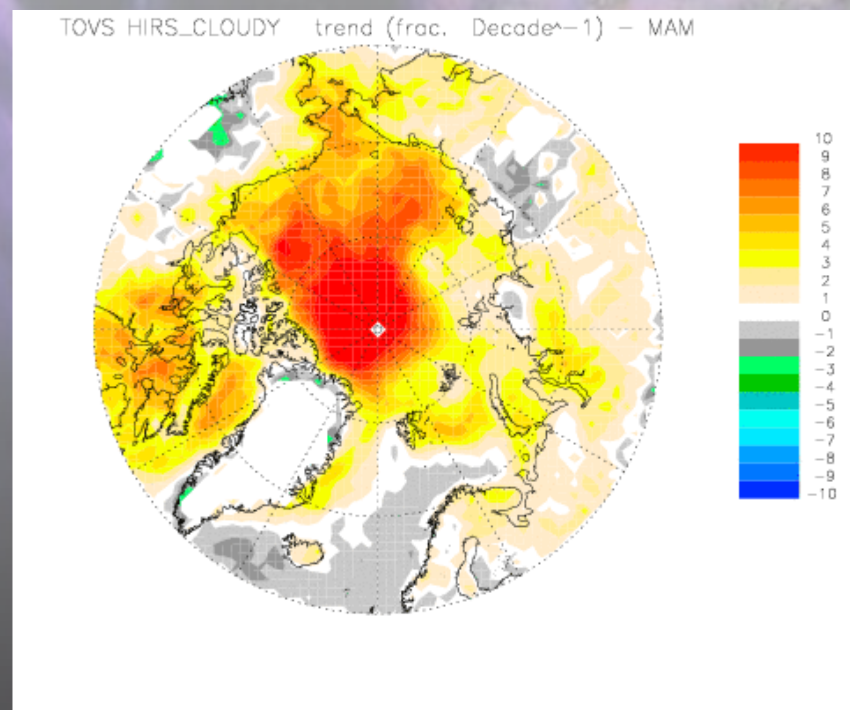
The Roles of Clouds and their Accomplices in Modulating the Trajectory of the Arctic System

Co-P.I.s:
Jennifer Francis, Rutgers University
Axel Schweiger, University of Washington
Steve Vavrus, University of Wisconsin

MODIS image

Motivation

- Cloud amounts over the Arctic Ocean have increased substantially in spring, summer, and fall, but they have decreased in winter



MODIS image

Motivation

- Cloud amounts over the Arctic Ocean have increased substantially in spring, summer, and fall, but they have decreased in winter
- Thicker clouds block more insolation but increase emission of longwave energy to the surface
- Clouds have net warming effect in the Arctic, but as snow/ice disappears, they will act more like mid-latitude clouds (net cooling effect)
- Perennial ice extent appears to be closely linked with variability in longwave emission, especially as it gets thinner
- Model study suggests that Arctic Tsfc is as sensitive to cloud changes in low-latitudes as to local cloud changes, while sea-ice changes in fall affect cloud type
- Poleward moisture transport expected to increase in future

MODIS image

Overarching focus:

Identify and evaluate *relationships* between cloud properties, surface radiation fluxes, horizontal heat and moisture transport, large-scale circulation patterns, sea ice extent, and melt onset in the *past*, when Arctic change was moderate, and in the *future*, which models project will be characterized by [even more] dramatic losses of permanent ice.

Science objectives:

Core hypothesis: Clouds and their linkages within the climate system play leading roles in modulating the trajectory of Arctic change, and that these linkages will evolve as the ice-albedo feedback gains momentum.

Sub-hypothesis #1: Recent changes in cloud properties are caused primarily by changes in the large-scale circulation, and to a lesser degree by surface changes.

Science objectives:

Core hypothesis: Clouds and their linkages within the climate system play leading roles in modulating the trajectory of Arctic change, and that these linkages will evolve as the ice-albedo feedback gains momentum.

Sub-hypothesis #2: Global models can simulate past cloud-system relationships sufficiently well to provide a tool to assess future relationships.

Science objectives:

Core hypothesis: Clouds and their linkages within the climate system play leading roles in modulating the trajectory of Arctic change, and that these linkages will evolve as the ice-albedo feedback gains momentum.

Sub-hypothesis #3: Observed tendencies for Arctic clouds to become more mid-latitude-like (net cooling influence) will continue as permanent ice declines further.

