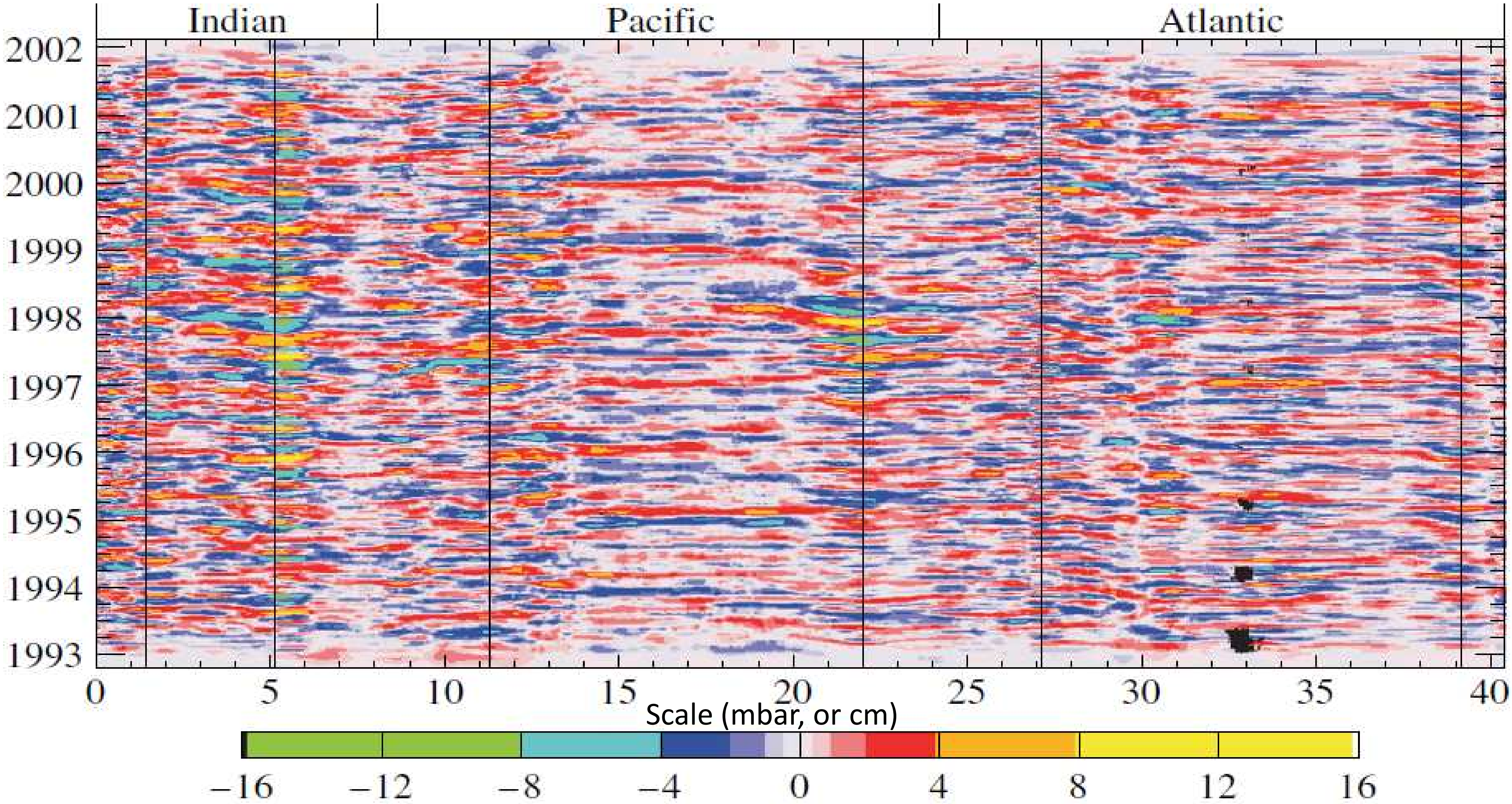
Deep ocean influence at ocean boundaries.
or: how can we monitor an ocean full of eddies?

Chris W. Hughes: University of Liverpool and NOC, Liverpool

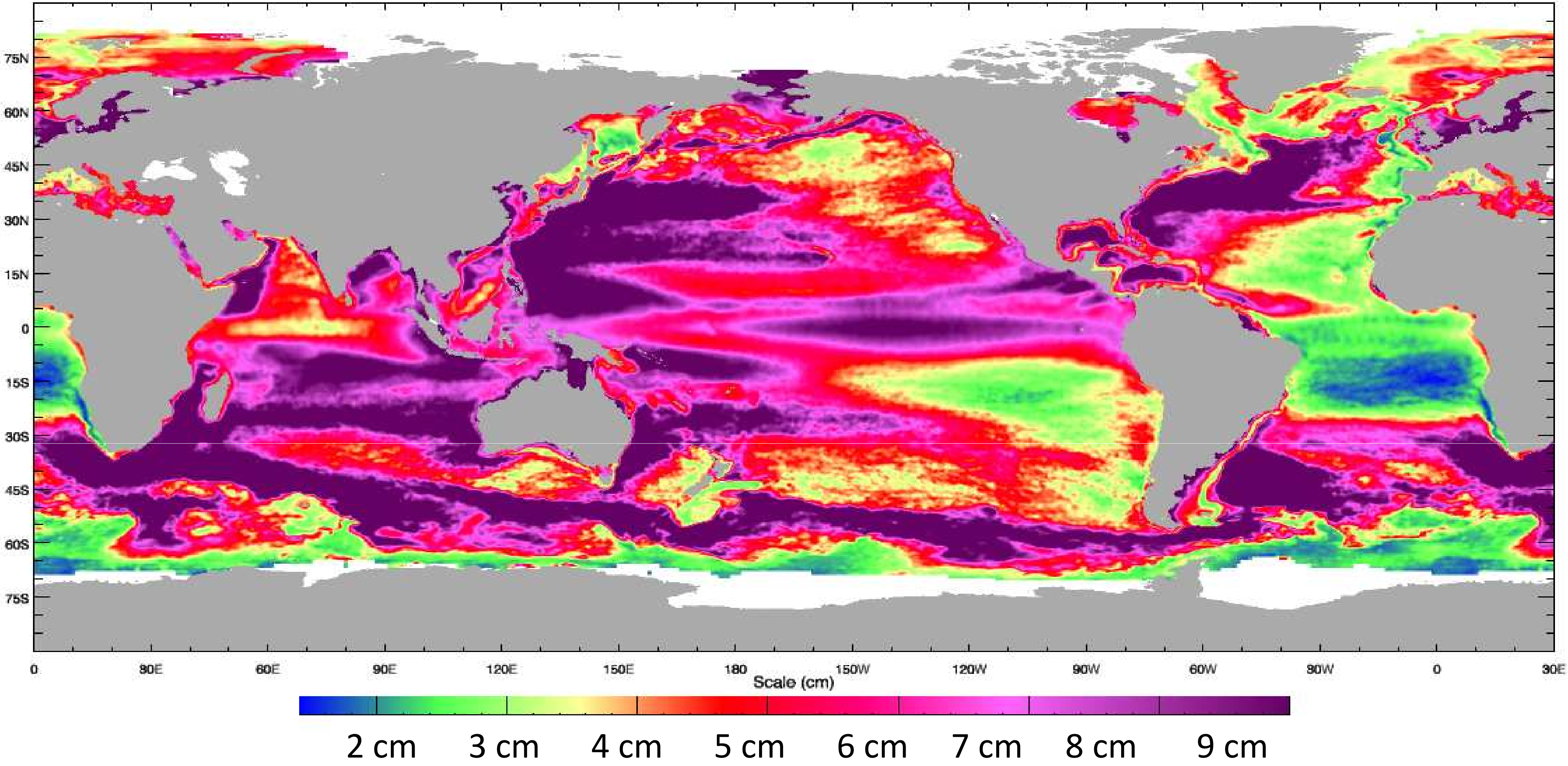
Joanne Williams: NOC Liverpool

Hughes, C. W., and M. P. Meredith, 2006: Coherent sea-level fluctuations along the global continental slope. *Phil. Trans. Roy. Soc. Lond. A*, **364**, 885-901, doi: [10.1098/rsta.2006.1744](https://doi.org/10.1098/rsta.2006.1744).



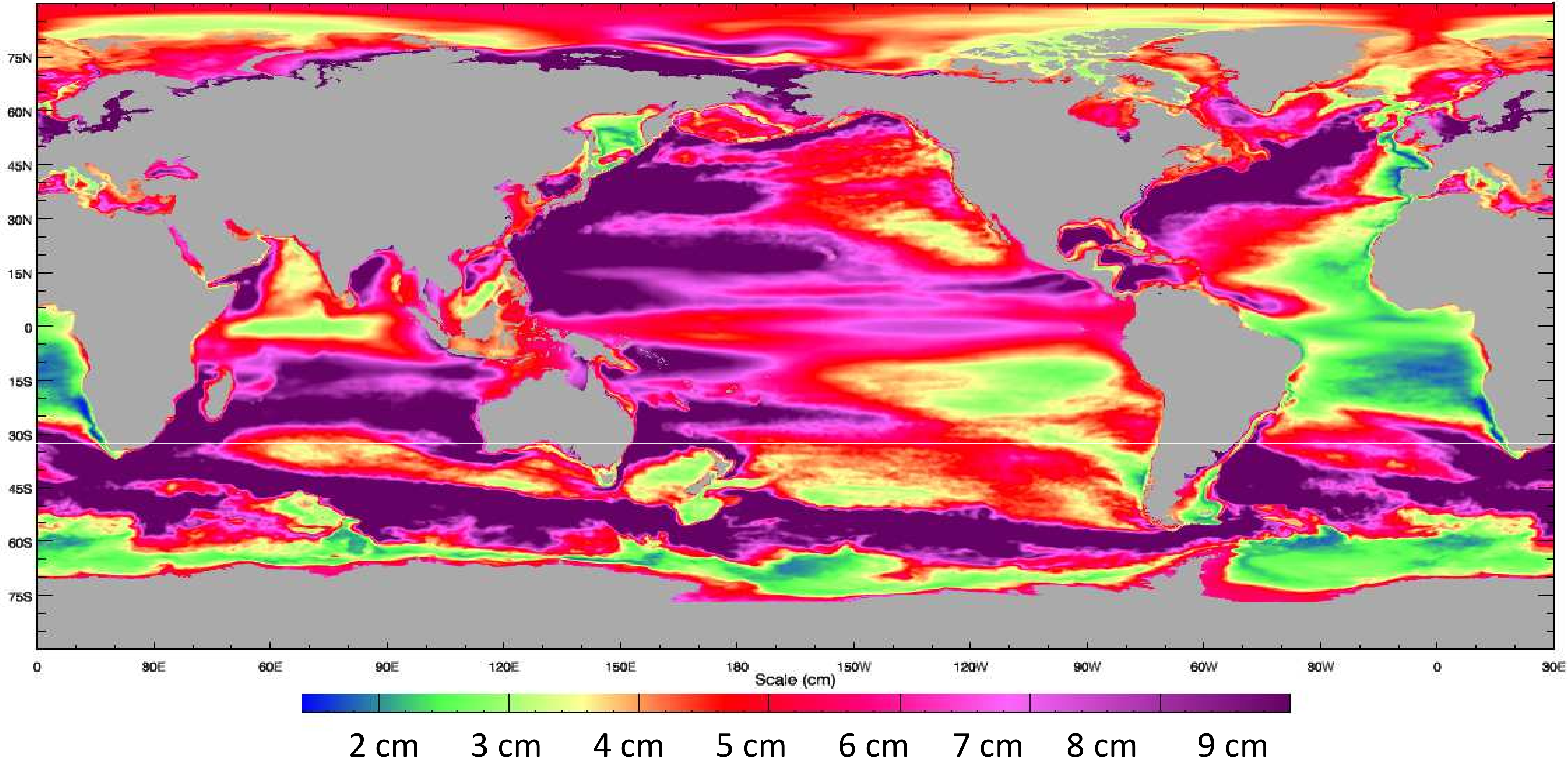
Large sea level correlations over long distances when following the continental slope. Left many questions – apparent propagation in some places, no discernible lags elsewhere…

