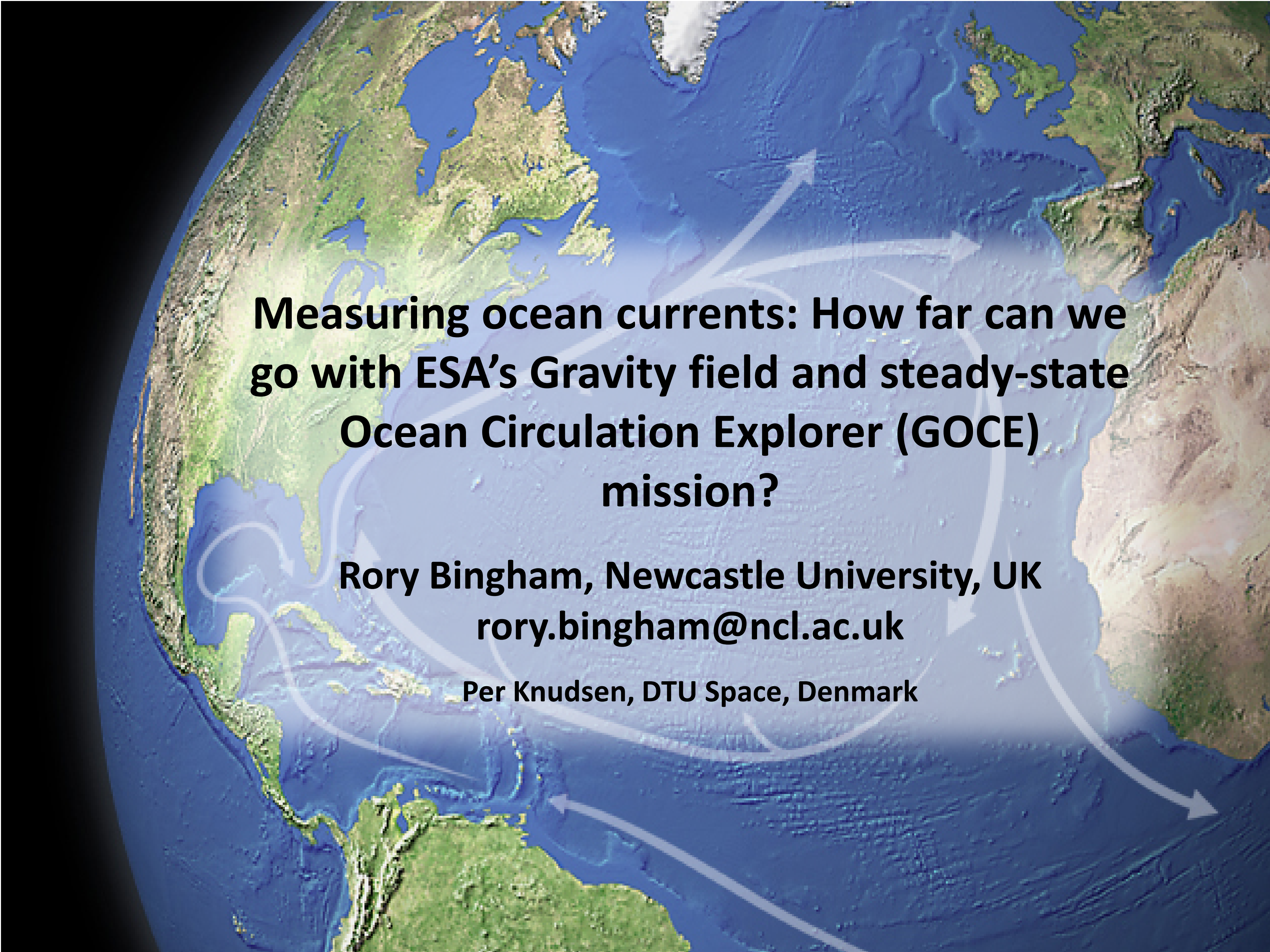

Measuring ocean currents: How far can we go with ESA's Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission?

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Per Knudsen, DTU Space, Denmark

The geodetic method

The geodetic method for estimating geostrophic surface currents:

$$\eta = H - N$$

η, Mean dynamic topography (MDT)

H, Mean sea surface (MSS)

N, Geoid

$$u = -\frac{f}{g}\frac{\partial \eta}{\partial y}, \quad v = \frac{f}{g}\frac{\partial \eta}{\partial x}$$

