COMBINE General Assembly
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Global sea-ice data assimilation in NEMO-LIM

Towards systematic biases reduction in modeled sea-ice concentration and thickness

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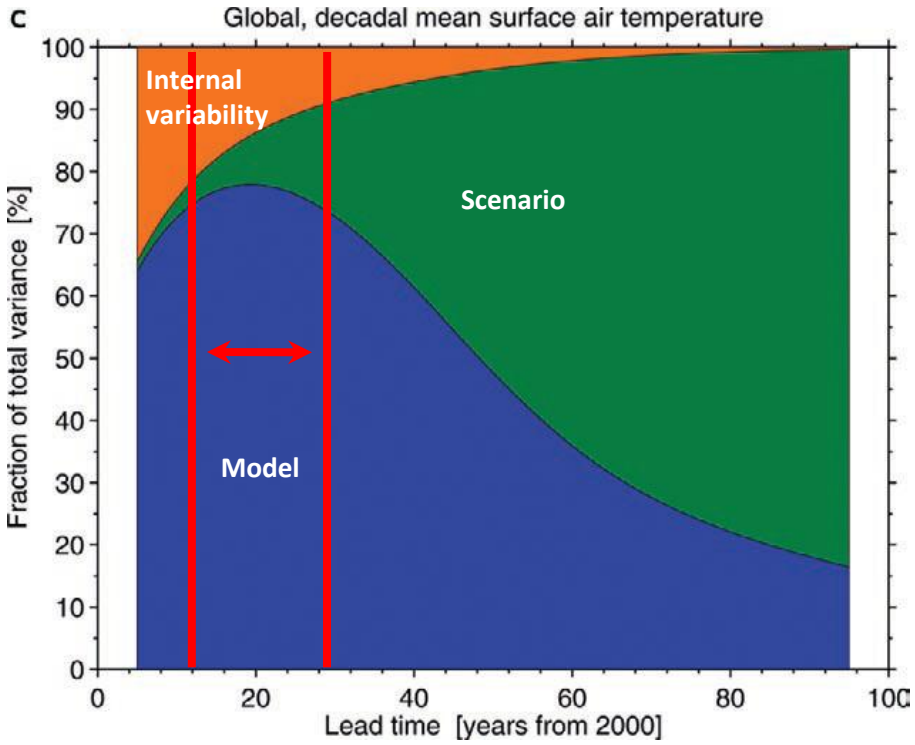
Decadal climate prediction: good practices



The fraction of total variance in decadal mean surface air temperature predictions explained by the three components of total uncertainty (Adapted from *Hawkins and Sutton, 2009*)

Reliable climate decadal predictions : what do they rest on?

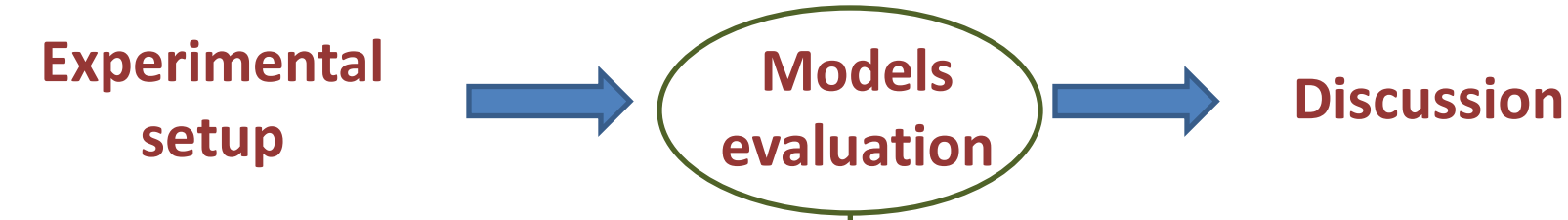
Sea-ice decadal prediction

Reliable models ?

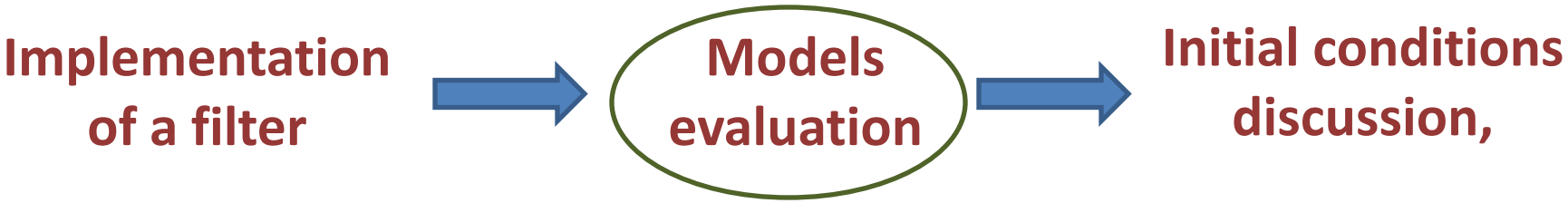
Reliable initial conditions ?

