Mean Arctic Climate and Climate Changes in CAM4 and CAM5 Climate Sensitivity Experiments

Jen Kay

NCAR/CGD/AMP

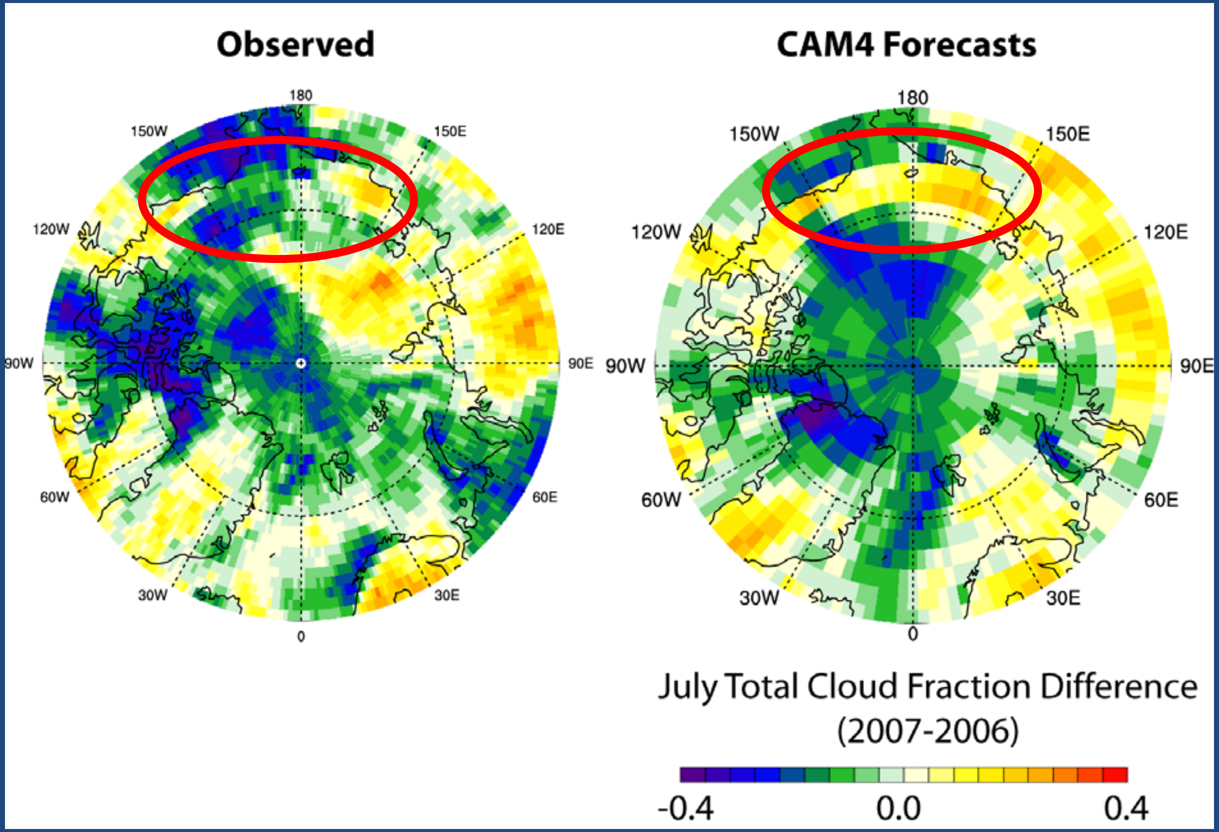
Andrew Gettelman, Dave Bailey, Marika Holland, Cecilia Bitz, Rich Neale, Cecile Hannay, Kevin Raeder, Jeff Anderson

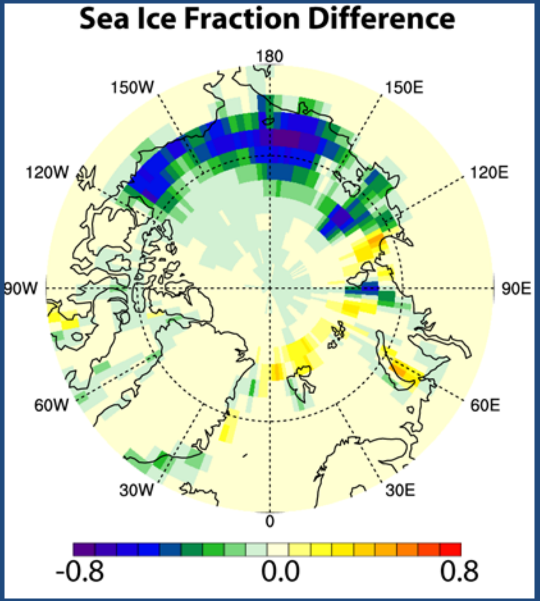
Today's topics….

Two Announcements

1) NCAR summer visit opportunity for senior graduate student/postdoc as a part of NSF's Arctic Observation Network.
2) In-line version of COSP part of CCSM4 release

CAM4 has an unrealistic cloud response to sea ice loss in stable atmospheric regimes.



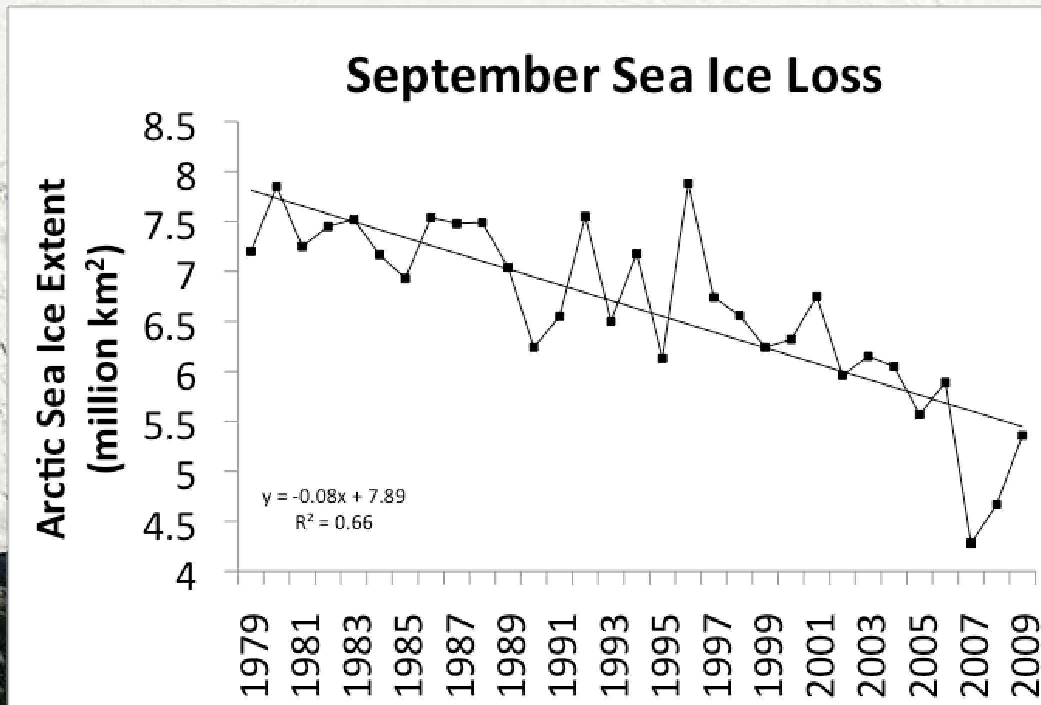


A physically motivated change to the stratus parameterization (requiring a well-mixed boundary layer) improved the cloud response to sea ice loss and increased surface energy budgets in July 2007 by 11 Wm^{-2}.

