Mass and motion terms of atmospheric and oceanic angular momentum contributions to polar motion excitation

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Introduction

Motion of the Earth's pole is excited by processes internal to the Earth system - continually changing mass distribution in the geophysical fluids, atmosphere, ocean, and land hydrology. The mass redistribution and its movements within the Earth system excite the Earth's rotational changes mainly at seasonal or shorter timescales. The importance of atmospheric and oceanic angular momentum signals for polar motion excitation at seasonal and interannual timescales is well known. However, previous studies showed that the AAM due to pressure changes and winds, provided from different models, are slightly different, especially in χ_1 component. The differences between various representations of ocean-bottom pressure and currents from different OAM models are apparent too.

An important technique for understanding Earth's rotational changes is the comparison of mass and motion terms of Atmospheric and Oceanic Angular Momentum from different models of AAM and OAM, which also leads to an assessment of their uncertainties, particularly in polar motion excitation.

The main goal of this study is to extend the present understanding of the problem of inconsistency of mass and especially motion terms of different AAM and OAM models at seasonal time scales, as well as trying to explain the observed variations of polar motion determined by geodetic techniques. The errors in both AAM and OAM time series were calculated using different statistical methods.

Data and methodology

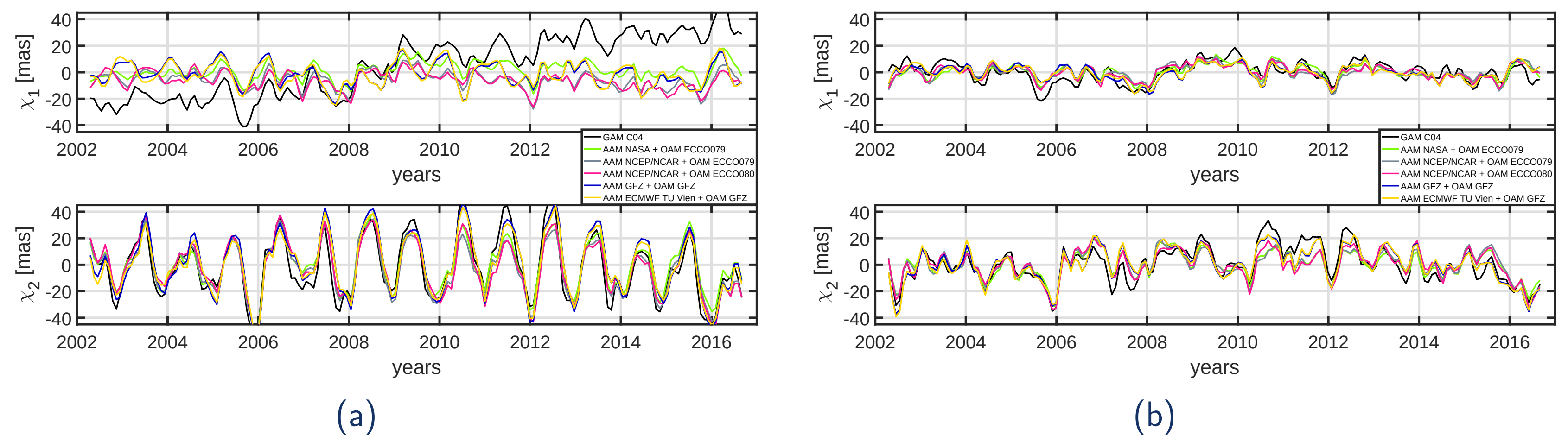
The following materials were required to complete the research:

