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EAST AUSTRALIAN CURRENT INFLUENCE ON SYDNEY ALONGSHORE CURRENTS

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ABSTRACT

As part of the Environmental Monitoring Program for some new deepwater outfalls, a current meter station has been installed in the coastal waters of Sydney. Established in late 1989, the length of data is now sufficient to commence a study of low frequency alongshore currents thought to be influenced by the East Australian Current (EAC) system. Comparing the measured current data with satellite images of sea surface temperature (SST) data, it is apparent that encroachment events associated with warm-core eddy calving occur three or four times per year and last for two to four months, giving rise to persistent southerly currents. Using offshore SST gradient at several points on the continental shelf as a signal of EAC activity, high multiple coherence shows the strong link between the EAC and the low frequency component of alongshore coastal current. Phase cross-spectra between measured currents at two sites (Sydney and Port Kembla) and between the SST images and the current at Sydney show the low frequency current patterns moving south at 7–25 km/day. Occasional bursts of northerly currents can be linked to two types of cold-core eddies – a large one that forms between the coast and a contorted EAC loop and a smaller type frequently present on the western edge of the EAC. Discrimination between these events and storm events can be made using vertical temperature profile data from thermistors recording with the current meters.

INTRODUCTION

Predicting the fate of pollutants discharged along the Sydney coastline requires an understanding of the behaviour of currents on the continental shelf. In contrast to many other coastal regions, currents on the New South Wales shelf are not tidally dominated but have contributions from a wide spectrum. It is known, for example, that local winds, shelf-trapped waves and the East Australian Current all influence both alongshore and across-shelf currents (Middleton, 1987). This paper examines some aspects of one of these factors (the EAC) on the alongshore component of the coastal current, using data from current meter moorings at Sydney and Port Kembla (Fig. 1) together with satellite sea surface temperature data.

EAC STRUCTURE AND COASTAL INFLUENCE

Much of the general structure and some detailed behaviour of the EAC is known from ship cruises, airborne experiments, buoyed instruments and, more recently, satellite imaging (see e.g. Creswell and Legeckis, 1986). The current originates in the Coral Sea, flows south hugging the continental shelf until separating from the shelf on the mid-north New South Wales coast (Godfrey et al., 1980). At some point in the Tasman Sea, the current turns north, forming a return current offshore from the EAC. Several times per year the loop formed by the EAC and its return current pinches off to form large (hundreds of km) warm-core eddies that meander irregularly around and beyond the south Tasman sea.

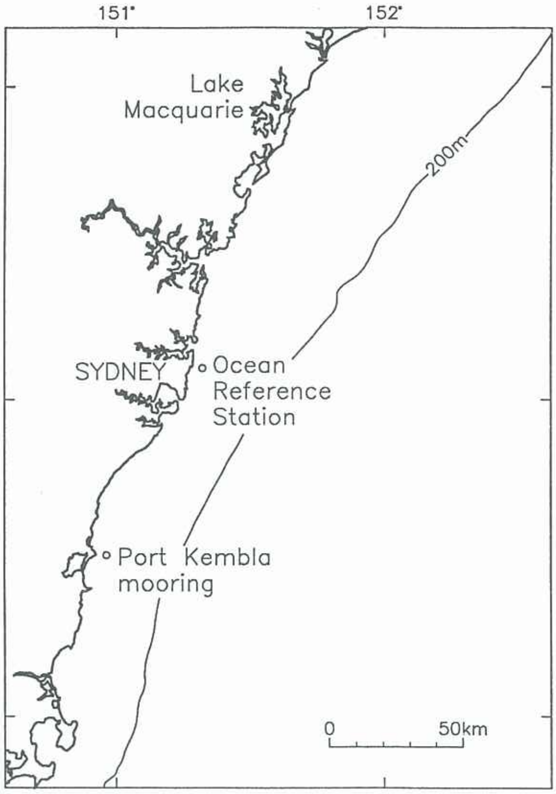

Fig. 1 *Study region showing approximate positions of the current moorings.*

The influence of the EAC on coastal currents along northern NSW was demonstrated by Hamon et al. (1975) and Godfrey (1973) who found a correlation for long period motions (50 to 170 days). The current patterns associated with this long period motion were found to travel south with a phase speed of 9 km/day. South of the separation zone, one would expect the influence to be more irregular, although the influence is certainly there, as evidenced by data captured during the Australian Coastal Experiment. Huyer et al. (1988) describe warm-core eddies approaching the coast, giving rise to strong persistent southward currents over the continental shelf and slope. In addition to this direct influence, both the study by Huyer et al. (1988) and one by Louis (1989) reported shorter period motions either due to small cyclonic eddies flanking the larger warm-core eddies, or dispersing internal shelf waves.

