Sea Ice (and Snow) Influences on Climate

Paul Kushner

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Sabbatical activities:

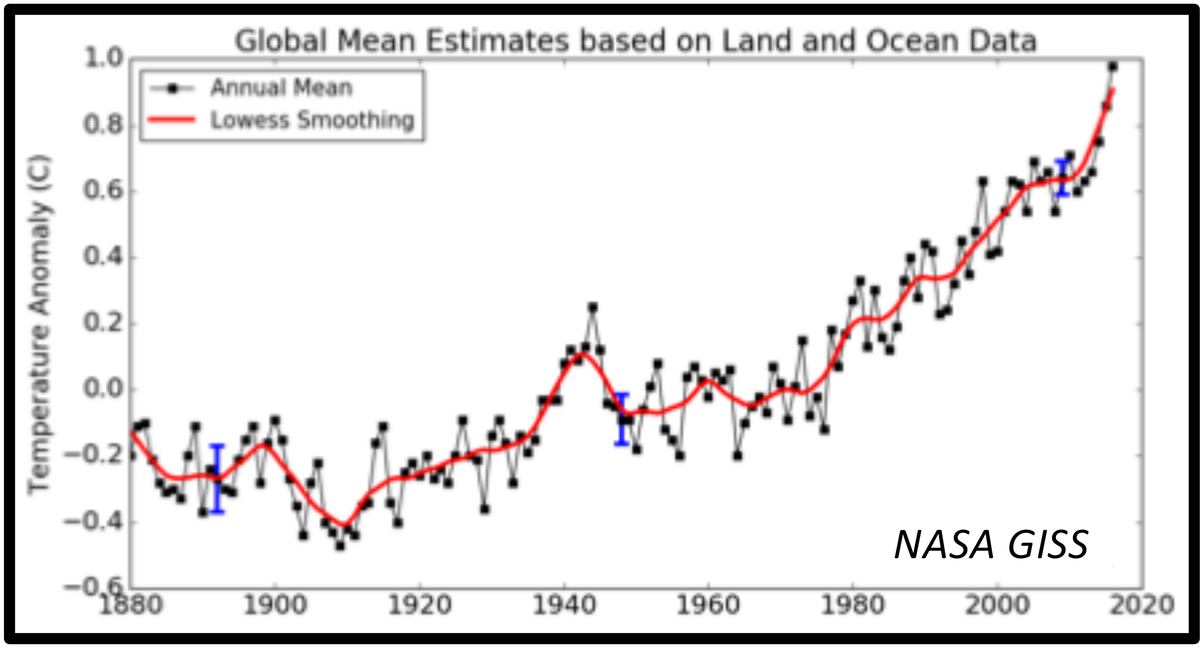
Invited participant for BL18 @ KITP/UCSB,

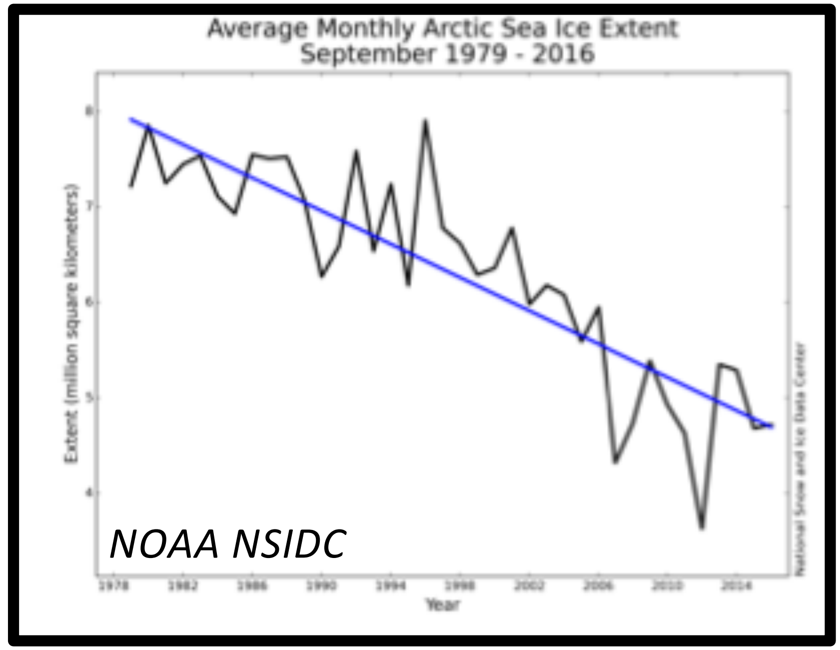
Visiting Scientist @ Paul G. Allen Philanthropies (Vulcan), Seattle WA

Collaborators: Russell Blackport (Exeter), Stephanie Hay (Toronto), Kelly McCusker (Rhodium), Fred Laliberté (Squarepoint), many others

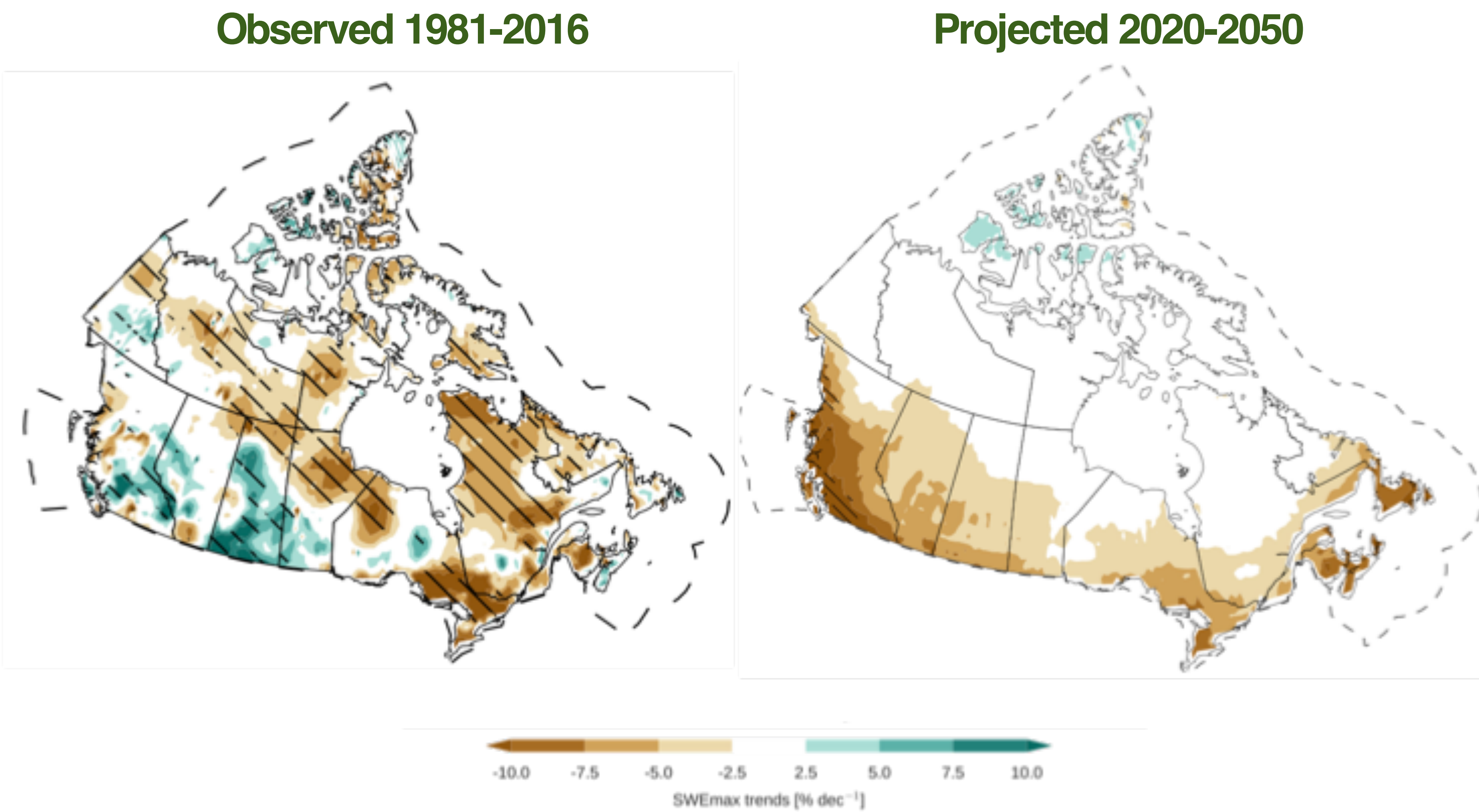
- **Emergent constraints on sea ice and snow sensitivity**
- **Circulation response to sea ice loss in coupled models**
- **Outstanding problems of coupling surface/BL to large-scale climate**
- **Lots of extra slides on CanSISE etc..**

Sea Ice Loss: Icon and Amplifier of Global Warming



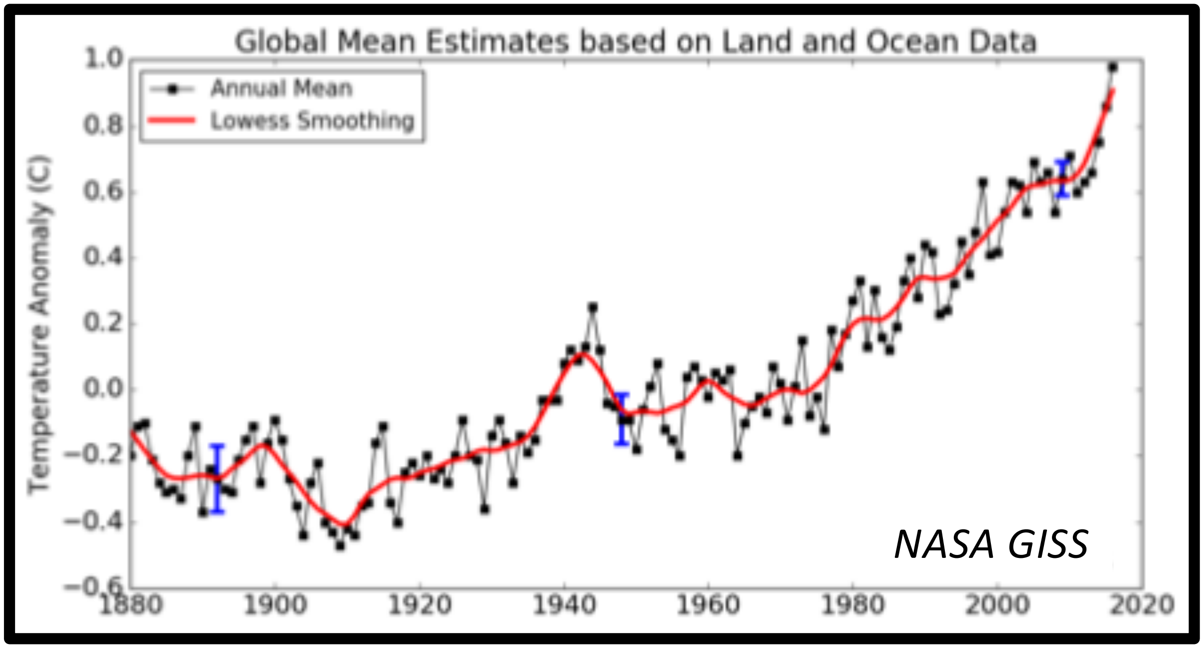


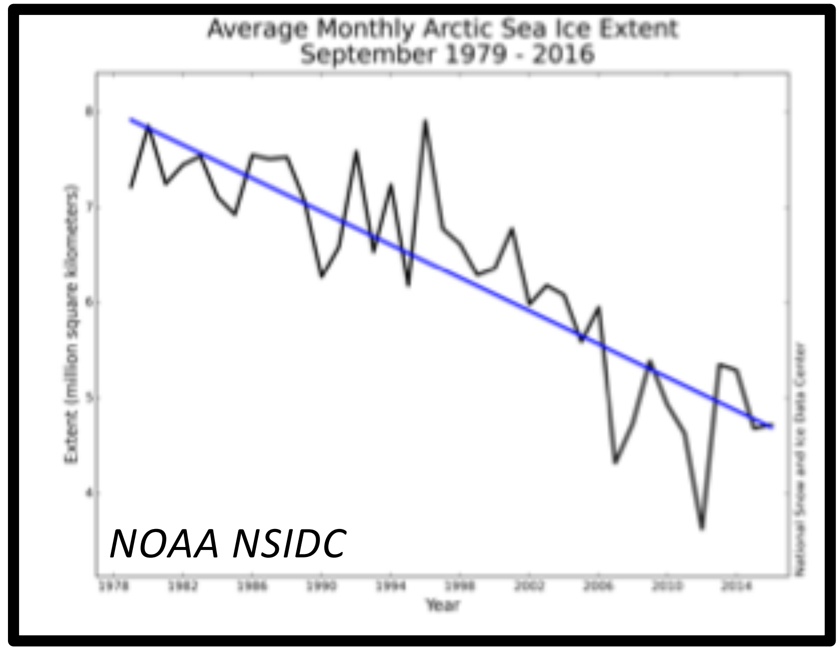
Recent and projected changes in maximum snow amounts - Canada

