THE METHOD STUDY OF ANTARCTIC ICE SHEET SNOWMELT DETECTION FROM MICROWAVE RADIOMETER MEASUREMENTS

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ABSTRCT: the detecting and monitoring of snowmelt is important for studying global changes in polar regions and for hydrological modelling of snowmelt-runoff in high-latitude and mountainous regions. The most of snowmelting detection methods were developed based on in situ measurement, so, the applicable area of the methods are limited and the operational of the methods is not robust. From this problems, two methods which independent of in situ measurements were proposed: the unsupervised XPGR snowmelt detection method based on generanized Gaussian model and the modified snowmelt detection method based on wavelet transformation edge detection. Through cross comprarison of two methods, the result indicate that two mthods were not only increased the computation efficiency, practicability and operability due to independent of in situ measurement, but also improved the ice sheet snowmelt detection accuracy to some extent. The propsed methods provided the methodology support for Antarctic ice sheet snowmelt detection.

1. INTRODUCTION

The detecting and monitoring of snowmelt is important for studying global changes in polar regions and for hydrological modelling of snowmelt-runoff in high-latitude and mountainous regions. The polar regions play an important role in the global heat budget by controlling the exchange of heat, moisture and momentum at the surface–atmosphere interface. In high-latitude and mountainous regions, the melt of snow and glacier ice can be a significant contributor to the total yearly runoff volume.

The highly sensitivity of microwave radiometric brightness temperature to physical characteristics change of ice sheet surface(for example, snowfall, snowmelting and densification) （Zwally and Gloersen,1977）makes microwave remote sensing technique important for snowmelting detection of ice sheet. From large scale long time series microwave radiometer datasets(for example, SMM/I and SMMR), many methodology and application study for ice sheet surface snowmelting have been conducted and good results have been obtained. In summary, the typical ice sheet snowmelting detection methods were categoried into five kinds: (1) singel channel snowmelting detection method(Mote et al., 1993； Zwally and Fiegles，1994；Ramage and Isacks，2003); (2) multiple channels snowmelting detection method(Stefffen et al., 1993；Abdalati and steffen，1995；Takala et al., 2009). The advantages of these two kinds of method are as follows: a) simple and easy operation; b) the determination of snowmelt threshold highly depends on the physical characteristics differences between wet snow and dry snow. The disadvantage is as follows: a) the snowmelting time estimation is not very accurate due to the methods depend on absolute brightness temperature; b) the large errors was introduced using in situ data to determine the snowmelt threshold; c) the expense for in situ measurement acquistion is high, furthermore, some area are not reachable. (3) Snowmelting detection approaches based on edge detection(Liu et al., 2005). The wavelet transform based edge detection approach proposed by Liu et al.(2005) has bee used to derive snowmelt extent, onset, endset and duration. The advantage of this kinds of approaches are indepnedent of in situ measurement, and only depend on relative brightness temperature. The disadvantage are as follows: a) the sharp or abrupt change of the edge is not ideal for change detection; b) the result from bi-gaussian model fitting was affected by the inputed initial value, furthermore, the selection of typical samples was time consumes. (4) ice sheet snowmelting detection method based on physical models(Ashcraft and Long,2006; Tedesco,2009). This kinds of method was develped from MEMLS (Mätzler and Wiesmann，1999) model. The method advantage are as follows: 1) the physical background is robust; b) the more accurate result will be obtained to some extent; the disadvantages are : a) much more in situ measurement and input parameters are needed; b) the method is not operational due to much more data and input parameters needed. (5) Snowmelting detection method based on image processing(Takala et al.,2008;Takala et al.,2009). This kinds of method make use of popular image processing algorithm such as self-organization neural network and back-forward neural network to detect the ice sheet snowmelting. The advantage is easy operational; disadvantage is as follows: a) the physical background is weak; b) in situ measurement is required to train the sample; c) the extra parameters are required such as snow water equilence(SWE); d) some methods are only applicable to boreal forest or finland test site.

