Separation of atmospheric, oceanic and hydrological polar motion excitation mechanisms by a combination of geometric and gravimetric space observations

F. Göttl, M. Schmidt, F. Seitz, and M. Bloßfeld
Deutsches Geodätisches Forschungsinstitut (DGFI), Munich, Germany, goettl@dgfi.badw.de

1. Introduction

The goal of our investigations is to determine accurate time series of geophysical Earth rotation excitations to study global dynamic processes in the Earth system. For this purpose, we developed an adjustment model which allows to combine precise observations from space geodetic observation systems, such as

- Satellite Laser Ranging (SLR),
- Very Long Baseline Interferometry (VLBI),
- Global Navigation Satellite Systems (GNSS),
- Doppler Orbit determination and Radiopositioning Integrated on Satellite (DORIS),
- Satellite altimetry and
- Satellite gravimetry

in order to separate geophysical excitation mechanisms of Earth rotation. We show that due to the combination the weaknesses of the individual processing strategies can be compensated and the technique specific strengths can be optimally accounted for.

2. Data Pre-Processing

Redistribution and motion of masses in the Earth system cause length-of-day variations and polar motion. Here polar motion excitation mechanisms are derived from **polar motion time series, time variable gravity field models** and **sea level anomalies** according to the computation strategies shown in Figure 1.

