

Identifying Uncertainties in Arctic Climate Predictions

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Motivation

- ① Many previous studies examining range of uncertainties in Arctic climate predictions from a variety of perspectives.
- ① Produce a summary of current knowledge of Uncertainty in Arctic climate predictions and a consistent analysis of model uncertainties
- ① Available as a final report mid October.

Outline

- ① Arctic Climate Processes
- ② Sources of uncertainty in climate model projections.
- ③ Quantifying model uncertainty.
- ④ Conclusions & Summary

Arctic Processes

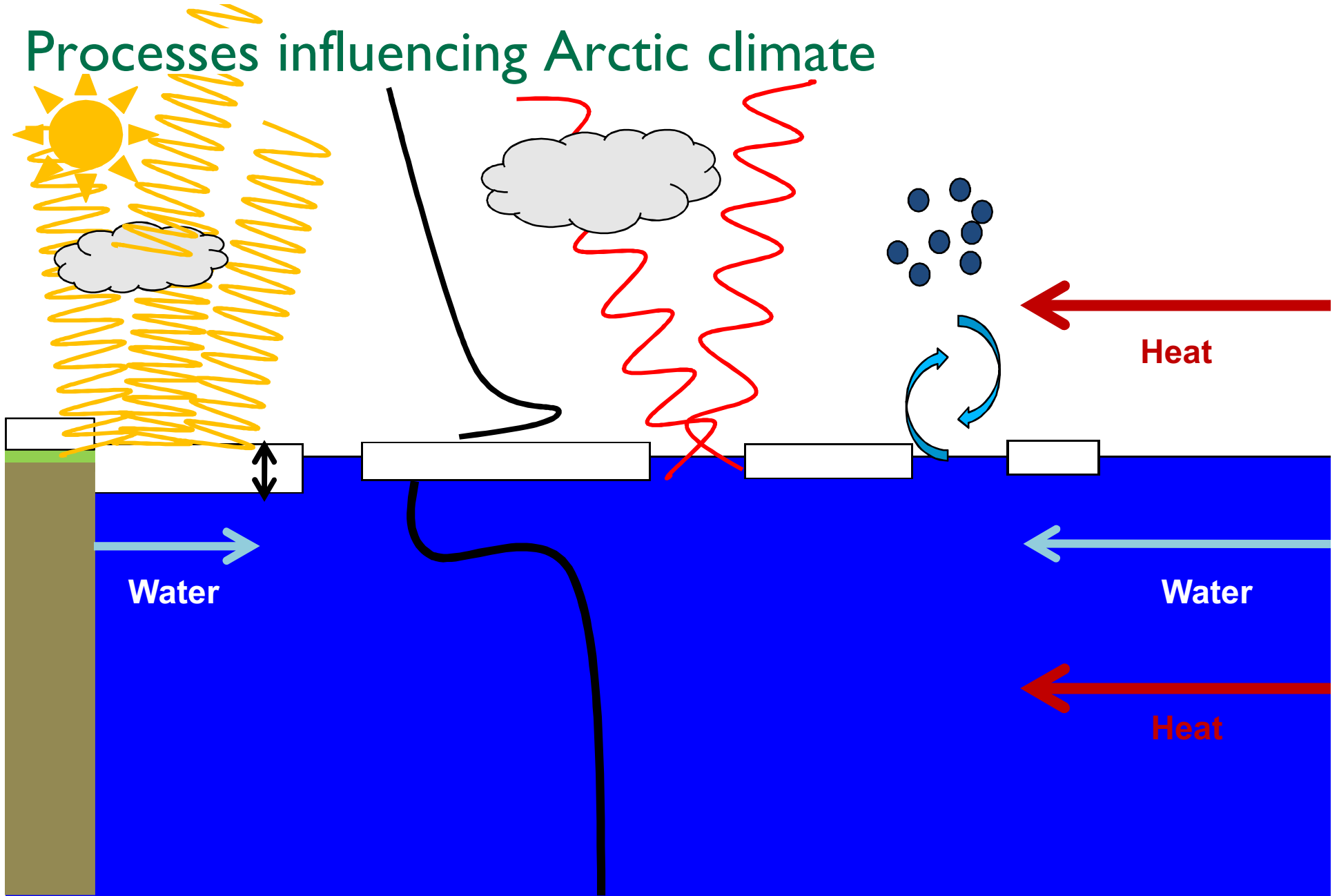


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Processes influencing Arctic climate



Subgrid processes: Parameterization

Some processes are too small-scale to be modelled explicitly: e.g. surface albedo over sea ice:



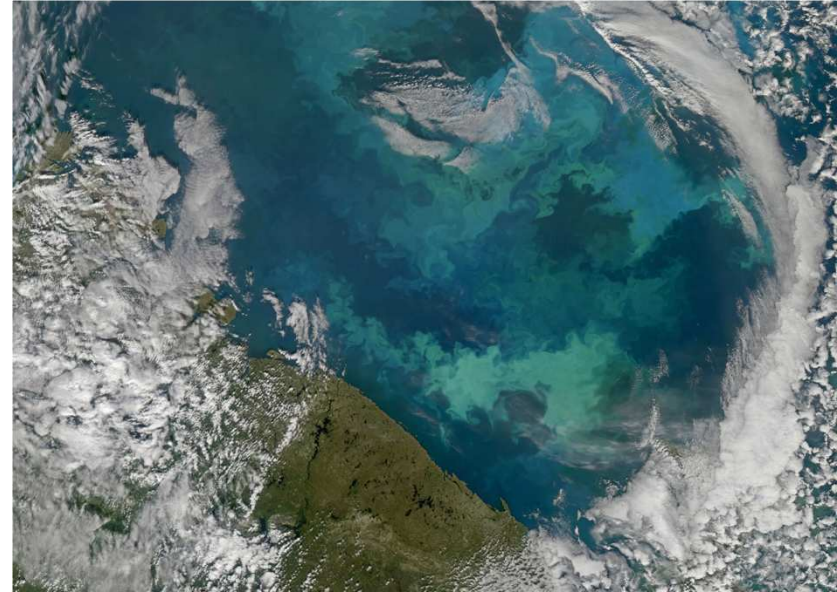
Patrick Kelley, U.S. Coast Guard

Use statistical models or **parameterizations** that are tuned to observations.

Unresolved processes

Some processes are not represented in climate models.

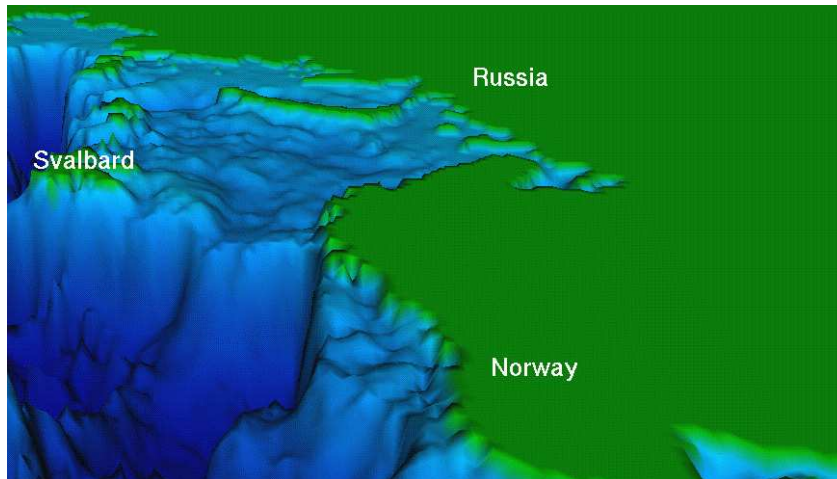
- 🌀 Ocean Biology
- 🌀 Permafrost
- 🌀 Shelf Seas



Norman Kuring, NASA



Hannes Grobe



Sources of Uncertainty



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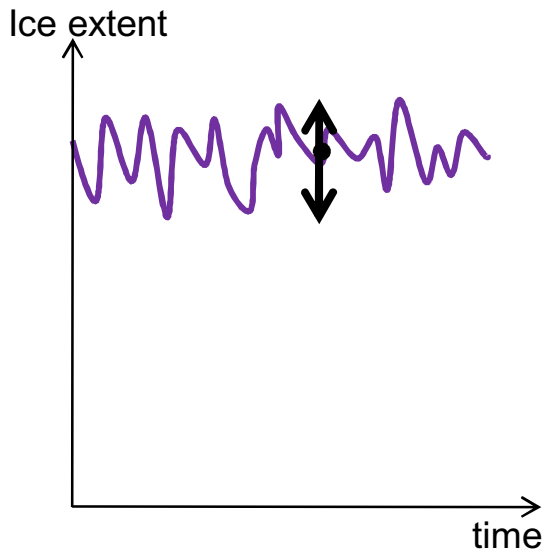
Sources of Uncertainty

There are four sources of uncertainty in climate model projections of Arctic climate:

