Influence of clouds on radiative fluxes in the Arctic

J. English, J. Kay, A. Gettelman

CESM Workshop / PCWG Meeting

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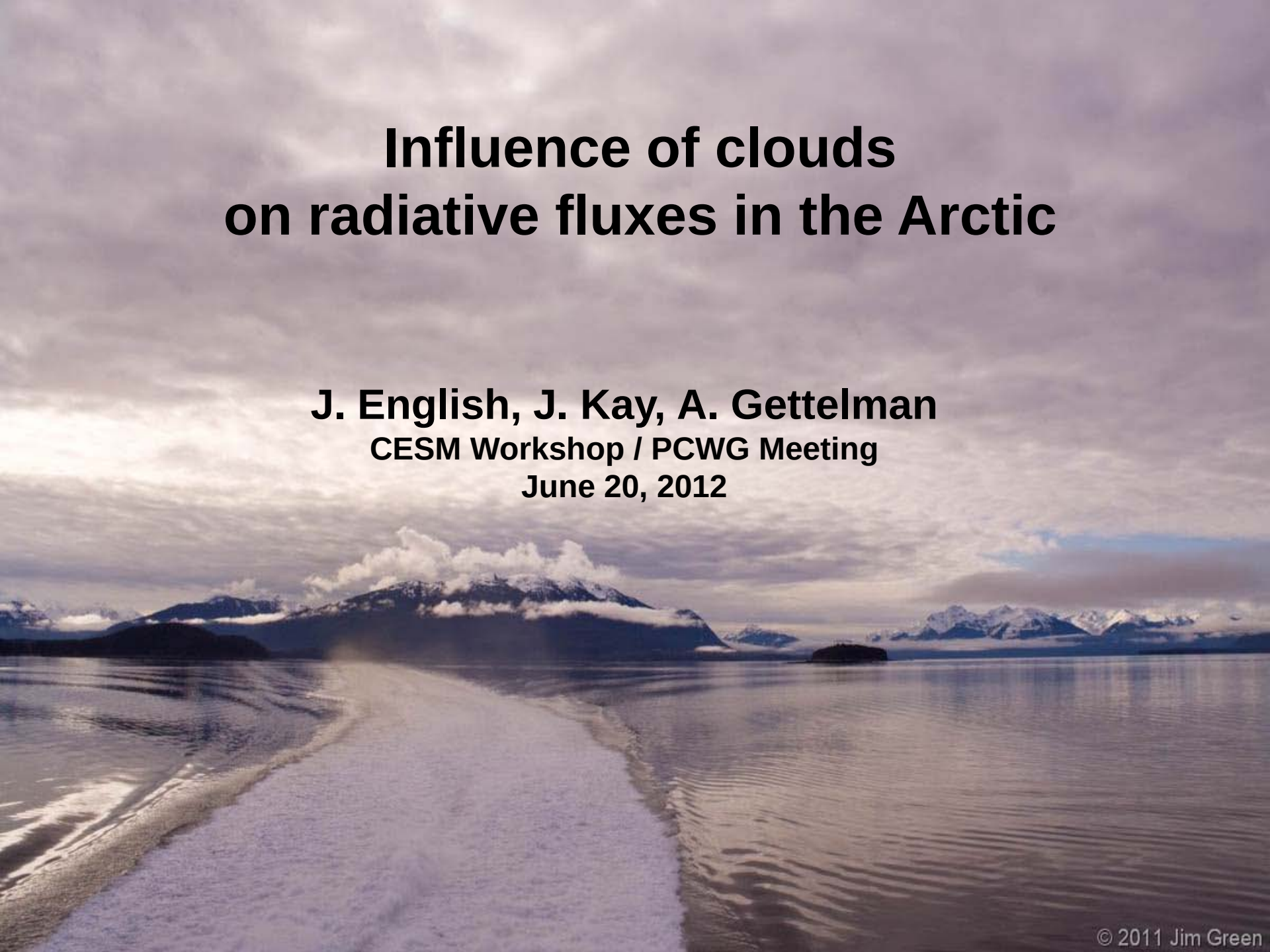
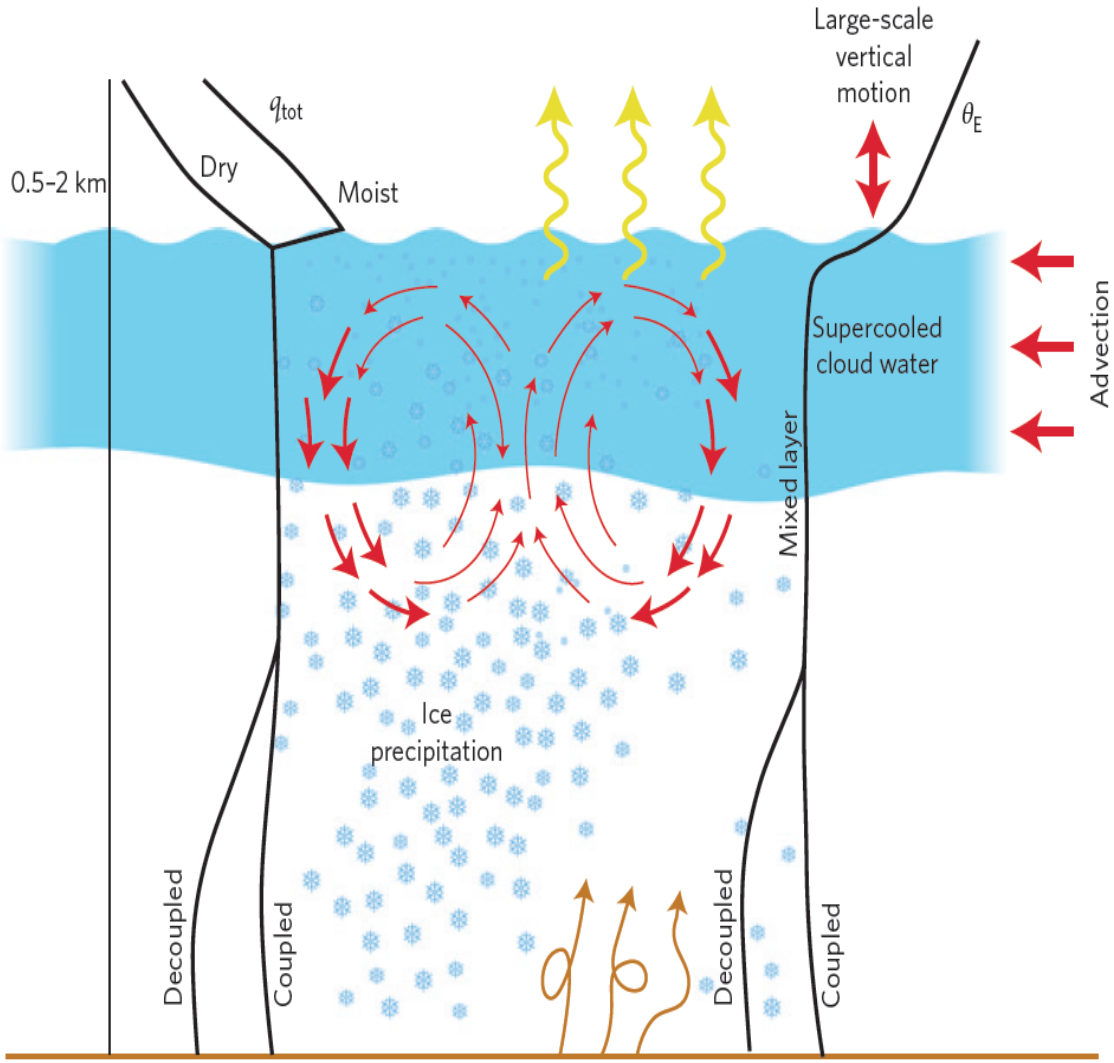


The complexity of arctic clouds

Arctic Mixed-Phase Clouds



Radiative Cooling
- Drives buoyant production of turbulence
- Forces direct condensation within inversion layer
- Requires minimum amount of cloud liquid water

Microphysics
- Liquid forms in updrafts and sometimes within the inversion layer
- Ice nucleates in cloud
- Rapid ice growth promotes sedimentation from cloud