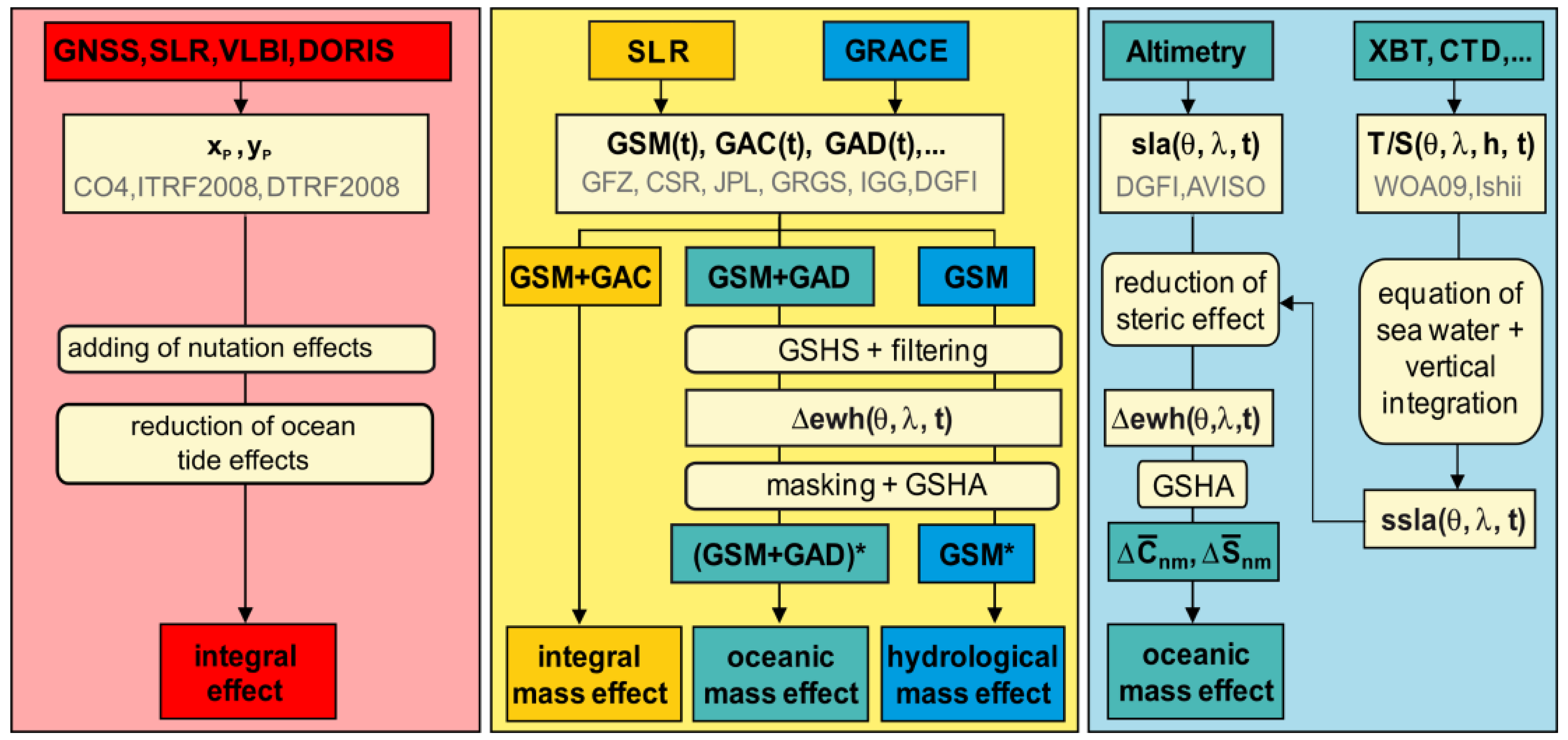

Fig. 1: Computation strategies for polar motion excitation functions from polar motion (x_P, y_P), time variable gravity fields (GSM, GAD, GAC), sea level anomalies (sla) reduced by the steric sea level anomalies (ssla) derived from temperature (T) and salinity (S) fields of the oceans. The global spherical harmonic synthesis (GSHS) and analysis (GSHA) are applied to derive equivalent water heights (Δewh) and Stokes coefficients ($\Delta\bar{C}_{n,m}$, $\Delta\bar{S}_{n,m}$).

Data Sources / Processing Centers:

Polar motion	EOP C04 08, ITRF2008, DTRF2008
ΔC_{21} and ΔS_{21}	CSR SLR RL04, DGFI SLR
Gravity field models	GFZ RL05, CSR RL05, JPL RL04, EIGEN-GRGS.RL02, ITG-Grace2010
Sea level anomalies	AVISO, DGFI

3. Adjustment model

The combination of several geodetic estimated excitation functions is based on the **linear Gauss-Markov model**. The polar motion excitation functions are indicated by $\chi^e_{j,p}(t_k)$ with $j \in \{1, 2\}$, $e \in \{A, O, H, \ldots\}$ denotes what kind of excitation mechanism is described by the excitation function and $p \in \{1, \ldots, P\}$ specifies from which processing center the data has been used. The time series of excitation functions are determined at discrete times $t = t_k$ with $k = 1, \ldots, K$ (total number of months). Using these definitions **five different observation equations** can be formulated, see Figure 2. The functional model does not consider polar motion excitations that are caused by mass displacements within the Earth core and mantle, the cryosphere and the biosphere. Thus, the so-called integral motion effect χ^{motion}_j of the functional model includes all non parameterized mass effects. The mass effects of the Earth core and mantle are very small because the geodetic estimated excitation functions do not include decadal variations due to the reduction of the linear trends. The cryospheric and biospheric mass effects are usually smaller than 0.1 mas. Therefore, we assume that χ^{motion}_j reflects the integral motion effect.

SLR, VLBI, GNSS, DORIS	$\chi^{all}_{j,p}(t_k) = \chi^A_j(t_k) + \chi^O_j(t_k) + \chi^H_j(t_k) + \chi^{motion}_j(t_k)$
SLR / GRACE	$\chi^{mass}_{j,p}(t_k) = \chi^A_j(t_k) + \chi^O_j(t_k) + \chi^H_j(t_k)$
GRACE / Altimetry	$\chi^O_{j,p}(t_k) = \chi^O_j(t_k)$
GRACE	$\chi^H_{j,p}(t_k) = \chi^H_j(t_k)$
Model	$\chi^A_{j,p}(t_k) = \chi^A_j(t_k)$

Fig. 2: Observation equations of the adjustment model which allow to combine geodetic estimated excitations (light grey) in order to estimate the atmospheric, oceanic and hydrological mass effects χ^A_j, χ^O_j and χ^H_j as well as the integral motion effect χ^{motion}_j (dark grey).

