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Bering Sea Shifts Toward an Earlier Spring Transition

Major changes have occurred in the northern high latitudes in the last two decades. These changes range from decreases in marine mammal populations to stratospheric cooling and permafrost warmings. Over Alaska and northwestern Canada, there is an earlier transition from winter to spring. Alaskan natives who live along the coast of the northern Bering Sea have noted warmer spring temperatures, thinner sea ice, and earlier melting of snow and ice. While winters over the northern Bering Sea are cold and dark, the long hours of daylight during spring and summer, coupled with high concentrations of nutrients, make this region among the most productive in the world. Change in timing of the transition between winter and spring is affecting the ecosystem, which in turn will impact the fishermen and natives who use the Bering Sea's living resources.

The greater Bering Sea region is characterized by large year-to-year variability, but it is also sensitive to climate changes on decadal and longer time scales. The Bering Sea, situated between the Arctic and the Pacific Oceans, responds to two dominant climate patterns: the Pacific Decadal Oscillation (PDO) and the Arctic Oscillation (AO). The PDO is the first mode of decadal variability in the sea surface temperature of the North Pacific [*Mantua et al.*, 1997]. Its major impact is on the North Pacific and southern Bering Sea. The AO is associated with the spin-up of the polar vortex (an increase of the 300 hPa zonal wind component) and has an influence from the surface to the stratosphere and from the Arctic to the mid-latitudes. The AO, in its more recent positive state, has lower-than-normal pressure over the central Arctic, and a weaker-than-normal Aleutian low [*Thompson and Wallace*, 2000]. The AO's primary impact occurs in winter.

The Bering Sea Ecosystem

The Bering Sea is a marginal ice zone that is typically free of ice from June through October. During November, cold winds from the Arctic cool the water and begin the formation of ice in the polynyas. This ice is advected southward by prevailing winds, melting and cooling the water column as it melts. During the last 3 decades, maximum ice extent over the southeastern Bering Sea usually occurred in March. During cold winters, ice can cover most of the eastern continental shelf. In the early and mid-1970s, there were a series of cold years over western Alaska, with extensive ice coverage over the eastern Bering Sea shelf. In 1977, however, the PDO and AO both changed sign.

From 1977 to 1989, ice was less common over the southeastern shelf than was typical during the previous regime. In 1989, the AO changed sign again and, while conditions did not return to the cold years of the early 1970s, ice coverage in winter slightly increased. Figure 1 shows contours of the average number of weeks that sea ice was present each year after March 15 over the Bering Sea during 1990–1998, minus the number of weeks it was present during 1978-1989. By springtime, ice persisted 2 weeks longer south of 61°N and west of 168°W in the 1990s compared to the 1980s. However, the ice in the northern Bering Sea retreated 1 week earlier. Thus, there was an extremely rapid melt-back in April during the 1990s, which goes from slightly more ice than normal in March to sea that is ice-free in May. Reduction in the ice coverage is enhanced by an albedo and cloud-radiative feedback.

The presence of ice over the southeastern shelf plays an important role in the timing of

Bering Sea (cont. on page 321)

