(Equatorial) water entering the bight from the south, principally by way of the California Undercurrent (at 300 m depth). The distribution of these waters in the bight is such that the top 200 m is typically low in salinity and high in oxygen content, which identifies this water mass as principally sub-arctic, even though the temperatures range between 9° and 18° C. The next 300 m are consistently high in salinity and low in dissolved oxygen, identifying it as equatorial Pacific water. The temperature range for this water mass is 9°– 5° C (Jackson 1986).

The circulation of the Southern California Bight is dominated by the Eastern Boundary Current of the North Pacific Gyre system, specifically the California Current, rather than by local wind forcing. The California Current carries subarctic water equatorward throughout the year, extends offshore a distance of about 400 km, and to a depth of 300 meters. The average speed of the California Current is approximately 0.25 m/s. Maximum speeds of the California Current are found at the surface with the strongest equatorward flow occurring during the spring and summer.

Nearer to the California coast, within 150 km, the surface current periodically reverses to the poleward direction, which, when it occurs is called the Inshore Countercurrent. The Inshore Countercurrent is strongest during the fall and winter, with its poleward flow reaching its maximum speeds (exceeding 0.04 m/s) typically within 50 km offshore of the coast.

In Figure 4.4-2, we see that the California Current, flowing in a southerly direction 200 – 500 km offshore Point Arguello, brings in cold, low-salinity, highly oxygenated water from the Subarctic region. The California Current continues in its southerly direction, mixing along the way with the warm, saline, north-central Pacific water coming in from the west. South of San Diego, part of the California Current spins eastward into the Southern California Bight and then poleward forming the California Counter-Current. It joins the poleward California Undercurrent which is deeper and inshore of the California Counter-Current.