SSH standard deviation from altimetry



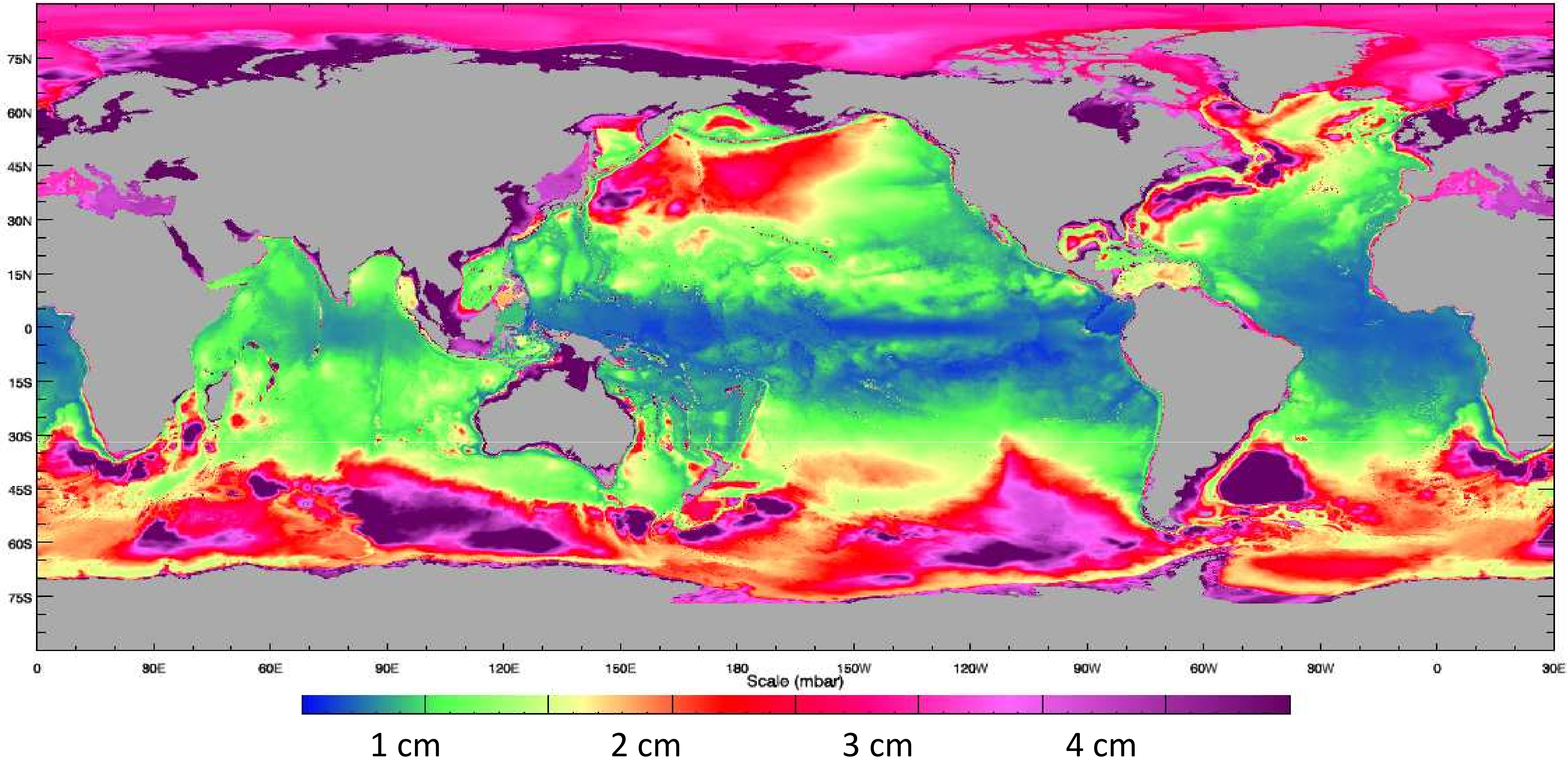
Second question: How can we monitor large scale flows variations (e.g. the MOC), when the associated signals are estimated to be ~1-2 cm or mbar, when this is swamped by eddies?

SSH standard deviation from 1/12 ocean model (NOC Nemo, 54 years of 5-day means)

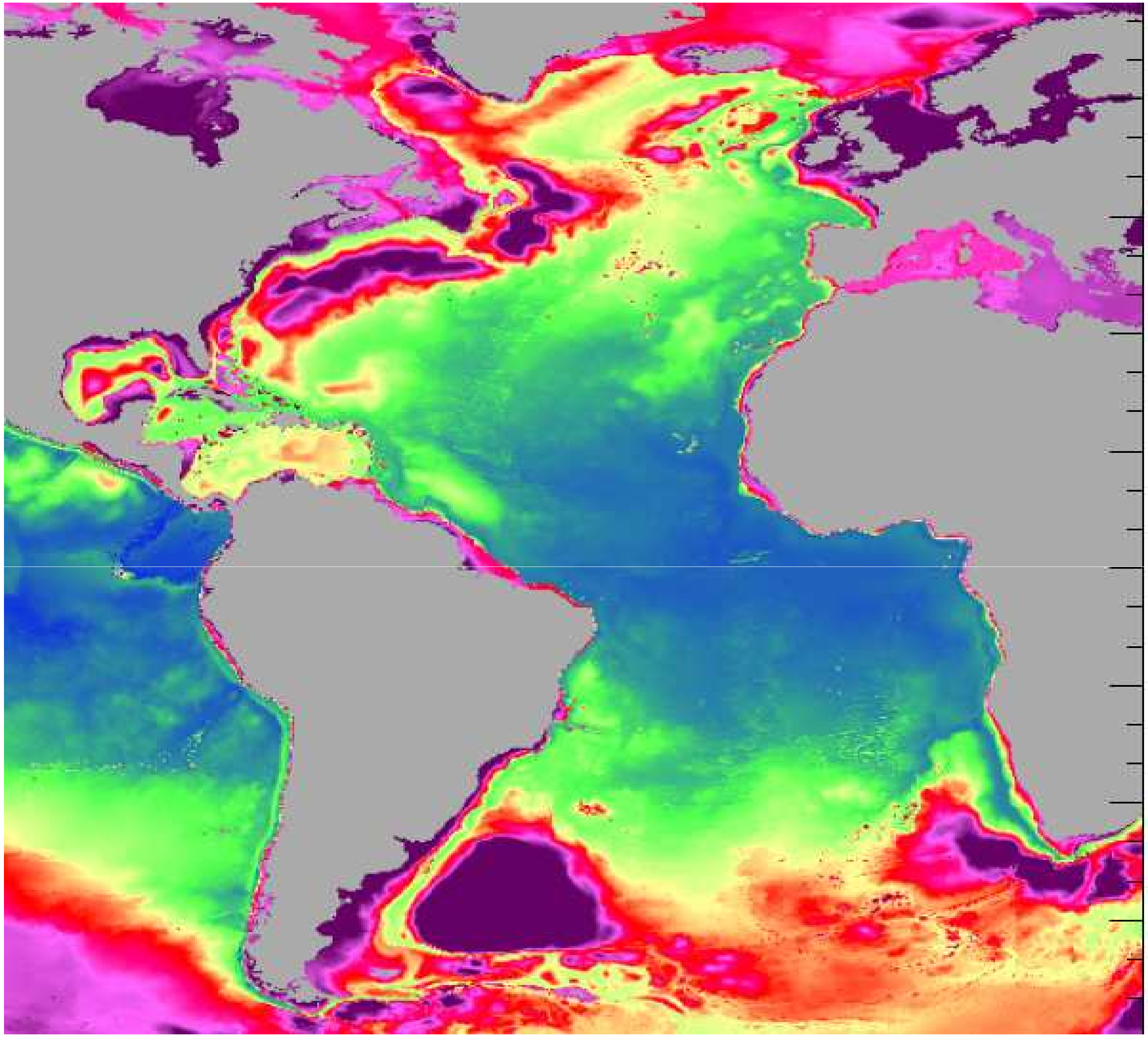


Look in a model: Sufficiently realistic, FINALLY has multiple grid points on the continental slope, allows us to look beneath the surface and interpret the dynamics

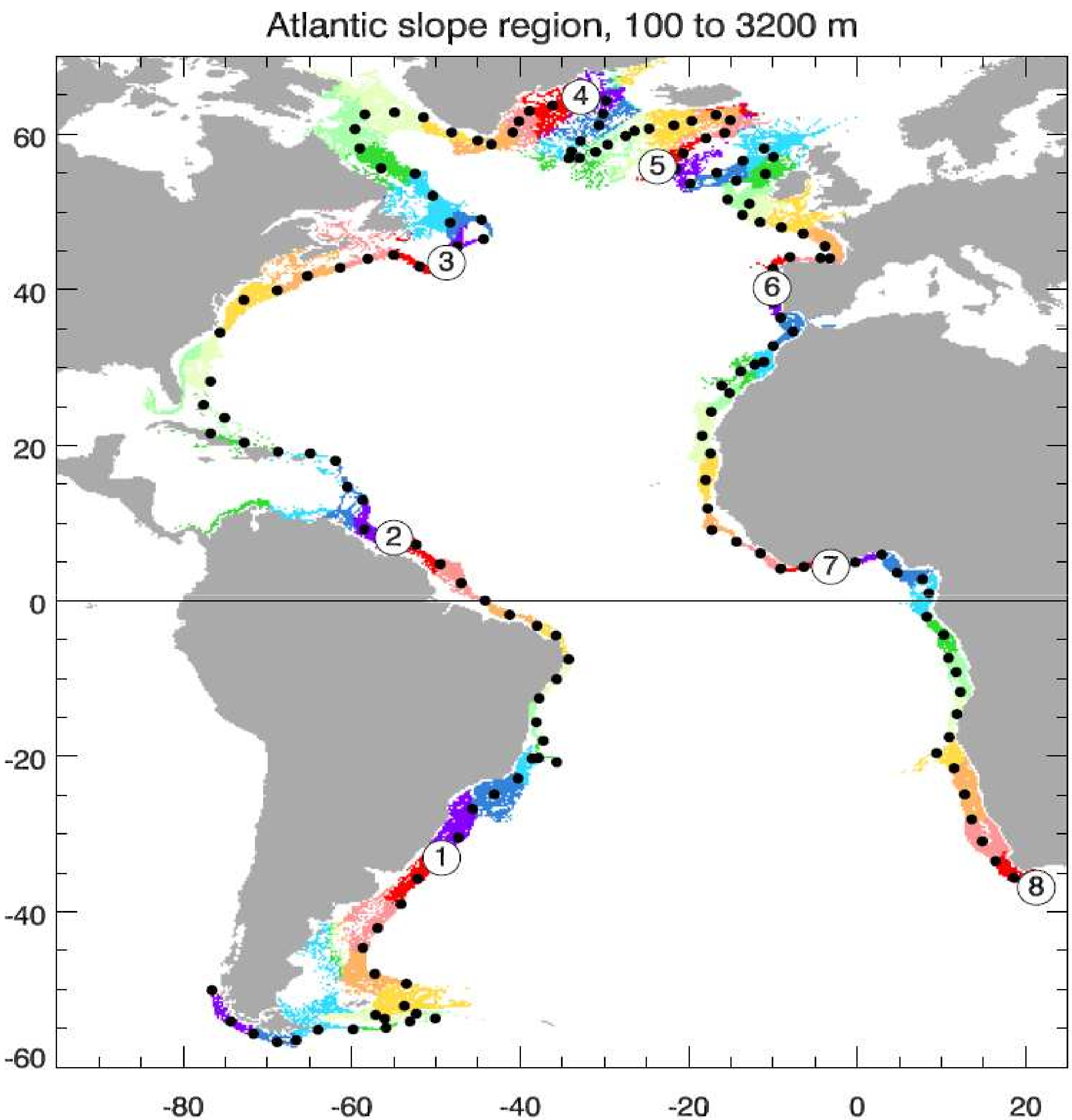
Model bottom pressure standard deviation



Bottom pressure is much quieter, especially on steep continental slopes (there's a scaling argument which predicts this: eddies can't interact strongly with steep topography)



Let's look particularly on the Atlantic continental slope, and plot as a function of distance along the slope and depth instead of latitude and longitude



Definition of the slope.

