Inversion of Sea Ice Concentration and Thickness in the Yellow Sea and Bohai Sea Based on HY-1C Data

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Abstract

Sea ice in the Yellow Sea and Bohai Sea affects maritime transportation and economic activities every winter. Hence, monitoring sea ice concentration and thickness, the key parameters, is vital. HY-1C onboard Chinese Ocean Color and Temperature Scanner (COCTS) has ten spectral bands for retrieving sea ice concentration and thickness. This study proposes a systematic and standardized method for extracting sea ice parameters based on HY-1C data. The raw COCTS data undergoes normative pre-processing, which includes geometric correction, atmospheric correction, radiometric calibration, and sea ice masking. Then, sea ice concentration and thickness are retrieved.

Research Data And Region

1.HY-1C

HY-1C and HY-1D are both the ocean color satellite series that provide optical data in the morning and afternoon, respectively. In the afternoon, rising temperatures may cause slight melting on the sea ice surface, which may hamper optical detection. Therefore, HY-1C is more suitable for Bohai sea ice monitoring than HY-1D.

Launching: September 7, 2018, 11:15 AM
Orbital Inclination And Altitude:98.5° and 782 km
Payloads: COCTS, CZI, UVI, SCS, AIS
Coverage Period: 1 day (COCTS, UVI, AIS); 3 days (CZI)
Spatial resolution: 1 (optical imagery data) , 2 m(radar data) , 10 m(microwave data) .
Data coverage: The HY-1C satellite dataset covers the global oceans

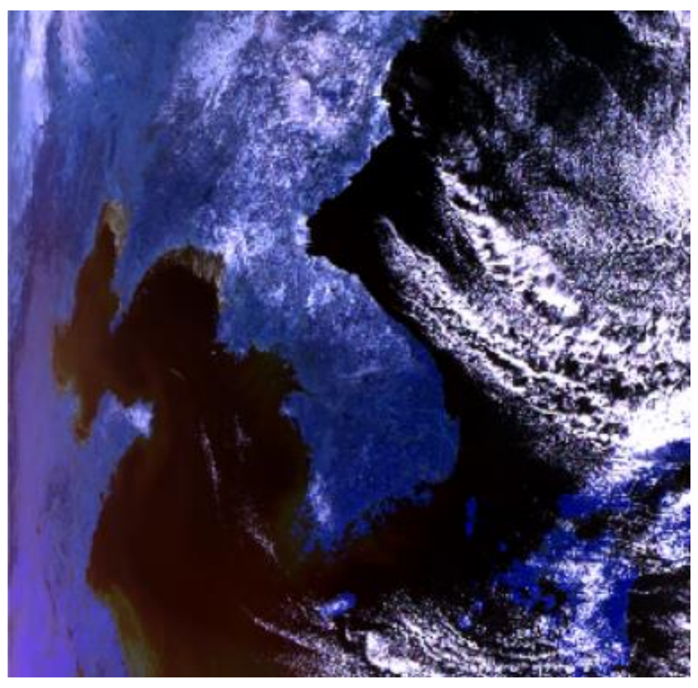


Fig.1 Original data images of HY-1C

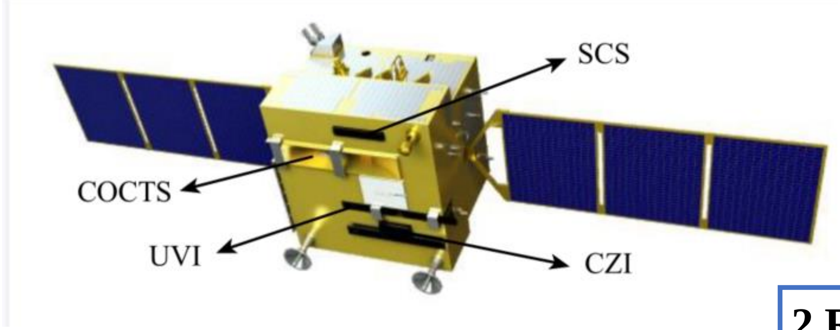


Fig.2 HY-1C

Fig.3 Study area

2.Research Region

The Bohai Sea and the northern Yellow Sea are crucial strategic maritime trade hubs in northern China, facing economic disruptions caused by severe winter sea ice events. These calamities lead to traffic disruptions, harbor damage, repercussions for oil and gas industries, and impairment of offshore structures. The sea ice cover disaster of 1969 resulted in ship collisions and platform damage. To counteract these perils, the establishment of a meticulous high-resolution sea ice monitoring system holds utmost importance in safeguarding the winter security of both the Bohai Sea and the northern Yellow Sea.