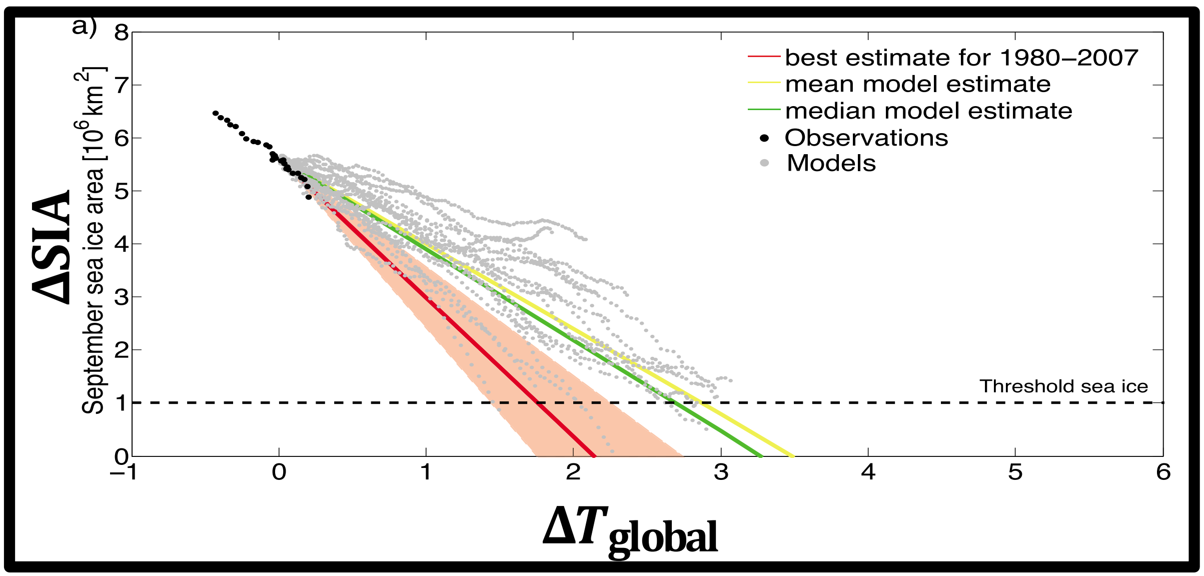


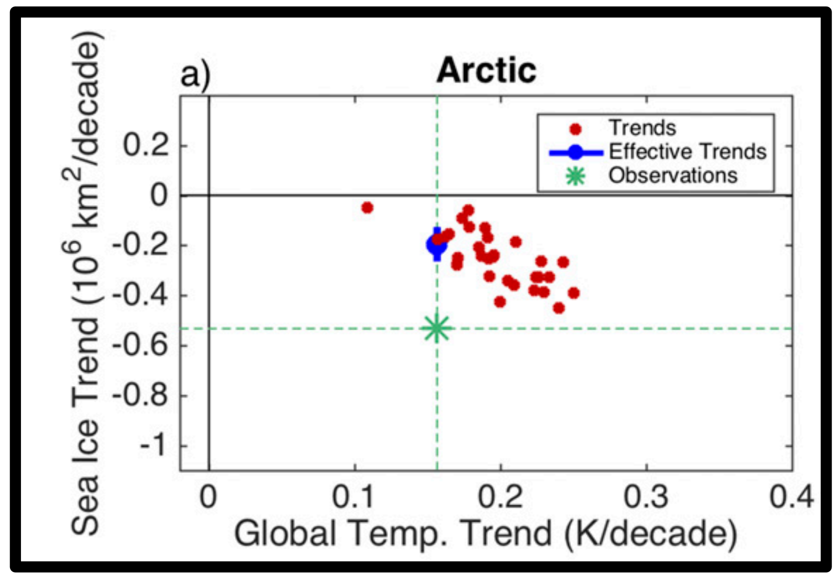
Mudryk et al. 2018, Slide from F. Laliberté

‘Emergent constraints’ for sea ice



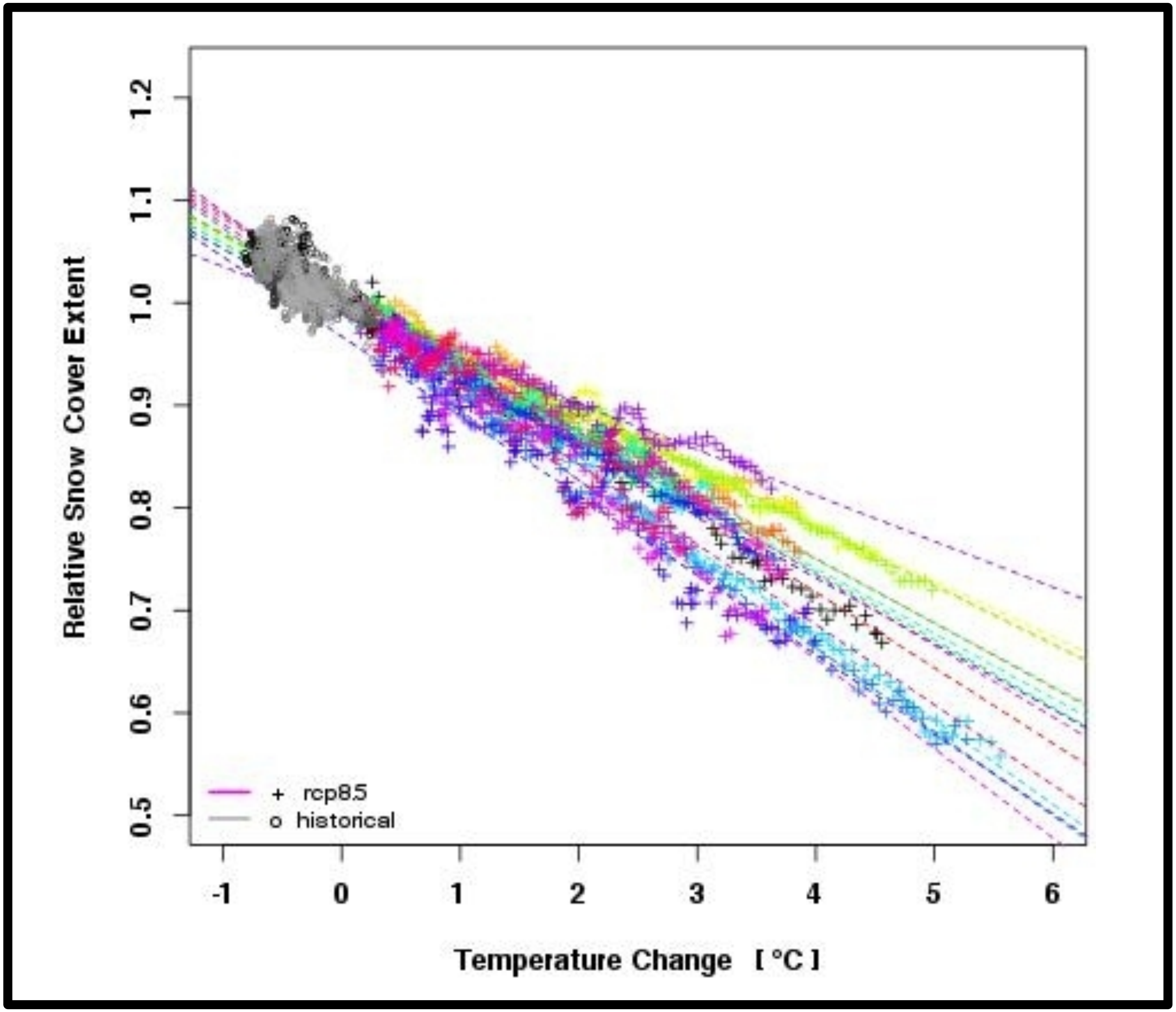






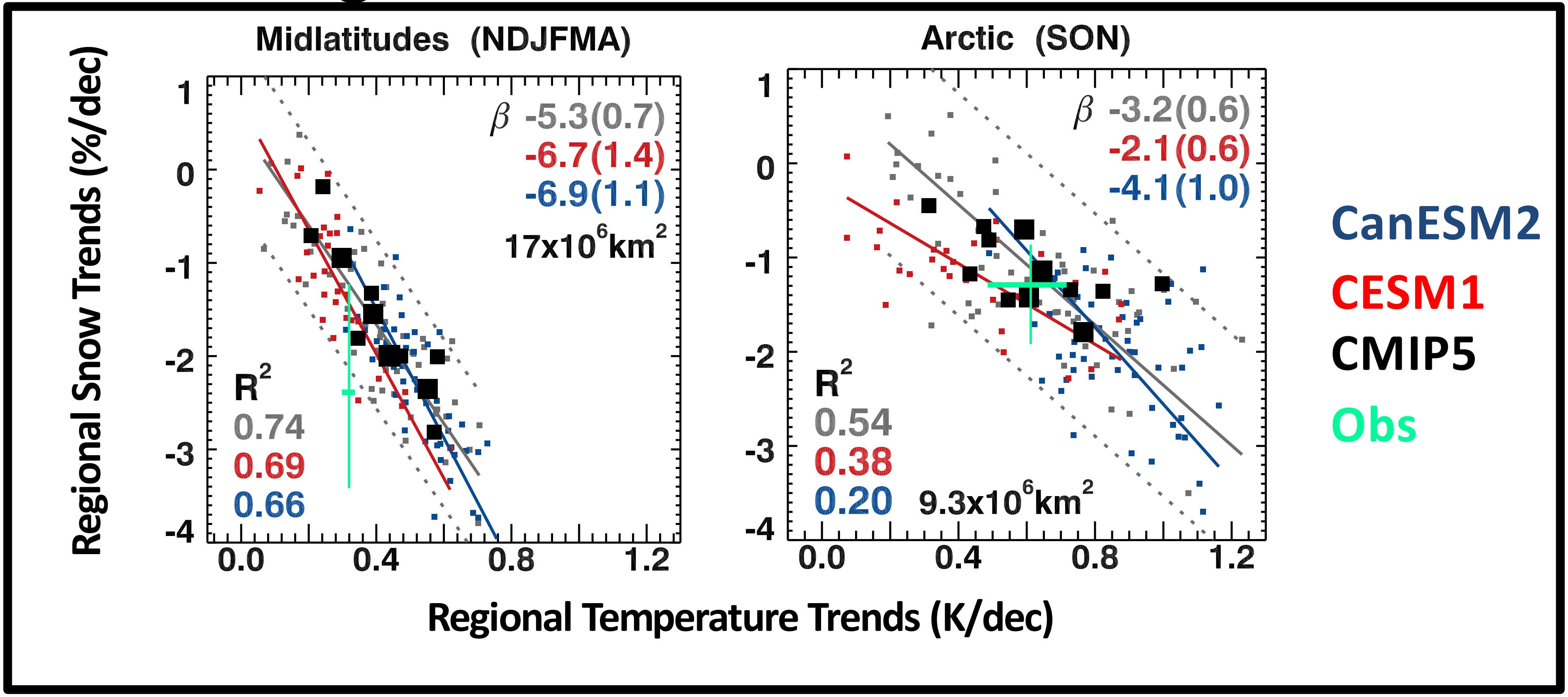
Mahlstein & Knutti 2012, Rosenblum and Eisenman 2017

Emergent constraints for snow cover



Brutel-Vuilmet et al. 2013

Emergent constraints for snow cover



- Models underestimate midlatitude sensitivity, seem to capture Arctic sensitivity.

Mudryk et al. 2017

The Issue at Hand

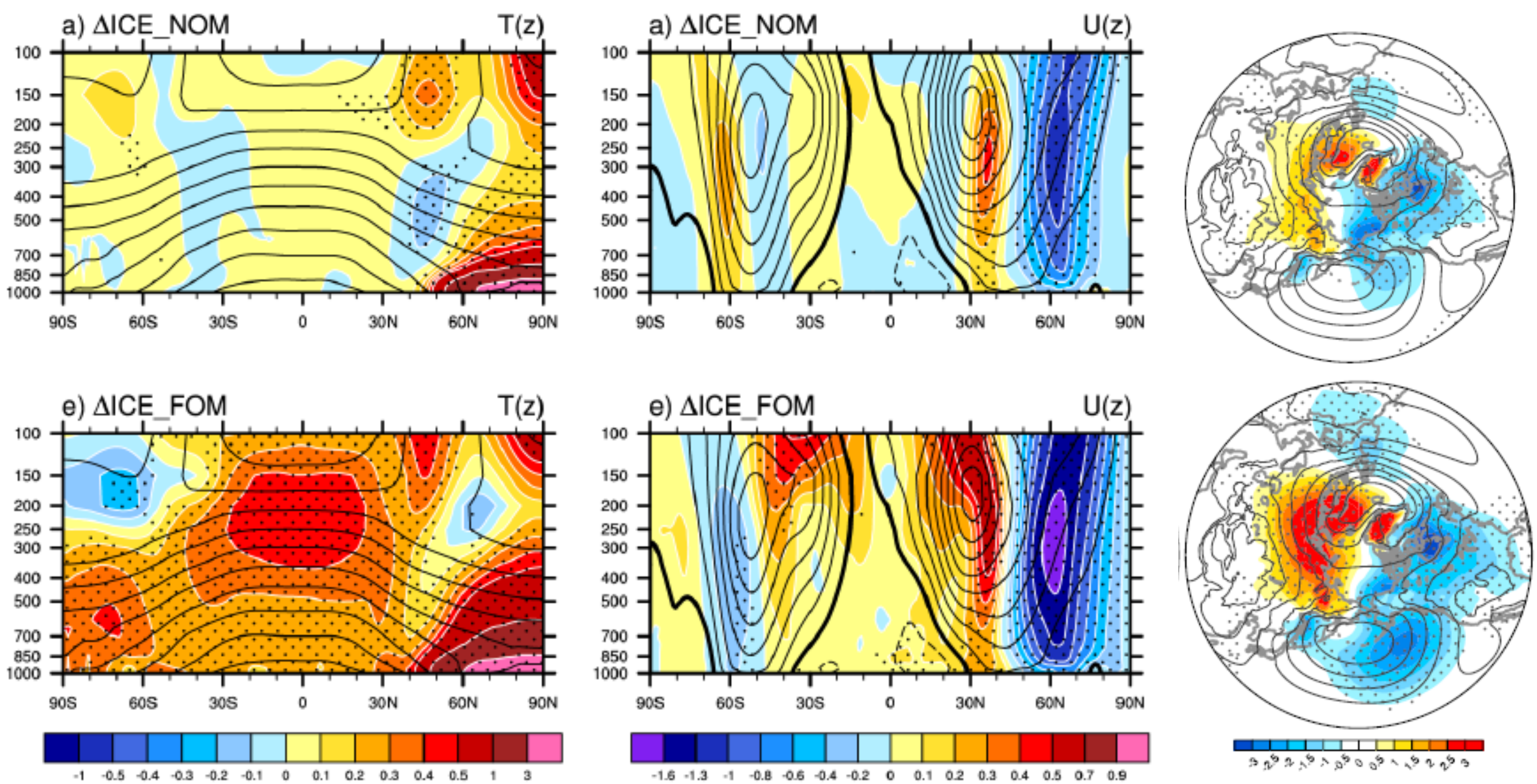
- The thermal sensitivity of snow and sea ice is reasonably well characterized, and models capture aspects of it.
- What about the sensitivity of other quantities, e.g. atmospheric circulation to these cryospheric fluctuations?
- This is arguably a critical question for climate prediction.
- But it’s a somewhat artificial question, since snow and sea ice are described quantitatively by internal state variables. Their coupling to the system is intrinsic.