From above analysis and discussion, the main problems of ice sheet snowmelt detection are as follows: (1) the applicable area of the methods are limited(for example, some of methods were only applicable to non-Antarctica area, so, the modification were required to make these methods applicable to ice sheet snowmelting detection of Antarctical area) since the most of snowmelting detection methods were developed based on in situ measurement; (2) the operational of the methods is not robust since it is difficult to obtain the in situ measurement in polar regions. From above problems, so, it is necessary to develop the ice sheet snowmelting detection method independent of in situ measurement in polar regions.

At this paper, from existed problems of ice sheet snowmelting detection, the ice sheet snowmelting detection study using microwave radiometer datasets were conducted at Antarctica region, two methods which independent of in situ measurements are proposed: the unsupervised XPGR snowmelt detection method based on generanized Gaussian model and the modified snowmelt detection method based on wavelet transformation edge detection. The propsed methods provided the methodology support for Antarctic Ice sheet snowmelt detection.

2. STUDY AREA AND DATASETS

The Antarctica and greenland of Arctic are selected as test site. SSM/I microwave radiometer datasests of Arctic Greenland area from 1988 to 1996 and of Antarctica from 1978 to 2009 were used. In addition, to validate the result, the tempearture measurement of automatic weather satation in Antarctica were also collected.

3. UNSUPERVISED XPGR ICE SHEET SNOWMELT DETECTION METHOD BASED ON AUTOMATIC THRESHOLD SEGMENTATION

3.1 XPGR ice sheet snowmelt detection method

The XPGR method proposed by Abdalati and steffen(1995) mainly utilized the different response of two frequecny(19GHz and 37GHz) and two polarization(Horizontal and Vertical) to ice sheet snowmelt to detect the snowmelting. The XPGR equation is seen in (1),

$$XPGR = \frac{T_b(19H) - T_b(37V)}{T_b(19H) + T_b(37V)} \quad (1)$$

The advantage of this method is that the response difference of frequency and polarization to emissivity and moisture contents were used, it clearly show snowmelting information, furthermore, the stability of model was good.

3.2 The existed problems of XPGR method

Since XPGR method used in situ measurement fitting to determine the threshold, the applicabe area and the operational of the method was limited. In addition, the XPGR method was develeped using in situ measurement of Greenland region, so, it is mainly applicable to Arctic regions. If we want to use XPGR method to detect ice sheet snowemelt of Antarctica region, the threshold must be determined again, however, as we mentioned before, being in situ measuremt of Antarctica ice sheet snowmelt was difficult to acquired, so, it is necessary for us to develop an ice sheet snowmelting detection method which is independt on in situ measurement.

3.3 Unsupervised XPGR method based on Generalized Gaussian Model(GGM)

One unsupervised XPGR method using GGM was proposed based on change characteristics of XPGR value during melting and frozen period.

Figure 1 shows XPGR long time series change derived from SSM/I datasets from 1978 to 2009 at Wilkins ice sheet area in Antarctica. From the figure 1, the XPGR value are obvious divided into two categories: XPGR value of melting snow(wet snow) and dry/frozen snow, from this charactersitics, it is possible to introuduce a unsupervised method to determine the optimal threshold, other than using in situ measurement as the method proposed by Abdalati and steffen(1995). To solve this problem, a generalized Guassian model method（Bazi et al.，2005）was introduced to determine the optimal threshold. The basic steps are as follows: (1) one histogram was generated using long time series XPGR value of one sample; (2) the optimal threshold which can effectively discriminate the dry and wet snow was obtained using generalized Guassian model method.

Assuming $h(X_I)$， $X_I = 0,1,\ldots,L-1$， is histogram of XPGR image, *L* represents the gray scale of the image. If the binarization of image is performed, $h(X_I)$ can be seen as the mixed probability function

$p(X_I)$ of dry and wet snow samples of XPGR image. To estimate the optimal threshold T^* of dry and wet snow discrimination from the histogram, *KI* criteria based on generalized Gaussian model was introduced as shown in equation (2)(Kittler and Illingworth, 1986).