Methods and Results

Preprocessing and Masking

Before inverting sea ice concentration and thickness, we need to perform standardized preprocessing on the raw COCTS data, including geometric correction, atmospheric correction, radiometric calibration, and sea ice masking.

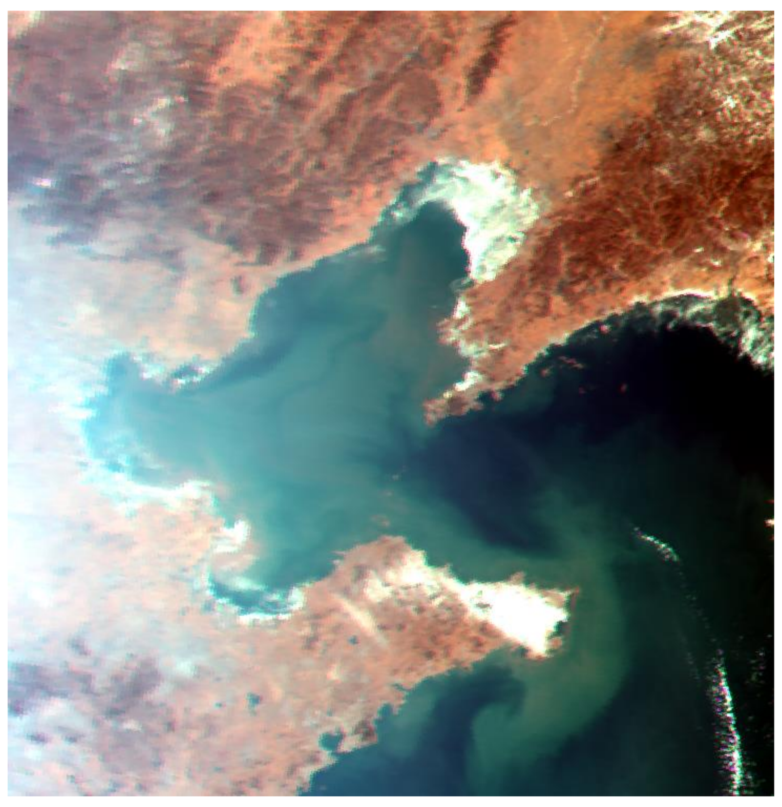


Fig.4 Preprocessing, images of the Bohai Sea region

Fig.5 Sea ice masking

Sea Ice Thickness

1. Synchronous MODIS and COCTS images are selected during the winter freezing period in the Bohai Sea and northern Yellow Sea, ensuring that the chosen MODIS and COCTS data are predominantly clear, with minimal cloud cover, no snow coverage, and stable sea ice conditions.
2. Utilizing the Liang method, sea ice shortwave broadband reflectance is calculated based on MODIS imagery in the Bohai Sea and northern Yellow Sea. A significant number of samples are selected where COCTS and MODIS positions correspond one-to-one. The analysis focuses on the correlation between MODIS reflectance and COCTS band reflectance across various wavelengths.
3. Based on the degree of correlation obtained, a linear regression equation is established between the MODIS shortwave broadband reflectance and the COCTS reflectance from highly correlated spectral bands. As a result, a linear regression model for COCTS shortwave broadband reflectance is derived.

$$\propto_{short}= -0.0356 \times\propto_1 +0.017 \times\propto_2 +0.430 \times\propto_3 +0.0274 \times\propto_4 -0.0472\alpha_5 + 0.0604 \times\propto_6 +0.0063\alpha_7 - 0.0012\alpha_8+0.0905$$

4. The existing research results suggest that for every increase of 0.11 to 0.24 in sea ice reflectance, the corresponding increase in sea ice thickness is around 2 to 9 cm. The obtained COCTS shortwave broadband reflectance is then applied to a theoretical model based on sea ice optical theory, which establishes a relationship between sea ice thickness and shortwave broadband reflectance.

