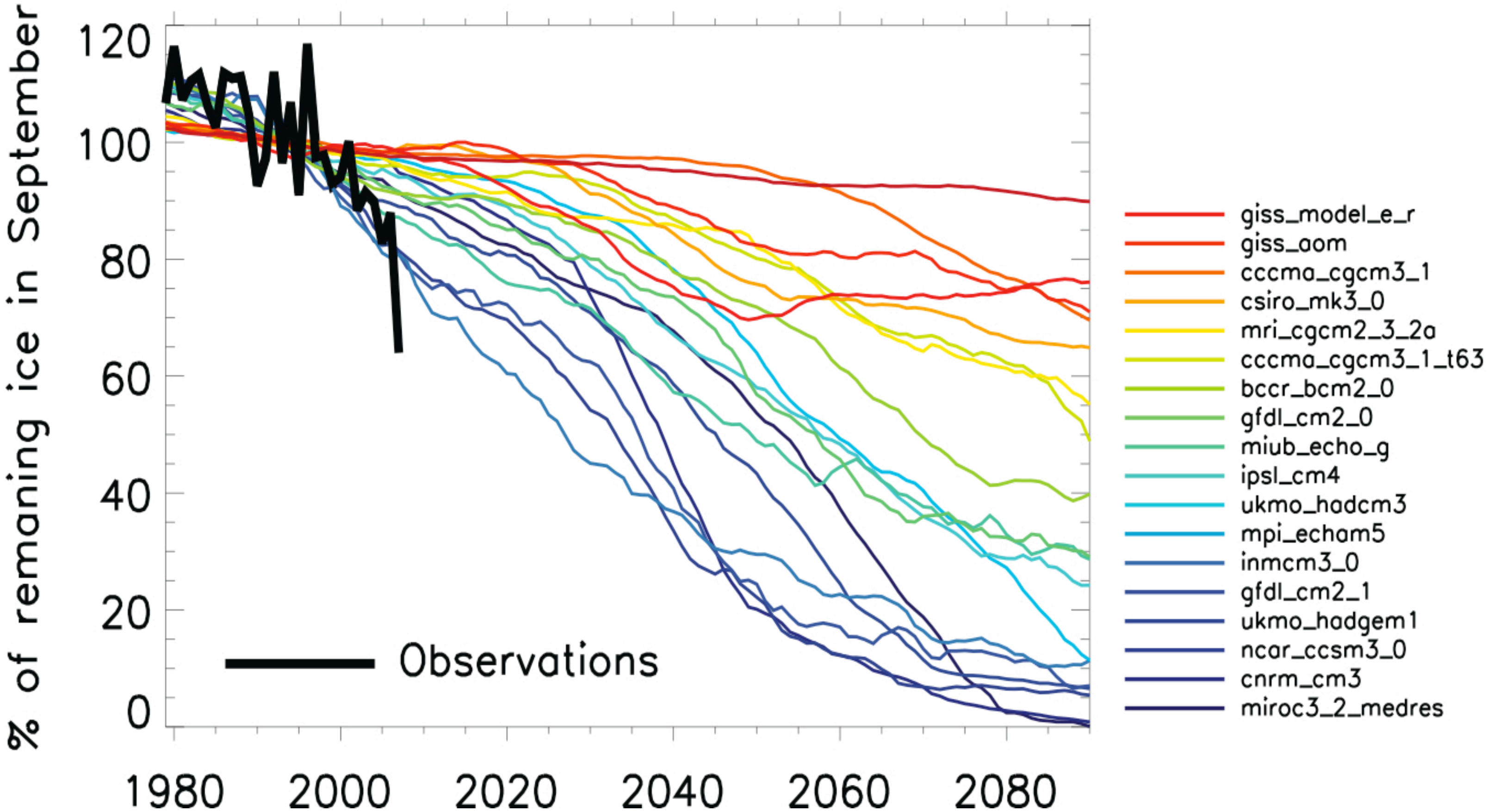
Simulated and Observed Arctic Sea Ice loss

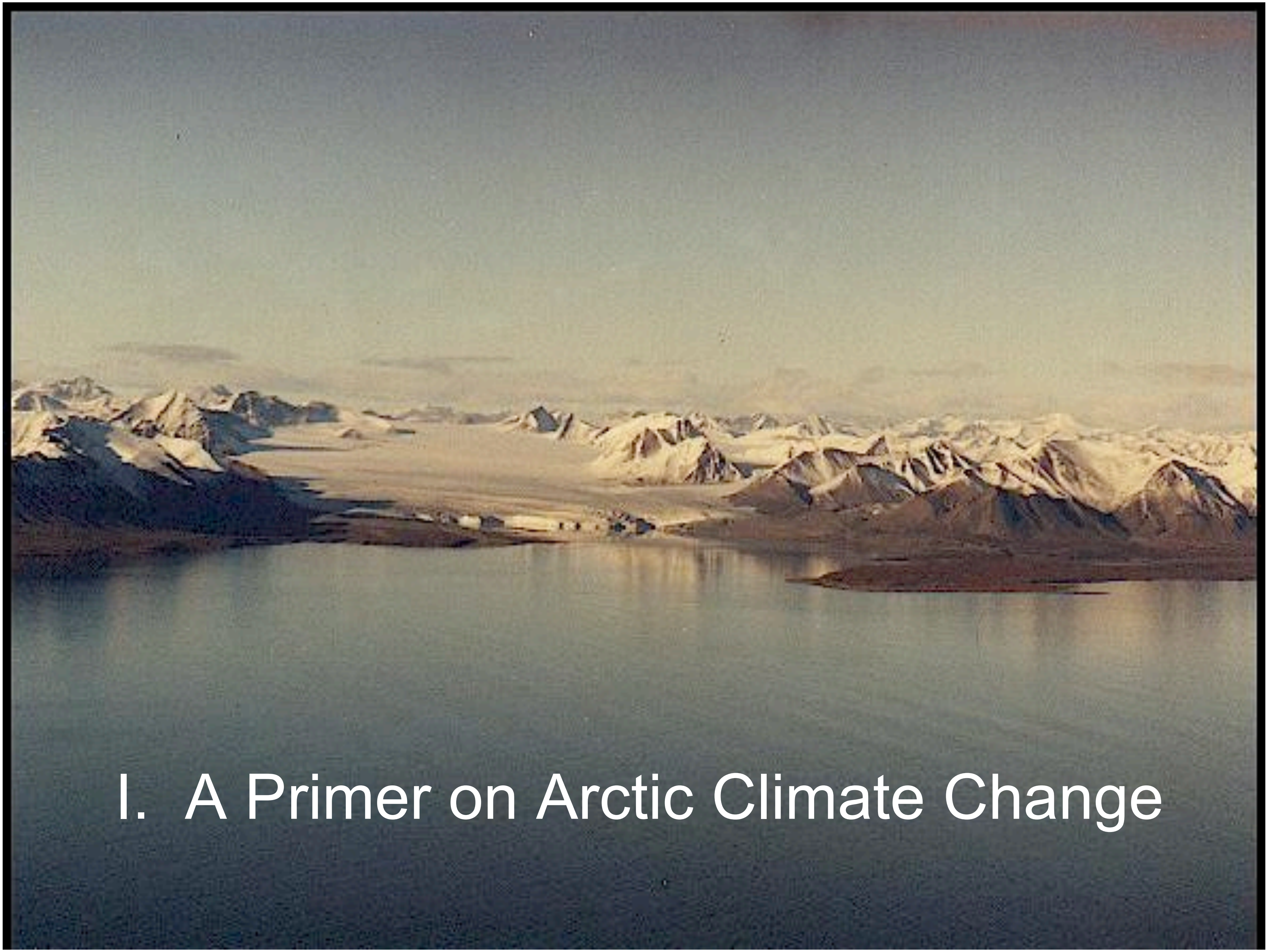


The models exhibit an enormous degree of spread, and generally undersimulate the observed sea ice loss over the past few decades.

