EIGEN-6S4

A time-variable satellite-only gravity field model to d/o 300 based on LAGEOS, GRACE and GOCE data from the collaboration of GFZ Potsdam and GRGS Toulouse

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Introduction

- GFZ Potsdam and GRGS/CNES Toulouse have a long-time close cooperation in the field of global gravity field determination using satellites which presently focuses among others on **"mean" time variable gravity field models**** using GRACE and GOCE data.
- EIGEN-6S* (published 2011) was the first "mean" time variable global gravity field model (satellite-only)
- The first upgrade EIGEN-6C2 has been published in 2012, it's a time variable combined gravity field model
- The next upgrade EIGEN-6S2 (2014) is a satellite-only model, which contains yearly drift parameters for the first time
- The new satellite-only model EIGEN-6S4 is subject of this presentation and will be published soon.

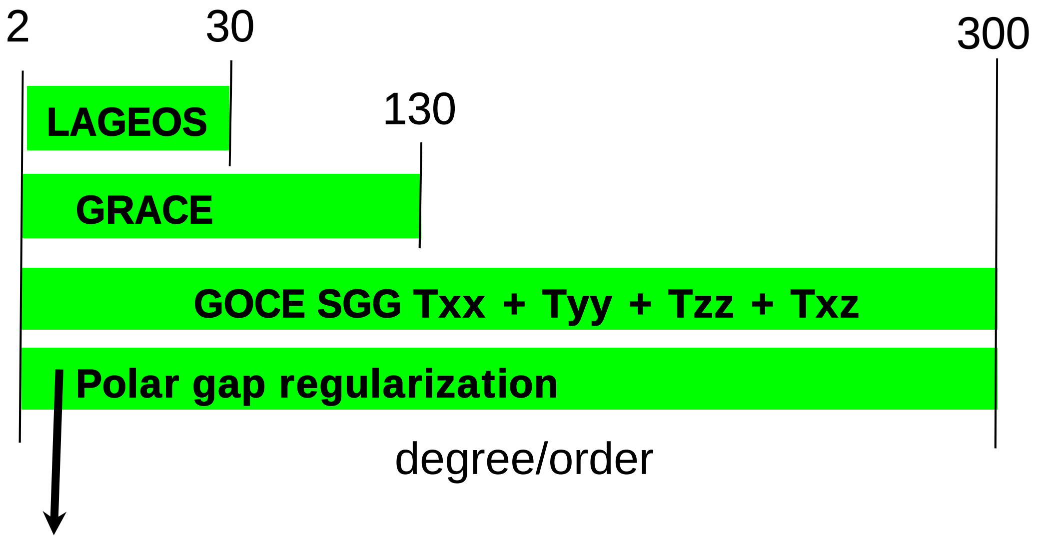
* EIGEN = European Improved Gravity model of the Earth by New techniques

** "mean" time variable gravity field model = approximate representation of the GRACE temporal variation of the Earth gravity field in one data set.

Main characteristics/differences of EIGEN-6S2 and EIGEN-6S4

	EIGEN-6S2 (2014)	EIGEN-6S4 (mid of 2015)
Maximum degree/order	**260**	**300**
LAGEOS: LAGEOS-1 and -2 SLR data	**GRGS, 1985 - 2010**	**GRGS, 1985 – 2014**
GRACE: GPS-SST & K-band range-rate	**GRGS RL02** **200303 - 201012**	**GRGS RL03 version 2** **200208 – 201407**
Max included d/o GRACE	**130**	**130**
Max d/o of the time variable parameters	**50**	**80**
GOCE SGG – processed by the direct approach (GFZ/GRGS within the GOCE High Level Processing Facility) – individual normal equations for each SGG component – application of (120 – 8 resp. 100 – 8) sec band pass filters for all SGG components	**350 days T_{xx} T_{yy} T_{zz} out of 20091101 – 20110419** **(i.e. the GOCE data of DIR-4)**	**nominal orbit altitude:** **837 days T_{xx} T_{yy} T_{zz} T_{xz} out of 20091101 – 20120801** **+ lower orbit phases:** **422 days T_{xx} T_{yy} T_{zz} T_{xz} out of 20120801 – 20131020** **(i.e. the GOCE data of DIR-5)**

Combination scheme of the normal equations for EIGEN-6S4



Application of external gravity field information over the polar gaps
For EIGEN-6S4: GRACE/LAGEOS to d/o 130 + zero coefficients to d/o 300
Algorithm: **Spherical cap regularization** (Metzler & Pail 2005)

All coefficients to d/o 80 were finally replaced by time variable parameters which have been separately derived from the time series of monthly GRACE solutions from CNES/GRGS RL03-v2

Generation of the time-variable parameters in EIGEN-6S4 (1)

Basis of the time-variable coefficients:

- The time-variable parameters in EIGEN-6S4 are based on the time series of monthly GRACE solutions from CNES/GRGS: **RL03-v2**
- **RL03-v2** spans from August 2002 to July 2014
- It includes GRACE GPS & KBR data, and Lageos-1 and Lageos-2 SLR data
- **RL03-v2** is complete to degree and order 80. It is obtained from a inversion by Cholesky decomposition for degrees 1 and 2 and from a truncated SVD inversion for the rest of the parameters.

Generation of the time-variable parameters in EIGEN-6S4 (2)

Conversion from time series to mean field:

- The time variable parameters for EIGEN-6S4 are obtained by regression on the **RL03 v2** time series. For each coefficient C/S(l,m) the mean model consists in:
  - One bias and one drift / year
  - One annual and one semi-annual Sine and Cosine adjusted over the complete time span
  - The resulting curve is continuous, except in the case of major earthquakes where a break is introduced

For EIGEN-6S and EIGEN-6C2 (as well as for GOCO05S):

