Pushing the Limits of Pattern Scaling to Separate Tropical and Polar Climate Change Signals

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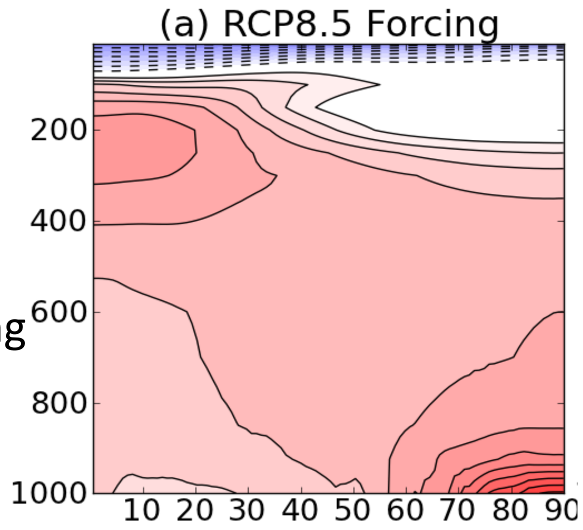
Key points:

- **We use pattern scaling to deal with different sea ice loss protocols and models.**
- **This analysis brings out both Arctic and tropical drivers.**
- **Pattern scaling fails in the North Atlantic sector given nonlinearity and experimental/model inconsistency.**

Response and Sensitivity for Zonal- and Annual-Mean Temperature, $[T]$

Response to greenhouse warming $\delta[T]_{GHG}$



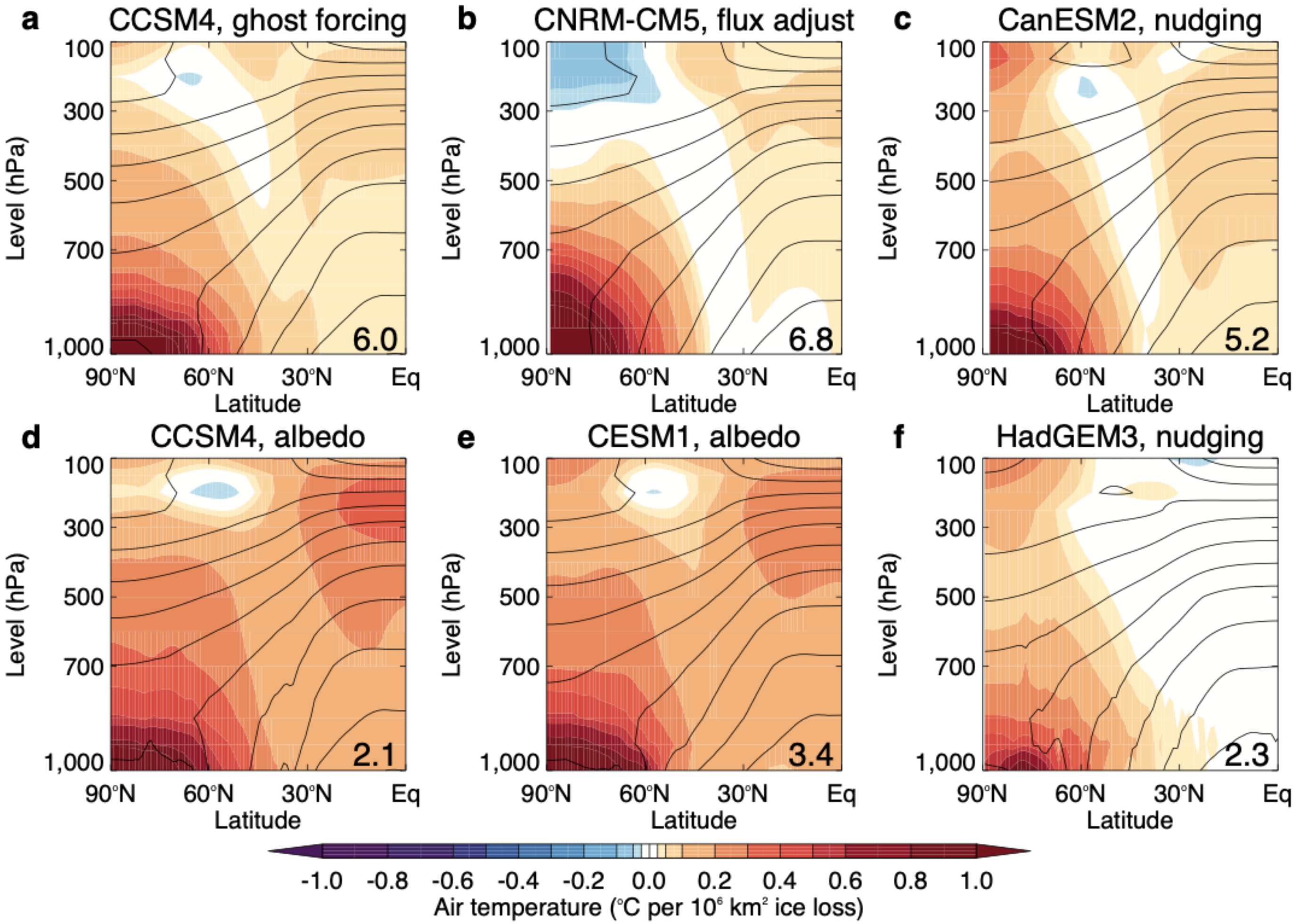
To account for cross coupling, Blackport and Kushner developed a multi-parameter pattern scaling approach.

Blackport and Kushner 2017

Mini Global Warming in the Response to Sea Ice Loss

- Coupled ocean-atmosphere models forced by sea ice loss exhibit *cross coupling* between Arctic and tropical responses.

