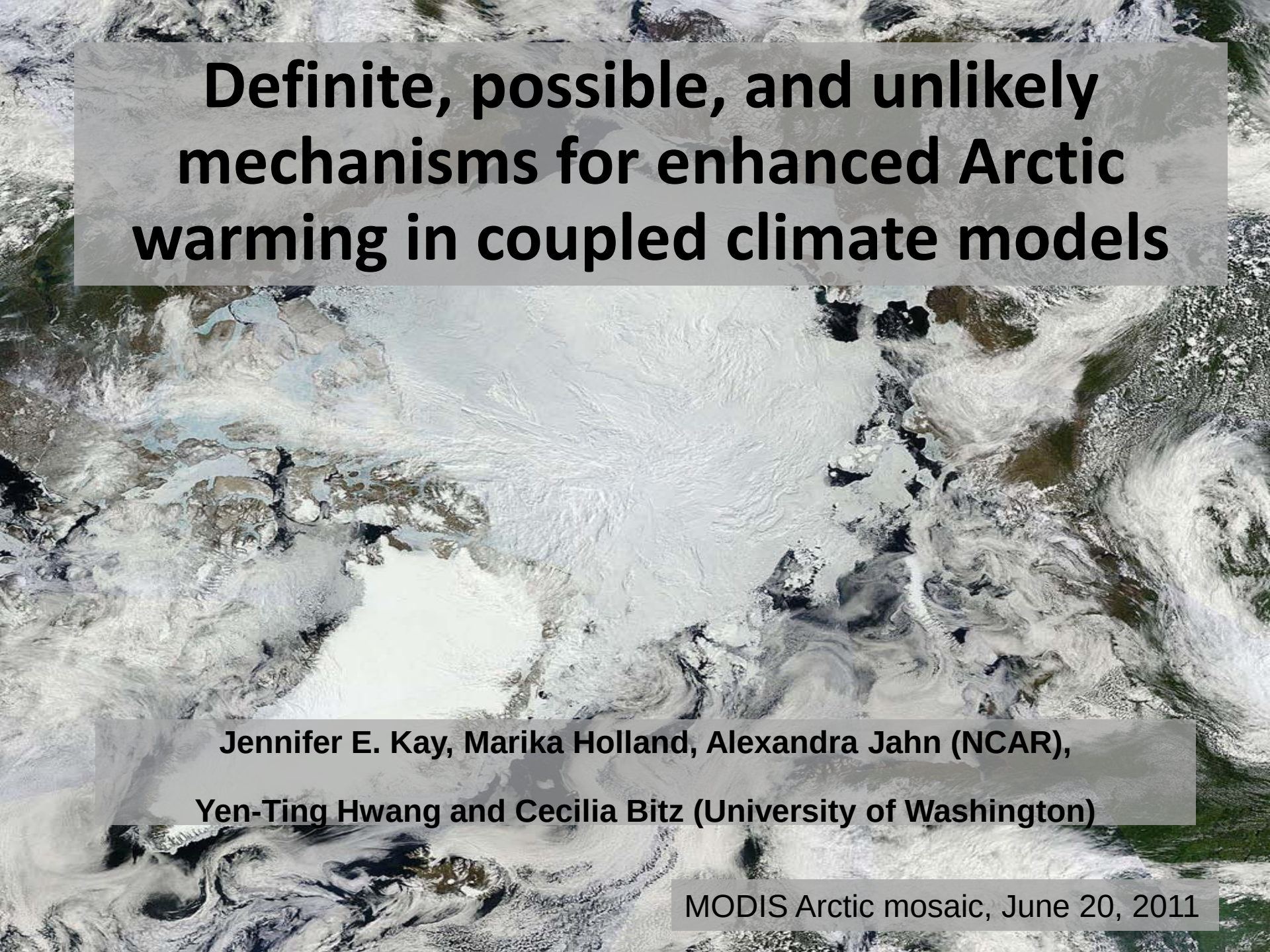
Definite, possible, and unlikely mechanisms for enhanced Arctic warming in coupled climate models

