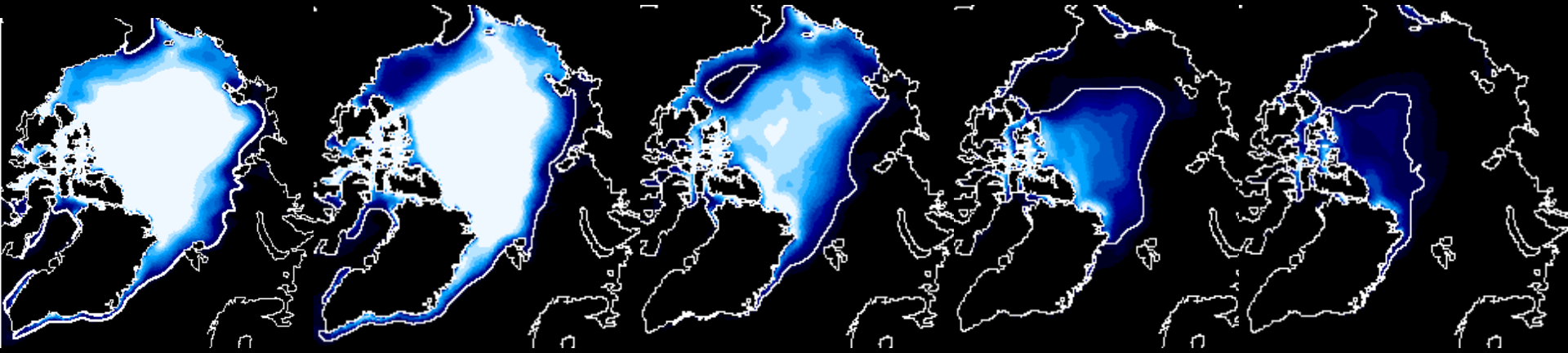

Uncertainties in Climate Model Projections of Future Arctic Sea Ice Loss

Marika Holland
National Center for Atmospheric Research

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14. ABSTRACT
Observations indicate that the Arctic has undergone rapid environmental change over the last thirty years. This includes significant reductions in sea ice cover that are most pronounced in summer. Climate model simulations consistently project that long-term sea ice loss will continue in the future in response to rising greenhouse gas forcing. However, models differ on the character of this future sea ice loss, including the rates of change, the likelihood that periods of abrupt loss could occur, and the timing at which a seasonally ice-free Arctic may be realized. Here we discuss climate model simulations of projected sea ice loss, the inherent uncertainties in these projections, and the factors that contribute to the range of model projections. This includes an analysis of the potential for periods of rapid sea ice loss. Finally some insights on the research needed to narrow climate model uncertainty are given.

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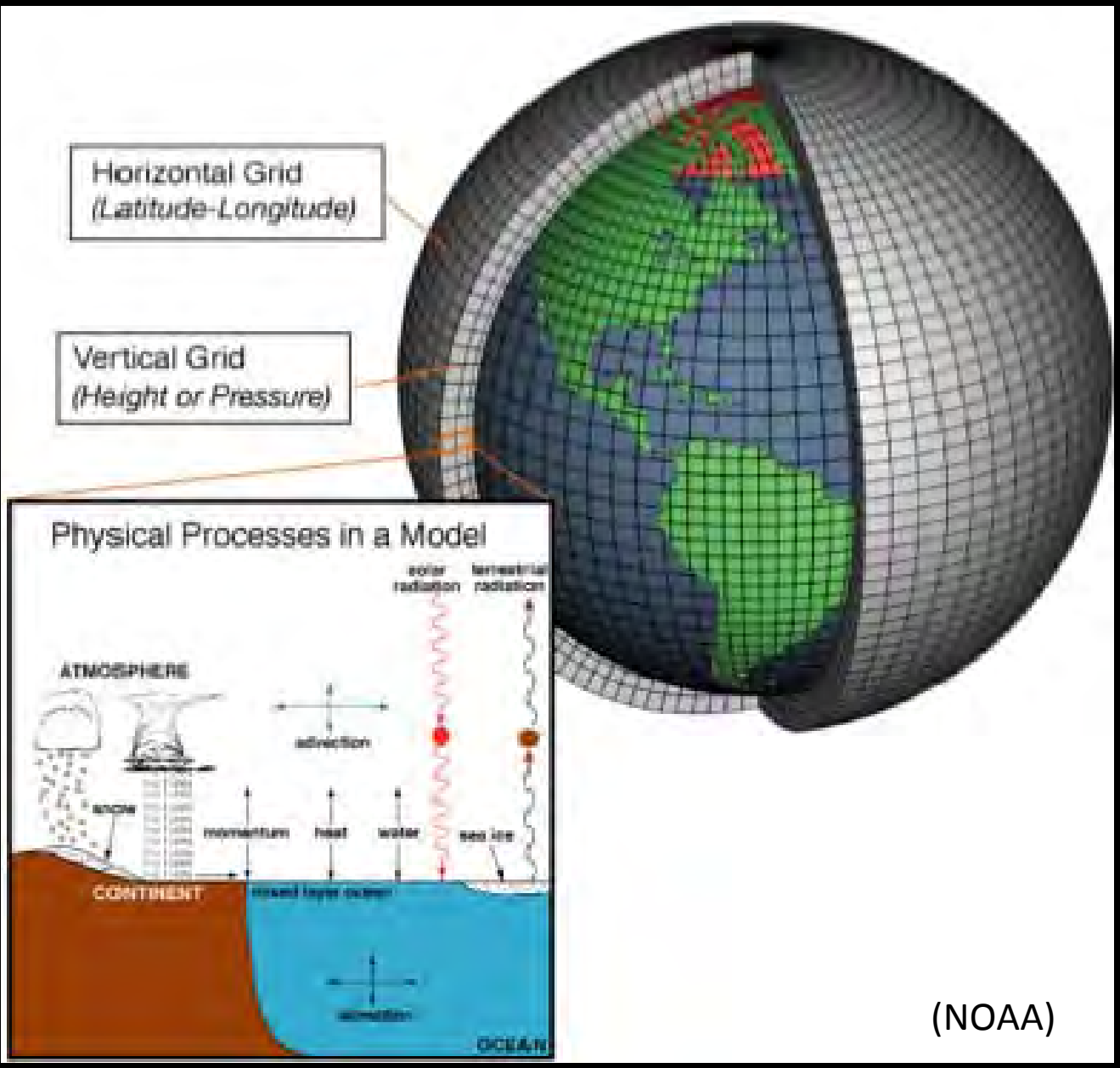
CLIMATE MODEL UNCERTAINTIES IN PROJECTING FUTURE ARCTIC SEA ICE LOSS

DR. MARIKA HOLLAND
National Center for Atmospheric Research
1850 Table Mesa Drive
Boulder, CO 80305
(303) 497-1734
mholland@ucar.edu

Observations indicate that the Arctic has undergone rapid environmental change over the last thirty years. This includes significant reductions in sea ice cover that are most pronounced in summer. Climate model simulations consistently project that long-term sea ice loss will continue in the future in response to rising greenhouse gas forcing. However, models differ on the character of this future sea ice loss, including the rates of change, the likelihood that periods of abrupt loss could occur, and the timing at which a seasonally ice-free Arctic may be realized. Here we discuss climate model simulations of projected sea ice loss, the inherent uncertainties in these projections, and the factors that contribute to the range of model projections. This includes an analysis of the potential for periods of rapid sea ice loss. Finally some insights on the research needed to narrow climate model uncertainty are given.

Climate model systems

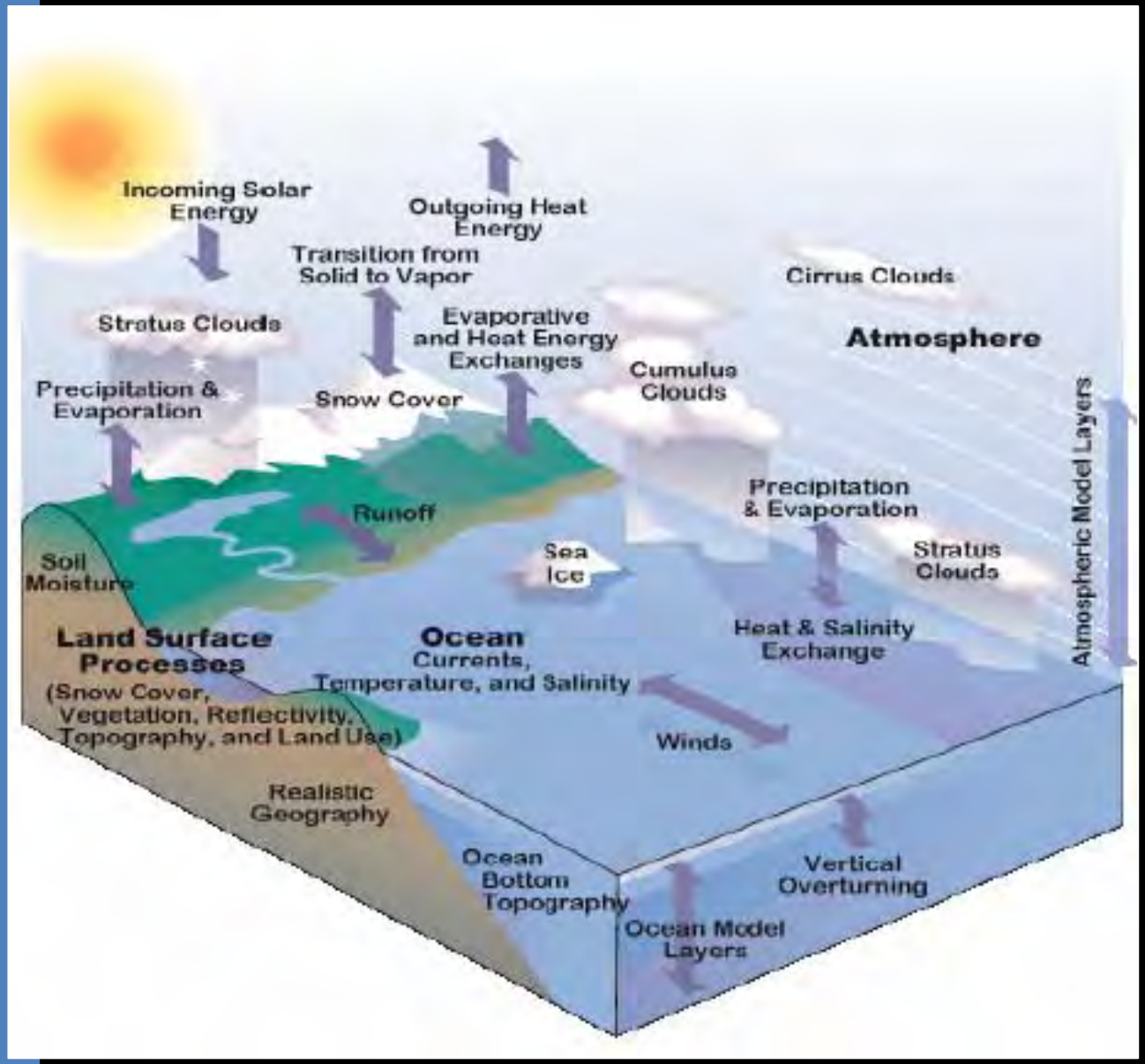


(NOAA)

