Potential influence of meltwater input on the skill of decadal forecast of sea ice in the Southern Ocean

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EGU 2014
Session NP5.2
Poster: B810

Background

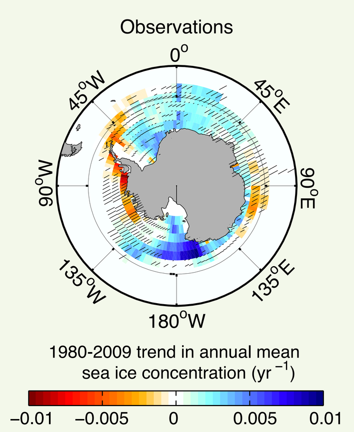


FIG. 1: Trend in observed sea ice concentration from NSIDC (Comiso, 1999).

1980-2009 sea ice extent trend: positive and statistically significant at the 99% level.

- Current GCMs are generally unable to reproduce the observed trend.
- Possible causes of the recent expansion of Southern Ocean are still debated.
- Among the proposed explanations, the freshening of the Southern Ocean resulting from the Antarctic ice-sheet melting may contribute to the expansion of sea ice.

Objectives of this study

To test the impact of an additional freshwater flux in the Southern Ocean on the simulated sea ice in both data assimilation simulation and in hindcasts.

Take home message

- An additional freshwater flux that follows an autoregressive process allows better reconstruction of the trend in sea ice concentration/extent from data assimilation simulation.
- The initialisation of hindcast from this reconstructed state provides satisfying results for the trend in sea ice concentration/extent provided that the additional freshwater flux is also included during hindcast simulation to prevent model drift.

1. Experimental setup

LOVECLIM model (Goosse et al., 2010)

- Earth-system Model of Intermediate Complexity.
- Low computational cost → many simulations.

Data assimilation

- **Nudging proposal particle filter** (Dubinkina and Goosse, 2013)

= **Particle filter with sequential resampling**

1. Propagating an ensemble of simulations (called *particles*).
2. Every 3 months, attributing of a weight to each particle, based on the agreement with the observations.
3. Resampling of the ensemble: duplication of particles with large weight, elimination of the others.

\+ **Nudging**

Adding a term to the heat flux between the atmosphere and the ocean to pull the surface air temperature towards the observations.

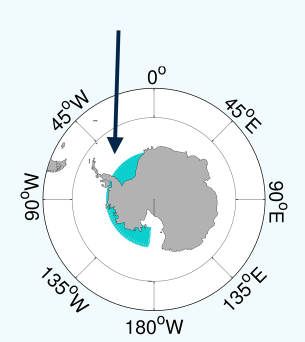
- Assimilation of surface air temperature anomalies w.r.t 1961-1990 (HadCRUT3 dataset, Borhan et al., 2006).
- Used to reconstruct the evolution of the system between 1850 and 2009.

Hindcasts

- Retrospective forecast spanning the period 1980-2009.
- Initialised on January 1st 1980 with a state extracted from a simulation with data assimilation.

Additional freshwater flux in simulation with data assimilation

- Autoregressive freshwater flux (FWF, in mSv), distributed evenly over the blue area



$$FWF(t)=FWF(t-1)+0.25\varepsilon_{FWF}(t-1)+\varepsilon_{FWF}(t)$$

random noise, Gaussian distribution $N(0,10)$

2. Summary of the simulations

Simulation	Time period	Initialisation	Data assimilation	Freshwater flux
NODA	Jan. 1850-Dec. 2009	NO	NO	NO
DA_NOFWF	Jan. 1850-Dec. 2009	NO	YES	NO
DA_FWF	Jan. 1850-Dec. 2009	NO	YES	autoregressive freshwater flux
HINDCAST_1	Jan. 1980-Dec. 2009	on Jan. 1, 1980 from DA_NOFWF	NO	NO
HINDCAST_2	Jan. 1980-Dec. 2009	on Jan. 1, 1980 from DA_FWF	NO	NO
HINDCAST_3	Jan. 1980-Dec. 2009	on Jan. 1, 1980 from DA_FWF	NO	ensemble mean of the FWF computed in DA_FWF between 1980 and 2009
HINDCAST_4	Jan. 1980-Dec. 2009	on Jan. 1, 1980 from DA_FWF	NO	1980-2009 average of the ensemble mean FWF computed in DA_FWF

All the simulations consist of 96-membre ensemble.

