How the Midlatitude Surface Influences the Polar Troposphere in Observations and Models

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Department of Physics, University of Toronto

Laliberté and Kushner, J. Climate 2014 and in prep.
Fajber et al. in prep.
CESM AMWG Meeting, February 2017

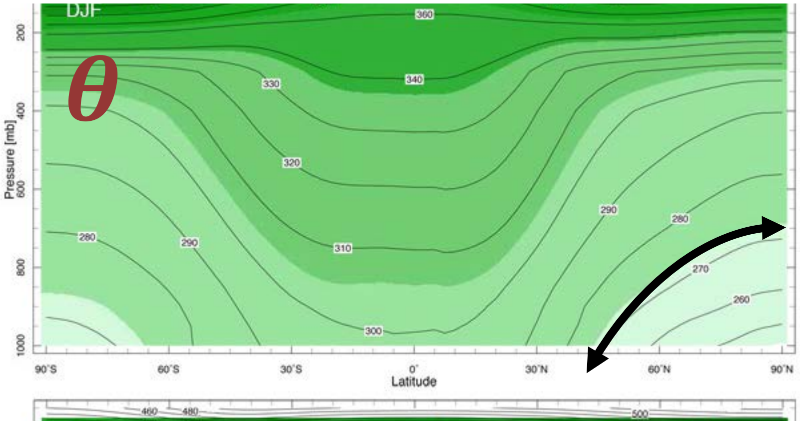
Feedbacks and Polar Amplification

Pithan & Mauritsen 2014

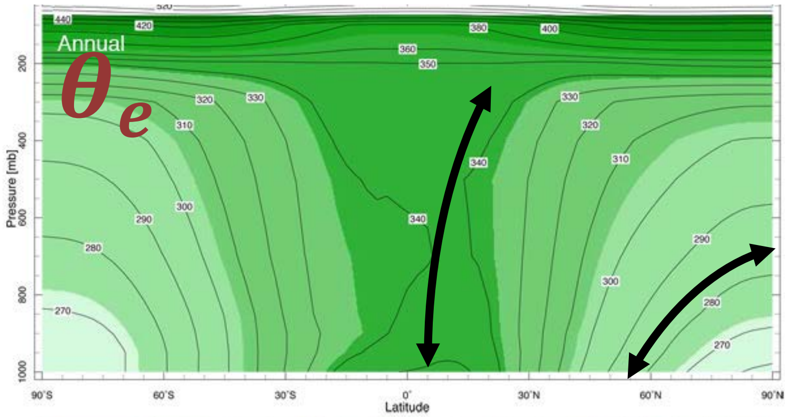
- Lapse-rate feedback contributes comparably to albedo feedback to drive polar amplification.
- What are the dynamical controls on the Arctic lapse rate?

Entropy Perspective (Frierson 2008, Pauluis 2008)

