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Freeze-thaw detection on Antarctic ice sheet based on deep learning

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Abstract: *The freeze-thaw state of polar ice sheets is an indicator of global change, and its weak changes will have a huge impact on the global environment. Long-term observation and research analysis of polar ice sheets using satellite remote sensing data will provide an important theoretical basis for studying global climate change. Using SSM/I (special sensor microwave imager) data and deep learning algorithms, 1 988-2017 daily freeze-thaw conditions of the Antarctic ice sheet were obtained The freeze-thaw changes of Antarctic ice sheet were analyzed based on four indicators: start time, end time, duration and melting area of ice sheet. The results show that from the spatial distribution, the freeze-thaw of the Antarctic ice sheet has strong spatial differences, the continental internal ice sheet basically does not melt, and the marginal area melts violently. From a temporal perspective, the duration of ice sheet melt is about 62 days and tends to decrease. The annual average melting area of the Antarctic ice sheet is* $2.553\times10^6\ km^2$*, accounting for about 15% of the total Antarctic area, and the annual variation is large*.

Keywords: *freeze-thaw of Antarctic ice sheet, deep learning, U-net network, spatiotemporal change analysis*

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I. INTRODUCTION

With global warming and rising global sea levels, environmental issues are being mentioned by more and more people. Antarctica, as the seventh continent, is also the only continent without human settlement, extremely sensitive to global climate change, the freeze-thaw state of the polar ice sheet is an indicator of global change, weak changes in the polar ice sheet will have a huge impact on the global environment, the detection of snowmelt on the surface of Antarctica is very important for studying the polar climate, but due to the remoteness and unfavorable environment, the field data is very limited, and the spaceborne microwave remote sensing has the ability to observe the ground around the clock. Provide frequent and extensive observations to monitor surface snowmelt in polar regions (Abdalati and Steffen, 1995). The effective detection of freeze-thaw changes in the Antarctic ice sheet by remote sensing can effectively reduce manpower and material resources and obtain effective usable real-time data.

At present, a lot of research has been carried out on the detection and analysis of ice sheet surfaces: Abdalati and Steffen proposed XPGR's ice sheet surface freeze-thaw detection algorithm, which uses the remote sensing data of 19h and 37 V in the SSMI microwave remote sensing data to calculate the difference, and compare the results with the threshold to determine the state of snow (Joshi et al., 2001). Picard et al. established a freeze-thaw diurnal variation model of the Antarctic ice sheet by using SSMI and SMMR data, and based on the model, the freeze-thaw detection of the ice sheet in the Antarctic region from 1979 to 2005 was studied (Picard et al., 2006). In 2013, based on the improved wavelet freeze-thaw detection algorithm and SMMR and SSM/I data, Liang et al. detected the freeze-thaw detection of the Antarctic ice sheet from 1978 to 2010, and found that the freeze-thaw of the Antarctic ice sheet was affected by temperature, and the freeze-thaw distribution of the eastern and western ice sheets was spatially presented by the thaw of the eastern and western ice sheets (Liang et al., 2013).
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II. STUDY AREAS AND DATA SOURCES

2.1 Overview of Antarctia.

Antarctica is located at the southern tip of the earth, surrounded by oceans, and Antarctica is the highest continent in the world. The Antarctic continent is almost completely covered by the ice sheet, and is completely closed, is a continent far from other continents, completely isolated from the civilized world, its average altitude is 2350 meters due to high altitude, thin air, coupled with the reflection of solar radiation on the surface of ice and snow, etc., making the Antarctic continent the coldest region in the world At the same time, due to the extremely high latitude position, no sunlight is obtained during the long polar night of the year.

2.2 Overview of the DMSP series of Microwave Imagers for Satellites (SSM/I).

The U.S. Defense Weather Satellite Program (DSMP) is a major project, with many satellites being launched. SSM/I radiometers are carried on these satellite platforms, which have four platforms: F8, F11, F13 and F17. The earliest F8 platform has been in use since July 1989, and the F17 platform is equipped with the latest generation of SSM/I sensors and a dedicated microwave imager or detector SSMI/S, the specific detailed parameters of which are shown in Table 1.

