Numerical Modeling project: East Australian Current

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I Introduction and modeling setup

The goal of this project was to use the croco model in order to study a realistic configuration of a selected region of the globe. To do this we first select the regional case in the cppdefs.h file and we take the BENGUELA _LR configuration name, as it will be simpler to keep it for the configuration even though we don't use that region. For this project I chose to study the East Australian Current (EAC) which is a southward warm western boundary current on the eastern coast of Australia in the Pacific Ocean and more precisely in the Tasman Sea.

For the modeling, I chose for the boundaries of the domain to be between 17 and 45°S in latitude and between 142 and 165°E in longitude. Those coordinates are entered in the crocotools _param.m Matlab file to configure the simulation. For the project I decided to put a 1/6 grid resolution to have more qualitative results similar to other studies compared to the default 1/3 resolution of the model.

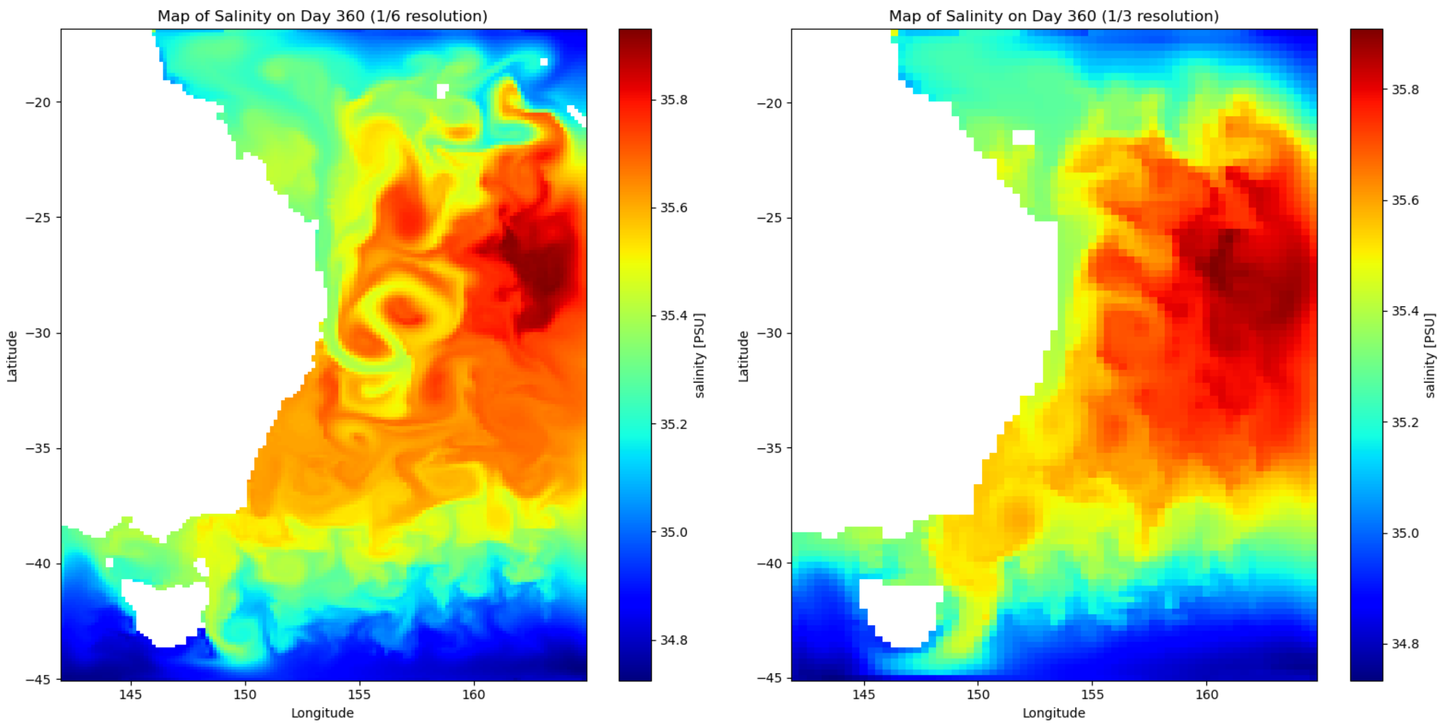

Figure 1: Comparisons between a 1/6 resolution simulation (left) and 1/3 resolution simulation (right)

The numerical cost is higher as the 1/3 resolution simulation has a size of 770 Mo and the 1/6 one is 2,91 Go. This being due to the smaller resolution having more pixels, but also because it requires a smaller time step and so more frames. It's still more realistic as we can see on figure 1 that the smaller islands are only visible with the 1/6 resolution and the currents are more marked. For the time step I found a maximum value for the 1/6 resolution of around 2250 seconds ($\sim 38 minutes$) which is coherent with the maximum time step I found for the 1/3 resolution which is 4500 seconds ($\sim 75 minutes$) or double the 1/6 time step. I however chose 1800 seconds or 30 minutes for the time step as I felt it was cleaner. In the next part I will answer to the different questions to analyse the realism of the simulation and compare it to previous studies.

