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HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

Alfred-Wegener-Institut, Telegrafenberg A43, 14473 Potsdam, Germany

The Cryosphere

Dr. Michael Fritz
Phone: +49/331-288-2203
Fax: +49/331-288-2188
E-Mail: Michael.Fritz@awi.de

28 May 2015

Revised manuscript: tc-2015-39

Dear Editor,

On behalf of my co-authors, I submit the revised version of the manuscript with the title "*Brief Communication: Future avenues for permafrost science from the perspective of early career researchers*".

Attached you will find:

- response to reviewer #1
- response to reviewer #2
- marked-up manuscript version
- supplement to the manuscript

Thank you very much for your time and efforts in this process and we look forward to seeing this manuscript accepted soon. Please, do not hesitate to contact me if you need further formation.

Best regards,

M. Fritz

Michael Fritz

Alfred Wegener Institute
Helmholtz Centre for
Polar and Marine Research

POTSDAM

Telegrafenberg A43
14473 Potsdam
Germany
Phone +49 331 288-2100
Fax +49 331 288-2137
www.awi.de

Public law institution

Head Office:
Am Handelshafen 12
27570 Bremerhaven
Germany
Phone +49 471 4831-0
Fax +49 471 4831-1149
www.awi.de

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Interactive comment on "Brief Communication: Future avenues for permafrost science from the perspective of early career researchers" *by* M. Fritz et al.

M. Fritz et al.

michael.fritz@awi.de

Received and published: 28 May 2015

Reply to Anonymous Referee No.1

We are grateful for the review and acknowledge your comments and suggestions. You will find all replies and changes that have been made below. Reviewer comments are cited in italic font.

Best regards,
Michael Fritz

(on behalf of the co-authors)

The paper by Fritz et al. reports on the outcomes of an Early Career Researcher forum aimed at identifying permafrost research priorities. This paper is submitted as a brief communication for the The Cryosphere, which can include reports or discussions of matters of policy and perspective or information on topical events. The paper would therefore fall within the scope for communications and be suitable for publication in the journal. The paper however is rather long with many references and may not fall within the length requirements for a brief communication.

The manuscript is one of the rare contributions that deal with research priorities and science policy issues. Because of its rather unusual scope and structure it might appear slightly longer than normal brief communication manuscripts. However, we have undertaken efforts to remove redundancies and to shorten where possible without losing content or message.

The paper gives a good overview of the objectives of the project, methodology and the results of the survey. A number of comments are however offered for the authors' consideration that will improve the paper.
The effort to identify permafrost research priorities, described in this paper is not occurring in isolation. The paper mentions (in the Introduction) that the International Permafrost Association (IPA) highlighted the need to identify research priorities in 2012 but the authors do not mention that the IPA is also leading a project to identify permafrost research priorities which contributes to the ICARP III process. The final outcome will be based on input from both the ECR and IPA processes. The authors should place their activity and its outcomes in the context of the larger effort to identify permafrost research priorities.

We agree that future research priorities for permafrost science under the umbrella of ICARP III will not appear in isolation. We have partnered with the IPA and CliC, who are leading a similar project called 'Permafrost Research Priorities' to use a similar approach to involve the community. In doing so, we achieve comparable results. Nevertheless, this manuscript is a stand-alone product issued by the community of early

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career researchers (ECRs). The purpose is to extract the ERCs' perspective. It is not absolutely clear yet how IASC will bring together the numerous and different kinds of activities that have taken place during the ICARP III process.
In the last part of the introductory chapter it is mentioned that our initiative has worked in close collaboration with the IPA. The synthesis chapter clearly mentions that "we need to ... ii) contribute our insights into larger efforts of the community such as the Permafrost Research Priorities initiative by the Climate and Cryosphere (CliC) Project together with the IPA (http://www.climate-cryosphere.org/activities/targeted/permafrost-research-priorities)".

In the Supplement, a very good summary of the results is provided including a list of all questions submitted, results of voting and ranking of questions. However, the highlighted questions presented in section 4 do not match exactly any of the original questions submitted. It is assumed that questions that were similar may have been combined or grouped according to theme and reworded. The authors could briefly mention in the text (section 3 or 4) any grouping/modification of questions that was done prior to the voting.

It is correct that none of the highlighted research questions match exactly with the originally submitted questions. Figure 1 mentions it several times that for example 'Reviewing, refining and grouping the questions' took place and that '... the general question structure was corrected'. After the voting process it is said that 'the five top questions were selected for further development and supplementation with information from the scientific literature.' Also the caption of table S4 mentions that the top five priority research questions after the voting process were developed further.

If this exercise is largely a contribution to ICARP which focuses on the arctic, then perhaps some of the text in section 4 should focus more on arctic issues. This might also make these sections a bit shorter.

This product is a contribution to ICARP III but not under a mandate of any Arctic initiative. Permafrost is a phenomenon of both polar areas, alpine regions and high plateaus. The same applies to the scientific background of the authors. The exercise behind the manuscript took place during a Permafrost science workshop, and so reflects the interests and expertise of ECRs present at that workshop. As opposed to excluding parts of the community we wanted to be as comprehensive as possible and include all communities and perspectives.

The authors' should consider reducing the paper length especially if it exceeds the requirements for a brief communication. Reduction of background information and some editorial revisions might help. Some suggestions are provided in the specific comments below.

We have reduced the length of the core part of the manuscript (abstract to acknowledgements) by 140 words.

Specific Comments Abstract Page 1211, line 7-8: *"spatial analysis of permafrost types" Do you mean characterizing the distribution of permafrost (or ground ice)?*

Changed to: "spatial distribution of ground ice"

Introduction Pg 1211, line 13: *suggested revision ". . ..the cryosphere underlying 24 %....." (Permafrost underlies the surface rather than occupying it)*

The phrasing was modified according to the suggestion.

Pg 1212, line 12: *Shouldn't reference be made to PYRN here as this was a permafrost event.* This event was not PYRN-specific, but was organised and included ECRs from multiple organisations/projects (APECS, ADAPT, PYRN, PAGE21).

Section 2 Page 1212 line 25 to page 1213 line 6: *Is all this information necessary? To reduce length you could focus on what is required to define the process of generating and voting on questions with additional information on workshop provided in the supplement.*

We removed:
a) “It was proceeded by breakout sessions hosted by senior scientist from IASC, the IPA and other organizations.”
b) “This activity format was selected due to its flexibility, prior positive experiences of workshop organizers, and highly collaborative nature.”

New shortened part: “For this activity, participants were provided with instructions (Supplement S3) and worked with more than 20 different members of the ECR permafrost research community, and viewed a variety of research topics, many of which were outside their own field of expertise.”

Section 3 Page 1213, line 14-20: *Be careful with use of the term “trend”. This might imply that an analysis of research topics over time has been done especially when referring to carbon research being a younger trend.*

The word “trend” was removed, and the paragraph was re-written.
line 14: removed “trending”
line 16: changed into “fields”
line 19: “...a more recent research interest”

This highlights the current changing nature of the terrestrial cryosphere environment and is directly linked to research topics on thermokarst, active-layer monitoring and drivers of change. Tied for second were keywords “ground ice” and “carbon”, which are linked to two distinct fields in permafrost research. Ground ice research hints at a more classical, geocryological approach to permafrost science and is concerned mostly with distribution, formation and sensitivity at thaw, while carbon research, a more recent research interest, links permafrost dynamics to carbon cycling by investigating its abundance, distribution and vulnerability.