(Stroeve et al. 2007)

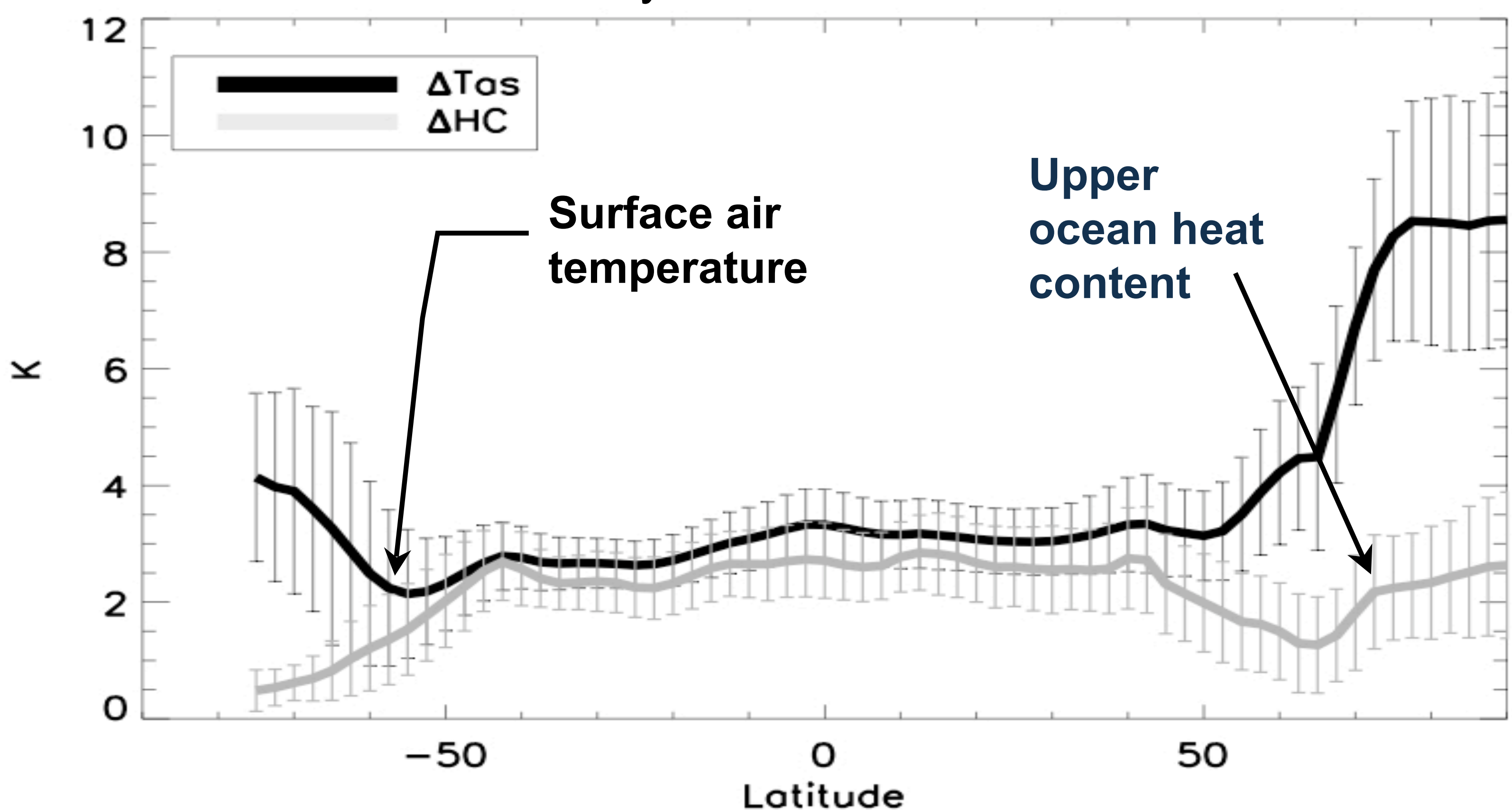
A word about the simulations examined here:

The IPCC AR4 models are forced by the SRESA1B scenario, for which the CO_2 concentration stabilizes at 720 ppm in 2100. The period used to compute the climatological anomalies is 2150-2199. Reference climatological means are computed over the 1900-1949 period.


I. A Primer on Arctic Climate Change

Zonal–mean warming in current climate models by the end of the 22nd century

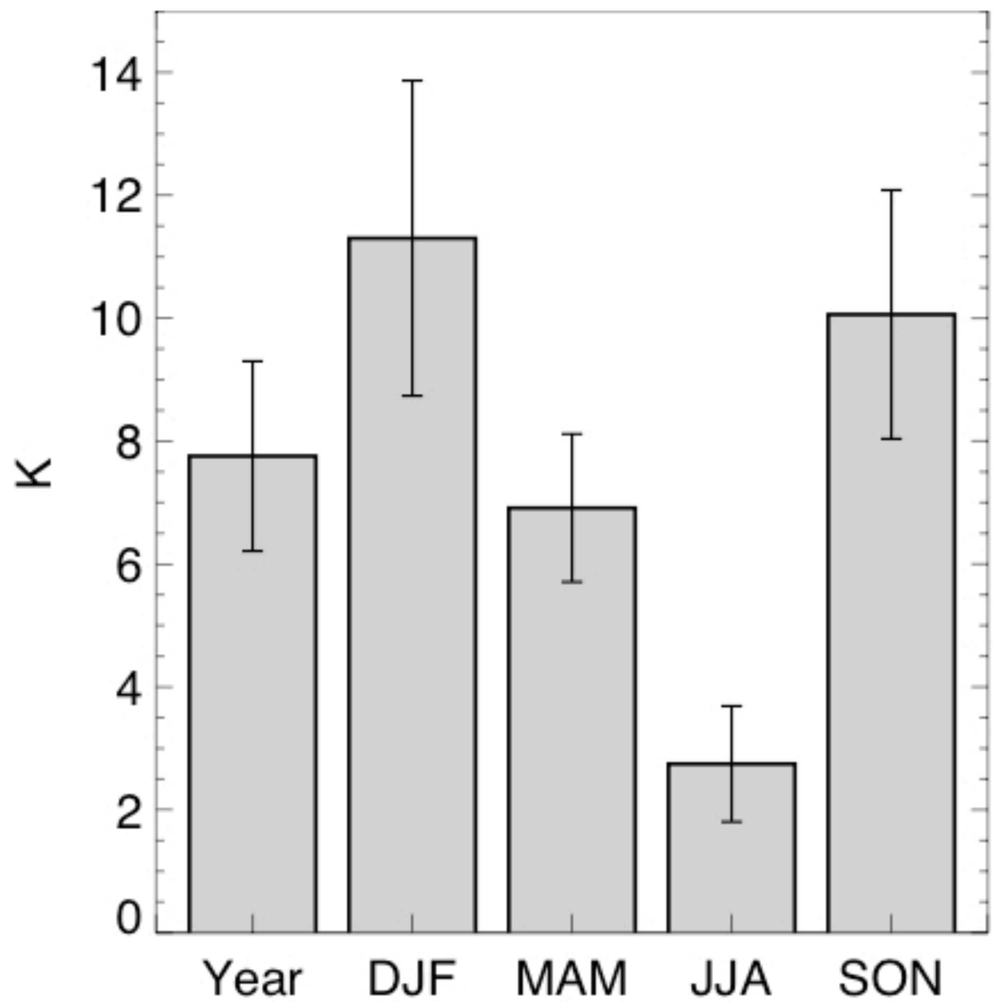
Lines are ensemble means, brackets denote intermodel spread, as measured by +/- one standard deviation .



The "polar amplification" seen in the surface air temperature increase is not seen in the ocean heat content increase.

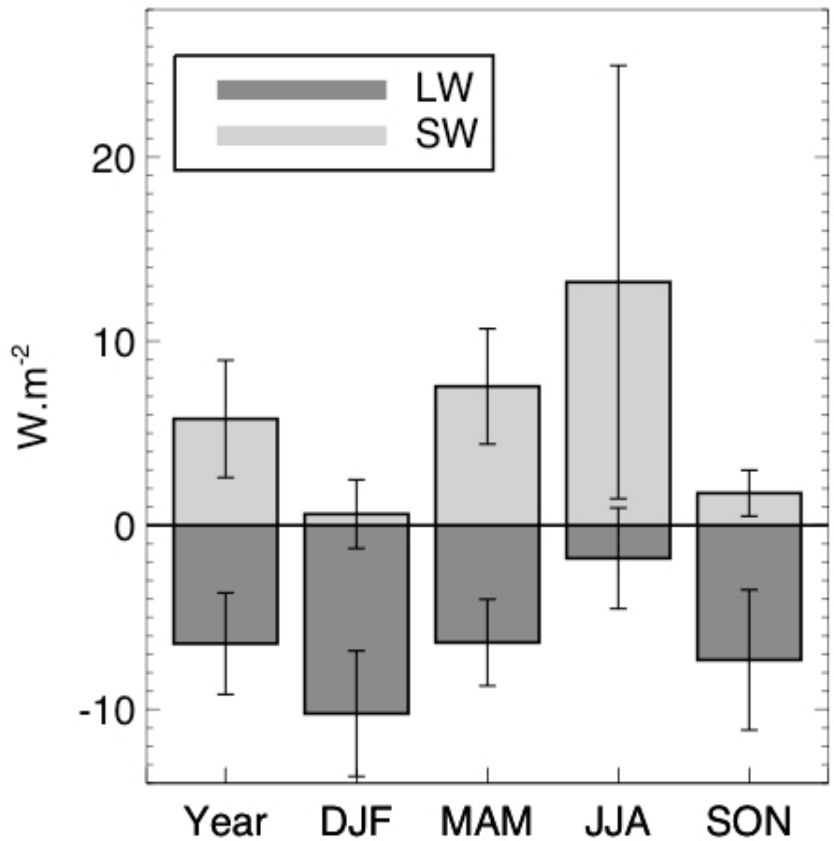
Surface Air Temperature Increase

The ensemble- mean surface air temperature increase is greatest in fall and winter, when thinning sea ice leads to larger heat transfer from the ocean to the atmosphere. In this sense, the surface warming can be seen as a passive response to thinning sea ice, rather than the most representative feature of a warming climate.

