The analysis of geodetic residuals based on recent gravity, atmosphere and ocean models

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Introduction (1/3)

- The changes in orientation of the Earth's rotational axis, known as polar motion, is excited by constantly changing mass distribution in the geophysical fluids (atmosphere, ocean, land hydrosphere). This mass redistribution movements excite the Earth's rotational changes primarily at seasonal and shorter time scales.
- An assessment of the impact of hydrological effects on polar motion is based on the determination of geodetic residuals (**GAO**). Being difference between Geodetic Angular Momentum (**GAM**) and the sum of Atmospheric and Oceanic Angular Momentum (**AAM** and **OAM**, respectively), geodetic residuals reflect hydrological signals in observed polar motion excitation.
- However, while **GAM** is determined from precise geodetic measurements, **AAM** and **OAM** are based on different models of atmosphere and ocean. The mass terms of **AAM** and **OAM**, related to air pressure and ocean bottom pressure, as well as motion terms connected with wind speed and currents, vary from one model to another. Consequently, the errors of geodetic residuals are mainly related to inaccurate geophysical models.

Introduction (2/3)

- Up to now studies of geophysical excitations of polar motion containing **AAM**, **OAM** and **HAM** excitations have not achieved full agreement between geophysical and determined geodetic excitation functions of polar motion.
- Studies of the sum of AAM and OAM bring the modelled excitation of polar motion closer to observed one, but do not entirely explain the observed variations of polar motion determined by geodetic techniques. The remaining power might be provided by other geophysical processes, like changes in land water storage, earthquakes, and others.
- Quantitave assessment of the hydrological effects on polar motion persists unclear because of the lack of global observations as well as differences between various atmospheric and oceanic models.

Introduction (3/3)

- Here, we analyse the hydrological effects on polar motion excitation in the two ways:
  1. First, we compare the three estimates of geodetic hydrological excitation functions, that are computed by removing modelled atmospheric and oceanic effects from precise observations of polar motion excitations.
  2. Secondly, we compare the resulting geodetic residuals with hydrological excitation functions based on: Gravity Recovery and Climate Experiment (GRACE) satellite mission (RL05 and new RL06 solutions) and a combination of the hydrological model LSDM and sea-level angular momentum SLAM (HAM GFZ + SLAM). These analyses are carried out at seasonal and non-seasonal time scales.

Data (1/6)

The following data sets were required to complete this research:

- **Geodetic Angular Momentum (GAM)** - observed geodetic polar motion excitations χ_1 and χ_2:

❑ obtained from International Earth Rotation and Reference System Service (IERS) C04 series of polar motion;

Data (2/6)

The following data sets were required to complete this research:

- **Atmospheric Angular Momentum (AAM)** ; **χ_1 and χ_2**

- **National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR)** model which is provided by the Special Bureau for the Atmosphere (SBA) of Global Geophysical Fluids Centre (GGFC). The series are in the form of mass and motion terms of atmospheric excitation functions (Cequatorial components) and they have temporal resolution of 6 hours.
- **European Centre for Medium-range Weather Forecasts (ECMWF)** model that was used by scientists from GeoForschungsZentrum (GFZ) for computation of mass and motion terms of atmospheric excitation functions (χ_1 and χ_2 equatorial components) as GFZ's contributions to the GGFC. These series are available at 3-hour intervals.

For both models mass excitation accounts for an inverted barometer (IB) response of the ocean to the atmospheric pressure.

Data (3/6)

The following data sets were required to complete this research:

- **Oceanic Angular Momentum (OAM); χ_1 and χ_2**

- **ECCO_v4r3_noFWF** model that is run at the Jet Propulsion Laboratory (JPL) and available through the IERS Special Bureau for the Oceans (SBO). The data set consists of mass and motion terms of oceanic excitation function (χ_1 and χ_2 equatorial components) provided at hourly intervals. The model is forced with data from ERA-Interim atmospheric model.
- **Max Planck Institute Ocean Model (MPIOM)** that was used by scientists from GeoForschungsZentrum (GFZ) for computation of mass and motion terms of oceanic excitation functions (χ_1 and χ_2 equatorial components) as GFZ's contributions to the GGFC. These series are available at 3-hour intervals. The model is forced with data from ECMWF atmospheric model.

