Gravity field signatures of ocean dynamics

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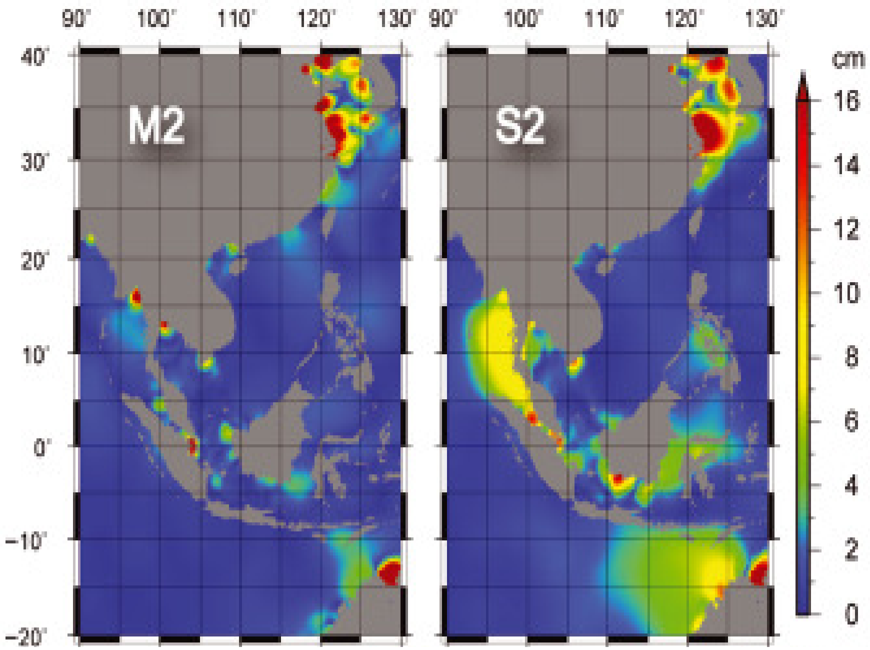
Section 1.5: Earth System Modelling

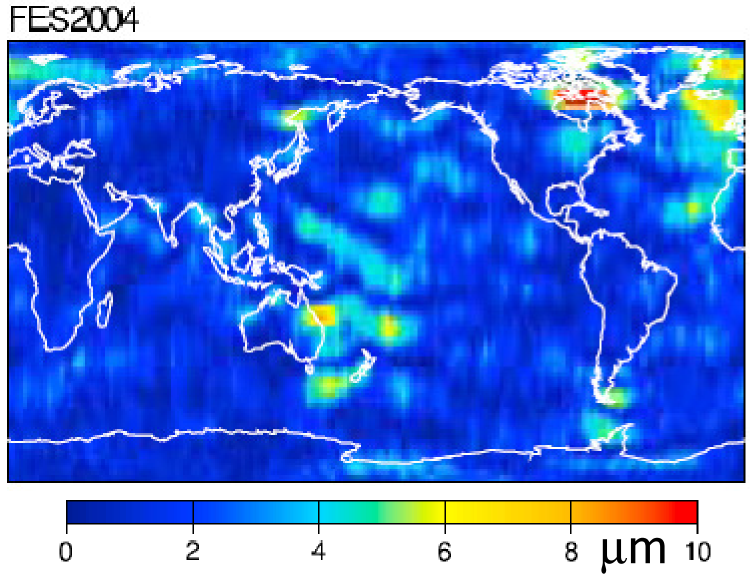
Outline

1. short-term variations
    - tides
    - non-tidal variability
2. basin-scale dynamics
    - total ocean mass
    - transport estimates
    - in-situ validation
    - assimilation into an OGCM
3. mass signals in shallow water areas
    - seasonal variations from GRACE and OMCT
    - bottom pressure trends related to climate change

1. Rapid variations: ocean tides



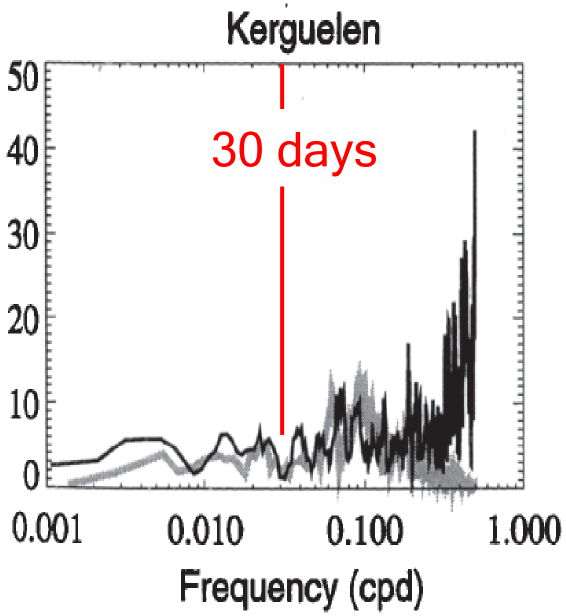
from: Bosch et al. (2009)



from: Ray et al. (2009)

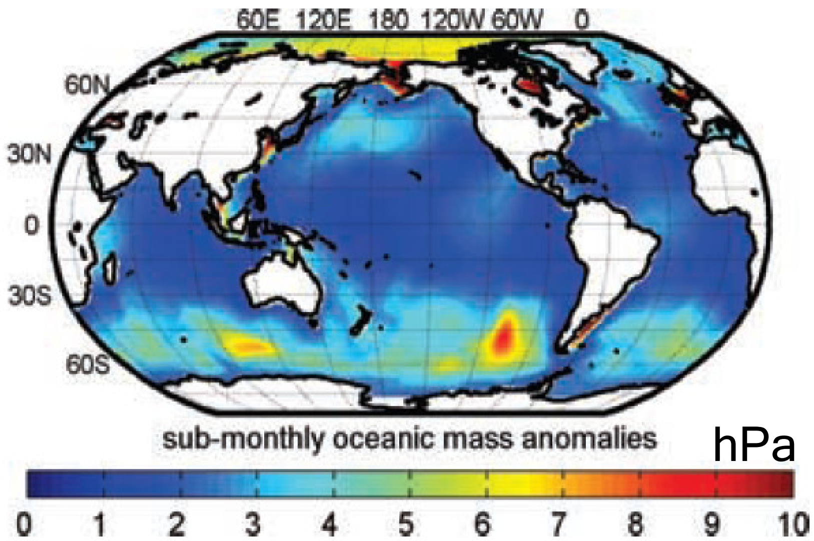
- analysis of residual tidal signals in altimetry and gravimetry observations
- significant signals remain: primarily in coastal areas, but also in the open ocean

1. Rapid variations: non-tidal variability



from: Fukumori et al. (1998)

OMCT forced with operational ECMWF data

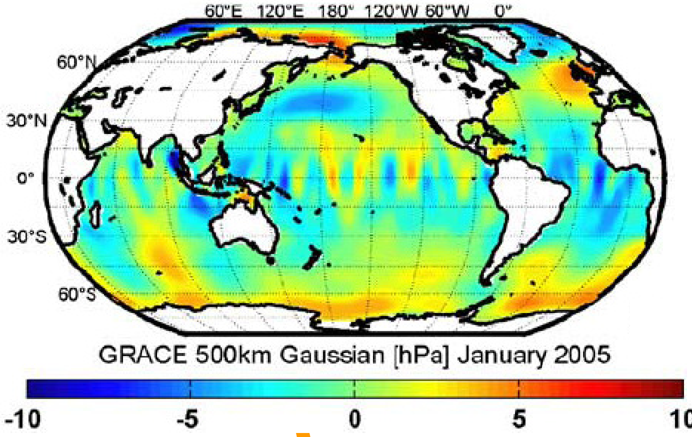


from: Dobslaw and Thomas (2007)

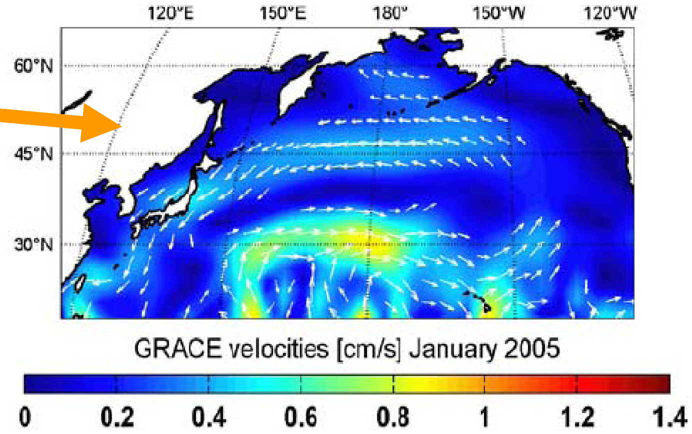
- mainly driven by wind stress and atmospheric pressure
- baroclinic signals are more relevant in lower latitudes and longer time-scales

2.1 Basin-scale dynamics

GFZ
Helmholtz-Zentrum
POTSDAM



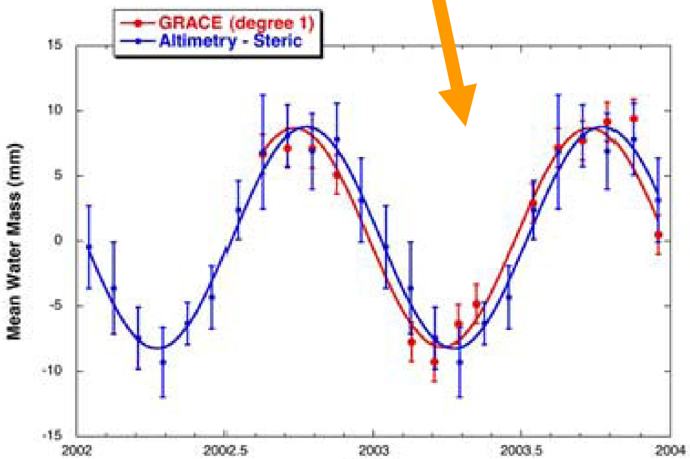
ocean currents



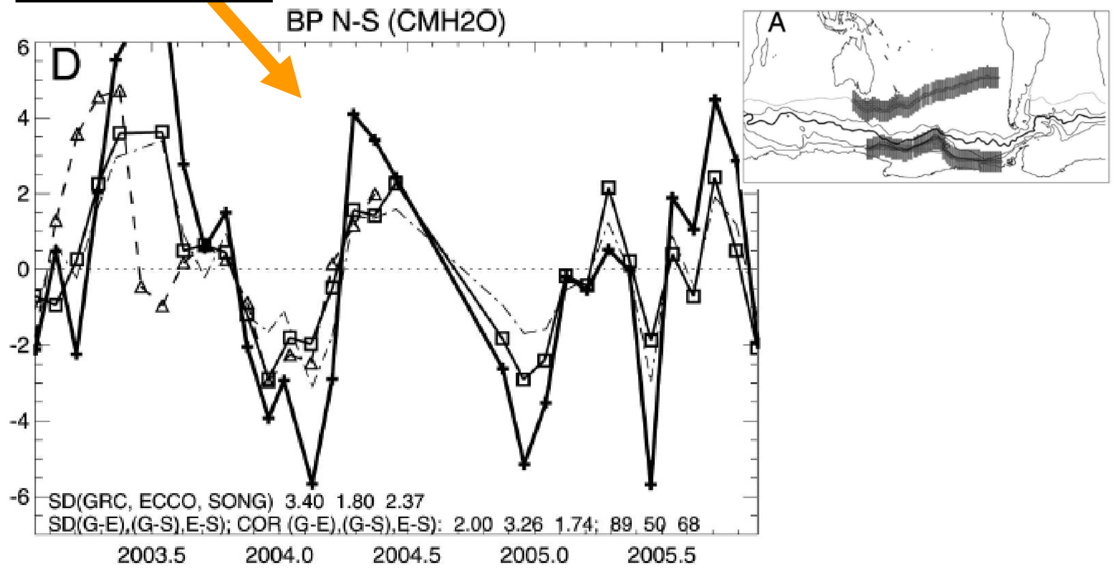
from: Dobslaw and Thomas (2007)

