Global hydrodynamic levelling.

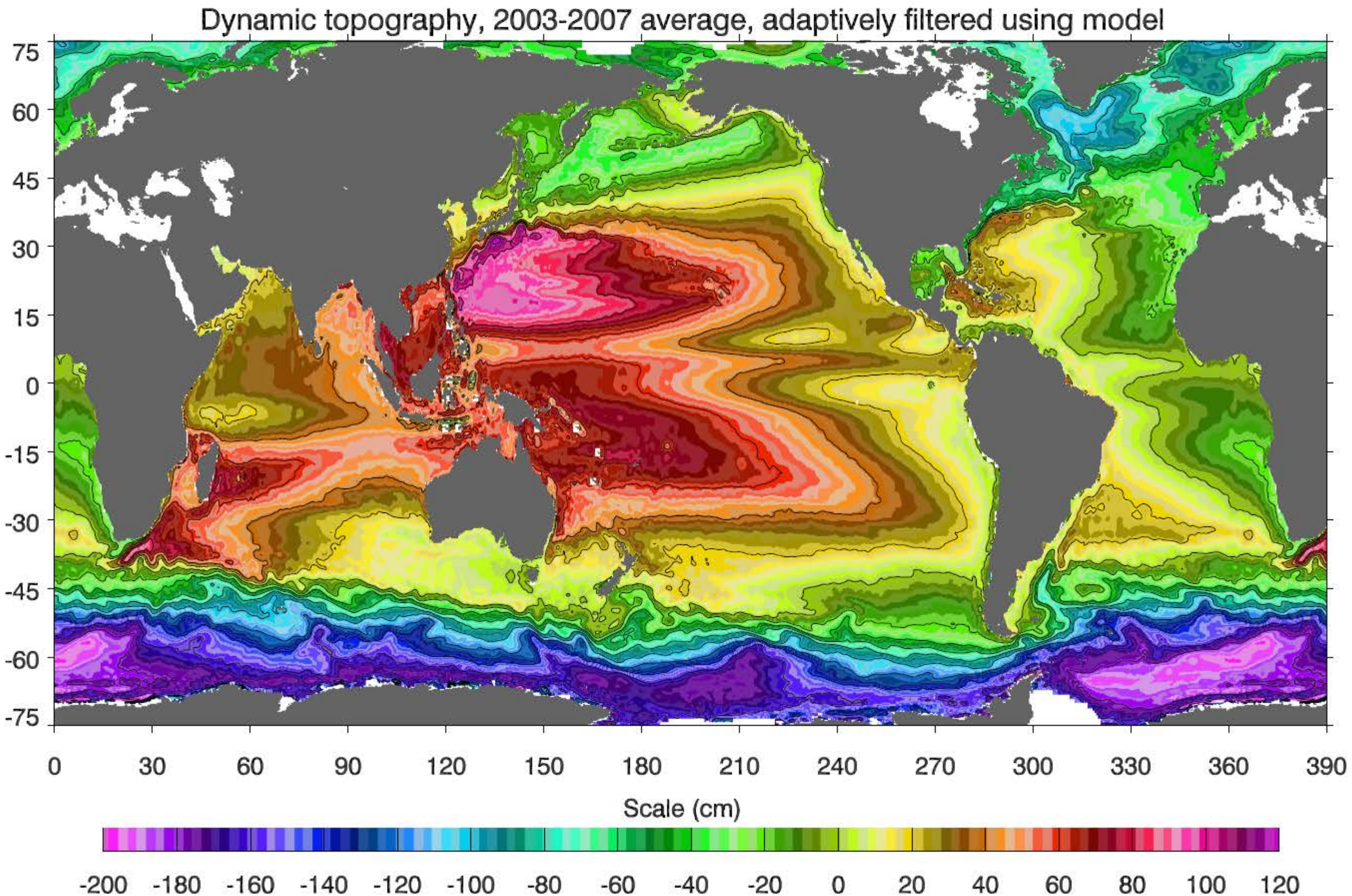
Chris W. Hughes (University of Liverpool, and NOC)

Many others! (NOC, Bristol, DTU, La Rochelle, TUM…)

