GLOBPERMAFROST - HOW SPACE-BASED EARTH OBSERVATION SUPPORTS UNDERSTANDING OF PERMAFROST

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ABSTRACT

The GlobPermafrost project develops, validates and implements Earth Observation (EO) products to support research communities and international organisations in their work on better understanding permafrost characteristics and dynamics. To facilitate usability of these products by the target audience, user requirements with respect to the planned products have been requested and collected through an online community survey as well as by interview. This paper provides an overview on the planned thematic EO products as well as results of the user requirement survey.

1. INTRODUCTION

Permafrost underlies approx. 24% of the terrestrial Northern Hemisphere. Permafrost is a phenomenon of the subsurface thermal state across vast areas. From borehole temperature data and active layer depth measurements we know that over the past three decades permafrost has been warming, and continues to warm, across the circumpolar North.

Changing permafrost interacts with ecosystems and climate on various spatial and temporal scales [1]. Environmental changes accelerate the microbial breakdown of organic carbon and the release of the greenhouse gases carbon dioxide and methane what can accelerate climate change [2]. Monitoring across scales is required to quantify the changes of variations in this Essential Climate Variable (ECV).

Permafrost cannot be directly detected from space, but many surface features of permafrost terrains and typical periglacial landforms are observable with a variety of EO sensors ranging from very high to medium resolution in various wavelengths. In addition, landscape dynamics associated with permafrost changes and geophysical variables relevant for characterizing the state of permafrost, such as land surface temperature or freeze-thaw state can be observed with space-based Earth Observation. Prototype product cases will cover different aspects of permafrost by integrating in situ measurements of subsurface properties (active layer depth, active layer and permafrost temperatures, organic layer thickness, liquid water content in the active layer and permafrost) and surface properties (vegetation cover, snow depth, surface and air temperatures), Earth Observation, and modelling to provide a better understanding of permafrost today.

The project will extend local process and permafrost monitoring to broader spatial domains, support permafrost distribution modelling, help implementing permafrost landscape and feature mapping in a GIS framework, and will complement active layer and thermal observing networks. Lowland (latitudinal) and mountain (altitudinal) permafrost issues need to be addressed.

2. PROJECT PHASES & TASKS

GlobPermafrost will be conducted in two phases. The focus of Phase 1 is in the design, demonstration, and prototyping of the products. Central to this is feedback from users of permafrost data which will serve as motivation for the products generated. This phase will run from 1 February 2016 until 31 March 2017.

Phase 2 will concentrate on the implementation and validation of the products. A major part of this phase is in the development of the Permafrost Information System. This phase is scheduled to run from 1 April 2017 until 31 January 2019.

Information regarding project status and events are available from www.globpermafrost.info

Proc. 'Living Planet Symposium 2016', Prague, Czech Republic, 9–13 May 2016 (ESA SP-740, August 2016)

Initial user requirements have been gathered for the ESA DUE Permafrost project [3]. They have been revised and extended to mountain permafrost at the DUE-IPA-GTNP-CliC workshop in Frascati in February 2014, which have been further consolidated within the Permafrost community during 2014 in request of the WMO Polar Space Task Group. They have been summarized in a community white paper [4]. A subset of these requirements will be demonstrated within GlobPermafrost and assessed by user organisations. A new user requirements survey has been conducted within the first months of GlobPermafrost.

The survey has been conducted online and questions split up into six categories, comprising a list of general questions and five sections dedicated to the thematic products of the project.

3. THEMATIC PRODUCTS

The following thematic products will be addressed within the project:

- Circumpolar permafrost extent
- Permafrost-region dedicated land cover class prototype
- Detailed EO environmental datasets for local sites of interest for the permafrost research community, termed “cold spots”
- Regional transects for identification of disturbance “hot spots” useful as indicators of permafrost change
- Surface deformation at selected mountain permafrost sites

Numerical permafrost models [5] will be employed to exploit the information content of different remote sensing products, in particular land surface temperature (LST) and snow water equivalent (SWE), to estimate the ground thermal state. One of the goals is to extend the method to model permafrost extent in the northern hemisphere north of 40° in Eurasia and 50° in North America, as well as for selected mountain regions outside this area.

An important parameter (surface deformation) of mountain permafrost is not monitored to date worldwide and in a systematic way. The goal is to, for the first time, build up a network of sites in different continents (Europe, Asia, North and South Amercia) for remote sensing based long-term monitoring of rockglacier motion.

