IASC/ICARP IV Research Priority Team (RPT) 1: The Role of the Arctic in the Global System --- An Overview

Xiangdong Zhang[1] and Kabir Rasouli[2]

[1]North Carolina State University; [2]Desert Research Institute

With Contributions From All RPT 1 Members

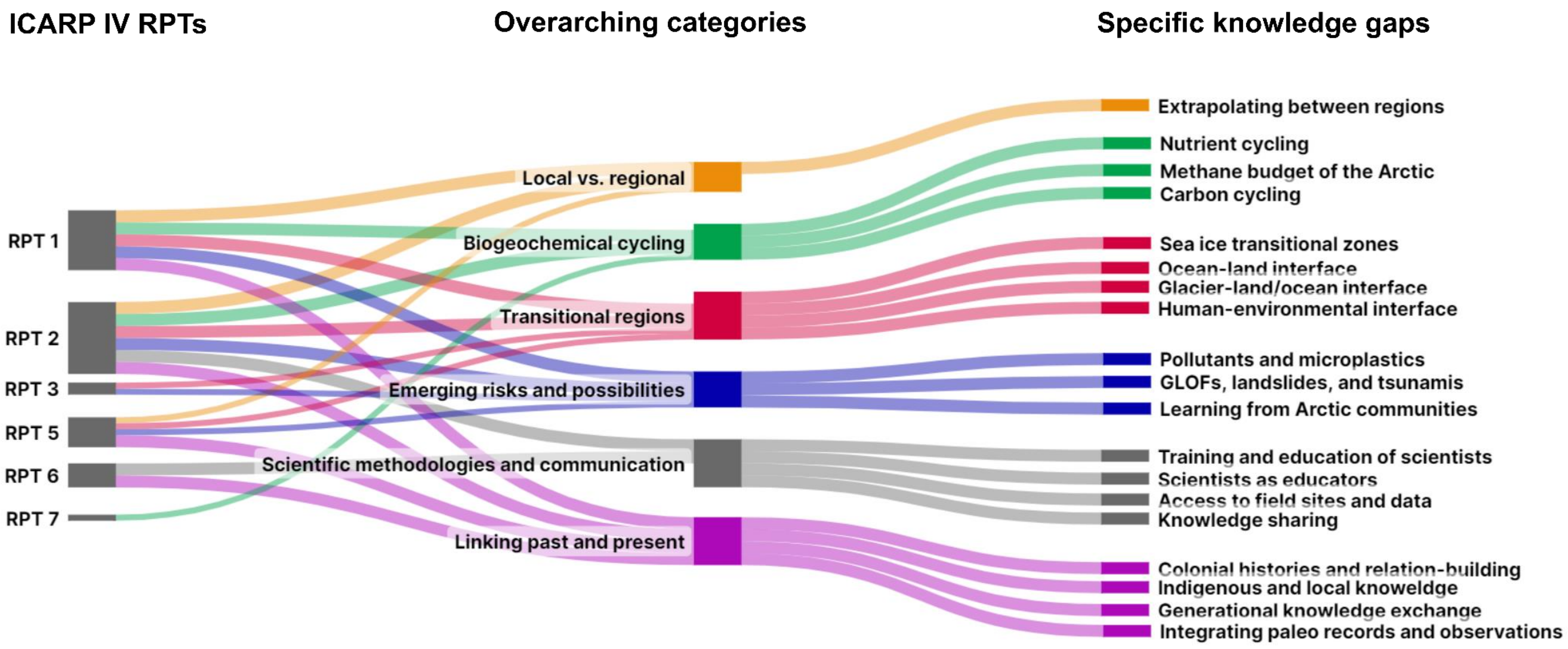
RPT 1 Town Hall, ASSW 2025/ICARP IV Summit, Boulder, CO, March 25, 2025.

Photo: Joo-Hong Kim

RPT 1 members covering atmospheric dynamics and chemistry, meteorology, physical and biogeochemical oceanography, sea ice, physical and biogeochemical terrestrial processes, Greenland Ice Sheet, and social impacts:

36 team members from 12 countries, with different career levels from senior to early career scientists.

RPT 1 makes contributions about foundational, solid science knowledge and interacts with all other teams as shown in the draft diagram (under developing).



Archana Dayal et al.

Objectives:

The RPT1 will address research needs, priorities, and their implementation regarding the role of the arctic in the global system.

Tasks:

1. Reviewing and analysing community Input ;
2. Defining research needs and priorities for the topic area;
3. Drafting recommendations on how to address and implement the needs and priorities;
4. Consulting on preliminary results from each RPT during the ICARP IV Summit / ASSW 2025 and online;
5. Finalizing the results of recommendations on research needs and priorities, and implementation plans.

Research Themes (covering the past, present, and future climate):

1. Improvement of and Integration Between Observations and Models

2. Earth Systems Linkage and Feedbacks Between the Arctic and Lower Latitudes

3. Attributions of Arctic Changes

4. The Role of Arctic Terrestrial Systems in Global Change

5. Socio-economic Implications and Consequences and Global Collaboration

Research Themes (covering the past, present, and future climate):

1. Improvement of and Integration Between Observations and Models

Members:

Co-Leads: Steve Arnold and Priscilla Mooney

Ed Blockley, Markus Frey, Stefania Gilardoni, Mats Granskog, Joo-Hong Kim, Malte Müller, Giovanni Muscari, Michael Tjernström, Xin Yang, Xiangdong Zhang

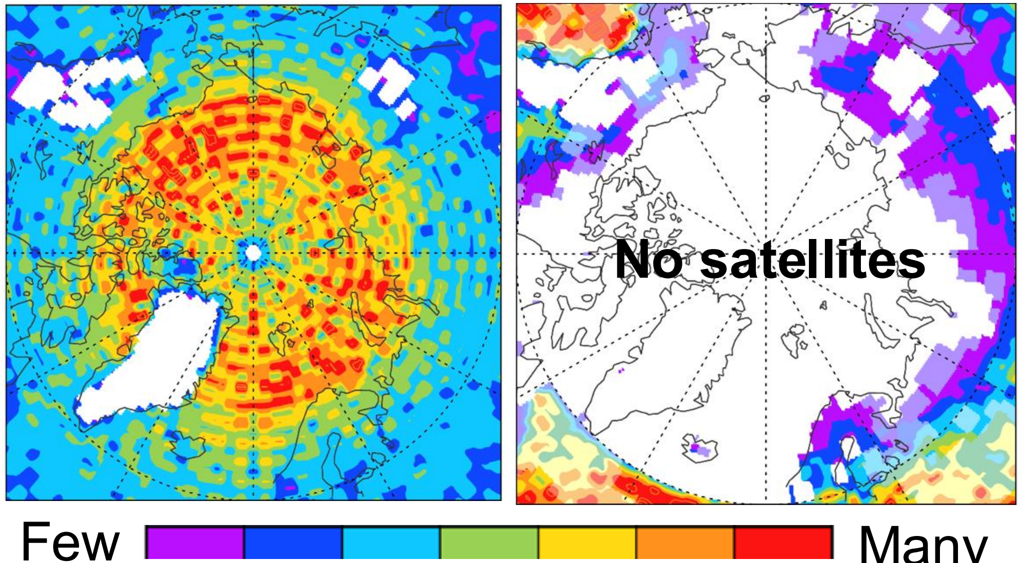
Focal areas:

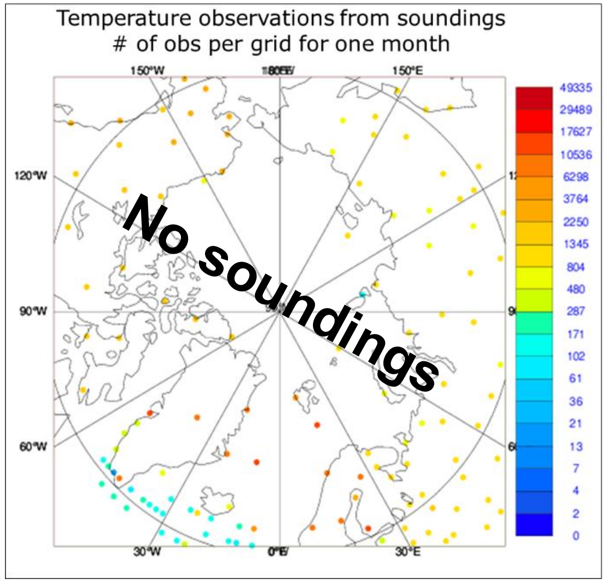
- Sustainability and enhancement of observations (in-situ and satellite observations);
- Improvement of sub-grid model processes (including vertical structures in the atmosphere, ocean, sea ice, and snow; super high model resolutions; different level of complexities of model physics);
- Assimilation of the observations leading to a better understanding of the coupled Arctic system, with special focus on winter processes.

