INTRODUCTION AND BACKGROUND

An extensive physical oceanographic data set was collected from the region off the coast of Central California in order to study the dominant features of the subtidal current variability between Point Conception and San Francisco Bay. This study began in 1983 and was motivated by the fact that relatively few direct measurements of slope and shelf currents were available from this portion of the California coast at that time. The current structure, dynamics and energetics of this region remained relatively ill-defined promoting assessments of environmental impacts which are correspondingly vague.

This synopsis presents some results derived from the analysis of the Central California Coastal Circulation Study (C4S) measurement set pertinent to the following topics: 1) description of the major features of the observed current field and their relationship to the local wind field, 2) description of seasonal transitions or trends observed in the flow field and relationship to other physical fields, 3) characterization of subtidal wave-like features in the flow field and probable forcing mechanisms. Results shown are taken from Bernstein et al. 1985; Bernstein et al. 1986; Bratkovich 1989; Bratkovich et al. 1985; Bratkovich et al. 1988; Bratkovich et al. 1991; Breaker and Bratkovich 1991; Chelton 1984; Chelton 1987; Chelton et al. 1988; Chelton et al. 1987; Chelton and Kosro 1987a, 1987b, 1987c, 1987d.

Historical observations from this region, supporting data and theoretical work, as of the initiation date for this project (e.g., Allen 1980; Bernstein et al. 1977; Brink 1983; Hickey 1979; Hickey and Pola 1983; Huyer 1983; Huyer et al. 1979; List and Koh 1976; Lynn et al. 1982; McClain and Thomas 1983; Munk et al. 1970; Nelson 1977; Nelson and Husby 1983; Reid et al. 1958; Reid and Schwartzlose 1962; Schwartzlose 1963; Smith 1968; Sverdrup et al. 1942; Traganza et al. 1980; Wickham 1975; Winant and Bratkovich 1981; Winant 1980; Wyllie 1966; Yoshida 1980) indicated that a coastal undercurrent flows poleward a large percentage of the time, and that a seasonally varying poleward countercurrent, the Davidson Current, opposed the mean equatorward surface flow further offshore which is the primary component of the California Current System. This representation of the coastal current variability off Central California was largely reconstructed from nonsynoptic, sporadic data which in many cases is based upon inferential relationships between water mass properties and currents. The C4S observational study, which was rich in longer-term direct measurements of current variability, was designed to quantify some of the dominant flow characteristics of this apparently complex oceanographic region.

The field measurement interval was February 1984 through July 1985. The field observations were conducted by Raytheon Service Company (RSC) as part of the Mineral Management Services (MMS), U.S. Department of the Interior, funded Central California Coastal Circulation Study (C4S). Hydrographic surveys, surface drifter measurements, and moored current,
temperature, salinity, and bottom pressure measurements were executed by RSC while supporting data (e.g., sea surface elevation and surface winds) were gathered from standard sources. SeaSpace provided remotely sensed sea surface temperature imagery for the region. Chetton et al. (1987) gives an overview of the field program.

Five mooring transects were occupied during this eighteen month period composed primarily of outer shelf (100 m total water depth) and upper slope (500 m total water depth) moorings with an alongshelf shelf spacing of 75 to 125 km. Figures 1 and 2 are detailed planview and perspective illustrations of the moored current meter array. Nominal instrument depths were 70, 220 and 470 m. Four hydrographic surveys were conducted as part of the observation set and SST imagery was gathered on a nearly continuous basis throughout the entire observation period. Four drifter sets were also deployed and tracked as part of the integrated measurement program.

Some parameters of geophysical and dynamical significance for this area are the local inertial frequency, f (0.00078 rad/s), the average buoyancy frequency, N (~0.003 rad/s), and the local bottom slope, s, which varies between 0.01 and 0.001 depending on location. The buoyancy frequency also varies with position in the water column and with season (by roughly a factor of three).

**REPRESENTATIVE ANALYSES AND RESULTS**

This presentation focuses primarily upon subtidal (time scales significantly longer than 1 day) flow variability, structure, and associated forcing and property transport. Here we differentiate between synoptic or "event" time scales (2 - 10 days), subsynoptic time scales (10 - 50 days), seasonal time scales (50 - 150 days) and annual time scales (150 - 500 days). No comparable spatial scale stratification is employed since the eccentric, anisotropic nature of coastal current features disallows such classification.