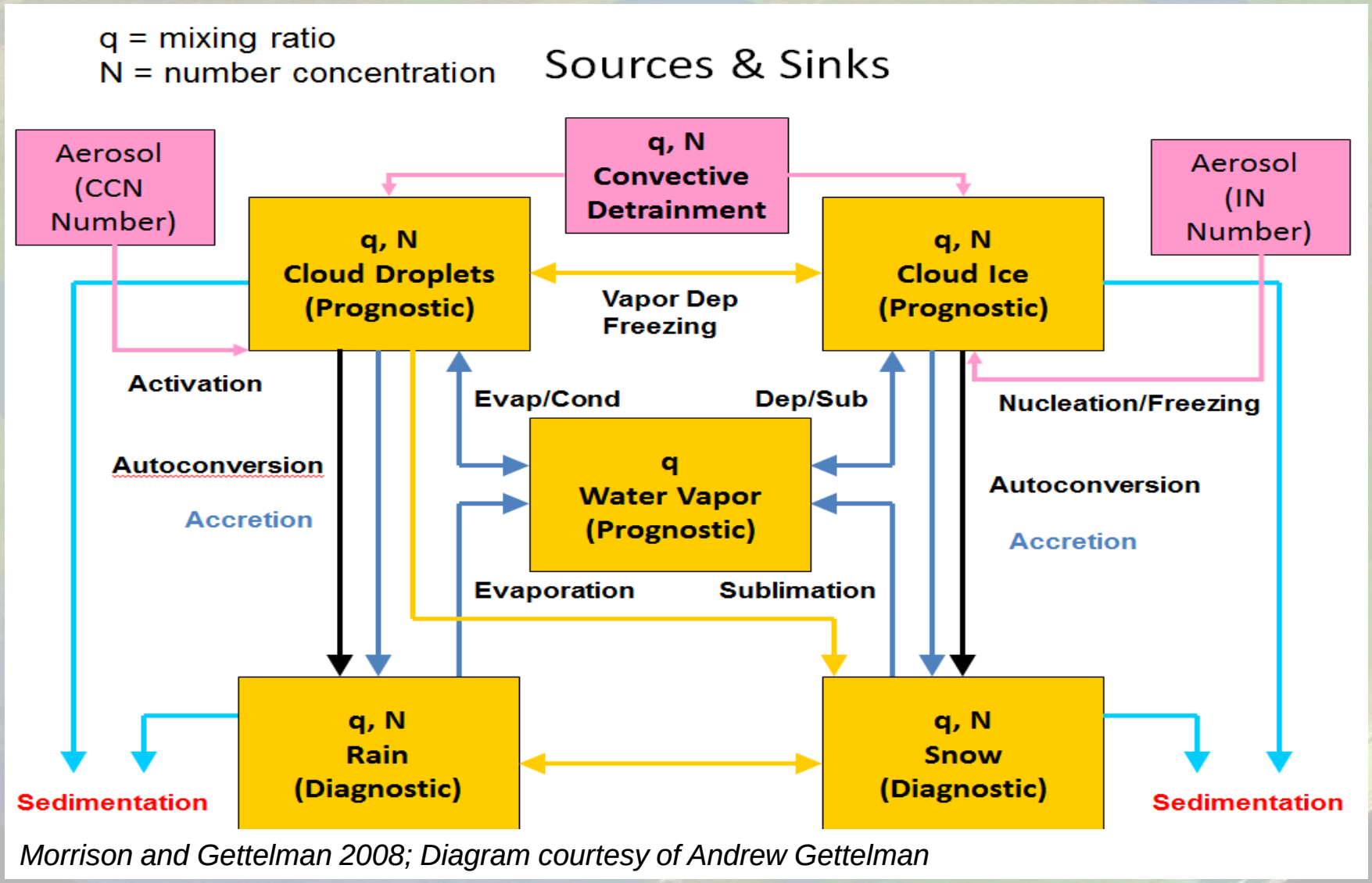
Dynamics
- Cloud-forced turbulent mixed layer with strong narrow downdrafts, weak broad updrafts, and q_{tot} and θ_E nearly constant with height
- Small-scale, weak turbulence in cloudy inversion layer
- Large-scale advection of water vapour important

Surface Layer
- Turbulence and q contributions can be weak or strong
- Sink of atmospheric moisture due to ice precipitation
- Surface type (ocean, ice, land) influences interaction with cloud

Morrison et al., Nature Geoscience, 2011

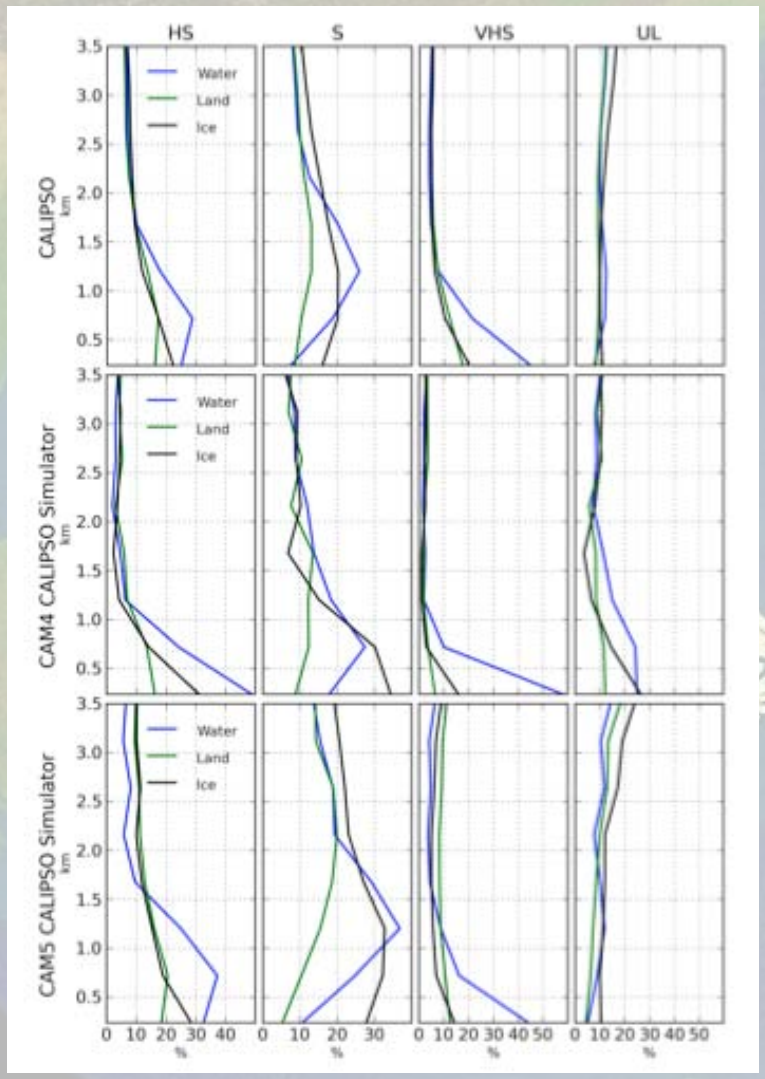
CAM5: "MG" cloud microphysics:

Treats many processes (nucleation, phase change, etc)
2-moment (mass, #) for both liquid and ice