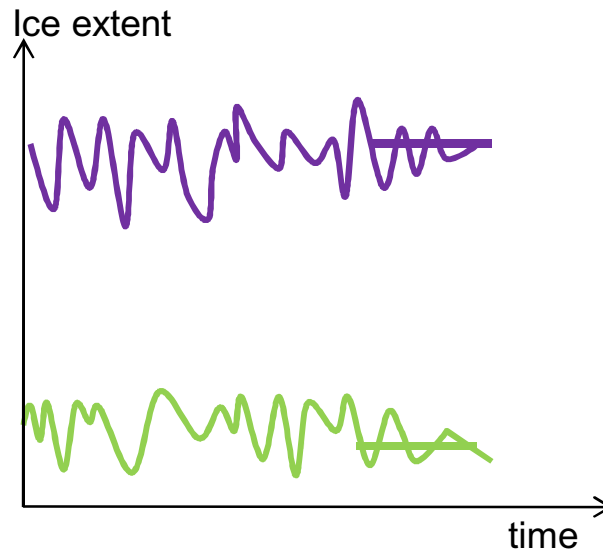
- Scenario uncertainty
 - E.g. Future levels of greenhouse gases.
- Structural uncertainty
 - The different methods different models use to represent the same physical process. E.g. Model resolution, coordinate systems (Constant density vs. constant height vertical).
- Parameter uncertainty
 - The value of a parameter within a parameterization (e.g surface ice albedo) chosen from within the given observational range.
- Intrinsic internal variability
 - The inherent variability, or noise, within the climate system, due to its chaotic nature.



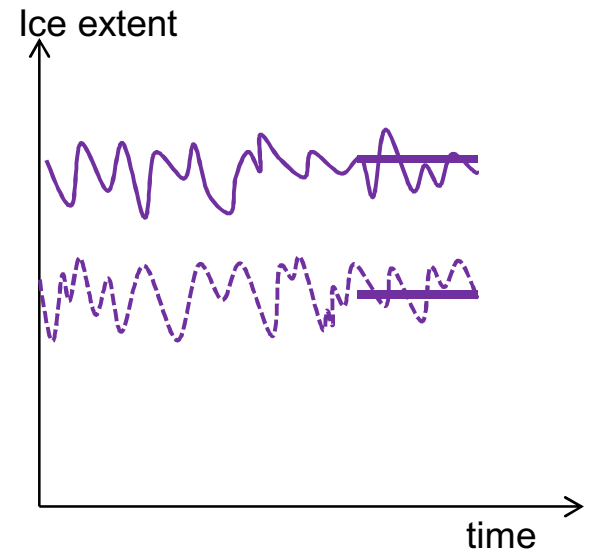
Uncertainty in the Model Control Mean State



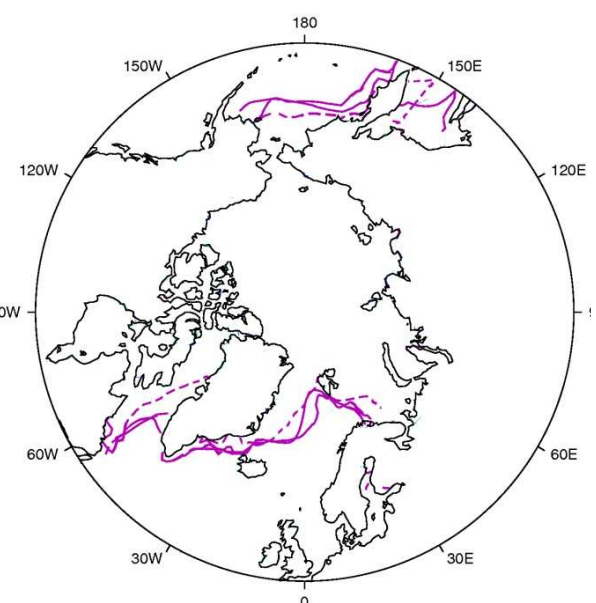
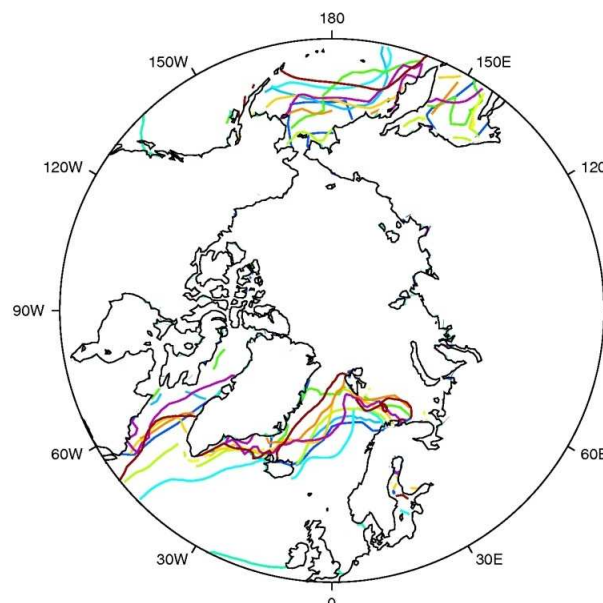
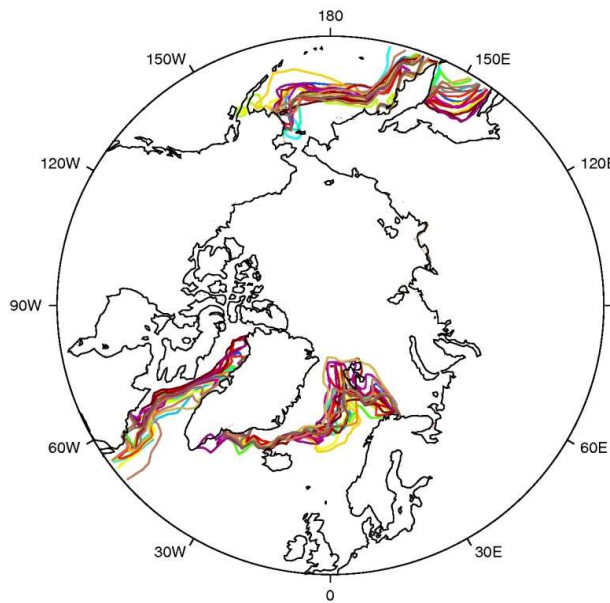
Internal variability



