Impact of the observed changes in Antarctic ice sheet mass balance on Southern Ocean properties and sea-ice

N. Merino [1], J. Le Sommer [1], G. Durand[1], N. Jourdain [1]. Pierre Mathiot [2]. Gurvan Madec [3]

(1) Univ. Grenoble Alpes, LGGE, CNRS, France
(2) BAS, Cambridge, UK
(3) LOCEAN, CNRS/MNHN/IRD/UPMC, Paris, France

1-Introduction

Freshwater run-off from Antarctica plays a crucial role in setting Southern Ocean properties and circulation. As a consequence, the observed speed-up of Antarctic outlet glaciers and associated increase of freshwater release may have a large influence on ocean properties and sea-ice. Increase in freshwater forcing is usually neglected or poorly considered by current ocean models but may contribute to explain the observed trends in the Southern Ocean. We present here the sensitivity experiment designed in order to study the potential signature of the recent Antarctic imbalance in the ocean properties and sea-ice.

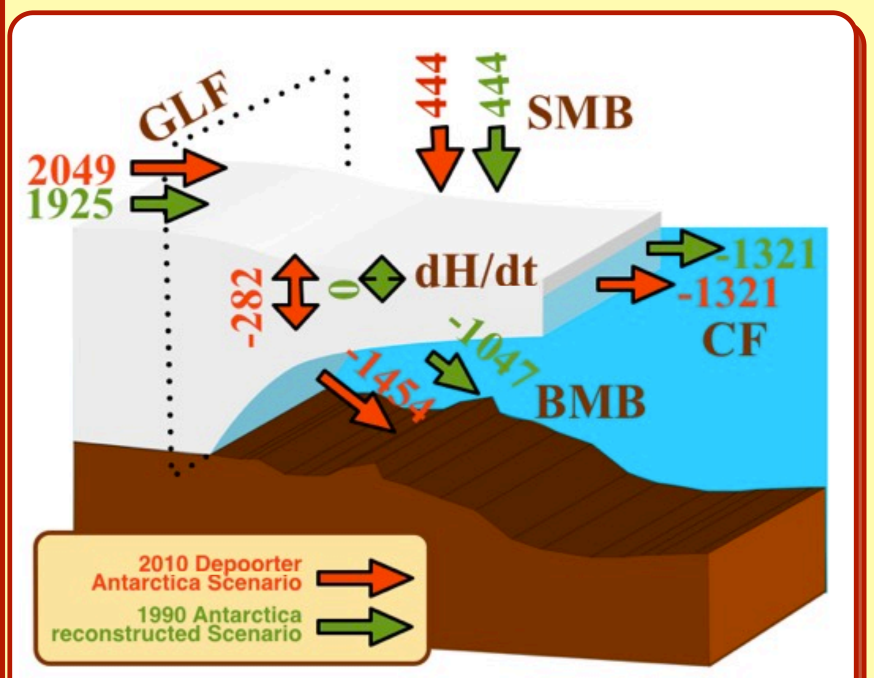
2- Objectives and Method

Our approach consists in the comparison of two NEMO ocean model simulations forced with two different Antarctic freshwater scenarios. One corresponding to a recent-year interaction, and another corresponding to a pre-imbalance scenario, about 20-25 years ago. The ocean model set up is a **0,25° global NEMO/ORCA025 configuration with 75 vertical levels and inter-annual DFS5.2 atmospherical forcing**. Ocean model is coupled with LIM2 sea-ice model

This poster is mainly focused in two important aspects of our study: the spatial repartition of the freshwater flux, and the construction of the two different forcing scenarios.

- **Constructing two freshwater release scenarios**. The more recent (about 2010) is based on Depoorter et al. 2013. The «pre-imbalance» scenario is reconstructed considering the mass balance of the ice shelves. This is a new approach of this work and differs from previous studies that simply take into account the grounded Antarctica mass balance (Bintanja et al. 2012, Swart and Fyfe et al. 2013). This common practice neglects the observed thinning of the ice shelves and the SMB trend of the interior of Antarctica, missing an important amount of freshwater (more than 4 times the extra injected freshwater in some cases).
- **Applying iceberg modeling to spread out the calving flux of ice shelves**. Transport of freshwater due to icebergs is usually forgot. The Antarctic counter-current acts as a solid freshwater distributor that feed three main lobes. This means that calving fluxes from one region can melt far away from their origin sector. The icebergs melt is shown to impact the sea ice production and a reasonable distribution seems crucial.

