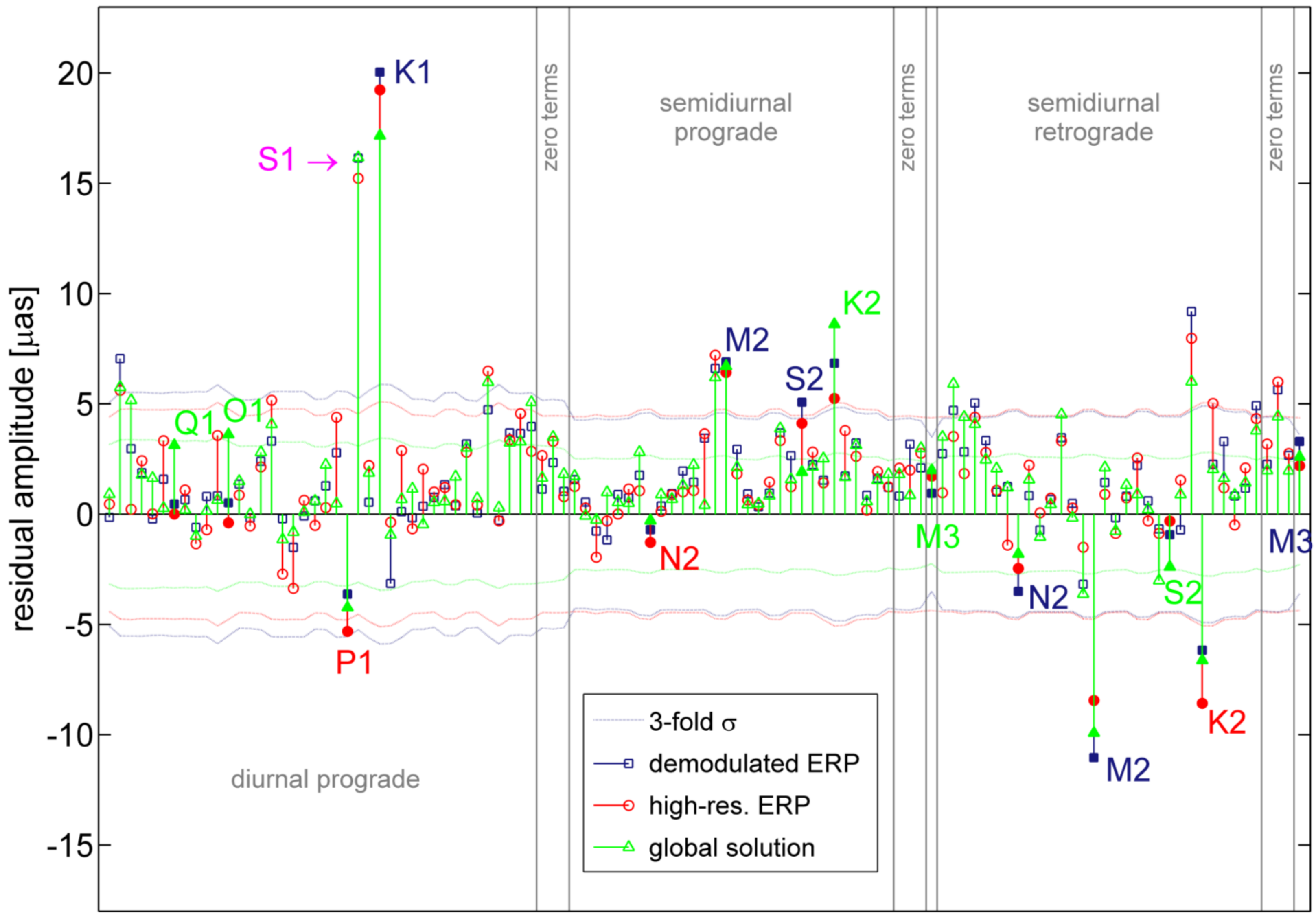
Option 1: highly resolved ERP time series

