CIRCULATION PATTERNS IN THE SANTA BARBARA CHANNEL

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ABSTRACT

Currents at depths of 5 m and 45 m as well as winds and sea surface pressures have been monitored since 1992 at moorings located in the Santa Barbara Channel and the Santa Maria Basin. Conditional averaging of the observed currents on local winds and on the measured along channel sea surface pressure difference reveals one circulation pattern individually forced by observed local winds, another individually forced by observed local gradients of sea surface pressure, and a third not attributable to either. These patterns closely resemble, but are not identical with, the upwelling, relaxation, and cyclonic synoptic patterns of Harms and Winant (1998).

Keywords: Santa Barbara Channel, Santa Maria Basin, ocean circulation, ocean currents, wind forcing, pressure gradient forcing, Minerals Management Service, sea surface pressure gradient.

INTRODUCTION

Materials And Methods

With the support of the Minerals Management Service, currents at depths of 5 m and 45 m as well as winds and sea surface pressures have been monitored since 1992 at moorings located in the Santa Barbara Channel and the Santa Maria Basin. At each mooring, sea surface pressure was constructed from simultaneous sea floor pressure gauge time series and water column temperature times series as in Harms and Winant (1994). For the present analysis, the wind stress in the Santa Barbara Channel-Santa Maria Basin will be represented by the wind at meteorological buoy NDBC54 in the western mouth of the Santa Barbara Channel; the analysis of Harms and Winant (1998; hereafter HW) justifies this choice and quantifies the amount of variance thus captured. The sea surface pressure gradient over this region will be represented by the difference between sea surface pressure at a mooring (ANMI) in the eastern mouth of the Santa Barbara Channel and that at a mooring (SMIN) just off Point Conception in the western Santa Barbara Channel. These series will be called simply "wind" and "pressure difference" in the following discussion.

All time series have been low pass filtered to remove variance associated with periods shorter than about 36 h. All correlations quoted have been computed after removal of the seasonal cycle, so that the results do *not* apply to the seasonal variation of currents. Positions of all stations to which the text makes reference are shown on Figure 1.

The unusual length of time over which data have been collected makes it possible to use conditional averaging to separate the circulation into a part driven by the wind and a part associated with the gradient of sea surface pressure. As an example, if the currents at the moorings are averaged over only those time intervals when the measured wind was below a small threshold and the measured pressure difference exceeded a large threshold, then the result is called a conditional average of the currents. It is reasonable to expect that this particular conditional average would be a pattern of currents that is strongly correlated with the pressure difference, but not with the wind. The question to be answered below is "does conditional averaging on observations of wind and pressure difference produce patterns individually directly attributable to winds and to pressure differences?"

RESULTS

Many surprising features emerge from the analysis. The first superficially surprising result (Figure 1) is that, when the 5 m currents are averaged over periods of gentle winds and large pressure differences, the 5 m currents then flow equatorward (poleward) when the sea surface pressure is higher (lower) at the east mouth of the Santa Barbara Channel (mooring ANMI) than it is beyond Point Conception (mooring PAIN). This is just the opposite of what would be expected in simple laboratory flows or in ocean flows where friction is important; in these, the flow would be away from regions of high pressure and towards regions of low pressure. What does it mean?

HW (their Figure 16) carried out a similar analysis, one, however, based upon the pressure difference between GOIN and PAIN and obtained the expected result; flow was equatorward (poleward) when the sea surface pressure was lower (higher) near the east mouth of the Santa Barbara Channel than it was beyond Point Conception. The contrary