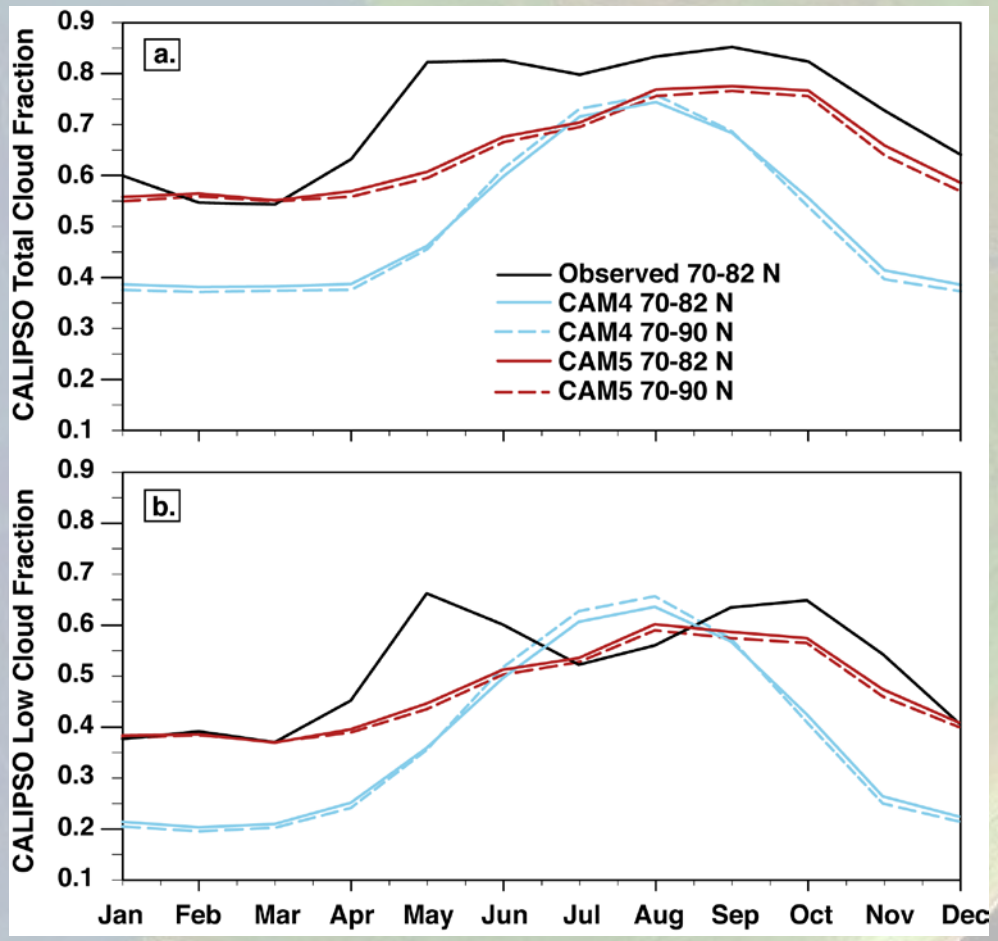


Morrison and Gettelman 2008; Diagram courtesy of Andrew Gettelman

COSP comparisons of Arctic cloud fractions show improvement from CAM4 to CAM5



Barton et al., under review



Kay et al. 2012, JClim

Question: How do CAM5 radiative fluxes compare to observations in the arctic?

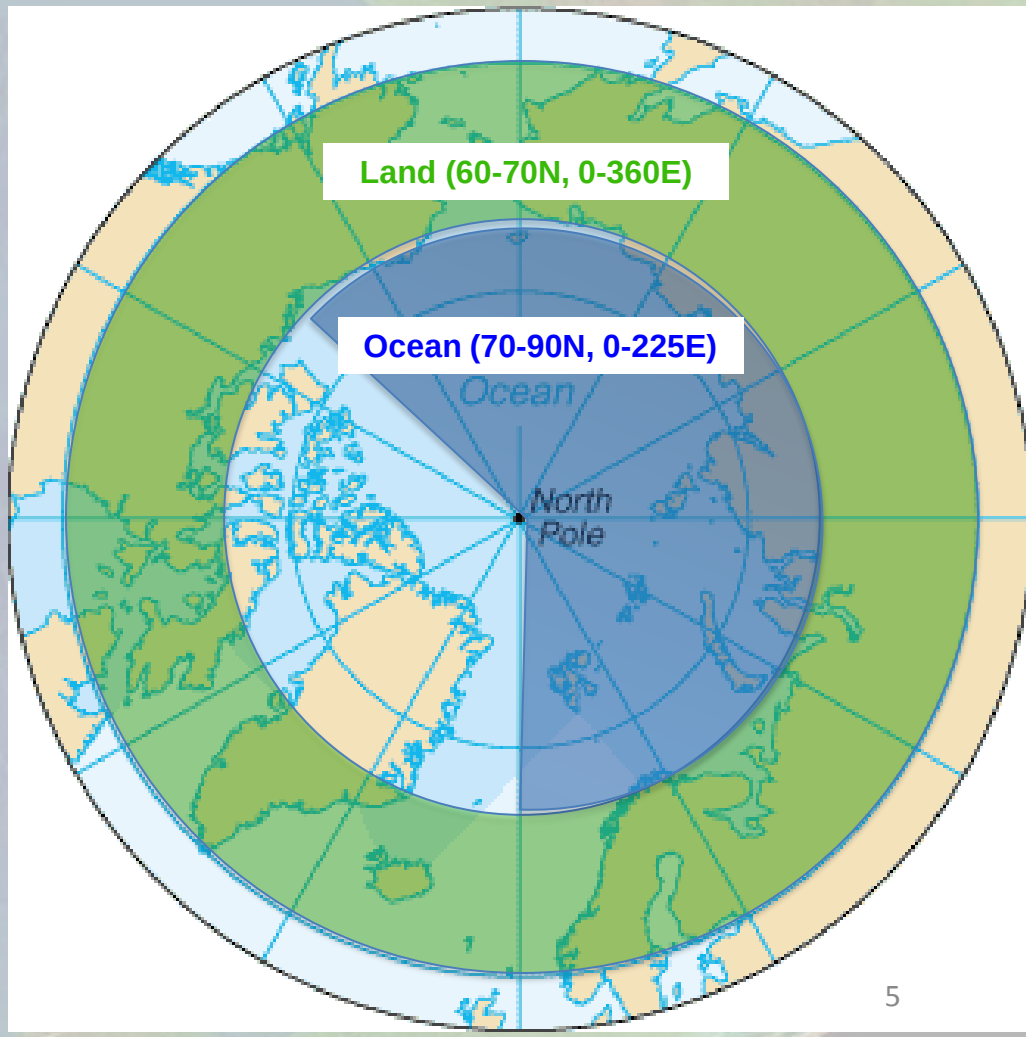
2 sets of CAM5 simulations:

1. **10-yr with monthly averages**
2. **2-yr with instantaneous output every 27-hr**

Both simulations used:

- **CAM5 w/MG microphysics**
- **Prescribed sea ice and SSTs (AMIP runs)**
- **0.95° x 1.25° res**

2 regions:

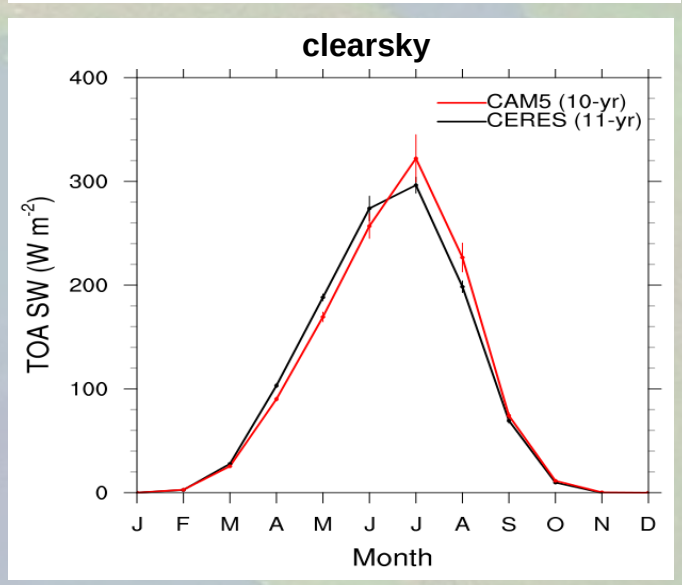


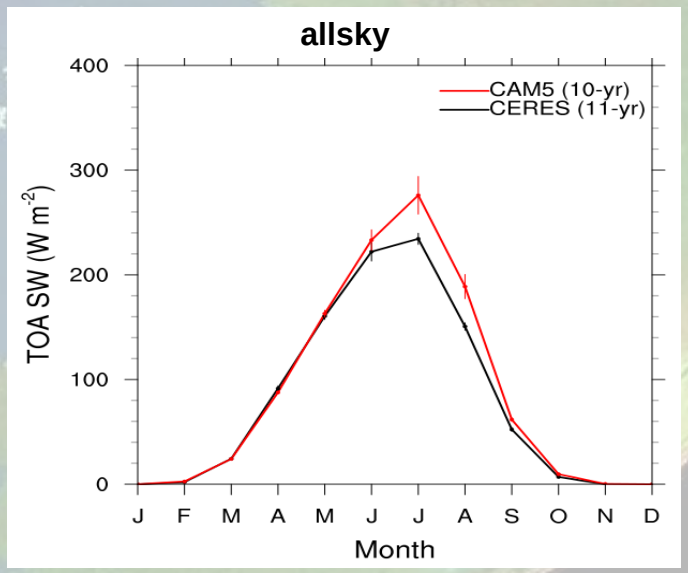
Net TOA SW: CAM5 good over land, clearsky/allsky too high in summer over ocean

Why might CAM5 net TOA SW be too high in summer over ocean?

