IMPLEMENTATION OF A SATELLITE DATA BASED PERMAFROST INFORMATION SYSTEM - THE DUE PERMAFROST PROJECT

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ABSTRACT

Permafrost is a subsurface phenomenon which cannot be directly measured with remotely sensed data. However, many parameters which influence the ground thermal regime and surface indicators can be captured with satellite data in an operational manner. Those are e.g. land surface temperature, land cover and snow parameters, soil moisture and terrain changes. Within the ESA DUE Permafrost project a wide range of EO datasets are investigated and integrated in an information system with extensive involvement of the permafrost research community. This comprises pan-boreal/arctic to regional and local scale investigations. The capabilities of currently available remotely sensed datasets have been assessed with respect to operational monitoring. This paper summarizes those components of the processing system which address automatized integration of remotely sensed products: land surface temperature, soil moisture (incl. freeze/thaw), open water, snow parameters and methane.

Key words: permafrost, high latitude, land surface temperature, landcover, soil moisture, freeze/thaw, lakes.

1. INTRODUCTION

Permafrost is an essential climate variable (ECV). It is a subsurface phenomenon which cannot be directly measured with remotely sensed data. Yet, monitoring can be done based on indicators and via permafrost models. Indicators are especially thermokarst lake dynamics and surface elevation changes. Those phenomena need to be observed on a local scale. Regional to circumpolar monitoring requires the use of permafrost models for which the following dataset will be provided:

- Land surface temperature can be derived from passive sensors such as MODIS, AATSR, and AMSR-E. It can be used as a forcing parameter for permafrost models.
- The amount of snow determines insulation properties. An operational monitoring service for snow extent and SWE is currently being set up within the ESA DUE project GlobSnow.
- Vegetation also plays a role for ground insulation. A number of global and regional land cover maps are available (e.g. from GlobCover). They need to be merged and assessed for the purpose of modelling of permafrost and fluxes.
- Thermal conductivity is influenced by soil moisture. A near real-time (NRT) product based on METOP ASCAT is available from EUMETSAT. This service will be improved within the project under the viewpoint of frozen ground conditions.

The information system will comprise those global datasets and also regional and local scale monitoring results. The latter cover sites in Alaska, Mackenzie basin, Southern Yakutia and Laptev and East Siberian Sea region. The database setup considers use by permafrost modelers and scientists working on local scale (hydrology, geomorphology, botany etc.). A combination with a WebGIS portal will allow efficient dissemination of results and free access. In this paper we present the current design of the processing system which forms part of the satellite data based monitoring system. It handles all type of satellite data which allow for operational integration into the monitoring system.

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2. MONITORING STRATEGY

The DUE Permafrost User group covers experts from various disciplines, with expertise from permafrost monitoring in the field to permafrost modelling. A major part of the core User group are members of the International Permafrost Association (IPA), and circum-Arctic networks such as ACCO-Net that serve as communication platforms. Also, a major part of the core User group is contributing to the Global Terrestrial Network for Permafrost (GTNP) that is currently collecting ground data through the Circumpolar Active Layer Monitoring (CALM) and the Thermal State of Permafrost (TSP) programs. Additional members of these programs and circumarctic networks have also been involved in the consulting process for the requirements engineering.

Pan-boreal/arctic products will cover all permafrost affected areas north of 55 °N. The regional service case region boundary definitions have been based on the geographic location of ground data provided by the users. Primary regional sites cover in total 1.5 Mio km^2 (Figure 1). A set of additional secondary regional sites has been identified of which some may be added to the service. They cover in total 800.000 km^2. Six to eight local sites will be covered with a minimum total area of 20.000 km^2. The major local site for product validation is the Lena Delta Observatory [1].

Satellite data from more than 20 different sensors are used for the implementation of the Permafrost monitoring system.

The circumpolar datasets will be provided weekly to monthly with a spatial resolution of 25 km x 25 km (Table 1). Selected areas will also be monitored at 1 km x 1 km for snow extent (SE), LST, soil moisture, and vegetation (Table 2). High resolution satellite data are used at selected local sites.

