The status of the Bering Sea during the first 8 months of 1998

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Dr. Phyllis J. Stabeno, a physical oceanographer at the Pacific Marine Environmental Laboratory (PMEL) of NOAA, conducts research focusses on understanding the dynamics of circulation of the North Pacific, Bering Sea and their adjoining shelves. She is the PMEL Director of NOAA Fishery Oceanography Coordinated Investigations (FOCI), and by applying her knowledge of physical processes to fisheries oceanography, she plays a vital role in its success. FOCI research focusses on building sustainable fishery resources in the Gulf of Alaska and Bering Sea while maintaining a healthy ecosystem. Phyllis is also a Principal Investigator on several research elements for other programs, including: Southeast Bering Sea Carrying Capacity (Coastal Ocean Program), the Bering Sea Green Belt: processes and ecosystem production (Arctice Research Initiative) and Prolonged Production and Trophic Transfer to Predators: processes at the inner front of the southeast Bering Sea (National Science Foundation). This research seeks to improve our understanding of ecosystems through the integration of physical and biological phenomena.

The southeast Bering Sea (*Figure 1*) is one of the most productive ecosystems of the world with commercially valuable fishing grounds, because of this, it is the focus of oceanographic research. Starting in late spring 1997, a variety of anomalous conditions were observed in the Bering Sea including major coccolithophorid blooms (1997 and 1998), a large die-off of shearwaters (1997), far below predicted salmon returns (1997 and 1998), presence of whales on the shelf (1997 and 1998), and unusually warm sea surface temperatures (1997 and 1998). The causal mechanism for these events is not known, but major shifts in the ecosystem have occurred in previous years and we may now be witnessing such an event. It is unlikely that the changes in the Bering Sea are isolated, but rather they are part of the large-scale changes occurring in the North Pacific ocean/atmosphere climate system. For the cool season, two prominent modes of variability stand out. On the 2-7 year time scale, there are the systematic effects that occur with the now familiar El Niño - Southern Oscillation (ENSO). On the time scale of decades, there is the Pacific Decadal Oscillation or PDO (Mantua et al., A Pacific Interdecadal Climate Oscillation with impacts on salmon production. Bulletin of the American. Meteorological Socierty, Vol. 78, No. 6, 1069-1079, 1997). This mode has received considerable attention recently, because of its apparent links to salmon production and other aspects of the North Pacific ecosystem and climate. The climate variations of the North Pacific and Bering Sea can often be attributed to the superposition of the effects of ENSO and the PDO.

During the early portion of 1998, the intense El Niño of 1997-1998 dominated the North Pacific. The consequences for the Bering Sea included a deeper than normal Aleutian Low and a relatively warm middle to late winter for Alaska. This El Niño ended abruptly during the spring with rapid cooling in the tropical Pacific to moderate La Niña conditions. It is difficult to ascertain, at this time, whether any systematic shift is occurring in the PDO. Its last drastic change (to a strongly positive state) occurred in the late 1970s; at present there is the suggestion that it is tending to a negative or perhaps neutral state. It must be noted that the ENSO and the PDO generally affect the Bering Sea weather more during winter than summer. While the Bering Sea experienced greater than normal storminess during the late spring and summer of the 1998, it is not clear that this weather can be attributed to anything more than the natural variability of the atmospheric circulation over the North Pacific.

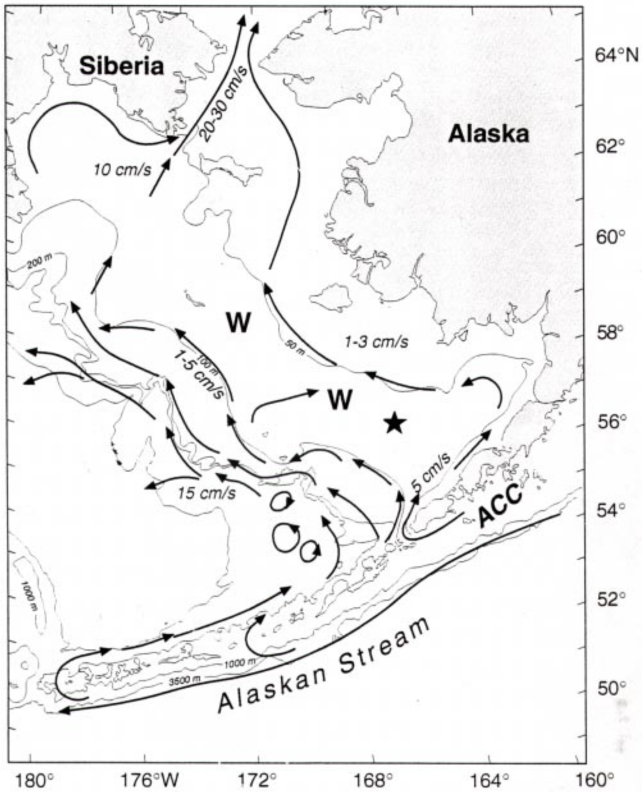

Fig. 1 *A schematic of the mean circulation in the eastern Bering Sea. The Bering Slope Current (BSC) and Aleutian North Slope Current (ANSC) are shown. Site 2 (the star), the location of the time series measurements is indicated.*