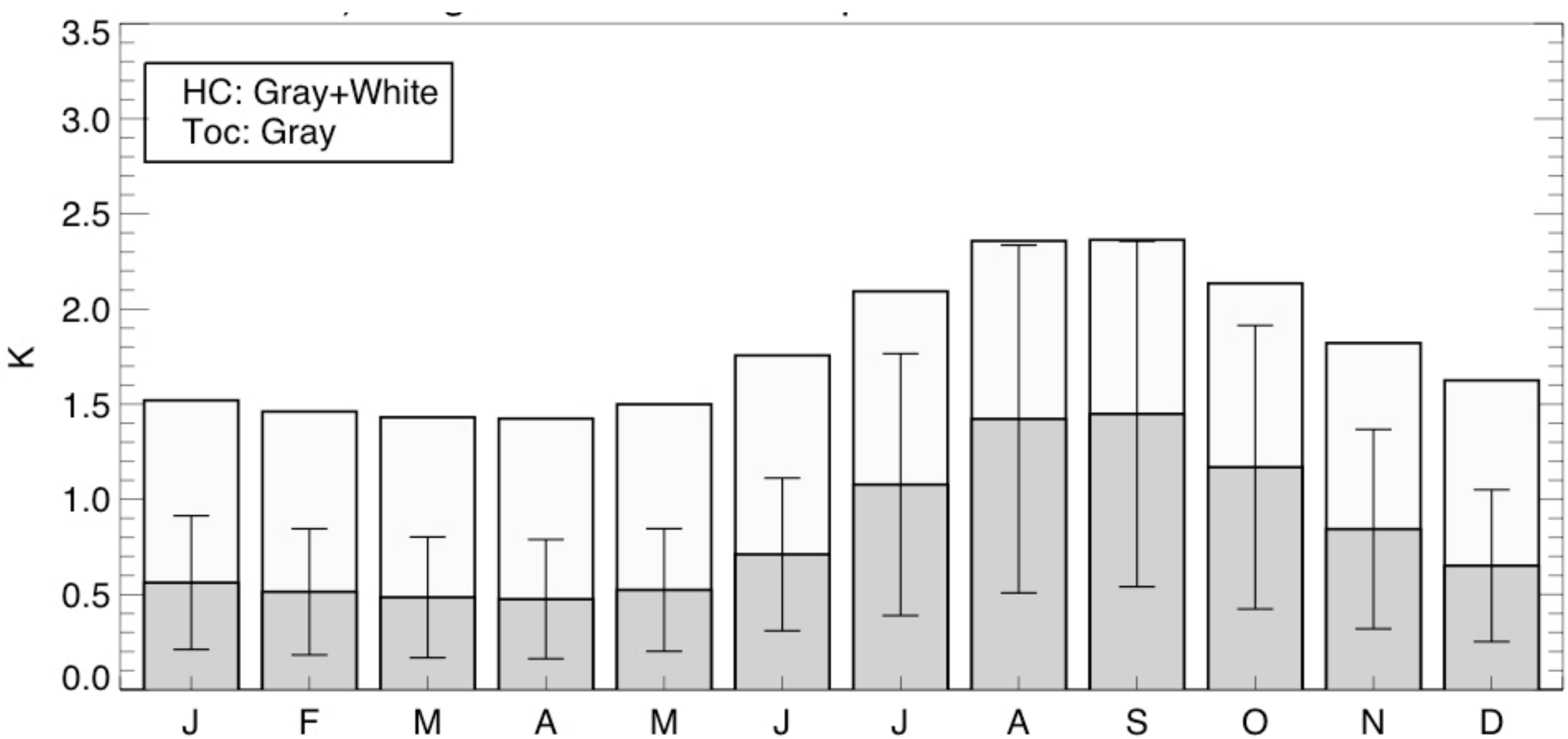


Change in Energy Budget at Top of Atmosphere

Longwave feedbacks play a large role in Arctic climate change, and dominate in fall and winter.



Integrated Upper Oceanic Temperature and Heat Content



The heat content increase is greatest in summer, the time of year when positive feedbacks are greatest.

II. Controls on Arctic Climate Sensitivity

Definition of feedback parameters…

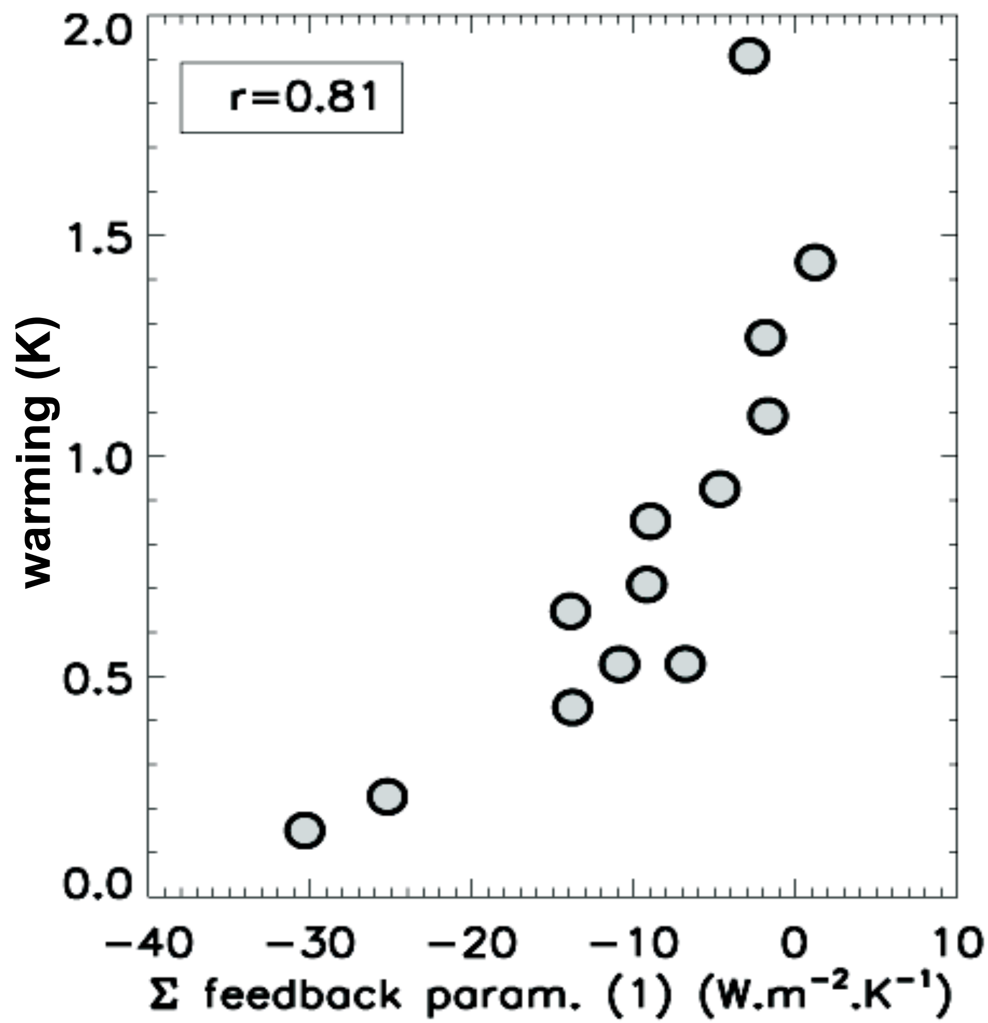
…must instead take into account the peculiarities of Arctic climate change.

We define the climate sensitivity in terms of upper ocean heat content, ΔT_{OC}, and fluxes are averaged over the Arctic region.

$$\lambda_{LW} = \frac{\Delta F}{\Delta T_{OC}} \qquad \lambda_{SW} = \frac{\Delta Q}{\Delta T_{OC}}$$

