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On the possibility and predictability of rapid Arctic winter sea-ice loss

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We examine the transition from a seasonally ice-covered Arctic to an Arctic Ocean that is sea-ice free all year round under increasing atmospheric CO_2 levels. Using two column models and nine Earth System Models, we investigate how rapid such Arctic winter sea-ice loss can be, and whether an abrupt ice loss can be predicted from observed trends in variance or autocorrelation. Such statistical indicators have been proposed as early warning signals of abrupt shifts that are caused by positive feedbacks.

We show that in comprehensive climate models, the loss of winter sea-ice area is faster than the preceding loss of summer sea-ice area for the same rate of warming. In two of the models, several million km2 of winter sea ice are lost within only one decade. Their behaviour resembles the catastrophic winter ice loss in a column model where the stable ice-covered state suddenly disappears at a bifurcation point, implying an irreversible and abrupt shift to the ice-free solution. However, we argue that winter sea-ice loss in comprehensive models is reversible and not associated with the existence of multiple steady states. The large sensitivity of winter sea-ice area in complex models is caused by the asymmetry between melting and freezing: An ice-free summer requires the complete melt of even the thickest sea ice, which is why the perennial ice coverage decreases only gradually as more and more of the thinner ice melts away. In winter, however, sea-ice areal coverage remains high as long as sea ice still forms, and then drops to zero wherever the ocean warms sufficiently to no longer form ice during winter. As this mechanism occurs in every model we analyse and is independent of any specific parameterisation, it is likely to be relevant in the real world.

We also find that expected trends in variance and autocorrelation of sea-ice area and thickness are not specific to the existence or the mechanism of abrupt ice loss. For example, natural fluctuations of ice volume become faster (i.e. autocorrelation decreases) before summer ice is lost because thinner ice can adjust more quickly to perturbations. Thereafter, the natural fluctuations become slower (i.e. autocorrelation increases), mainly because the system becomes dominated by the ocean water's large heat capacity when the ice-free season becomes longer. Altogether, we conclude that Arctic winter sea-ice loss is a gradual process, but more sensitive to warming than the loss of summer sea ice. While the gradual thinning of sea ice can provide a warning of rapid area loss, statistical indicators are not specific enough to predict such rapid loss or attribute it to a certain mechanism.