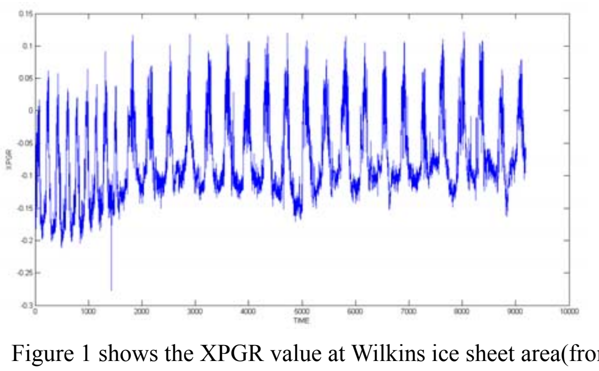
$$\begin{aligned} J(T) = & \sum_{X_I=0}^{T} h(X_I)\left[b_1(T)\left|X_I - m_1(T)\right|\right]^{\beta_1(T)} \\ & + \sum_{X_I=T+1}^{L-1} h(X_I)\left[b_2(T)\left|X_I - m_2(T)\right|\right]^{\beta_2(T)} \\ & + H(\Omega, T) - \left[P_1(T)\ln a_1(T) + P_2(T)\ln a_2(T)\right] \end{aligned} \quad (2)$$

where $P_1(T) = \sum_{X_I=0}^{T} h(X_I)$, $m_1(T) = \frac{1}{P_1(T)}\sum_{X_I=0}^{T} X_I h(X_I)$, $P_2(T) = 1 - P_1(T)$, $m_2(T) = \frac{1}{P_2(T)}\sum_{X_I=T+1}^{L-1} X_I h(X_I)$, $\sigma_1^2(T) = \frac{1}{P_1(T)}\sum_{X_I=0}^{T}\left[X_I - m_1(T)\right]^2 h(X_I)$, $\sigma_2^2(T) = \frac{1}{P_2(T)}\sum_{X_I=T+1}^{L-1}\left[X_I - m_2(T)\right]^2 h(X_I)$, $P_1(T)$ and $P_2(T)$ represents the priori probability of XPGR of dry and wet snow samples respectively; $m_1(T)$ and $m_2(T)$represents the mean of XPGR of dry and wet snow samples respectively; $\sigma_1^2(T)$ and $\sigma_2^2(T)$ are variance of XPGR of dry and wet snow respectively; $H(\Omega,T)$ is the entropy of $\Omega = \{\omega_1, \omega_1\}$; β_i is the shape parameters of $p(X_I \mid \omega_i) = a_i e^{-[b_i|X_i - m_i|]^{\beta_i}}$, $i = 1,2$, a_i , b_i is positive constant. The steps to estimate a_i , b_i , β_i , please see reference Sharifi and Leon-Garcia (1995). To obtain the optimal threshold of dry and wet snow, the optimization of error probability minimum of equation (2) was performed as follows:

$$T^* = \underset{T=0,1,...,L-1}{\arg\min}\ J(T) \quad (3)$$

The T value which makes the equation (3) reach minimum is the optimal XPGR segmentation threshold of dry and wet snow.

Figure 2 and Figure 3 were the examples of the ice sheet snowmelting threshold determination using generalized Gaussian model. Figure 2 shows the XPGR histogram obtained from SSM/I datasets from 1978 to 2009 at Wilkins ice sheet region, figure 2 also shows the optimal segmentation threshold between dry snow and wet snow obtianed from GGM method. From figure 2, we can see that the XPGR distribution of dry snow and wet snow comply the bi-Gaussian distribution. Left histogram shows the distribution characteristics of dry snow, right histogram represents the characteristics of wet snow. The XPGR optimal threshold from GGM is -0.0407. From the red line of figure 3, we can see that the optimal XPGR value corresponds to sharply change region, namely, it corresponds to time points which snow changed from dry to wet or from wet snow to frozen.