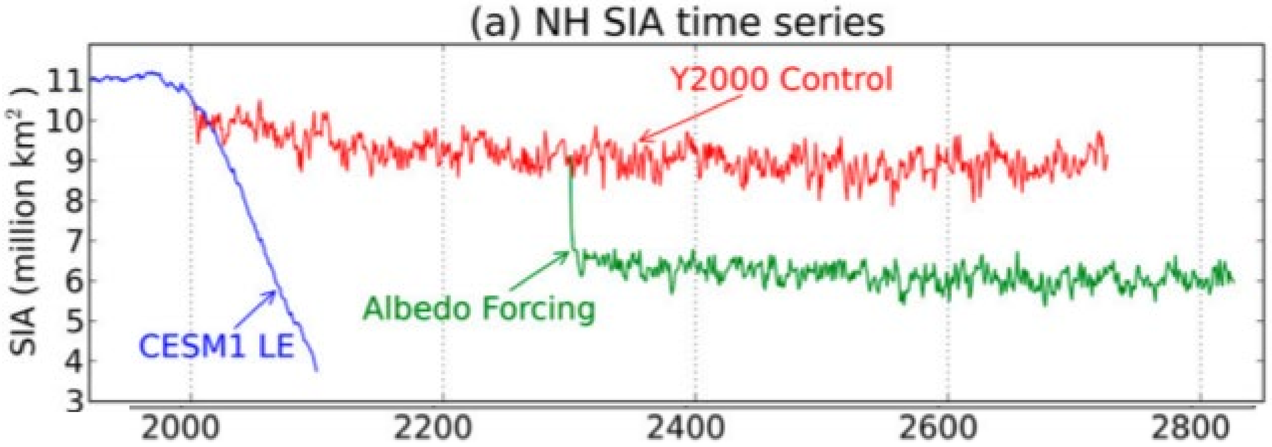
DJF T Response, per unit sea ice loss



Screen et al. 2018 (Deser et al. 2015, Oudar et al. 2017, Blackport and Kushner 2017, etc.)

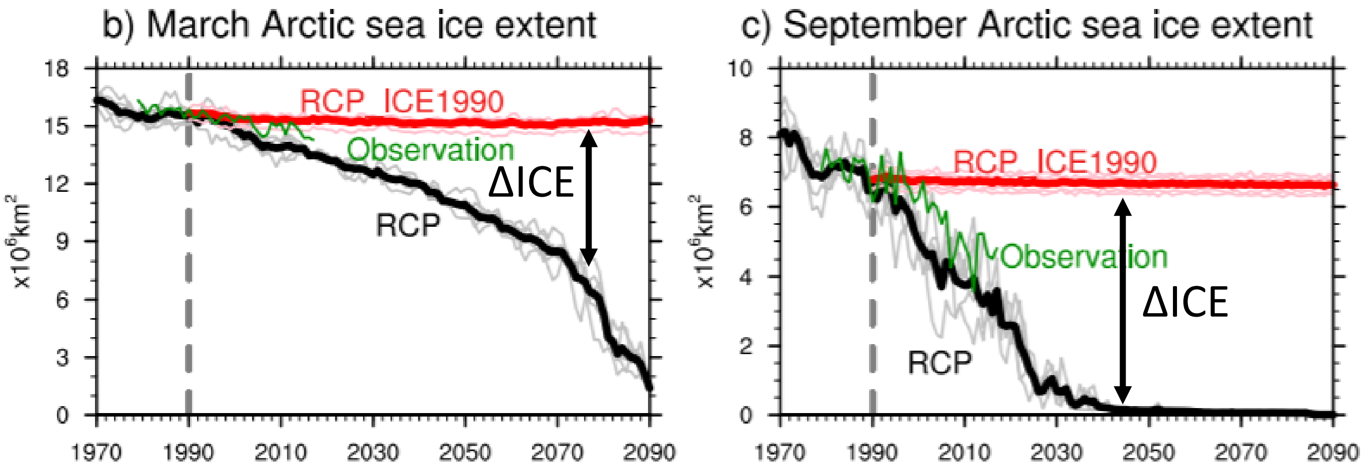
Different models and experimental protocols
⇒ *Model Experiments* (MEs)

Model: CESM1:
Experiments:
- Projected greenhouse warming (transient LENS RCP8.5)
- Albedo reduction (time slice)

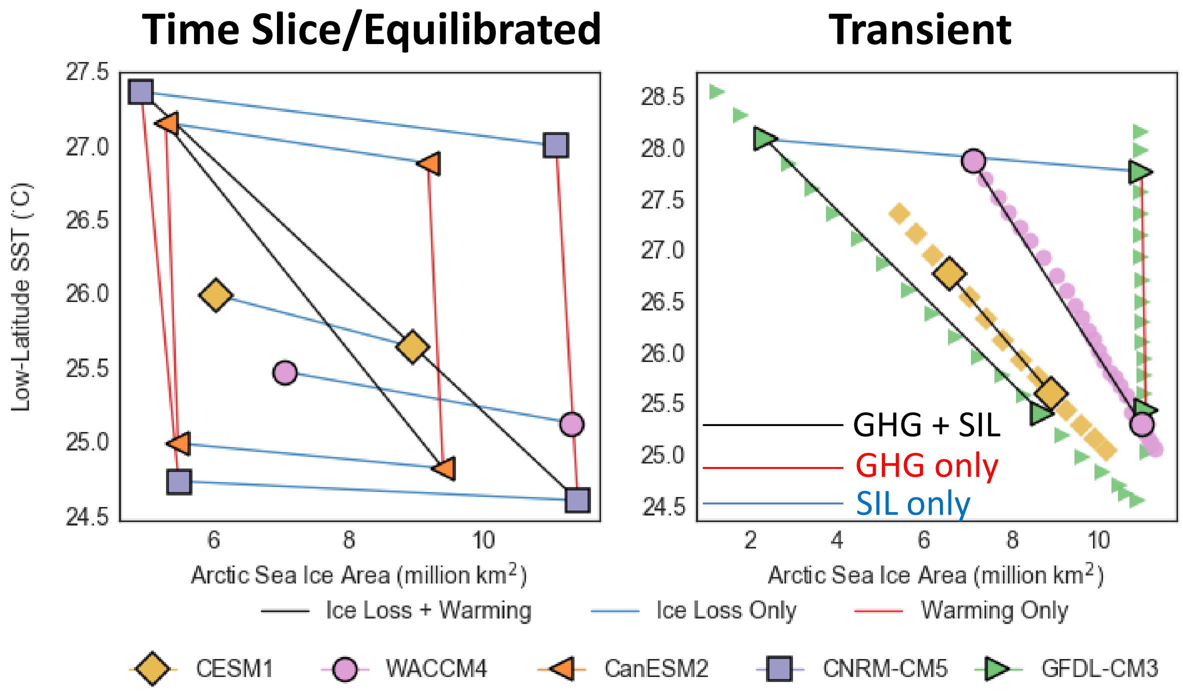


Blackport and Kushner 2017

Model: GFDL-CM3
Experiments:
- RCP8.5 (transient)
- Sea ice nudging (transient)



Sun et al. 2018



Hay et al. in prep

We combined five sets of model experiments (MEs), all featuring cross coupling.