- **GAM - Geodetic Angular Momentum**, 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 Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis model is provided by the Special bureau for the Atmosphere of Global Geophysical Fluids Centre with the mass excitation accounting for an inverted barometer response of the ocean overlying atmospheric pressure;
  - European Centre for Medium-Range Weather Forecasts (ECMWF). The data are split up into matter (c_{13}, c_{23}, c_{33} components of the inertia tensor, units are $kg\ m^2$) and motion terms (relative angular momentum, units $kg\ m^2\ /\ sec$), with time and spatial resolution 6 hours and 1 degree, respectively. The data are provided by Technische Universität Wien (TU Wien) and they are an official product of the IERS.
  - NASA GEOS AAM model - here the 4D output of numerical weather model GEOS-FPIT that is run by NASA's Global Modeling and Assimilation Office (GMAO) is used for computation of the AAM, the data are available here `http://alt.aam.earthrotation.net/`
  - Effective Atmospheric Angular Momentum (EAAM) of matter and motion terms, obtained from GeoForschungsZentrum (GFZ) and provided with a temporal resolution of down to 3 hours as GFZ's contributions to the GGFC (also χ_1, and χ_2 components, called AAM GFZ). The series were calculated from 6-hourly ECMWF (European Centre for Medium-range Weather Forecasts) operational atmospheric forcing data, given at 25 pressure levels with the model top at 1 hPa.
- **Oceanic Angular Momentum (OAM) models**
  - The data sets of oceanic angular momentum function were obtained from the IERS Special Bureau for the Oceans. These series are composed of daily values of currents and bottom pressure of OAM. Here we used the ocean models running at the Jet Propulsion Laboratory (JPL), ECCO kf079 and ECCO kf080 ocean models. Both ocean models consist of 46 levels ranging in thickness from 10 m at surface to 400 m at depth and are forced with data from NCEP/NCAR re-analysis project. The information assimilated by ECCO kf080 ocean model includes altimetric measurements of sea surface height and expendable bathythermograph (XBT) data, the ECCO kf079 ocean model were computed without data assimilation.
  - Effective Angular Momentum Functions (EAMF) of the ocean were calculated from 6 - hourly Max Planck Institute Ocean Model (MPIOM) and was obtained from the GFZ Research Center. The EAMF are divided into mass and motion term and are given in 3 - hourly intervals as GFZ's contribution to the Global Geophysical Fluid Center (GGFC) of the International Earth Rotation and Reference Systems Service (IERS) and are called here as OAM GFZ.

Results and analysis

We compare geodetic excitation function of polar motion with geophysical ecxitations of polar motion being the sum of atmospherical (AAM) and oceanic (OAM) excitation functions:

$$GAM\ \ vs.\ AAM_{mass+motion} + OAM_{currents+pressure} \tag{1}$$



(a) (b)

Figure 1: Comparison of the components, χ_1 and χ_2, of the GAM with various AAM+OAM excitation functions. The mean values were removed, the Gauss filter with the parameter FWHM$=60$ were applied to each time series (1a), the seasonal components with the periods of 365.25, 180.00 and 120.00 days and the second order polynomial were removed from time series shown at 1b.