Annual Mean Potential Temperature



Annual Mean Moist Potential Temperature

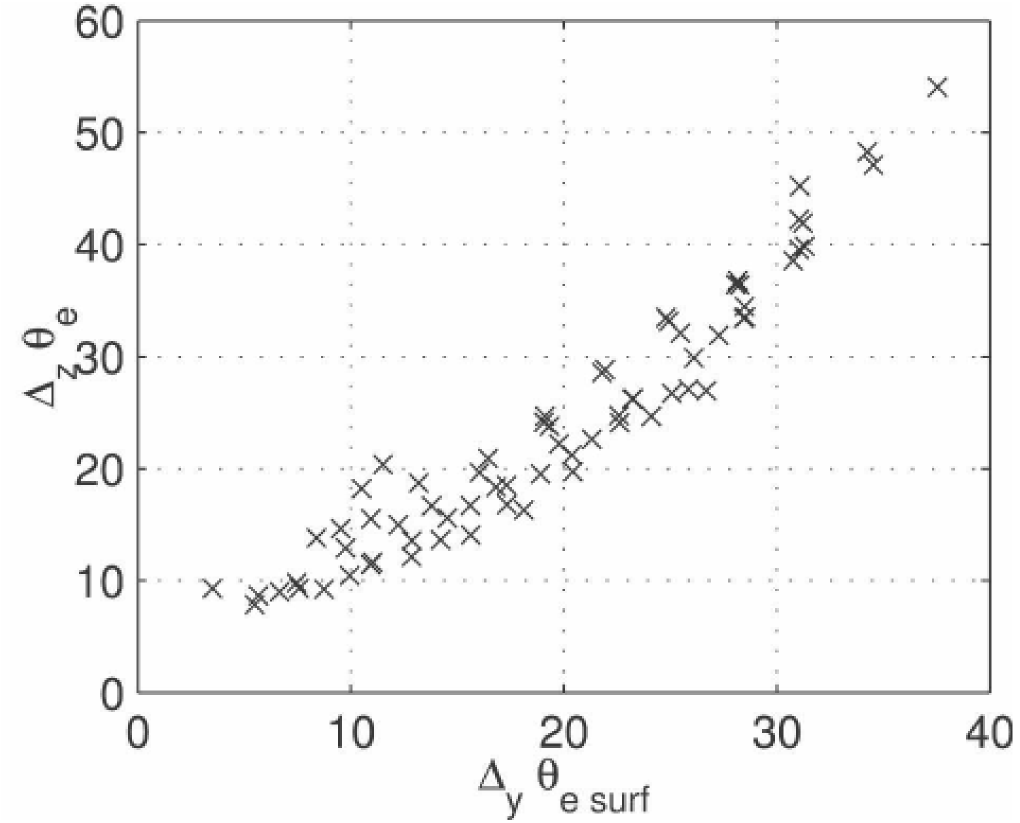


http://paoc.mit.edu/labweb/notes/chap5.pdf

- The extratropical wave-driven circulation moves mass along isentropic surfaces.
- Isentropes link the Arctic troposphere to the lower latitude surface.
- Midlatitude surface moist isentropes are 10-15^0 latitude poleward of corresponding dry isentropes.

Surface Baroclinicity and Stratification Are Linked

Bulk Moist Stability up to Tropopause



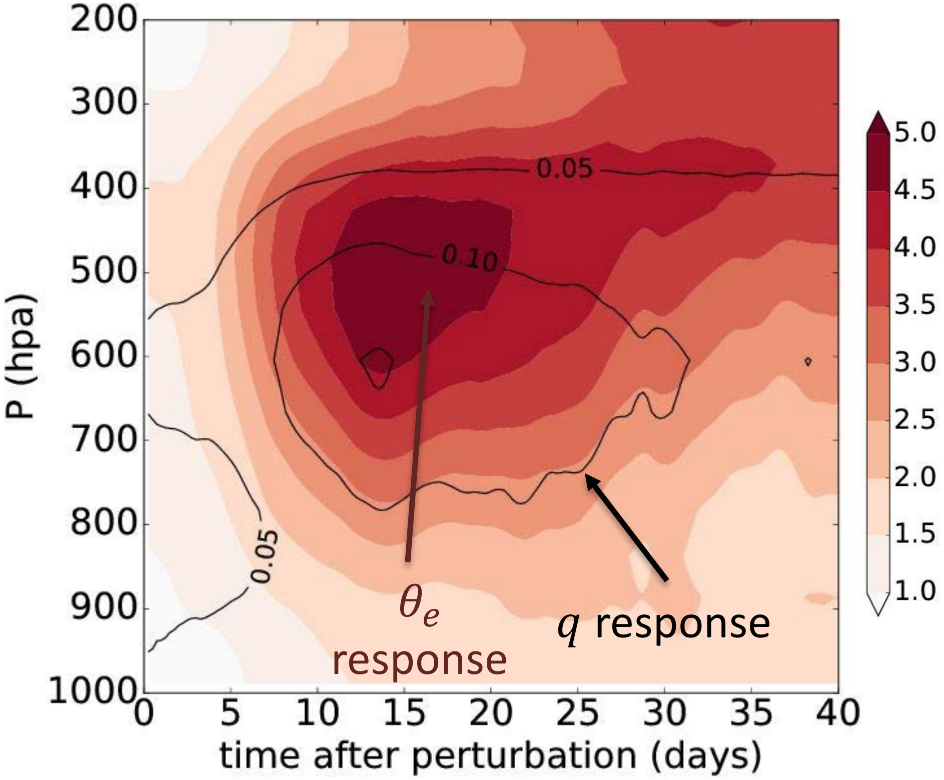
Surface moist potential temperature gradients

Frierson 2008

- There is a tight connection between the horizontal and vertical distribution of moist entropy in aquaplanet GCMs.

