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An Improved Data Detection Method for Mesoscale Vortex Flow Field Based on Optimum Launching Environment of Major Launch Weapons

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Abstract. As a common ocean phenomenon, mesoscale eddies have strong internal flow velocity and large vertical depth scale, which affect the horizontal non-uniform variation of sound velocity profile. Mesoscale eddies affect the use of underwater sonar. While improving the concealment of submarine navigation, they may cause serious interference to the launch and guidance of missile weapon. Geometric methods can identify more mesoscale vortices with relatively small scales, but there are some missing and wrong judgements. Based on the current mainstream algorithms, this paper improves and improves the mesoscale eddy recognition and information extraction algorithm by improving the quadrant restriction and restricting the boundary conditions, so as to reduce the rate of missed judgment and false judgment.

1. Introduction

As a common oceanic phenomenon, mesoscale eddies, unlike ordinary oceanic circulation, have fast rotating speed (up to several meters per second), strong current velocity and vertical depth up to several thousand meters. They carry huge energy larger than average current by one order of magnitude. The spatial scale is tens or hundreds of kilometers, and the span is relatively large. The time scale is from several days to several hundred days, and the maximum vertical depth Maximum vertical depth can deep up to the seabed^[2]. Mesoscale vortices play an important role in underwater warfare. The existence of mesoscale vortices will affect the horizontal non-uniformity of sound velocity profile, the efficiency of underwater sonar, the use of underwater weapons and the movement direction of underwater weapons. Historically, underwater torpedo launches have been hit by vortices on their own submarines.

With the development of computer technology, ocean numerical simulation technology has become more and more mature. The ocean simulation field has become clearer and clearer in representing the structure of ocean water body. The direction and size of vortices can be accurately represented by the size and direction of arrows. Remote sensing technology also provides us with a wealth of data sources for eddy detection, including ocean surface temperature data and altimeter data. These data provide the possibility of automatic detection, tracking, statistics and so on.

Whether simulated field data or remote sensing data, the data representing mesoscale vortices can be compared to horizontal flow field data. Among the mesoscale eddy detection methods based on horizontal flow field data, the W method proposed by Okubo (1970) and Weiss (1991) ^[3]and the geometric algorithm proposed by Nencioli (2010) ^[1]are two typical detection methods. Relevant results show that both W method and geometry method can identify the location of mesoscale vortices



well, and then extract the information of radius and intensity energy of mesoscale vortices. Compared with W method, geometry method can identify more mesoscale vortices with relatively small scale. However, these two automatic identification methods also have a certain proportion of missed and misjudged phenomena. It is necessary to further improve and improve the identification and information extraction algorithm of mesoscale vortices. In this paper, the geometric algorithm proposed by Nencioli et al. is improved to reduce the number of omissions and errors.

2. The Principle of Geometric Detection Algorithms

The Nencioli algorithm defines four constraints by using the ocean surface velocity, so that the center and range of mesoscale eddies can be determined quickly. These four constraints are^{[3][4]}:

(1) When crossing the vorticity center along latitudinal (east-west) direction, the velocity direction of the north-south flow on the left and right sides of the center is opposite and the farther away from the center, the larger the value is.

(2) When crossing the vortex center along meridional (north-south) direction, the velocity direction of East-West flow on both sides of the center is opposite, and the farther away from the center, the larger the value is.

(3) The central velocity of the vortices is the local minimum.

(4) Near the vorticity center, along the same rotation direction, the two adjacent velocity vectors must be in the same quadrant or in the two adjacent quadrants.

According to these four constraints, the basic steps of Nencioli's detection algorithm are as follows:

(1) Two parameters a and b are needed to determine the range of the minimum value (how many grid points are used to judge the local minimum), and b is used to determine how many grid points are used to test the variation of v component along the east-west axis and u component along the North-South axis. In the algorithm, the values of a and b are elastic, so that they can be used to set the minimum scale of scroll detection and make the algorithm suitable for different resolution grids. The values of these two parameters have a great influence on the results of successful and excessive eddy detection. In Nencioli's algorithm, these two parameters are $a=4$ and $b=3$.

(2) Searching for local minimum points of velocity

(3) To judge whether u and v satisfy the constraints (1) and (2), and to judge whether the vortices are cyclonic or anticyclonic. For cyclone vortices, the direction of rotation in the northern hemisphere is counter-clockwise, that is, the direction of velocity V changes from west to east from negative to positive on both sides of min-point, the direction of velocity u changes from positive to negative on both sides of min-point from south to north, and the direction of velocity u changes from positive to negative on both sides of min-point, while for anticyclone, the direction of velocity v (from West to east) changes from positive to negative on both sides of min-point and the direction of velocity u goes north. On both sides of the min-point, it changes from negative to positive, whereas in the southern hemisphere, it changes from negative to positive.