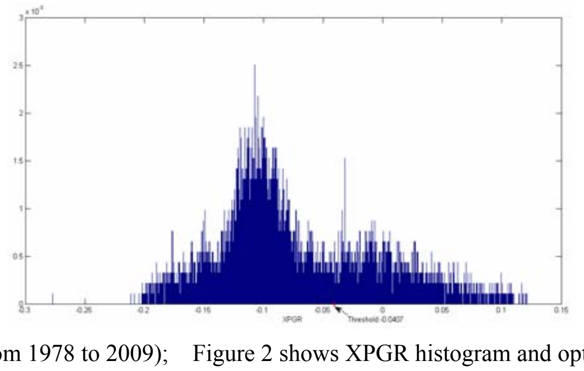


Figure 1 shows the XPGR value at Wilkins ice sheet area(from 1978 to 2009); Figure 2 shows XPGR histogram and optimal threshold at Wilkins ice sheet area(from 1978 to 2009)

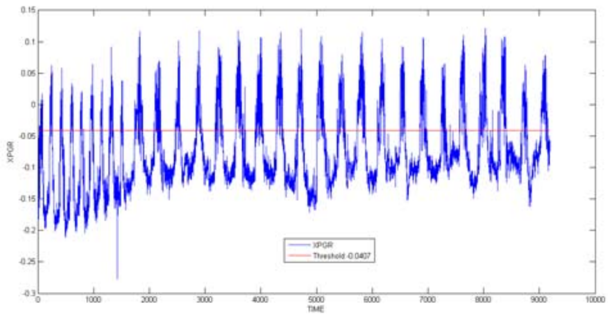


Figure 3 shows the segmentation line of optimal threshold at Wilkins ice sheet area (from 1978 to 2009)

4. MODIFIED ICE SHEET SNOWMELT DETECTION METHOD BASED ON WAVELET TRANSFORM

4.1 Ice sheet snowmelt detection method based on wavelet transform

The basic steps of ice sheet snowmelt using wavelet transform based method is as follows(Liu et al., 2005): first, wavelet transform were used to decomposite the time series brightness temperature into three scales, and then, the edge information of different scale were analyzed; then, variance analysis and bi-Gaussian model were used to determine the optimal edge threshold, and the prelimnary snowmelting result were obtained. Next, the error correction operator of space neighborhood was used to detect and correct the errors caused by noise. Finally, the spatial distribution, onset time, endset time and duration of ice sheet snowmelting were obtained.

4.2 Optimal automatic threshold segmentation based on generalized Gaussian model

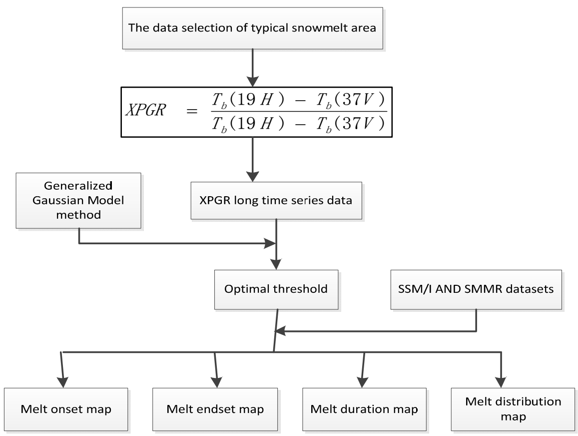
Liu et al.(2005) used the bi-Gaussian fitting model to determine the optimal threshold, the disadvantage is as follows: (1) the result of optimal threshold was significantly affected by inputed initial value using Levenberg–Marquardt fitting algorithm; (2) the process of optimal threshold determination is numerous and trivial. So, at this paper, the generalized Guassian model was proposed to determine the optimal threshold, please see section 3.3. The advantage is as follows: (1) Less manual input parameters; (2) the classification result is unique(namely, the threshold is unique), about the basic principle of generalized Guassian model method.

