Impact of the Initialization Method on the Skill of Decadal Climate Predictions in the Southern Ocean

UCL Université catholique de Louvain

Violette Zunz[1] (violette.zunz@uclouvain.be), Hugues Goosse[1], Johann Jungclaus[2], Svetlana Dubinkina[1] and Yoann Sallaz-Damaz[1]

[1]Georges Lemaître Centre for Earth and Climate Research, Earth and Life Institute, Université catholique de Louvain, Louvain-la-Neuve, Belgium.

[2]Max Planck Institute for Meteorology, Hamburg, Germany.

1. Introduction

Performing efficient decadal climate predictions over the Southern Ocean relies partly on:

- a model that represents relatively well the physical process in this region;
- an optimal estimate of the initial state of the system.

Data assimilation (DA) methods can provide an optimal estimate of the initial state given imperfect model equations and inaccurate and incomplete observations.

Objective: testing a sophisticated DA method to check if it can improve decacal climate predictions skill in the Southern Ocean area.

2. Methodology

2.1. Model

Coupled climate model **LOVECLIM** [1]:

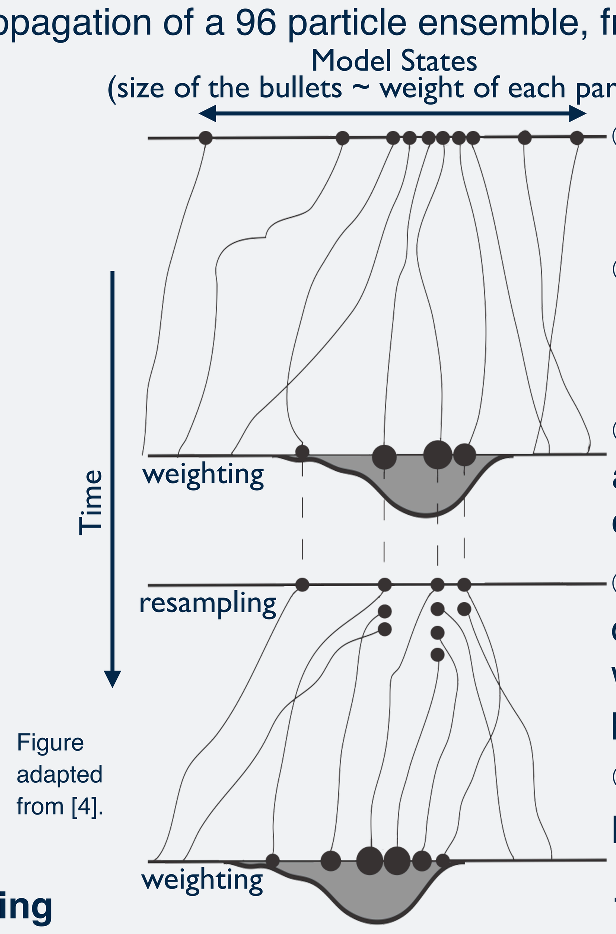
- 3D Earth system model of intermediate complexity;
- Lower level of complexity and coarser resolution than general circulation model (GCM);
- Lower computational cost than GCM.

➡ Large number of tests can be performed within a reasonable computational time.

2.2. Data Assimilation: Combination of a Particle Filter and Nudging

- Used to reconstruct the evolution of the climate system between 1850 and 2010;
- Variable assimilated: anomaly of the surface temperature w.r.t. 1961-1990 from HadCRUT3 dataset [2].

- **Particle Filter with Resampling [3]**
  - ➡Seasonal DA over the area southward of 30°S.
  - ➡Propagation of a 96 particle ensemble, from 1850 to 2010.



① t = 0: all particles have equal weights.

② t = 0 month → t = 3 months: propagation using the model.

③ t = 3 months: particles are weighted according to the likelihood (the closer to the observation, the higher the weight).

④ t = 3 months: particles are resampled to obtain an equal-weight ensemble. Particles with high weight are duplicated and a small perturbation is added to them.

⑤ t = 3 months → t = 6 months: propagation using the model.

... and so on.

- **Nudging**

$-k(T_{mod} - T_{obs})$

is added to the heat flux between the atmosphere and the ocean (for each grid point of the ocean free of sea ice), in order to nudge the solution towards the observation.

T_{mod} and T_{obs} = modeled and observed surface temperature anomaly;

k = relaxation coefficient (~ relaxation time of 6 months).

Nudging limited to a maximum flux of 50 Wm^{-2}.

