Temporal variations in the Earth's gravity field from multiple SLR satellites: Toward the investigation of polar ice sheet mass balance

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Satellite Laser Ranging (SLR)

SLR satellite

Measuring the distance between a satellite with corner reflectors and a ground-based laser station

Temporal variations in low-degree gravity field of the Earth from SLR observation

Yoder et al. (Nature, 1983) :

Secular increase in the Earth's oblateness (C_{20}) by GIA and tidal braking

Nerem et al. (GRL, 1993) :

Seasonal variation in the C_{20} and C_{30} terms by atmospheric and hydrological mass movements

Cheng and Tapley (JGR, 1999) :

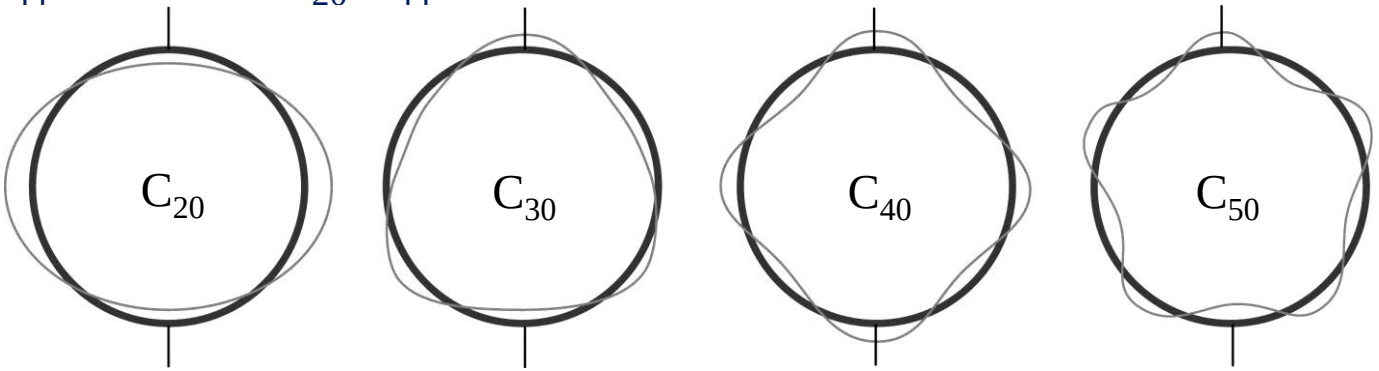
Detection of seasonal, inter-annual, and secular variations in the C_{20}-C_{80} terms

Cox and Chao (Science, 2002) :

Sudden shift in the C_{20} trend from increase to decrease in 1998

Matsuo, Chao, Otsubo, Heki (GRL, 2013) :

Detection of accelerated ice mass depletion in Greenland from the trend in the C_{20}-C_{44} terms and S_{20}-S_{44} terms



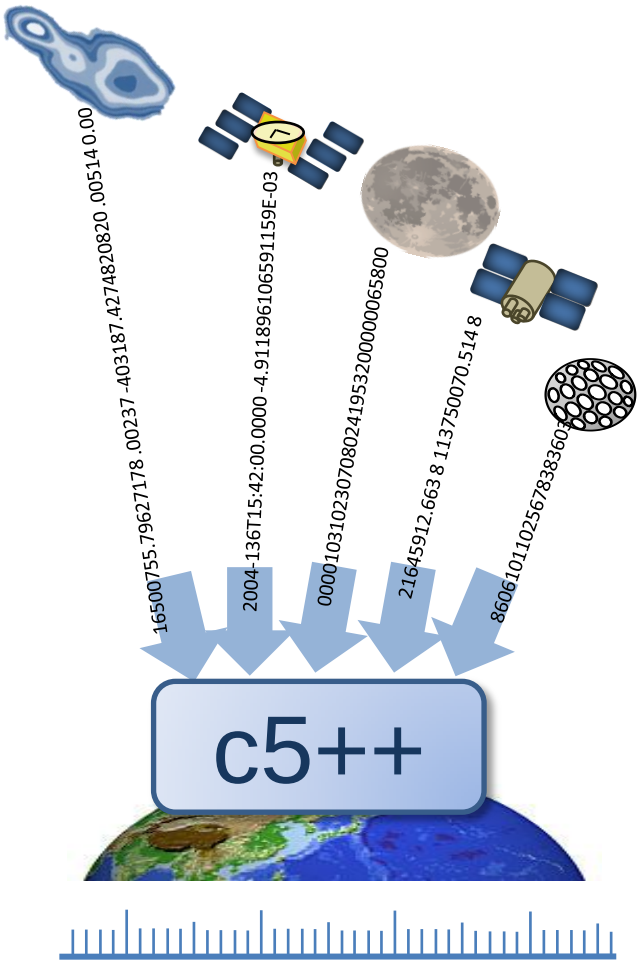
Recovery of the Earth's gravity field using a multi-technique space geodetic analysis software 'c5++'

(Otsubo et al, 1994; Hobiger et al., 2013)

The perturbation forces acting to artificial satellites are corrected based on the IERS conventions 2010

The satellite force model is based on the EGM 2008 model

The coordinate of SLR tracking stations are kept fixed to the ITRF 2008



SLR/HIT-U gravity solution

The graviational Stokes' coefficients of harmonic degree and order up to 4 for 27-years between 1986 Sep. and 2013 May derived from 'c5++' software and the tracking data by 6 SLR satellites

1975 : STARLETTE

1976 : LAGEOS-1

1986 : AJISAI

1992 : LAGEOS-2

1993 : STELLA

2012 : LARES

Outline of this study

- Evaluate the accuracy and quality of our SLR gravity solution by comparing the surface mass redistribution models and the other geodetic data
- Investigate the changes in polar ice sheet mass balance using our SLR gravity solution especially before the launch of GRACE in 2002.

Evaluation of SLR/HIT-U solution

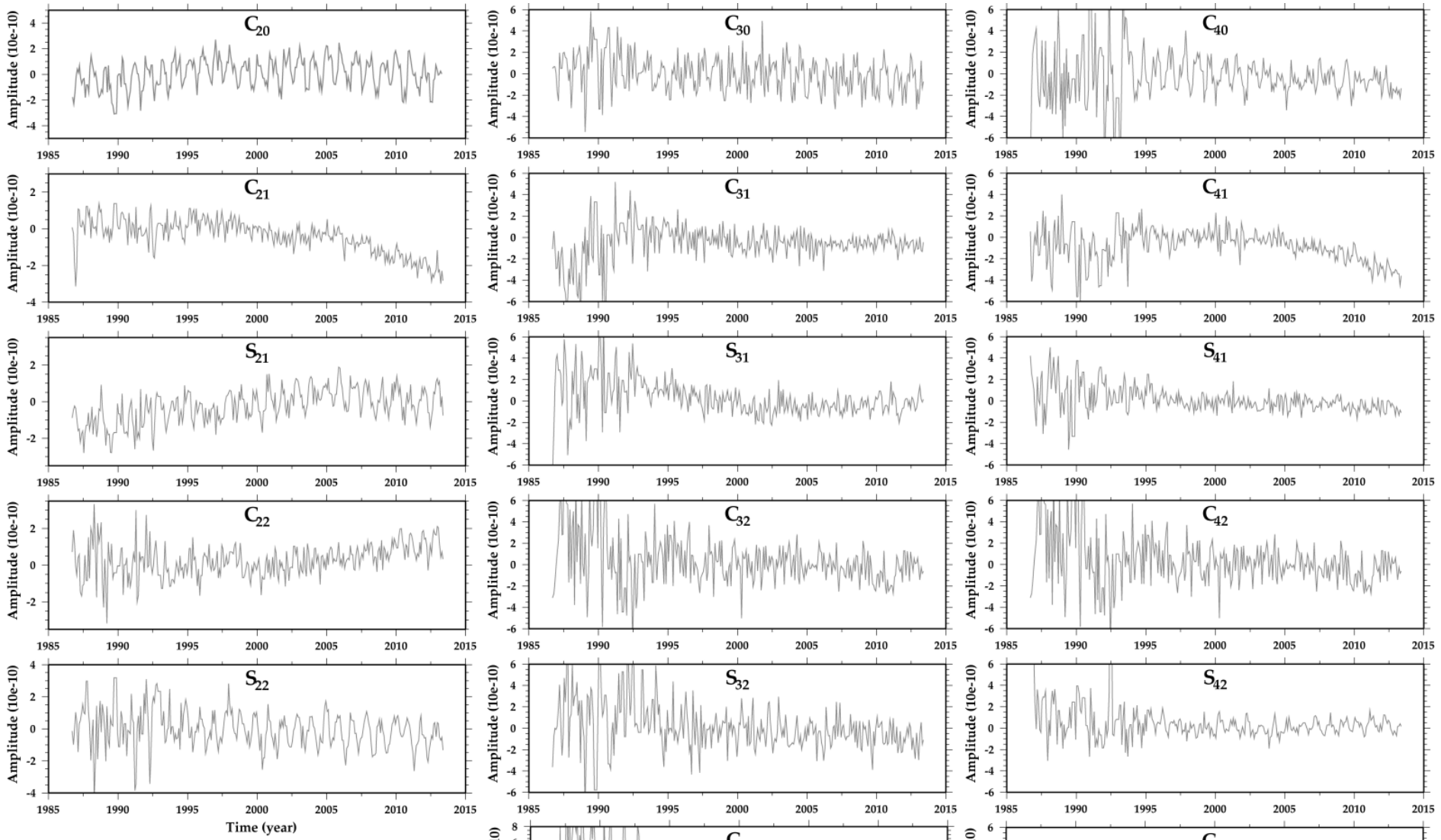
- ## Focus on annual variation

  Compare SLR annual gravity variations with non-tidal atmospheric and oceanic mass transport model (AOD1B) and land hydrological mass transport model (GLDAS), and check their consistency

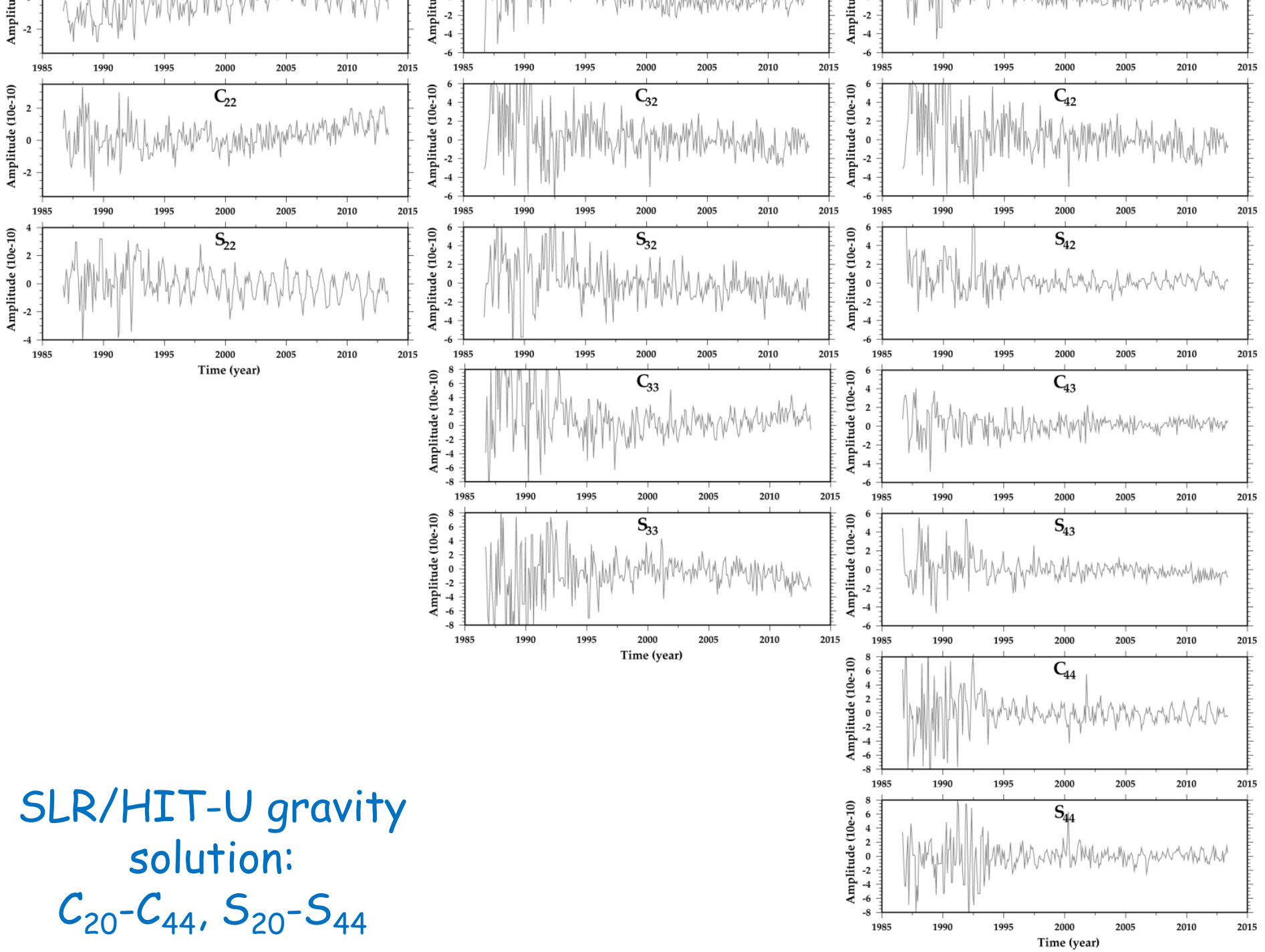
- ## Compare with the other geodetic data