Data (4/6)

The following data sets were required to complete this research:

- **Joint AAM and OAM models from GRACE**

χ_1 and χ_2 equatorial components computed from

❑ **GAC JPL RL06 -** GRACE degree-2 non-tidal atmosphere and ocean geopotential coefficients

Data (5/6)

The following data sets were required to complete this research:

- **Hydrological Angular Momentum (HAM) χ_1 and χ_2 computed from**

- **GRACE JPL RL05**, RL05 time series of monthly time-variable gravity field estimates from GRACE observations;
- **GRACE JPL RL06**, RL06 series of monthly time-variable gravity field estimates from GRACE observations;
- **GRACE CSR RL05**, RL05 time series of monthly time-variable gravity field estimates from GRACE observations;
- **GRACE CSR RL06**, RL06 time series of monthly time-variable gravity field estimates from GRACE observations;

- **LSDM + SLAM**, Land Surface Discharge Model LSDM + Sea-level angular momentum SLAM provided by the GFZ Potsdam.

Data (6/6)

Geodetic residuals χ_1 and χ_2

Three series of geodetic residuals, being the differences between GAM and the following combinations of AAM and OAM:

- **GAO1 =** GAM - [AAM(NCEP/NCAR) + OAM(ECCO_v4r3_noFWF)]
- **GAO2 =** GAM - [AAM(ECMWF) + OAM (MPIOM)]
- **GAO3 =** GAM - [GAC JPL RL06 + motion terms of AAM and OAM obtained from ECMWF and MPIOM, respectively)]

Results (1/6)

