Contribution of increasing glacial freshwater fluxes to observed trends in Antarctic sea-ice

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1-Introduction

Glacial freshwater fluxes 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 experiments designed in order to study the potential signature of the recent Antarctic imbalance in the Southern Ocean.

2- Objectives and Method

Our approach consists in the comparison of three ocean/sea-ice/icebergs model simulations based on NEMO. We apply state-of-the-art iceberg modeling and realistic glacial runoff forcing. Our set up notably improves the freshwater distribution in the Southern Ocean compared to previous similar studies. The 3-experiment comparison allow us to extract robust conclusions about the potential role of the ongoing Southern Ocean freshening on sea-ice trends.

Model Set up:

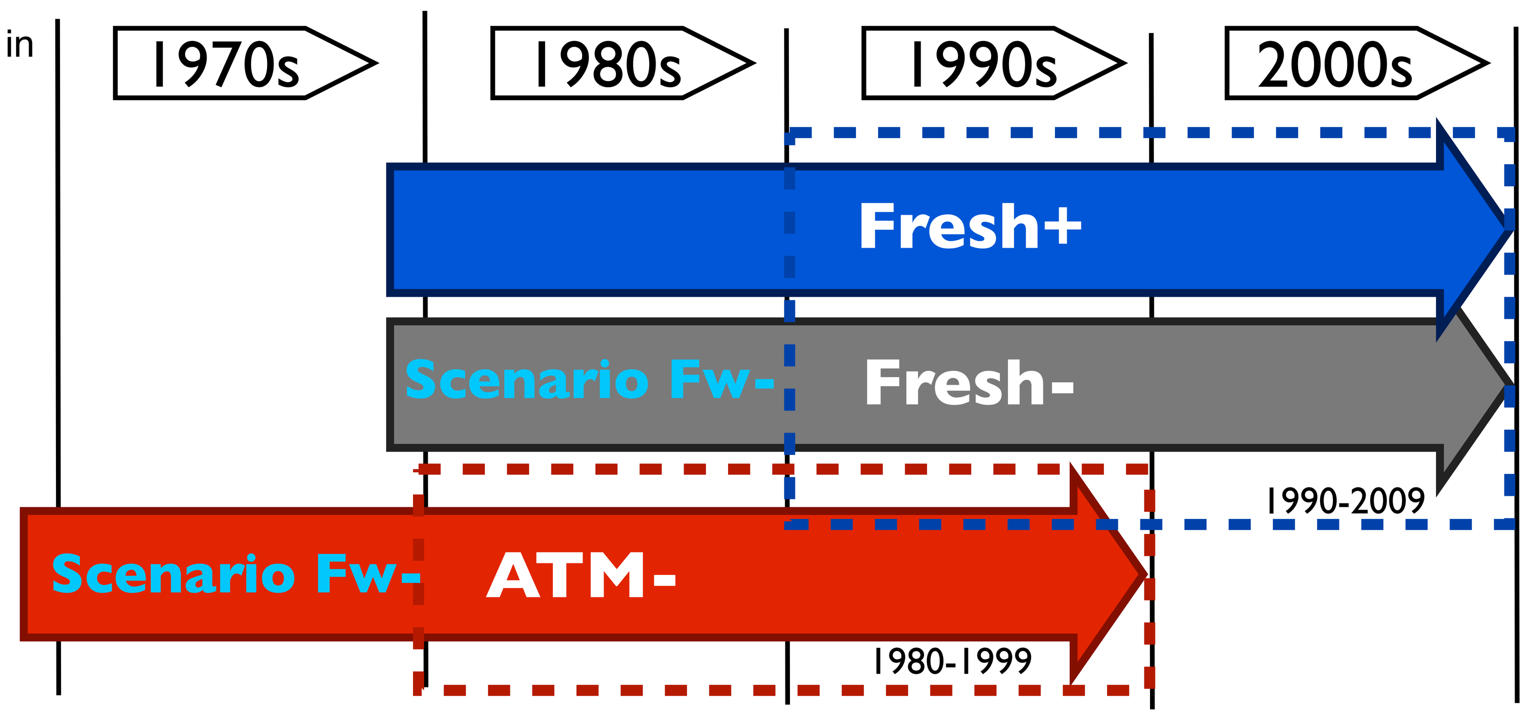
- **NEMO-ORCA025** with **75 vertical levels**, **DFS5.2** Atm. forcing, **LIM2** Sea-ice model, **Explicit icebergs model** Merino et. al 2016 (in Rev.)