Science objectives:

Core hypothesis: Clouds and their linkages within the climate system play leading roles in modulating the trajectory of Arctic change, and that these linkages will evolve as the ice-albedo feedback gains momentum.

Sub-hypothesis #4: Horizontal sensible heat transport near the surface will decrease in the future, but increased latent heat advection will more than compensate, contributing to increased cloudiness and competing changes in surface radiation.

Synthesis: Data and Approaches

Data sources: Output from IPCC GCMs for 20th and 21st centuries, reanalysis/operational fields (1980 on), satellite retrievals (1980 on).

Variables:

- Clouds: amount, height, phase, liquid/water path
- Accomplices: water vapor, net precipitation, horizontal fluxes, surface fluxes, surface characteristics

Synthesis: Data and Approaches

Approaches:

- "Hammer Analysis" – assess co-variability in driver variables (e.g., moisture advection, sea-ice cover) with response variables (cloud forcing, radiation fluxes) during extreme, large-scale events (e.g., major sea-ice loss, prolonged AO phase, blocking patterns)
- Use relationships among variables in the real world to validate relationships in models
- Compare relationships in control model run to GHG-forced simulation to identify causes of cloud trends

Synthesis: Data and Approaches

Approaches (cont.):

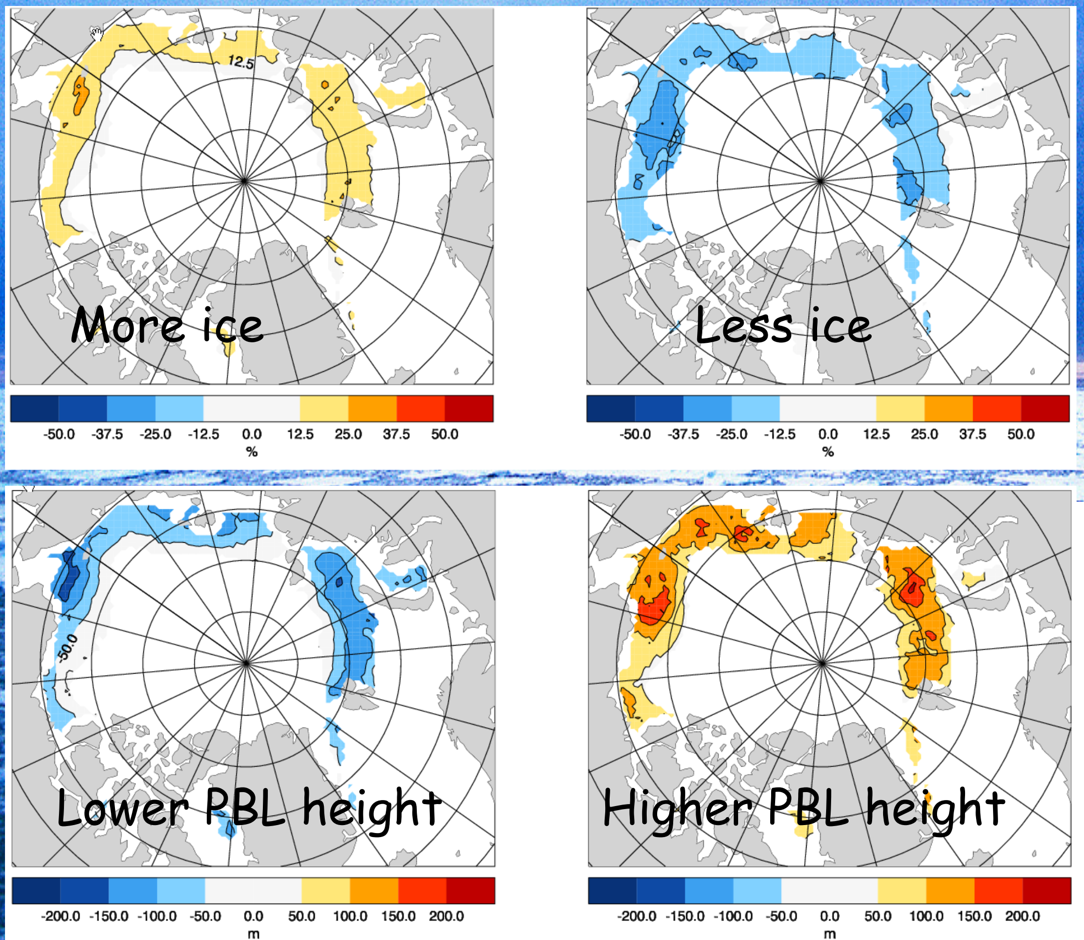
- Compare future co-variability to past during hammer events to see if relationships are maintained.

