ECOSYSTEM INDICATORS AND TRENDS USED BY FOCI

NORTH PACIFIC REGION

Interannual variability of atmospheric forcing

Two patterns represent interannual variability of atmospheric forcing over the North Pacific Ocean and Bering Sea area. They are the magnitude and position of the Aleutian Low during winter and spring. The Aleutian Low is a statistical feature of the climate field, generated by averaging North Pacific sea level pressure for long periods. Because this is a region of frequent storm progression, the averaged pressure appears as a low-pressure area, much like a weather map showing an individual storm. The magnitude and position of the Aleutian Low have a strong bearing on weather in the region and are correlated with other climate indices such as ENSO (El Niño Southern Oscillation). These winter and spring patterns are somewhat independent and have different oceanographic consequences.

The winter index is referred to as the North Pacific Index (NPI, Fig. 1) and is the sea level pressure over the North Pacific averaged for January through February. There is a shift from high to low values of the index in 1925, a shift to high values in 1946, and a shift back to low in 1977. If the data are smoothed, secondary shifts appear (one and a half secondary shifts for each major shift) such as in 1958 and 1989. Lower pressure implies stronger winds and warmer temperatures over the Bering Sea.

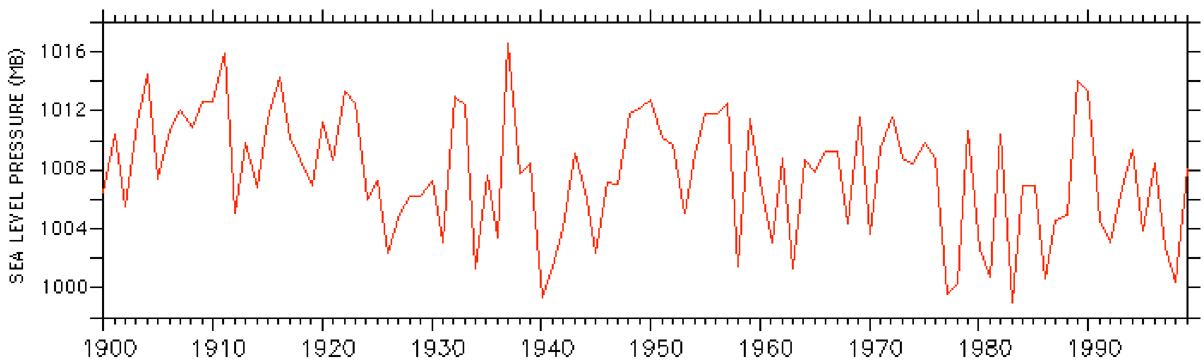


Figure 1. The North Pacific Index (NPI) from 1900 through 1999 is the sea-level pressure averaged for January through February.

In spring, the index is a displacement in pressure northward or southward. This is referred to as the NP Index (Fig. 2). The shift to lower values in the 1970s occurred earlier than in the winter pattern. A shift to positive values is clear in the 1990s. This provides for higher pressure and