**Current Structure and Subtidal Temporal Variability**

The flow on the upper slope and outer shelf between Point Conception and Monterey Bay appears to be predominantly poleward throughout the field measurement period. The mean current speeds (over ~3 month intervals) at the 70 m depth level are 0(15 cm/s) with standard deviations for subtidal time scales of comparable amplitude (Figure 3). Current means and
Figure 2. Perspective view of C4S moored array and shelf/slope geometry. For most mooring sites primary current meter depth levels are 70 m, 220 m and 470 m. During the later third of the overall observation period, near-surface current meters were successfully deployed at Stations C, D and E at 10 m or 30 m depth levels using surface buoyancy slack moorings (Bratkovich 1989).
Figure 3. Time series of surface winds, water temperature and alongshelf currents for selected locations and depth levels in C4S array. The positive cross-shelf (alongshelf) axis is directed towards SS T (325 T) (Chelton et al. 1987).
standard deviations at the 220 and 470 m measurement levels are significantly smaller than 70 m depth level values (means and standard deviations of 10 cm/s or less) at most mooring locations and during most deployment intervals. The deeper instrument locations at the Point Sur and, to a lesser degree, the Piedras Blancas mooring transects are an exception to this tendency. Figure 3 also shows energetic mean (time averaged over a month or more) and variable flow components at 220 and 470 m depths at these locations, most notably during late spring and early summer of both 1984 and 1985.

The time series data displayed in Figure 3 demonstrate the tendency (at least in the upper 300 m of the water column) for currents to flow poleward a large percentage of the time (80% or more) between Piedras Blancas (Station F/G) and Point Sur (Station J). The most energetic flows approach 50 cm/s in amplitude and persist at 25 cm/s or greater for periods of 10 to 30 days. For the 70 m depth instrument located in 500 m water depth off Piedras Blancas, the subtidal component of flow reverses infrequently (about 20 times per annual cycle). Episodes of zero crossings tend to be spaced by intervals of 20 to 40 days, a dominant time scale in the variability of the subtidal alongshelf flow.

Less frequent measurements of near-surface currents show that fluctuations tend to be comparably energetic (to 70 m depth level currents), but less directionally consistent than currents at depth levels of 70 m and greater. All of the 10 and 30 m depth level instruments were deployed on the Point Sal line during spring and summer of 1985. During this time interval, surface currents tended to be directed shoreward with alongshelf component means (taken over the deployment interval) which were less than 5 cm/s and directed equatorward. Compared to the rest of the moored array (depths greater than 30 m), these locations were occupied less than 30% of the time and resulting statistically based results are thus less conclusive or representative.

Standard deviation values for the subtidal current components indicate that a typical advection range perturbation for a 1 day interval would be 8 to 13 km (an average advection rate of 10 to 15 cm/s for a duration of 1 day). Assuming the horizontal current fluctuations are normally distributed, the advection range perturbation would be double (triple) this value less than 5% (1%) of the time. These perturbations would be biased by a mean value of daily advection range of 5 to 20 km.

Some of the unique circulation features in the C4S region are shown in Figure 4 including a region of persistent offshore flow in the vicinity of Point Sur and an apparent onshore flow at Point Sal (70 m depth level) which is unusually persistent and energetic (~10 cm/s) considering its proximity to the coastline. This latter feature may be a manifestation of a near-surface pressure gradient field which has a significant equatorward component. A purely geostrophic balance would require onshore flow in the vicinity of the pressure front. For an unsteady quasigeostrophic flow field, an equatorward pressure gradient component would tend to accelerate fluid poleward as opposing forcing contributions (such as surface wind stress) subside. This tendency towards poleward acceleration during periods of slackened equatorward surface winds is one of the dominant characteristics of the flow between Point Sal (Stations C, D and E) and Piedras Blancas (Stations F and G). Chelton et al. (1988) have established that the wind and current fluctuations which occur in the Point Sal region profoundly influence the current variability, and associated water mass characteristics such as near-surface temperature, at locations further poleward in the study area. They show that about 50% of the variability in
Southern California Bight Physical Oceanography Workshop

currents off Point Sal is correlated with local wind forcing and that currents observed at mooring transects further upcoast tend to be better correlated with winds at Point Sal than for more local wind observations. A tentative hypothesis based on this result is that the Point Sal - Point Arguello region provides dynamical control for currents over the upper slope and outer shelf for most of coastal Central California.

