Mesoscale Eddy Detection and Edge Structure Extraction Method in SAR Image

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ABSTRACT: In this paper, the existence of mesoscale eddy is confirmed by comparing the data of historical earth transfer with the eddy found in historical SAR images. The eddy phenomena in SAR images were identified by multi-region segmentation and direction detection. The structure characteristics of eddy edges were extracted and the center position of mesoscale eddy was estimated by edge characteristics. The effectiveness of the proposed method is verified by comparing it with the data of ground transfer.

1. INTRODUCTION
Because of the instability of ocean currents or fronts, eddies are formed in the ocean [1]. Eddies are almost everywhere in the ocean, and its spatial scale can range from several kilometers to several hundred kilometers. It can be kept for several weeks to several months in the ocean, the larger the scale and the larger the eddy velocity, the longer the time. Mesoscale eddy is an important part of ocean dynamics, which affects the distribution and structure of ocean elements such as temperature and salinity [2][3], thus affecting marine military activities, Marine Fisheries and so on. In marine military activities, the existence of mesoscale eddy will lead to distortion, band and weakening of acoustic wave propagation in the ocean, and cause a series of problems in acoustic field calculation, convergence area detection and target detection, which seriously affect the detection efficiency of underwater sonar. Therefore, the research on Mesoscale eddy is getting more and more attention in the field of Marine Battlefield Environment.

Since the discovery of mesoscale eddy in 1970s, the observation of mesoscale eddy in the ocean mainly relies on the use of satellite altimeter to obtain the dynamic altitude data of the sea surface, from which the mesoscale eddy can be retrieved and tracked [4]. However, due to the low spatial resolution of altimeter data, it is impossible to accurately depict the edge of mesoscale eddy, thus affecting the battlefield environment situation analysis.

In recent years, the study of mesoscale eddy has gradually turned to SAR image detection [5][6]. SAR has the remarkable advantage of all-day and all-weather observation, and it has a wide range and high geometric resolution, which is very advantageous to mesoscale eddy observation. In terms of SAR observation mechanism, mesoscale eddy can be observed mainly because the shear flow at the edge of the eddy changes the roughness of the sea surface, thus affecting the backscattering coefficient of SAR on the sea surface. However, the effect of shear flow on sea surface roughness is not significant, most mesoscale eddy are tens of kilometers in size, it is difficult for SAR images to cover the whole eddy completely. Therefore, there are few images of ocean eddy observed in spaceborne images, only when the local shear flow is large and the scale of the eddy is small, the complete eddy can be observed in SAR images.
With the further enlargement of SAR width and radiation resolution, the observation of ocean mesoscale eddy using SAR images will inevitably become a trend in the future\textsuperscript{[7]}. Therefore, the detection of mesoscale eddy and the extraction of edge structure features in SAR images will also become the key technologies for the application of mesoscale eddy detection in future SAR images.

In this paper, the mesoscale eddy phenomena found in the historical SAR image data are detected by eddy detection, edge structure feature extraction and eddy center estimation. The validity of these phenomena is proved by comparing with the geostrophic data.

2. AUTOMATIC DISCRIMINATION AND FEATURE EXTRACTION PROCESS

The automatic discrimination and feature extraction of SAR images mainly aim at the eddy edge texture information in SAR images. Firstly, the SAR image process filtering process is used to reduce the speckle noise in the image, at the same time, the image is smoothed to eliminate the influence of sea waves and so on. Secondly, the eddy ROI is extracted artificially and the location of the center of the eddy is predicted. The edge gradient of the image is detected by the edge extraction operator. After the detected area is refined appropriately, the slope of the edge line segment is calculated, and the existence of the eddy is judged by the slope and location of the line segment. Finally, the eddy edge structure is extracted, and the eddy center is further fitted and searched. The overall process is shown in Fig.1.

