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Global tracking of surface mesoscale eddies in climate simulations & observations

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Introduction

We know from observations, eddies are found everywhere and are important in local processes such as heat transport, air-sea interaction and the upwelling of nutrients. They are non-linear structures formed through baroclinic (and barotropic) instability. Eddies extract energy from the mean flow and generally travel westward across the ocean with similarities to linear Rossby Waves. Emerging research has shown mesoscale eddies may play a role in large scale ocean circulation as well [1]: it is therefore crucial to determine where and if mesoscale eddies are correctly represented.

As models move to higher resolution, mesoscale eddies can start to be resolved explicitly rather than parameterized, with associated improvements in the mean state [2]:

- *In the North Atlantic, an increase in northward ocean heat transport and MOC strength is found [3].*
- *Response to wind changes (Ekman transport) in the Southern Ocean critically depends on mesoscale eddy dynamics, to reduce Southern Ocean biases.[4].*

- *We produce a global study of comparing how well eddies are explicitly represented in a coupled climate prediction model compared to satellite observations.*

Method: Data

Daily ocean eddies are identified and tracked from sea level anomaly (SLA) in **HadGEM3-GC3.1** at eddy-permitting **ORCA025** (1/4º) and eddy-resolving **ORCA12** (1/12 º) ocean coupled to N216 (60km) atmosphere **over 20 years** [5]. Results have been validated against observational studies from daily **AVISO** merged all-sat DT14 1/4º satellite altimetry data.

Identification and tracking algorithm

- A geometry-based SLA detection algorithm, adapted from Mason et al. [6] (based on Chelton et al. [7]). Closed contours of SLA are identified and meet a set of criteria to be considered as an 'eddy'.
- <u>Adaptations:</u>
  - irregular NEMO grid
  - increase computational efficiency to run globally by splitting the identification and tracking for parallelization. Tracking can be resumed to extend dataset from eddies left 'active'
- High-pass Gaussian filtering of SLA of 10º x 5º to remove large-scale features and seasonality
- Minimum eddy lifetime is 7 days.

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Results

A key difference between observations and model is the distribution of eddy tracks : eddy tracks in the model at both resolutions (figure 1, right maps) are mainly found in regions of strong currents as expected such as the western boundary currents and Southern Ocean, rather than ubiquitous in observations (left map).

In ORCA025 (1/4º) mesoscale eddies were expected to be only resolved at the mid-latitudes (figure 1 middle subplot): 2 * horizontal grid resolution (solid line) should be less than the Rossby radius of deformation Rd (dotted line) [8]. However we are able to capture eddies up to the high latitudes in ORCA025 (bottom right).

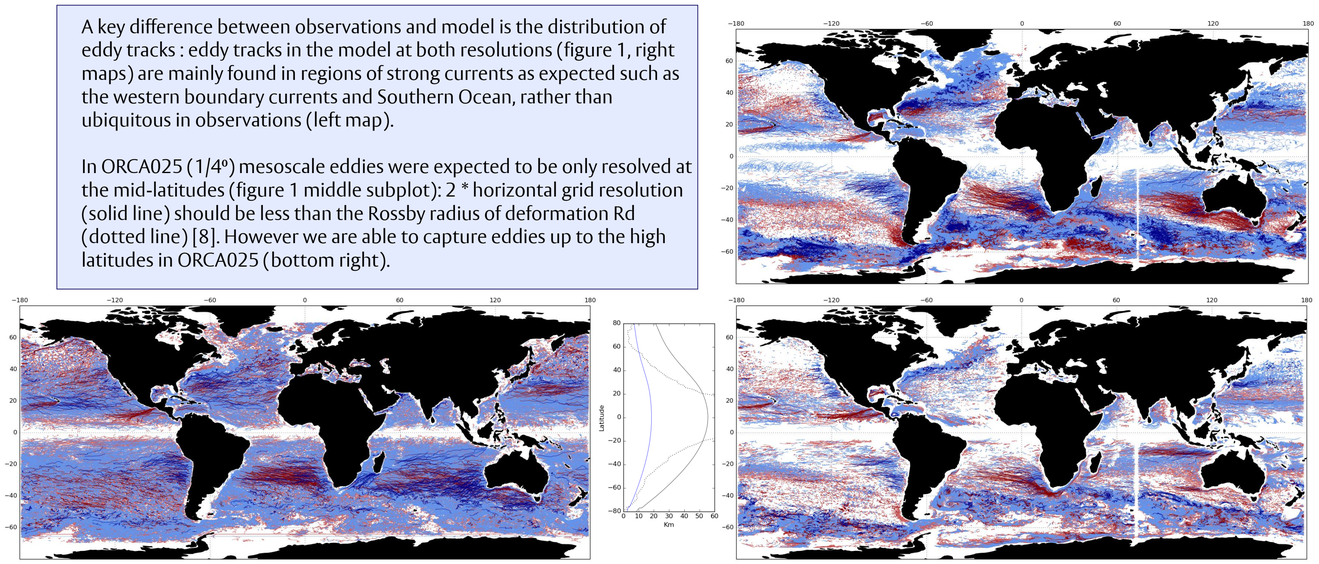

Figure 1: All eddy tracks >4 weeks over 20 years: AVISO observations (left map), ORCA12 (top right) and ORCA025 (bottom right). Red= Anti-cyclonic, Blue = Cyclonic. Tracks longer than 26 weeks are overlaid and shown in dark red (or blue) respectively. The middle subplot is the zonal average of 2 x grid resolution in ORCA025 (solid black line), ORCA12 (blue line) and Rossby radius of deformation Rd (dotted line).

