Is Arctic Sea Ice Approaching a Tipping Point?

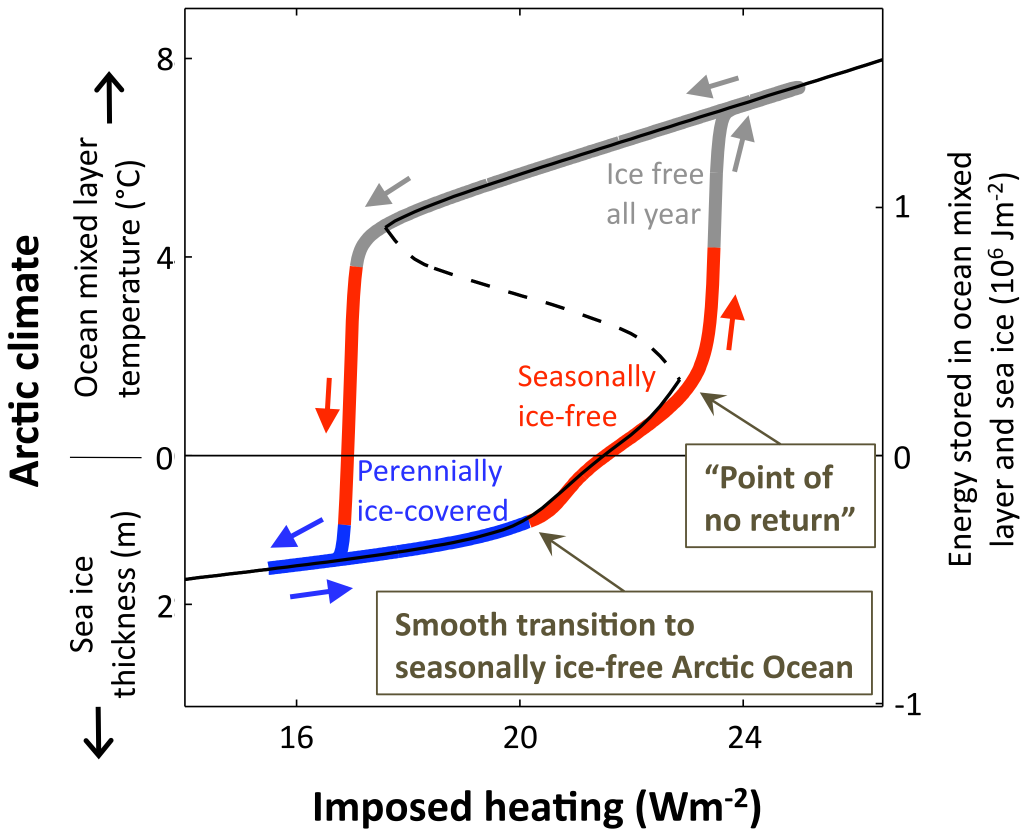
Because sea ice has a high reflectivity (i.e., albedo) to solar radiation, the increased area of open water that is exposed as sea ice recedes leads to an increase in absorbed solar radiation, thereby contributing to further loss of ice. In light of the observed rapid retreat of Arctic sea ice area during recent decades, the possibility that this ice-albedo feedback may drive an irreversible tipping point has garnered considerable attention. The focus has typically been centered on the annual minimum sea ice cover, which is often seen as particularly susceptible to destabilization by the ice-albedo feedback due to its occurrence at the end of summer. The results of our analysis, however, suggest that such a tipping point should not occur before the climate has warmed sufficiently that the Arctic Ocean is ice-free during much of the year.

We assessed the possibility of a sea ice tipping point by examining the central physical processes associated with the transition from ice-covered to ice-free Arctic Ocean conditions. Starting with the basic physical equations that describe the thermodynamics of a column of sea ice, radiative transfer in the atmosphere above, and a thermodynamic ocean mixed layer, we used a series of standard mathematical approximations to arrive at an idealized representation of the seasonally-varying Arctic sea ice, ocean, and atmosphere system. Next, we performed a bifurcation analysis on the model to look for threshold behavior involving sudden jumps.

Our analysis rests on basic facts regarding heat conduction and phase changes. During polar winter, heat from the ocean diffuses upward through the ice to the frigid atmosphere above, causing solidification of seawater at the base of the ice. Because this process is more effective for thinner ice, thin ice grows far more rapidly than thick ice. This represents a strong stabilizing feedback for the sea ice cover: the more the ice cover is thinned by a warming perturbation, the more rapidly it grows back.

As Arctic sea ice becomes thinner and more ocean water is exposed in a warming climate, we find that there is a competition between the destabilizing ice-albedo feedback and the stabilizing feedback associated with ice thickness. During the initial transition from a perennially ice-covered Arctic Ocean to seasonally ice-free conditions, thin sea ice covers the ocean for most of the year, giving the ice thickness feedback the upper hand. But as the climate is further warmed, a point occurs when there is ice cover during a sufficiently short portion of the year that the ice-albedo feedback wins out and all the ice rapidly disappears. This is an “irreversible process” in the sense that the ocean will only refreeze after the climate has cooled to a considerably colder level than the point at which the ice initially disappeared.

Our results suggest that an irreversible tipping point brought on by the ice-albedo feedback is unlikely in the hotly debated discussion regarding an imminent approach from current perennial sea ice conditions to seasonally ice-free conditions. In a further warmed climate, however, a critical threshold associated with the sudden loss of the remaining wintertime-only sea ice cover may potentially be likely. Further details are online at
http://gps.caltech.edu/ ian/publications/Eisenman-Wettlaufer-2009.html



Caption: Evolution of Arctic sea ice in response to warming simulated with an idealized physical model. The vertical axis represents the annual mean state of the upper ocean in terms of how much energy it would take to get to this point from an ice-free ocean that is at the freezing point. Initially (bottom left) there is a perennial sea ice cover (blue curve) with an annual mean thickness of about 1.5 meters. A transition to seasonally-ice free conditions (red curve) occurs in response to warming. At this point, cooling the climate would cause the ice cover to grow back to its original thickness. Further warming, however, causes the system to cross a bifurcation threshold and undergo a rapid transition to conditions which are ice-free throughout the year (gray curve). This transition represents an "irreversible process": considerable cooling would be required to get the ice to grow again (arrows to left along upper branch of the hysteresis loop). The stable and unstable steady-state solutions are indicated by the solid and dashed black curves, respectively.

–Ian Eisenman (California Institute of Technology, and University of Washington) and J.S. Wettlaufer, Is Arctic Sea Ice Approaching a Tipping Point? Presented at the 10th Conference on Polar Meteorology and Oceanography, 18-21 May 2009, Madison, Wisconsin.