GRACE Status and Results

M. Rothacher et al.
Deutsches GeoForschungsZentrum (GFZ)

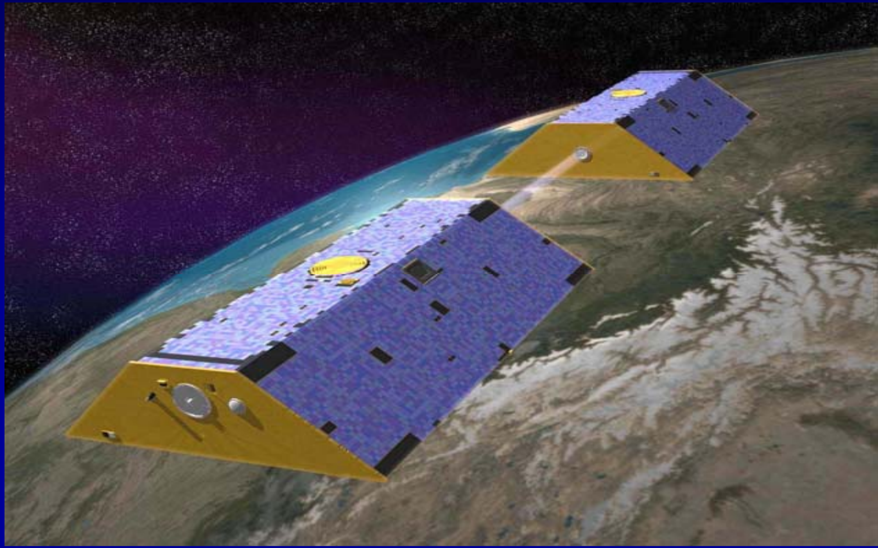
First IGCP 565 Workshop
December 11, 2008
San Francisco, USA

Overview

- GRACE Mission Status
- GFZ/GRGS EIGEN Gravity Field Models
- Comparison of GRACE with Super-Conducting Gravimeters (SG) and Hydrology
- Integrated Modeling and Assimilation
- Conclusions

GRACE Mission Status (1)

- **Mission Accomplishments**
  - Completed Nominal 5-Year Mission in March,2007
  - Gravity Model Release
    - Mean field(GGM03S and Eigen05C)
    - Time Variable Signals(75 monthly solutions through September, 2008)
  - Time variable effects in gravity field are enabling mass flux studies in Hydrology, Oceanography, Glaciology and Solid Earth Sciences
  - Multidisciplinary science results are demonstrating importance of " global mass flux measurements"



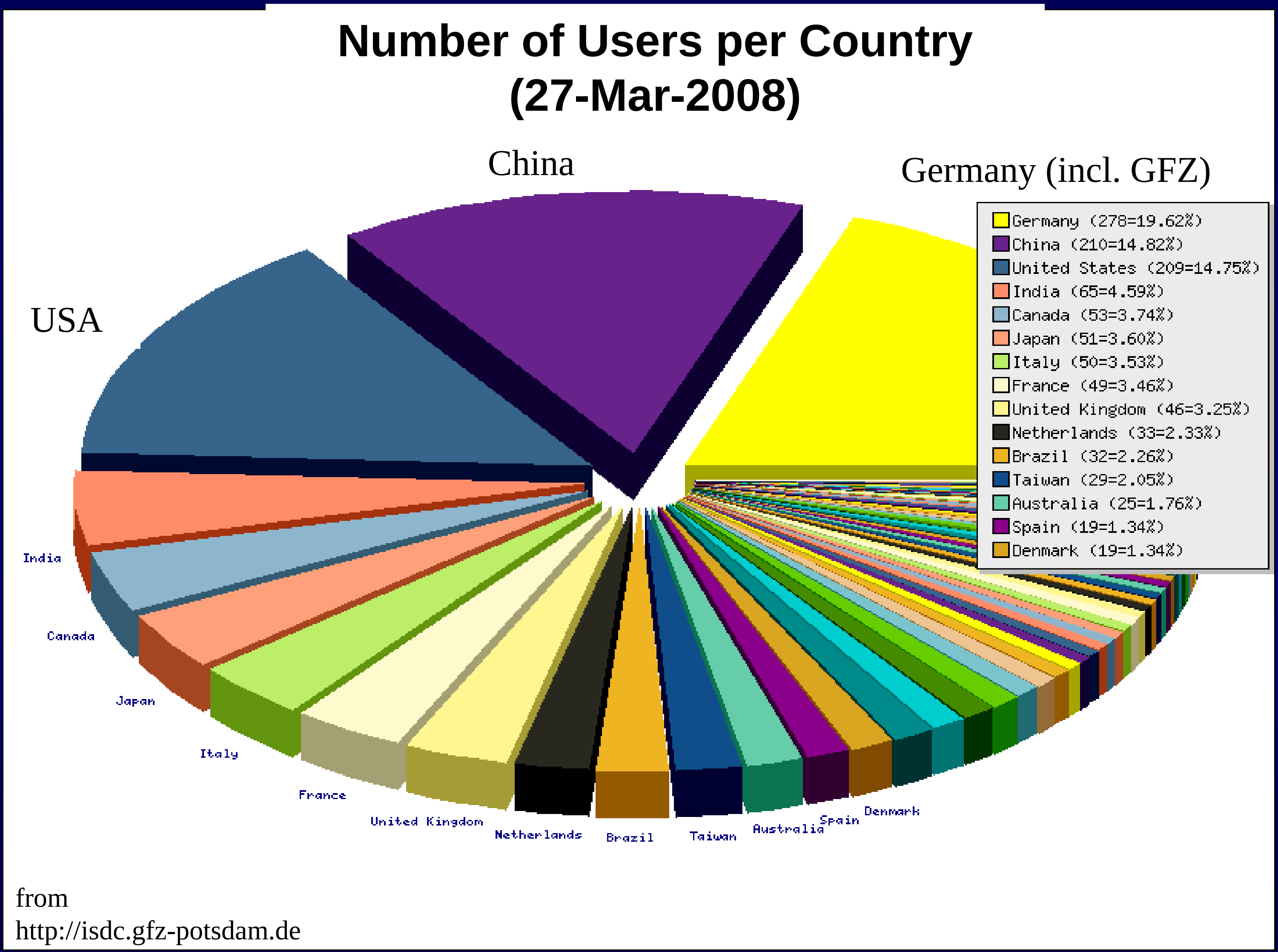
- **NASA and DLR have approved mission extension and funding through 2009**
  - Extension to 2011 approved by NASA 2007 SR
  - Funding will be addresses in 2009 Senior Review
- **Flight Segment**
  - Nearly 100 % of scientific measurements during 5.6-years have been collected and analyzed
  - Instrument performance meeting mission requirements
  - Mission lifetime is a concern (batteries, redundant instruments, …)

GRACE Mission Status (2)

Orbit:

- **Launched: March 17, 2002**
  - **Over 6.7 years in orbit (2461 days)**
- **Initial Altitude: 500 km**
  - **Current Altitude: ~465 km (-10 m/day)**
- **Inclination: 89 deg**
- **Eccentricity: ~0.001**
- **Separation Distance: ~220 km**
- **Nominal Mission : 5 years**
- **Non-Repeat Ground Track, Earth Pointed, 3-Axis Stable**
- **Predicted Lifetime 2013**

International Impact of GRACE



1417 Users worldwide (exclusive GRACE data originators)

≈ 50 % of users from USA, China and Germany (797)

≈ 82 % of users from 15 countries (1168)

≈ 8 % of users from another 20 countries (249)

Status EIGEN Gravity Field Products (Cooperation of GFZ and GRGS)

- EIGEN-GRACE05S (RL04) monthly product generation (n=120) ongoing (August 2002 – September 2008 available).

- EIGEN-CHAMP05S monthly fields reprocessed (n=60) with GRACE RL04 standards for September 2002 till September 2008. Good agreement for low degrees (see next slide). Products will be made available at ISDC shortly. Missing products at the beginning and end of the mission will be provided.

- Pure weekly RL04 products up to n=30 (aligned to GPS week) have been generated for the entire GRACE period. GSM products, corresponding Gax and calibrated errors are available at ISDC (see next slide).

- New GFZ/GRGS combination model EIGEN05C (n=360) available (see next slide). Shows reduced striping and improved POD results compared to previous EIGEN combination models. Poster presentation at AGU on Monday.

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Processing of Monthly RL04 Gravity Fields

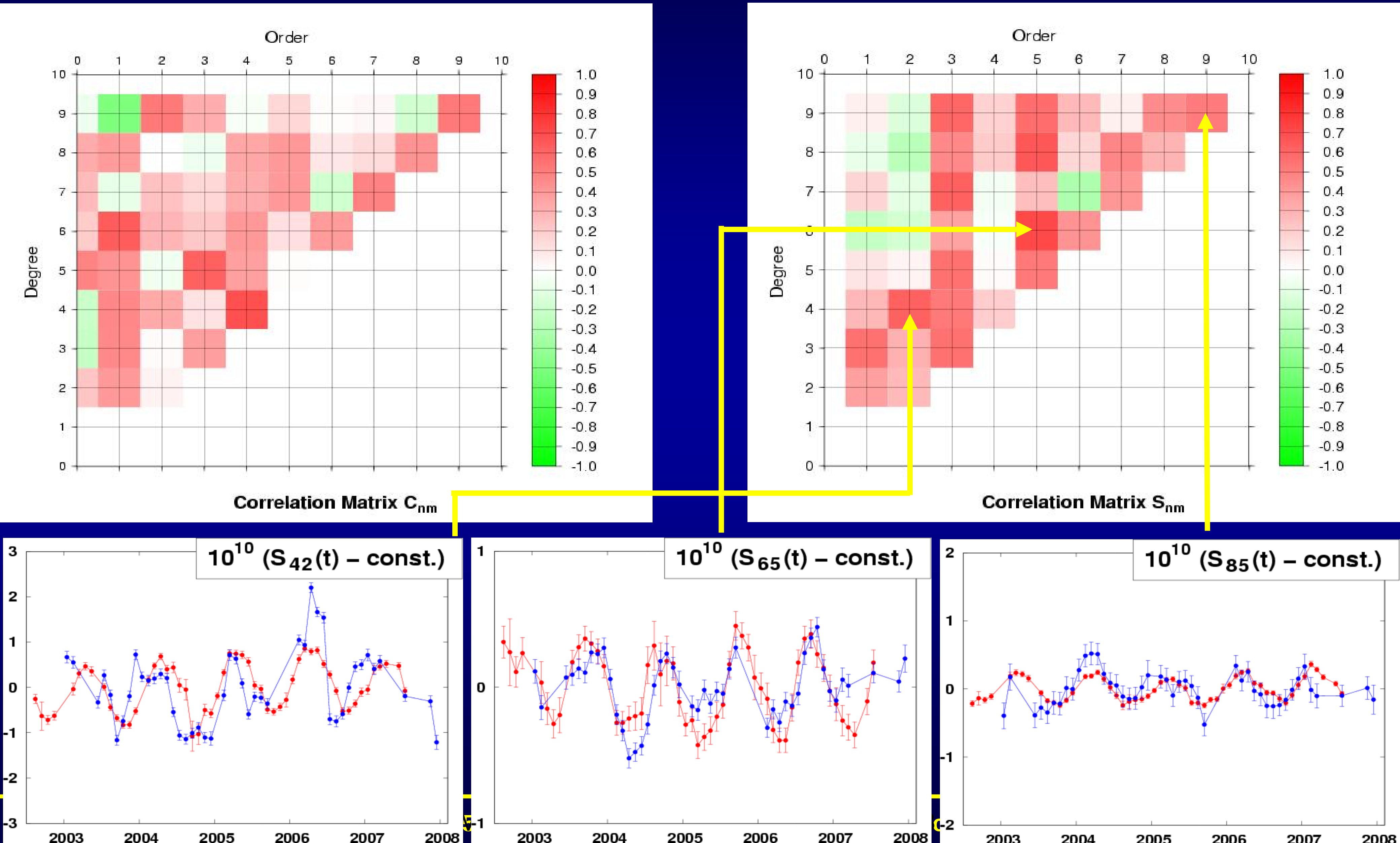
- Contniuous Continuous processing of the GRACE RL04 de-aliasing products and of the monthly gravity fields EIGEN-GRACE05S
- CHAMP was reprocessed with identical standards
  - for the consistent combination (e.g. gliding CHAMP mean over 3 months) with GRACE and
  - for the extension of the GRACE time series before May 2002
  - monthly gravity fields up to n=60: EIGEN-CHAMP05S, available at ISDC

CHAMP	J	F	M	A	M	J	J	A	S	O	N	D
2000												
2001												
2002												
2003												
2004												
2005												
2006												
2007												
2008												

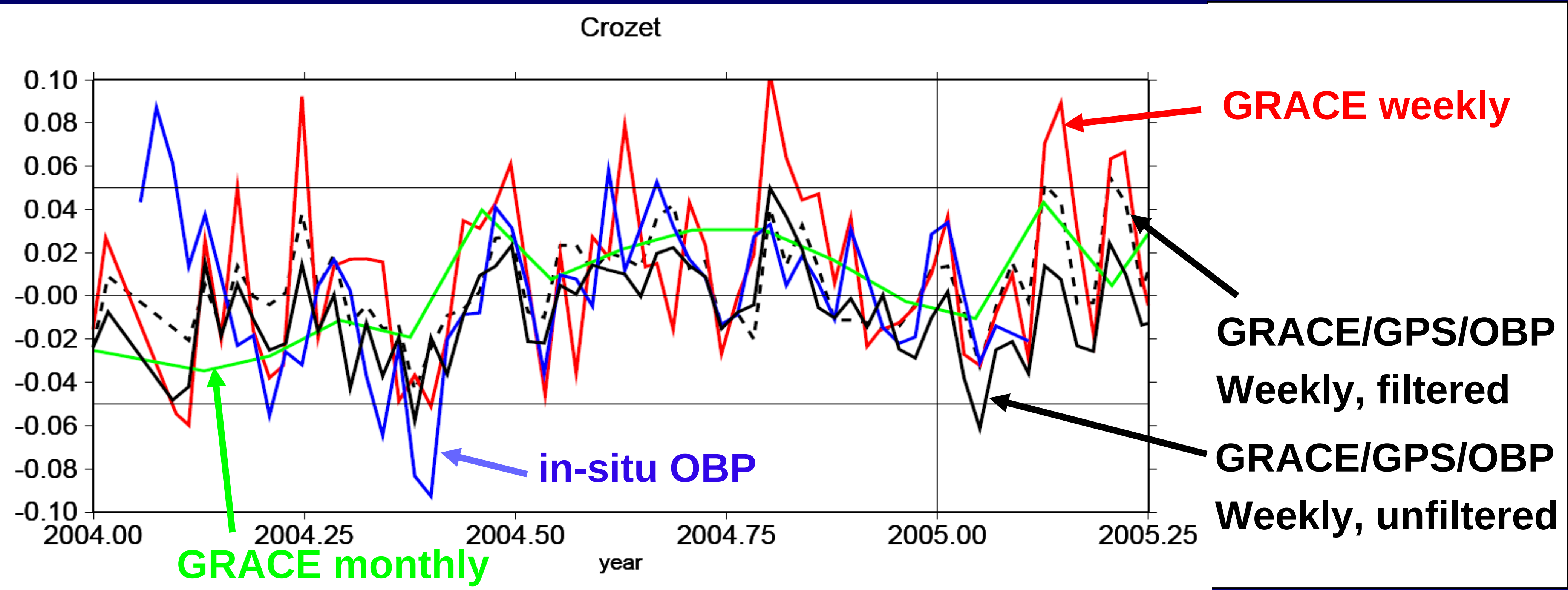
Yellow: not computed yet, red: no data, C: constrained solution