Hydrographic data shown in Figures 5 and 6 indicate the apparent persistence and spatial continuity of the alongshelf geostrophic velocity component field. A nearly synoptic picture (Figure 5) of the alongshelf geostrophic velocity field at five different sections shows that the undercurrent is nearly continuous in space and apparently NOT distinct from a shelf-trapped surface countercurrent. Figures 6a and 6b also shows the current structure in plainviw and at one transect for all four of the surveys. The undercurrent is a persistent feature with maximum poleward speeds of 20 to 30 cm/s. Direct observations of currents at depth at the same shelf transect confirm that these maximal values are accurate in an absolute sense not just relative to a geostrophic "reference level."

Relationship to Surface Wind Forcing

The relationship between surface winds and 70 m depth level currents is examined for a selected time window and locations in Table 1. The correlation between subtidal wind and current fluctuations attains a maximum value of ~0.73 at a time lag of +0.25 days for Station K alongshelf currents and alongshelf wind stress component measured at Buoy 46012 (Half Moon Bay). A positive time lag implies wind stress component fluctuations which lead current component fluctuations. There are also relatively high correlations (0.61) between Stations A and C and the alongshelf wind stress component estimated using buoy winds measured off Point Sal (Buoy 46011) at time lags of 0.5 and 0.0 days respectively. These correlation levels imply that 37 - 54% of the low frequency alongshelf current variance at 70 m depth on the shelf can be directly associated with local wind forcing. For these particular calculations, the 95% nonzero significance level corresponds to an "artificial agreement" of ~4 to 10% of the alongshelf current variance with alongshelf surface wind stress.

For slope moorings at the 70 m depth level and local surface wind stress there are lower maximum significant correlation values (0.32 - 0.43), and the lag of maximum correlation tends to be longer (0.25 - 1.25 days, wind stress leading currents). Roughly characterized, the

Figure 4. Planview of mean currents at 70 m depth horizon showing representative persistent features in regional flow field. All values shown are averaged over approximately 100 day period encompassing spring and early summer of 1984 (Bratkovich 1986).
Figure 5. Alongshelf geostrophic flow field for six transects along central California. Positive values are poleward (Chelton and Kosro 1987a).
currents above the slope at the 70 m depth level appear to be much less responsive to local wind forcing than are the shelf currents at the same depth level. This finding is consistent with results based on local wind and current measurements from the Coastal Ocean Dynamics Experiment (CODE) (e.g., Winant et al. 1987) conducted on the continental shelf and slope north of San Francisco Bay.

For the Piedras Blancas case, the alongshelf component of flow at 70 m opposes the alongshelf component of wind about 90% of the time and local maxima in poleward flow coincide with local minima in equatorward winds about 75% of the time. Periods of slack equatorward winds are accompanied by poleward current accelerations at depth of magnitude \(-0.0002\) cm/s\(^2\). This acceleration value when balanced with an equivalent pressure gradient force would be equivalent to a spatially averaged sea surface tilt of order 2 cm/100 km. A geostrophically balanced average onshore flow of 5 cm/s would indicate that the local value of the cross-shelf component of pressure gradient force (or equivalent sea surface tilt) in the region near Point Sal might exceed this spatially averaged value by a factor of two or more.

**Seasonal Variability of Surface Winds and Subtidal Circulation**

The seasonal cycles in oceanographic fields for this region are generally weak compared to the synoptic and subsynoptic scale variability. One notable exception is the annual cycle in near surface water temperature which responds on larger spatial scales to seasonal variations in solar insolation and air temperature. The annual cycle in water temperature lags that of solar insolation by several months due to the thermal inertia of the coastal water mass and the effects of vigorous upwelling favorable winds. List and Koh (1976) analyzed long time series of water temperatures at various locations along coastal California. They found that the annual water temperature cycle was much smaller for
A. Bratkovich, R.L. Bernstein, D.B. Chelton, and P.M. Kosro
Central California Coastal Circulation Study

Table 1. Maximum correlations and corresponding time lags between 70 m alongshore currents at C4S moorings and alongshore wind stress. Alongshore is defined by the major principal axes determined from the February through July 1984 time series. Also given in the table are the 95% significance levels of the correlations (computed as in Chelton 1983), the percent variance explained by the correlations, and the lags of maximum correlation. Positive lags indicate that currents lag wind stress. Dashes indicate that the correlation was not statistically significant at the 95% confidence level at any lag (From Chelton et al. 1988).