  Compare the C21 and S21 terms with Earth Orientation Parameters (EOP)

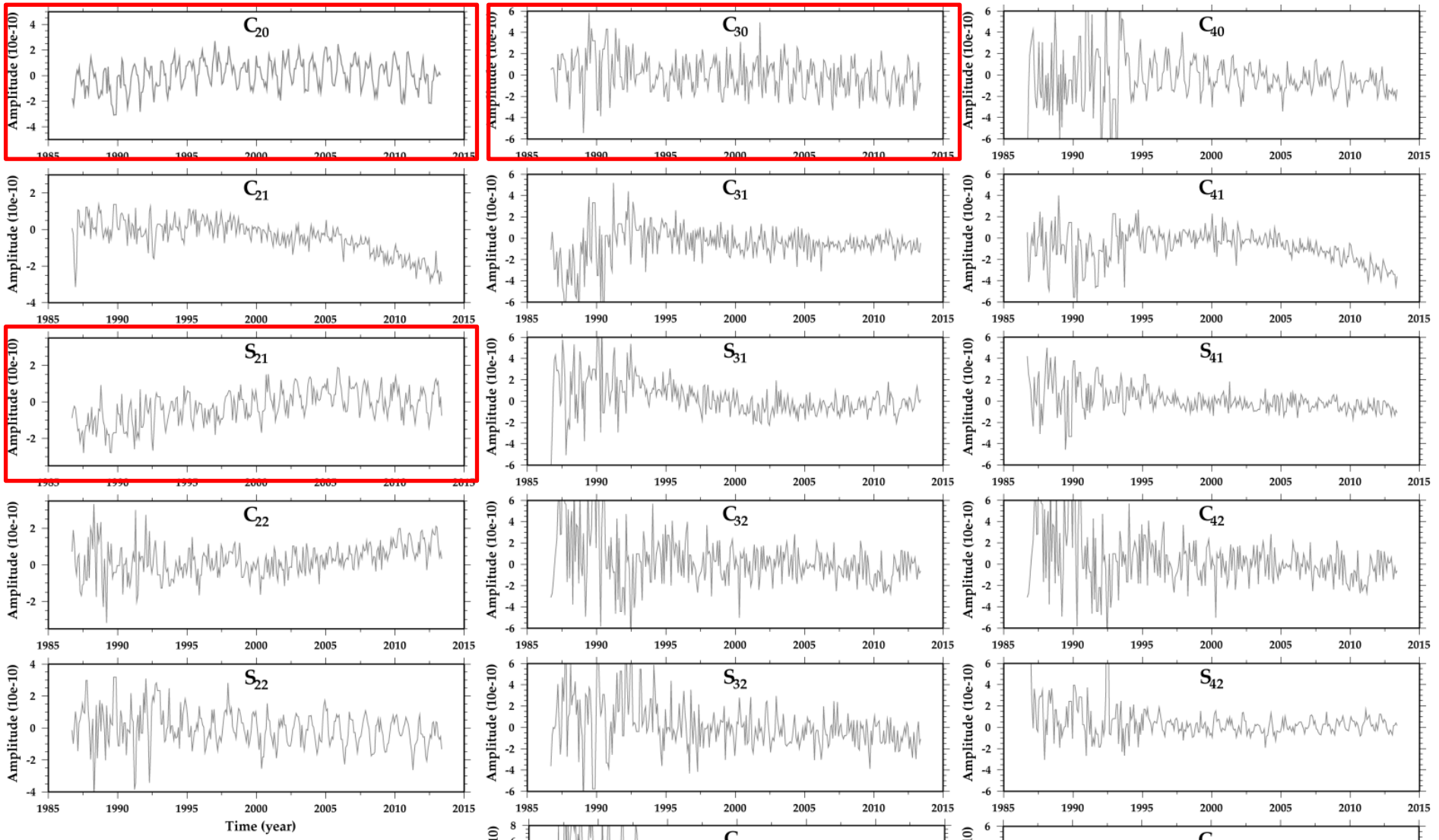
  Compare the gravitational Stokes' coefficients from GRACE after 2003



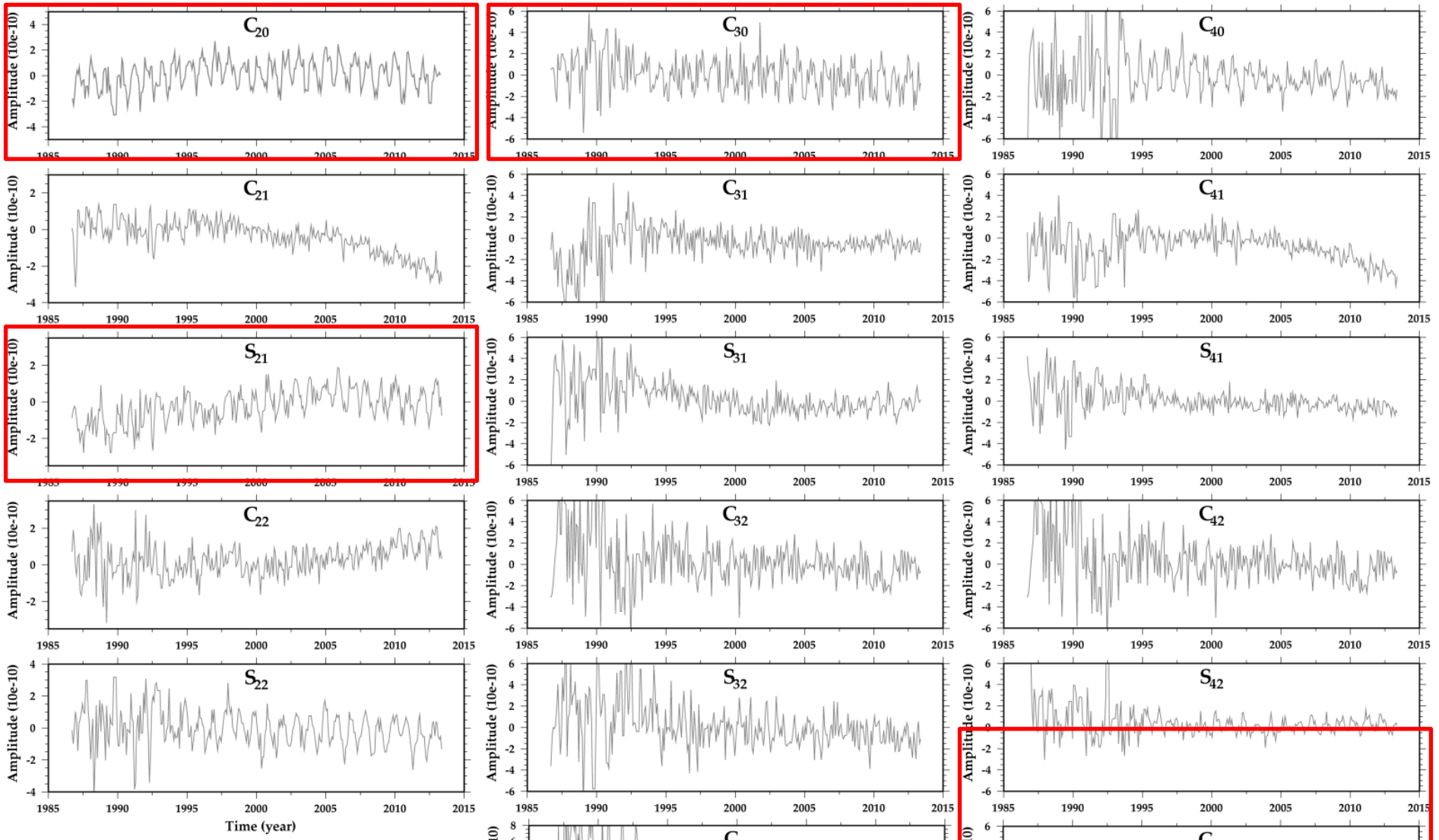
SLR/HIT-U gravity solution: C_{20}-C_{44}, S_{20}-S_{44}



SLR/HIT-U gravity solution:
C_{20}-C_{44}, S_{20}-S_{44}



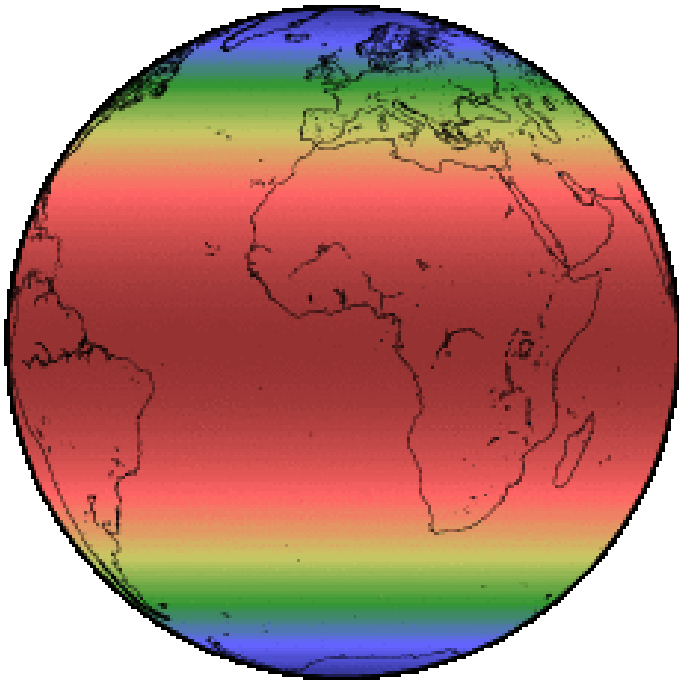
SLR/HIT-U gravity solution: C_{20}-C_{44}, S_{20}-S_{44}