CURRENT AND ASSOCIATED DATA

Motivation for this study stems from a major environmental monitoring program (EMP) for the Sydney deepwater outfalls which were coming into operation during 1990/91 (Gordon and Fagan, 1991). An important component of the physical oceanography branch of the EMP was the installation of an ocean reference station (ORS) incorporating two electromagnetic current meters (also containing temperature sensors), a thermistor string, and an anemometer (Lawson and Treloar, 1987). The current meters were first installed in July 1989 (at depths of about 15 and 45 m in 65 m of water seaward of Bondi); supplemented by the thermistor string in December 1989 and the anemometer in November 1990. The ORS has been recording up to present virtually continuously, although gaps of several weeks occur in November-December 1989, April-September 1990, and February-March 1991. Analysis for this paper ceases at June 1991, thus encompassing fourteen months' worth of ORS data spanning two years.

Data from a second current meter mooring operated by the Water Board were available from Port Kembla, 75 km south of the ORS. Spanning May 1990 to April 1991 (with gaps in June-July and October-November 1990) this data not only fills some of the missing ORS records, but also provides information on spatial distribution.

Current, Wind and Temperature Data Reduction

The steps in data reduction were as follows:

(i) All vector data (current and wind) were transformed into cartesian coordinates orthogonal to the general coastline (taken to be 13.5° east of north).

(ii) Some of the data sets, delivered with sampling intervals of five or ten minutes, were low-pass filtered (using FFT) at two hours to produce standard hourly records. Short gaps (< 3 days) were interpolated linearly before filtering.

(iii) The hourly data were filtered again at two days to produce daily data.

(iv) Lengthy gaps (largest 35 days) were interpolated using a linear prediction technique (Press et al., 1986) that not only smoothly joins the ends but also simulates the spectral content of the existing records.

(v) For some of the analysis, Port Kembla data were transformed into equivalent ORS data using the spectral transfer function. (The coherence is discussed below.)

(vi) Using measured data, interpolated data and Port Kembla transformed data, a composite daily ORS record spanning eleven months from August 1990 to June 1991 was created.

(vii) The alongshore component of the top meter current was low-pass filtered at 20 days for comparison with the satellite data.

Spectral Energy Partition

The contribution of various frequency bands to the total current energy was examined via the autospectra (using FFT) of the alongshore current records. Because of the wide range of frequencies present, this analysis was done in stages. Two days' worth of 5 minute data provided spectral estimates up to two hours, three months' hourly data provided estimates between two hours and two days, while ten months' daily data (some interpolated) provided estimates above two days. The areas under representative portions of the composite spectrum provide estimates of the relative contributions (Figure. 2). The partitions chosen were: 5 minutes to 7 hours (high frequency band), 7 hours to 1.5 days ('tidal' band), 1.5 to 18 days ('weather' band), and 18 days to 128 days ('EAC' band).

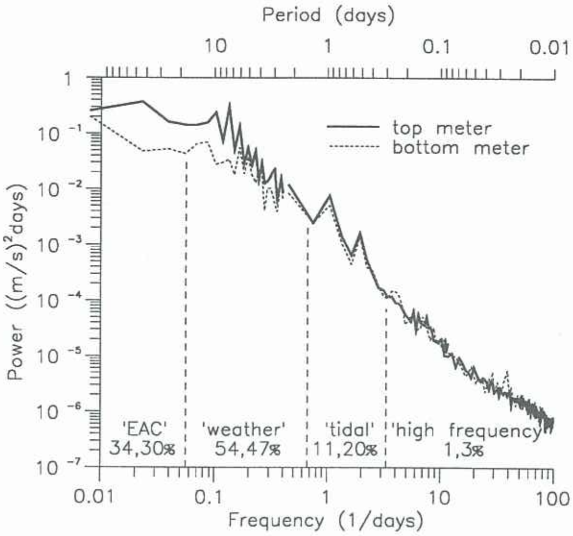

Fig. 2 *Autospectra of alongshore currents at Sydney ORS position. The percentages in the partition boxes refer to top and bottom meters respectively.*

The combined autospectra show several features:

(i) Much of the energy (>30%) lies in the low frequency (EAC) band.