Finally, we added the reference ‘Hubberten, H.-W., Lewkowicz, A. G., Christiansen, H. H., Drozdov, D. S., Ma, W., Romanovsky, V. E., and Lantuit, H.: Report from the international permafrost association: A new strategy and structure for the international per-

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mafrost association, Permafrost and Periglacial Processes, 22, 195-197, 2011.' They show the clear trend in the increasing number of permafrost-related publications between 1970 and 2010.

Page 1213, line 20-23: *These topics are not really independent of the other ones mentioned, i.e. there are linkages between them (eg. links between ground ice and hydrology or process)*

Changed to 'Inter-related research topics...'

Section 4.1: *This section is fairly long and could perhaps be made shorter.*

Section 4.1 has been shortened so that each subchapter in section 4 is almost equally long.

Page 1214, line 24: *should this be "at the ground surface"*

The phrasing was modified according to the reviewer's suggestion.

Section 4.2 Page 1215, line 13: *suggested revision ". . ...effect on the environment and human. . ." or ". . ..effect on environmental process and. . ."*

The phrasing was modified according to the reviewer's suggestion: "...effect on the environment and human. . .".

Page 1215, line 19: *suggest you delete "presently"*

The phrasing was modified according to the reviewer's suggestion.

Page 1215, line 23-28: *Isn't one of the key issues here the lack of adequate information on ground conditions (i.e. soil properties, ground ice etc.)*

It is indeed, and we address this issue when we say "Hereby, a main problem is the availability of forcing data sets at such scales, which requires permafrost modeling in conjunction with downscaling approaches". Later in the paragraph we mention the same challenges the reviewer raised: "vegetation, snow cover, soil moisture, ...".

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9, C894–C904, 2015

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Page 1215, line 25-26: *Suggested revision – delete "Hereby" and just say "In particular, the thermal evolution. . .." (I assume you are referring to the thermal evolution here)*

The phrasing was modified according to the reviewer's suggestion.

Section 4.3 Page 1216, line 19-20: *Revision suggested – "The description of environmental processes by the non-scientific community, including indigenous people, often differs from that by the scientific community."*

The phrasing was modified according to the reviewer's suggestion.

Section 4.4 Q4: *Do you mean amount of ice rather than types. Perhaps you should just say "spatial distribution of ground ice".*

The question of ice type can affect permafrost dynamics in a way that is not covered by only looking at total ice content. For example, micro-lenticular cryostructures can contain as much ice on a local scale as ice wedges or massive ice bodies, yet degradation of an ice wedge does not affect the landscape in the same way as micro-lenticular ice does. Carbon contents in permafrost are also influenced by the type of ice and its formation process. The type of permafrost and of ice therefore can tell a greater story than the sole ice content, and this is what the question is addressing.

Page 1217, line 18-19: *Revision suggested – "The presence of excess ice, including massive ice, is a key factor affecting the thaw sensitivity of permafrost to warmer temperatures and mechanical disturbance as ice melt can result in thermokarst topography (subsidence and collapse)"*

The phrasing was modified according to the reviewer's suggestion.

Page 1217, Line 25: *Suggest you use "ice-bearing permafrost" (i.e. delete "ground")*

The phrasing was modified according to the reviewer's suggestion.

Page 1218, Line 1-3: *Researchers can submit databases to the Frozen Ground*

Database so it isn't clear what the issue is here. Note that this is also more of a data rescue issue as this information probably exists in less available forms such as engineering reports etc.

The Frozen Ground Data Center (or Database) does not really exist anymore. We argue for a single database for this type of information, which could become GTN-P, instead of the many different portals and reports that exist.

Page 1218, Line 3-5: *Note that the objective of GTN-P is to monitor ECVs (permafrost thermal state and active layer). It is not meant to be an archive of all permafrost information. Within site descriptions (metadata) information is provided on soil conditions including ground ice. More appropriate references for GTN-P would be Burgess et al. (2000) or Smith and Brown (2009). Smith, S.L., and Brown, J. 2009. T7 Permafrost: Permafrost and seasonally frozen ground. Global Terrestrial Observing System, GTOS 62, Rome 2009, 19 pp. Burgess, M.M., Smith, S.L., Brown, J., Romanovsky, V., and Hinkel, K. 2000. Global Terrestrial Network for Permafrost (GTNet-P): permafrost monitoring contributing to global climate observations. Geological Survey of Canada Current Research 2000-E14 (http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/downloade.websearch1=R=211621)*

We replaced the URL with the following latest publication:
Biskaborn, B. K., Lanckman, J. P., Lantuit, H., Elger, K., Streletskiy, D. A., Cable, W. L., and Romanovsky, V. E.: The Global Terrestrial Network for Permafrost Database: metadata statistics and prospective analysis on future permafrost temperature and active layer depth monitoring site distribution, Earth Syst. Sci. Data Discuss., 8, 279-315, 2015. doi: 10.5194/essdd-8-279-2015

Section 4.5 Page 1218, line 16: *Revision suggested – ". . .transportation systems often rely on the. . ." (whether infrastructure relies on frozen conditions will depend on its design).*

The phrasing was modified according to the reviewer's suggestion.

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Page 1218, line 22: *McGregor et al 2010 should probably be referenced as Transportation Association of Canada 2010. (this is the correct citation for Transportation Association of Canada documents). There was also a similar document for community infrastructure by Canadian Standards Association (CSA): Canadian Standards Association 2010. Technical Guide - Infrastructure in permafrost: a guideline for climate change adaptation, Report Plus 4011-10.*

We removed:
McGregor, R. V., Hayley, D., Wilkins, G., Hoeve, E., Grozic, E., Roujanski, V., Jansen, A., and Doré, G.: Guidelines for development and management of transportation infrastructure in permafrost regions, Transportation Association of Canada, Ottawa, 2010.

Changed to:
Transportation Association of Canada: Guidelines for development and management of transportation infrastructure in permafrost regions, Ottawa, Canada, 177 p., 2010.

We added:
Canadian Standards Association: Technical Guide - Infrastructure in permafrost: a guideline for climate change adaptation, Special Publication PLUS 4011-10, Canadian Standards Association, Mississauga, Canada, 112 p., 2010.

Page 1218, line 25-26: *There is integration already as engineers do conduct terrain mapping and also sensitivity mapping for major projects.*

Changed into: “future research needs to **systematically** integrate permafrost engineering with earth sciences.”

Page 1219, line 1-5: *More recent papers could be referred to here such as Lepage et al. (2010, 2012) for the Beaver Creek test section and overview by Burgess et al. (2010) for Norman Wells Pipeline. The 2012 AMAP update of ACIA would probably better to use than the ACIA report.*

We replaced Instanes et al. (2005) with: Callaghan, T.V., Johansson, M., Anisimov, O.,

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Christiansen, H.H., Instanes, A., Romanovsky, V., and Smith, S.: Changing permafrost and its impacts. In: AMAP. Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, pp. 62, 2011.

We added: Malenfant-Lepage et al. (2012) which presents the latest results from the Beaver Creek test section:
Malenfant-Lepage, J., Doré, G., and Fortier, F.: Thermal effectiveness of the mitigation techniques tested at Beaver Creek Experimental road site based on a heat balance analysis (Yukon, Canada), 15th International Conference on Cold Regions Engineering, Quebec, Canada, 42-51, 2012.

