Geocenter motion excited by large-scale mass redistribution

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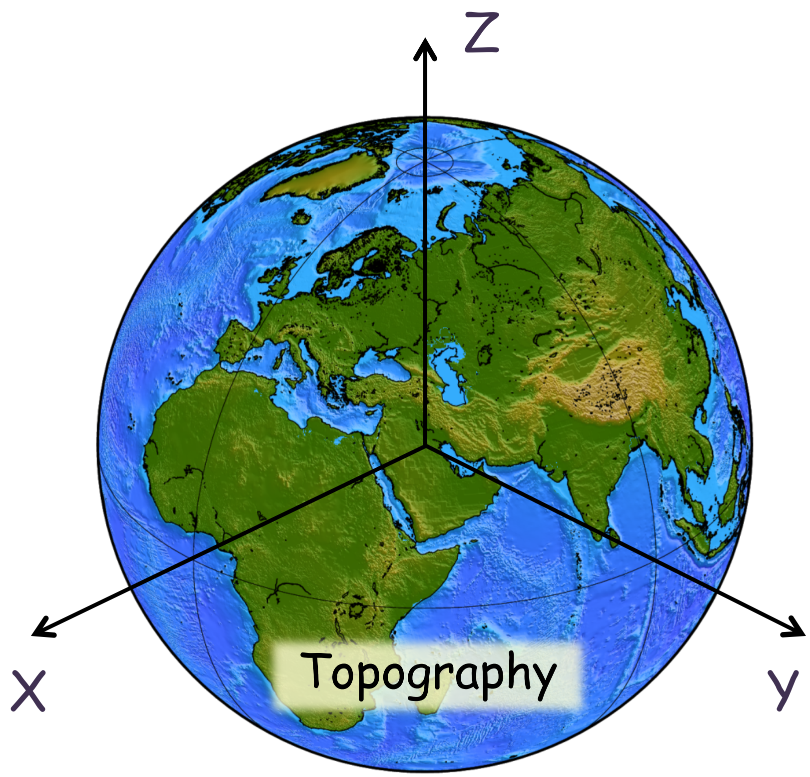
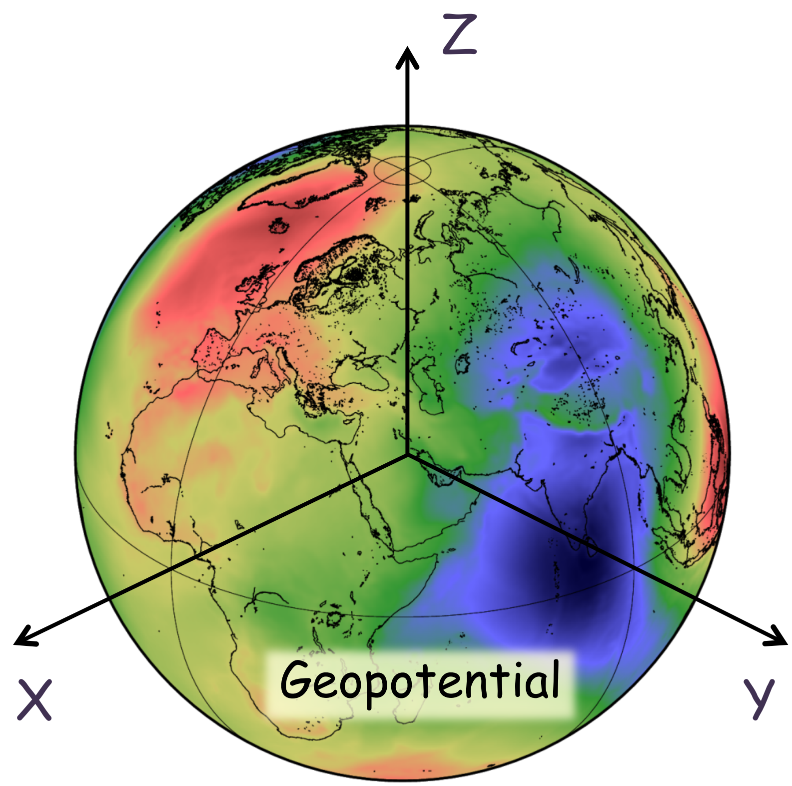
Definition of Geocenter

Center of Figure (CoF)

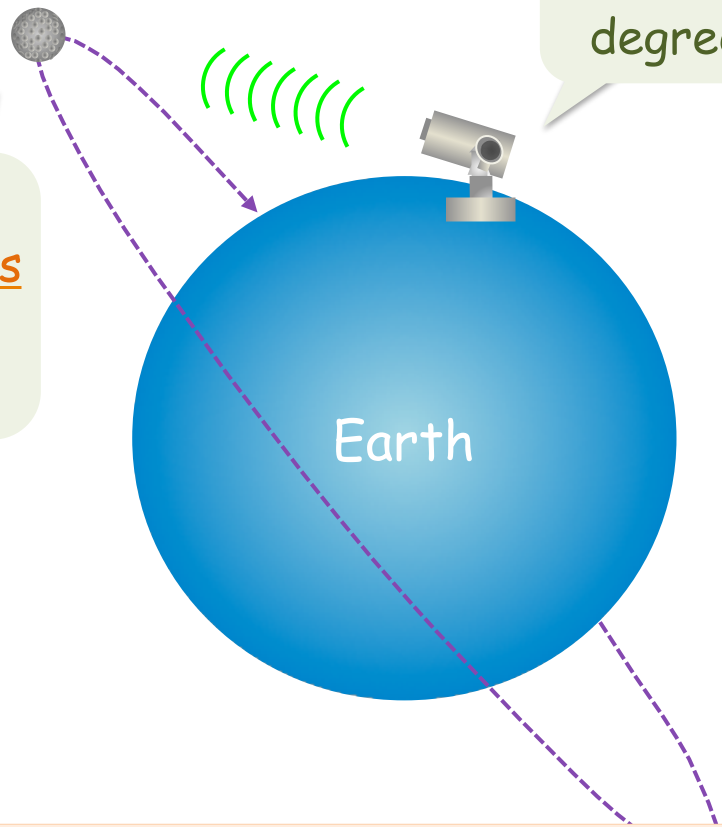


Center of Mass (CoM)



Geocenter = CoM w.r.t. CoF

Measurement of geocenter motion from SLR



Measuring loading deformation which <u>includes</u> degree-1 components

Measuring gravity variations which <u>does not include</u> degree-1 components

SLR is the best technique to measure geocenter motion at present

Observed deformation – gravity-derived deformation
= degree-1 deformation = <u>Geocenter motion</u>

Objective of this study

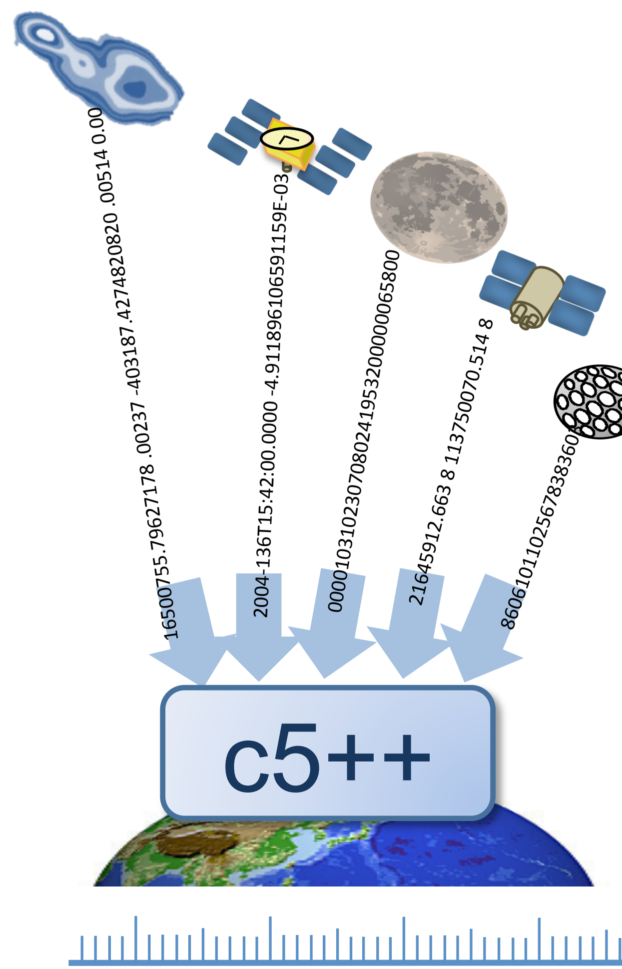
- To derive geocenter motion from SLR observation using our original software package "c5++"
- To assess our "c5++" solution by comparing with CSR solution
- To investigate driving sources of recent long-term geocenter motion

SLR analysis software: CONCERTO 5++ (c5++)

