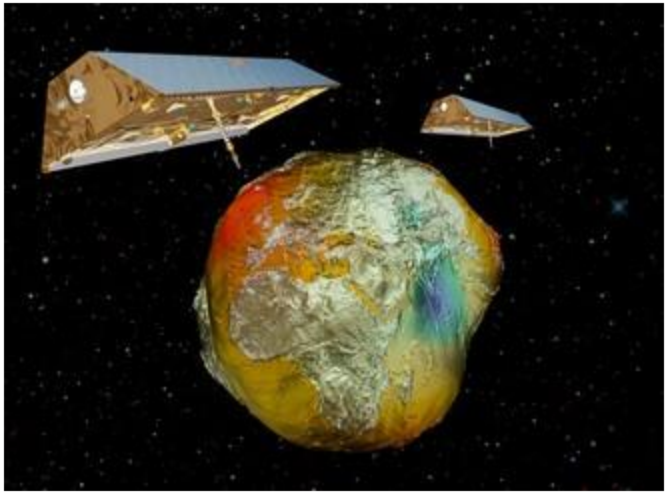
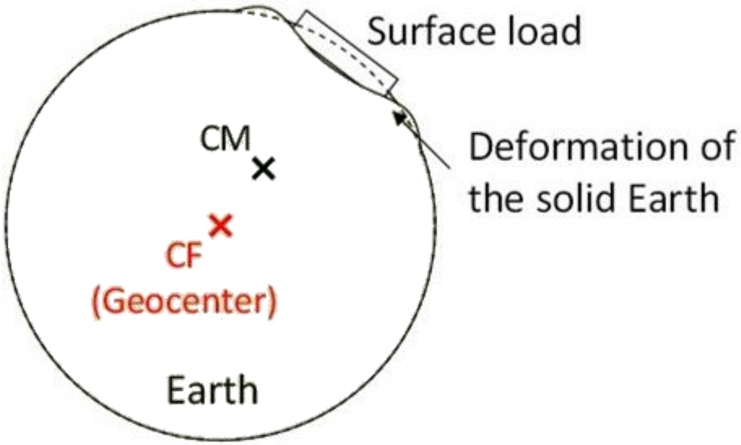
Geocenter motion estimation from GRACE and its impact on basin-averaged terrestrial water storage variations

Liangjing Zhang , Inga Bergmann-Wolf , Henryk Dobslaw and Volker Klemann
Helmholtz-Centre Potsdam, GFZ German Research Centre for Geosciences, Potsdam, Germany

