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WINTER WIND DRIVEN FLOW IN BASS STRAIT

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SUMMARY The response of the coastal ocean to strong wind forcing is little understood, partly because of the small number of complete data sets obtained during these rather infrequent events. The oil platforms in Bass Strait have provided an opportunity to make accurate measurements in an environment where strong winds are a frequent occurrence. The Kingfish B oil platform, about a quarter of a Rosby radius away from the coast, has been instrumented with wind, wave and current sensors that are robust enough to make accurate measurements under extreme conditions and these were calibrated each month. The water currents were detected at three depths in the 77 m water column using spherical electromagnetic current meters. Also water height was determined at a second platform 50 km inshore of the first. During the winter cooling period the water at this region of Bass Strait is unstratified. By carrying out multiple linear regression on the wind and current components, the statistical response of the current to the wind stress can be determined. The regression coefficients predict mass flux greater than the Ekman transport and roughly along the isobaths. Water height is also correlated with wind stress and so it is deduced that a significant fraction of the flow is induced by pressure gradients.

1. INTRODUCTION

Continental shelves are one of the most important regions of the ocean because it is here that most of man's experience and exploitation of the sea occurs. Effluents are disposed of in this area, while oil and sand are extracted from the ocean floor. Coastal shipping carries many of our products and the fishing industry extracts protein from the same area. Finally, coastal inhabitants often take their recreation over the continental shelf.

The more extreme currents over the continental shelves are driven by the wind. Tidal forces can produce rapid water movements in restricted areas but over the broad open regions the strong storms, and in northern regions, tropical cyclones, induce large currents and storm surge. When these are augmented by tidal flows and the orbital motions of the waves they produce extreme loads on off shore structures, change the acoustic propagation characteristics of the water column and often move bottom sediments (and effluents) in as yet unknown ways.

As we are interested here in wind forcing, we must separate such from the tidally driven flow. While time filtering could be employed, we have chosen regression analysis to look for motions correlated with the wind. Tidal motion is coupled to the wind driven flow through the bottom friction, but the importance of such non linear coupling remains to be explored. Water height variations across the shelf were available in this study due to the presence of wave gauges on two platforms in Bass Strait. This slope measurement allows us to advance our understanding of the balance of the competing forces in the coastal oceans by making an estimate of the dominant terms in the momentum equation.

2. APPARATUS

Currents were measured from the Kingfish B oil production platform located at 38°36'S, 148°11'E in 77 m of water. Three spherical electromagnetic current meters were supported between two 16 mm stainless steel cables, tensioned to approximately 22 kN to resist the movement of the current meters in heavy weather. The depths of the current meters were 7 m, 40 m and 75 m below the mean sea level.

Wind speed was also measured from a radio mast on this platform while the surface elevation was detected by a Baylor wave staff held taut by a tension of 15 kN.

Seventeen minute averages were carried out on the current components and other variables and these numbers stored on magnetic tape for later analysis.

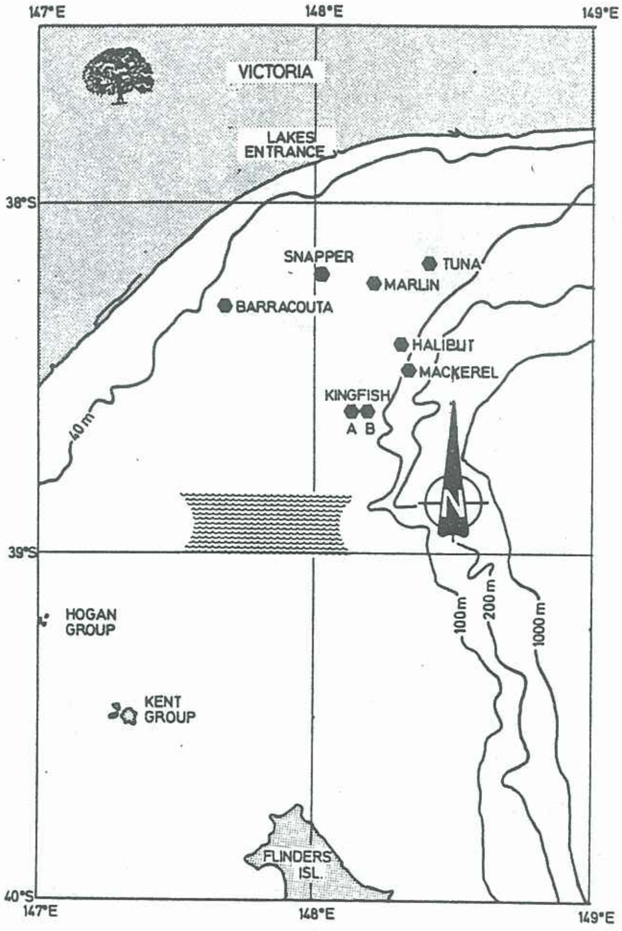

Figure 1. The location of the experimental site in Bass Strait.

piece of data when the wind sensor was moved to 65 m we used $C_D = 1.2 \times 10^{-3}$.