Structural uncertainty



Parameter uncertainty



Quantifying Uncertainty



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Analysis

Use two coupled climate model **ensembles**:

- **AR4** ensemble

Structural + Parameter Uncertainty

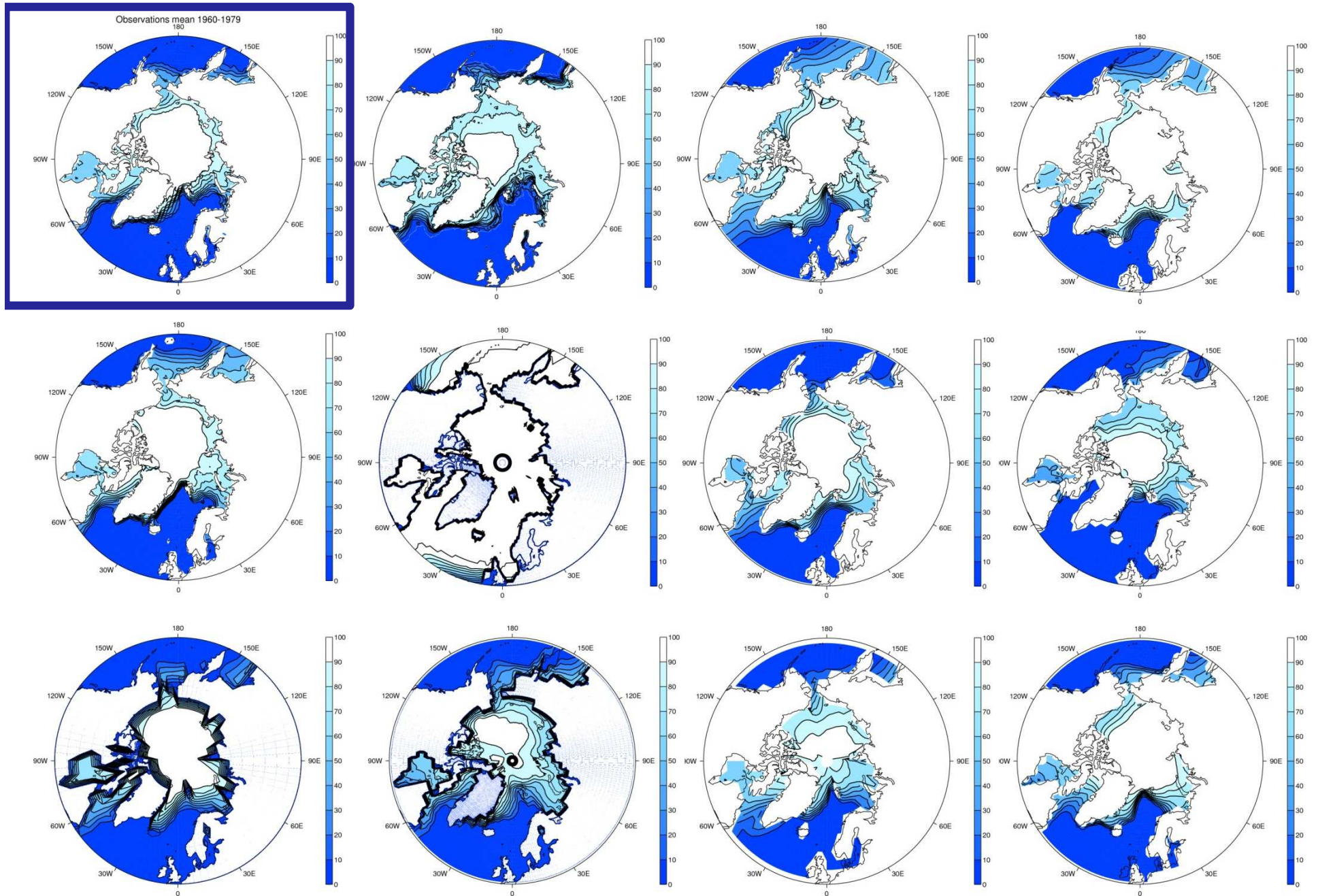
- 22 coupled climate models used in the IPCC AR4

