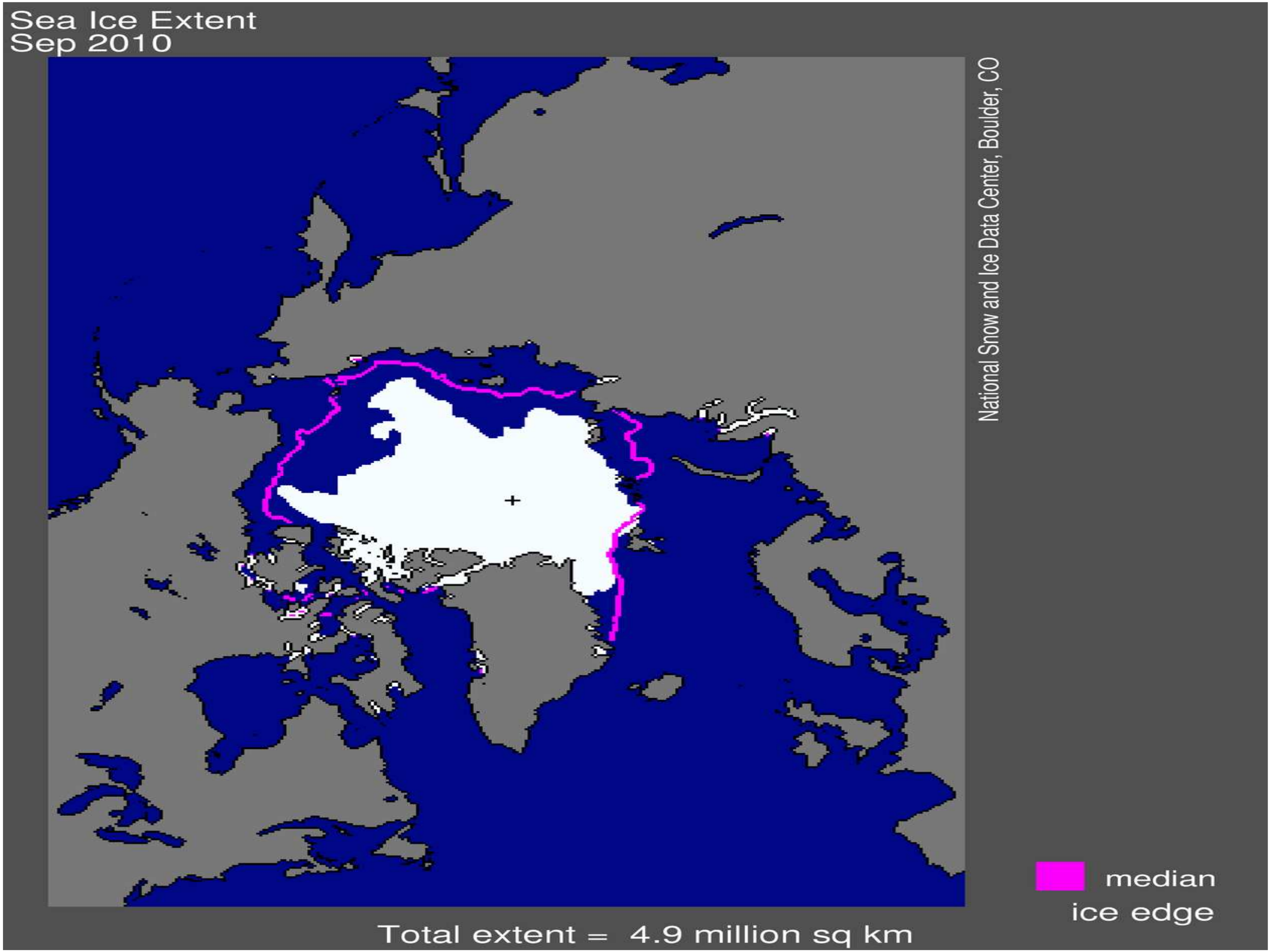

Sea Ice Extent
Sep 2010
National Snow and Ice Data Center, Boulder, CO
median
ice edge
Total extent = 4.9 million sq km

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Arctic Climate Modelling

Ralf Döscher
(Rossby Centre/SMHI)

- The role of the Arctic in global climate
- Arctic climate in global models
- Regional Arctic climate models
- Sea ice modelling
- Arctic climate process and feedback studies
- Climate change scenarios of the Arctic
- Uncertainties and user perspective

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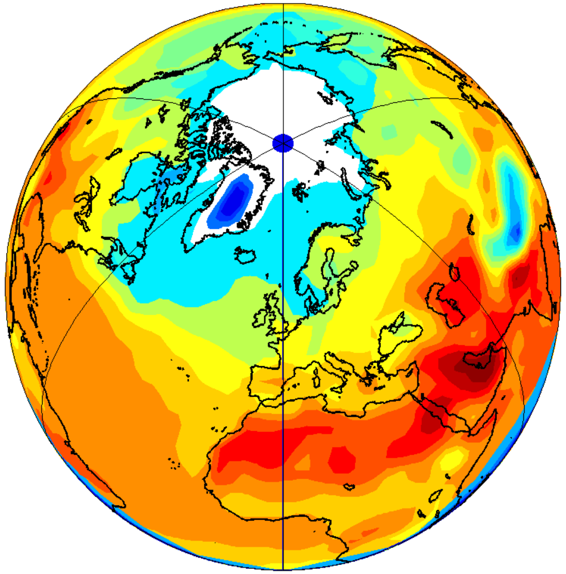
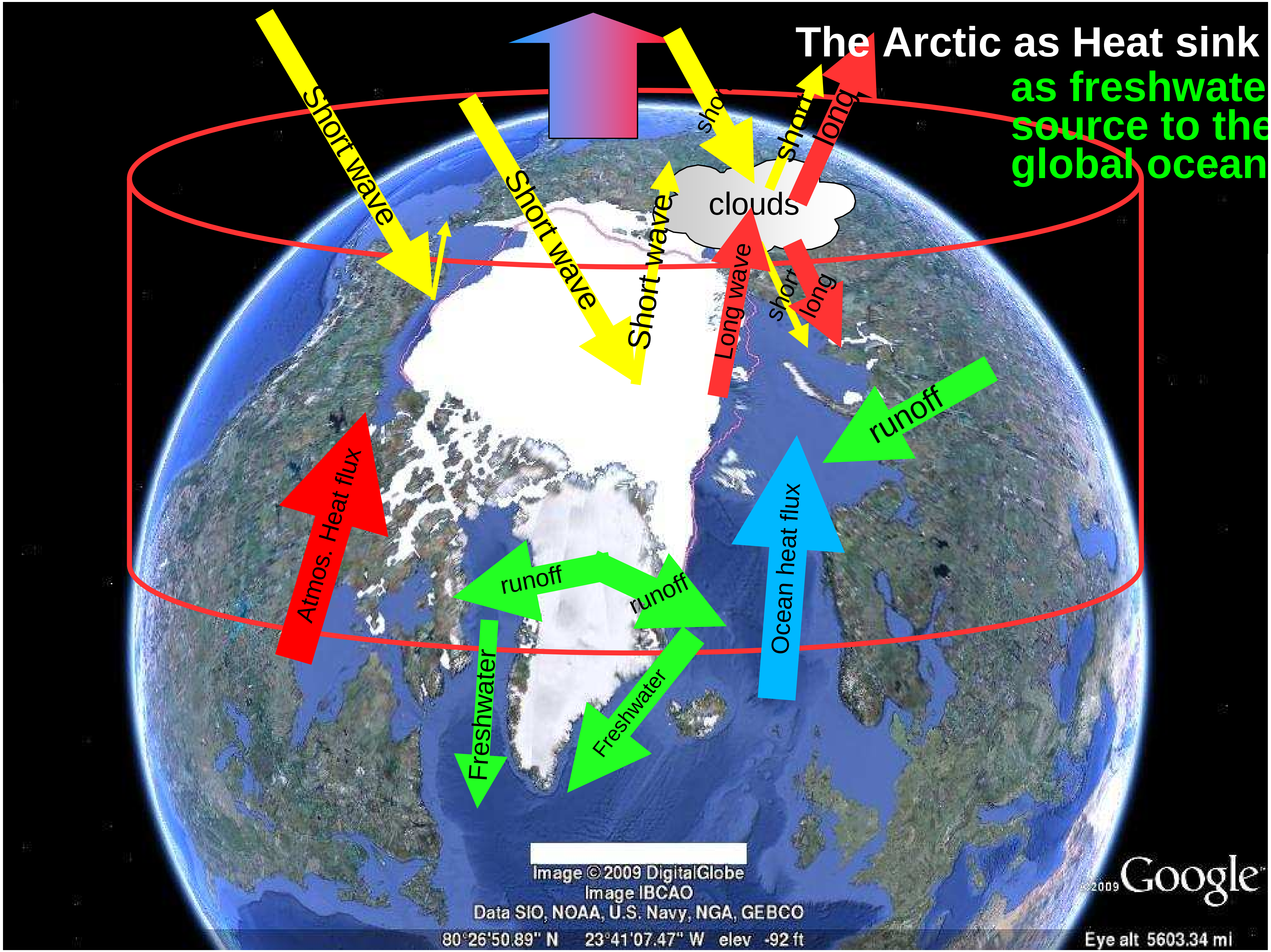
The Role of the Arctic in Global Climate

- Heat sink
- Water conversion warm -> cold
- Freshwater controller
- Arctic amplification
- Changing sea ice is directly affecting northern land conditions
- Impact on atmospheric circulation and oscillation patterns

} affecting global ocean circulation




The Arctic as Heat sink
as freshwate
source to the
global ocean
Short wave
Short wave
Short wave
clouds
Long wave
long
short
long
runoff
Atmos. Heat flux
Ocean heat flux
runoff
runoff
Freshwater
Freshwater
Image © 2009 DigitalGlobe
Image IBCAO
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
80°26'50.89" N 23°41'07.47" W elev -92 ft
Eye alt 5603.34 mi
©2009 Google

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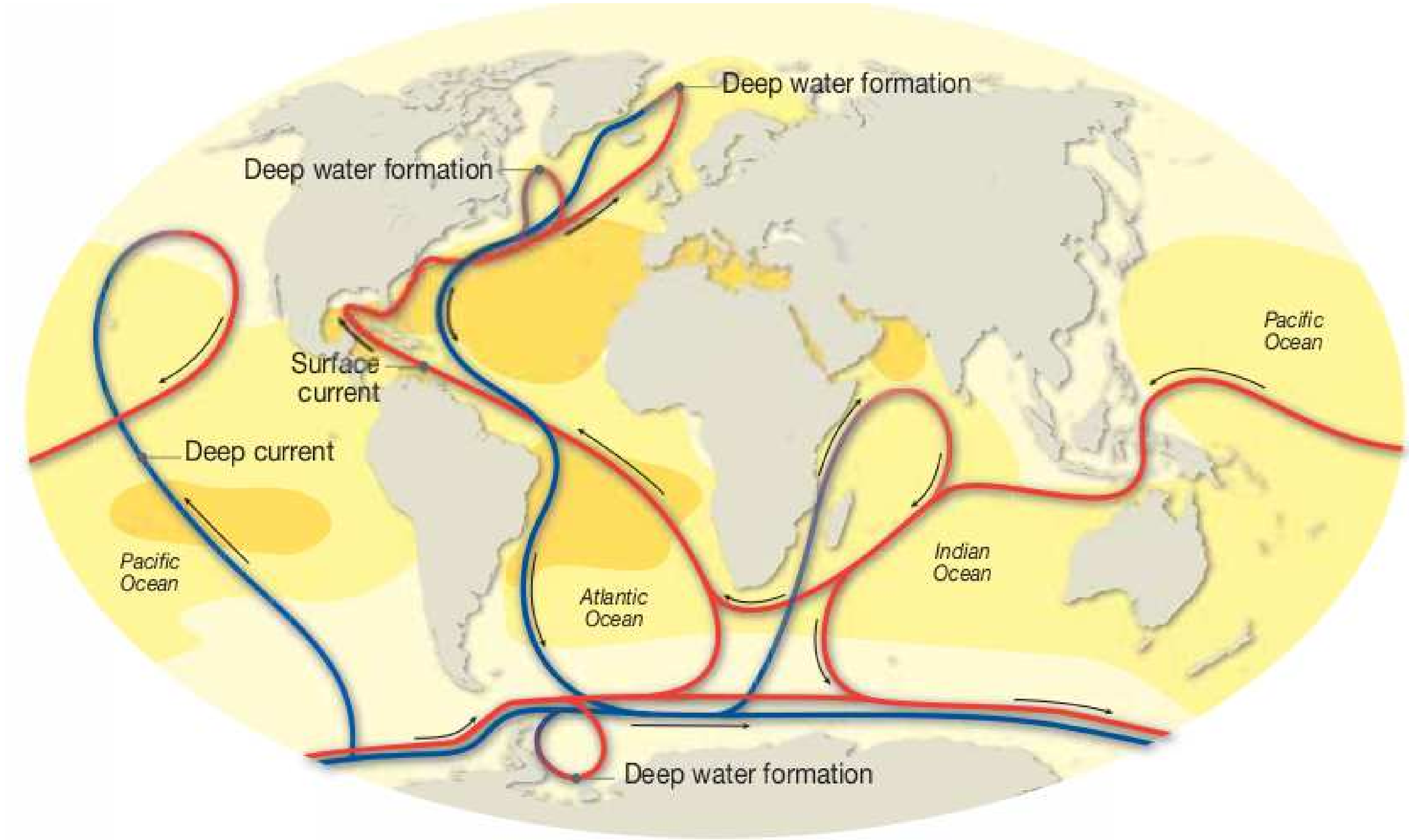
The Global Ocean Overturning
"Ocean Conveyor Belt" (Broecker, 1981)



In this schematic of the MOC, warm surface currents are shown in red, and cold deep currents are shown in blue. The surface currents are transformed to deep currents at high latitudes both in the South and in the North (adapted from NASA).

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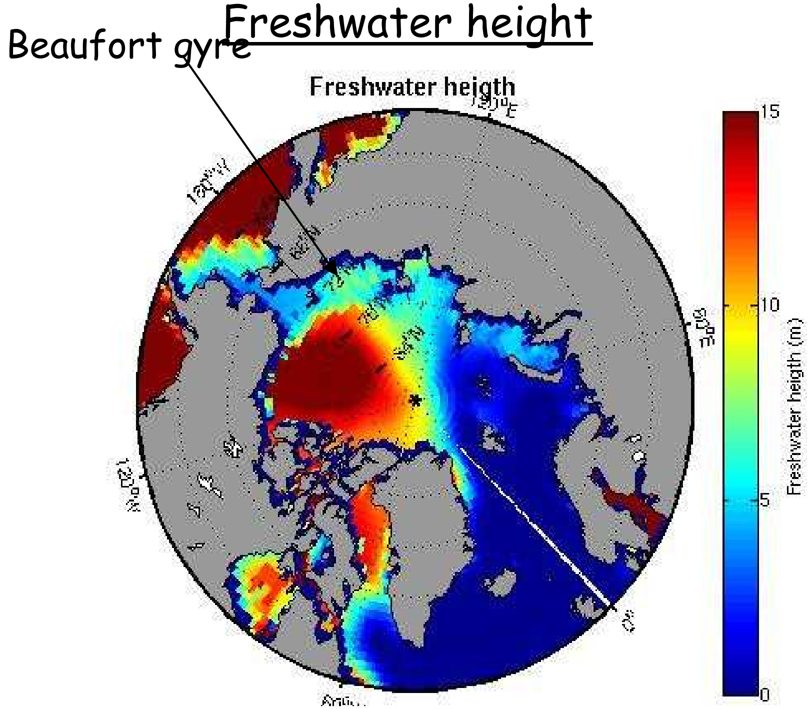
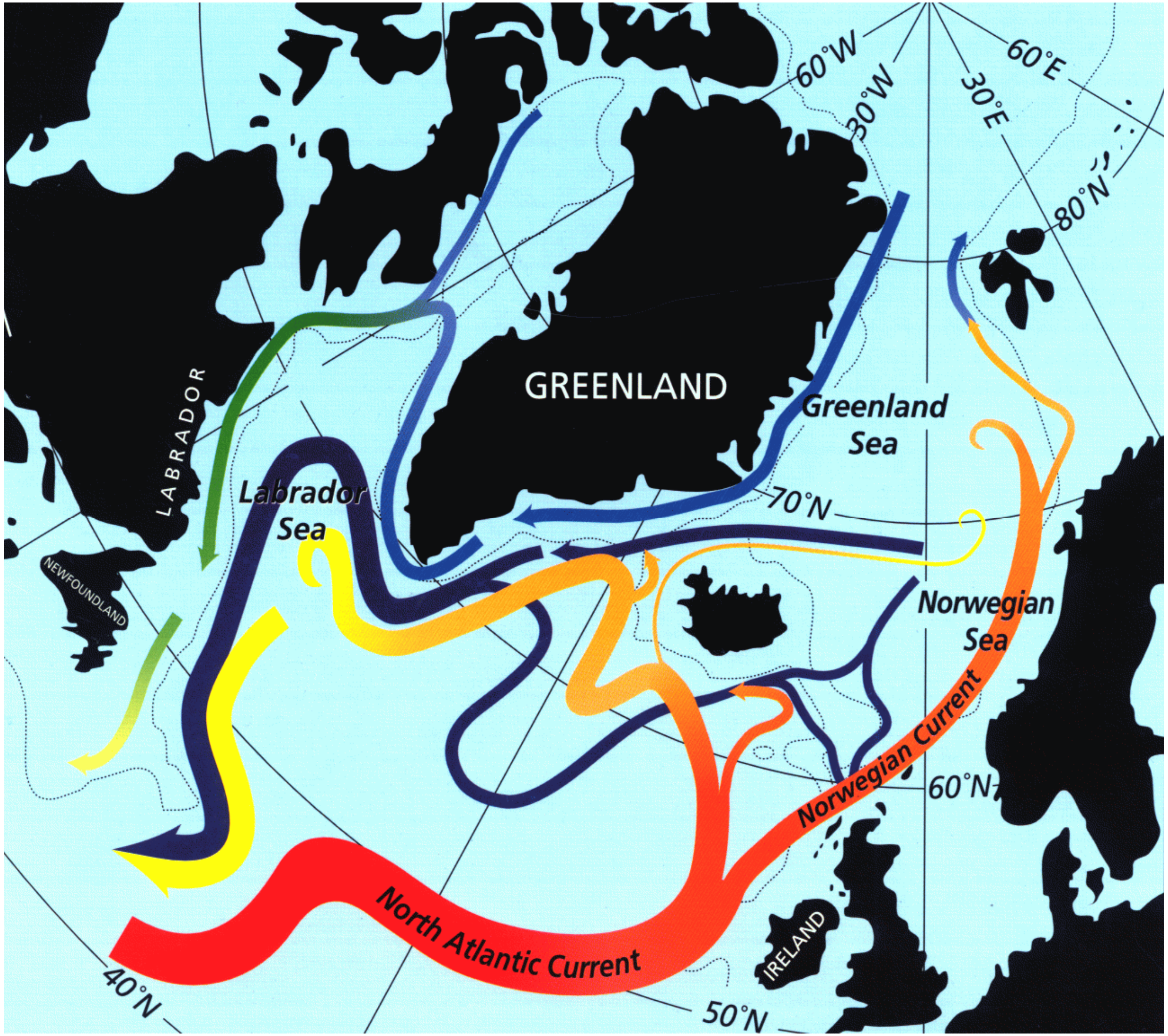
Freshwater storage and release in the Arctic

