Separating the Coupled Climate Response to Sea Ice Loss and Greenhouse Warming

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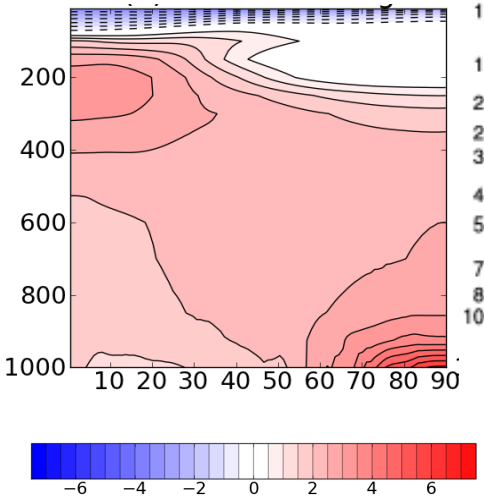
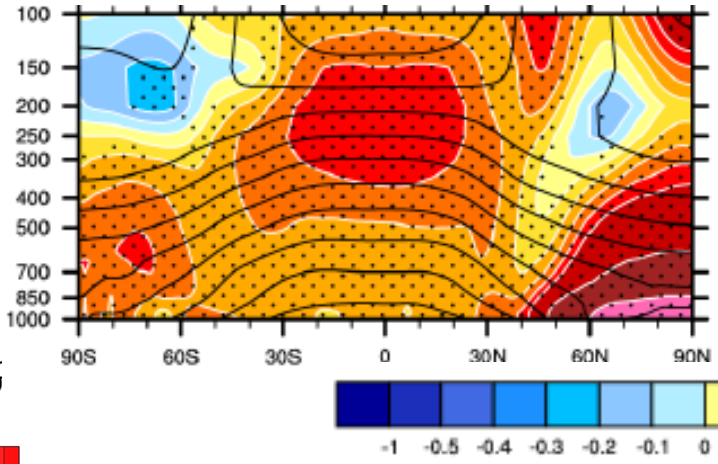
Can We Isolate the Impact of Sea Ice Loss on Circulation?

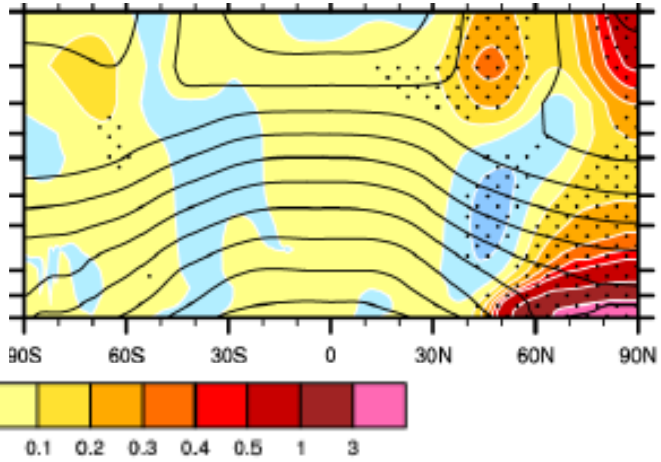
CESM1 RCP8.5 $\Delta[T]$



CCSM4 Sea Ice Loss $\Delta[T]$

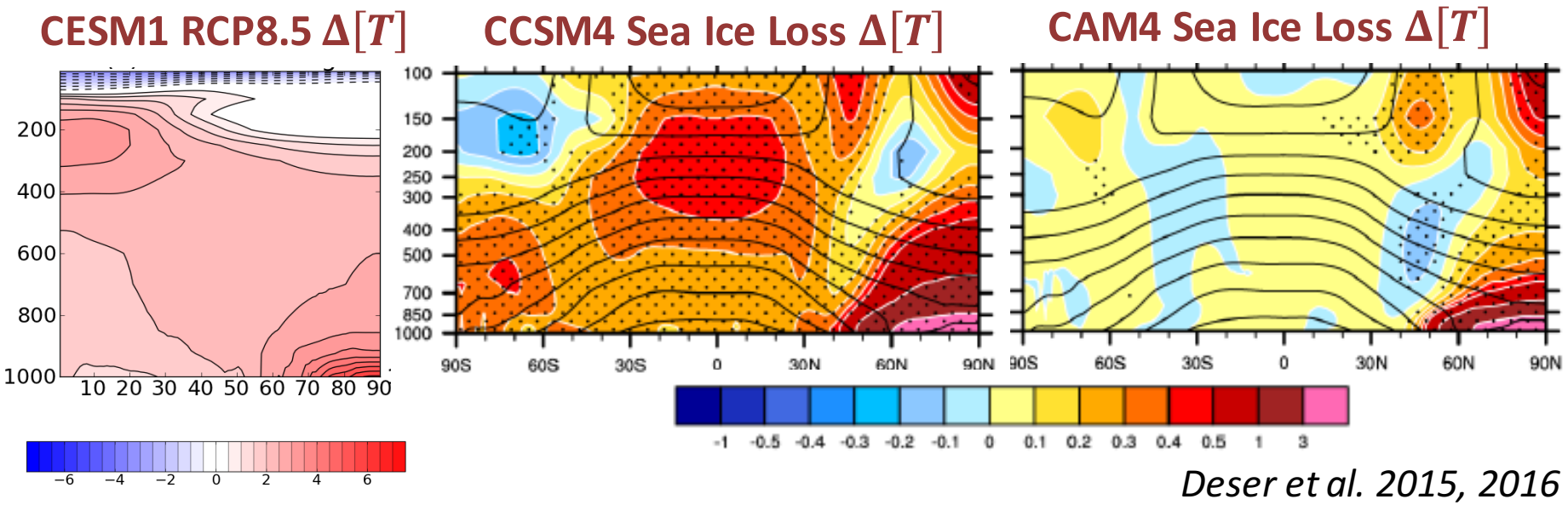


CAM4 Sea Ice Loss $\Delta[T]$



Deser et al. 2015, 2016

Can We Isolate the Impact of Sea Ice Loss on Circulation?

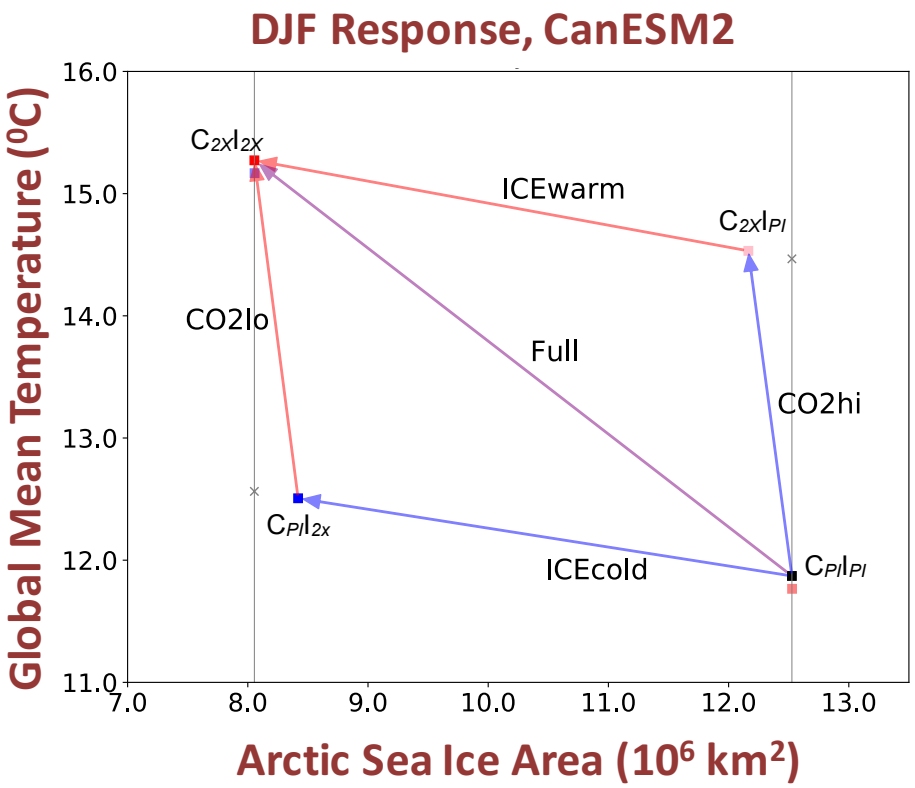


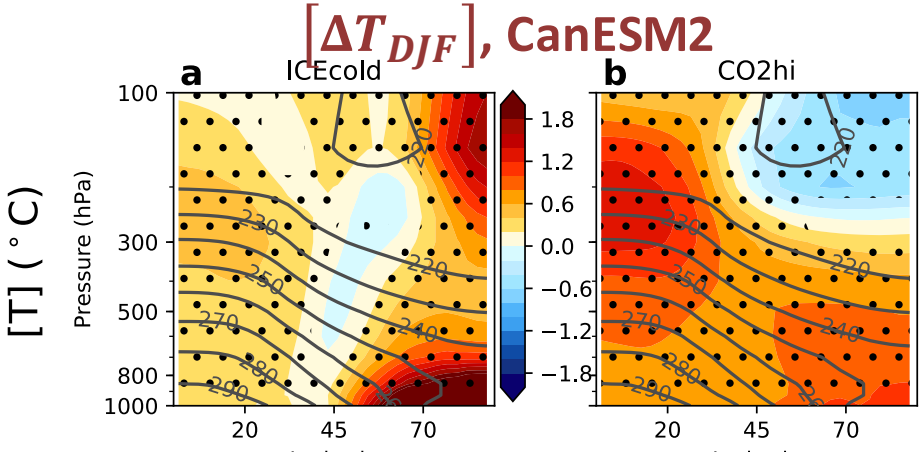
Deser et al. 2015, 2016

In very well sampled coupled climate simulations:

- The greenhouse warming response is remarkably separable from the sea ice loss response.
- *Multivariate pattern scaling* helps divide the response between sea ice loss and low latitude warming.
- The response to sea ice loss is more robust than the low latitude warming response.

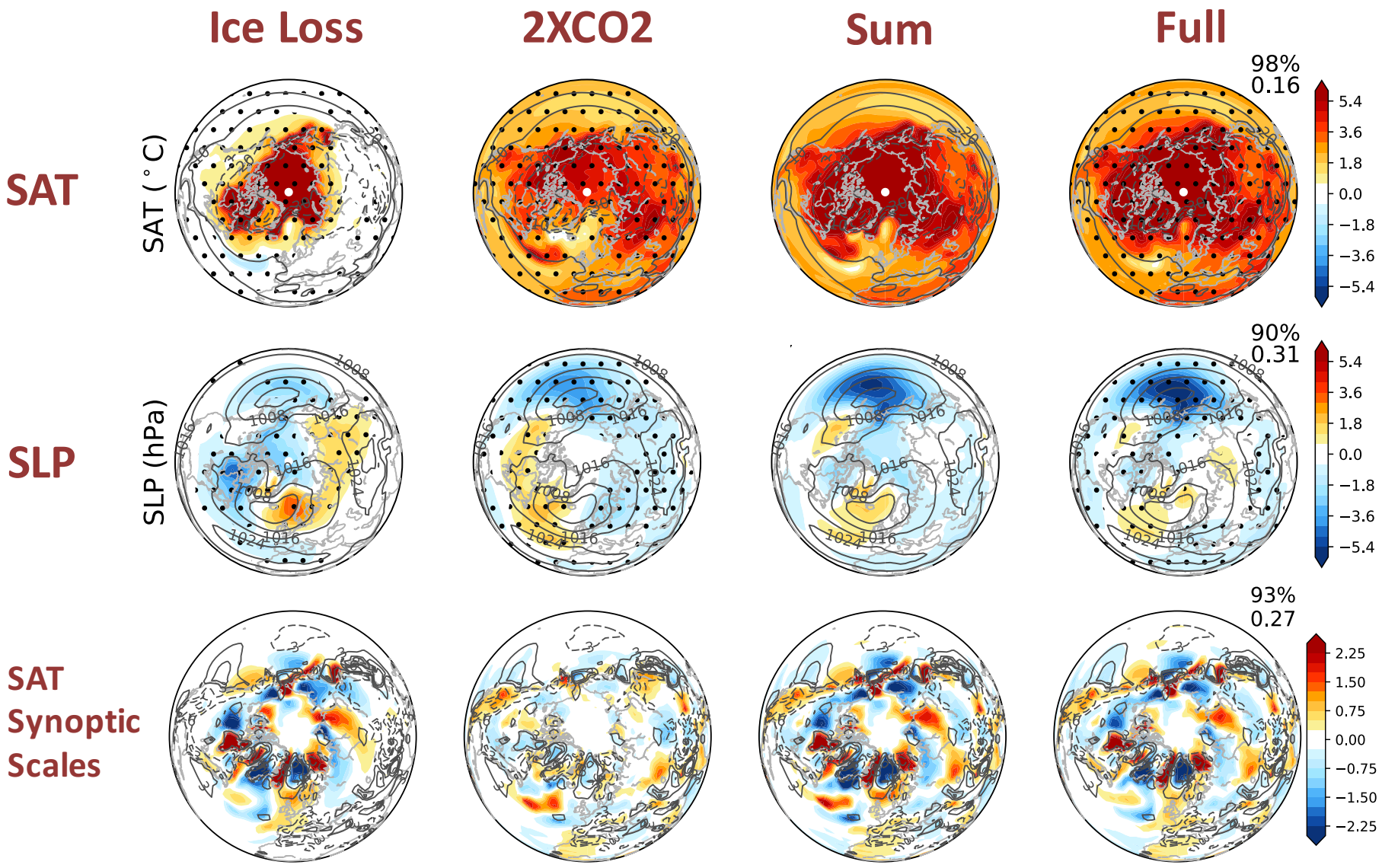
Paired Sea Ice and CO2 Perturbation Experiments