GRACE	J	F	M	A	M	J	J	A	S	O	N	D
2002												
2003												
2004						C	C	C	C			
2005												
2006												C
2007												
2008												

Correlation of CHAMP/GRACE RL04 Products



GFZ RL04 vs. in situ: Ocean Bottom Pressure (Weekly GRACE Solutions)



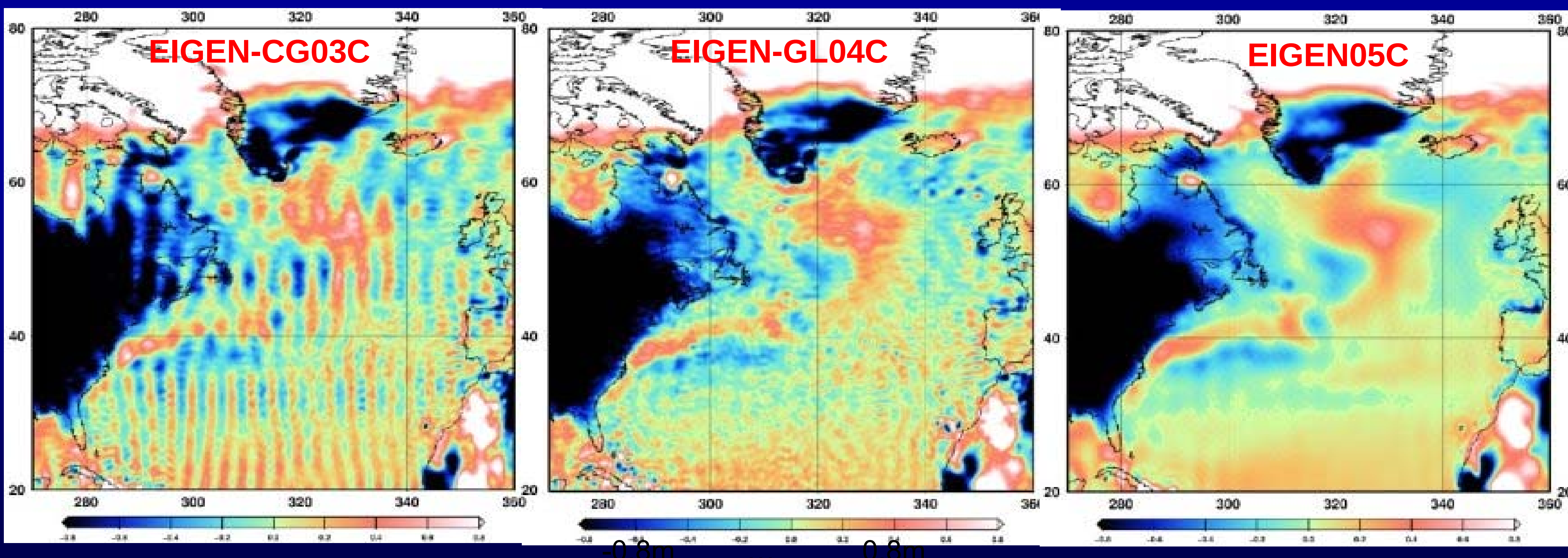
GRACE captures weekly variations of OBP

→ joint inversion

Combination Model EIGEN05C (n=360)

- 4 years of EIGEN-GRACE05S (RL04) GFZ satellite-only model
- 4.25 years of GRGS 10d GRACE solutions
- 5 years of LAGEOS data
- Improved surface gravity data sets

➢ Geoid variability with respect to marine geoid (MSSH(GFZ)-ECCO):

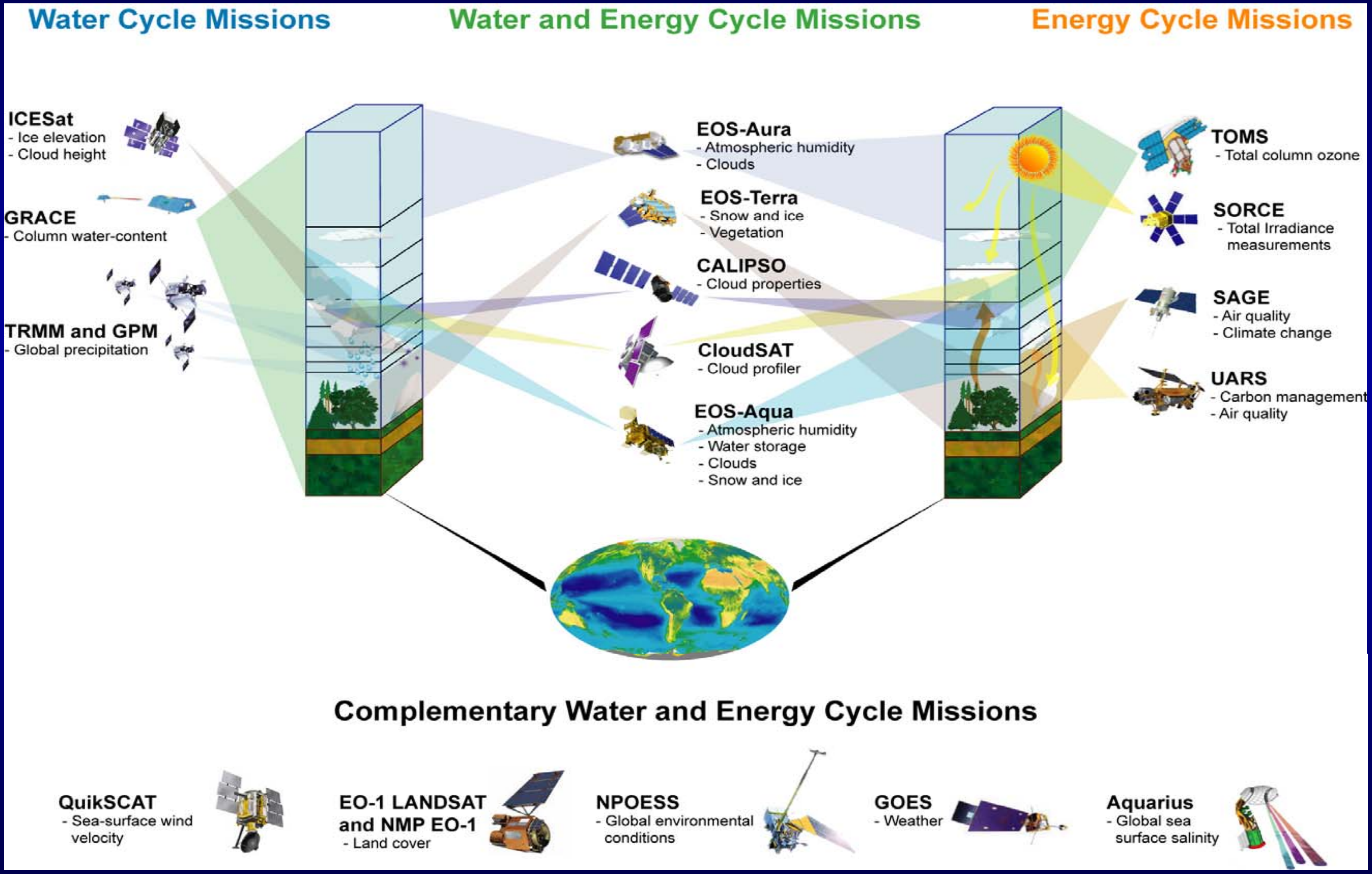


Outlook GFZ Status

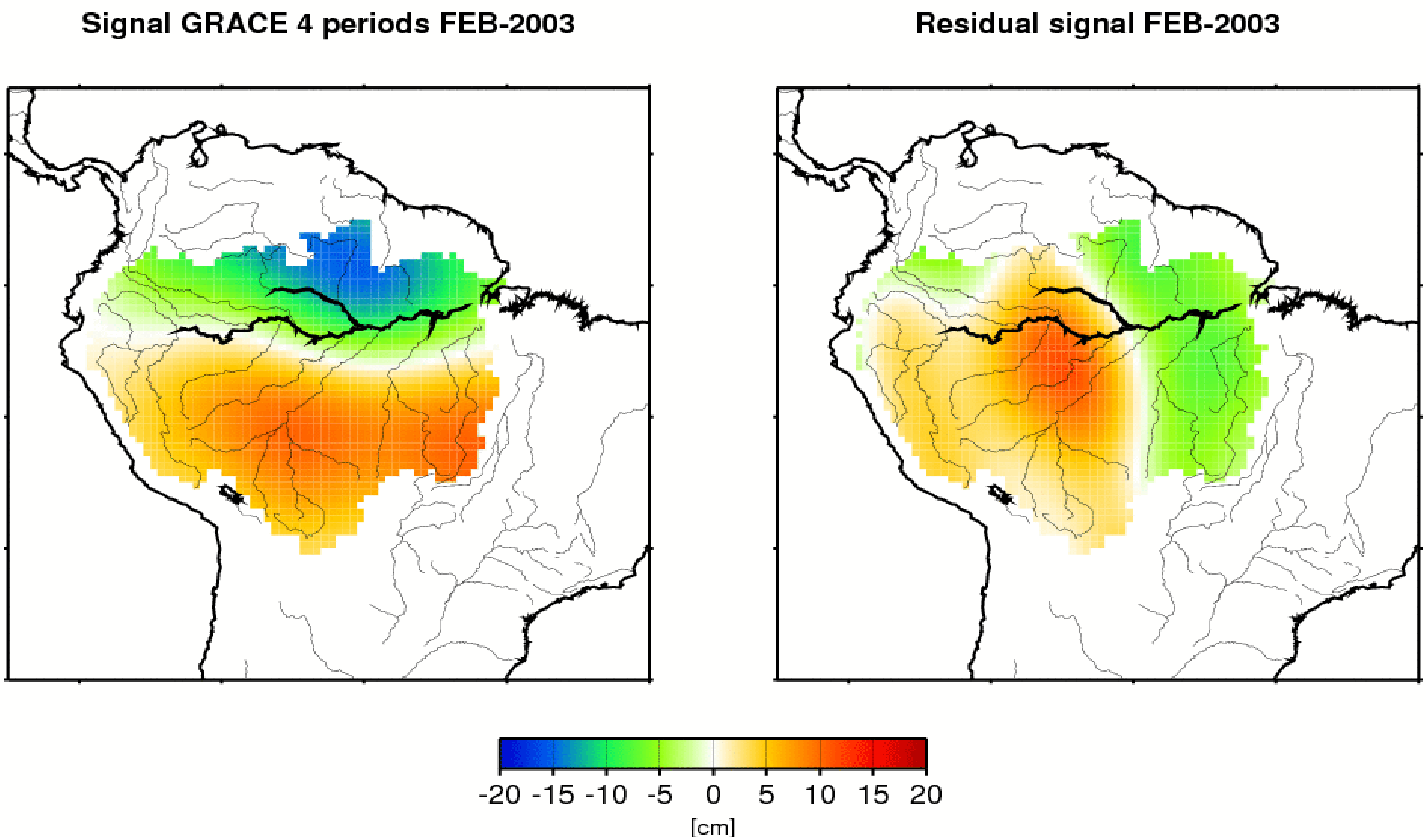
Plans for RL05 and GRACE Follow-on:

- Plans for RL05 already exist and will cover improved instrument data processing, background models and processing standards (see talks at GSTM/AGU)
- A RL05 AOD1B is not planned for 2009
- Distribution of reprocessed RL05 gravity field time series around Summer 09
- GFZ is currently working on a GRACE Follow-on feasibility study (GRAF) with industry partner STI. Final Report expected for end of February. The results of the study form the basis for further discussions with potential national and international partners in 2009.

