Mathematics of Sea Ice and Polar Ecosystems Summer School, Fairbanks, June 2025

Grand challenges in Arctic research & how to meet them

Hajo Eicken • Director

International Arctic Research Center on the UAF Troth Yeddha' Campus

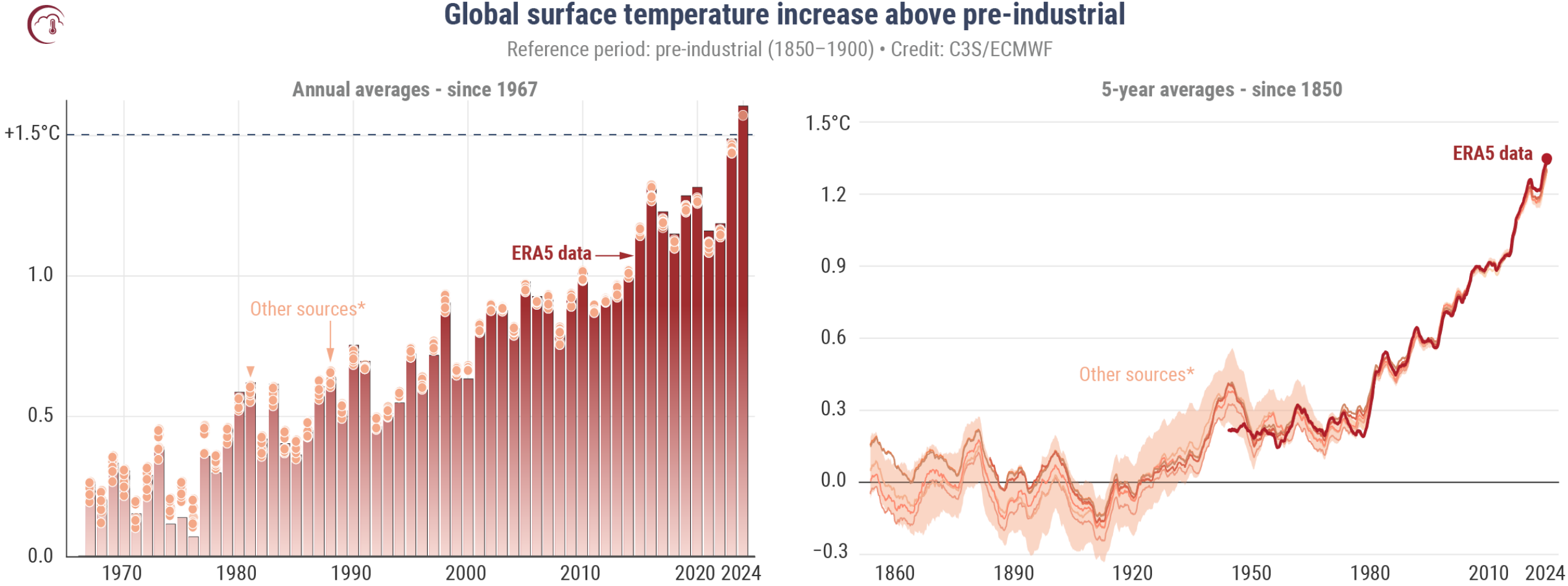
Outline

1. Grand challenges: Disruptive climate change
   → Permafrost degradation
   → Sea ice loss
   → Ecosystem restructuring
2. What to do:
   → Identify benefits (local-regional-global scale)
   → Collaborate effectively
   → Provide decision support
3. Conclusions

Climate reality check

- Limiting global warming to 1.5 ˚C unattainable as near/mid-term goal

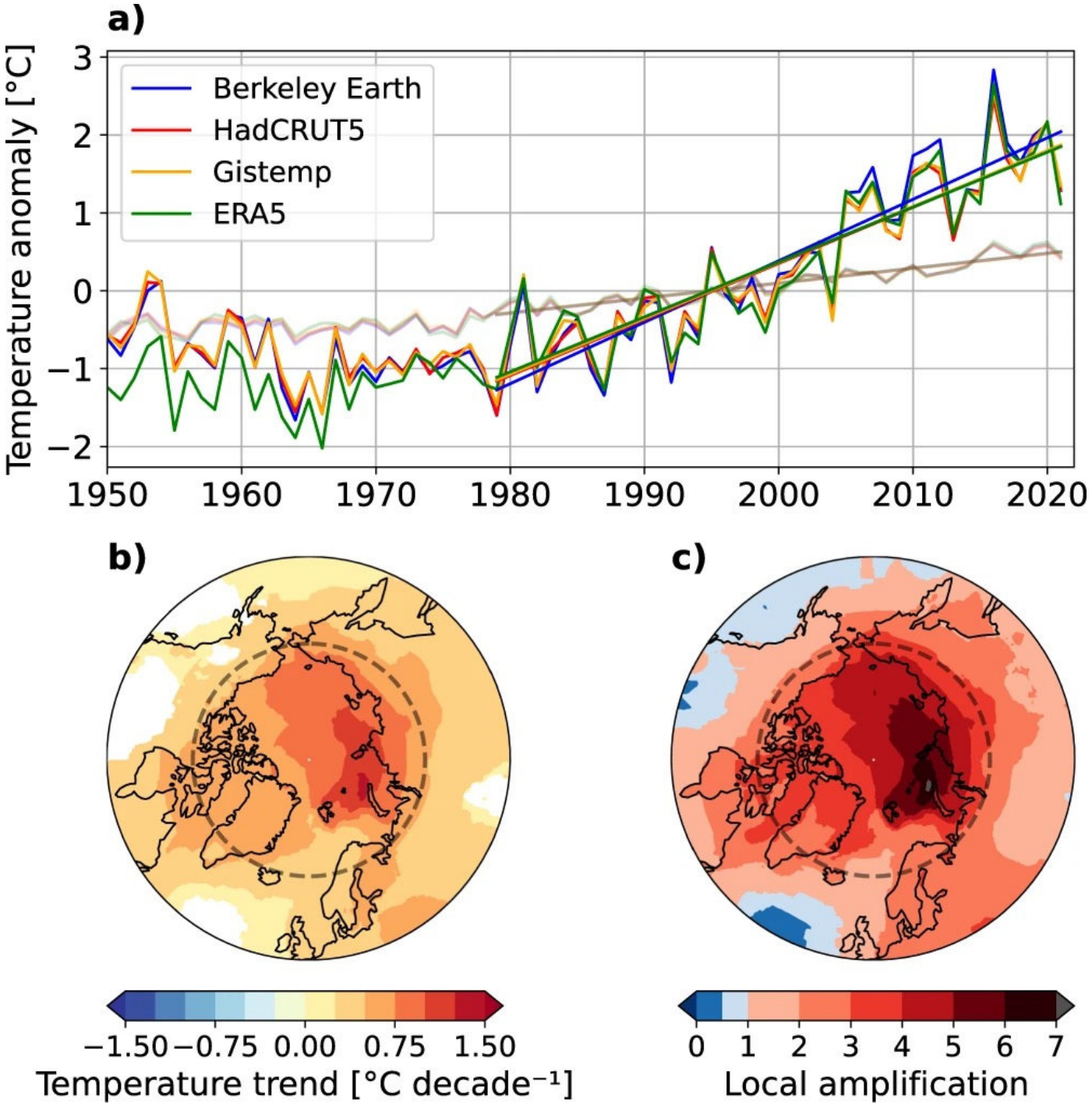
→ Implications for Arctic, Arctic research community & globe?



***Other sources** include JRA-3Q, GISTEMPv4, NOAAGlobalTempv6, Berkeley Earth and the HadCRUT5 ensemble mean. Shading shows the range of the HadCRUT5 ensemble.

PROGRAMME OF THE EUROPEAN UNION · opernicus Europe's eyes on Earth · Climate Change Service climate.copernicus.eu · IMPLEMENTED BY ECMWF

Arctic amplification of global warming



- 3-fold warming rate for Arctic relative to globe (Zhou et al., 2024)
- Arctic amplification key to understanding impacts & informing responses

Rantanen et al. (2022) Comm. Earth & Env.

Potential for disruption of key services & benefits Arctic provides for humanity

Regulation of, e.g.,:
- Climate
- Sealevel

Support of, e.g.,:
- Marine foodwebs
- Biodiversity

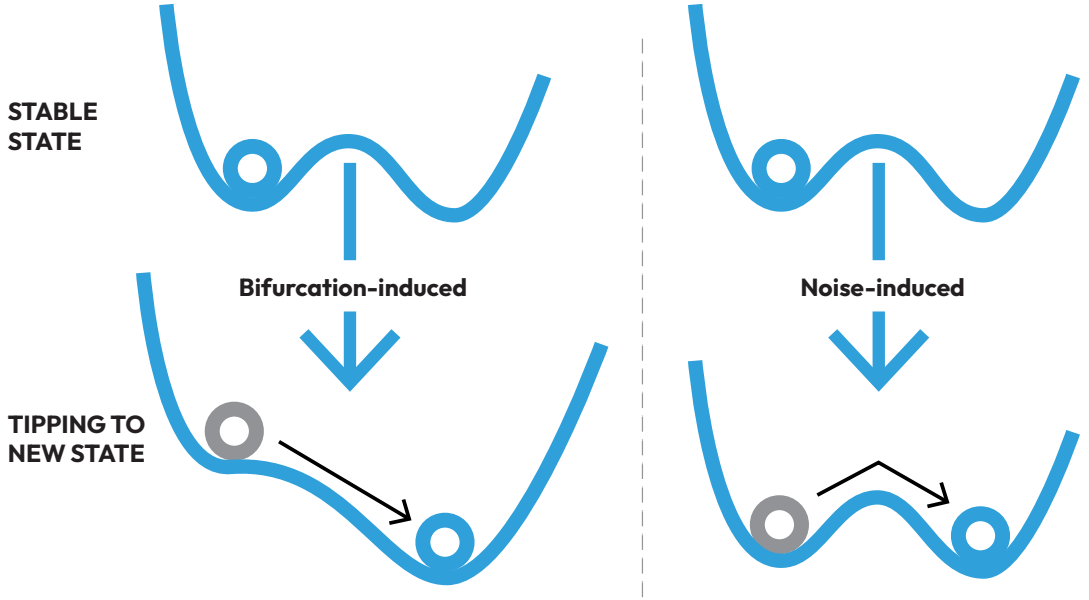
Provision of, e.g.:
- Food
- Transportation corridor

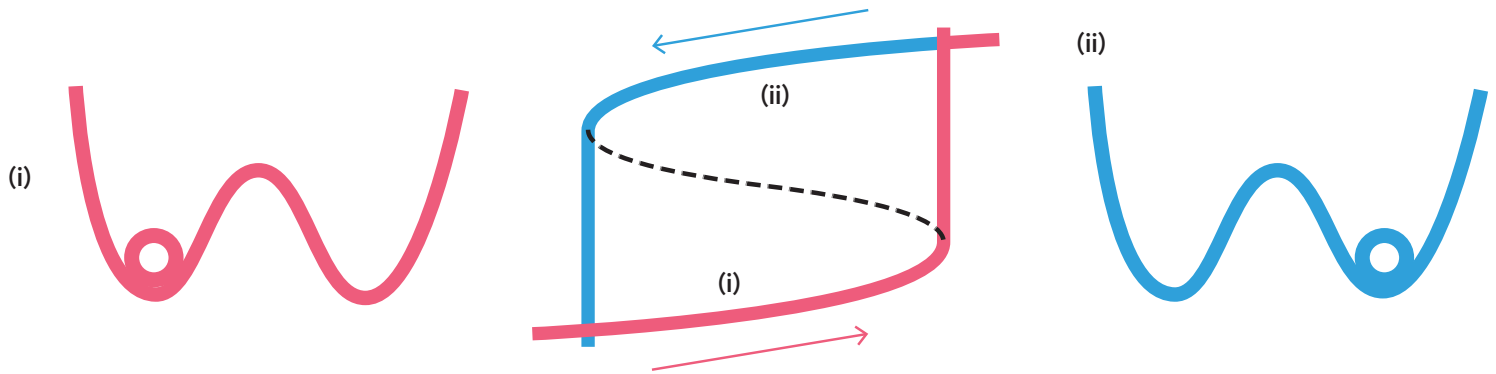
Cultural services for, e.g.:
- Subsistence activities
- Cultural landscape

Eicken et al. (2009) Arctic

Rapid change and “tipping elements”

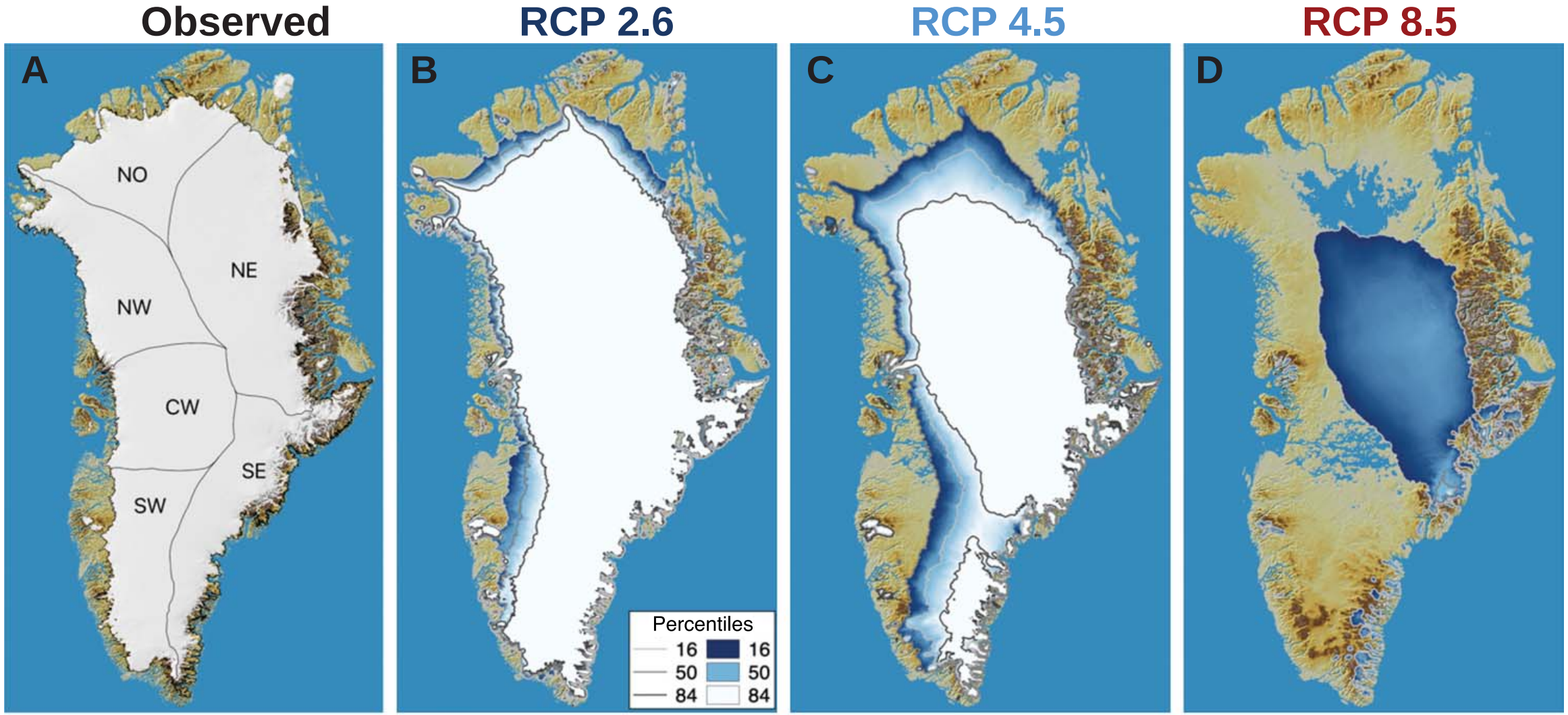
- External forcing or internal variability
  → state changes of key earth system components (tipping elements)
- Relevance for earth system:
  - Feedbacks
  - Path dependency & hysteresis