3. PROCESSING SYSTEM

The Permafrost Processing System (from Earth Observation data - PEO) follows a modular approach. This approach was selected to take into account the

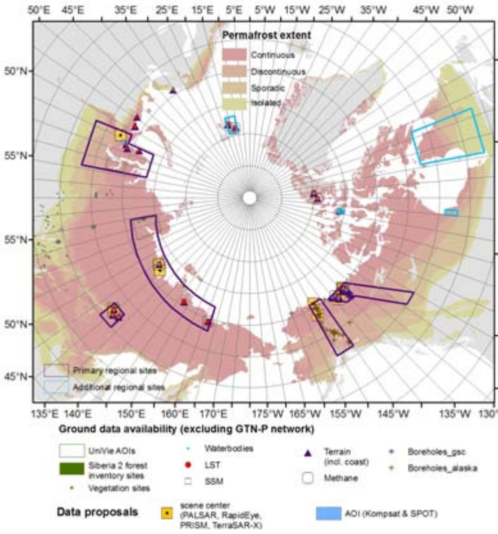

Figure 1. Circumpolar ground data availability, boundaries of regional service case and locations of currently in-cluded sites in satellite data proposals for local scale analyses (source of permafrost extent: NSIDC).

different data sources and product contributors and to have an easy to adapt solution. The PEO consists of the kernel part that contains the database, input and output data interfaces to external, and some data processing functionality. Data processing covers on the one hand general functionality such as reprojetion, mosaicking etc, but also the homogenization of some of the Permafrost products. The database organizes all the data that are stored permanently on the PEO and that are made available externally.

3.1. Land surface temperature

Surface temperature is a critical parameter to measure for understanding biological, hydrological and climatological systems, and their interactions. In Arctic and sub-Arctic regions, permafrost (i.e. soil that is frozen for more than two consecutive years), due to increase of temperatures, is subject to thaw and become unstable. Average surface temperatures strongly contribute to the thermal state of the permafrost. Prolonged systematic differences in average surface temperature will eventually result in different thermal energy contents of the soil.

The Land Surface processing subsystem integrates land surface temperature (LST) products from MODIS onboard of NASA's Terra and Aqua satellites. Post-processing functions will allow the creation of weekly and monthly surface temperature products at both scales. The value of adding AATSR, SSMI and ASMR-E to MODIS data for the generation of improved products is currently being investigated [2].

Table 1. DUE Permafrost service case scenario - pan boreal/arctic level.

EO Product	Source Sensor/External Source	Temporal resolution	Spatial resolution	Time span
LST	MODIS, AATSR, AMSR-E	monthly	25km	2002-
Surface Soil moisture (incl. refreeze)	WACMOS, ASCAT	weekly	25 km	1978 - (sensor specific)
Snow extent	GlobeSnow	weekly	1 km	1995-
SWE	GlobeSnow	weekly	25 km	2002-
Vegetation (incl. disturbances)	GlobCover, GlobCarbon, CAVM, GlobSCAR	Once	300 m	
Water bodies	GlobCover	Once	300 m	
DEM	SRTM, regional DEMs	Once	100 m	

Table 2. DUE Permafrost service case scenario - regional scale

EO Product	Source Sensor/External Source	Temporal resolution	Spatial resolution	Time span
LST	MODIS, AATSR, AMSR-E	weekly	1km	2002-
Surface Soil moisture (incl. refreeze)	ENVISAT ASAR GM	weekly	1 km	2005 -
Water bodies	ENVISAT ASAR WS	annually	150 m	2003-
Methane	Bremen/KNMI	monthly	60x30km	2003-

LST products at different spatial and temporal resolutions derived from the MODIS sensor are available independently for the Terra (MOD) and Aqua (MYD) satellites, and for daytime (ascending mode) and nighttime (descending mode) acquisitions. LST products (version 5) from NASA at about 6 km and at the 1 km resolution are used for both the pan-boreal/arctic and regional scales. The suitability of these medium resolution products for local scale permafrost monitoring has been demonstrated by [3].