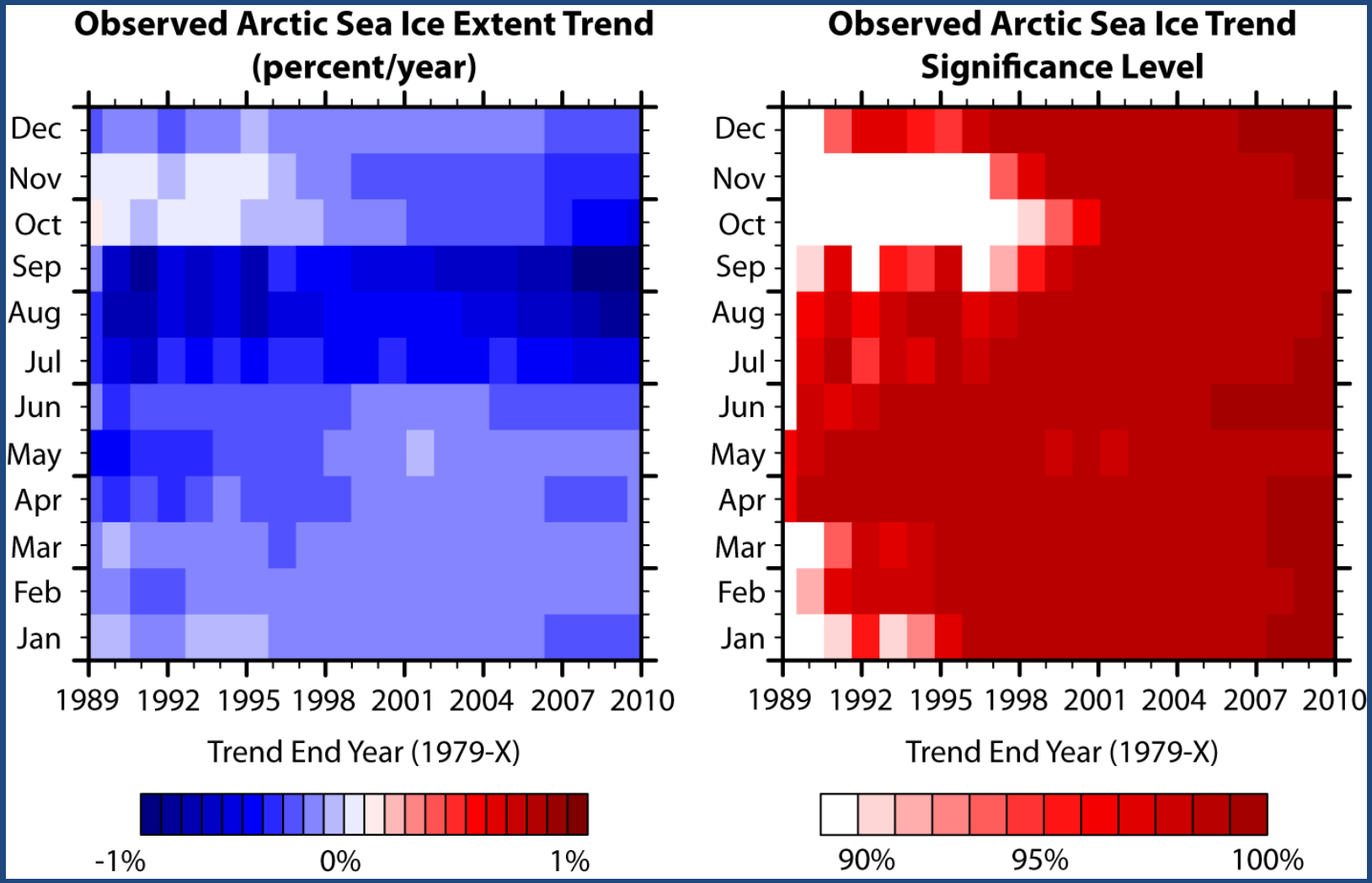


Jennifer E. Kay, Marika Holland, Alexandra Jahn (NCAR),

Yen-Ting Hwang and Cecilia Bitz (University of Washington)

