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Importance of physics, resolution and forcing in hindcast simulations of Arctic and Antarctic sea ice variability and trends

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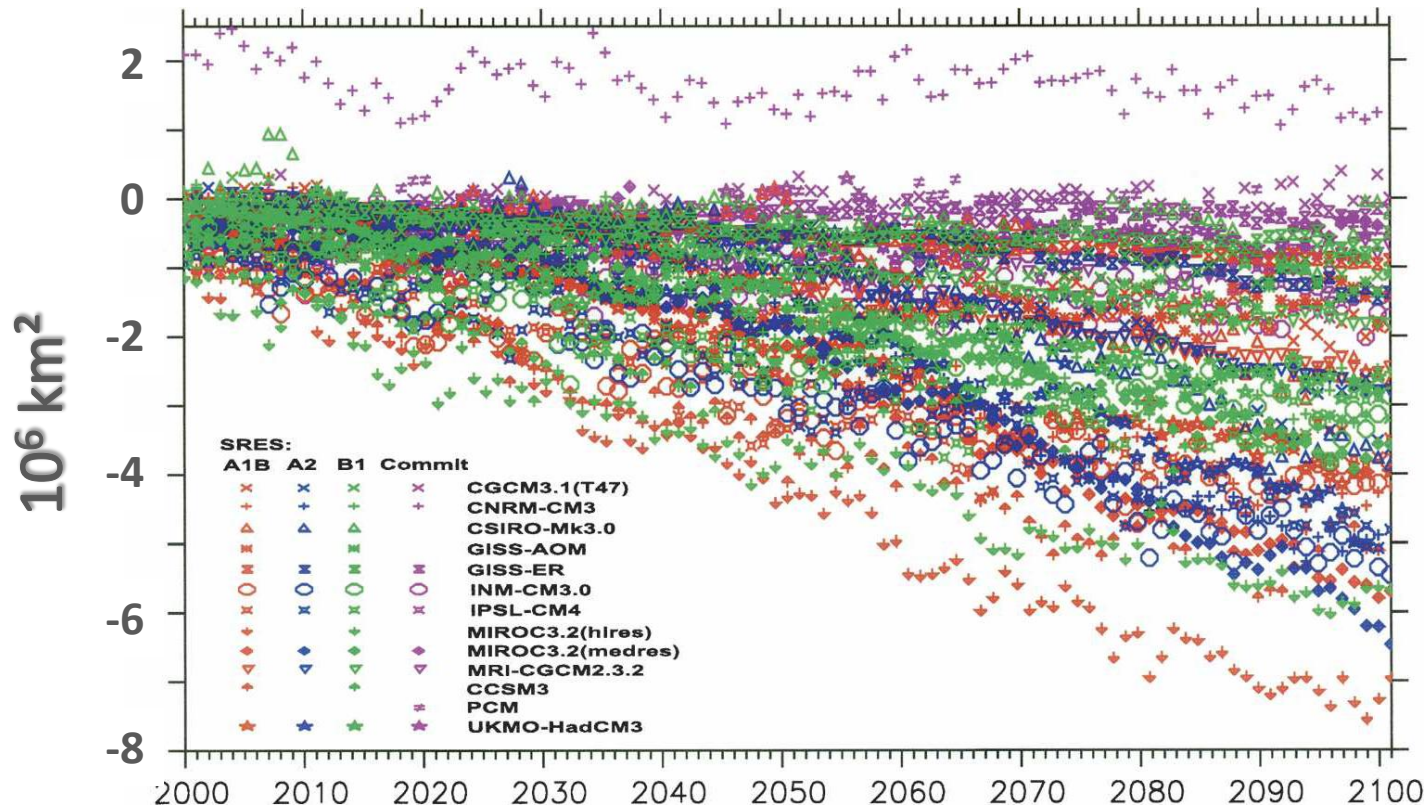
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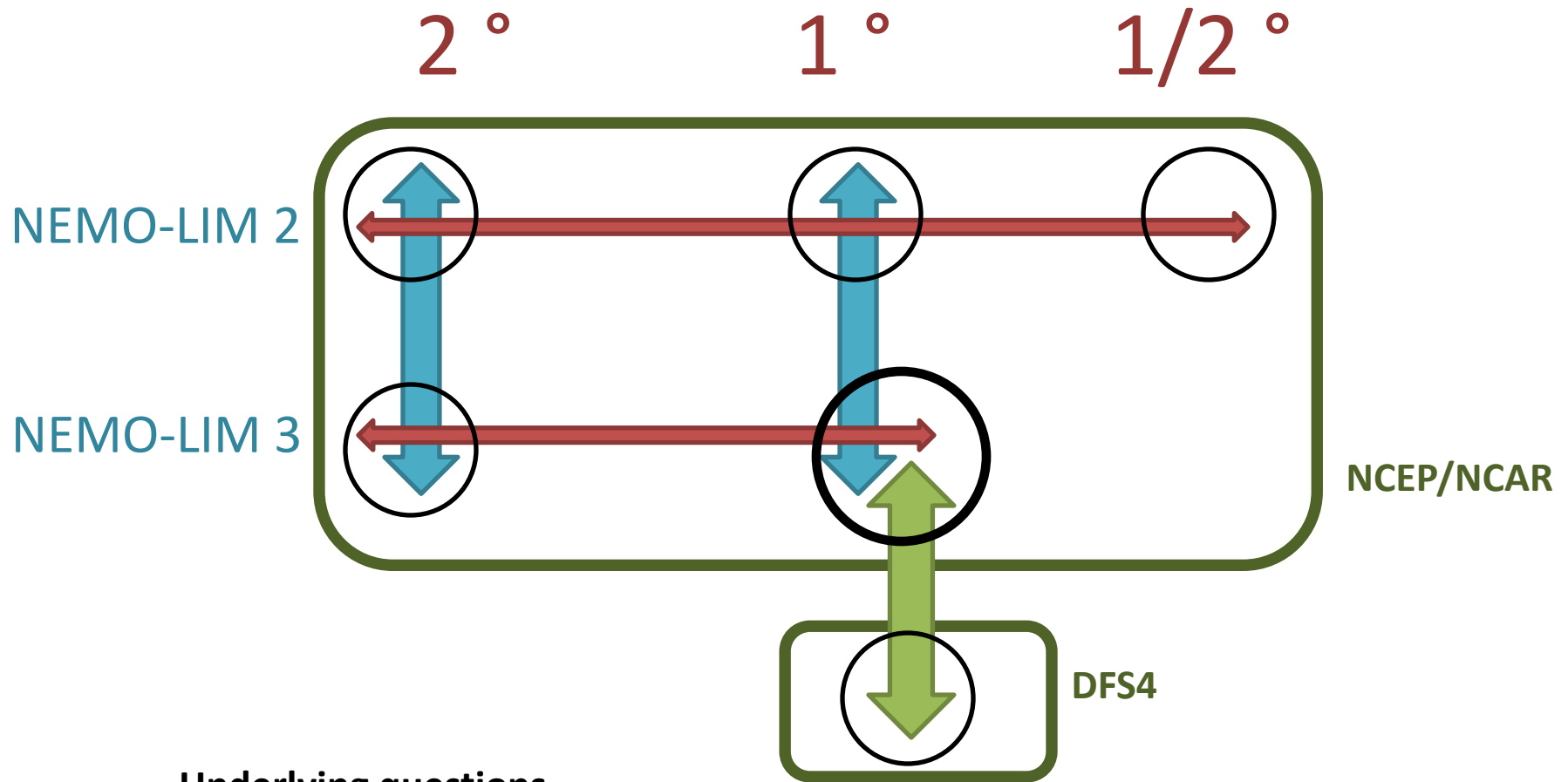
Uncertainties in sea ice variability



