Degradation of Agulhas Leakage estimates corresponding to temporal resolution

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Abstract

The Agulhas current and its leakage of warm and salty indian-ocean water, play crucial role in the climate system by influencing Atlantic Meridional Overturning Circulation stability. While the ocean circulation models are not capable due to lacking of couplings, and the fully-coupled climate models fail because of inability to resolve mesoscale features, the high-resolution coupled model is the only viable tool to access this topic.

Here we attempt to establish a strategy to quantify the Agulhas leakage in a high-resolution Community Climate System Model simulation. We test the effect of temporal averaging of velocity fields on the Agulhas leakage estimates using Lagrangian particle tracking approach. Results show that, with our strategy, the Agulhas leakage estimates using both five-daily and monthly velocity fields are closely related. The time series also reasonably capture the intermittent ring crossing events at the GoodHope line. We plan to test the same strategy to longer time-span data, and eventually apply it to existed dataset.

Keywords: Agulhas leakage, high-resolution coupled models, Lagrangian particle, temporal resolution

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1. Introduction

The Agulhas system plays a critical role in the global thermohaline circulation through the control of Indo-Atlantic inter-basin water exchange (Gordon et al., 1992). The part of Indian ocean water advected to Atlantic ocean, or Agulhas leakage, feeds to the upper arm of the Atlantic meridional overturning circulation (AMOC) with warm and salty water, which may affect the stability of the AMOC, and hence the climate (Beal et al., 2011; Weijer et al., 1999). To address the possible relation between the Agulhas leakage and the AMOC, a coupled model study is necessary; however, this was previously limited by the lack of horizontal resolution in coupled model simulations. Here, we attempt to quantify the Agulhas leakage in the high-resolution CCSM3.5 (Kirtman et al., 2012) climate change simulation, with the aid of a the Connectivity Modeling System (CMS) Lagrangian particle tracking toolbox (Paris et al., 2013). Due to limited computational resources, most current generation coupled model outputs are archived monthly, which is not ideal for Lagrangian particle integration. The temporal degradation that arises from monthly averaged velocity fields leads to the inability to capture high-frequency variability associated with mesoscale features, and false estimates of trajectory and transit time. We want to test, in this particular model, whether using the monthly fields for Lagrangian experiments is capable of capturing leakage estimates, comparing to the case using the five-daily output over the same period.

2. Methodology

Several approaches have been proposed to estimate Agulhas leakage, Agulhas ring counting, the difference between Agulhas current and return current (Le Bars et al., 2014), and the surface Lagrangian drifter experiments (Richardson, 2007). Nevertheless, because the Agulhas current is in the vicinity of major current systems such as the Antarctic Counter Current and the subtropical super gyres, there is yet an established way to monitor the Agulhas leakage.

In numerical models, where we have gridded data, a widely accepted approach to quantify Agulhas leakage is Lagrangian particle tracking (Biastoch et al., 2008). The Lagrangian approach is chosen due to its advantage of including leakage of every forms, such as Agulhas Rings, eddies and filaments. With the aid of Connectivity Modeling System (CMS), we release particles along the ACT array, whenever the local cross-transect velocity is south-westward. Each particle is tagged with a volume flux equivalent to the local velocity times the corresponding grid cell size. They are released daily, and advected forward in time with the aid of CMS for a maximum of two years. The particle positions are stored at a daily frequency.

Particles are typically considered as Agulhas leakage when their trajectory intersects with the GoodHope Line. Most of previous Lagrangian studies relied on Ariane toolbox, in which integration stops when a particle reaches prescribed boundaries. However, we noticed that many trajectories cross the GoodHope Line multiple times, which is likely related to the energetic mesoscale processes in this region. Also, particles that have previously crossed the GoodHope line may be recaptured into the Agulhas Return Current. Hence, only particles with odd-number crossings and at the last crossing are considered as Agulhas leakage.