total ocean mass changes

ocean transports



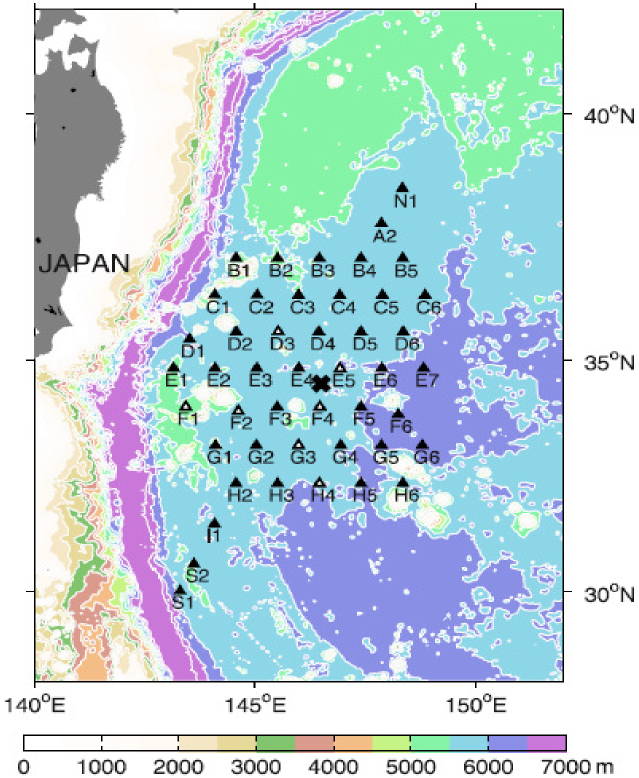
from: Chambers et al. (2004)



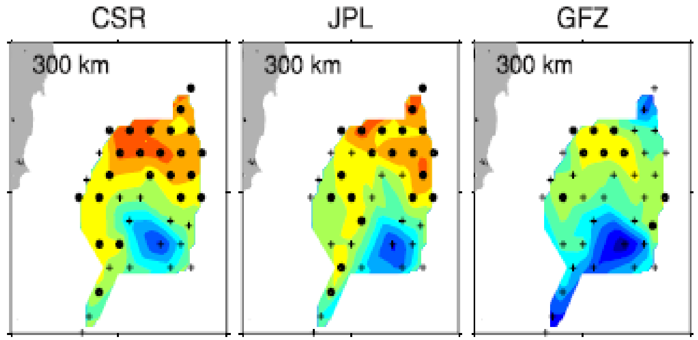
from: Zlotnicki et al. (2007)

2.2 In-situ ocean bottom pressure

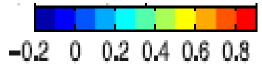
array of 46 bottom pressure recorders with inverted echo sounders (PIES)

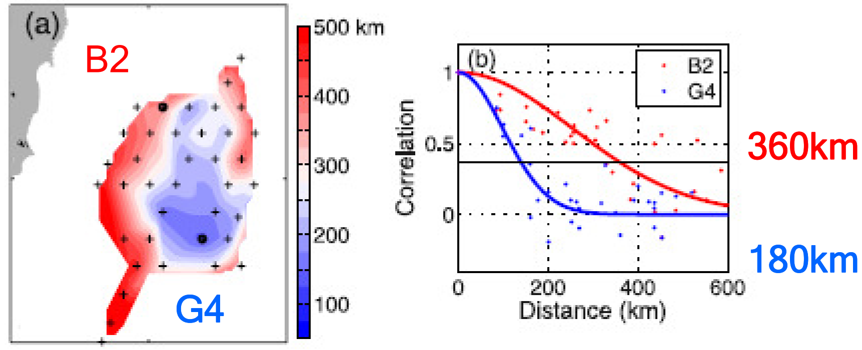


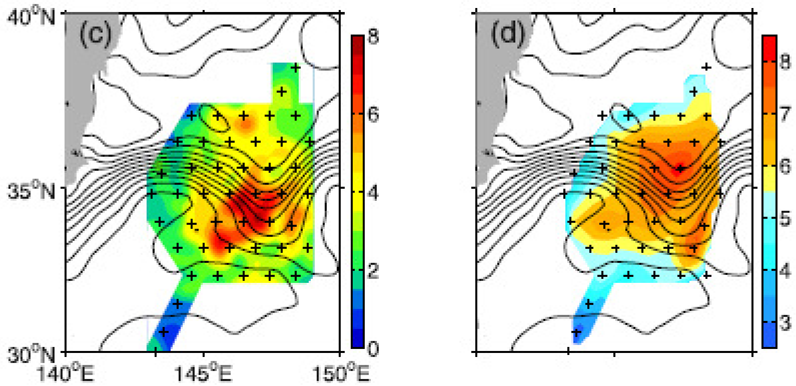
Park, J.-H., Watts, D.R., Donohue, K.A., Jayne, S.R. (2008), A comparison of in-situ bottom pressure array measurements in the Kuroshio extension, Geophys. Res. Lett., 35, L17601.



correlations with RL04: 05/04-06/06







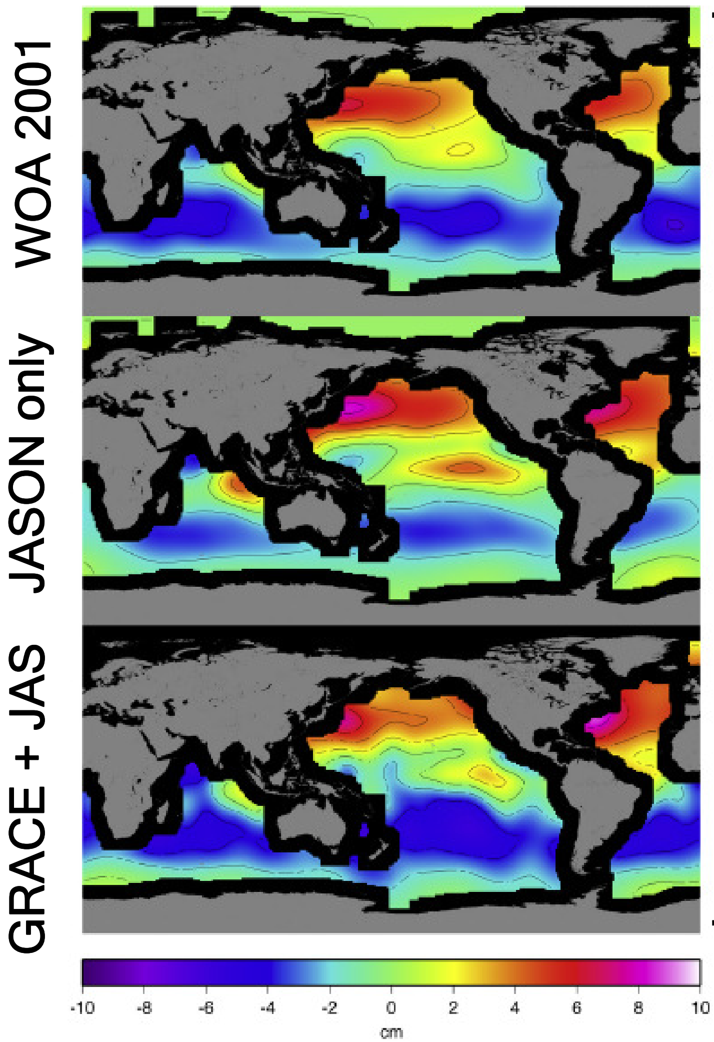
Eddy kinetic energy

variability p_{bot}

2.3 Seasonal steric sea-level variations

GFZ
Helmholtz-Zentrum
POTSDAM

Chambers, D.P. (2006), Observing seasonal steric sea level variations with GRACE and satellite altimetry, J. Geophys. Res., 111, C03010.



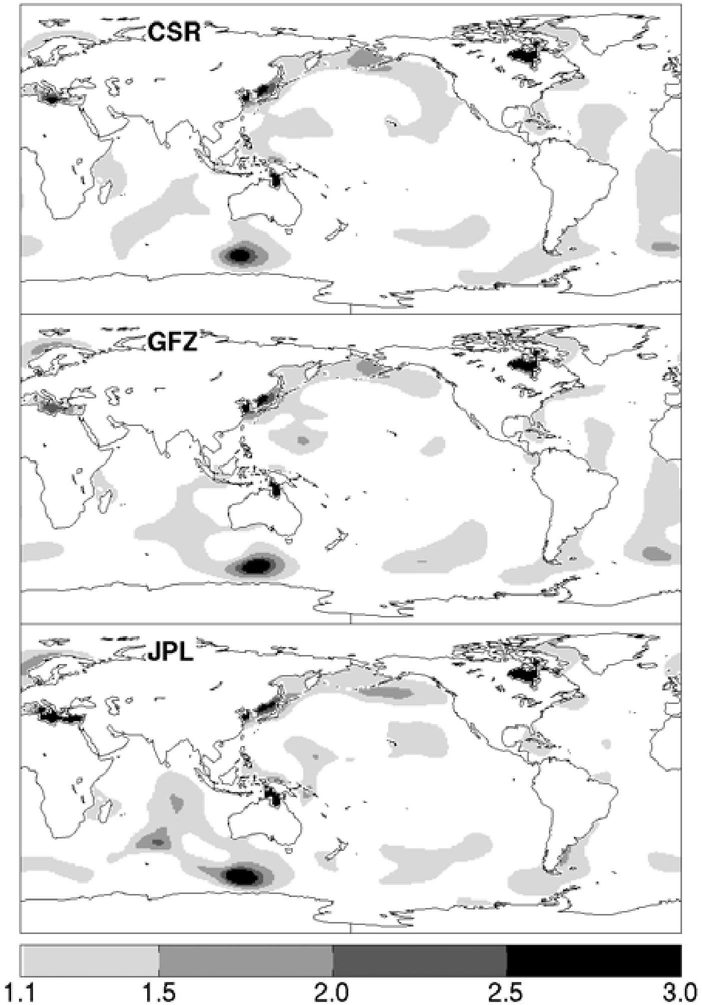
incorporation of GRACE fields to study seasonal variations of steric sea level, which is closely related to changes in ocean heat content

leading saisonal EOF of steric sea-level derived from in-situ data, satellite altimetry and a combination of satellite altimetry and GRACE.