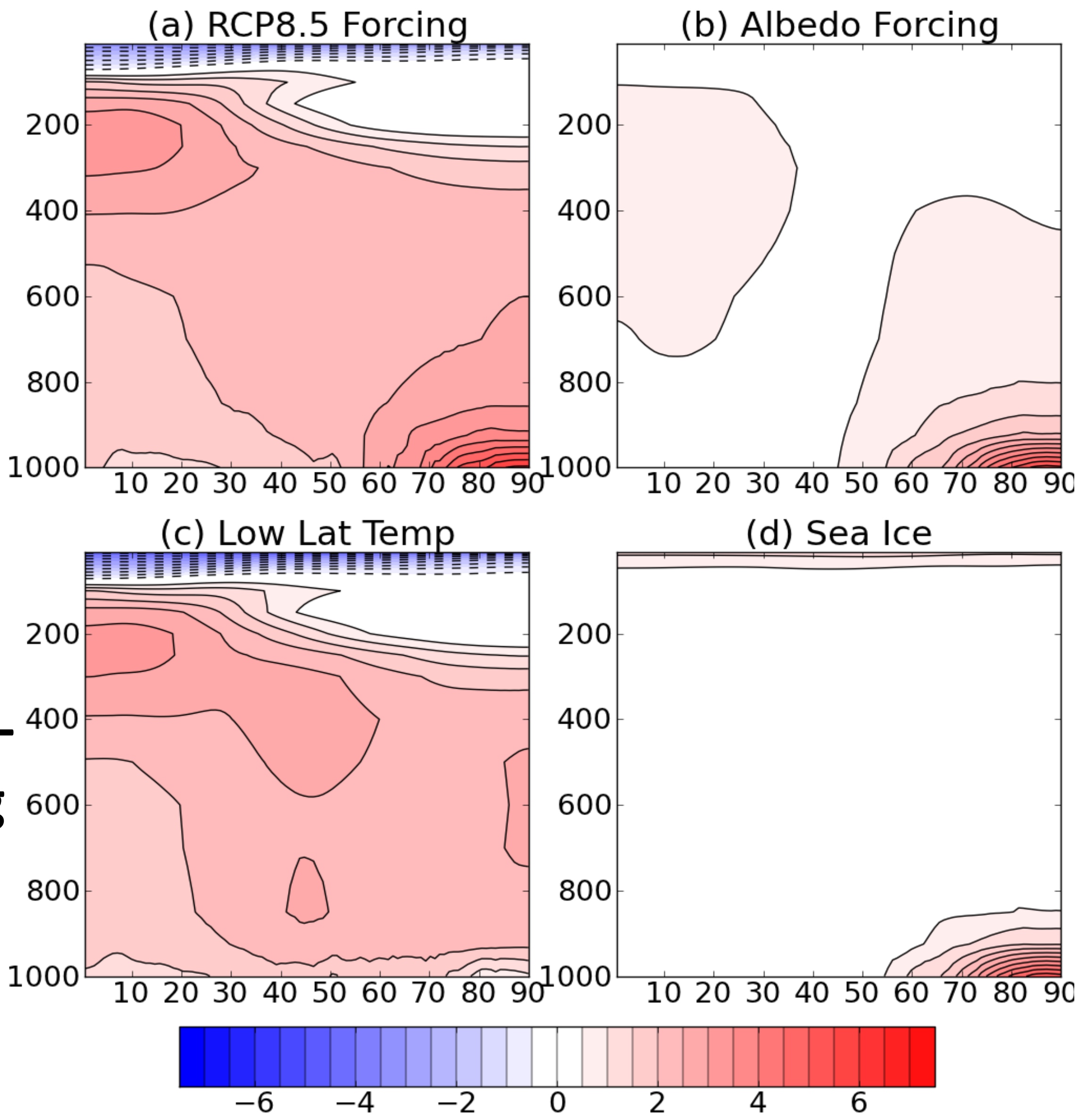
We use pattern scaling (e.g *Harvey et al. 2012, Blackport and Kushner 2017)* to find *sensitivity patterns*

- Sensitivity $\left(\frac{\partial Z}{\partial T_l}\right)_I$ of field Z to low-latitude warming in absence of sea ice loss.
- Sensitivity $\left(\frac{\partial Z}{\partial I}\right)_{T_l}$ of field Z to change in sea ice in absence of low-latitude warming.