- **THC-QUMP** ensemble

Parameter Uncertainty

- 22 versions of a single coupled climate model (HadCM3) created by varying values for model parameters, e.g.:
 - cloud formation and precipitation
 - ice structure and albedo

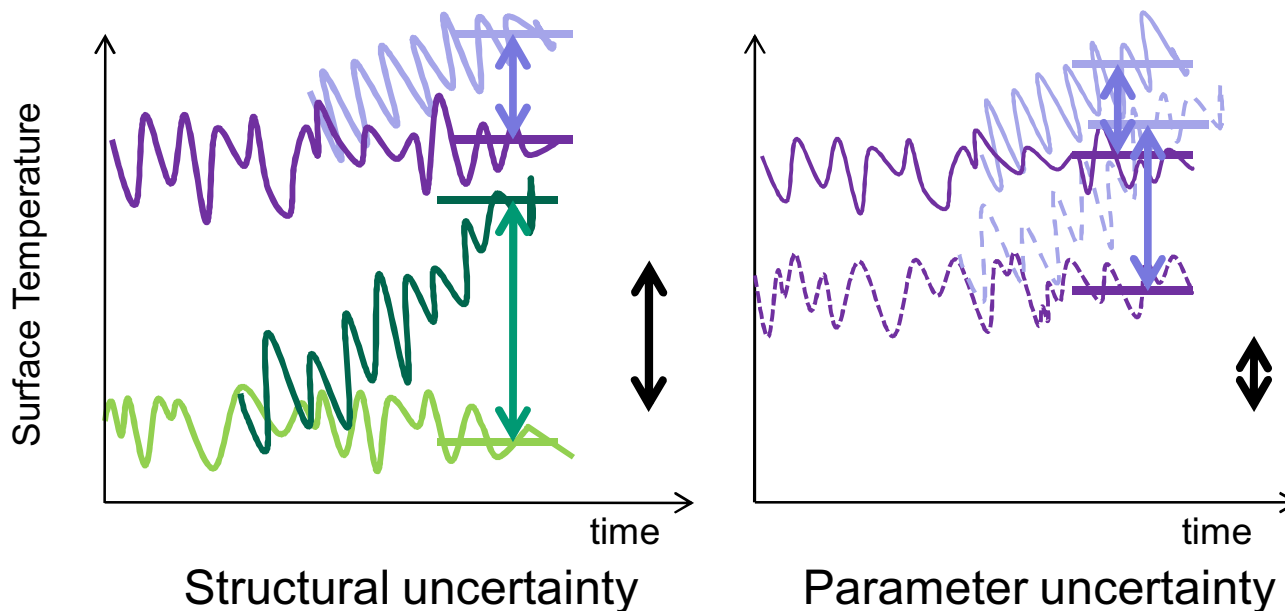
AR4 Mean State of Control: Sea Ice fraction



Analysis

Examine the **change** in Arctic variables (e.g. sea ice extent) under doubling of CO_2 .

Assess the **uncertainty** in this change, represented by the **spread** of the changes across the model ensemble



Spread in Key Variables

How uncertain are Arctic model projections?

Ensemble	Change at double pre-industrial CO ₂ concentration (20 year means)			
	ice extent /10 ⁶ km ²	ice volume /10 ³ km ³	surface air temperature (SAT) /°C	precipitation /10 ⁻⁶ mm/s)
THC-QUMP (parameter uncertainty)	-2.56 ± 0.74 29%	-7.49 ± 4.03 54%	4.26 ± 0.63 15%	1.74 ± 0.36 21%
IPCC AR4 (structural +parameter uncertainty)	-2.07 ± 0.90 43%	-9.44 ± 4.57 48%	3.96 ± 1.11 28%	1.74 ± 0.53 30%