Response to Midlatitude Heating in a Relatively Simple Moist GCM (Fajber et al., in prep)

Polar-cap response to switch-on surface heating at 45^0N



θ_e response

q response

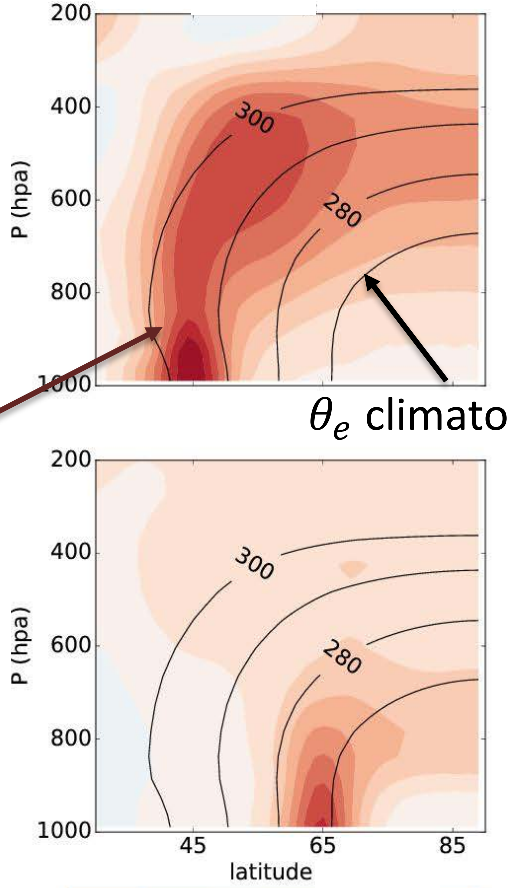
Day 10-20 θ_e Response

Heating at 45N

θ_e response

θ_e climatology

Heating at 65N



- Peak heating amplified in free troposphere, 10-20 days after perturbation.
- Response oriented along moist isentropic surfaces.

Aims of this project

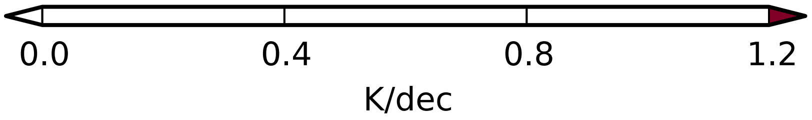
- Investigate connections between surface thermal anomalies and Arctic midtropospheric warming via moist isentropic circulation.
- Explore this connection in models.

August trends, 1979-2012

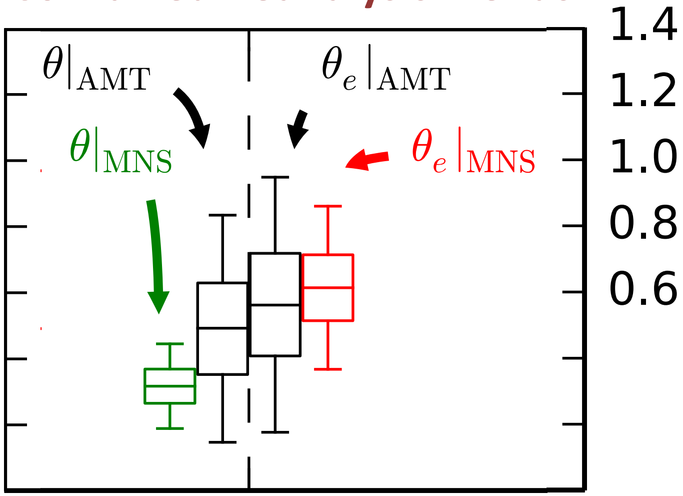
MERRA **ERA-INTERIM**

θ

θ_e



Combined Reanalysis Trends



AMT = **A**rctic **M**id-**T**roposphere

MNS = **M**idlatitude **N**ear **S**urface

LK 2014 and in prep

- Long-term trends reflect propagation of surface signals along moist isentropes more than along dry isentropes.