- **Low cloud thickness or fraction would increase allsky TOA SW**
- **Low surface albedo would increase clearsky & allsky TOA SW**

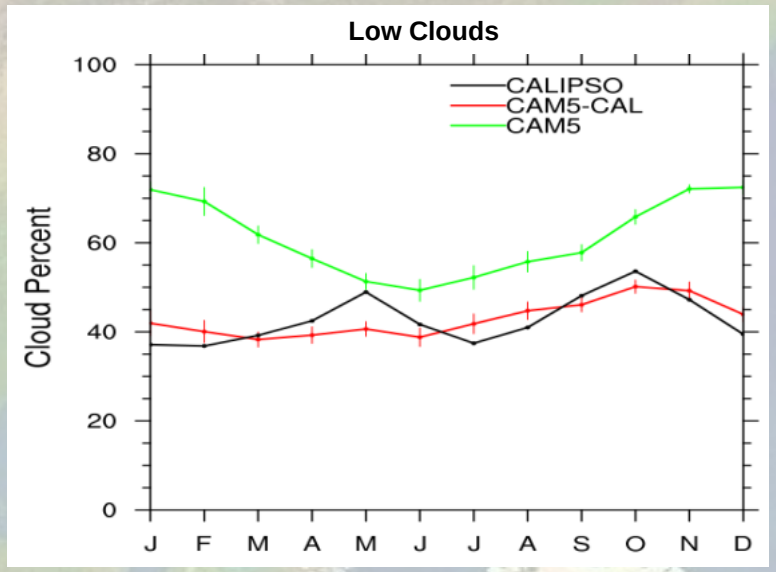
Ocean (70-90N, 0-225E)

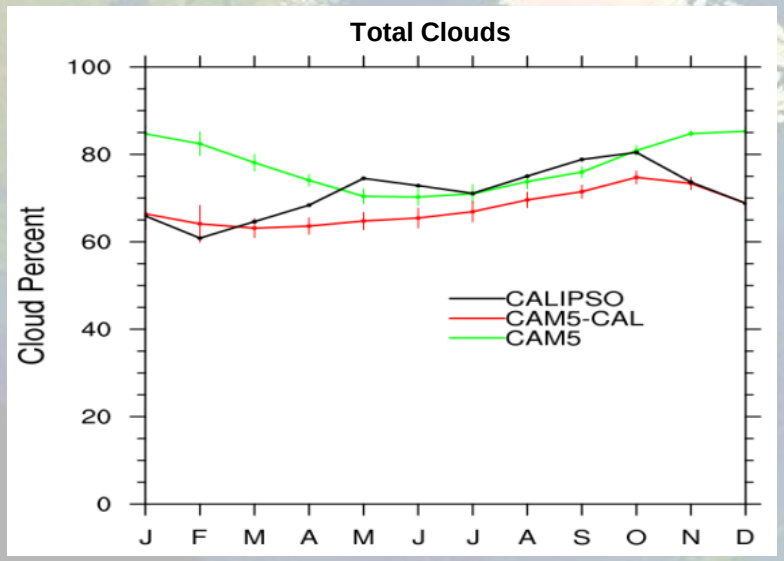




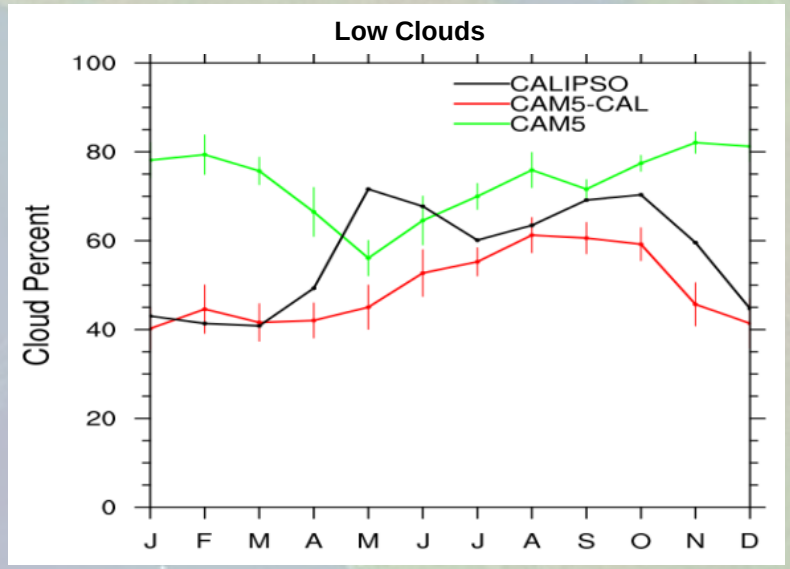
Cloud Frac: CAM5 is good in winter, but too low in spring-summer-fall

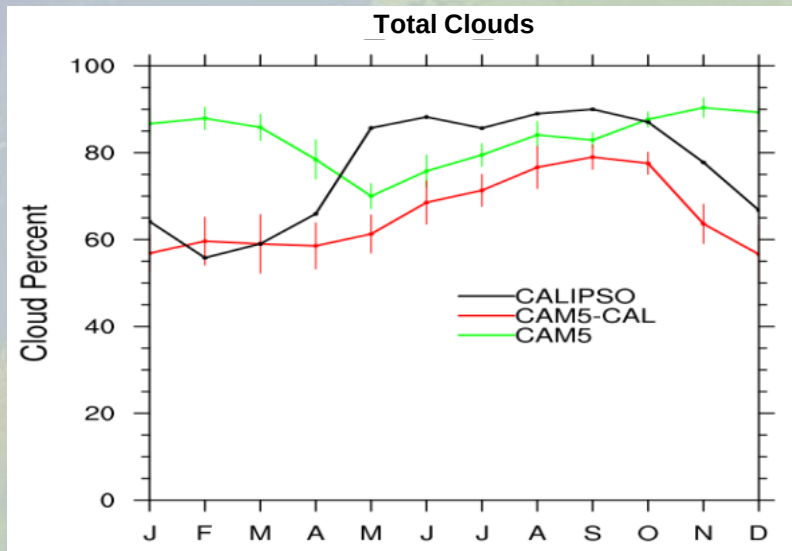
Land (60-70N, 0-360E)





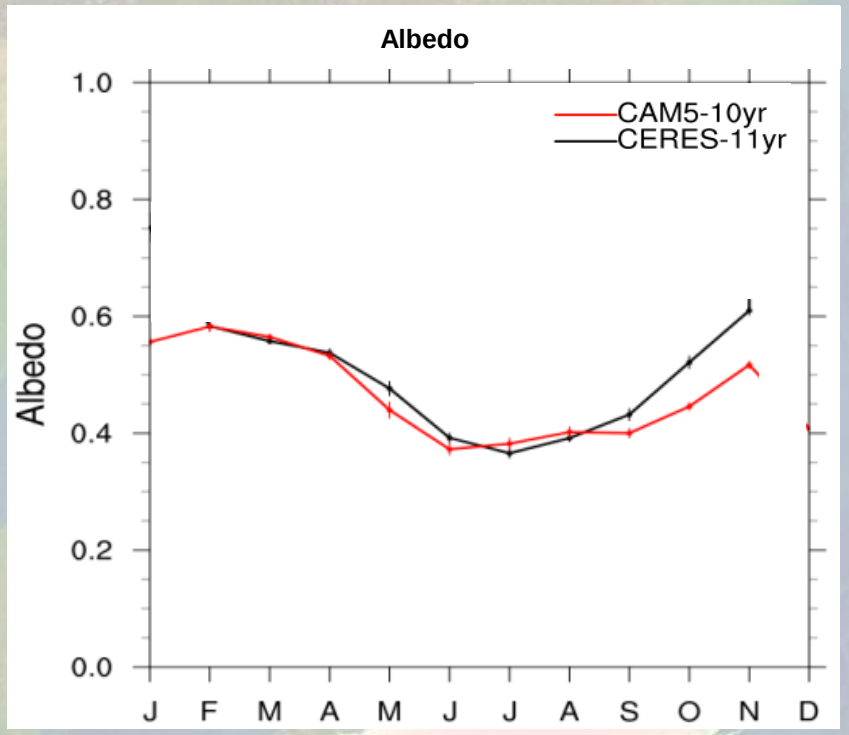
Ocean (70-90N, 0-225E)



