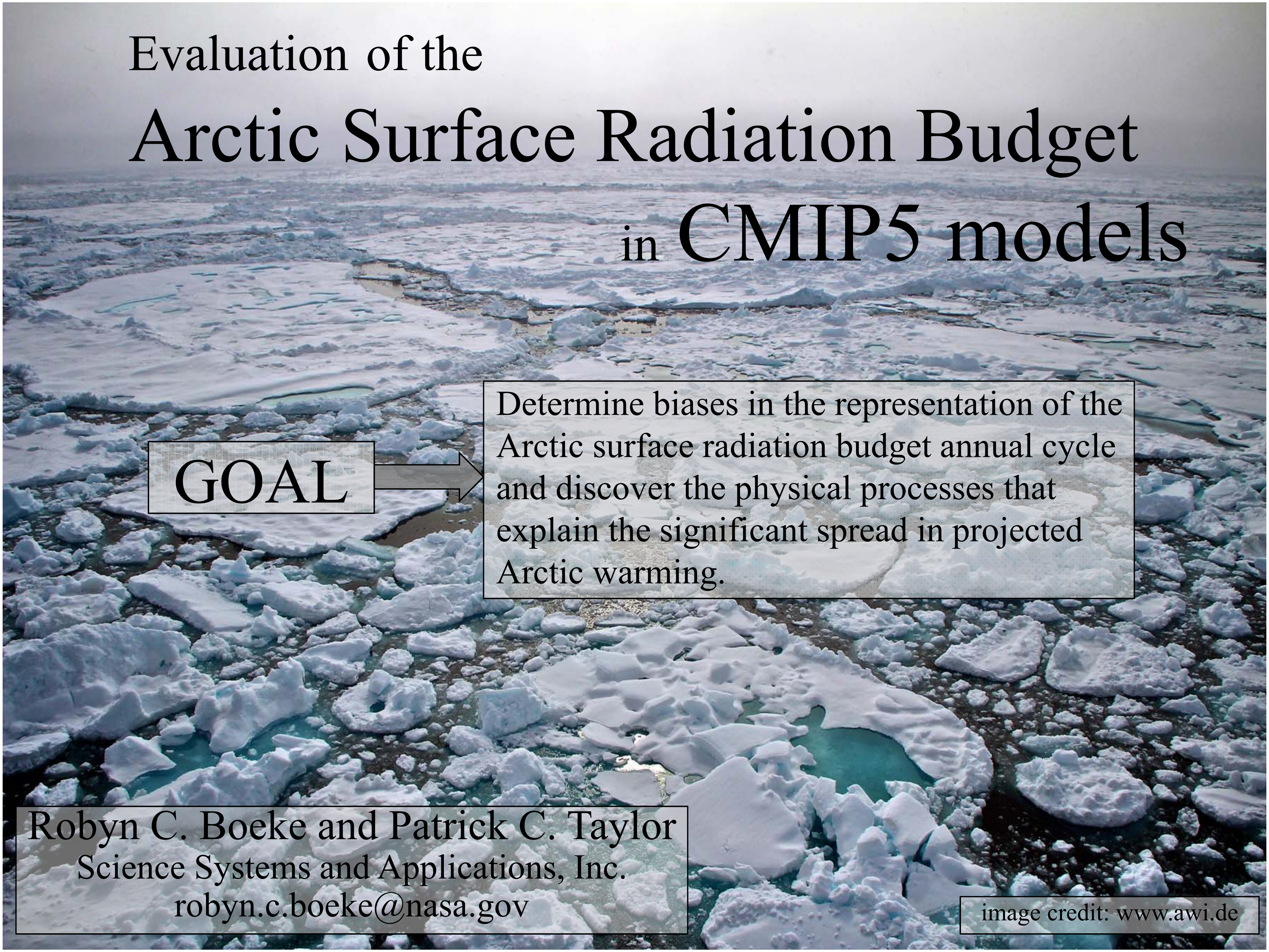

Evaluation of the Arctic Surface Radiation Budget in CMIP5 models

GOAL

Determine biases in the representation of the Arctic surface radiation budget annual cycle and discover the physical processes that explain the significant spread in projected Arctic warming.

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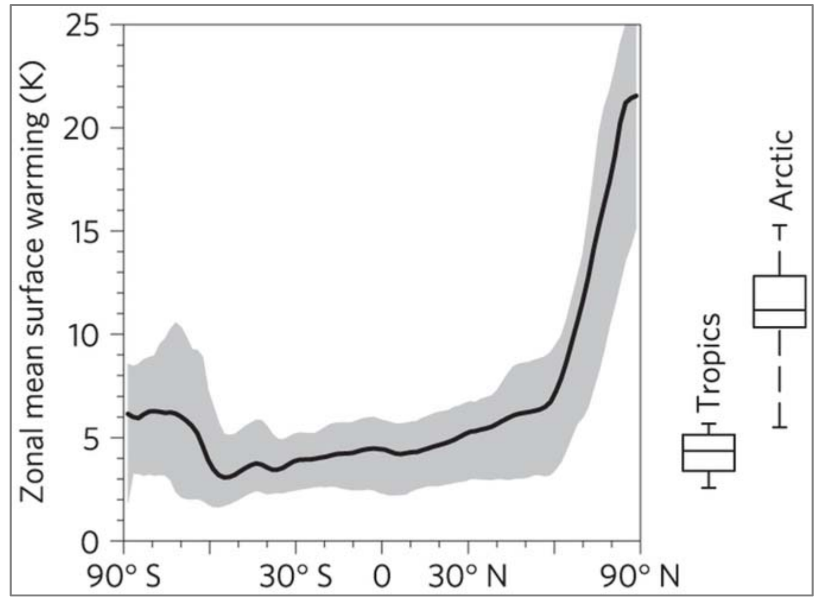
image credit: www.awi.de

The Arctic climate is rapidly changing

Arctic surface temperature is increasing at a rate outpacing the rest of the globe, and the projected Arctic temperature response to increasing CO_2 is larger than that for the tropics.



