Ice thickness distribution and observed ice edge

March 1979-2007 (mean)

September 1979-2007 (mean)
Importance of physics, resolution and forcing in hindcast simulations of Arctic and Antarctic sea ice variability and trends

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Uncertainties in sea ice variability

**IPCC model projections of annual Arctic mean sea ice area anomalies (under various scenarios).** From Zhang and Walsh, 2005

- What are the reasons for this spread?
- *Stroeve et al. (2007)* note that GCMs tend to underestimate summer Arctic sea ice losses, but sophisticated sea ice models perform better than others.
Understanding sea ice variability with an OGCM

Underlying questions

1) How is model’s variability performance modified along arrows?

2) How does model variability behave along arrows?
1. Reference simulation
2. Sensitivity to physics representation
3. Sensitivity to resolution
4. Sensitivity to atmospheric forcing
5. Illustration of sensitivity experiments
6. Conclusions
1. Reference Simulation (NEMO-LIM3-1°-NCEP/NCAR)

Mean extent seasonal cycle 1979-2007

- Mod NH
- Obs NH

- Mod SH
- Obs SH

-16.4 %
-5.3 %
-1.2 %
1.7 %
1. Reference Simulation (NEMO-LIM3-1°-NCEP/NCAR)

**NH sea ice extent anomalies**

- Correlation: 0.77
- Error Variance: -19.9 %
- Error Trend: -45.7 %

**SH sea ice extent anomalies**

- Correlation: 0.45
- Error Variance: 36.2 %
- Error Trend: 106.5 %

**Warm bias in reanalysis** (see Tartinville et al., 2002)
## 2. Sensitivity to physics representation

### Main differences LIM2 – LIM3

<table>
<thead>
<tr>
<th>LIM 2</th>
<th>LIM 3</th>
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<tbody>
<tr>
<td>Fichet and Morales Maqueda, 1997</td>
<td>Vancoppenolle et al., 2009</td>
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#### 1. Ice thickness representation
- **1-category Ice Thickness Distribution (ITD)**
  - *2 + 1 layers*
  - **Effective thermal conductivity**
    - *Basic brine modelling*
  - **Viscous Plastic**

#### 2. Vertical thermodynamics
- *2 + 1 layers*
- **Effective thermal conductivity**
- *Basic brine modelling*
- **Explicit brine + drainage**

#### 3. Rheology
- **Viscous Plastic**
- **Elastic Viscous Plastic**
2. Sensitivity to physics representation

Absolute relative error of simulated VS observed variability

Overall:
LIM3 « better » 28 times / 44
Mean abs err: 27.7% - 38.8%

NH:
LIM3 « better » 23 times / 34
Mean abs err: 23.8% - 38.0%

SH:
LIM3 « better » 5 times / 10
Mean abs err: 41.2% - 41.2%

• Physics seem to play a key role in governing the skill of models to simulate variability...
• ... only in NH
3. Sensitivity to resolution

**Absolute relative error of simulated VS observed variability**

- **Overall:** Mean abs err: 33.9% - 32.6% - 36.3%
- **NH:** Mean abs err: 31.9% - 29.9% - 36.1%
- **SH:** Mean abs err: 40.6% - 41.8% - 36.9%

- No significant improvement with resolution (for this range)
- But: LIM calibrated for 2°

```plaintext

corranoHS

trendexthS

stdanoextHS

minexthS

maxexthS

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stdframannualVol

corrframannualArea

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4. Sensitivity to atmospheric forcing

**Absolute relative error of simulated VS observed variability**

- **Overall:**
  - Mean abs err: 28.4% - 49.1%

- **NH:**
  - Mean abs err: 24.1% - 47.5%

- **SH:**
  - Mean abs err: 43.0% - 54.6%

- DFS4 (Brodeau et al., 2010) is based on ERA-40 fields

- LIM calibrated for NCEP reanalysis
4. Sensitivity to atmospheric forcing

Mean 1979-2006 2m air temperature difference [K] « DFS4 » minus « NCEP »

- DFS4 2m air temperatures known to be warmer than NCEP (Bromwich and Wang, 2005)
- Higher winter temperatures → smaller summer ice extents
5. Illustration of sensitivity experiments

- Higher variability for smaller mean extents (as in Goosse et al., 2009)

- Higher variability with ITD representation, through ice-albedo feedback (Holland et al., 2006)

- Previous studies (e.g. Bitz et al., 2001): ITD → thicker ice. However...

- Increased ice thickness variability with higher mean ice thickness (as in Holland and Curry, 1999)
6. Conclusions

Resolution
No significant changes for this range of resolutions

Physics
Significant improvement LIM3 vs LIM2 (only NH). Increased variability in ice extent (NH and SH), in Arctic ice thickness. Reduced variability in ice volume (NH and SH)

Atmospheric Forcing
High sensitivity

NCEP/NCAR

DFS4

NEMO-LIM 2

NEMO-LIM 3
6. Conclusions

**Take home message**

- Keep in mind that this study considers sensitivity of sea ice *variability* for atmosphere-driven OGCMS at a *decadal time scale*

- Don’t direct your priorities to higher resolutions if you work at ~ 1°. Eddy-permitting resolutions (< ¼ °) have not been tested here. Also, higher resolution for the reanalyses could be important (DeWeaver and Bitz, 2006)

- Include a subgrid parametrization of ice thickness distribution to better simulate observed variability (NH). For GCMs, ITD also allows warmer surface air temperatures above perennial ice (Holland et al., 2006)

- Quality of atmospheric reanalyses are of higher importance. For GCMs, much effort should be directed to atmosphere modelling
THANK YOU

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References

- Arzel O., Fichefet T., Goosse H., 2006: *Sea ice evolution over the 20th and 21st centuries as simulated by current AOGCMS*, Ocean Modelling 12 401-415
- DeWeaver E., Bitz C., 2006 *Atmospheric Circulation and its effect on arctic sea ice in CCSM3 simulations at Medium and High resolution*, American Meteorological Society 19 2415-2436
- Holland M., Curry J., 1999: *The role of physical processes in Determining the Interdecadal Variability of Central Arctic sea ice*, American Meteorological Society, 12 3319-3330
- Zhang X., Walsh J. E.,2006: *Toward a Seasonally Ice-Covered Arctic Ocean: Scenarios from the IPCC AR4 Model Simulations*, Journal of Climate 19 1730-1747