LOCAL WIND FORCING AND SMALL SCALE UPWELLING

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ABSTRACT

This study characterizes some wind stress effects on a coastal site which is a focus of small scale upwelling having a scale of the order of 10 km. Two time scales are considered. Firstly the seasonal character of wind stress with the associated sea temperature fluctuations is described. Secondly individual wind events of a few days duration are characterized by extent and rate of upwelling and offshore displacement of the thermocline front. Data on the thermocline displacement is fitted to Csanady's model of coastal upwelling, which leads to the prediction of upwelling parameters for given wind events.

INTRODUCTION

The occurrence of coastal upwelling induced by favourable alongshore winds is well known off Oregon, Northwest Africa, Peru and in the Southern Benguela region, (Huyer 1974); (Barber 1977); (Walsh 1971); (Andrews 1980). These upwellings are on a scale of 100's km alongshore and several tens of kilometer offshore. Less well known are the small scale localized upwellings with a length scale of about 10 km. These small scale upwellings are the result of orographic effects and changes in coastline orientation. Such sites are often embedded in the large scale upwelling regions, and have also been studied in the Great Lakes, (Csanady 1980) and in Gulf of Lions (Mediterranean), (Millot 1979).

Airborne radiation thermometry (ART) surveys have revealed several such areas of intense upwelling along the Cape Peninsula and adjacent west coast of South Africa, (Andrews 1969); (Bain 1976). The study site is a strong focus of localized upwelling with a scale of the order of 10 km^2 just north of the Melkboschstrand headland some 30 km north of Cape Town. (Fig. 1) Eight km north of Melkbosch is the site of South Africas first nuclear power station. A considerable amount of oceanographic and meteorological data has therefore been collected for this site (Loewy 1976) over several years by the Electricity Supply Commision of South Africa (ESCOM). This data provided an essential backup to the work reported here, which forms part of a more comprehensive study of wind stress effects on oceanographic parameters at the site.

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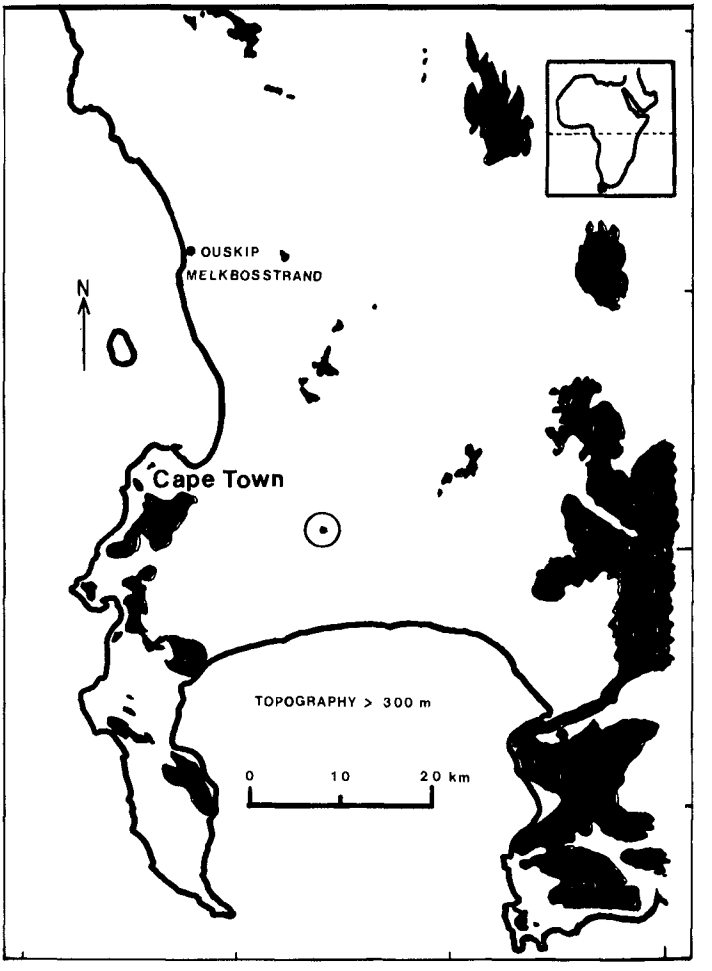

Fig. 1

In this report we discuss wind stress effects on two time scales. Firstly we characterize the seasonal wind pattern and the associated sea temperature fluctuations. Secondly we consider wind events of a few days duration, characterized by rate of upwelling and offshore displacement of the thermocline front. This displacement is compared with Csanady's model of coastal upwelling.

