Low degree Earth's gravity coefficients determined from different space geodetic observations and climate models

Malgorzata *Winska*[1,2]
Jolanta *Nastula*[2]

(1) Faculty of Civil Engineering, Warsaw University of Technology, Warsaw, POLAND
(2) Space Research Center Polish Academy of Sciences, Warsaw, POLAND

Warsaw University of Technology

Introduction

Large scale mass redistribution and its transport within the Earth system causes changes in the Earth's rotation in space, gravity field and Earth's ellipsoid shape. These changes are observed in the ΔC_{21}, ΔS_{21}, spherical harmonics gravity coefficients, which are proportional to the mass load-induced Earth rotational excitations.
In this study, inter-annual, seasonal and short-periods variations of low degree spherical harmonics coefficients of Earth's gravity field, determined from different space geodetic techniques, Gravity Recovery and Climate Experiment (GRACE), satellite laser ranging (SLR), Global Navigation Satellite System (GNSS), Earth rotation, and climate models, are examined. In this way, we want to show the contribution of each measurement technique to interpreting the low degree surface mass density of the Earth.
Especially, we evaluate an usefulness of several climate models from the Coupled Model Intercomparison Project phase 5 (CMIP5) to determine the low degree Earth's gravity coefficients using GRACE satellite observations. To do that, CMIP5 climate models estimates of low degree Stokes coefficients ΔC_{21}, ΔS_{21}, are the sum of atmosphere and ocean mass effect (GAC values) taken from GRACE and a land surface hydrological estimate from the CMIP5 climate models.
Low degree Stokes coefficients of the surface mass density determined from GRACE, SLR, GNSS, Earth rotation measurements and climate models are compared to each other in order to assess their consistency.

Data description

Several independent time series of variations in low degree Stokes coefficients are estimated from different geodetic techniques measurements, hydrological and climate models, and from Earth rotation:

- GNSS: GPS+GLONASS, time resolution - monthly, AOD1B-RL05, mean pole definition-IERS2010, computed by K. Sośnica
- SLR: LAGEOS - 1/2, Starlette, Stella, AJISAI, LARES, Blits, Larets, Bacon-C, time resolution - monthly, AOD1B-RL05, mean pole definition-IERS2010, computed by K. Sośnica
- GRACE UTCSR RL05, Level-2: the non-tidal variability in the atmosphere and oceans is removed through using the AOD1B Release-05 product (combination of the ECMWF operational atmospheric model and the baroclinic OMCT ocean model)
- Global models of land hydrosphere:
  - A Global Land Data Assimilation System (GLDAS) the NOAH 2.7.1 model, $1^0 \times 1^0$ resolution, range from 1979 to the present, resolution - monthly, `https://disc.sci.gsfc.nasa.gov/uui/datasets/GLDAS_NOAH10_M_V001/`
  - Land Surface Discharge Model (LSDM), data in terms of Effective Angular Momentum Functions as Associated Product Centre by order of the International Earth Rotation and Reference System Service (IERS), functions are consistently to the GRACE de-aliasing products AOD1B Release 06 [1]
- Global climate models from CMIP5 project:
  - Miroc5, determined on 2.80×2.80 latitude-longitude grid with monthly frequency, soil column layers – 5, depth – 4 m. Miroc5 couples the following models: atmosphere the CCSR–NIES–Frontier Research Center for Global Change (FRCGC) AGCM, the CCSR Ocean Component Model which includes a sea ice model, a land model that includes a river module.
  - MPI, determined on 1.8750×1.8750 latitude-longitude grid with monthly frequency, it is a New Earth system model of Max Planck Institute for Meteorology. The MPI-ESM couples the atmosphere, ocean and land surface through the exchange of energy, momentum, water. Model consists of general circulation models for the atmosphere (ECHAM6), the ocean and sea ice (MPIOM) - coupled by OASIS3 -, the land surface model JSBACH, and optionally includes dynamical land vegetation (DYNVEG).
- EOP time series from International Earth Rotation and Reference System (IERS), C04 time series.

To retrive ΔC_{21}, ΔS_{21} variations from EOP time series, the Effective Angular Momentum Functions of atmosphere (ECMWF model, `ftp://ig2-dmz.gfz-potsdam.de/EAM/operational_AAM/`) and ocean (OMCT model, `ftp://ig2-dmz.gfz-potsdam.de/EAM/operational_OAM/`) of motion terms, obtained from GeoForschungsZentrum, were used [1].

