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Studies of the Arctic Ocean Sea Ice Cover and Hydrothermal Heat Fluxes

Christian Stranne
Institutionen för geovetenskaper
Naturvetenskapliga fakulteten

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Examinator:
Professor Anders Stigebrandt

Fakultetsopponent:
Professor James Overland
NOOA – Pacific Marine Environmenral Laboratory, Seattle, WA, USA

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ABSTRACT

Since reliable ice extent estimates from satellite data became available in 1979 the Arctic sea ice cover has followed a declining long term trend. Over the last decade the decline has accelerated with record low sea ice extents recorded in 2002, 2005, 2007 and 2012. In order to explain the mechanisms behind the observed ice cover decline it is critical to gain a better understanding of the climate system as a whole which in turn requires detailed studies of the involved processes. The main objective of the work presented in this thesis is to improve the knowledge of the Arctic ice cover sensitivity to climate change through detailed studies of some key processes involved.

The observed sea ice cover reduction has not been homogeneous over the Arctic Ocean. A typical pattern is that the thinning has been larger in regions with thick ice compared to regions with thinner ice. It has been argued that the ice thickness - ice growth rate feedback mechanism is the dominating process explaining these regional variations. The sea ice thickness response to variations in the atmospheric forcing is studied with a succession of increased model complexity. When the model realism is increased by the inclusion of processes such as ice divergence and variable surface albedo, the ice cover response properties become more complex with e.g. a very high sensitivity close to the transition between perennial and seasonal ice. These results imply that other mechanisms than the ice thickness - ice growth rate feedback might be more important for explaining the observed regional variations of the sea ice cover decline. It is suggested that temporal variations in the local ice divergence is one such mechanism and supporting observational data are presented.

Simulations of the present Arctic sea ice cover performed with coupled 3D models (both global and regional) show large inter-model scatter. Analyses of the mechanism behind this scatter point at differences in the surface albedo parameterization as one of the major factors. In the present thesis we address this problem by running a model with identical forcing and using a number of different albedo parameterizations taken from well-known global climate models. It is shown that the surface short wave radiation budget is strongly influenced by the choice of albedo parameterization. This means that for the same forcing the different parameterizations cannot all yield a realistic Arctic sea ice cover. Global climate models need then differences in e.g. the atmospheric composition in order to compensate for the different surface albedos such that they all produce ice covers that are fairly consistent with observations.

The effect on the Arctic sea ice cover of variations in solar insolation associated with Earth’s orbital parameters is also studied. It is shown that the increased solar forcing in the Arctic during the early Holocene insolation maximum (~9500 years before present) had the potential to force the ice cover into a state dominated by seasonal ice. A compilation of available ice cover proxy data is also presented and the emerging picture is consistent with the model results.

The thesis also includes a separate study on hydrothermal plume modeling based on data collected during the AGAVE 2007 Expedition. An indirect method for estimating the heat flux of hydrothermal vents using buoyant plume dynamics in combination with water column observations is presented. The results show that one of the plumes investigated likely stems from a hydrothermal vent with a heat flux comparable to the largest known vents on Earth.

Keywords: Arctic Ocean, Sea ice, Sensitivity, Ice divergence, Albedo feedback, Ice export, Tipping point, Hysteresis, Milankovitch cycles, Holocene, Insolation, Climatic feedback, Gakkel Ridge, Hydrothermal vent, Hydrothermal plume, Hydrothermal heat flux