II Analyse of the simulation and comparison with other studies

In this section I will show the different plots asked in the project, comment them and I will see if the results are similar to the ones we can find in prior studies. The simulation was done over two years with a time step of 1800 seconds, with monthly averages and history files being updated every 10 days. All the plots have been done during the second year as to avoid any problems while the simulation is being setup during the first year.

The first part was to plot the time evolution of the surface kinetic energy integrated over the domain. Figure 2 present the results. The results present strong kinetic energy during the austral summer (December-February) and it is weak during the austral winter (June-August), those results are in accordance with studies presenting the seasonal variations of Kinetic energy in the EAC like Xu et al.(2022) [6] or also Liu et al.(2022) [2]. The values found from the croco model however are higher than the ones from the articles studied, this is probably due to how the initial conditions are taken and how the kinetic energy is calculated. In fact those studies use satellite altimetry for the data.

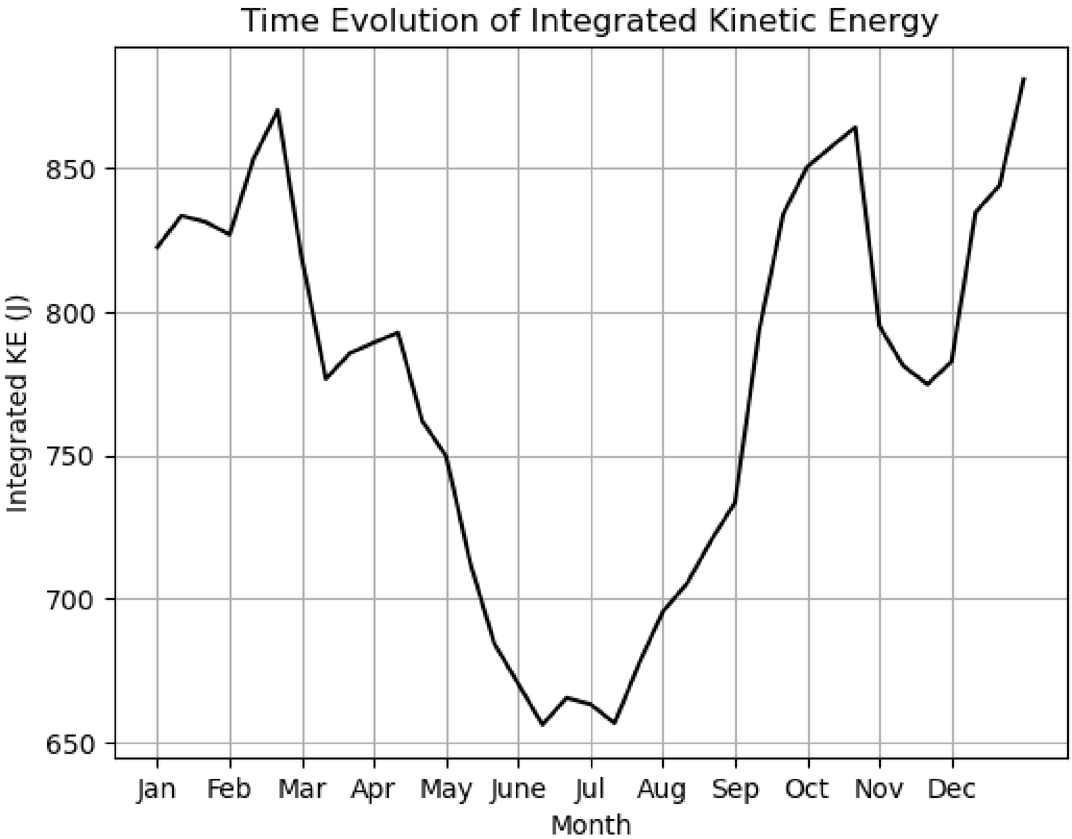

Figure 2: Time evolution of the integrated kinetic energy from january to december of the second year.

Xu et al.(2022) [6] shows a link between the strength of the Kinetic Energy and the barotropic instabilities of the background circulation as they present the same seasonal cycle. According to the study this is due to the stronger southward EAC promoting the formation of anticyclonic recirculation which favor those barotropic instabilities during the austral summer, these processes are then reversed during winter.

Now we want to study the vorticity of the current by looking at maps of relative vorticity at the surface and at z=-400m at different moment of the years. Figures 3 and 4 present the results respectively at the surface and at 400 meter depth.