The Global Reach of Arctic Sea Ice Loss

Zonal mean T | **Zonal mean U** | **SLP**

Prescribed SST and sea ice, imposed sea ice loss.

Dynamical ocean and sea ice, induced sea ice loss



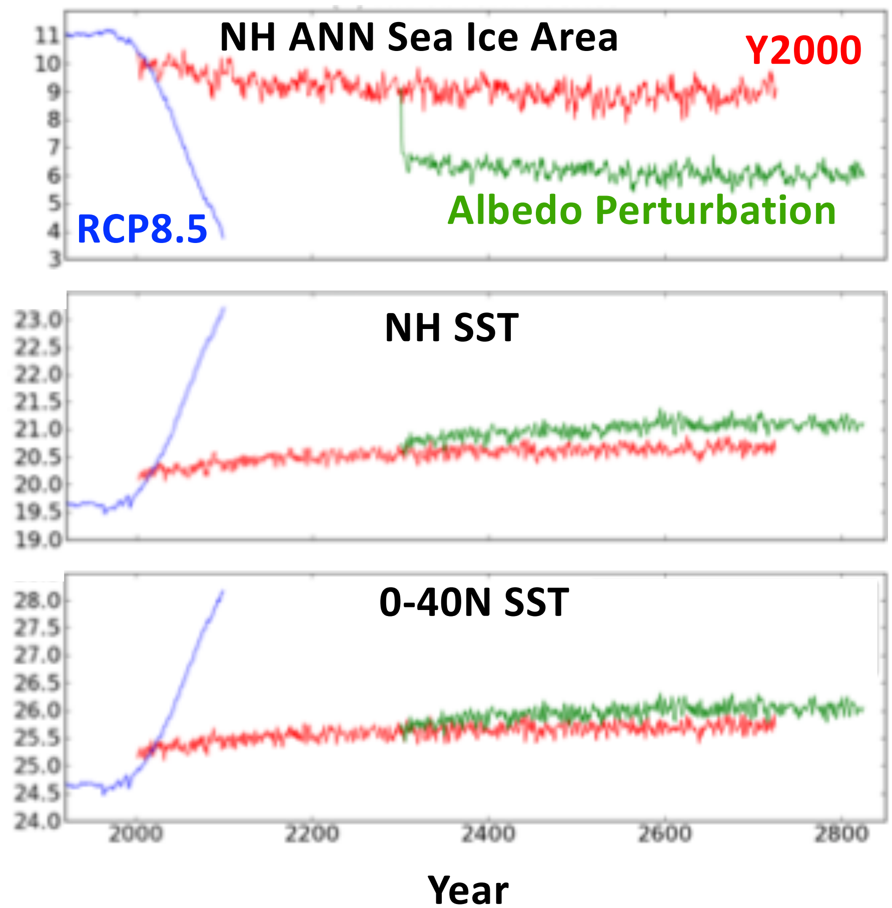
Deser et al. 2015

Sea ice loss with ocean-atmosphere coupling drives a ‘mini global warming’.

Coupling increases the amplitude and extent of the response to Arctic sea-ice loss.

Climate Change Projections and Coupled Sea Ice Loss Simulations

RCP8.5 Forced Experiment (CESM1)	Sea ice albedo forced experiment (CESM1)
• Large Ensemble 1920-2100 (30 members)	• Year 2000 Control (725 y) • Reduced sea ice albedo (525 y)
• A lot of sea ice loss year round.	• A lot of sea ice loss, more sea ice loss in summer.
• More low latitude warming.	• Less low latitude warming



Blackport and Kushner 2017

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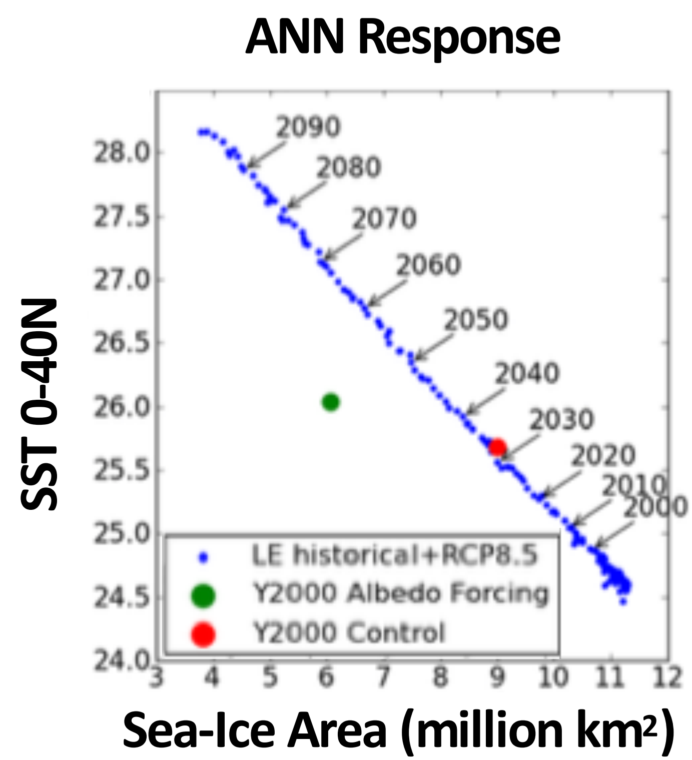

Blackport and Kushner 2017

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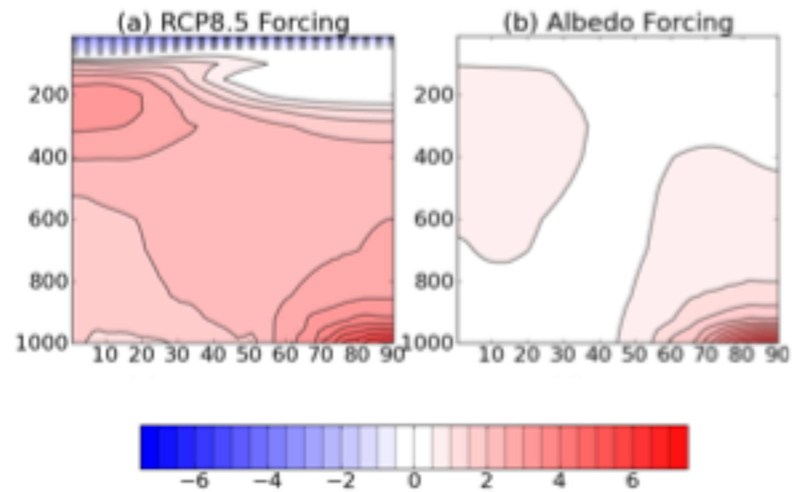
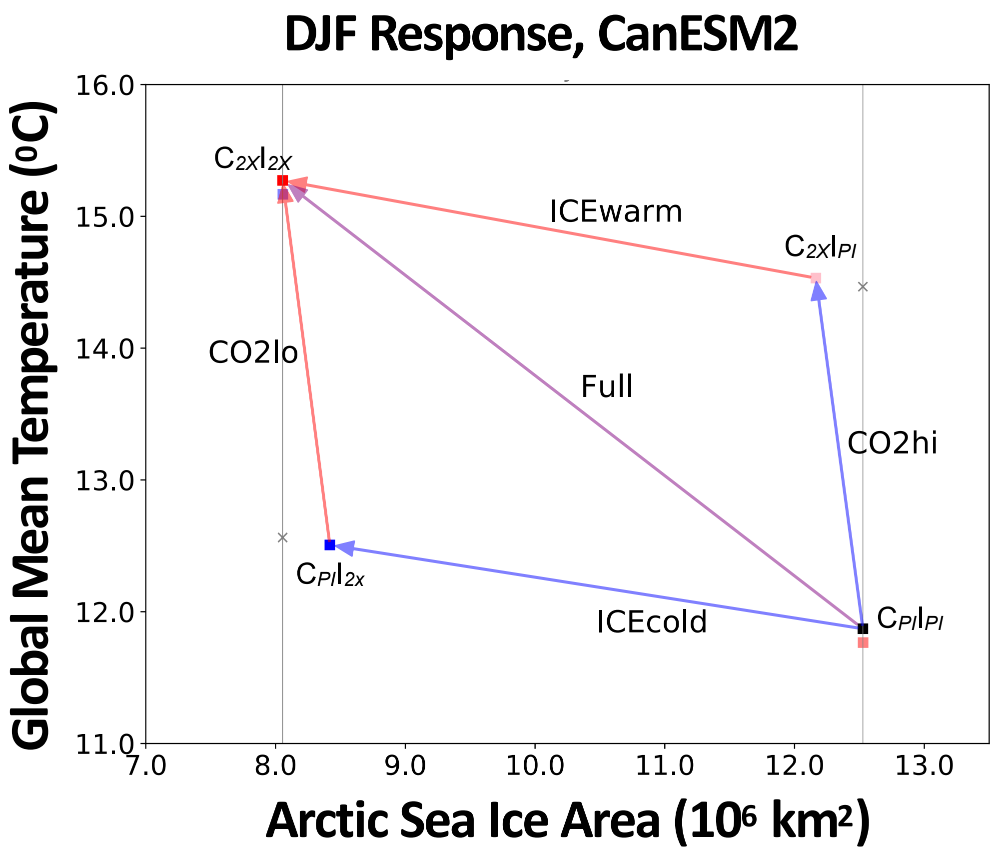
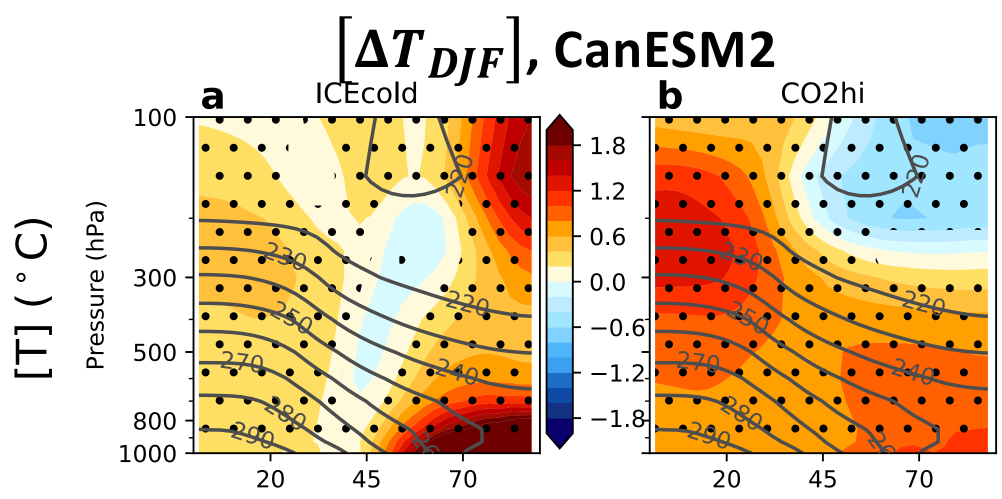
Zonal Mean and Annual Mean Temperature Response



Blackport and Kushner 2017

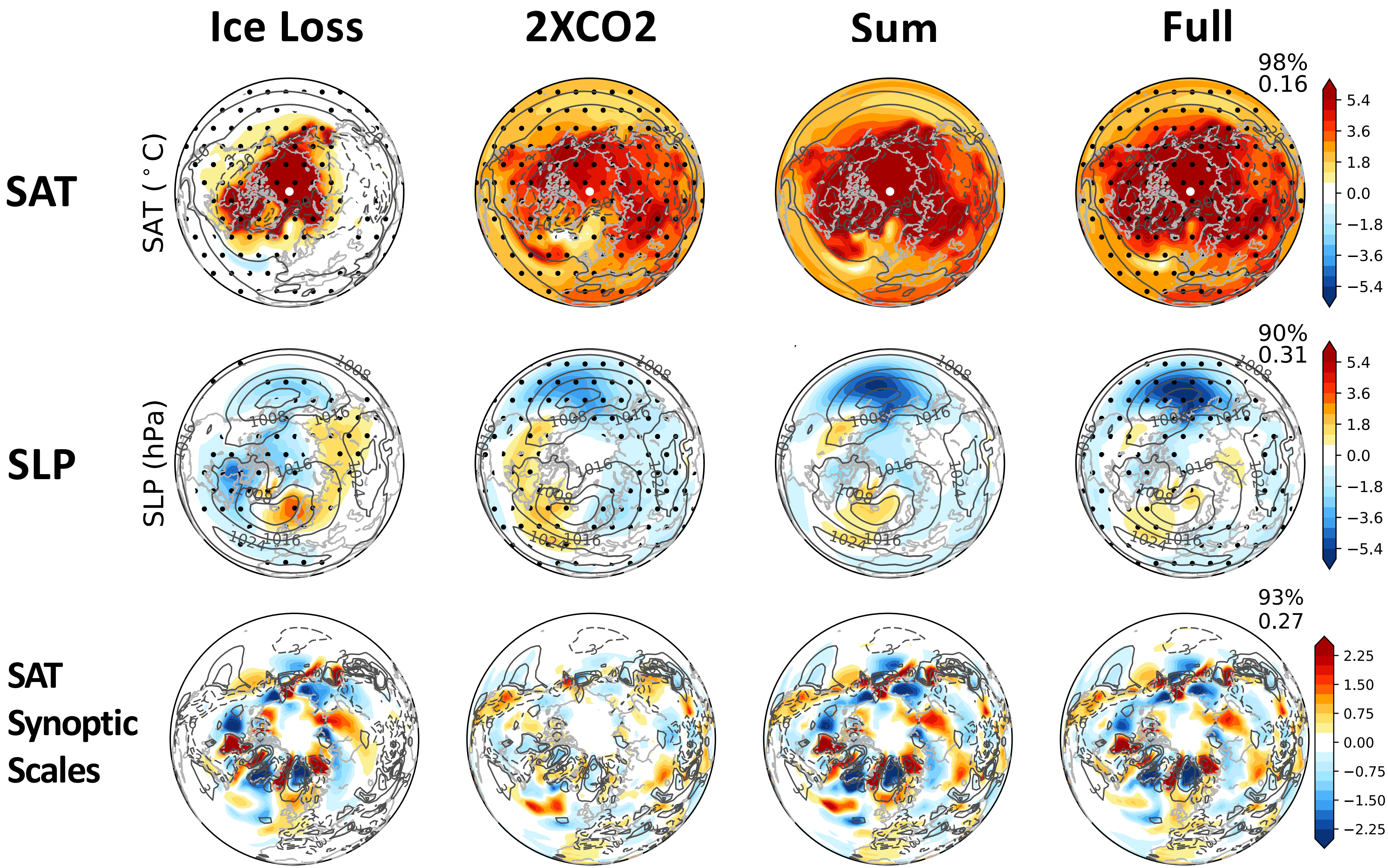
Paired Sea Ice and CO2 Perturbation Experiments





