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?

- None of the 15 GCMs evaluated in Arzel et al. (2006) study can simultaneously capture observed mean state, trend and interannual variability with < 10% error for 1981-2000

- 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)

**Atmospheric Forcing**
- NCEP/NCAR daily surface air temperatures and wind speeds (1948-2008) + monthly climatological surface relative humidities, cloud fractions and precipitation rates + monthly climatological river runoffs

**Bulk formulas**
- Surface fluxes of heat, freshwater and momentum (*salinity restoring*)

**Tripolar global grid, 1° resolution**
- 1948-2008 runs; analyses for 1979-2007

**LIM3 (SEA ICE MODEL)**
- Explicit representation of the subgrid-scale ice thickness, enthalpy, salinity and age distributions (5 categories)
- Multi-layer halo-thermodynamic component (1 snow layer + 5 ice layers)
- Mechanical redistribution that takes into account ridging/rafting processes and ridge porosity
- EVP rheology on a C-grid

**NEMO (OCEAN MODEL)**
- Primitive equation, free surface ocean general circulation model on a C-grid
- Level-1.5 turbulence closure scheme
- Isopycnal mixing + G&M parameterisation of eddy-induced tracer advection
- Bottom boundary layer scheme + partial step topography, 42 levels

1. Reference Simulation (NEMO-LIM3-1°-NCEP/NCAR)

Mean extent seasonal cycle 1979-2007

- **Mod NH**
- **Obs NH**
- **Mod SH**
- **Obs SH**

**About observations**

- OSISAF 1979-2007 reprocessed data set for ice concentrations (*EUMETSAT OSISAF, 2010*), interpolated to respective model grids

- ULS for ice thicknesses (*Rothrock et al., 2003*)

- PMW and ULS for Fram Strait outflow (*Kwok et al., 2004*)
1. Reference Simulation (NEMO-LIM3-1°-NCEP/NCAR)

NH sea ice extent anomalies

- **Correlation:** 0.77
- **Err. Variance:** -19.9 %
- **Err. Trend:** -45.7 %

Warm bias in reanalysis (see Tartinville et al., 2002)

SH sea ice extent anomalies

- **Correlation:** 0.45
- **Err. Variance:** 36.2 %
- **Err. Trend:** 106.5 %
1. Reference Simulation (NEMO-LIM3-1°-NCEP/NCAR)

Ice thickness distribution and observed ice edge ( — )

March 1979-2007

Sept. 1979-2007
2. Sensitivity to physics representation

**Main differences LIM2 – LIM3**

**LIM 2**
- Fichefet and Morales Maqueda, 1997
- 1-category Ice Thickness Distribution (ITD)
- 2 + 1 layers
- Effective thermal conductivity
- Basic brine modelling
- Viscous Plastic

**LIM 3**
- Vancoppenolle et al., 2009
- 5 categories ITD
- 5 + 1 layers
- Explicit brine + drainage
- Elastic Viscous Plastic

**1. Ice thickness representation**

**2. Vertical thermodynamics**

**3. Rheology**
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°
4. Sensitivity to atmospheric forcing

**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 »

Oct–Nov–Dec

- DFS4 2m air temperatures known to be warmer than NCEP (Bromwich and Wang, 2005)

- Higher winter temperatures → smaller summer ice extents

Apr–May–Jun
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 \(\rightarrow\) 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
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
References

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