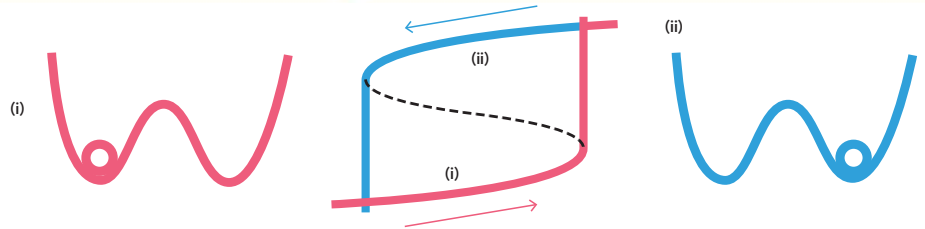
Lenton et al. (2023) - https://global-tipping-points.org/

Rapid change and “tipping elements”

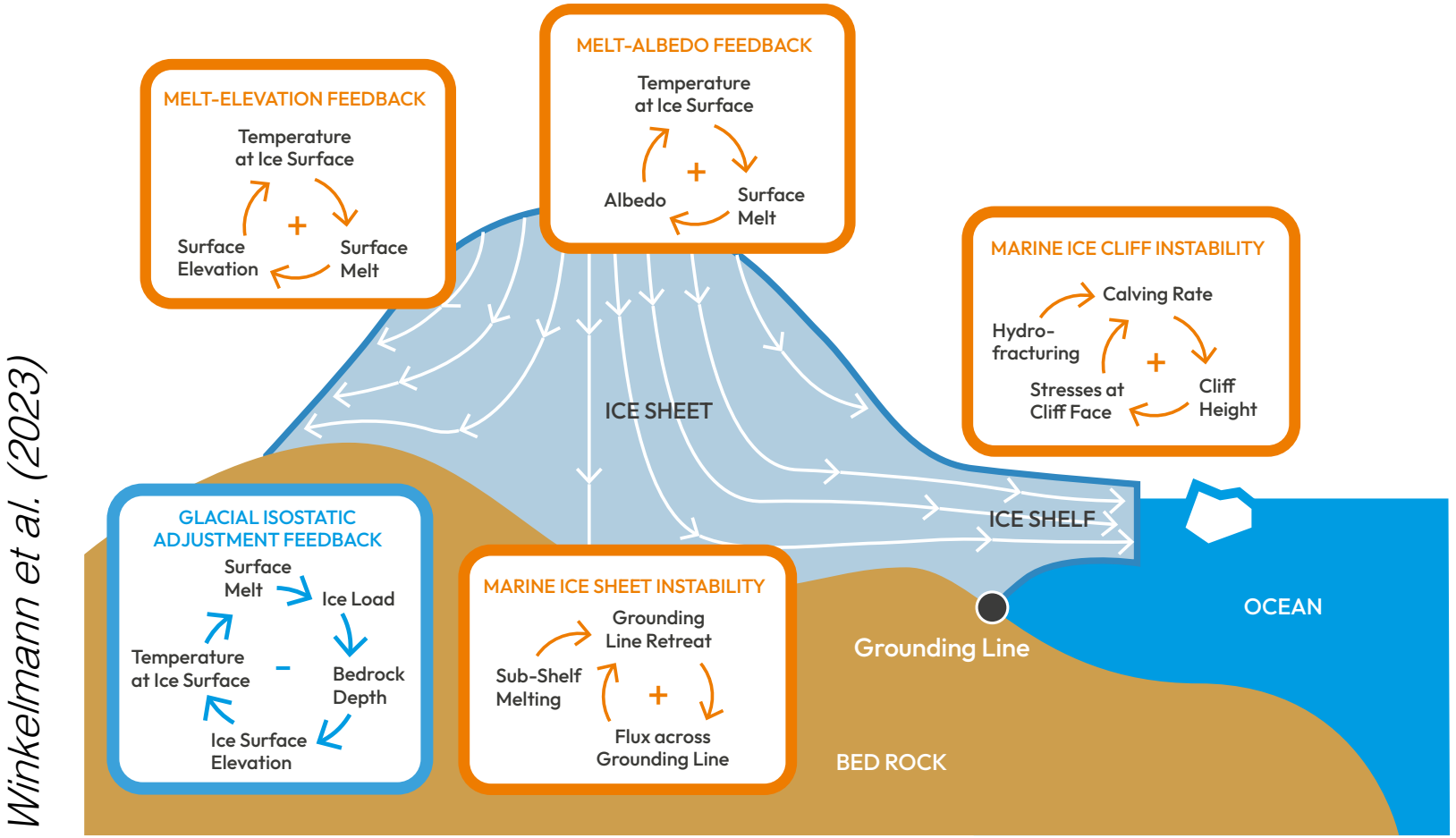


Aschwanden et al. (2019) Sci Adv

- Example: Greenland Ice sheet loss (shown here: Present day v. Year 3000

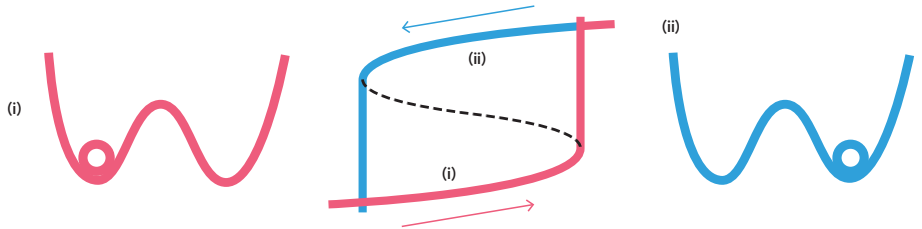


Rapid change and “tipping elements”



Winkelmann et al. (2023)

- Example: Greenland Ice sheet loss



Rapid change and “tipping elements”

- External forcing or internal variability → state changes of key earth system components (tipping elements)
- Arctic contains dispro-portionate number of globally relevant tipping elements

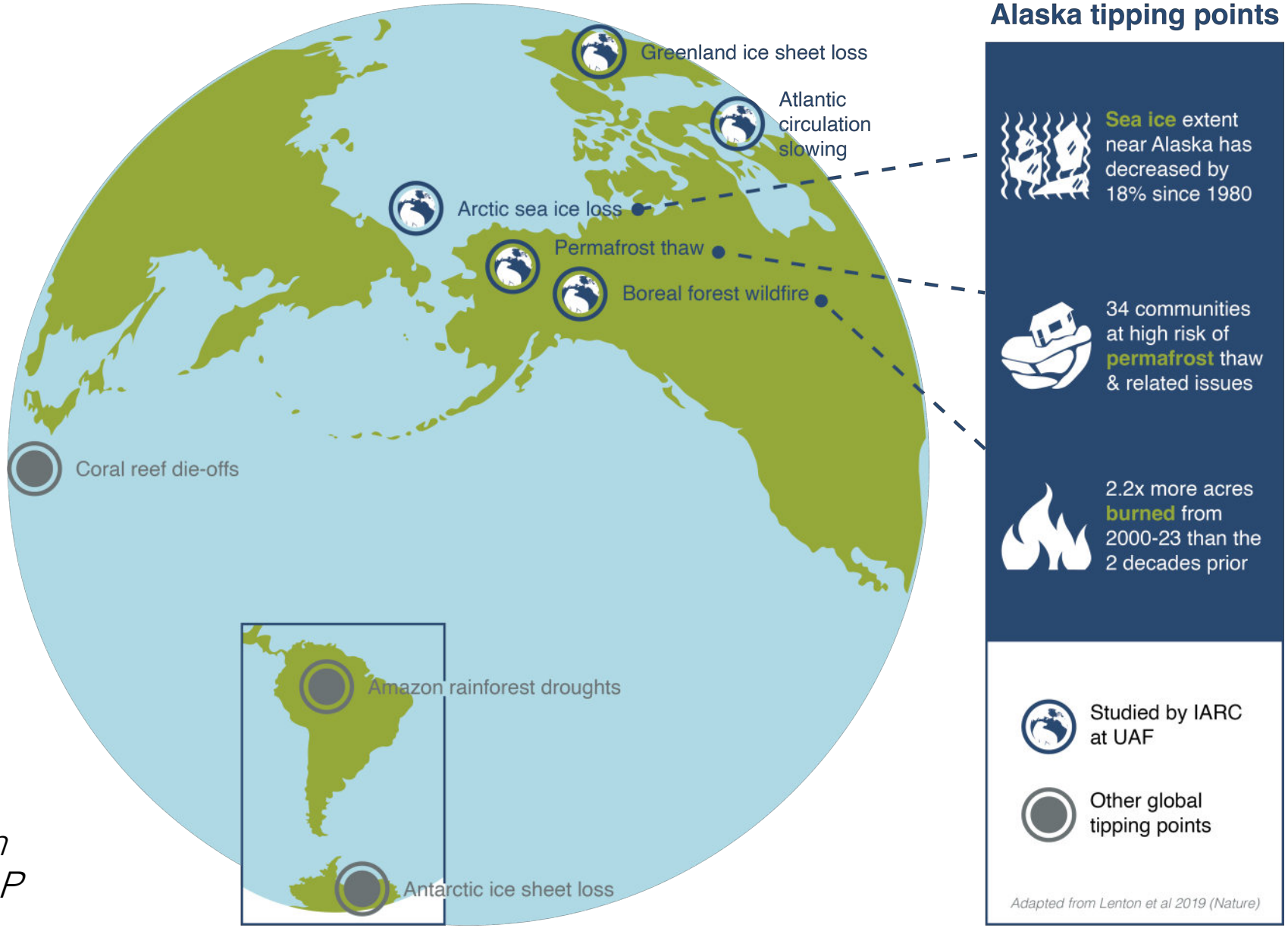


Fig. by McFarland, based on Lenton et al. (2019) & ACCAP

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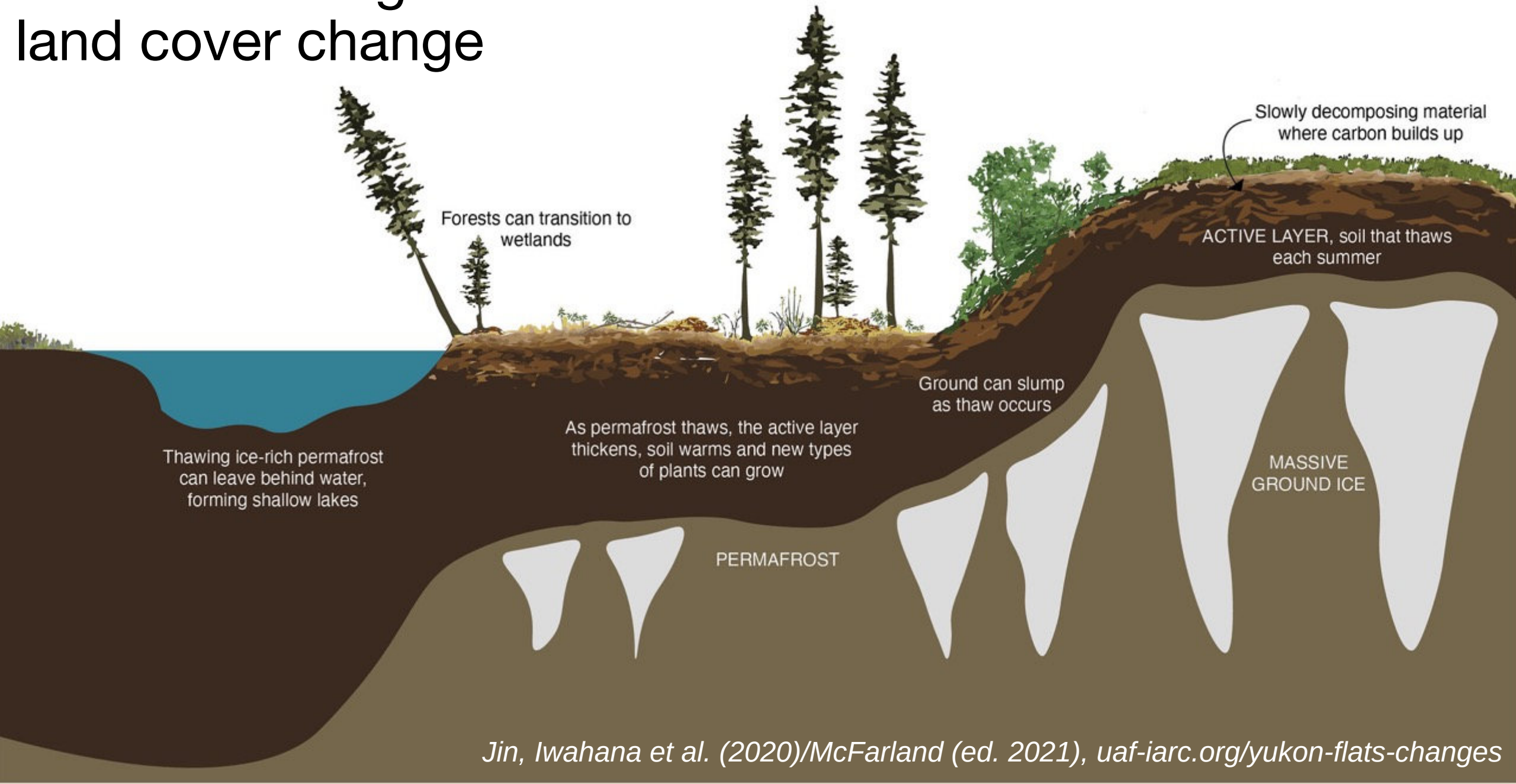
Arctic cryosphere

- Cryosphere: Sea ice, glaciers & ice sheets, permafrost, seasonal snow
- Key in global climate system: Albedo, methane, atmosphere & ocean circulation
  → Slow onset hazards
- Rapid onset hazards:
  → Sea ice hazards
  → Permafrost degradation & failure

Arctic Portal (2020)

Permafrost degradation & land cover change



Jin, Iwahana et al. (2020)/McFarland (ed. 2021), uaf-iarc.org/yukon-flats-changes

