Future Cloud Changes in the Arctic: What's ice got to do with it?

Steve Vavrus
Center for Climatic Research (CCR)
U. Of Wisconsin

Uma Bhatt
Department of Atmospheric Sciences
U. Of Alaska-Fairbanks

Vladimir Alexeev
International Arctic Research Center (IARC)
U. Of Alaska-Fairbanks

Collaborators: Marika Holland and Dave Bailey (NCAR), Axel Schweiger (Washington), Jennifer Francis (Rutgers)

Key Questions

Are future Arctic cloud changes primarily driven locally or remotely?

What are the mechanisms for local and remote forcing of Arctic clouds?

What are the impacts of future cloud changes in the Arctic?

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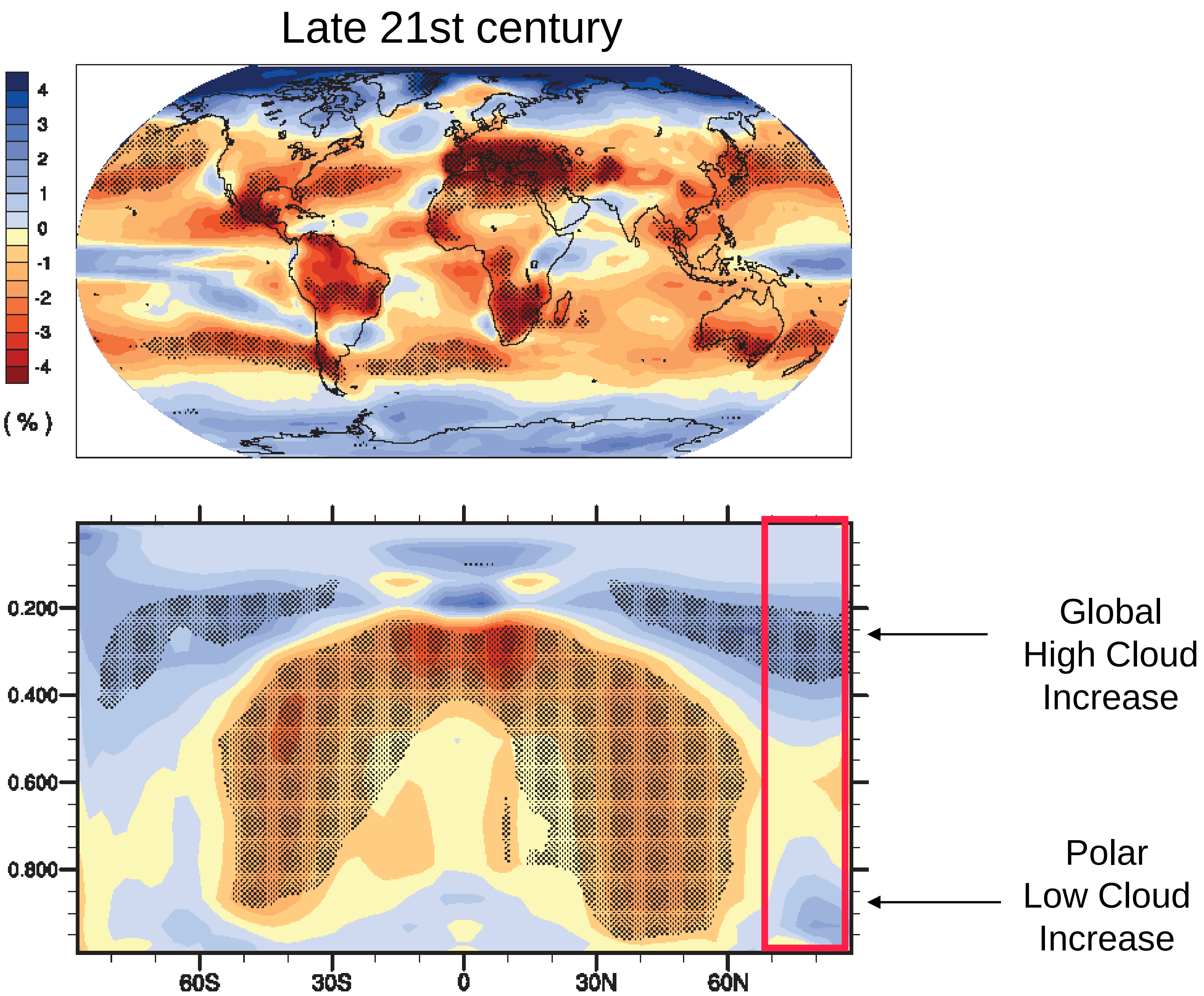
What are the impacts of future cloud changes in the Arctic?

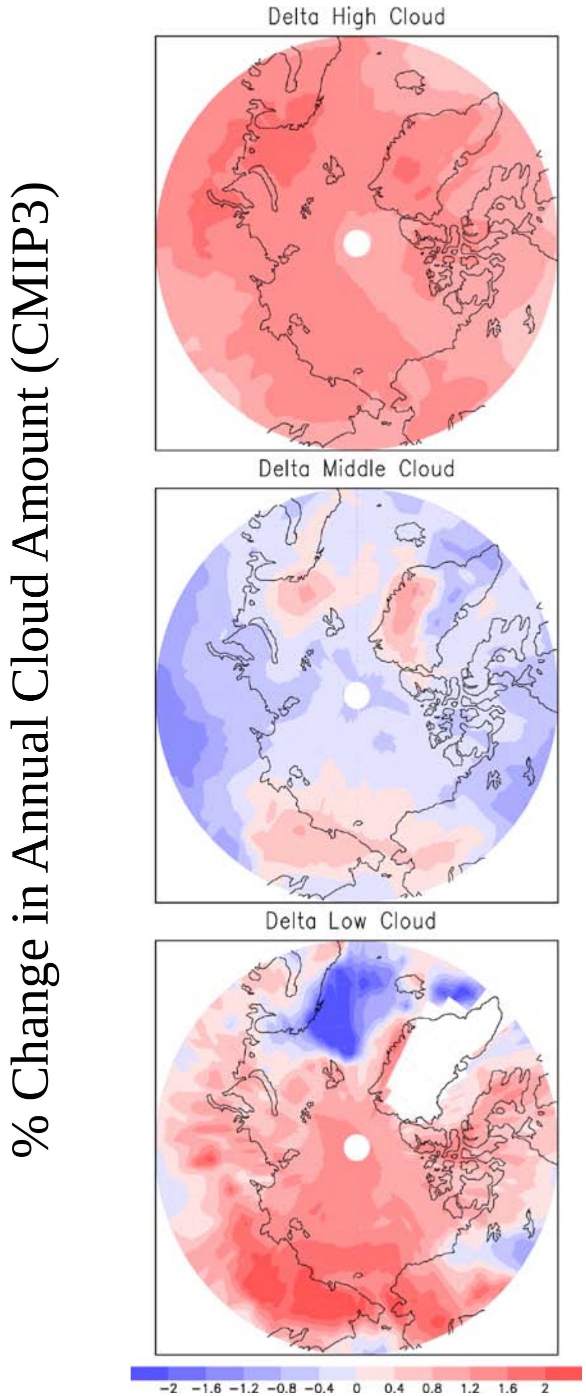
Approach

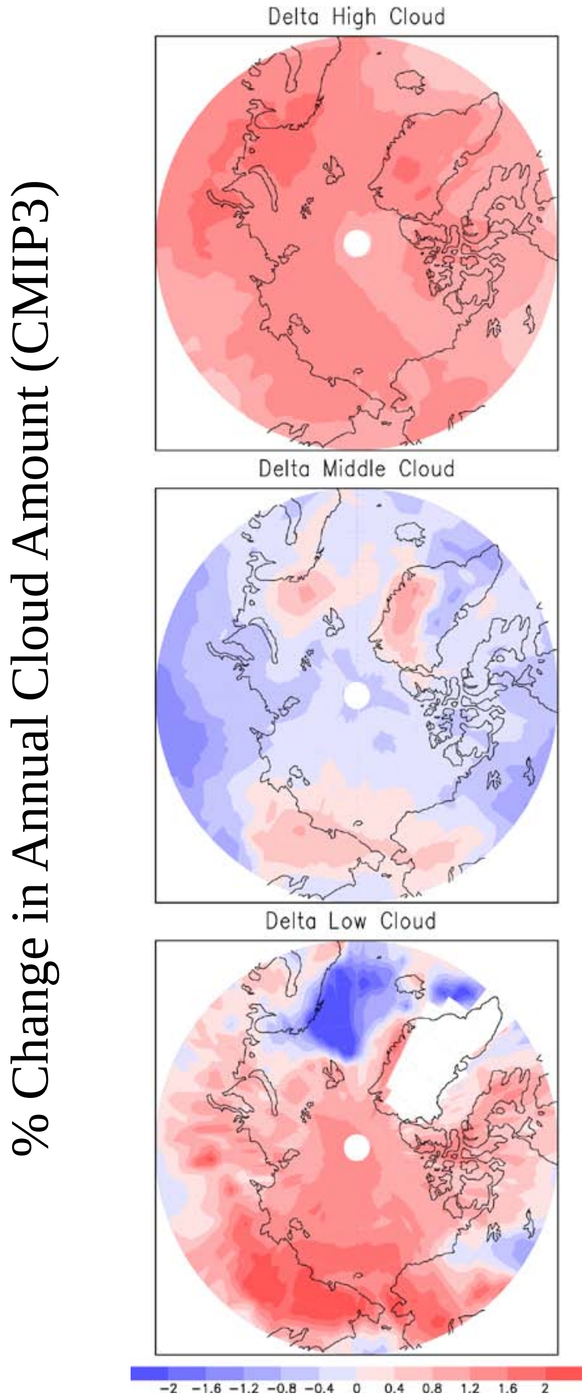
Use CCSM3 in fully coupled and uncoupled mode (CAM3) to address these questions

Intermodel Mean Cloud Changes (CMIP3)



IPCC (2007)


