USER INTERACTION WITHIN THE FRAMEWORK OF ESA DUE PERMAFROST: A CIRCUM-POLAR REMOTE SENSING SERVICE FOR PERMAFROST

B. Heim[(1)], A. Bartsch[(2)], K. Elger[(1)], C. Duguay[(3)], F.M. Seifert[(4)] & the DUE Permafrost Team[(5)]

[(1)] *Alfred Wegener Institute for Polar and Marine Research, 14473 Potsdam, Germany, Email: birgit.heim@awi.de; Kirsten.elger@awi.de*
[(2)] *Department of Geodesy and Geoinformation, Vienna University of Technology, 1040 Vienna, Austria, Email: annett.bartsch@.tuwien.ac.at*
[(3)] *Interdisciplinary Centre on Climate Change, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada, Email: crduguay@uwaterloo.ca*
[(4)] *European Space Agency, ESRIN, 00044 Frascati, Italy, Email: frank.martin.seifert@esa.int*
[(5)] *http://www.ipf.tuwien.ac.at/permafrost/*

ABSTRACT

Permafrost has been addressed as one of the Essential Climate Variables (ECV's) in the Global Climate Observing System (GCOS). The objective of the Data User Element (DUE) Permafrost project funded by the European Space Agency (ESA) was to establish a permafrost-related monitoring system based on satellite data. The international permafrost research community requires permafrost-related end-products that are valid for high-latitude landscapes. The products are regional and circumpolar Land Surface Temperature (LST), Surface Soil Moisture (SSM), ground frozen/ non frozen state, terrain parameters, Land Cover, and surface waters.

Climate and permafrost modelers as well as field investigators are associated users including the International Permafrost Association (IPA). This paper provides detail on the user interaction, how the products were evaluated using data of the Global Terrestrial Network for Permafrost (GTN-P) and how remote sensing shall provide information on the current state of permafrost and add value to the existing ground-monitoring networks and model-based approaches.

1. DUE PERMAFROST PROJECT

The ESA DUE Permafrost project provides a circumpolar Remote Sensing Service for permafrost-related applications [1][2][3]. Permafrost is a subsurface phenomenon, i.e. frozen ground below 0 °C for at least two consecutive years (IPA) and cannot be directly observed with remote sensing. In February 2008, the ESA held an expert consultation workshop at the Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany. Aims were to define permafrost indicators which are observable from space, describe opportunities for trend analyses from data archives (Earth Observation and in-situ), generate a strategy for present Earth Observation capabilities, and develop recommendations for a future permafrost monitoring program.

The project itself started in June 2009. The DUE Permafrost consortium is led by the Vienna University of Technology, Austria (TUW) and supported by four partners: University of Waterloo (UW, Interdisciplinary Centre on Climate Change, Canada), Friedrich Schiller University (FSU, Department of Remote Sensing, Jena, Germany), Gamma Remote Sensing (GAMMA, Switzerland), and the Alfred Wegener Institute for Polar and Marine Research (AWI, Potsdam, Germany). TUW is responsible for all parameters based on microwave remote-sensing technology (SSM, Freeze/Thaw and Surface Waters). The UW provides spatio-temporally gridded higher level products for the Land Surface Temperature Services (LST). The FSU is responsible for land cover and burned areas products. GAMMA assembled national DEM data-sets and build-up the first circumpolar Digital Elevation Model (DEM) dataset with 100 m pixel resolution north of 55°N. AWI organized the exchange between the scientific stakeholders of the permafrost community and the project consortium, including the management of ground data and the adaptation of remote sensing products into the modeling.

The first phase comprised the collection of user requirements, the definition of a monitoring strategy, the service design engineering, and the system development. Researchers from permafrost monitoring and modeling groups (permafrost, climate) provided feedback to a survey based on questionnaires in 2009.

As part of the user requirement engineering, the user survey did not only include the collection of requirements but also an assessment on ground data availability. The location and extent of service case areas has been defined based on the user feedback (see Fig. 1).

The observation strategy of the project ranges from local indicators to regional and circumpolar geophysical parameters that are required by the modeling communities. Local permafrost-related indicators are surface water dynamics and surface elevation changes, and are provided by experimental products. The DUE Permafrost remote sensing products are regional and circumpolar LST, SSM, ground frozen/ non frozen state, terrain parameters, Land Cover, and surface waters.

