Sensitivity of two melt pond schemes to the uncertainties in atmospheric reanalyses for global climate models

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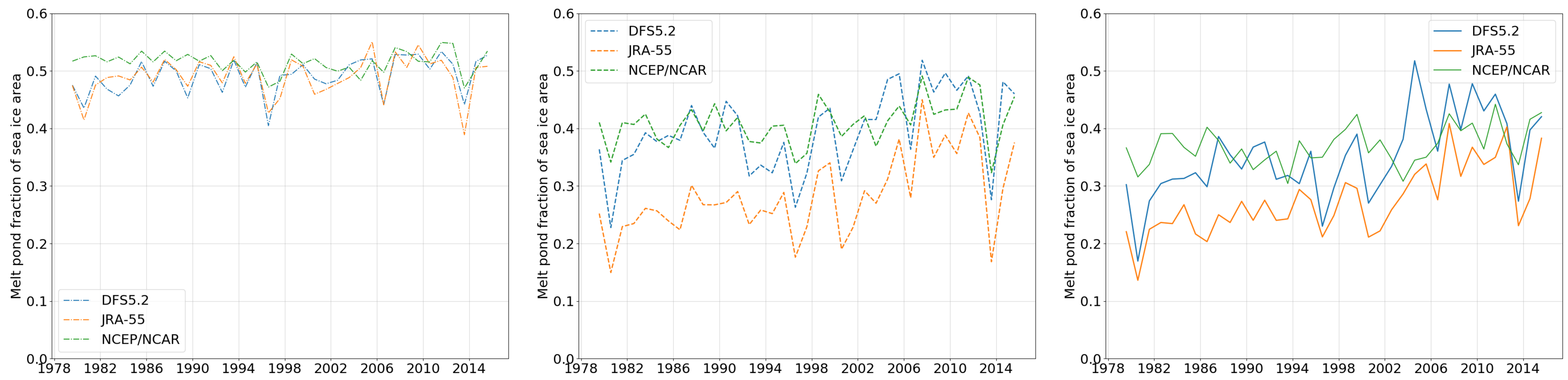
Introduction

Melt ponds appear during the melt season in the Arctic, when the surface melt water collects in the depressions of the ice field. The albedo of the ponds is lower than the surrounding ice and snow areas, and for this reason the ponds are hot-spots for the ice-albedo feedback. There are two main approaches to represent the melt ponds in Global Climate Models. First, an explicit formulation of the aspect ratio between the area fraction and depth of the ponds can be used to estimate their water capacity. Then, a fraction of the surface melt water accumulates in the ponds. The second approach makes hypotheses on the surface topography of the ice, using for instance the Ice Thickness Distribution. Although the role of melt ponds has been extensively studied, less is known on the response of the ponds to climate change. Insights can be gained from using different reanalyses of the atmospheric surface state to force the ocean and ice components. Because of a lack of observations in remote areas, reanalyses still suffer from biases notably in the polar regions. The choice of a reanalysis has a strong influence on the representation of the sea ice state of the Antarctic. We expect similar deviations in the Northern Hemisphere. To evaluate the effect of the melt pond schemes on the sea ice when subject to uncertainties in the atmospheric state, we have run the CESM melt pond scheme (Holland et al., 2012) and the topographic scheme of Flocco et al. (2012) along with JRA-55, DFS5.2, and NCEP/NCAR atmospheric reanalyses. We examine the degree of difference between the pond schemes and the influence of the forcing onto their climatic response. We assess the importance of the melt ponds for the climate and check the consistency of the schemes. We formulate a recommendation on the use of melt ponds in climate models.

Trends in melt pond area fraction



(a) CESM scheme with κ=−2.00 °C (b) CESM scheme with κ=−0.15 °C (c) Topographic scheme with κ=−0.15 °C

Fig. 1: Time series of melt pond area fraction (of sea ice) in August using DFS5.2, JRA-55, and NCEP/NCAR reanalyses as surface boundary conditions

In order to have comparable results between the simulations, we have replaced the ice lid formulation of the topographic scheme with the CESM refreezing mechanism (Holland et al., 2012).

$$v_{i+1}^{ip} = v_i^{ip} \exp\left(0.01 \frac{T_{melt} - T_{sfc} + \kappa}{T_{melt} + \kappa}\right)$$

Where v_i^{ip} is the volume of melt water in the ponds at time step i, T_{sfc} is the surface temperature of the ice, κ a threshold temperature for refreezing, $T_{mlt} = 0$ °C the melting temperature for sea ice.