Gravity Missions Uniquely Measure Subsurface Water



Filtered GRACE Gravity Signal – Amazon



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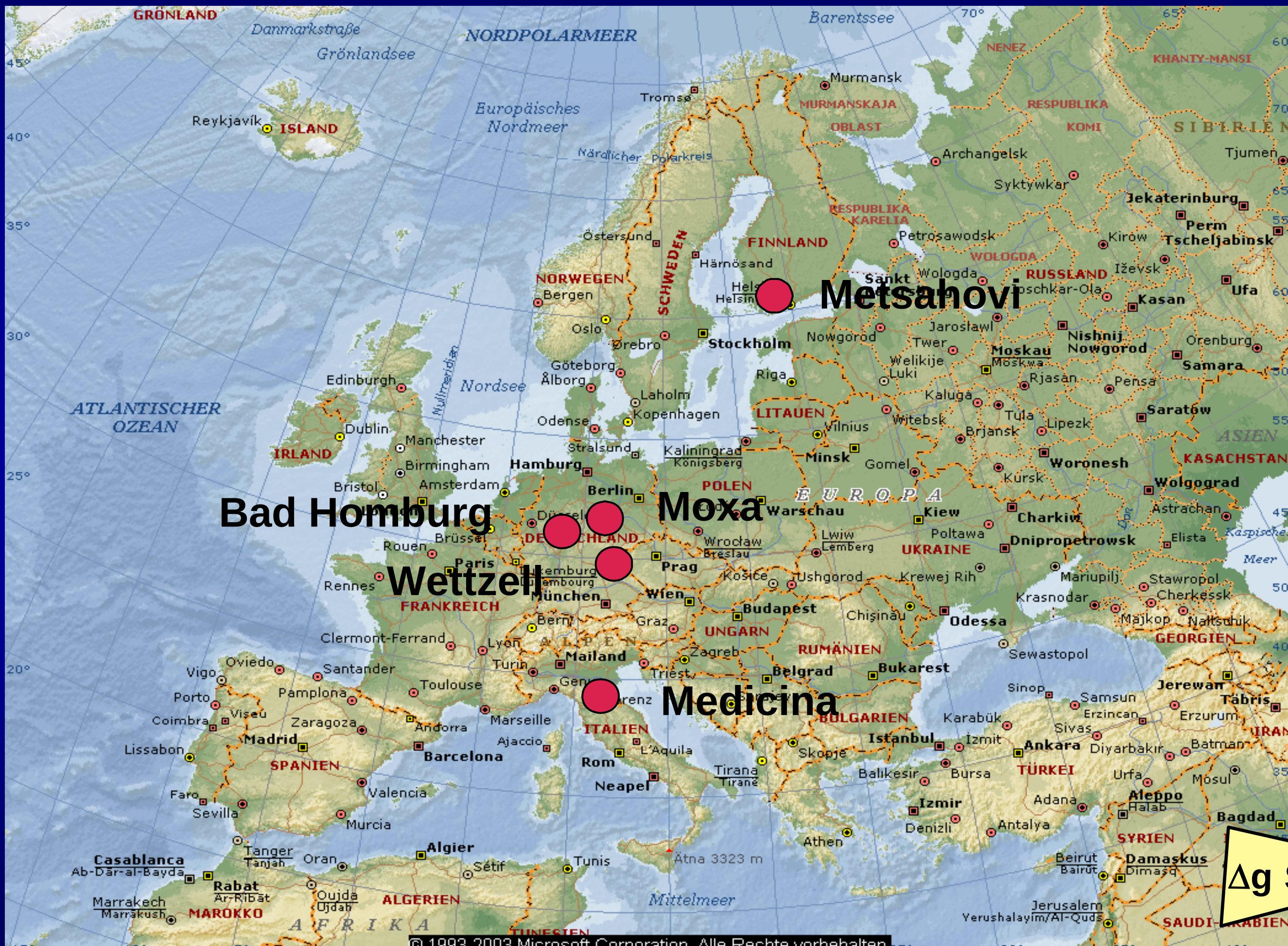
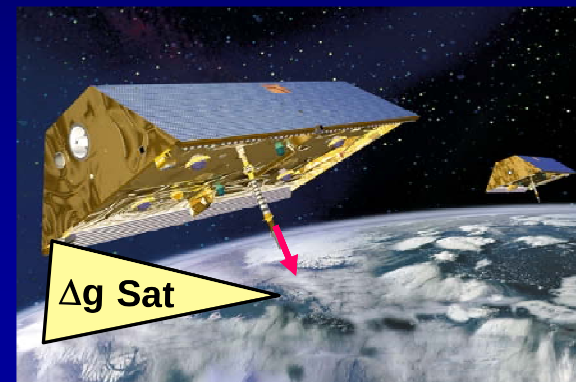
Comparison of GRACE with Superconducting Gravimeters (SG) and Hydrology

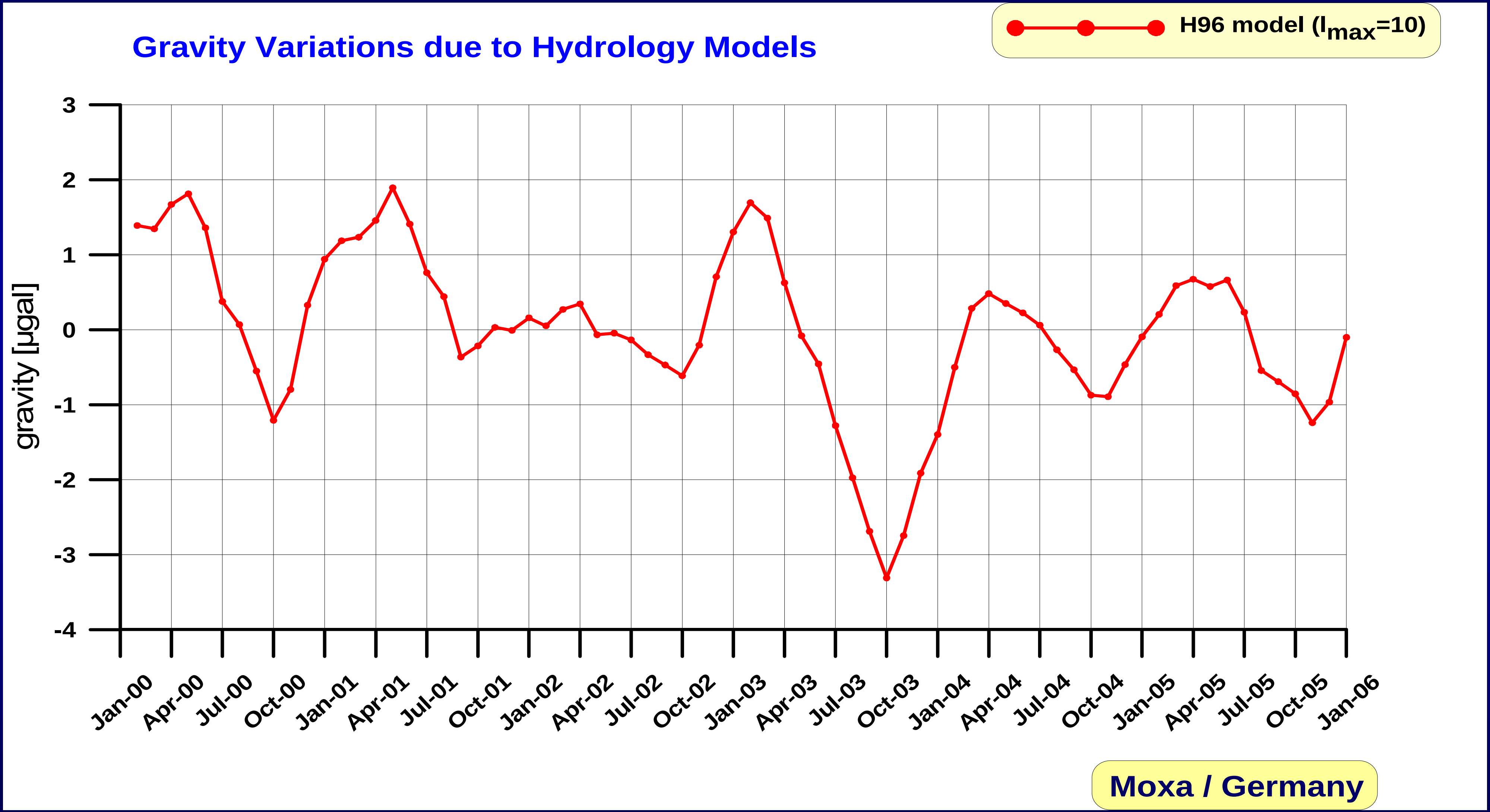




Performance Parameters of GRACE - SG

	GRACE		SG
Gravity resolution	10 µgal	0.5 µgal	0.1µgal (10^{-8} m/s^2)
Spatial resolution λ/2	500 km	2000 km	point measurement
Sph. harm. coeff.	ℓ_{max} = 40	ℓ_{max} = 10	--
Temporal resolution	1 month		10 seconds
Long term stability (drift)	no drift		~ 3 µgal/year (linear)

Gravity Variations at SGs: Hydrological Models



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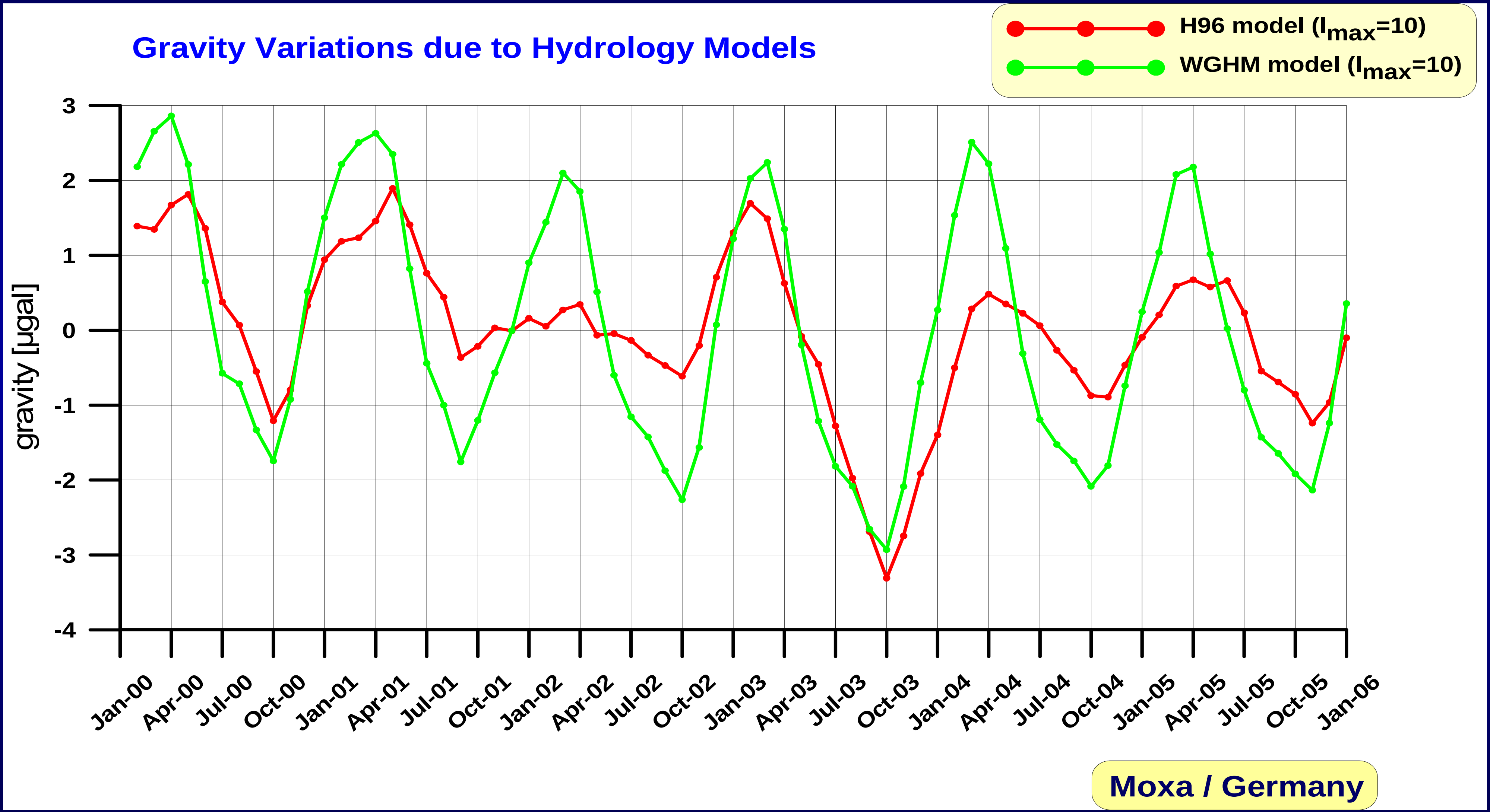
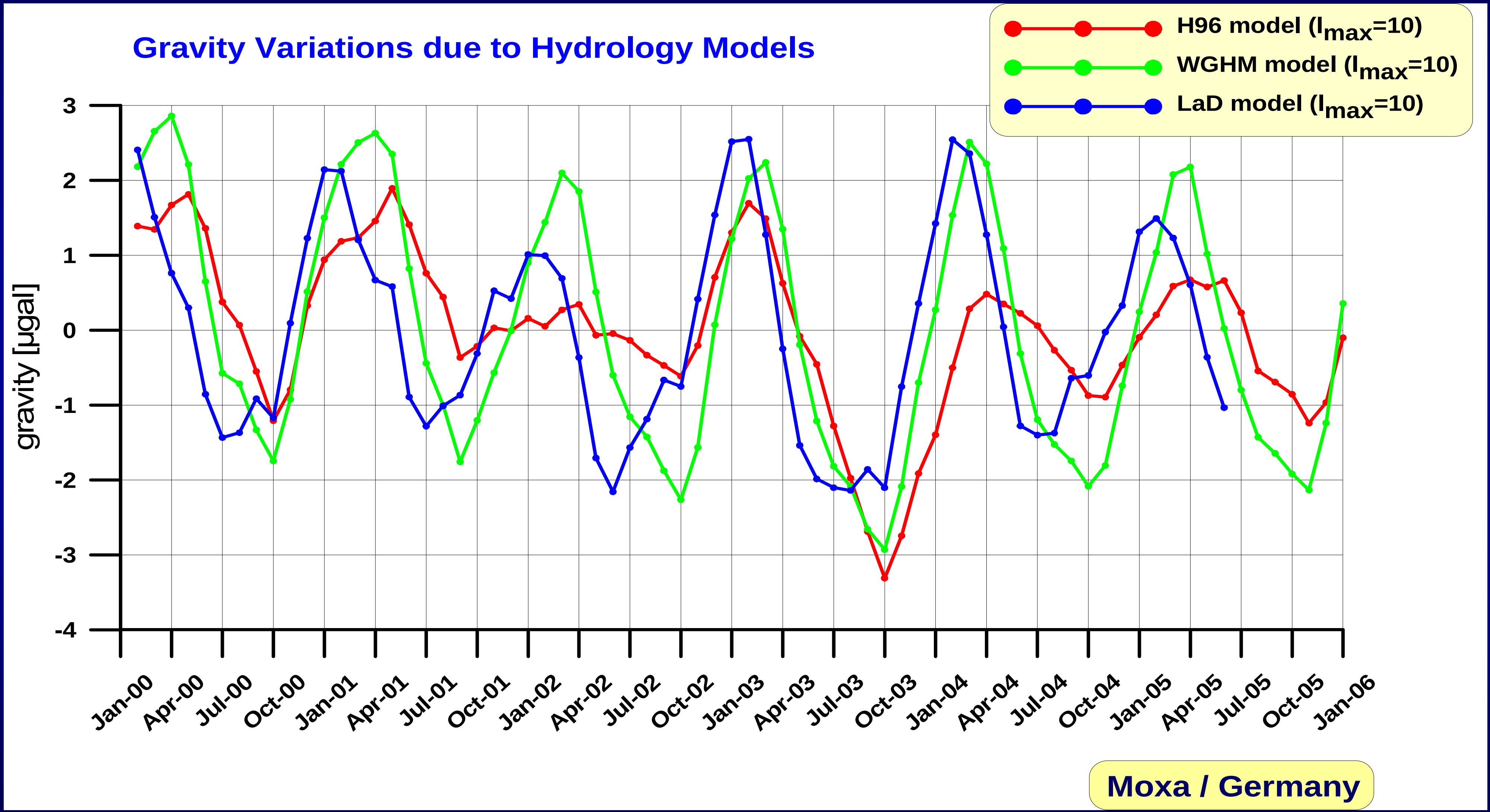
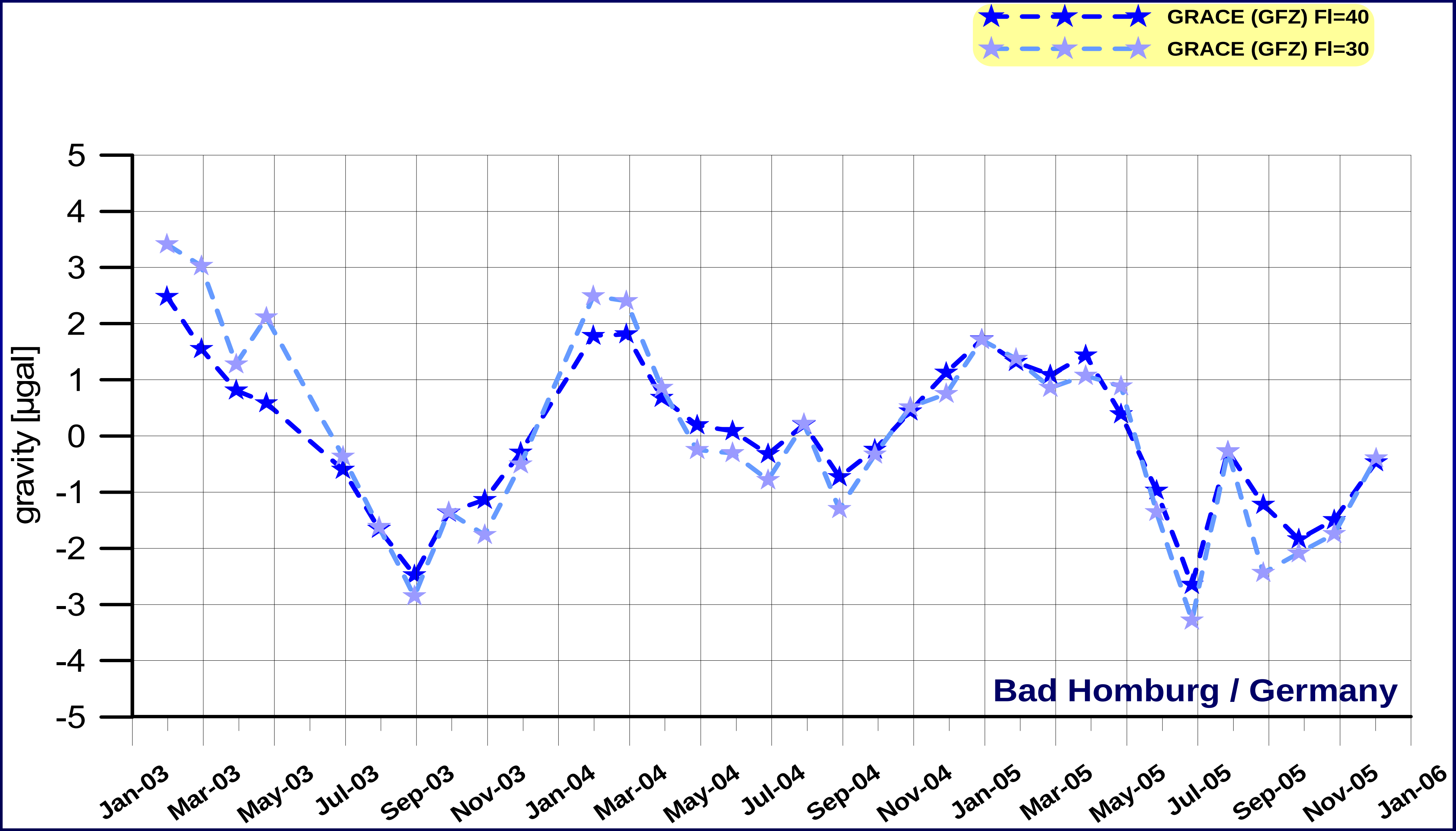