(ii) The spectral peak has not been detected, i.e. there are important contributions at periods longer than the ten month record. (Hamon et al. 1990) found a peak at about 100 days for NSW north coast currents.)

(iii) While peaks at diurnal and semidiurnal tidal periods exist, they are by no means dominant.

(iv) Spectra for top and bottom meters are similar, diverging only in the low frequency bands.

(v) The spectra are continuous, i.e. there is no frequency band where energy is absent.

Sydney-Port Kembla Currents Comparison

Given the considerable overlap between the ORS and Port Kembla data, there is opportunity to examine their coherence. The coherence function of the alongshore top current meters based on the daily data with band averaging of 9 adjacent frequencies (95% confidence level of 0.56 on coherence) is shown in Figure 3.

While there are some peaks at higher frequencies (periods below 15 days), of most interest to this study is the broad peak for periods above 25 days, indicating significant coherence on the EAC band. At these frequencies, there is a phase shift of about $\pi/3$ and the slope of the phase spectrum signifies a lag of between 2.5 and 7

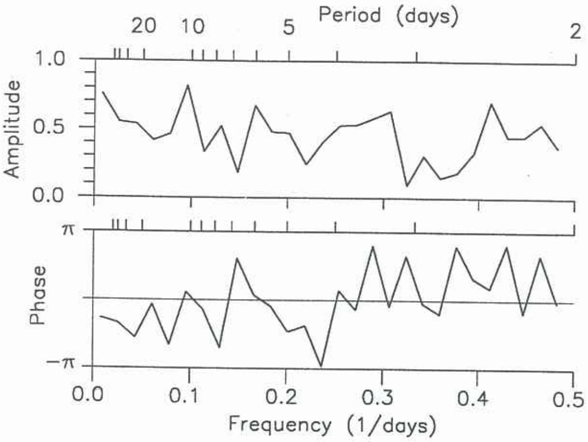

Fig. 3 *Coherence function (amplitude and phase) between Sydney ORS and Port Kembla top meter alongshore currents (2 day filter).*

days – corresponding to phase speeds of between 11 and 30 km/day. This compares with the 9 km/day found by Hamon et al. (1975) for the southward speed of current features on the NSW north coast.

A highly smoothed transfer function deduced from the coherence function (not shown here) was used to construct an equivalent ORS record – providing an extension to the ORS data for use in comparing with the satellite data.

SATELLITE IMAGES

Thermal infrared images from the Advanced Very High Resolution Radiometer on board the NOAA weather satellites are routinely converted to sea surface temperatures SST by CSIRO Division of Oceanography. Cloud cover permitting, there are two images per day (0330 and 1530). Data was available for this study in two formats – weekly colour prints (sometimes composites over a day or two) starting before the ORS commissioning, and digital images from July 1990. The images encompass 100 km of the southeast Australian coastline from Brisbane to Cape Howe, and extend seaward about one third the distance to New Zealand.

SST Subjective Analysis

The colour prints were visually assessed for likely influence on Sydney currents according to whether or not the EAC loop or a warm-core eddy was encroaching onto the shelf. Figure 4 shows the timing of these events together with the measured current and wind data. Additional features such as the point of current separation from the coast, the existence of cold-core eddies, and calving of warm-core eddies were also noted.

Seven encroachment events lasting two to four months can be identified for the two year period of the study. Onset of the encroachment events is associated with northerly movement of the EAC coastal separation point. During the event, the EAC current path becomes increasingly contorted and towards the end of the event a warm-core eddy is calved.

Two quite different types of cold-core eddy occur during the events. A large eddy not much smaller in scale than the warm-core eddies can form in the region between the separation zone (when it has moved north) and a point of reattachment in the Sydney region. The second type is smaller (of order 10's of kilometres) and is associated with shear at the front between warm EAC water and colder Tasman Sea water. Whereas at most one of the large cold-core eddies occurs during an event, there may be several of the smaller type at the same time.

The principle current response is a persistent southerly bias, stronger in the top layers than the bottom. These southerly currents generate upwelling with onshore currents at the bottom meter and offshore currents at the top.

Shorter-lived northerly bursts of current also occur, some of which may be caused by passing cold-core eddies. These events are accompanied by temperature drops often preceded by a temperature rise at both the top and bottom current meters. A contrasting temperature behaviour is observed when local storms generate bursts of northerly currents. In this case the thermocline is destroyed or drastically reduced.