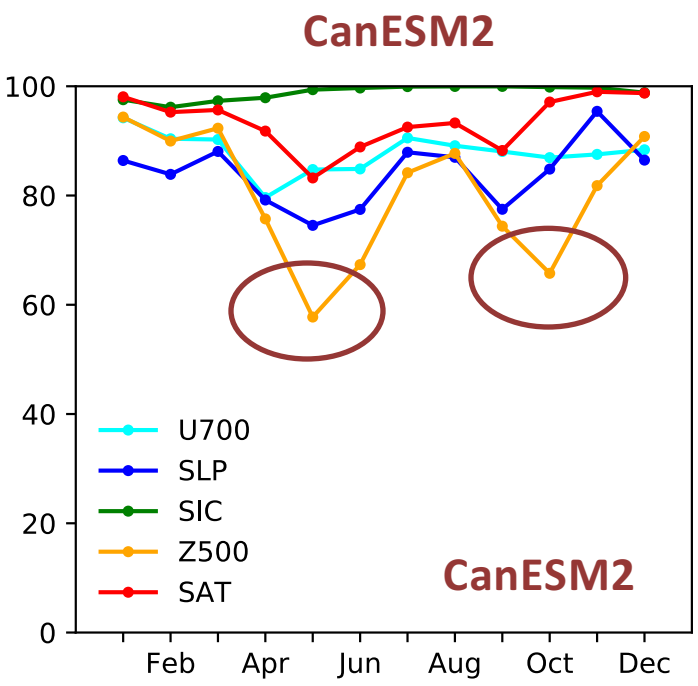


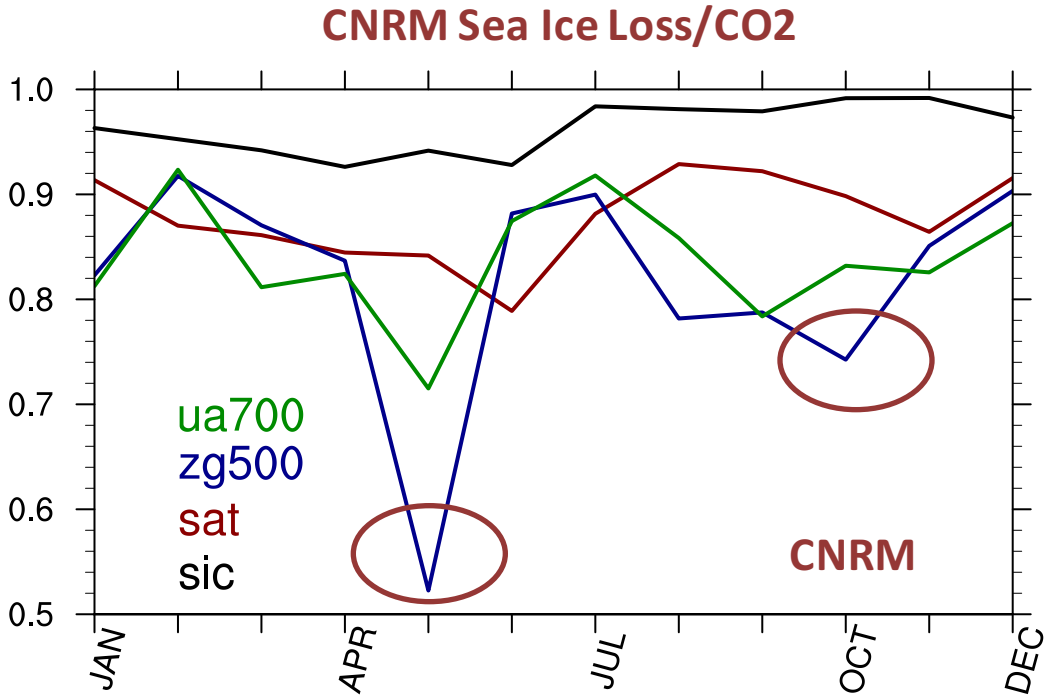
McCusker et al. submitted, building on Oudar et al. 2017

Additivity of Sea Ice Loss and CO2



McCusker et al. submitted

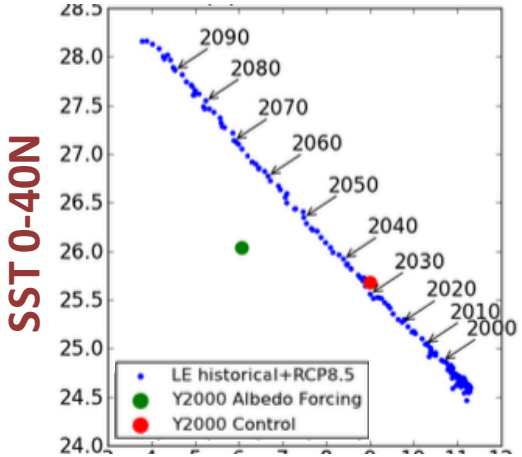




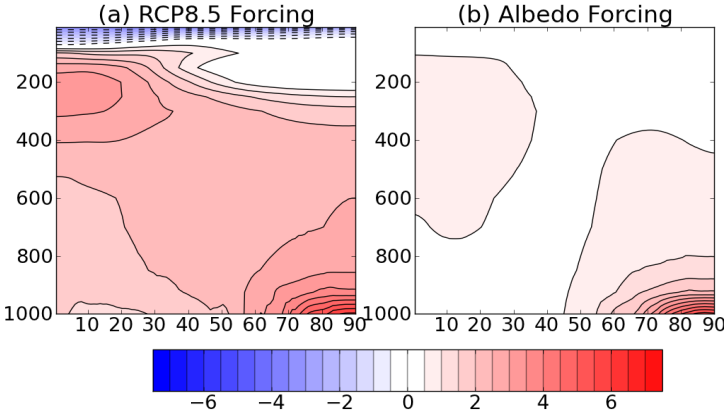
McCusker et al. submitted, Thomas Oudar pers. comm.

Sea Ice Loss and Projected Climate Change

ANN Response, CESM1



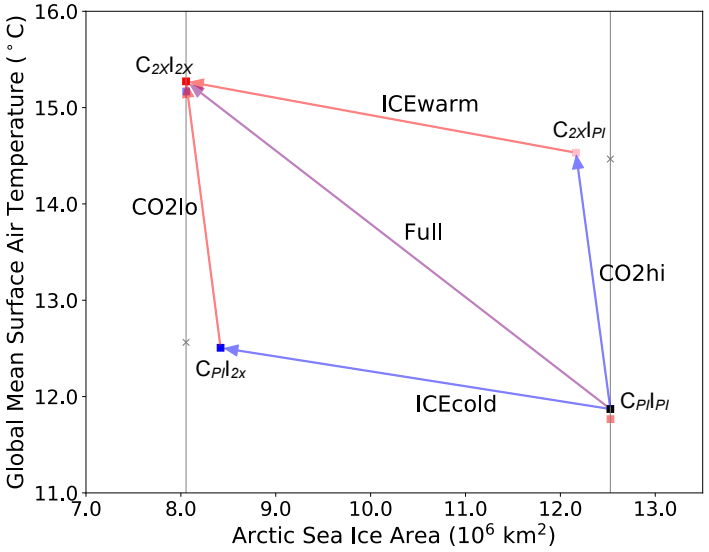
ANN $[\Delta T]$



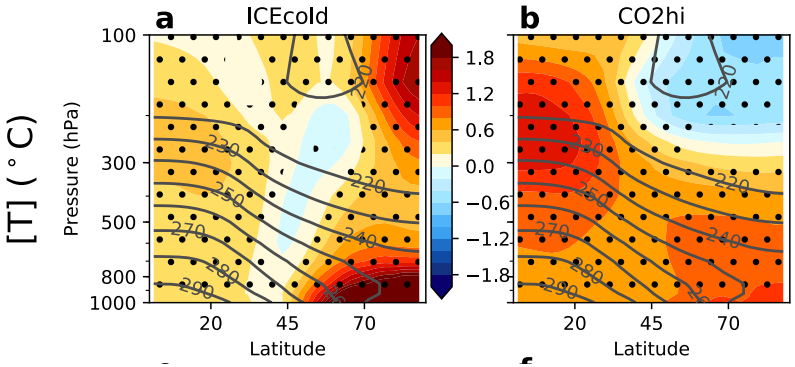
Blackport and Kushner 2017

Paired Sea Ice and CO2 Perturbation Experiments

DJF Response, CanESM2



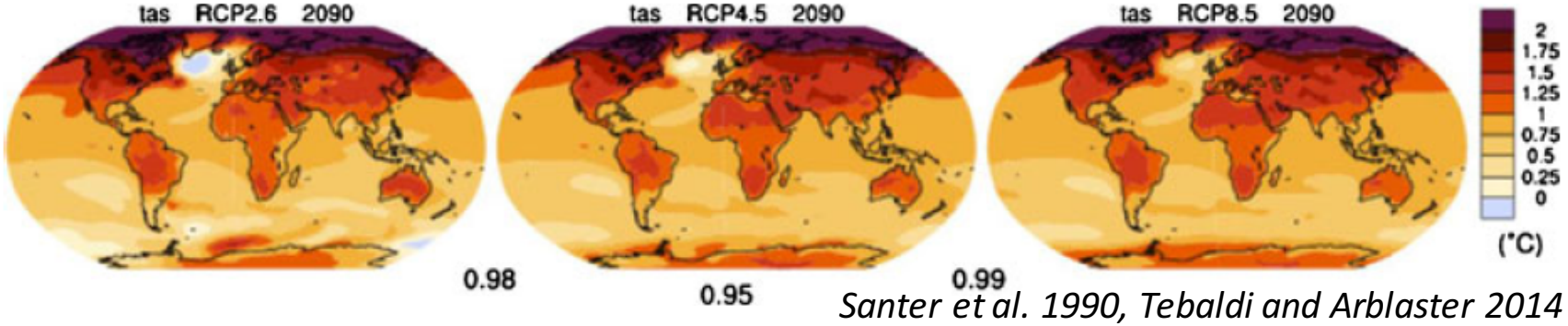
ANN $[\Delta T]$



McCusker et al. 2017

Pattern Scaling on Temperature

ANN Surface Temperature Response Per Global mean temperature, CMIP5



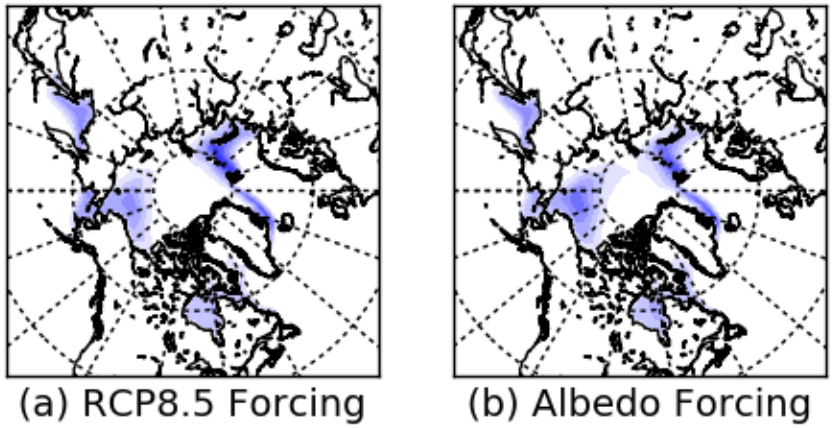
Santer et al. 1990, Tebaldi and Arblaster 2014

For small change in global mean temperature δT_g,

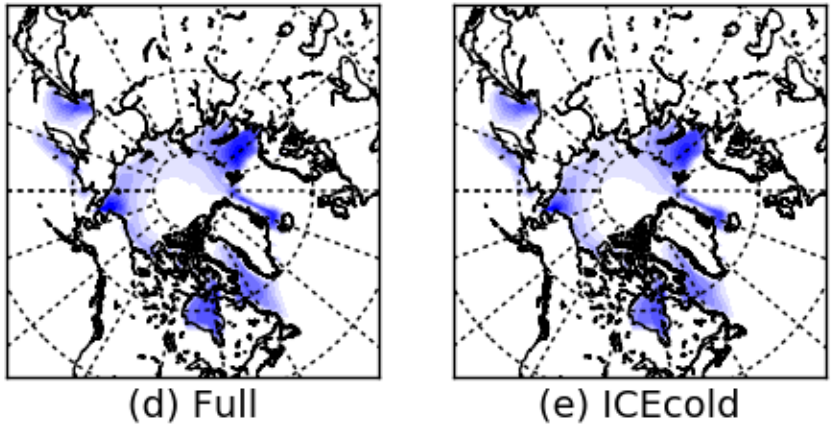
$$\delta Z = Z(T_g + \delta T_g) - Z(T_g) \approx \frac{\partial Z}{\partial T_g} \delta T_g$$

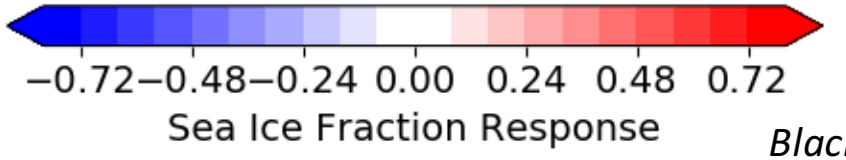
Can we Pattern Scale on Sea Ice?