$$\lambda = \lambda_{LW} + \lambda_{SW}$$

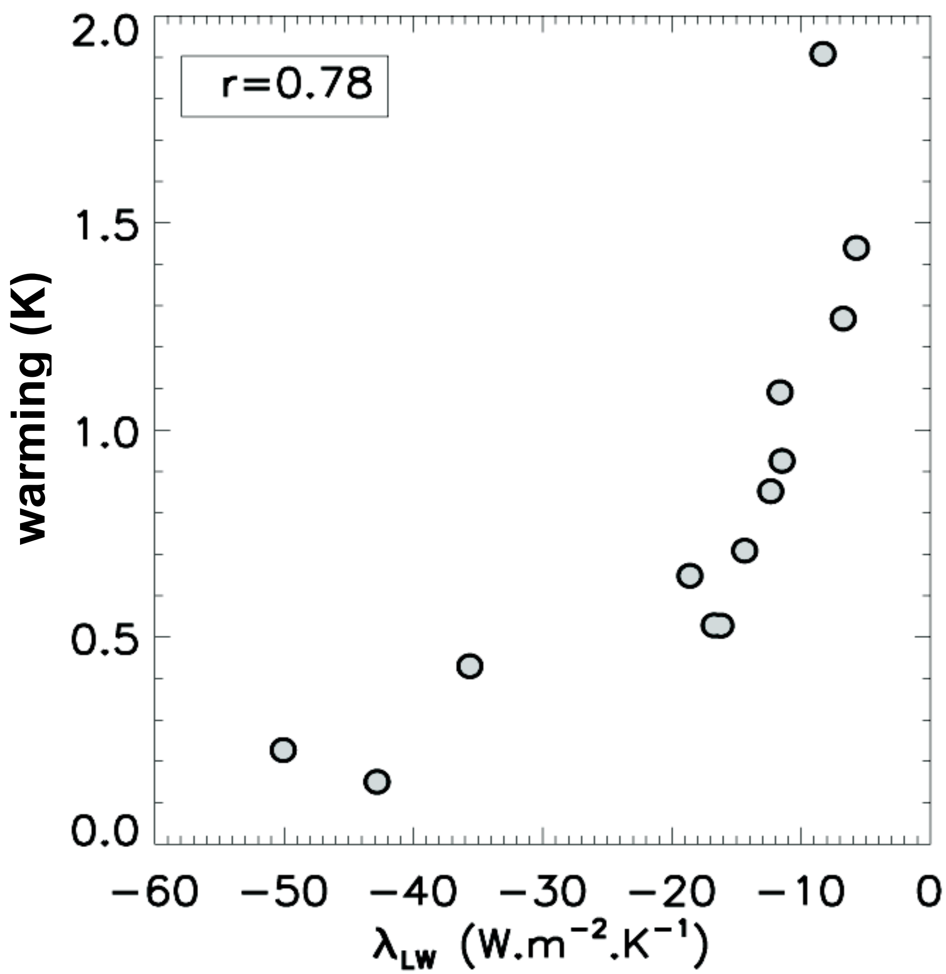
Predictive skill of Arctic-specific λ



Regionally-defined radiative feedbacks based on ΔT_{oc} account for the spread in the Arctic's quasi-equilibrium climate response to external forcing. The remaining spread is likely due to variations in heat transport into the Arctic.

(Boé et al. 2009a)

Negative longwave feedback, which has greatest strength in winter, is primarily responsible for the spread in warming.

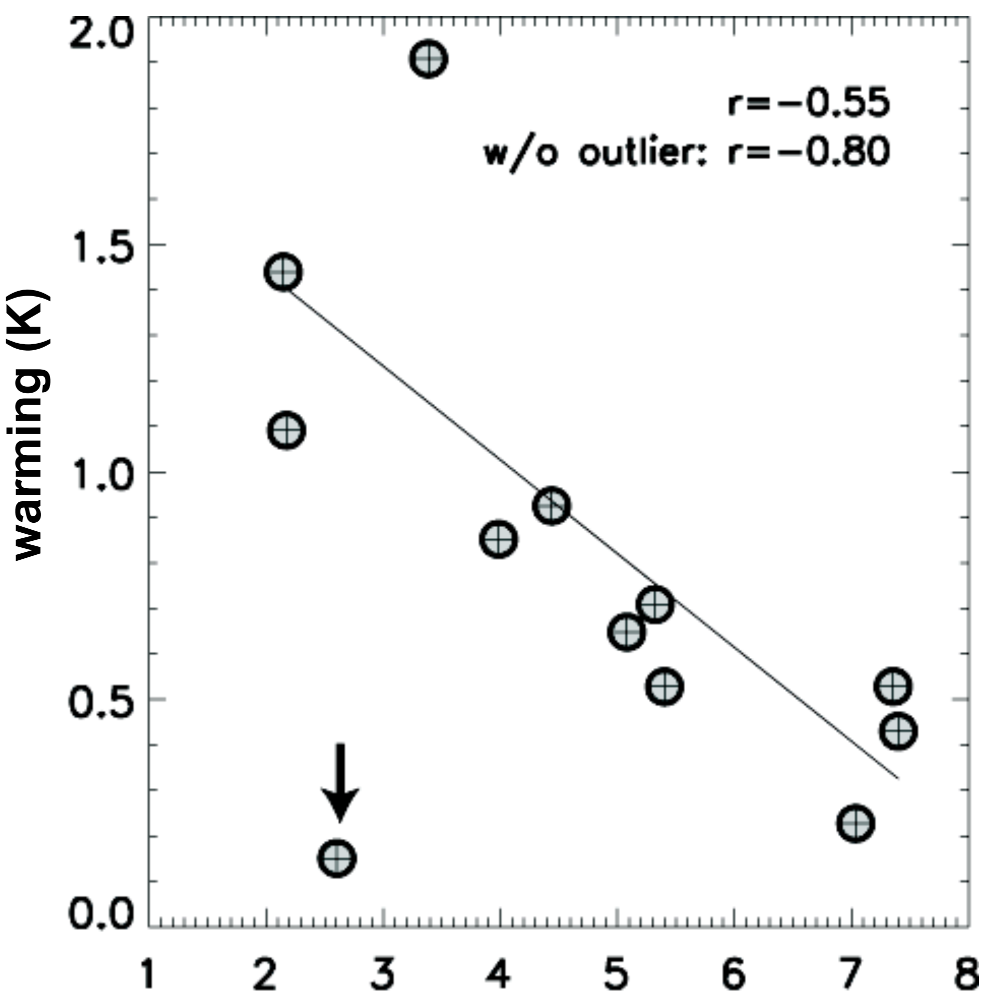


Though shortwave feedbacks are positive in all models, they exhibit less intermodel variability, and are generally smaller in magnitude than their longwave counterparts.

Surprisingly, almost all the intermodel variation in the longwave feedback arises from the clear-sky component (not shown).

(Boé et al. 2009a)

Inversion Strength and Climate response

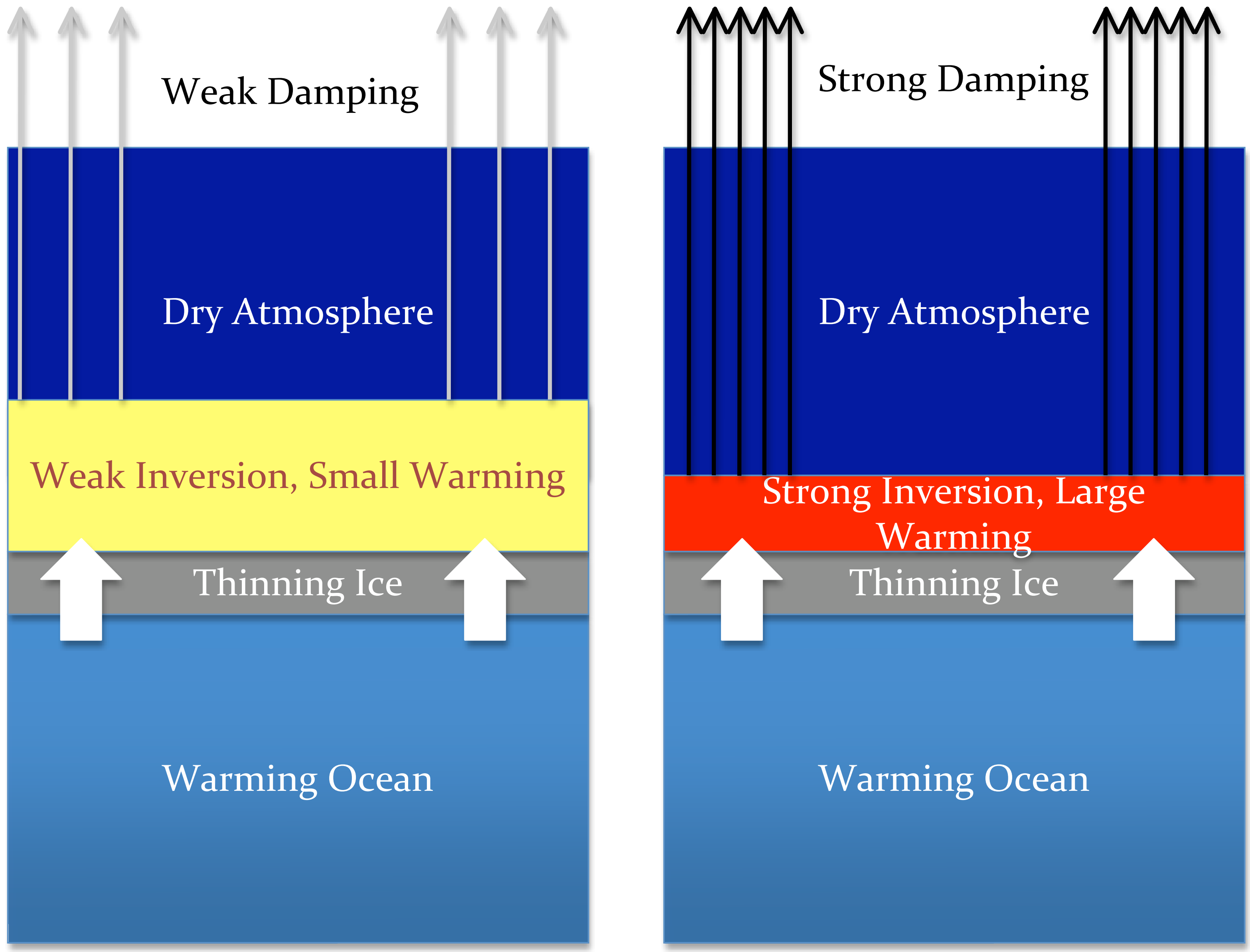


winter inversion strength (diff between T at 850 hPa and surface)

The climatological strength of the winter atmospheric temperature inversion controls longwave feedback, and climate response