Outline

1. Importance of sea-ice model physics



2. Multivariate sea-ice data assimilation



1. Model sea-ice physics

How sensitive is the skill of sea-ice models to the representation of physical processes?

Experimental setup

NCEP/NCAR daily surface temperatures and winds
Monthly climatologies of relative humidity,
cloud cover, precipitations and river runoff

~ 1° resolution (climatic-like)
1948-2007 simulation
Focus on 1983-2007

2 sea ice models

LIM2

Fichefet and Morales Maqueda, 1997

- **Simple ice thickness dist.**
- **2+1 layers ice and snow**
- **Basic brine modelling**
- **VP rheology**
- **B-grid**

LIM3

Vancoppenolle et al., 2009

- **5 ice categories**
- **5+1 layers ice and snow**
- **Explicit brine, salinity distribution**
- **EVP rheology**
- **C-grid**

www.climate.be/lim

Ocean model

NEMO 3.1

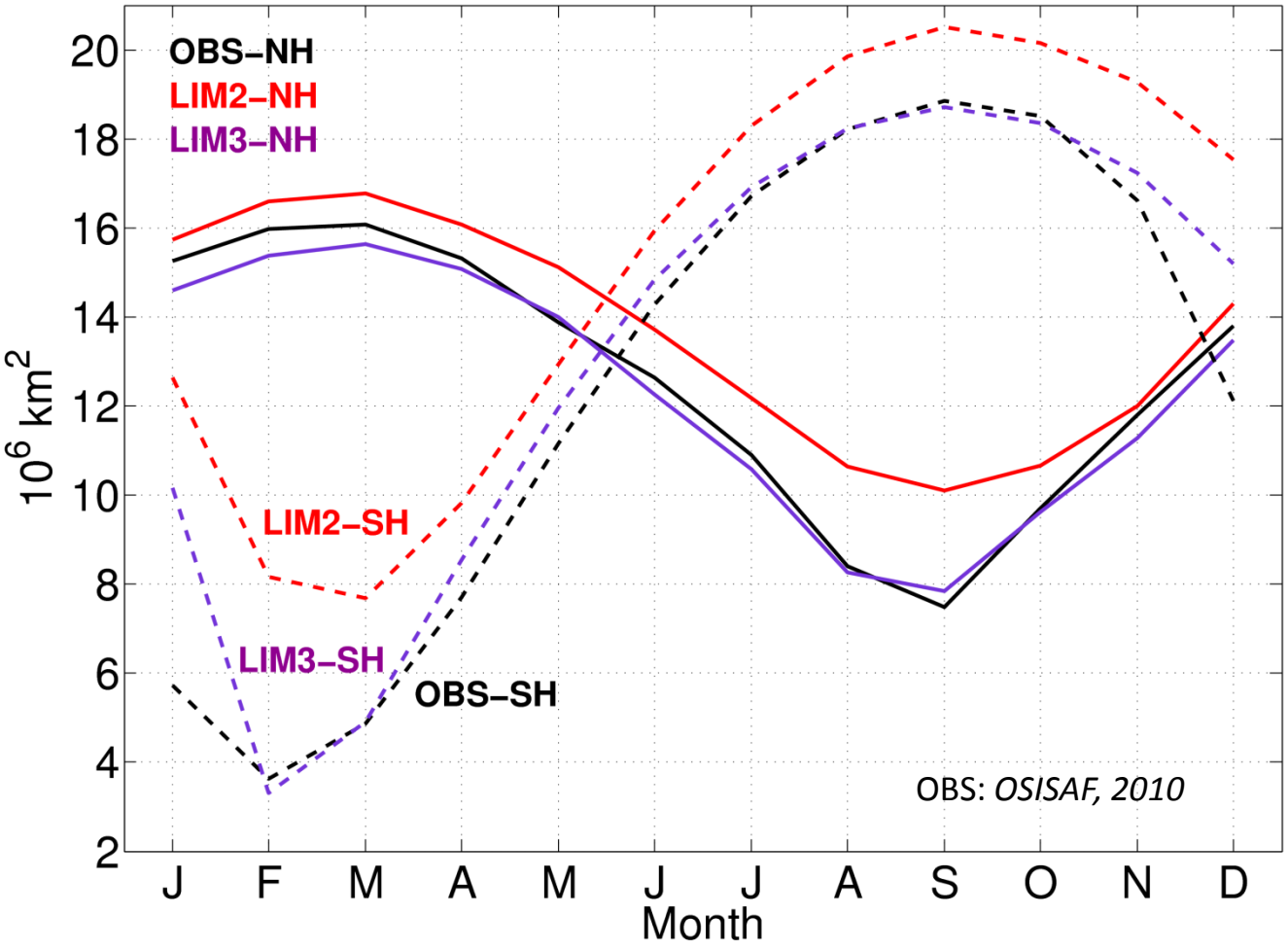
Madec, 2008

- Primitive equation free surface OGCM
- Level-1.5 turbulence closure scheme
- Isopycnal mixing + G&M param. of eddy-induced tracer advection
- 42 vertical levels
- **Salinity restoring**