Melt pond area fraction trends

- **No trends with the CESM scheme** (κ=−2 °C). Half of the sea ice is covered with ponds in August.
- **Positive trends with the topographic scheme** (κ=−0.15 °C), between 1.13 (NCEP/NCAR) and 4.05 (JRA-55) percent per decade.
- **When using κ=−0.15 °C with the CESM scheme, we find positive trends comparable to the topographic scheme.**

How can we explain the difference in trends?

T_{sfc} and κ control the exponential decay of the melt water during freezing events. **The refreezing is more efficient when T_{sfc} is low and κ tends toward zero** (see eq. above).

The threshold κ also impacts the number of days fulfilling the condition for pond refreezing. **In August, there are 8 to 15 days with air surface temperature below −0.15 °C, but only 3 to 5 days below −2 °C.**

Setting a higher value for κ results in more days with pond freezing conditions and a more efficient refreezing function. **The volume in the ponds is more impacted by surface conditions with $\kappa = -0.15$ °C.**

The default CESM threshold temperature −2 °C delays the refreezing of the ponds to September. With reduced surface melt in late summer and no other sinks of melt water, **the ponds quantities remain constant in August with the CESM scheme**.

Aspect ratio of the ponds and surface albedo

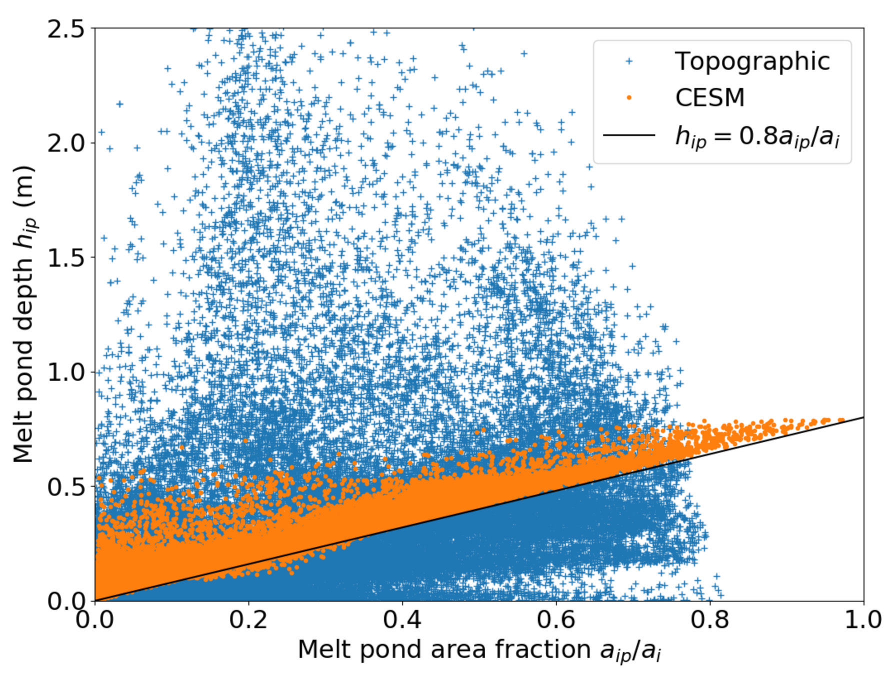


Fig. 2: Pond aspect ratios, from May to September, 1980 to 2015, with the CESM and topographic schemes ($\kappa = -0.15$ °C)

The albedo of the ponds α_{pnd} decreases exponentially with the ponds depth h_{ip}, from bare ice albedo α_{ice}^{ref} to the minimum reference pond albedo α_{pnd}^{ref}.

$$\alpha_{pnd}(h_{ip}) = \alpha_{pnd}^{ref} - (\alpha_{pnd}^{ref} - \alpha_{ice}^{ref}) \exp(-h_{ip}/0.05)$$

Aspect ratios

- **The aspect ratio of the ponds with the CESM scheme is strongly bounded by the SHEBA relation** $h_{ip} = 0.8a_{ip}/a_i$.
- **The range of depth and area simulated by the topographic scheme is wide**, e.g. shallow ponds reaching 80 % of the ice area.
- The CESM scheme can simulate unrealistic pond area fraction, up to 100 % of the ice area.
- In the topographic scheme, most of the ponds are less than 0.50 m deep, but can reach unphysical depths (greater than 1 m).