Table 1 Several parameters of SSM/I sensors

Frequency (GHz)	Polarization mode	Resolution along track (km)	Cross-orbit resolution (km)	Spatial sampling (km)	Instrument Noise (K)
19.35	H	69	43	25	0.42
19.35	In	69	43	25	0.45
22.235	In	50	40	25	0.74
37.0	H	37	28	25	0.38
37.0	In	37	28	25	0.37
85.5	H	15	13	12.5	0.73
85.5	In	15	13	12.5	0.69

The SSM/I platform has been upgraded from F-08, F-11, and F-13 to F-17, and the data version has been upgraded from V3 to V4. If you want to conduct a long series of studies, cross-platform issues may arise. The data for this project is from 1988-2017, the data from 1988-1991 is from the F-08 platform, the data from 1992-1997 is from the F-11 platform, the data from 1998-2006 is from the F-13 platform, and the data from 2007 and later are from the F17 platform.

Using the overlapping data of four types of data, the data on different platforms can be normalized, and their overlapping dates are December 3 to December 30, 1991, May 3 to September 30, 1995, and January 1 to April 29, 2009, respectively, while the data on the F11, F13 and F17 platforms are calibrated to the F8 platform using formula (1).

$$T_1 = a * T_2 + b \tag{1}$$

Among them, T_1 is the 19GHz horizontal polarization bright temperature data of platform F8, T 2 is the 19GHz horizontal polarization bright temperature data of platforms F11, F13 and F17, and a and b are the regression coefficients. The regression coefficients for converting data from different platforms to the F8 platform are shown in Table 2.

Table 2 Regression coefficients for different platform data

Data transformation	slope	intercept	correlation coefficient
SSM/I F11 F13 19H	1.008	-1.17	R>0.99
SSM/I F17 19H	1.0286	-3.0094	R>0.99

III. THEORETICAL BASIS

3.1 . Semantic segmentation technology based on U-net

With the continuous development of deep learning technology, different network models have been studied, and researchers have proposed an improved U-net network model based on FCN network, Figure 1 For the structure of the U-net network, it can be seen that the U-net network is a fully convolutional neural network, the input and output are images, and there is no fully connected layer. Shallower, high-resolution layers are used to solve pixel positioning problems, and darker layers are used to solve pixel classification problems. The U-net network is mainly composed of two parts: compression path and expansion path. The compression path is achieved by stacking the convolutional layer and pooling layer multiple times, and the purpose of multiple convolution and pooling is to fully extract the high-level abstract features of the image. The expansion path on the right half first deconvolves the feature map once, and then stitches the feature map obtained by deconvolution with the feature map clipped by the corresponding compression path to achieve the purpose of information fusion, and then uses two convolutional layers for feature extraction and repeats this structure [4].

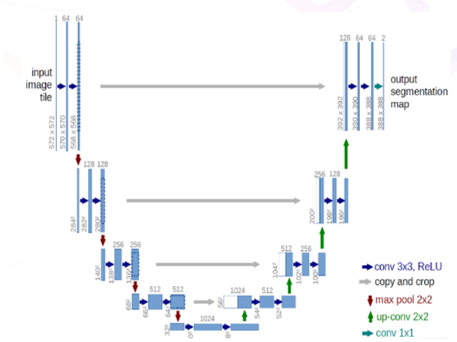

Figure 1 U-net network structure

U-net network integrates the characteristics of hop connection and encoding-decoding structure, each hidden layer has multi-dimensional features, which is more conducive to the neural network model to extract rich and detailed features. Moreover, the U-shaped structure makes the splicing and clipping operations more reasonable and intuitive, and the splicing of high-level and underlying feature maps and the cross-accumulation of convolution enable the model to obtain more accurate prediction results from the combination of detailed information and sample information [5].

The semantic segmentation model based on U-net mainly has the following steps, namely downsampling process, upsampling process and pixel classification process. The downsampling stage is used to abstract the semantic features of an image, usually a convolutional neural network with reduced feature map resolution and increased channel dimensionality to extract features. The upsampling phase, on the other hand, is mainly used to recover semantic content. The classification stage completes the classification task and classifies each pixel [6].

