Preliminary investigation into the impacts of assimilating SST and SLA on the surface velocities in a HYCOM of the Agulhas Current

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Abstract

Data assimilative ocean models play crucial roles in furthering the understanding, and providing forecasts of the Agulhas Current system. This study investigates the impact that assimilating sea surface temperatures (SST) combined with sea level anomalies (SLA) has on the simulated surface velocities of the Agulhas Current in a Hybrid Coordinate Ocean Model. A preliminary comparison of a free running simulation (FREE) and two assimilation experiments, (1) SLA only assimilation ($ASSIM_{SLA}$) and (2) combined SLA and SST assimilation ($ASSIM_{combined}$), indicates that the impact is sensitive to the observed/simulated velocity magnitude in the Agulhas Current, while the mean velocities are overestimated compared to drifter observations.

Keywords

Forecasts, Agulhas Current, data assimilation, SST, SLA, surface velocities

Introduction

The Agulhas Current system, one of the world's most dynamic and energetic western boundary currents, plays a vital role in the resources and ecosystem of the regional marine environment, as well as impacting local weather and global climate (Lutjeharms, 2006).

Recent studies by Rouault et al., (2009) and Backeberg et al., (2012) have indicated that the Agulhas system is undergoing climate related changes. Rouault et al., (2009) noted a decadal warming trend in the region associated with an intensified Agulhas Current, while Backeberg et al., (2012) found that the mesoscale variability in the region has intensified. It has also been hypothesised that the Agulhas leakage, a process of inter-ocean exchange south of Africa, has increased over the past few decades, supplying more warm and saline waters to the Atlantic Meridional Overturning Circulation. This has the potential to counteract the North Atlantic freshening from melting ice-sheets and glaciers due to the anthropogenic warming of the global climate (Biastoch et al., 2008, 2009). A lack of data in the Agulhas systems hinders our ability to quantify the extent to which the Agulhas Leakage has changed, including its potential impact on the global ocean circulation and climate.

Due to the Agulhas' influence on the regional and global climate, it is crucial that these changes are understood, mapped and monitored accurately. The ability to predict these changes on scales of days to decades would enable stakeholders (governments, environmental agencies etc.), to plan for changes as well as implement mitigation strategies.

This study builds on Backeberg et al., (2014) where the impacts of assimilating along-track SLA into a Hybrid Coordinate Ocean Model (HYCOM) of the Agulhas region were assessed. This study presents a preliminary investigation into how Agulhas Current surface velocities are affected by the combined assimilation of along-track SLA and SST data.

Method

Ocean forecasting and reanalysis systems are dependent on a dynamical numerical ocean model, a data assimilation scheme, and access to regularly available observational data (Backeberg et al., 2014). Using such systems in forecast mode requires that observational data is available in near-real time.

A regional implementation of HYCOM was used in this study. It has been shown to recreate the dynamics in the region to an acceptable degree of accuracy (Backeberg et al., 2008; 2009; 2014). The regional model is set up in a nested configuration, consisting of a $1/10^{th}$ of a degree resolution HYCOM of the Agulhas System, nested within a basin-scale HYCOM of the Indian and Southern Ocean (George et al., 2010) providing boundary conditions every 6 hours (Backeberg et al., 2014). The model forcing fields and configurations are described in detail in Backeberg et al., (2014).

The Ensemble Optimal Interpolation (EnOI) data assimilation scheme was used to assimilate along-track SLA only and along-track SLA combined with SST. The EnOI is 3-dimensional and multivariate, and updates the model at an efficient computational cost (Backeberg et al., 2014). This scheme had been previously used in regions with similar dynamics to the Agulhas Current, including the East Australia Current region (Oke et al., 2007), the Gulf of Mexico (Counillon and Bertino, 2009; Srinivasan et al., 2011) and the South China Sea (Xie et al., 2011).

The static ensemble is derived from an unassimilated simulation of the Agulhas HYCOM sampled every 5-days for the period 1998–2007. The model was spun-up prior to the sampling period in order to avoid model drift, which can produce artificial erroneous correlations during the assimilation (Backeberg et al. 2014). The static ensemble is important to the EnOI because it represents the forecast error of the model.

Observations are generally sparse and sporadic in space and time. To assimilate sparse observations it would be impractical to stop the model at random intervals whenever an observation becomes available. Therefore observations are collected over a weekly cycle and assimilated as one batch once a week.

