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RETRIEVAL OF THIN ICE THICKNESS FROM FY-3D/MWRI BRIGHTNESS TEMPERATURE IN THE ARCTIC

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ABSTRACT

Thin ice thickness retrieval algorithm was developed by using FY-3D/MWRI brightness temperature in the Arctic. The algorithm was based on the fitting function models between polarization ratios of MWRI brightness temperature from 36GHz and 89GHz channels (PR_{89} and PR_{36}) and the thermal ice thickness. Thermal ice thickness was obtained by using MODIS sea ice surface temperature data (MYD29) and ERA5 reanalyze meteorological data through the thermodynamic balance function of sea ice surface. The linear fitting model and the exponential fitting model were used to fit PR_{89} and PR_{36} respectively to thermal ice thickness. The root mean square errors of the thin ice thickness fitted by PR_{89} and PR_{36} were 0.003m and 0.0019m, respectively, and the corresponding standard deviations were 0.0505m and 0.0496m.

***Index Terms*—**Thin ice thickness, FY-3D, Brightness temperature (T_b), Arctic

1. INTRODUCTION

Arctic is an indicator of global climate change and an important part of the global climate system. The changes of sea ice play an important role in the global heat balance, atmospheric circulation, ocean water cycle, and temperature and salt balance [1]. Due to the effects of global warming, the area of Arctic sea ice has been decreasing rapidly, and the thickness of sea ice has been thinning. Sea ice will affect the heat exchange between the ocean and the atmosphere. The study of the retrieval and change of thin ice thickness in the Arctic has important practical significance for understanding the impact mechanism and climate changing.

Methods of obtaining sea ice thickness include field observation, looking up sonar, walking observation [2-3], electromagnetic induction, satellite remote sensing. Compared with other remote sensing data, passive microwave has the characteristics of all-day and all-weather, and is not affected by cloud cover, which can detect signals on the surface of sea ice in any situation. Yu and Rothrock used ice surface temperature data from the AVHRR (Advanced Very High Resolution Radiometer) to retrieval thermal ice thickness [4]. Martin used the polarization ratio R_{37} calculated by 37GHz T_b data from SSM/I (Special Sensor Microwave/Image) to study the thin ice thickness retrieval algorithm in the Chukchi sea [5]. Martin modified the above algorithm [5] and used 36GHz polarization ratio R36 from the AMSR-E (Advanced Microwave Scanning Radiometer—Earth Observing System) to get the thin ice thickness algorithm [6]. Tamura used the polarization ratios of 37GHz and 85GHz from SSM/I to obtain the SSM/I thin ice thickness retrieval algorithm [7]. Nihashi used the polarization ratio of 36GHz from AMSR-E to get the ice thickness retrieval algorithm [8]. Singh used AMSR-E data to research the thin ice thickness inversion algorithm of the Chukchi Sea [9]. Tamura and Ohshima applied the SSM/I thin ice thickness retrieval algorithm to the polynya using SSM/I 37GHz and 85GHz data [10].

In this paper, the retrieval algorithm of Arctic thin ice thickness based on FY-3D/MWRI T_b was studied. The remainder of this paper is organized as follows: Section 2 introduces the research data, Section 3 describes the thin ice thickness retrieval algorithm, Section 4 analyzes the main results, and Section 5 presents our conclusions.

2. DATA SETS

The data sets include the FY-3D/MWRI T_b data, the ERA5 reanalysis data, and the MODIS sea ice surface temperature data. MWRI is a microwave imager mounted on the China's second-generation polar-orbiting meteorological FY-3 satellite, which can continuously obtain various characteristic parameters of the atmosphere, land surface and ocean surface on a global scale in all weathers. The FY-3D/MWRI instrument parameter settings are basically the same as AMSR-E and AMSR2, and can complement each other with internationally mature microwave radiometer data. ERA5 is a reanalysis meteorological data from the ECMWF (European Center of Medium-Range Weather Forecasts). with 0.25°×0.25° resolution. The parameters required for this article are the temperature at 2m, the dew point temperature at 2m, the surface pressure and cloud cover, and the wind speed at 10m for 24 hours a day. MYD29 and MYD03 are secondary standard format data from MODIS, updated every 5 minutes. MYD29 includes sea ice extent and ice surface temperature data with 1km resolution. The MYD03 data file provides latitude and longitude data with a resolution of 1km, which is matched with ERA5.