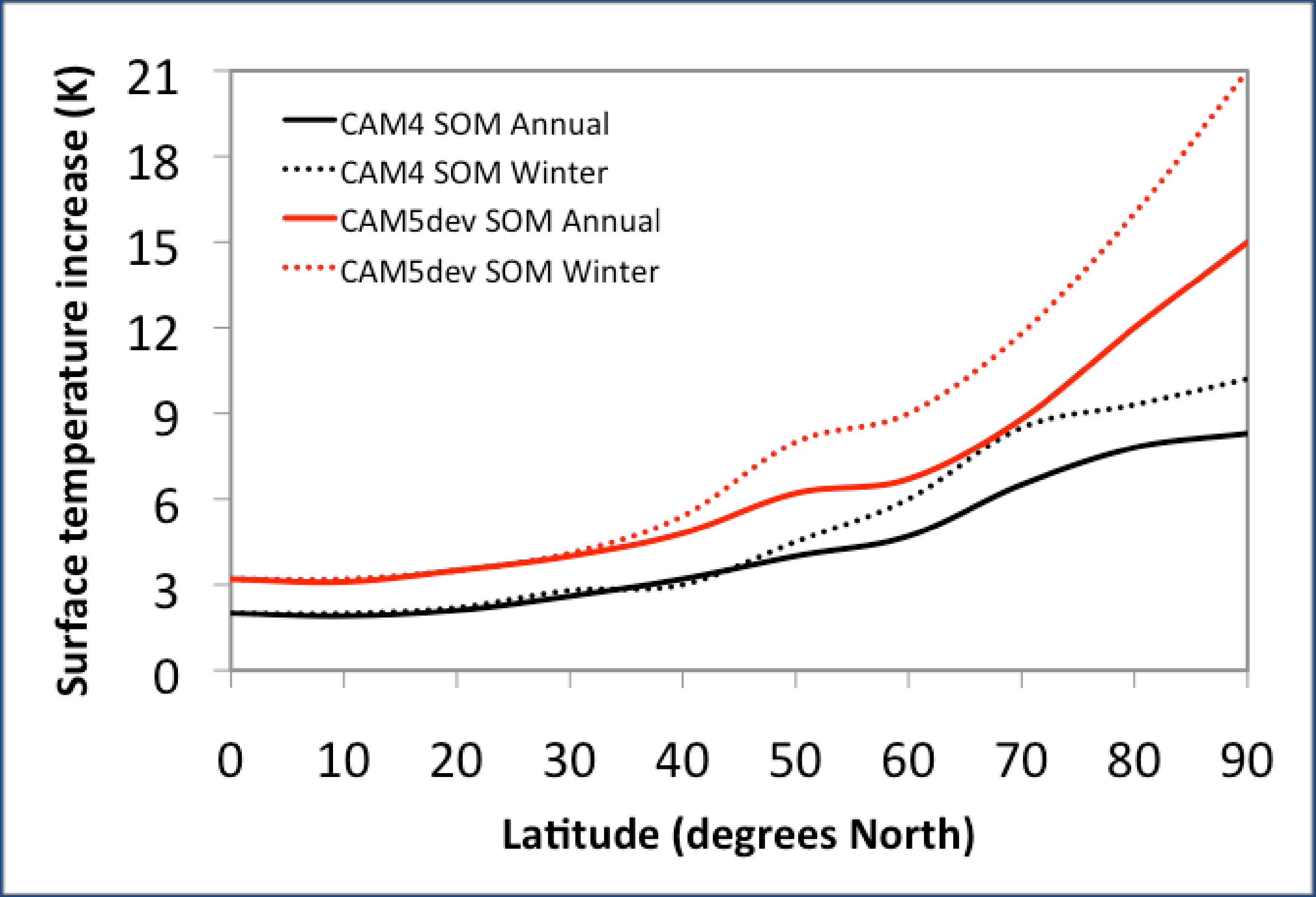
Due to unrealistic Arctic cloud increases over newly open water, CCSM3/CCSM4 under-predict sea ice loss in stable atmospheric regimes (e.g., 2007-like extreme events).

Does this error affect modeled sea ice trends?

Maybe not. Little year-to-year memory in observations.

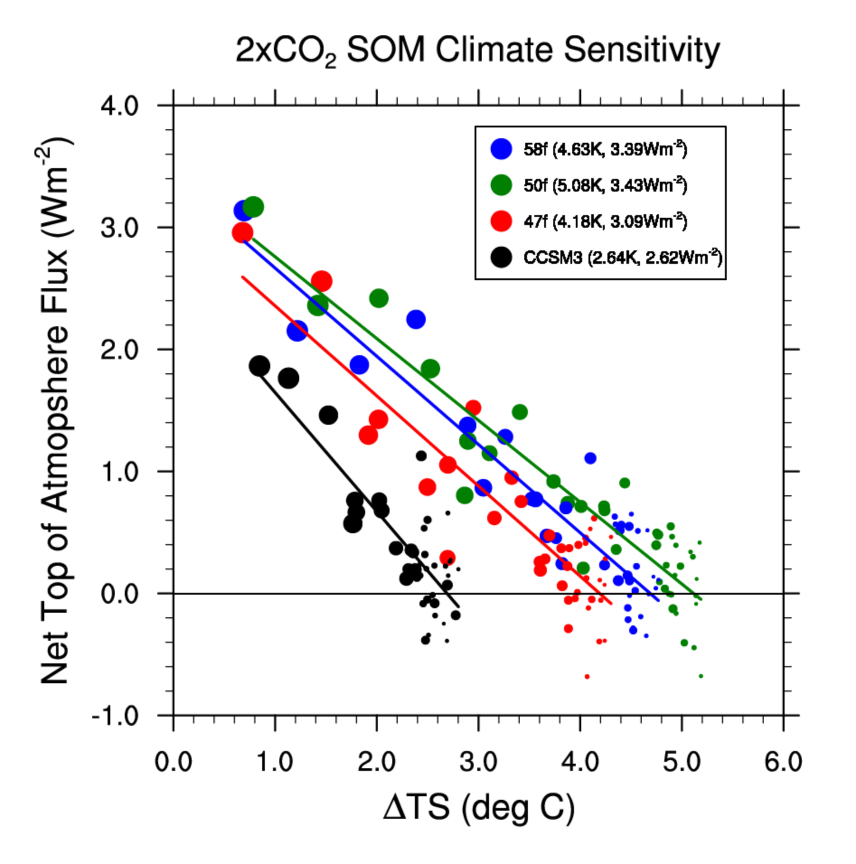


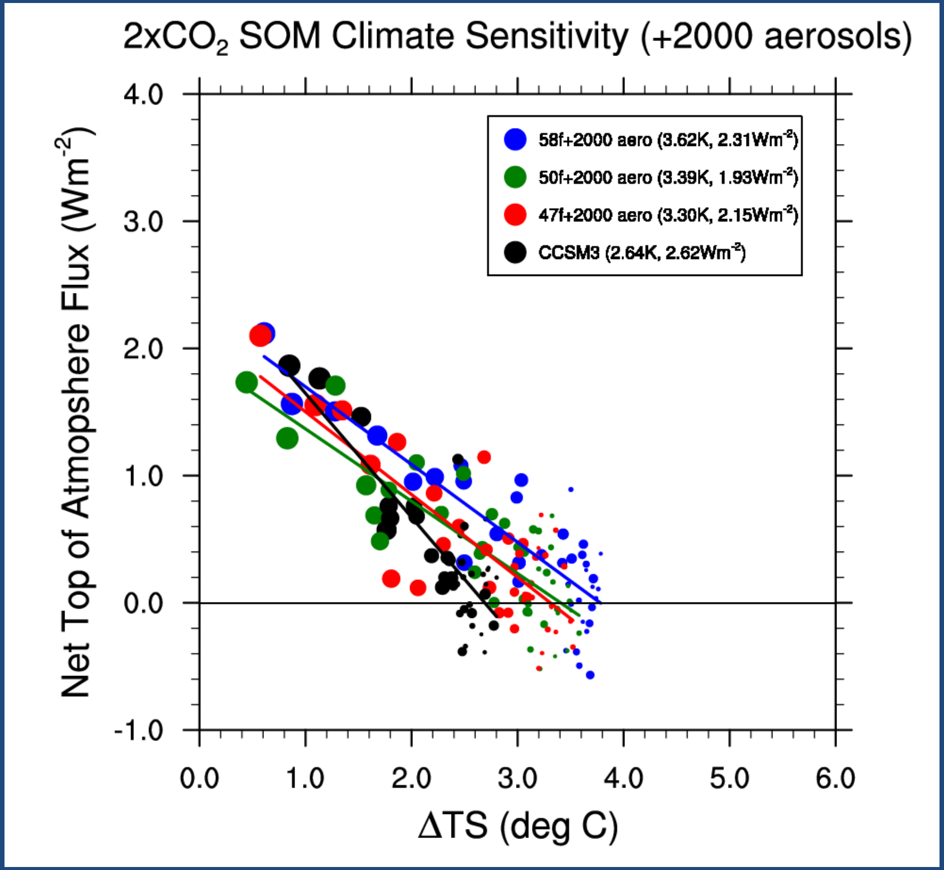
How hot is the Arctic in CAM4/CAM5 climate sensitivity experiments?



