Studies of Sea Ice Condition in the East Siberian, Chukchi, Bering and Beaufort Seas (1979-2006)

Belchansky G.I., Eremeev V.A., Mordvintsev I.N., Platonov N.G.
A.N. Severtsov Institute of Ecology and Evolution, Moscow, Russia

Introduction. Recent dramatic changes in the Arctic sea ice extent, thickness and melt conditions have been studied in different publication [*Rothrock et al*., 2003; *Belchansky et al*., 2004a,b,c, 2005a,b; *Francis et al*., 2005; *Lindsay et al*., 2005; *Overland et al*., 2005; *Overpeck et al*., 2005; *Serreze. et al*., 2006; *Stroeve et al*., 2005]. These changes affect the sea ice habitats of marine mammals, such as the bowhead whales (*Balaena mysticetus*) and gray whales (*Eschrichtius robustus*) and other ecosystem components. A significant problem to making predictions on the potential impact of climate change on ecosystems is the lack of understanding of their association with sea ice habitats, lack of predictive ability of sea ice conditions at regional scales, and the impact of ice habitats to marine mammals behaviors. Studies suggest that wind anomalies over the Bering Sea play a dominant role in the year-to-year ice variations [*Belchansky et al*, 2005b]. For the thermodynamic mechanism, winds may contribute to anomalous sea ice formations via heat flux anomalies. Northerly winds bring cold and dry air onto the Bering Sea, which increases the ocean-to-atmosphere heat fluxes, and in turn can result in greater ice formations.

Study area. The studies have been focused on the Chukchi, East-Siberian, Bering and Beaufort seas (Figure 1).

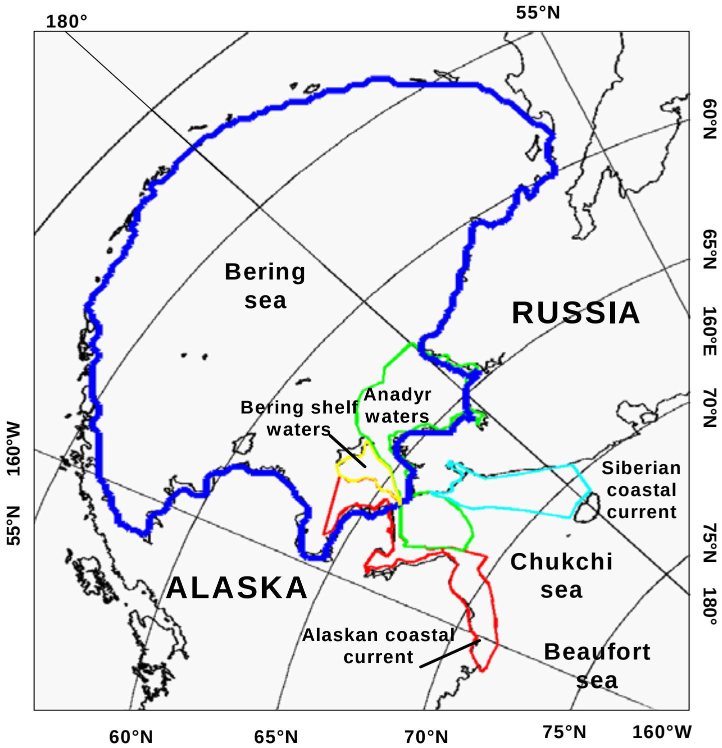

Figure 1. Study area.

Data description. The following data sets were used: 1) SMMR-SSM/I daily polar gridded brightness temperatures (1979-2006) [*Gloerson et al*, 1990; *Maslanik, J., and J. Stroeve* (1990, updated 2006)]; 2) Daily polar gridded bootstrap sea ice concentrations [*Comiso*, 1990 updated 2006], derived from the SMMR-SSM/I brightness temperatures; 3) Historical observations of the Arctic sea ice concentrations compiled by [*Chapman and Walsh*, 1991] from various sources, including observational archives from Danish Meteorlogical Institute, Japan Meteorological Agency, U.S. Naval Oceanographic Office, and passive microwave satellite measurements; 4) Output of the Community Climate System Model version 3 (CCSM3) [*Collins et al*, 2006], run for simulating the future climate according to the scenarios, presented in the Special Report on Emission Scenarios (SRES) [*IPCC*, 2000].