(4) A 7*7 rectangular box with 28 boundary points is formed when $b=3$. Starting from the lower left corner, the direction of each velocity vector is judged clockwise or counter-clockwise, and the two adjacent velocity vectors are connected head to tail to determine whether the two adjacent velocity vectors are in the same quadrant or in the two adjacent quadrants.

3. The Implementation and Improvement of Geometric Detection Algorithms

The data used in this paper is the data of NetCDF. It is the reanalysis data of the fusion of altimeter data and model calculation. The resolution of the data is 25 km x 25 km. The region selected in this paper is the Northwest Pacific region.

In order to investigate the eddy detection algorithm, the Kuroshio region east of Japan is taken as the focus area of this algorithm. The flow field distribution in the box area of Fig. 1 is shown in Fig.1.

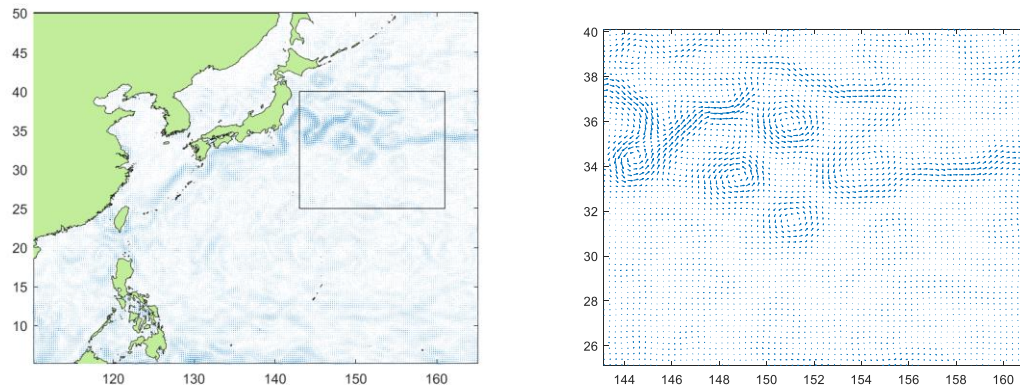


Fig.1. Flow field data in Kuroshio area east of Japan (2019.01.12)

The Nencioli's geometric detection algorithm is used to detect the vortex center. When $a=4, b=3$ is selected, 179 minimum points are detected in the flow field shown in Fig.2. The results of the Nencioli's algorithm are shown in Figure 3. The circle in the figure shows the detected vortex center, and the rectangular area is a 7×7 flow field investigation area when $b=3$ is taken around the center, numbered as the minimum. It can be seen that the Nencioli's algorithm can detect vortices with smaller scale and weaker intensity, but through the analysis of artificial convection flow field, it can be seen that the algorithm has a large false alarm, such as the 32, 55, 86, 113, 110 and 169 regions, all of which are shear zone or shear zone. At the same time, Nencioli's algorithm also has some omissions.

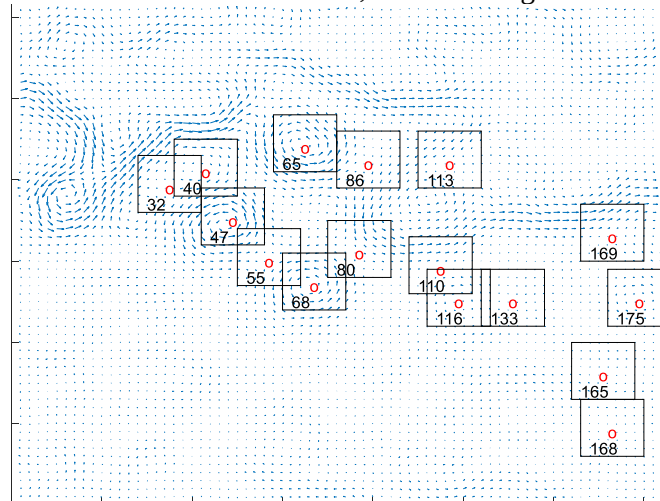


Fig.2. Eddy Center Detection Results Based on Nencioli's Algorithm

We investigate the region near the minimum 86. Comparing with the four constraints of Nencioli's algorithm, the distribution and size of the flow field satisfy the first three conditions. For the fourth condition, the flow field around the minimum 86 is taken as 7×7 , as shown in Fig. 3.

