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The transient versus the equilibrium response of sea ice to global warming

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To understand the long-term stability of Arctic Antarctic sea ice in a future warm climate, an idealized prescribed atmospheric CO_2 concentration is applied to ECHAM5/MPIOM, where atmospheric CO_2 extremely slowly increased up to quadrupling and extremely slowly decreased down to pre-industrial level over 2000 years. Consistent with previous studies, the Arctic summer sea-ice cover retreats linearly with CO_2 increase in a warm climate. But we find a rapid transition during the loss of the Arctic winter sea-ice cover in a warm climate once the NH-averaged annual-mean surface temperature has increased by about 8.0K. This rapid transition is triggered by atmospheric convection which can warm the Arctic by trapping the outgoing long-wave radiation and keep the Arctic ice-free in winter time. We find no evidence of multiple equilibria and hysteresis behavior of Arctic winter and summer sea-ice cover in response to atmospheric CO_2 forcing. However, both Arctic summer and winter sea ice shows a lagged response to the change in atmospheric CO_2 forcing due to the thermal inertia of the Arctic Ocean. The Antarctic sea-ice cover retreats continuously without any rapid transition during the warming trajectories, and it also shows no evidence of hysteresis behavior and multiple equilibria in response to the atmospheric CO_2 forcing. The Antarctic sea-ice cover shows much stronger lagged response to the atmospheric CO_2 forcing compared to the Arctic sea ice, and the response of Antarctic sea-ice cover significantly lags behind the Southern Hemisphere (SH) surface air temperature change. Because different from the Arctic sea ice, the surface temperature change is not the controlling factor for the Antarctic sea-ice change in a warm climate, deep ocean convection and sea-ice dynamics can also play an important role in determining the Antarctic sea-ice long-term stability.