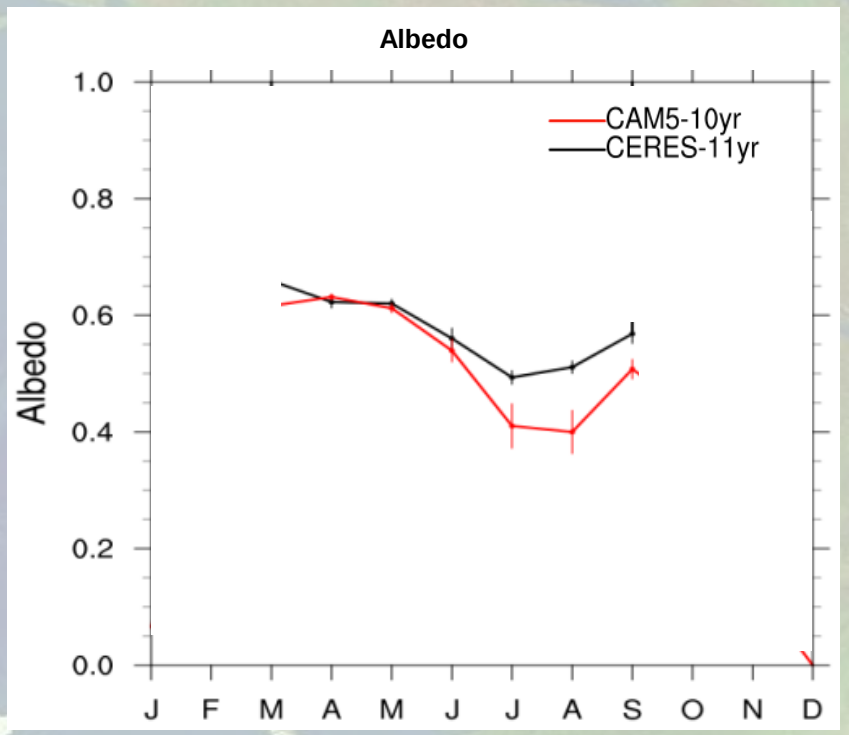


Albedo: CAM5 is good except too low in summer over ocean

Land (60-70N, 0-360E)



Ocean (70-90N, 0-225E)

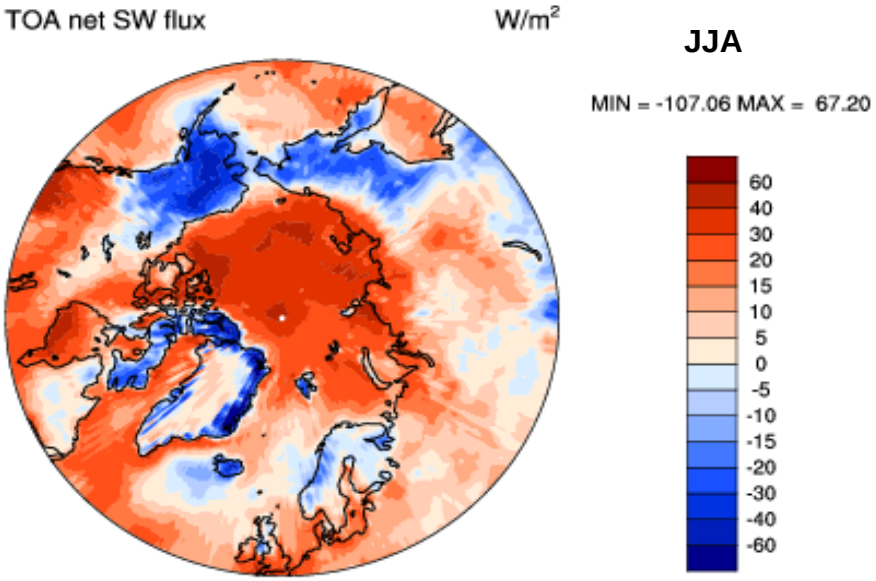


Since sea ice is prescribed, what else could explain albedo bias?

- **Errors in CAM albedo calcs for sea ice, snow or water (unlikely)**
- **Insufficient snow on ice (more likely, in progress..)**

CAM5 has spatial biases in summer, over land and water

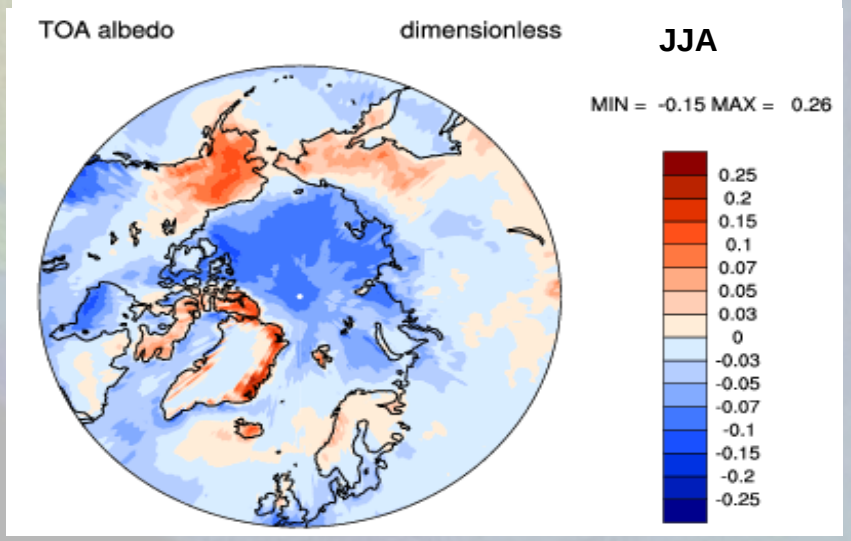
net TOA SW: CAM5 – CERES/EBAF



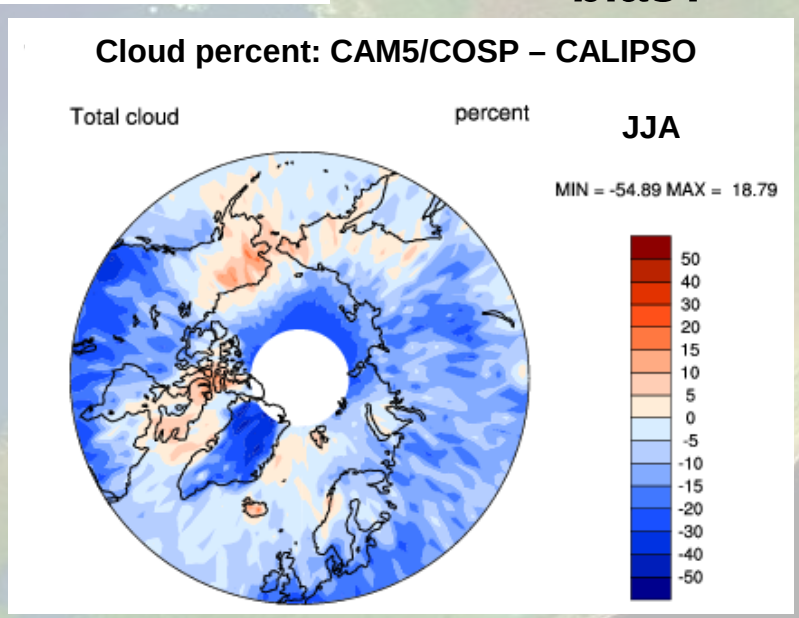
Supported by albedo…

Driven by clouds. SLP bias?

Albedo: CAM5 – CERES/EBAF



Cloud percent: CAM5/COSP – CALIPSO

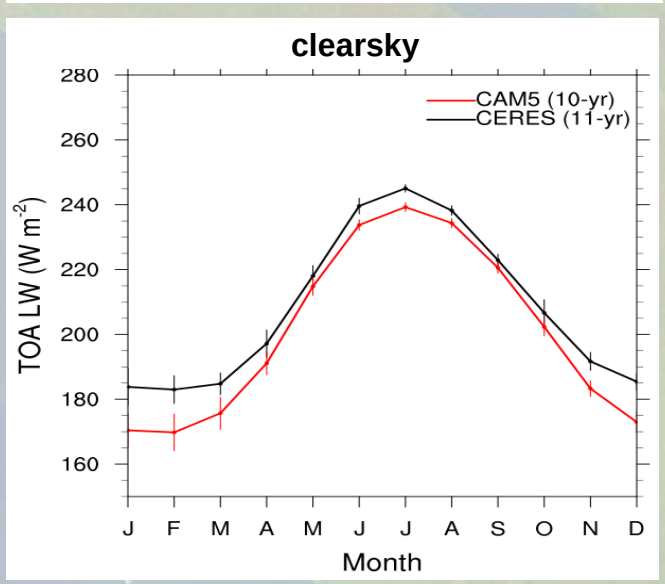


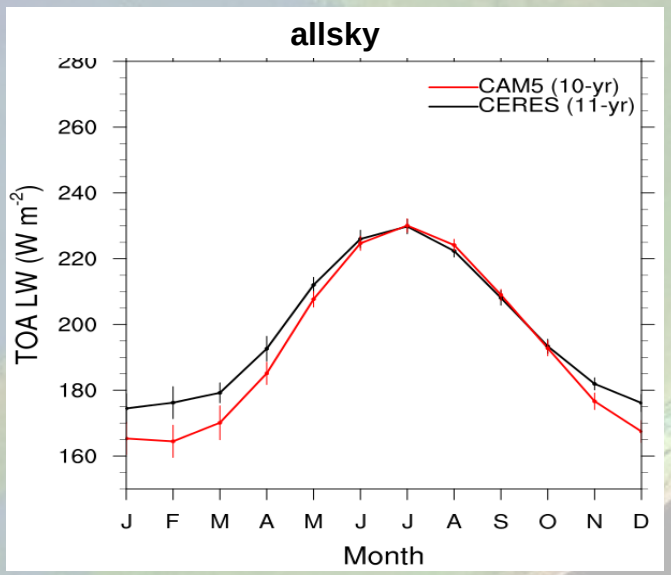
Net TOA LW (OLR): CAM5 is too low across all months, all skies, over both land and water

Why might CAM5 OLR be consistently too low?

