Impact of the Agulhas Current mesoscale variability on surface dispersion in the KwaZulu-Natal Bight

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The KwaZulu-Natal (KZN) Bight has dynamic upwelling cells and retention zones which result in favourable conditions for recruitment. As a result, several Marine Protected Areas (MPAs) were established, including the uThukela Banks MPA (within the KZN Bight), the iSimangaliso MPA (north of the KZN Bight) and the Aliwal Shoal MPA (south of the KZN Bight). In this study, a Lagrangian approach is used to investigate the impact of the Agulhas Current's mesoscale variability on the surface dispersion in the KZN Bight. Virtual particles are released in a high-resolution ocean model, in a region encompassing the iSimangaliso MPA. They are then left to drift within the model for 32 days, in a steady and in a meandering Agulhas Current, and their outputs are analysed. Drifters are used as a comparable observational dataset. The results show that the residence times of the virtual particles are the longest over the continental shelf (inshore of the 200m isobath) with typical residence times of 4 to 8 days. The residence times over the shelf are very variable, reflecting the ocean variability. Residence times over the shelf break (between the 200m and 1000m isobaths) are short with the virtual particles either moving inshore or being advected offshore into the Agulhas Current. A steady Agulhas Current favours the retention in the KZN Bight, as a greater percentage (49.83%) of virtual particles move onto the shelf compared to when the Agulhas Current is meandering (9.52%). These differences are due to the presence of an anticyclonic eddy when the Agulhas Current is meandering as well as the different alignment of the Agulhas Current relative to the isobaths. The anticyclonic eddy pulls particles offshore and the meandering Agulhas Current has an isobath-following trajectory near the KZN Bight, which does not favour the inshore movement of the virtual particles. A steady Agulhas Current has a cross-isobath flow, allowing virtual particles to move inshore of the KZN Bight. It also has a northward circulation in the northern KZN Bight, which favours the connectivity between the iSimangaliso and uThukela Banks MPAs. Overall, the steady Agulhas Current forms more favourable conditions for recruitment.

1. Introduction

The KwaZulu-Natal (KZN) Bight is situated on Africa's south-east coast. It is an area which stretches from Cape St Lucia to Durban (30.5° - 32.5°E, 28° - 30.5°S). Here the otherwise straight south-east African coastline, which generally has a narrow continental shelf and steep slope, is interrupted by a widening of the shelf and a slightly bay-shaped coastline. The KZN Bight is considered to be a retention zone which traps water from the adjacent Agulhas Current (Hutchings et al, 2002). The strong south-westward flowing Agulhas Current is generally oligotrophic/mesotrophic (Bustamante et al., 1995). However, the KZN Bight is richer in nutrients due to dynamical upwelling processes, driven by the Agulhas Current or local cyclonic eddies, and nutrient inputs from rivers such as the Thukela River. The region offshore of Cape St Lucia, for example, is a well-known upwelling cell (Meyer et al., 2002 and Lutjeharms et al., 1989). The retention of water and the higher nutrient concentrations in the KZN Bight make this region an interesting study area which is likely to be biologically important for the recruitment of many species (Hutchings et al., 2002). However, not much research has been done on the biology of the KZN Bight, resulting in large knowledge gaps (Ayers & Scharler 2011). The CAPTOR (Connectivity And disPersal beTween prOtected aReas) project, funded by the African Coelacanth Ecosystem Programme (ACEP), focuses on examining the connectivity and dispersal between marine protected areas (MPAs) and adjacent areas along South Africa's east coast. In particular, the project aims at determining if the MPAs of iSimangaliso, uThukela Banks, Aliwal Shoal, Protea Banks and Pondoland form a network. In this study, we use outputs from a high-resolution ocean model to gain insight on the pathways and dispersion of surface particles across the iSimangaliso and the uThukela Banks MPA domains. Large mesoscale meanders in the Agulhas Current are major drivers of variability for the coastal and shelf regions. A recent study has shown that the Agulhas Current is likely to broaden rather than intensify in the future, possibly due to an increase in the Agulhas Current's meandering (Beal & Elipot, 2016). Therefore, it is important to understand how meanders impact particle dispersion in the KZN Bight and what the potential implications for larvae retention and fish recruitment are.