% Change in Annual Cloud Amount (CMIP3)
Delta High Cloud
Delta Middle Cloud
Delta Low Cloud
−2 −1.6 −1.2 −0.8 −0.4 0 0.4 0.8 1.2 1.6 2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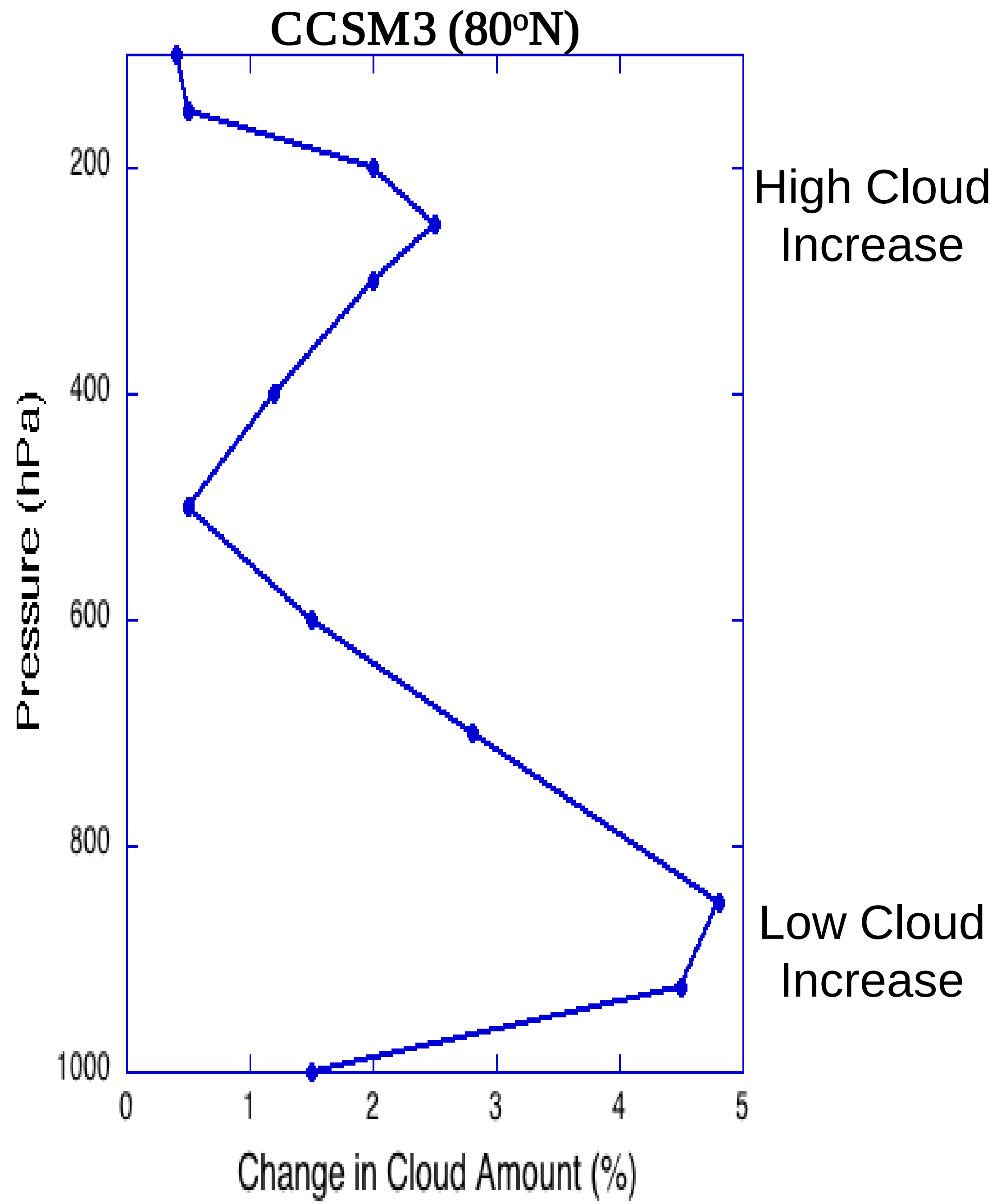
CCSM3 (80°N)
Pressure (hPa)
200
400
600
800
1000
0 1 2 3 4 5
Change in Cloud Amount (%)
High Cloud Increase
Low Cloud Increase

Four Experiments

Fully coupled CCSM3:

* $2xCO_2$ transient forcing (“**CCSM3**”)

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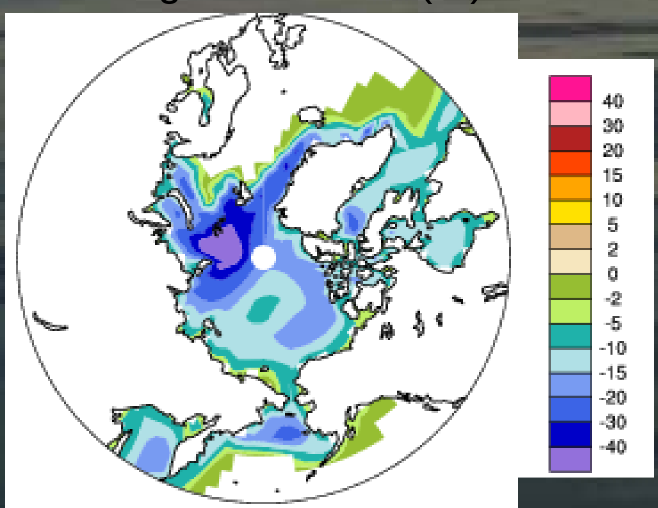
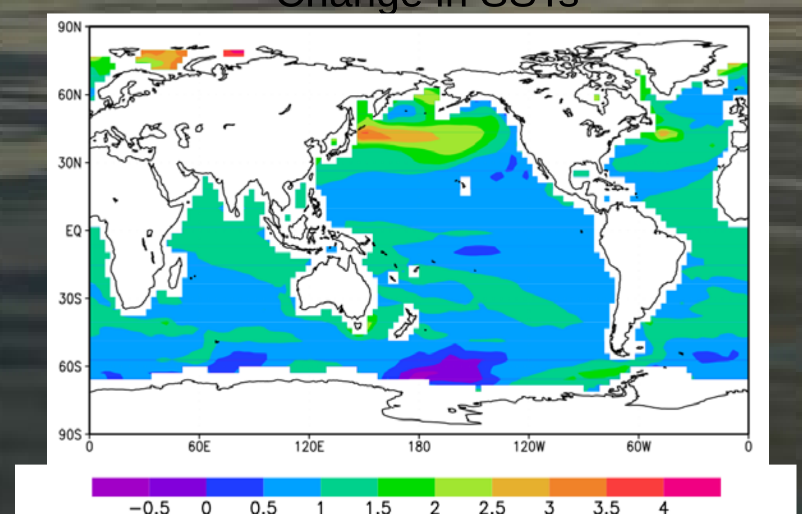
<u>Uncoupled CAM3:</u>

* Future sea ice and SSTs globally from **CCSM3 (“CAM_BOTH”)**

Change in Sea Ice (%)



Change in SSTs



Four Experiments

Fully coupled CCSM3:

* $2xCO_2$ transient forcing (“**CCSM3**”)

Uncoupled CAM3:

* Future sea ice and SSTs globally from **CCSM3 (“CAM_BOTH”)**

* Future SSTs from **CCSM3** but modern sea ice (“**CAM_SST**”)

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* Future sea ice from **CCSM3** but modern SSTs **(“CAM_ICE”)**

Four Experiments

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All CAM3 simulations use modern CO_2 to isolate role of sea ice and SSTs

Four Experiments

Fully coupled CCSM3:

* 2xCO_2 transient forcing ("**CCSM3**")

Uncoupled CAM3:

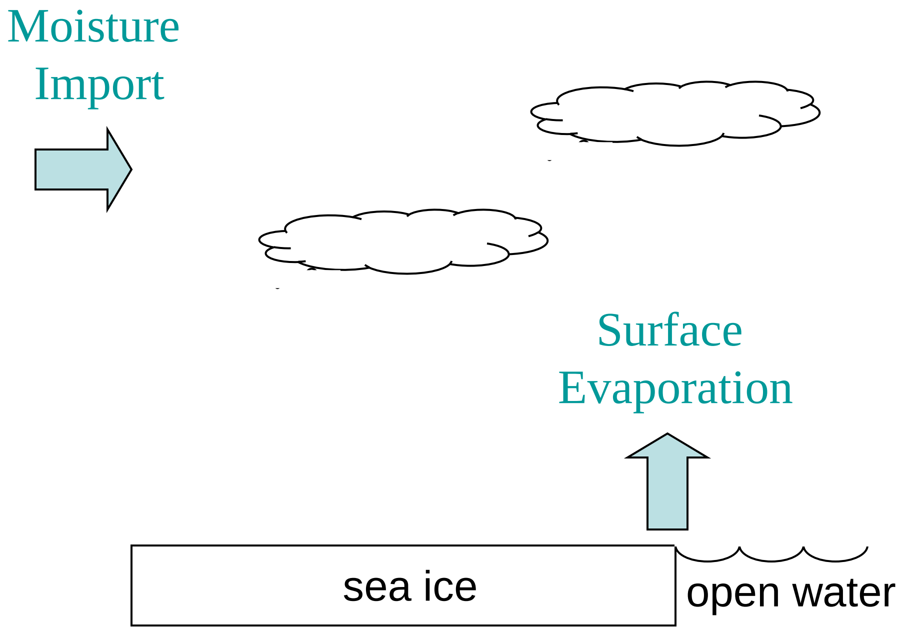
* Future sea ice and SSTs globally from **CCSM3 ("CAM_BOTH")** Forcing