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

Implement up-to-date geophysical models and TRF

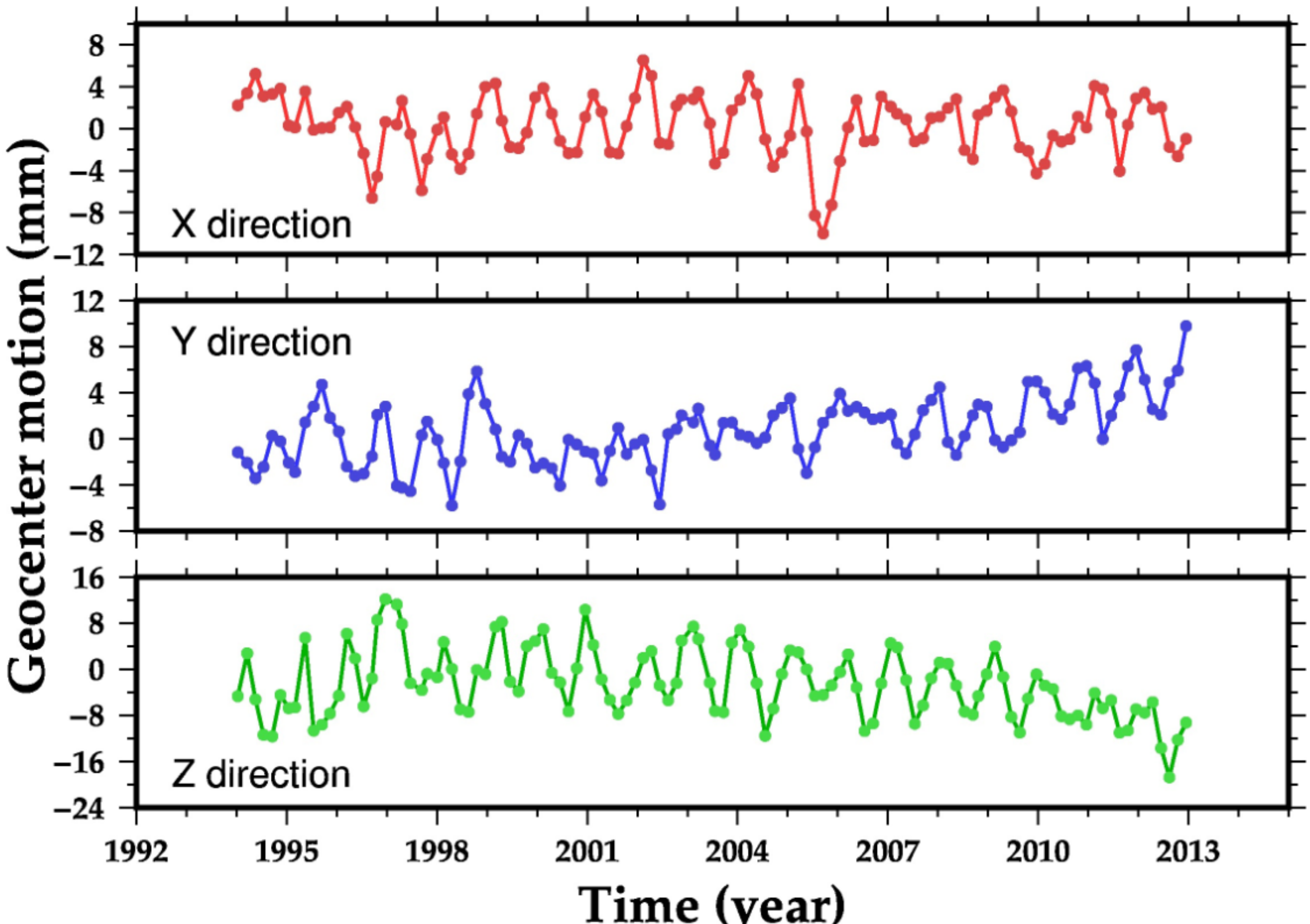
- IERS Conventions 2010
- EGM 2008 model
- ITRF 2008
- etc



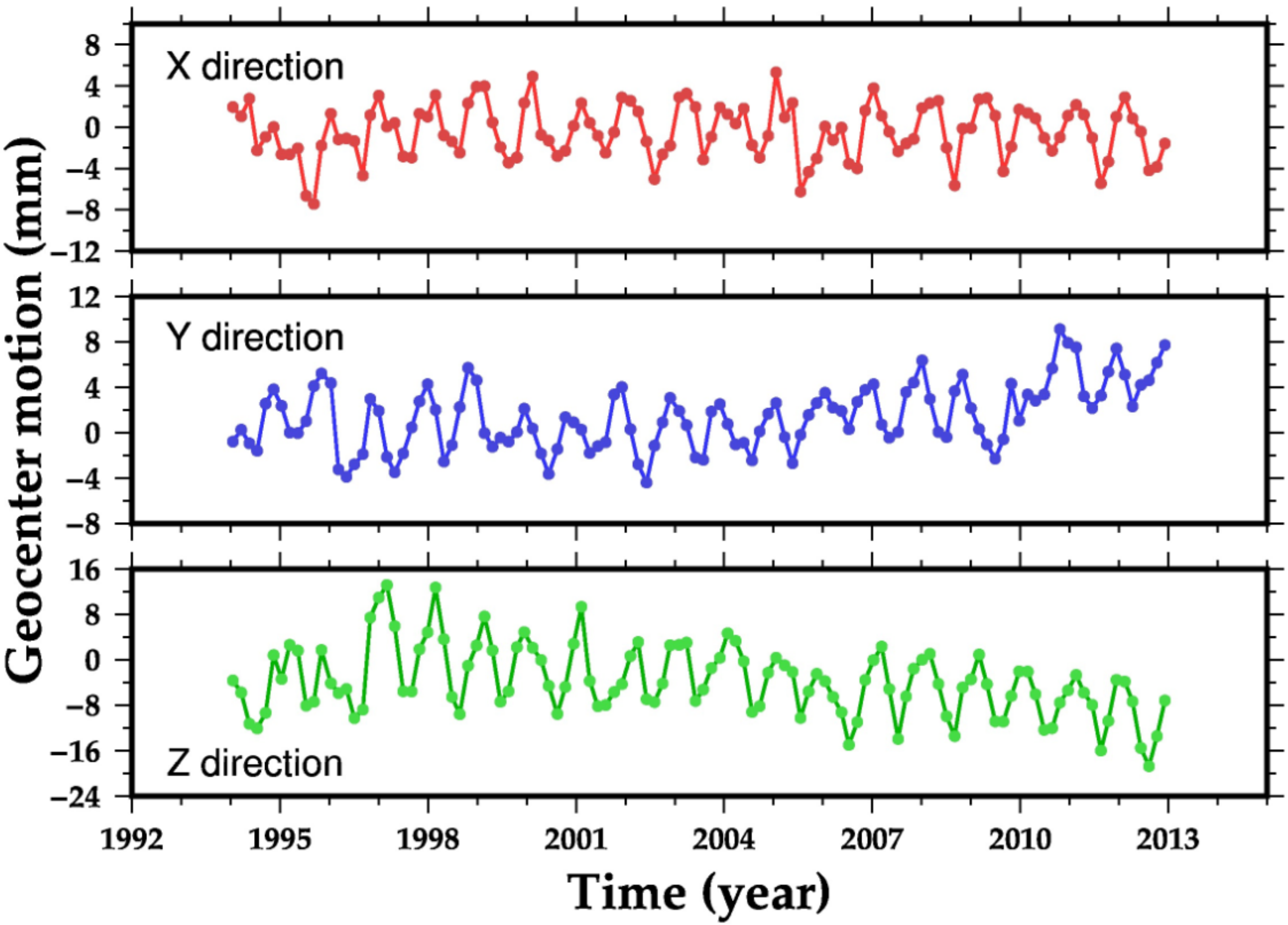
Strategy of SLR data analysis

- 5 SLR satellites data (LAGEOS-1/2, Ajisai, Starlette, Stella) from Jan. 1994 to Dec. 2012
- Arc length is 3 days
- Empirical acceleration (constant and one-per-rev) is estimated at 1.5 days interval
- 60 days -average geocenter motion is calculated

Results: Geocenter motion from c5++

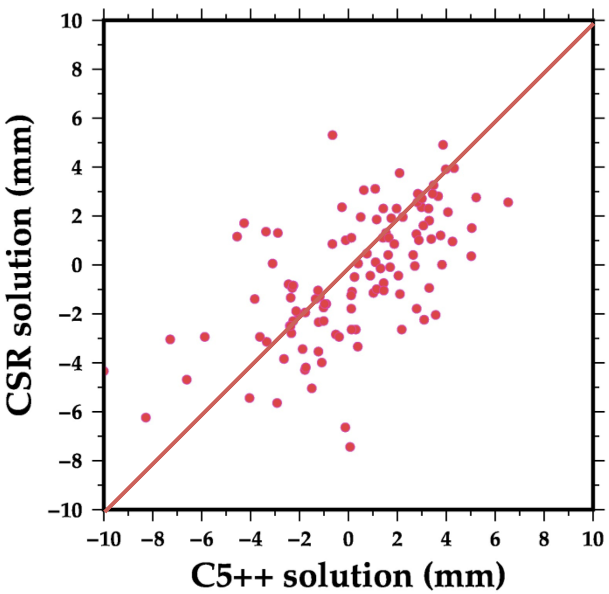


Geocenter motion from CSR (provided by Dr. Ries)



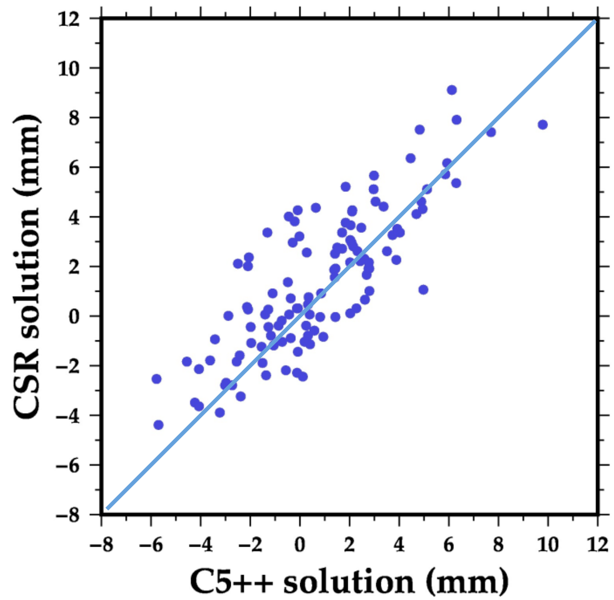
Scatter plot : c5++ solution vs. CSR solution