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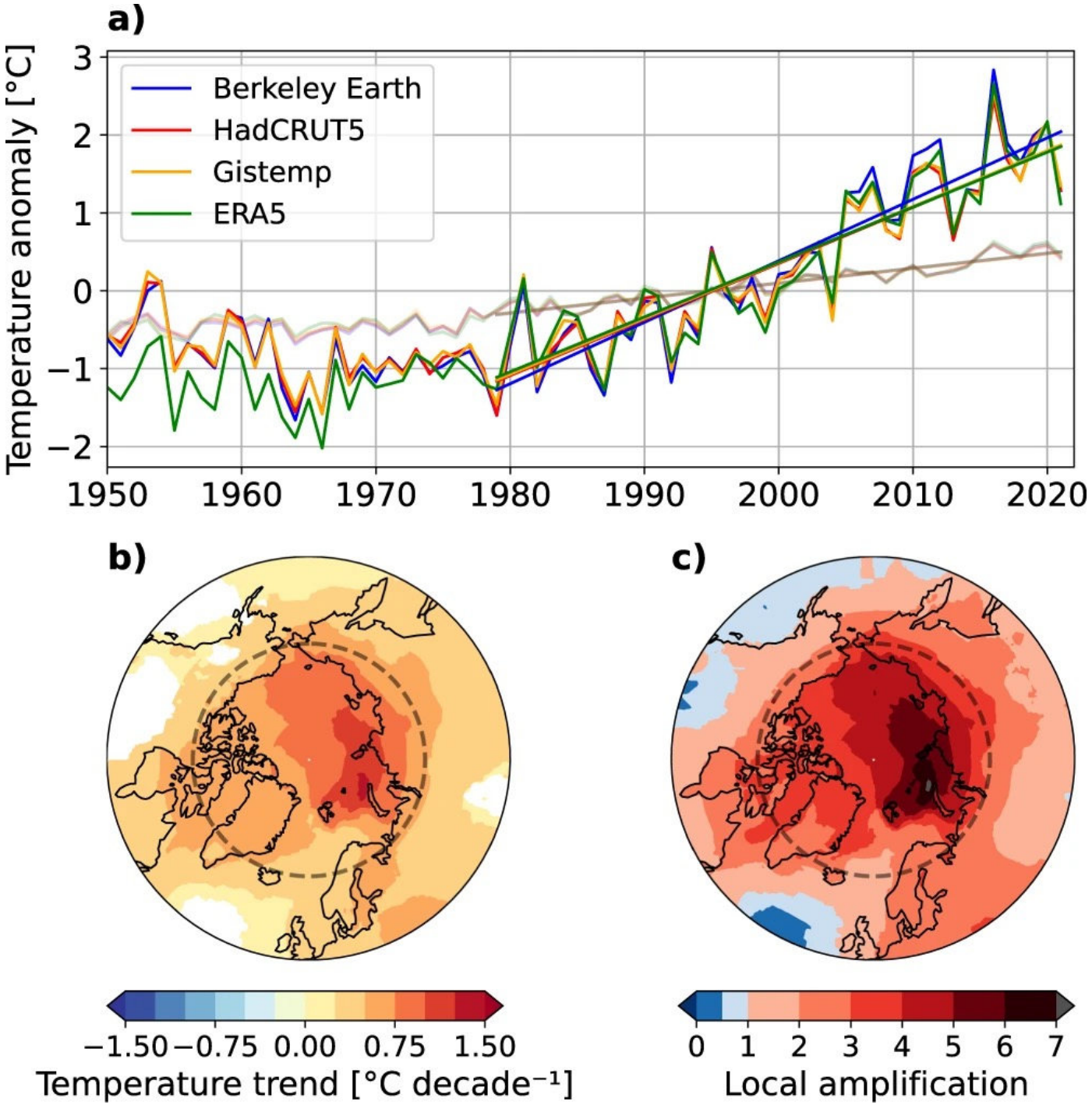
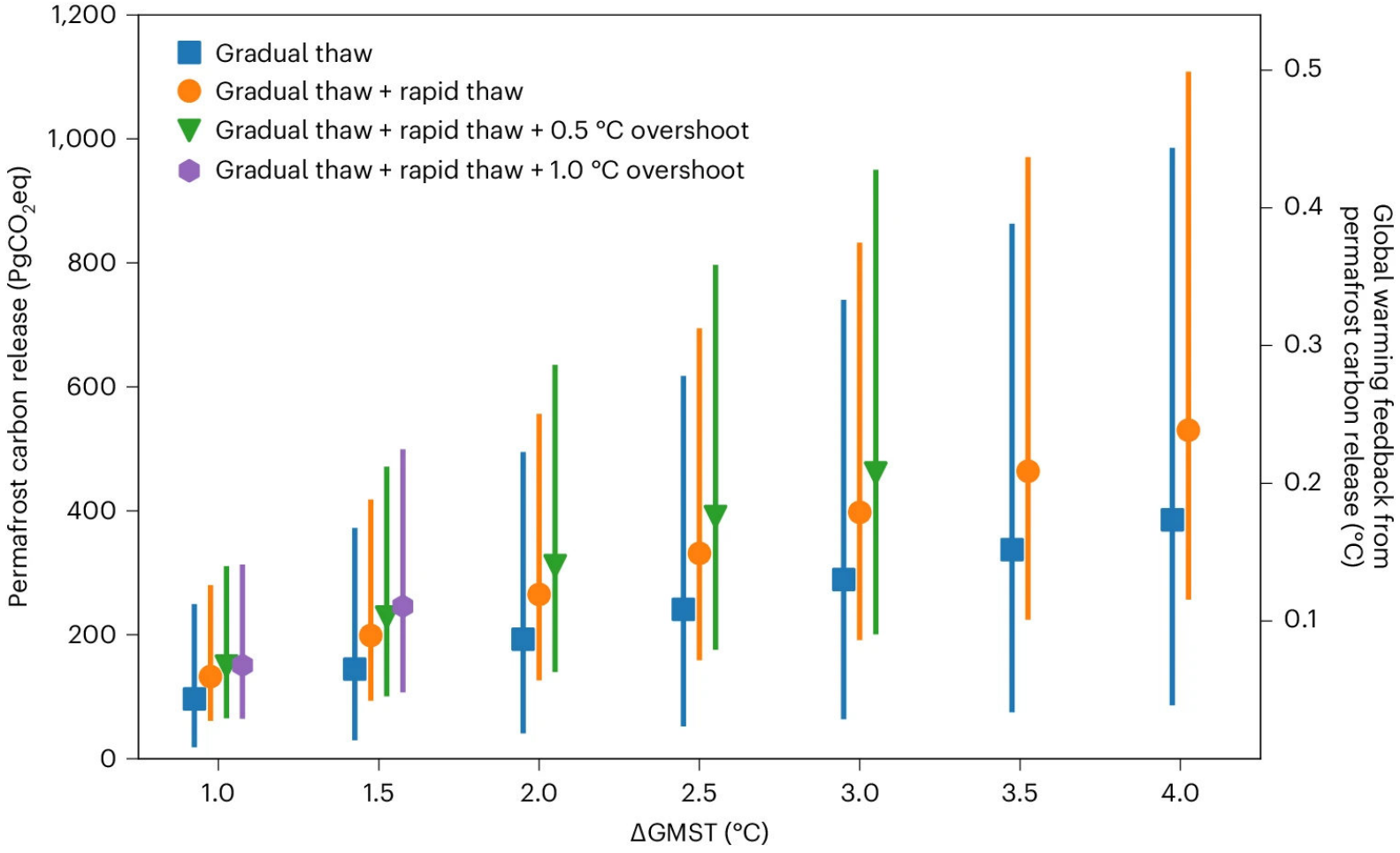


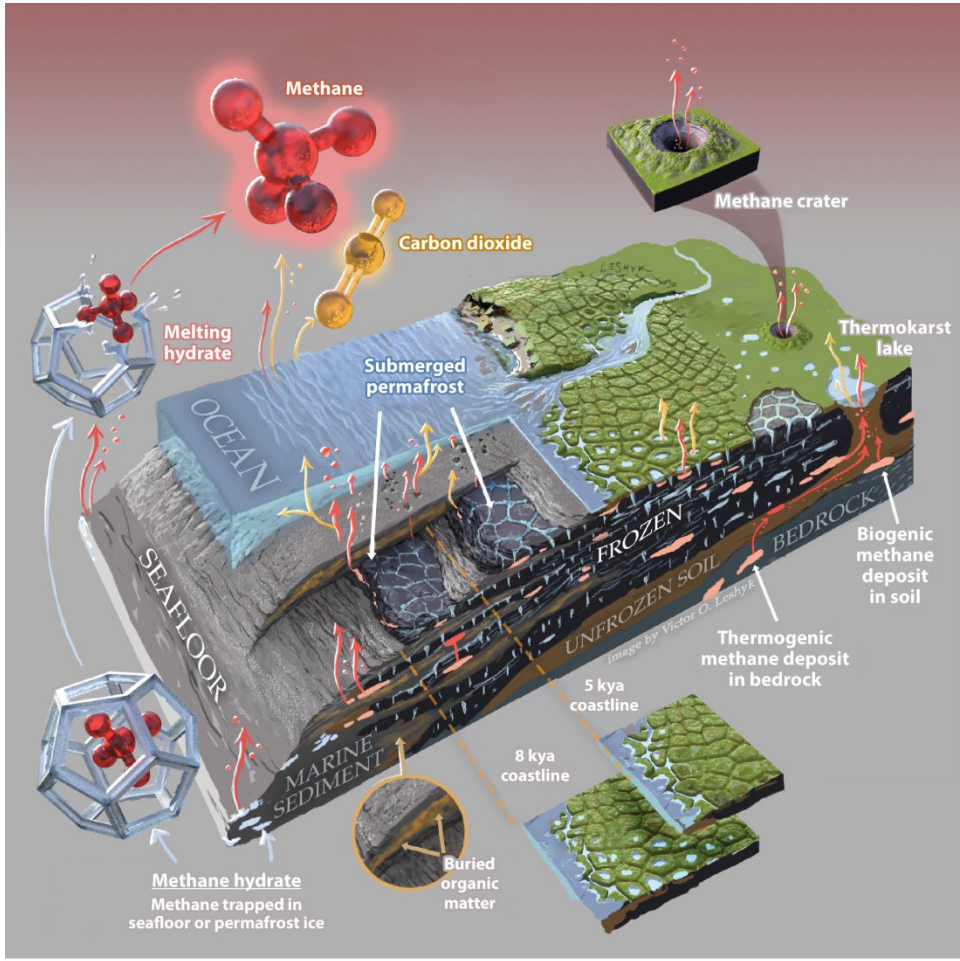
- Arctic amplification key to understanding impacts & informing responses:
  → Regional patterns aggravate permafrost degradation
  → Ice-albedo feedback impacts ecosystems & human activities

Rantanen et al. (2022) Comm. Earth & Env.

Greenhouse gas release from thawing permafrost



Nitzbon et al. (2024)
Nature Climate Change



Schuur et al. (2022)
Ann. Rev. Env. Resources

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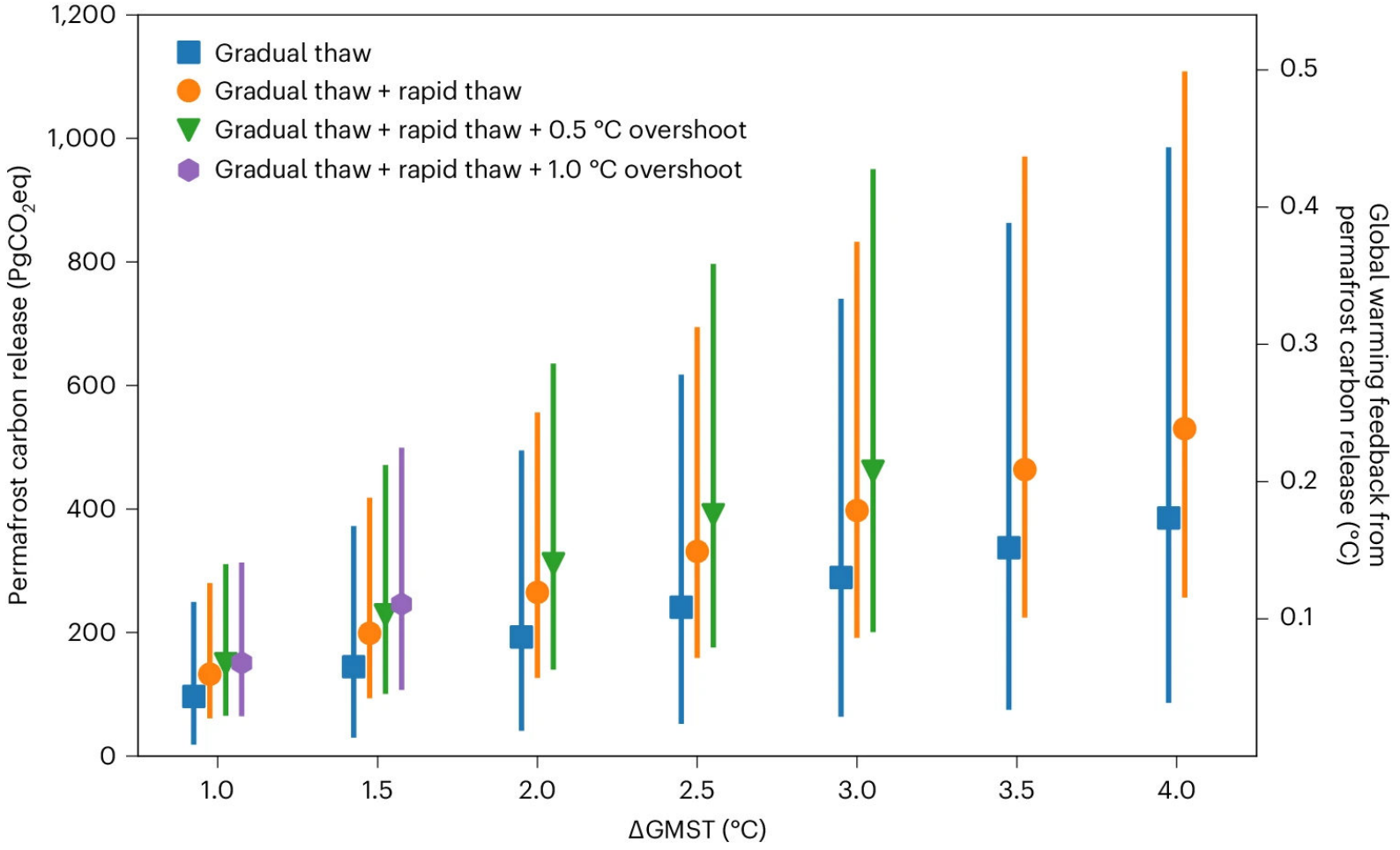

Nitzbon et al. (2024)
Nature Climate Change

- Major feedback in global warming (methane release)
- Uncertainties require attention
- Global-scale consequences