Gravity Variations at SGs: Hydrological Models



Comparison of GRACE with Superconducting Gravimeters and Hydrology



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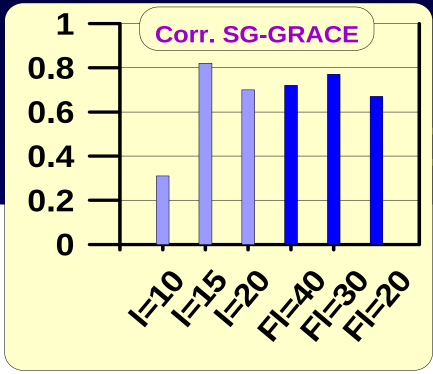
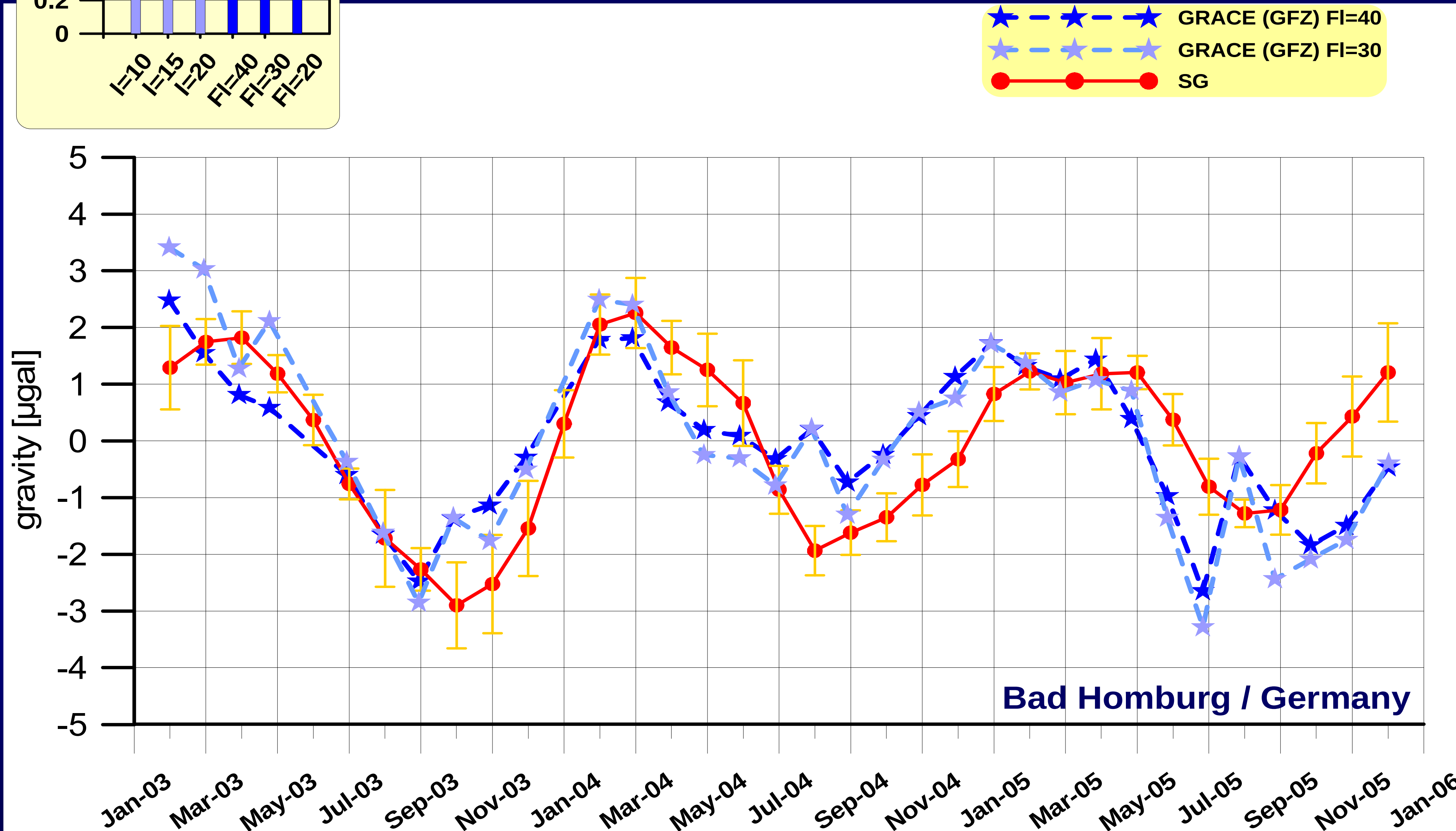
Comparison of GRACE with ...conducting Gravimeters and Hydrology





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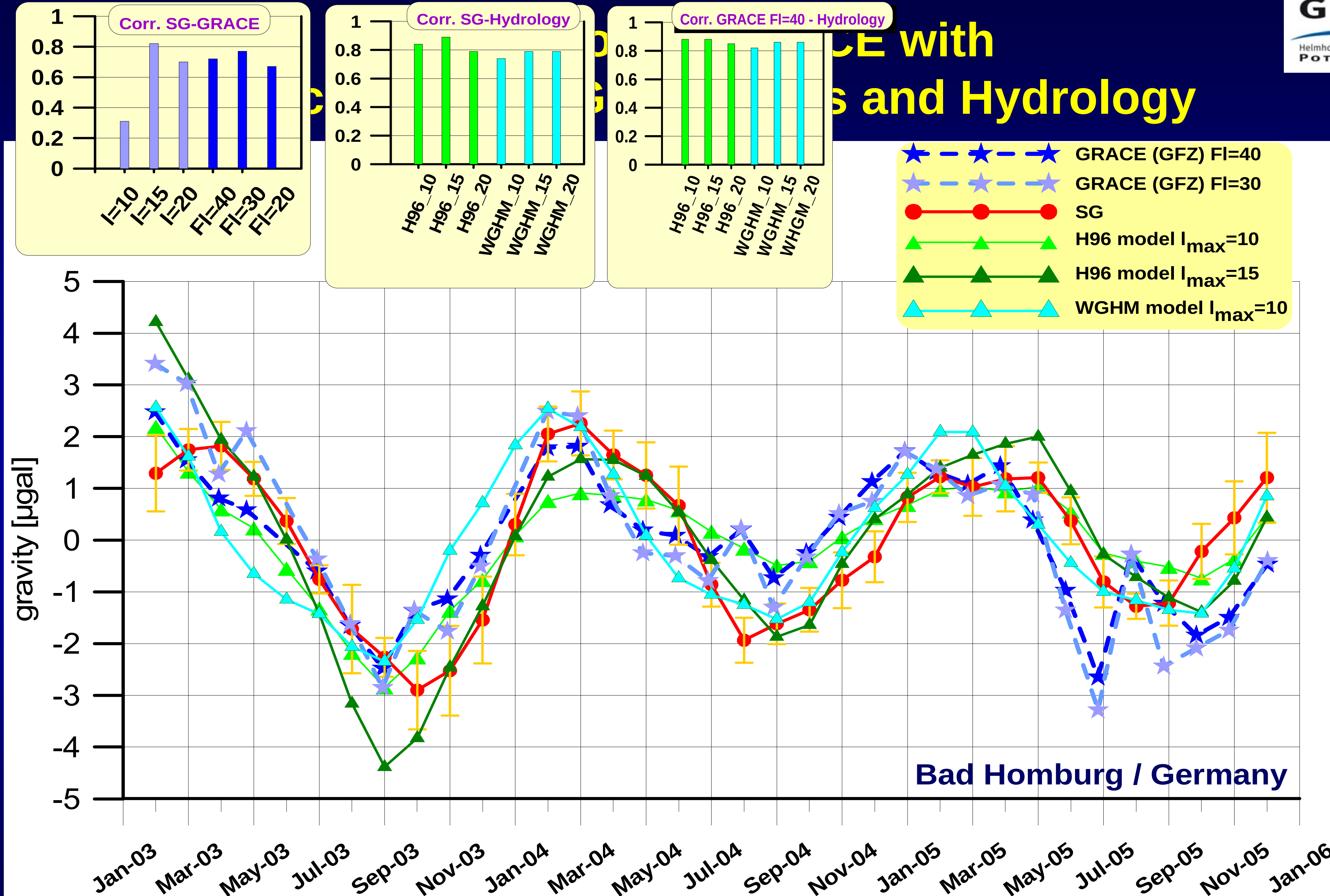

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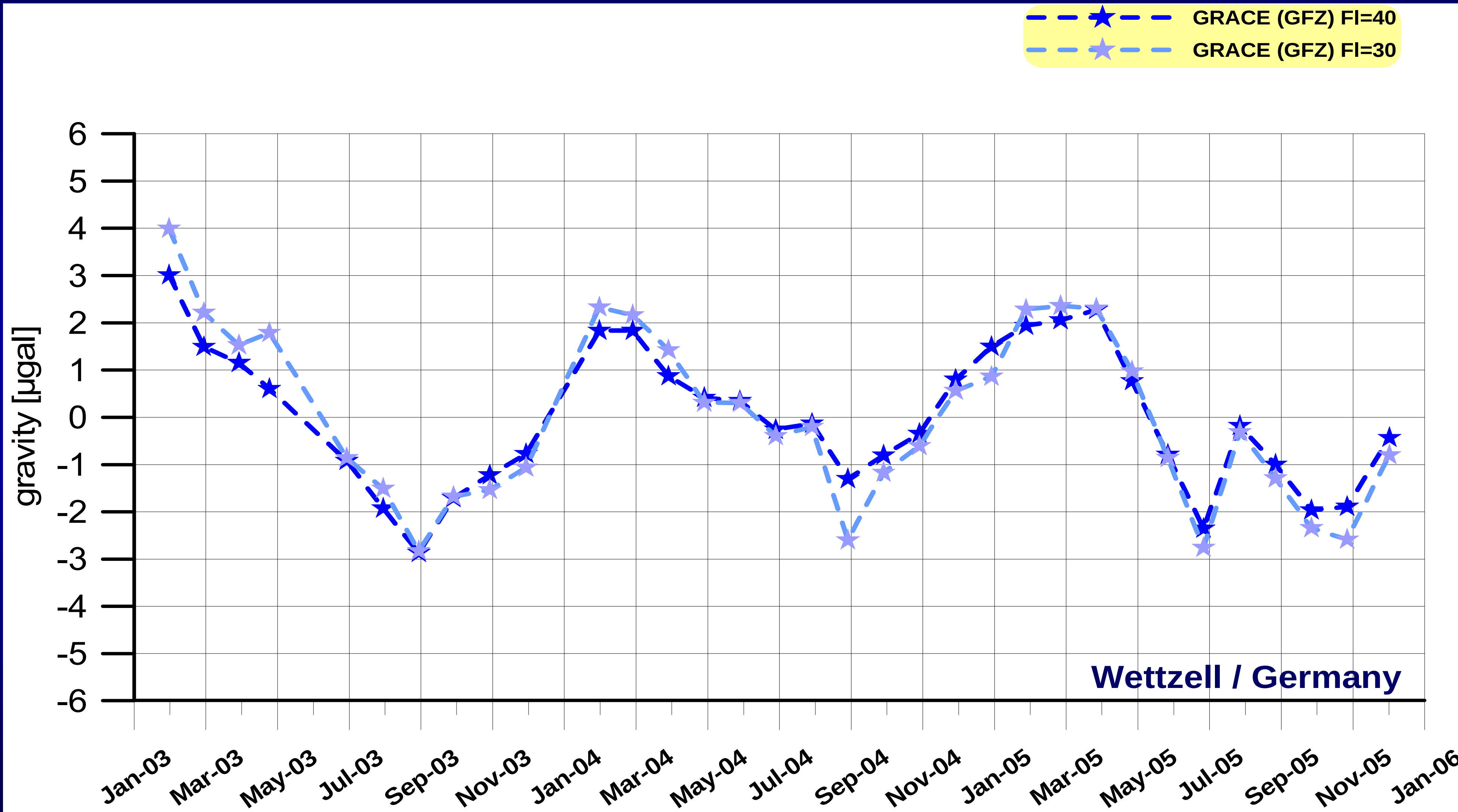