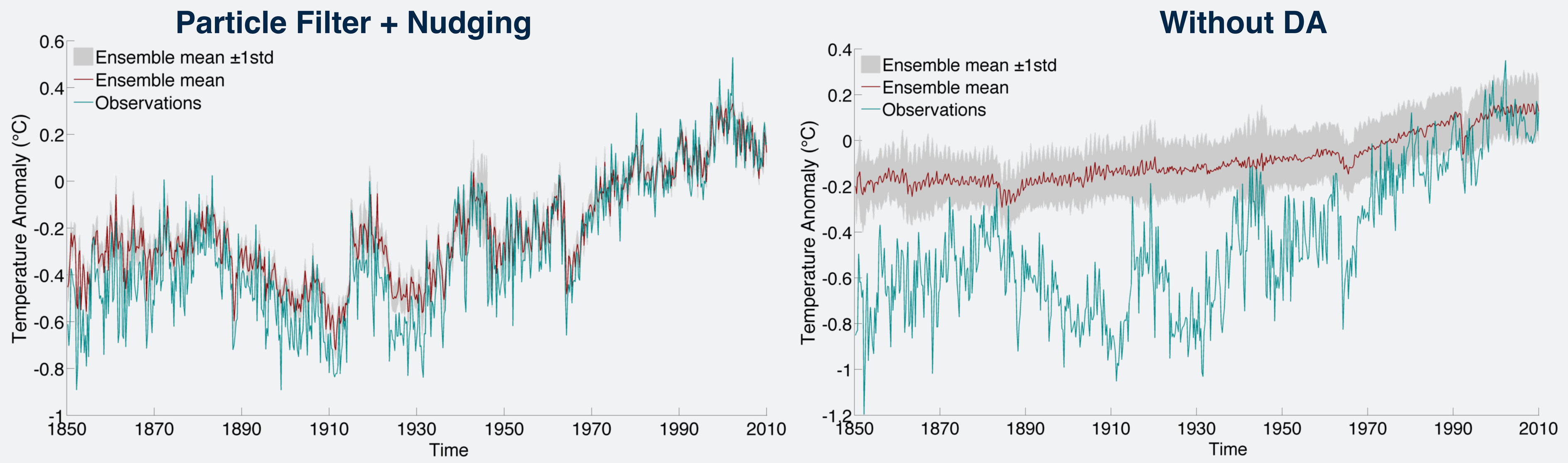
2.3. Hindcast Experiments

- 5-year ensemble simulations (96 members):
  - Start in January, every 2 years from 1980 to 2002;
- 10-year ensemble simulations (96 members):
  - Start in January, every 5 years from 1975 to 1990;
- 2 series of hindcasts for each time period: one series whose initial condition has been extracted after the resampling step of the particle filter (**hindcasts with DA**), the other one initialized without DA (**hindcasts without DA**).

The accuracy of these hindcasts is assessed by comparing their results with available observations. Hindcasts performed with LOVECLIM are compared to the ones from the ECHAM6/MPI-OM model in section 5.

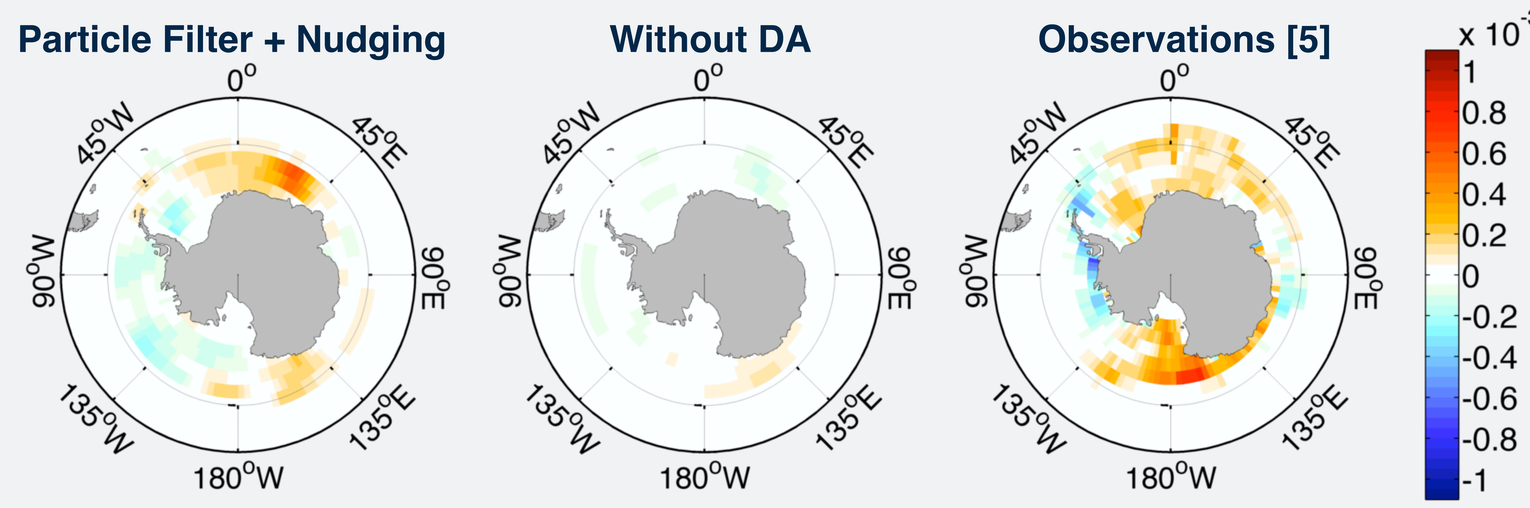
3. Reconstruction of the Surface Temperature