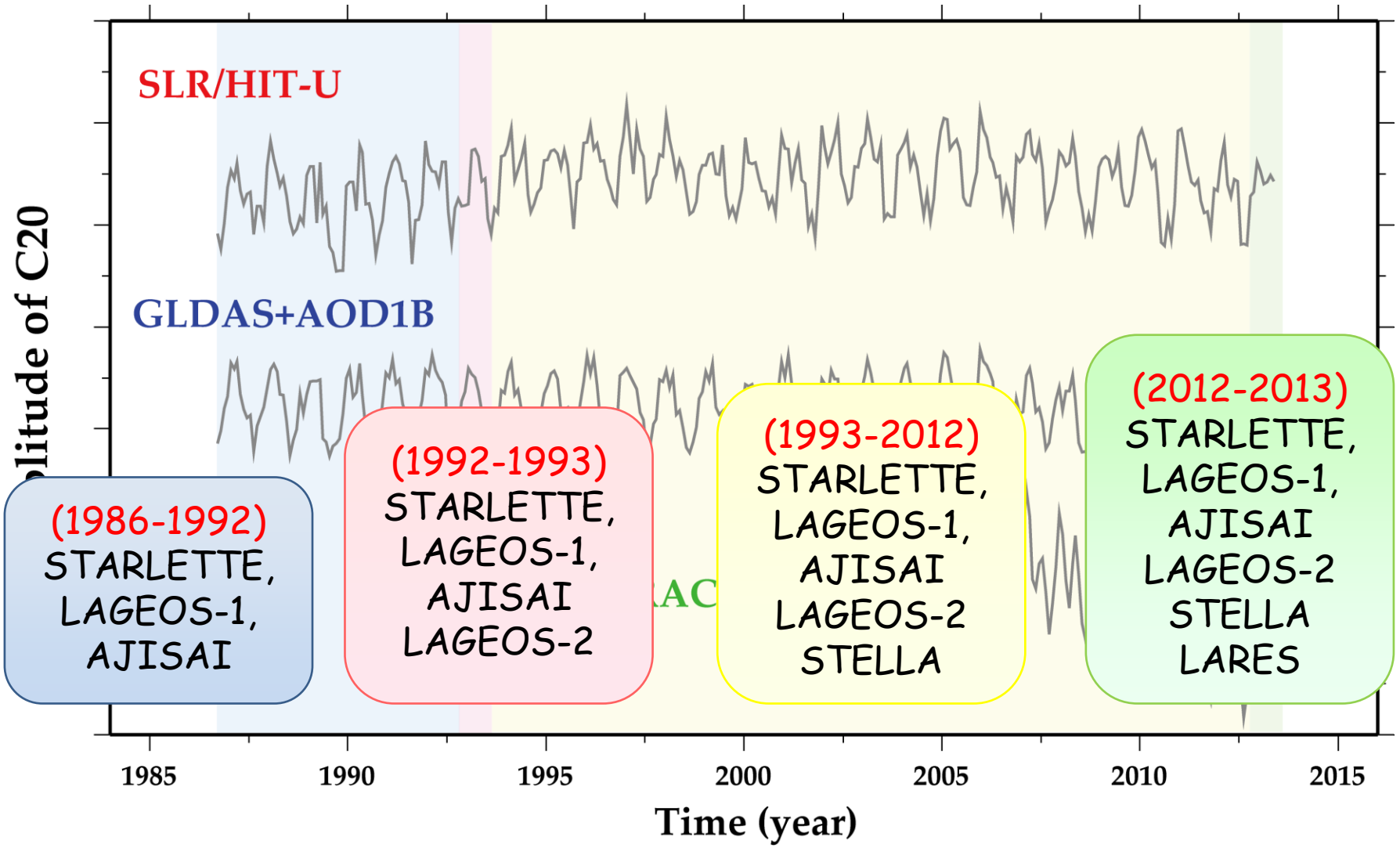
SLR/HIT-U gravity solution:

C_{20}-C_{44}, S_{20}-S_{44}

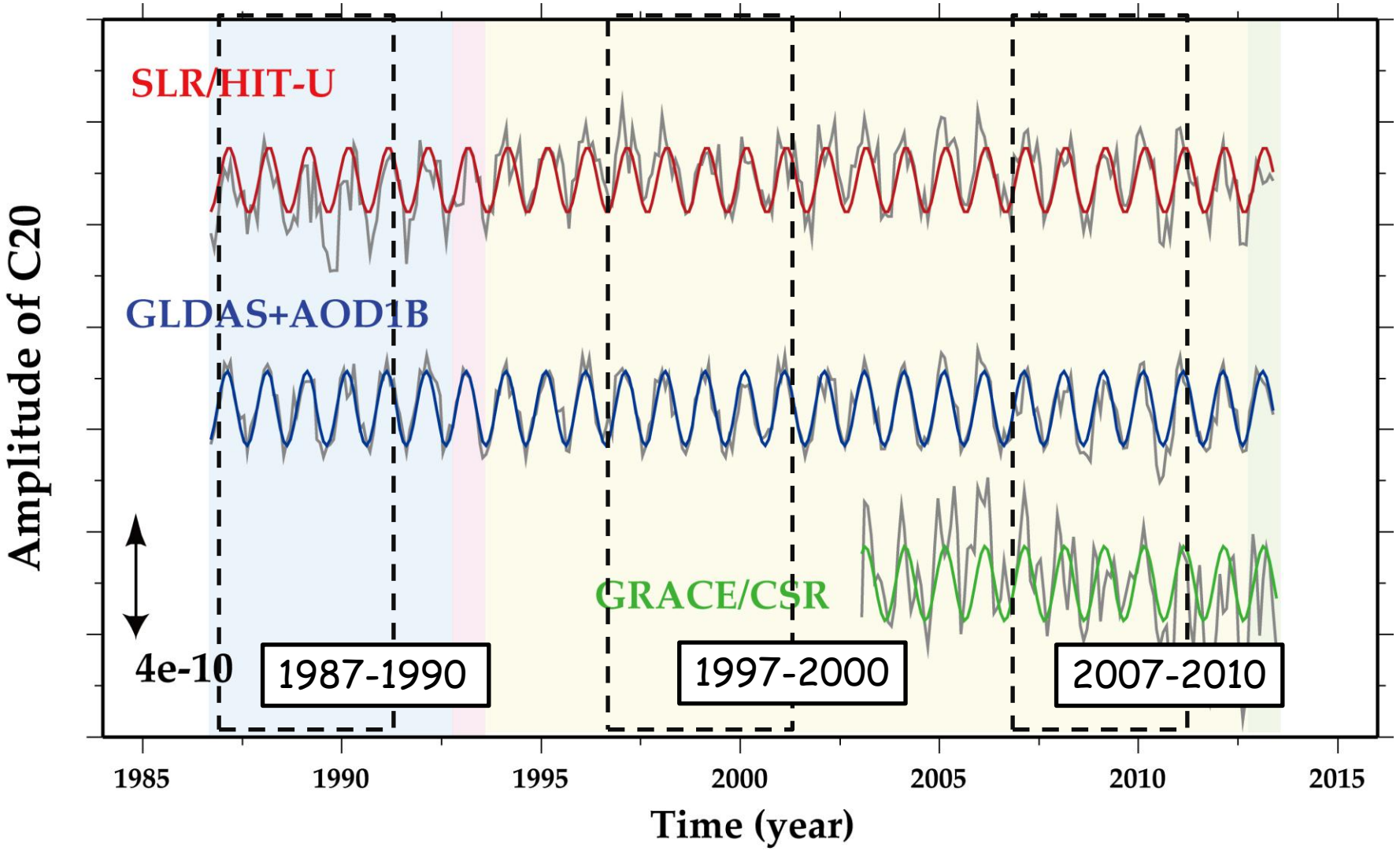
The C_{20} term (The Earth's oblateness)