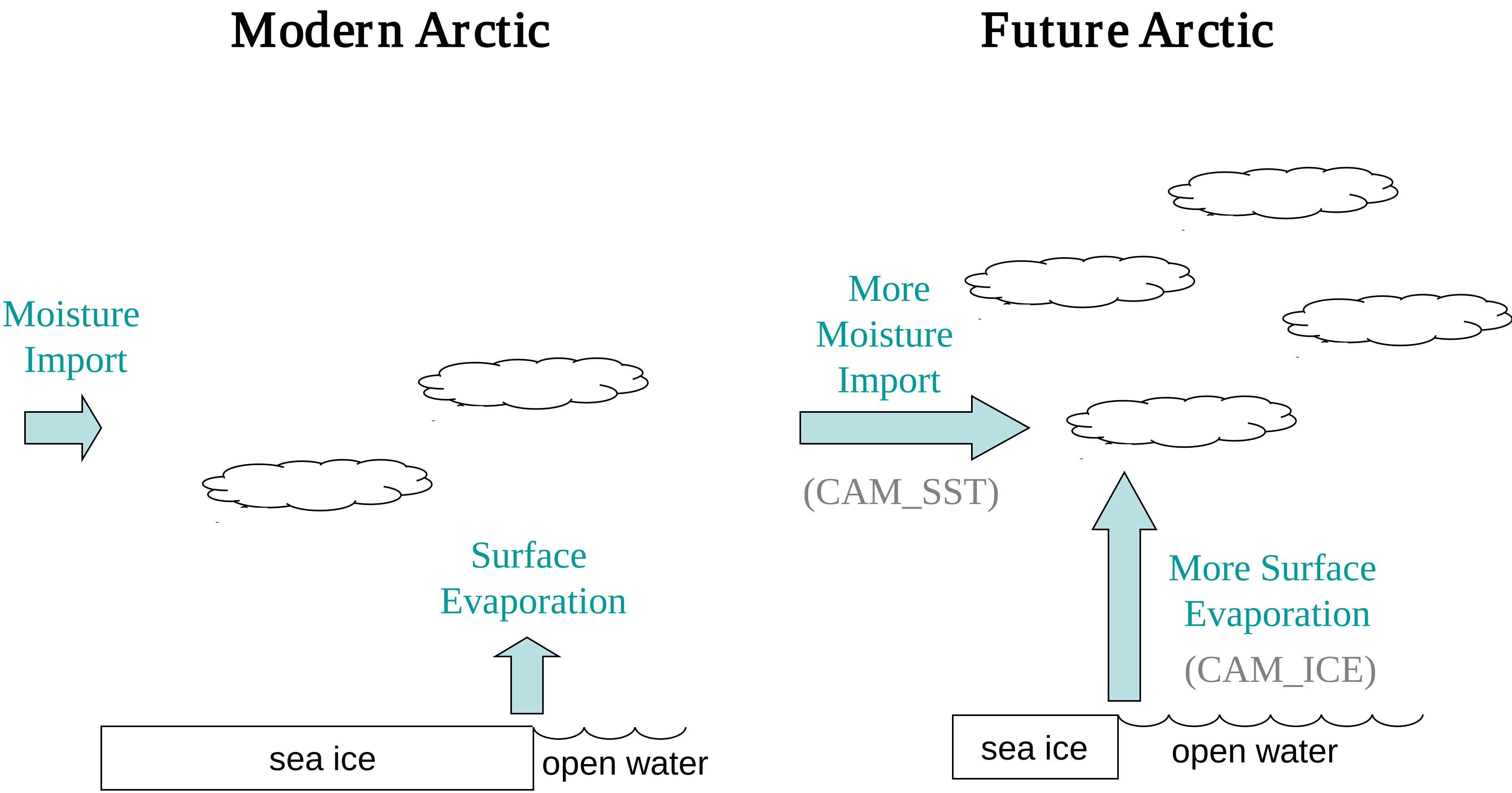
* Future SSTs from **CCSM3** but modern sea ice ("**CAM_SST**") Remote

* Future sea ice from **CCSM3** but modern SSTs **("CAM_ICE")** Local

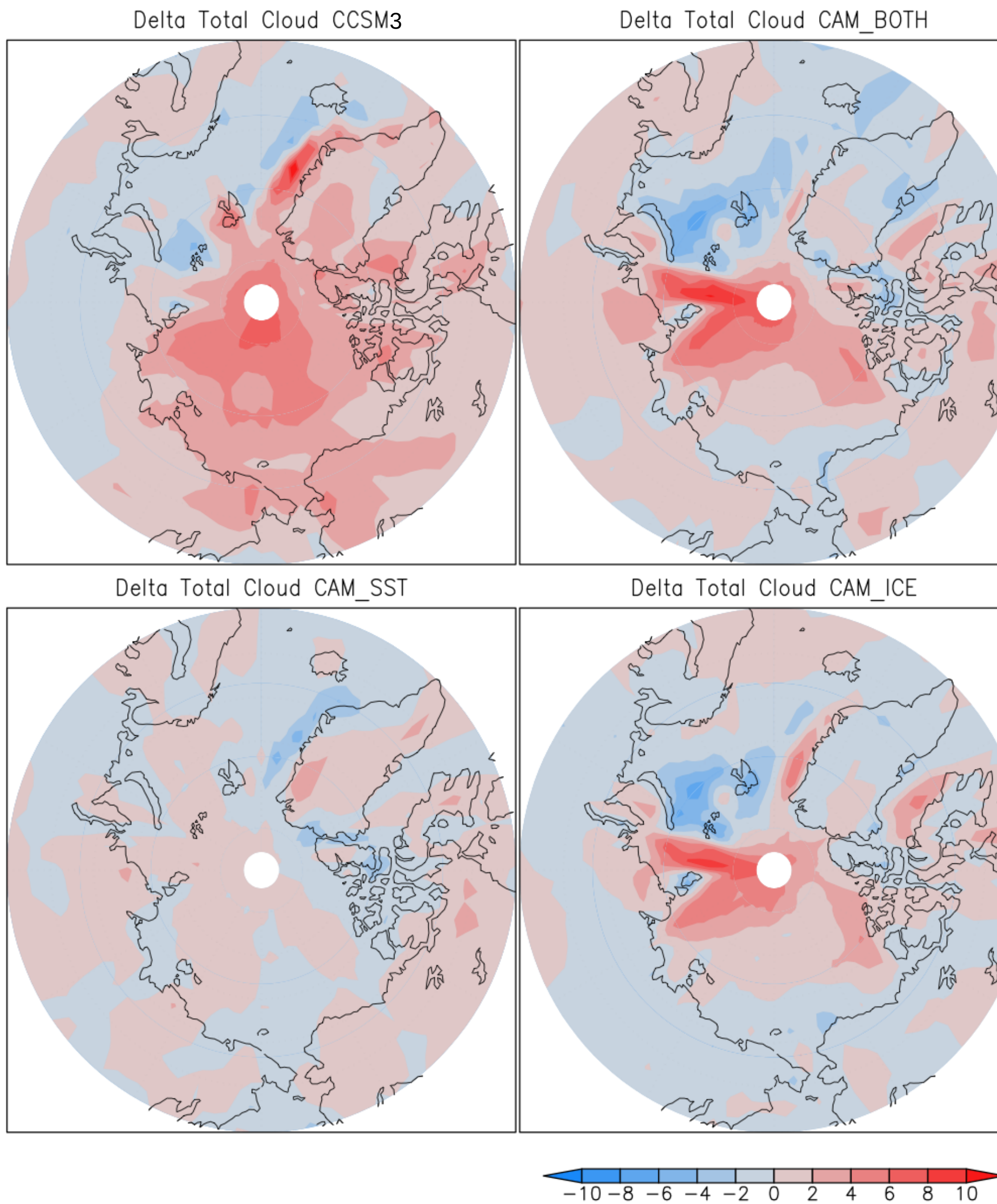
All CAM3 simulations use modern CO_2 to isolate role of sea ice and SSTs