The eddies found in ocean interiors in observations are born in the ocean interior and are the result of increased birth rates at the eastern ocean boundaries [figure 2]. Both are not seen in the model. This is suggested to be a result of weaker eastern boundary upwelling systems in the model causing these 'empty' subtropical gyres.

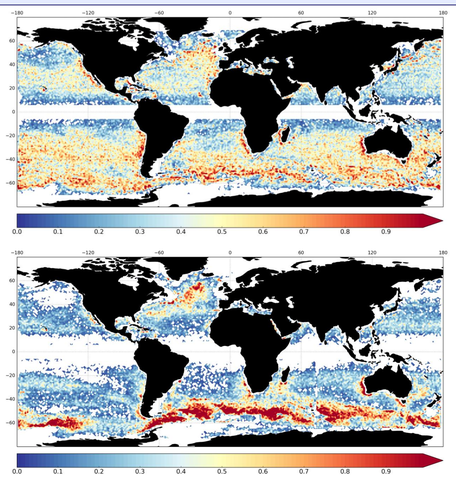

Figure 2: Eddy birth locations per year per 1 degree squared for all eddies > 4 weeks: AVISO observations (top), ORCA12(lower). (White =no births). The ORCA025 map above looks similar to ORCA12 so is not shown.

A noticeably increased number of larger eddies are captured from AVISO observations compared to ORCA025 [figure 3].The radius is selected at the closed SLA contour of maximum geostrophic velocity.

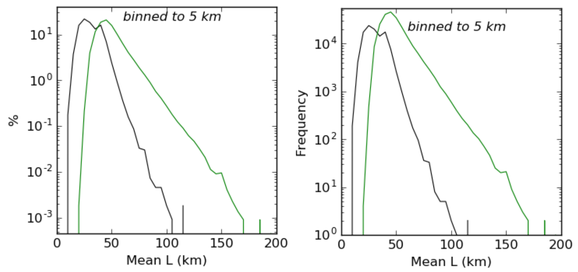

Figure 3: Pdf of mean eddy sizes (over its lifetime) for ORCA025 (black) and observations (green). The left plot is as a % for each input (normalized) and right plot is total number of eddies. Note there are more eddies identified in observations than the model (even at both resolutions).

Conclusions

- There are less eddies in ocean interiors in the model than observed and it is implied there is subsequently **less eddy heat and nutrient transport ,** for example in the southern Indian ocean.
- Eddies in the model are either too small or in **observational data they are artificially enlarged**– potentially related to the post-processing of the satellite data and inability to accurately resolve small-scale features less than 40km [7].

Eddy amplitude, geostrophic (rotational) velocity and lifetime in the model compared to observations are very similar [figure 4].

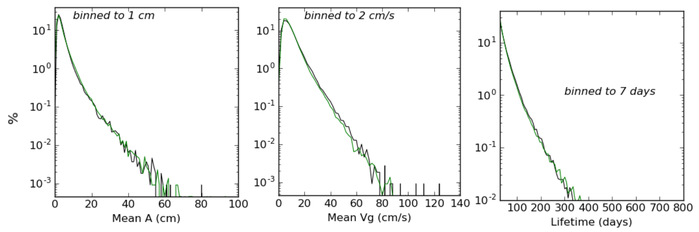

Figure 4: Pdfs of mean eddy amplitude A and geostrophic velocity Vg (over its lifetime) and lifetime for ORCA025 (black) and observations (green). All eddies are selected >4 weeks and normalised to % of total values for each input.

In the model and observations eddies propagate westward at a speed similar to the propagation speed of Rossby waves (unless carried by strong eastward currents). The tracked eddies separate from theory towards the equator [figure 5]. $Cg = -\beta\, Rd^2$

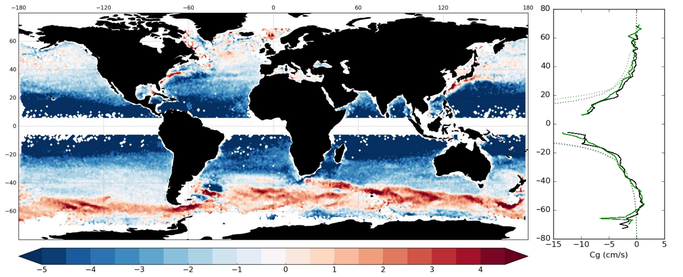

Figure 5: Zonal propagation speed from the tracked eddies (>4 weeks) binned to 1 degree squared (cm/s) (left). The zonal average is on the right (dotted line is the theory shown by the equation, solid black line is ORCA025, green solid line is observations).

Ongoing work

- Further analysis of ORCA12 and ORCA12 regridded to 1/4º and ½ º to explore eddy size.
- Global tracked eddy composites are being matched to SST and air-sea fluxes to explore the ocean-atmosphere interaction over mesoscale eddies.

References

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