Seasonal lagrangian study of eddies produced at the capes of Kamchatka

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Abstract

In this work, the positions of Lagrangian particles were integrated in the daily AVISO geostrophic velocity fields around the Kamchatka peninsula. The goal of the study was to find the destination of water masses that are trapped by the eddies created in the capes of Kamchatka. The trajectories of the particles showed us that eddies created at the capes travel mostly southwestward. We found that the seasonality of the Eastern Kamchatka Current has an impact on the characteristics of the flow, and thus on the trajectories of the particles. The seeded particles can stay trapped around the position of the quasi-stationnary Kamchatka Eddy through summer, in particular the ones coming from the northernmost cape. We also show that our study is coherent with previous Lagrangian studies on buoys in the area.

1 Introduction

Eddies are an important feature in the ocean. They can transport water masses, nutrients and living species. They contribute to the global climate, the weather and the mixing in the ocean. In this work, we focus our study on anticyclonic eddies present all year long along the coast of the Kamchatka peninsula.

Situated in the most Eastern part of Russia, southwest of the Bering Straight, the Kamchatka peninsula is located in the western part of the Pacific Ocean. Its eastern coast, which main features are three capes, is bathed by the Eastern Kamchatka Current (EKC). This southward current, extending through the Oyashio, forms the western boundary current of the North-Pacific Subpolar Gyre. The EKC presents mainly seasonal variations in its intensity : it strengthens in winter and weakens in summer.

Because of the current meandering and interacting with the irregular coast, anticyclonic eddies are formed along the coast of Kamchatka and in particular at the capes. This behavior has been observed and studied for a long time [3].

Here, we will focus on an anticyclonic eddy, namely the Kamchatka Eddy (KE), south of Kamchatka. It has been regularly observed on Sea Level Anomaly (SLA) maps and geostrophic velocity fields [5], [2] with its center around 50°N, 157° E. It is formed almost every year at the beginning of summer ; and is quasi-stationary - compared with the other eddies that are advected southwestward by the EKC. Tipically, it grows all summer - up to 200km diameter - by merging with other anticyclonic eddies coming from the north and is usually destroyed when the EKC strengthens in winter.

The goal of this study is to find out if the eddies formed at the capes of Kamchatka are the ones that merge with the KE. To answer this question, we will seed Lagrangian particles at the capes and integrate their position using geostrophic velocity fields to get their trajectories, through summer and through winter.

2 Method

For this study, we used the daily surface geostrophic velocity fields - derived from ADT - from the Global 1/4° AVISO Altimetry. We focused on the area between 150°E, 170°E and 45°N, 60°N containing the Kamchatka peninsula, the EKC, and the main eddies we are interested in.

To integrate forward the position of the particles, we modified a one-dimensional fourth order Runge-Kutta algorithm to integrate a two-dimensional field. This required interpolation in space as well as in time. To interpolate in space we used Optimal Interpolation, which minimizes the variance of the velocity field, while we used a simple linear interpolation in time. In a future work, Lagrange polynomials could be used for the time interpolation, such as in [1].

The time interval was set to 0.2 days to avoid blowups. This setting was deduced from a scaling of the maximum value of the velocity and the grid size. The algorithm was first tested on a dummy field composed of 3 ideal vortices constant in time ; it dealt correctly with the known trajectories as well as the saddle points (not shown here).

