Modélisation des surcharges induites par les fluides superficiels

Modeling loading effects induced by surface fluids

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Habilitation à Diriger les Recherches

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- Introduction
- Atmospheric and non-tidal oceanic loading effects on surface gravity measurements
- Ocean tidal loading and gravity observations
- Calibration/Validation of space gravity mission
  - Example of the Three Gorges Dam water impoundment
- Conclusion

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Modeling loading effects induced by surface fluids

The circulation of surface fluids induces mass redistributions at the Earth surface, and therefore global Earth deformation and gravity changes:

1. Correct geodetic observations using general circulation models (atmosphere, ocean, *etc.*), in order to observe solid Earth contributions (core modes, tectonics, *etc.*).
2. Use geodetic observations to validate circulation models (ocean tides, non-tidal ocean circulation, *etc.*).
3. Derive surface fluid dynamics (mass redistribution) from geodetic observations (GRACE).

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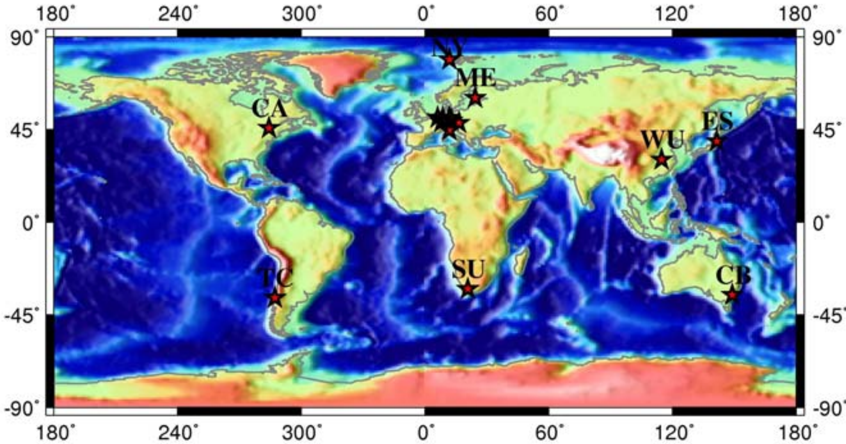
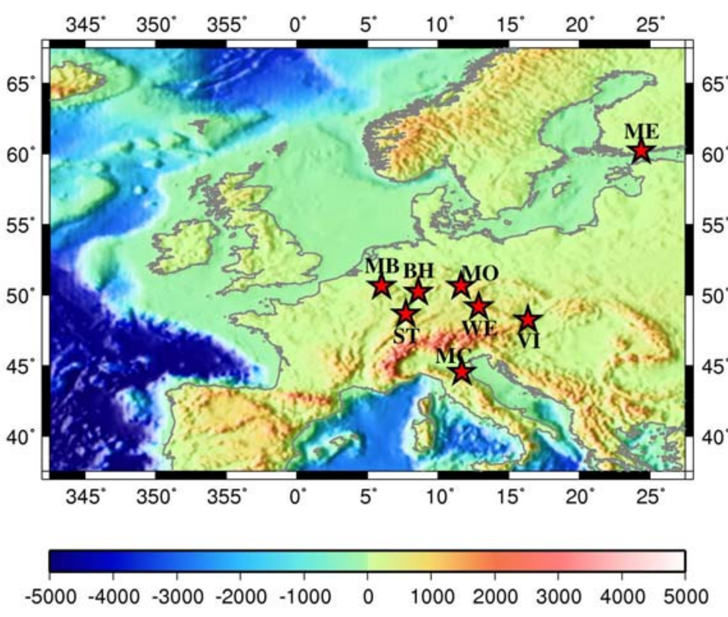
Atmospheric and non-tidal oceanic loading effects on surface gravity measurements





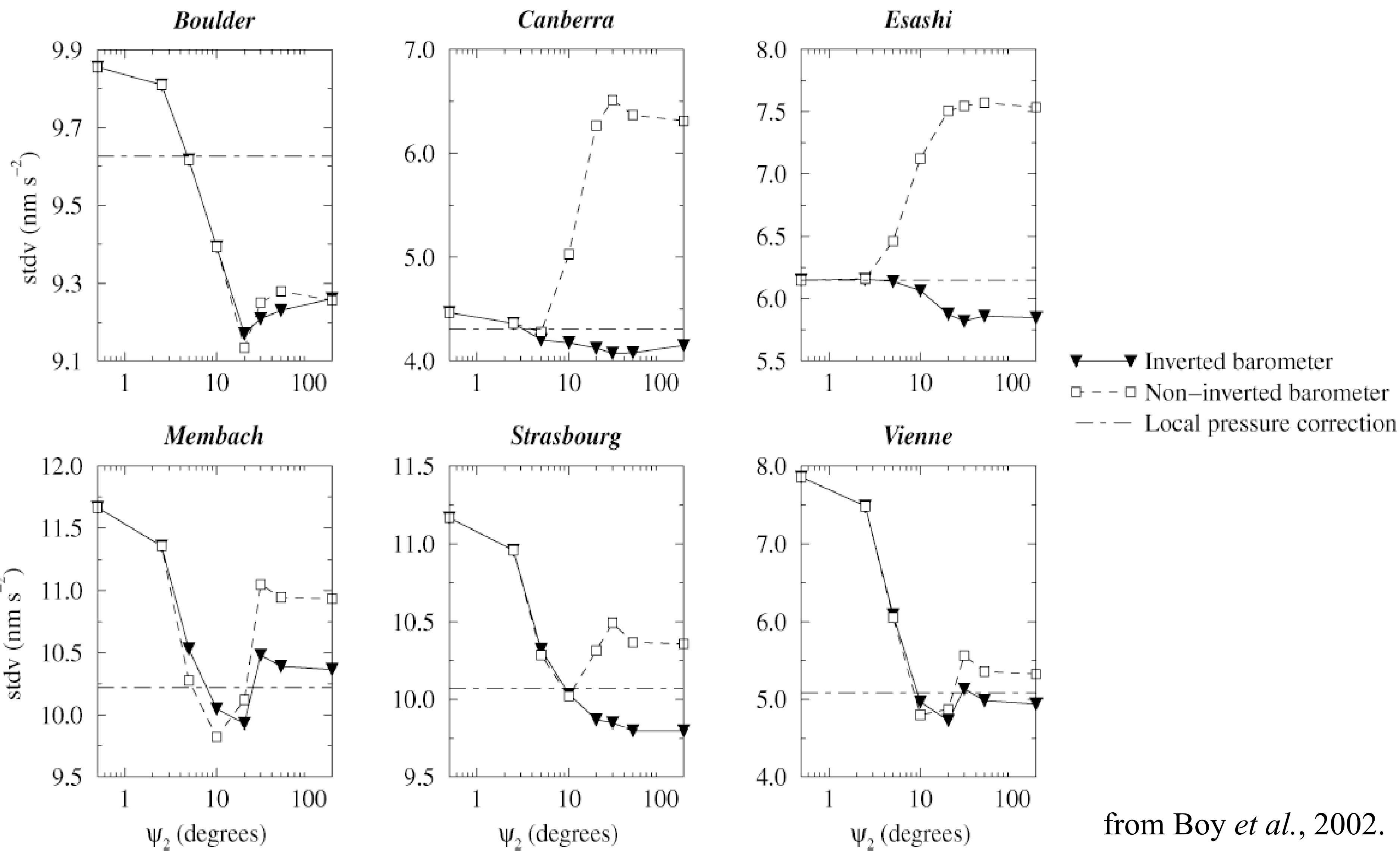
- Atmospheric loading is one of the major sources of gravity changes over a wide frequency range (from a few seconds to seasonal timescales).

- Global surface pressure field allow a systematic and significant reduction of gravity residuals for periods from a few days to a few hundred days (Boy *et al.*, 2002).

- The ocean response to atmospheric pressure forcing is supposed to follow the *Inverted Barometer* assumption, which is only valid for periods exceeding typically a few weeks.

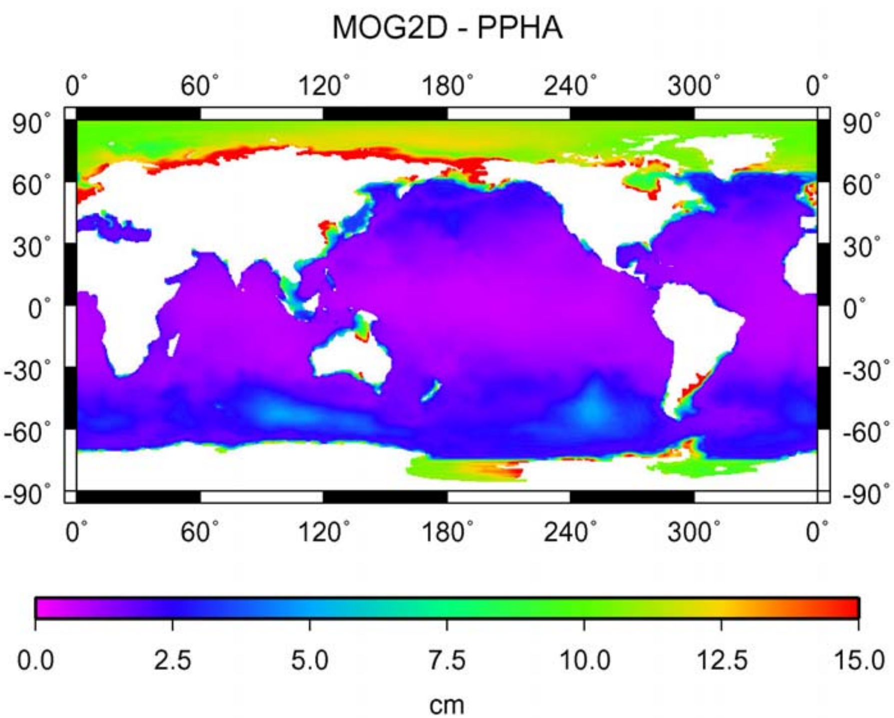
- Loading effects are computed by a convolution of Green's functions (elastic Earth's response) and the acting sources (pressure, etc.).

Atmospheric loading: local approach versus the global convolution

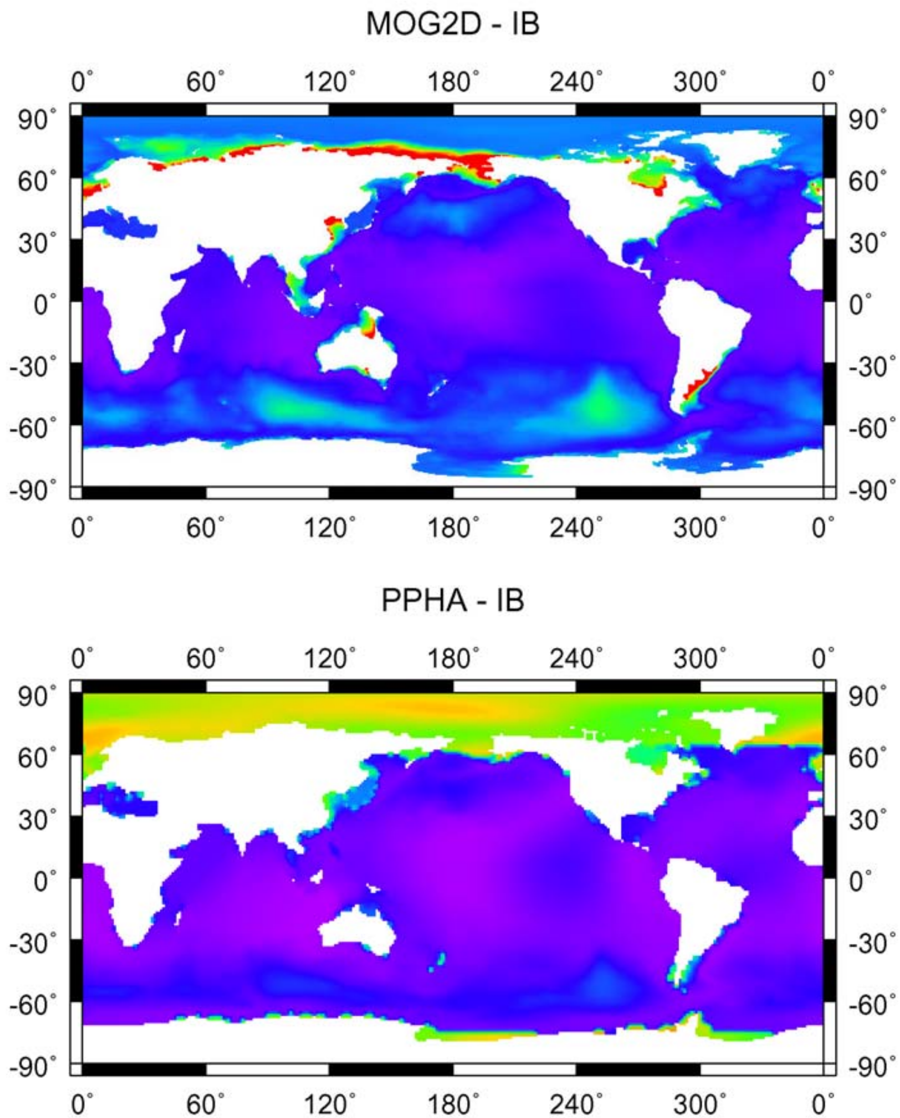


from Boy *et al.*, 2002.

Ocean response to pressure forcing

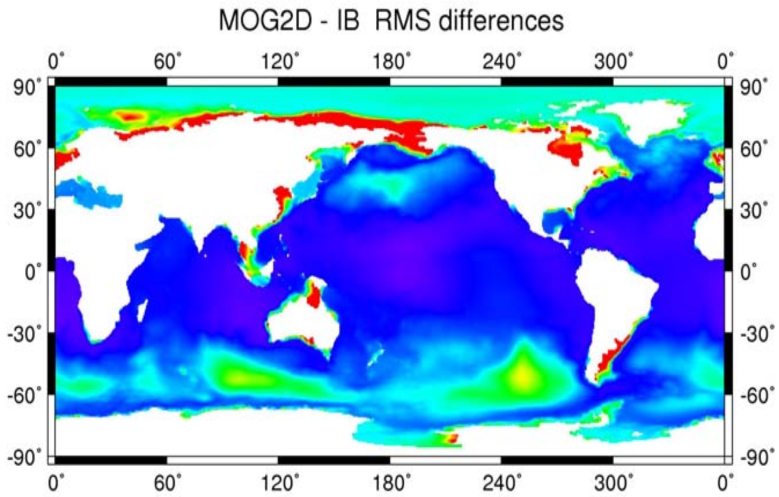


RMS differences between IB and 2 barotropic ocean models, forced by pressure and winds

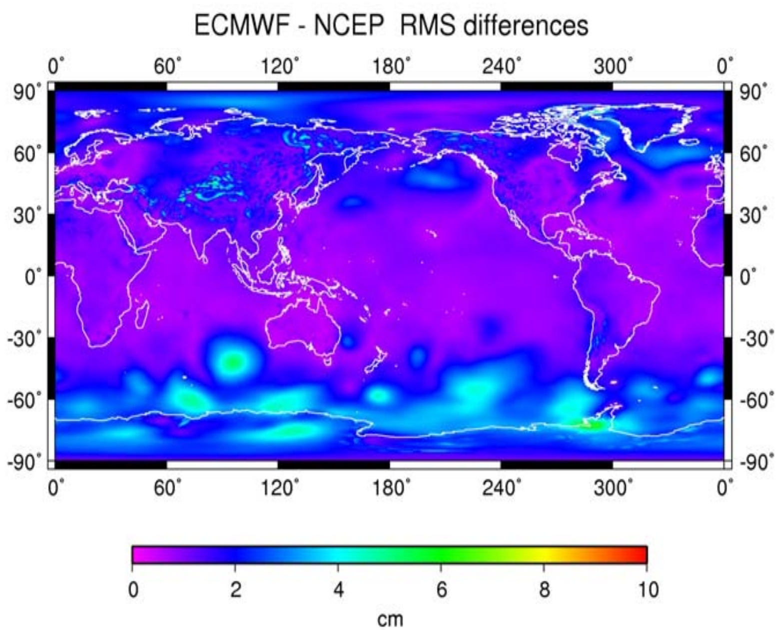


Inverted barometer: air pressure variations are fully compensated by static sea height variations.