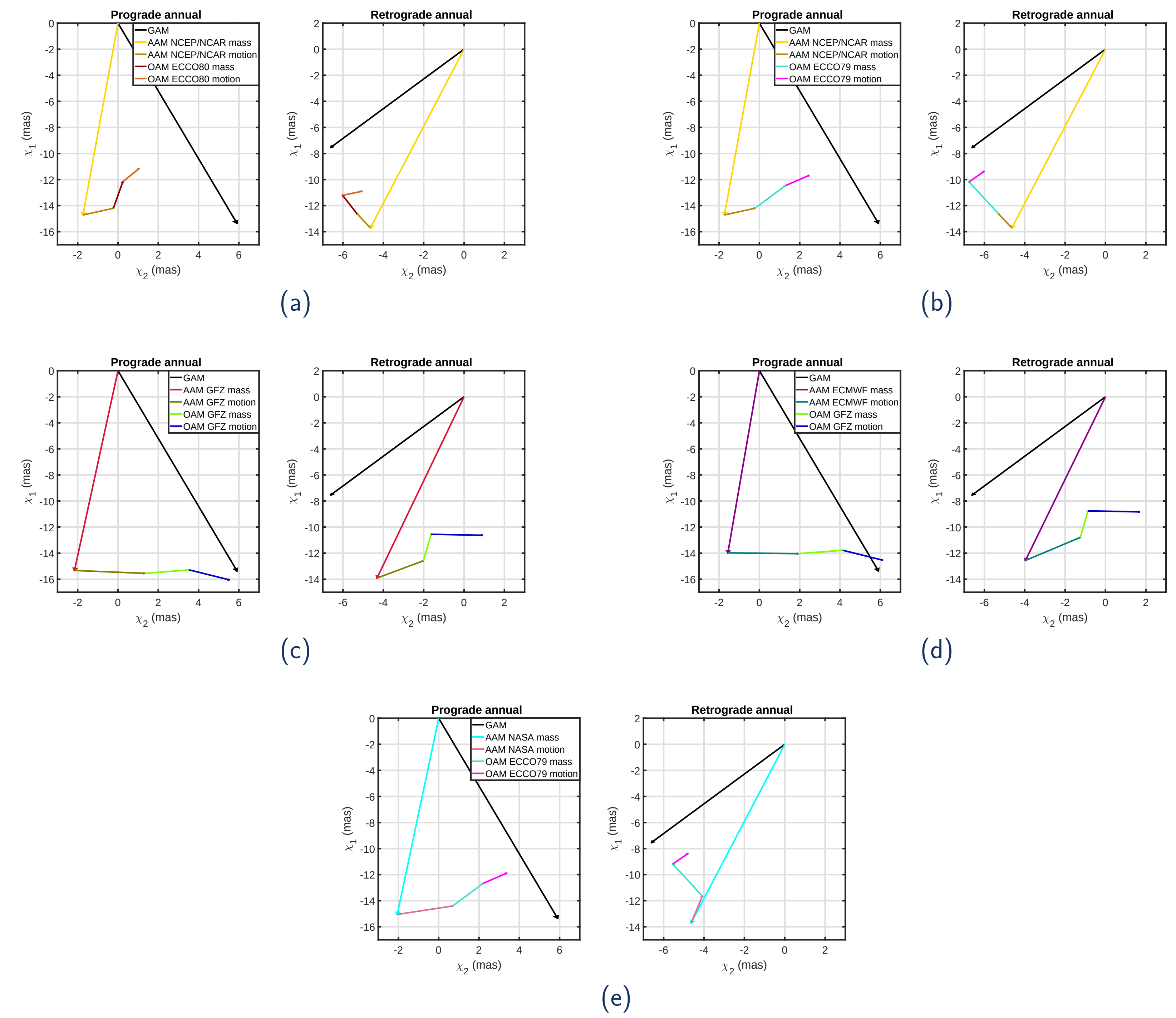


Figure 2: Amplitudes and phases of annual prograde and retrograde oscillations of GAM excitation and different atmospherical AAM and ocean OAM excitation functions for their mass and motion components. Phase ϕ is defined here by the annual term as $sin(2\pi(t-t_0)+\phi)$, where t_0 is a reference epoch for January 1 2002.

Table 1: Comparison of the observed (IERS C04) and modeled excitations of polar motion. The seasonal - polynomial model has been removed from each time series. Variance explained means the coefficients $100\%\times[var(obs.)-var(obs.-model)]/var(obs.)$.

$GAM\ vs.$	Variance explained [%]	
	χ_1	χ_2
$AAM\ NCEP/NCAR+\ OAM\ ECCOkf079$	49	68
$AAM\ NCEP/NCAR+\ OAM\ ECCOkf080$	58	71
$AAM\ GFZ+OAM\ GFZ$	51	77
$AAM\ ECMWF\ TU\ Wien+OAM\ GFZ$	53	76
$AAM\ NASA\ GEOS+\ OAM\ ECCOkf079$	49	68

Results and analysis

Table 2: Comparison of the different AAM and OAM mass and motion terms between themselves. The seasonal - polynomial model has been removed from each time series.