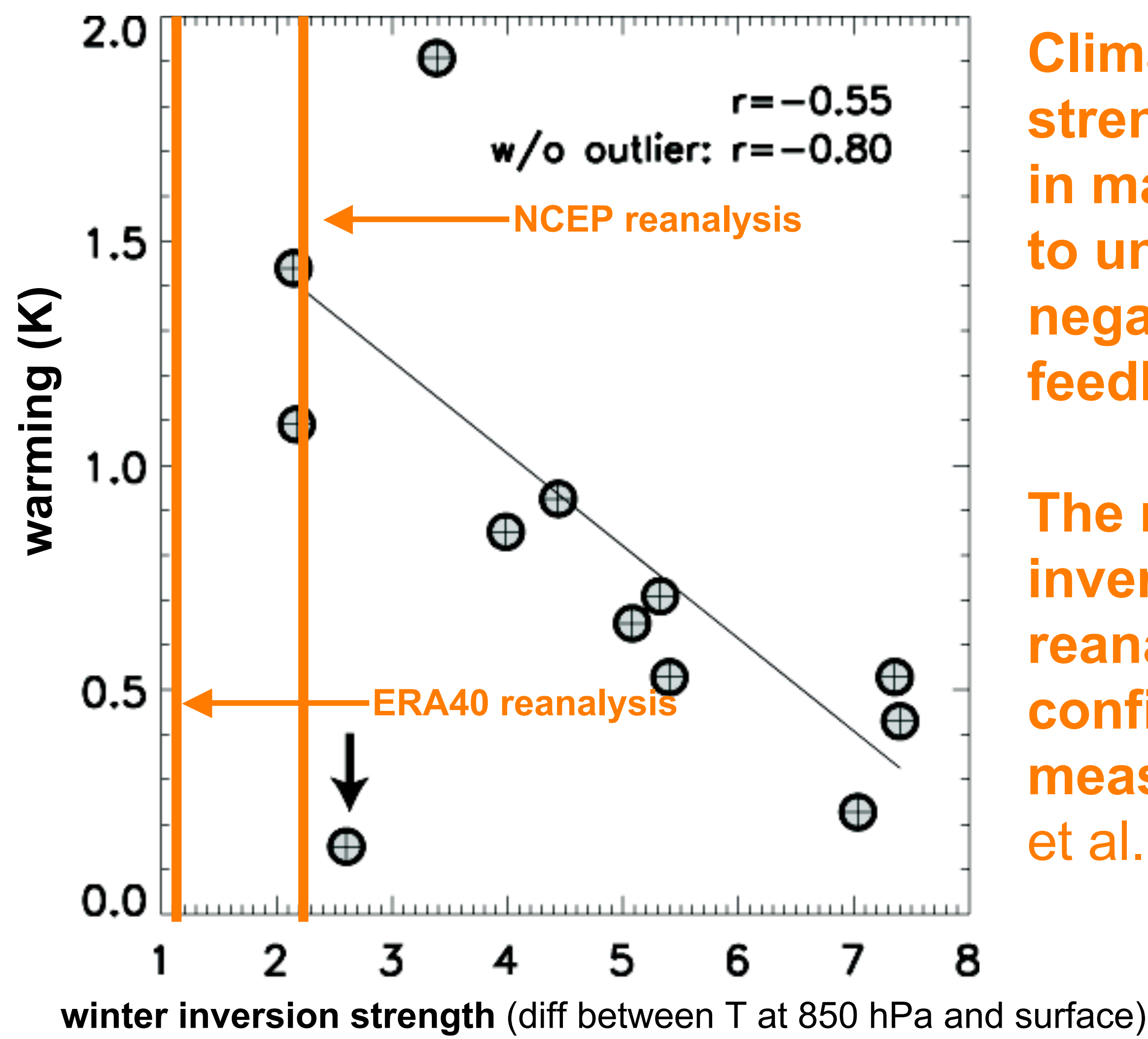
The greater the winter inversion strength, the larger the near-surface temperature increase for the same increase in surface fluxes through thinning sea ice. This results in a larger emission of longwave radiation to space. The large loss of energy in winter means less overall warming on an annual-mean basis

(Boé et al. 2009a)



WEAK INVERSION CASE **STRONG INVERSION CASE**

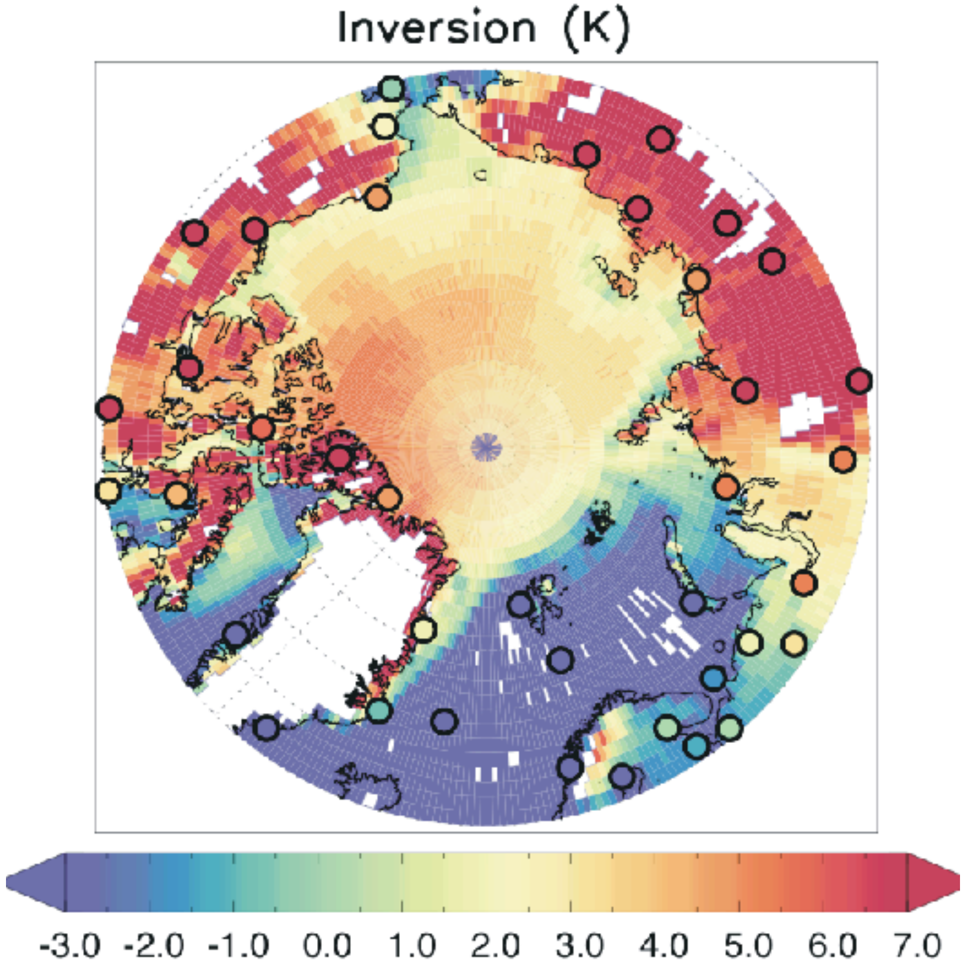
Inversion Strength and Climate response



Climatological inversion strength may be too large in many models, leading to unrealistically large negative longwave feedback.

The relatively low inversion strength in the reanalyses can be confirmed by satellite measurements. (Pavelsky et al. 2009)

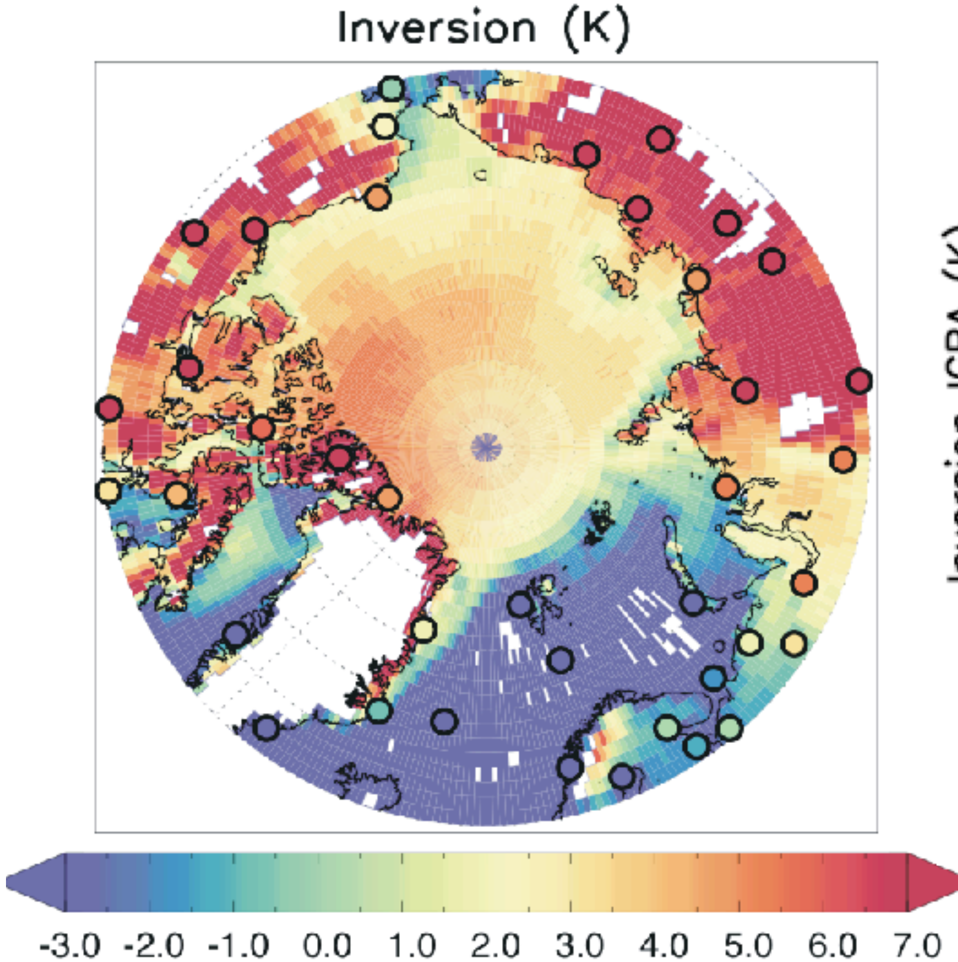
(Boé et al. 2009a)

