The Arctic cloud response to anthropogenic forcing and its impact on Arctic climate feedbacks

Jennifer E. Kay
National Center for Atmospheric Research (USA)

Gunilla Svensson, Stockholm University
Sandrine Bony, Laboratoire de Météorologie Dynamique
Johannes Karlsson, Stockholm University

New data + Ice loss = New discoveries

No observed cloud response to summer Arctic sea ice loss

Low cloud increases over newly open water during early fall

Kay and Gettelman 2009 JGR

See also Palm et al. 2010 JGR, and Wu and Lee 2012 JGR on early fall cloud response

Models project a cloudier Arctic as the climate warms

1) Negative shortwave cloud feedback
(reduces Arctic amplification)

2) Positive longwave cloud feedback
(enhances Arctic amplification)

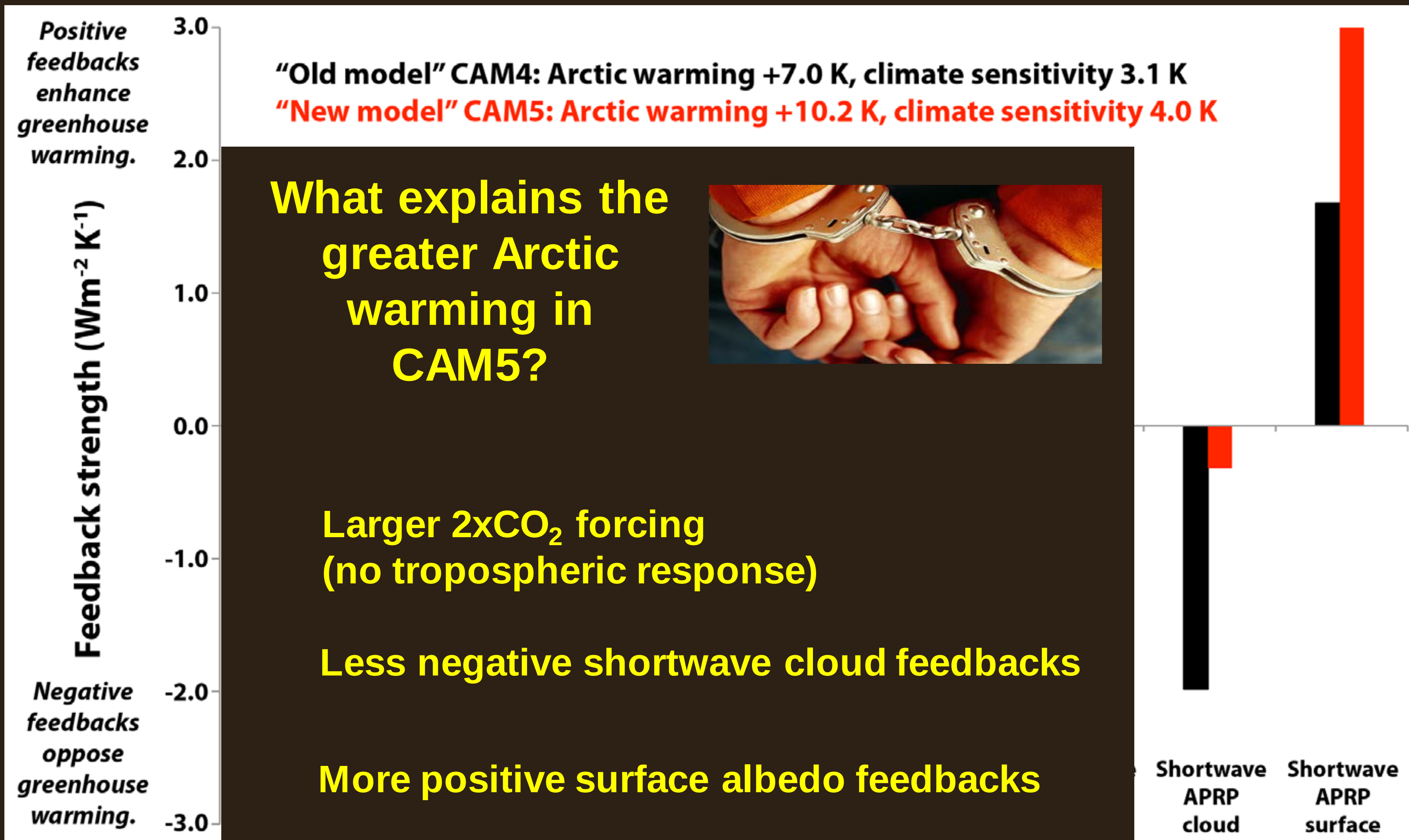
Arctic clouds affect non-cloud feedbacks (e.g., surface albedo feedback).

Today's talk:
How do Arctic clouds affect modeled greenhouse warming?

1. Arctic climate feedbacks in two CMIP5 models

2. Arctic warming and shortwave feedbacks in the CMIP5 "ensemble of opportunity"

Equilibrium Arctic response to $2xCO_2$



What explains the greater Arctic warming in CAM5?

Larger $2xCO_2$ forcing
(no tropospheric response)

