The status of the Bering Sea in the first eight months of 1997

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Dr. Phyllis Stabeno, a physical oceanographer at the Pacific Marine Environmental Laboratory of the NOAA, conducts research focused on understanding the dynamics of circulation of the N. Pacific, Bering Sea and their adjoining shelves. By applying knowledge of physical processes to fisheries oceanography, Dr. Stabeno plays a vital role in the success of NOAA's FOCI (Fishery Oceanography Coordinated Investigations) program. Phyllis is also a Principal Invistigator 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 unmderstanding of ecosystems through the integration of physical and biological phenomena.

During late spring and summer of 1997, a variety of anomalous conditions existed in the Bering Sea including a major coccolithophorid bloom, large die–off of marine birds (shearwaters), salmon returns far below predicted, calm sunny days and unusually warm sea surface temperatures. These events were likely related, in part, to the atmospheric perturbations associated with the strong equatorial El Niño. To present these in a timely manner this article has been expanded to include July and August of 1997. Because the southeast Bering Sea is one of the most productive ecosystems of the world, with commercially valuable fishing grounds, it is the focus of several research projects. These projects collected data throughout 1997 and future analysis will provide insight into the causes of the anomalous conditions and their impact on the ecosystem. The programs include National Science Foundation (NSF) funded research on prolonged production along the structure front (~50m isobath) and a group of programs funded by National Oceanic Atmospheric Administration (annual trawl surveys conducted by Alaska Fisheries Science Center/National Marine Fisheries Service; monitoring from biophysical platforms and hydrographic sections by Southeast Bering Sea Carrying Capacity and Coastal Ocean Program; biophysical measurements of the green belt by the Arctic Research Initiative; and research by Fisheries Oceanography Coordinated Investigations). The scientists (N. A. Bond, R. D. Brodeur, K. O. Coyle, M. B. Decker, G. L. Hunt Jr., J. M. Napp, J. D. Schumacher, P. J. Stabeno, D. Stockwell, C. T. Tynan, T. C. Vance, T. E. Whitledge, T. Wyllie Echeverraind and S. Zeeman) from these programs provided much of the information that is reported in this article.

The seasonal variation of sea ice over the southeast Bering Sea is one of the striking characteristics of this shelf. The extent of sea ice is largely determined by the strength and direction of the winds. Strong, frigid winds out of the north blow the ice southward over the shelf. Typically sea ice reaches the Pribilof Islands (*Figure 1*) in March or April and then retreats within the month. The ice field at the end of December 1996 was more extensive than usual, but it did not advance significantly during January since the winds were particularly weak (*Figure 2a*). February-April winds were typical (*Figure 2b,c*), resulting in an average ice coverage by early April. Melt back, however, appeared to be unusually rapid and ice was gone from the region by late April.

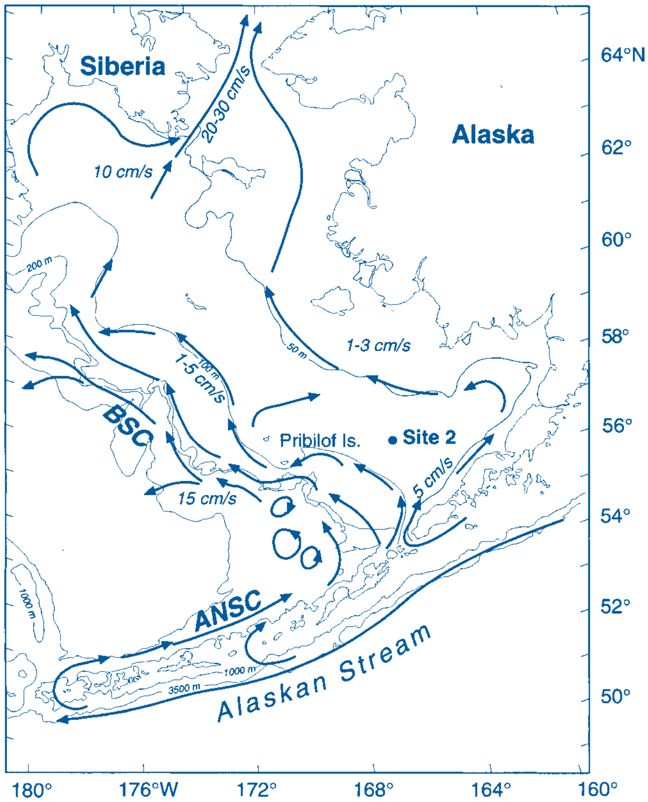

Fig. 1 A schematic of the mean circulation in the eastern Bering Sea. The Bering Slope Current (BSC) and Aleutian North Slope Current (ANSC) are shown. Site 2, the location of the time series measurements, is indicated.

