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Modelling sea ice for climate studies: recent advances and future challenges (Louis Agassiz Medal Lecture)

Thierry Fichefet

Université catholique de Louvain, Earth and Life Institute, Georges Lemaître Centre for Earth and Climate Research, B-1348 Louvain-la-Neuve, Belgium (thierry.fichefet@uclouvain.be)

Since the beginning of satellite measurements in 1979, the summer Arctic sea ice extent has shrunk at a mean rate of $\sim$12% per decade, and there is evidence that the rate of decline has accelerated over the last decade. Current global climate models project further decrease in Arctic sea ice areal coverage through the 21st century if atmospheric greenhouse gas concentrations continue to increase. However, rates of loss vary greatly between models, yielding a large uncertainty as to when a seasonally ice-free Arctic Ocean may be realized. Narrowing this uncertainty is of crucial importance since such changes in the Arctic sea ice cover might have profound ramifications, including the global ocean circulation and heat budget, regional ecosystems and wildlife, the indigenous human population, and commercial exploration and transportation. Regarding the Antarctic sea ice, its extent has been observed to slightly increase during the last 37 years, which appears puzzling in a global warming context. Several hypotheses have been proposed to explain this feature, but the issue is far from being settled. On the other hand, the majority of global climate models simulate a decreasing trend in Antarctic sea ice extent over this period, which questions the validity of their Antarctic sea ice projections for the coming decades.

In this lecture, we show through simulations conducted with the state of the art Louvain-la-Neuve Sea Ice Model (LIM) coupled to the Nucleous European Modelling of the Ocean (NEMO) platform that a number of small-scale sea ice processes, which are omitted or crudely represented in global climate models (in particular, the subgrid-scale sea ice thickness distribution, the thermodynamics and dynamics of brine pockets trapped within sea ice, processes related to snow on top of sea ice, including surface melt ponds, the sea ice mechanical deformation, and the subgrid-scale heterogeneity of atmosphere-ice-ocean interactions), play a significant role in determining the mean state and variability of sea ice in both hemispheres. There is therefore an urgent need to account for these processes in the next generation of global climate models. We also demonstrate that sea ice data assimilation in models is a powerful tool to calibrate sea ice parameters and to improve seasonal sea ice predictions. Furthermore, we show that it is possible to understand to a certain extent differences between models and to reduce sea ice projection uncertainties by using appropriate sea ice process-oriented diagnostics and emergent constraints. Finally, we discuss possible future developments and challenges in sea ice modelling for climate studies.