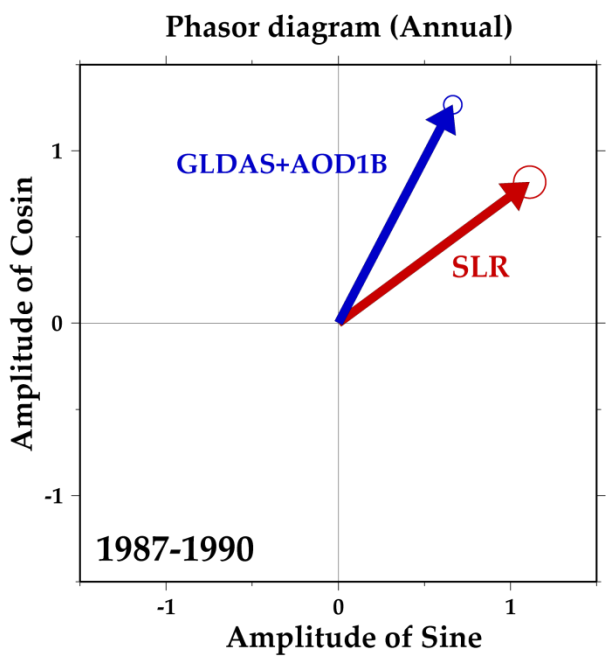


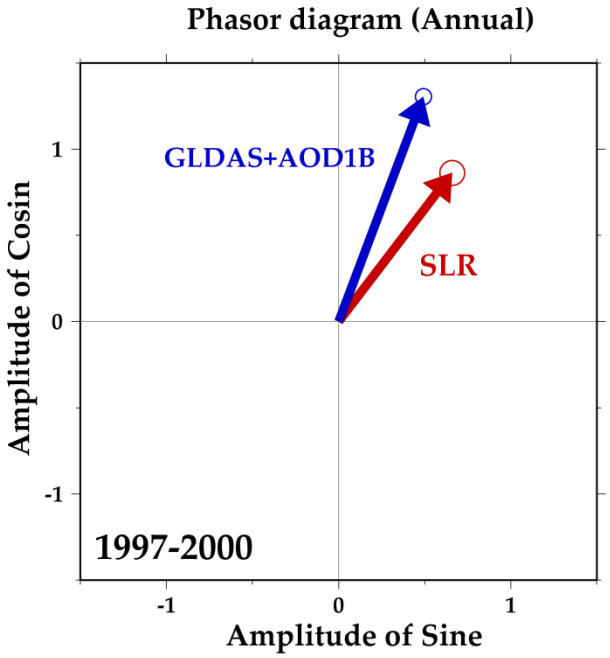
Time-series of the C_{20} term

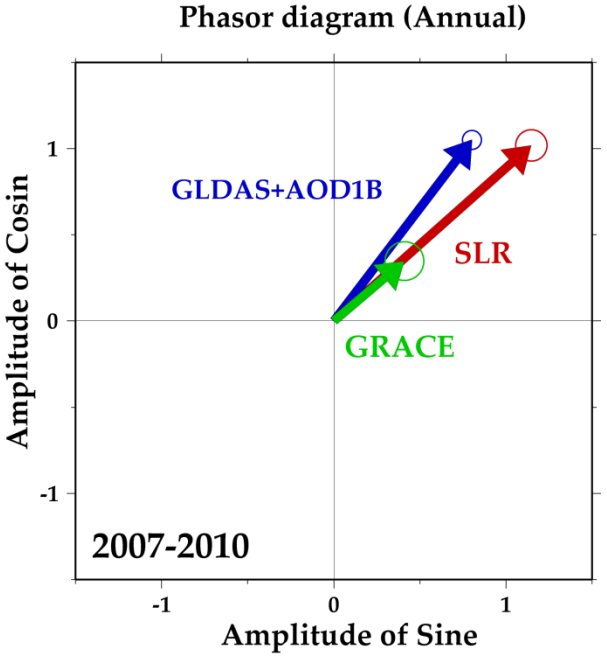


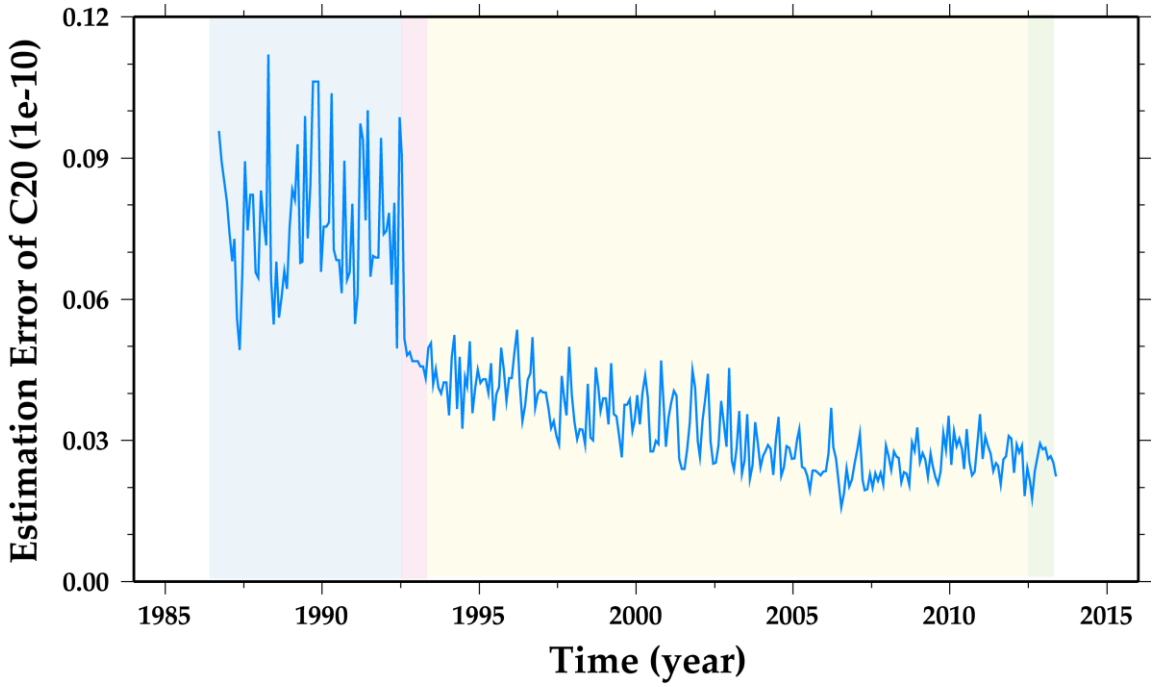
Time-series of the C_{20} term





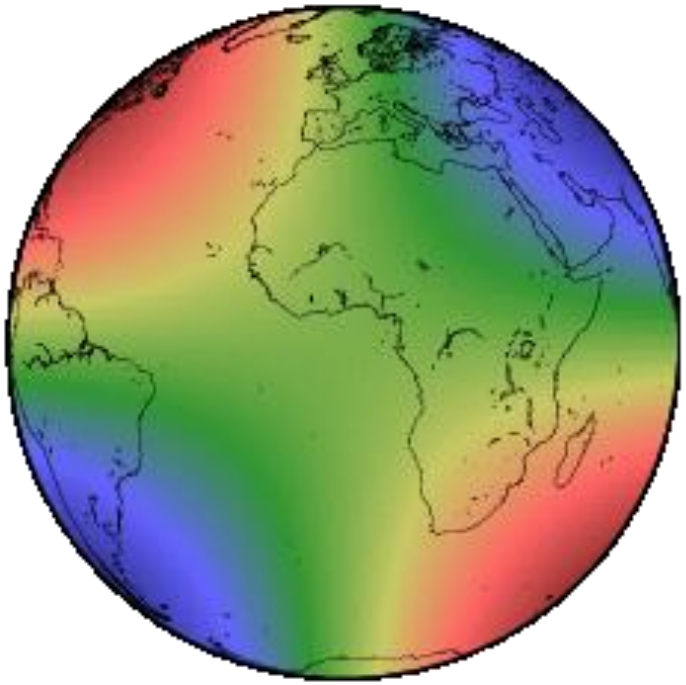




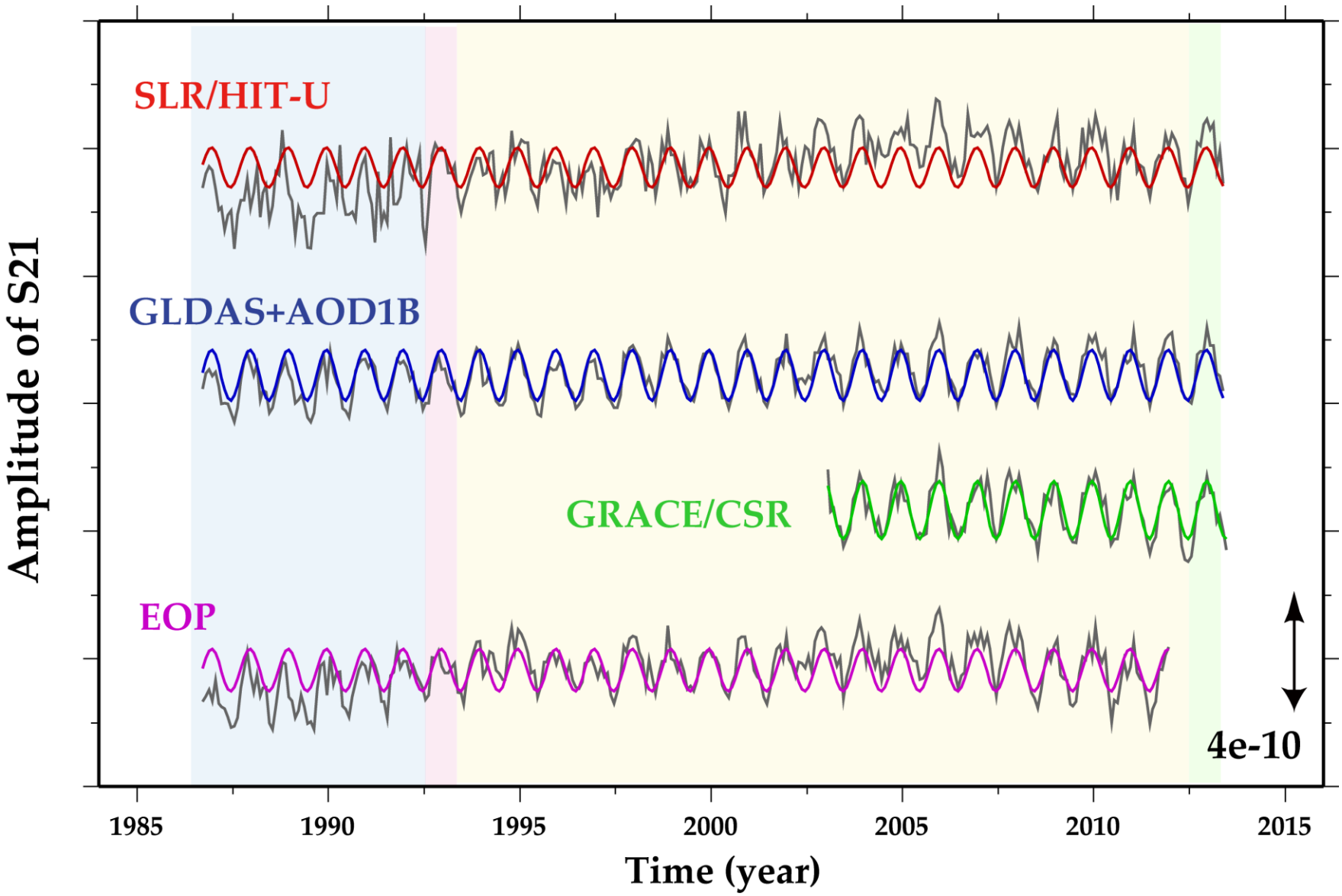


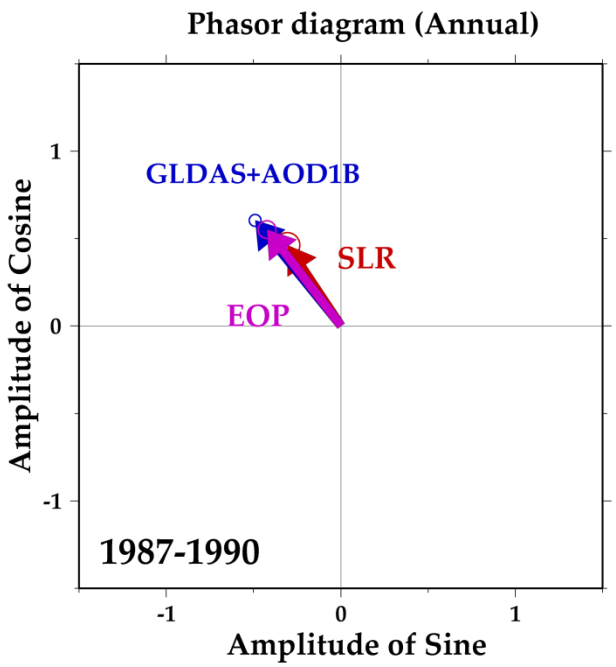
Phasor diagram and estimation error of the C_{20} term

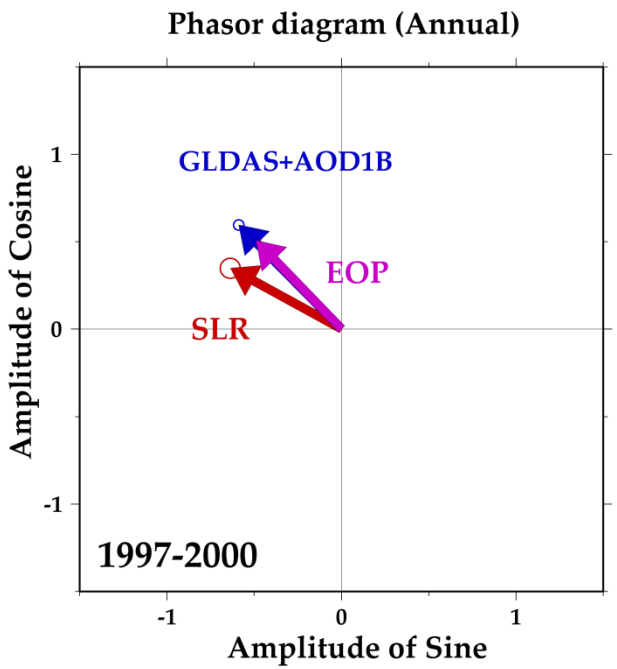
The S_{21} term
(polar motion toward Y direction)

