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The atmospheric response to sea ice and snow cover changes induced by global warming

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Two atmospheric general circulation model experiments are conducted with Arctic sea ice states of 1980-99 and 2080-99. The sea ice states are obtained from twentieth-century and twenty-first-century coupled climate model integrations in which greenhouse gas concentrations in the 21st century are from the A1B scenario. Sea surface temperatures, sea ice, and greenhouse gas concentrations are set to 1980-99 values in both atmospheric model experiments to isolate the effect of the sea ice changes. While the loss of Arctic sea ice is greatest in summer and fall, the response of the net surface energy budget over the Arctic Ocean is largest in winter. Air temperature and precipitation responses also maximize in winter, both over the Arctic Ocean and over the adjacent high-latitude continents. Snow depths increase over Siberia and northern Canada because of the enhanced winter precipitation. A significant large-scale atmospheric circulation response is found during winter, with a baroclinic (equivalent barotropic) vertical structure over the Arctic in November-December (January-March) and resembles the negative phase of the North Atlantic Oscillation in February only. Comparison with the fully coupled model reveals that Arctic sea ice loss accounts for most of the seasonal, spatial, and vertical structure of the high-latitude warming response to greenhouse gas forcing at the end of the twenty-first century. A similar pair of experiments were conducted for changes in snow cover. The reduction in snow cover in the twenty-first century relative to the twentieth century increases the solar radiation absorbed by the surface, and it enhances the upward longwave radiation and latent and sensible fluxes that warm the overlying atmosphere. The maximum twenty-first-century minus twentieth-century surface air temperature (SAT) differences are relatively small ($<3^{o}C$) compared with those due to Arctic sea ice changes ($10^{o}C$). The circulation response to the snow changes, while of modest amplitude, involves multiple components, including a local low-level trough, remote Rossby wave trains, an annular pattern that is strongest in the stratosphere, and a hemispheric increase in geopotential height.