3.2． Freeze-thaw detection algorithm of Antarctic ice sheet based on deep learning

Due to the cold, dry, not easy for humans to observe in the field, the measured data of ice sheet freeze-thaw is very difficult to obtain, the lack of the true value of ice sheet freeze-thaw classification is a problem in the freeze-thaw detection of the Antarctic ice sheet, and the use of deep learning based on the Antarctic ice sheet freeze-thaw detection algorithm can solve this problem well, the neural network model can extract the deep features of the remote sensing image, and transform the freeze-thaw problem of the Antarctic ice sheet into a classification problem, because Antarctica is almost covered by the ice sheet, only a very small part of the bare land, Therefore, it can be idealized as a binary classification problem in image semantic segmentation, that is, Antarctica can be regarded as the melted part of the ice sheet and the unmelted part of the unfrozen sheet, so the deep learning model can be used to detect the freeze-thaw of the Antarctic ice sheet.

The steps of the freeze-thaw detection algorithm of Antarctic ice sheet based on deep learning mainly include the following steps: (1) The SSMI data obtained from the US Ice and Snow Data Center is clipped, radiocorrected, and the data are preprocessed. (2) Using ENVI software to reasonably annotate SSMI Antarctic remote sensing images and make a reasonable training sample set is based on the key to the success of deep learning. (3) The training set is trained by using the semantic segmentation technology of the U-net network, and then the preprocessed test set is put into the network for training. Output results by controlling the network. (4) Finally, the freeze-thaw situation of the Antarctic ice sheet of each pixel is obtained, and then the freeze-thaw distribution map of the Antarctic ice sheet is obtained.

3.2.1 Remote sensing image preprocessing

The first step is to obtain the data, import the microwave remote sensing data SSMI data downloaded from the official website of the US Ice and Snow Data Center into the remote sensing image processing software ENVI, and open the microwave remote sensing SSMI data on the F17 platform 19h on January 1, 2016, as shown in Figure 2.

The second step is to carry out radiation correction processing, because of external reasons, there will be systematic errors in the process of data acquisition and transmission, and we need to correct them to eliminate the impact caused by radiation errors. In order to perform radiometric correction processing on Antarctica remote sensing data, it is necessary to enter and process equation (2) as b1 through the band calculation function in ENVI to obtain b2radiometrically corrected Antarctic data (Figure 3).

$$b2 = float(b1) / 10*1.0286 - 3.009 \quad (2)$$

The third step is to mask the data, using the B3 Antarctic mask file obtained in advance (Figure 4), because our study area is the melting of the ice sheet of the entire Antarctic continent, and does not include the melting of sea ice in the nearby seas, in order to separate the ocean from the continent in the original data. We use the band math (band calculation function) in the remote sensing image processing software ENVI to mask the original data, and use formula (3) to multiply image b2 and mask image b3 to obtain image b 4, so that the value of the ocean part in the original data is 0, so as to achieve the result of separation of continent and seawater. 19 h microwave remote sensing SSMI image after masking Antarctica remote sensing image (Figure 5).

$$b4 = b3 * b2 \quad (3)$$

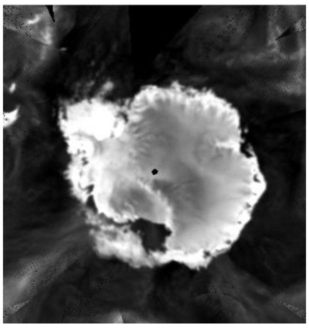

Figure 2 19h microwave remote sensing SSMI data diagram.

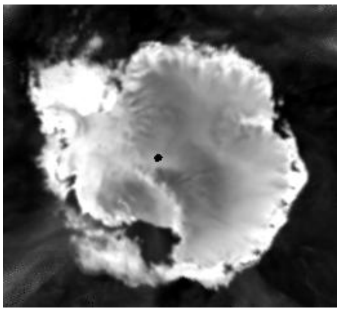

Figure 3 Radiometric remote sensing image of Antarctica

Figure 4 Antarctic continent mask image

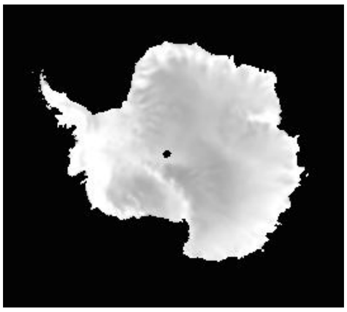

Figure 5 Remote sensing image of Antarctica after masking

3.2.2 Sample Set Annotation

Because of the large number of annotated datasets and now highly powerful computers, deep learning technology has developed rapidly. We need to train the neural network by using the training set to get the desired result. Since there is currently no existing dataset of freeze-thaw conditions of the Antarctic ice sheet, it is because there is no automatic identification method for freeze-thaw division of ice sheets in current practice, and there is a lack of semantic segmentation dataset that divides labels into two categories of objects that are thawed and unmelted. Therefore, we need to label the Antarctic ice sheet ourselves. The preprocessed remote sensing images need to be annotated. Because the Antarctic ice sheet usually begins to melt in summer, the freeze-thaw status of the Antarctic ice sheet is labelled by using the pretreated Antarctic remote sensing data from July 1, 1988 to July 1, 2018. A total of 2,000 images were obtained as a sample set.