- One bias and one drift over the complete time span

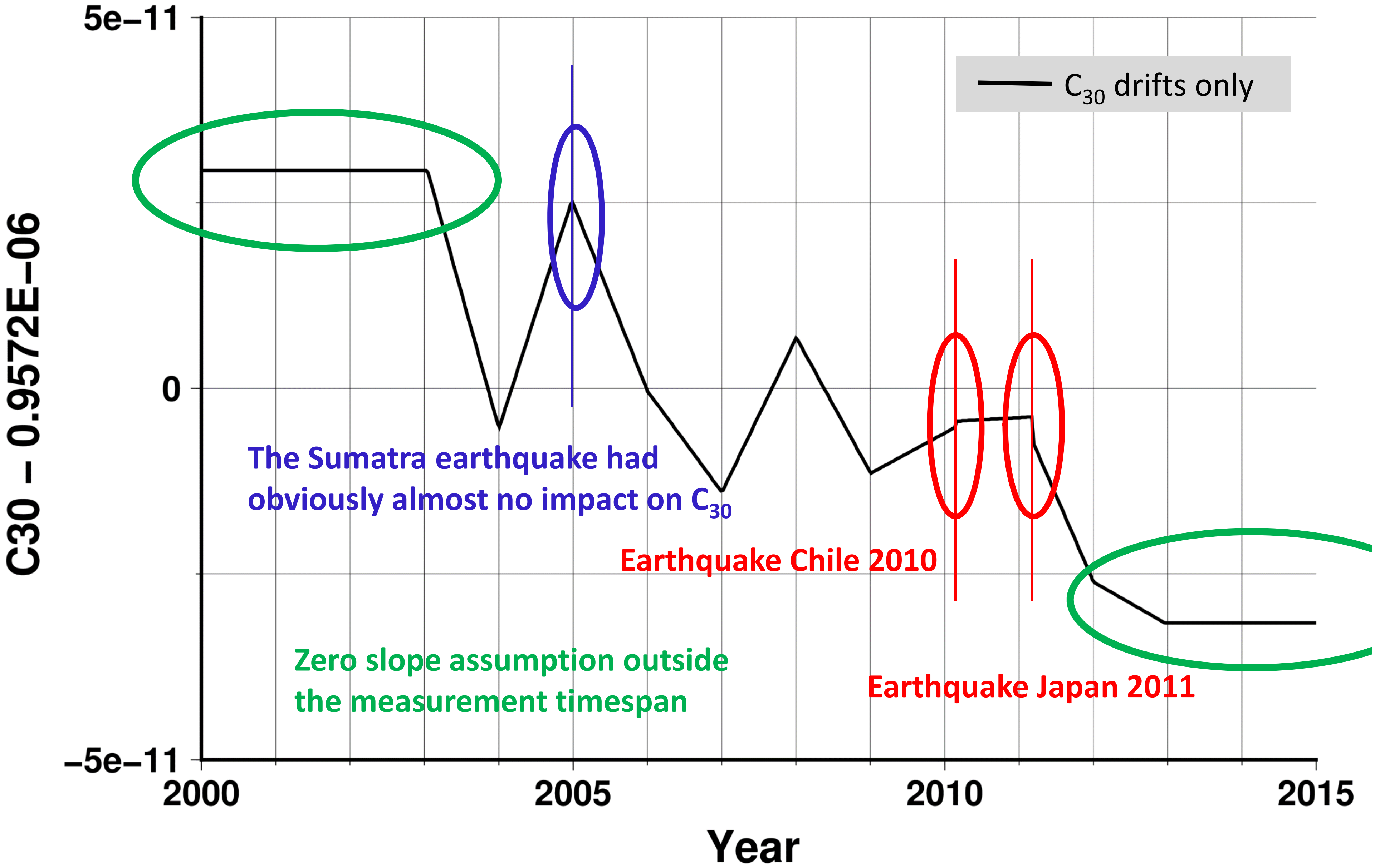
- **Degree 2:** Thanks to the inclusion of Lageos-1 and Lageos-2, the deterministic modelling of degree 2 to can be extended to 1985-2014.

- **Extrapolation strategy before and beyond the measurement time span:**

- The slope of the coefficients is more or less unpredictable outside of the data span (1985-2014 for degree 2, 2002-2014 for the other coefficients)
  → as a consequence, a zero-slope assumption in extrapolation has been chosen (conservative option).
- The annual and semi-annual signals are much more stable than the slope
  → they are kept in extrapolation

Examples for time variable spherical harmornic coefficients in EIGEN-6S4

Example for the temporal behaviour of the spher. harm. coefficients: C_{30}



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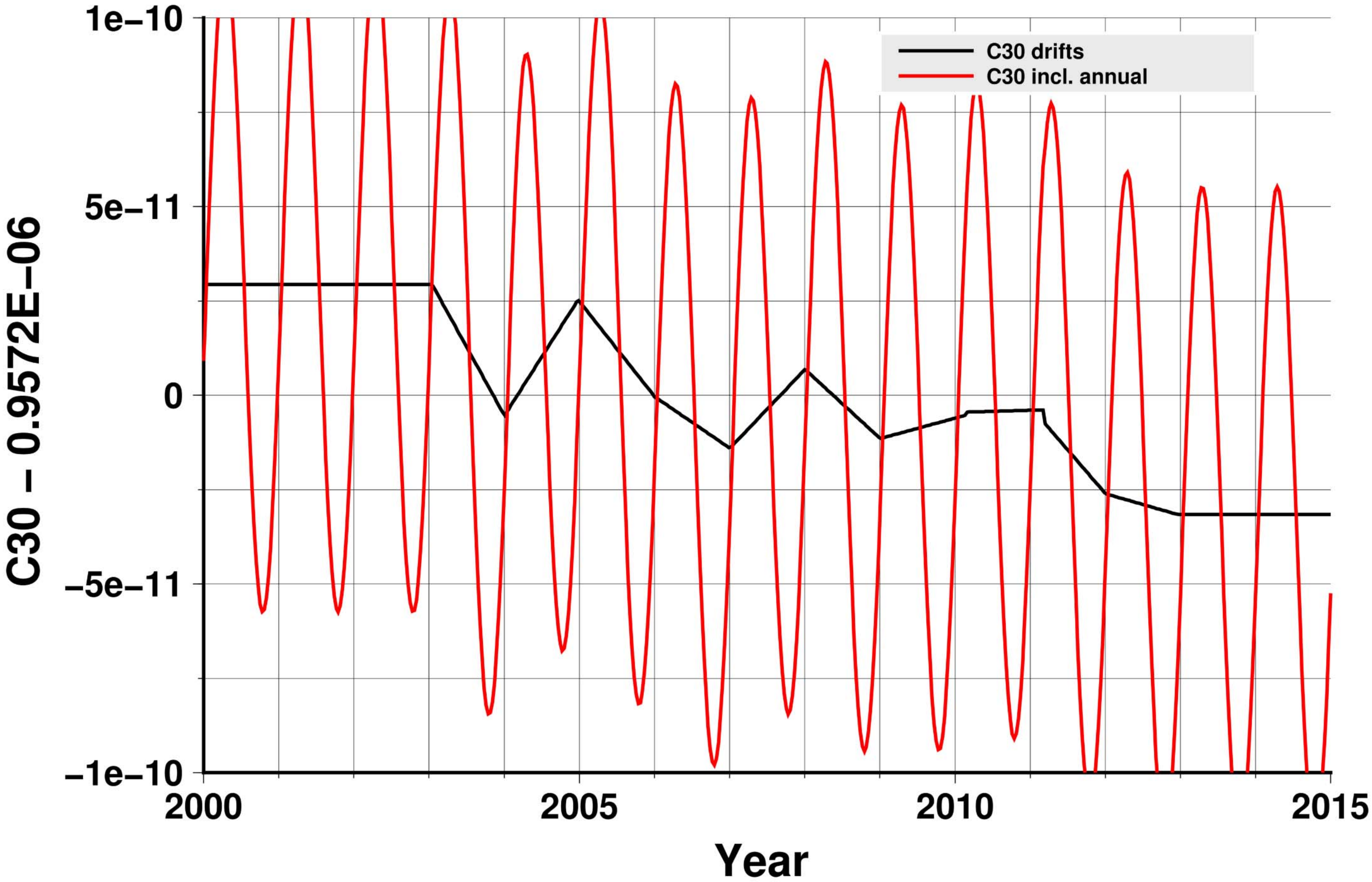