$H, N: \quad \mathrm{O}(100\,\mathrm{m})$

$\eta: \mathrm{O}(1\,\mathrm{m})$

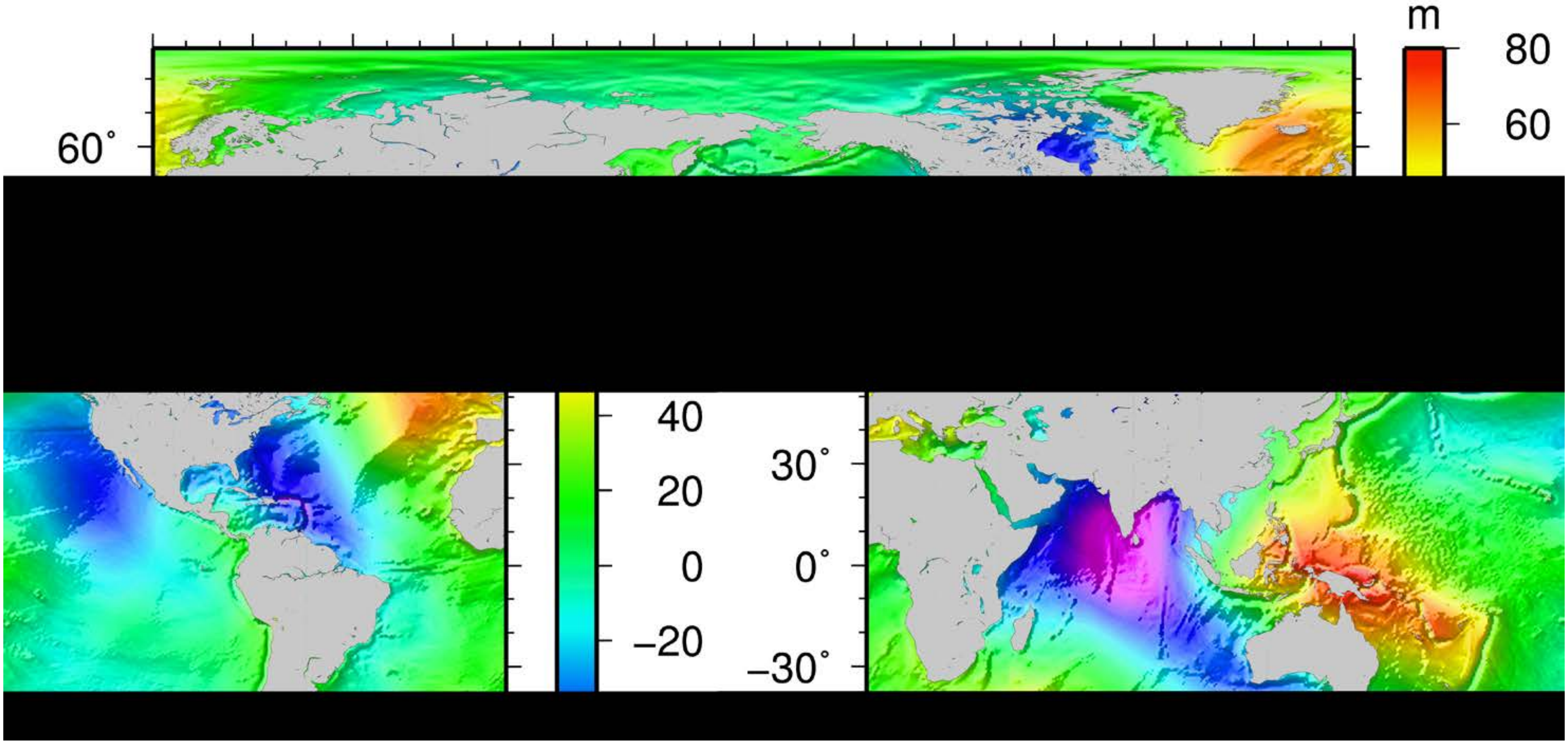
Geoid spherical harmonic model

The mean sea surface

Satellite altimetry provides a beautifully detailed time-mean picture of the ocean's surface

Resolution:
2 arc mins / 2.5 km (mid-latitudes)

Dominated by static-equilibrium response of ocean to Earth's gravity field: The geoid



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The time-mean sea surface as measured by satellite altimetry

GOCE: What is it?

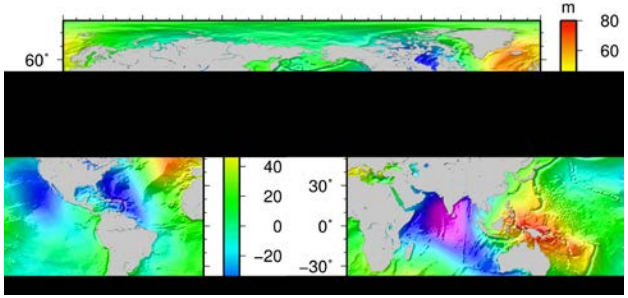
Key features:

- Six three-axis gradiometers
- Low orbit – 254 km
- Ion propulsion – drag free
- Streamlined
- SST and star tracker
- 40 km spacing at equator
- 1 cycle = 61 days = 979 orbits
- Gravity model accuracy < 1cm at 100 km
- Error covariance

Timeline:

- **17 Mar 09 – launch; alt=283km**
- 20 Mar 09 – early orbit phase completed; SSTI switched on; first science data