Seasonal oscillations

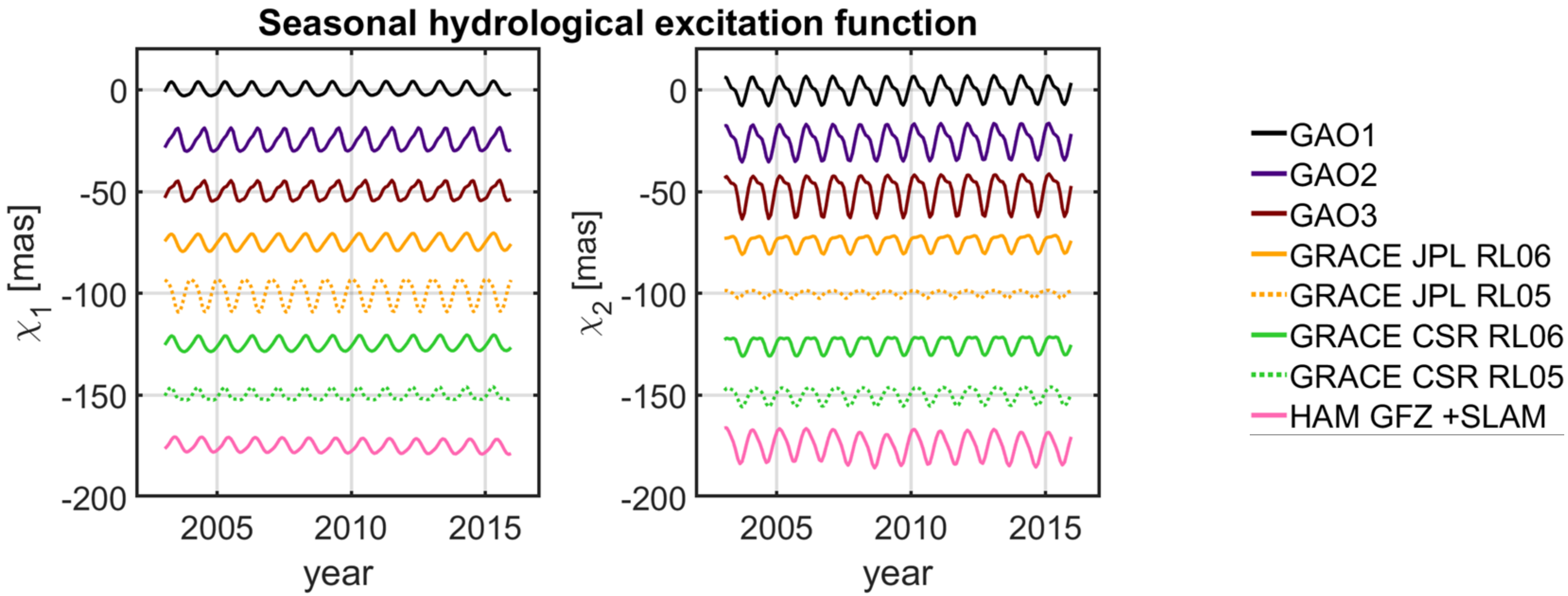

Figure 1 Seasonal hydrological excitation functions, χ_1 and χ_2 components, computed: as geodetic residuals GAO=GAM-AAM-OAM, from GRACE RL05 and GRACE RL06 solutions, from LSDM hydrological model with sea-level angular momentum correction (HAM GFZ + SLAM).

Results (2/6)

Seasonal oscillations

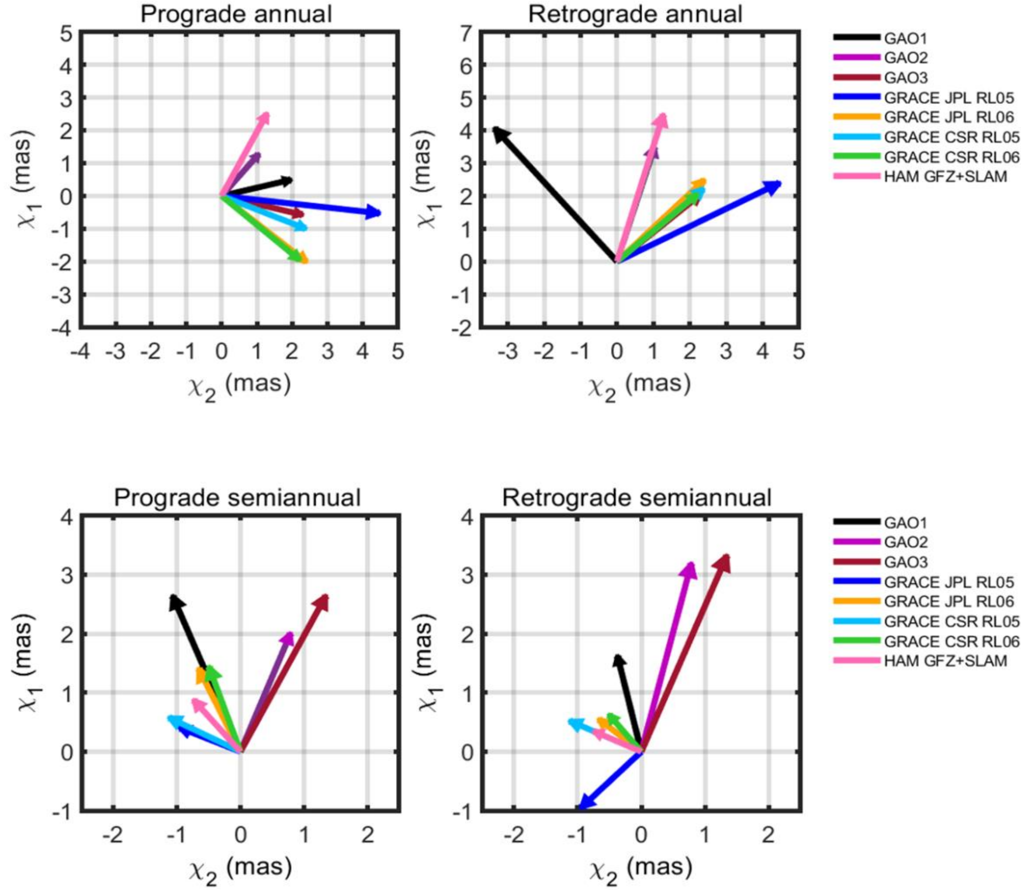

Figure 2 Amplitudes and phases of annual and semiannual oscillations of hydrological excitation functions, computed: : as geodetic residuals GAO=GAM-AAM-OAM, from GRACE RL05 and GRACE RL06 solutions, from LSDM hydrological model with sea-level angular momentum correction (HAM GFZ + SLAM).