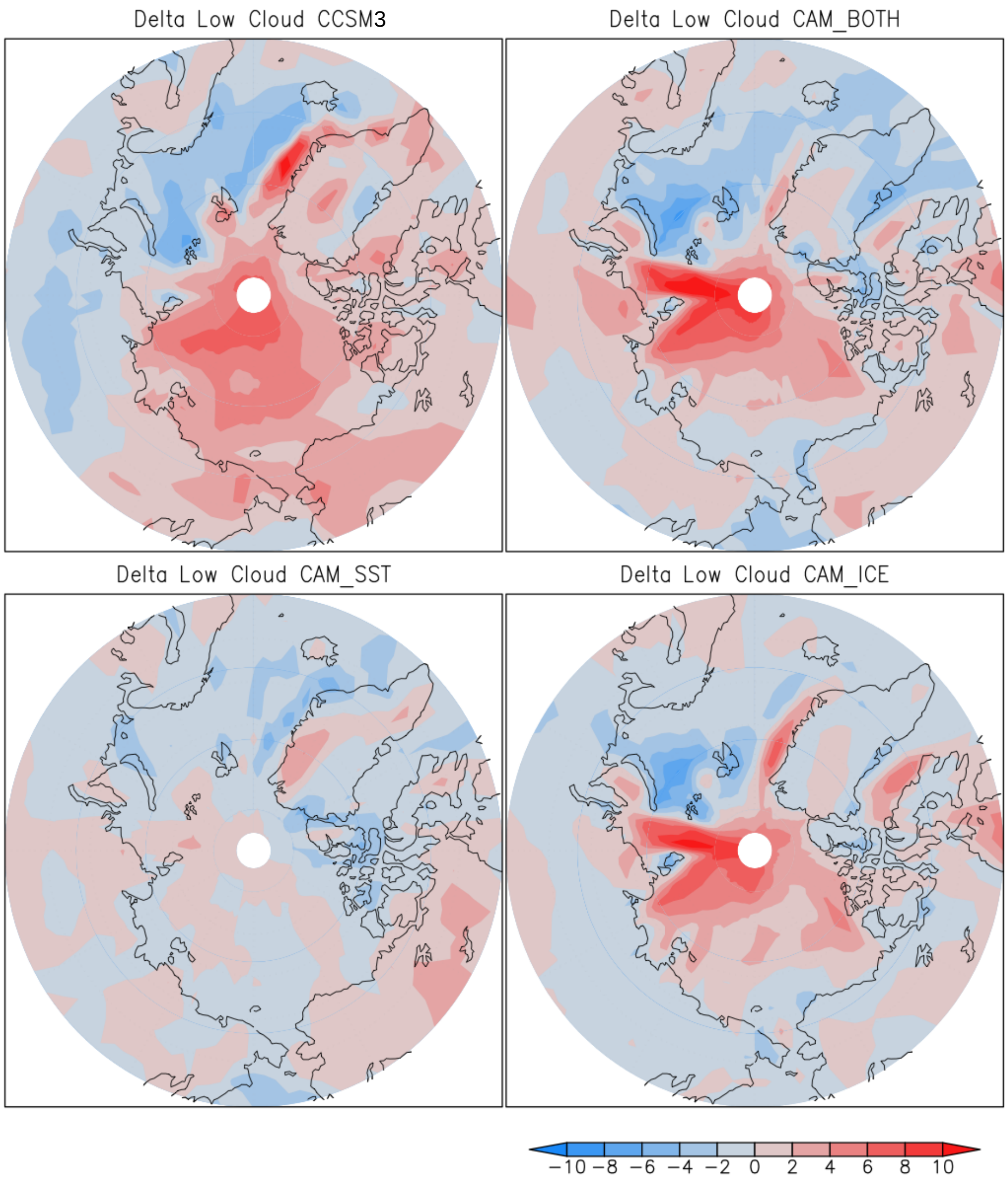
Modern Arctic

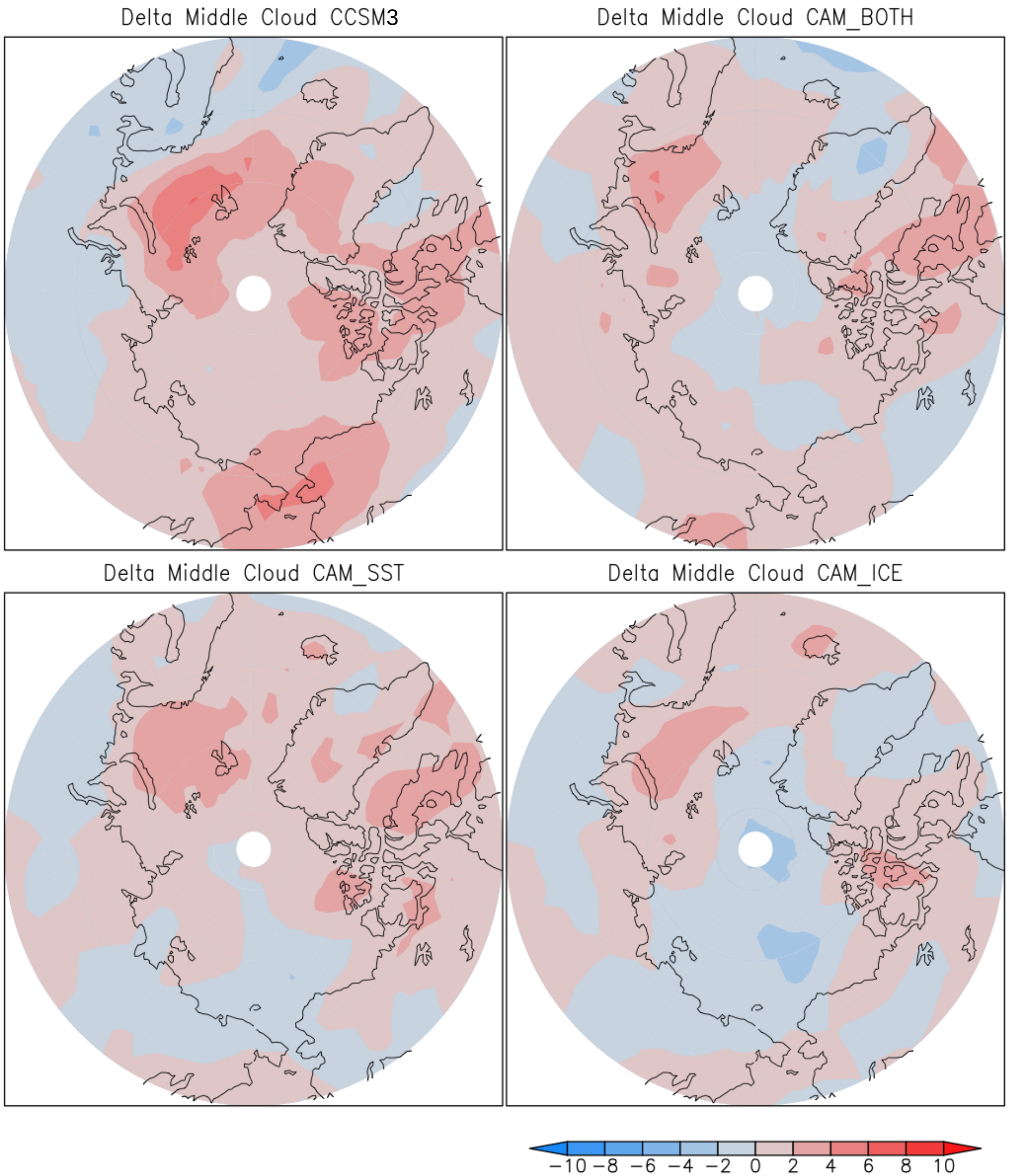




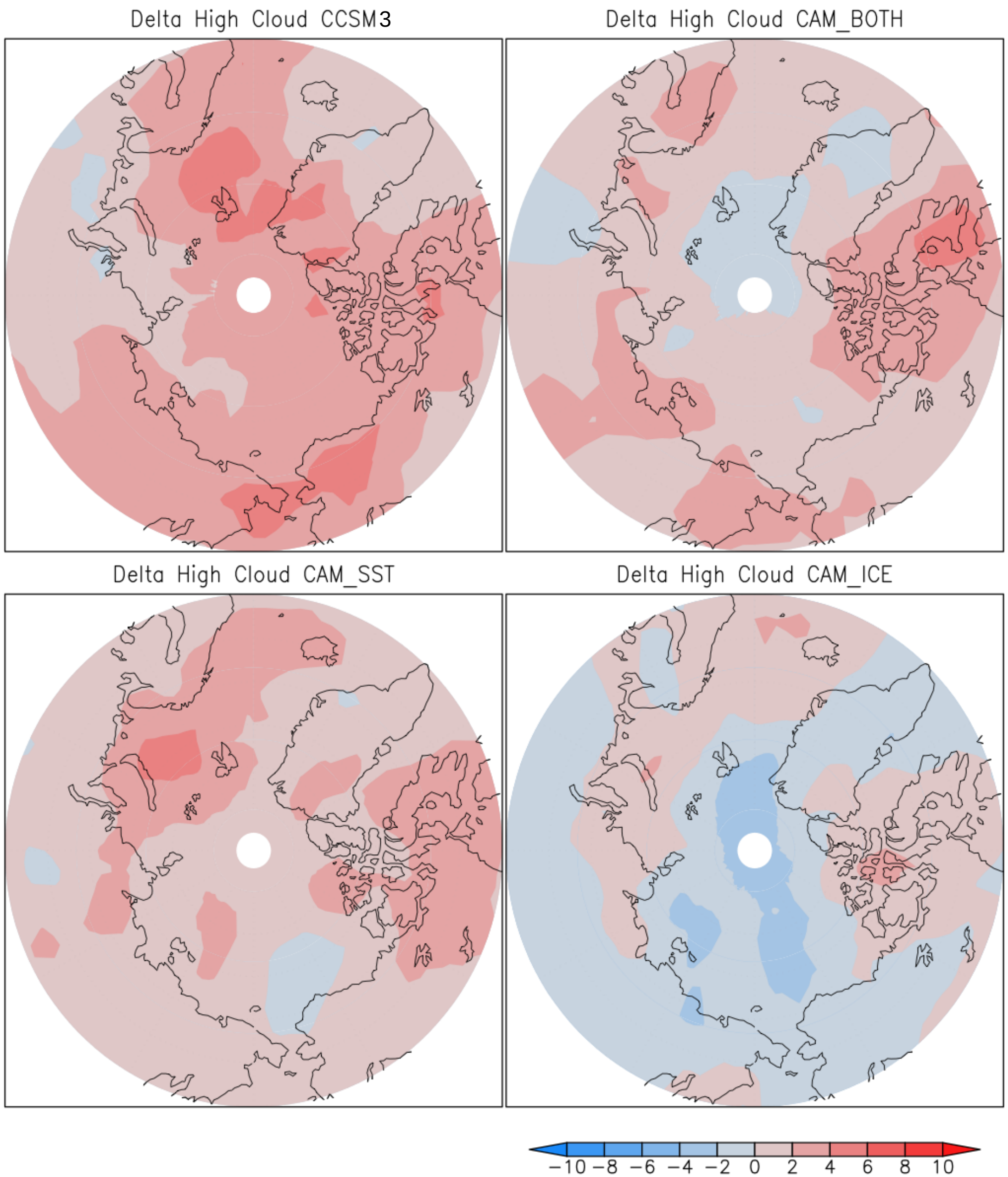
Modern Arctic
Future Arctic
Moisture Import
Surface Evaporation
sea ice
open water
More Moisture Import
(CAM_SST)
More Surface Evaporation
(CAM_ICE)
sea ice
open water


Delta Total Cloud CCSM3
Delta Total Cloud CAM_BOTH
Delta Total Cloud CAM_SST
Delta Total Cloud CAM_ICE
−10 −8 −6 −4 −2 0 2 4 6 8 10


Delta Low Cloud CCSM3
Delta Low Cloud CAM_BOTH
Delta Low Cloud CAM_SST
Delta Low Cloud CAM_ICE
−10 −8 −6 −4 −2 0 2 4 6 8 10