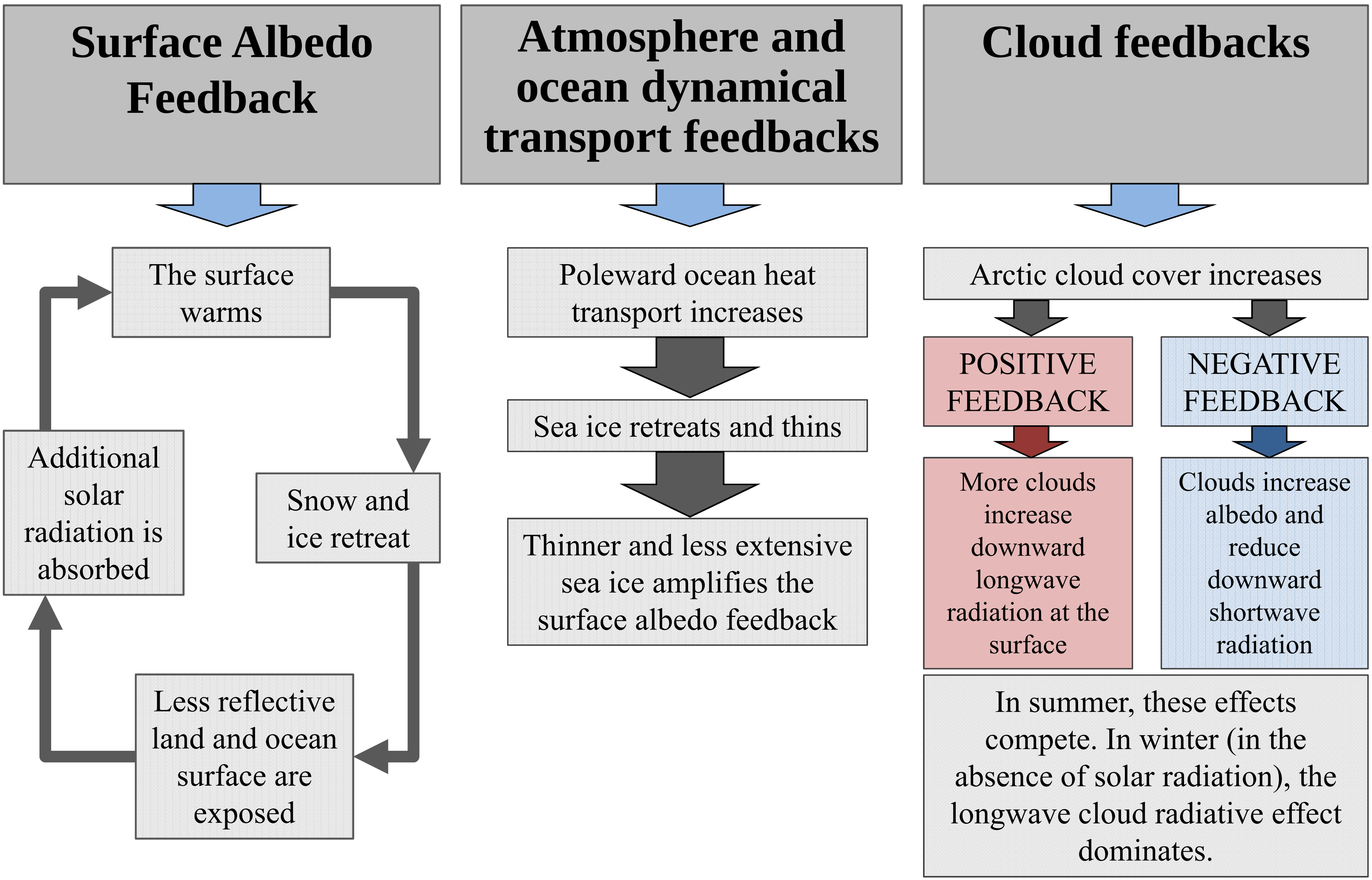
credit: Pithan and Mauritsen 2013

Studying the Arctic climate presents unique challenges.

- The largest intermodel spread in projected surface temperature warming is found in the Arctic.
- Satellite observations are difficult, lack of in-situ measurements

Understanding and reducing intermodel spread in the simulation of the surface energy budget can improve future projections.

Radiative and non-radiative feedback processes lead to polar warming amplification



Use the concept of cloud radiative forcing to evaluate the influence of clouds on shortwave and longwave fluxes at the surface.

$$CRE = (SW\downarrow - SW\downarrow_{clr\text{-}sky})\cdot(1 - \alpha) + (LW\downarrow - LW\downarrow_{clr\text{-}sky})$$

"Cloud Radiative Effect"

where
- $SW\downarrow$, $LW\downarrow$ are all-sky fluxes
- $SW\downarrow_{clr\text{-}sky}$, $LW\downarrow_{clr\text{-}sky}$ are clear-sky fluxes
- α is the albedo calculated using clr-sky sw fluxes, $SW\uparrow_{clr\text{-}sky}/SW\downarrow_{clr\text{-}sky}$

Terms in the equation represent cloud influence on solar and infrared radiation

$(SW\downarrow - SW\downarrow_{clr\text{-}sky})\cdot(1 - \alpha)$ →

Shortwave cloud radiative forcing (SW CRE)

Usually negative because downwelling solar flux decreases with the presence of clouds

Magnitude of SW CRE is smaller over a white surface than over ocean

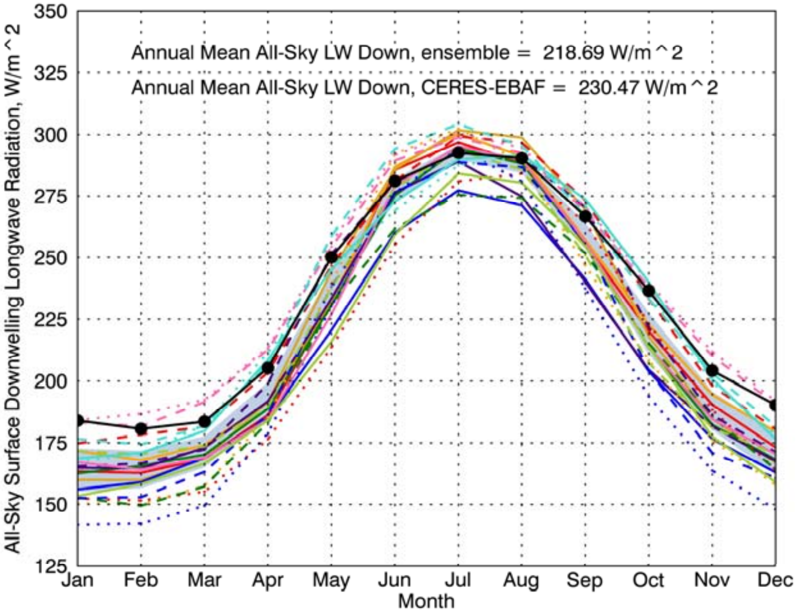
$(LW\downarrow - LW\downarrow_{clr\text{-}sky})$ →

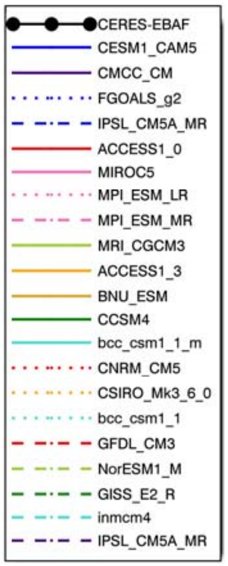
Longwave cloud radiative forcing (LW CRE)

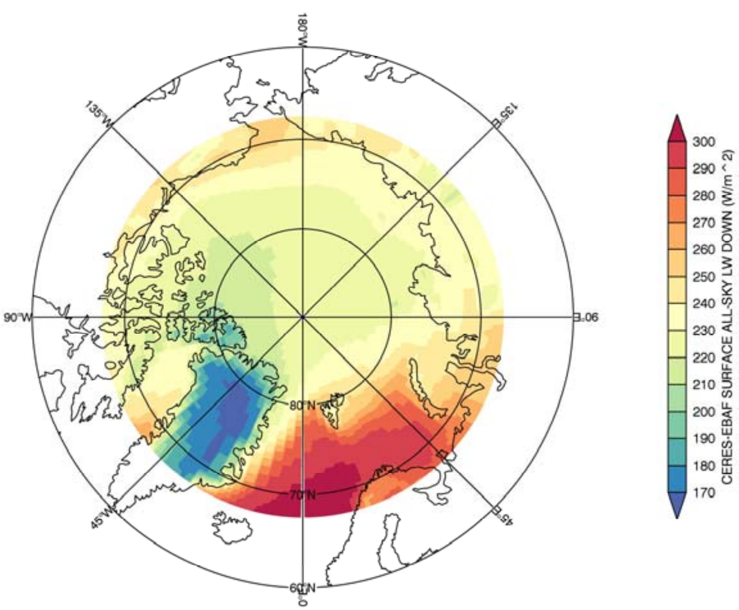
Usually positive because downwelling longwave radiation increases with the presence of clouds