NCAR CESM1



CanESM2





Blackport and Kushner 2017;
Hay et al. in prep.

Pattern Scaling on Multiple Variables

- Assume field Z depends parameterically on *internal* integrated variables X_i (e.g. surface temperature, sea ice extent, …).
- Want to know sensitivities of Z to separate change in each X_i:

$$\partial Z / \partial X_i \Big|_{X_j}$$

- Assume coupled simulations generate responses δZ_m with distinctive responses δX_i:

$$\delta Z_m = \sum_i \partial Z / \partial X_i \Big|_{X_j} \delta X_{i,m}$$

- We infer sensitivities by inverting this relationship.

Pattern Scaling on low-latitude temperature T_l and sea ice I

$$Z = Z(T_l, I)$$

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

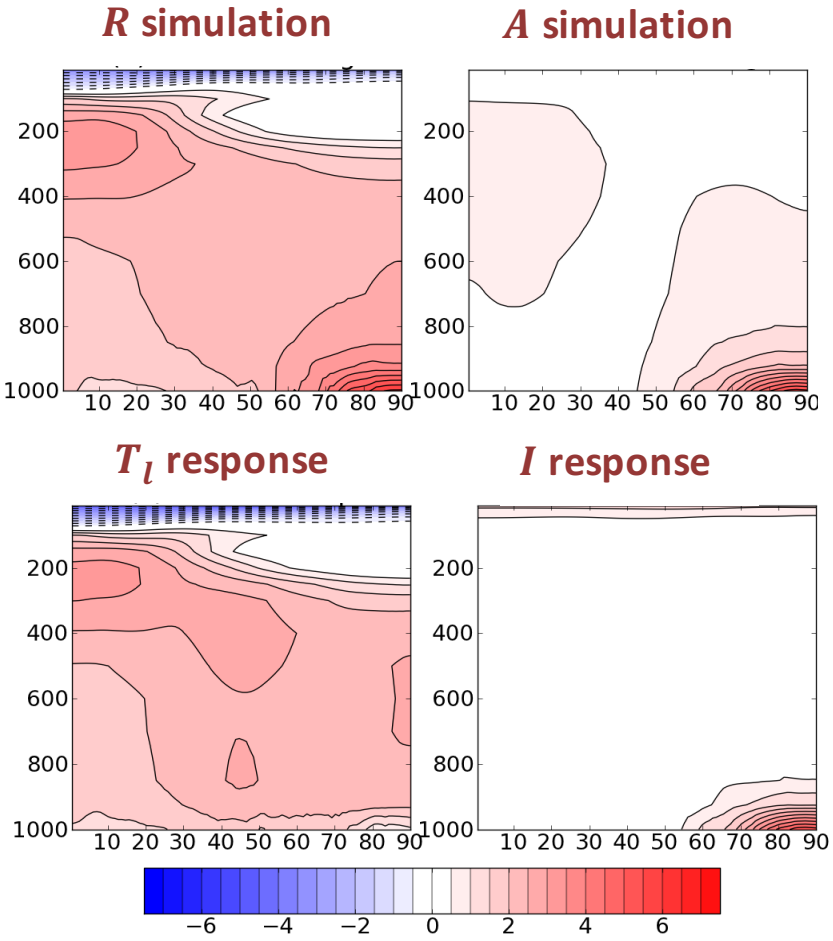
$$\begin{pmatrix} \left.\frac{\partial Z}{\partial T_l}\right|_I \\ \left.\frac{\partial Z}{\partial I}\right|_{T_l} \end{pmatrix} = \begin{pmatrix} \delta T_{l,R} & \delta I_R \\ \delta T_{l.A} & \delta I_A \end{pmatrix}^{-1} \begin{pmatrix} \delta Z_R \\ \delta Z_A \end{pmatrix}$$

Sensitivity to T_l or I changes, with the other held fixed.

$\delta T_l, \delta I, \delta Z$

- From coupled model simulations R and A.

CESM1 [ΔT], ANN



Blackport and Kushner 2017

Pattern Scaling on low-latitude temperature T_l and sea ice I

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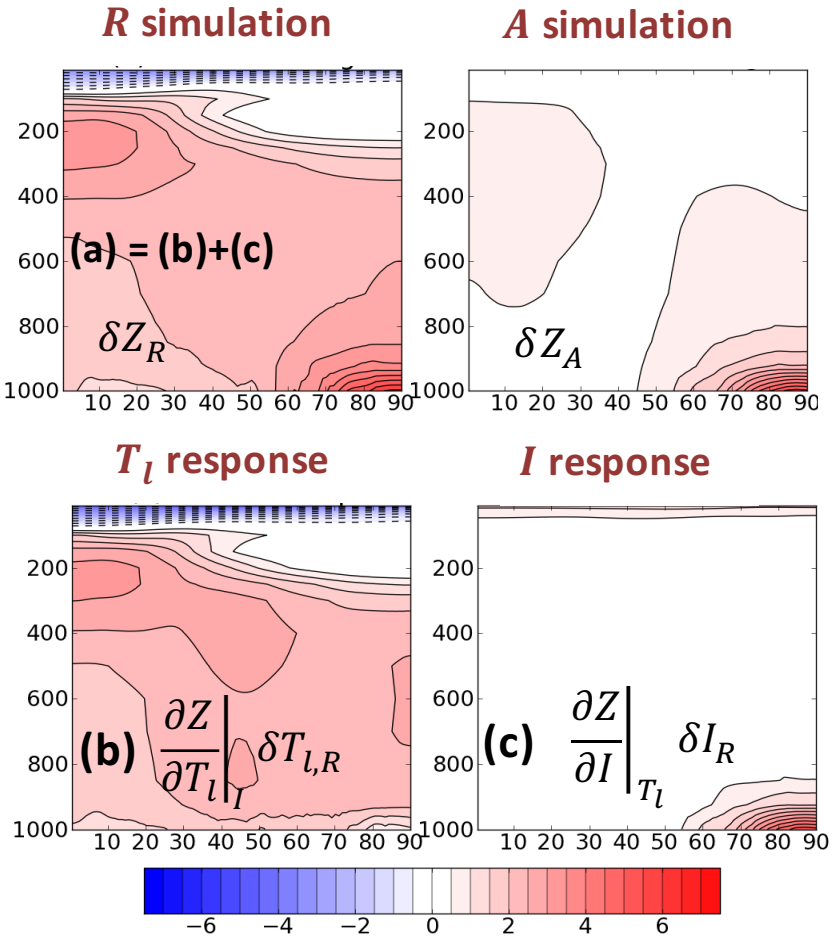
CESM1 [ΔT], ANN