3. RESEARCH METHODS

The paper uses the ice surface temperature data from MODIS to obtain sea ice thickness in the Arctic based on the thermodynamic equation [11], and obtains thin ice thickness retrieval model by matching between the polarization ratio of the MWRI T_b data and the MODIS thermal ice thickness.

3.1. Thermal ice thickness in the Arctic

The section used the thermodynamic equilibrium equation proposed by Maykut and Untersteiner as the basis for the retrieval of sea ice thickness [11]. Figure 1 shows the flow chart of inverting thermal ice thickness.

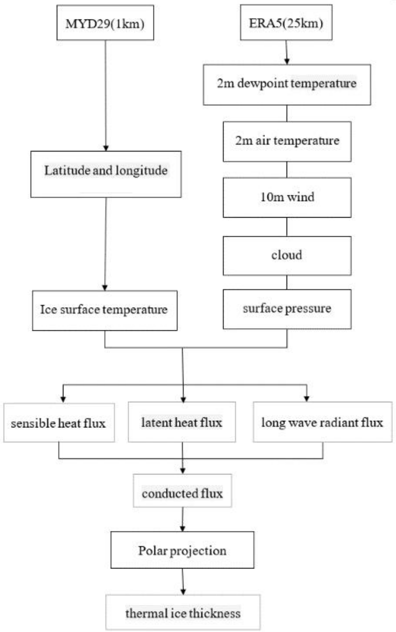


Fig. 1 Flow chart of inverting thermal ice thickness

We assume that the thickness of sea ice is the same within a grid pixel, and sea ice is only affected by heat. The heat balance equation on the ice surface can be expressed as:

$$(1-\alpha_s)F_r - I_0 - F_l^{up} + F_l^{dn} + F_s + F_e + F_c = F_a \qquad (1)$$

where α_s is the surface radiation albedo of ice or snow, F_r is the shortwave radiation flux on the ice surface, I_0 is the shortwave radiation flux passing through the ice, F_l^{up} is the longwave radiation flux emitted from the surface, and F_l^{dn} is the downward longwave radiation flux, F_s is sensible heat flux, F_e is latent heat flux, F_c is heat flux conducted inside ice, F_a is residual heat flux caused by ice melting or horizontal advection of heat. In the absence of a phase transition, F_a is usually assumed to be zero. The heat balance formula is simplified to:

$$F_l^{dn} - F_l^{up} + F_s + F_e + F_c = 0 \qquad (2)$$

According to the method provided by Nihashi and others [12], F_l^{up}, F_l^{dn}, F_s, and F_e can be obtained. According to the heat balance formula, the conducted heat flux inside ice is:

$$F_c = \gamma\left(T_f - T_s\right) \qquad (3)$$

$$\gamma = \frac{k_i k_s}{k_s h_i + k_i h_s} \qquad (4)$$

where k_i, k_s are the thermal conductivity of ice and water respectively, and T_f (=273.15K) is the freezing point temperature of seawater. h_i, h_s are the thickness of ice and snow respectively. T_s is the ice surface temperature. h_s is the AMSR snow thickness data from the NSIDC (National Snow and Ice Data Center). The formula for calculating sea ice thickness is:

$$h_i = \frac{k_i(T_f - T_s)}{F_c} - \frac{k_i h_s}{k_s} \qquad (5)$$

3.2. Ice thickness retrieval model based on FY-3D/MWRI polarization ratio

By analyzing the relationship between the polarization ratios and the thermal ice thickness, it can be seen that the thermal ice thickness decreases as the polarization ratio increases. The section used linear function and exponential function to obtain the relationship of the thermal ice thickness data with the polarization ratio of the MWRI T_b data. The formula for the polarization ratio is:

$$PR = \frac{T_{b,v} - T_{b.h}}{T_{b,v} + T_{b.h}} \qquad (6)$$

$T_{b,v}$ and $T_{b,h}$ refer to the T_b data of vertical polarization and horizontal polarization respectively. Martin proposed an exponential fitting model between thermal ice thickness and polarization ratio [5]:

$$h_i = \exp\left[\frac{1}{\alpha PR + \beta}\right] - \delta \qquad (7)$$

Tamura and Nihashi proposed a linear fitting model between thermal ice thickness and polarization ratio [6-7]:

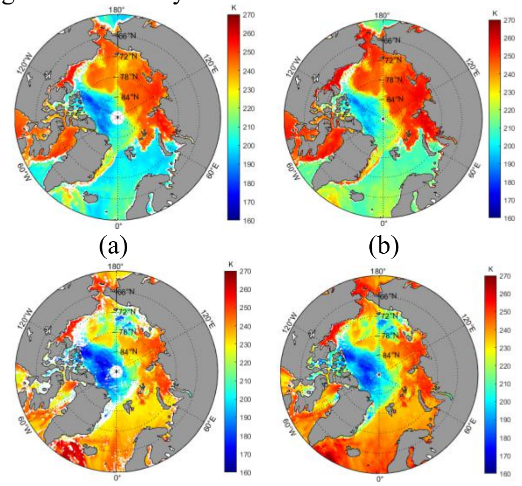
$$h_i = aPR + b \qquad (8)$$

According to the above two fitting models, the polarization ratio calculated from MWRI T_b data is fitted with MODIS thermal ice thickness.

4 RESULTS AND ANALYSIS

The polarization ratios of the T_b data of the 36GHz and 89GHz channels of AMSR-E is usually used for the retrieval of sea ice thickness [13]. In view of this, the paper selects the polarization ratio of the T_b data of the 36GHz and 89GHz channels of MWRI to retrieve thin ice thickness.

The MWRI T_b data after cross-calibration with AMSR2 [15] is used to match the MODIS thermal ice thickness. Figure 2 shows the T_b data of AMSR2 and MWRI on the 36GHz and 89GHz channels on January 1, 2019. After cross-calibration, the daily T_b data of MWRI and AMSR2 show good consistency.



(a) (b)

(c) (d)

Fig. 2 Daily mean of T_b, (a) T_b data of MWRI 36GHz, (b) T_b data of AMSR2 36GHz, (c) T_b data of MWRI 89GHz, (d) T_b data of AMSR2 89GHz

The relationship between PR and thermal ice thickness is analyzed by linear function and exponential function, and the following equation is obtained:

For PR_{89}:

$$h_i =- 7.21PR_{89} + 0.56 \tag{9}$$

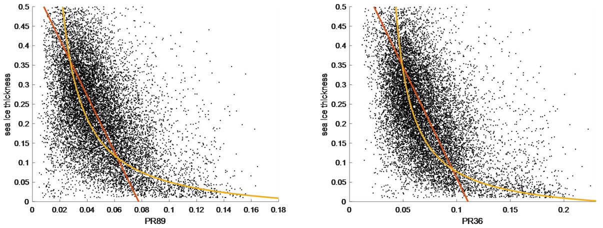
$$h_i = \exp\left[\frac{1}{118PR_{89} - 0.286}\right] - 1.04 \tag{10}$$

For PR_{36}:

$$h_i =- 5.7PR_{36} + 0.63 \tag{11}$$

$$h_i = \exp\left[\frac{1}{118PR_{36} - 2.764}\right] - 1.04 \tag{12}$$

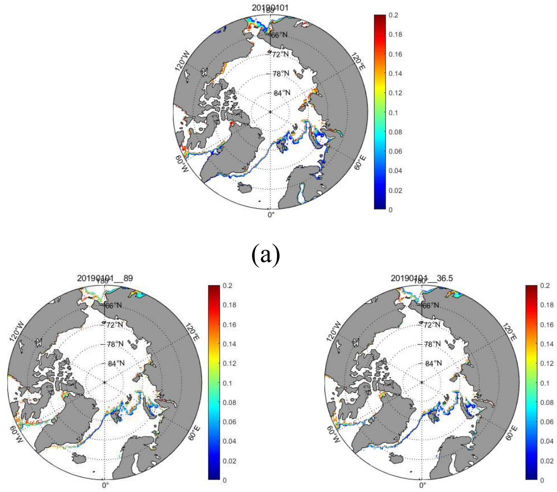
The relationship between PR_{89}, PR_{36} and the thermal ice thickness are as follows in Fig.3, the red line is linear fitting, and the yellow line is exponential fitting:



(a) (b)

Fig. 3 (a) Fitting function between PR_{89} and thermal ice thickness (b) Fitting function between PR_{36} and thermal ice thickness

In order to verify the accuracy of the fitted model, we compared the fitted ice thickness data with the thermal ice thickness data. The thin ice thickness are selected from the ratio $T_{b,v89}$ and $T_{b,v18.7}$ [16], and the sea ice thickness of SMOS (Soil Moisture and Ocean Salinity) production. Figure 4 shows the thin ice thickness based on MWRI 89GHz T_b data and the SMOS thin ice thickness on January 1.



(a)

(b) (c)

Fig. 4 (a) The SMOS thin ice thickness Thin ice thickness based on MWRI 89GHz T_b (b) Thin ice thickness based on MWRI 89GHz T_b (c) Thin ice thickness based on MWRI 36GHz T_b

The RMSE (root mean square errors) of sea ice thickness fitted by the exponential fitting model is smaller than the sea ice thickness fitted by the linear fitting model, and the STD (standard deviation) fitted by the exponential fitting is smaller than the linear fitting by using the MWRI T_b data on January (31 day), 2019. The RMSE of sea ice thickness by the PR_{89} is smaller than that by the PR_{36}, and the STD of the sea ice thickness fitted by the PR_{89} is almost the same as less that by the PR_{36}. Therefore, the sea ice thickness fitted by the exponential fitting model using the PR_{89} is more accuracy. Table 1 shows the deviation between the fitted sea ice thickness and the thermal ice thickness.

Table 1 Deviation between the MWRI sea ice thickness and the thermal ice thickness

Fitting method	Polarization ratio	RMSE(m)	std(m)	bias(m)
Linear	PR_{89}	0.0054	0.0567	-0.0039
Linear	PR_{36}	0.0061	0.0564	-0.0377
Exponential	PR_{89}	0.0024	0.0509	0.0033
Exponential	PR_{36}	0.0029	0.0508	-0.0193

The polarization ratio data calculated using MWRI 89GHz and 36GHz T_b data is fitted with an exponential fitting model to compare the thin ice thickness with the SMOS thin ice thickness. It can be seen that the relationship between polarization ratio and sea ice thickness is more ambiguous in the region >0.5m [14], this algorithm has the highest accuracy within 0-0.2m. We compare the sea ice thickness of 0-0.2m with the SMOS thin ice area as shown in Fig.4. Table 2 shows the deviation between the fitted sea ice thickness and the SMOS sea ice thickness.

Table 2 Deviation between the MWRI sea ice thickness and the SMOS sea ice thickness

Fitting method	Polarization ratio	RMSE(m)	Std(m)	Bias(m)
Linear	PR_{89}	0.0050	0.0548	0.0253
Linear	PR_{36}	0.0044	0.0532	0.0256
Exponential	PR_{89}	0.0030	0.0505	0.0279
Exponential	PR_{36}	0.0019	0.0496	0.0138

5 CONCLUSIONS

In this paper, the polarization ratios of T_b data of the FY-3D/MWRI 36GHz and 89GHz channels were used to fit the MODIS thermal ice thickness to obtain the thin ice thickness retrieval algorithm in the Arctic. The exponential fitting model and the linear fitting model were used to calculate the sea ice thickness in January, 2019 by using the polarization ratios of the FY-3D/MWRI 36GHz and 89GHz channels, respectively.

The accuracy comparison results of the exponential inversion model and the linear inversion model are available. The standard deviation of thin ice thickness fitted by the exponential fitting model using the 89GHz polarization ratio is the smallest, which is considered the optimal model in this paper. In order to verify the accuracy of the thickness of the thin ice, the thickness of the thin ice retrieved by the polarization ratio of 89 GHz and 36GHz is compared with the SMOS sea ice thickness. The average value and standard deviation of the two are approximately the same.

6 ACKNOWLEDGMENT

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