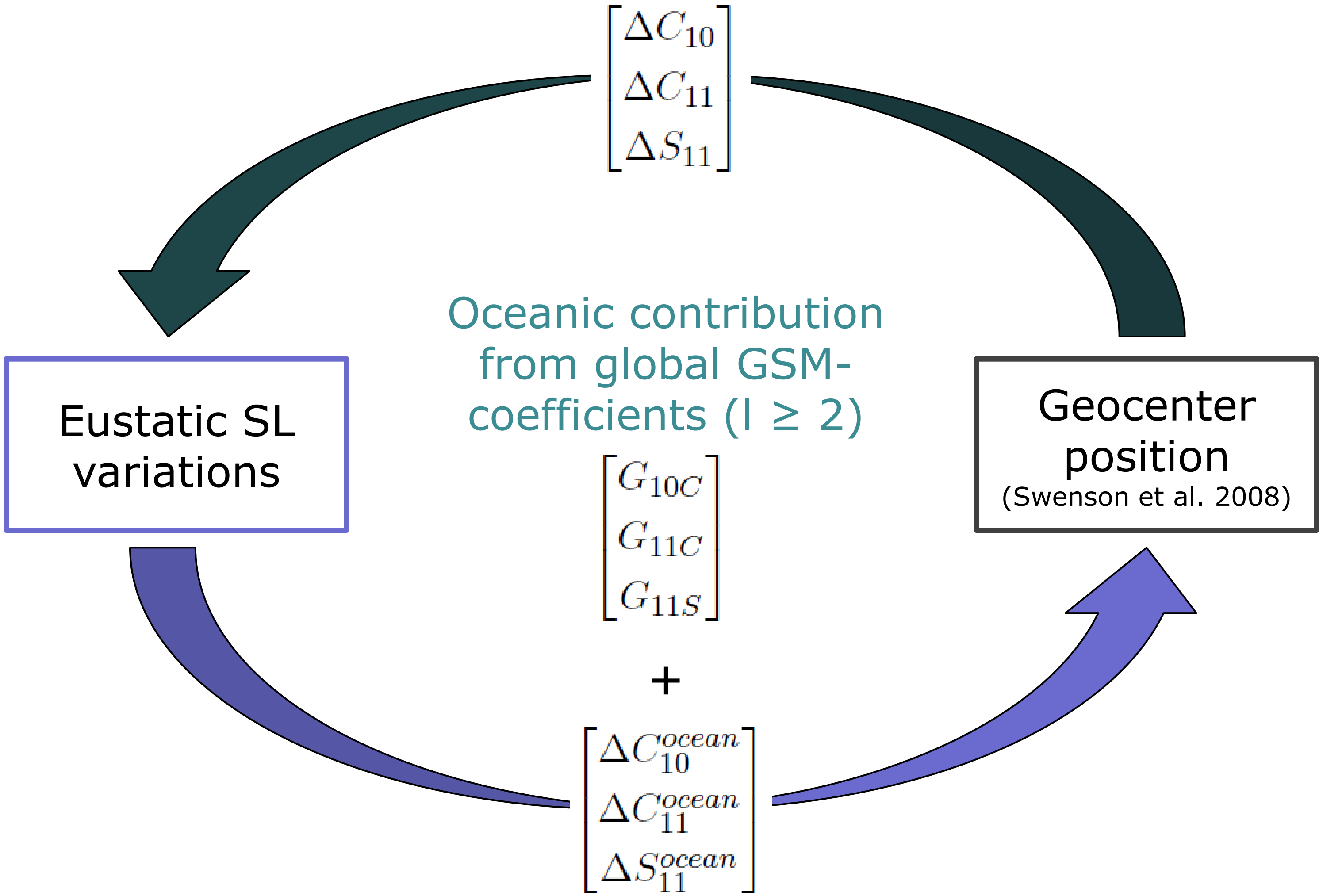
Motivation

- GRACE: surface fluid mass changes
- GRACE satellites orbit around the center of mass (CM) of the Earth system
- change the observer's perspective from the space-based frame to the center of figure frame to observe surface loading from GRACE
- Effect on the basin-averaged TWS variations and validating with global geophysical models





main algorithm - problem



Data & Processing Scheme

GFZ RL05

-Time period: 01/2003 – 12/2009

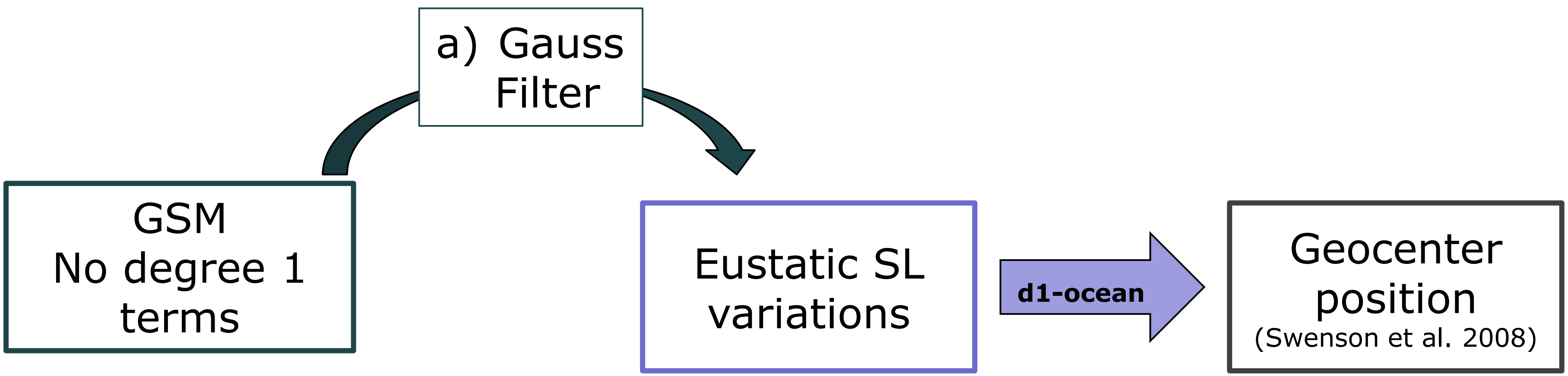
-Up to d/o=90

-GIA reduction with Paulson et al. (2007)