To constrain the model with such a limited number of observations, the multivariate covariance between one observation and the model grid, needs to be calculated. At each point the model is projected into the observational space, a covariance matrix between the model and the observation is then constructed and weighted against the total error covariance, which is the sum of the model error covariance and the observation error covariance. This is then multiplied by the innovation factor, defined as the difference between the model and the observation. In determining the innovation factor, a first-guess approach is employed, where the analysis model forecast and the collected observations are then compared for the same day in the weekly cycle. The resultant analysis is then projected back into the model space and the model is moved forward in time. A full explanation of the method can be found in Counillon and Bertino, (2009) and Backeberg et al., (2014).

For this study three model simulations were run; FREE, the unassimilated numerical model; $ASSIM_{SLA}$, only along-track SLA was assimilated; and $ASSIM_{combined}$, both SST and along-track SLA were assimilated**.**

Data

Assimilated data

All satellite altimetry data used in the study was produced by Ssalto/Duacs and distributed by Aviso (Archiving, Validation and Interpretation of Satellite Oceanographic), supported by CNES. The delayed time unfiltered along-track SLA from satellite altimeters was used and assimilated into the model (Backeberg et al. 2014).

The SST data assimilated was obtained from the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA). OSTIA analysis uses satellite data from sensors that include the Advanced Very High Resolution Radiometer (AVHRR), Advanced Along Track Scanning Radiometer (AATSR), Spinning Enhanced Visible and Infrared Imager (SEVIRI), Advanced Microwave Scanning

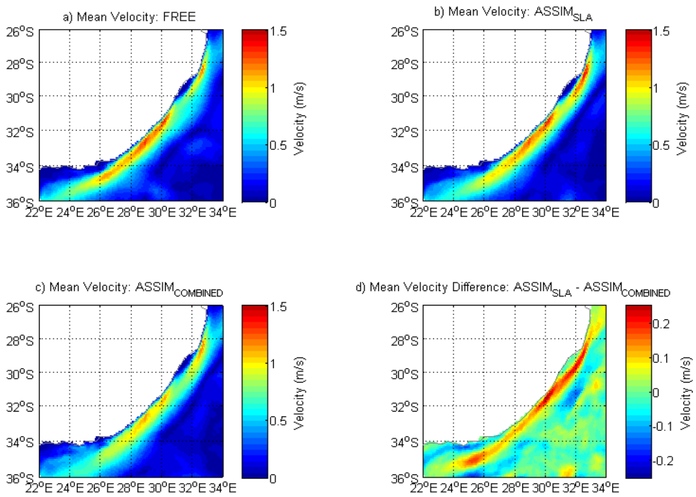

Figure 1. *a) 2008 – 2009 mean velocity map from the FREE;* ***b)*** *mean velocity map from* $ASSIM_{SLA}$*;* ***c)*** *mean velocity map from* $ASSIM_{combined}$*;* ***d)*** *Difference map, of mean velocities,* $ASSIM_{SLA}$ *minus* $ASSIM_{combined}$*. Red colours indicate where* $ASSIM_{SLA}$ *has higher velocities than* $ASSIM_{SST}$*, while blue indicates the opposite.*

Radiometer-EOS (AMSRE), and the Tropical Rainfall Measuring Mission Microwave Imager (TMI). The data set has a global coverage, with a grid resolution of 0.054º, and a temporal resolution of one day. OSTIA is produced by the Group for High Resolution Sea Surface Temperature (GHRSST) project. The OSTIA SST data was specifically produced to support SST data assimilation into Numerical Weather Prediction (NWP) models.

Validation data

To determine the accuracy of the assimilation system against independent (unassimilated) observations, surface velocity data from satellite tracked surface drifting buoys (drifters) were used. These drifters consist of a surface buoy and a 15m deep subsurface drogue. The surface buoy measures temperature and records its position, which is then transmitted to a satellite. The raw drifter data is interpolated to 6 hourly positions, with surface *u* and *v* velocities and surface temperatures provided for each corresponding position. The drifter data are managed and distributed by the Global Drifter Program (GDP).

Results and discussion

To allow for the comparison between the simulated surface velocities and the *in situ* drifter data, daily surface velocities from all drifters entering the region 26-36ºS 22-34ºE, between 2008 and 2009 are first calculated. The model fields are then interpolated to the median latitudinal and longitudinal positions of the daily averaged drifter velocities, using the nearest neighbour method of interpolation. Median positions of the drifters were used to ensure that the daily position fell on the drifter track; as opposed to using the mean position, where the position may fall outside the drifter's daily track, thereby representing incorrect dynamics.

From fig.1 (a-c) the impact of the various assimilations on FREE is evident. FREE maintains high velocities along the Agulhas Current, extending further south, compared to both assimilations. This only differs north of the Natal Bight, where the velocities are reduced, similar to that seen in $ASSIM_{combined}$. FREE and $ASSIM_{SLA}$ show velocities up to 1.4 $m.s^{-1}$ along the Agulhas Current, while $ASSIM_{combined}$ only contains velocities up to 1.2 $m.s^{-1}$. FREE produces a narrower Agulhas Current as compared to $ASSIM_{SLA}$ and $ASSIM_{combined}$, with $ASSIM_{combined}$ simulating the widest current.