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

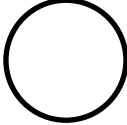



Understanding sea ice variability with an OGCM



Underlying questions

- 1) How is *model's variability performance* **modified** along arrows?
- 2) How does *model variability* **behave** along arrows?

Outline

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

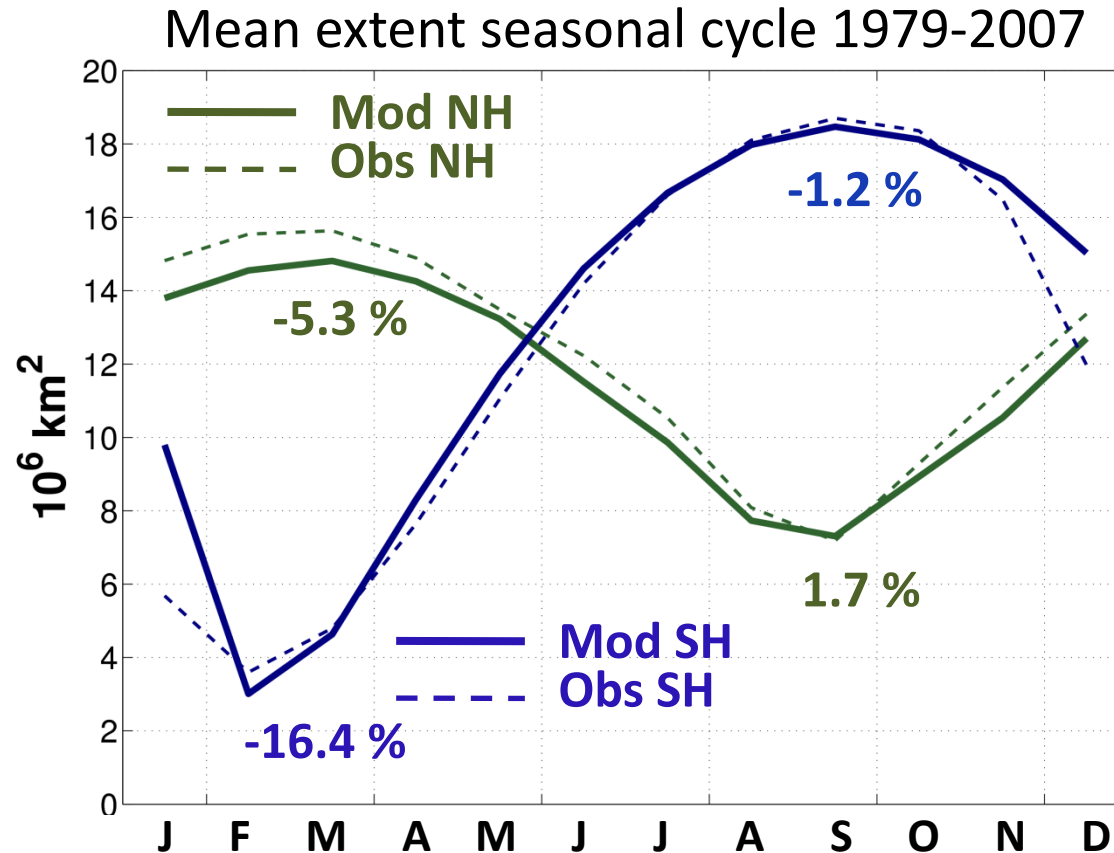
www.climate.be/lim

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

www.nemo-ocean.eu

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

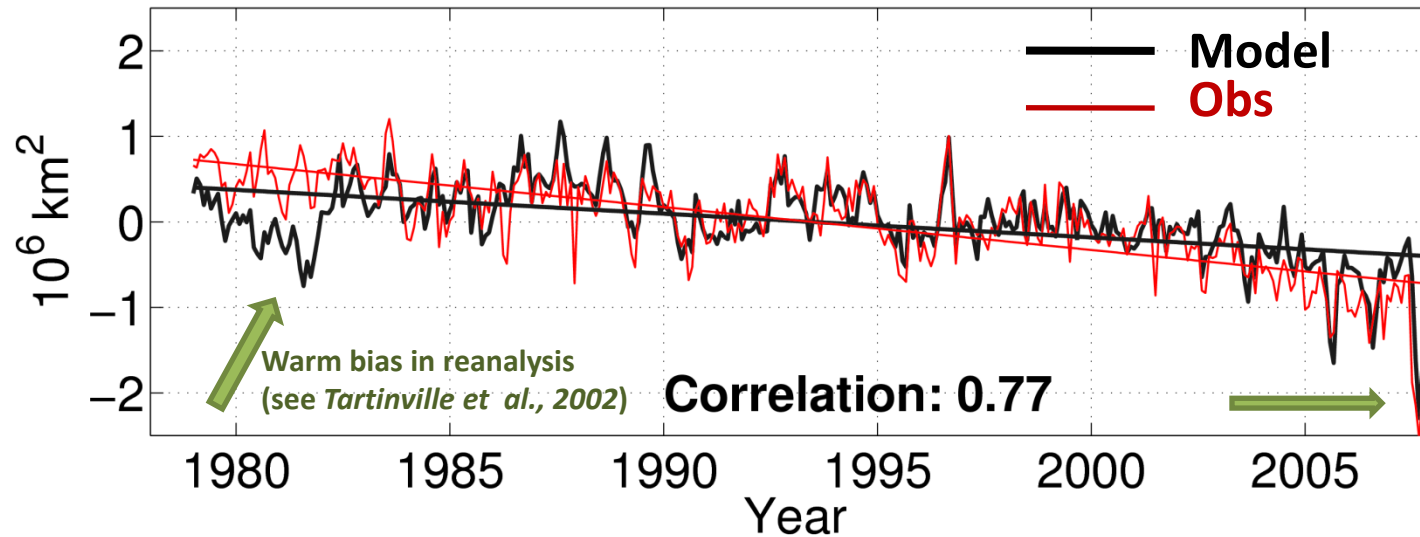


About observations

- 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*)

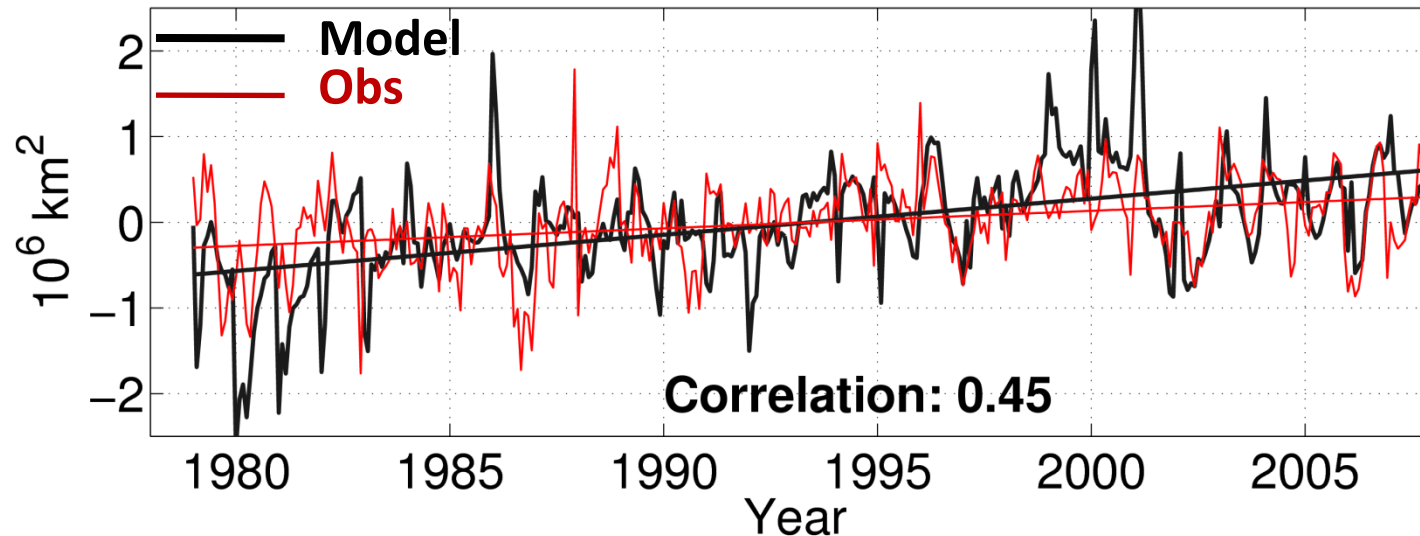
1. Reference Simulation (NEMO-LIM3-1°-NCEP/NCAR)