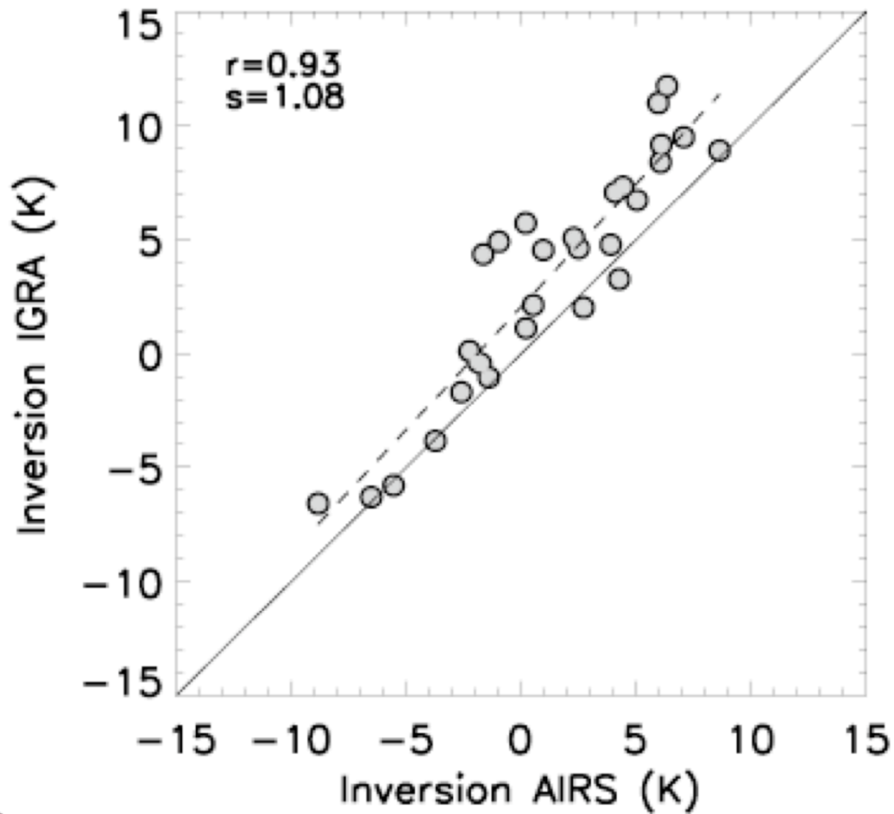


The Arctic Ocean area is not nearly as stratified in wintertime as the surrounding permafrost-covered land areas. The inversion strength is closely linked to sea ice concentration, being stronger where sea ice concentration is higher.

Mean DJF AIRS inversion strength from December 2002- February 2008, with mean DJF inversion strength from radiosondes over the same period superimposed.

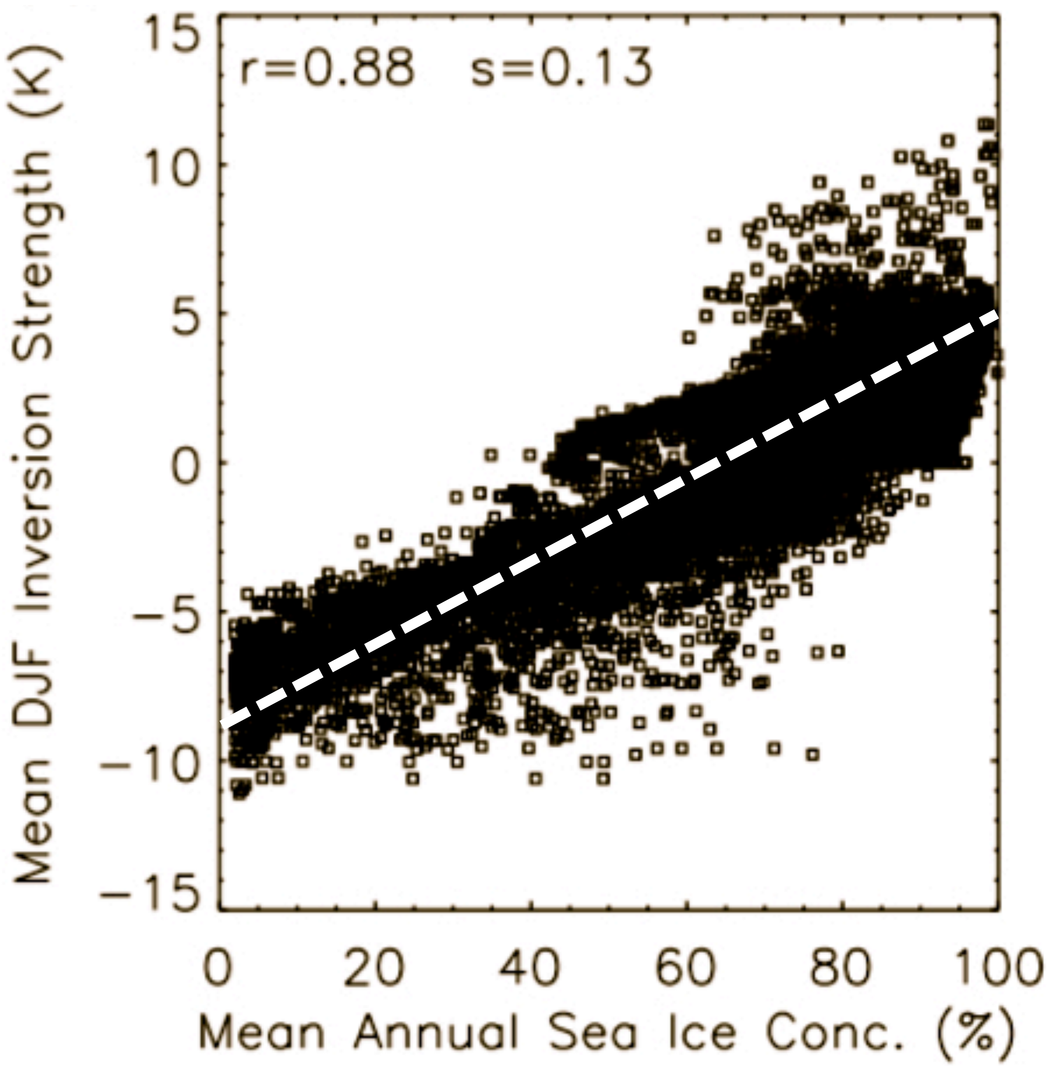
(Pavelsky et al. 2009)





A scatterplot of the mean DJF inversion strength from AIRS against that calculated from radiosondes demonstrates that AIRS is accurately measuring inversion strength in polar regions.