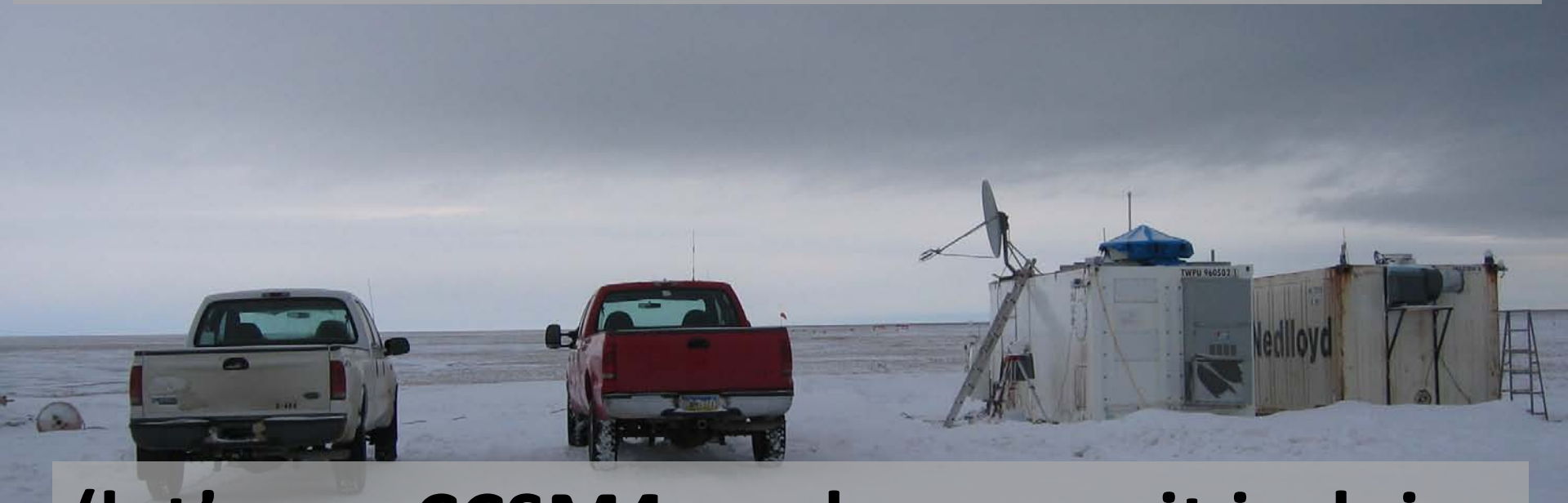
MODIS Arctic mosaic, June 20, 2011

Observed Arctic Sea Ice Extent Trends



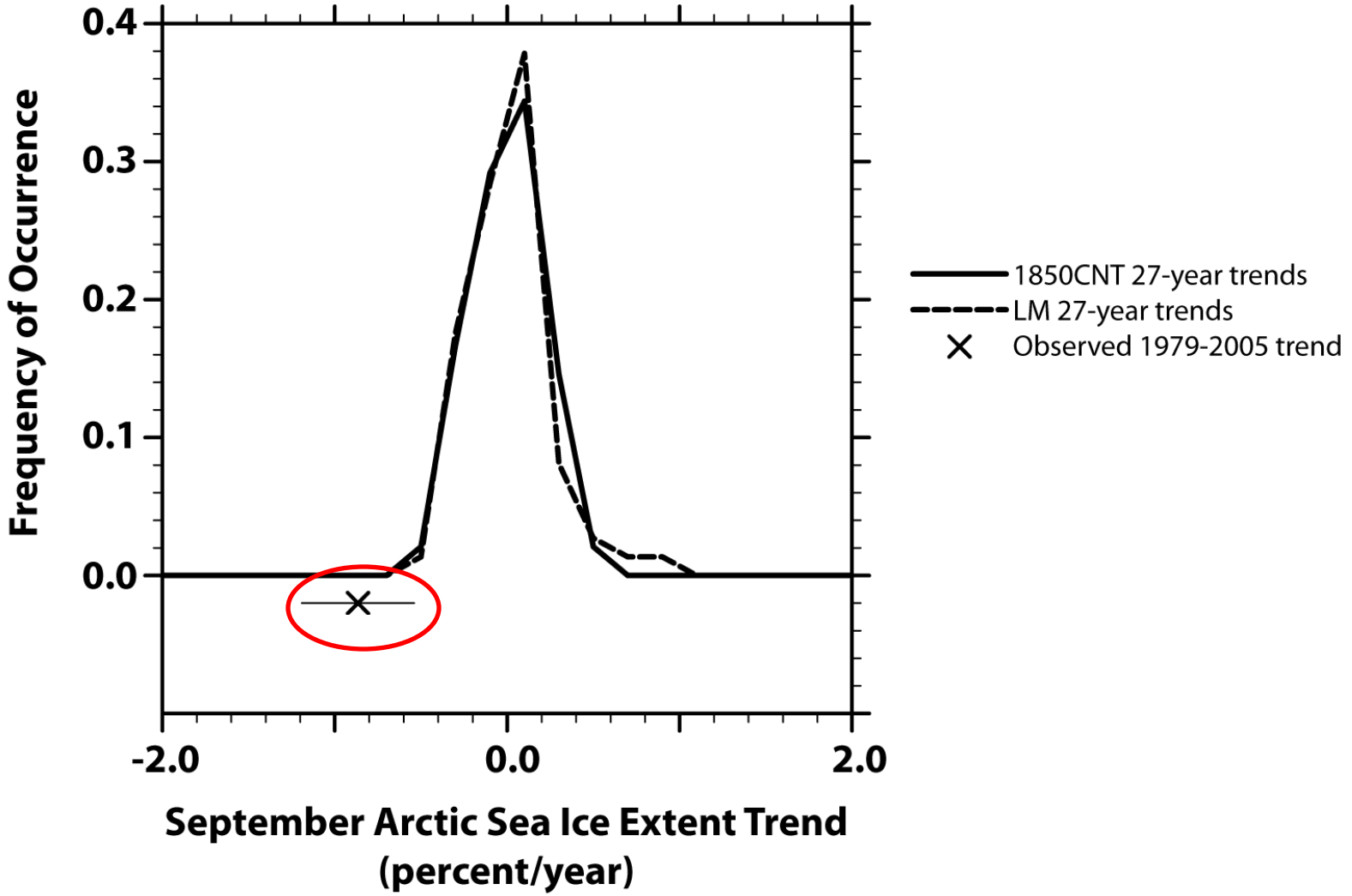
Trends and Trend Significance
(1979-variable end year)

Is it possible to reproduce late 20th century observed Arctic sea ice trends with natural forcing or variability alone?



(let's use CCSM4, and assume it is doing a reasonable job of capturing processes influencing trend variability)