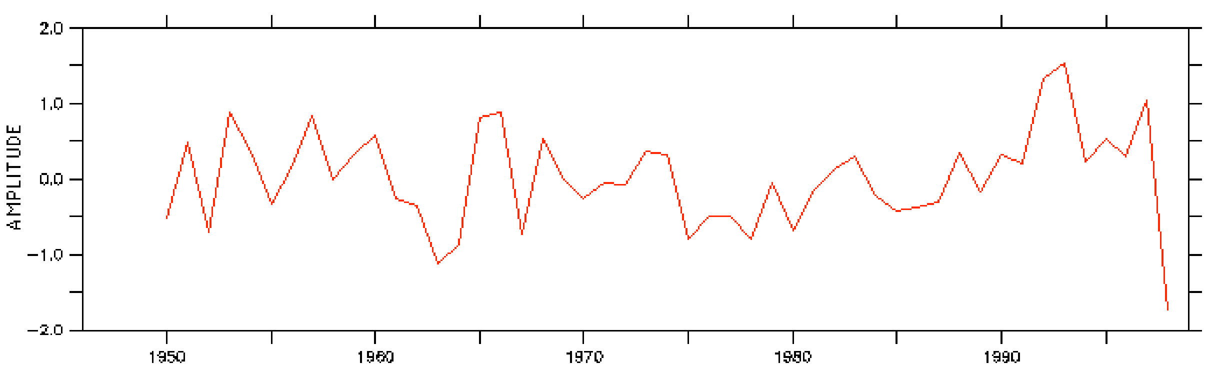


Figure 2. The NP Index for April-July 1950 through 1999 is a measure of the displacement of the Aleutian Low.

WESTERN GULF OF ALASKA

Seasonal rainfall at Kodiak

There is a propensity for the coincidence of patches of larval walleye pollock and mesoscale eddies. For early larvae, presence within an eddy is conducive to survival. Eddies in Shelikof Strait are caused by baroclinic instabilities in the Alaska Coastal Current (ACC). The baroclinity of this current fluctuates with the amount of fresh water discharged along the coast. A time series of Kodiak rainfall (inches) is a proxy for baroclinity and thus an index for survival success of species such as walleye pollock that benefit from spending their earliest stages in eddies. Greater than average late winter (January, February, March) precipitation produces a greater snow pack for spring and summer freshwater discharge into the ACC. Similarly, greater than average spring and early summer rainfall also favor increased baroclinity after spawning. Conversely, decreased rainfall is likely detrimental to pollock survival. A pollock survival index based on precipitation is shown in Fig. 3. Although there is large interannual variability, a trend toward increased survival potential is apparent from 1962 (the start of the time series) until the mid 1980s. Over the last 15 years, the survival potential has been more level.

