Importance of deformed ice in the polar regions for the climate models

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Introduction

Sea ice comes in a variety of sizes and shapes depending on the mechanical and thermodynamical events it has undergone. New ice offers little resistance to the winds and currents, while deformed ice contains hummocks and ridges that influence how heat and momentum are transferred at the atmosphere-ice-ocean interfaces. In most climate models, the surface fluxes are determined from "bulk formulas" with constant drag coefficients based on roughness length estimates. Therefore, these formulations do not account for the space-time variability of transfer coefficients due to variations in ice roughness. However, the ice roughness can be estimated from the models by quantifying the amount of deformed ice (Tsamados et al, 2013). To study the effect of ice deformation on the surface fluxes and the associated impact on the sea ice, we implement a tracer of deformed ice into the ocean-ice model NEMO-LIM3 v3.6 and modify the drag coefficients accordingly. From a run of NEMO-LIM3 between 1990 and 2010 at 1 degree resolution, we examine the spatial and temporal evolution of the drag coefficients in the Arctic and Antarctic regions. We investigate possible effects on the surface fluxes and impacts on the sea ice state. This study allows us to formulate an initial assessment on the importance of deformed ice variability for the current climate models.

Estimation of the Deformed Ice in NEMO-LIM3

The volume and concentration of deformed ice are estimated following a method comparable to the Los Alamos CICE model, that is by tracking the levelled/not deformed ice volume and concentration instead. Using levelled ice quantities solves the issue of identifying newly built deformed ice during a mechanical process, from the older deformed ice. The difference between the ice volume (concentration) and the levelled ice volume (concentration) gives the corresponding deformed ice quantity:

$$a = a_{def} + a_{lvl}$$
$$v = v_{def} + v_{lvl}$$

Where a and v are the concentration and volume of ice, and the subscripts $_{def}$ and $_{lvl}$ stand for the deformed and levelled ice. In LIM3, the tracers a_{lvl} and v_{lvl} follow the same conservative equation of the ice concentration and volume, but with the exception of a sink collecting the ridging and rafting ice loss quantities.

