Decadal Variability in the Arctic Ocean – Greenland-Iceland-Norwegian Seas Ice-Ocean-Atmosphere Climate System

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Recent studies suggested decadal time scale as the most dominant of the Arctic climate variability [e.g., *Mysak and Venegas*, 1998]. The origin of the Arctic climate decadal variability and mechanisms regulating this variability are still unclear and need to be determined and investigated. In this study we generalize and investigate in detail a mechanism of decadal variability in the Arctic proposed by *Proshutinsky and Johnson* [1997] and *Proshutinsky et al.* [2002].

The Arctic Ocean and the GIN Sea (Greenland, Iceland, Norwegian Seas) are viewed as a closed ice-ocean-atmosphere climate system. Decadal variability in this system is driven by fresh water (FW) and sensible heat fluxes controlled by alternating between-basin oceanic and atmospheric gradients. When the Arctic High prevails (anticyclonic circulation regime (ACCR) or low AO/NAO), the interaction between basins is suppressed and the fluxes are weak. When the Icelandic Low prevails (cyclonic circulation regime (CCR) or high AO/NAO), the interaction between the basins is intense and the fluxes are strong. The hypothesized behavior of the system is shown on Fig. 1.

An idealized Arctic Ocean – Greenland Sea model has been designed (Fig. 2) to reproduce the cyclic anticyclonic/cyclonic (low/high AO or NAO) regime shift in the Arctic Ocean as an auto-oscillatory behavior of the studied region. The Arctic module includes an Arctic Ocean model coupled to a thermodynamic sea ice model, a sea-ice shelf model, and an atmospheric box model. The Arctic Ocean model is one-dimensional, three-layer and time-dependent similar to *Björk* [1989]. The atmospheric box model estimates SAT from the total energy balance, with interannual variability induced by varying heat flux, F_h, from the Greenland Sea atmospheric box. F_h is a function of surface air temperature (SAT) difference between the Arctic and the Greenland Sea modules. The Greenland Sea ocean model is one-dimensional and time dependent and is, in general, similar to the Arctic Ocean model. The oceanic model is coupled to a thermodynamic sea ice model and an atmospheric model. The atmospheric model calculates SAT anomalies for computed surface heat flux. The Greenland Sea module describes the seasonal and interannual variability of the heat content of the GIN Sea region assuming that it is related to the air-sea surface heat flux. The air-sea heat flux, in turn, is determined by the intensity of deep convection in the Greenland gyre which is controlled by the amount of FW advected from the Arctic Ocean (F_{fw}). The model has been run for 110 years, with the first 10 years spin-up. Different climate states are reproduced in the model by different rates of F_{fw} and F_h (Figs. 3a and 3b).

The major result of the study is that the model reproduces the hypothesized behavior of the system (compare Fig. 3c with Fig. 1). The period of simulated oscillations is 10 to 15 years (Fig. 3d) which agrees with *Proshutinsky and Johnson* [1997]. To demonstrate the correspondence of the model output to observations, simulated and observed SAT and net surface heat flux in the Arctic and Greenland Sea are presented in Fig. 4. Note the difference between the characteristics simulated for different regimes (blue and red curves).

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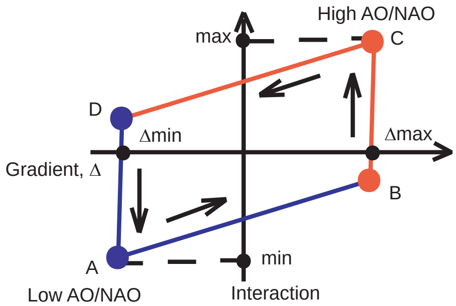

Fig. 1. Hypothesized behavior of the Arctic – GIN Sea climate system. Abscissa is the between-basin gradient of SAT or dynamic height. Ordinate is the intensity of interaction between the basins, either FW or heat flux. Blue segments denote weak interaction and red segments intense interaction.