Summertime θ_e Propagation

Reanalysis

August Arctic Midtroposphere θ_e

Predicted from July

August Arctic midtropospheric θ_e with July near surface θ_e

–

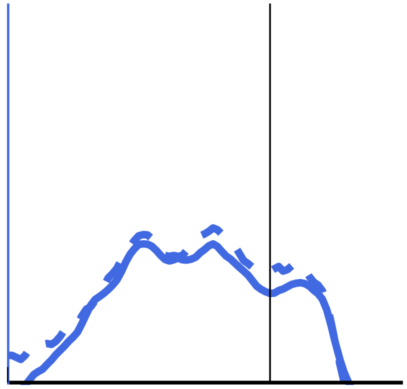
- July midlatitude surface θ_e anomalies lead August Arctic midtropospheric θ_e anomalies.
- July θ_e hotspots are concentrated over land.
- Polar-cap Arctic midtropospheric θ_e budget is dominated by a handful of large wave driven flux events each season.

Laliberté and Kushner 2014

Fast and Slow Intraseasonal Couplings

Lag regressions in reanalysis products

1. Midlatitudes: near-surface to midtroposphere (< 1 week)
2. Arctic: midtroposphere to near-surface (< 1 week).
3. Midlatitude near-surface to Arctic midtroposphere (several weeks).



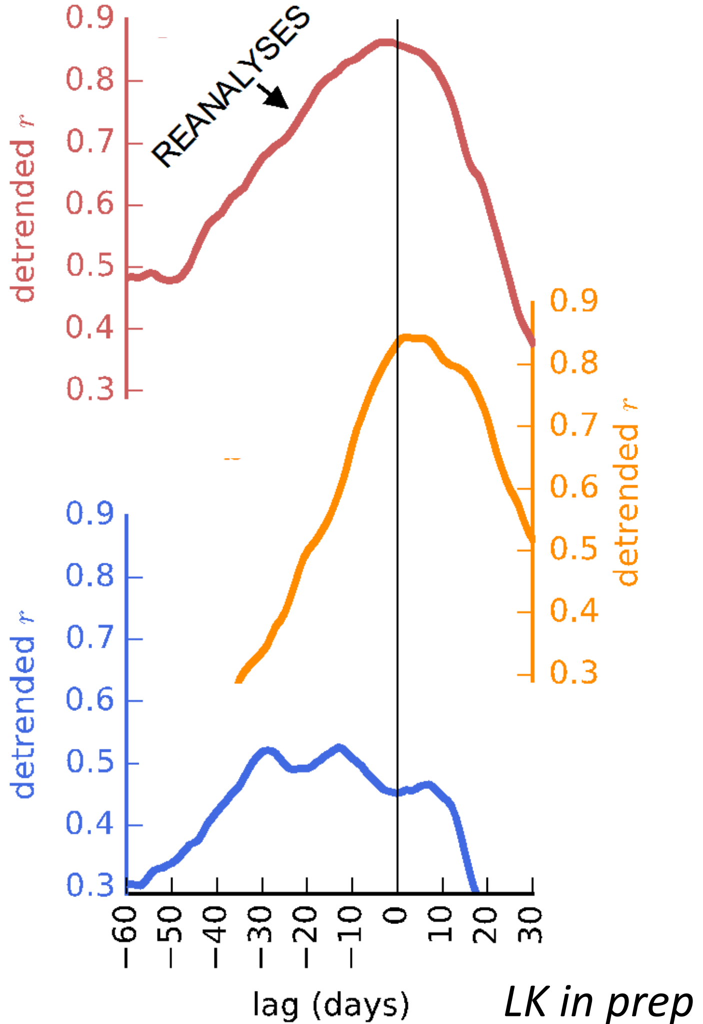
LK in prep

Fast and Slow Intraseasonal Couplings

- Models capture the fast vertical couplings to some degree.

- But struggle to capture the slow midlatitude surface/Arctic coupling.

