Oceanic Eddy Detection from SAR Imagery Based on Deep Learning Network

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Abstract

Oceanic eddies are widely distributed in the global ocean, they play a crucial role in the global ocean energy cycle, the transport of heat and salt, and the distribution of nutrients. Synthetic Aperture Radar (SAR) is an ideal sensor for studying ocean eddies due to its high spatial resolution and independence of daytime and weather conditions. This paper proposes a method based on the deep learning networks of the YOLO family, named EOLO, to detect and extract geographic information of ocean eddies on C-band spaceborne SAR images. Several key enhancements were made to improve the performance of EOLO, including the introductions of spatial attention mechanism and new up-sampling operator, and improvements of the feature fusion method, loss function, and anchor box size, which contribute to an average precision of 91.5%. We also conducted experiments using Sentinel-1 images in the Red Sea, the Baltic Sea, and the Western Mediterranean Sea to verify the generalization of EOLO in different seas, reaching 96.8%, 95.7%, and 96.5% precision respectively. Furthermore, 8569 eddies were extracted by EOLO in the Western Mediterranean Sea in 2021, compared with the eddies from the altimeter data, the results show that the SAR eddies based on EOLO can detect at least 45% of the ocean eddies invisible to altimeters and are more realistic.

Objective

Inspired by the YOLO series network, we aim to develop an automatic eddy detection network with high precision and good generalization by SAR data. We also would like to achieve the actual application of the network to analyze ocean eddies observed in SAR images, that is, to automatically extract the geographic information (e.g., diameter and location) of the eddies.

Methods

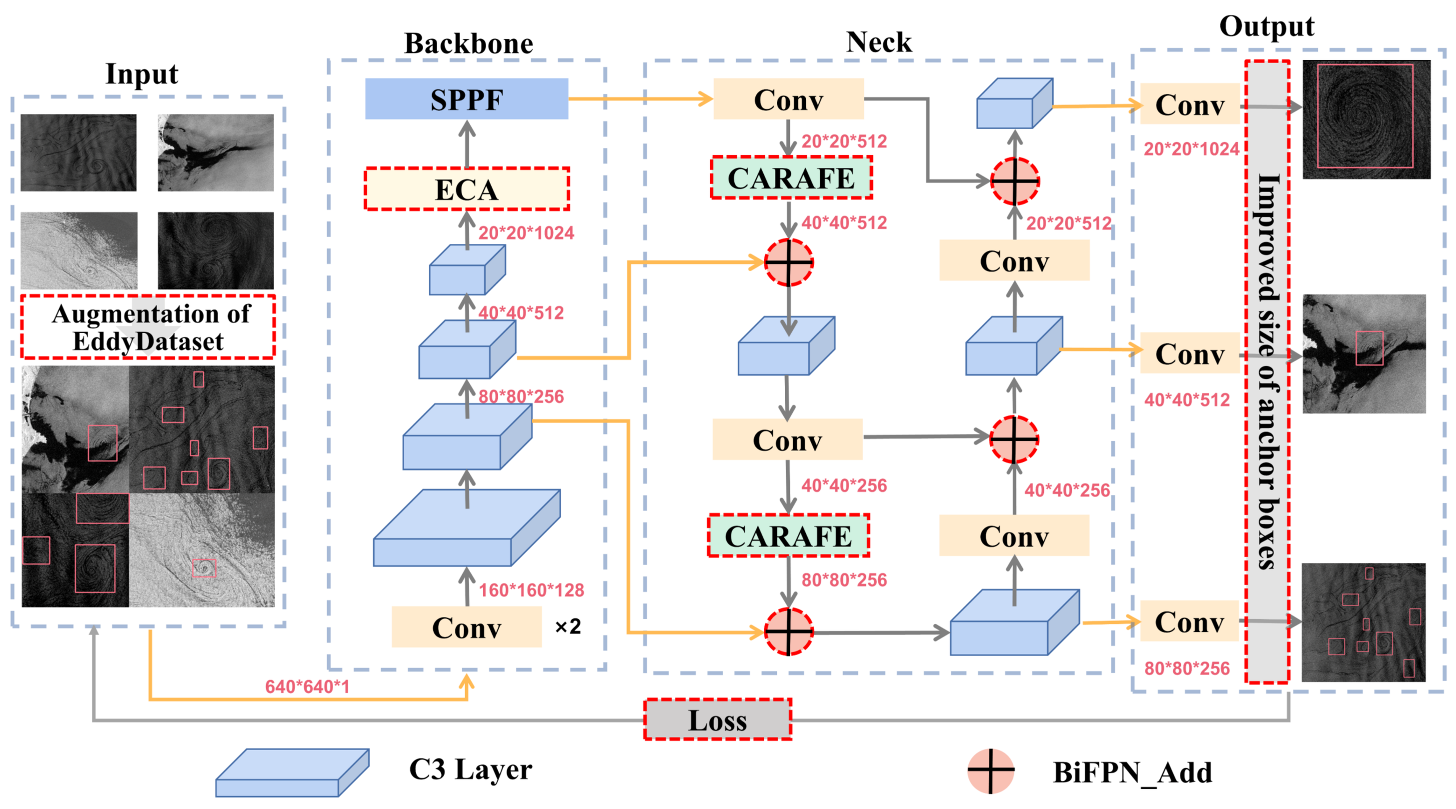

Fig.1 The structure of eddy automatic detection network in EOLO.

