Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 63 (1991)

Artikel: Surface current monitoring in coastal waters

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DOI: https://doi.org/10.5169/seals-48509

Surface Current Monitoring in Coastal Waters
Enregistrement des courants de surface dans les eaux côtiéres
Ueberwachung von Oberflächenströmungen in Küstengewässern

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SUMMARY
An HF coastal ocean surface radar (COSRAD) has been operated in several areas of engineering importance in Australian waters, for which technical information is given on the system. Areas of typically 200 km^2 can be mapped in half an hour. Observations show that the surface water responds rapidly to mescoscale boundary layer winds to provide complex convergence and divergence flows. Some recent work is reviewed which uses radar determinations of surface water movement to calibrate 3D flow models.
This technique has a unique monitoring role when warm or low-salinity water forms a thin stratified layer which is not well coupled to the main water column

Enregistrement des courants de surface dans les eaux côtières

Résumé
Une technique de radar à haute fréquence (COSRAD= coastal ocean surface radar) a été utilisée dans plusieurs régions côtières australiennes. Des explications techniques sont données. Des zones de 200 km2 peuvent être enregistrées en une demi-heure. L'observation montre que les eaux de surface réagissent rapidement à certains vents locaux et produisent des courants marins complexes. Un travail récent est passé en revue lequel utilise une détermination par radar des mouvement d'eaux de surface permettant la calibration de modèles de courants tridimensionnels. Cette technique joue un rôle d'enregistrement exceptionel lorsque des eaux chaudes ou de faible salinité forment une couche stratifiée fine, laquelle ne participe pas aux courants marins principaux.

Ueberwachung von Oberflächenströmungen in Küstengewässern

Zusammenfassung
In mehreren Regionen der australischen Küstengewässer wurde eine Hochfrequenzradartechnik (COSRAD = costal ocean surface radar) der nachfolgend beschriebenen Technik eingesetzt. Daten über Zonen von üblicherweise 200 Quadratkilometern können binnen einer halben Stunde aufgenommen werden. Beobachtungen zeigen, dass das Oberflächenwasser sehr schnell auf gewisse lokale Winde mit komplexen maritimen Strömungen reagiert. In einer kürzlich erschienenen Arbeit wurden Radarbestimmungen der Oberflächenwasserbewegung zum Kalibrieren dreidimensionaler Strömungsmodelle verwendet. Diese Technik spielt eine Rolle bei der Ueberwachung von warmen oder schwach salzhaltigen Strömungen, die dünne, geschichtete Lagen bilden, die nicht gut mit der Hauptwassersäule gekoppelt sind.

1. HF OCEAN RADAR

1.1 Principle of Operation

When a radio wave encounters the ocean surface it is scattered into a polar pattern which is determined by the wave–wave interactions between the electromagnetic wave and the spectrum of sea–surface gravity waves. In particular there is a resonant backscatter from the two sea–surface gravity waves which have vector wave numbers $\pm 2\underset{\sim}{k}$ when the grazing incident radio wave has wavenumber $\underset{\sim}{k}$ [3]. The radar echo from these two very specific ocean waves is a pair of first–order echoes in the Doppler shift spectrum which generally dominate over the other backscattered energy. This is shown by peaks A and B in Figure 1.

The two sea surface gravity waves which produce the resonant backscatter peaks have phase velocities given by the deep water dispersion relation

$$c = \pm(g/2k)^{\frac{1}{2}}$$

and the corresponding Doppler shifts for the resonance or Bragg spectral peaks are

$$\omega_B = \pm\,(2gk)^{\frac{1}{2}}$$

If there is a current present then to a very good approximation the Doppler shift of the Bragg peaks becomes

$$\omega = \omega_B - 2\underset{\sim}{v}.\underset{\sim}{k}$$

This means that it is the radial component of the current, as seen from the radar station, which contributes Doppler shift.