„...dominant annual SSL variation, using GRACE improves the estimation over using altimetry alone for about 75% of the ocean area...“

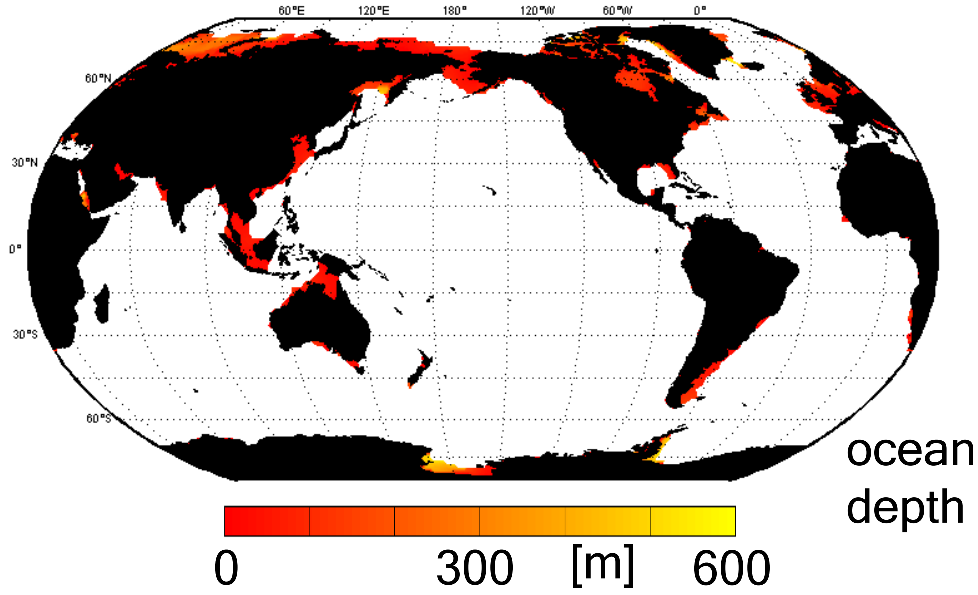
2.4 Incorporation into numerical models

Quinn, K.J., Ponte, R.M. (2008), Estimating weights for the use of time-dependent gravity recovery and climate experiment data in constraining ocean models, J. Geophys. Res., 113, C12013.



- RL04 GRACE (destriped, land contam minimized, 750km gaussian) have been used to constrain b_P from the MIT OGCM
- white areas = no impact
- GRACE data errors are not zonally uniform, due to aliasing, etc.

3. Shelf areas



• relevance of coastal areas for mankind:

regional sea-level changes
marine food & mineral ressources
local and regional effects on weather and climate

• various coastal observing systems are in operation or under development

• coordinated efforts to improve coastal altimetry (>10km off-shore):

Smith, W.H., Strub, T., Miller, L. (2008), First Coastal Altimetry Workshop, EOS Trans., 89(40).

3.1 Annual harmonics from GRACE

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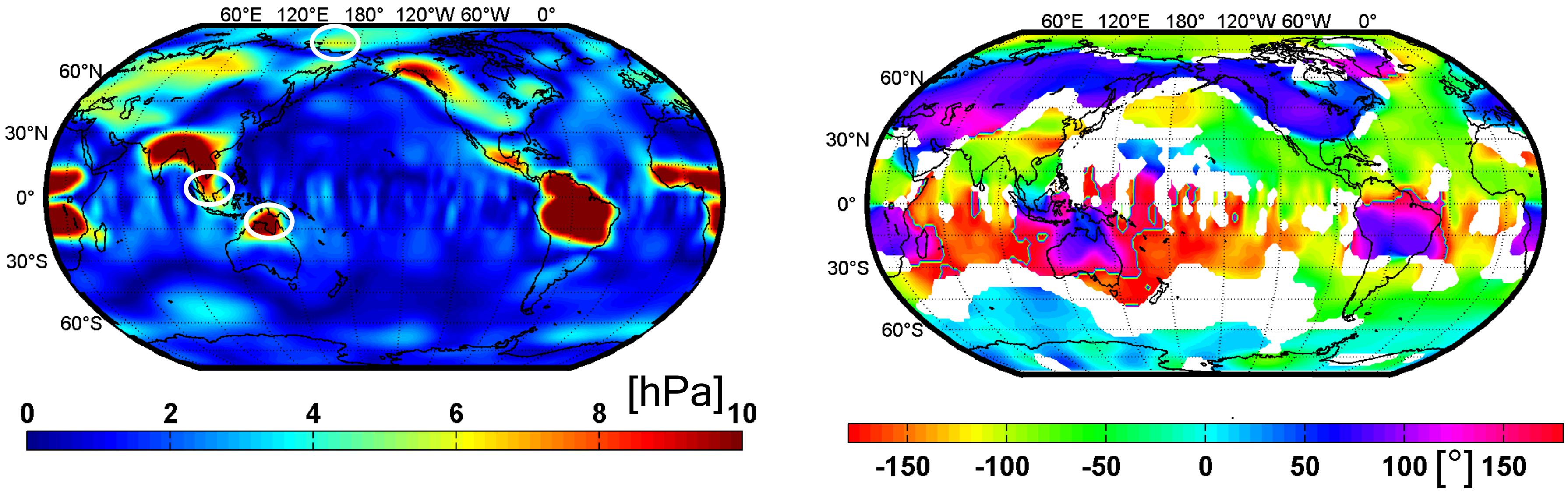
GFZ RL04, de-striped, 400km Gaussian,
annual geocenter variations added, GAD added back

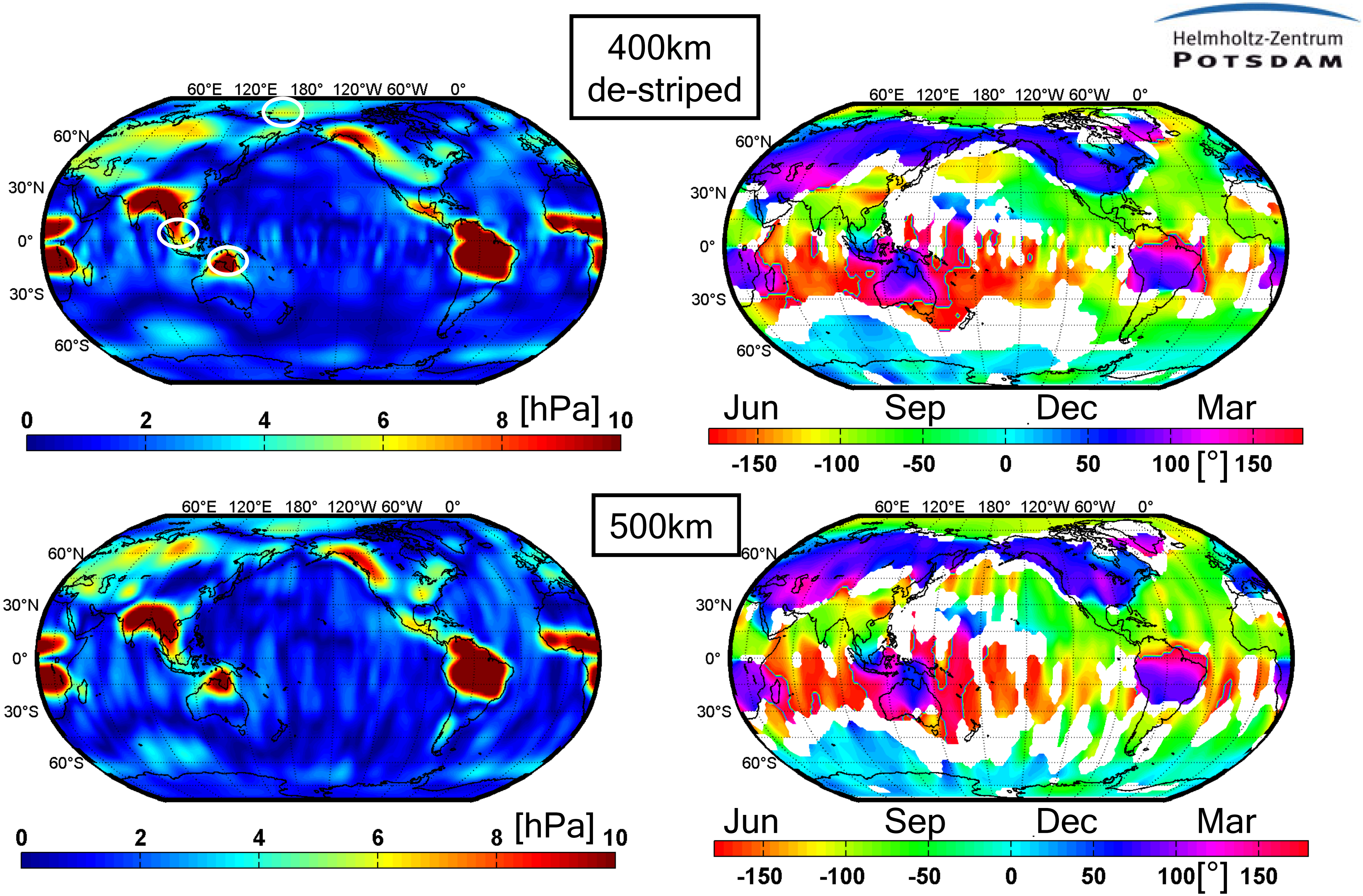


focus on shelf areas with distinct annual signals:

- East Siberian Sea
- South China Sea
- Arafura Sea

3.1 Annual harmonics from GRACE

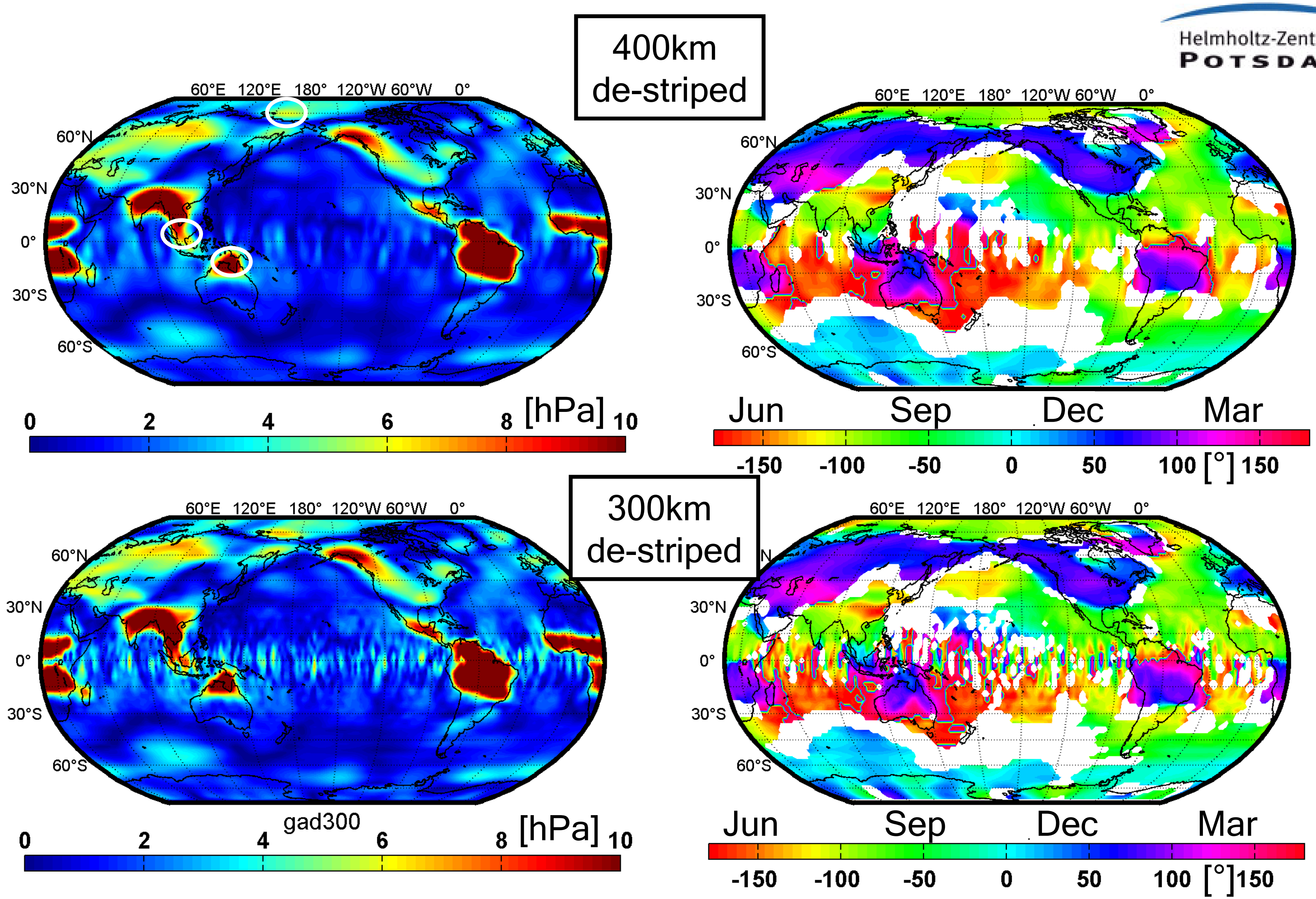
GFZ
Helmholtz-Zentrum
POTSDAM



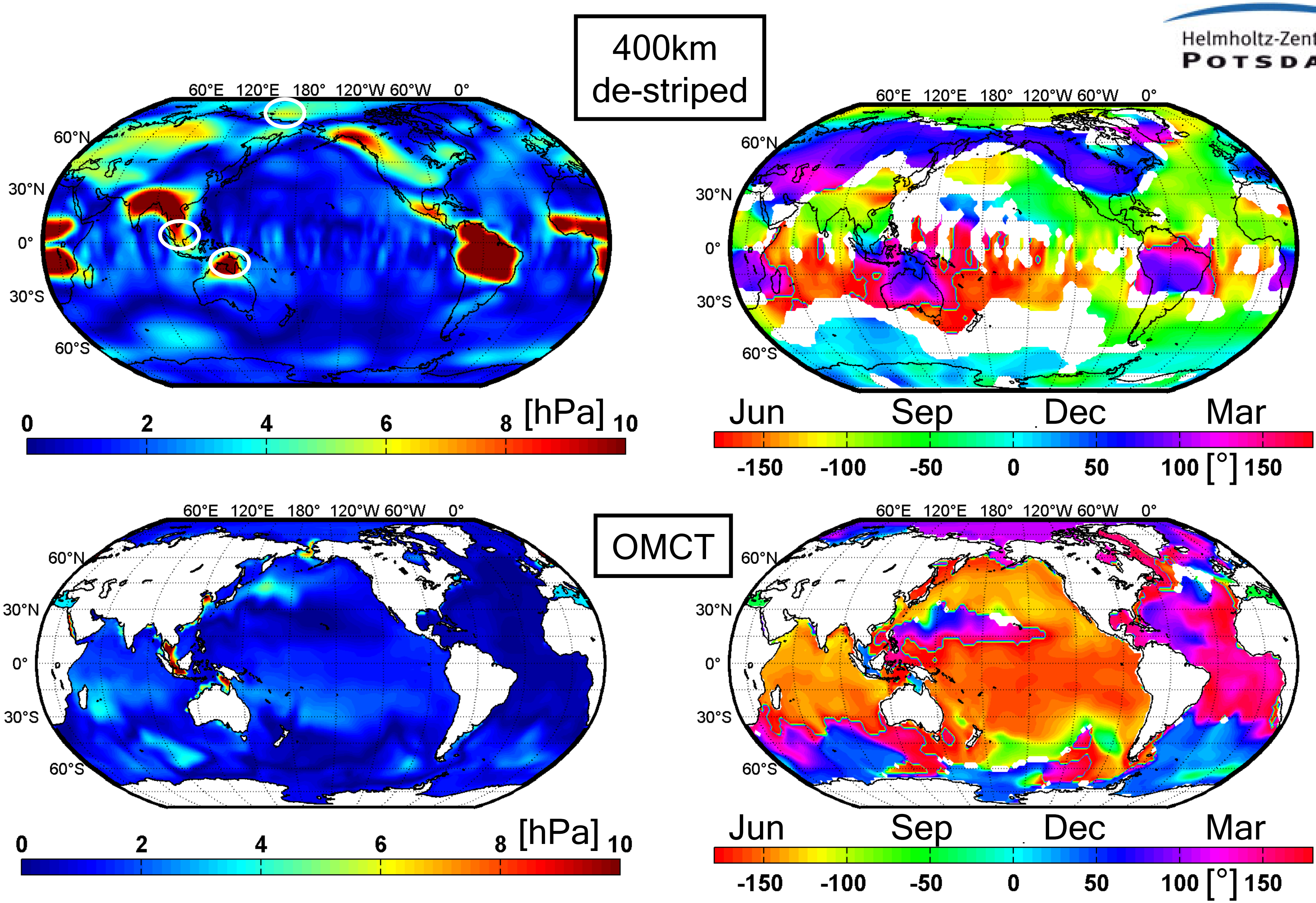
Dobslaw et al.: Gravity field signatures of ocean dynamics

3.1 Annual harmonics from GRACE

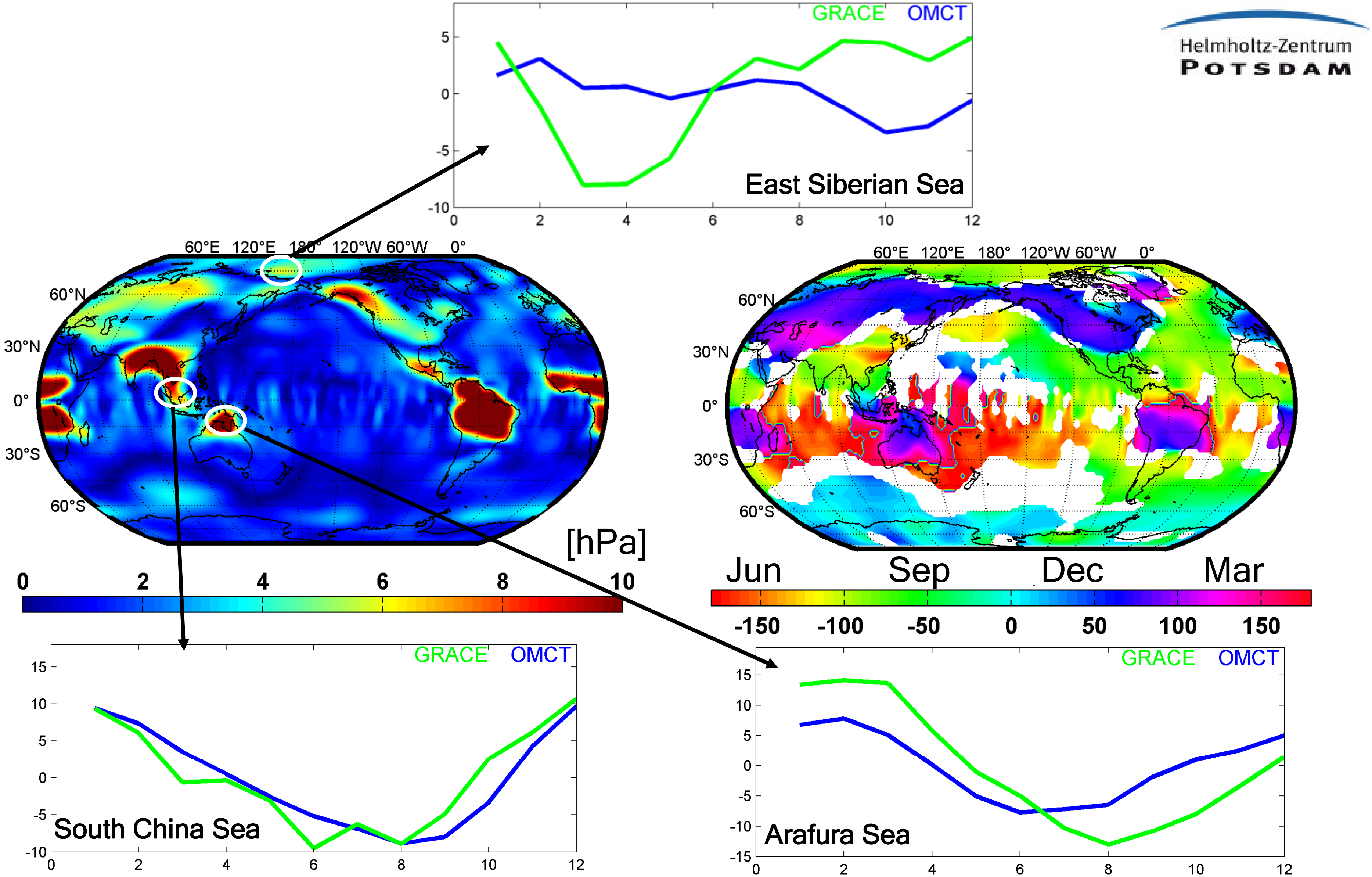
GFZ Helmholtz-Zentrum POTSDAM



3.1 Annual harmonics from GRACE & OMCT



3.1 Saisonal variations from GRACE & OMCT



see also Tregoning et al. (2008)

3.2 Sterically induced ocean mass signals

Landerer, F.W., Jungclaus, J.H., Marotzke, J. (2007), Ocean bottom pressure changes lead to a decreasing length-of-day in a warming climate, Geophys. Res. Lett., 34, L06307.