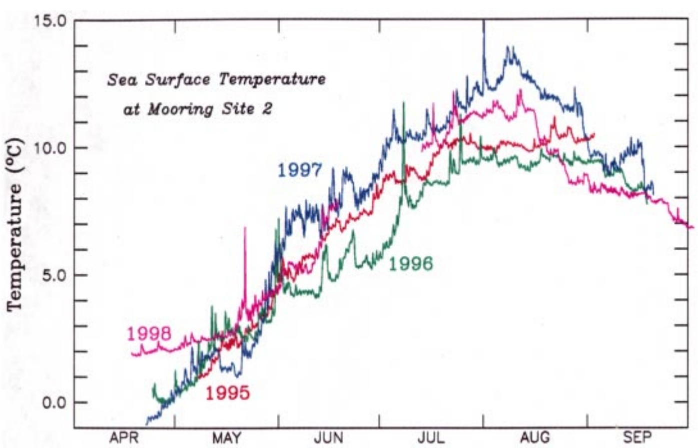

Fig. 2 *Time series of sea surface temperature at Site 2 during spring and summer 1995, 1996, 1997 and 1998.*

The seasonal variation of sea ice over the southeast Bering Sea is one of the striking characteristics of this shelf. The 1990s has seen an increase in the extent of sea ice over that which occurred in the previous decade. The extent of sea ice is largely determined by the strength and direction of winds. Strong, frigid winds out of the north blow the ice southward over the shelf. During 1998, ice arrived early (January) over the southeast shelf, and also retreated early (February). Historically we have observed that when sea ice is present over the southeast Bering Sea shelf during March, there is an accompanying spring bloom of phytoplankton which depletes the nutrients in the upper mixed layer. The retreat of ice in 1998 occurred early, before sufficient light was present to trigger a spring phytoplankton bloom. Ice melt provides an input of fresh water, that is the major contributor to stratification of the water column early in the year, while later in spring and summer, solar heating becomes the primary source of buoyancy. The southeast Bering Sea shelf is separated into domains characterized by their vertical structure. Over the middle shelf (50-70m water depth), the water column forms a two-layer system typically during April. Ice melt can provide fresh water to the upper layer thus initiating stratification. Beginning in April, solar heating can enhance this stratified system. In 1998, stratification of the water column occurred unusually late. Until June, winds were sufficiently strong over the shelf to keep the water column well mixed, thus delaying the formation of the two-layer system. The late setup and lack of low-salinity surface water caused by the early ice retreat resulted in a relatively weak density difference between the upper and lower layers. In addition, the warm water from the anonymously warm 1997 was still present over the southeast Bering Sea shelf in April. Sea surface temperature (SST) was warmer than in the previous 3 years at mooring 2 (*Figure 2*). The deepening of the mixed layer during April and May resulted in the SST increasing only slightly during those two months. The SST then increased rapidly through July. In mid-August, strong winds mixed the relatively weakly stratified water column, sharply reducing SST. Maximum temperature was not as warm as observed in 1997, but the warmest SST since the 1960s were observed in 1997 and 1998. The early ice retreat and lack of early stratification of the water column prevented the occurrence of a strong spring bloom. Typically the spring bloom completely uses the nutrients in the upper mixed layer (nutrients in the lower layer are isolated and high concentration remains through the summer). During 1998 there was a slow draw down of nutrients during the spring and summer, resulting in depleted nutrients over the shelf. These low nutrient conditions are very similar to conditions observed in 1997. The anomalous physical conditions during the last two years likely contributed to the large coccolithophorid bloom that was, and continues to be, observed. The bloom began in July 1997. Images in February 1998 show the aquamarine color that is indicative of these blooms.