The GRACE Atmosphere and Ocean De-aliasing (AOD1B) data set contains spherical harmonic coefficients of combined baroclinic sea level and vertical integrated pressure variations. The AOD1B data set were added back to the low degree Stokes coefficients determined from hydrological and climate models, as well to the SLR and GNSS time series. The AOD1B products are available on the website:`http://icgem.gfz-potsdam.de/ICGEM/`.

References

[1] Dobslaw, H., R. Dill, A. Groetzsch, A. Brzezinski, and M. Thomas (2010), *Seasonal polar motion excitation from numerical models of atmosphere, ocean, and continental hydrosphere*, J. Geophys. Res., doi:10.1029/2009JB007127
[2] Cooper G. R. J., and Cowan D. R. (2008) *Comparing time series using wavelet-based semblance analysis,*, Computer Geosciences, 34, 95-102, doi:10.1016/j.cageo.2007.03.009.

Methodology

Fully normalized ΔC_{21}, ΔS_{21} variations are derived from Earth Orientation Parameters (EOP) excitations after ocean currents and wind effects removing:

$$\chi_{1mass}^{GAO} = \chi_1^{GAM} - \chi_{1motion}^{AAM} - \chi_{1motion}^{OAM} \quad (1)$$

$$\chi_{2mass}^{GAO} = \chi_2^{GAM} - \chi_{2motion}^{AAM} - \chi_{2motion}^{OAM} \quad (2)$$

These excitations are proportional to the spherical harmonics variations:

$$\Delta C_{21} = -(1 + k_2') \cdot \sqrt{\frac{3}{5}} \cdot \frac{C - A}{1.098MR^2} \cdot \chi_1^{mass} \quad (3)$$

$$\Delta S_{21} = -(1 + k_2') \cdot \sqrt{\frac{3}{5}} \cdot \frac{C - A}{1.098MR^2} \cdot \chi_2^{mass} \quad (4)$$

Here: M - mass of the Earth, R - radius of the Earth, $C - A$=2.61·10^{35} $kg \cdot m^2$ - two principal inertia moments of the Earth, k_2' - degree - 2 load Love number.