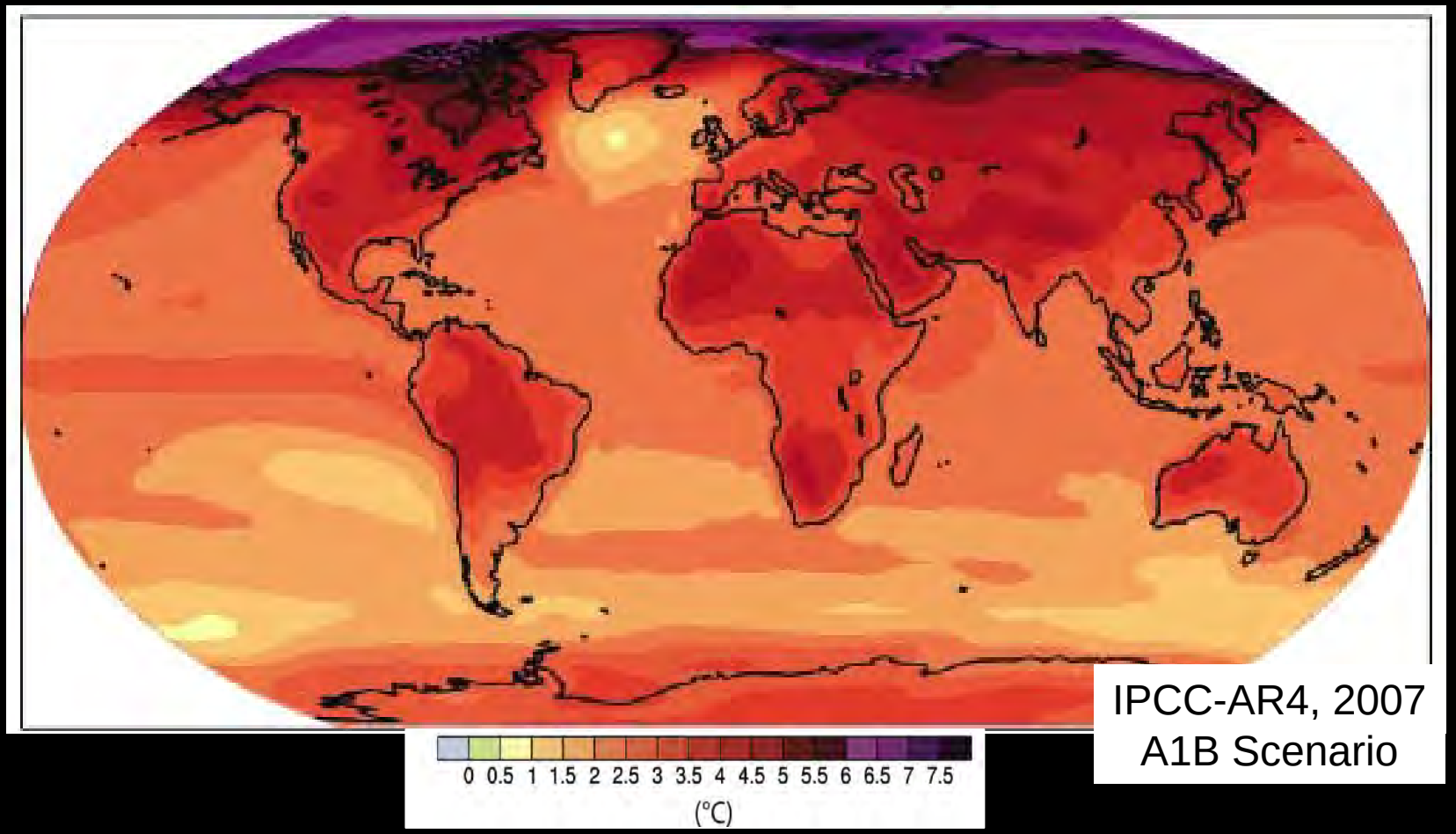
- Systems of differential equations that describe fluid motion, heat transfer, etc.
- Planet divided into 3-dimensional grid and equations solved on that grid
- Sub-gridscale processes need to be parameterized

Coupled Climate Models

- Includes ocean, atmosphere, land, sea ice components
- Conservative exchange of heat, water, momentum across components
- Can apply changes in external forcing; solar input, GHG levels, volcanic eruptions
- Provide a “virtual laboratory” for experimentation



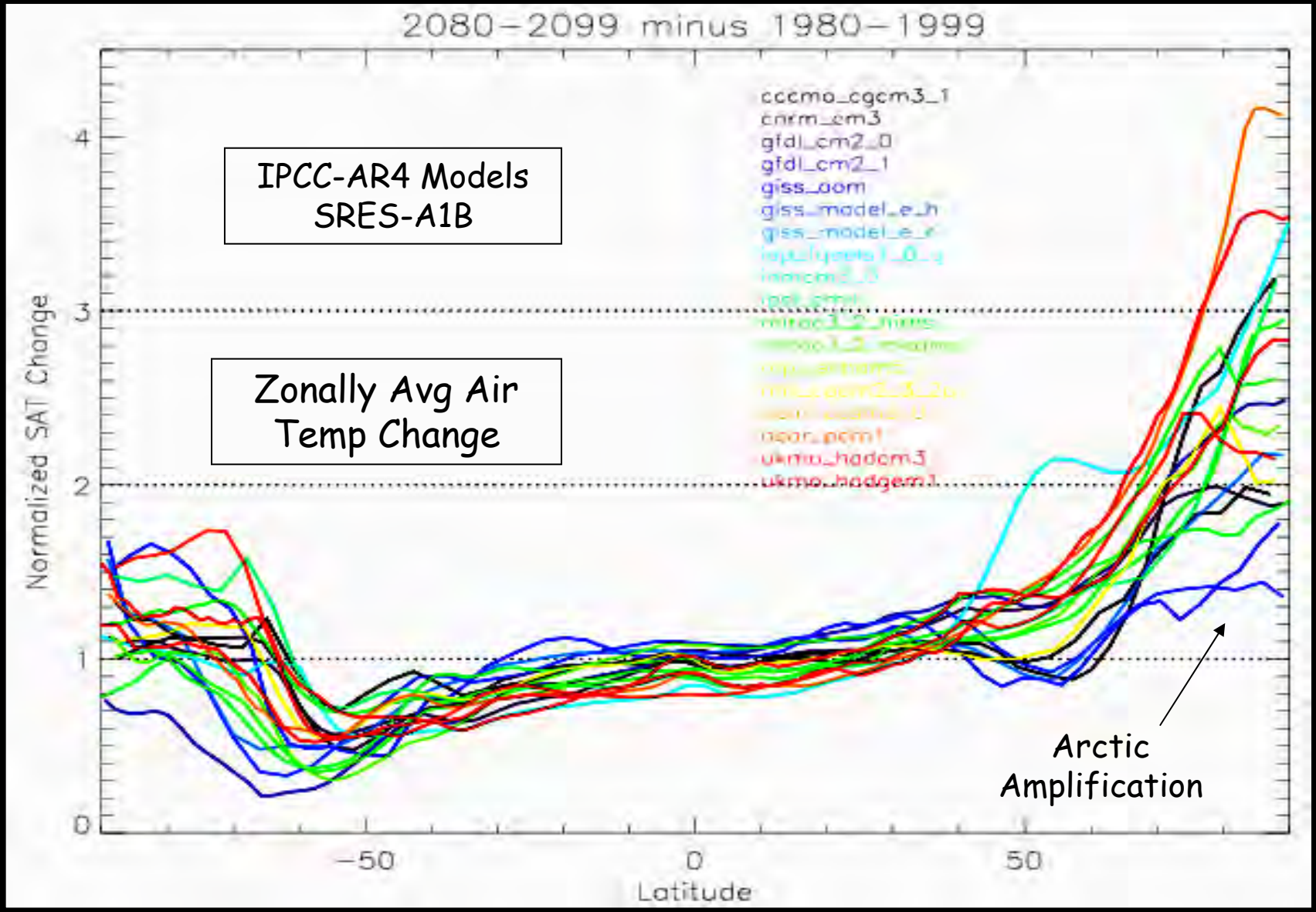
In response to rising greenhouse gases models project continued surface warming