3.2.3 Network training

The network model selected in this study is the U-net neural network model, and its network structure is shown in Figure 3-1. The activation function is the relu function commonly used in the U-net neural network model (Figure 6), and its function expression is such as formula (4), if the activation function is not used, each layer of the neural network can only do linear transformation, although it is still linear transformation after multi-layer input superposition. If the nonlinear excitation function is added, it is possible for the neural network to learn a smooth curve to divide the plane, instead of using complex linear combinations to approximate the smooth curve to divide the plane, so that the expression ability and learning ability of the neural network are greatly enhanced, so that the objective function can be better fitted. At the same time, compared with other activation functions, the advantage of using the relu function is that it can speed up training and reduce training time, which is a good choice when the hardware conditions are not very good.

$$reluf(x) = max(0. x) \quad (4)$$

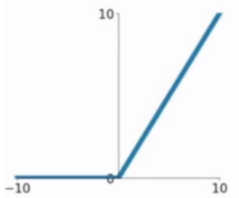

Figure 6 Image of the relu function

In this study, the commonly used cross-entropy function (Cross Entropy) is used, and its function expression is shown in equation (5). The process of training a neural network model is the process of reducing the value of the loss function. Because the second classification of this topic only separates melting from melting ice, in the case of dichotomous, the final result that the model needs to predict is only two cases, for the melting part, assuming that the probability obtained by our prediction is p, and the probability predicted by us is 1-p for the unmelted part, so its expression becomes equation (6).

$$loss(p,q) = -\sum_{i-1}^{n} p(xi) \log (q(xi)) \quad (5)$$

$$loss(p,q) = \frac{1}{n}\sum_{i} - [y \times \log (p) + (1-p) \times \log (1-p)] \quad (6)$$

where y represents the label of sample i, the melted part is 1, the unmelted part is 0, and p represents the probability that sample I is predicted to be melted.

In this study, 2000 images were trained on every 10 as a batch input model, and the EarlyStopping function was used to detect the training status of the model and decide whether it needed to terminate. By using the multi-gpu-model() function, the computer GPU is mobilized for training and processing. At the same time, we use the cross-entropy loss function mentioned above this time and its function expression such as Equation 4-4, use the ModelCheckpoint function to store the optimal model in the process of model training, set the object to Val acc, automatically save the optimal parameters, use the RedecelROnPlateau function to automatically adjust the learning rate in the neural network during training, when the value of the loss function tends to be stable, The model tends to converge, and the model is obtained. The test set is imported into our trained neural network model for testing, and the freeze-thaw distribution of the Antarctic ice sheet is obtained.

IV. RESULTS AND ANALYSIS

4.1 Freeze-thaw spatial analysis of the Antarctic ice sheet

In order to evaluate and analyze the freeze-thaw situation of the Antarctic ice sheet, the spatial changes of the melting start time, melting end time and melting duration of the Antarctic ice sheet will be studied. Through the processing of SSM/I Antarctic data from 1988 to 2017, the freeze-thaw detection algorithm of Antarctic ice sheet based on deep learning is used to determine the thawing state of each pixel every day, and the freeze-thaw situation of the Antarctic ice sheet is obtained, and the time of the first melt and the last thaw of each pixel are calculated every year The time for each pixel to continue to melt was averaged over the 30-year period, and ArcMap software was used to obtain the average start time, end time (Figure 8), and duration of the Antarctic ice sheet from 1988 to 2017 (Figure 7).

It can be seen from Figure 7 that the melting of the Antarctic ice sheet is extremely regional, and the interior of the Antarctic continent basically does not melt, while a large amount of melting will occur in the coastal area of the edge of Antarctica. In general, the melting time of the Antarctic ice sheet begins between October 4 and November 4 every year, as the two largest ice shelves in Antarctica, the Ronny Ice Shelf and the Ross Ice Shelf, the Ross Ice Shelf will begin to melt before October 4 every year, and the Ronny Ice Shelf begins to melt on November 4 every year. The melting of the Finbull Ice Shelf in the north began relatively early, before November 4 each year. The Antarctic Peninsula, West Ice Shelf and Bombleton Ice Shelf began to melt relatively late, starting to melt after December 15 each year.