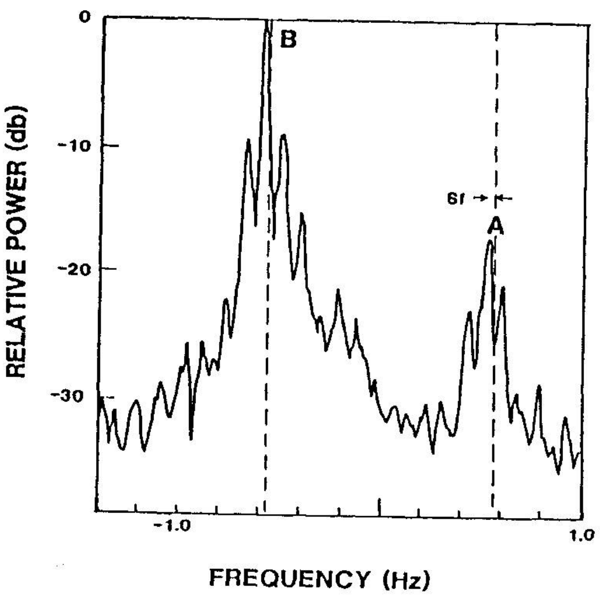


Figure 1. A typical ocean surface backscatter spectrum at 30 MHz. The spectral lines marked A and B are used to determine surface currents. The Doppler frequency shift f is caused by currents.

The wave–wave interaction which produces the backscattered Doppler shift spectrum is limited to the sea–surface by virtue of the finite depth penetration of the sea surface gravity wave which has wavenumber $2\underset{\sim}{k}$. Stewart and Joy [10] and Barrick et al [2] have analysed the effective depth of the surface current layer to which the HF radar would respond. For a linear vertical shear in current ($\frac{dv}{dz}$ = constant) the Doppler shift produced corresponds to the mean velocity over a water depth of approximately 1/2k where k is the radio wavenumber.

The second–order energy on the Doppler shift spectrum shown in Figure 1 is characteristic of a further wave–wave interaction at the point of scatter due to double scatter and hydrodynamical non–linearities. Barrick [1] and Robson [8] have provided two different approaches to the calculation of the second–order Doppler shift spectrum starting from the full directional wave spectrum of the sea–surface waves. The second–order energy may be used to measure wave heights, wave periods and wave directions. [7], [6], [11].

1.2 Radar Configurations

For the mapping of sea–surface currents it is usual to use a pair of radar stations sweeping across the mapped area from different vantage points. At each pixel in the target area, components of the surface current are measured in two different directions and the surface current vector may be calculated. This general technique has been used by several groups [4].

There are several different radar configurations of radar systems for HF ocean surface current mapping which are reviewed by Shearman [10]. The Coastal Ocean Surface Radar system used for the work in Australia consists of a single narrow beam antenna which is used for both transmission and reception. This offers a convenient and efficient use of the radio–frequency power and represents a solution to the problem of switching from about 10^3 watt to about 10^{-14} watt of power in a few microseconds.

The single antenna for the 30MHz COSRAD system is 8 wavelengths long (80 metres). The system is transportable and can be installed in a few hours.

A typical two station configuration is shown in Figure 2. The computer software plots a current vector at each diamond–shaped area of intersection, however the spatial resolution of the mapping is approximately 1.5 cm. Validation tests have indicated that the current components measured have an accuracy of better than 1.5 km per second, [6].

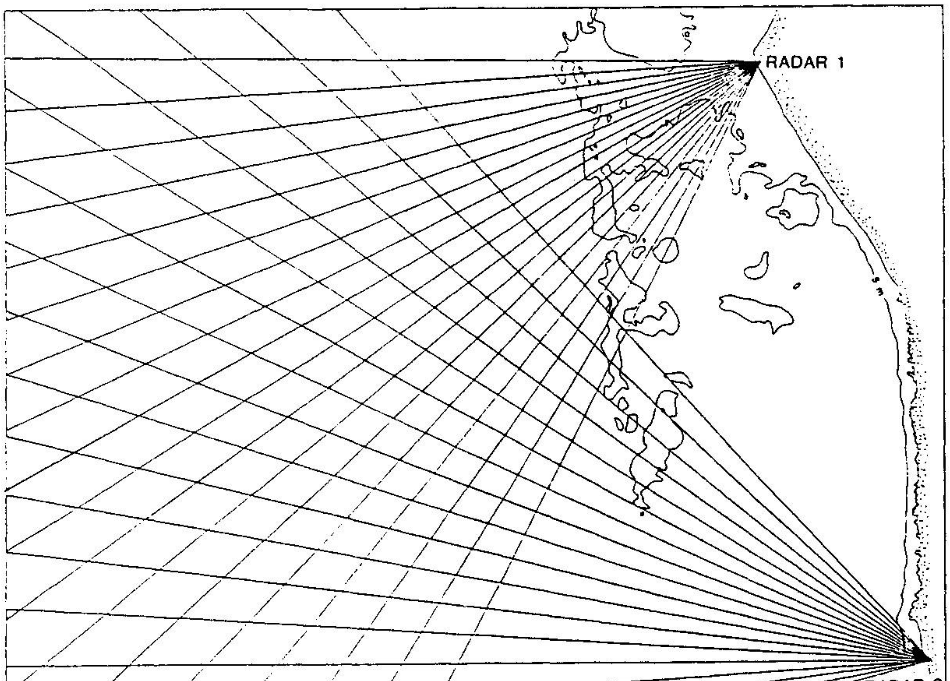


Figure 2. Scanning pattern of two COSRAD stations deployed to monitor surface currents. Current vectors are plotted at each diamond–shaped overlap area.