Longwave Surface Fluxes

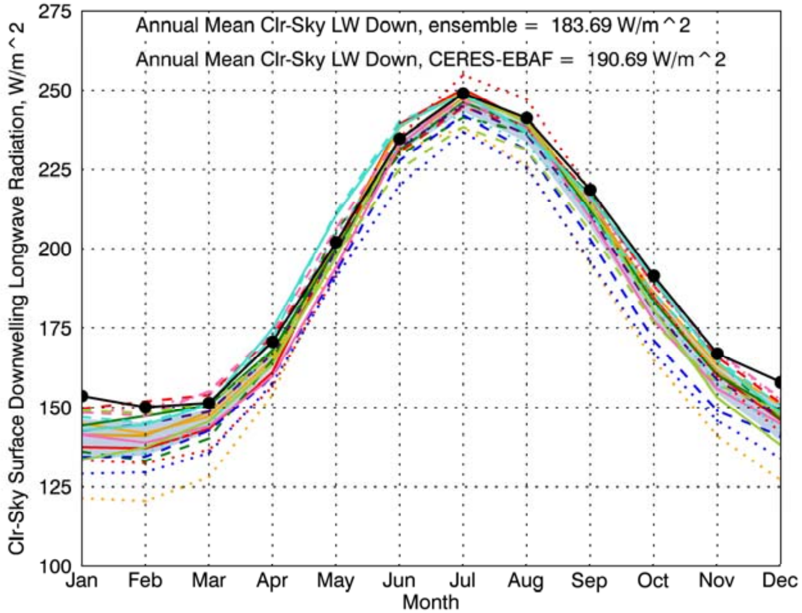
All-Sky

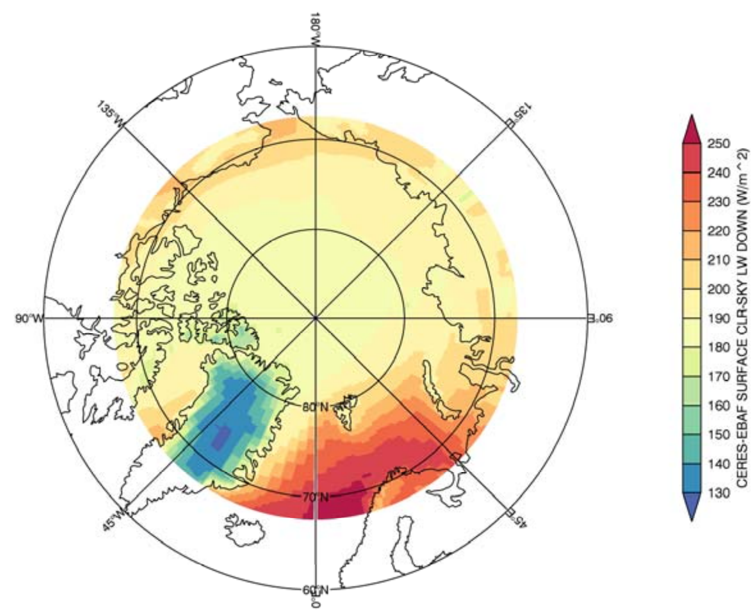




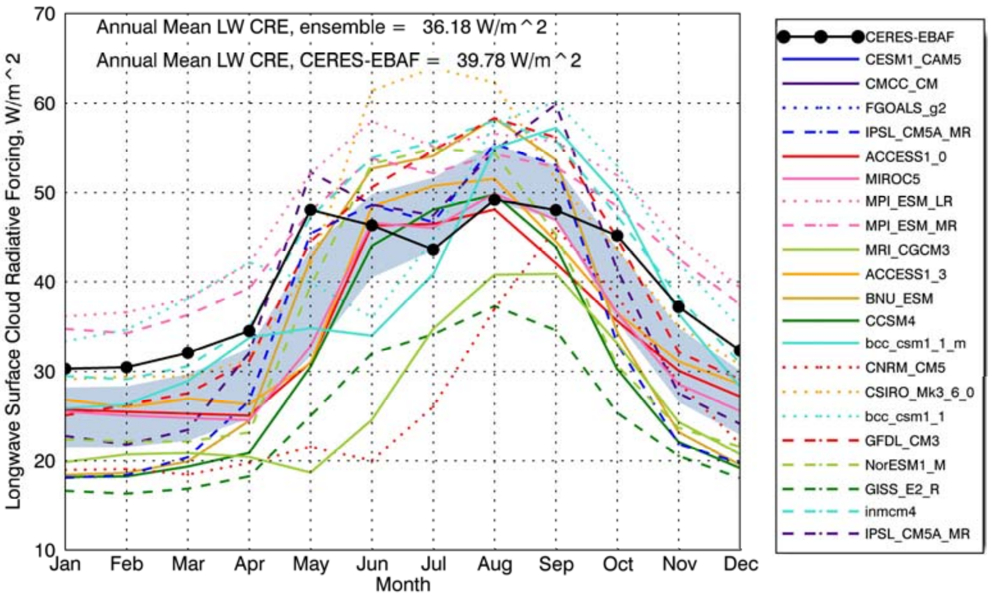


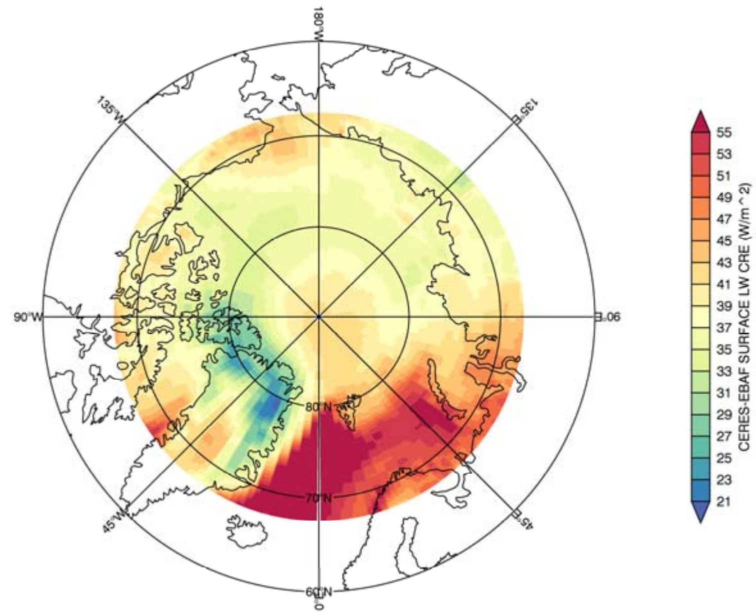
Clr-Sky



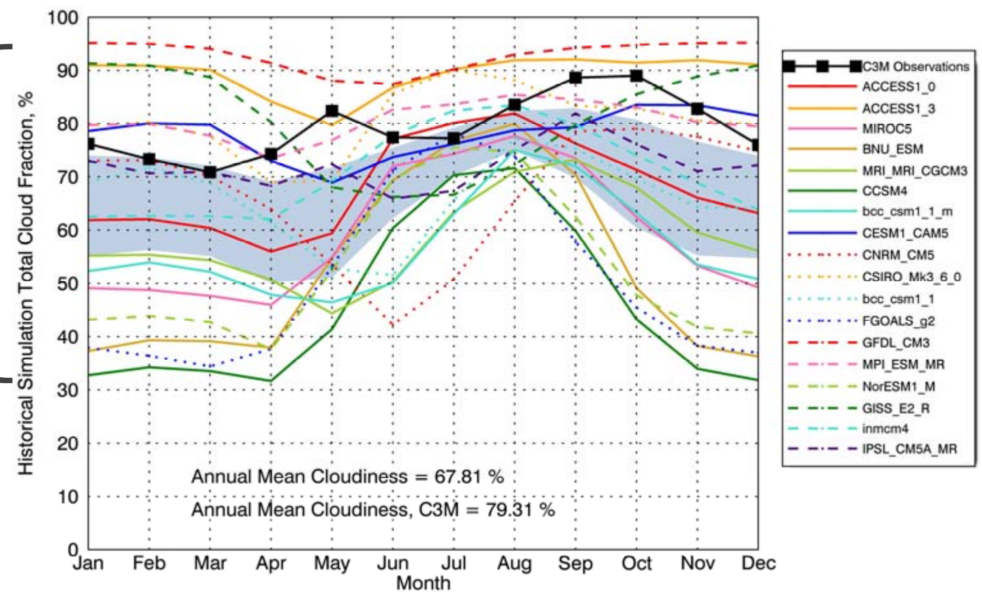


Longwave Cloud Radiative Effect





The large discrepancy in wintertime cloudiness is due to the representation of low clouds (Karlsson 2011)



What causes differences in LW CRE?

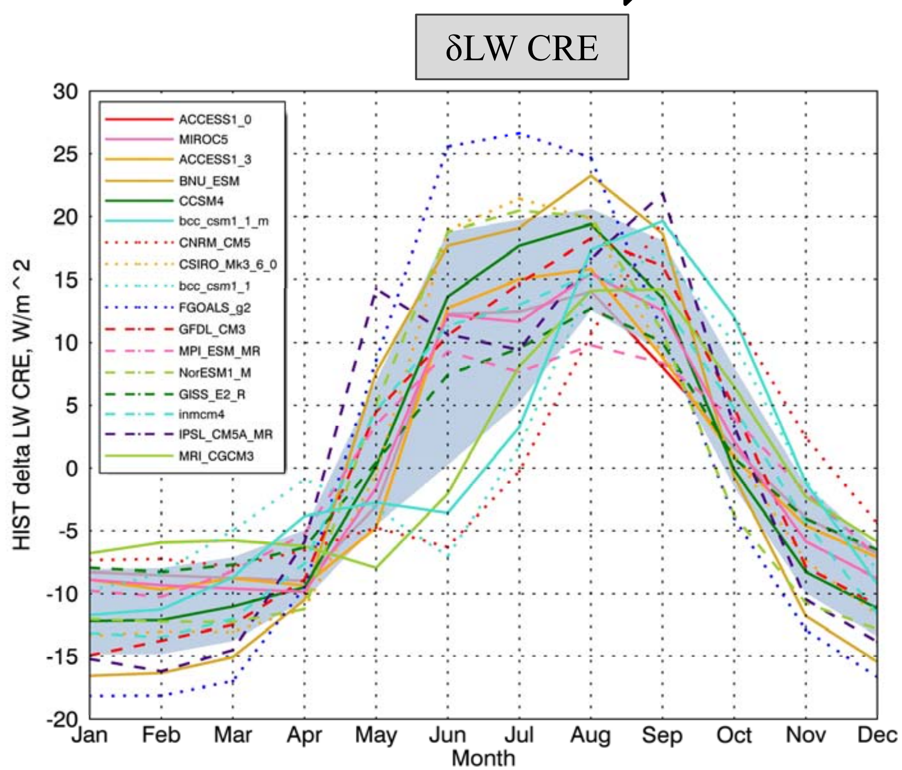
$$\text{LW CRE} = \text{LW}\downarrow_{all} - \text{LW}\downarrow_{clr} = N(F\downarrow_{cld,lw} - F\downarrow_{clr,lw})$$

