Non-linear Anisotropic Filtering Applied to the Ocean's Mean Dynamic Topography

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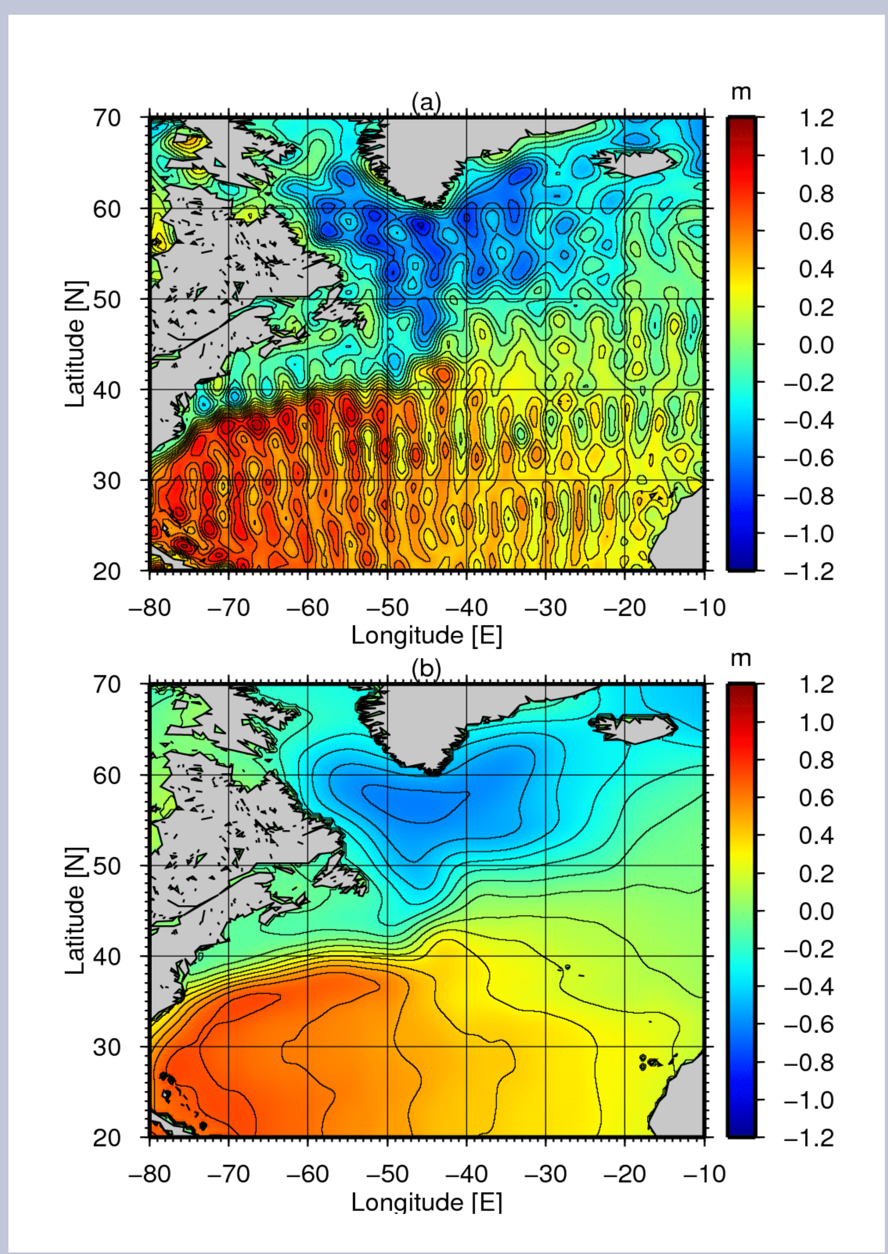
1. Motivation