3. SAR IMAGE PREPROCESSING

The ERS-2 synthetic aperture radar data collected are collated in this paper. Among them, a scene SAR image on 3 May 1998 contains a significant mesoscale eddy phenomenon, as shown in Fig.2. The image is taken in the South China Sea between Taiwan Island and Hainan Island. The center is located at 19.571 ° N, 115.930 ° E, the spatial resolution of the image is 12.5 meters, and the width is about 100 × 100km.
After geographical registration of the image, compared with the same day of the earth transfer fusion image, it was found that there was indeed a smaller eddy in the area where the SAR image was located, as shown in Fig.3. It can be found that in the area where the SAR image is taken, there is a very small central flow rate, a large flow rate around it, and an eddy shape is formed in the direction of the flow field. The flow direction is also basically the same as the texture direction expressed in the SAR image. By comparing SAR images with ground transfer distribution images, it can be basically determined that the texture observed by SAR images is indeed an eddy texture.

In order to be able to further process SAR images and form SAR image eddy judgment and feature detection methods, this paper takes the SAR image of May 3, 1998 as an example to describe SAR image eddy judgment and feature detection methods in detail.

Due to the inevitable spot noise in SAR images, considering the large mesoscale eddy space scale, smooth filtering and image reduction can be performed first. In this paper, the mean filter is used to filter the image and reduce it. The processed image is shown in Fig.4. It can be found that the resolution of eddy texture in the image is obviously improved.

3. ROI (region of interest) extraction and eddy center prediction

Considering that the SAR image has a large width and only a part of the region with eddy is occupied, in order to make better eddy judgment and feature extraction, the ROI is first selected by manual method. The result of ROI extraction is shown in Fig.5. The subsequent processing mainly deals with ROI data, which can eliminate the interference of other ocean phenomena and sea surface ripple on eddy detection.

After the selection of artificial ROI, the possible location of vortices center is predicted according to the texture information in the ROI region, which is used as the basis for the subsequent identification of vortices edge direction characteristics.
4. EDDY DISCRIMINATION BASED ON EDGE DIRECTIONAL CHARACTERISTICS

In order to distinguish whether the ROI contains vortices or not, edge texture of the image needs to be extracted. In this paper, Canny is used to calculate the edge gradient of the image. Fig.6. shows the result of image edge gradient calculation for Canny operator.

Then the gradient image is processed, the threshold is automatically determined, and the edges in the image are extracted. In this paper, the threshold is estimated by calculating gray histogram. The gray level of bright pixels at 30% image energy is selected as the threshold of edge detection.

Step1: fetching edge angle data set

In order to obtain the inclination angle of these narrow areas, each edge line is processed, the curvature of the ellipse outside the edge line is calculated, and the edge line with small curvature is removed from the binary graph. Get the edge angle data set \{S_i\} formed by the edge line.

Step2: polar coordinate transformation

To determine whether there is a mesoscale eddy in the image, the polar coordinate transformation of the edge image is performed with the pre-determined eddy center in step 2.

Step3: eight angles region segmentation

According to the angles in polar coordinates and according to the angle in polar coordinates, the image is divided into eight regions: angle [0, 45], [45, 90], [90, 135], [135, 180], [180, 225], [225, 270], [270, 315], [315, 360]. Eight the distribution of the edges of the regions after segmentation is shown in Fig.7.
Fig. 7. Eight directions segmentation of the image edges

Step 4: Calculation of vortex edge coincidence rate

In these eight regions, the inclination angles of the edge lines which fully conform to the eddy edge criteria are \( T = [67.5, 22.5, -22.5, 67.5, 22.5, -22.5, -22.5, 67.5] \). Because the slope of the eddy edge can't fully conform to the circular criterion, and some edge lines deviate from the center, the thresholds of the eight angles are set as follows:

\[
T_{sl} = T_i - 30, \\
T_{sih} = T_i + 30
\]  

(1)

When the slope in the region meets the threshold requirement, an increase is achieved:

\[ \text{If}(S_i > T_{sih} \& S_i < T_{sl}), P_m = P_m + 1 \]  