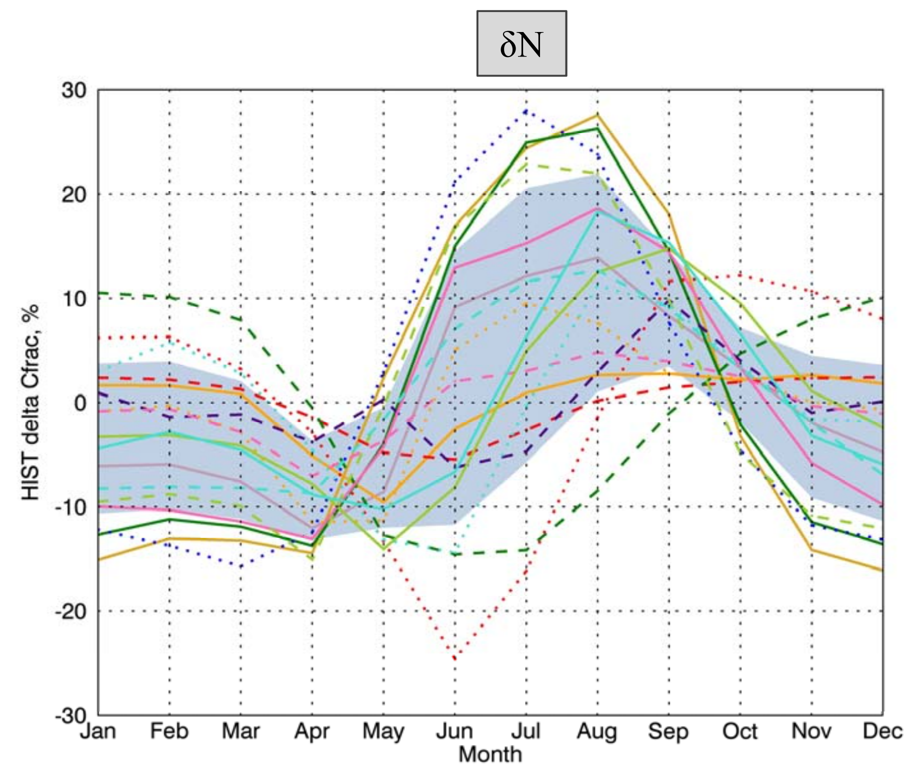
$$\delta\text{LW CRE} = \delta N(F\downarrow_{cld,lw} - F\downarrow_{clr,lw}) + N\times\delta F\downarrow_{cld,lw} - N\times\delta F\downarrow_{clr,lw}$$

Clr-Sky Component

Cloud Property Component

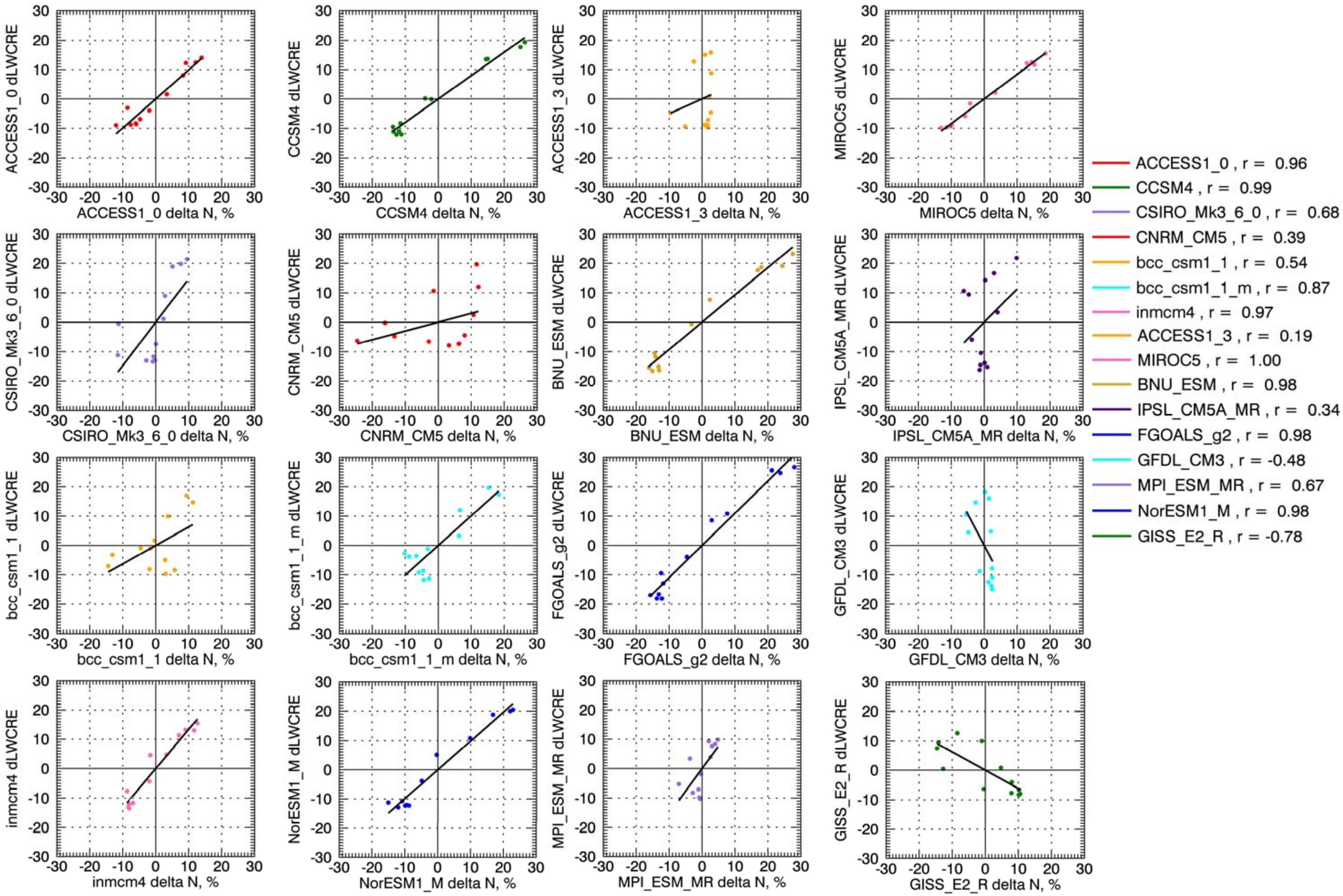
Cloud Fraction Component





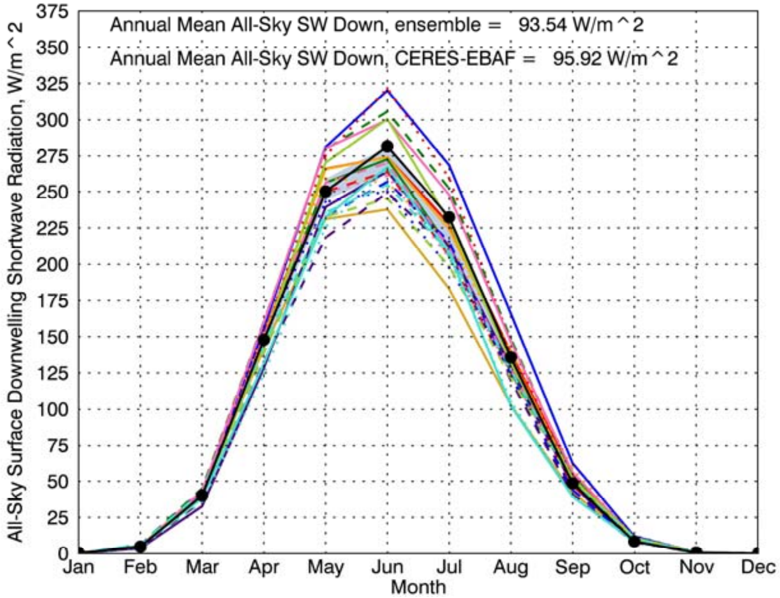
(grey shaded region is the ensemble mean +/- one standard deviation)