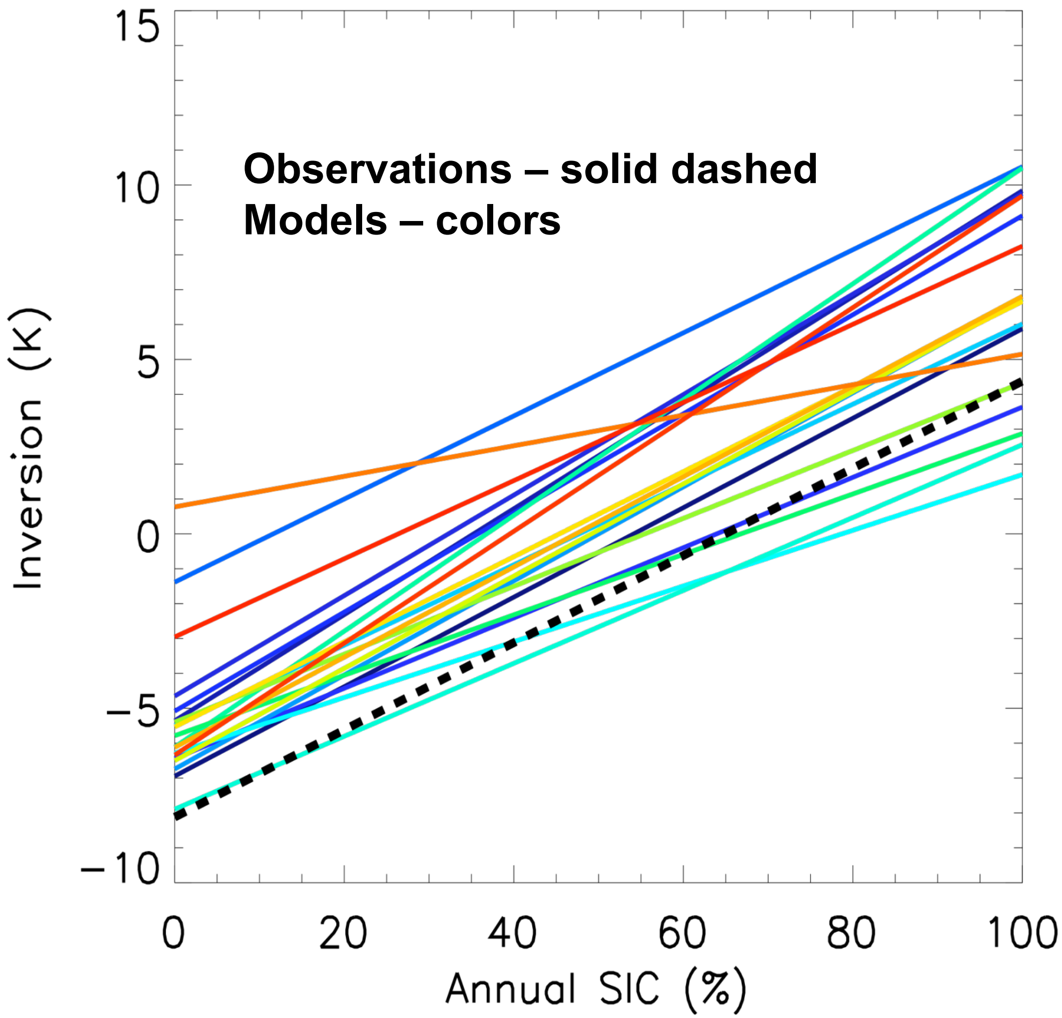
Observed Controls on Inversion Strength



The inversion strength is closely linked to sea ice concentration, increasing roughly linearly with sea ice concentration.

Pavelsky et al. 2009

Comparison to the AR4 models

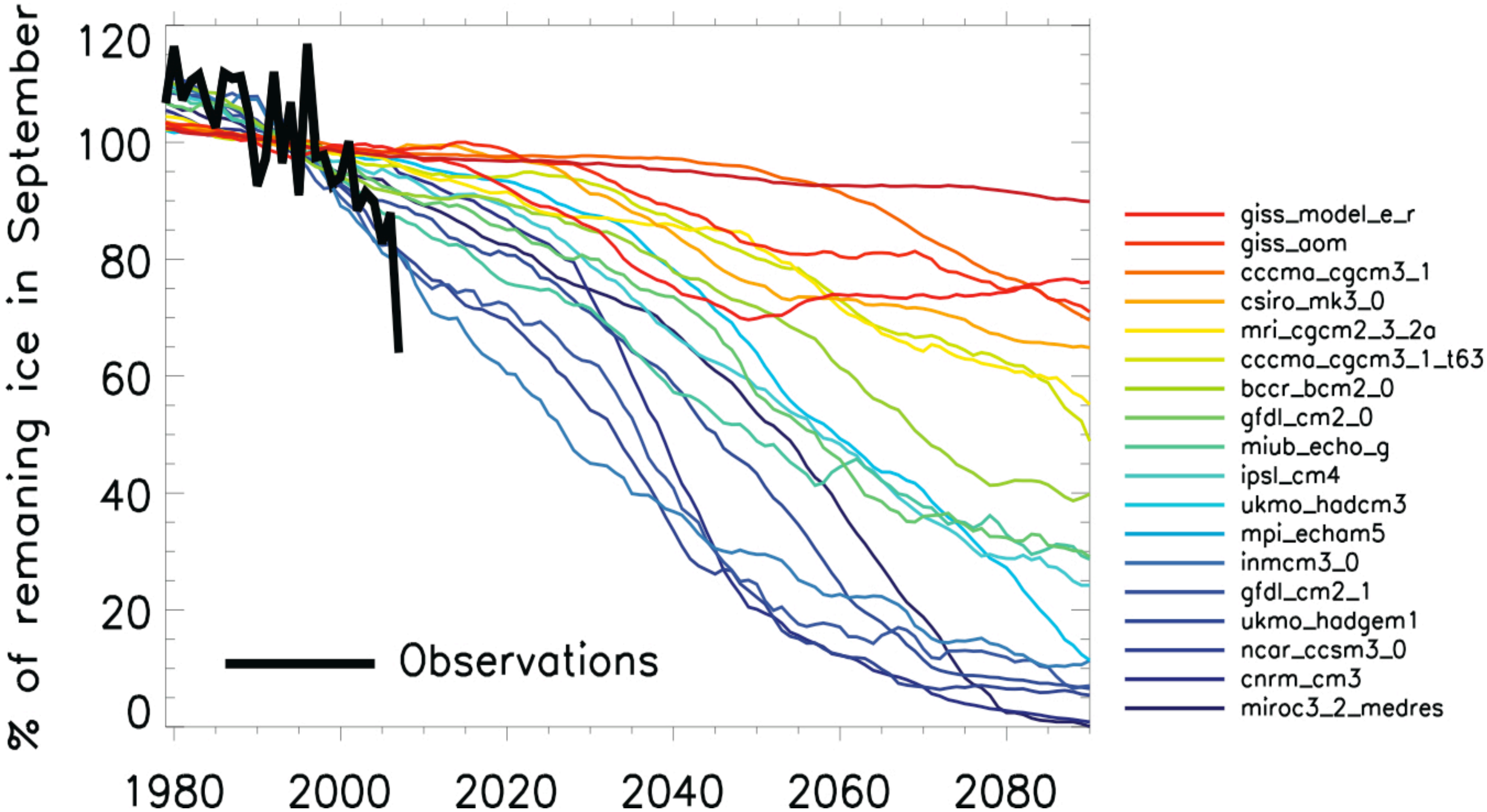


The models generally have the correct inversion strength increase per unit change in sea ice concentration. However, the model lines are generally shifted upwards compared to observations, i.e. the intercept is too high.

So in general, the models are systematically too stratified compared to observations.

III. Controls on Transient Arctic Climate Change

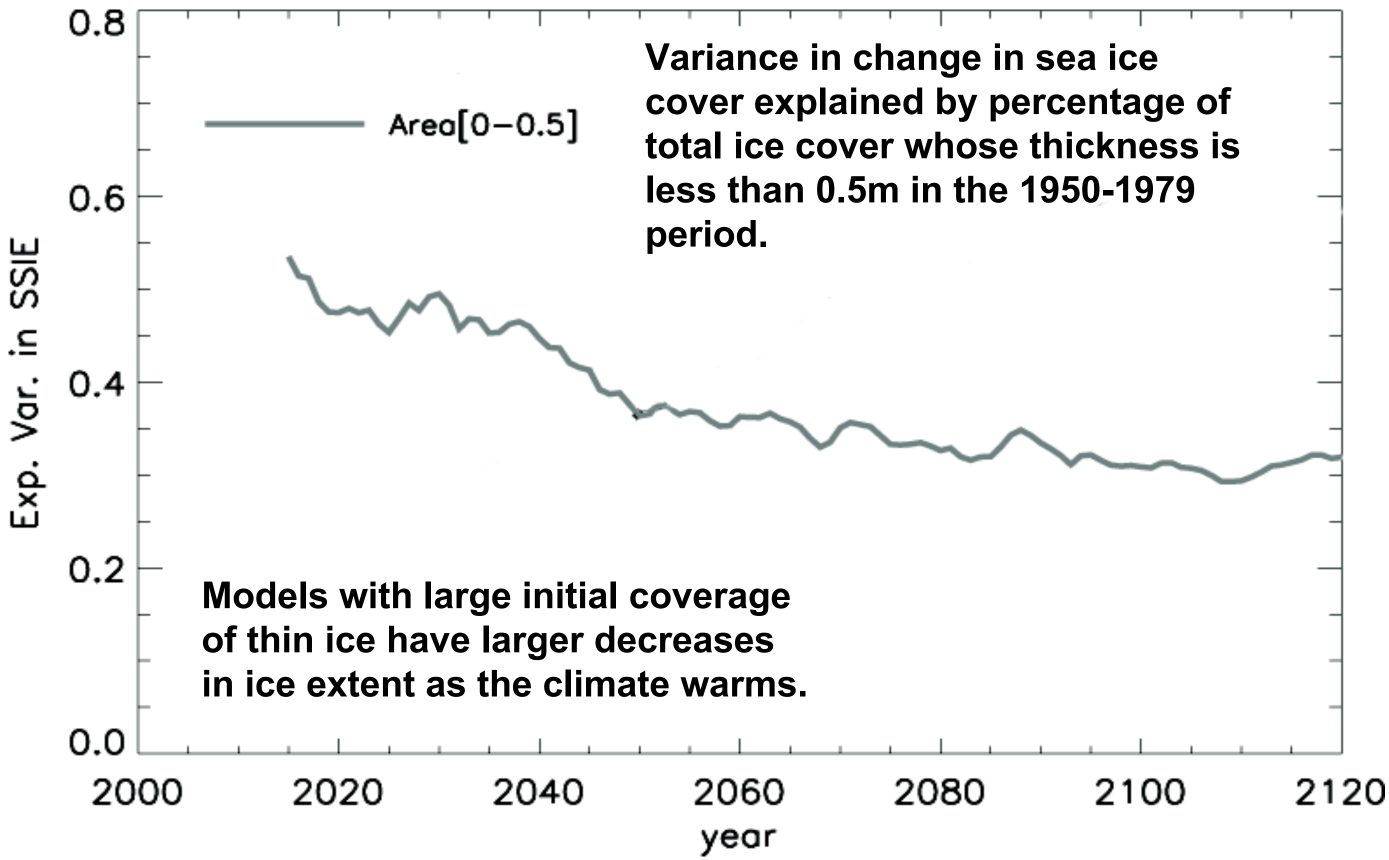
Simulated and Observed Arctic Sea Ice loss



The models generally undersimulate the observed sea ice loss over the past few decades.