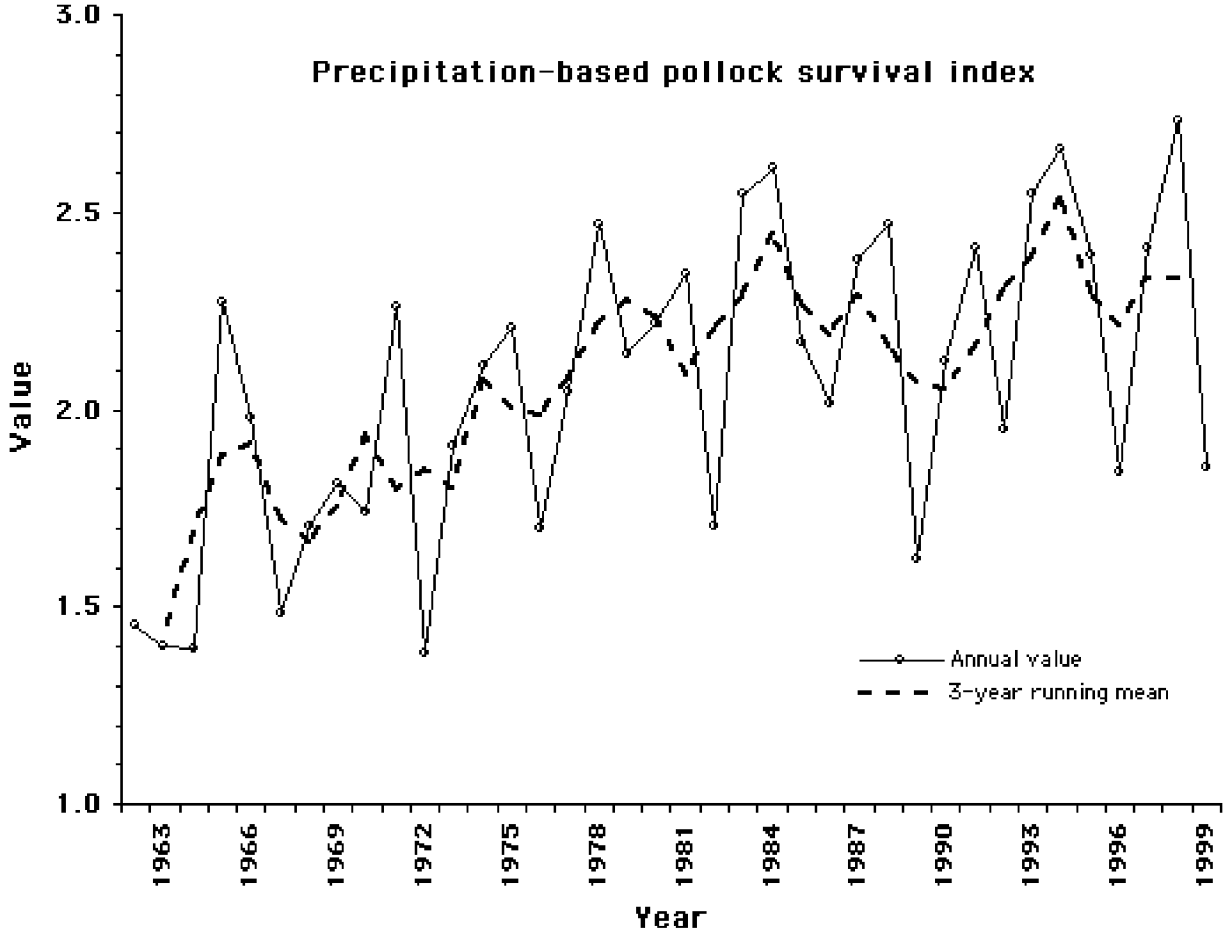


Figure 3. Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 1999. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Wind mixing south of Shelikof Strait

Another survival index relates to first-feeding pollock larvae, a key survival stage when they have exhausted their yolk sacs and need to capture food. Possibly because increased turbulence interferes with larvae's ability to feed, strong wind mixing events during the first-feeding period are detrimental to survival of pollock larvae. A time series of wind mixing energy (W m^{-2}) at [57°N, 156°W] near the southern end of Shelikof Strait is the basis for a survival index (Fig. 4) wherein stronger than average mixing before spawning and weaker than average mixing after spawning favor survival of pollock. As with precipitation at Kodiak, there is wide interannual variability with a less noticeable and shorter trend to increasing survival potential from 1962 to the late 1970s.