Results. Our studies demonstrate dramatic decreasing in sea ice extent in the East Siberian, Chukchi, and Beaufort Seas (Figure 1) during last 30 years. Annual dynamics of the sea ice concentrations during summer ice minimum and monthly summer sea ice edges, estimated from the passive microwave satellite data [*Gloerson et al*, 1990; *Comiso*, 1990], are shown in Figure 2. Among the Arctic's peripheral seas, reductions in ice extent during autumn have been most pronounced in the Chukchi Sea. Increasing in average monthly open water fraction during autumn is demonstrated in Figure 3.

Sea ice in the Arctic Ocean off the coasts of Alaska and Chukchi Peninsula has been receding since 2002. However, recent satellite images show that the sea ice is closer to the Alaska coast during last 3-4 years (Figure 2). The advance toward the Alaska coast is counter to what the greenhouse effect predicts: that sea ice is supposed to continue to move away from the Alaska coast as it shrinks. Although it is generally agreed that the Arctic sea ice is shrinking, the movement of sea ice away from the Siberian coast and toward Greenland and Alaska is most likely due to natural causes such as a shift in wind pattern and many other factors.

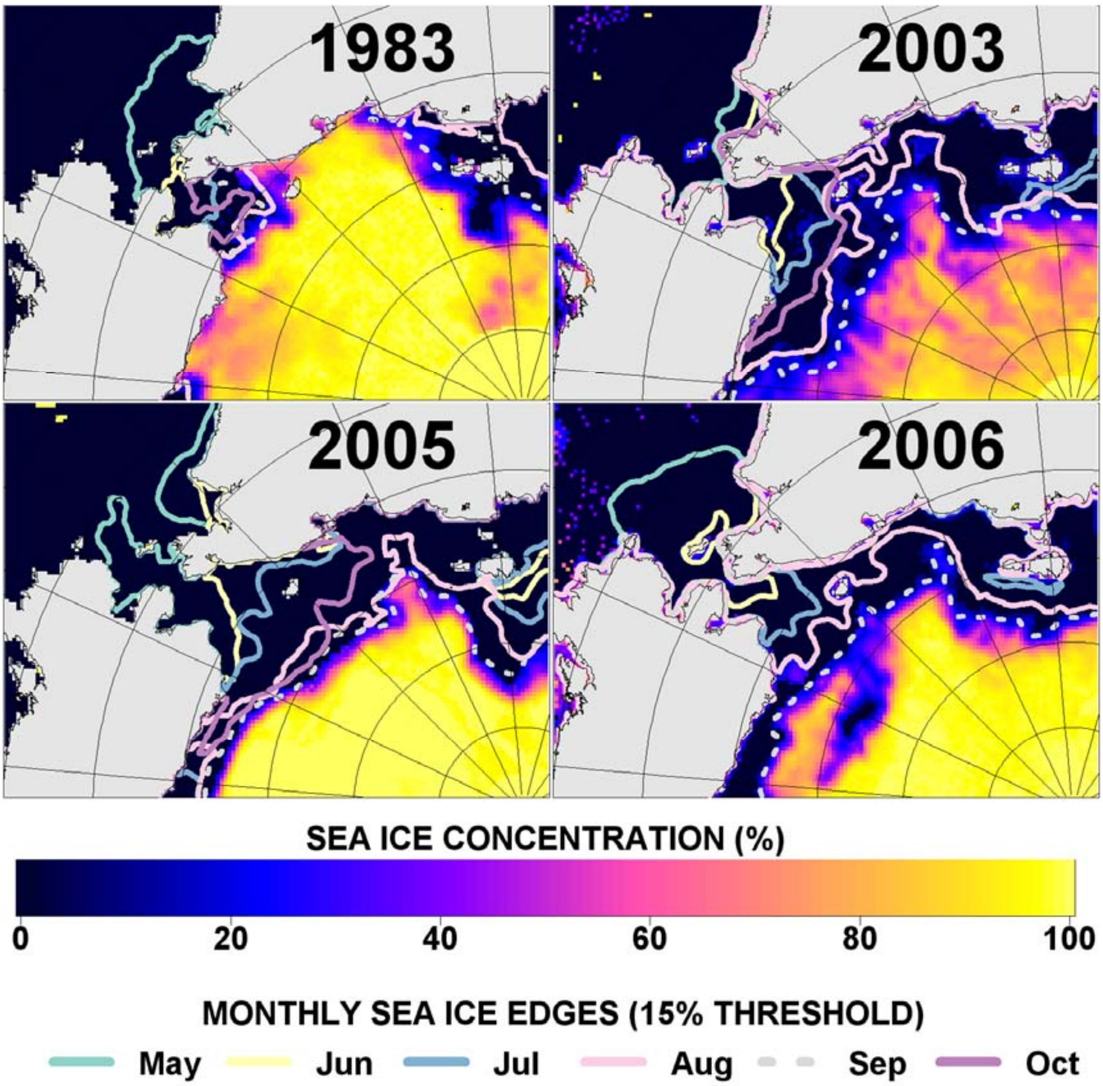

Figure 2. Sea ice concentrations in the Chukchi, Bering and East-Siberian seas at the moment of the summer ice minimum (colors) and summer monthly sea ice edges (colored lines), estimated from the passive microwave satellite data (1983-2006).

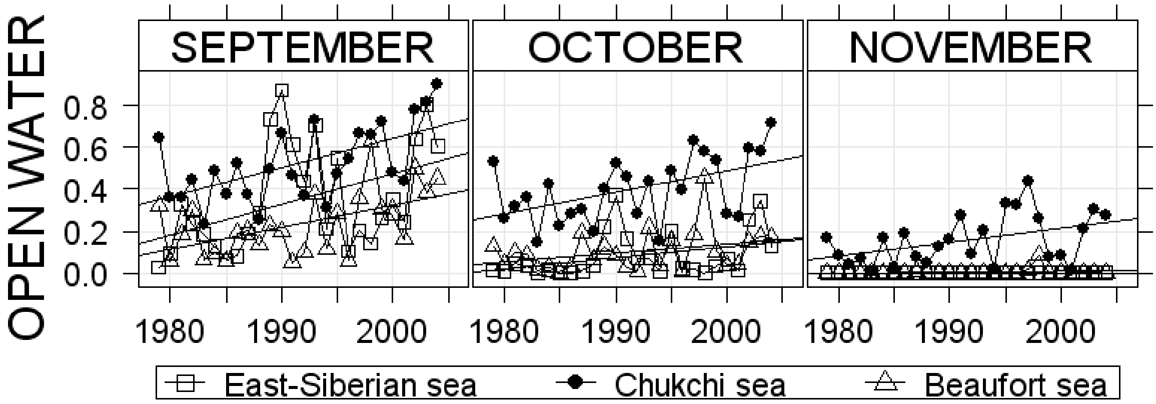

Figure 3. Dynamics and trends in the average monthly open water fraction estimated from the passive microwave satellite data during autumn in the Chukchi, Beaufort, and East Siberian Seas.

Regular daily long-term satellite measurements of the study area allowed estimating dates of the melt onset of the snow on the sea ice, and dates, when the sea ice completely disappears from each pixel of the study area in spring or summer and appears in autumn for each year during 1979-2006.