Results and analysis - Seasonal oscillations

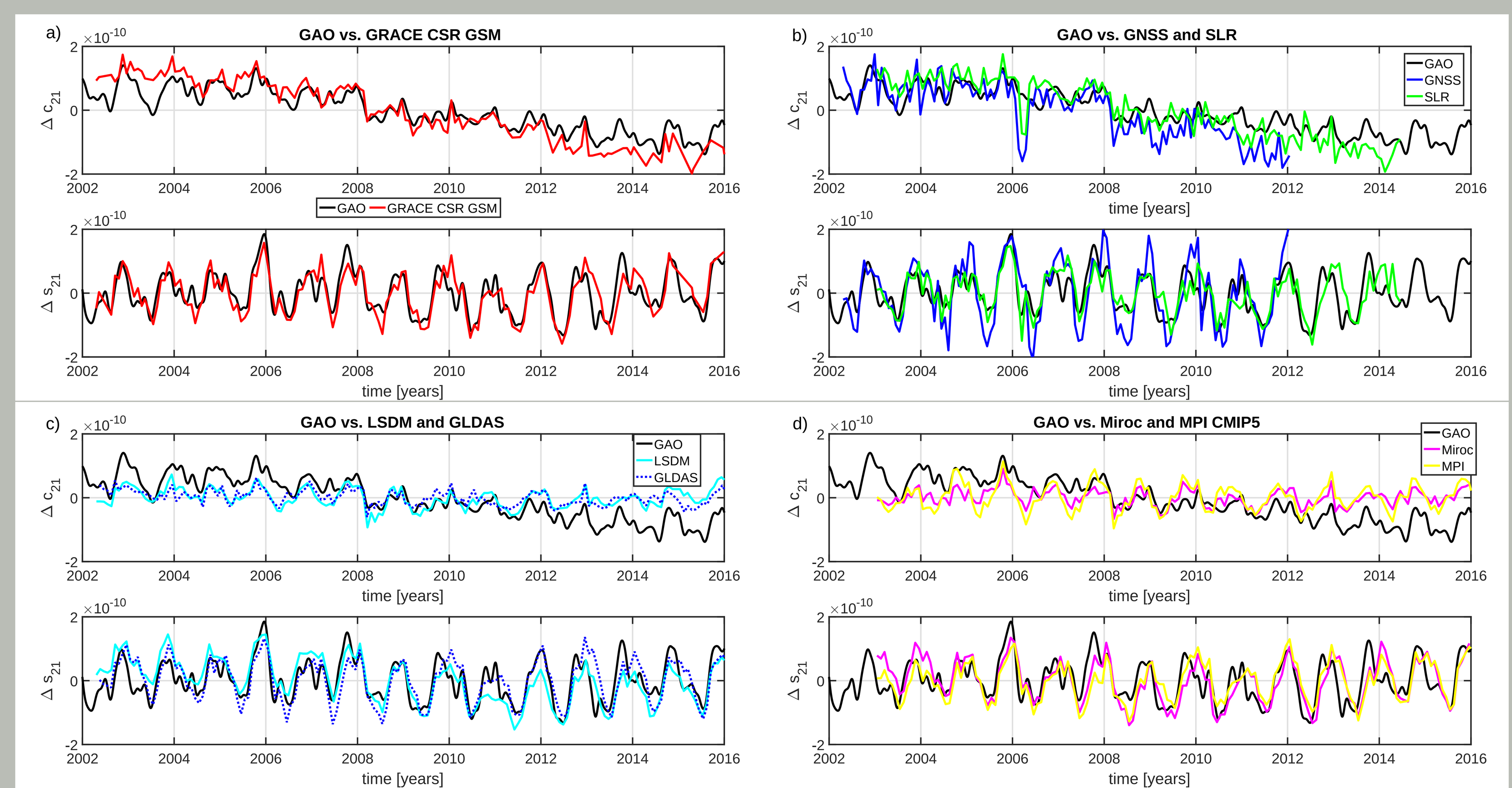

Figure: Monthly 2-degree Stokes coefficients (ΔC_{21}, ΔS_{21}) from EOP excitation are compared with Stokes coefficients determined from: a) GRACE, b) SLR and GNSS, c) hydrological models LSDM and GLDAS, d) global climate models Miroc and MPI from CMIP5 project.

Table: Amplitudes and phases of annual and semiannual ΔC_{21}, ΔS_{21} gravity changes estimated from GRACE, SLR, GNSS, hydrological and climate models.

	Annual		Semiannual	
Gravity change	Amplitude [10^{-11}]	Phase [deg]	Amplitude [10^{-11}]	Phase
ΔC_{21} GAO	3.17	328	0.80	268
ΔC_{21} GRACE	1.90	307	0.92	345
ΔC_{21} SLR	1.52	249	0.59	294
ΔC_{21} GNSS	2.00	287	1.16	286
ΔC_{21} GLDAS	1.75	304	0.51	322
ΔC_{21} LSDM	2.90	320	0.26	297
ΔC_{21} Miroc5 CMIP5	2.49	294	0.54	321
ΔC_{21} MPI CMPI5	4.96	287	0.54	320
ΔS_{21} GAO	6.78	130	2.04	232
ΔS_{21} GRACE	8.01	105	1.59	268
ΔS_{21} SLR	6.51	100	1.79	274
ΔS_{21} GNSS	12.2	104	1.13	264
ΔS_{21} GLDAS	8.06	100	1.55	271
ΔS_{21} LSDM	6.51	117	1.22	272
ΔS_{21} Miroc5 CMIP5	7.87	88	0.67	271
ΔS_{21} MPI CMPI5	6.91	87	1.22	251

Acknowledgments

This work was supported by the Polish national science foundation NCN under grant No. $UMO-2013/11/B/ST10/04975$.