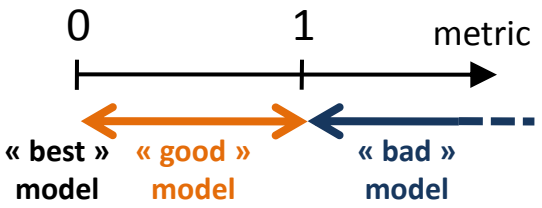
www.nemo-ocean.eu

Models evaluation

Monthly mean seasonal cycle of sea ice extent (1983-2007)



$$\text{Metric} \equiv \frac{\text{abs(model – obs)}}{\text{typical error}}$$



Northern Hemisphere (NH)

LIM2: 1.33

LIM3: 0.43

Southern Hemisphere (SH)

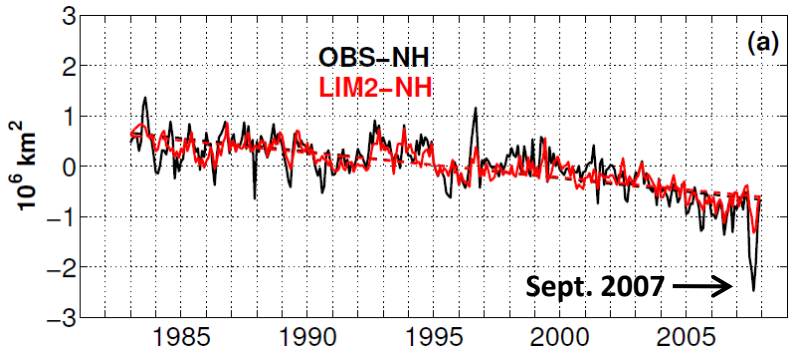
LIM2: 3.58

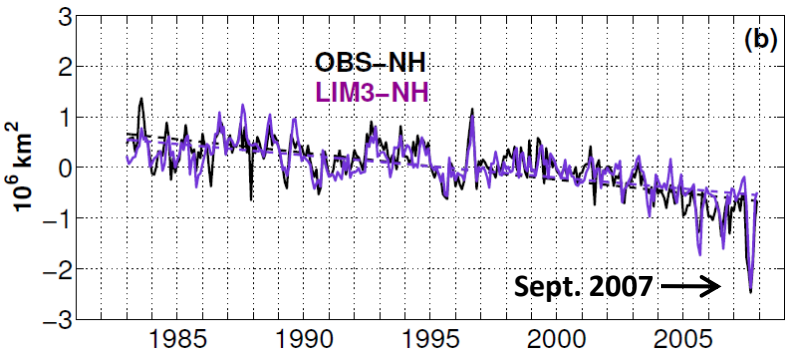
LIM3: 1.17

(the lower, the better)

Models evaluation

Monthly anomalies of sea ice extent (NH)