Projected Air Temperature change by 2100

Global warms ~2.8°C, Land warms ~3.5°C, Arctic warms ~7°C

Projected Surface Air Temperature Change

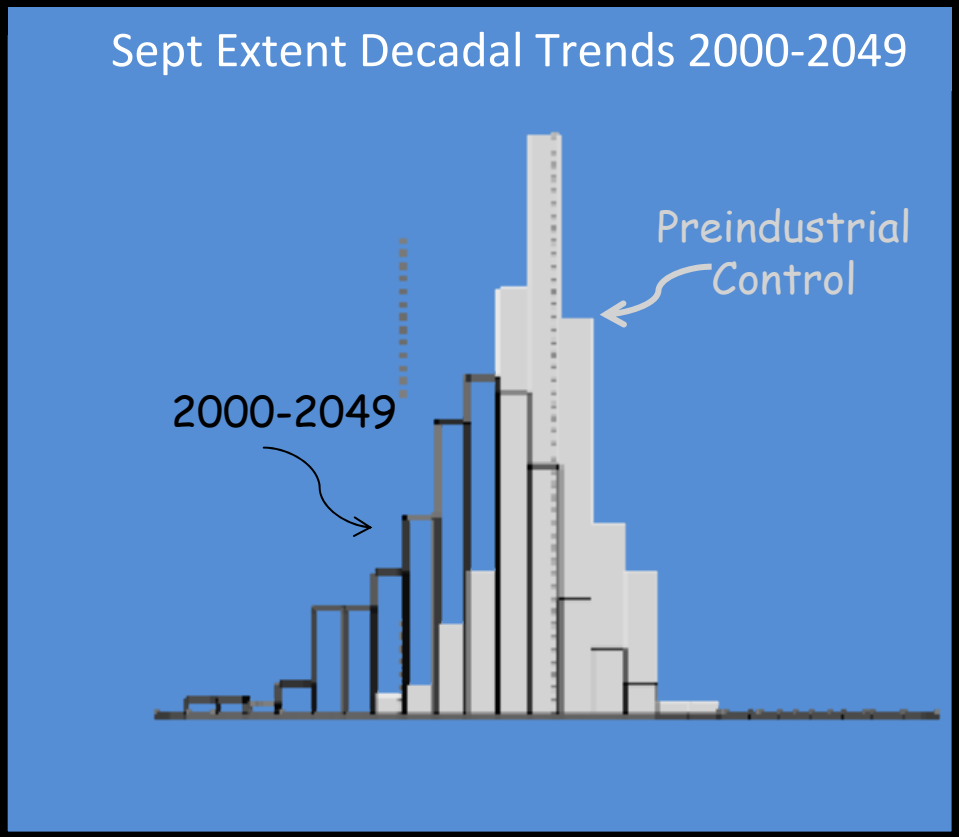


(After Holland and Bitz, 2003)

Sources of Uncertainty in Projections of Future Climate Change

- Intrinsic climate variability

Climate models simulate the statistics of climate, not the events of any particular year



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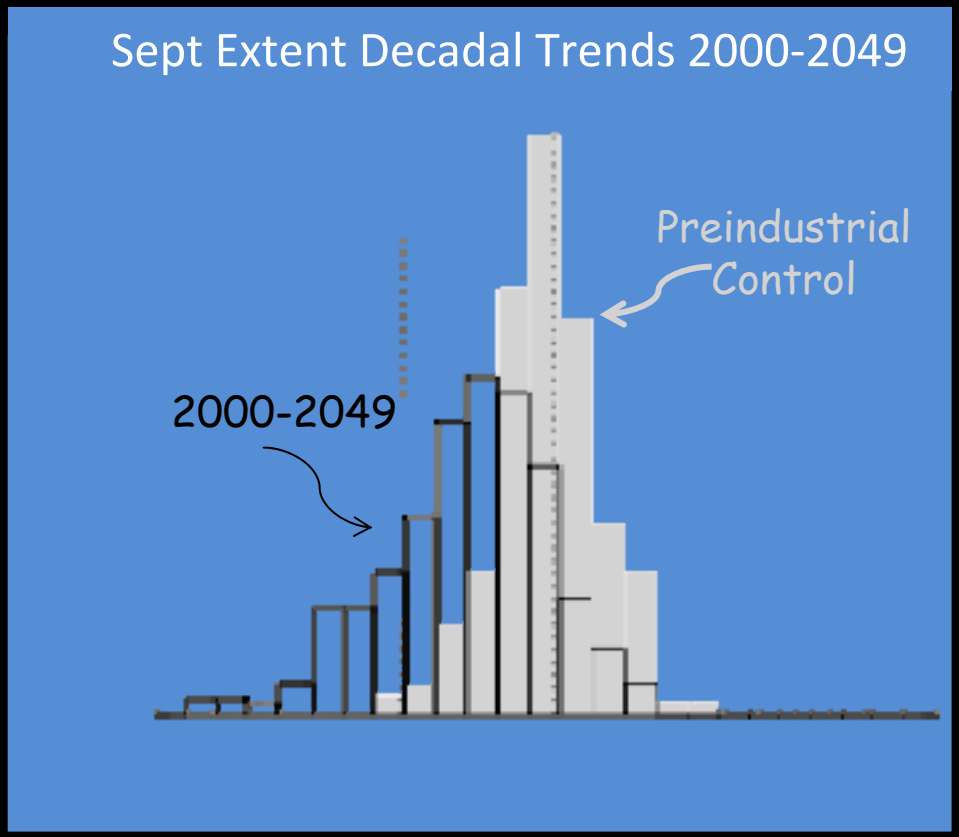
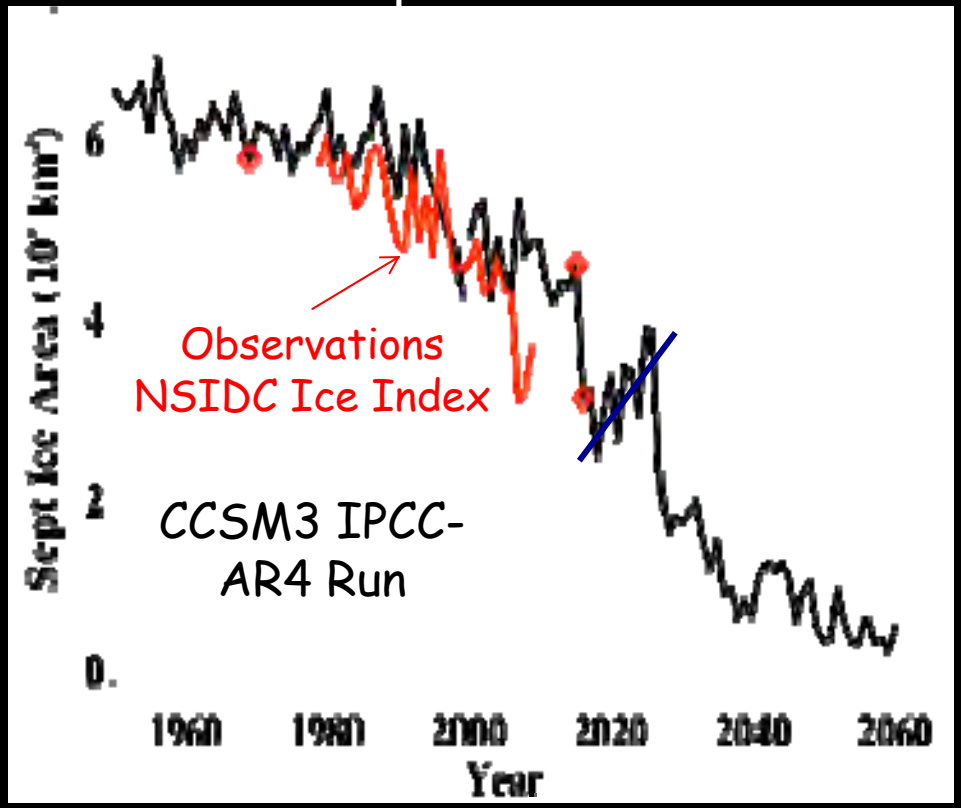
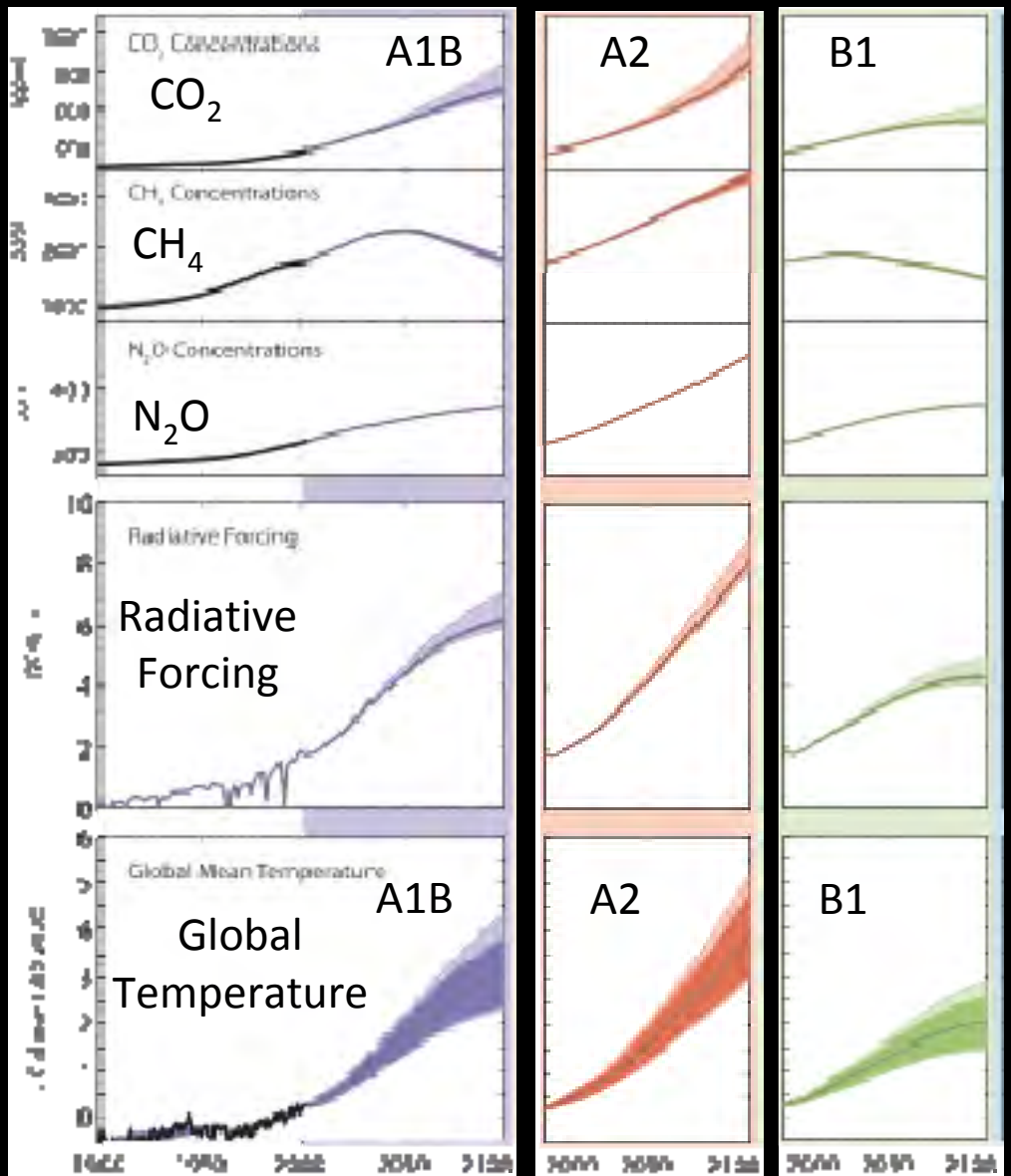