Factors about the site that are relevant to this report include: its position in the temperate zone which is subject to seasonal variations in the wind field as the semi-permanent south Atlantic anticyclone follows the solar incident. During summers, high pressure systems pass south of the country resulting in alongshore equatorward winds that are greatly influenced by the orography south and south east of the site. Strong thermal-diurnal mechanisms also feature at that time. In winter, low pressure systems skirt the southern corner of Africa and generate north-westerly onshore winds (Jury 1980). The temperature salinity properties of these coastal waters are such that temperature fluctuations are the main contributor to density changes and at a first approximation salinity changes can be ignored (Bang; 1973); (Gunn 1977). Temperature variations are therefore a good signature of upwelling processes in summer.

TECHNIQUES ANO OATA BASE USED

For the seasonal analysis use was made of ESCOM data. Their tabulations of hourly wind speed and direction at Ouskip (Lampbrecht anemometer situated on a tower ~ 20 m above sea level a few meters from the highwater mark) covering several years were coded for computer analysis. An ESCOM maintained sea tower one kilometer offshore in a depth of 11 meters was equipped with three temperature probes at 2 m, 5 m and 8,5 m depths. The temperature data was recorded continuously on a multipen chart recorder. A number of years of this raw chart data was digitized on an hourly basis and coded for computer analysis.

The event time scale study made use of the above data as well as bathythermograph temperature sections taken on a number of lines perpendicular to the coast and out to a distance of 6 to 10 km. The lines were run with a small ski boat with stations at 0,5 km intervals, on a number of consecutive days covering a wind event cycle.

There is a general lack of current data, particularly on a continuous time base. Lagrangian current trajectories and moored buoy current readings are available for the overall project but are not reported here.

ANALYSIS

The wind and temperature time series data were filtered with a twice applied 41 hour running mean filter (Chelton 1982) to suppress tidal and inertial oscillations and with a twice applied 23 day running mean filter (half power point of 50 days) to produce a very low passed time series. Simple statistical computations for standard deviations and

linear correlations between wind components and the different depth temperature records were computed for year long and seasonal sections of data.

The temperature section data was plotted and estimates made of the distance offshore that the thermocline intersected the surface to compare with (Csanadys 1977) model for full upwelling for a longshore wind impulse.

Assuming a two layer fluid with top layer having a thickness h_t and density ρ and the bottom layer having a thickness h_b and density ρ^1 the distance of the upwelled front from the coast is given by Csanady as:

$$Y_o = -R_i - \frac{I\, h_b}{f\, h_t\, (h_t + h_b)}$$

where $R_i = \frac{1}{f}\left(\frac{g\, \varepsilon\, h_t\, h_b}{h_t + h_b}\right)^{\frac{1}{2}}$, $\varepsilon = (\rho^1 - \rho)/\rho^1$

and I the wind impulse = $\int_o^{t_1} (\tau/\rho)dt$.

RESULTS

The study shows on a seasonal time scale that there are two major wind regimes. The southerly component dominates for on average about eight months over the spring/summer period, and the north component with a reduced amplitude dominates for about four months during winter. Fig. 2 for 1976 shows the main trends for very low passed filtered daily record but 1976 had a shorter than average winter regime and an anomously long duration northerly event at the end of November. Over a number of years the average duration of the transition between the summer and winter regime is only about 10 days; the winter to summer transition is longer about 30 days in duration.

The very low pass filtered temperature record shows a higher temperature during the winter months and generally lower temperature during the summer regime when active upwelling brings cold water to the surface. The 1976 data Fig. 3 shows this effect but also illustrates the marked rise in temperature during the anomolous onshore winds in November. In January 1976 the average monthly temperature was 10,7 ± 1,2 and 11,6 ± 1,3°C for the 8,5 m and 2 m depth probes respectively and in July 1976 the averages were 13,9 ± 0,9 and 14,1 ± 0,8°C for 8,5 and 2 m respectively. The mean annual temperatures for 1976 were 12,5 ± 2,0°C and 12,9 ± 1,9°C respectively.