3- Constructing two freshwater release scenarios



Scenario 2010: A scenario corresponding to an Antarctic imbalanced situation. The budget and spatial distribution of the calving flux and the basal melt water flux is token from Depoorter et al. 2013. It provides the terms of the ice shelves mass balance equation (1) for each ice shelf bigger than 100km2.

$$GLF + SMB - CF - BMB = dH/dt \quad (1)$$

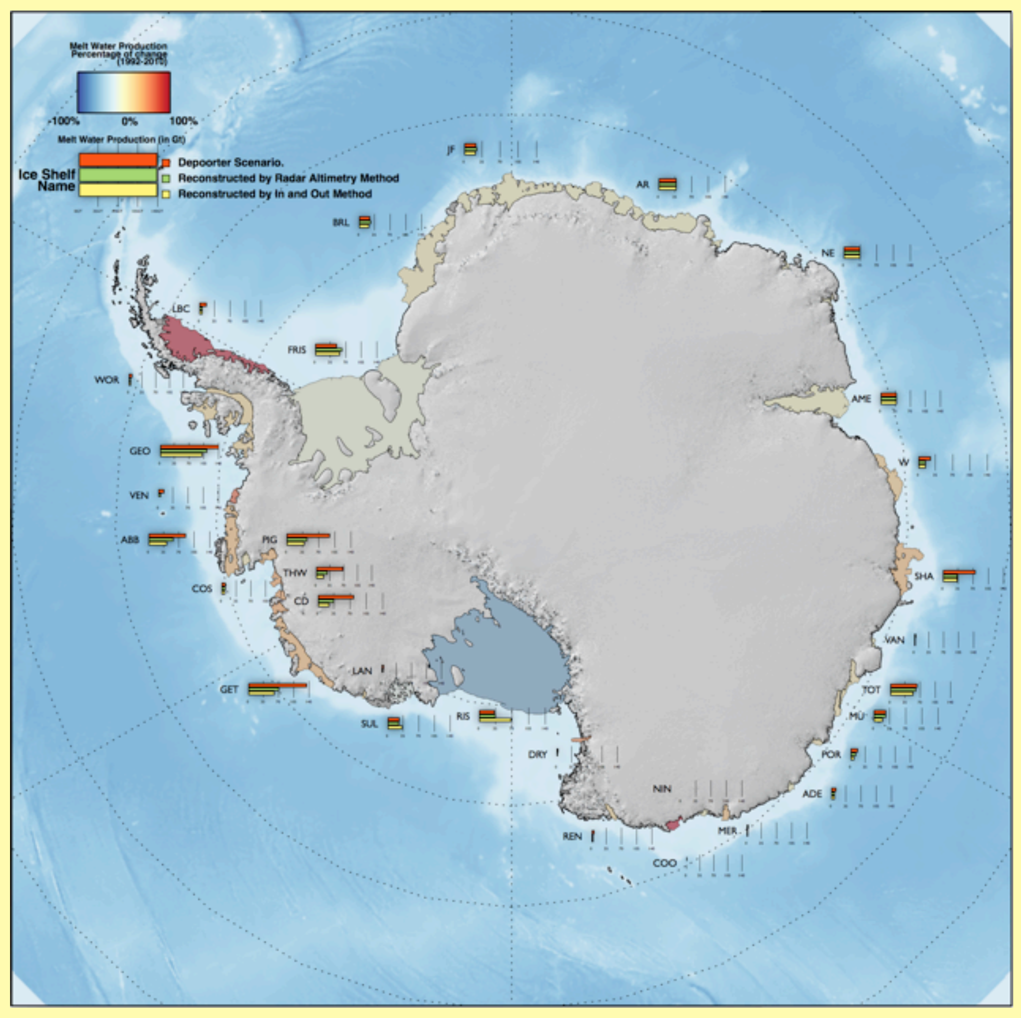
Scenario pre-imbalance. A scenario corresponding to a reconstructed interaction of the end of the 80s / beginning of the 90s. Each term of the equation of ice shelves mass balance (1) is reconstructed back in time to the Antarctic pre-imbalance period (about 20 years ago) in order to estimate a reasonable BMB (Basal Melt Balance).

