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Sea ice parameter retrieval in the Bohai Sea using GOCI data from 2011-2020

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The Bohai Sea and its surrounding areas are rich in oil and natural gas, and play an important role in the industry, agriculture and economy. However, the Bohai Sea suffers severely from the sea ice in the winter. The Geostationary Ocean Color Imager (GOCI) is the first geostationary orbit ocean color satellite, providing high spatial and temporal resolution for extraction of sea ice parameters in the Bohai Sea. Based on GOCI data, a systematic and standardized method is developed for extracting sea ice parameters. This method can perform normalized preprocessing on the GOCI raw data, including atmospheric correction, relative radiation correction, and sea ice or cloud masking. Subsequently, it extracts relevant sea ice parameters, including sea ice concentration, sea ice thickness, and sea ice drift velocity. The unique advantage of GOCI is its geostationary orbit and short imaging interval (1 hour), which enables tracking the daily drift of the sea ice in the Bohai Sea. Using this method, sea ice parameters are retrieved in the Bohai Sea in winter from 2017 to 2021, and the retrieval accuracy meets the sea ice forecast demand.

Study Area and Data

1. Study Area

The Bohai Sea is situated between 37°N to 41°N latitude and 117°E to 121°E longitude. It is a semi-enclosed inland sea surrounded by the provinces of Shandong, Hebei, Tianjin, and Liaoning. The Bohai Sea can be primarily divided into four main regions: **Liaodong Bay**, **Laizhou Bay**, **Bohai Bay**, and the **Middle Bohai Sea**, as shown in Figure 1. The central part, being far from river mouths and the mainland, experiences minimal influence from the land and river runoff. The sea ice in this area is mainly propagated from Liaodong Bay, and its ice conditions are relatively mild. Therefore, in the study of sea ice in the Bohai Sea, the central part is often grouped with Liaodong Bay.

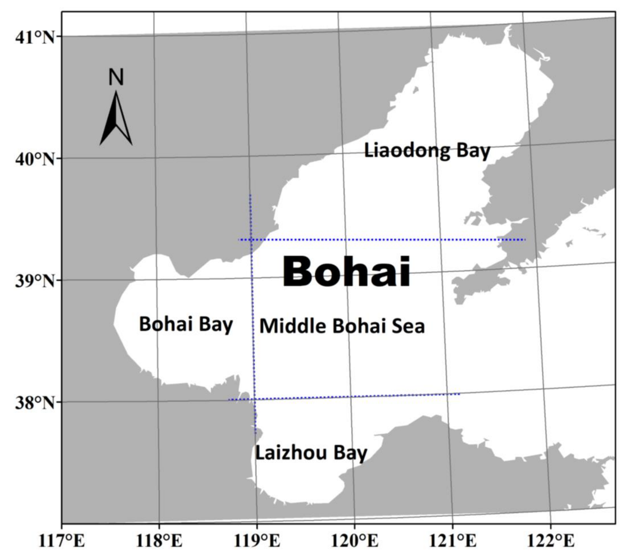

Fig.1 The geographical location of the Bohai Sea.

2. Geostationary Ocean Color Imager (GOCI)

Korea successfully launched the Communication Ocean and Meteorological Satellite (COMS) in 2010. The Geostationary Ocean Color Image (GOCI) is the first Earth geostationary orbit ocean color remote sensing satellite.

- Center position of imaging: 130°E, 36°N
- Spatial resolution: 500m
- Time resolution: 1 hour
- Images size: 5568×5685 pixels
- Bands: 6 visible light bands and 2 near-infrared bands

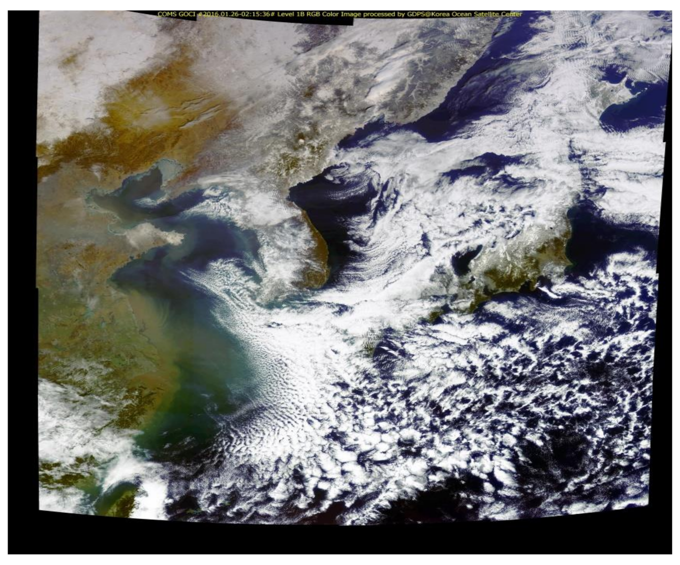

Fig.2 The original image 20180131_02

Methods and Results

Data preprocessing

1. Atmospheric correction

In this study, the official GOCI Data Processing System (GDPS), namely the SeaWiFS method, was adopted for atmospheric correction, resulting in the GOCI L2C product with Ralyeigh scattering removed.