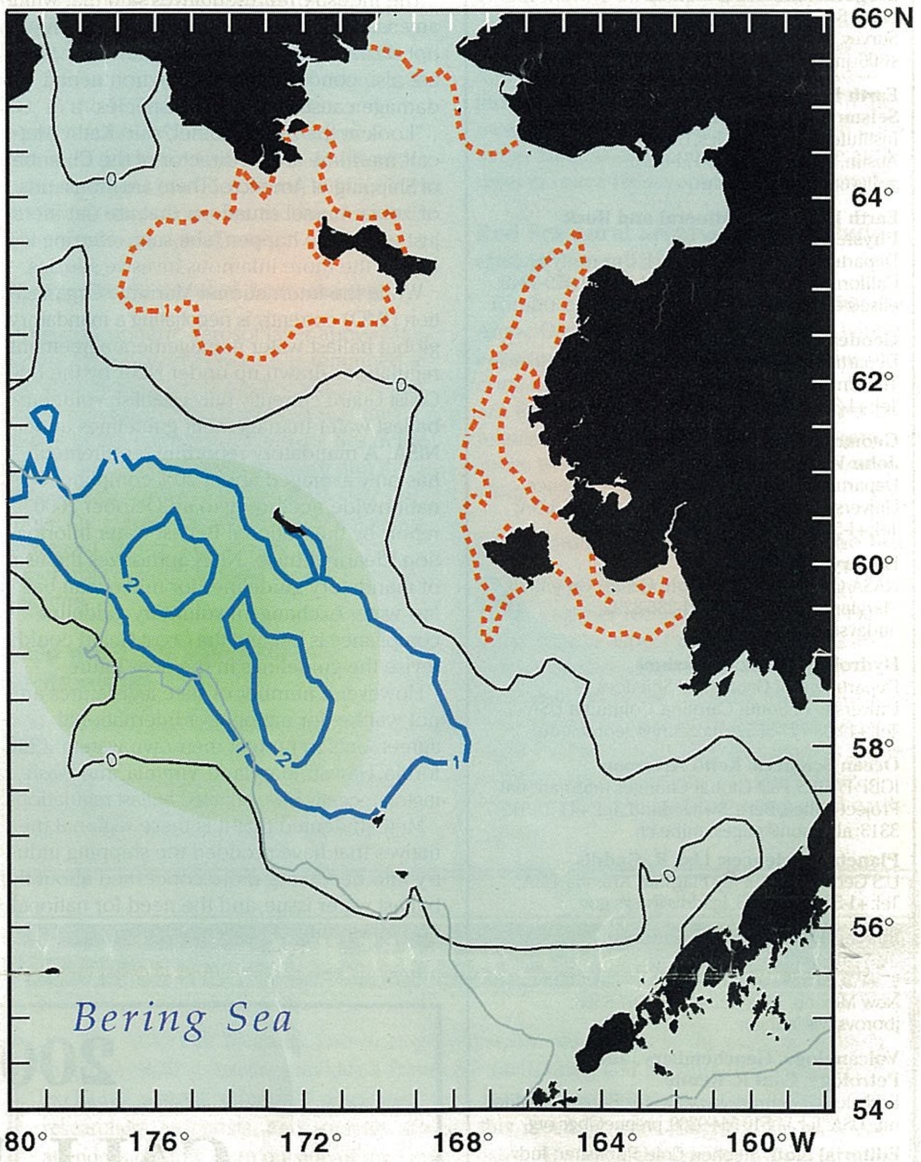
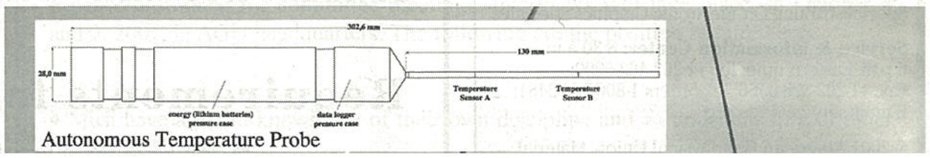


Fig. 1. Contours of the average number of weeks per year after March 15 that sea ice was present in the Bering Sea for the period 1990–1998 minus the average number of weeks for the period 1978–1989. Green shading denotes later ice melt in the 1990s and red shading denotes earlier melt.

Deep-penetration Heat Flow Probes Raise Questions about Interpretations from Shorter Probes



Bering Sea (cont. from page 317)