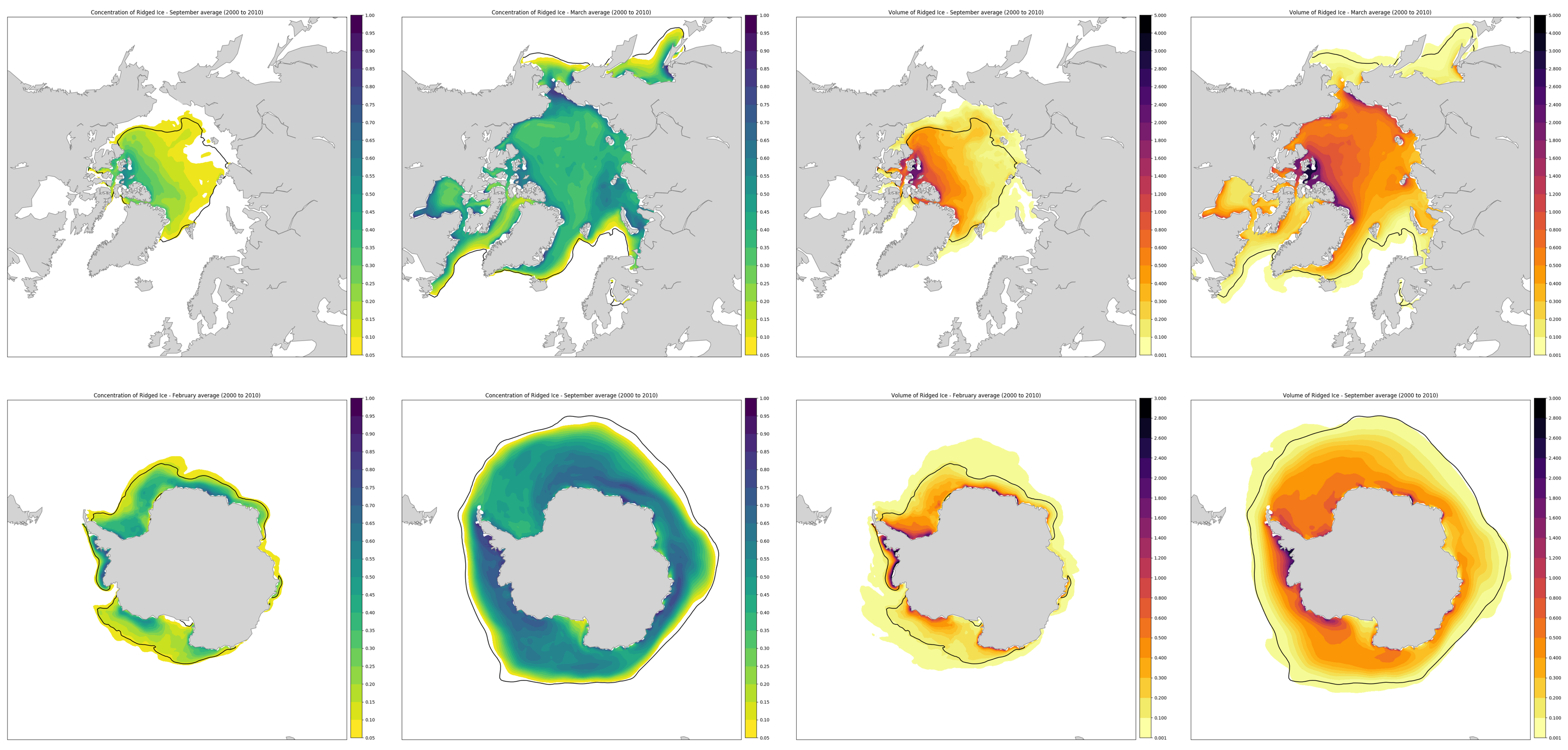

Fig. 1: Climatology of the deformed ice concentration (1st and 2nd columns) and volume (3rd and 4th columns), averaged between 2000 and 2010, during minimum ice extent months (March in the north hemisphere. and Feb. in south) and maximum ice extent (Sept. in both hemispheres). The black line indicates the the 15% ice concentration line.

Neutral Drag Coefficients

The turbulent fluxes of momentum, sensible heat and latent heat can be estimated through bulk formula. They are proportional to transfer coefficients. In NEMO-LIM3, the coefficients are set equal and constant over the ice: 1.4×10^{-3} for the ice-atm. and 5.0×10^{-3} for the ice-ocean interface. However, the coefficients are known to vary with the form of the ice and the stratification of the surface layers.

Tsamados et al. (2014) introduced a parametrisation of the drag coefficients accounting for the form of the ice in neutral stratifications. The "neutral" coefficients are decomposed into the sum of a skin drag and form drags (sails, keels, floe edges, melt ponds). The tracers of deformed ice are used to estimates the height and distance between the ice sails and keels.

Here, we use the parametrisation of Tsamados et al. (2014) to estimate the total drag coefficients for the ocean-ice and atmosphere-ice interfaces, without the melt pond contribution, and as diagnostics: no feedback on the fluxes; the model drag coefficients are kept constant. The simulation runs from 1990 to 2010, on a global ORCA 1° grid and are forced with DFS5.2. The model is NEMO-LIM3 rev8292.