- density changes in the water column due to variations in temperature and salinity are compensated by a local adjustment of the sea surface height

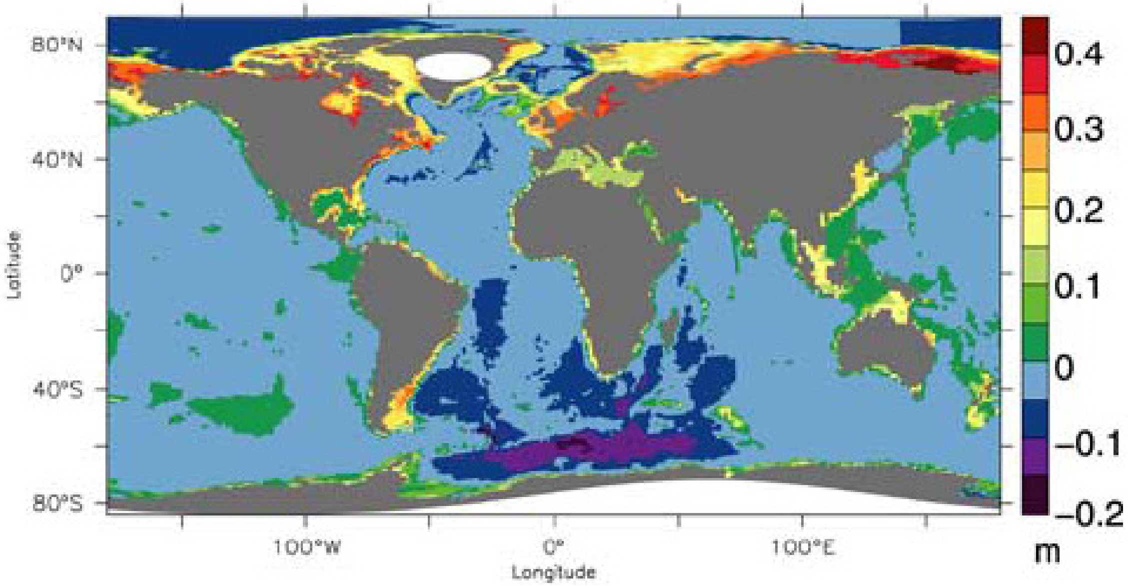
- as long as density changes do not reach the bottom, steric anomalies do not cause bottom pressure changes

- heating of deeper layers causes higher steric anomalies away from the shelf

- steric anomalies do not remain locally (as it is mainly the case for seasonal variations), but are distributed evenly over the entire oceans

3.2 Sterically induced ocean mass signals

Landerer, F.W., Jungclaus, J.H., Marotzke, J. (2007), Ocean bottom pressure changes lead to a decreasing length-of-day in a warming climate, Geophys. Res. Lett., 34, L06307.



bottom pressure increase after 200 years (mean 2090-2099)

ECHAM5/MPI-OM
with IPCC-A1B scenario:

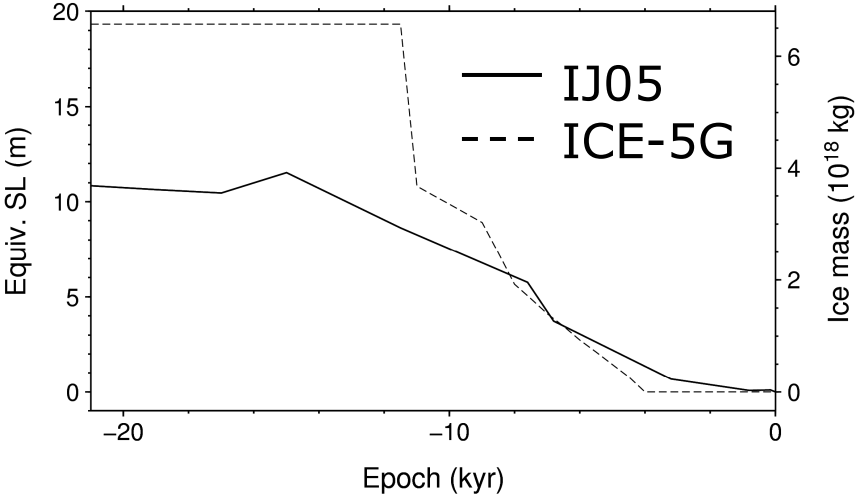
1860 – 2000: 280…367ppm CO_2
2001 – 2100: 367..703ppm CO_2

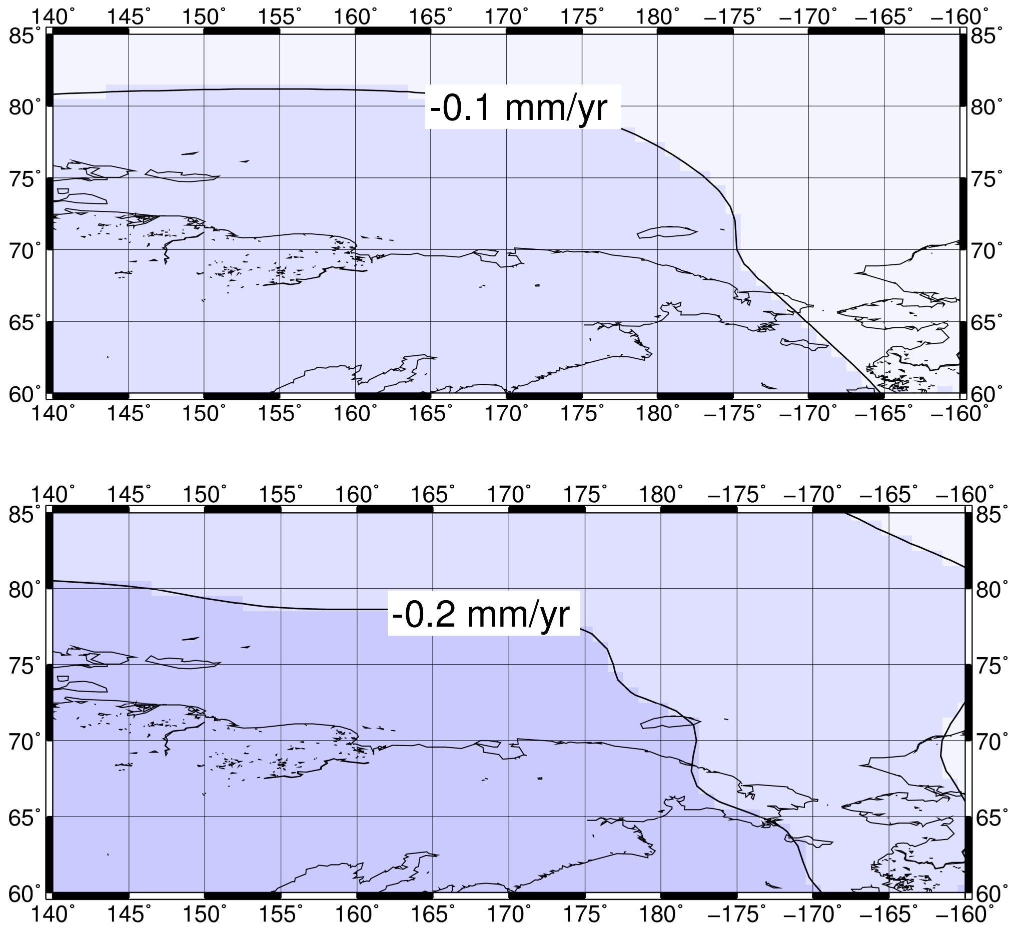
control run with pre-industrial conditions (i.e. 280ppm CO_2)

Bottom pressure trends of 0.1 hPa y^{-1} are predicted in most shelf areas with peak rates of 0.2 hPa y^{-1} over the East Siberian Shelf

3.2 Interference with other processes: GIA

ICE-5G
Peltier (2004)





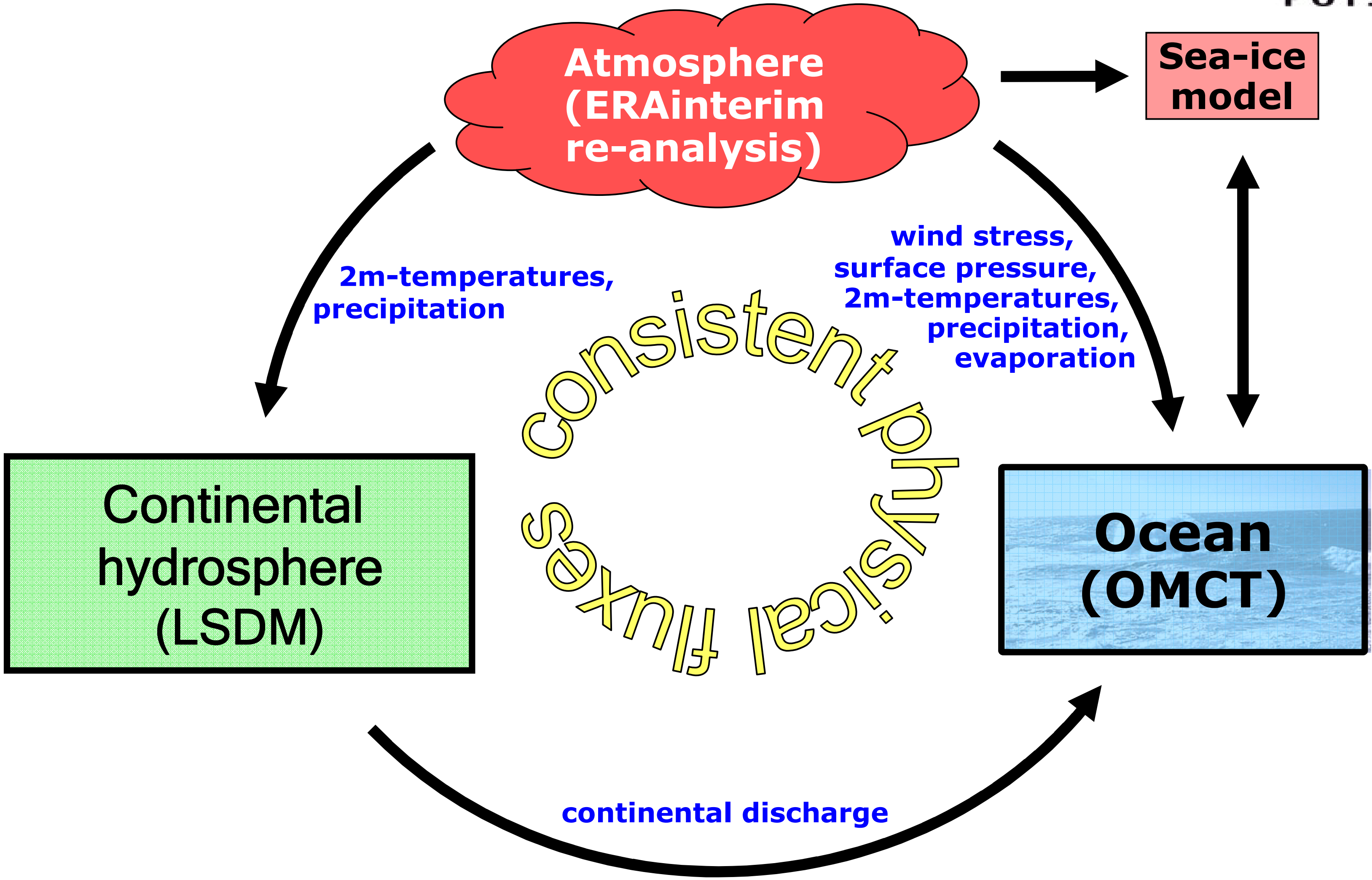
ICE-5G/IJ05
Ivins and James (2005)