The Efficient Channel Attention (ECA) mechanism in the backbone, the up-sampling operator Content-Aware Reassembly of The Features (CARAFE), and a new feature fusion method in the neck was introduced to learn the complex texture features of ocean eddies. Moreover, the redesign default anchor boxes and loss function were redesigned for ocean eddy detection.

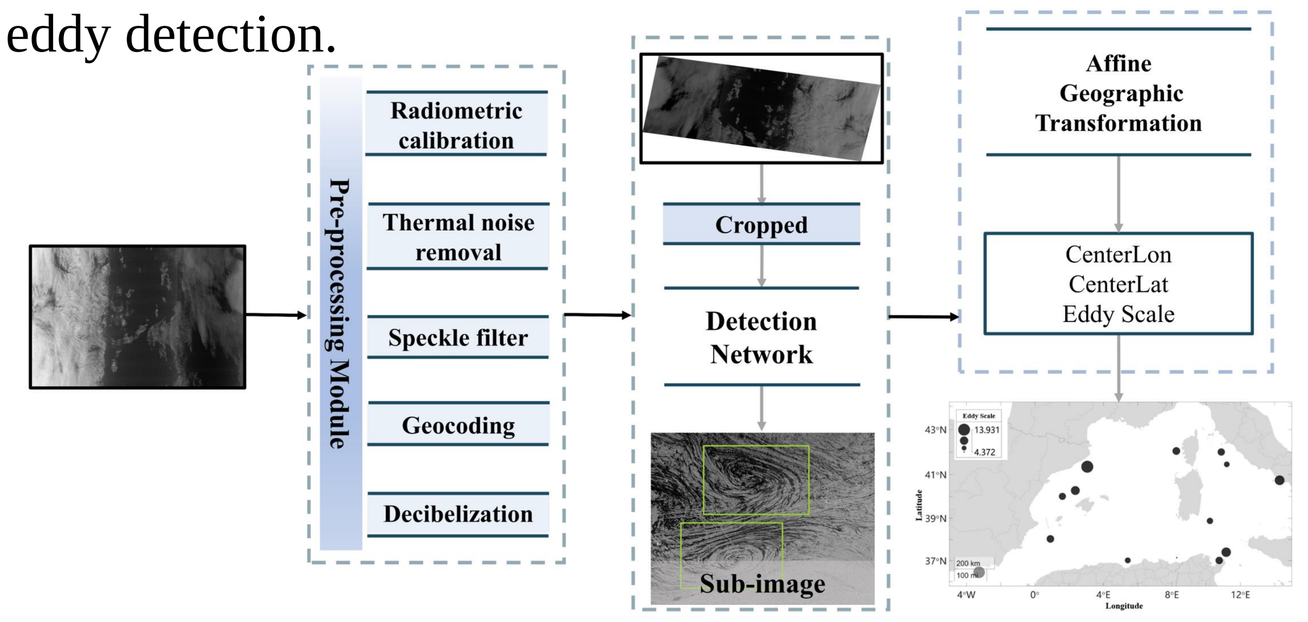

Fig.2 Diagram of detecting ocean eddies and extracting their geographic information by EOLO.

