INTERCOMPARISON OF ACTIVE MICROWAVE DERIVED SURFACE STATUS AND MODIS LAND SURFACE TEMPERATURE AT HIGH LATITUDES

C. Paulik, A. Bartsch, D. Sabel, W. Wagner *

Vienna University of Technology
Institute of Photogrammetry
and Remote Sensing
Gusshausstrasse 27-29, 1040 Vienna
Austria

C. Duguay, A. Soliman

University of Waterloo
Interdisciplinary Centre
on Climate Change
200 University Avenue West, Waterloo,
Canada

ABSTRACT

Knowledge about the freeze/thaw state of the surface is of major importance for climate modelling, hydrology and numerous other applications. In this study, a freeze/thaw state detection algorithm using the ASCAT scatterometer is compared to Land Surface Temperature (LST) from MODIS as well as to a product derived from ENVISAT ASAR data. Good agreement with the LST product was found over the study area in Northern Siberia with disagreement below 22% for all 8-day periods of 2007. SAR derived surface status can, if sufficient sampling is available, provide similar results as with ASCAT but even with higher spatial detail.

Index Terms— radar remote sensing, arctic, land surface temperature, hydrology

1. INTRODUCTION

The status of the surface regarding unfrozen and frozen conditions can be determined with passive as well as active microwave data [1, 2]. This also includes melting snow (e.g. [3, 4]). Most studies [1, 5] use air temperature measurements from meteorological stations or atmospheric reanalysis datasets for validation. A further option is the use of satellite derived land surface (skin) temperature (LST). Such datasets are available e.g. from MODIS and AATSR. As part of the ESA DUE Permafrost and ALANIS-Methane projects, pan-arctic mosaics of LST [6] as well as scatterometer-based surface status [7] have been prepared at regular time intervals. This allows intercomparison and assessment of both type of datasets at high latitudes. Temperature information is of special interest for permafrost research in these regions. This paper details the outcome of scatterometer (25 km) assessment with LST (gridded to 25 km) as well as with the higher spatial resolution (1 km) SAR method [2, 8].

2. METHODOLOGY

The surface status from Metop ASCAT scatterometer onboard Metop satellite is based on a threshold-analysis method developed to derive a set of parameters to be used in evaluating the normalized backscatter measurements through decision trees and anomaly detection modules [1]. Backscatter measurements have been collocated with ECMWF ReAnalysis (ERA-Interim) soil temperature. The output product, so called Surface State Flag (SSF), compares well with two modeled soil temperature datasets as well as the air temperature measurements from synoptic meteorological stations across the northern hemisphere. The SSF time series have been also validated with soil temperature data from permafrost boreholes showing the overall accuracy of about %80 to %90 [1, 9].

*This study was carried out as part of the PERMAFROST project, which is funded by ESA's Data User Element (DUE) program as a component of the Earth Observation Envelope Program (EOEP) (ESRIN Contr. No. 22185/09/I-OL) and co-ordinated by TU Wien. It is also part of the ESA ALANIS-Methane project, which is funded by the Support to Science Element (STSE) program (ESRIN Contr. No. 4000100647/10/I-LG) and co-ordinated by CEH, UK. A. Bartsch is a recipient of a fellowship by the Austrian Science Fund (V150-N21).

The surface status flags (SSF) derived from ASCAT provide the folowing information: 1 - unfrozen, 2- frozen, 3 - melting and 4 - permanently frozen/ice covered. The intercomparison with LST and SAR output has been made for several sites of the DUE Permafrost project [10]. The paper details analyses from Northern Siberia. It includes quantitative as well as qualitative assessment. The LST as well as the SAR freeze/thaw cannot be directly compared. Temperature thresholds in case of LST and temporal reclassification in case of the SAR product have been used to produce indicators for frozen or un-frozen ground.