2. Relative radiation correction

The "dark pixel" method was applied to eliminate aerosol and other atmospheric effects from the GOCI L2C product .

3. Sea ice or cloud masking

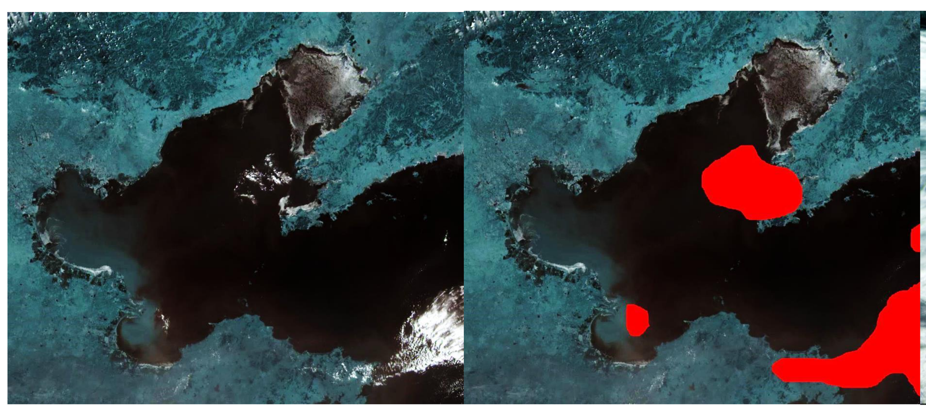

Fig.3 Cloud masking

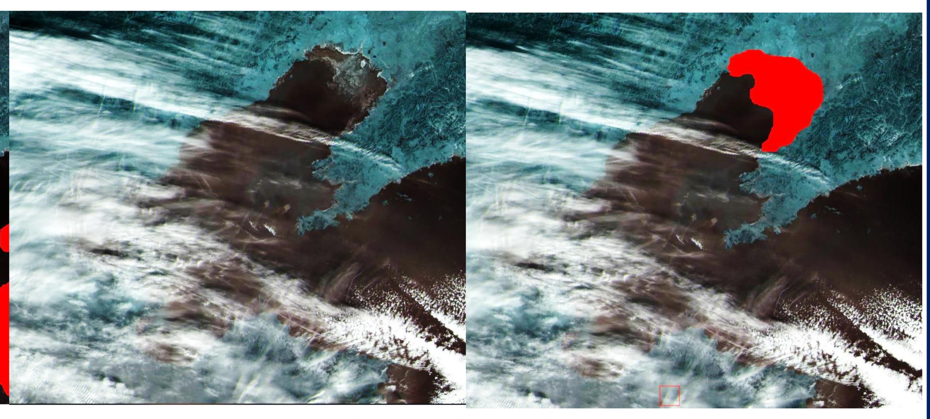

Fig.4 Sea ice masking

Sea ice parameters

1. Sea ice thickness

A relationship between MODIS shortwave broadband albedo and preprocessed reflectance in various GOCI data bands was established: $\alpha_{short} = -0.1356\alpha_1 - 0.2704\alpha_2 + 1.4087\alpha_3 - 0.3284\alpha_4 - 0.0812\alpha_5 + 0.6204\alpha_6 - 0.1474\alpha_7 - 0.0268\alpha_8 - 0.0464$
Established the relationship between sea ice thickness and sea ice shortwave broadband albedo.

$$\alpha_{short} = \alpha_{max}\left[1 - \left(1 - {}^{\alpha_{sea}}/_{\alpha_{max}}\right) \cdot e^{-\mu_\alpha H}\right]$$

2. Sea ice concentration

Sea ice concentration was calculated using the shortwave mean values of sea ice and open water. The sea ice concentration for each pixel of GOCI data was obtained by taking the difference between the shortwave albedo of that pixel and the mean shortwave albedo of open water, and then dividing it by the difference between the shortwave albedo of sea ice and the mean shortwave albedo of open water.