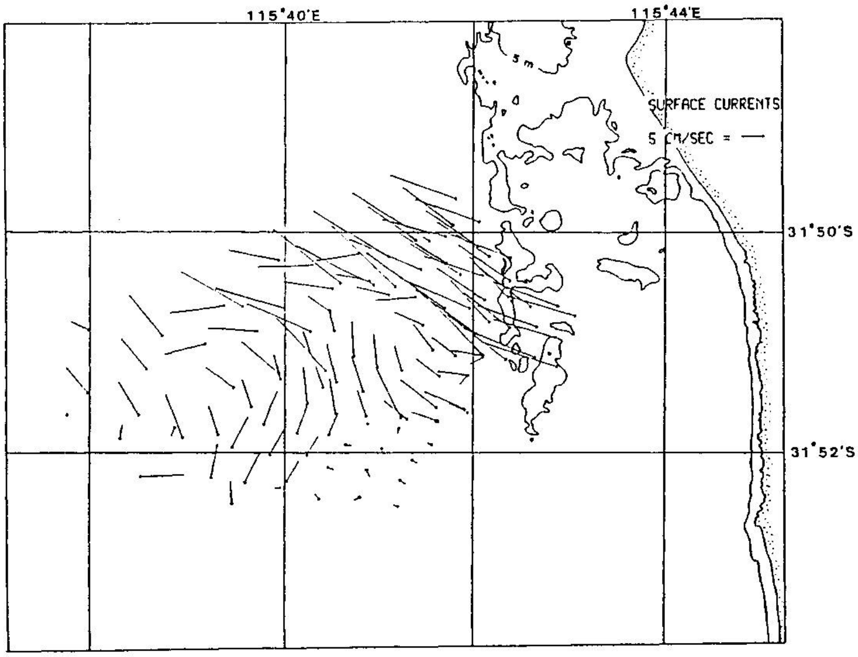


Figure 3. Surface current map during the early part of a storm in shallow water close to Perth, Australia

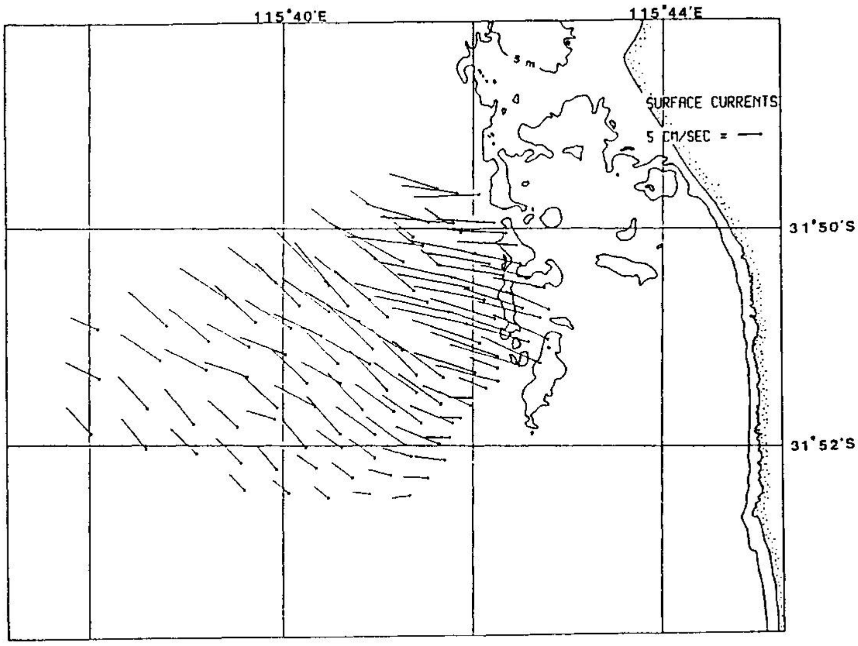
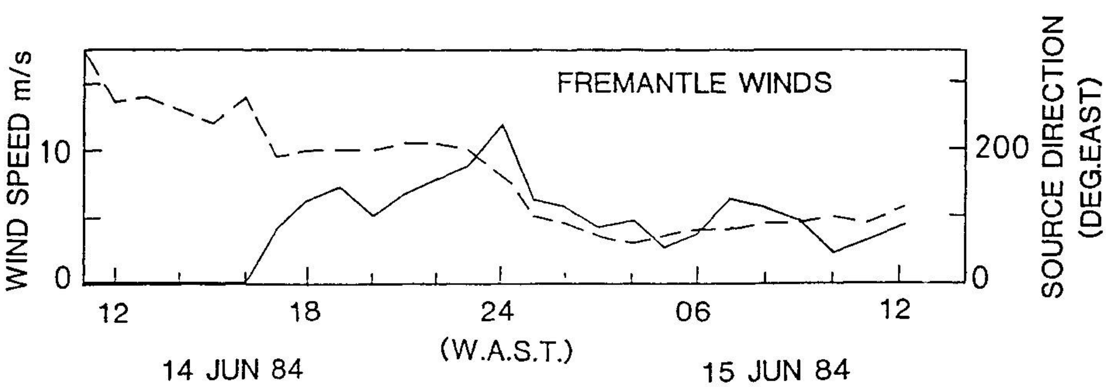