The low pass filtered (41 hour running mean) time series for the wind data of 1976 Fig. 4 shows a good number of southerly wind events and only a few large northerly events. The associated temperature time series Fig. 5 shows a good correlation between temperature decreases during southerly (upwelling) events and increases during northerly or onshore winds. The temperature variability is most marked during the summer regime. A simple linear correlation between the N/S wind

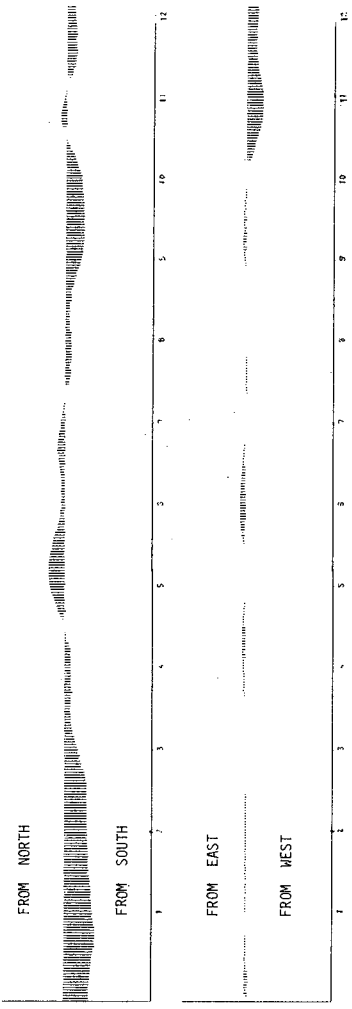

FIG 2 OUSKIP WINDS 1976 DAILY MEAN 2X23 DAY FILTER. TOP NORTH COMPONENT, BOTTOM EAST COMPONENT.