By firstly considering the response for along-shore stress, we see in Fig. 3 a response at the three depths that exhibit a clockwise spiral, the opposite direction to the anticlockwise direction (looking down) expected for the southern hemisphere. Again only the cross-shelf mid-water regression has a confidence level below 99%.

Notice however that all the currents correlated with the wind exceed the depth integrated value $\rho f H U_1/\tau_j^w = 1$. The momentum induced by the wind stress exceeds that balanced locally by the Coriolis force.

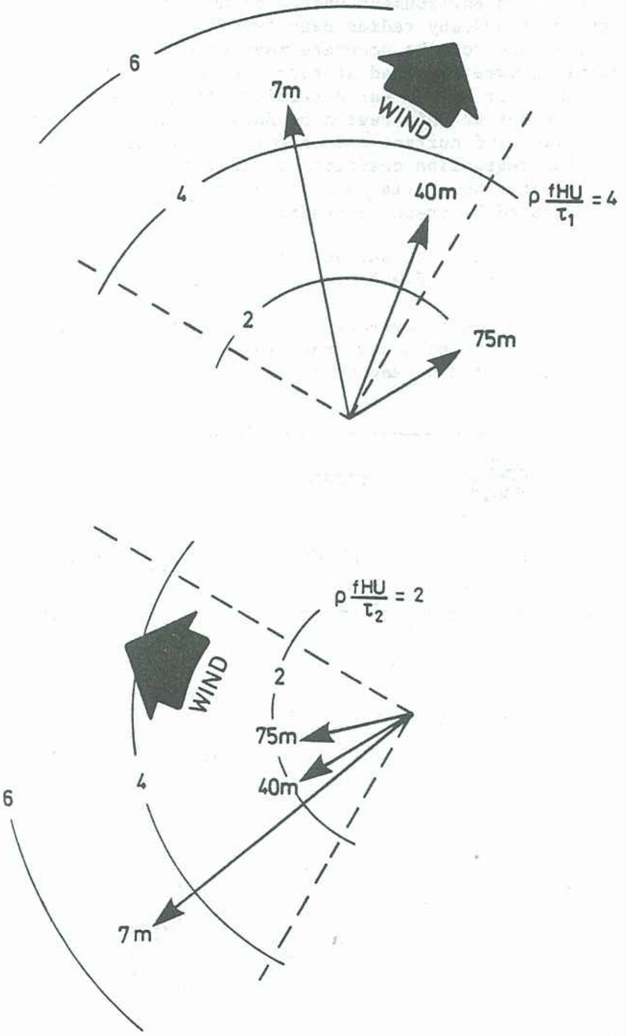

Figure 3. Current response to wind stress. Numbers at the head of the arrows indicate current sensor depth. Magnitude scale is $\rho f H U_i/\tau_j^w$.

5. PRESSURE DRIVEN FLOW

The next important term in the momentum equation that we are able to examine is the offshore pressure gradient. Atmospheric pressure affects the sea level and J.L. McClean (private communication) was able to show that, at the Kingfish B site, fluctuations in water height were related to the atmospheric pressure by the expression

$$h' = B \left[\frac{p - p_o}{p_o}\right]$$

$$B \doteqdot 10^{-6} \quad \text{m}$$

where p_o is a suitable standard atmoshperic pressure.

When we carried out regression between wind stress, measured in N m^{-2}, and water height, measured in m, we obtained the following relationships

$$h' = .33\,\tau_1^w - .21\,\tau_2^w \qquad 1$$

for the Kingfish B site in 1978, and

$$h' = .33\,\tau_1^w - .37\,\tau_2^w \qquad 2$$

for the Barracouta site in 1982. As the atmospheric pressure and the wind stress are undoubtably connected, both Eq 1 and Eq 2 will have some "inverse barometer" effect present. It is reasonable to assume that this is the same for separations small compared with the storm size.

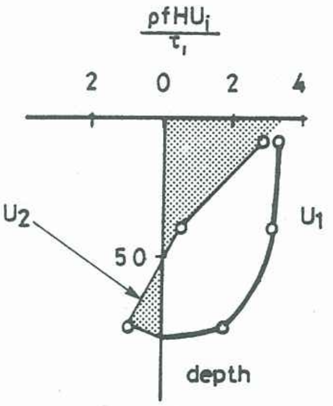

Figure 4. The current response to an along-shore wind stress. The cross-shelf current changes sign at mid-depth.