courtesy V.Klemann

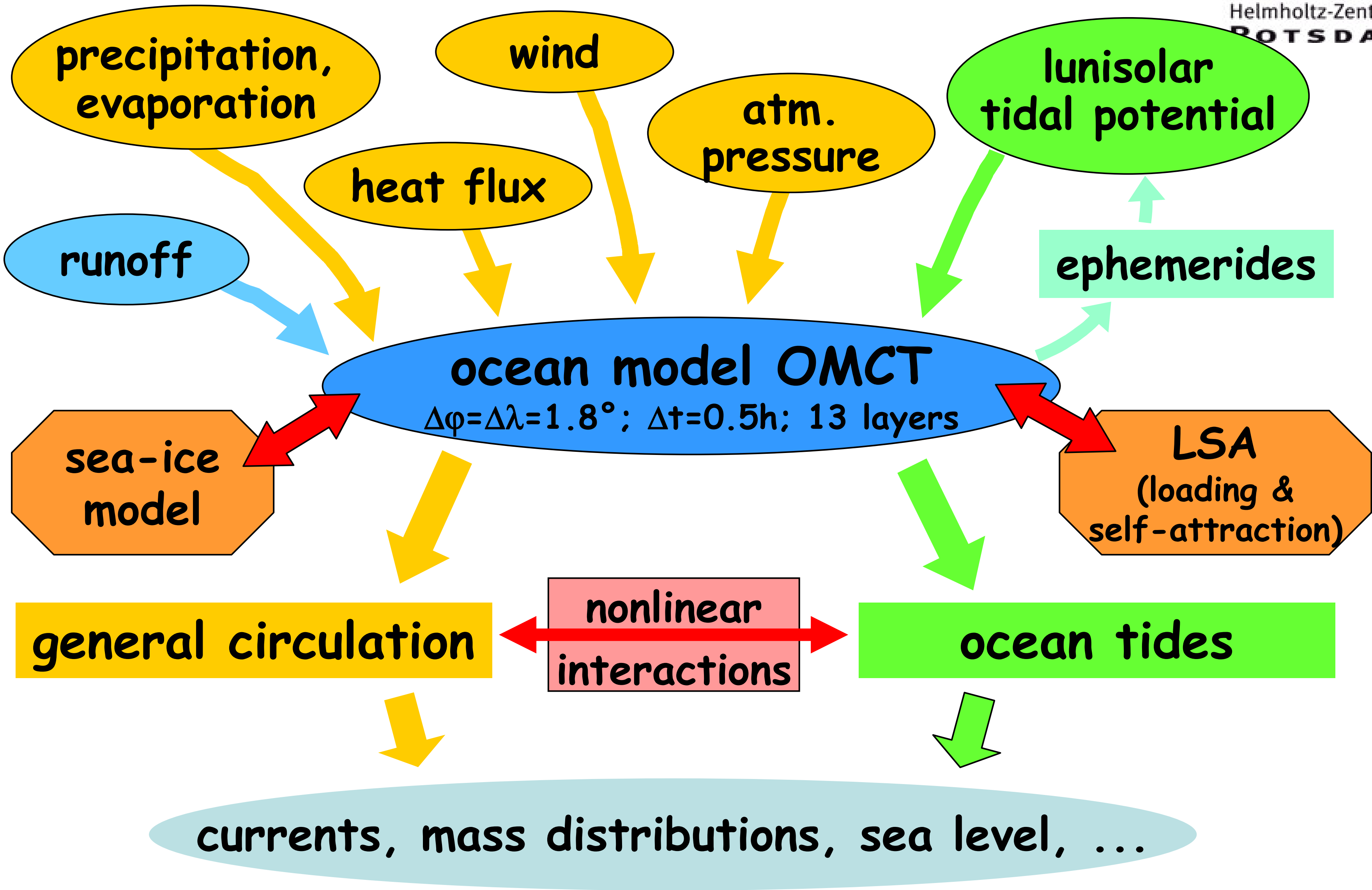
Conclusions

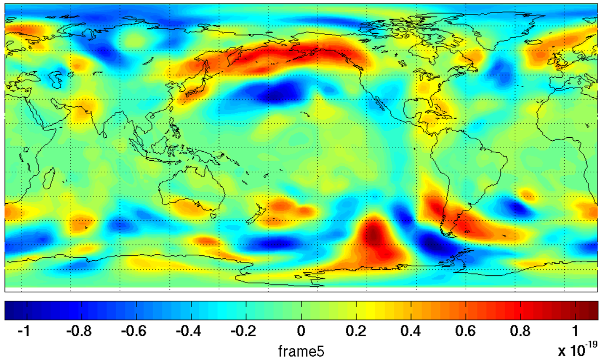
- short-term variability due to tides and wind & pressure forcing remains critical to the accuracy of satellite gravimetry over the oceans
    - reduction of aliasing effects from short-term variability
- GRACE has allowed promising results for oceanographic research: total ocean mass, ACC transports, refinement of heat content estimates
    - continuation of time-series
- shelf areas and enclosed seas show distinctly different bottom pressure signals that are not fully explained by present-day models and theories
    - increased spatial resolution
- model simulations predict ocean bottom pressure trends related to climate change of 0.1 hPa per year
    - consistent modelling for separation of processes

Numerical models of the hydrosphere

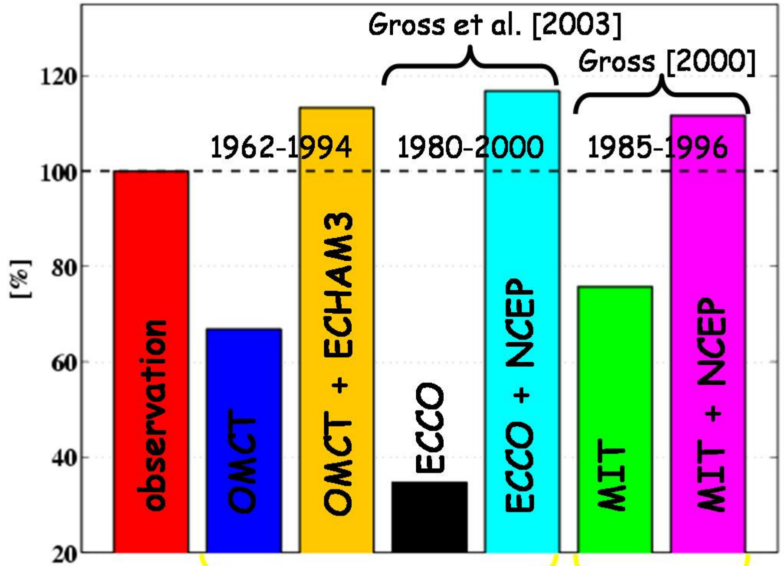


Ocean Model for Circulation and Tides (OMCT)

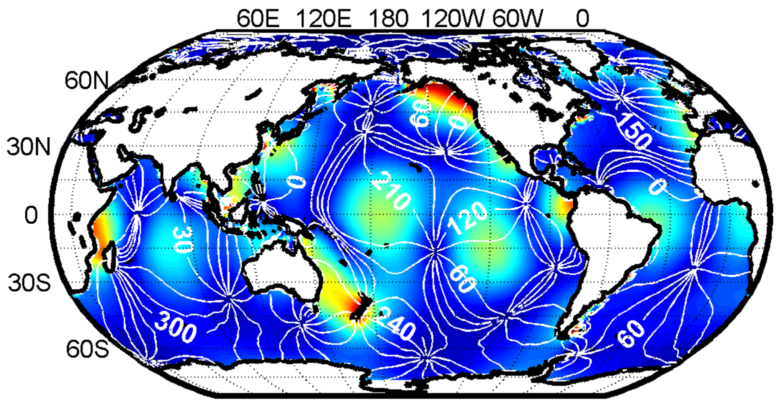




Regional contributions to simulated EAM functions

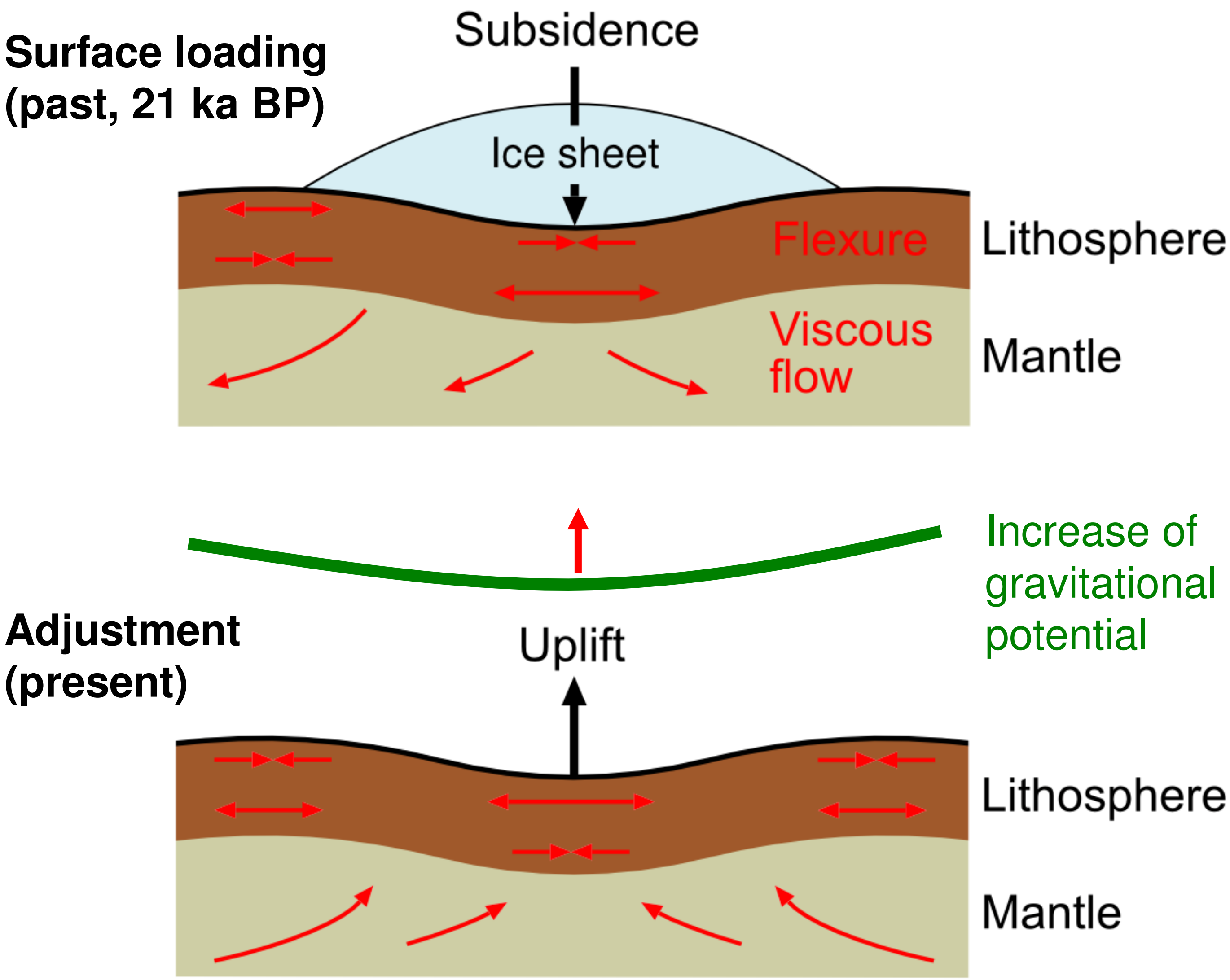


Assessment of Chandler-wobble contributions (Thomas et al., 2005)



Analysis of sub-diurnal variability related to atmospheric tides

Glacial-isostatic adjustment (GIA)