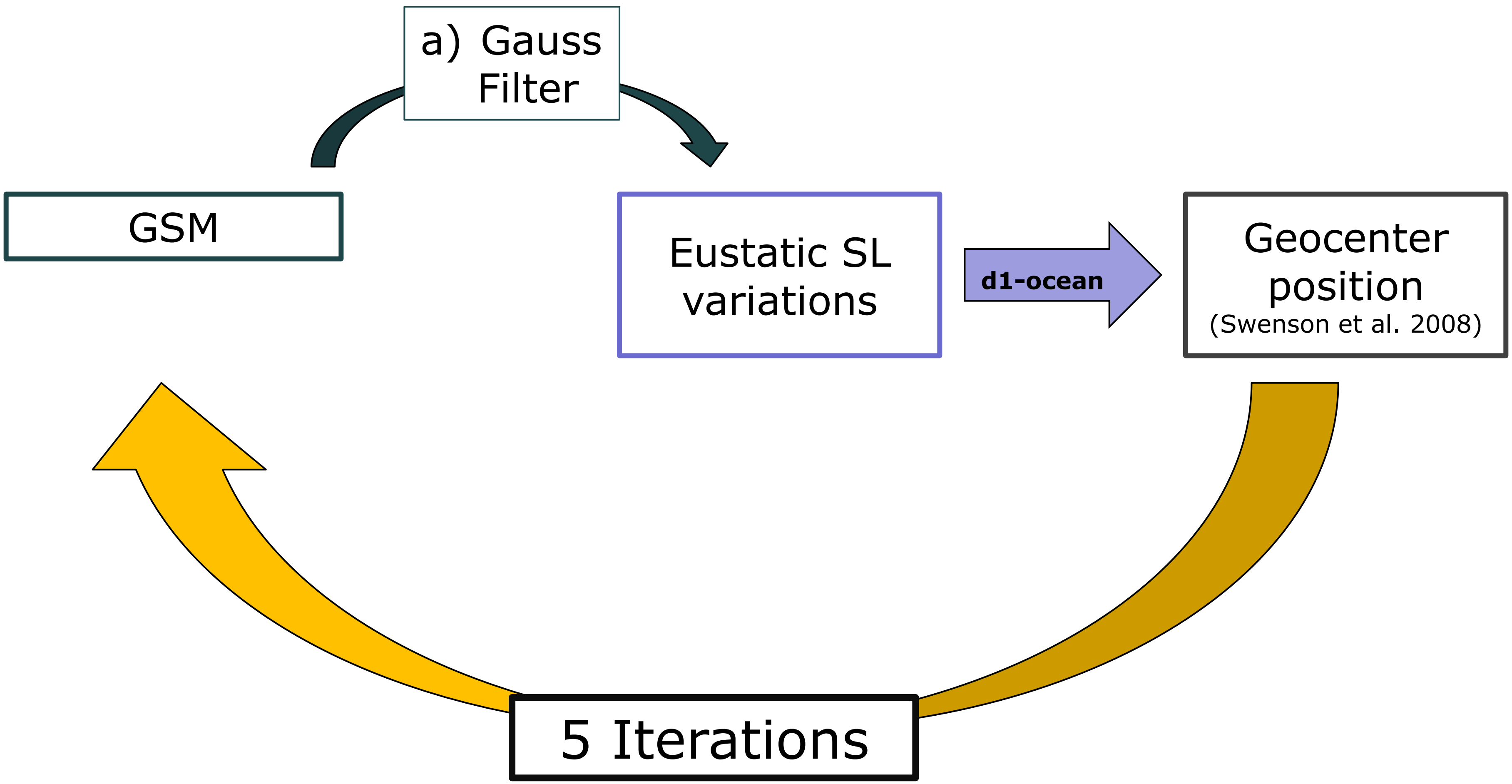
⇨ GSM-coefficients

- 300km Gaussian filtering
- A region of 300km around the coast is left out

⇨ Eustatic signal

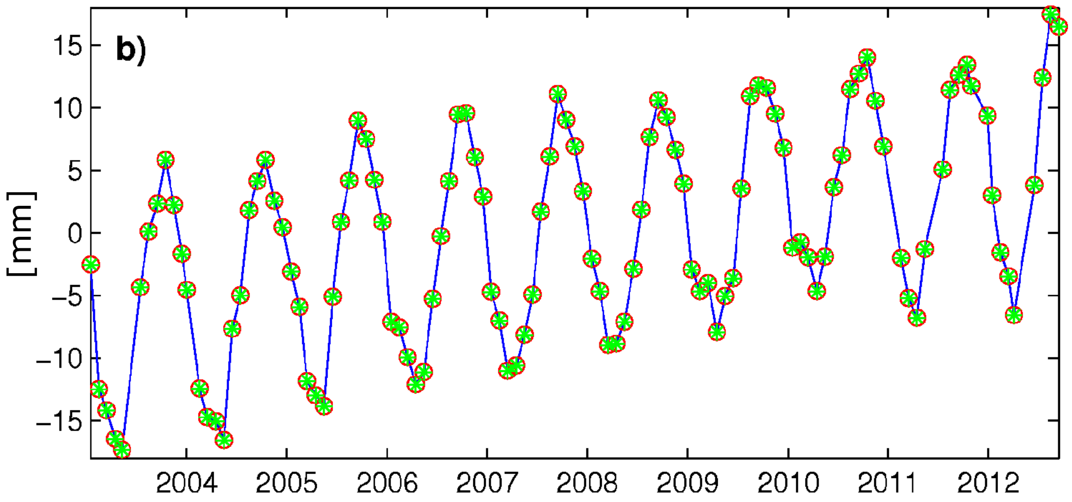


Iterative Processing



Results

Eustatic SL variations (5 iterations)



- no d1 information - no euSL information

Annual signal:

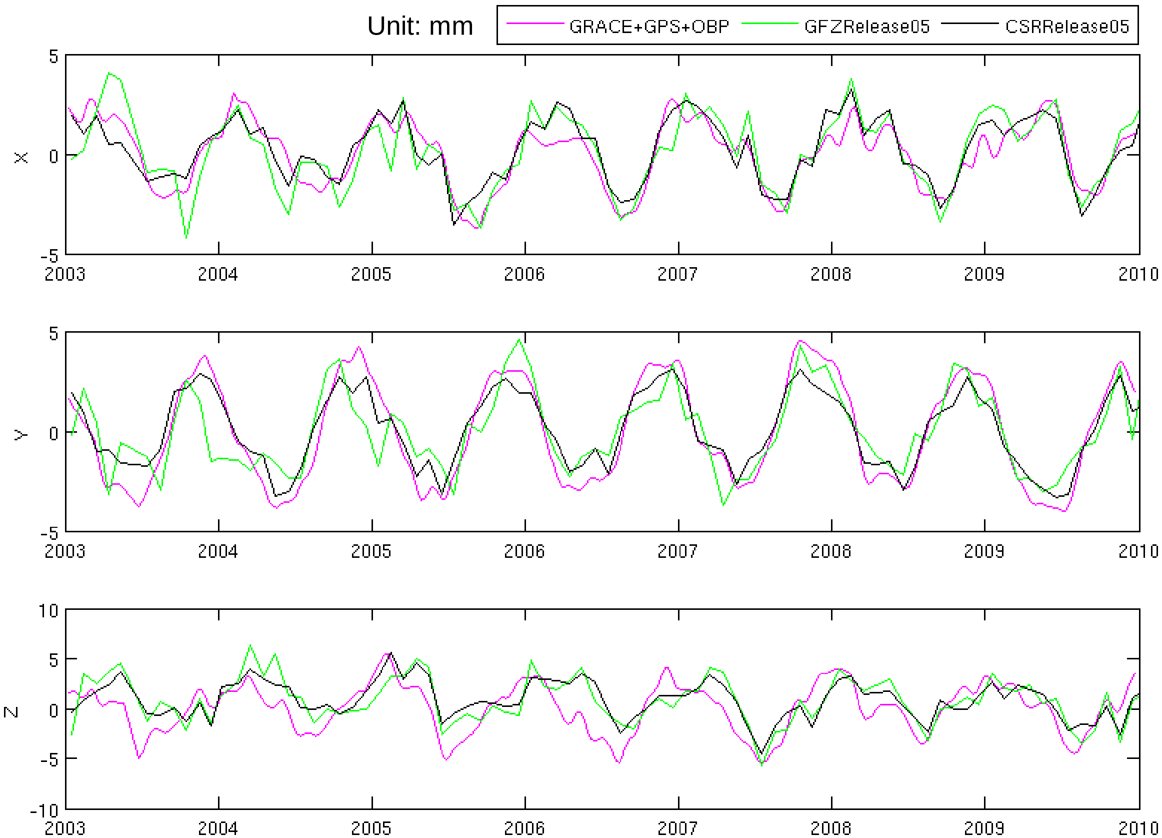
9.80±0.54 mm / 278 days

Trend:

1.41±0.11 mm/yr

	Amplitude [mm]	Phase [days]
Chambers (2004)	8.40	266
Rietbroek et al. (2009)	8.70	247
Wouters et al. (2011)	9.40	280
Hughes et al. (2012)	8.12	266

Geocenter Comparison



	Annual (mm,days)	GFZ	CSR	Rietbroek (2012)
X	Amp	2.0	1.92	1.94
	Phase	5[illegible]	[illegible]	62.3
Y	Amp	[illegible]	[illegible]	3.47
	Phase	-[illegible]	[illegible]	-38.7
Z	Amp	2.4	2.2	3.0
	Phase	70.2	67.3	19.2

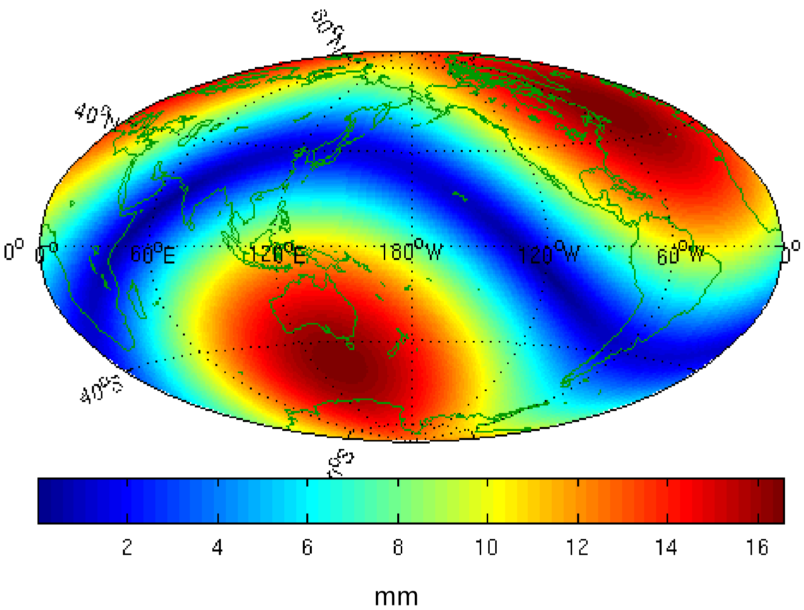
Rietbroek (2009)