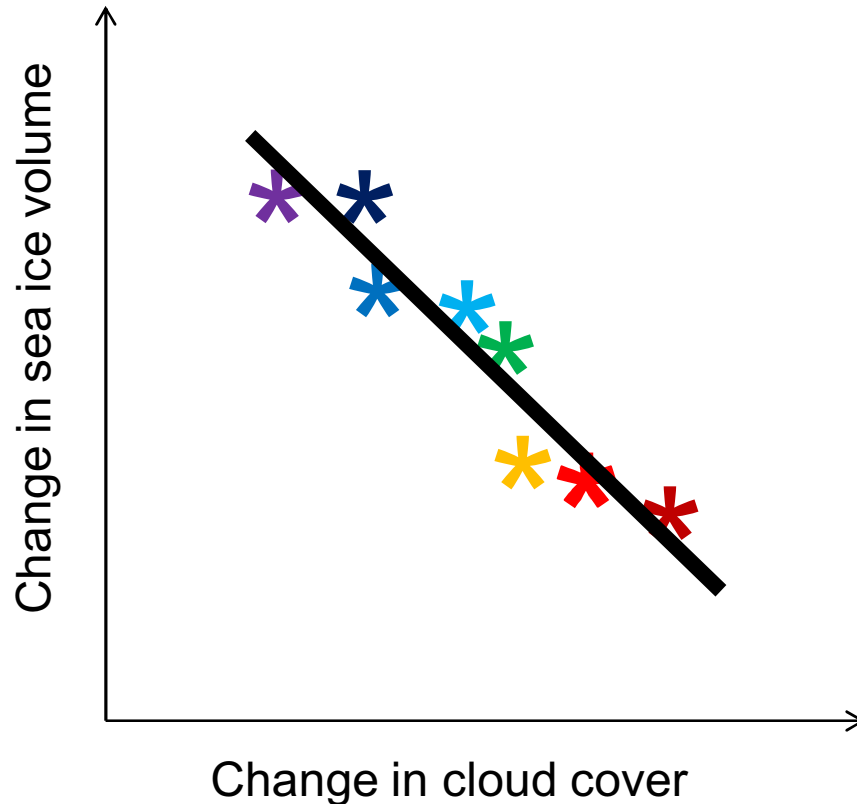
Spread in Key Variables

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	ice extent /10 ⁶ km ²	ice volume /10 ³ km ³	surface air temperature (SAT) /°C	precipitation /10 ⁻⁶ mm/s
THC-QUMP (parameter uncertainty)	± 0.74	± 4.03	± 0.63	± 0.36
IPCC AR4 (structural + parameter uncertainty)	± 0.90	± 4.57	± 1.11	± 0.53
Contribution from Internal variability (AR4)	± 0.18 20%	± 0.40 9%	± 0.18 16%	± 0.13 25%

- ❑ Internal variability important
- ❑ Major contribution to model spread from both structural and parameter uncertainty.

Examining across-model spread



Plot change in cloud cover vs change in sea ice volume, for **each model** in ensemble

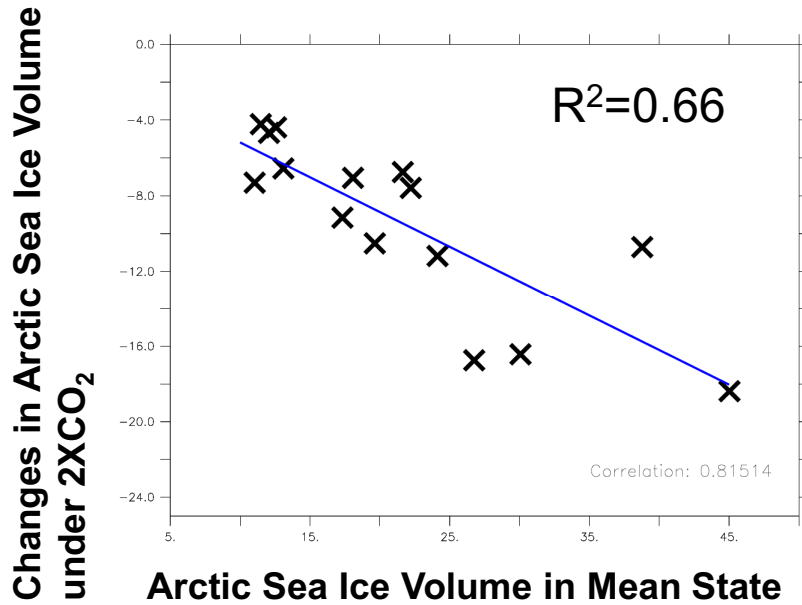
Ensemble spread in cloud cover **can** help explain spread, hence uncertainty, in the change in sea ice volume

