Sea ice thickness

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Part II: variability
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Part I: predictability

Part II: variability
Part I: ice predictability

Lindsay et al, 2007

- ice thickness
- thin ice fractions
- upper ocean temps

Lindsay et al, 2007
(diagnostic) ice predictability

CCSM3
Obs
(diagnostic) ice predictability

CCSM3

Obs

correlation volume - extent
ice concentration & extent: CESM3

Sep lag 0  March lag 6  August lag 12

Contours: sea ice concentration variability
Shading: Sep sea ice extent vs lagged thickness correlation
B-W et al, 2011
ice concentration & extent: other GCMs

Day et al, 2014
Perfect model predictability & Sea ice thickness

Day et al, 2014
Sea ice thickness & sea ice predictability

Day et al, 2014
Perfect models: seasonal summer ice forecasts should have skill, and that skill will depend on ice thickness initialization. Hindcasts (e.g., Chevallier et al., 2013) similar results.
Seasonal predictability: the Sea Ice Outlook
Seasonal predictability: the Sea Ice Outlook

2014 Sea Ice Outlook: July Report

September Sea Ice Extent (Million Square Kilometers)

(+/- sigma)
Seasonal predictability: the Sea Ice Outlook

Hamilton & Stroeve, 2016
Errors in sea ice reanalysis/reconstruction
(from which ICs are taken)

Annual volume of sea ice

Chevallier et al (2016)
Errors in sea ice reanalysis/reconstruction (from which ICs are taken)

Mean March 2003-2007 Sea Ice Thickness (m) in global ocean-sea ice reanalyses with assimilation of sea ice concentration

Chevallier et al (2016)
We have built a control run, that uses climatological (2007-2014) PIOMAS May 1 sea ice thickness, and an experiment run, that uses 2015 May 1 sea ice thickness.

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<tr>
<th>Model</th>
<th>Model type</th>
<th>Ensemble size</th>
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<td>UCL (Barthelemy et al)</td>
<td>Global ice-ocean model forced with past atmosphere reanalysis</td>
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<td>NRL (Posey et al)</td>
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<tr>
<td>PIOMAS (Zhang &amp; Lindsay)</td>
<td>Regional ice-ocean model forced with past atmosphere reanalysis</td>
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<td>NCAR CCSM4 (BW et al)</td>
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<td>NASA GMAO (Cullather et al)</td>
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<td>NOAA CFSv2 (Wang et al)</td>
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<td>CNRM (Chevallier et al)</td>
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<td>Ec-EARTH (Fuckar et al)</td>
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Blanchard-W et al, 2016
Control: mean May 1 2007-2014 sea ice thickness in Arctic basin

Experiment: May 1 2015 sea ice thickness in Arctic basin

May 1 ice edge
Control: mean May 1 2007-2014 sea ice thickness in Arctic basin

Experiment: May 1 2015 sea ice thickness in Arctic basin
No change in sea ice area between experiment & control ICs

Control: mean May 1 2007-2014 sea ice thickness in Arctic basin

Experiment: May 1 2015 sea ice thickness in Arctic basin

May 1 ice edge

Sep ice edge

No change in sea ice area between experiment & control ICs
Control: mean May 1 2007-2014 sea ice thickness in Arctic basin

Experiment: May 1 2015 sea ice thickness in Arctic basin

No change in sea ice area between experiment & control ICs

Spring thickness —> summer sea ice area
On forecast uncertainty

Model A

Obs

t=0

t=T

'Irreducible error'
(chaotic error growth)
On forecast uncertainty

Model A
Model B

Obs

t=0

$t=T$
On forecast uncertainty
On forecast uncertainty

Model A

Model B

Obs

$t=0$

$t=T$
On forecast uncertainty

Model A

Model B

Obs

$t=0$

$t=T$

'Model uncertainty'
Results: error growth volume

- $\sigma$(ensemble means)
- $\sigma$(anom ens means)
- Model uncertainty raw
- Model uncertainty post-proc.
- Chaotic error growth
- $\text{mean}(\sigma(\text{ensemble}))$
Results: error growth regional thickness

Forecast uncertainty grows fastest along coastlines, model uncertainty becomes important in central basin too
Part II: ice variability

Ice thickness variability in ‘simple’ models

Single-column models (i.e., thermodynamics, Bitz et al. 1996) forced with realistic random perturbations: 15-year decorrelation timescales
Monthly ice thickness anomalies (meters) in a model A
Monthly ice thickness anomalies (meters) in a model A
Monthly ice thickness anomalies (meters) in a model B
Monthly ice thickness anomalies (meters) in a model B
Annual sea ice thickness variability (from detrended anomalies)
One point correlation map of monthly thickness anomalies
One point correlation map of monthly thickness anomalies
One point correlation map of monthly thickness anomalies

![Correlation map of monthly thickness anomalies in CCSM4](image)

1/e
One point correlation map of monthly thickness anomalies
Lengthscale (footprint) and timescale of ice thickness anomalies.