- 6 Apr 09 – electronic ion prop engine switched on; alt=280km, decay=190m/day
- 8 Apr 09 – gradiometer on and producing data
- 26 May 09 – drag free op. with ion engine and gradiometer working together
- **30 Sep 09 – in measurement mode and delivering data; alt=255km**
- **30 Jun 10 – First results L2 data – earth gravity models and gradients – released**
- 6 Sep 10 - GOCE recovers from telemetry glitch that had prevented the satellite from sending its scientific data to Earth for several weeks
- 3 Mar 2011 - Second EGM’s released
- 11 Nov 2011 – Third EGM’s released

The GOCE geoid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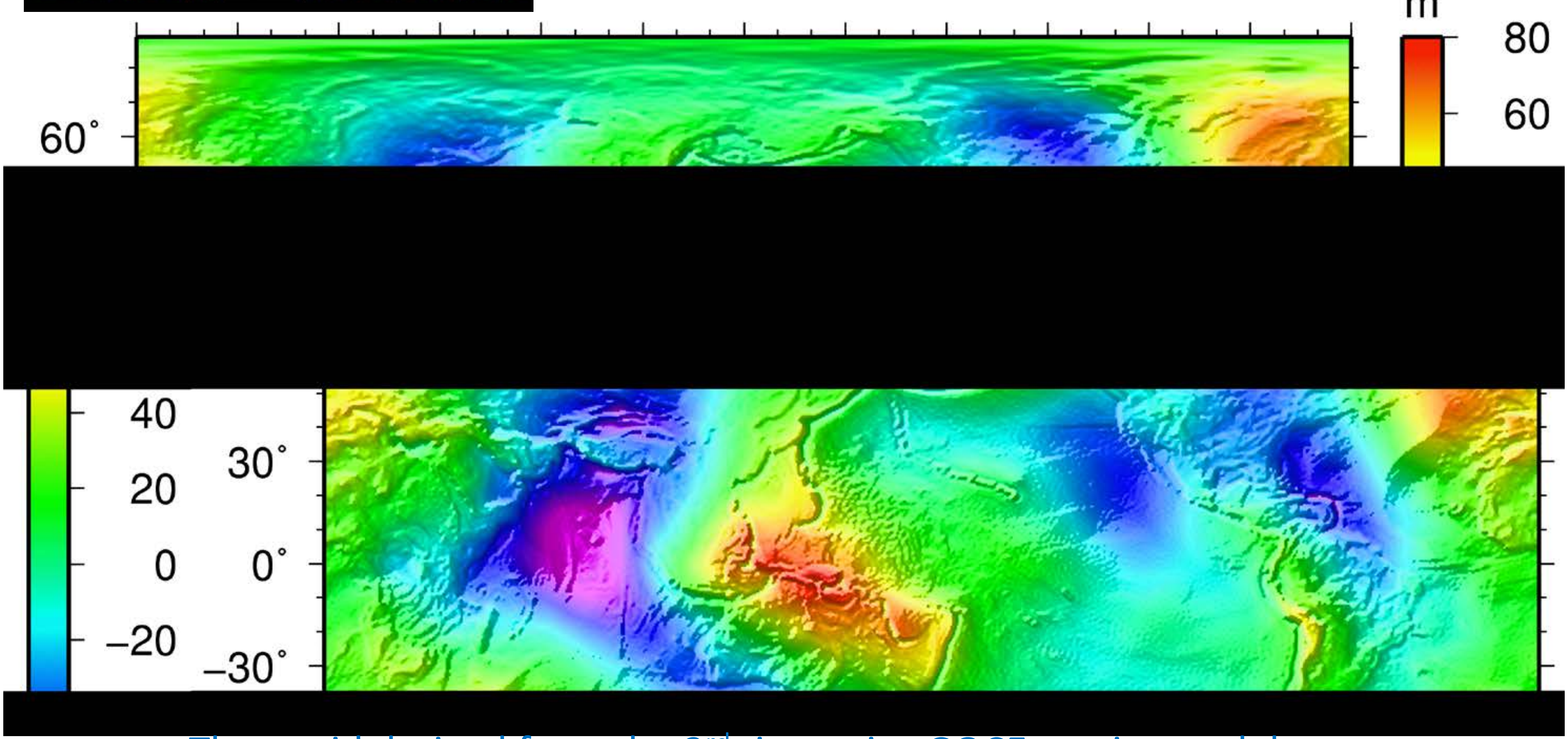
The time-mean sea surface as measured by satellite altimetry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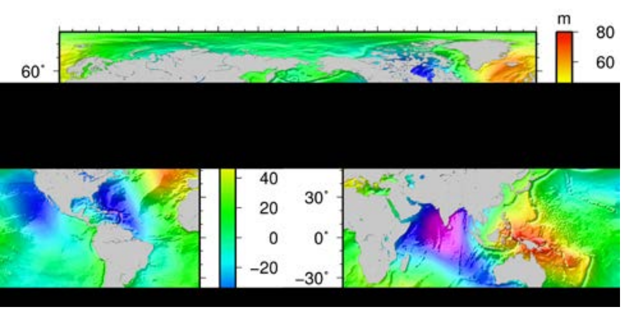
The geoid derived from the 3rd time-wise GOCE gravity model