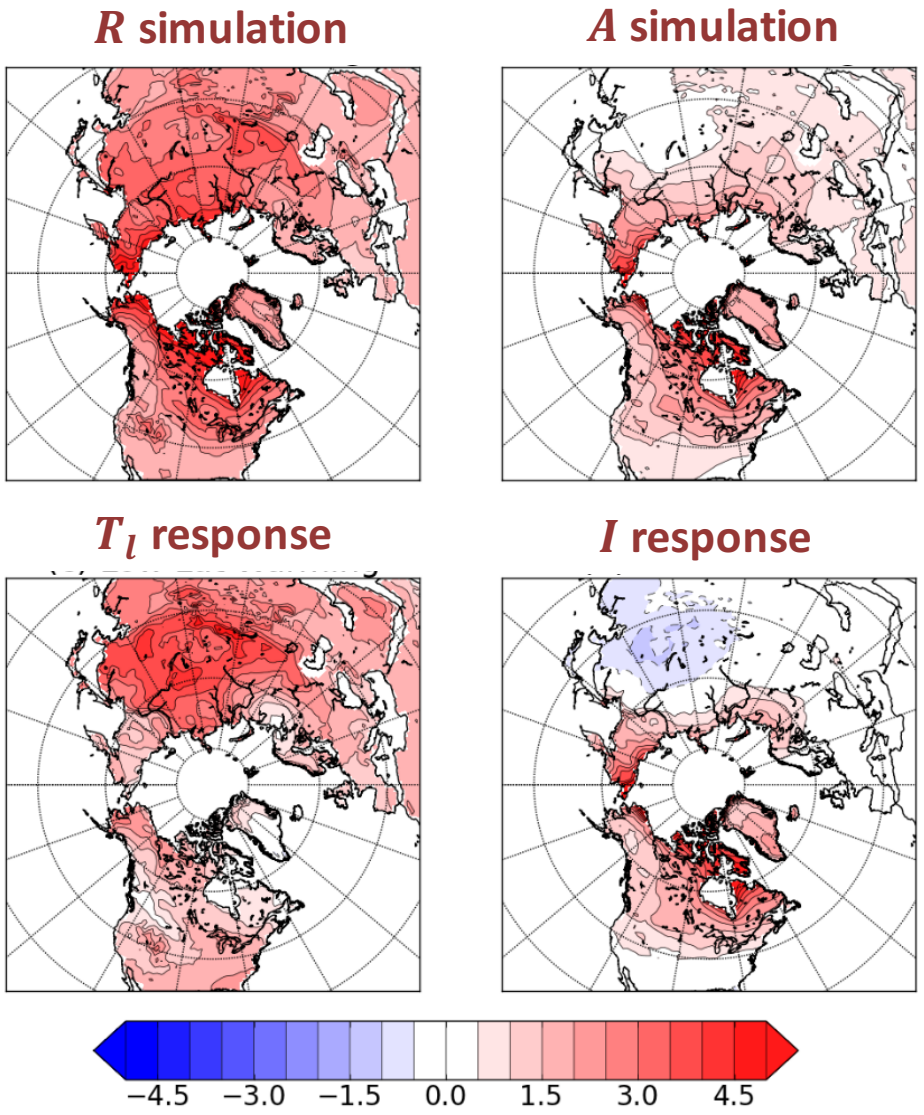


Blackport and Kushner 2017

CESM1 $\Delta T_{2\mathrm{m,DJF}}$

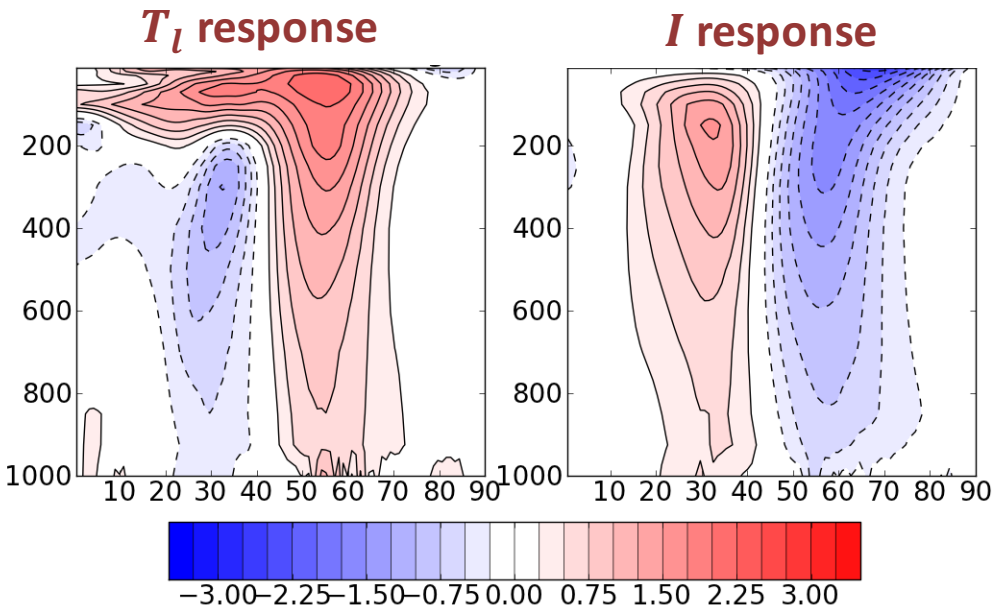
Coupled Model Experiments

Diagnosed Decomposition

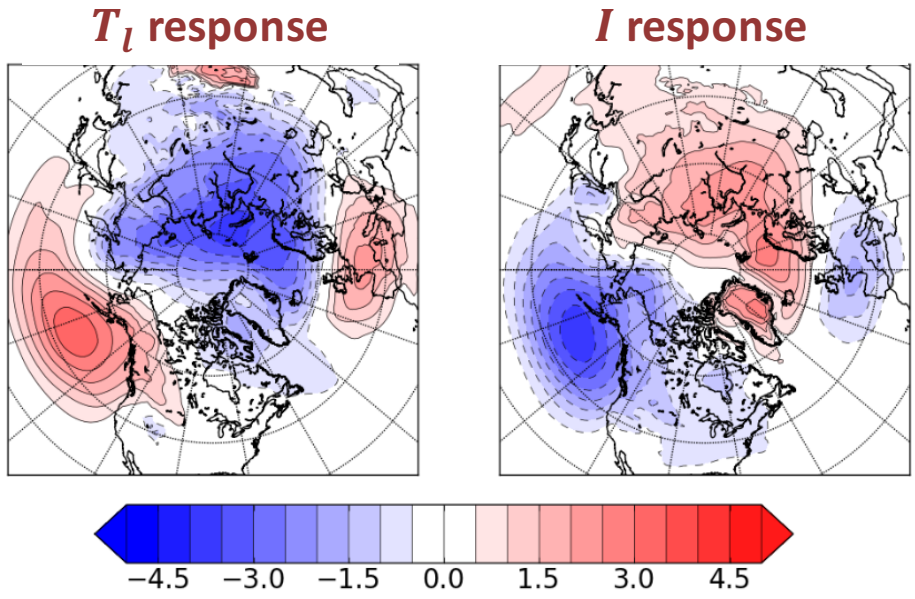


Blackport and Kushner 2017

CESM1 $\Delta[U_{\mathrm{DJF}}]$



CESM1 $\Delta SLP_{\mathrm{DJF}}$

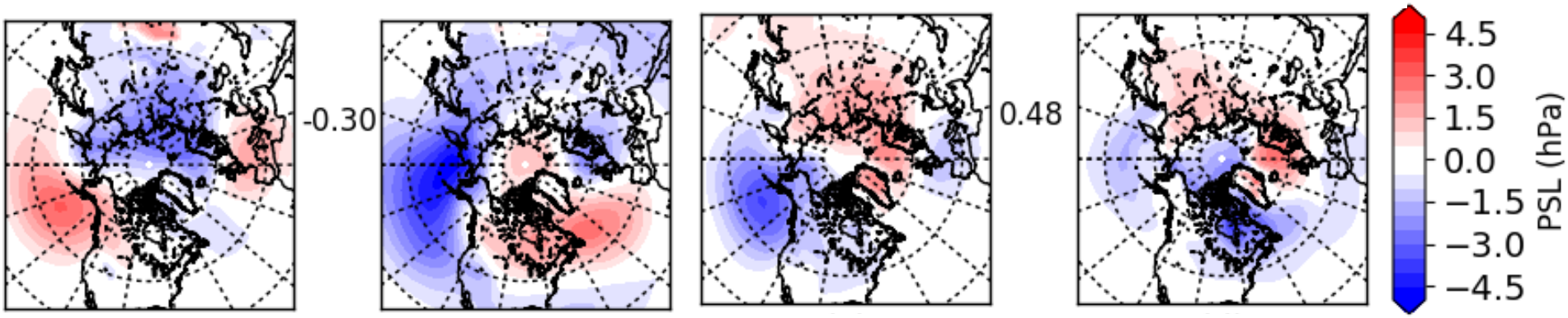


$\Delta SLP_{\mathrm{DJF}}$ (hPa)

T_l response

I response

CESM1 CanESM2 CESM1 CanESM2



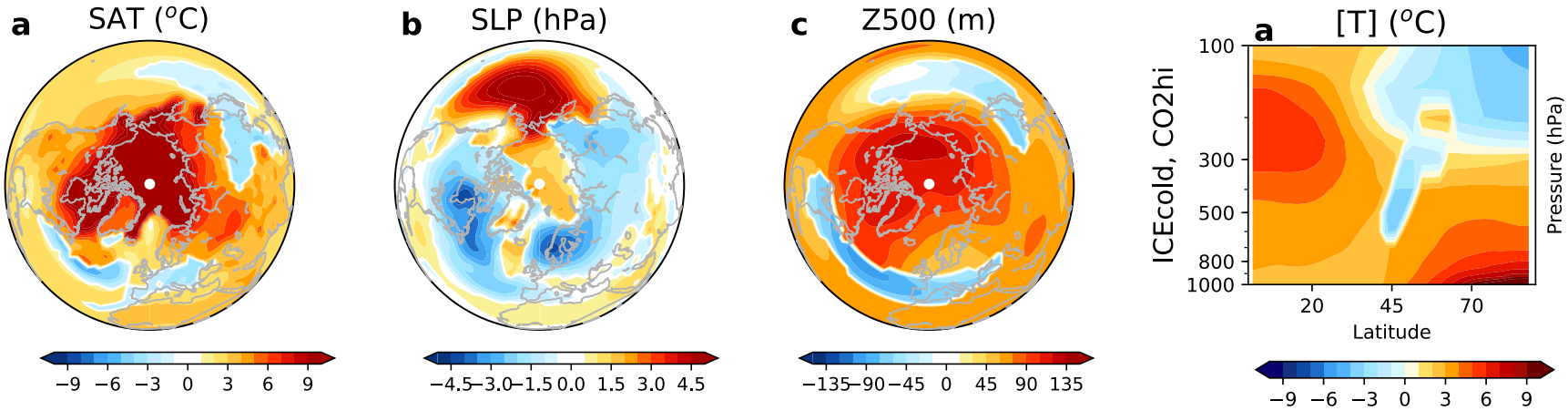
- Strengthened Aleutian Low and Eurasian high seen in several papers: Sun et al. 2015, Deser et al. 2016, Blackport and Kushner 2017, Oudar et al. 2017
- Robust sea ice loss response seen in several other fields: surface temperature, u850, precipitation
- Response to low latitude warming is less robust except in summer.

Hay et al. in prep.

- **Key point #1**: AOGCM simulations of sea ice loss are worth carrying out despite the computational cost, and we can use pattern scaling for further insight.
- **Key point #2:** Sea ice loss and radiative forcing responses are remarkably separable, enabling attribution.
- **Key point #3:** The response to sea ice loss is more robust across models than the response to low latitude warming, especially in the North Pacific.
- **Topics of current interest: a few slides**.

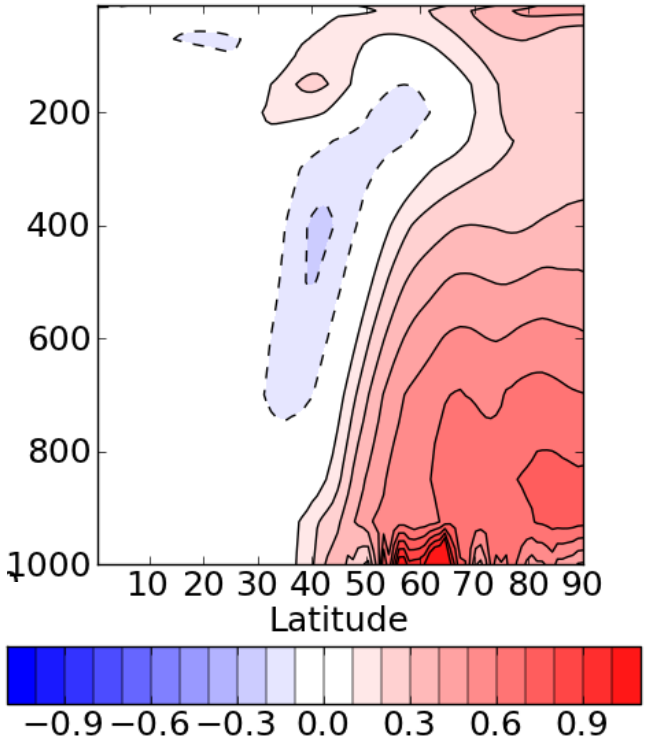
Diagnosing Feedbacks in CanESM2

"Agreement" $A = (|I| + |C|)\,\mathrm{sign}(I)\,\mathrm{sign}(C)$



McCusker et al. submitted,

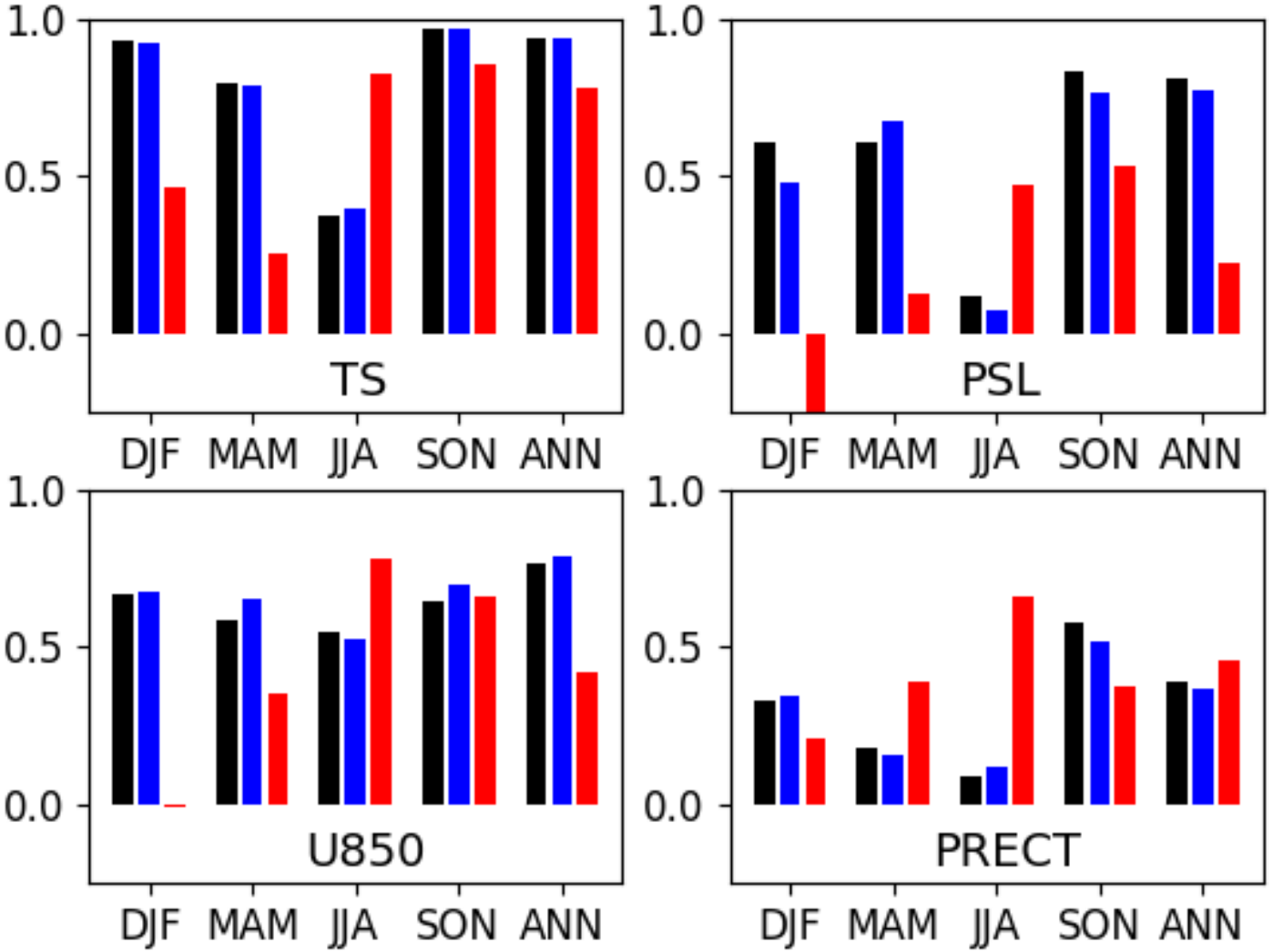
$[\Delta T_{\mathrm{DJF}}]$ from SST warming caused by sea ice loss



Blackport and Kushner in prep.

Are CESM1 and CanESM2 consistent?

Spatial pattern correlation between CESM1 and CanESM2 responses



CESM Sea Ice Albedo and CanESM2 Sea Ice Loss (A simulations)

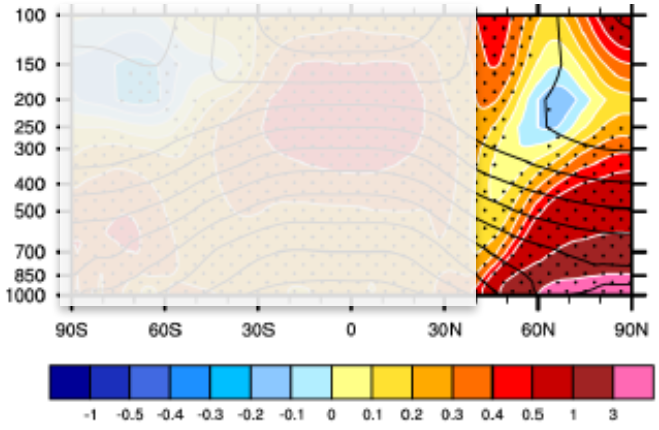
I response

T_l response

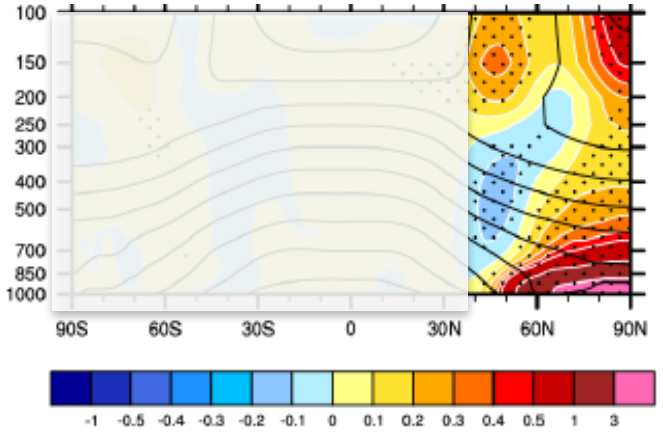
Hay et al. in prep.