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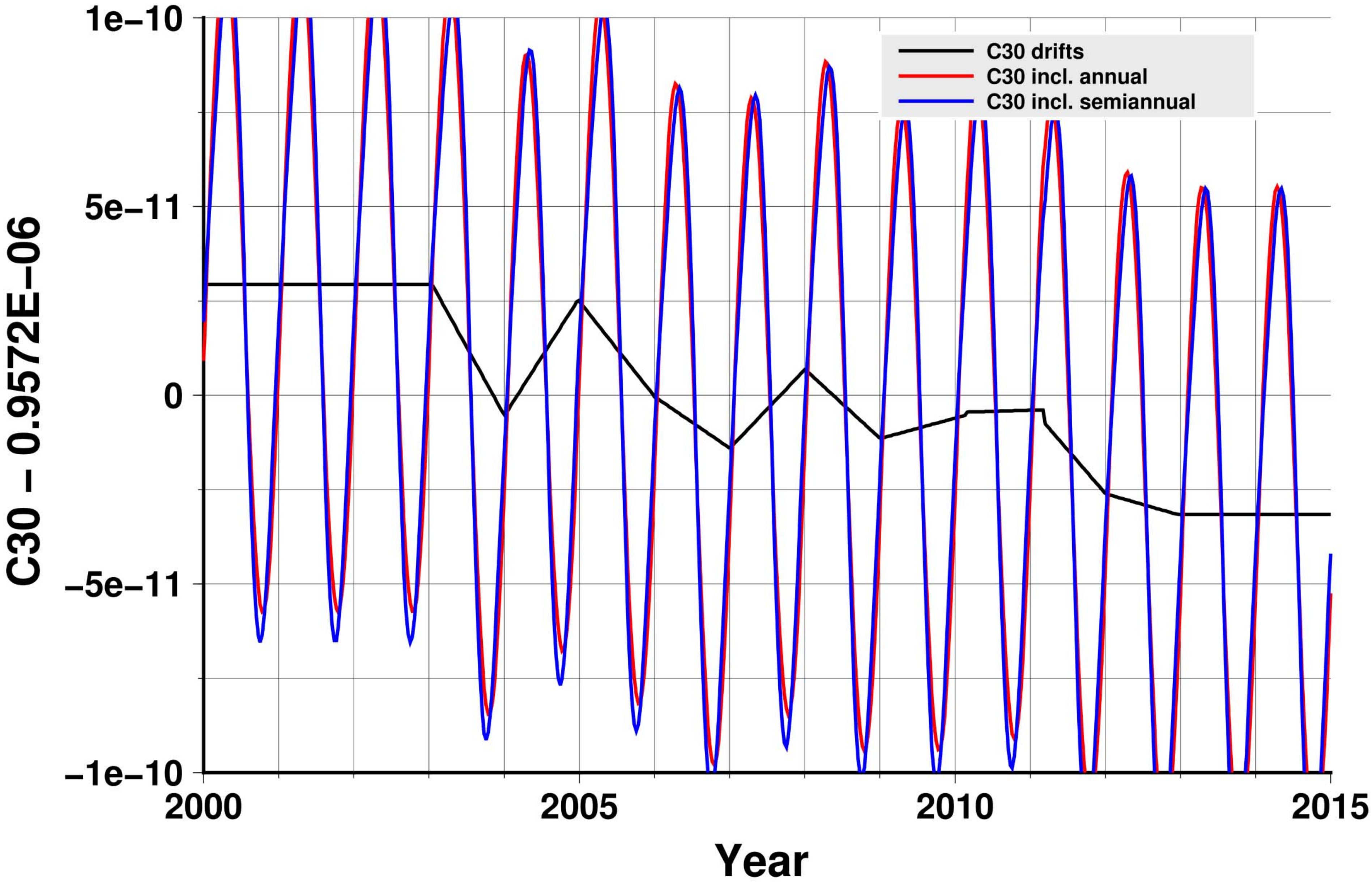