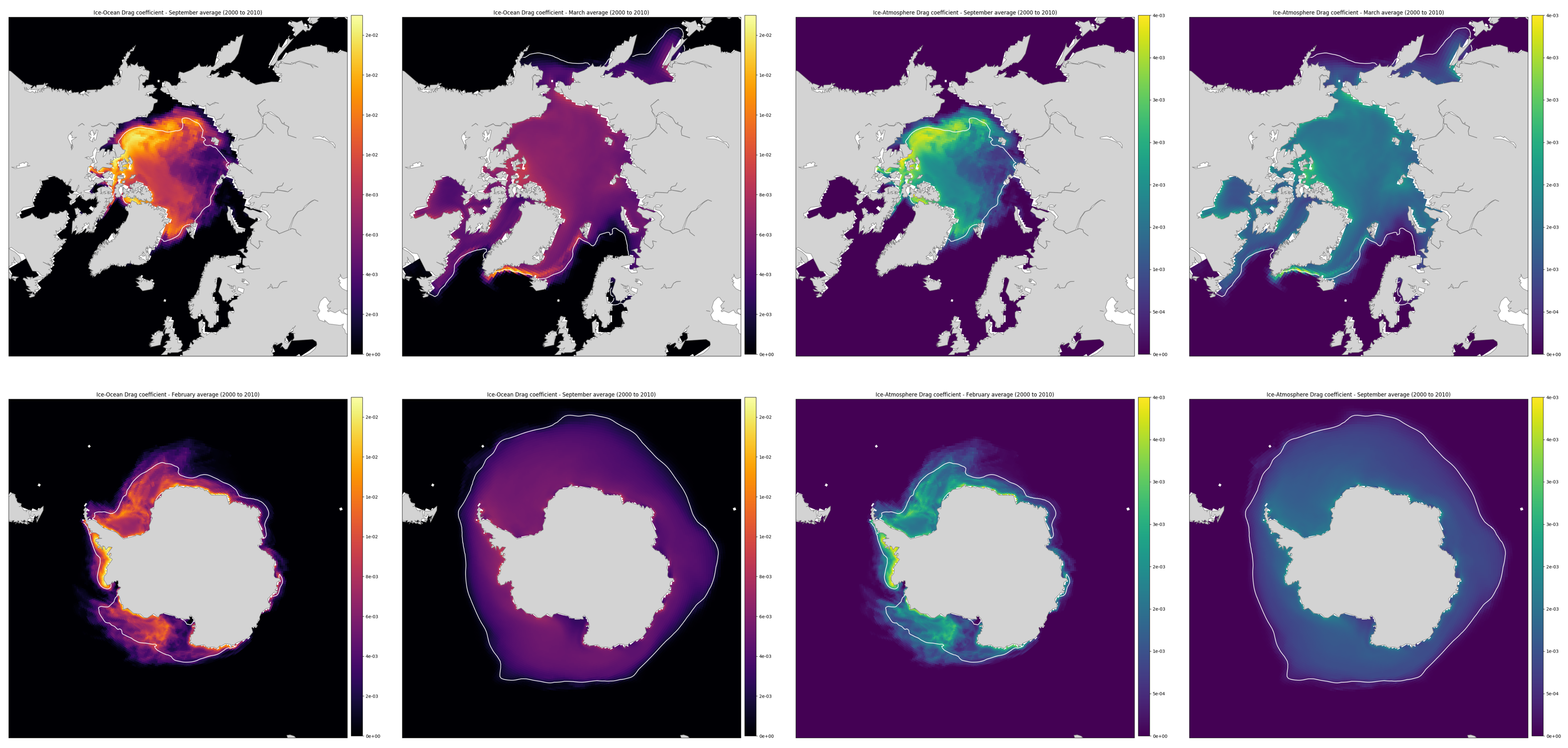

Fig. 2: Climatology of the Ice-Ocean (1st and 2nd columns) and Ice-Atmosphere (3rd and 4th columns) neutral drag coefficients, averaged between 2000 and 2010, during minimum ice extent months (March in the north hemisphere. and Feb. in south) and maximum ice extent (Sept. in both hemispheres). The white line indicates the the 15% ice concentration line.

Key points on the deformed ice

- The deformed ice tracers are generally low in the Marginal Ice Zone (MIZ)
- Hot-spots for ice creation through thermodynamical processeses lower the deformed ice locally (cf. Weddell Sea in Antarctica)
- The deformed ice volume is at its highest near the Canadian Archipelago, during winter
- Within the pack in winter, the deformed ice concentration is moderate
- During summer, the deformed ice concentration matches the deformed ice volume spatial distribution

Key points on the drag coefficients

- The drag coefficients are the highest during the melting seasons, with a high spatial variability
- During winter in Antarctica, the coefficients are nearly constant within the ice pack
- In the Arctic, the drag coefficients are high in the MIZ of the Greenland sea, in the Canadian Archipelago, and other coastal areas

Conclusion

The variability of the drag coefficients highlights the importance of the form drag for the determination of the surface fluxes at the poles. In a next step, we will modify NEMO-LIM3 to use the drag coefficients in the fluxes calculations, so as to activate a feedback. A full study in the Antarctic is yet to be done to our knowledge. The form drag formulation still relies on secondary parametrizations, such as on the floe length and the distance between floes. The development of a Floe Size Distribution (FSD) would help to represent more accurately the effects of the floes on the drag form, and finalise the Tsamados formulation. Finally, the neutral drag coefficients have been designed for neutral stratificiations. The parametrization could be improved by considering the stratification of the boundary layers.

Reference

Michel Tsamados, Daniel L. Feltham, David Schroeder, Daniela Flocco, Sinead L. Farrell, Nathan Kurtz, Seymour W. Laxon, and Sheldon Bacon. Impact of variable atmospheric and oceanic form drag on simulations of arctic sea ice. Journal of Physical Oceanography, 44(5): 1329-1353, 2014. doi : 10.1175/JPO-D-13-0215.1.