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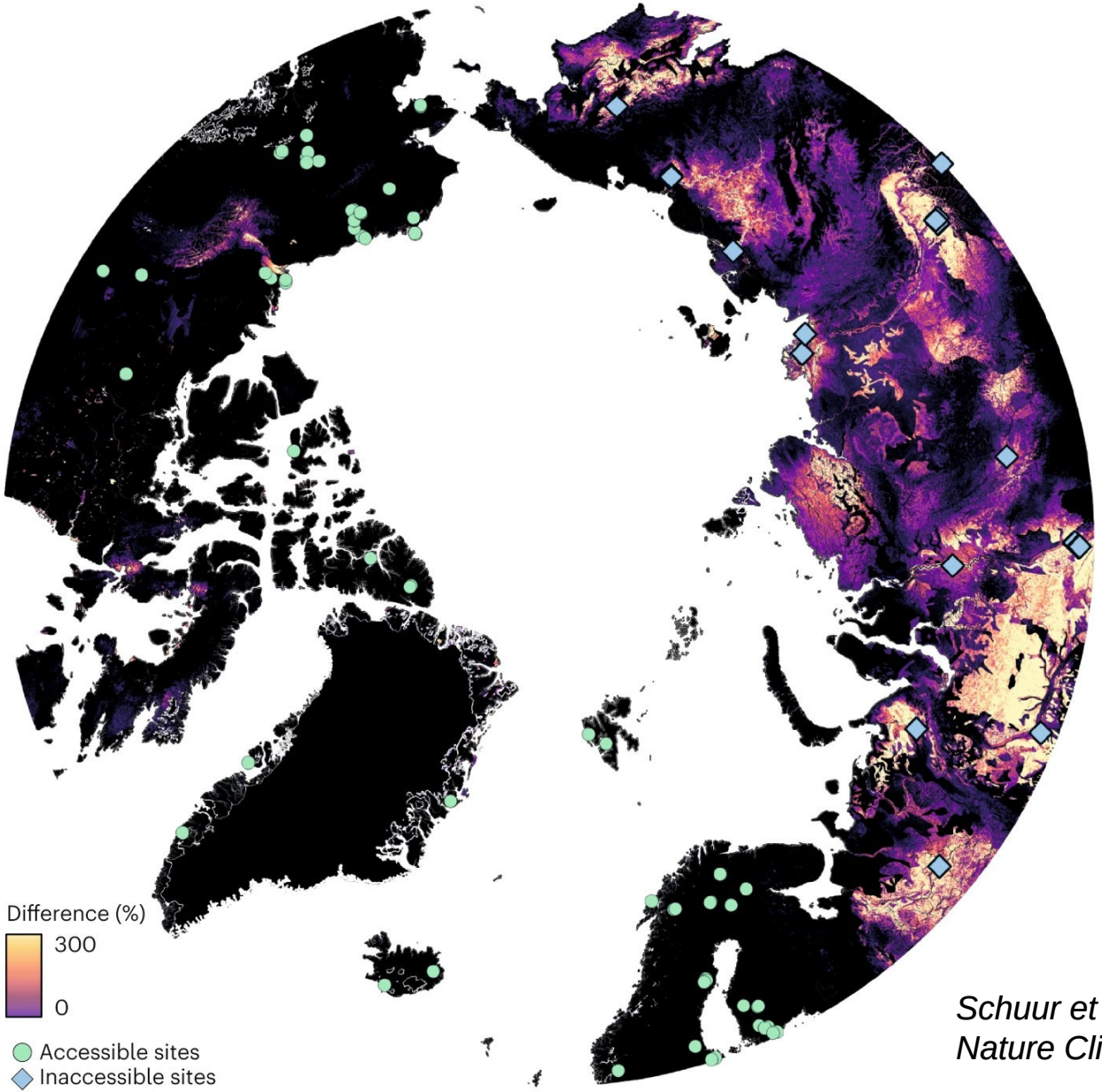
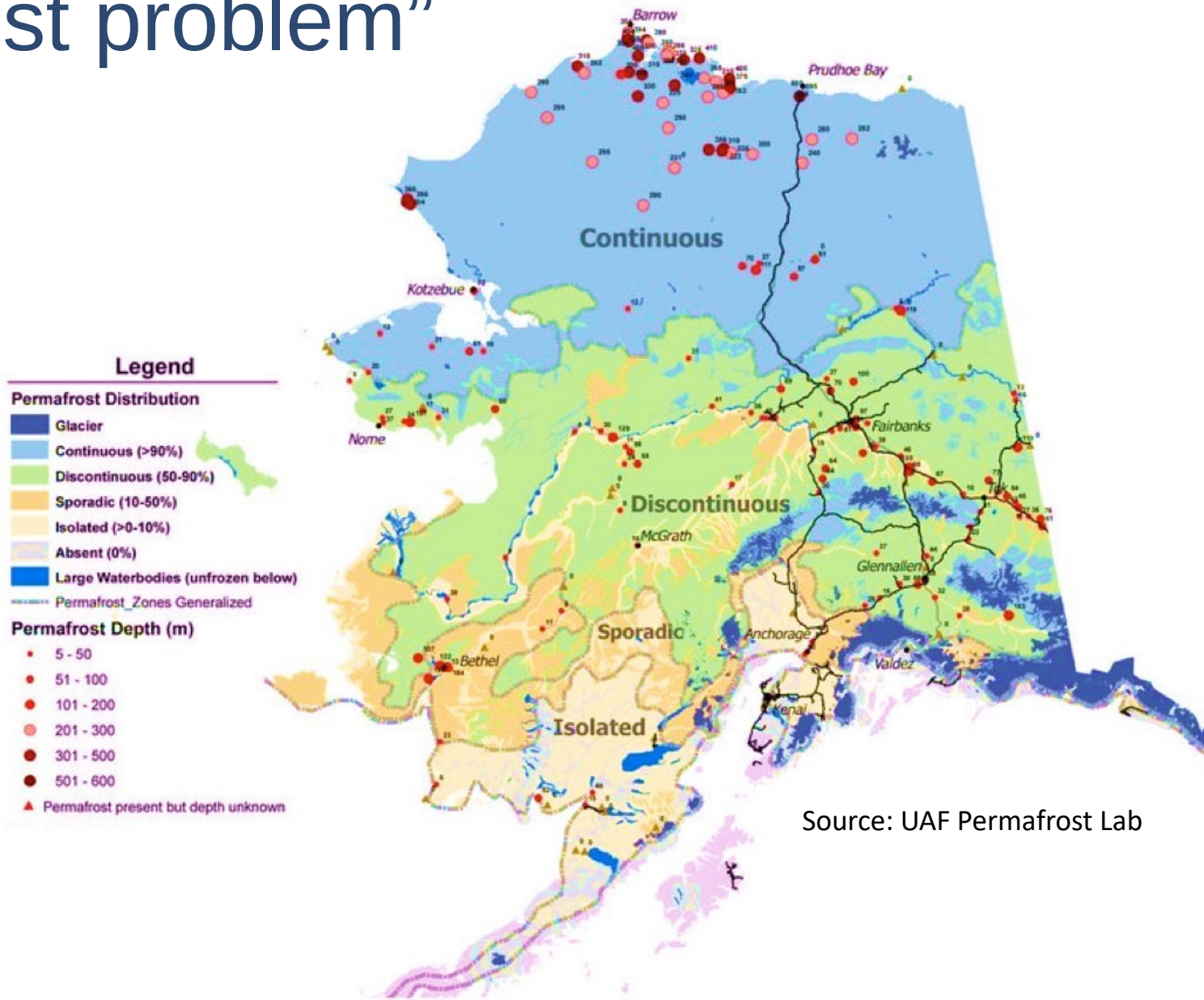


Schuur et al. (2024)
Nature Climate Change

- Major feedback in global warming (methane release)
- Uncertainties in magnitude require attention
- Global-scale consequences
- Loss of Russian collaboration puts data & sites in Siberian Arctic at risk

Scale of the “permafrost problem” - Alaska as example

- Infrastructure damage - Road and building integrity
- 78% of highways underlain with >50% permafrost
- 52% of communities underlain with >50% permafrost
- Ecosystem change: Increased erosion, sudden lake draining

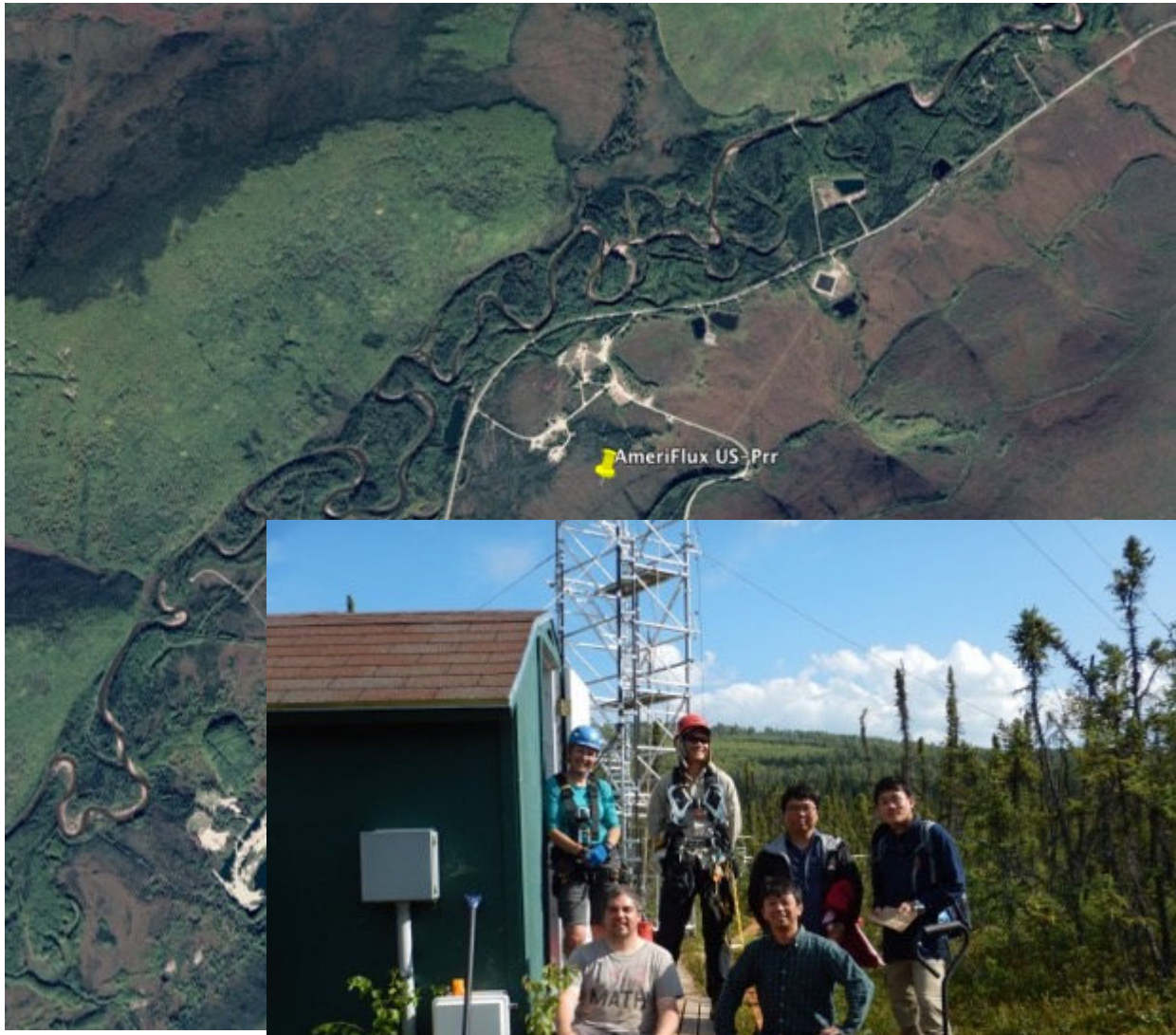


Source: UAF Permafrost Lab

Rick Thoman ● Alaska Center for Climate Assessment & Policy
International Arctic Research Center

Transitions in the boreal forest & permafrost belt

- Boreal forests & permafrost as carbon sources & sinks
- Long-term studies of changing boreal forest, permafrost and seasonal snow environments at UAF's Poker Flat Research Range – Ameriflux Supersite
- JAMSTEC (Kobayashi et al.) & IARC (Busey, Iwahana, Kim et al.) collaborative research; NIPR & UAF infrastructure support



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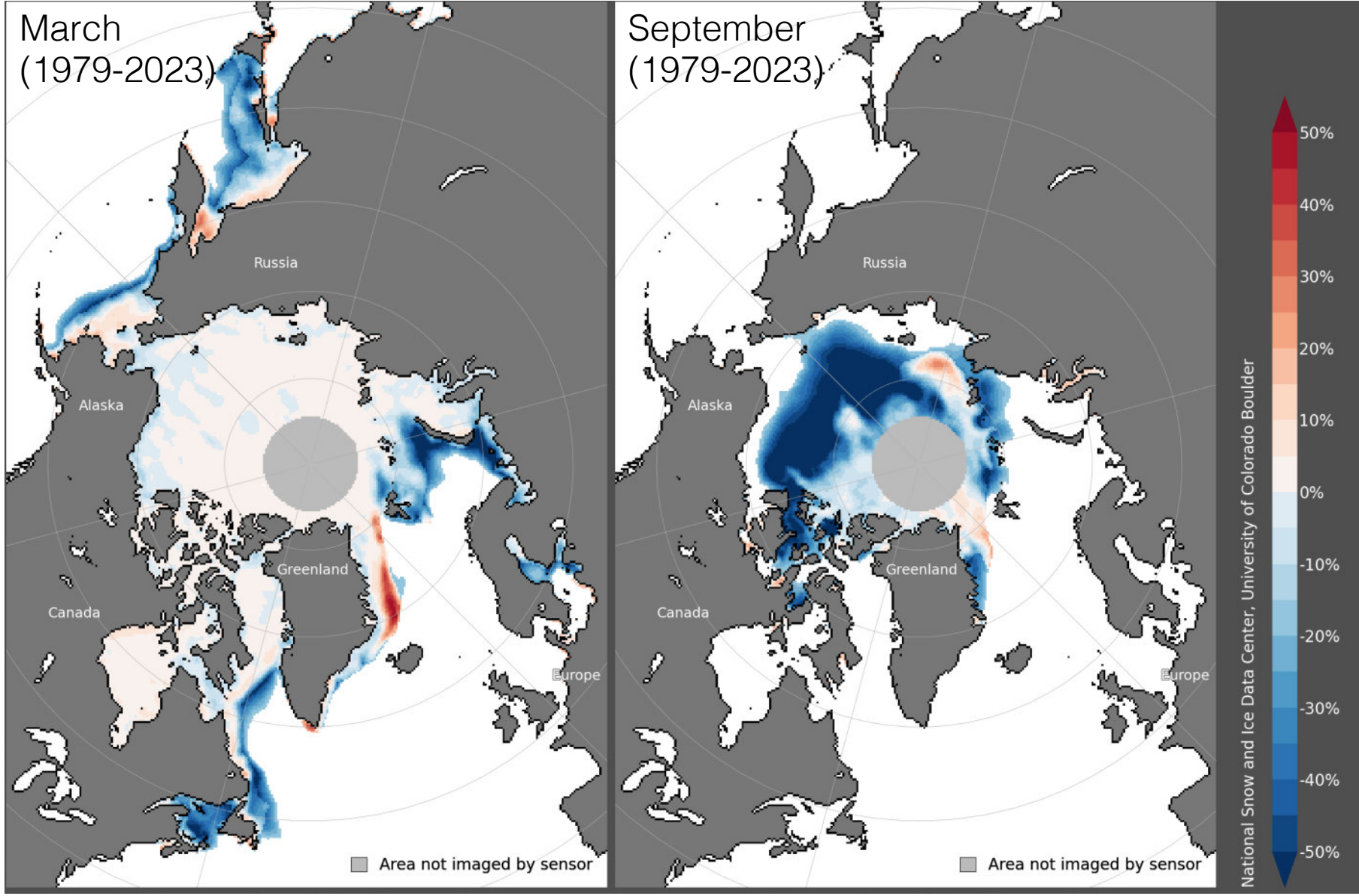
Sea ice loss

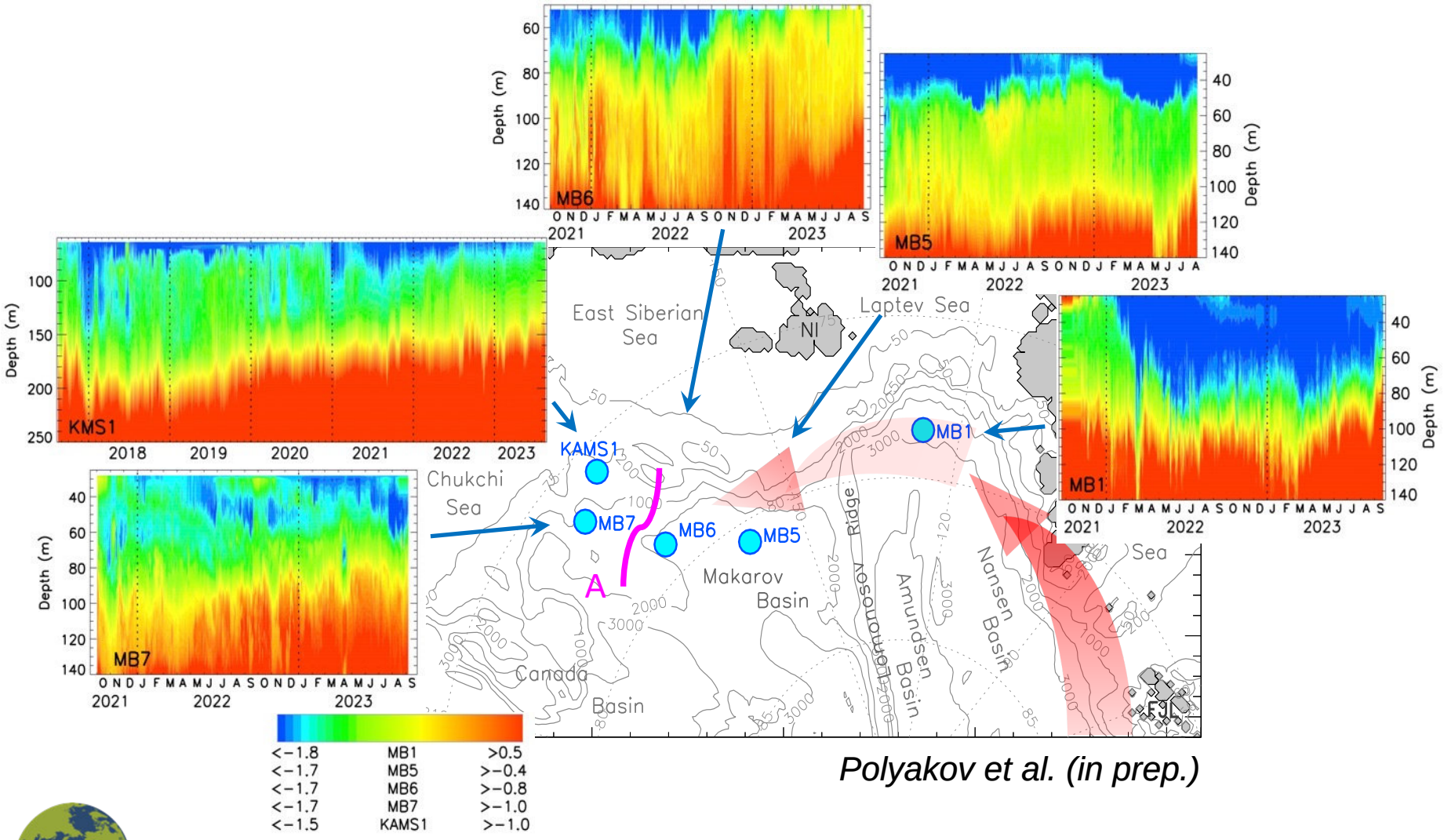
- Winter ice loss in Okhotsk, Bering, Kara Labrador Seas
- Summer ice loss centered on Pacific Arctic sector