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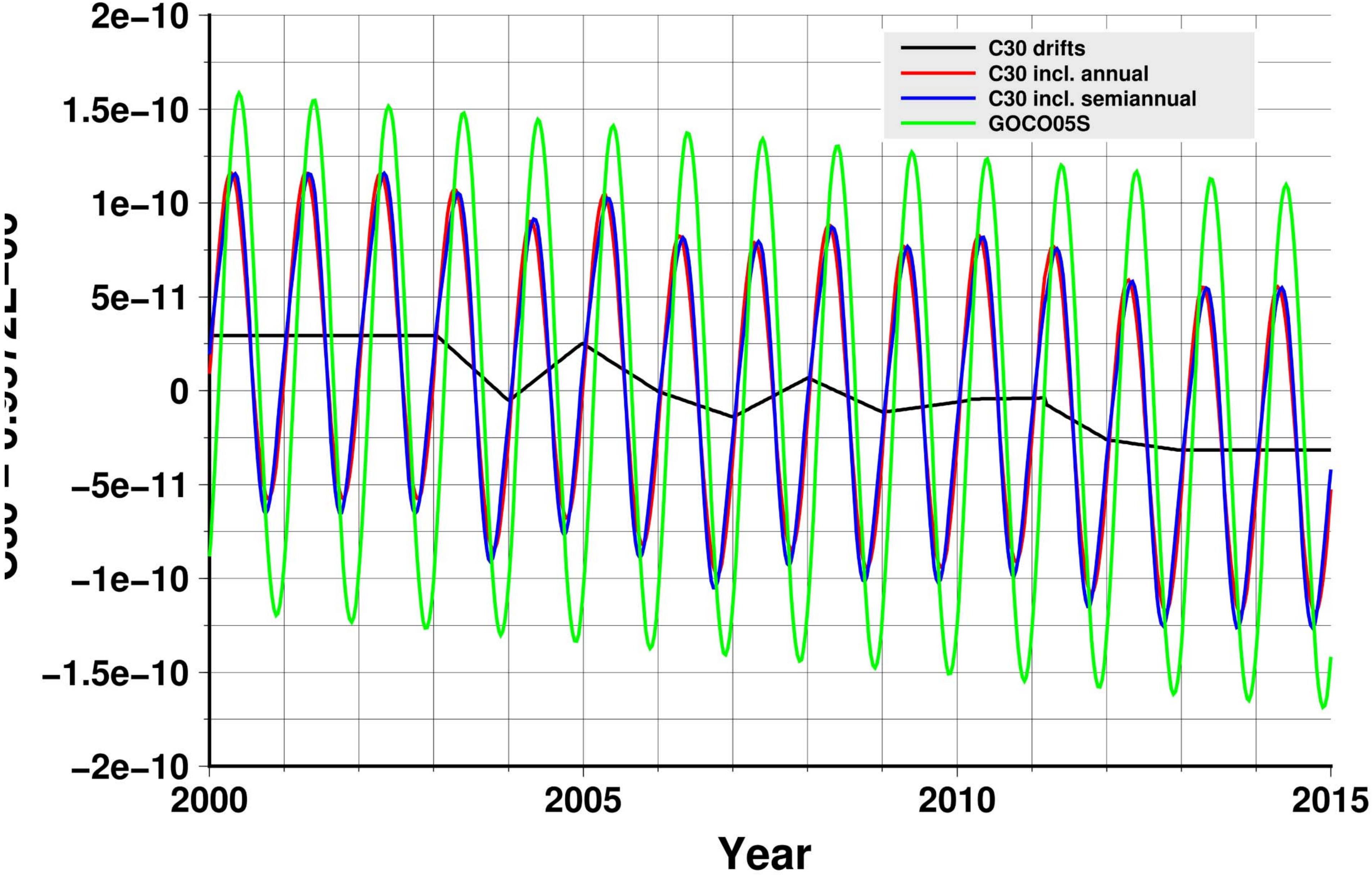
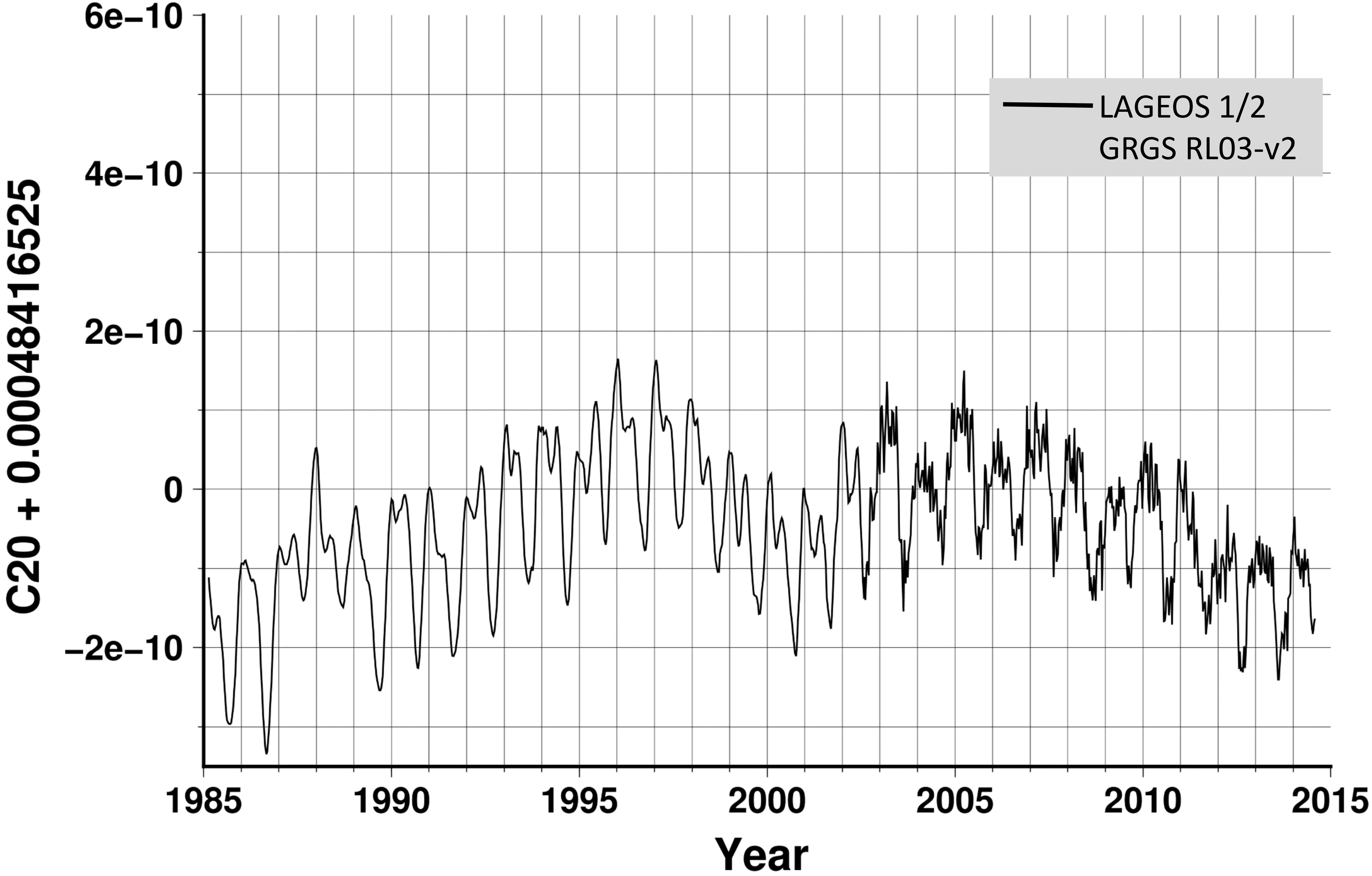


Example for the temporal behaviour of the spher. harm. coefficients: C_{20}



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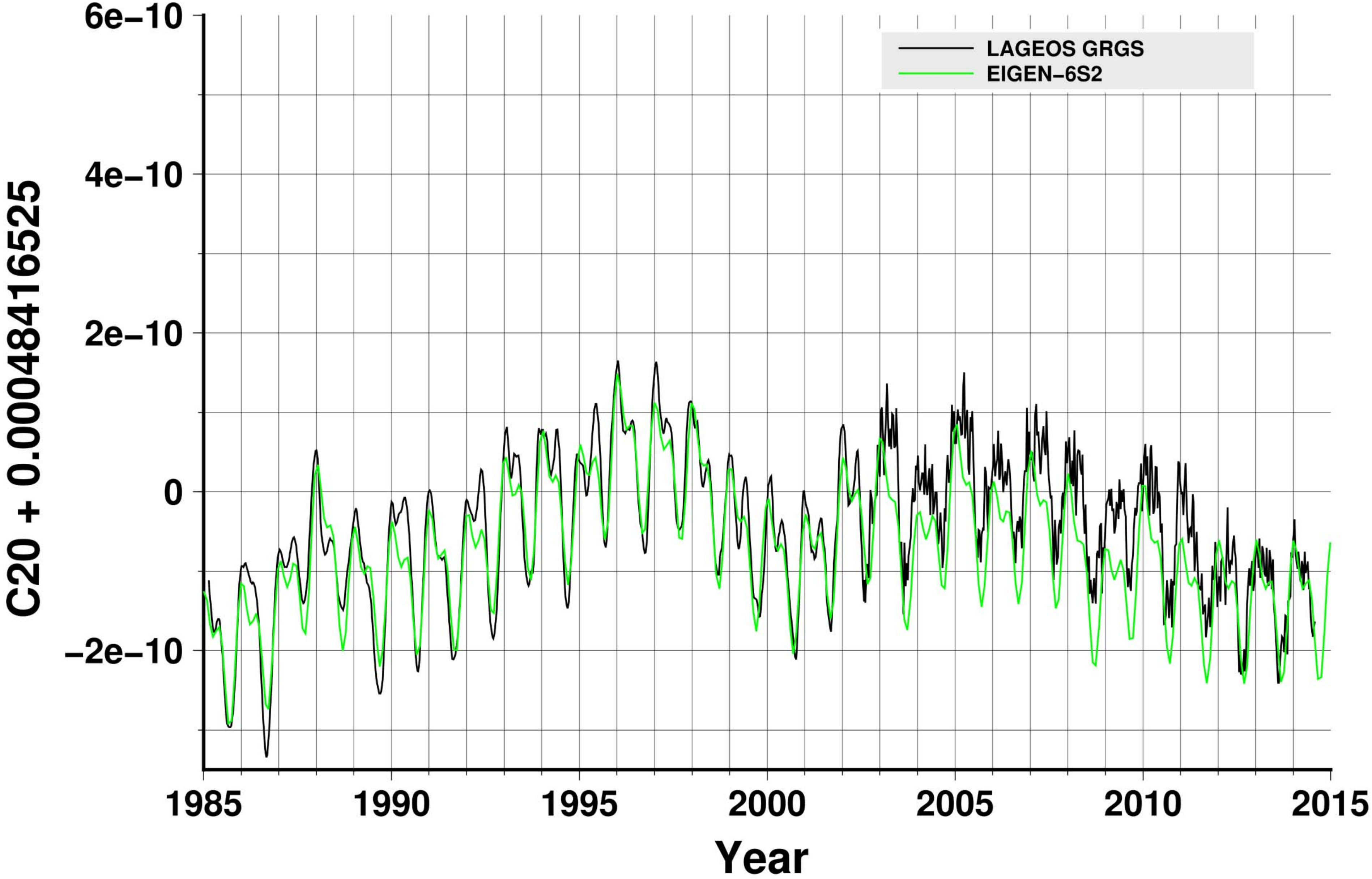