Simulated September Ice Extent



Sources of Uncertainty in Projections of Future Climate Change

- Intrinsic climate variability
- Future greenhouse gas (and other external forcing) changes

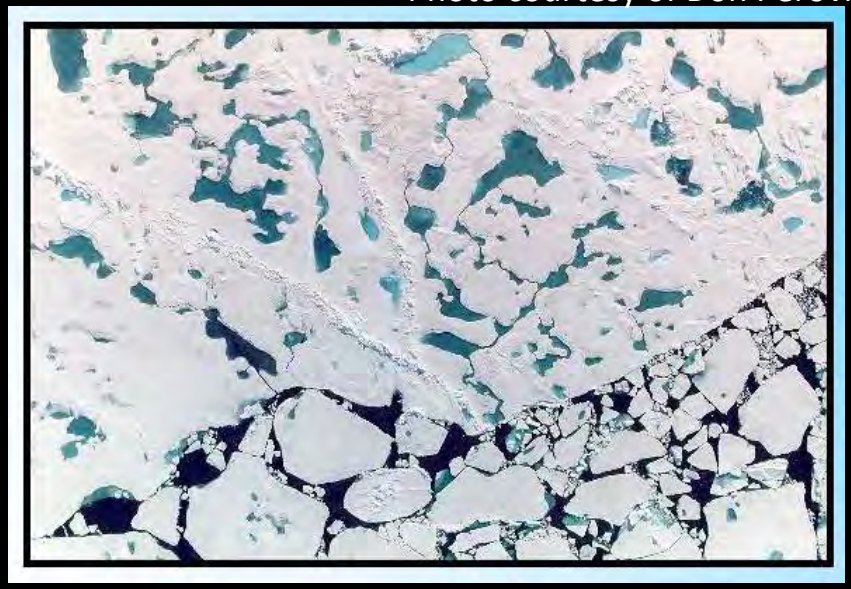


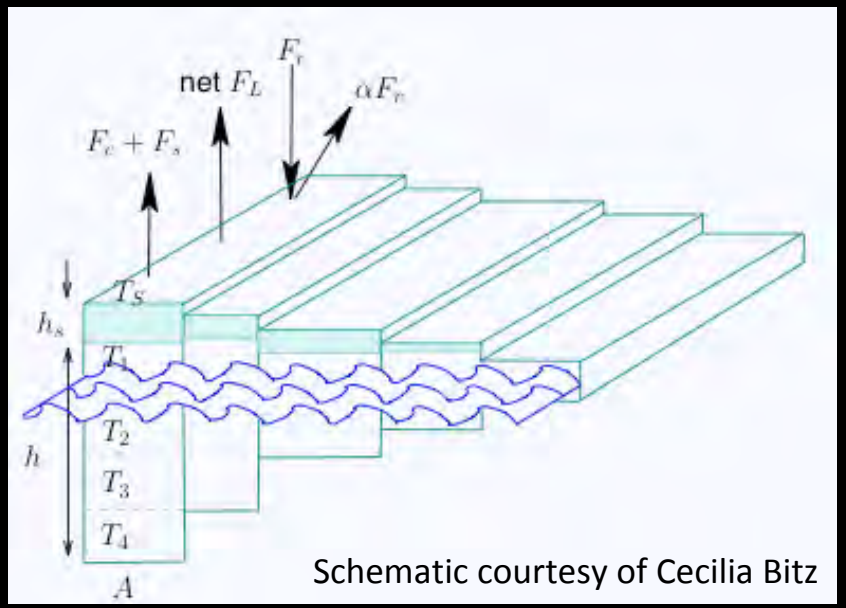
IPCC AR4, 2007

Sources of Uncertainty in Projections of Future Climate Change

- Intrinsic climate variability
- Future greenhouse gas (and other external forcing) changes
- Climate Model approximations