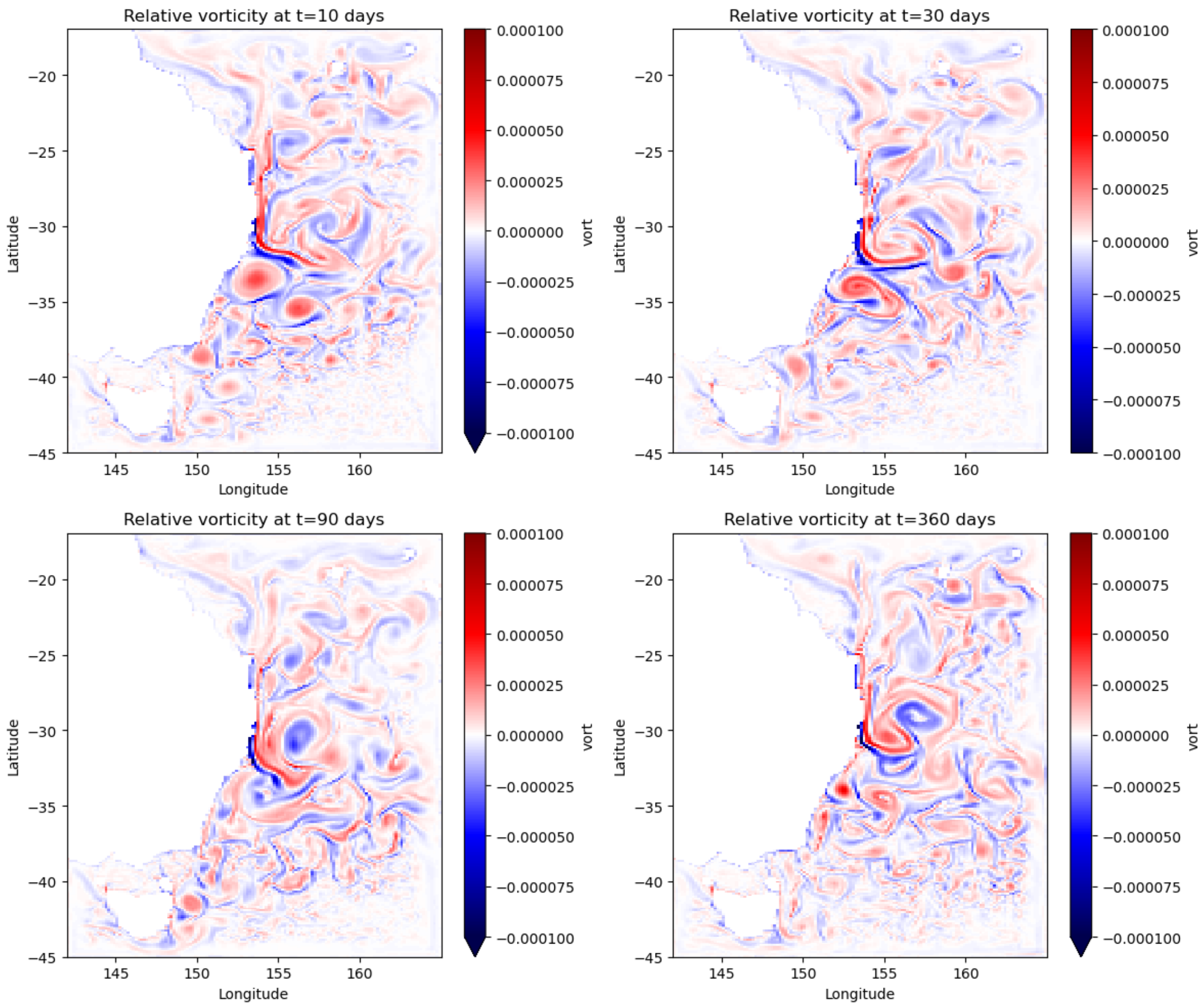

Figure 3: Relative vorticity at the surface at different times: on the upper line at day 10 (left) and day 30 (right), on the lower line at day 90 (left) and day 360 (right).