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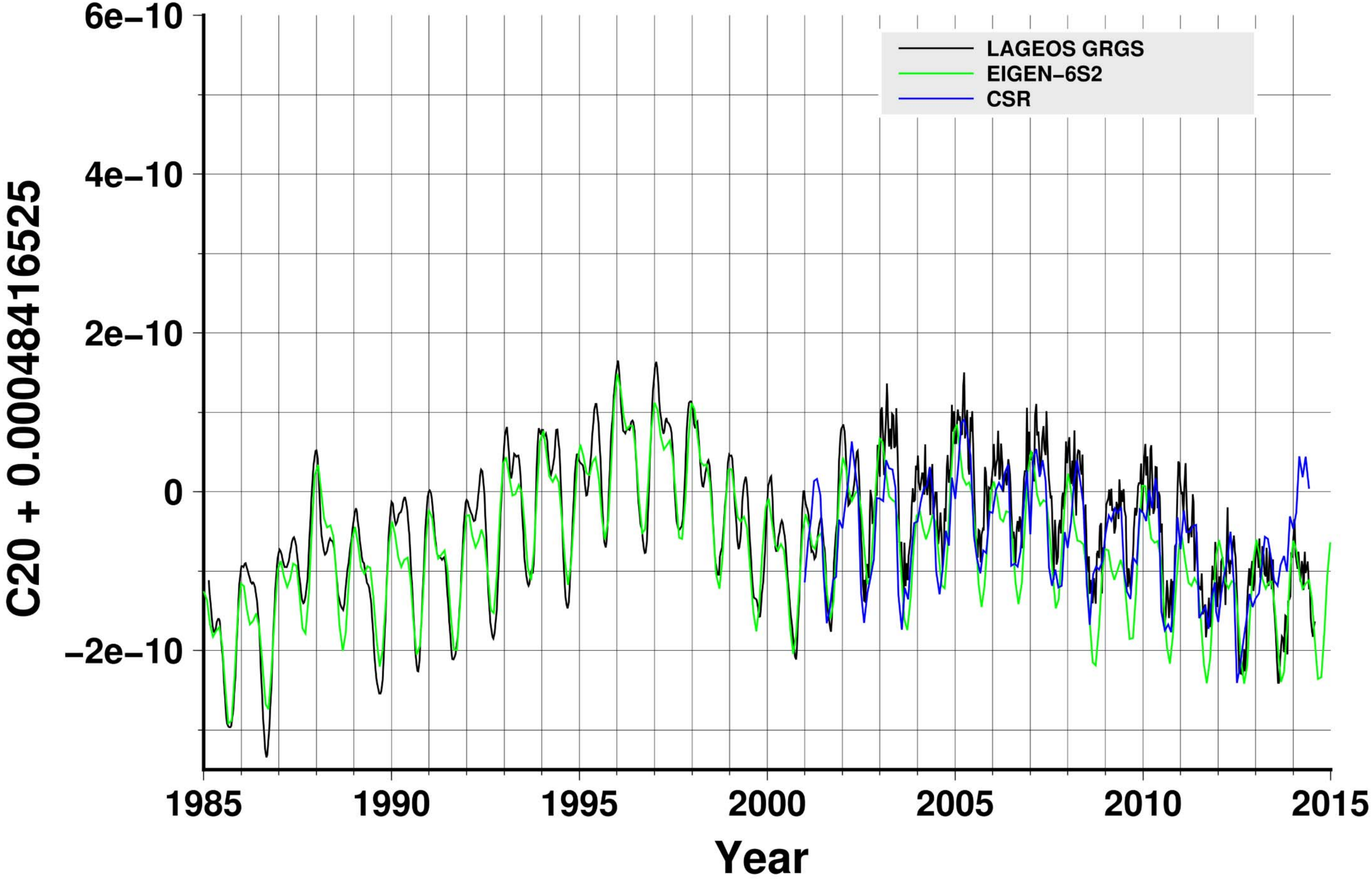