We added: Burgess, M.M., Oswell, J., and Smith, S.L.: Government-industry collaborative monitoring of a pipeline in permafrost – the Norman Wells Pipeline experience, Canada, In: GEO2010, 63rd Canadian Geotechnical Conference and 6th Canadian Conference on Permafrost, Calgary, Canada, 579- 586, 2010.

Section 5 Page 1219, line 10-19: *The key thing here is the interactions which makes it difficult to categorize the questions. Q1 and Q2 deal directly with the permafrost aspects of determining the carbon fluxes so perhaps are the relevant permafrost questions. For carbon there are permafrost and non permafrost aspects.*

We agree.

Page 1220, line 3: *APECS and PYRN need to be defined.*

These have now been defined.

Page 1220, line 9: *replace "identifying" with "identify"*

The phrasing was modified according to the reviewer's suggestion.

References Page 1223, line 4: *Define IPCC*

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It is explained in the title of the reference.

Page 1223, line 3: *see earlier comment re McGregor et al. (should refer to Transportation Association of Canada as author)*

The phrasing was modified according to the reviewer's suggestion. See above.

Interactive comment on The Cryosphere Discuss., 9, 1209, 2015.

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The Cryosphere Discuss., 9, C890–C893, 2015
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Interactive comment on "Brief Communication: Future avenues for permafrost science from the perspective of early career researchers" *by* M. Fritz et al.

M. Fritz et al.

michael.fritz@awi.de

Received and published: 28 May 2015

Reply to Anonymous Referee No.2

We are grateful for the review and acknowledge your comments and suggestions. You will find all replies or changes that have been made below. Reviewer comments are cited in italic font.

Best regards,
Michael Fritz

(on behalf of the co-authors)

General comments: *The overall quality of the discussion paper is high, the text is well structured, the authors' point of view is clear. The paper is recommended for publication after discussion following the specific comments.*

Specific comments: *The article contains the attempt of extracting the most perspective topics of future permafrost science progress supporting. The grouping of original permafrost research questions in the "Supplement of Brief Communication. . ." is enough strange. It looks like "Green" and "Large": the groups are not comparable and stay in different categories. Some questions are not suitable to group name, e.g. the question "Can permafrost effectively be used to depose tailings and other toxic materials" must belong to Engineering or Ecology groups, not Physical Processes.*

In the beginning of this process the authors had set up a Google Form to receive community input and initial questions. There, categories were defined as the ones presented in the appendix. Online participants had the chance to choose the most appropriate category, or suggest their own; therefore the sorting was not done randomly by the authors. Instead, we have attempted to follow the intentions of the initial question creators as closely as possible. We agree that many of the questions span multiple categories, or that researchers of different domains may debate which questions belong where. We thank you for your comment on this topic, and feel this is part of the richness of discussion and critical reflection one can have during a cross- or inter-disciplinary activity such as the one detailed within this paper.

It seems that the key words using is not useful because the different specialists have the different understanding of the same terms. The carbon cycle specialist uses the "permafrost degradation" term as a proved process, like self-evident axiom. On the contrary, the permafrost mapping specialist understood the weakness of actual data to show the degradation as proved fact. He tries to drawing-up the sophisticated methods to integrate the sparse pointed data on different reaction of permafrost to climate change. The modeling specialist has the third point of view.

We are uncertain about which keywords the reviewer is referring to, specifically. Some of the keywords in our manuscript are the headings of our categories (i.e. Physical processes, Biogeochemistry, Social Interactions and impacts, Engineering, Ecology, Modelling) under which participants were asked to submit question(s). We proposed a set of topics and specialties to later evaluate to breadth of questions and interest the audience represents. These topics came from existing literature, and from the CliC/IPA initiative 'Permafrost Research Priorities'.

We do agree with the reviewer that certain terms can be perceived differently across various domains, and indeed feel that this is present in any cross- or inter-disciplinary activity. However, we view this as part of the richness in bringing together ECRs from many disciplines, departments, universities, countries, cultures, etc. The use of keywords often encouraged conversation around various meanings of terms from the viewpoints of mapping specialists, to modellers, to field-scientists, and others. We agree that the difference of perception of various terms may lead to confusion and disagreements, though we feel that this can also lead to enriched conversations, and careful reflection by both parties about the words they use to communicate their current perception of permafrost science.

However the "dialogue between research and the public" is not a priority in case of absence of real scientific progress (see page 12, line 16).

This has now been changed to: Disseminating the knowledge, i.e. to communicate our main findings into society for a dialogue between research and the public, is a priority, along with active and ongoing scientific research.

In the conclusion is not evident what kind of breakthrough is expected in permafrost science. In medicine one of actual goal is the rising of human lifetime. What about permafrost science? It's depend on the objects of investigation that are need be classified. E.g. geocryological bodies, phase transitions mechanisms, geocryological phenomena, geocryological landscapes, ground temperature regime, mechanical processes *within the phase transitions etc. May be the sectorial principle will be useful when each branch of science formulates proper priorities in permafrost territories. After them the integrative priorities will be drawing-up in interdisciplinary programs and in the sites of intensive investigation, like Toolik-Lake in Alaska.*

This is an interesting point of view, though one that we did not explore in our activity nor in our paper. We sought to provide a space and context for discussion regarding the future of permafrost science for ECRs. We felt this was an effective and interesting topic for which ECRs could be actively engaged, and also via which we could encourage on-going interest throughout their scientific careers. We feel that exploring what a "breakthrough" or ultimate end goal of permafrost science is potentially a large question, one that could be explored through its own forum in the future.

Technical corrections:
Page 12 - line 13: *In fact IPA coordinates already the initiative by action group activity. No other evident technical corrections.*

This has now been changed to: IASC and the IPA, together with SCAR on bipolar activities, should coordinate the research agendas in a proactive manner engaging all partners, including funding agencies and policy makers.

Interactive comment on The Cryosphere Discuss., 9, 1209, 2015.

Brief Communication: Future avenues for permafrost science from the perspective of early career researchers

M. Fritz[1], B.N. Deshpande[2,3], F. Bouchard[3,4,5], E. Högström[6,7], J. Malenfant-Lepage[3,8], A. Morgenstern[1], A. Nieuwendam[9], M. Oliva[9], M. Paquette[3,4], A.C.A. Rudy[10], M.B. Siewert[11,12], Y. Sjöberg[11,12], S. Weege[1,13]

[1] {Department of Periglacial Research, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, ~~Telegrafenberg A43,~~ 14473 Potsdam, Germany}

[2] {Département de Biologie, Université Laval, Québec, QC, G1V 0A6, Canada}

[3] {Centre for Northern Studies (CEN), Université Laval, Québec, QC, G1V 0A6, Canada}

[4] {Department of Geography, University of Montreal, QC, H2V 2B8, Canada}

[5] {Centre Eau Terre Environnement, INRS, Québec, QC, G1K 9A9, Canada}

[6] {Department of Geodesy and Geoinformation (GEO), Vienna University of Technology (TUW), ~~Gußhausstraße 27-29,~~ 1040 Vienna, Austria}~~Vienna}~~

[7] {Austrian Polar Research Institute, Vienna University,~~ Althanstraße 14,~~ 1090 Vienna, Austria}