3.2. Soil moisture (incl. freeze/thaw status)

Soil moisture influences the land energy balance and thus impacts the land surface temperature along with vegetation coverage. The thermal properties of the soil layers are a function of soil type and liquid water content [4]. The dynamics of the physical condition of the water contained in the active layer are descriptive for the permafrost status. Soil moisture reflects changes in the energy and water balance which influence greenhouse gas emissions.

Pan-boreal/arctic The scatterometer SSM offline processing subsystem for pan-boral/arctic monitoring integrates EUMETSAT ASCAT Level 2 data [5, 6], applies quality check for frozen ground conditions [7, 8] and snow cover. The quality check procedure for frozen soil uses the parameters which are already extracted from offline pre-processing of historical ASCAT soil moisture data. The PEO subsystem will include post-processing functions, which will primarily provide regriding and format conversion, but eventually also derivation of anomalies [9, 10] and parameters for seasonal variability.

Regional The soil moisture extraction approach for regional scale monitoring will be adopted based the existing ASAR soil moisture product, developed within the ESA DUE Tiger SHARE project [11, 12]. The product is derived with the change detection approach originally developed for the C-band Scatterometer on board of the European satellites ERS-1 and ERS-2 [13] and used for the EUMETSAT ASCAT Level 2 data (see above). The offline SAR SSM processing algorithm for the 1 km Surface Soil Moisture product uses ENVISAT ASAR Global Monitoring level 1b data, a Digital Elevation Model and orbit state vector information (e.g. DORIS files). Auxiliary information on freeze and thaw dates, derived from the ASAR GM data, are used in the processing and are also provided as an additional

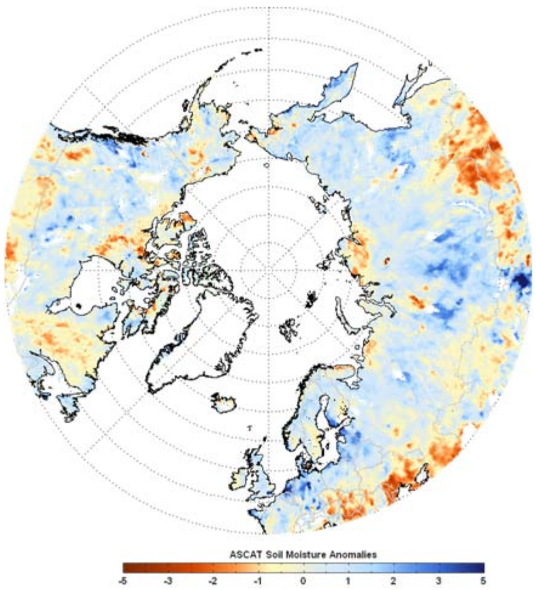

Figure 2. Example: Soil moisture anomalies from Metop ASCAT (25km), 3-day composite, 27th of July 2007 (period of continuous tundra fires in Alaska).

information layer. Post-processing consists of generation of weekly composite soil moisture maps and masking of data acquired during frozen ground conditions. The online PEO SAR SSM processing subsystem allows mosaicking of specified regions of interest and output as GeoTiff. This component of PEO is setup with respect to the possibilities of the upcoming Sentinel-1 satellite [14].

3.3. Lakes (regional scale)

Thaw lakes and water bodies are characteristic landscape features of arctic permafrost regions. Water is a class in all available global and regional land cover maps. The spatial resolution of those existing products ranges between 300m to 1km. The majority of lakes within tundra environment is however much smaller than the spatial resolution of those maps. ENVISAT ASAR Wide Swath data with 150 m resolution can identify more than 50% more open water surface areas than land over maps based on MODIS [15]. Additional advantages of ENVISAT ASAR WS data are the frequent data availability, the possibility of straight forward identification of open water surfaces with SAR data and capability of operational pre-processing setup.

The SAR offline-processing subsystem for the Water Bodies (WB) product uses ENVISAT ASAR Wide Swath level 1b data, a Digital Elevation Model and orbit state vector information (e.g. DORIS files). A seasonal water body extent map is produced for each regional site. Post-processing consists of producing maps of annual changes in water body extent. The processing to be carried out on the PEO system consists of data type and format control and mosaicking image tiles into user ready GeoTiff images.