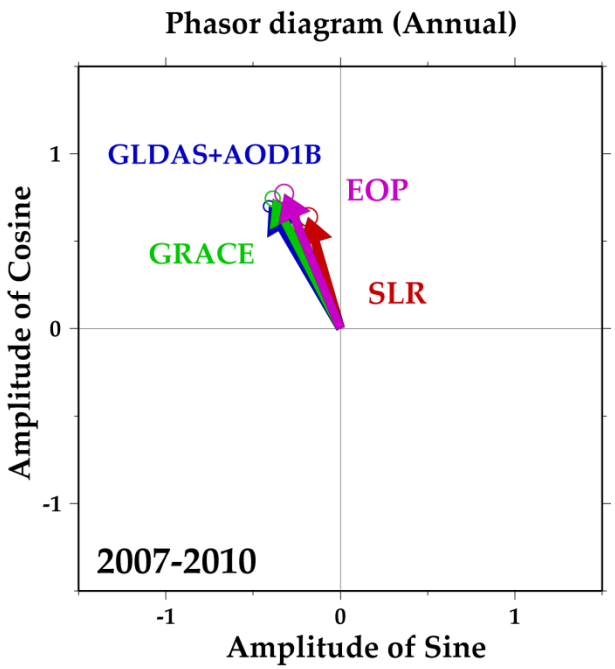


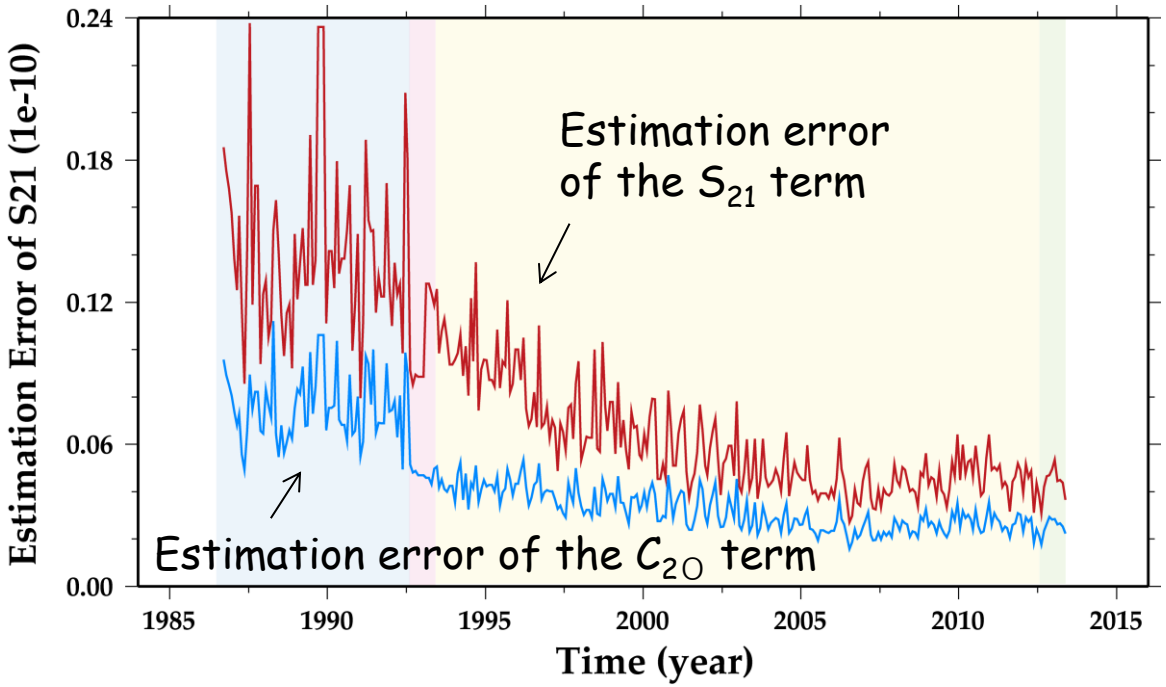
Time-series of the S_{21} term





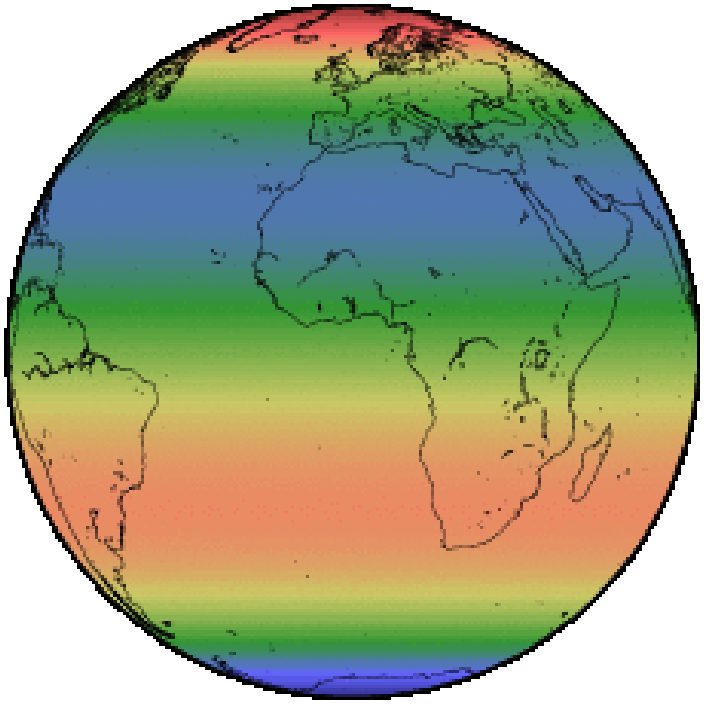




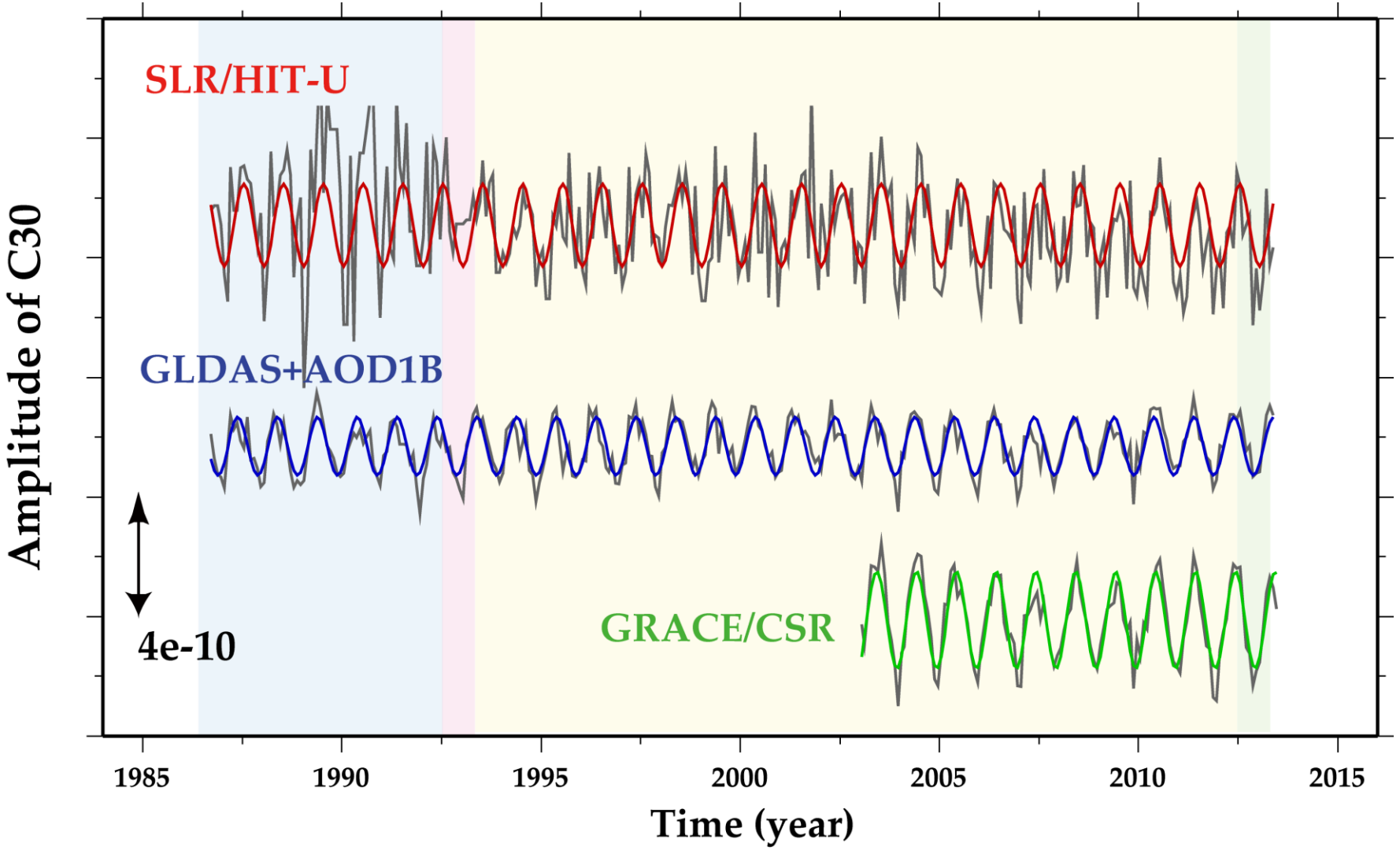


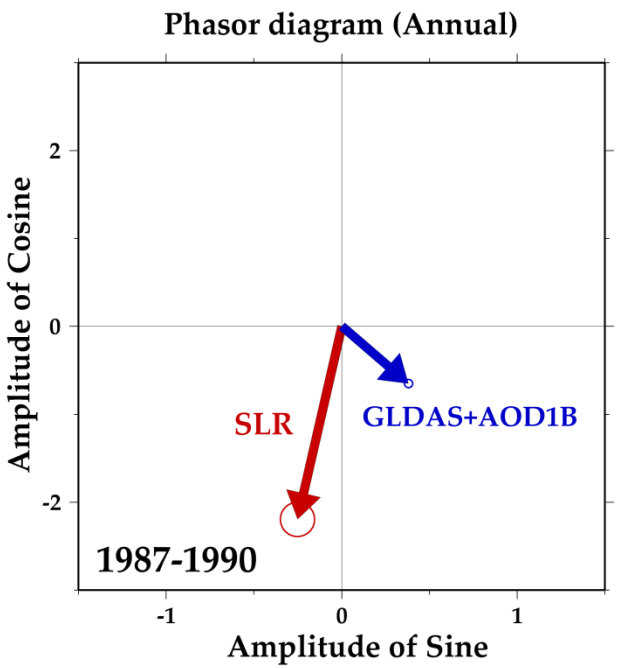
Phasor diagram and estimation error of the S_{21} term