Dates of melt onset of the snow on the sea ice don’t show any significant trends, during 1979-2006 (Figure 4, A). Sea ice disappearance date in the Chukchi Sea, estimated from the satellite data, strongly tends to get earlier, and sea ice appearance date strongly tends to get later (Figure 4 B, C), which prolongs sea ice free period in the Chukchi sea.

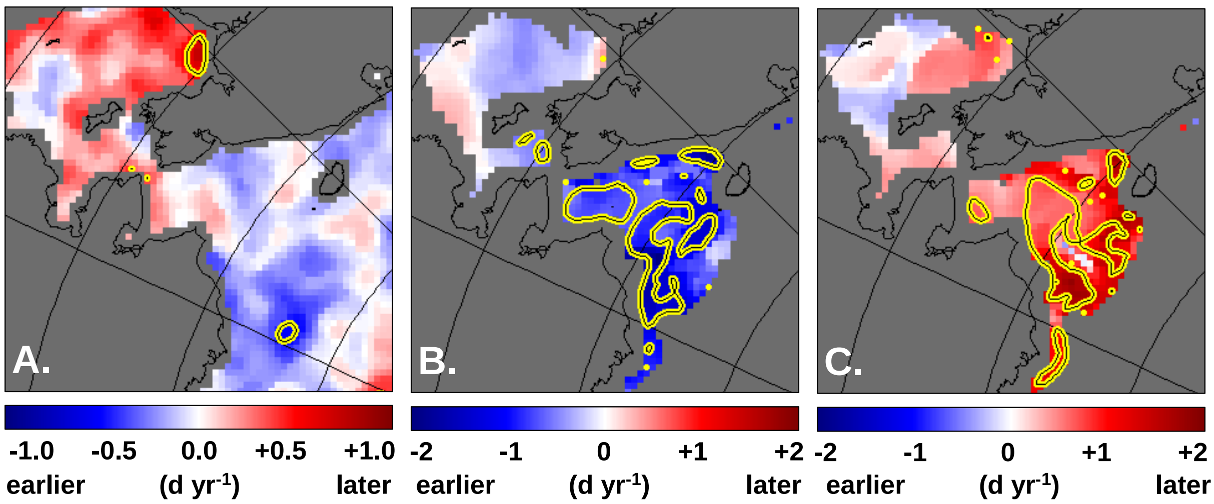

Figure 4. Trends in dates of the melt onset (A), sea ice disappearance (B), and sea ice appearance (C) during 1979-2006 in the Bering and the Chukchi Seas. Yellow contours indicate areas with ≥95% significance (t-test).

Annual sea ice thickness in the Bering and Chukchi seas, estimated by two methods, indicates slight reduction during 1982 – 2002 (Figure 5).