Less negative shortwave cloud feedbacks

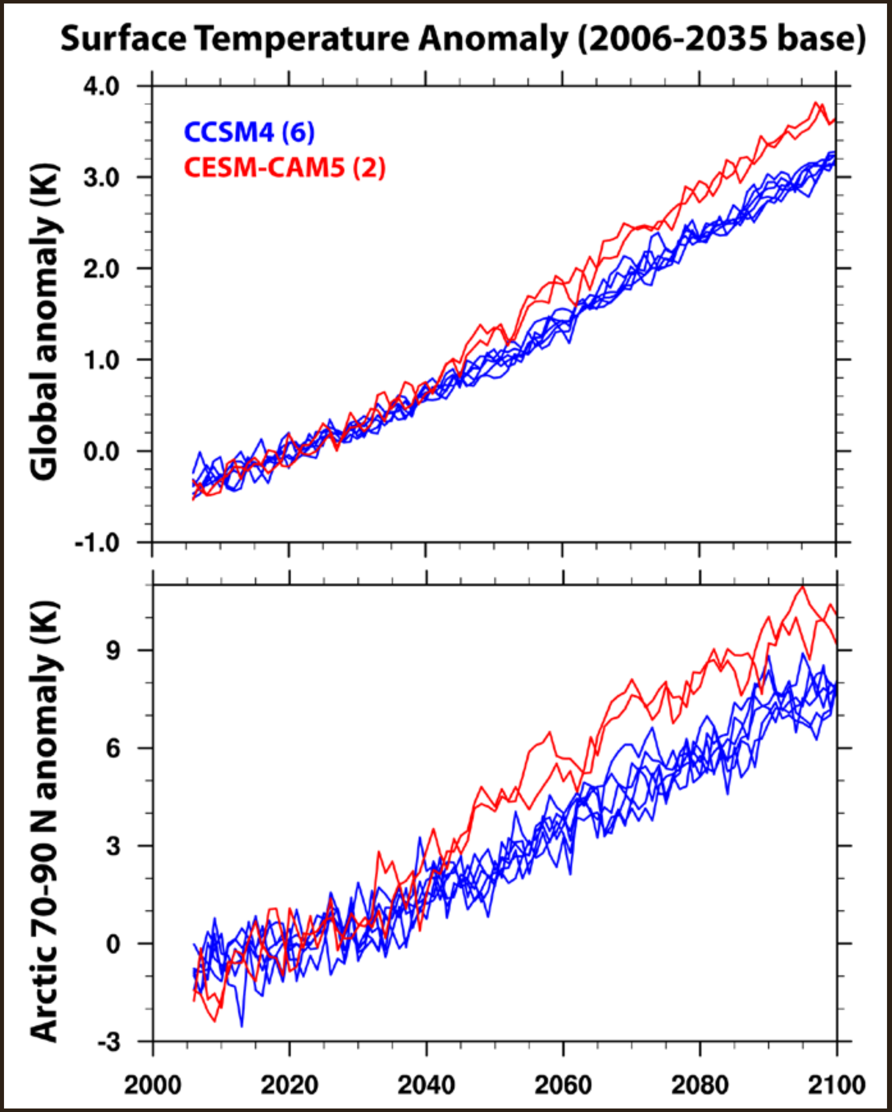
More positive surface albedo feedbacks

Kay et al. 2012a, JClim

Transient 21st century simulations

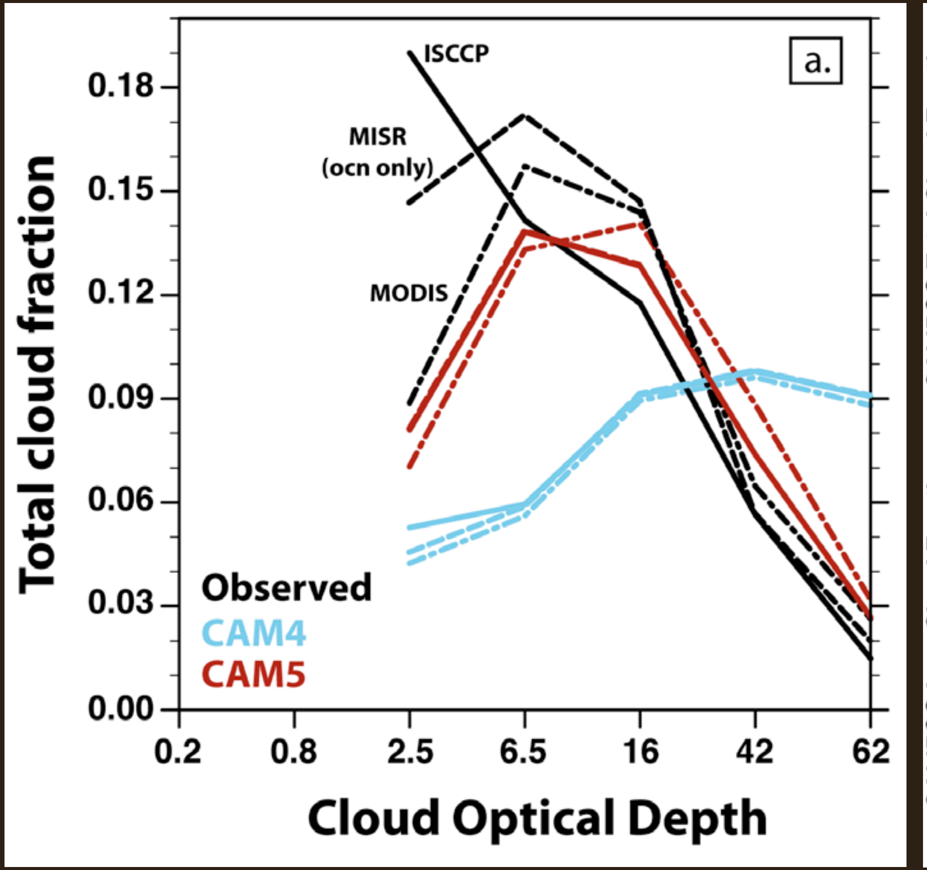
CESM-CAM5 warms more than CCSM4 by the mid-late 21st century, both globally and in the Arctic.

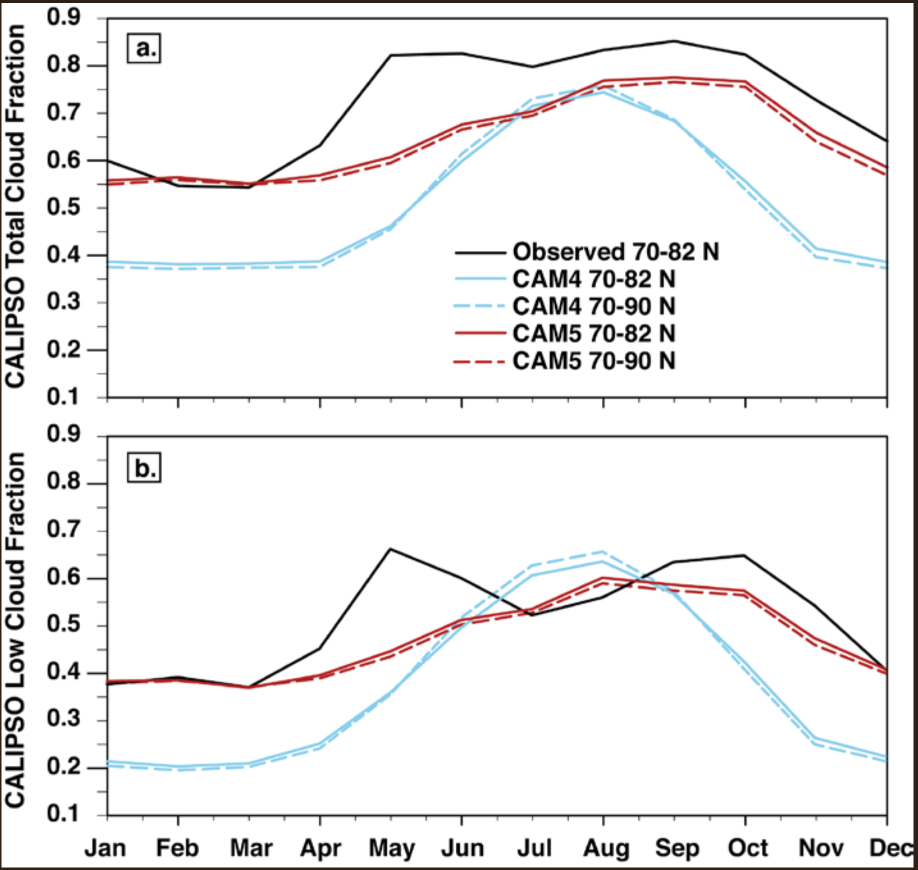
(similar to $2xCO_2$)



CAM5 clouds better than CAM4 clouds, both globally and in Arctic

e.g., global (left) and Arctic (right) evaluation of CAM clouds using satellite observations and instrument simulators (COSP)