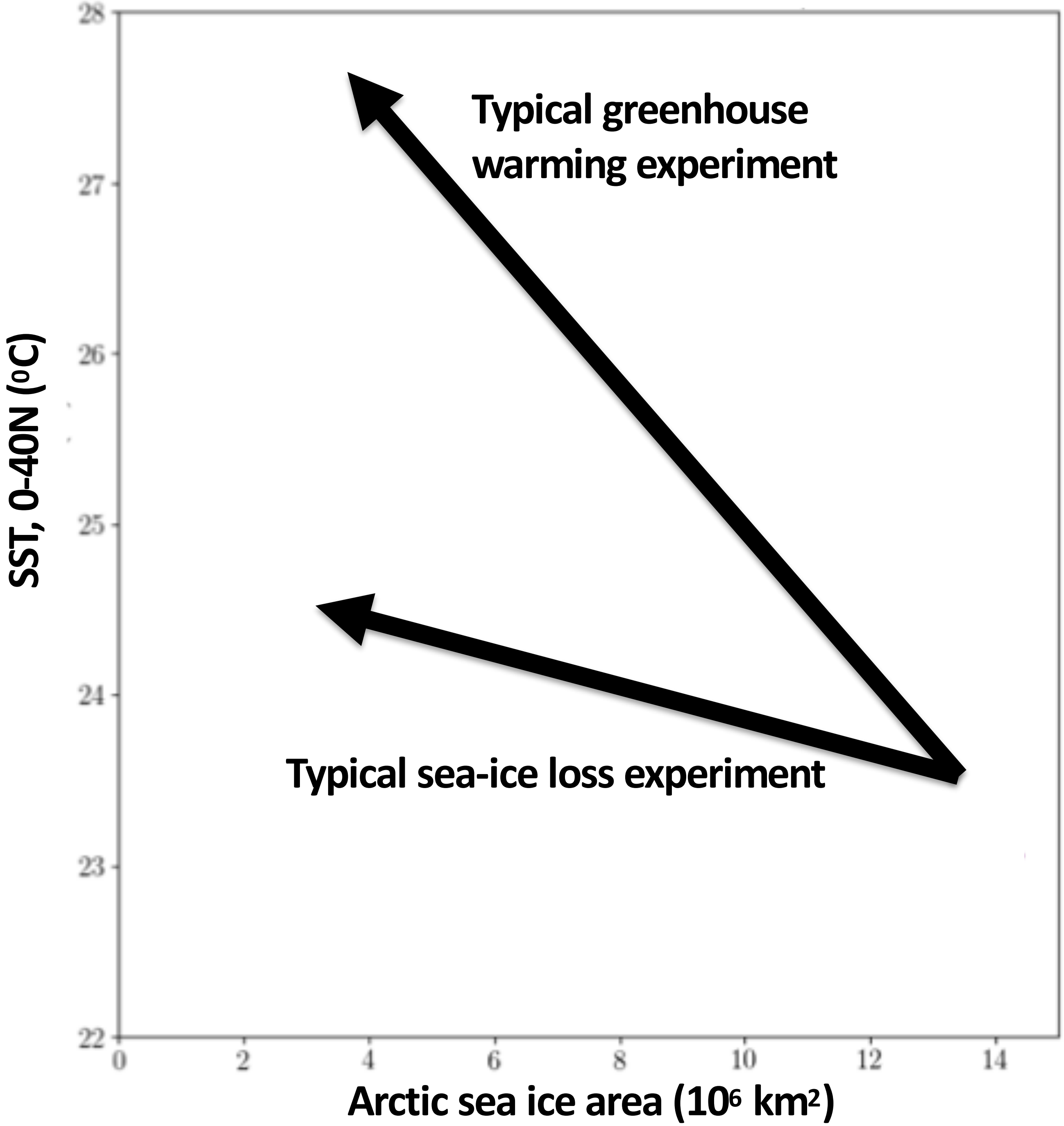
McCusker et al. 2017, (Building on Oudar et al. 2017)

Aside: Sea Ice Loss and CO2 Responses Are Additive



McCusker et al. 2017

Arctic and Tropical Change Are Entangled



Interpreting the response to sea ice loss is complicated by the tropical feedback effect.

(Because both tropics and high latitudes could influence low latitudes.)

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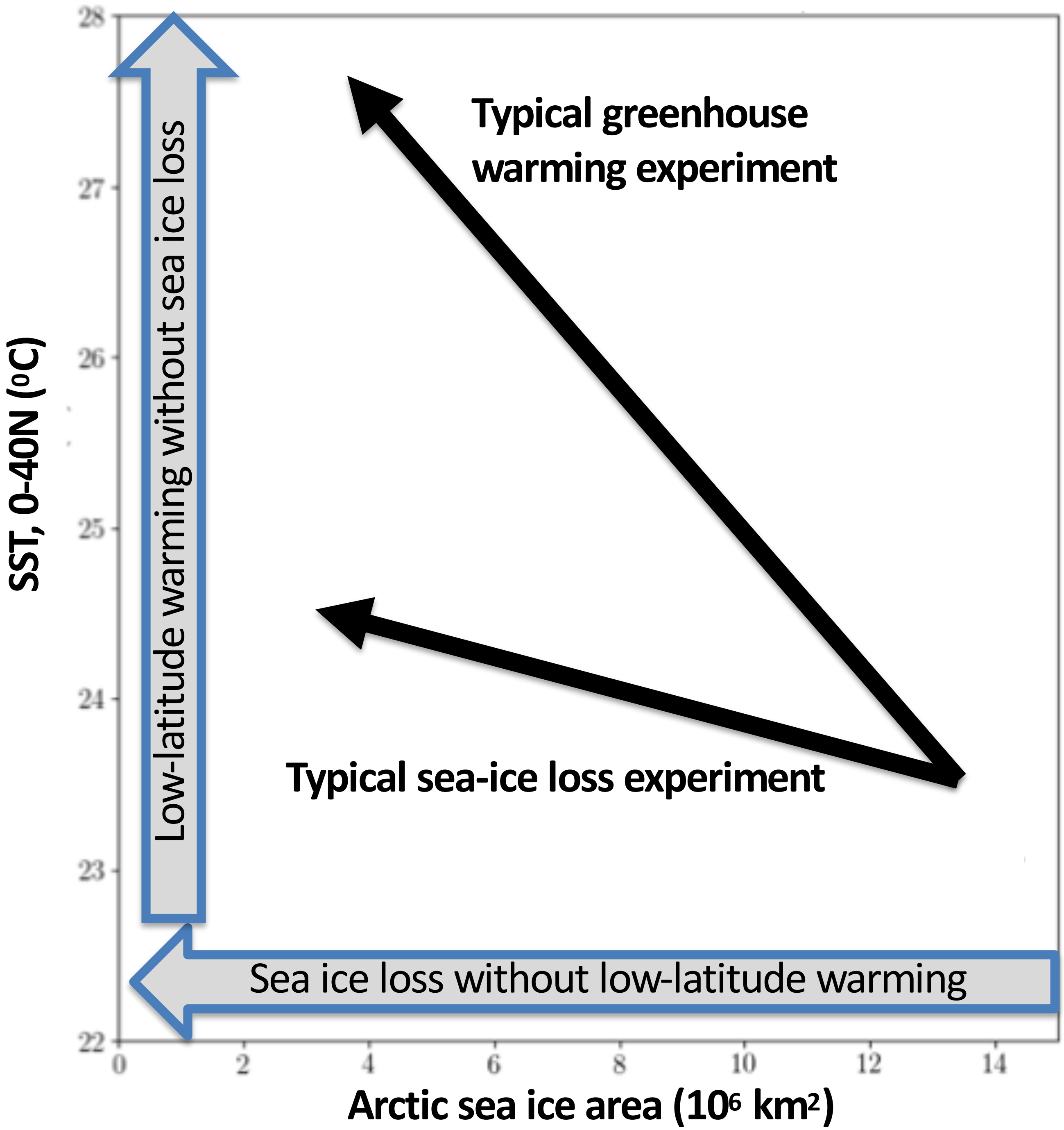
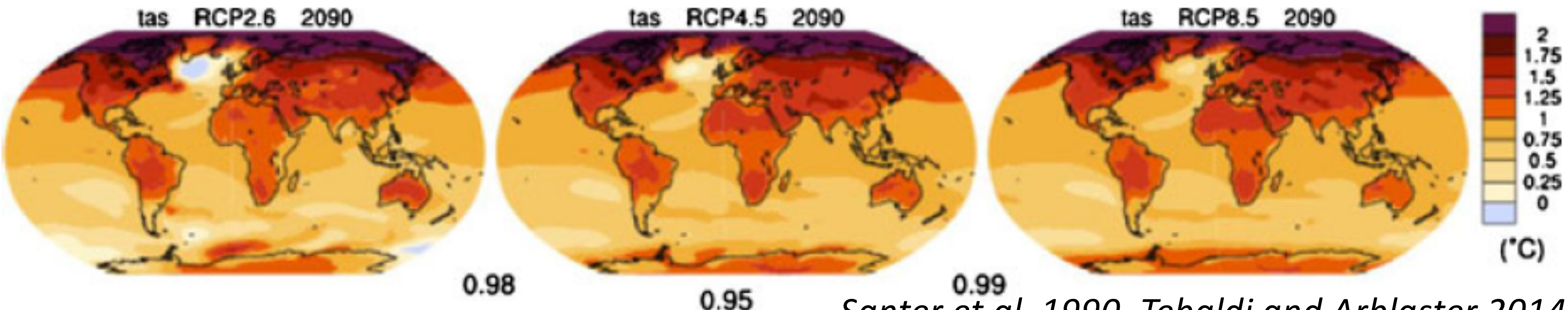


To disentangle these effects, we have developed a two-parameter pattern scaling technique (Blackport and Kushner 2017; Hay et al. in press and in prep.)

What Is Pattern Scaling?

Classical pattern scaling: climate response is approximately a fixed pattern multiplied by change in global mean surface temperature.

ANN Surface Temperature Response Per Degree GMT Change, CMIP5



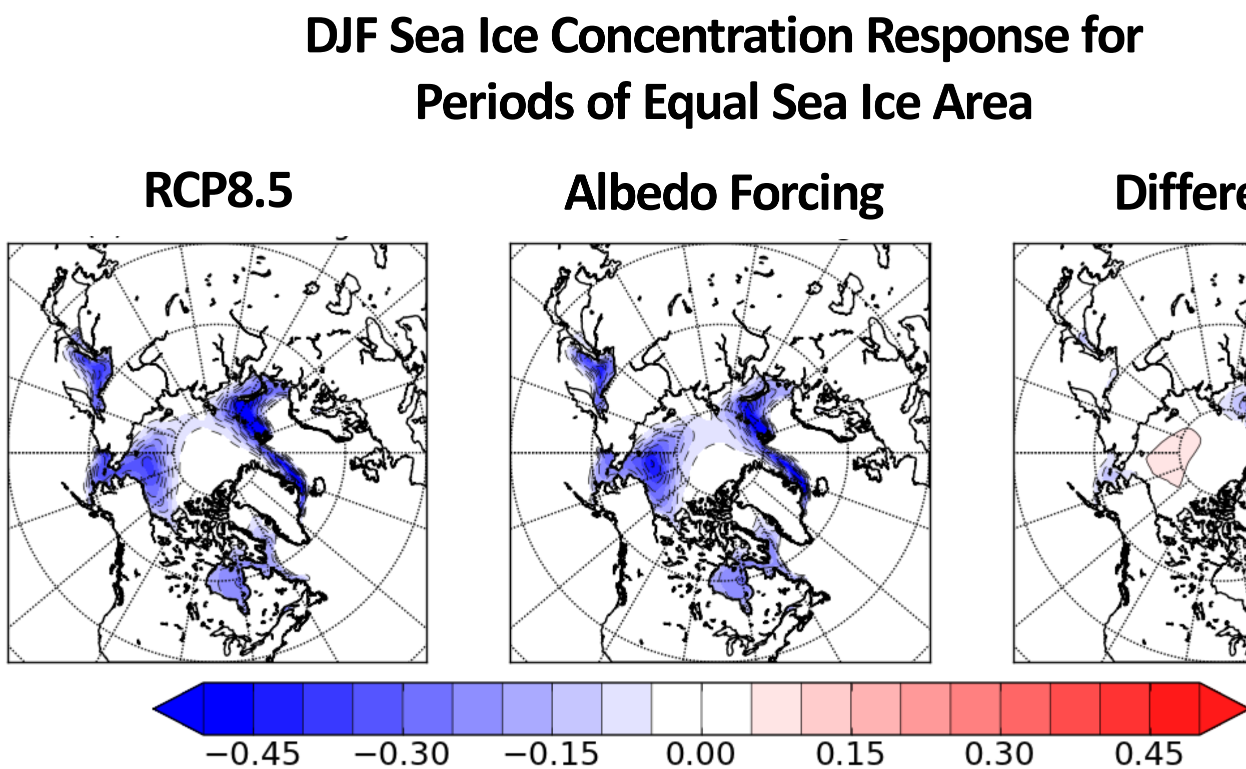
Santer et al. 1990, Tebaldi and Arblaster 2014

For field of interest $Z = Z(T)$, response to perturbation in temperature T is, schematically:

$$\delta Z = Z(T + \delta T) - Z(T) \approx \frac{dZ}{dT}\delta T$$

Response pattern dZ/dT is independent of forcing details.