Why do recent slab ocean model experiments project dramatic differences in their equilibrium Arctic response to $2xC0_2$ forcing?

I ignore aerosol indirect effects today, but they are critical for projected Arctic change



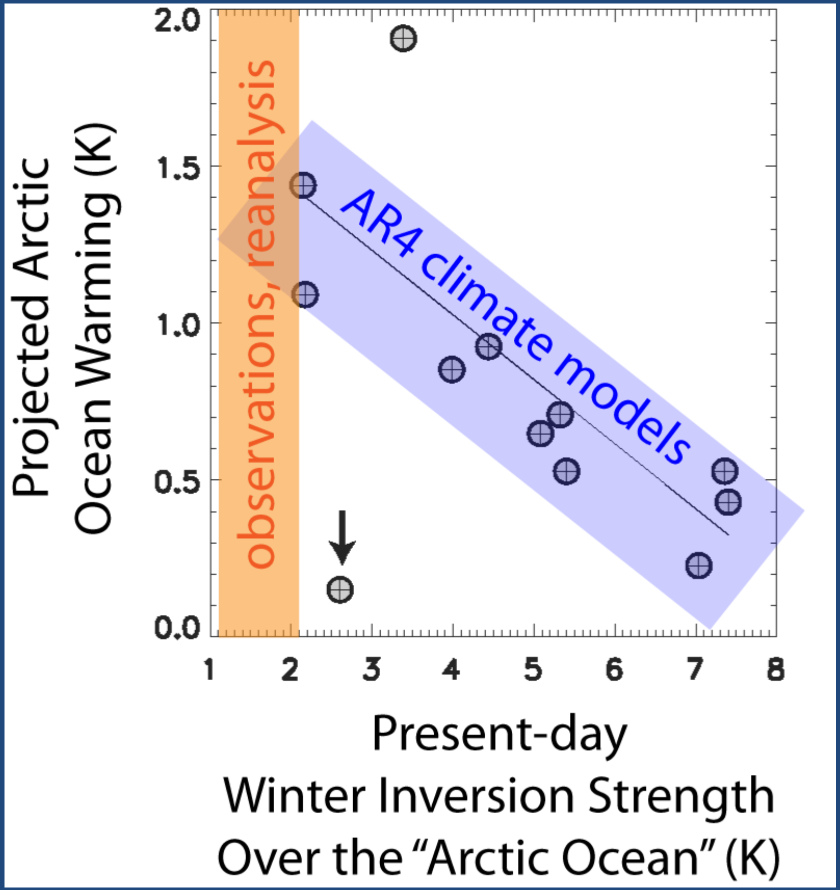


CAM5 climate sensitivity: 4.2-5.1 K

CAM5 total response: 3.3-3.6 K

What controls Arctic climate response in $2xC0_2$ climate sensitivity experiments?

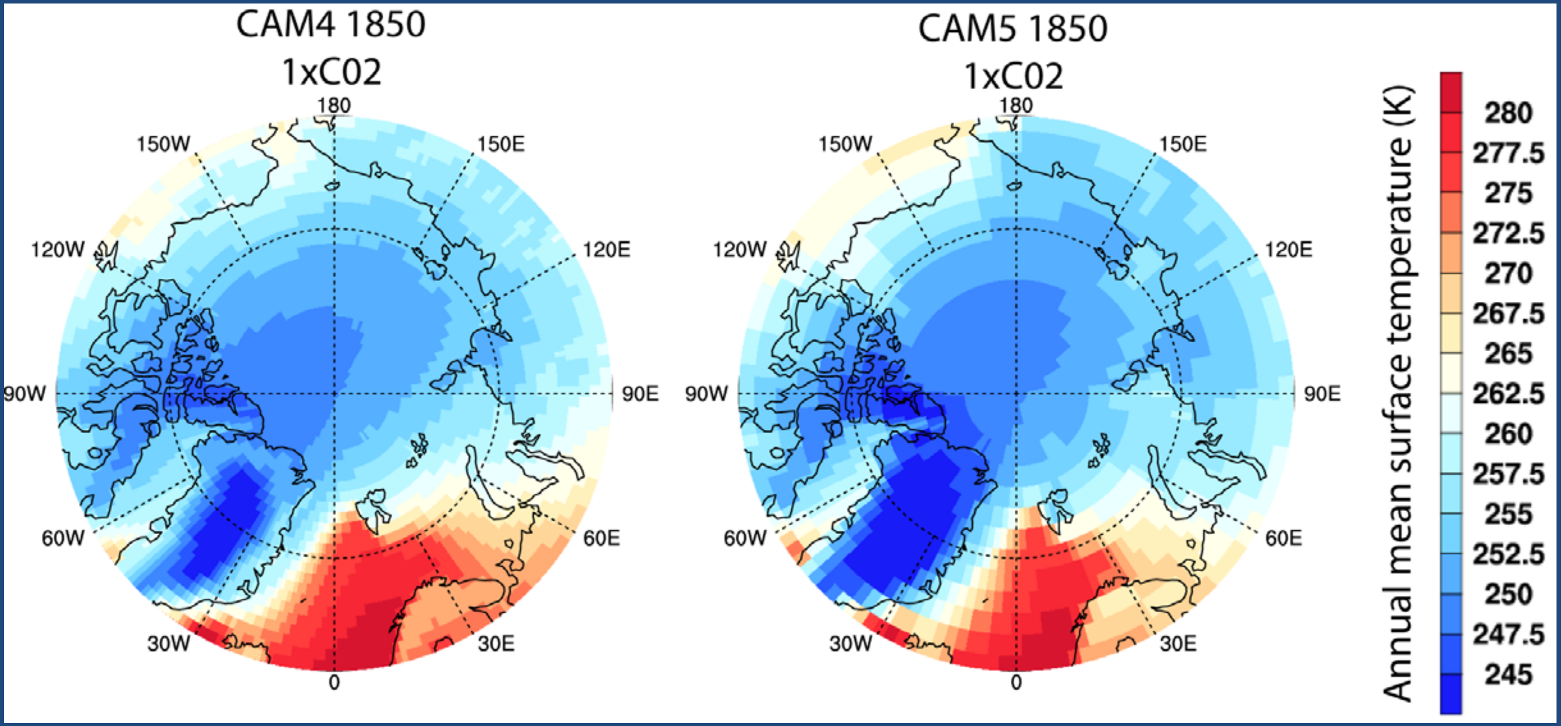
Strategy: compare mean state in 1850 control



e.g., recent paper by Boe et al. (2009) showed that present day winter inversion strength explains spread in AR4 IPCC models Arctic amplification

1850 Mean State - Surface Temperature (Ts)

Arctic Ts are very similar in CAM4 and CAM5



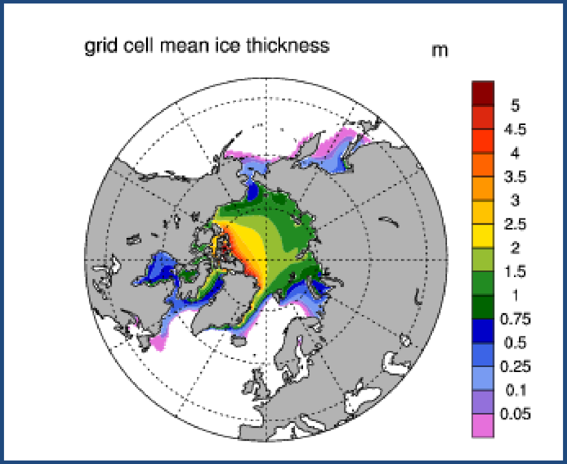
Arctic Ocean Ts (70-90 N)