The observational gap: Lack observations of atmospheric vertical structure

~3 – 8 km

< ~3 km

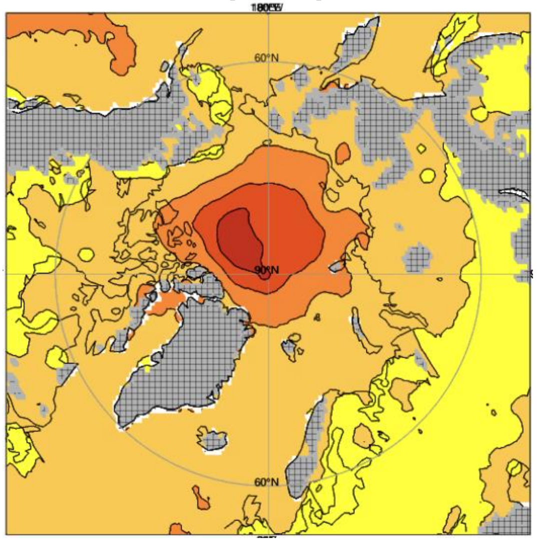




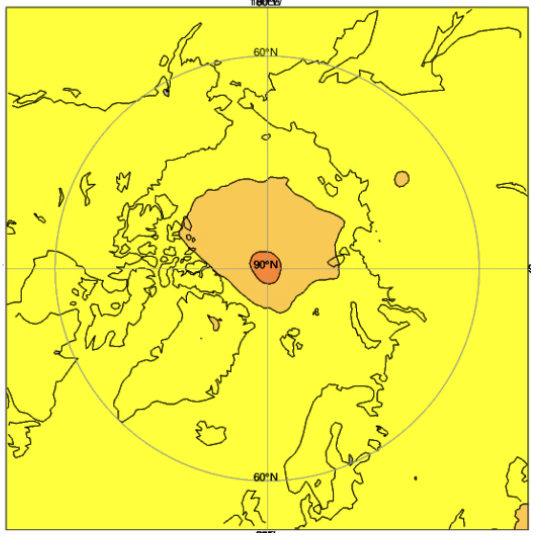
Satellite information below ~3 km cannot be utilized because of "surface contamination and no soundings to constrain or bias correct

Analysis uncertainty

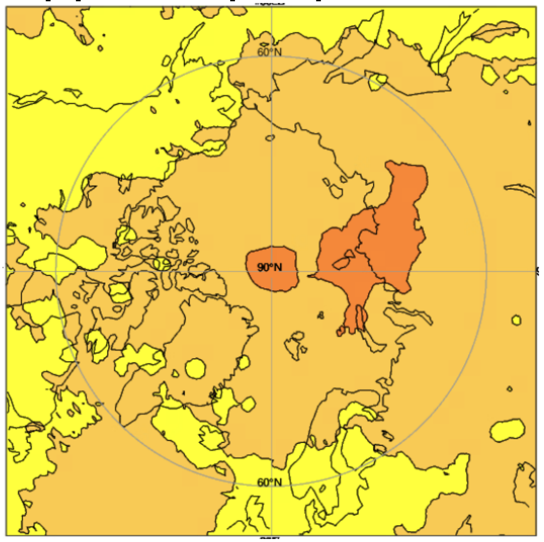
Lower troposphere



Middle troposphere



Upper troposphere

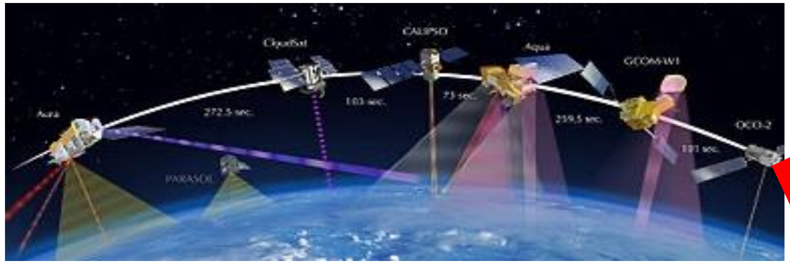


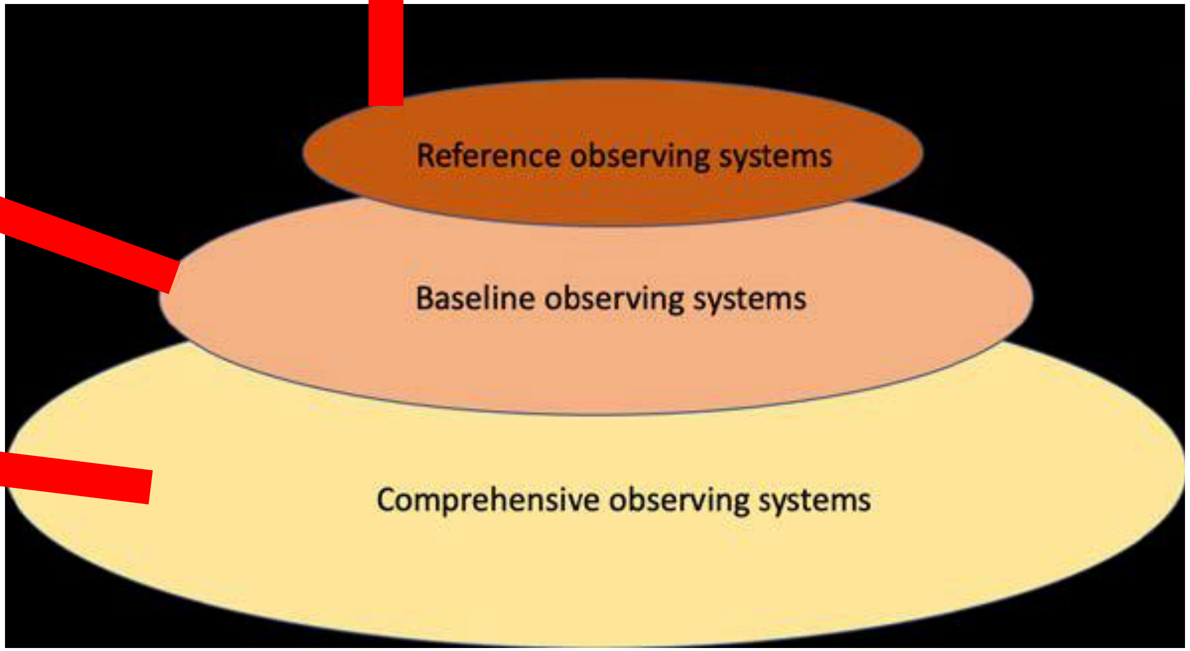
Evaluated from real differences between model anlyses

Michael Tjernström

A sustained atmospheric observing system has to be optimising around satellite observations, using all the information available

Implementation - No single implementation will suffice; it requires model improvments and assimilation, understanding of the surface and reference observations