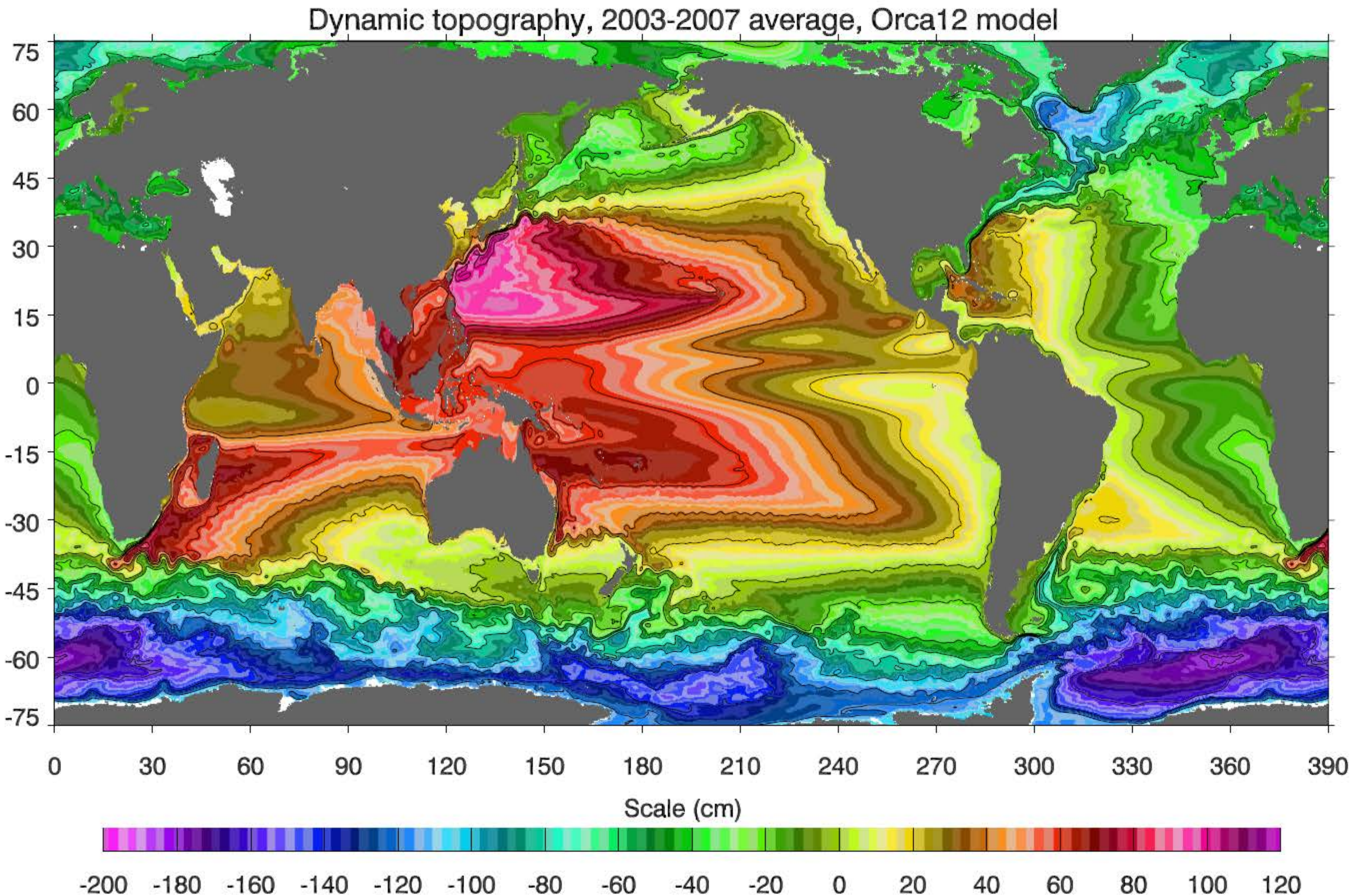
Part of this work can be found in

Hughes, C. W., J. Williams, A. Blaker, A. Coward and V. Stepanov, 2018: A window on the deep ocean: The special value of ocean bottom pressure for monitoring the large-scale, deep-ocean circulation. *Progress in Oceanograph*y **161**, 19-46. doi: 10.1016/j.pocean.2018.01.011.