Experiments:

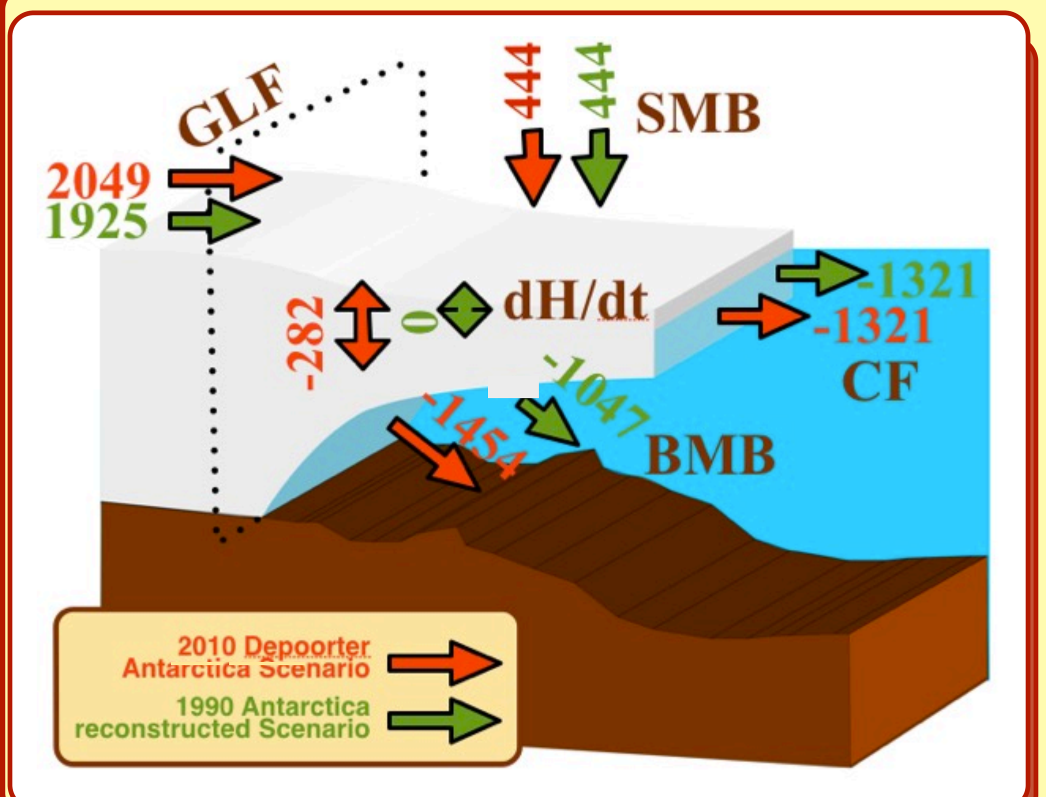
- **Fresh+**: 1978-2010 simulation with the 2000s freshwater scenario (see below)
- **Fresh-**: 1978-2010 simulation with the perturbed FW- freshwater scenario
- **ATM-**: 1968-2000 simulation with the perturbed FW- freshwater scenario

Comparisons

Fresh+ - ATM-: Impact of combined glacial freshwater forcing and a 10-years shifted atmosphere
Fresh+ - Fresh-: Impact of a the perturbed glacial freshwater forcing
Fresh- - ATM-: Impact of a 10-years shifted atmosphere with the same glacial freshwater forcing



3- Two glacial freshwater scenarios (coastal runoff + iceberg calving)



Scenario 2000s: A realistic scenario corresponding to the ongoing Antarctic imbalanced situation (2000-2010). The budget and spatial distribution of the calving flux and the basal melt water flux is prescribed from Depoorter et al. 2013. It provides the terms of the ice shelves mass balance equation (1) for each ice shelf larger than 100km2.

