Synthesis report: IPaC survey

IPAC prioritized permafrost and carbon research topics

The International Permafrost Association (IPA) Permafrost and Carbon budgets Interest Group (IPaC) provides a formalized pathway for IPA experts to give feedback on the reflection of permafrost in datasets used for broad-scale carbon budgets.

If you wish to contribute to IPaC, please email the coordinator Dr. Justine Ramage at this address: ipa.permafrostcarbon@gmail.com

The first IPaC permafrost researcher survey solicited inputs and ideas on carbon (C) and nitrogen (N) related topics that could improve both estimations of permafrost carbon and the understanding of its contribution to the global carbon budget.
The permafrost research community was asked:
"***What are your ideas for prioritized permafrost and carbon (or nitrogen) research topics and how can IPaC facilitate progress?***".

The survey aimed at identifying knowledge gaps in permafrost carbon (or nitrogen) cycling. Participants were asked to contribute ideas on processes important in global or regional carbon budgets and that might generate significant progress within one to two years.
The survey was sent to the 151 members of IPaC on September 19th, 2019 and remained open until October 18th, 2019. In total, 25 participants contributed to the survey. Based on their suggestions, we identified 8 key topics described below: field sampling protocols, ecology of permafrost C and N, process-understanding for soil carbon mineralisation, mapping of ground ice and permafrost C, land-sea coast interactions, ecosystem recovery after disturbances, aquatic ecosystems, and permafrost peatlands. Finally, researchers called for an updated review of permafrost carbon budgets.

1. Field sampling protocols

Researchers emphasized the need for homogenous sampling protocols to improve the capacity for data comparison across the permafrost region. Field protocols for sampling carbon stocks as well as measurement of CO_2 and CH_4 fluxes and incubations should be designed and approved by the permafrost research community and later be integrated with global inventory efforts. Protocols should take into account differences in sampling procedures between soil pedons, yedoma and other deep sediments, and other carbon pools. Protocols should also be designed for archiving and preserving soil or vegetation samples as well as for providing data curation and access. Improved data access and exchange would permit and increase in the number of analyses performed on the same sample. One example could be to adopt established data curation protocols, such as the FAIR dataset protocols.

2. Ecology of permafrost C and N

More ecosystem-ecology research in permafrost systems, notably including plants, roots and microbes, is needed to better quantify the permafrost carbon budget. Responses on ecology-related topics can be grouped into four main themes: 1) impact of permafrost disturbance on plant ecology, 2) CO_2 compensation by increased plant growth, 3) turnover time and source of greenhouse gas fluxes, and 4) coupled Nitrogen-Carbon cycles.

Impact of permafrost disturbance on plant ecology would address questions about plant recovery on bare ground and the influence of permafrost thaw and increasing temperatures on plant growth and carbon release. The role of plant growth on CO_2 compensation, especially relating to plant recovery on bare ground needs to be assessed to better understand the impact of vegetation on the carbon budget. Studies of turnover time and source of CO_2 fluxes should include: differentiating between ancient permafrost carbon and "fresh" plant respiration and the potential of a priming effect from vegetation or dissolved organic matter. More emphasis should be put on estimating soil Nitrogen storage and coupled Nitrogen-Carbon cycles, in order to assess the potential for climate change to limit Arctic greening and increased biomass accumulation through the nitrogen supply.

3. Process-understanding for soil C mineralisation

There are still large uncertainties in understanding the processes of soil carbon mineralisation including the importance of various soil stabilization mechanisms such as mineral interactions and aggregate formation. Current knowledge from permafrost soils relies on a few incubation experiments on various soil horizons under aerobic and anaerobic conditions. Additional in-situ or incubation experiments focusing on processes such as differentiating between CO_2 and CH_4 production under anaerobic conditions, stabilization processes for the net mineralization rate, or interactions with priming effects, would help estimate potential carbon mineralisation rates at broad scales. Expanding beyond studies of near surface soils and compiling data sets for deeper permafrost are also needed. Abrupt thaw processes may also remobilize deep carbon rapidly. Comparison of results from incubation experiments between deposits of different ages and origins will improve understanding of organic carbon and nitrogen transformation in permafrost deposits.