Figure 8 shows that most of the Antarctic ice sheet will end thawing by March 4 of the following year, and the northern coastal area of the Fenbull Ice Shelf will end melting earlier, between December 31 and January 7 each year. The West and East Antarctic regions, including the Antarctic Peninsula, the West Ice Shelf, the Pockleton Ice Shelf, the Ronny Ice Shelf, the Emory Ice Shelf, and the Ross Ice Shelf, finish melting late, ending from February 1 to March 3 each year.

The duration of the melting duration of the Antarctic ice sheet can be a proxy for the extent to which the Antarctic ice sheet melts. From Figure 9, it can be seen that the melting of the Antarctic ice sheet is extremely spatial, the Antarctic ice sheet will experience a large amount of melting every year, the interior of the Antarctic continent basically does not melt, and a large amount of melting will occur in the coastal area of the edge of Antarctica. Among them, the Antarctic Peninsula and the Ronnie Ice Shelf melted the most violently, with an average melting duration of more than 65 days, and the eastern coastal areas including the West Ice Shelf, the Pockleton Ice Shelf, and the Emory Ice Shelf will undergo strong melting, with an average melting duration of 49-64 days, and the northern Fenbull Ice Shelf and the Gates Ice Shelf in the southwest are not violent, with an average melting duration of 17-32 days.

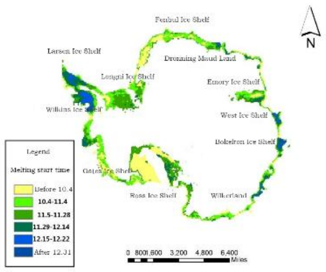

Fig.7 Antarctic melting start time 1988-2017

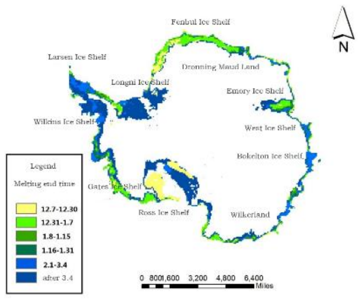

Fig.8 End of Antarctic melting from 1988 to 2017

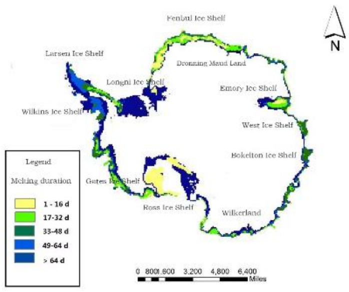

Fig.9 Average duration of melting of the Antarctic ice sheet from 1988 to 2017

In summary, the melting of the Antarctic ice sheet has a strong spatial difference, the continental internal ice sheet basically does not melt, the near edge area melts violently, the Antarctic Peninsula in the northwest of Antarctica is the most violent, the western ice shelf, the Pockleton ice shelf, and the Emory ice shelf in the eastern coastal area will undergo strong melting, the northern Finbull ice shelf and the southwestern Gates ice shelf melting is not violent, and there is a law that the sooner the melt starts, the later the melting ends, the longer the duration of the melt.

4.2 Analysis of long-term freeze-thaw changes in Antarctic and Antarctic peninsula ice sheets

4.2.1 Analysis of long-term changes in freeze-thaw of the Antarctic ice sheet

According to Figure 10, it can be seen that the Antarctic ice sheet experiences large-scale melting every year, and the average melting area of the Antarctic ice sheet from 1988 to 2017 was 2.553×10^6 km^2, accounting for about 15% of the entire Antarctic area. During these 30 years, the largest melted area in 1990 was 3.153×10 6 km 2, and in 1999 the melted area was the smallest 2.121×10^6 km^2 。 From the trend line, it can be seen that the melting area of the Antarctic ice sheet remained basically stable from 1988 to 2017, but the interannual variation was large, the largest melting area appeared in 1991, but in 1993 it became a minimum value, and then in 1997 it came to a maximum value, and every few years there would be repeated the pattern of rapid growth of the melting area, and then rapid decline.