Ice melt provides an input of fresh water, that is the major contributor to stratification of the water column early in the year, while in late spring and summer solar heating becomes the primary source of buoyancy. Water properties and water column structure separate this shelf into domains. Coastal waters (z < 50 m) are typically mixed (or weakly stratified) by a combination of tidal and wind stirring. During spring and summer, water over the middle shelf (50 < z < 100 m) is two layered with the upper layer wind mixed and lower tidally mixed. The depth of upper mixed layer usually varies from 15 to 30m depending upon wind strength and duration in a given year. Separating these two domains is a structure front (the inner front). Seabirds (Shearwaters-Puffinnus tenuirostris) return here each year, attracted by high food concentrations (euphausiids). In a "normal" year their prey thrive on prolonged and/or enhanced production from the base of the food web (phytoplankton) as a result of the persistent flux of nutrients into the sunlit waters.

Through April, both oceanographic and atmospheric conditions were not markedly atypical. In May, weather patterns changed, the winds weakened, so that by June and July winds were significantly weaker than usual (*Figure 2e,f*). In addition, the weather patterns resulted in more cloud free days than usual and thus an increase of solar radiation to the sea surface.

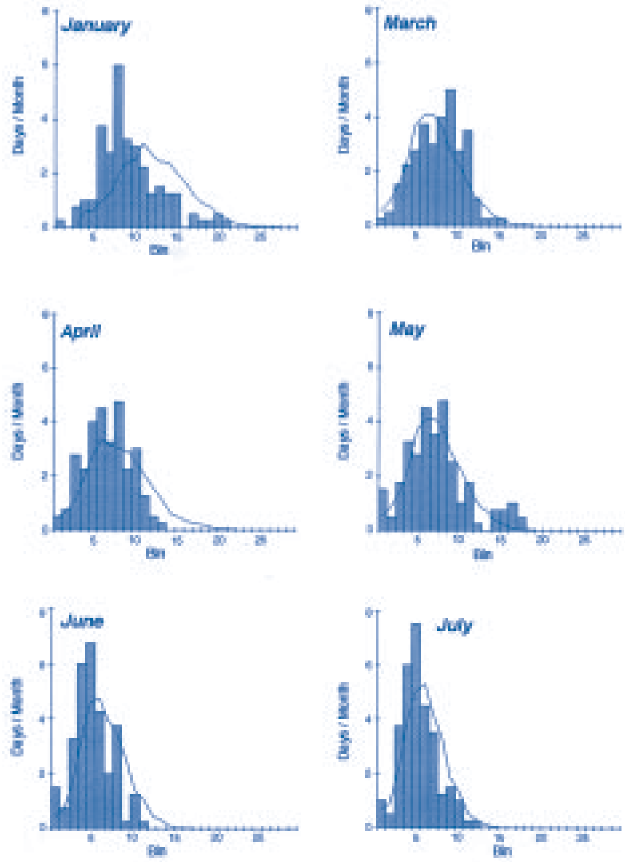

Fig.2 Histogram of wind speed at the Pribilof Islands for January, March, April, May, June and July 1997. Superimposed (line) is the histogram of mean (1950–1997) wind speed for same months. Each represents 2 discrete values of knots. (i.e. bin 1 is the number of days that had winds of 0 or 1 knot; bin 2 is the number of days that had winds of 2 or 3 knots, etc.)

One consequence of these unusual atmospheric conditions was that the coastal domain was strongly stratified even in water depths of 30m. The middle shelf domain usually characterized by two layers, with a sharp thermocline between them, was markedly different this year. Beneath the shallow mixed layer (< 10m for much of June and July) was a transition zone (~20m) to the lower tidally mixed layer. This weaker stratification permitted greater transfer of heat into the lower layer. Thus, the bottom temperatures warmed by 4˚C over the summer.

The changes observed in the water column of both the middle shelf and coastal domains resulted in a structure front that was not as well developed as previously reported. The shallow mixed layer, together with the enhanced radiation resulted in warmer sea surface temperature. A time series of sea–surface temperature on the shelf *(Site 2 in Figure 1)* exists for April of the last three years. This summer temperatures were significantly warmer than usual *(Figure 3)*.

