SURFACE CIRCULATION PATTERNS IN THE SANTA BARBARA CHANNEL

C. D. Winant[1] and S. Harms[2]

[1] Scripps Institution of Oceanography, Center for Coastal Studies, UCSD
9500 Gilman Drive, La Jolla, CA 92093-0209
(858) 534-2067, FAX (858) 534-0300, E-mail: cdw@coast.ucsd.edu
[2] Alfred Wegener Institute for Polar and Marine Research
Postfach 12 01 61, D-27515 Bremerhaven, Germany
E-mail: sharms@awi-bremerhaven.de

ABSTRACT

Under the auspices of the Minerals Management Service (MMS), a four-year long program of measurements was conducted in the Santa Barbara Channel (SBC) to describe the circulation of waters and to relate that circulation to different forcing factors. The observational program consisted of five components. Meteorological measurements were acquired from a wide variety of sources. Currents and related physical parameters were measured at moored locations. Water-tracking drifters were deployed from 12 sites at regular intervals. Spatially intensive surveys of currents and water mass properties were conducted biannually. Maps of sea surface temperatures (SST) were obtained from satellite images several times each day. These diverse observations were synthesized into a description of the ocean circulation consisting of a finite number of characteristic patterns, or synoptic views. In the summer the four dominant patterns are labeled Upwelling, Relaxation, Cyclonic, and Propagating Cyclones. In the winter the circulation usually falls into either of two patterns labeled Flood East and Flood West. Different patterns prevail depending on the strength of two forcing functions: the stress imposed by the wind on the ocean surface at the western entrance to the channel, and the sea level difference between the Southern California Bight and the central California shelf.

Keywords: Santa Barbara Channel, Minerals Management Service, ocean circulation, currents, Southern California Bight, OSRA, oil spill risk.

INTRODUCTION

Observations of the surface circulation in the Santa Barbara Channel (SBC) (Figure 1) have been acquired over a four-year period (1993 to 1996), sponsored by the Minerals Management Service (MMS) of the U.S. Department of the Interior. The project was designed to achieve two parallel objectives. The first is to provide a description of the various components of the circulation, and a dynamical explanation suitable to guide the development of a predictive model. The second is to translate results into a form of immediate use to analysts charged with making decisions relating to development of resources.

The SBC is bounded to the north by the mainland coast of California, which is oriented from east to west in this area. The four Channel Islands: San Miguel, Santa Rosa, Santa Cruz, and Anacapa constitute the southern boundary. The passages between the islands are typically 40 m deep. The channel is about 100 km long and 40 km wide. The central basin extends to 500 m, and there are narrow, 3 to 10 km wide shelves on either side. The eastern sill has a depth of 220 m and the depth at the western sill is 400 m.

METHODS

The field effort consisted of five separate components. The first was designed to provide a comprehensive description of the atmosphere over the area of interest. Previous descriptions (Caldwell et al. 1986) suggest that the SBC is an area characterized by large variability, requiring high spatial resolution. This description is based primarily on fixed station observations from a variety of sources. The National Data Buoy Center (NDBC), also sponsored by MMS, maintains several meteorological buoys in and around the periphery of the channel (all these sites are located on Figure 1). In addition we have deployed an array of stations on four oil platforms and on two of the Channel Islands (Santa Rosa and Santa Cruz). Finally routine observations from Vandenberg AFB, the NDBC coastal stations, and the Santa Barbara Air Pollution Control District are integrated into the set of observations. Dorman and Winant (1998) summarize the results of this component.

The second component of the field effort relied on moored observations of physical parameters, horizontal currents, temperature salinity, and pressure to provide long time series (about four years long) of these parameters. The moorings, located on Figure 1, were deployed over the shelf along the 100 m isobath and at 200 m depth in the eastern entrance. In addition the meteorological buoys (53 and 54)