Ocean response to pressure (and wind) forcing

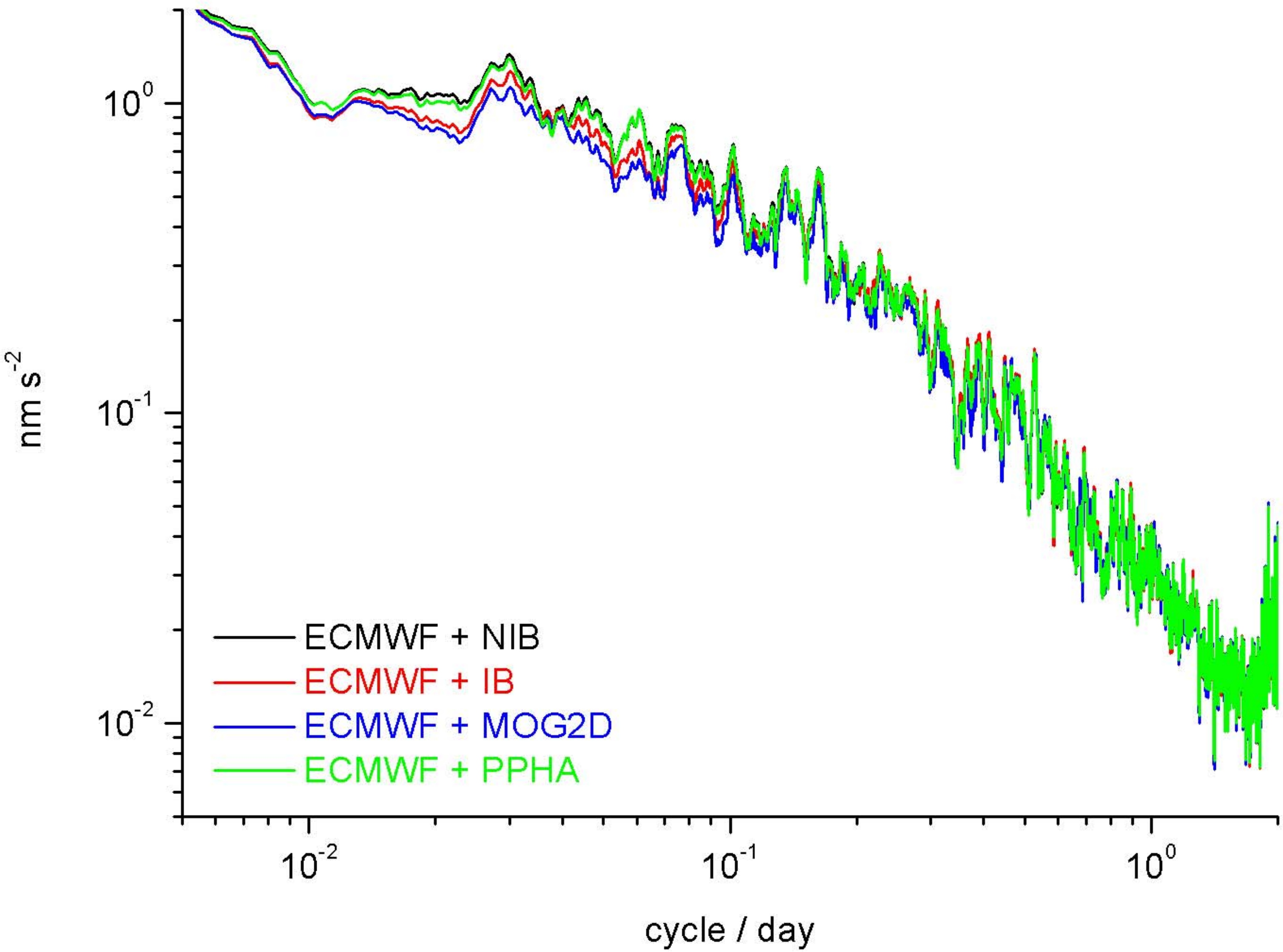


The differences between the classical IB assumption and a dynamic ocean model (forced by pressure and winds) are at least 5 times larger than the errors in the surface pressure fields.

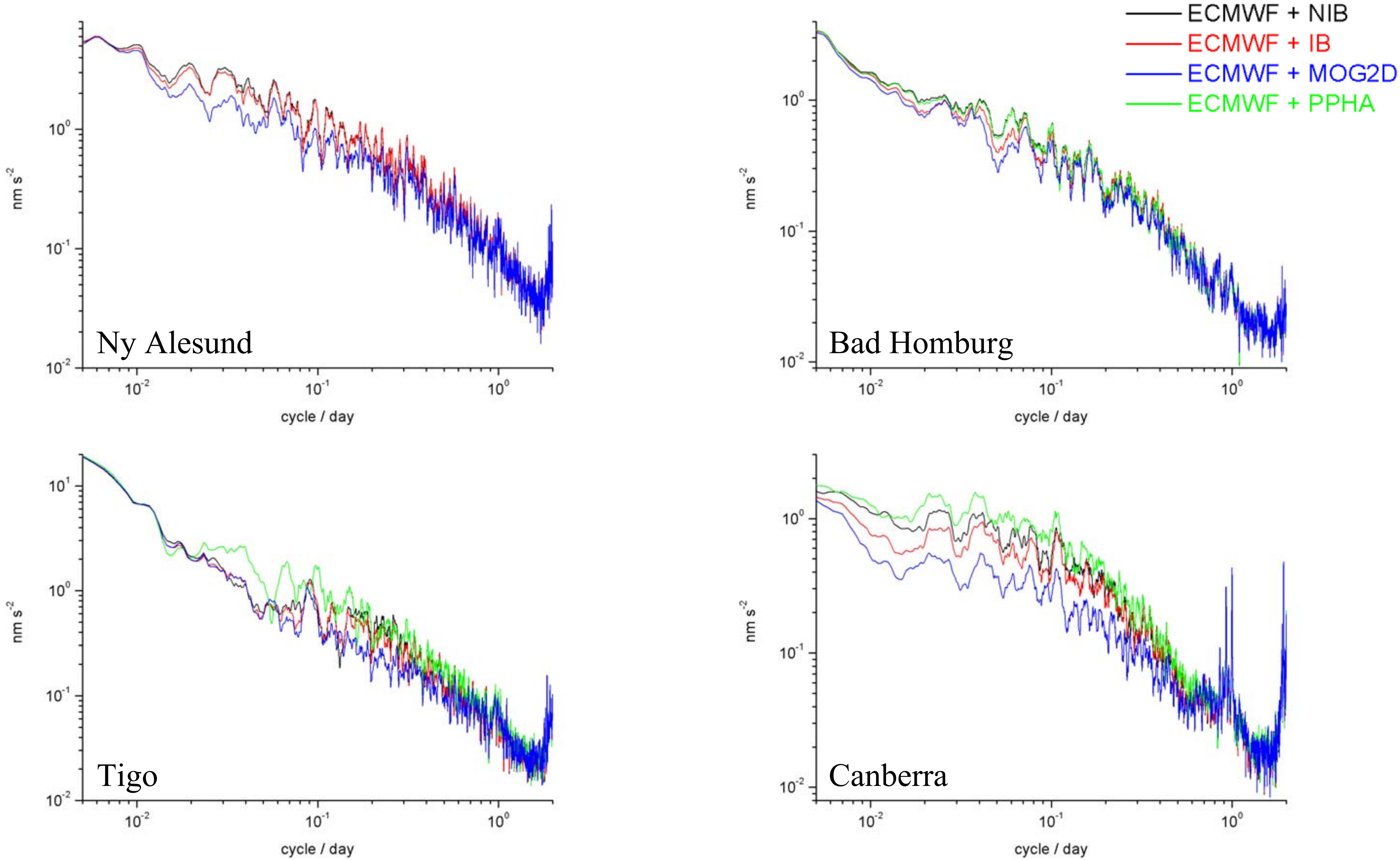


RMS differences between IB and MOG2D models, compared to the "precision" of surface pressure fields.

Spectrum of gravity residuals (Strasbourg) with different loading corrections



Spectrum of gravity residuals with different loading corrections



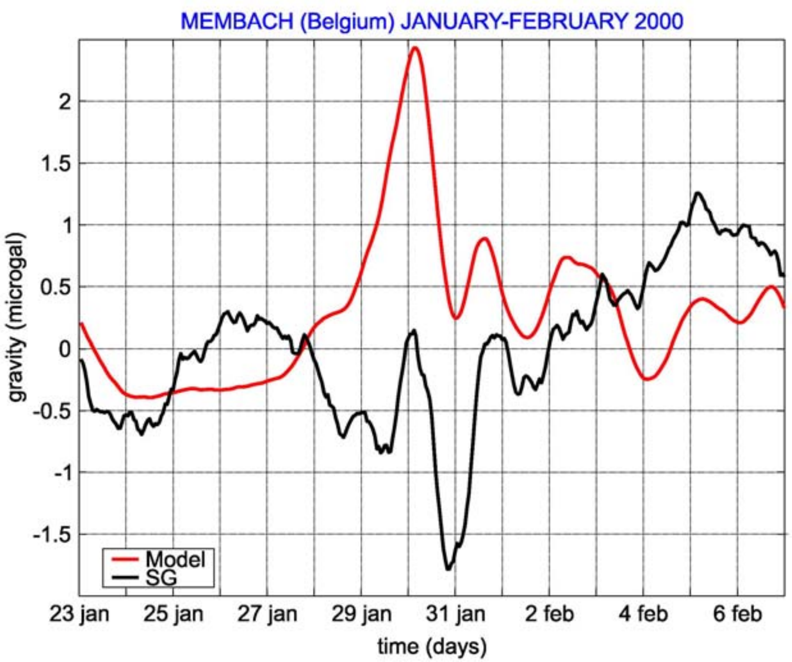
Non-tidal oceanic loading effects

- Reduction of the gravity residuals using MOG2D ocean model, compared to the classical IB assumption, for periods between a few days and a few hundred of days.
  - at longer periods, hydrology becomes the main source of gravity changes,
  - Validity of ocean models for short periods?

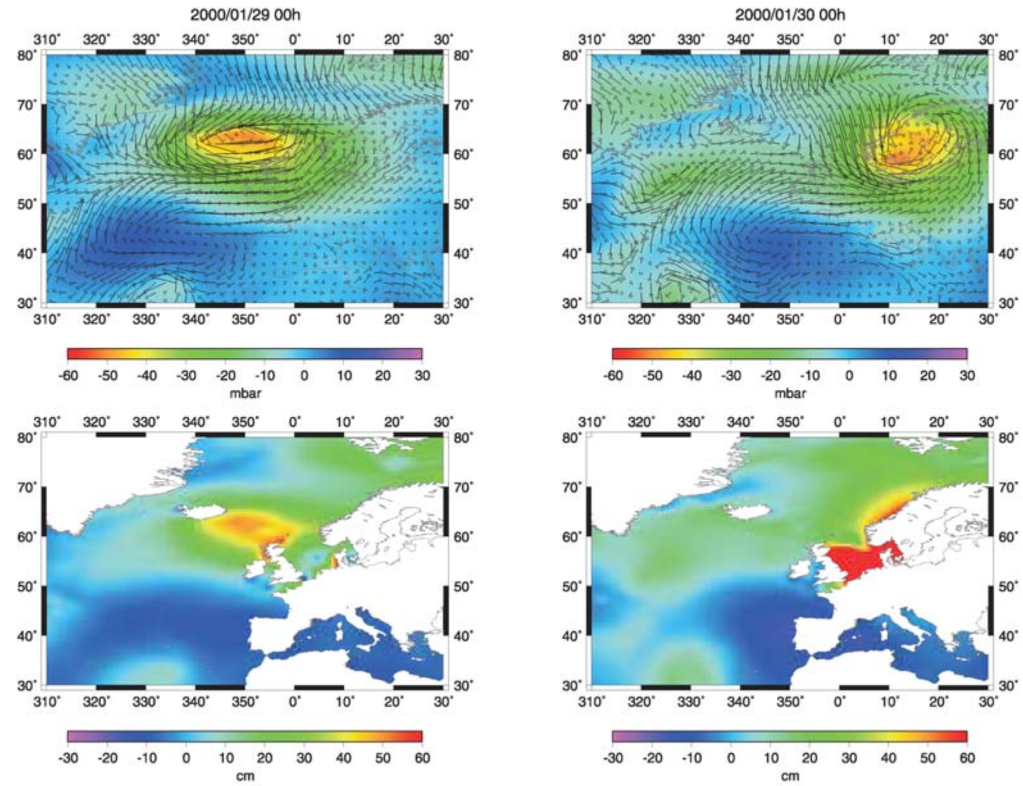
- PPHA cannot be used for correcting non-tidal ocean loading from superconducting gravimeter records due to its poor resolution (especially over continental shelves).

- Modeling the direct attraction of the full 3-D atmosphere

Atmospheric and non-tidal ocean loading: example of a storm surge

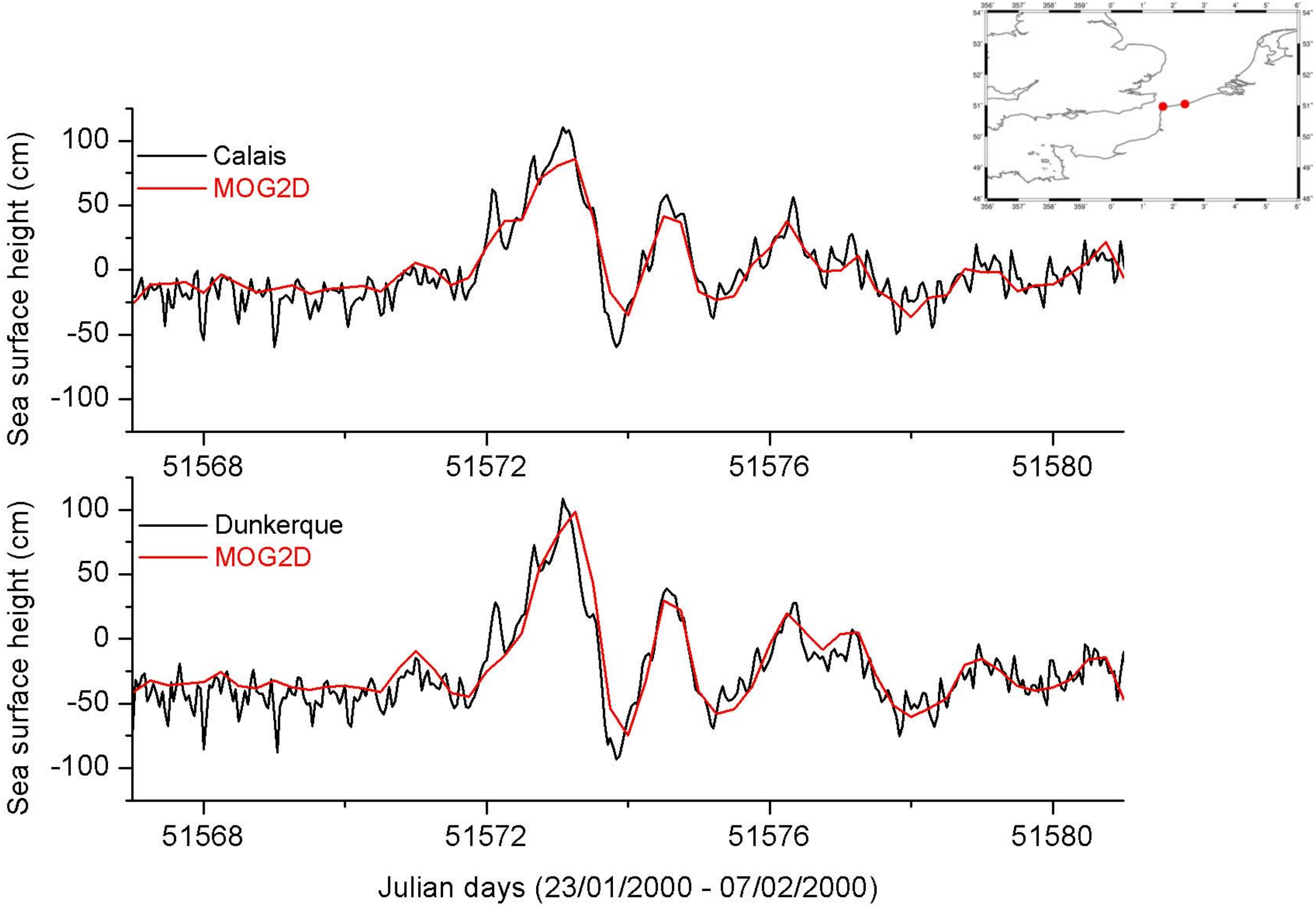


Gravity residuals at Membach and non-tidal oceanic loading (POL storm surge model), from Fratepietro *et al.* (2006).