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

Scenario Fw-: It represents an idealized stable ice shelf-ocean interaction corresponding to a pre-outlet-glacier-speed-up situation (80s-90s). It is constructed by correcting the Scenario 2000s based on the equation 1. **Grounding line fluxes (GLF)** are corrected using the grounded ice mass trends from Shepherd 2012 (only when the imbalance has dynamical origin). The **Surface Mass Balance** (**SMB**) on the shelves are maintained with respect to the Scenario 2000s. This is because there is no evidences of any Antarctic coastal SMB trend (Monaghan 2006). The **Calving Fluxes (CF)** are also the same than in Scenario 2000s since there is no significant observed trends in the calving front position. Finally, this scenario is based on the assumption of having ice shelves in equilibrium, so **dH/dt is set to zero in all the ice shelves.** Some studies (Bintanja 2013, Swart and Fyfe 2013) neglects the observed trends in the thinning of the ice shelves, which is, in terms of freshwater release, as significant as the grounded Antarctic mass loss. Those assumptions produce **a perturbation of about 400Gt/yr of freshwater** injected at the ice shelve front of our model.

4- Model validation

Figures 1 and 2 show the ability of our model set up to produce reasonable sea ice estimations. Sea-ice seasonal means for the FRESH+ simulation are compared to NSDIC sea-ice concentration climatology in Figure 1. The model correctly reproduce the extend and the seasonal changes in sea-ice concentration. Figure 2 shows the capacity of our experiment strategy to study sea-ice trends by comparing sea-ice concentration means from different simulations. In this case, the comparison of FRESH+ and ATM- seems to be a reasonable estimation of the observed recent sea-ice concentration trend. This comparison account at the same time for the decadal atmospheric trends and the recent increase in glacial freshwater release from Antarctica

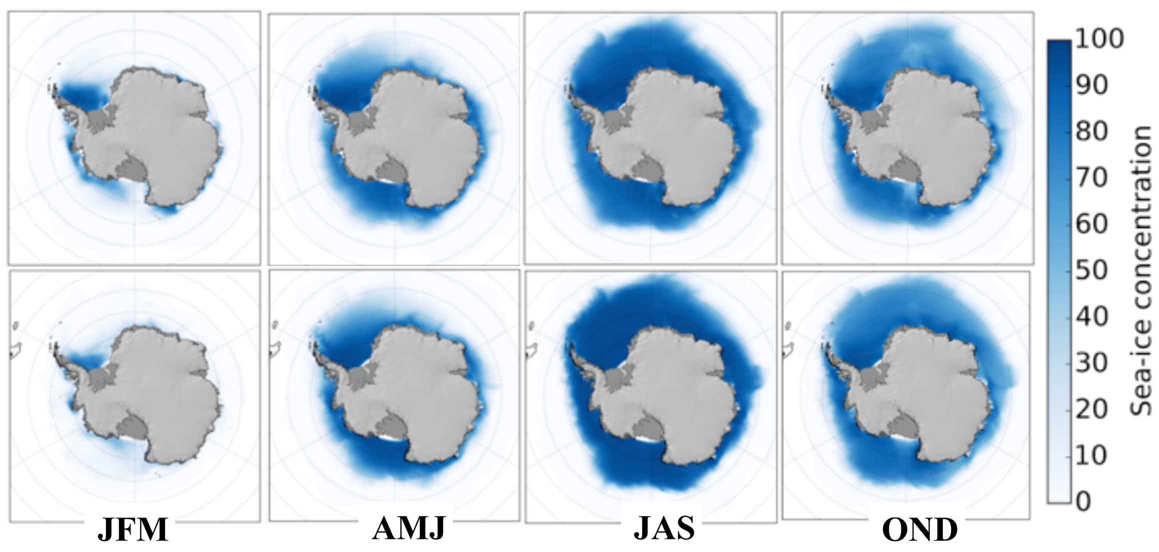


Figure 1. Comparison of the seasonal sea-ice concentration for NSDIC climatology (top) and Fresh+ model results (bottom).

