THE LENA RIVER DELTA, ARCTIC SIBERIA: AN ARCTIC GROUND DATA OBSERVATORY OF THE DUE PERMAFROST REMOTE SENSING PROJECT

B. Heim[(1)], A. Bartsch[(2)], J. Boike[(1)], M. Langer[(1)], H. Lantuit[(1)], S. Muster[(1)], T. Opel[(1)], K. Piel[(1)], G. Stroof[(1)], and F.M. Seifert[(3)]

[(1)]*Alfred Wegener Institute for Polar and Marine Research, 14473 Potsdam, Germany, Email: birgit.heim@awi.de*
[(2)]*Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, 1040 Vienna, Austria, Email: ab@ipf.tuwien.ac.at*
[3]*European Space Agency, ESRIN, Frascati, Italy, Email: frank.martin.seifert@esa.int*

ABSTRACT

Permafrost landscapes are a challenge for the validation of remote sensing products. The land surface is characterized by high heterogeneity, patterned ground, disturbances, abundance of small-sized water bodies, and sharp moisture gradients. A significant challenge in the evaluation of remote sensing products for high-latitude permafrost landscapes are the very sparse ground data: there are only a limited number of well-described and multi-instrumented field sites.

Within the ESA Data User Element DUE PERMAFROST project an important component is the evaluation and the assessment by the users and remote sensing experts to lend confidence in the scientific utility of the DUE PERMAFROST products.

The long-term and multi-instrumented Russian-German Samoylov Station in the Lena River Delta (Arctic Siberia) is a prime site for evaluation in DUE PERMAFROST PERMAFROST and serves as an important platform to answer the following questions:

- Are plot data representative of surrounding parameters at satellite spatial resolutions?
- How are the statistics derived from the match-up analysis against in-situ Diagnostic Data Sets (DDS) (absolute validation)?
- How is the credibility of DUE Permafrost products against ‘descriptive truth’ (relative validation)?

1. INTRODUCTION

1.1. ESA DUE PERMAFROST

The major task of the European Space Agency ESA Data User Element DUE projects is to develop Earth observation services for specific user communities. The DUE PERMAFROST consortium is led by the Vienna University of Technology, Austria, and supported by four partners: Gamma Remote Sensing, Switzerland, Department of Geography and Environmental Management, University of Waterloo, Canada, Department of Remote Sensing, Friedrich Schiller University, Jena, Germany, and the Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany. Since June 2009, DUE PERMAFROST develops a wide range of remote sensing services and products for permafrost monitoring and modeling of permafrost, fluxes and climate [1]: The products are Land Surface Temperature, LST, Surface Soil Moisture, SSM, Land Cover, LC, surface waters and terrain parameters (www.ipf.tuwien.ac.at/permafrost).

The DUE PERMAFROST datasets will be processed in the EO-PERMAFROST Information System and provided on a WebGIS-interface.

1.2. Concept of Evaluation

Match-up data sets of ground data coincident in time and location with satellite observations are being built up for the evaluation of the DUE PERMAFROST data sets.

Ground measurements in the high-latitude landscapes involve challenging logistics and are networked on multidisciplinary and circum-arctic level by the Permafrost community. The International Permafrost Association IPA has built up the Global Terrestrial Network for Permafrost (GTN-P) (www.gtnp.org), that is a network of the Circumpolar Active Layer Monitoring (CALM)*(*www.udel.edu/Geography/calm*)* and the Thermal State of Permafrost (TSP) (http://www.gi.alaska.edu/snowice/Permafrost-lab/ projects/ projects_active/proj_tsp.html).

The CALM and TSP programs have been thoroughly overhauled during the International Polar Year (IPY) and extended their coverage to provide a true circumpolar network. At this stage, the Information System of the IPA is not yet operational, however, it is foreseen that it will heavily rely on existing World Data Centres (WDCs).

A major part of the DUE PERMAFROST core User group is contributing to GTN-P. Additional members of these programs and circumarctic networks have also been involved in the consulting process and ground data providing process.

Within the AWI SPARC project (Sensitivity of Permafrost in the Arctic-a multi-scale approach) ground measurements, airborne data and spaceborne data are retrieved at various temporal and spatial scales. Well-instrumented sites are in the Lena River Delta (Siberia), Spitsbergen (Ny-Alesund) and Canadian High Arctic (Bathurst Island) e.g., [2],[3].