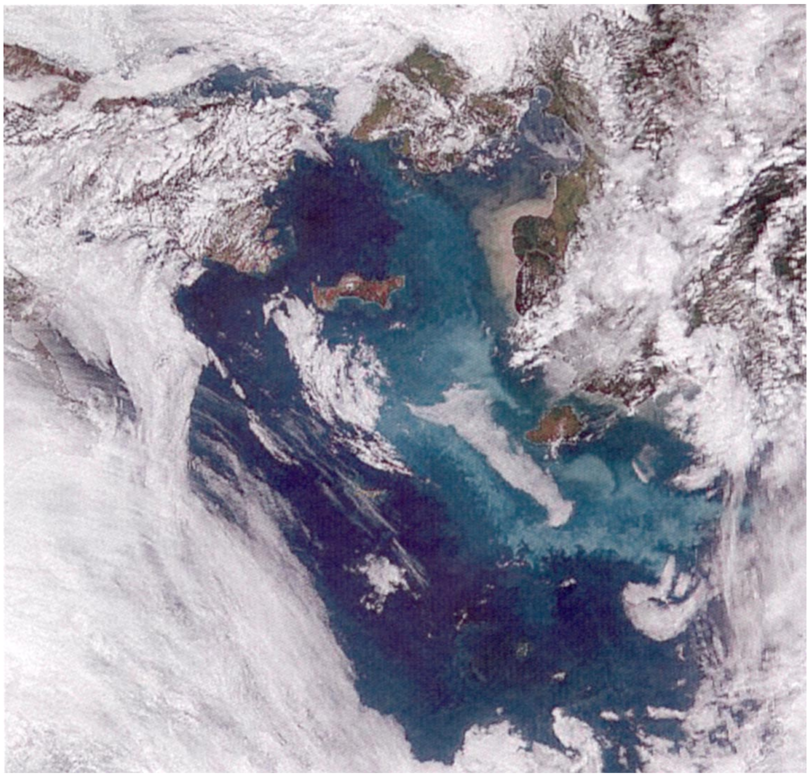

Fig. 3 SeaWiFs composite true color image (July 20, 1998) showing the extent of the aquamarine water which indicates the coccolithophorid bloom. Bering Strait is near the center at the top of the figure, with St. Lawrence Island just below. Runoff from the Yukon River is evident along the coast of Alaska. Figure provided by SeaWiFS Project, NASA/Goddard Space Flight Center.

An image in April shows the bloom covering much of the shelf. Satellite images (*Figure 3*) show the presence of a dense population of coccolithophores over the shelf in July 1998. The coccolithophores likely over-wintered due to mild temperatures on the shelf during this last winter. The 1998 bloom was more extensive than that observed in 1997, stretching north through Bering Strait. Cruises during July and August reported the aquamarine color, although it was not evident to personnel on cruises earlier in the year. Thus it appears that satellites can reveal coccolithophores in lower concentrations than the human eye can detect onboard ships.

The number of salmon returning to Bristol Bay during the last two years was far below expected. Traditionally it has been viewed that most salmon mortality occurs in early life, but research in the 1980s indicates the importance on early marine life. A recent paper by Kruse (Kruse, G. H., Salmon run failures in 1997-1998: A link to anomalous ocean conditions. Alaska Fishery Research Bulletin, 55-63, 1998.) discusses the Bering Sea salmon failures in 1997 and 1998 in detail. He concludes that marine environment contributed to the weaker than expected salmon runs in the last two years. Changing conditions have been observed during the last two years in the Bering Sea. Hopefully, the observations being made presently in the Bering Sea will be sufficient to elucidate the mechanisms that are resulting in the changes in the physical and biological environment of this productive ecosystem.

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Carbon Dioxide

JMA observed the distribution of carbon dioxide (CO_2) in the western North Pacific onboard the *R/V Ryofu Maru* from January 27 to March 2, 1998 (*Figure 6*). The CO_2 concentration (partial pressure, $pCO_{2,sea}$) in the surface water were 20 µatm higher than those in February 1997, in the western equtorial Pacific (3˚N, 137˚E), and this area was a source for atmospheric CO_2. At 3˚N, 137˚E, the SST was about 1.1˚C lower (which corresponds to a decrease in $pCO_{2,\ sea}$ of about 20 µatm), whereas total inorganic carbon (TIC) concentration was 70 µmol/l higher (an increase in $pCO_{2,\ sea}$ of about 40 µatm), as compared to those observed in February 1997. The difference in $pCO_{2,\ sea}$ between the two years can be quantitatively explained by the reduction of the SST and the elevated TIC concentration. It is also evident that the elevated TIC concentration contributed to the increase in $pCO_{2,\ sea}$.

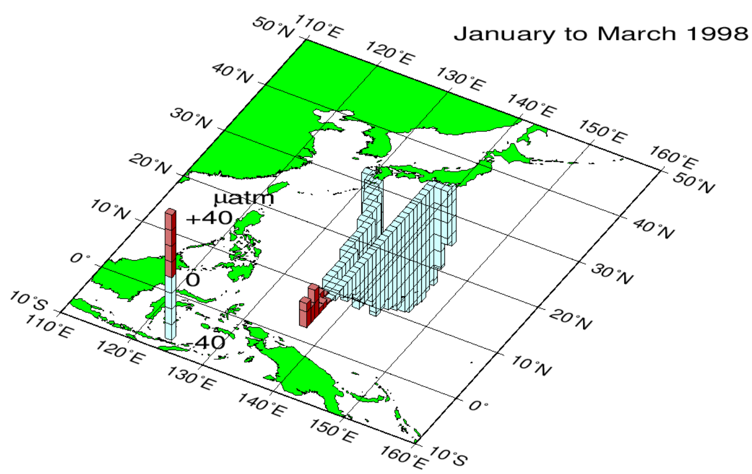

Fig. 6 CO_2 concentration difference between sea surface water and air in January - March 1998. Red upward bars indicate that the ocean emits CO_2 and blue downward bars indicate atmospheric CO_2 absorption by the ocean.