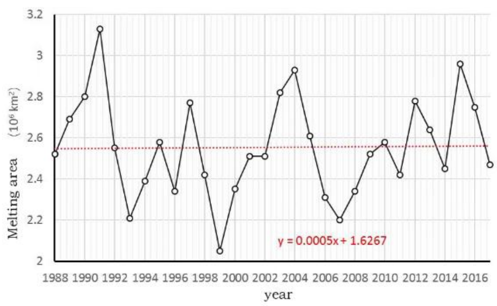

Fig. 10 Antarctic melting area change map from 1988 to 2017

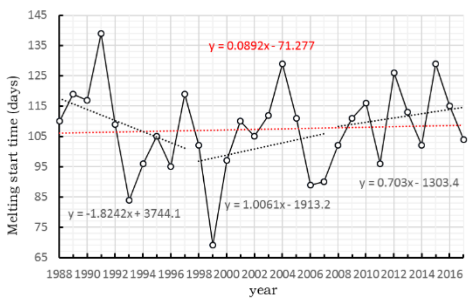

Fig. 11 Change of Antarctic melting start time from 1988 to 2017

According to Figure 11, it can be seen that the melting of the Antarctic ice sheet begins between September and November each year, with an average of 107 days, that is, October 15 of each year. In 1999, the melting began as early as day 69, which occurred on 7 September 1999, and at the latest on day 139, on 16 November 1991. From the change trend in the figure, the start time of melting of the Antarctic ice sheet remained basically stable and had a slight delay, and the rate of change was 0.0892 d/a. From 1988 to 1997, the onset time of Antarctic melting showed a large trend of advance, with a rate of change of -1.8242 d/a. From 1998 to 2007, the onset of Antarctic melting showed a delayed trend, with a rate of change of 1.0061 d/a. From 2008 to 2017, the onset time of Antarctic melting showed a delayed trend, with a rate of change of 0.703 d/a.

As can be seen from Figure 12, the end time of the melting of the Antarctic ice sheet is between December and February of each year, with an average of 178th day, that is, December 25 of each year, and the end time of Antarctic melting is as early as November 30, 1999, and the latest is 211th day on January 27, 1992. From the 30-year melting trend, the melting end time of the Antarctic ice sheet remained basically stable and slightly advanced, and the change rate was -0.0038 d/a. From 1988 to 1997, there was a significant upward trend, with a rate of change of -2.5273 d/a. From 1998 to 2007, there was a delayed trend, with a rate of change of 0.4424 d/a. From 2008 to 2017, there was a trend of significant delay, with a rate of change of 1.7394d/a.

Combining Figure 11 and Figure 12, the melting start time and end time were the same as the maximum value in 1991, 1997, 2004, 2012 and 2015, and the melting start time and end time in 1993, 1999, 2011 and 2014, and the minimum value in 1988-1997, 1998-2007, The start time of melting from 2008 to 2017 has the same trend as the end time, that is, the earlier the melting of the Antarctic ice sheet begins, the earlier the melting ends, and vice versa

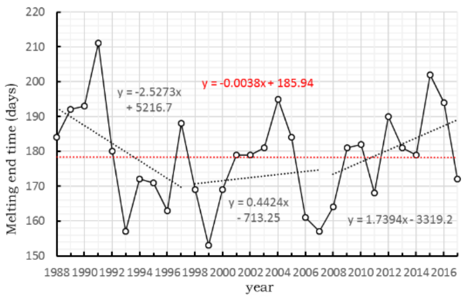

Fig. 12 Change of Antarctic melting end time from 1988 to 2017

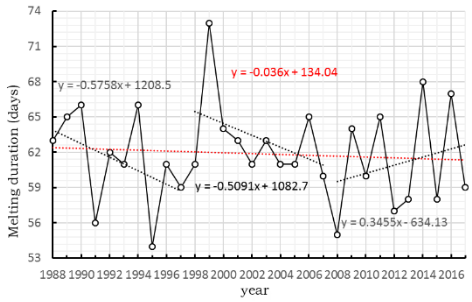

Figure 13 Change in Antarctic melting duration from 1988 to 2017

Figure 13 shows that the average duration of melting the Antarctic ice sheet was 62 days, with the shortest being 53 days in 1995 and the longest being 73 days in 1999. Overall, the duration of melting of the Antarctic ice sheet showed a slight downward trend, with a rate of change of -0.036 d/a. The years 1988-1997 and 1998-2007 showed a downward trend, with the rate of change being -0.5758d/a and -0.5091d/a, respectively. However, from 2008 to 2017, there was an upward trend, with a rate of change of 0.3455 d/a.