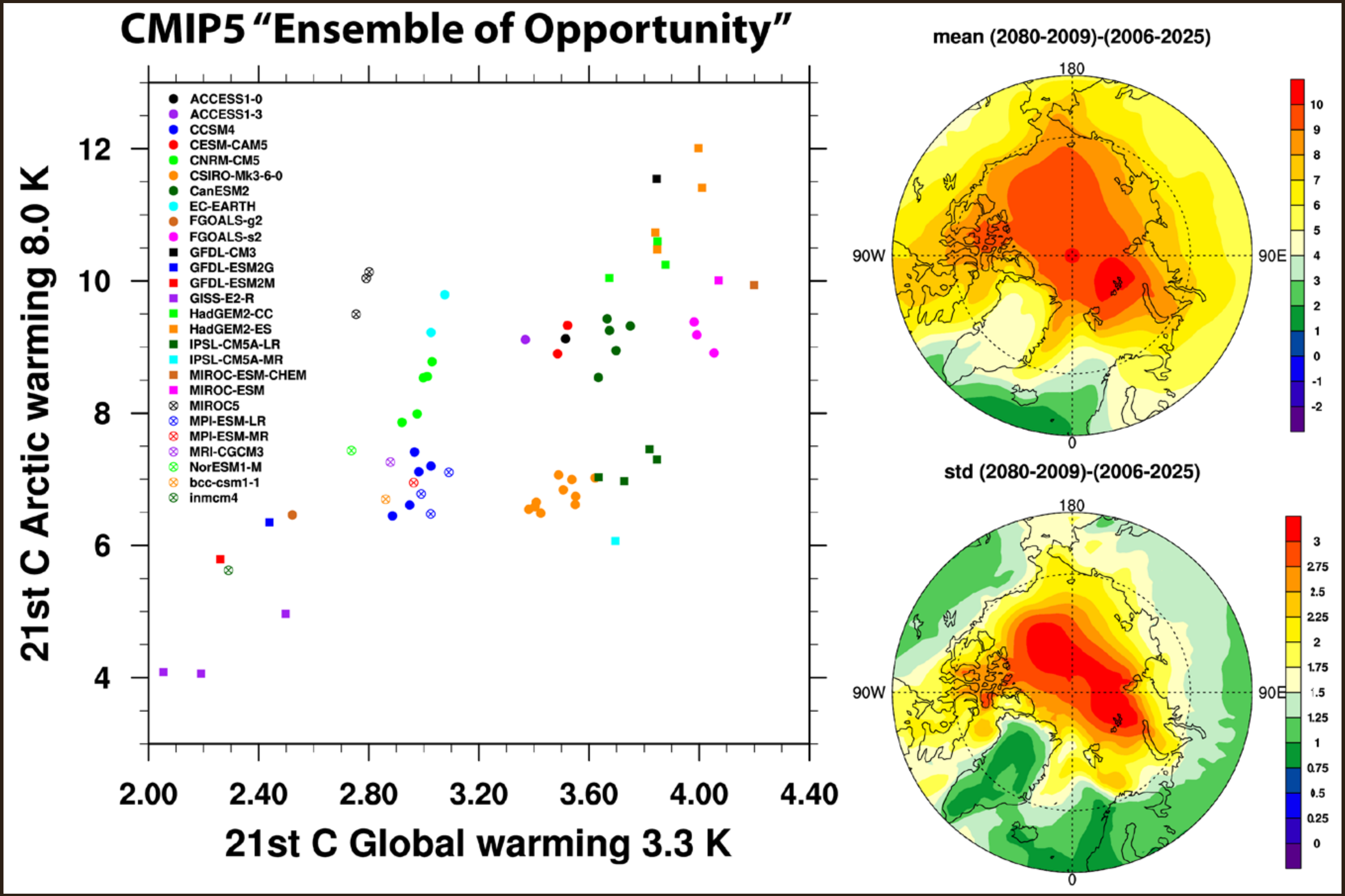
Figures from Kay et al. 2012b, JClim

Today's talk

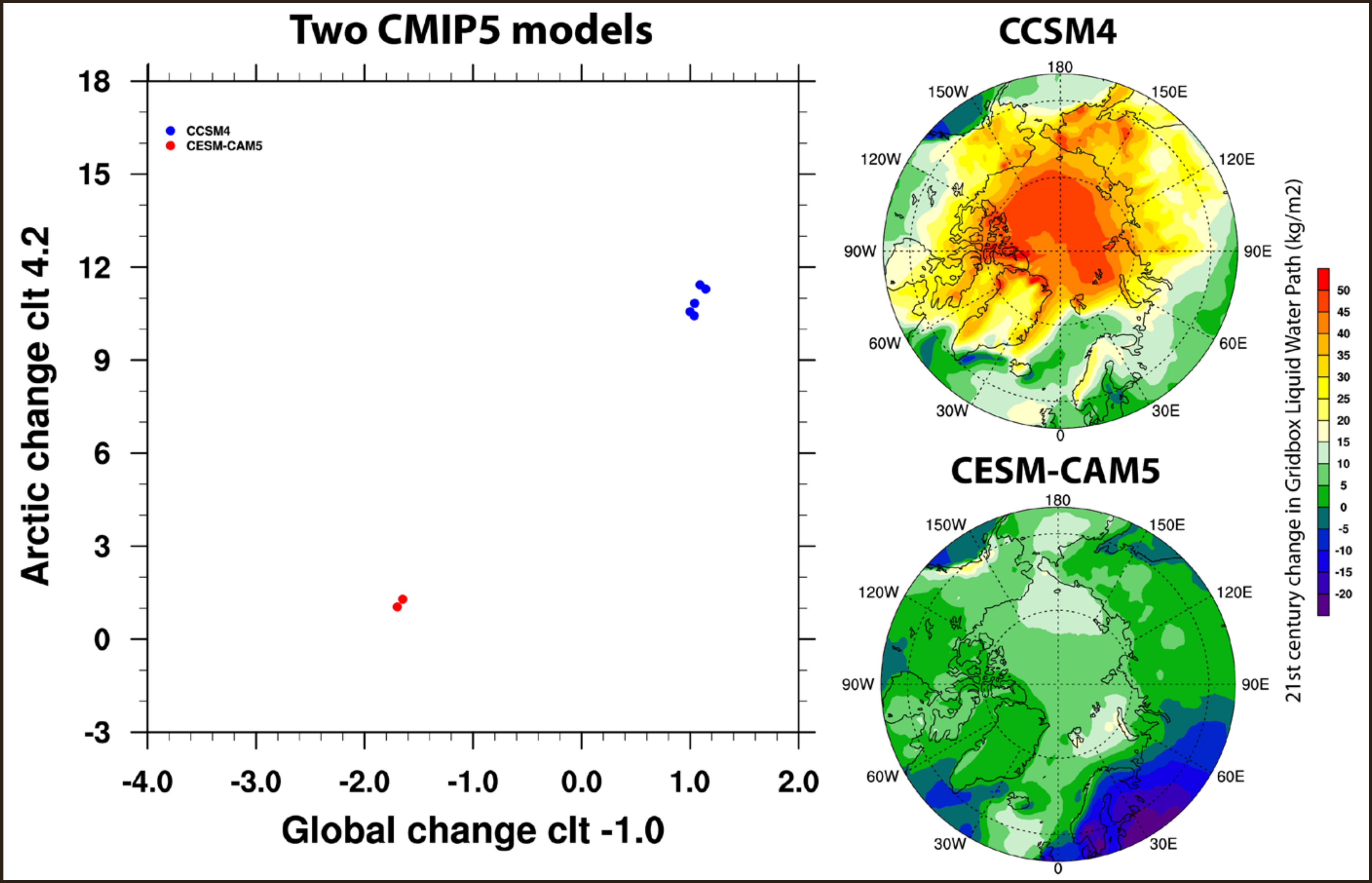
1. Arctic climate feedbacks in two CMIP5 models

2. How do these two models fit into the broader CMIP5 landscape?

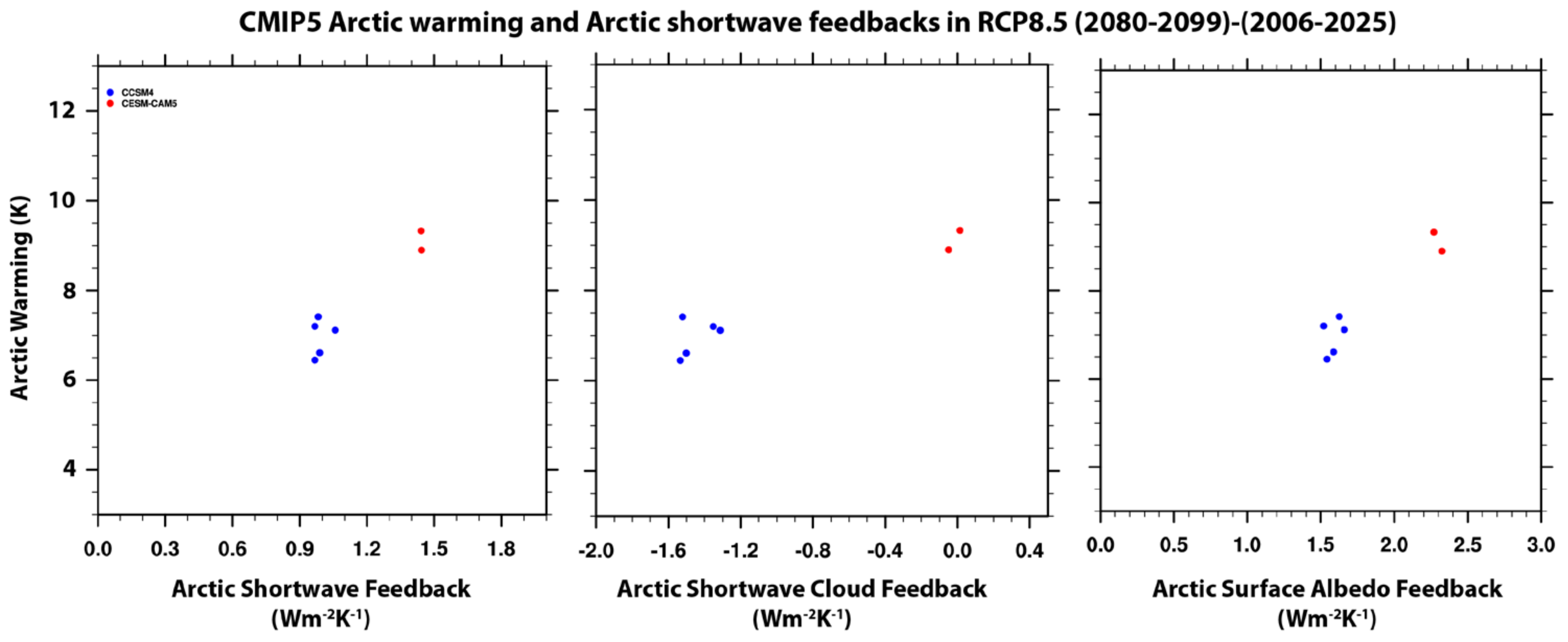
21st century Surface Warming (RCP8.5)



21st century cloud response RCP8.5



Shortwave Arctic feedbacks in CMIP5



Summary

We found greater Arctic warming in the model with relatively large $2xCO_2$ forcing, weak negative shortwave cloud feedbacks, and strong positive surface albedo feedbacks (CAM5). Clouds have a large influence on the amount of modeled Arctic warming.

Kay, J. E., Holland, M. M., Bitz, C., Blanchard-Wrigglesworth, E., Gettelman, A., Conley, A., and D. Bailey (2012): The influence of local feedbacks and northward heat transport on the equilibrium Arctic climate response to increased greenhouse gas forcing in coupled climate models, *J. Climate*, doi: 10.1175/JCLI-D-11-00622.1.

