

Sea ice thickness retrieval with ice surface temperature (IST) data over the Liaodong Bay

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Introduction

Liaodong Bay (38.5 - 41.0°N, 119.0 - 123.0°E) is located in the northern Bohai Sea, which is seasonally covered by ice from late December until end of March. Historically, Sea ice has created serious damages to marine transportation, off-shore oil platforms, fishing industry and coastal constructions in Liaodong Bay, especially during severe ice winters when large portion of the Bohai Sea was covered by ice. The maximum ice extent occurred in early February, the average level ice thickness can reach from 20 to 40 cm, depending on weather conditions.

MODIS thermal infrared imagery data and sea ice surface heat balance equation were applied to estimate level ice thickness for the Liaodong Bay during winter 2012-2013, and then the in-situ measurements from two oil platforms are used to validate the ice thickness results.



Data and Method

Data

The input data for this work include:

Data	Source	Application
MODIS/L1B	NASA	To estimate sea ice surface temperature
Wind Speed	ECMWF	Input data for the sea ice surface heat balance equation
Air Temperature	ECMWF	Input data for the sea ice surface heat balance equation
In-situ Measurements	NMEFC	To validate the sea ice thickness results

Method

1) Sea ice surface heat balance equation

In cold calm conditions (no ice deformation), freezing of sea ice is a result of heat loss from the ice surface to the air and conduction of latent heat released at the ice bottom. The inner ice temperature has a linear profile in vertical direction. The heat balance equation of thin ice is:

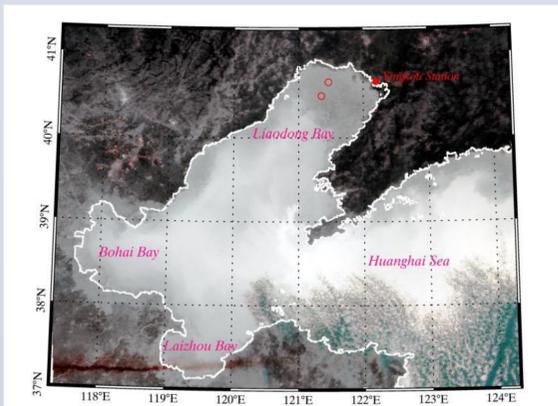
$$Q_d - Q_b(T_s) + Q_h(T_s) + Q_{le}(T_s) + F_c(T_s) = Q_t(T_s) + F_c(T_s) = 0$$

where Q_d , and Q_b are incoming atmospheric longwave radiation and longwave radiation emitted by the surface, The turbulent fluxes of sensible heat and latent heat are Q_h and Q_{le} , respectively. F_c is the surface conductive heat flux. These five factors can be expressed as a function of ice thickness, sea ice surface temperature, air temperature, wind speed.

Then the ice thickness can be retrieved from the ice surface temperature with preconditions of 1) no solar radiation(night-time),2) no thermal inertia of ice, 3) no heat flux on ice from ocean, and 4) no surface melting.

2) Sea ice surface temperature

Sea ice surface temperature is calculated from MODIS L1B data acquired under night-time clear-sky conditions. A split-window technique is employed to estimate the sea ice surface temperature using MODIS bands 31th and 32th.

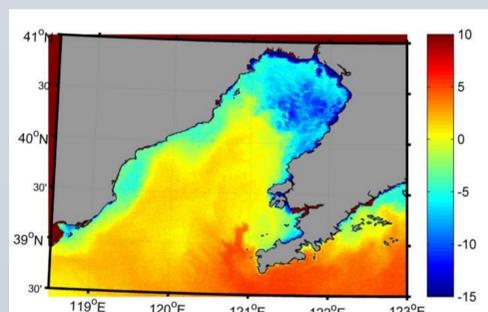


The MODIS thermal band RGB (bands 20, 31 and 32) image on the left was acquired on 14:20 (UTC) of January 3 in 2013.

The image show the location Bohai Sea, which is consist of Liaodong Bay, Bohai Bay and Laizhou Bay. The Liaodong Bay is located in the north of the Bohai Sea, two red circles in the middle of the Liaodong Bay show the locations of the two oil-platforms, where the in-situ measurements data were observed.

The map on the right shows the surface temperature (unit: °C) of Liaodong Bay estimated with MODIS on 14:20 (UTC) of January 3, 2013.

