Towards understanding the impact of assimilating along-track SLA data on simulated eddy characteristics in the Agulhas System

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Abstract

The impact of assimilating along-track sea level anomaly (SLA) data into a regional Hybrid Coordinate Ocean Model (HYCOM) is investigated with regard to the simulation of mesoscale eddy characteristics in the Agulhas System. Eddy characteristics from an assimilated (*Assim*) and an unassimilated (*Free*) simulation experiment in HYCOM are compared with each other, using satellite altimetry derived eddy characteristics as a basis to evaluate accuracy. Overall, *Assim* yields improvements over *Free* in eddy density distribution and dynamics. South of Madagascar, the number of eddies simulated by both HYCOM experiments is too low, although *Assim* offers some improvements in this regard.

Keywords

Along-track SLA, HYCOM, mesoscale eddies, Agulhas System, data assimilation, satellite altimetry,

Introduction

The Agulhas Current is one of the most important currents in the global ocean-atmosphere system by virtue of its role in energy transport (Beal et al., 2011). An important transfer of warm, salty waters from the south-west Indian Ocean to the south Atlantic Ocean occurs in the region of the current's eastward retroflection which occurs south of South Africa. This is facilitated primarily by the periodic shedding of Agulhas Rings (mesoscale, anticyclonic eddies) (Lutjeharms & van Ballegooyen, 1988). An enhanced understanding and predictability of the Agulhas Current system would prove beneficial to industrial, commercial and recreational interests in the region, as well as in the event of oil spills and harmful algal blooms (Backeberg et al., 2014). Furthermore, Agulhas leakage has itself an important influence on the Atlantic Ocean Meridional Overturning Circulation (AMOC) and hence, on global ocean circulation (Beal et al., 2011) and climate.

The shedding of Agulhas Rings in the region of the Agulhas Current retroflection is thought to be linked to the propagation of eddies from the Mozambique Channel and East Madagascar Current. Eddies and dipoles reach the Agulhas Current frequently and on occasion propagate all the way to the retroflection, influencing its position and modulating ring shedding events there (Schouten et al., 2002; Ridderinkhof et al., 2013) potentially impacting the AMOC.

Mesoscale eddies are also important determinants of the marine ecology in the region, for example in the western reaches of the Mozambique Channel seabirds have been observed to forage at the boundaries of eddies (Weimerskirch et al., 2004). Their impact probably extends further, given their associated high nutrient and low oxygen anomalies (Swart et al., 2010) and their tendency to advect phytoplankton-rich, coastal waters offshore (Omta et al., 2009). Mesoscale eddies may also boost primary production by raising nutrients from deep waters to upper ocean levels (e.g. Lathuiliere et al., 2010). Given the dearth of coherent monitoring systems in the Agulhas system (Backeberg et al., 2014), as well as lingering inaccuracies in model results due to the highly non-linear nature of the dynamics (Biastoch et al., 2008b), concrete conclusions about the magnitude of Agulhas leakage and the variability thereof remain elusive (Backeberg et al., 2014). Model simulations of the Agulhas system have been shown to be highly sensitive to subtle

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changes in the numerics (Backeberg et al., 2009; Barnier et al., 2006). Data assimilation processes seek to compute the most probable model state by strategically combining an accurate dynamical model with a set of observational data (Evenson, 2003). Continuous data assimilation constrains model solutions such that forecast accuracy is usefully enhanced (Backeberg et al., 2014).

In this study the impact of assimilating satellite altimetry data into a HYCOM simulation is investigated with respect to simulated eddy characteristics.

Methodology

The HYCOM model configuration, satellite altimetry data for assimilation and EnOI data assimilation scheme are employed as in Backeberg et al. (2014). The satellite altimetry data used for validation with HYCOM were produced by Ssalto/Duacs and distributed by Aviso. Support for this product is provided by CNES (http://www.aviso.oceanobs.com/duacs/). They are distributed as merged daily gridded maps of global ocean gridded absolute dynamic topography (MADT), with a spatial resolution of 0.25° Weekly means were created from the daily maps of MADT to coincide temporally with model results. The altimetry used for assimilation into HYCOM is the delayed-time, unfiltered, along-track SLA product.

The automated eddy detection algorithm used here is based on the work in Halo et al. (2014). Modifications were made to the algorithm code to account for spatial variability of the observational error..

Root mean squared errors for all eddy statistics were computed as per Eq. (1).

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(y_o - y_e)^2}{n}} \qquad \text{Eq. 1.}$$

where n is the number of estimations, y_o is the reference value (*Aviso*) and y_e is the estimated value (*Free* or *Assim*).