<table>
<thead>
<tr>
<th>Mooring Site</th>
<th>Major Axis (*T)</th>
<th>Wind Buoy</th>
<th>Max. Correl.</th>
<th>95% signif. Level</th>
<th>% Var. Explained</th>
<th>Lag of Max. Correl. (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelf Moorings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>326.8</td>
<td>46012</td>
<td>0.73</td>
<td>0.34</td>
<td>53.3</td>
<td>0.25</td>
</tr>
<tr>
<td>F</td>
<td>304.1</td>
<td>46011</td>
<td>0.61</td>
<td>0.25</td>
<td>37.2</td>
<td>0.50</td>
</tr>
<tr>
<td>C</td>
<td>320.3</td>
<td>46011</td>
<td>0.61</td>
<td>0.26</td>
<td>37.2</td>
<td>0.00</td>
</tr>
<tr>
<td>A</td>
<td>302.0</td>
<td>46011</td>
<td>-</td>
<td>0.21</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Slope Moorings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>352.1</td>
<td>46012</td>
<td>0.40</td>
<td>0.34</td>
<td>16.0</td>
<td>1.25</td>
</tr>
<tr>
<td>J</td>
<td>316.1</td>
<td>16028</td>
<td>0.32</td>
<td>0.31</td>
<td>10.2</td>
<td>1.00</td>
</tr>
<tr>
<td>G</td>
<td>328.0</td>
<td>46011</td>
<td>0.36</td>
<td>0.31</td>
<td>13.0</td>
<td>0.75</td>
</tr>
<tr>
<td>D</td>
<td>334.7</td>
<td>46011</td>
<td>0.43</td>
<td>0.21</td>
<td>18.5</td>
<td>0.25</td>
</tr>
<tr>
<td>B</td>
<td>284.9</td>
<td>46011</td>
<td>-</td>
<td>0.23</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Central California stations (~3°C peak-to-trough) than for stations to the north or south (~8°C peak-to-trough). Nelson (1977) and Nelson and Husby (1983) indicate significant long-term average annual cycles in surface wind stress and surface heat flux for the Central California coast.

The C4S observation set was consistent with the above as illustrated in Figure 7. Near surface meteorological observations showed a strong annual cycle in surface water temperature (~5°C peak-to-trough). Over-water winds (as reported from coastal NDBC data buoys) were persistently upwelling favorable peaking in May at ~9 m/s. Winds remain upwelling favorable at this location throughout the year, but weaken substantially in winter months. The 70 m depth horizon temperature measurements (see also Figure 8) showed a weak annual cycle (~2.5°C peak-to-trough). At this same depth horizon, the currents were consistently poleward peaking (~25 cm/s) in the last half of the year and diminishing to less than 10 cm/s in spring. Synoptic and subsynoptic variability appear to play a much more dominant role on the outer shelf and upper slope in this region.

Subtidal Wavelike Features

For the subtidal (less than 1 cpd) frequency range resolvable with this moored data set (an acceptable level of statistical stability can probably be achieved down to ~0.03 cpd), sea surface and current variability should be due in part to the passage of long, wind-forced, frictionally modified, coastal-trapped waves (e.g., as described by Chapman (1987) for the
Figure 7. Monthly averaged data (dots are averages, sticks show standard deviation) for surface water temperature and winds (top), temperature and currents at Station F (middle frames), and temperature currents at Station G (bottom frames) for the Piedras Blancas transect (see Figure 1) (Bratkovich 1999).
CODE region) and to the response to local variations in the wind stress, bottom stress and pressure force components. The local wind-forced response is one dominant type of variability expected in this region as exhibited by the correlation levels of Table 1. Examining the time-space lagged correlation of sea surface fluctuations, currents, and winds over the array region, helps quantify the percentage variance contributed to variable fields of interest by wavelike disturbances propagating through the study region. If a limited number of wave modes (one or two) dominate the variability, and these modes have stable phase propagation characteristics, the modes should be readily identifiable in time-space domain statistics (cross-correlation functions).

Table 2 shows results from a multivariate regression analysis derived from the first 6 months of the 70 m depth current and offshore wind data. The alongshelf current fluctuations at a given outer shelf location were regressed on local alongshelf wind stress component at fixed lag (wind stress leads by 0.25 days) and alongshelf currents at 70 m depth for the next most equatorward outer shelf mooring location. These results give an indication of the relative importance of poleward propagating disturbances in the current field compared to local wind forcing effects. The highest correlation values observed range from 0.64 at Station C to 0.78 at Station F with 41% and 61% of the current variance explained respectively. The alongshelf propagation speed associated with the lag for maximum correlation was 69.3 and 204 cm/s respectively.

