FREEZE/THAW DETECTION IN PERMAFROST REGION WITH C-BAND SCATTEROMETERS

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ABSTRACT

Distribution of permafrost is largely controlled by climatic conditions. Current permafrost monitoring methods are based on in-situ measurements and modeling and they are mostly local measurements which offer only limited insight in the impacts of global climate variations on the regional to global scale. Permafrost is a subsurface phenomenon which cannot be directly measured with remotely sensed data. But the spatial distribution, thickness and temperature of permafrost is highly dependent on the condition of the active layer overlaying the permafrost. Satellite data can be utilized for operational monitoring of the permafrost active layer by means of a number of indicators and parameters, which are highly valuable for permafrost modeling and monitoring. In this study we present the usage of backscatter measurements from ASCAT scatterometer onboard Metop for detection of freeze/thaw conditions in high latitudes and validate the results with synoptic meteorological measurements. It is shown that there is a high correlation between frozen/unfrozen flag extracted from ASCAT data and the in-situ air temperature measurements.

Key words: scatterometer, frozen ground, circumpolar

1. INTRODUCTION

The availability of high temporal resolution datasets which provide information on the freeze/thaw status of the ground is limited. LST (land surface temperature) products from MODIS or AATSR are impacted by cloud coverage and limited insolation at high latitudes [1]. Passive [2] as well as active microwave [3] satellite data are suitable for thaw and refreeze detection. Spring ground thaw coincides in general with snowmelt timing and can be thus determined using snow cover products. Fluxes do however already increase as soon as the snow starts melting [4]. Freeze-up in autumn often starts before snow covers the ground. The development of an approach for detection of snowmelt start, ground thaw and autumn freeze-up timing is therefore required for the purpose of land-surface modelling (including permafrost) at high latitudes. This can be achieved by using microwave sensors. The suitability of Metop ASCAT for this purpose is demonstrated within this paper. The study relates to two ESA funded projects: DUE Permafrost and STSE ALANIS-Methane. The objective of the ESA DUE Permafrost (www.ipf.tuwien.ac.at/permafrost) project [5] is to establish a monitoring system for high latitude permafrost based on satellite data. Input parameters for models (numerical heat transfer, coupled atmosphere-land and dynamic vegetation models) as well as indicators at the land surface are addressed. ALANIS Methane (www.alanis-methane.info) is a research project to produce and use a suite of relevant earth observation (EO) derived information to validate and improve one of the next generation land-surface models and thus reduce current uncertainties in wetland-related CH4 emissions [6]. It is part of ESA's Support to Science Element Program. (www.esa.int/stse). The focus on the remote sensing side of the project is the development of new and/or improved wetland maps, and snowmelt and frozen ground information [7]. Wetland dynamics are investigated on regional to local scale over Northern Eurasia for the years 2007 and 2008.

2. SCATTEROMETER DATA

Scatterometers are active microwave instruments. Spaceborne scatterometers have been originally developed for operational ocean wind monitoring but they have also been proven of high value for applications over land [8].

ASCAT (Advanced SCATterometer) onboard Metop, launched in October 2006, is a real-aperture radar operating at 5.255 GHz (C-band) with high radiometric resolution and stability. ASCAT Measurements are consistent with the preceding sensors and allow continuation of products developed for the scatterometers flown on the European Remote Sensing (ERS-1 & ERS-2) satellites [9, 10, 11]. The new instrument has the advantage of supplying information more than twice as much as the previous scatterometers

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per orbit and is able to provide quasi-global data coverage over two swaths instead of one. Unlike optical instruments, ASCAT performance is unaffected by cloud cover or solar illumination and can therefore be used effectively in all-weather conditions. The long term availability of the ASCAT data together with the already existing ERS-Scatterometer dataset provide a valuable tool for long term (1991- 2020) monitoring of the Earth.

3. METHODOLOGY

Microwave backscatter differs significantly between frozen and unfrozen ground due to changing dielectric properties [12, 13, 14]. In C-band, the summer backscatter is higher than when snow is present or the ground is frozen. When the snow surfaces recrystallize after a midwinter short-term melt event, backscatter can increase up to summer levels in C-band [3]. The magnitude of the backscattered scatterometer signal is dependent on the geometric and dielectric properties of the surface. When the soil surface freezes, dielectric properties of the soil changes significantly which usually results in low backscatter values. As snow begins to fall and accumulates over the surface, due to volume scattering, backscatter signals may increase depending on microwave frequency. The response of dry snow volume to microwaves is rather complex and depends on snow properties like snow depth, density, and average grain size as well as the age of snowpack. With increasing temperature in spring, snow begins to melt and water covers the surface of snow pack which causes a sudden drop in backscatter. After the snow melting period, soil and vegetation begin to thaw and consequently backscatter arise again.