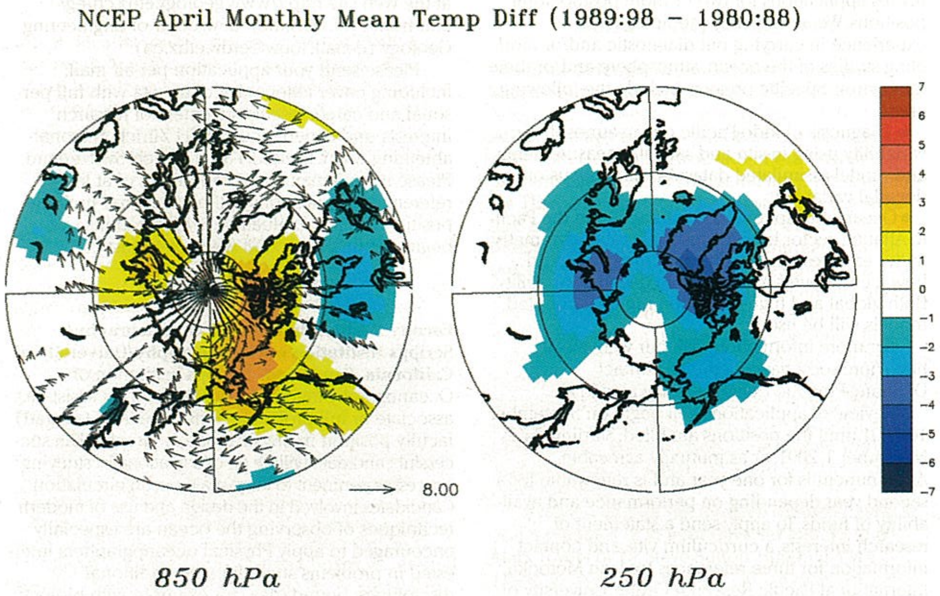


Fig. 2. Northern Hemisphere plots of April monthly mean temperature differences with the North Pacific in the low portion of the panels. Left panel: Average April temperatures at 850 hPa for the period 1989–1998 minus average April temperatures for 1980-1988. Also shown are the wind vector differences for the same two periods. Right panel: Temperature differences at 250 hPa for the same periods as in the left panel. Both sets of data are from NCEP/NCAR re-analysis.

spring phytoplankton bloom. If ice is present after mid-March, an early ice-associated bloom occurs; otherwise, a spring bloom occurs typically in May. During an ice edge bloom in March and early April, much of the phytoplankton will sink to the bottom, providing food for the benthic community. Alternately, during May, large populations of zooplankton will consume the phytoplankton and thus support the pelagic food web. Even though the pathways are not well understood, the shift toward an ice edge bloom in the 1990s, and from a pelagic to benthic focus at the bottom of the food web, is a major shift of the Bering Sea ecosystem.

The Hemispheric Connection

Early ice retreat is associated with changes in temperature and atmospheric circulation. Although linear winter temperature trends for Alaska from 1966 to 1995 show a degree-per-decade increase, there is actually a slight decrease in winter temperatures from the 1980s to the 1990s. However, very large temperature increases are seen in spring. Average April temperatures at 850 hPa for 1989–1998 are 3°C warmer than those for 1980–1988 over northern Alaska, the southern Beaufort Sea, and the Canadian archipelago (Figure 2, left). These data are from the National Centers for Environmental Protection/National Center for Atmospheric Research (NCEP/NCAR) re-analysis project, and they correspond to the TIROS Operational Vertical Sounder (TOVS) satellite sounder data when the data have been corrected for inter-satellite calibration differences. A warming is also seen in April in the eastern hemisphere, centered on the Kara Sea.

Also shown in Figure 2 (left) are the vector differences of 850 hPa winds for 1989-1998 minus 1980–1989. There are southerly components over the western Bering Sea/Kamchatka Peninsula and easterly components across the southern Bering Sea. Because northerly winds over Kamchatka and westerly winds across the southern Bering Sea are the typical winter pattern of cold air advection, the weakening of these winds, and even the presence of southeast winds over the southeast Bering Sea, suggest an earlier winter/spring transition. These near-surface wind and temperature anomalies in turn affect the sea ice distribution.

Warm temperature anomalies exist from the surface up to the upper troposphere. In the stratosphere, there are colder temperatures at 250 hPa in the 1990s relative to the 1980s (Figure 2, right). The region of cold temperatures are located above the centers of warming in the troposphere: Alaska, northern Canada, and the Kara Sea. This pattern of cold above warm is a signature of the AO. The breakdown of the polar vortex in April from one center to several centers affects the anomalous wind patterns and focuses the impact of the AO over the marginal seas. By May, the strong vertical structure of the AO in the troposphere and stratosphere is no longer present. There is some warming near the surface north of Alaska and Siberia, but the influence decays with height.

From Figures 1 and 2 we note that although the AO has a strong polar vortex signature in winter, its impact in marginal seas has a special character in March and April at the end of winter. This is a time when solar and air chemistry processes are important. Model results [*Shindell et al.*, 1999] suggest an association between the stratospheric cooling and increased greenhouse gas forcing; this connection is still under debate. In recent decades it has become clear, however, that the AO is a major feature of global climate change in the Northern Hemisphere, with consequences for Alaska and the Bering Sea. It connects the stratosphere and lower troposphere, and mid-latitudes and the Arctic.

Summary

The impacts of reduced sea ice in spring in the western Arctic are clear and immediate. Lack of ice removes the platform that walrus, polar bears, and northern natives use for hunting. Less ice means longer and fewer trips to feeding grounds for the marine mammals. In addition, changes in the AO are associated with long-term changes in fish populations in the Bering Sea [*Hare and Mantua*, 2000]. Northern ecosystems and cultures are adapted to large inter-annual variability, but how will they adapt to persistent change? A recent report from the U.S. Arctic Research Commission recognizes that pronounced effects from climate change, or at least decadal variability, may be observed in the Arctic. The sensitivity of sea ice in the Bering Sea and of temperatures over Alaska in response to the AO point to an earlier spring transition as one example of how these changes will be manifested.

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