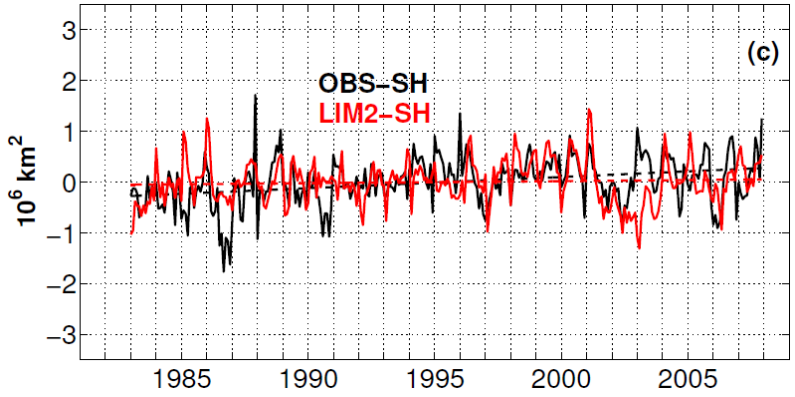


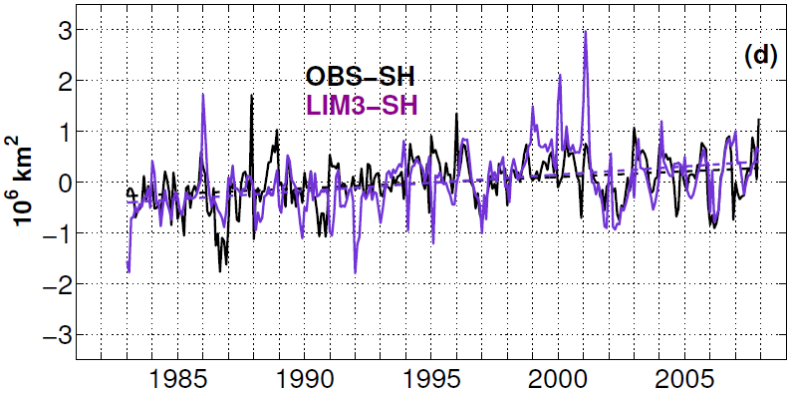


Metrics std anomalies:

LIM2: 1.22 **LIM3: 0.61** *(the lower, the better)*

Monthly anomalies of sea ice extent (SH)

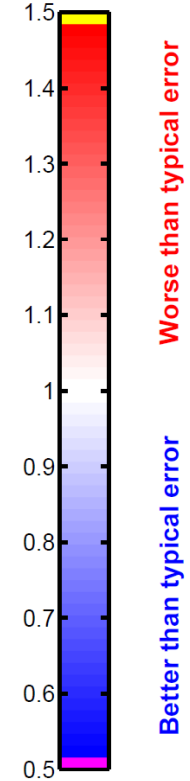




Metrics std anomalies:

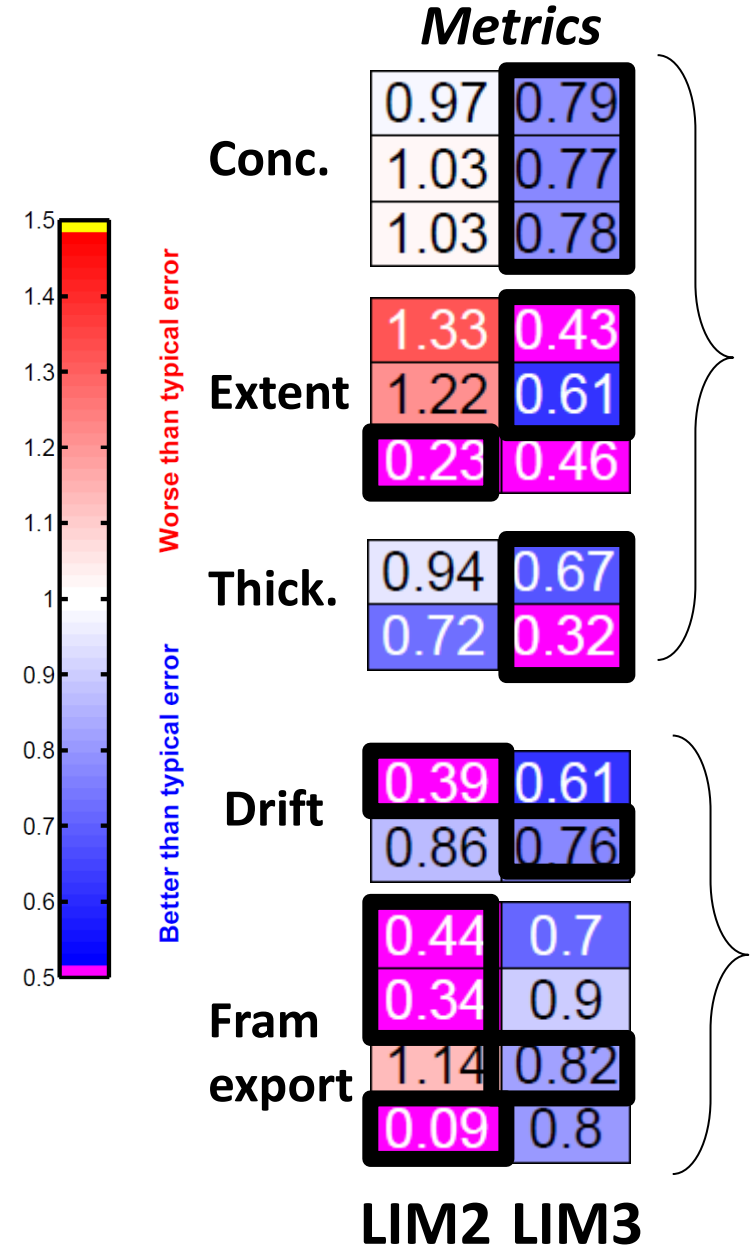
LIM2: 0.48 **LIM3: 1.10** *(the lower, the better)*

Discussion (NH)