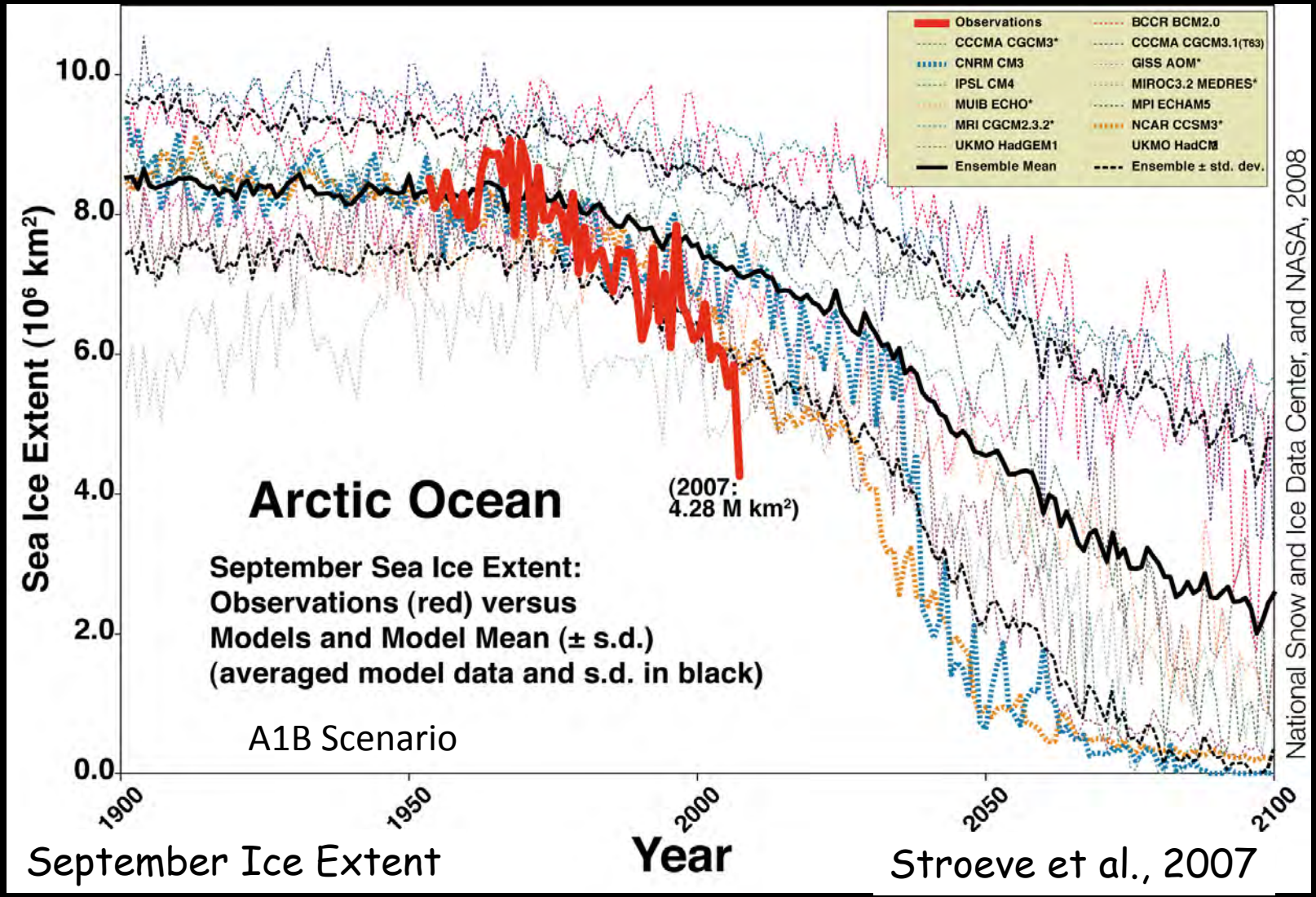
Photo courtesy of Don Perovich





Schematic courtesy of Cecilia Bitz

Model projections of September Arctic sea ice cover



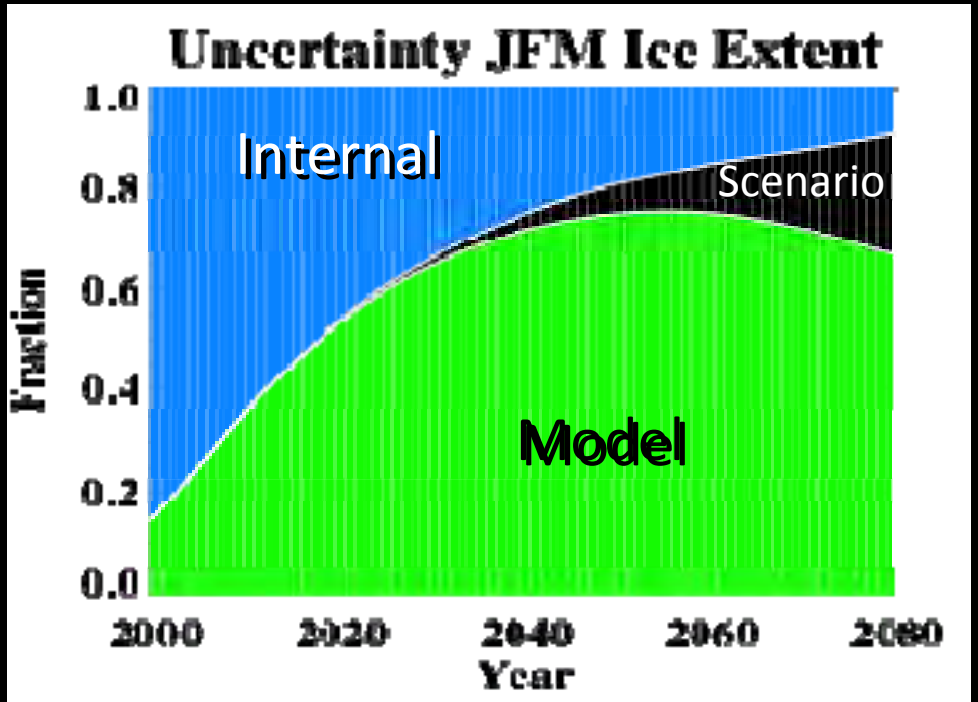
September Ice Extent

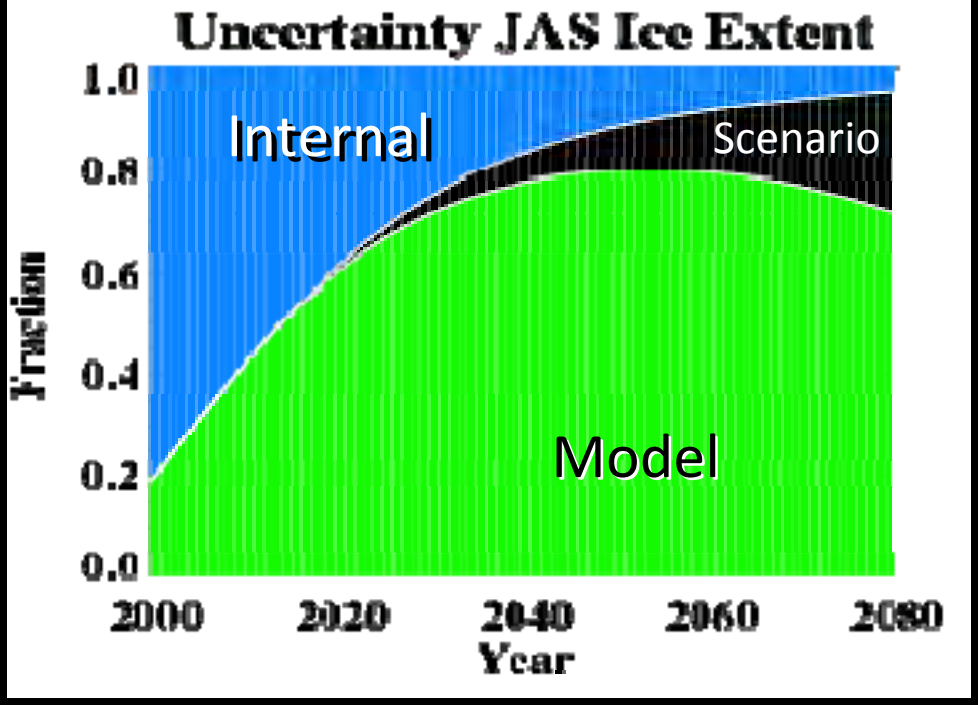
Stroeve et al., 2007

All models simulate ice loss

Large range in magnitude of this loss

Models simulate smaller trends than observations





Sources of Uncertainty for Arctic ice change

Using projections with different models & forcing scenarios, we can approximate the sources of uncertainty

- On <15 years intrinsic variability dominates
- On 20+ years, model uncertainty dominates
- On 50+ years, future GHG scenario uncertainty becomes important

(Following Hawkins and Sutton, 2009)

Reducing "Internal Uncertainty"

- Decadal climate prediction efforts underway.
- Involve initialized "forecasts".
- Still very much a research problem.
- Have the potential to reduce the uncertainty associated with natural climate variations on 10-20 year timescales

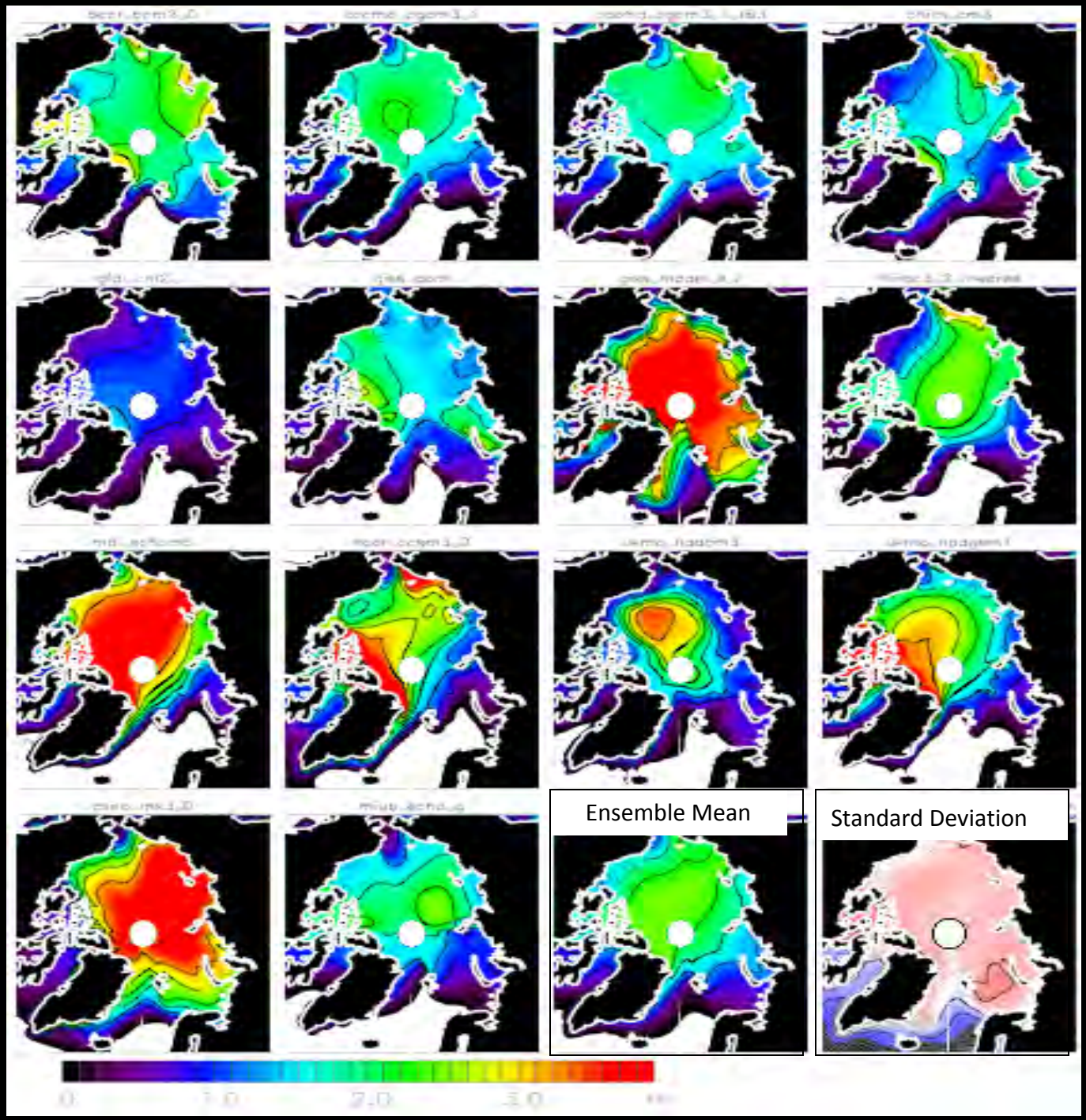
Reducing "Model Uncertainty"

- Climate models are very complex systems
- Improvements and new capabilities are being incorporated continuously
- To reduce uncertainty for a particular model aspect, we need to understand what contributes to that uncertainty

What factors contribute to model uncertainty in future Arctic ice loss projections?

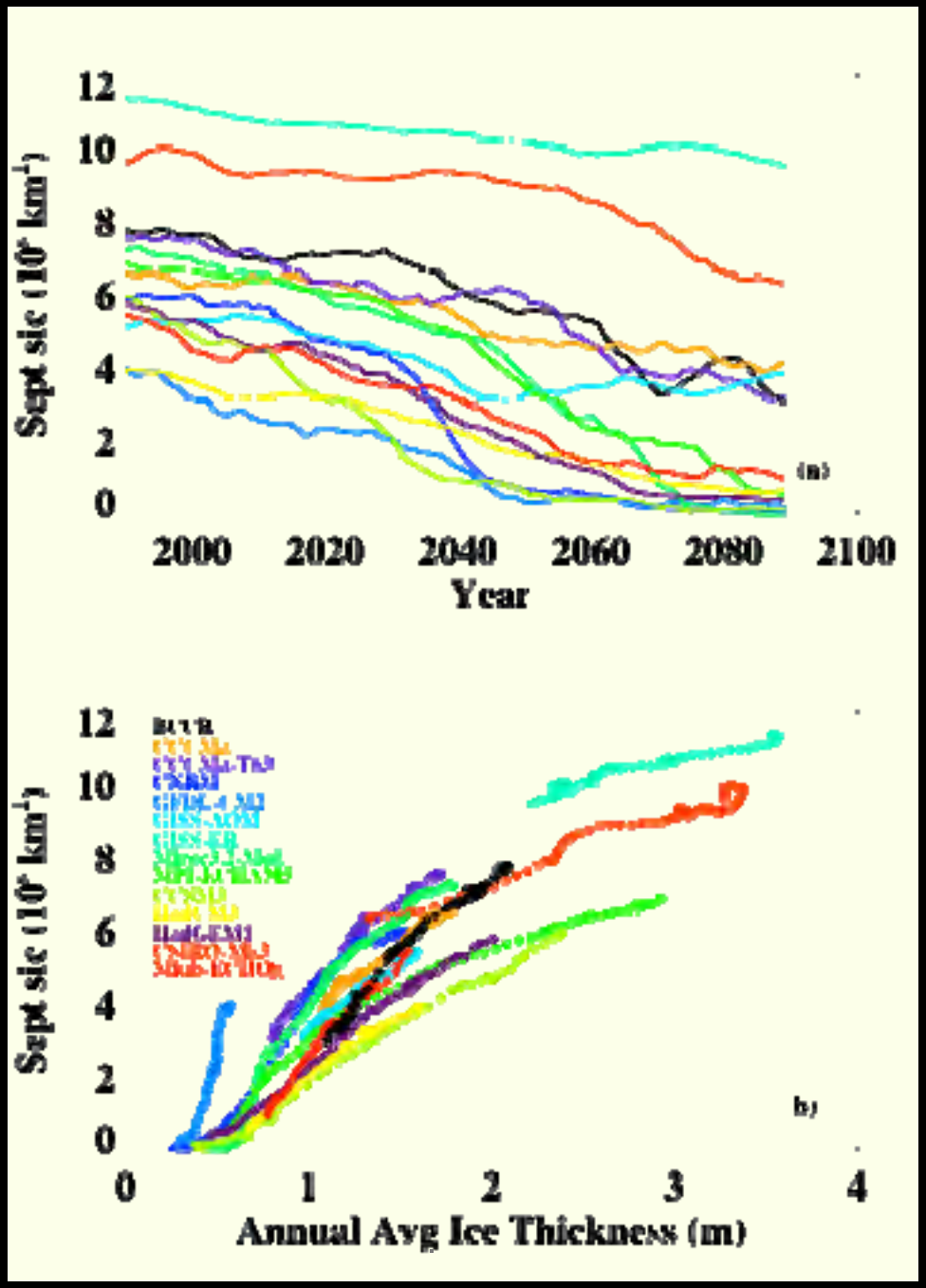
Factors in "Model Uncertainty" of Projected Arctic ice loss