X axis



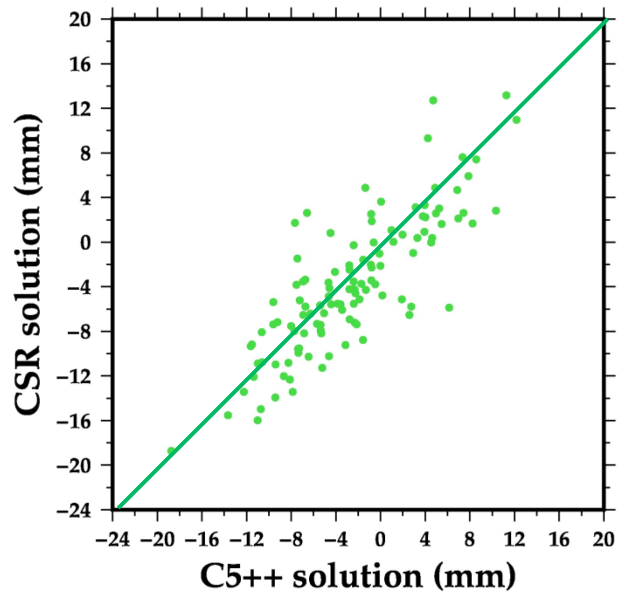
Correlation = 0.61

Y axis



Correlation = 0.82

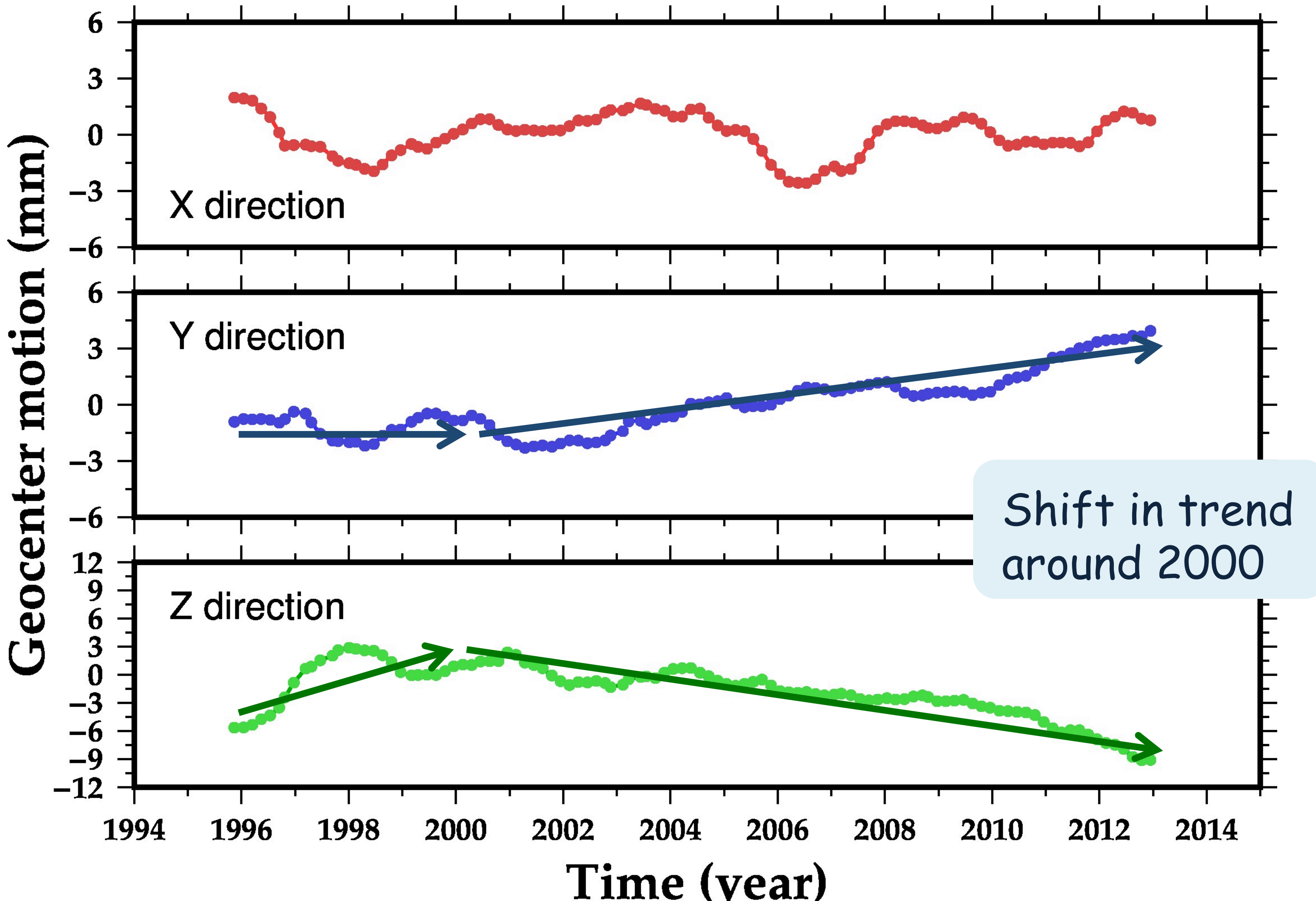
Z axis



Correlation = 0.83

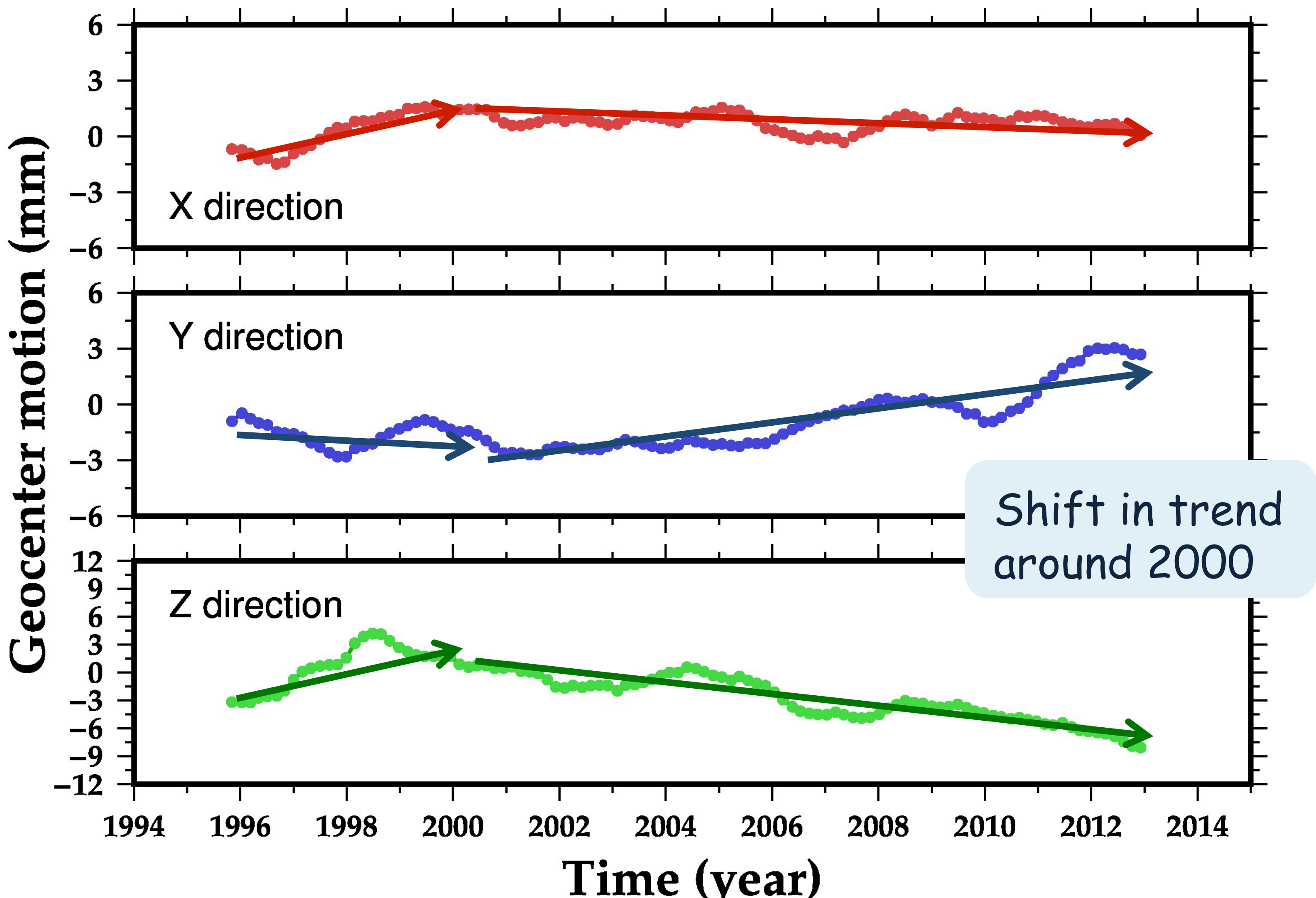
Long-term geocenter motion: c5++ solution

