Explication of relation between fishery and vortices using 3-D visualization

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1. Introduction

The ocean ecosystem such as the marine resources and habitation quantity keeps changing for dozens of years. The typical example is "fish species change" which recent climatic variation such as global warming causes.

For such change, the fishermen often fail to find their fishery spot, which had not occurred before. That means a vain consumption of oils caused by the failure. It is sure that the fishery distribution has been different from what it had been. Thus, it is required that we need to pinpoint the fishery spot by a high-precision ocean model assimilated by observation datasets.

In this article, we focus on the neon flying squids which is in the middle of the ocean food chain resources. It is observed that the fishery spots of the saury fish often are located near a subtle vortex, whose diameter is about 10km [1]. The vortices are often found around a small vortex [1], whose diameter is about 100-200km. The saury fish is also a kind of fish migration as the same as the neon flying squids. We assume that the observation is also true for the neon flying squids.

Although the experience of the fishermen indicates that the fishery of the neon flying squids is located near the vortex, the relation between the vortex and the fishery had not been made clear so far. Our main target is in the offing of the Aomori North Pacific sea. The fishery can be characterized by using an index of catches per unit effort (CPUE).

In this article, we apply the critical point theory to the simulation results using the high-precision ocean model in order to explore the vortices. In the critical point theory, we first search for the critical point where the velocity vanishes and then classify the critical point by calculating the eigenvalues of the vector gradient tensor.

2. Proposed method

2.1 Critical point extraction

The velocity vector data values are defined at vertices of the orthogonal grid in the ocean simulation result. In each grid cell, the velocity vector (u_i, v_i, w_i) were given in each vertex P_i (i = 0-7) as shown in figure 2.1. Since the velocity vector is interpolated inside the grid cell using tri-linear interpolation function, the critical point can be determined by finding the location where the interpolated vector becomes

(u, v, w) = (0, 0, 0).

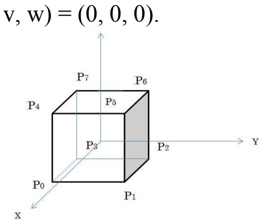

Fig. 2.1 Vertices of the orthogonal grid.

The velocity vector can be linearly approximated by its first order Taylor expansion as shown in equation 2.1. Here we describe the vector gradient tensor as J.

$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} & \frac{\partial u}{\partial z} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} & \frac{\partial v}{\partial z} \\ \frac{\partial w}{\partial x} & \frac{\partial w}{\partial y} & \frac{\partial w}{\partial z} \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = J \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (2.1)$$

2.2 Classification of the Critical point

In the critical point theory, the critical point can be classified by the eigenvalues of the vector gradient tensor, J [2]. The critical point can be classified as a vortex center if a pair of complex conjugate numbers is included in the eigenvalues. As shown in figure 2.2, the vortex center is classified as a repelling or attracting focus if the real parts are positive or negative, respectively. If the real part is zero, concentric ellipses occur around the critical point.

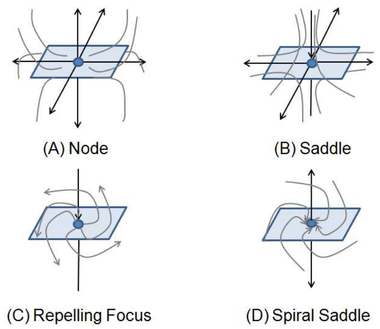

Fig. 2.2 Classification of the critical point.

2.3 Estimation of the vortex domain

To understand the velocity field around the vortex center, we often calculate a streamline whose starting point is located near the vortex center. In this case, the streamline is often terminated using a criteria which defines a vortex domain. We employ a definition of the vortex domain proposed by Patrikalakis and et al[3]. According to the definition, the streamline is calculated as follows:

1. Calculate a plane on which a vortex flow dominates by calculating an eigenvector whose eigenvalue becomes real.
2. Calculate a streamline from a point which is located near the vortex center and on the plane.
3. Project the streamline onto the plane in order to calculate the incremental in the radius.
4. Terminate the streamline calculation if the incremental exceeds a pre-determined value as shown in figure 2.3.