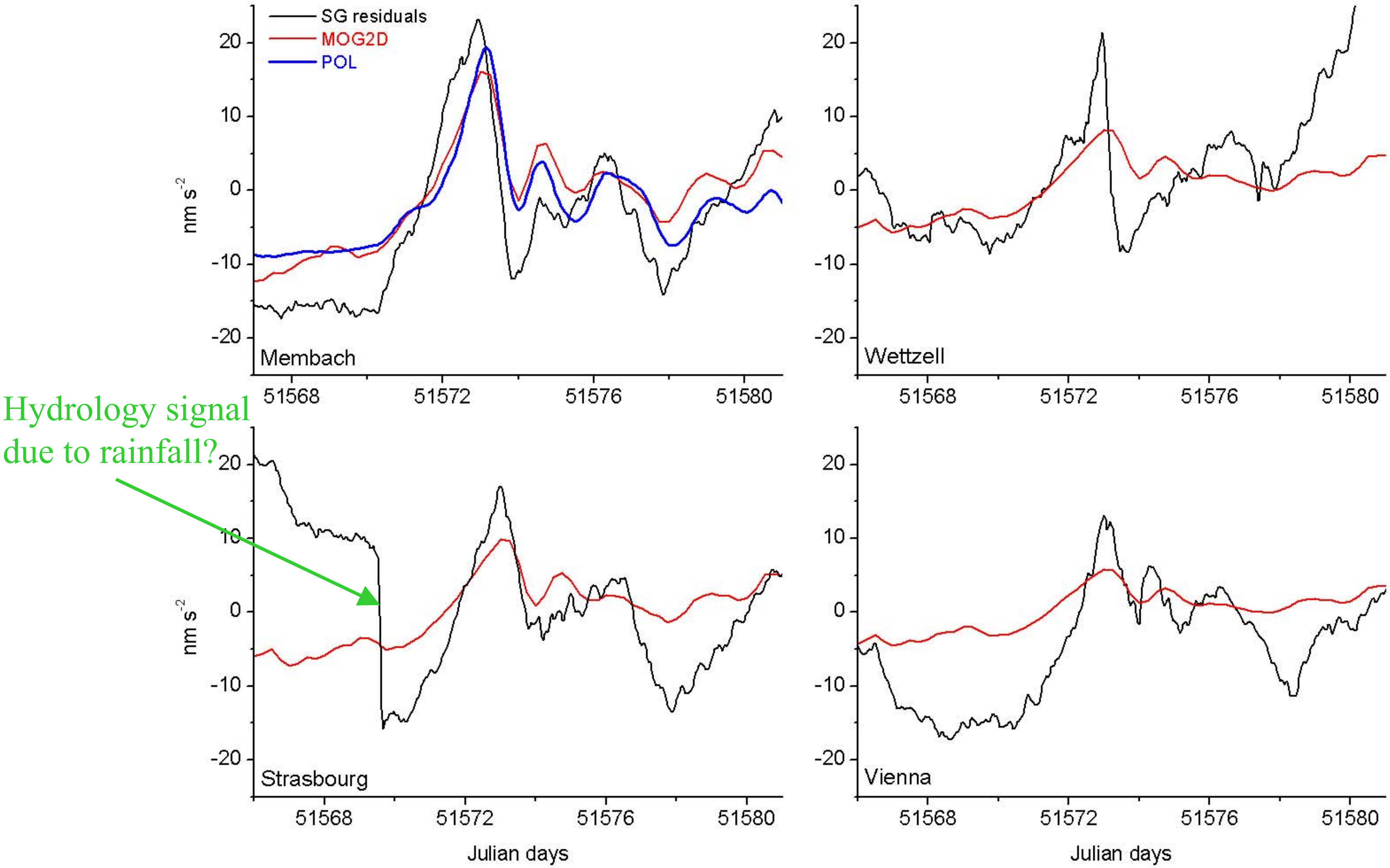


Pressure variations & surface winds from ECMWF (top) and sea surface height variations from MOG2D (bottom).

Comparison of MOG2D and tide gauges



Gravity residuals in Europe and non-tidal oceanic loading



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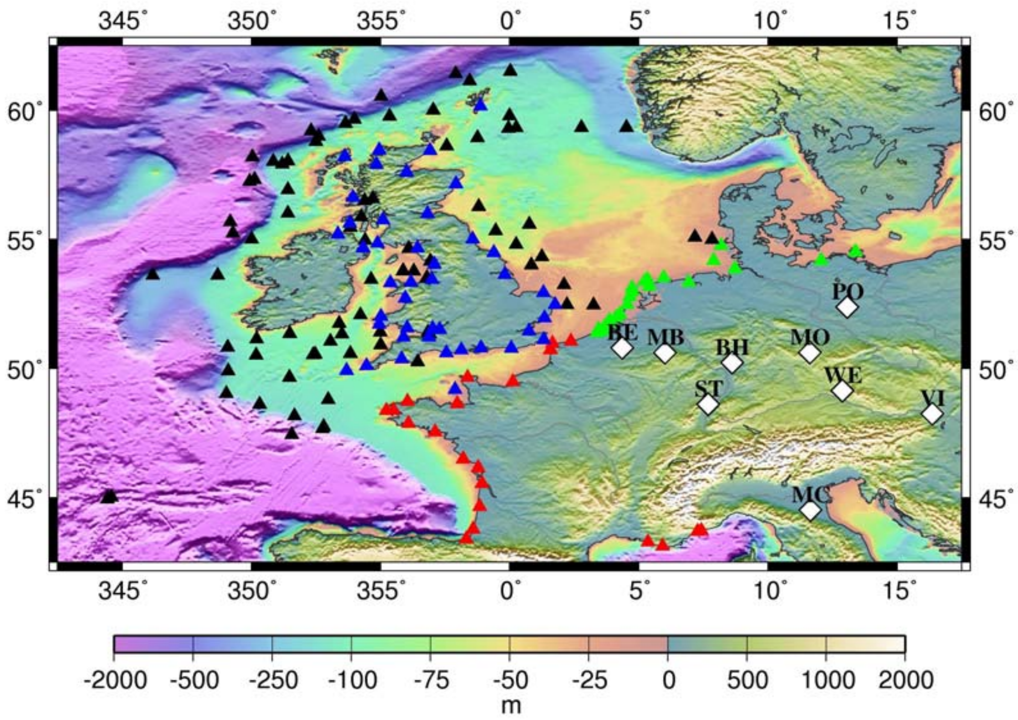
Ocean tidal loading & gravity measurements

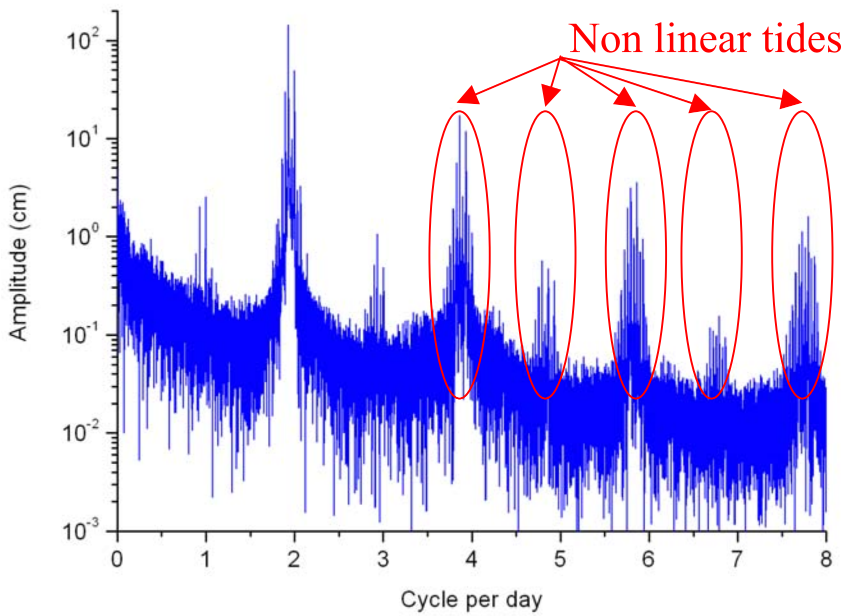
- Diurnal and semi-diurnal constituents:
  - Boy *et al.*, A comparison of tidal ocean loading models using superconducting gravimeter data, *J. Geophys. Res.*, 2003.
- Long period tides:
  - Boy *et al.*, Validation of long-period oceanic tidal models with superconducting gravimeters, *J. Geodynamics.*, 2006.
- Non-linear tidal loading in Western Europe:
  - Boy *et al.*, Non-linear ceanic tides observed by superconducting gravimeters in Europe, *J. Geodynamics.*, 2004.

Non-linear ocean tidal loading in Europe

Tide gauges and bottom pressure records over the European shelf

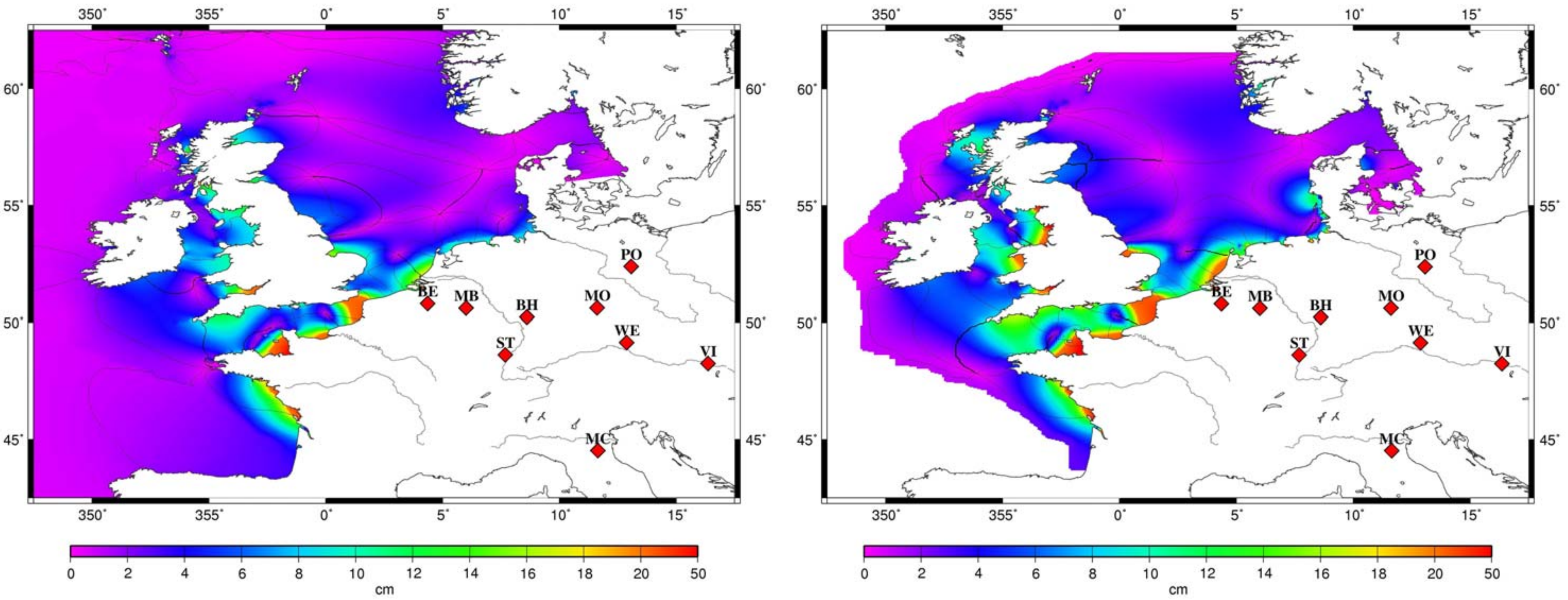


Spectrum of Boulogne tide gauge



M4 tide models over the European shelf

MOG2D | Pingree & Griffiths (1980, 1981)



<u>RMS of tidal observations:</u>

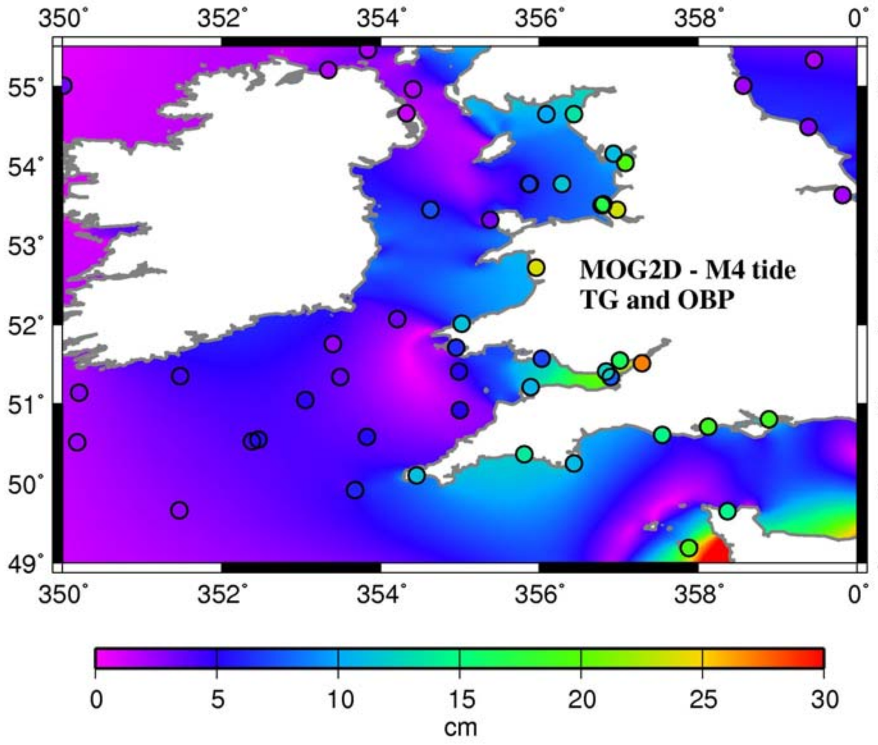
9.9 cm 10.3 cm

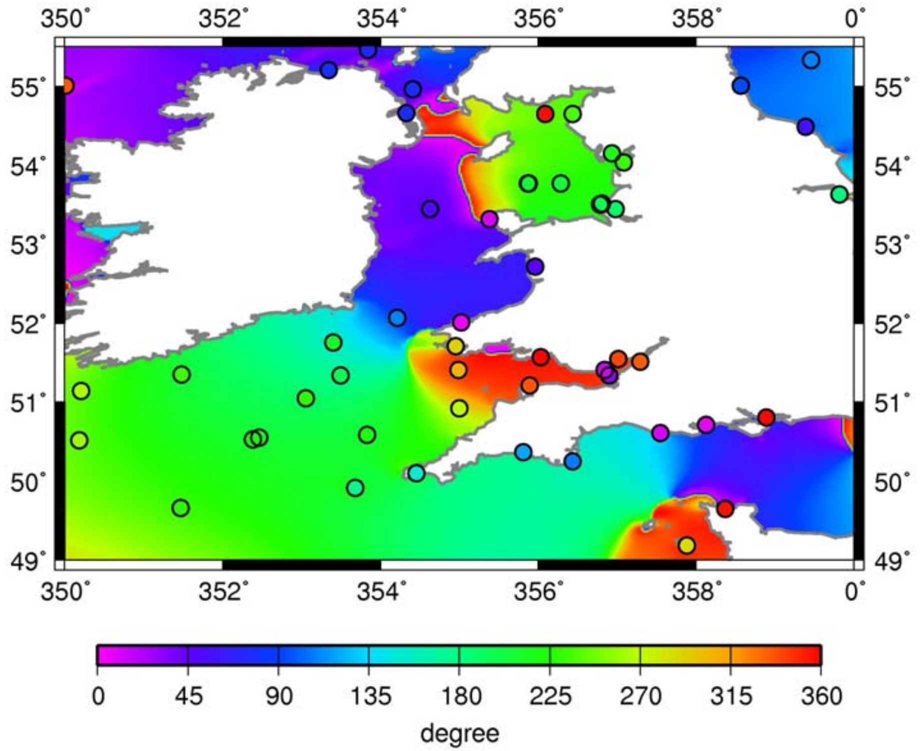
<u>RMS differences between observations and models:</u>

9.5 cm 11.5 cm

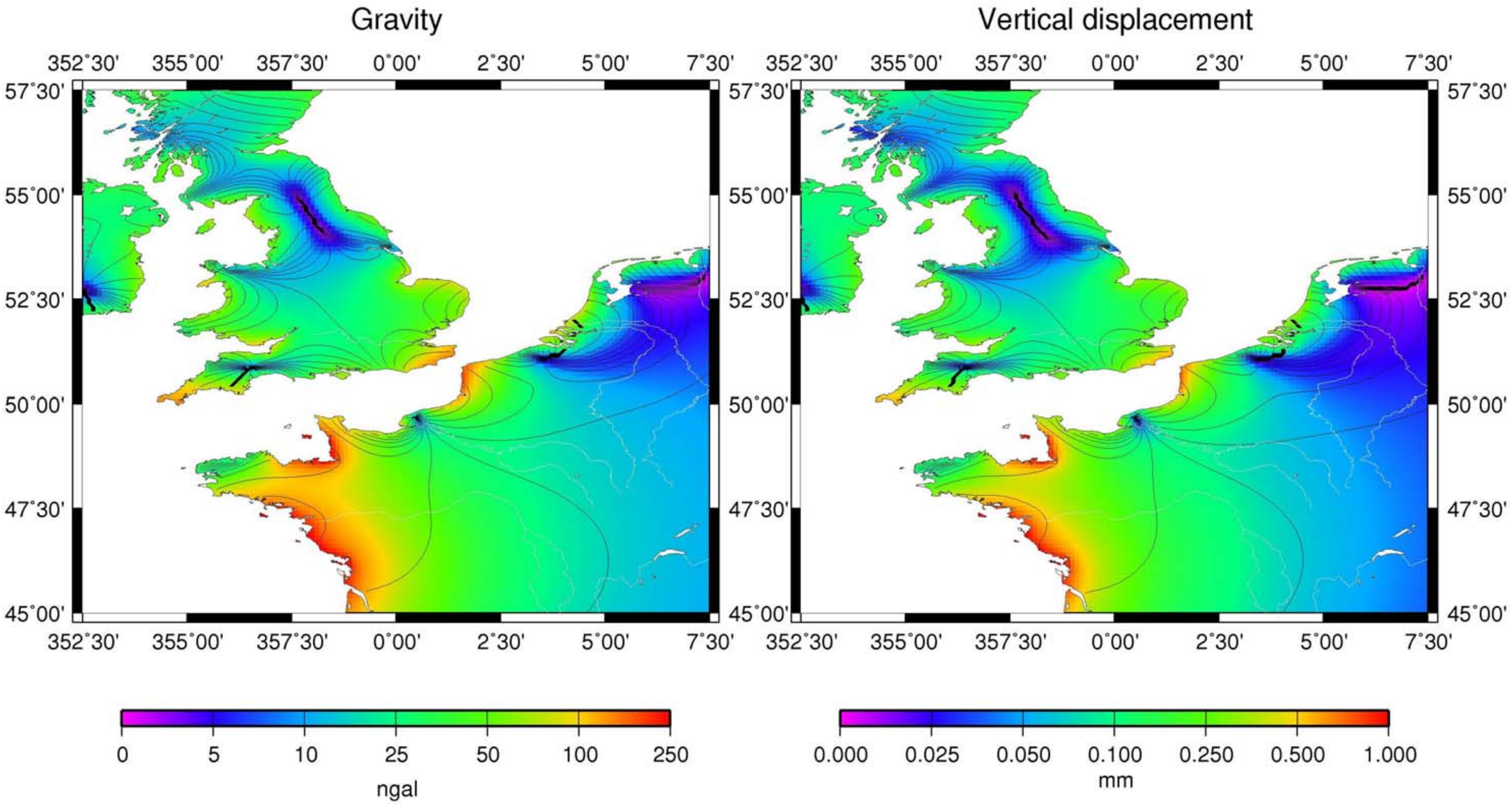
=> Effects due to small wavelengths along the coasts.