Response and Sensitivity for Zonal- and Annual-Mean Temperature, $[T]$

Response to greenhouse warming
$\delta[T]_{GHG}$

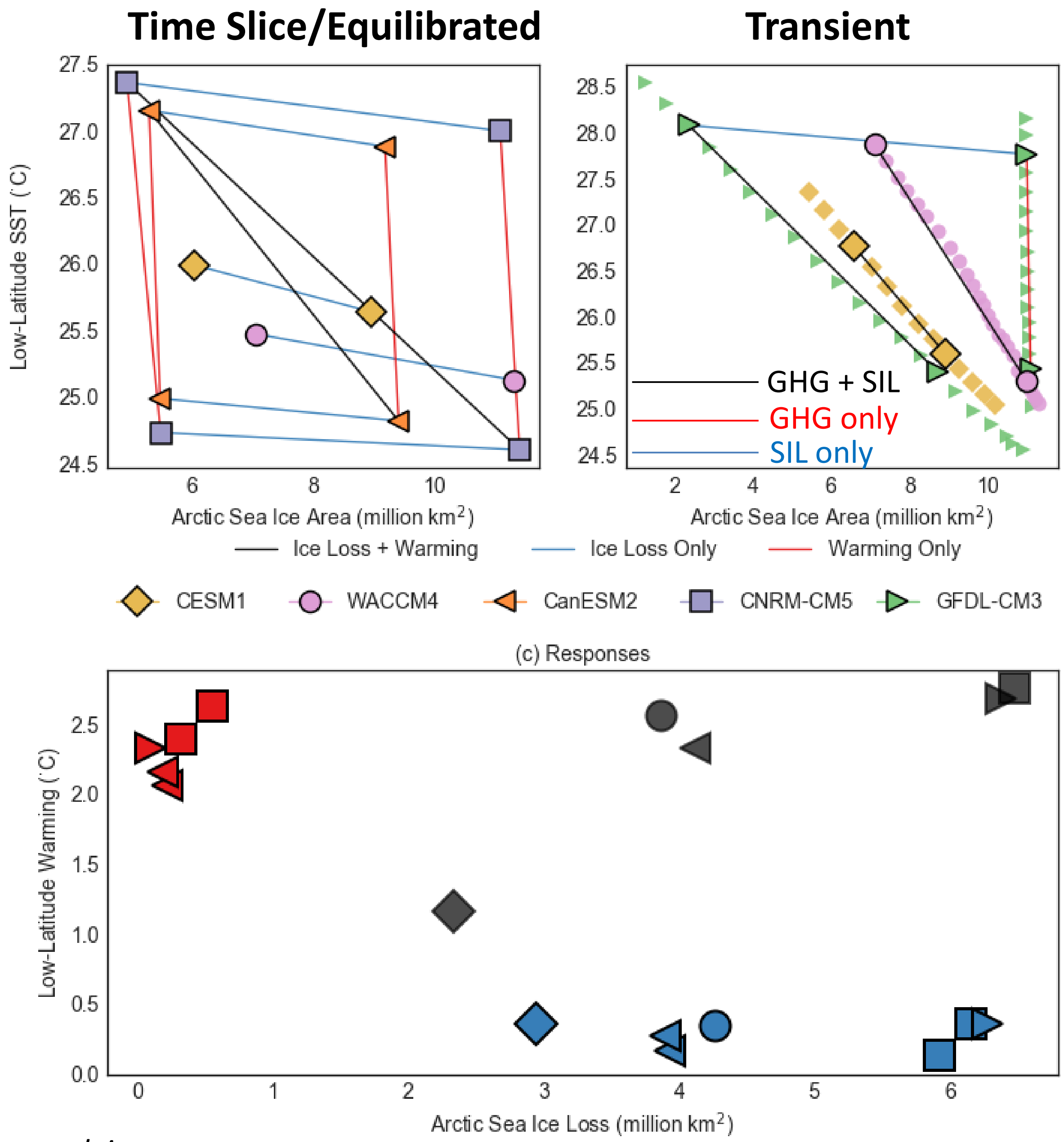
Response to albedo change
$\delta[T]_{albedo}$



Sensitivity to low-latitude warming
$\left(\frac{\partial[T]}{\partial T_l}\right)_I$

Sensitivity to sea ice loss
$\left(\frac{\partial[T]}{\partial I}\right)_{T_l}$

Blackport and Kushner 2017



Hay et al. in prep

In this ensemble of opportunity, which atmosphere-ocean sensitivities are robust?

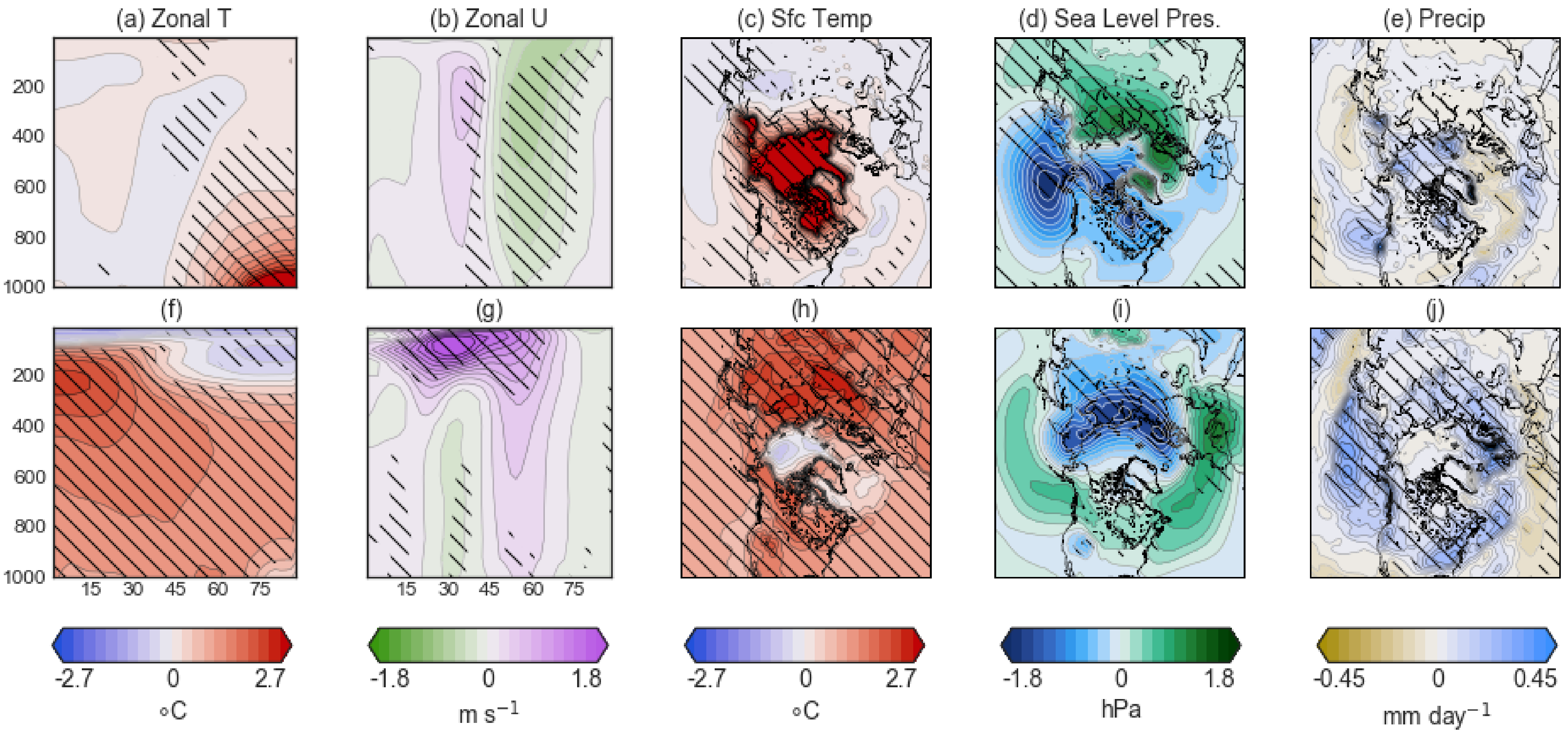
How do the sea ice loss responses relate to the rest of global warming?

And where will we hit the limits of pattern scaling approaches?