The data products are freely downloadable via http://www.ipf.tuwien.ac.at/permafrost and are published at the PANGAEA World Data Centre [4]. The ongoing service will also include the time series of 2011 and 2012 for selected parameters.

The snow parameters (snow extent and snow water equivalent) can be derived from the DUE project GlobSnow (http://www.globsnow.info).

2. DUE PERMAFROST PRODUCTS & SERVICE

Pan-boreal/ arctic products cover all permafrost affected areas north of 55°N [2][3]. Five regional service cases were identified based on ground data availability and user requirements (see Fig. 1). These regions are:

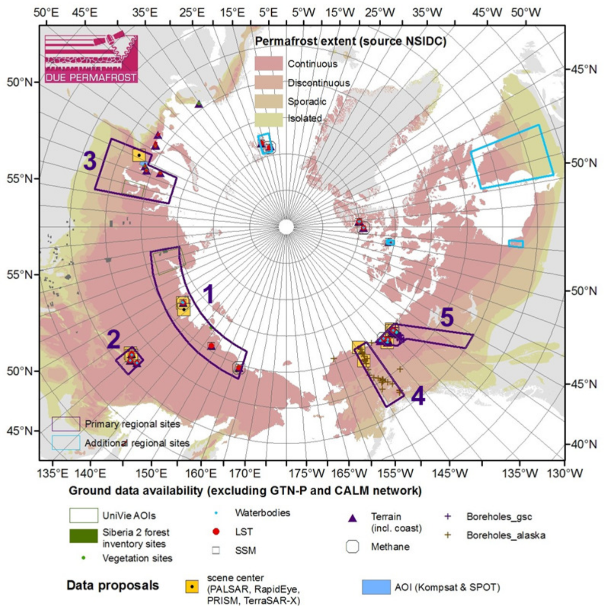

Figure 1: Key regions of the DUE Permafrost project. See text for explanation.

(1) the Laptev Sea and Eastern Siberian Sea region including East Taymir, Lena-Delta and Cherskii (RU; continuous very cold permafrost/tundra), (2) the Yakutsk region (RU; continuous cold permafrost/taiga), (3) the Western Siberian transect (RU; continuous to discontinuous/ taiga-tundra) including the Yamal Peninsula and the Ob region, (4) the Alaska North Slope/ Borehole transect (US; continuous to discontinuous/taiga-tundra), and (5) the Mackenzie Delta and Valley Borehole Transect (CA; continuous to discontinuous/taiga-tundra)

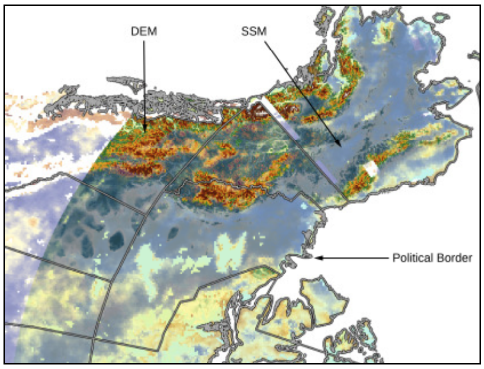

Figure 2: Visualization of layers within the DUE Permafrost WEB-GIS. The layer of the SSM overlaps the layer of the DEM. The opacity of SSM has been set to the value 0.5 so that the DEM is shining through. Projection is polar stereographic (from [5])

Remote sensing products are regional and circumpolar LST, SSM, ground frozen/non frozen state terrain parameters, land cover parameters, and surface waters. Temporal coverage varies from product to product. The overlapping period for all products is 2007 to 2009. The time series of the circumpolar LST and SSM offer weekly and monthly averaged data products from 2007 to 2010. Circumpolar ground frozen/ non frozen state is based on the MetOp ASCAT Surface Status Flag (SSF) as daily dataset. The circumpolar terrain and land cover products are static. More detailed information is given in [1].