IAG WG Q3 December 2020

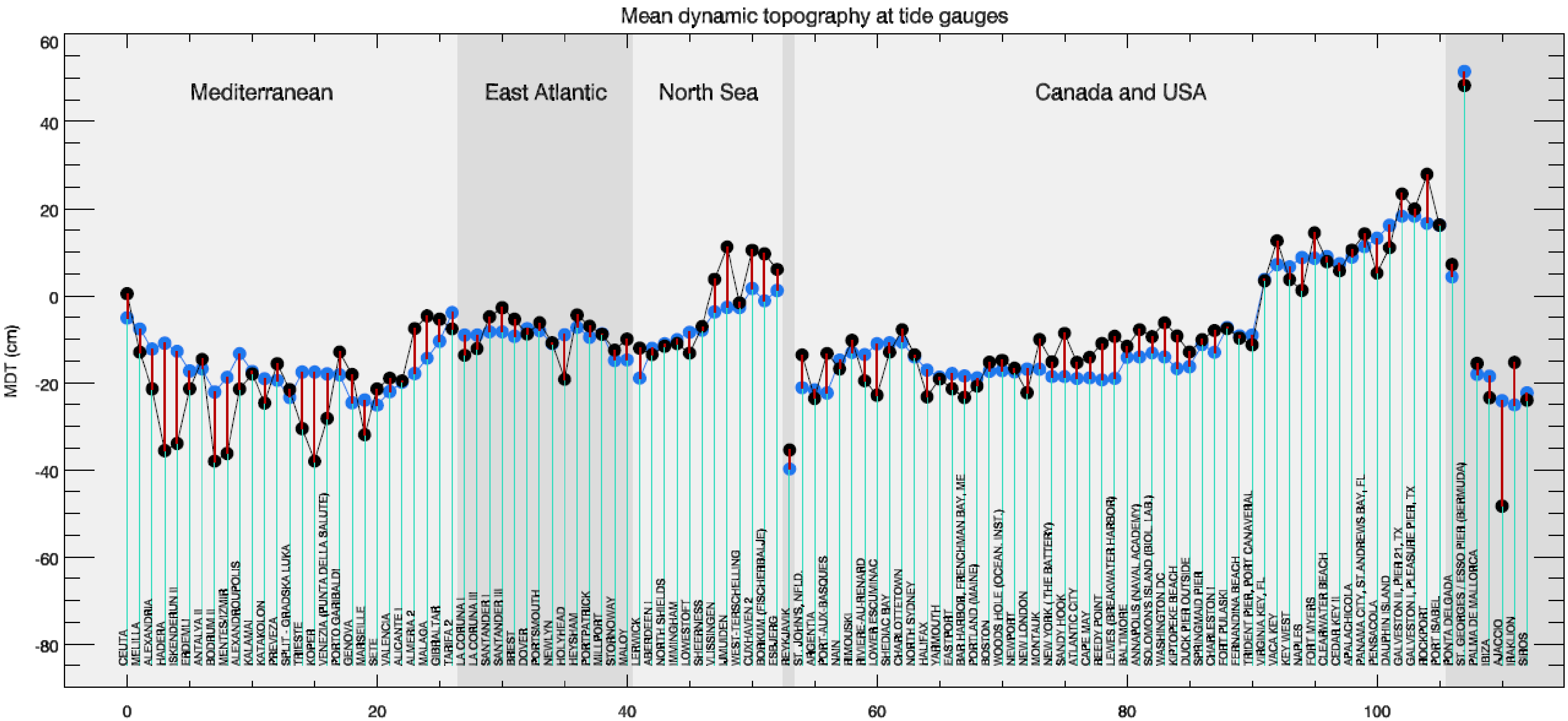


Dynamic topography from satellite data plus in-situ gravity. Only spectral information from ocean model used to design an appropriate filter



Dynamic topography from an ocean model, initialised with density measurements and forced by observed winds, rainfall, and atmospheric temperature. Independent of all geodesy.

Coastal dynamic topography of the North Atlantic



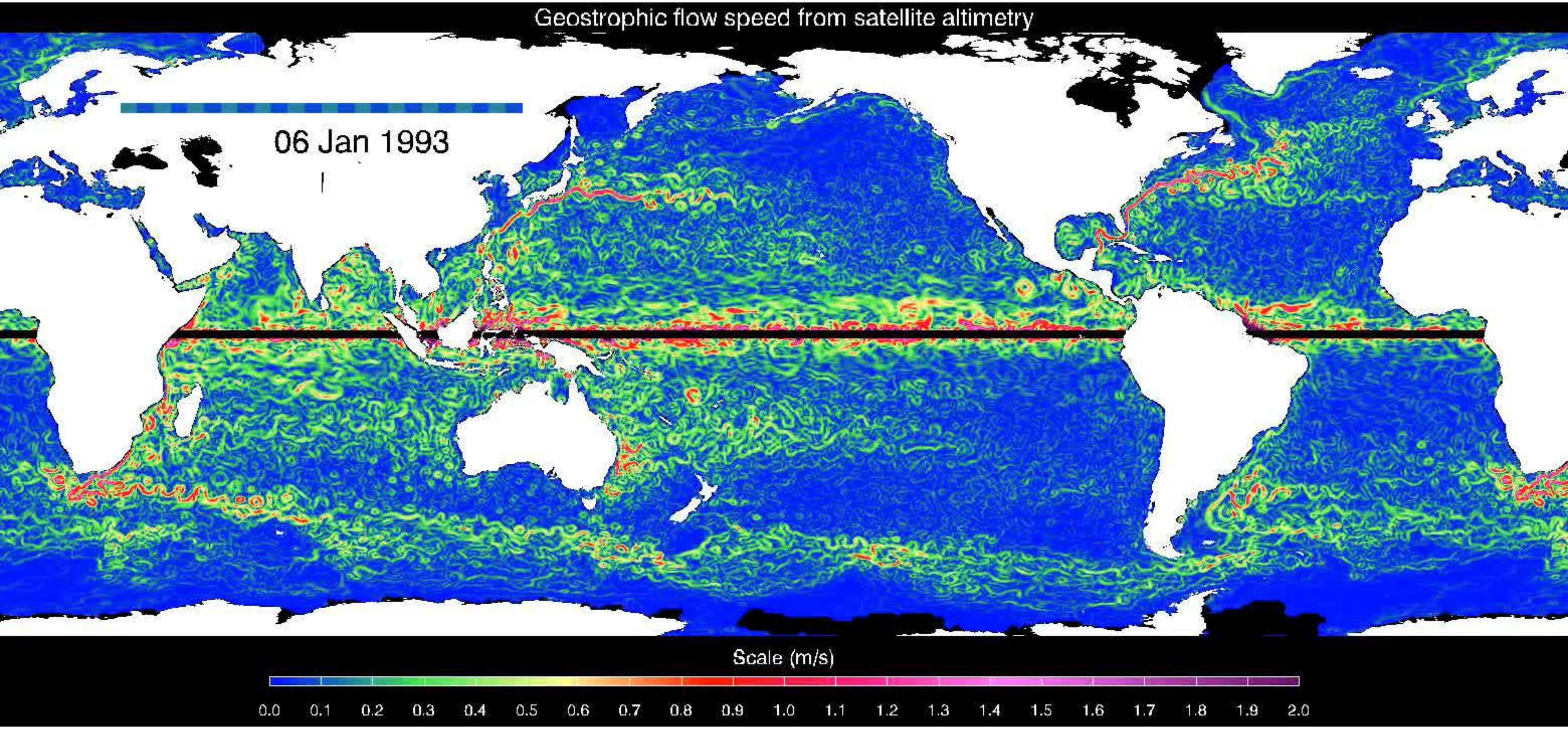
Tide gauges
Hydrodynamic levelling

Point measurements – no spatial smoothing – bigger errors (~10 cm)

