Southern Hemisphere Sea Ice and Climate Change

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Sea Ice Extent 1979-2010

Million Square Kilometers


Antarctic
Arctic
Figure 2. The spatial pattern of Autumn sea ice concentration changes over 1979–2007.

Turner et al 2009
Loss of Sea Ice in the Bellingshausen Sea appears to be via tropical teleconnections and/or SAM

But there are multiple theories for the expansion elsewhere
1) SAM trends (driven by ozone primarily)
2) Freshwater trends
Antarctic Annual Sea Ice Area 1979-2010

Observation

IPCC Models
21st century warming SRES A1B
Antarctic sea ice trends by month
Largest, but insignificant in Autumn
Is $O_3$ trend actually lessening expansion in Jan-Feb?

Figure 1. Monthly trends in sea ice extent for 1979–2007

Turner et al 2009
Sea ice regressed on SAM variability with 2 month lag
Figure by Yuan and Li 2008

SAM variability impacts according to Lefevbre and Goosse 2005, 2008 are sea ice dynamical and thermodynamic loss (blue/green) in Weddell and weak thermodynamic increase elsewhere (yellow)
Few trends are significant (6 out of 30)

While autumn trends are large, the only region with a significant trend is the ABS where the trend is NEGATIVE!

Turner et al 2009
CCSM3 Change in Ocean Temperature (Celsius) from rise of greenhouse gases in a half century
Depth integrated Ocean Temperature Change from CCSM3 2XCO2

below 500m

Full Depth

°C m
Liu and Curry (2011)

SVD of observed SST (left) and Precipitation (right)

Both patterns have upward trend

The authors argue this increase in precipitation would stabilize the ocean, weaken convection, reduce upward heat flux, and cause net sea ice production.
Aiken and England (2008) added 3 cm freshwater per year in sea ice zone.

Found modest cooling and expanded sea ice.
Anomalous Sea Ice Freshwater from GHG

Ice motion

Sea ice

LESS growth = anomalous freshening

LESS melting = anomalous salting

NO NEED TO CHANGE EXTENT
Change in surface density flux by component in response to CO2, weighted by ocean fraction along latitude circle

Kirkman and Bitz, 2011
We tested our hypothesis by eliminating sea ice freshwater anomalies in a CO2 ramprun of CCSM3 (warming but no sea ice freshwater anomalies).

Ice motion

LESS growth
= anomalous freshening

LESS melting
= anomalous salting
Affect of 2XCO2 in idealized ramp run

Surface Temperature Change (K)

Isolating affect of anomalous sea ice freshwater

2-3K less warming owing to sea ice freshwater anomalies

Kirkman and Bitz, 2011
Role of Sea Ice Freshwater/Brine Exchange

Temperature Change at 2XCO2 due to sea ice freshwater

Ocean potential temperature

Explain heat uptake
south of 50S and in deep ocean

Kirkman and Bitz, 2011
Isotherms (colored) and Isopycnals (dashed)
CCSM3 1XCO2
Affect of 2XCO2 in idealized ramp run

Isolating affect of anomalous sea ice freshwater
How much can reducing sea ice alone account for climate change?

Run with sea ice albedo artificially lowered to mimic sea ice change from doubling CO2

1XCO2 Control
Lowered Albedo Run
2XCO2 Run

Surface air temperature change

2XCO2

Reduced Sea Ice Albedo
Depth integrated Ocean Temperature Change from 2XCO2

below 500m

Full Depth

°C m
Depth integrated Ocean Temperature Change below 500m depth

2XCO2

Reducing Sea Ice Albedo Only
Depth integrated Ocean Temperature Change below 500m depth

2XCO2

portion cause by sea ice melt

°C m
Experiments to test the role of winds in CCSM3

Kirkman, PhD thesis
# Changes in the mean flow

<table>
<thead>
<tr>
<th>Drake Passage throughput (Sv)</th>
<th>-1x</th>
<th>Control</th>
<th>+1x</th>
<th>+2x</th>
<th>+1x+co2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations: 135 Sv (Cunningham et al. 2003)</td>
<td>156.6</td>
<td>178</td>
<td>205.7</td>
<td>238.6</td>
<td>199.8</td>
</tr>
<tr>
<td>Difference from prior column (Sv)</td>
<td>---</td>
<td>21.4</td>
<td>27.7</td>
<td>32.9</td>
<td>---</td>
</tr>
</tbody>
</table>
Near-surface air temperature
Response to +1 Wind
Near-surface air temperature

-1x

+1x

°C
ACC and mode water summary

+1 Winds cause northward Ekman drift, upwelling near continent and downwelling at about 45S
Weddell Sea Temperature Response to Wind

-1x

+1x

°C
Australian Antarctic Ocean Temperature Response to Wind

-1x

+1x

°C
Summary

I do not know why sea ice models disagree with nature

Wind (ozone) anomalies make sea ice area decrease

Fresh water from the sea ice makes sea ice area expand, but not nearly enough

This problem is prevent us from knowing even the sign of future change