Initial Climate State



Ice Thickness Climatology from CMIP3 Climate Models 1980-1999

Projected ice loss



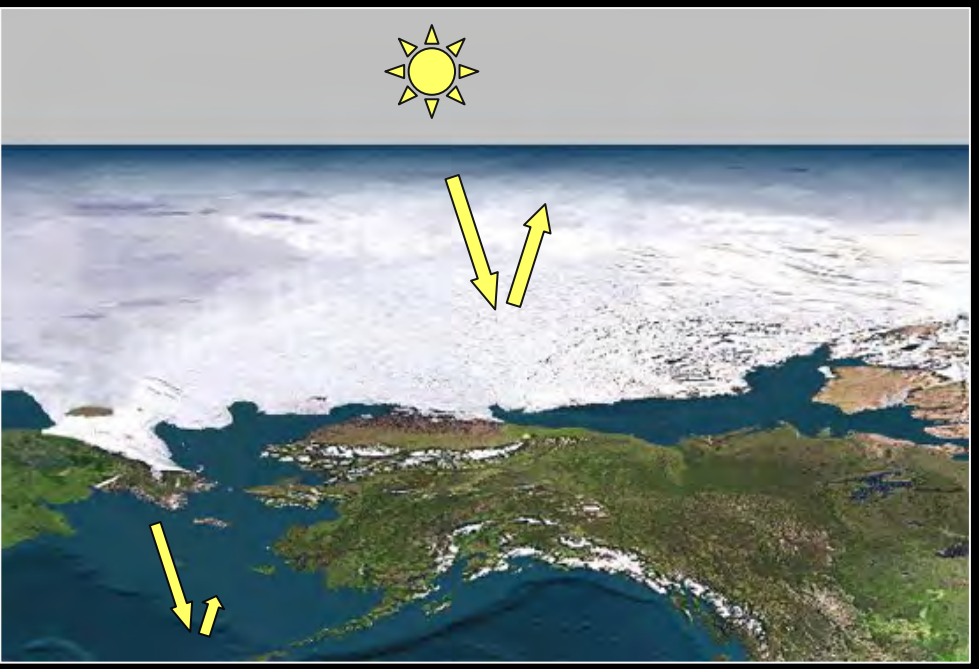
- Dependent on late 20th century conditions
- Models with thicker ice have larger ice volume loss but smaller ice area change
- In models with similar late 20th century ice thickness, spatial pattern of ice thickness matters
- Differences in albedo and cloud response are important for uncertainty in ice volume change

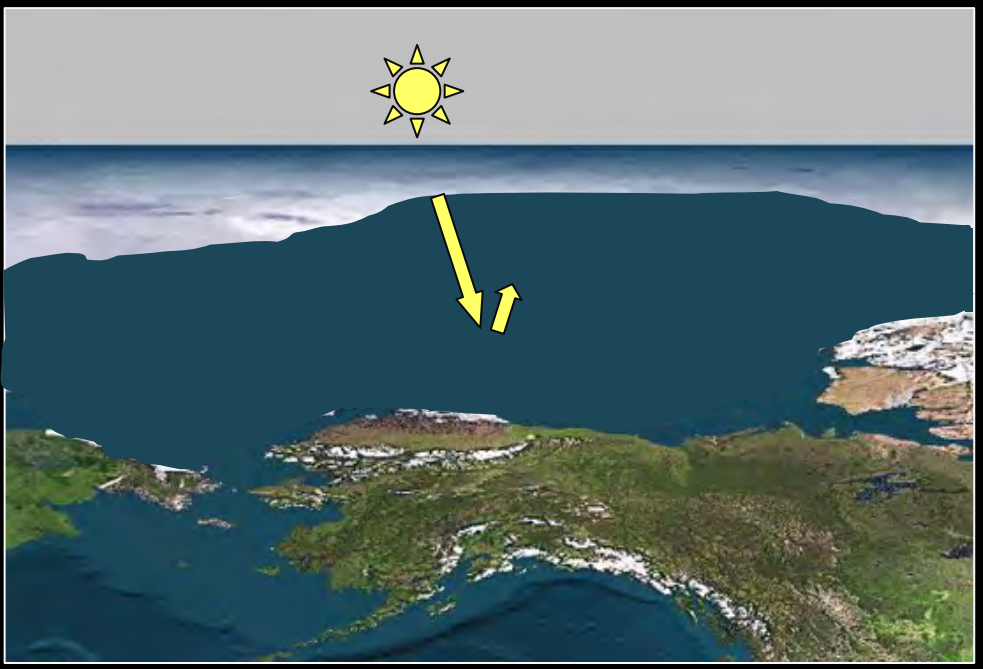
(Holland et al., 2010)

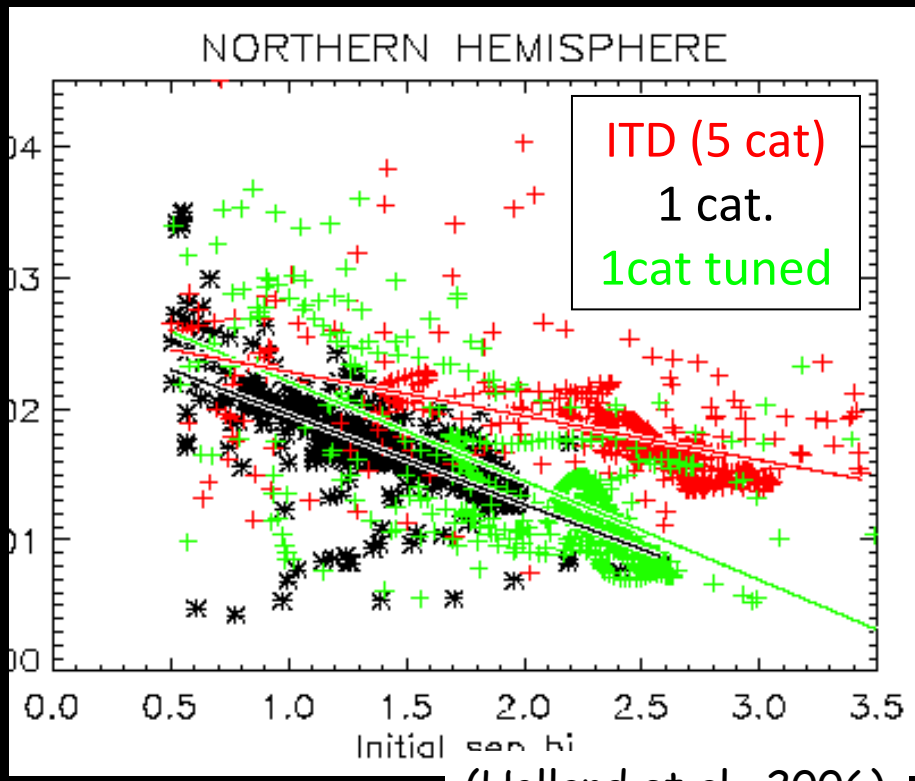
Factors in "Model Uncertainty" of Projected Arctic ice loss

Model Parameterizations

albedo feedback strength modified by inclusion of subgridscale ITD







(Holland et al., 2006)