2.5

67

GRACE+GPS+OBP: a joint-inversion of GRACE, GPS and insitu OBP data by [Rietbroek et al (2012)]

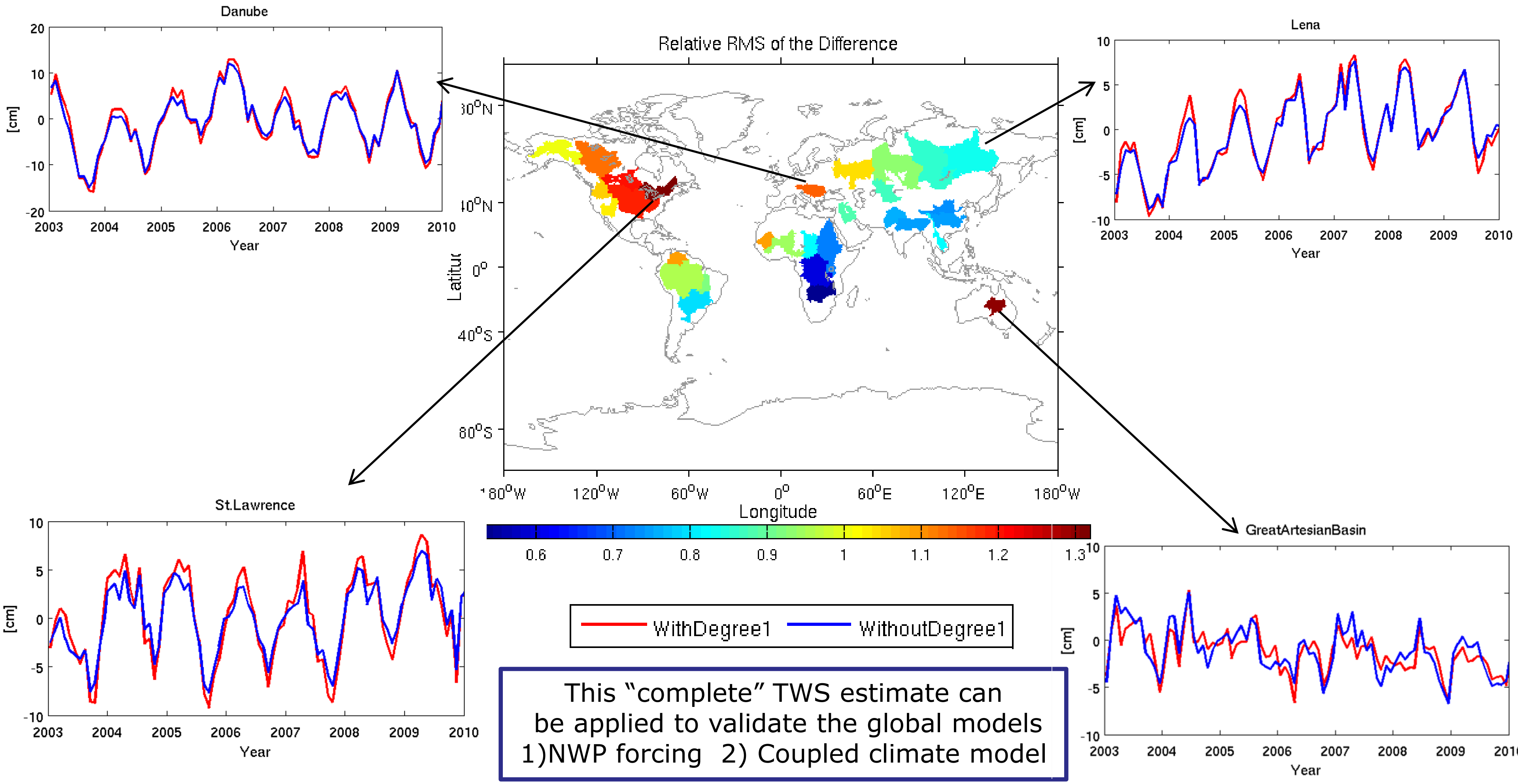
Effect on basin-averaged TWS



Basin	Diff (Amplitude) cm	Diff (Phase) days
Amazon	0.83	-0.63
Nile	-0.56	-0.93
Zaire	0.22	3.71
Mississippi	1.34	0.33
Parana	0.47	1.45
Yenisei	0.63	1.10
Ob	0.79	-0.98
Lena	0.63	-0.85
Niger	-1.04	0.09
Zambezi	0.01	0.41
ChangJiang	0.03	2.34
Mackenzie	1.27	0.25
Ganges	0.00	0.29
Chari	-0.81	0.19
Volga	1.05	0.92