The GOCE mean dynamic topography



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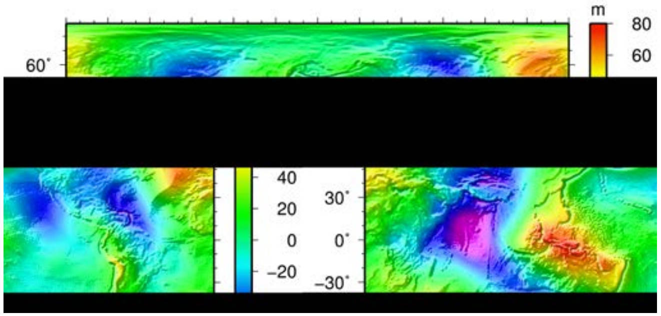

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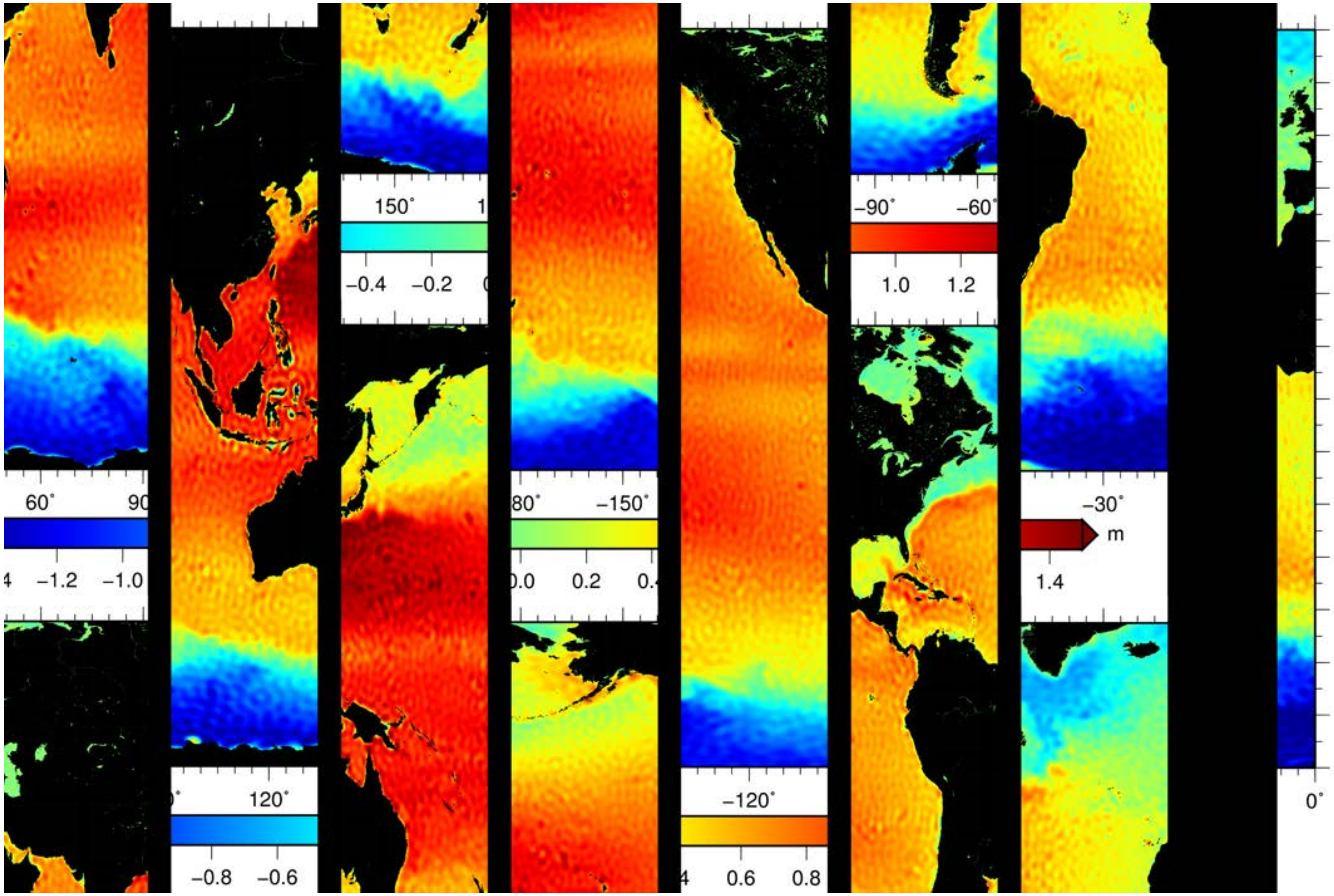
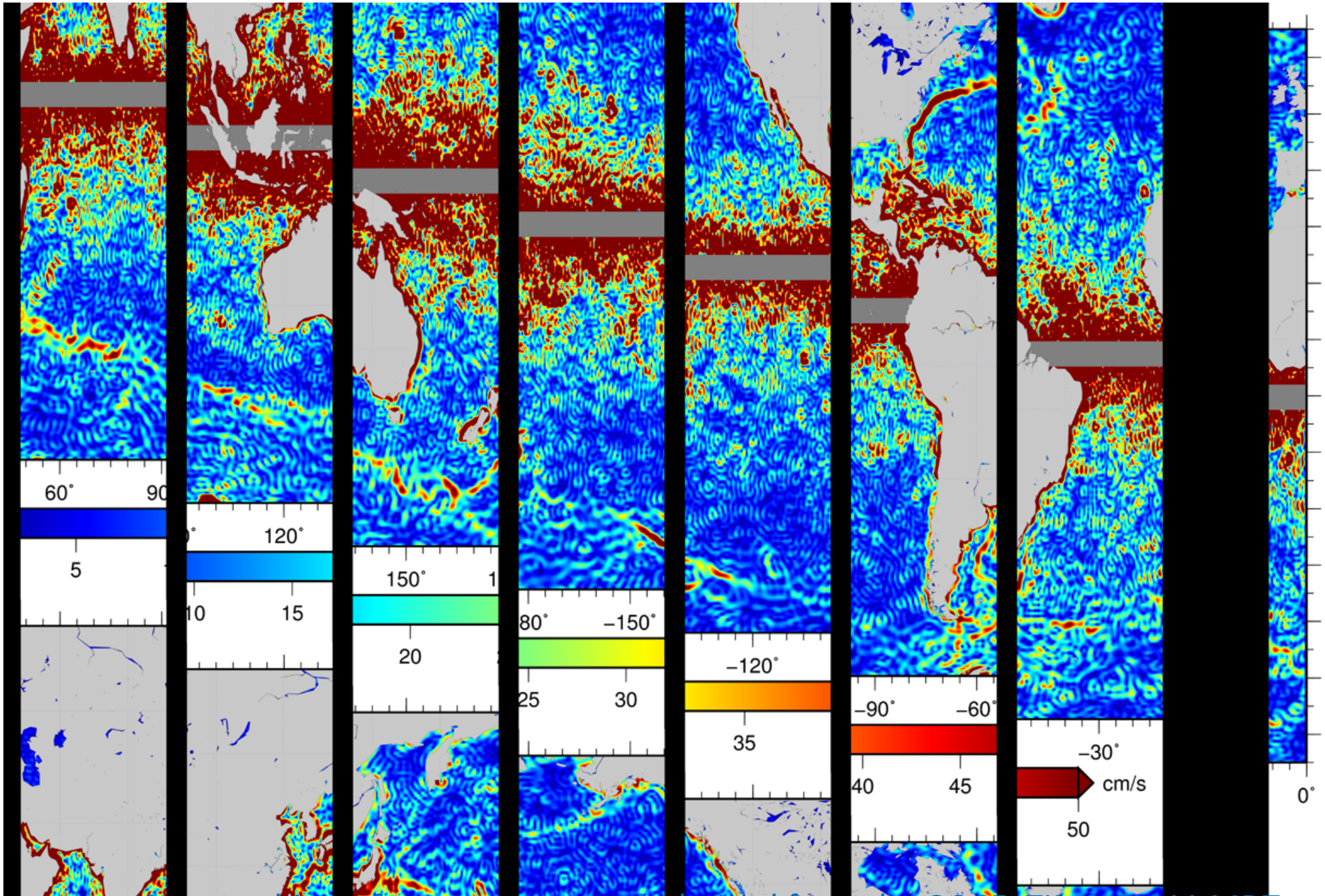
Subtracting the geoid from the MSS reveals the ocean’s mean dynamic topography (MDT)