Observed and Modeled 27-year Trends

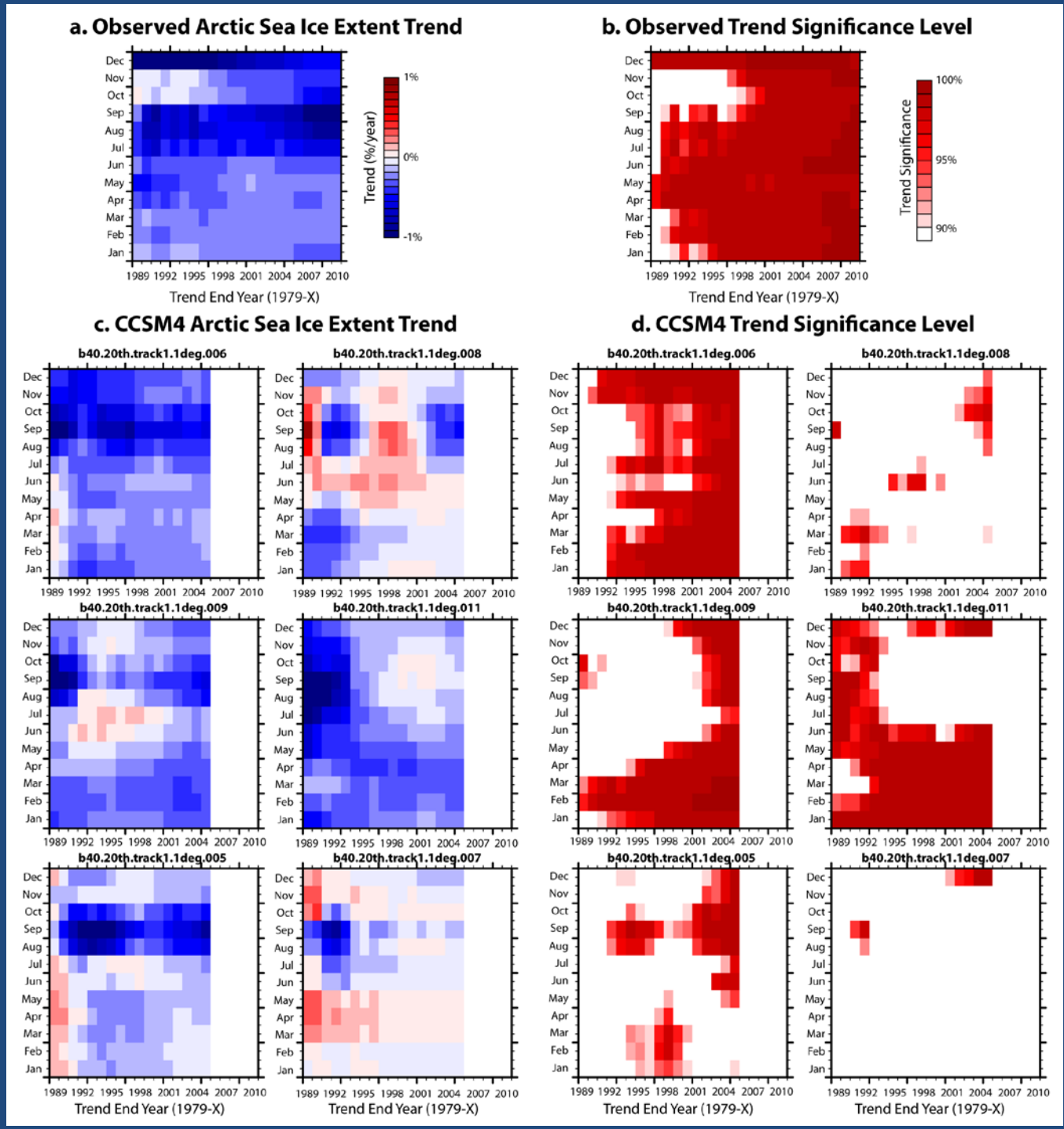


Kay, Holland, and Jahn (GRL 2011)

Natural variability influence on observed Arctic sea ice trends?