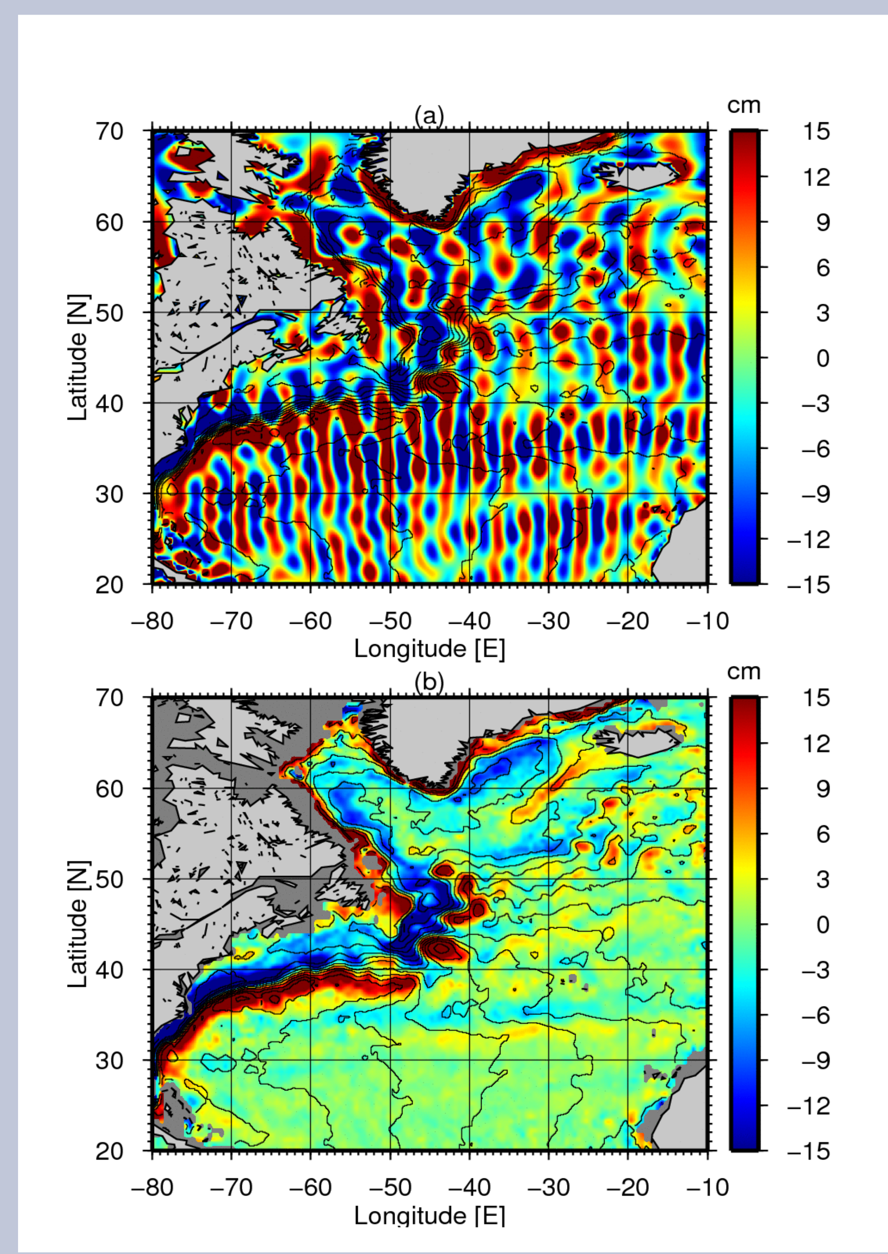


Despite recent improvements in satellite geoid determination it remains necessary to filter the mean dynamic topography (MDT) computed from such geoids to remove residual noise. Commonly this achieved through spatial smoothing with a Gaussian or similar filter.

To the left we see (a) the un-smoothed MDT for the North Atlantic computed from the GRACE gravity model GGM02S truncated at degree 120 and (b) this MDT smoothed with a Gaussian filter of half-weight radius of 200 km.

In addition to removing unwanted noise, conventional filtering also results in the attenuation of MDT gradients associated with ocean currents. This results in the underestimation of current speeds.

To the right we see (a) what the Gaussian filter has removed from the original MDT. The parallel positive and negative bands just visible beneath the noise along the path of the Gulf Stream are indicative of undesired signal attenuation. This is reinforced by comparison with (b) which shows a similar residual obtained from an MDT produced by Niiler et al. (2003) using in-situ data only.



