Geodetic hydrological excitation functions by different atmosphere and ocean models and comparison with hydrological excitation functions and GRACE solutions

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Objectives

Here, we compare the results of several geodetic hydrological excitation functions GAO, that are calculated by removing modeled atmospheric m(AAM) and oceanic (OAM) effects from precise observations of full polar motion excitation (GAM). These geodetic residuals are compared to each other and with hydrological excitation function determined from hydrological model and Gravity Recovery and Climate Experiment (GRACE) satellite mission. We analyze the polar motion budget at seasonal, and short term oscillations for a most often used models of atmosphere and oceans considered the global mass balance inside AAM, OAM, and HAM excitation functions using follwoing approach:

$$GAM - AAM - OAM \; vs. \; HAM + SLAM \; vs. \; GRACE \tag{1}$$

Models and data description

The following materials were required to complete the research:

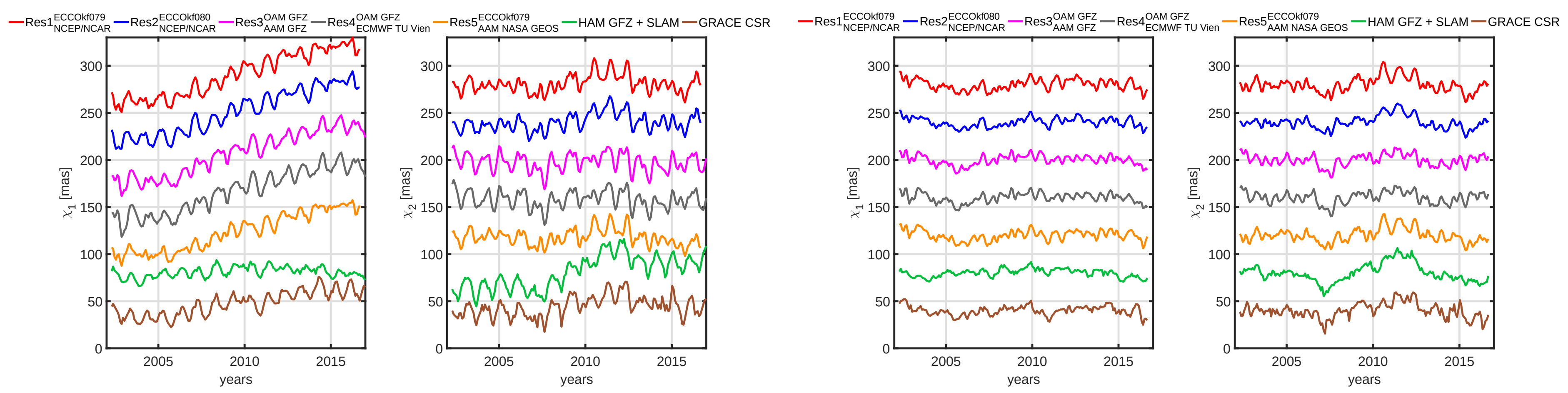
- **GAM observed polar motion excitations**:
  - obtained from International Earth Rotation and Reference System Service (IERS) C04 series of polar motion;
- **Atmospheric Angular Momentum (AAM) models:**
  - National Center for Environmental Prospect/National Center for Atmospheric Research (NCEP/NCAR) reanalysis model provided by the Sub-bureau for the Atmosphere of Global Geophysical Fluids Centre with IB correstions;
  - European Centre for Medium-Range Weather Forecasts (ECMWF)- the data provided by Technische Universität Wien (TU Wien); official product of the IERS.
  - NASA GEOS AAM model - 4D output of numerical weather model GEOS-FPIT, run by the NASA The Global Modeling and Assimilation Office (GMAO), the data are available here `http://alt.aam.earthrotation.net/`
  - Effective Atmospheric Angular Momentum (EAAM) of matter and motion terms, obtained from GeoForschungsZentrum (GFZ); official product of the IERS.
- **Oceanic Angular Momentum (OAM) models:**
  - The the Jet Propulsion Laboratory (JPL) ocean models, ECCO kf079 (ocean model - without data assimilation) and ECCO kf080 (ocean model includes altimetric measurements of sea surface height and expendable bathythermograph (XBT) data), assimilation; product of the IERS Special Bureau for the Oceans.
  - Effective Angular Momentum Functions (EAMF) of the ocean were calculated from 6 - hourly Max Planc Institute Ocean Model (MPIOM) and was obtained from the GFZ Research Center.
- **GRACE solutions and HAM excitations:**
  - GRACE GSM CSR, total gravity variability due to land surface hydrology, cryospheric changes, episodic (earthquake) processes, glacial isostatic adjustment (GIA), and corrections to the background models for atmospheric and oceanic processes, `(http://isdc.gfz-potsdam.de/grace`
  - HAM GFZ, daily product, model LSDM: forcing: 2-m temperature, precipitation (product of EAM from GFZ)
  - SLAM, sea level mass balance, atmosphere and terrestrial mass exchange (product of EAM from GFZ).

