Study on Arctic Sea Ice Distribution Based on Otsu Algorithm for SSM/I Data

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Abstract: The coverage of Arctic sea ice has a very important significance on the global climate, because the reflectivity of sea ice is far higher than that of the seawater, and it will cause the reduction of sea ice due to the seawater increasing, and then the sea ice absorbs more solar radiation, which will lead to more sea ice melting. 37GHz data of SSM/I (Special Sensor Microwave/Image) provides a new detection method based on microwave irradiation of Arctic sea ice distribution, that is, the use of the biggest difference of polarization characteristics for seawater and sea ice in 37 Ghz, and then obtain the classification threshold for the seawater and sea ice by Otsu algorithm, and obtain the distribution map of the Arctic sea ice. The results were compared with National Snow and Ice Data Center (NSIDC) and NASA-Team algorithm, and the results show that the proposed Arctic sea ice distribution detection method using the polarization difference of the vertical polarization and polarization level for 37 GHz combined with Otsu algorithm is feasible.

Keywords: Arctic sea ice distribution, Microwave radiometer SSM/I, Otsu algorithm, Polarization difference

1. Introduction

As the cold source of global climate, the movement of atmosphere, ocean and sea ice directly or indirectly influences the intensity of global water vapor circulation, global thermal balance and climate change. Sea ice is the key factor affecting global climate system [1, 2]. The sea ice with high albedo is a key factor that affect the global climate system [3, 4]. In recent decades, Arctic sea ice has been shrinking and thinning year to year, due to the effects of global warming. Accurately understanding and grasping the trend of Arctic sea ice change is a must for studying and understanding sea ice. It is also an important content for studying the influence and function of sea ice on the global climate system [5, 6]. Quantitative calculation of the variations of Arctic sea ice for many years can reflect the trend of Arctic sea ice variations to the greatest extent, and further determine whether Arctic sea ice has abnormal variations in some year, and dig out more useful information [7].

Microwave radiometer SSM/I can work normally both during the day and at night, and it can penetrate the clouds without the influence of the clouds. It is widely used in the study of sea ice [8]. Andersen et al. [9] summarized seven sea ice concentration inversion algorithms for SSM/I data. In the current sea ice concentration retrieval algorithms, NASA-Team algorithm [10] and Bootstrap algorithm [11] are the low-resolution inversion algorithm based on 19 GHz and 37 GHz data. NASA-Team2 algorithm [12], SEA LION algorithm, and ARTSIST Sea Ice (ASI) [13] algorithms all include the 85 GHz data of SSM/I, which can generate the sea ice concentration with the resolution 12.5 km. The ASI algorithm has the advantage without additional data, and the sea ice concentration is similar with the other algorithms using other channels [14]. The above sea ice distribution algorithm is based on the sea ice concentration which needs the site data. In order increase the level of automation, the proposed OSTU algorithm determines the classification threshold of sea ice and seawater, and then the distribution information of Arctic sea ice is obtained.

On the basis of the change characteristics of emissivity for seawater and sea ice (first-year ice and multiyear ice), we proposed a new sea ice detection method based on the difference between the horizontal polarization and the vertical polarization of 37 GHz for microwave radiometer SSM/I, which is the largest polarization difference in all the frequencies, and then the difference combined with Otsu algorithm (determining the classification threshold of sea ice and seawater) to detect the Arctic sea ice distribution. And the Arctic sea ice distribution map is obtained based on the proposed method on January 1, 2016.

2. Sea Ice Distribution Detection Method

2.1. Polarization Difference

The spectral characteristics of object are the basis of the inversion by remote sensing data, and the spectral characteristic curves of different objects as shown in Fig.1 are the concentrated reflection of the differences of electromagnetic waves from different objects [15]. It is known from the definition of the brightness temperature that when the physical temperature of an object is certain, the brightness temperature of a certain frequency is only related to the radiant rate of the object. Because the physical temperature of the same object is the same when the vertical polarized and horizontal polarized electromagnetic waves are emitted at the same time, so the polarization difference is only affected by the radiation rate. From Fig.1, we know that the polarization differences of 37GHz between the first-year ice and the multiyear ice are about the same and the polarization differences 37GHz for seawater are the largest in the seven frequency points of the microwave radiometer. So we can use the polarization difference P=37V-37H to identify sea ice and seawater to get the distribution information of sea ice. That is, if P>T, then this pixel is seawater, otherwise it's sea ice.

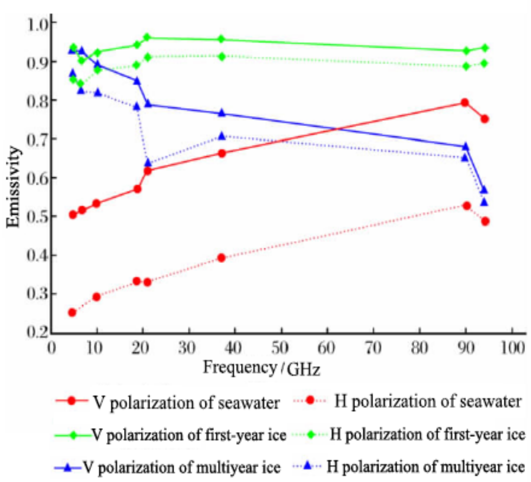

Figure 1. Relationship between sea ice and seawater for emissivity and frequency.