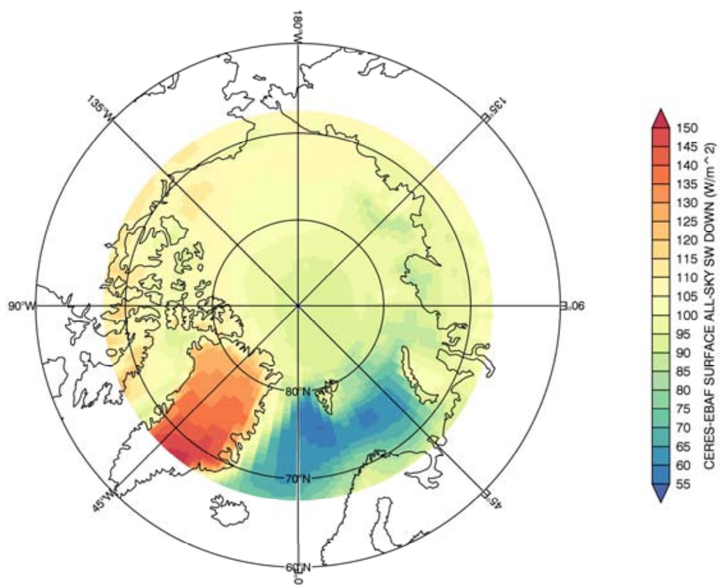
For some models, changes in LW CRE are closely coupled to changes in cloud fraction