Land cover serves as a base dataset for upscaling of ecosystem characteristics also in permafrost regions. With respect to user requirements (including permafrost modelling, hydrology, and soil carbon upscaling), targeted approaches for characterization of land cover in permafrost regions will be undertaken. For this we investigate the suitability of synthetic aperture radar (SAR) as well as optical instruments, specifically Sentinel-1 and Sentinel-2.

In-situ monitoring provides localised detailed measurements. Through a multi-sensor EO approach, such measurements will be broadened to a wider spatial and temporal extent. Specific topics that will be addressed at local scale include terrain change by InSAR, seasonal and long-term change in open water extent, change in fraction of bottom fast lake ice, and the detection of features related to periglacial processes, thermokarst, ice wedge networks and coastal erosion, to name but a few.

Observations made at high spatial and temporal resolution are essential in order to track Hot spot Regions of Permafrost Change (HRPC). The goal is to detect, map, and classify press (gradual) and pulse (rapid) disturbances of land surface properties associated with permafrost changes to identify HRPC at high spatial resolution (30 m) using the full Landsat and Sentinel-2 record for selected transects.

4. SURVEY RESULTS

4.1. General information

The GlobPermafrost user requirements survey was completed by 47 participants. The majority of participants are affiliated with Universities and Research institutes. One participant was affiliated with Government and one with an Engineering company. The greatest number of participants work in Russia/ Siberia (Fig. 1).

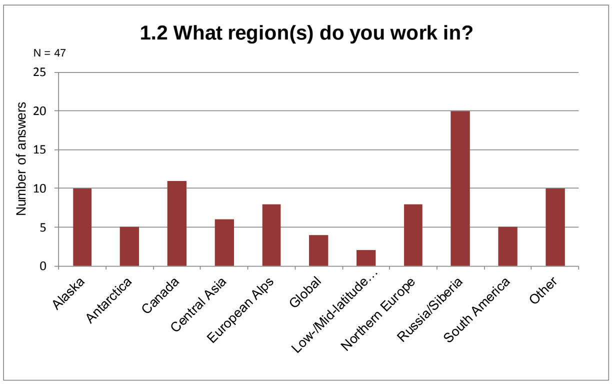

Figure 1: Survey results, question 1.2

Respondents are interested in all of the ESA GlobPermafrost topics, but the most of the interest received Cold spots and Transect identifications. Participants have very diverse interests but the highest number is focusing on field measurements and investigations and remote sensing (Fig. 2). They work predominantly on local scales, many of them work on regional and across the scales and few are working on global scale.

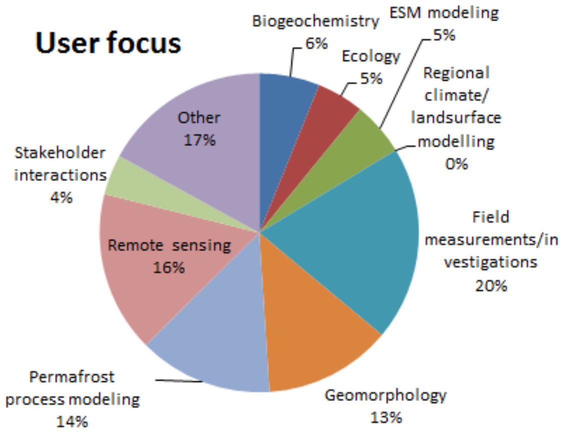

Figure 2: Survey results, question 1.4: How would you best describe the focus of your work?

4.2. Permafrost extent

The RS-based permafrost extent product uses the equilibrium permafrost model CryoGrid 1 to deliver ranges of ground temperatures and the probability of permafrost occurrence within a 1km grid cell, as described in a prototype study for the N Atlantic region [5]. Over large spatial scales, the probability of permafrost occurrence corresponds to permafrost fractions within an area, so that the zonation of continuous, discontinuous and sporadic permafrost can be inferred. Users show a high amount of support for these targeted variables (Fig. 3). The spatial resolution of 1 km is adequate for about one third of the users, but a higher spatial resolution can at present not be achieved due to the lack of better resolved LST and SWE products.