- **Excess water vapor would decrease OLR**
- **Cold surface T would decrease OLR**
- **Clouds decrease OLR if they are thick and the air below them is warmer, but inversions are common in the arctic**
- **Clear skies initially increase OLR but radiative cooling can cause surface T too low**

Ocean (70-90N, 0-225E)





CAM5 has too much water vapor, esp. in summer

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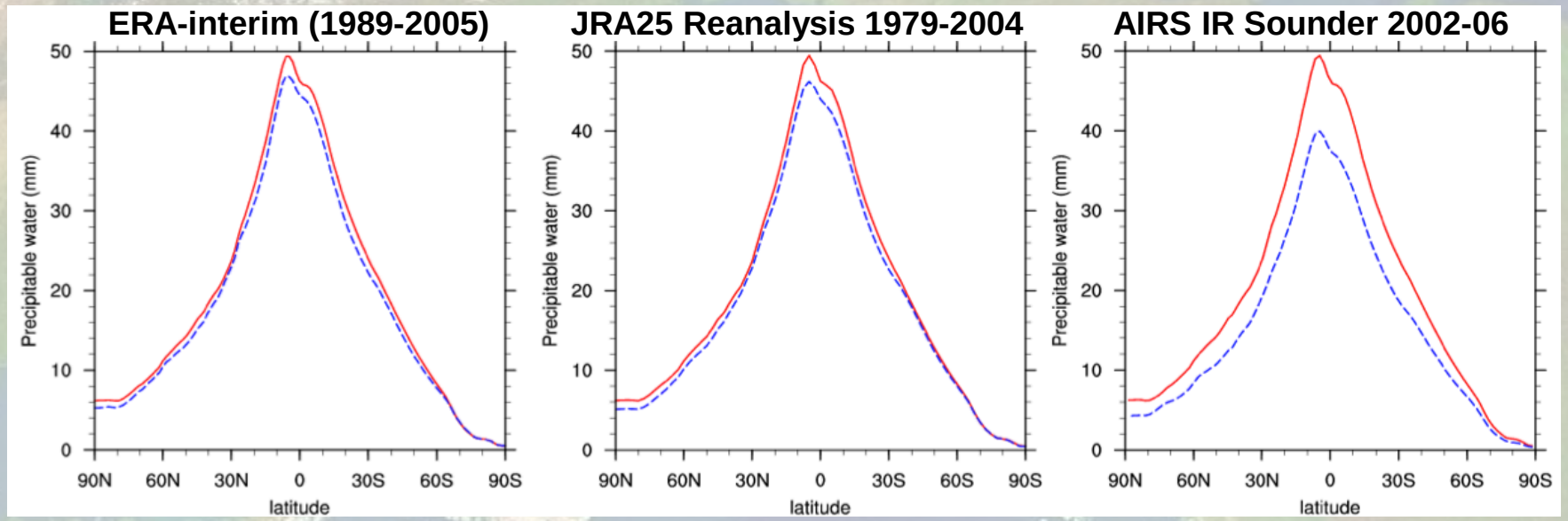
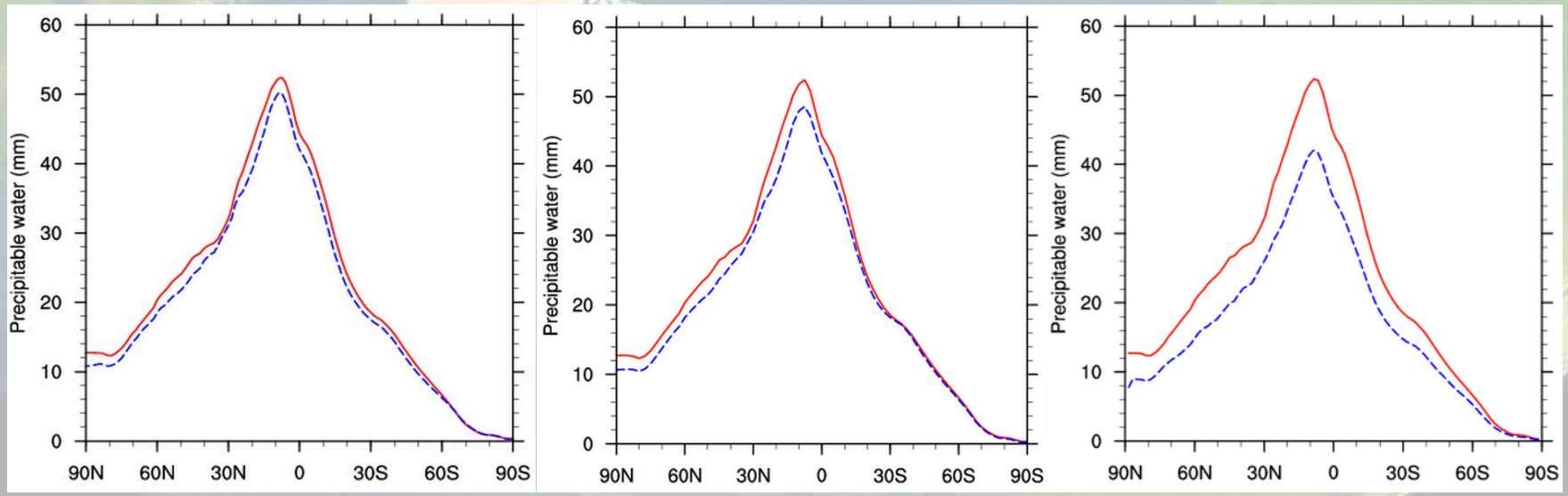
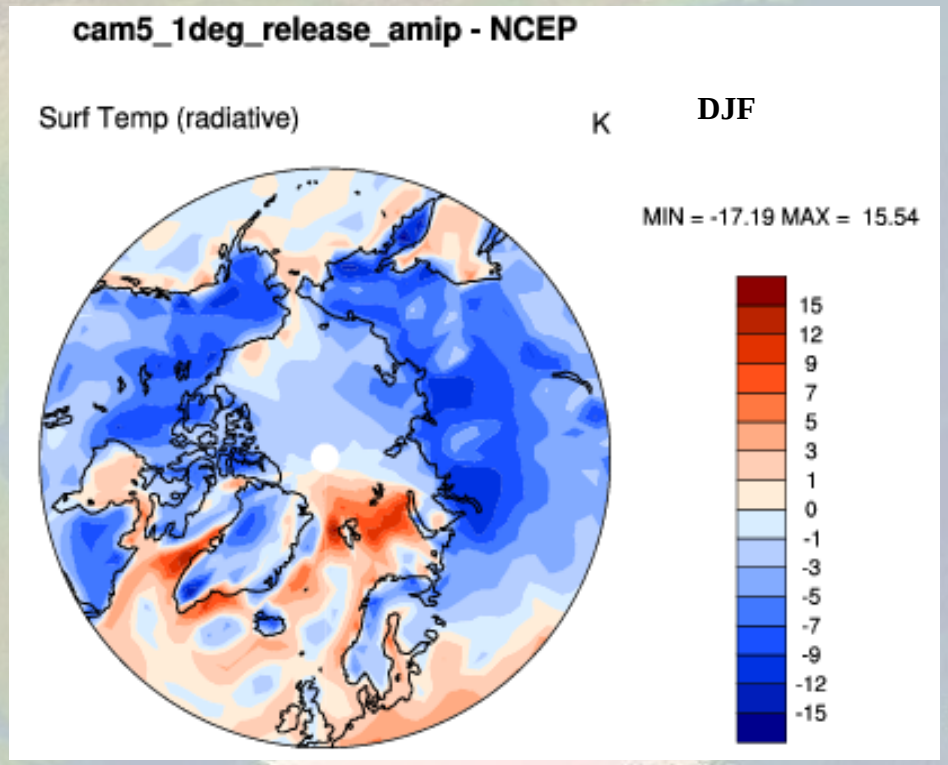
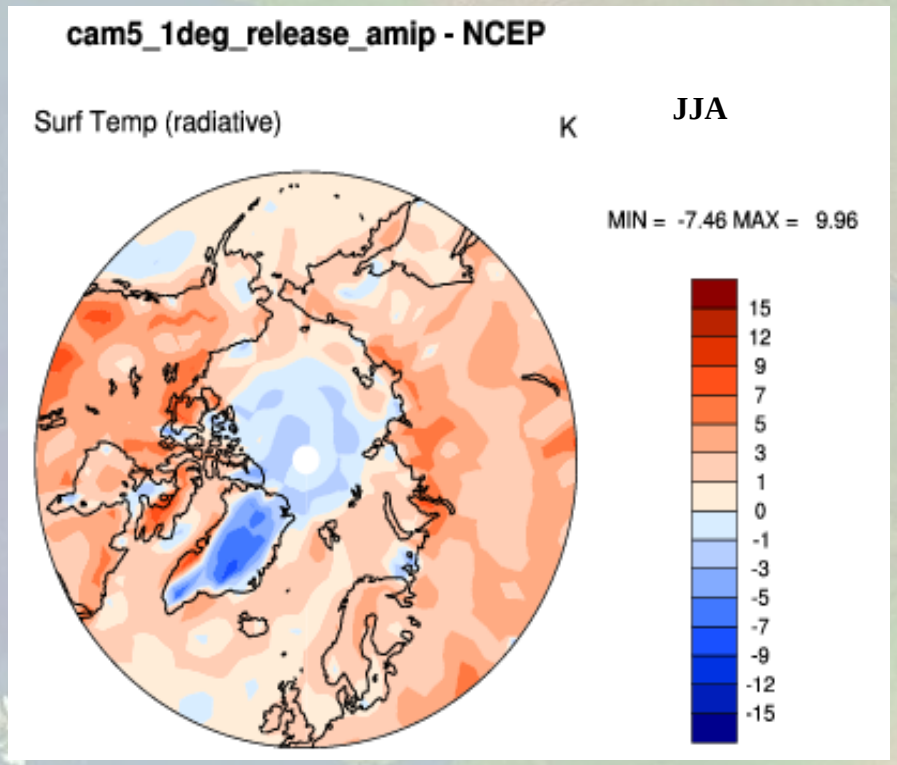