2-year moving average

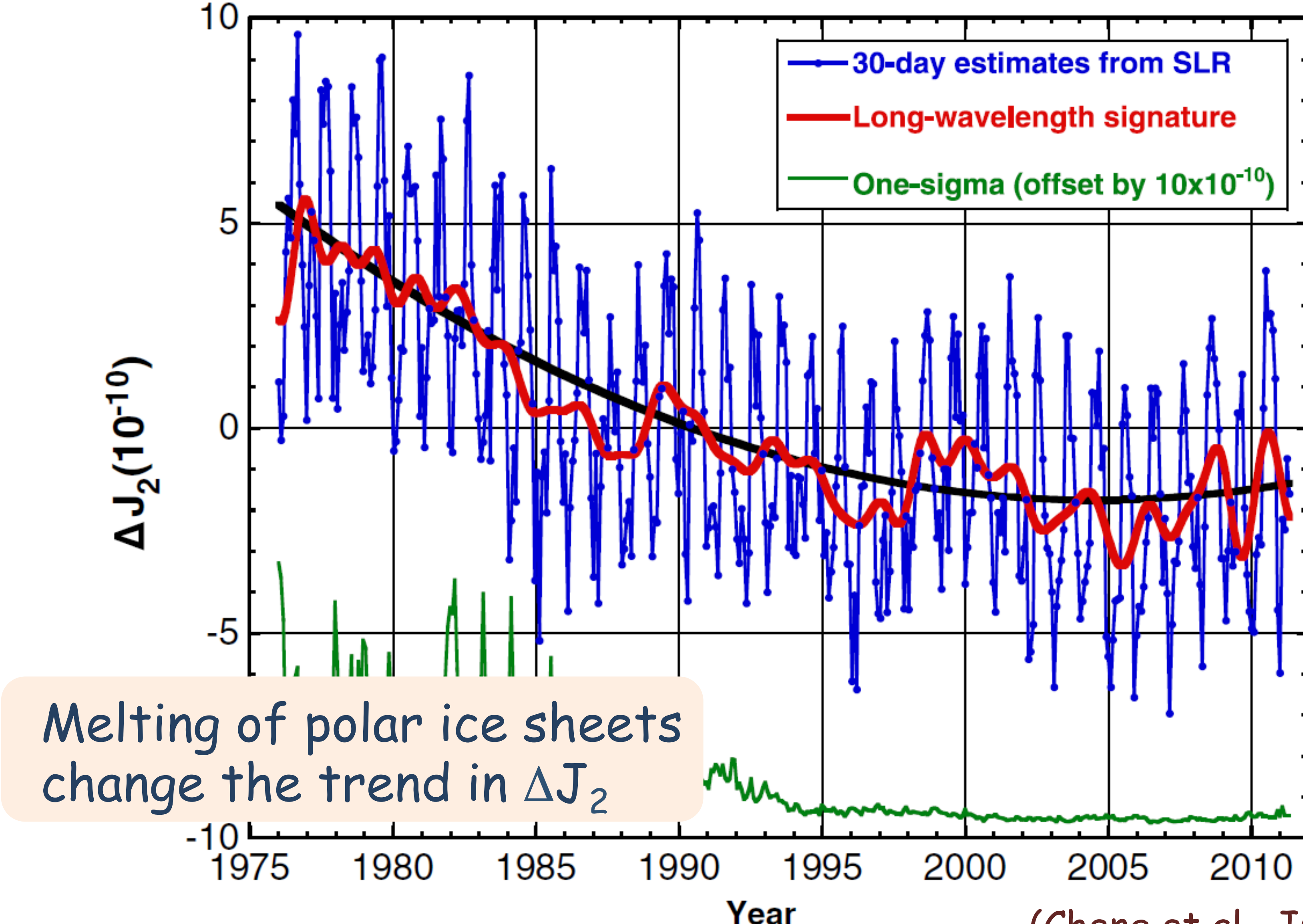


Long-term geocenter motion: CSR solution

2-year moving average



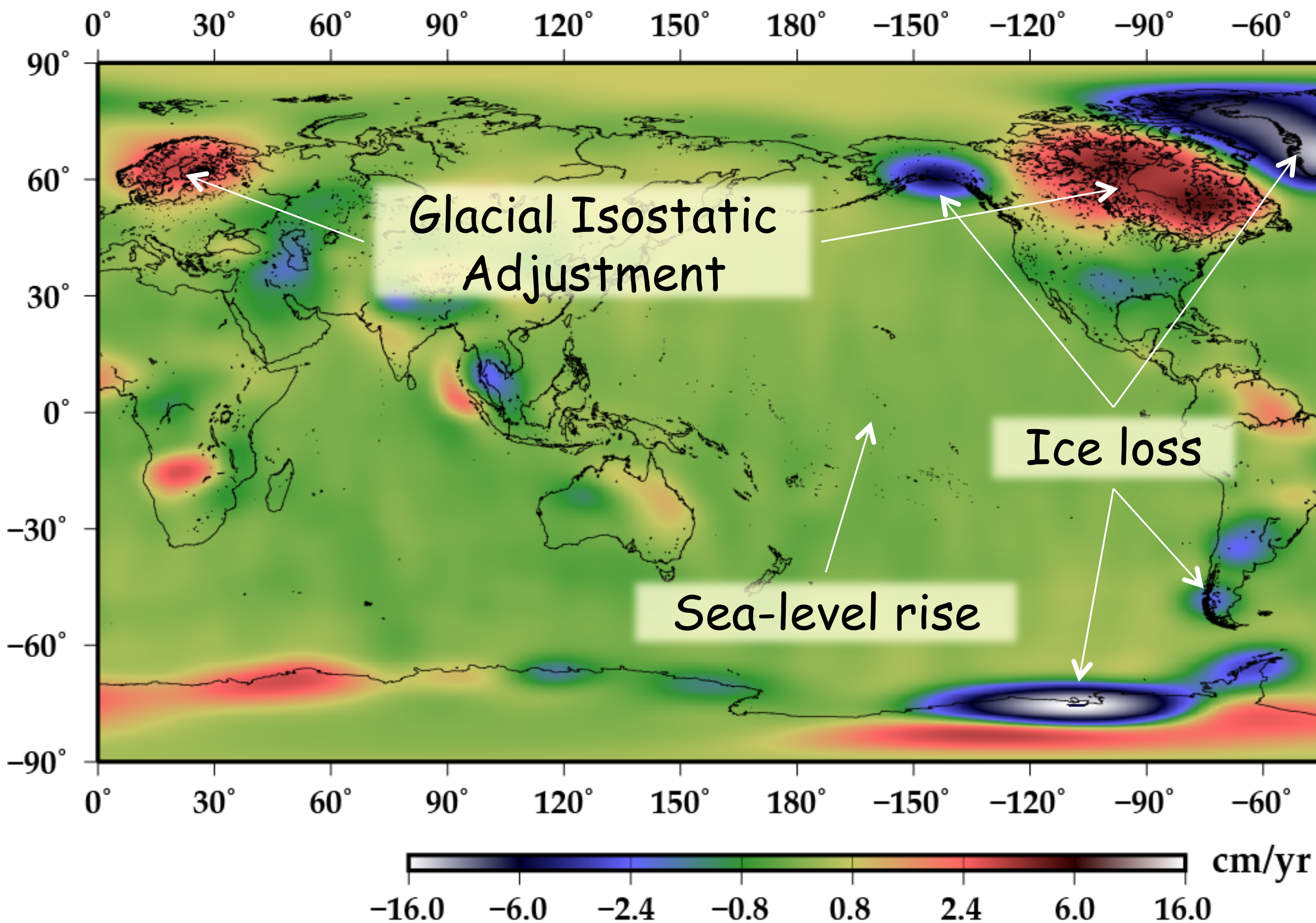
Trend shift in ΔJ_2 from SLR observation



(Cheng et al., JGR 2013)

Main sources of mass redistribution in 2000s

Linear mass trend in 2003-2013 from GRACE gravimetry



Estimation of mass-driven geocenter motion

1. Polar ice sheets

Ice thickness variations from ICESat altimetry from 2003 Oct. to 2009 Sep.

2. Sea level rise

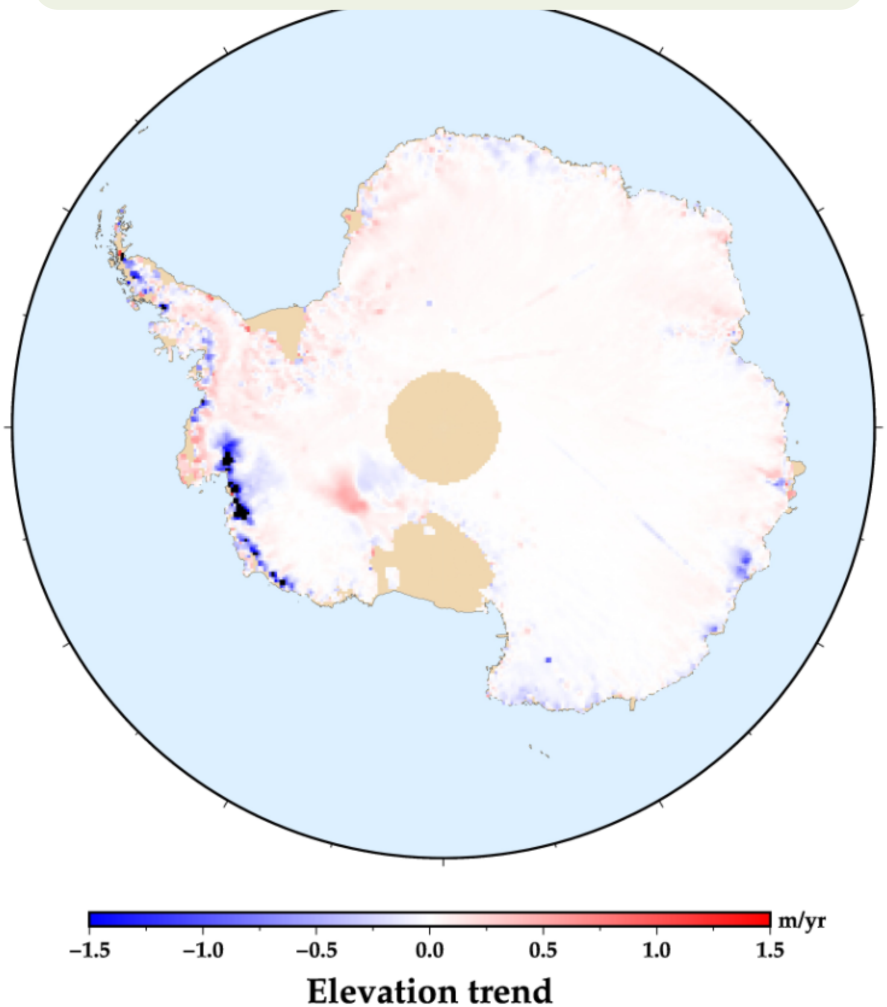
Solve sea-level equation using ice mass variations from ICESat

