Geophysical Research Abstracts, Vol. 8, 05423, 2006
SRef-ID: 1607-7962/gra/EGU06-A-05423

Sea ice mechanics as a climatic feedback mechanism

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Observations of the Arctic and Antarctic Sea ice cover show the Arctic ice pack to be receding and thinning while the Antarctic ice pack appears relatively stable in extent and thickness. The conventional wisdom for explaining this phenomenon by meteorologists and ocean modelers who mainly comprise the Climate modeling community, is that the ocean circulation characteristics and climate regime are somehow much different in the Antarctic than the Arctic, and hence the sea ice cover, being a passive tracer to the oceans and atmosphere, responds differently. In this paper a simpler more direct explanation based on ice mechanics is proposed and examined. The fact that this result has not appeared more prominently in the suite of Atmosphere-Ice-Ocean climate models used in IPCC reports appears to be due to the overreliance on computationally fast formulations of sea ice dynamics with bogus energy sources rather than utilizing somewhat slower solution procedures that properly reproduce the nonlinear aspects of sea ice mechanics, sea-ice thermodynamics and ice ocean coupling.

In this paper we examine how sea ice mechanics affects the changing character of the ice mass budget under either anthropomorphic forcing or natural climate change, but with a particular focus on climatic warming effects. While sea ice mechanics affects critically the mass budget of both the Antarctic and Arctic ice covers, the constrained nature of the Arctic ice cover causes ice mechanics to affect ice mass and extent under climatic warming much differently than in the Antarctic. Perhaps the most graphic illustration of this is the demonstration that, in a constrained basin like the Arctic, sea-ice mechanics can make possible the presence of multiple equilibrium states of the pack ice for identical forcings depending on the initial state. The main mechanism for these multiple states is the nonlinear modification of flow thru narrow passages by plastic sea ice rheologies with cohesive strengths, in conjunction with thermodynamic growth. Under climatic warming the net effect of the unstable equilibrium states in the suite of possible solutions tends to cause a rather discontinuous shift from a thick ice state dominated more by static thermodynamic effects, to a thinner ice state, with a significantly different response to climatic warming. In a crude sense we may thus think the critical factor under climatic warming in the Arctic to be the weakening of the sea ice which causes a shift in the balance between ice flow, growth and decay. Due to the unconstrained nature of the Antarctic pack ice this effect is absent but other ice mechanics effects can dominate.

In the case of the Arctic sea ice cover the presence and character of multiple equilibrium states is explicitely demonstrated and examined using a relatively high resolution ice ocean dynamic thermodynamic sea ice model employing a nonlinear rheology justified by observation (Hibler and Schulson,2000) together with realistic daily winds and variable sea ice thermodynamics. The ice ocean coupling, barotropic ocean model, and numerical formulation of this model, is essentially that of Hibler et. al. (2006). The effects of different rheologies on these multiple equilibrium states is also investigated utilizing idealized channel flow. Finally, aspects of this nonlinear ice modification on the changing ice cover over the last few decades will be examined and discussed, as well as different aspects of ice mechanics particularly relevant to, say the Antarctic ice cover mass balance evolution, such as ice tide inertial interaction.