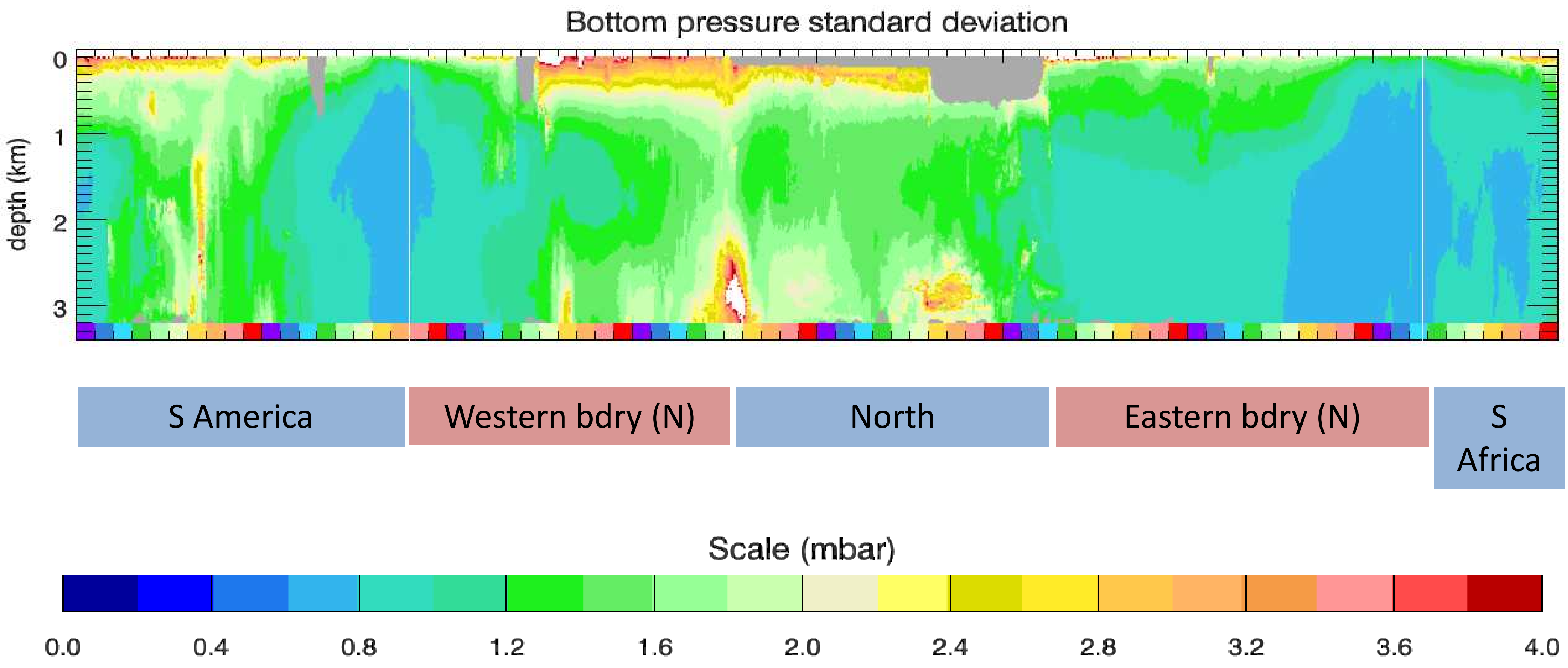
Defined by contour following (so no seamounts etc included)

Depth range is 200 m to 3200 m

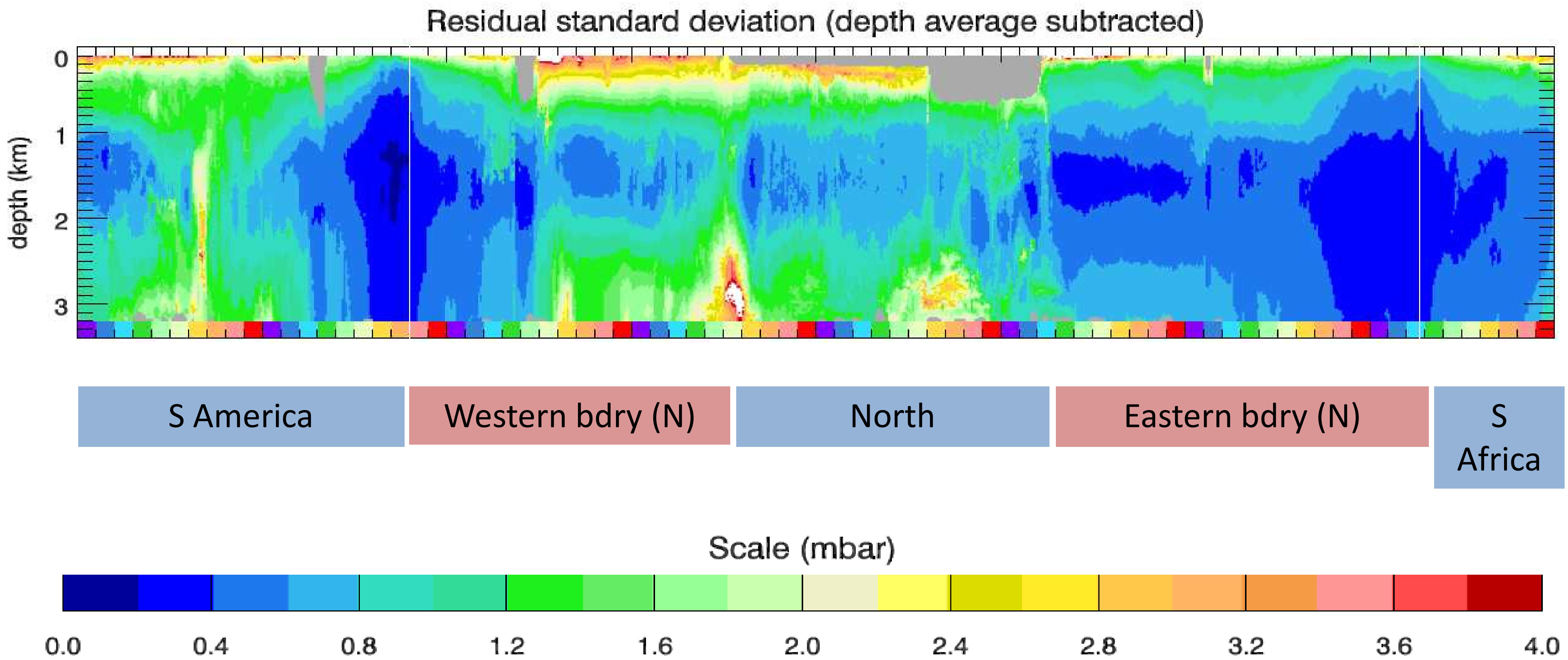
Distance along is defined on the 2000 m contour.

Numbers are every 10,000 km

Cut off regions which are too far from the 2000 m contour (Arctic, Med, Gulf of Mexico)



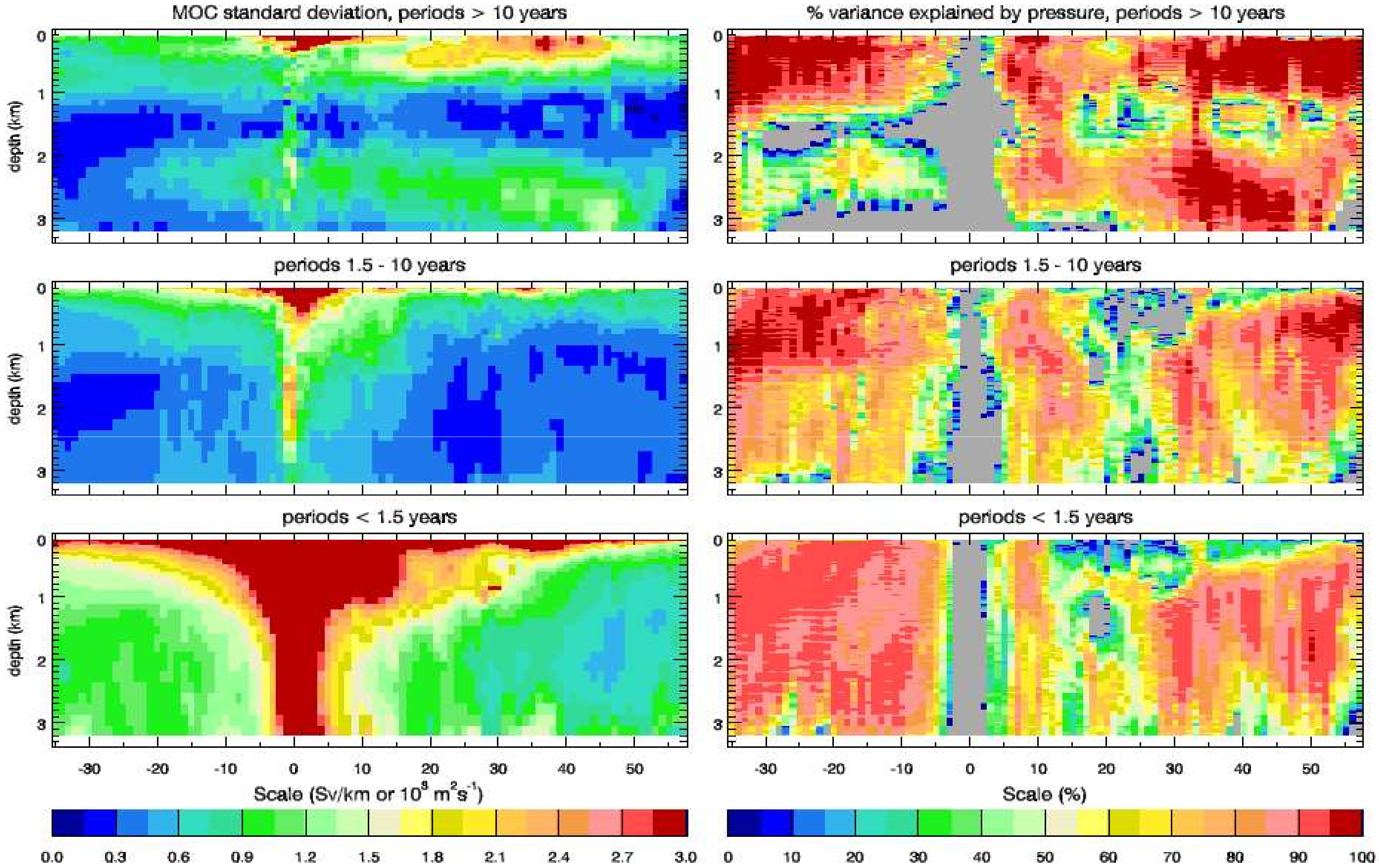
Bottom pressure on the continental slope is quiet!