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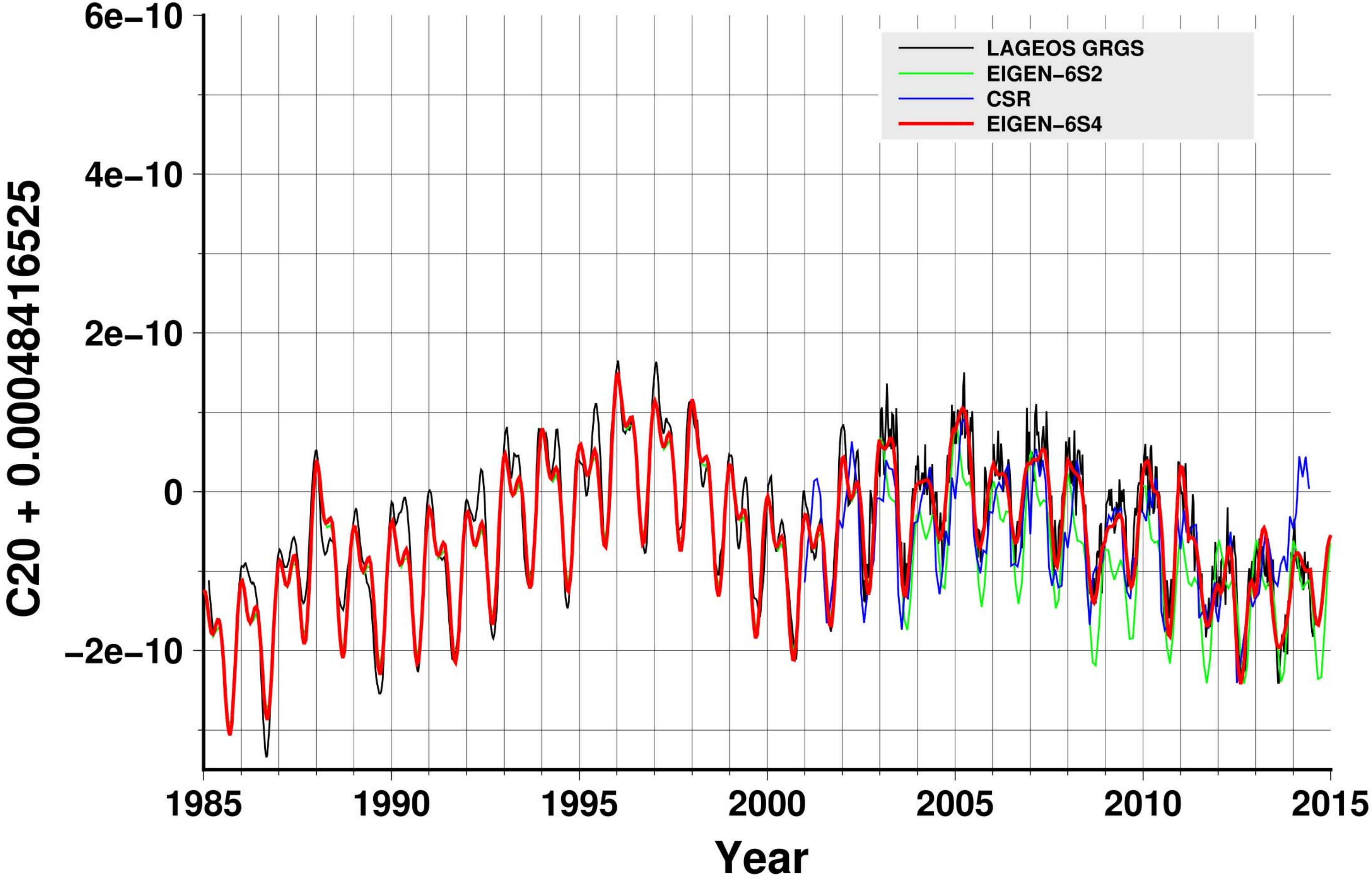

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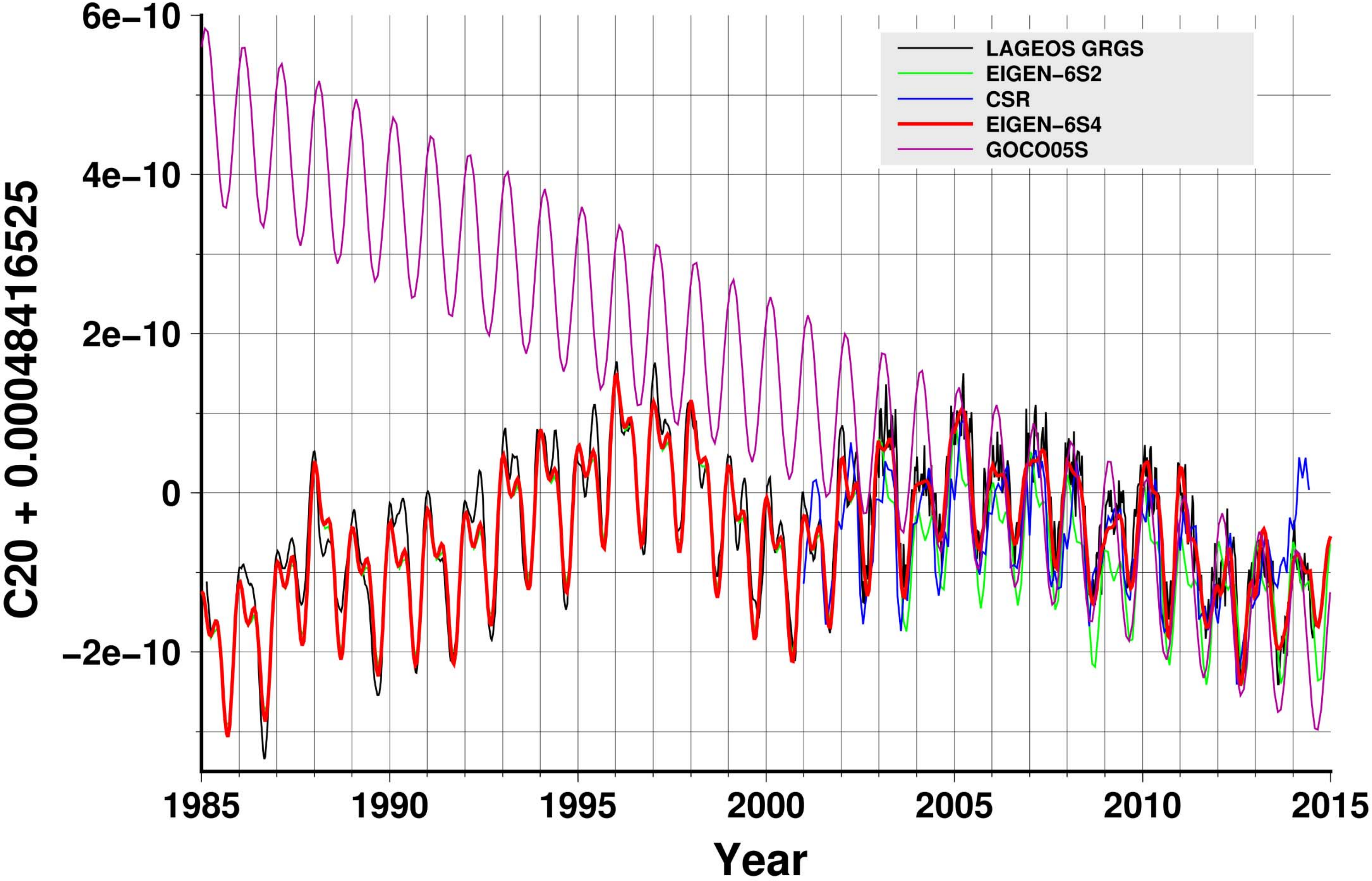


Evaluation of EIGEN-6S4

→ Orbit computation for GOCE, CHAMP and JASON-2

GOCE Orbit adjustment tests

- Observations: Kinematic GOCE (Bock et al. 2011) orbit positions
- Dynamic orbit computation
- **GOCE: 60 arcs** (01.11. – 31.12.2009). Arclength = **1.25 days**
- Parametrization for GOCE:
  - Accelerometer **biases**: 2/rev for cross track / radial / along track
  - Accelerometer **scaling factor**: along track fixed (set to 1.0). 1/arc for cross track / radial