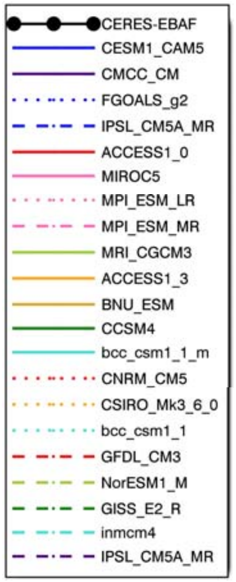


Shortwave Surface Fluxes

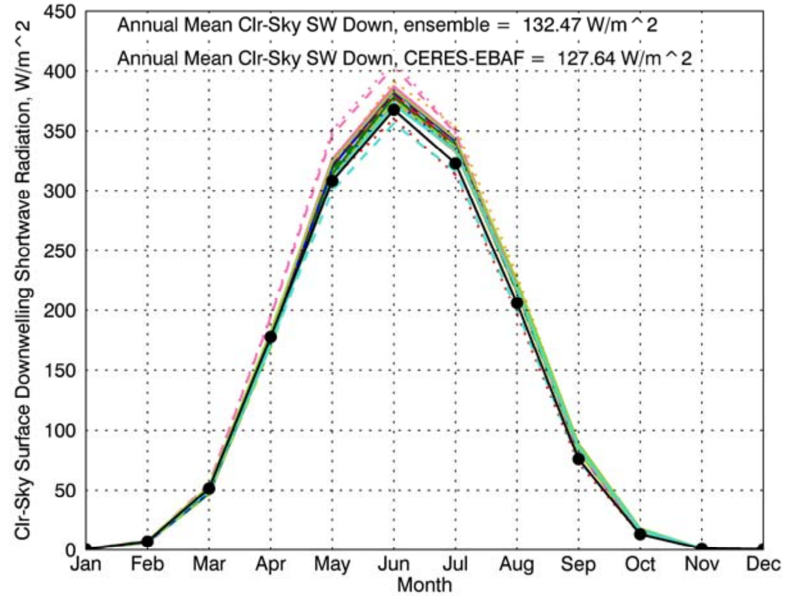
All-Sky

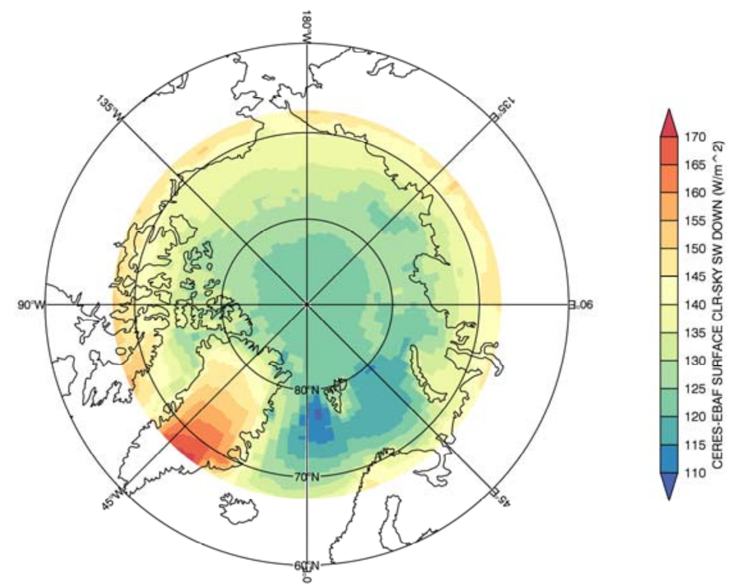




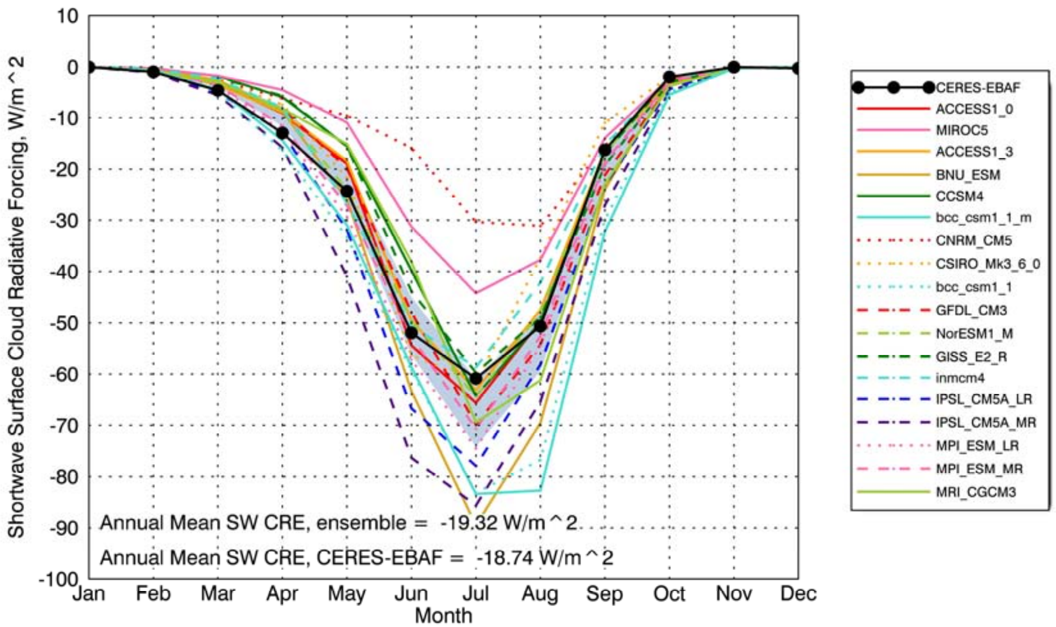


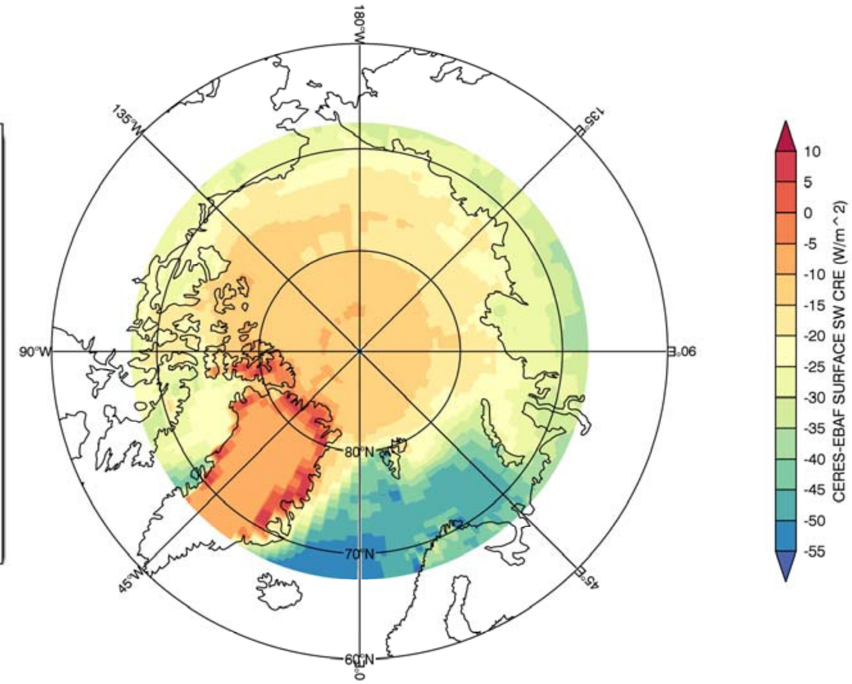
Clr-Sky



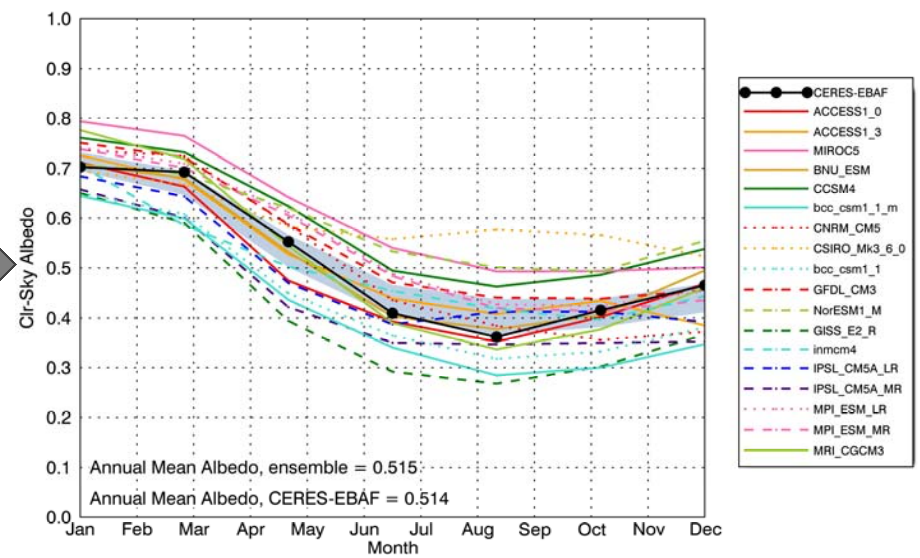


Shortwave Cloud Radiative Effect

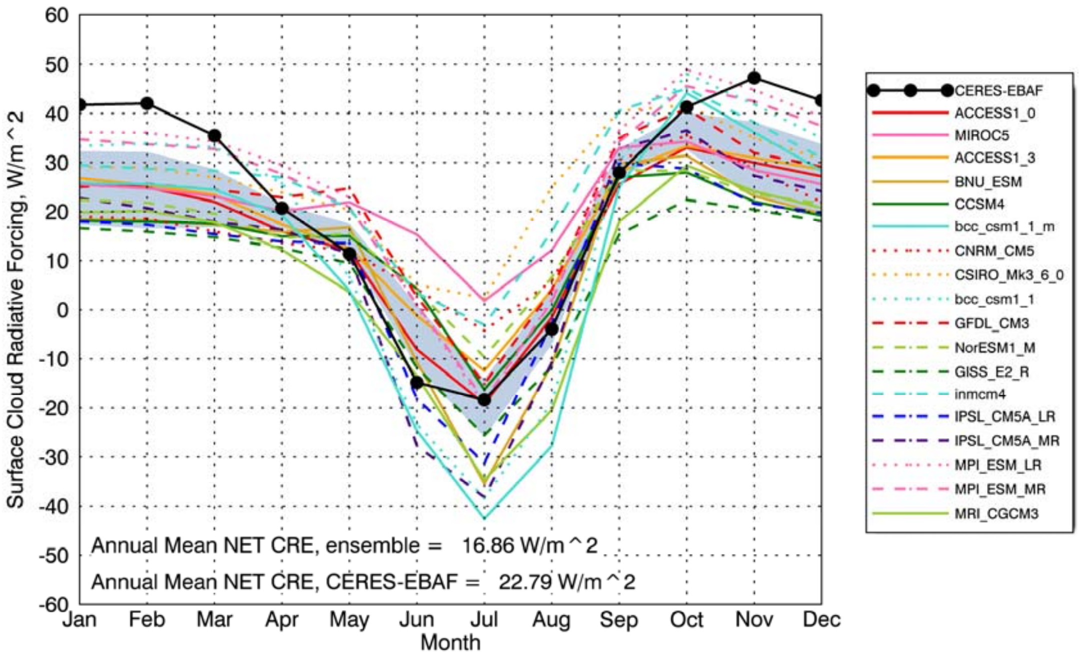


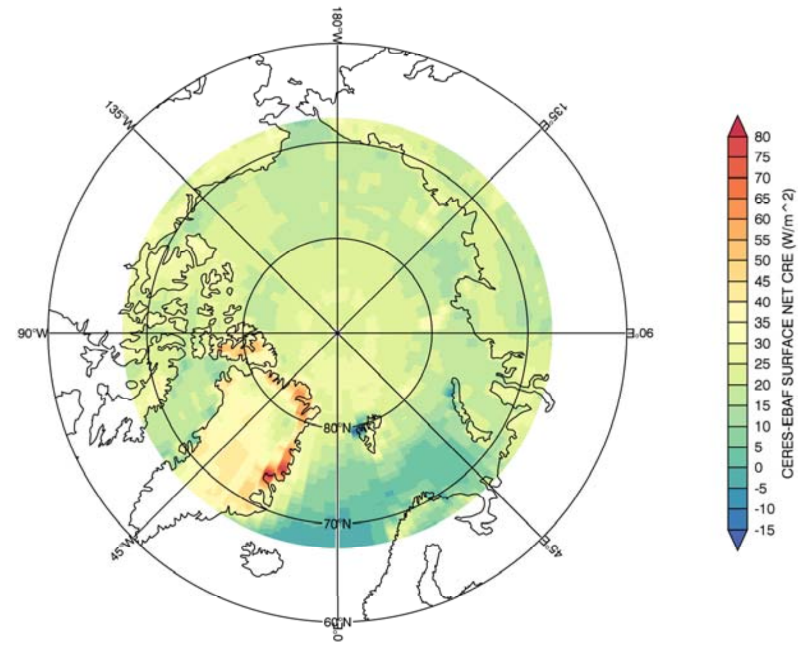


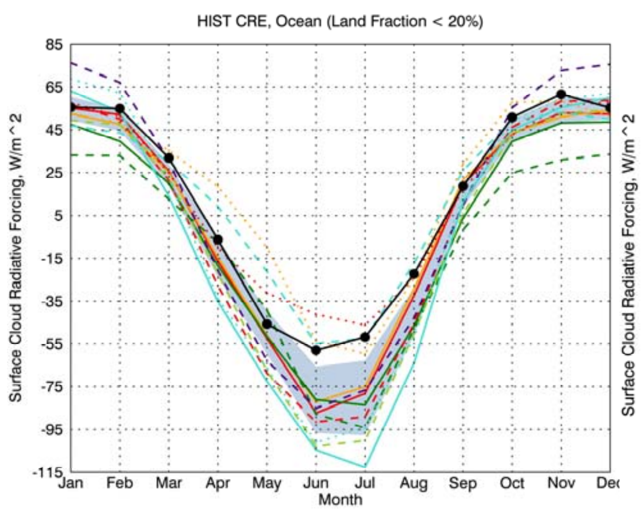
Generally, models with higher surface albedo have a weaker SW CRE and vice versa