A numerical algorithm for detection of freeze/thaw conditions has been developed at the Vienna University of Technology (TU-Wien) based on the parameters and thresholds extracted by processing of the ASCAT normalized backscatter time series and using distinctive decision trees. Decisions trees are set differently with respect to the time of year. A year is divided to four main zones as depicted in fig. 3 based on seasonal Transition Points (PT1 and PT2).

In TU-Wien method, soil surface state is determined by evaluating the normalized backscatter measurement [15] at 40° incidence angle with a set of parameters, which have been calculated using two years (2007-2008) ASCAT data and comparing with modeled soil temperature data from the ECMWF ReAnalysis (ERA-Interim) dataset. The ERA-Interim dataset is based on the ECMWF Integrated Forecast Model, a global numerical weather prediction model. The resulted freeze/thaw parameter database includes seasonal transition times of year from summer to winter and vice versa (figures 1, 2), which have been calculated by

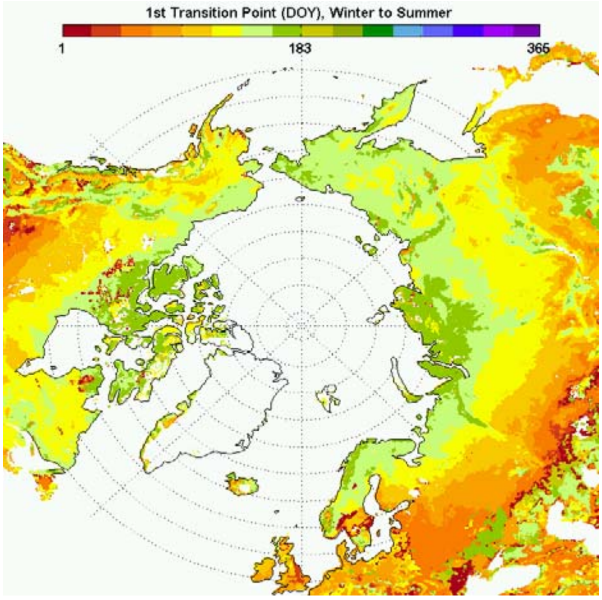

Figure 1. Seasonal transition time from summer to winter.

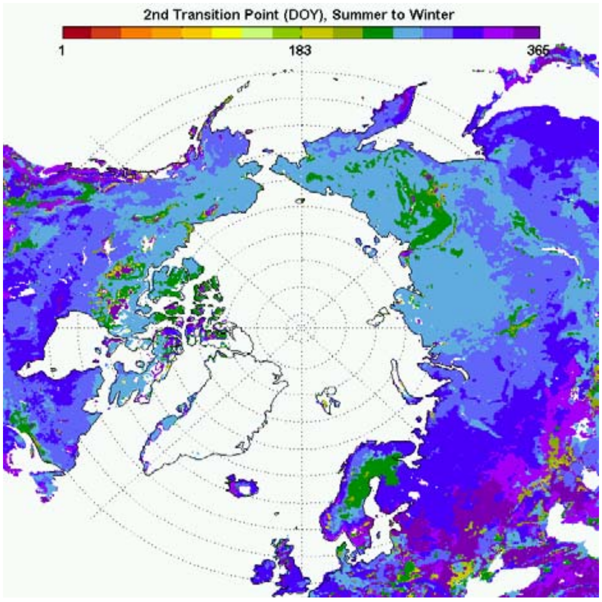

Figure 2. Seasonal transition time from winter to summer.

Figure 3. A year is divided to four main time periods based on Transition Points (PT): 1- Winter time, 2-First transition period (winter to summer), 3 Summer time, 4- Second transition period (from summer to winter)

implementing a step function into the time series of backscatter measurements, backscatter level during frozen conditions, and some additional statistics like the mean of backscatter in summer and winter. Fig. 4 indicates the normalized backscatter values during frozen conditions. Colors represent backscatter thresholds at frozen level in global scale and white areas indicate unknown conditions, where either the method failed to estimate the frozen level or there was not enough backscatter measurements at minus temperature to calculate the frozen level. Eventually, determination of surface state is succeeded through decision trees and by using information on normalized backscatter and freeze/thaw parameters. Fig. 5 illustrates six examples of the determined surface state for different dates.