3. Data assimilation results

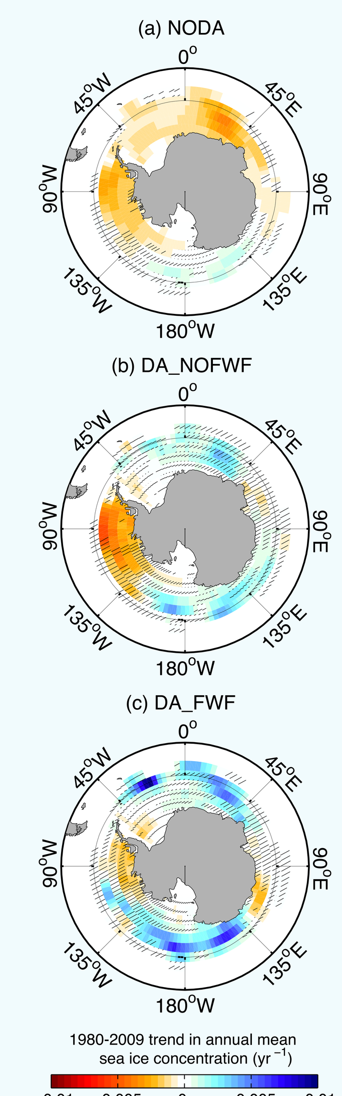
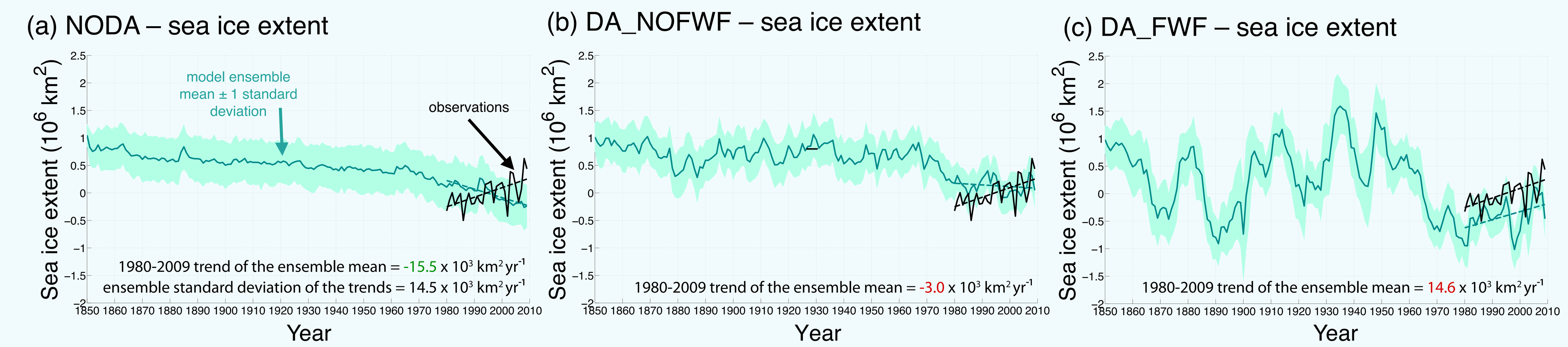


FIG. 2: Trend in yearly mean sea ice concentration between 1980 and 2009. Hatched areas highlight the grid cells where the trend is not significant at the 99% level.



Trend obs 1980-2009 = 17.4 x 10³ km² yr⁻¹

FIG. 3: Yearly mean sea ice extent anomalies with regard to 1980-2009 Observations are from the NSIDC (Fetterer et al., 2002, updated daily). Trends that are (non-)significant at the 99% level are shown in green (red)

- **NODA**: overall melting of the sea ice around Antarctica (Fig. 2a and Fig. 3a).
- **DA_NOFWF**: data assimilation improves the regional pattern of the trend in sea ice concentration (Fig. 2b) but the trend in sea ice extent is still negative (Fig. 3b).
- **DA_FWF**: the addition of a freshwater flux in conjunction with data assimilation simulation shifts the mean state of the sea ice extent but the simulated trend agrees with the observations (Fig. 3c). This shift is a consequence of a bias reduction in the surface air temperature anomalies, i.e. the assimilated variable, achieved thanks to the addition of the freshwater flux (not shown).

The data assimilation combined with an additional autoregressive freshwater flux provides the most satisfying reconstruction of the trend in sea ice concentration and extent obtained in this study. (Fig. 1 d and Fig. 2 c).