2. Anisotropic diffusive filtering

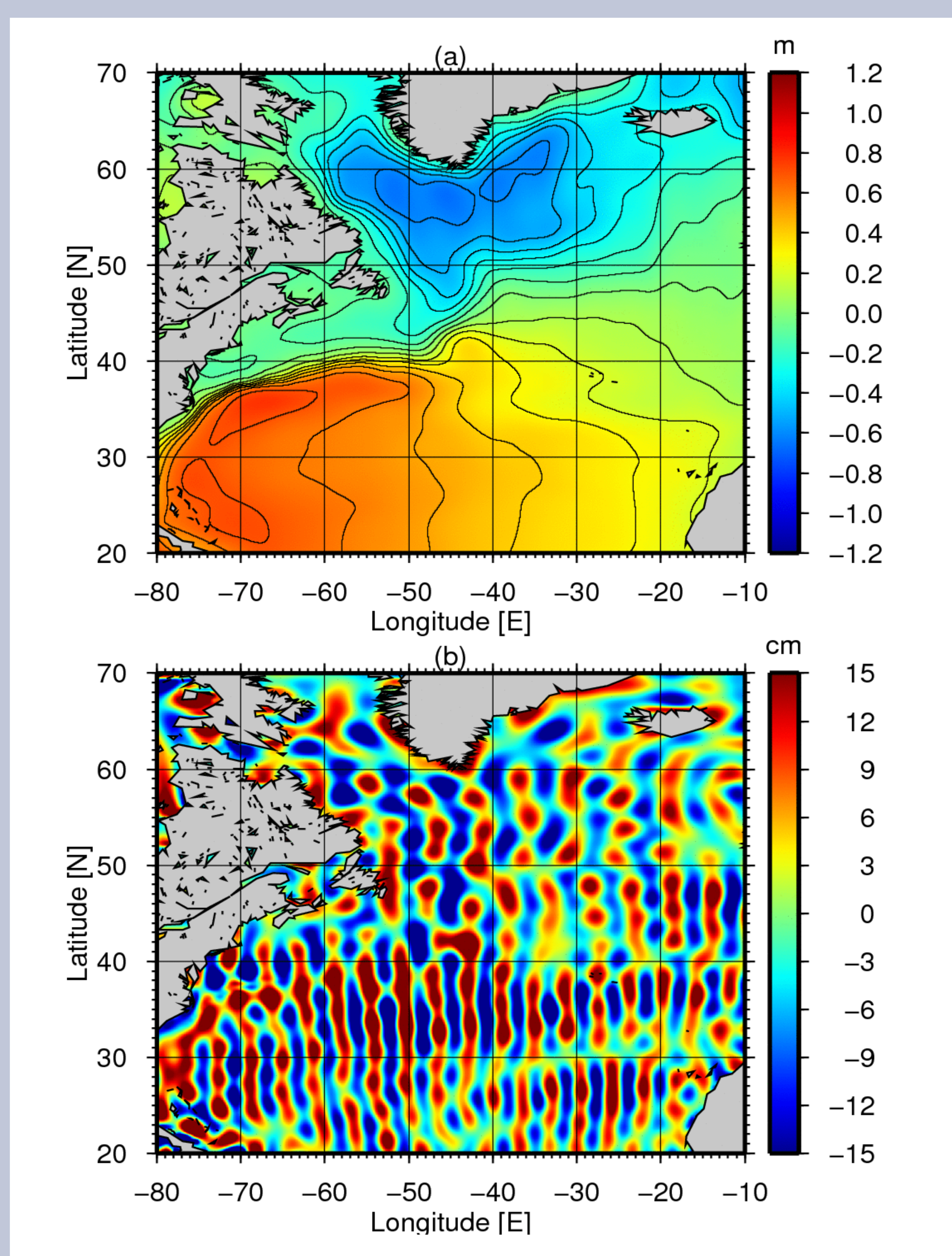
Non-linear anisotropic filtering reduces the attenuation of the MDT's oceanographic content by preferentially filtering along rather than across MDT gradients.