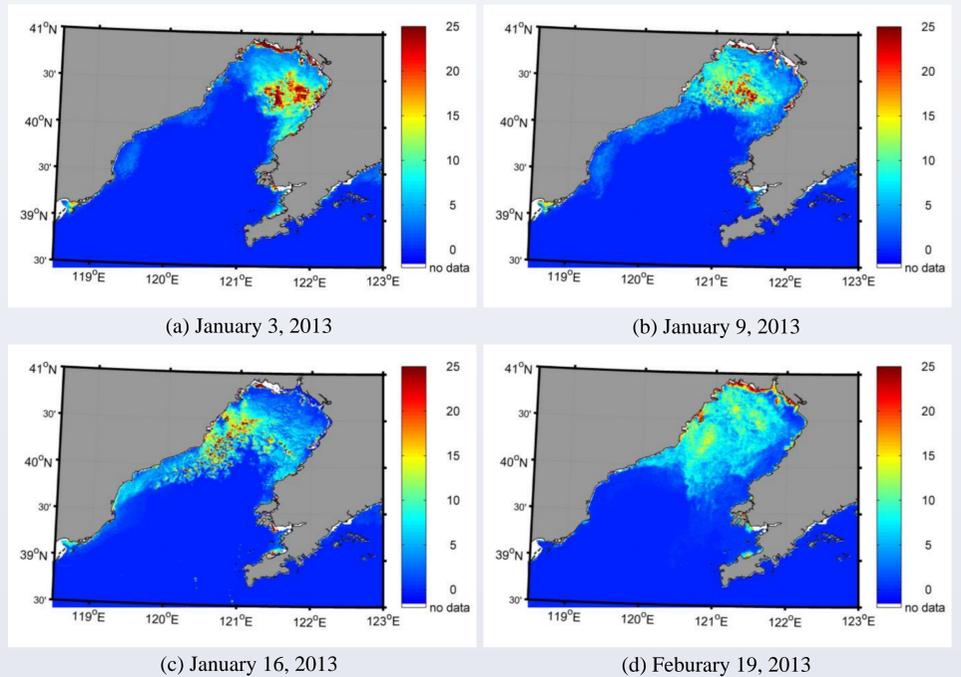
There is a gradual ice temperature change between ice areas and open ocean areas, and the temperature of ice is clearly lower than that of open ocean.



Results

Retrieve of sea ice thickness

Four examples of MODIS Liaodong Bay sea ice thickness (unit: cm) images are shown below, the majority of the ice thickness were between 5 to 20 cm. The thicker ice was mainly distributed at the eastern part of the Bay at the early winter (Fig. a), and at the later time, the ice moves toward the western part gradually (Fig. b,c,d).

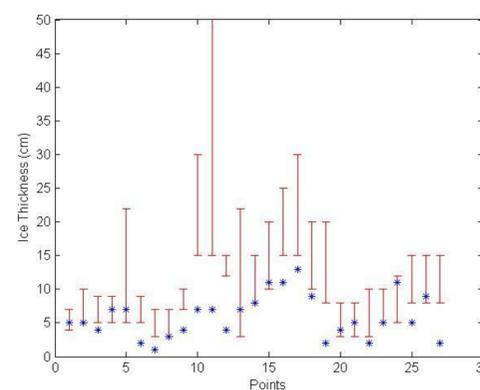


Validation

The two oil platforms in-situ sea ice thickness were used to validate MODIS ice thickness. Totally, 14 scenes of MODIS ice thickness were estimated and 27 pairs of matched results are compared.

Table 1. MODIS ice thickness VS. in-situ ice thickness (unit: cm)

Date	Oil Platform 1		Oil Platform 2	
	MODIS	In-situ	MODIS	In-situ
2013.1.3	5	4-7	8	8-15
2013.1.5	5	5-10	11	10-20
2013.1.7	4	5-9	11	15-25
2013.1.9	7	5-9	13	15-30
2013.1.12	7	5-22	9	10-20
2013.1.18	2	5-9	2	8-20
2013.1.24	1	3-7	4	3-8
2013.1.25	3	3-7	5	3-8
2013.2.1	4	7-10	2	3-10
2013.2.4	7	15-30	5	5-10
2013.2.6	7	15-50	11	5-12
2013.2.15	4	12-15	5	8-15
2013.2.19	7	3-22	9	8-15
2013.2.22			2	8-15



The figure on the left show the retrieved ice thickness and in-situ ice thickness ranges as a function of time series, the first 13 points and the following 14 points are from two different oil platforms respectively.

The overall RMSD between the MODIS and in-situ thickness data is 5.6 cm. When in-situ thickness is less than 15 cm (typical case), the MODIS and in-situ ice thickness are in a good agreements, but the retrieved ice thickness results are smaller than the measurements when ice thickness reaches 20cm.

Conclusion

A total of 14 night-time MODIS images were identified manually as cloud free for a major ice covered area in the Liaodong Bay, and used to estimate ice thickness. The time period of these images are confined in a cold weather condition that from Jan to Feb 2013.

A typical retrieved ice thickness around oil platforms ranged from 1 to 20 cm, which was in reasonable agreement with the in-situ ice thickness. The overall root mean square error of the MODIS ice thickness was 5.6 cm. The difference can be partly attributed by ice movement during the time gap between MODIS acquisitions and in-situ measurements, and the spatial scale difference between the in-situ measurements and MODIS observations. The MODIS sea ice thickness was in good agreement with in-situ data when thickness less than 15 cm (typical case). For the in-situ thickness more than 20 cm, the MODIS thickness was typically smaller. An error source for the MODIS ice thickness underestimation is the sea ice physical model, as ice dynamics and possible snow cover are not included.