Multi-Model Mean Atmospheric Sensitivity Patterns

Sensitivity to ice loss (per 2M km^2 Arctic ice loss)

Sensitivity to low-latitude warming (per 1^0C low-latitude warming)



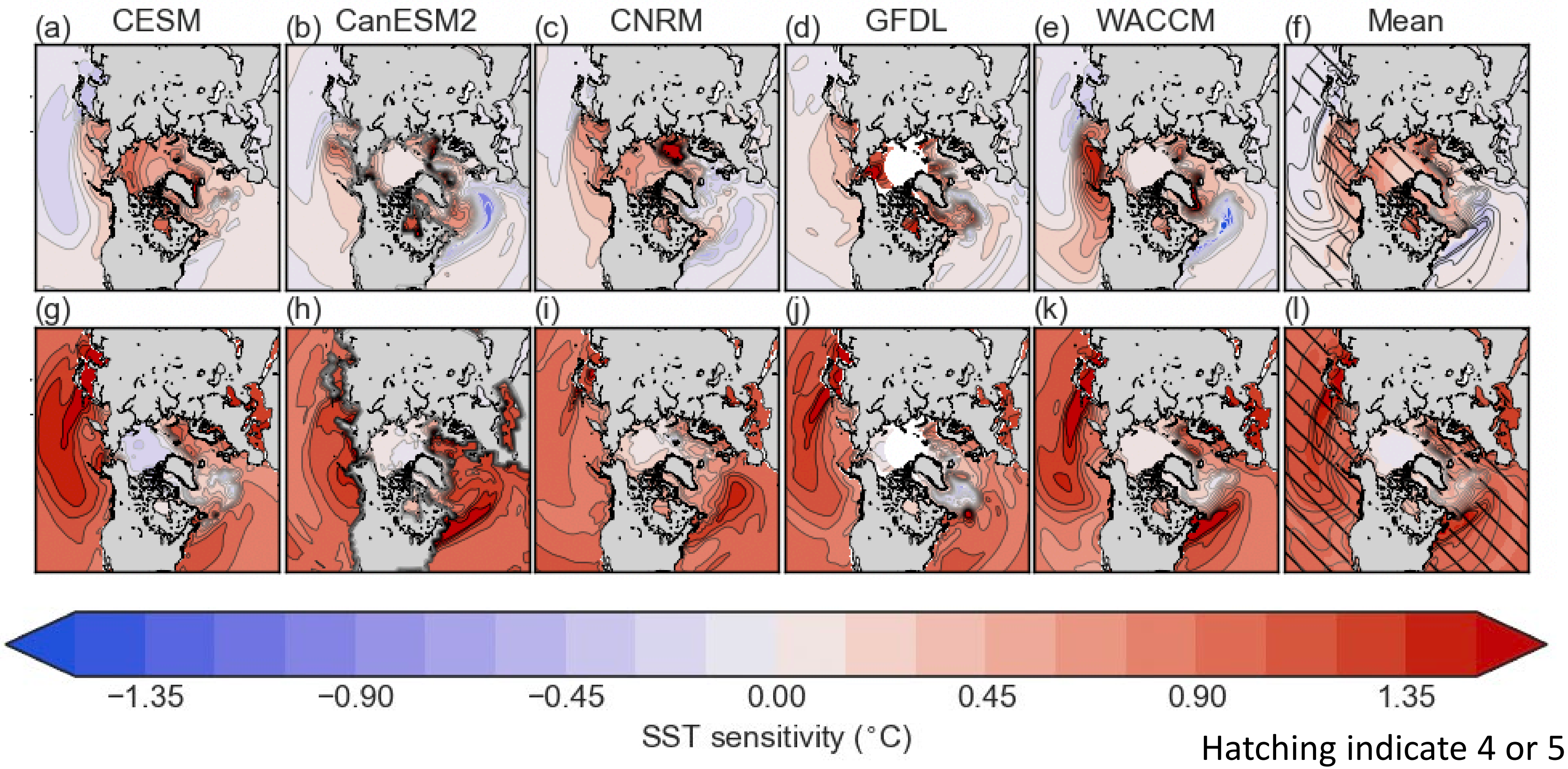
DJF climatological and multi-model mean. Hatching indicate 4 or 5 out of 5 experiments agree in sign

Hay et al. in prep

Sensitivity Patterns for the Ocean: SST

Sensitivity to ice loss (per 2M km^2 Arctic ice loss)

Sensitivity to low-latitude warming (per 1^0C low-latitude warming)



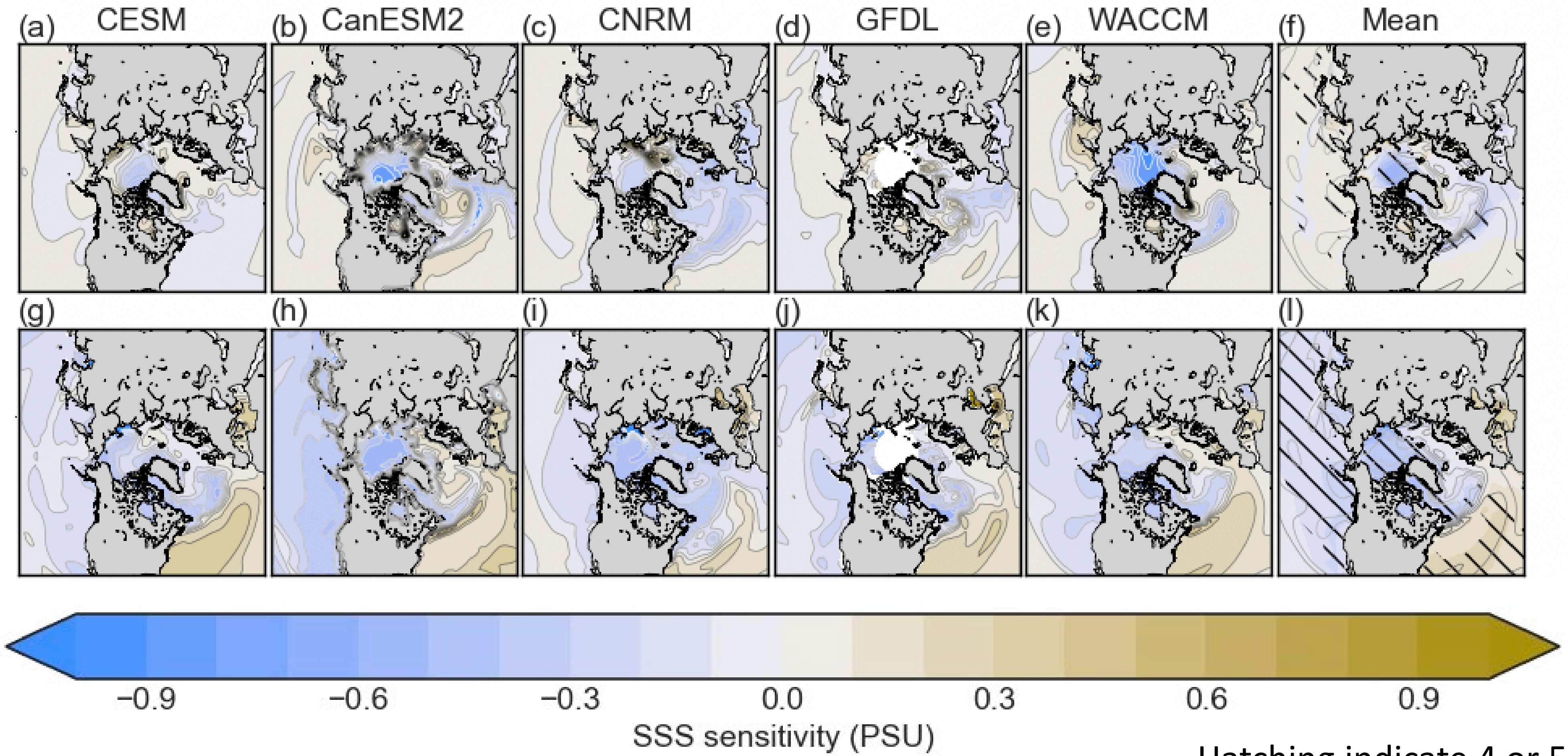
ANN climatological mean for individual and multiple models.