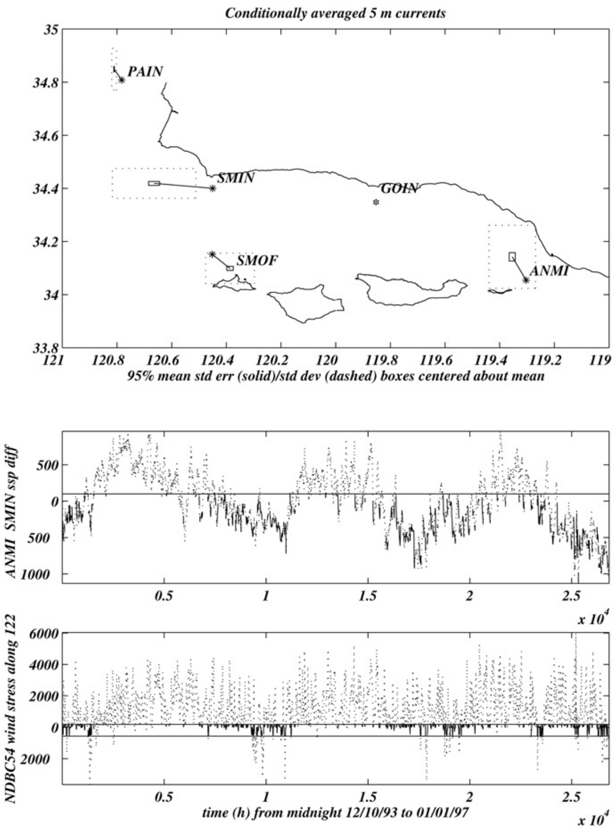

Figure 1. Top panel shows 5 m current vector in conditional average over the ANMI-SMIN sea surface pressure difference bins defined in the middle panel and wind stress bins defined in the lower panel. Mean wind stress is -0.001 dy/cm^2, and mean ANMI-SMIN sea surface pressure difference is -0.302 kPa (ANMI pressure is *lower* than SMIN; see text). Middle and lower panels, respectively, show 1177 days of ANMI-SMIN sea surface pressure difference and of wind stress at meteorological buoy NDBC54 along 122^o starting at midnight, 12/10/1993. Full series are dotted lines, values included in conditional average bins are solid lines, bin limits are solid horizontal lines.

result of the present analysis may be understood as follows. On account of the earth's rotation, equatorward (poleward) currents give rise to pressure that is high (low) some distance directly offshore relative to pressure nearer the coast. If both the earth's rotation and friction were important, if the coast of the Santa Barbara Channel-Santa Maria Basin were straight, and if GOIN and PAIN were exactly the same distance from the coast but ANMI was a little further from the coast than SMIN, then equatorward (poleward) flow would be associated with high (low) pressure at PAIN relative to GOIN, but also with high pressure at ANMI relative to SMIN. The coast is not straight enough that this line of reasoning may be directly applied to the observations by measuring the distances from the moorings to the coast, but the difference between the present analysis based on ANMI-SMIN and that of HW based on GOIN-PAIN means that it has to be an important factor in setting up the observed pressure field. The present interpretation is thus that the pressure field observed at the moorings is a combination of an along channel pressure difference directly set up by the wind in opposition to the wind stress and the pressure field that results on account of the earth's rotation when the wind directly forces along channel currents.

Does the local wind account for all of the observed pressure difference? The answer is no. The maximum lagged correlation between the wind stress series and the ANMI-SMIN pressure difference series is only 0.341 at a lag of 12 hours. The positive sign of the correlation and of the lag means that equatorward winds are followed by a rise in sea surface pressure at ANMI relative to SMIN, the smallness of the correlation relative to unity means that most of the measured pressure difference signal does not originate in the measured wind signal. This is consonant with the fact that, in a numerical model of the circulation in the entire Southern California Bight, Oey (1998) has found that a large monthly mean model pressure difference signal is generated in the Santa Barbara Channel by monthly mean observed nearshore winds hundreds of km equatorward of the Santa Barbara Channel. It is not yet known whether his mechanism accounts for all of the observed pressure difference within the Santa Barbara Channel at this and/or shorter periods.

The 5 m current pattern of Figure 1 is an average over those times when the wind is small and sea surface pressure at ANMI is lower than sea surface pressure at SMIN. We might next average over times when the wind is large and the pressure difference is small. If we called these two patterns the pressure dominated pattern and the wind dominated pattern, respectively, then the implicit assumption would be that if we next averaged over times when both the wind and the pressure difference are small, there would be little 5 m flow anywhere. This turns out not to be the case. A trivial reason could be is that even an error as small as a few cm in getting the bottom pressure sensors at the same depth at two different moorings would result in a nonzero offset in the pressure difference series between the two moorings even if the true pressure difference between the two moorings were zero. In that case we would just average over times of small winds and different pressure differences, and take as the offset that pressure difference that gave small flow everywhere. But no choice of pressure difference over which to average ever gave small 5 m flow at all the moorings. The best that could be done was to choose a pressure difference over which to average that minimized the flow at ANMI and PAIN.

Figure 2 correspondingly shows that in average over times of small winds, 5 m flow persists at SMIN and at SMOF even when the pressure difference over which the average is carried out has been chosen to minimize the 5 m flow at ANMI and at PAIN. If we interpret that particular pressure difference as an offset associated with (very plausible) error in bottom pressure sensor depth, then Figure 2 shows the 5 m circulation pattern that prevails when both local winds and the pressure difference are small. This null pattern must