2.1. LST

MODIS data [6] has been investigated. The SSF is based on the ASCAT sigma 40 time series. It does not have a fixed temporal resolution but provides a measurement every 1 to 3 days. In order to compare the 8- day composite LST data with the SSF the temporal resolution of the latter had to be changed to an 8-day, exponentially weighted, average. This was done by counting the occurrence of each SSF value and then weighing them exponentially by the time difference between the observation time and the point in time of the 8-day average. After that the value with the biggest weight is chosen as the value of the 8-day composite, if 2 values have the same weight then the SSF value of the previous composite is favored.

The conditions for each class are explained in Table 1. Since the accuracy of satellite derived LST products is between 1 and 3°K [11] a "buffer" zone of $\pm$ 2 degrees was used were the classification is not counted as correct or incorrect. An example of the classification results can be found in Figure 1.

2.2. SAR

Due to the high temporal sampling rate of ENVISAT ASAR Global Monitoring (GM) mode, it has a high application potential for analyzing the land surface freeze/thaw process in high latitudes. A least square fitting of piecewise step

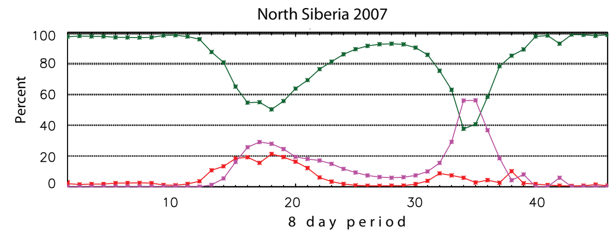

Fig. 1. Percent of correct (green), incorrect (red) and around zero (magenta) data points for every 8-day period over Northern Siberia in 2007.

function can be applied [2] when sufficient acquistions are available. Maps including information on acquisition numbers as quality indicators have been produced for the five regions of the DUE Permafrost project [8]. One of the sites (North Eastern Siberia - Laptev Seas Coast region) has been selected for the comparison.

The surface status is given by the day of thaw in spring and the day of freeze-up in autumn. This differs from the ASCAT SSF. Classification into unfrozen/frozen status can be extracted for each day of the year by assuming frozen surface before the day of thaw in spring and unfrozen surface before the freeze-up in autumn.

3. RESULTS

In winter and summer the SSF is nearly 100 % in agreement with the LST data. In spring the SSF flag indicates unfrozen soil earlier. Figure 3 shows that most of the differences can be attributed to the fact that the SSF indicates temporary water surface/melting conditions during that time and also that the $\pm$ 2°C class is distributed on the boundary between unfrozen and frozen SSF's. If the 8-day composite LST has a value below -2 °C and the SSF flag shows temporary water surface/melting conditions then this is not necessarily contradictory, if it happens in a thawing period. Mean agreement between the 2 datasets is 84% with incorrect flagging never above 22%.

Differences between ASCAT SSF and LST occur also in autumn. ASCAT shows unfrozen conditions after an initial freeze period. Such warming periods might be coincident with periods of cloud cover which impede correct derivation of LST with MODIS. Another possibility could be that the

Class	Correct	Around zero	Incorrect
Condition	LST < -2°C and SSF 2/4 LST > 2°C and SSF 1/3	LST in ± 2°C range	LST < -2°C and SSF 1/3 LST > 2°C and SSF 2/4

Table 1. Conditions for classification investigation surface status flags (SSF) 1 - unfrozen, 2- frozen, 3 - melting and 4 - permanently frozen/ice covered