[8] {Department of Civil and Water Engineering, Université Laval, Québec, QC, G1V 0A6, Canada}

[9] {Center of Geographic Studies, IGOT, University of Lisbon, Lisbon, Portugal}

[10] {Department of Geography, Queen's University, Kingston, ON, K7L 3N6, Canada}

[11] {Department of Physical Geography, Stockholm University, 10691 Stockholm, Sweden}

[12] {The Bolin Centre for Climate Research, Stockholm University, 10691~~,~~ Stockholm, Sweden}

[13] {Institute of Earth and Environmental Science, University of Potsdam, 14476 Potsdam, Germany}

Correspondence to: M. Fritz (Michael.Fritz@awi.de)

Abstract

Accelerating climate change and increased economic and environmental interest in permafrost-affected regions have resulted in an acute need for more directed permafrost research. In June 2014, 88 early career researchers convened to identify future priorities for permafrost research. This multidisciplinary forum concluded that five research topics deserve greatest attention: permafrost landscape dynamics; permafrost thermal modelling; integration of traditional knowledge; spatial distribution~~analysis~~ of ground ice; ~~permafrost types and vulnerability;~~ and engineering issues. These topics underline the need for integrated research across a spectrum of permafrost-related domains and constitute a contribution to the Third International Conference on Arctic Research Planning (ICARP III).

1 Introduction

Permafrost is a major component of the cryosphere, underlying~~occupying~~ 24% of the northern hemisphere~~northern hemisphere~~’~~s~~ land surface (Zhang et al., 1999), as well as parts of Antarctica, ~~and~~ alpine areas and high plateaus around the world. Due to rapid warming in the Arctic, permafrost areas are now changing, with global implications for the carbon cycle and climate feedback mechanisms (Schaefer et al., 2012).~~,~~ The World Meteorological Organization and the United Nations consider permafrost to be an essential climate variable. ~~and stakeholders are found at all levels of society, from the mining, oil and gas industries to indigenous communities and governments.~~ Despite the knowledge that permafrost areas contain twice as much carbon (~ 1100–1500 Pg) than is currently in the atmosphere (Hugelius et al., 2014) and that permafrost temperatures have increased significantly during the last 20–30 years (Romanovsky et al., 2010), climate projections in the IPCC Fifth Assessment Report (AR5) did not account for emissions from thawing permafrost, nor for~~and~~ the effects of~~the~~ permafrost carbon feedback on global climate (IPCC, 2013). Circumpolar permafrost areas in the Arctic have been used for settlements and hunting grounds for indigenous peoples,~~ for more than ten thousand years,~~ resulting in a legacy of knowledge.~~ about these areas. However,~~ conservation of cultural heritage sites and the construction of industrial and municipal infrastructure on permafrost are costly and ~~intellectually~~ challenging.

Over the past two decades, the International Arctic Science Committee (IASC) and the Scientific Committee on Antarctic Research (SCAR) have organized activities focused on international and interdisciplinary perspectives for advancing Arctic and Antarctic research cooperation and knowledge dissemination in many subject areas. For permafrost science, however, no consensus document exists ~~as yet~~ at the international level to identify future research priorities, although the International Permafrost Association (IPA) highlighted the need for such a document during the 24th IPA Council meeting in June 2012 (IPA, 2012), and has been working toward building such a document in time for the Third International Conference on Arctic Research Planning (ICARP III).~~2012).~~

This manuscript presents the outcome of an international and interdisciplinary effort conducted by early career researchers (ECRs) in 2014. Online community input and a conference workshop highlighted five priority research questions on the future avenues of permafrost science. This consensus statement has been formulated in collaboration with the IPA as a contribution to ~~the Third International Conference on Arctic Research Planning (~~ICARP III from ECRs in order~~),~~ to raise permafrost issues to the prominent position that they urgently deserve.

2 Community consultation process

Community input exercises are increasingly viewed as a valuable step towards elaborating future research priorities or ~~research~~ questions in a well-defined scientific community (e.g. Kennicutt et al., 2014; Seddon et al., 2014). We aimed to meet our goals of hosting an effective large group dialogue by means of online question development followed by a World Café conversational process (Brown and Isaacs, 2001). This process has been continually evaluated following the research question guidelines presented by Sutherland et al. (2011). An overview of the process is provided in Figure 1.

This activity took place as part of an ECR Workshop held prior to the 4th European Conference on Permafrost (EUCOP) in Évora, Portugal (Schollaen et al., 2014). ~~. It was proceeded by break-out sessions hosted by senior scientist from IASC, the IPA and other organizsations. For this activity, p~~Participants were provided with live instructions

(Supplement S3) and worked~~. This activity format was selected due to its flexibility, prior positive experiences of workshop organizers, and highly collaborative nature. Throughout the workshop, each individual participant had the opportunity to work~~ with more than 20 different members of the ECR permafrost research community while viewing~~, and to view~~ a variety of research topics.~~topics, many of which were outside their own field of expertise.~~

3 Breadth of questions

The submitted questions covered a broad range of topics that focused on ~~the~~ physical processes~~environment~~ (32), biogeochemistry (14), social interactions and impacts (9), engineering (9), ecology (4), and modelling (3) (Supplement Table S1). Of the 20 questions that received votes at the end of the World Café, 11 were associated with permafrost degradation or changes in permafrost properties (Supplement Table S4). This highlights the current changing nature of the terrestrial cryosphere environment and is directly linked to ~~the trending~~ research interests in~~topics on~~ thermokarst, active-layer monitoring and drivers of change. Tied for second were the keywords “ground ice” and “carbon”, which are linked to two distinct fields~~trends~~ in permafrost research. Ground ice research hints at a more classical, geocryological approach to permafrost science and is concerned mostly with permafrost distribution, formation processes and sensitivity to~~at~~ thaw, while carbon research follows a more recent research focus~~younger trend,~~ linking permafrost dynamics to carbon cycling by investigating its abundance, distribution and vulnerability. Inter-related ~~R~~research topics such as “permafrost distribution”, “process-related” questions, “hydrology” and “subsea permafrost” followed these three, and expressed less frequent but nonetheless important research avenues.

4 Highlighted research questions for permafrost science

4.1 How does permafrost degradation affect landscape dynamics at different spatial and temporal scales? (Q1)

Warming ~~—— Recent climate change in many cold-climate regions on Earth is entailing significant environmental consequences, particularly in~~ permafrost in areas of the polar regions ~~regions. This is the case of permafrost degradation in (sub)Arctic, Antarctic, high plateaus~~ and mountain and high-plateau~~environments, where some of the edaphic, ecological, and geomorphological processes, which shape the landscape, are changing in magnitude, and in some cases even reinforce permafrost thawing through positive feedback effects. While some of the processes may react to long-term changes, others may respond rapidly, sometimes abruptly, to threshold crossing (Rowland et al., 2010).~~

~~Permafrost thawing has wide social and economic implications for northern communities (Schaefer et al., 2012). With the extension of permafrost warming to greater areas of the Arctic, subarctic and mountain~~ landscapes results in degradation, and with it various interactions and feedback processes (e.g. ~~(~~Haeberli et al., 2010; Romanovsky et al., 2010; Oliva and Ruiz-Fernández, in press).~~2010), the interactions and feedbacks among the different processes causing degradation, and those being affected by it, need to be better understood.~~ These changes are complex and~~processes~~ operate at different spatio-temporal scales, sometimes involving~~ and can involve~~ remarkable changes to~~on the~~ landscape dynamics. While some of these regions react slowly to long-term changes, others may respond rapidly or even abruptly to threshold crossing (Rowland et al., 2010). Thermoerosion~~ Thermo-erosion~~ and mass movements can affect sediment, nutrient and soil organic carbon fluxes (Bowden et al., 2008; Grosse et al., 2011). Melting of ground ice and the evolution of thaw lakes will affect the water composition, hydrological transport and water storage capacity of the land (Grosse et al., 2007). These changes also interact with vegetation and snow cover, in a series of complex positive and negative feedbacks at~~in~~ the ground surface as well as in the active layer of the permafrost.