5. Result analysis and validation

After discussion on specific modifications of these methods, at this section, the results comparsion and validation of these modified methods will be analyzed and discussed.

5.1 Unsupervised XPGR ice sheet snowmelt detection method

The difference between proposed unsupervised XPGR detection method and the XPGR method is that the ways which determine the threshold is different. the XPGR method used in situ measurement to determine threshold, which is often impracticable in unreachable areas or harsh natural environment. the unsupervised XPGR method used the generalized Gaussian model(GGM) method to automatic seek optimal threshold. It avoided the requirement of in situ measurement. To analyze and compare the result with that proposed by Abdalati and Steffen （1997）, SSM/I data from 1988 to 2000 at same experimental area (a place in Greenland) is used. Figure 4 is the flowchart of unsupervised XPGR detection method.



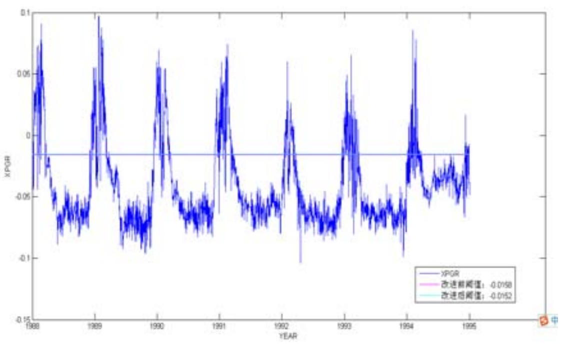


Figure 4. The flowchart of unsupervised XPGR detection method; Figure 5. XPGR threshold from the XPGR and unsupervised methods at Greeland area

Figure 5 shows the XPGR threshold from the XPGR and unsupervised methods at Greeland area. The Blue solid line is XPGR value from 1988 to 1996, the red one is the XPGR threshold -0.0158 obtained by Abdalati and Steffen（1997）method, and the light blue one is the unsupervised XPGR threshold -0.0152. From the result, we can see that the difference is very small.

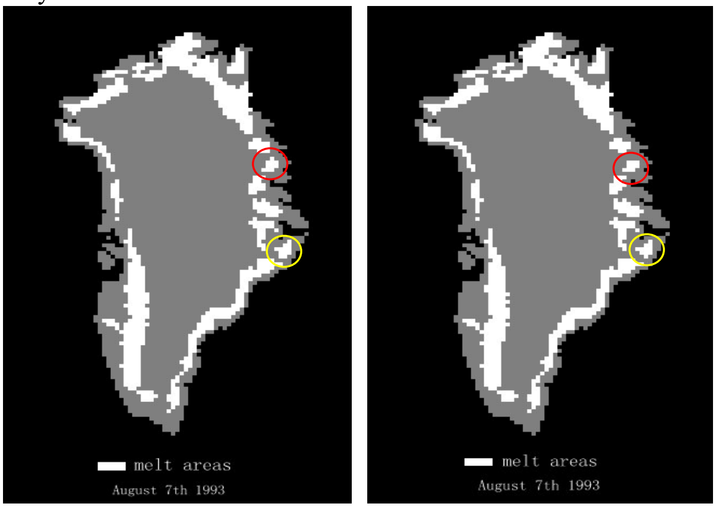
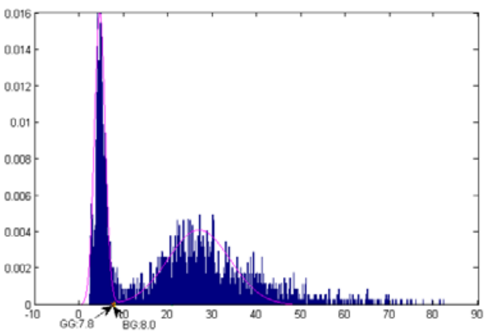


