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

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,

Michael Fritz

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Reply to the Editor

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

Best regards,
Michael Fritz

(on behalf of the co-authors)

Dear authors

Thank you for the revised version of your manuscript it has received two favorable reviews; one of them with some suggestions for improvement. This is an interesting but also unusual manuscript in terms of what it reports. It is nearly ready for publication.

My most important point is making it more concise. Much of the text can be shortened significantly by removing unnecessary fill words, clauses, or repetition. I would like you to give the text one more round of careful editing to shorten it by about 30%. Similarly, please reduce to 20 references. Below are a few minor edits and suggestions.
The manuscript was shortened by 29% and reduced to 21 references.

Furthermore, it would be good to explain better what a “priority research question” (P3L7) or a “highlighted research question” is. In Figure 1, this is described as “found most compelling”. But this could mean a number of things such as scientifically most intriguing, or having the greatest societal relevance. In my view, it is important to explain this as the value of presenting the five selected questions hinges upon what they were selected for.
Supplement S3 gives the full range of detail about the criteria for research questions according to Sutherland et al. (2011). These are:

- ❑ 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.

To make it more clear in the text we added the following part to the last sentence of chapter 2: “...including criteria what makes a research question (cf. Sutherland et al., 2011).”

Finally, a ‘priority research question’ or a ’highlighted research question‘ is a research question that was formulated and democratically selected/prioritized by the community.

P2L7–L10: Remove “These topics … planning (ICARP III)”
Done.

P2L14: The logic does not work, please change: Northern Hemisphere as well as alpine areas and Plateaus. “As well as” implies that the latter are in addition to the former but they are not.
The sentence was shortened so that it makes sense.

P2L18: Permafrost is not an essential climate variable, but two metrics are. Please be more specific.
We removed the sentence.

P5L15 Delete “in the … landscapes”
There is no such wording in P5L15.
On page 4, we shortened a similar sentence.

P4L31 Delete “of currently degrading sites” and “and recovery”
Done.

P5L8 Delete “monitoring and”
Done.

P6L6 “permafrost conditions” insert blank space
Done.

P7L5 do you mean “disturbances SUCH as ice melt”
We removed the sentence.

P7L12 “buried glacier ice would be”
We removed the sentence.

P7L13 “… to create terrain sensitivity maps.”
We removed the sentence.

P7L17 Biskarbon et al 2015 is not a suitable reference for GTN-P as a program.
The reference is not to the program itself, but to the statement of its primacy as an international permafrost monitoring program. It is the only reference to GTN-P in a peer-reviewed journal so far. Website URLs may change; this reference will probably stay longer. We urgently request to keep the reference.

P7L26 “The economic development in permafrost regions is facing….”
Changed to: “The economic development in the Arctic is facing…”

I look forward to reading your revised manuscript.
Kind regards,
Stephan Gruber

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 red font.

Best regards,
Michael Fritz

(on behalf of the co-authors)

For final publication, the manuscript should be accepted as is.
Thank you.

Reply to Anonymous Referee No.2

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 red font.

Best regards,
Michael Fritz

(on behalf of the co-authors)

For final publication, the manuscript should be accepted subject to minor revisions.
Minor Editorial revisions

Page 2, line 21 – Although IPCC is defined in reference list you still should spell it out the first time it is used in the text.
We removed the sentence and the reference.

Page 4, line 15-16 – Some of the information in the sentence is covered below so it is suggested to revise to: "Warming and degradation of permafrost affects the landscapes of the polar, mountain and high-plateau regions.
We shortened the sentence before so that there is no redundancy left.

Page 4 line 31-32 – Long-term monitoring helps with the identification and quantification of tipping points. Suggested revision: "Long-term monitoring of currently degrading sites will facilitate identification and quantification of tipping points and provide useful information on the development and recovery of the landscape.
Done.

Page 5 line 6 – You could consider using the term "thermal model" rather than temperature.
Done.

Page 5, line 17-18 – Suggested revision: "….communities will face in the near future. A main problem is…."
Done.