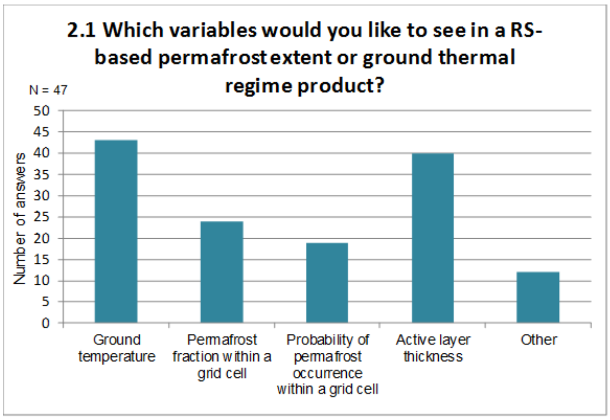

Figure 3: Survey results, question 2.1

In addition, users show a high interest in active layer thickness which unfortunately is not accessible with the equilibrium approach used for the permafrost extent product. With a transient permafrost model, on the other hand, active layer thickness can be estimated, but RS-based transient modeling of the ground thermal regime is currently not mature enough to be applied on the pan-arctic scale. However, we will demonstrate the potential of such a transient model approach [6] on the regional scale for the Lena River Delta in Northern Siberia. This is in line with the feedback of more than half of the users who found time-resolved information on the ground thermal state useful (Fig. 4).

4.3. Dedicated land cover

Survey participants showed relatively equal interest in different thematic content of a RS-based land surface product. Information on physical subsurface properties is desired the most (Fig. 5). Almost equal attention received soil moisture, Geomorphology, physical surface properties and vegetation and water classes. The participants are additionally interested in peatlands and detailed vegetation classes. Of high interest are also different types of surface debris.

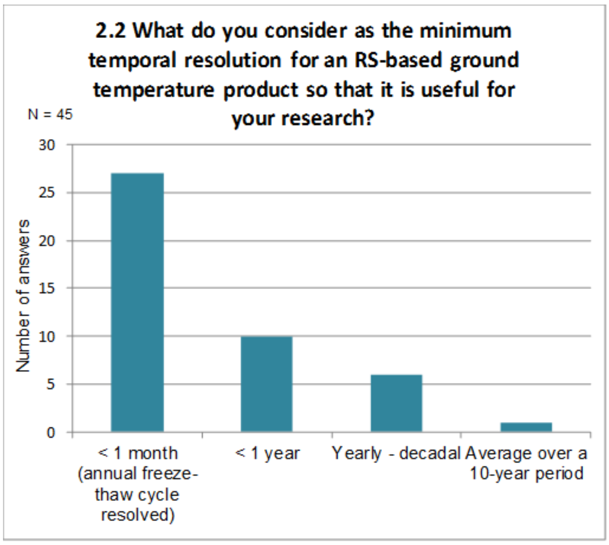

Figure 4: Survey results, question 2.2

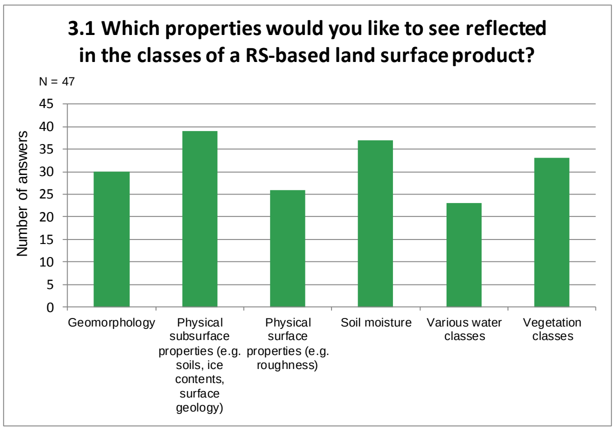

Figure 5: Survey results, Question 3.1

Almost half of the users indicated horizontal resolution of less than 10 m as optimal for their research area. Horizontal resolution between 10 and 30 m would be optimal for 25 % of the respondents and only few would be interested in lower resolutions. However, the minimum required spatial resolution would be for the majority of users between 10 and 100 m. Only 30 % of users consider spatial resolution lower than 100 m as a minimum. Almost all users indicated that subgrid information on land cover units would be useful.

4.4. Local scale

47 survey participants responded to the question as to whether they worked at one of the GlobPermafrost “cold spot” candidate sites. Of these, only 18 respondents (38%) indicated they were working at one of the sites while a larger proportion (29 or 62%) conducted research at another site.