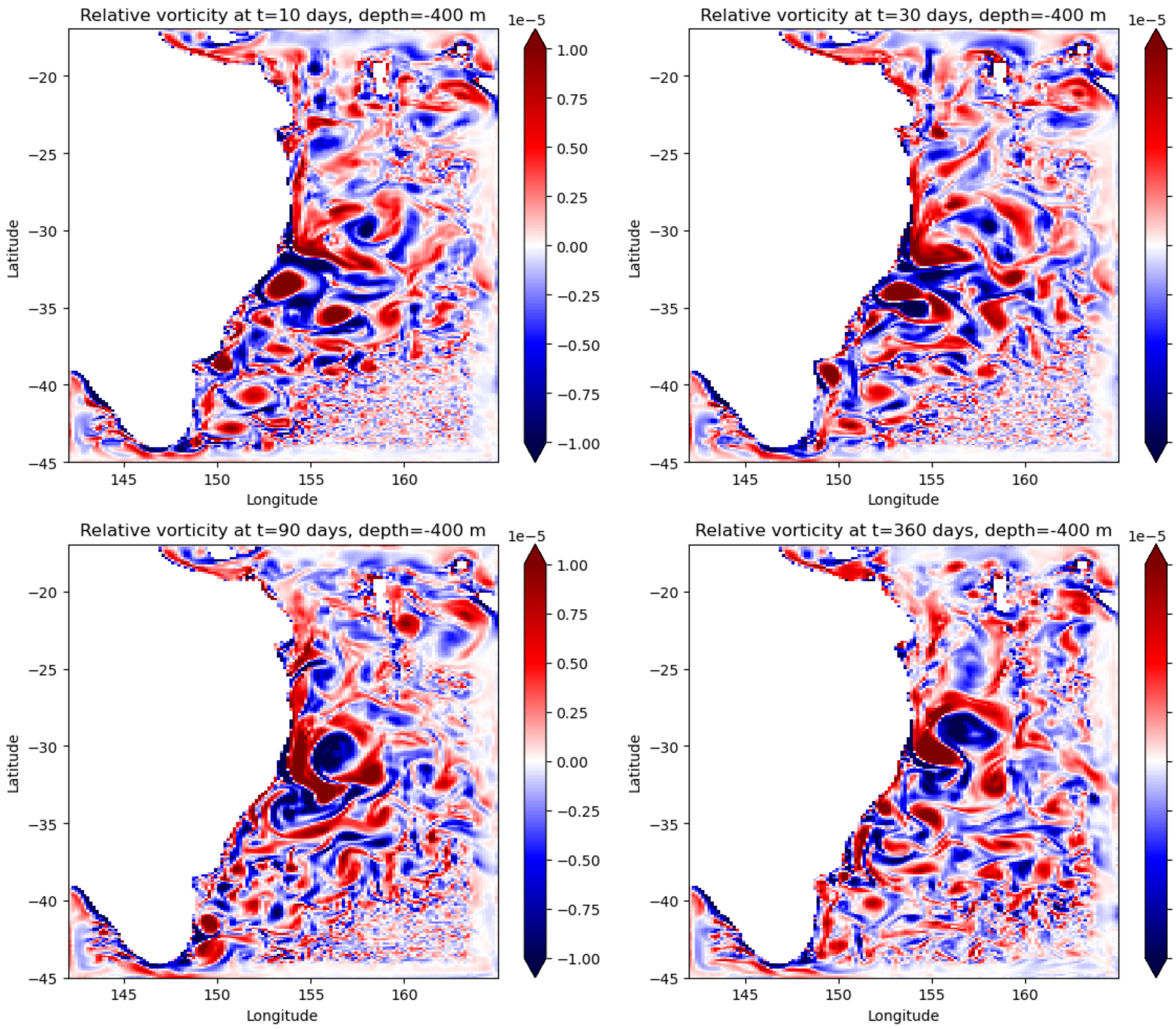

Figure 4: Relative vorticity at z=-400m at different times: on the upper line at day 10 (left) and day 30 (right), on the lower line at day 90 (left) and day 360 (right).

Comparing both figures, we notice that vorticity decreases with depth. It is also stronger near the coast and more specifically around 34°S which correspond to the point where the EAC is separated from the coast of Australia as stated by Talley (2011) [5]. At this point the EAC reaches its maximum transport at $35Sv$ and is separated between the eastward flowing Tasman Front and the extension of the EAC flowing southward [7]. As for the size of the vortices, Talley [5] describes them as around 200 to 300 km in diameters which seems to be in agreement with the width of the observed vortices in figure 4. One could thus conclude that the simulation is pretty realistic on that front.

Next we look at a map of temperature in the same conditions as for the vorticity at 400 meters depth on the same days (see Figure 5). First thing we notice is that the water is warmer in the upper part of the sea with a clear separation at 35°S coinciding as we saw before with the separation of the EAC. On the east coast of Australia, the temperature reaches values around 18°C which is in accordance with other measurements made in the area [1].