GLF (Grounding Line Flux): We use the **grounded ice mass balance** of each Antarctic basin given by Shepherd 2012 to estimate the **grounding line flux changes**. We applied this to glaciers that have shown a dynamical origin change (West, Peninsula, Cook and Totem sectors). We consider no GLF change for glaciers with mass changes driven by SMB anomalies (rest of East Antarctica glaciers).

CF (Calving Flux): No important changes in the ice shelves front position. **We maintain the same CF** in both scenarios.

dH/dt: Our hypothesis for the pre-imbalance scenario is that ice shelves were in equilibrium with the ocean. An unstable ice shelf thinning or thickening would mean a change in the buttressing and in the upstream glacier dynamics. That is not consistent with a well balanced Antarctica mass loss. We consider **dH/dt = 0** to globally represent this situation.

SMB: There are no evidences of any important SMB trend in coastal regions of Antarctica (Monaghan 2006). **SMB of ice shelves is maintained**.



4 - Explicit modeling of icebergs freshwater flux distribution (Merino et al. 2015)

Calving fluxes from Depoorter et al. 2013 are the input of an iceberg model. Our iceberg model is based on *Marsh et al 2015* that basically follows the same physics than *Martin and Adcroft 2010*. The model considers 10 different size classes of prism icebergs up to 250m thick. They are pushed by winds, sea ice and ocean surface currents. The melting rates are computed by surface waves, buoyant plumes and basal turbulence parameterizations based on the SST. The melted freshwater is injected on the ocean surface.

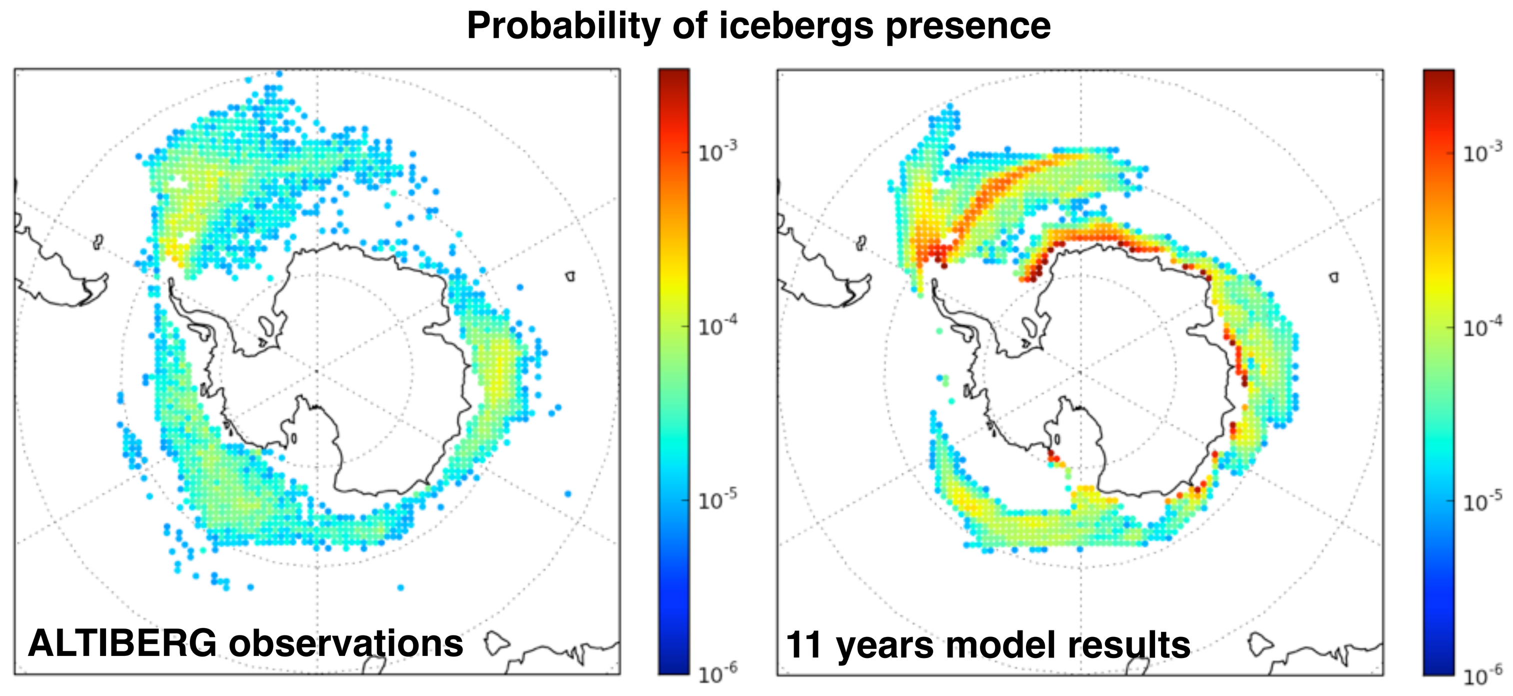
We have included some improvements in the vertical physics representation that impact the trajectories and the melting of icebergs:

Vertical integration of the ocean currents: In our model, the ocean velocity needed to compute the iceberg dynamics is the vertical integration of the ocean currents along the iceberg thickness. We do this instead of just considering the ocean surface velocity. This leads to account for the various water mass velocities and the Ekman drift

Considering the vertical temperature profile: In our model, the melting parameterization depends on the 3D temperature profile instead of the SST. Southern Ocean can present very complex temperature profiles that was not token into account in the previous icebergs model versions.

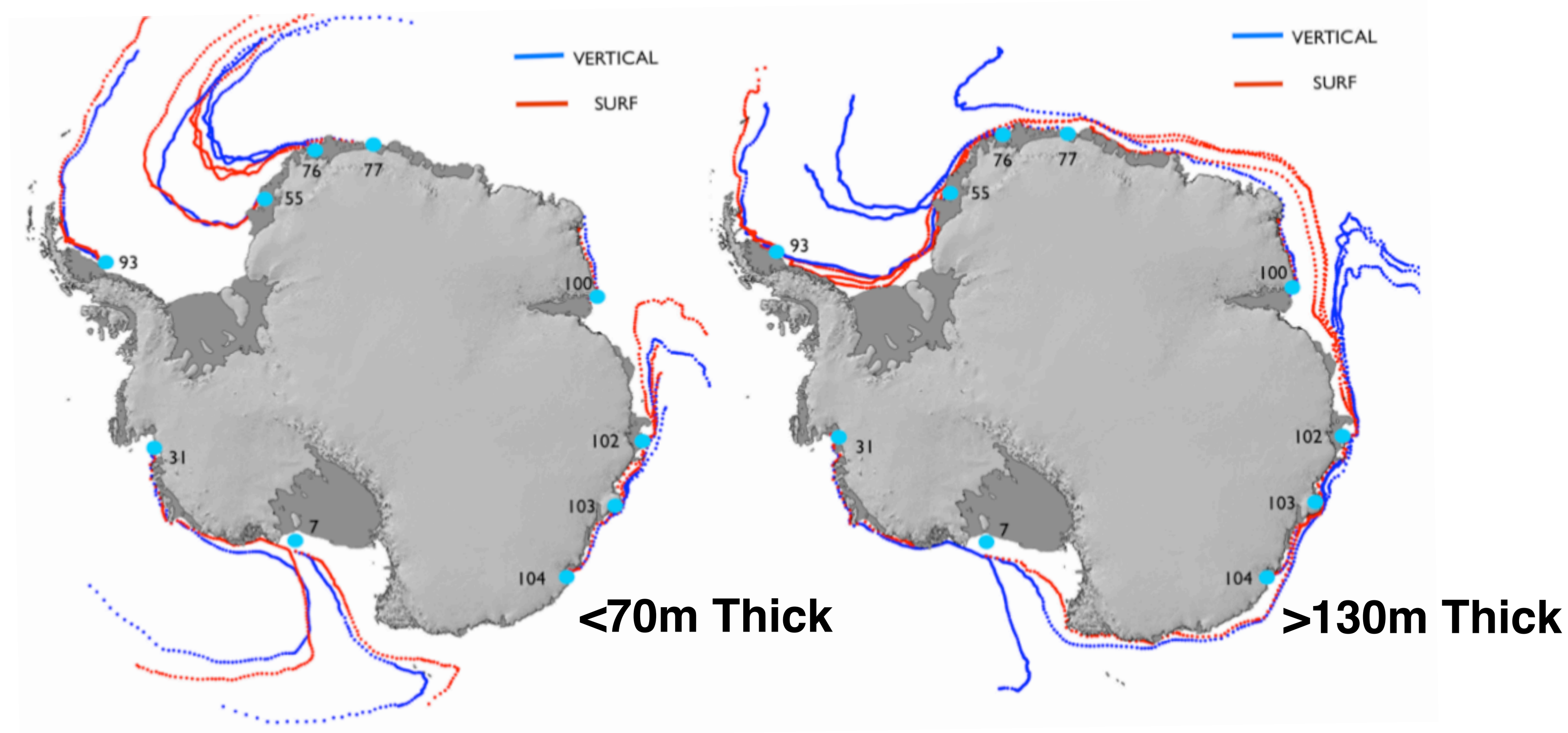
Interaction with shallow bathymetry: Is known that icebergs can get stuck in coastal areas. The ocean model resolution is not thin enough to block icebergs and avoid some trajectories. We decide to parametrize this situation by slowing down the icebergs when traversing shallow regions.