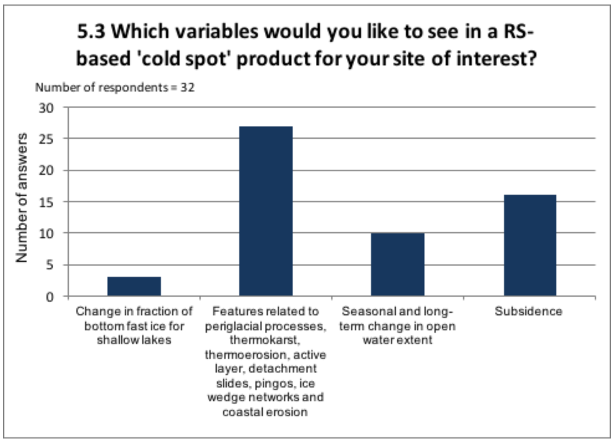

Figure 6: Survey results, question 5.3

Survey participants were also asked which variables they would like to see in a remote sensing based “cold spot” product for their site of interest (Fig. 6). Of the 32 respondents to this question, some identified more than one variable they would like to see derived from remote sensing for their “cold spot” site. Features related to periglacial processes were identified as of most interest (27 out of 56 answers compiled) followed by subsidence (16), change in open water extent (10), and change in fraction of bottom fast ice for shallow lakes (3). The greater interest in remote sensing based products associated with permafrost features by those surveyed is well reflected in the minimum spatial resolution identified by respondents (Fig. 7). The majority (29 out of 38 or 76%) indicate a requirement in spatial resolution of 10 m or better for the creation of remote sensing based “cold spot” products.

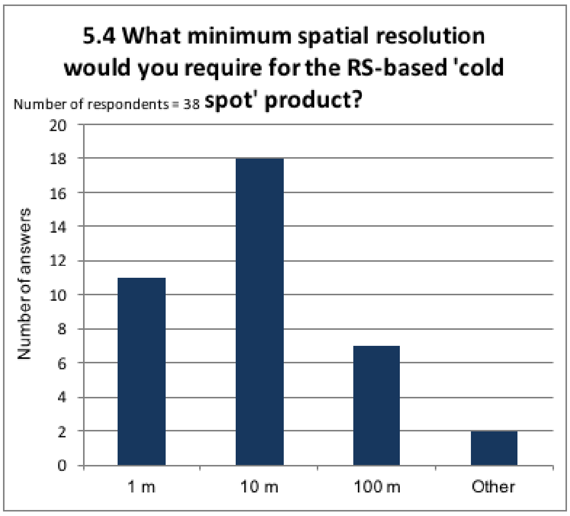

Figure 7: Survey results, question 5.4

4.5. Hot spot detection

Of all respondents, 25 users found their study areas covered in the proposed transects. Users were approximately evenly interested in the proposed transects with exception of T4 (eastern Hudson Bay region) which received lower numbers of potential users but has been suggested to be extended (northwestern-most Canadian Archipelago) to better address user needs. The nearby study regions in Central Yakutia, Southern Siberia, should be includedin the Lena region transect. An extension will be considered after checking the available image archive.

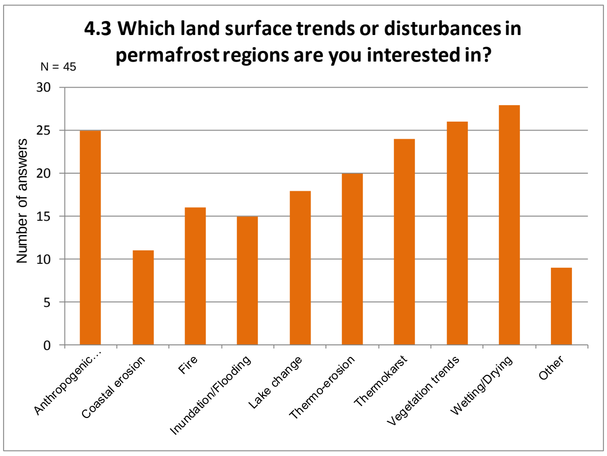

Figure 8: Survey results, question 4.3

Users expressed significant interest in a variety of land surface trends and disturbances in the HRPC transects (Fig. 8). In particular, wetting and drying, vegetation trends, thermokarst and thermos-erosion, and anthropogenic disturbances each received more than 20 votes as the dynamics of most interest.