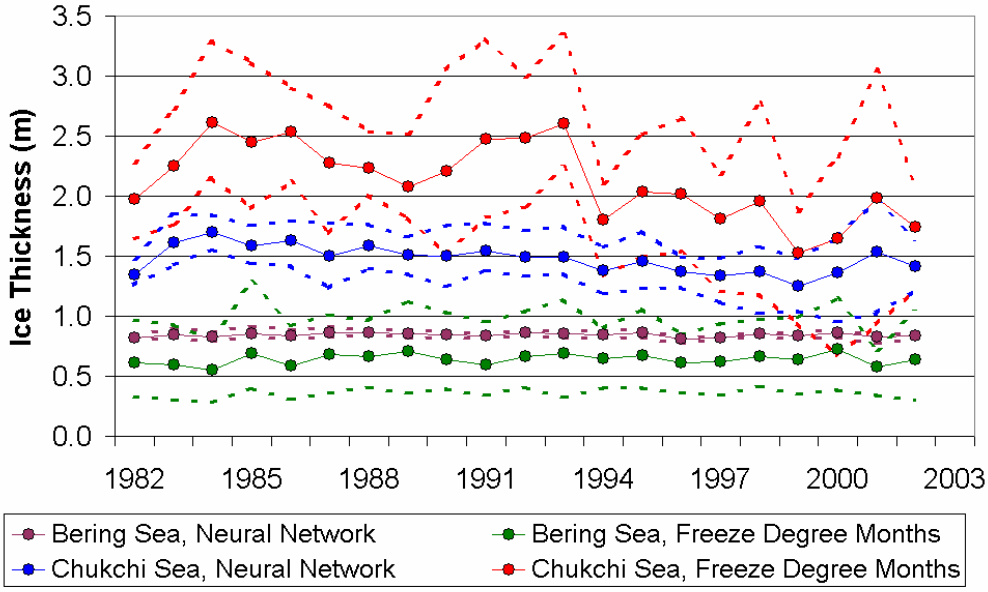

Figure 5. Interannual variability of the sea ice thickness in the Bering and Chukchi seas during (1982-2002), calculated using two different methods. The contours denote minimal and maximal values.

A number of climate change scenario simulations were conducted with the state-of-the-art Community Climate System Model [*Meehl et al*, 2006]. The CCSM3 is a fully coupled climate model for simulations of the future, past and present climate at various resolutions. It consists of four components, representing the atmosphere, ocean, sea ice and land, synchronized and coupled through mass and heat exchange implemented in the so-called flux coupler [*Collins et al*, 2006]. The CCSM3 simulations included simulation of the 20th century climate and climate change scenarios, presented in the Special Report on Emission Scenarios [*IPCC*, 2000]. The IPCC scenarios are used to analyze the driving forces and greenhouse gas (GHG) emissions. Totally forty scenarios were developed, all of them are valid on equal grounds, and none has assigned probability to happen. They form four storyline families: A1, A2, B1, and B2. The A1B scenario portrays a very fast growth in economics, quick development of new technologies and balanced use of all energy sources, with population growing till the middle of 21st century and declining after. The A2 scenario depicts constantly growing global population in a very heterogeneous world, having slower economic and technological development than in other scenarios. The B1 scenario is like the A1, but with more resource-conserving policies and technologies [*IPCC*, 2000].

CCSM3 output was obtained from the data archive, established by the Program for Climate Model Diagnosis and Intercomparison (PCMDI). Currently, this archive contains the data for the SRES A1B, A2, and B1 scenario simulations.

Historical estimates of the Chukchi Sea ice area (1900-2004) are based on the historical observations of the sea ice concentrations derived by [*Chapman and Walsh*, 1991]. Data were acquired using different techniques, such as land and ship observations, airplane and satellite based monitoring, gaps in observations were filled with climatologies or other statistically derived estimates [*Chapman and Walsh*, 1991].

All scenario simulations demonstrate a good agreement with the observations, especially during the last decade of the 20th century, and the negative trends in the sea ice area within 100 years (Figure 6). Some overestimating of the CCSM3 sea ice area is its known feature [*Meehl et al*, 2006], related to the overestimated simulated sea ice concentrations.