The Permafrost Processing System Earth Observation (PEO) follows a modular approach to take into account the different data sources and product contributors [2]. Automated processing chains for database updates have been implemented for LST, SSM, SSF on ground frozen/ non frozen state and surface waters. Static components (no regular updates, although time series partly available) are land cover and terrain parameters.

A dedicated GeoServer has been set up for data catalogue query and download [1]. Users need to register and obtain a user login.

Download dataset as tab-delimited text *(use the following character encoding: ISO-8859-1: ISO Western (PANGAEA default))*

1 Author(s)	2 Year	3 Title	4 File name	5 URL data
Duguay, C; Hachem, S; Soliman, A	2012	Land Surface Temperature (LST) with links to geotiff images and netCDF files	DUEPermafrost_LST	doi:10.1594/PANGAEA.775962
Paulik, C; Melzer, T; Hahn, S; Bartsch, Heim, B; Elger, K; A; Wagner, W	2012	Circumpolar surface soil moisture and freeze/thaw surface status remote sensing products with links to geotiff images and netCDF files	DUEPermafrost_ALANIS_SSM_F_T	doi:10.1594/PANGAEA.775959
Sabel, D; Park, S-E; Bartsch, A; Schlaffer, S; Klein, J-P; Wagner, W	2012	Regional surface soil moisture and freeze/thaw timing remote sensing products with links to geotiff images	DUEPermafrost_SAR_SSM_F_T	doi:10.1594/PANGAEA.779658
Santoro, M; Strozzi, T	2012	Circumpolar digital elevation models > 55° N with links to geotiff images	DUEPermafrost_DEM	doi:10.1594/PANGAEA.779748
Schlaffer, S; Sabel, D; Bartsch, A; Wagner, W	2012	Regional water bodies remote sensing products with links to geotiff images	DUEPermafrost_water	doi:10.1594/PANGAEA.779754
Urban, M; Hese, S; Herold, M; Pöcking, S; Schmullius, C	2012	A fractional vegetation cover remote sensing product on pan-arctic scale, version 2, with link to geotiff image	DUEPermafrost_LandCover	doi:10.1594/PANGAEA.780464

Figure 3: The parent for the ESA DUE Permafrost complete data set with the DOI child data sets for each product [4].

Table 1 Publications related to DUE Permafrost:

focus on the DUE Permafrost project	Bartsch et al., 2012 (IGARSS Munich, DE), Bartsch et al., 2010 (ESA Bergen, NO); Heim et al.; 2011 (EARSeL)
land surface temperature at high latitudes	Soliman et al., 2012 (RS); Hachem et al., 2012 (Cryosphere); Duguay et al., 2010 (ESA Bergen, NO)
surface soil moisture at high latitudes	Bartsch et al., 2012 (TICOP Salechard, RU), Bartsch et al., 2011 (IGARSS Vancouver, CA); Sabel et al., 2012 (IGARSS Munich, DE);
freeze/thaw at high latitudes	Naeimi et al. 2012 (IEEE), Paulik et al., 2012 (IGARSS Munich, DE); Park et al. 2011 (RSE); Park et al. 2010 (IGARSS Hawaii, US);
surface waters at high latitudes	Bartsch et al., 2012 (BGS); Trofaier et al., 2012 (TICOP Salechard, RU);
land cover at high latitudes	Urban et al., 2009 (PFG); Pöcking et al., 2010 (ESA Bergen, NO)
focus on evaluation of RS-derived parameters	Westermann et al., 2012 (RSE), 2011 (RSE); Elger et al. 2012 (TICOP Salechard, RU); Langer et al. 2010 (RSE); Heim et al., 2010 (ESA Bergen, NO)

BGS=BioGeoSciences; ESA=ESA Living Planet; IGARSS = International Geoscience and Remote Sensing Symposium; IEEE = IEEE Transactions on Geoscience and Remote Sensing; PFG=Photogrammetrie Fernerkundung Geoinformation; RS = Remote Sensing; RSE=Remote Sensing of Environment; TICOP = 10th International Conference on Permafrost; EARSeL= EARSeL eProceedings

A Web-GIS Service has been implemented for visualization with user-defined styling tools [1][5] (Fig. 2).
The DUE Permafrost dataset is also published in the Pangaea World Data Center: ESA Data User Element (DUE) Permafrost: Circumpolar Remote Sensing Service for Permafrost (Full Product Set) with links to datasets, with doi:10.1594/PANGAEA.780111 (DUE Permafrost Project Consortium 2012 [4]; see Fig. 3).