Spread in Arctic Change: Key Results

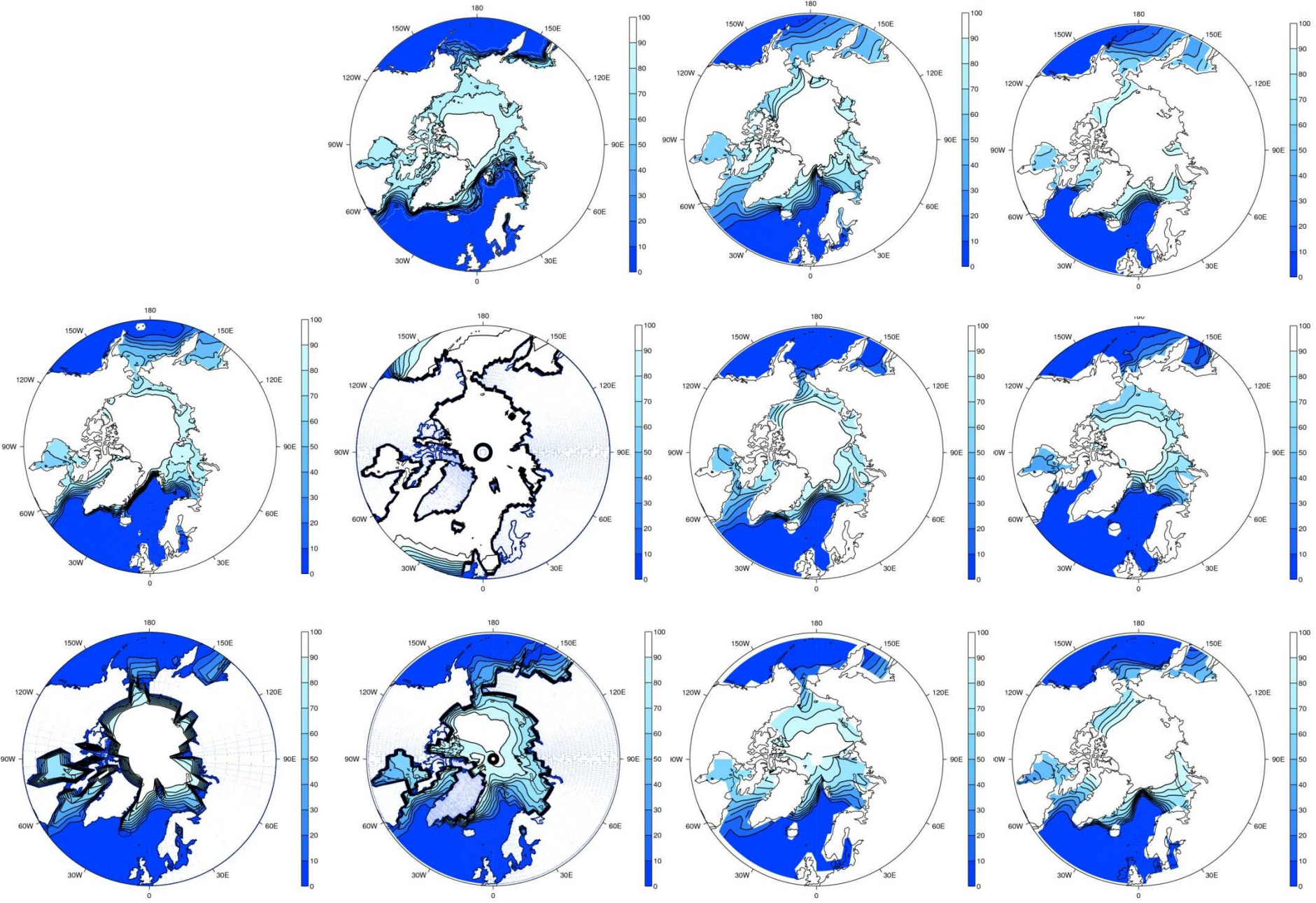
Examining correlations between model spread in this way:

- ① Model spread in predictions of Sea ice volume changes under $2XCO_2$ partly explained by:
 - ① spread in change in **cloud forcing**
 - ① spread in change in **Atlantic ocean heat transport**
- ① Model spread in predictions of Precipitation changes under $2XCO_2$ strongly related to changes in surface temperature.
- ① More results and discussion in final report.