3. Glacial Isostatic Adjustment

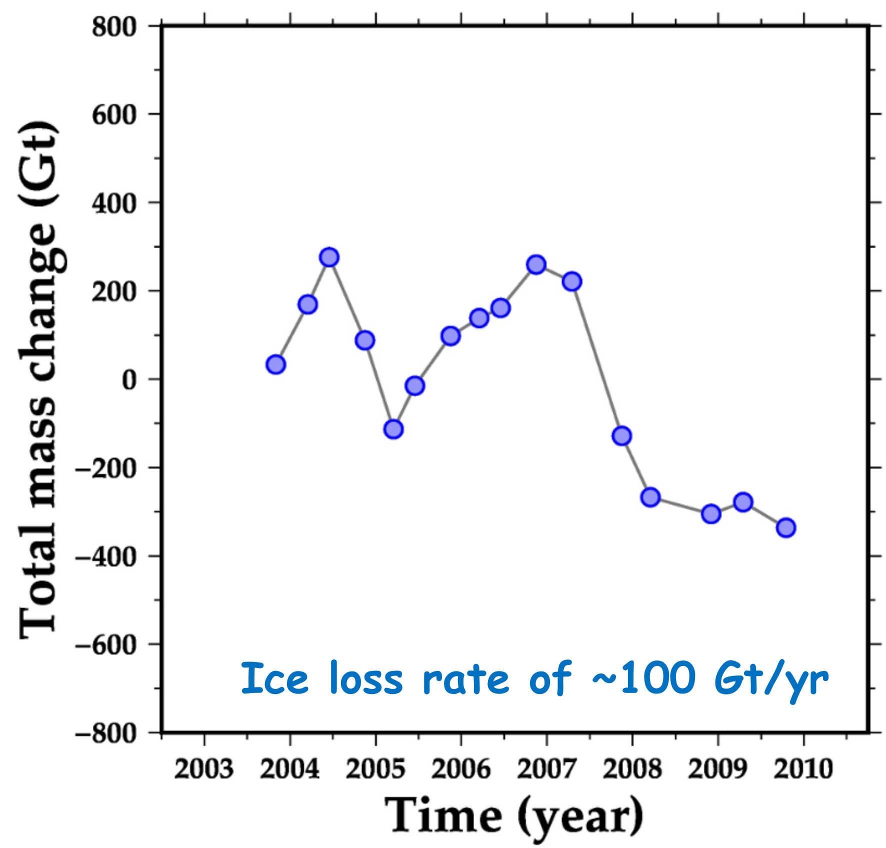
Theoretical values by Greff-Lefftz (*JGR* 2000)

1. Polar ice sheets: Antarctica

Linear trend in ice thickness from ICESat (2003-2009)



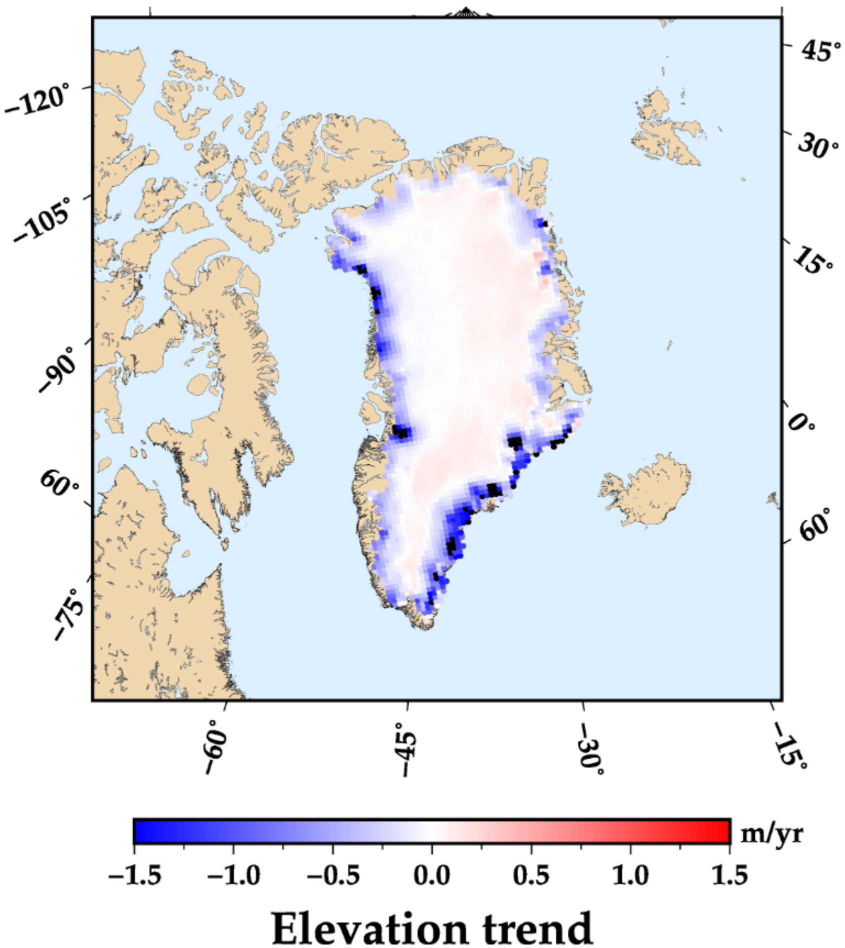
Total mass change in Antarctica



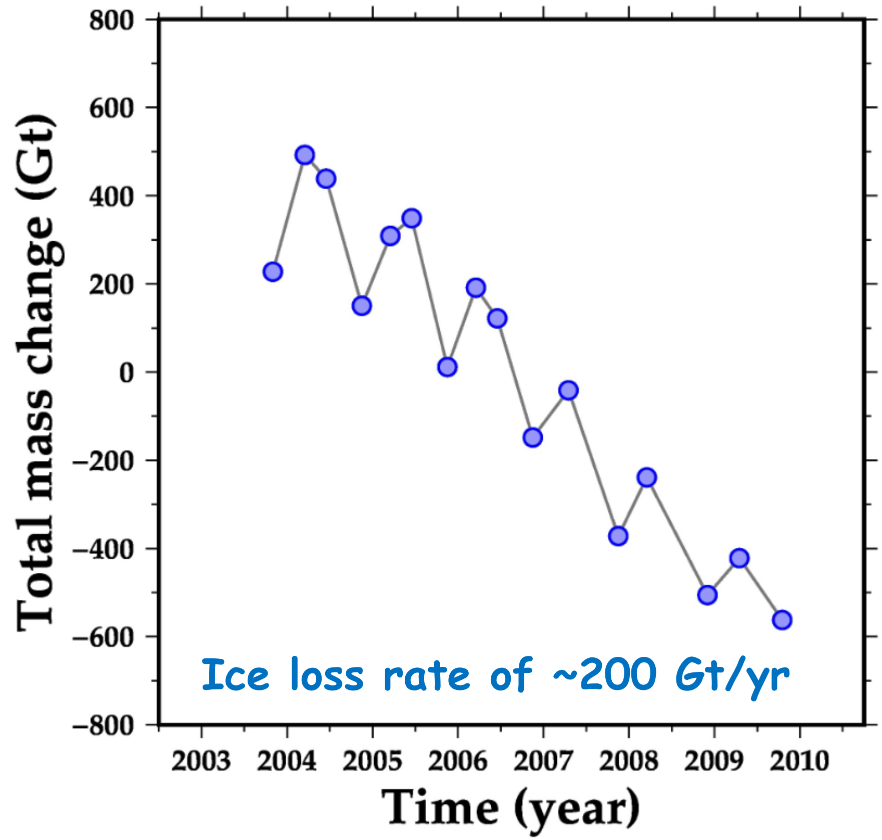
Assumes ice density as 700 kg/m^3 for ablation area, 300 kg/m^3 for accumulation area

1. Polar ice sheets: Greenland

Linear trend in Ice thickness from ICESat (2003-2009)