The regression coefficients for the Barracouta site are less certain, with only 95% confidence that they are not zero. However, the predicted level changes for typical storms are larger than the estimated errors in determining the water heights and so analysis of additional data is in order.

Proceeding with our expressions, despite their shortcomings, we can estimate the average gradient between the two platforms 53 km apart by subtracting Eq 1 from Eq 2 to obtain

$$\frac{\Delta h}{\Delta y_2} = 1.2 \times 10^{-5}\,\tau_1^w - 0.25 \times 10^{-5}\,\tau_2^w \qquad 3$$

If we express this non-dimensionally we obtain

$$\frac{g}{f}\frac{\partial \zeta}{\partial y_2} \simeq 8.4\,\frac{\tau_1^w}{f\rho H} \qquad 4$$

where we have neglected the second term in Eq 3 as not significant.

The water height at the Barracouta platform was also determined from 17 min averages of the Baylor wave gauge. Calibration of the upper part of this gauge showed drifts of less than a few centimeters over the 125 days of data used in this paper. Shorting the two wires of the gauge together at known distances along the wave staff provided the calibration.

The 17 minutes averaged currents and winds were resolved into a direction along the isobaths (030°T) and into a cross shelf direction (300°T). From these time series, regressions and auto correlations were carried out by digital computer.

One expects the water column over this part of the shelf to be unstratified in winter and so the first section of data used was August, September and October 1978. Some data from an earlier period was discussed by Jones and Gerlach (1980). There were 6300 records, each averages of 17 minutes, to eliminate surface wave motions, with some breaks due to data recording failures. The second piece of data was from July, August, September and October 1982. Here we have temperature profiles in July and October which show that the water column was near isothermal.

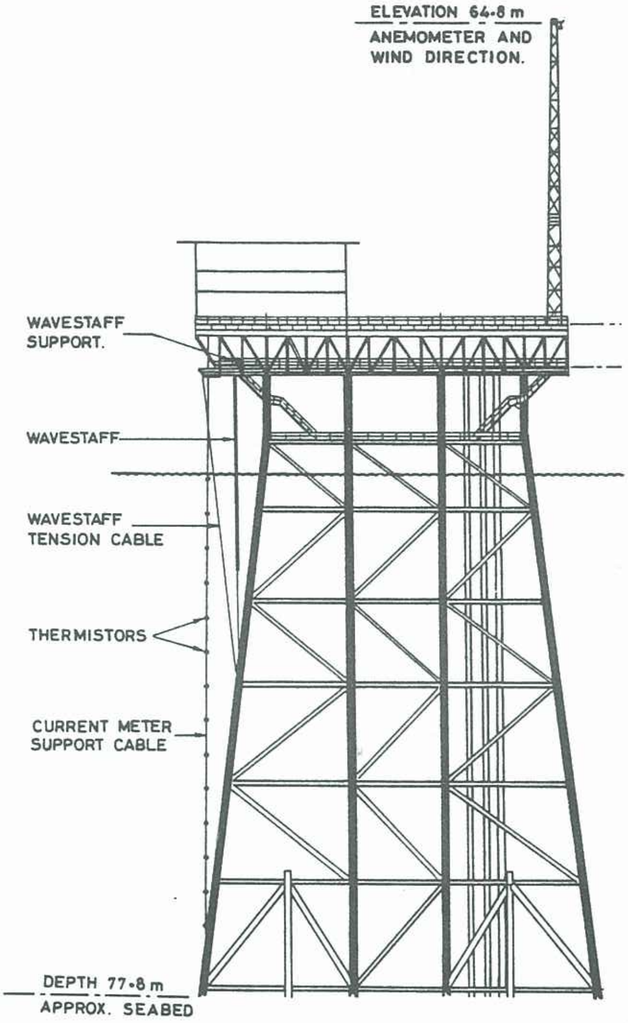

Figure 2. Diagram of the Kingfish B oil production platform showing the location of the current meters, wave staff and wind sensor. The view is as seen by an observer looking west.

3. REGRESSION

Multiple linear regression was carried out on the wind and the current. The response of the current vector to the wind, w_i, is a tensor of order 2, i.e.

$$u_i = R_{ij}W_j$$

and non dimensional. The appropriate correlations are shown in Table 1. These results are generally consistent with the regression coefficients (a little to the north of this site) presented in Jones (1980). In the earlier work a north-south and east-west co-ordinate system was used.

We have omitted the constant in Table 1 as this presumably is dependent on other forcing such as dynamic height across Bass Strait, tidal non linearities and the like.