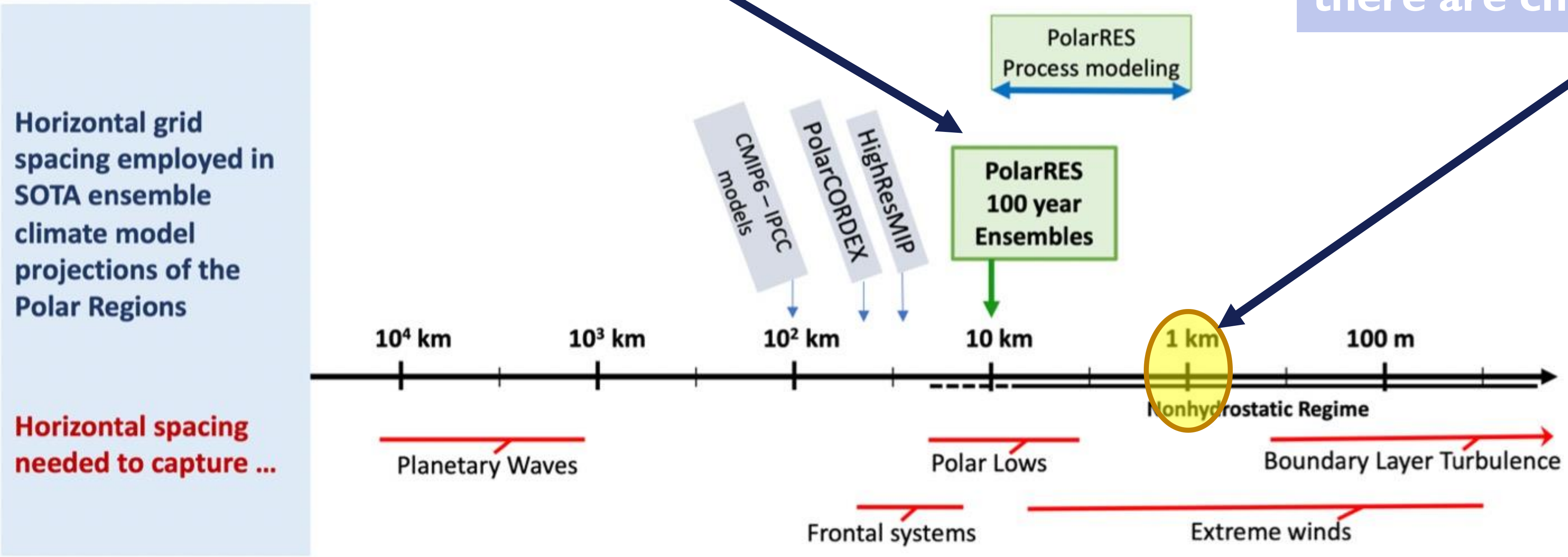


Michael Tjernström

Latest advances in modelling Arctic climate change

An ensemble of regional climate projectionsfor the Arctic **at unprecedented resolutions** for assessing climate impacts.

=> Before projecting future changes at km scales and lower there are challenges to be met …

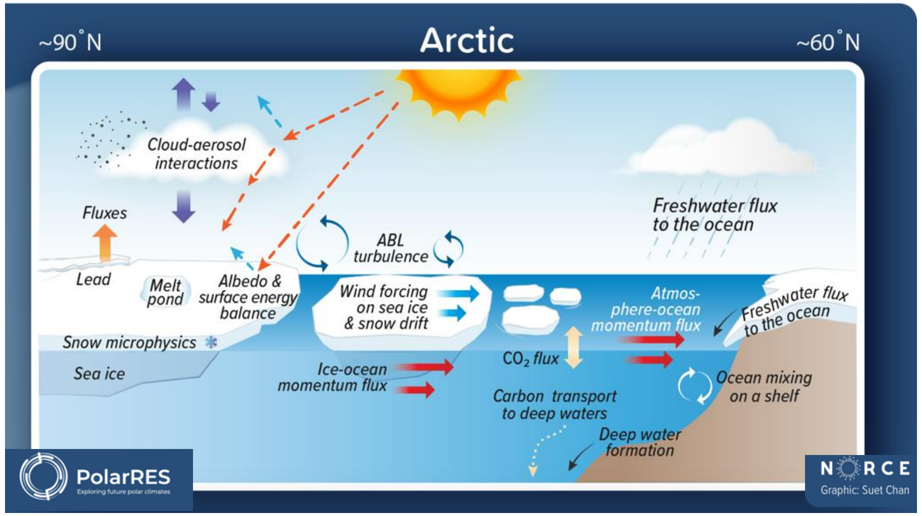


Priscilla A. Mooney

Knowledge, modelling and observation priorities

Knowledge needs:

- Improved understanding of atmosphere-ice-ocean interactions across scales.
- Atmospheric vertical structure in the Arctic, including thermodynamic variables (e.g. temperature & moisture), clouds (coverage, physical characteristics, formation processes), dynamics (winds) or atmospheric composition (aerosols & gases).
- Key processes that require parameterisation in models, particularly those that are unique to the Arctic in terms of parameter space or the process itself.



- **Fully coupled atmosphere-ocean-sea ice models at km scales**
  - Improved model representation of unresolved processes and phenomena.
- **Increased observational coverage in time and space**
  - More in situ observations especially of processes and parameters that can narrow knowledge gaps and support development of EO products

=> Greater collaboration between the modelling and observation communities

Priscilla A. Mooney

Research Themes (covering the past, present, and future climate):

2. Earth Systems Linkage and Feedbacks Between the Arctic and Lower Latitudes

Members:

Co-Lead: Marianne Tronstad Lund and Xiangdong Zhang

Steve Arnold, Marius Årthun, Ed Blockley, Markus Frey, Stefania Gilardoni, Joo-Hong Kim, Seong-Joong Kim, Will Kochtitzky, Priscilla Mooney, Malte Müller, Kabir Rasouli, Armina Soleymani, Michael Tjernström, Claire Waelbroeck, Yutian Wu, Xin Yang, Masakazu Yoshimori

Focal areas:

- Interactions and feedbacks within the dynamic and chemical components and between them;
- Two-way linkage between the Arctic climate system components and between the Arctic and Global Systems (including sources, e.g., natural and anthropogenic, and sinks of greenhouse gasses and particles; transport in the atmosphere, ocean, and sea ice; AMOC; interactions between the atmosphere-ocean-sea ice-glacier/ice sheet; teleconnections; extreme events).

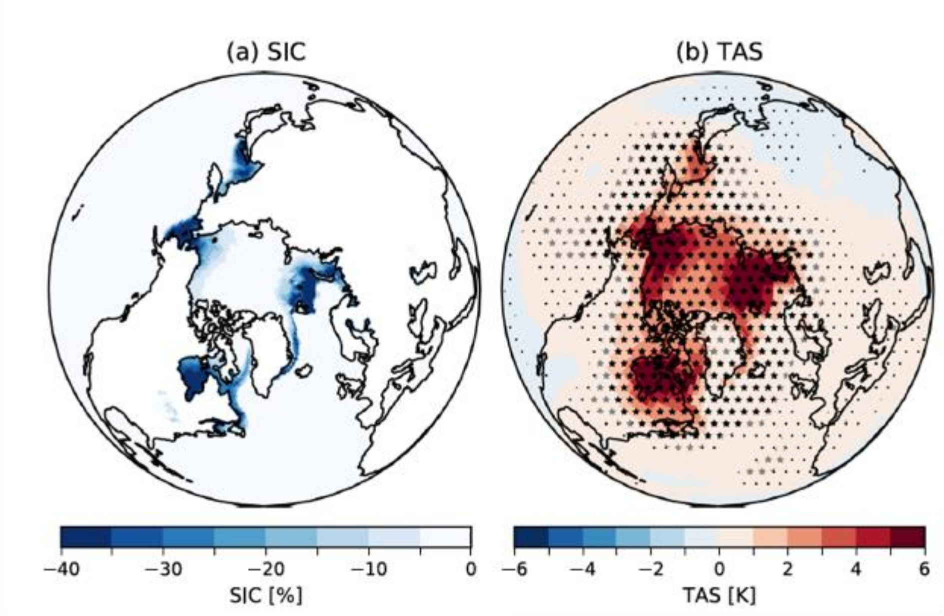
Arctic-to-midlatitude Impact on Circulation and Weather Extremes

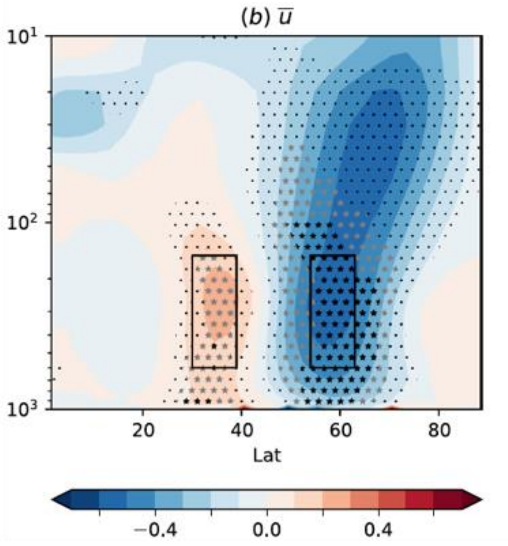
- **What do we know and has been done?**

1. Improved mechanistic understanding: Theory of Rossby waves at high latitudes, role of stratospheric pathway, role of ocean-atmosphere coupling

2. Successfully coordinated modeling efforts: Polar Amplification Model Intercomparison Project (PAMIP)

3. Improved understanding of the impact: Robust but weak winter atmospheric circulation response, decreased wintertime subseasonal temperature variability (less cold extremes)