2. Data and method

We present in-situ observations from surface drifters as well as trajectories derived from virtual particles deployed in a high-resolution hydrodynamic ocean model to better understand how passive drifting surface particles such as fish larvae are transported and dispersed in the KZN Bight. The ocean model used for the virtual particle tracking experiments is CROCO (Coastal and Regional Ocean Community). We used a triple-nested simulation with the two-way nesting approach between each grid. From the data provided, the daily mean outputs of 32 days from 1st February 2012 and 32 days from 1st March 2014 are investigated and compared. March 2014 has an exceptionally stable Agulhas Current trajectory and in February 2012 a large meander starts to form in the KZN Bight. A total of 10890 virtual particles are released in the surface waters of the Agulhas Current in the model just north of the KZN Bight, in the iSimangaliso MPA, in an area stretching from 32°E to 33°E and from 27.25°S to 27.75°S. Their pathways are tracked using 6-hourly intervals and forward integration in time. The tool used for the virtual particle tracking is Parcels (Probably A Really Computationally Efficient Lagrangian Simulator, Delandmeter and van Sebille (2019)). The surface drifters used, which act as an observational comparable dataset, are NOAA drifters with a 15m drogue (https://www.aoml.noaa.gov/phod/gdp/) and CARTHE drifters, which have a very short drogue (https://www.marinetechnologynews.com/news/carthe-drifter-553428). Spatial masks of the areas inshore of the 200m isobath, the 1000m isobath and between the 200m and 1000m isobaths are applied to the virtual particles and drifters. Assuming that virtual particles and drifters within the Agulhas Current are lost to the system, the rationale behind selecting these depths is to see what happens to them once they are inshore of the Agulhas Current front (the 1000m isobath), to see how many of these are then advected across the shelf break (between the 200m and 1000m isobaths) and onto the shelf (inshore of the 200m isobath). We anticipated that larvae have the best chance of successful recruitment on the shelf. The pathways of the virtual particles in a steady and in a meandering Agulhas Current and the residence times in the different inshore regions are compared to each other and to the results of the drifters.

3. Results and Discussion

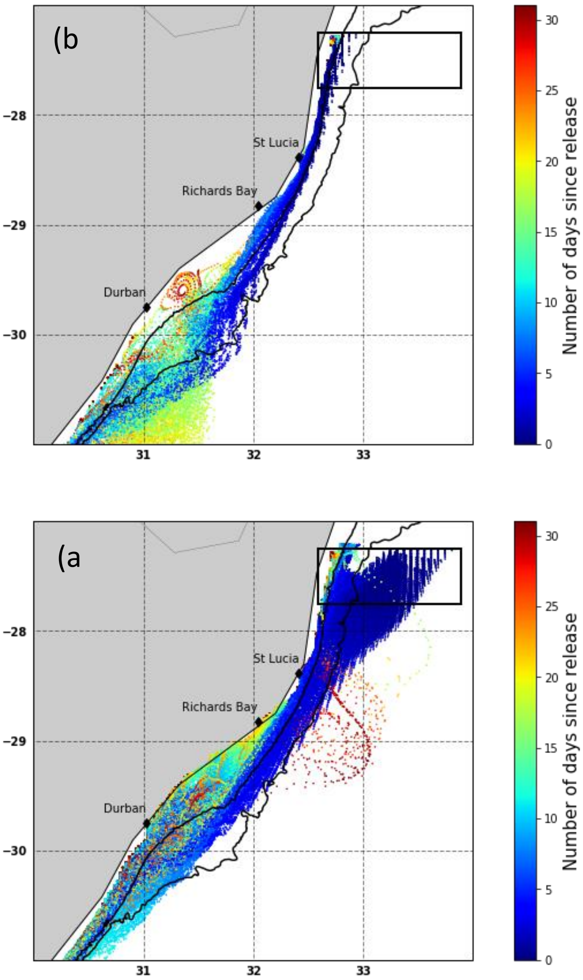

Figure 1: Virtual particles that move inshore of the 200m isobath. In a), the virtual particles are released in a stable Agulhas Current and in b) the particles are released in a meandering current. The trajectories are colour coded by the time in days that the particles spend in the water after being released. The particles are blue on the day on which they were released and on the last day of the month, the particles are red. The black box is the box in which the investigated virtual particles were released.