In this study, two sets of Lagrangian experiments are conducted, where the only difference is the velocity fields for integration and corresponding release particles. For Pent2day case, five-daily velocity fields are used to calculate particle trajectories, while the Mon2day case, monthly velocity fields are used instead. The velocity fields are both from a ten-year long (1941-1950) high-resolution CCSM3.5 climate change simulation, with spatial resolution of 0.1 deg and 42 vertical layers. To keep the treatment of the velocity fields within CMS consistent, we interpolate these fields back to daily resolution using a cubic-spline interpolation.

3. Pent2day vs Mon2day

In this section, I am comparing the Agulhas Leakage estimates from our two cases: Pent2day and Mon2day. Figure 1 shows the 10-years (1941-1950) time series of both cases, before and after 31-days running mean smoothing. The correlation coefficients are calculated without the first two and the last one years to avoid the ramping-up effect due to particle traveling from the ACT array to the GoodHope line.

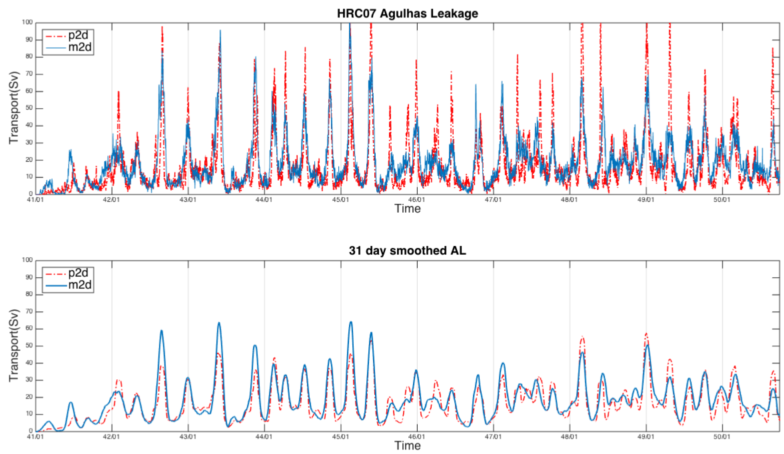

Figure 1: Ten years of Agulhas leakage time series of *Mon2day* (red-dashed) and *Pent2day* (blue) from 1941 to 1950. The bottom panel shows those after 31-day running mean smoothing. The mean leakage transport of Pent2day case reaches 18.2 Sv, while the Mon2day has 20.3 Sv.

Time series comparison. It is worth noting that, the mean Agulahs Leakage volume transports of Pent2day and Mon2day cases are 18.2 Sv and 20.3 respectively: greatly improved comparing to previous study based on a lower-resolution version of CCSM (Weijer et al., 2012; Weijer and van Sebille, 2014), not far from the observational and OGCM-based estimates of 12-17 Sv. The variability of both time series correlate well (r=0.7 before smoothing, 0.9 after 31-days running mean), and we suspect those intermittent peaks are caused by the passing of mesoscale features – most likely the Agulhas rings. We'll further show the evidence in following paragraphs.

Transit time. The conventional view states that for Lagrangian particle experiments, five-daily or higher temporal-resolution velocity fields are ideal. Temporal averaging may smooth out eddy fields and create direct paths that result in higher mean transports and false estimates of trajectories (Qin et al., 2014). This is clearly to be seen in Figure 2: most of water volumes arrived in the GoodHope section within 100 days for Mon2day case. On the other hand, for