Comparison of GRACE with
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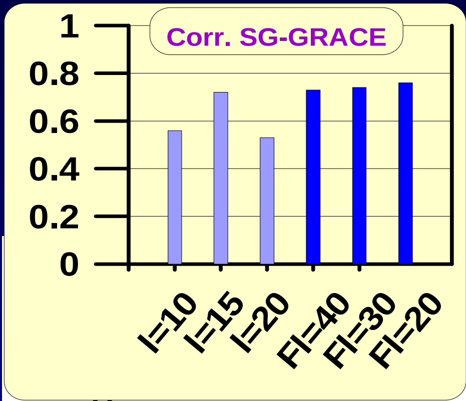
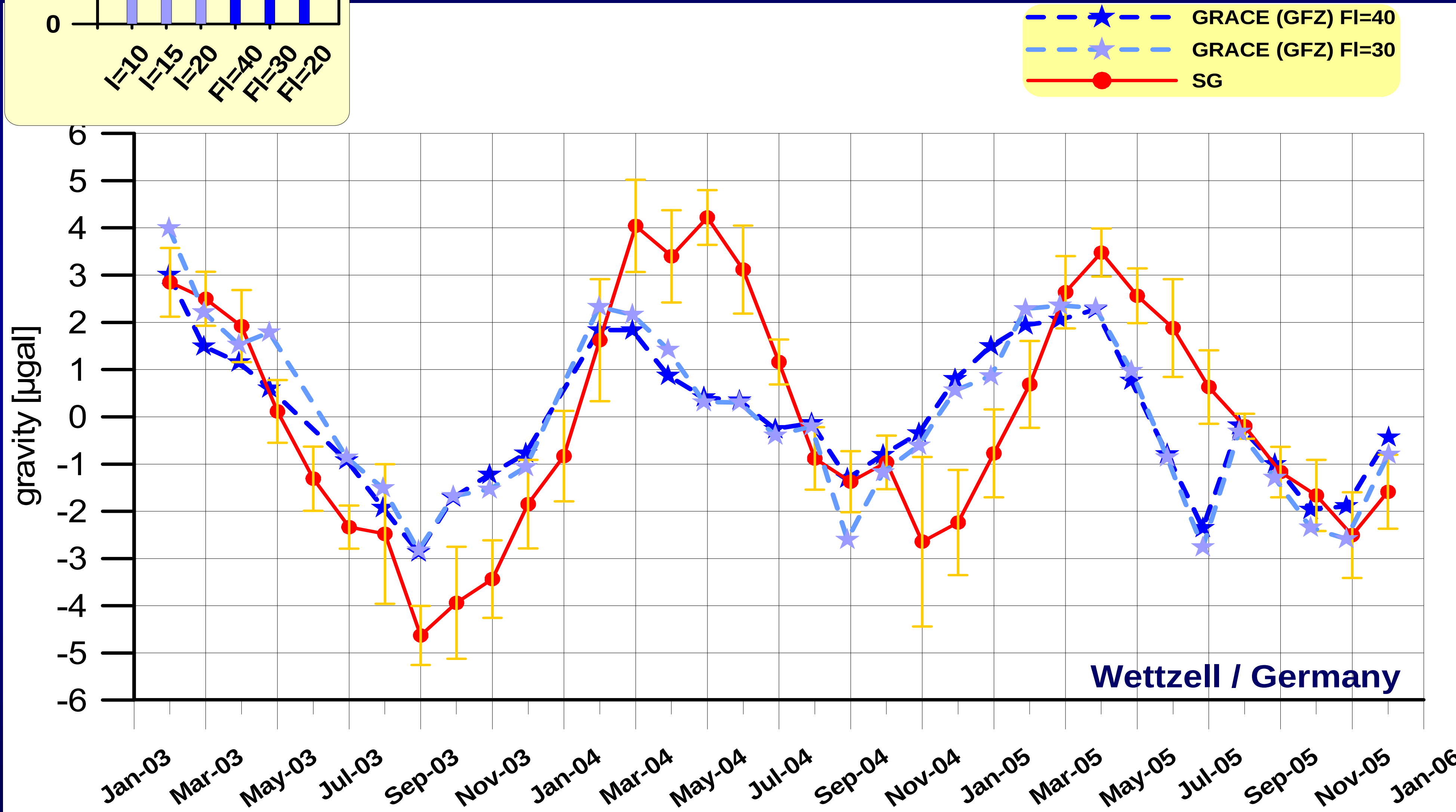
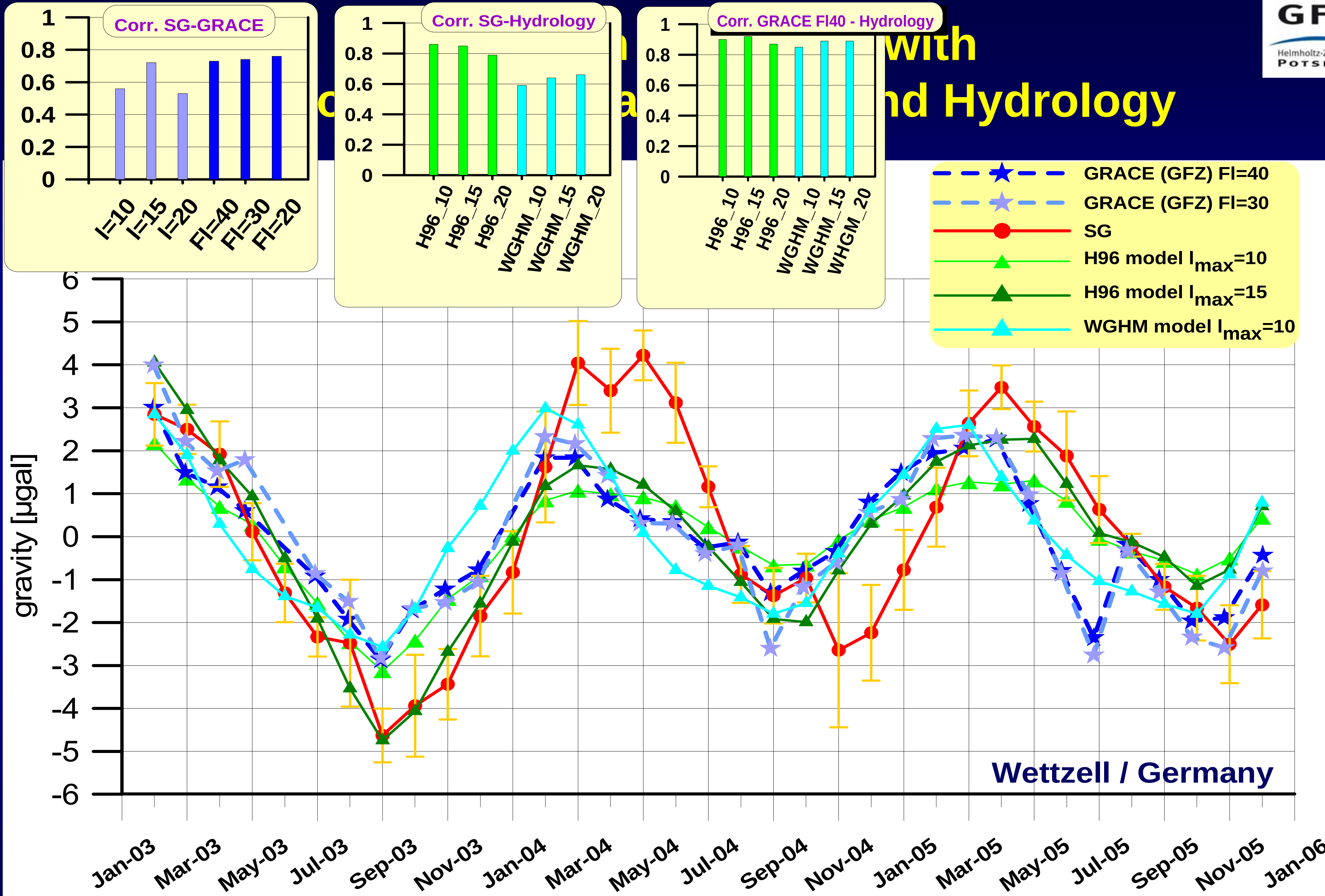


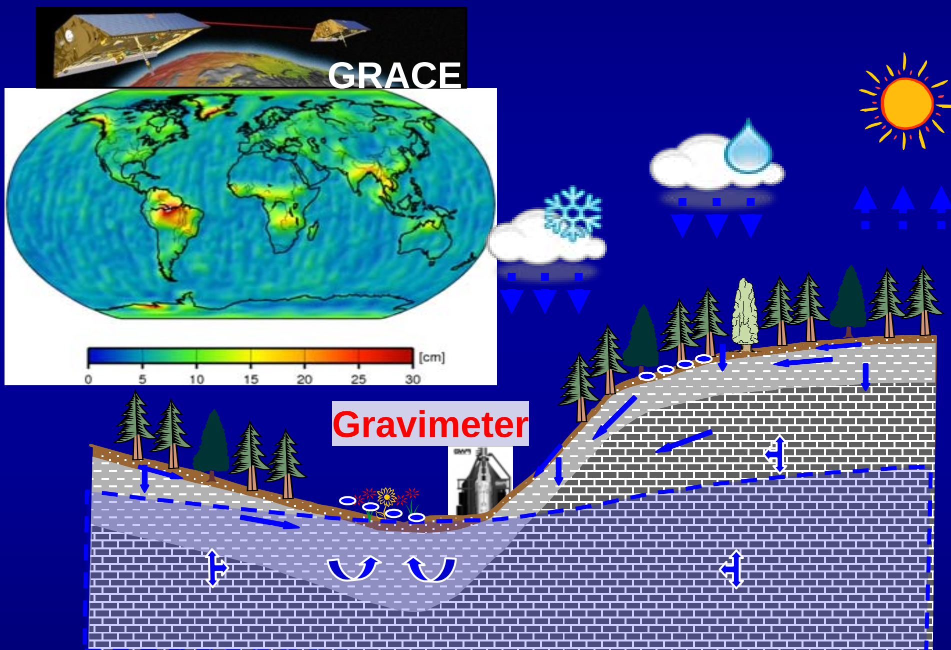



with
nd Hydrology
Corr. SG-GRACE
l=10
l=15
l=20
Fl=40
Fl=30
Fl=20
Corr. SG-Hydrology
H96_10
H96_15
H96_20
WGHM_10
WGHM_15
WGHM_20
Corr. GRACE Fl40 - Hydrology
H96_10
H96_15
H96_20
WGHM_10
WGHM_15
WHGM_20
GRACE (GFZ) Fl=40
GRACE (GFZ) Fl=30
SG
H96 model lmax=10
H96 model lmax=15
WGHM model lmax=10
gravity [µgal]
Wettzell / Germany
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Nov-04
Jan-05
Mar-05
May-05
Jul-05
Sep-05
Nov-05
Jan-06

Quantification of the Global Hydrological Cycle

Monitoring

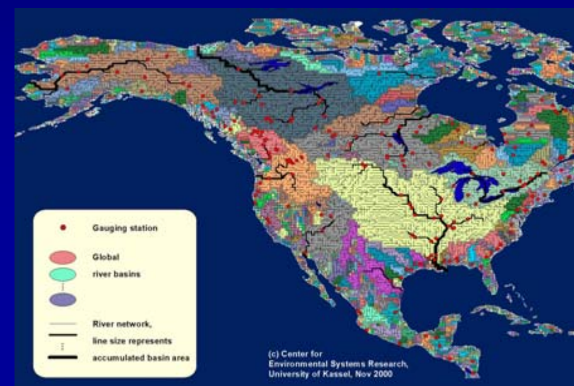
Water storage changes from time-variable gravity (GRACE, superconducting gravimeters)



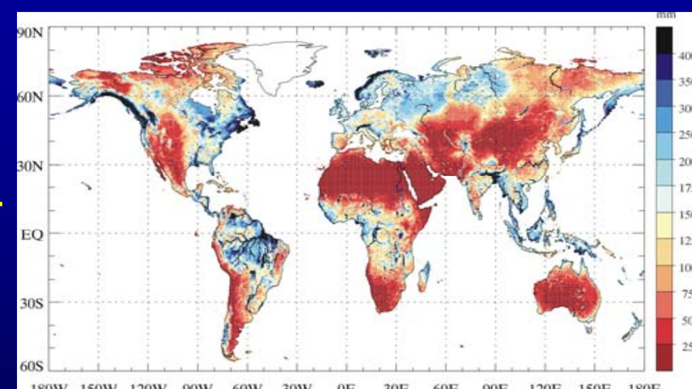
+ Ground-based hydrological measurements

Modelling

WaterGAP Global Hydrology Model (WGHM)