$$\propto_{short}=\propto_{max}\ [1-kexp(-\mu_{\propto}H)]$$

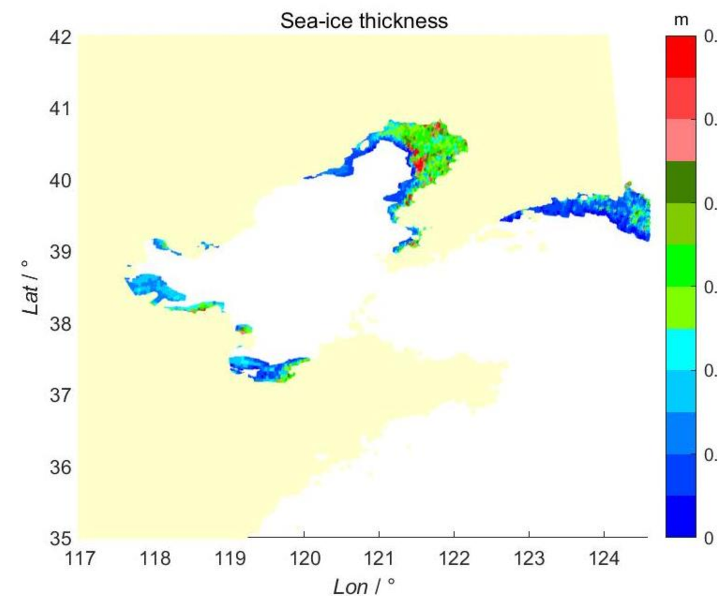


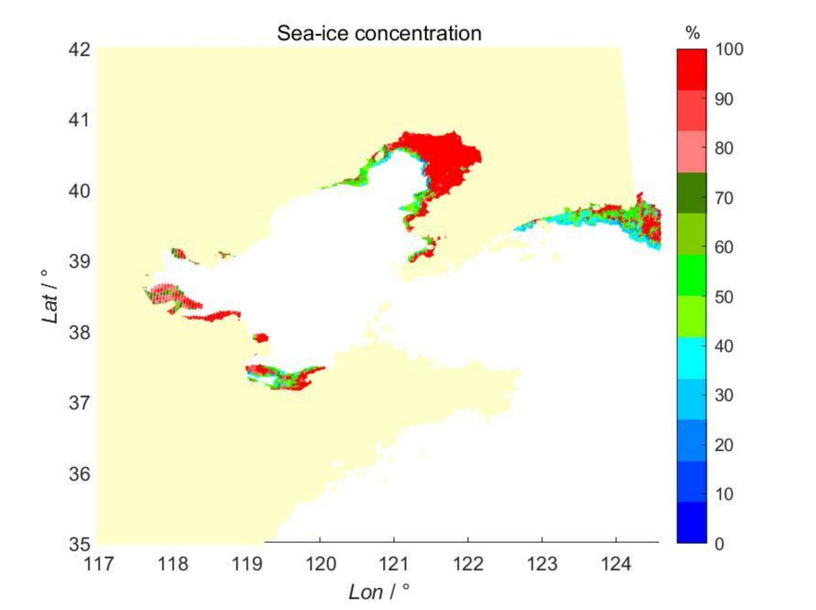
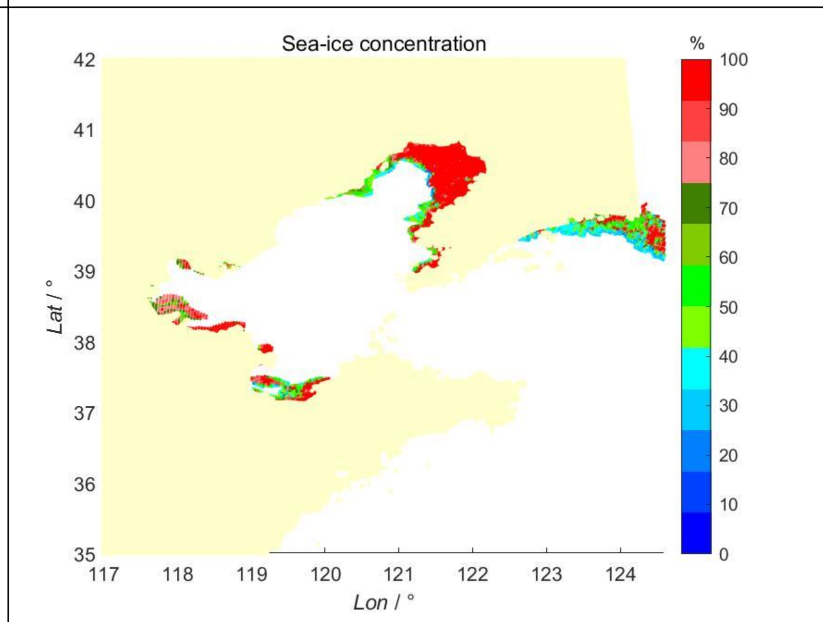
