International Max Planck Research School on Earth System Modelling

Variability of Arctic sea ice

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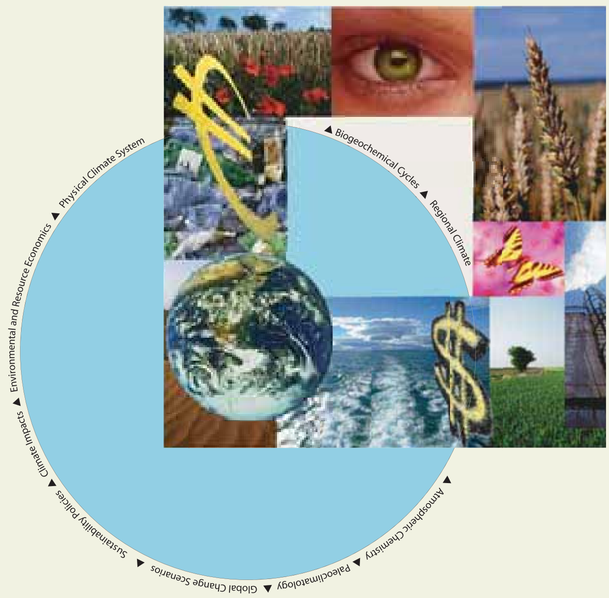

Abstract

Arctic sea ice is considered to be an important climate change indicator due to its large sensitivity to a changing climate. At the same time changing arctic sea ice has a large feedback potential on the climate. Understanding the relation between changes in sea ice (especially the summer sea ice distribution and thickness as monitored typically by September values) and changes in the ocean or atmosphere is therefore important for understanding future sea ice and climate variations. In this thesis Arctic sea ice parameters are being analyzed in observations and climate models, and the sensitivity of sea ice changes over the Arctic to atmospheric forcing fields are analyzed using an adjoint modeling framework.

The work is divided in two parts. In the first part the primary focus is on concentrations, thickness and transports of Arctic sea ice, as simulated by the Max-Planck-Institute for Meteorology (MPI-M) coupled model for the period 1980 to 1999, and as observed simultaneously during field programs and by satellites. The comparison of model results with observations is based on two model realizations: (1) a fully coupled ECHAM5/MPI-OM run forced by 20^{th} century CO_2 concentrations and (2) an ocean-ice MPI-OM run forced by the NCEP atmospheric reanalysis-1. Results of the fully-coupled run show significant discrepancies to observations with respect to the spatial distribution of the ice concentration and ice thickness during summer months. The coupled model tends to overestimate the ice concentration in the Siberian shelf seas and near the Canadian coast, likely because of deficits in the model's Beaufort Gyre and Transpolar Drift. Moreover, the coupled run essentially lacks interannual variability in ice and ocean parameters that is simulated when using NCEP surface forcing. Causes for such big discrepancies arise from errors in the ECHAM5/MPI-OM atmosphere and associated errors in surface forcing fields (especially wind stress); potentially they could arise also from insufficient atmospheric variability in the ECHAM model, e.g., associated with AO/NAO. As can be expected, the NCEP-forced run shows much increased skill in its ice and ocean circulation parameters; nevertheless it still lacks many details present in the ice observations. Common to both model runs is too strong an ice export through Fram Straight and too much heat content in the interior of the Arctic Ocean, both of which may affect sea ice budgets and decadal to centennial projections of sea ice in the Arctic.

In the second part of the thesis we investigate spatial and temporal distribution of adjoint-based sensitivities of the mean September sea ice area (AREA) and volume (VOLUME) to surface atmospheric temperature and wind in the regional Arctic Ocean setup of the Massachusetts Institute of Technology global circulation model (MITgcm) for the period 1980 to 2007. The adjoint-based sensitivities allows us to document influences of the atmosphere (as well as the ocean) on sea ice and follow those influences throughout the year. We show that during October-May atmospheric forcing fields have a minor effect on the September sea ice characteristics, while after the onset of the spring melting until the end of September atmospheric forcing influence September sea ice characteristics considerably. The AREA is highly sensitive to temperature changes during June-July over the regions close to the ice edge in the Arctic seas. The VOLUME is highly sensitive to temperature changes over the central parts of the Arctic Ocean, also during June-July. The export of thicker ice from the central parts of the Arctic Ocean to the Siberian Shelf seas on average increases the AREA, but decreases the VOLUME. The sensitivities of AREA and VOLUME to thermodynamical and dynamical atmospheric forcing are mainly controlled by the background distribution of sea ice concentration (SIC) and sea ice thickness (SIT).

A comparison of the sea ice conditions during the periods 1980-1989, 1990-1999 and 2000-2007 reveals that during 2000-2007, due to dramatic decline of SIC and SIT, sea ice sensitivities to atmospheric forcing increase, suggesting that a comparable atmospheric forcing led to a stronger sea ice response compared to the two other periods. Both AREA and VOLUME sensitivities demonstrate that some influence of the atmospheric conditions extends at least four years into the future. Strength of the sensitivities gradually increase from year to year and show the same seasonal cycle as one-year sensitivities. We believe that SIT is the primary agent that carries atmospheric influence through the years.