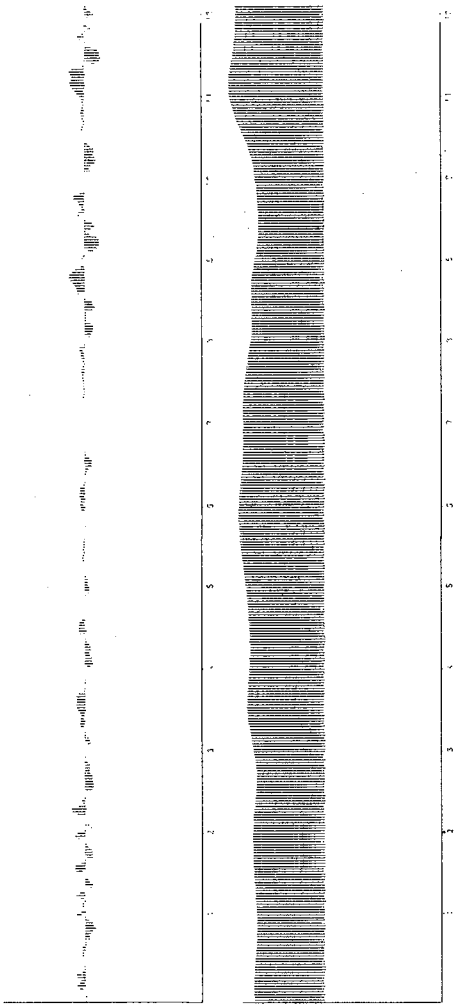

FIG 3 SEA TEMPERATURE 1976 2 METER DEPTH DAILY MEAN OF 2x23 DAY FILTER AND RESIDUALS

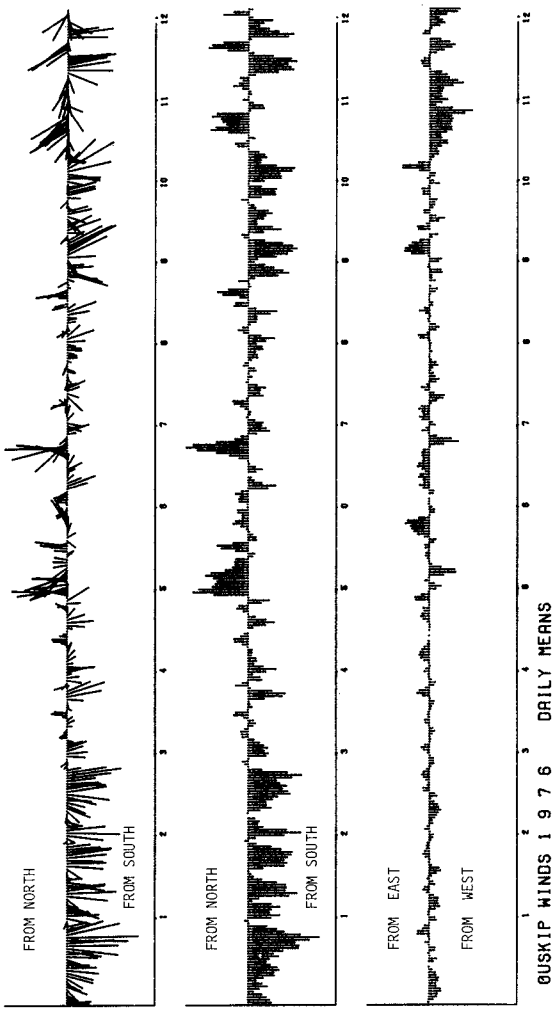
FROM NORTH
FROM SOUTH
FROM NORTH
FROM SOUTH
FROM EAST
FROM WEST
1
2
3
4
5
6
7
8
9
10
11
12
BUSKIP WINDS 1 9 7 6 DAILY MEANS
LLP 2X 41 HR FILTER. N COMPT. E COMPT. MEAN VECTOR

FIG 4

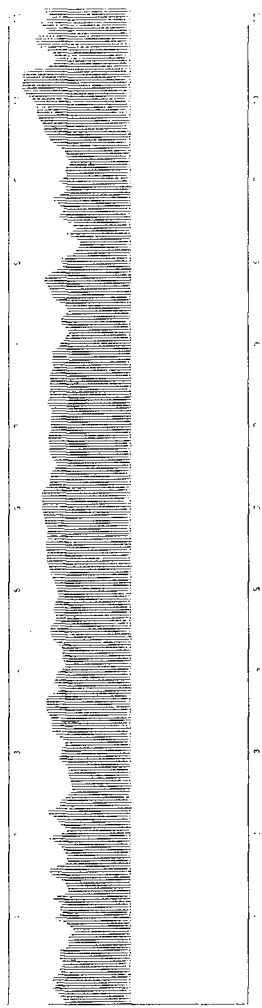

FIG 5 SEA TEMPERATURE 1976 2 METER DEPTH. DAILY MEAN 2X41 HOUR FILTER

component and the 2 m depth temperature low passed time series gave a correlation coefficient of 0,61 for January to April 1976 and of 0,11 for May and August. The significant correlation coefficient at the 95% confidence level is about 0,13. The explanation for the non significant correlation during winter is that the site, embedded in the larger scale Benguela upwelling region, has a more homogeneous water mass close inshore with the cold waters displaced offshore. In contrast during the summer regime, primed by the larger scale effects, stratified water comes close inshore and oscillates with the Ekman forcing of the wind event cycles.

The rapid responce of the thermocline to the onset of a wind event is shown in the bathythermograph temperature section data for 16 February 1978, Figs. 6 and 7. For the two days prior to these measurements the wind was light westerly veering to northerly causing the thermocline to be flattened. By the early hours of the 16th the wind had backed to strong SSE and veered to strong SSW at the time of the measurements. Within a few hours the 13°C isotherm is seen to be displaced a few kilometers offshore. In order to make comparisons with Csanadys model, events were chosen that had an initial sea condition approaching the ideal two layer system, followed by a wind impulse that lifted the thermocline. Table 1 shows reasonable agreement obtained between the theory and field observations.

TABLE 1

WIND EVENT	LAYER PROPERTIES				DISTANCE OF FRONT OFFSHORE			
					Predicted		Observed Y_o	
	h_t	h_b	T_t	T_b	Y_o	12^o	13^o	14^o
	m	m	C°	C°	km	km	km	km
12h00 77.01.26 till 10h00 77.01.27	15	25	16	12	0,94	1,2	1,8	-
till 10h00 77.01.28	15	25	16	12	1,98	~2	2,5	-
08h30 78.02.16 till 15h00 *	11	39	12,5	10,8	3,05	-	2,0	3.1
till 17h00 **	13	27	12,5	10,8	0,8	0,2	0,2	>5