Comparison of OBP and TG measurements with MOG2D M4 model



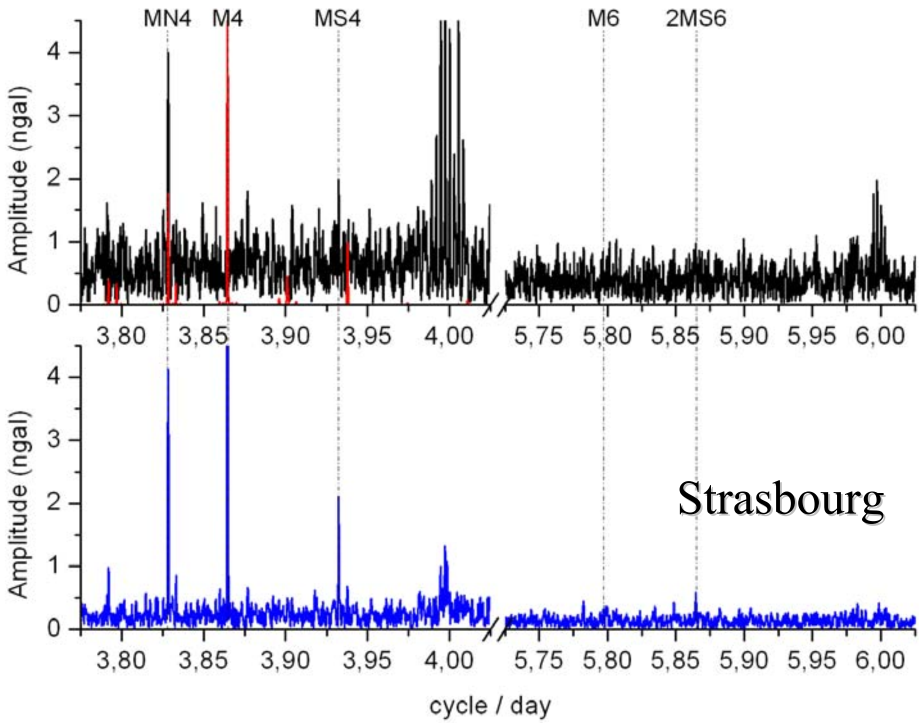


Non-linear ocean tidal loading in Europe



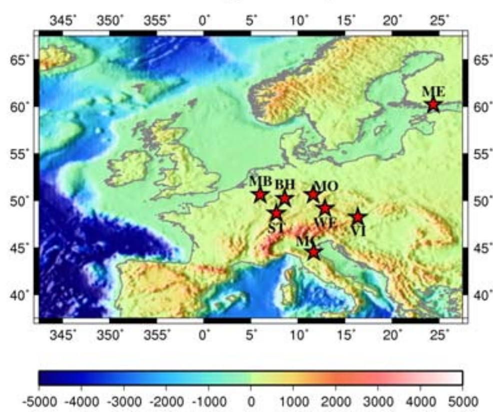
M4 ocean tide from MOG2D model. Phases are with respect to Greenwich

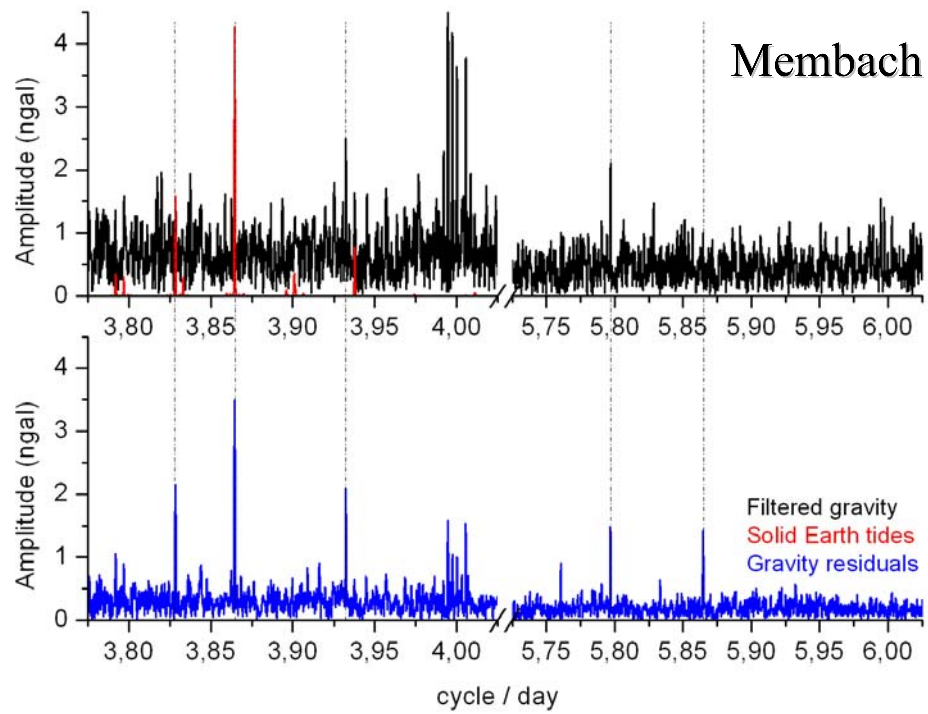
Non-linear ocean tidal loading and gravity observations



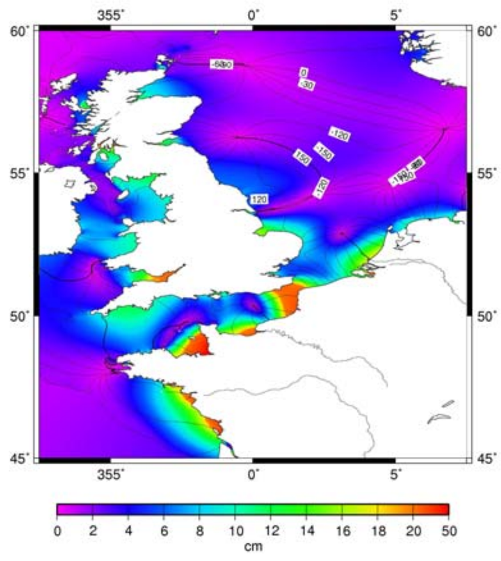
Filtered "raw" gravity

Gravity residuals after "despiking" and correcting for solid Earth tides and pressure.