	CAM4	CAM5
Annual	255	254
Winter	242	240
Summer	270	271

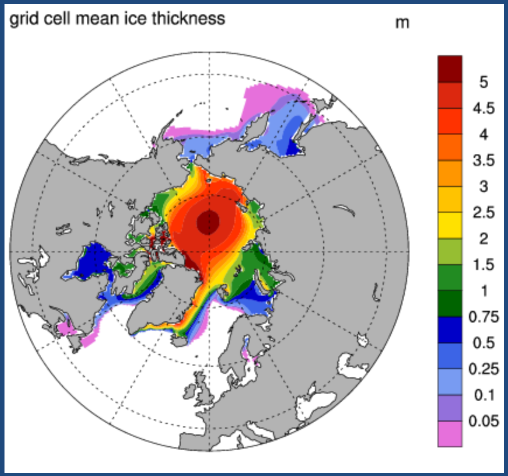
No huge differences in 1850 Arctic sea ice extent between CAM4 and CAM5.

1850 Mean State – Sea Ice Thickness

CAM4 thickness

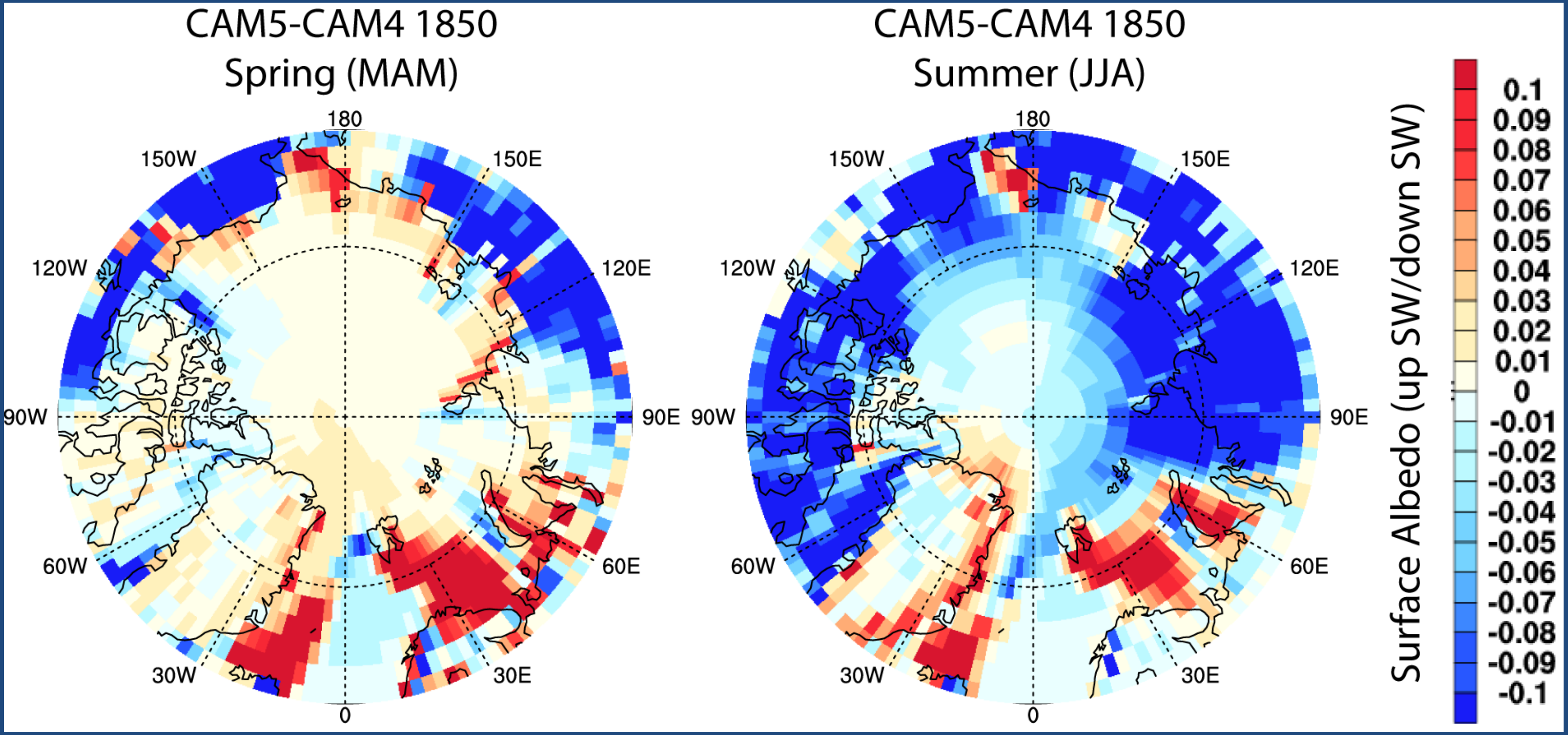


CAM5 thickness



No big differences in 1850 sea ice extent but CAM5 Arctic sea ice is thicker than CAM4.

1850 Mean State - Arctic surface albedo

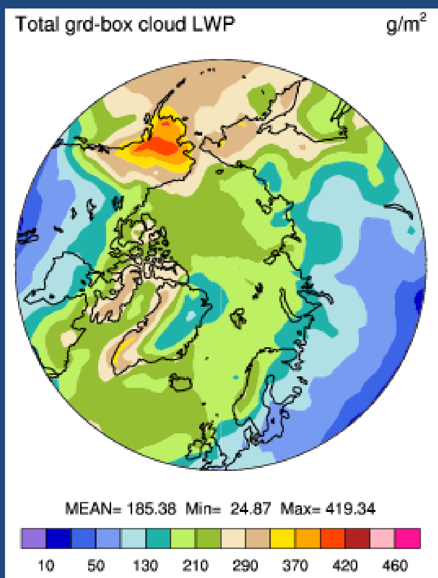


Surface albedos lower over land in CAM5 than CAM4 (CLM prognostic veg). Higher snow albedos over sea ice in CAM5 than in CAM4.

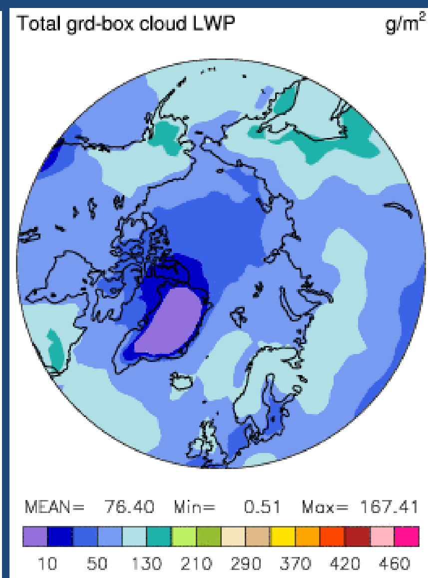
1850 Mean State – Summer clouds

Arctic clouds and shortwave radiation budgets are very different!!