How Can We Extend Pattern Scaling?



Blackport and Kushner 2017

The pattern of sea ice loss is similar for realistic anthropogenic forcing or 'fake' sea ice changes. Sea ice area is also a good scaling parameter, like temperature.

Let's explore the assumption that responses scale **separately** with 1) low latitude temperature and 2) sea ice area.

Two-parameter pattern scaling

- How does any field *Z* respond separately to variations in sea ice area (*I)* and low-latitude temperature (*T*)?

$$Z = Z(T, I)$$

$$\delta Z = Z(T + \delta T, I + \delta I) - Z(T, I)$$

RCP8.5 forcing

$$\delta Z_R \cong \left.\frac{\partial Z}{\partial T}\right|_I \delta T_R + \left.\frac{\partial Z}{\partial I}\right|_T \delta I_R$$

Albedo forcing

$$\delta Z_A \cong \left.\frac{\partial Z}{\partial T}\right|_I \delta T_A + \left.\frac{\partial Z}{\partial I}\right|_T \delta I_A$$

$$\begin{pmatrix} \left.\frac{\partial Z}{\partial T}\right|_I \\ \left.\frac{\partial Z}{\partial I}\right|_T \end{pmatrix} = \begin{pmatrix} \delta T_R & \delta I_R \\ \delta T_A & \delta I_A \end{pmatrix}^{-1} \begin{pmatrix} \delta Z_R \\ \delta Z_A \end{pmatrix}$$

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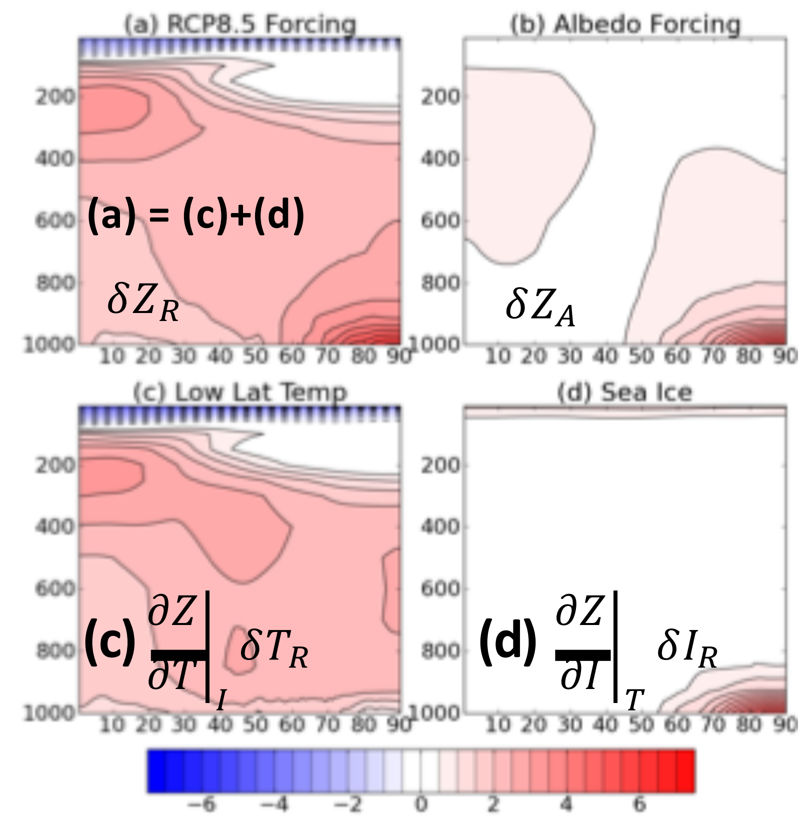
Zonal Mean ANN Temperature Response



Blackport and Kushner 2017

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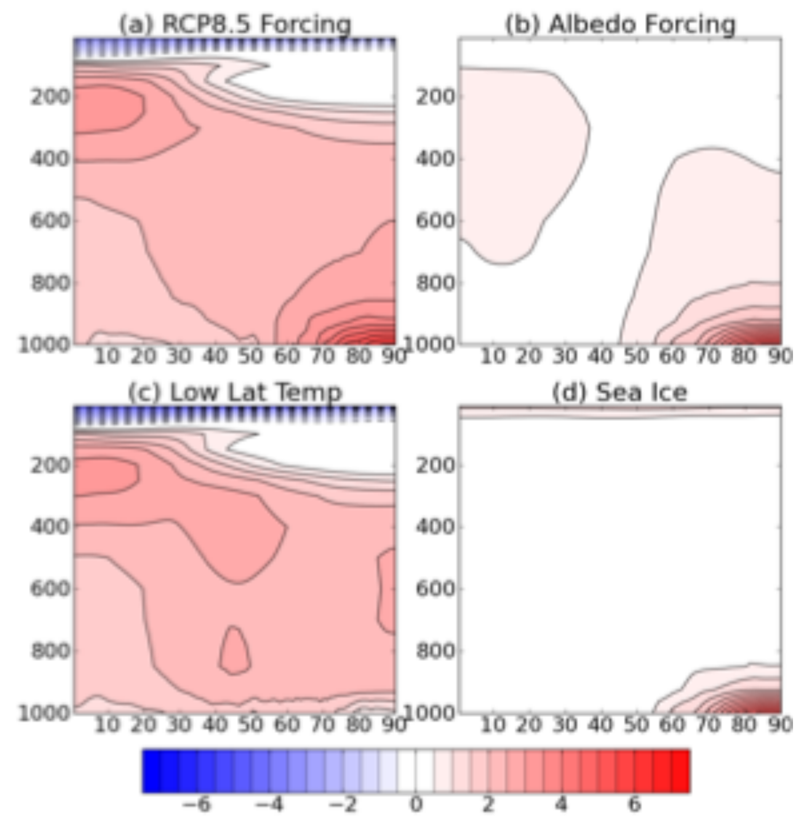
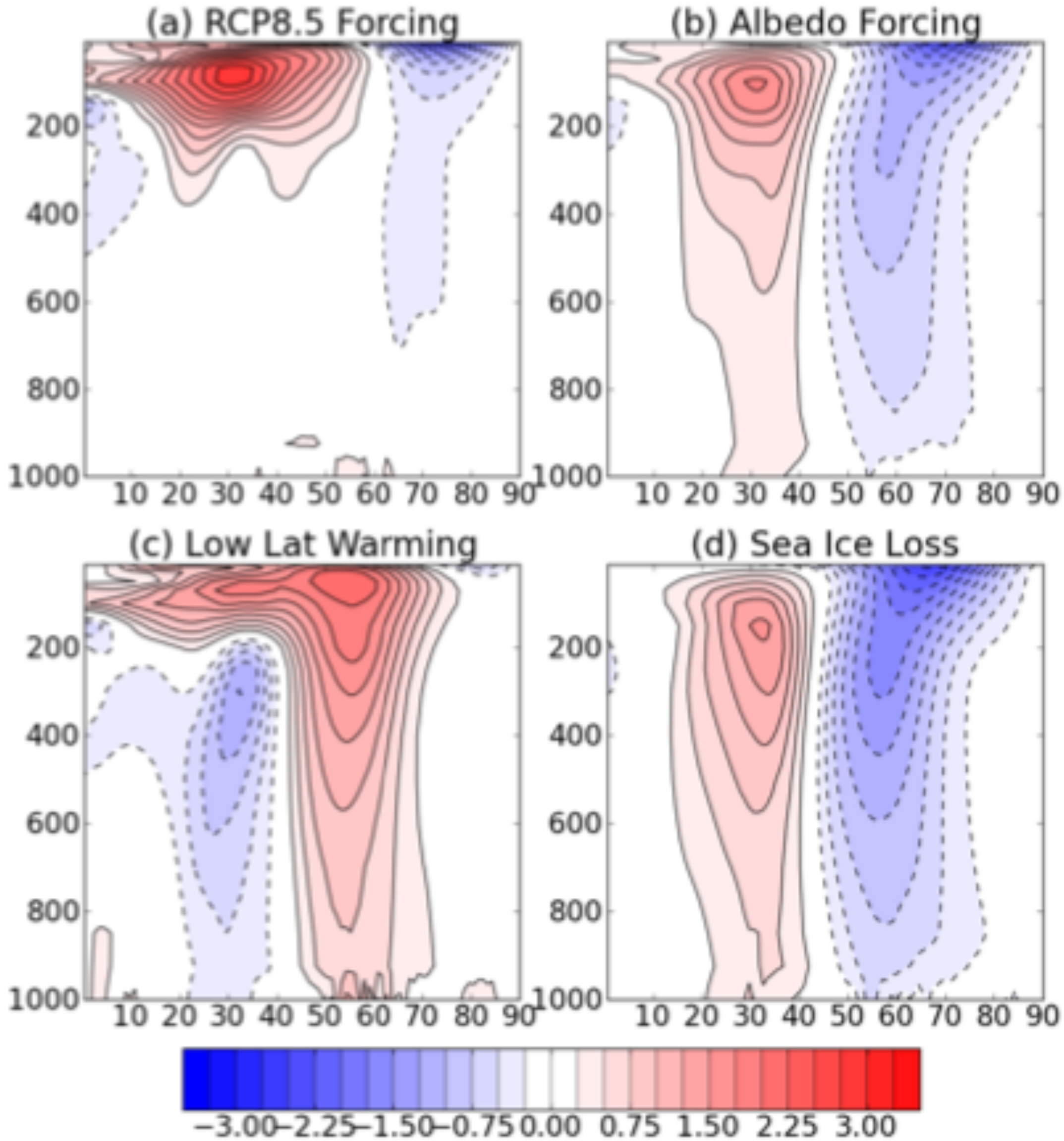


Blackport and Kushner 2017

$\Delta[U]$, DJF

Coupled Model Experiments

Diagnosed Decomposition



Blackport and Kushner 2017

ΔSLP, **DJF**

Coupled Model Experiments

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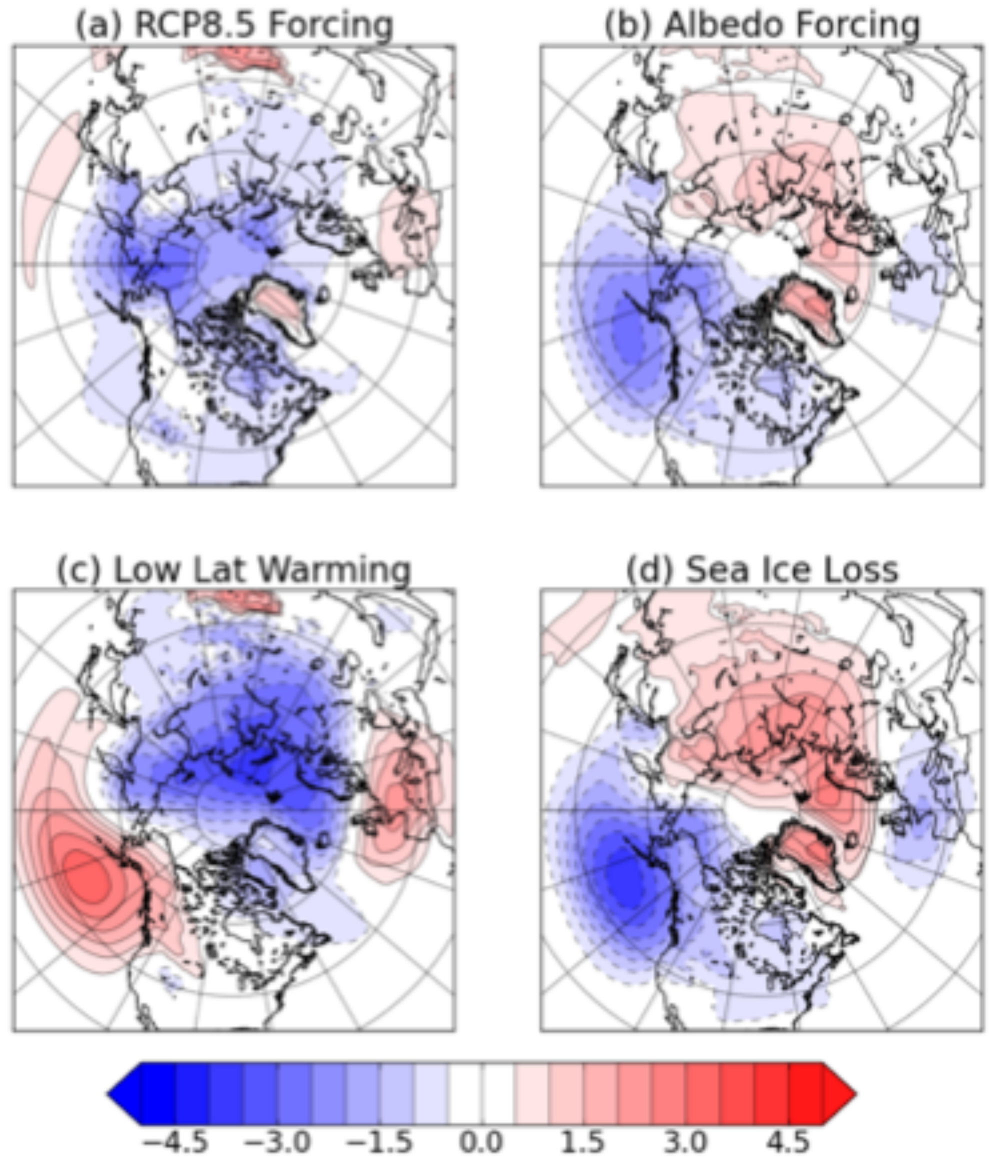
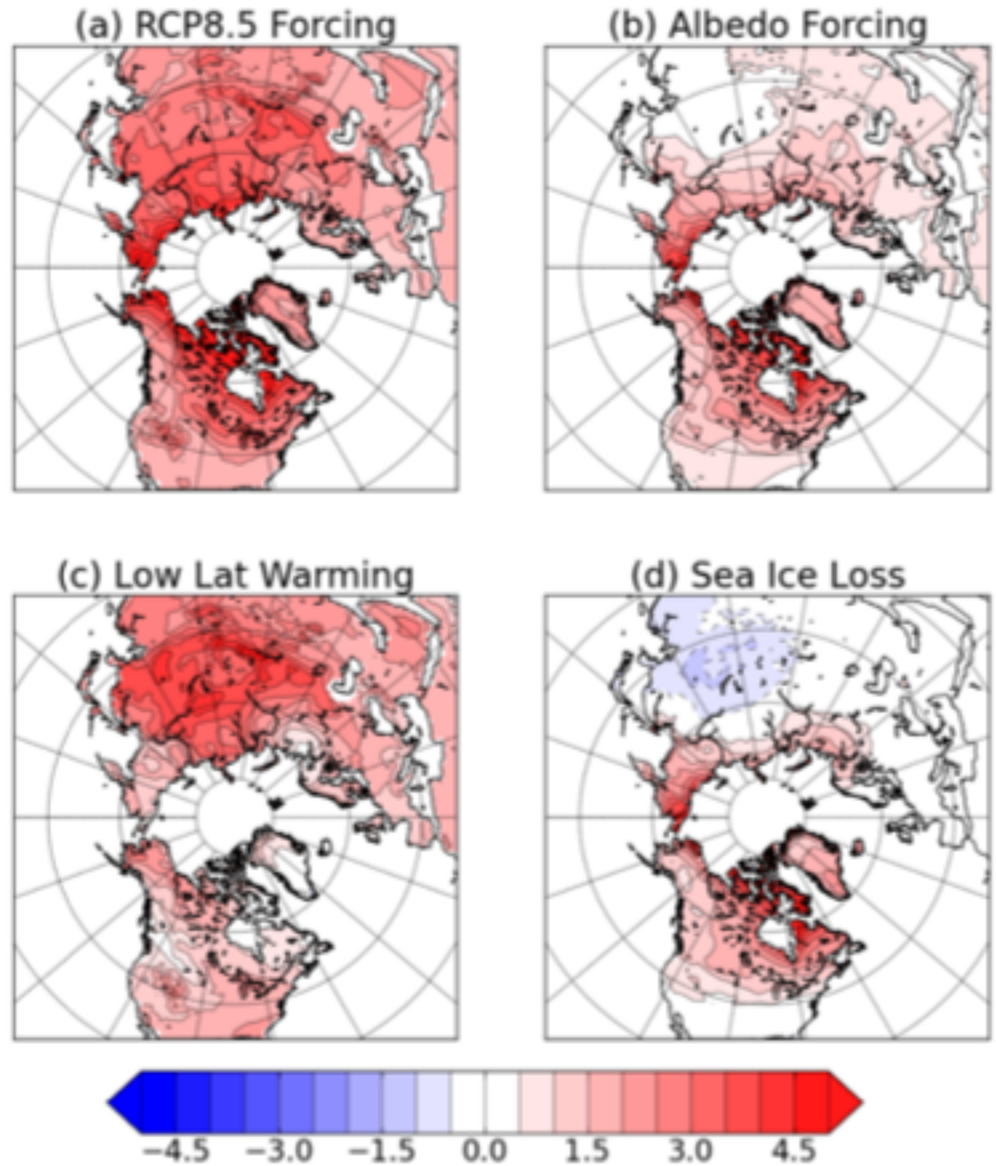