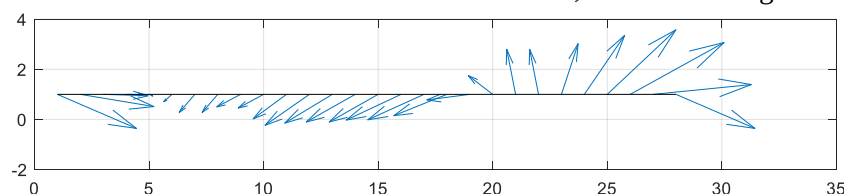


Fig. 3. Angular Vector Change of Boundary Flow Field

From Fig.3, it can be seen that the boundary flow field vector changes from the fourth quadrant to the third quadrant of the second quadrant of the first quadrant, satisfying the condition that the two adjacent velocity vectors must be in the same quadrant or in the two adjacent quadrants. It can be seen that the test results shown in Fig. 3 satisfy the four constraints of Nencioli's Algorithm.

In order to improve the detection rate, the study area is changed so that $b = 2$. In this way, when the flow field vector near the minimum is inspected, the scope is narrowed, and it becomes the area of 5×5 , i.e. $125 \text{ km} \times 125 \text{ km}$. The test results are shown in Fig. 4.

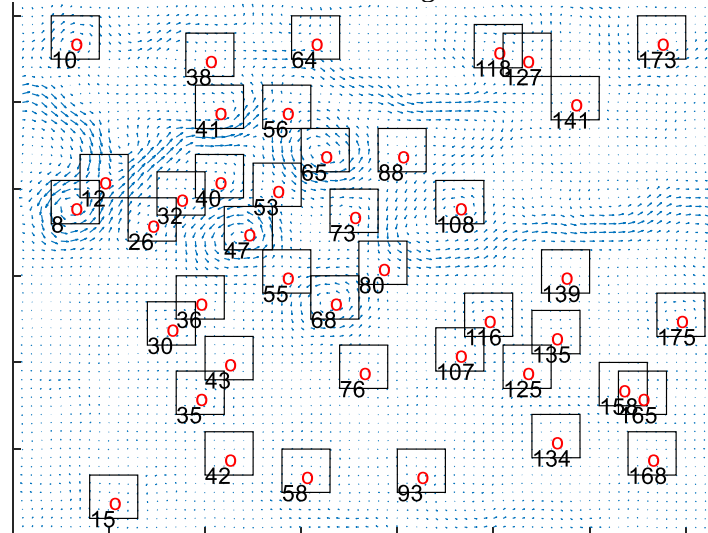


Fig. 4. Test results of changing $b=2$

After changing the parameters, the rate of missed detection is greatly reduced, but the false alarm is further increased. In order to reduce the false alarm rate, two constraints are introduced to improve the Nencioli's algorithm.

Firstly, by observing the vortices and false alarm zones, we can see that the velocities of the vortices are mostly the same on the boundary of the 5×5 flow field around the center, showing a trend of annular increase, while the velocities of the shear flow and the flow sleeve zones tend to increase slowly on one or both sides, which makes the velocities of the 5×5 flow field very different. The velocity difference parameter C requires that the velocity difference on the boundary of 5×5 flow field should not exceed a certain threshold, where the value of C is related to the spatial resolution of the data. In this paper, $c = 0.05 \text{ m/s}$. The test results are shown in Fig. 5.

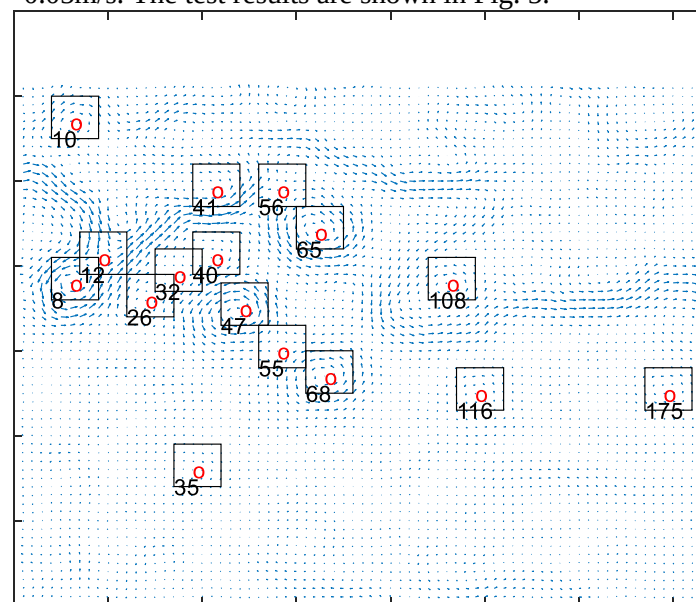


Fig. 5. Test results after introducing flow velocity difference parameters

Secondly, in the shear flow or shear sleeve region, although the false alarm rate is greatly reduced after the Fourth Treaty of the Nencioli's algorithm, it is still impossible to guarantee that all false alarms can be eliminated. These false alarm regions meet the conditions that the two velocity vectors