CCSM4 says it is significant…

Kay, Holland, and Jahn (GRL 2011)



How do sea ice extent trends change in a warming climate?

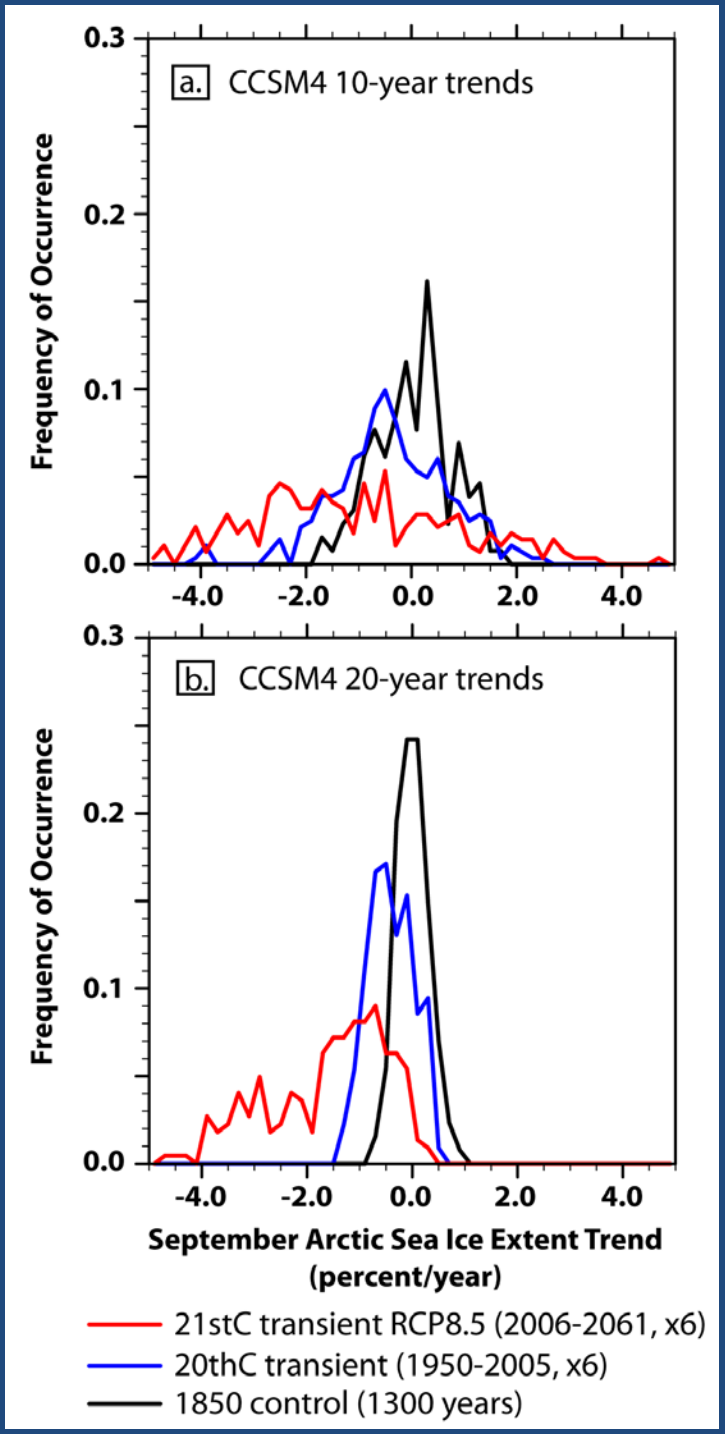
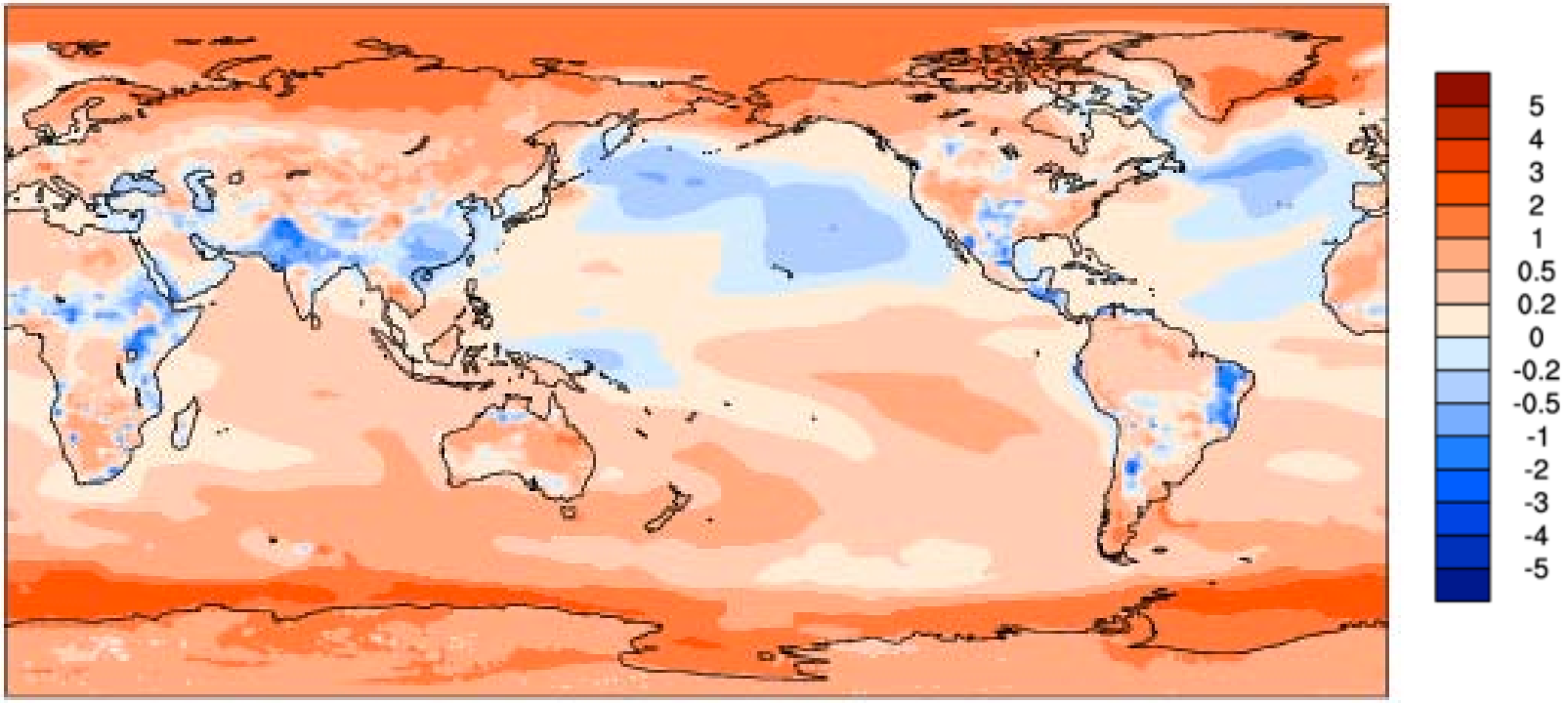