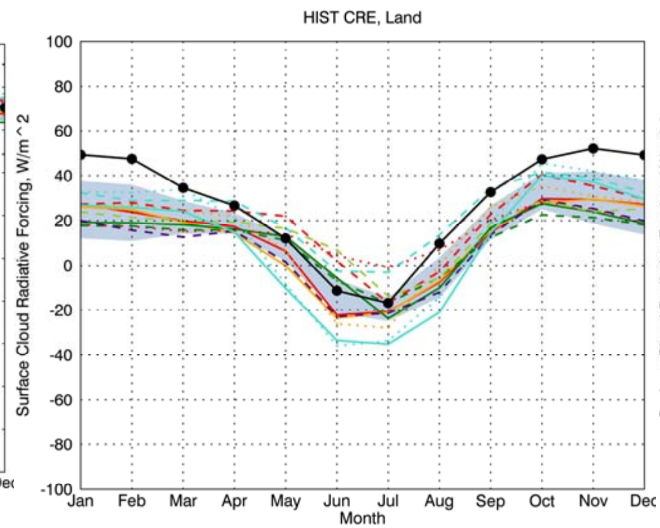


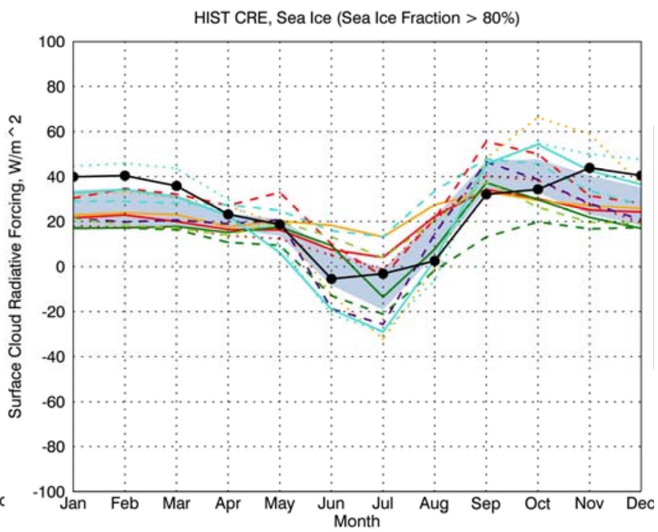
Net Cloud Radiative Effect





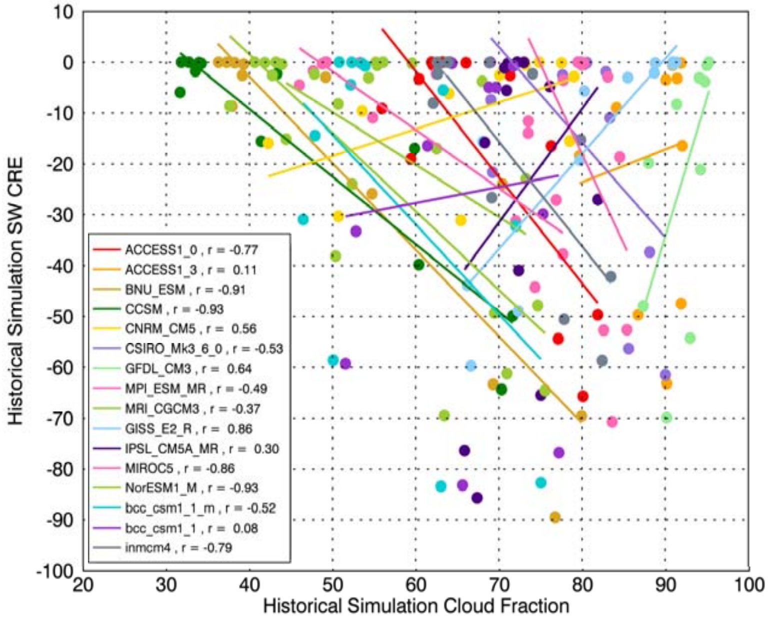




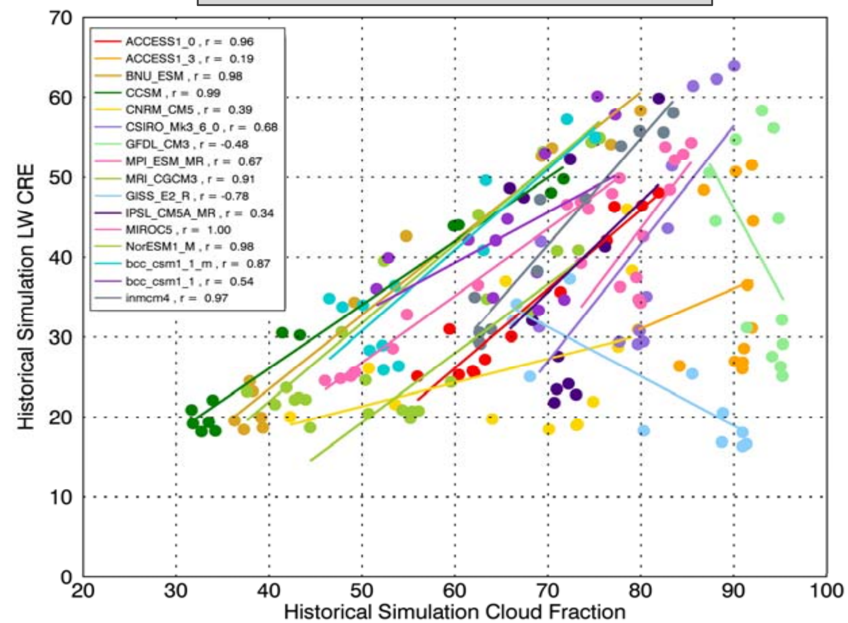


Regressions between cloud fraction and net CRE show whether a model is more strongly forced by a **cloud albedo effect** or a **cloud greenhouse effect**

