Specification of a Permafrost Reference Product in Succession of the IPA Map

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Contributions

This text is the final report of the IPA Action Group *Specification of a Permafrost Reference Product in Succession of the IPA Map,* lead by Stephan Gruber. An initial meeting at AGU 2013 in San Francisco had contributions from J Brown, A Slater, F Nelson, T Zhang, J Boike, S Westermann, C Hauck and S Gruber. Email comments were subsequently received and incorporated from A Brenning, D Lawrence, J Brown and E Cremonese. Further discussion partners in 2014 and 2015 included A Lewkowicz, H Christiansen, P Bonnaventure and A Heginbottom. In 2016, 28 experts were again given a draft of this text and asked for input. Of these, input was received from E Cremonese, CR Burn, A Heginbottom, D Lawrence, P Overduin, S Westermann, G Grosse, J Boike, W Haeberli, P Bonnaventure.

Towards a Permafrost Reference Product in Succession of the IPA Map

The *Circum-Arctic Map of Permafrost and Ground-Ice Conditions* (here called 'IPA map'; Heginbottom et al. 1993; Brown et al. 1997) has been a milestone accomplishment in the 1990ies. It is widely used in the scientific community and for communication. Today, fast change in environmental conditions and the diverse needs for permafrost data in permafrost research and engineering give rise to discussion about a successor product. At the same time, it is not clear whether a new map will be the best way to address emerging needs. This text is intended to better define, what product or service is best suited as a successor to the IPA map.

The current map: The IPA map has been published as a paper map at a scale of 1:10,000,000 (1 cm on the map is equivalent to 100 km in reality). It covers the northern hemisphere north of about 30°N. It provides classes of permafrost extent (permafrost, thermally defined) and and ground-ice content (permafrost as an Earth material) based on a compilation and homogenisation of manually-delineated regional maps. The map provided for the first time a visual communication of the areal abundance of permafrost and of its approximate patterns of distribution. A digital version of the map is available.

Limitations: The criteria used for delineation (e.g., following isotherms of mean annual air temperature) are likely to be geographically inconsistent (Gruber 2012). Similarly, the accuracy of delineation is likely subject to spatial variation based on the expertise of the mapper and the quality of auxiliary information (e.g., air temperature, topography). The definition of permafrost extent (percentage of ground underlain by permafrost) does not explicitly include a spatial scale: should it be understood relative to areas of 1 km^2 or 10,000 km^2? Given the coarse scale of the map and the imprecision in the definition of permafrost extent, it is best to view the map as a tool for communication rather than as a data source.

Issues: Classes of permafrost extent (continuous, discontinuous, etc.) are useful concepts for verbally describing the physical character of a landscape. Several decades ago, when the geography of permafrost regions was first compiled, these classes provided an effective concept for describing a spatially heterogeneous landscape and for describing uncertainty while mapping with pencil lines. Today, digital data showing 'permafrost limits' miscommunicates to laypersons: it obfuscates the uncertainty inherent in the data and the spatial heterogeneity that is so important to understanding permafrost landscapes. The term 'permafrost limit' is now deeply engrained in the literature despite neither being clearly defined nor being measurable in the context of permafrost extent. Mapped permafrost extent is often wrongly used to test global models of permafrost and then treated as an observational dataset. In this, differing rules are sometimes proposed to establish an equivalency of simulated ground temperature and classes of permafrost extent. These practices often ignore the uncertainty and subjectivity of the data in the map as well as the conceptual difficulty of comparing temperature with a measure of heterogeneity. The southern hemisphere (Andes, Antarctica, New Zealand) is not included in the map. The mapping of temporal change in permafrost conditions is challenging based on a map that cannot easily be assessed in terms of its accuracy. A more general issue is the broader perception that we already know about the extent and state of global permafrost whereas in many areas we actually do not.

Needs: Expert consultation revealed that a successor product for the IPA map was desired for the visual communication of the distribution and state of permafrost, as a reference product for model evaluation, as model input, as a basis for assessing landscape functioning or hazards, and to support aggregation of local findings to regional, continental, or global scales. The incorporation of time and transient changes of permafrost are important. A large number of variables and a broad range of resolutions and extends in time and space was called for. Most needs identified related to having reliable reference data, fewer to an actual map.

