Regional changes of Arctic sea ice and freshwater balance components from model simulations with anthropogenic forcing

V.Ch. Khon and I.I. Mokhov

Obukhov Institute of Atmospheric Physics RAS, Moscow, Russia (khon@ifaran.ru)

Arctic freshwater fluxes (such as Arctic sea ice export through Fram Strait and major Siberian rivers runoff) and their relationship to regional changes of sea ice, surface salinity and thermohaline circulation (THC) in the North Atlantic basin are analyzed using simulations of the coupled atmosphere-ocean general circulation model ECHAM4/OPYC3 (Roeckner et al., 1999) forced by the anthropogenic scenario IS92a.

Figure 1 shows time series of the annual mean export of Arctic sea ice through Frame Strait (a), sea ice concentration (a, b) and surface salinity (b) in the Greenland-Iceland-Norwegian (GIN) Sea basin for the period 1860-2100. According to the model simulations there is a statistically significant correlation between variations of Arctic sea ice flux through Frame Strait and anomalies of sea ice concentration in the GIN Sea (corresponding correlation coefficient r = 0.8). These changes of regional sea ice are negatively correlated (r = -0.9) to sea surface salinity in the GIN Sea (Fig. 1b).

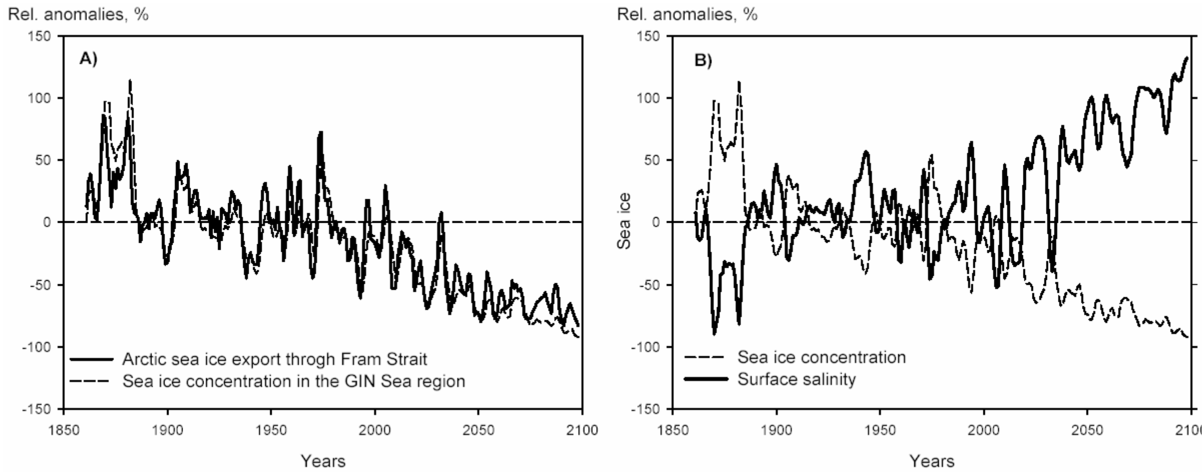

Figure 1. Annual mean anomalies (relative to 1961-1990) of the Arctic sea ice flux through Frame Strait and sea ice concentration in the GIN Sea (a); sea ice concentration and surface salinity in the GIN Sea (b) simulated by ECHAM4/OPYC3 (IS92a scenario) for the period 1860-2100.

Thus, the tendency of decrease of the Arctic sea ice flux through Fram Strait leads to significant positive anomaly of surface salinity in the GIN Sea basin in the 21st century. This effect is opposite to the "Great Salinity Anomaly" effect in the northern North Atlantic during the late 1960s (Dickson et al., 1982). The reduced sea ice export out of the Arctic basin induces anomalously high salinities in the North Atlantic basin and leads to an intensification of North Atlantic THC (Latif et al., 2000) during the 21st century. The correlation between salinity in the GIN Seas and the North Atlantic THC significantly increases in the 21st century (Table 1) with a maximum correlation coefficient at 0.67 when salinity leads THC by about 7 years.

Table 1. Maximum correlation coefficients (and corresponding time lags (years), in brackets) between Arctic sea ice volume flux through Frame Strait (IVF_FS) and sea surface salinity in the GIN Sea (SSS_GIN); between SSS_GIN and index of the North Atlantic thermohaline circulation (THC_NA).