The stochastic model is based on the **empirical variances** of the geodetic estimated excitation functions which are calculated via

$$\left(\sigma^e_{j,p}\right)^2 = \frac{\sum_{k=1}^{K}\left[\chi^e_{j,p}(t_k) - \bar{\chi}^e_j(t_k)\right]^2}{K-1}$$ with $\bar{\chi}^e_j$ being the average of the P time series

and the **auto-covariances** which are computed via

$$\sigma^e_{j,p,p}(t_k, t_{k'}) = R_{j,p,p}\left(\left|t_k - t_{k'}\right|\right)\left(\sigma^e_{j,p}\right)^2$$ with $R_{j,p,p}$ being the auto-corr. function.

The stochastic model does not consider the correlations between the geodetic estimated excitation functions because they are unknown.

Reference

Göttl F. (2013): Kombination geodätischer Raumbeobachtungen zur Bestimmung von geophysikalischen Anregungsmechanismen der Polbewegung, Deutsche Geodätische Kommission, C 741, Verlag der Bayerischen Akademie der Wissenschaften

Göttl F., Schmidt M., Seitz F., Bloßfeld M.: Separation of atmospheric, oceanic and hydrological polar motion excitation mechanisms by a combination of geometric and gravimetric space observations. J Geod, submitted

Acknowledgement

The authors want to thank the German Research Foundation DFG for supporting this work within the Research Unit "Earth rotation and global dynamic processes" (FOR584).

4. Validation with geophysical model results

Figure 3 shows the adjusted results for the atmospheric, oceanic and hydrological mass effects as well as for the integral motion effect together with geophysical model results (NCEP, ECMWF, ECCO, OMCT, GLDAS, LSDM). The RMS differences and correlation coefficients not only for the adjusted geodetic results but also for the individual gravimetric and altimetric solutions are shown in Table 1. The adjusted geodetic solutions for the oceanic mass effect agree better with the oceanic model results than the single gravimetric and altimetric solutions. These improvements confirm that the combination is successfully considering the strengths of the individual space geodetic techniques.