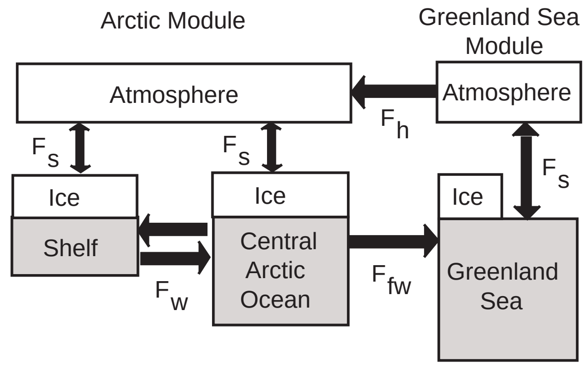

Fig. 2. Schematic of the Arctic Ocean – Greenland Sea model system. F_s is surface heat flux, Fw is water exchange between the Arctic Ocean model and Arctic shelf box model, F_{fw} is the freshwater flux to the Greenland Sea model, F_h is heat flux to the Arctic atmospheric model.

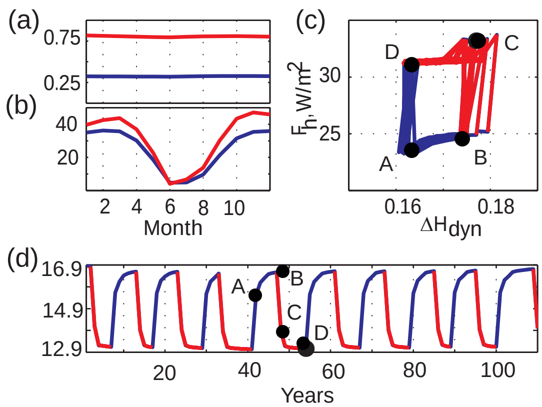

Fig. 3. (a) Monthly freshwater outflow from the upper 100 m of the Arctic Ocean during the weak interaction phase (blue) and strong interaction phase (red). (b) Similar to (a) but for the heat flux. (c) Heat flux vs. gradient of dynamic height (ΔH_{dyn}) for 110 years of simulated behavior (compare with Fig. 1). (d) Annually averaged SAT gradient (ΔT) for 110 years. Bullets denote system states shown on (c). On (c) and (d), red segments denote high AO/NAO years, blue low AO/NAO.

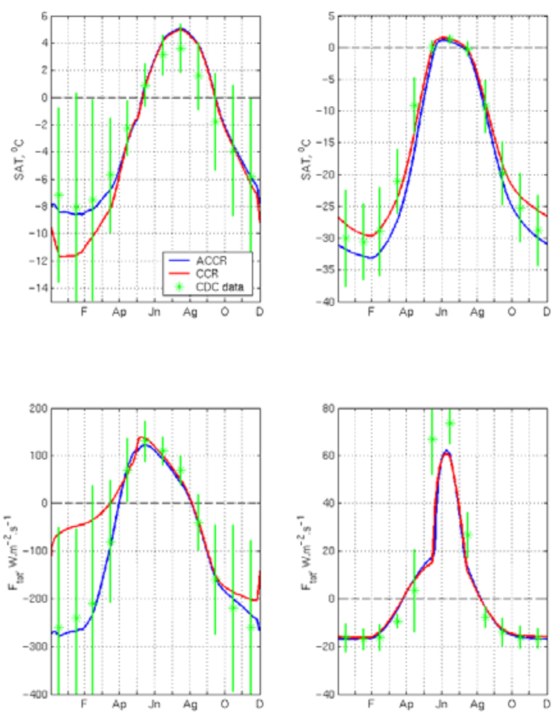

Fig. 4. Model output: Mean ACCR and CCR SAT and surface heat flux in the Arctic Ocean and Greenland Sea. Time series of simulated daily SAT in the Greenland Sea (a) and the Arctic Ocean (b) averaged over the last years of ACCR (blue lines) and CCR (red lines) forcing. Green asterisks denote monthly mean values obtained from NOAA-CIRES CDC data over the period 1948-2001. Vertical green bars are the 98% confidence intervals for the CDC means. Abscissa is time, end of months. (c) Same as (a) but for the Greenland Sea surface heat flux. (d) Same as (b) but for the Arctic Ocean surface heat flux.