Lag regressions in CMIP historical/RCP4.5

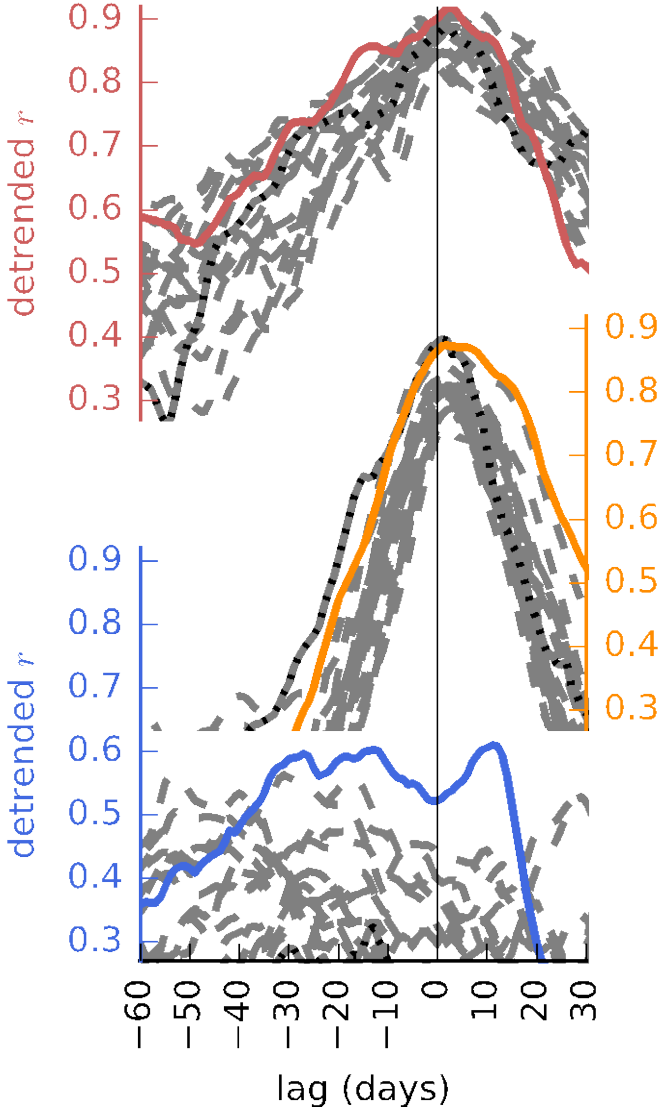


LK in prep

Highlighting CCSM4 and CanESM

CanESM and CCSM4 are shown as grey lines.

These two models are within the range of other CMIP5 models.



Reanalysis lines (thick) include several reanalysis products.

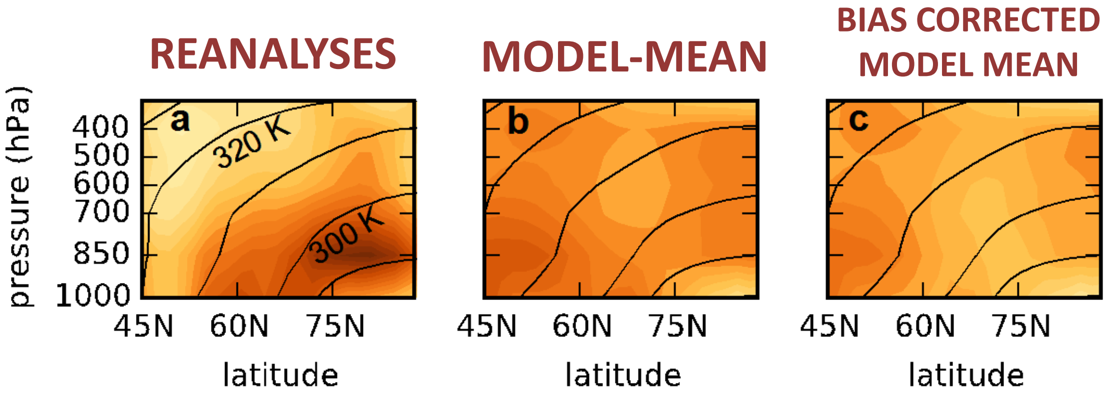
LK in prep

In CMIP5, Arctic θ_e changes are generally disconnected from midlatitude warming.

But models that capture the intraseasonal connection (red outline) tend to exhibit a stronger midlatitude/polar linkage.