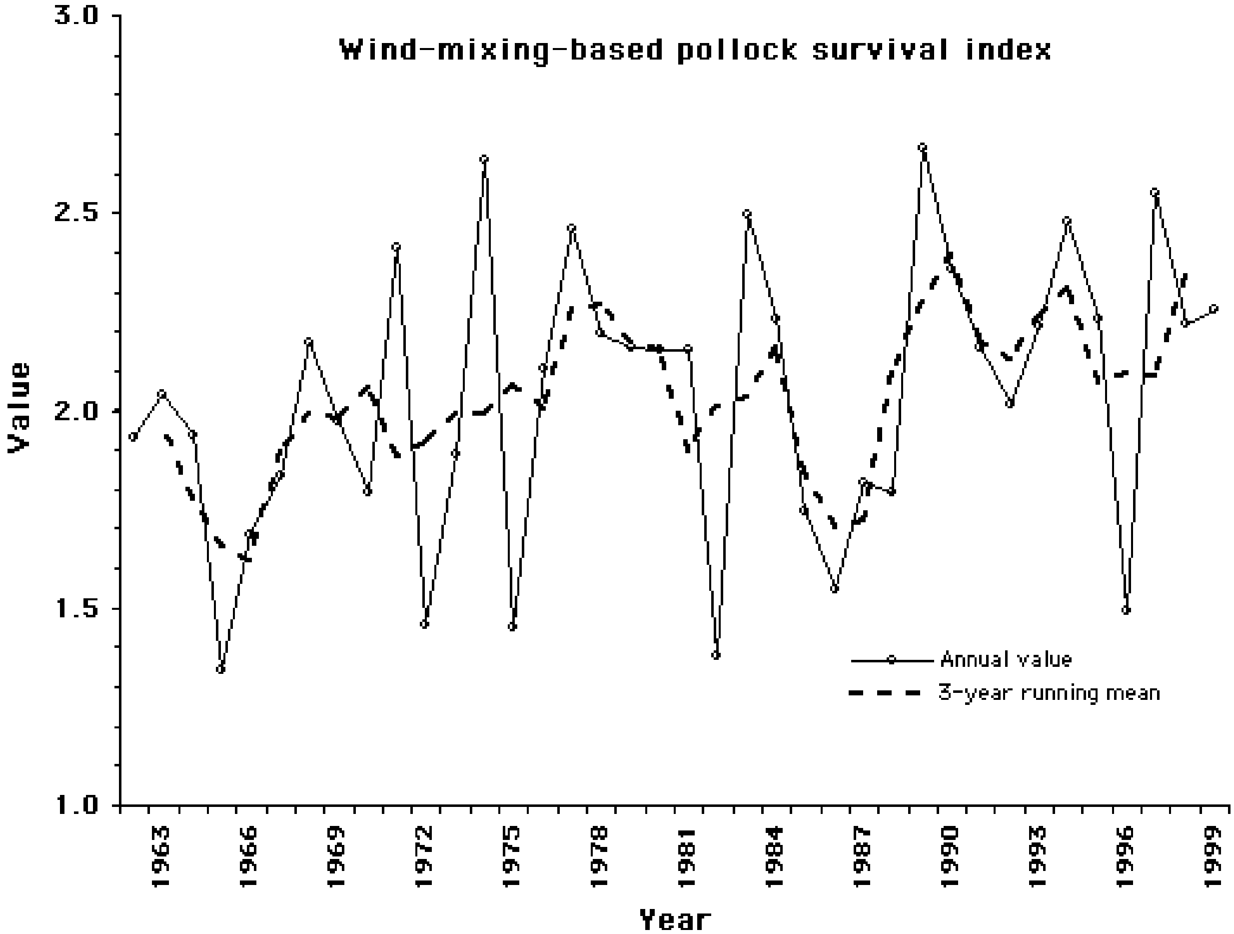


Figure 4. Index of pollock survival potential based on estimated wind mixing energy at a location south of Shelikof Strait from 1962 through 1999. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

EASTERN BERING SEA

Sea ice extent and timing

The extent and timing of seasonal sea ice over the Bering Sea shelf plays an important role, if not the determining role, in the timing of the spring bloom and modifies the temperature and salinity of the water column. Sea ice is formed in polynyas and advected southward across the shelf. The leading edge continues to melt as it encounters above freezing waters. The ice pack acts as a conveyor belt with more saline waters occurring as a result of brine rejection in the polynyas and freshening occurring at the leading edge as the ice melts. Over the southern shelf, the timing of the spring bloom is directly related to the presence of ice. If ice is present in mid-March or later, a phytoplankton bloom will be triggered that consumes the available nutrients. If ice is not present during this time, the bloom occurs later, typically during May, after the water column has stratified.

The presence of ice will cool the water column to -1.7°C. Usually spring heating results in a warm upper mixed layer that caps the water column. This insulates the bottom water, and the cold water (<2°C) will persist through the summer as the “cold pool.” Fish, particularly pollock, appear to avoid the very cold temperatures of the cold pool. In addition the cold temperatures delay the maturing of fish eggs and hence affect their survival.

Figure 5 shows the presence of ice over the southeastern shelf during the last 30 years. Heavy black lines in the figure denote the presence of sea ice at mooring site 2 [56.9°N, 164.0°W] on the shelf. Ice was most common at this location until 1976. After that came a warm period that lasted until the late 1980s. Since then, ice has been more persistent but not as extensive as it was prior to 1977. Recently, 1995 had the most extensive seasonal sea ice pack since 1976. There appears to be a slight reduction in ice cover during El Niño years (dashed lines in Fig. 5), but the relationship is weak.