Total mass change in Greenland



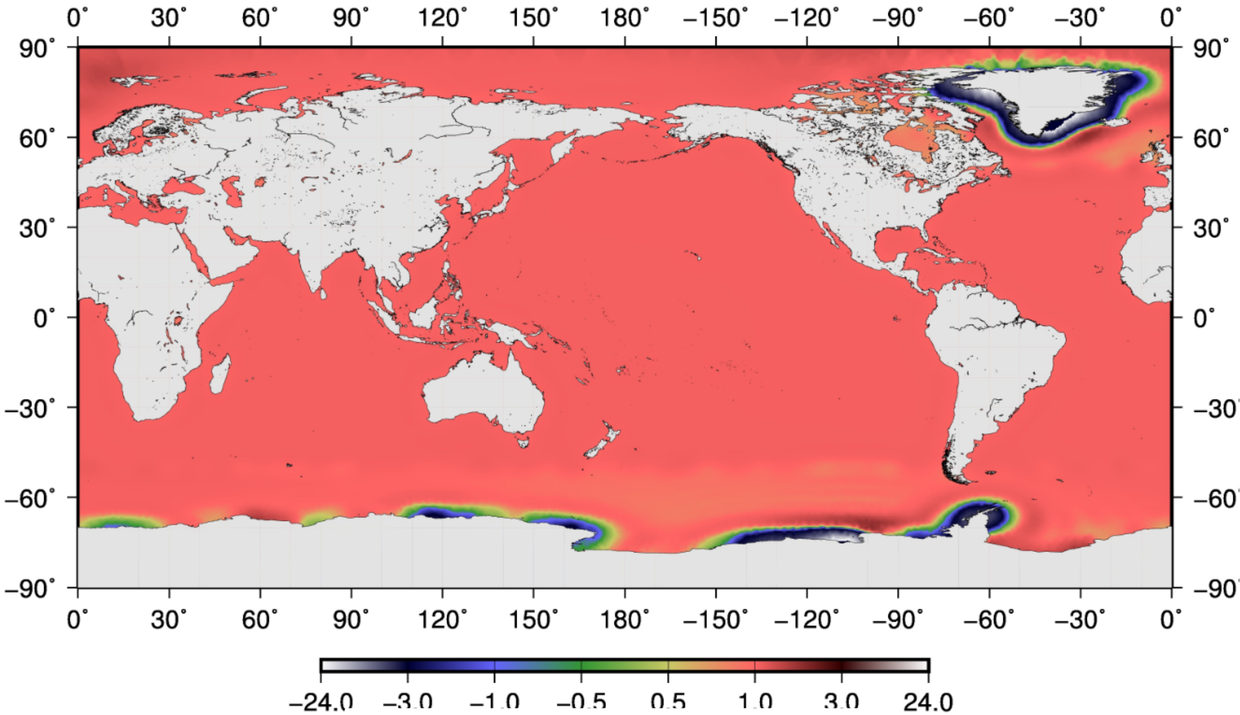
Assumes ice density as 700 kg/m³ for ablation area, 300 kg/m³ for accumulation area

2. Sea level rise

Sea level equation [e.g. Métivier et al., EPSL 2010]

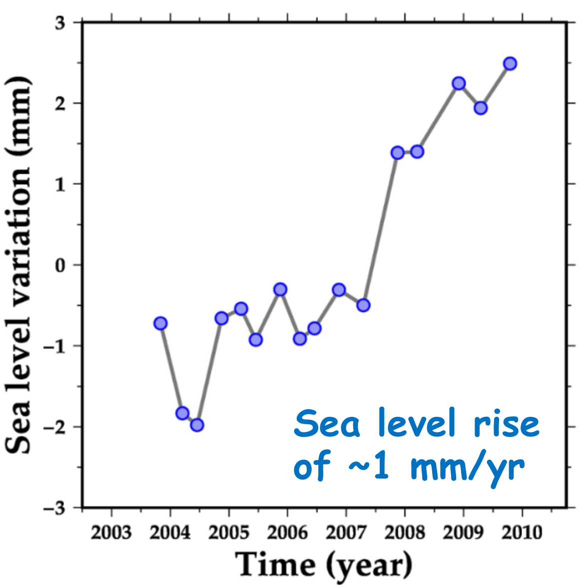
$$h_{SL}(\theta,\varphi,t) = \frac{\rho_I}{g_0}\Phi(\theta,\varphi)*h_I(\theta,\varphi,t) + \frac{\rho_{oc}}{g_0}\Phi(\theta,\varphi)*h_{SL}(\theta,\varphi,t)^{SL} + C(t)$$

Sea level rise by polar ice mass variations



Sea level rise (mm/yr)

Total sea level variation by polar ice mass variations



3. Glacial Isostatic Adjustment

Theoretical estimation by Greff-Lefftz (JGR 2000)

GIA-driven geocenter motion depends on viscosity of lower mantle and upper mantle

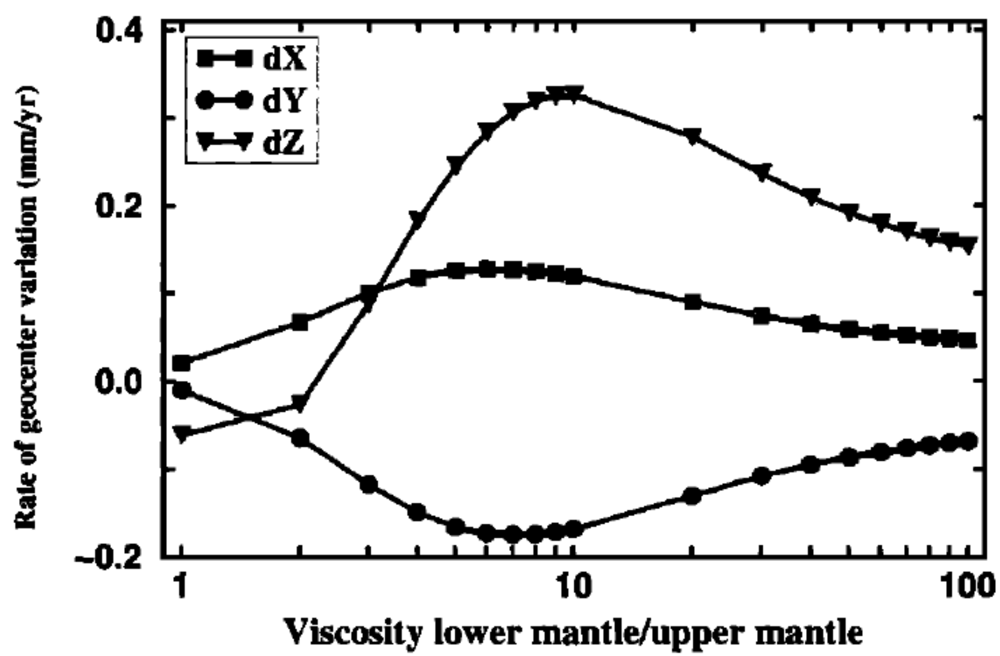
Here, we pick up the average values of the right figure