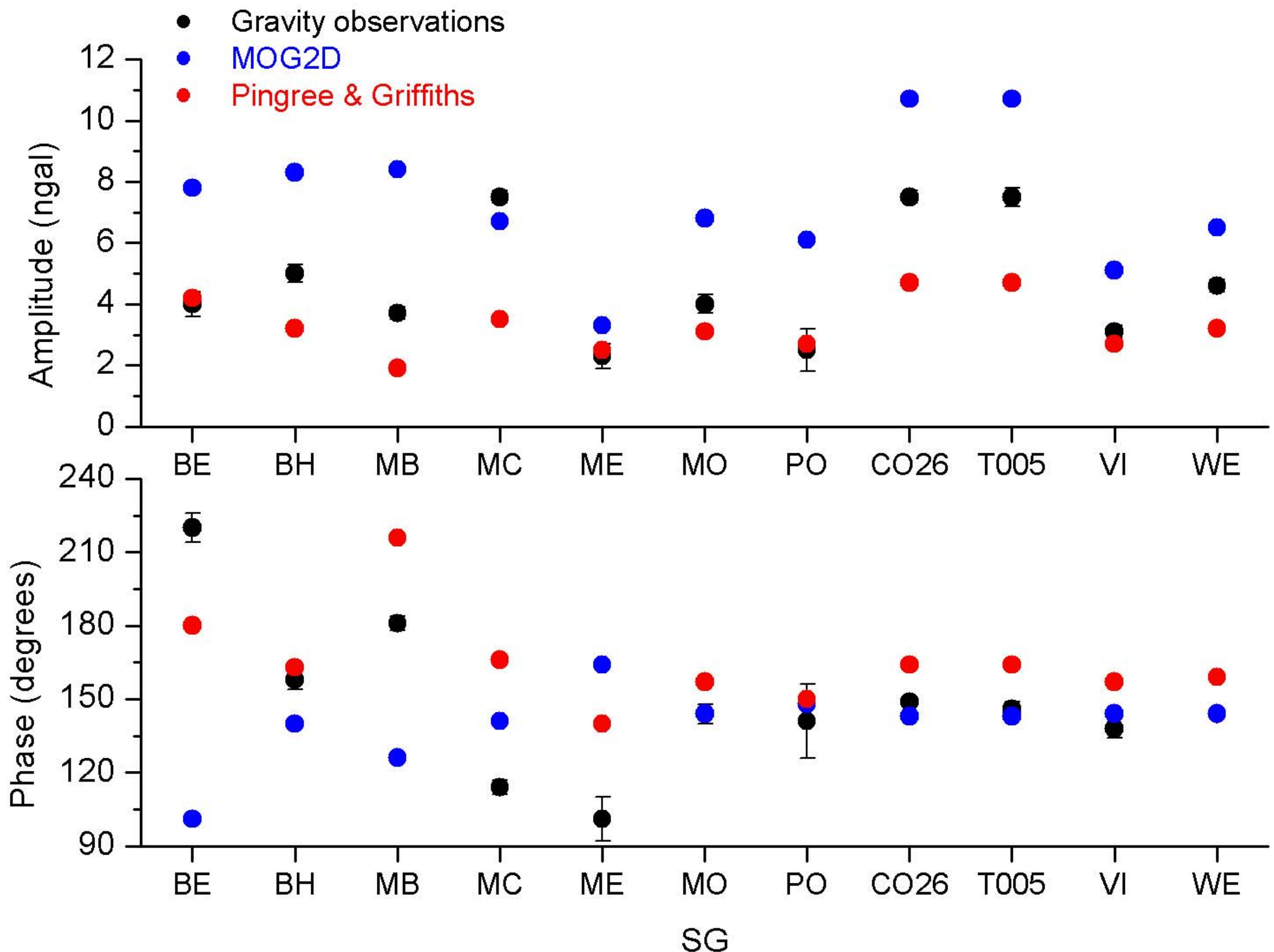




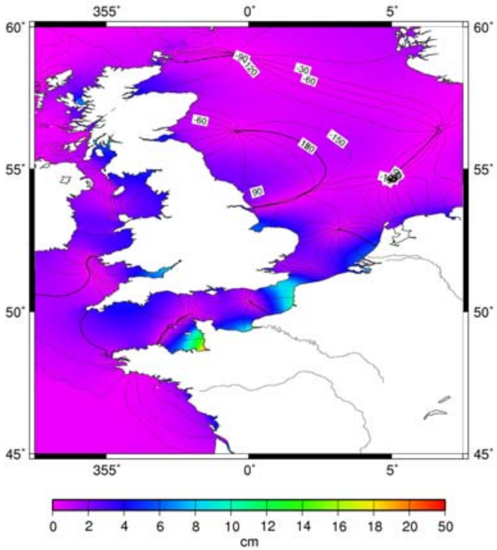
SG observations and M4 tidal loading



RMS differences with TG
- 9.5 cm
- 11.5 cm

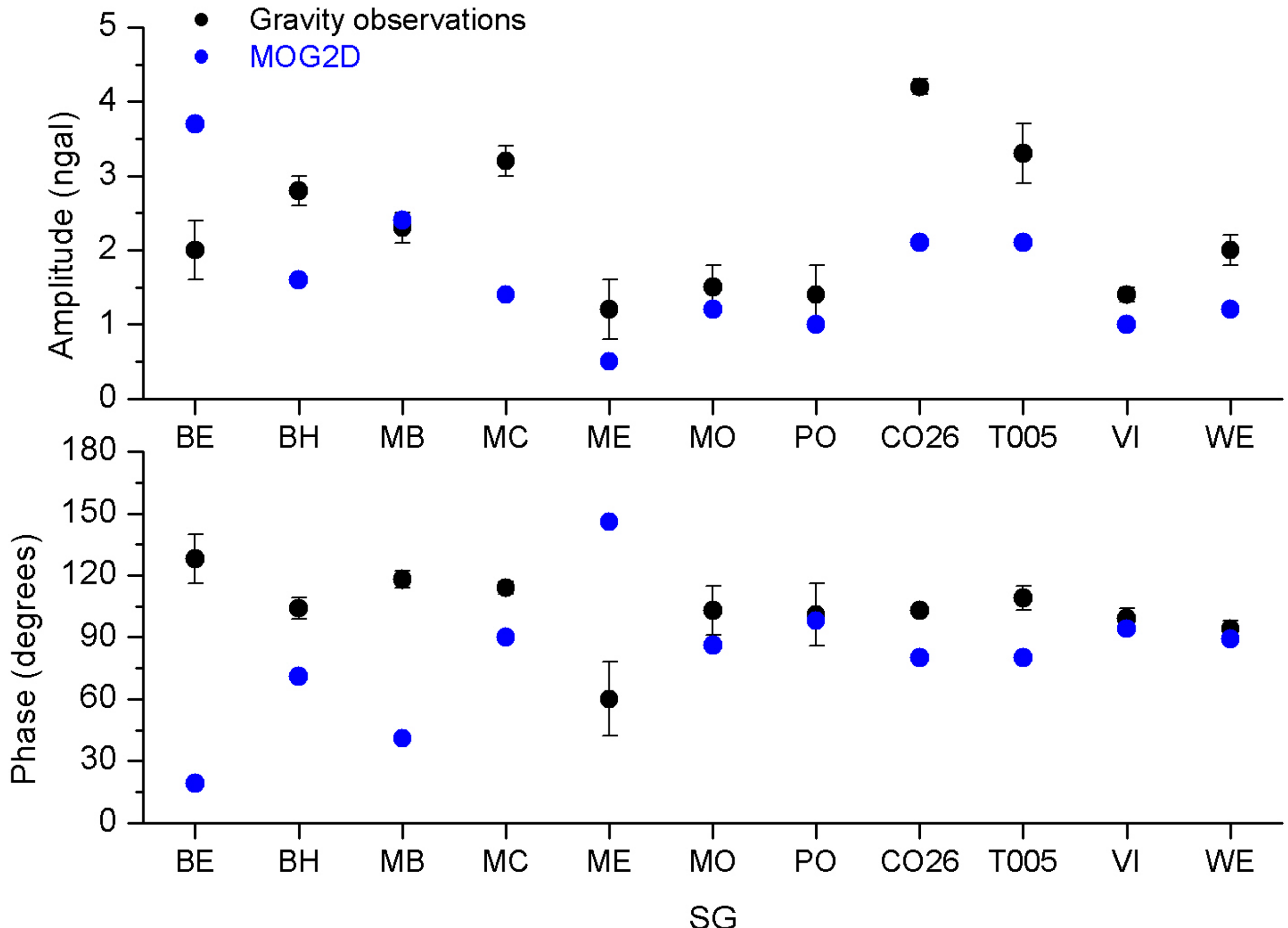


SG observations and MN4 tidal loading

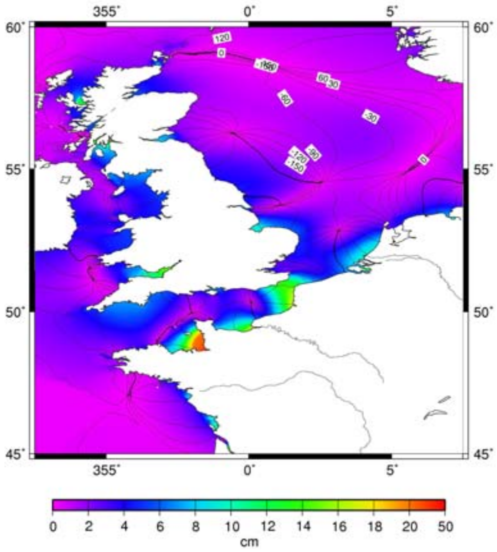


RMS differences with TG

- 3.5 cm

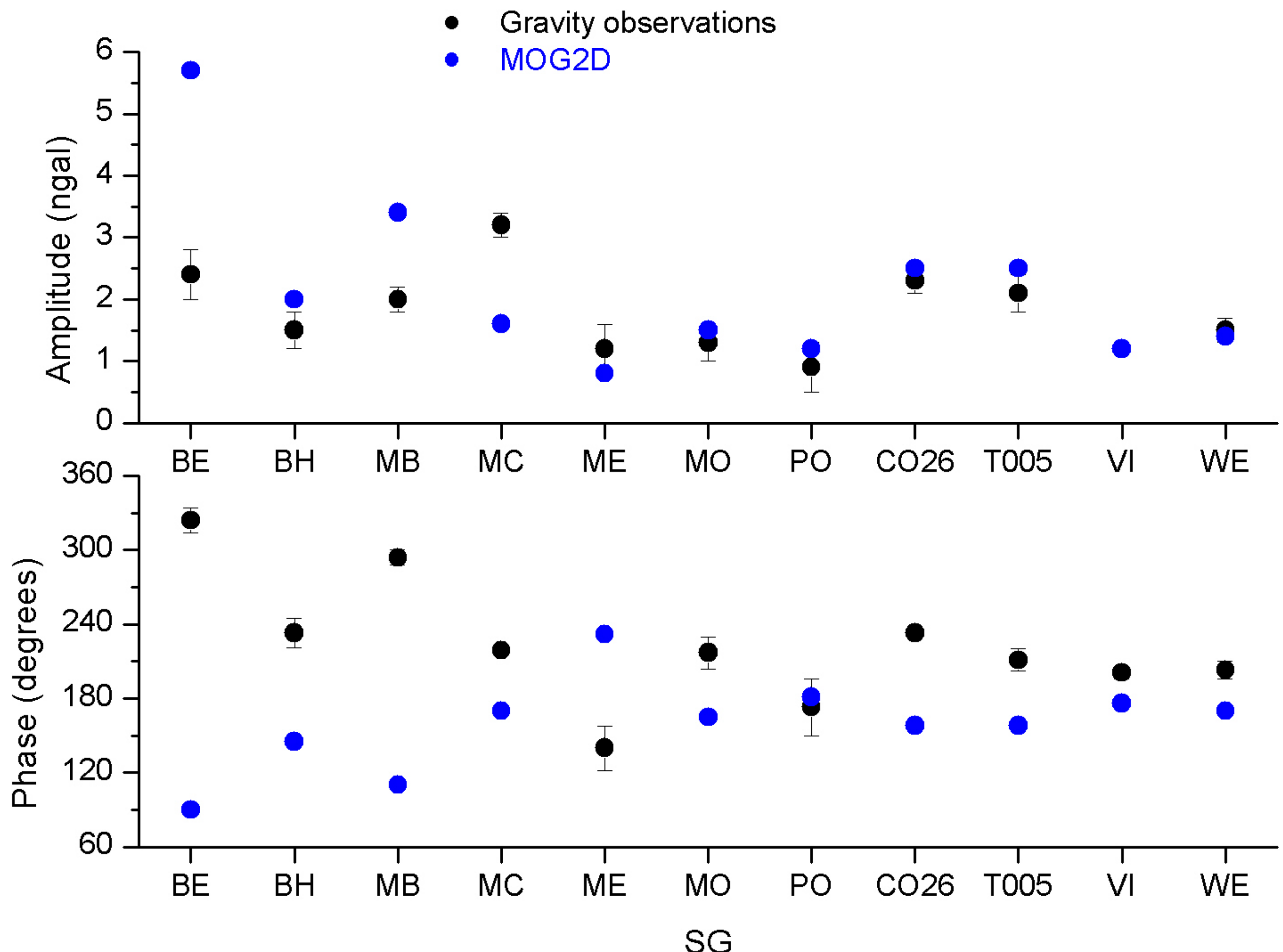


SG observations and MS4 tidal loading

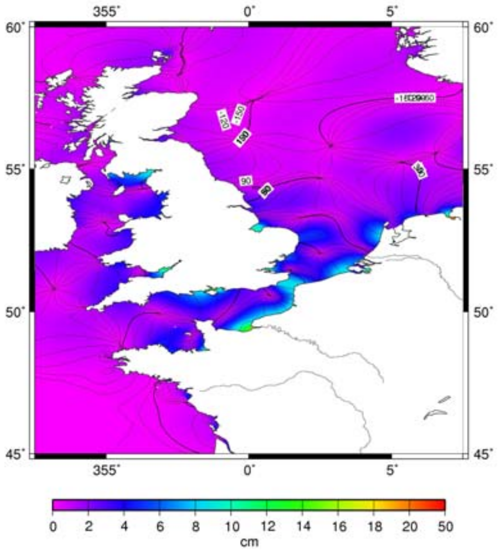


RMS differences with TG

- 6.0 cm

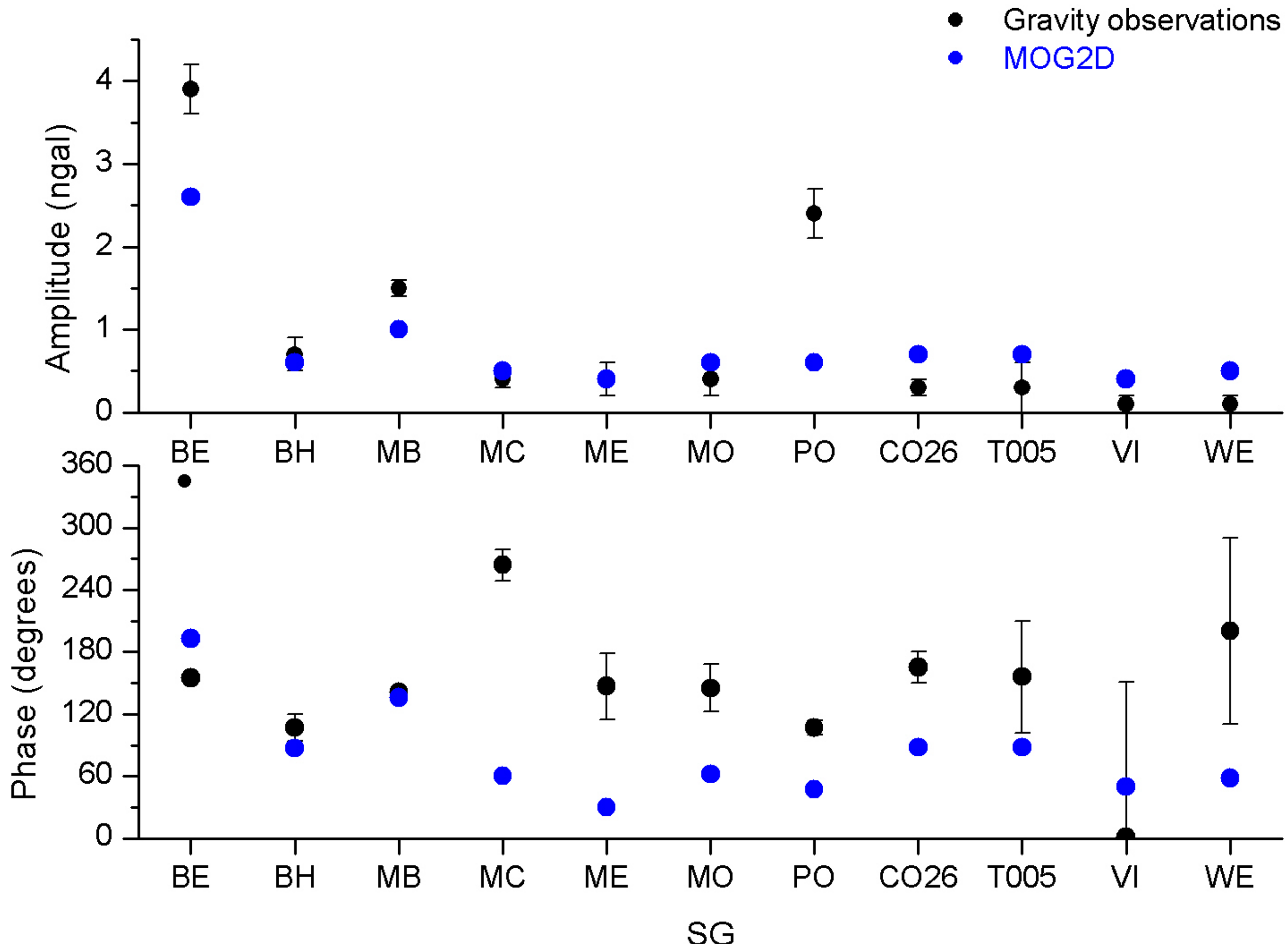


SG observations and M6 tidal loading



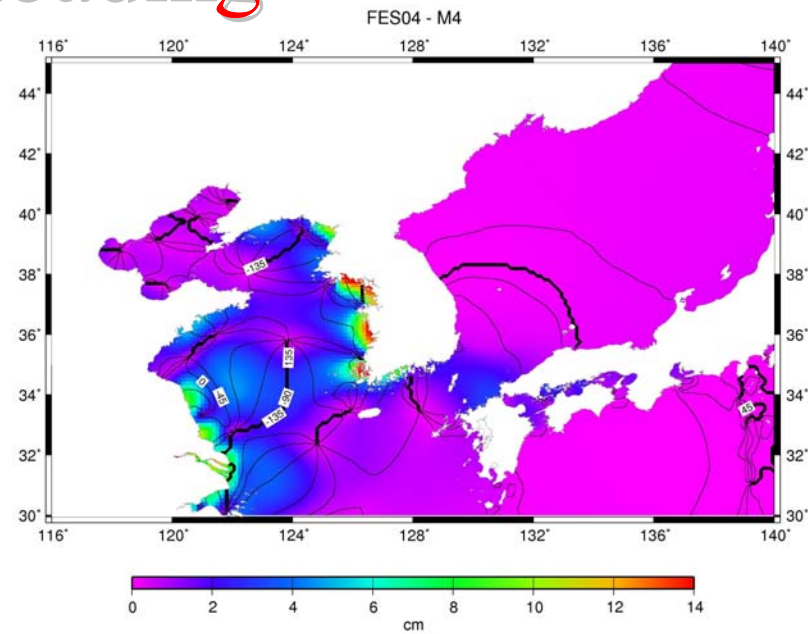
RMS differences with TG

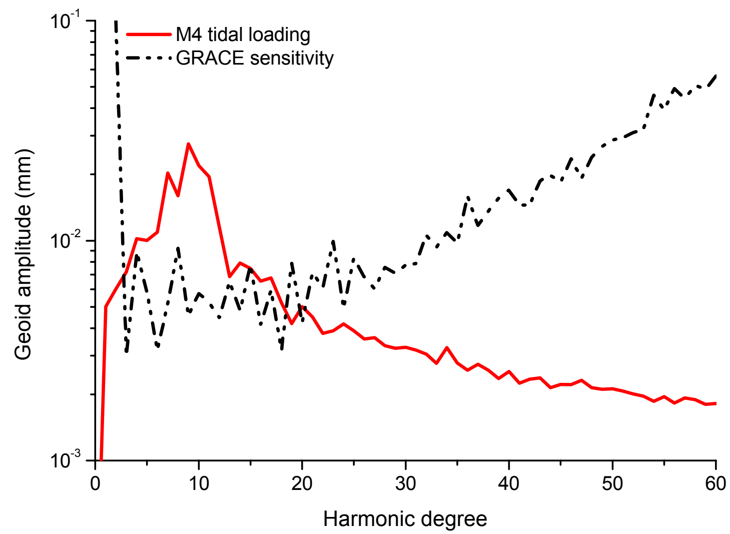
- 3.7 cm



SG observations and non-linear ocean tidal loading

- Clear evidence of the non-linear tidal loading effects in all European superconducting gravimeters.
- Good agreement between loading estimates from the MOG2D tidal model and gravity observations, except for the stations closest to the coast (Brussels and Membach).
- Extension of this study to the Yellow Sea, thanks to the new stations in Asia.
- Significant contribution to gravity field variations (GRACE).





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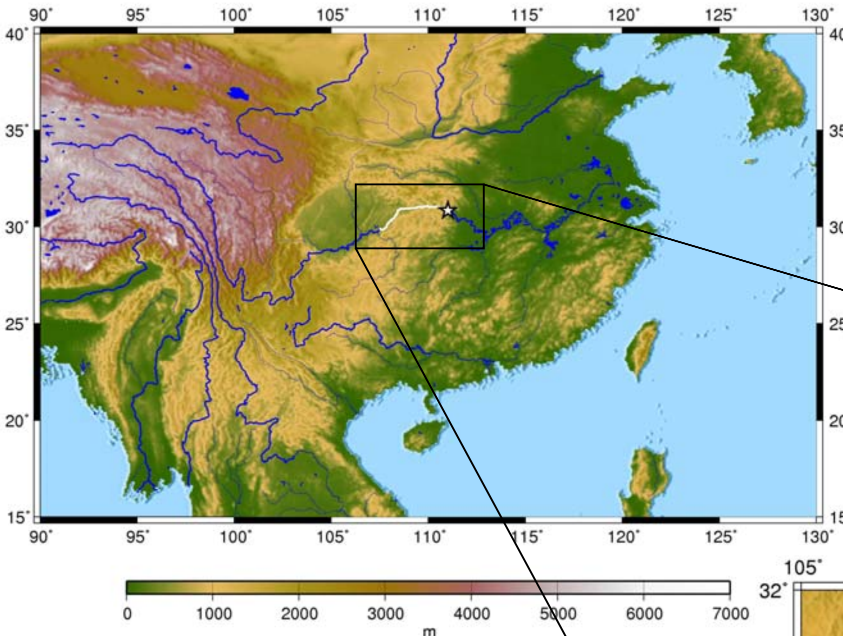
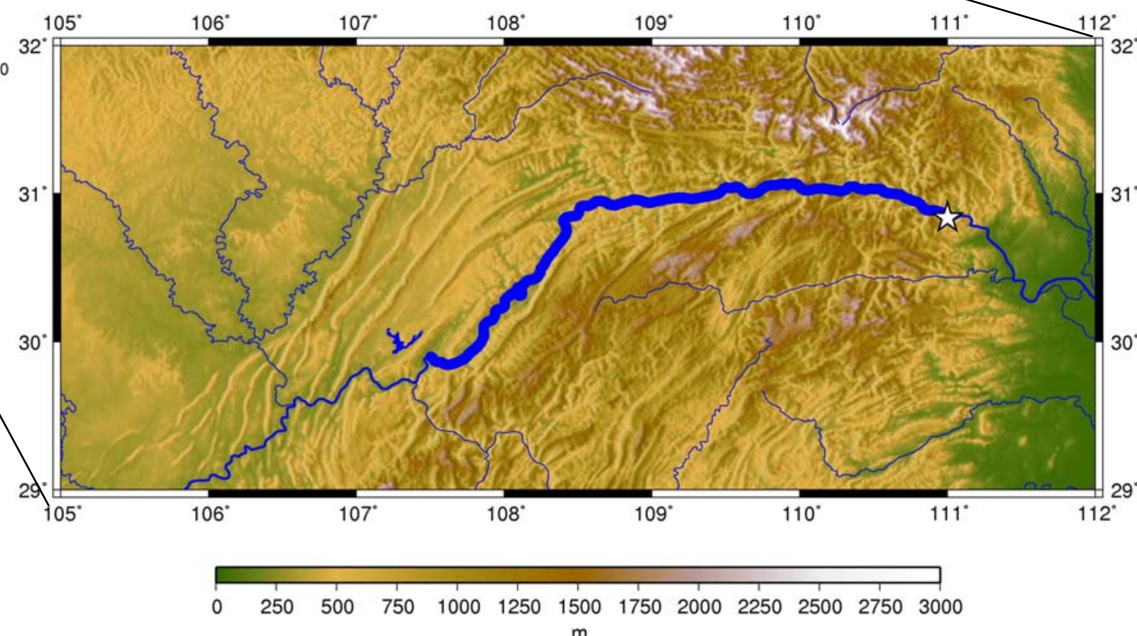
Validation of space gravity missions: Three Gorges Dam