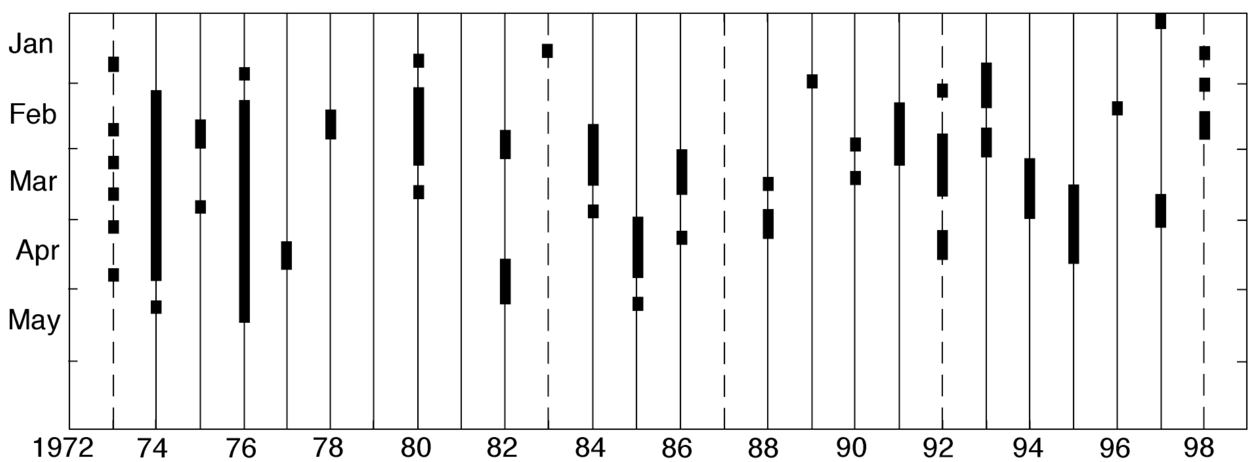
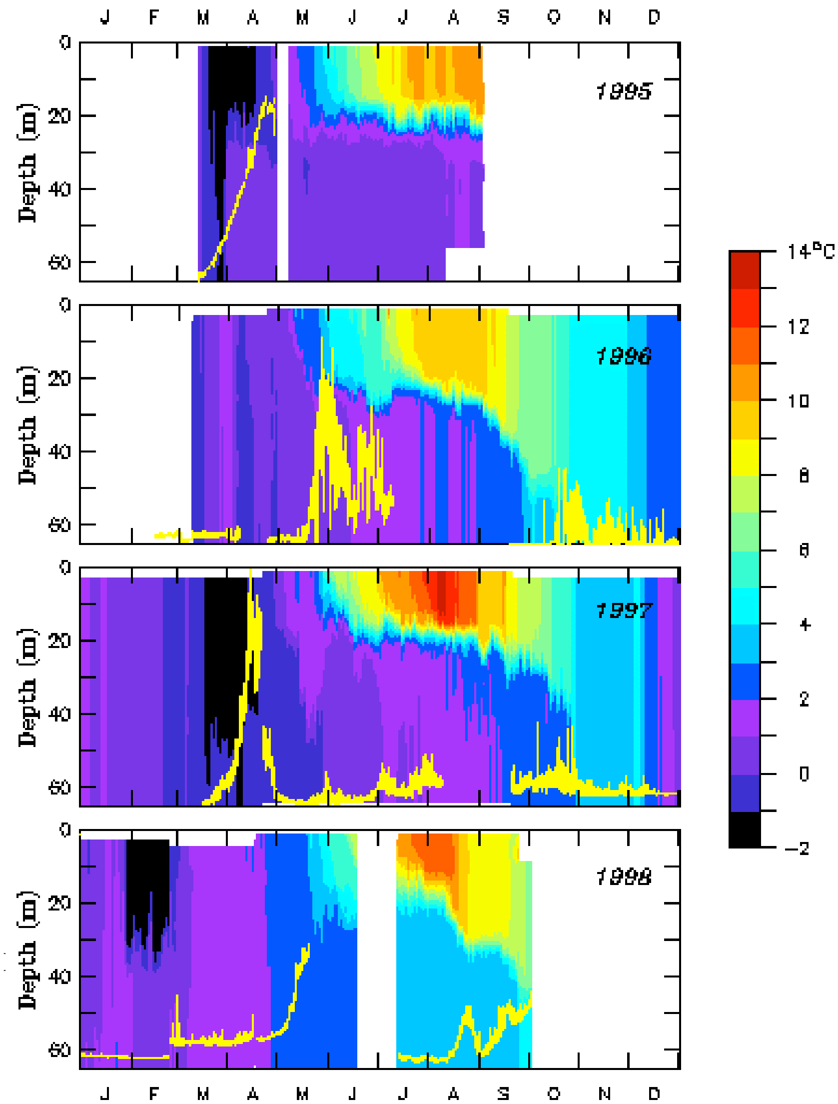