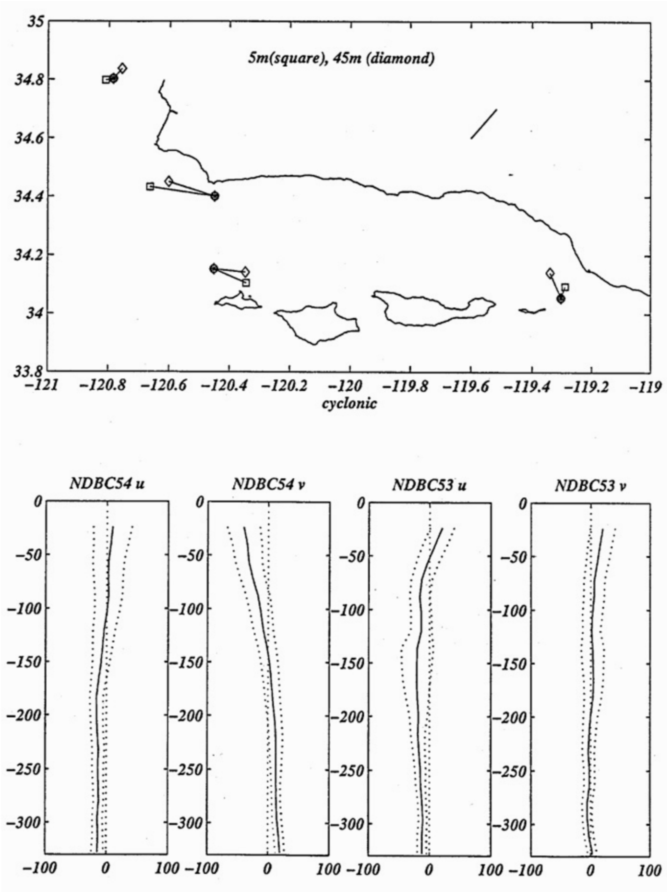

Figure 2. Upwelling pattern of currents whose amplitude is proportional to wind stress. Upper panel shows currents at 5 m (square) and 45 m (diamond). Reference arrow is 10 cm/s. Lower panels show eastward (u) and northward (v) currents at meteorological buoys NDBC54 and NDBC53 (units of mm/s) plotted against depth (m). Mean wind stress is 2.9 dy/cm^2, and mean ANMI-SMIN sea surface pressure difference 0.122 kPa is virtually the null bin 0.119 kPa.

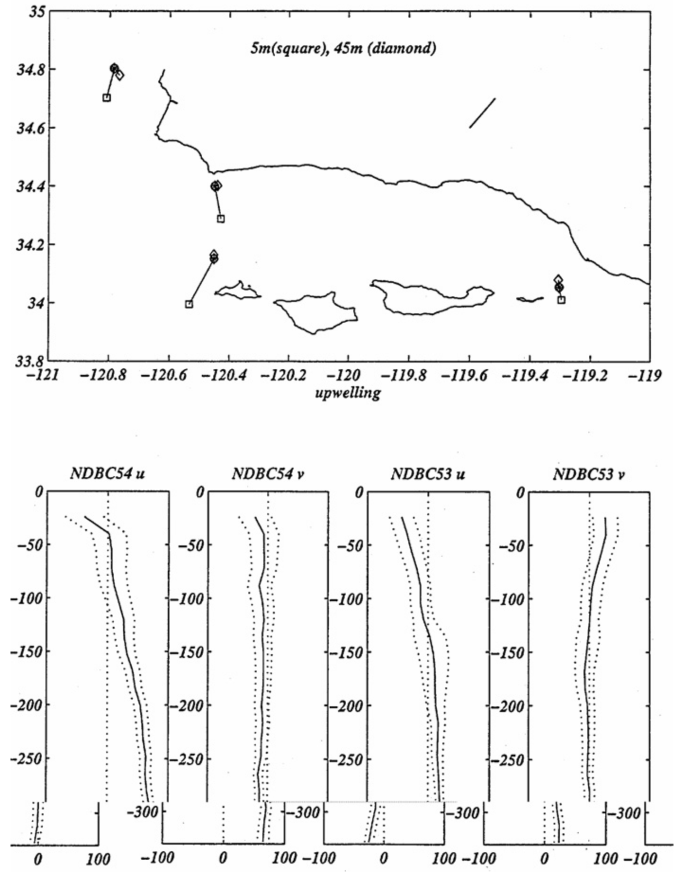

Figure 3. Relaxation pattern of currents whose amplitude is proportional to along channel sea surface pressure difference. Upper panel shows currents at 5 m (square) and 45 m (diamond). Reference arrow is 10 cm/s. Lower panels show eastward (u) and northward (v) currents at meteorological buoys NDBC54 and NDBC53 (units of mm/s) plotted against depth (m). Mean wind stress 0.01 dy/cm^2 is virtually null, and ANMI-SMIN sea surface pressure difference is -0.330 kPa (ANMI pressure is lower than SMIN).

be subtracted from what were above called the pressure dominated and wind dominated patterns in order to obtain patterns whose amplitude may be expected to become small when the corresponding forcing agent, wind or along channel sea surface pressure difference, is small. The resulting patterns are shown in Figures 3 and 4.