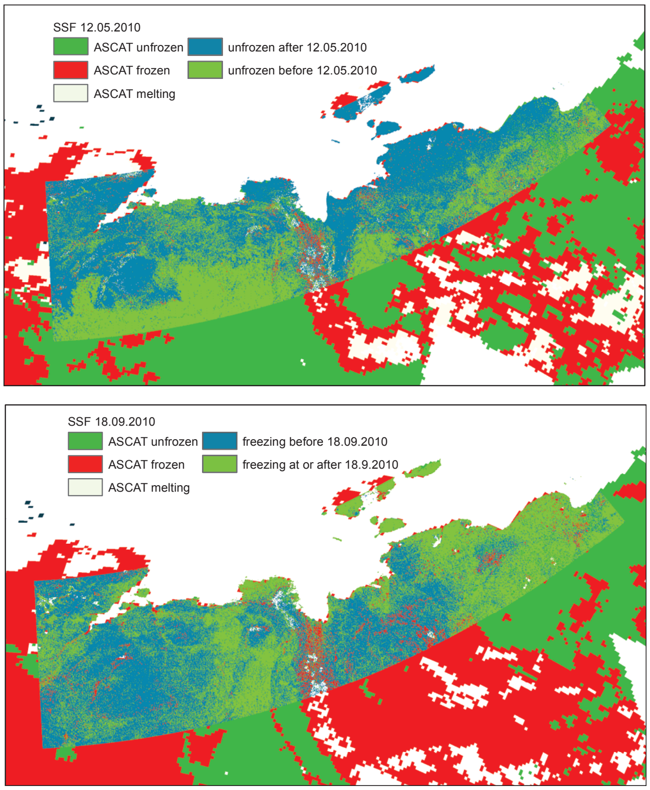

Fig. 2. ASCAT SSF overlayed with ASAR thaw and freezeup timing information.

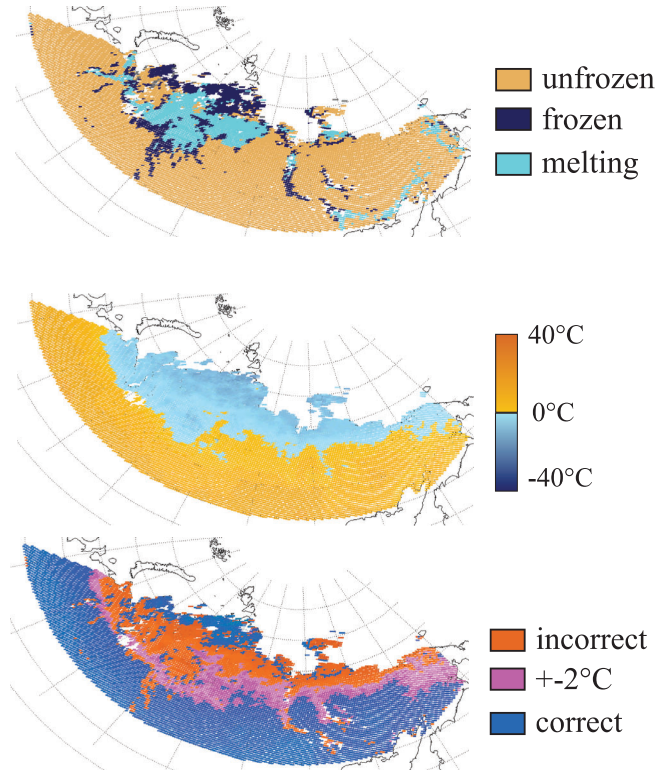

Fig. 3. From top to bottom: SSF, LST and classification results for 8-day period 19, 2007.

freezing of the soil lags behind the first occurrence of slightly negative LST because of the time water requires to change its phase from liquid to solid. It also has to be noted that it could be that the LST is generally slightly cooler than the "real" spatiotemporal mean temperature [12, 13].

Day-to-day comparison between SAR and scatterometer results show good agreement regarding the general patterns (example in Figure 2). The actual number of SAR acquisitions has been shown to be crucial for the detection of spring melt timing by [2] when compared to QuikScat snowmelt records. This can also be demonstrated by ASCAT comparison for both snowmelt and freeze-up.