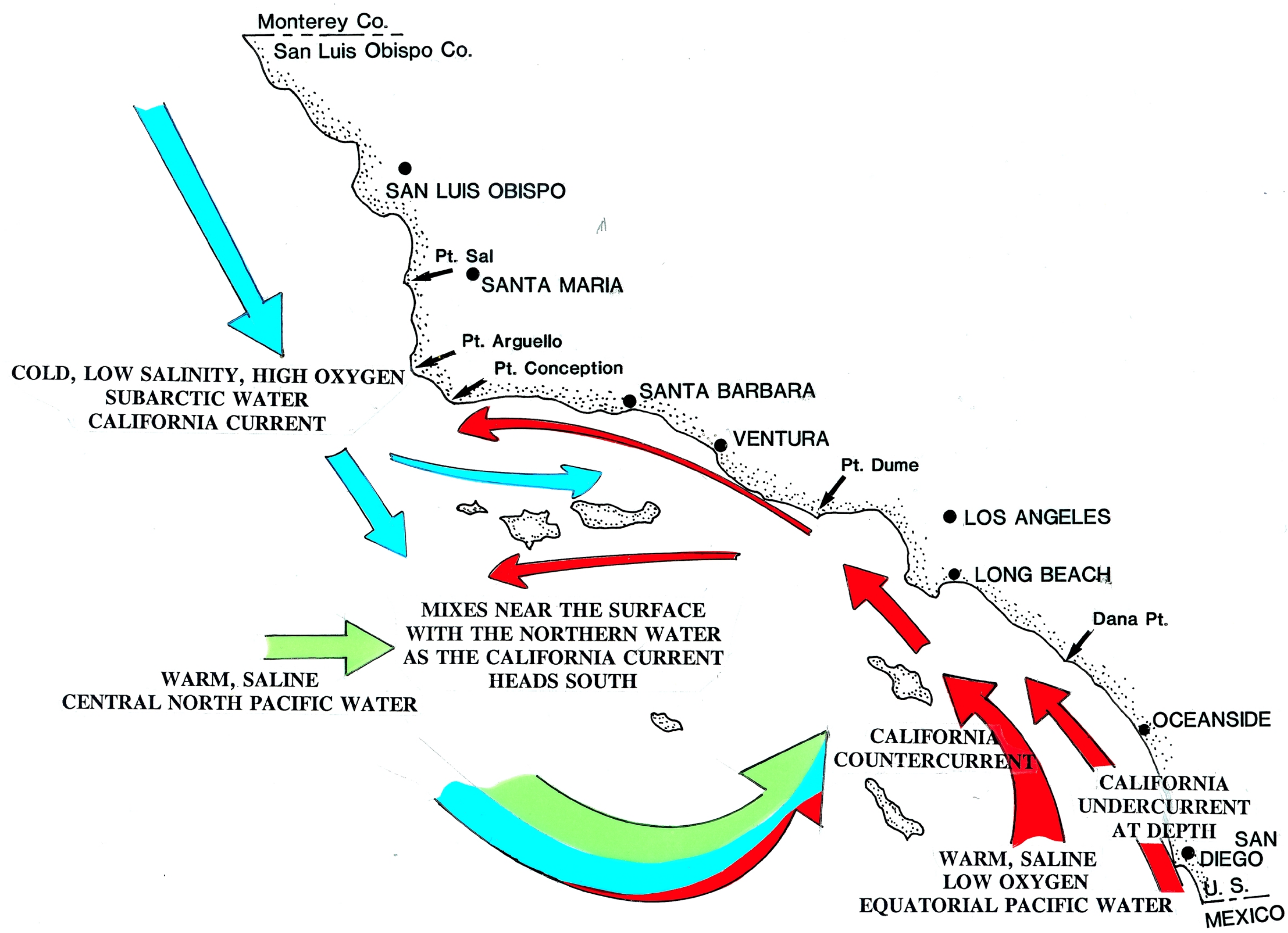

Figure 4.4-2. Characteristic oceanic circulation in, and sources of water of, the Southern California Bight (Browne 1994).

Below 200 m depth, the poleward California Undercurrent exists throughout the year and is generally confined to within 100 km of the coast along the continental slope. The California Undercurrent originates in the eastern equatorial Pacific and brings these warm, saline, low dissolved oxygen waters poleward into the Southern California Bight. At either end of the Santa Barbara Channel, the California Undercurrent shows considerable seasonal variability. In winter and early spring, the California Undercurrent is its weakest with its maximum poleward core flow found below 200 m depth. During this time the surface flow is typically equatorward. In late summer, fall, and early winter its poleward core flow increases in strength and ascends to shallower depths, at times reaching the surface where it becomes indistinguishable from the poleward Inshore Countercurrent.

Currents at the top 200 m within the boundaries of the Santa Monica-San Pedro Basins are poleward year round (Hickey 1992), with their speed ranging from 15 cm/sec to 20 cm/sec from late spring to winter and approximately 5 cm/sec from late winter to early spring. Coastally-trapped waves traveling up the west coast of Mexico are thought to be a primary reason for surface current fluctuations in the Bight shelf region. The surface currents are driven geostrophically by these long period waves and not by local winds occurring in the Bight.

Previously, biologists have thought that benthic (sea bottom) sediments were depleting the oxygen content from the waters in the deep basins (700 – 900 m depth). This may only be partially true, for they reasoned that this apparent consistent lack of oxygen was due to a very slow overturning of basin water (6 – 18 months). They were looking at water properties only and had no idea of the nature of the bottom currents in those basins. Hickey's measurements indicated that complete overturning in the basins occurred in only 1-3 months. The lack of oxygen content in the basins results from a good part of the basin waters coming from the California Undercurrent, bringing in highly saline, low-oxygenated, equatorial Pacific water.

During the fall, a relatively large water mass located between the depths of 300 and 600 m and within the Santa Monica-San Pedro boundaries flows equatorward against the current direction of the rest of the water column.

Upon reaching the northern region of the Bight, the poleward flow typically bifurcates and enters both Santa Barbara and Santa Cruz Basins at their eastern sills. However, during strong, continuous, northwest winds (upwelling favorable) along the central California coast, the flow sometimes reverses and Channel water flows out of its eastern entrance. In this instance, the poleward moving current in the Bight is completely diverted to the west flowing along the southern coasts of the Channel Islands.