→ Climate regulation
→ Coastal community & ecosystem impacts

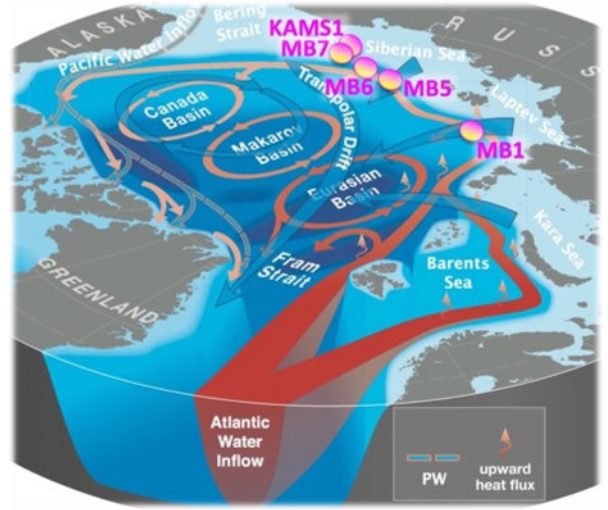


National Snow and Ice Data Center (2024)

Atlantification has reached Amerasian Basin Center of action – Siberian Arctic Ocean



Polyakov et al. (in prep.)



- Oceanic heat fluxes explain up to 1m (!) of sea ice loss in the Eurasian Basin in 2021-2023

Igor Polyakov, International Arctic Research Center

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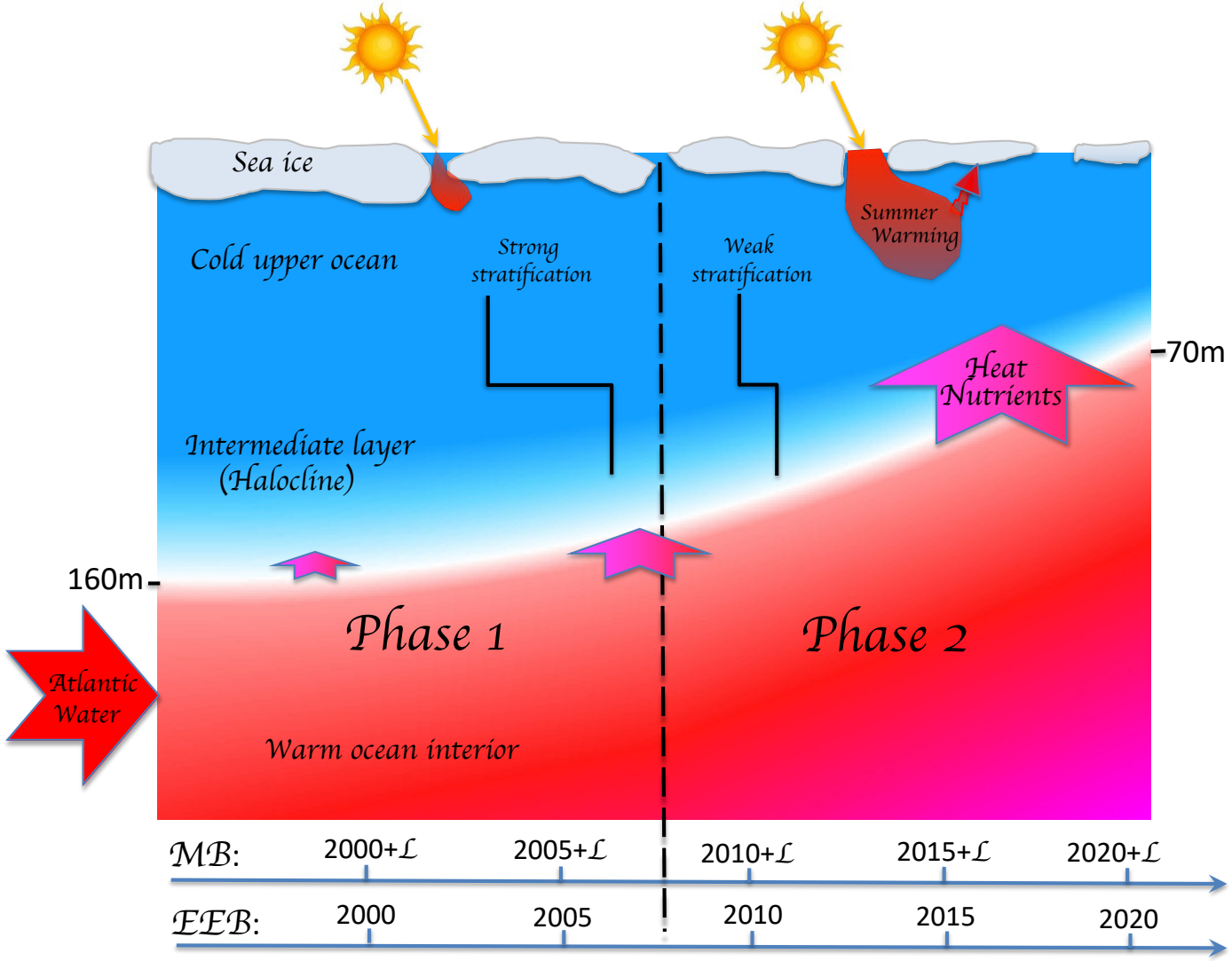

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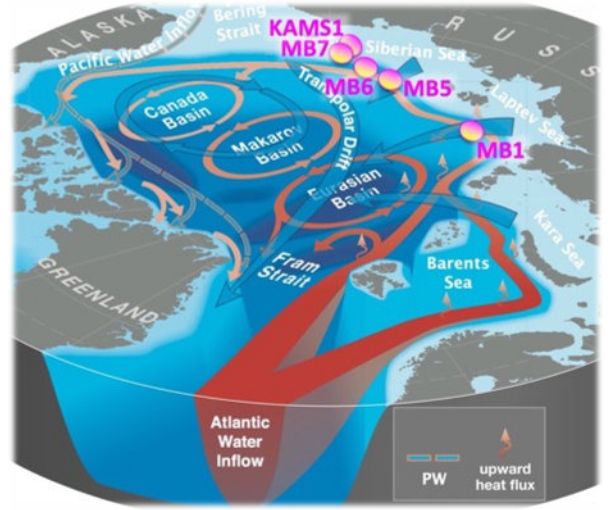

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Sea ice loss

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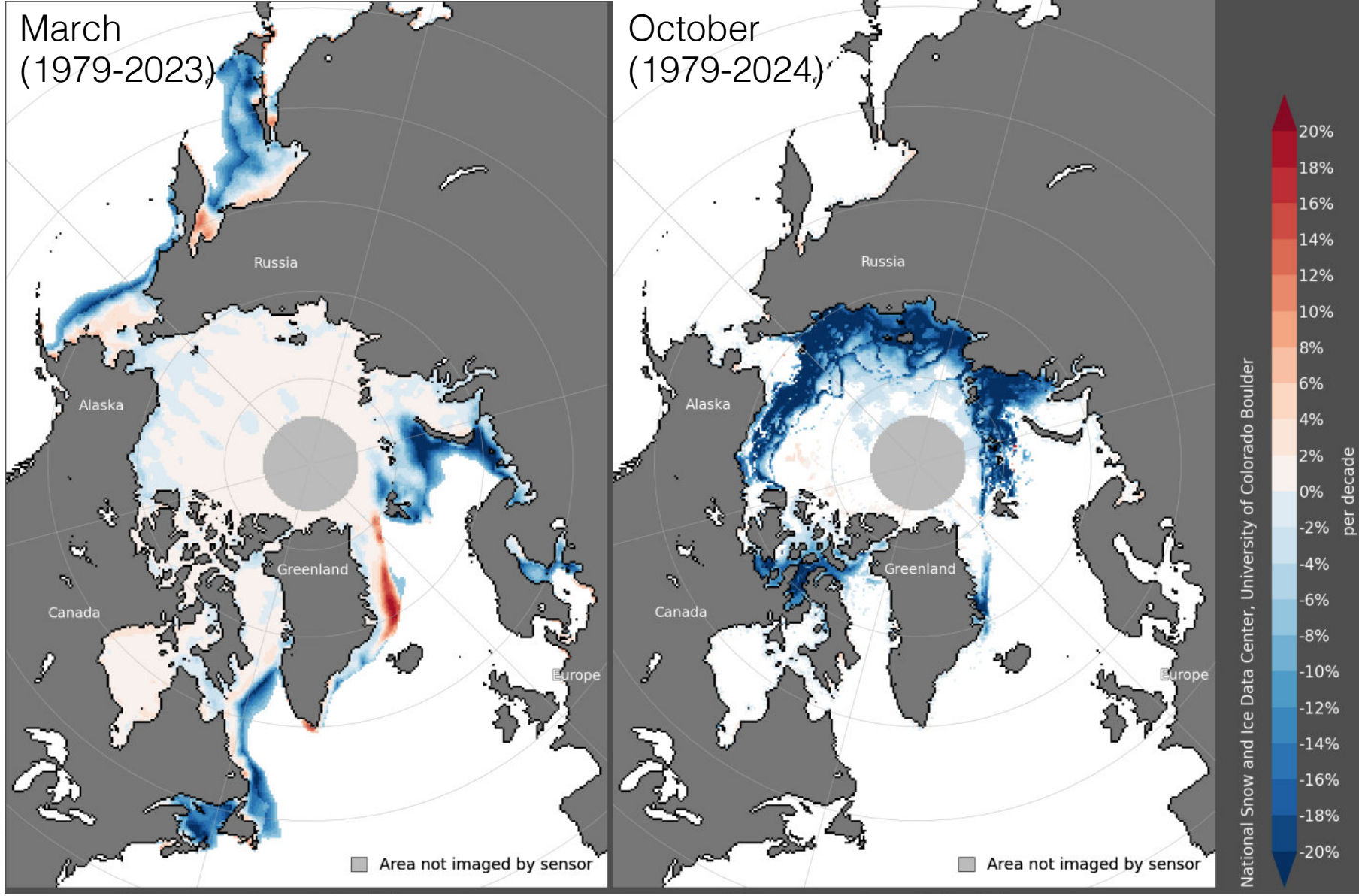
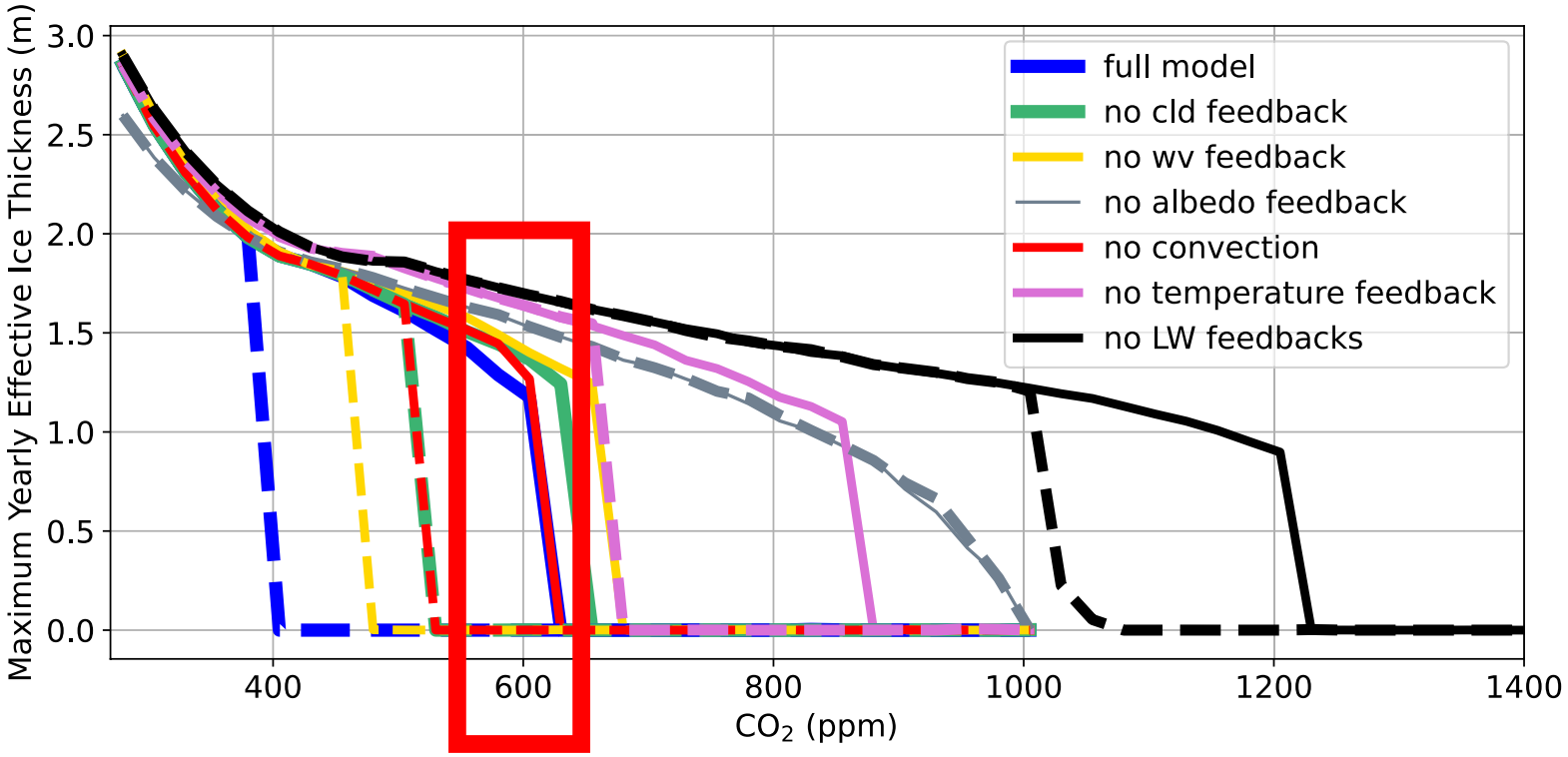
- Summer ice loss centered on Pacific Arctic sector
- Incipient winter ice loss across Siberian shelves

→ Climate regulation
→ Coastal community & ecosystem impacts



National Snow and Ice Data Center (2024)

Potential for complete loss of Arctic sea ice (summer & winter)



Hankel & Tziperman (2023) Nonlin. Processes Geophys.