4. CONCLUSIONS

A combined use of the LST and ASCAT SSF products may be viable for further use. Additionally snow cover data could be used to make the interpretation of the data during spring easier. SAR derived surface status can, if sufficient sampling is available, provide similar results as with ASCAT but even with higher spatial detail. More frequent temporal sampling with future satellites such as by Sentinel-1 may allow high detail surface status mapping.

5. REFERENCES

[1] V. Naeimi, C. Paulik, A. Bartsch, W. Wagner, R. Kidd, J. Boike, and K. Elger, "ASCAT Surface State Flag (SSF): Extracting information on surface freeze/thaw conditions from backscatter data using an empirical threshold-analysis algorithm," *IEEE Transactions on Geoscience and Remote Sensing*, in press.

[2] S.-E. Park, A. Bartsch, D. Sabel, W. Wagner, V. Naeimi, and Y. Yamaguchi, "Monitoring Freeze/Thaw cycles using ENVISAT ASAR global mode remote sensing of environment.," *Remote Sensing of Environment*, vol. 115, pp. 3457–3467, 2011.

[3] A. Bartsch, R. A. Kidd, W. Wagner, and Z. Bartalis, "Temporal and spatial variability of the beginning and end of daily spring freeze/thaw cycles derived from scatterometer data," *Remote Sensing of Environment*, vol. 106, pp. 360–374, 2007.

[4] A. Bartsch, "Ten years of SeaWinds on QuikSCAT for snow applications," *Remote Sensing*, vol. 2, no. 4, pp. 1142–1156, 2010.

[5] S. Zwieback, A. Bartsch, T. Melzer, and W. Wagner, "Probabilistic Fusion of Ku and C Band Scatterometer Data for Determining the Freeze/Thaw State," *IEEE Transactions on Geoscience and Remote Sensing*, vol. in press, pp. 1–12, 2012.

[6] C. Duguay, A. Soliman, S. Hachem, and W. Saunders, "Circumpolar and regional land surface temperature (LST) with links to geotiff images and netCDF files," doi:10.1594/PANGAEA.775962, 2012.

[7] C. Paulik, T. Melzer, S. Hahn, A. Bartsch, B. Heim, K. Elger, and W. Wagner, "Circumpolar surface soil moisture and freeze/thaw surface status remote sensing products with links to geotiff images and netCDF files.," doi:10.1594/PANGAEA.775959, 2012.

[8] D. Sabel, S.E. Park, A. Bartsch, S. Schlaffer, J.P. Klein, and W. Wagner, "Regional surface soil moisture and freeze/thaw timing remote sensing products with links to geotiff images," doi:10.1594/PANGAEA.779658, 2012.

[9] K. Elger, B. Heim, A. Bartsch, C. Paulik, C. Duguay, S. Hachem, A. Soliman, H. Lantuit, J. Boike, and F.-M. Seifert, "Evaluation of ESA DUE Permafrost remote sensing products using global permafrost networks (GTN-P)," in *Proceedings of the Tenth International Conference on Permafrost*, 2012.

[10] A. Bartsch, V. Naeimi, S.-E. Park, and D. Sabel, "Active microwave satellite data for high latitude panboreal/arctic permafrost monitoring," in *Proceedings of The Earth Observation and Water Cycle Scieny Conference, Frascati, November 2009*. 2009, ESA.

[11] W. Zhengming, "MODIS land-surface temperature algorithm theoretical basis document (LST ATBD)," Tech. Rep., Institute for Computational Earth System Science University of California.

[12] S. Westermann, M. Langer, and J. Boike, "Systematic bias of average winter-time land surface temperatures inferred from MODIS at a site on Svalbard, Norway," *Remote Sensing of Environment*, vol. 118, pp. 162–167, Mar. 2012.

[13] A. Soliman, C. Duguay, S. Hachem, W. Saunders, and K. Kang, "Estimating thermal offset between land surface and screen height air temperature over the pan-Arctic region using operational satellite images," *Geophysical Research Abstracts, EGU2011-11773*, 2011.