Results (3/6)

Nonseasonal oscillations

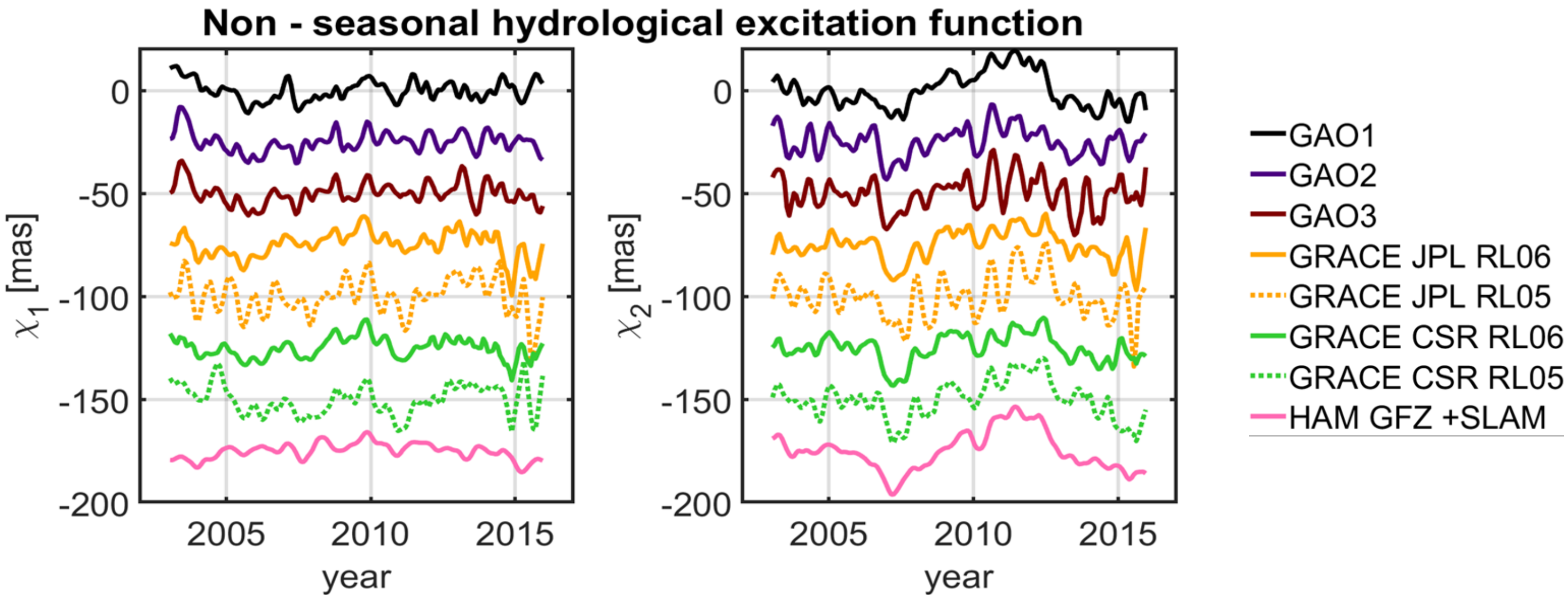

Figure 3 Non-seasonal hydrological excitation functions, χ_1 and χ_2 components, computed: as geodetic residuals GAO=GAM-AAM-OAM, from GRACE RL05 and GRACE RL06 solutions, from LSDM hydrological model with sea-level angular momentum correction (HAM GFZ + SLAM).