3 Results

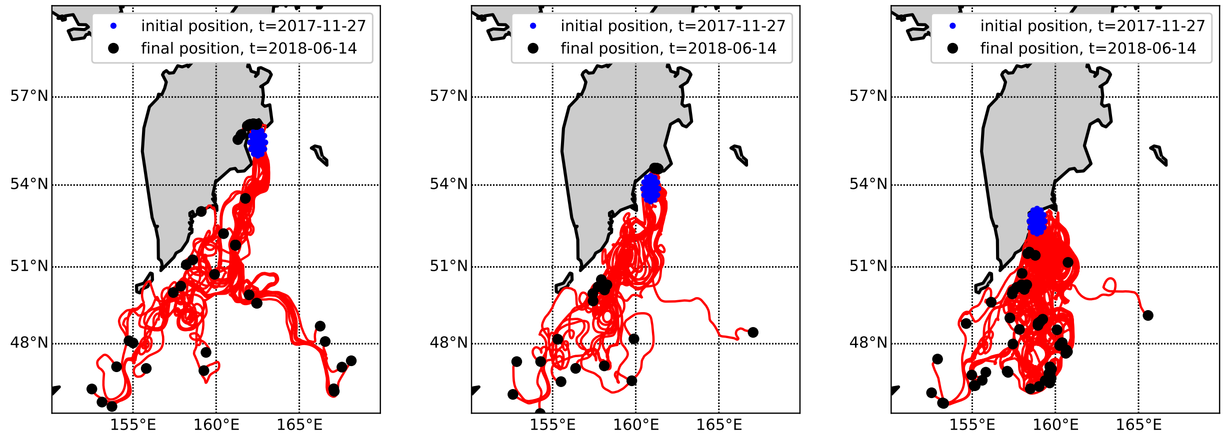
Lagrangian particles were seeded at the 3 capes of the Kamchatka coast. Their positions were integrated forward in time for 200 days (figures 3.1 and 3.2).

The particles in figure 3.1 were seeded in fall, and their positions were integrated through winter. The particles in figure 3.2 were seeded in spring, and their positions were integrated through summer.

3.1 Trajectories during winter

In figure 3.1, most of the particles seeded at the capes travel southwest, along the Kamchatka coast. On their way, they travel through the KE that is situated around 50°N, 158°E and then exit it from the south and southwest. Some particles go southeastward, through a current that separates the area containing the Kamchatka eddy from the Aleutian eddy, this has also be seen in the tracking of drifting buoys in [4].

In figure 3.1, the flow from the northern cape looks coherent at first : all the trajectories are parallel, and they start to lose their coherence as they pass the middle cape. The particles are scattered everywhere along the EKC, this suggests a strong mixing in the current and thus a high eddy activity.



(a) Particles seeded in the first cape (b) Particles seeded in the second cape (c) Particles seeded in the third cape

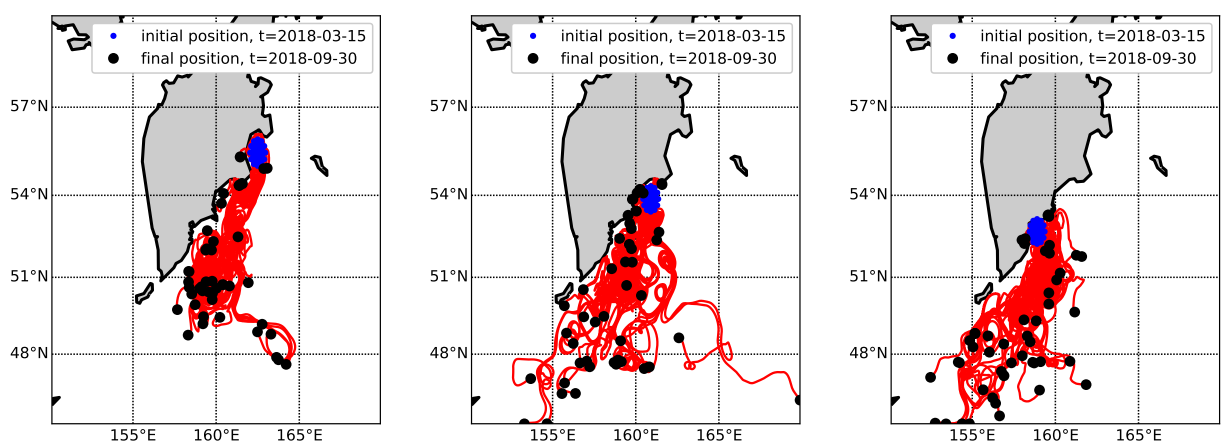
Fig. 3.1: Trajectories of particles seeded in the capes in fall

The particles going out from the middle cape seem to have coherent trajectories at the beginning, but they start looping in what looks like a big eddy. They escape it to go mostly southward. In the end, the particles from the middle cape are much less scattered than the particles from the northermost cape.

