Indicators of Arctic Sea Ice Bistability in Climate Model Simulations and Observations

Ian Eisenman
Scripps Institution of Oceanography
9500 Gilman Dr
La Jolla, CA 92093-0230
phone: (858) 822-5176 fax: (858) 822-4307 email: eisenman@ucsd.edu

Award Number: N00014-13-1-0469
http://eisenman.ucsd.edu

LONG-TERM GOALS

Assess the possibility that the climate system supports multiple Arctic sea ice states that are relevant for the evolution of sea ice during the next several decades.

OBJECTIVES

(1) Assess the influence of seasonal variations and spatial variations on the stability of the sea ice cover.

(2) Identify the most relevant scalar quantities related to the hemisphere-scale Arctic sea ice cover that indicate the presence of bistability, as well as the approach and crossing of bifurcation thresholds.

(3) Assess whether the presence of a second attractor has influenced the observed evolution of the Arctic sea ice cover during the past few decades and whether a second attractor influences projections of sea ice changes during the next several decades.

APPROACH

This work is being carried out by the PI and a postdoc (Till Wagner) who was hired by the PI's group to work on this project. The approach is as follows:

(1) Develop an idealized physical process model of Arctic sea ice and climate evolution that includes the nonlinearities associated with the ice-albedo feedback and the seasonal melt and growth of sea ice, as well as horizontal climate variations on a global domain.

(2) Use this model to identify quantities that indicate the stability of the system.

(3) Examine these quantities in comprehensive climate model simulations using the Coupled Model Intercomparison Project phase 5 (CMIP5) archive.

(4) Examine these quantities in observations.

(5) Use this framework to examine whether bistability of the sea ice cover appears to be playing a role in other predictive simulations from the ONR ACNFS and other high-resolution models of the Arctic system.

WORK COMPLETED

During this first year, we completed Approach item #1 and Objective item #1. This work is now submitted (see Publications below).

The idealized model development was a particularly daunting task. The goal was to create a model that included at each grid point the physics represented in prevous single-column sea ice models, with the grid points spanning the latitudes from the equator to the pole and communicating with each other via meridional heat transport in the atmosphere that is modeled as diffusion of the surface temperature. One hurdle was that in prevous single-column sea ice models, the surface temperature was calculated from an implicit equation, which did not allow the equations representing each column to be diffusively coupled in a straightforward way. We ultimately developed a novel mathematical method to solve the system of equations involving the addition of a numerical "ghost" layer, as described in the publication listed below. The idealized model development is now complete.

We also made substantial progress toward Approach item #3 during this first year. Specifically, we have nearly completed analysis of the relevant quantities in the CMIP5 archive.

RESULTS

Previous studies have identified instabilities for a shrinking Arctic sea ice cover in two types of idealized models: *(i)* annual-mean latitudinally-varying diffusive energy balance models (EBMs) and *(ii)* seasonally-varying single-column models (SCMs). As described in Approach item #1, we developed an idealized model that includes both latitudinal and seasonal variations (Fig. 1). The model reduces to a standard EBM or SCM as limiting cases in the parameter space, thus reconciling the two previous lines of research.

Using this model, we found that the stability of the ice cover vastly increases with the inclusion of meridional heat transport or a seasonal cycle in solar forcing, being most stable when both are included (Fig. 2).

IMPACT/APPLICATIONS

The results imply that the sea ice cover may be substantially more stable than has been suggested in previous idealized modeling studies.

This work helps bridge the gap between idealized process models and comprehensive climate models, and it fills a previously unpopulated space in the hierachy of modeling complexities. As such, it opens a range of new capabilities for addressing questions related to the core physical processes governing the hemispheric-scale evolution of the Arctic sea ice cover.

RELATED PROJECTS

NONE

PUBLICATIONS

T.J.W. Wagner and I. Eisenman (2014). The influence of spatial and seasonal variations on the stability of the sea ice cover. *J Climate*. [submitted, refereed]