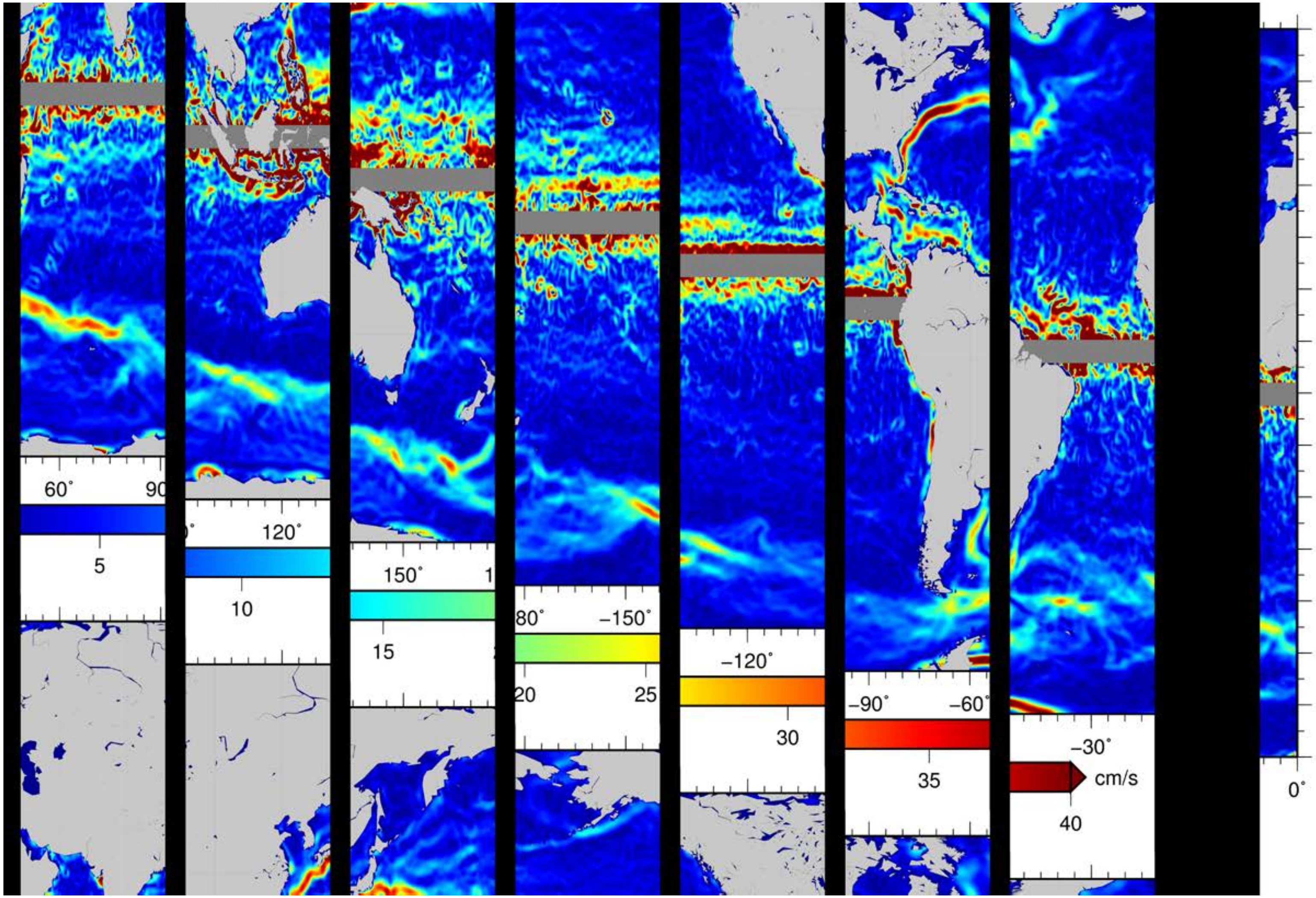
Geostrophic currents from GOCE



Geostrophic surface current speeds derived from the GOCE_TIM3-CLS11 MDT

$$U = \frac{f}{g}\sqrt{\left(\frac{\partial \eta}{\partial x}\right)^2 + \left(\frac{\partial \eta}{\partial y}\right)^2}$$

Geostrophic currents from GOCE

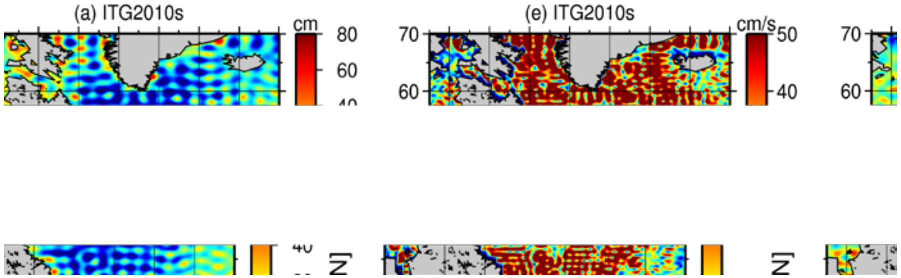


Geostrophic surface current speeds derived from the **filtered** GOCE_TIM3-CLS11 MDT

Progress so far: North Atlantic MDT and currents

GRACE (8 yrs)

GOCE (2 mnths)



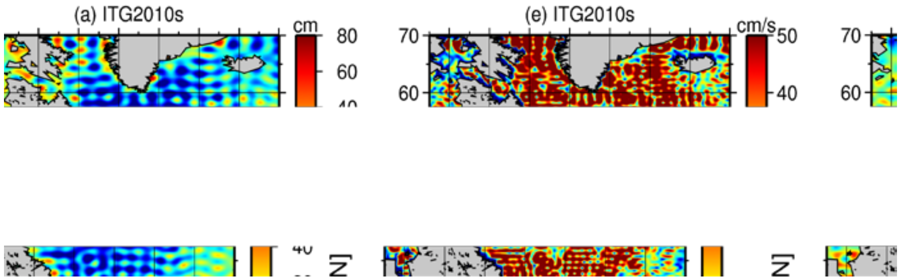
GOCE (1 yr)

Comparison at d/o=180 (111 km)

GOCE considerably less noisy

Some filtering still required

Progress so far: North Atlantic MDT and currents



Filtering

less noise

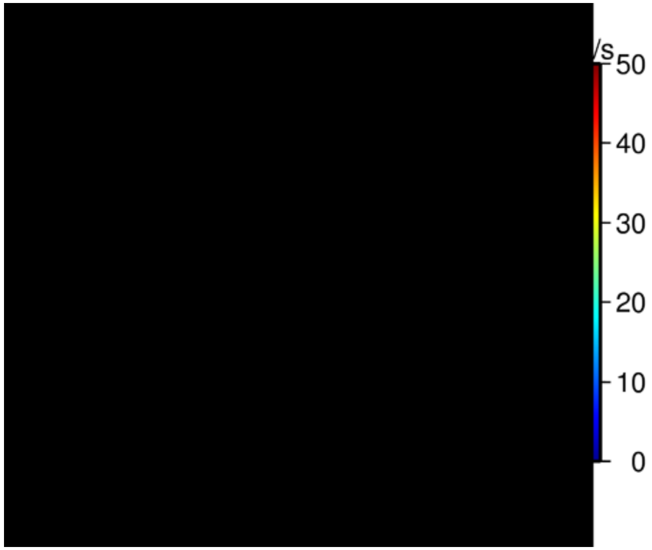
⇩

less filtering

⇩

better currents

Filtering



Progress so far: North Atlantic MDT and currents

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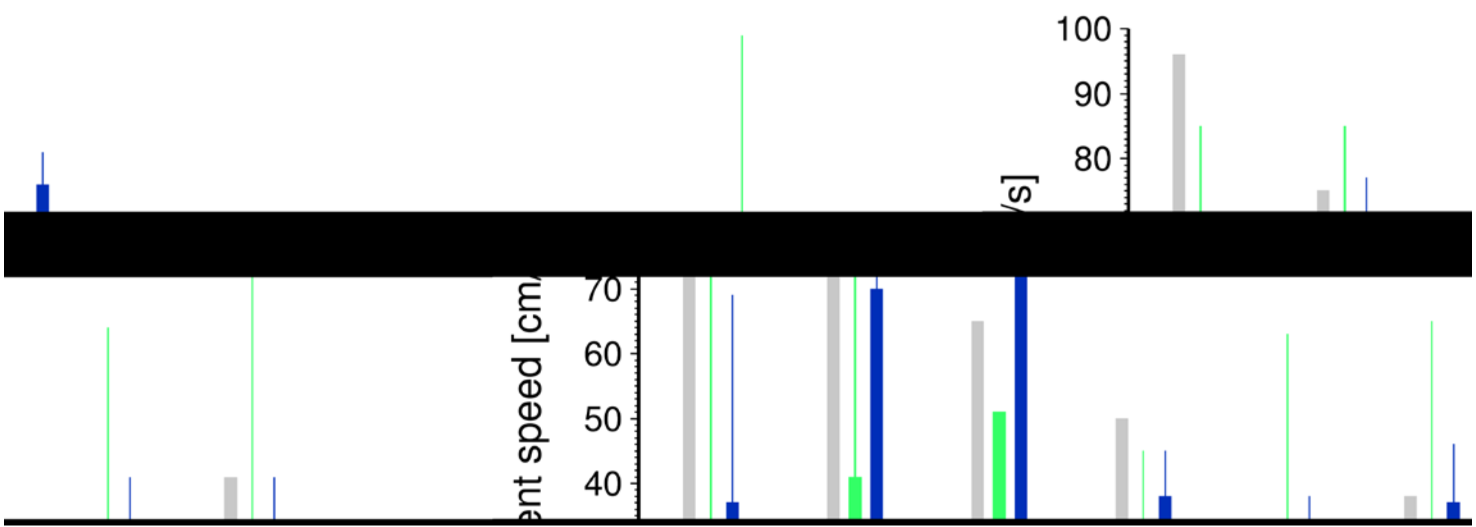

