On the reliability of simulated Arctic sea ice in global climate models

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[1] While most of the global climate models (GCMs) currently being evaluated for the IPCC Fourth Assessment Report simulate present-day Arctic sea ice in reasonably good agreement with observations, the intermodel differences in simulated Arctic cloud cover are large and produce significant differences in downwelling longwave radiation. Using the standard thermodynamic models of sea ice, we find that the GCM-generated spread in longwave radiation produces equilibrium ice thicknesses that range from 1 to more than 10 meters. However, equilibrium ice thickness is an extremely sensitive function of the ice albedo, allowing errors in simulated cloud cover to be compensated by tuning of the ice albedo. This analysis suggests that the results of current GCMs cannot be relied upon at face value for credible predictions of future Arctic sea ice. [2] Here we consider intermodel differences in Arctic cloud cover, which are large in the and produce significant differences in downwelling longwave radiation. At the time of this analysis, output fields were available from 16 of the models evaluated for the IPCC AR4 (Figure 1) the range of simulated fields in the GCMs cloud cover and downwelling longwave vertical level in the atmosphere. As an example, we consider spread in cloudiness, seasonal cycle in total vertical fraction is plotted for each GCM in Figure 1 in cloudiness is associated with a 40 W range in downwelling longwave radiative surface (Figure 1b). [3] We use two standard thermodynamic


Global models in the Arctic

“Ice Free” Arctic (summer ~ 1Mskm) when?
Deep waters of the Atlantic

Potential Temperature at 25W

from http://sam.ucsd.edu/sio210/gifimages/A16_THETA.gif

Global role of Arctic Freshwater

A Freshwater source for the Atlantic Ocean

Broecker, 1991

Freshwaters exit the Arctic through the Fram Strait and through the Canadian Archipelago (Alley et al, 2003)

Freshwater inhibits deep convection, slowing the Atlantic Ocean overturning circulation (see Wadley & Bigg, 2002, for a discussion)

Models suggest the Bering Strait throughflow also influences the deep western boundary currents & the Gulf stream separation (Huang & Schmidt, 1993)

Paleo role of Bering Strait

Stabilizer for World Climate?

- if Bering Strait is open, excess freshwater in the Atlantic (from, for example, ice sheet collapse) can “vent” through the Bering Strait, allowing a speedy return to deep convection in the Atlantic.

Land Bridge for migration of mammals and people?

Note: in modern times, people have swum, driven and walked across!

Where do waters sink?

GIN Seas

Labrador Sea

Irminger Sea

What feeds NADW (North Atlantic Deep Water)?
**Denmark Strait Overflow**

Dickson et al, refs

- Denmark Strait ~ 650m deep
- Iceland Scotland Ridge ~ 400-650m deep

*i.e. Deep water from the Arctic and the GIN Seas doesn’t get out!*

What exits through Denmark Strait?
- near surface
- at depth

from [http://iodp.tamu.edu/publications/PR/303PR/images/Fig01.jpg](http://iodp.tamu.edu/publications/PR/303PR/images/Fig01.jpg)

**Source for Denmark Strait Overflow Water?**

Still debated:

- Swift 1980, Swift & Aagaard, 1981 - uAIW from Iceland Sea
- Strass et al, 1993 - rAW & uAIW carried in East Greenland Current
- Mauritzen 1996a and b - rAW plus FSBW from Arctic
- Jonsson & Valdimarsson, 2004 - Iceland Sea

Role for Arctic and GIN seas in Deep Overflows ...
... and in surface layers

**Climate Change?**

Aagaard and Carmack, 1994

- Bitz et al., 2006 - effects of increasing CO2
- separate out ice-albedo effect

- more overturning at shallow depths in Arctic
- more ocean heat uptake

**Arctic Ocean warming and its consequences for the Denmark Strait overflow**

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1) Two anomalously warm inflow pulses into the Atlantic Water Layer of the Arctic Ocean have occurred since the late 1980s. As a consequence temperatures of the Arctic basins at 200–800 m depth have increased considerably in comparison to earlier decades. The warm inflow pulses also had a low density. Owing to the decadal time scale of the circulation in the Atlantic Water Layer large pools of anomalously light water have thereby formed in the Arctic Ocean. These will slowly drain back south into the Nordic Seas. We submit that they will be able to influence the overflows into the Atlantic across the Greenland-Scotland ridges. The Atlantic meridional overturning is fed by these overflows. Our model experiments indicate that the low-density anomalies from the Arctic Ocean may be able to reduce the Denmark Strait overflows 15–25 years after the entrance of the original signal through Fram Strait into the Arctic Ocean. The actual size of the reduction depends on the exact path and speed of the anomalies inside the Arctic proper and on local processes in the Arctic Ocean and the Nordic Sea.