Basin	Diff (Amplitude) cm	Diff (Phase) days
St.Lawrence	1.52	3.59
Indus	0.01	-6.55
Syr-Darya	0.62	-1.75
Nelson	1.30	-10.05
Orinoco	-0.98	-1.60
ShattelArab	0.76	-1.53
HuangHe	0.02	2.61
Yukon	1.08	0.66
Senegal	-1.24	2.51
Colorado(Ari)	1.10	0.37
Danube	1.23	2.83
Mekong	0.45	0.32
Tocantins	0.81	0.31
Columbia	1.15	-0.02
GreatArtesian	-1.07	32.92

Effect on basin-averaged TWS



This “complete” TWS estimate can be applied to validate the global models
1)NWP forcing 2) Coupled climate model

GFZ Helmholtz Centre Potsdam

HELMHOLTZ ASSOCIATION

Validation-NWP models

- Water cycle simulations with forcing from Numerical Weather Prediction (NWP) Models
  - LSDM (Dill 2008)
  - WGHM (Döll et al., 2003; Güntner et al., 2007)
  - GLDAS (Rodell et al., 2004)
- Represent the water cycle dynamics of the last decades
- Some attempts for data assimilation (in-situ, remote sensing, modeling)
- Simulating the main components of TWS

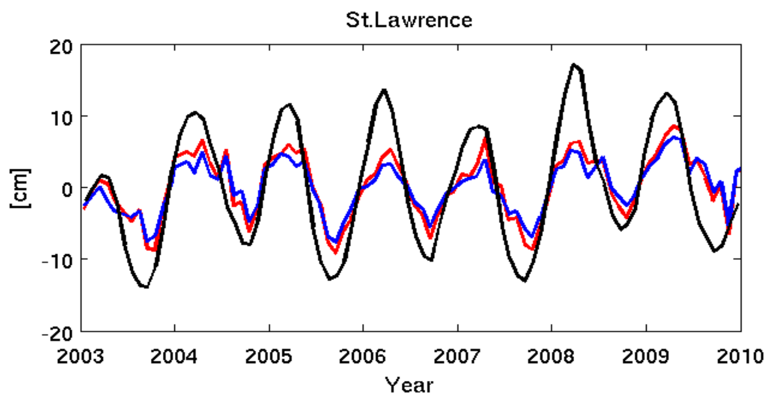
  -soil moisture

  -snow component

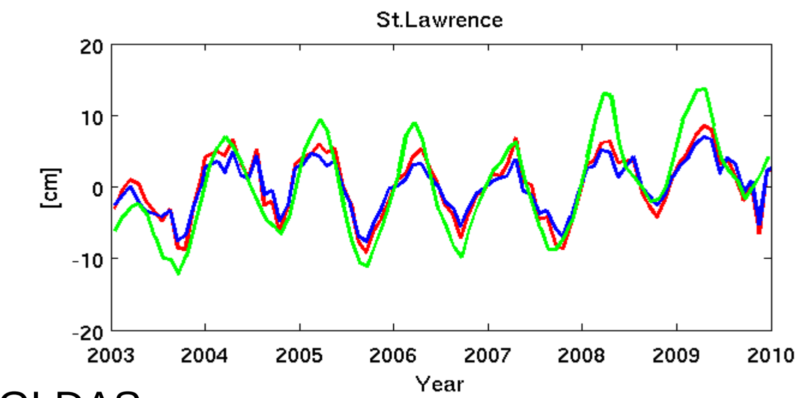
  -deep aquifers

Validation-NWP models

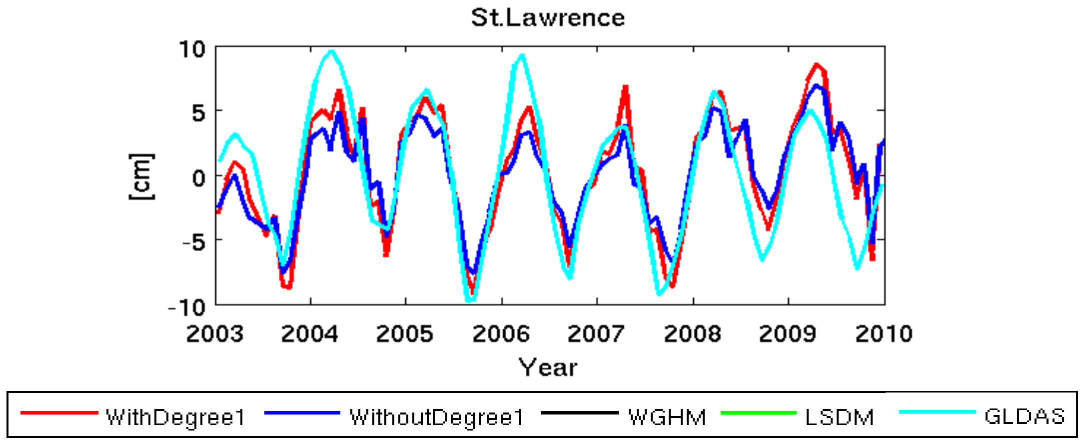
WGHM



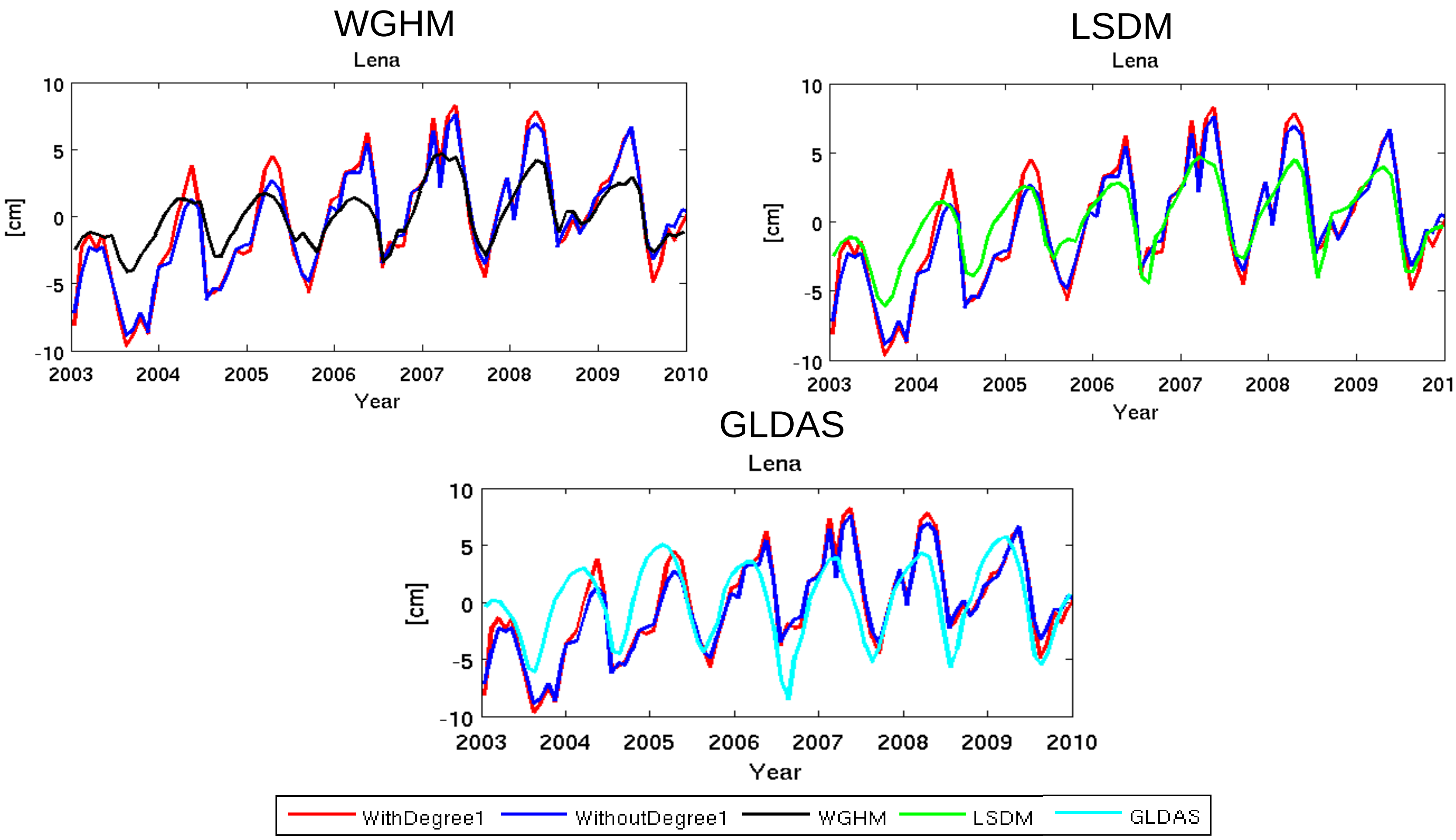
LSDM



GLDAS



Validation-NWP models