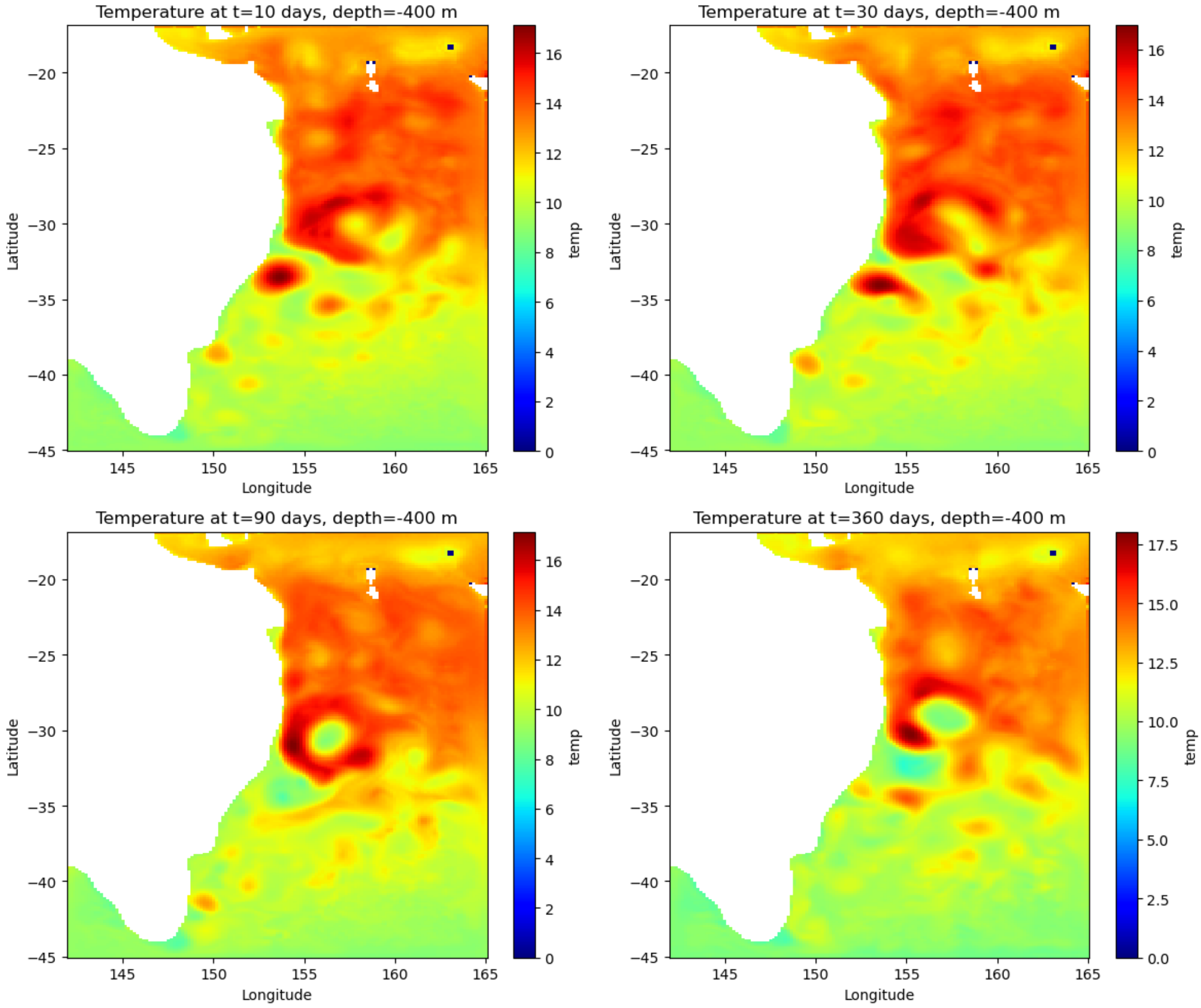

Figure 5: Relative vorticity at z=-400m at different times: on the upper line at day 10 (left) and day 30 (right), on the lower line at day 90 (left) and day 360 (right).

We now look at sections of the zonal and meridional velocities at 35°S which is the area with the most activity as we have seen before. Looking at figure 6 we can see that meridional velocities create vortices which is in accordance with what we saw on figure 4. The high values in zonal velocities seem to show the separation of the EAC from the coast to form the eastward flowing Tasman front. As for the values, according to Talley [5], the velocties reach a maximum of $90cm/s$ at 30°S which is in accordance with the values observed here.

We also plot density sections in the same conditions and notice no particular difference between the beginning and the end of the year (see figure 7). A closer look at the data on python show a very small decrease but nothing very conclusive. These might be due to the equation of state used to calculate the density.