4. Better mapping of ground ice and permafrost carbon

The environmental factors controlling carbon and nitrogen cycling in permafrost terrain are strongly linked to hydrology and ground ice distribution. Abrupt thaw processes and thermokarst formation are important for the vulnerability of permafrost C but needs to be better quantified. A first step towards full quantification of long-term warming impacts on frozen carbon is to have good maps of ground ice and carbon distributions. While surface soil carbon stocks are relatively well mapped, knowledge of ground-ice distribution and deeper carbon stocks remains patchy and insufficient. Systematic compilation of field observations in databases is a way to fill this gap (see point 1). Combining such field data with, for example, maps of Quaternary deposits, topographic indexes, and remote sensing data might improve estimates of ground ice and deep carbon across the permafrost region. Improved data on ground ice and deep carbon distribution may pave the way to modelling the environmental factors controlling soil moisture and temperature and improved estimates of abrupt thaw processes.

Moreover, there is little data on the age of permafrost carbon stocks beyond the local scale. By comparing ages of mineral and organic soils in the permafrost region one could estimate the overall permafrost carbon accumulation history. Such representations would allow framing the global carbon-cycle and climate history, such as comparing permafrost carbon stocks with ice-core records of the carbon-cycle or climate changes.

5. Land-Coast-Sea interaction

Coastal environments are dynamic and influenced by erosion and accumulation processes. Fluxes of C, N, and contaminants from coastal erosion are poorly quantified. More research in this field, combined with better modelling of coastal erosion in the Arctic would significantly help fill the gap of permafrost carbon. The role of Arctic deltas in the carbon cycle is uncertain. It is necessary to identify their role as a sink or source of carbon and nitrogen and to understand the processes that can enhance or inhibit carbon fluxes from deltaic sediments. Moreover, little is known about the impacts of delta dynamics on the biogeochemistry of the near-shore zone in the context of sea-level rise. Another uncertainty relates to the sub-sea storage of carbon-containing gases and gas hydrates in the near shore zone. Possible ways to estimate these storages are to map the tectonic structures using databases of seeps or to derive gas hydrate storage from the contribution of isotopically heavy carbon to measured emissions.

6. Ecosystem recovery after disturbances

The impact of permafrost disturbances-following e.g. thermokarst, fire or human impacts-on the redistribution of carbon within landscapes is unknown (see also point 4). Depending on local conditions, the post-disturbance trajectories of permafrost and ecosystems vary greatly. Under an ever-warming climate, the occurrence of such episodic events is likely to increase significantly in coming decades. Several questions regarding the fate of ecosystems following such events need answering: when do these areas remain sources of greenhouse gases and when do they become sink. Which properties determine whether an ecosystem resiliently recovers to pre-disturbance states or shifts to another state? The impact of thermokarst landforms and fires on the carbon budget needs to be physically understood and then modeled to support projections into the future.

7. Aquatic ecosystems

Leaks during transport of carbon through aquatic ecosystems, as well as carbon turnover times in water bodies (wetlands, lakes, streams, rivers), are still poorly defined. To address this, lateral fluxes and losses of carbon from permafrost degradation and erosion should be estimated. Further the fate of organic matter and sediments in the aquatic system as well as its impact on aquatic biogeochemistry and food webs needs more study.

Moreover, there remains a limited understanding of the lateral fluxes and losses of carbon caused by permafrost thaw and erosion. Studies covering this topic, including modelling lateral and vertical fluxes of carbon, should quantify and reduce the uncertainty in the estimates of net carbon uptake from aquatic environments.

8. Permafrost peatlands

Along its southern margins, much of the permafrost is ecosystem-protected in peatland complexes. To a large extent, this permafrost is found in areas where it is out of equilibrium with current climate. These systems will eventually thaw even if climate stabilized at present temperatures. Despite comprehensive work on northern peatlands, research on permafrost affected carbon and nitrogen stocks in changing peat environments remains insufficient. Improved mapping of these ecosystems, including their extent, properties and peat depth is needed. Peat model comparisons at peat warming or draining experimental sites could give some hints on the impact of warming on these ecosystems. A better understanding of the spatial distribution of bare peat and the response of peat to active layer deepening, soil moisture and subsidence, will help better quantify fluxes of greenhouse gases from peat environments. In particular, the implication of the above changes on the methane budget and syntheses of existing work on methane budgets will allow updating the currently available estimates.