X_g = 0.1±0.05 mm/yr

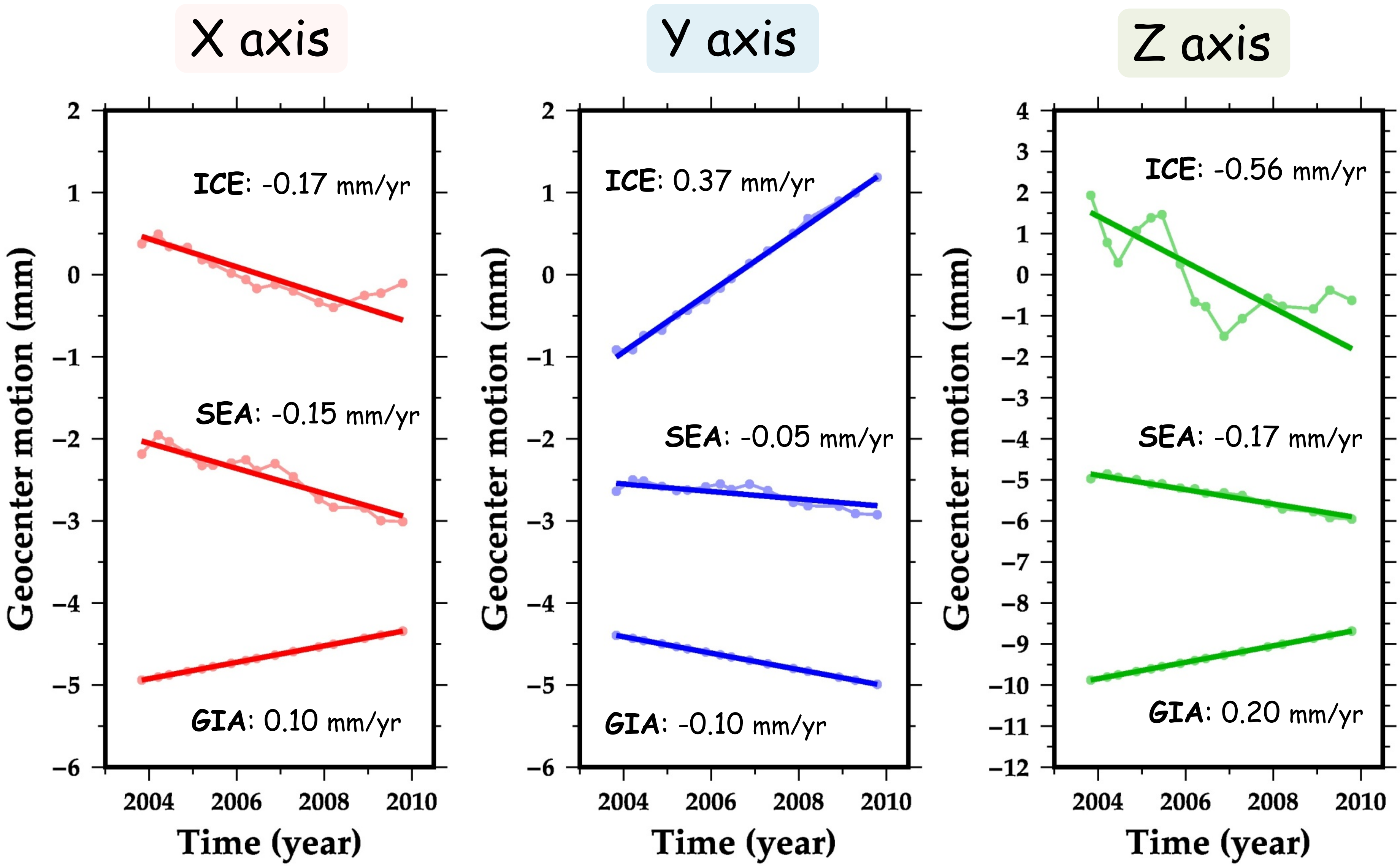
Y_g = -0.1±0.1 mm/yr

Z_g = 0.2±0.2 mm/yr

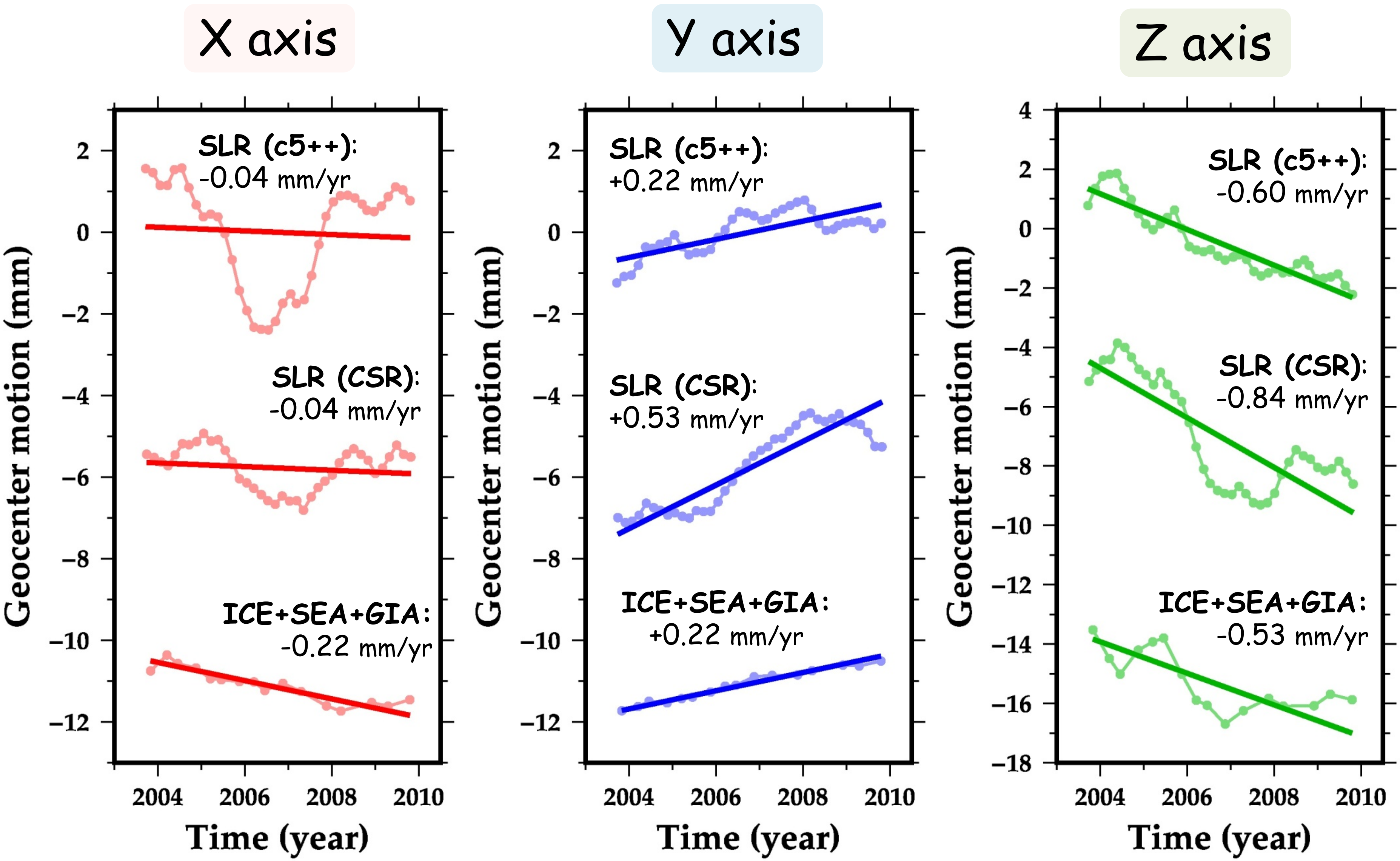
Theoretical values of GIA-driven geocenter motion vs. assumed viscosity



Results: Estimated geocenter motion



Results: Comparison between SLR and estimation



Results: Linear rates of geocenter motion

	X axis (mm/yr)	Y axis (mm/yr)	Z axis (mm/yr)
SLR (c5++)	-0.04 ± 0.08	+0.22 ± 0.02	-0.60 ± 0.03
SLR (CSR)	-0.05 ± 0.04	+0.53 ± 0.04	-0.84 ± 0.08
ICE+SEA+GIA	-0.22 ± 0.06	+0.22 ± 0.10	-0.53 ± 0.24
ICE	-0.17 ± 0.02	+0.37 ± 0.01	-0.56 ± 0.14
SEA	-0.15 ± 0.02	-0.05 ± 0.01	-0.17 ± 0.01
GIA	+0.10 ± 0.05	-0.10 ± 0.10	+0.20 ± 0.20

Summary

- Recent large-scale mass redistributions move geocenter to south by ~0.5 mm/yr and 135E direction by ~0.3 mm/yr
- Mass losses in polar ice sheets are the main sources of recent geocenter motion
- SLR observation roughly agrees with the estimated results
- Our X component solution appears to be noisy (currently being investigated)

Future works

- To include contributions from ice mass variations in mountain glaciers using ICESat altimetry data

- To examine contributions of massive earthquakes using dislocation theory

Thank you for your attention!

Significance of precise geocenter determination

- Construction of Terrestrial Reference Frame (TRF)
- Precise determination of crustal velocity field
- Construction of global geoid model

Estimation of mass-driven geocenter motion

Computational formula of geocenter motion [e.g. Munekane, JGR 2007]

$$X_g = R\sqrt{3}\frac{\left(1-\frac{h_1'+2l_1'}{3}\right)}{1+k_1'}\Delta C_{11}$$

$$Y_g = R\sqrt{3}\frac{\left(1-\frac{h_1'+2l_1'}{3}\right)}{1+k_1'}\Delta S_{11}$$

$$Z_g = R\sqrt{3}\frac{\left(1-\frac{h_1'+2l_1'}{3}\right)}{1+k_1'}\Delta C_{10}$$