More accurate~~precise~~ knowledge on the causes and consequences of permafrost degradation will help to better assess community planning and landscape evolution models. Future research should focus on the identification and quantitative description of processes affecting different types of landscapes and integrating or ~~/~~applying the results at multiple spatial scales. The identification and quantification of tipping points and long-term monitoring of currently degrading sites will provide useful information on the development and recovery of the landscape. This~~ knowledge~~ will further enable the development of conceptual models that can help to understand the timeframe, scale and frequency at which these processes operate. This information is crucial to form a more solid foundation for predicting and modelling the long-term evolution of the landscape morphology along with aquatic and atmospheric fluxes.

4.2 How can ground temperature models be improved to better reflect permafrost dynamics at high spatial resolution? (Q2)

In the rapidly warming Arctic, better monitoring and prediction of permafrost degradation at a variety of spatial scales is critical for providing a range of stakeholders - ~~,~~ from scientist to local government and industry -~~,~~ with the tools they need to observe and plan for future effects~~the effect~~ on the environment~~al~~ and human activities. While models capable of representing many of the important processes at relevant scales have been recently developed, they remain too complex to be used by others than modelling experts and for more than generic scenarios. From~~On~~ global to regional scales, a number of approaches have facilitated mapping of the ground -thermal regime~~state~~ and its evolution over time in the past years (e.g. Gruber, 2012; Westermann et al., 2013). However, on the local scale, ~~presently~~ existing tools are either too simplistic or too complex to provide answers to many of the~~ local~~ problems that Arctic communities will be facing in the near future. Hereby, a main problem is the availability of forcing data sets at such scales, which requires permafrost modeling in conjunction with downscaling approaches (e.g. Zhang et al., 2012; Gruber, 2012). Future research should be focused on identifying which processes are most important for a variety of scales and problems, so that usable models with varying levels of complexity can be developed for all arctic stakeholders. ~~Hereby, i~~In particular, the thermal evolution of permafrost soils with high ground ice content poses a challenge for modeling, with thermokarst, ground subsidence and, in general, a modification of the hydrological regime over time. These processes are controlled by factors with high spatial variability, such as the type and density of vegetation, snow cover, soil moisture, human activity, which are in many cases interdependent ~~of each other~~ (e.g. Painter et al., 2013). Developing model representations for these processes is amongst the most urgent challenges,~~ for future~~

~~permafrost research,~~ both on local scale to better inform stakeholders (e.g. on ground stability), ~~stability,~~ as well as on large scales to improve the projections on the fate of permafrost ecosystems and their carbon cycle.

4.3 How can traditional environmental knowledge be integrated in permafrost research? (Q3)

The circumpolar Arctic is inhabited by indigenous peoples, such as Inupiat, Aletus and Alutiiq in Alaska; Inuit, Dene and Athabaskans in northern Canada; Kalaallit in Greenland; Sami in Fennoscandinavia and Chukchi, Yupiaq and Sakha in Russian Siberia. Having lived in close contact to the nature in the Arctic for a long time, ~~the~~ indigenous peoples have observed the consequences of the variations in permafrost~~-~~ conditions ~~state~~ that could provide valuable information to scientists. Traditional Environmental Knowledge (TEK) incorporates practice and belief and evolves by adaptive processes which are handed down through generations by cultural transmission. The highly specialized knowledge about the Arctic~~harsh permafrost- underlain~~ environment ~~of the Arctic~~ is thus preserved in the collective memory (Henry et al., 2013 and references therein).

The description of environmental processes by the non-scientific community, including indigenous peoples, often differs from that of the scientific community. ~~The ways environmental processes and events are described by the non-scientific community, including indigenous people, often differ from those within the scientific community.~~ It is challenging for the scientific community to incorporate TEK into existing scientific methods and to find ways to build up trust for communication. Indigenous observations and concerns have been taken into account increasingly in the literature and recent initiatives exist where the northern communities actively participate~~s~~ in research projects (Bennett and Lantz, 2014; Bull and Juutilainen, 2014; Tondu et al., 2014).

Although there are examples of successful applications and integration of TEK in the Arctic for the purpose of co-management of natural resources~~, studies related to wildfire and forestry, sea ice monitoring and ecology~~ (Bennett and Lantz, 2014; Tondu et al., 2014), increased effort is still needed to ~~involve TEK into the permafrost community. Further integration and application of TEK with science is needed to~~ evaluate the resilience of Arctic communities~~' resilience in general~~ (Henry et al., 2013). Successful adaptation to environmental changes demands a holistic system perspective, to which permafrost science in the case of the Arctic clearly can and should contribute. For the scientific community to document and assess traditional knowledge, as well as for adaptation in the socio-ecological and socio-economical systems in the Arctic, finding ways to work together in mutually beneficial and respectful ways seems to be the key to succeed with communication.

4.4 What is the spatial distribution of different ground ice types and how susceptible is ice-rich permafrost to future environmental change? (Q4)

Ground ice is a fundamental component of permafrost soils. In the Arctic lowlands of Eurasia and North America ground ice can occupy up to 80% of the soil volume in the upper 20-30 meters of permafrost (Brown et al., 1998). The amount of ice and its vertical and lateral distribution are central parameters controlling the thermal, physical and geochemical properties of permafrost deposits as well as their behavior to~~at~~ thaw. The presence of excess ice, including ~~and~~ massive ice, is a key factor affecting the thaw sensitivity~~vulnerability~~ of permafrost to warmer temperatures and mechanical disturbance~~,~~ as ice melt can result in thermokarst topography (~~will give rise to surface~~ subsidence and collapse)~~thermal collapse, also known as thermokarst~~ (Czudek and Demek, 1970). Although many field studies characterize cryostructures, measure ground ice content and map ground ice distribution, a concerted and organized mapping initiative that feeds into international databases is still lacking. Differentiating between epigenetic and syngenetic ground ice development could become a key for classifying~~to classify~~ and mapping the susceptibility of ~~ground~~ ice -bearing permafrost landscapes to warming, thaw, ground ice melt and finally for~~to~~ landscape reorganisation. The localisation~~localisation~~ of massive ice bodies such as ice wedges and buried glacier would be essential to create sensitivity maps to upcoming environmental changes. Until now, the National S~~s~~now and Ice Data Center~~data center (NSIDC)~~ has been the principal database on ground ice conditions, but it does not support the direct input of field-based information by international researchers. Similarly, the Global Terrestrial Network for Permafrost (GTN-P) is the primary international program concerned with monitoring permafrost parameters (Biskaborn et al., 2015~~http://gtnp.arcticportal.org/index.php/about-the-gtnp~~), but it does not include or provide information on ground ice.