Zonal mean DJF T Response to Sea Ice Loss

Coupled ocean atmosphere GCM



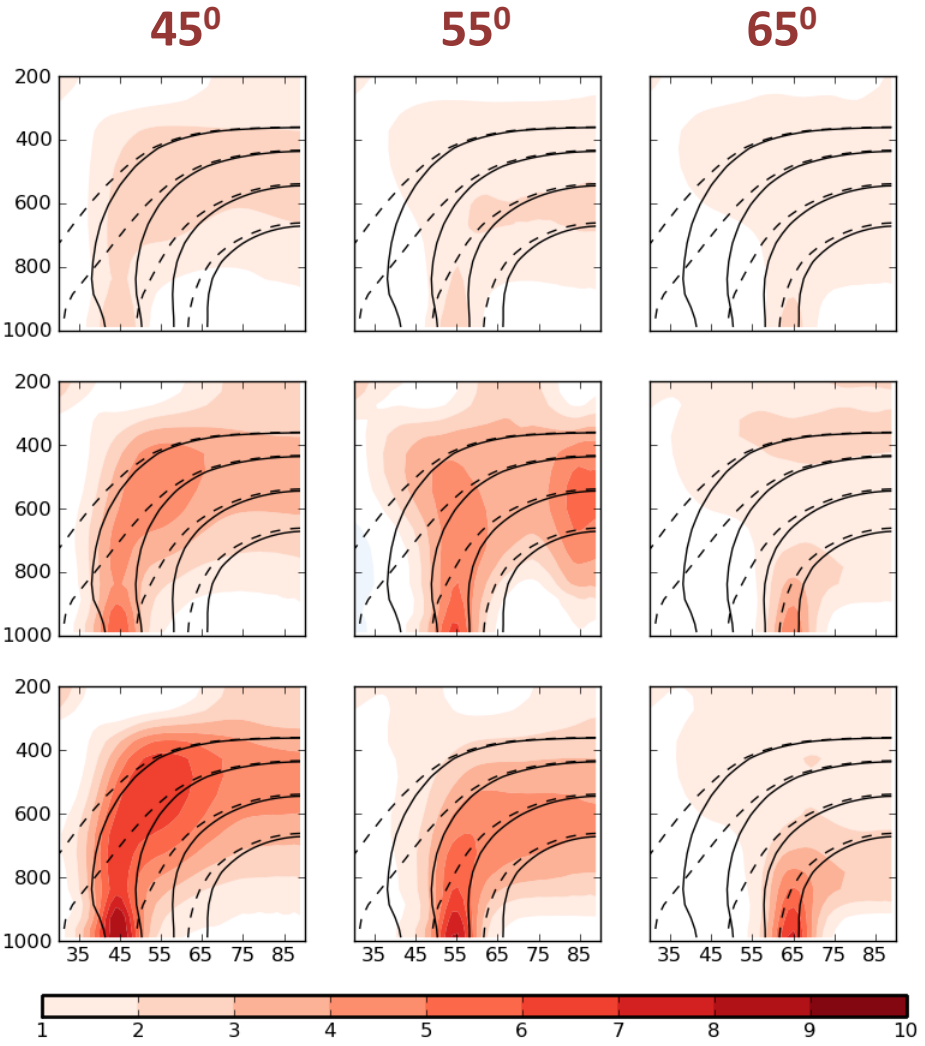
AGCM



- Why is the Arctic free tropospheric response to sea ice loss amplified in the coupled model?

Response to Midlatitude Surface Heating

- Simplified aquaplanet GCM.
- Transient (10-20) day response.
- Response roughly organized by θ_e distribution.
- Response warms and stabilizes the polar troposphere.



Solid: Control θ

Dashed: Control θ_e

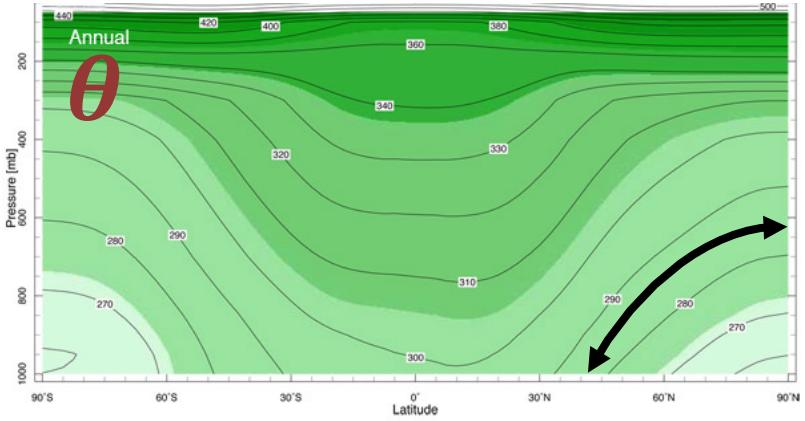
Fajber, Kushner, Laliberte in prep.

- **Topics of current interest:**
  - Consistent strengthening of the Aleutian Low
  - The “tug of war” on the circulation response over the North Atlantic
  - The non-additivity in the shoulder seasons.
  - A positive feedback from the North Pacific SST to the Arctic mid troposphere.

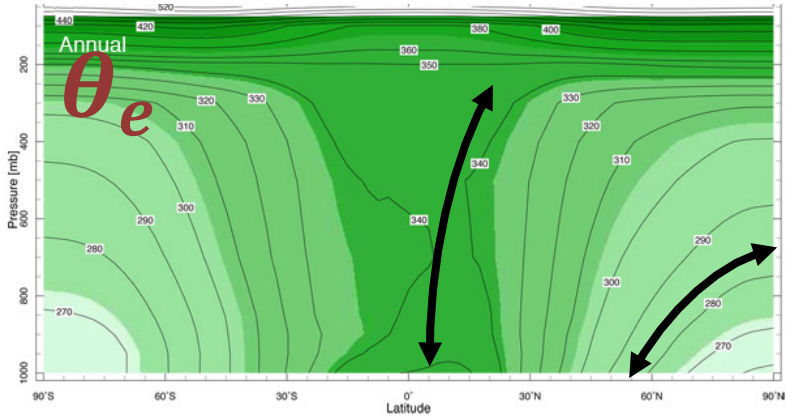
Extra slides

Entropy Perspective

Annual Mean Potential Temperature



Annual Mean Moist Potential Temperature

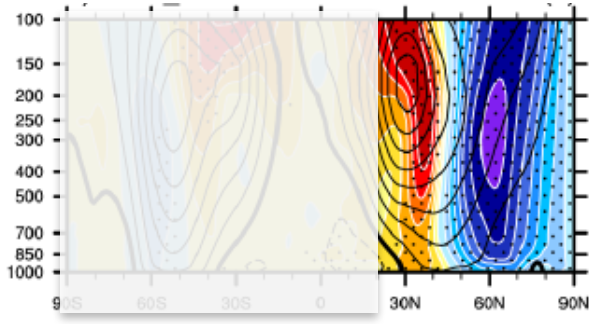


http://paoc.mit.edu/labweb/notes/chap5.pdf

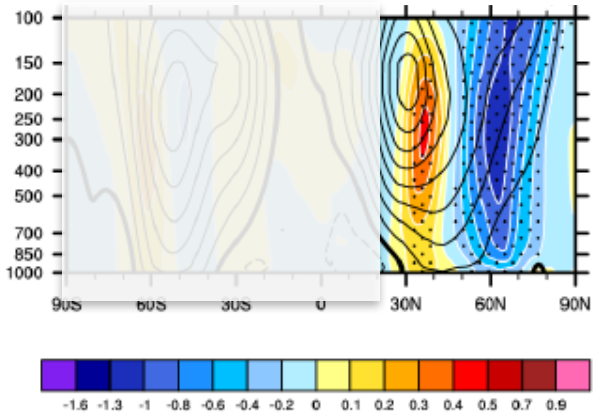
- Moist isentropic circulations in extratropical dynamics (Juckes 2000, Frierson 2008, Wu and Pauluis 2014, Laliberté and Kushner 2014)
- Isentropes link the Arctic troposphere to the midlatitude surface.

Zonal mean DJF U Response to Sea Ice Loss

Coupled ocean atmosphere GCM

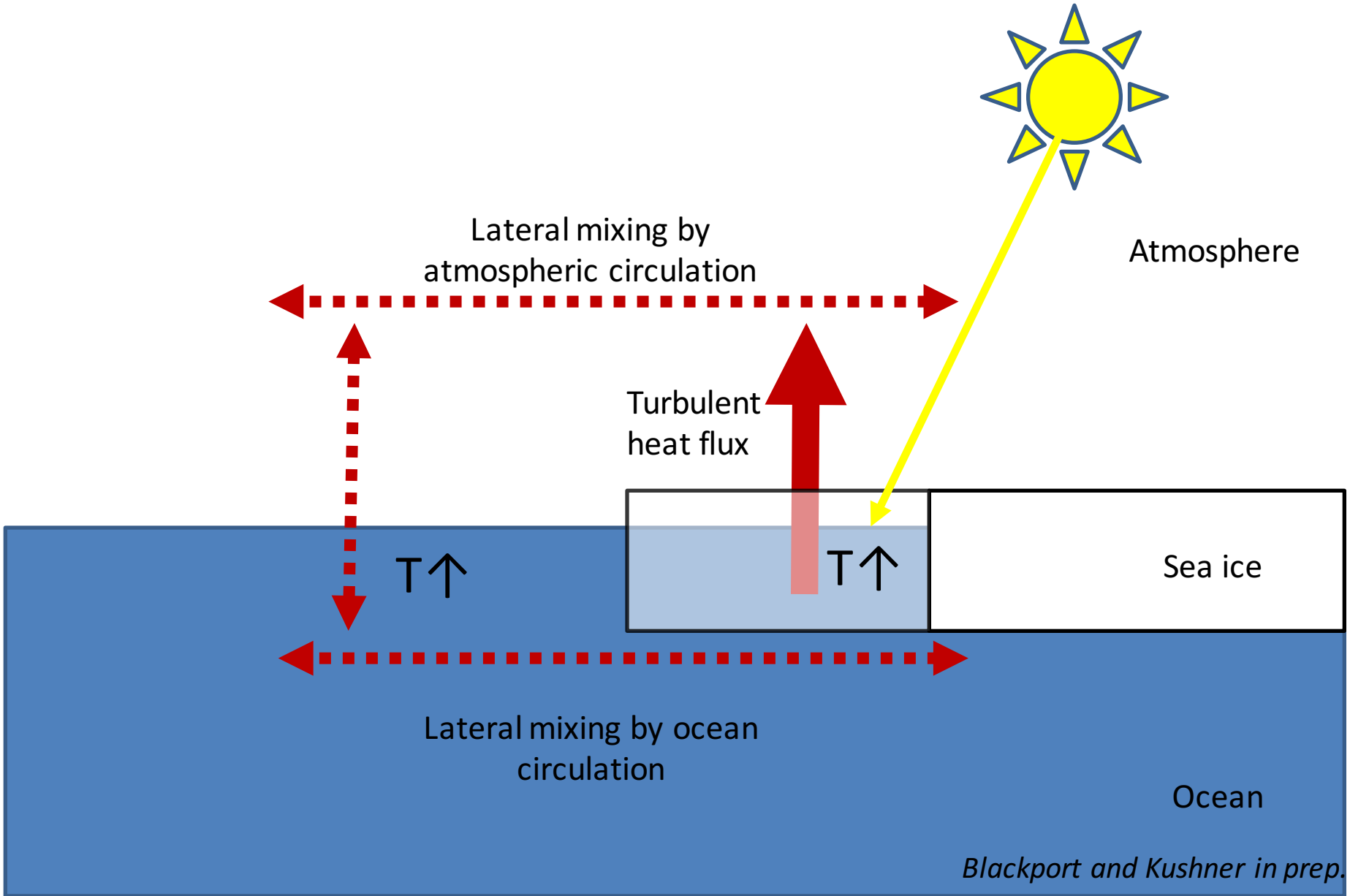


AGCM



- Circulation is also impacted by coupling.