* SECTION 2

** SECTION 1

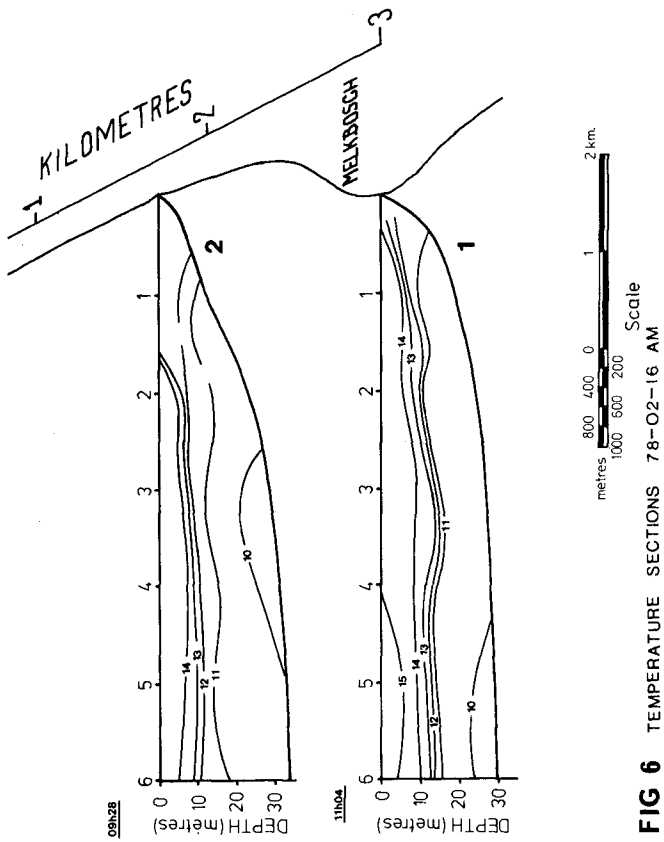

FIG 6 TEMPERATURE SECTIONS 78-02-16 AM

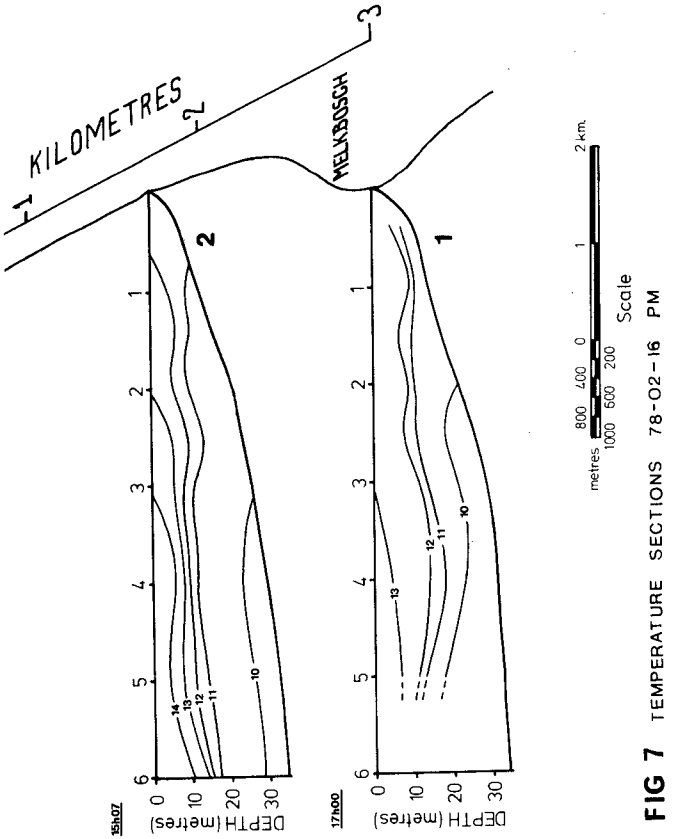

FIG 7 TEMPERATURE SECTIONS 78-02-16 PM

CONCLUSIONS

The study characterizes the wind stress and sea temperature response on a seasonal and event basis for a small scale coastal site. The displacement of the thermocline front from the coast is predicted for some wind conditions by the Csanady model. In the more comprehensive project of which this report forms part other aspects of Csanadys model including double wind impulses and current response are investigated. Initial rotary spectral analysis of the time series data indicate further potentially useful information for this small scale site. Useful 'edge effect' information for correlation with the much larger scale investigation of other workers of the Benguela upwelling program is obtained. Mans impact on the ocean occurs chiefly at the coast. The results of the complete study will provide needed background for both biological studies in the nearshore environment and dispersion studies of ocean outfalls and thermal water releases from power stations.

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