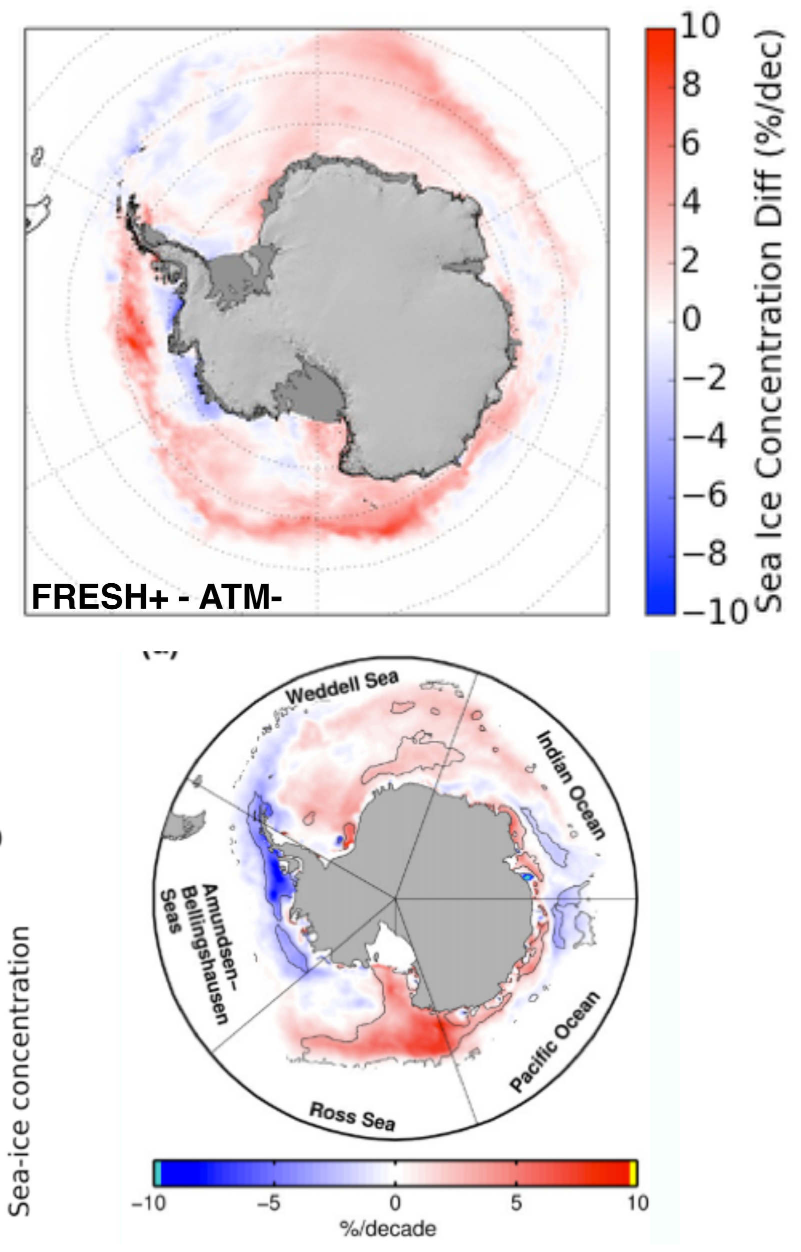


Figure 2. Difference in annual mean sea-ice concentration between Fresh+ and ATM- simulations (top). Sea-ice concentration trend from Massonet et al. (2014).