$$seaice_{con} = \frac{ashort - ashort_{sea\_mean}}{ashort_{ice\_mean} - ashort_{sea\_mean}}$$

3. Sea ice drift

The maximum cross-correlation (MCC) method is employed for sea ice drift monitoring and tracking. This method utilizes the pixel differences of sea ice features to calculate correlation coefficients and establish correlations between two sequential images. The GOCI images are acquired at a time interval of 1 hour. In the first image, different sea ice feature points (x_1, y_1) are selected, and the corresponding best matching positions (x_2, y_2) are obtained in the second image by calculating the cross-correlation coefficients. Therefore, the sea ice drift velocity and direction can be obtained using the formulas.

$$d_x = x_2 - x_1,\quad d_y = y_2 - y_1,\quad v = \frac{\sqrt{{d_x}^2 + {d_y}^2} \times 500}{3600 \times h},\quad \theta = arctan\left(\frac{d_y}{d_x}\right)$$

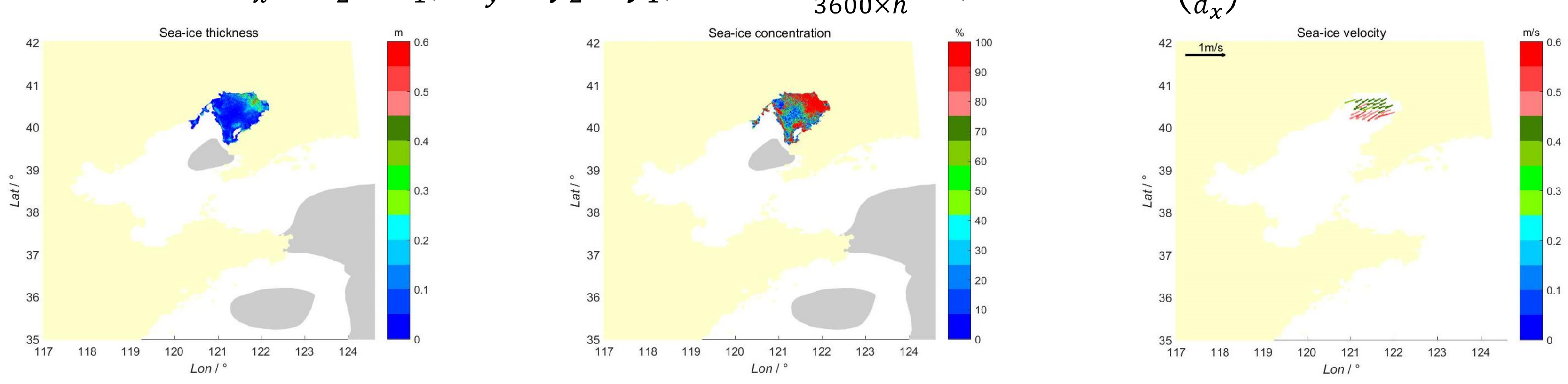

Fig.5 The results of sea ice parameters

Sea ice variations

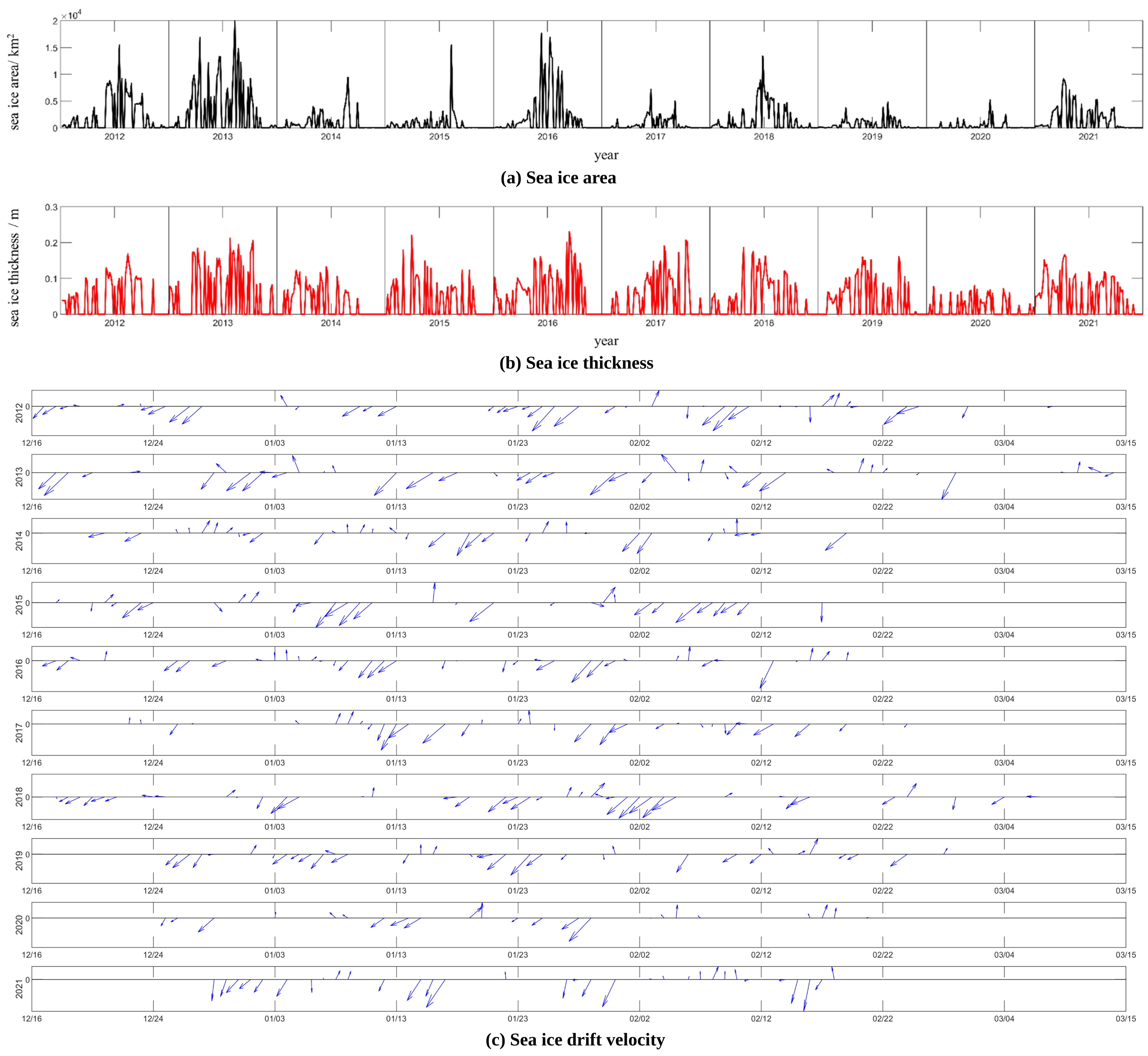

Fig.6 The variations of sea ice parameters in 2011-2021

By analyzing the winter data from December to March in 2011-2021, we observed consistent ice period in the Bohai Sea, with clear interannual variations in sea ice area. The years 2012, 2013, 2016, 2018, and 2021 exhibited substantial sea ice area, representing high ice extent years. During the years 2014, 2015, 2017, 2019, and 2020, the Bohai Sea experienced relatively low sea ice area, signifying these years as low sea ice extent years. Compared to high sea ice extent years, the variations in sea ice area during low sea ice extent years generally lagged by about 10 days. The interannual variations in Bohai Sea ice thickness showed a relatively minor impact compared to the sea ice area trends. With the