4.4.4 SANTA BARBARA CHANNEL - SANTA MARIA BASIN SURFACE CIRCULATION

The description of the physical oceanography of the Santa Barbara Channel – Santa Maria Basin as it relates to the surface circulation in this area is a composite summary of Harms 1996, Hendershott and Winant 1996, Harms and Winant 1998, Dorman and Winant 1995, Winant and Dorman 1997, Dorman and Winant 2000, Dever 2000, Browne 1994, and Browne 2001. Heaviest emphasis in writing this description was placed on Harms 1996, Harms and Winant 1998, and Dever 2000.

4.4.4.1 DESCRIPTION OF THE SANTA BARBARA CHANNEL AND RECENT OBSERVATIONAL FIELD ARRAYS

The Santa Barbara Channel basin (fig. 4.4-1) is located at the northern edge of the Southern California Bight with an east to west orientation. It is bounded to the north by the California mainland, from Port Hueneme to Pt. Conception, and to the south by a string of four islands running from east to west: Anacapa, Santa Cruz, Santa Rosa, and San Miguel. The Channel is approximately 100 km long and 40 km wide with a maximum depth of 500 m in its central basin. The shelf width on both sides ranges from 3 to 10 km, the sill depths at the eastern and western entrances are 220 m and 430 m respectively, and the island passages are approximately 40 m deep.

The Minerals Management Service entered into a series of cooperative agreements with the Scripps Institution of Oceanography, University of California to conduct research regarding the oceanic circulation of the Santa Barbara Channel and the southern central California coastal area called the Santa Maria Basin. The Santa Barbara Channel – Santa Maria

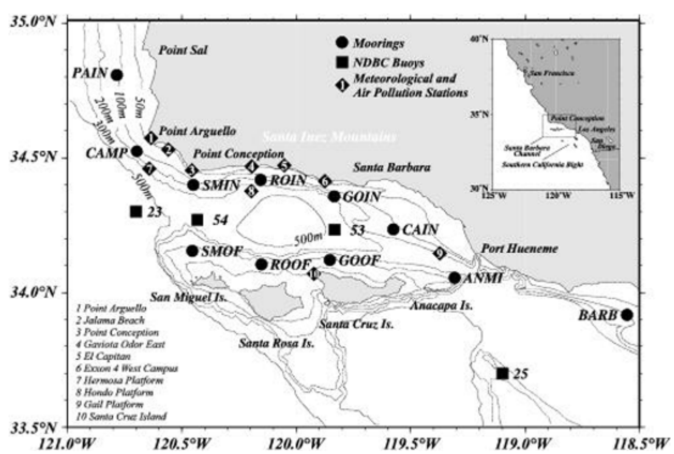

Figure 4.4-3. Santa Barbara Channel-Santa Maria Basin circulation study moored and meteorological instrument locations (Harms 1996).

Basin Circulation Study (1991 to 2002) consisted of two consecutive major field programs: one focusing on the circulation in the Channel and one focusing on circulation in the Santa Maria Basin. The information provided below will reflect the analysis and peer-reviewed research coming out of the observations of the first field program (fig. 4.4-3). Analysis and research based on the observations taken in the second field program is underway at the writing of this document.

4.4.4.2 LARGE-SCALE FORCING

The seasonal variation in the wind field in the SBC-SMB region is determined by two large-scale atmospheric pressure patterns: the North Pacific anticyclone (high) and the thermal low located over the southwestern United States, resulting in persistent winds from the northwest. In the spring the North Pacific high strengthens and moves northward and the Southwestern U. S. Low intensifies. The resulting increase in the atmospheric pressure gradient results in persistently strong southeastward winds off the central California coast, which separate from the coastline in the vicinity of Point Conception, leaving the winds in the Southern California Bight more weak and variable. In the summer the gradient between the two pressure systems reaches a maximum with the North Pacific high being displaced slightly further to the north, causing the winds off the central California coast to be directed more to the south. The gradients in the wind off Point Conception intensify (are stronger and occur over a shorter distance) in the summer. During the fall months, the North Pacific high gradually weakens and eventually moves south to its wintertime position. Fall wind fluctuations off Point Conception are comparable in magnitude to those in the summer but are typically of shorter duration. They last no longer than a few days and are interrupted by equal periods of calm. In the winter the most energetic atmospheric fluctuations along the south and central California coast result from propagating storm tracks. These storm systems pass over the SBC in 2-4 days and are large in size compared to the size of the Channel.