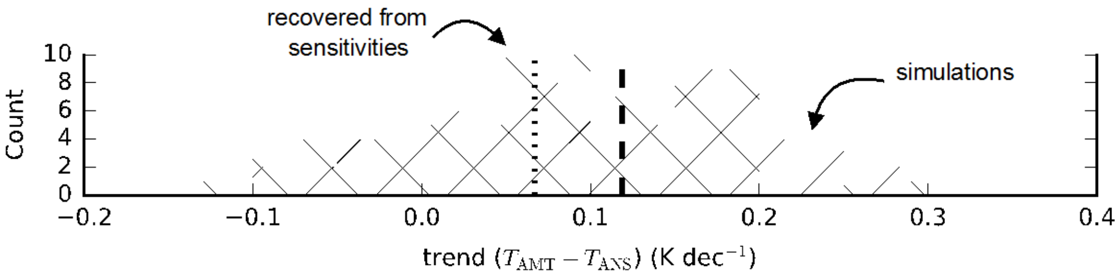
Generally, the distribution of midlatitude surface trends is consistent with Arctic free tropospheric warming trends.

1979-2012 Trends



CANESM2 **BNU-ESM** **CCSM4**

Propagated and Actual θ_e Trends



Key Ideas

The large-scale wave-driven *moist isentropic circulation* connects the midlatitude surface to the Arctic midtroposphere, particularly in summer.

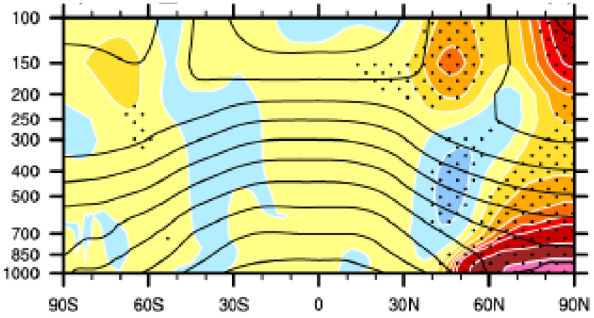
Midsummer midlatitude surface heating leads late-summer Arctic midtropospheric heating, on intraseasonal to multidecadal timescales.

GCMs capture some aspects of the observed linkage, but they do this somewhat weakly.

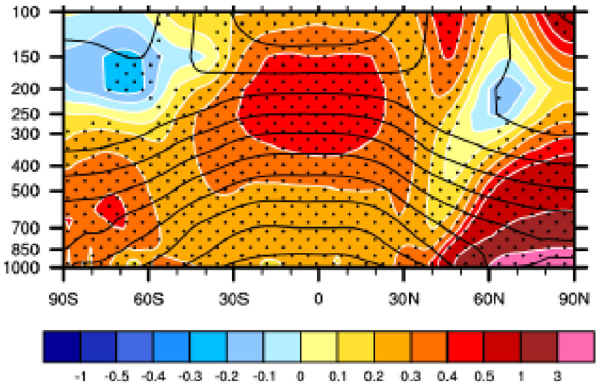
We suggest monitoring this midlatitude-Arctic connection in CESM development.

Boreal Winter Temperature Responses

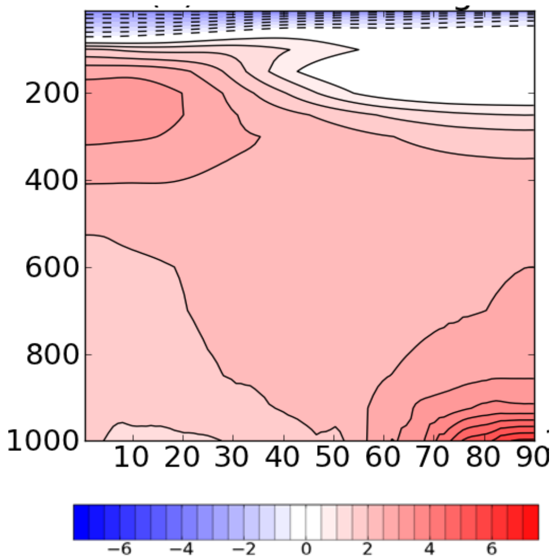
SICE, AGCM CAM5



Induced SICE, coupled CESM1



RCP8.5, CESM1



Screen et al. 2012, Perlwitz et al. 2015, Deser et al. 2015, Blackport and Kushner in press.

- Ocean coupling enhances Arctic free tropospheric warming in the sea ice loss process.
- This is presumably at work under climate change.
- Do midlatitude SSTs play a role in this warming?