And even quieter once the large-scale barotropic mode is subtracted

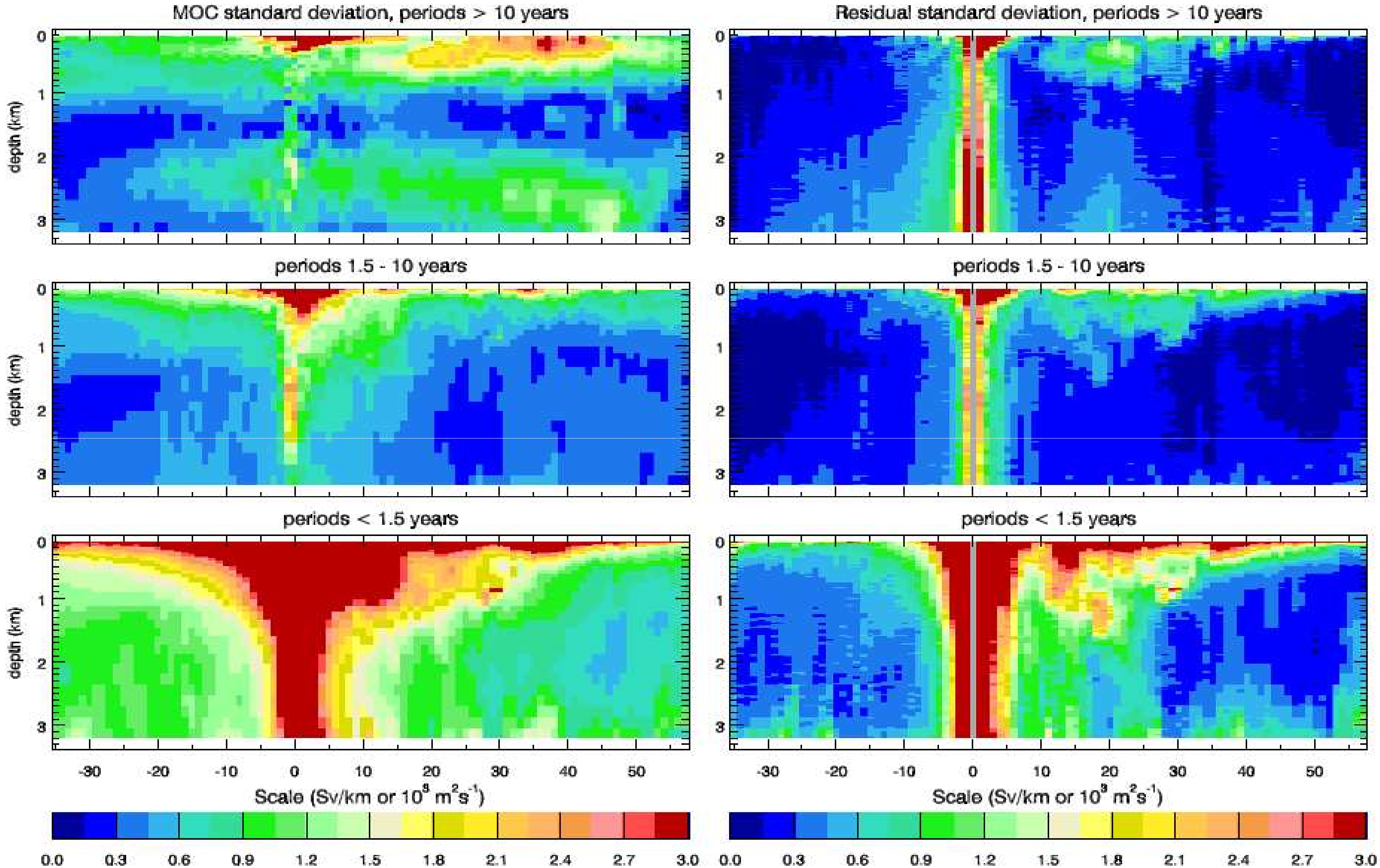
The model overturning circulation: How much can be explained by boundary pressure?

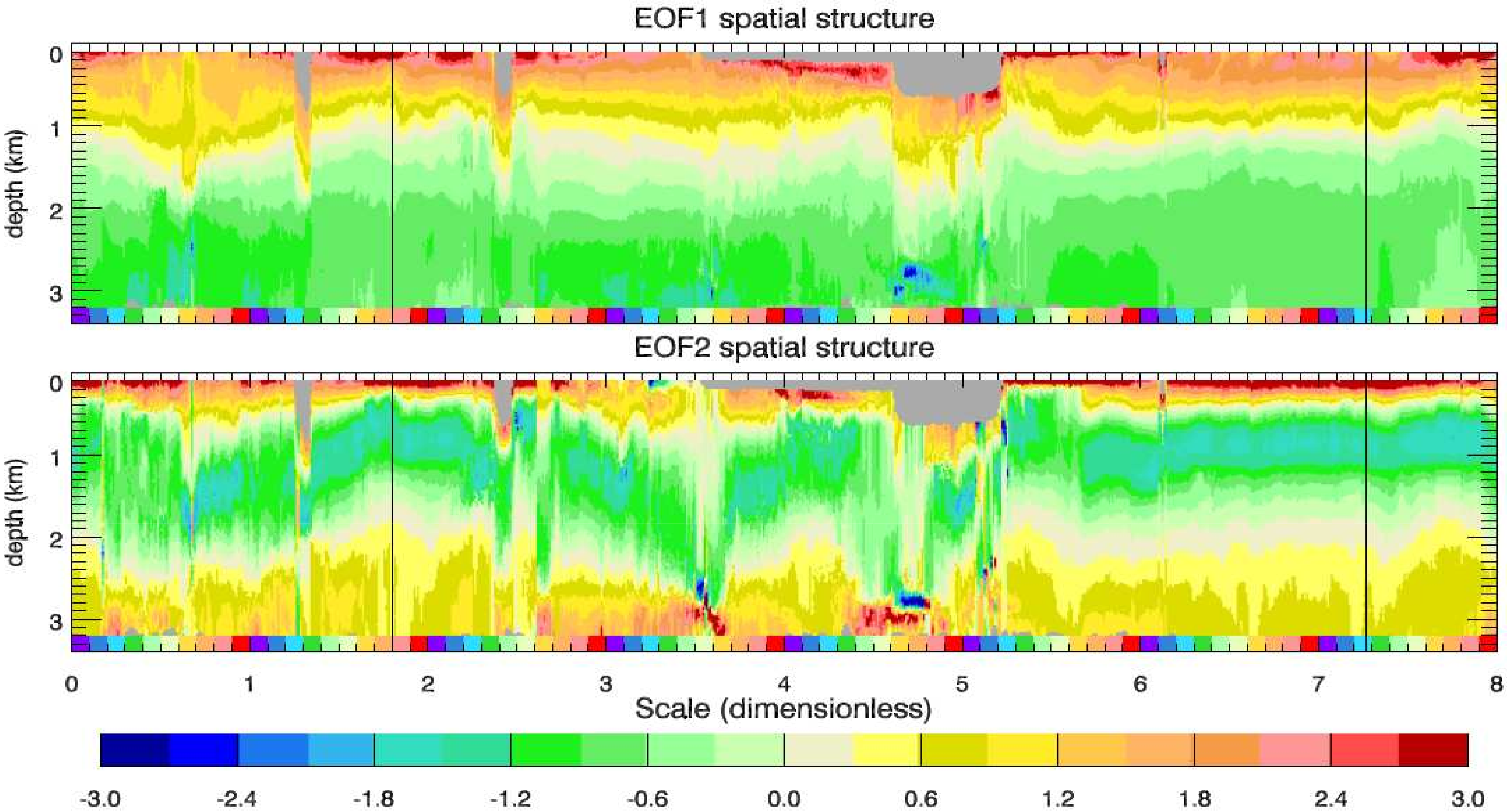
% of variance explained



The model overturning circulation: How much can be explained by boundary pressure?