Currents in the Channel are a superposition of large-scale flow (scales larger than the length of the Channel) and a cyclonic circulation characteristic to the Channel's interior. Surface pressure observations off Pt. Sal (PAIN) and in the Southern California Bight (BARB) and current observations at PAIN and at the eastern entrance to the Channel (ANMI) indicate close agreement between direct measurements and geostrophic calculations of the flow in these areas. The large scale surface flow is equatorward in the spring due to strong equatorward wind stress. This increase in equatorward oceanic flow in the spring is accompanied by a decrease in the ocean's surface temperature and pressure. In late spring and early summer the equatorward wind stress off Pt. Conception increases to its seasonal maximum, but the current flow reverses to the poleward direction which is maintained throughout the summer, fall, and early winter. This flow reversal in the Southern California Bight, in the northern part of the Channel, and at times in the inner Santa Maria Basin is due to the setup and increase in the poleward alongshore pressure gradient. The setup of the alongshore pressure gradient is due to the markedly lower wind stress and the accompanying increase in the surface pressure (due to rising temperatures) in the Southern California Bight compared to waters offshore Pt. Conception. The alongshore pressure gradient is fully established by early summer and remains strong until early fall, when it declines as both the equatorward wind stress off Pt. Conception and gradients in the wind stress field between Pt. Conception and the lower Southern California Bight weaken. The reversal of flow in the eastern Channel entrance from equatorward in the spring to poleward the rest of the year as well as the poleward flow in the northern Channel shelf appears to be related to the strengthening of the alongshore surface pressure gradient. Fluctuations (reversals) in these seasonal trends can last for periods up to a week.

The currents measured at SMOF in the southwestern corner of the Channel respond to the upwelling-favorable wind stress fluctuations year round, whereas the correlation between wind stress and the currents in the northern segment of the western Channel entrance (SMOF) lasts only during the late winter and spring. During the late winter and spring the flow is typically equatorward all along the western entrance in a manner consistent of other observations subject to upwelling. In late May and throughout the remainder of the year there is very little correlation of the currents in the northwestern corner of the channel and the windstress as measured at NDBC Buoy 54. Alongshelf currents in the northern Channel shelf are typically westbound and in opposition to (anti-correlated with) the currents on the southern shelf. The persistently year-round eastbound flow along the northern coastline of the islands is primarily due to wind stress, and except for late winter to early spring, is weaker than the westbound jet flowing on the northern shelf. The wind stress at GOOF is 1/2 to 1/3 that at NDBC 54 at the western Channel entrance. This cross-basin shear between alongshelf currents sets up a cyclonic circulation in the western half of the Channel. It intensifies to its maximum in the summer and early fall, weakens in late fall and early winter, and is weakest (to near non-existence at times) in the winter and early spring. Measurements at SMIN-SMOF, ROIN-ROOF, and GOIN-GOOF indicate recurring anti-correlated fluctuations in the alongshelf flow on the opposing shelves that last on the order of weeks during the summer and early fall, becoming shorter in duration as the cross basin shear decreases as the winter season approaches, to non-existence in the late winter and early spring.

4.4.4.3 SEASONAL VARIATION OF MONTHLY MEANS

4.4.4.3.1 WINDS

The seasonal and spatial variability of wind stress in the Santa Barbara Channel is depicted in figure 4.4-4. Wind stress amplitudes decrease in magnitude from the western SBC entrance toward the east all along the Channel. They are smallest along the northern SBC coastline and its adjacent shelf and in the Southern California Bight due to sheltering from the coastal mountain range. The maximum wind stress occurs in the summer at the western SBC entrance, south of Pt. Conception at NDBC Buoy 54. In the eastern SBC and in the Southern California Bight, wind stress is strongest in the spring. Minimum monthly means occur everywhere in February. The slight displacement to the north of the North Pacific high during the summer months causes a tremendous difference in the wind stress gradient near Pt. Conception. They become stronger over a shorter distance. In spring the wind speeds are twice as strong at the western entrance than they are in the central Channel, whereas in the summer this difference is doubled (Dorman 2000, Harms and Winant 1998, Dorman and Winant 1995).