Efforts to address this issue should focus on remote sensing applications for landform classification and on geophysical tools and drilling for the detection of subsurface ice. Ground-ice-related information should be integrated in a dedicated database, such as GTN-P, opening the door to regional extrapolation by integrating these data into climate models.

4.5 *What is the influence of infrastructures on the thermal regime and stability of permafrost in different environmental settings? (Q5)*

The economic development of the Arctic, ~~and~~ subarctic, and ~~as well as of mountain~~ permafrost regions at lower latitudes is~~, are~~ facing numerous engineering challenges since the performance of engineering structures and transportation systems are reliant on the strength of permanently frozen soil and bedrock. Numerous examples exist~~,~~ where the combined effects of climate change and inappropriate technical solutions due to lack of knowledge led to irreversible damages or have required intensive maintenance, adaptation and premature reconstruction (Bommer et al., 2010 and references therein).

National guidelines and recommendations have recently been developed to adapt infrastructures in permafrost areas (e.g. Bommer et al., 2010; Transportation Association of Canada,~~McGregor et al.,~~ 2010; Canadian Standards Association, 2010). Still, long-term evaluations of these practices (e.g. Burgess et al., 2010) are needed to establish reliable tools and standardized guidelines. In order to facilitate the evaluation of the construction and performance of the infrastructure in their specific environmental context, future research needs to systematically integrate permafrost engineering with earth sciences. This could be done through a geosystem approach to assess the potential for natural hazards caused by human activity (USARC, 2003). A main challenge is to improve predictions of the behavior and performance of structures and to act prior to unstable permafrost conditions. ~~Monitoring new~~ test infrastructures in problematic permafrost sites are~~is~~ one way to work on this challenge (Malenfant-Lepage et al., 2012).~~.~~ Furthermore, it helps bridging the gap between meteorological and permafrost monitoring data which are useful for risk assessments and recurrence interval projections of extreme events (Callaghan et al., 2011).~~(Instanes et al., 2005). Sites characterized by the presence of warm ice-rich permafrost, poorly drained soils and active water flow should be prioritized.~~ Overall, integrating engineering knowledge with other fields of science would benefit from and contribute to the impact assessments, socio-economic scenarios and adaptation strategies (USARC, 2003; Vincent et al., 2013).

5 Synthesis

This collaborative, discussion-based workshop allowed 88 ECRs to share ideas, generate new research questions and better understand a myriad of complex topics relating to the future of permafrost science. The~~ The top~~ five questions presented in this article cover a wide range of topics in permafrost research and are highly~~often~~ interrelated. Additionally, we would like to highlight research questions related to~~ One example for topical diversity and interrelationship is the lack of a~~ carbon as~~-specific question among the top five, although~~ permafrost carbon and its feedback dynamics are some~~is one~~ of the most popular topics in our research field today~~,~~ based on the number of publications and citations (Hubberten et al., 2011).~~. However,~~ questions Q1, Q2, and Q4 are all indirectly related to carbon dynamics and Q9, Q13, Q14, and Q16 (Supplement Table S4) directly deal with this topic. This demonstrates~~merely indicates~~ a fragmentation and specialization of this~~our~~ field as it grows rather than lack of interest, and also~~there is~~ a need for integration across disciplines (Vincent et al., 2013).

A~~The required~~ framework to answer the raised questions was~~ already~~ outlined by Kennicutt et al. (2014) as a result of the first SCAR Antarctic and Southern Ocean Science Horizon Scan. It can directly be adapted to permafrost research priorities in the polar areas,~~ and~~ alpine and high-plateau regions. We require predictable and stable long-term funding; year-round and multinational access to research stations in permafrost areas; improved and continuous satellite observation, transparent national licensing procedures, application of emerging technologies; transdisciplinary international cooperation; and improved communication among all interested parties (cf. Kennicutt et al., 2014). As the next generation of permafrost researchers, we see the need and the opportunity to participate in framing this process. Across the polar sciences ECRs have built powerful networks, such as the Association of Polar Early Career Scientists (APECS) and the Permafrost Young Researchers Network (PYRN), which have enabled us to efficiently consult with the community. Many participants of this community -input exercise will be involved and also affected by the Arctic science priorities for the next decade within permafrost research. Therefore, we need to i) actively frame this process; ii) contribute our insights into larger efforts of the community such as the Permafrost Research Priorities initiative by the Climate and Cryosphere (CliC) Project together with the IPA (http://www.climate-cryosphere.org/activities/targeted/permafrost-research-priorities); and iii) help identify~~ing~~ relevant gaps and a suitable roadmap for the future of Arctic research. To critically evaluate the progress made since ICARP II and to revisit the science plans and recommendations will be crucial.

IASC and the IPA, together with SCAR on bipolar activities, should coordinate the research agendas in a proactive manner engaging all partners, including funding agencies~~funders~~ and policy makers. Disseminating the knowledge, i.e. communicating~~to communicate of~~ our main findings ~~in~~to society for a dialogue between research and the public~~,~~ is a priority, along with active and ongoing scientific research.~~priority.~~ Special emphasis must be given to indigenous peoples living on permafrost, where knowledge exchange creates a mutual benefit for science and local communities. The ICARP III process is an opportunity to better communicate the global importance of permafrost to policy makers and the public.~~ and how permafrost affects and is influenced by people's daily lives.~~

The Supplement related to this article is available online at:

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Figure captions

Figure 1. Flowchart of the process used to develop and refine future research questions. Questions were initially developed via an online survey. After some refinement, the process continued with an on-site World Café (Brown and Isaacs, 2001) workshop. Questions asked throughout the World Café enabled participants via group discussion to consider structure, breadth and depth of the questions (Sutherland et al., 2011). Workshop participants (Supplement Fig. S2) voted to identify the questions they believed to be the most compelling as a final step in the on-site activities. Based on votes, five questions were selected for further development and dissemination. The collaborative nature of the activities, coupled with substantial interest from all participating ECRs, enabled high levels of participation and thoughtful discussions about the future of permafrost research. Detailed workshop guidelines are given in Supplement S3.

Table S1. Original permafrost research questions (n=71) submitted by early career researchers through an online questionnaire and grouped according to research topics.

No.	Physical processes (n=32)
1	What are the biggest changes that should be included into a new permafrost map of the northern hemisphere?
2	Which new techniques can be used to identify ice wedges and permafrost in the southern permafrost zone?
3	Can permafrost effectively be used to depose tailings and other toxic materials?
4	Can the Landsat 8 Thermal band be used to detect frozen ground?
5	What are the specific contributions of 'non warming' factors (e.g., human activity, surface disturbance, forest fires, hydrology, precipitation changes) on permafrost degradation? Can we disentangle and quantify these at different spatial and temporal scales?
6	How can we better capture small-scale processes in permafrost regions on the larger scale of global land surface models?
7	How can we better determine the portion of observed methane levels that are attributed to decomposing submarine permafrost vs. decomposing gas hydrates?
8	How can we deepen our investigation to better model soil temperatures at greater depth?
9	How can we detect circum-polar permafrost related changes using satellite data?
10	How can we improve methods to express permafrost distribution?
11	How can we improve the information on ground ice distribution?
12	How can we use geophysics to effectively delineate and monitor periglacial properties including ground ice, wetlands, seasonal ice (related to heave, subsidence) and drainage networks?
13	How do density-driven flows, such as salt fingering in marine sediments, affect the stability of submarine permafrost and the formation of taliks in submarine permafrost?
14	How do variations in submarine groundwater discharge affect offshore submarine permafrost evolution and how can we measure or observe evidence of submarine groundwater discharge?
15	How does climate change impact sediment movement in permafrost landscapes (terrestrial and hydrological)?
16	How does decomposing submarine permafrost on the circum-Arctic shelf contribute to the seawater methane concentration in shallow Arctic waters?
17	How important is subsurface denudation for landscape evolution in permafrost environments?