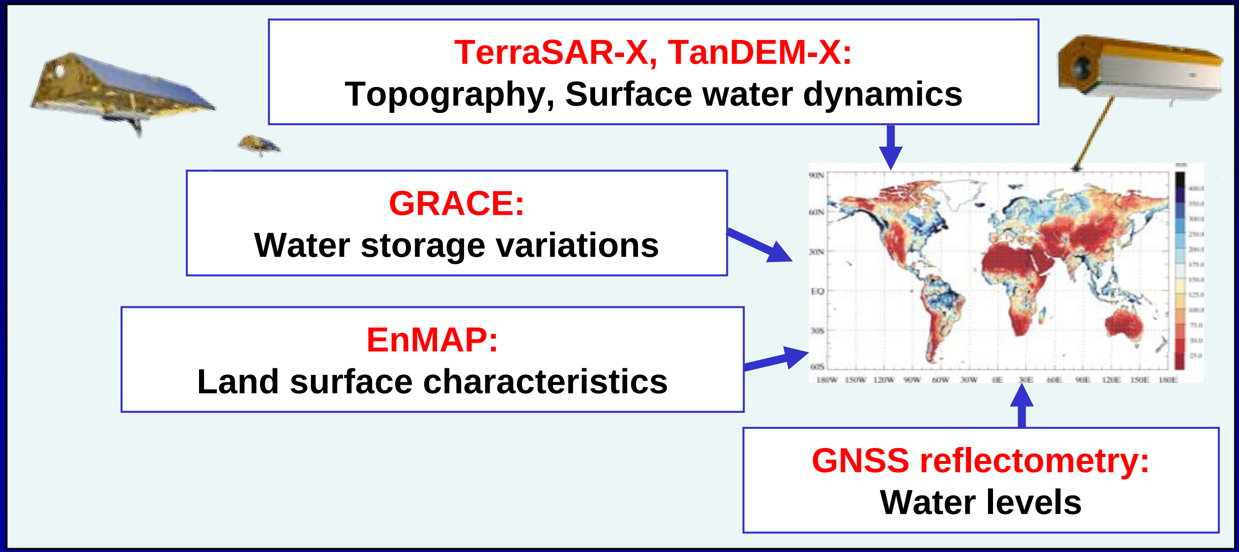
Simulated seasonal water storage change

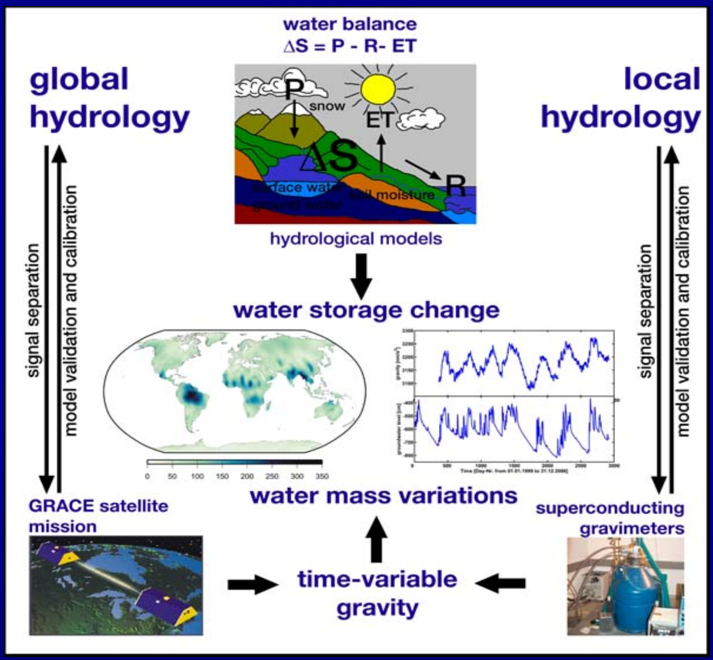


Güntner et al., GFZ

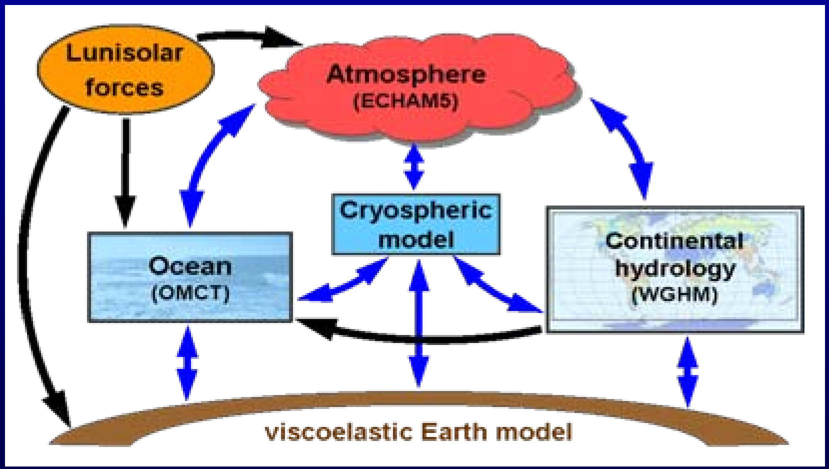
Quantification of the Global Hydrological Cycle

- Improved global hydrological modelling by monitoring data assimilation





- Signal separation for gravity observations, detection of long-term variations and trends



- Integration of hydrology into coupled Earth System Model and evaluation of feedbacks

New Satellite Missions: EnMAP and ARES

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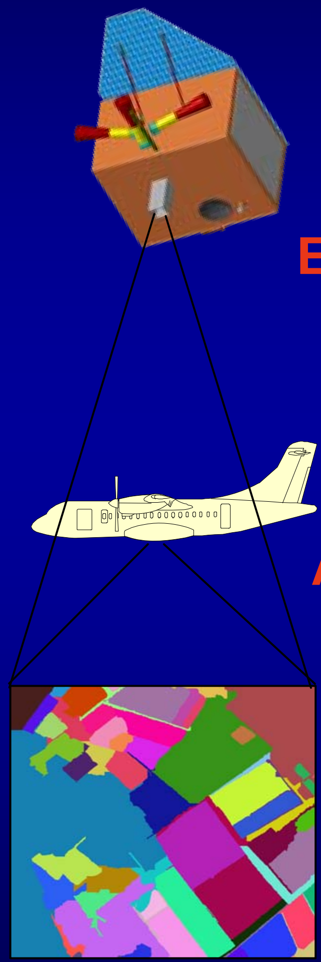
Hyperspectral Program for Environmental Analysis

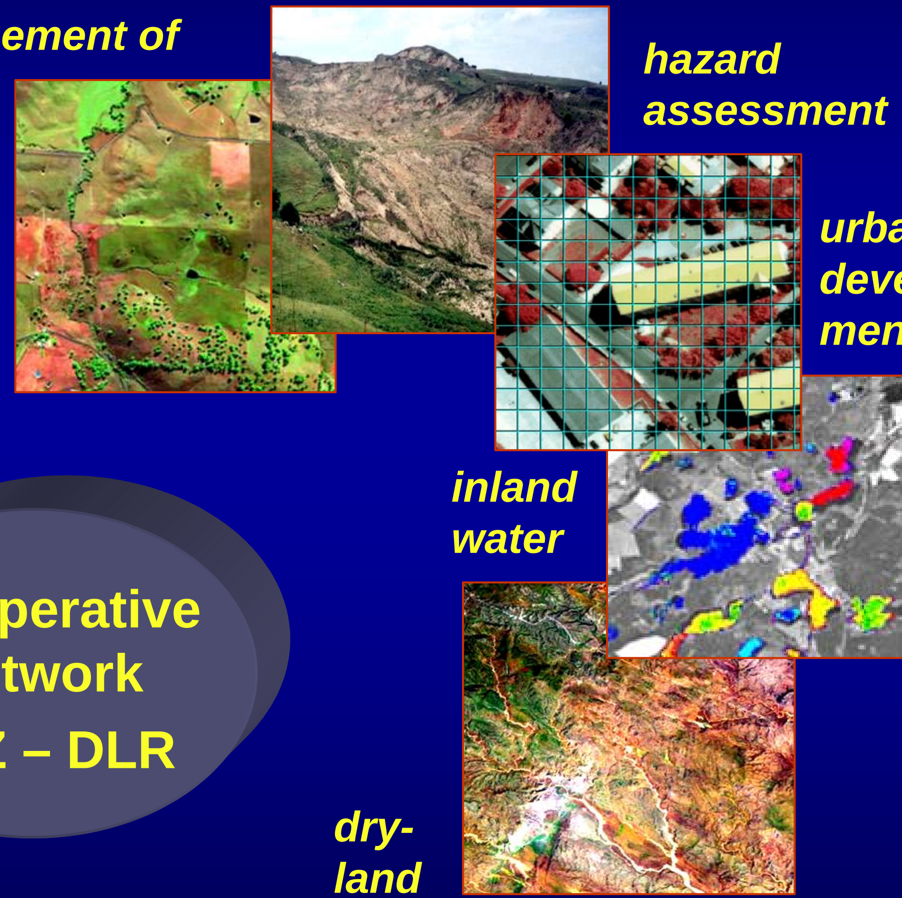


EnMAP

ARES

parameter extraction and modeling

management of agricultural and forest ecosystems



hazard assessment

urban develop-ment

inland water

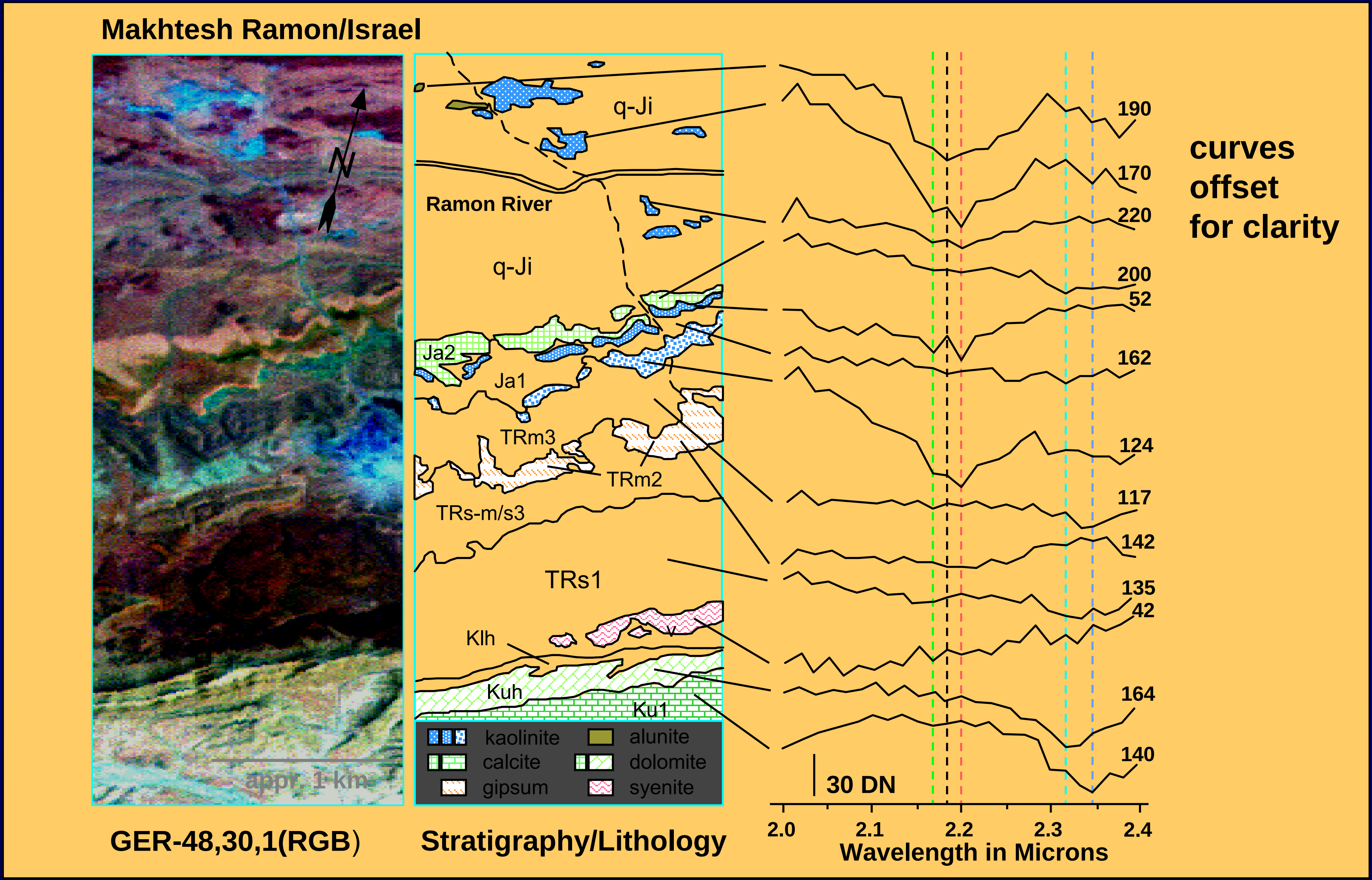
dry-land degradation

Co-operative Network

GFZ – DLR

PI: Prof. H. Kaufmann (GFZ)

EnMAP: Qualification → Identification → Quantification



Chlorophyll-a Derived from Airborne Data (HyMap)