Results and analysis - non-seasonal oscillations

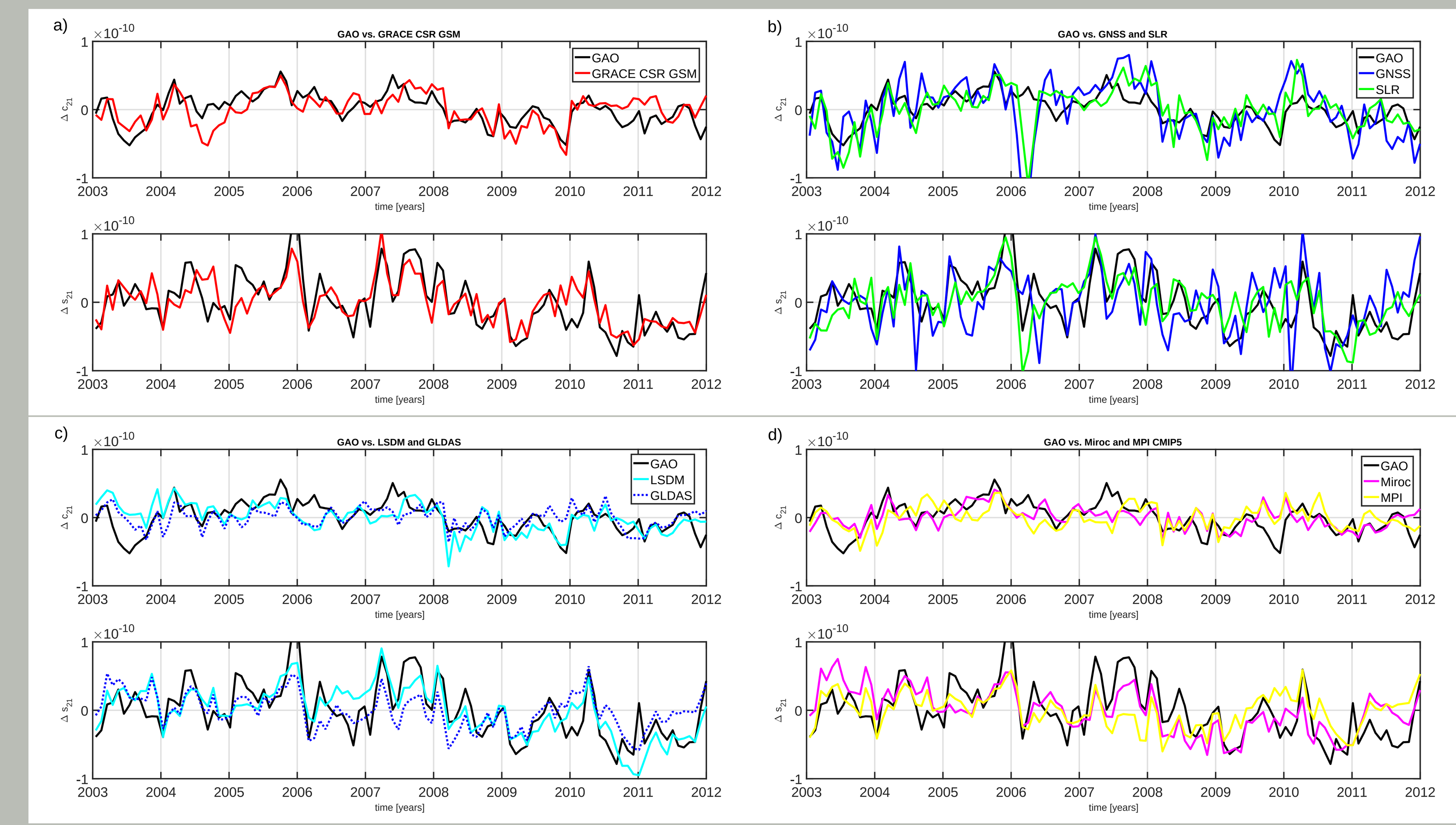

Figure: Monthly, non-seasonal, 2-degree Stokes coefficients (ΔC_{21}, ΔS_{21}) from EOP excitation are compared with Stokes coefficients determined from: a) GRACE, b) SLR and GNSS, c) hydrological models LSDM and GLDAS, d) global climate models Miroc and MPI from CMIP5 project. Seasonal oscillations, 365.25, 180.8, 121 days periods, are removed from time series.