Comparing these results to those used to evaluate the effect of local wind forcing (see Table 1), one can estimate, to first order, the relative contributions of local wind forcing and subtidal wavelike effects with respect to shelf currents. By adding terms due to wavelike effects, the percent variance explained at a given outer shelf location increases by roughly 5 to 15%. While this contribution is a significant part of the total variance explained, it appears that the response to local wind forcing is a more significant determinant of alongshelf current variability than poleward propagating wavelike disturbances. Nevertheless, the phase speed values derived from this analysis are in a realistic range for continental shelf waves (e.g., Chapman 1987) as illustrated in Figure 8.

Energetic Events

The most energetic current amplitude and variability episodes observed in the C4S region during the limited observation period occurred during late summer 1984 between Point Sal and Monterey Bay. Three energetic pulses of poleward flow in the 40-60 cm/s amplitude range (~70 m depth horizon, Piedras Blancas and Point Sur) were spaced by ~30 days. The stack plots in Figure 3 show the detailed variability of physical fields during this timeframe. The middle pulse was preceded and followed by more equatorward (less poleward) directed currents. The peak-to-trough amplitude of these oscillations approached 70 cm/s and was easily identifiable at the 220 m depth level where their amplitude was attenuated by ~30%. There was no discernable signal in the current field at 470 m associated with these pulses.
Table 2. Multivariate regression of the alongshore component of 70 m currents $v$ on local alongshore wind stress $T_y$ and alongshore 70 m currents $v_x$ at the neighboring C4S shelf mooring to the south. Alongshore is defined by the major principal axes. The form of the regression is $v(t) = a T_y(t-t_1) + b v_x(t-t_2)$, where $a$ and $b$ are the regression coefficients. The lag $t_1$ for local wind forcing was fixed at 0.25 days and the lag $t_2$ for currents to the south was varied from -1 to +1 week. The maximum multiple correlations, 95% significance levels of the multiple correlations (computed as in Chetton 1983), and percent variance explained by the correlations are given in the table. Also listed in the table are the lag $t_2$ of maximum correlation, mooring separation, and the corresponding alongshore propagation phase speed (positive poleward) (From Chetton et al. 1988).

<table>
<thead>
<tr>
<th>Mooring Site</th>
<th>South Site</th>
<th>Wind Buoy</th>
<th>Max. Correl.</th>
<th>95% Signif. Level</th>
<th>% Var. Explained</th>
<th>Lag of Max. Correl. (days)</th>
<th>Mooring Separ. (km)</th>
<th>Phase Speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>F</td>
<td>46012</td>
<td>0.78</td>
<td>0.39</td>
<td>61</td>
<td>1.25</td>
<td>221.1</td>
<td>204.7</td>
</tr>
<tr>
<td>F</td>
<td>C</td>
<td>46011</td>
<td>0.73</td>
<td>0.26</td>
<td>53</td>
<td>0.50</td>
<td>75.2</td>
<td>174.1</td>
</tr>
<tr>
<td>C</td>
<td>A</td>
<td>46011</td>
<td>0.64</td>
<td>0.30</td>
<td>41</td>
<td>1.25</td>
<td>74.8</td>
<td>69.3</td>
</tr>
</tbody>
</table>

The maximum local alongshelf fluid accelerations observed were $\sim 10^{-4}$ cm/s$^2$ while the local coriolis correction (cross-shelf momentum balance) was $\sim 50$ times larger as expected for a dominantly geostrophic balance. Associated pressure gradient force contributions would be equivalent to sea surface slopes of 1 cm/100 km (alongshelf gradient component) and 50 cm/100 km (cross-shelf gradient component) respectively. Since the associated velocity component signal varies in amplitude with depth, one expects the geostrophic flow field to be essentially baroclinic. This baroclinic tendency would set up internal density structure slopes which are of opposing sign and more than an order of magnitude larger than equivalent sea surface tilts if barotropic and baroclinic contributions to the upper water column (depth less than 500 m) pressure gradient field are of comparable amplitude.