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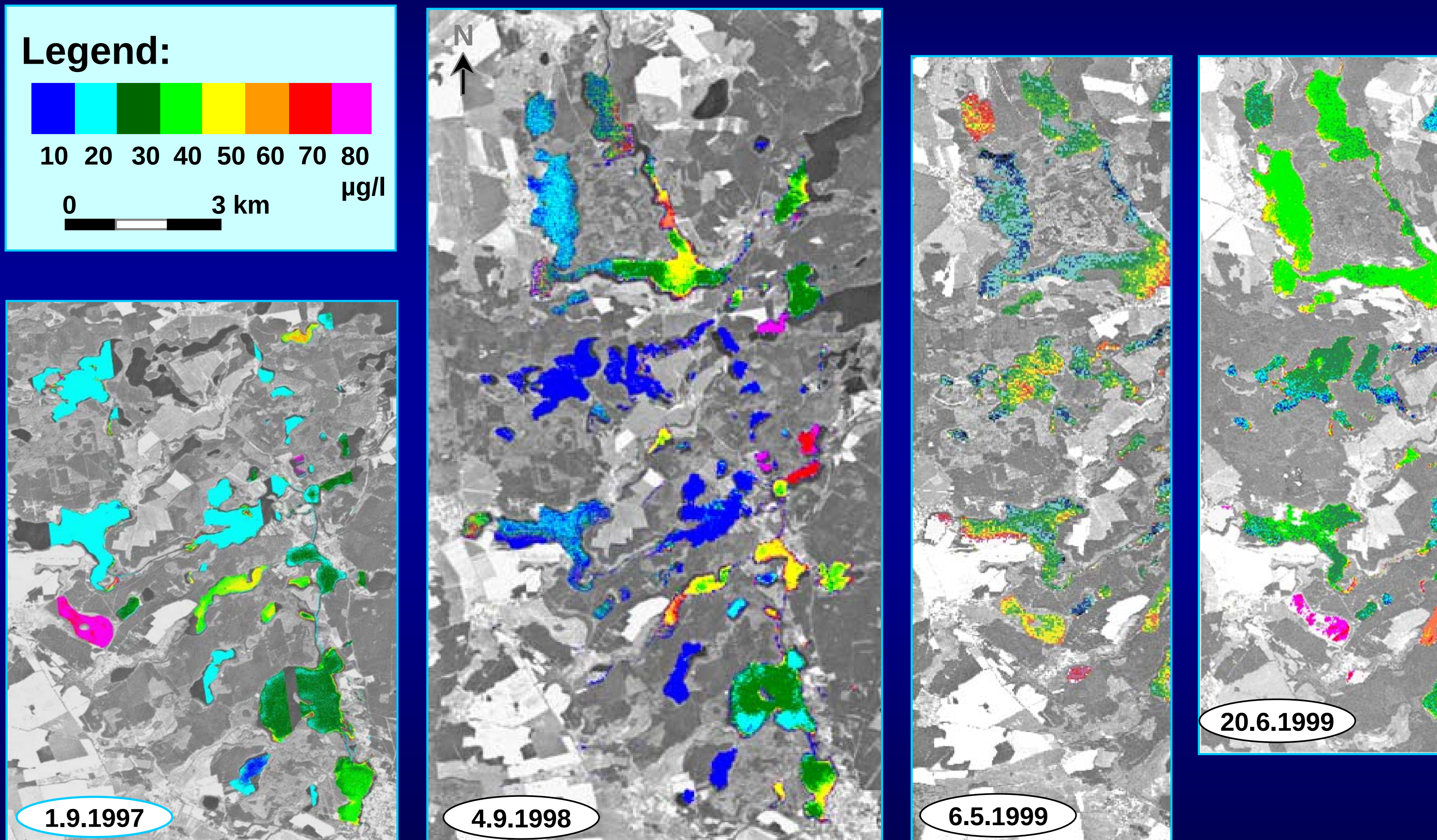
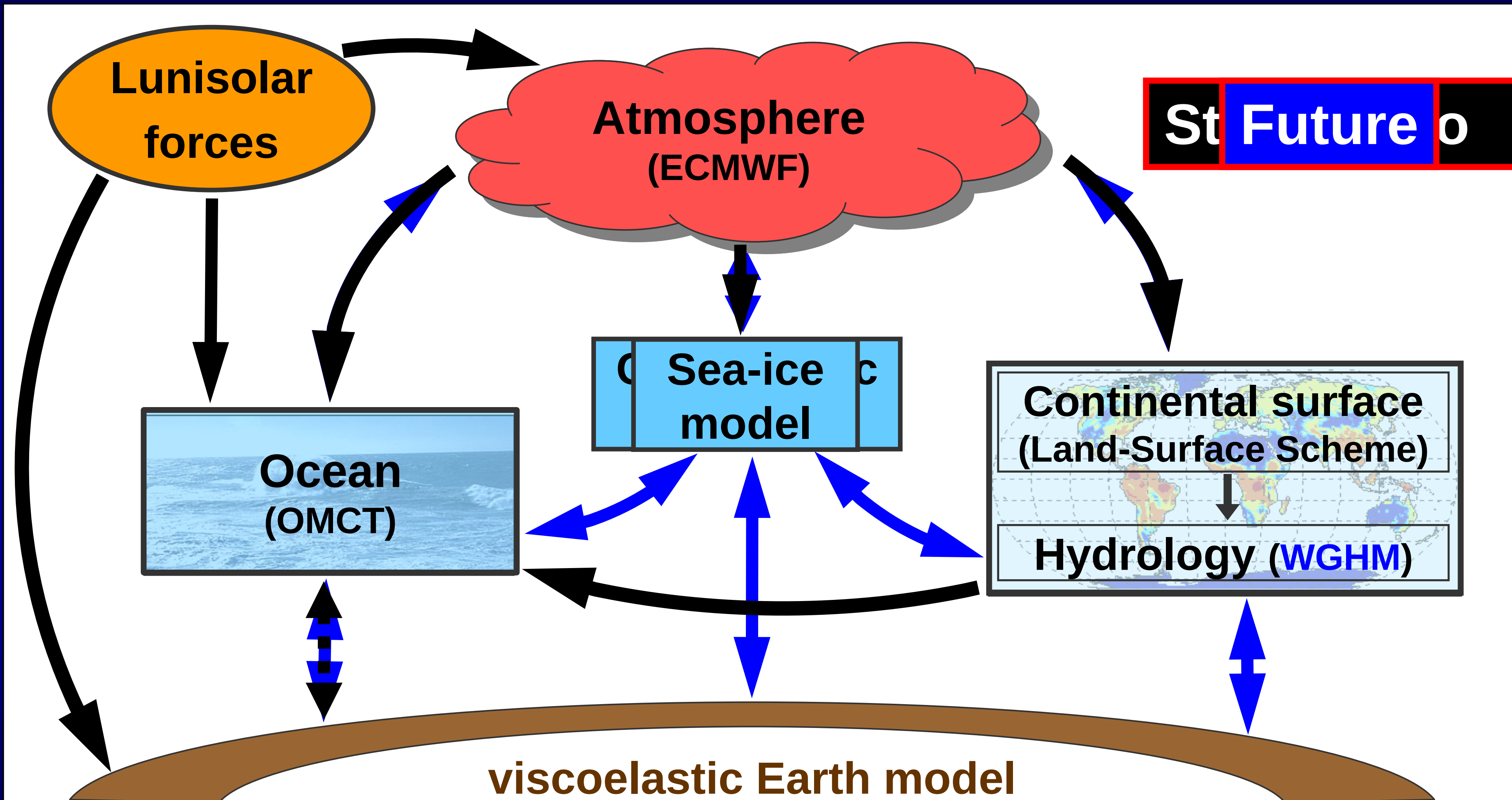


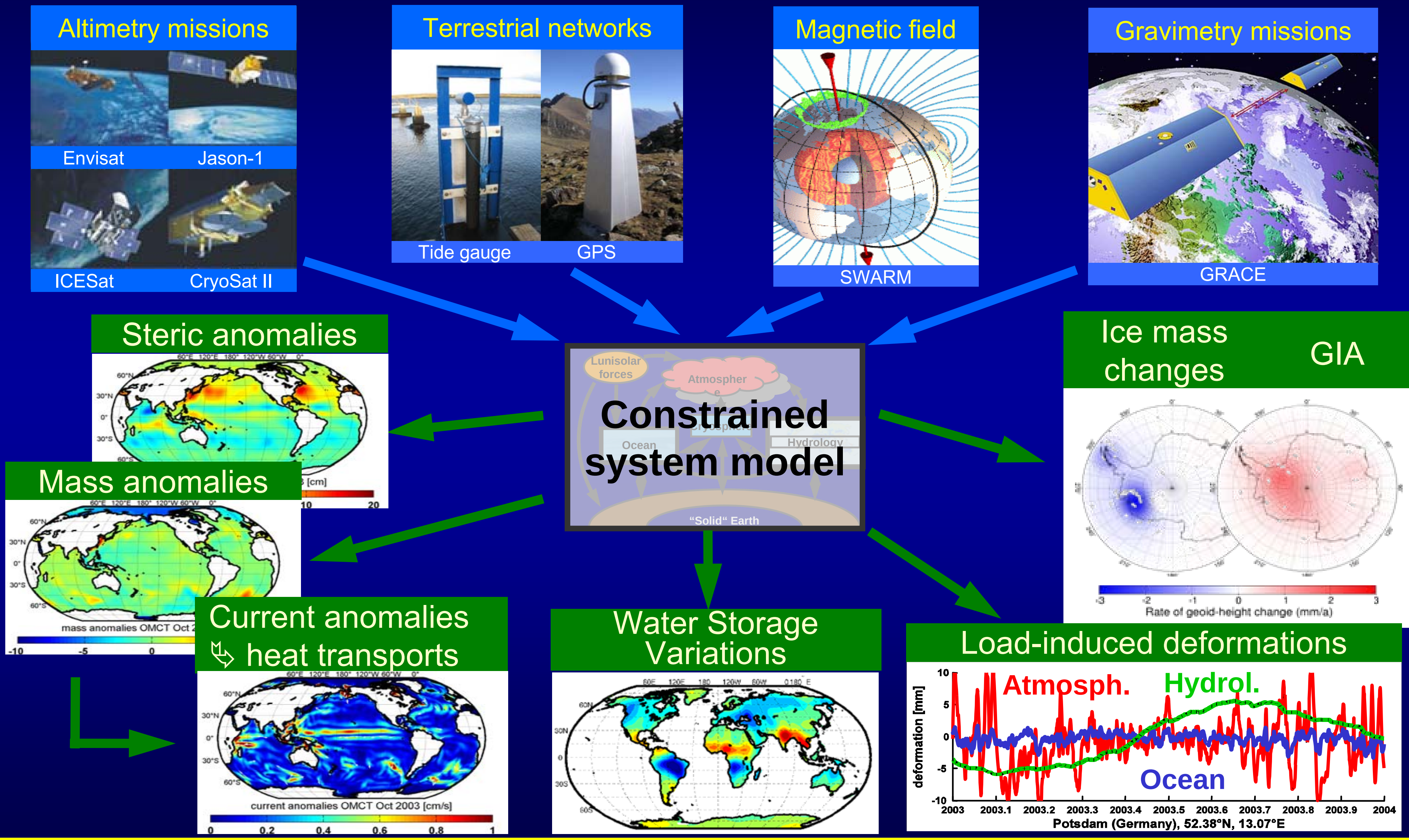
Mecklenburg Lake District

Earth System Modelling at GFZ
4D Model of Surface Mass/Momentum Transport



- Develop a coupled modular Earth system model
- Assimilate global monitoring data

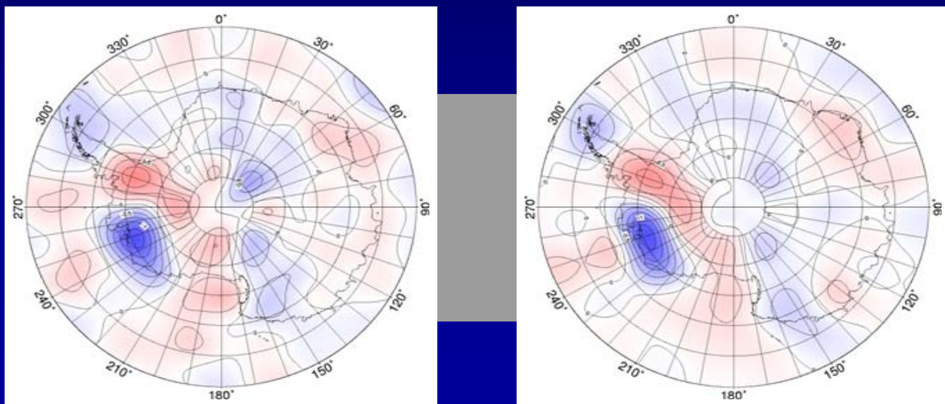
Model Approaches:
A Tool for the Interpretation of Monitoring Data



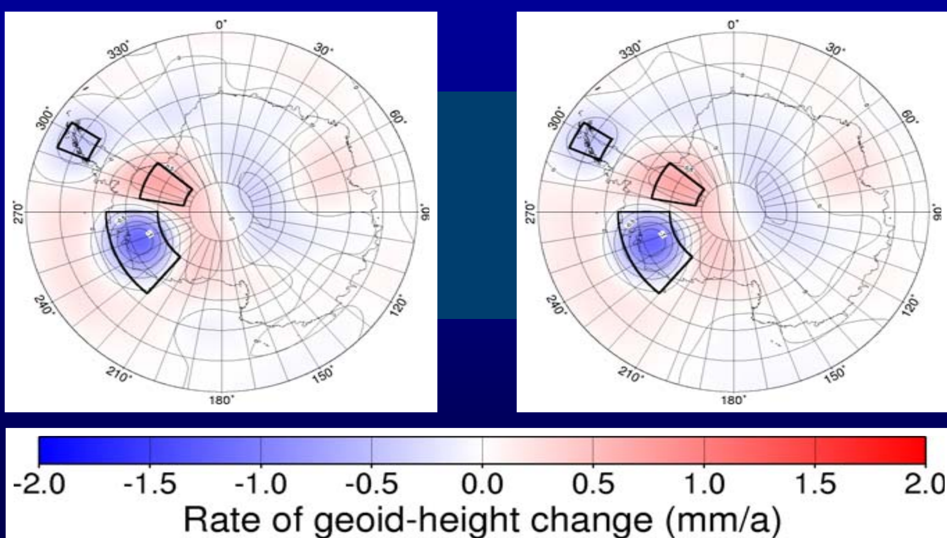
GRACE over Antarctica

GRACE observations

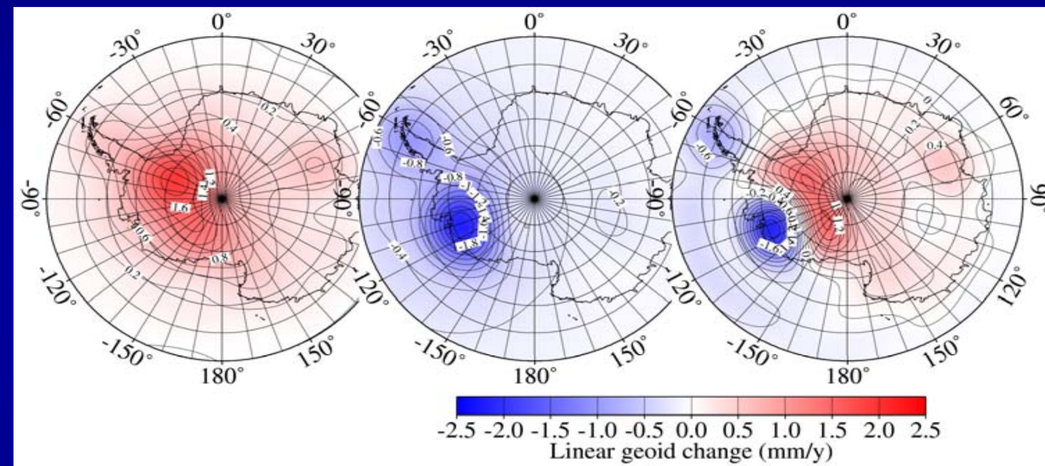
GFZ RL04 | JPL RL04



model of ice mass changes & GIA



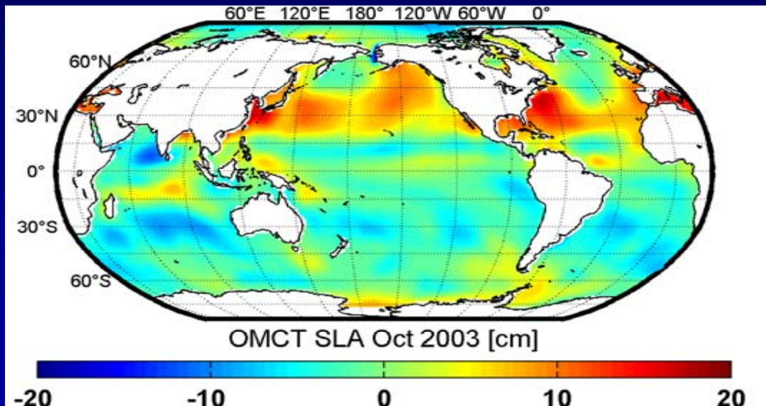
ongoing GIA | **ice mass change** | **total**



