IOP Conf. Series: Earth and Environmental Science **17** (2014) 012142 doi:10.1088/1755-1315/17/1/012142

Research on the temporal-spatial changes of near-surface soil freeze/thaw cycles in China based on Radiometer

Lin Guoqing[1, 2], Guo Huadong[2], Li Xinwu[2], Zhang Lu[2]
[1] University of Chinese Academy of Sciences, Beijing, 100049, China
[2] Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, 100094, China

E-mail: gqlin@ceode.ac.cn

Abstract. Near-surface soil freeze-thaw cycles (NSC) would have dramatic influences on hydrologic processes, ecosystem and engineering operations. Passive microwave remote sensing (PMRS) has been a powerful tool for detecting the changes of NSC. The research on NSC based on large-scale and long-time series PMRS data is still rare. In this research, we used the decision tree to extract daily soil freeze/thaw states derived from Special Sensor Microwave/Imager (SSM/I) data from 1988 to 2008. 7-day moving average method was employed to extract the yearly area-averaged frozen days, freeze/thaw onset date of each pixel and frozen pixels from 1988 to 2008. Through analysis of the results above, we found that about 3/4 of the land surface experienced the NSC every year, and less than 4% was always in frozen states which mainly distributed in snow mountains of Qinghai-Tibet Plateau. The changes of NSC in most part of China were seasonal variations, and changed significantly during a year. The general trends of these changes are later freeze onset dates, earlier thaw onset dates, fewer freeze days and longer growing season. Our research would have contributed to understanding near-surface earth systems and extreme environmental events such as the dust emission in semi-arid and arid regions of East Asia.

1. Introduction

Frozen soil distributes widely in China, and seasonally frozen soil and permafrost impact about 70% of China land surface. And if adding short-term frozen soil, nearly ninety percent of China land surface will be impacted [1]. More importantly, every year the surface frozen soil experiences the NSC. The NSC would have dramatic influence on land-atmosphere energy exchange, surface runoff, crop growth, carbon cycle and it is an important factor which must be considered in the environment researches, resource exploitation and engineering construction [2]. Much evidence indicates that the cryosphere has been changing rapidly [3], but most evidence relies on sporadic observations. A broad understanding of regional-scale changes in cryosphere has not yet been established [4].The freeze/thaw states of land surface are very sensitive to climate changes, so the changes of onset and offset dates of the freeze/thaw are effective indicators of climate changes. However, because of the scarcity of in situ observations, changes in the NSC have only been observed in limited areas [5]. Most of research on frozen soil in China focuses on the Qinghai-Tibetan Plateau (QTP) [4]. So the objective of this paper is to provide a reliable analysis of changes in the NSC over China by taking advantage of long-term, continuous observation brightness temperature (BT) from PMRS.

Over past few years researchers have developed three types of methods to detect the freeze/thaw states of the surface soil using passive microwave remote sensing. The first type is the dual-indices method which uses a negative spectral gradient between higher (36/37 GHz) and lower (18/19 GHZ) channels and a low brightness temperature at 36/37 GHz [6]. The second type uses a time series analysis [7]. The third type is the decision tree method, which combines the above mechanisms with a scattering index and other existing classification rules to sort out other factors related to land status, such as rainfall and snow [8].

Most of the results indicate that the surface soil has been thawing and that the growing season has been significantly prolonged in many areas [7][9]. However, the NSC in China has not been systematically investigated. Therefore, we applied the newly developed decision tree classification algorithm [8] in this paper to detect the changes in the NSC over China based on the SSM/I data from 1988 to 2008.

2. Data and method

2.1 Data

In this paper we used the daily SSM/I data from 1988 to 2008 from the National Snow and Ice Data Center and they are EASE-Grid format with a resolution of 25 km [10]. The vertical polarization BT at 19, 22, 37 and 85 GHz and the horizontal polarization BT at 19GHz for the SSM/I data were selected for the decision tree algorithm. The overpass time occurs around 06:00 local time. Because the NSC change quickly with the soil temperature, we used the cold-overpass data in the early morning to capture the daily soil freeze/thaw states, specifically including the F8-SSM/I ascending data, F11-SSM/I descending data and F13-SSM/I descending data.