Water level measurements with ICESat:

~70 m footprints every 170 m (along track)

~20 cm accuracy over flat surface



Three Gorges Dam

(water level & volume)

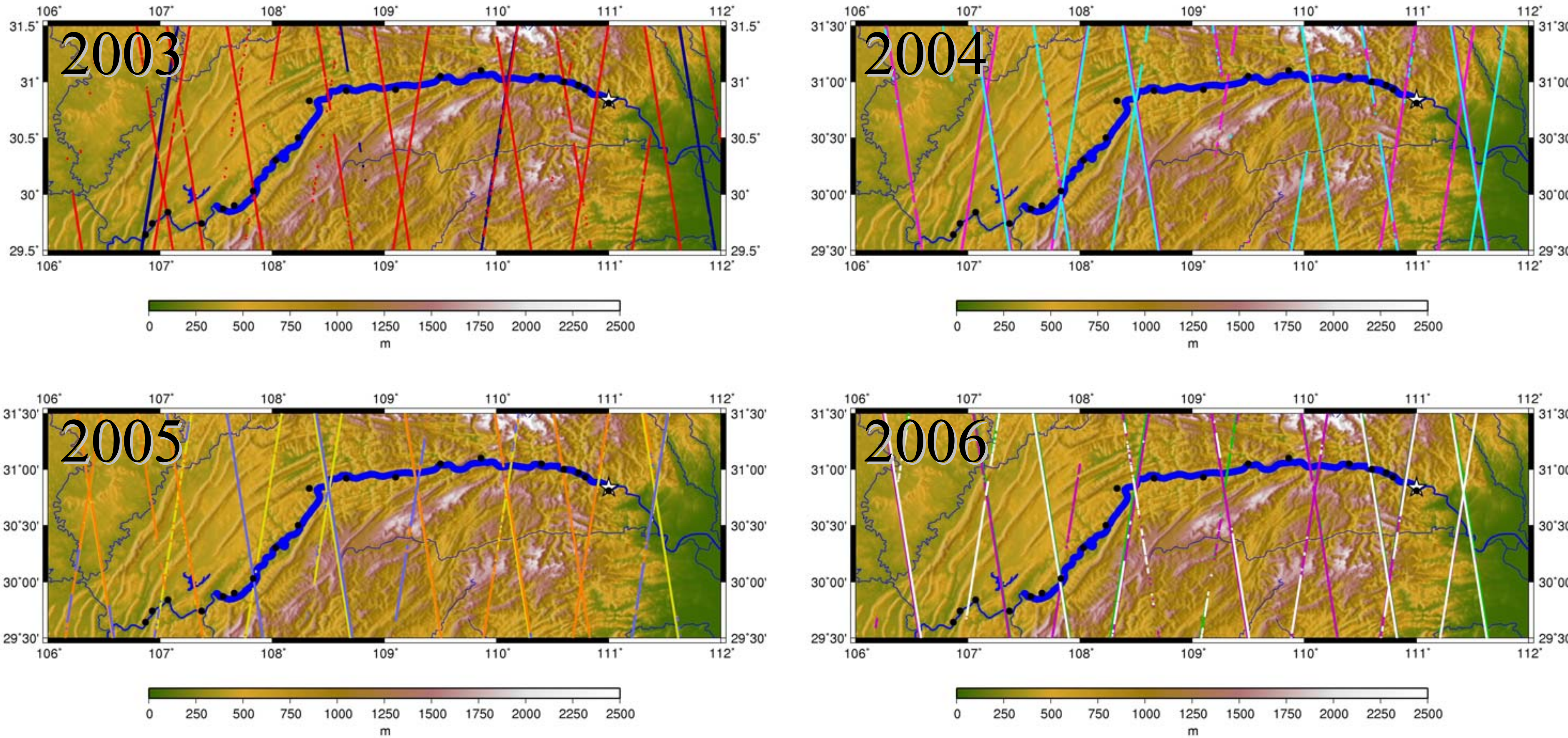
1998: 55 m

2003: 135m, 17.15 km3

2006: 156m, 22.8 km3

2009: 175m, 39.3 km3

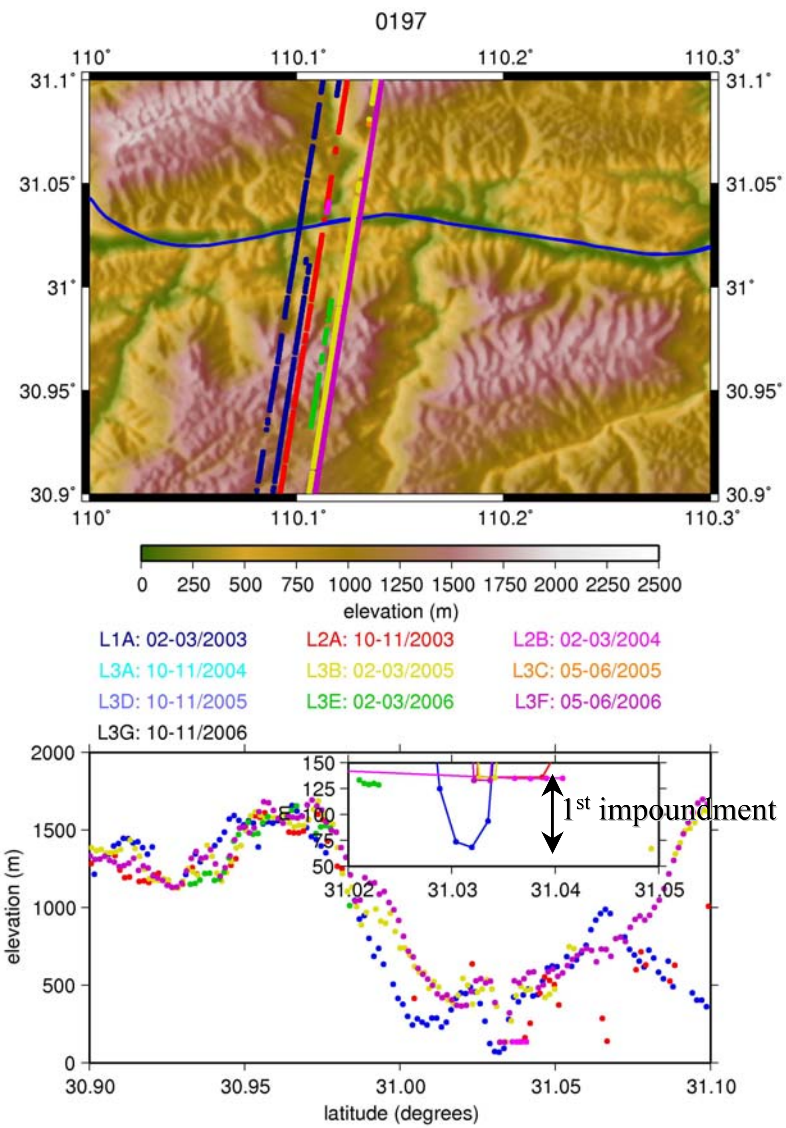
ICESat profiles across the Yangtze river

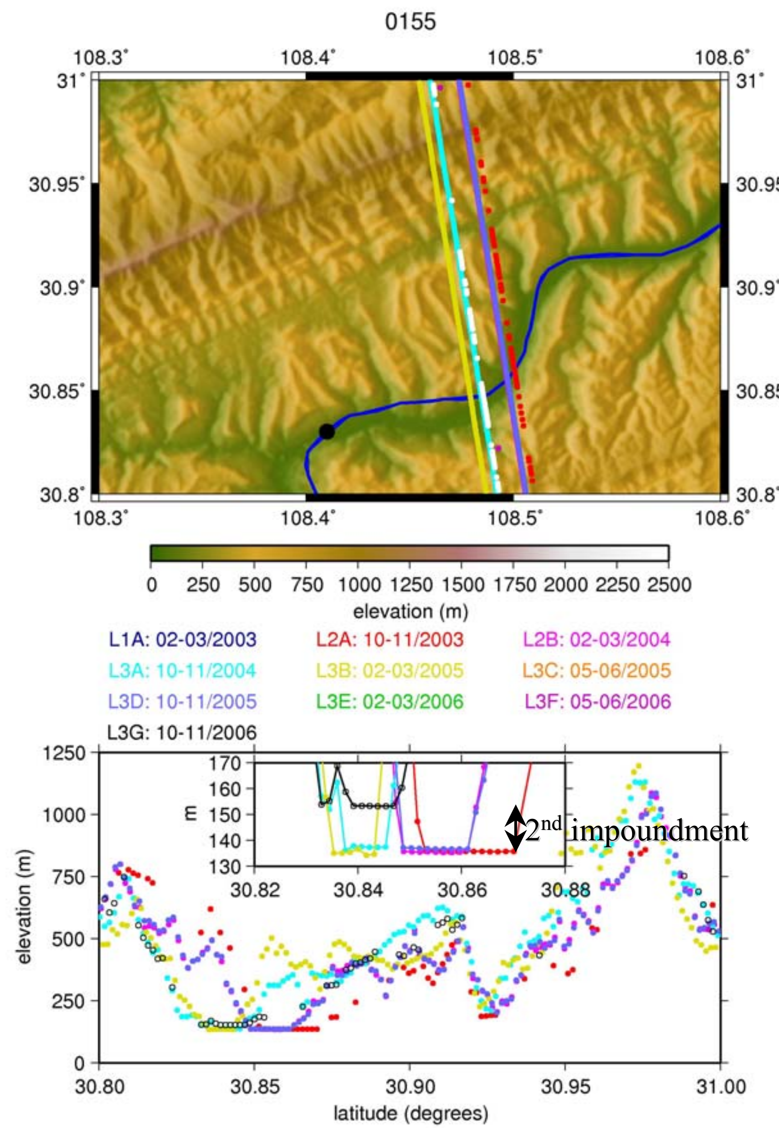


L1A: 02-03/2003
L2A: 10-11/2003
L2B: 02-03/2004
L3A: 10-11/2004
L3B: 02-03/2005
L3C: 05-06/2005
L3D: 10-11/2005
L3E: 02-03/2006
L3F: 05-06/2006
L3G: 10-11/2006

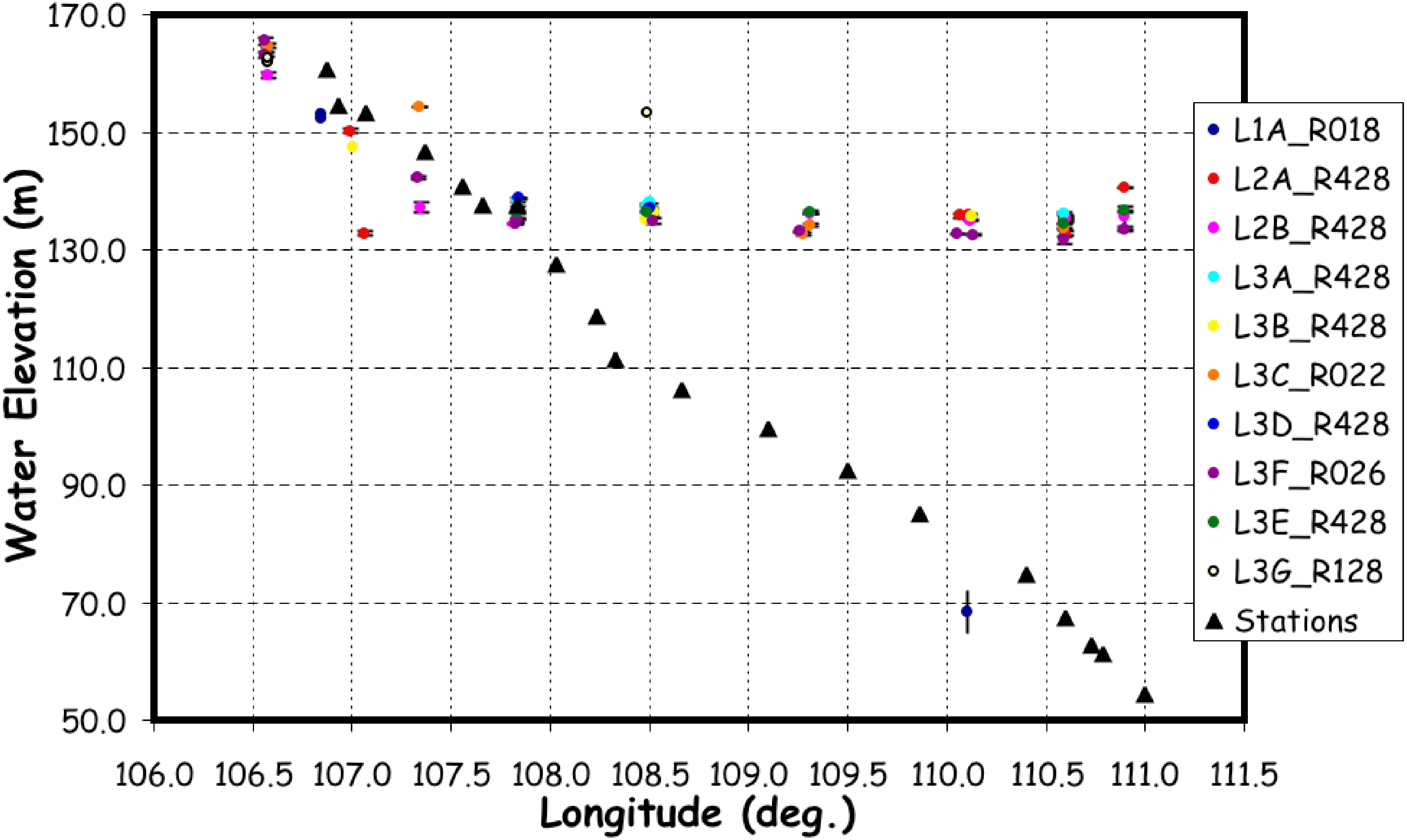
from Carabajal *et al.*, 2006.

ICESat profiles across the Yangtze river

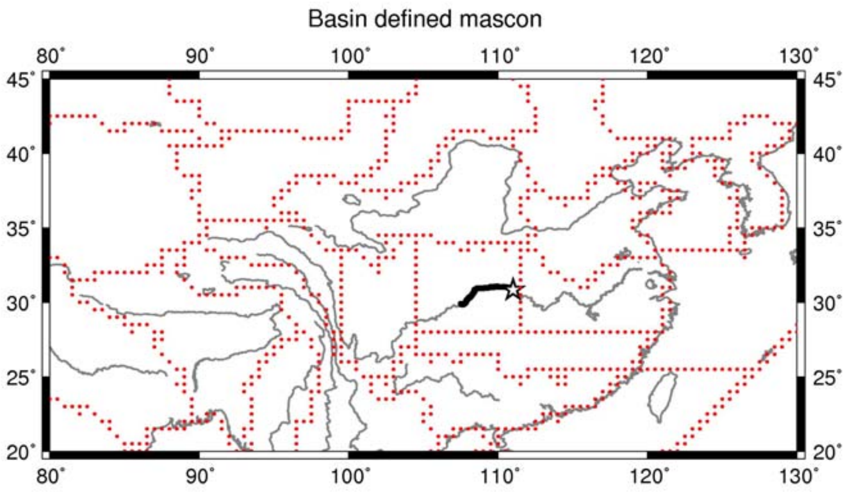


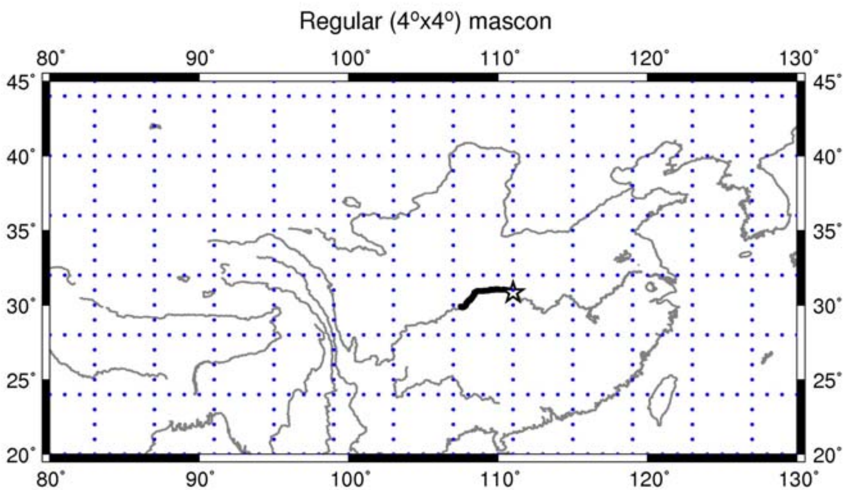


Water level observations from ICESat



“Mascon” solutions

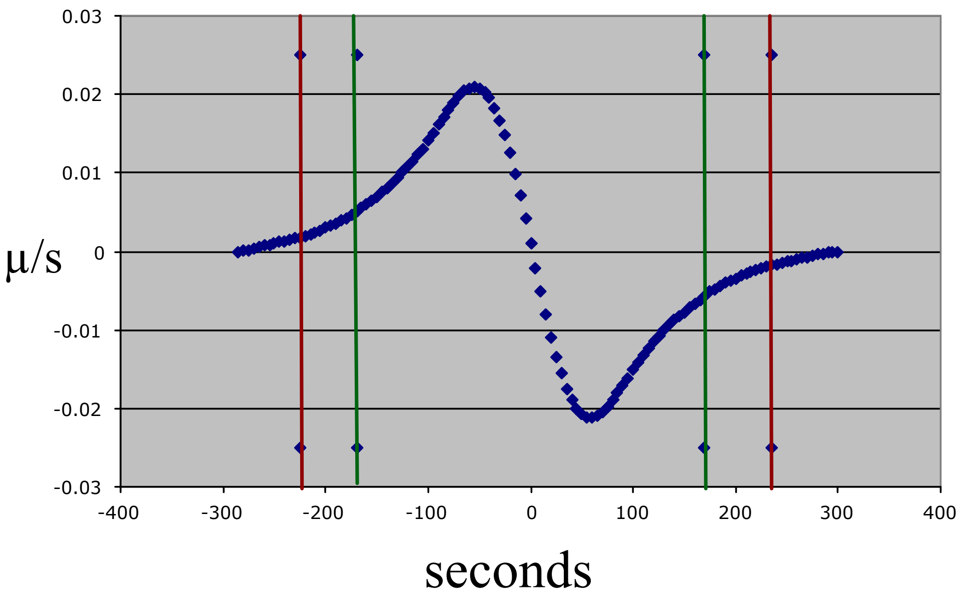




<u>2 different mascon solutions:</u>

- From River basin database (TRIP)
- Regular 4°x4° grid

No, 150 km and 250 km spatial constraints.