model separation

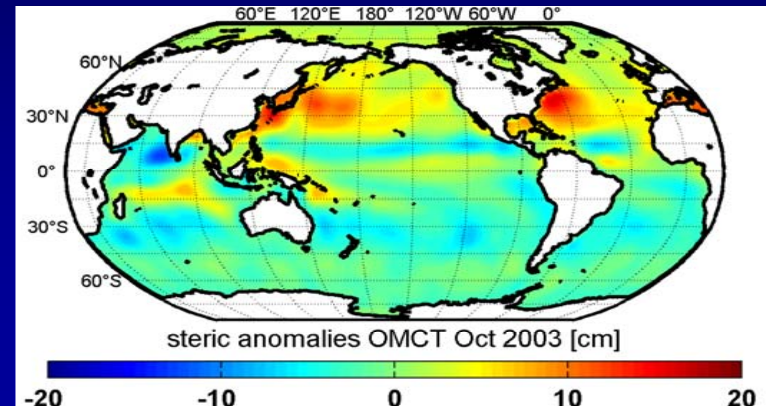
Modelling and Interpretation: From Sea Surface Heights to Heat Transports

total sea surface height anomalies



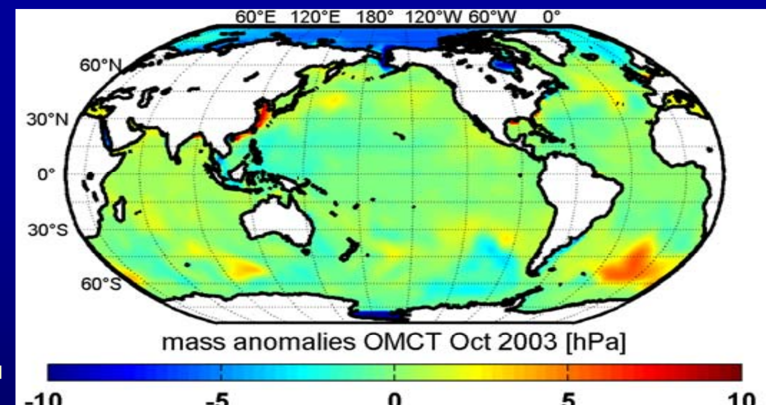
by means of numerical models separable into …

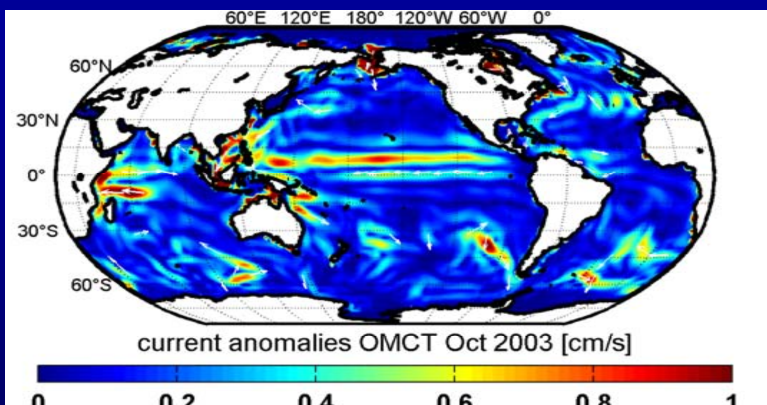
steric anomalies



and

mass anomalies

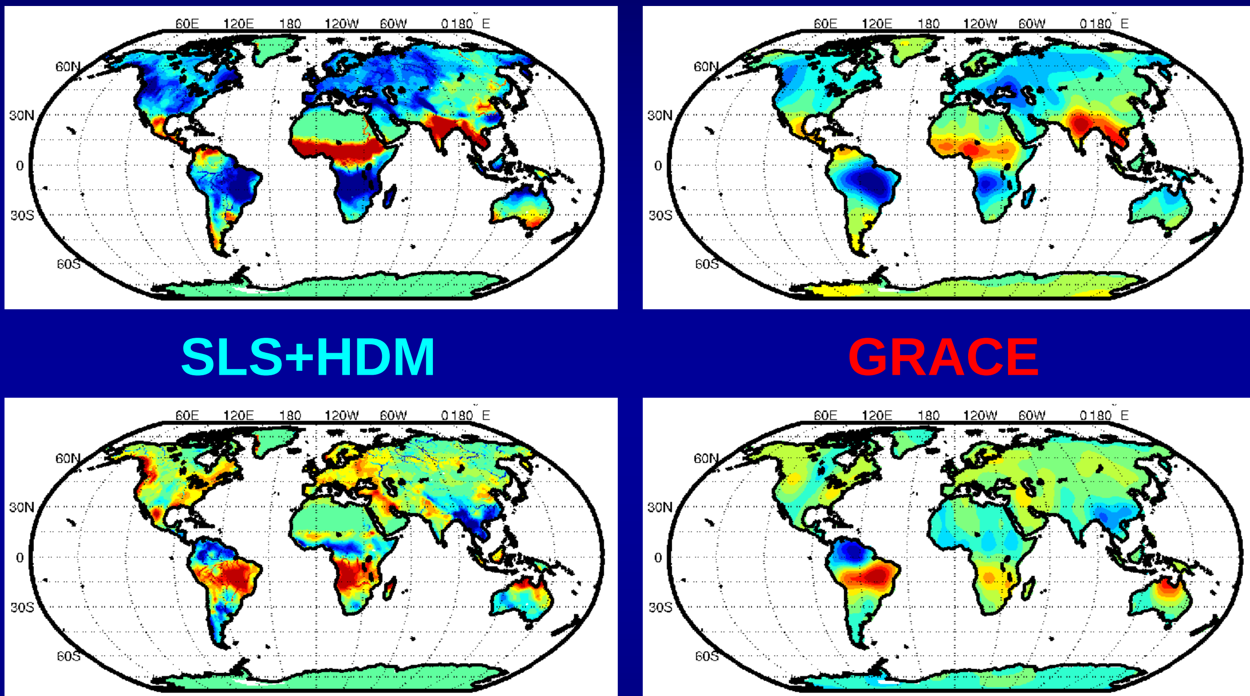




transformation to barotropic current anomalies associated with variations in oceanic heat transports

Hydrological Mass Anomalies: Simulations vs. GRACE

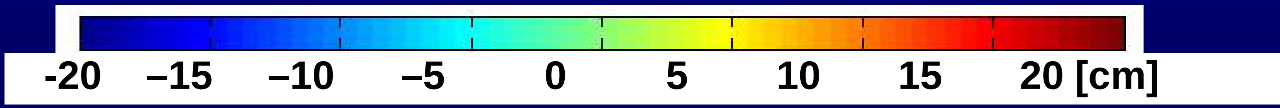
October 2003



SLS+HDM

GRACE

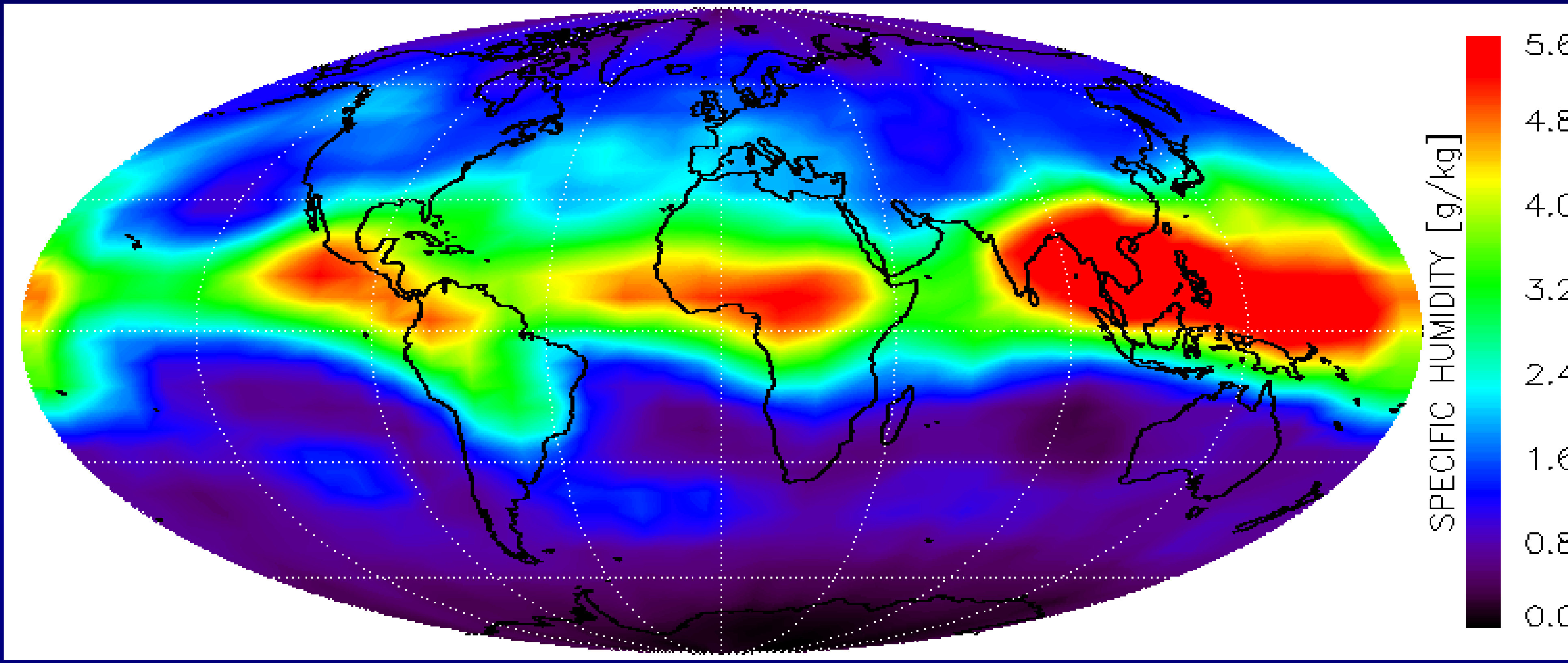
February 2004



equivalent water thickness

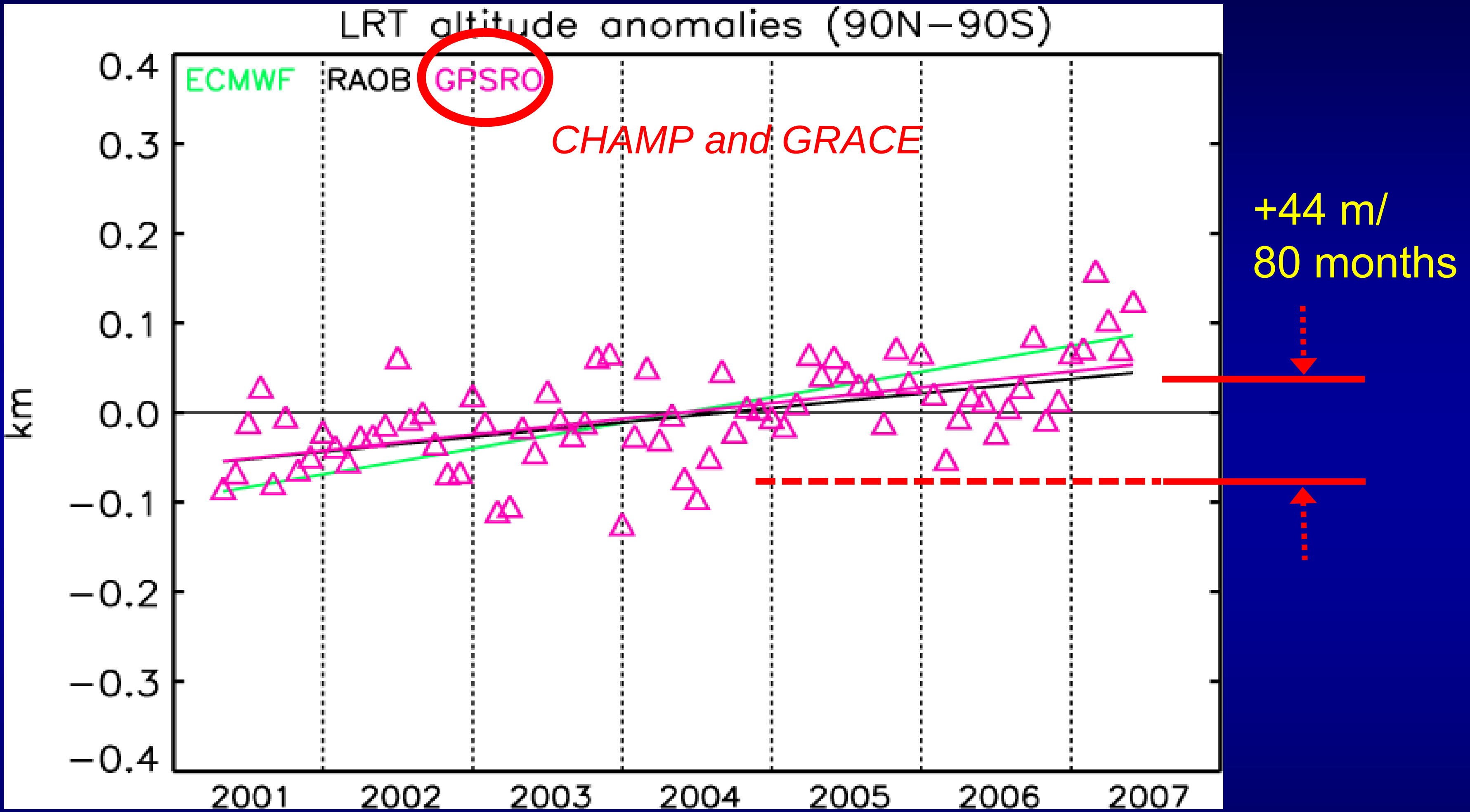
- **Currently:** observation of hydrological mass redistributions
- **Future:** removal of hydrological signals to assess secondary effects?

Global Water Vapor Distribution: CHAMP and GRACE



Mean global water vapor distribution at 4 km height from CHAMP and GRACE (September 2006)

Tropopause Climatology



Increase ~66m per decade , agrees with global RS data, e.g. Seidel/Randel 2006, ~64m/dec 1980-2004)

Schmidt et al, GRL, 2008

Conclusions

- GRACE mission is performing very well, longer and longer time series → detection of trends
- Weekly resolution of the gravity field gives reasonable results
- Comparison between GRACE, SG and hydrological models → encouraging, combination of sensors
- Assimilation of geodetic measurements/products into hydrological models to improve these models
- Modeling has to go beyond separate models for hydrology, oceans, atmosphere, …

→ an integrated Earth system model is necessary to separate and interprete the monitoring data