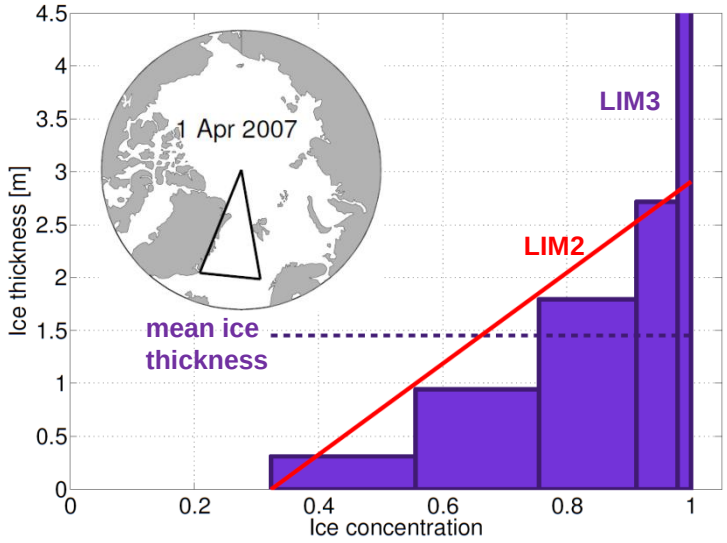


	Metrics		
Conc.	0.97	0.79	Mean
	1.03	0.77	Std of anomalies
	1.03	0.78	Trend
Extent	1.33	0.43	Mean
	1.22	0.61	Std of anomalies
	0.23	0.46	Trend
Thick.	0.94	0.67	Mean
	0.72	0.32	Trend
Drift	0.39	0.61	Mean kinetic energy
	0.86	0.76	Circulation pattern
Fram export	0.44	0.7	Mean area
	0.34	0.9	Std anomalies area
	1.14	0.82	Mean volume
	0.09	0.8	Std anomalies volume
	LIM2	**LIM3**	

Discussion (NH)

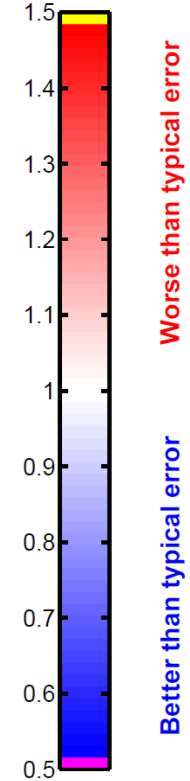


- Ice thickness distribution: Metrics confirm earlier results of Bitz et al. (2001) and Holland et al. (2006) with GCMs.
- Importance of salinity variations in LIM3 (*Vancoppenolle et al., 2009*)



- Models parameters not tuned for optimizing drift
- LIM2 (VP) versus LIM3 (EVP); EVP more responsive to wind forcing (*Hunke and Dukowicz, 1997*)

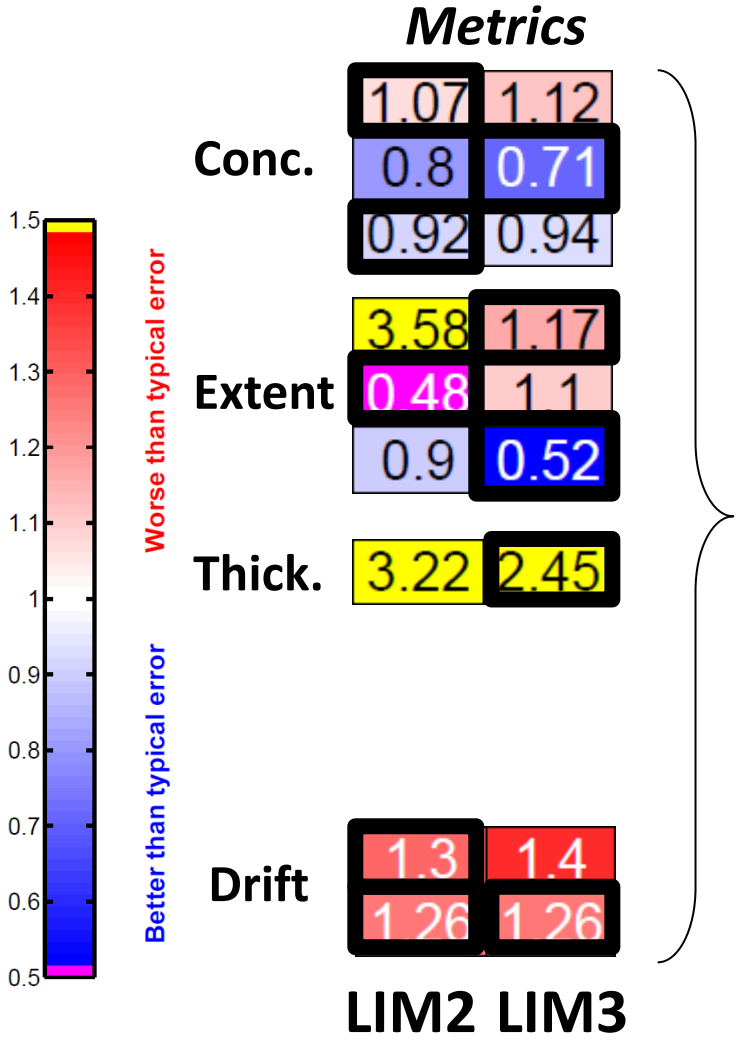
Discussion (SH)