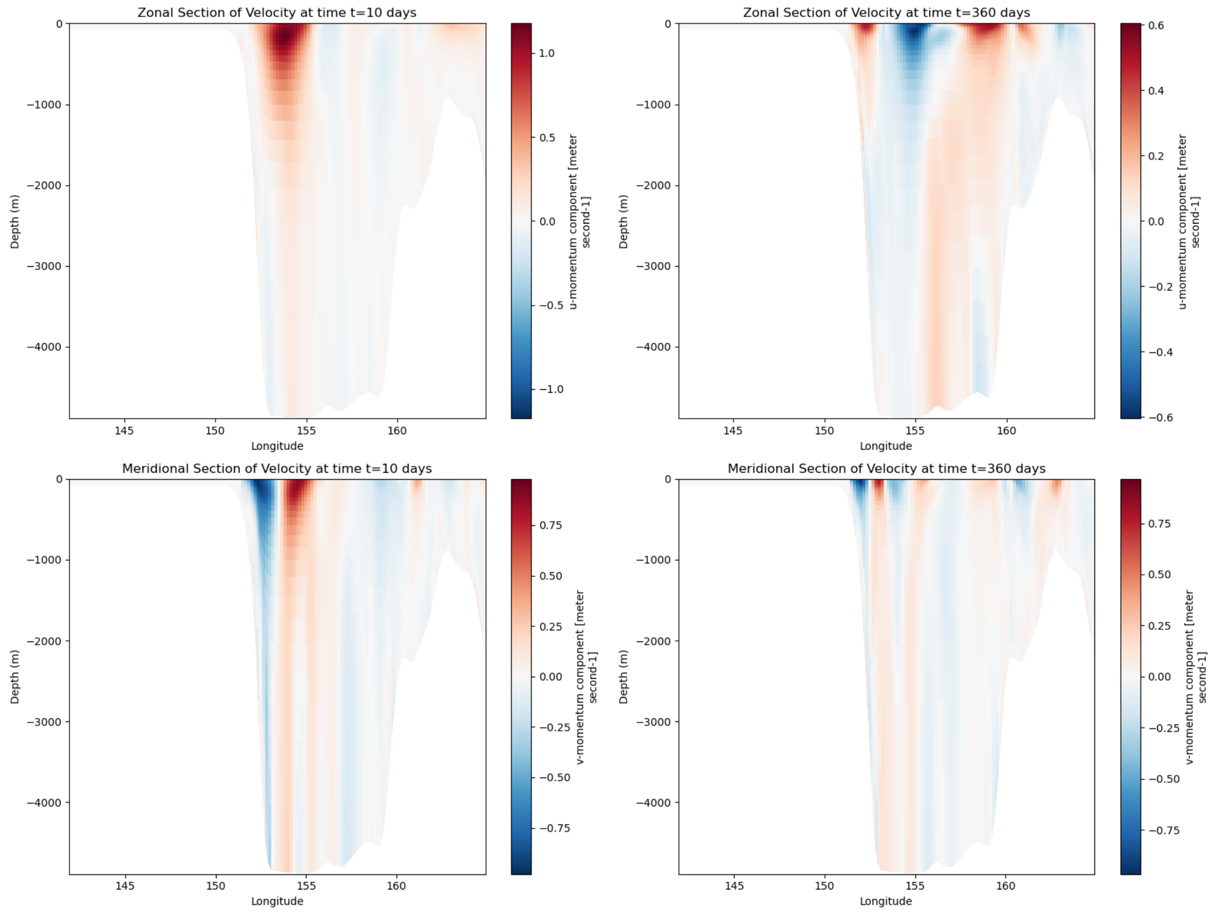

Figure 6: Zonal (upper) and meridional (lower) velocity sections at 35°S on day 10 (left) and 360 (right).

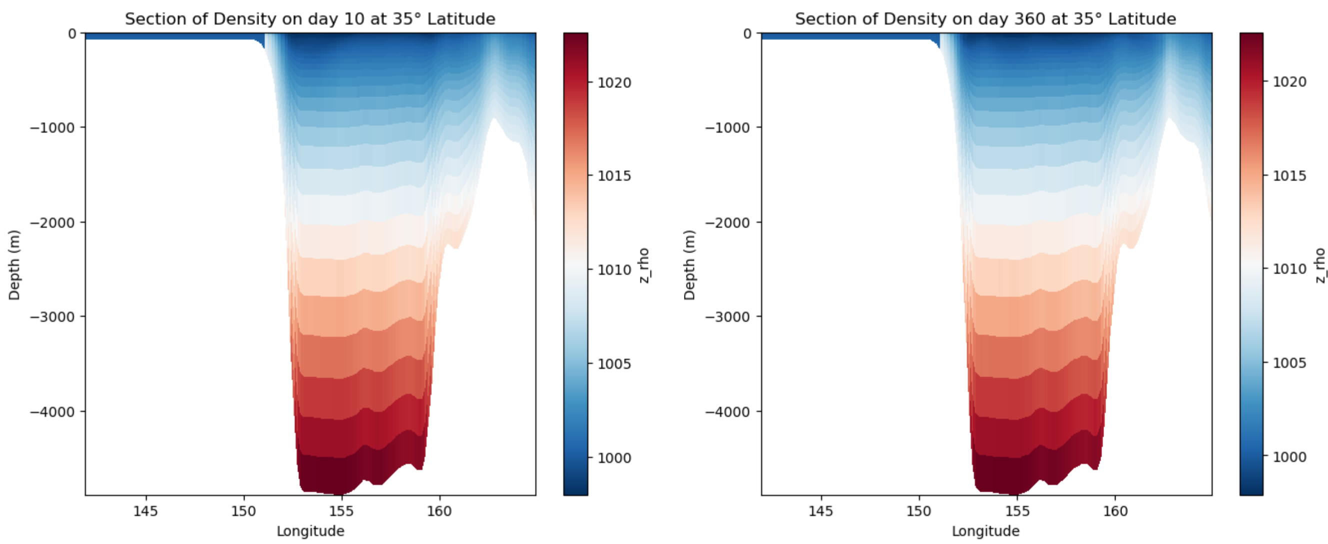

Figure 7: Density sections at 35°S on day 10 (left) and 360 (right).

Figure 8 shows the mean zonal and meridional velocity over the second year of simulation. Looking at the meridional velocity map allow us to clearly see the EAC along the Australian coastline. The negative meridional velocity shows that the current is southward and the positive zonal velocity at 35°S is another indicator of the separation of the current in the Tasman sea.