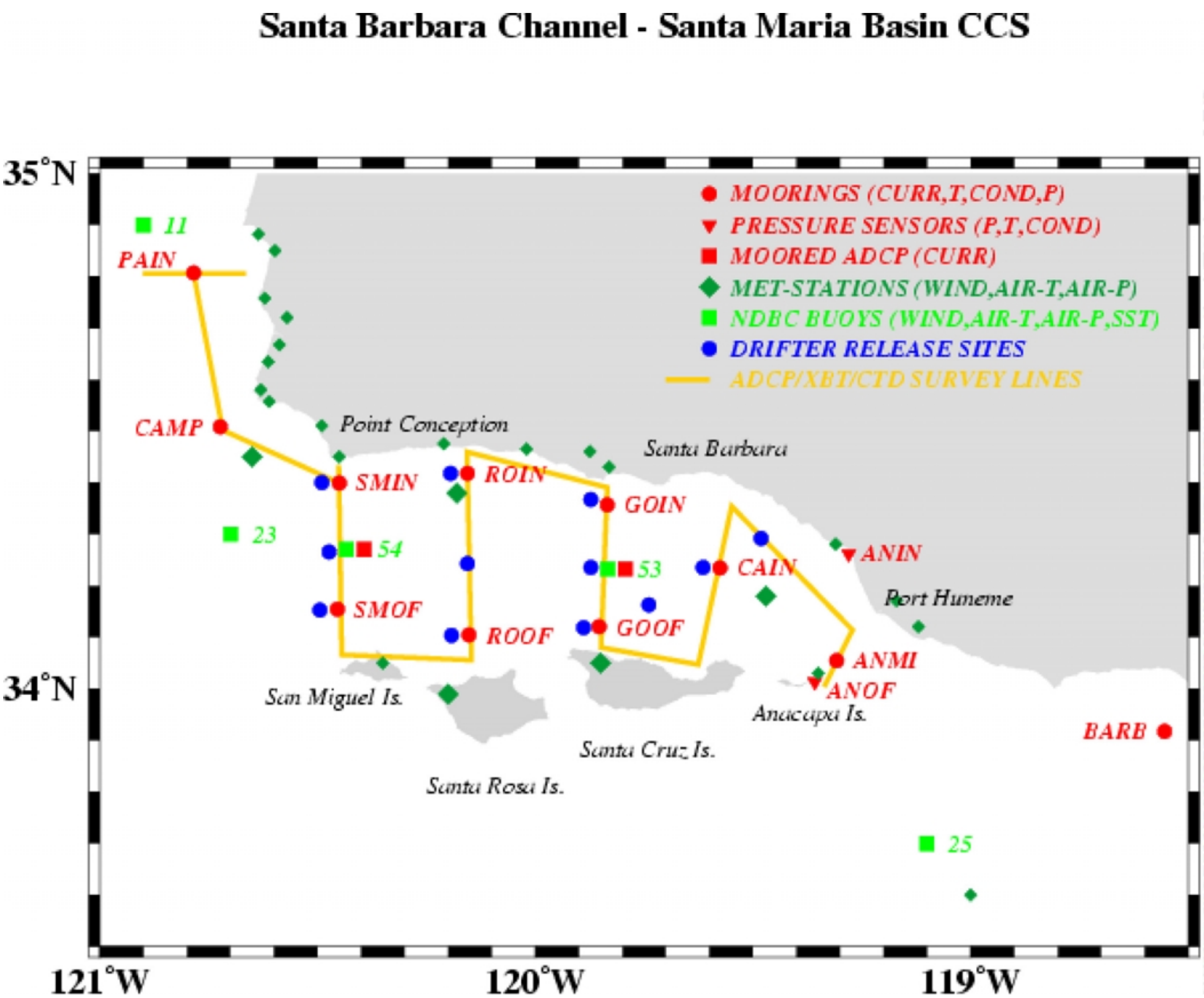

Figure 1. Santa Barbara Channel-Santa Maria Basin Coastal Circulation Study. Location of moorings, meteorological stations, drifter release sites, and survey tracks.

were equipped with current profilers. Current measurements were made at 5 and 45 m, except for the meteorological buoys where measurements are available at 16 m intervals, beginning 24 m beneath the surface. Results of this part of the field work are described by Harms and Winant (1998).

The third component of the work provides a description of near surface trajectories using drifters. These instruments are designed to follow surface water parcels, and telemeter their location back to shore several times each day. Drifters were released at the twelve locations illustrated in Figure 1, approximately every two months. Descriptive aspects of this component are summarized by Winant et al. (1999) and a statistical and dynamical interpretation is presented in Dever et al. (1998).

Spatially intensive snapshots of the flow constitute the fourth component. Shipboard surveys are conducted using Acoustic Doppler Current Profilers (ADCPs), expendable bathythermographs, (XBTs) and Conductivity-Temperature-Depth (CTD) surveys conducted at regular intervals. Daily archiving of satellite imagery provides another source of spatially intensive data (Hendershott and Winant 1996).

The fifth component consists of a number of modeling efforts aimed at synthesizing the observations as well as to provide a means of interpolating between observations which are either spatially sparse (moored measurements) or temporally sparse (surveys). The models are intended to eventually provide a capability to forecast flow situations.