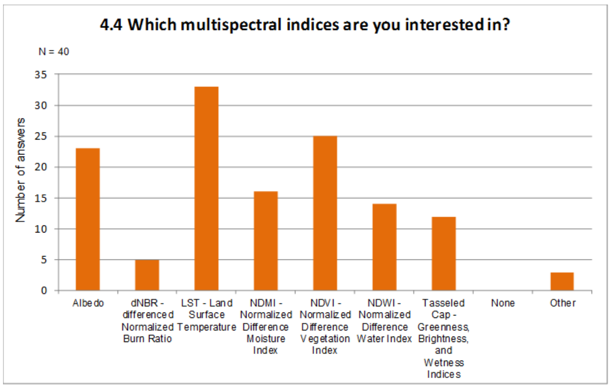

Figure 9: Survey results, Question 4.4

A range of multispectral indices and geophysical variables can be provides for each transect. Users expressed most interest in the LST, NDVI, and albedo products, followed by NDWI and NDMI as moisture and wetness indicators (Fig. 9). For the transects, the majority of respondents are interested in summer observation period (broadly stated from May/June to September/October), while a few also mentioned interest in winter observations and year-round monitoring.

An excellent feedback was received from most survey participants on the question whether they can provide field data for the transect regions. More than 35 respondents have field data, 29 are willing to share this data, and close to 20 are able to provide high resolution remote sensing datasets for ground truthing.

4.6. Mountain permafrost areas

In total 26 survey participants work on mountain permafrost and that their sites are spread over three continents (Fig. 10). In addition to the ESA Globptermafrost candidate mountain permafrost sites, several other locations were proposed, including Canada, Greenland and the Antarctic Peninsula.

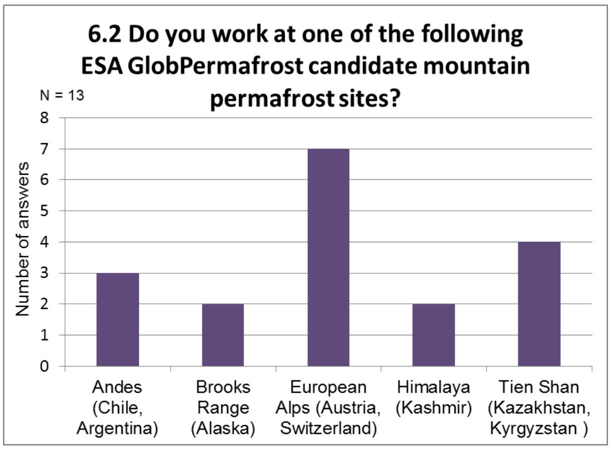

Figure 10: Survey results, Question 6.2

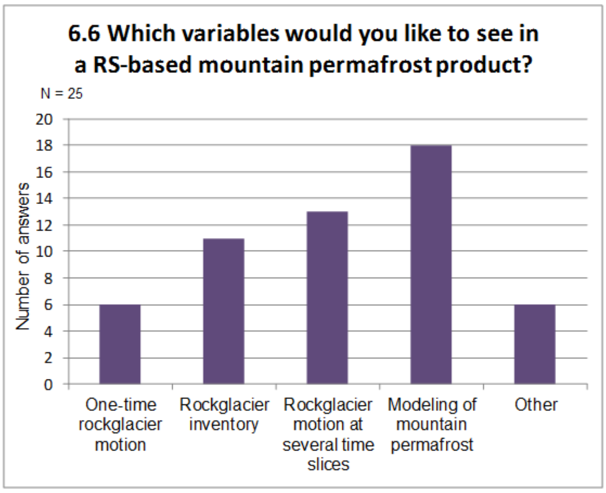

Figure 11: Survey results, Question 6.6

Regarding the variables to be included in a remote-sensing based mountain permafrost product (Fig. 11), the modelling of permafrost extend and a rockglacier motion monitoring over time were considered of large interest. However, the spatial resolution of 1 km for the planned RS-based permafrost extend product in mountain areas was assessed by 15 out 21 participants to the survey too coarse. The majority of the participants to the survey indicated that the minimum spatial resolution for a RS-based rockglacier inventory and a RS-based rockglacier motion field should be 10 m. In addition, they indicated that the temporal resolution for a RS-based rockglacier motion field should be 10 years and that a time-series of rockglacier motion should be at least 30 years long to be able to record a climate induced signal.

5. OUTLOOK

Within upcoming conferences additional interactions with potential product users are foreseen to facilitate further input, including dedicated User Meetings at the 11th International Conference on Permafrost (ICOP2016) in Potsdam, Germany, in June 2016, and the American Geophysical Union (AGU) Fall Meeting in San Francisco, USA, in December 2016.

6. ACKNOWLEDGEMENTS

This work was carried out within the framework of the European Space Agency DUE GlobPermafrost project [4000116196/15/I-NB].

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