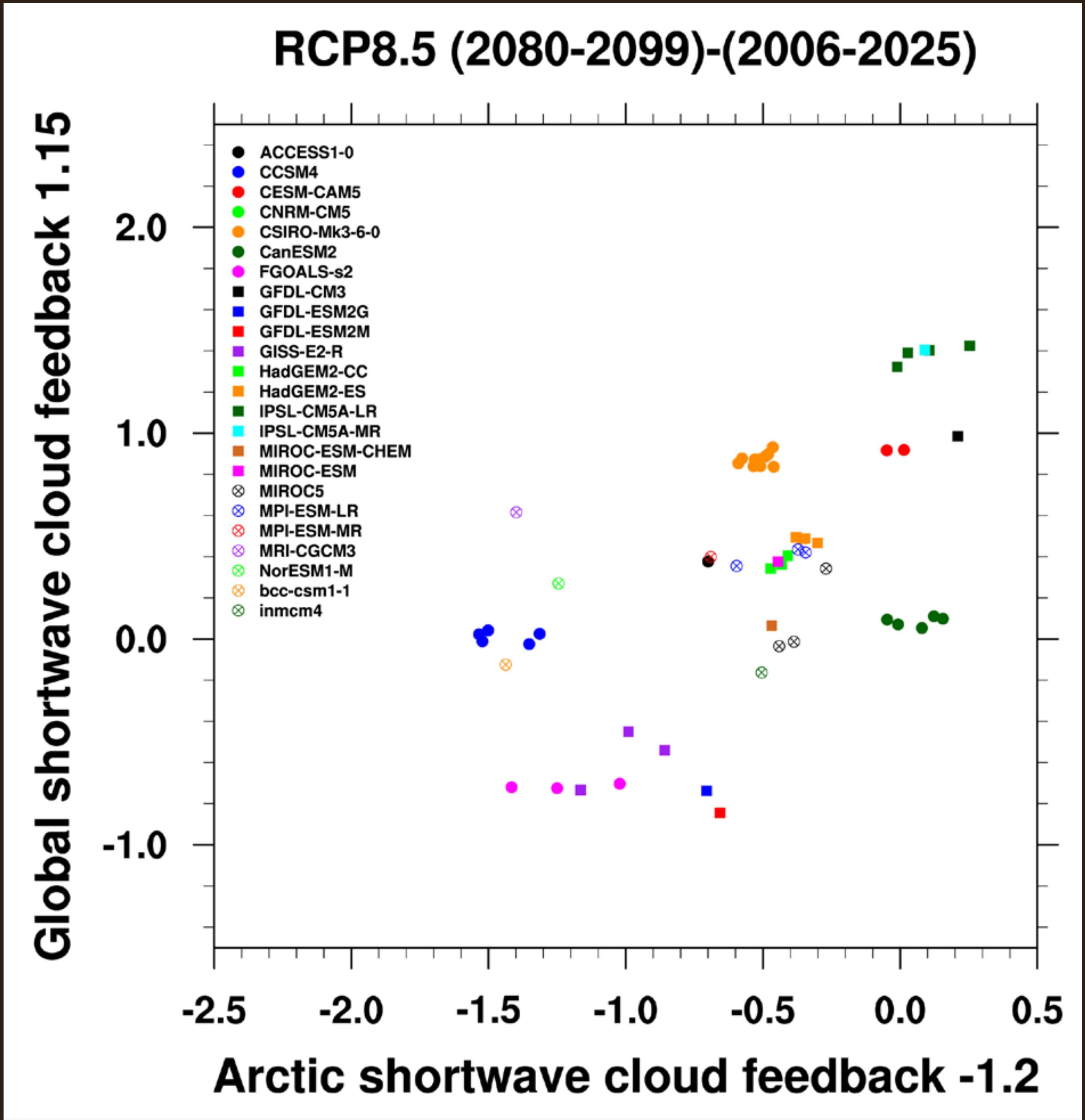
COSP-enabled evaluations show CAM5 has reduced many longstanding cloud biases in CAM4/CMIP3 climate models.

Kay, J. E., Hillman, B., Klein, S., Zhang, Y., Medeiros, B., Gettelman, G., Pincus, R., Eaton, B., Boyle, J., Marchand, R. and T. Ackerman (2012): Exposing global cloud biases in the Community Atmosphere Model (CAM) using satellite observations and their corresponding instrument simulators, *J. Climate*, doi:10.1175/JCLI-D-11-00469.1

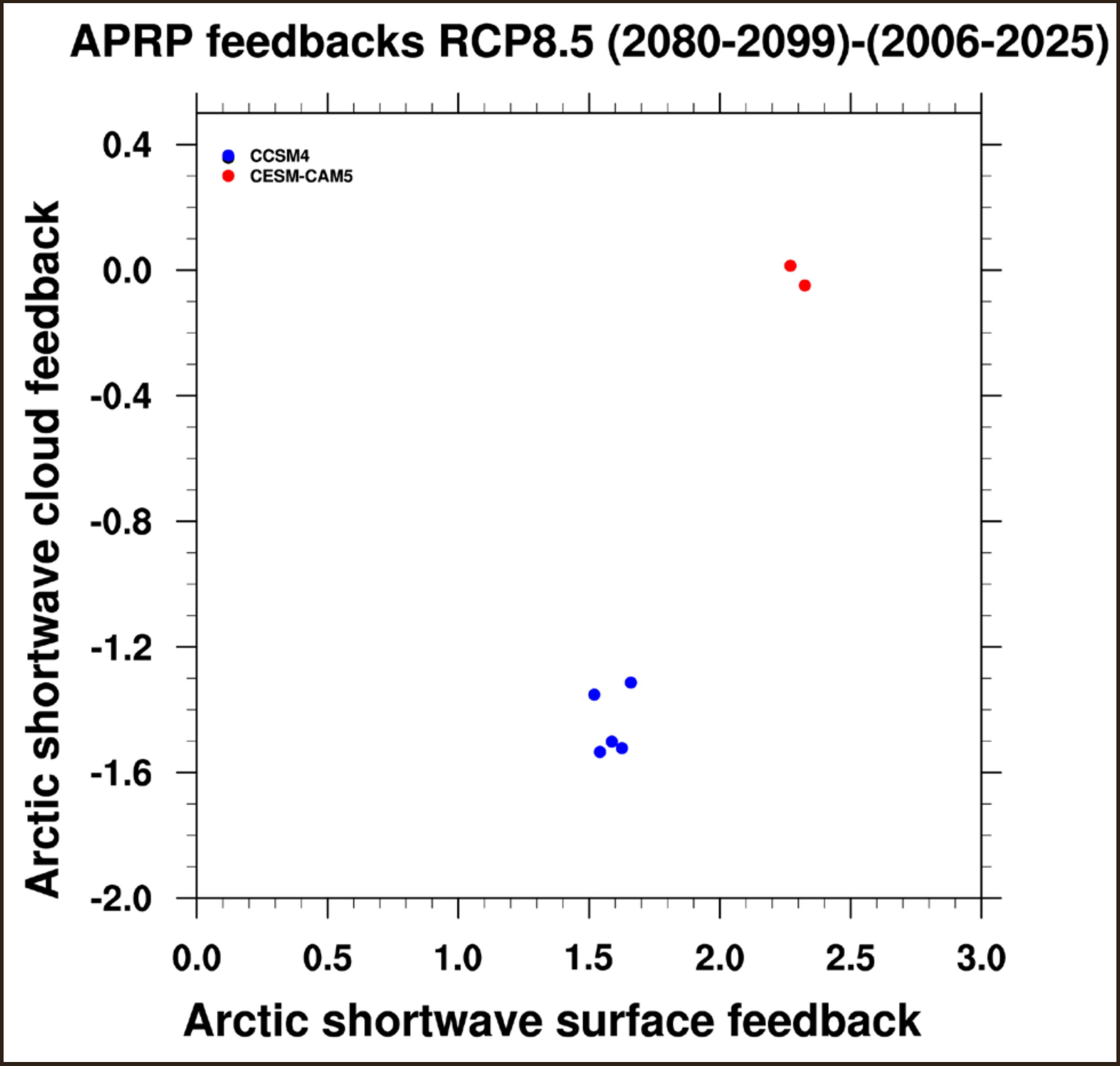
Ongoing evaluation of Arctic cloud processes and feedbacks in CMIP5 and CFMIP experiments and in satellite observations.

Weak relationship between Arctic and global shortwave cloud feedbacks.