- FW storage of 84,000 km^3, 10 times larger than the annual FW input
- Mean residence time of 10-15 years
- Input variability is not correlated with output variability
- Flushing ruled by variations in atmospheric circulation

Freshwater height



Ocean Currents in deep water formation regions



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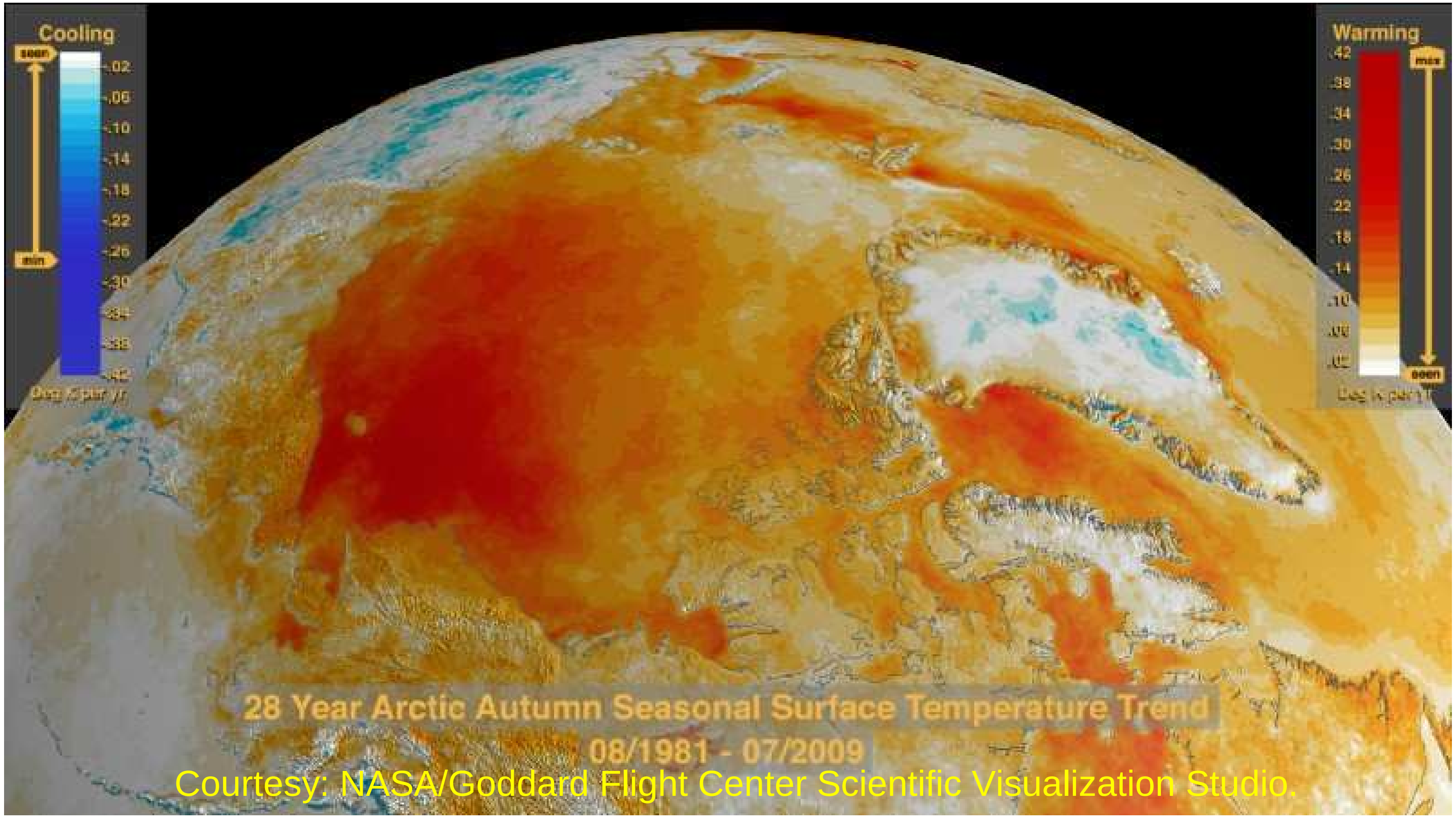
Arctic Amplification



Courtesy: NASA/Goddard Flight Center Scientific Visualization Studio.

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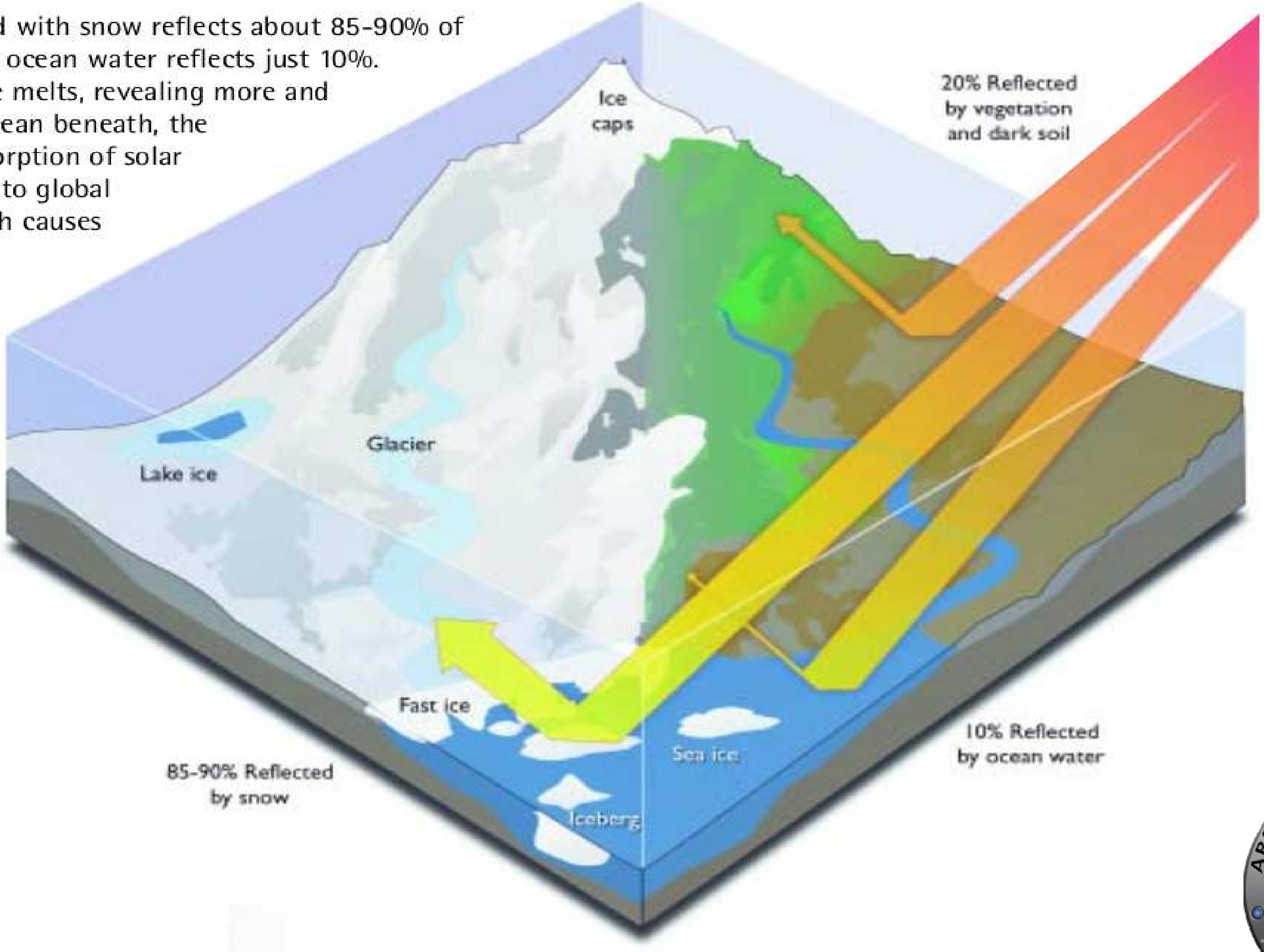
Arctic feedbacks: ice albedo feedback

Sea ice covered with snow reflects about 85-90% of sunlight, while ocean water reflects just 10%. Thus, as sea ice melts, revealing more and more of the ocean beneath, the increasing absorption of solar radiation adds to global warming, which causes more melting, which in turn causes more warming, and so on...



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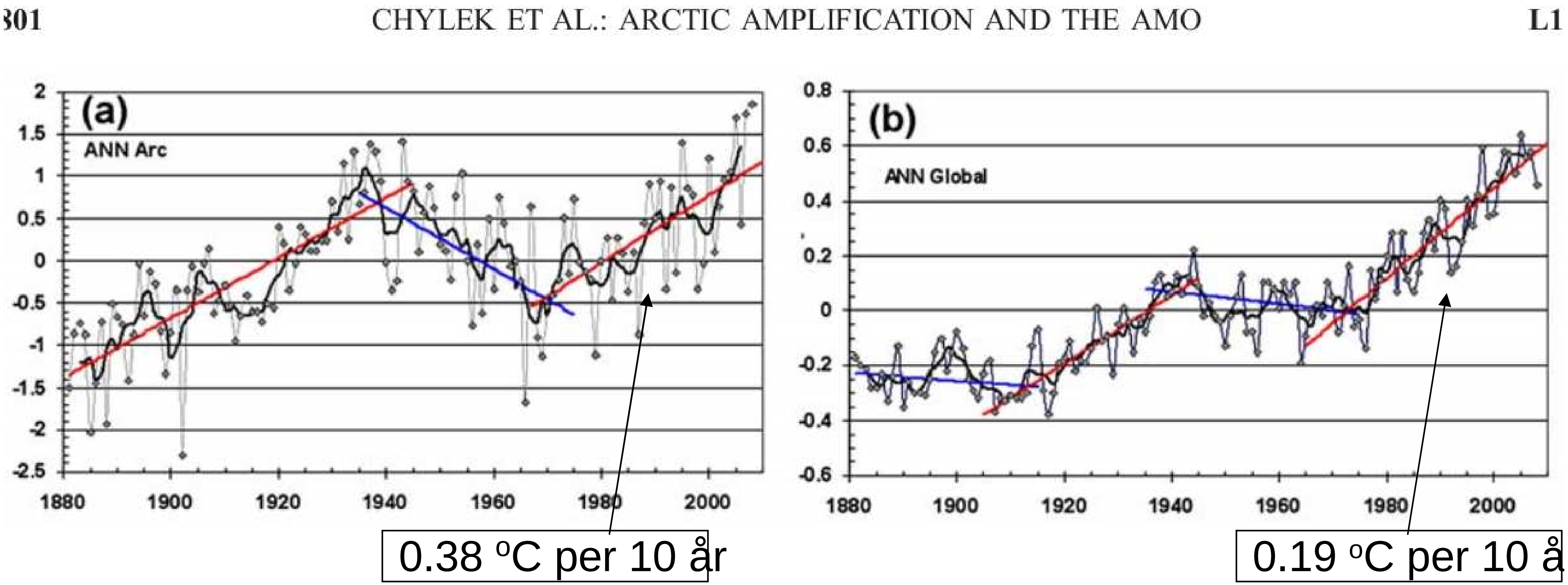
Arctic Amplification



Arctic and global temperature anomalies

relative to the 1910-2008 average

=> The Arctic is warming faster

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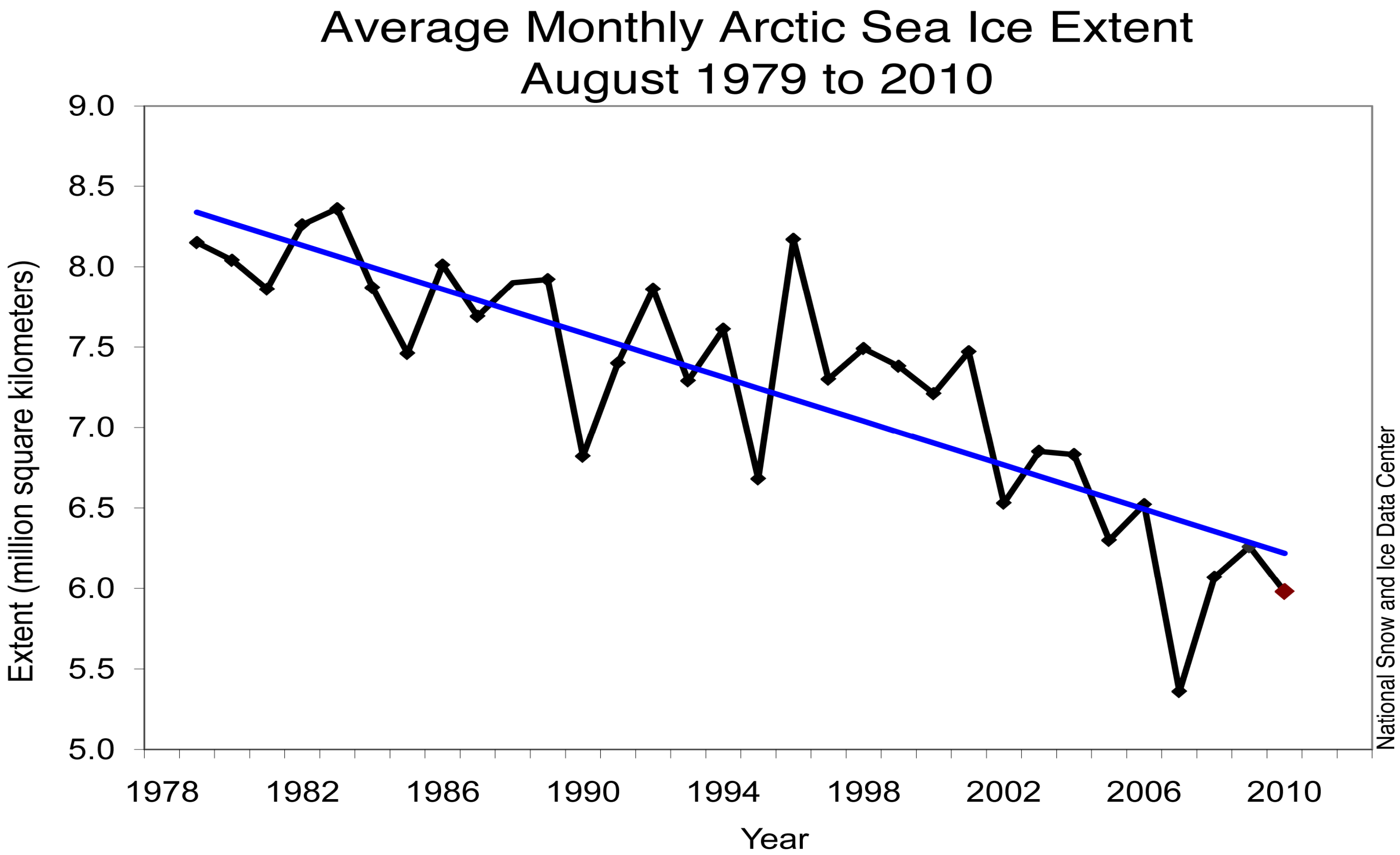
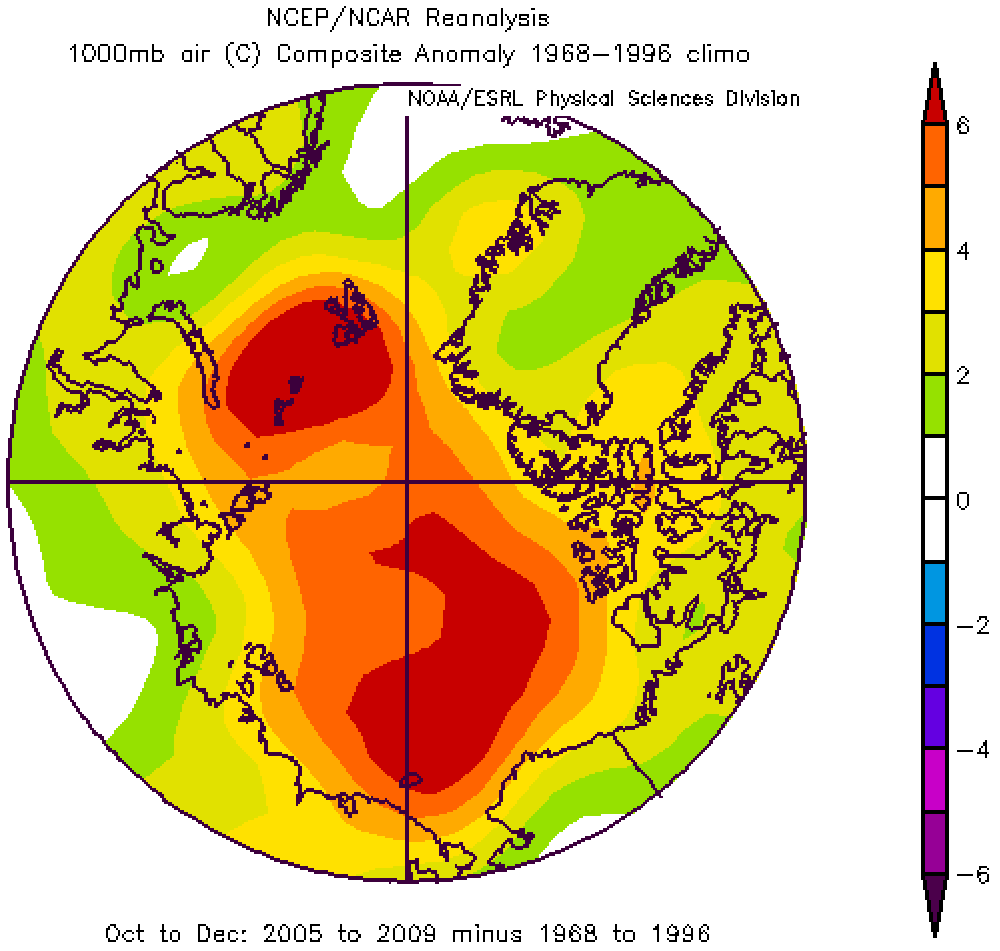
Sea ice extent