The difference in relative error (R.E.) between *Free* and *Assim* was then mapped on a grid (see Fig. 2d), with the difference shown in each grid cell computed as per Eqs. (2, 3).

$$R.E.Improvement\ (\%) = \frac{y_e - y_o}{y_o} \times 100 \qquad \text{Eq. 2.}$$

where y_o is the reference value (*Aviso*) and y_e is the estimated value (*Free* or *Assim*).

$$Error\ Diff. = \%\,R.E._{free} - \%\,R.E._{assim} \qquad \text{Eq. 3.}$$

where $\%\,R.E._{free}$ and $\%\,R.E._{assim}$ are the $R.E.Improvements$ (%) as calculated in Eq. 2.

A range of dynamical and geometric properties was computed for individual eddies by the detection and tracking algorithm, and used for comparison of *Free*, *Assim* and *Aviso*.

Results & Discussion

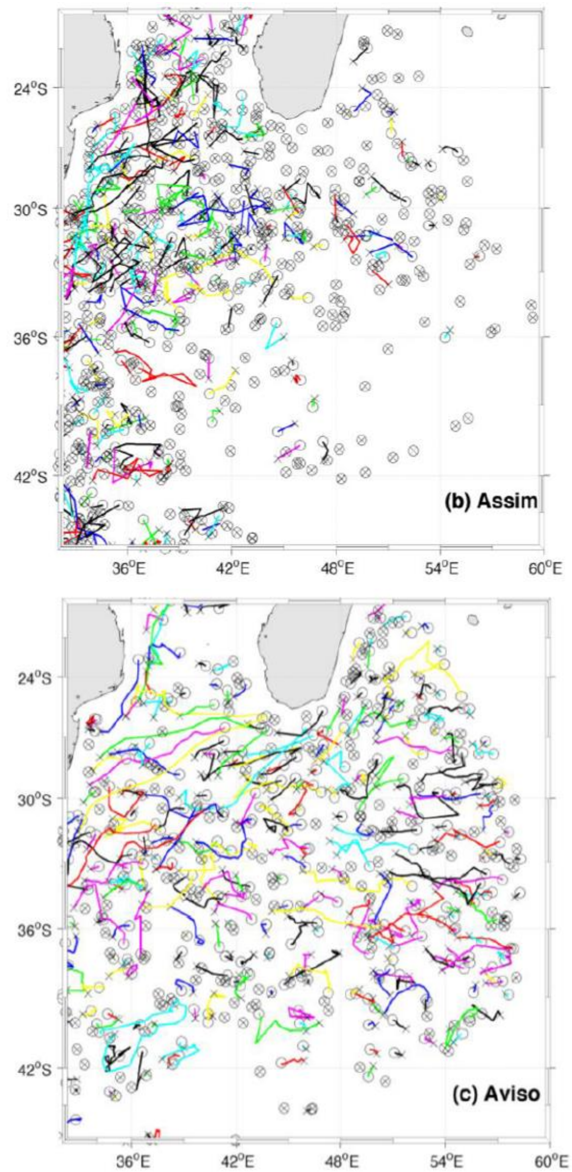

Figure 4*. All eddy formation sites, dissipation sites and trajectories are shown for a) Assim. and b) Aviso, 2009 (Free not shown). Colours distinguish different eddies. Formation sites are marked 'O' whilst dissipation sites are marked 'X'. Eddies of all lifetimes are shown.*