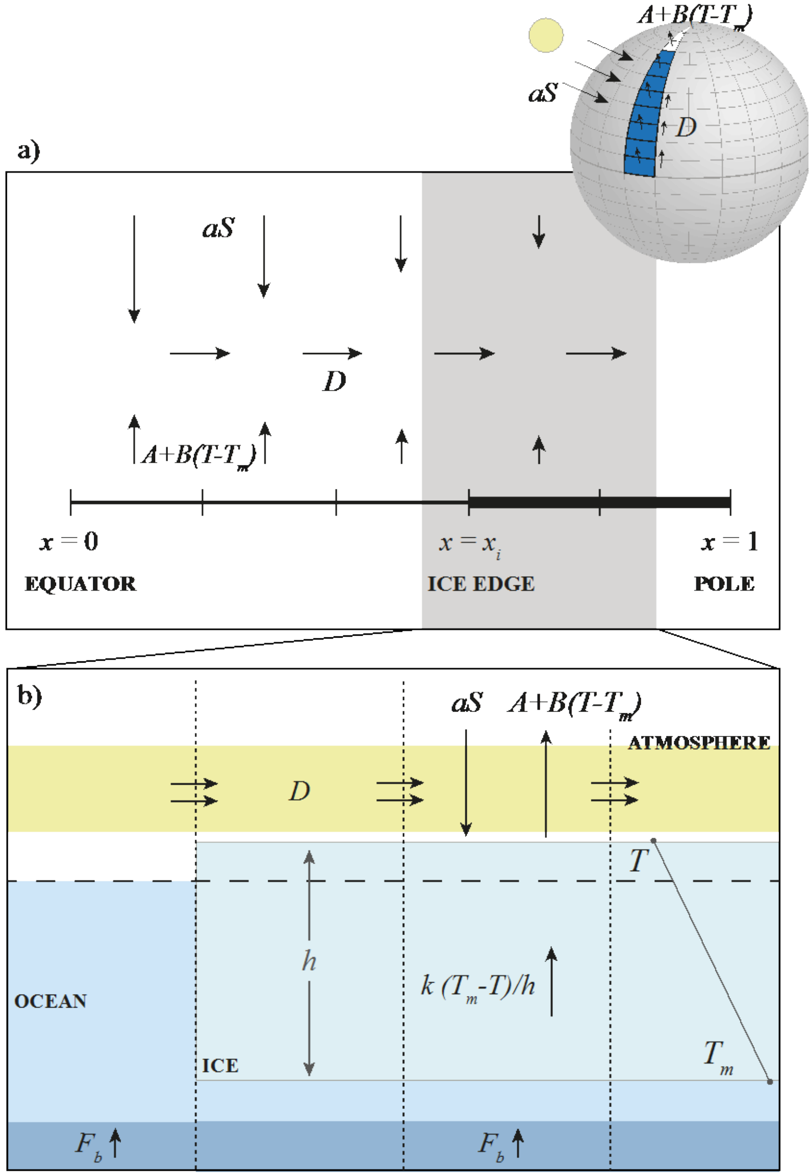

Figure 1: Schematic of the global sea ice and climate model developed under this project. Globe inset: Illustration of the model domain, a zonally-averaged aquaplanet. (a) Energy fluxes in the model atmosphere in the full model domain. (b) Energy fluxes in the model atmosphere, sea ice, and ocean in a subset of the model domain near the ice edge.

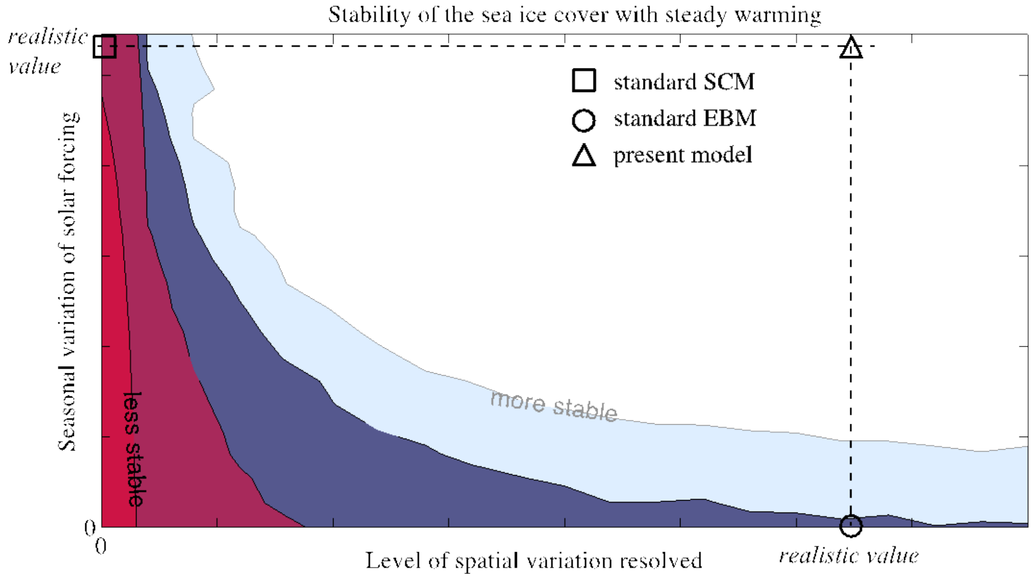

Figure 2: Dependence of the stability of the ice cover on horizontal diffusivity and seasonal variations. This is the result from 441 ~700-year simulations of warming and then cooling using the model described above.