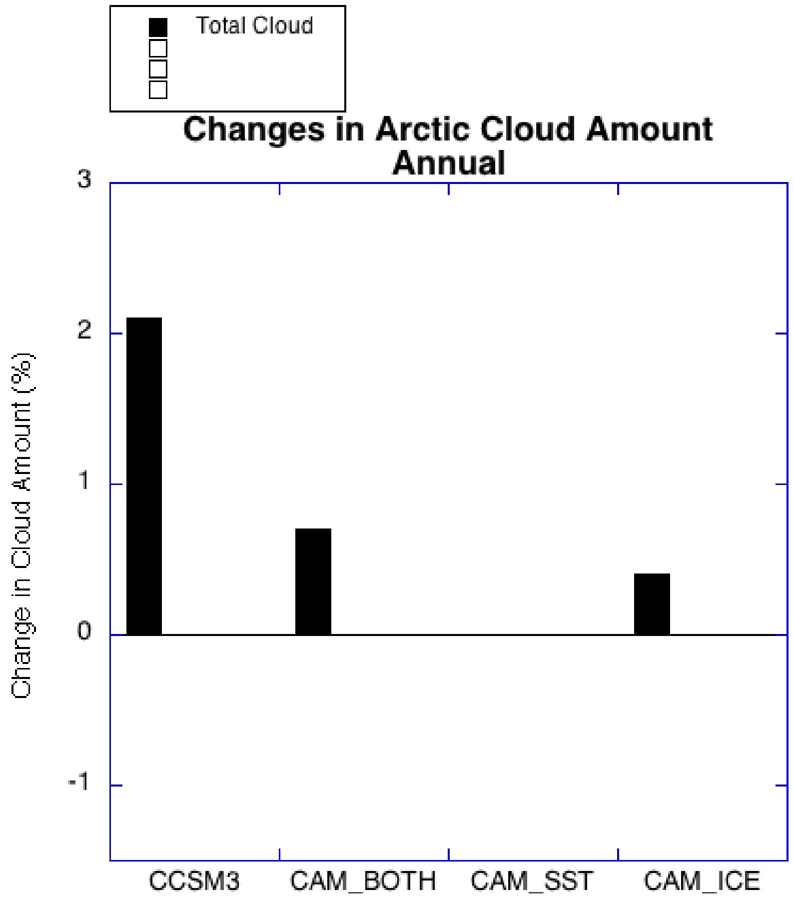


Delta Middle Cloud CCSM3
Delta Middle Cloud CAM_BOTH
Delta Middle Cloud CAM_SST
Delta Middle Cloud CAM_ICE
−10 −8 −6 −4 −2 0 2 4 6 8 10



Delta High Cloud CCSM3
Delta High Cloud CAM_BOTH
Delta High Cloud CAM_SST
Delta High Cloud CAM_ICE
−10 −8 −6 −4 −2 0 2 4 6 8 10

Areally Averaged Cloud Changes in Arctic (70-90N)



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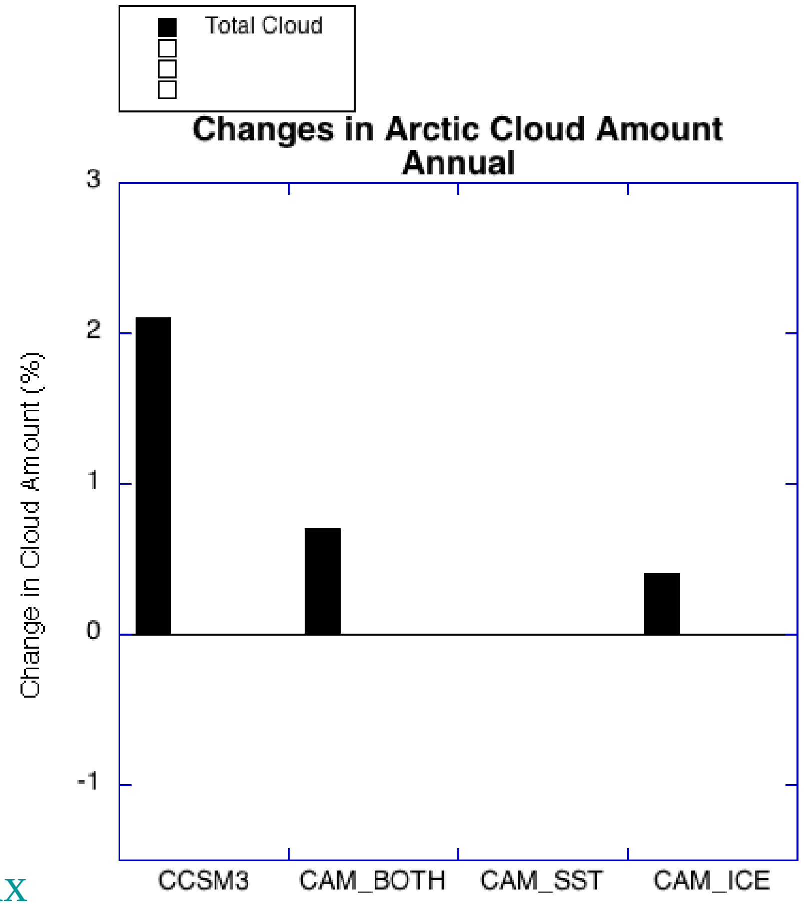

Change in Moisture Flux

Convergence to Arctic (W/m^2): +2.16 +1.92 +2.13 +0.27

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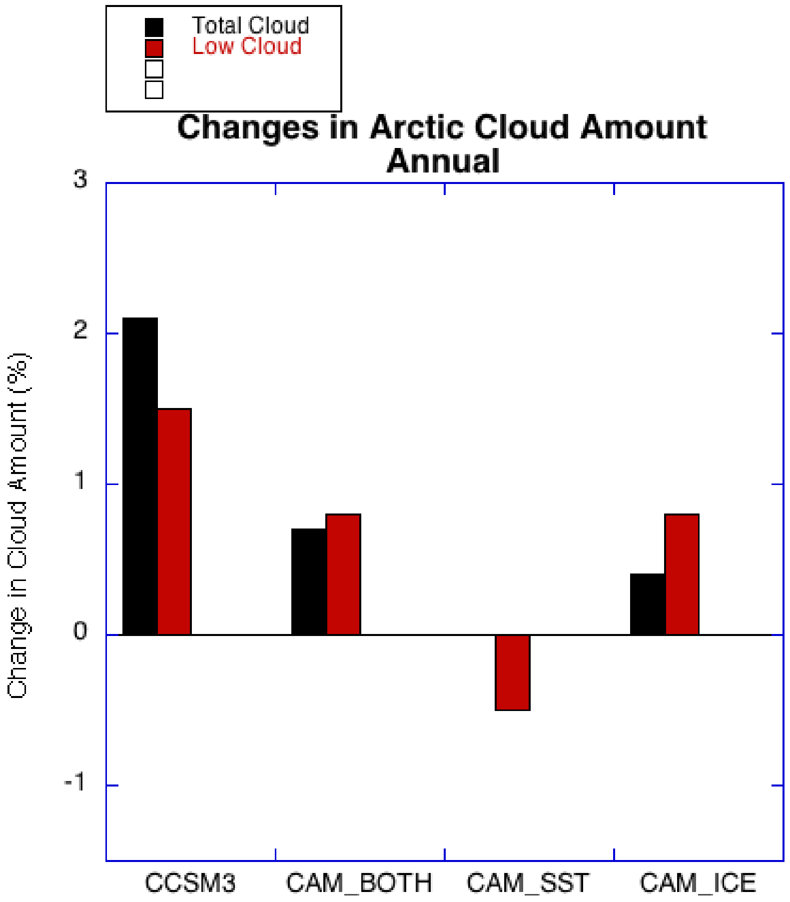

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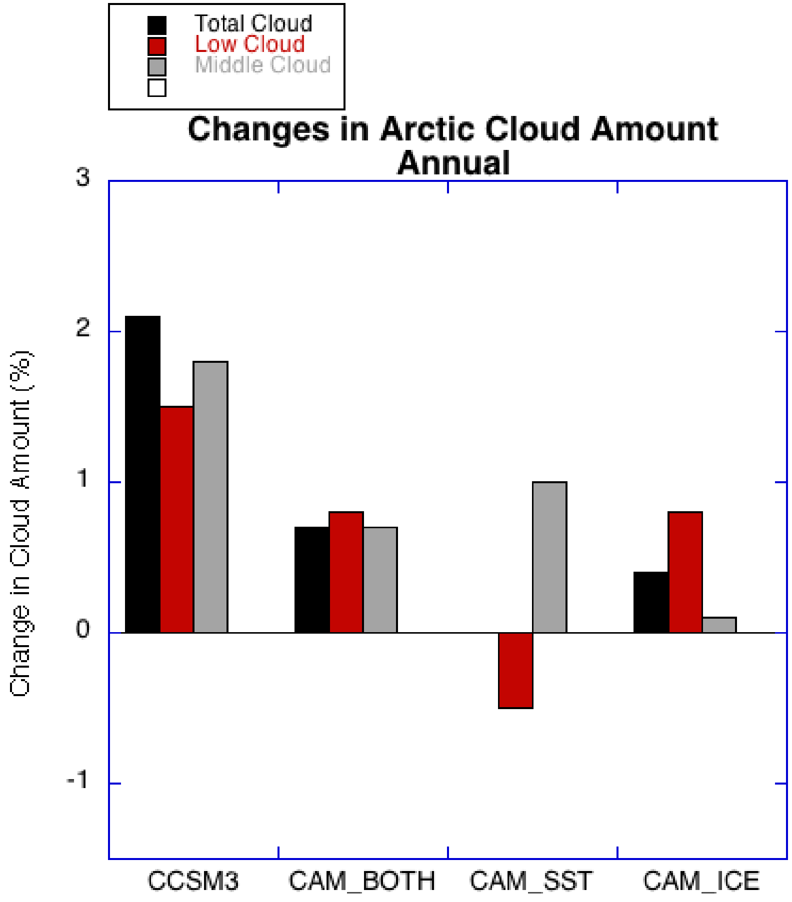