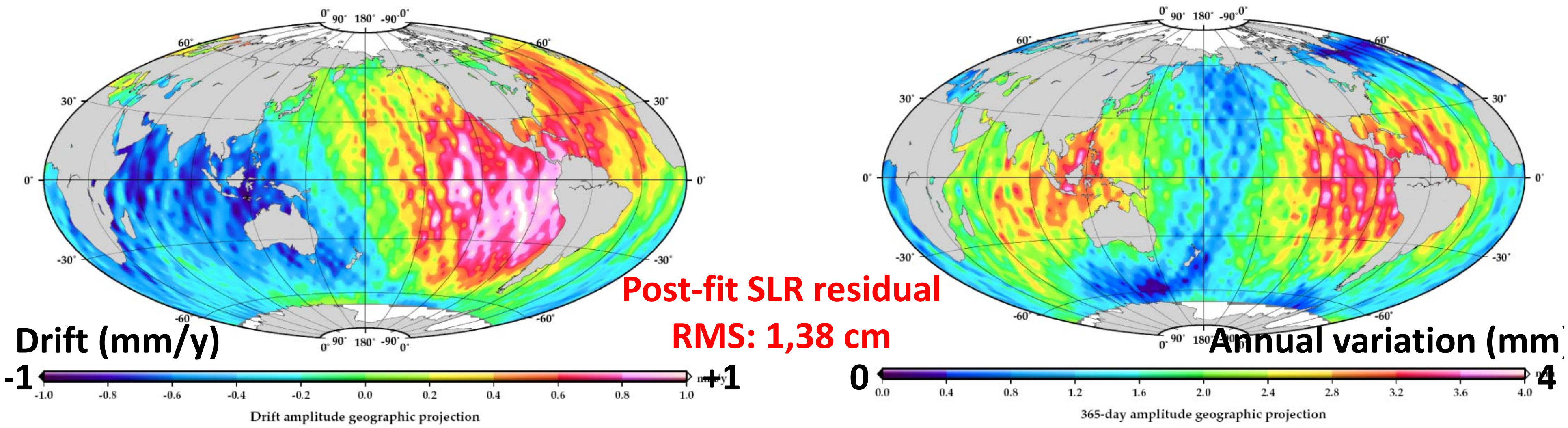
Rms values [cm] of the orbit fit residuals (mean values from the 60 resp. 75 arcs)

Gravity field model	GOCE max. d/o 180 x 180
EGM2008 (Pavlis et al. 2012)	2.70
GIF48 (Ries et al. 2011)	1.64
GOCO03S (Mayer-Gürr et al. 2012)	1.64
EIGEN-6C4	1.50
GO_CONS_GCF_2_TIM_R5	1.52
GO_CONS_GCF_2_DIR_R5	1.51
EIGEN-6S (time variable) at 20091201	1,48
EIGEN-6S2 (time variable) at 20091201	1.47
GOCO05S (time variable, Mayer-Gürr 2015) at 20091201	1.42
EIGEN-6S4 (time variable) at 20091201 (GOCE)	1.43

Conclusion

- Clear improvement of the dynamic orbit computation for GOCE when using time variable gravity field models
- Best results for the most recent models EIGEN-6S4 and GOCO05S

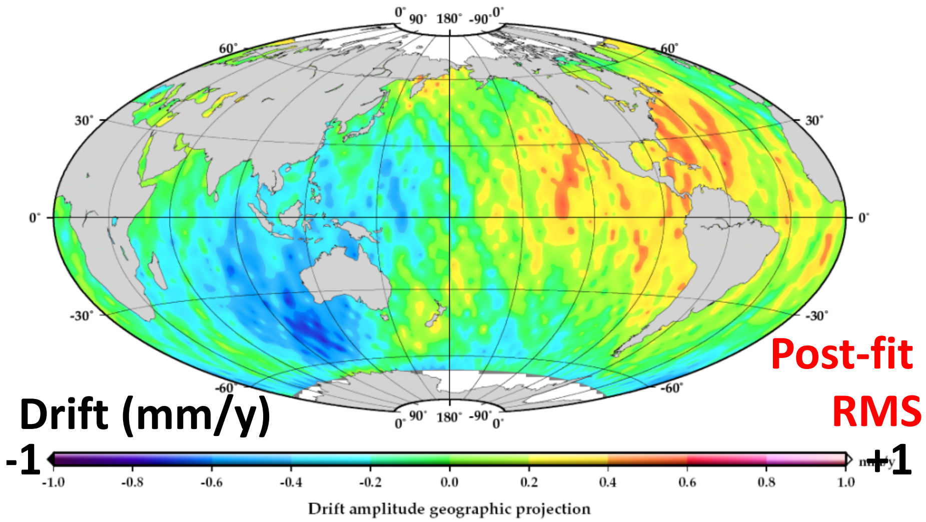
JASON-2 dynamic orbit computation* - EIGEN-6S2 (as for the J2 GDR-D)



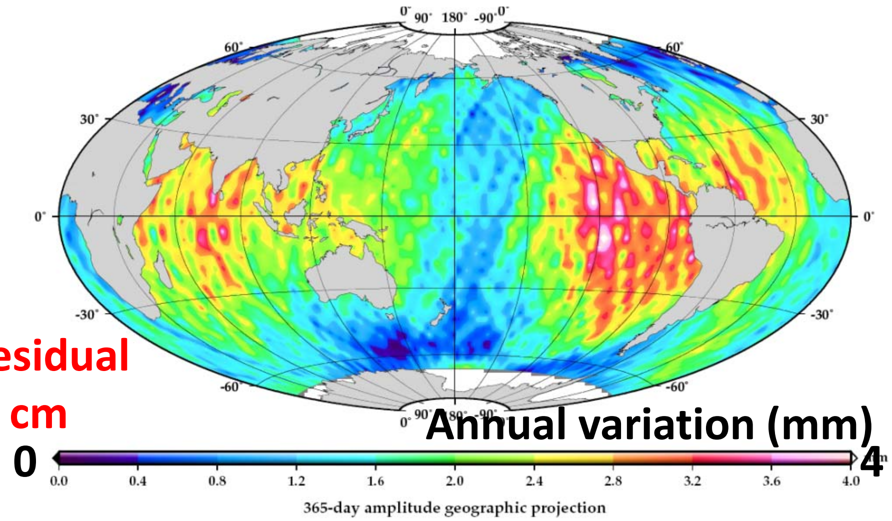
- Temporal behaviour (over ~ 6 years in terms of drift + annual variation) of the radial orbit differences w.r.t. the JPL14A reduced dynamic orbits (where the impact of the gravity field is assumed to be suppressed) = geographically correlated radial orbit error.
- Over the oceans only – to show the erroneous impact on sea level estimation