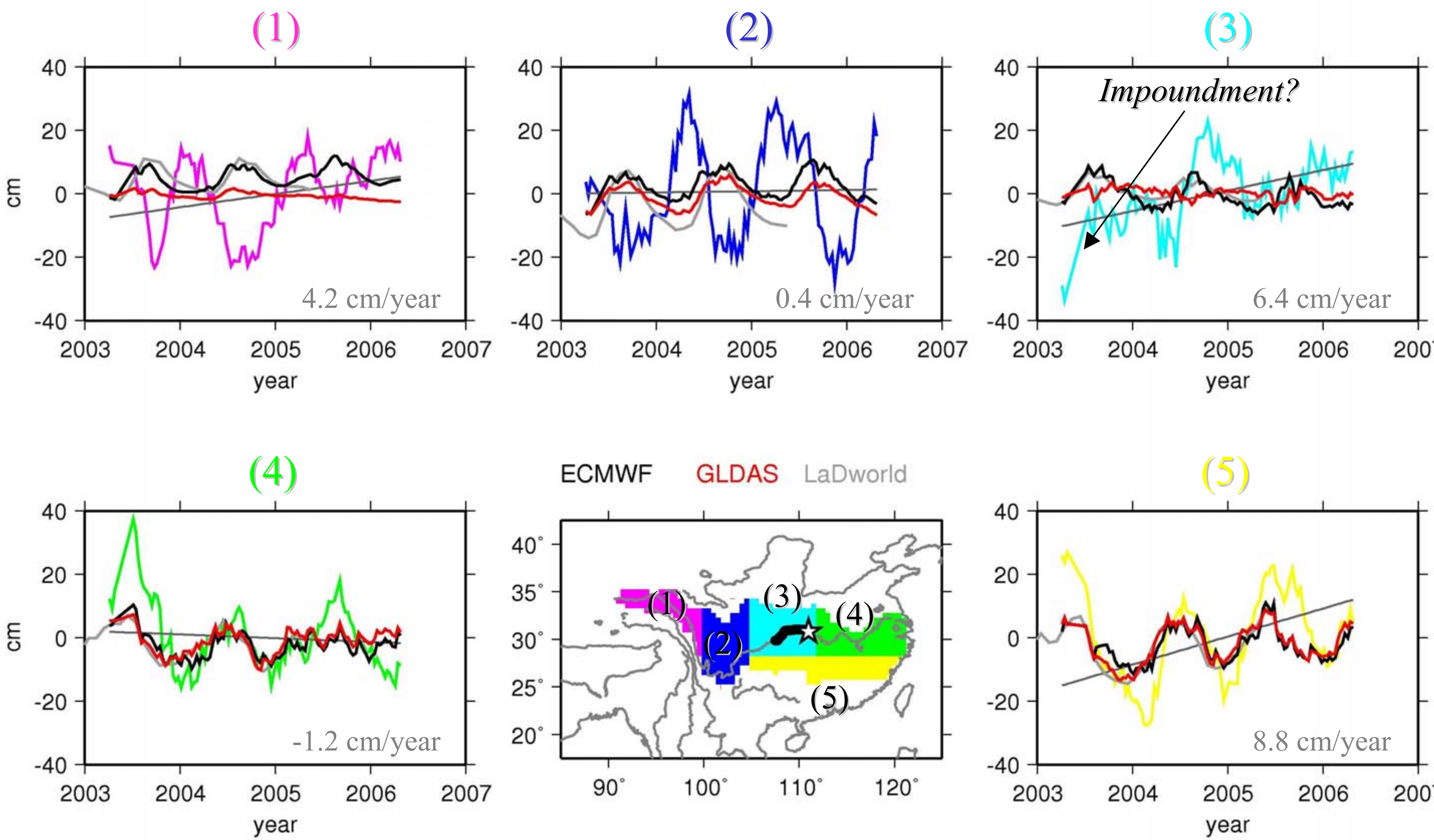


KBRR Simulation of Direct Overflight of 5 cm of Water in 4°x4°Mascon.

Threshold occurs ±225 seconds or ±14° in latitude from center of Mascon.

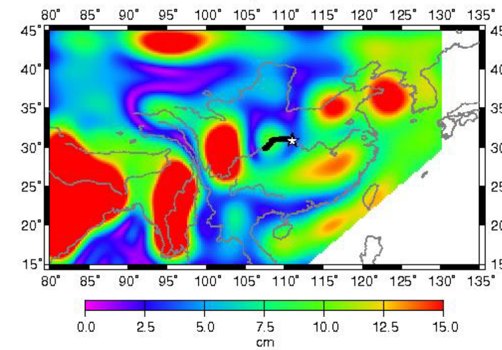
90 % of signal occurs ±170 seconds or ±11° in latitude from center of Mascon.

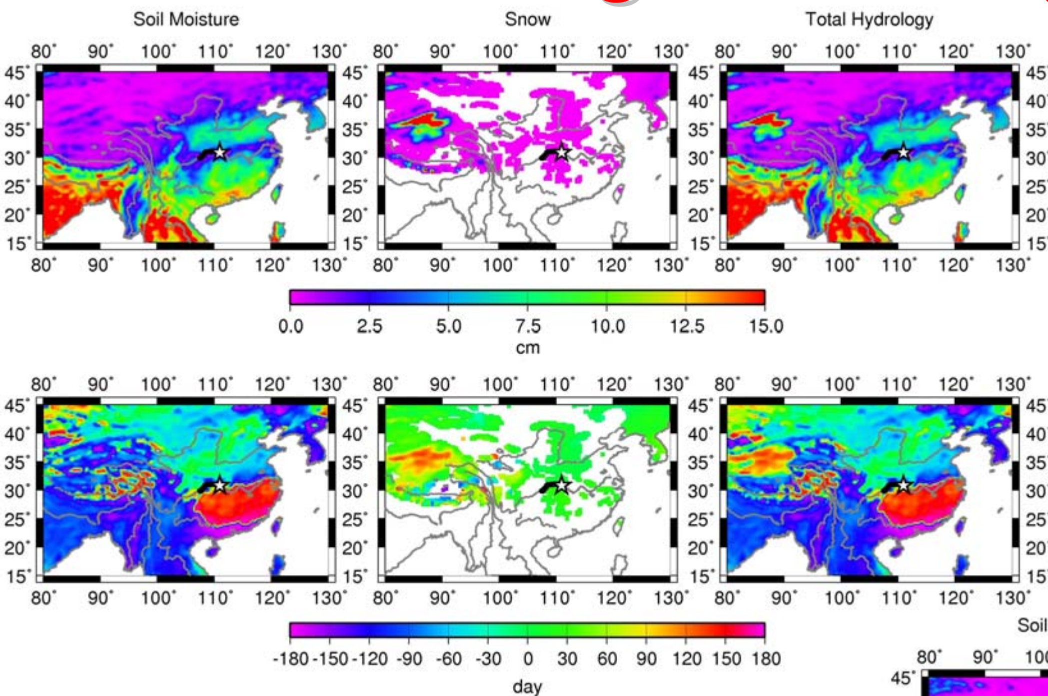
Mascon solution over the Yangtze basin



Annual signal from hydrology models

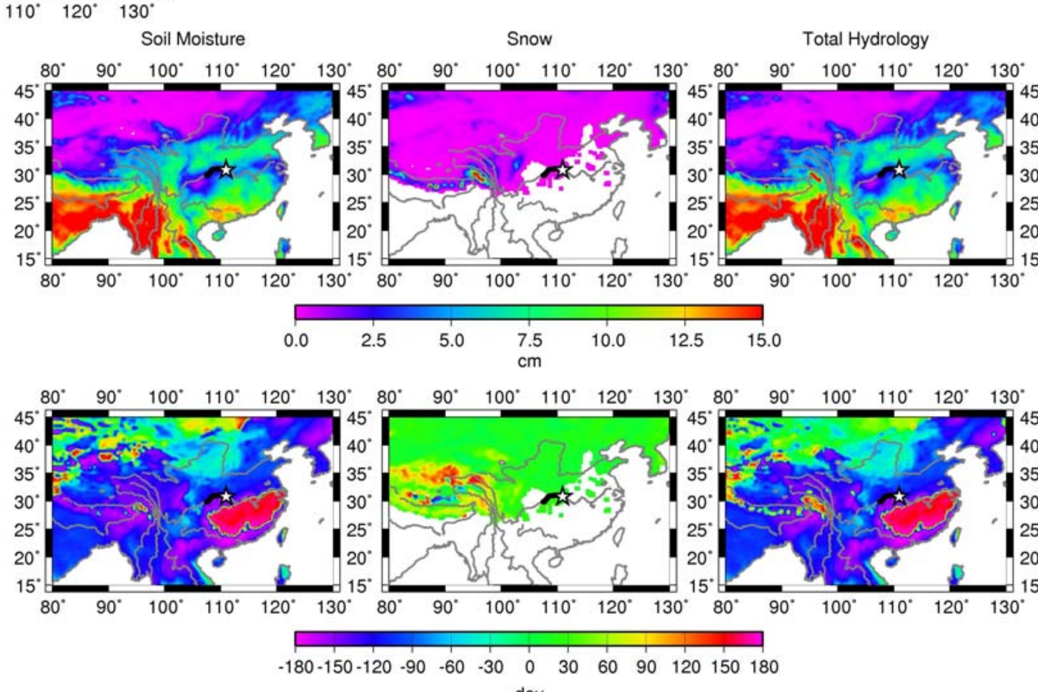
Observed amplitude





GLDAS

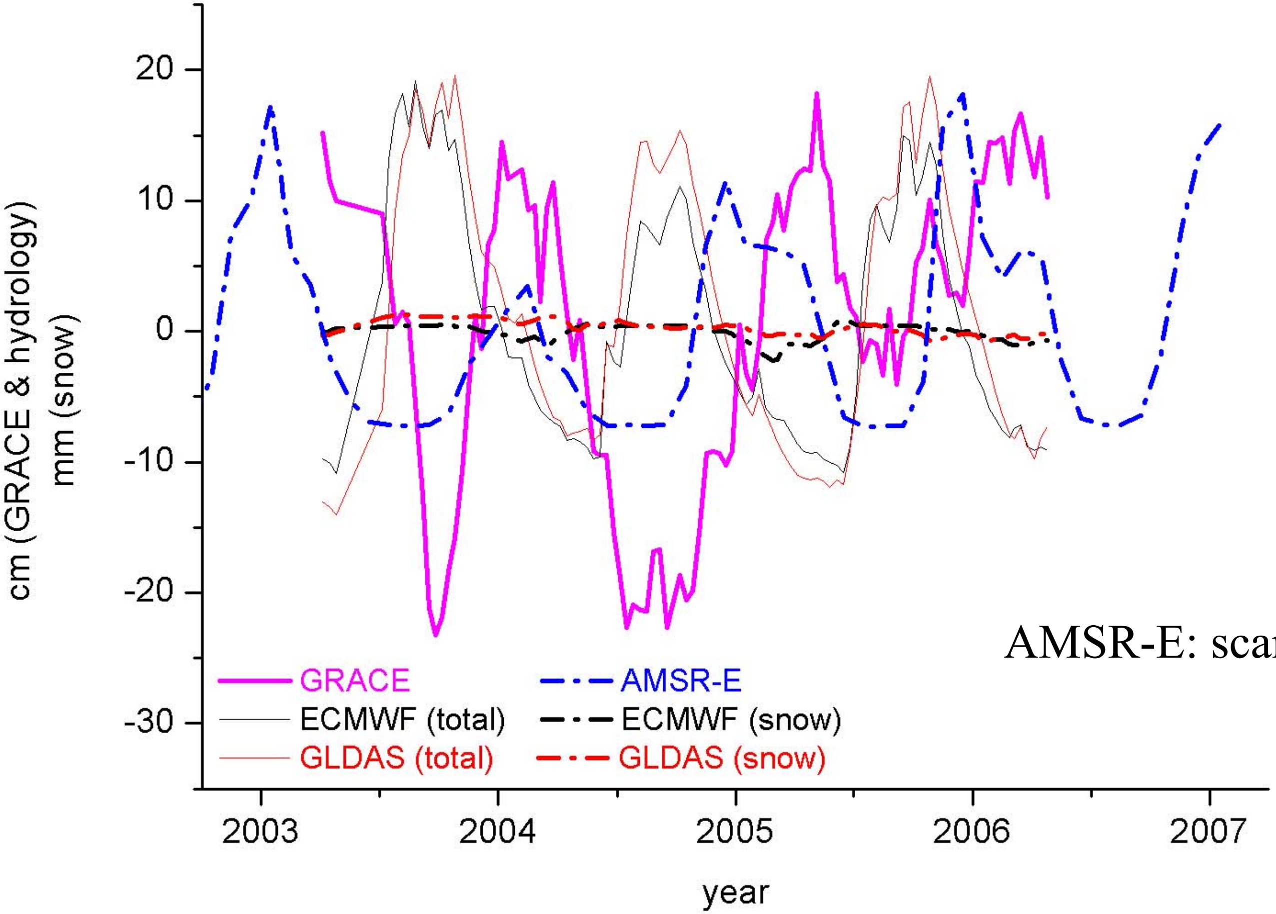
ECMWF

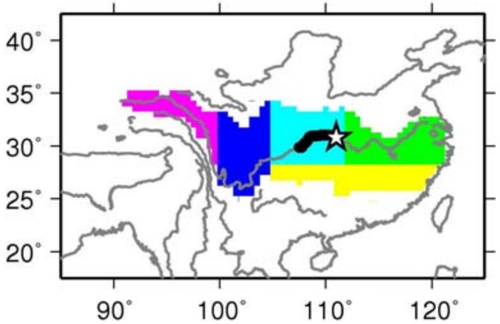


- Similar patterns for the soil moisture component.
- Large discrepancies (amplitude and phase) for the snow component.

