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A directed percolation model for the permeability of young sea ice

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The permeability of sea ice is an important property with regard to the role of sea ice in the earth system. It controls fluid flow within sea ice, and thus affects processes like desalination and melt pond drainage. It also impacts the role of sea ice in hosting sea ice algae and organisms, and the uptake and release of nutrients and pollutants from Arctic surface waters. However, as sea ice permeability is difficult to measure in the field, observations are sparse and vary, even for similar porosity, over orders of magnitude. This range is related to the evolution of the sea ice pore space during aging from young ice to thick first year ice. In young ice, the pore network is dominated by primary pores constrained by brine layers and the near-interface microstructure. In older sea ice, the ongoing desalination and thermal fluctuations have created wider secondary brine channels, implying a several orders of magnitude higher permeability. It is a challenge to understand and model these changes in pore space and permeability. Here a directed percolation model for the permeability of young sea ice is proposed. The model describes the dependence of sea ice permeability and electrical conductivity on brine porosity, and its critical behaviour and percolation transition due to necking of pores, and related disconnection of pore networks. Its parameters are based on 3D X-ray micro-tomographic imaging of young sea ice and direct numerical simulation of its transport properties, that strongly support the application of directed percolation theory to young sea ice, with a threshold porosity (impermeable ice) of 2 to 3 percent. Combined to an approach to predict the crystal structure at the ice-ocean interface, the model also the growth-velocity dependence and evolution of permeability near the ice-ocean interface. As the model is strictly valid for growing and cooling sea ice, without present of wider secondary brine channels, it is mostly relevant for sea ice desalination processes during winter. Modelling permeability of older and summer ice (and melt pond drainage) will require more observations of the pore space evolution in warming sea ice, for which the present results can be considered as a starting point.