exceptions of 2013 and 2020, the mean sea ice thickness for the other years fluctuated between 0.08 meters and 0.1 meters. Figure 6 (c) showed the sea ice drift velocity in the Liaodong Bay. It could be observed that the majority of the sea ice drifts in the southwest direction, while a small portion drifts in the north direction. The sea ice drift velocity was significantly influenced by the daily ocean dynamic parameters, and its distribution did not exhibit distinct interannual or annual characteristics.

Conclusion

Our research quantify and standardize the high resolution and high precision sea ice monitoring in the Bohai Sea. Based on GOCI, this paper extracted a standardized dataset of sea ice parameters with high spatial resolution from 2011 to 2021 in the Bohai Sea, including sea ice thickness, sea ice concentration, sea ice area and sea ice drift velocity, quantitatively analyzed the 10 year statistical distribution of sea ice parameters. The sea ice extent and thickness in the Bohai Sea reached their maximum in 2012 and their minimum in 2019, respectively. The sea ice growth during each winter follows the same pattern: the sea ice forms in late December, reaches its maximum extent in January, begins to shrink in early February, and disappears completely by early March. The sea ice drift velocity is largely influenced by the wind and currents, without significant rules of inter-annual or annual changes. The extraction of these parameters will provide initial field data of the sea ice for sea ice forecasting in the Bohai Sea. Furthermore, it will provide valuable data support for sea ice monitoring and ocean environmental research, helping to better understand the trends in oceanic changes and ultimately contribute to the preservation of the health and stability of marine ecosystems.