Option 2: demodulated ERP time series

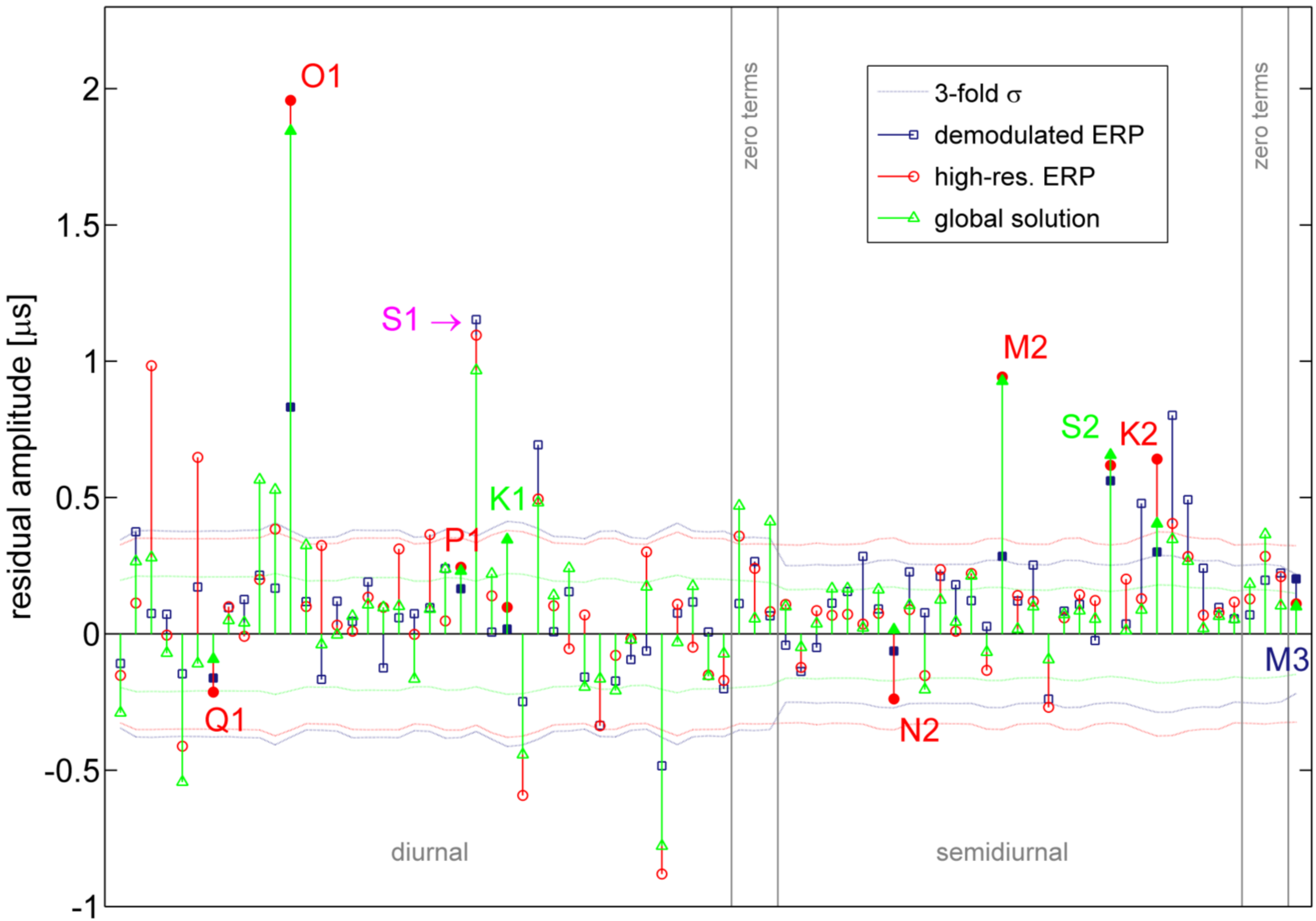
Option 3: global solution

VieVS
Vienna VLBI Software

Polar motion w.r.t. IERS2010



Universal time w.r.t. IERS2010



RMS differences in terms of coefficients*

ocean tide models

VLBI global solution

Model	IERS2010	TPXO7.2	HAM11a	VieVS 3	Artz et al.	*ERP*
IERS2010		4.05	3.47	4.60	4.90	**polar motion [µas]**
TPXO7.2	0.32		3.07	**4.21**	**4.53**	
HAM11a	0.45	0.30		5.31	5.86	
VieVS 3	0.38	**0.35**	0.41		2.31	
Artz et al.	0.38	**0.35**	0.43	0.16		
ERP	**universal time [µs]**					

empirical model from a VLBI global solution, derived with Calc/Solve Software: Artz et al. (2011), *J Geod.*

* calculated only from the terms which are part of this model

- 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.

Funded by the Austrian Science Fund, P23143-N21: “Integrated VLBI”