5- Results

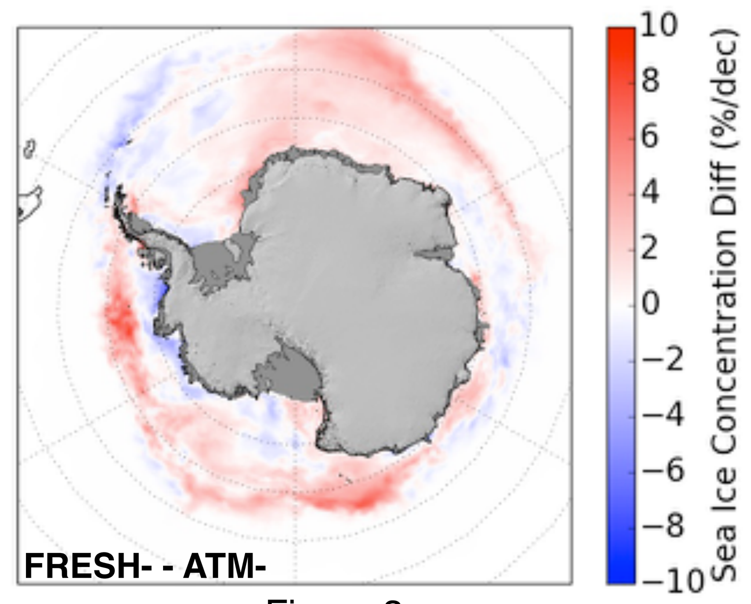


Figure 3

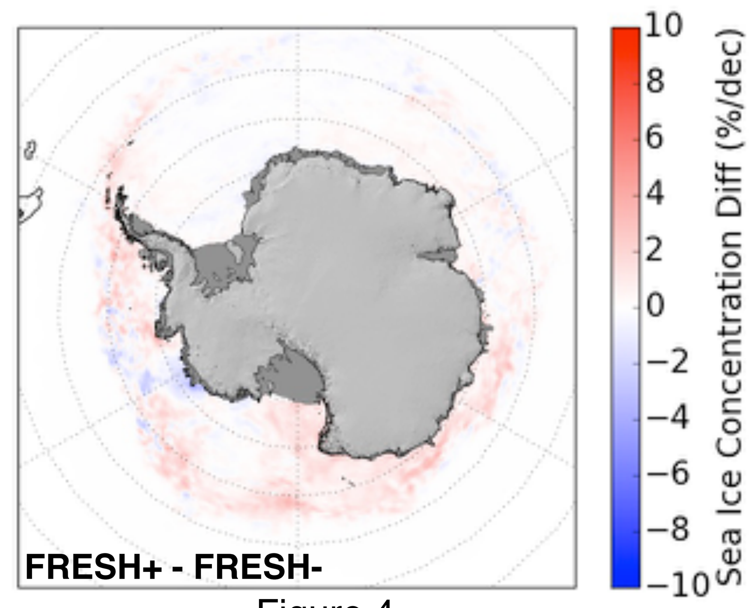
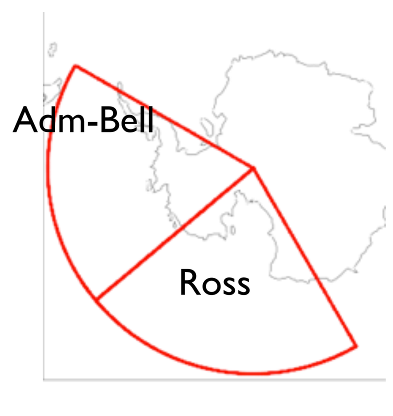


Figure 4

Figure 3 and 4 show sea-ice concentration differences between Fresh- and ATM- and Fresh+ and Fresh- respectively. The trends of sea-ice in the Atlantic sector seems to be mostly driven by atmospherical trends (comparison FRESH- with ATM-). However, sea-ice concentration in the Pacific sector seems to be potentially affected by the difference in glacial freshwater flux between FRESH+ and FRESH- simulations.

Relative △Sea-Ice Area = (**Fresh+ - Fresh-**) / (**Fresh+ - ATM-**)

Integrals:
Global: **Relative △Sea-Ice Area: + 26%**
Adm-Bell: **Relative △Sea-Ice Area: + 23.5%**
Ross: **Relative △Sea-Ice Area: + 36%**