2.2 Classification method

In this paper we detected the freeze/thaw states using the decision tree algorithm which is based on the theory of the dual-indices algorithm [2][6]. This method clears away the interference from desert, snow and rainfall through sample analysis and accumulation of priori knowledge using SSM/I BT. Overall classification accuracy is about 91.66%, so it is very suitable for extracting the freeze/thaw states in China. The flow chart of this method is showed in the paper from Jin et al (2009). Based on the decision tree, we obtained the daily surface soil freeze/thaw state classification results of China from 1988 to 2008 except the three years of 1989-1991, and carried out indirect validations to make sure the results reliable. We used a 7-days moving average method to fill the data gaps.

2.3 Classification criteria

In this paper we chose the following criteria to detect the changes of NSC.

1) The freeze/thaw dates of each pixel. According to the criteria in Specifications for ground meteorological observation from China Meterological Administration, we chose the first day after September 1st as soil freeze onset date when the soil surface was frozen, the last day before August 31st as soil freeze offset date which is defined as the soil thaw onset date in this paper. 2) Total numbers of frozen days for each pixel. 3) The numbers of yearly frozen days. 4) The numbers of area-average yearly frozen days. 5) Total numbers of frozen pixels.

Based on these criteria, we used line regression to calculate the change rates of these criteria.

3. Results

3.1 Spatial distribution of the near-surface soil freeze/thaw state

Fig.1 shows the spatial patterns in the number of frozen days averaged over the last 20 years from 1988 to 2008. The number of frozen days on the QTP and Greater Khingan Range area is very large: over 330 days in the north-western QTP; over 300 days in the Qilian Mountains, the Himalayas, and other high mountains. The number of frozen days on the Loess Plateau Region is about 100 days; 30-60 days on the North China Plain; less than 30 days in the south of the middle and lower reaches of Changjiang River and on the Yunnan-Guizhou Plateau.

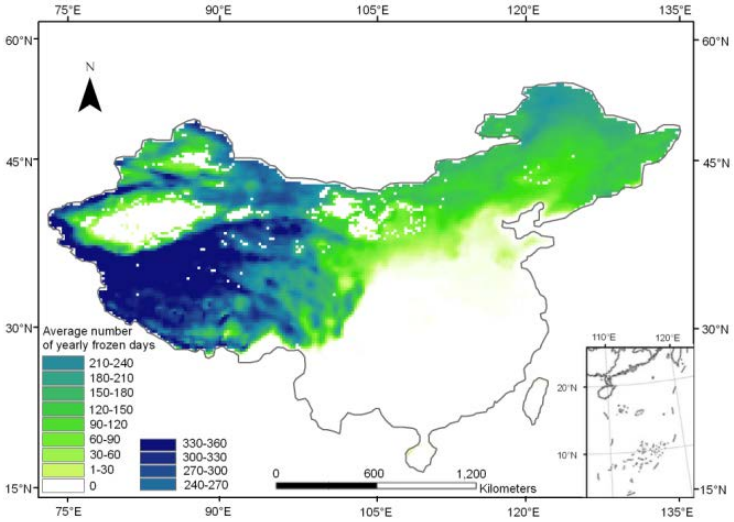
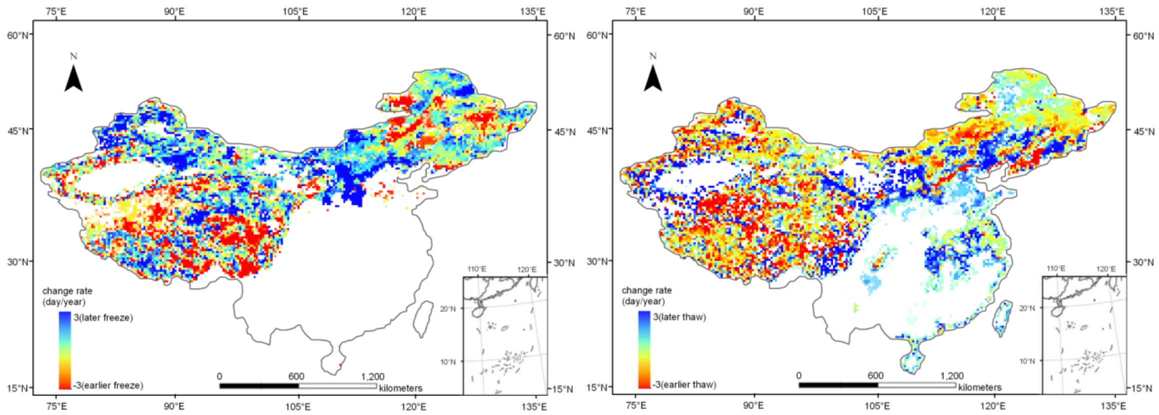


Figure 1. The mean numbers of frozen days between 1988 and 2008 over China.