We determined five combined geodetic residuals models as following: $Res1^{ECCOkf079}_{NCEP/NCAR}$, $Res2^{ECCOkf080}_{NCEP/NCAR}$, $Res3^{OAMGFZ}_{AAMGFZ}$, $Res4^{OAMGFZ}_{ECMWFTUVien}$, $Res5^{ECCOkf079}_{AAMNASAGEOS-FPIT}$.

Methodology

The study contains the following analyses of geodetic residuals, HAM GFZ and GRACE time series: 1) the comparison of seasonal and non-seasonal oscillations of all considered functions , 2) the study of seasonal components of geodetic residuals and hydrological excitation functions in terms of their annual amplitudes and phases (prograde and retrograde oscillations), 3) the variance explained coefficients between nonseasonal components of HAM LSDM + SLAM and geodetic residuals and GRACE excitation function, 4) correlation coefficients between HAM LSDM + SLAM excitation functions of polar motion and geodetic residuals and GRACE excitation.

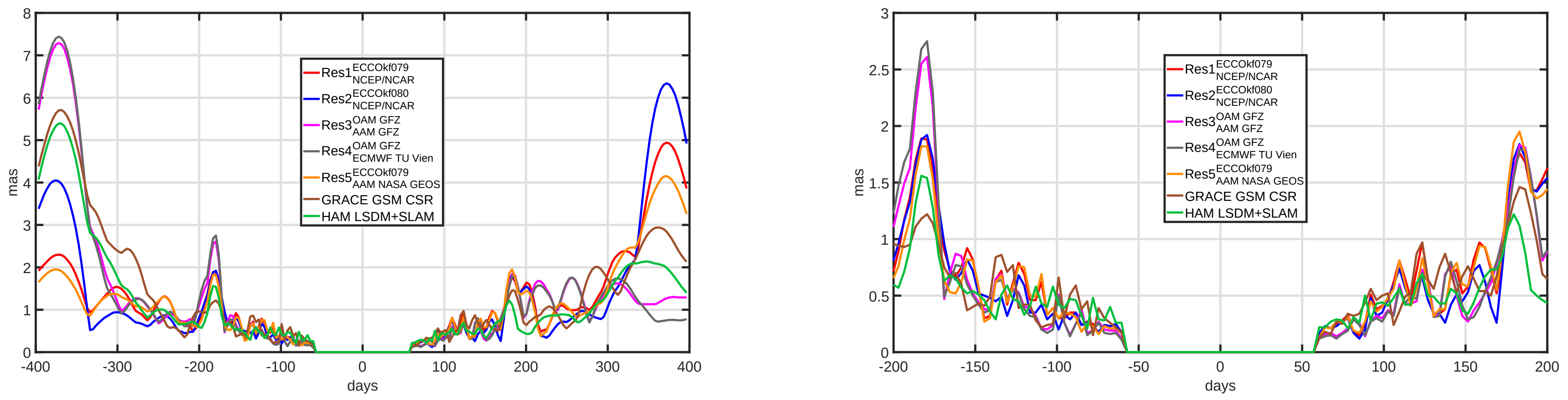
Results and analysis



(a) (b)

Figure 1: Comparison of the components, χ_1 and χ_2, of the various geodetic residuals GAO, $Res1^{ECCOkf079}_{NCEP/NCAR}$, $Res2^{ECCOkf080}_{NCEP/NCAR}$, $Res3^{OAMGFZ}_{AAMGFZ}$, $Res4^{OAMGFZ}_{ECMWFTUVien}$, $Res5^{ECCOkf079}_{AAMNASAGEOS-FPIT}$, with each other and with HAM GFZ hydrological excitation functions and GRACE gravitation hydrological excitation functions. The mean values were removed, the Gauss filter with the parameter FWHM$=60$ were applied to each time series (1a, 1b), the seasonal components with the periods of 365.25, 180.00 and 120.00 days and the second order polynomial were removed from each time series(1b)

Seasonal oscillations



(a) (b)

Figure 2: Fourier Transform Band Pass Filter (FTBPF) amplitude spectra of the different complex geodetic hydrological excitation functions of polar motion and gravimetric and hydrological excitation function; (2a) strong annual signal remains after removing AAM and OAM excitations from geodetic observations GAM, as well as strong annual signal in retrograde part of polar motion for HAM LSDM+SLAM and GRACE excitations is observed; (2b) 180.0 days oscillations remain in prograde and retrograde geodetic residuals ans well as HAM LSDM+SLAM and GRACE excitations.