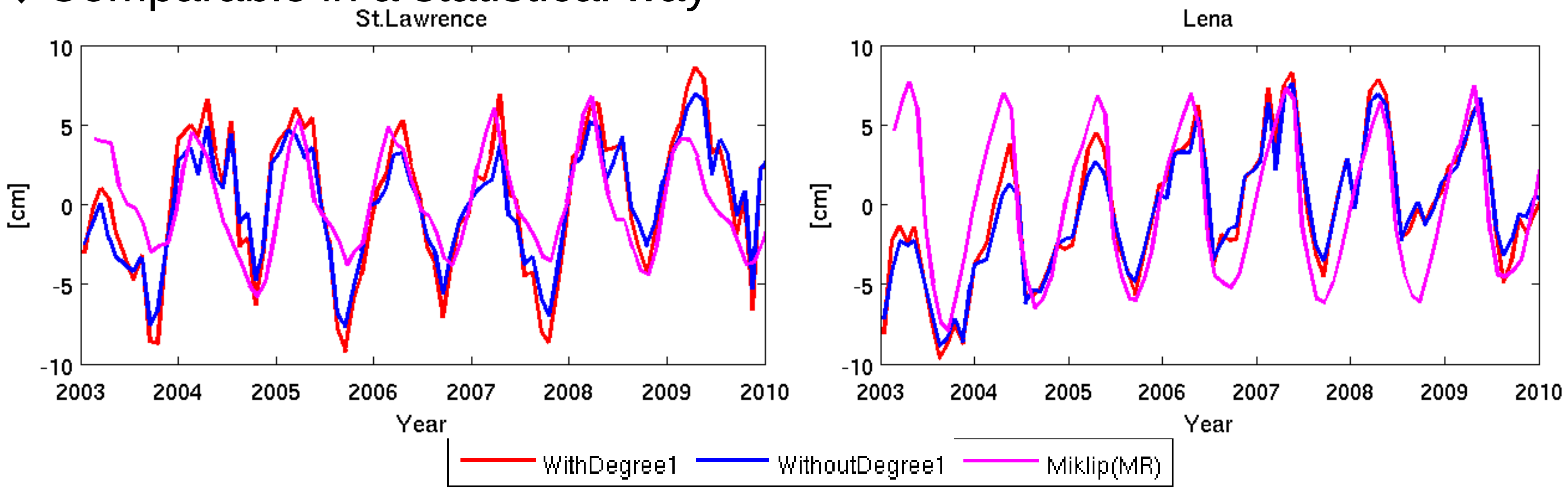
Validation- Coupled climate model

- Coupled Climate Model Simulations
  - Miklip (Pohlmann et al., 2009) .BMBF initiative on decadal climate prediction
  - MPI Earth System Model (LR-MR):ECHAM6, MPIOM, JSBACH
  - Historical runs(1850-2005)
  - RCP scenarios (2006-2100) (RCP4.5, RCP8.5)
  - Decadal hindcasts (3 ensemble members every year) and predictions
- Employ common climatic forcings like sea surface temperature, greenhouse gas, solar cycle activity, land cover etc

Validation- couple climate model

- Example: MPI-ESM-LR,historical runs (2003 – 2005) + RCP4.5 (2006 – 2009.12)

◆Comparable in a statistical way



		With Degree1	Without Degree1	Miklip		With Degree1	Without Degree1	Miklip
Amplitude (cm)	St.Lawrence	3,91	3,37	6,34	Lena	4,99	3,46	4,46
Phase(days)		89,7	90,6	84,54		86,8	86.3	83.2
RMS(cm)		3,97	3,62	4,72		4,46	3.51	2,98

GFZ Helmholtz Centre POTSDAM

HELMHOLTZ ASSOCIATION

Summary

- Estimating geocenter variation with method of Swenson et al. (2008) only from GRACE data without any auxiliary data is possible with iterative processing
- Reduced error budget of GRACE derived TWS variations
- Cannot be neglected when compared with hydrological models especially at certain basins