Spatial dimension: 100s to 1000s km

Forward modelling of GIA over North America

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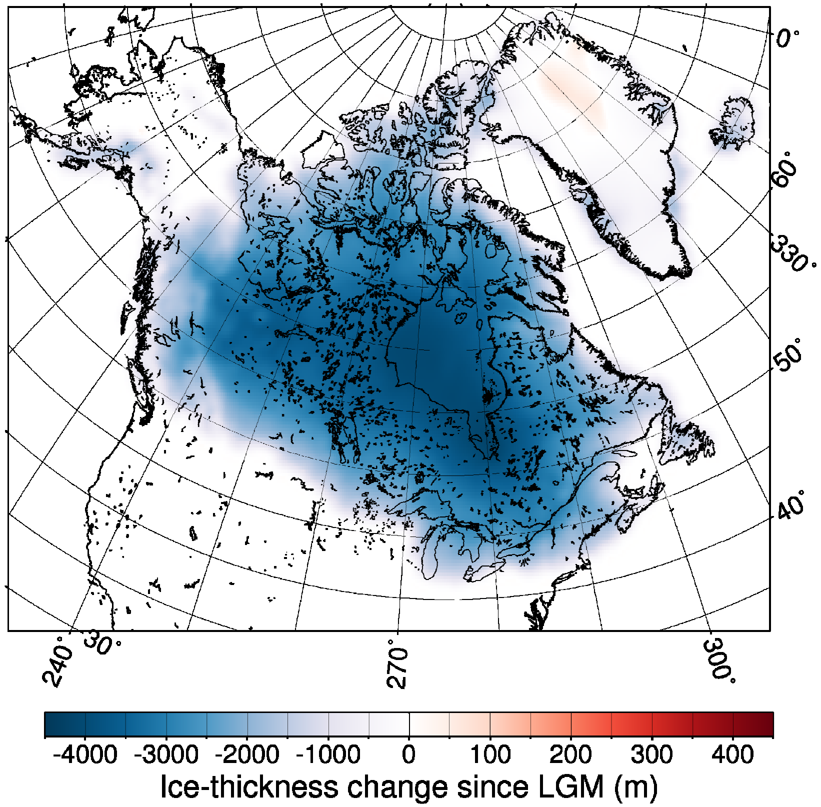
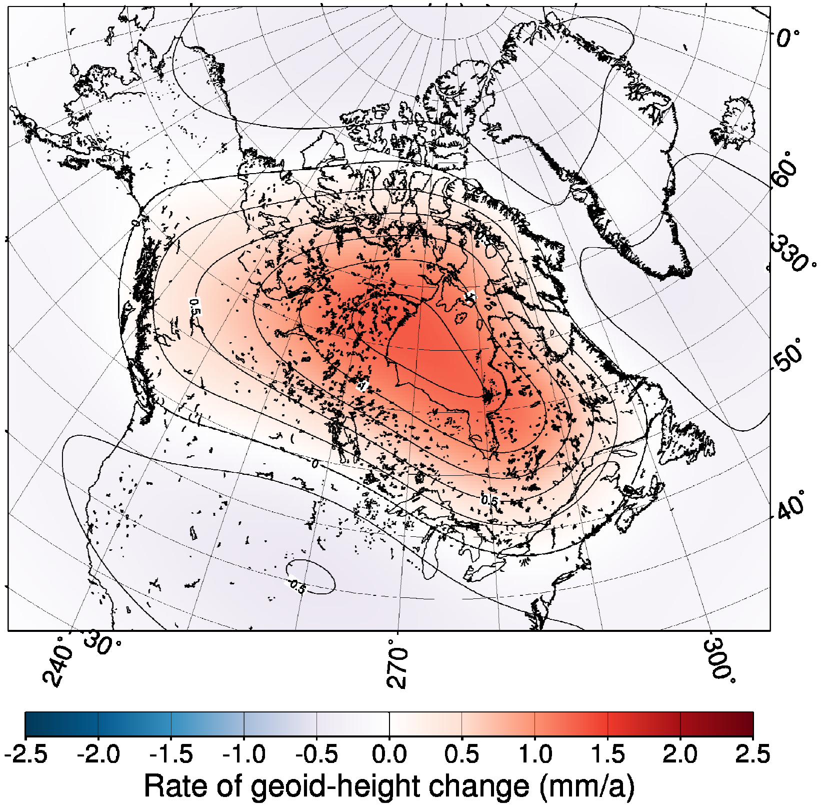
Load model
Ice-thickness change
since LGM (~ 21 ka BP)



Load model NAWI:
Northern Hemisphere, Zweck & Huybrechts (2005)

GIA model
Rate of geoid-height change



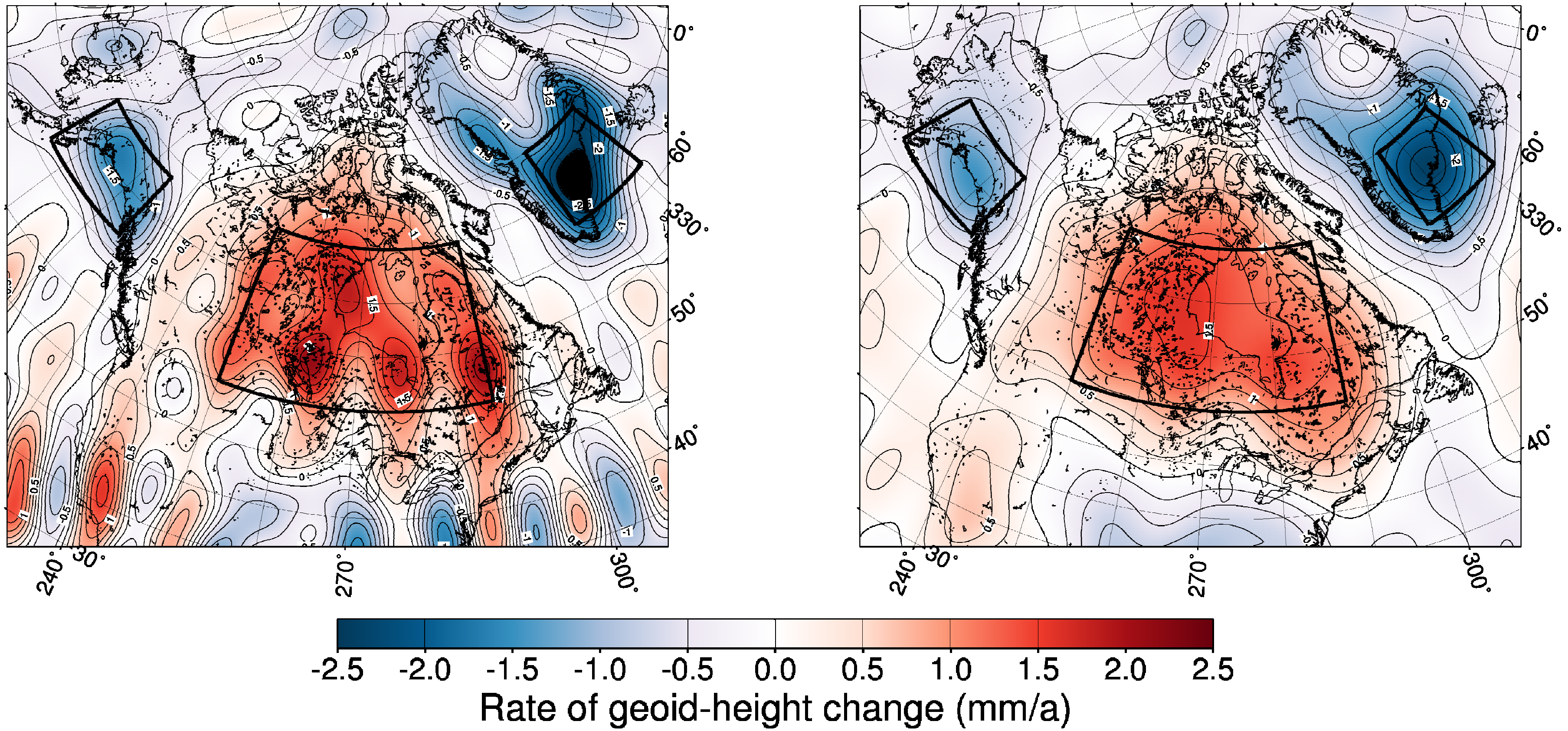
Earth model parameters:
h_L=100 km; η_{UM} = 4.0 10^{20} Pa s; η_{LM} = 4.0 10^{22} Pa s