Snow from AMSR-E, GLDAS and ECMWF

(Equivalent water height)

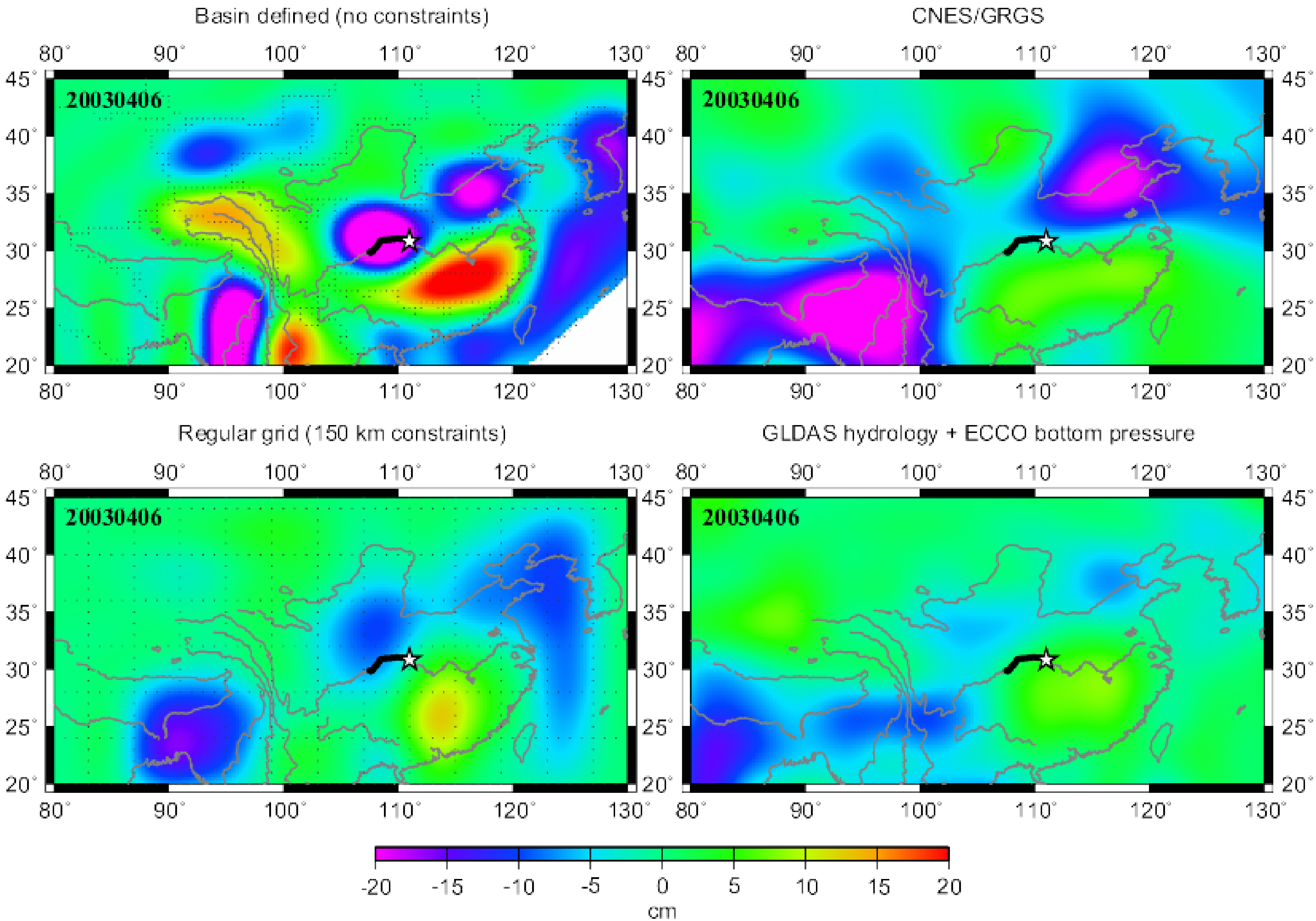




AMSR-E: scanning radiometer on AQUA

AMSR-E retrieved snow equivalent height:

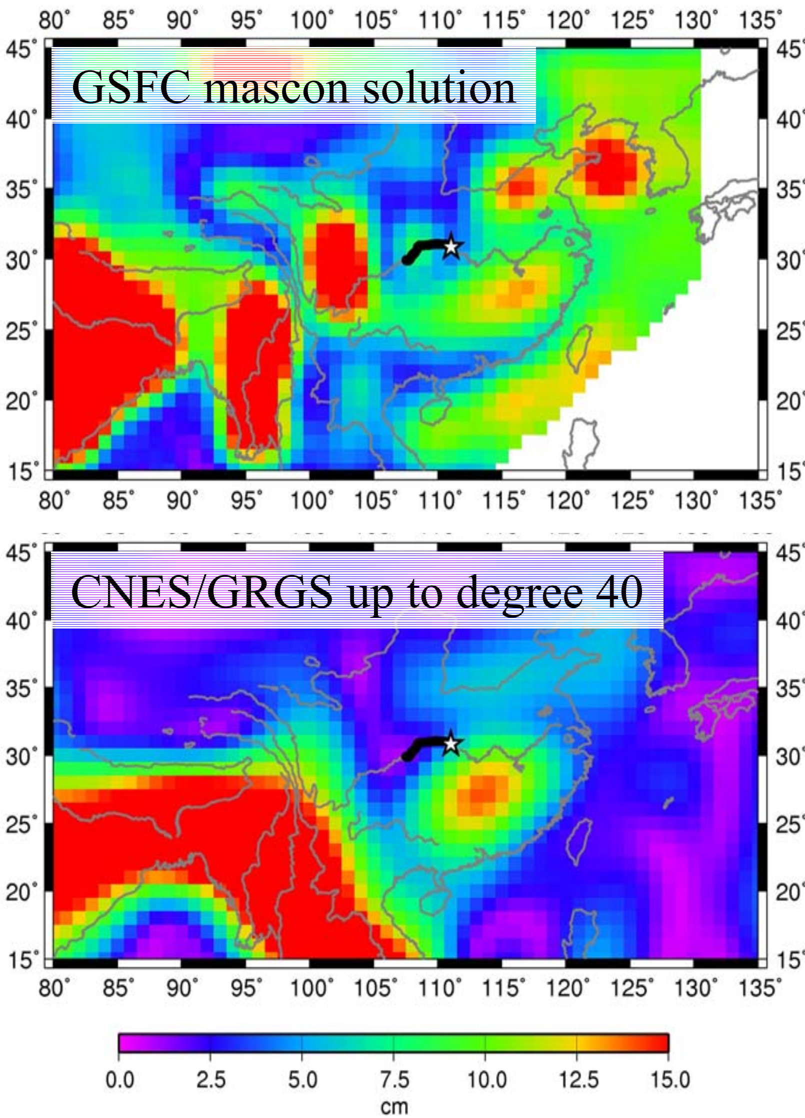
- 10 times smaller than GRACE solution, with a 1 to 2 month delay,
- 5 to 10 times larger than ECMWF and GLDAS snow model.



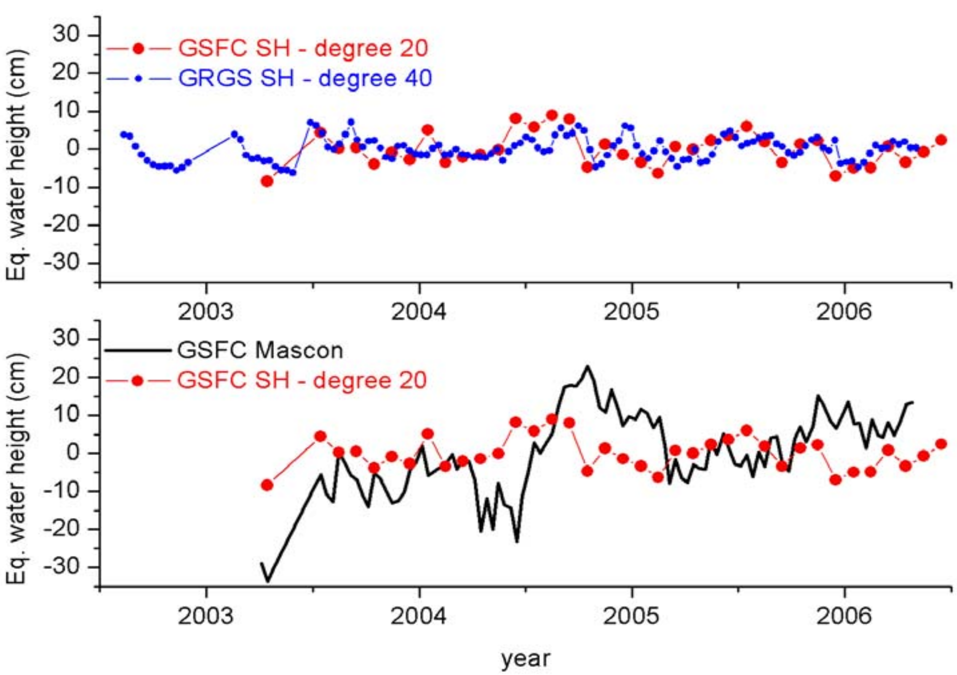
Basin defined (no constraints)
CNES/GRGS
Regular grid (150 km constraints)
GLDAS hydrology + ECCO bottom pressure
20030406
20030406
20030406
20030406
-20
-15
-10
-5
0
5
10
15
20
cm

"mascon" versus spherical harmonic solutions

Annual amplitude



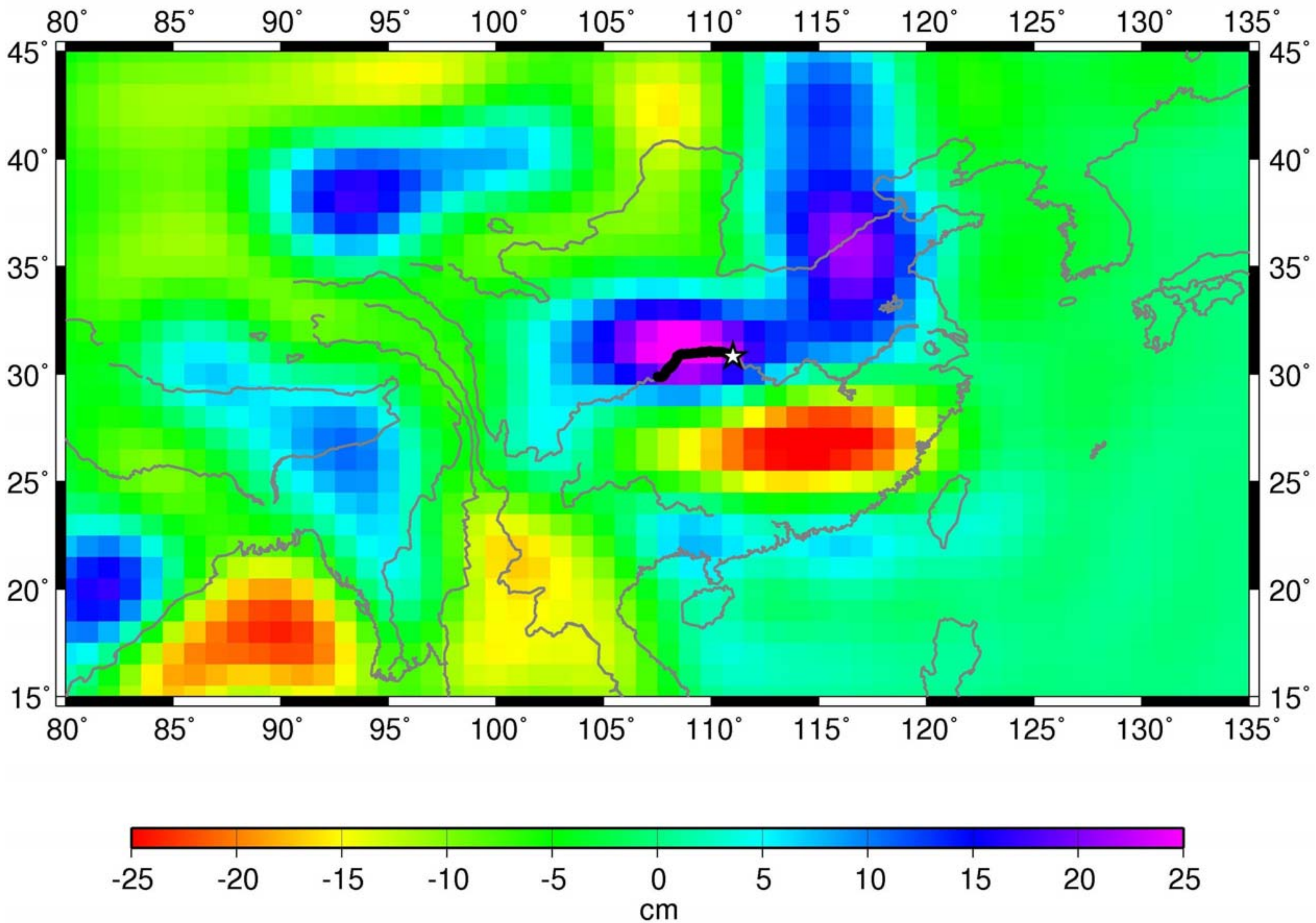
GSFC and CNES/GRGS SH solutions



Present-time SH solutions do not allow a complete recovery of small wavelength features, such as the TGD water impoundment (1km by 600 km).

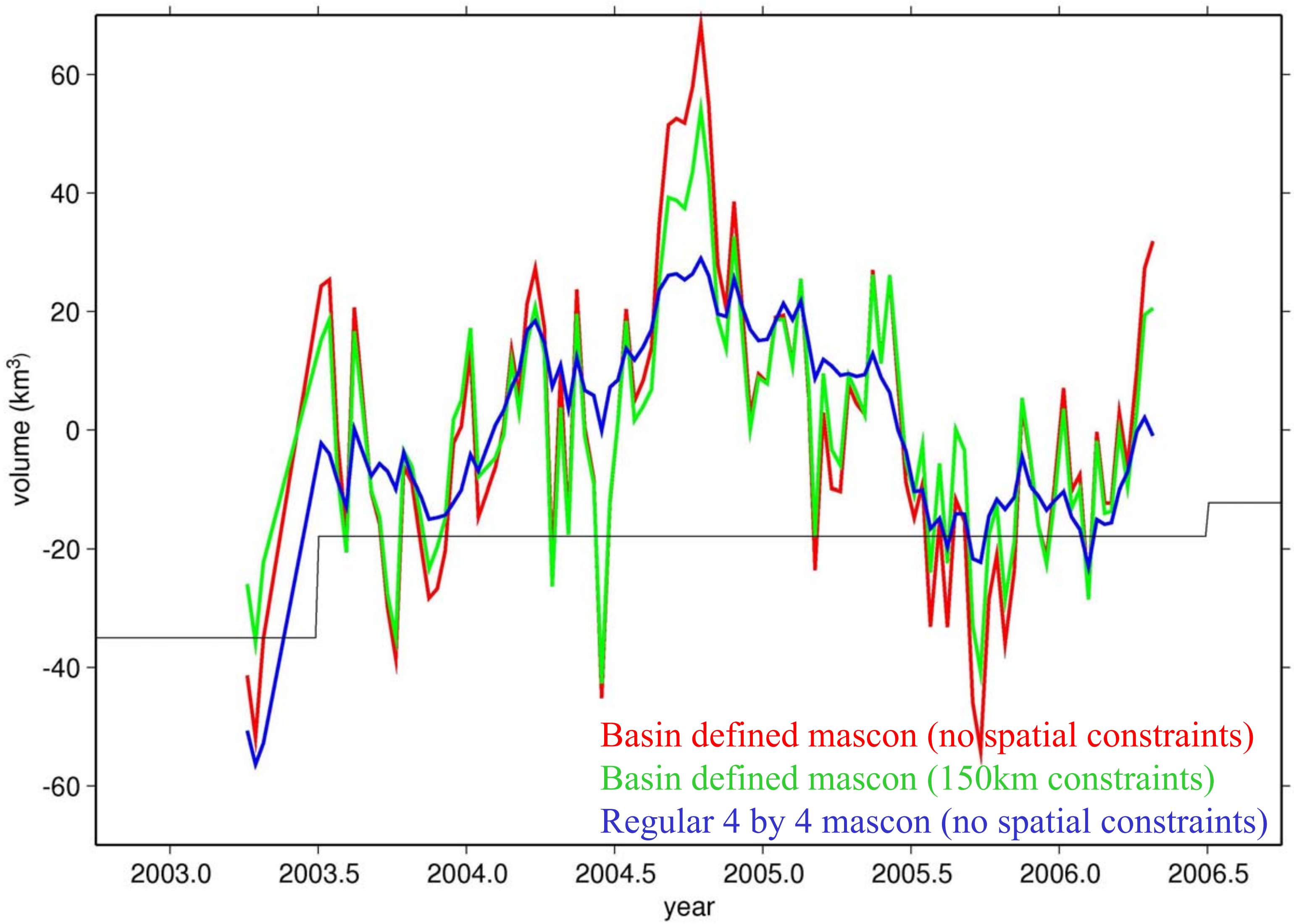
Differences between July and April 2003

slope, annual, semi-annual and 161 days (S2 aliasing) removed



Volume of water retrieved by GRACE

slope, annual, semi-annual and 161 days (S2 aliasing) removed



Three Gorges Dam impoundment signal

- At the present time, only mascon solutions can retrieve the TGD impoundment signal, as SH solutions have to be truncated at least to degree ~ 30 (~ 800 km wavelengths).
- There is a significant disagreement between global hydrology models and GRACE for short wavelengths (less than 2000 km).
- Large differences for the snow components between hydrology models, AMSR-E and GRACE (upstream regions of the Yangtze river).
- Extend the solutions prior to April 2003, and up to now (2nd water impoundment in September/October 2006).
- Precise estimates (~ 10 cm) of water levels thanks to ICESat.

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Conclusion & Prospects

- Precise computation of surface fluid loading effects using general circulation models (atmosphere, ocean, continental hydrology):
  - 3-D atmosphere,
  - Combination of global hydrology models (seasonal timescales) and “local” measurements (higher frequencies),
  - Operational/Standard.
- Space gravity missions (GRACE, GOCE):
  - Still a need to improve atmospheric and oceanic corrections (dealiasing),
  - Validation of (sub-)river basin scales derived hydrology, especially for mid-latitude regions.