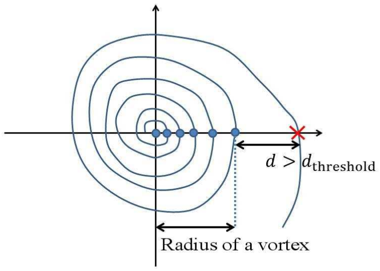

Fig. 2.3 Termination of the streamline

3. Experimental Setup

3.1 Velocity vector field

We used the velocity vector field included in the dataset calculated by using MOVE (MRI Multivariate Ocean Variational Estimation) System, which is an ocean data assimilation system developed in Japan Meteorological Agency (JMA) / Meteorological Research Institute (MRI).

In this research, the region of interest is the offing of Aomori, western North Pacific. The 4DVAR version of MOVE system (MOVE-4DVAR) adopts, as the control variables (i.e., the values optimized by the 4DVAR technique), a time-spreading correction term instead of the initial value. Its feature includes time-spreading correction, considering horizontal correlation of the control variables and employing vertical coupled corrections to temperature and salinity fields.

3.2 Fishery data of the neon flying squids

Datasets on the catch of the neon flying squids were provided by a test ship of the Aomori Prefectural Fisheries Research Center. The datasets include the operation start date and time and fishery position (latitude, longitude) water temperature, the number of the fishing device, total capture quantity, the operating hours, CPUE(Catch per unit effort), which is expressed as follows:

CPUE = Cq / Fd / Oh (3.1)
Cq : capture quantity
Fd : the number of fishing device
Oh : operating hours

4. Results and Discussions

4.1 Relations with vortex and CPUE

Figure 4.1 shows a set of streamlines calculated from near vortex centers in the MOVE dataset of February 13, 2002. The sea surface temperature and CPUE locations are superimposed.

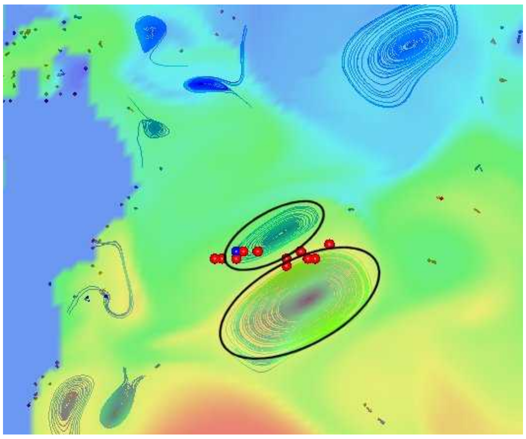

Fig.4.1 February 13, 2002 CPUE and Vortices sea surface temperature distribution

In the colormap of the sea surface temperature, the high and low temperature values are continuously mapped to red and blue, respectively. The spheres indicate the locations where CPUE datasets were measured.

Figure 4.1 shows that the CPUE locations are distributed near the edges of two vortices, where the sea surface temperatures are differently distributed. In the north or south vortex, the temperature has the local minima or maxima. It is well known that the Oyashio Current and the Kuroshio Current collide in this domain and the collision facilitates the generation vortices. The CPUE locations indicates that the vortices play an important role in the activation of the ocean food chain resources.

Figure 4.2 shows the temperature distribution on a vertical cross section which passes through the vortex center.

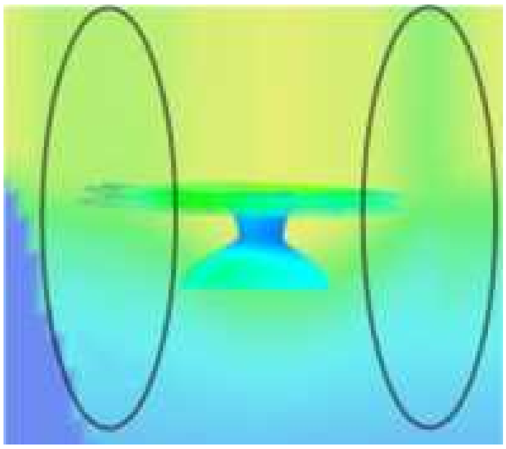

Fig.4.2 Vortex shape and seawater temperature distribution

The steep change in the temperature around the vortex center may imply that there exists some vertical flow, that is an upwelling current, which transports nutrient salts from the bottom of the sea to the near of the sea surface.

5. Conclusion

In this article, we figured out that vortex centers have relation with CPUE locations where the Oyashio Current and the Kuroshio Current collide. We identified the vortex centers by applying the critical point theory to the velocity field calculated by the MOVE system.

In future, we will investigate the three-dimensional structure which explains the way how the upwelling flow occurs near the vortex center by employing the velocity field defined on a higher resolution grid which can express a subtle vortex, the scale of which ranges from a hundred meter to one kilometer.

References

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