Figure 5. Black bands denote the presence of sea ice at mooring site 2 on the southeastern Bering Sea shelf. Dashed vertical lines designate El Niño years.

Mooring 2: The cycle in the middle shelf

The cycle in water column temperatures is similar each year. In January, the water column is well mixed. This condition persists until buoyancy is introduced to the water column either through ice melt or solar heating. The very cold temperatures (shown in black in Fig. 6) that occurred in 1995, 1997 and 1998, resulted from the arrival and melting of ice. During 1996, ice was present for only a short time in February, however no mooring was in place. Generally, stratification develops during April. The water column exhibits a well defined two-layer structure throughout the summer consisting of a 15 to 25-m wind-mixed layer and a 35 to 40-m tidally mixed bottom layer (the cold pool if temperatures are sufficiently low). Deepening of the mixed layer by strong winds and heat loss begins in August, and by early November the water column is again well mixed.

The depth of the upper mixed layer and the strength of the thermocline contribute to the amount of nutrients available for primary production. A deeper upper mixed layer makes available a greater amount of nutrients. In addition, a weak thermocline (more common with a deeper upper mixed layer) permits more nutrients to be "leaked" into the upper layer photic zone and thus permits prolonged production. The temperature of the upper layer influences the type of phytoplankton that will flourish. For instance, warmer sea surface temperatures (>11°C) during 1997 and 1998 may have supported the coccolithophorid bloom.



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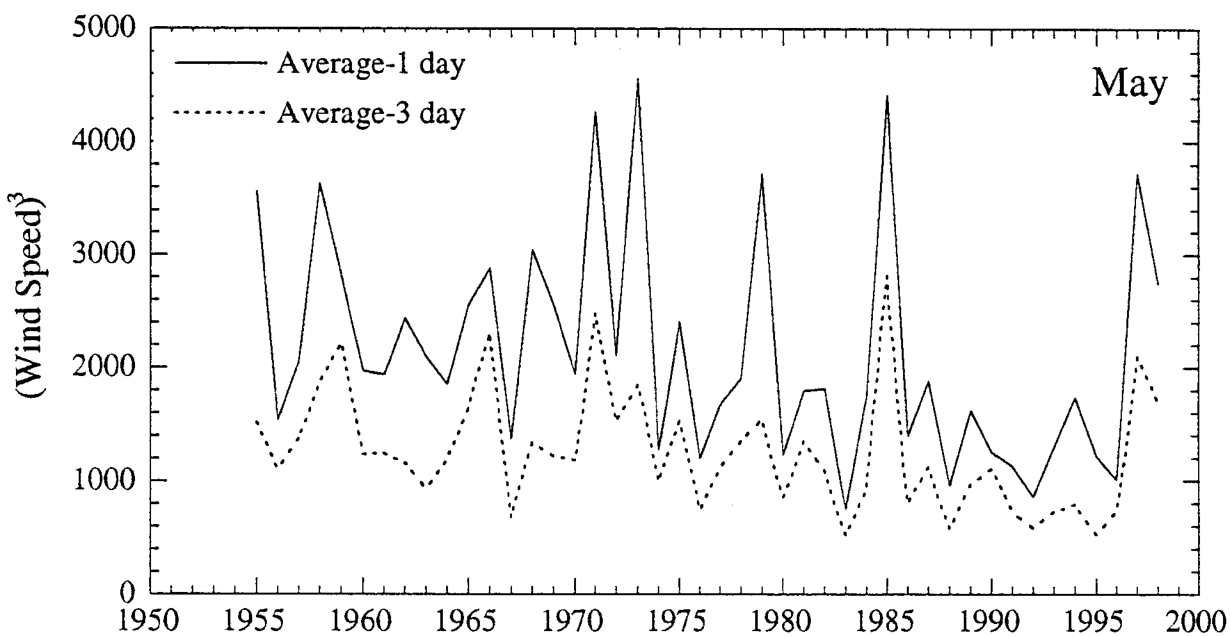
6. Ocean temperature (°C) as a function of depth (m) and time (month of year) measured at mooring site 2 during 1995 through 1998.