Figure 3
Kay, Holland, and Jahn (GRL 2011)

CAM5.1 20th Century Warming (K)



(plot from Cecile Hannay)

What controls the Arctic climate response to increased greenhouse gas forcing in coupled climate models?

1. Greenhouse gas forcing

2. Heat transport
   - atmosphere
   - sea ice
   - ocean

3. Local feedback strength
   - temperature, Planck (no change in stratification)
   - temperature, lapse rate
   - water vapor
   - surface albedo
   - clouds

Holland and Bitz (2003), Winton (2006), Bitz (2008), Boé et al. (2009), Kay et al. (under revision)

Does the top of atmosphere forcing produced by 2xCO_2 enhance Arctic Amplification?

	CAM4	CAM5
Global	3.5 Wm^{-2}	3.8 Wm^{-2}
Arctic (70-90 N)	2.6 Wm^{-2}	2.8 Wm^{-2}

No. It's all in the feedbacks. Not new news.

Which feedbacks enhance Arctic Amplification?

DEFINITE

Surface albedo feedbacks
(Arctic more positive)

Planck feedback
(Arctic less negative)

Lapse rate feedback
(Arctic positive, negative globally)

NO WAY

Water vapor feedback
(Arctic less positive)

DEBATED

Atmospheric heat transport

Ocean heat transport

Clouds

Northward heat transport and Arctic Amplification in the CMIP3 model ensemble

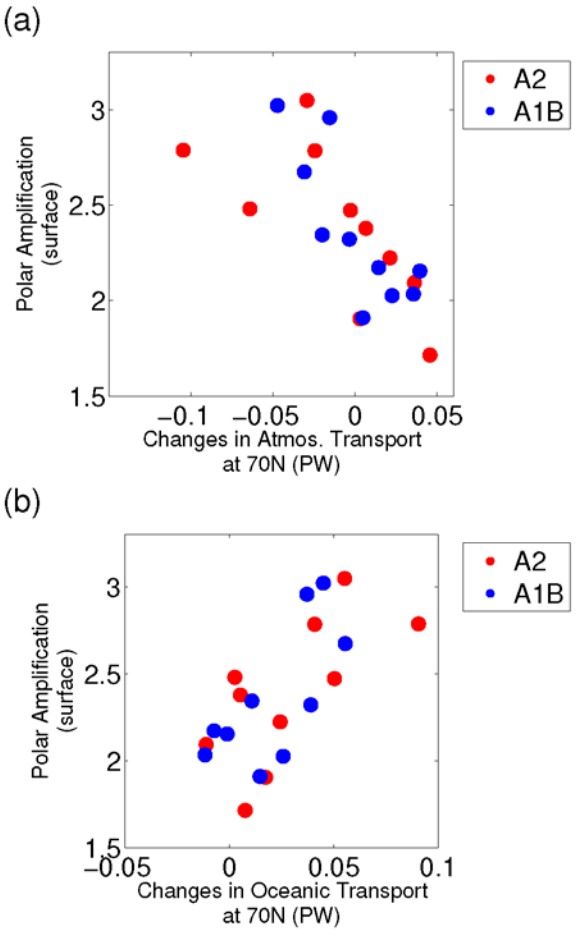
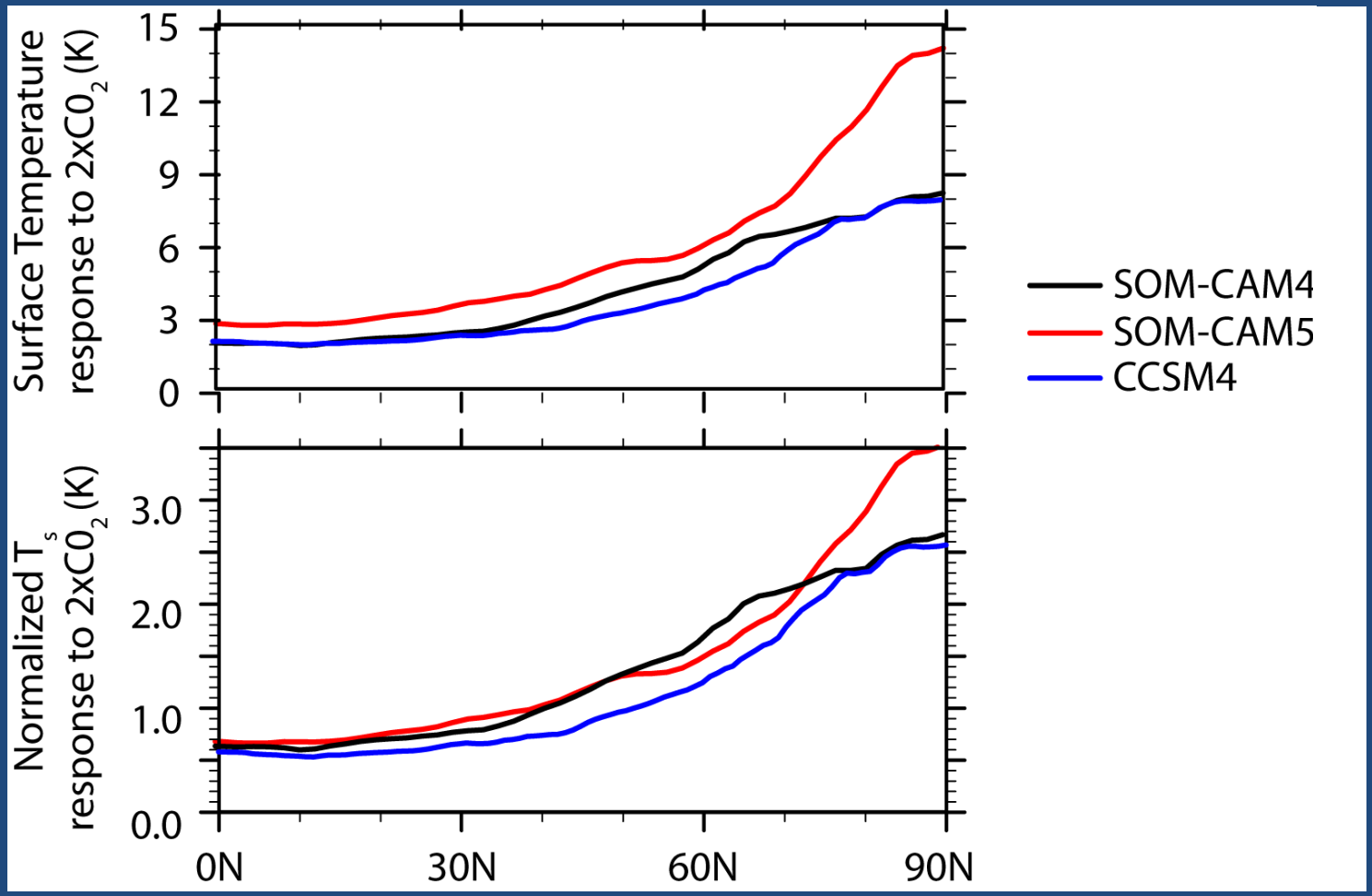


Figure 2. Polar amplification versus (a) changes in atmospheric energy transport at 70N (b) changes in oceanic transport at 70N.

Hwang, Frierson, and Kay (submitted)

Within CESM, the atmospheric model was more important to the Arctic temperature response than increasing ocean heat transport associated with deep ocean feedbacks.