NH sea ice extent anomalies



Err. Variance: -19.9 %
Err. Trend: -45.7 %

SH sea ice extent anomalies

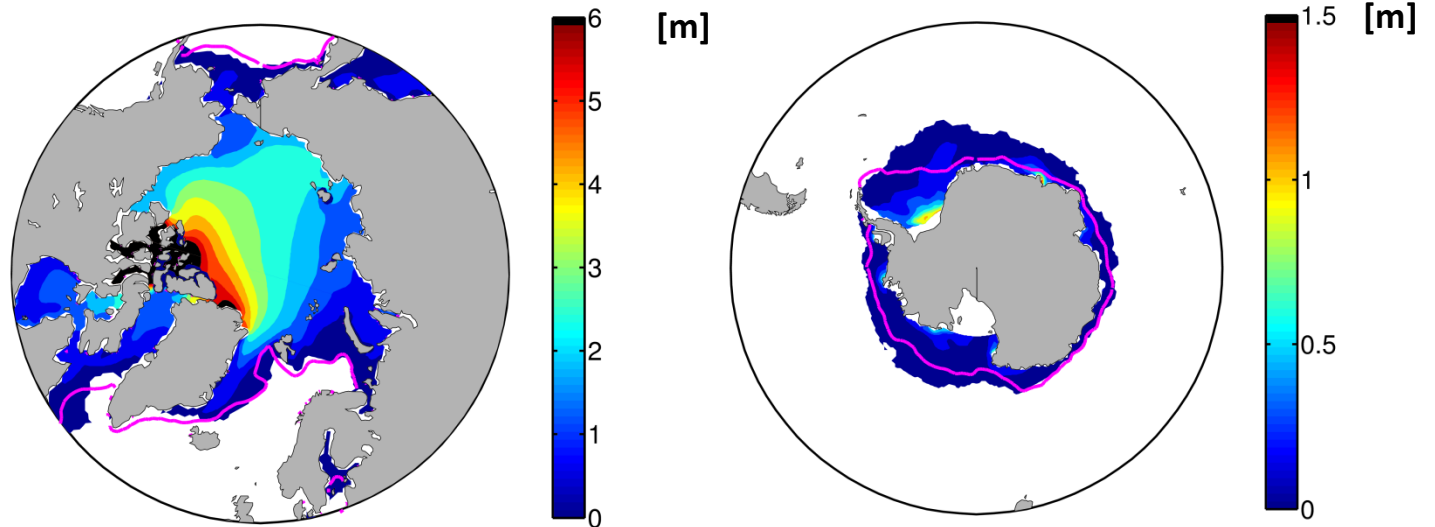


Err. Variance: 36.2 %
Err. Trend: 106.5 %

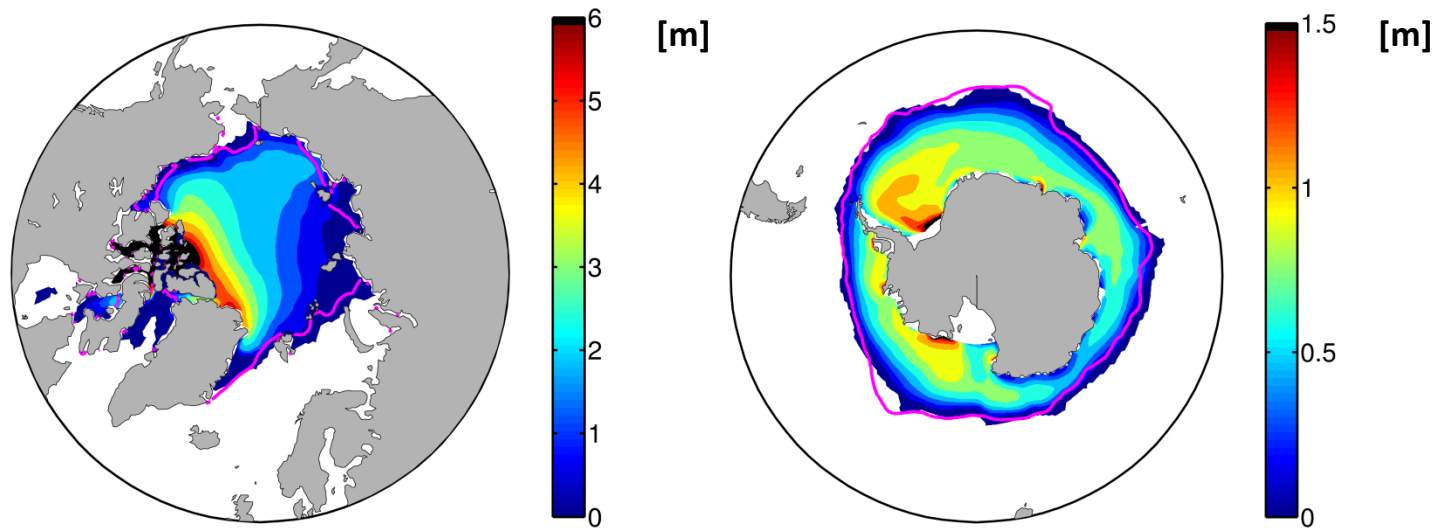
1. Reference Simulation (NEMO-LIM3-1°-NCEP/NCAR)

Ice thickness distribution and observed ice edge (—)

March 1979-2007



Sept. 1979-2007



2. Sensitivity to physics representation

Main differences LIM2 – LIM3



LIM 2

LIM 3

Fichefet and Morales Maqueda, 1997

Vancoppenolle et al., 2009

1

Ice thickness representation

1-category Ice Thickness Distribution (ITD)