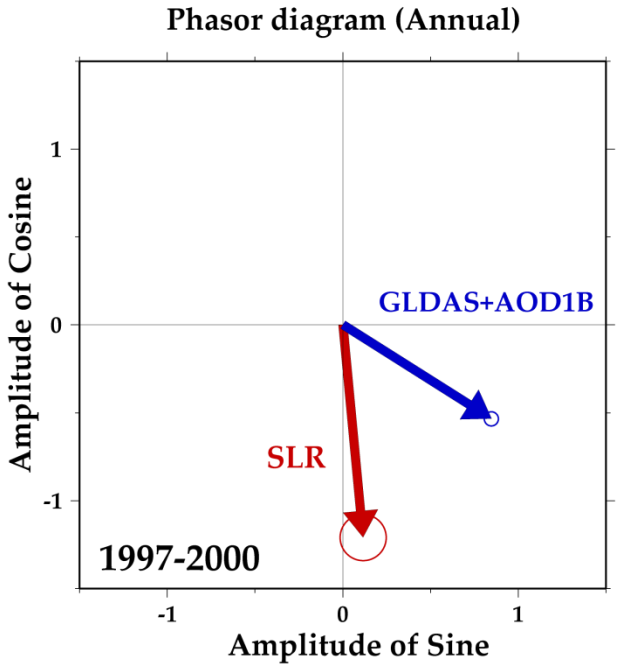
The C_{30} term

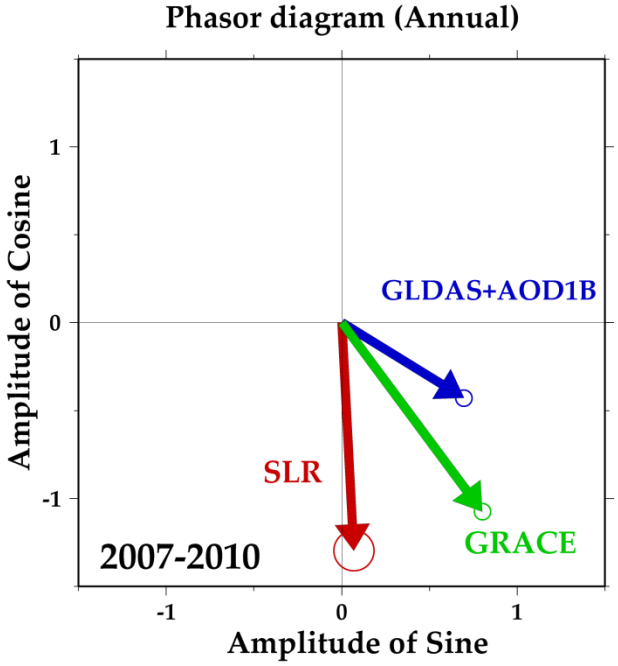


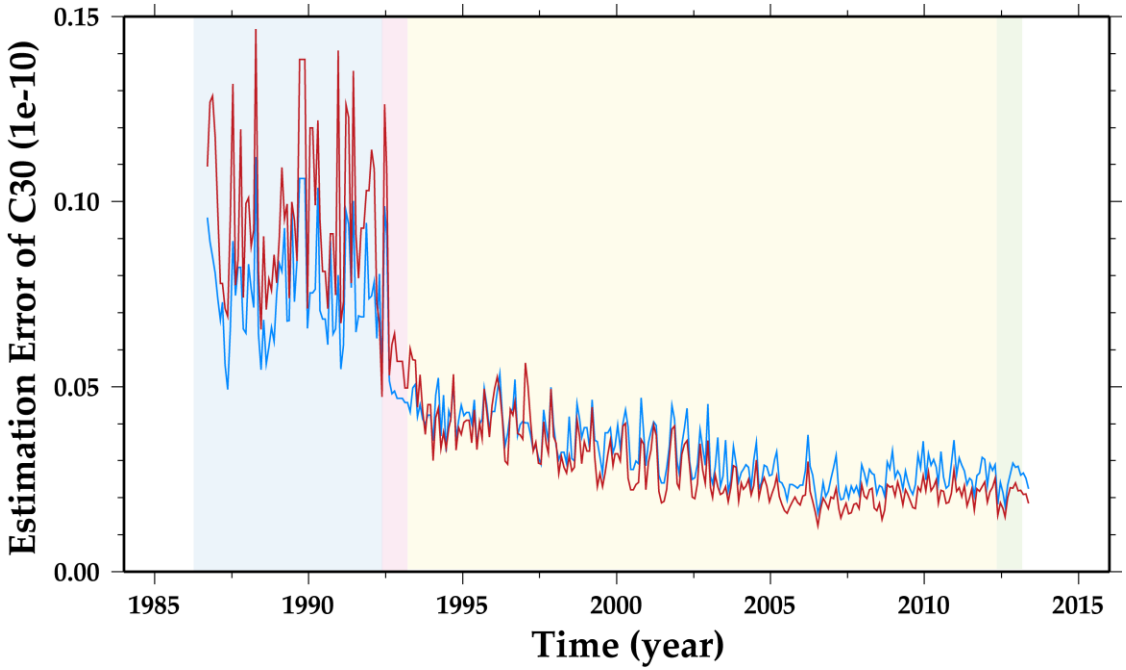
Time-series of the C_{30} term





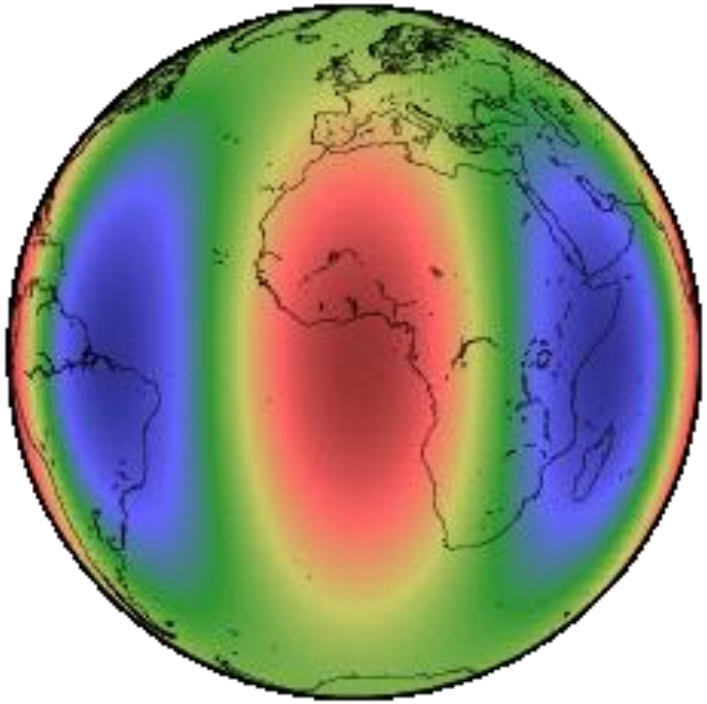




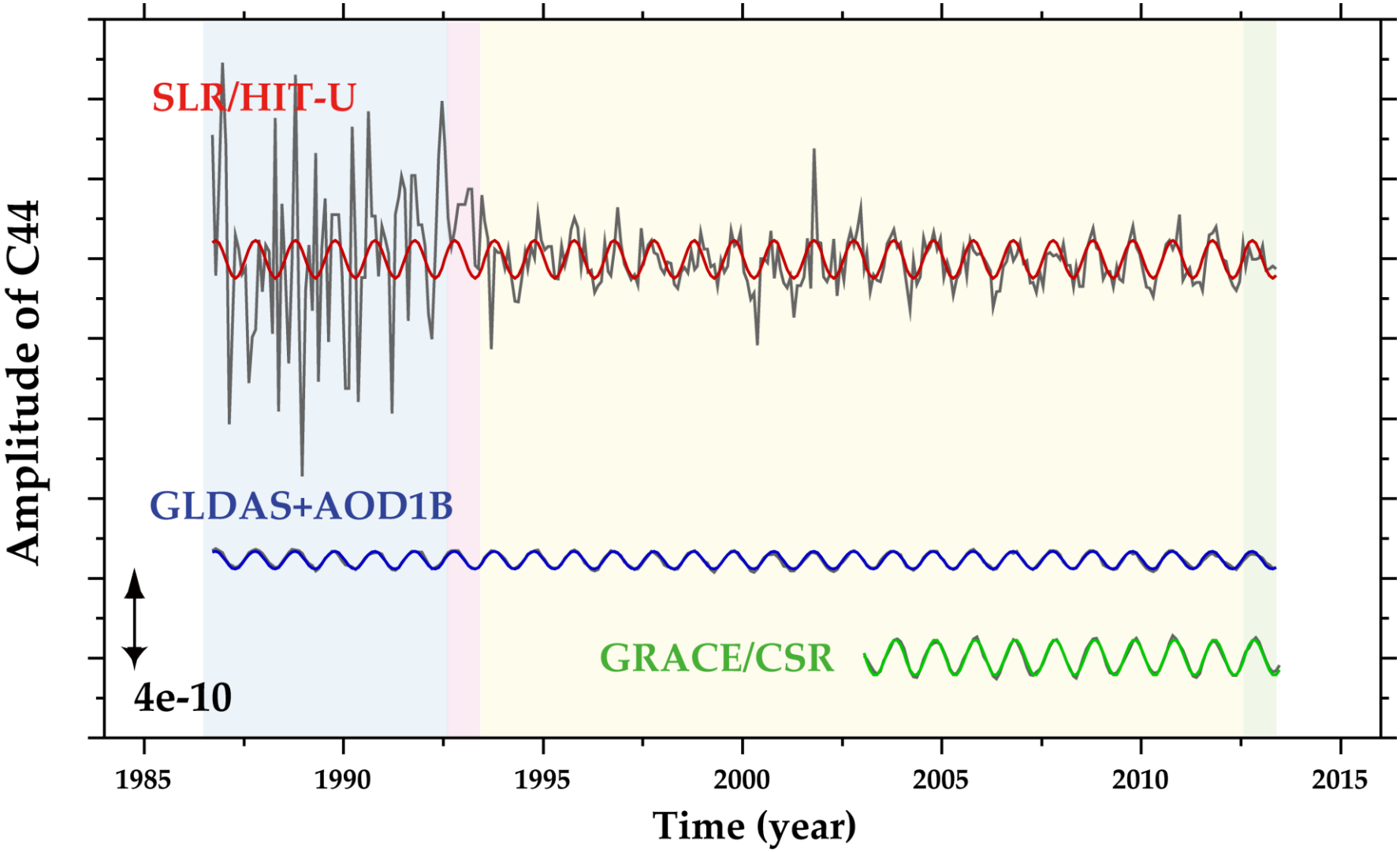


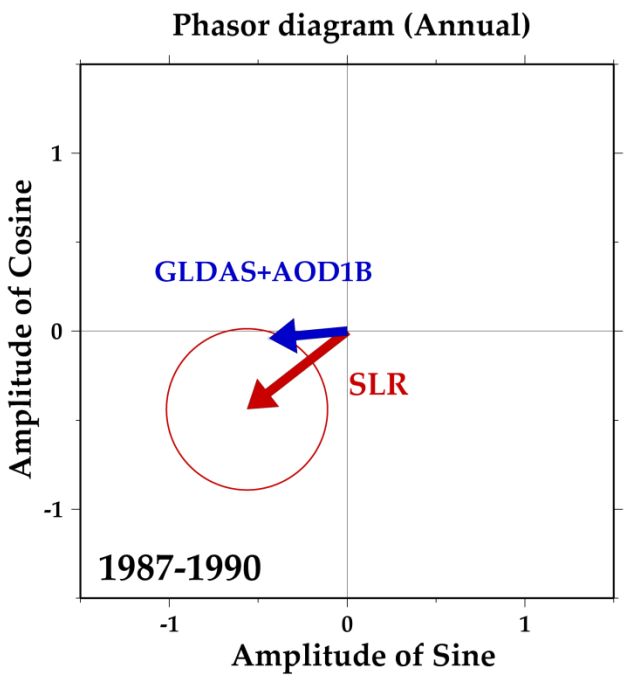
Phasor diagram and estimation error of the C_{30} term

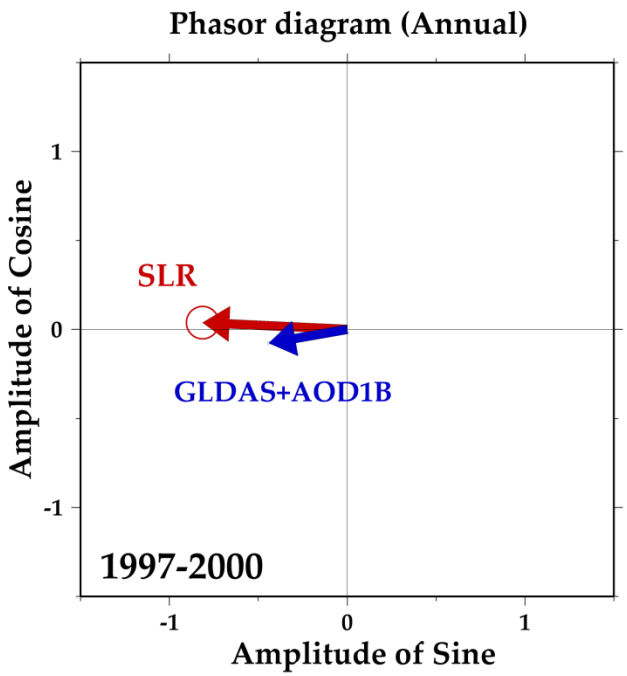
The C_{44} term

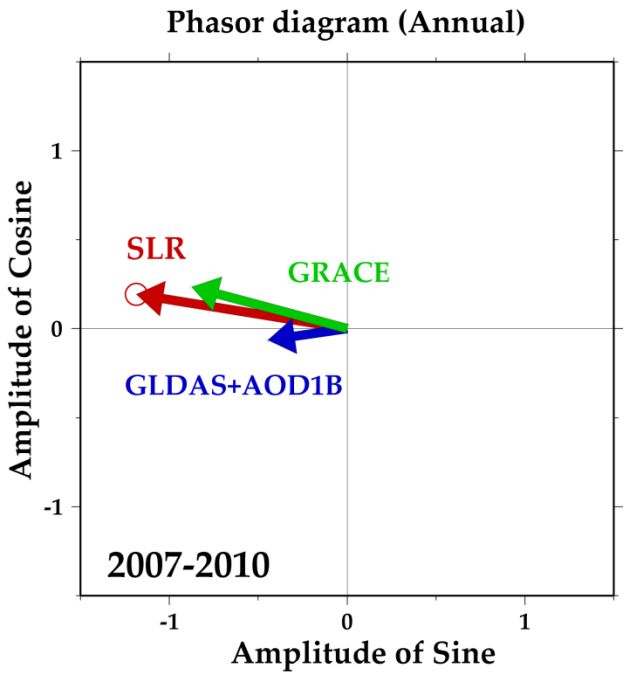


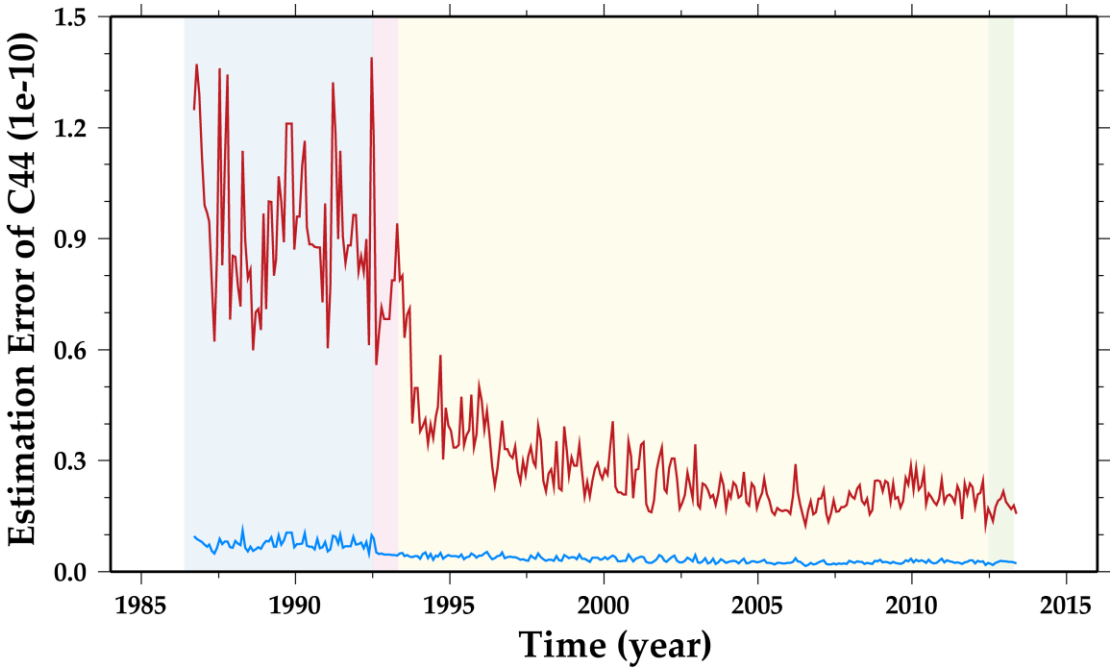
Time-series of the C_{44} term











Phasor diagram and estimation error of the C_{44} term

On quality of our gravity solution

- The degree 2 terms are good quality including 1980s. Their quality has been improved after 1992 when the LAGEOS-2 data were added.
- The degree 3 terms are also good quality, but are relatively lower quality in 1986-1992.
- The degree 4 terms in 1986-1992 are low quality, but those after 1993, when the STELLA data were added, are good quality.