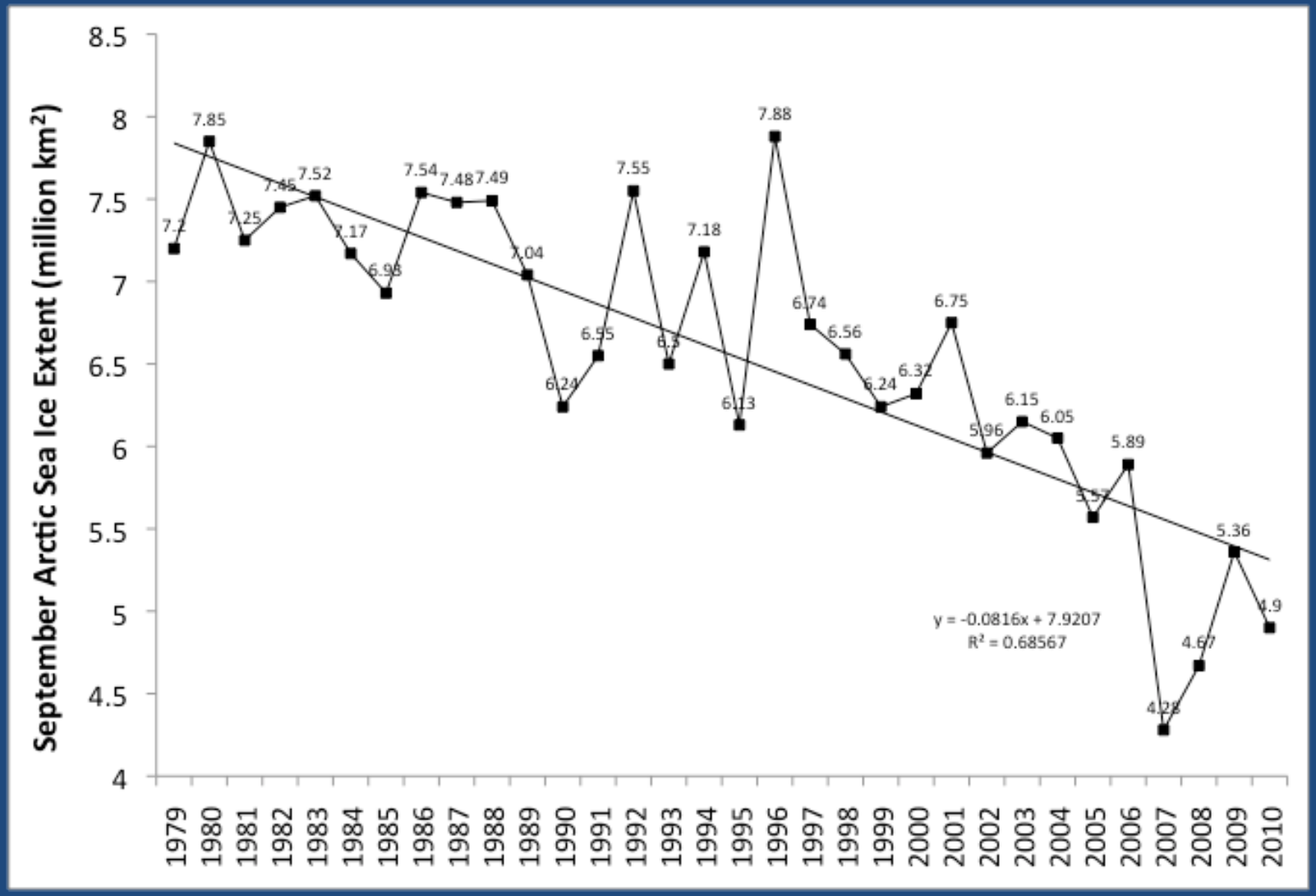


Summary

1. Natural variability complicates efforts to evaluate climate models and to understand why observed Arctic sea ice extent loss is “faster than predicted”. A six-member CCSM4 ensemble suggests we live in a “faster than average” Arctic sea ice loss realization and that positive trends over 10+ years are still likely to occur.

2. Because greenhouse gas forcing is weaker in the Arctic than it is at lower latitudes, feedbacks are required to explain Arctic amplification. In my opinion, the most uncertain of these feedbacks relate to clouds, and northward heat transport in the ocean.

Observed September Arctic Sea Ice Extent (1979-2010)




Questions?

Introducing a "laboratory" of global coupled climate models that we can use to test hypotheses about what controls the equilibrium Arctic climate response to increased greenhouse gases.

Name	Model description	Global Climate Sensitivity
CAM4	Slab ocean model , 2 degree Atmospheric model CAM4	3.1 K
CAM4_h	Slab ocean model, 1 degree Atmospheric model CAM4	3.1 K
CAM5	Slab ocean model, 2 degree Atmospheric model CAM5	4.0 K
CCSM4	Fully coupled model, 1 degree Atmospheric model CAM4	2.9 K