Three 5 m patterns thus finally emerge from the conditional averaging; one (the wind dominated pattern minus the null pattern) whose amplitude is proportional to local wind stress (Figure 3), one (the pressure dominated pattern minus the null pattern) whose amplitude is proportional to the along channel sea surface pressure difference (Figure 4), and one (the null pattern) whose amplitude is not well correlated with either wind stress or along channel sea surface pressure difference (Figure 2). These correspond closely to the three synoptic patterns called upwelling, relaxation and cyclonic previously identified by HW. Their zero lag correlation coefficients with the wind stress are 0.61, -0.10, and 0.02 respectively; their zero lag correlation coefficients with the ANMI-SMIN sea surface pressure difference series are 0.27, -0.33, and 0.13 respectively. The upwelling pattern is thus best correlated with the wind or the pressure difference. Even though the relaxation pattern was constructed using observations over which the wind stress averaged to virtually zero so that this pattern should reflect circulation response only to the pressure difference, the pressure difference itself is correlated with the wind and this results in partial correlation between the relaxation pattern and the wind.

The upwelling pattern is everywhere much less pronounced at 45 m than at 5 m, in accord with simple Ekman theory. The relaxation pattern at 5 m is concentrated along the California coast of the Santa Barbara Channel-Santa Maria Basin, and is only slightly attenuated at 45 m. The cyclonic pattern at 5 m within the Santa Barbara Channel is not very different from that at 45 m. Both the relaxation and cyclonic patterns do not appear to persist below about 100 m in the western Santa Barbara Channel (at NDBC54), the situation is more complicated in the interior (at NDBC53) with some suggestion of deep counter currents. A final surprise however is that at depths greater than about 100 m in

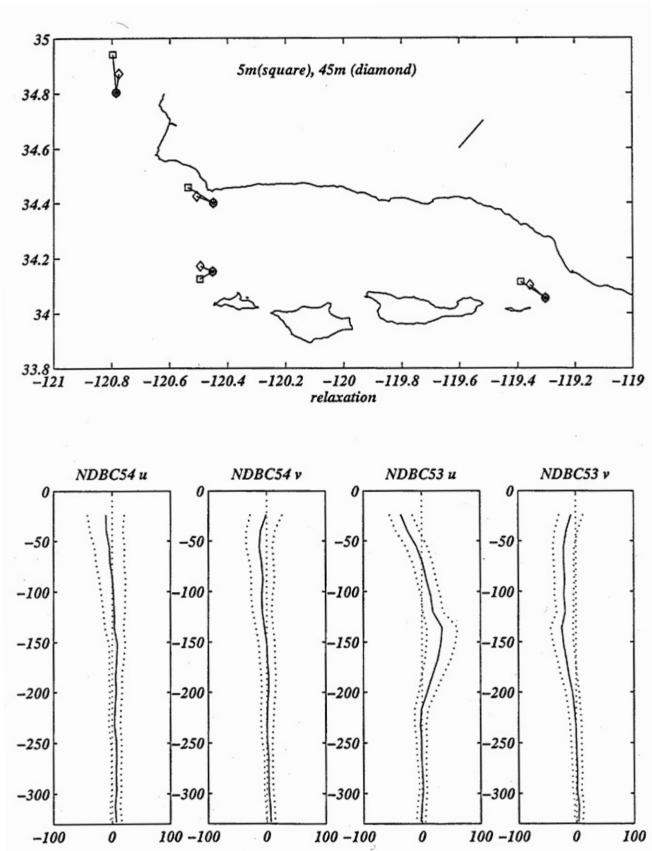

Figure 4. Cyclonic pattern of currents whose amplitude is proportional neither to wind stress nor to along channel sea surface pressure difference. Upper panel shows currents at 5 m (square) and 45 m (diamond). Reference arrow is 10 cm/s. Lower panels show eastward (u) and northward (v) currents at meteorological buoys NDBC54 and NDBC53 (units of mm/s) plotted against depth (m). Wind stress -0.043 dy/cm^2 is virtually null, and ANMI-SMIN sea surface pressure difference is the null bin 0.119 kPa.

the western Santa Barbara Channel, the most energetic pattern is the upwelling pattern; very strong equatorward flow below 100 m is associated with equatorward winds. The manner in which this deep flow is driven is not yet understood.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Harms, S. and C. D. Winant. 1998. Characteristic patterns of the circulation in the Santa Barbara Channel. Journal of Geophysical Research 101(C2):3041-3065.

Harms, S. and C. D. Winant. 1994. Synthetic subsurface pressure derived from bottom pressure and tide gauge observations. Journal of Oceanic and Atmospheric Technology 11(6):1625-1637.

Oey, L.-Y. 1998. A Forcing Mechanism for the Poleward Flow off the Southern California Coast. Manuscript.