Standard deviation of residual

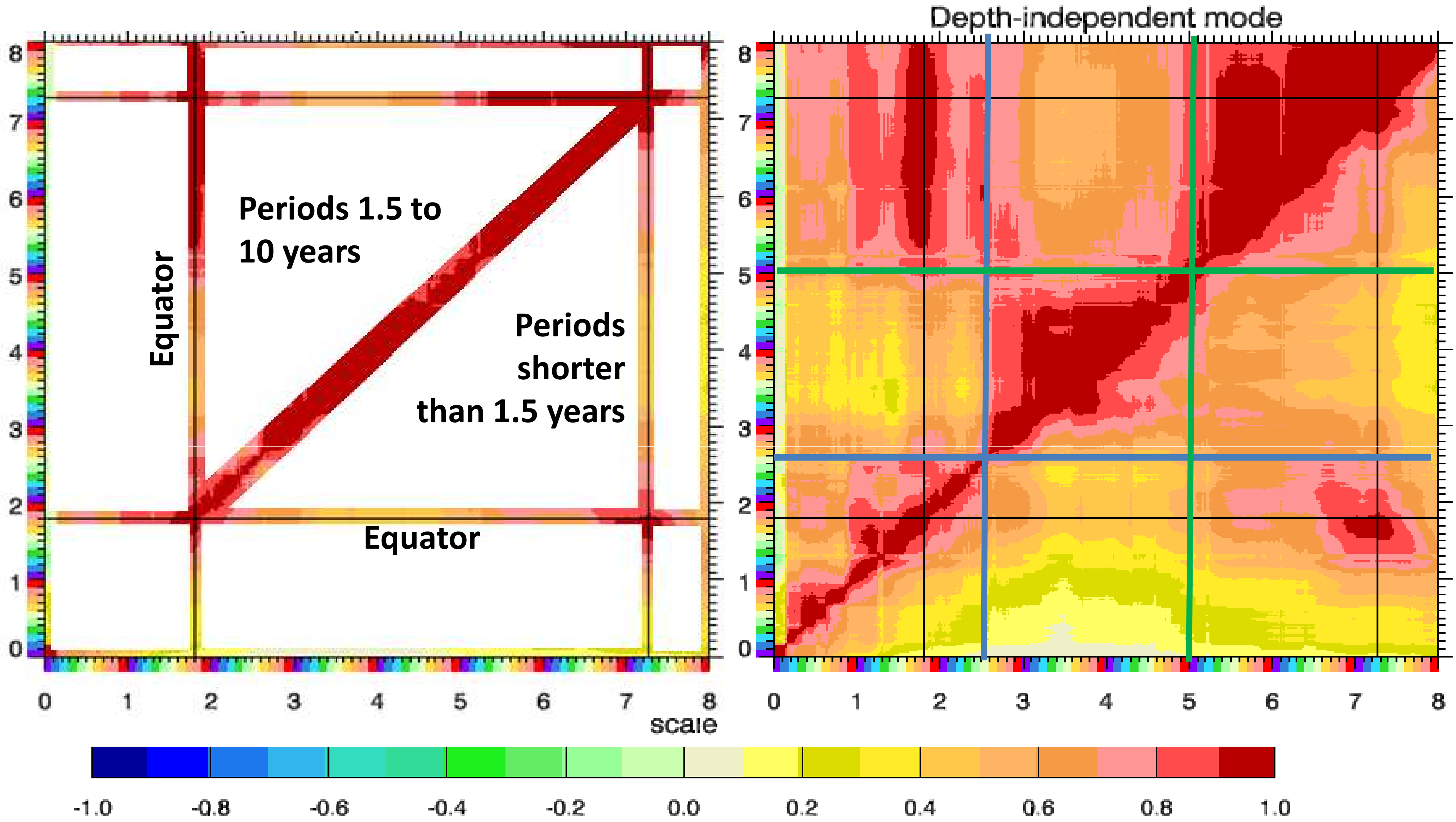




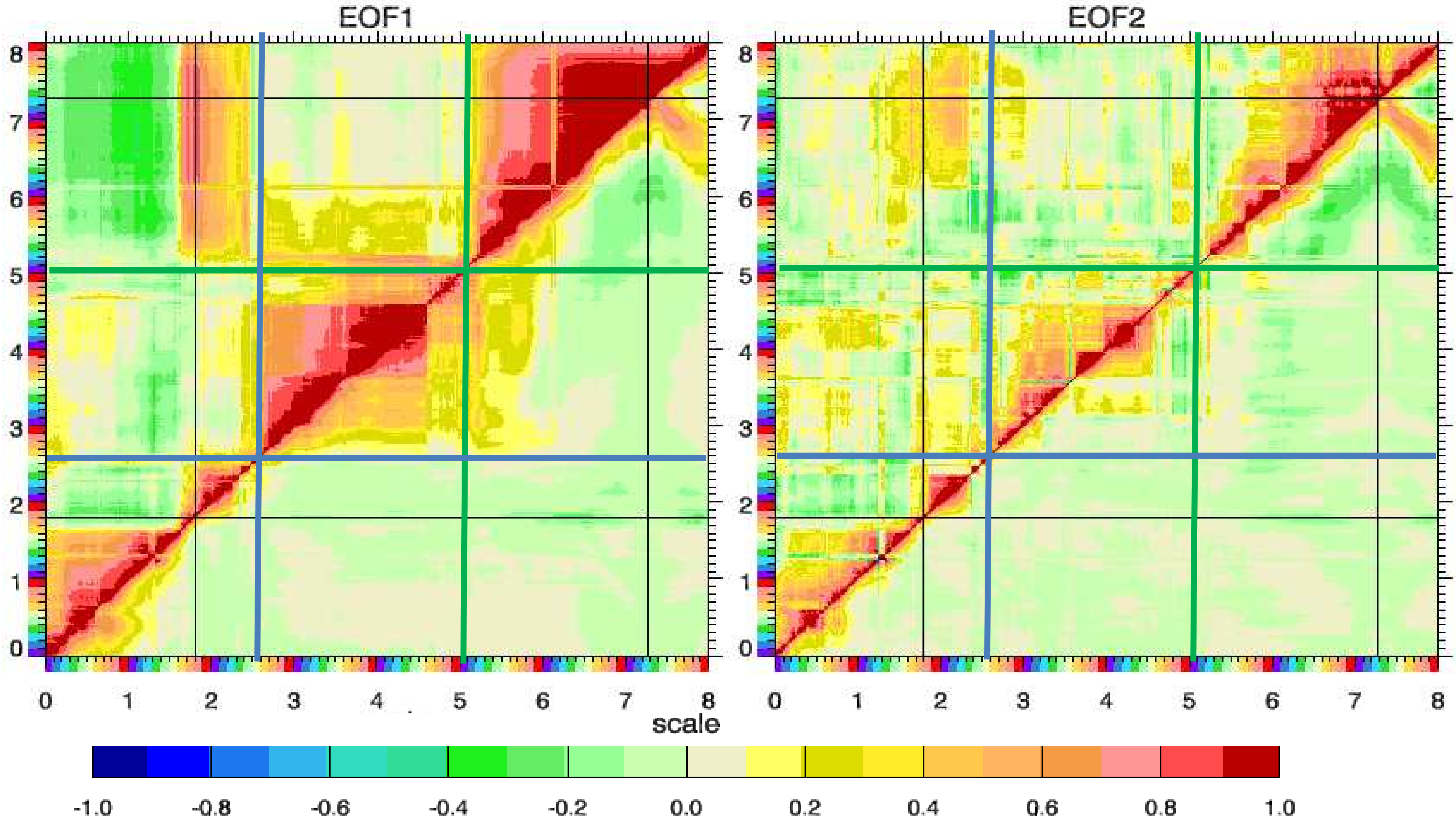
And the vertical structure of the remaining signal is very consistent from place to place
N.B. These are depth-time EOFs calculated independently at each distance along the slope

Cape Hatteras (Gulf Stream separation)

Iceland-Scotland

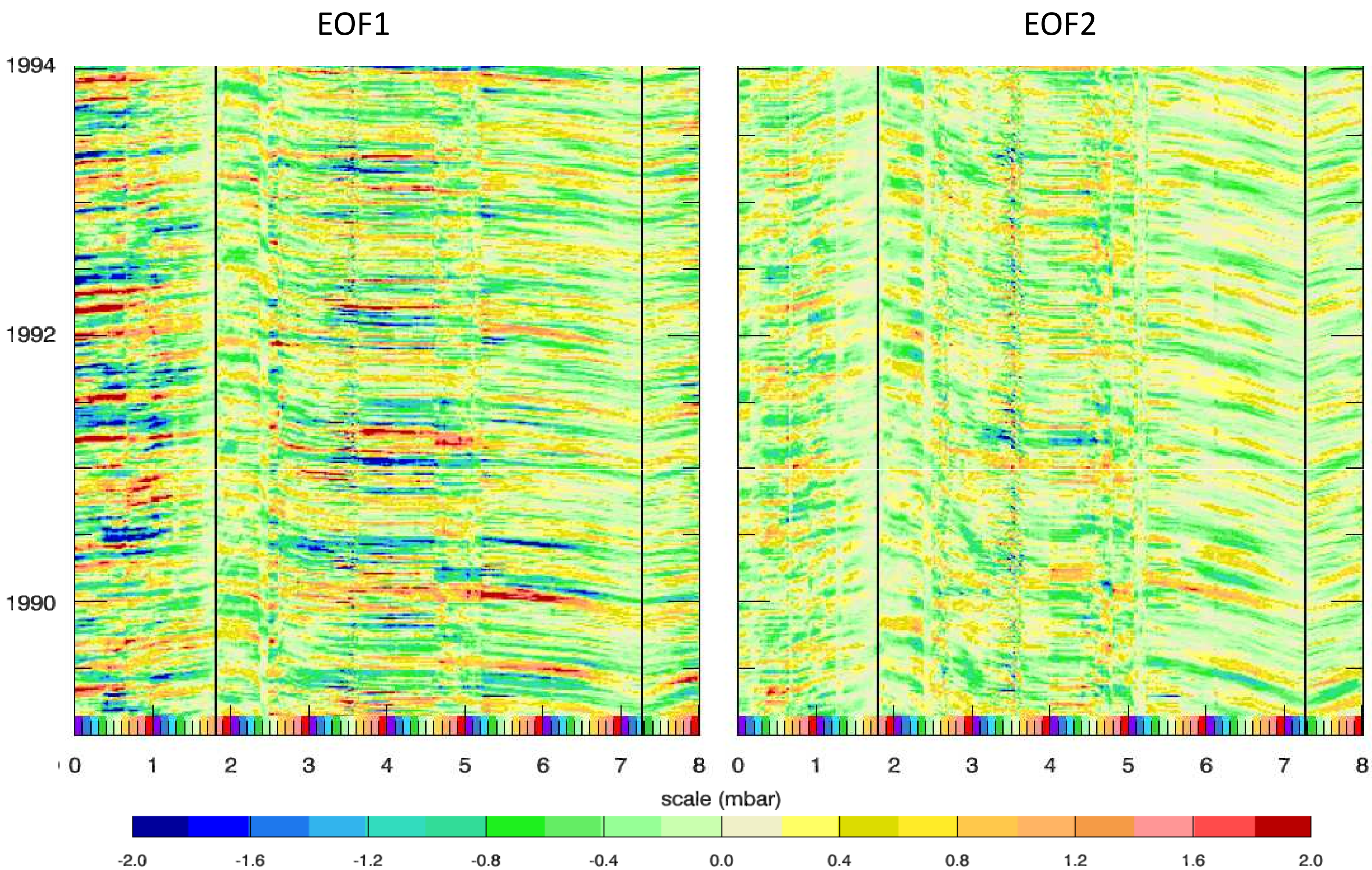


Cross-correlations between pairs of time series



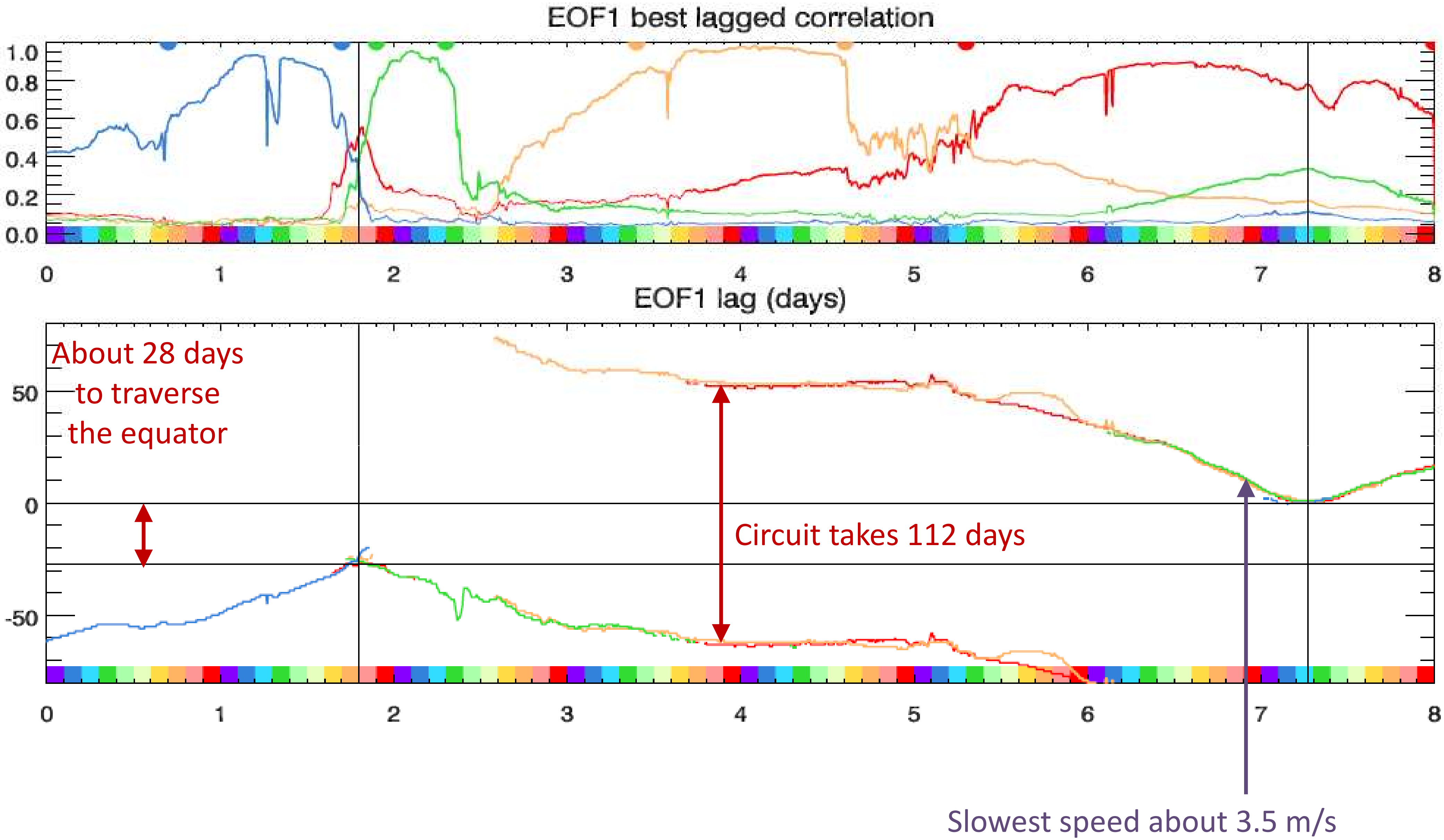
Cross-correlations between pairs of time series