Figure 4. Surface current map subsequent to that in figure 3.

Figure 5. Surface wind during the storm relating to Figures 3 and 4. Wind speed is shown as a solid line; wind source direction is shown with a broken line.



The routine operation of the COSRAD system involves moving sequentially from one azimuthal beam position to the next, spending 102.4 seconds on each sector and completing the sweep of 17 sectors (corresponding to ± 30°) in 30 minutes. At each beam position all of the range cells are recorded within the 102.4 second record length. In this prototype system the spectral analysis of the multiple time series to produce Doppler shift echo spectra is done off–line back in the laboratory.

2. RESULTS

2.1 Case Study – Western Australia

An experimental deployment was made on metropolitan beaches in the northern suburbs of the City of Perth in 1984. During the study period the tidal range was small and the surface currents were dominated by the passage of a meteorological cold front and its accompanying stormy weather.

Two successive four–hour averages of surface currents are shown in Figure 3 and 4. The wind record is shown in Figure 5. The surface currents are dynamic and changing rapidly in response to the wind. Simultaneous measurements on a current meter moored in mid–column in the mapped area showed no such fast responses. Work done more recently at another site (unpublished) incidates that the surface has localised convergences and divergences as surface water moves in response to localised storms.

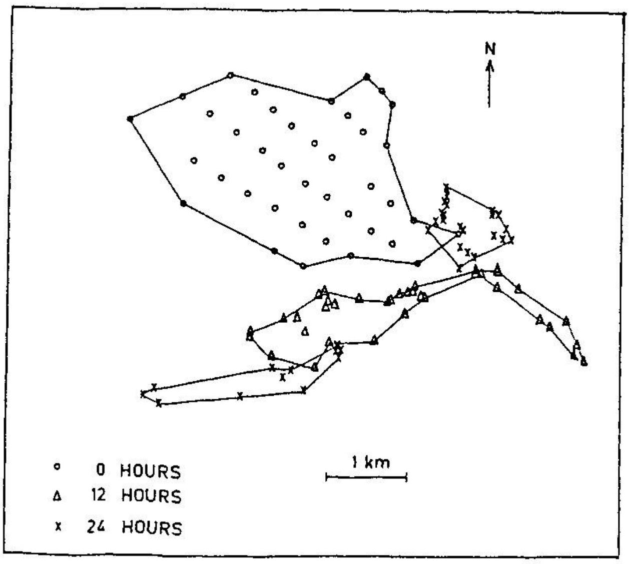


Figure 6. Notional particle tracking at points o before the storm then after 12 hours they would be located at Δ and after 24 hours they would be at x

A further analysis of this event can be done by tracking notional particles along Lagrangian paths using successive half–hour maps of vector surface currents. Figure 6 shows a matrix of starting points for particles and then their positions after 12 hours and 24 hours. Quite clearly on this scale of time and space the normal separation of particles according to the law

$$\frac{1}{2}\frac{d}{dt}<s^2> = a <s^2>^{2/3}$$

has not worked, where s is particle separation.