Timing of the last spring storm

One of the striking features of the atmosphere during 1997 and 1998 was a change in the timing of the last storm and strength of summer mixing over the eastern Bering Sea. This ecosystem is particularly sensitive to storms during May. The spring bloom strips nutrients from the upper layer, and the stability of the water column isolates nutrients in the lower layer. Thus mixing and deepening of the upper mixed layer by storms in mid to late May provide important nutrients for continuation of blooms into summer. June and July storms are less effective mixers because they are weaker and the thermocline has strengthened. May storms also lessen the density difference between the two layers (entraining denser water into the upper layer), thus permitting subsequent minor mixing events to supply nutrients into the photic zone. From 1986 to 1996, the weather during May was particularly calm; by contrast, May of 1997 and 1998 were characterized by strong individual wind events (Fig. 7). These storms presented a pathway for greater nutrient supply, more prolonged primary production, and weaker stability of the water column than observed between 1986 and 1996. In addition to stronger winds in May, the summers of 1997 and 1998 had the weakest mean wind speed cubed (a measure of mixing energy) since at least 1955. This allowed for a shallow mixed layer and thus higher sea surface temperatures. A pattern of late spring storms and weak summer winds could change the phytoplankton community. If production is prolonged into summer, the total productivity of the shelf could be enhanced, thereby affecting higher trophic levels.

Figure 7. Cube of wind speed (proportional to wind mixing energy) measured at St. Paul, Alaska. The solid line is the daily average; the dashed line is the 3-day average.

Cross shelf advection



Each spring and summer over the Bering Sea shelf, approximately half the nutrients are consumed. These nutrients apparently are replenished during winter and early spring. Cross shelf advection moves nutrient-rich basin water onto the shelf. A reduction of onshelf flow will reduce the available nutrients and thus productivity of the shelf. Understanding and monitoring the mechanisms that induce cross shelf flow are critical to management of the Bering Sea's living resources.

During the last ten years, FOCI released more than 100 satellite-tracked drift buoys in the Bering Sea. Prior to 1996, drifters deployed in the southeastern corner of the Bering Sea typically revealed persistent northwestward flow along the 100-m isobath, with cross shelf flow occurring intermittently. In 1997 and 1999, flow along the 100-m isobath was weak or nonexistent, and there were no occurrences of onshelf flow. Flow patterns in 1998 are less well known as no drifters were deployed that year. Indices of onshelf flow and strength of the 100-m-isobath flow are derived from trajectories of the satellite-tracked drifters. Such indices are important in determining changes in flow patterns, particularly if there has been a climate regime shift as some scientists believe occurred in 1997.