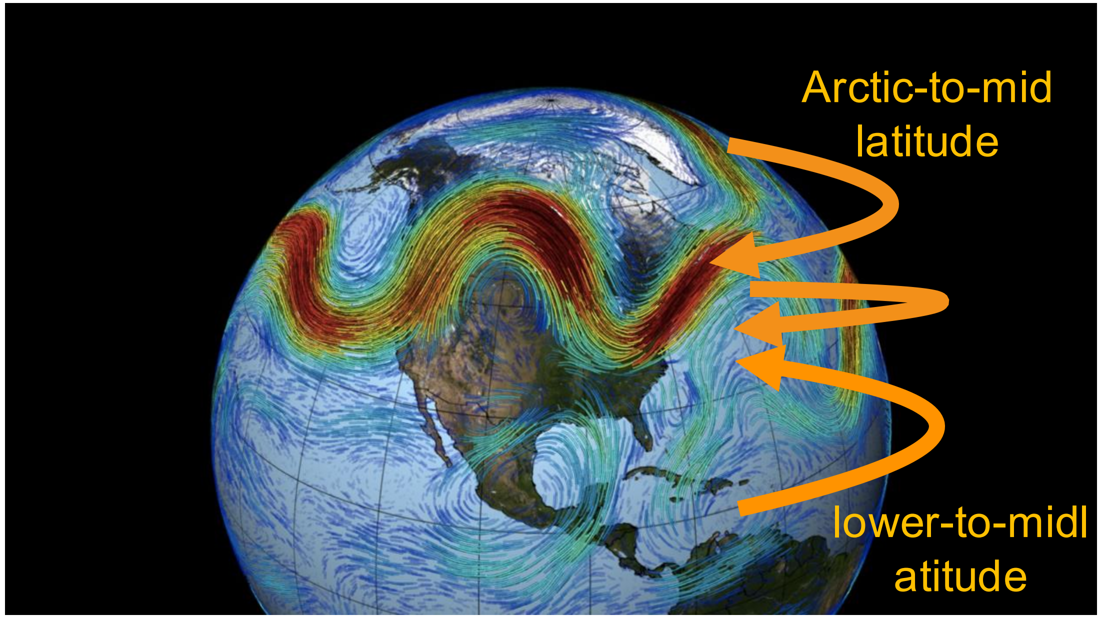


a robust weakening of midlatitude westerlies, but a small magnitude

Smith et al. (2022)

Yutian Wu

Arctic-to-midlatitude Impact on Circulation and Weather Extremes



Schematic from NASA/Goddard Scientific Visualization Studio; Modified

- **What are the open questions?**

1. How to isolate the role of Arctic-to-midlatitude impact among everything else in observations? Novel approaches such as Causal Effect Networks and other ML methods are recommended.

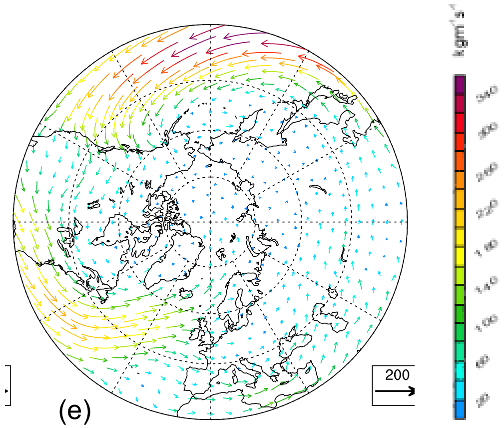
2. How to better design model experiments to isolate the role of Arctic-to-midlatitude impact? This is being discussed in PAMIP2; experiments to simulate the effect of Arctic amplification, instead of Arctic sea ice loss.

3. How to better compare model results with observations? Recommendations include a better framing of questions (Outten et al. 2023).

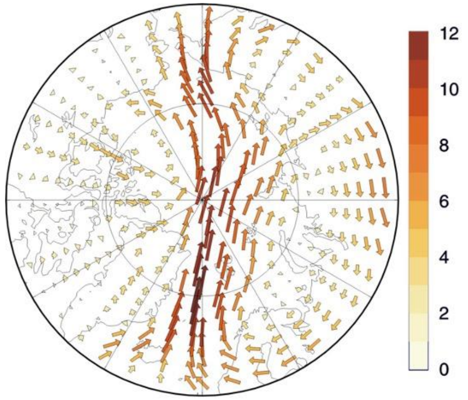
4. How does ice sheet and sea ice melting affect dense water formation, the Atlantic Meridional Overturning circulation and global ocean circulation? Coordinated coupled modeling efforts might be needed.

Yutian Wu

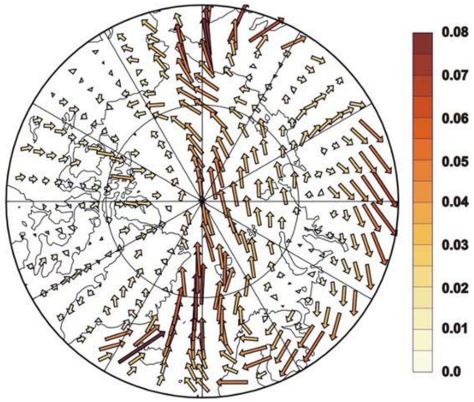
<u>Lower latitude impacts on the Arctic:</u> More frequently enhanced poleward heat transport in both the atmosphere and ocean from the lower latitudes into the Arctic



Atmospheric Moisture Transport in Negative ARP

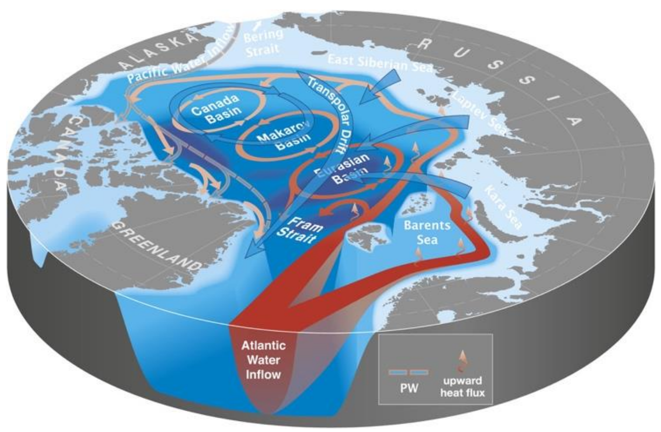


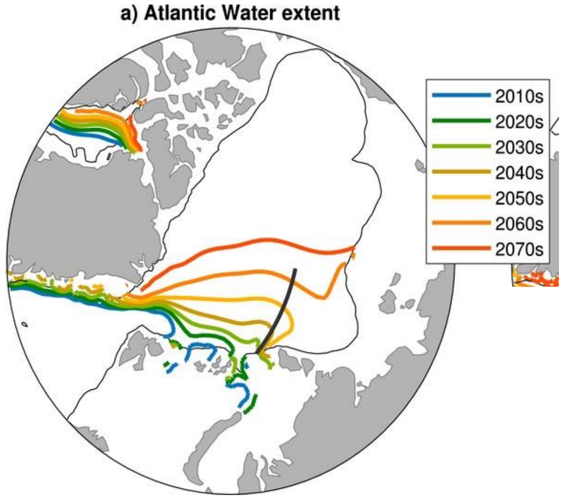
Heat transport regressed onto winter ARP index (surface - 850 hpa)



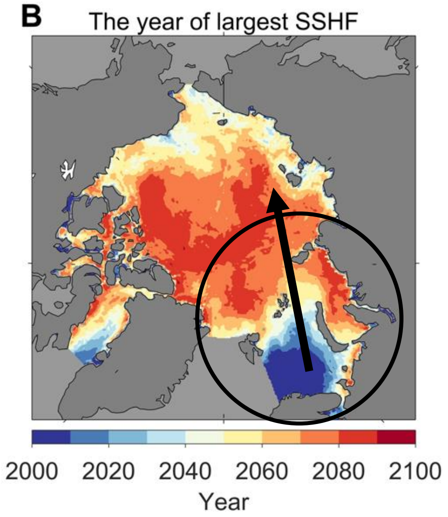
Surface wind stress regressed onto winter ARP index

Zhang et al. (2008, 2012)





Årthun et al. (2019)



Shu et al. (2022)

Open questions would include:

- What are the mechanisms driving the meridionally transformed atmospheric circulation?
- How do ocean mixing and stratification change?
- How do the Atlantic and Pacific warm water layers release heat to sea ice and the atmosphere?