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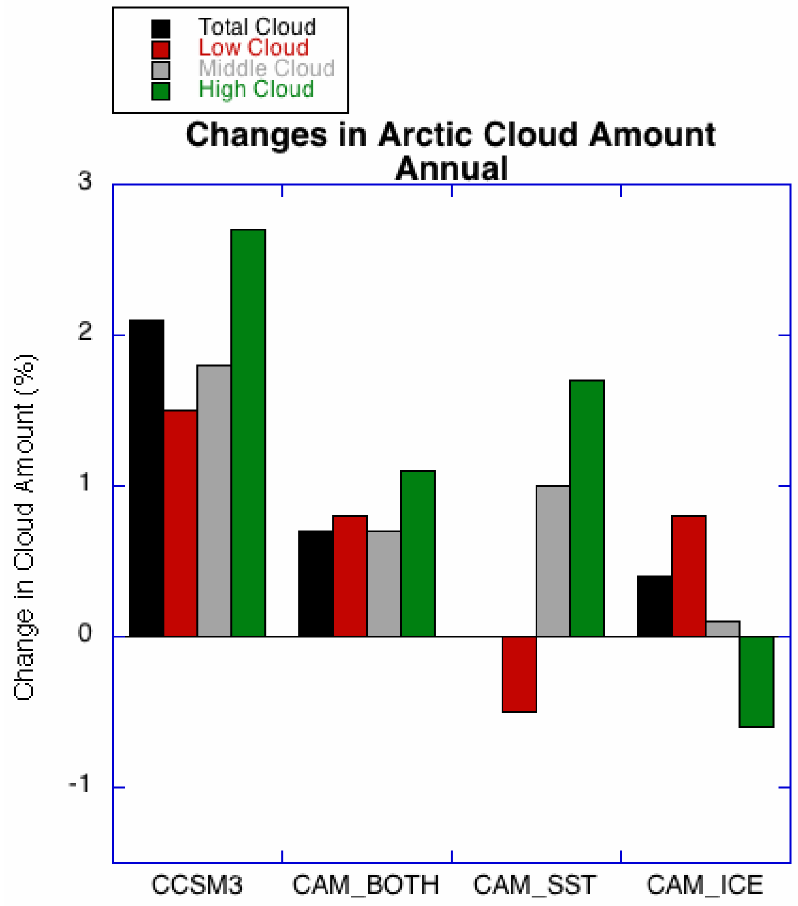
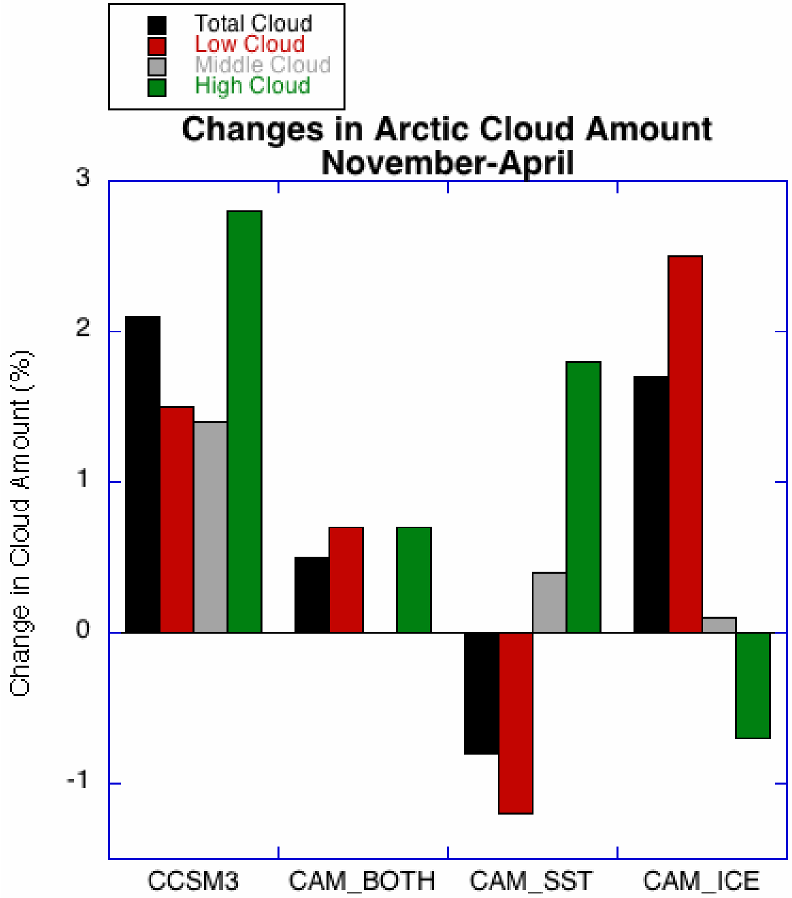


Cold Half-Year Cloud Changes (Nov.-Apr.)



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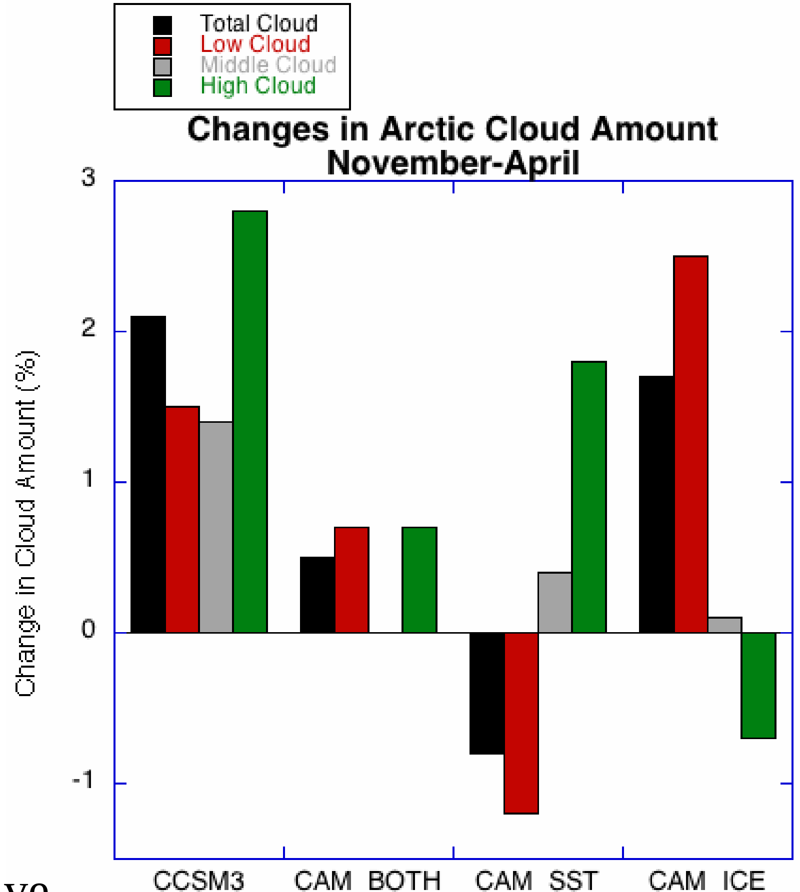
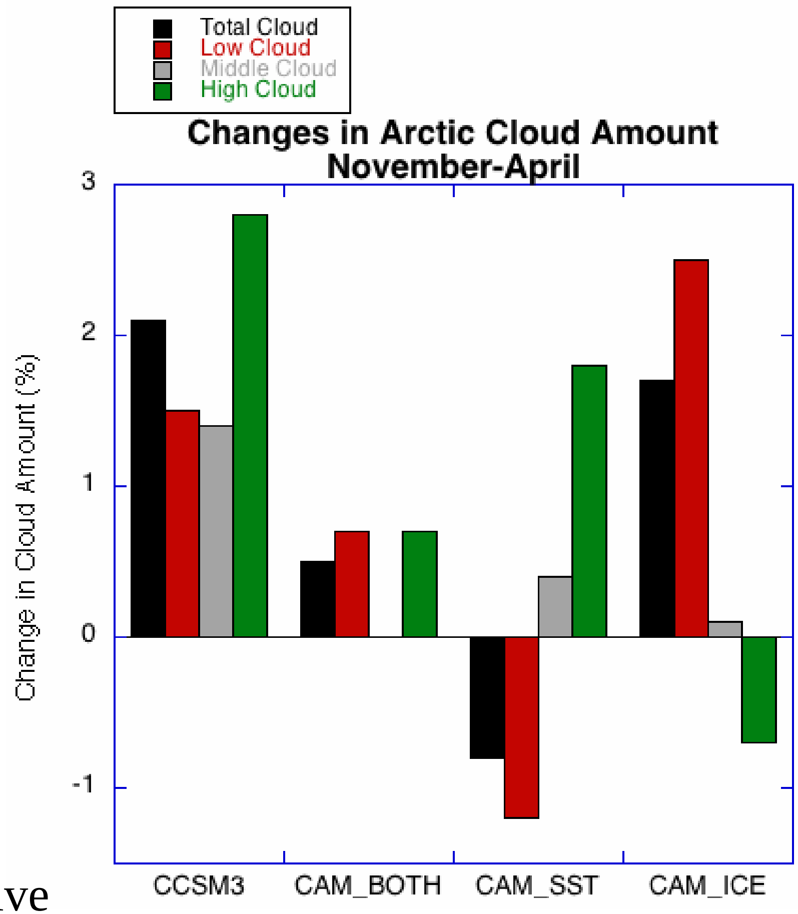


Change in Cloud Radiative Forcing at Surface (W/m^2): +3.84 +4.75 +0.51 +5.52 (November-April)