5 categories ITD

2

Vertical thermodynamics

2 + 1 layers

5 + 1 layers

Effective thermal conductivity

/

Basic brine modelling

Explicit brine +drainage

3

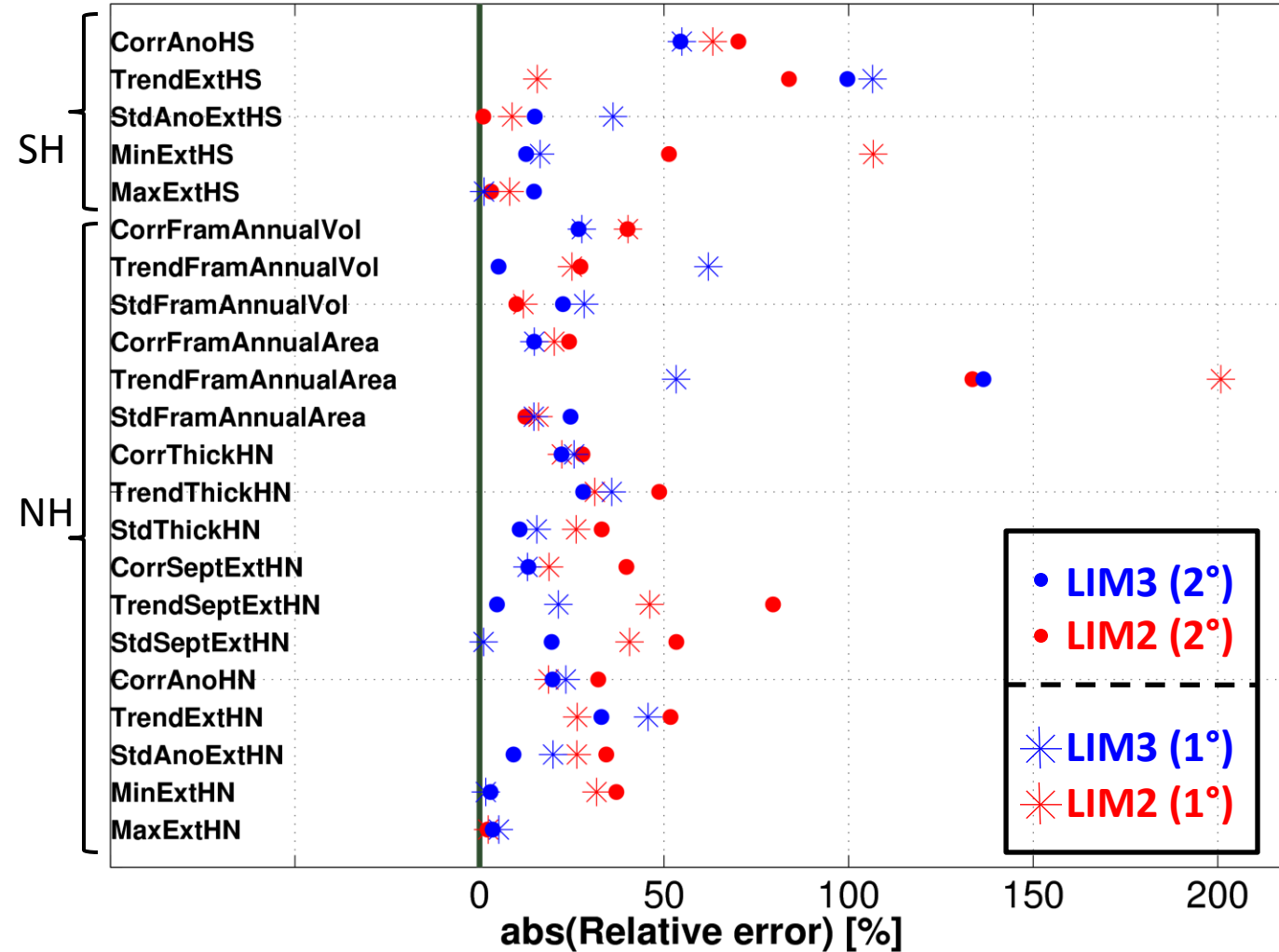
Rheology

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%

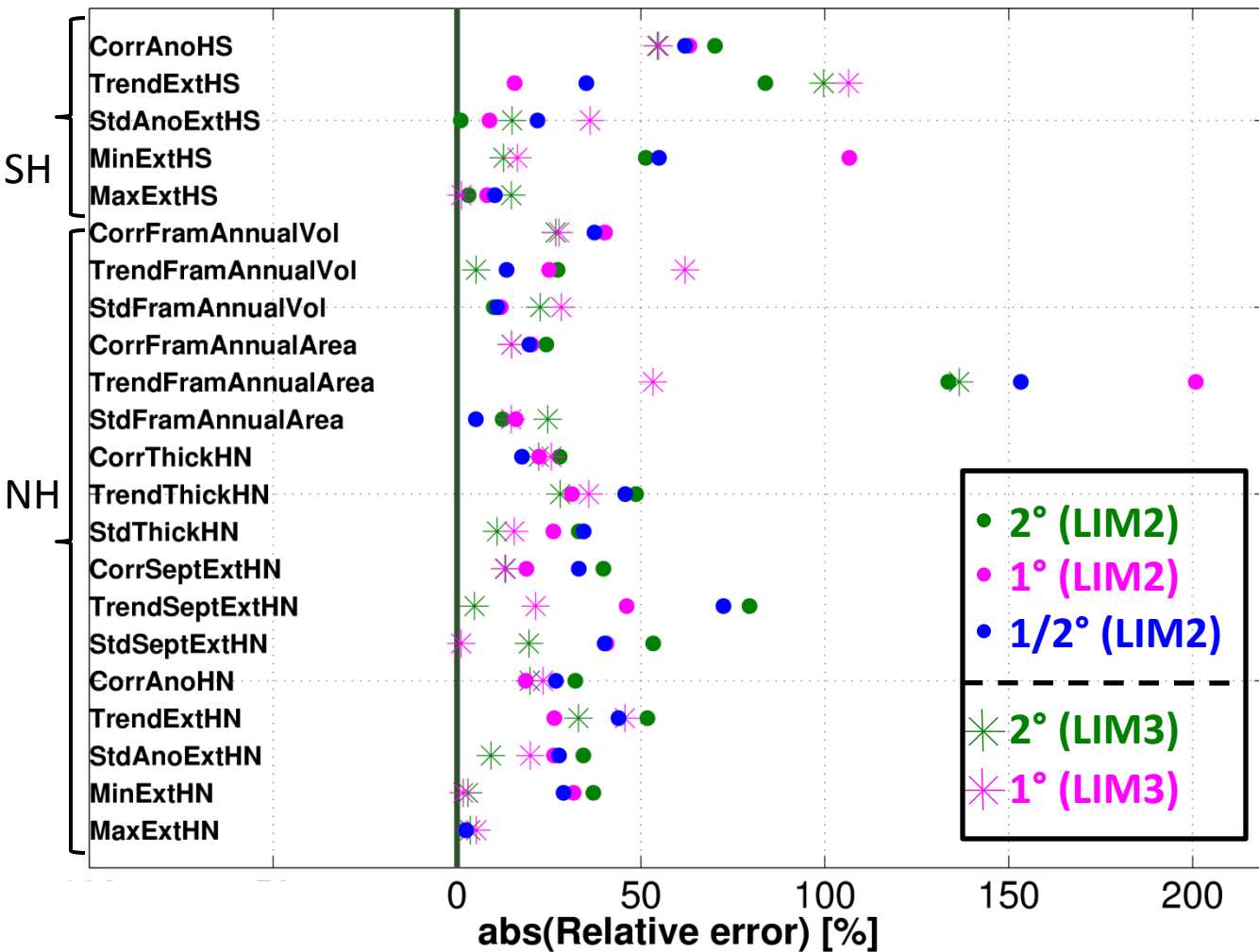
SH:

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:

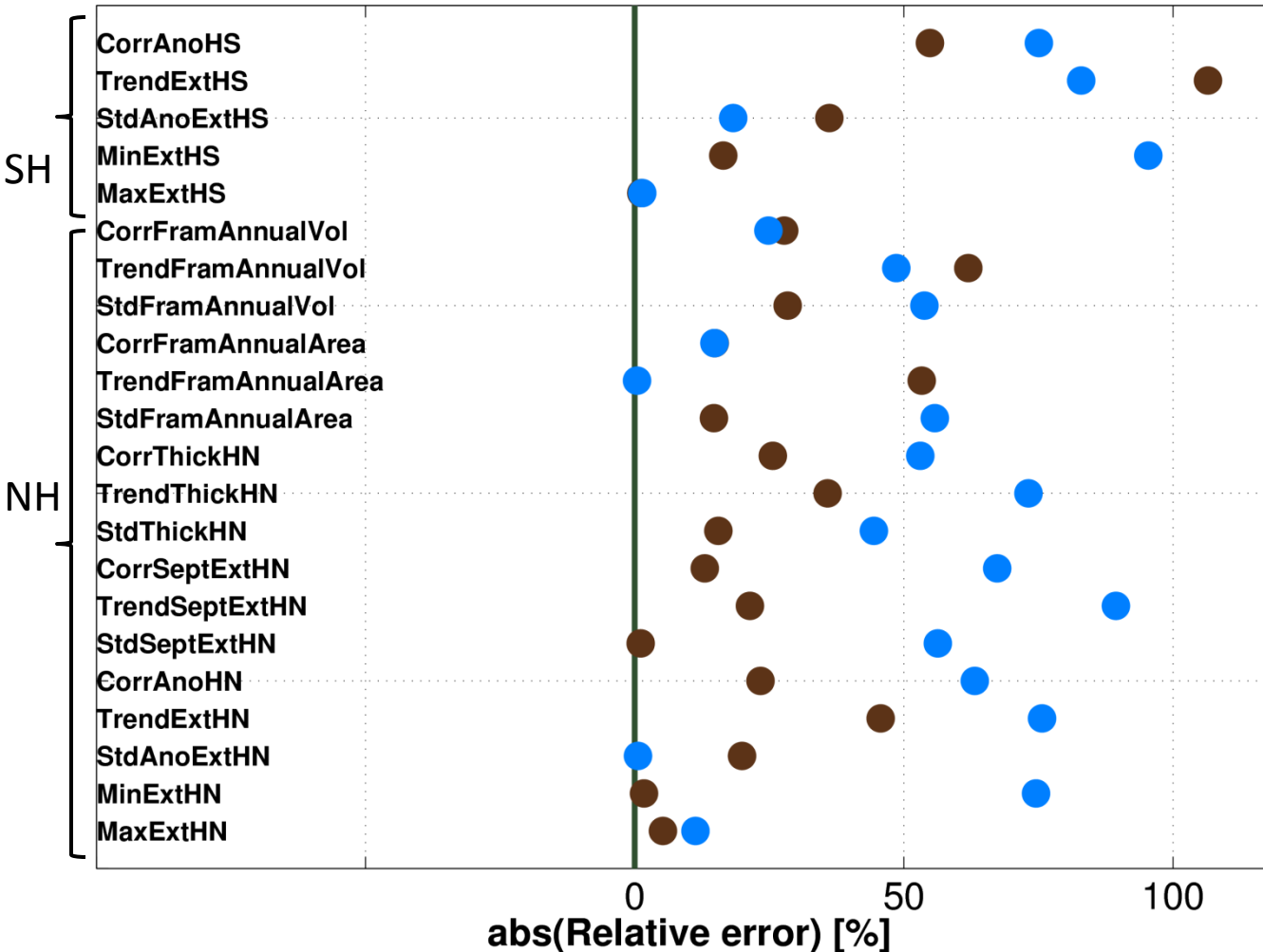
Mean abs err: 40.6% - 41.8% - 36.9%

• No significant improvement with resolution (for this range)

• But: LIM calibrated for 2°

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%

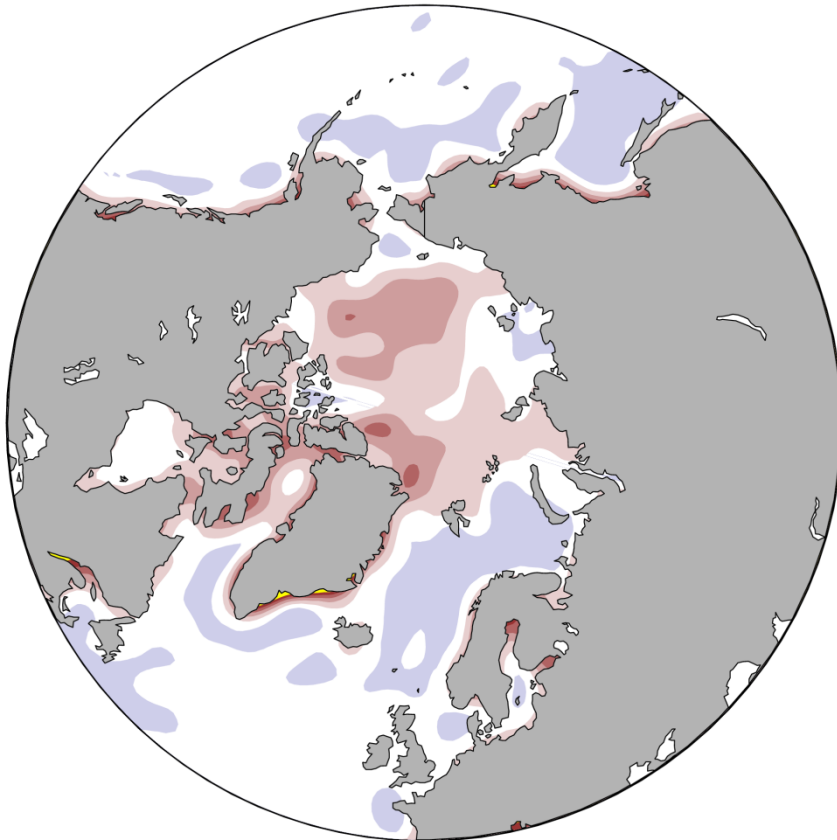
- DFS4 (Brodeau et al., 2010) is based on ERA-40 fields