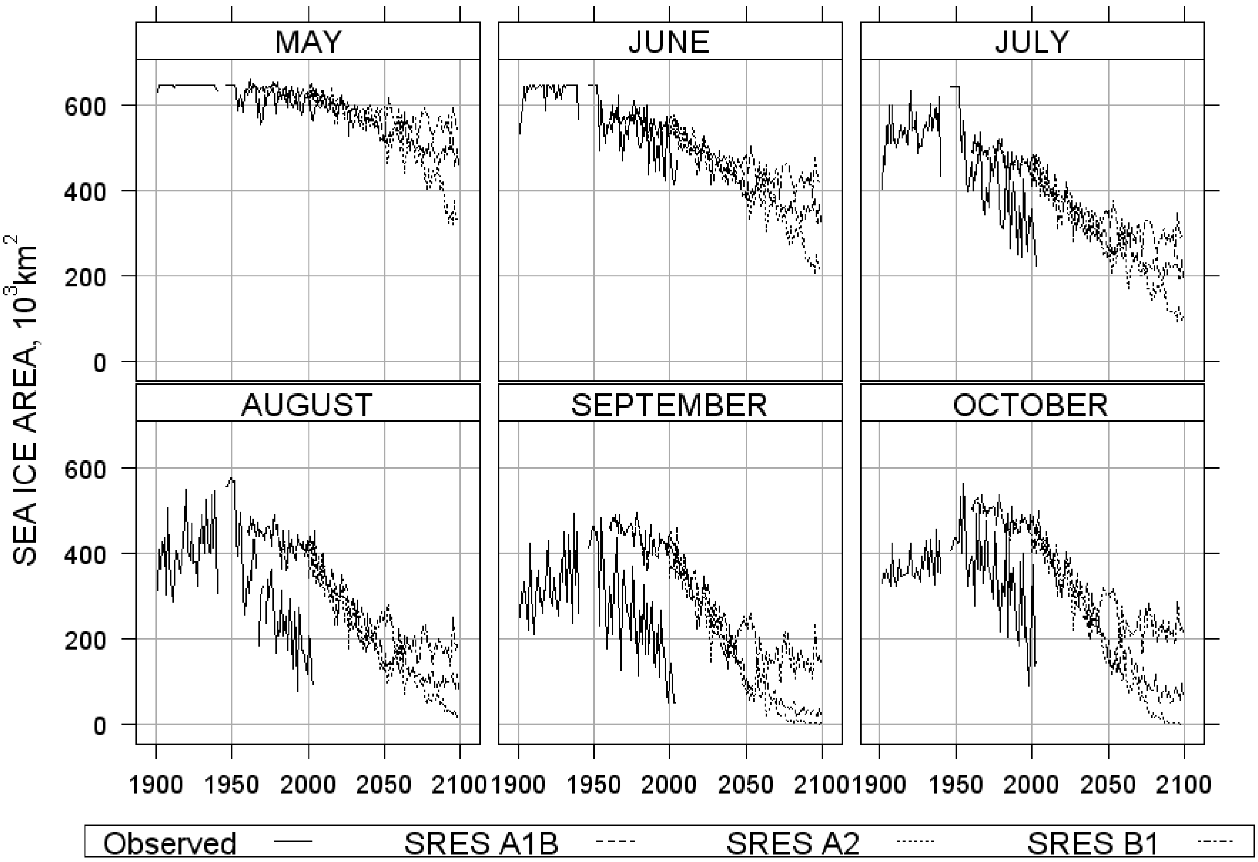

Figure 6. Historical Chukchi sea ice area observations (1900-2004), results of simulations of the 20th century sea ice conditions (1960-2000) and modeling prognosis during spring, summer and fall (2000-2100).

Plots of the historical Chukchi sea ice area suggest its cyclical dynamics, caused by natural factors. All modeled scenarios do show Chukchi sea ice decreasing. In two of them (A1B and B1), the Chukchi sea ice area is quasi-stable by the end of the 21st century and one more scenario (A2) shows complete disappearing of the sea ice in the Chukchi Sea during summer and autumn.

Conclusion. Sea ice in the Chukchi, Bering and East-siberian seas shows high seasonal and interannual variability. Our studies demonstrate dramatic decreasing in sea ice extent in the East Siberian, Chukchi, and Beaufort Seas during last 30 years. Studies suggest that sea ice retreat away from the Siberian coast toward Greenland and Alaska is most likely due to natural causes such as a shift in wind pattern and many other factors. Length of the sea ice-free season in the Chukchi Sea, estimated using daily passive microwave satellite measurements demonstrates the strong tendency to increase during 1979-2005. Climate projections, simulated according to the GHG emission scenarios, show decreasing summer Chukchi sea ice area within next 100 years. In two of those scenarios it becomes quasi-stable by the end of the 21st century and completely disappears in the third one.

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