Effect of ice retreat on land areas

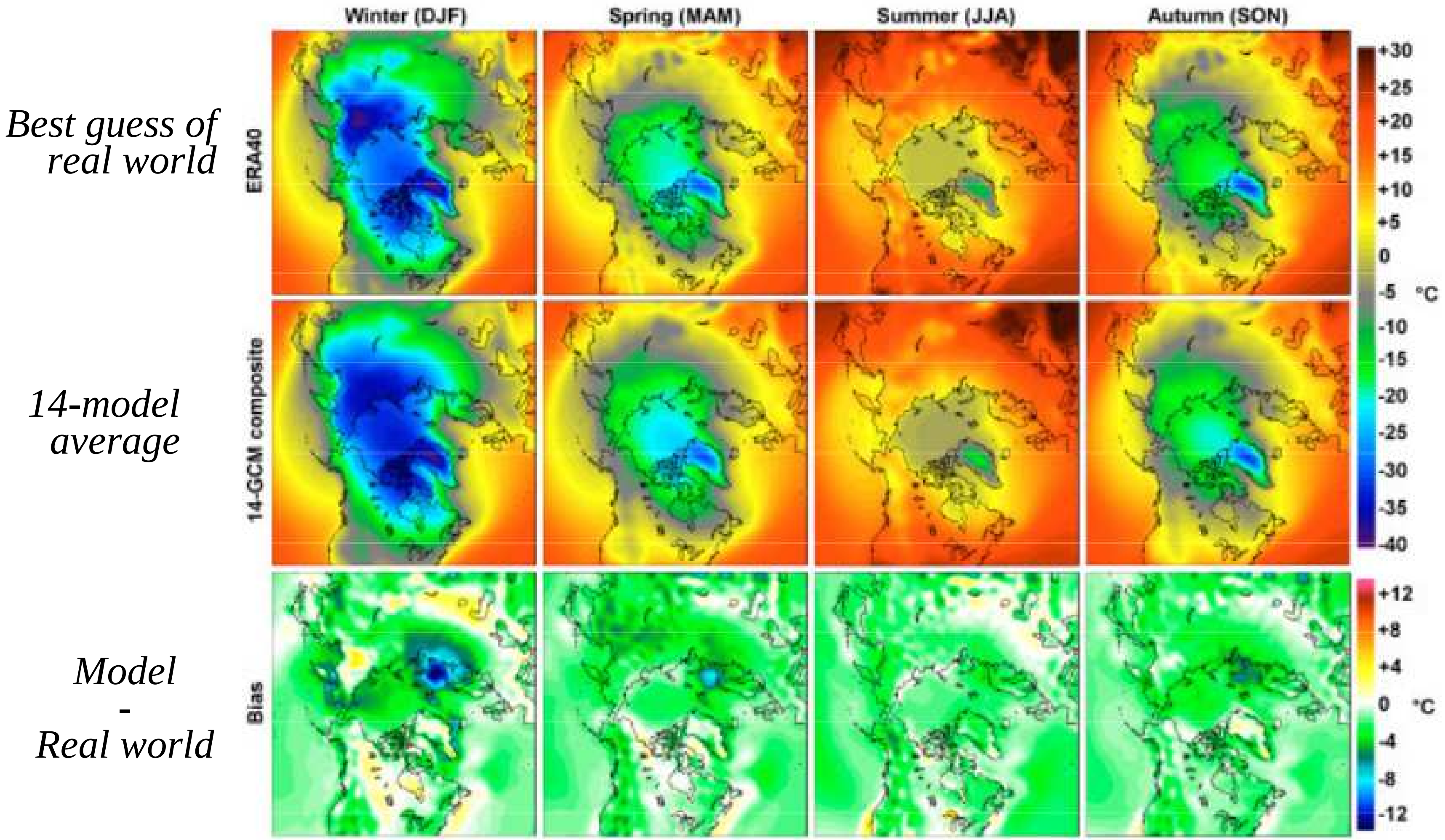


Near surface air temperature anomalies. Data are from the NCEP, generated online at www.cdc.noaa.gov .

Arctic Climate in Global Climate Models (GCMs)

- Control climates
- Arctic Amplification in GCMs
- Representation of recent sea ice change

Surface temperature control climate in 14 GCMs



Individual models disagree from the average

Chapman, Walsh et al. 2006

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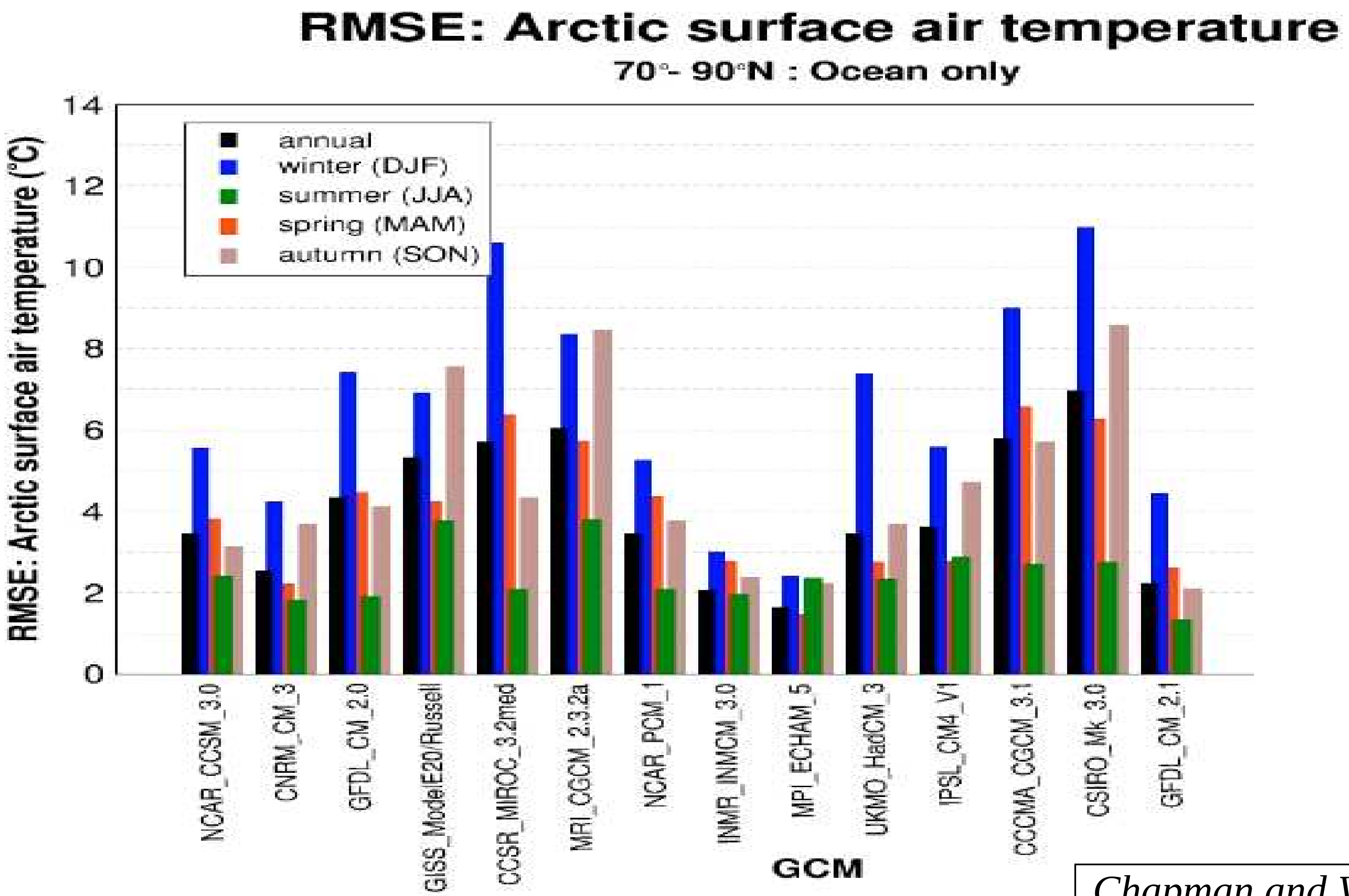
Arctic Temperature: differences between GCMs



Chapman and Walsh (2006)

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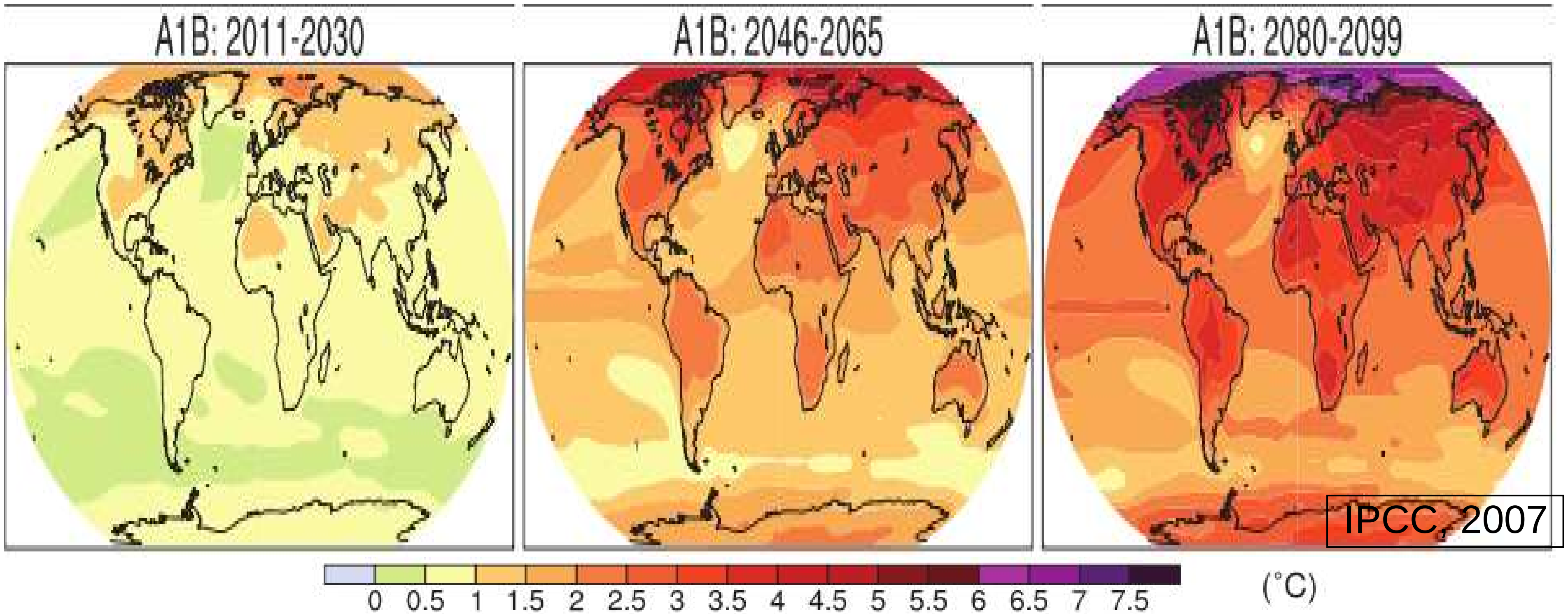
Arctic Amplification in GCMs



IPCC, 2007: Multi-model mean of annual mean surface warming (surface air temperature change, °C) for three time periods. Anomalies are relative to the average of the period 1980 to 1999.

Reasons:
Temperature – ice albedo feedback
Changed large scale circulation and heat flux into the Arctic

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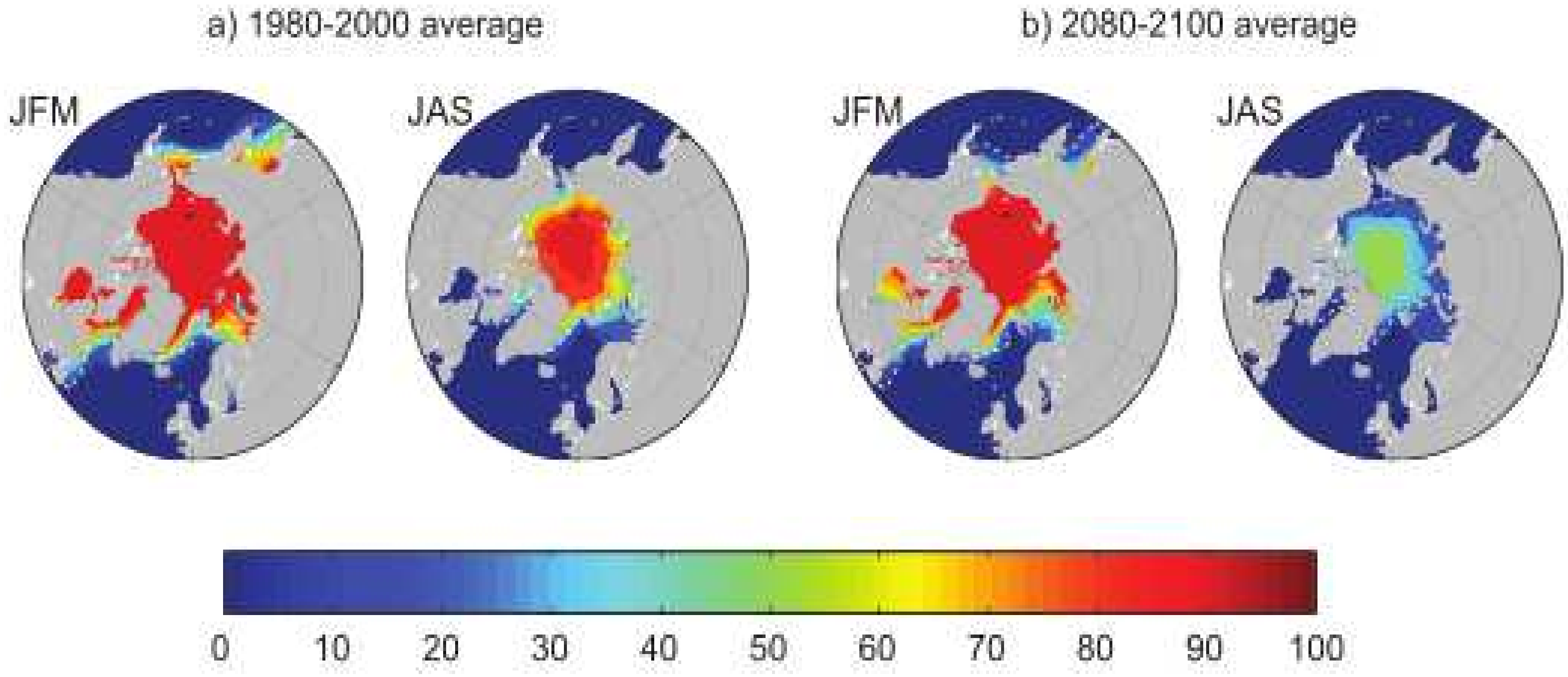
Sea ice extent in GCMs



Multi-model mean sea ice concentration (%) for January to March (JFM) and June to September (JAS), in the Arctic (top) for the periods (a) 1980 to 2000 and b) 2080 to 2100 for the SRES A1B scenario. The dashed white line indicates the present-day 15% average sea ice concentration limit. Modified from Flato et al. (2004).