3. PRODUCT EVALUATION

Most of the foreseen DUE Permafrost remote-sensing applications were well established and can optimally become operational. However, permafrost landscapes are a challenge for qualitative and quantitative remote sensing. The permafrost landscape is characterized by high heterogeneity, patterned ground, disturbances, abundance of small-sized water bodies, and sharp moisture gradients.
Evaluation was essential to test the scientific validity of the DUE Permafrost data products for these high-latitude permafrost landscapes. There exist no standard evaluation methods for the broad range of remote sensing products within DUE Permafrost, specifically not for permafrost landscapes. DUE Permafrost followed the strategy of the Blended Evaluation – a mixture of strategies and methods using quantitative and qualitative metrics. Evaluation experiments and inter-comparison was done on a case-by-case basis, adding value and experience in validating products for Northern High Latitudes.
An additional and important component was the evaluation of the DUE Permafrost products also by the user organizations to lend confidence in their scientific utility for high-latitude permafrost landscapes. Ground measurements in arctic permafrost regions involve challenging logistics and are networked on multidisciplinary and circum-arctic level by the permafrost community. The IPA initiated the Global Terrestrial Network for Permafrost (GTN-P) to organize and manage a global network of Permafrost observatories for detecting, monitoring, and predicting climate change. A major part of the DUE Permafrost core user group is contributing to GTN-P. The network, authorized under the GCOS and its associated organizations, has been thoroughly overhauled during the International Polar Year (2007-2008) and extended to provide a true circum-arctic network. All GTN-P data is freely accessible via the World Wide Web.
Descriptive truth provides the qualitative evaluation using field description, field photos, and expert information. Match-up data sets of ground data coincident in time and location with satellite observations were being built up.
For the DUE Permafrost products MODIS LST and ASCAT SSF, temperature was the evaluating parameter. [6] and [7] describe the evaluation of MODIS LST for several sites in Alaska and Canada. The correlation between air and soil temperature and MODIS LST shows a high correlation coefficient for the period of almost four years (R^2 = 0.98). [6] also demonstrates that it is possible to use time series of daily averaged air temperatures, which are available for much more sites than data with hourly resolution, for the evaluation of the LST products.
Recent publications on the evaluation of ASCAT SSF can be found in [6] and [8]. The accuracy of the ASCAT SSF has been assessed with air and near surface temperature measurements at permafrost boreholes in Western Siberia and Alaska. The agreement was in general >90 % (and >80 % at grid points in proximity to coasts)(see Fig. 3).
Associated with GTN-P, soil moisture time series were obtained from the United States Department of Agriculture (USDA) where measurements are made at 20-minute intervals and averaged and recorded every hour. Daily average values are available for download. The first positive evaluation results of the DUE Permafrost ASCAT Surface Soil Moisture Product were described in [9].