Seasonal mean of the surface temperature anomaly averaged over the area southward of 30°S



4. Reconstruction of the Trends of the Sea Ice Concentration

1979 - 2007 Trends of Sea Ice Concentration (month⁻¹)

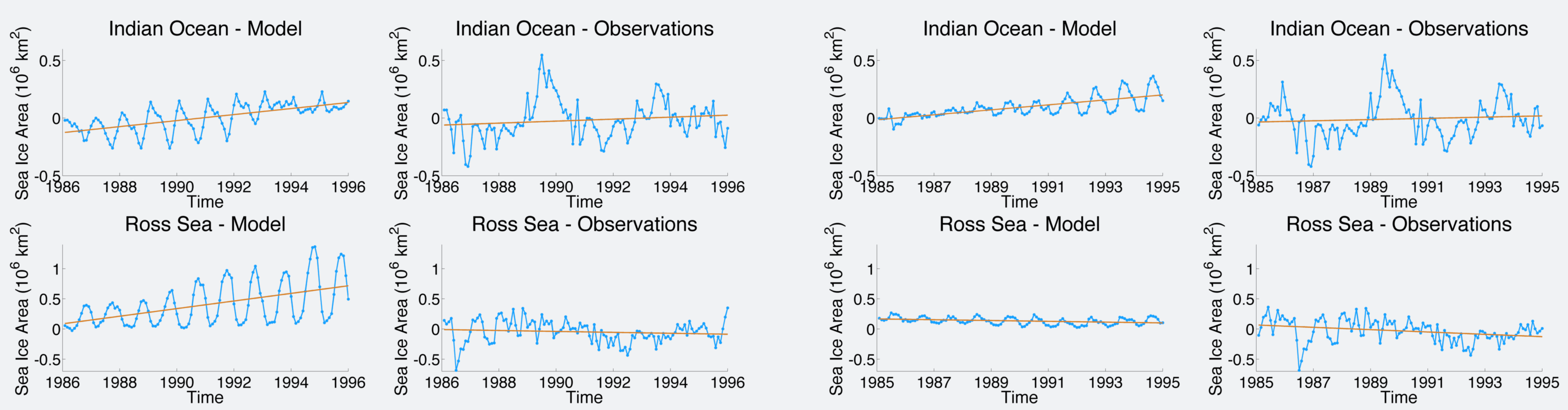


5. 10-Year Hindcasts Performed with LOVECLIM and with ECHAM6/MPI-OM

Hindcasts performed with the **ECHAM6/MPI-OM** atmosphere-ocean-sea-ice coupled model are **10 members** ensemble. They are initialized through the assimilation (with only a nudging) of the 3D temperature and salinity anomalies (except in the area covered by sea ice) taken from an ensemble of MPI-OM ocean experiments forced with the NCEP-NCAR atmospheric forcing [6].

Monthly Deviations (w.r.t. 1979 - 2007) of Sea Ice Area Fitted with Linear Trend Line

1986 - 1996 Hindcast Performed with ECHAM6/MPI-OM **1985 - 1995 Hindcast Performed with LOVECLIM**



The figures above show that the methods used to initialize the hindcasts triggers strong oscillation of the sea ice area monthly deviation, for both models used here. Monthly deviation usually reaches a maximum in September, when sea ice area is itself at its maximum. Linear trends computed over 10 years of evolution of sea ice are therefore meaningless. However, for hindcasts performed with LOVECLIM, these oscillations usually appear after around 5 years of simulation, letting us compute reliable sea ice trends for 5-year hindcasts.

References

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[6] Matei, D. et al., 2011. *Two tales of initializing decadal climate predictions experiments with the ECHAM5/MPI-OM model*, Journal of Climate (to be submitted).

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6. 5-Year Hindcasts Performed with LOVECLIM

6.1. Accuracy Measure of the Hindcasts [7]

Proportion Correct (PC):

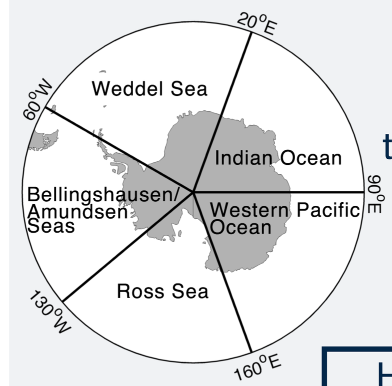
PC = $\frac{a+d}{n}$; n = a+b+c+d.