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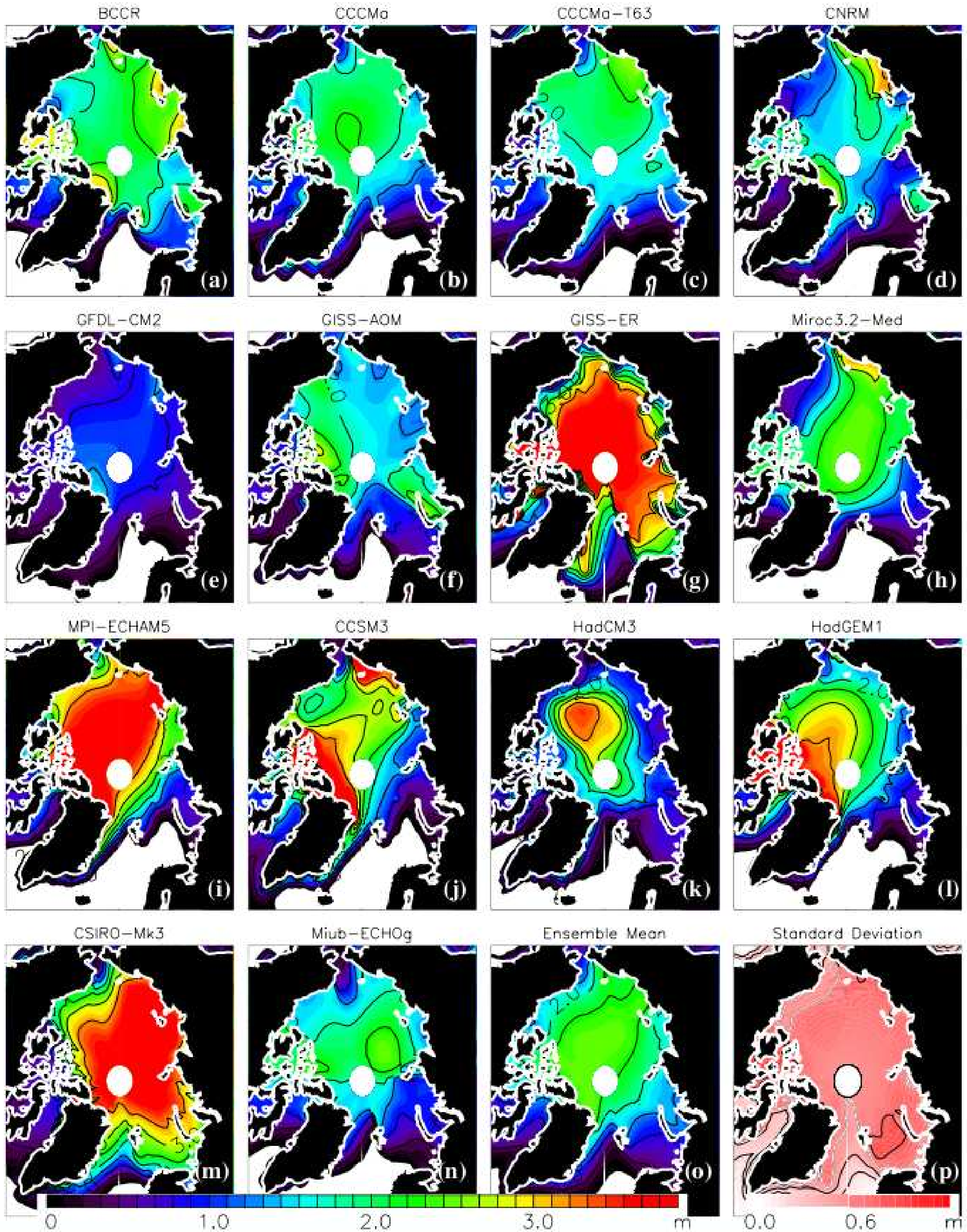
Climatological late twentieth century annual ice thickness averaged from 1980 to 1999 from the 14 models considered, the multi-model ensemble mean thickness, and the inter-model SD (the latter two as the last two panels of the *bottom row*). The isolines are at intervals of 0.5 m intervals, except for the *bottom right panel*, where the interval is 0.25 m



Differences due to

- Sea ice rheology
- Atmospheric forcing
- Ocean forcing

Holland et al. 2010

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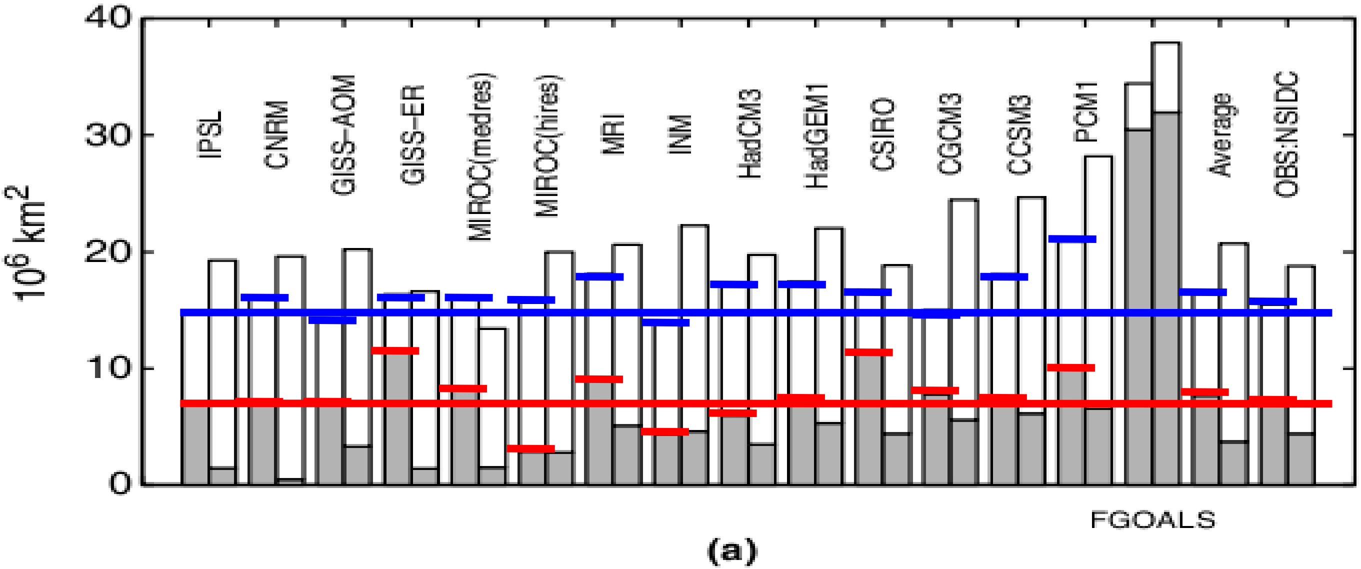
Sea ice extent in GCMs

O. Arzel et al. / Ocean Modelling 12 (2006) 401–415

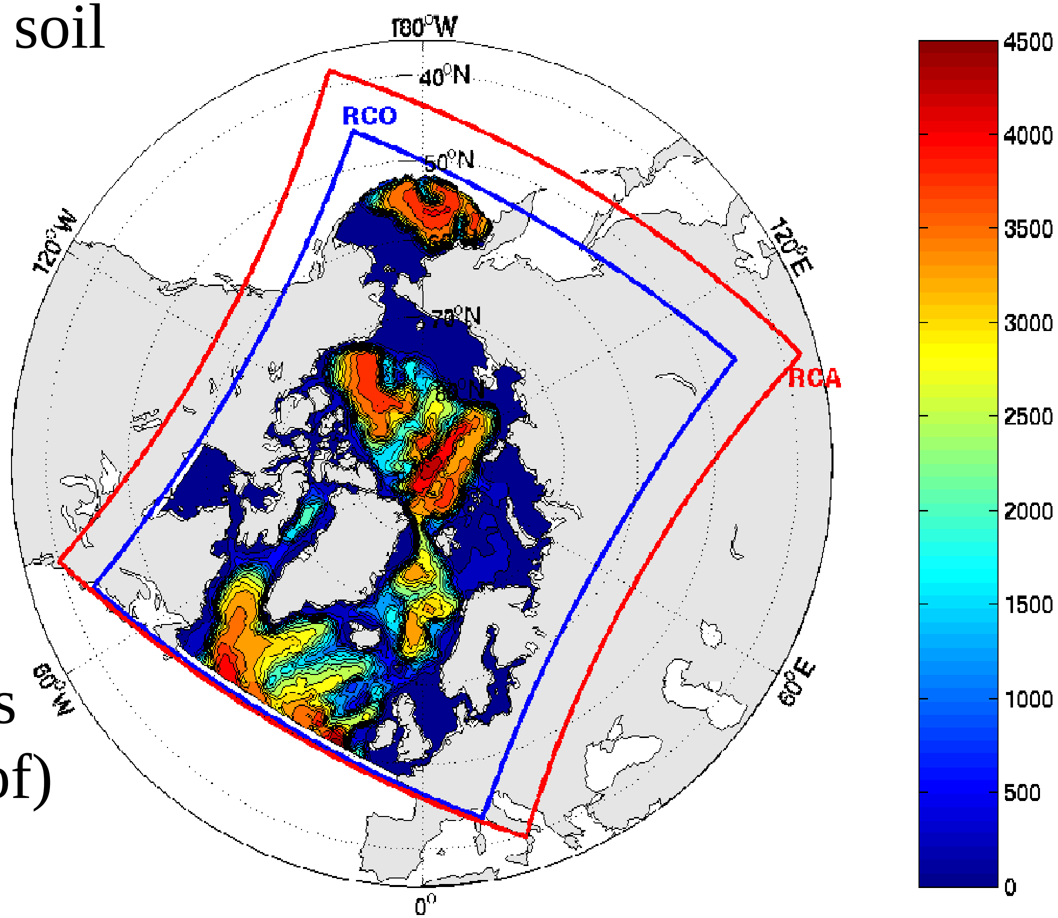


Mean Arctic sea ice extent (left bars) averaged over 1981–2000.
The white shading represents the absolute value of the ice extent difference between March and September, whereas the gray shading indicates the ice extent at the end of the melt season

Results would potentially be much better if the ocean/ice model would be forced by observed atmospheric fields

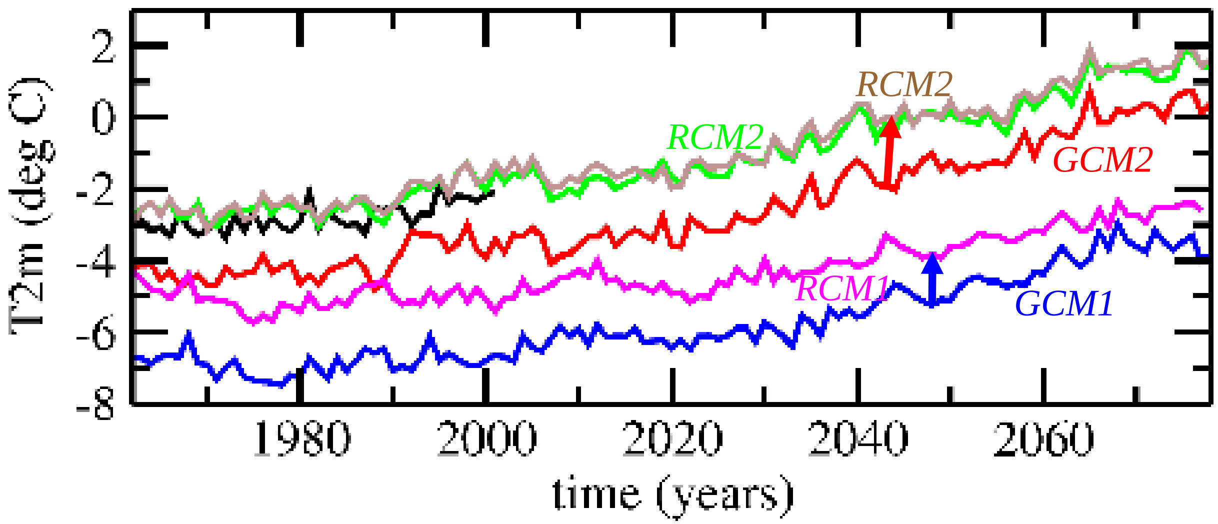
Regional Climate Models: Downscaling

- Atmosphere, ocean, sea ice, soil
- Coupling frequency 3h



- Forcing at lateral boundaries
- “observations” (best guess of)
- Global climate model

Regional models can potentially perform better than GCMs



Annual mean 2m air temperature in ^{o}C, averaged over the entire RCA-domain (top)

Koenigk et al, 2010

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Sea ice modelling

- Thermodynamics
- Dynamics
- Ice classes
- Melting and freezing
- Sensitivities

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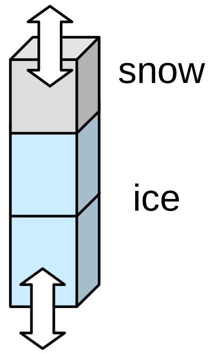
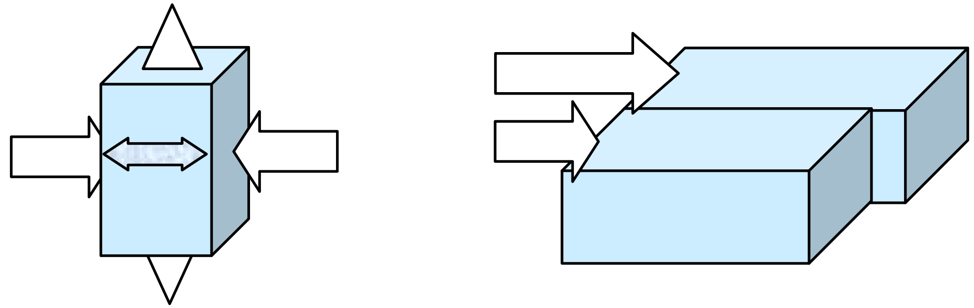
Basics of sea ice modelling





Thermodynamics:

Response to thermal forcing,
Surface reflectivity,
heat conduction,
Inhomogenities,
Snow-to-ice conversion,
...

Dynamics, rheology:

Response to stress from ocean and atmosphere.
Stress, strain,
shear, distortion,
...

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Sea ice parameterizations in climate models:

- ice/snow albedo, melt ponds
  - Important for summer ice retreat

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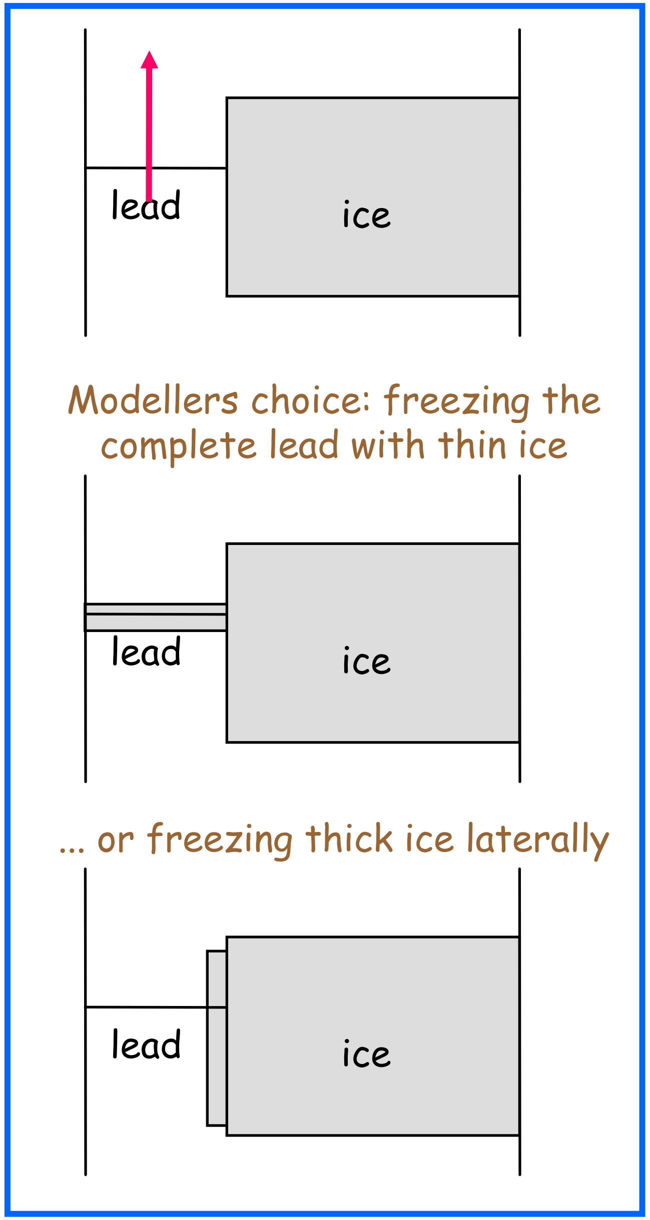
Sea ice parameterizations in climate models

- Lateral freezing
  - Important for winter buildup of thickness



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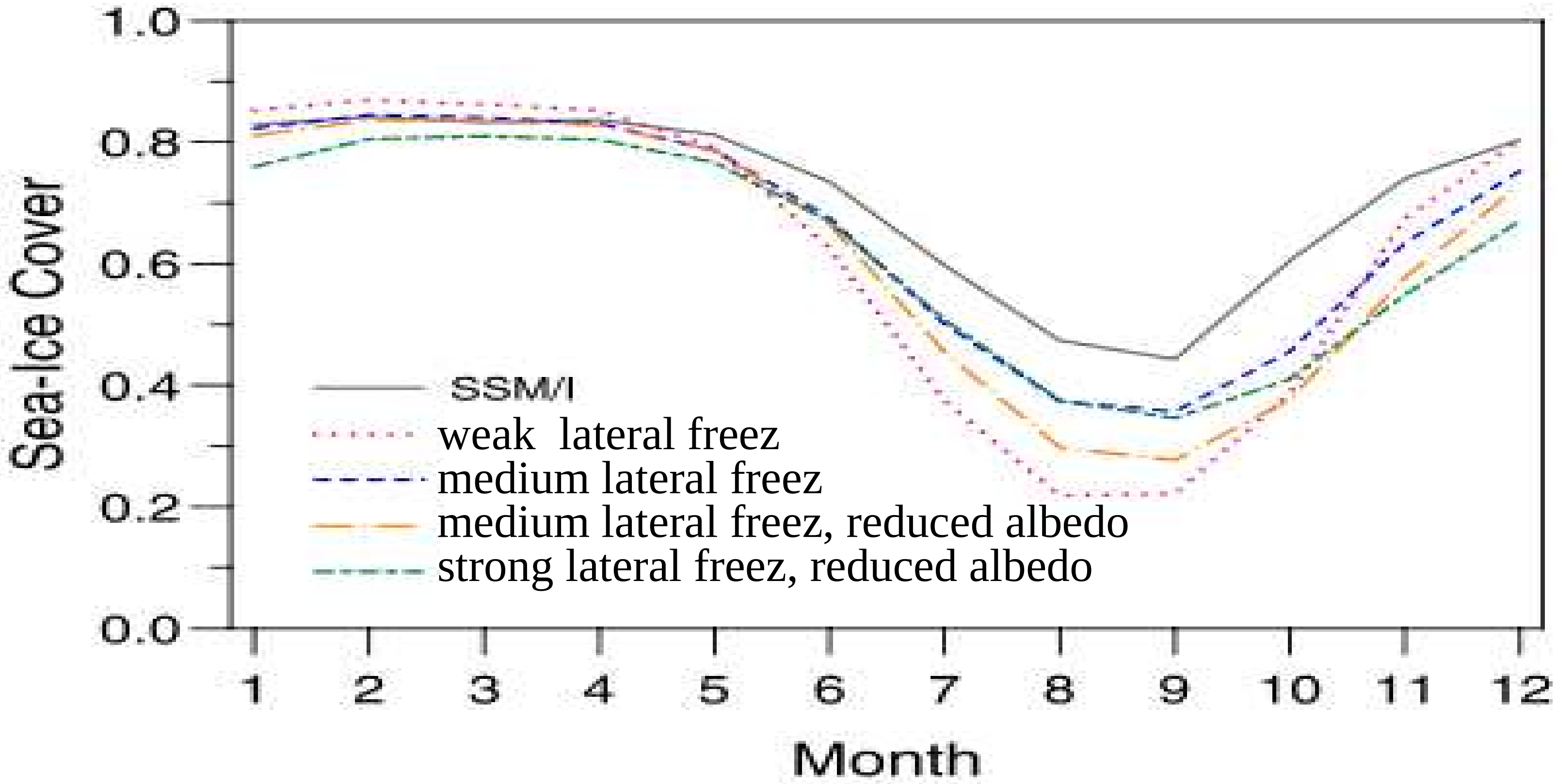
Sea ice parameterizations in a coupled climate model