Temporal structures of each EOF

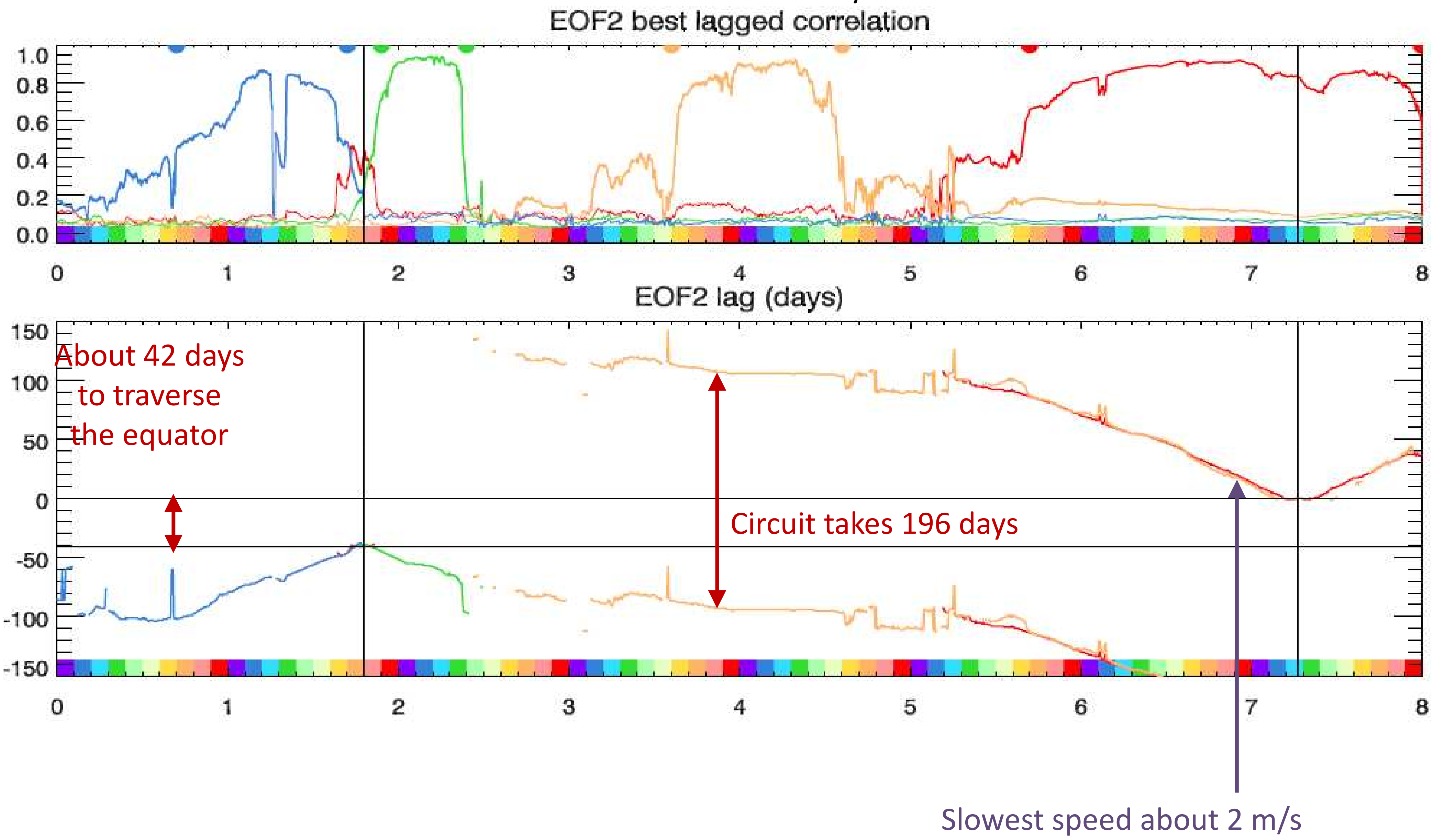


Waves propagate away from the equator (East), towards equator (West)

Periods shorter than 1.5 years



Periods shorter than 1.5 years



So, these boundary signals are:

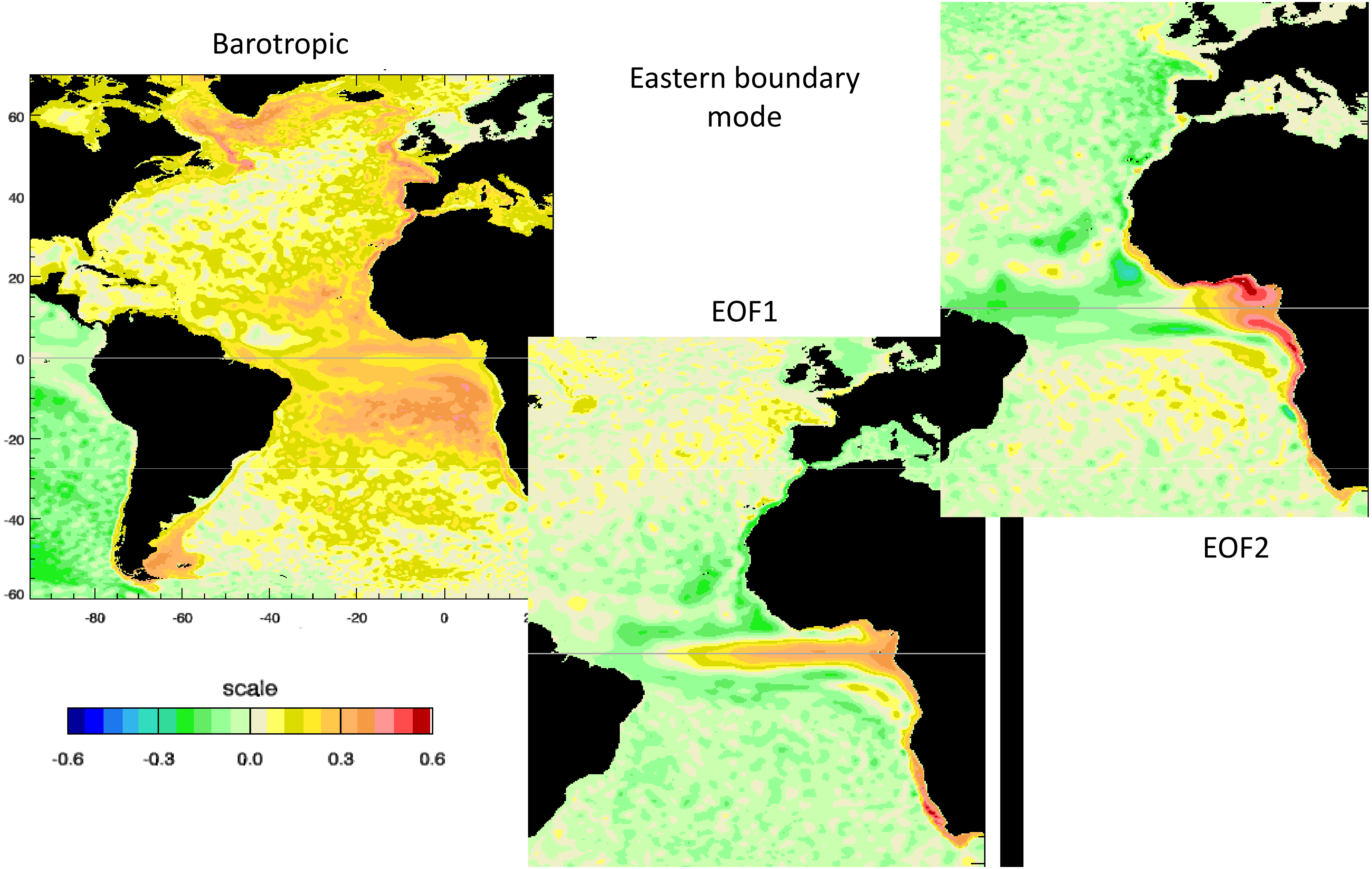
- **Small** though substantially larger on west than east, especially at longer time scales

- **Coherent** over very large distances (tens of thousands of km)

- Behave as expected for **boundary waves** (sensible speeds, slower for higher modes). Though note: slowest near the equator (unlike Kelvin waves) because they become more barotropic at higher latitudes -> topographic Rossby waves.

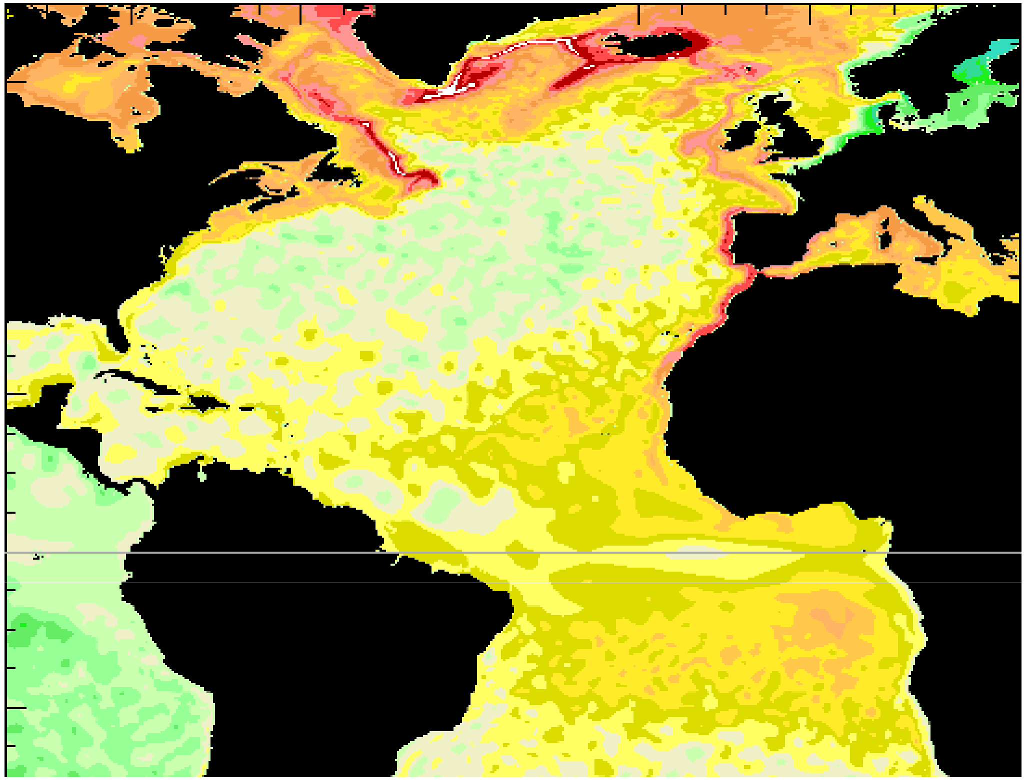
Remaining question: do they have a surface signal that would allow us to identify them from satellite data?

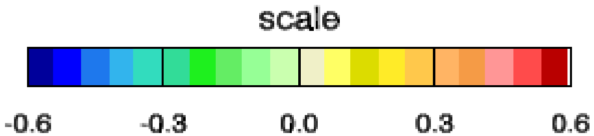
Preliminary answers based on high frequency variability and not yet accounting for lags (so could get better with further analysis)…


Barotropic
Eastern boundary
mode
EOF1
EOF2
60
40
20
0
-20
-40
-60
-80
-60
-40
-20
0
scale
-0.6
-0.3
0.0
0.3
0.6