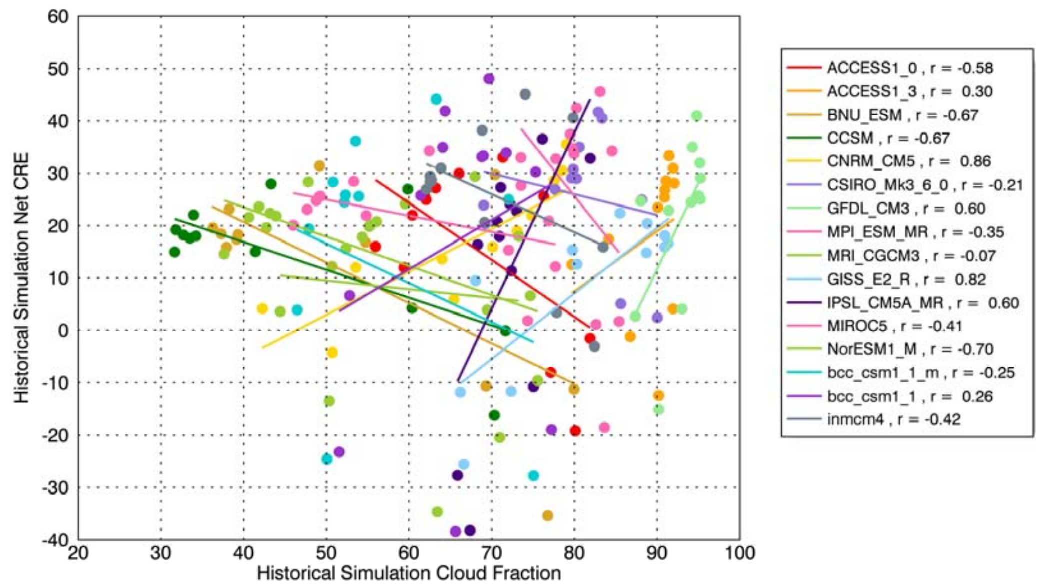
SW CRE vs Cloud Fraction



LW CRE vs Cloud Fraction



Net CRE is the result of adding the longwave and shortwave forcings

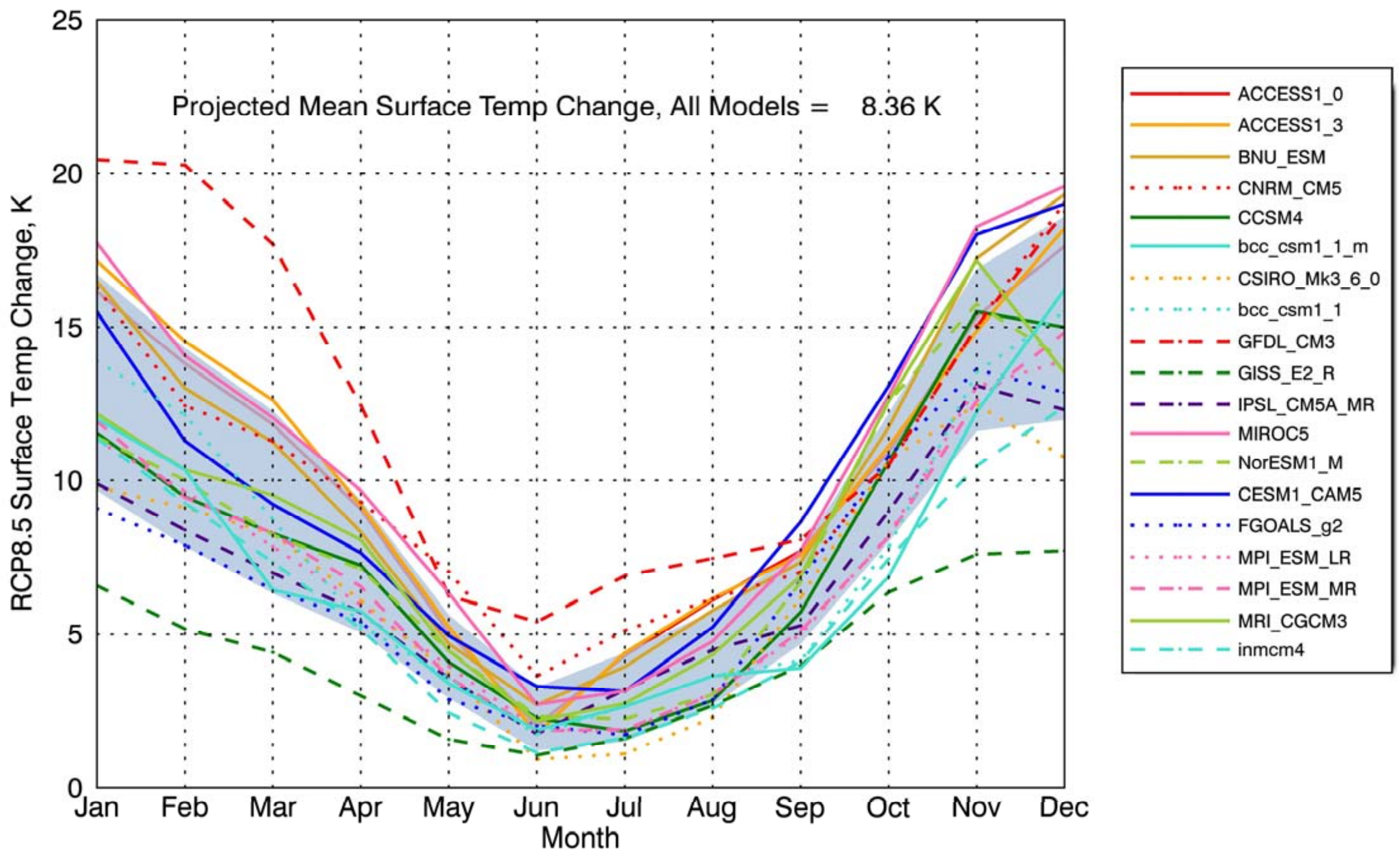


How will Arctic surface temperature change in the future?

Future surface temperature is obtained using the RCP 8.5 simulation (**R**adiative **C**oncentration **P**athway 8.5, a projection dataset with an 8.5 W/m^2 forcing)

RCP 8.5 runs from 2006 to 2100. Temperature change is calculated as follows:

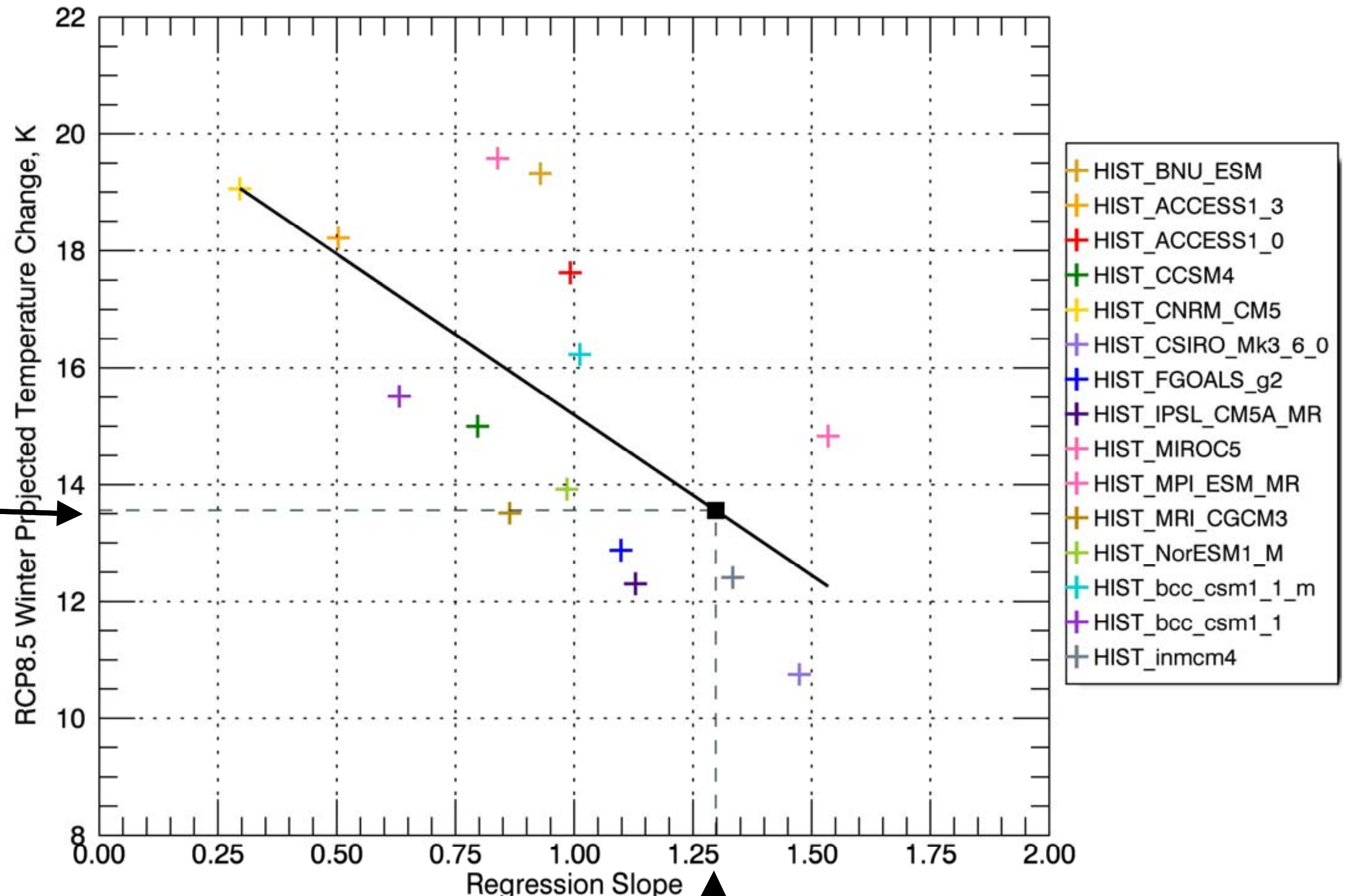
ΔT_{surf} = Mean T_{surf} for the last 20 years of the simulation - Mean T_{surf} for the first 20 years of the simulation



(grey shaded region is the ensemble mean +/- one standard deviation)

The sensitivity of a model to changes in clouds is correlated to projected surface temperature change

The slope of the regression line from the δN vs δLW CRE is compared to projected ΔT_{surf} for CMIP5 models and C3M observations



Using the model line fit and the C3M regression slope, a predicted ΔT_{surf} for observations is ~13.6 K

C3M regression slope

Questions?

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