The triggered baroclinic waves reported by Huyer et al., (1988) and Louis, (1989), while not the prime subject of this study, are not obvious from the current records – with the possible exception of a series of three or four waves with period 7 days occurring in January 1990.

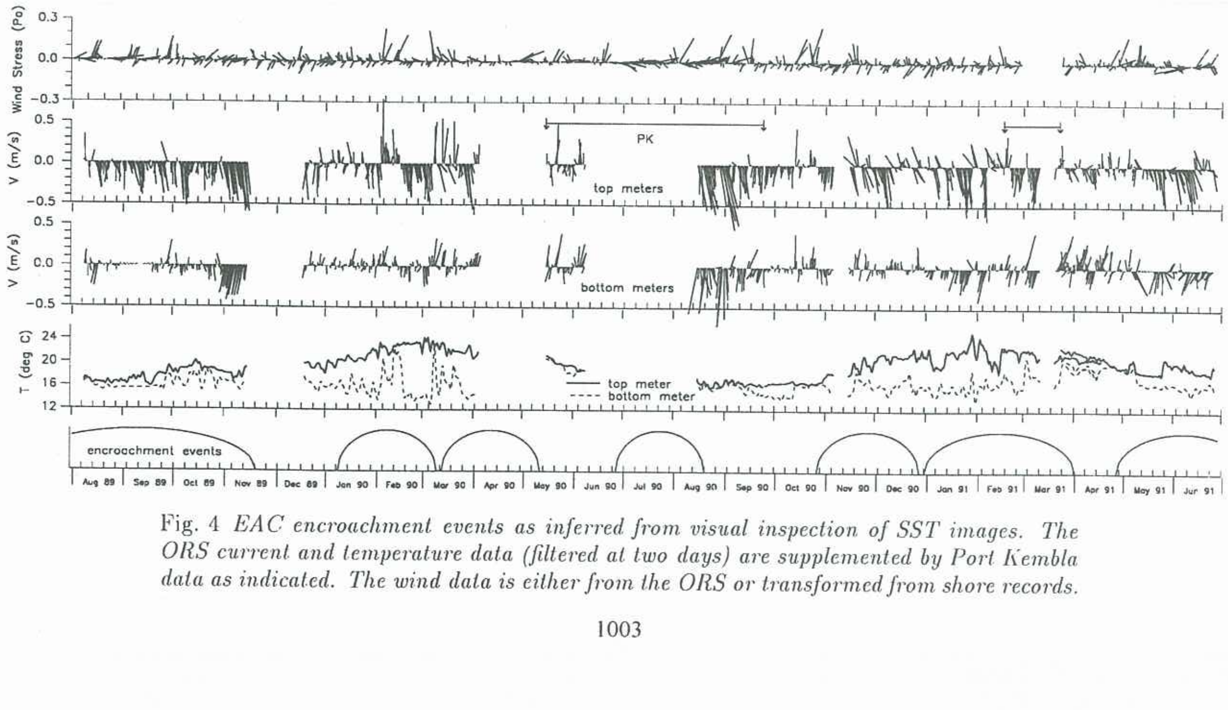

Fig. 4 *EAC encroachment events as inferred from visual inspection of SST images. The ORS current and temperature data (filtered at two days) are supplemented by Port Kembla data as indicated. The wind data is either from the ORS or transformed from shore records.*

SST-Current Coherence

In order to quantify the EAC influence, a 256 km square segment centred 85 km east of Sydney (corresponding to the portion of coastline shown in Figure 1) was extracted from the one year's digital SST images. Under the assumption that EAC behaviour is geostrophic, and that surface temperature gradients mimic deeper structures, temperature gradient was used as the signal for EAC current. Given that the study concentrates on alongshore current, the offshore temperature gradient was computed using a centred difference followed by a 3 by 3 km block filter for smoothing. An example of the gradient images is given in Figure 5.