- **CCSM3**: ~650km
- **CCSM4**: ~700km
- **PIOMAS**: ~950km
- **CCSM4IO**: ~1100km

‘Footprint’ area scales as the square of lengthscale.
Lengthscale (footprint) and timescale of ice thickness anomalies.

- **CCSM3**: 
  - Footprint: ~650 km

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‘Footprint’ area scales as the square of lengthscale.

IceBridge
Mean distance 2009-2015
Lengthscale (footprint) and timescale of ice thickness anomalies.

CCSM3
~10.9mo

CCSM4
~11.8mo

PIOMAS
~9.4mo

CCSM4IO
~9.6mo

months
Lengthscale (footprint) and timescale of ice thickness anomalies.

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Lengthscale (footprint) and **timescale** of ice thickness anomalies.

**CCSM3**

- Footprint: \(~10.9\) mo

**CCSM4**

- Footprint: \(~11.8\) mo

**PIOMAS**

- Footprint: \(~9.4\) mo

**CCSM4IC**

- Footprint: \(~9.6\) mo
Mean values in Arctic for all models

CCSM3  CCSM4  CCSM4IO  PIOMAS  CMIP5 models
Mean values in Arctic for all models

Thicker ice tends to have larger anomalies that are longer lived, but smaller in spatial scale
Mean values in Arctic for all models

Thicker ice tends to have larger anomalies that are longer lived, but smaller in spatial scale.

Very large spread across models.
Mean values in Arctic for all models

Lots of reasons why models can be different but... why are CCSM4 and CCSM4IO so different?
Mean values in Arctic for all models

Lots of reasons why models can be different but... why are CCSM4 and CCSM4IO so different?
Dynamic vs Thermodynamic contributions to ice thickness variability

CESM outputs ice thickness tendencies from both

@ 85N, 90E

\[ r(\text{dyn}, \text{tot}) = 0.8; \quad r(\text{thermo}, \text{tot}) = 0.34; \quad r(\text{thermo}, \text{dyn}) = -0.3 \]
Dynamic vs Thermodynamic contributions to ice thickness variability

CESM outputs ice thickness tendencies from both Dynamic vs Thermodynamic contributions to ice thickness variability.
Dynamic vs Thermodynamic contributions to ice thickness variability

CESM outputs ice thickness tendencies from both

A. CCSM4 DYN–TOTAL

B. CCSM4 THERMO–TOTAL
Dynamic vs Thermodynamic contributions to ice thickness variability

Dynamics and thermodynamics are negatively coupled, but especially in ice-ocean model

A. CCSM4

B. CCSM4IO

![Map A: CCSM4](image1)

![Map B: CCSM4IO](image2)
Sea ice thickness variability in observations

IceBridge obs 2009-2013 (Richter-Menge & Farrell, 2013)
Sea ice thickness variability in observations

IceBridge obs 2009-2013 (Richter-Menge & Farrell, 2013)
How long of a dataset do we need to assess ice thickness spatial variability pattern?

Sub-sample CESM control run, calculate pattern correlation with long control run

Promise for 15-20+ year observational (blended) datasets?
How will thickness and extent relate in changing mean state?

Thickness variability decreases ... extent variability increases (for a bit)
Final thoughts

Perfect model and hindcasts shows that seasonal forecasts of summer sea ice should be skilfull, and depend on sea ice thickness initial condition.

Recent SIO period (2008-2015) shows low skill. Bad luck?

While recent period may have been inherently less predictable, difference in initial conditions, model uncertainty and forecast bias correction likely play significant role.

• Large differences in GCMs’ thickness variability, spatial and timescales...
• Ice thickness in models *might* be more persistent than in observations
• Dynamics mostly drive monthly, regional sea ice thickness anomalies.
• Link between variability and mean state has implications for future variability of ice thickness in 21st Century (what about predictability?).