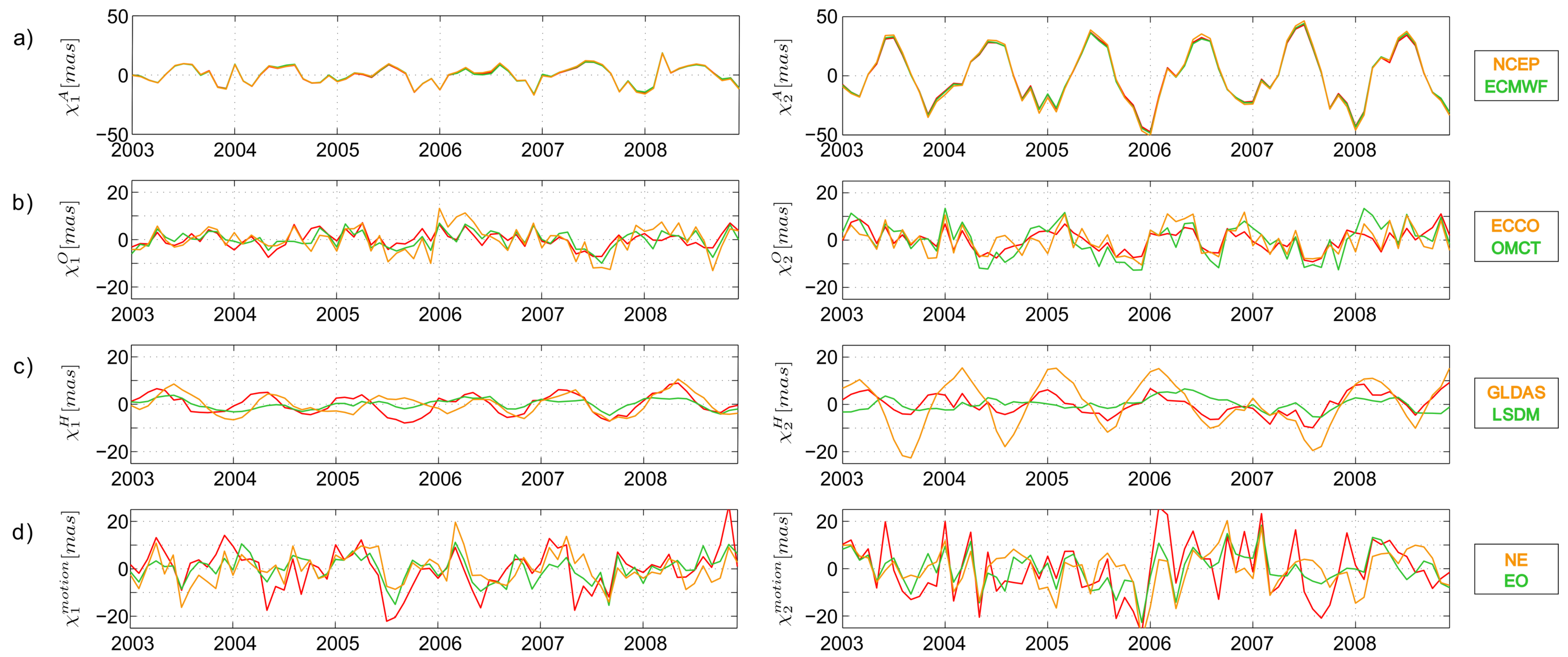

Fig. 3: Monthly polar motion excitation functions for the (a) atmospheric, (b) oceanic and (c) hydrological mass effects as well as the (d) integral motion effect: Adjusted geodetic results (red), model solutions (orange and green).

	model	mean grav.	mean alti.	adjust. results
χ_1^A	NCEP			0.39 / 1.00
	ECMWF			0.54 / 1.00
χ_1^O	ECCO	4.23 / 0.54	4.63 / 0.37	2.53 / 0.73
	OMCT	5.34 / 0.49	5.77 / 0.37	4.22 / 0.65
χ_1^H	GLDAS	3.47 / 0.65		3.18 / 0.67
	LSDM	4.23 / 0.51		4.06 / 0.51
χ_1^m	NE			6.31 / 0.68
	EO			7.65 / 0.52

	model	mean grav.	mean alti.	adjust. results
χ_2^A	NCEP			0.89 / 1.00
	ECMWF			2.23 / 1.00
χ_2^O	ECCO	6.06 / 0.59	5.37 / 0.66	4.31 / 0.82
	OMCT	4.90 / 0.66	5.66 / 0.50	4.06 / 0.73
χ_2^H	GLDAS	4.73 / 0.25		4.54 / 0.23
	LSDM	7.73 / 0.66		7.10 / 0.77
χ_2^m	NE			7.92 / 0.76
	EO			10.69 / 0.49

Tab. 1: RMS differences [mas] / correlation coefficients between geodetic and model solutions for polar motion excitations. The integral motion effect χ^m_j can be estimated from the model combinations NCEP and ECCO (NE) as well as ECMWF and OMCT (EO).

The formal errors of the adjusted geodetic solutions are significantly smaller than the RMS differences of the geophysical model solutions. Thus the individual polar motion excitations can be estimated more precisely due to combination of precise geodetic observations than by geophysical models:

- χ^A_j: factor 1.1 better than model estimates,
- χ^O_j: factor 1.8 better than model estimates,
- χ^H_j: factor 3.0 better than model estimates,
- χ^{motion}_j: factor 2.2 better than model estimates.

The improved excitation time series can be used to learn more about global dynamic processes in the Earth system and to improve the geophysical modelling.

EGU General Assembly 2014, Vienna, 27 April – 02 May 2014