Factors in "Model Uncertainty" of Projected Arctic ice loss

Missing (or Incomplete) Capabilities

Methane release from thawing permafrost

Soot deposition on snow and ice

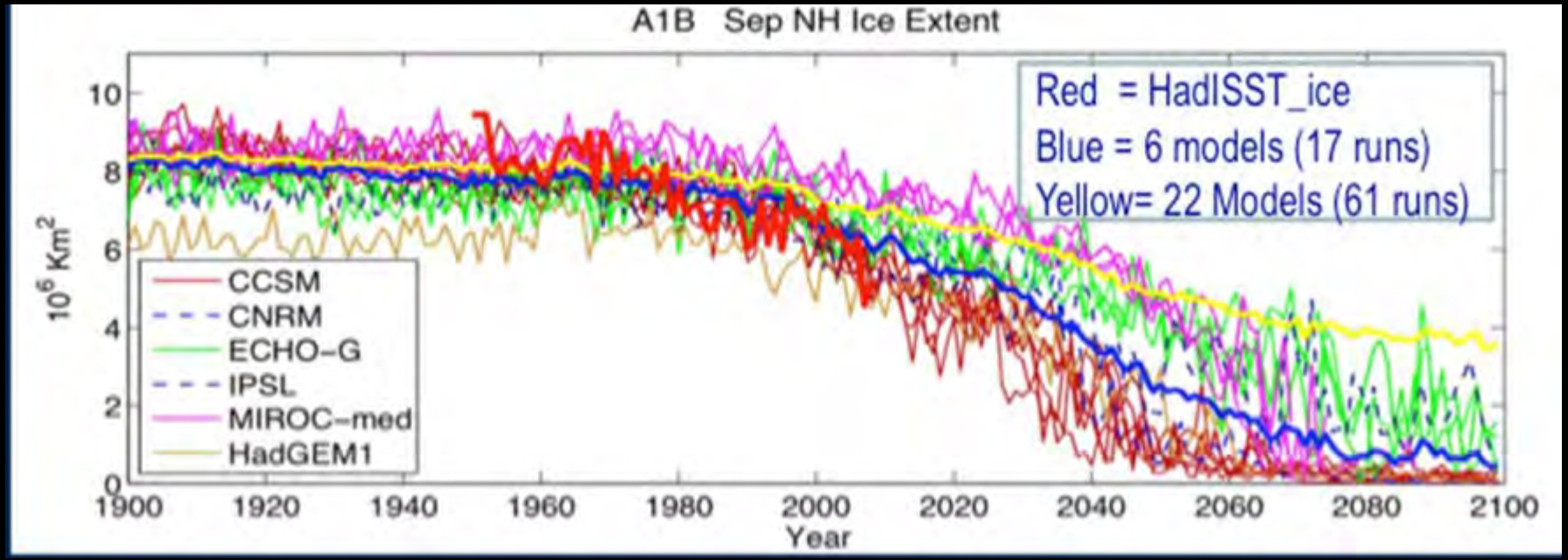
Aerosol effects on cloud formation

Ice sheet and glacier components

Factors in "Model Uncertainty" of Projected Arctic ice loss

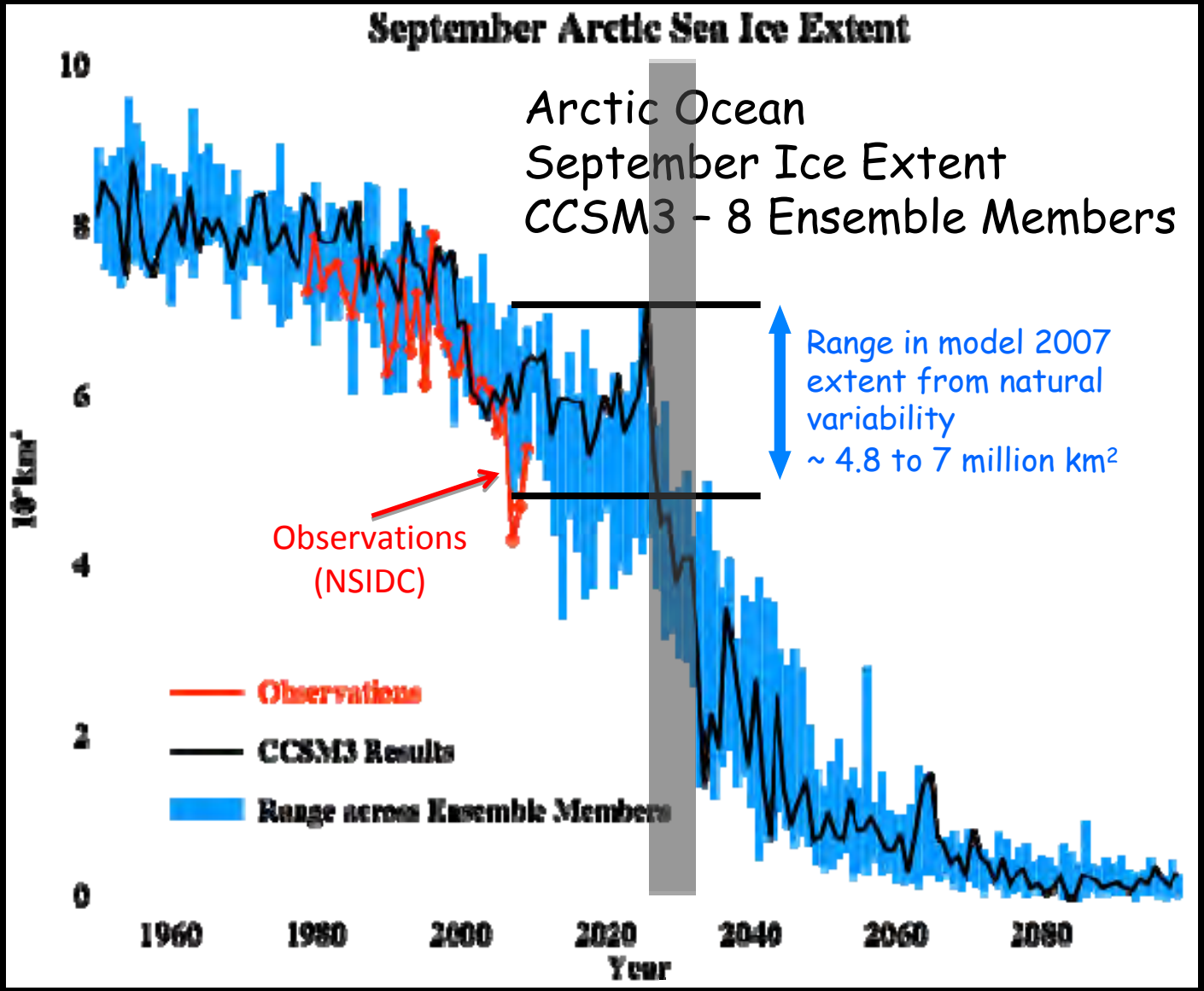
Suggest that more faith should be placed in projections from models with:

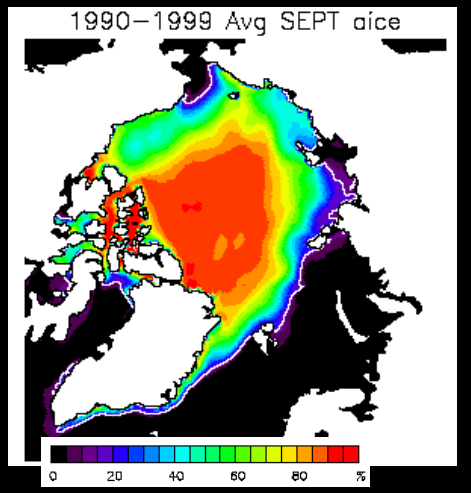
Well represented late 20th century Arctic sea ice
More sophisticated physics and thermodynamics

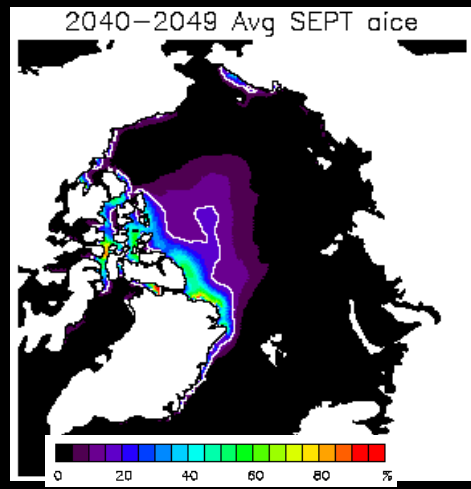


(Wang and Overland, 2009)

Potential abrupt loss of perennial sea ice







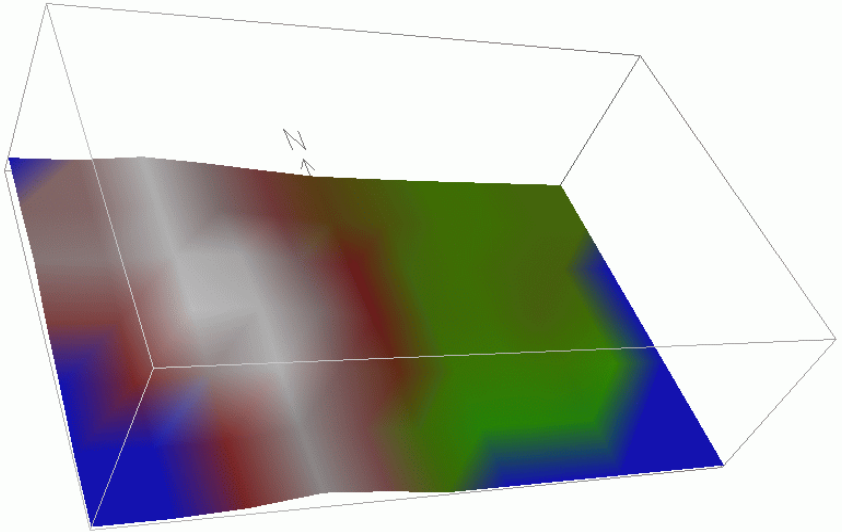
(Holland et al., 2006)

Summary

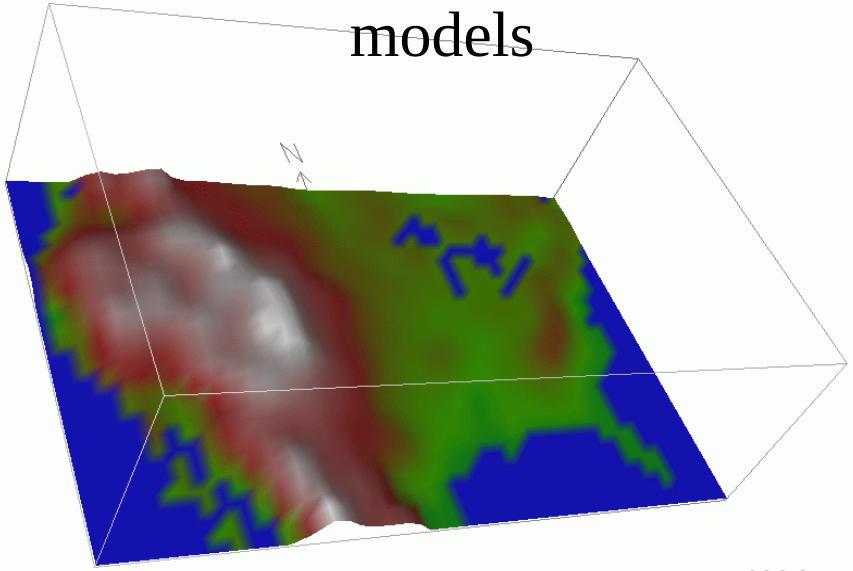
- Future projections of Arctic sea ice loss are uncertain due to: intrinsic climate variability, forcing scenario uncertainty, model uncertainty
- Model uncertainty is influenced by simulated late 20th century conditions and the role of model representations on climate feedbacks
- Nevertheless, all models simulate enhanced Arctic warming and Arctic sea ice decline
- Faster rates of decline and a potential for abrupt changes in September sea ice are simulated by many of the better Arctic models


Questions?