Results (4/6)

Nonseasonal oscillations – correlation coefficients for χ_1

Table 1 Correlation coefficients of non-seasonal components χ_1 between various geodetic residuals, hydrological excitation functions from GRACE solutions and from HAM GFZ + SLAM model

χ_1	GAO1	GAO2	GAO3	GRACE JPL RL05	GRACE JPL RL06	GRACE CSR RL05	GRACE CSR RL06	HAM GFZ+ SLAM
GAO1	1	0.64	0.62	0.45	0.76	0.70	0.83	0.71
GAO2	-	1	0.98	0.42	0.69	0.44	0.69	0.45
GAO3	-	-	1	0.47	0.71	0.46	0.71	0.43
GRACE JPL RL05	-	-	-	1	0.63	0.72	0.67	0.43
GRACE JPL RL06	-	-	-	-	1	0.69	0.91	0.62
GRACE CSR RL05	-	-	-	-	-	1	0.63	0.43
GRACE CSR RL06	-	-	-	-	-	-	1	0.62
HAM GFZ+SLAM	-	-	-	-	-	-	-	1

Results (5/6)

Nonseasonal oscillations – correlation coefficients for χ_2

Table 2 Correlation coefficients of non-seasonal components χ_2 between various geodetic residuals, hydrological excitation functions from GRACE solutions and from HAM GFZ + SLAM model

χ_2	GAO1	GAO2	GAO3	GRACE JPL RL05	GRACE JPL RL06	GRACE CSR RL05	GRACE CSR RL06	HAM GFZ+ SLAM
GAO1	1	0.75	0.64	0.50	0.76	0.83	0.75	0.88
GAO2	-	1	0.95	0.75	0.87	0.80	0.87	0.78
GAO3	-	-	1	0.76	0.83	0.80	0.82	0.78
GRACE JPL RL05	-	-	-	1	0.75	0.77	0.75	0.52
GRACE JPL RL06	-	-	-	-	1	0.89	0.97	0.85
GRACE CSR RL05	-	-	-	-	-	1	0.75	0.52
GRACE CSR RL06	-	-	-	-	-	-	1	0.85
HAM GFZ+SLAM	-	-	-	-	-	-	-	1

Results (6/6)

Nonseasonal oscillations – relative explained variance for χ_2 and χ_2

Table 3 Percentage of relative variance of non-seasonal GAO oscillations explained by different hydrological functions of polar motion.

Variance explained of GAO1	χ_1	χ_2	Variance explained of GAO2	χ_1	χ_2	Variance explained of GAO3	χ_1	χ_2
GAO2	28%	53%	GAO1			GAO1		
GAO3	24%	32%	GAO3	96%	90%	GAO2		
GRACE JPL RL05	-98%	-8%	GRACE JPL RL05	-107%	40%	GRACE JPL RL05	-91%	45%
GRACE JPL RL06	41%	56%	GRACE JPL RL06	26%	74%	GRACE JPL RL06	30%	67%
GRACE CSR RL05	23%	65%	GRACE CSR RL05	-39%	55%	GRACE CSR RL05	-33%	41%
GRACE CSR RL06	54%	53%	GRACE CSR RL06	20%	75%	GRACE CSR RL06	24%	66%
HAM GFZ+SLAM	51%	67%	HAM GFZ+SLAM	14%	35%	HAM GFZ+SLAM	12%	7%

Summary and conclusions (1/2)

- Here we compare monthly variability in the components of different geodetic residuals time series, reflecting changes in the hydrological signal in polar motion:
  - ❑ with respect to each other ,
  - ❑ with the hydrological excitations from the new GRACE CSR and JPL RL06 solutions ,
  - ❑ with previous GRACE CSR and JPL RL05 solutions,
  - ❑ with the HAM GFZ+SLAM hydrological model.
- Last results are promising and indicate a significant correlation between GRACE RL06 -derived excitation and a corresponding excitation from geodetic observations in non-seasonal part of spectrum. However, there is still no satisfactory amplitude compatibility.

Summary and conclusions (2/2)

- The highest improvement of RL06 solution in relative to RL05 is observed for JPL series.
- In contrast to the previous results, there is a good consistency between gravimetric excitation functions derived from JPL RL06 and CSR RL06.
- The choice of combination of atmospheric and oceanic models used for the determination of geodetic residuals has significant impact on the amplitudes and phases of the resulting seasonal oscillations.
- On the other hand, in the non seasonal part of spectrum, the combination of AAM+OAM has no significant influence on the level of correlation with the GRACE based series, but meaningful impact on the agreement in amplitudes.

Thank you