Figure 6. the Ice sheet snowmelt distribution of two methods on August 7th, 1997

Figure 6 show ice sheet snowmelt distribution of two methods on August 7th, 1997. The white indicates melt area, and gray indicates the non-melt area or bare rock area. From the result of two methods, we can see that the result is almost same, and only small difference is presented, for example, red circle and blue circle region shows small difference respectively. This result indicates that the proposed unsupervised XPGR detection method is effective, ftheremore, it is independent of in situ measurement.

5.2 Modified wavelet transform detection method

Analysis and comparison on result of modified and original wavelet transform detection method are based on the Antarctic SSM/I data from 1995 to 2008. The difference between the modified wavelet transform detection method and the original one is that the original one used bi-modal Gaussian distribution model to determine optimal threshold, and the modified wavelet transform detection method used the Generalized Gaussian Model (GGM) method to seek optimal threshold. The samples of wet and dry snow on Antarctic based on Liu's metrics (Liu et al. 2005) was selected. Figure 7 shows the two optimal threshold respectively derived from fitted bi-modal Gaussian distribution model and GGM automatic threshold segmentation method. From the figure, we can see that the former optimal threshold value is 7.8 and the latter is 8.0.



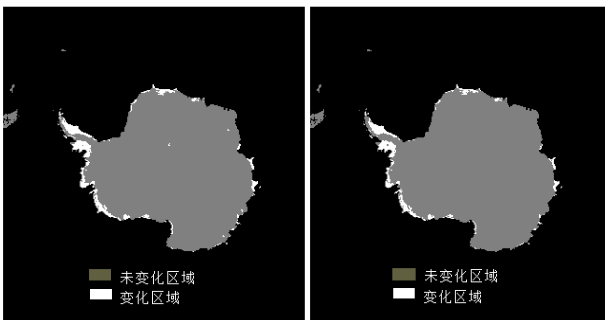


Figure 7 two optimal threshold obtained from bi-modal Gaussian distribution model and GGM; Figure 8 Ice sheet snowmelt distribution derived from two methods

Figure 8 shows two Ice sheet snowmelt distribution respectively obtained from modified wavelet transform detection method and the original one. Figure 8(a) shows the average melting distribution obtained from bi-modal Gaussian distribution model optimal threshold during 2007-2008. Figure 8(b) shows the average melting distribution obtained from GGM automatic threshold segmentation during 2007-2008. From figure 8, we can see that two results are similar, but, the result obtained from bi-modal Gaussian distribution model shows there have some melting areas in Antarctic inland. Based on the Antarctic environment and snowmelt distribution characteristic, it is impossible that Antarctic inland appear meting phenomenon. However, there is no melting area in the result obtained from GGM automatic threshold segmentation.

Through above analysis and comparison above, we can see that the optimal threshold and classification result based on GGM method are almost as the same as those based on bi-modal Gaussian distribution model. However, the GGM method increases efficiency of threshold determination and have higher accuracy, and it is independent of estimation and setting of initial value.

Through cross validation between results and the comparison with temperature data, unsupervised XPGR detection method and modified wavelet transform based method are reliable and effective on Antarctic ice sheet snowmelt detection, and the results have high precision.

6. CONCLUSION AND DISCUSSION

At this paper, two ice sheet snowmelt detecion methods which independent of in situ measurements were proposed: the unsupervised XPGR snowmelt method based on GGM and the modified snowmelt detection method based on wavelet transformation edge detection. Through cross comprarison of two methods and validation using temperature datasets from automatic weather station, the result indicate that two mthods were not only increased the computation efficiency, practicability and operability due to independent of in situ measurement, but also improved the ice sheet snowmelt detection accuracy to some extent. The propsed methods provided the methodology support for Antarctic ice sheet snowmelt detection.

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