	20th century	21st century
IVF_FS - SSS_GIN	-0.71 (1)	-0.83 (1)
SSS_GIN - THC_NA	0.27 (9)	0.67 (7)

Model simulations of sea ice dynamics and its connection with the large-scale atmospheric circulation is also investigated for winter season. Figure 2a shows correlation coefficients between wintertime-mean (December-March) index of Arctic Oscillation (AO index) and meridional drift of sea ice at Fram Strait for the 30-year running periods based on anthropogenic simulations with ECHAM4/OPYC3. According to Fig.2a the positive correlation between winter sea ice circulation and the AO index increases in the second half of the 20th century. This correlation becomes statistically significant at the confidence level > 90 % during winter of the 21st century. Figures 2b, c demonstrate anomalies of sea level pressure (SLP) associated with the AO index during the period of the anomalously low (b) and high (c) positive correlation between the AO index and meridional sea ice circulation. During phase of low correlation the AO-related SLP anomalies are mainly located in the northern North Atlantic basin (especially near Iceland) (Fig. 2b). The phase of high positive correlation (Fig. 2c) is characterized by anomalously low SLP in most eastern Arctic basin (Norwegian, Barents, Kara and Laptev Seas). This northeastward shift of the AO-related SLP anomalies (Fig.2c) leads to the pronounced anomalous southerly wind component between Greenland and Spitzbergen and, therefore, to the in-phase variability between the AO index and sea ice flux out of the Arctic basin.

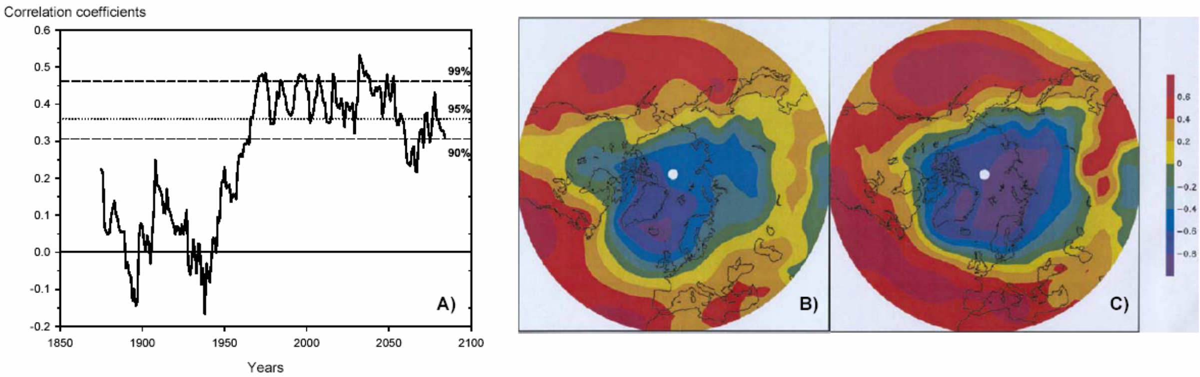

Figure 2. Correlation coefficients between AO index and meridional sea ice drift (a) for the 30-yr running periods; maps of correlation coefficients between winter AO index and SLP fields for selected periods of anomalously low (b) and high (c) correlations based on simulations with ECHAM4/OPYC3 (IS92a scenario).

Connection of major Siberian rivers (Ob, Yenisei and Lena) runoff (Mokhov et al., 2003) with the sea ice formation in the Kara and Laptev Seas is also investigated. Analysis of monthly observational data (Lammers et al., 2001; Rayner et al., 2003) shows that anomalies of sea ice in eastern Arctic basin (Kara and Laptev Seas) is positively correlated to variations of Siberian rivers runoff in the first months of cold season (especially in November) for the period 1935-1999. Analysis of ECHAM4/OPYC3 simulation indicates that model reproduces the positive correlation between regional sea ice and runoff of major Siberian rivers for the same period (and season) in the 20th century. Estimates of anthropogenic changes also demonstrate positive correlation of sea ice in Kara Sea with Ob and Yenisei runoff for the 21st century. According to model simulations the correlation between Lena runoff and sea ice in Laptev Sea becomes statistically insignificant in the 21st century.

References

Dickson, R.R., J. Meincke, S.-A. Malmberg, A.J. Lee, 1988: The ‘‘Great Salinity Anomaly’’ in the northern North Atlantic 1968– 1982. *Prog. Oceanogr.,* **20,** 103–151.

Lammers, R.B., A.I. Shiklomanov, C.J. Vorosmarty, B.M. Fekete, B.J. Peterson, 2001: Assessment of contemporary Arctic river runoff based on observational discharge records. *J. Geophys. Res.,* **106,** 3321-3334.

Latif, M., E. Roeckner, U. Mikolaewicz, and R. Voss, 2000: Tropical stabilization of the thermohaline circulation in a greenhouse warming simulation. *J. Climate,* **13,** 1809-1813.

Mokhov, I.I., V.A. Semenov, V.C. Khon, 2003: Estimates of possible regional hydrologic regime changes in the 21st century based on global climate models. *Izvestiya, Atmospheric and Oceanic Physics,* **39,** 130–144.

Rayner, N.A., D.E. Parker, E.B. Horton, C.K. Folland, L.V. Alexander, D.P. Rowell, E.C. Kent, A. Kaplan, 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res.,* **108,** 4407.

Roeckner, E., L. Bengtsson, J. Feichter, J. Lelieveld, and H. Rodhe, 1999: Transient climate change simulation with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle. *J. Climate,* **12,** 3004-3032.