4. Hindcast results

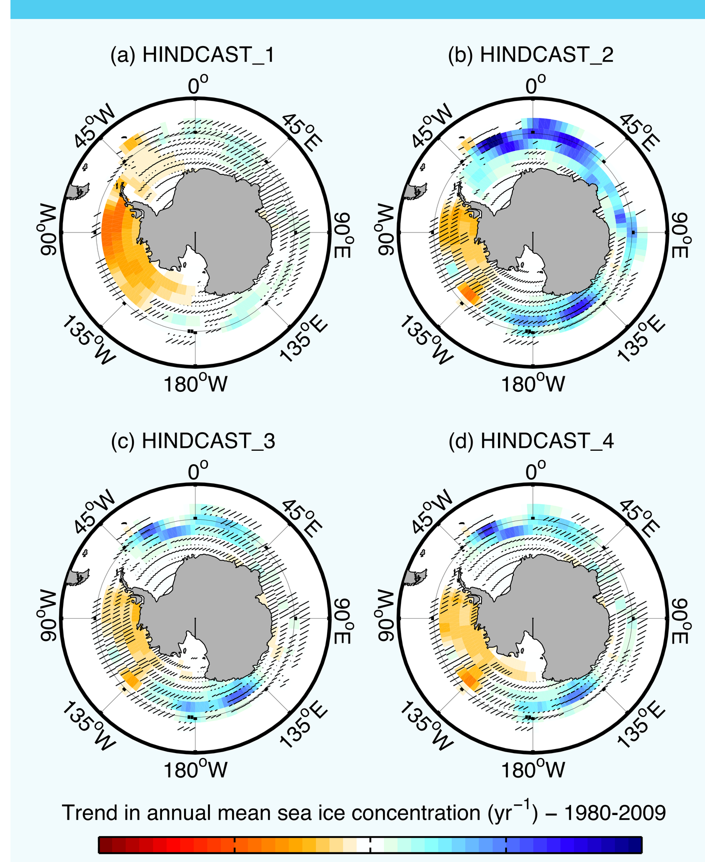


FIG. 4: Same as Fig. 2 but here for hindcast simulations.

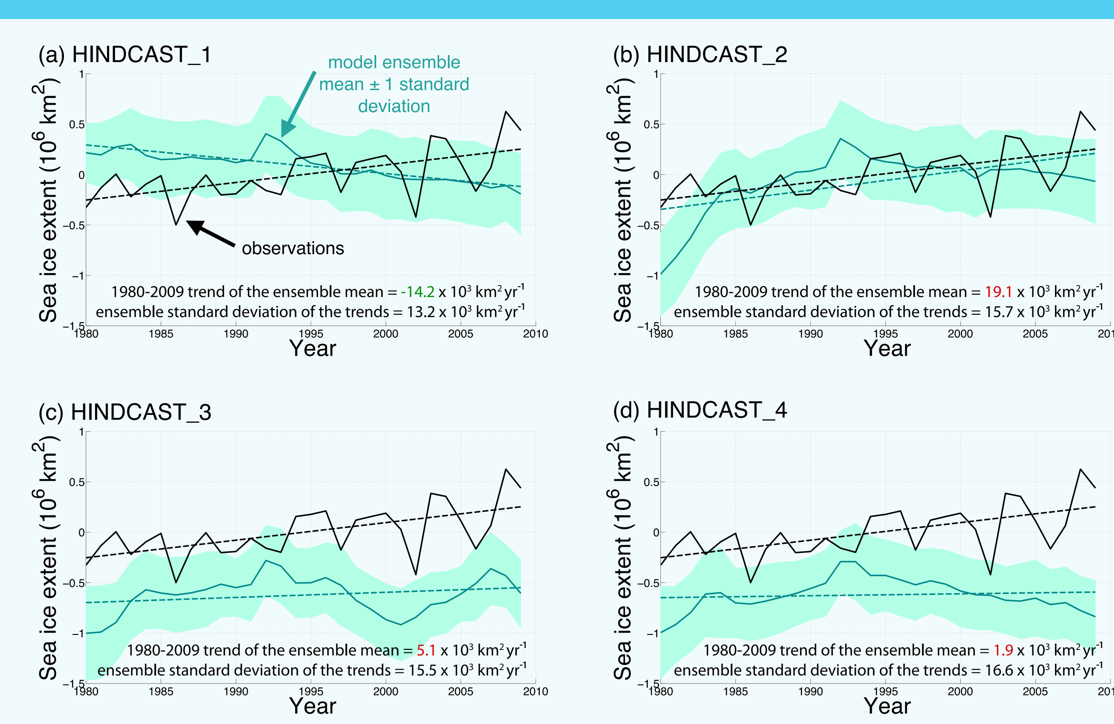


FIG. 5: Same as Fig. 3 but here for hindcast simulations.

- **HINDCAST_1**: behaves as DA_NOFWF, i.e. the data assimilation used to initialise this hindcast → impact of the initialisation over several decades but unadequate initial state (Fig. 4a and Fig. 5a).
- **HINDCAST_2**: model drift from the absence of a meltwater input and from the initialisation with a mean state shifted away from the model climatology (Fig. 5b). Regional pattern in agreement with the observations (Fig. 4b).
- **HINDCAST_3**: reduction of the model drift thanks to the addition of the freshwater flux diagnosed in DA_FWF (Fig. 5c). Regional pattern in agreement with the observations (Fig. 4c).
- **HINDCAST_4**: results similar to HINDCAST_3, indicating that the additional freshwater flux does not have to evolve in time to obtain a positive trend in sea ice extent, a mean constant value being sufficient to prevent the drift of the model.

The results of the hindcast simulations show a clear impact of the initialisation on the simulated trend in sea ice concentration and extent in hindcast simulation. Nevertheless, if the initial state comes from a data assimilation simulation that was forced with an additional freshwater flux, a freshwater flux of similar amplitude has to be included in the hindcast to prevent a model drift.

References

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Acknowledgements

Violette Zunz is Research Fellow with the Fonds pour la formation à la Recherche dans l'Industrie et dans l'Agronomie (FRIA-Belgium).