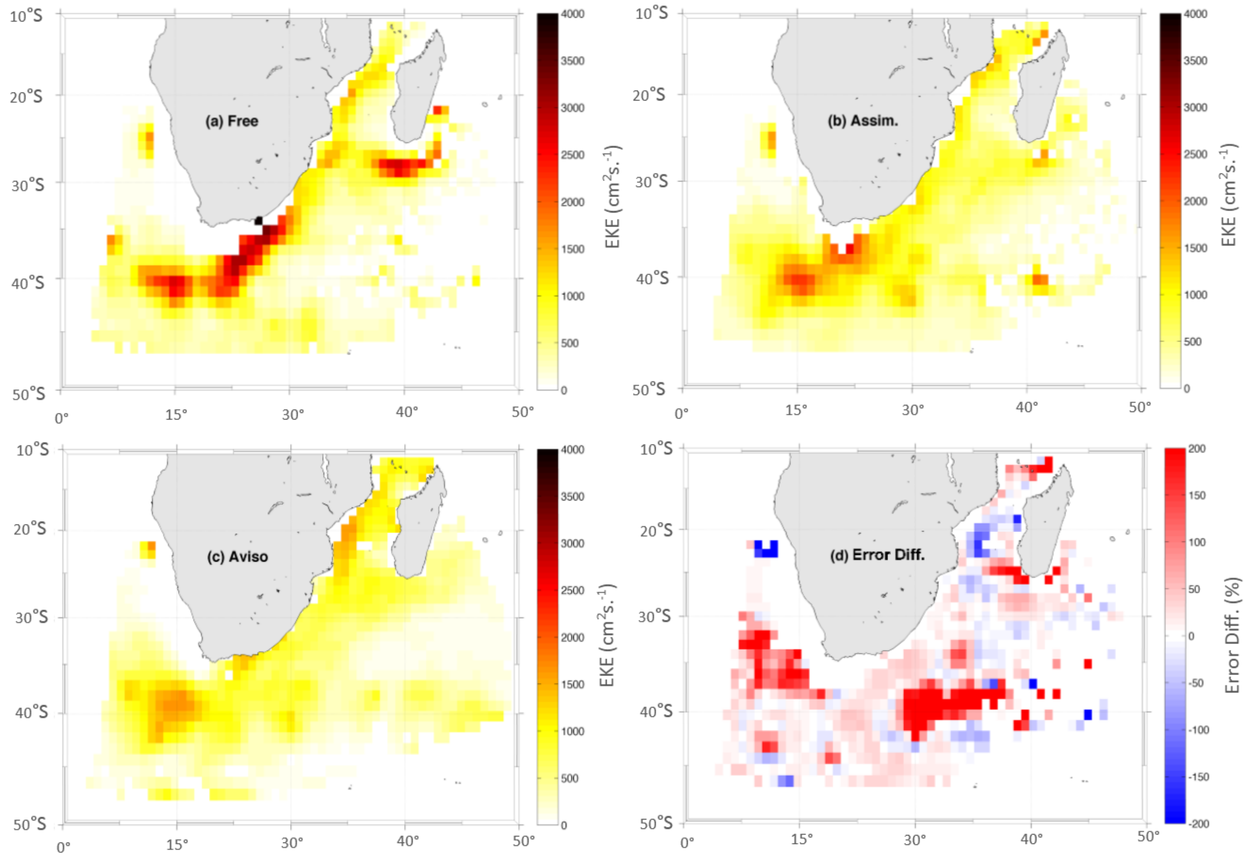

***Figure 5**. Eddy kinetic energy for a) Free, b) Assim and c) Aviso as computed by the detection and tracking algorithm. d) Shows difference in relative error as per Eq. 3, with redder tones indicating closer adherence of Assim to Aviso, and bluer areas indicating closer adherence of Free to Aviso.*

Assim shows improvement across a range of derived dynamical eddy properties compared to *Free*, with the exception of cyclonic vorticity (figures not shown). Root mean squared errors (RMSE) for eddy amplitude and rotational speed are reduced in *Assim* by 36.5 %, and 27.5 % respectively. A slight degradation is also evident in eddy size (radii and area). Two results of particular interest are those of eddy density distribution (Fig. 1) and eddy kinetic energy (EKE) which shows an improvement of 13.7 % in RMSE in *Assim* (Fig. 2).

Whilst the number of eddies simulated by *Assim* is improved from that of *Free*, the eddy field remains deficient in the regions south and south east of Madagascar (Fig. 1). Analysis of eddy lifetimes revealed that HYCOM configurations initialise a number of eddies with coherent geometric and dynamical properties, but unrealistically short life times. As such, they do not appear in more than one frame (i.e. life time < 7 days), and therefore exhibit co-incident birth and death sites (Fig. 1).

EKE is a proxy for mesoscale variability, including eddies (Backeberg et al., 2014). Previous studies (e.g. Backeberg et al., 2014) have shown EKE from HYCOM in this region to be, at times, exaggerated. In such studies, EKE is calculated from continuous velocity fields. As such, whilst it might sometimes be valid to do so, EKE cannot be explicitly linked to eddy activity, and could be the result of meandering currents or other chaotic flow. In this study, computing EKE associated exclusively with eddies detected by the algorithm, allows EKE in the region to be attributed explicitly to mesoscale eddies, and highlights the importance of separating the eddy field from the continuous field. Further, this result suggests that, whilst the model appears to be simulating sufficient variability in the mean flow, it is not able to simulate and sustain eddies realistically.

Conclusions

Assimilating along-track SLA data in an eddy resolving HYCOM of the Agulhas system provides general improvement in eddy density distribution. Concerns remain however regarding the absence and lifespan of simulated eddies in the region south and south east of Madagascar. Eddies simulated here are unrealistically short lived. Derived statistics show improvement in *Assim* across a wide range of dynamical properties including amplitude, rotational speed and EKE The accuracy of the eddy sizes simulated by *Assim* are somewhat degraded compared to *Free*. The study suggests that the strategy for the analysis of eddy properties should be carefully selected, for example, EKE calculated from a continuous velocity field is not a good proxy for eddy energy and validation.

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