2.2. Otsu Algorithm

Otsu algorithm selects a threshold based on the variance between the image data. The principles are as follows:

It is assumed that the threshold can divide the images of L level data into two categories:

The corresponding probability of $C_0 \in [0, T]$ and $C_1 \in [T+1, L+1]$ is:

$$p_i = \frac{n_i}{N} \tag{1}$$

which, N is the total number of pixels, n_i is the number of pixels with the data level i, and there is $p_i \geq 0$, $\sum_{i=0}^{L-1} p_i = 1$. The probability of C_0 and C_1 is:

$$w_0 = p_r(C_0) = \sum_{i=0}^{T} p_i = w(T) \tag{2}$$

$$w_1 = p_r(C_1) = \sum_{T+1}^{L+1} p_i = 1 - w(T) \tag{3}$$

The mean values of C_0 and C_1 are as follows:

$$u_0 = \sum_{i=0}^{T} \frac{ip_i}{w_0} = \frac{u(T)}{w(T)} \tag{4}$$

$$u_1 = \sum_{i=T}^{L-1} \frac{ip_i}{w_1} = \frac{\bar{u} - u(T)}{1 - w(T)} \tag{5}$$

Which, $\bar{u} = \sum_{i=0}^{L-1} ip_i$ is the mean of the image. The inter-class variance of C_0 and C_1 is:

$$\sigma_g^2 = w_0 w_1 (u_1 - u_0)^2 \tag{6}$$

The optimal classification threshold T^* of sea ice and seawater should make the largest inter-class variance, that is:

$$T^* = \arg \max_{0 \leq T \leq L-1} \sigma_g^2 \tag{7}$$

2.3. Sea Ice Distribution Detection Based on Polarization Difference Combined with Otsu Algorithm

The Otsu algorithm is used to deal with 37 GHz polarization difference P, and the classification threshold of sea ice and seawater is obtained, and then the distribution information of Arctic sea ice is obtained. Fig. 2 is the flow chart of the sea ice distribution detection method. The basic steps are as follows:

2.3.1. Data preprocessing

Radiometric calibration, masking, and abnormal data processing (When there is too much difference between a data and the median of the data in its central window, the data is defined as an abnormal data, instead of the median value of the data in the window).

2.3.2. Calculate polarization difference

The polarization difference P=37V-37H is calculated by using the vertical and horizontal polarization of 37 GHz.

2.3.3. Determining the optimal classification threshold for sea ice and seawater

Select sample points and process polarization difference P based on Otsu algorithm, and obtain the optimal classification threshold T of sea ice and seawater.

2.3.4. Obtain Sea ice distribution map

The polarization difference P is classified according to the threshold T, and the Arctic sea ice distribution map is obtained.

2.3.5. Result verification

The results are compared with the results obtained from NSIDC (National Snow and Ice Data Center) and NASA-Team algorithm.

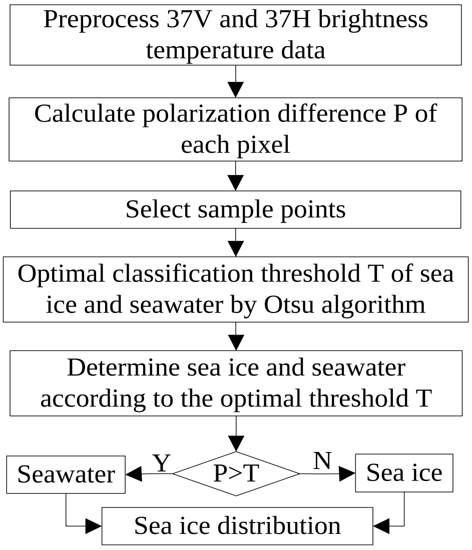

Figure 2. Flow chart of sea ice distribution for 37GHz data

3. Results and Discussion

The horizontal polarization and vertical polarization data of 37GHz on January 10, 2016 are used as sea ice distribution detection, and select the sample data, and then obtain the threshold 39.912 of dry snow and wet snow by Otsu algorithm. Get the Arctic sea ice distribution figure as shown in Fig. 3 on January 10, 2016 by the threshold.

To verify the reasonableness of the proposed algorithm, the Arctic sea ice distribution on January 10, 2016 is shown in Fig. 4 based on NSIDC. From Fig.3 and Fig.4, we can see that the sea ice in Fig.3 is more than Fig.4 in the margin of land in the high latitudes. Moreover, the sea ice areas obtained by NSIDC is slightly larger than that obtained by the proposed algorithm. On the whole, the Arctic sea ice distribution map based on the proposed algorithm is basically consistent with that based on NSIDC, to a certain extent, which shows that the proposed method in this paper is feasible.