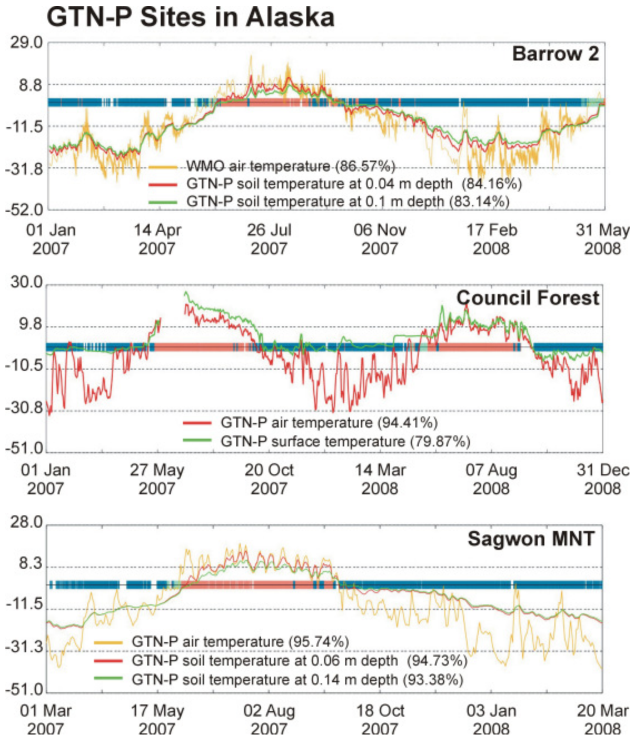

Figure 3: Time series of SSF and temperature data (2007-2008) for GTN-P sites Barrow-2, Council Forest, Sagwon-MNT in Alaska (US). The quality of the correlation is given in [% agreement]. Figure in [6], more detailed information in [8].

Evaluation experiments were also a major component of the joint ESA-DUE Permafrost – NASA Land-Cover and Land-Use Change LCUCL Yamal Workshop in January 2011 at the AWI as scientific exchange between two large programs focusing on Remote-Sensing Applications in Northern High-Latitudes. The first outcomes are that the classification of tundra landscapes as 'sparse, i.e. <15 % vegetation cover' is erroneous and will in turn lead to wrong parameterization of external input parameters into models for albedo, thermal emissivity, thermal ground fluxes, and others [3]. DUE Permafrost is preparing a statistical report on the evaluation of Land Cover in Northern High Latitudes using the GTN-P data in cooperation with the IPA.

There are only a limited number of well-described and multi-instrumented field sites in the Arctic. The long-term and multi-instrumented Russian-German Samoylov Station in the Lena River Delta (Arctic Siberia) is one of the prime sites of the AWI research program. Land surface classification is obtained through high-spatial resolution spectral-imaging using unmanned vehicles, kites, and zeppelins. Therefore, the Samoylov Island in the Lena River Delta has become a test site for evaluation of DUE Permafrost products for the landscape type wet polygonal tundra. Evaluation studies and experiments have been described in detail in [3][6][7][8][9][10][11][12][13].

The involvement of scientific stakeholders and the IPA, and the ongoing evaluation of the remote sensing derived products make the DUE Permafrost products widely accepted by the scientific community. The project has been featured in the annual news bulletin of the IPA (http://ipa.arcticportal.org/publications/frozen-ground) 'Frozen Ground' in Issue 34, 2010 and 35, 2011.

4. DISCUSSED ADDED VALUES OF REMOTE SENSING PRODUCTS

As a concept within the ESA DUE programs, user workshops are an important tool for the interaction between the scientific user's community and remote sensing experts. The 1st DUE Permafrost User Workshop was held in May 2010 in Vienna as an official side-event of the EGU General Assembly. The observation strategy for all products and regions was presented by the project team and reviewed with the participants.

The service has been also demonstrated and validated during the second phase. The first version of the full dataset has been released in the beginning of 2011 and could be assessed and discussed at the 2nd DUE Permafrost User Workshop that took place from March 2 to 4, 2011, in Fairbanks, Alaska (US). The International Arctic Research Centre, IARC at the University of Alaska Fairbanks (US) hosted and financially supported the workshop that was attended by more than 40 scientists from national and international scientific and governmental institutions. The workshop offered assessments of the released DUE Permafrost products Version 1 via tutorials (using the freely available software packages ESA BEAM-VISAT and Quantum-GIS). During in-depth sessions the participants discussed remote sensing products with respect to modeling and permafrost monitoring. The 3rd DUE Permafrost User Workshop took place at the AWI Potsdam (DE) from February 15 to 17, 2012, back-to-back with the final ESA STSE ALANIS User Workshop, with overall 62 participants from Austria, Canada, Finland, France, Germany, Italy, Japan, Norway, Poland, Russia, Sweden Switzerland, UK, and the US (22 oral and 20 poster presentations). The workshop started with a welcome by Prof. Dr. Hans-Wolfgang Hubberten, appointed IPA-President.

The presentation of recent international remote sensing programs included GlobSnow, STSE Northern Hydrology, CoastColour, STSE-Alanis, EuRuCAS and MONARCH-A by various speakers representing these programs. Projects on remote sensing in permafrost areas on various scales were presented using data from e.g. interferometry, gravimetry (GRACE) and satellite altimetry (catchment hydrology).