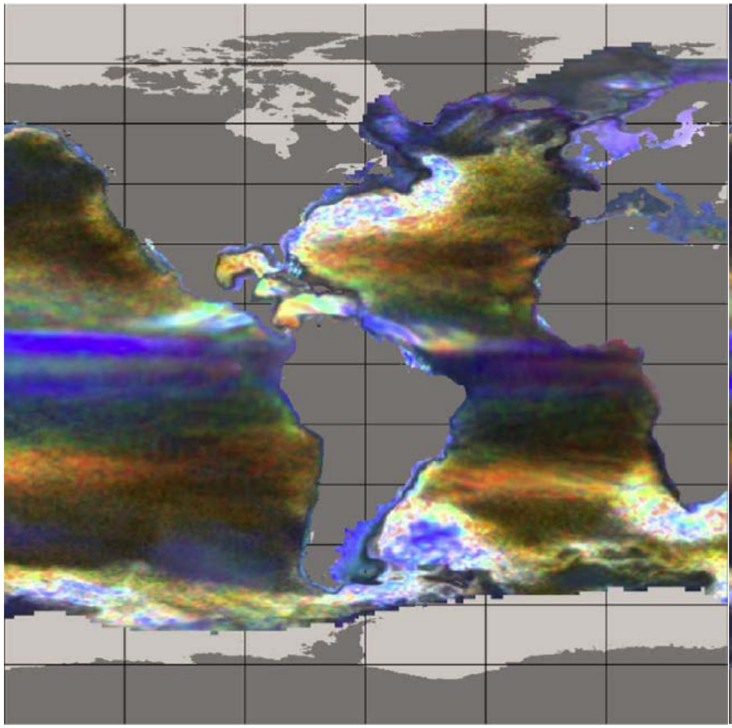
Hughes, C. W., R. J. Bingham, V. Roussenov, Joanne Williams and P. L. Woodworth, 2015: The effect of Mediterranean exchange flow on European time mean sea level. *Geophys. Res. Lett.* **42**(2), 466-474 doi: [10.1002/2014GL062654](10.1002/2014GL062654).

Need for reconciliation of the two methods:

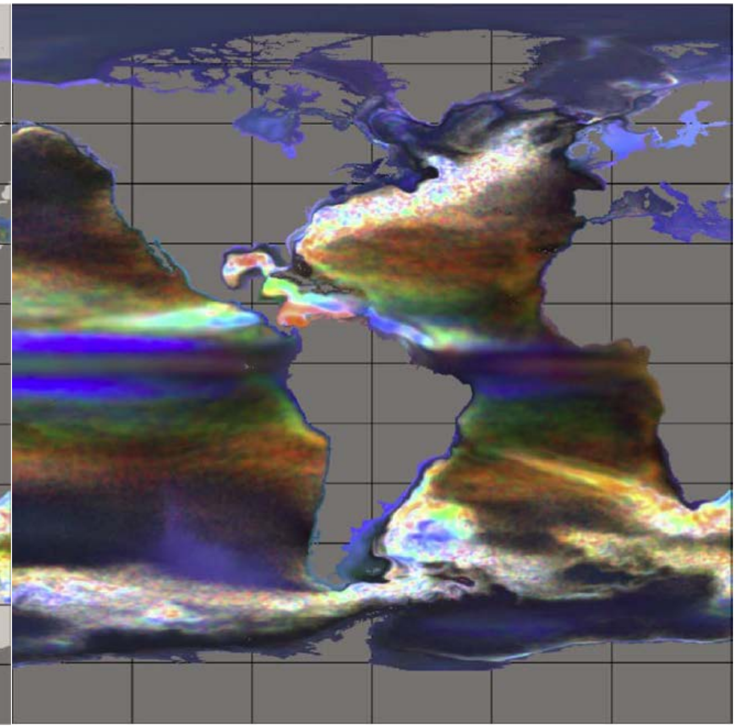
- Coastal sea level causes flooding – one of the major impacts of projected climate change.
- Sea level change will come from changing dynamics, as well as warming and melting of ice – it's not just the global mean sea level, but also the dynamic topography that matters.
- Not clear whether we can trust climate model projections on time scales long enough for density changes to become significant, when we don't understand the processes properly.
- The ocean's boundaries are special places. The dynamics is different.
- A problem: Ocean dynamics is dominated by small scale, energetic variability…


Geostrophic flow speed from satellite altimetry
06 Jan 1993
Scale (m/s)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0