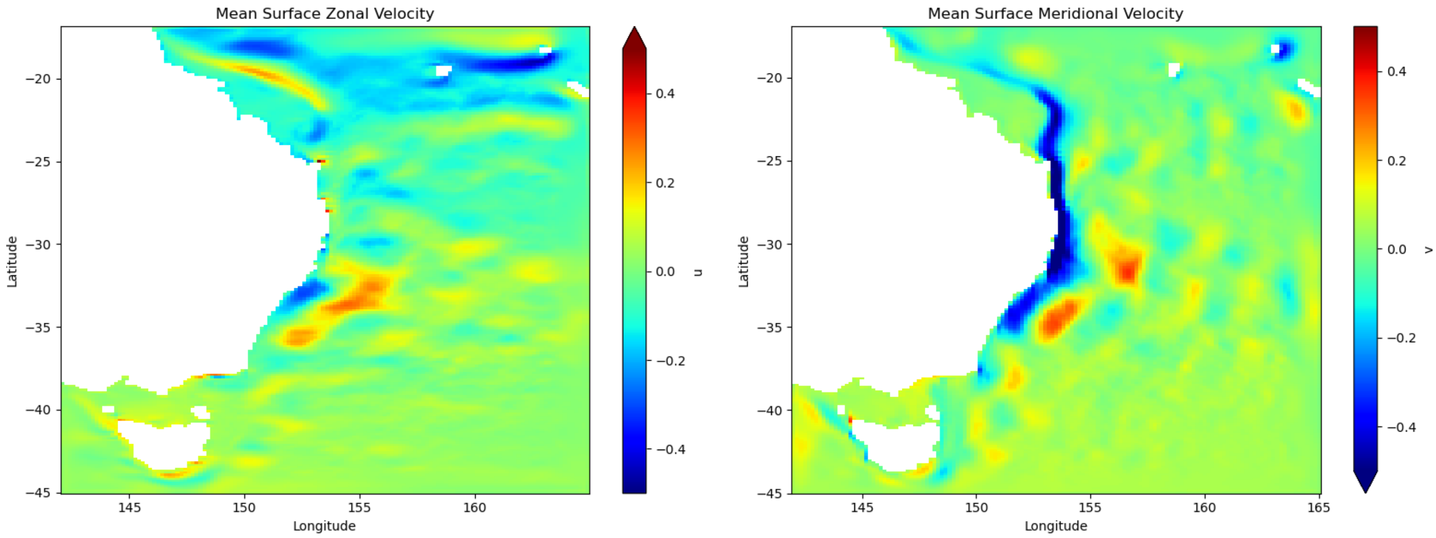

Figure 8: Mean zonal (left) and meridional (right) velocities over the last year of the simulation.

Figure 9 presents the variation of the sea surface height during the second year of the simulation. We can see that the separation of the EAC creates an high SSH anomaly during the vortex shedding cycle. Our results are similar to the ones from Mata et al.(2006) [3] which presents a similar figure. The values found in the article are however double the ones we find here.

Finally, figure 10 is a map of the mean eddy kinetic energy over the last year. We can see a peak of EKE at 32°S which correspond as seen before to the point where the EAC reaches its maximum velocity. At 20°S another current is also visible: the South Equatorial Current, which is one of the influence for the formation of the EAC.

The different plots showcased in this project show the different aspects of the EAC from its origin in the equatorial Pacific Ocean to its separation near the coast of Australia, however one could wonder why does the EAC separates itself where it does. According to Oke et al.(2019) [4], the EAC is a continuous, meandering stream, flowing adjacent to the coast of Australia adjacent to a field of mesoscale eddies, the Tasman front and the extension of the EAC being a continuation of it. Compared to other Western Boundary Current (WBC), the energetic eddy field is only restricted to the area where the EAC separates itself from the coast (evident from the ssh anomaly and EKE peak seen in figures 9 and 10). They also conclude that the EAC is one of the weakest WBC and it is still unknown what the principal cause of its separation is, citing mechanisms from previous studies as possibilities affecting the EAC at different times.