Finally, the particles from the southern cape do not travel as far as the particles seeded in the other capes, this suggests that they stay trapped in eddies. They are also looping trajectories offshore the southern cape, which was already seen from the particles in figure 3.1b.

A more exhaustive study could be done to look mathematically for looping and non-looping trajectories, this would clearly show us which particles get trapped in eddies.

3.2 Trajectories during summer



(a) Particles seeded in the first cape (b) Particles seeded in the second cape (c) Particles seeded in the third cape

Fig. 3.2: Trajectories of particles seeded in the capes in spring

In figure 3.2, a few trajectories are quite different from those in figure 3.1. In particular, in figure 3.2a, the particles seeded at the northern-most cape do not go as far south as the same particles seeded in fall : they remain trapped in eddies. In particular they stay where the Kamchatka eddy is situated at this moment in time : its center is positioned around 160°E, 50.7°N.

The particles seeded in the middle cape (figure 3.2b) and the southern cape (figure 3.2c) are scattered all over the area of the EKC. This shows that there is a strong eddy activity south of the tip of Kamchatka.

Note that the particles from the northern cape stay in the area of the KE, while particles from the other capes escape this area. For a better understanding, we should study in a future work the time spent in the KE by the particles in function of their initial position.

3.3 Velocity of the particles

Knowing the trajectories of the particles allowed us to calculate the drifting velocities. We extracted the mean and the maximum velocity, and show the results in tables 1 and 2.

Origin	North Cape	Middle Cape	South Cape
Winter	5 cm/s	4 cm/s	10 cm/s
Summer	7 cm/s	7 cm/s	9 cm/s

Tab. 1: Mean velocity of the particles over the 200 days of integration

Origin	North Cape	Middle Cape	South Cape
Winter	58 cm/s	57 cm/s	62 cm/s
Summer	57 cm/s	65 cm/s	61 cm/s

Tab. 2: Maximum velocity of the particles over the 200 days of integration

Our results are comparable with the velocities found by Stabeno et al. [4]. Indeed, they found mean velocities of drifters in our region of study going from 2 to 50 cm/s and daily maximum velocities ranging from 13 to 86 cm/s, depending on the buoy. The differences in drifting velocities could be related to the coarse resolution of our velocity fields.

The relatively high mean velocity of the particles coming from the southern cape could be related to the high eddy activity at the southern tip of Kamchatka. Particles in this region will spend most of the time trapped in eddies than being purely advected by the EKC.

The mean velocity may give us an information about the presence of eddies. Indeed, the EKC is stronger in winter than in summer, but the mean velocity of the particles is lower in winter than in summer. This suggests that the higher eddy activity in summer has a strong effect on the mean velocity of the particles.

Because the EKC has a maximum surface velocity of around 25 cm/s, the maximum velocity of the particles shown in table 2 is only affected by the eddies. The small differences in maximum velocities between summer and winter show that eddies are more important for the displacement of particles than the EKC.

4 Conclusion

The forward integration of the position of seeded particles gave us much information about the flow characteristics. In particular, most of the particles coming from the capes are advected southwestward. This advection takes more or less time depending on the flow along the coast of Kamchatka. Those results are similar to results by [4], where they tracked drifters in the Kamchatka Current. Indeed, they found that most drifters travel southwestward after passing through eddies ; and also that some drifters may go southeastward between the Aleutian eddy and the Kuril-Kamchatka eddies.

We further observed that there is a difference between hot and cold months in the dynamics of the ocean in this area due to an intensification of the Kamchatka Current in winter. This intensification advects and mixes particles over longer distances. When the EKC is weaker, the eddies are less advected by the currents, so they can mix the particles over geographically-limited regions, or keep them trapped.

Finally, the presence of the Kamchatka Eddy changes the trajectories of the particles, in particular the ones coming from the northernmost cape. This confirms that the anticyclonic eddies - which are formed by the interaction of the EKC with the capes - get advected southwestward by the current and merge with the Kamchatka Eddy.

More studies should be done on the trajectories of the particles to discern clearly the loopers from the non-loopers. This would also allow us to evaluate the time that particles stay trapped in the eddies. We should also keep in mind that our integration has limitations. In particular, some particles are allowed to cross the boundary of the coast. This problem should be resolved in future works.

References

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