Blackport and Kushner 2017

$\Delta T_{2\mathrm{m}}$, DJF

Coupled Model Experiments

Diagnosed Decomposition

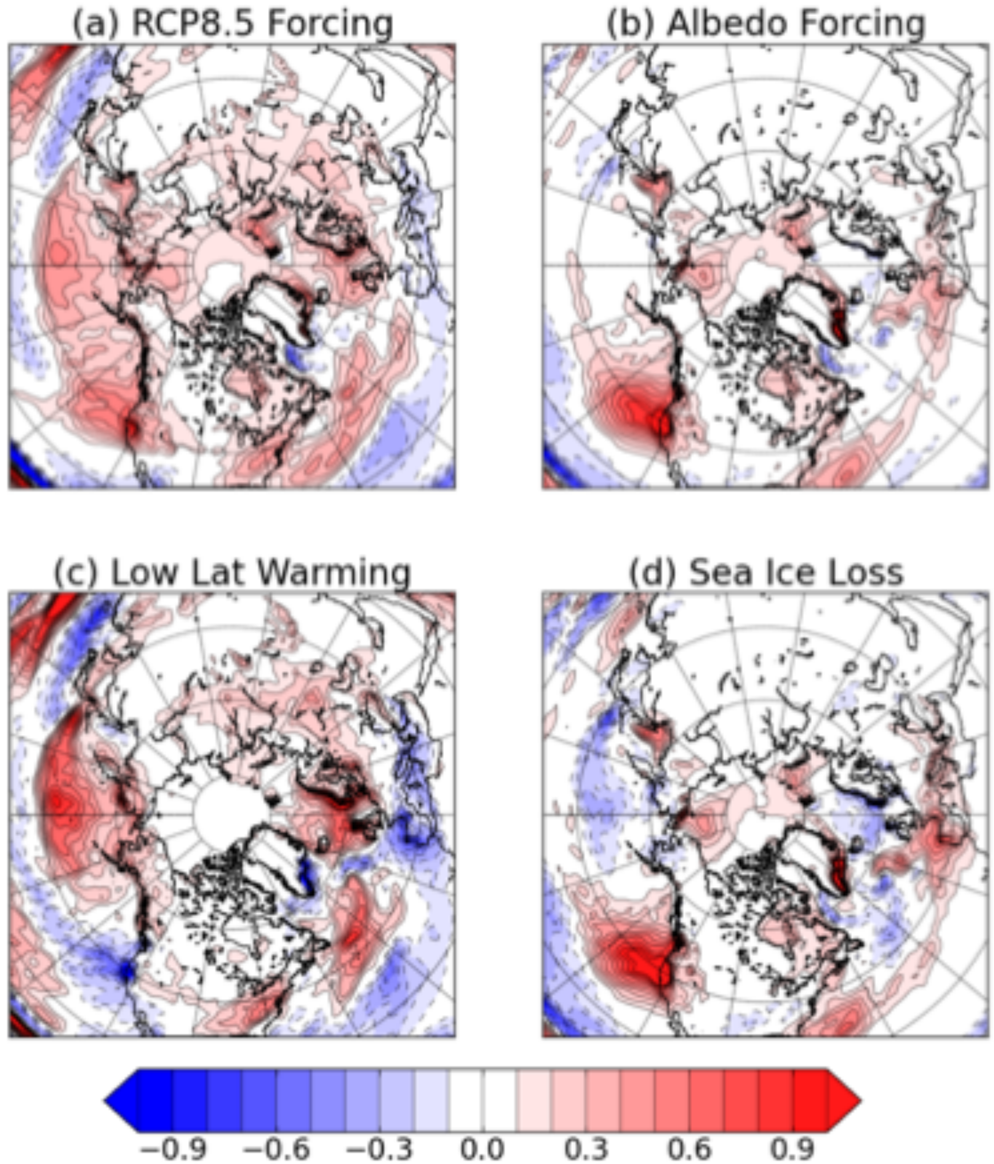


Blackport and Kushner 2017

ΔPRC, **DJF**

Coupled Model Experiments

Diagnosed Decomposition



Blackport and Kushner 2017

Change in 2-6 Day Band Pass SLP, DJF

Coupled Model Experiments

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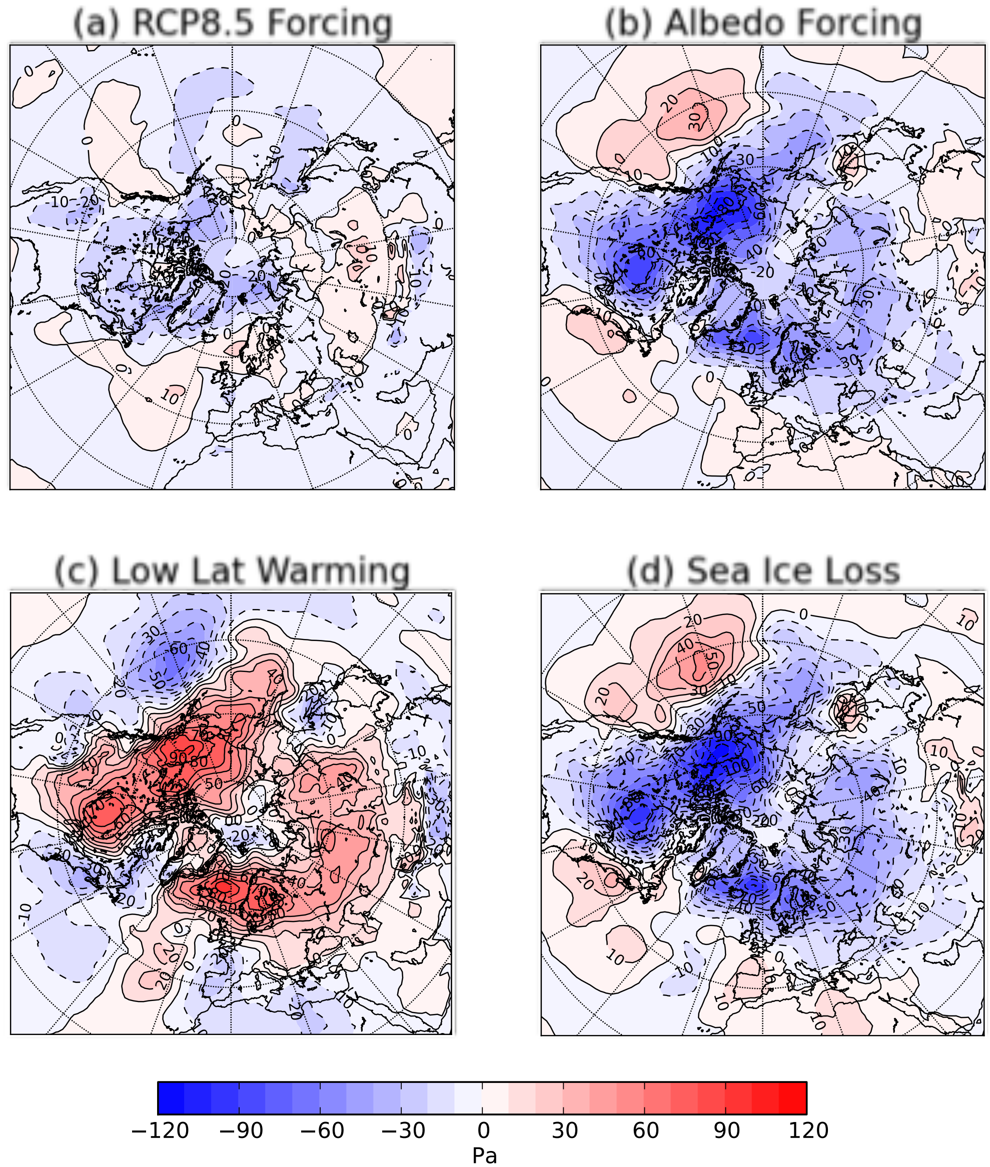
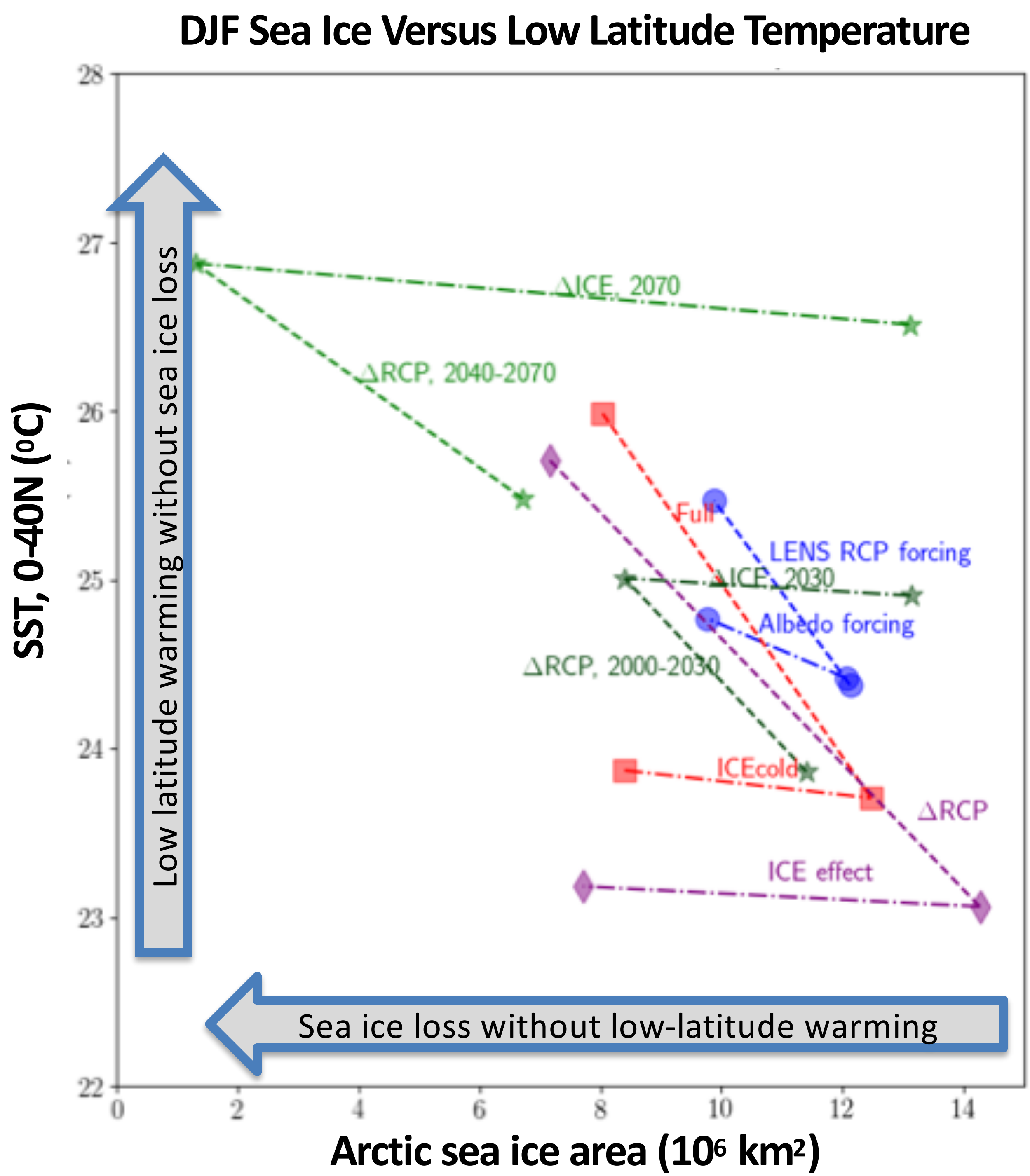