Table 1: Amplitudes and phases of annual prograde and retrograde oscillations of different geodetic residuals GAO and HAM and GRACE excitation functions. Phase ϕ is defined here by the annual term as $sin(2\pi(t-t_0)+\phi)$, where t_0 is a reference epoch for January 1 2002. For seasonal oscillations, the excitations of $HAMLSDM$ and $Res3^{OAMGFZ}_{AAMGFZ}$ agree quite well with each other because of the consistency of mass resulting from couplet global circulation model of the hydro-atmosphere.

	Annual amplitudes		Annual phases	
	Prograde amplitudes [mas]	Retrograde amplitudes [mas]	Prograde phases [deg]	Retrograde phases [deg]
Res1(NCEP/NCAR, ECCOkf079)	4.88 ± 0.46	1.67 ±0.38	-42 ± 5	115 ±9
Res2(NCEP/NCAR, ECCOkf080	6.27 ± 0.61	3.45 ±0.61	-40 ±19	119 ±4
Res3(AAM GFZ, OAM GFZ)	1.00 ±0.55	7.95 ±0.59	58 ±4	157 ±3
Res4(ECMWF TU Vien, OAM GFZ)	0.68 ± 0.43	8.23 ±0.36	-95 ±4	171 ±2
Res5(AAM NASA GEOS, ECCOkf079)	4.10 ±0.43	2.02 ±0.42	-54 ±6	146 ±3
HAM GFZ + SLAM	2.69 ±0.45	6.54 ±0.60	68±6	133 ±5
GRACE GSM CSR	2.45 ±0.39	3.32 ±0.53	-20±6	144 ±6

Nonseasonal oscillations

Table 2: Comparison of the nonseasonal hydrological excitation function of polar motion and geodetic residuals from different models of AAM and OAand GRACE excitations of polar motion. The seasonal - polynomial model has been removed from each time series. Variance explained means the coefficients $100\%\times[var(HAM)-var(HAM-Res_n)]/var(HAM)$.

HAM LSDM+SLAM vs.	Variance explained [%]	
	$\chi 1$	$\chi 2$
Res1(NCEP/NCAR, ECCOkf079)	89	54
Res2(NCEP/NCAR, ECCOkf080)	60	61
Res3(AAM GFZ, OAM GFZ)	58	40
Res4(ECMWF TU Vien, OAM GFZ)	60	38
Res5(AAM NASA GEOS, ECCOkf079)	101	58
GRACE GSM CSR	38	64

Table 3: Correlation coefficients of the different geodetic residuals GAO and gravimetric excitation function with HAM LSDM+SLAM excitation function of polar motion. The seasonal - polynomial model has been removed from each time series. Statistical significance p=0.3.

HAM LSDM+SLAM vs.	Standard deviations [mas]		Correlation coefficients	
	$\chi 1$	$\chi 2$	$\chi 1$	$\chi 2$
HAM LSDM+SLAM	4.29	9.79	1.00	1.00
Res1(NCEP/NCAR, ECCOkf079)	5.76	7.89	0.34	0.74
Res2(NCEP/NCAR, ECCOkf080)	4.92	7.89	0.32	0.78
Res3(AAM GFZ, OAM GFZ)	5.33	6.26	0.38	0.63
Res4(ECMWF TU Vien, OAM GFZ)	5.21	6.46	0.37	0.62
Res5(AAM NASA GEOS, ECCOkf079)	5.45	7.40	0.24	0.76
GRACE GSM CSR	5.00	8.13	0.42	0.80

Conclusion

We detected that $\chi 1$ and χ_2 components of of geodetic residuals and HAM excitations (from model and GRACE observations), in seasonal and non-seasonal oscillations, are considerably different. For seasonal oscillations the agreement between geodetic residuals and HAM LSDM +SLAM and GRACE observations excitations is better than for non-seasonal oscillations.

The major conclusion of this study is that the hydrological signals in polar motion, studied here as differences between observed geodetic angular momentum and a sum of atmospheric and oceanic angular momentum from different AAM and OAM models, should be improved to achieve full consistency between different geodetic residuals and hydrological angular momentum functions as well, especially in non-seasonal part of oscillations.

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