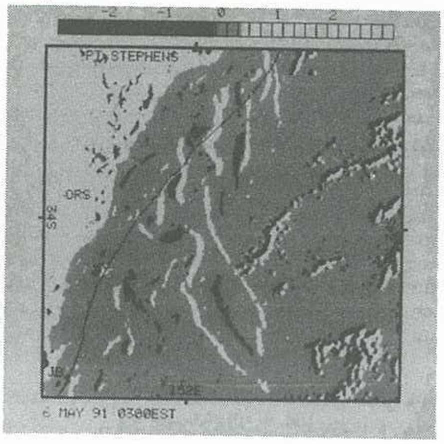

Fig. 5 *SST offshore gradient image. Light grey features represent south-flowing current, while dark features represent north-flowing current. Cloud features on the right should be ignored.*

Gradient time series at six points on the shelf (offshore from Lake Macquarie, Sydney and Port Kembla, at mid shelf and shelf-break) were extracted from the images and filtered at 20 days, matching the composite ORS alongshore current. While some wave-like features can be seen progressing from point to point, a relation between EAC and coastal current is not obvious from the time series and indeed, the coherence function between the ORS alongshore current and any of the gradient time series is generally less than 0.5. However, the combined signal from the SST series is highly coherent with the current, as evidenced by a multiple coherence of over 0.9 at all frequencies. Demonstration of this coherence is best made via a comparison of the measured time series with a modelled time series using the multiple transfer function associated with the coherence. (Figure 6).

Although not shown here, slopes on the phases of the transfer function, (as well as the individual coherences) confirm the notion that low frequency current patterns move south at speeds between 7 and 25 km/day.

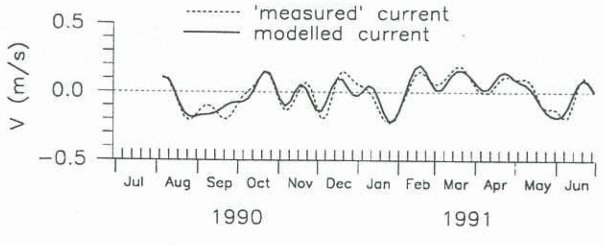

Fig. 6 *Comparison of alongshore current with reconstruction from SST offshore gradients. Band averaging over eight adjacent frequencies was used in the multiple transfer function.*

CONCLUSIONS

The persistent southerly bias, much of the low frequency variability and occasional short duration episodes in Sydney coastal currents can be linked with EAC behaviour as deduced from visual inspection of SST images. The link may also be established qualitatively using offshore SST gradient as the EAC signal. While the comparison of modelled long period current with the filtered data appears promising, caution is dictated by the fact that data from six positions were used to generate a time series containing only three frequencies. Experiments with longer data sets (work now in progress) should be more conclusive.

ACKNOWLEDGEMENTS

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REFERENCES

Creswell GR and Legeckis R (1986) Eddies off south-eastern Australia, Deep-Sea Res., 33, Nos 11/12, 1527-1562.

Godfrey JS (1973), Comparison of the East Australian Current with the western boundary flow in Bryan and Cox's (1968) numerical model ocean, Deep-Sea Res., 20, 1059-1076.

Godfrey JS, Cresswell GR, Golding TJ and Pearce AF (1980) The separation of the East Australian Current, J. Phys. Oceanogr.,10, 430-440.

Gordon AD and Fagan PW (1991) Ocean outfall performance performance monitoring, Proc. Int. Symp. Environmental Hydraulics, Lee JHW and Cheung YK (ed), Balkema Rotterdam 243-248.

Hamon BV, Godfrey JS, and Grieg MA (1975) Relation between mean sea level, current and wind stress on the east coast of Australia, Aust. J. Marine and Freshwater Res., 26, 389-400.

Huyer A, Smith RL, Stabeno PJ, Church JA, and White NJ (1988) Currents off South-eastern Australia: Results from the Australian Coastal Experiment, Aust. J. Marine and Freshwater Res., 39, 245-288.

Lawson and Treloar Pty Ltd (1987), Sydney Deepwater Outfalls Environmental Monitoring Program Pilot Study Vol. 12: Ocean Reference Station, Lawson and Treloar Pty Ltd Rep. No. 1188, report series by Water Board, March 1988.

Louis JP (1989) Current-shelf interactions during the Australian Coastal Experiment, Aust. J. Marine and Freshwater Res., 40, 571-585.

Middleton JH (1987) Sydney Deepwater Outfalls Environmental Monitoring Program Pilot Study Volume 2: Oceanographic Component, Unisearch Rep. R1318, Dec. 1987, report series by Water Board, March 1988.

Webb AT (1991) Sydney Deepwater Outfalls, Environmental Monitoring Program, influence of the East Australian Current on Sydney coastal currents, Unisearch Rep. for Australian Water and Coastal Studies, Report 91/01/26, Sydney.