PC = 1 for perfectly accurate hindcasts.

		Observed	
		Case 1	Case 2
Hindcast	Case 1	a	b
	Case 2	c	d

6.2. Proportion Correct of 5-Year Trends of Sea Ice Extent and Area

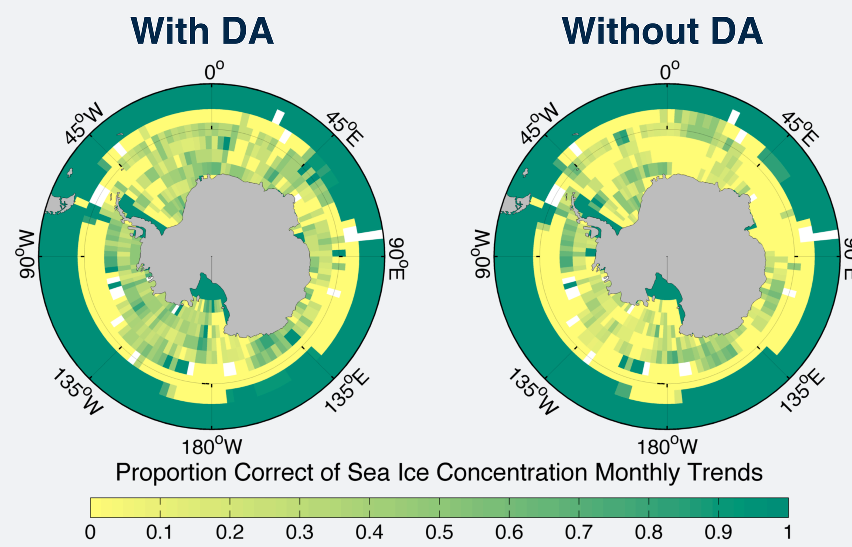
case 1 → trends > 0; case 2 → trends < 0.



Only significative observed trends at the 90% level have been taken into account to compute PC.

	Hindcasts with DA		Hindcasts without DA	
	Extent	Area	Extent	Area
Weddell Sea	0,38	0,25	0,50	0,50
Indian Ocean	0,33	0,22	0,11	0,22
Western Pacific Ocean	0,43	0,43	0,00	0,29
Ross Sea	0,57	0,43	0,14	0,14
Bellingshausen/ Amundsen Seas	0,75	0,75	0,75	0,75
Southern Ocean	0,11	0,11	0,22	0,22

6.3. Proportion Correct of 5-Year Trends of Sea Ice Concentration



6.4. Proportion correct of 5-Year Trends of Sea Ice Extent Dipole between Bellingshausen/Amundsen and Ross Sectors

For some time period, observed 5-year trends of sea ice extent presents a dipole between Bellingshausen/Amudsen Seas and Ross Sea, i.e. if the sea ice extent trends in one area is positive, it is negative in the other area and conversely.

case 1
→ Ross > 0 and Bellingshausen/Amundsen <0;
case 2
→ Ross < 0 and Bellingshausen/Amundsen >0.

Hindcasts with DA	Hindcasts without DA
0,50	0,38

7. Discussion

- Data assimilation of surface temperature anomaly clearly improves the reconstruction of the surface temperature in the Southern Ocean area.
- Sea ice concentration trends between 1979 and 2007 computed by the model with DA present pattern closer to the observed trends than the model without DA.
- Caution must be taken while initializing hindcasts in the Southern Ocean: hindcasts initialized with the nudging can present non physical oscillations of the sea ice area in several sectors of the Southern Ocean, these oscillations appearing later in the simulation with LOVECLIM than with ECHAM6/MPI-OM.
- 5-year hindcasts performed with LOVECLIM shows that even if the proportion correct is not very high for both hindcasts initialized with and without DA, the score is usually better for hindcasts initialised with DA, especially in the Ross Sea sector.
- In conclusion, data assimilation of the surface temperature used to initialize hindcasts seems to improve slightly the forecast skill of the Southern Ocean sea ice at decadal time scale.

8. Next Steps

- Deeper investigation of the behaviour of Southern Ocean sea ice in hindcasts initialized with DA.
- Test of an initialization method wich doesn't trigger non physical oscillation of the Southern Ocean sea ice.
- Improvement of the combination of the particle filter with the nudging by taking into account the nudging in the computation of the weight of the particles.
- Tests with assimilation of 3D temperature and salinity in the ocean.
- Implementation of a method to assess the quality of hindcasts of Southern Ocean sea ice based on empirical orthogonal function (EOF) to point out spatial mode of variability.