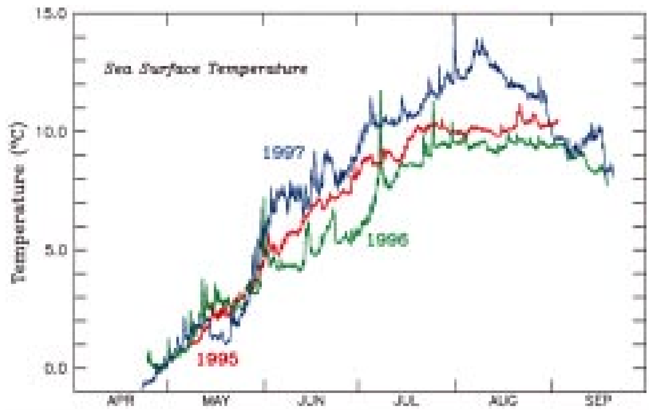

Fig. 3 Time series of sea surface temperature at Site 2 during spring and summer 1995,1996 and 1997

Satellite remote sensing supports the warm sea surface temperatures observed at site 2 and provides the following sequence of sea surface temperature conditions throughout the region: in early May temperatures were slightly below normal (~0.0 to -1.0˚C) but by mid-June the anomaly was strongly positive (2.0-2.5˚C above normal). A positive anomaly persisted through September. The anomalous physical conditions likely supported a coccolithophorid bloom that was first observed during early July over the southeastern Bering Sea shelf. By this time, the normal summertime plant community had probably been replaced by coccolithophores. Reflectance of light off their calcium carbonate plates (coccoliths) gave the water its anomalous color which was clearly visible from space (*Figure 4*). Light penetration into the water column, essential for primary production, was markedly reduced. This potentially had detrimental effects throughout the food chain.

Fig. 4 SeaWiFs composite true color image (Sept. 18–25, 1997) showing the extent of the aquamarine water indicating a coccolithophorid bloom (proved by SeaWiFS Project, NASA/Goddard Space Flight Center courtesy of Gene Feldman)

In June, the shearwaters were found to be eating their normal diet of adult euphausiids and exhibited normal body weights. As the summer progressed, however, massive die–offs of seabirds were observed. During late summer, both dead and living shearwaters had significantly reduced body mass when compared with birds collected during June. The diets of shearwaters in late summer were notably more diverse than in June with fish and squid being ingested. During late summer, birds ingesting euphausiids were preying upon juveniles, not adults. The juvenile euphausiids are much smaller than adults, and are likely to have a lower energy density. These observations suggested that starvation was the prime cause of the shearwater die-off. Additionally, foraging shearwaters appeared to avoid areas with aqua marine water, where they may have had difficulty in detecting and capturing euphausiid prey under the existing low underwater light conditions.

In addition to die–off of birds, the number of salmon returning to Bristol Bay was far below expected. This resulted in a catch of ~12 million sockeye, instead of the forecasted 25 million. Candidates for this decrease that are not related to conditions found in the Bering Sea this year exist, however, evidence from test fishing at Point Moller suggests that the fish are dying on their way to Bristol Bay, not earlier in their lives.

Just as water properties, particularly temperature, were anomalous, the currents over the basin and shelf were unusual. Typically there is a moderate flow (5–10 cm s^{-1}) northwestward along the 100m isobath (*Figure 1*). This year, however, trajectories of satellite–tracked drifters revealed no net flow from May through August. In addition, stronger volume transports were observed in the Bering Slope Current (BSC) and the Aleutian North Slope Current (ANSC). The flow in the deep basin is cyclonic gyre, with a strong, steady ANSC flowing northeastward along the Aleutian Islands turning northwestward into BSC, an eastern boundary current (*Figure 1*). Typically transports in these flows range from 2–4x10^6 m^3 s^{-1}. This year, baroclinic transports from March through July were greater than 6x10^6 m^3 s^{-1}. The transport through Amchitka Pass, the primary source of flow in the ANSC, was 5x10^6 m^3 s^{-1}, also larger than earlier measurements

The long-term effects of this summer on the Bering Sea ecosystem are not known and likely will remain a mystery until the year class strength of a variety of fish can be determined. The percentage of birds which died and the influence of this on the ecosystem is also unknown and must be evaluated. Hopefully, enough observations were made this year to elucidate the mechanisms that resulted in the coccolithophorid bloom and attended changes in the biota.