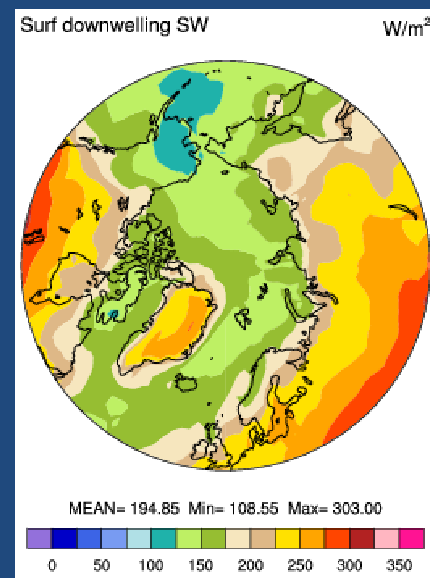
CAM4 1850



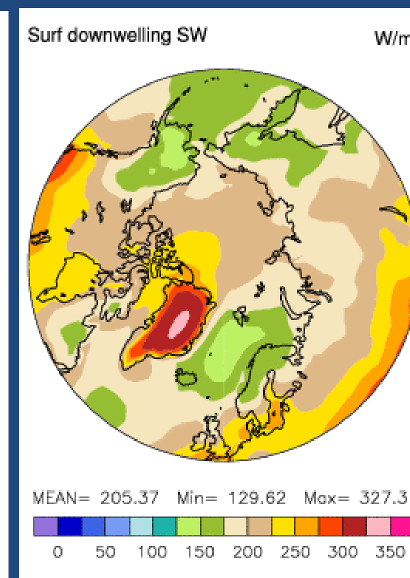
CAM5 1850



CAM4 1850



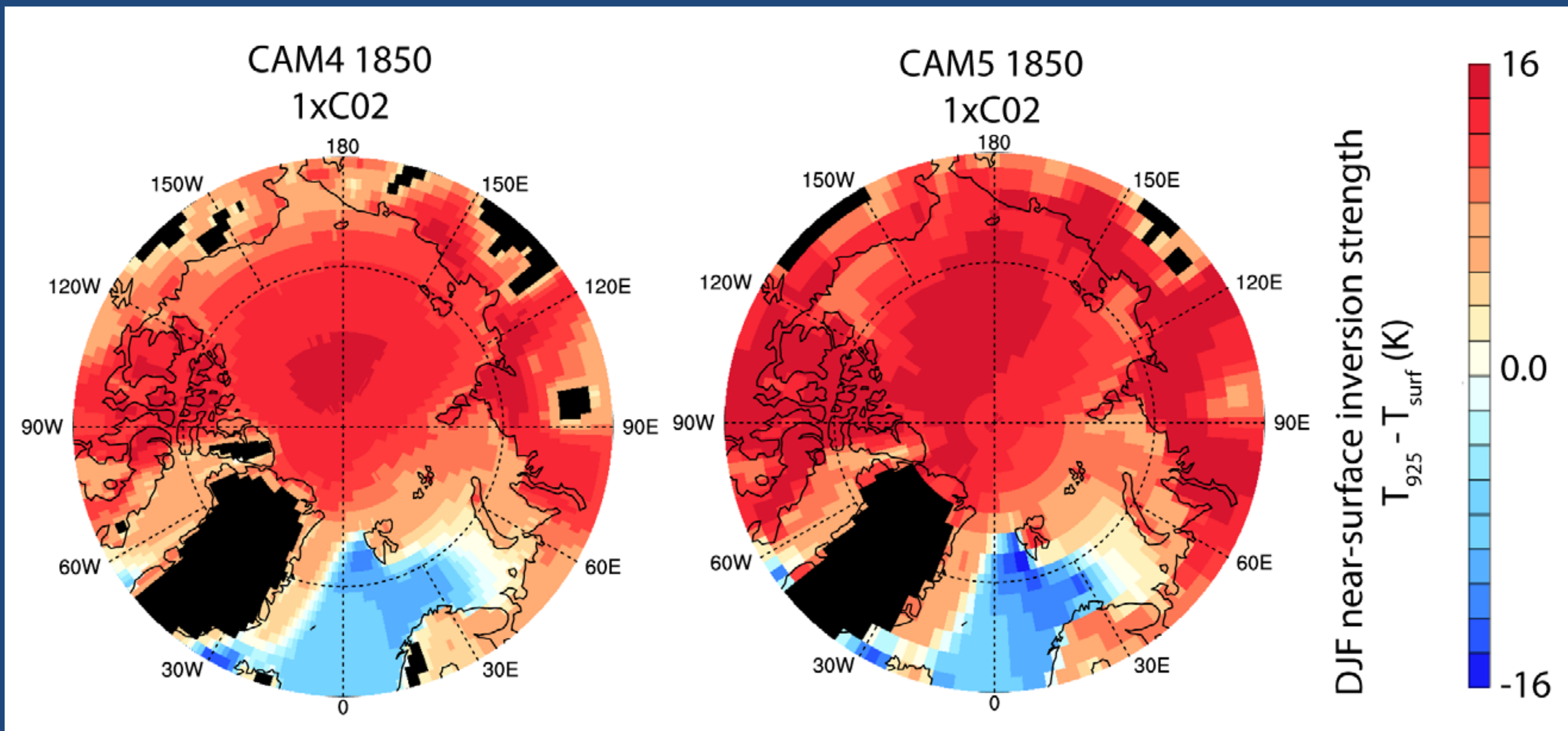
CAM5 1850



Cloud water paths are much greater in CAM5 than in CAM4.

Downwelling shortwave greater in CAM5 than in CAM4 (weaker Arctic SWCF).

1850 Mean State - Arctic winter inversion



Inversion strength greater in CAM5 than in CAM4 (11.7 K vs. 10.7 K), yet CAM5 has more Arctic warming/sea ice loss than CAM4…

This finding is inconsistent with Boe et al. (2009)…

Another approach to assess why Arctic climate change differs in CAM4 and CAM5?

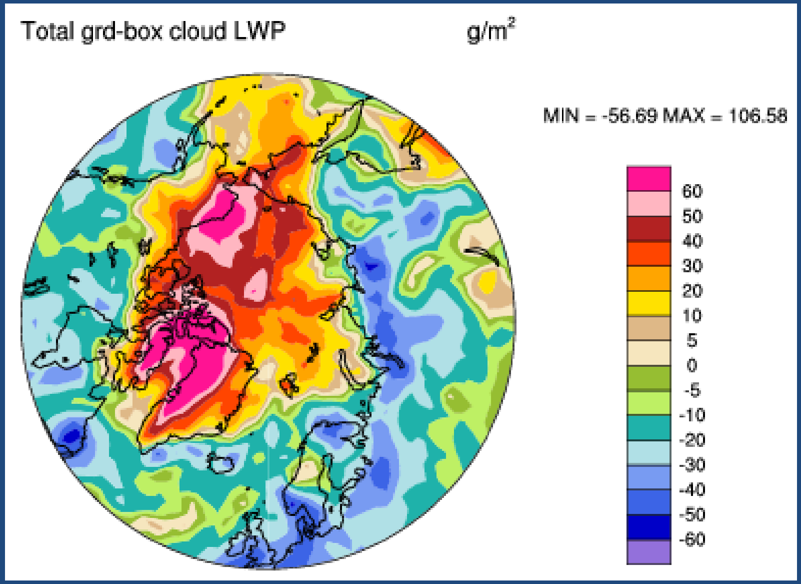
Evaluate local feedback parameters in the 2xC0_2 climate sensitivity experiments

