Auxiliary material for paper 2011GL048739

The reversibility of sea ice loss in a state-of-the-art climate model

K. C. Armour[1], I. Eisenman[2,3], E. Blanchard-Wrigglesworth[3], K. E. McCusker[3], and C. M. Bitz[3]

[1] Department of Physics, University of Washington, Seattle, Washington, USA.
[2] Geological and Planetary Sciences, California Institute of Technology, Pasadena, California, USA.
[3] Department of Atmospheric Sciences, University of Washington, Seattle, Washington, USA.

Armour, K. C., I. Eisenman, E. Blanchard-Wrigglesworth, K. E. McCusker, and C. M. Bitz (2011), The reversibility of sea ice loss in a state-of-the-art climate model, *Geophys. Res. Lett.*, doi: 10.1029/2011GL048739.

Introduction

This auxiliary material contains: 1) An analysis of the reversibility of hemispheric sea ice area with respect to changes in CO_2 using a specified memory timescale, and 2) NH March equivalent ice area as a function of NH-mean annual-mean surface temperature anomaly.

1) Assessing sea ice reversibility with respect to CO_2 using a specified memory timescale

In the main text we assessed the evidence for hysteresis in sea ice area with respect to hemispheric-mean annual-mean surface temperature in order to account for the lag between forcing changes and climate response. A potential limitation of this method is that the memory timescale of hemispheric-mean temperature and of ice area may not depend on the same physical factors. Furthermore, to the extent that hemispheric-mean temperature itself depends slightly on sea ice area, the analysis in the main text could plausibly be missing an element of hysteresis in the sea ice cover. Here we use an alternate method to assess the possibility of hysteresis in the sea ice cover.

We define $F(t) \equiv \log(\mathrm{CO_2}(t))$ as the control parameter that is varied throughout the simulation. Since CO_2 increases and decreases at 1% yr^{-1} over the course of the rampings, F increases and decreases linearly with time ($+0.01\ \mathrm{yr}^{-1}$ and $-0.01\ \mathrm{yr}^{-1}$, respectively). Figure S1a-f shows hemispheric areas with respect to $F = \log(\mathrm{CO_2})$. Within the simulation, F is ramped relatively quickly and the climate does not maintain an exact steady state with the forcing, introducing a lag in the sea ice response to changes in F. To account for this effect, we further define a "lagged forcing", $G(t)$, as the solution to the differential equation

$$\frac{\mathrm{d}G}{\mathrm{d}t} = \frac{F - G}{\tau}.$$

The characteristic memory timescale, τ, is assumed to be constant over the simulation but may take on different values depending on season and hemisphere.

Figure S1g-l shows hemispheric ice area with respect to the lagged forcing G, where values of τ have been chosen to visually maximize agreement between warming and cooling trajectories. Values of τ are longer for the SH than the NH, consistent with the relatively slower adjustment of the SH climate to changes in forcing. The wintertime ice cover warming and cooling trajectories appear to diverge slightly when the ice cover is near its most extensive, particularly in the NH. As discussed in the main text, this appears to arise because the winter ice edge advances, under reduced CO_2, into regions of the ocean that have anomalously long timescales of adjustment to forcing changes, particularly under cooling.

Figure S1 demonstrates that accounting for a simple linear memory is sufficient to explain most of the differences between warming and cooling sea ice trajectories under changes in F.