Probability of icebergs presence



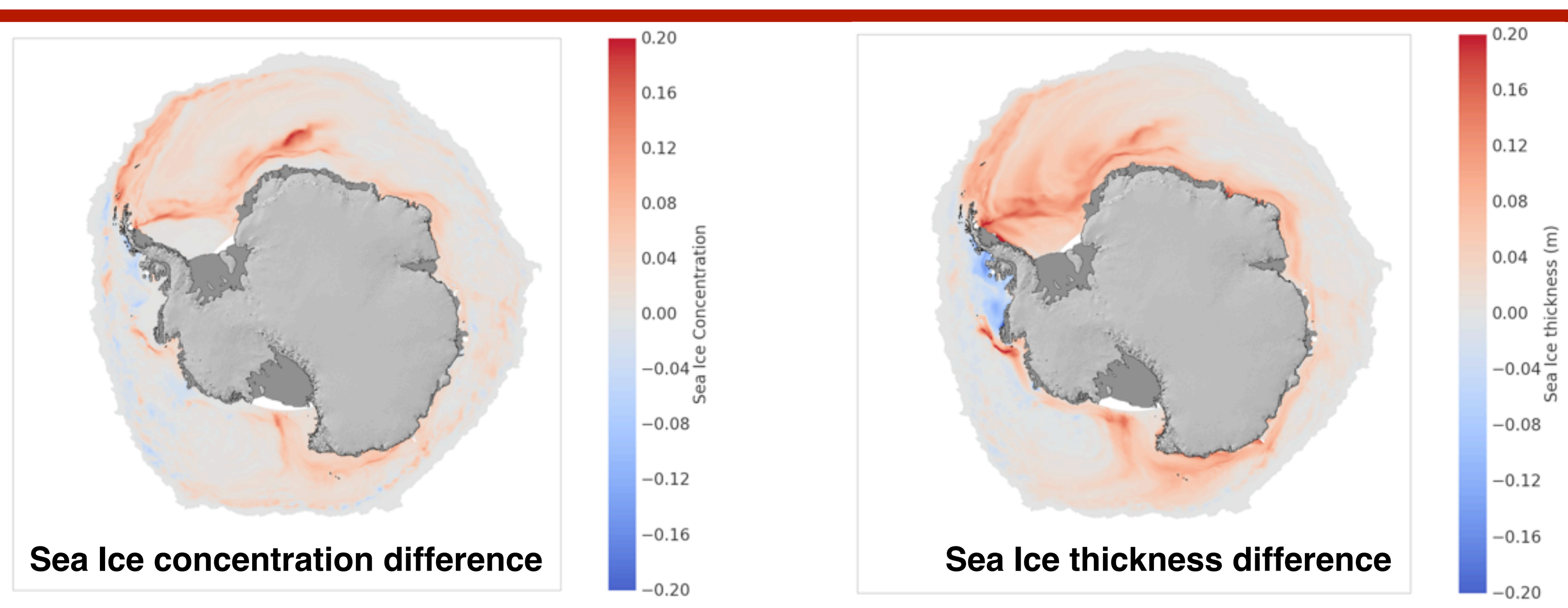
What about observations?