GRACE observation over North America

GFZ
Helmholtz-Zentrum
POTSDAM

GRACE:
Without filter
GFZ RL04, 2002 to 2007

GRACE:
Statistical filter
GFZ RL04, 2002 to 2007

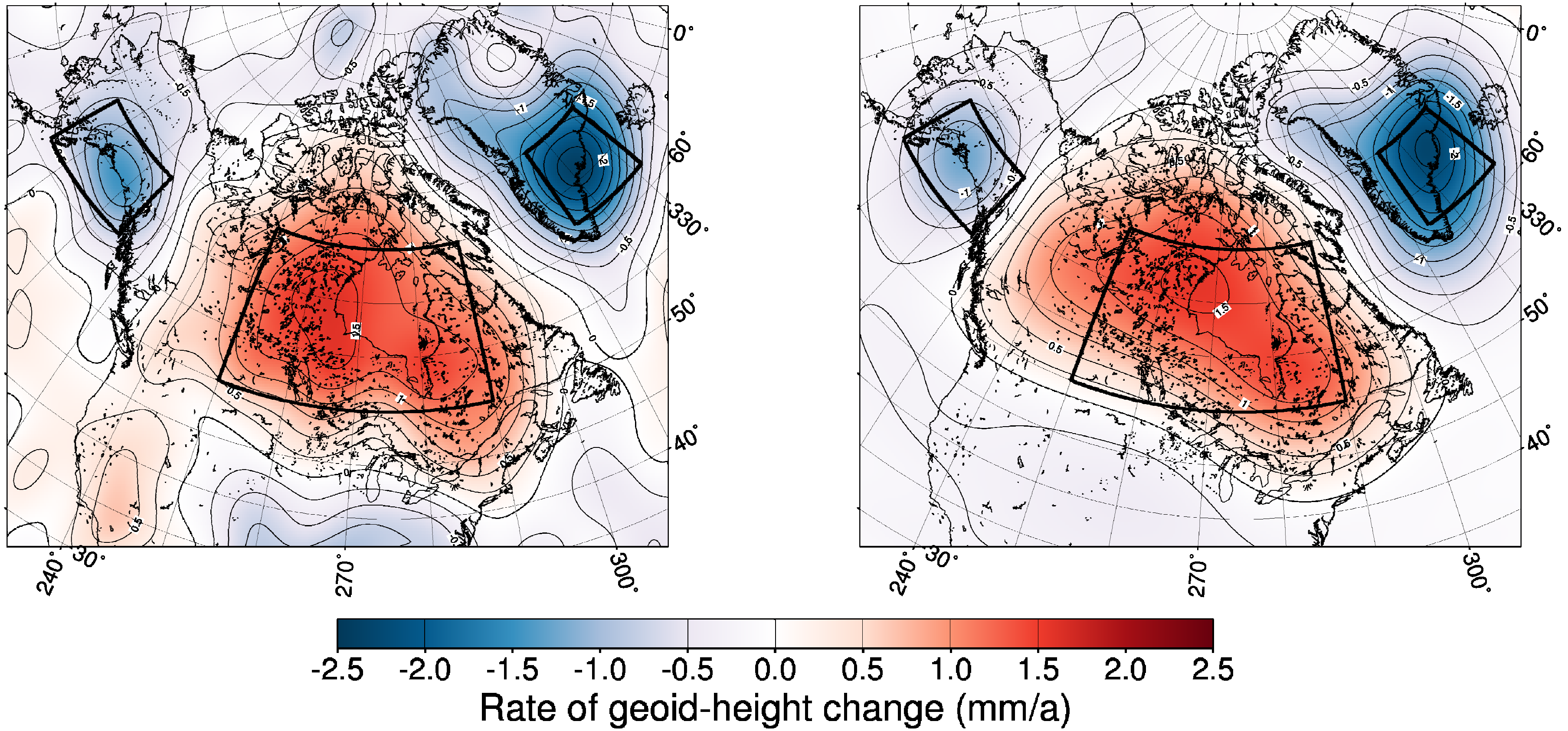


Spherical harmonic cut-off degrees 5 to 60

Comparison of GRACE data and adjusted model

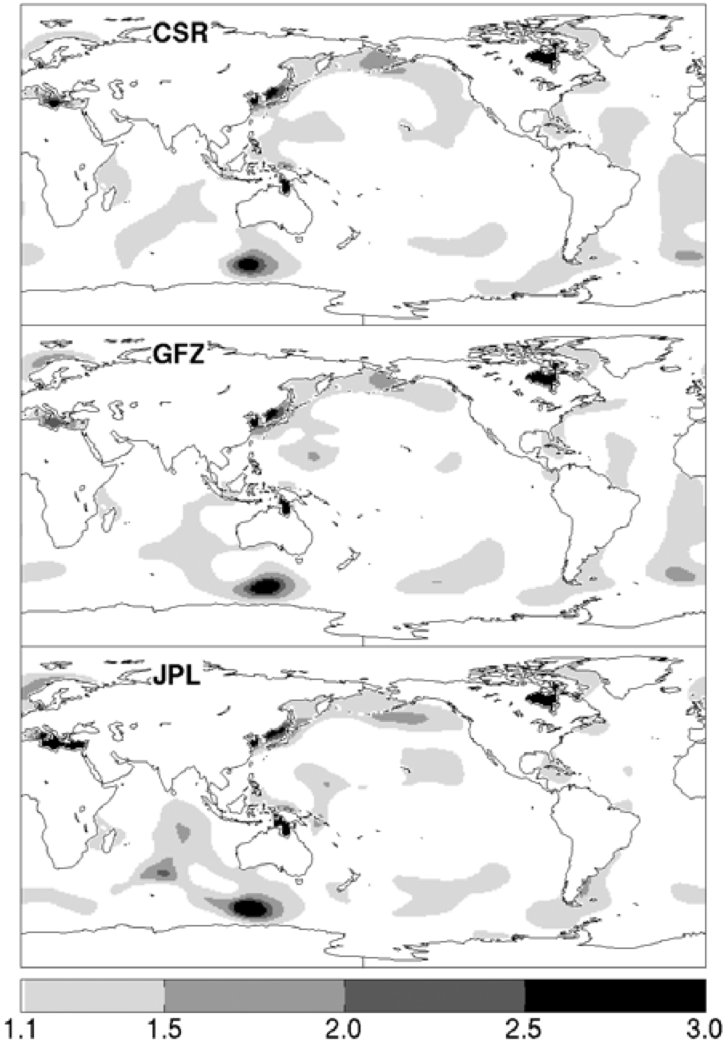
GRACE:
GFZ RL04, 2002 to 2007
(statistical filter, WGHM corrected)

Adjusted models:
Present-day ice-mass change (PD) +
glacial-isostatic adjustment (GIA)



Spherical harmonic cut-off degrees 5 to 60

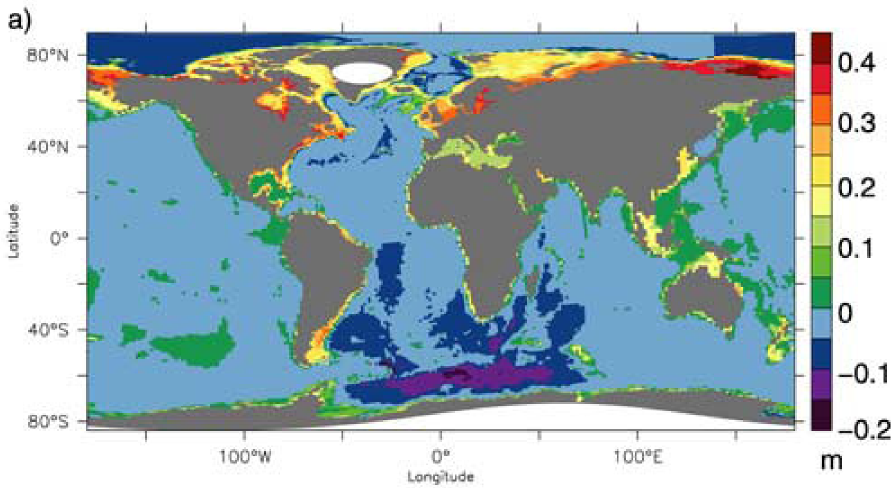
Time-Varying Gravity to constrain Numerical Ocean Models



- Where GRACE data from each center is likely to constrain b_P from a numerical ocean model, based on $<|d-m|^2>/<e_D^2>$, where d, e_D are GRACE data (destriped, land contam minimized, 750km gaussian), and its error.
- White areas = no improvement.
- MORAL:
  - GRACE data errors are NOT zonally uniform, due to aliasing, etc.
  - Need to increase gray shaded areas.

Quinn, K. J., and R. M. Ponte (2008), Estimating weights for the use of time-dependent gravity recovery and climate experiment data in constraining ocean models, J. Geophys. Res., 113, C12013, doi:10.1029/2008JC004903

Detecting Climate-driven decadal TRENDS in OBP

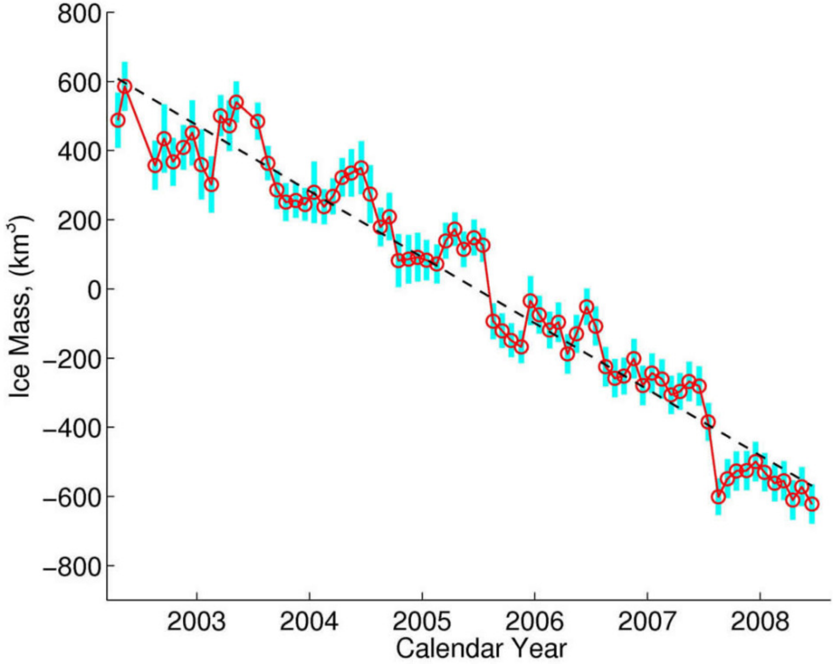


- Anomaly in OBP after 100 yrs (1090-1099 average) of climate change: IPCC (2001)-A1B emission scenario: atmospheric CO2 rises from 367 ppmv in 2000 to 703 ppmv by 2100.
- Relative to preindustrial conditions, global mean thermosteric sea level rises 0.26 m by 2100
- Mapped changes are ONLY due to changes in ocean temperature and salinity.

Landerer, F. W., J. H. Jungclaus, and J. Marotzke (2007), Ocean bottom pressure changes lead to a decreasing length-of-day in a warming climate, Geophys. Res. Lett., 34, L06307, doi:10.1029/2006GL029106

Ice Sheet melt: acceleration

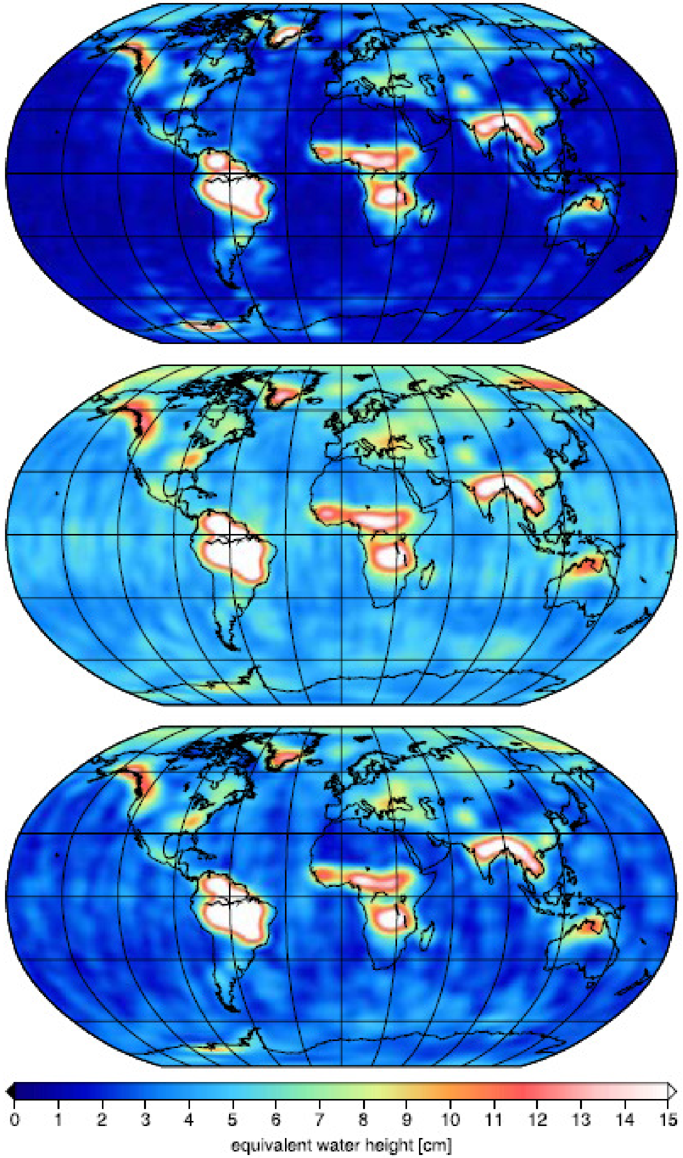
GFZ
Helmholtz-Zentrum
POTSDAM



- GRACE has been most useful in detecting true MASS change in ice sheets.
- ACCELERATION in ice sheet melt, If present, is a true signal of accelerating climate change.
- It is also less sensitive to GIA signals.

Velicogna, I., J. Wahr, Acceleration of Greenland Ice Mass Loss in Spring 2004,Nature 022 Sep 2006|doi:10.1038/nature05168, 21 Sep 2006. Updated time series.

GFZ
Helmholtz-Zentrum
POTSDAM



daily Kalman solutions

weekly GFZ RL04

monthly GFZ RL04

Kurtenbach et al., GRL, 2009