BASIN-TO-BASIN WATER EXCHANGE IN THE SOUTHERN CALIFORNIA BIGHT

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ABSTRACT

An array of moored current meters was deployed for a nine-month period on the sills surrounding the Santa Monica and San Pedro basins (the SILL study). The goal was to determine the frequency and mechanisms of interaction between the Santa Monica and San Pedro basins, and the Santa Barbara Channel, Santa Cruz Basin, and the San Diego Trough. Hydrographic surveys were made on three occasions during the deployment. The sediments in the Santa Monica Basin are near-anoxic to anoxic, and the anoxic area has been growing with time. Our results from measurements on the sill (depth ~740 m) demonstrate that renewal of bottom water (addition of oxygen, as identified by the appearance of water with colder temperatures) occurs in isolated events of several days duration, with intervals of several years between renewal periods. These events are associated with processes occurring in the upper water column over the basin; in particular, with strong upwelling and southeastward flow from the Santa Barbara Channel into the Santa Monica Basin. Thus, as with much of the current and water property fluctuations in the basins of the Southern California Bight, it appears that basin anoxia is controlled in large part by large-scale environmental conditions.

INTRODUCTION

The topography of the Southern California Bight consists of a series of relatively deep offshore basins separated by ridges and islands (Figure 1). The lower portions of these basins are frequently separated from adjacent basins by sills so that renewal of water in the lower basins is only accomplished if water flows over the sill from one basin to the next. Renewal is important for maintaining oxygen levels within the basins. In general, oxygen near the bottom decreases northward from basin to basin (Hickey 1993). Some basins are nearly anoxic. In particular, anoxic sediments covered about 10% of the floor of the Santa Monica and San Pedro basin sediments 200 years ago. Today, almost the entire basin floor is near-anoxic (Gorsline 1988). Growth of the anoxic area depresses the ability of basin sediments to support marine life.

The large-scale oceanography of the Southern California Bight is dominated by the California Current system (e.g., Hickey 1979, 1992, 1993, 1998; Lynn and Simpson 1987, 1990; Bray et al. 1998). The California Current flows southeastward year-round offshore of the California Bight, bringing colder, fresher Subarctic water southward. South of Point Conception, the California Current turns southeastward and then shoreward and northwestward in a large eddy known as the Southern California Countercurrent or the Southern California Eddy. This northwestward flowing surface countercurrent and the subsurface California Undercurrent are the dominant features in the upper water column of the nearshore basins. The northwestward flow divides at the northwestern end of the Santa Monica Basin into two components, one flowing northwestward through the Santa Barbara Channel, the other flowing westward south of Santa Cruz and the other Channel Islands.

Fluctuations with dominant time scales from 3 to 30 d are superimposed on seasonal means. In winter and spring, a significant fraction of the variance is related to local wind driving at most locations (Hickey 1993; Harms and Winant 1998). In the Santa Barbara Channel, Harms and Winant (1998) have identified westward or upcoast advection in the Santa Barbara Channel during periods of winter storms ("flood west") and eastward or downcoast advection during upwelling periods ("flood east"). Seasonal maps of available current meter data in the Southern California Bight up to 1993 demonstrate that during winter and spring upwelling events, flow is southward nearshore in much of the Southern California Bight (Hickey 1993). During upwelling events,

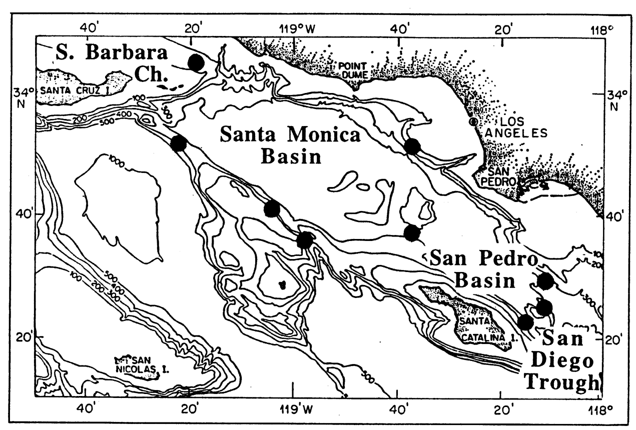

Figure 1. Bottom topography and mooring locations for the SILL study.