Euan Joly-Smith

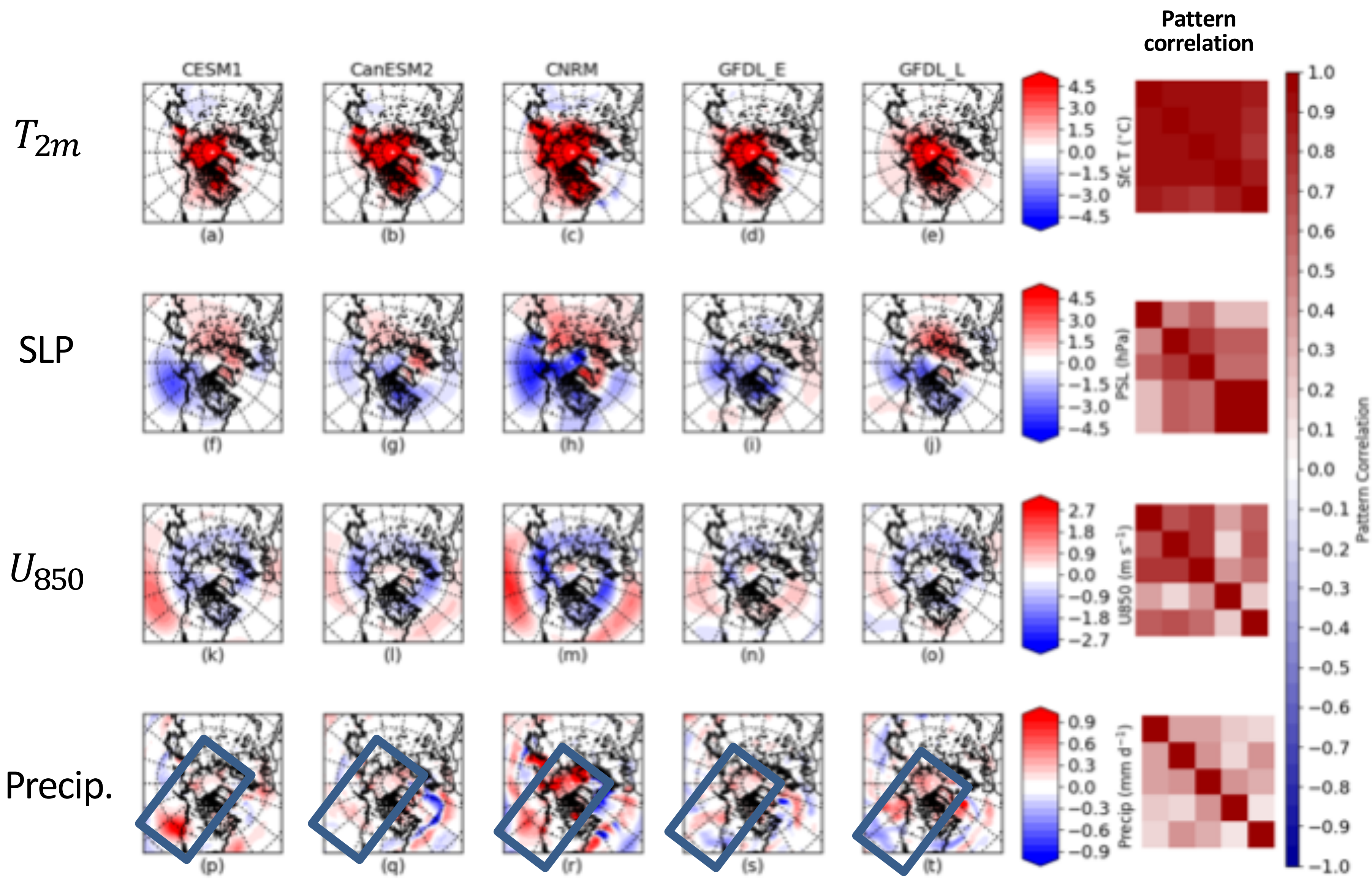
Stephanie Hay applied two-parameter pattern scaling to a large set of coupled model experiments that included some type of forced sea ice loss.

These experiments used different models and were all forced in different ways.



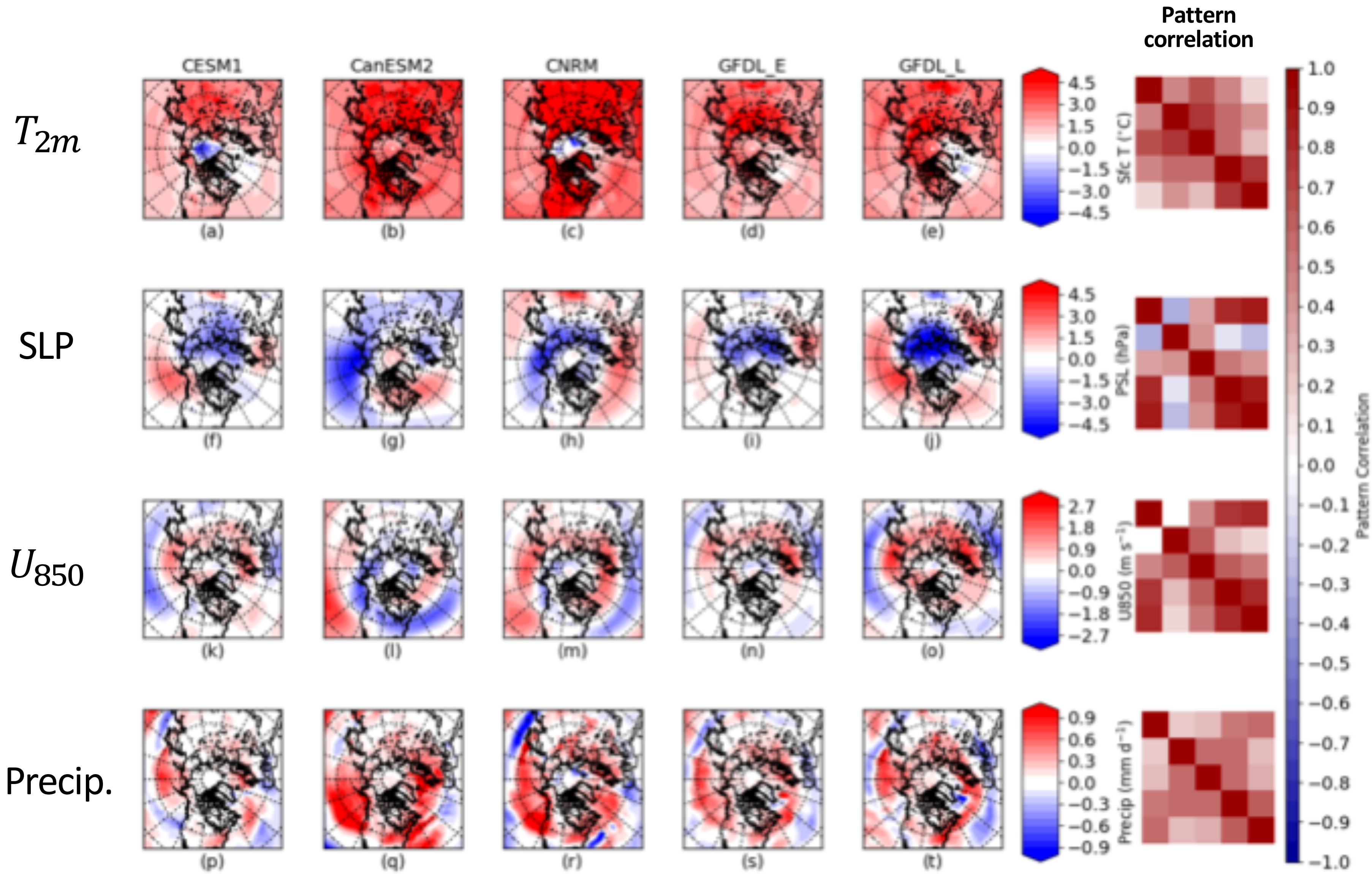
Hay et al. 2018 and in prep.

The part of the response that scales with sea ice loss



Hay et al. 2018 and in prep.

The part of the response that scales with low-latitude warming



Hay et al. 2018 and in prep.

Four outstanding problems

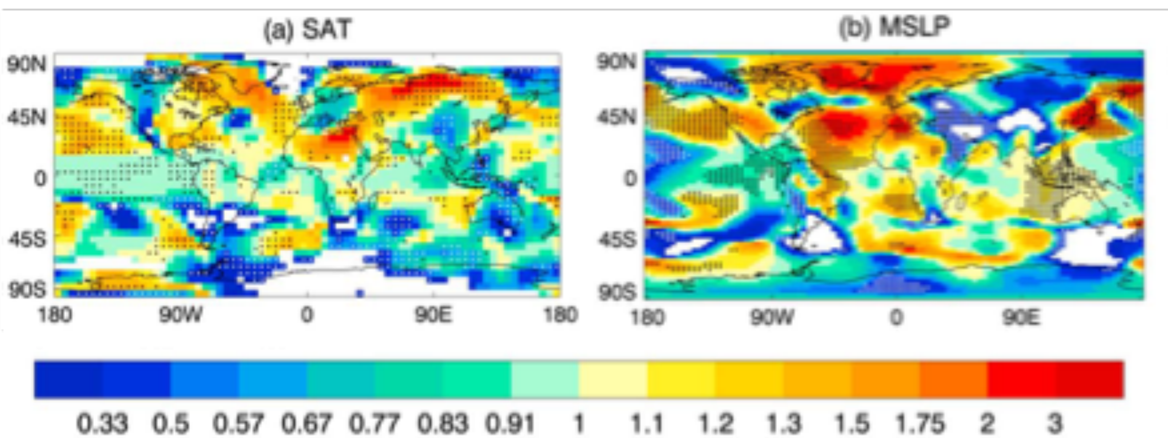
1. Drivers of Arctic Amplification

- I spoke about this at the conference – please see that presentation. http://online.kitp.ucsb.edu/online/blayers-c18/kushner/

2. The *Signal to Noise Paradox* in Climate Prediction

- NAO ensemble mean forecast skill is *better* than you might expect based on internal correlations: individual initialized climate forecast realizations are closer to observations than they are to each other.
- Is the model troposphere poorly constrained by ocean heat content, sea ice, snow, stratospheric conditions, etc.? Will high resolution change this?

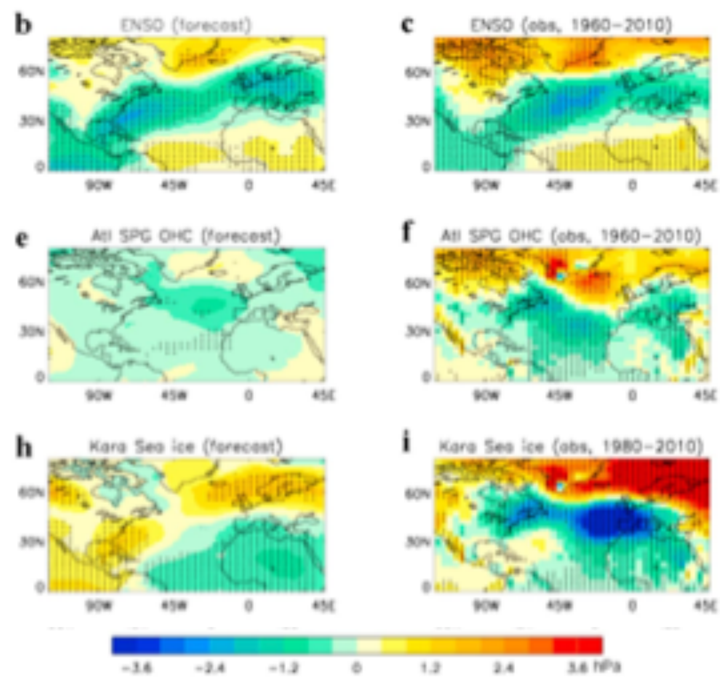
Ratio of predictable components



Models over confident

Models under confident

SLP composite anomalies for forecasts (left) and obs (right)

