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SUMMARY OF DOCTORAL THESIS

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Title: Active and passive microwave remote sensing of near-surface soil freeze/thaw event in northern China and Mongolia
中国北部及びモンゴルを対象とした表土凍結融解現象の受動型・能動型マイクロ波リモートセンシング

Near surface soil freeze–thaw cycles play a significant role in our understanding of near-surface earth system. Satellite remote sensing verified by ground truth has been used to investigate the near-surface soil freeze–thaw cycle from local to regional scales and has advantages over the ground measurement and modeling. However, remote sensing based near-surface soil freeze–thaw cycles detection is still rare in mid-latitudes especially where near-surface changing seriously. This research was therefore focusing on active and passive microwave remote sensing of near-surface soil freeze-thaw event in a typical mid-latitude region, northern China and Mongolia. This dissertation consists of 7 chapters. The first chapter introduces the nature of near-surface soil freeze-thaw events, traditional and remote sensing methods for detecting the events and objectives, study area, and technical flow of this dissertation. The second chapter gives an illustration of springtime near-surface soil freeze-thaw events by filed observation. Chapters from 3, 4 and 5 are methodology improvements of near-surface soil freeze-thaw detection. Especially, Chapter 3 adapts a soil freeze-thaw algorithm to passive microwave remote sensing data for near-surface soil freeze-thaw cycle detection; Chapter 4 proposes a multi-step method for springtime near-surface soil thaw event detection by taking active microwave remote sensing data as source; and Chapter 5 compares the results from active and passive microwave remote sensing data, analyzes the typical signatures when springtime soil thaw event occurred and proposes a theoretical method for springtime soil thaw detection by employing both active and passive microwave remote sensing data. In Chapter 6, Near-surface soil freeze-thaw events response to climate and impact on dust outbreak are studied. And finally, main achievements in this study are summarized and future necessary improvement and application are discussed in the last chapter.

Soil temperature and 7-day maximum/minimum combined passive microwave brightness temperature were employed to apply a soil freeze–thaw algorithm in the study area. A random sampling technique was proposed to determine brightness temperature thresholds for 37 GHz vertically polarized radiation: 258.2 and 260.1 K for the morning and evening satellite passes, respectively, and determined the onset, offset, and duration of the phases of the near-surface soil freeze–thaw cycle. During the 10 years from 1998 to 2007, the onset and offset of soil frozen/thawed in spring and autumn progressed from south to north and northwest, and from low elevation to high elevation. The durations of the freeze–thaw transitions in spring, autumn and whole year were longest in the Loess Plateau, Ordos Plateau, and Songnen Plain, where they were 1–3 weeks longer than in other regions. The total annual durations of soil frozen/thawed increased/decreased progressively from the south to both the northwest and northeast. Over the 10 years, changes to both the timing and duration of phases of the freeze–thaw cycle were greater in spring than in autumn. Most of the changes were less than two weeks, but there were changes of up to three or four weeks on the Northeast Plain, Loess Plateau, and at Mt. Yinshan.

In order to validate the application of radar backscatter time series for surface

thaw detection in mid-latitude areas, a new multi-step method was proposed based on the significant signature of radar backscatter time series when springtime soil thaw event happened. The method mainly focuses on the estimated geographical boundary of thaw events and detection of the primary thaw date; the duration of the freeze–thaw transition period was a lesser focus. The method was applied to soil freeze–thaw conditions in the study area, and achieved a reliability of $R^2 = 0.678 \pm 0.021$ ($P < 0.01$) by comparison with ground truth measurements. The results indicate that elevation/temperature and soil moisture conditions are the key drivers of the timing of springtime soil thaw events. And 8 years' Geographical boundaries of springtime soil thaw occurrence was studied, from which five typical regions were highlighted: significant relationship were found in northeast of China ($R = 0.71$, $P < 0.01$) and northeast of Mongolia ($R = 0.75$, $P < 0.01$) between temperature change and boundary shift; but no any significant relationship was found in the other three regions, west of China, northwest of Mongolia, and Tibetan Plateau.

Sensitivities of results from active and passive microwave remote sensing were analyzed. Generally, result from active microwave remote sensing is sensitive to limited surface soil moisture amount, lower than which no thaw event could be detected. While, result from passive microwave remote sensing is sensitive to near-surface soil temperature. Based on those differences, active and passive microwave remote sensing data were then used for identifying springtime near-surface soil thaw events by comparing time series in the first 180 days of a year with meteorological records to infer typical signatures in regions characterized by three different winter soil conditions: high moisture and frozen ground, non-frozen ground, and desert in which the ground freezes but has low moisture content. In all regions, brightness temperature showed an increasing trend during the first 180 days of the year, but backscatter trends decreased in frozen ground, increased in non-frozen ground, and were steady in desert regions. The brightness temperature difference between morning and evening satellite tracks was also distinctive among the three regions. A theoretical method based on these signature analysis results was proposed: First, frozen ground, non-frozen ground, and desert regions could be distinguished by using two proposed indices, the temporal difference between morning and evening brightness temperatures (*TI*) and the slope ratio between backscatter and brightness temperature time series (*SI*). Second, a logistic function of the daily signal difference between active and passive time series (DI_i) could detect the beginning and end of the freeze–thaw transition.

The influence of both springtime frozen ground and soil moisture after the spring thaw on dust outbreaks was also examined on the eastern Mongolian Plateau, principal contributor to long-range transport of dust to the North Pacific, during the springs of 2000 – 2007. Dust storms occurred mainly after the spring thaw. Threshold wind speeds for dust outbreaks were estimated to be 9.5 m/s for low soil moisture content (<13.3%) and 14.7 m/s for high soil moisture (>16.7%). Dust outbreaks when soil was frozen required stronger winds (15.7 m/s). The number of dust events that occurred before the thaw correlated positively ($R^2 = 0.82$, $P < 0.01$) with the proportion of non-frozen ground. The number of dust events after the thaw, when water content was high, correlated negatively ($R^2 = 0.88$, $P < 0.01$) with the proportion of frozen ground.

In summary, the success of this study demonstrates the potential for the adapted, proposed and theoretical methods to be applied in mid-latitude areas, and widens the application potential of microwave remote sensing time series beyond high north and permafrost studies. And this research has contributed to understanding near-surface earth systems and suggests that changes in earth surface may cause extreme environmental events such as the dust emission in semi-arid and arid regions of East Asia.