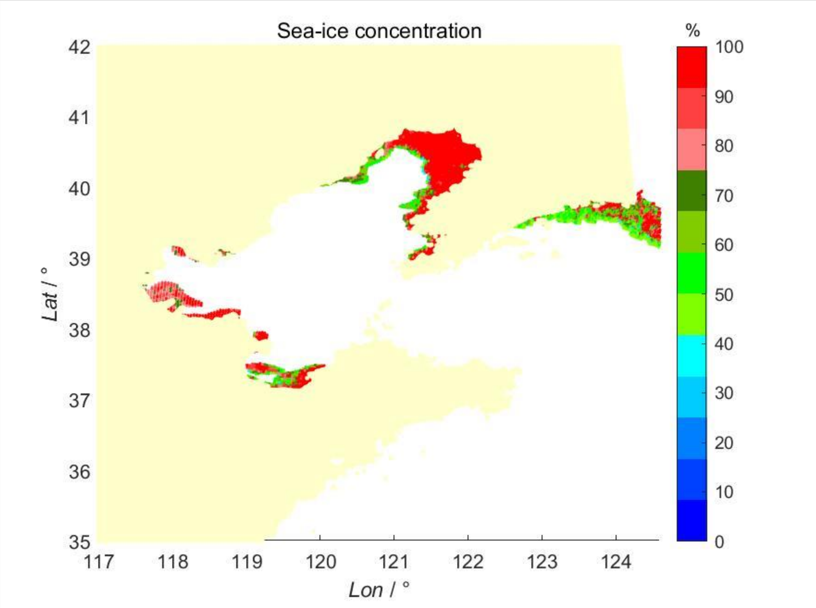
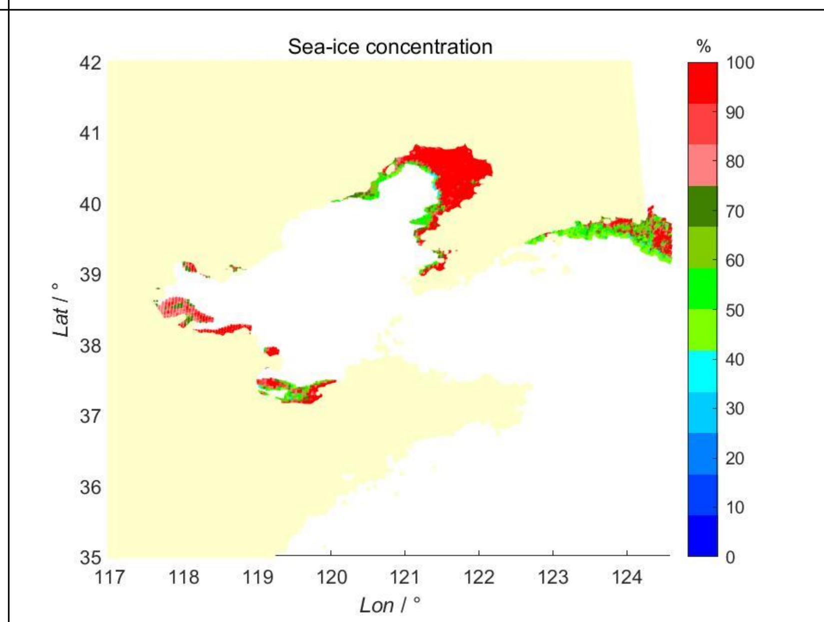
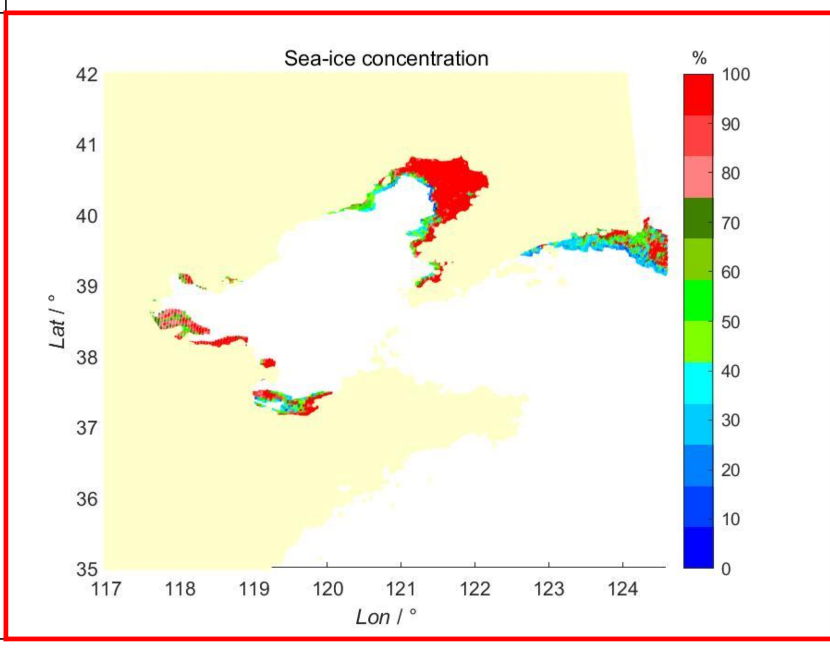
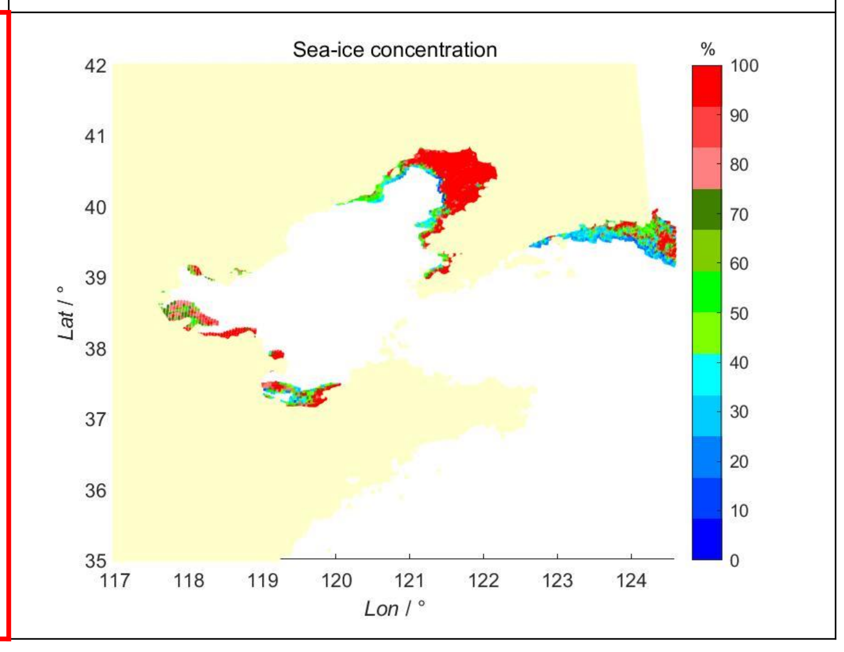
Fig.6 Sea ice thickness