4. RESULTS AND DISCUSSION

Comparison of the results of TU-Wien freeze/thaw detection algorithm with the air temperature data from synoptic meteorological data as well as the modeled data from Global Land Data Assimilation System (GLDAS) show significant agreement.

Fig. 6 shows a time series example of the surface state flag compared with minimum and maximum air temperature data from the nearest in-situ synoptic meteorological measurements.

The Calculated surface state flag indicate high correlation with air temperature measurements. The

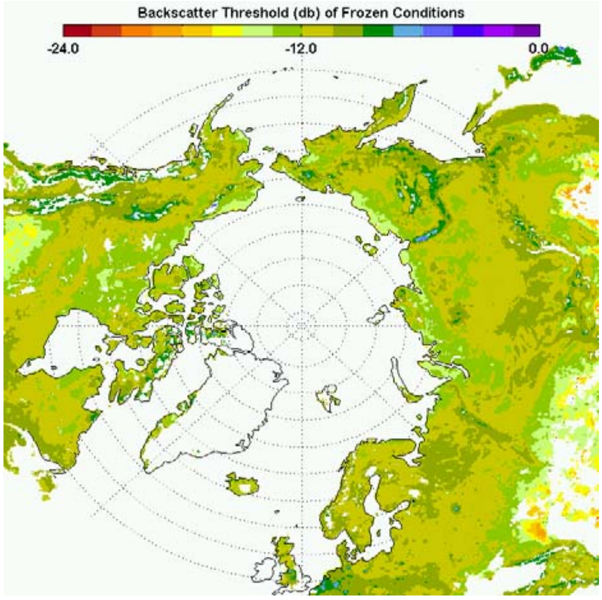

Figure 4. Backscatter level indicating threshold of frozen conditions.