Metrics

	LIM2	LIM3	
Conc.	1.07	1.12	Mean
	0.8	0.71	Std of anomalies
	0.92	0.94	Trend
Extent	3.58	1.17	Mean
	0.48	1.1	Std of anomalies
	0.9	0.52	Trend
Thick.	3.22	2.45	Mean
Drift	1.3	1.4	Mean kinetic energy
	1.26	1.26	Circulation pattern

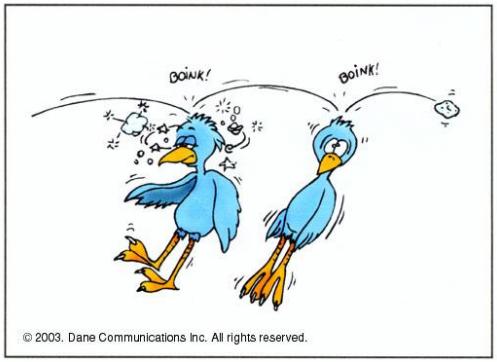
Discussion (SH)



- No outstanding model!
- SH is different from NH in many respects:
  - Dynamics of the Southern Ocean and unresolved small-scale processes (Rintoul et al., 2001)
  - Quality of the reanalyses (Vancoppenolle et al., 2010; Vihma et al., 2002; Timmerman et al., 2004)
  - Thinner ice than NH

2. Sea-ice data assimilation

Can we partly overcome the systematic biases of LIM2?



An EnKF approach

The **En**semble **K**alman **F**ilter (*Evensen, 2003*)

$$\mathbf{x}^a = \mathbf{x}^f + \mathbf{K}\left(\mathbf{d} - \mathbf{H}\,\mathbf{x}^f\right)$$

Analysis

Forecast
(daily, LIM2, ORCA2)

Kalman gain
Includes obs. error and model forecast error covariance matrices

Observations
Global, daily sea-ice **concentrations**
1979-2005
(OSISAF, 2010)

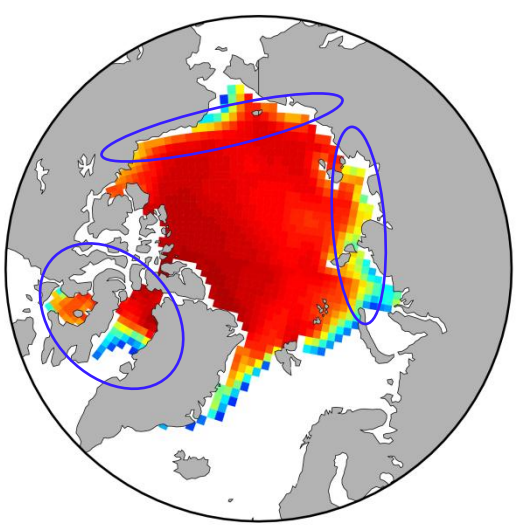
Projection
Interpolation model-observation grids

- Observational errors: ➡ provided with the sea-ice concentration products
- Model forecast errors: ➡ 25 members, gaussian wind perturbations

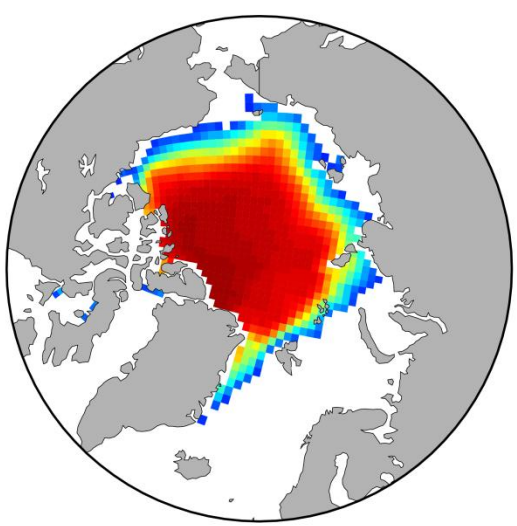
✓ EnKF is statistically consistent
✓ Multivariate data assimilation