In order to decrease the surface albedo by 99 %, h_{ip} has to rise to 0.23 m. **The albedo of ponds shallower than 0.23 m is sensitive to h_{ip}, whereas deeper ponds have a nearly constant albedo.** The topographic scheme is able to simulate melt pond depth lower than 0.23 m on a wide range of pond area fraction: from 0 up to 0.80. On the other hand, the CESM scheme is limited in the values the melt ponds can take. The aspect ratio follows closely the relation fitted from SHEBA campaign. Using this relation, we find that only ponds with area fractions lower than 0.29 can have depths lower than 0.23 m. **Thus, the sensitivity of the albedo to h_{ip} is restricted when using the CESM scheme compared to the topographic scheme**.

Arctic sea ice budget

Concerning the sea ice extent, the choice of a melt pond scheme and reanalysis has an effect only during the melt season. The total ice area is however less impacted, suggesting spatial differences across the simulations. Simulations with DFS5.2 or JRA-55 are closer to the observations. The main differences lie in the Beaufort sea, the Arctic Archipelago, parts of the Kara sea and GIN seas.

The mean seasonal cycle of the total ice volume is similar across the simulations, with only a **near constant offset in the total ice volume**.

Using the same reanalyse, **the simulations with the CESM scheme have less ice extent and volume than those with the topographic scheme**. This is the result of the lack of sensitivity of the albedo to the CESM pond depths. Rapidly, as the volume in the ponds increase, the albedo reaches its minimum value.

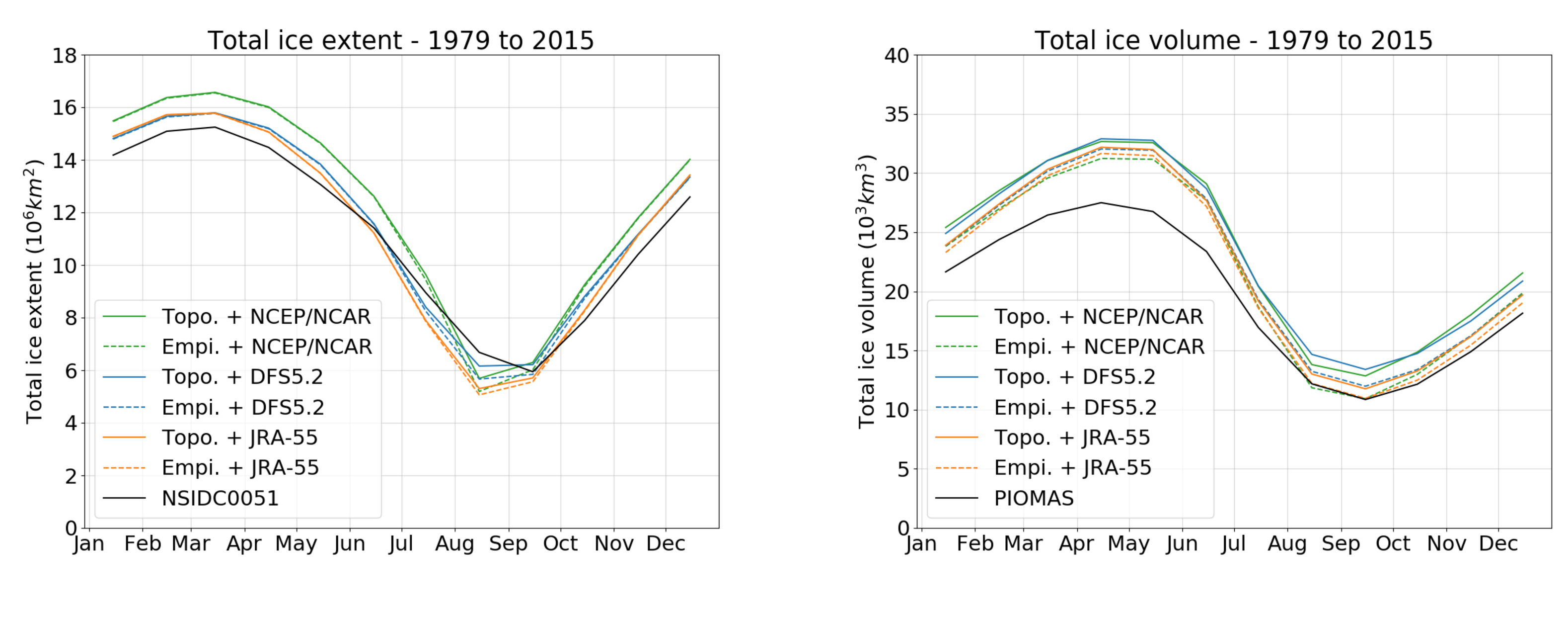


Fig. 3: Mean seasonal cycle of the total sea ice extent (left) and volume (right) between 1980 and 2015