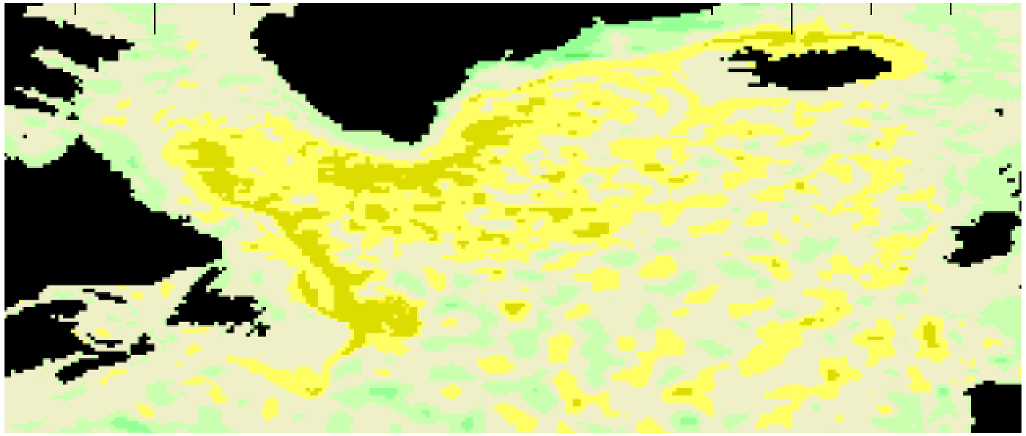
Northern boundary mode

Barotropic

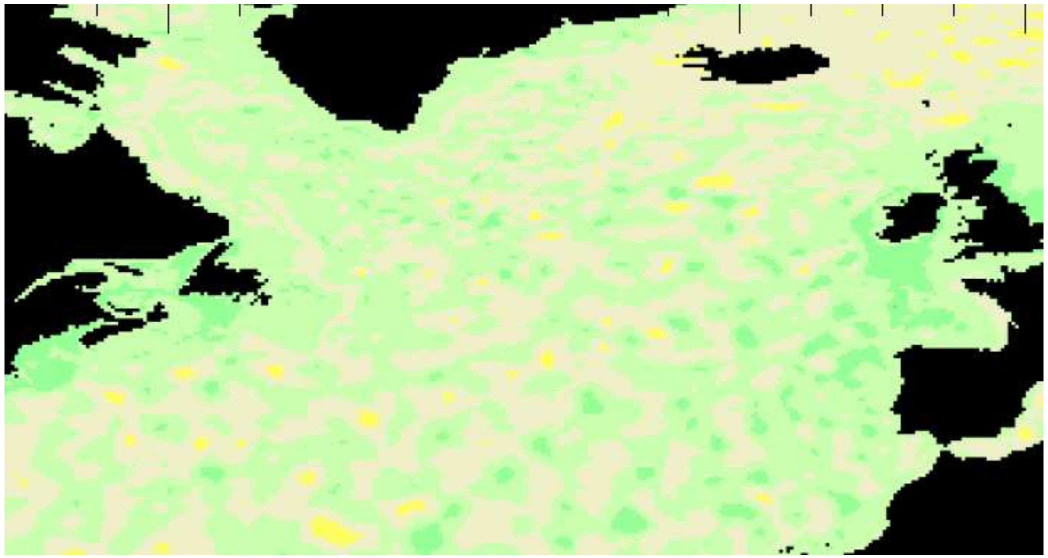




EOF1

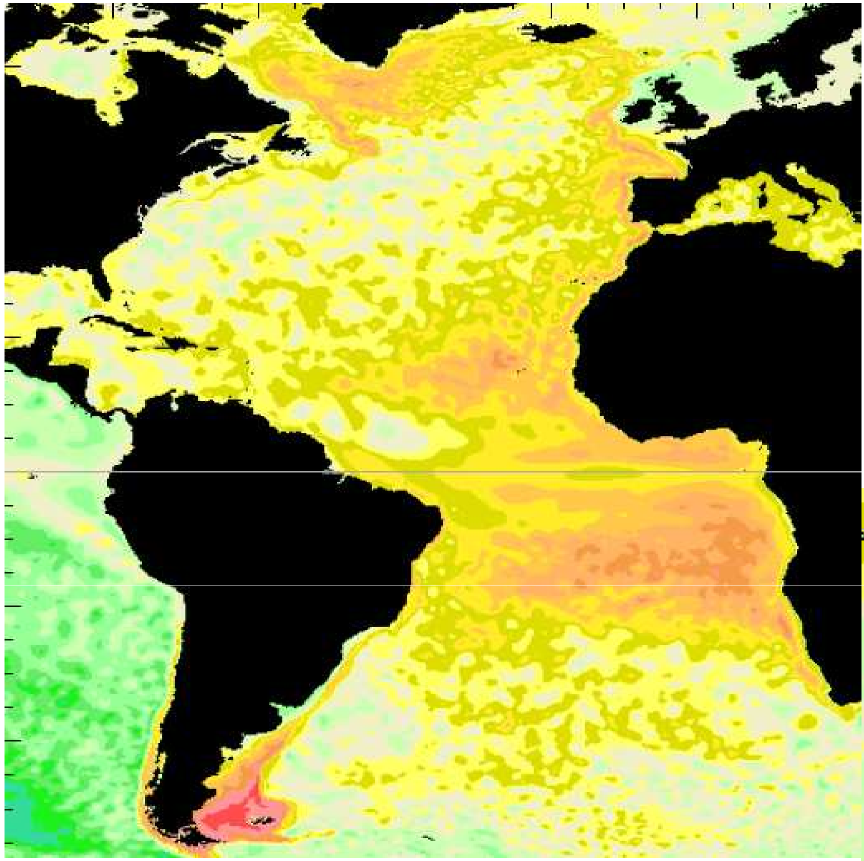


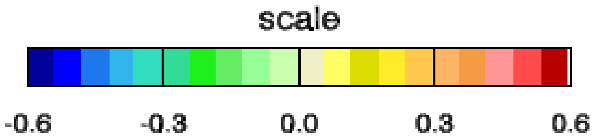
EOF2

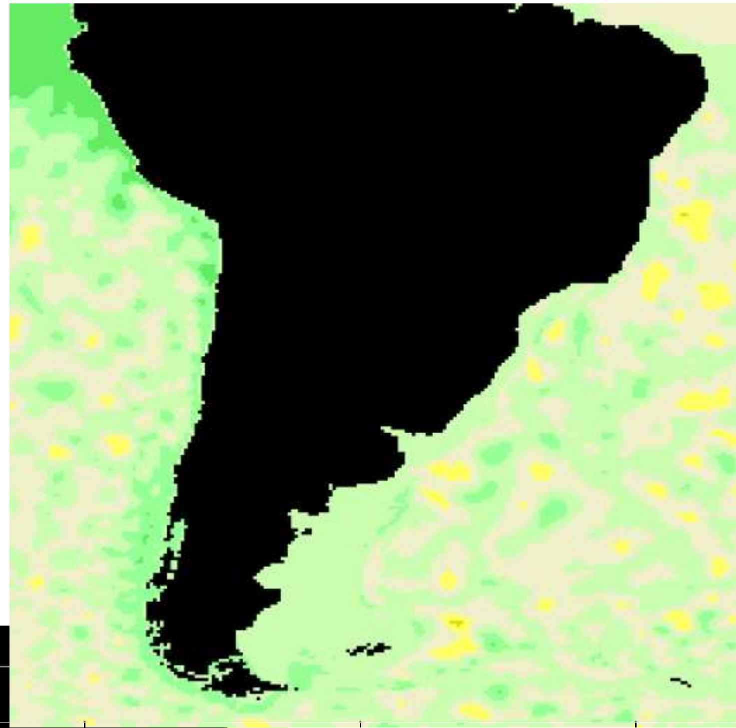


Southern hemisphere western boundary mode

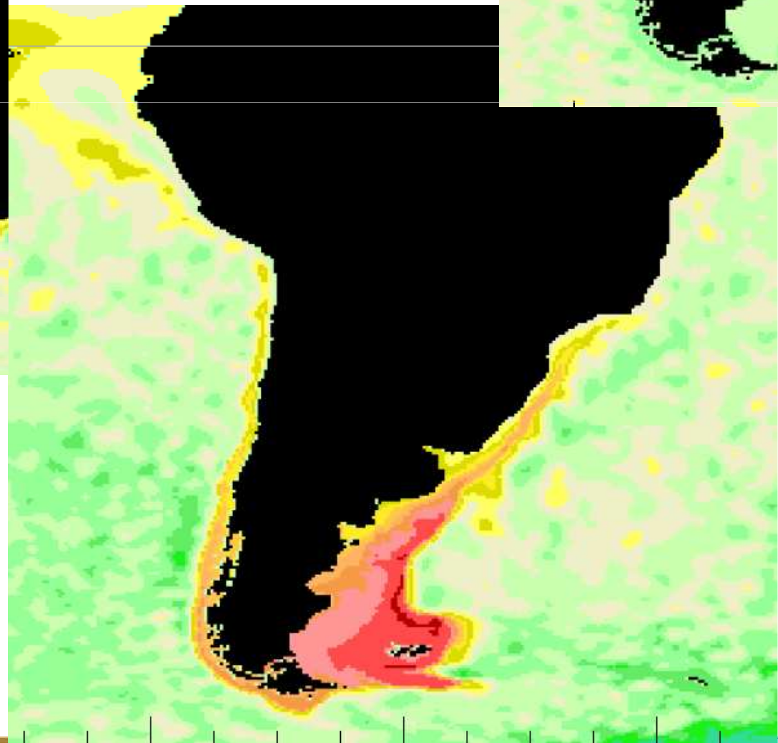
Barotropic







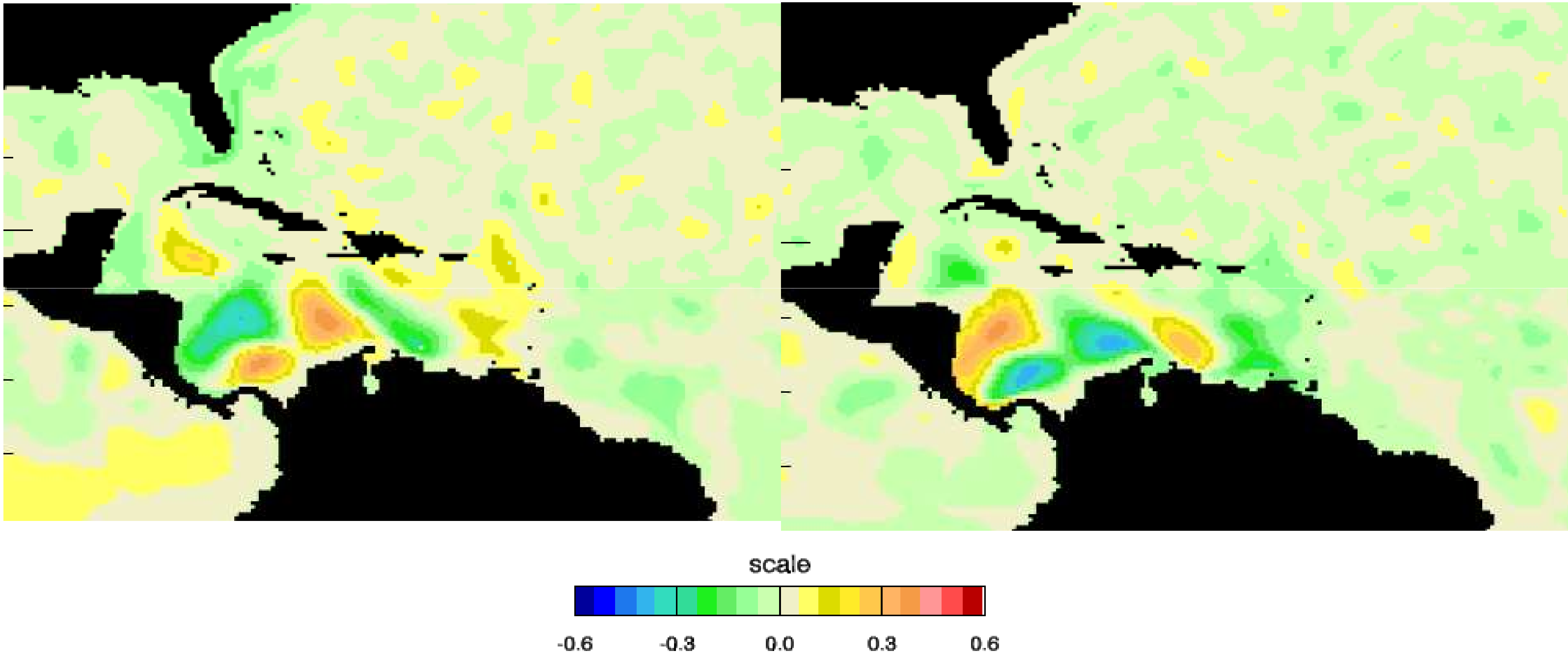
EOF2



EOF1

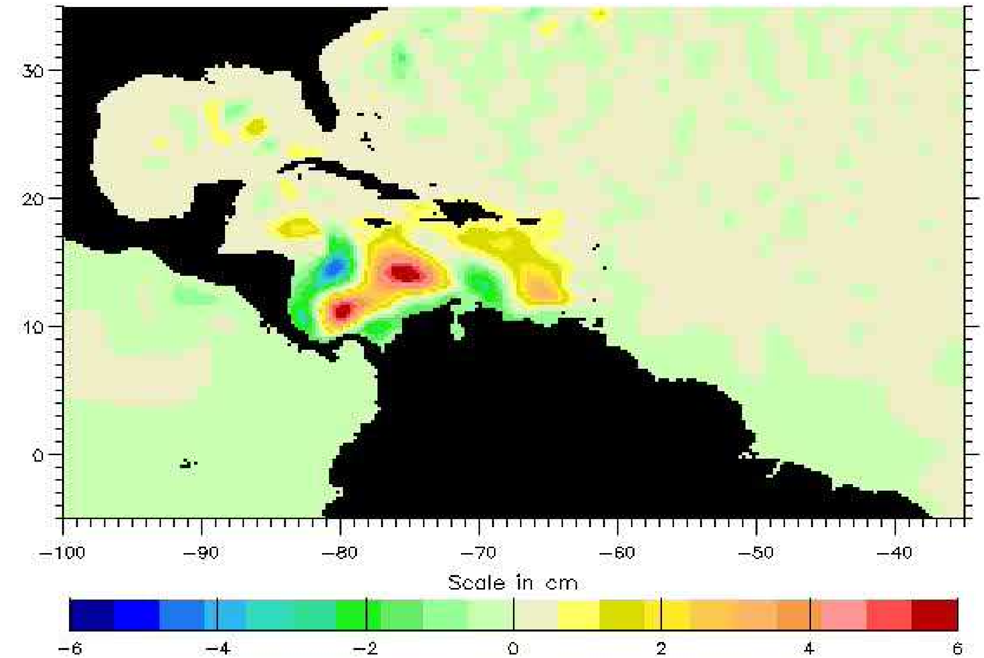
Northern hemisphere South American mode

EOF1 EOF2

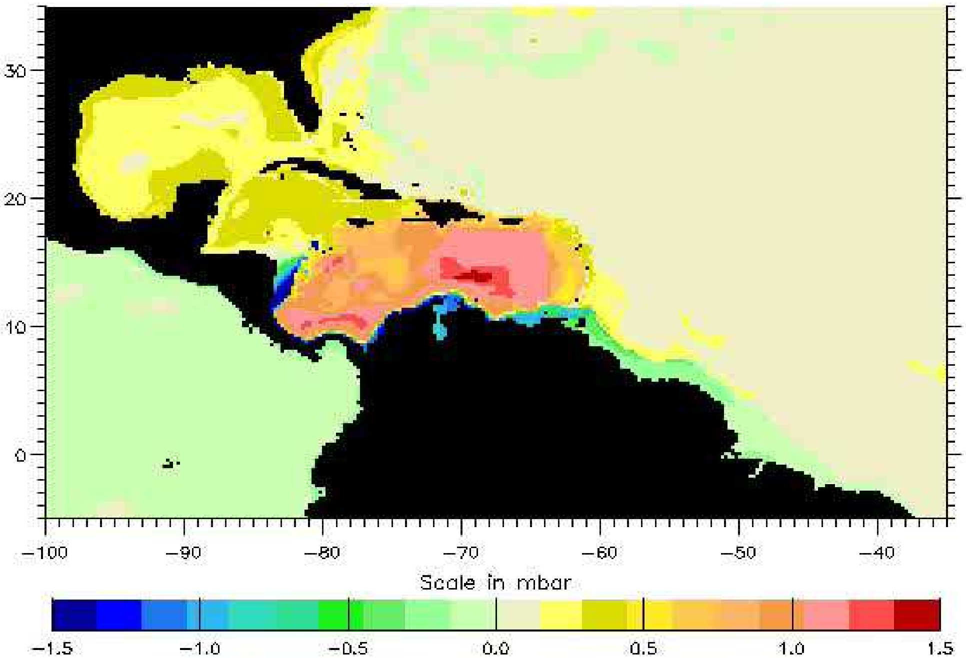


The one clear instance of the mesoscale influencing the boundary pressure

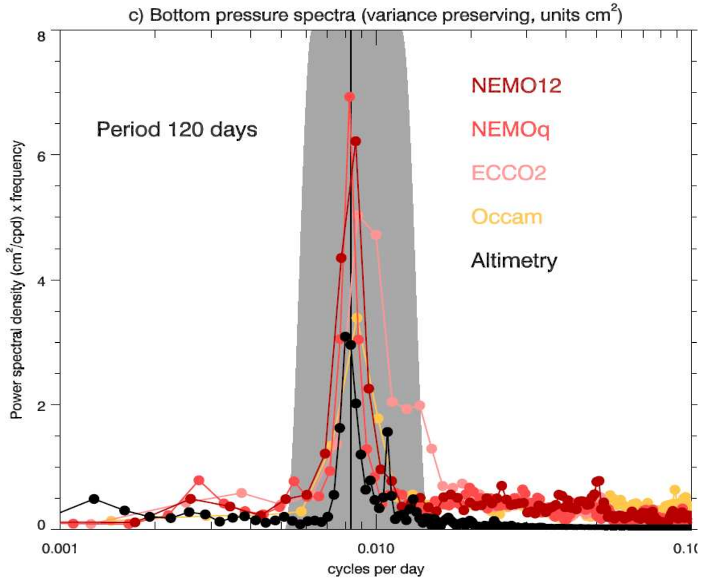
Sea Level



Bottom Pressure

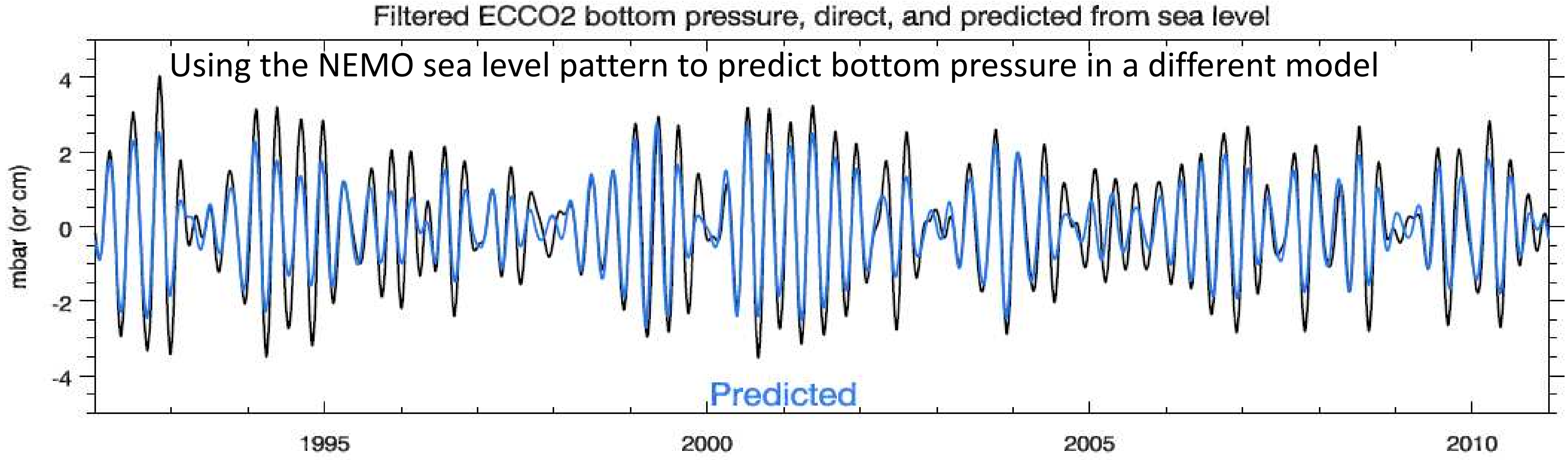


Hughes, C. W., Joanne Williams, A. Hibbert, C. Boening and J. Oram, 2016: A Rossby whistle: A resonant basin mode observed in the Caribbean Sea. *Geophys. Res. Lett.* **43**, 7036-7043, doi: 10.1002/2016GL069573