- Arctic Ocean sediment cores indicate complete lack of ice cover for atm. CO_2 > 700-1000ppm (Stein, 2019)
- First model-based assessment of winter sea-ice loss tipping point for transient (non-equilibrium) conditions:
  "We […] conclude that on policy-relevant timescales the significant irreversibility of winter Arctic sea ice […] is likely to occur in the real climate system […] regardless of whether an actual bifurcation (tipping point) in the equilibrium exists."
  (Hankel & Tziperman, 2023)

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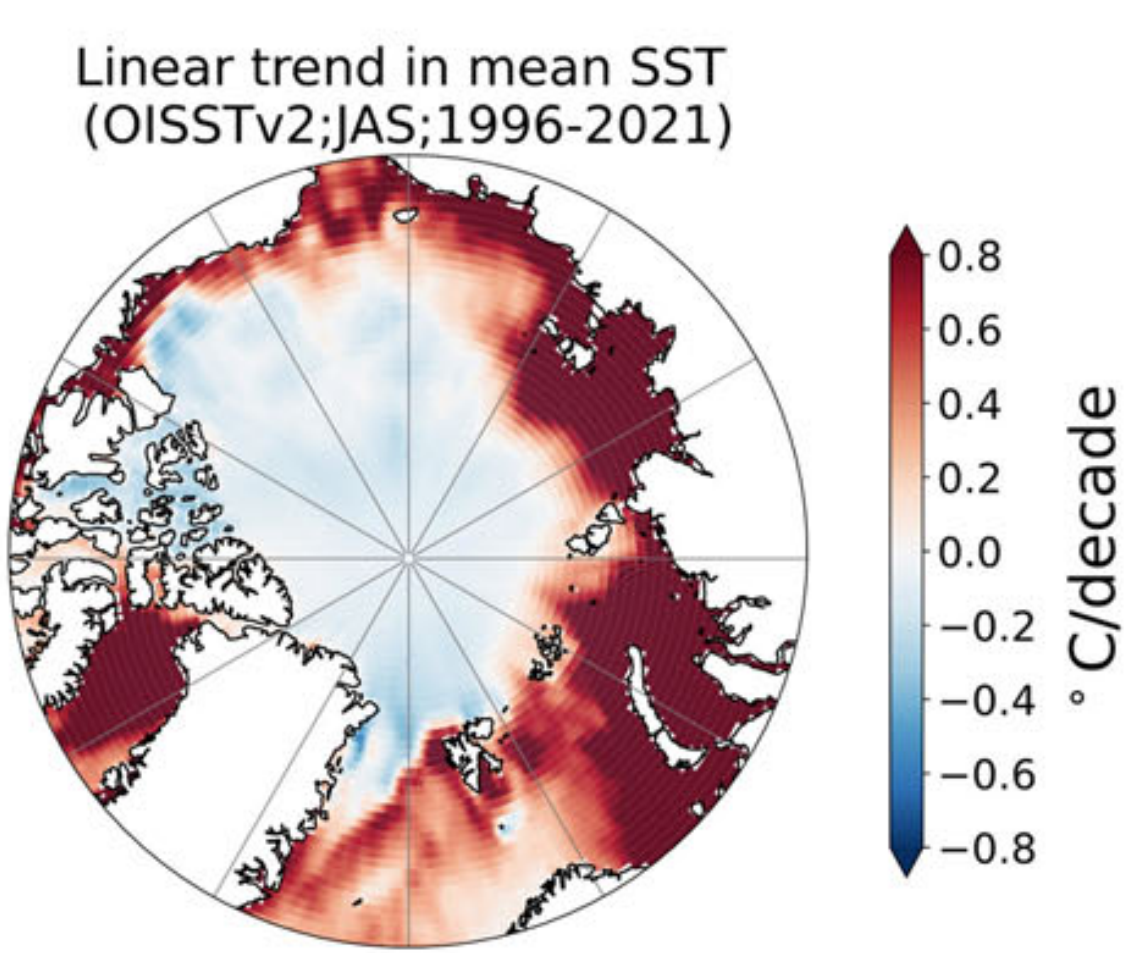
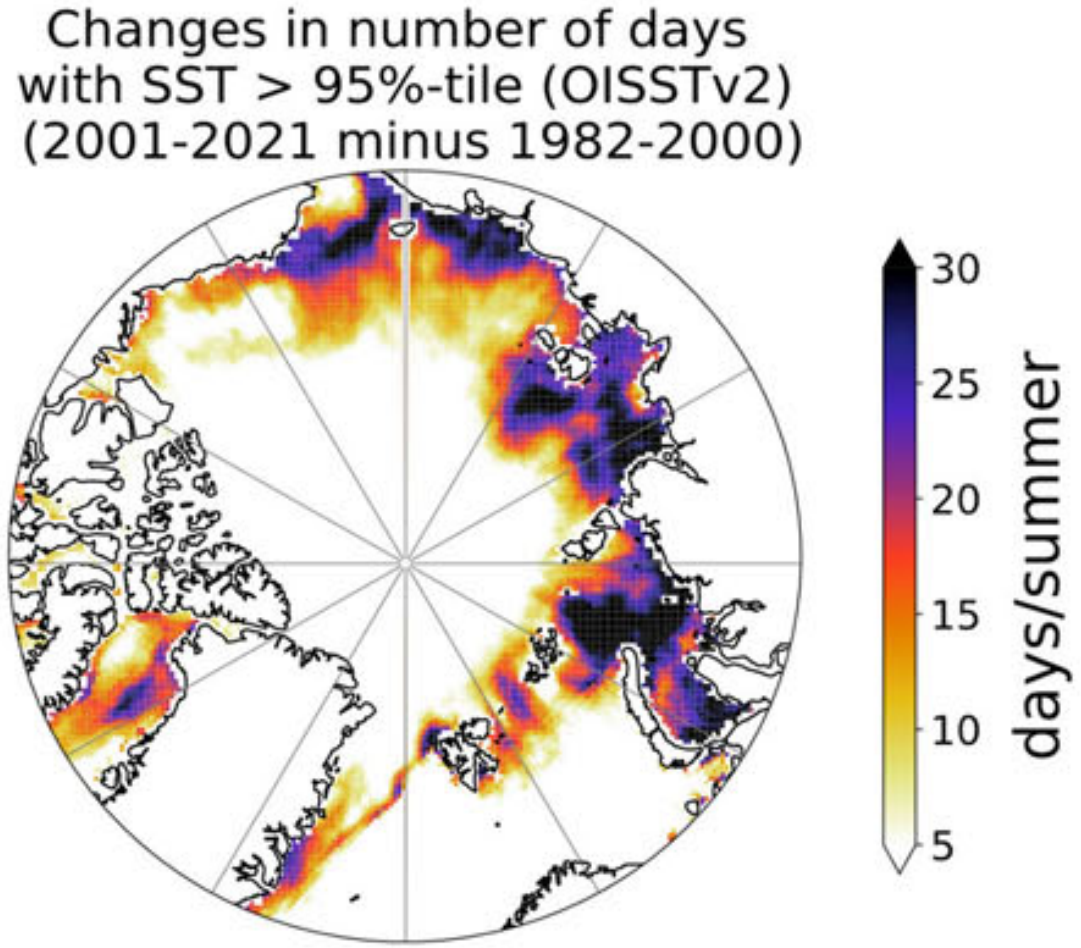
Arctic warming & marine heatwaves

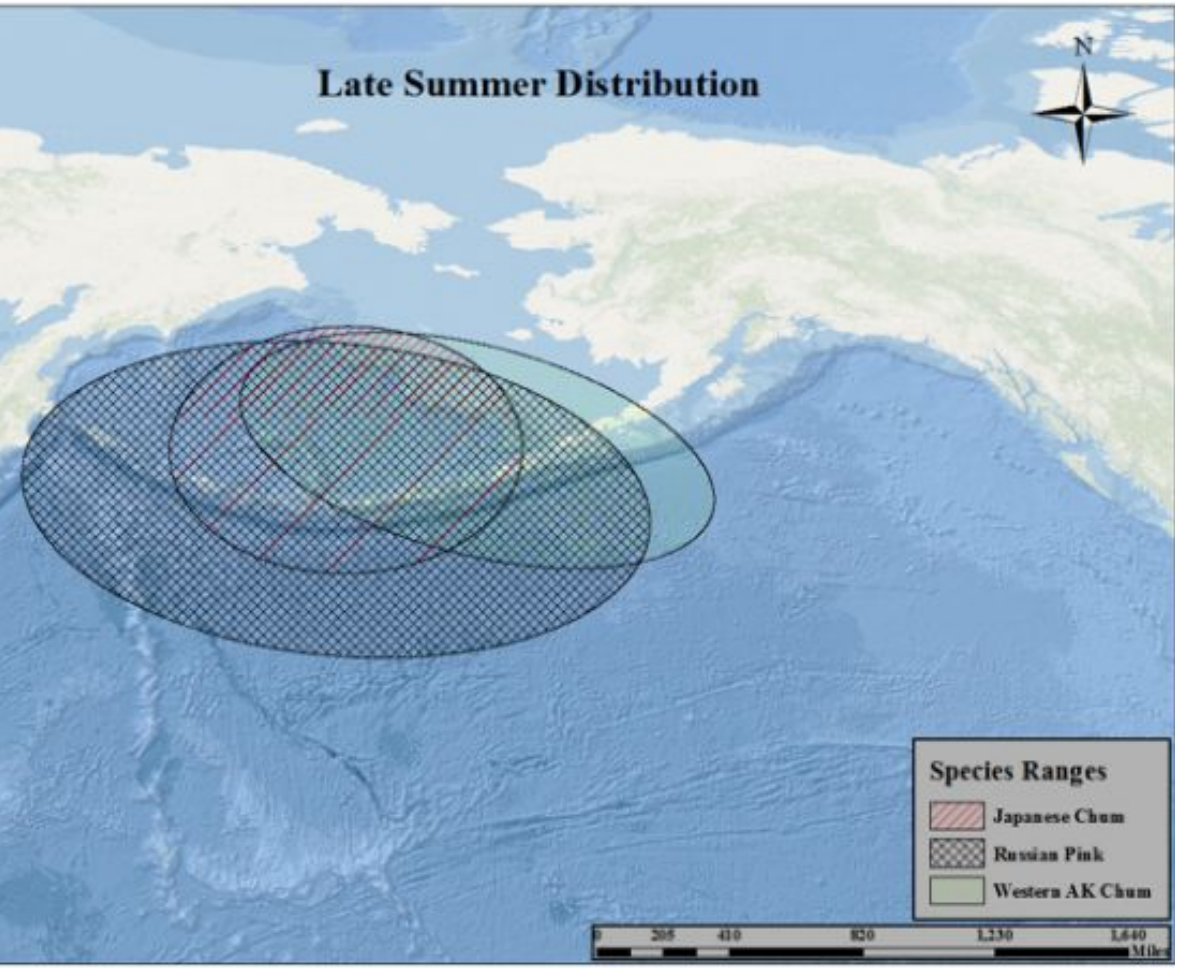




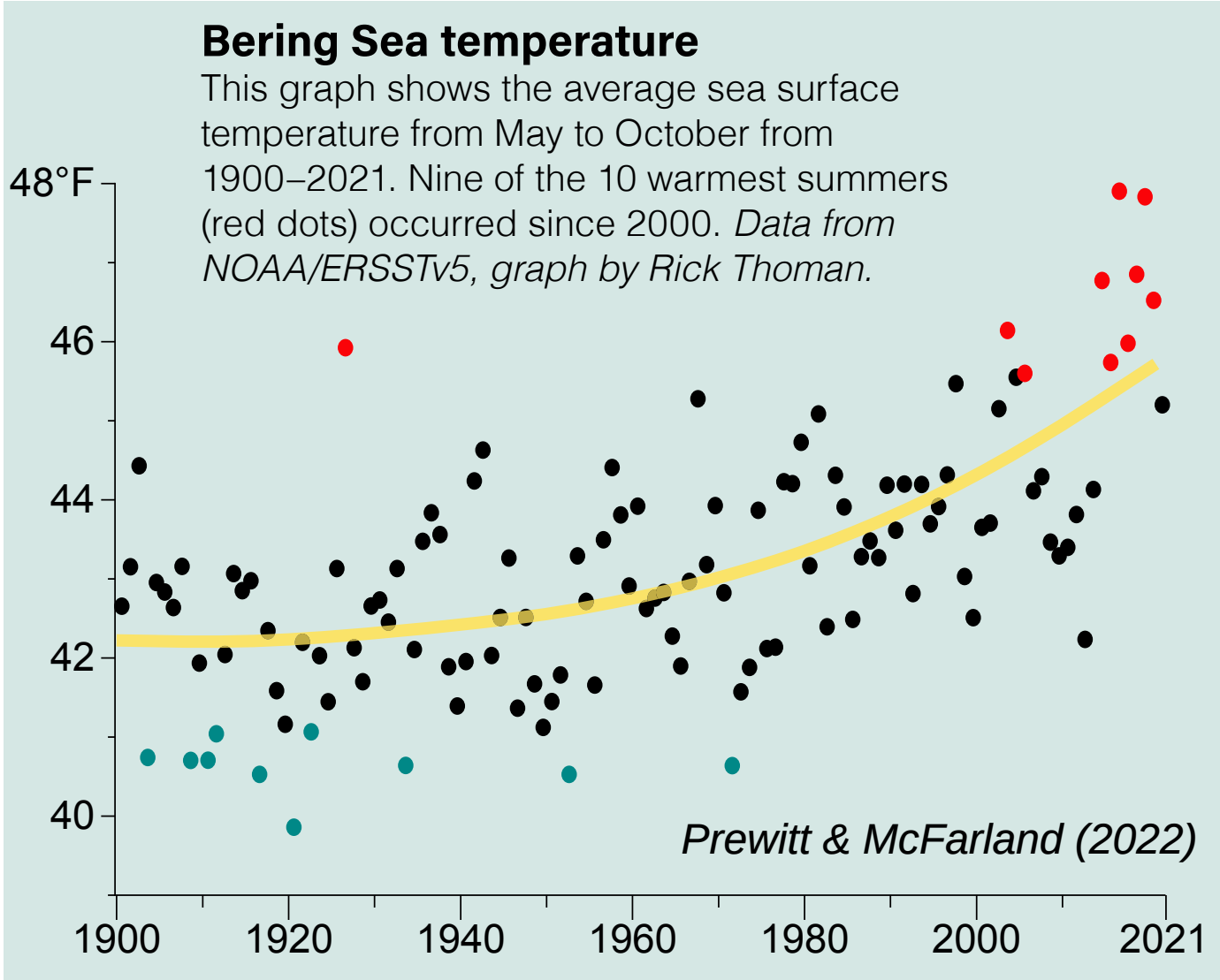
Barkhordarian et al., Comm. Earth Env., 2024

Observing context: Marine ecosystems & food security

Ocean change → Food security → Regional policy & local response



McPhee & Minicucci (2018)



Observing context: Marine ecosystems & food security

Ocean change → Food security → Regional policy & local response

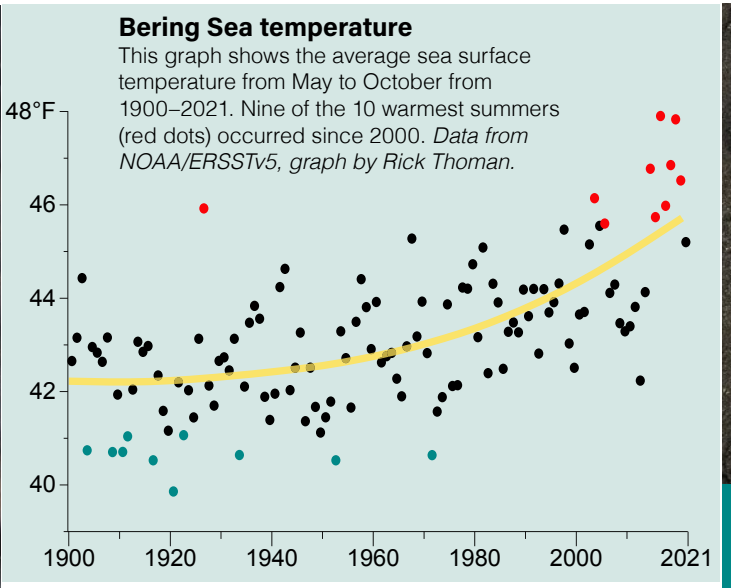
Photos by **MARC LESTER** / ADN

In a normal year, Herman Hootch said, his Emmonak smokehouse would be filled with chum salmon. "We haven't been able to fish to date, all summer, not even once," he said.