RESULTS AND DISCUSSION

Synoptic Patterns of Circulation

Maps of daily averaged currents, including temperature and pressure fields were prepared for each day of the observational period. These maps were subjectively sorted to identify characteristic flow patterns, in the same way that meteorologists identify synoptic views for different weather patterns The observations can be sorted into six different synoptic states illustrated in Figure 2. These states are called the Upwelling, Relaxation, Cyclonic, and Propagating cyclone patterns, which are most commonly observed during spring, summer, and early fall; the Flood East and Flood West patterns tend to occur more frequently during the winter. About 60% of the daily average maps corresponds to one of these patterns. The remaining observations either correspond to transitions between patterns or involve much smaller scale features than can be resolved by the moored array.

As illustrated in Figure 2, there is always a cyclonic component to the circulation. The cyclonicity is strongest in summer and weakest in winter. In the Upwelling pattern, the circulation appears to result from the superposition of an equatorward (towards the southeast) current and the cyclonic eddy. In the relaxation pattern, a strong jet carries flow along the northern boundary towards the west, past Point Conception, while the flow along the Channel Islands is weak and towards the east. The Cyclonic pattern corresponds to a condition when the central eddy is at maximum strength with little net flow into the channel. The Propagating Cyclone pattern corresponds to a number of smaller cyclonic eddies which drift through the channel towards the west. Two modifications of the patterns just described occur in the winter, Flood East and Flood West. The first describe conditions in which the flow is everywhere directed towards the Southern California Bight, and the other pattern is the reverse. The patterns are similar to the Upwelling and Relaxation patterns, with reduced cyclonic circulation.

A more objective analysis of the current observations has been completed using Empirical Orthogonal Functions (EOFs). Eigenvectors and eigenvalues of the matrix of covariance coefficients between low-frequency components (periods longer than 38 hours) are determined. The EOF analysis is based on patterns from which the time average has been removed. The mean flow near the surface, as described by Harms and Winant (1998), consists of a westward flowing current on the northern shelf and a weaker eastward flow over the southern shelf. These opposing flows lead to a cyclonic circulation similar to pattern (C) in Figure 2. In the EOF analysis, each pair of eigenvalues and eigenvectors describes a mode of co-variation of currents. Details of the analysis are described by Harms and Winant (1998). Three modes account for 50% of the variance, the remainder is probably caused by smaller scale flow features. The dominant mode of circulation corresponds to a net flow through the channel, either poleward or equatorward. The second mode describes a cyclonic eddy. In combination with the mean flow, these modes are consistent with the subjectively derived patterns illustrated in Figure 2. The EOF analysis also describes how each pattern occurs as a function of season, or as a function of the external forcing.

Forcing of the Circulation

Harms and Winant (1998) suggest that circulation in the SBC is driven by a combination of two different forcing mechanisms. One is provided by the wind stress. During spring, summer, and early fall, the wind stress is very strong over the western portion of the SBC, and weaker along the northern boundary, as the strong winds which blow along