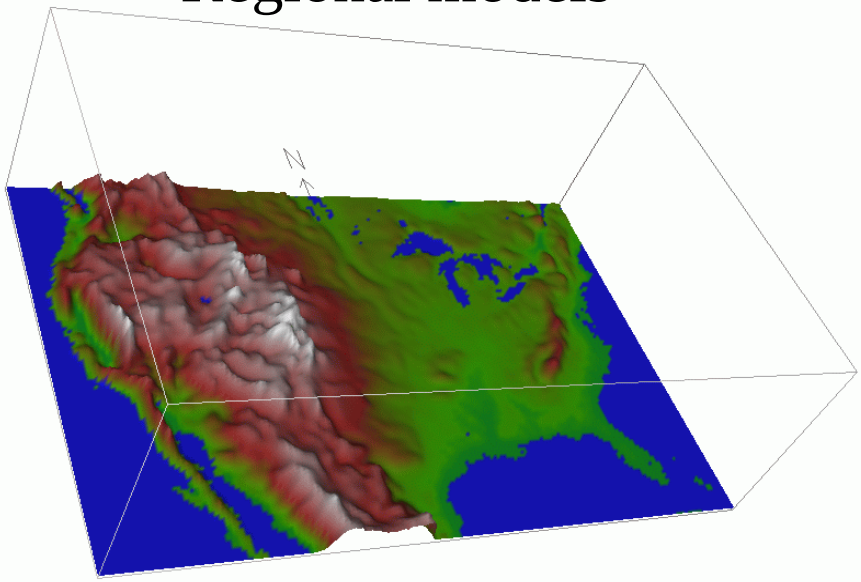
Climate Models circa early 1990s



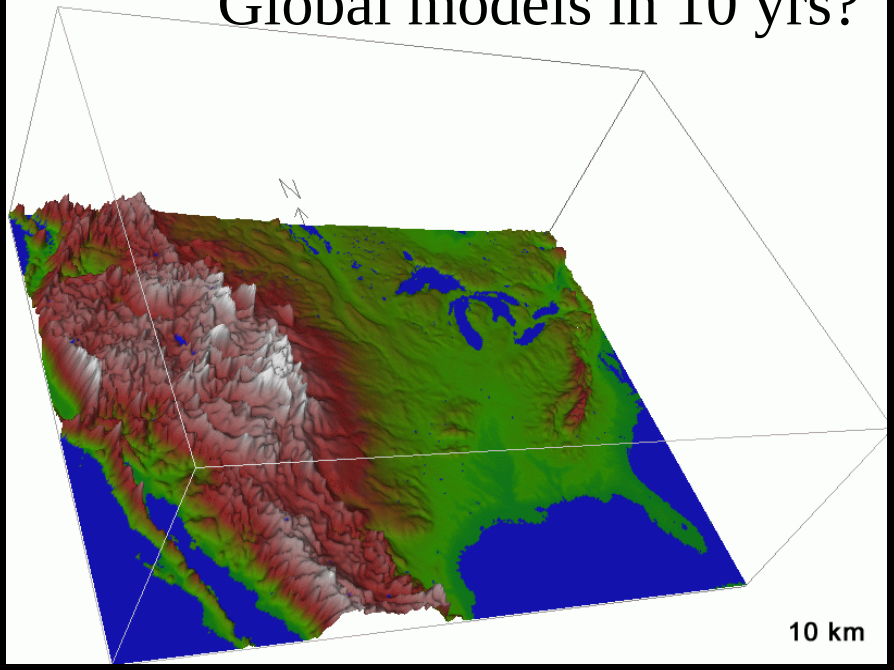
Current global coupled climate models



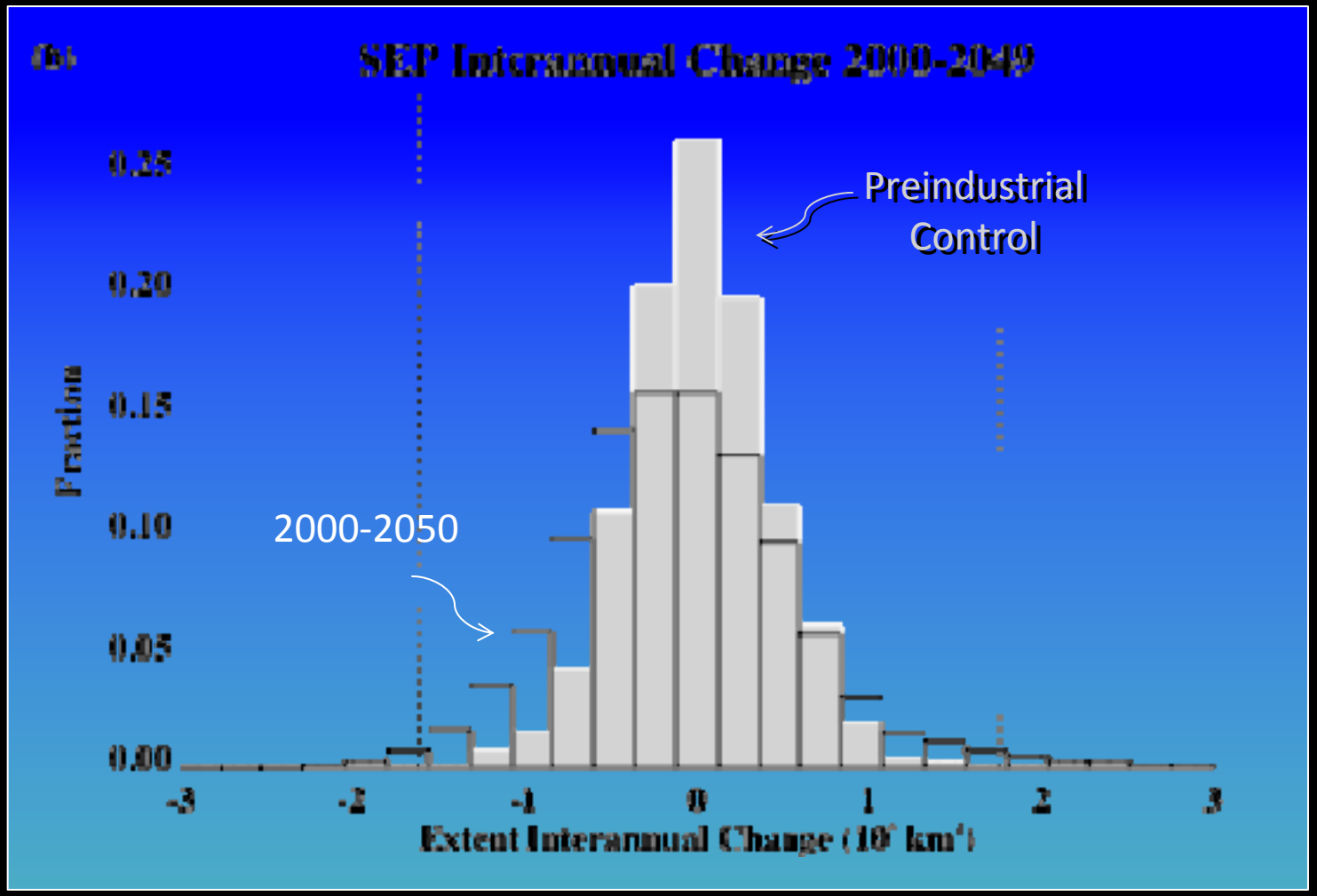
Regional models



Global models in 10 yrs?

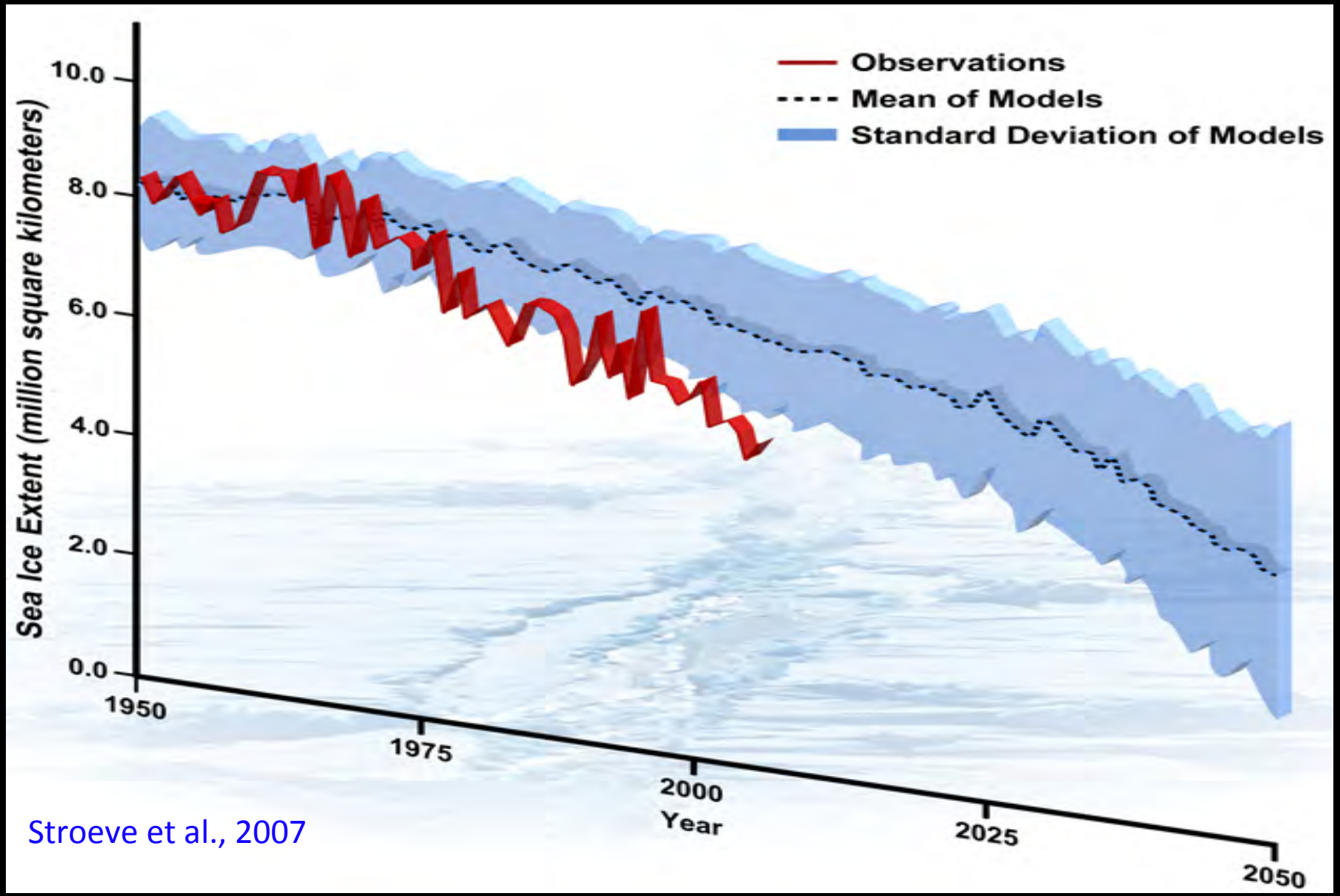


Models indicate changing sea ice variability with changing climate state



(Holland et al., 2008)

Climate model projections: IPCC-AR4 models reach ice free Sept conditions between 2050 to after 2100.



Stroeve et al., 2007