Sea Ice concentration

For the extraction of sea ice concentration, this study employs the average shortwave reflectance of both sea ice and seawater. A program is utilized to select the pixels for extracting sea ice concentration. The concentration of sea ice is obtained by dividing the difference between the shortwave reflectance of the pixel and the average seawater shortwave reflectance by the difference between the shortwave reflectance of sea ice and the average seawater shortwave reflectance.

$$seaice\_con=\frac{\alpha short-\alpha short_{sea\_mean}}{\alpha short_{ice\_mean}-\alpha short_{sea\_mean}}$$

Three methods are used to calculate the shortwave reflectance of sea water: standard, mean, and direct assignment. Two methods are used to calculate the shortwave reflectance of the sea ice: the standard method and mean method. Six sea ice concentration results from these method combinations are obtained and compared. The comparison shows that using the direct assignment method for sea water shortwave reflectance and the standard method for sea ice shortwave reflectance yields the most accurate results relative to the original image.

$\alpha short_{sea\_mean}$	$\alpha short_{ice\_mean}$	
	Standard method	Maximum and minimum averaging
Standard method		
Maximum and minimum averaging		
Direct assignment		

Conclusion

This study proposes a systematic and standardized method for extracting sea ice parameters based on HY-1C data. For sea ice thickness, the linear correlation between MODIS shortwave broadband reflectance and HY-1C band reflectance is analyzed. Then, a linear regression equation is established between MODIS shortwave broadband reflectance and HY-1C band reflectance to obtain shortwave broadband reflectance from HY-1C data. Subsequently, based on the theoretical model of sea ice thickness and shortwave broadband reflectance, the Bohai Sea ice thickness is calculated. Sea ice concentration is extracted using the shortwave reflectances of sea ice and sea water. The comparison shows that using the direct assignment method for sea water shortwave reflectance and the standard method for sea ice shortwave reflectance yields the most accurate results relative to the original image. Hence, this approach is adopted for sea ice concentration extraction. Using these methods, we have monitored sea ice in the Yellow Sea and Bohai Sea from 2021 to 2023. This project provides initial fields of sea ice parameters for forecasting in the Yellow Sea and Bohai Sea, which is vital for shipping, transportation, and resource development.