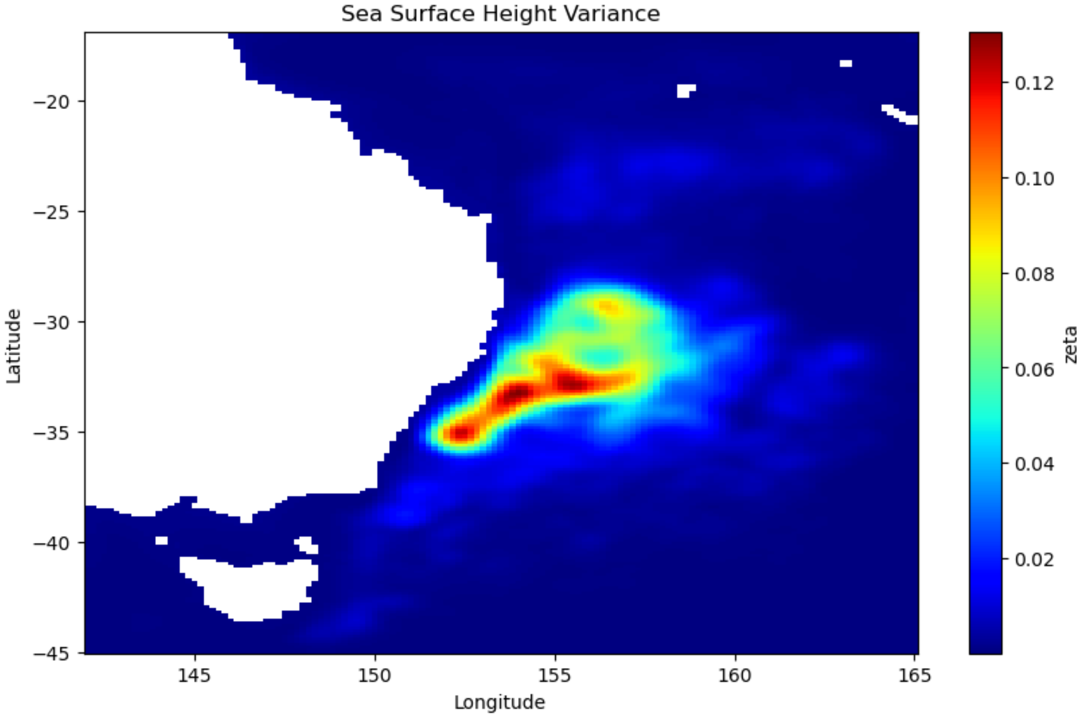

Figure 9: Variance of the sea surface height over the last year.

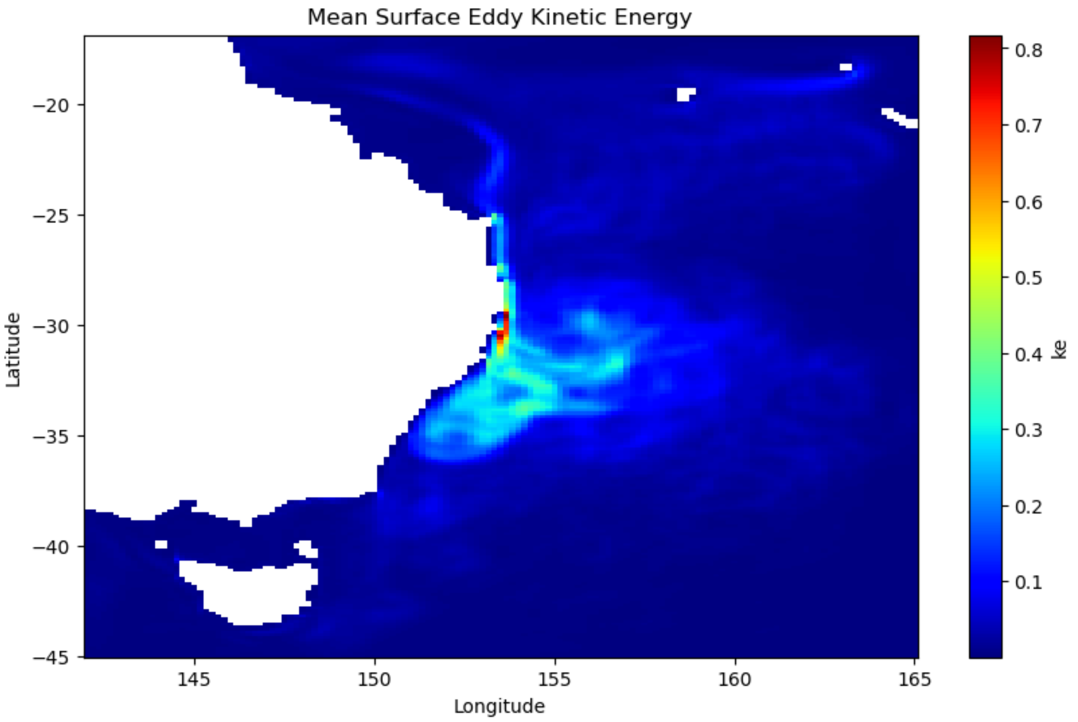

Figure 10: Mean Eddy Kinetic Energy over the last year.

III Conclusion on the realism of the simulation

To conclude on the realism of the simulation, the croco model is very effective in reproducing the main phenomenon from a region, and in our case allows us to see the different part of the East Australian Current from its origin to its separation in two branches.

However, even if we can see the phenomenon, comparisons with others studies using more precises data (satellite altimetry, etc.) shows a difference in the range of the values, in fact even if we find the same scales, it is usual in our study to find values twice as small or bigger. This being probably a results of the initial climatology used to make the simulation. One advantage of croco nonetheless is its flexibility, in fact we could have increase the resolution even more and input a more precise climatology as initial conditions to get even better results. But as it requires an higher numerical cost it would only be necessary for important studies requiring maximum precision. However in our case, the simulation is realistic enough to look at what we want and see that our results are in accordance with past studies.

References

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