Page 5 line 28-29 – Suggested revision "…challenges both at local scales to better inform stakeholders…..as well as at regional and global scales to improve projections…." I would suggest you use the term regional and global scales rather than large scales. When we refer to large scale for map scale this would imply more local scale detailed modelling. Regional and global are more descriptive and probably better to use.
The sentence at the beginning of the paragraph already includes the alignment of research foci to stakeholder interests. Page 5 line 28-29 was significantly shortened "Developing model representations for these processes is amongst the most urgent challenges to improve projections on the fate of permafrost ecosystems and the carbon cycle."

Page 7 line 6 – You could probably use any of the references cited in section 4.1 here as they are relevant to thermokarst and more recent than Czudek and Demek (Callaghan et al. 2011 probably works). This would allow you to remove one from your list.
We removed the sentence and the reference.

Page 7 line 11 – You could just say "…and mapping the susceptibility of ice-bearing permafrost landscapes to warming." Susceptibility of the landscape would imply the impacts of melting ice on the landscape etc.
We removed the sentence.

Page 8, line 10-11 Revision suggested: Test sites in problematic permafrost areas are one way…"
Done.

Page 8, line 12-13 Revision suggested: "Bridging the gap between meteorological and permafrost monitoring data would also support risk assessments and …."
We removed the sentence.

Page 8, line 31 Revision suggested "…to answer the questions raised was outlined by…."
We removed the sentence.

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

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Abstract

Accelerating climate change and increased economic and environmental interests 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 of ground ice; 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 24% of the Northern Hemisphere's land surface (Zhang et al., 1999), as well as parts of Antarctica, 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 now consider permafrost to be an essential climate variable. Despite the knowledge that permafrost areas contain twice as much carbon (~ 1100–1500 Pg) asthan 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 the effects of 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, resulting in a legacy of knowledge. Conservation of cultural heritage sites and the construction of industrial and municipal infrastructures on permafrost are costly and 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 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 onesuch a document in time for the Third International Conference on Arctic Research Planning (ICARP III).

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 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 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). Participants were provided with live instructions (Supplement S3) and worked with more than 20 different members of the ECR permafrost research community while viewing a variety of research topics including criteria what makes a research question (cf. Sutherland et al., 2011).

3 Breadth of questions

S~~The s~~ubmitted questions covered a broad range of topics that focused on physical processes (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 research interests in 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 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 thaw, while carbon research follows a more recent research focus linking permafrost dynamics to carbon cycling by investigating its abundance, distribution and vulnerability.~~ Inter-related 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 permafrost~~ in the polar regions and in mountain and high-plateau landscapes~~ results in its degradation and~~, with it,~~ in various interactions and feedback processes (~~e.g. Haeberli et al., 2010;~~ Romanovsky et al., 2010~~; Oliva and Ruiz-Fernández, in press~~)~~. These changes are complex and~~ operating~~e~~ at multiple~~different~~ spatio-temporal scales, sometimes involving remarkable changes to 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). Thermo~~-~~erosion and mass movements can affect sediment~~,~~ and 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 hydrology and ~~the~~ water chemistry~~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 the ground surface and~~as well as~~ in the active layer~~of the permafrost~~.

More accurate 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.~~ Long-term monitoring of currently degrading sites will facilitate identification and quantification of tipping points and provide useful information on the development and recovery of the landscape.~~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 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 thermal~~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 on the environment 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 global to regional scales, a number of approaches have facilitated mapping of the ground-thermal regime and its evolution over time in the past years (e.g. ~~Gruber, 2012;~~ Westermann et al., 2013). However, on the local scale, ~~existing~~ modelling tools are either too simplistic or too complex to be used by others than modeling experts to provide answers to many of the problems that Arctic communities will face~~will be facing~~ in the near future. A~~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~~ focus~~ed~~ 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~~ A~~a~~rctic stakeholders. ~~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.~~ Such ~~These~~ processes are for example controlled by ~~factors with high spatial variability, such as~~ the type and density of vegetation, snow cover, soil moisture and~~,~~ human activity, which are in many cases interdependent (e.g. Painter et al., 2013). Developing model representations for these processes is amongst the most urgent challenges~~, both on local scale~~ ~~for local~~~~to better inform stakeholders (e.g. on ground stability), as well as on large scales~~ to improve ~~the~~ projections on the fate of permafrost ecosystems and the~~ir~~ carbon cycle.