Boreal Winter Temperature Responses

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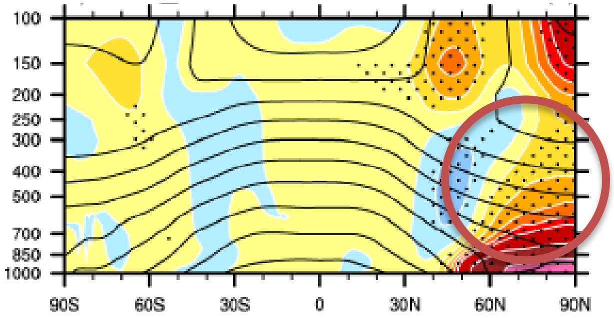

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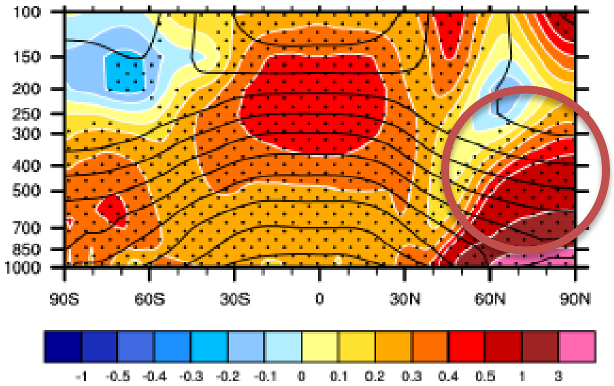

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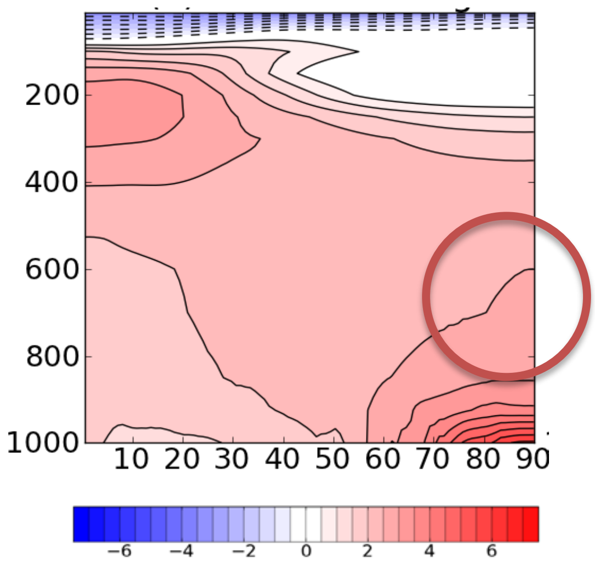

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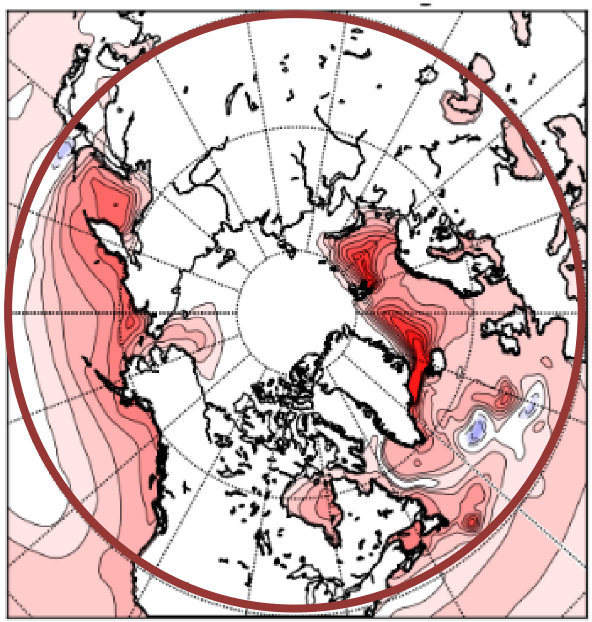
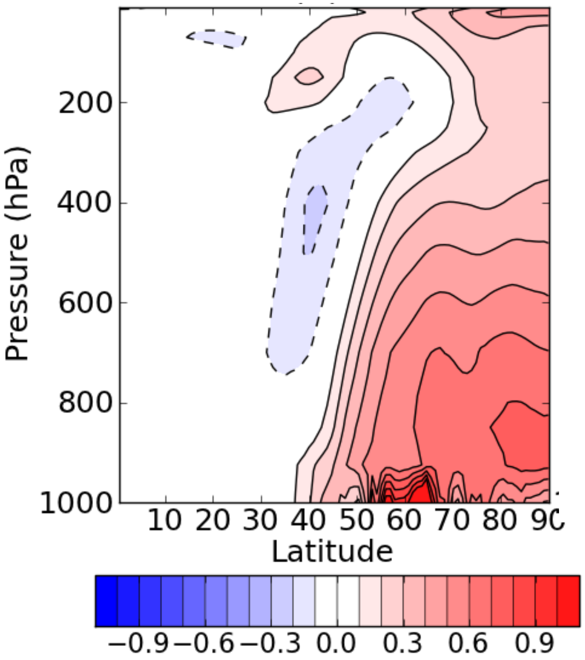
ΔSST, CESM1 Sea Ice Albedo