upwelled water from regions north of the Bight appears to enter the western end of the Santa Barbara Channel and move eastward along its southern boundary (Hickey 1992; Hendershott and Winant 1996). The alongshore pressure gradient is also responsible for a significant percent of the variance, particularly at longer (20 to 30 d and seasonal) time scales (Lentz and Winant 1986; Hickey 1992; Harms 1996; Harms and Winant 1998). In particular, in the Santa Barbara Channel, the alongshore pressure gradient causes currents to push warm water westward through the Channel when equatorward wind stress weakens (Harms and Winant 1998). In the Santa Barbara Channel, currents at some locations also appear to be driven equatorward by wind stress curl (Wang 1997).

A study of the Santa Monica and San Pedro sediments and the ocean circulation in the region was carried out by the Department of Energy from 1985 to 1990. Data collected in this program have been used to describe the water circulation in the region (Hickey 1991, 1992, 1993). In particular, in 1987 a study of flow across the basin sills was carried out. The goal of the study was to determine the mechanisms and frequency of exchange between the Santa Monica and San Pedro Basin and the adjacent basins. This paper summarizes results of that study.

MATERIALS AND METHODS

Subsurface arrays of moored sensors were deployed on all four sills or entrances of the Santa Monica and San Pedro basins from April to October of 1987 (Figure 1). Instruments included mechanical current meters (Aanderaas) as well as electromagnetic current meters (S4s), vector measuring current meters (VMCMs) and Doppler profilers (ADCPs). Data were processed to remove outliers and filtered to remove tidal and higher frequency fluctuations.

Conductivity, temperature, and depth (CTD) surveys were taken upon deployment and retrieval of the moored arrays. These data were calibrated to accuracies of about 0.003 psu and 0.001ºC. Additional data are included from mid-basin bottle samples used to calibrate the CTD data. These data were obtained over a period of five years.

RESULTS

Time series of water properties (salinity, temperature and sigma t) just above the floor of the Santa Monica and San Pedro basins illustrate that abrupt changes, bringing colder, saltier, denser water into the basin, occur infrequently (Figure 2). In particular, during the five-year interval shown, renewal events occurred between April and May 1987, and in May 1988. Recovery to near-normal conditions occurs over a period of one to two years, a result of vertical and lateral mixing (Ledwell and Hickey 1995). A similar event was reported in the San Pedro Basin in 1984 (Berelson 1991).

Fortuitously, the moored array discussed in this paper was deployed during a year when renewal events occurred.

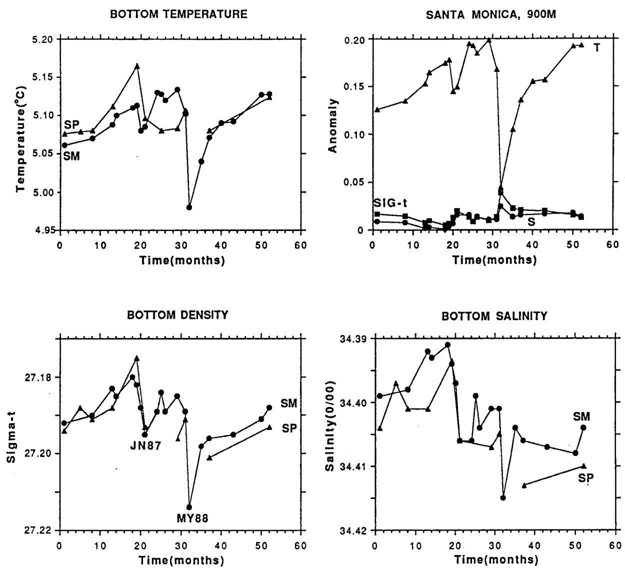

Figure 2. Five-year time series of water properties (temperature, salinity and sigma-t) as well as anomalies near bottom (~900 m) in the Santa Monica and San Pedro basins (Hickey 1992).