- This GRACE-based TWS is suited to validate:

  (1)Water Cycle Simulations with NWP forcing

  (2)Coupled climate simulations

Thank you for your attention!

Geocenter Determination

- Based on method described by Swenson et al. (2008)
- only GRACE data needed → mass coefficients
- Solving a system of linear equations of rank = 3 in CF-frame

$$\begin{bmatrix} \Delta C_{10}^{ocean} \\ \Delta C_{11}^{ocean} \\ \Delta S_{11}^{ocean} \end{bmatrix} = \begin{bmatrix} I_{10C}^{10C} & I_{11C}^{10C} & I_{11S}^{10C} \\ I_{10C}^{11C} & I_{11C}^{11C} & I_{11S}^{11C} \\ I_{10C}^{11S} & I_{11C}^{11S} & I_{11S}^{11S} \end{bmatrix} \begin{bmatrix} \Delta C_{10} \\ \Delta C_{11} \\ \Delta S_{11} \end{bmatrix} + \begin{bmatrix} G_{10C} \\ G_{11C} \\ G_{11S} \end{bmatrix}$$

Eustatic SL input for d1-terms

unknown d1-terms (geocenter variation)

Oceanic contribution from global GSM-coefficients (l ≥ 2)

- Estimated d1-terms translated into CM-frame by modification of k_1 load Love number → $(1+k_1)/(RE*\rho_{earth})$

		With Degree1	Without Degree1	Miklip
Amplitude (cm)	St.Lawrence	3,91	3,37	6,34
Phase(days)		89,7	90,6	84,54
RMS(cm)		3,97	3,62	4,72

	With Degree1	Without Degree1	Miklip
Lena	4,99	3,46	4,46
	86,8	83,2	79.1
	4,46	86,3	2,98