2.2 Case Study – Sydney Sewerage Outfalls Area

The Sydney Water Board is in the process of commissioning deep water diffusive sewerage outfalls to minimise the impact of ocean sewage disposal on the metropolitan beaches. As a part of a feasibility study for long term monitoring the COSRAD system was deployed in July 1989 in a demonstration phase. Under normal conditions the surface water cleared the area to the south. However under certain meteorological conditions a persistent gyre was found to recur off the Sydney coast (Fig. 7). This is an advective vortex which may be associated with the south–bound East Australian Current.

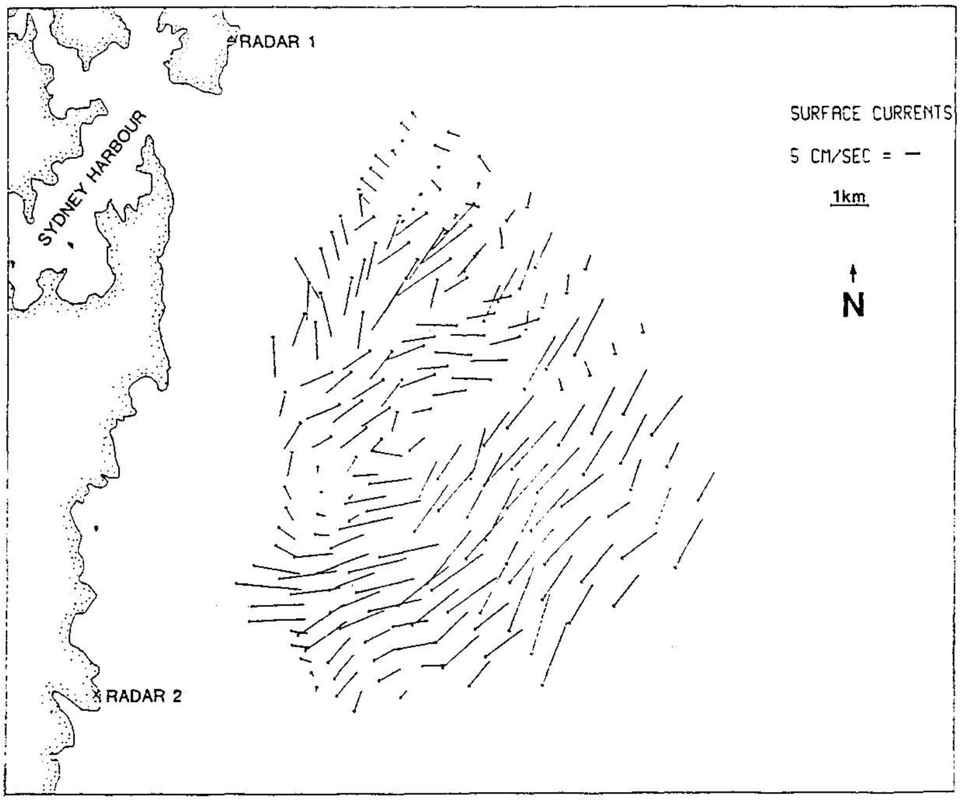


Figure 7. Surface current maps in near the edge of the continential shelf off Sydney, Australia

2.3 Case Study – Moreton Bay, Brisbane

The Brisbane River debouches into Moreton Bay in the South–East corner of Queensland. Moreton Bay is effectively closed on all sides except the North, and within it are several wide–mouthed bays including Bramble Bay and Deception Bay. A programme of mapping of surface currents has been undertaken in Bramble and Deception Bays to find the flow patterns under low wind conditions. A selected sample of particle tracks for Deception Bay is shown in Figure 8 which illustrates our general conclusion. There is a topographical line of divergence in the surface flow which separates Deception Bay water from the larger Moreton Bay. On the basis of these data one would advise locating waste outfalls to the East of the divergence line.