JJA



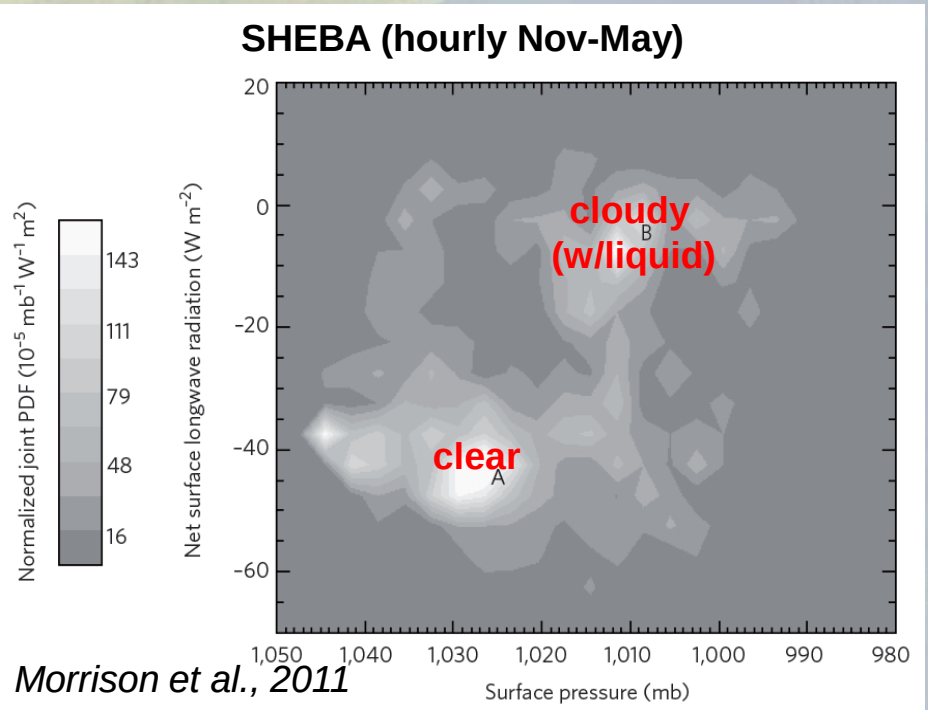
Winter LW bias in CAM5 can also be attributed to surface T too cold. Summer T is ok.



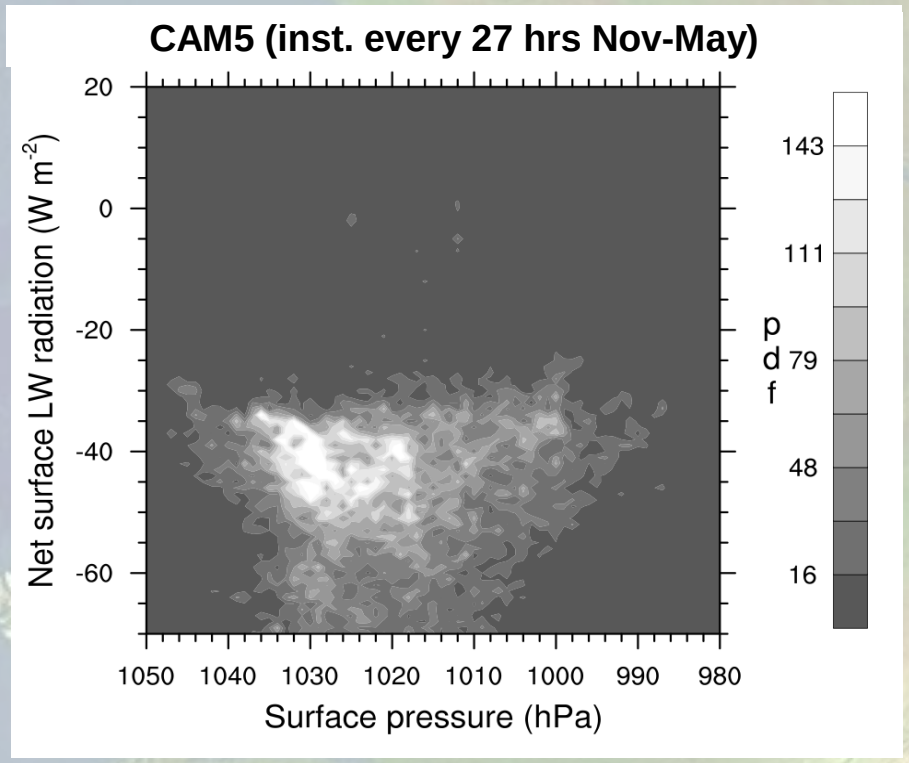


Surface LW comparison to SHEBA suggests CAM5 has insufficient LWP

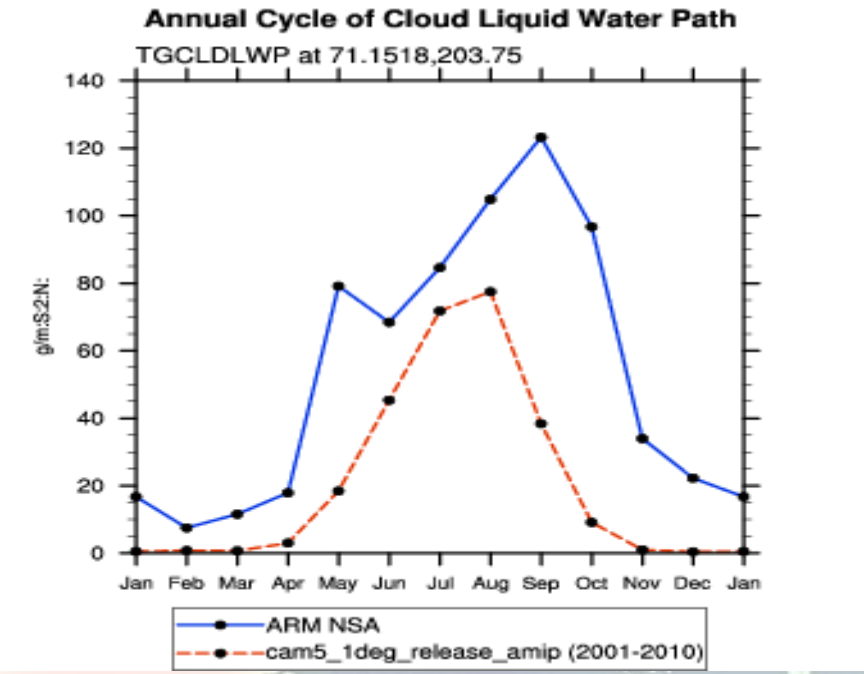
Analysis: 70-80N, 190-240E, Nov through May, all data with clouds above 3 km removed to eliminate synoptic events