Feedback parameters for 70-90 N annual mean values

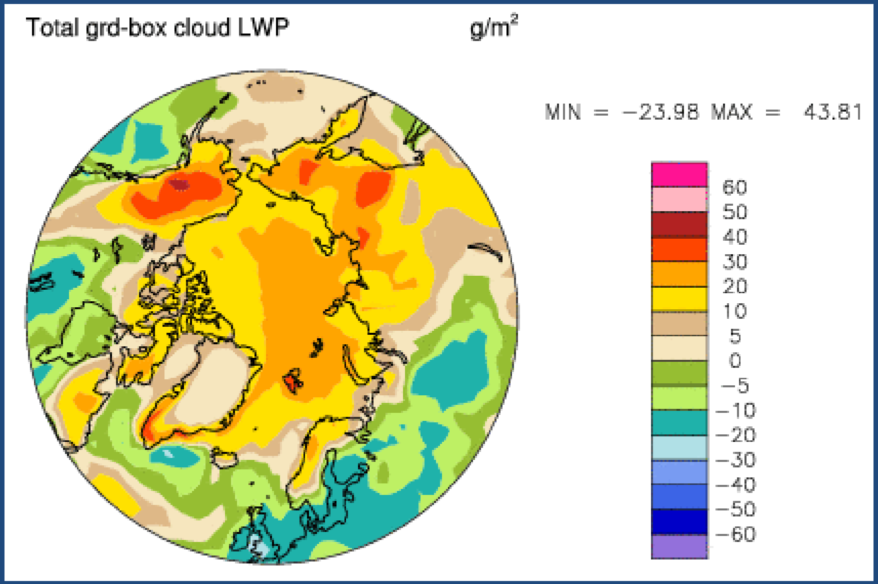
	CAM4	CAM5
ΔT_{surf} (K)	7.2	12.6
Longwave feedback parameter $\lambda_{lw} = \Delta_{netlwTOA}/\Delta T_{surf}$ ($Wm^{-2}K^{-1}$)	-0.9	-1.2
Shortwave feedback parameter $\lambda_{sw} = \Delta_{netswTOA}/\Delta T_{surf}$ ($Wm^{-2}K^{-1}$)	1.1	1.4

Arctic JJA cloud response to $2xC0_2$

CAM4



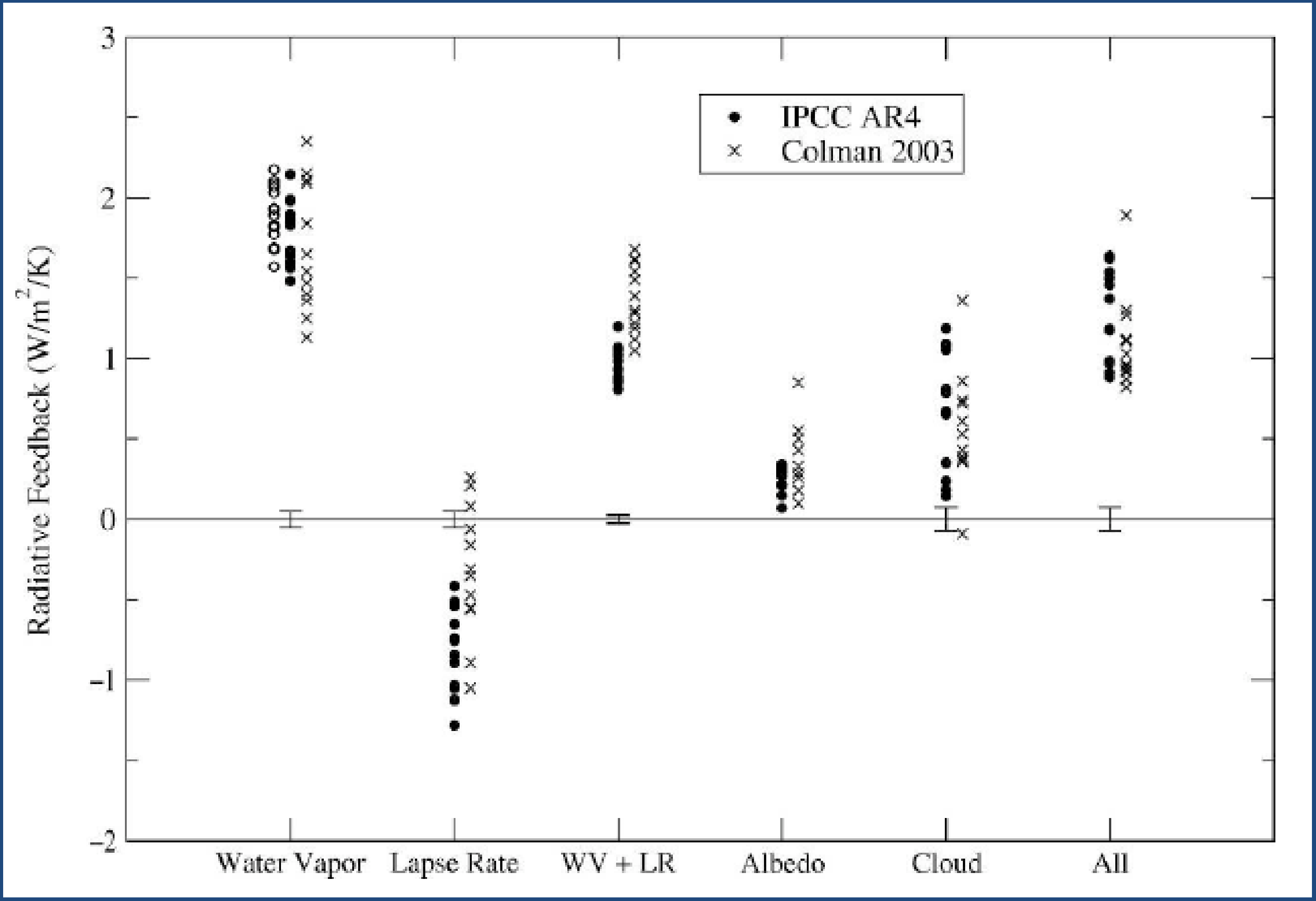
CAM5



JJA clouds are consistent with stronger shortwave feedbacks and Arctic amplification in CAM5 than in CAM4

Assess local feedbacks using radiative kernels

Global feedback parameters using radiative kernels
e.g., Soden and Held (2006)



Feedback strength in CAM4/CAM5 assessed with radiative kernels from CAM3

Feedback values for 70-90 N annual mean values ($Wm^{-2}K^{-1}$)

	CAM4	CAM5
Temperature feedback	-1.9	-1.9
Lapse rate feedback ***aside: opposite sign from global value***	+0.14	+0.08
Water vapor feedback (SW, LW)	+0.4, +0.5	+0.4, +0.5
Surface albedo feedback	+4.3	+6.2
Cloud feedback (residual)	?	?

Preliminary calculations from work with Andrew Gettelman/Karen Shell.
Andrew will discuss this work more…

Summary:

Recent 2x$C0_2$ model experiments using CAM4 and CAM5 have dramatic differences in Arctic temperature amplification and sea ice loss. These experiments provide a sandbox for understanding Arctic feedbacks.

We are evaluating both the mean state and local feedback parameters to understand the modeled Arctic response to anthropogenic forcing.

EXTRA

TO DO

- compare cloud particle sizes
- compare ice thickness in 1850 controls
- compare sea ice and snow albedo values in CAM4 and CAM5

Can a local feedback parameter analysis help explain the Arctic differences?

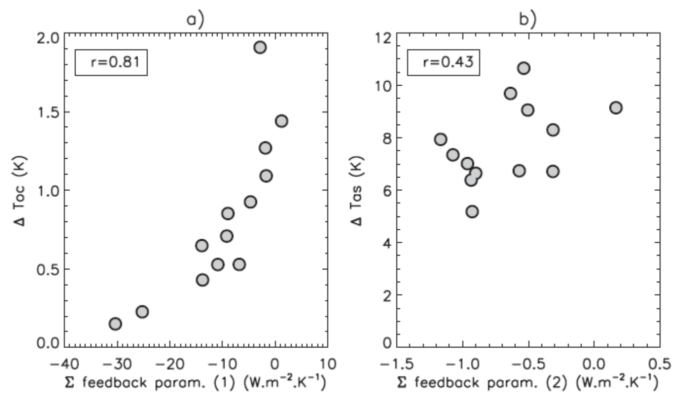


FIG. 3. Link between the sum of the longwave and shortwave feedback parameters and (a) T_{oc} when the feedback parameters are defined using T_{oc} and (b) T_{as} when the feedback parameters are classically defined using T_{as}. The value of the linear correlation coefficient is given on the graph. Note that for a sample of 13 values, the correlation corresponding to the 0.05 (0.01) significance level is 0.553 (0.684).

Boé et al. (2009): Normalizing by surface temperature not appropriate in the Arctic, use ocean temperatures.