Diagnostics from a model



Observations
20 years of satellite altimetry – AVISO gridded data

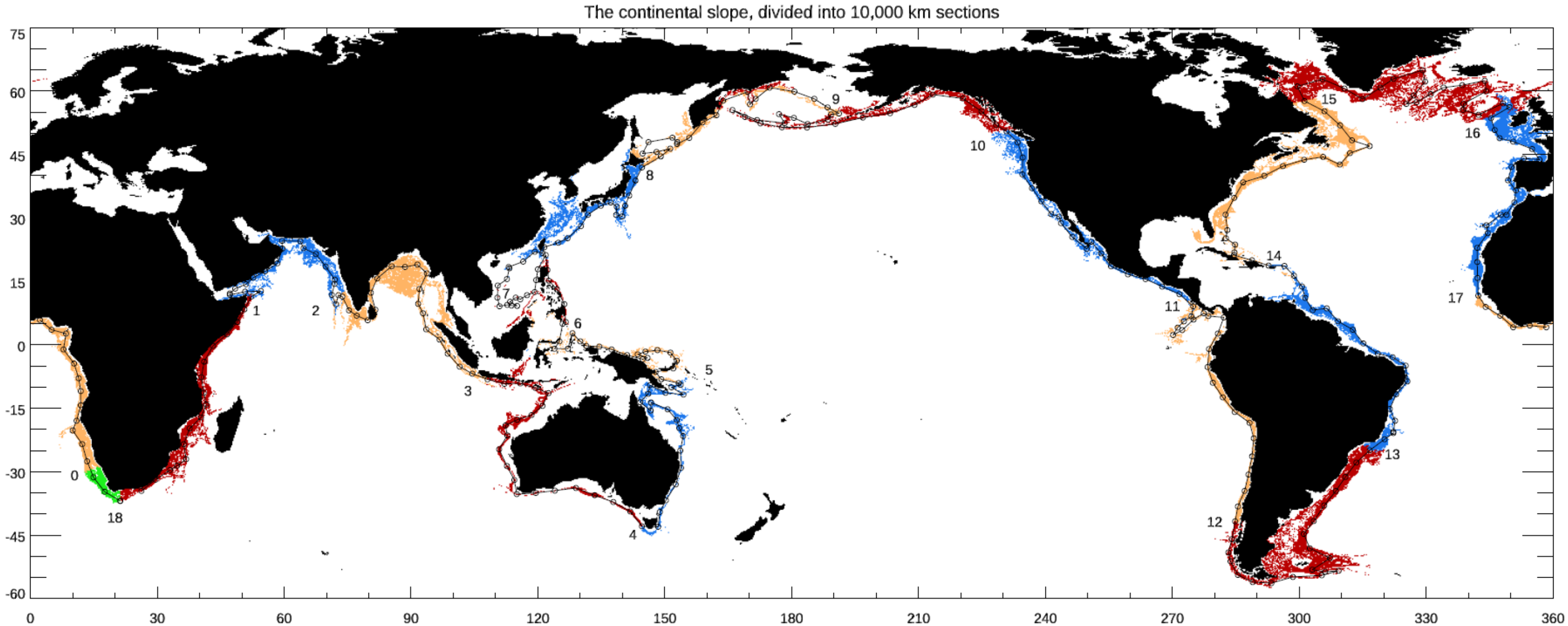


Model
28 years of 5-day means

- NEMO at 1/12 degree resolution.
- 60-year model run.
- Linear trends, annual and semiannual cycles removed in all diagnostics.
- 5-day means, or monthly means for MOC (later).

In these plots, brightness is a measure of amplitude of variability, and colour is a measure of shape of the spectrum. Clearly the model does a good job of representing both. The mesoscale has realistic amplitude and spectrum.