This is the first direct comparison of icebergs modeling against observations. It is the annual probability of iceberg detection based on the covered area by the icebergs. The atmospheric forcing of the model is a mean climatological year for the period (1979-2010). Observations correspond to ALTIBERG project, able to detect by altimetry up to 3km length icebergs. Detections are not considered in coastal regions, neither when sea ice is > 40%. These two facts are token into account in the model results in order to properly produce this comparison. It is important to note that our model obtains icebergs in the eastern brach of the Weddell Gyre. This was suggested by observations (Tournadre et al 2012) as a weak point of icebergs modeling distributions. The lack of wind variability in the atmospheric forcing can explain the lack of icebergs in West Peninsula and the overestimation of icebergs presence in the Weddell Sea. Modeled icebergs are too attached to the Antarctic counter current and finally escape at Peninsula



What is the effect of considering the integration of vertical currents? This is the comparison of the trajectories of icebergs belonging to two different size categories. Class 2 are about 70m thick and Class 3 are about 140 m thick. In blue we have the icebergs that take the vertical integrated ocean velocity, as it is done in our model. In red, the icebergs which use the ocean surface velocity. As expected, not very remarkable differences when regarding the small icebergs (class 2) . However, from class 3 on (65% of the global icebergs mass), blue icebergs present very different patterns of trajectories crossing the Weddell, the Ross, and the Amery Seas sectors. Those trajectories are supported by observations (*Schodlok et al. 2006*) and notably impact the distribution of the freshwater injection in the three sectors.

Does the Icebergs distribution matter? This is the comparison of CTR run (no icebergs freshwater fluxes), and ICBT (with the freshwater icebergs fluxes applied on the surface). Results suggest that icebergs melt affect positively the sea ice formation in most of the oceanic sectors. We can observe the signature of iceberg melt in most of the coastal regions, the Weddell and the Ross Seas, where the iceberg presence is very important. The freshening of the ocean surface due to the icebergs melt affects the heat upwelling from deep water masses in the ocean. This leads to more sea ice production. However, those results also show sea ice thinning in the Bellingshausen Sea. This suggest that completely different regimes of sea ice production can be triggered by icebergs. A good representation of icebergs in ocean models seems crucial to better simulate the sea ice formation processes.



-Depoorter, M., J. Bamber, J. Griggs, J. Lenaerts, S. Ligtenberg, M. van den Broeke, and G. Moholdt (2013), Calving fluxes and basal melt rates of antarctic ice shelves, Nature.
-Martin, T., and A. Adcroft (2010), Parameterizing the fresh-water flux from land ice to ocean with interactive icebergs in a coupled climate model, Ocean Modelling, 34(3), 111–124.
-Marsh, R., V. O. Ivchenko, N. Skliris, S. Alderson, G. R. Bigg, G. Madec, A. T. Blaker, Y. Aksenov, B. Sinha, A. C. Coward, J. Le Sommer, N. Merino, and V. B. Zalesny (2015), NEMOICB (v1.0): interactive icebergs in the NEMO ocean model globally configured at eddy-permitting resolution, Geosci. Model Dev., 8(5), 1547–1562, doi: 10.5194/gmd-8-1547-2015.
-Merino, N., J. Le Sommer, G. Durand, N. Jourdain, G. Madec, P. Mathiot and J. Tournadre (2015). Antarctic icebergs melt over the Southern Ocean : climatology and impact on sea-ice . Submitted in GRL
-Tournadre, J., F. Girard-Ardhuin, and B. Legŕesy (2012), Antarctic icebergs distributions, 2002–2010, Journal of Geophysical Research: Oceans (1978–2012), 117 (C5)
-Tournadre, J., N. Bouhier, F. Girard-Ardhuin, and F. Remy (2015), Large icebergs characteristics from altimeter waveforms analysis, Journal of Geophysical Research: Oceans