Importance of Model Control Mean State

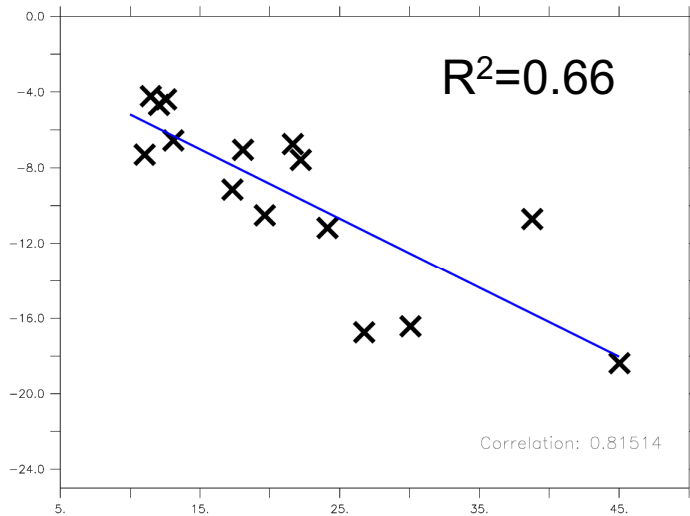


AR4 Mean State of Control: Sea Ice fraction



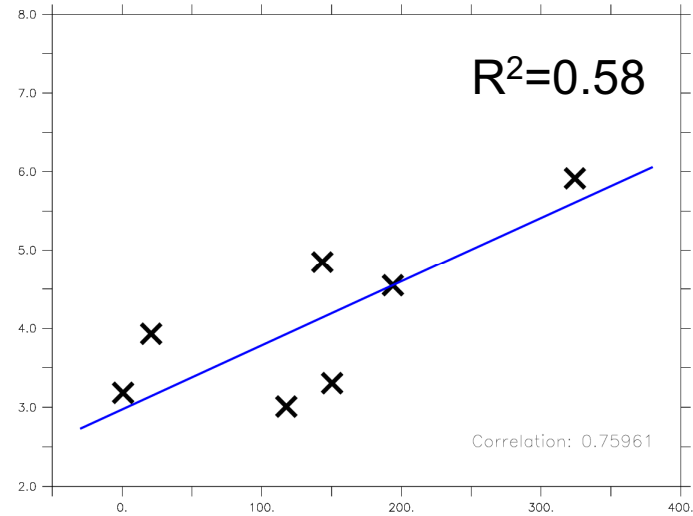
Importance of Model Control Mean State

Changes in Arctic Sea Ice Volume under 2XCO₂



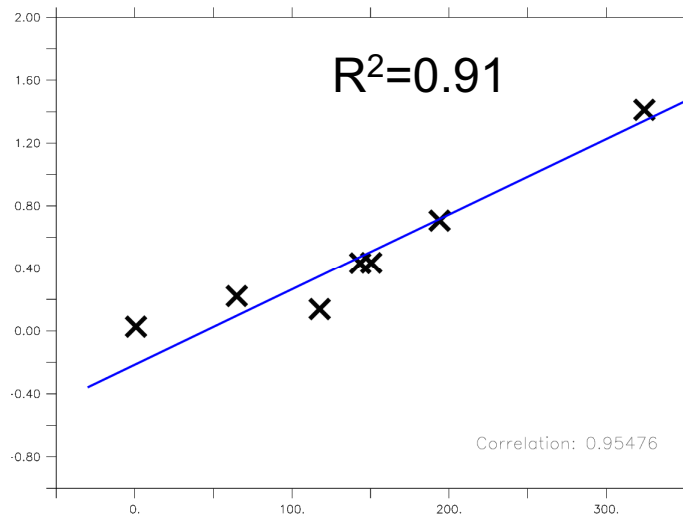
Arctic Sea Ice Volume in Mean State

Changes in Arctic Surface Temperature under 2XCO₂



Atlantic Ocean Heat Transport in Mean State

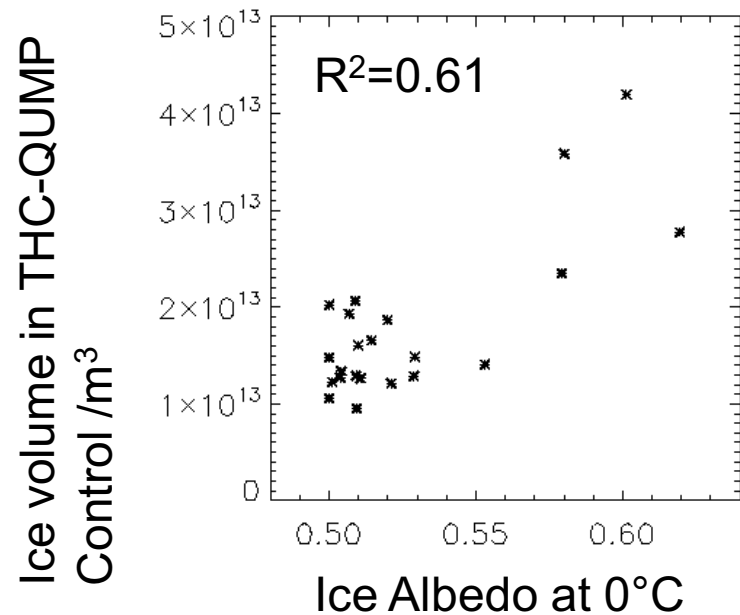
Changes in Arctic Mixed Layer Temperature under 2XCO₂



Atlantic Ocean Heat Transport in Mean State

Impact of Parameters

Some aspects of parameter uncertainty can be directly attributed to parameter variations.



The spread in initial ice volume (mean state) is set by the choice of Ice Albedo parameter.

Conclusions

- ① Ice volume is a large model uncertainty. Observational constraints of current ice volume needed to constrain and improve models.
- ② Uncertainty in Ocean heat transport into Arctic partly drives uncertainty in model Arctic climate.
- ③ Initial ice volume and ocean heat transport can explain part of spread in changes in Arctic climate.
- ④ Variations in model parameters can explain part of spread in changes in Arctic climate.

Summary

- ① There are significant uncertainties in projections of Arctic climate change.
 - ① Both model structure and model parameters contribute to these uncertainties.
 - ① Model control mean state (e.g. initial ice volume) is important for projections of change in Arctic climate.
 - ① Improved parameterizations and observation datasets (sea ice albedo & thickness, ocean heat transports & clouds) will constrain and improve models and hence reduce uncertainties in future projections.
- ◀ Final project report: Mid October.

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