Hatching indicate 4 or 5 out of 5 experiments agree in sign

Sensitivity Patterns for the Ocean: SSS

Sensitivity to ice loss (per $2\mathrm{M}\ \mathrm{km}^2$ Arctic ice loss)

Sensitivity to low-latitude warming (per $1^0\mathrm{C}$ low-latitude warming)

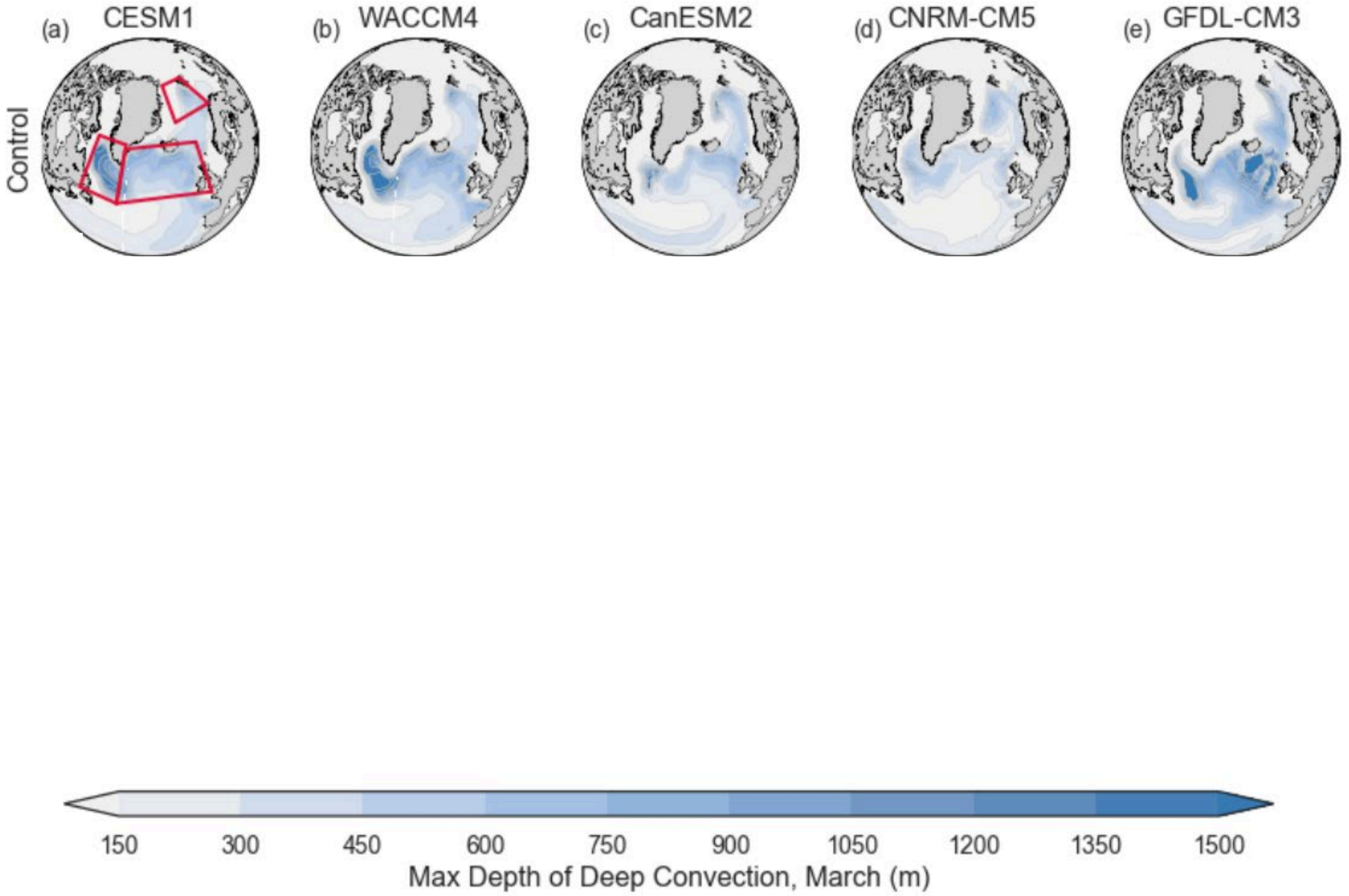


ANN climatological mean for individual and multiple models.