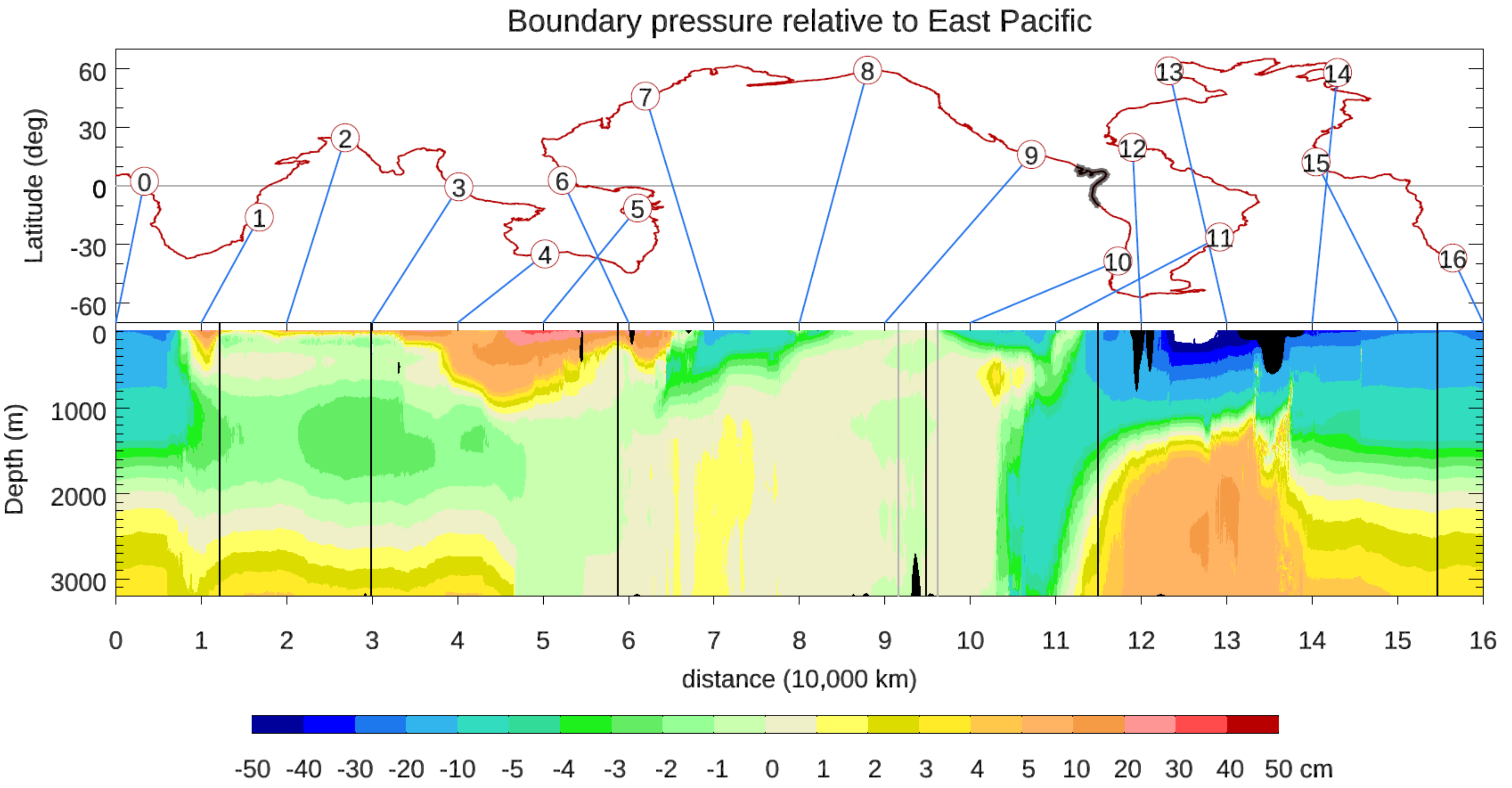
Globally, looking at the time-mean bottom pressure



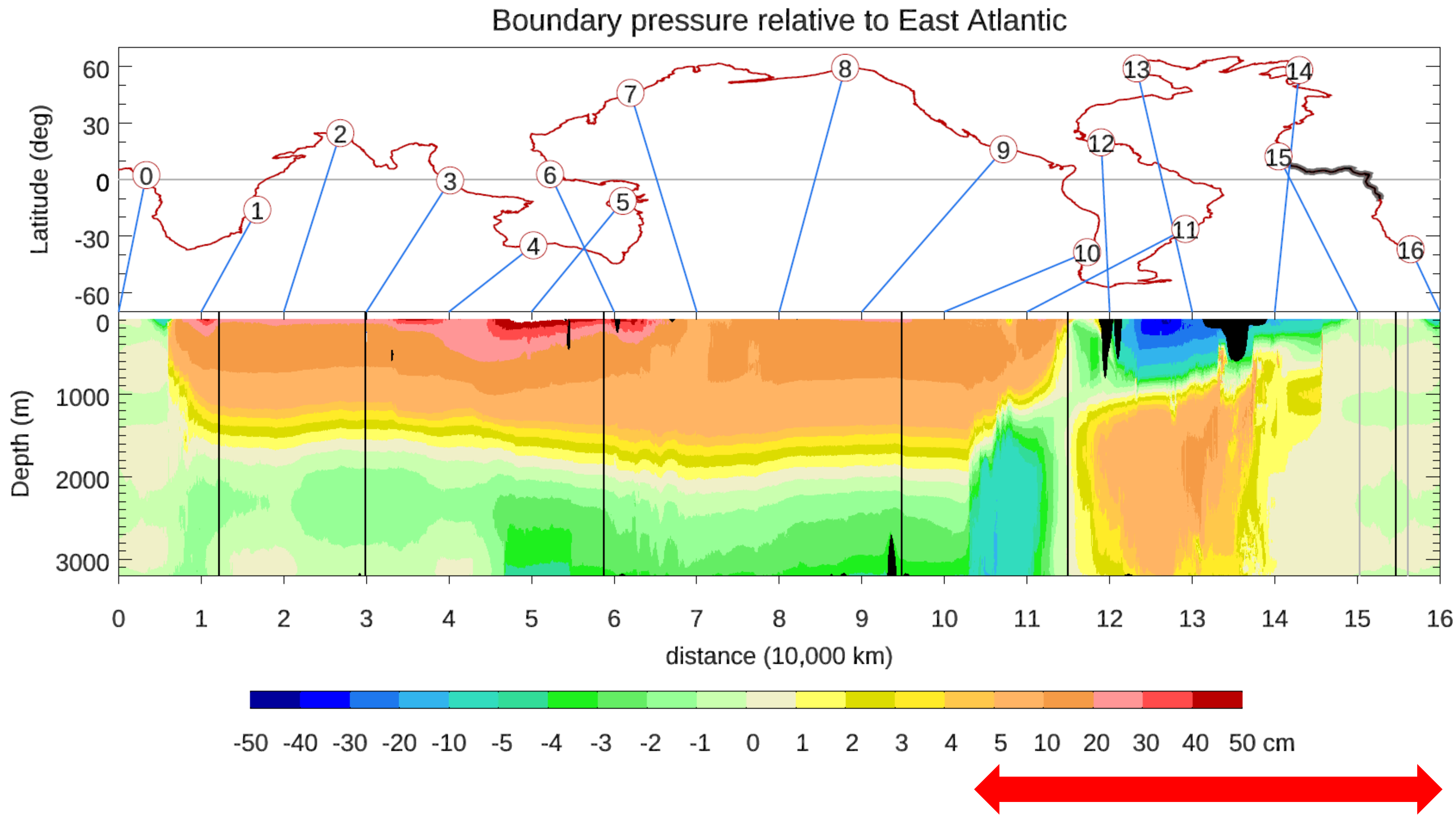
This tiny areal fraction of the ocean covers the depth range from 50 to 3200 m