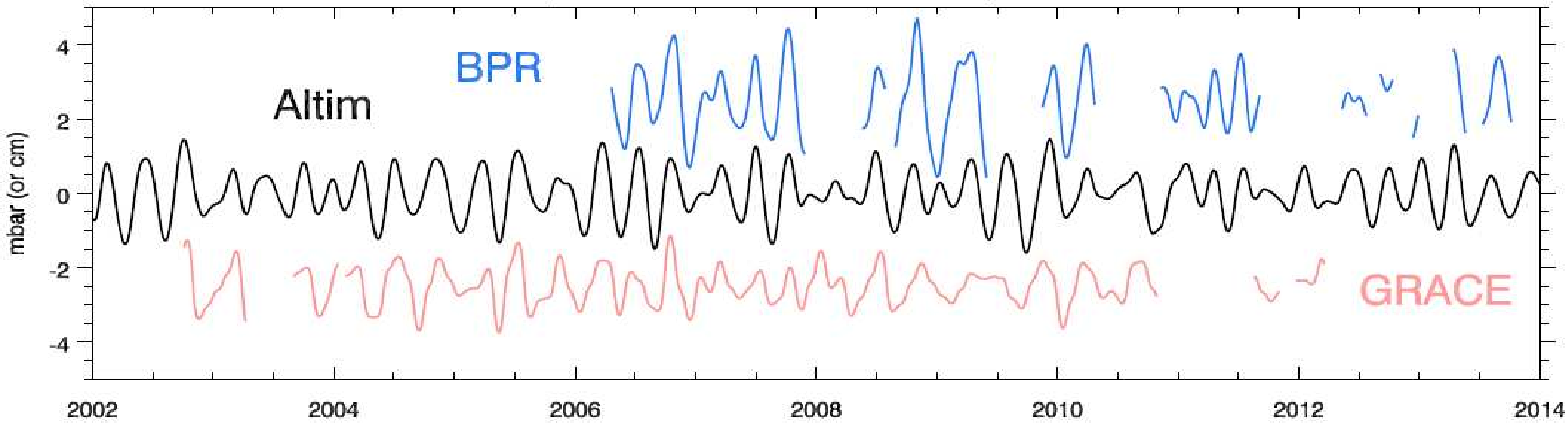


Turns out to be a resonant basin mode, excited by instability of the Caribbean Current, seen in a variety of ocean models and in the real ocean too.

Mode has a period of 120 days and dominates the basinwide bottom pressure

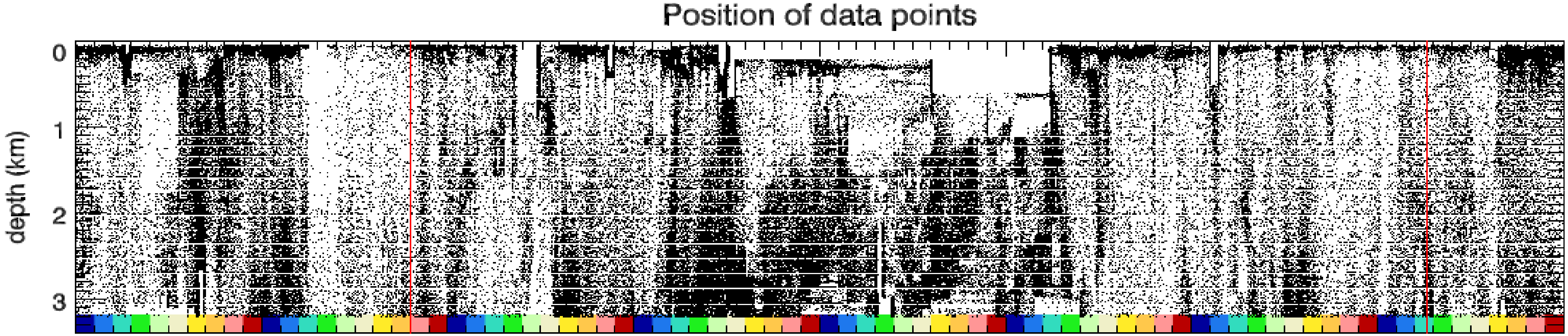


… and to predict real ocean bottom pressure from altimetry



Conclusions

- Boundary pressure allows us to see through the usually dominant eddy variability to the genuinely large scale ocean dynamics.
- In some cases there are clear surface manifestations of these boundary signals.
- We have demonstrated reconstruction of deep variability from surface patterns in the Caribbean Sea.
- More work is needed elsewhere.


Position of data points
depth (km)
0
1
2
3