Results

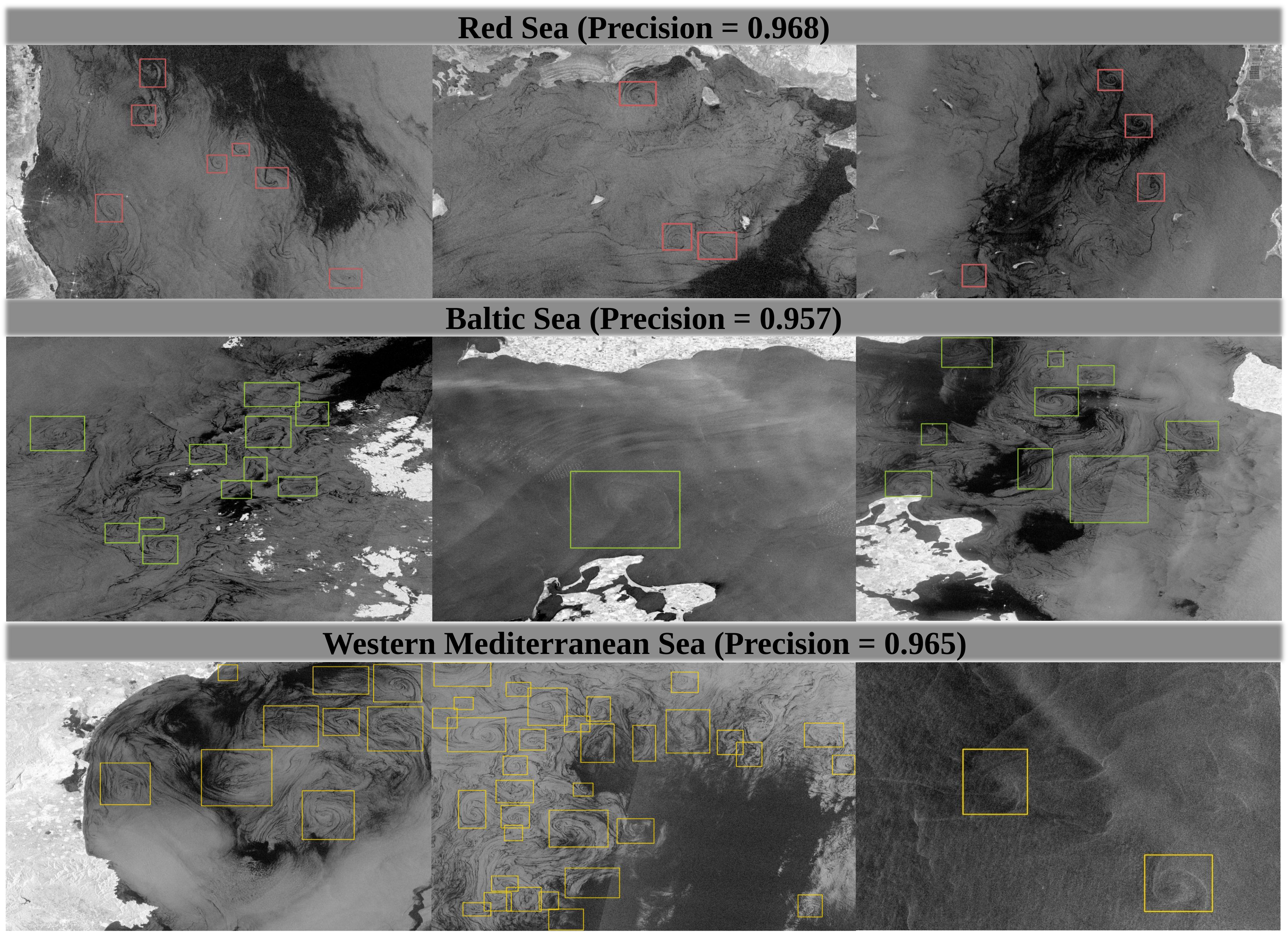

Fig.3 Visualization of EOLO detection cases in the three seas.

Discussion

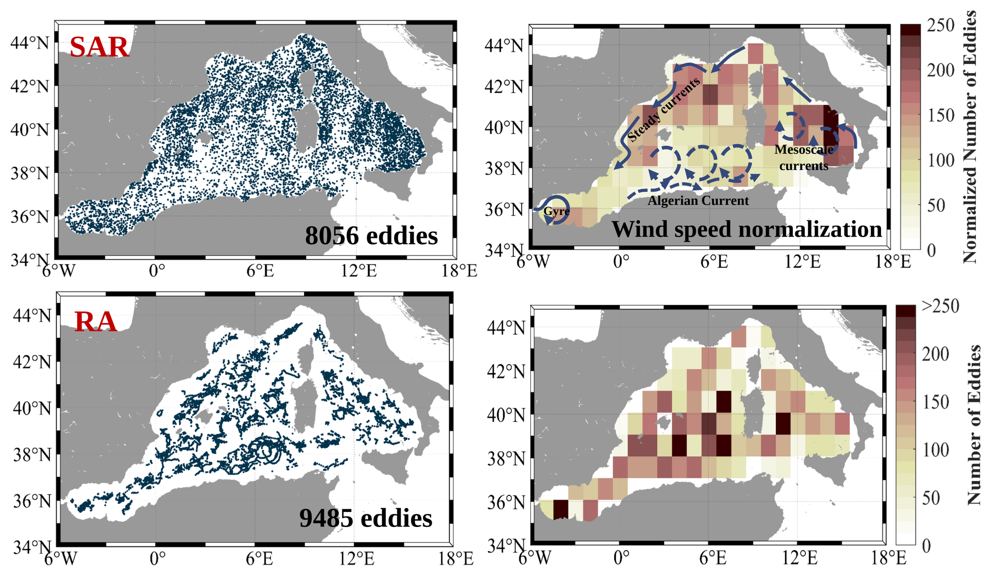

Fig.4 The spatial distribution of SAR and RA ocean eddies.

