EFFECTS OF ICE-ALBEDO FEEDBACK ON GLOBAL CLIMATE CHANGE

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1 INTRODUCTION
The ice-albedo feedback has been considered an important factor of discussion in the global climate change. It is based on the hypothesis that changes in surface albedo associated with changes in snow and ice cover as a result of temperature change might cause a significant positive feedback on climate change (e.g., Croll 1875). As climate warms, snow and ice cover will decrease, leading to a decrease in surface albedo, an increase in the absorption of solar radiation at the Earth's surface, and consequent further warming. This air-ocean feedback has been proved to be quite important (Chu, 1990; Manabe and Stouffer 1980; Spelman and Manabe 1984; Washington and Mehl 1986; Ingram et al. 1989; Manabe et al. 1991; Schlesinger and Jiang 1991; Rind et al. 1995). We use a coupled atmosphere-ocean model to investigate the ice-albedo effect on global climate change. Different from the traditional treatment, we compare two simulations: (1) control run (using ice-albedo for sea-ice), and (b) anomaly run (using ocean albedo for sea-ice). Difference between the two runs shows the ice-albedo effects on the climate system.

2 COUPLED ATMOSPHERE-OCEAN MODEL
2.1 GENERAL DESCRIPTION
A coupled atmosphere-ocean model developed at the Institute for Space Studies at NASA/Goddard Space Flight Center (Russell et al., 1965), called the GISS coupled model, was used for this study. The atmospheric model is similar to that of Hansen et al. (1983) except that the atmospheric dynamic equations for mass and momentum are solved using a staggered grid scheme and the advection of potential enthalpy and water vapor uses the linear upstream scheme (Russell and Lerner, 1981). The global ocean model conserves mass, allows for divergent flow, has a free surface and uses the linear upstream scheme for the advection of potential enthalpy and salt.

Both models run at 4° × 5° resolution, with 9 vertical layers and 13 layers for the ocean. Twelve straits are included, allowing for subgrid-scale water flow. Runoff from land is routed into approximate ocean basins. Atmospheric and oceanic surface fluxes of water, heat (excluding solar radiation), and momentum are of opposite sign and are applied synchronously. Flux adjustments are not used. Except for partial strength alternating binomial filters (Shapiro, 1970), which are applied to the momentum components in the atmosphere and oceans, there is no explicit horizontal diffusion. The solar irradiance is taken as 1367 W m⁻². For more information about this coupled model, readers are referred to Russell (1994) and Russell et al. (1995).

2.2 SEA-ICE PARAMETRIZATION
When the energy losses cause the first layer of the open ocean to cool below the freezing point, the ocean stays at the freezing point and 0.5 m thick ice is formed. With additional energy loss the sea ice thickens, as seen in Hansen et al. (1988). Since the model assumes no salt in the sea ice, the salt concentration of the first ocean layer increases when sea ice forms or thickens. When surface fluxes, principally insolation, case the sea ice temperature to rise above 0°C and snow or sea ice melts, which joins the ocean below. If sea ice becomes thinner than 0.5 m, then it is contracted horizontally so that it remains 0.5 m thick. If the temperature of the first ocean layer rises above 0°C, then sea ice is melted vertically and horizontally, drawing the necessary energy from the ocean which cools back to 0°C. The temperature within the sea ice is determined by a two-layer model. Leads in the sea ice are calculated as was done by Hansen et al. (1981): the minimum fraction of open ocean in a grid box is 0.1λ⁻¹, where λ is the sea ice thickness in meter.

2.3 LAND ALBEDO
Land albedo is a function of vegetation type including seasonal variations and separate albedos for the visible...
4 GLOBAL CLIMATE CHANGE CAUSED BY THE ABSENCE OF THE ICE-ALBEDO EFFECT

Absence of the ice-albedo effect causes severe global change, such as high latitude warming, reduction of latitudinal sea surface temperature (SST) gradient, weakening of atmospheric activities, and attenuation of ocean overturning. There is almost no solar radiative flux deposited to the polar ocean surface in winter. The ice-albedo effect should be more evident in hemisphere summer than in winter.

