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Ocean Science Discussions

Interactive comment on "Evaluating two numerical advection schemes in HYCOM for eddy-resolving modelling of the Agulhas Current" *by* B. C. Backeberg et al.

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Reviewer #2 Comments

Reviewer comments are given in bold font, with the responses following below.

1.1 Page 431: The vertical coordinate system of HYCOM is documented elsewhere. Since the analysis of the authors does not rely on the particular coordinate system, this paragraph should be removed.

This paragraph provides background information about the model and motivates for the use of HYCOM in regional simulations. The discussion of how isopycnic and Cartesian coordinate models do things differently may also motivate for future inter-model experiments and further the advancement of numerical models, and is thus relevant.

1.2 Page 437: "In these experiments with HYCOM, the QUICK scheme was only applied to momentum advection following the arguments by Sanderson (1998)". This reads as if Sanderson showed that higher order advection scheme for tracers are useless. This statement should be nuanced and better placed in the context.

Adjusted to: "In these experiments with HYCOM, the 4th order scheme was only applied to momentum advection since the horizontal grid resolution is smaller than the Rossby radius of deformation, as discussed in Sect. 1."

The motivation for applying higher order numerics only to momentum advection is discussed on page 432, Lines 11-17.

1.3 Page 440, line 19: What is the average vertical of the HYCOM model at this depth and which coordinate system it used? If the model uses isopycnals at this location, shouldn't it be able to represent the extent of the current by adjusting the layer thickness?

The model uses the hybrid vertical coordinates, i.e. z-level in the upper 100 m and isopycnal the open ocean water column. At depths of 2000 m the density changes are small and the isopycnal coordinates, hence also the layer thickness, are limited by their reference densities. Therefore, more vertical layers would have provided a better solution. This was however not possible due to lack of computing resources at the time of implementation.

1.4 Page 441: The manuscript would benefit if the authors would try to explain why the transport is increased using the 4th advection scheme. Certainly less numerical diffusion on momentum plays a role. But are also the temperature and salinity gradients enhanced by using a 4th order advection scheme for momen-

tum?

The following text is included:

In the discussions of the vertical structure of the Agulhas Current (Sect. 3.2) it was shown that the vertical characteristics of the Agulhas Current are much improved in the O4 scheme. A much deeper and well-defined current is evident, which (partially) accounts for an increase in the transports. Additionally, there is a $1°$C increase in the vertical temperatures of the upper 100 m and a 0.2 psu increase in salinity in the upper 200 m in the O4 scheme (not shown). This results in enhanced temperature and salinity gradients of the upper 500 m, and according to the thermal wind equation an increased density gradient will result in an increased transport. Furthermore, as will be shown in Sect. 4, there is an overall increase of mesoscale variability in the O4 scheme. The Agulhas Current transport is sensitive to mesoscale eddies, and their enhancement also acts to increase the average transport.

1.5 Page 441, line 27: Why does the transport become negative in O2? What is the spatial structure of the current at this time? Is it due to a uniform decrease of the velocity at this location or is the current displaced from its mean track, possibly by an eddy?

The following text is included:

The negative transport at this time is due to the passage of a mesoscale eddy which caused poleward transports in the Agulhas Current at its trailing edge.

1.6 Page 446 and figure 6: It is difficult to see from figure 6 which model gives the best overall results. Please provide a quantitative measure which model results are closer to the standard deviation of the observations.

Figure 6 is discussed in detail in Sect. 4, with the overall conclusion that distribution of the mean SSH and its standard deviation is improved in the O4 scheme. It remains that these comparisons are qualitative, and a more quantitative analysis is required, as stated in Sect. 4.2 (page 446, Lines 7-8) which aims to address this issue.

Additionally, as suggested by reviewer #1, a vorticity analysis of the two experiments will be included.

1.7 Page 450: Using the skewness to determine the preference of cyclonic and anticyclonic eddies is an interesting approach. How large has the sample to be to distinguish between positive and negative skewness (for a given significance level)? How large is the zone where the skewness is not significantly different from zero around the mean current? This is related to the question how accurately the central position of the current can be determined by using skewness.

Refer to Appendix A in Thompson and Demirov (2006). The standard deviation of sample skewness based on a random sample of size N drawn from a normal distribution is approximately $\sqrt{6/N}$ for large N. One of the reasons one cannot use this result to assess the statistical significance of the skewness estimates is that the sea level observations are serially and seasonally dependent. Both of these effects will reduce the effective degrees of freedom of the estimator to a value less than N. To assess the statistical significance of the skewness estimates first calculate the skewness for each of the calendar years (in our case 6). Average these 6 annual skewness maps to find the mean skewness at each grid point. For the Agulhas Current region the average of these 6 skewness maps closely resembles Figure 7a provided. The standard error of the mean skewness can be calculated by $\frac{s}{\sqrt{N}}$. This standard error calculation assumes the annual skewness estimates are uncorrelated (which is a reasonable assumption) but does allow for seasonality and serial dependence within each calendar year. A typical standard error of the mean skewness over most of the ocean is 0.2, which is also the case for the Agulhas Current region.

How accurately the skewness is able to determine the central position of the current can only be ascertained qualitatively by comparing to other observations, which we have done in this case comparing to geostrophic surface currents derived from altimetry

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(overlaid on Figure 7a).

1.8 Page 454, lines 5-10: Consider to reword this paragraph to make it more readable.

Reworded to:

C is the amplitude of the Gaussian / cosine function, h the distance between points and a the range, or radius. In Eq. 5 the subscripts g and c refer to the Gaussian and cosine variables respectively. Note that in a Gaussian model the range a_g corresponds to a length scale of $a_g \times 2.5$, which in this case is 275 km ($a_g = 110$ km).

1.9 Section 4.3: I believe that most readers of Ocean Science will be familiar with the concept of covariance but not necessarily with variogram. Since there is a straight forward relationship between both, please include this in your manuscript. A brief discussion why you prefer to interpret a variogram instead of the covariance would also be useful.

The following text is included:

In geostatistics analyses of spatial data often rely on the assumption of stationarity for the random process (Gneiting et al., 2001). In the stationary case, the variogram can be simply deduced from the covariance as C0 – C(h), where C0 is the variance and C(h) the covariance. The variogram averages squared differences of the variable, which filters the influence of a spatially varying mean. Therefore, the variogram can be defined in some cases where the covariance function cannot. For example in the non-stationary case, the variance may keep increasing with increasing lag, rather than leveling off, corresponding to an infinite global variance. In this case the covariance function is undefined, while the variogram remains valid.

1.10 Section 4.3.1: How are land points treated in the Fast Fourier Transform and the fact that the model grid is curvilinear?

Land points do not need to be dealt with in the sections extracted, refer to Fig. 7a and

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8 for the locations of sections used in these analyses.

The section data was extracted from the gridded data by interpolating to 10 km of the nearest longitude / latitude coordinate.

1.11 Page 458, conclusions: "Moreover, this is achieved at a fraction of the computational cost of increasing the grid resolution. " This is to be expected but not shown in the manuscript. The authors compare the realism of an O2 momentum advection scheme versus an O4 scheme. However a comparison of the necessary resolution to achieve with an O2 scheme similar results than with O4 scheme was not shown in this paper. This statement should therefore not appear in the conclusions (but may appear in the introduction by citing the relevant research).

Agree.

1.12 Quality of figures needs to be improved. In particular the font-size too small.

For Ocean Science publication to decide.

These comments will be included in the updated version of the manuscript, and will be submitted in due course. Thank you for your constructive review of our work.

Best regards,

Bjorn Backeberg et al.

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