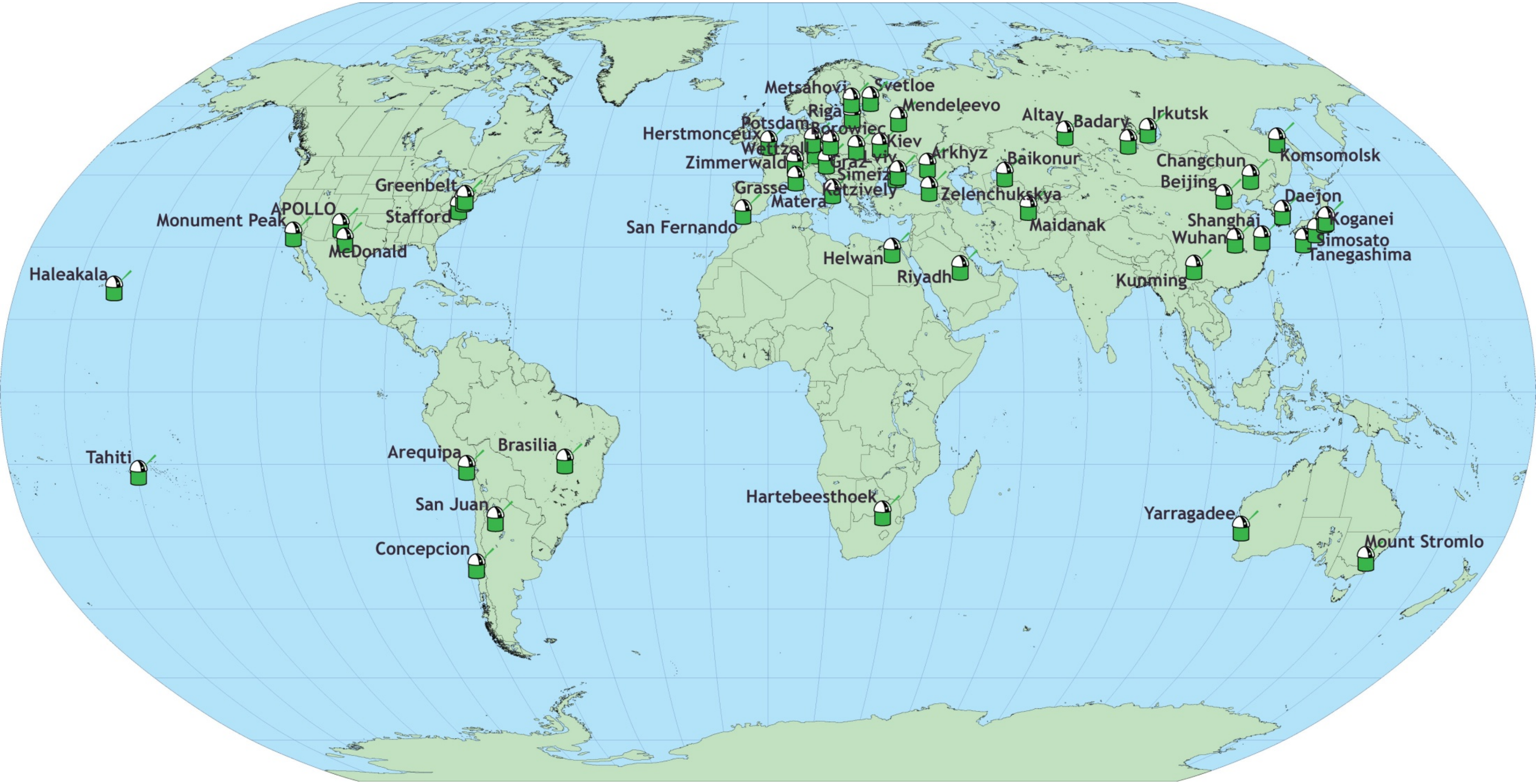
X_g, Y_g, Z_g:
Geocenter motion

ΔC10, ΔC11, ΔS11:
dimensionless Stokes' coefficients of geopotential

R: Radius of the Earth

k_1', h_1', l_1':
load love and Shida number of degree-1 components

Map of SLR stations



http://ilrs.gsfc.nasa.gov/images/slrmap_symbols_2014_large.jpg

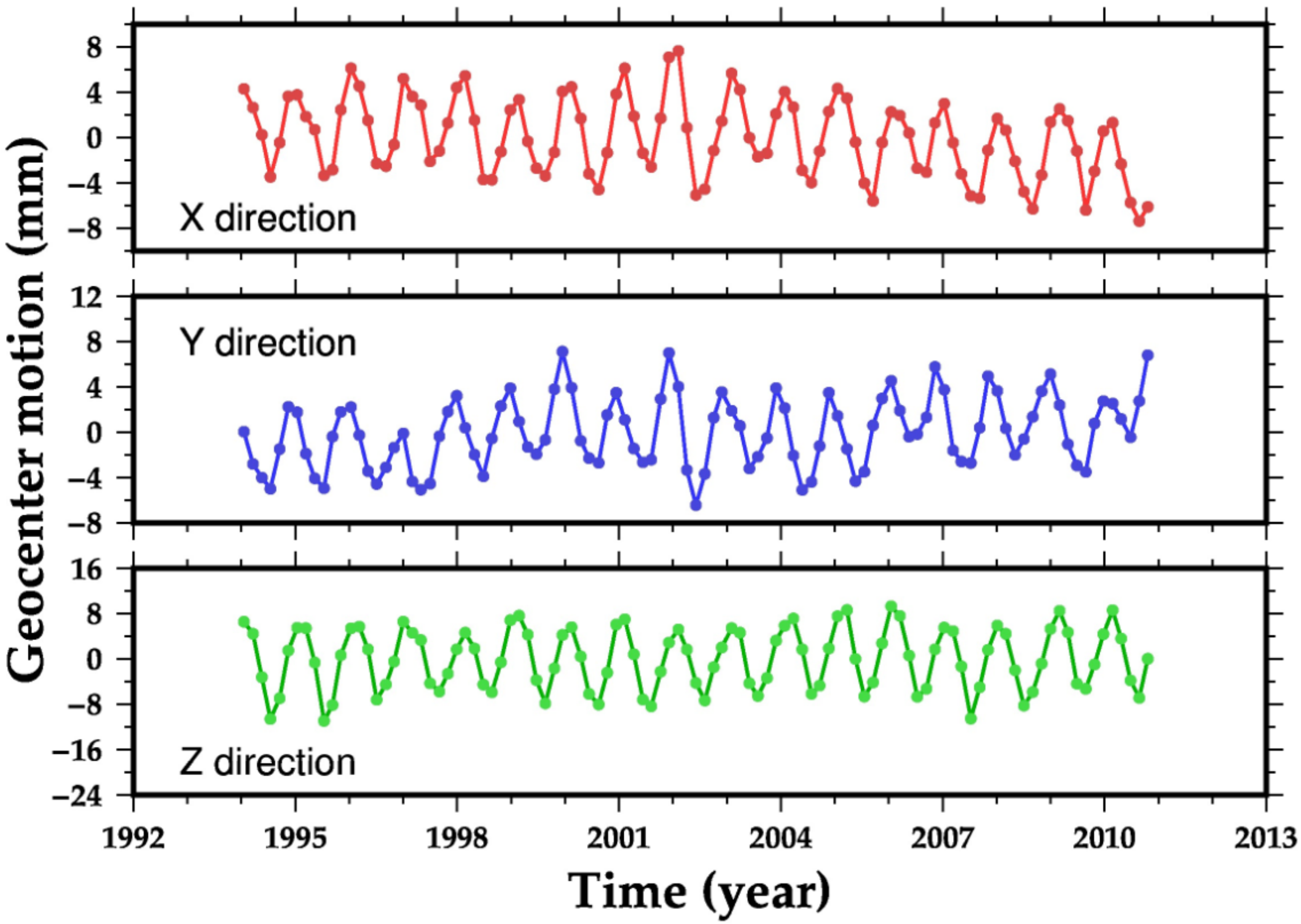
Annual variation

Atmosphere (ECMWF model)

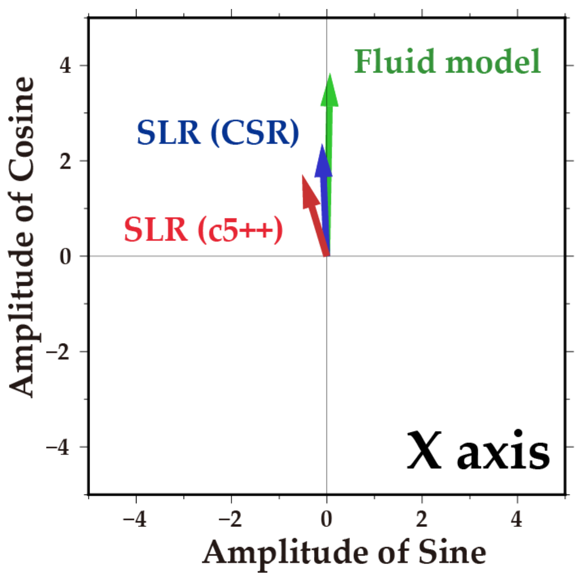
Ocean (ECCO model)

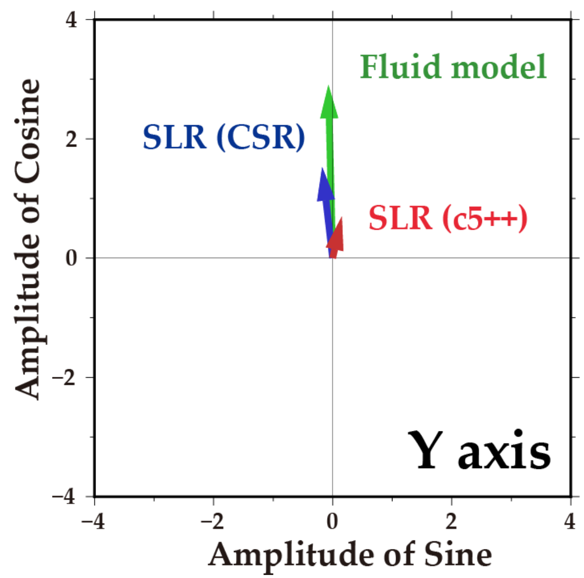
Land water (GLDAS model)

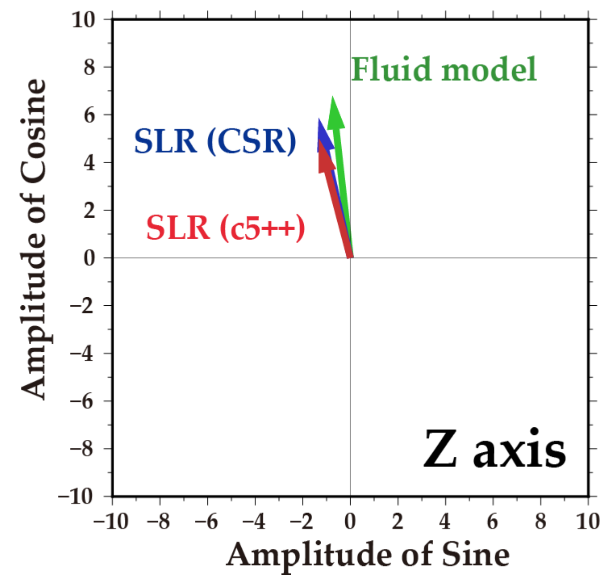
Geocenter motion estimated from geophysical fluid models



Phasor diagram of annual components







SLR (c5++)

1.79 ± 0.34 mm

SLR (CSR)

2.37 ± 0.49 mm

Fluid model

3.85 ± 0.29 mm

SLR (c5++)

0.72 ± 0.35 mm

SLR (CSR)

1.54 ± 0.31 mm

Fluid model

2.91 ± 0.30 mm

SLR (c5++)

5.17 ± 0.69 mm

SLR (CSR)

6.02 ± 0.68 mm

Fluid model

6.84 ± 0.31 mm