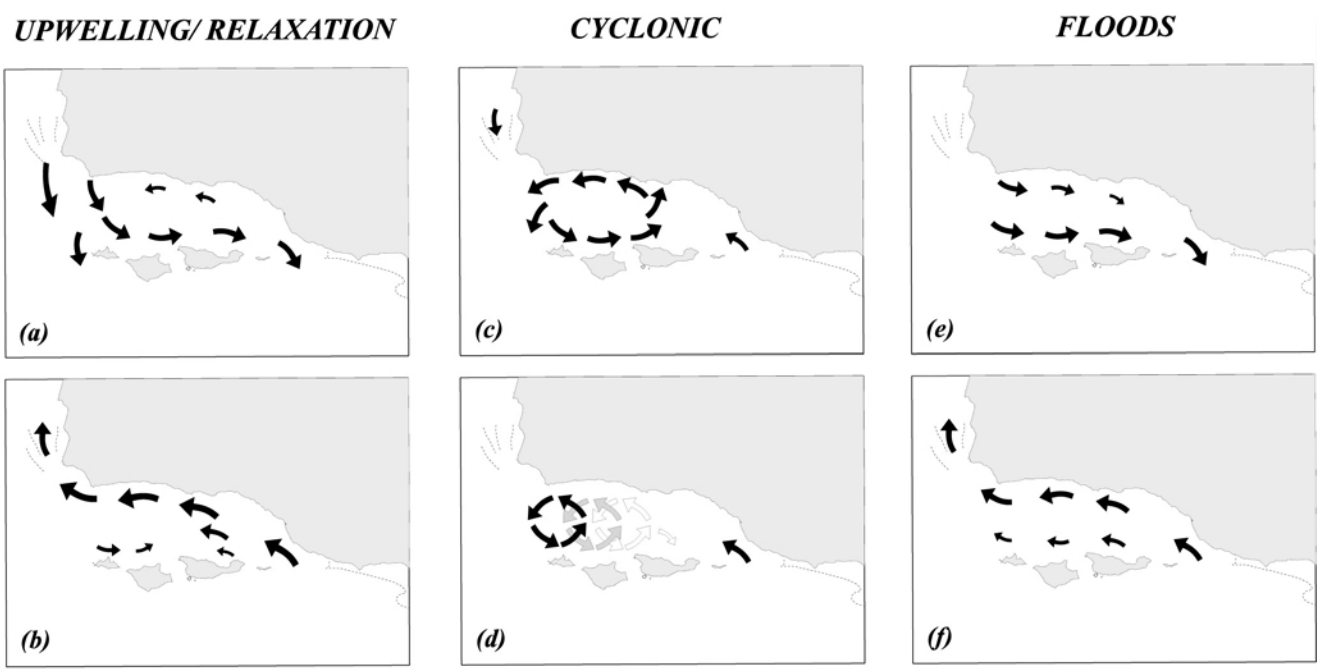

Figure 2. Schematic diagram of the six synoptic views of circulation in the Santa Barbara Channel. (a) Upwelling; (b) Relaxation; (c) Cyclonic; (d) Propagating Cyclones; (e) Flood East; and (f) Flood West.