Mean seasonal cycle (1996 –1999) sea ice cover north of 70°N from SSM/I data and simulations of HIRHAM-NAOSIM. Taken from Dorn et al. (2006)

=> "Model tuning" is necessary and needs to be done within the limits of process observations

Impact of using ice categories

Louvain-la-Neuve Ice Model (LIM)

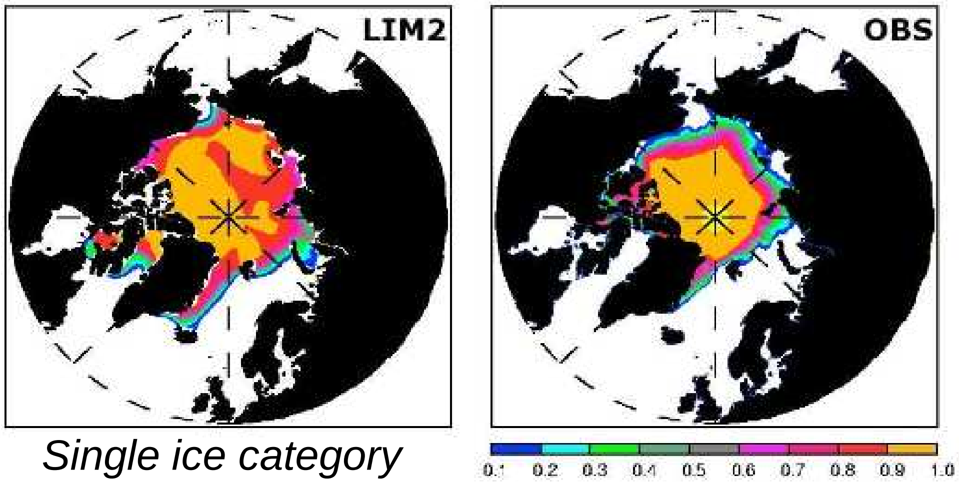
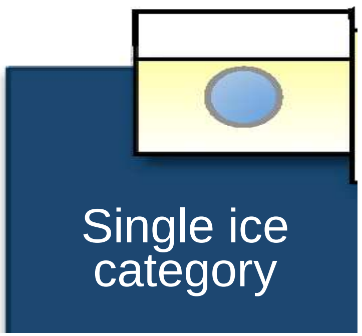
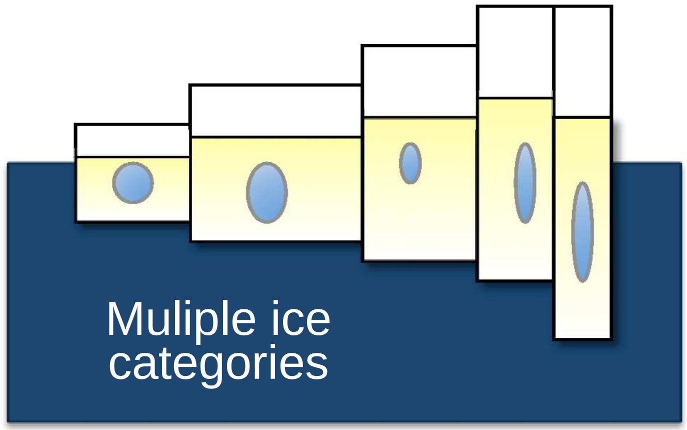


Fig. 2: Simulated September geographical distribution of ice concentration in the Arctic, simulated by LIM2 (left), as derived from passive microwave observations (Comiso, 2007, center), and simulated by LIM3 (right).





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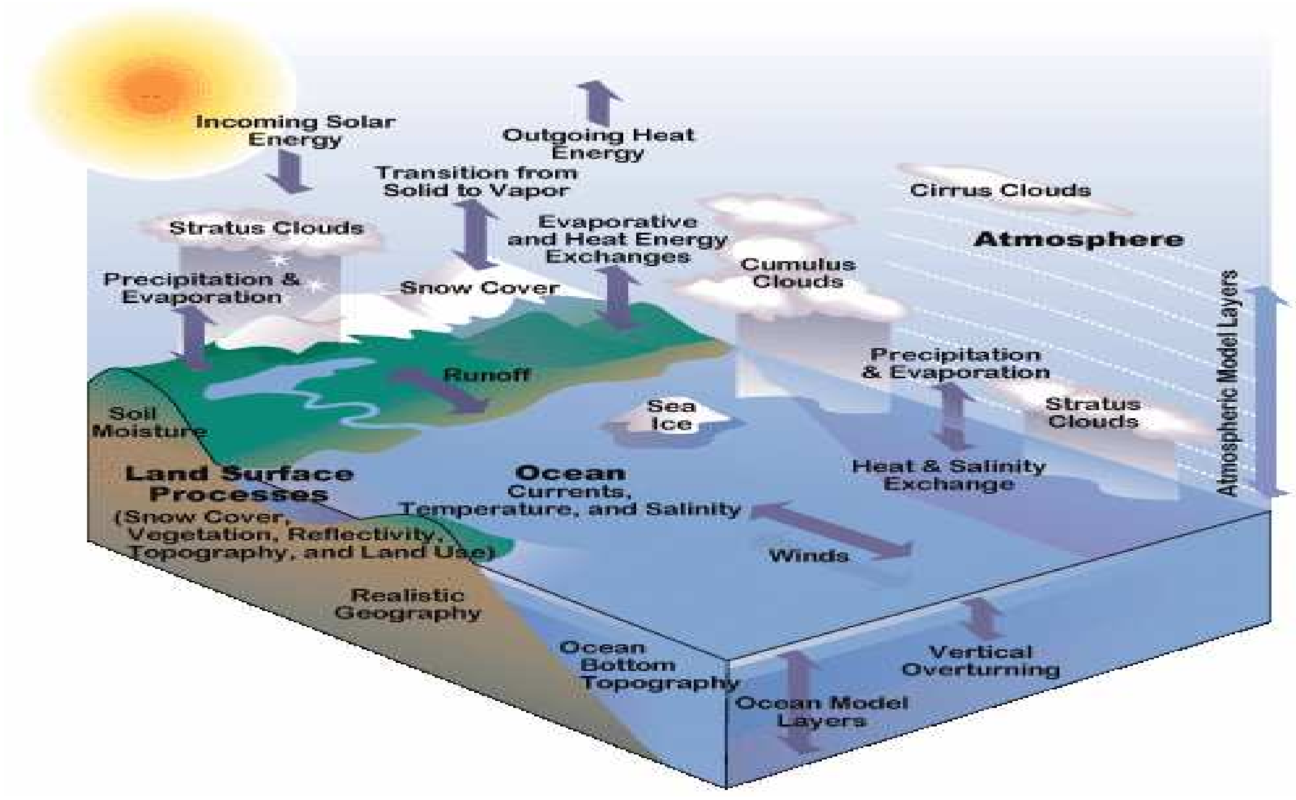
Arctic Climate Process and Feedback Studies



To simulate and understand the climate system we develop models that describe mathematically the key processes in the climate system

Wind drives the ice

Bitz et al. (2002):
Sea ice model, driven by different wind forcing.

Sensitivity experiments that test the model response to the wind composition show the ice thickness patterns depend primarily on the climatological mean annual cycle of the geostrophic winds.

=> seasonal mean wind is ruling the large scale structure of ice cover. Weather is not important

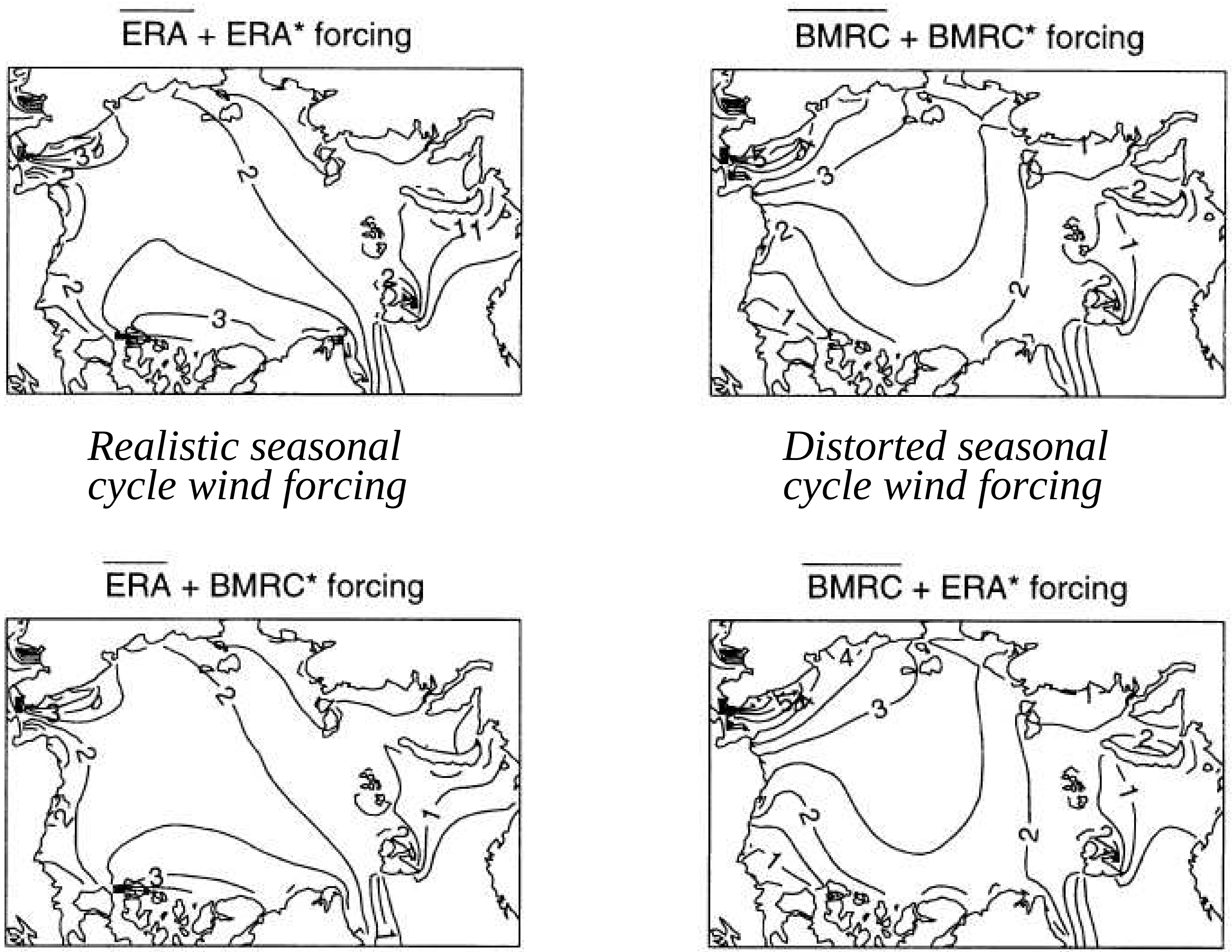
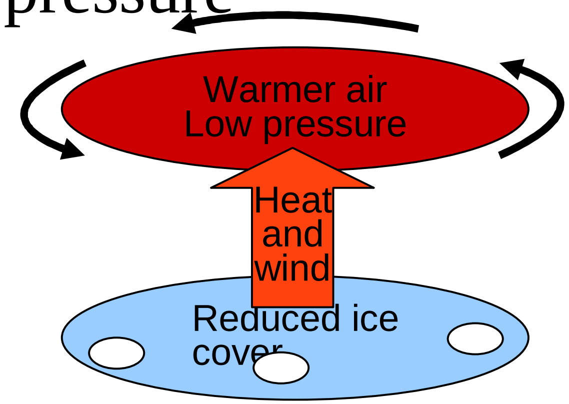


FIG. 11. Apr sea ice thickness pattern when the ice model is forced by a combinations of winds from ERA-15 or BMRC climatological mean annual cycle (denoted by overline) plus daily anomalies (denoted by superscripted star).

Ice cover feeds back on winds

- Reduction of ice cover gives local low pressure anomalies



- Large scale response is less clear
  - Negative NAO response (e.g. Alexander et al. 2004, Seierstad and Bader, 2010)
  - Positive NAO response (e.g. Singarayer 2006)
  - Increase of storm intensity due to increased (e.g. Bengtsson et al. 2006)
  - Reduced storm intensity in late winter directly coupled to reduced ice cover (e.g. Seierstad and Bader, 2010)

Arctic feedbacks

- Temperature - albedo feedback
  - (+) Temperature rise - less ice/more wet ice - increased heat absorption - warmer ice/ocean
- Temperature - cloud feedback
  - Temperature rise – increased evaporation – increased cloud cover -
    - (-) increased reflection of solar radiation - temperature reduction
    - (+) increased absorption of LW radiation from the surface - further temperature rise

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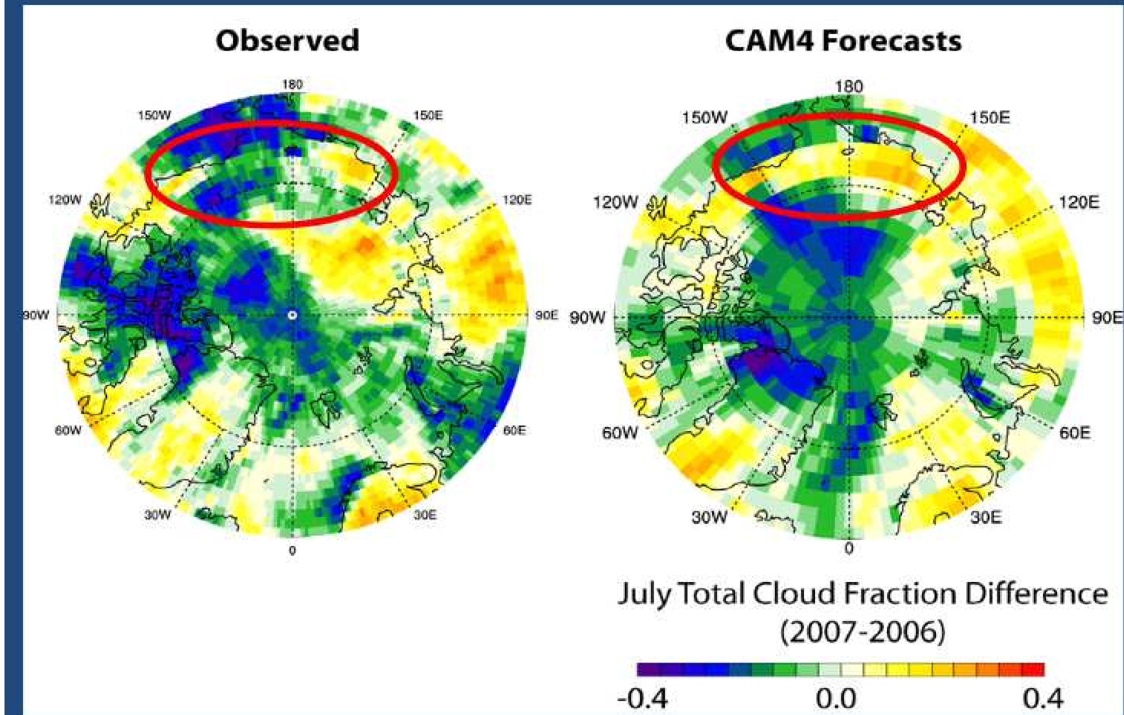
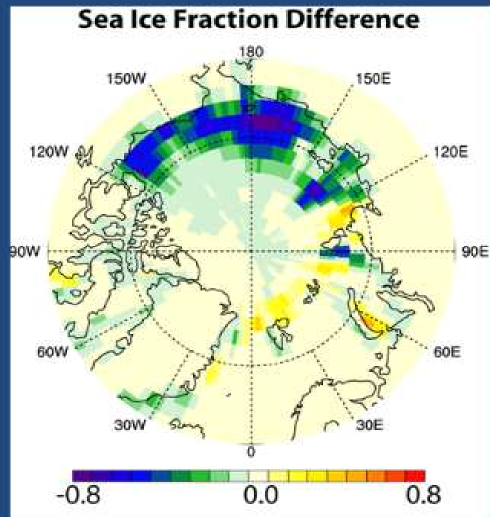
CAM4 predicts an unrealistic cloud response to sea ice loss during July 2007.