Warming as a function of height

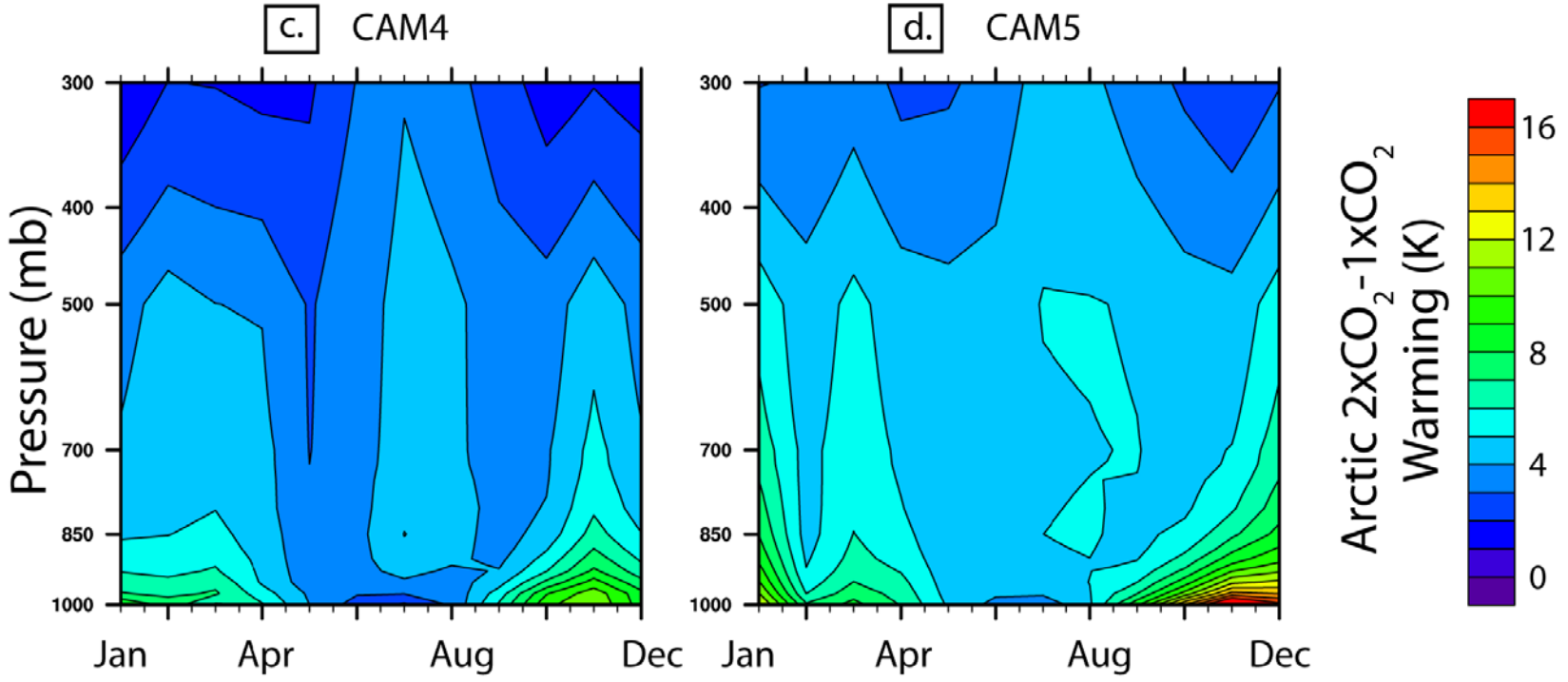
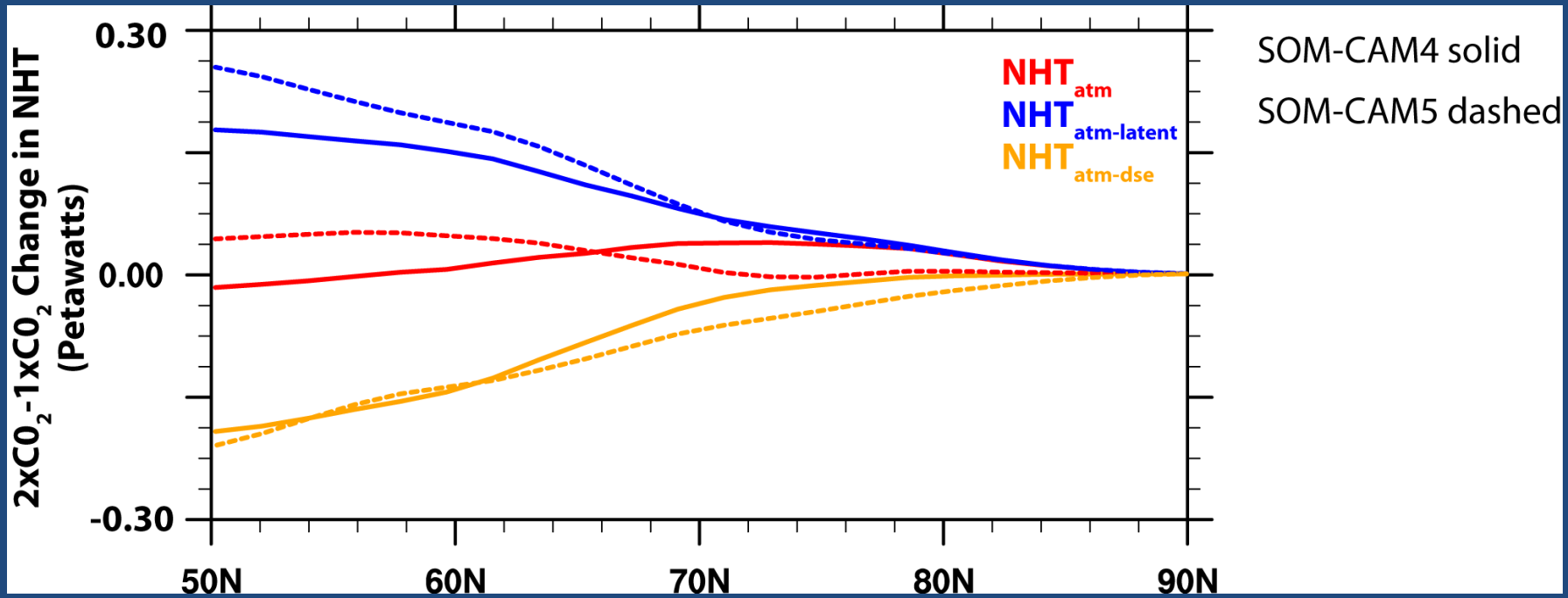


Figure 2. Monthly evolution of Arctic CAM4 and CAM5 climate variables: a) Arctic surface temperature in 1850 control climate and 2xCO_2 climate, b) Northern Hemisphere (NH) sea ice extent in 1850 control climate and 2xCO_2 climate, c) vertical distribution of the equilibrium Arctic air temperature response to 2xCO_2 in CAM4, d) as in c) but for CAM5.

Does Northward Atmospheric Heat Transport enhance Arctic warming and Amplification?



Increased latent heat transport is balanced by decreased sensible heat transport with increasing greenhouse gases… the net change in atmospheric heat transport is small.
Similar results seen in Boer et al. (1995).