Morrison et al., 2011

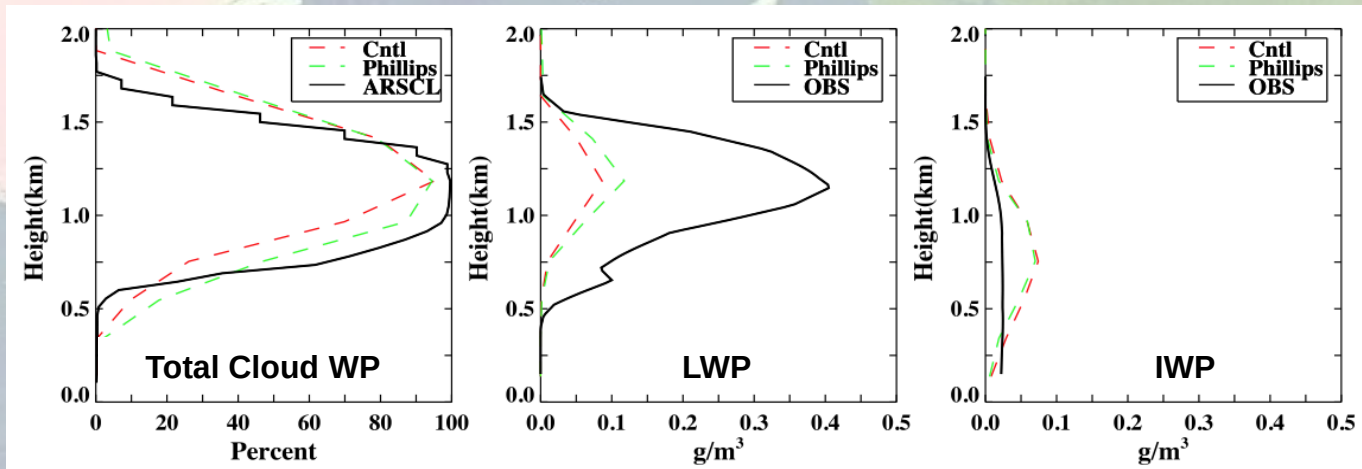


Low LWP in CAM5 Arctic may explain insufficient clouds in spring/fall, excess water vapor, cold Ts, and the lack of weather states



Low Arctic LWP is supported by other studies, and is a persistent problem in GCMs

Liu et al., 2011



Summary of CAM5 in the arctic

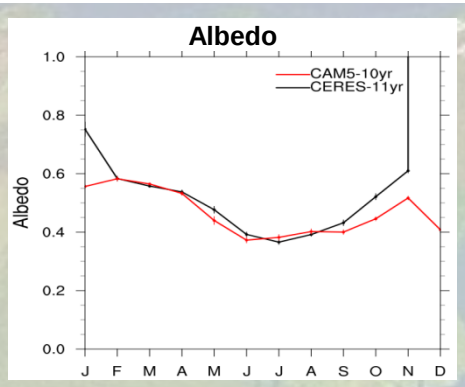
- CAM5 treats many cloud processes, and arctic clouds are much improved over CAM4 compared to observations
- Net TOA SW: CAM5 average over land compares well with CERES, but:
  - CAM5 is too high in summer over ocean (insufficient snow on ice?)
  - Spatial biases over land/ocean, due to cloud fraction biases
- Net TOA LW: CAM5 has consistently low OLR, due to:
  - Too much water vapor year-round, esp. in summer
  - Winter surface T too cold
- CAM5's arctic LWP is low by many comparisons (e.g. SHEBA, M-PACE [Liu et al.]), and is a common problem in models (e.g. Prenni et al.)

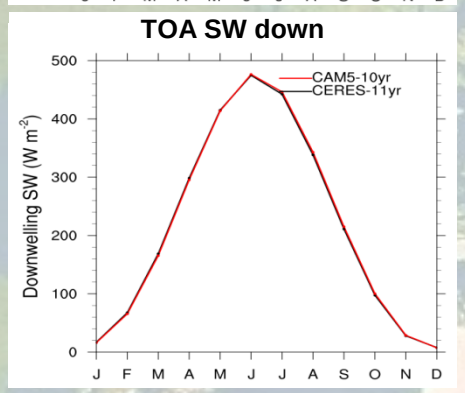
Next Steps

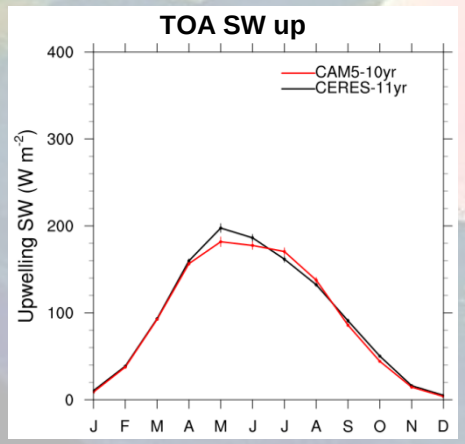
- Identify best surface T datasets for arctic evaluation
- Improve CAM5 LWP/IWP phase fractioning (P. Caldwell?)
- Add improved ice nucleation scheme to CAM5
- Evaluate CAM-CLUBB in the arctic

Incoming TOA SW matches obs (good sanity check)

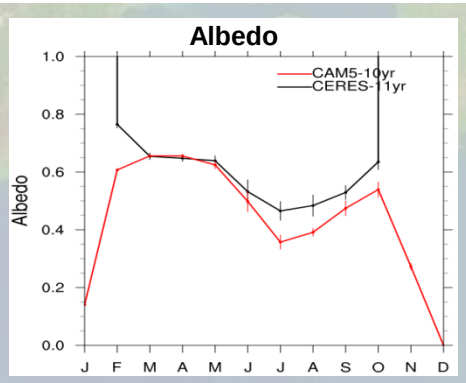
Land (60-70N, 0-360E)

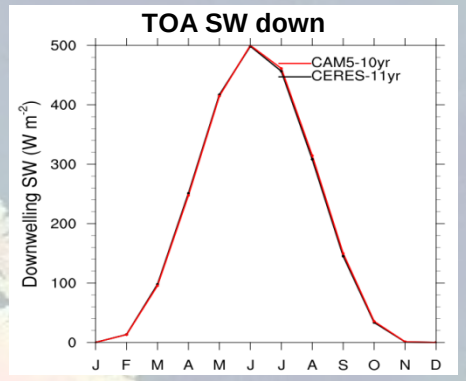




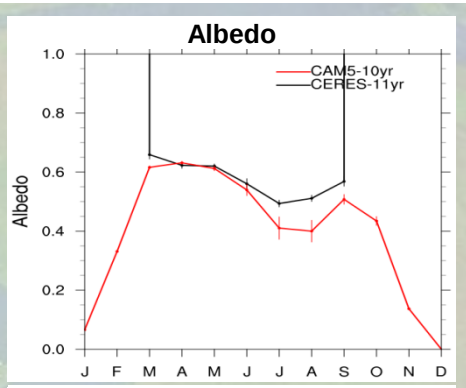


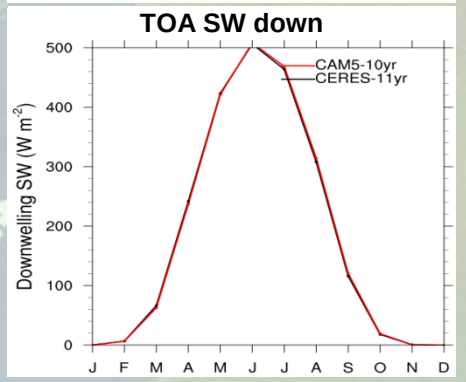
Beaufort Sea (70-80N, 190-240E)

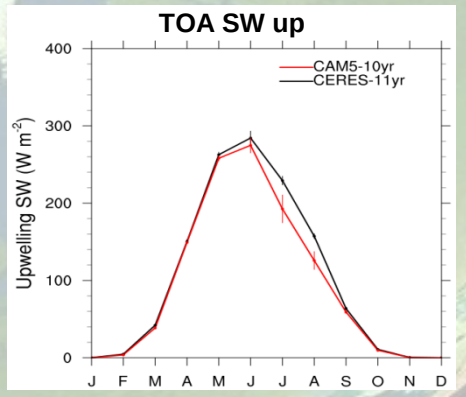




Ocean (70-90N, 0-180E)







CAM5 has more cloudy states in warmer months