3.2 Changes of near-surface soil thaw and freeze onset dates

In this paper we used the slopes of linear regression equation of the onset dates of freeze/thaw to show the change rates of them, which are showed in figure 2. Through analysis of the results above, we found significant changes of them in China: during the past two decades, earlier freeze mainly happened in Taihang Mountains, Inner Mongolian Plateau and Mt. Tianshan. Later freeze happened in most parts of the Tibetan Plateau, Greater Khingan Range and the North China Plain.

In past two decades earlier thaw mainly happened in the area with high latitude and high altitude, including most parts of the Tibetan Plateau, Greater Khingan Range, Inner Mongolian Plateau and Northeast Plataeu. These areas distributed permafrost and deep seasonally frozen soil. And later thaw happened in the transition areas of different kinds of frozen soil.

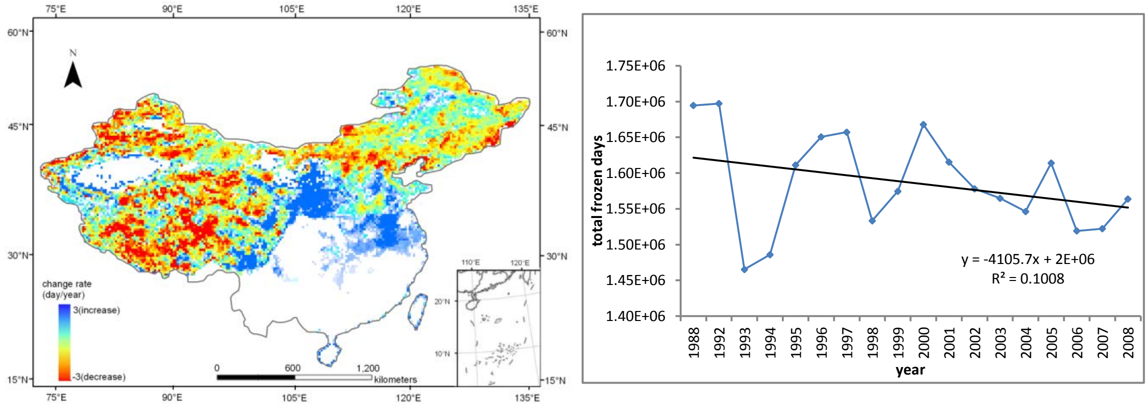


(a) (b)

Figure 2.(a) Changes of onset dates of freeze in land surface over China from 1988 to 2008.(b) Changes of onset dates of thaw in land surface over China from 1988 to 2008.

3.3 Changes in the number of frozen days

From Figure 3.(a), we can see that the yearly frozen days of most parts of China decreased during the last two decades. The number of frozen days in the areas with high latitude and high altitude decreased by 3 days every year, including most parts of the Tibetan Plateau, Altun Mountains, the Qilian Mountains Inner Mongolian Plateau, Mt. Tianshan and so on. And the number of frozen days increased in Loess Plateau and North China Plain, which is distributed by seasonally frozen soil and short-time frozen soil.



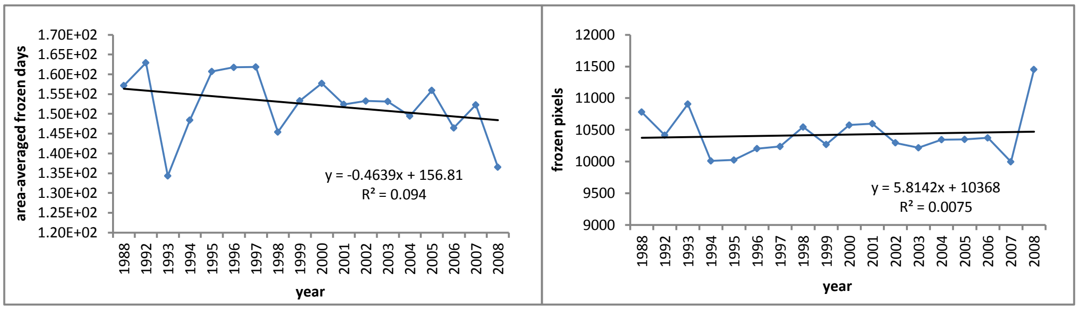
(a) (b)