3.4. Methane

The SCIAMACHY data processed by the WFM-DOAS (Weighting Function Modified Differential Optical Absorption Spectroscopy) retrieval algorithm is available as monthly ASCII files and containing global absolute methane columns in 0.5 degrees spatial resolution. Information provided from quality flags can be used to remove missing and inconsistent values (clouds, snow, ice). The main processing steps within PEO are: import of data from ASCII-files, conversion of ASCII files into vector point format, elimination of data gaps or inconsistent values, conversion of point information into 0.5 degree raster cells and re-projection of data and extraction of subsets.

3.5. Snow

Snow cover and Snow Water Equivalent (SWE) information is required for permafrost distribution modeling. Its dynamics impact albedo, runoff, soil moisture and vegetation. The timing of steady snow cover destruction coincides with the rise of land surface temperature above zero degree Celsius.

Snow extent and snow water equivalent is provided through GlobSnow [16]. The Snow Water Equivalent (SWE) product will be generated on a daily, weekly and monthly basis using SSM/I and AMSR-E data along with ground-based weather station data. The global areal Snow Extent (SE) product will include a weekly and a monthly snow cover composite based on ESA ERS-2 ATSR-2, Envisat AATSR and Envisat ASAR data. Weekly pan-boreal/arctic products will be retrieved for PEO.

4. OTHER DUE PERMAFROST PRODUCTS

Remotely sensed information which is also relevant to permafrost monitoring but is not subject to automated integration via PEO includes terrain (digital elevation models and terrain changes) and vegetation related information (see Table 1). These offline generated datasets will be added to the output database of PEO.

DUE PERMAFROST remote sensing terrain products are combnined of SRTM data, regional DEMs from mapping agencies and local scale DEMs from photogrammetric processing of ALOS-Prism Triplets. Subsidence is assessed with InSAR techniques [17].

The analysis of vegetation structures and dynamics on the pan-boreal scale is being carried out using global land cover, phenology and fire products [18]. At local scale, high resolution satellite data (RapidEye, Kompsat-2, ALOS PRISM) is classified using object based classification approaches. Specific object characteristics like shape, spectral properties and information within different hierarchical levels are used to map arctic vegetation classes [19].

5. SUMMARY

A monitoring system for permafrost issues based on satellite data is implemented within the ESA DUE permafrost project. A database is setup which consideres permafrost change indicators and parameters relevant for permafrost modelling. It is linked to a processing system (PEO) which handles all type of satellite data which allow for operational integration into the monitoring system. Those are land surface temperature (MODIS and AATSR), soil moisture (incl. freeze/thaw; Metop ASCAT and ENVISAT ASAR GM), open water (ENVISAT ASAR WS), snow parameters (GlobSnow: AMSR-E and AATSR) and methane (SCIAMACHY). These services are suitable for pan-boreal/arctic (mostly 25kmx25km) and regional scale (150m-1km) monitoring.

More information is available at www.ipf.tuwien.ac.at/permafrost/

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REFERENCES

[1] B. Heim, J. Boike, M. Langer, S. Muster, J. Sobiech, K. Piel, and A. Bartsch. The Lena River Delta, Arctic Siberia: An arctic ground data observatory of the DUE Permafrost project. In *ESA Living Planet Symposium, Bergen*, 2010.

[2] C. Duguay, S. Hachem, and A. Soliman. The DUE Permafrost project - land surface temperature products: Overview and cross-comparison between MODIS and AATSR. In *ESA Living Planet Symposium, Bergen*, 2010.

[3] M. Langer, S. Westermann, and J. Boike. Spatial and tem-poral variations of summer surface temperatures of wet polygonal tundra in Siberia - implications for MODIS LST based permafrost monitoring. *Remote Sensing of Environment.*, in press.

[4] K. Saito, M. Kimoto, T. Zhang Amd K. Takata, and S. Emori. Evaluating a high-resolution climate model: Simulated hydrothermal regimes in frozen ground regions and their change under the global warming scenario. *Journal of Geophysical Research*, 112:F02S11, 2007.