- LIM calibrated for NCEP reanalysis

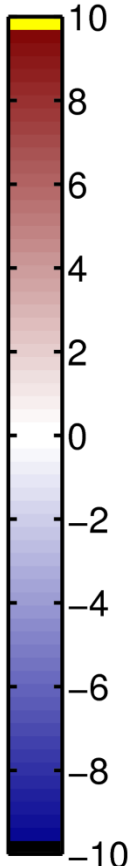
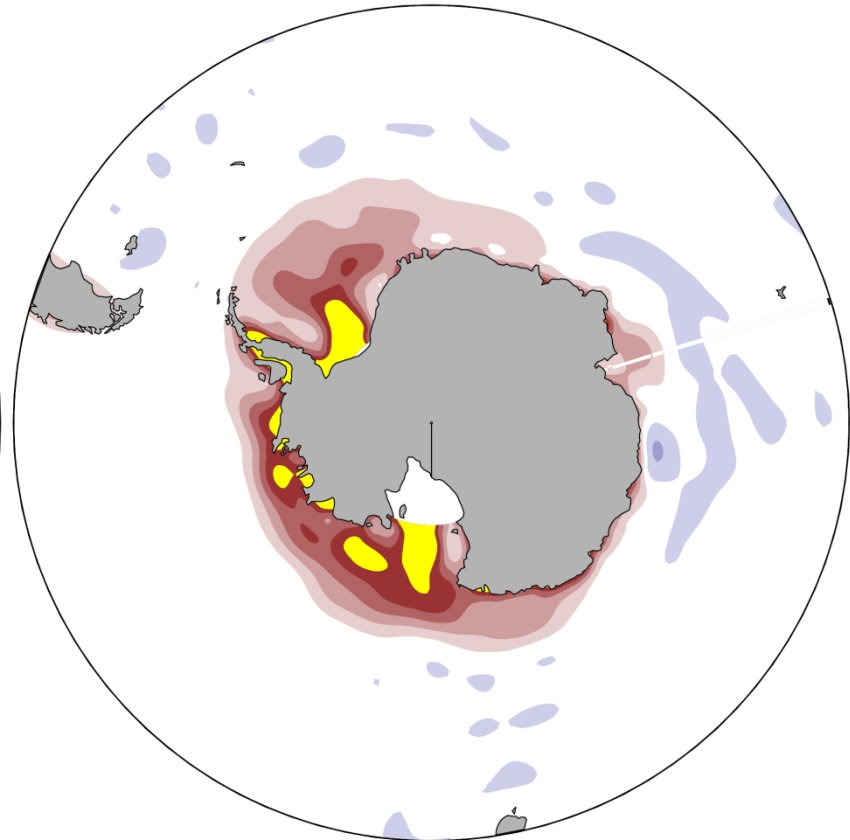
4. Sensitivity to atmospheric forcing

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

Oct–Nov–Dec



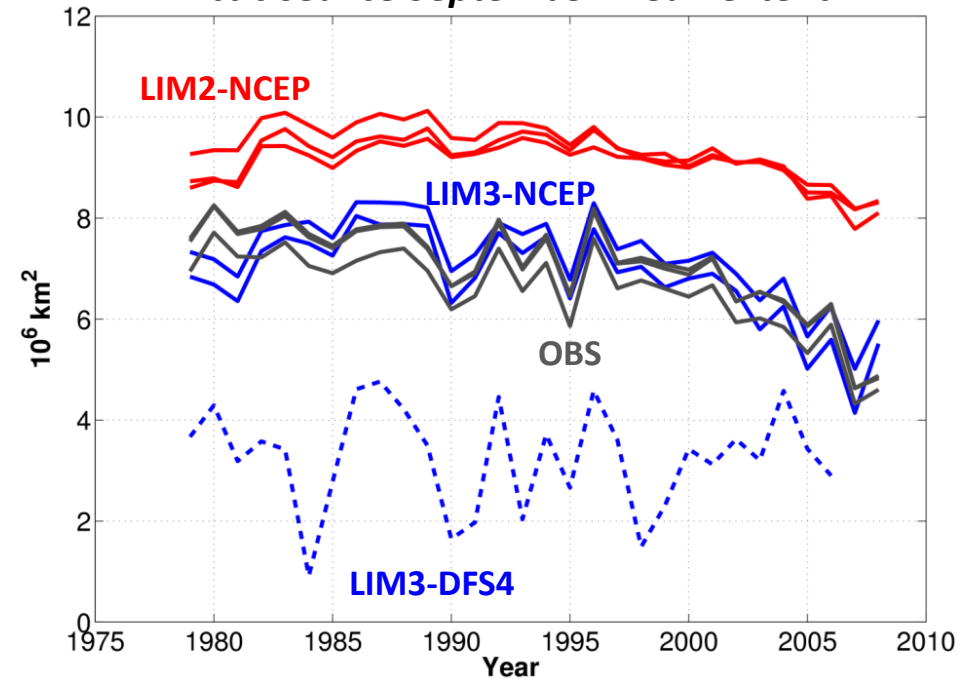
Apr–May–Jun



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

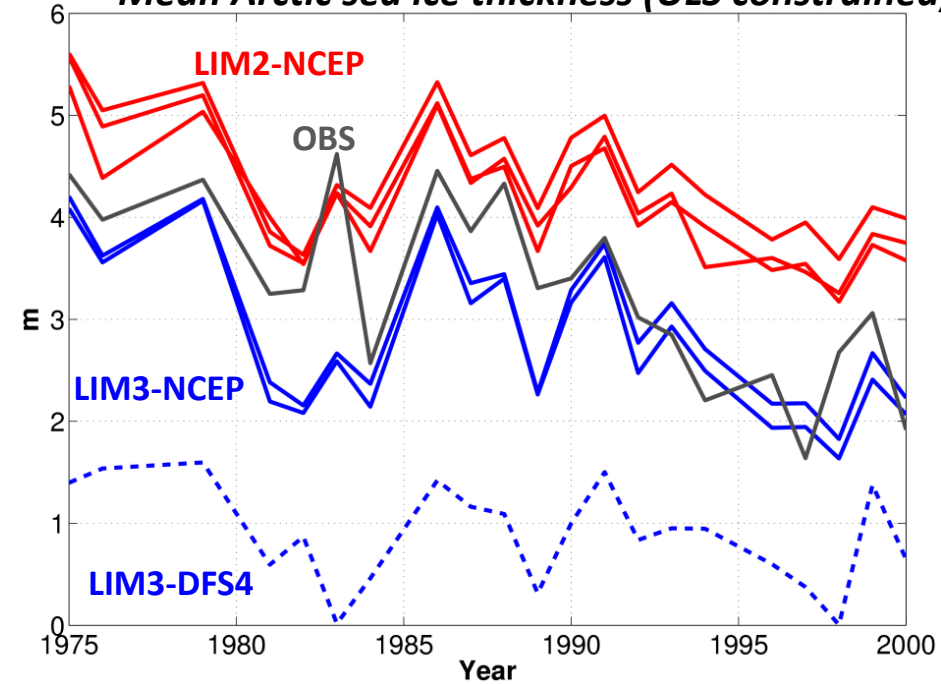
5. Illustration of sensitivity experiments