4.2.2 Analysis of long-term freeze-thaw changes in the ice sheet of the Antarctic Peninsula

Figure 14 shows that the melting of the Antarctic Peninsula begins between October and December each year, with an average of 135 days (November 12). The earliest start of melting was 107 days (October 15) in 2013 and as late as 152 days (November 29) in 1988. Overall, the onset time of melting in the Antarctic Peninsula showed an early change trend, with a change rate of -0.366 d/a. The three 10-year periods from 1988 to 1997, 1998 to 2007 and 2008 to 2017 showed an advance trend, and the change rates were -2.0121d/a, -0.7576d/a and -0.897d/a, respectively. In the past 10 years (2008-2017), the onset of melting of the Antarctic Peninsula ice sheet has changed greatly from year to year.

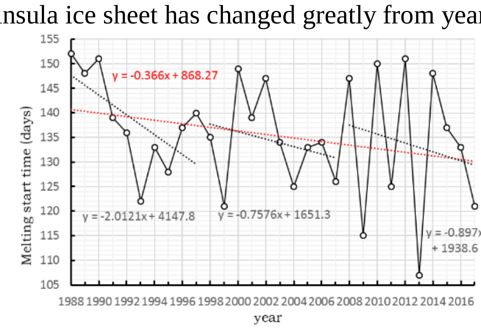

Fig. 14 Change of melting start time in the Antarctic Peninsula from 1988 to 2017

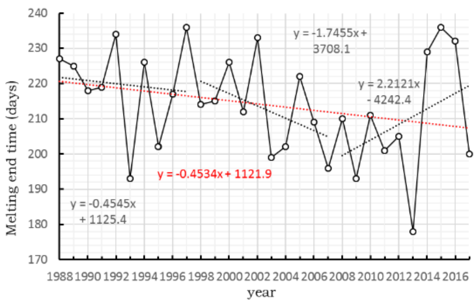

Figure 15 Change of melting end time in the Antarctic Peninsula from 1988 to 2017

Figure 15 shows that the melting of the Antarctic Peninsula ends between December and March of each year, with an average of 214th day (January 30), 178th day (December 25, 2013) at the earliest, and 236th day (February 21, 2016) at the latest 。 In general, the melting end time of the Antarctic Peninsula showed a large trend of advance, and the rate of change was -0.4534 d/a. From 1988 to 1997, there was an early trend, with a rate of change of -0.4545 d/a. The trend in advance from 1998 to 2007 increased further, with a rate of change of -1.7455 d/a. From 2008 to 2017, there was a trend of large delay, and the rate of change was 2.2121d/a.

Figure 16 shows that the average duration of melting of the Antarctic Peninsula ice sheet is 68 days, with the shortest 48 days occurring in 2012 and the longest 89 days occurring in 1992. Overall, the duration of ice sheet melt in the Antarctic Peninsula showed a slight downward trend, with a rate of change of -0.2687 d/a. From 1988 to 1997, there was an upward trend, with a rate of change of 0.7333 d/a. From 1998 to 2007, there was a downward trend, with a rate of change of -1.0303 d/a. From 2008 to 2017, there was an upward trend, with a rate of change of 1.4606 d/a.

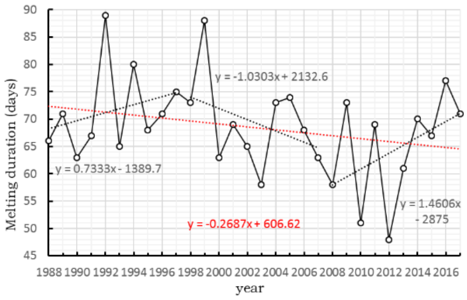

Figure 16 Change in the duration of melting of the Antarctic Peninsula ice sheet from 1988 to 2017

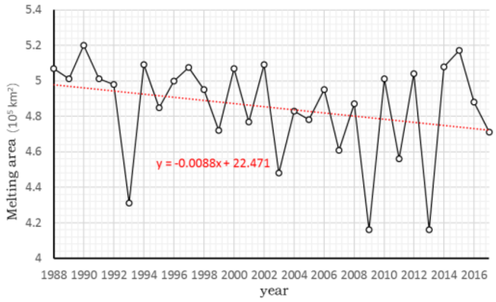

Figure 17 Changes in melting area of ice sheet in the Antarctic Peninsula from 1988 to 2017