The statistical reliability of these regressions depend, in part, on the number of degrees of freedom in the data. While there were 6300 lines of data for each regression, the number of independent points were much lower. Storms in this region of Bass Strait have an average repetition rate of 3.3 days and so the 71 days of data in Table 1 may be considered to have 20 degrees of freedom. On this rather conservative estimate, we can say with 99% confidence that none of the coefficients are zero. The one exception is the mid-depth cross-shelf current where the regression coefficient is small. For the assumptions used to obtain confidence limits, consult Draper and Smith (1966).

Thus the water column in winter responds to wind forcing even down to a depth of 80 m. How is the momentum imparted to the water and does the coast some 80 km away play an important role in the dynamics?

4. MOMENTUM BALANCE

If we depth integrate the equations of motion for a constant depth coastal ocean it can be shown that the along-shore momentum balance is:

$$\frac{\partial U_1}{\partial t} = - fU_2 + \frac{\tau_1^w}{\rho H} - \frac{\tau_1^b}{\rho H} - g\frac{\partial \zeta}{\partial y_1}$$

while the cross-shelf balance is:

$$\frac{\partial U_2}{\partial t} = + fU_1 + \frac{\tau_2^w}{\rho H} - \frac{\tau_2^b}{\rho H} - g\frac{\partial \zeta}{\partial y_2}$$

where y_1 is the along-shelf direction, U the depth integrated velocity, f the Coriolis parameter (positive number), τ^w the wind stress and τ^b the bottom stress.

If we look for a steady state solution to the balance between Coriolis force and wind stress we obtain

$$\frac{\rho fHU_2}{\tau_1^w} = 1$$

and $$\frac{\rho fHU_1}{\tau_2^w} = -1.$$

In order to increase our understanding of the momentum balance we regressed the current vectors (not the depth integrated current) against the wind stress. This enabled comparison of the Coriolis force with the surface stress and other terms in the momentum balance.

The wind stress was calculated from the expression

$$\underset{\sim}{\tau} = C_D \rho_a |\underset{\sim}{W}|\underset{\sim}{W}$$

where W is the wind vector at a height of 37 m above the sea surface and $C_D = 1.3 \times 10^{-3}$. For the second

Fandry (1982) has constructed an unstratified model of Bass Strait and we can compare the storm surge in the results he presents with Eq 3. Choosing steady state for a somewhat along shore wind, his Fig 6d gives a slope of 0.5×10^{-5} for a wind stress of $1\ \mathrm{N\ m^{-2}}$, a value smaller, but somewhat similar to that given by Eq 3. The onshore wind case (his Fig 7) gives lower slopes.

The above statistical results are as one would expect from a classical picture of coastal flow for, although Kingfish B is some 80 km offshore, it is only a quarter of a Rosby radius from the coast. Consider the longshore wind stress situation where the coastline is on the left. Equation 4 shows that an increase in water level near the shore (positive slope) can be expected. When the results from Fig 3 are replotted in Fig 4 we can see the surface water flows onshore while the deeper water provides the outflow needed for a mass balance. This is the situation for downwelling for wind stress to the north east and upwelling for wind to the south west. Rochford (1977) has reported such behaviour on this coast in summer when stratification leads to a clear surface expression of upwelling.

6. CONCLUSIONS

While both tidal and wind forcing compete in importance in driving the water column in eastern Bass Strait, regression analysis between the wind, currents and water slope allows us to separate the wind driven flow from the tidal flow and analyse the important terms in the momentum equation.

We have shown statistically that storm surge is an important component of the wind driven response in north eastern Bass Strait. Wind stress drives the surface water and is correlated with motions throughout the column but more momentum is imparted by the surface tilting due to a basin wide response to storm systems. The lowest current meter shows the compensating onshore/offshore flow when an along shore wind stress induces surface flow and the resulting surface tilt.

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TABLE 1 - CURRENT WIND REGRESSION KFB

Period day 213 - day 284, 1978

$U(1)$ = current at 7 m depth
$U(2)$ = current at 40 m depth
$U(3)$ = current at 75 m depth
W_1 = along shore wind (+ NE sector)
W_2 = cross shelf wind (+ NW sector)

$U(1)$ (along shore) $= .0093\ W_1 - .013\ W_2$
$U(2)$ (cross shelf) $= .0073\ W_1 + .005\ W_2$
$U(2)$ (along shore) $= .0076\ W_1 - .0052\ W_2$
$U(2)$ (cross shelf) $= .0009^{*} W_1 + .002\ W_2$
$U(3)$ (along shore) $= .0045\ W_1 - .0035\ W_2$
$U(3)$ (cross shelf) $= .0021\ W_1 + .0037\ W_2$

* not significantly different from zero