Direct improvements

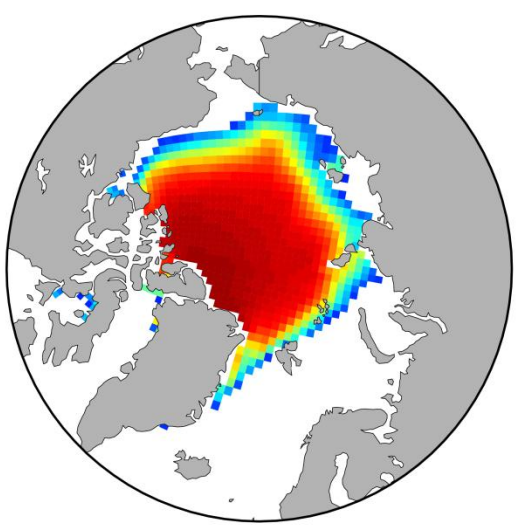
Mean September 1983-2005 sea-ice concentrations



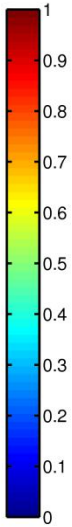
LIM2 - FREE

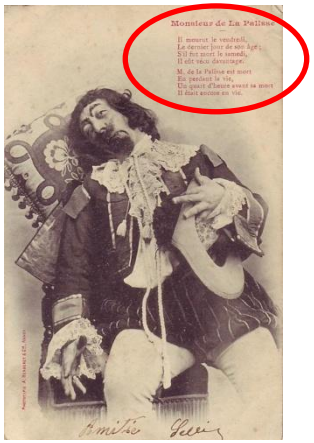


OBS



LIM2 - ASSIM



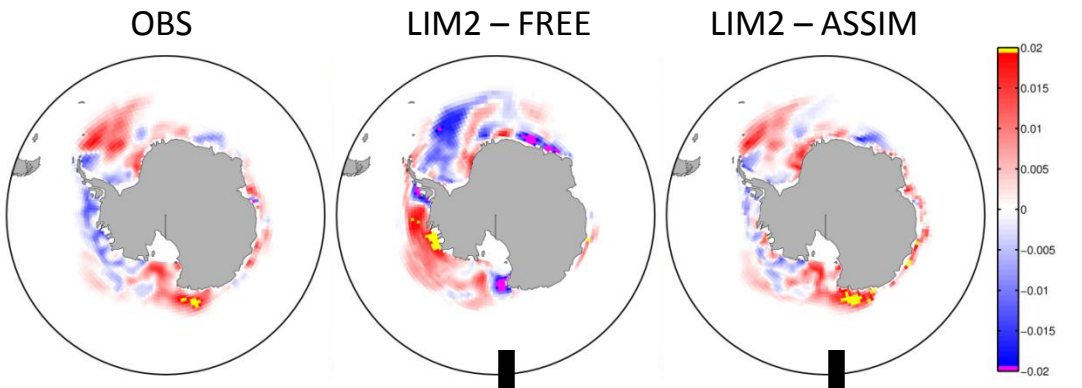


« […] 15 minutes before he died, he was still alive […] »

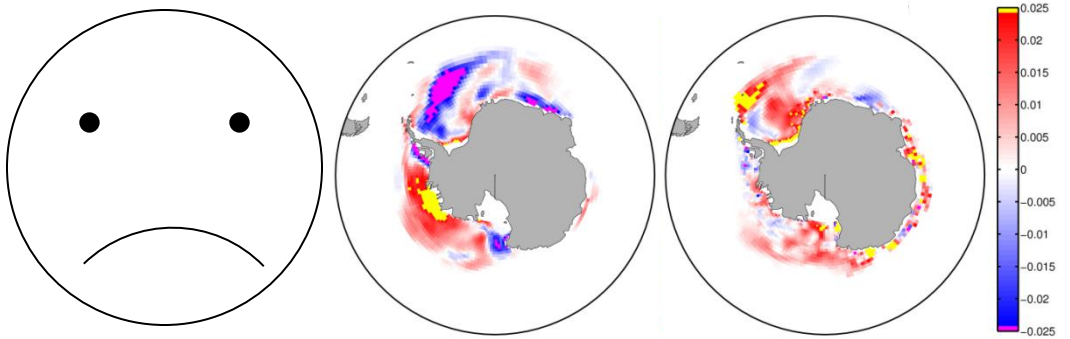
Monsieur de La Palisse (~ 1500)