Hatching indicate 4 or 5 out of 5 experiments agree in sign

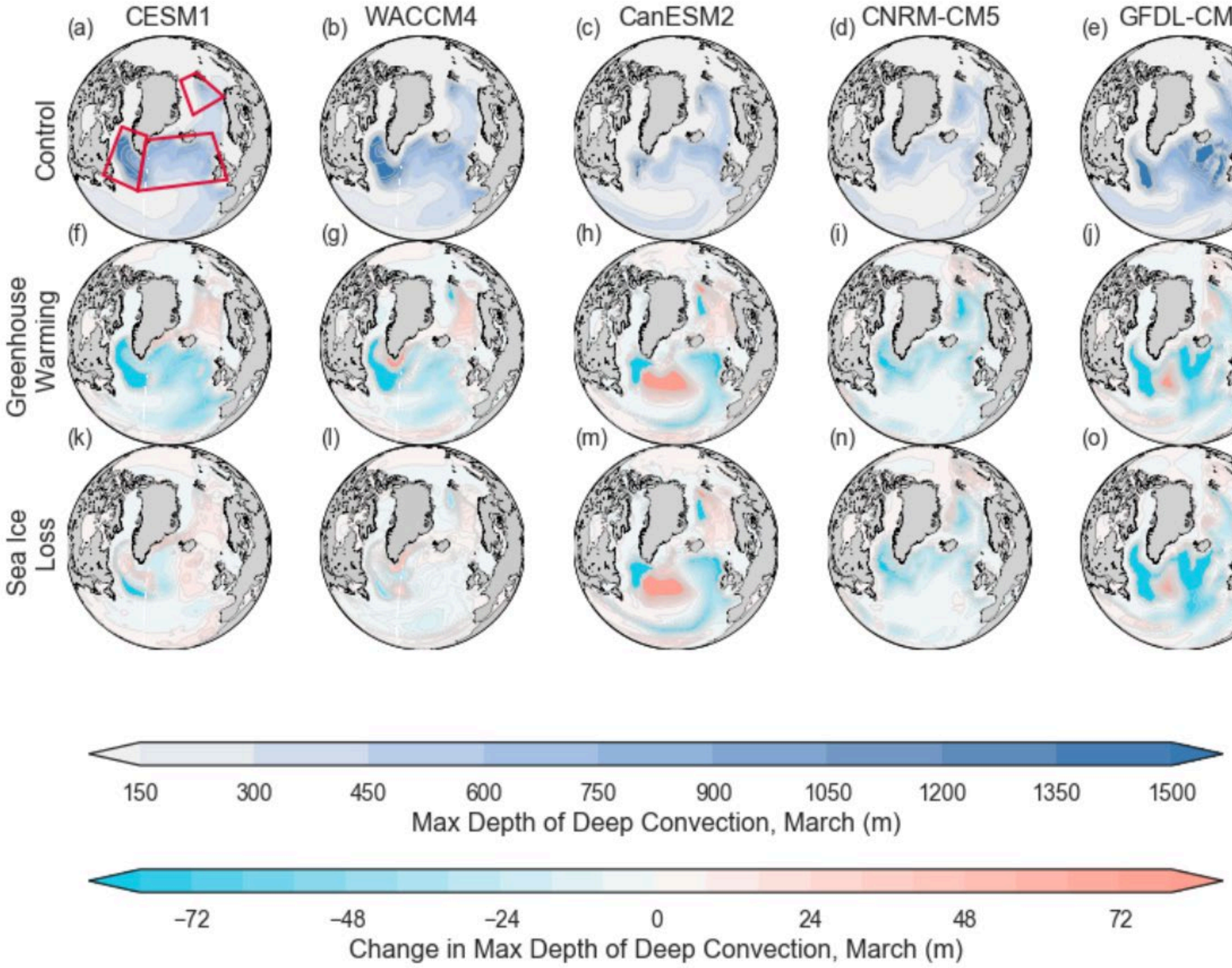
The North Atlantic: where pattern scaling breaks down …

- Ocean convection changes are too ME dependent for pattern scaling.
  - Inconsistent control simulations
  - Different experimental protocols for sea ice loss.
- So we'll look at *responses* instead of *sensitivities.*



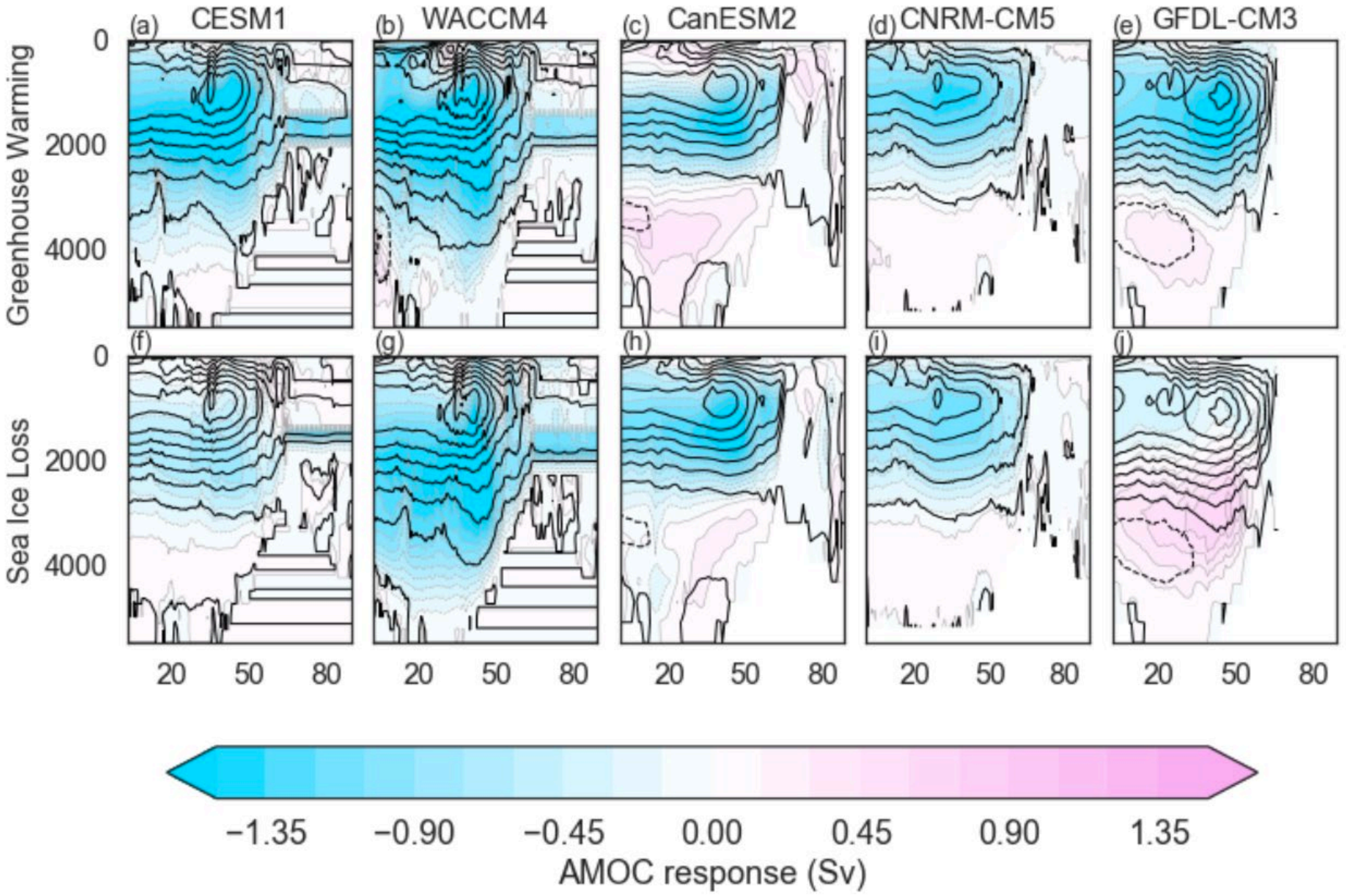
The North Atlantic: where pattern scaling breaks down …