Proc. ‘ESA Living Planet Symposium’, Bergen, Norway
28 June – 2 July 2010 (ESA SP-686, December 2010)

1.3. Meta-Theory of Evaluation

DUE PERMAFROST will undertake the strategy of The Blended Validation - a mixture of strategies and methods using quantitative and qualitative metrics. The data sets to be evaluated are on local / regional / pan-permafrost scales: LST, SSM & freeze/thaw, surface waters, LC, methane, Digital Elevation Model (DEM) & subsidence.

The evaluation will be conducted using absolute and descriptive methods and using thematic and regional knowledge to assess

- the temporal variability
- the regional variability
- the scaling variability

The absolute validation is against in-situ Diagnostic Data Sets (DDS) using match-ups. The seasonal variability is investigated matching the mean values and standard deviations from weekly and monthly products at regional province scale, at local scale and at ecosystem scale. The inter-annual variability is investigated matching the mean values and standard deviations from monthly products/ year and yearly products.

Diagnostic Data Sets DDS are temperature (soil/surface/air), moisture (surface/soil), freeze/thaw, active layer depth, snow height, methane (air), terrain, (GPS, dGPS), land cover (aerial maps), surface water (water level, aerial maps). The expert information will provide the qualitative evaluation (thematic/regional) using 'descriptive truth': (field description, field photos, expert information).

2. LENA RIVER DELTA OBSERVATORY

2.1. Samoylov Island, Lena River Delta

Since 1998, the Alfred Wegener Institute for Polar and Marine Research (AWI) in collaboration with the Lena Delta Reserve in Tiksi is operating a German- Russian research station on Samoylov Island (72° 22' N, 126° 28' E), in the central delta *(Fig. 1)*. The Lena River Delta (about 29,000 km^2) is a key region for understanding permafrost in the Siberian Arctic: permafrost formation and decay, thermal and hydrological studies on the active layer, transformation and emission of green house gases.

Samoylov Island (~ 1200 ha) is centrally located and part of the young Holocene delta. The measurement stations and experimental plots are located on the main island terrace.

The main terrace is characterised by a wet polygonal tundra landscape with mossy tundra and wet fen and flooded sedge communities. The mean annual air temperature is -13.6 °C, the annual precipitation: 263 mm, the snow-free period is from June to September. It is cold continuous permafrost.

Figure 1. on the right: airborne quasi-true colour orthophoto-mosaic (AWI-SPARC) of the Samoylov Island, Lena River Delta, Arctic Siberia.

2.1. The Measurement Field, Samoylov Island

The Samoylov Station is a multi-instrumented measurement field that has been fully developed by the SPARC project (Sensitivity of Permafrost in the Arctic- a multi-scale approach) *http://www.awi.de/en/go/sparc*. Automatic stations are continuously logging relevant parameters (air temperature, radiation, snow, soil temperature and moisture). SPARC automatic thermal infrared TIR camera measurements mounted on high masts provide an innovative upscaling temperature measurement technique [4]. SPARC land surface classification is obtained through high spatial resolution spectral imaging (VIS, NIR) using unmanned vehicles, kites and zeppelins [5].

Meteorological Stations (since 1998)

Parameter	Instrument
Rainfall	Tipping bucket rain gauge ARG 100 / EC
Wind speed	Young Anemometer 05103-5
Temperature 0,5 m	Rotronic MP 103A
Temperature 2 m	Rotronic MP 103A
Relative humidity 0,5 m	Rotronic MP 103A
Relative humidity 2 m	Rotronic MP 103A
Radiation	Q7 Net Radiometer REBS, USA (1999-2000) Kipp & Zonen Net Radiometer NR-Lite (2000-2008)
Snow height	Campbell Scientific Sonic Ranging Sensor SR50

Soil Stations (since 1998)

	1998-2002		2002-current		
	Slope	Apex	Center	Slope	Apex
Depth (cm)	7, 13, 23, 32, 42	6, 9, 15, 28, 37	1, 5, 10, 20, 30, 40	3, 7, 16, 22, 32, 42	2, 6, 11, 16, 21, 27, 33, 38, 51, 61, 71