Audience: The IPA map has a high standing and broad usage due to its perceived nature of a consensus product. The issues listed above illustrate that a next-generation product has to communicate major limitations in a way that is suitable to the most of it users. Potential users include permafrost scientists, but also (social) media, scientists from other communities, and decision makers on differing levels in government and industry. When aiming for a new product with consensus character, suitable communication to all these audiences will be important.

Considerations for next steps: The production of a new overview map to be only used for coarse-scale communication is possible based on current knowledge. It requires careful design and explanation rather than new data. This would be a good product to carry the stamp of approval of the IPA as representing permafrost researchers globally. Existing permafrost maps represent current knowledge in differing parts of the world. As such they are useful for informing research, planning, hazard assessment and other activities. Making, these maps available to a broader public (without needing to judge their quality) will result in a better mobilization of current understanding. A mechanism for gathering experience in the use of such maps may be valuable to inform research on required improvements. Producing a successor map to the IPA map is challenging. Because permafrost is a heterogeneous subsurface phenomenon and reliable detection is limited, all maps essentially are model results. Models (physics-based, heuristic, statistical) provide interpolation or extrapolation of observations. The current IPA map, for instance, is strongly based on a conceptual model linking mean annual air temperature with permafrost extent. To make progress, we need the capability to measure whether a new map (model output) is of superior quality compared with an old one. For this, we (as a community) need to develop and provide the necessary data, methods, and standards. This ability to quantify model performance will be more important than consensus on one model or map. This is because the increasing availability of data and models as well as the fast change of permafrost environments and permafrost science itself will result in a high cadence of new developments. The approximate delineation of ground ice content is an important element of the current IPA map. For nearly all future models or mapping products, the characterisation of ground properties (ice content and distribution with depth, etc.) will be even more important as it strongly governs the transient reaction of permafrost to climate change.

Proposed successor products:

1. **A global overview map of permafrost areas**
   - *Purpose:* To illustrate (in small figures rather than a detailed map) where on the planet permafrost occurs.
   - *Characteristics:* Cartography avoids crisp classes. Maps delivered as image files at global and continental scales. Resolution suitable for figures but not for data digitisation. Concise explanatory text.

2. **One-stop source for existing permafrost maps**
   - *Purpose:* To support the use of existing maps.
   - *Characteristics:* Provides spatial data ready to use, contains information on map generation and evaluation, lists maps by attribute (date, resolution, model type, evaluation), has forum to collect feedback on usability.

3. **Data for model evaluation**
   - *Purpose:* To enable the efficient and comprehensive evaluation of permafrost simulation results.
   - *Characteristics:* System to make available measurements as well as site information needed for simulation (especially thermal regime and ice/liquid water content, surface condition, soil properties); supports remote querying and bulk download, lists current methods for evaluating simulation results.

The **global overview map of permafrost areas** will be a static product without change expected over the coming decade. The **one-stop source for existing permafrost maps** and the **data for model evaluation** will be continuous efforts subject to ongoing improvement and updating. Likely, their scope will expand from permafrost occurrence or extent to include time series of temperature, active layer depth, thaw subsidence, and subsurface ice content as well as subsurface and surface data required for computer simulations. Having good data available for model evaluation is expected to boost the availability of methods/standards for model evaluation and the delivery of model results together with measures of reliability or uncertainty. The growing capabilities of simulations driven with remote sensing and atmospheric re-analysis products will improve our ability to predict permafrost characteristics and their changes spatially. At the same time, current remote sensing products cannot fully replace permafrost data in model evaluation. The **technical form of delivery** for maps and data will need to be flexible in adapting to differing communities (e.g., engineering, climate simulation) and evolving needs.

Synergies, in content and/or in governance, exist with coordinated monitoring initiatives (e.g., GTN-P, PERMOS), with initiatives of data collection (e.g., Frozen Ground Data Centre, the GTN-P data base, the Arctic Permafrost Geospatial Center, or alpine-permafrostdata.eu), with remote sensing initiatives (DUE Permafrost, GLOBPERMAFROST, ABOVE), and with national and international research programmes (e.g., PAGE21, ADAPT). Long-term initiatives like a **one-stop**

source for existing permafrost maps or a system for collecting and disseminating **data for model evaluation** will likely grow organically in response to researcher needs and funding. To be successful, they require the co-evolution of suitable governance mechanism as well as financial resources for their longer-term operation. The IPA is well positioned to communicate these needs to governments and funding agencies.

References

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