9. Overarching syntheses

It is over a decade since a dedicated and comprehensive overview of the Arctic carbon cycle was published by McGuire and others. Several contributors called for an updated review of the permafrost carbon budget, taking into account all new data on permafrost carbon, including a suggestion for full accounting of anthropogenic effects on the permafrost carbon cycle. Given that large inconsistencies remain in estimates of the northern methane cycle, there is also a call to update methane fluxes for the permafrost region, by synthesizing existing data focusing on top-down and bottom-up approaches.

Future of IPaC

Through dissemination of this synthesis report, IPaC will help emphasize the need for further research relating to the prioritized permafrost and carbon research topics. IPaC will also facilitate collaboration between researchers working with the prioritized topics and will support initiatives from the research community in this direction.
If you want to be involved or need help to strengthen your research collaboration, please contact IPaC: ipa.permafrostcarbon@gmail.com. Please contact one of our contact persons if you wish to initiate or be part in a specific working group:

Topic	Contacts	
Field sampling protocols	Matthias Siewert matthias.siewert@umu.se	Fréderic Bouchard frederic.bouchard@universite-paris-saclay.fr
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Ongoing research projects covering at least one of the above topics:

- Standardized methods across Permafrost Landscapes: from Arctic Soils to Hydrosystems (SPLASH) (2020-2021)

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- The CACOON (Changing Arctic Carbon cycle in the cOastal Ocean Near-shore) project is investigating the near-shore regions of the two major Arctic rivers, the Lena and Kolyma, which together drain 19% of the pan-Arctic watershed area. CACOON will quantify the effect of changing freshwater export and terrestrial permafrost thaw on the type and fate of river-borne organic matter delivered to Arctic coastal waters, and the resultant changes to ecosystem functioning in the coastal Arctic Ocean. We will achieve this through a combined observational, experimental and modelling study. We will conduct laboratory experiments to parameterize the susceptibility of terrigenous carbon to abiotic and biotic transformation and losses, then use the results from these to deliver a marine ecosystem model of the major biogeochemical cycles of carbon, nutrients and organic matter cycling in these regions.

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Web: https://www.changing-arctic-ocean.ac.uk/project/cacoon/

- The Yedoma Region: A Synthesis of Circum-Arctic Distribution and Thickness

Contact: Jens Strauss - Jens.Strauss@awi.de
Web: https://ipa.arcticportal.org/images/stories/AG_reports/AG4_for_website.pdf

- The project PROPERAQUA (Primary Productivity in Permafrost Influenced Ecosystems of the Arctic) (Funded by the German Research Foundation for 2019-2021) aims to investigate the spatial and temporal changes of aquatic net community production in a portion of Kolyma River in Northeast Siberia during the spring to summer transition. These measurements will support the understanding of the C fluxes interacting in the aquatic continuum of this river and will provide a perspective of the regional scale contribution to the global C balance in a portion of an Arctic river completely underlain by continuous permafrost. Results of this project will provide a two-year spring and summer survey for a suit of river water properties. Historical data from point measurements on the biogeochemistry of Kolyma River (such as from the Arctic Great Rivers Observatory) will be investigated for temporal comparison purposes for the available parameters.

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- EU Project Nunataryuk: Synthesis products will be compiled to calculate current fluxes of OM (and contaminants) from coastal erosion. In addition, the modeling of coastal erosion will be used to create projections of these fluxes until 2100.

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- RECCAP2-Permafrost: The REgional Carbon Cycle Assessment and Processes-2 (RECCAP2) is led by the Global Carbon Project, and aims to provide to develop regional-scale robust observation-based estimates of changes in carbon storage and greenhouse gas emissions and sinks by the oceans and terrestrial ecosystems, distinguishing whenever possible anthropogenic vs. natural fluxes and their driving processes. RECCAP2-Permafrost focuses on natural fluxes within the permafrost region and is co-led by Gustaf Hugelius and Ted Schuur.

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https://www.globalcarbonproject.org/global/pdf/meetings/Justification_and_Objectives_of_RECCAP2.pdf