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

The circumpolar Arctic is inhabited by a variety of 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 with ~~to the~~ nature in the Arctic for a long time, they~~indigenous peoples~~ have observed changing~~the consequences of the variations in~~ permafrost conditions 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~~-~~ environment 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. This makes it~~, being~~ ~~. 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~~ increasingly ~~been taken into account increasingly in the literature and recent initiatives exist where the northern communities actively participate 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 (Bennett and Lantz, 2014; Tondu et al., 2014), increased effort is still needed to evaluate the resilience of Arctic communities (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 it 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 thaw. The presence of excess ice, including massive ice, is a key factor affecting the thaw sensitivity of permafrost to warmer temperatures and the melting of ice causes mechanical disturbance that as ice melts can result in thermokarst topography (subsidence and collapse) (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 and mapping the susceptibility of ice-bearing permafrost landscapes to warming, thaw, ground-ice melt and finally for landscape reorganisation. The localisation of massive ice bodies such as ice wedges and buried glacier ice would be essential to create terrain sensitivity maps to upcoming environmental changes. Until now, the National Snow and Ice Data Center 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), 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)

E~~The e~~conomic development in permafrost regions ~~of the Arctic, subarctic, and permafrost regions at lower latitudes~~ is facing numerous ~~engineering~~ challenges since the performance of engineering structures and transportation systems are reliant on the strength of permanently frozen ground~~soil and bedrock~~. Numerous examples exist where the combined effects of climate change and inappropriate technical solutions have ~~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~~; Canadian Standards Association, 2010; Transportation Association of Canada, 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 develop. T~~t~~est ~~infrastructures~~ sites in problematic permafrost ~~sites~~ areas are one way to address~~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).~~ 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 consultation process allowed the community of permafrost ECRs to work out the most urgent share ideas, generate new research questions and better understand a myriad of complex topics relating to the future of permafrost science. The five questions presented in this article cov er a wide range of topics in permafrost research and are highly interrelated. As suchAdditionally, we would like to highlight research questions related to carbon as permafrost carbon and its feedback dynamics as these are amongsome of the most popular topics in the permafrostour research field today based on the number of publications and citations (Hubberten et al., 2011). 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 a specialization and fragmentation of our field as it grows rather than lack of interest, and also a need for integration across disciplines (Vincent et al., 2013).

A framework to answer the raised questions was 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, 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 the future research prioritiesthis 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 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, and policy makers, and local populations. CDisseminating the knowledge, i.e. communicating our main findings to society infor a dialogue between researchers and the public is a priority, along with active and ongoing scientific research. Special attentionemphasis 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.

The Supplement related to this article is available online at:

Acknowledgements

We wish to express our sincere gratitude to the workshop sponsors: th e International Arctic Science Committee (IASC), the International Permafrost Association (IPA), the Climate and Cryosphere (CliC) Project, the Bolin Centre for Climate Research, the PAGE21 project (grant agreement number 282700, funded by the EC 7th Framework Programme theme FP7-ENV-2011), and the ADAPT project ('Arctic Development and Adaptation to Permafrost in Transition'). We would also like to thank the local organizers of the 4th European Conference on Permafrost at the University of Lisbon and the University of Evora (Portugal) for hosting this event. Special thanks to the numerous mentors and speakers who shared their expertise with ECRs andand participated in the development and delivery of the workshop, especially to Alison Cassidy who helped organizing the workshop. We also appreciate comments from Nikolaus Gantner, Guy Doré, Sebastian Westermann, Scott Lamoureux, Boris Biskaborn, Hugues Lantuit and Warwick F. Vincent regarding this manuscript. FourTwo anonymous reviewers helped to improve the manuscript. Lastly, sincere thanks to all PYRN, APECS, ADAPT and PAGE21 early career researchers who took part in this process. This is an official contribution to ICARP III.