Temperature time series from the sill separating the San Pedro Basin from the San Diego Trough (the Avalon sill) indicate two major events, one in late May and one in mid-September (Figure 3). Temperature five meters above the bottom drops by almost 0.5ºC in each of the events. Lowered temperatures are observed as high as 200 m above the sill. Note that the September event does not appear in water properties near 900 m in the Santa Monica Basin although it appears in the San Pedro Basin (as a failure to recover towards "normal" conditions) (Figure 2). The San Pedro Basin is the first basin encountered after water leaves the Avalon sill.

Subtidal temperature data reveal that three smaller renewal events took place between the two larger events that dominated the tidal time series (Figure 4). Subtidal velocity time series demonstrate that flow five meters above the floor of the sill was indeed directed into the Santa Monica Basin at the time of all five low temperature events (Figure 4). Flow was also northwestward on the sill that separates the San Pedro and Santa Monica basins (not shown).

Comparison between velocity five meters above the floor of the sill and velocity 30 m below the sea surface at a location in the mouth of the Santa Barbara Channel, illustrates that northwestward flow over the sill into the San Pedro and Santa Monica basin is strongly correlated with upper water column southeastward inflow into the Santa Monica Basin from the Santa Barbara Channel (Figure 4). Southeastward flow into the Santa Monica Basin is typically associated with major upwelling events that occur near the mouth of the Santa Barbara Channel.

Along-sill sections of oxygen, density and light attenuation taken during an event in which water over the sill is flowing southeastward <u>out</u> of the Santa Monica and San Pedro basins show the along-basin near sill depth gradients

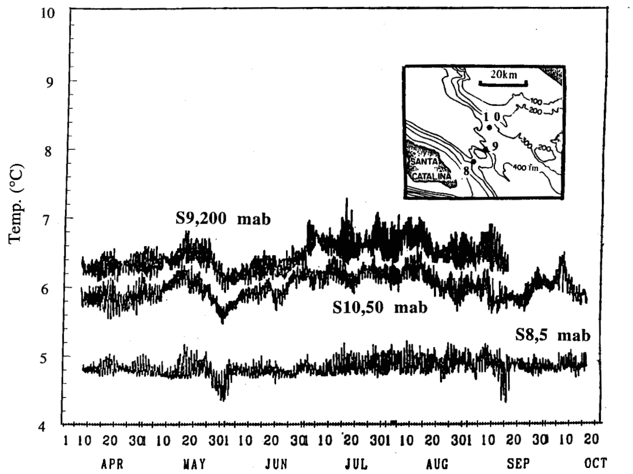

Figure 3. Time series of temperature at selected depths and locations on the Avalon sill, the sill separating the San Diego Trough from the San Pedro Basin.