- DSOW fed by Atlantic Layer in the Arctic
- incoming warming exits and affects DSOW 15-25 years later
- model study
Where do waters sink?
- Antarctica

Antarctic = major source
Some mechanisms invoke
High Salinity Shelf Water
and processes under Ice Shelves

Polar Amplification

In a global warming scenario,
the Poles warm faster
- likely, cos of ice
- Antarctic doesn’t warm?

Arctic as a bellwether
(leading indicator)
of climate change
Atmos ~ 826 Pg C in 2010 (increased ~ 6 Pg C in 2009) (Fossil Fuel in 21st Century ~ 1500 Pg C)

The contemporary state of the carbon budget of the northern cryosphere region presented by McGuire et al. [11]. Pg = 10^13 g, Pg = 10^15 g, and Pg = 10^17 g figure reprinted with permission.

McGuire et al., 2010

**STOCKS OF ARCTIC CARBON**

- Biggest Arctic storage of C is in soil
- C stored significant, but less than soil mostly as dissolved gas, not organic material

**FUTURE ARCTIC CHANGE??**

- Increased ocean biological uptake?
- Increasing ocean warming means less DIC uptake?
- Ocean warming means less Decomposition of organic material?
- Likely all small compared to land changes e.g. fires and especially permafrost melt

- Arctic CO2 uptake important globally (~ 0-25%) Most of that is in Arctic forests Uptake only a small fraction of storage

**Predicted Permafrost Melt**

This figure shows the mean extent of permafrost in the Arctic, estimated for (a) the years 1990-2000 and (b) the years 2090-2100. In (c), the estimation of loss of permafrost in 2100 is overlaid on estimates for the year 2000. Credit: A. David McGuire, USGS.
Sea level Rise

- 1.8 mm per year (IPCC) (inch every 14 years)
  - or twice that (Copenhagen Diagnosis, 2009)
- 2007 prediction was for ~0.5m by 2100
- Now predictions are for more, but < 2m by 2100
- varies spatially (sea level fingerprints)
  - about half due to warming
  - about half due to melt
- Greenland melting ~ 7m
- Antarctic melting ~ 60m

(IPCC, Copenhagen Diagnosis 2009)

Greenland melt accelerating
1961-2003: 0.05 ± 0.12 mm/yr
1993-2003: 0.21 ± 0.07 mm/yr
2003-2007: ~0.5 mm/yr

Increased Glacier Calving


(Non-Local) Humans on the Ice

UNEPA – United Nations Environmental Program

From Arctic to Global

Traditional Climate Issues
- Ice Albedo Feedback
- Global Ocean Conveyor
- Polar Amplification (bellwether of climate change)

Less Traditional Climate Issues
- CO2 uptake
- Methane Gas Hydrates
- Sea-level Rise?
  - Arctic
  - Greenland
  - Ice bergs

Even Less Traditional Climate Issues
- Ozone Hole
- Clouds (frost flowers, DMS)
- Polar Vortex (Cold Air outbreaks)

Economic
- Oil and Gas
  - extra reserves, extra CO2
  - extra stability, extra disasters
- Shipping routes
  - extra trade, extra responsibility
- Borders and Security
  - shipping and submarines

Habitat for Humanity
- Permafrost thawing
  - local infrastructure
  - oil and gas infrastructure
- Coastal Erosion
- Sea level rise
- Contaminants

Ecological
- Fisheries
  - management & prediction
- Displaced Species
- Biodiversity and extinctions
- Ocean Acidification
- Life on other planets

http://www.arctic-council.org

Formed 1996, Ottawa Declaration

MEMBER STATES (Countries)
Canada
Denmark (incl Greenland & Faroes)
Finland
Iceland
Norway
Russian Federation
USA

PERMANENT PARTICIPANTS
  (Indigenous peoples’ organisations)
  Arctic Athabaskan Council (AAC)
  Aleut International Association (AIA)
  Gwich’in Council International (GCI)
  Inuit Circumpolar Council (ICC)
  Russia Arctic Indigenous Peoples of the north (RAIPON)
  Saami Council (ISC)

PERMANENT OBSERVERS
  (Countries without Arctic land)
France
Germany
The Netherlands
Poland
Spain
United Kingdom

OBSERVERS
  9 intergovernmental -Inter-Parliamentary Organizations, including
  Red Cross/Red Crescent,
  United Nations Development and Environmental Programs
  11 Non-government Organizations, including
  International Union for Circumpolar Health
  International Arctic Science Committee, WWF, University of the Arctic
  Association of World Reindeer Herders