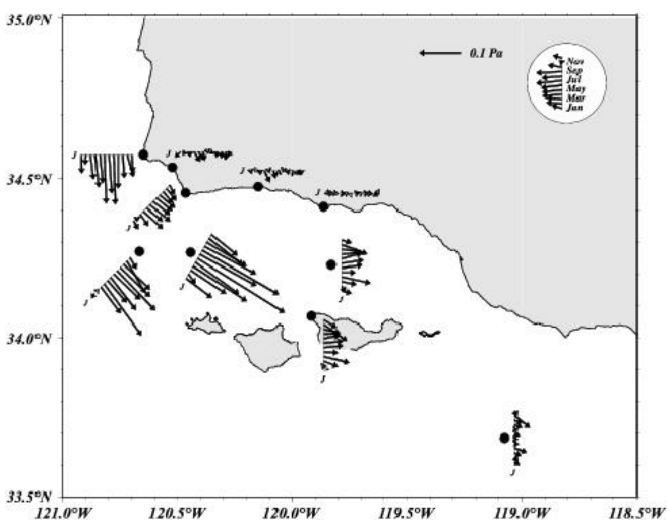

Figure 4.4-4. Seasonal cycle of wind stress in the Santa Barbara Channel region. The monthly mean time series are rotated for convenience. The direction of each arrow is the actual direction of the mean wind stress for that particular month. Arrows are proportional to the wind stress magnitude during individual months in pascals. Solid circles next to the time series show the actual location of the measurement sites. The beginning of the year is indicated by "J" (January) (Harms and Winant 1998).

4.4.4.3.2 CURRENTS

Seasonal near-surface currents (5m) in the SBC are depicted in figure 4.4-5. As stated before the currents in the Santa Barbara Channel are a superposition of cyclonic flow in its interior superimposed on the larger-scale flow (central California coast to the Southern California Bight). Monthly averaged currents on the southern Channel shelf are eastward year-round: they reach a maximum in the spring when the large-scale flow is equatorward, and a minimum in the late fall and winter when the large-scale flow is poleward. Currents on the northern shelf of the Channel are westward throughout the year with maximum westward velocities occurring during the summer and early fall. Currents on the southern and northern

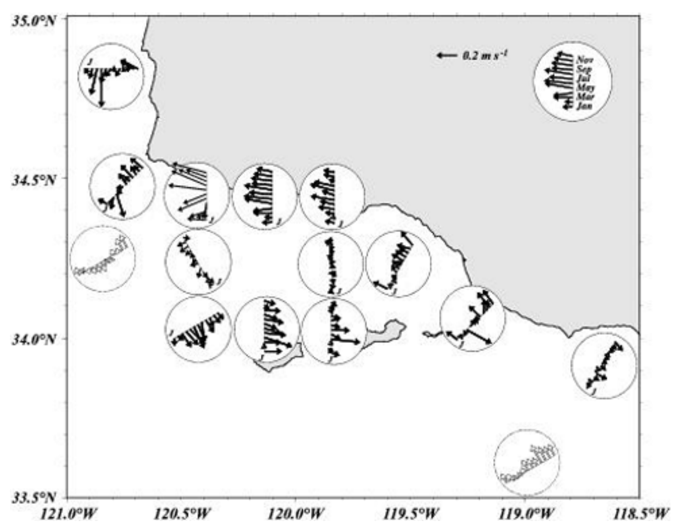

Figure 4.4-5. Seasonal cycle of 5-m currents in the Santa Barbara Channel region. The monthly mean time series are rotated for convenience. The direction of each arrow is the actual direction of the mean currents for that particular month. Arrows are proportional to the current magnitude during individual months in unit m s^{-1}. The locations of the time series corresponds to the buoy locations. The beginning of the year is indicated by "J". Monthly averaged alongshelf geostrophic velocities at the surface relative to 500 dbar computed from CalCOFI hydrographic observations obtained between 1949 and 1995 are shown at two locations to illustrate seasonal variations in large scale flow in this region. (Harms).