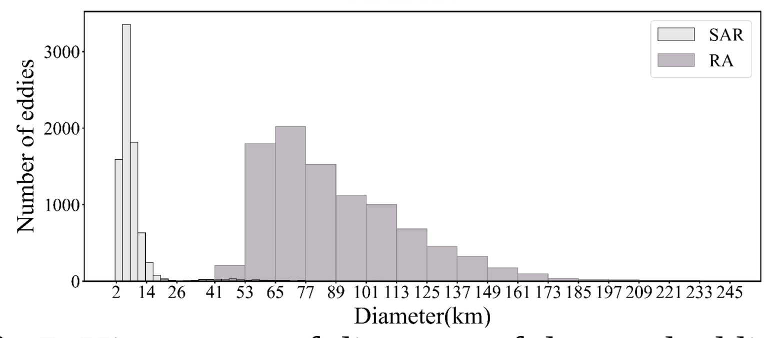

Fig.5 Histograms of diameter of detected eddies by SAR and RA in the Western Mediterranean Sea in 2021.

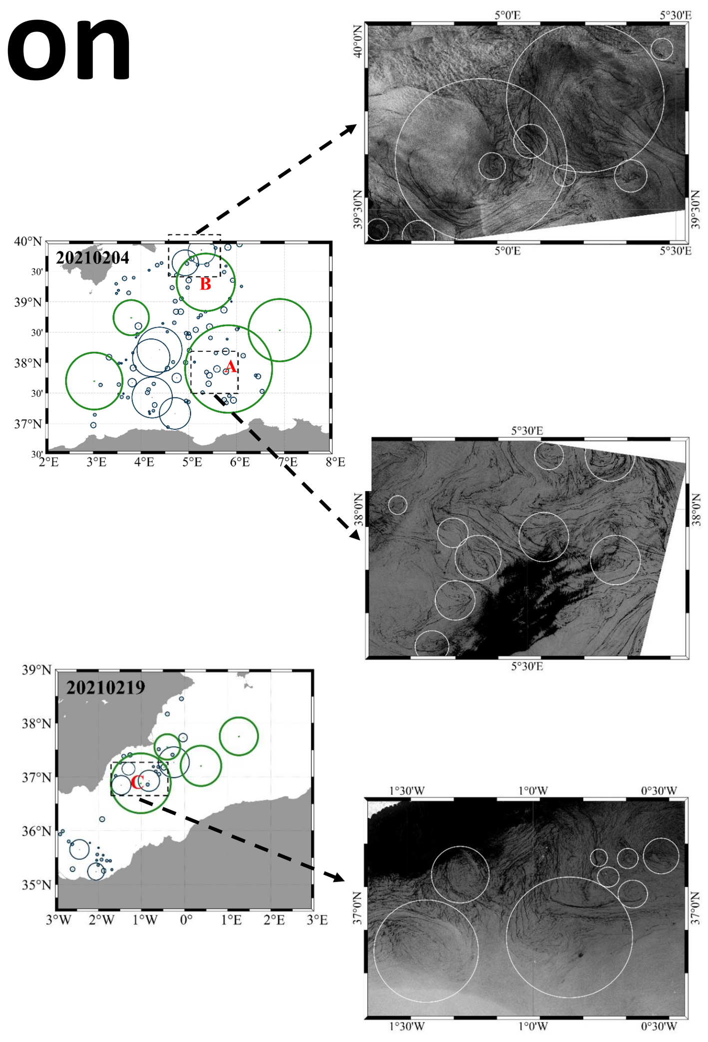

Fig.6 Cases of small eddies merging into large eddies.

Conclusions

- The result of the experiment in three seas shows that the detection precision of EOLO in the Red Sea, Baltic Sea, and Western Mediterranean Sea reaches 96.8%, 95.7%, and 96.5% respectively, suggesting EOLO has good generalization and can apply in other seas.
- High occurrence areas for SAR and RA eddies are not consistent, primarily due to the spatial resolution limitations of RA. The coarse spatial resolution of RA data hinders its detection of small eddies. Attempting to compensate for this resolution deficiency by utilizing a fused map product developed from multiple RA along-track data always leads to the artificial merging of eddies.

References

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Amores, A., Jordà, G., Arsouze, T., Le Sommer, J., 2018. Up to what extent can we characterize ocean eddies using present-day gridded altimetric products?. J. Geophys. Res. Oceans 123(10), 7220-7236.