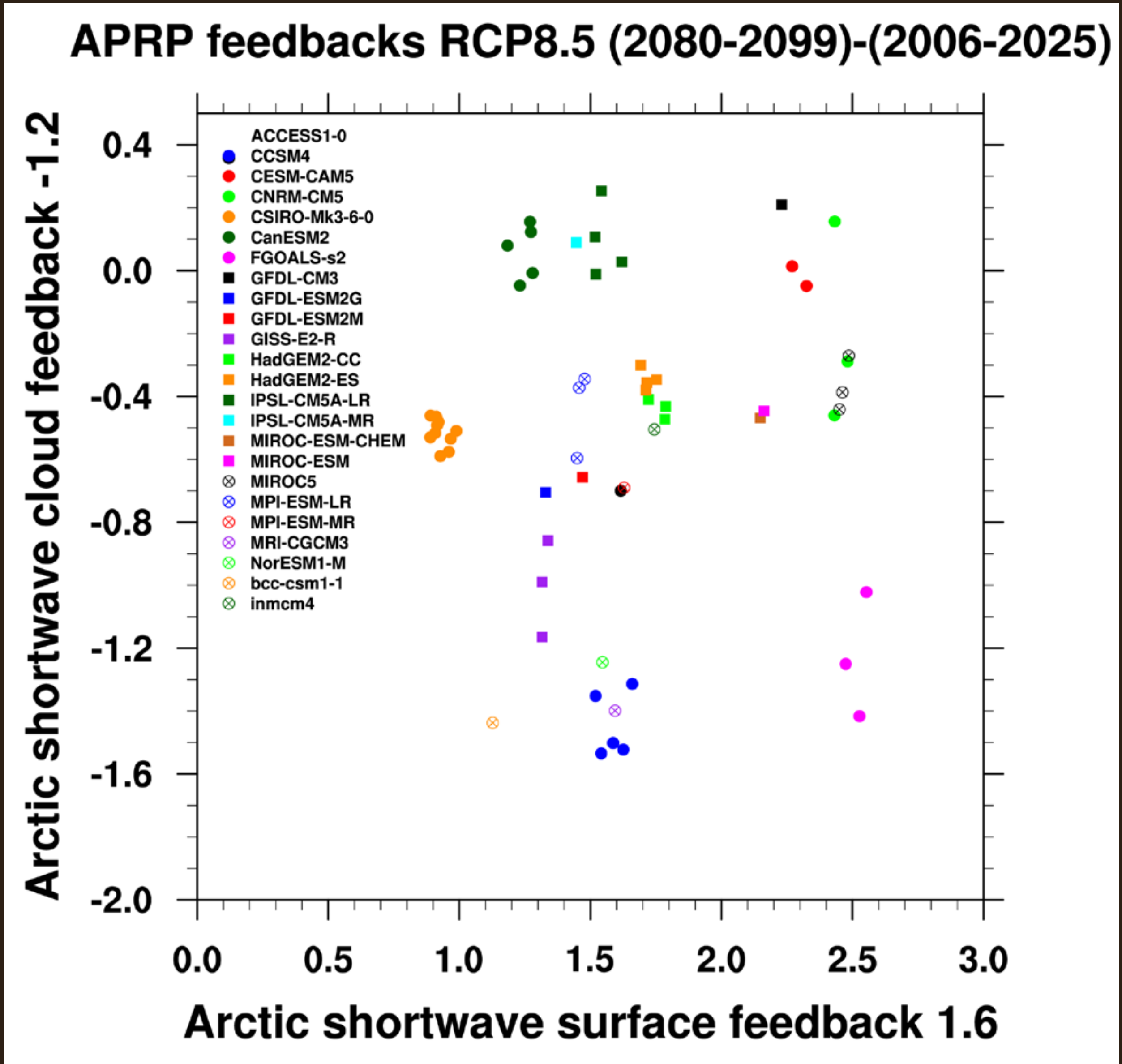
Why?



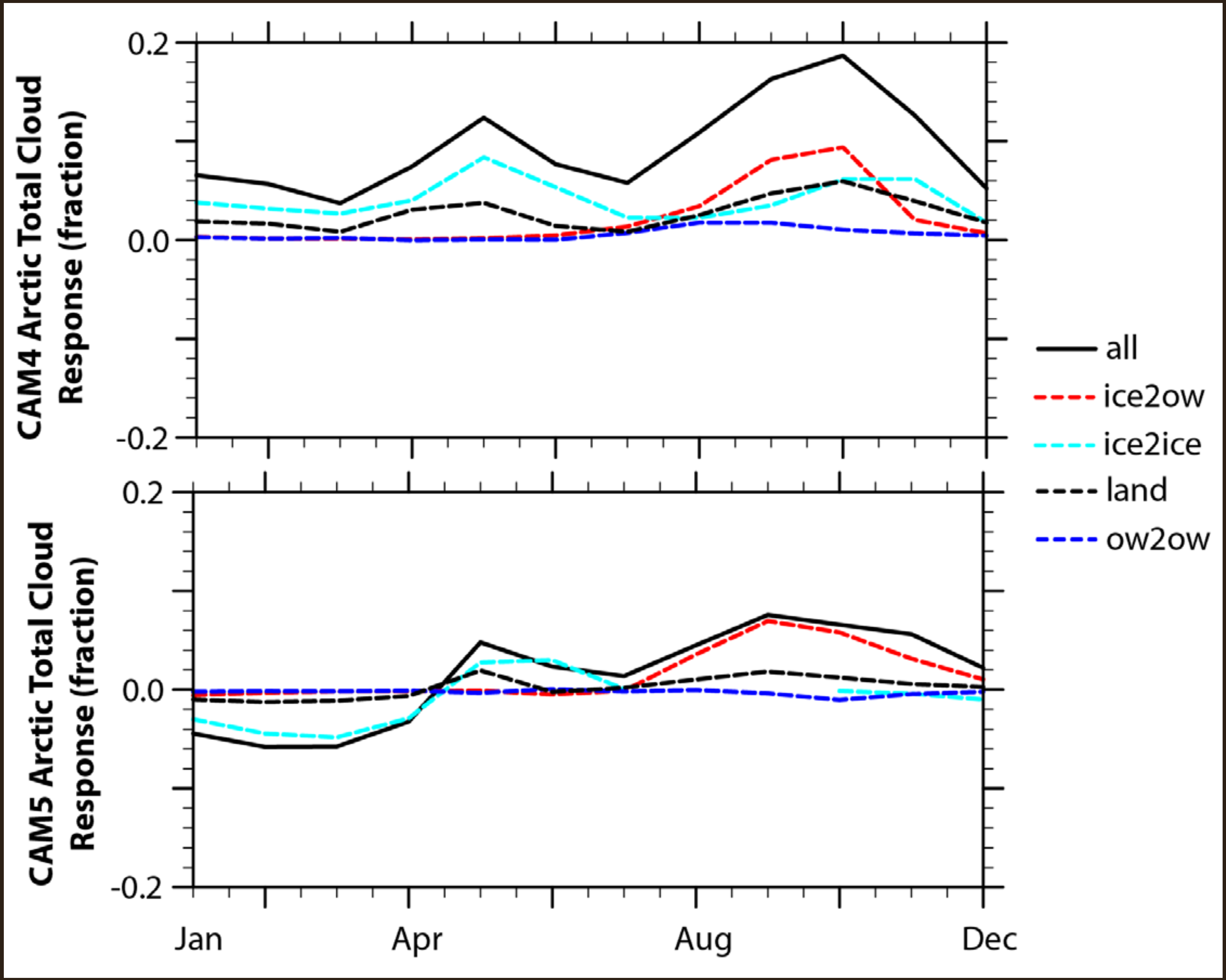
Are positive surface albedo feedbacks and negative shortwave cloud feedbacks related?



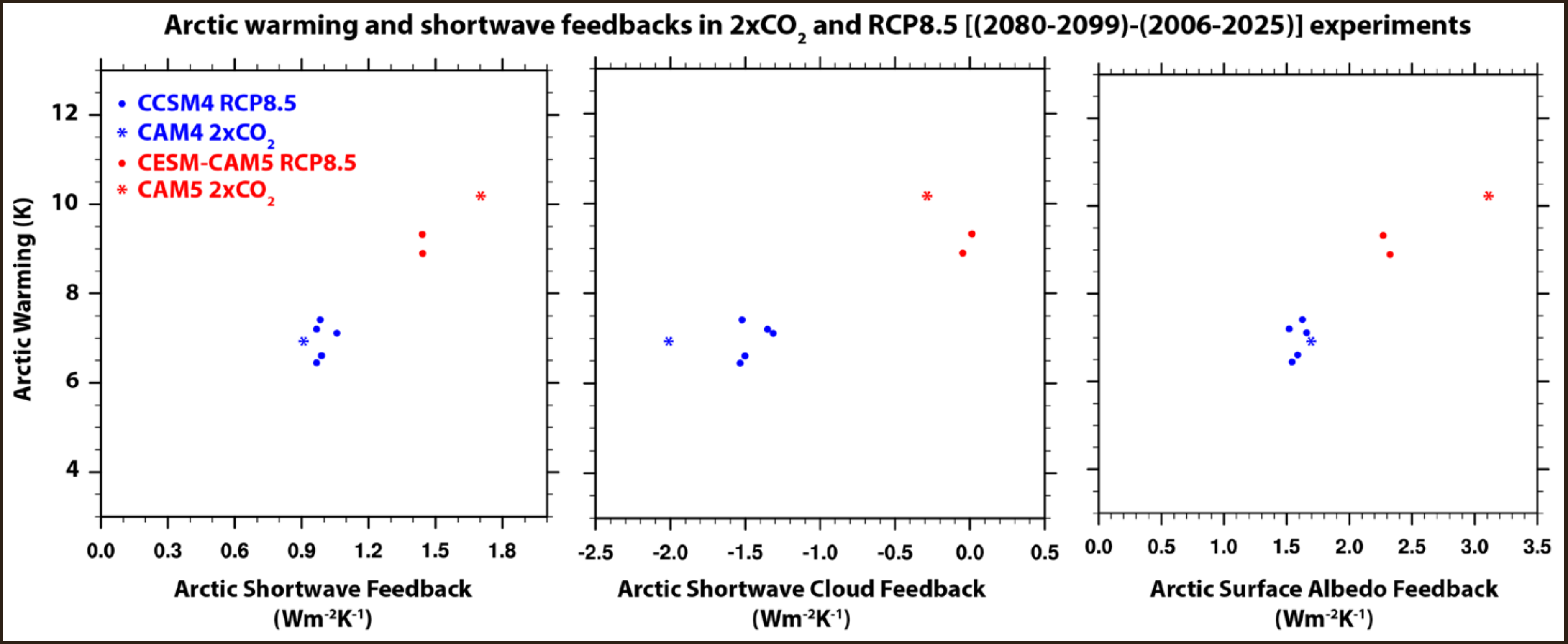
No correlation between positive surface albedo feedbacks and negative shortwave cloud feedbacks