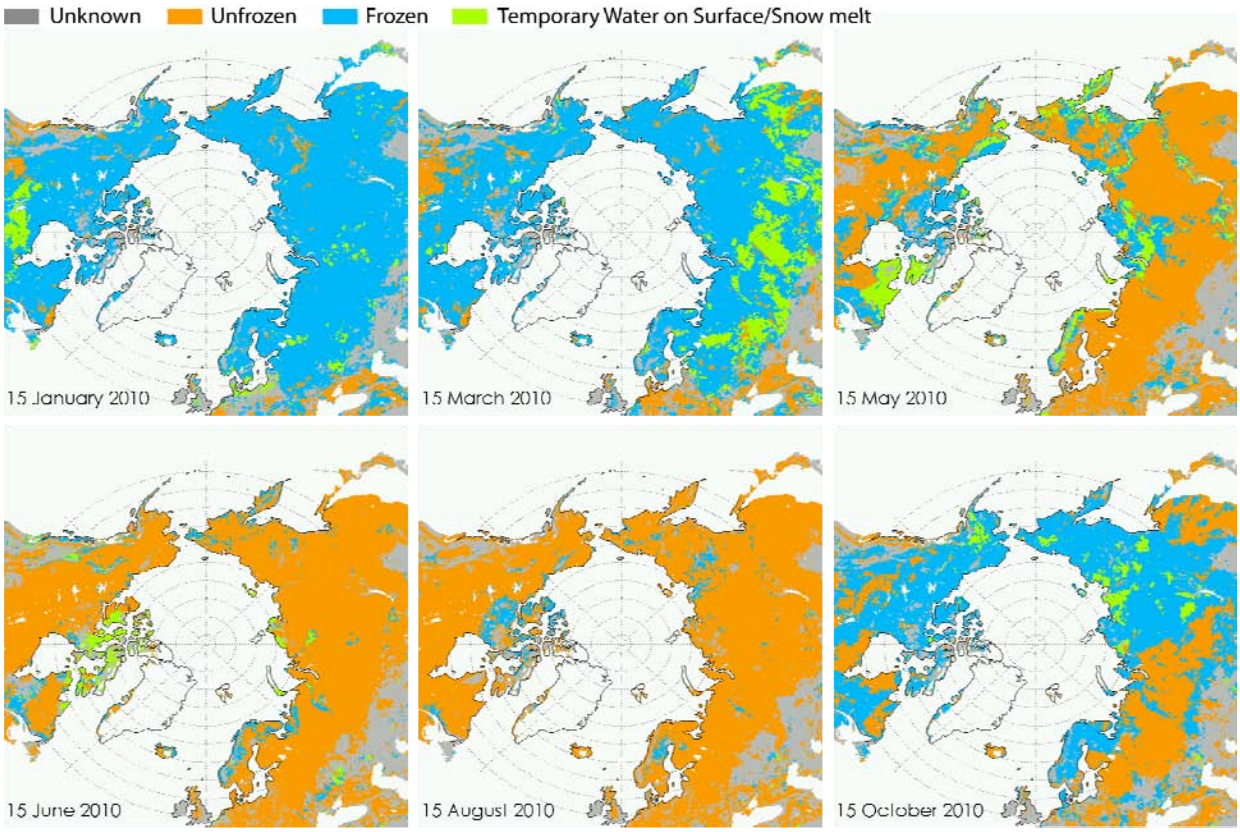

Figure 5. Estimated surface state as: frozen/unfrozen surface, temporary water on the surface or snowmelt and unknown flag.

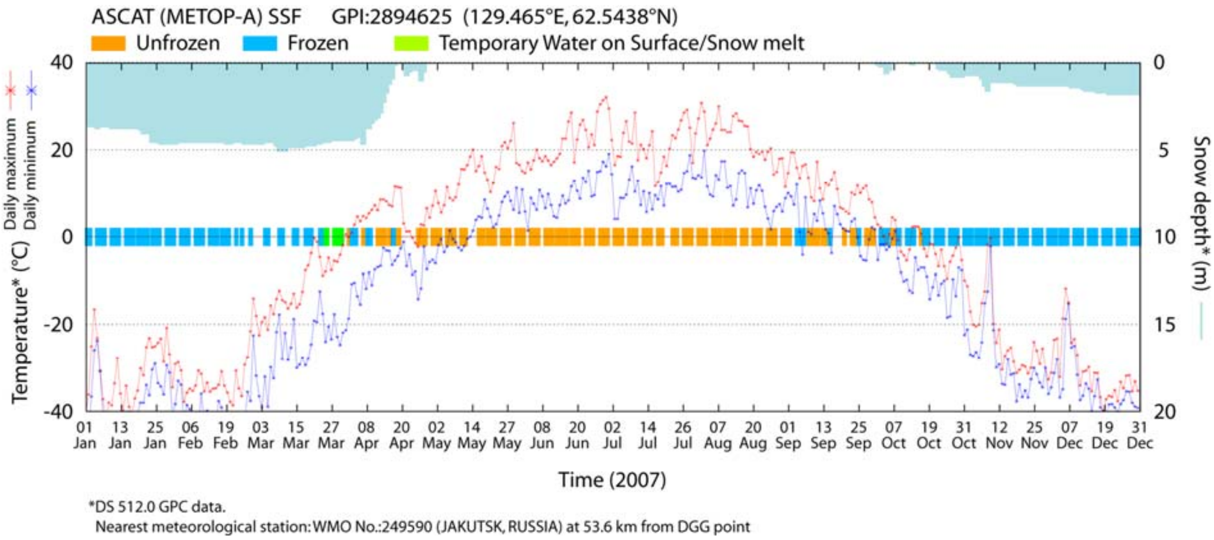

Figure 6. Time series of the estimates surface state flag compared with min/max air temperature and snow depth measurements.

agreement between the estimated surface state in this example and interpolated temperature measurements in first and second seasonal transition periods are respectively 78,8, and 85.2%. The agreement in winter and summer periods reach to respectively 98.4% and 100%.

The results of comparison between the estimated surface state flag with the GLDAS modeled temperature data in permafrost region and beyond (colored areas in fig. 4) is illustrated as in fig. 7. The most agreement is in summer and winter periods and the most distinction appears in seasonal transition periods, which are the most critical time zones for freeze/thaw detection. The existing disagreement partly comes from the uncertainties related to the estimated surface state and the modeled temperature data and partly is due to the natural difference between air and soil surface temperature.

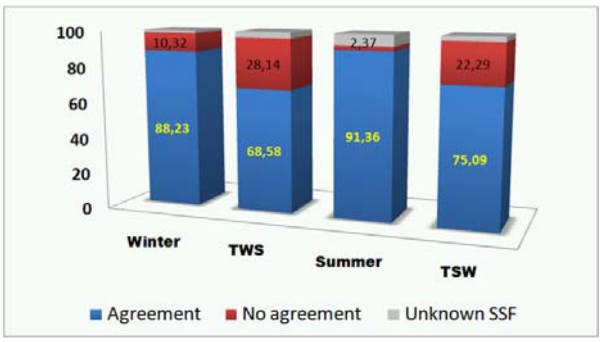

Figure 7. Comparison between the estimated surface state flag and the GLDAS modeled air temperature.

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