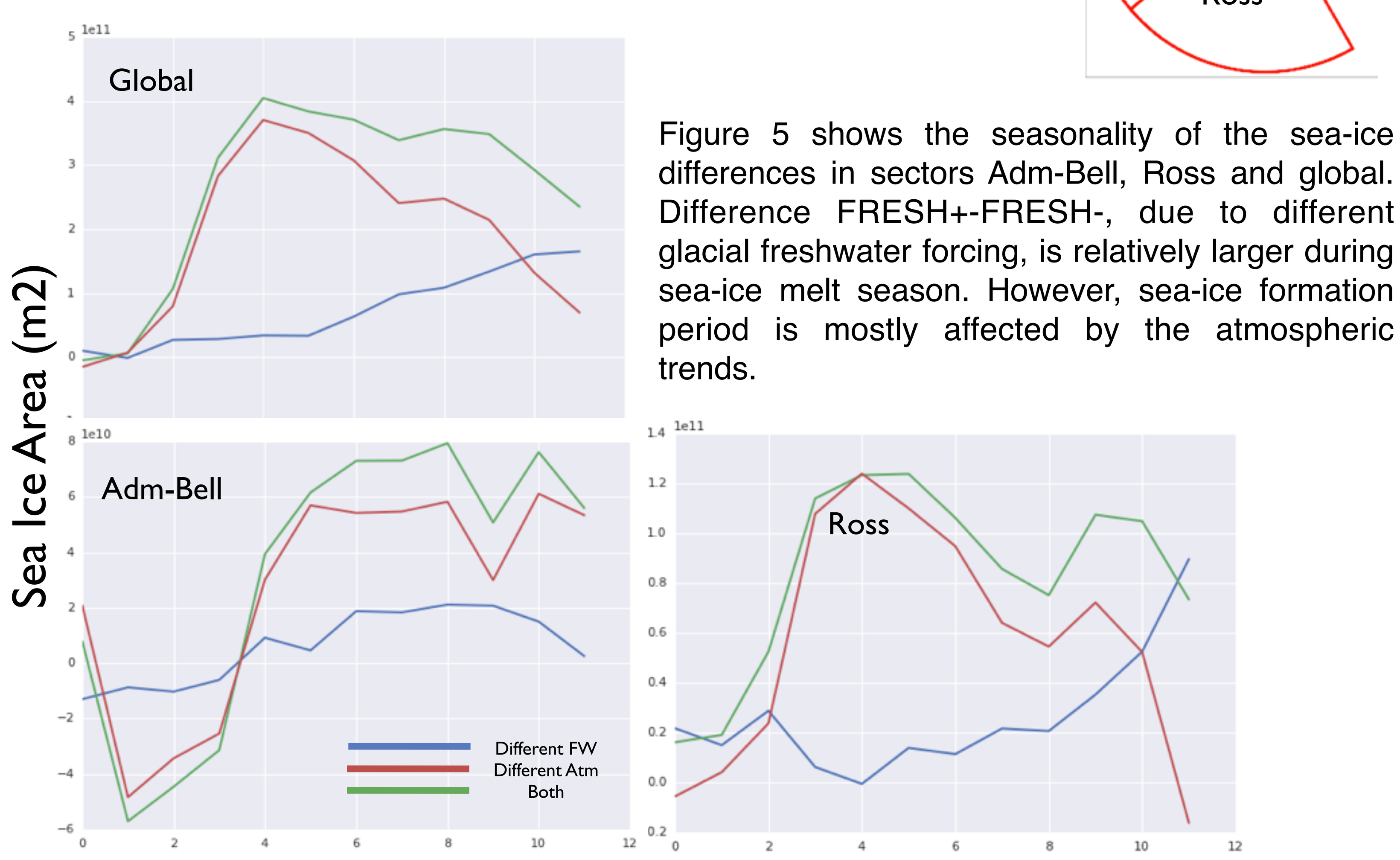


Figure 5 shows the seasonality of the sea-ice differences in sectors Adm-Bell, Ross and global. Difference FRESH+-FRESH-, due to different glacial freshwater forcing, is relatively larger during sea-ice melt season. However, sea-ice formation period is mostly affected by the atmospheric trends.

Figure 5

6-Conclusions

- 3 simulations were compared in order to study the sensibility of Antarctic sea-ice to atmospheric and freshwater forcings corresponding to recent decades. Simulations use state-of-the-art glacial freshwater repartition
- Control freshwater forcing is based on glaciological estimations accounting for the spatial repartition of the fluxes.
- A perturbed freshwater forcing is constructed considering the imbalance of the ice shelves (-400Gt/yr)
- Model set up successfully simulate the mean and seasonal sea-ice cover.
- The response of sea ice to the combination of atmospheric and freshwater perturbations mostly matches the amplitude and spatial pattern of the observed sea-ice concentration trend.
- The impact of the freshwater perturbation in the sea-ice concentration has a very distinctive spatial pattern.
- Freshwater perturbation is responsible of about 26% of the change in annual sea ice area around Antarctica, and accounts for 36% of the changes in the Ross sector.
-The observed increase in glacial freshwater from Antarctica needs to be considered to account for the amplitude of the sea-ice trends in the Southern Ocean

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