	CAM4	**CAM5**
ΔT_{ocean} (K)	0.3	0.5
Longwave feedback parameter $\lambda_{lw} = \Delta_{netlwTOA}/\Delta T_{ocean}$ ($Wm^{-2}K^{-1}$)	-20.2	-27.8
Shortwave feedback parameter $\lambda_{sw} = \Delta_{netswTOA}/\Delta T_{ocean}$ ($Wm^{-2}K^{-1}$)	23.1	32.7

Conclusions not affected by using approximate mixed layer temperature (T_{ocean}) instead of surface temperature (T_{surf}).

Summary of cloud, albedo, and radiation changes associated with sea ice loss

	CAM4	CAM5
Low cloud	+16%	-3%
Surface albedo	-13%	-8%
TOA, Surface CF (Wm^{-2})	-22.7, -18.9	-12.7, -11.5
Surface net radiation (Wm^{-2})	+13.3	+5.1
Surface shortwave fluxes (Wm^{-2})	Net: +15.0 Down: -23.7 Up: -38.7	Net: +9.9 Down: -11.3 Up: -21.2

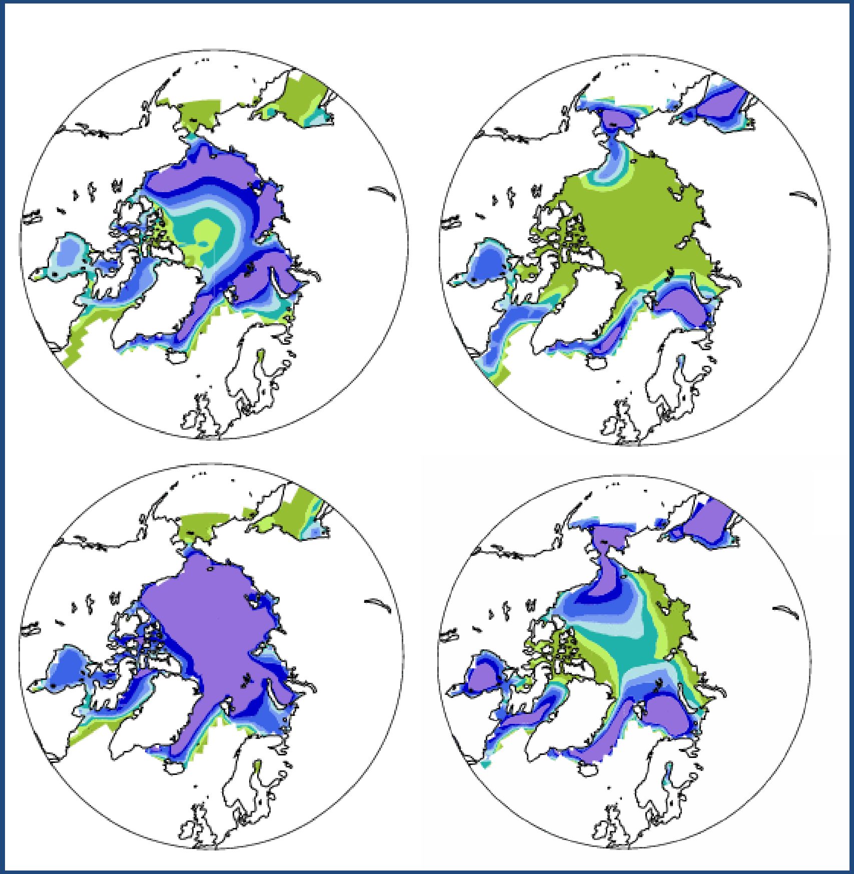
Largest surface net radiation increase in CLDMOD CAM3.5 forecasts due to weak cloud response and large surface albedo decrease.

Arctic sea ice loss in response to 2xC02

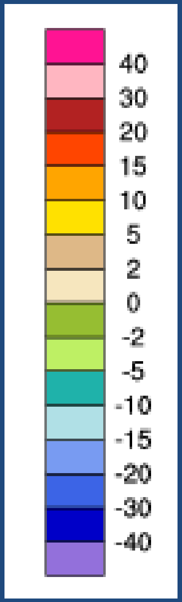
Summer (JJA) Winter (DJF)