According to Figure 17, it can be seen that the Antarctic Peninsula ice sheet experiences large-scale melting every year, and the average melting area of the Antarctic Peninsula ice sheet from 1988 to 2017 was 4.8453×10^5 km^2, accounting for about 22% of the total melting area of the Antarctic ice sheet. During these 30 years, the largest melted area in 1990 was 5.213×10 5 km 2, and in 2009 the melting area was the smallest 4.182×10^5 km^2 。 From the trend line, it can be seen that the melting area of the Antarctic Peninsula ice sheet maintained a downward trend from 1988 to 2017, with a rate of change of -0.2687 km^2/a. At the same time, the melting area of the Antarctic Peninsula has changed drastically in the past 10 years.

In summary, the Antarctic ice sheet experiences large-scale melting every year, with the average melting area of the Antarctic ice sheet from 1988 to 2017 being 2.553×10^6 km 2, and the average melting area of the Antarctic Peninsula ice sheet being 4.8453×10^5 km ^{2}, accounting for about 22% of the entire melting area of the Antarctic ice sheet, the change trend of the melting area of Antarctica remains basically unchanged, while the Antarctic Peninsula has a huge downward trend. At the same time, the melting of the Antarctic Peninsula began later than that of Antarctica, and the onset time of Antarctic melting in the past 30 years had a delayed change trend, and the Antarctic Peninsula showed the opposite change trend. The melting end time of the Antarctic Peninsula is later than that of Antarctica, and the melting end time of the Antarctic Peninsula has the same trend as the end time of the Antarctic Peninsula. The melting duration of the Antarctic Peninsula is longer than that of Antarctica, and the melting duration of the Antarctic and Antarctic Peninsulas has the same trend of change. The start time, end time and duration of melting of the Antarctic ice sheet remained basically stable with only a small change, and the start time, end time and duration of melting in the Antarctic Peninsula changed greatly.

V. CONCLUSION

This study uses SSM/I data and deep learning algorithms from the US defense weather satellite DMSP to detect the freeze-thaw of the Antarctic ice sheet from 1988 to 2017. The spatial and temporal changes of the onset, end, duration and melting area of the Antarctic ice sheet from 1988 to 2017 were obtained, and on this basis, the characteristics of freeze-thaw changes of the Antarctic ice sheet were studied, and the change trend of the freeze-thaw of the Antarctic ice sheet was revealed, and the following conclusions were obtained(1) The melting of the Antarctic ice sheet has a strong spatial difference, the continental internal ice sheet basically does not melt, the near edge area melts violently, the Antarctic Peninsula in the northwest Antarctic melts the most violently, the melting begins and ends relatively late, and the melting lasts for a long time. Strong melting will occur in the western ice shelf, the Pockleton ice shelf and the Emory ice shelf in the eastern coastal area, with the melting starting earlier, ending later and lasting shorter. The melting of the Finbull Ice Shelf in the north and the Gates Ice Shelf in the southwest is not violent, the melting starts and ends relatively early, and the melting duration is short.

(2) The Antarctic ice sheet experiences a large area of melting every year, with an average melting area of 2.553×10^6 km^2, accounting for about 15% of the entire Antarctic area. During these 30 years, Antarctica began to melt on average on October 15 and ended on January 30 of the following year, lasting an average of 62 days of melting. The interannual variation of the Antarctic ice sheet is large, but on the whole, the melting trend has remained basically stable in the past 30 years, with only a small change.

(3) The Antarctic Peninsula is the most intense melting place in Antarctica, with an average melting area of 4.8453×10^5 km 2, accounting for about 22% of the melting area of the entire Antarctic ice sheet, and is continuously decreasing, with a change rate of -0.2687 km^2/a. The Antarctic Peninsula begins to melt on average on November 12, later than the average start time in Antarctica, and ends on January 30 of the following year, with an average duration of 68 days. The melting trend of the Antarctic Peninsula was obvious, the start time and end time of the melting of the Antarctic Peninsula had a trend of advance, and the duration had a downward trend, and the change rates were -0.366 d/a, -0.4534 d/a and -0.2687 d/a, respectively.

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