$AAM\ NCEP/NCAR\ mass\ vs.$	Standard deviations [mas]		Correlation coefficient	
	χ_1	χ_2	χ_1	χ_2
$AAM\ NCEP/NCAR$	3.03	5.13	1.00	1.00
$AAMGFZ$	2.93	5.03	0.99	0.99
$AAMECMWFTUVienna$	2.87	4.96	0.99	0.99
$AAMNASAGEOS$	3.15	5.23	0.99	0.99
$AAM\ NCEP/NCAR\ motion\ vs.$	Standard deviations [mas]		Correlation coefficient	
	χ_1	χ_2	χ_1	χ_2
$AAM\ NCEP/NCAR$	3.50	3.58	1.00	1.00
$AAMGFZ$	3.45	3.47	0.64	0.73
$AAMECMWFTUVienna$	3.47	3.74	0.67	0.72
$AAMNASAGEOS$	2.92	3.14	0.77	0.83
$AAM\ NCEP/NCAR\ mass + motion\ vs.$	Standard deviations [mas]		Correlation coefficient	
	χ_1	χ_2	χ_1	χ_2
$AAM\ NCEP/NCAR$	5.16	7.25	1.00	1.00
$AAMGFZ$	4.83	7.19	0.84	0.94
$AAMECMWFTUVienna$	4.71	7.32	0.86	0.93
$AAMNASAGEOS$	4.90	6.91	0.91	0.96
$OAM\ ECCO079\ mass\ vs.$	Standard deviations [mas]		Correlation coefficient	
	χ_1	χ_2	χ_1	χ_2
$OAM\ ECCO079$	2.35	5.18	1.00	1.00
$ECCO080$	2.72	5.30	0.90	0.94
$OAMGFZ$	3.20	7.08	0.81	0.85
$OAM\ ECCO079\ motion\ vs.$	Standard deviations [mas]		Correlation coefficient	
	χ_1	χ_2	χ_1	χ_2
$OAM\ ECCO079$	2.42	3.08	1.00	1.00
$ECCO080$	2.41	3.26	0.91	0.93
$OAMGFZ$	2.64	3.52	0.86	0.86
$OAM\ ECCO079\ mass + motion\ vs.$	Standard deviations [mas]		Correlation coefficient	
	χ_1	χ_2	χ_1	χ_2
$OAM\ ECCO079$	3.78	8.00	1.00	1.00
$ECCO080$	4.04	8.34	0.90	0.94
$OAMGFZ$	4.36	10.00	0.83	0.88

Table 3: Comparison of the GAM excitation function of polar motion with the sum of atmospherical and oceanic angular momentum from different AAM and OAM models. The seasonal - polynomial model has been removed from each time series.

$GAM\ vs.$	Standard deviations [mas]		Correlation coefficient	
	χ_1	χ_2	χ_1	χ_2
GAM	7.61	13.18	1.00	1.00
$AAM\ NCEP/NCAR + OAM\ ECCO080$	5.45	11.03	0.76	0.85
$AAM\ NCEP/NCAR + OAM\ ECCO079$	5.63	10.45	0.66	0.80
$AAM\ GFZ + OAM\ GFZ$	5.94	12.43	0.71	0.88
$AAM\ ECMWF\ TU\ Wien + OAM\ GFZ$	5.83	12.52	0.73	0.88
$AAM\ NASA + OAM\ ECCO079$	5.70	9.95	0.70	0.83

Conclusions

Here, the agreement between seasonal and nonseasonal geodetic and geophysical excitations of polar motion were studied. Comparison of the seasonal components of χ_1 and χ_2 shows that, in general, adding successively atmospheric mass and motion and oceanic currents and presuure vectors to geodetic observations, increase the agreement between GAM and sum of AAM and OAM. The nonseasonal part of the sum AAM+OAM agree pretty well with GAM, especialy in the case of AAM ECMWF and OAM MPIOM models. Differences in various AAM motion terms are large and may be a source (with OAM models) of not closing the geodetic budget.

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