CAM4

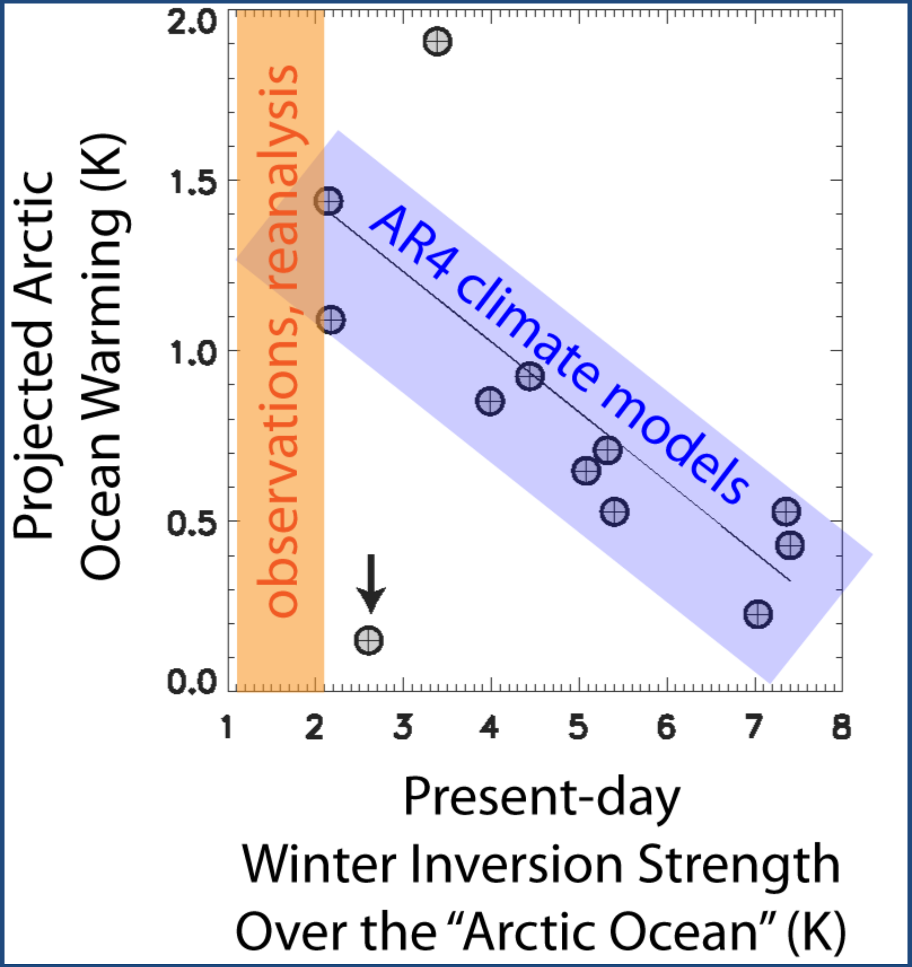
CAM5



Sea Ice Fraction Loss



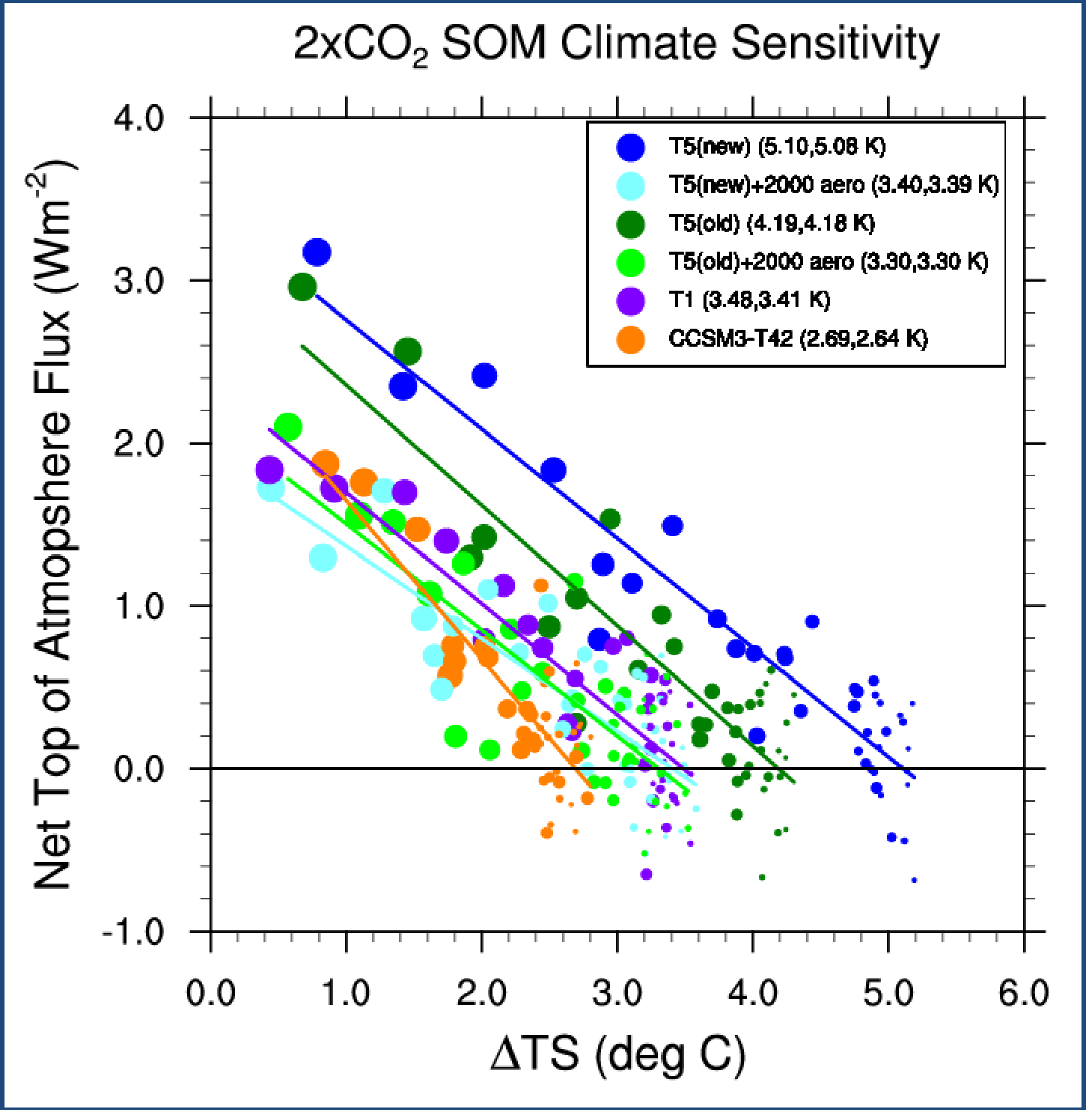
Inversion strength explains spread in projected Arctic warming in IPCC models



Adapted from Boé et al. (2009)

Models with excessive inversion strength may under-predict Arctic warming.

Slab Ocean Model (SOM) 2x$C0_2$ climate sensitivity experiments

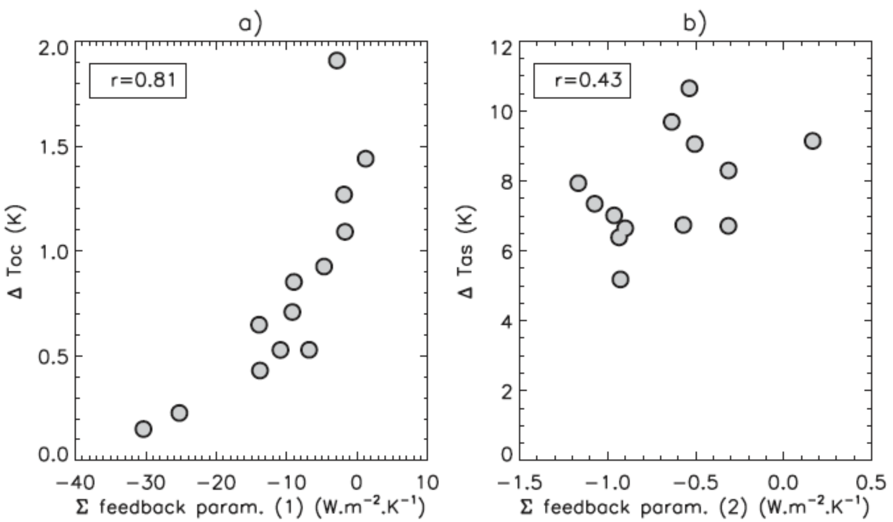


Recent SOM climate sensitivity experiments (plot from Rich Neale)

Arctic Feedback Parameter Comparison

$$\lambda_{LW} = \frac{\Delta F}{\Delta T_{oc}},$$

$$\lambda_{SW} = \frac{\Delta Q}{\Delta T_{oc}}.$$



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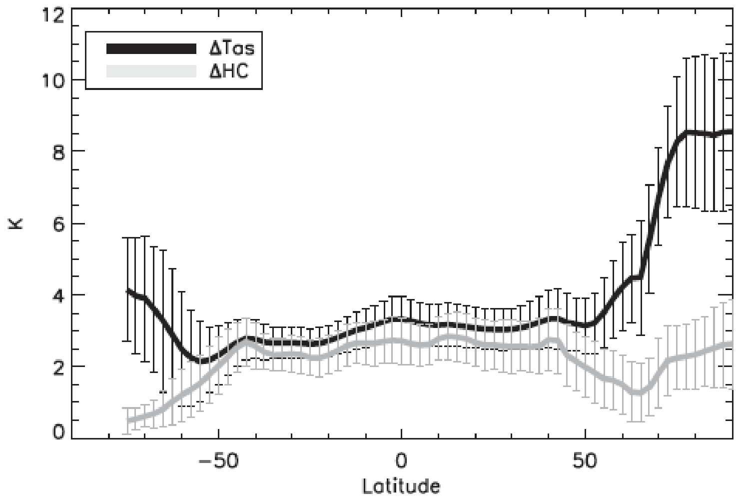

FIG. 1. Annual zonal mean change of surface temperature (T_{as}, K) over oceans and of heat content of the oceanic mixed layer–atmosphere system expressed as a change of temperature within the uppermost 70 m of ocean (HC, K) (see text for the calculation of the heat content) at the end of the twenty-second century. The lines stand for the ensemble means and the bars stand for the intermodel spread measured by one std dev.

Boé et al. (2009)

Soden and Held (2006)

TABLE 1. Tabulated values of the feedback parameters shown in Fig. 1. Model integrations for the Goddard Institute for Space Studies (GISS) atmosphere–ocean model (AOM) and GISS EH models end at year 2100 and therefore estimates of the effective sensitivity and cloud feedback are not performed.

	Planck	Lapse rate	Water vapor	Surface albedo	Effective sensitivity	Cloud feedback
CNRM	−3.21	−0.89	1.83	0.31	−1.17	0.79
GFDL CM2_0	−3.20	−0.85	1.87	0.33	−1.18	0.67
GFDL CM2_1	−3.24	−1.12	1.97	0.21	−1.37	0.81
GISS AOM	−3.25	−1.27	2.14	0.27		
GISS EH	−3.26	−1.12	1.99	0.07		
GISS ER	−3.24	−1.05	1.86	0.15	−1.64	0.65
INMCM3	−3.18	−0.51	1.56	0.32	−1.46	0.35
IPSL	−3.24	−0.84	1.83	0.22	−0.98	1.06
MIROC MEDRES	−3.20	−0.75	1.64	0.31	−0.91	1.09
MRI	−3.21	−0.65	1.85	0.27	−1.50	0.24
MPI ECHAM5	−3.22	−1.03	1.90	0.29	−0.88	1.18
NCAR CCSM3	−3.17	−0.54	1.60	0.34	−1.62	0.14
NCAR PCM1	−3.13	−0.41	1.48	0.34	−1.53	0.18
UKMO HADCM3	−3.20	−0.74	1.67	0.22	−0.97	1.08