Jen Kay et al., 2010

A physically motivated change to the stratus cloud parameterization improved the cloud response to sea ice loss and increased surface energy budgets in July 2007 by 11 Wm^{-2}.

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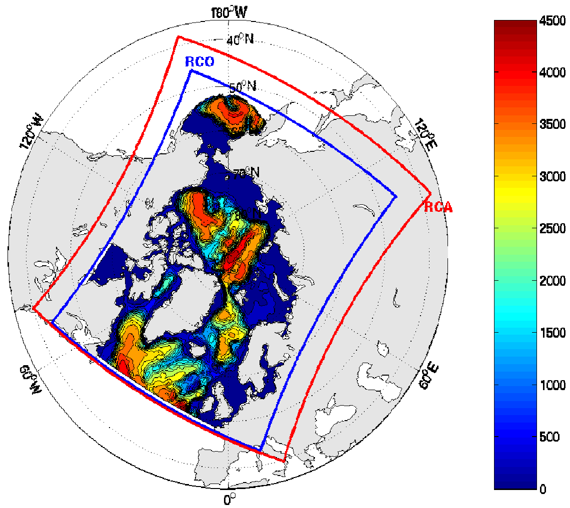
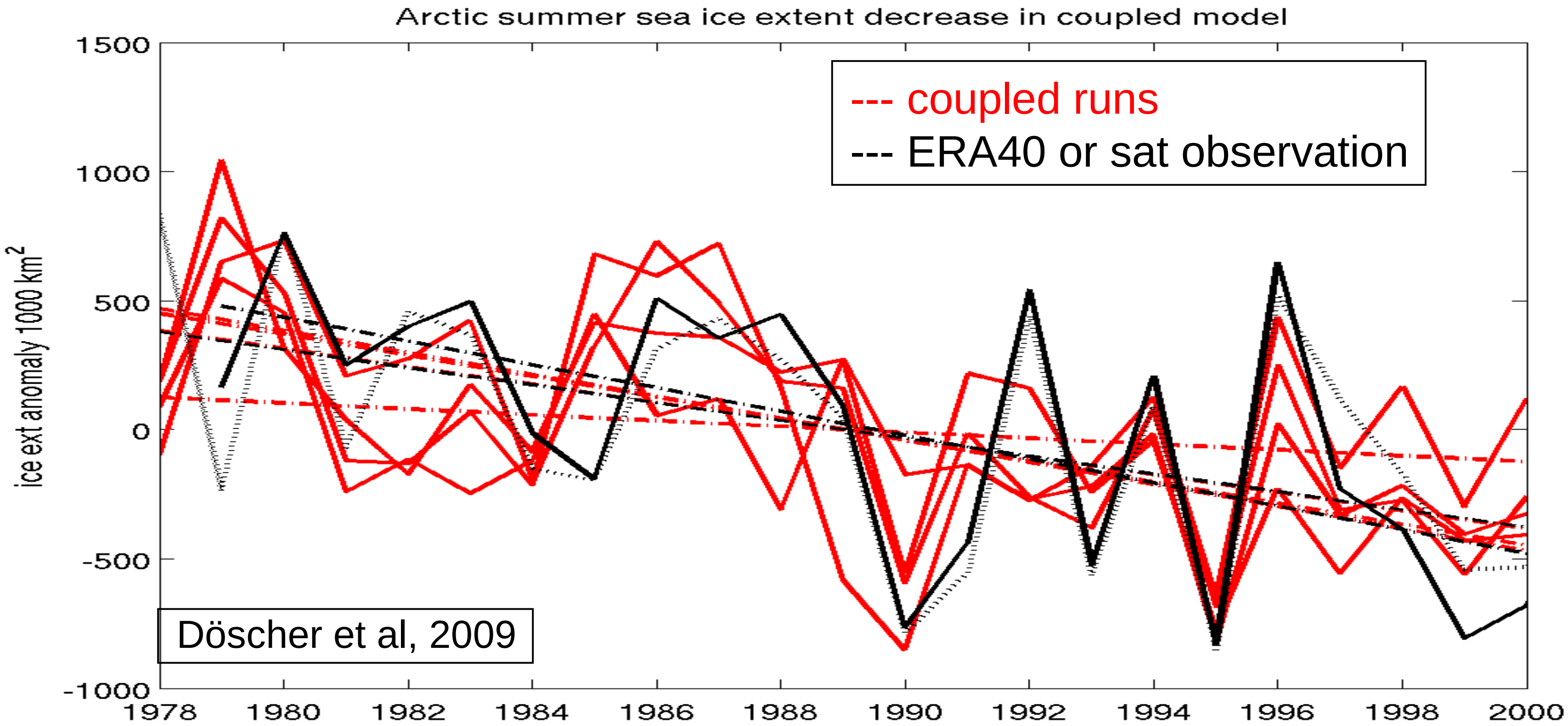
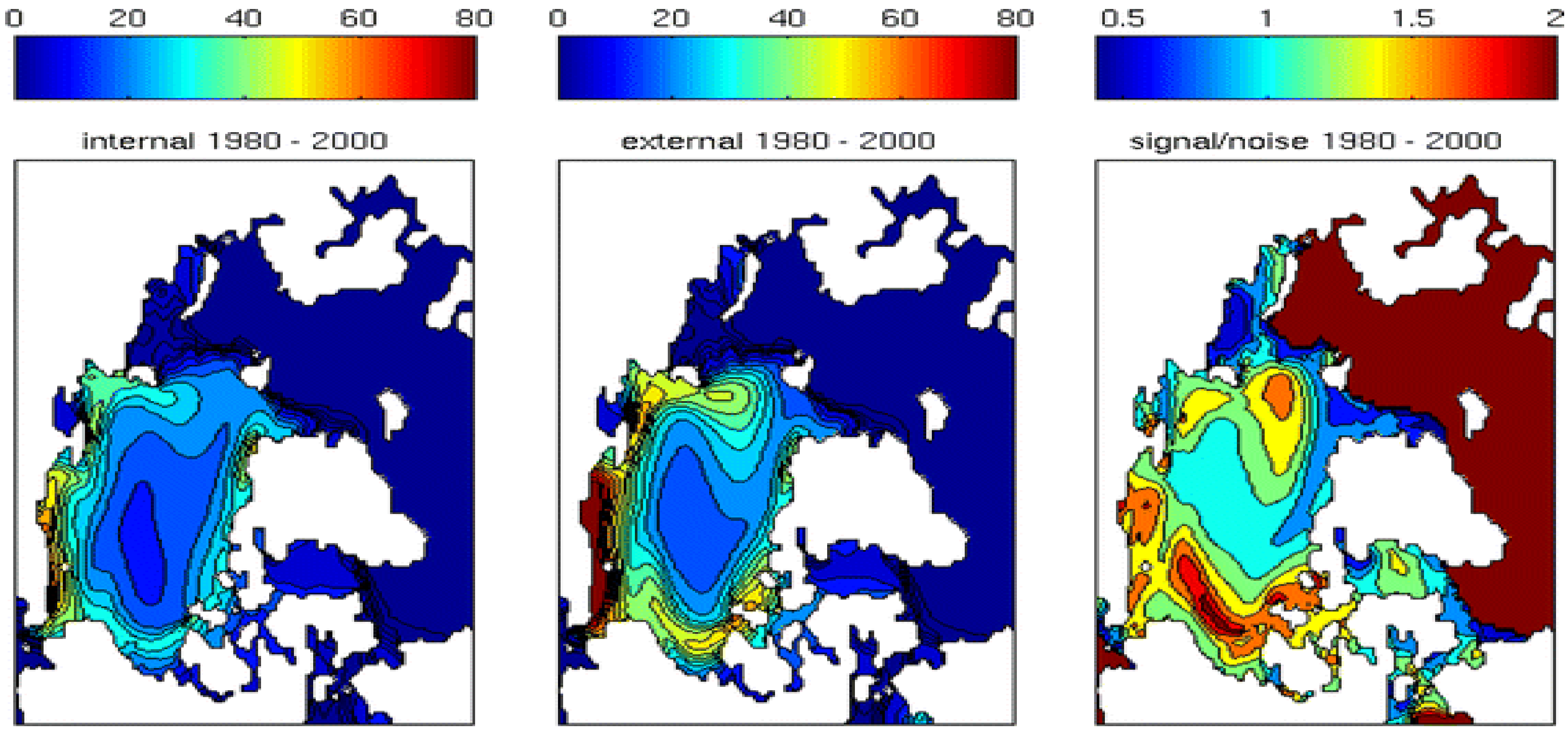
Regional process studies:

Simulated summer sea ice extent





Ice thickness variability and control of variability



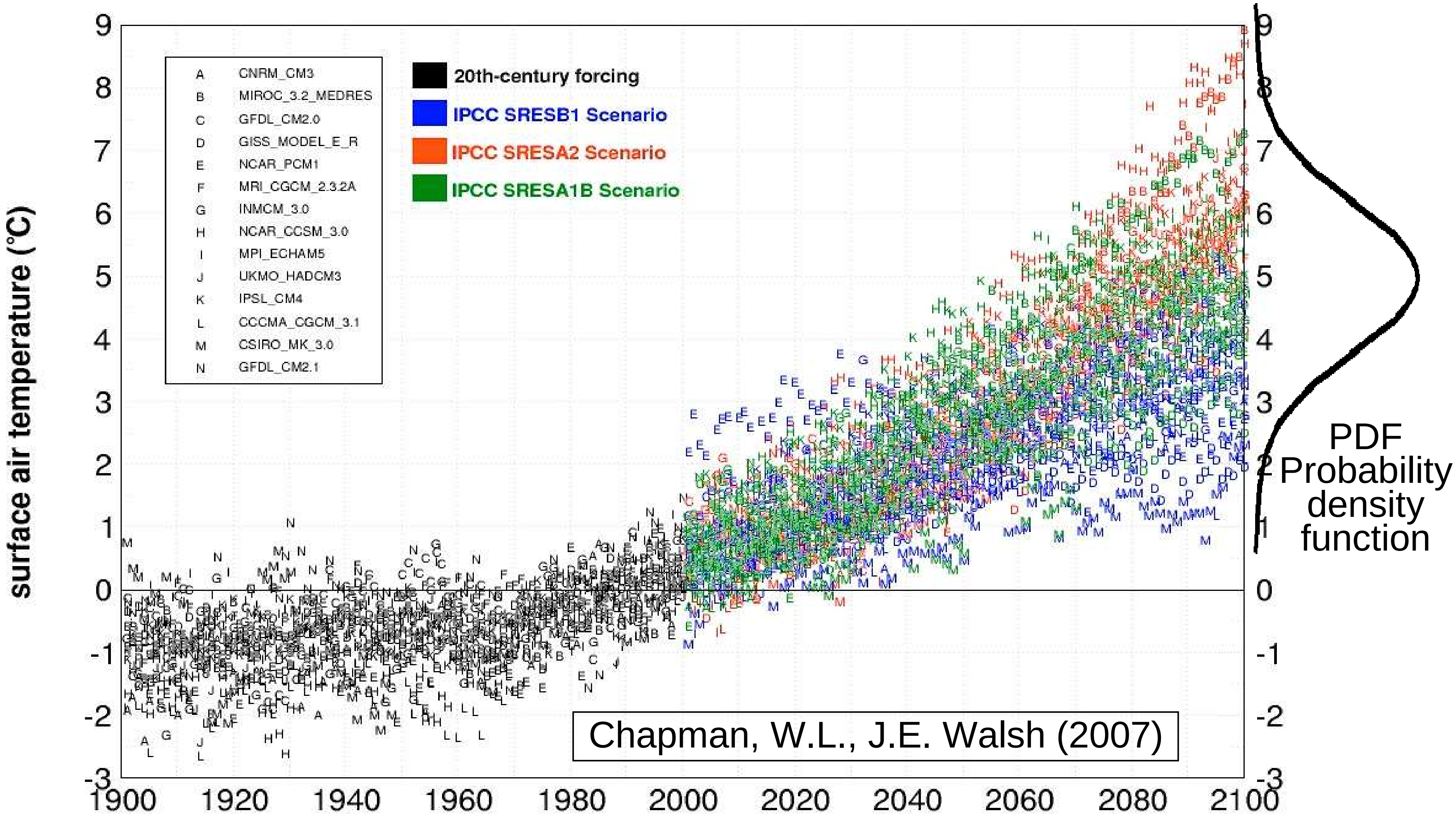
Internal (left), external (center) variability of Arctic summer (JAS) sea ice thickness for the period 1980–2000 in cm, and signal/noise ratio (external/internal) (right)

Döscher et al, 2009

Climate Scenarios of the Arctic

- IPCC
- Sea ice cover: too conservative?
- Regional scenarios
- Uncertainties

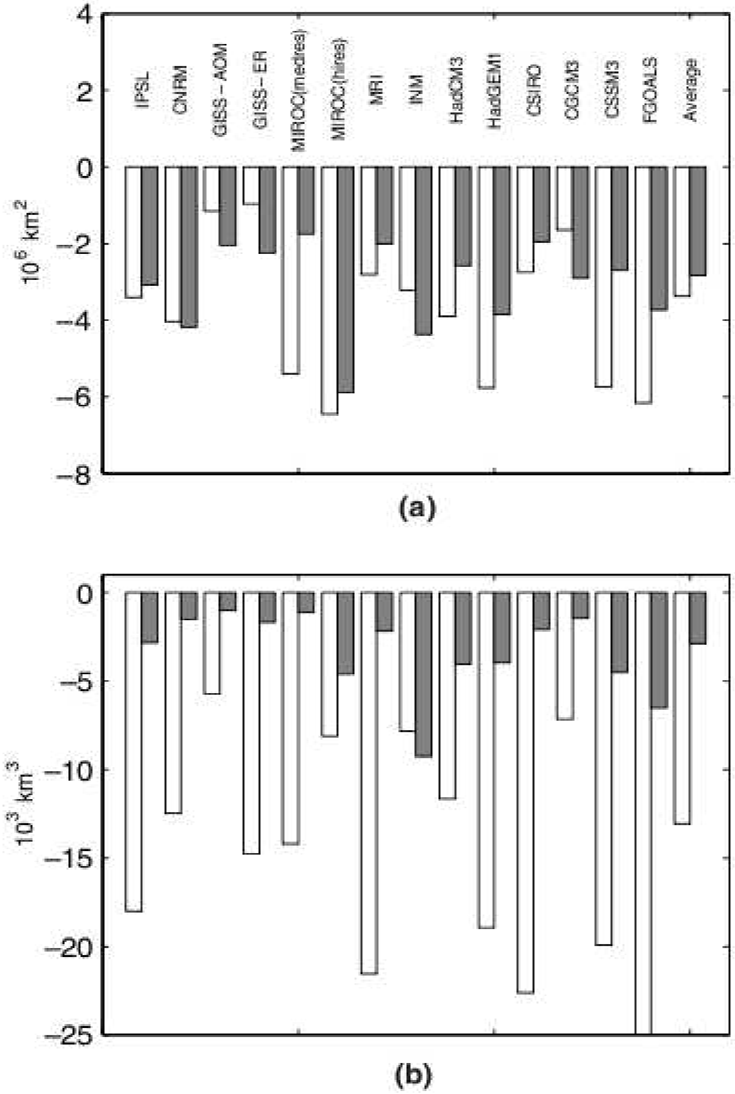
The Arctic in global climate change scenarios



Simulated and projected annual mean ***surface air temperature****, expressed as departures from 1981-2000 means, by 14 global climate models for the 20th- and 21st- centuries. Average 60°-90°N*

Sea ice changes

O. Arzel et al. / Ocean Modelling 12 (2006) 401–415



Sea ice extent

Sea ice volume

white=Arctic
grey=Antarctic

Fig. 3. Changes in Arctic and Antarctic annual mean sea ice extent (a) and volume (b) at the end of the 21st century. For each model the left (right) bar represents Arctic (Antarctic). The model FGOALS-g1.0 was excluded from the model average.