adjacent to the boundary of the 5*5 flow field must be in the same quadrant or in the two adjacent quadrants, but they are carefully studied. It can be found that the flow field around the vortex distributes uniformly in four quadrants, while the shear flow field and the flow field around the vortex distribute more in some quadrants and less in some quadrants. In this paper, we take $d \geq 0.6 * (b * 2 + 1)$ and $d \geq 3$ when $b = 2$. The result of the improved algorithm is shown in Fig.6. after changing b to 2 and introducing the flow velocity difference parameter c and the quantity limit condition d of each quadrant distribution.

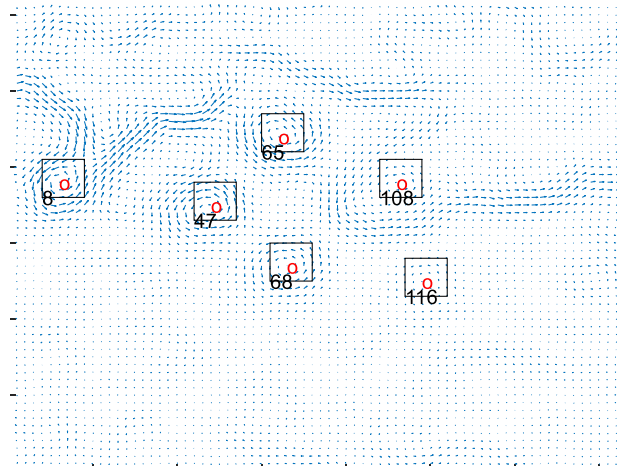


Fig.6. Test results of improved algorithm

As can be seen from Fig.6., the detection rate of the improved algorithm is greatly improved, there is no obvious miss detection, and the false detection of shear flow and flow jacket area is greatly reduced.

After the center of the vortex is detected, the edge and radius of the vortex can be detected. According to the velocity field^[5], the variation trend of velocity and sea surface height is calculated along different directions. The maximum velocity in different directions within a reasonable radius is selected as the edge prediction of mesoscale vortices, and the average distance from the edge position to the core position of mesoscale vortices in each direction is taken as the radius of mesoscale vortices. In this paper, 625 km * 625 km near the center is selected as the range of eddy edge search, and 25 * 25 rectangular region near the center is searched for the edge. The 25 * 25 rectangular region is transformed into polar coordinates to find the maximum point near the center in each direction as the edge point, and then it is transformed into Cartesian coordinate system, that is, all edge points can be marked and the edge points can be connected. The result is shown in Fig.7.

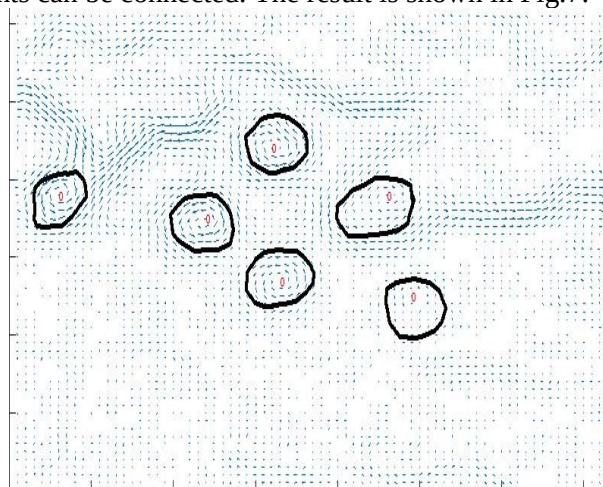


Fig.7. Eddy Edge Detection

4. Conclusion and Discussion

In this paper, an improved mesoscale eddy detection algorithm for flow field data is proposed. The parameters of edge velocity transformation and the number of edge quadrant distribution are introduced. From the test results, the improved algorithm can greatly improve the detection rate and reduce the false alarm rate. In this algorithm, the selection of parameters b , c and d is mainly based on the spatial resolution of flow field data. When the spatial resolution of data changes, these parameters should also be adjusted accordingly.

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