(2)

Step 5: Vortex discrimination

According to the slope threshold, the percentage of the number of edges that meet the threshold condition to the total number of edges in the eight regions is calculated, that is:

\[ P_i = \frac{P_{im}}{P_{in}} \times 100\% \]  

(3)

When the percentage is more than 60%, it is considered that the edge of the angle region meets the requirement of mesoscale eddy edge. At this time, an additional \( N_{sum} \) added. When all eight angle regions are calculated, the existence of vortices is determined according to the number of angle regions that meet the requirement of the edge:

\[ E = \begin{cases} 
1 & \text{if}(N_{sum} \geq T_e) \\
0 & \text{if}(N_{sum} < T_e)
\end{cases} \]  

(4)

5. VORTEX EDGE STRUCTURE FEATURE EXTRACTION AND CENTER LOCATION ESTIMATION

After judging the existence of the vortices according to the discriminant rules, the edge structure features of the vortices can be extracted, and the location of the vortices can be determined by searching the edge position near the artificial pre-judged vortices center.

The feature extraction of eddy edge structure can then be determined by the eight-direction mid-edge line used in eddy discrimination, and the edge line that meets the requirement of inclination angle can be extracted and merged. As shown in Fig. 8.

The final determination of the eddy center is related to the edge line of the eddy. The distance between each position and the edge line is calculated by searching near the original predicted center position. According to the criterion of circle center, the minimum square sum of distance is the center
of the eddy. The results of the vortex center location search in this paper are shown in Fig.8.

![Fig.8. the eddy's edges and center](image)

By comparing the eddy edge, center and the geostrophic current data, it is found that the eddy parameters detected from SAR images are basically consistent with the direction, position and center of the flow field data stream edge, which proves the validity of the proposed method for judging mesoscale eddy and extracting eddy characteristic parameters from SAR images.

6. CONCLUSION

In this paper, based on the texture information of mesoscale eddies in SAR images, polar coordinate transformation and angle region segmentation are used to automatically determine the existence of mesoscale eddies according to the texture direction of image edges, and the edges of mesoscale eddies are extracted to search and fit the location of vortices center. With the increasing application of SAR images in ocean field, especially in the field of ocean mesoscale phenomena, the detection of mesoscale eddies and extraction of feature parameters in SAR images are of great significance to mesoscale eddies detection and feature extraction. But there are still some deficiencies, for example, in the selection of ROI, there is still need for manual intervention. We will make further efforts in this area, trying to achieve automatic identification and detection.

REFERENCES

[1] Chen, B., Zhang, B., He, W. (2002) Detection of Ocean Fronts from Spaceborne SAR Images [J]. Remote sensing technology and application, 17(4):177-180.
[2] Ian Grooms, Laure Zanna. A note on ‘Toward a stochastic parameterization of ocean mesoscale eddies’[J]. Ocean Modelling, 2017, 113.
[3] W. Callendar, J. M. Klymak, M. G. G. Foreman. Tidal generation of large sub-mesoscale eddy dipoles[J]. Ocean Science Discussions (OSD), 2011, 8(2).
[4] V. Pérez-Muñuzuri, F. Huhn. The role of mesoscale eddies time and length scales on phytoplankton production[J]. Nonlinear Processes in Geophysics, 2010, 17(2).
[5] Yang Yang, Tao Xing, Yinxia Wang et al. The topography effect on the sudden deceleration of the mesoscale eddy propagation speed around the Dongsha Islands in northern South China Sea[J]. Aquatic Ecosystem Health & Management, 2016, 19(3).
[6] John Marshall, Jeffery R. Scott, Anastasia Romanou et al.. The dependence of the ocean’s MOC on mesoscale eddy diffusivities: A model study[J]. Ocean Modelling, 2017, 111.
[7] Lyzenga D R, Wackerman C. Detection and classification of ocean eddies using ERS—1 and aircraft SAR images. Proc3rd ERS Symp. 1997