Arctic cloud response to 2xCO_2 by surface type in two CMIP5 models

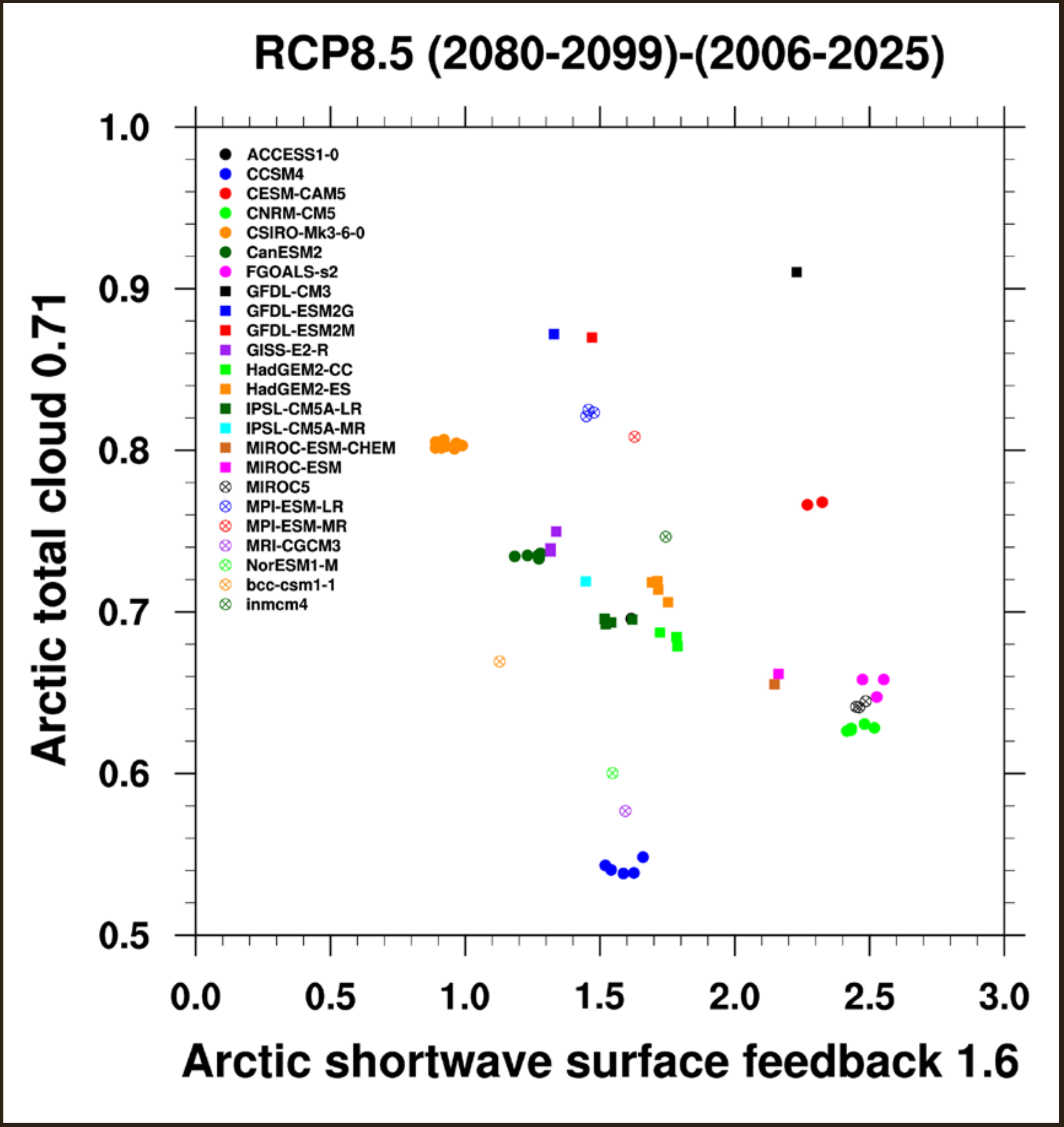


Similar warming and shortwave feedbacks in response to $2xCO_2$ and RCP8.5

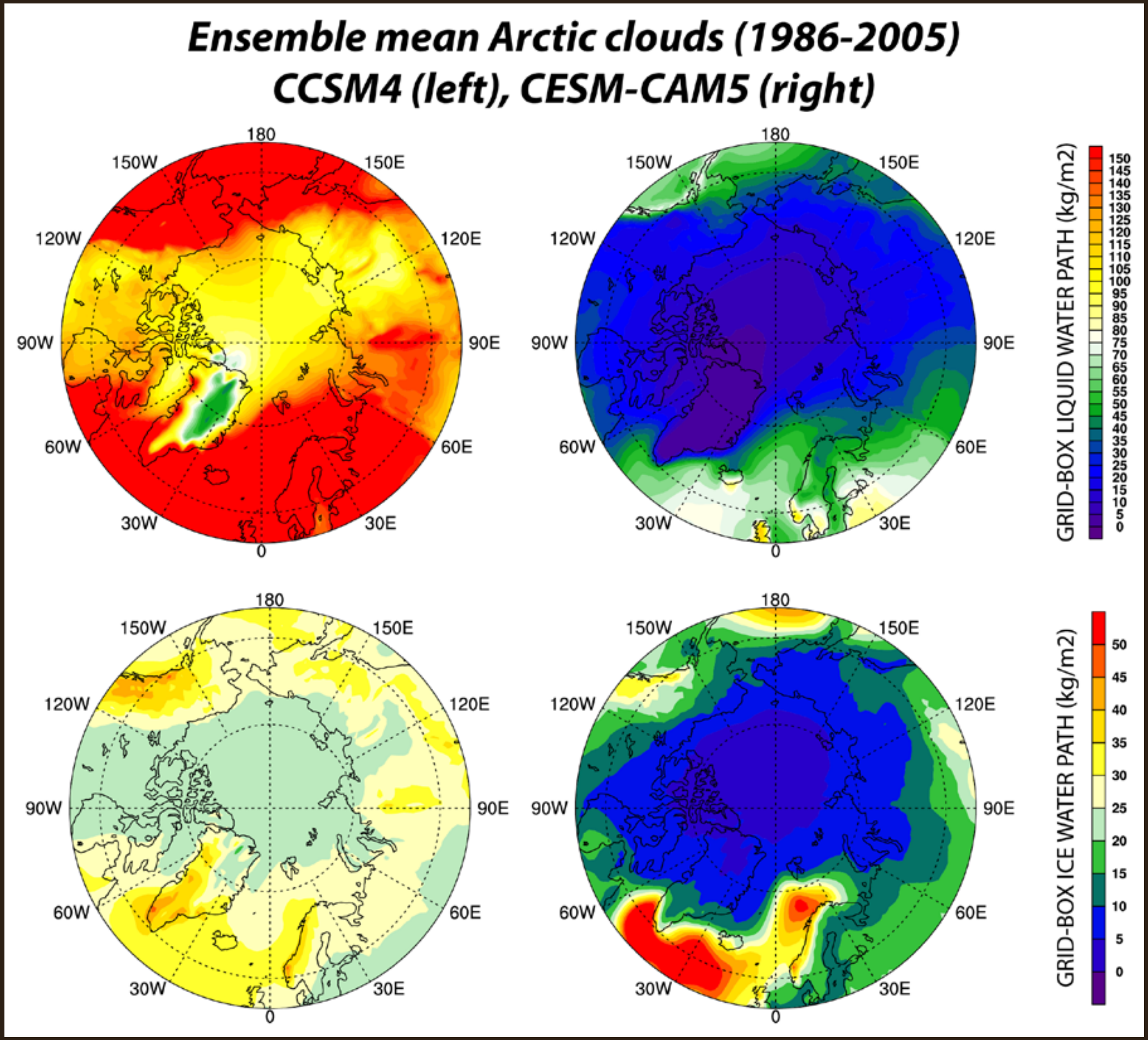


Understanding the $2xCO_2$ equilibrium response is relevant for transient 21st century projections.