Parameter	Instrument
Soil temperature	Campbell Scientific Thermistor Probe 107
Soil moisture	Campbell Scientific CS 605

Thermal Upscaling Experiments (SPARC)

Instrument	Time
Infra Tec Variocam HR 8	Summers 2008, 2009

Aerial Imagery (SPARC)

Parameter	Instrument
VISIBLE	VIS Nikon D200 (07/2006, 07/2007, 08-09/2008)
NIR	NIR Nikon D200 (08-09/2008)

3. EVALUATION ASSESSMENTS

3.1 Land Surface Temperature LST

To investigate the thermal upscaling, an automated Thermal-InfraRed TIR camera (Uncooled Micro-Bolometer, 7.5 to 14 µm) has been mounted on high masts in the Lena River Delta *(Fig. 2)* and Spitsbergen [4]. The upscaled thermal camera measurements cover the summer months in 2008 and 2009 at both sites. The authors [6] describe their successful experimental thermal upscaling for typical wet tundra landscape and also have been successful in thermal upscaling experiments at the Spitsbergen permafrost site Ny-Alesund (barren–moss and lichen cover–water) [7].
The authors conclude that:
-The spatial surface temperature variations at both highly heterogeneous sites are greatly reduced for averaging periods longer than the diurnal cycle. This has strong implications for satellite based permafrost monitoring schemes, since the validity of surface temperature averages is not affected by unresolved landscape heterogeneities, except for the free water bodies.

Figure 2. Samoylov Island, SPARC set-up for thermal upscaling: TIR camera mounted on 10 m mast, summer 2008.

-Water bodies show sustained differences in surface temperature to the remaining surface. Hence, high resolution land-water masks are essential for the interpretation of satellite LST products, since unresolved water bodies can bias the satellite observations, if a high fraction occurs in the satellite footprint area.
-The success rate of MODIS LST data acquisition is limited due a frequent cloud cover, which is typical for arctic regions. Reliable surface temperature averages therefore require the development of gap filling procedures. Furthermore, the satellite data are biased by occasional erroneous measurements, which are caused by an incorrect cloud cover mask.

3.2 Surface Soil Moisture SSM

Microwave based soil moisture dataset have so far rarely been validated over high latitudes [8]. It is thus required to extent these validation activities within the DUE Permafrost project. There is sufficient ENVISAT ASAR GM coverage at the Lena River Delta in order to also allow retrieval of near surface soil moisture at medium scale using a time series approach [9],[10].
At the soil stations, the TDR Sensor depth profiles are deployed at the centre and at the apex of a representative low centred polygon (*Fig. 3).* The measurements closest to the surface have been compared to ENVISAT ASAR GM soil moisture measurements (1x1km, after exclusions of measurements under frozen ground conditions) for two locations on the island during Summer 2005 and 2006.
The dynamics of the surface wetness captured with ENVISAT ASAR Global Mode relate to soil moisture measured at the centre of low lying polygons. These conditions are dominant for Samoylov Island [5]. The variations are similar for different sites of the island.

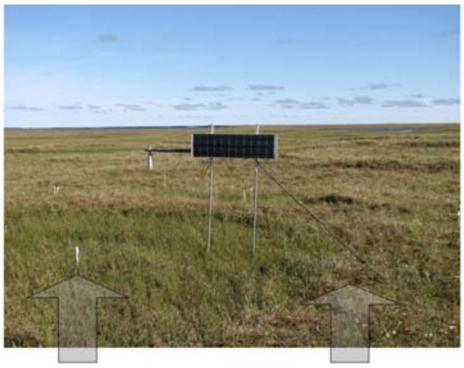
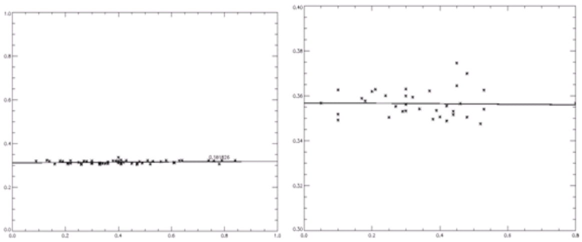