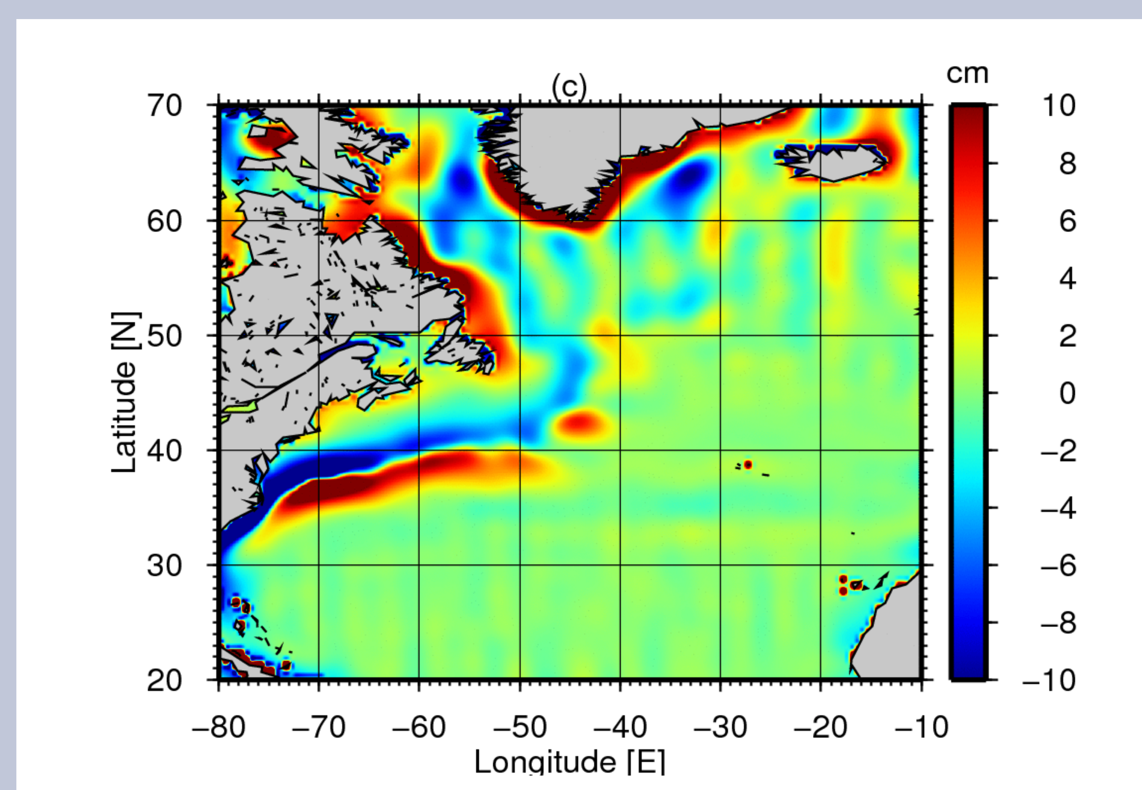
This achieved by representing the MDT undergoing smoothing as a time-dependent function $\eta(x, y, t)$ subject to the non-linear anisotropic diffusion equation:

$$\frac{\partial \eta}{\partial t} = \nabla \cdot \left[D(|\nabla \eta|) \nabla \eta \right]$$

The unsmoothed MDT $\eta_0(x,y)$ provides the initial condition. The degree of smoothing is controlled globally by the pseudo-time variable t, and locally the smoothing is governed by an arbitrary diffusion operator $D(x,y,t)$, which depends on the magnitude of the MDT gradient. See Bingham (2009) for further details.