<u>Marius Årthun</u>

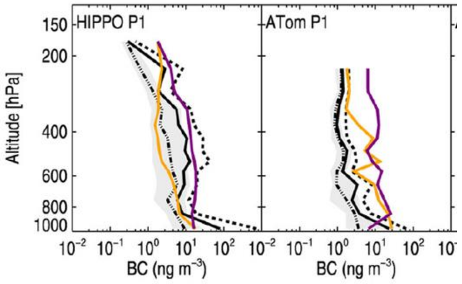
SLCFs provide a key contribution to human-induced climate change globally and in the Arctic

Research gaps/needs (a non-exhaustive list…)

- While models may agree on overall trend of Arctic SLCF concentrations, **significant model-model and model-observation discrepancies remain** – how can we make further progress?
- **Natural sources** (e.g. sea salt aerosol produced from blowing snow) provide an important contribution to Arctic SLCFs, but **are poorly represented** in many current models.
- Understanding **long-range transport** pathways for SLCFs, including climate-driven changes, and relative role of **local and remote sources** for Arctic forcing and response.
- Improved understanding of **climatic and environmental feedbacks on SLCF** sources/sinks and atmospheric processes, as well as the magnitude of the total non-CO2 **biogeochemical feedbacks.**
- **Light absorbing particles (LAP) on snow/ice**: few new studies of radiative forcing, no comprehensive global assessments of mineral dust deposition on snow available.
- Understanding **aerosol-cloud-precipitation effects**, including remote, teleconnection impacts.

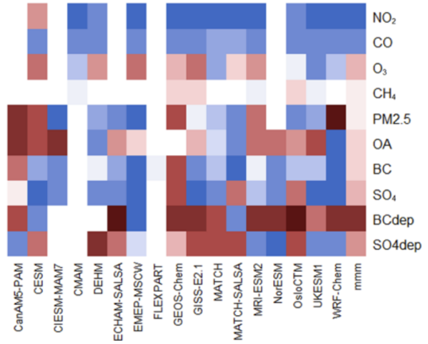
Marianne T. Lund, Xin Yang

Arctic BC vertical profiles



Lund et al., npj Climate and Atmospheric Science, 2018

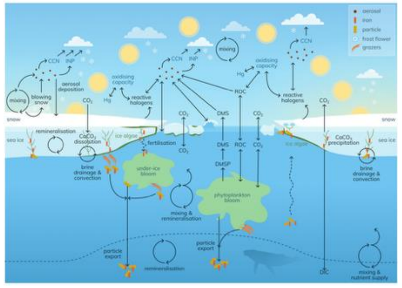
(b) Arctic model biases for 2014-15 annual mean



Whaley et al. ACP, 2022

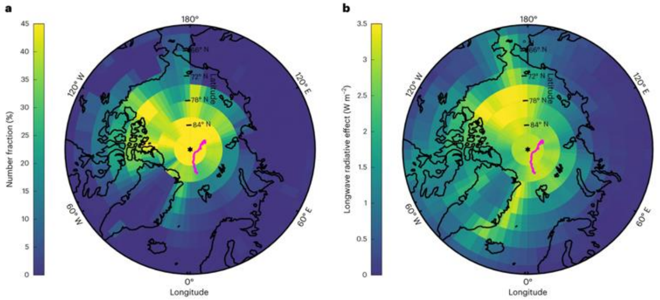
Smoke from unprecedented high latitude wildfire activity in recent years

Sea ice/ocean interactions



Willis et al., Elementa, 2023

Blowing snow contributes to (a) Arctic winter aerosol budget and (b) surface warming.



Gong et al., Nature Geoscience, 2023

Research Themes (covering the past, present, and future climate):

3. Attributions of Arctic Changes

Members:

Co-Lead: Masakazu Yoshimori and Hans Linderholm

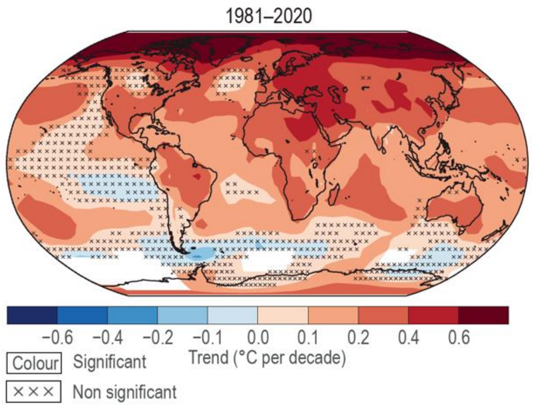
Marius Årthun, Haiyan Jin, Erika Roesler, Margit Simon, Armina Soleymani, Tommaso Tesi, Yutian Wu, Xiangdong Zhang

Focal areas:

- Contributions from natural variability and anthropogenic forcings to Arctic system changes (including the atmosphere, ocean, sea ice, glacier/ice sheet, and biogeochemical components).

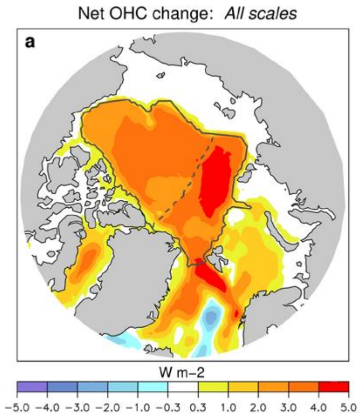
Attribution of Arctic system changes

Atmosphere



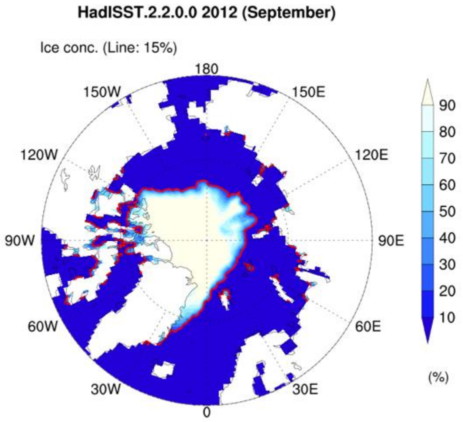
(IPCC-AR6, 2021, Fig. 2.11)

Ocean

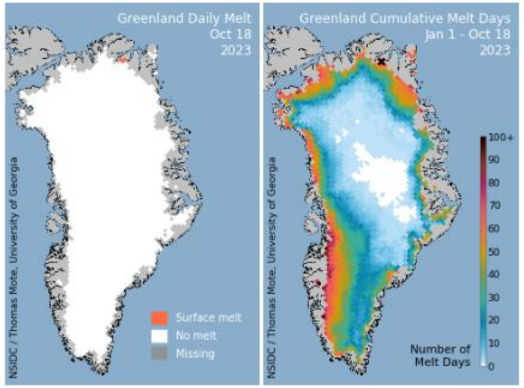


(Saenko et al., 2023, Clim. Dyn.)

Sea Ice



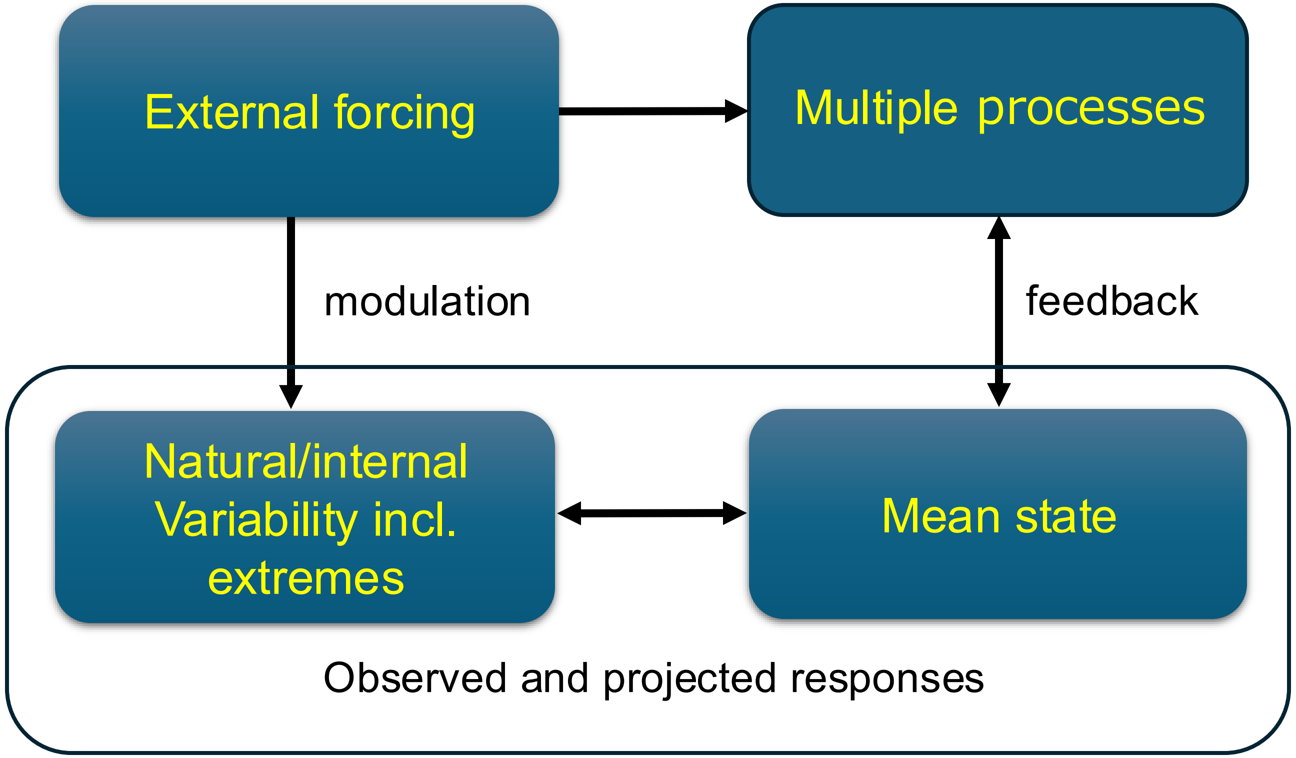
Ice sheet



(NSIDC)