Weak relationship between Arctic total cloud fraction and the positive shortwave surface albedo feedback



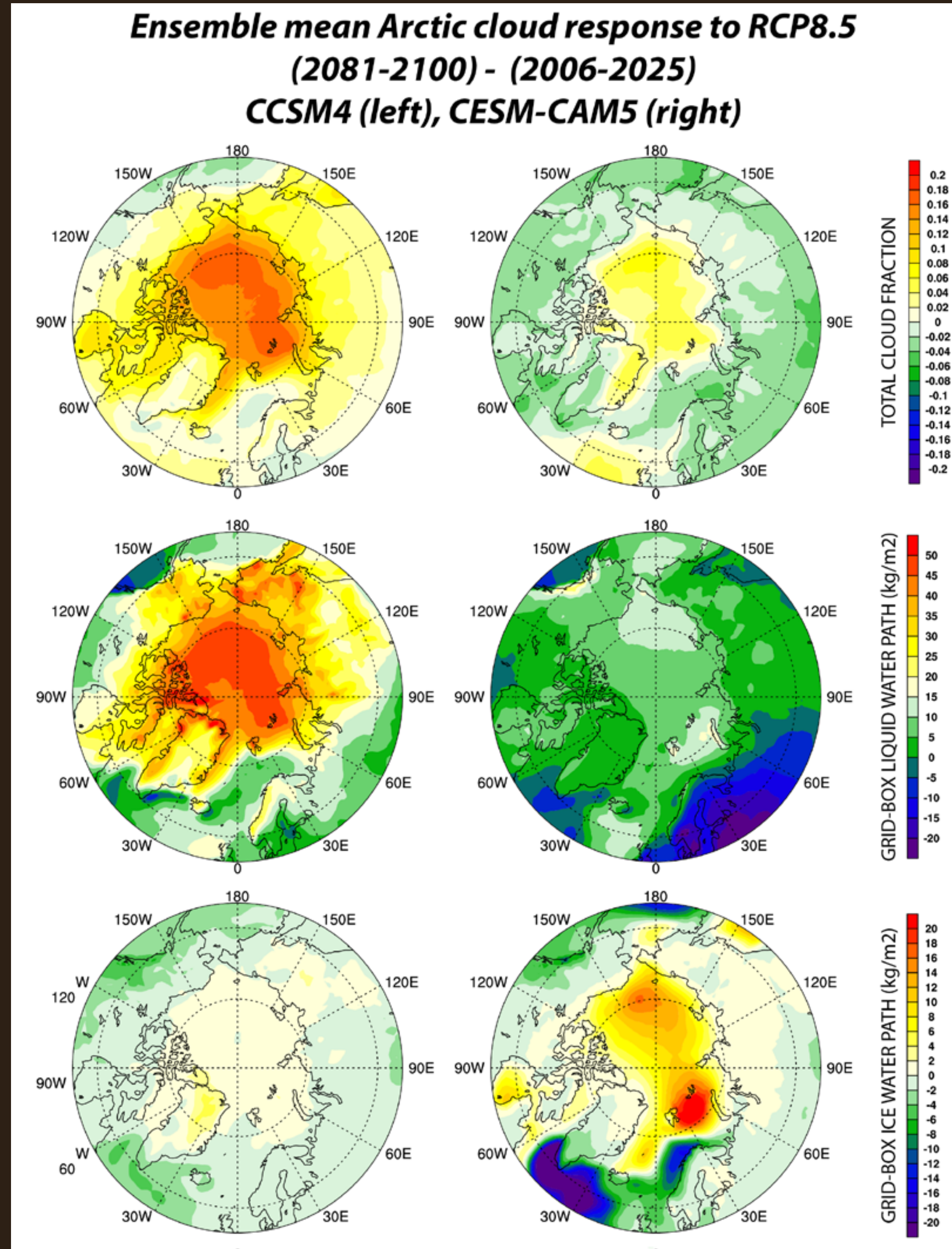
Evidence that Arctic cloud properties affect albedo feedbacks



CESM-CAM5 has *optically thinner clouds* and *stronger positive surface albedo feedbacks* than CCSM4.

Evidence that negative Arctic shortwave cloud feedbacks affect Arctic warming

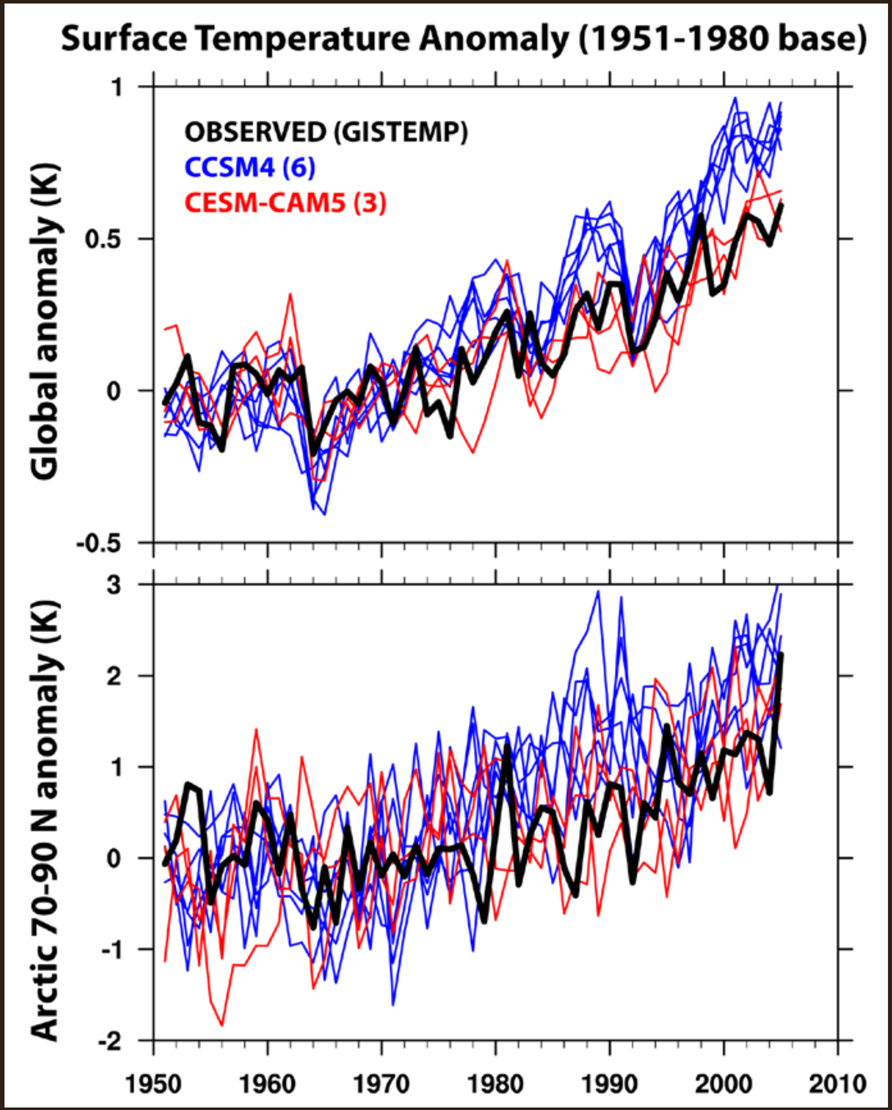
CESM-CAM5 has ***smaller Arctic cloud amount and cloud liquid water path increases*** and ***less negative shortwave cloud feedbacks*** than CCSM4.