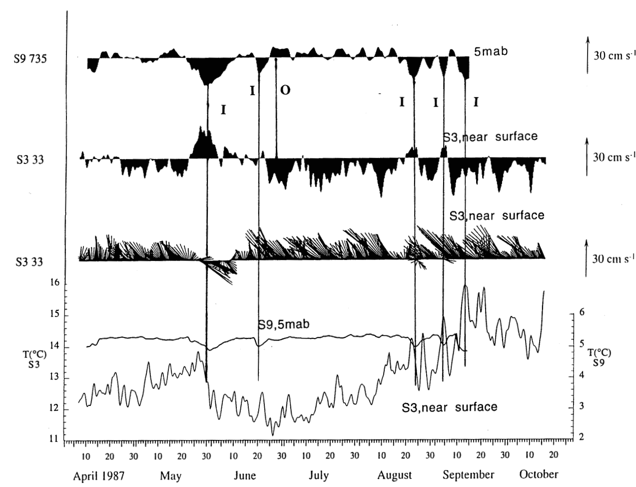

Figure 4. Time series of subtidal velocity (east-west component only) and temperature at sites on the Avalon sill (S9) as well as at a location in the mouth of the Santa Barbara Channel (S3). Negative velocity indicates flow over the sill <u>into</u> the San Pedro Basin or <u>into</u> the Santa Barbara Channel. Note that inflow over the sill is strongly related to outflow from the channel. Events discussed in the text are marked by vertical lines ("I" or "O" signifying inflow or outflow, respectively).

in oxygen (lower to the north), density (denser to the north), and light transmission (more turbid to the north). The density data suggest that the along-basin baroclinic (density-related) pressure gradient would be directed southeastward at this time. This relationship suggests that the direction of flow over the sill may be related to the along-basin pressure gradient, which is largely determined by upper water column processes.

DISCUSSION

A map of varved sediments in the basins shows that varved sediments cover almost the entire floor of the Santa Monica Basin (Figure 5). The existence of varved sediments, indicating a lack of bioturbation, is usually associated with low oxygen levels, or near-anoxic conditions. The near-anoxic region has increased rapidly over the last two centuries, from about 10% to almost 100% at present. Results presented herein shed some light on processes controlling the rate of renewal of bottom water in the basin. In particular, results indicate that renewal occurs infrequently (several year intervals) and that renewal events are of relatively short duration (a few days).

Renewal events appear to occur during strong upwelling events in the Santa Barbara Channel. During these events, sea level is set down toward the east in the channel. Moreover, Harms (1996) suggests that sea level in the adjacent basin (Santa Monica) rises in opposition to the southeastward wind stress. The resulting northwestward pressure gradient over the basin could be responsible for the northwestward flow over the basin sill.

The density of the water crossing the sill is such that in the absence of entrainment and mixing, the water would fall to the bottom in the San Pedro Basin in a localized region near the sill. The fact that the resulting temperature anomaly at a depth near 900 m (Figure 3) is about five times less than the temperature anomaly over the sill suggests that this is not the case (Figure 2). The dense plume likely entrains ambient water as it cascades off the sill, subsequently spreading out laterally on the density surface corresponding to the density resulting after entrainment.

Renewal of bottom water in the Santa Monica and San Pedro basins does not occur every year, in spite of several strong upwelling events that occur each year. Moreover, renewal events do not appear to be strongly correlated to upper water column flow directly overhead of the sill (not shown). These mysteries and other aspects of the renewal process are the subject of ongoing research which will eventually lead to a better understanding of the mechanisms controlling renewal in these and other basins of the California borderland.

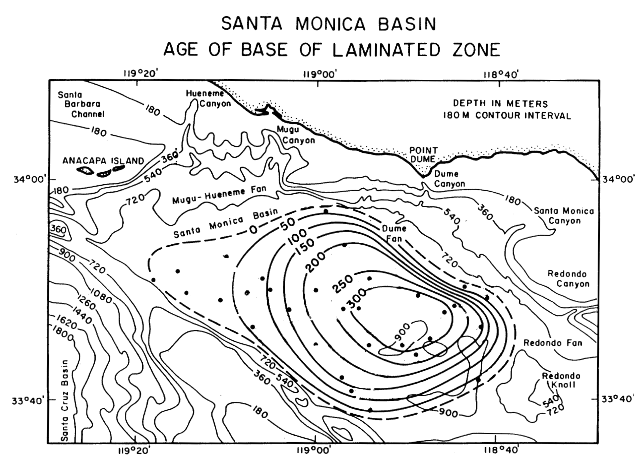

Figure 5. Thickness of varved sediments in the Santa Monica and San Pedro basins. Varved sediments are an indicator of near-anoxic conditions (Gorsline 1988).

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