Hydrological cycle, Biogeochemical component, Vegetation, Permafrost, Forest fire, …

Grand Challenge: to disentangle causes (external vs. internal) and mechanisms (process vs. process) leading to the observed and projected responses



Approaches: data analysis, a large ensemble simulations, well-designed experiments, …

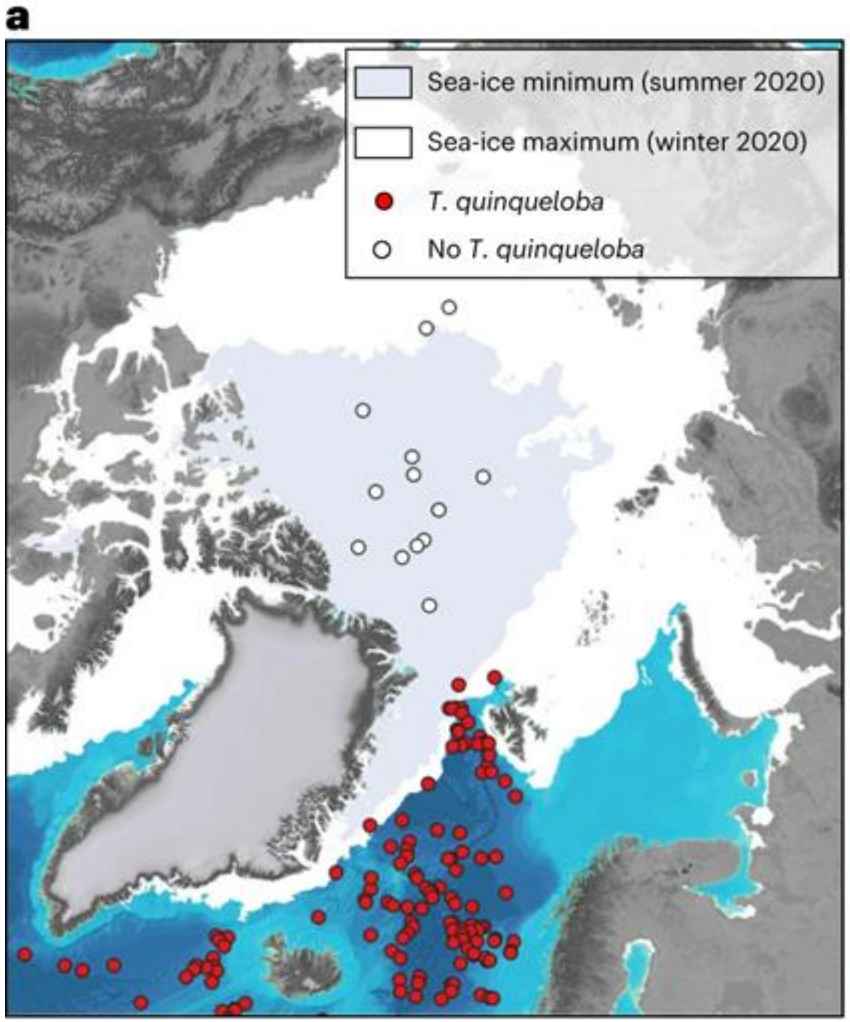
Masakazu Yoshimori

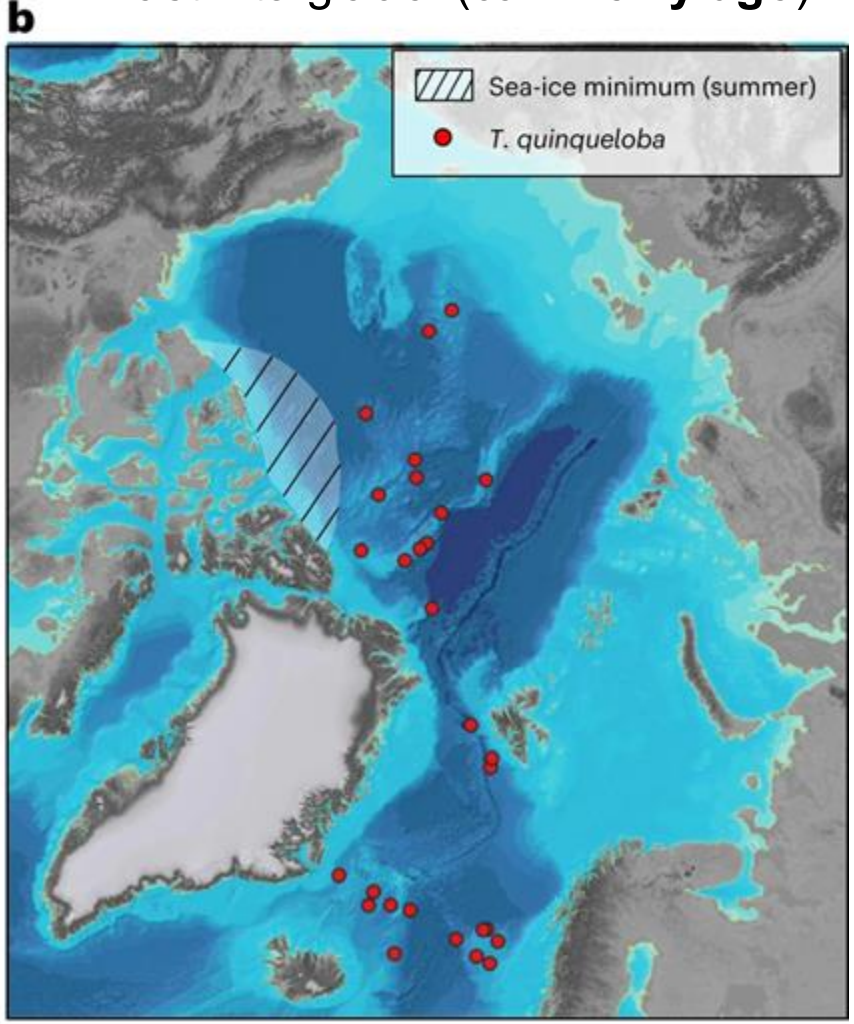
External and interval sea ice variability in the past climate

Natural example of sea ice decline similar to what expected in the future but without anthropogenic forcing

Sea ice **2020**, min and max

Summer sea ice
Last interglacial (ca. **125 ky ago**)