The dynamic height field, contoured in Figure 9, shows that the baroclinic component of the geostrophic field is consistent with poleward surface flow from Point Conception to San Francisco Bay. The 70 m depth horizon time-averaged currents (shown as red vectors) are also consistent with poleward flowing surface waters. The blue streak is a smoothed surface drifter track for the time

![Figure 8: Spatial lag versus time lag for maximum time-space lagged correlations found in Chetton et al. (1988) are shown as dashed lines and correspond to results presented in Table 2. Solid lines correspond to maximum time-space lagged correlation regions based on Chapman (1987) model phase speed values (Brethkovitch 1989).](image)
period 12-20 July which is consistent in orientation with the flow at 70 m off Piedras Blancas and, for this specific case, the associated surface drifter and measured current speeds are of comparable amplitude (~40 cm/s).

The sea surface temperature (SST) signature of this poleward flow event is very evident in Figure 9, which shows a plume of warmer water (darker shades) extending poleward from the western Santa Barbara Channel towards San Francisco Bay. For the later half of July, SST measured at the four NDBC buoys between the Channel Islands and San Francisco Bay show elevating surface temperatures which peak in the last half of July and then subside (2 to 4°C) by early August. This signal structure is partly due to the subsidence of upwelling favorable winds along this portion of coast during the first half of July followed by the re-establishment of upwelling favorable wind conditions in last July and on into August. It is clear from the data presented in Figure 9, that to some degree, the alongshelf poleward advection of heat also
plays an important role in influencing SST conditions, especially in the southern half of the region.

Analysis Associated with an Actual Oil Spill Event

Breaker and Bratkovitch (1991) have reported results associated with an oil spill which occurred near the northern edge of the C4S study region close to the midpoint of the observation period. The oil slick path is shown by the time sequence of locations and times in Figures 10a and 10b. A simple estimator for oil slick location was constructed using three components: advection by "mean" currents, drift due to surface wind forcing, and displacement perturbations due to tidal currents (which can be significant near the mouth of San Francisco Bay). Using historical values (determined a priori) of mean current (6 cm/s to the NW), wind drift coefficient (3.5% of surface wind speed), and tidal current ellipses for the region, ~70% of the mean square oil slick displacement could be accounted for using this model. About 90% of the mean square displacement could be accounted for using a "best fit" value for wind drift coefficient (~4.4% of surface wind speed). A reversal in oil slick direction early in its evolution could be attributed to the onset of a large scale reversal in shelf currents. This conclusion was reached using indirect evidence associated with advection of large scale temperature gradients and regionally averaged rates of change in the surface temperature field.

The accurate hindcasting or prediction of oil spill trajectories appears to be technically feasible, but practically out of reach. We still do not have the necessary coastal observation networks and the near-real-time communication and modeling components required to provide logistical guidance for environmental emergencies like the case reported and analyzed above.

ACKNOWLEDGMENTS

The work was funded by the Minerals Management Service, U.S. Department of the Interior under contract to Raytheon Service Company (RSC) as part of the analysis component of the Central California Coastal Circulation Study. We would like to acknowledge the key roles D. Cook, R. Tait (RSC) and S. Larson (MMS) played in the management of the overall project. D. Lindner, G. Parker, N. Plutchak, M. Speranza and W. Van Atta coordinated and executed the field observation program for Raytheon Service Company. M. Falla and G. Davis (RSC) processed and organized the extensive time series data base. T. Kan, J. Faulkner, and I. Wang organized the time series data base and were instrumental in the overall data analysis activity for this component of C4S. The support of the Center for Earth Sciences, University of Southern California, and of the NOAA Great Lakes Environmental Research Laboratory is gratefully acknowledged by A.B.
Figure 10a. Oil slick locations at different times along the central California coast during the period of the PUERTO RICAN tanker oil spill between 3 and 12 November 1984. Approximate shapes of the oil slick pattern are also indicated; hence, the bulbous extremities associated with the oil slick at locations 1 and 2 (Breaker and Bratkovich 1991).
Figure 10b. Progressive vector diagrams of A) oil slick displacements, B) wind drift currents (based on NDBC buoy winds), and C) residual currents which were modeled as a "mean current" plus tidally induced "noise component" (Breaker and Bratkovich 1991).

REFERENCES


Breaker, L.C., and A. Bratkovich. 1991. Oceanic processes contributing to the displacement of oil spilled off San Francisco by the M/V Puerto Rican. Submitted to Oil and Chemical Pollution. 46 p.


Southern California Bight Physical Oceanography Workshop


Schwartzlose, R.A. 1963. Nearshore currents of the western United States and Baja California as measured by drift bottles. CalCOFI Reports. 9:15-22.


SOUTHERN CALIFORNIA BIGHT PHYSICAL OCEANOGRAPHY

Proceedings of a Workshop
As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.