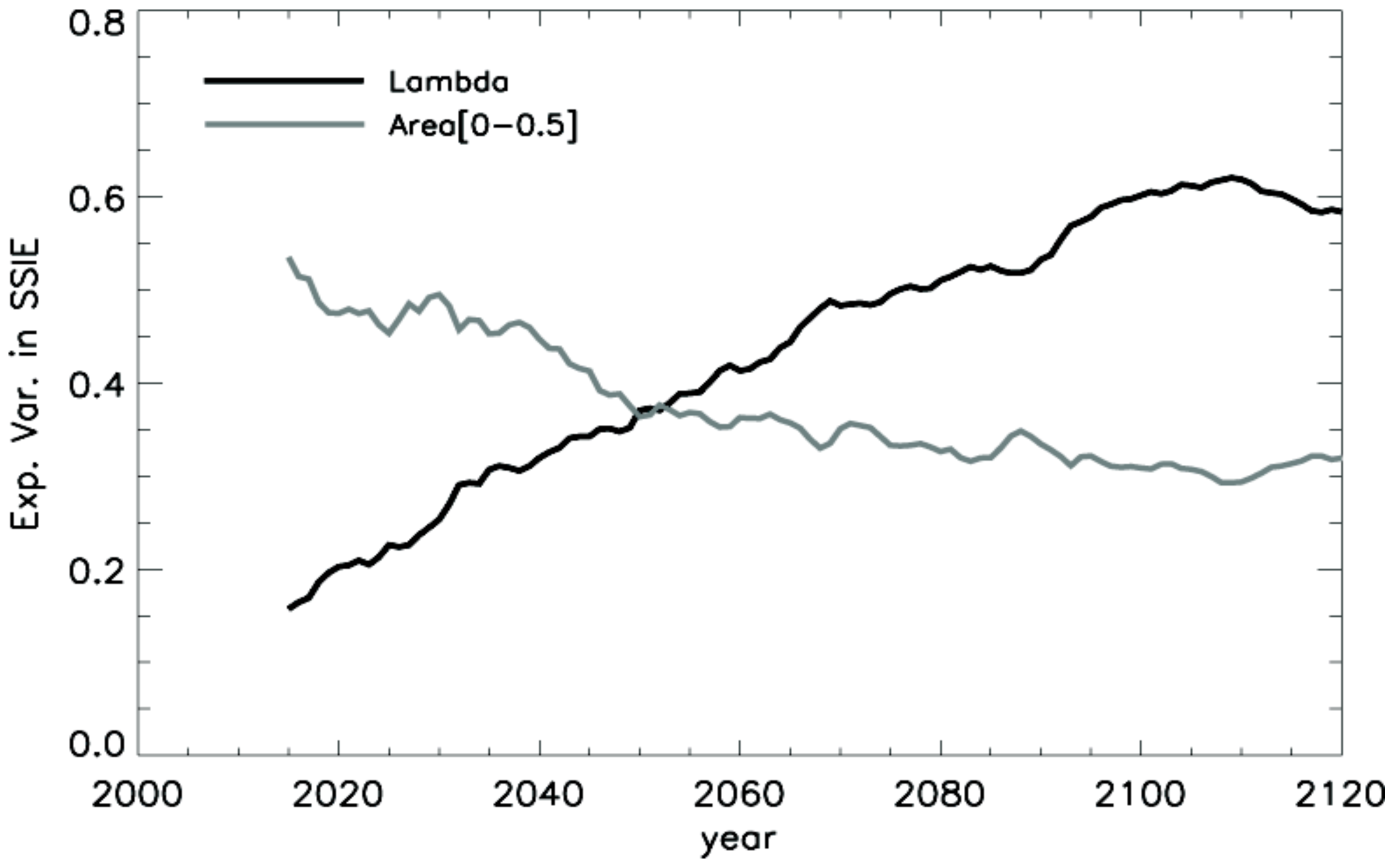
(Stroeve et al. 2007)

(Boé et al. 2009b)



Intermodel variations in sea ice cover loss are well-correlated with late 20th century variations in the climatological extent of thin ice. This is particularly true *early in the 21st century*.

(Boé et al. 2009b)



However, by the late 21st century and into the 22nd century, the sea ice loss is controlled mostly by the Arctic's radiative feedbacks. Throughout the 21st century, the intermodel variability in Arctic ice loss can be explained by just two factors, both of which may be constrained.

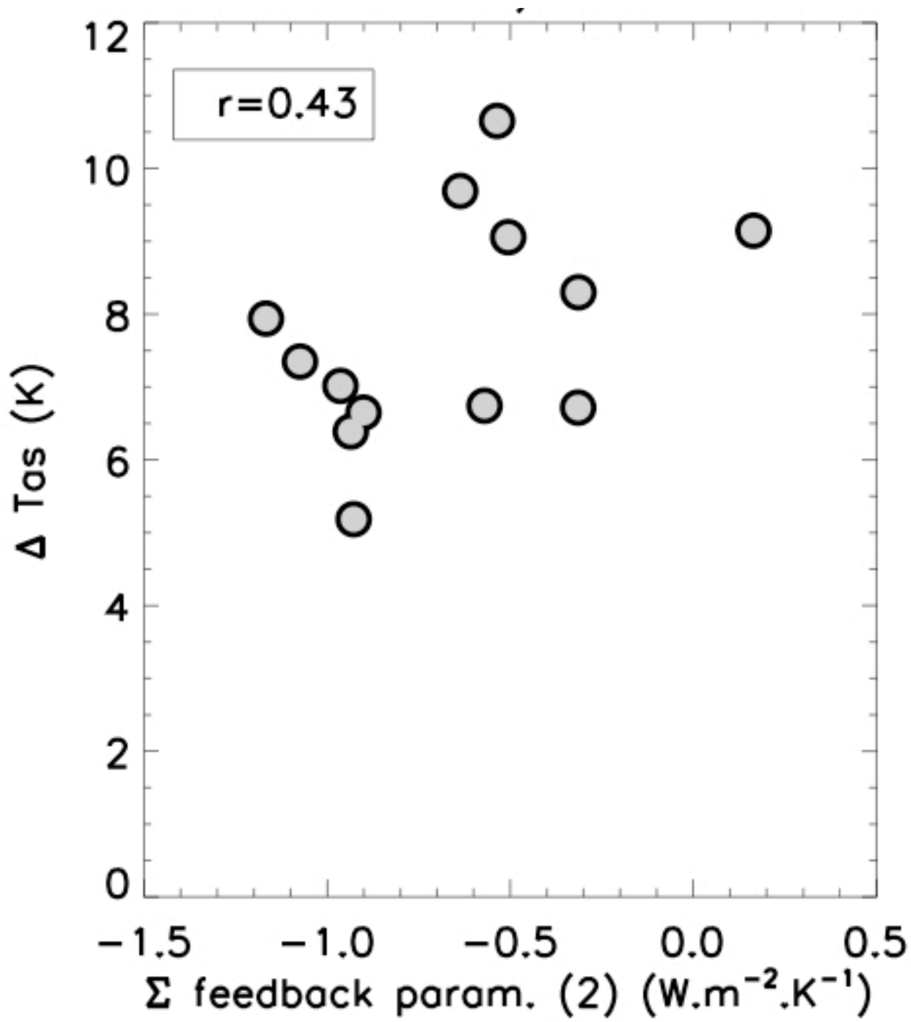
Conclusions

● Intermodel variation in Arctic climate response is controlled mainly by the strength of the wintertime temperature inversion.

● The temperature inversion is unrealistically strong in most models, indicating the models generally have excessive negative longwave feedback.

● Initial ice thickness distribution is the main control on sea ice loss for the first half of the 21st century. Subsequently, the Arctic climate feedback parameter is the main control on ice loss.

To the extent the simulated response to climate change can be related to observable aspects of the current climate, model validation should focus on those aspects.



If we use the conventional ΔT_a to define λ, we end up with a feedback parameter that is not predictive of Arctic climate change