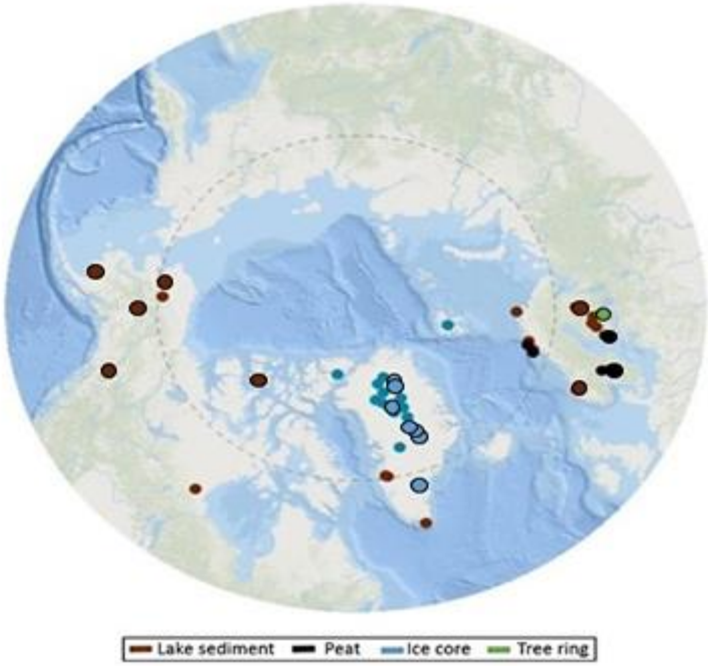


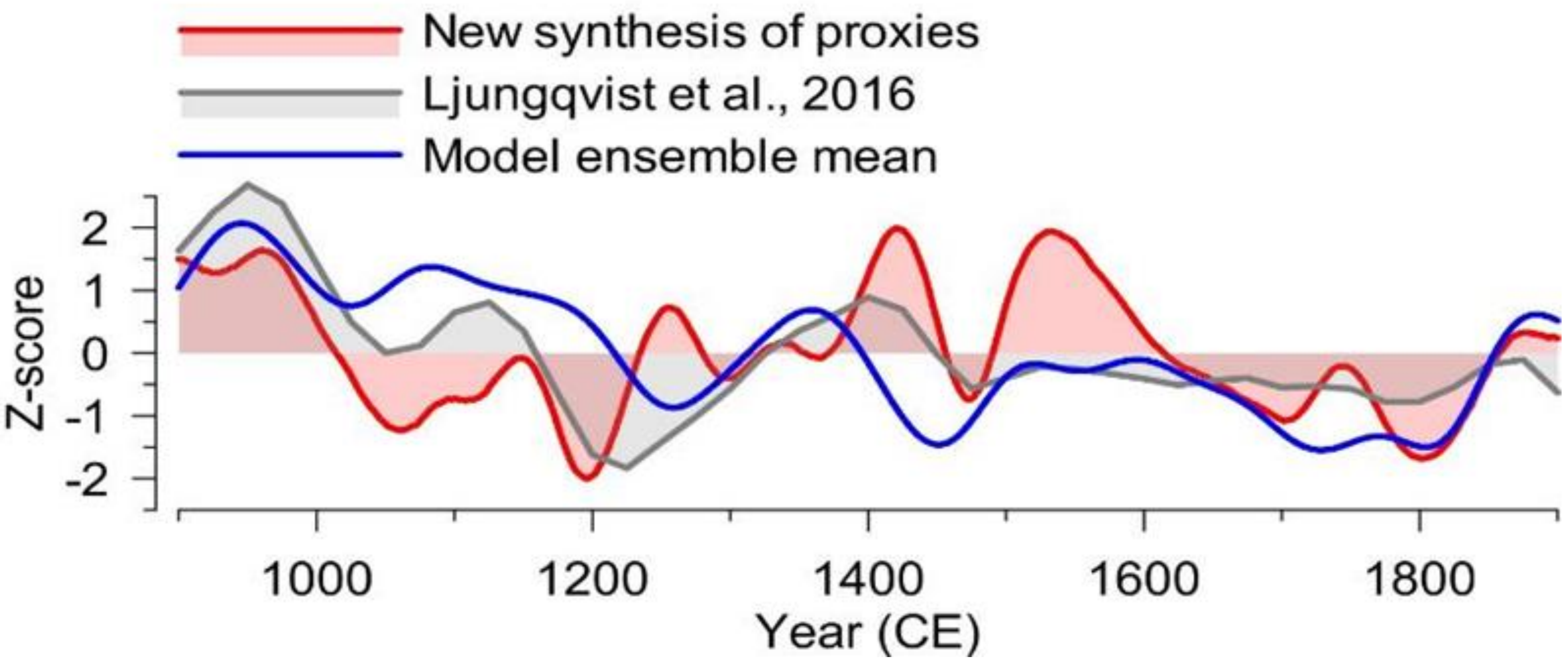


Vermassen, 2023
NatGeo

Hans Linderholm

Increased spatial representations of proxies needed, not only temperature but also hydroclimate





Centennial-scale annual hydroclimate variability in the Arctic (≥ 60°N) from Ljungqvist et al. (2016, grey), Linderholm et al. (2018, red) and an ensemble mean of 6 last-millennium precipitation simulations (blue).

Hans Linderholm

Research Themes (covering the past, present, and future climate):

4. The Role of Arctic Terrestrial Systems in Global Change

Members:

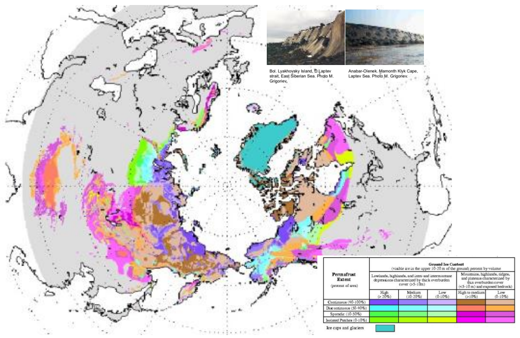
Co-Leads: Kabir Rasouli and Hotaek Park

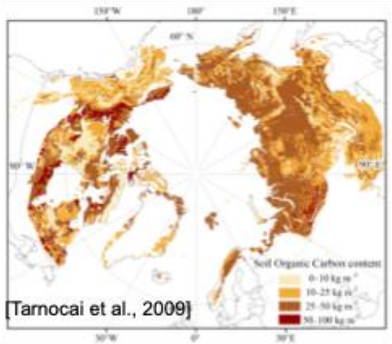
Archana Daya, Will Kochtitzky, Hans Linderhom, Greta Wells

Focal areas:

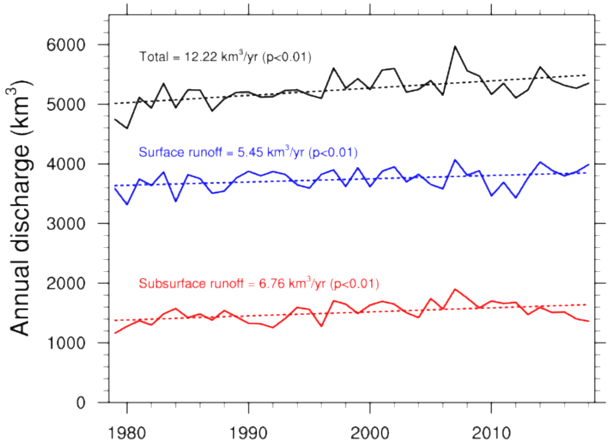
- Permafrost, geohazards, hydrological cycle, land use changes, vegetation wildfires, land-terminating glaciers;
- Snow-vegetation interactions, snowmelt-fjord ecosystem interactions,
- Coastal erosion from the releasing carbon perspective with focus in the Arctic region

Thawing permofrost contributes to stronger Arctic/global water, energy, and carbon cycle



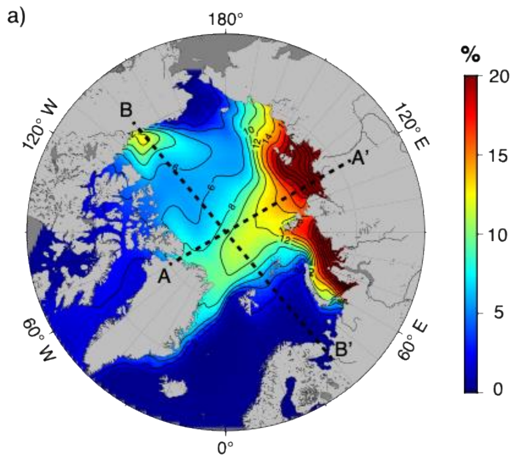


Increasing Arctic river discharge

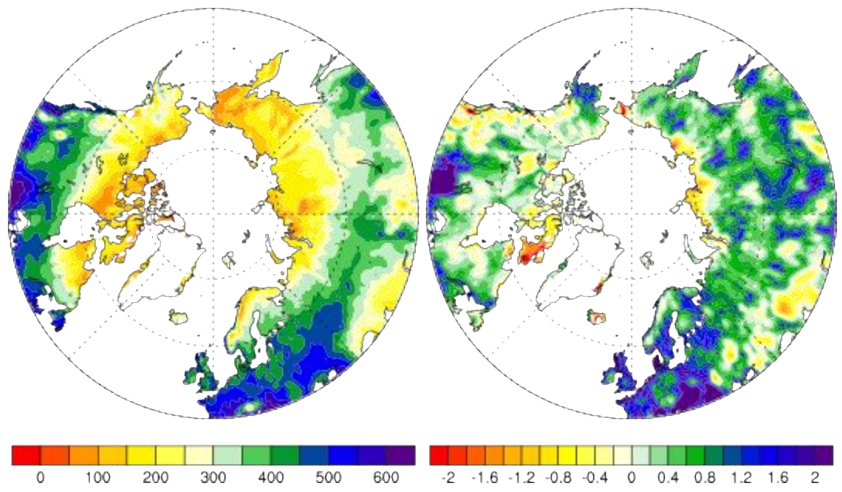


Park et al. (2023, PEPS)

River water tracer fraction (1989-2018)



Zhang et al. (JGR-O, 2024)



Contributions of warming climate forced permafrost thawing: an increase in terrestrial water storage; an increase in river discharge causing a freshening of the Arctic Ocean; an increase in evapotranspiration moistening the atmosphere and, in turn, increasing precipitation and cloud-forced warming.

