3A.9

ON THE RESPONSE OF THE ARCTIC OCEAN ICE THICKNESS DISTRIBUTION TO CHANGES IN EXTERNAL FORCING

Johan Söderkvist* and Göran Björk
Earth Sciences Centre, Göteborg University, Sweden

1. INTRODUCTION

The Arctic Ocean ice cover together with the overlying atmosphere makes up a complicated dynamic and thermodynamic system. This system includes numerous sub-processes which are certainly important but hard to describe in detail. Examples of such processes are formation of pressure ridges, melt ponds on the ice floes, cloud formation and precipitation. Although internal sub-processes can play an important role there should also exist a strong and fundamental coupling between the basic state of the system and the energy supply from external sources. The main energy sources for the Arctic atmosphere and ice cover are: atmospheric transport of warm and moist air from lower latitudes, solar radiation, and oceanic heat conducted through the ice. Here we present the response of the ice thickness distribution to changes in the atmospheric poleward energy flux, using a coupled ocean-ice-atmosphere model.

2. MODEL DESCRIPTION AND FORCING

The ocean model is a column with a dynamic mixed layer on top. The column below the mixed layer is maintained by inflow from rivers and Bering Strait, and a geostrophically controlled outflow (see Figure 1 for a schematic sketch). The model ice cover is partitioned in thickness categories which develops independently in a Lagrangian fashion in time. New categories are created when new ice is formed in the leads during winter and by ridging which transform thin ice to piles of thicker ice. Categories disappears when thin ice melt completely during summer. Each ice category has one internal temperature point and a snow layer on top. The surface albedo parameterization for bare ice, which play a central role in this analyze, is given by

$$\alpha_{ice} = min(0.08 + 0.44H^{0.28},\ \ 0.64) \qquad (1)$$

according to Maykut (1982), where H is the ice thickness. The maximum value for α_{ice} is reached when H=2.3 m. The atmospheric model is similar to Thorndike (1992) and is a two stream, grey body, radiative equilibrium, atmosphere which is transparent to solar radiation. Clouds, water vapor and other absorbing gases at different levels are collectively described by one single parameter, the total optical thickness. Here we have included the effect of the turbulent heat flux at the surface. The model is forced by monthly means of poleward energy flux at the vertical boundary, solar radiation at the surface, snow precipitation, river runoff, Bering Strait inflow, ice export, and wind.

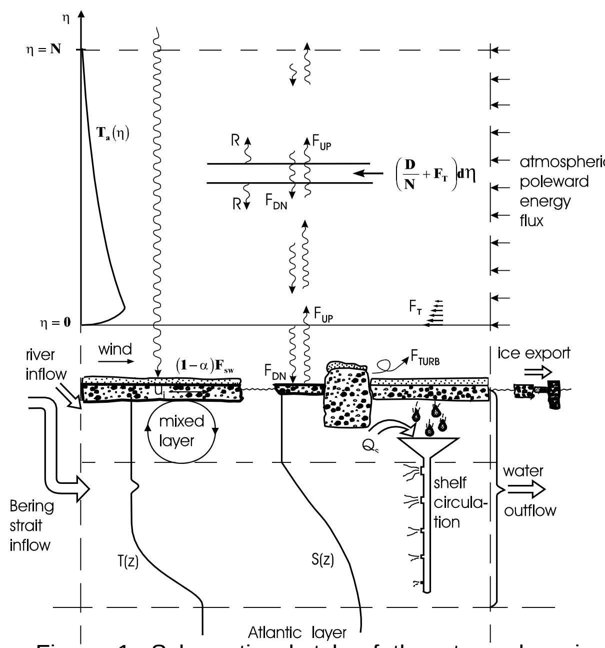

Figure 1. Schematic sketch of the atmosphere-ice-ocean model. F_{SW}, F_{UP} and F_{DN}, are the shortwave, upward longwave and downward longwave radiations, respectively, D is the poleward energy flux in the atmosphere, R is the reradiation, F_{TURB} is the turbulent heat flux from/to the surface, F_T determines the distribution of F_{TURB} in the atmosphere, h is the optical height, N is the total optical thickness at the top of the atmosphere. The funnel-like structure in the ocean visualizes the parameterization of the shelf circulation.