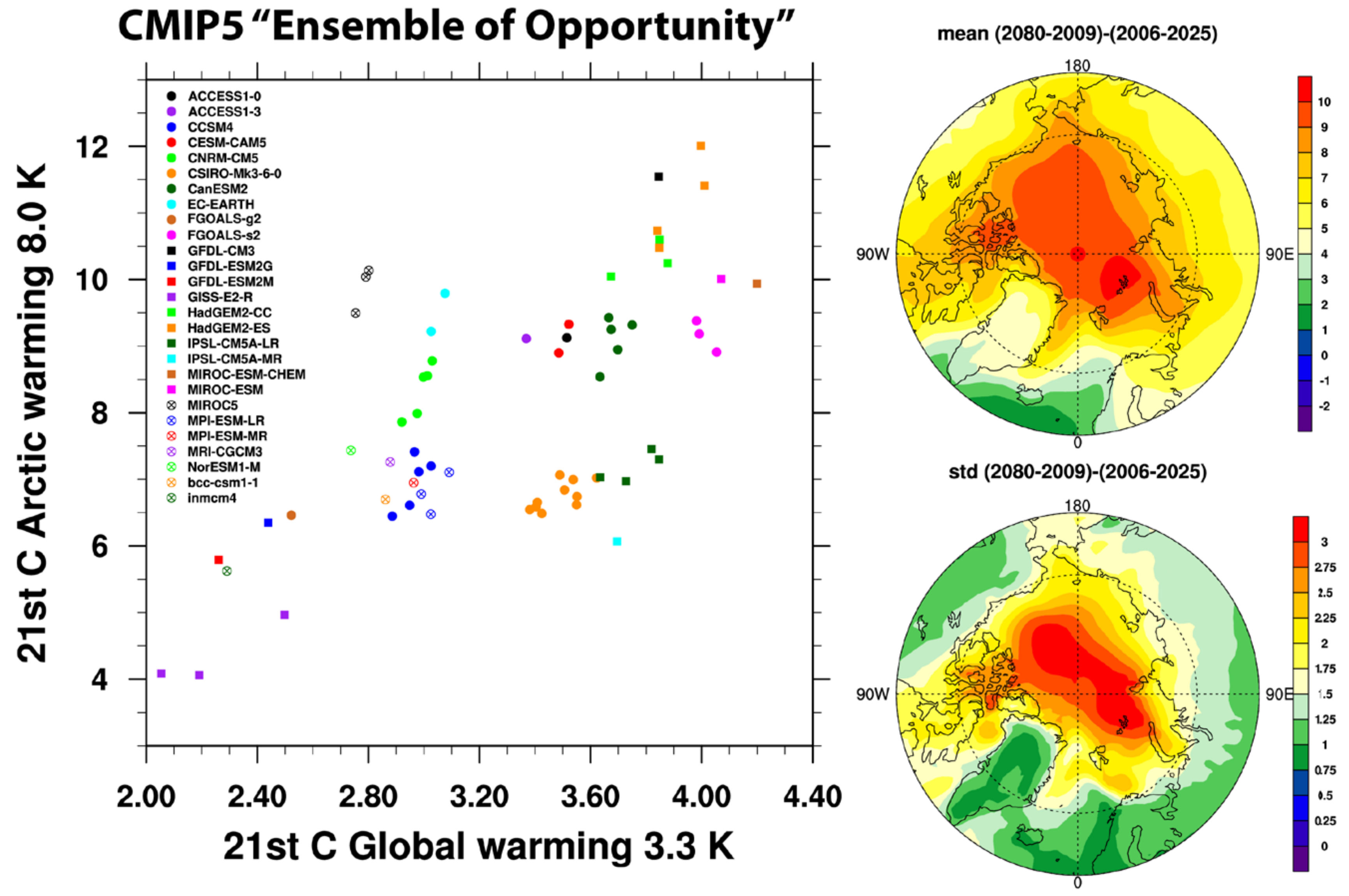
Transient 20th century simulations: Old model warms more than new model

Aerosol and greenhouse gas responses both important for explaining 20th century warming amounts.

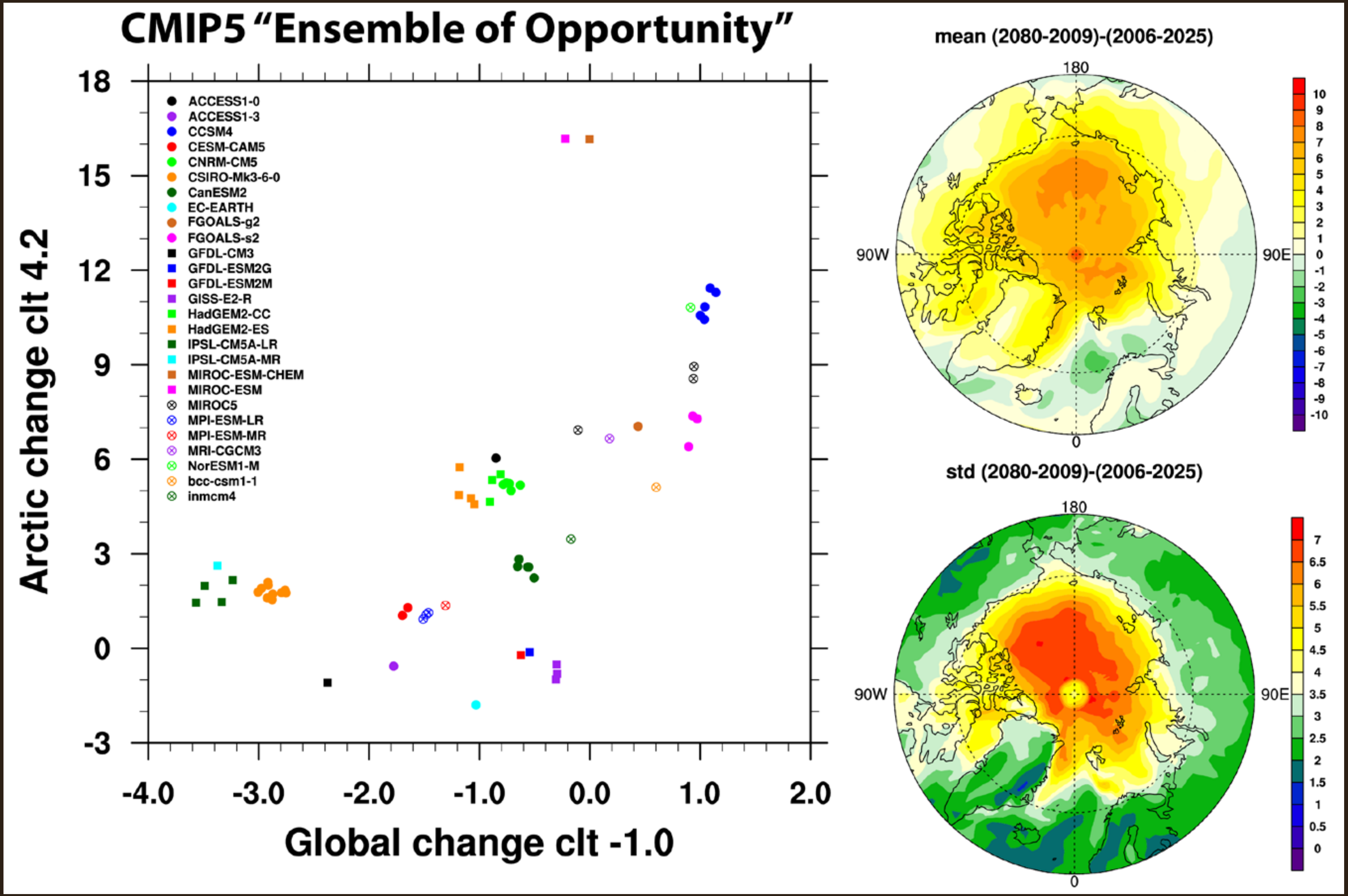
What about 21st century projections?



21st century Surface Warming (RCP8.5)



21st century Arctic cloud increases in CMIP5 (RCP8.5)



Feedback parameter primer

Feedback parameter (λ) = top-of-atmosphere flux change per degree surface air temperature warming

GLOBAL

$$\lambda = \lambda_{lw} + \lambda_{sw} = \frac{\Delta N_{lw} - Q_{2xCO2}}{\Delta T} + \frac{\Delta N_{sw}}{\Delta T} \quad (1)$$

ARCTIC

$$\lambda_A = \lambda_{lw,A} + \lambda_{sw,A} + \lambda_{NHT,A} = \frac{\Delta N_{lw,A} - Q_{2xCO2,A}}{\Delta T_A} + \frac{\Delta N_{sw,A}}{\Delta T_A} + \frac{\Delta NHT_A * SA_A^{-1}}{\Delta T_A} \quad (2)$$

Gregory and Mitchell 1997, Taylor et al. 2007, Gettelman et al. 2012, Kay et al. 2012

Which processes enhance GHG-induced Arctic amplification?

DEFINITE	NO	DEBATED
Surface albedo feedbacks (Arctic more positive)	GHG forcing (Arctic less positive)	**Atmospheric heat transport**
Planck feedback (Arctic less negative)	Water vapor feedback (Arctic less positive)	**Clouds**
Lapse rate feedback (Arctic positive, negative globally)		
Ocean heat transport (increases with increasing GHG)		

What is most important?

Do forcing differences contribute to more warming in CAM5 than in CAM4?

Yes

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	CAM4	CAM5
Global $2xCO_2$ forcing	3.5 Wm^{-2}	3.8 Wm^{-2}
Arctic $2xCO_2$ forcing	2.6 Wm^{-2}	2.8 Wm^{-2}

Note: IPCC AR4 says global $2xCO_2$ forcing is 3.7 Wm^{-2} with 10% uncertainty. These values are within that range.