Arctic sea ice September mean extent



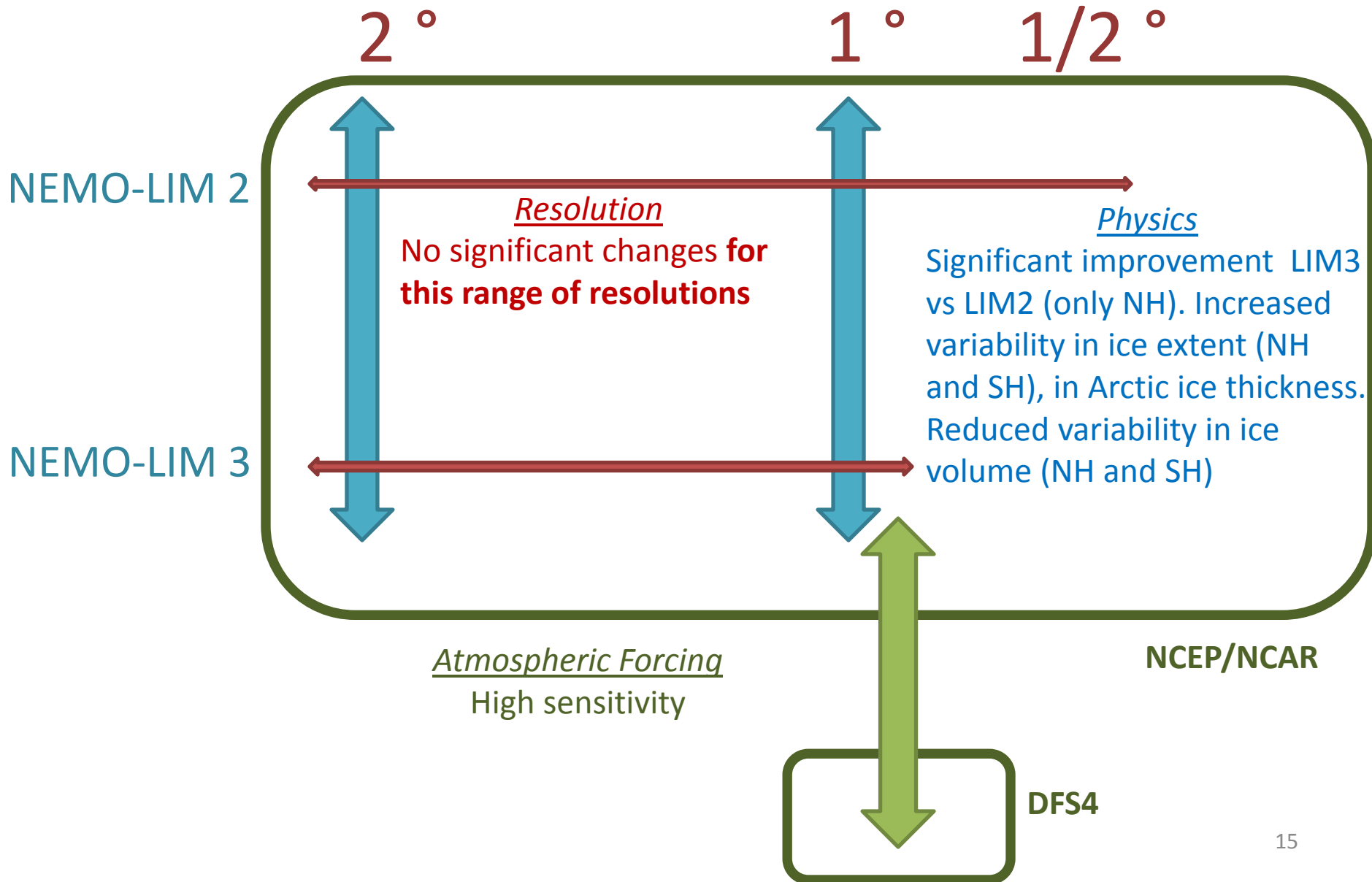
- Higher variability for smaller mean extents (as in *Goosse et al., 2009*)
- Higher variability with ITD representation, through ice-albedo feedback (*Holland et al., 2006*)

Mean Arctic sea ice thickness (ULS constrained)



- 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*)

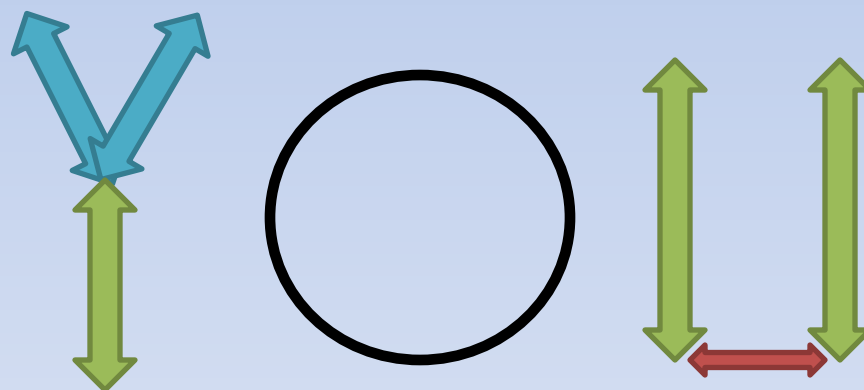
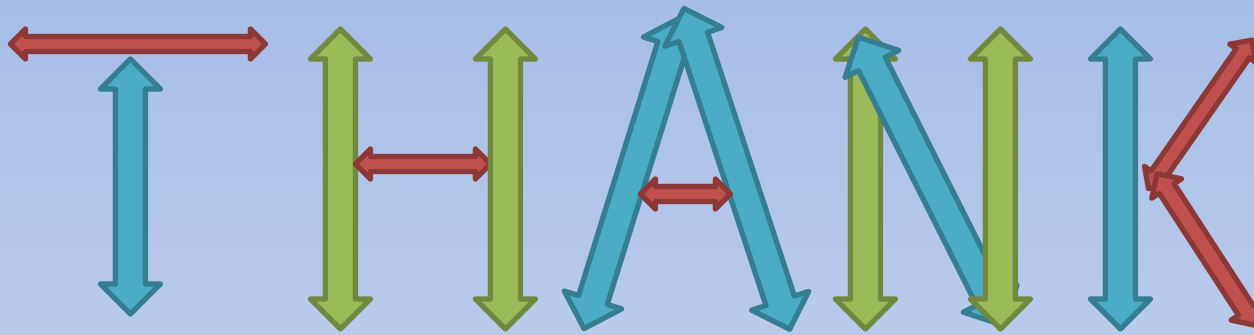
6. Conclusions



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 $\sim 1^\circ$. Eddy-permitting resolutions ($< \frac{1}{4}^\circ$) 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



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