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Figures

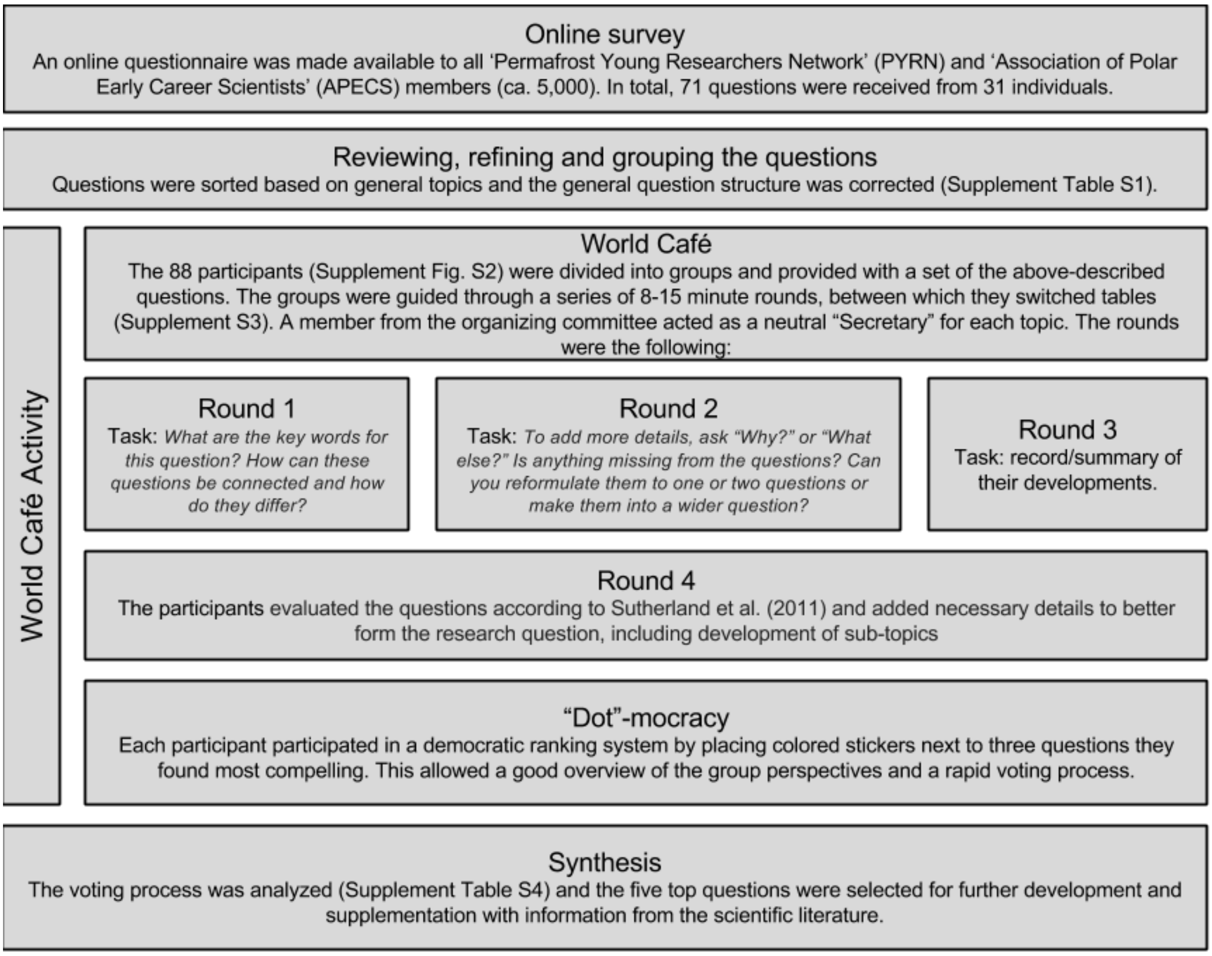

Figure 1. Flowchart of the process used to develop and refine future research questions. Questions were initially developed via an online survey. After some refinement, the process continued with an on-site World Café (Brown and Isaacs, 2001) workshop. Questions asked throughout the World Café enabled 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.