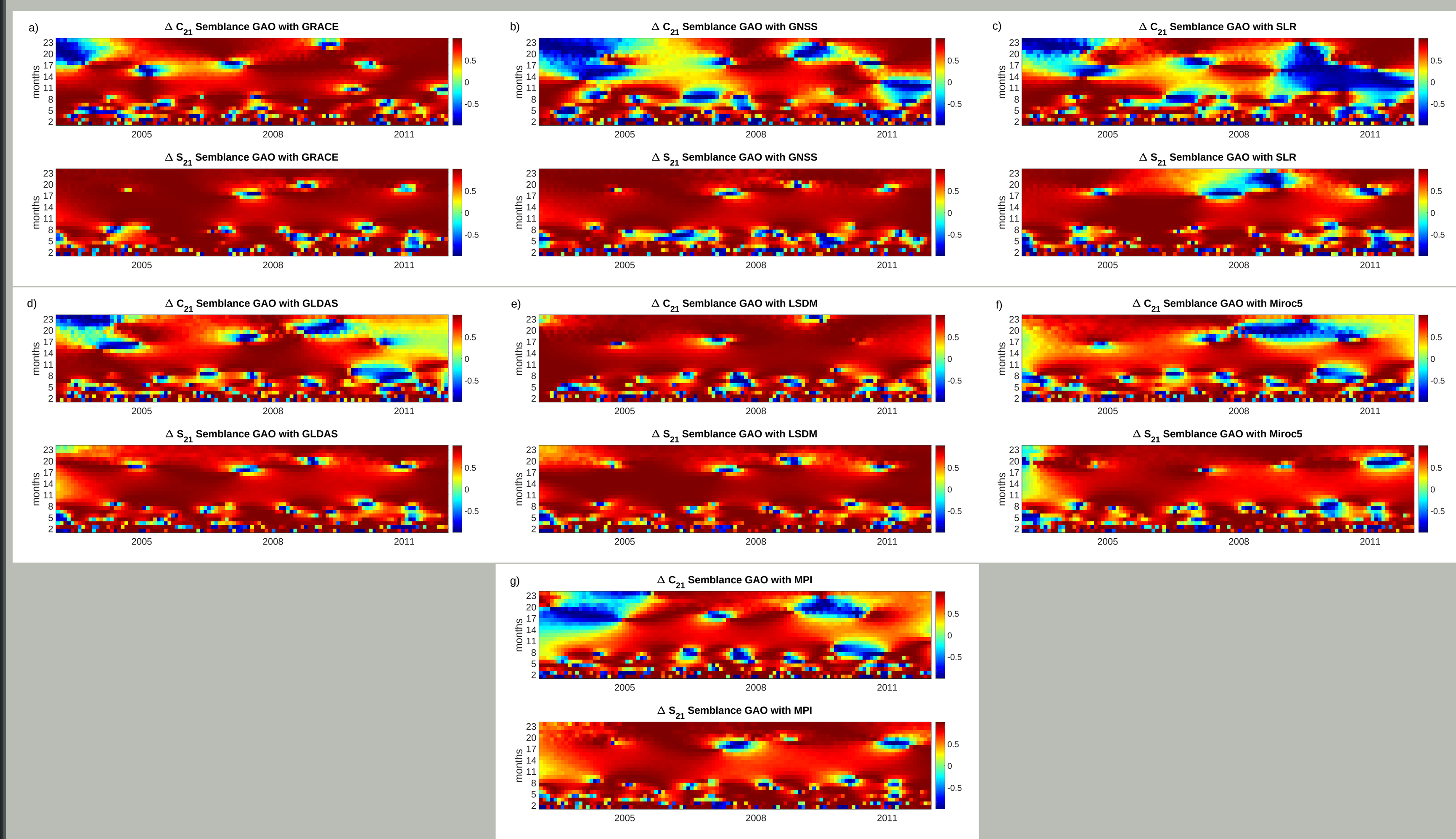

Figure: Semblance of dataset, ΔC_{21}, ΔS_{21} components, shown in Fig. 1, calculated with n=1. Semblance between EOP excitation (GAO) and (a) GRACE, (b) GNSS, (c), SLR, (d), GLDAS hydrological model, (e), LSDM hydrological model, (f) Miroc5 CMIP5 climate model and, (g) MPI CMIP5 climate model. These correlations between nonseasonal Stokes coefficients ΔC_{21} and ΔS_{21} and other space geodetic measurements and hydrological and climate models were computed using wavelet-based semblance analysis [2].

Conclusions

Independent estimations of ΔC_{21}, ΔS_{21} from EOP, SLR, GNSS, GRACE data, hydrological and climate models in seasonal and non-seasonal timescales were analyzed. Comparison of EOP estimates with other independent models and data shows pretty good agreement between them (see Figure 1). The best agreement in seasonal oscillations is between spherical harmonics determined from EOP estimates and hydrological model LSDM, both in ΔC_{21} and ΔS_{21} components. Larger discrepancies exists between EOP estimates and spherical harmonics determined from climate models, especially in phases (see Table 1). In short period oscillations, agreement between low degree spherical harmonics from EOP and other sources is the best for GRACE and LSDM model (see Figure 2 and 3).

m.winska@il.pw.edu.pl