Fig.1d illustrates the difference the additional assimilation of SST has had on $ASSIM_{SLA}$. The most notable difference is in the core of the Agulhas Current. Here the surface velocities in $ASSIM_{SLA}$ are up to 0.25 $m.s^{-1}$ higher than in $ASSIM_{combined}$. There are also areas, adjacent to the current and inshore of the current south of Port Elizabeth, where $ASSIM_{SLA}$ is around 0.2 $m.s^{-1}$ lower than $ASSIM_{combined}$.

To better quantify these differences a quantile-quantile analysis was performed (fig.2). This compares *in situ* drifter derived velocities against the corresponding simulated velocities. Simulated velocities that lie closer to the drifter magnitudes are more accurate than those further away. From fig.2 it is visible that the FREE and $ASSIM_{SLA}$ are more accurate at producing surface velocities when they are below 1 $m.s^{-1}$, with FREE being the most accurate.

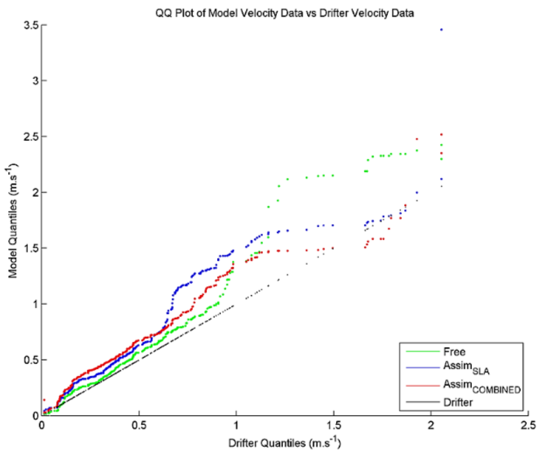

Figure 2. *Quantile-quantile (QQ) plot of the in situ drifter derived velocities compared to the modelled corresponding velocities. Illustrates how the modelled velocities compare to the in situ measurements.*

While $ASSIM_{combined}$ is shown to be more accurate when velocities are above 1 $m.s^{-1}$. $ASSIM_{SST}$ over-estimates velocities below 1 $m.s^{-1}$, while $ASSIM_{SLA}$ over-estimates velocities over 1 $m.s^{-1}$ (fig.1c).

What these preliminary analyses suggest is that the assimilation of SST benefits regions in the Agulhas Current, where SSTs are high and their gradients are strong. In regions outside the Agulhas Current where SSTs are lower and the gradients are weaker, the combined SLA-SST assimilation has led to an exaggeration of surface velocities. This may be due to incorrect correlations between SST and SSH in the static ensemble used in the EnOI, similar to the finding by Backeberg et al., (2014) in the Agulhas Return Current.

A correlation between the simulated (FREE, $ASSIM_{SLA}$ and $ASSIM_{combined}$) and drifter-derived *u* and *v* component velocities was used as a proxy for the placement and timing of mesoscale features as in Backeberg et al., (2014); in the region 26-36°S 22-34°E. An improvement in the correlation of $ASSIM_{combined}$ (0.41) over $ASSIM_{SLA}$ (0.36) and FREE (0.06) is noted, suggesting that the combined SST-SLA assimilation has improved the models ability to correctly place mesoscale features in space and time. Comparing the root mean squared error (RMSE), a statistical measure of accuracy, showed an improvement in $ASSIM_{combined}$ (0.46) over $ASSIM_{SLA}$ (0.53) and FREE (0.63).

Conclusions

This preliminary investigation into the impact of combined SST-SLA assimilation in an eddy resolving model of the Agulhas Current has revealed promising results. The initial analysis suggests that the inclusion of SST in the assimilation scheme has improved upon HYCOM's overall accuracy in simulating surface velocities in the core of the Agulhas Current, while also improving the placement and timing of mesoscale features.

Further research is needed to understand the reasons behind $ASSIM_{combined}$ over-estimating surface velocities in the Agulhas Current less than 0.5 $m.s^{-1}$, compared to both $ASSIM_{SLA}$ and FREE, whilst markedly improving upon $ASSIM_{SLA}$ in the velocity range 0.6-1.5 $m.s^{-1}$, and FREE where velocities exceed 1.2 $m.s^{-1}$.

This preliminary analysis indicates that the assimilation of SST appears to improve the simulated surface velocities in core of the Agulhas Current.

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Acknowledgments

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