When the Agulhas Current is stable, close to half of the virtual particles (49.83 %) end up on the shelf (inshore of the 200m isobath) (figure 1a). Virtual particles which are released further offshore move southwards faster than the virtual particles which are released further inshore. Therefore, the KZN Bight acts as a retention area, trapping virtual particles for up to one month, particularly in the southern section of the KZN Bight. In the inshore northern section of the KZN Bight, the circulation seems less variable as the virtual particles move together and most are about 10-15 days old. A northward movement can be observed. In the inshore southern section of the KZN Bight, the circulation seems more variable as adjacent virtual particles have very variable ages.

When the Agulhas Current is meandering, fewer of the released virtual particles (9.52%) move inshore of the 200m isobath. The released virtual particles at first tend to stay within the isobath in which they were released, until they move south of Richards Bay, where the virtual particles slowly start to move offshore (figure 1b). A large inshore eddy is observed slightly north of Durban which traps some particles for the rest of the month, indicating a retention area. In this case very few virtual particles move inshore within the northern section of the KZN Bight, and therefore it is difficult to make a statement on the water dynamics in this section. The eddy inshore of the 200m isobath and slightly north of Durban (31.2 - 31.5°E, 29.5 - 29.7°S) traps virtual particles for the entire duration of the month. Therefore, the residence times are longest in the mid- and southern sections of the KZN Bight.

Less virtual particles move inshore of the 200m isobath when the Agulhas Current is meandering because the current has more of an isobath-following trajectory in this case, compared to the inshore moving cross-isobath flow of the stable Agulhas Current (figure 1). Additionally, an anticyclonic eddy, which results in the formation of the Natal Pulse (Schouten et al., 2002) and is therefore present when the current is meandering, pulls virtual particles offshore and is also responsible for less virtual particles moving inshore of the 200m isobath when the current is meandering. Therefore, overall, the KZN Bight is more favourable to recruitment when the Agulhas Current is stable. It allows more virtual particles to move onto the sheltered shelf and their residence times on the shelf are longer. The connectivity between the iSimangaliso and uThukela Banks MPAs is also stronger when the current is steady, which is due to the presence of a northward flow in the northern KZN Bight only observed in the steady current.

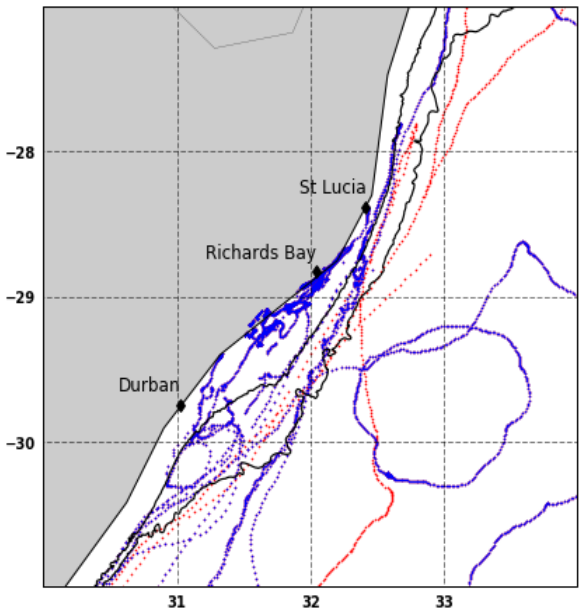

Figure 2: A map of the trajectories of drifters in the KZN Bight region. The pathways of drifters that went inshore of the 200m isobath are plotted in blue while the pathways of drifters that went inshore of the 1000m isobath, but not inshore of the 200m isobath, are plotted in red. The 200m and 1000m isobaths are plotted as black lines.

The observational drifters display similar dynamical features as the virtual particles. These include an offshore anticyclonic eddy (32.5 - 33.5°E, 29.2 - 30.3°S) and a Durban Eddy, which is south of Durban between the 200m and 1000m isobaths (Guastella & Roberts, 2016). However, the residence times cannot be compared to those of the virtual particles because some of the drifters were released within the KZN Bight rather than north of it, affecting the results. Overall, only 12 drifters moved onto the shelf of the KZN Bight. This study demonstrates the strong impact of the Agulhas Current mesoscale variability on the particle pathways, dispersion and recruitment success in the KZN Bight. Understanding how the Agulhas Current varies and how this variability might be impacted by climate change is necessary for the successful management of MPAs in and near the KZN Bight. Virtual particle tracking can help to understand the pathways of larvae and recruits (Singh et al., 2018), which are otherwise difficult to obtain due to factors such as their small sizes. Additional observations and further work in this region, using both forward and backward particle tracking, are needed to improve our knowledge of the connectivity between MPAs.

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