Investigation of polar ice sheet mass balance through use of SLR

Strength and weakness of SLR gravity data

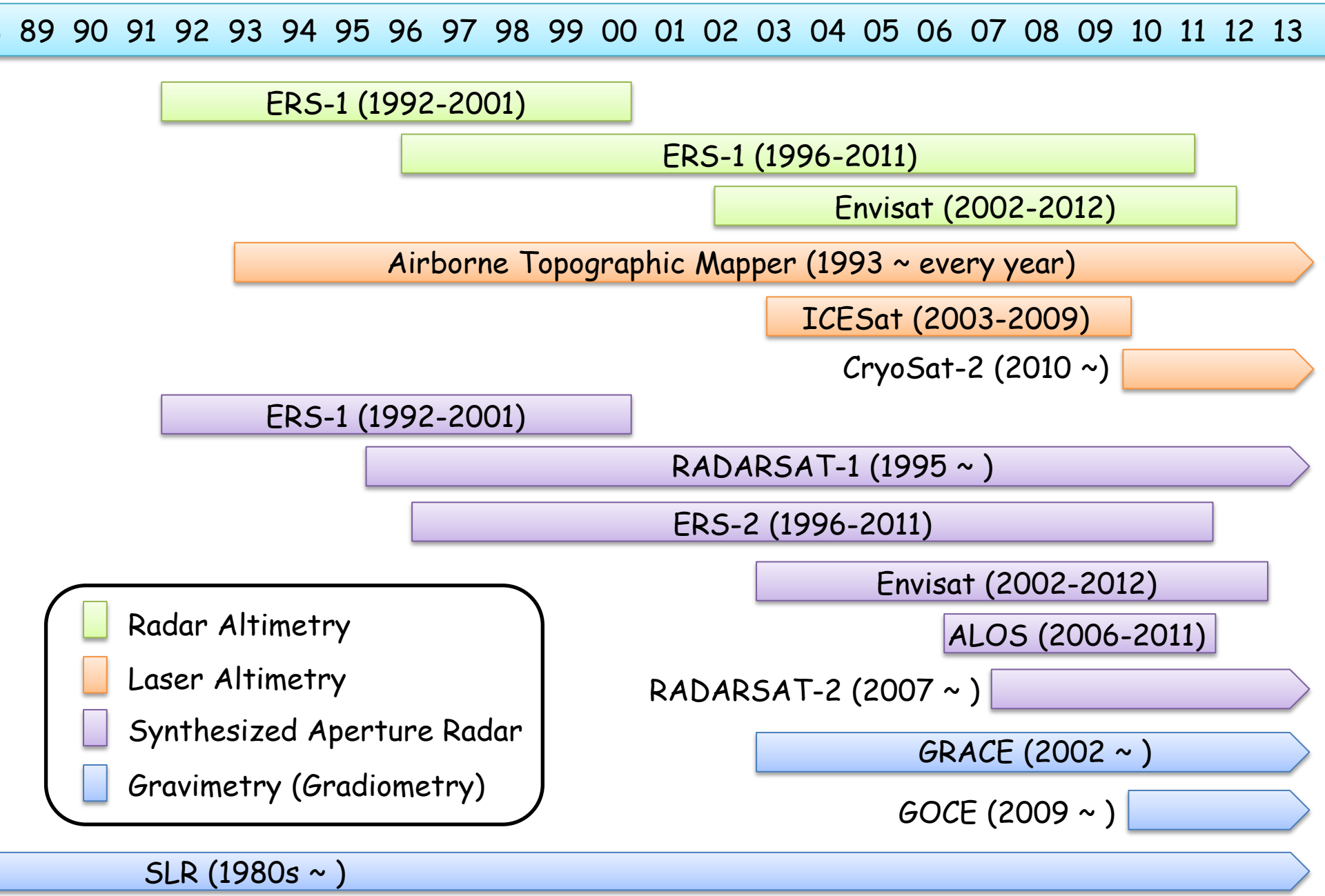
Strength : Longer time span of data accumulation

(SLR: 1980s ~, GRACE : 2002 ~)

Weakness : Low spatial resolution

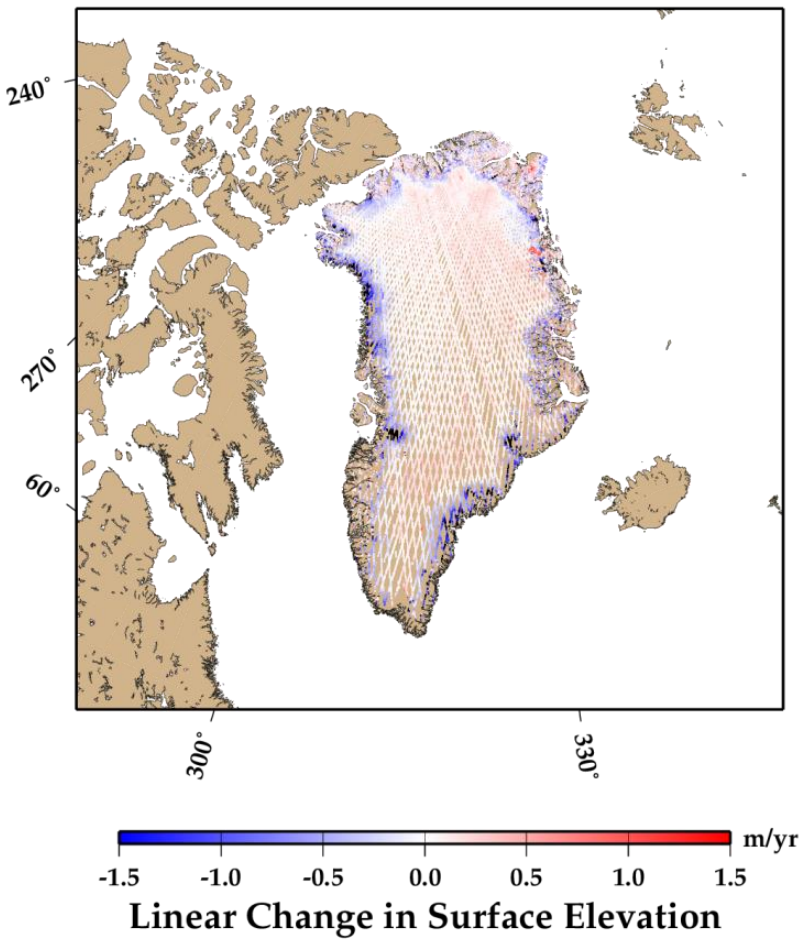
(SLR: degree and order up to 4, equivalent to ~5000km
GRACE : degree and order up to 60, equivalent to ~300km)

Space geodetic observations of polar ice sheet mass balance

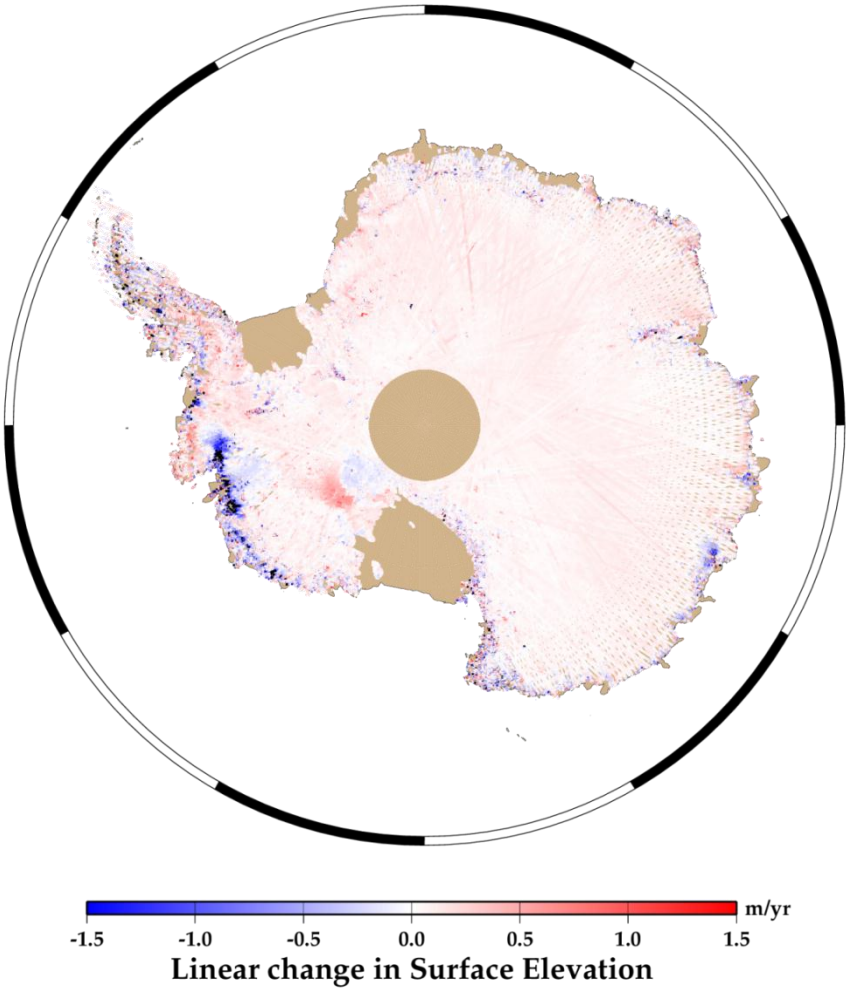


Linear change in ice thickness in Greenland and Antarctica from ICESat altimetry (2003-2009)