- Sea ice loss and greenhouse warming have mixed impacts on convection.
- Sometimes sea ice loss can be isolated as the primary driver, and sometimes not.



The North Atlantic: where pattern scaling breaks down …

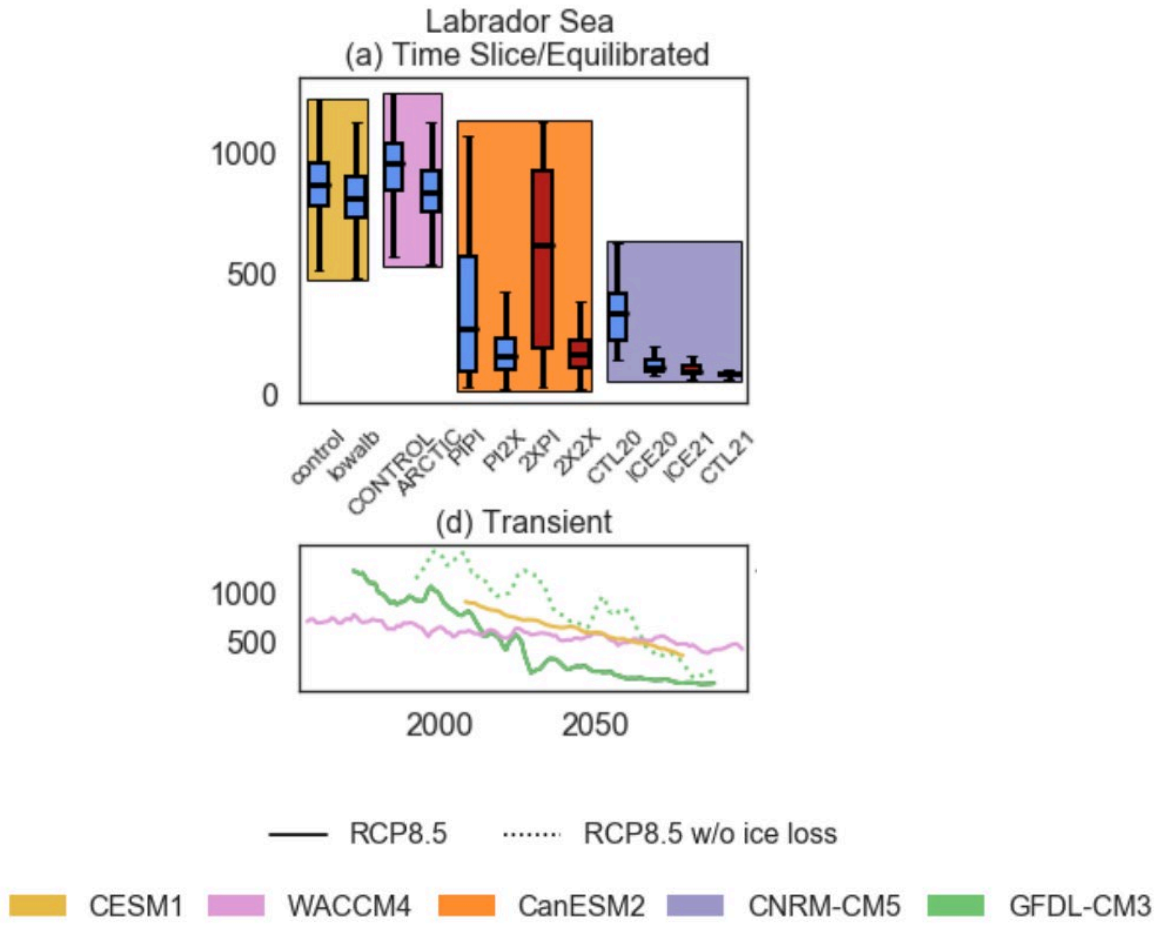
- ME dependence is also a feature of AMOC responses …
- NCAR models with similar ocean components can have very different AMOC control simulations and responses.
- One model (CanESM2) shows a greater reduction in AMOC from sea ice loss than from greenhouse warming!



Conclusion

- Pattern scaling provides an estimate of model sensitivity kernels, to learn about the consequences of Arctic and tropical warming.
    - Sea ice loss $\rightarrow$ negative feedback on the circulation response (“tug of war”).
    - Precipitation response from low-latitude warming extends well into Arctic domain.
    - Salinity and precipitation changes from sea ice loss localized to Arctic.
- Model and experimental protocol dependence is too pronounced for pattern scaling to work in the North Atlantic.
    - Convection and AMOC responses are not robust.
- PAMIP (or similar) coordination required to obtain robust characterization of sensitivity of overturning circulation and convection.

Response of Deep Convection by Convection Zone



Sensitivity Patterns for the Ocean: North Atlantic Convection

Sensitivity to ice loss (per 2M km^2 Arctic ice loss)

Sensitivity to low-latitude warming (Per 1^0C low-latitude warming)