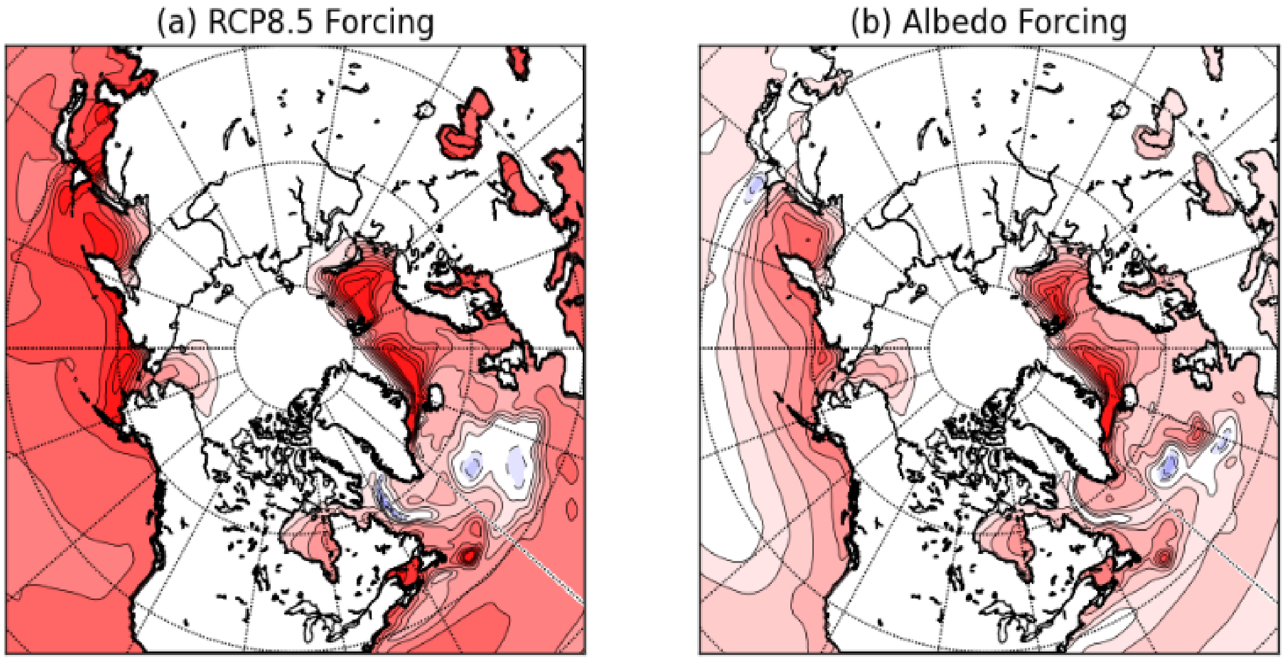


ΔT DJF, AGCM CAM5, ΔSST (40N+)



- In CAM5, we impose SST perturbation from the coupled sea ice albedo simulations, poleward of 40N (left).
- The result (right) suggests that ocean warming from sea ice loss significantly warms the polar troposphere.
- We have yet to diagnose the isentropic circulation response.

Ocean Warming Induced by Sea-Ice Loss



- Blackport and Kushner (in press) carried out sea ice albedo perturbation experiments in CESM1.
- This induced Arctic sea ice loss as well as hemispheric ocean warming (above right).