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Niiler (drifters)
GRACE (ITG2010s)
GOCE (TIM3)

A comparison of current speeds at 9 locations in the North Atlantic

GOCE: How far can we go?

- The spatial resolution of GOCE is the limiting factor:

Relationship between spatial res. (S) max degree (L):

$$S = \frac{20000}{L}\ \text{km}$$

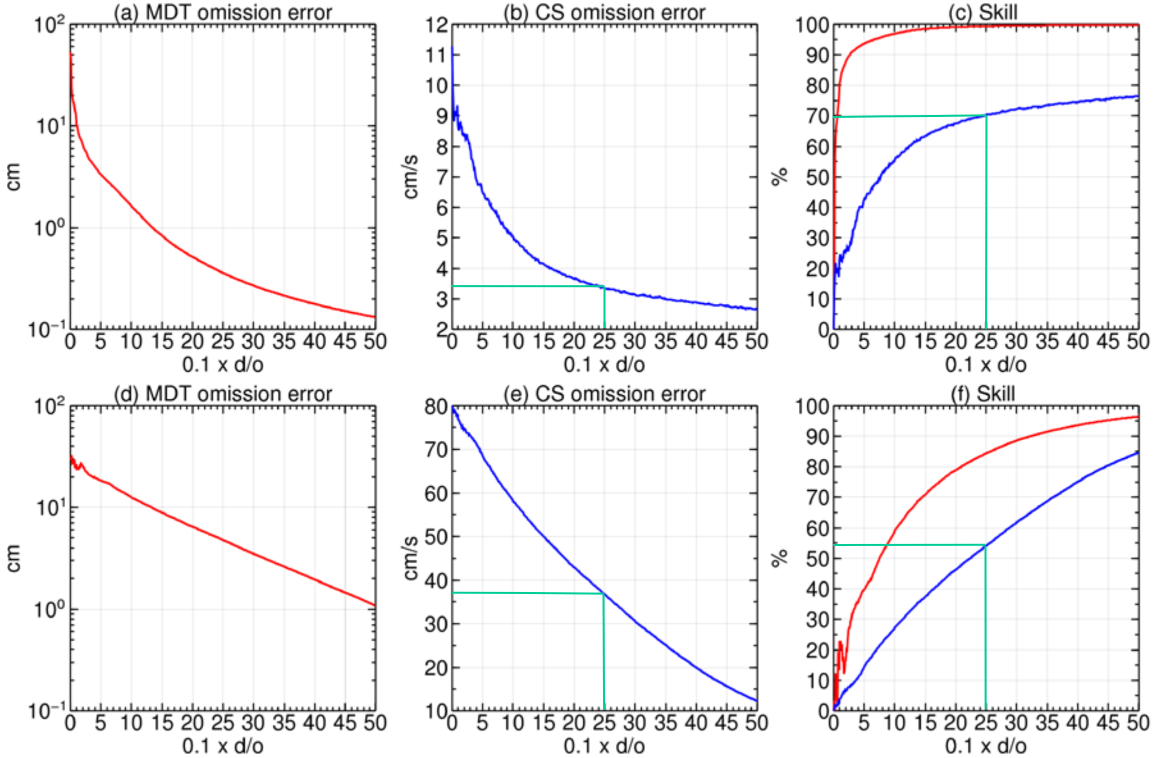
Spatial resolution of GOCE:

$$L = 250 \Rightarrow S = 80\ \text{km}$$

SH degrees in MSS:

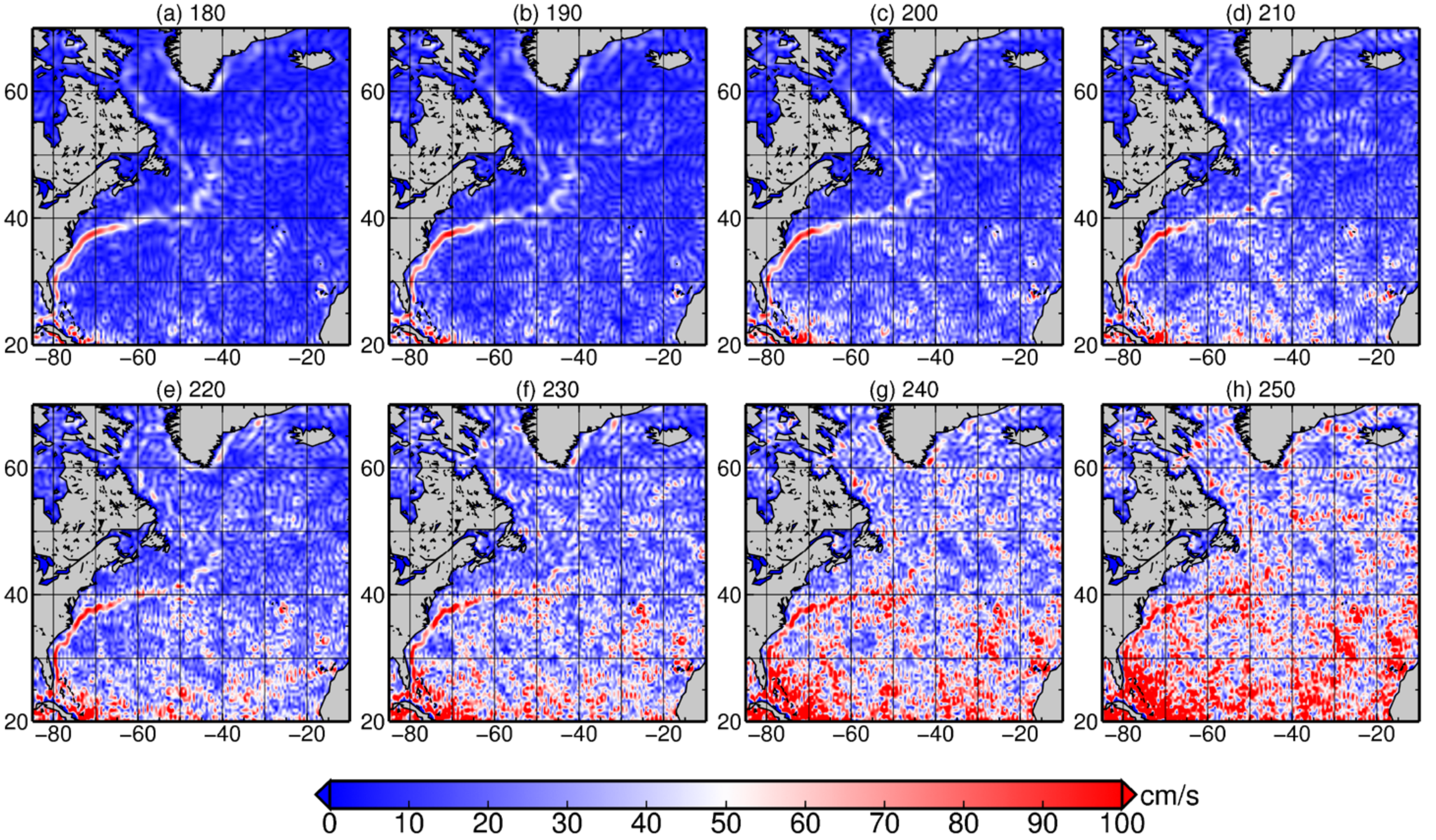
$$S = 5\ \text{km} \Rightarrow L = 4000$$

A model of MDT omission error (1/12th degree OCCAM)



- Currents – high degrees more important
- Particularly for strong currents
- At degree 250, global error:
  - 3 cm/s
  - 70% recovery
- At degree 250, Gulf Stream error:
  - 35 cm/s
  - 55% recovery
- Pessimistic

The issue of geoid commission error



North Atlantic currents speeds obtained from MDTs based on the 3rd timewise GOCE gravity model with increasing MDT truncation from d/o=180 to 250.

Realising the potential of GOCE

Realising the full potential of the GOCE mission will depend on how geoid commission errors can be dealt with:

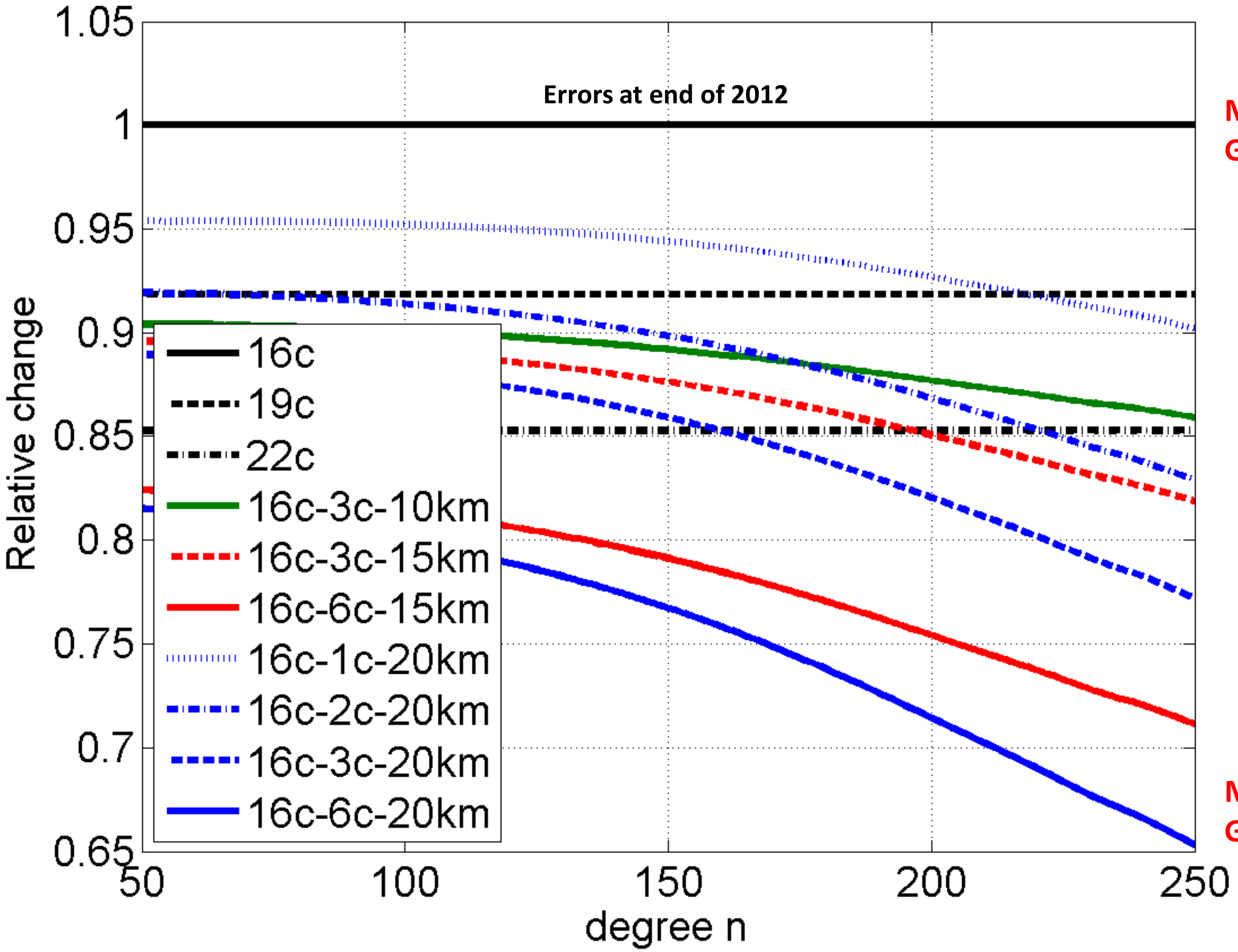
- More data
- Lower orbit

Mission scenarios

- Filtering strategies
- Data synthesis

Post processing

Realising the potential of GOCE: Mission scenarios

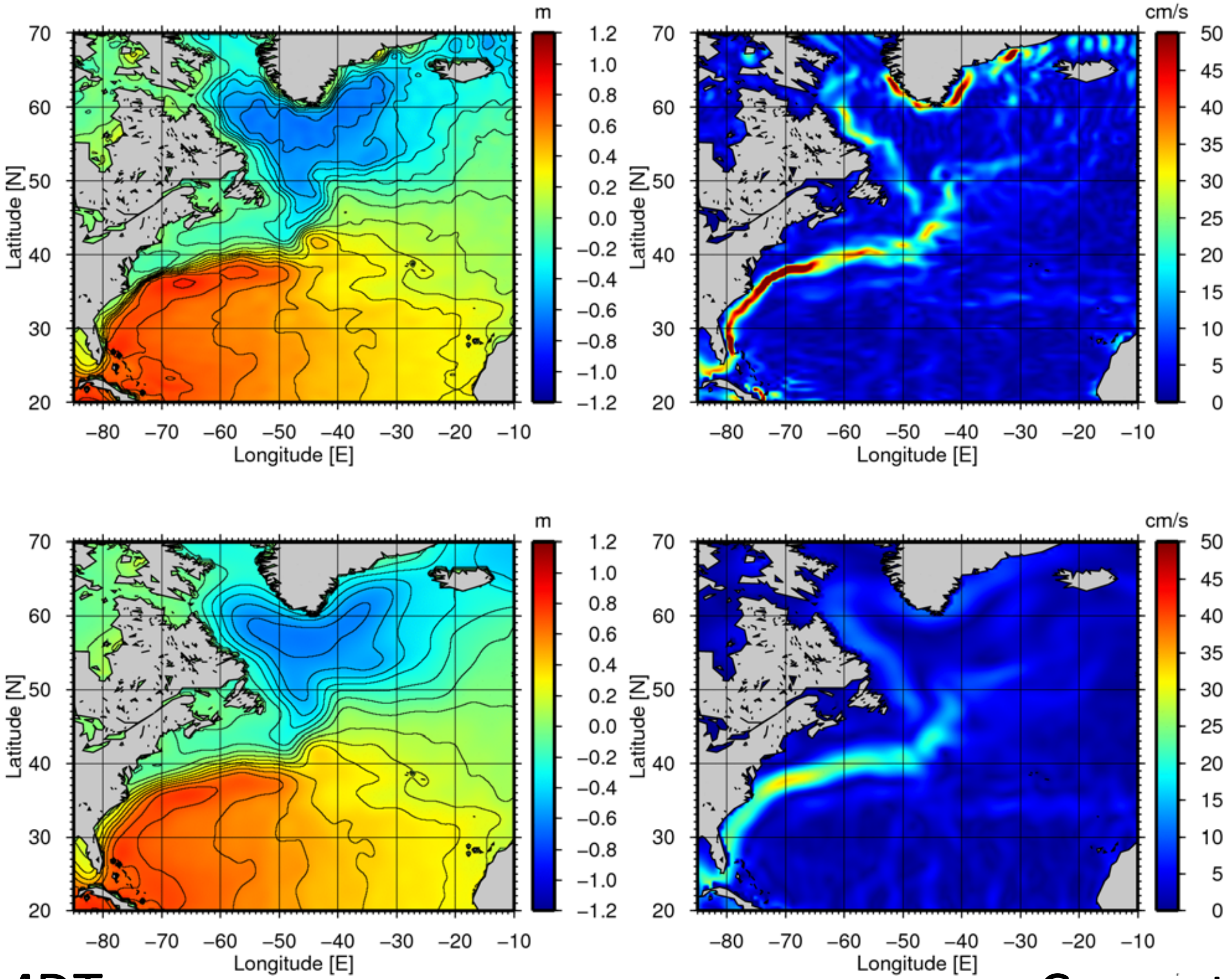


MDT: 10.5 cm
GCS: 31.5 cm/s

MDT: 6.8 cm
GCS: 20.5 cm/s

Realising the potential of GOCE: Filtering

Diffusive filter



MDTs

Gaussian filter – 150km

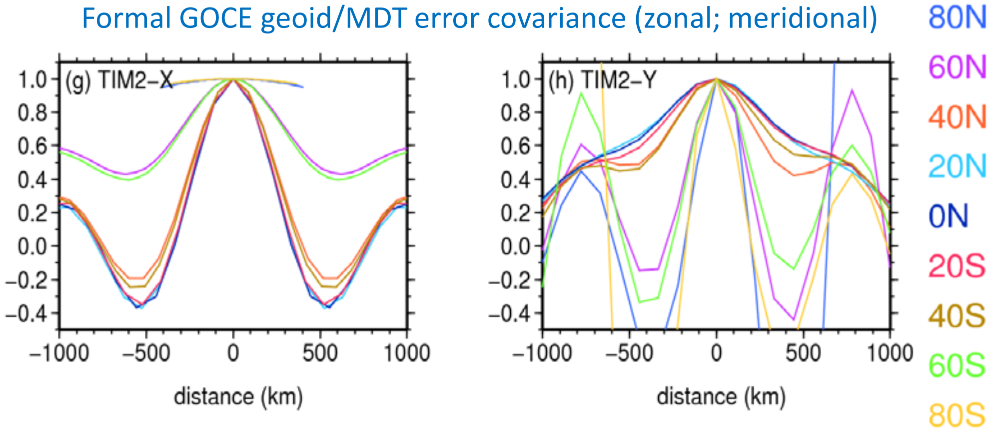
Currents

Diffusive filtering effectively removes noise while preserving gradients associated with strong currents

Realising the potential of GOCE: Data synthesis

Formal GOCE geoid/MDT error

Formal GOCE geoid/MDT error covariance (zonal; meridional)



- Error variance-covariance
- Formal errors on geoid/MDT
- Error structure
- Optimal filtering
- Rigorous data synthesis
- Data assimilation

Summary

- Significant improvement over GRACE
- Potential: 80 km
- At least 70% of geostrophic current field captured
- Commission errors – signal to noise ratio:
  - More data
  - 20 km lower in 2013: GSC errors = 20 cm/s
  - More sophisticated filtering: error information; auxiliary data
- GOCE will never provide the meso-scale but:
  - Most accurate at scales resolved
  - Provides foundation
  - Formal error for optimal/rigours blending
- Data assimilation