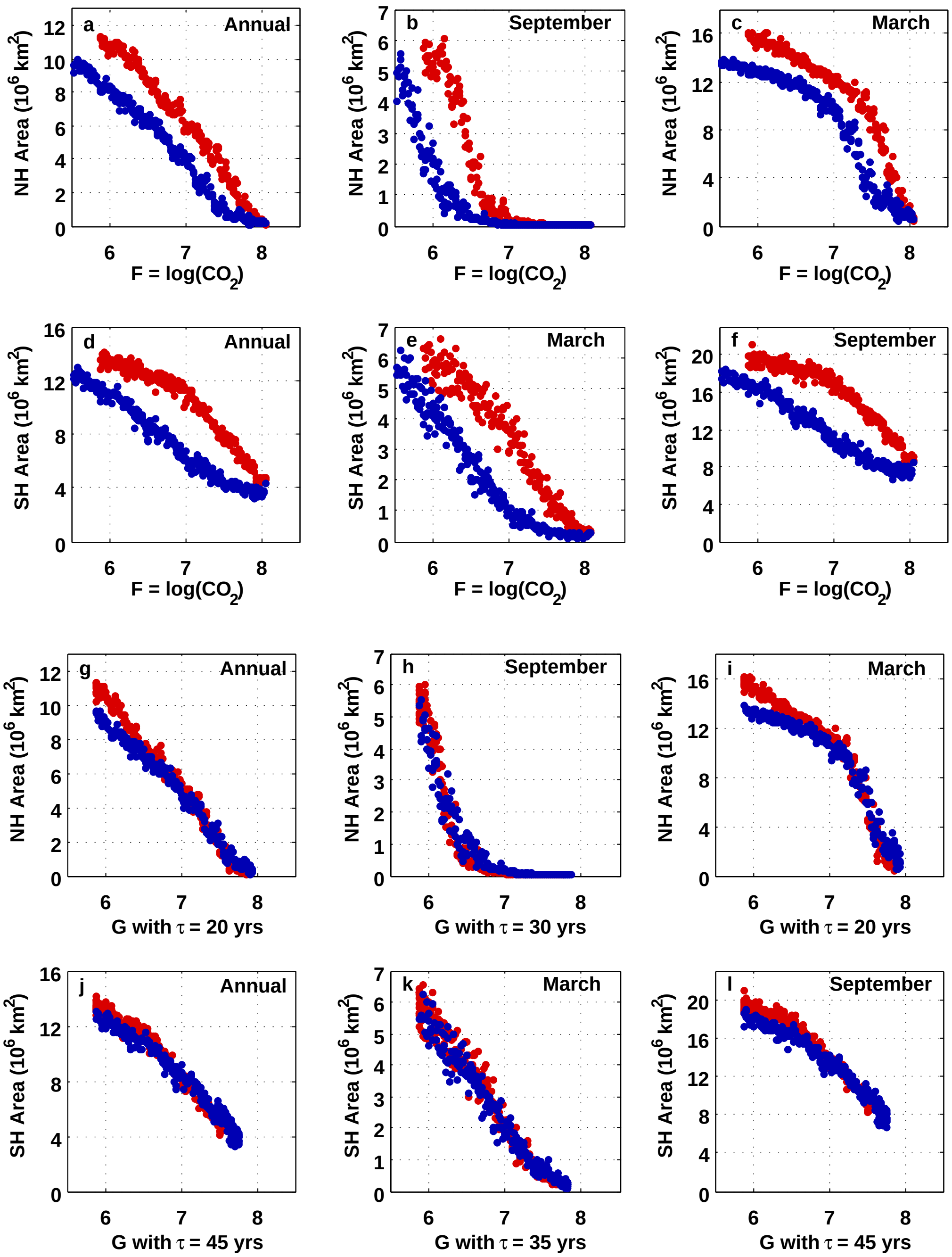

Figure S1. (a-f) Hemispheric ice area as a function of forcing [$F = \log(\mathrm{CO}_2)$]. (g-l) Hemispheric ice area as a function of forcing lagged with a memory timescale τ (G, defined in auxiliary material text). The period with increasing CO_2 concentration is shown in red, and the period with decreasing concentration is shown in blue.

2) Northern Hemisphere March equivalent ice area

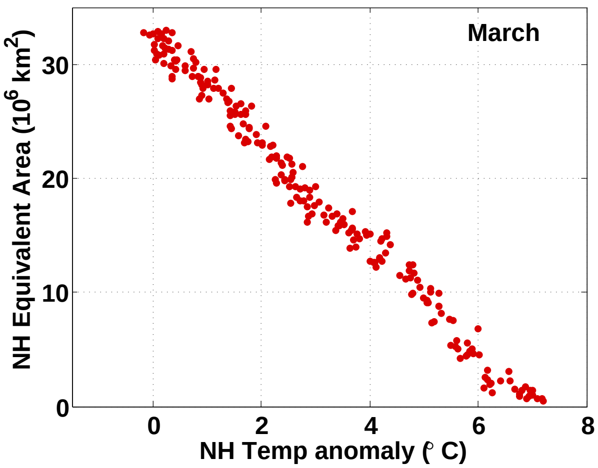

Figure S2. NH March "equivalent ice area" (as defined by *Eisenman* [2010]) as a function of NH-mean annual-mean surface temperature anomaly over the warming simulation. Equivalent ice area accounts for the effect of geography on the ice area, and hence its linearity with NH temperature suggests that the change in NH March sea ice sensitivity (Figure 2) is due to the influence of the coastlines. We compute the equivalent ice area by finding the total land plus ocean area poleward of the latitude with poleward ocean area equal to the actual ice area [*Eisenman*, 2010].