Side effects

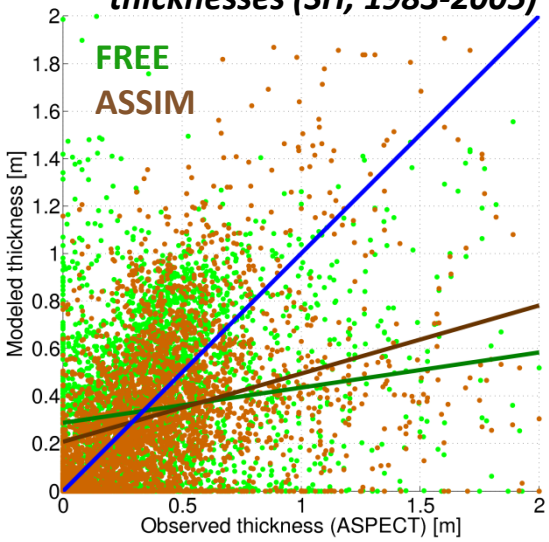
Trends in sea-ice concentration in January (1983-2005)



Trends in sea-ice thickness in January (1983-2005)



Modeled versus observed sea-ice thicknesses (SH, 1983-2005)

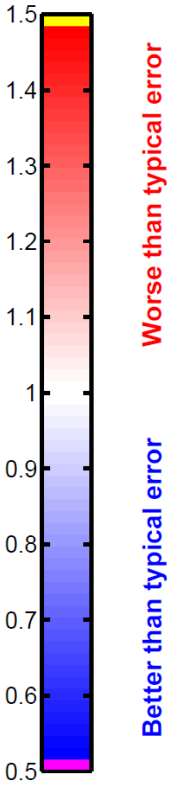


Assimilation of sea-ice concentration **only**

- improves trends in sea-ice concentration
- has a high effect on the simulated trends of sea-ice thickness
- slightly improves the simulated sea-ice thickness

ASPeCT: *Worby et al., 2008*

Evaluation (NH)



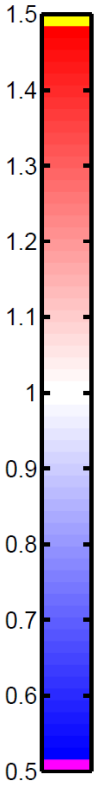
	LIM2 *ASSIM*	LIM2 *FREE*	LIM3 *FREE*	
Conc.	0.35	0.81	0.66	Mean
	0.39	0.88	0.61	Std of anomalies
	0.47	0.81	0.72	Trend
Extent	0.32	1.42	0.44	Mean
	0.35	0.95	0.04	Std of anomalies
	0.16	0.58	0.05	Trend
Thick.	0.6	0.84	0.77	Mean
	0.39	0.78	0.13	Trend
Drift	1.31	0.75	0.57	Mean kinetic energy
	0.75	0.86	0.75	Circulation pattern
Fram export	0.5	0.74	0.88	Mean area
	0.93	1.21	1.36	Std anomalies area
	0.5	1.69	0.76	Mean volume
	0.15	1.74	0.24	Std anomalies volume
	LIM2 *ASSIM*	LIM2 *FREE*	LIM3 *FREE*	

(the lower, the better)

In the NH

- Assimilation of ice concentration ➞ right mean state
- Model physics are still crucial to reproduce interannual variability
- Impact of assimilation on dynamics is not clear
- Integrated quantities (Fram) better reproduced

Evaluation (SH)



	LIM2 *ASSIM*	LIM2 *FREE*	LIM3 *FREE*	
Conc.	0.29	0.73	0.99	Mean
	0.19	0.64	0.91	Std of anomalies
	0.3	1.02	1.4	Trend
Extent	0.85	1.62	1.62	Mean
	0.1	0.44	0.46	Std of anomalies
	0.23	0.98	0.7	Trend
Thick.	2.02	2.33	2.34	Mean
Drift	3.1	2.47	1.82	Mean kinetic energy
	1.38	1.38	1.42	Circulation pattern

(the lower, the better)

In the SH

- Assimilation of sea-ice concentration takes over model physics, for mean state **and** interannual variability
- Impact of assimilation on dynamics is not clear
- Better regional representation of ice concentration

Take home message

- The sea-ice models LIM2 and LIM3 show
  - different skills in the NH (mainly due to model physics)
  - similar, lower skill in the SH (mainly due to external factors)

- Data assimilation of sea-ice concentration in LIM2
  - efficiently corrects the model biases in sea-ice concentration
  - slighly improves the simulated sea-ice thickness
  - provides a continous set of initial conditions (COMBINE, WP6) to be coupled with NEMOVAR ocean initial conditions

- Data assimilation of sea-ice freeboard in Arctic (2005-2007)
  - Recent satellite data have also been assimilated (*Mathiot et al., in prep.*)
  - Main changes occur at the centre of the ice pack

	Obs. : Kwok et al. (2009) [10^3 km^3]	LIM2–**no assim**. [10^3 km^3]	LIM2–**ice conc. assim**. [10^3 km^3]	LIM2–**ice conc. and freeboard assim**. [10^3 km^3]
Central Arctic sea-ice volume in March–April 2007	16.5	23.5	18.6	17.5