Figure 3.(a) Changes of frozen days of land surface over China from 1988 to 2008. (b) Trends of the yearly total number of frozen days over China from 1988 to 2008.

Figure 3.(b) shows the trends of the yearly total numbers of frozen days for all pixels over China during 1988-2008. The general trend is that the total number of frozen days is decreasing about 10,000 days for all pixels, although there are some fluctuations. After the year of 2000, the number decreases dramatically. These changes may have some relations with the climate changes.

3.3.1 Changes in the numbers of area-averaged frozen days and yearly frozen pixels

Figure 4.(a) shows the trends in the numbers of yearly area-averaged frozen days from 1988 to 2008 over China. Before the year of 2000, there are some significant fluctuations in the numbers of area-averaged frozen days. However after 2000 the number is always decreasing till the smallest value of 2008.



(a) (b)

Figure 4.(a) Changes in the numbers of yearly area-averaged frozen days from 1988 to 2008 over China. (b) Changes in the numbers of yearly frozen pixels from 1988 to 2008 over China.

According to the numbers of frozen pixels, we can figure out the land surface frozen area because each pixel stands for about 625km2. Figure 4.(b) shows the changes of the numbers of yearly frozen pixels. Except the year of 2008, the trend of frozen area is decreasing in the last two decades, but during 1988-2008 the trend is opposite. The reason is that there was a severe snow and frozen disaster happening in the south of China in 2008. So most part of land surface of China was frozen in 2008. The number of frozen pixels of 2008 is the biggest among the last two decades.

4. Conclusions

All the analysis criteria have significant changes over China during the last two decades. In this research we found significant changes of the NSC in China: the total numbers of frozen area and area-averaged frozen days of China decreased about 1000 pixels and 10 days from 1988 to 2008; the biggest frozen area happened in 2008 because of the snow and frozen disaster happened in the south of China. The most significant changes of the durations of soil freeze occurred in the QTP and the north of Greater Khingan Mountains; the most significant changes of the onset dates of soil freeze/thaw occurred in Northeast Plain and the QTP, the south of North China Plain and the middle and lower Yangtze River Plain, where discontinuous permafrost, island permafrost, and seasonally frozen ground are distributed. The northwest of the QTP had small changes, where stable permafrost exists [4][8]. The general trend is later freeze onset dates, earlier thaw onset dates, fewer freeze days and longer growing season. The hydrology in China will respond to changes in the NSC accordingly. Greenhouse gas emissions from frozen soil will tend to increase. However, the impacts on hydrology and ecology need further investigations.

Acknowledgments
This research is financially supported by the National Basic Research Program of China (973 Program, No. 2009CB723906) and the National Key Technology R&D Program (Grant No. 2012BAH27B05).

References
[1] Zhao L et al 2004 Global and Planetary Change. 43 19–31
[2] Zhang T et al 2001 *Geophysical Research Letters*. **28** 763–766
[3] Kang S C et al 2010 *Environmental Research Letters* 5, doi:10.1088/1748-9326/5/1/015101.
[4] Li X et al 2011 *Int. J. Appl. Earth Observ. Geoinf.* doi:10.1016/j.jag.2011.12.002
[5] Zhao L et al 2010 *Permafrost and Periglacial Processes.* **21** 198–207
[6] Zuerndorfer B et al 1992 *IEEE Transactions on Geoscience and Remote Sensing.* **30** 89–102
[7] Smith N et al 2004 *Journal of Geophysical Research.* **109** D12101
[8] Jin R et al 2009 *Remote Sensing of Environment.* **113** 2651–2660
[9] Kim Y et al 2011 *IEEE Transactions on Geoscience and Remote Sensing.* **49** 949–960
[10] Armstrong R L et al 1995 *Advances in Space Research.* **16** 155–163