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IPCC sea ice cover

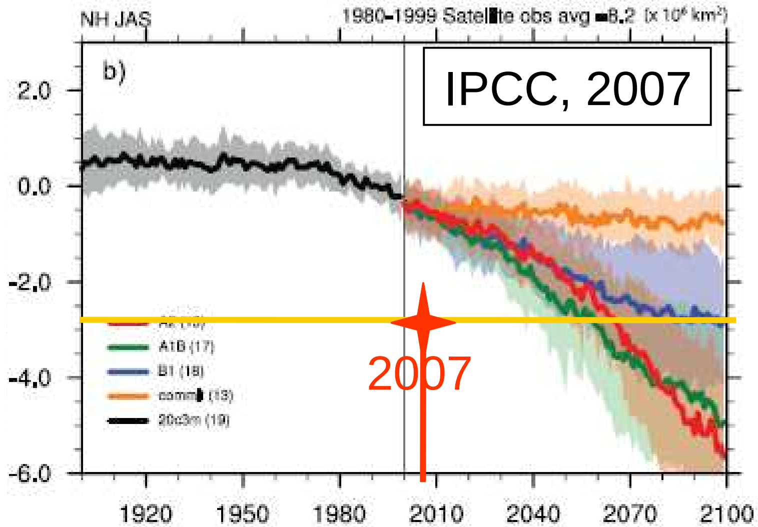
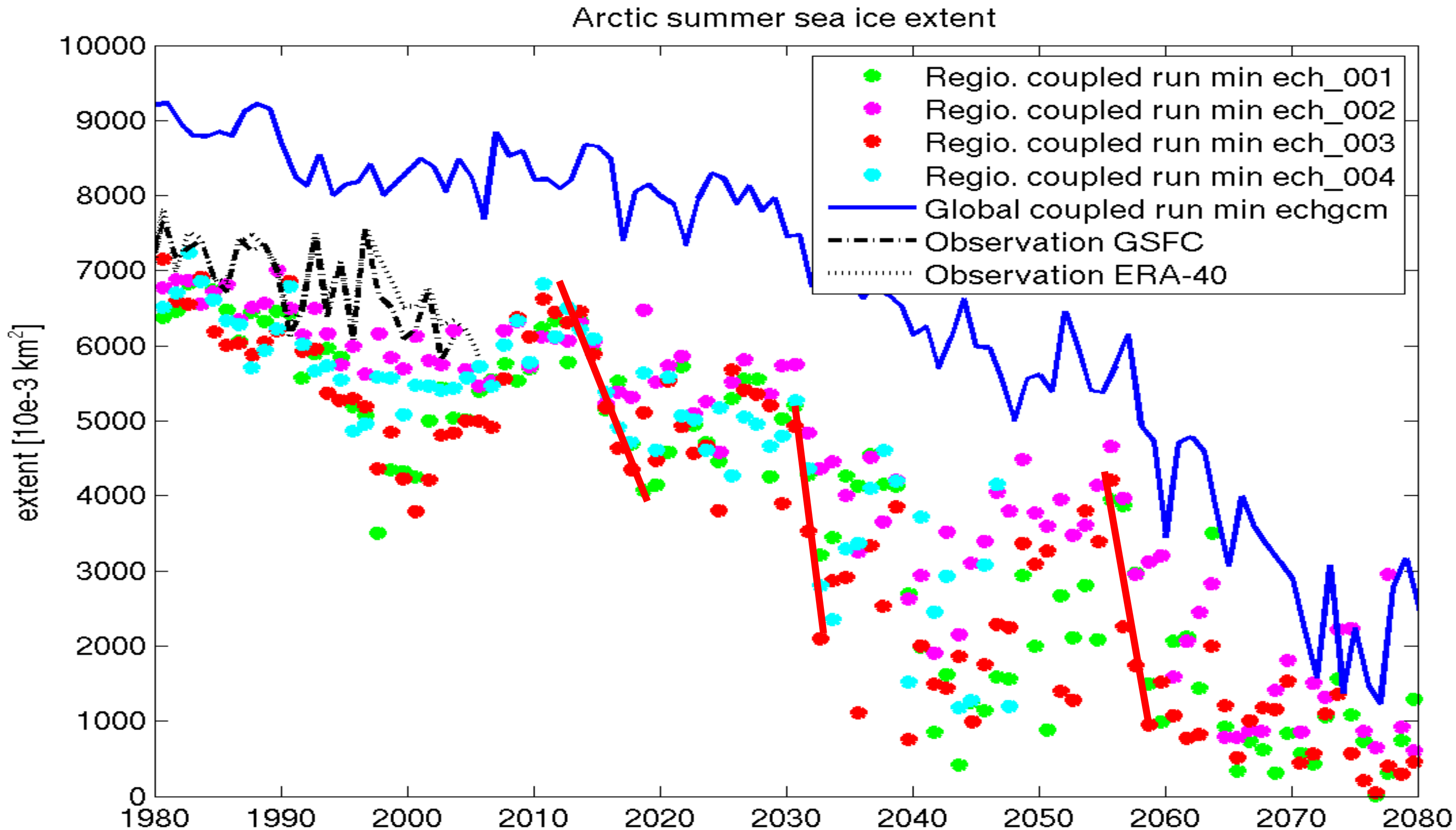


Figure 10.13. *Multi-model simulated anomalies in sea ice extent for the 20th century (20c3m) and 21st century using the SRES A2, A1B and B1 as well as the commitment scenario for (a) Northern Hemisphere January to March (JFM), (b) Northern Hemisphere July to September (JAS). Panels (c) and (d) are as for (a) and (b) but for the Southern Hemisphere. The solid lines show the multi-model mean, shaded areas denote ±1 standard deviation. Sea ice extent is defined as the total area where sea ice concentration exceeds 15%. Anomalies are relative to the period 1980 to 2000. The number of models is given in the legend and is different for each scenario.*

Sea ice too conservative in IPCC ?

Climate Scenario Experiments
- Dynamic Regional Downscaling -



Koenigk et al. (2010)

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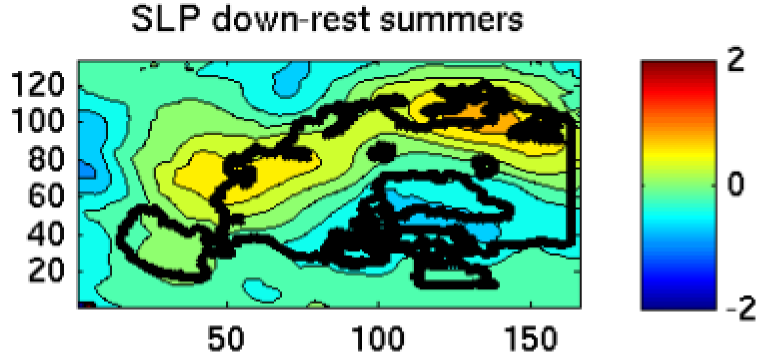
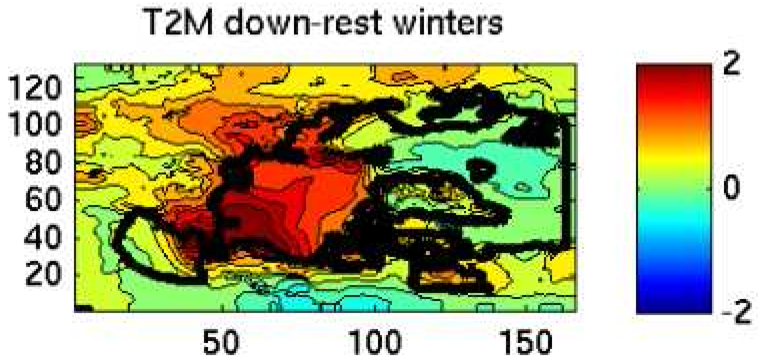
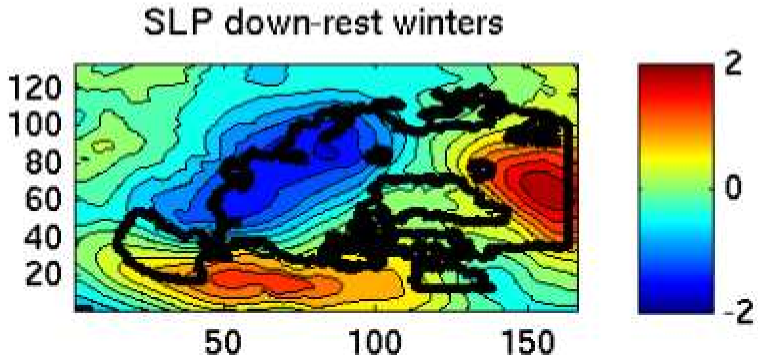
The average summer of rapid change



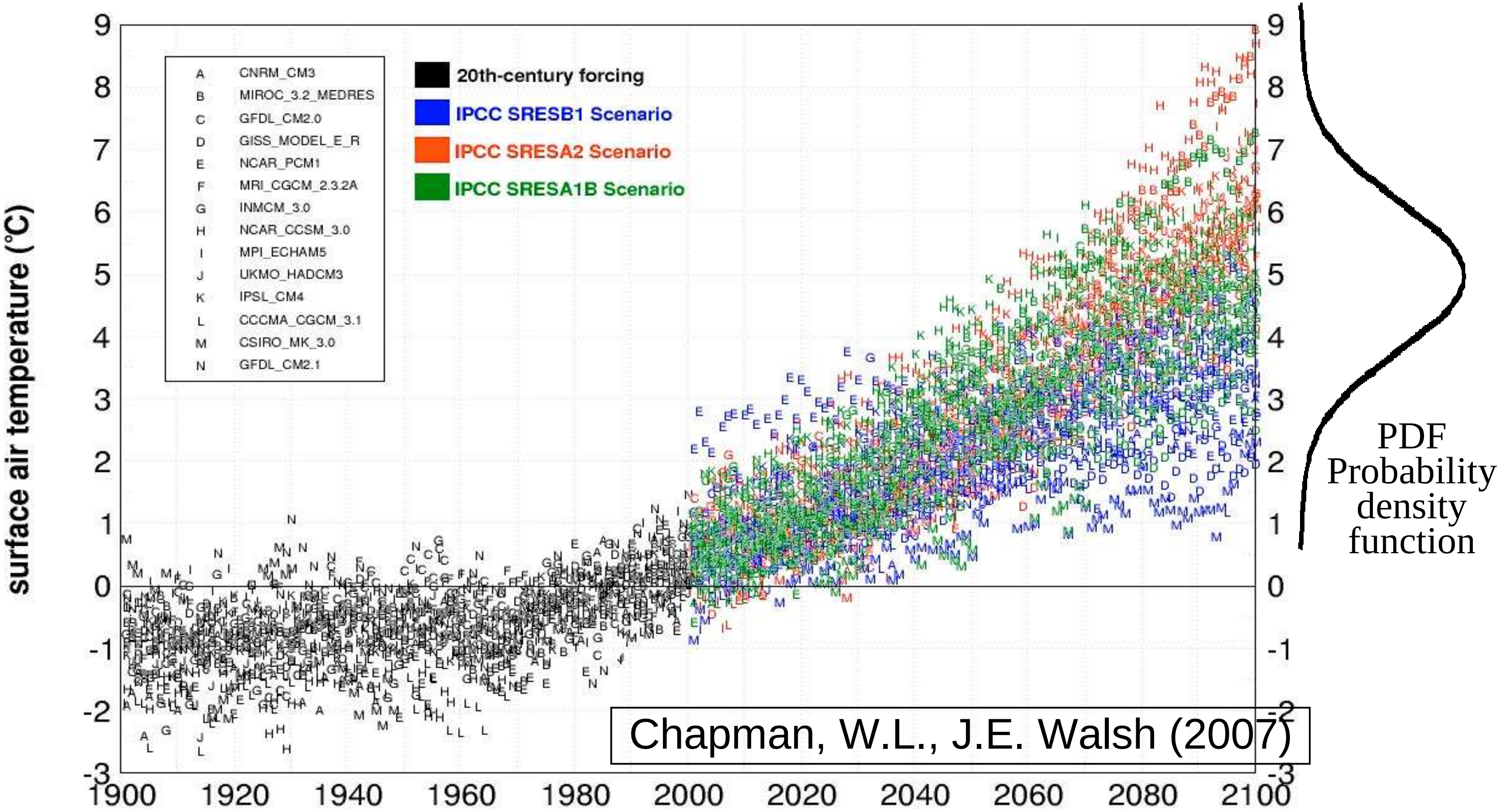
The average winter before rapid change



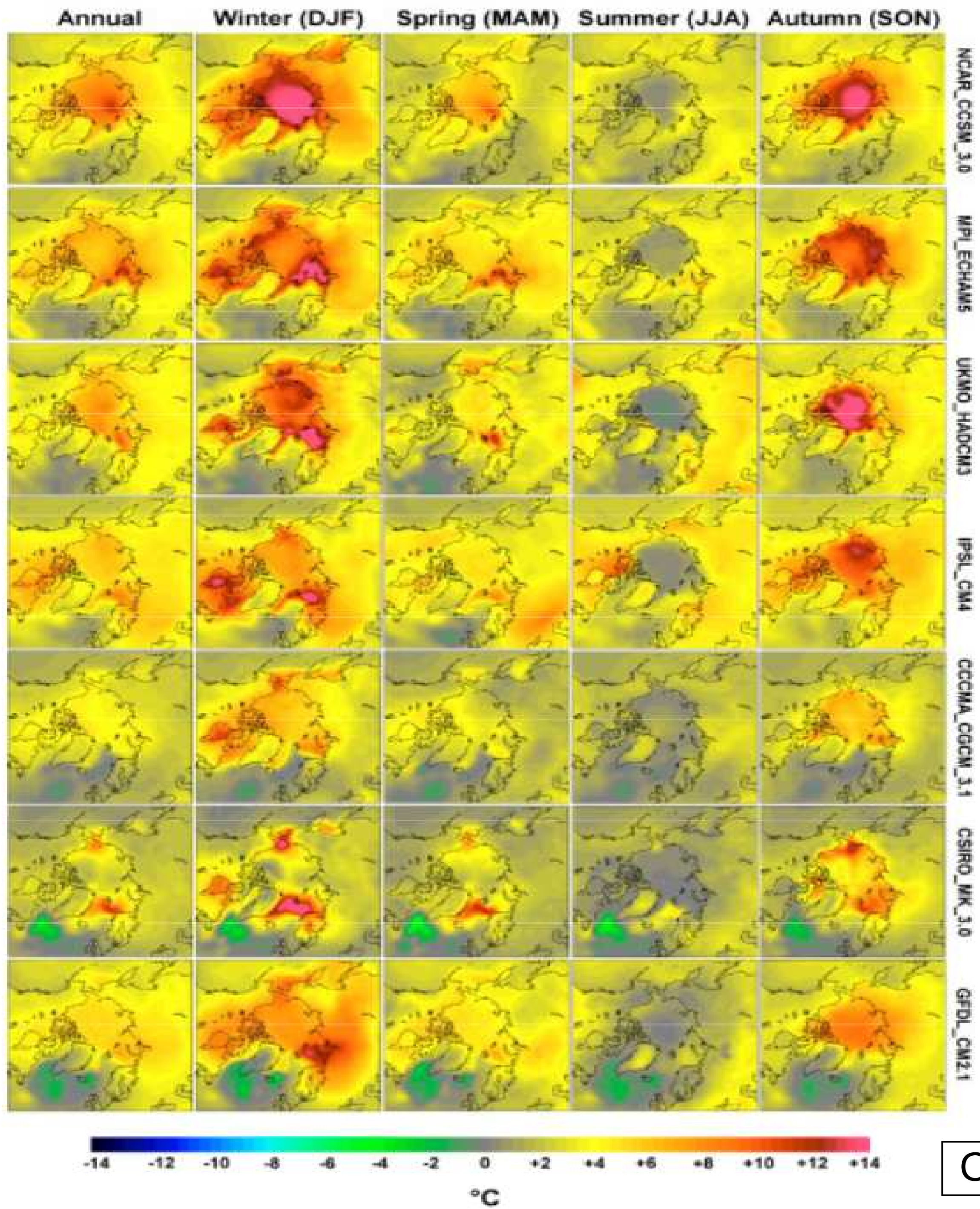


Döscher et al. /SMHI Rossby Centre

Uncertainties and user perspective



Simulated and projected annual mean ***surface air temperature****, expressed as departures from 1981-2000 means, by 14 global climate models for the 20th- and 21st- centuries. Average 60º-90ºN*



The Arctic in global climate change scenarios

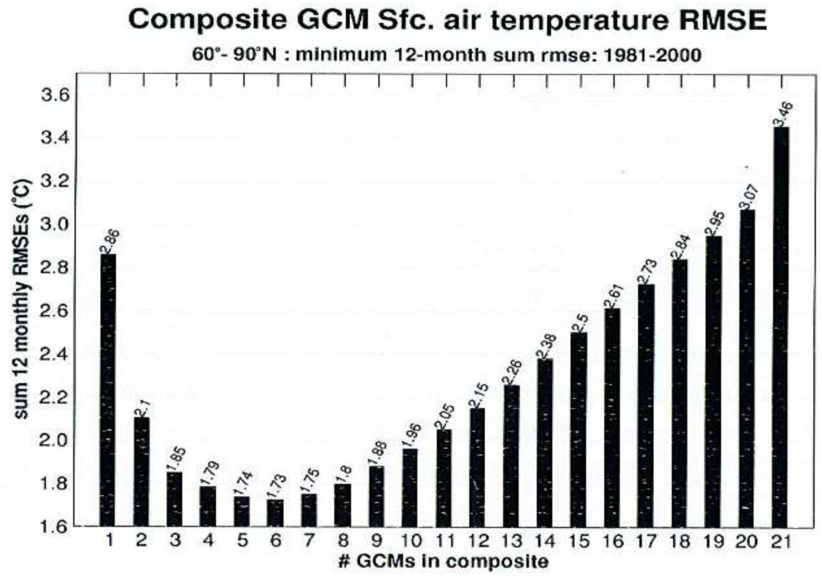
*Projected **surface air temperature** change from 7 GCMs*

(2070 ... 2089) – (1981 ... 2000)

Chapman, W.L., J.E. Walsh (2007)

How to deal with uncertainties?