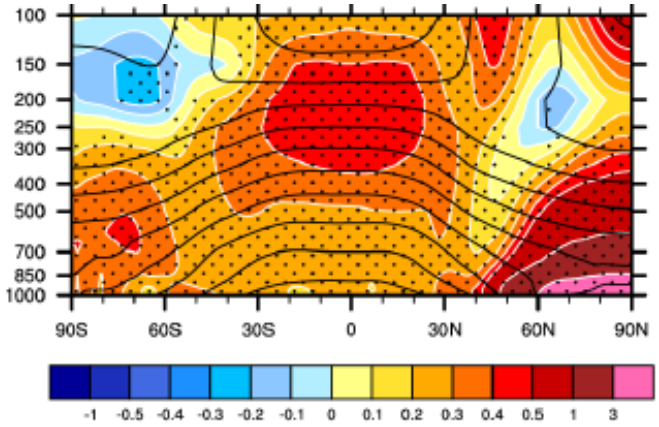
Ocean warming from sea-ice loss



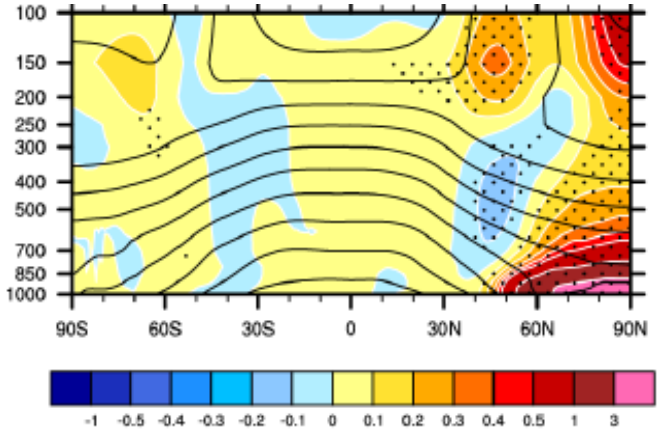
Blackport and Kushner in prep.

Zonal mean DJF T Response to Sea Ice Loss

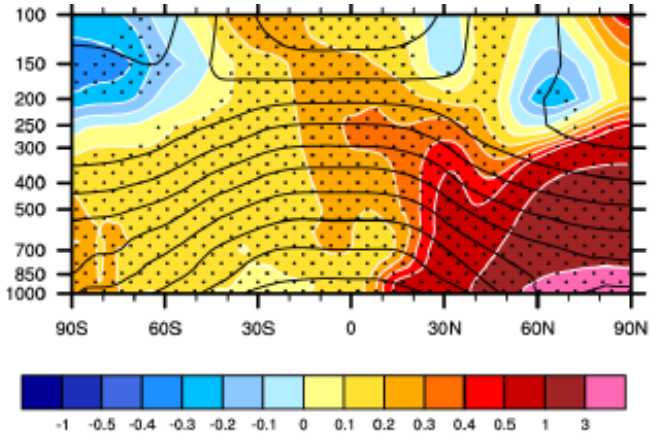
Coupled ocean atmosphere GCM



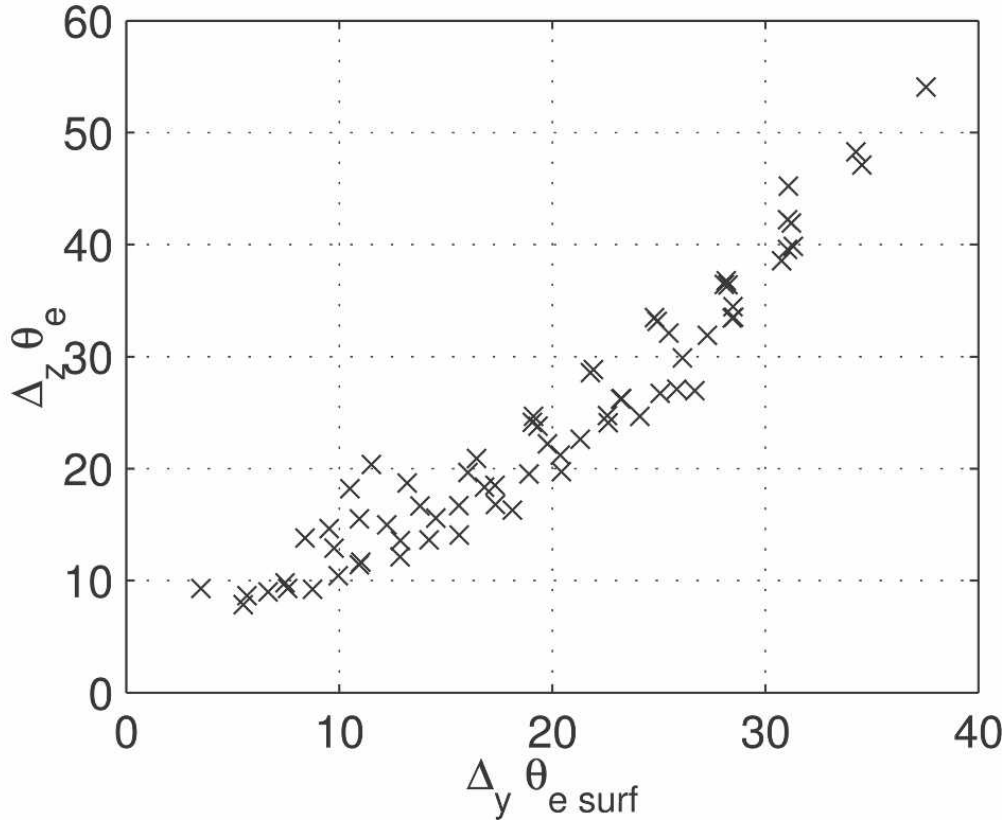
AGCM



Slab Ocean Model + AGCM



Midlatitude Responses in GCMs (Frierson 2008)

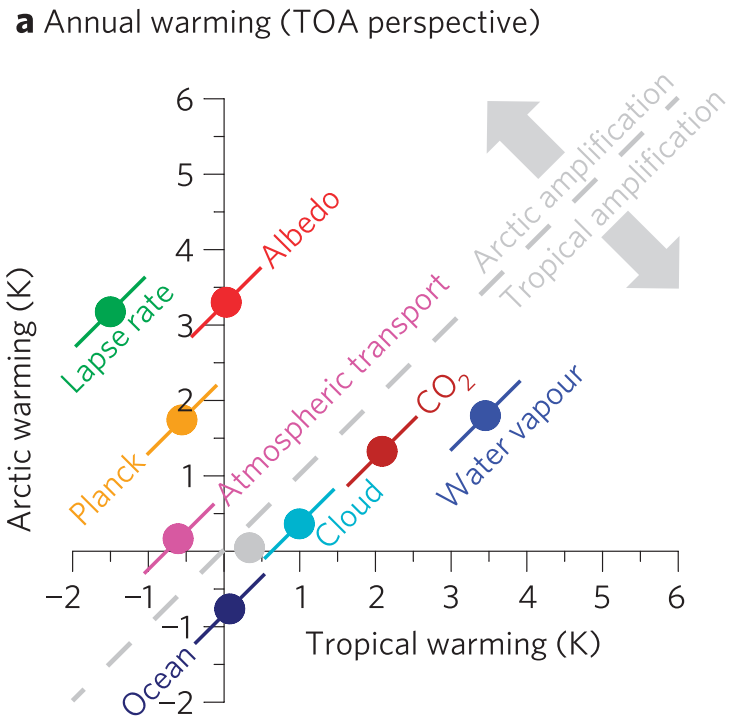


- Bulk stability up to tropopause versus θ_e gradient of baroclinic zone in aquaplanet comprehensive GCMs.

Questions

- Can we improve on the prescribed SST framework to study this feedback process?
- Moist isentropic mechanisms are better established in summer/shoulder seasons. In winter, can it be disentangled from other mechanisms, such as tropical moisture driving surface polar amplification (Sukyoung Lee et al.)?
- What are the broader implications of this enhanced Arctic tropospheric warming?

How might Arctic free tropospheric warming impact surface Arctic amplification?



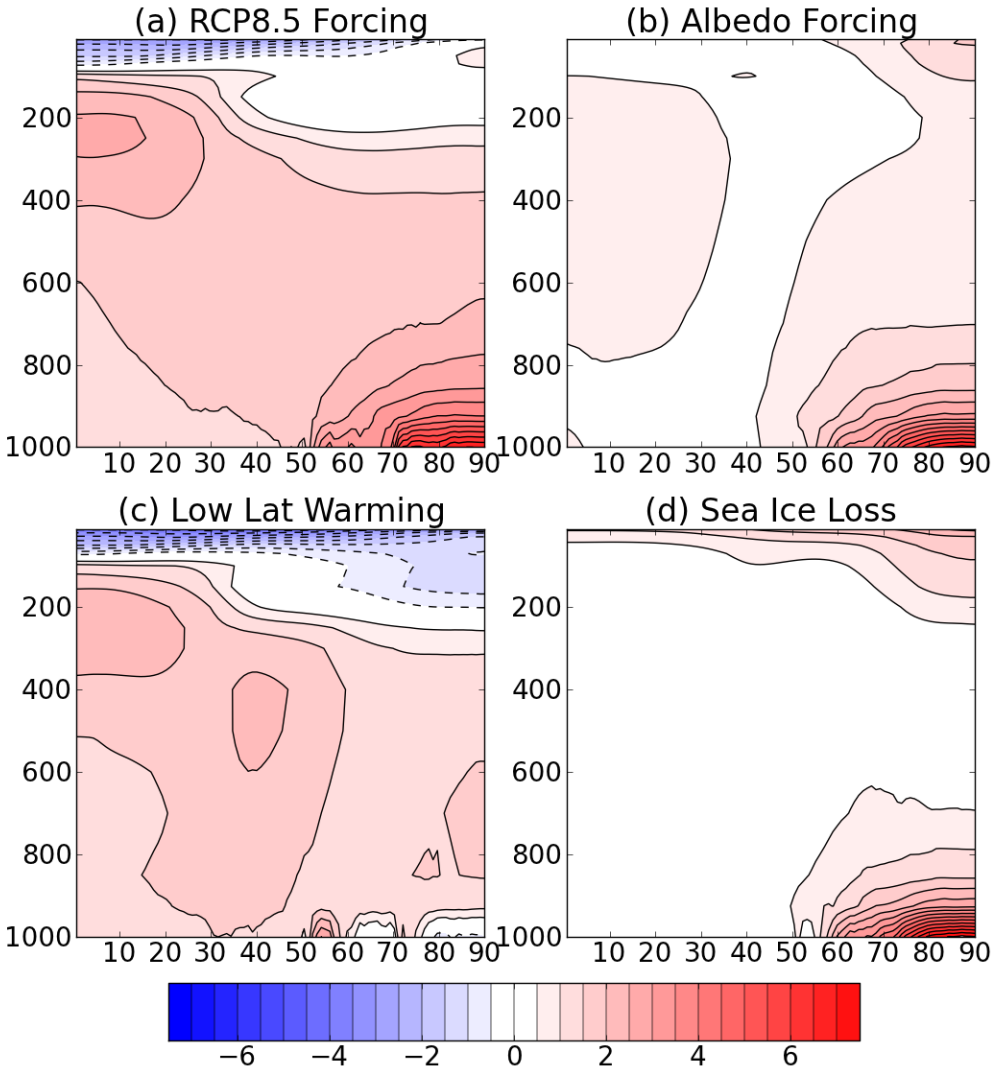
Pithan & Mauritsen 2014

- Coupled response to sea ice loss influences Arctic lapse rate and related radiative feedbacks.