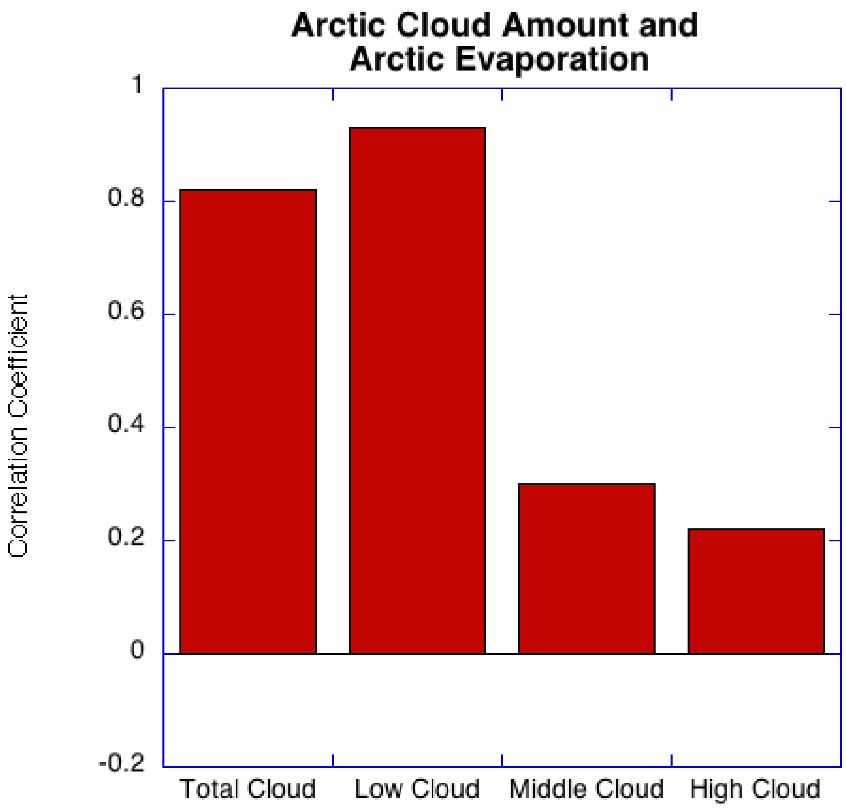
Cold Half-Year Cloud Changes (Nov.-Apr.)



Change in Cloud Radiative Forcing at Surface (W/m^2):	CCSM3	CAM_BOTH	CAM_SST	CAM_ICE	
	+3.84	+4.75	+0.51	+5.52	(November-April)
	-1.52	-0.88	-1.08	+1.37	(Annual)

Correlations between Changes in Clouds and Moisture Forcing

(across the 4 experiments)



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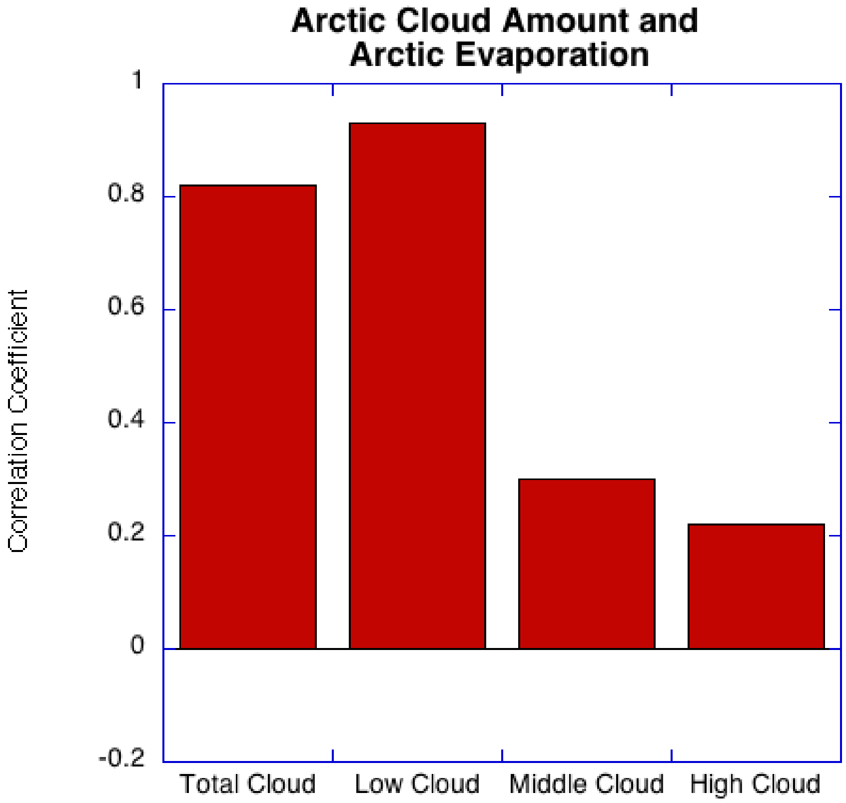

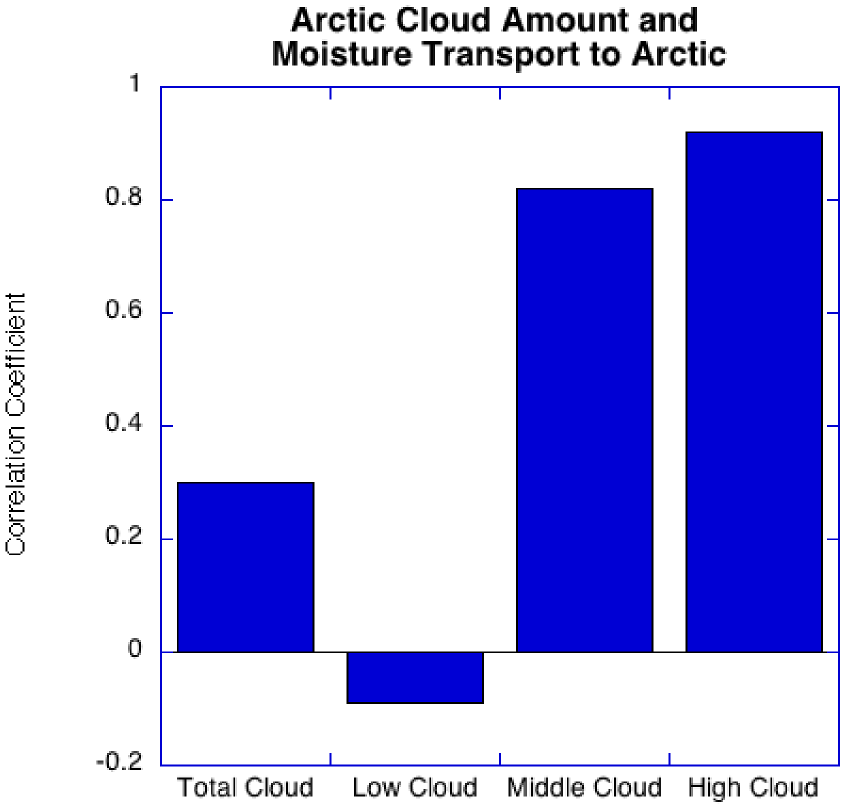

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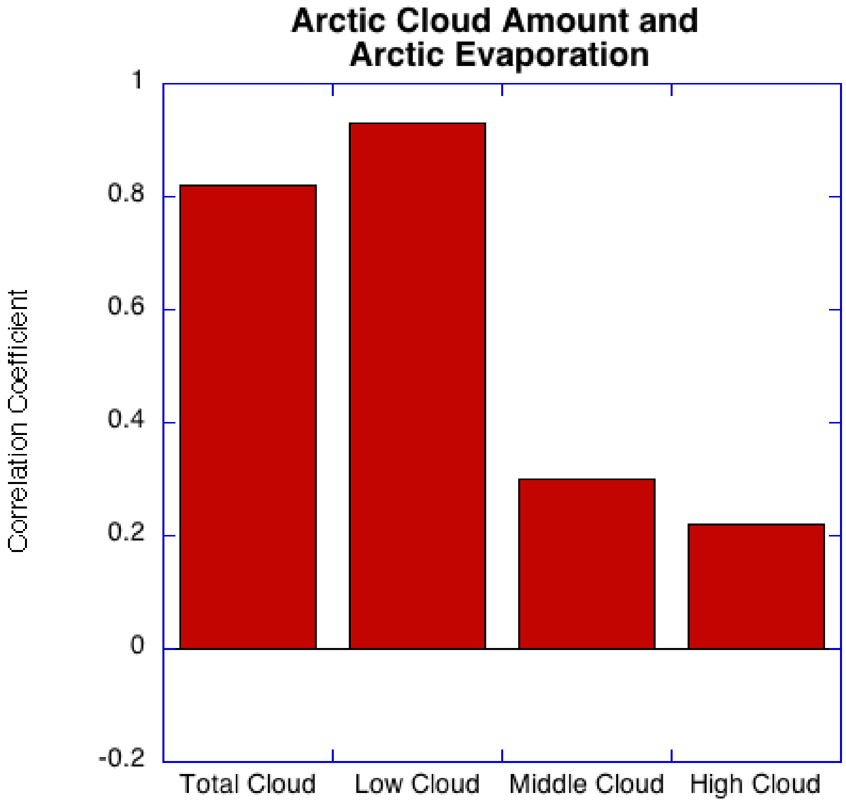