[5] Z. Bartalis, W. Wagner, V. Naeimi, S. Hasenauer, K. Scipal, H. Bonekamp, J. Figa, and C. Anderson. Initial soil moisture retrievals from the METOP-a advanced scatterometer (ASCAT). *Geophysical Research Letters*, 34:L20401, 2007.

[6] Vahid Naeimi, Zoltan Bartalis, and Wolfgang Wagner. ASCAT soil moisture: An assessment of the data quality and consistency with the ERS scatterometer heritage. *Journal of Hydrometeorology*, 10:555–563, 2009.

[7] 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 Eath Observation and Water Cycle Scieny Conference, Frascati, November 2009*. ESA, 2009.

[8] A. Bartsch, W. Wagner, and V. Naeimi. The legacy of 10 years QuikScat land applications - possibilities and limitations for a continuation with Metop ASCAT. In *ESA Living Planet Symposium, Bergen*, 2010.

[9] Klaus Scipal, Cornelia Scheffler, and Wolfgang Wagner. Soil moisture-runoff relation at the catchment scale as observed with coarse resolution microwave remote sensing. *Hydrology and Earth System Sciences*, 9:173–183, 2005.

[10] A. Bartsch, H. Balzter, and C. George. Influence of regional surface soil moisture anomalies on forest fires in Siberia observed from satellites. *Environmental Research Letters*, 4:045021, 2009.

[11] Annett Bartsch, Klaus Scipal, Piotr Wolski, Carsten Pathe, Daniel Sabel, and Wolfgang Wagner. Microwave remote sensing of hydrology in southern africa. In *Proceedings of the 2nd Göttingen GIS and Remote Sensing Days: Global Change Issues in Developing and Emerging Countries, 4 – 6 October, 2006*, 2006.

[12] D. Sabel, Z. Bartalis, A. Bartsch, M. Doubkova, S. Hasenauer und V. Naeimi, C. Pathe, and W. Wagner. Synergistic use of scatterometer and ScanSAR data for extraction of surface soil moisture information in Australia. In *EUMETSAT Meteorological Satellite Conference*, Darmstadt, 2008.

[13] W. Wagner, G. Lemoine, and H. Rott. A method for estimating soil moisture from ERS scatterometer and soil data. *Remote Sensing of Environment*, 70:191–207, 1999.

[14] D. Sabel, W. Wagner, C. Pathe, M. Doubkova, W. Dorigo, and A. Bartsch. Global monitoring of the hydrosphere: From ENVISAT ASAR to Sentinel-1. In *ESA Living Planet Symposium, Bergen*, 2010.

[15] A. Bartsch, C. Pathe, W. Wagner, and K. Scipal. Detection of permanent open water surfaces in central Siberia with ENVISAT ASAR wide swath data with special emphasis on the estimation of methane fluxes from tundra wetlands. *Hydrology Research*, 39(2):89–100, 2008.

[16] K. Luojus, J. Pulliainen, H. Rott, T. Nagler, R. Solberg, A. Wiesmann, C. Derksen, S. Metsämäki, E. Malnes, and B. Bojkov. Esa Due Globsnow-global snow database for climate research. In *ESA Living Planet Symposium, Bergen*, 2010.

[17] T. Strozzi, U. Wegmüller, R. Delaloye, H. Raetzo, A. Kos, A. Bartsch, and C. Lambiel. Radar interferometric observations of permafrost related surface deformation. In *European Permafrost Conference, Longyearbyen*, 2010.

[18] M. Urban, M. Herold, S. Hese, S. Pöcking, and C. Schmullius. Synergistic analysis of coarse resolution vegetation and land cover data for permafrost monitoring. In *ESA Living Planet Symposium, Bergen*, 2010.

[19] S. Pöcking, S. Hese, M. Urban, M. Herold, and Schmullius. High resolution vegetation and water body mapping in arctic permafrost regions. In *ESA Living Planet Syposium, Bergen*, 2010.