Greenland

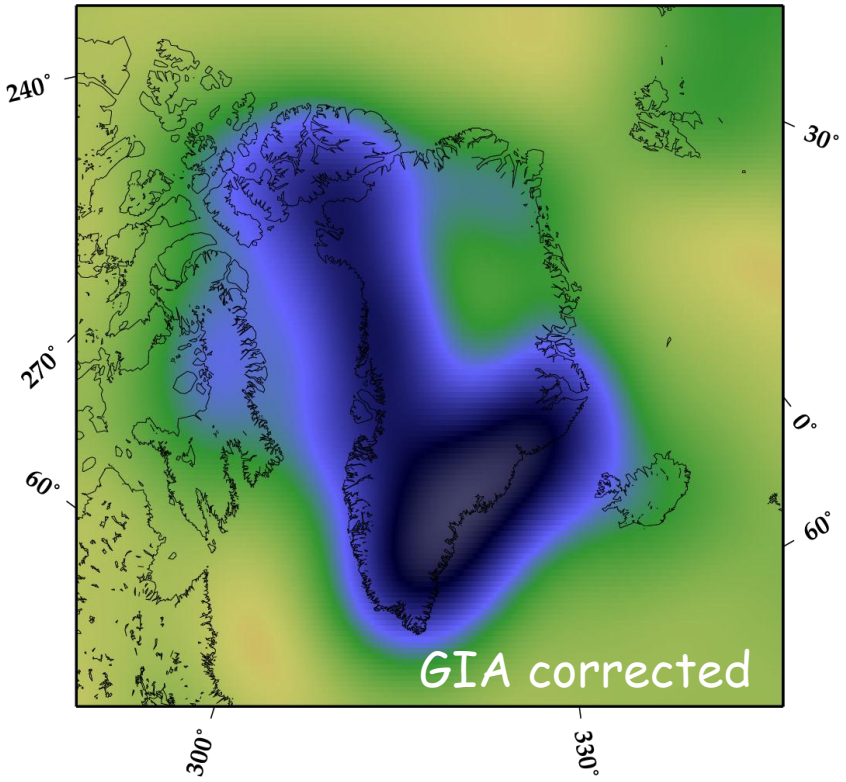


Antarctica

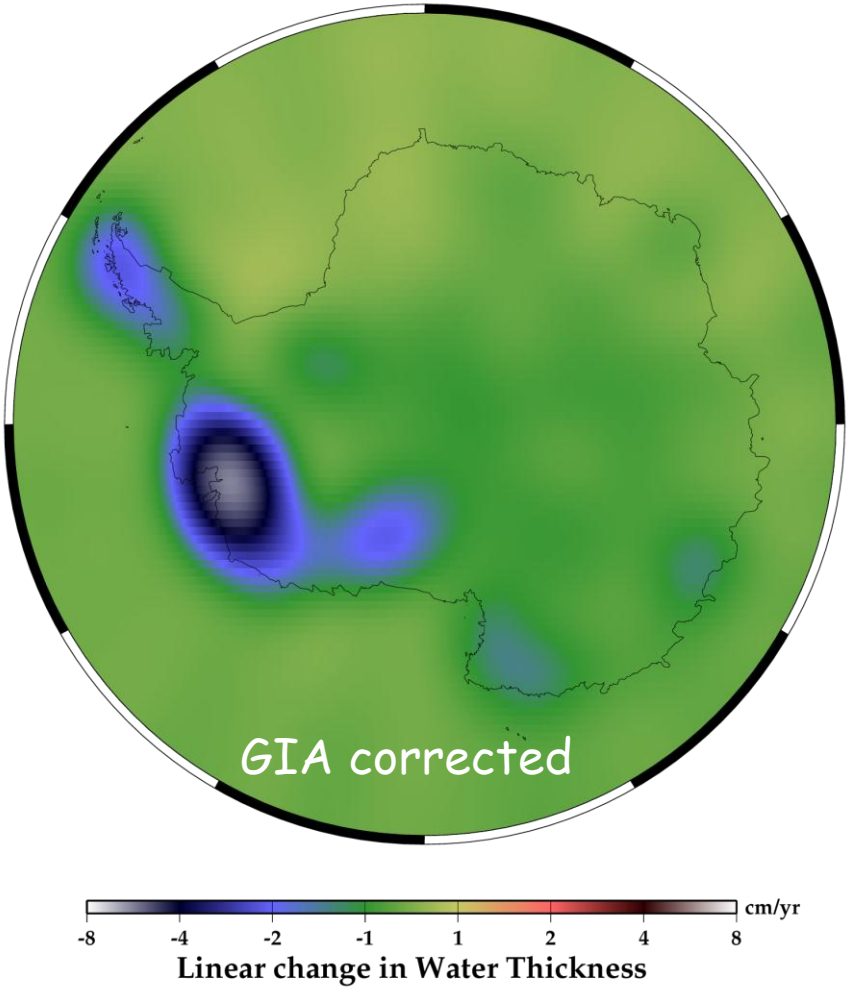


Linear change in ice mass in Greenland and Antarctica from GRACE gravimetry (2003-2013)

Greenland

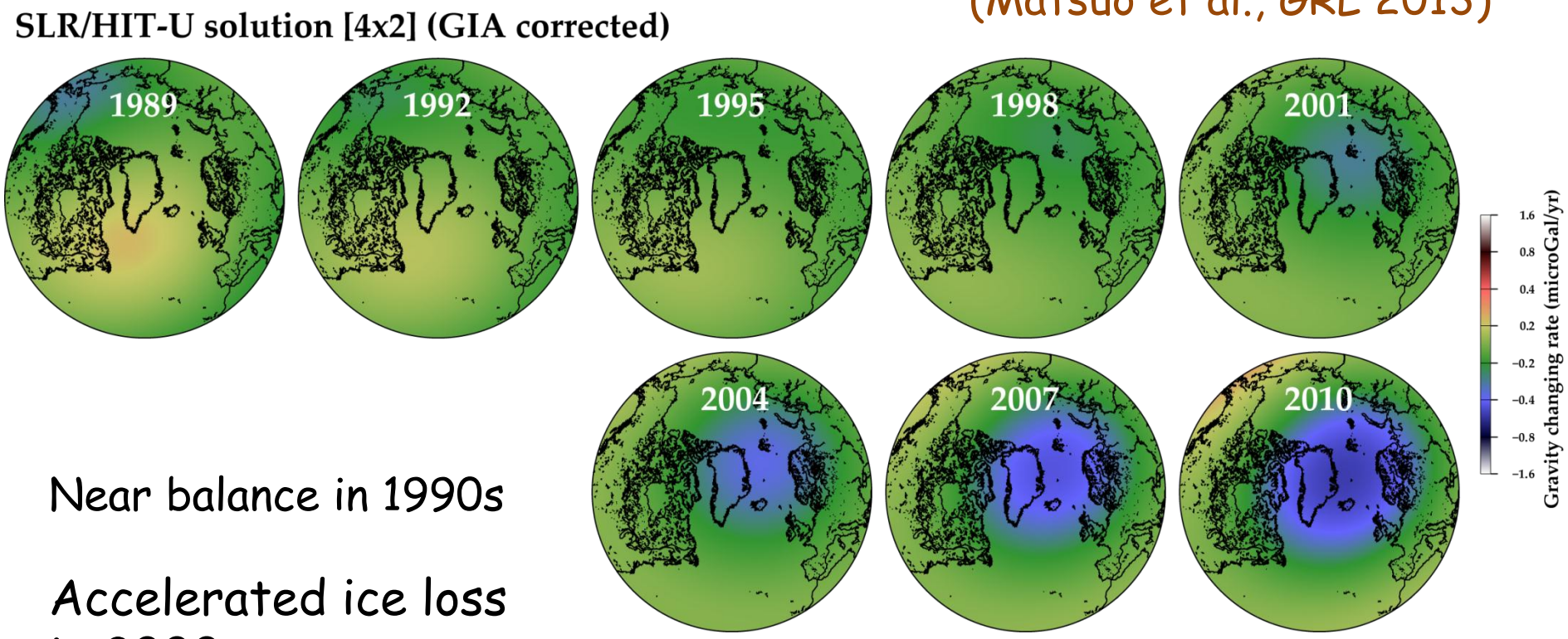


Antarctica



Greenland mass balance has already been reported

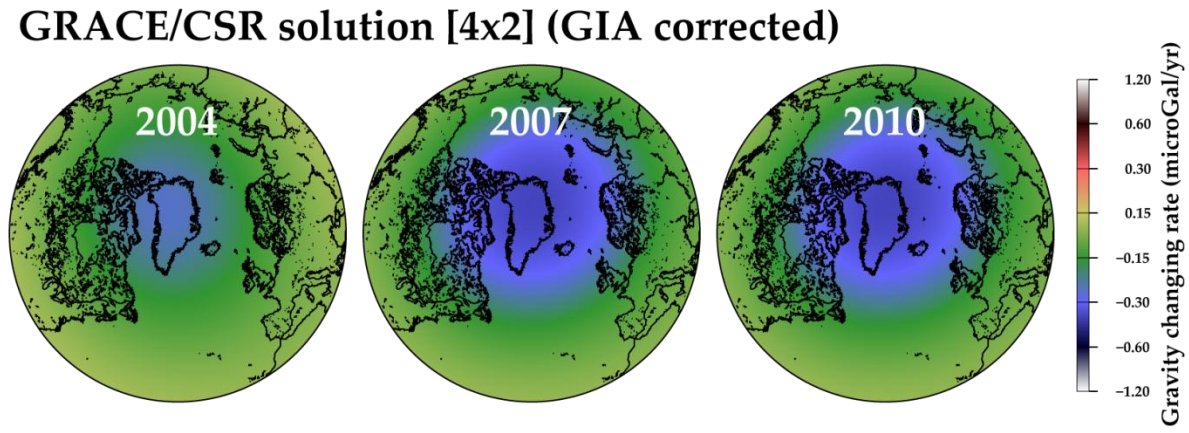
(Matsuo et al., GRL 2013)



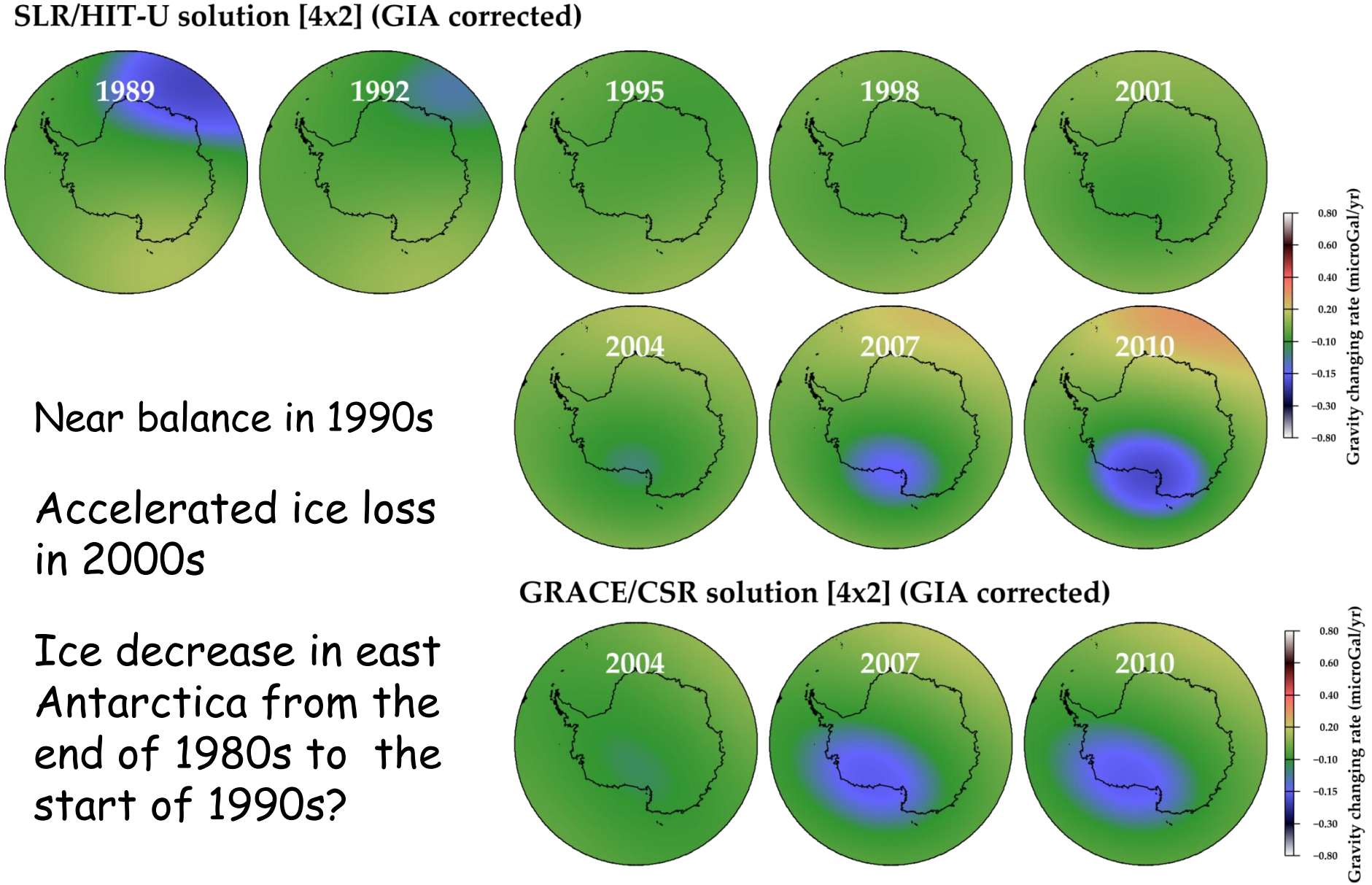
Near balance in 1990s

Accelerated ice loss in 2000s

Ice increase from the end of 1980s to the start of 1990s?



Antarctic mass balance has also been detected



Near balance in 1990s

Accelerated ice loss in 2000s

Ice decrease in east Antarctica from the end of 1980s to the start of 1990s?

Acknowledgement

The software "c5++" is developed in the collaboration among Hitotsubashi Univ., NICT, and JAXA.

We thank Dr Vincenza Luceri of e-GEOS SpA, Italy, for providing the SLR Normal Point Data of AJISAI and STARLETTE in 1980's. We also thank Dr John Ries, Univ. Texas/CSR, USA, for providing the initial state vector of LAGEOS-1, AJISAI and STARLETTE in 1980's. All other SLR observations and orbits are indebted to the ILRS.