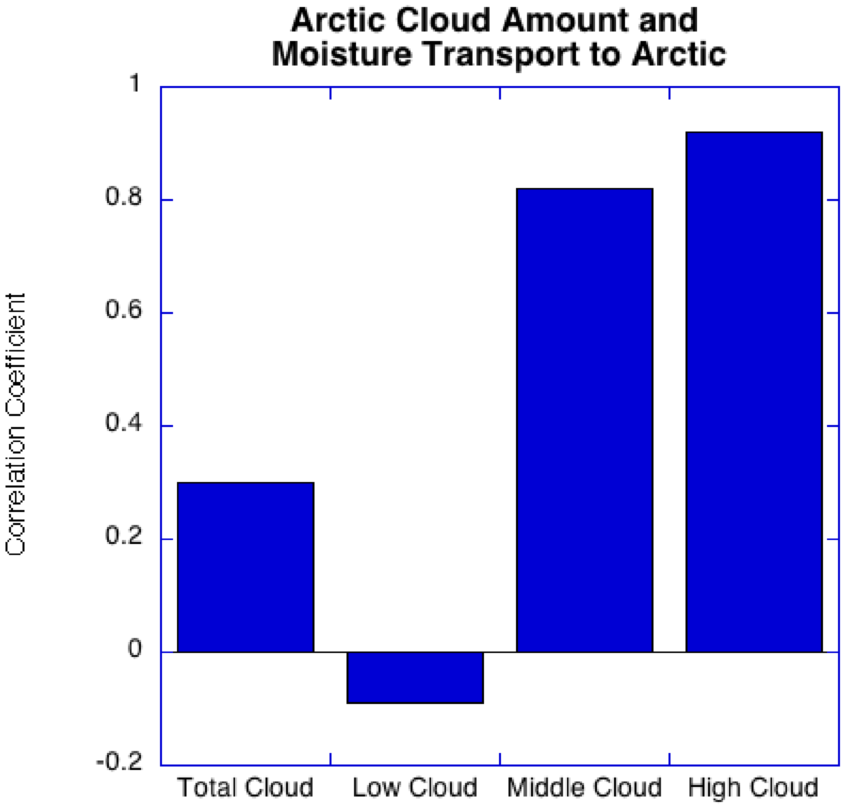

More Evaporation <==> More Low, Total Clouds

More Moisture Import <==> More Mid, High Clouds

Conclusions

• More clouds in a future Arctic, especially at low and high levels (CCSM3, CAM_BOTH)

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- Low cloud and total cloud increases driven locally by greater evaporation, whereas middle and high cloud increases driven remotely by greater meridional moisture transport

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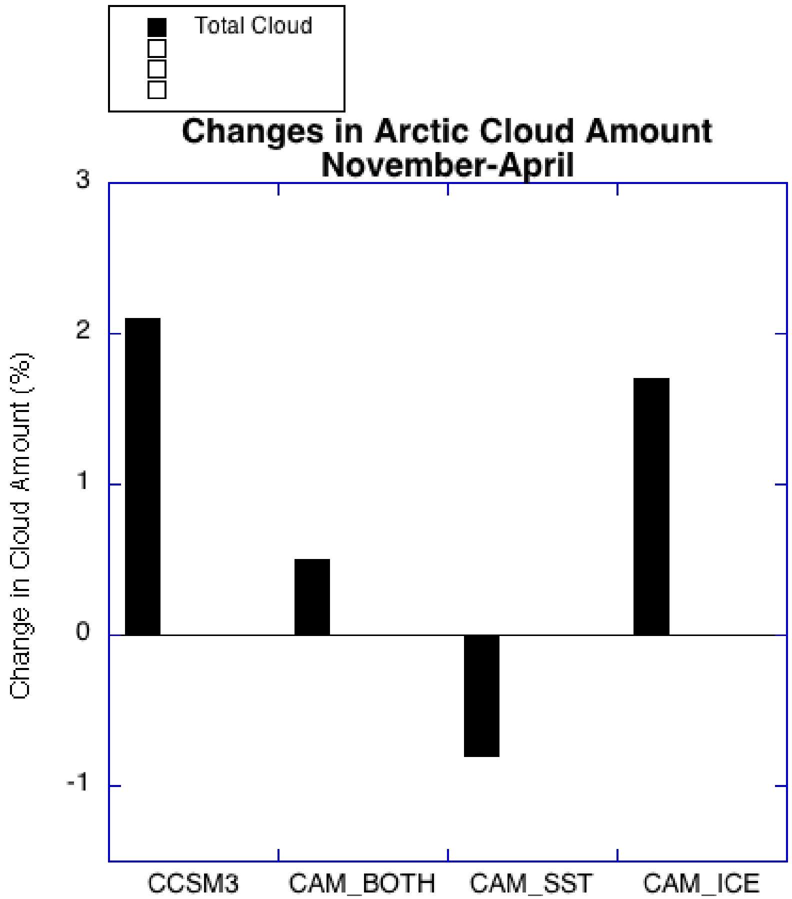
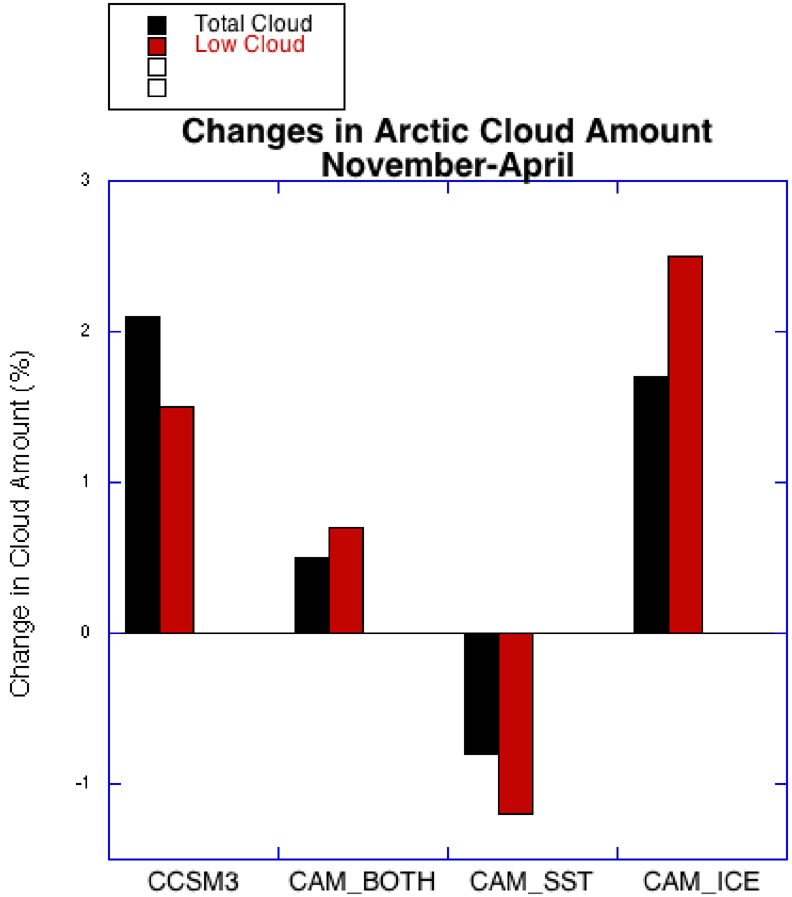
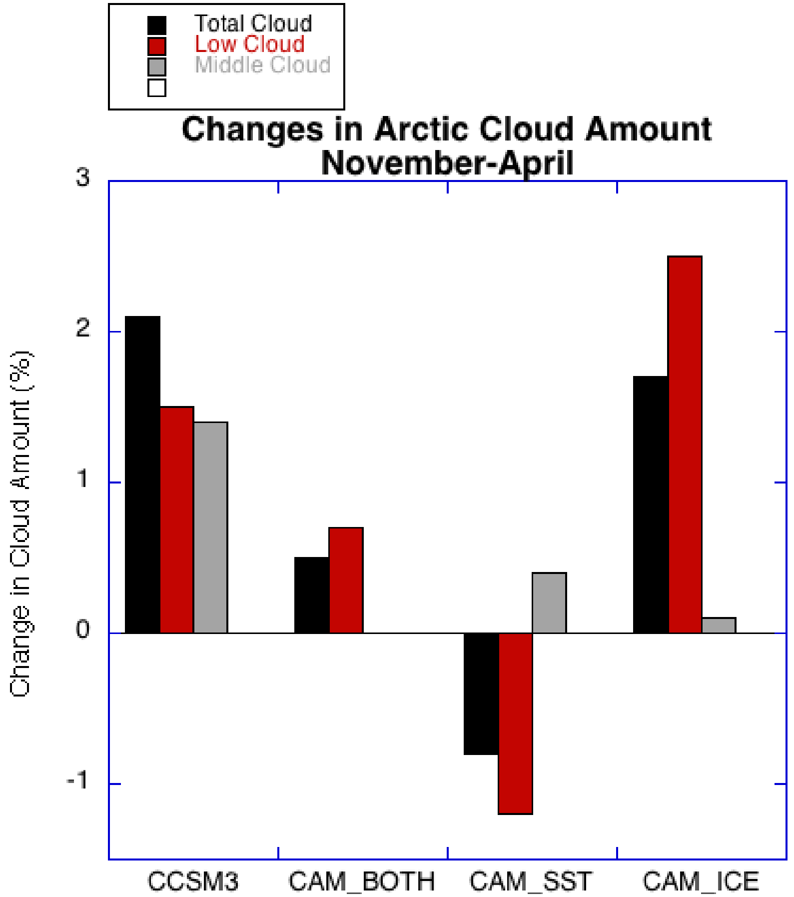
- Low cloud and total cloud increases driven locally by greater evaporation, whereas middle and high cloud increases driven remotely by greater meridional moisture transport

- CAM_ICE: large low cloud gain during coldest months greatly enhances surface warming, leading to a CRF <u>increase</u> annually

- CAM_SST: low cloud loss during coldest months offsets warming influence from more middle and high-clouds, leading to a CRF <u>decrease</u> annually


Total Cloud
Changes in Arctic Cloud Amount
November-April
Change in Cloud Amount (%)
3
2
1
0
-1
CCSM3
CAM_BOTH
CAM_SST
CAM_ICE


Total Cloud
Low Cloud
Changes in Arctic Cloud Amount
November-April
Change in Cloud Amount (%)
3
2
1
0
-1
CCSM3
CAM_BOTH
CAM_SST
CAM_ICE


Total Cloud
Low Cloud
Middle Cloud
Changes in Arctic Cloud Amount
November-April
Change in Cloud Amount (%)
3
2
1
0
-1
CCSM3
CAM_BOTH
CAM_SST
CAM_ICE