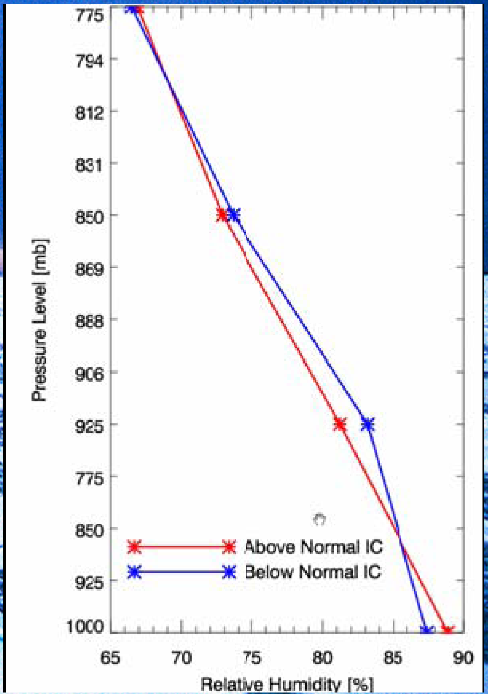
Examples: as LWP increases, it will have little effect on longwave fluxes to surface, but shading effect will increase. As sea ice cover gets very small, ice-albedo feedback will wane.

- Run CCSM with fixed cloud fractions a) in the Arctic, b) outside of the Arctic, c) everywhere, to determine local and remote impacts. Compare GHG scenario with same runs in control conditions.

Results: Done and In the Works

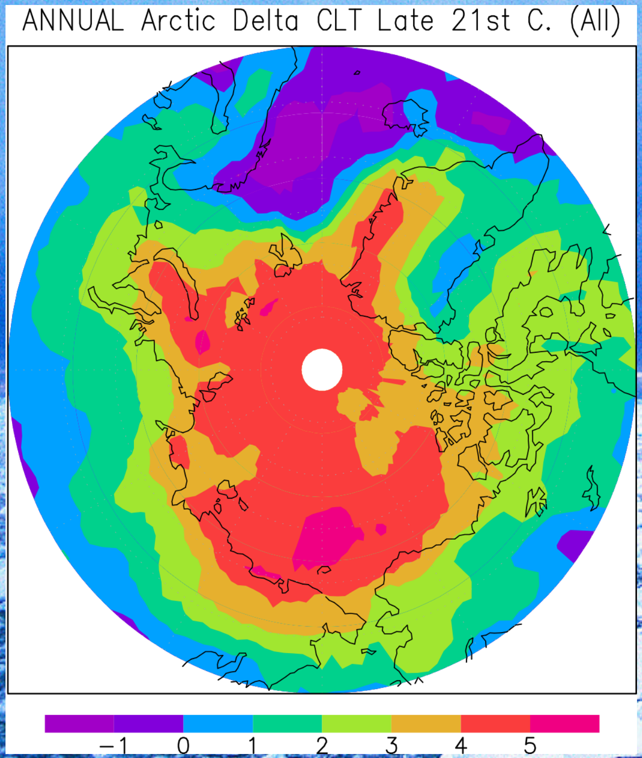
Relationships between Arctic Sea Ice and Clouds during Autumn.
Schweiger, Lindsay, Vavrus, and Francis, J. Climate, submitted.





Results: Done and In the Works

Assessment of Arctic Clouds in IPCC GCMs. Vavrus, in preparation.