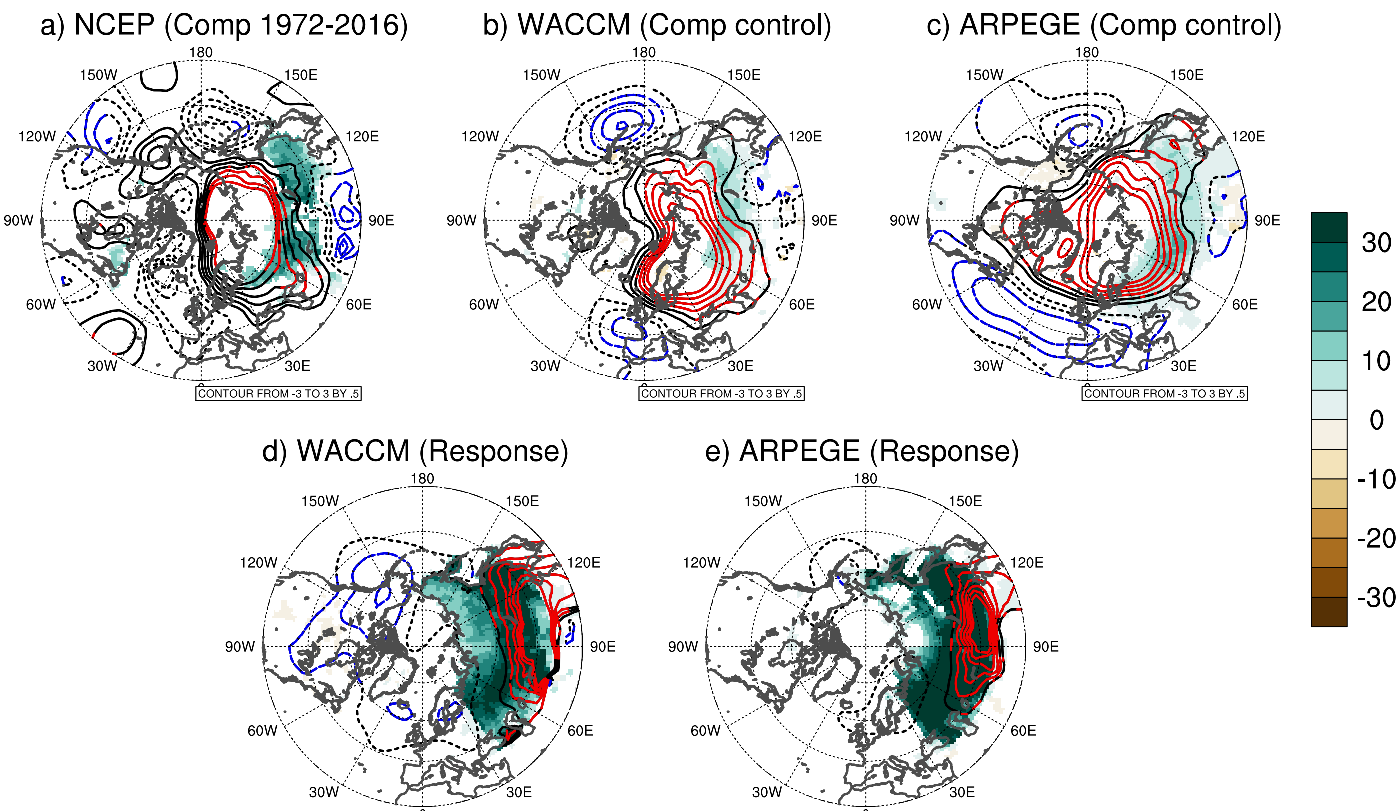


Eade et al. 2014, Scaife et al. 2014

3. Ambiguous Causality in Model Experiments

- Snow anomalies in fall over Eurasia might trigger winter circulation anomalies with a one-to-two month lag (Cohen and Entekhabi 1999).
- Experimental method that force snow anomalies can yield ambiguous results.
- This is symptomatic of a broader problem in the design of these experiments.

Spontaneous snow-circulation relationships, October, in reanalysis and models. Suggests snow anomaly is forced by atmospheric circulation.

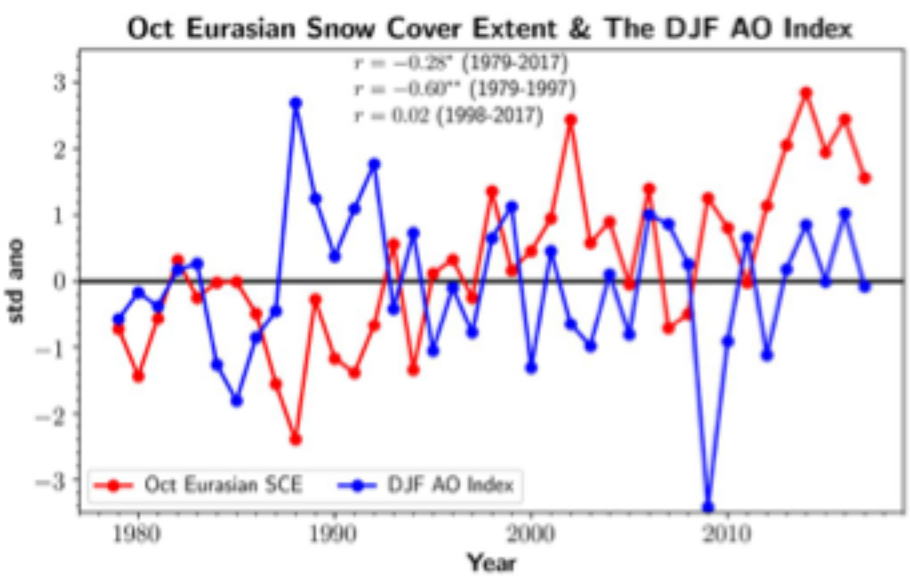


Response to snow forcing produce a different circulation pattern.

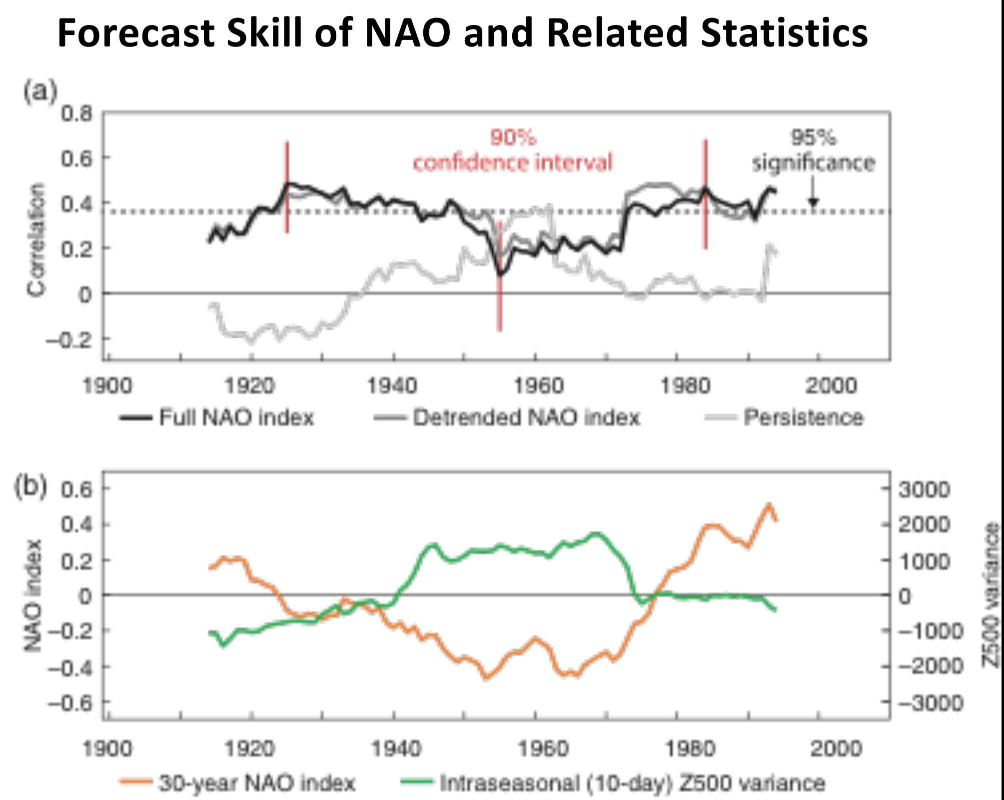
Y. Peings, from Henderson et al. in review; also Sorokina et al. 2016, Blackport and Screen in review

4. Non-Stationarity and Decadal Variability of Predictability

- Empirical connections between snow/sea ice and circulation can be non-robust.
- There is evidence that seasonal and longer timescale NAO predictability is state dependent.



Jason Furtado, from Henderson et al. in review



Weisheimer et al. 2017

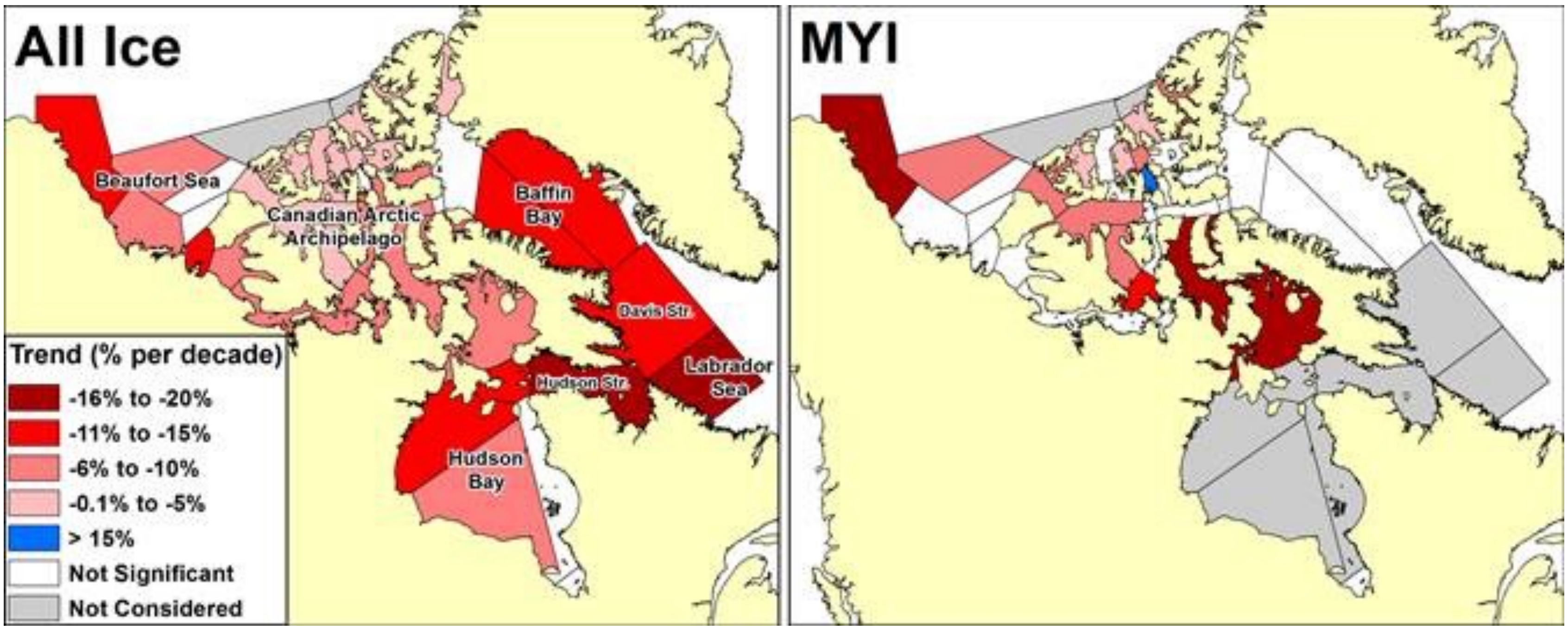
Three Key Points

1. We have diagnosed the circulation response directly attributable to sea ice loss in the coupled system.
2. Cryospheric response to climate change feeds back positively onto global warming, but we can anticipate negative feedbacks in the circulation response.
3. We need to consider the oceanic response in midlatitudes, which can feed back onto the polar regions.

Thanks for a great program!

Extra Slides

Recent changes in September Sea Ice from Ice Charts

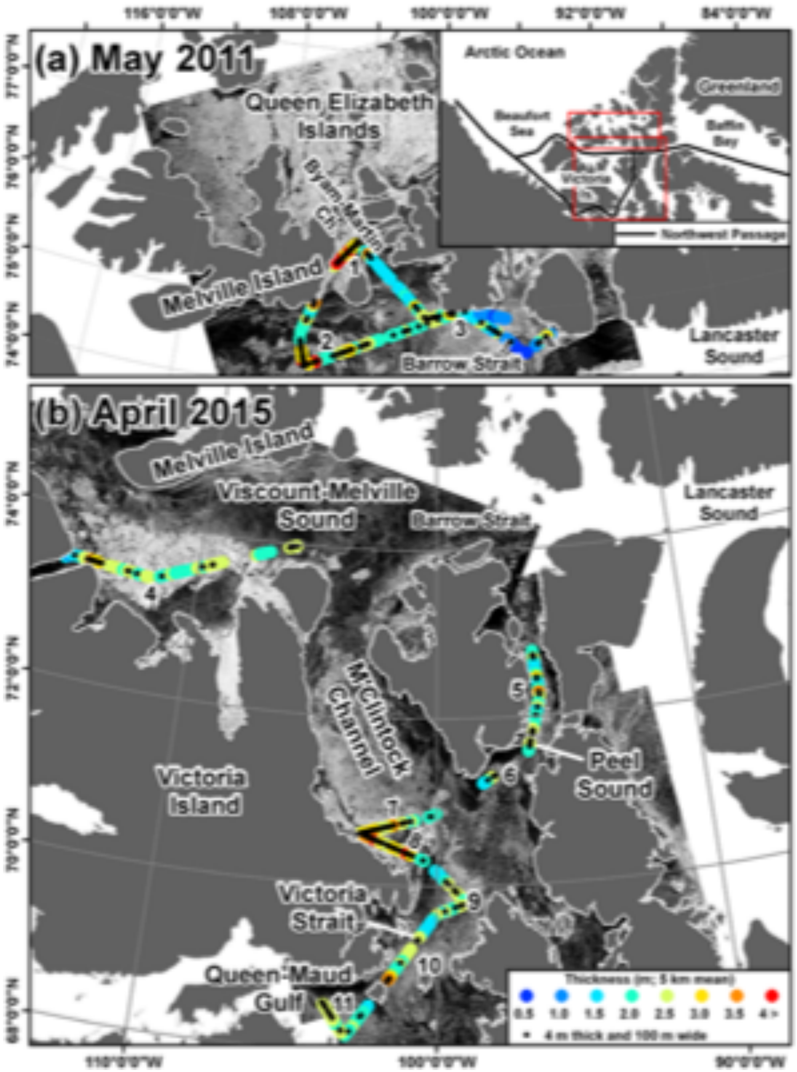


1968-2016 (Updated from Tivy et al. 2011)

Mudryk et al. 2018, Slide from S. Howell

Environment and Climate Change Canada — Environnement et Changement climatique Canada

Ice thickness in the Northwest Passage



Haas and Howell, 2015, GRL

- First ever airborne electromagnetic induction (AEM) ice thickness surveys over the Northwest Passage carried out in April and May 2011 and 2015
- Even in today's climate ice is still very thick (3-4 m) and potentially hazardous
- Thick ice features more than 100 m wide and thicker than 4 m occurred frequently