The dynamics here are NOT dominated by the mesoscale, but by small amplitude variability with length scales of order 10,000 km

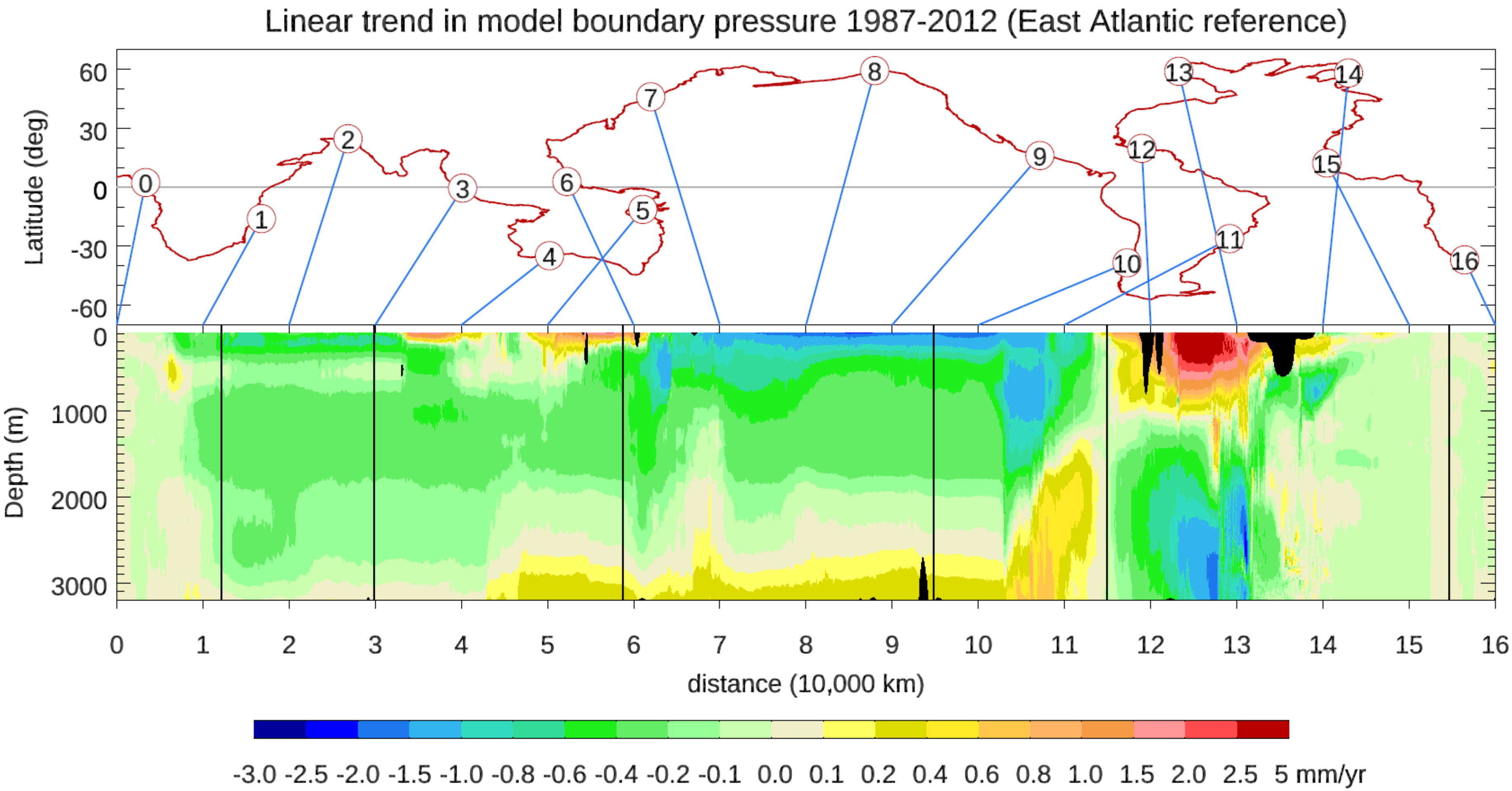
There is great value to being able to measure point values of bottom pressure along the continental slope