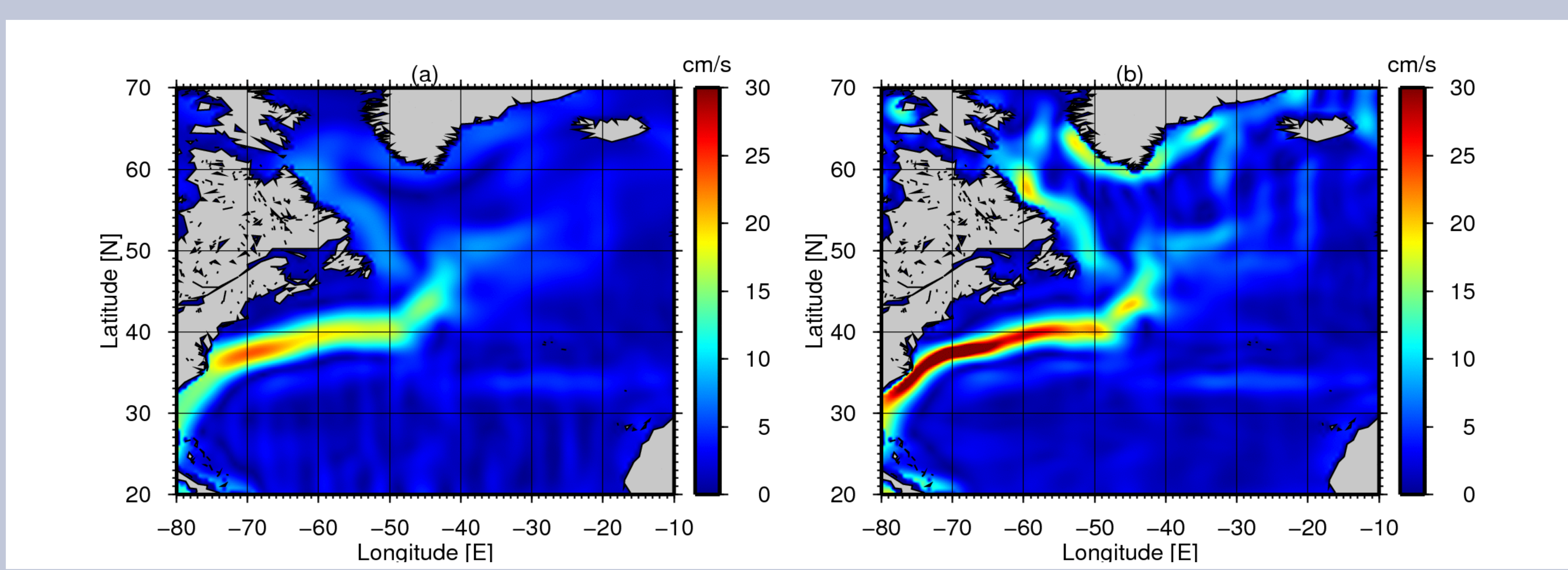
To the right we see (a) the original MDT smoothed by the diffusion method and (b) what has been removed by the filter. As intended, the diffusive filtering method has successfully removed the unwanted noise from the MDT while preserving MDT gradients.





Above we see the difference between the MDTs produced by the conventional and diffusion methods. The positive and negative parallel bands visible along the path of the Gulf stream and sub-polar boundary currents reflect the reduction in MDT attenuation achieved by the diffusive filtering approach. The attenuation of the MDT gradient has been reduced in places by more than 20 cm over the width of the Gulf stream.

3. North Atlantic currents



Comparing the left and right panels above, which show, respectively, geostrophic current speeds in the North Atlantic determined from the conventionally and diffusively filtered MDTs, the improvement given by the latter method is clear. Along the Gulf stream current speeds are greater by up to a factor of two and its position is much better determined. Subpolar boundary currents are also better resolved.

4. Conclusions

For the North Atlantic diffusive filtering results in significant improvements in the resolution of important currents including the Gulf Stream and Greenland and Labrador Currents. Current speeds are up to twice that estimated from a conventionally filtered MDT; An important result given the crucial role played by these currents in regulating the Earth's climate.

Similar improvements are seen for other strong currents, including the Antarctic Circumpolar Current and the Kuroshio Current and its extension.

It is expected the filtering method presented here will yield similar or greater improvements over conventional smoothing when applied to an MDT derived from GOCE.

References
Bingham, R.J., Nonlinear anisotropic diffusive filtering applied to the ocean's mean dynamic topography, Remote Sensing Letters, Vol. 1, No. 4. (2010), pp. 205-212.
Niiler, P., Maximenko, N. and Mcwilliams, J., 2003, Dynamically balanced absolute sea level of the global ocean derived from near surface velocity observations. Geophysical Research Letters, 30, 2164, doi:10.1029/2003GL018628.

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