SPECIAL REPORT

'We've never seen this before'

Salmon collapse sends Alaskans on the Lower Yukon River scrambling for scarce food alternatives as winter approaches



Prewitt & McFarland (2022)

Chum salmon found dead along the Koyukok River in summer 2019. Since the eggs and sperm were retained the salmon died before spawning. *Photo by Stephanie Quinn-Davidson.*

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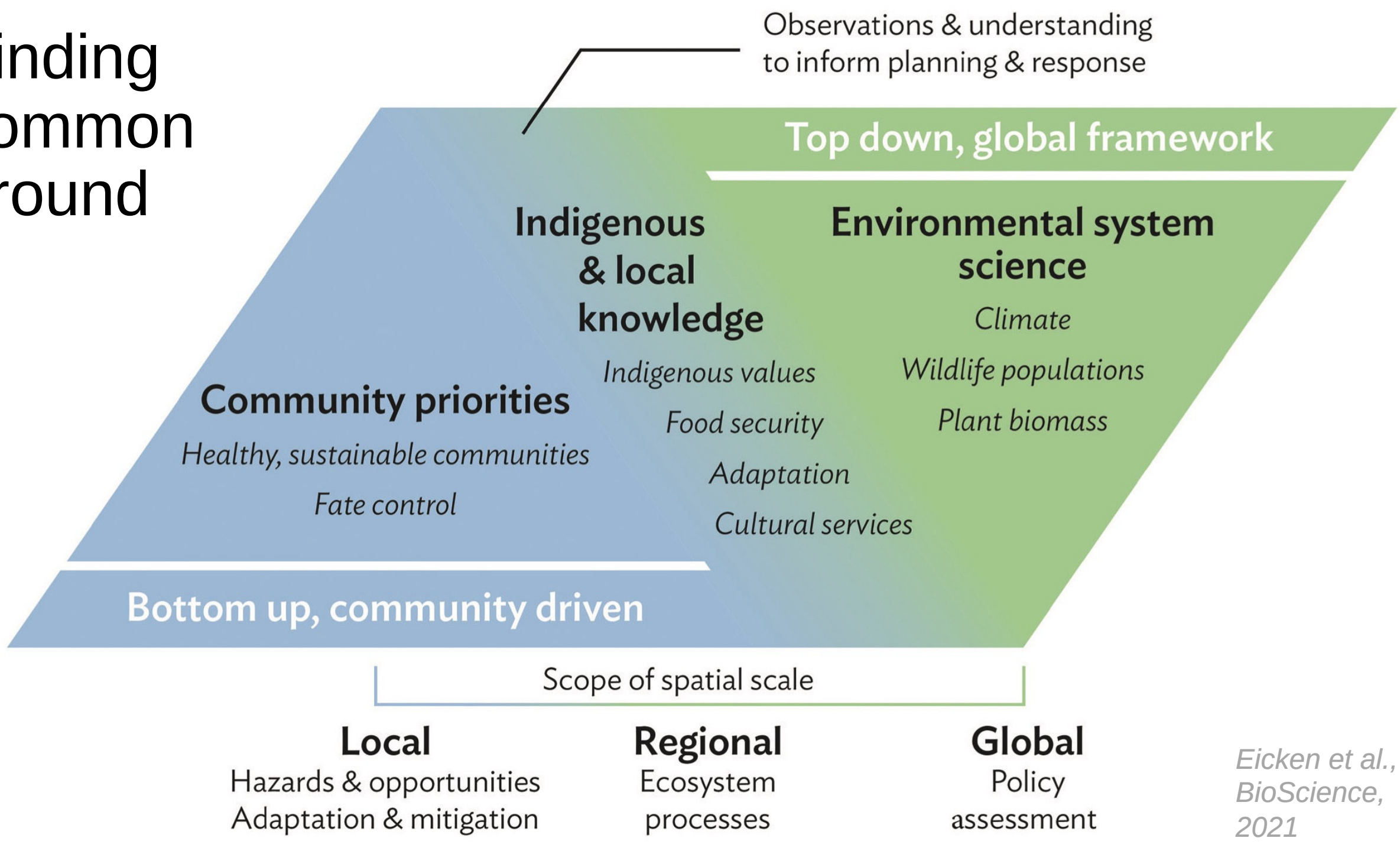
Eicken et al. (2009) Arctic

Finding common ground



Eicken et al., BioScience, 2021

SAON
SUSTAINING ARCTIC OBSERVING NETWORKS

SAON ROADS

SAON

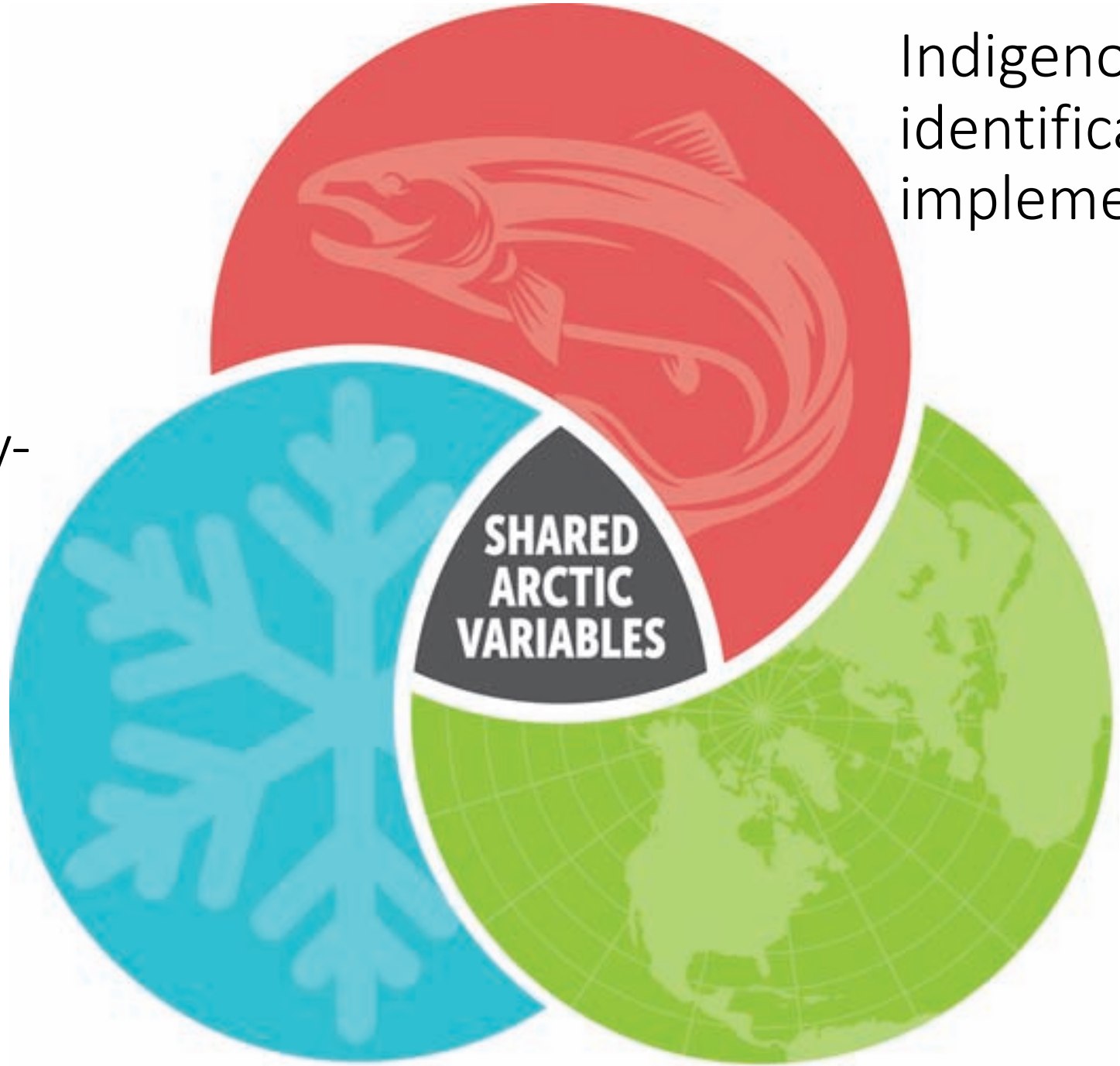
Sustaining Arctic Observing Networks joint initiative of Arctic Council & International Arctic Science Committee (IASC)

ROADS

SAON **Roadmap for Arctic Observing and Data Systems** as an effort to develop partnerships & well-defined plans for improving observing & data systems to provide societal benefits

Indigenous-led benefit identification & system implementation

Regionally-identified science & decision-making needs



Essential variables of global networks

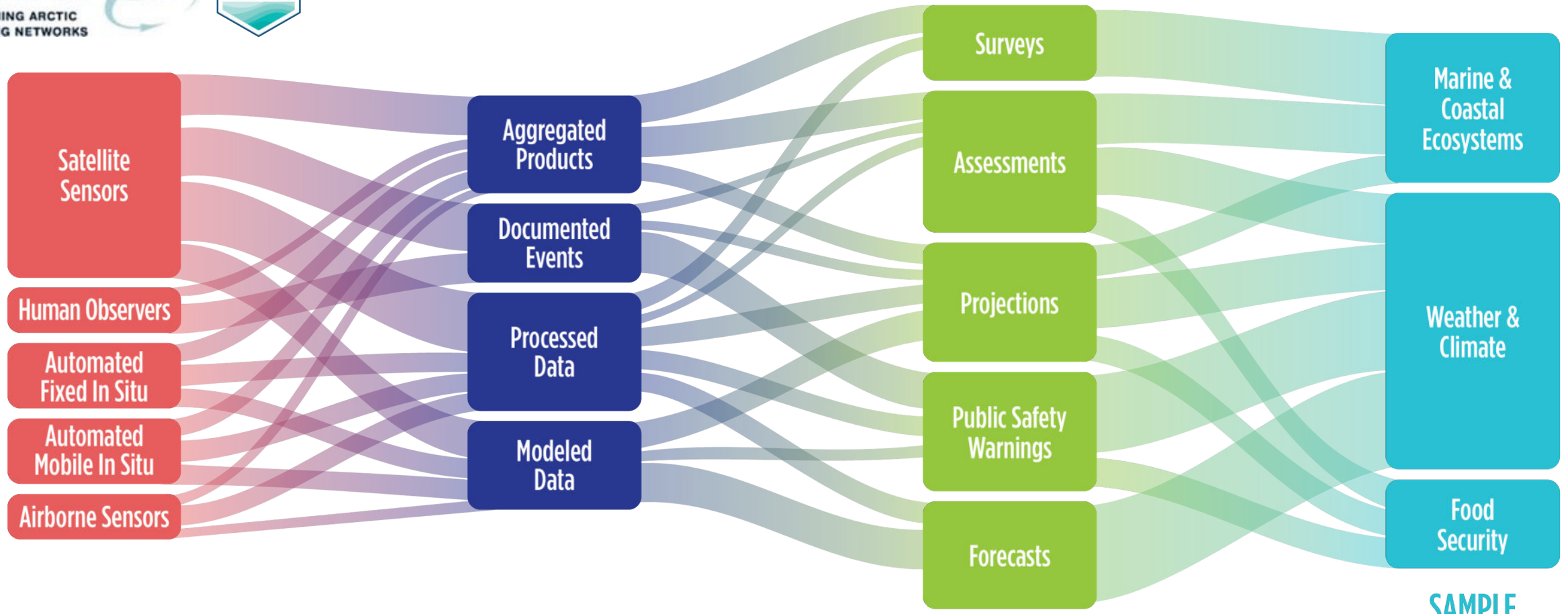
Starkweather et al., ARCTIC, 2021

US AON Value Tree Analysis & Online Benefits Tool

SAON
SUSTAINING ARCTIC OBSERVING NETWORKS

US AON

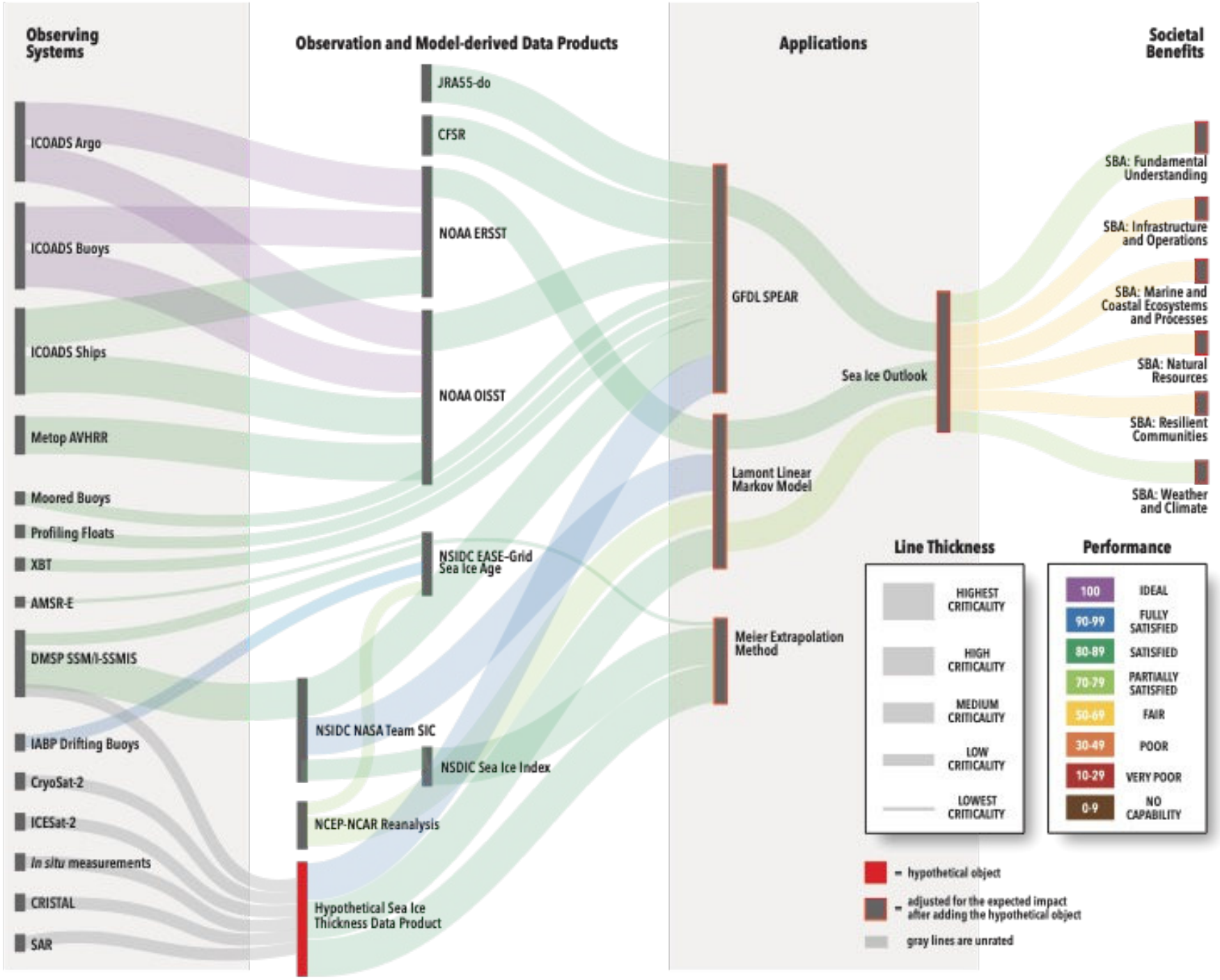
https://usaon.org/evaluation-and-planning/benefit-tool