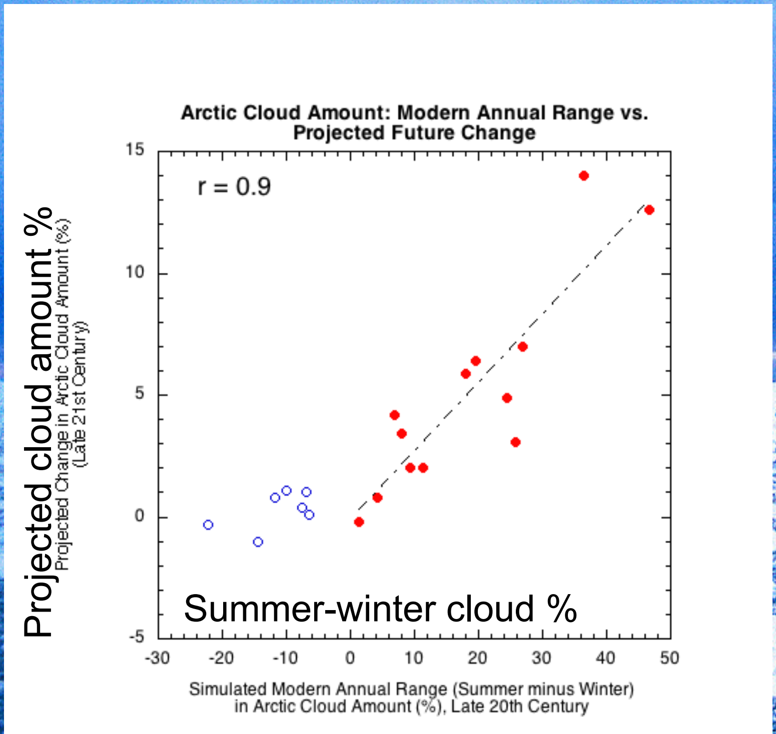


IPCC models project cloud increases over the Arctic in the 21st century over ice, decreases over open water.

Models underestimate cloud variability.

Results: Done and In the Works

Assessment of Arctic Clouds in IPCC GCMs. Vavrus, in preparation.

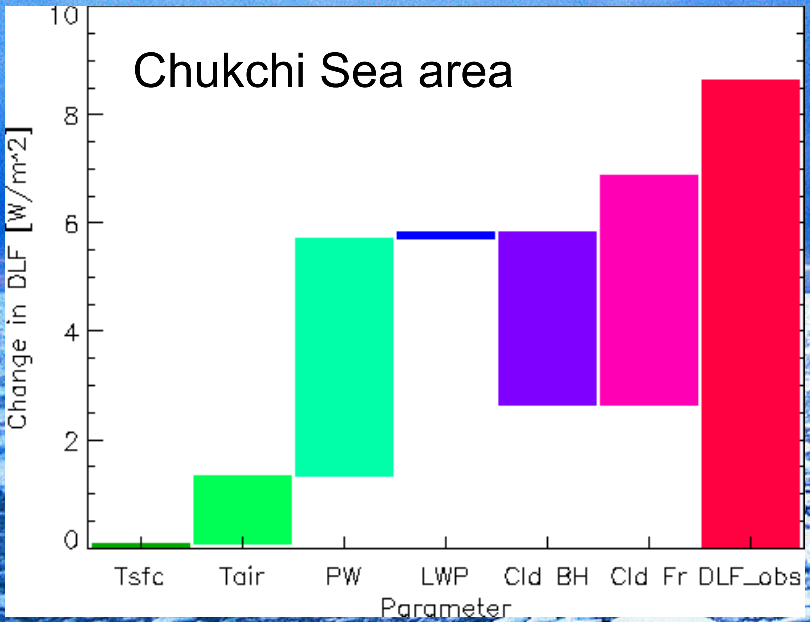


Models that correctly simulate annual cycle of cloud amount and changes during recent decades project largest increases in cloud amount during 21st century.

New cloud parameterization implemented in CCSM3 (so-called "freeze-dry") dramatically improves Arctic cloud simulations

Results: Done and In the Works

Changes in the Fabric of the Arctic's Greenhouse Blanket. Francis and Hunter, Environ. Res. Lett., in press.



The emission of longwave radiation from the atmosphere is increasing during the melt season, but why?

Increasing water vapor and cloud fraction are the main culprits, but uncertainties in cloud-base height and cloud phase need attention.

Potential Strong Linkages with other SASSy Projects

- Heat Budget (Serreze)
- Sunlight (Perovich)
- Reanalysis (Zhang)
- Marine primary productivity (Matrai)

Linkages with other ARCSS Projects

- **Roles of Moist Static Energy Transport in the Changing Arctic System**, NSF/ARCSS, Francis
- **Interactions and Feedbacks in the Changing Arctic Hydrologic System**, NSF/ARCSS Freshwater Integration Project, Changes and Attribution Working Group synthesis paper
- **Interactions among Observations of Lateral Advection, Clouds, and Surface Properties in the Arctic**, NSF/ARCSS Francis and Ackerman.