- Climate modeller
  - Reduce uncertainties as possible
  - Explain uncertainties
- Climate analyst
  - Optimize use of model output and quantify uncertainties
    - Use many global models
    - Many variants of regional models



Adding value for users

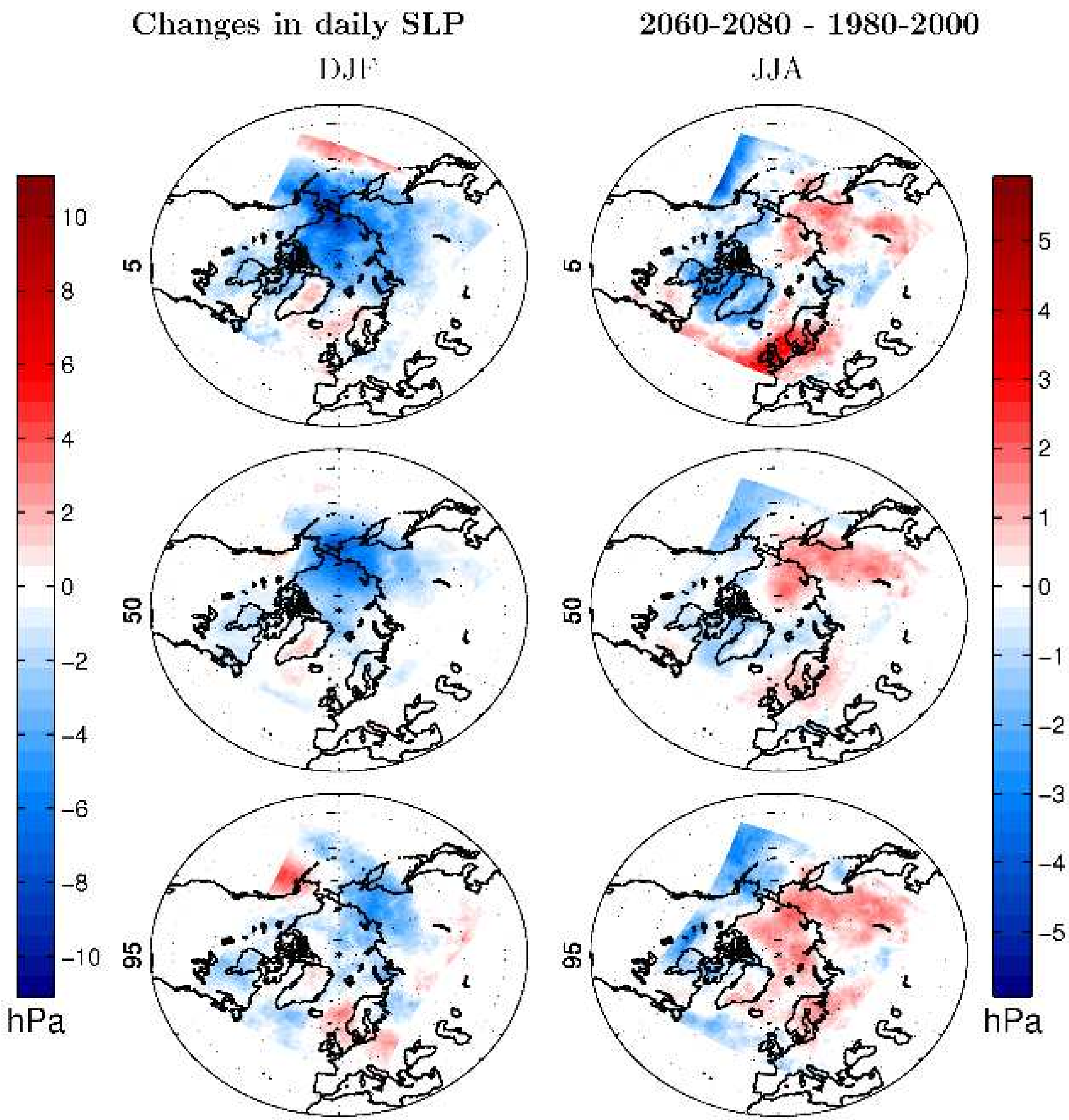


Figure 13: Changes in daily extremes of SLP between 2060-2080 and 1980-2000 in ECHstand in winter and summer: Top: SLP change of the 5 % days with lowest SLP, middle: mean change, bottom: SLP change of the 5 % days with highest SLP.

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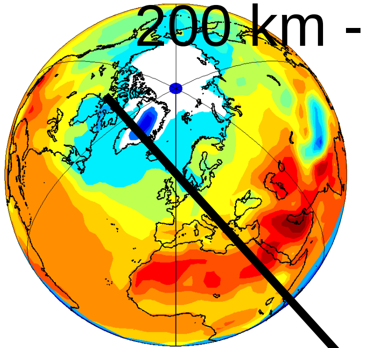
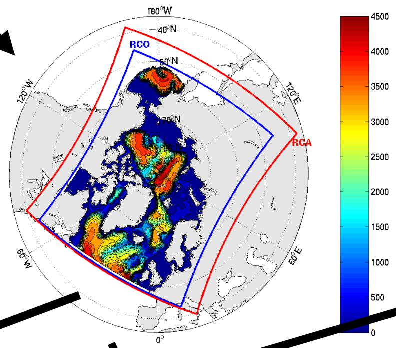
Scenario chain down to local scale

Global model ”EC-EARTH”

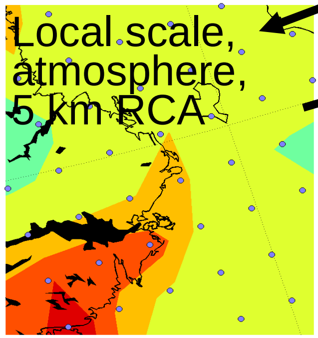
200 km -- 100 km



Regional Arctic modell
”RCAO” 25 km



Impact models
marine environment, land ecology, hydrolog, atmospheric chemistry, etc



LOCAL SCALE

Permafrost, ecology, etc

100 m – 5000 m

User

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Local impact studies require high resolution

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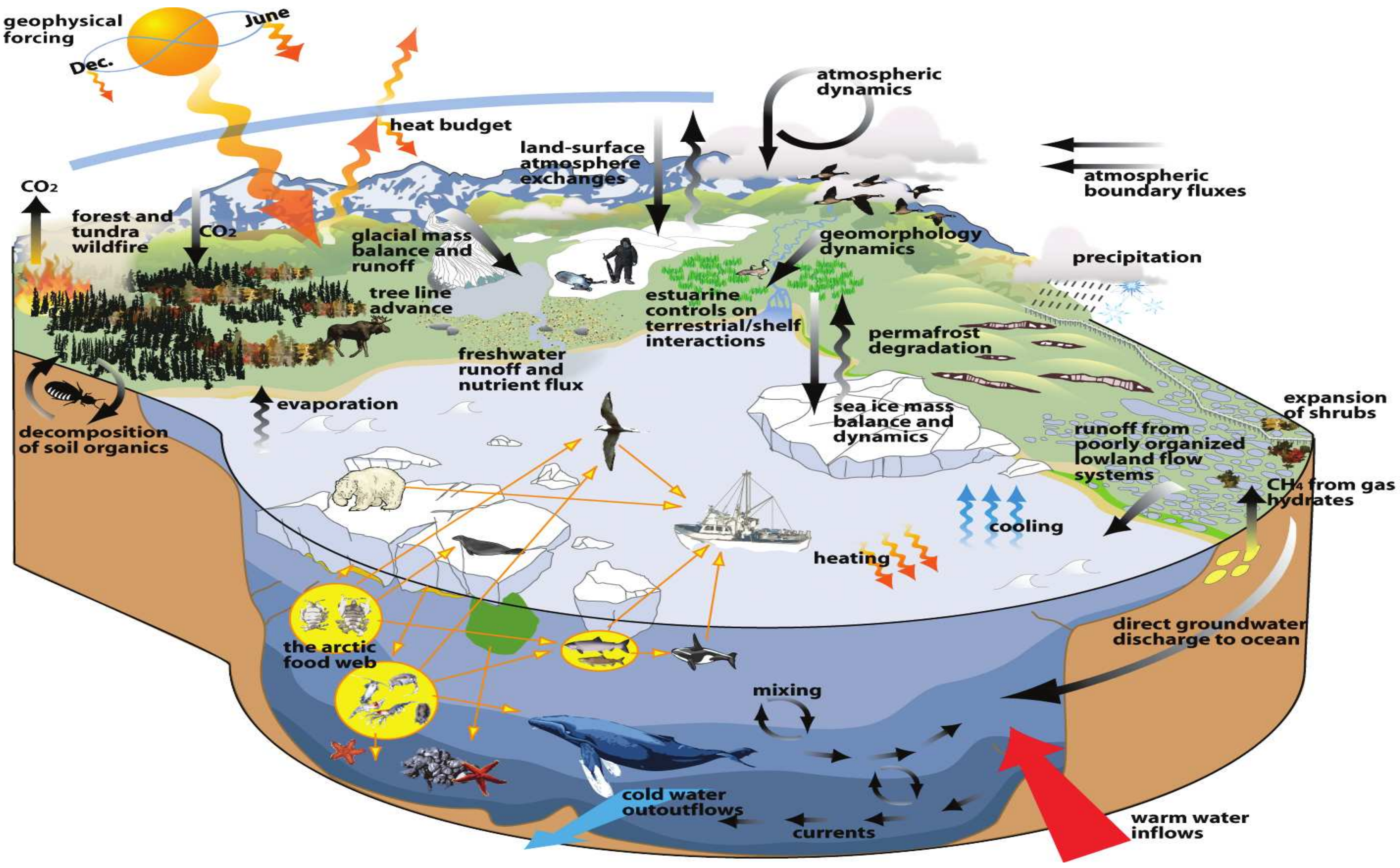
Next step: Arctic System Modelling



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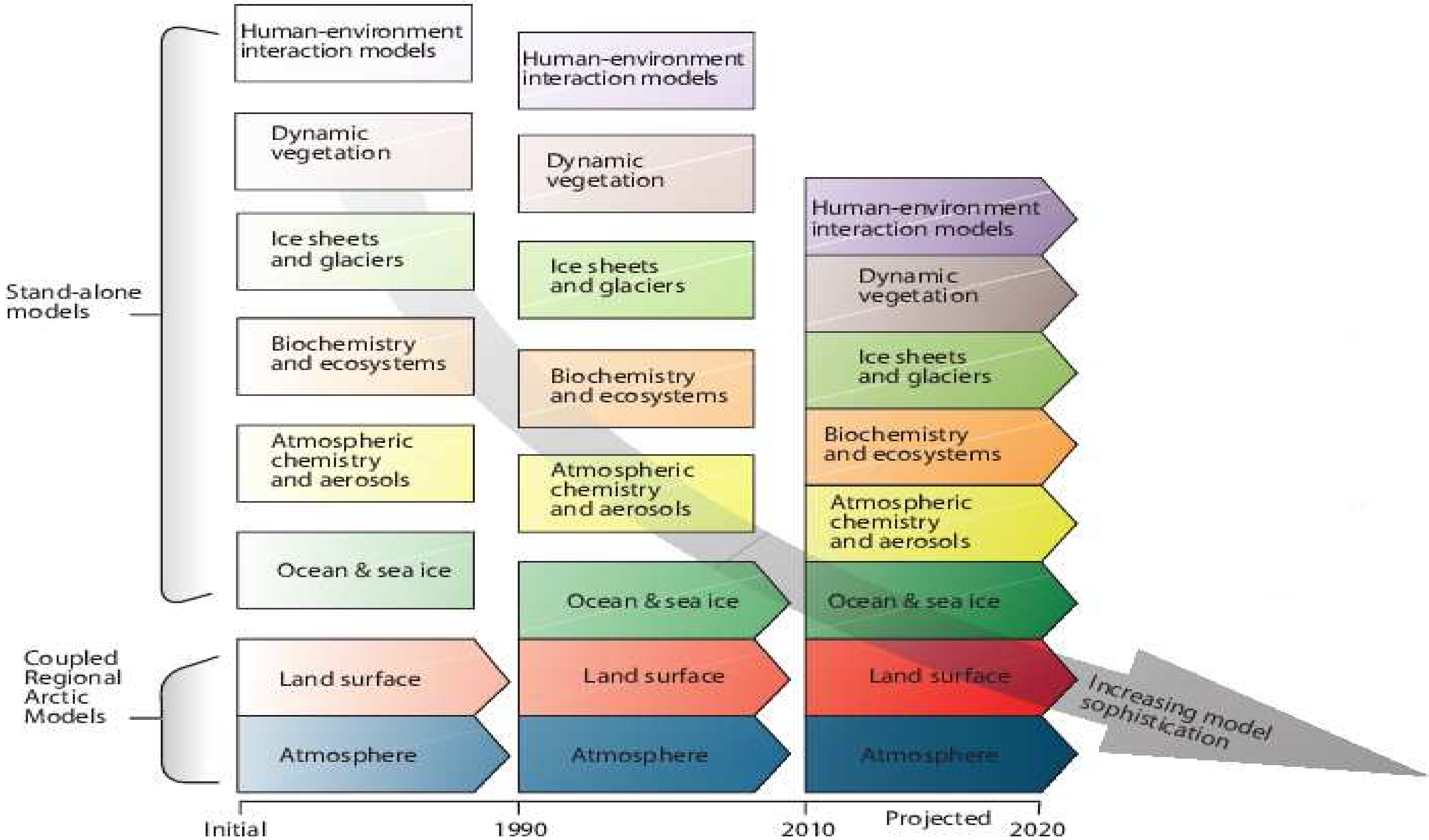
Arctic System Modelling



To take home

- The Arctic interacts with the global climate
- Arctic amplification
- Sea ice is decreasing / surface air temperature is increasing
- Multi-parameter model adjustment ("tuning") is necessary
- Local feedbacks compete and interact
- Arctic-interal interaction accounts for large parts of interannual variability
- Feedbacks between sea ice change and large scale wind changes are unclear
- Climate models of the Arctic have uncertainties
- Regional models and single GCMs are capable of generating "2007"-like sea ice reduction events
- Impact users and end users need higher resolution and more sofisticated model ranking

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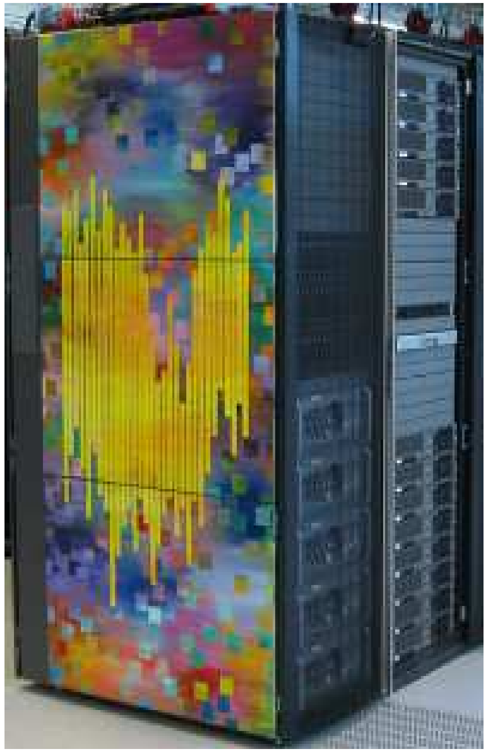
Missing due to time constraints

- AO/NAO
- Seasonal outlook
- predictability
- Glaciers
- Bio-geo-chemistry
- Permafrost
- ...

The End



Linux clusters
at NSC, Linköping

Possible change of large scale atmospheric circulation: more meridional

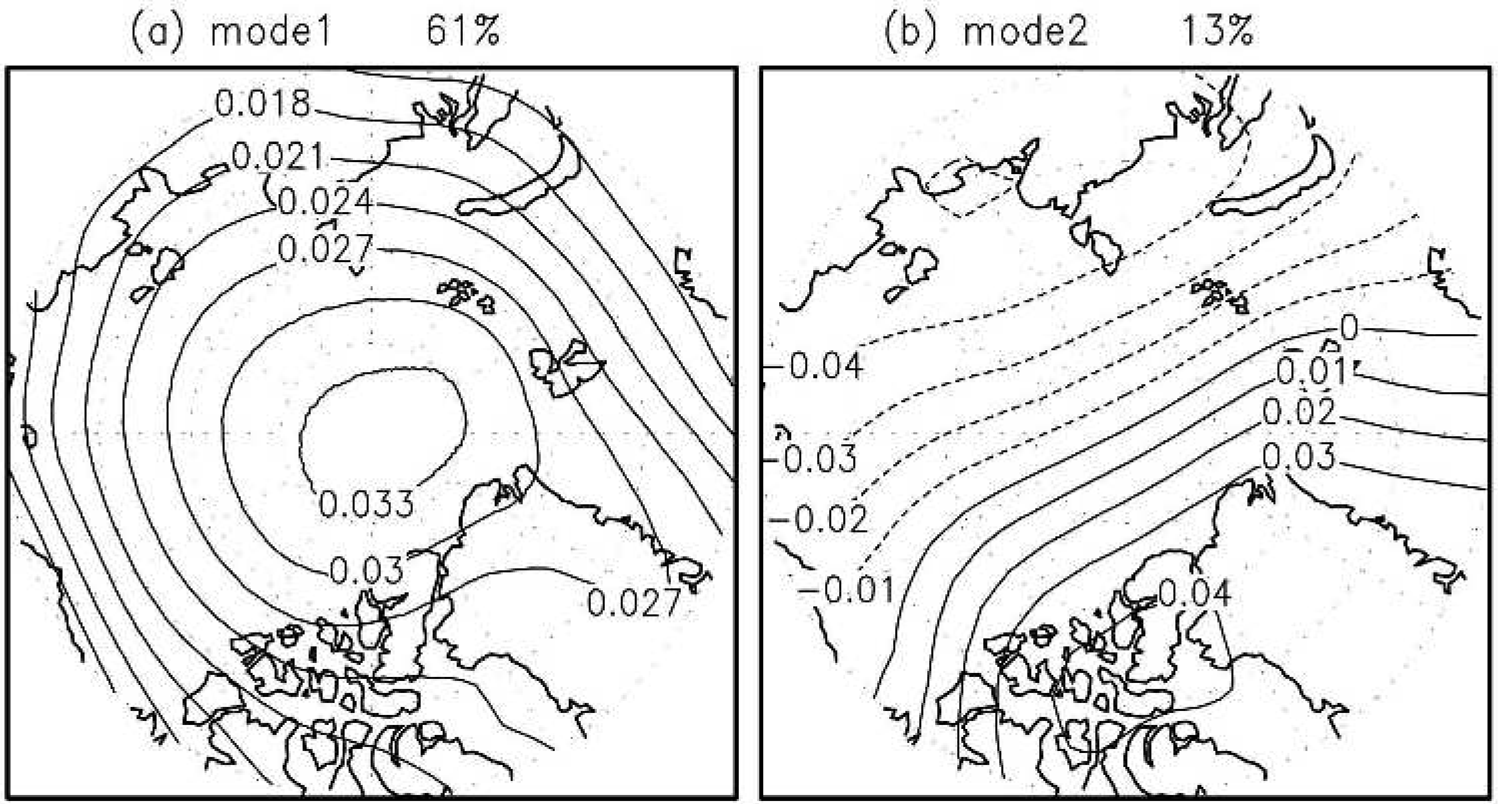


FIG. 1. Spatial distributions of the first two leading EOF modes of winter monthly mean SLP (October–March): (a) EOF1 and (b) EOF2, accounting for 61% and 13% of total variance, respectively.

Wu et al. (2006)