$\Delta[T]$, DJF

Coupled Model Experiments

Diagnosed Decomposition

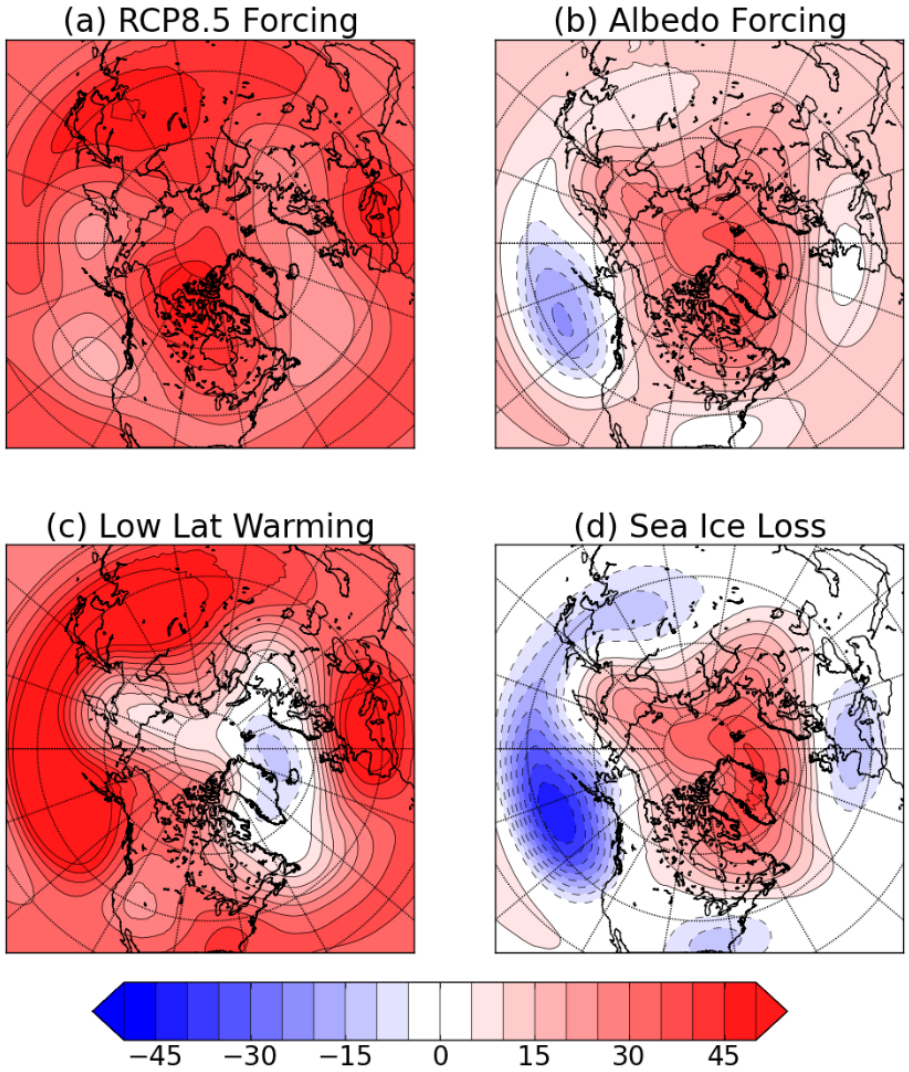


Blackport and Kushner (in press)

$\Delta Z500$, DJF

Coupled Model Experiments

Diagnosed Decomposition

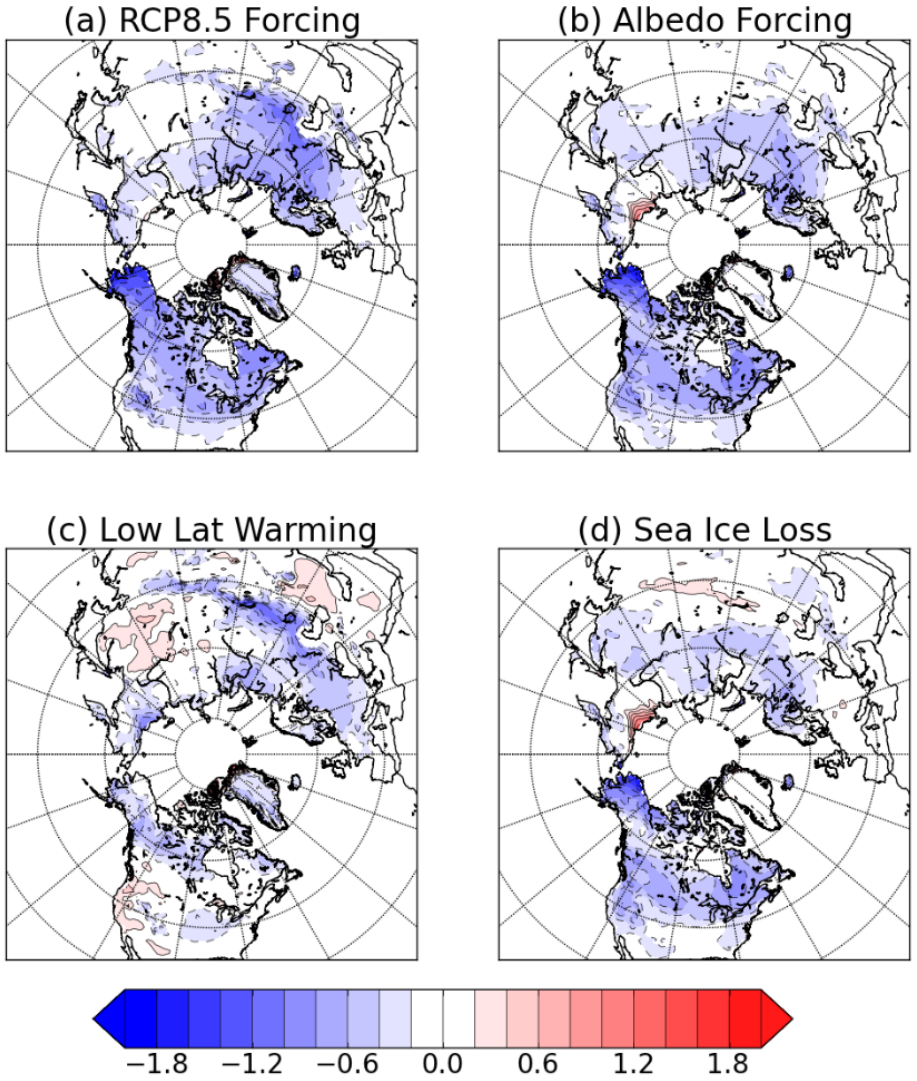


Blackport and Kushner (in press)

Change in subseasonal T_{2m} variability, DJF

Coupled Model Experiments

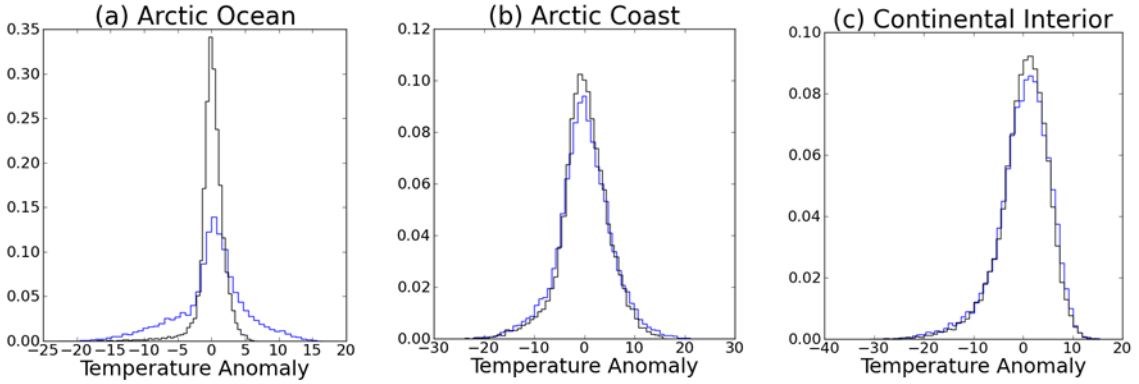
Diagnosed Decomposition



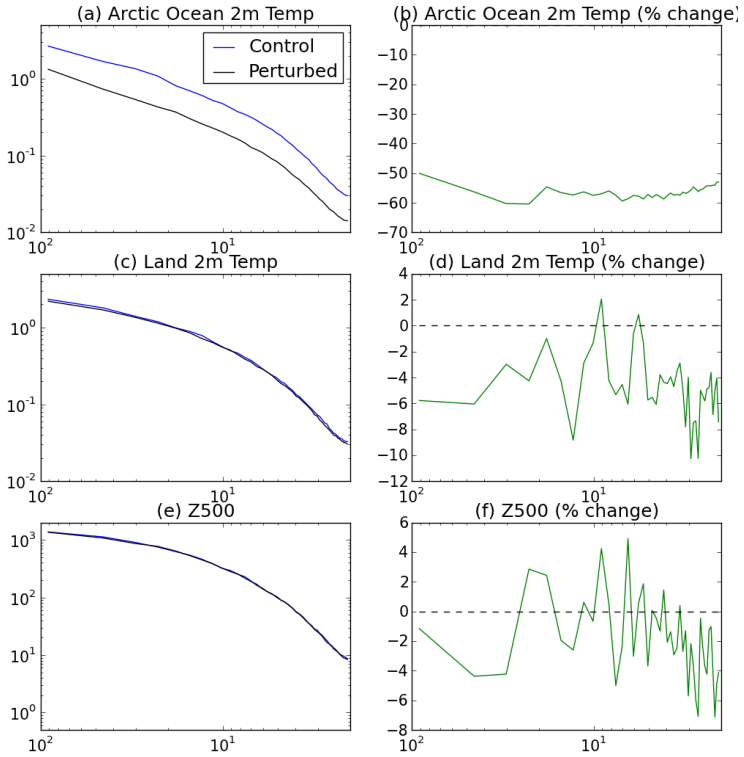
Blackport and Kushner (in press)

- Sea ice loss creates a more maritime environment.
- Stronger ocean-atmosphere coupling and polar amplification reduce temperature variability over the ocean and close to coasts.
- We generally find that polar amplification leads to a weakening of the storm tracks, but with lots of structural details.

