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CO2 as a driver of sea ice tipping points

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The recent Arctic summer sea ice reduction has led to the disscussion that the Arctic might cross a tipping point, inducing an irreversible shift in the system. Using a simple model, Eisenmann and Wettlaufer (2009) find that critical threshold behavior is unlikely during the approach from current perennial sea-ice conditions to seasonally ice-free conditions, but a tipping point with the sudden loss of the remaining winter sea ice cover may be likely.

We examine the conjecture of the hysteresis behavior of Arctic sea ice in response to atmospheric CO_2 change by using the state-of-the-art AOGCM ECHAM5/MPIOM. In contrast to the IPCC emission scenario, we very slowly increase the atmospheric CO_2 from pre-industrial level to quadrupling over 2000 years and continue the integration until the whole system reaches equilibrium; after that we slowly decrease the atmospheric CO_2 to pre-industrial level over 2000 years. We change the atmospheric CO_2 concentration very slowly to remain close to a quasi-equilibrium.

Our results show that the Arctic summer sea ice extent decreases to zero without any tipping point, but we find a tipping point of Arctic winter sea ice during the seasonally ice-free conditions. This result is consistent with the result from the simple model by Eisenmann and Wettlaufer (2009). In the Antarctic, we do not directly find a tipping point in the winter and summer sea ice extent time series. However, the time series show very strong hysteresis behavior. After the decrease of CO_2, the sea ice in the Antarctic takes much longer time to recover than Arctic sea ice.

A heat-budget analysis over the Arctic ocean shows that the increasing atmospheric latent heat transport induces a net warming of the Arctic ocean. This amplifies the Arctic sea ice retreat and stabilizes the ice-free state. The Arctic ocean exports heat from the Arctic to the surrounding oceans after warming up. This change in direction of the ocean heat transport is a negative feedback to the Arctic sea ice change in our experiments, in contrast to the findings by Bitz et al. (2006) who find an increased poleward heat transport for reduced ice cover.