18	How much of the Arctic shelf is underlain by subsea permafrost?
19	How quickly does bedrock permafrost in steep rock faces react to rising temperatures?
20	How strong is/will be the permafrost carbon feedback?
21	How will permafrost thaw affect freshwater fluxes to the Arctic ocean in the next 10 to 100 years?
22	How will thawing permafrost in combination with changes in the components of the hydrological cycle affect wetland areas in the next 50 years?
23	How will the components of the surface energy balance of arctic ecosystems respond to predicted future climate scenarios and what will be the feedback exerted on the climate system?
24	Is submarine groundwater discharge fundamentally different in the coastal Arctic due to the influence of a permafrost layer?
25	What have been the rates of coastal erosion in permafrost areas since the end of the last ice age?
26	What impacts do ice lenses in the seasonal snowpack have on the surface offset between air and ground surface temperatures?
27	What is the best way to conduct continuous measurements in remote permafrost environments while accounting for limited funding?
28	What is the role of ground ice for the resilience and vulnerability of permafrost against rising air temperatures and thermal degradation?
29	What is the role of volcanic ashes for preserving glacial ice and permafrost?
30	Where does new permafrost formation take place?
31	Which paleoclimate signals are stored in different kinds of ground ice and how can this information be used as a substantial contribution to the permafrost community and to paleoclimate research for defined time periods and regions?
32	How does the stability of permafrost-affected rock faces react to recent climate warming?
	Biogeochemistry (n=14)
33	How can we assess the relative importance of lateral transport, storage, burial and mineralization of carbon in short- and long-term reservoirs resulting in delayed or attenuated GHG emissions and their impacts on greenhouse gas emissions? At what spatial and temporal scales?
34	How can we better model soil carbon distribution and dynamics?
35	What are the future steps required to produce quality soil carbon models?
36	How do changes in active layer thickness and permafrost coverage influence ecosystem-scale carbon budgets and what are the impacts of these changes on vegetation patterns and productivity on the one hand and decomposition of soil

	organic matter on the other hand?
37	How do soil organic matter mineralization rates and nutrient availability for plants (with particular attention to nitrogen) change?
38	How much carbon, nutrients and sediments are expected to be delivered to the Arctic Ocean due to coastal erosion under different IPCC scenarios?
39	How will the hydrological part of the carbon cycle be affected by climate change across spatial scales?
40	Is degrading permafrost altering riverine fluxes of major elements to the polar oceans, and if there is a change, is it significant enough to alter global biogeochemical cycling?
41	Is degrading permafrost increasing riverine fluxes of organic and inorganic carbon (and other nutrients) to the Arctic Ocean?
42	What are the best methods of quantifying balance dynamics between the methanogenesis and methanotrophy in the water column of thermokarst lakes? What are the key determinants of these dynamics?
43	What are the impacts of thawing permafrost on aquatic ecosystems (ponds, streams, lakes)?
44	What are the rates of carbon turnover in warming and deepening active layers?
45	What is the role of ground ice as a potential source of carbon and nutrients upon permafrost degradation?
46	What will be the role of subsea permafrost in the global carbon cycle in the next 100 years?
	Social Interactions and impacts (n=9)
47	How have indigenous people actively shaped certain permafrost landscapes in the past and what will be the impact of increasing land use on permafrost degradation processes?
48	How are indigenous people in southern permafrost zone dealing with climate changes?
49	How can indigenous people living on permafrost adapt to or mitigate the degradation of natural resources, settlement areas and hunting/fishing grounds due to thermal and mechanical permafrost degradation?
50	How can the predicted increased rockfall risk for permafrost-affected rock faces be implemented within the risk management cycle?
51	How can we evaluate of the potential land use of high latitude regions under climate change and vulnerability of existing infrastructures.
52	How is present climate change likely to change permafrost landscapes and indigenous land use and what are the possibilities for local communities to adapt to these changes?
53	Is it possible to technically involve people living on permafrost in field studies, in particular the indigenous populations?

54	What is the best way to transfer scientific knowledge to policy makers and the general public?
55	Where and how was periglacial research funding distributed (spatially and by topic)? What was the long-term impact of this funding?
	Engineering (n=9)
56	What is the influence of transport infrastructure on permafrost degradation?
57	How will an expected expansion in infrastructure in the Arctic be affected by degrading permafrost in the next 50 years?
58	How are the locations of roads in cold climate regions reacting on the influence of seasonal frost penetration?
59	How can the seismic risk be considered in the design of northern infrastructures built on permafrost?
60	How can we make the chilling system of thermopiles changeable with minimum loss of its efficiency?
61	How exactly are the mechanical properties of frozen rock containing ice altered by an increase of temperature?
62	How is the deformation mode of soil changing during the process of frost heaving?
63	How to optimally freeze soil layers defined by their grain-size using thermosyphones?
64	What is required to adapt available thermo-hydro-mechanical models for simulating pile-heaving soil interactions?
	Ecology (n=4)
65	How will climate change affect the specific composition, vegetation cover fraction and primary productivity of the arctic terrestrial biome?
66	What are the feedbacks of change in landscape-scale permafrost hydrology on vegetation dynamics and how are these feedbacks controlled by degrading permafrost?
67	What impacts do changes in permafrost have on the grazing and migration patterns of caribou?
68	How can we connect permafrost thawing with eco-hydrological degradations in boreal forest regions?
	Modelling (n=3)
69	What is the best way (algorithms, models, approach) to simulate coupled permafrost-hydrological systems for the past and future?
70	How can we monitor and survey carbon-rich permafrost tundra lowlands and transfer observations into transient meso-scale models?
71	Is permafrost likely to completely disappear in the future?