Boundary pressure relative to East Pacific
Latitude (deg)
60
30
0
-30
-60
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Depth (m)
0
1000
2000
3000
distance (10,000 km)
-50 -40 -30 -20 -10 -5 -4 -3 -2 -1 0 1 2 3 4 5 10 20 30 40 50 cm

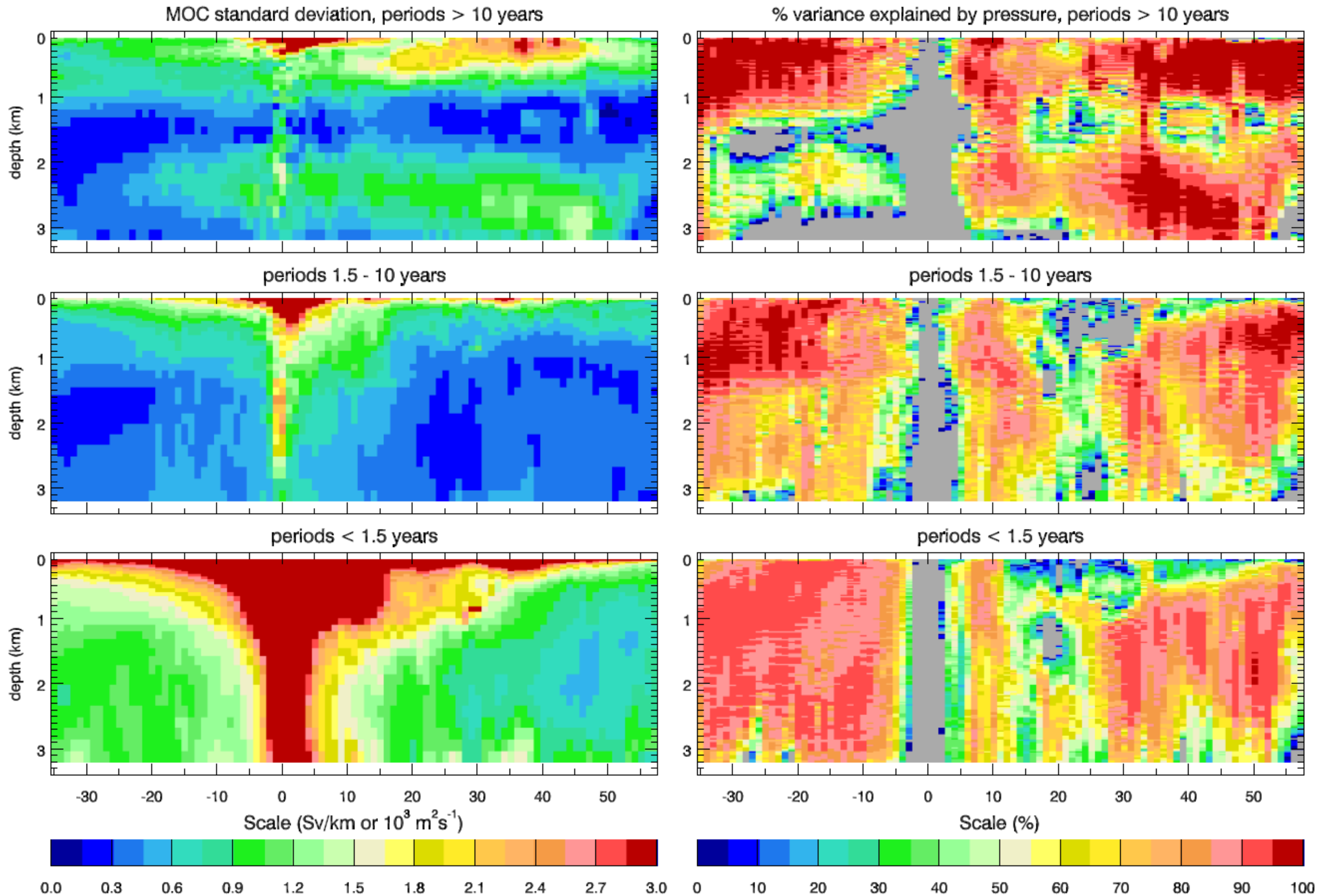


This Atlantic pattern represents the Meridional Overturning Circulation – a major climate mode responsible for warming Europe – there are multimillion dollar projects to measure this, and to understand its likely future behaviour


Linear trend in model boundary pressure 1987-2012 (East Atlantic reference)
Latitude (deg)
60
30
0
-30
-60
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Depth (m)
0
1000
2000
3000
distance (10,000 km)
-3.0 -2.5 -2.0 -1.5 -1.0 -0.8 -0.6 -0.4 -0.2 -0.1 0.0 0.1 0.2 0.4 0.6 0.8 1.0 1.5 2.0 2.5 5 mm/yr

AMOC predicted from east-west pressure differences, and actual model AMOC, at different time scales. Agreement is very good except

1) where signal is very small
2) near the equator
3) where marginal seas complicate the geometry



Conclusions

- Along the global continental slope, pressure on level surfaces is constant to within a few cm of water over global distances.
- The small pressure differences are representative of the global ocean circulation and important climate modes.
- The next stage of reconciliation of geodesy and hydrodynamic levelling requires measurements at this boundary – while coherence is strong along the slope, the cross-slope length scales are small. As with tide gauges, we will need point measurements of geopotential.