ERC Synergy project Q-ARCTIC (Quantify disturbance impacts on feedbacks between Arctic permafrost and global climate)

Arctic ecosystems are of paramount importance for the global climate system, since permafrost-affected soils store vast amounts of organic matter and the high-latitudes are predicted to experience about twice-than-average warming under future climate change. With an intensification of permafrost degradation already observed to date, carbon reservoirs currently locked away in frozen soil layers will become accessible to microbial decomposition in case thaw depths increase under a warming climate. If degraded, the permafrost carbon may lead to large emissions of greenhouse gases (CO_2 and CH_4), potentially constituting a strong positive feedback with climate change.

Earth System Models (ESMs) are the best available tools to project coupled dynamics of climate and biogeochemistry under future emission scenarios. During the last decade, land surface components of ESMs included physical and biogeochemical permafrost processes and became capable of roughly quantifying the amplification of global warming due to permafrost carbon thaw. However, the magnitude of this feedback is highly uncertain because of the complexity of the underlying processes. The Arctic carbon cycle and the sustainability of permafrost carbon pools are not only controlled by temperatures but also moderated by secondary warming impacts on hydrology, topography, vegetation community, nutrient availability, or the snow cover regime.

The assessment of feedbacks between climate change and Arctic permafrost ecosystems is especially complicated because the interactions between biogeochemical and biogeophysical factors often vary at very fine spatial scales and are highly susceptible to nonlinear and often abrupt changes. Prominent examples are geomorphological processes linked to the degradation of permafrost, shifts in vegetation communities (e.g. Arctic Greening) associated with new climate states, or disturbances such as wildfires. Geomorphological processes include thermokarst features such as the formation of a system of connected troughs through the preferential degradation of ice wedges in ice-rich permafrost, or thaw lake formation and drainage. As a common feature, these change processes are affected by but also alter the distribution or the usage of water in Arctic ecosystems. Accordingly, associated shifts in hydrological conditions play a pivotal role in re-shaping Arctic ecosystems and, therefore, form a key challenge for improved future predictions of Arctic biogeochemical cycles. To address these challenges, a high spatial resolution is a key prerequisite for any ESM to adequately account for land surface heterogeneity in permafrost regions. The primary objective of Q-ARCTIC is therefore to close the gap between the process scale and the standard ESM grid resolution and break new ground in process-based understanding, quantifying and simulating the fate of the Arctic carbon pool. This will allow addressing the following key scientific questions:

- Will the Arctic become a net source for carbon in the future?
- What was the land carbon budget in Arctic during the Last Glacial Maximum?
- How abrupt could Arctic land carbon stock changes be in the past and in the future?

Q-ARCTIC will establish a next generation coupled land-surface model that explicitly resolves highest resolution landscape features and disturbance processes in the Arctic. Model development will be informed by novel remote sensing methodologies linking landscape characteristics and change potential at an exceptional level of detail. Interdisciplinary observations at multiple spatiotemporal scales will deliver novel insight into permafrost carbon cycle processes. All components are essential for Q-ARCTIC objective to generate an unprecedented process-based hindcast of glacial permafrost carbon state and projection of permafrost sustainability under future scenarios with a focus on abrupt changes.

Q-ARCTIC ground-breaking research is based on the newly developed ICON-ESM that enables highest-resolution simulations based on high-performance computing infrastructure. The required remote sensing information can for the first time be produced from new pan-Arctic data streams, such as the European Sentinel satellites. Finally, recent breakthroughs in ultraportable instrumentation and mobile air- and water-borne platforms facilitate bridging the gap between in-situ process understanding and landscape-scale surface-atmosphere exchange. The Q-ARCTIC PI-consortium will combine their world-leading expertise in these fields to close the scaling gap between high-resolution processes and the coarser ESM resolution.

Project website: q-arctic.net

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