4.1 SEA-ICe REDUCTION

Absence of the ice-albedo effect causing sea-ice reduction is identified by the latitudinal-temporal cross-section of zonal mean sea-ice concentration (%) difference (Fig.1), $\Delta C_i$. Notice that the latitudinal span in Fig.1 is 60ºS-90ºN. This is because the sea-ice exists year-round in the central Arctic but around Antarctic continent at the latitudes near 60ºS. The quantity $\Delta C_i$ shows a strong reduction of sea-ice especially during hemisphere summer: 35% reduction in Arctic during June-August, and 56% decrease in Antarctic during December-February.

4.2 REDUCTION OF LATITUDINAL SST GRADIENT,

Absence of ice-albedo effect causes the reduction of sea surface temperature (SST) gradient. Fig.2 shows latitudinal-temporal cross-section of zonal mean SST difference, $\Delta SST$. We see obvious warming (positive $\Delta SST$) in the polar regions especially during the hemisphere summer (maximum $\Delta SST$ around 2ºC). In the mid-latitudes (20ºN-45ºN, 30ºS-45ºS), $\Delta SST$ is generally negative with a maximum reduction of 0.5ºC. Polar warming/mid-latitude cooling leads to a weakening of the latitudinal SST gradient.

4.3 OCEANIC OVERTURNING

Attenuation of the latitudinal temperature gradient reduces the heat transport from tropical to polar regions. This can be identified by the global oceanic overturning difference $\Delta \chi$. Here, $\chi$ is the zonally integrated meridional overturning circulation with the unit of Sv (1 Sv = $10^6$ m$^3$s$^{-1}$). The control run of July Atlantic $\chi$-field (Fig.3a) shows a three-cell structure: northern (north of 40ºS) clockwise circulation, southern hemisphere narrow subpolar (40º-48ºS) anti-clockwise circulation, and southern polar clockwise circulation (south of 48ºS). The overturning difference $\Delta \chi$, however, is quite small in
the northern hemisphere (less than 2 Sv), but is quite large and almost opposite to the $\chi$-field in the southern hemisphere. For example, $\Delta \chi$ is strong negative between 8°-24°S indicating anticlockwise circulation; and $\Delta \chi$ is strong positive between 30°-48°S indicating clockwise circulation. Thus, absence of the ice-albedo effect leads to a weakening of the thermohaline circulation.

4.4 ATMOSPHERIC SURFACE PRESSURE
The attenuation of the latitudinal SST gradient reduces the baroclinicity, which in turn weakens the strength of atmospheric circulation. This can be identified by the January global atmospheric surface pressure $(p_a)$ difference $\Delta p_a$. Notice that the ice-albedo effect is more evident for the hemisphere summer. Therefore, we pay attention to the southern hemisphere for January. The control run of January $p_a$-field (Fig.4a) shows a tropical-subtropical high pressure zone (0°-35°S), a mid-latitudes low pressure zone (35°-65°S), and a southern polar high (65°-90°S). Notice that 1,000 mb has been subtracted from $p_a$-values in Fig.4a. The surface atmospheric pressure difference $(\Delta p_a)$ pattern, however, is almost opposite to the $p_a$-field in the southern hemisphere. For example, $\Delta p_a$ is negative (-2.3 mb) in the tropics-subtropics between 0°-30°S, positive (15 mb) in the mid-latitudes between 30°-55°S, and negative (-19 mb) in the southern polar region. Thus, absence of the ice-albedo effect leads to a weakening of the atmospheric general circulation.

5 CONCLUSIONS
The ice-albedo effect on the global climate change has been identified by the GISS coupled model. Our results show that the absence of the ice-albedo effect causes a drastic warming of the polar regions and an evident weakening of the polar-tropical thermal contrast, which in turn reduces polar-tropical exchange of mass, momentum, and heat. The strengths of the atmospheric activity centers and the oceanic thermohaline circulation are evidently weakened.

6 ACKNOWLEDGMENTS
Authors are indebted to Gary L. Russell at NASA/Goddard Institute for Space Studies for allowing us to use the coupled atmosphere-ocean model. This work was funded by the Office of Naval Research I.IL and NOMP Programs, and the Naval Postgraduate School.
Figure 3 – July Atlantic overturning circulation (Sv) represented by the meridional stream function: (a) control run, (b) anomaly minus control runs. Solid/dashed curves denote clockwise/anticlockwise circulation.

Figure 4 – July atmospheric surface pressure (mb) fields: (a) control run (1000 mb has been subtracted), and (b) anomaly minus control runs.

REFERENCES