The Workshop then offered discussion sessions on remote sensing products as drivers and boundary parameters for permafrost and climate modeling, and remote-sensing applications for permafrost monitoring. Arctic climate modelers pointed out that permafrost land surface conditions are more and more implemented

Figure 4: 2nd User Workshop at the International Arctic Research Centre, University of Alaska, Fairbanks, March 2011

to run regional models. Researchers involved in permafrost monitoring are interested in the highest possible spatial and temporal resolution of all parameters. High-spatial resolution data is needed for the up-scaling and evaluation/ validation processes and has been explicitly claimed by a wide range of researchers and by the IPA as a must for permafrost observations. Remotely sensed data shall provide information on relief and vertical and horizontal change detection where the disturbances are mainly due to subsidence and erosion processes. Users inform that numerous types of permafrost landscapes are covered by small to medium-sized water bodies, ponds, and lakes. The area percentage of water bodies in the coarser-scale remote sensing pixel needs to be known to understand the physical and bio-physical properties of products.

The following modeling groups provided feedback:

- Geophysical Institute Permafrost Lab Model GIPL (Fairbanks, US)
- Lund-Potsdam-Jena Dynamic Global Vegetation Model LPJ (Jena, DE)
- Minimal Advanced Treatments of Surface Interaction and Runoff Model MATSIRO (Fairbanks, US)

Table 2 gives a summary of model requirements. All models require near-surface air temperature as forcing parameter. For atmosphere-coupled calculations only monthly averages are required and pseudo intra-monthly variations can be calculated. The required parameter accuracy of the temperature product is high around the freezing point (~0.1°C), and 1°C when far from the freezing point.

Soil moisture, the snow water equivalent, and optionally the water body ratio within a grid point are used for initialization and validation. Since soil moisture is a prognostic value in the model, moisture-related values are important in terms of model performance validations. Parameter accuracy for 'soil moisture' should be 5 to 10 % of the volumetric water content. The modeling community was also interested in surface parameters that may be extracted from satellite-derived data including roughness criteria, biomass patterns, snow properties, and land surface temperatures across the North validated by in-situ surface measurements.

Table 2: Summary of model requirements

spatial coverage	largest possible coverage: panarctic
classes of required spatial resolution	<1 km information for up-scaling 10 km, 25 km, 0.1°
required driving forces	**near-surface air temperature** (required, highest priority): *seasonal range of air temperature variations, monthly near-surface air temperature, mean annual air temperature* **soil moisture** (required for initialization and validation) *moisture content at different depths, freeze/thaw-degree days, solid-liquid ratio* **snow water equivalent, snow coverage**
classes of boundary parameters	[fixed] **land cover**: *vegetation physiognomy / bare soils / water body/ sand / peatland / moss /; area percentage of water body; area percentage of vegetation physiognomy, area percentage of bare soil* [fixed] **elevation** and **topography** *variance and aspect* [variable] **albedo** *i.e. no snow, no leaf condition* [variable, e.g. monthly] **leaf area index LAI**

5. OUTLOOK

The following parameters had been identified as sufficiently mature to be included into the Permafrost Information System – Earth Observation (PEO): Land Surface Temperature, Land Cover (incl. vegetation and water bodies), Surface Soil Moisture, ground frozen/ non frozen state, and terrain parameters. Snow extent and snow water equivalent is currently available from DUE GlobSnow.

The present service relies only partly on operational services. Only acquisitions from Metop ASCAT (soil moisture and surface status) are ensured in the future. Land surface temperature monitoring is based on MODIS and complemented by ENVISAT AATSR. Regional services for land surface hydrology rely on ENVISAT ASAR. Regional to pan-arctic services can be continued on the long term based on the GMES Sentinel program and ESA CCI initiatives.

Snow depth and structure are of high interest for permafrost modeling since these parameters influence winter time heat-conductivity. Therefore dedicated missions, such as the proposed CoReH2O, would be beneficial for future permafrost monitoring.