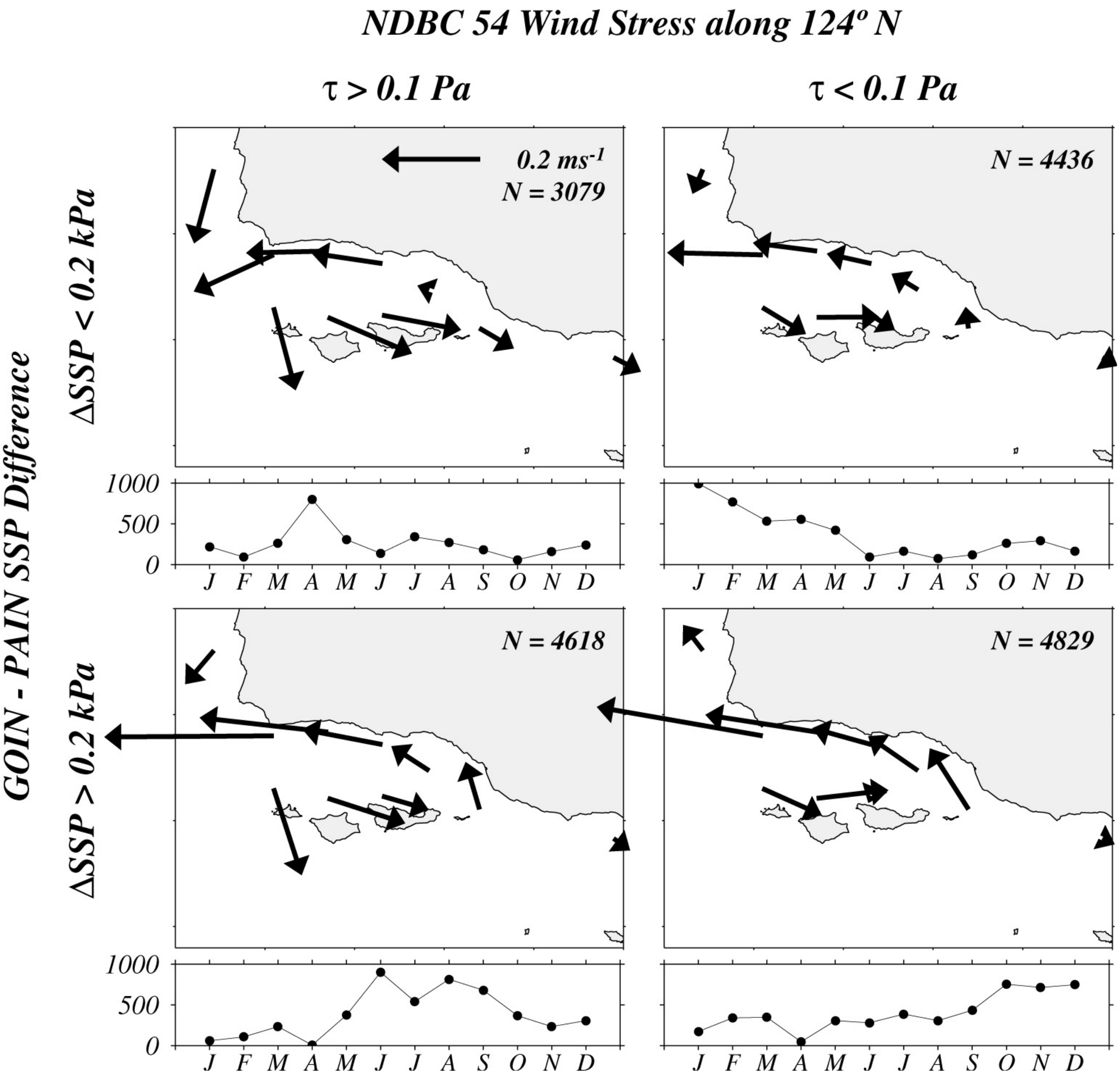

Figure 3. Conditionally averaged 5-m current velocity (ms-1) as a function of equatorward wind stress (in Pa) at NDBC 46054 along 124º N, and the along-channel SSP difference (in k Pa) between GOIN and PAIN. The number in the upper right corner of each panel is the number of realizations (hourly averages) upon which the conditional average is based.

the central California coast separate from the coast in the vicinity of Point Conception. The winds during these seasons are characterized not only by large wind stress, but by large spatial gradients in the wind stress alone. It is however not possible to explain the flow in the SBC on the basis of local wind stress alone. The most obvious reason being that the average wind stress is directed towards the southeast whereas the average current is directed in the opposite direction.

It is known that the areas on either side of the SBC, the central California coast and the Southern California Bight, have significantly different temperatures, particularly during the summer and early fall. Analyses demonstrate that areas of warmer temperature correspond to higher pressure at the surface than areas of lower temperature, and on this basis it is expected that a pressure gradient exists in the direction parallel to the coast. The mean pressure difference is the direction to oppose the mean wind stress. Quantitative estimates of the pressure difference suggest that it can have a comparable effect to that of the wind stress.

In order to define the relative effect of wind stress and alongshore pressure difference on the circulation, current observations have been sorted according to the direction and strength of each forcing function, as illustrated in Figure 3. The component of the wind stress along 124º N at NDBC buoy 54 is chosen as an index of the strength of the local wind, and the difference in synthetic surface pressure (equivalent to sea level) between stations GOIN (in the channel) and PAIN (north of Point Conception) represents the pressure gradient. Each map represents the average of all available current measurements under the illustrated conditions of wind stress and pressure difference.

The pattern of circulations changes systematically as the winds stress and pressure difference change, although the cyclonic tendency is always present. When the wind stress is strong and the pressure gradient is weak, the circulation resembles the Upwelling pattern, with a net flow through the channel towards the southwest, along the direction of the wind stress. When the wind stress is weak and the pressure difference is large, the circulation resembles the Relaxation pattern, characterized by a strong jet towards the west, consistent with the direction of the pressure difference. In intermediate situations, the flow resembles the Cyclonic pattern.

Synthesis

This research has established that the circulation of surface waters in the SBC can be described in terms of a finite number of circulation patterns, similar to the synoptic patterns used by forecast meteorologists to describe weather patterns. All patterns include a cyclonic tendency. A comparison of the synoptic patterns and two distinct forcing functions, the wind stress acting over the surface of the ocean and the pressure difference between the central California shelf and the Southern California Bight account for the different circulation patterns.

LITERATURE CITED

Caldwell, P. C., D. W. Stuart, and K. H. Brink. 1986. Mesoscale wind variability near Point Conception, California, during spring 1983. Journal of Climate and Applied Meteorology 25:1241-1254.

Dever, E. P., M. C. Hendershott, and C. D. Winant. 1998. Statistical aspects of surface drifter observations of circulation in the Santa Barbara Channel. Journal of Geophysical Research 103(C11):24,781-24,797.

Dorman, C. E. and C. D. Winant. The structure and variability of the marine atmosphere around the Santa Barbara Channel. Submitted to Monthly Weather Review, August 1998.

Harms, S. and C. D. Winant. 1998. Characteristic patterns of the circulation in the Santa Barbara Channel. Journal of Geophysical Research 103(C2):3041-3065.

Hendershott, M. C. and C. D. Winant. 1996. Surface Circulation in the Santa Barbara Channel. Oceanography 9(2):14-121.

Winant, C. D., D. J. Alden, E. P. Dever, K. A. Edwards and M. C. Hendershott. 1998. Near-surface trajectories off central and southern California. Submitted to Journal of Geophysical Research, July 1998.