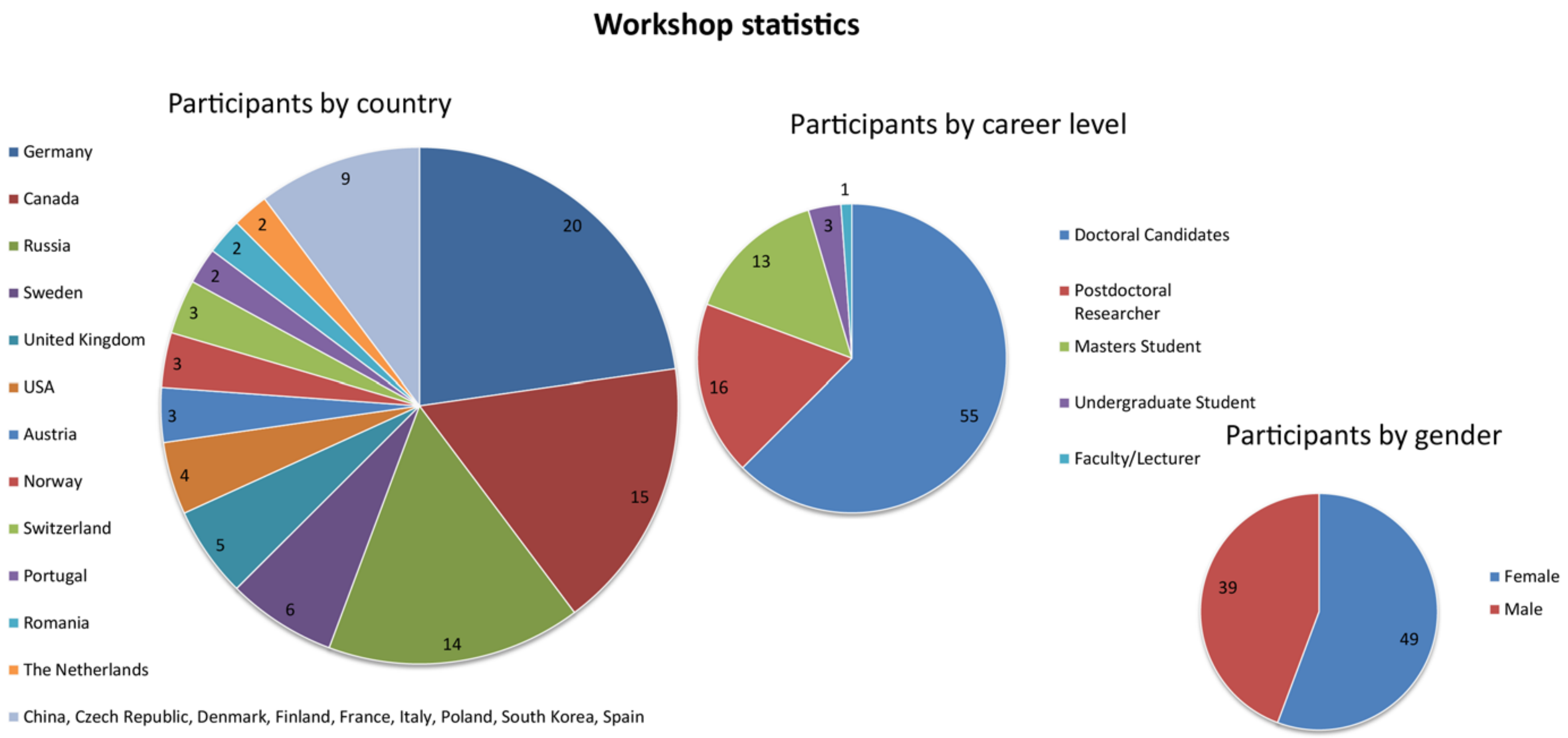

Figure S2. Statistics of workshop participants (n=88) grouped by country, career level, and gender.

S3: World Café Guidelines

Overall Purpose

- Diversify thinking and ideas regarding key permafrost research questions for the next decade, encourage out-of-the-box and unique ideas to emerge
- Expand thinking and ideas regarding the topics and questions posed
- Provide an opportunity for Permafrost Young Researchers to interact in a unique environment
- Link, connect and share ideas to promote multi-disciplinary, cross-disciplinary and inter-disciplinary thinking
- Produce a final set of questions to be part of a Permafrost Priority Sheet to define early-career researchers perspective on:
    - Permafrost science priorities for the next decade & research agendas
    - Informing policy makers, people who live in or near the Arctic and the global community
    - Building constructive relationships between producers and users of knowledge.
    - Integrating priorities for forward-looking, collaborative, interdisciplinary permafrost research and observing
    - Establishing an inventory of recent and current synthesis documents and major developments in permafrost research.

Guidelines for all participants:

- Focus on what matters
- Contribute your thinking
- Speak your mind
- Listen actively to understand
- Link and connect ideas
- Listen together for insights and deeper questions
- Play, doodle, draw; Have fun

Guidelines for table moderators:

- Take notes to record what happens at your table
- Ensure participation from all members of your table
- Try to balance open sharing and brain-storming with staying focused on what matters

Criteria for research questions

Please read through the questions at your table and identify if they fulfill the following criteria (Sutherland et al., 2011). If they do not fulfill the criteria, feel free to adjust, edit, combine or eliminate questions if necessary.

- ❏ Answerable through a realistic research design,
- ❏ Not answerable with "it all depends",
- ❏ Should not be answerable by "yes" or "no",
- ❏ Addresses important gaps in knowledge,
- ❏ Of a spatial and temporal scope that reasonably could be addressed by a research team,
- ❏ Have a factual answer that does not depend on value judgments,
- ❏ Not formulated as a general topic area,
- ❏ If related to impact and interventions, contains a subject, an intervention, and a measurable outcome.

Sutherland, W. J., Fleishman, E., Mascia, M. B., Pretty, J., and Rudd, M. A.: Methods for collaboratively identifying research priorities and emerging issues in science and policy, Methods in Ecology and Evolution, 2, 238-247, 10.1111/j.2041-210X.2010.00083.x, 2011.

Table S4. Permafrost research questions (n=20) that received votes during the World Café process (“Dot”-mocracy), including the top five priority research questions, which were developed further.

No.	Question	Weighted votes
1	**How does permafrost degradation affect landscape dynamics at different spatio-temporal scales? Which are the most important processes?**	**88**
2	**How can ground temperature models be improved to better reflect factors affecting degradation/preservation/aggradation of permafrost at high spatial resolution? (factors: ground ice, snow cover, volcanic ashes, vegetation, other insulating layers, moisture, ground physical properties, climate, human impact)**	**85**
3	**In what ways can traditional environment knowledge be quantified and used in scientific research?**	**52**
4	**What is the spatial distribution of: a) massive ground ice, b) syngenetic ground ice, c) epigenetic ground ice? What is the vertical distribution of: a) massive ground ice, b) syngenetic ground ice, c) epigenetic ground ice? And how susceptible is it to thaw and warming?**	**45**
5	**What is the influence of different types of infrastructure on the permafrost thermal regime and stability in different environmental settings?**	**43**
6	How to create a georeferenced database of permafrost distribution that is easy to contribute to and continuously updated?	36
7	What geophysical methods can be used to validate remotely-sensed ground ice data?	33
8	What are the impacts of thawing permafrost on aquatic ecosystems?	29
9	What are the most significant feedback mechanisms between permafrost changes and wildlife, hydrology, the carbon cycle, and vegetation dynamics?	27
10	What is the past and future of permafrost distribution?	25
11	How can we standardize techniques to determine permafrost distribution while including key local factors?	25
12	Which processes control new permafrost aggradation and where does it occur?	23
13	What are the turnover rates of carbon and nutrients in warming and deepening active layers (including lateral and vertical fluxes)?	19
14	How can we obtain soil carbon distribution and model dynamics and which are the key parameters that need improvement?	14
15	What are the magnitudes of feedbacks between changing permafrost and hydrology?	13

16	What is the role of ground ice as a potential source of carbon and nutrients on permafrost degradation?	12
17	Under which climatological and geological conditions is ground ice forming today?	9
18	How do variations in submarine groundwater discharge affect offshore submarine permafrost evolution? How does decomposing subsea permafrost and circum-arctic shelf contribute to the seawater methane concentration in shallow arctic waters?	9
19	What are the most important parameters to use in permafrost models to capture the interactions between permafrost and the hydrological cycle?	7
20	What increases the likelihood of subsea permafrost thaw and its extent?	2