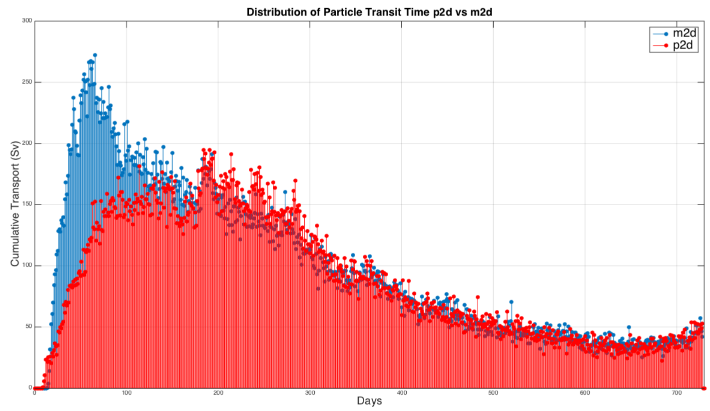

Figure 2: Distribution of particle transit time. Blue bars represent the Mon2day case, while the red bars shows the Pent2day case. Information of volume associating with each particle is included.

Pent2day case, there is no distinguished peak like in Mon2day case, while the maximum occurs a little less than 200 days. It is interesting that even though the transit time patterns are very different, the transport time-series are well-correlated.

Ring crossing. In Figure 1, both Pent2day and Mon2day time series show well correlated intermittent peaks, which are represented by large standard deviations. The Figure 3 depicts the corresponding surface speed, vertical profile of cross-transect speed, as well as particle crossing positions at a specific time-step (1943/01/15) of Pent2day case. A peak in the time series is associated with an Agulhas ring crossing the GoodHope line at the surface. Most of particles concentrate in the top 500 meters, associated with the north-westward velocity caused by the anticyclonic Agulhas ring.

4. Conclusion

In this study, we attempt to quantify Agulhas leakage in a high-resolution coupled model using Lagrangian particle tracking approach. We examine the

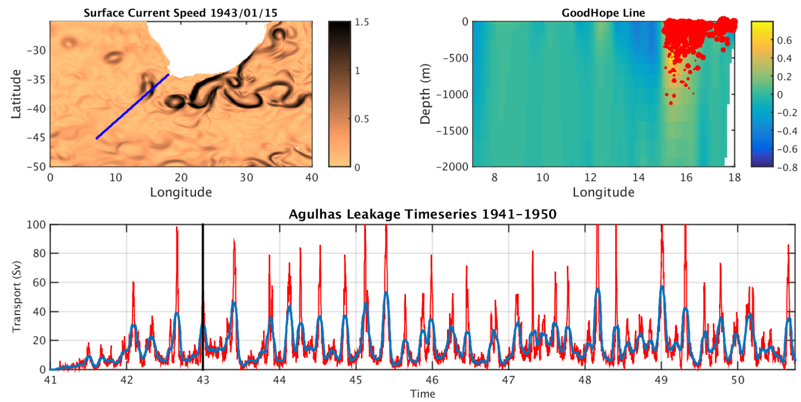

Figure 3: Surface current speed (top-left), vertical profile of cross-sectional speed (shaded, top-right), and the crossing-particles tagged by the transport per unit depth (red dots) at corresponding time in the time-series.

effect of temporal averaging on the leakage estimates. Even though the Mon2day case, with smeared out velocity field, introduces errors in transit times and trajectories, the overall Agulhas leakage time series is well correlated to that of the Pent2day case. This could be explained by the regular eddy-shedding events in this particular model. That is, while the velocity is smoothed out in monthly fields, since the eddy-shedding events are regular, the eddy positions and numbers are well preserved. With our strategy: interpolating velocity field to daily, and release particle daily, the direct paths introduced by monthly-averaging, are compensated by smaller magnitude of velocity fields and less volume that each particle carries.

The peaks in time series can be explained by the ring-crossing events, which appear to be regular comparing to observational estimates. Nevertheless, the co-occurrence convinces us that the time series reasonably capture the variability of the Agulhas leakage. Nevertheless, even though the time series of Pent2day and Mon2day cases are close, the ten-years data this study based on is too short for us to reach any conclusions. Before applying it to existed monthly coupled-model outputs, the test of the same strategy using longer time span of model outputs is therefore necessary.

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