Distributions of T2m at Selected Points, CCSM4



Time Spectra for CCSM4 Experiments

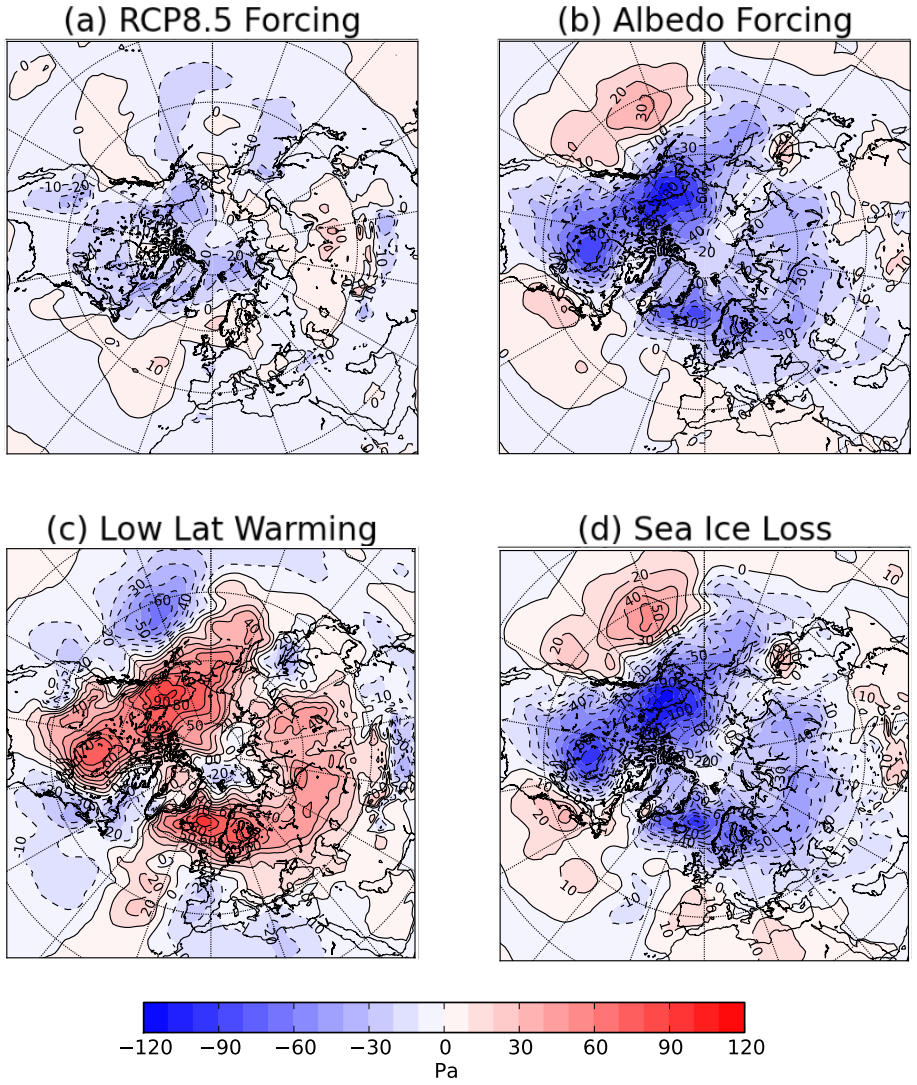


Blackport and Kushner 2016

Change in 2-6 Day Band Pass SLP, DJF

Coupled Model Experiments

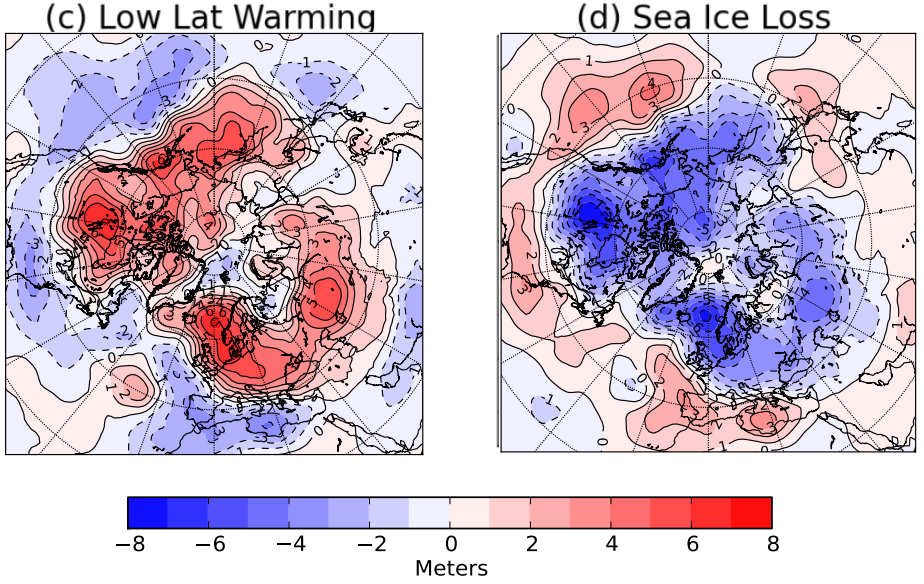
Diagnosed Decomposition



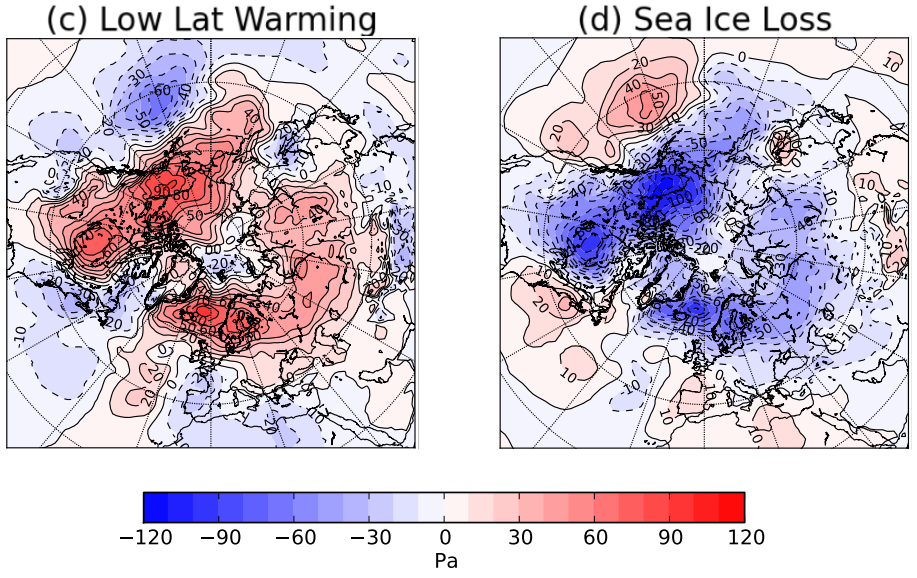
Euan Joly-Smith

Change in 2-6 Day Band Pass SLP and Z500, DJF

Diagnosed Decomposition 2-6 Day Band Pass Z500



Diagnosed Decomposition 2-6 Day Band Pass SLP

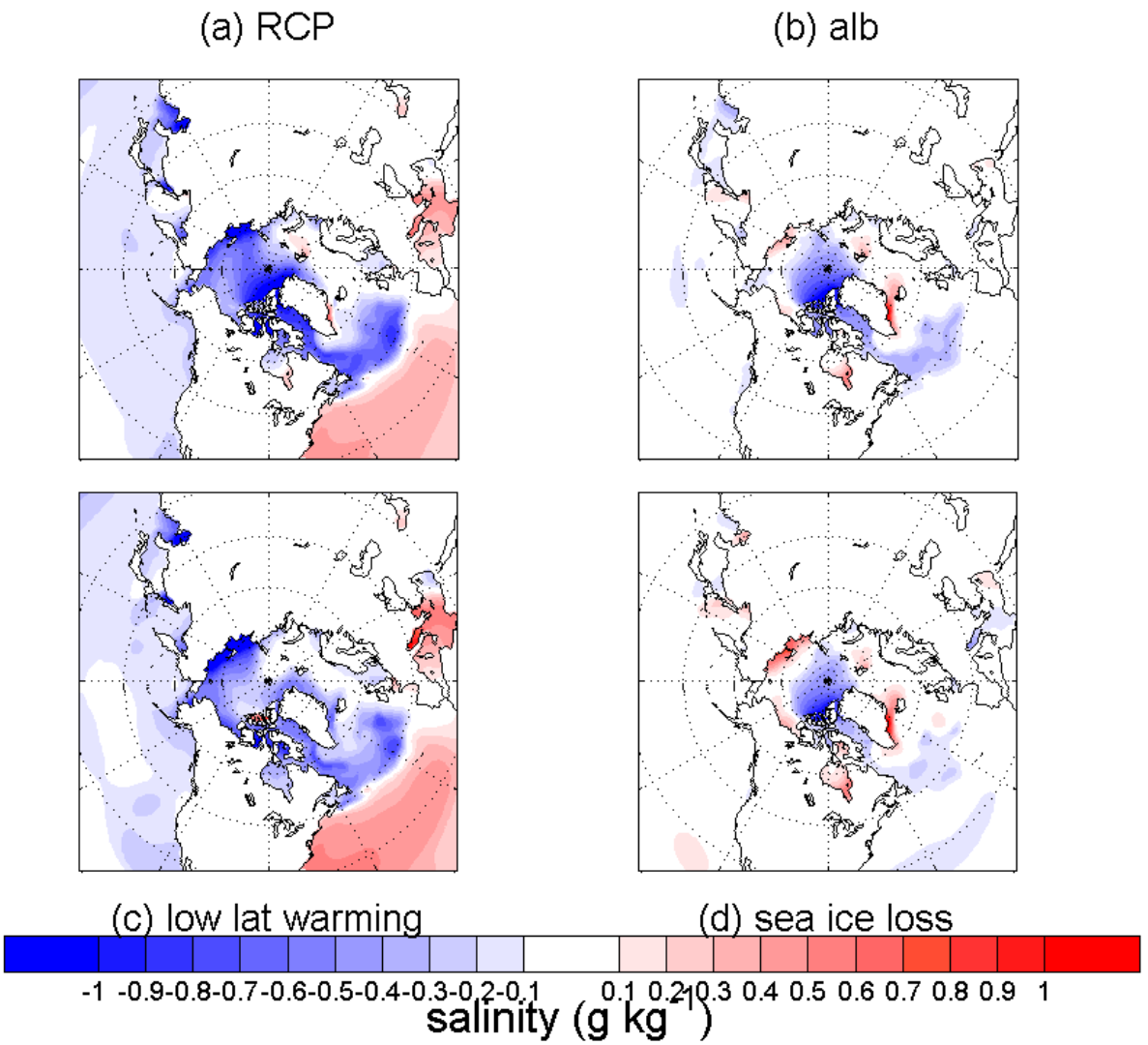


Euan Joly-Smith

DJF Sea Surface Salinity Response

Coupled Model Experiments

Diagnosed Decomposition

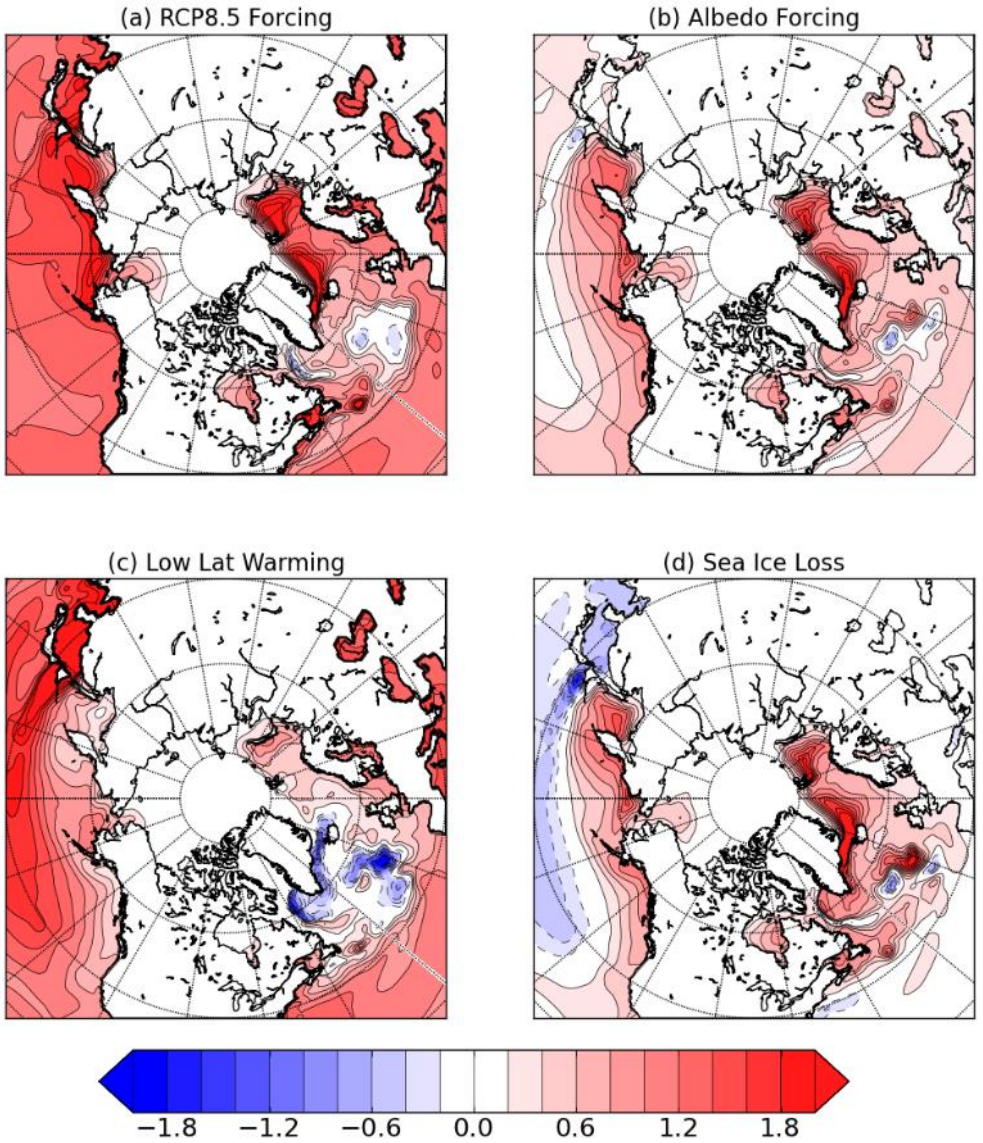


Hay et al. in prep.

DJF Ocean Surface Temperature Response

Coupled Model Experiments

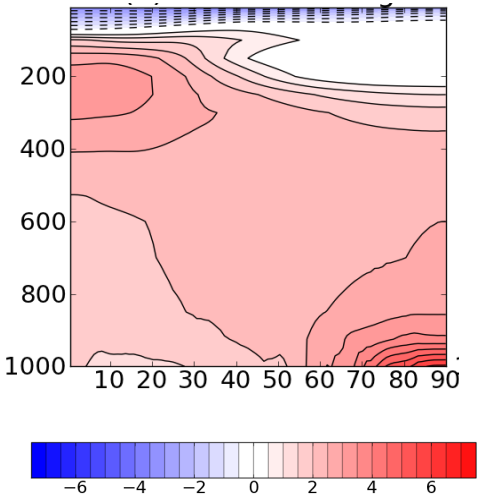
Diagnosed Decomposition



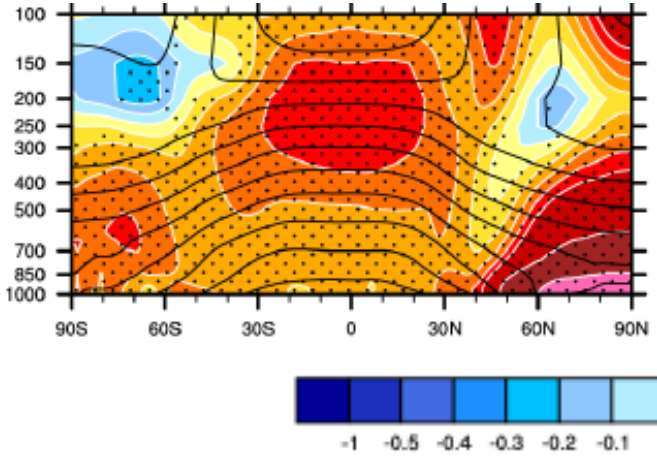
Hay et al. in prep
Blackport and Kushner in prep.

Can we Isolate the Impact of Sea Ice Loss on Circulation?

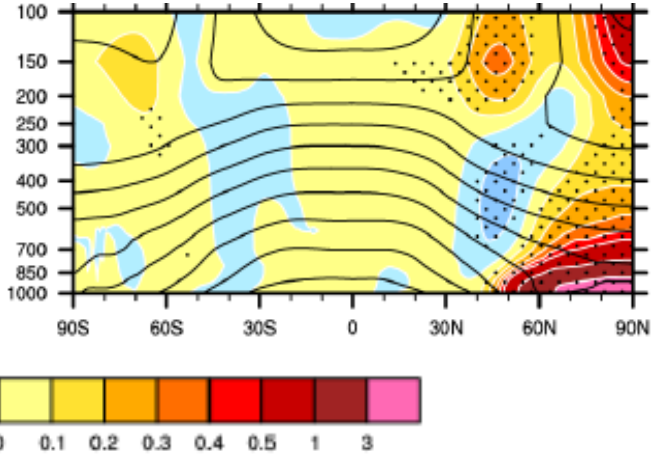
CESM1 RCP8.5 $\Delta[T]$



CCSM4 Sea Ice Loss $\Delta[T]$



CAM4 Sea Ice Loss $\Delta[T]$



Deser et al. 2015