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# Parameterization of sea ice processes in a changing climate

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Parameterizations of sea ice processes in ocean-sea ice models were developed and tuned for sea ice conditions of the recent past. They do not reflect recent changes in sea ice characteristics. The demise of multiyear sea ice in the Arctic implies that surface drag coefficients and the ocean sea ice drag will be considerably different from previous conditions. Here, we will report on the consequences of sea ice thickness distribution changes on the atmosphere-sea ice-ocean momentum transfer, on sea ice drift and oceanic circulation. Furthermore, the snow thickness distribution changes with the ice thickness distribution with serious consequences for sea ice thermodynamics.

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By their nature, sea ice models are highly parameterized. In numerical models, the ensemble of floes that make up the sea ice is treated as a continuum. Therefore, a number of parameterizations is necessary to describe the effect of small scale interactions on the large scale sea ice fields. This is especially relevant because of the strong coupling of ocean and sea ice and because of the role of sea ice as a mediator of fluxes between the ocean and the atmosphere.
Usually, parameterizations are designed and tuned for the current climate. It is questionable whether such parameterizations are valid for a different background climate. Regarding the rapidly changing Arctic, the most significant change of background conditions is the shift in the sea ice thickness distribution: The volume of the thickest and oldest ice is decreasing at a higher rate than that of the thinner and younger sea ice. While there are algorithms to simulate changes of ice thickness distribution (Thorndike et al., 1975), most sea ice models work only with a small and constant number of ice thickness categories to better simulate the heat fluxes through the ice (Semptner 1976, Hibler 1979). Here we present several parameterizations that take these changes into account. The parameterizations are not inherently superior to previous parameterizations because they still rely on an unchanging climate state. We have tested the sensitivity of sea ice and ocean sub system model to some new parameterizations which are briefly described below.

We utilize the **N**orth **A**tlantic **A**rctic **O**cean **S**ea **I**ce **M**odel NAOSIM ( Fieg et al., 2010) of the Alfred Wegener Institute. Because of several climate system feedbacks involving sea ice, more meaningful sensitivity tests could be done with fully coupled climate models. We were not able to perform such tests because of computer power constraints.

To quantify sea ice thickness distribution changes, we analyzed EM and laser altimeter thickness profiles taken from ship based helicopters over the central Arctic. From this data Castellani et al., 2013 derived average ice thickness and sail and keel heights as well as the average distance between sails and keels respectively. In recent years, large parts of the Arctic are covered with first year ice that has replaced the thick and rough multiyear ice. Castellani et al., 2013 consider the reduction in the surface and bottom roughness of sea ice in the Arctic by adapting a parameterization for the drag coefficients. Those take into account the actually observed surface or statistical information about floe size, melt ponds and ridged sea ice sails, topography of the sea ice and its snow layer. As the sea ice surface roughness decreases on average, the momentum flux from the atmosphere into sea ice and ocean has become smaller and the quick demise of the multi-year sea ice cannot explain the observed (Rampal et al., 2011) acceleration of the ice drift. Apparently, other processes overcompensate for the reduction in surface roughness. However, the impact on the ocean through changes in the Ekman transport divergence still needs further assessment.

More direct effects of the shift in the sea ice thickness distribution are to be expected regarding the thermodynamics of sea ice and thus the overall melting and freezing rates. It is well known that freezing of sea ice reacts very sensitively to changes in thickness distribution: freezing ceases when the sea ice exceeds a certain thickness because the ocean beneath the ice is no longer sufficiently cooled as that newly formed ice could accrete at the bottom of the existing sea ice. The ice formation under sea ice strongly depends on the thickness distribution. To improve the representation of ice formation beneath sea ice, we have prescribed in NAOSIM a realistic ice thickness probability density distribution (pdf) obtained from airborne electromagnetic sounding measurements from ca. 120 flights performed over the Arctic between 2001 and 2011.

In addition to the more realistic ice thickness probability density distribution, we have evaluated the model's response to two different types of snow parameterization that are commonly used in sea-ice models: a homogeneous distribution independent of the sea ice thickness underneath snow, and a distribution proportional to the applied ice thickness probability function (thick snow over thick ice as is to be expected from the longer winter exposure to snowfall for the older and thicker ice). Our simulations were performed for the period between 1990 and 2007 and results show a considerable improvement in sea-ice thickness when compared to recent EM thickness measurements.

Another process influencing the thermodynamics is light transmission through sea ice and its absorption in the underlying ocean. It is often neglected as small compared to other terms in the thermodynamic balance of sea ice. This is, however not generally justified since energy fluxes through the ice into the mixed layer reach 20 $Wm^{-2}$in many places, comparable to the downward long wave radiation (Arndt, 2013). Regarding sea ice melting, the heat flux into the mixed layer is especially effective as most of the energy is available to melt sea ice and very little is emitted as long wave radiation to the atmosphere. The transmittance of thin ice is much higher than that of multiyear ice. Thus, transmission of shortwave radiation through sea ice establishes another positive feedback that contributes to the retreat and thinning of sea ice in the Arctic. We have not yet tested the sensitivity of ocean - sea ice models to this process.

The parameterization for sea ice strength which mainly describes the resistance of sea ice to compression explicitly takes into account changes in the background state, the mean sea ice concentration and thickness, namely

$$P=P^* h \exp(-C(1-A)) \qquad \textbf{[1]}$$

where $P^*$ and C are empirical parameters, A is the ice concentration and h is the mean sea ice thickness within one grid cell of the model. When P* is sufficiently large, the model is capable of forming ice arches between adjacent fixed points on land. The length of an arch increases with increasing P*. Arches are obstacles for drifting sea ice and are important for the formation and destruction of land fast ice (Itkin et al, 2013). The location of open water in relation to the salinity distribution in the ocean influences the formation and properties of dense waters on the Arctic shelves and with that the deep water mass distribution and subsurface ocean circulation in the Arctic Ocean and the Nordic seas (Itkin et al., 2013). The ice strength governs the formation of open water, e.g. in front of coasts and fast ice where winds blow parallel to the edge.

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