Example: Seasonal sea-ice forecasts (Arctic Sea Ice Outlook)

- International prediction effort that connects observations to specific applications
- Value Tree Analysis (VTA) approach
- VTA also applied to Japan's Arctic research program relative to Japan Arctic policy (Harada, Shibata, Sylak-Glassman & Gallo (2019)

Hazel Shapiro, Sandy Starkweather & Arctic Sea Ice Outlook Team (2024)



Outline


Two red fox kits play in the snow outside of Toolik Field Station, Alaska.
Photo by Kim Young, (PolarTREC 2018), Courtesy of ARCUS

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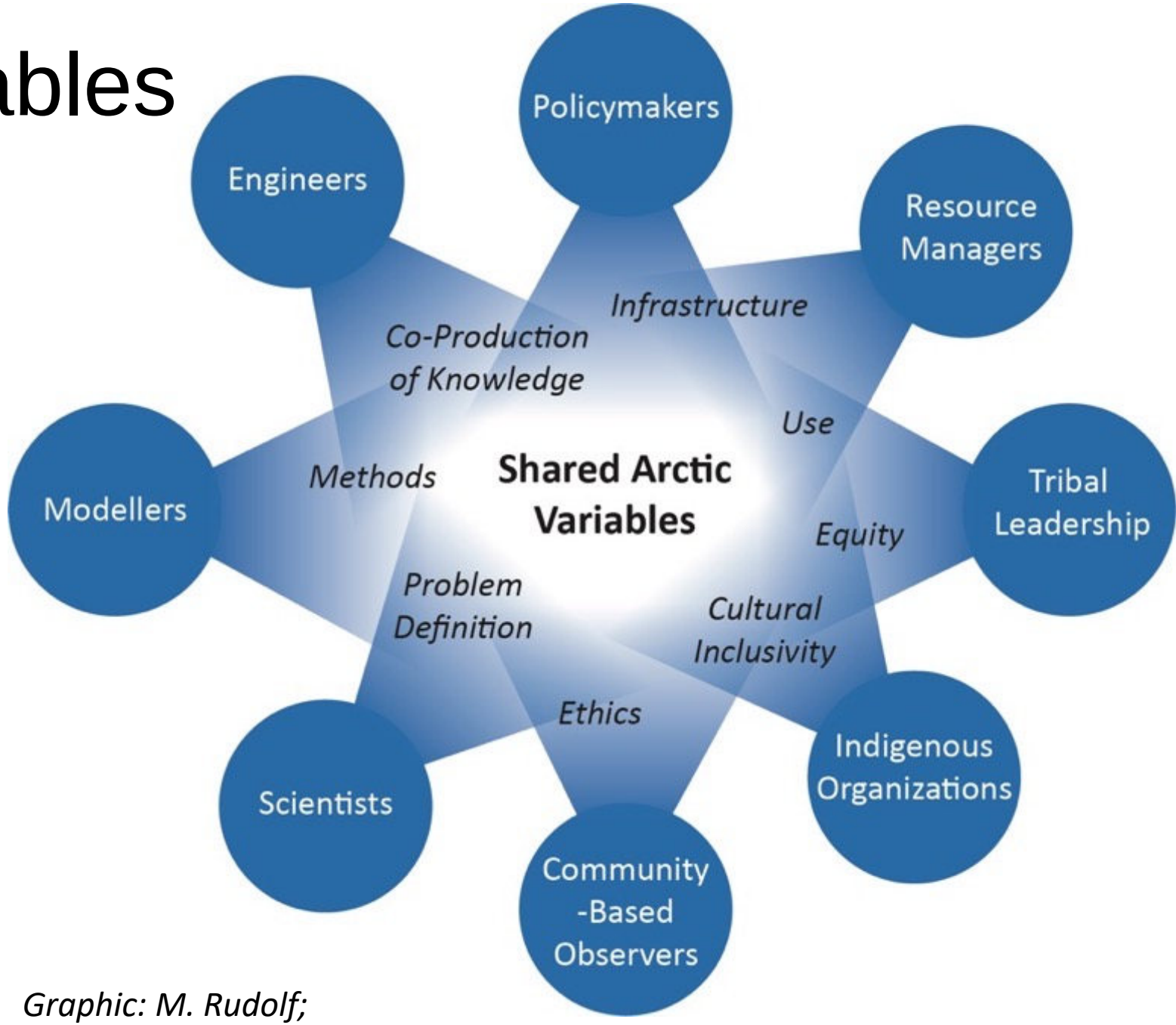
Shared Arctic Variables

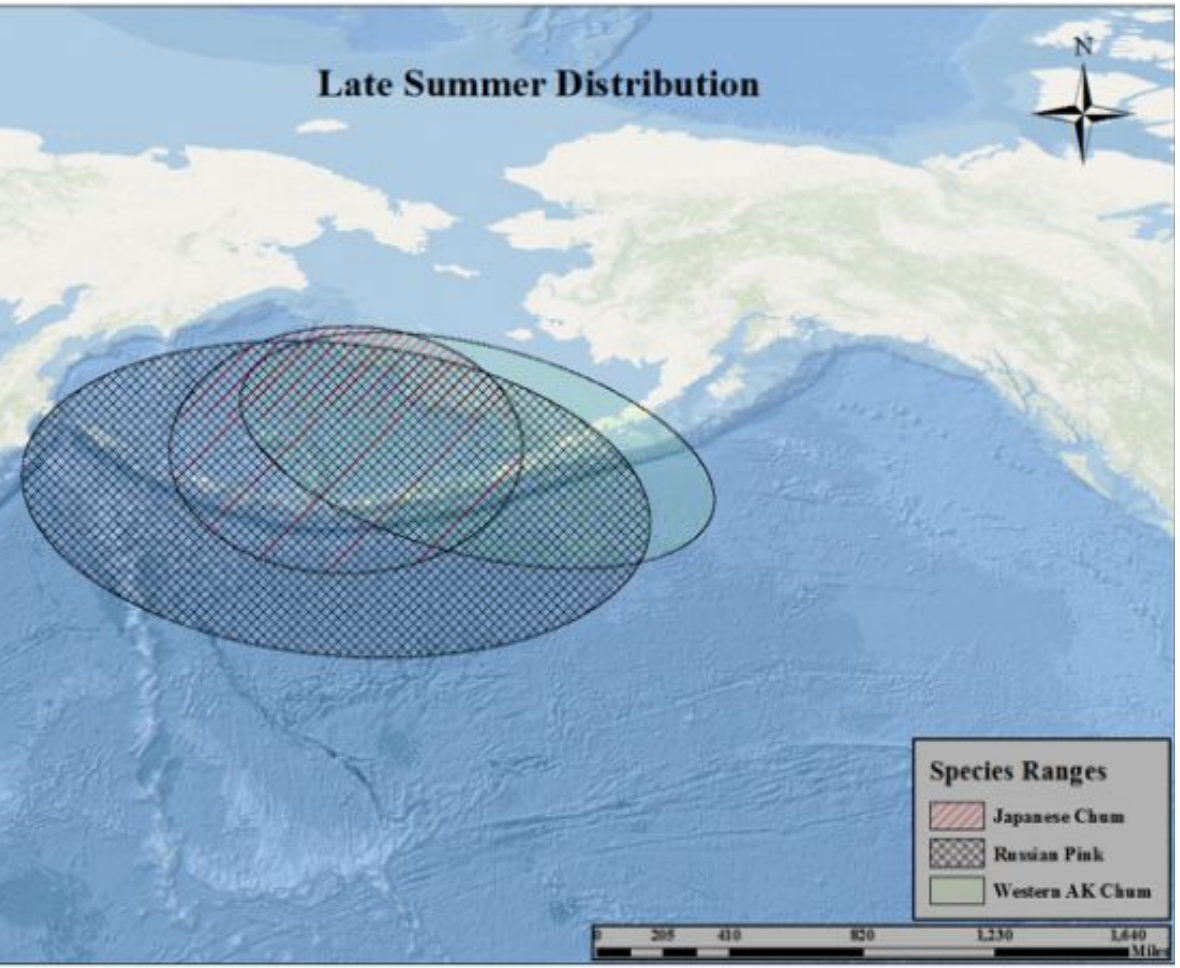
- SAVs as a starting point for discussions about improved observations & networks serving local to regional to global information needs
- Forming communities of practice around SAVs
- Moving towards co-design of networks & co-production of knowledge



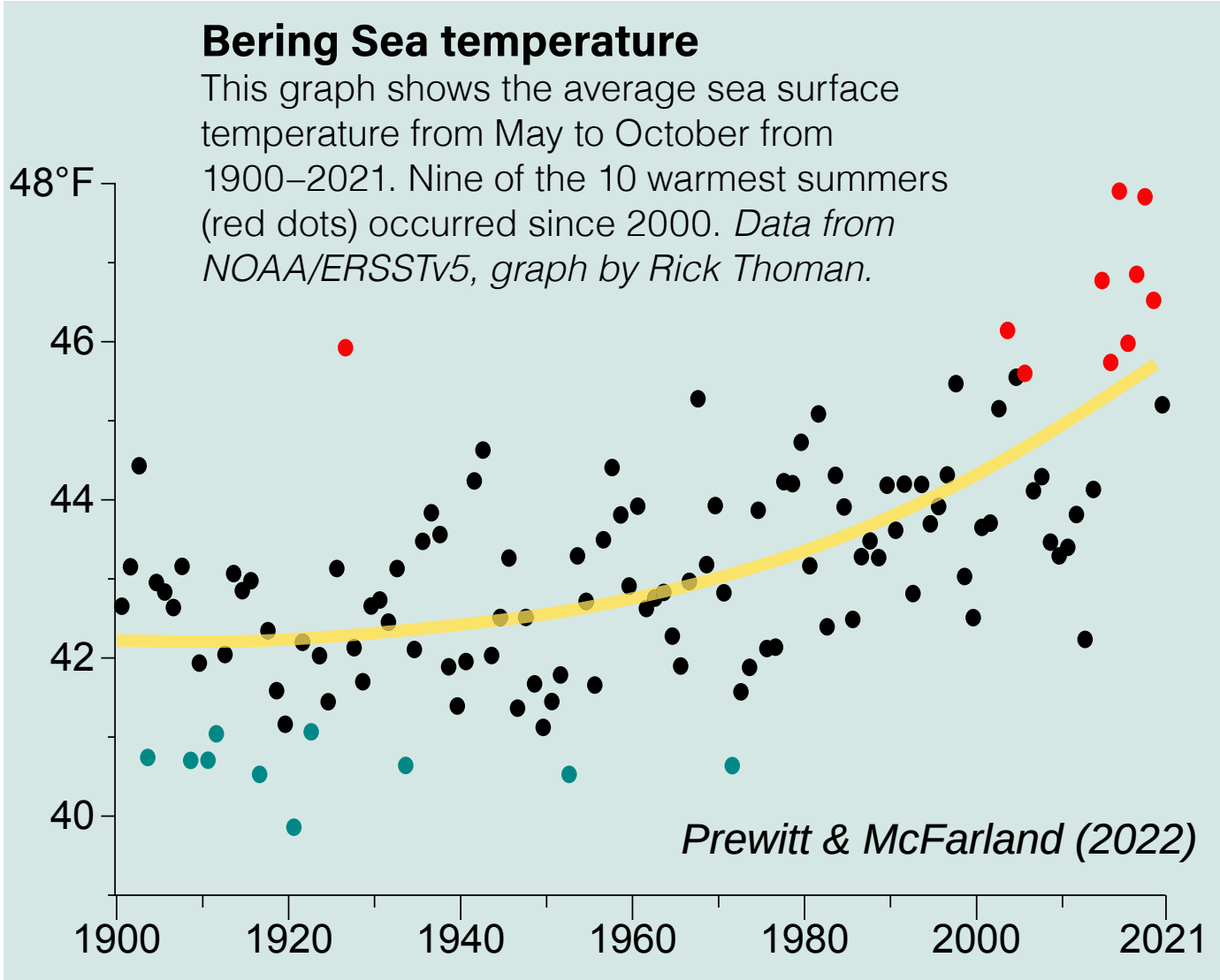
Graphic: M. Rudolf;
In: Chythlook et al., Oceanogr., 2022

Observing context: Marine ecosystems & food security

Ocean change → Food security → Regional policy & local response



McPhee & Minicucci (2018)



SAON ROADS Salmon Expert Panel Composition

1 Executive officer of commercial fishermen's coalition

1 State Biologist

2 Non-Profit conservation group

2 Fisheries Consultants

2 Federal Fisheries Staff

6 University affiliates, Sea Grant and Tamamta Fellows

14 total (including facilitators, 5 Indigenous participants)

→ *International participation to increase as focus shifts from local to regional to pan-Arctic*

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UNIVERSITY OF ALASKA FAIRBANKS | ALASKA CLIMATE ADAPTATION SCIENCE CENTER

Home What are climate projections? What data and places are shown here?

Northern Climate Reports

FOR CHANGING ARCTIC ECOSYSTEMS

northernclimatereports.org

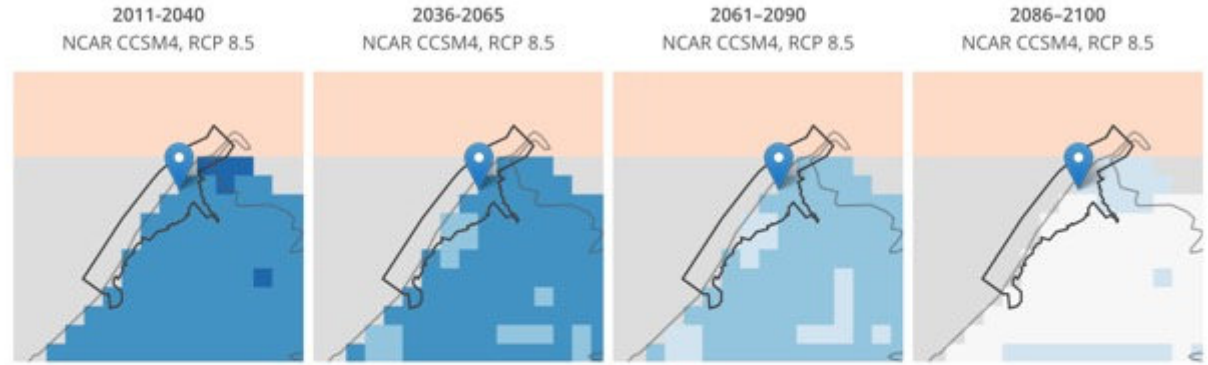
Projected Conditions for Utqiaġvik (Barrow)

In **Utqiaġvik (Barrow)**,
average annual temperatures
may increase by about **18°F** by the end of the century.

Winter temperatures are increasing the most (**+31°F**).

Models have higher uncertainty with regard to precipitation,
but **summer** is likely to have more precipitation (**+67%**).

By the late century, permafrost within about 10ft of the ground
surface may **disappear**.



This table is a legend for the maps above.

Category	Mean Annual Ground Temperature
Continuous Permafrost	<21°F
Cold Discontinuous	≥21°F, <25°F
Discontinuous	≥25°F, <28°F
Cold Sporadic	≥28°F, <30°F
Sporadic	≥30°F, <32°F
Permafrost Possible	≥32°F, <34°F
Permafrost Unlikely	≥34°F, <36°F
No Permafrost	≥36°F

Projected permafrost active layer thickness and ground freeze depth through the end of the century are shown below. The active layer is the layer of soil above permafrost that thaws seasonally. Ground freeze is the maximum depth to which winter freeze occurs in non-permafrost areas.

Outline

1. Grand challenges: Disruptive climate change
   → Permafrost degradation
   → Sea ice loss
   → Ecosystem restructuring
2. What to do:
   →Identify benefits (local-regional-global scale)
   → Collaborate effectively
   → Provide decision support
3. **Conclusions**

Math and Climate, Sea Ice, Polar Ecosystems

1. Tipping elements & tipping points
2. Complex system dynamics
3. Earth system modeling
4. Science communication

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