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-February south of Japan, implying that atmospheric CO_2 was being absorbed into the ocean (*Fig. 4a*). This is a typical feature of the carbon dioxide distribution in the western North Pacific in winter. On the other hand, CO_2 concentration in surface water was higher than that in the atmosphere in June-July south of Japan. In the seas east of Japan, CO_2 concentration in the sea surface water was much lower than that in the atmosphere in June-July. The CO_2 concentration difference was particularly large from 30˚N to 45˚N east of Japan, and the difference of 120 ppm observed at 43˚N, 153˚E in the June-July cruise was the largest difference observed since 1989 by Ryofu Maru in the western North Pacific (*Fig. 4b*). Similar pattern of the distribution of CO_2 difference in the seas east of Japan was observed during the Ryofu Maru cruise in April-June 1996 (PICES Press Vol.5 No.2).

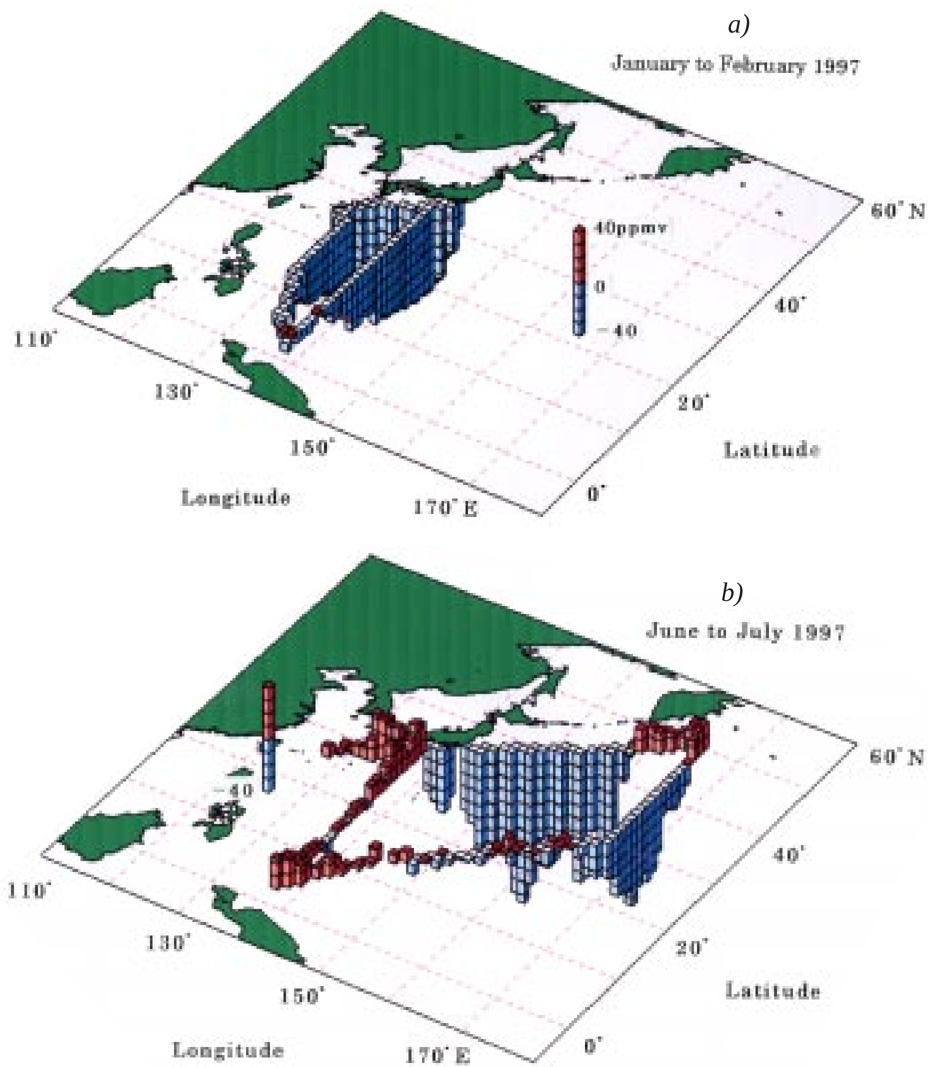

Fig 4. Difference in CO_2 concentration between sea surface water and air in January-February, 1997 (a) and June-July, 1997 (b). Red upward bars indicate that the ocean was emitting CO_2; blue downward bars indicate absorption of CO_2 by the ocean.