Permafrost thawing also increases the decomposition of organic carbon within the permafrost, positively feedback to the Arctic warming.

Hotaek Park

Research Themes (covering the past, present, and future climate):

5. Socio-economic Implications and Consequences and Global Collaboration

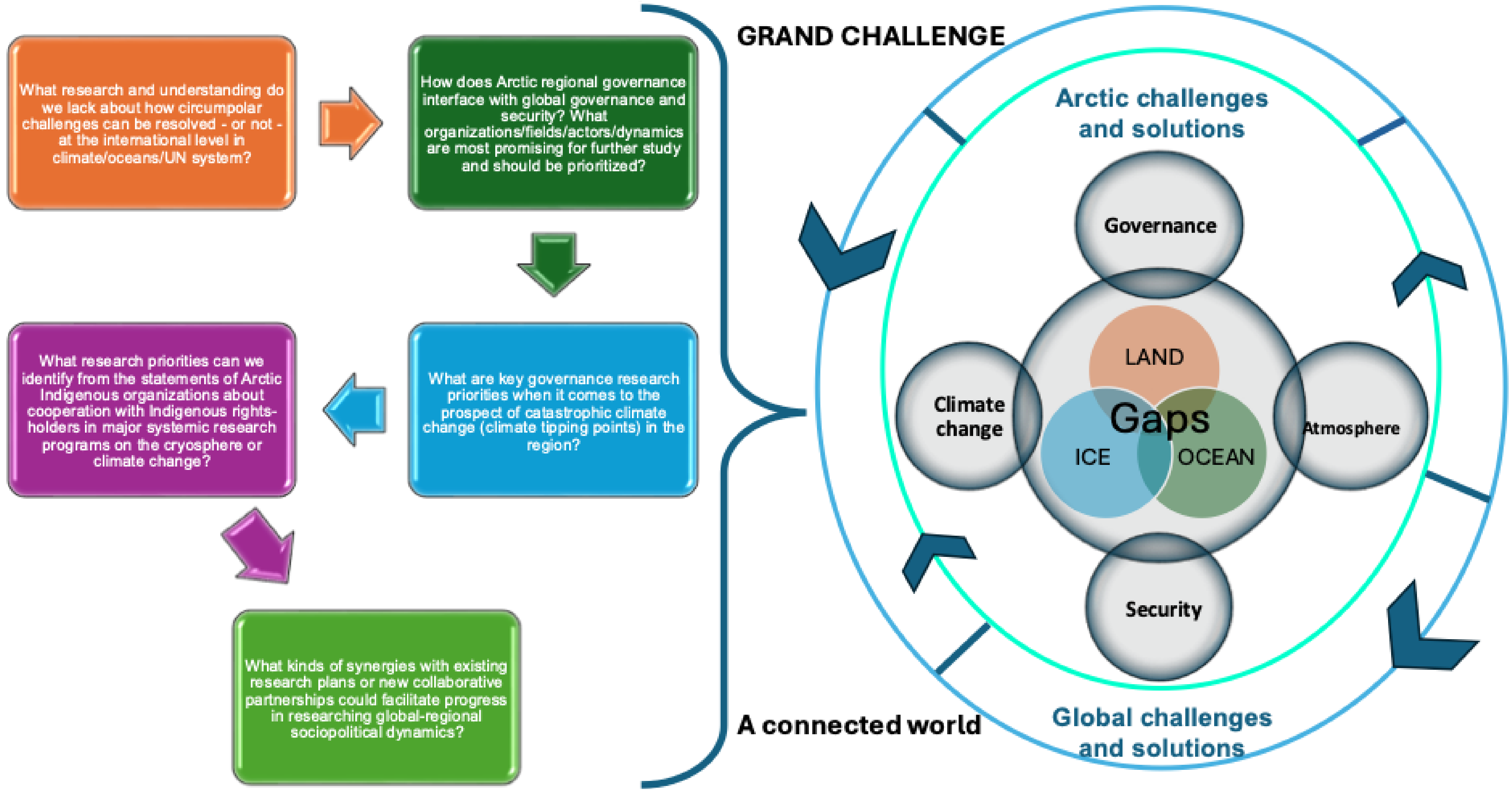
Members:

Céline Rodrigues, Elana W. Rowe, Erika Roesler

Focal areas:

- Consequences in the Arctic region/Arctic indigenous Peoples and globally (defining case studies: countries where socio-economic consequences are felt in the region and worldwide);
- Weather, sea ice, and climate services. co-production;
- Global collaboration to mitigate impacts in the Arctic and the rest of the globe

Political and social science research at the Arctic regional-global interface: Status and priorities



Céline Rodrigues, Elana Wilson-Rowe and Erika Roesler

Preliminarily Identified Grand Challenges (Research Needs and Priorities):

1. Coordinate, enhance, and exploit observations, including data assimilation methods, in the context of the Arctic warming and Arctic-global linkages (poleward heat and moisture/freshwater transport).
2. Improve observations (satellite and in-situ) in coordination with other communities to reduce the biases in the simulations of vertical profiles of meteorological variables and atmospheric trace constituents.
3. Improve the/our understanding of coupling processes between the atmosphere, sea ice, snow, ice sheet/glacier, and ocean, and fill out key gaps such as blowing snow or wildfire processes in regional and global models.
4. Distinguish the roles/contributions of the natural variability and anthropogenic forcing in the Arctic climate changes and the linkage between the Arctic and global climate system (including the changes in SPV).
5. Better understand anthropogenic forcings both locally and remotely and the relative roles of natural and anthropogenic gases and particles in the context of the coupled chemical and dynamical processes.
6. Understand changes in Pacific and Atlantic poleward heat transport into the Arctic and subsequent heat release to the overlying sea ice and the atmosphere.
7. Improve representation of the essential processes and exploit observational data to develop/implement super high resolution (km scale) Arctic regional model and coordinate the efforts with the global modeling community.
8. Understand how changes in the hydrological cycle are influenced by competing processes between atmosphere, soil, and vegetation, then influencing the Arctic freshwater budget.

Preliminarily Identified Grand Challenges (Continuing):

9. Improve understanding of how a rapidly changing Arctic climate impacts on ocean circulation and water masses in the Arctic Ocean, and how these changes could impact large-scale ocean circulation (e.g., AMOC).

10. Understand how carbon sources and sinks have changed and will change, in response to climate change, i.e., how permafrost thawing will affect the atmospheric CO2/CH4 and how greening will impact carbon sequestration.

11. Improve our physical understanding of the Arctic-global linkage using observations and novel methodologies such as machine learning.

12. Understand the role of glacier mass balance in the climate system, how it is impacted by changes in the atmosphere and ocean and the magnitude of sea level rise to expect in the coming decades and centuries. What are the major uncertainties (i.e. glacier stability)?

13. Include and increase open science and build tools to answer these questions that promote open collaboration.

14. Understand the implications of Arctic climate and environmental change on carbon and biogeochemical climate feedback mechanisms.

15. Evolution of Arctic physical hazards/CIDs and impact of Arctic change on remote extremes/hazards.

16. Understand the environmental, climatic, societal, cultural and economic implications of Arctic economic development, as a consequence Arctic changes, at global scale (interdisciplinary approach needed).

Steps forward: Research Needs and Priorities and Implementation Plan:

1. Refining the preliminarily identified grand changes to develop an overarching grand challenge;
2. Identifying high-level, specific grand challenges and knowledge gaps that are scientifically robust and can be implemented and addressed over the next decade, such as IPY5.

Approaches and Methodology:

1. Synthetical analysis based on team members' expertise, understanding, and experience and based on published literature, national and international reports, and other sources.
2. Engaging the broader communities (across the Arctic and globe) and integrating their input into our team's analysis.
3. Informing other RPTs, collaborating with other RPTs, and getting feedbacks from other RPTs.

Thanks!

Welcome Comments, Feedbacks, and Suggestions!