Figure 3. Location of TDR sensors in polygon centre and on apex on Samoylov Island.

a) surface, apex

2005 2006



b) ***surface, centre***

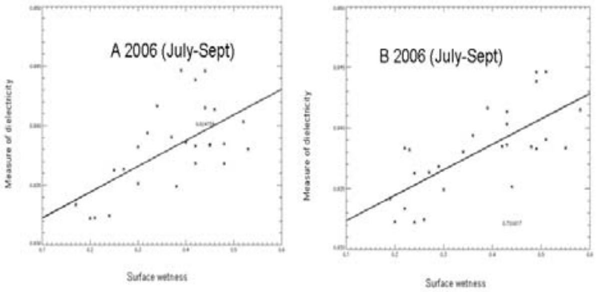


Figure 4. Comparison of ASAR GM surface wetness and in situ TDR measurements
a) surface apex, 2005 and 2006,
b) surface center, at 2 locations (A and B), 2006 .

3.3 Land Cover LC

High spatial resolution land surface classification is obtained using VIS, NIR and TIR cameras on unmanned platforms (kites, zeppelins) [5]. The airborne VIS and NIR data are acquired with Nikon D200 cameras and feature a resolution of up to 0.3 m. The SPARC orthophoto-mosaic of Samoylov Island has been constructed with oblique acquisitions. Multi-temporal nadir airborne VNIR imagery has been acquired in 2006, 2007 and 2008 to map seasonal and intra-annual dynamics of surface water, moisture, and vegetation.The authors [5] extracted a water body ratio of 0.2 that they assign to the moist to wet polygonal tundra landscape.

Figure 5. The SPARC helium-filled dirigibles on Samoylov Island.

This is relevant as meta-data information for the DUE PERMAFROST products and grids. The spatial high resolution of the surface water product will support validation and scaling investigations. The smallest water bodies already disappear in mixed pixels with resolutions as small as 5m (e.g., extracted from RapidEye). A high fraction of surface water within geo- and bio-physical parameter pixels will considerably influence the values, e.g. regarding surface resistance as input for modeling of the near-surface energy and water budget.

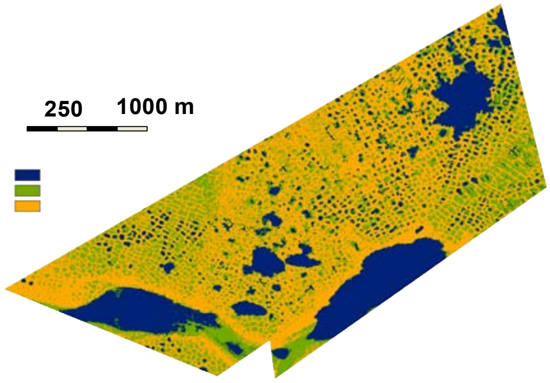


Figure 6. [5] 2008-08-09, airborne VNIR LC, Samoylov Island , UTM, WGS84 .
multispectral classification
blue: surface waters (22.5%);
green: wet (47%);
yellow: moist (30.5%).

4. SUMMARY

Most of the foreseen DUE PERMAFROST remote sensing applications are well established and can optimally become operational. The goal of DUE PERMAFROST is to lend confidence in their scientific utility for high-latitude permafrost landscapes.

There are no standard evaluation methods for all the diverse remote sensing products within DUE PERMAFROST, specifically not for these latitudes. Evaluation experiments and intercomparison is done on a case-by-case basis, adding value and experience in validating products for these regions.

A poor agreement between the satellite and ground-based estimates will not necessarily mean that the products are performing poorly. The authors need to investigate the 'true values' of what the satellite sensor 'sees' in terms of the ground-based estimates. For scaling and verification issues, investigation of the water body fraction in the pixels will be essential.

The multi-instrumented Arctic Russian-German Samoylov Station in the Lena River Delta is a prime site for the evaluation and the understanding of DUE PERMAFROST products. It allows to deeply

investigate the clustering of the match-up data according to vegetation and moisture dependences and intra- and inter-annual variations, and to investigate scaling issues.
DUE PERMAFROST will strengthen remote sensing applications in high Northern latitudes.

5. REFERENCES

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