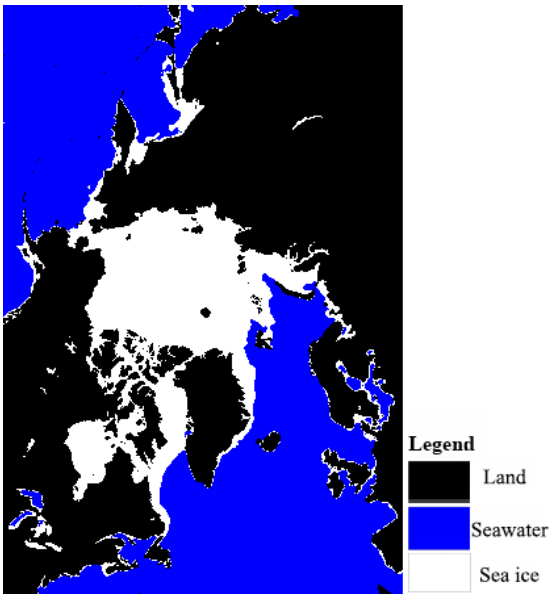

Figure 3. Results of the proposed method.

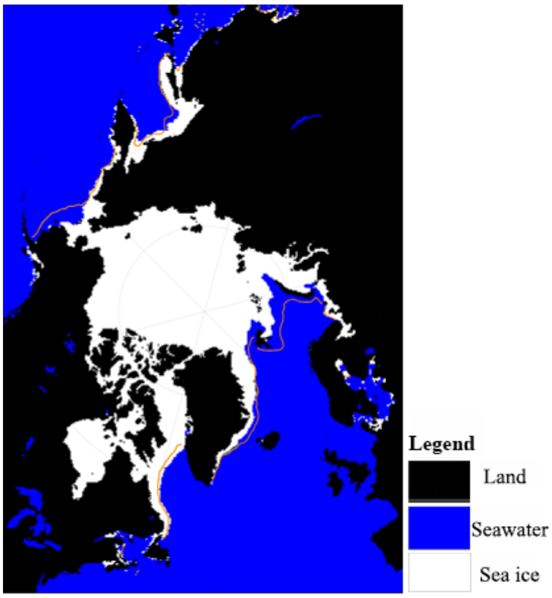

Figure 4. Results of NSIDC

NASA-Team is a classic sea ice distribution detection algorithm which is widely used. The Arctic sea ice distribution map is shown in Fig.5 based on NASA-Team algorithm.

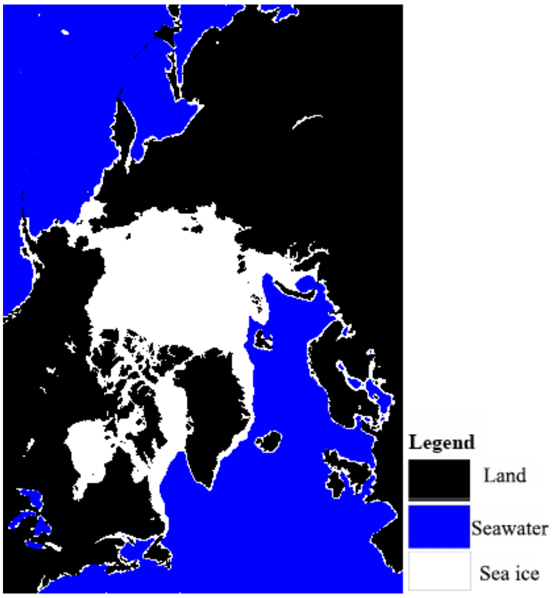

Figure 5. Results of NASA-Team algorithm

The sea ice concentration is obtained based on the NASA-Team algorithm, and the image is classified by the threshold 15%, and the Arctic sea ice distribution map is obtained. It can be obtained by the contrast of Fig.3 and Fig.5: There are some differences in the margin of land for Fig.3 and Fig.5, because NASA-Team algorithm will appear some false sea ice in the margin of land. In addition to the margin of land, the difference between the two results is mainly in both sides of Greenland and the Bering Strait. In addition, the result based on NASA-Team is a little more sea ice.

4. Conclusion

According to the emissivity difference between sea ice and seawater, the horizontal polarization and vertical polarization data of 37 GHz of microwave radiometer are pretreated, and the polarization difference operation is carried out. The classification threshold of sea ice and seawater is obtained based on the Otsu algorithm, and then the sea ice distribution information of the Arctic is obtained. The results of the proposed method are compared with the results obtained from NSIDC and NASA-Team algorithm, which shows that the sea ice distribution is basically the same. To a certain extent, it is proved that the sea ice distribution detection method proposed in this paper is feasible.

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