* By courtesy of A. Couhert and J. Moyard / CNES

JASON-2 dynamic orbit computation*:
- EIGEN-6S4



Post-fit SLR residual RMS: 1,34 cm



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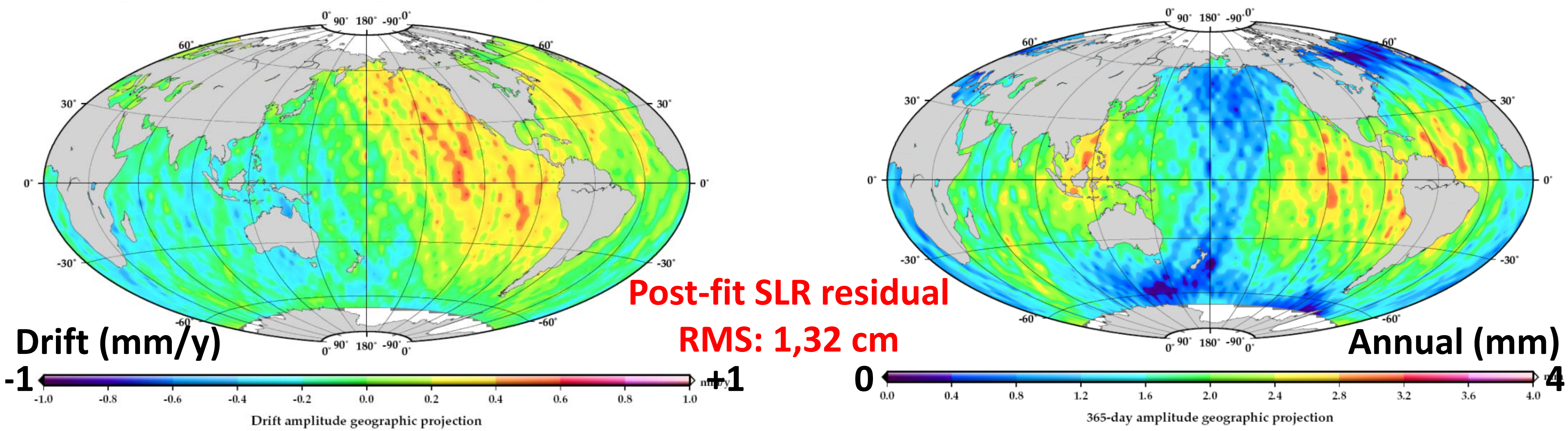
JASON-2 dynamic orbit computation
- CSR RL05 monthly gravity solution*



- Temporal behaviour (over ~ 6 years in terms of drift + annual variation) of the radial orbit differences w.r.t. the <u>JPL14A reduced dynamic orbits</u> (where the impact of the gravity field is assumed to be suppressed) = geographically correlated radial orbit error.
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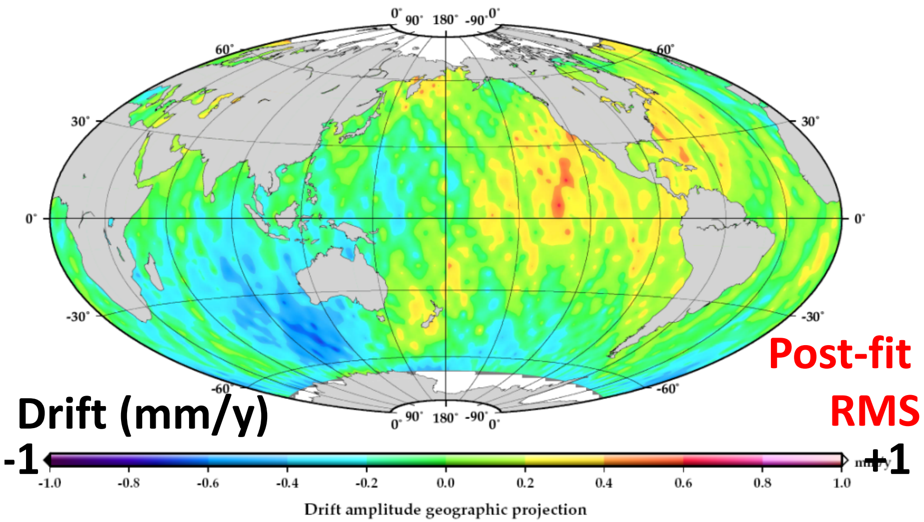
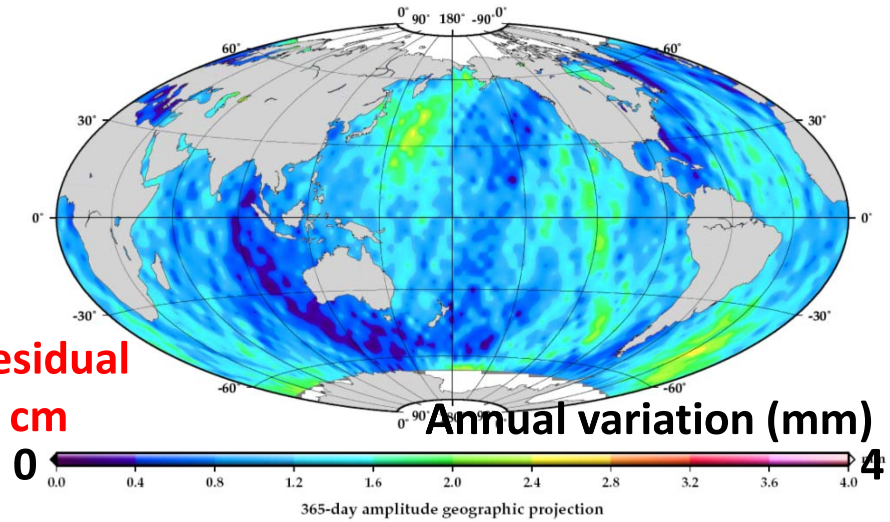
*The CSR monthly gravity field solution is taken as a reference among the different GRACE analysis centers (CSR, GFZ, JPL, CNES/GRGS).

JASON-2 dynamic orbit computation*: - EIGEN-6S4 incl. estimation of C/S_{31}



Post-fit SLR residual
RMS: 1,33 cm



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Conclusion for the JASON-2 dynamic orbit computation

- The new model EIGEN-6S4 reduces the geographically correlated radial orbit drift rate, from more than 1 mm/y (for EIGEN-6S2) to less than 0.6 mm/y over ~ 6 years, with respect to reduced dynamic orbits.
- The improvement is close to the level reached with the CSR monthly GRACE solutions (instead of a mean gravity field model).
- The mean RMS of SLR post-fit residuals also confirm that the dynamic orbits perform better when using EIGEN-6S4.

Summary

– EIGEN-6S4 is a new time-variable global satellite-only gravity field model of maximum d/o 300

– This model has been inferred from the combination of LAGEOS, GRACE and GOCE and is practically a time-variable version of the GOCE DIR-5 model

– EIGEN-6S4 contain time variable parameters for all spher. harm. coeff. up to degree 80 (drift parameters per year, annual and semiannual terms).

– EIGEN-6S4 shows improvements in orbit determination for Earth observation satellites w.r.t. precursor time variable models

– The final version of EIGEN-6S4 will be released mid of 2015 and will be available via the ICGEM data base at GFZ Potsdam

http://icgem.gfz-potsdam.de

Thank you for your attention!