3. RESULTS

Two characteristics of the ice cover are the annual mean of the area averaged ice thickness, $\langle\overline{H}\rangle$, and the thermodynamic equilibrium ice thickness, H_{eq}, which is

*Corresponding author address: Johan Söderkvist, Box 460, S-405 30 Göteborg; email: joso@oce.gu.se

the thickness an individual ice floe will reach if it remains long enough in the basin to reach thermodynamic equilibrium such that the growth during winter equals the summer melting. There are two important times scales that determines the shape of the ice

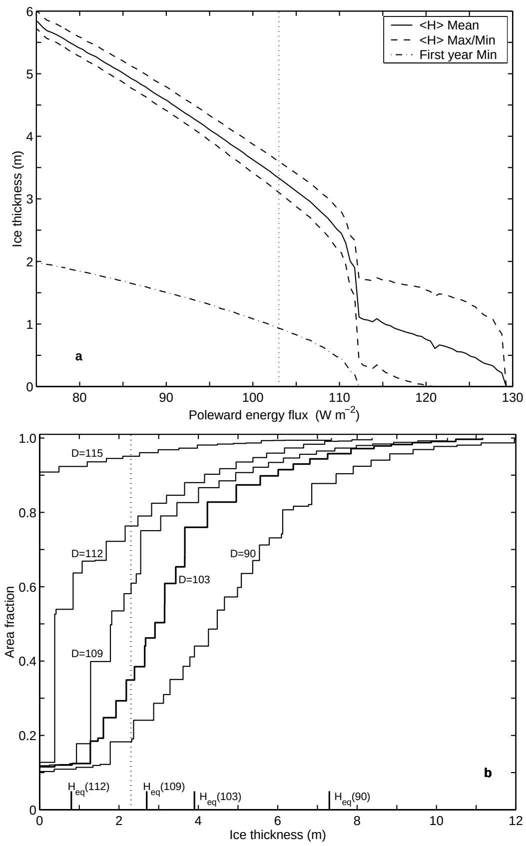

Figure 2. a) Dependence of the ice cover characteristics on the poleward energy flux in the atmosphere, *D*. The solid line shows the annual mean of the area averaged ice thickness, <$\overline{H}$>, the dashed line the area averaged ice thickness at the end of growing and melting season, respectively. The dashed dotted line shows the thickness of first year ice at the end of melting season. Vertical dotted line indicates the standard case energy flux, *D*=103 W m^{-2}. b) The cumulative thickness distribution at the end of melting season for different values of poleward energy flux in the atmosphere. The thick solid line shows the standard case thickness distribution, *D*=103 W m^{-2}. Ice categories to the left of the vertical dotted line (thinner than 2.3 m) have a thickness dependent albedo, and categories to the right have a constant albedo. The marks on the lower ice thickness axis indicate the equilibrium thickness, H_{eq}, for different *D*-values (within brackets).

thickness distribution. T_{eq} is the thermodynamic adjustment time scale for a flow to reach H_{eq}, starting from zero thickness, and T_{res} is the residence time scale for a typical flow in the basin. The ice thickness response to changes in the annual mean of the poleward energy transport, *D*, is shown in Figure 2a. The response is nearly linear for negative perturbations from the standard value (103 W m^{-2}), with about 1 m increase of ice thickness when decreasing *D* with 10 W m^{-2}. For positive perturbations there is a dramatically increased sensitivity which starts at about 109 W m^{-2} giving a knee like structure of the response curve. The ice thickness decrease with about 1.5 m when *D* is increased 3 W m^{-2} and is a result of the thickness distribution in combination with the nonlinear ice albedo function (1). Generally, the ice cover gets thinner with increasing *D* but the shape of the distribution change also and becomes more steep (Figure 2b), comparing e.g. *D*=90 W m^{-2} and *D*=103 W m^{-2}. This steepening results from the decrease of H_{eq} with *D* and also shorter T_{eq}, which at some point becomes less than T_{res}. When the steep part of the distribution is thinner than 2.3 m, where the bare ice albedo is a function of thickness, the albedo effect is magnified resulting in a much stronger response. Near *D*=112 W m^{-2} the ice cover goes from a regime where first year level ice survives the summer and continues to grow during the following winter, to a regime when all ice at the end of the melting season is ridged ice and no level ice remains. For 113<*D*<130 the curve becomes more linear and <$\overline{H}$> is mainly controlled by ice growth during one single winter season starting from zero thickness. The Arctic Ocean is ice free during the whole year for *D* larger than 130 W m^{-2}.

4. CONCLUSIONS

The ice thickness distribution together with the albedo parameterization gives a strong nonlinear response in ice thickness to positive perturbations of the poleward energy flux.

5. REFERENCES

Björk, G., 1997: The relation between ice deformation oceanic heat flux and the ice thickness distribution in the Arctic ocean, *J. Geophys. Res.*, **102**, 18681-18698.

Maykut, G. A., 1982: Large scale heat exchange and ice production in the central Arctic, *J. Geophys. Res.*, **87**, 7971-7984.

Thorndike, A. S., 1992: A Toy model linking atmospheric thermal radiation and sea ice growth, *J. Geophys. Res.*, **97**, 9401-9410.