Further experimental applications of the DUE Permafrost products are experimentally developed by the DUE Permafrost team and modeling groups (permafrost and climate). Two modeling groups joined this experiment: the climate modeling groups of AWI with the

- *HIRHAM4 - regional climate model (RCM) for the Arctic,*

and the HZG Helmholtz Research Centre Geesthacht, Germany with the

- *regional climate model COSMO-CLM (climate version of the COSMO numerical weather prediction model)*

Within the EU project PAGE21 'Changing permafrost in the Arctic and its Global Effects in the 21st Century', that has started in 2011, more modeling groups are being actively involved (www.page21.eu).

The experiments carried out will range from (i) the evaluation of external data of the models, with modifying or providing new external data (e.g. tundra land cover, surface water ratio for permafrost regions, soil distribution), to (ii) new drivers for regional models derived from remote sensing (e.g., Land Surface Temperature), and (iii) the evaluation of the output data from the modeling (e.g. spatial patterns of moisture and temperature).

6. REFERENCES

1. Bartsch, A., Seifert, F.M. & DUE Permafrost team (2012). The ESA DUE Permafrost project - a service for high latitude research. Proc. IGARSS, Munich 2012.

2. Bartsch, A., Wiesmann, A., Strozzi, T., Schmullius, C., Hese, S., Duguay, C., Heim, B. & Seifert F. M (2010). Implementation of a satellite data based permafrost information system - The DUE Permafrost Project. Proc. ESA Living Planet Symposium, Bergen, 2010.

3. Heim, B., Bartsch, A., Elger, K., Lantuit, H., Boike, J. Muster, S., Langer, M., Duguay, C., Hachem, S., Soliman, A., Paulik, Chr., Strozzi, T. & Seifert, F.-M. (2011). ESA DUE Permafrost: an Earth Observation Permafrost Monitoring System. EARSeL eProceedings, 10(2), 73-82.

4. DUE Permafrost Project Consortium (2012): ESA Data User Element (DUE) Permafrost: Circumpolar Remote Sensing Service for Permafrost (Full Product Set). doi:10.1594/PANGAEA.780111.

5. Stabel, F. (2012). User-driven Manipulation of Geospatial Data. Diploma Thesis, Technical University of Vienna, pp.87.

6. Elger, K., Heim, B., Bartsch, A., Paulik, C., Duguay, C., Hachem, S., Soliman, A., Lantuit, H., Boike, J. & Seifert, F.-M. (2012). Using ground data from the Global Terrestrial Network of Permafrost (GTN-P) for the evaluation of the ESA DUE Permafrost remote sensing derived products land surface temperature and surface frozen and thawed status. 10^{th} Int. Conf. on Permafrost, TICOP2012, Salechard, Russia.

7. Hachem, S., Duguay, C. & Allard, M. (2012). Comparison of MODIS-derived land surface temperatures with near-surface soil and air temperature measurements in continuous permafrost terrain, The Cryosphere, 6, 51-69.

8. Naeimi, V., Paulik, C., Bartsch, A., Wagner, W., Kidd, R., Park, S. E., Boike, J. & Elger, K. (2012). 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, Special Issue on Recent Advances in C-band Scatterometry.

9. Bartsch, A., Melzer, T., Elger, K. & Heim, B. (2012). Soil moisture from satellite data at high latitudes. 10^{th} Int. Conf. on Permafrost, TICOP2012, Salechard, Russia.

10. Langer, M., Westermann, S. & Boike, J. (2010). Spatial and temporal variations of summer surface temperatures of wet polygonal tundra in Siberia - implications for MODIS LST based permafrost monitoring. Remote Sensing of Environment, 114(9), 2059-2069.

11. Westermann, S., Langer, M. & Boike, J. (2011). Spatial and temporal variations of summer surface temperatures of high-arctic tundra on Svalbard - Implications for MODIS LST based permafrost monitoring. Remote Sensing of Environment, 115(3), 908-922.

12. Westermann, S., Langer, M. & J. Boike (2012). Systematic bias of average winter-time land surface temperatures inferred from MODIS at a site on Svalbard, Norway. Remote Sensing of Environment, 118, 162-167

13. Soliman, A., Duguay, C., Saunders W. and Hachem, S. (2012). Pan-Arctic Land Surface Temperature from MODIS and AATSR: Product Development and Intercomparison. Remote Sensing. 2012, 4(12), 3833-3856.