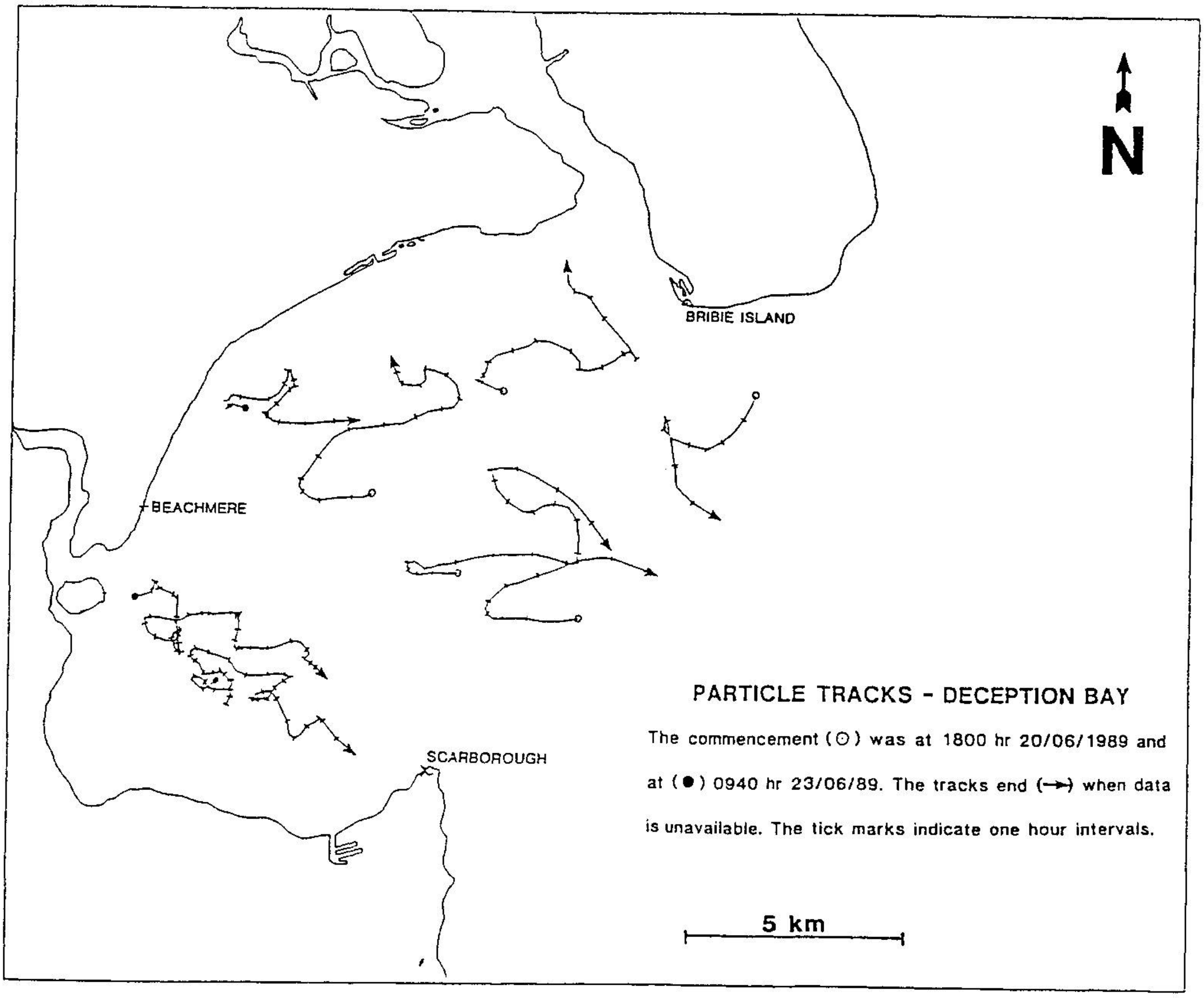


Figure 8. Notional particle tracks in Deception Bay near Brisbane, Australia in low wind conditions

3. LONG RANGE VERSION OF COSRAD

The 30 MHz system described in this paper is transportable and can be set up on public beaches, parks etc for specific studies. It is limited in range to less than 30 km and generally 25 km.

There is a need for the longer ranges in HF radar remote sensing particularly for wave parameters. A prototype system has been developed at Townsville, North Queensland for wave and current measurements. It is not movable, being a fixed antenna operating at 6 – 7 MHz. It is being evaluated by Woodside Offshore Petroleum Pty Ltd for the possible use of this technology in the Remote Offshore Warning System of the North West Shelf Gas Project.

4. CONCLUSION

The use of the 30MHz transportable COSRAD system for mapping currents in bays or harbours of typically 200 sq km has been prototyped to an automatic status. It is a cost effective monitoring system which has provided additional insights into water movement which current meters and drifter drogues cannot provide because of their spatial limitations.

The pure–science thrust of the COSRAD research at James Cook University is now centred on properties of wind–waves and swell.

Due to its ability to measure the bulk surface current in the presence of waves the COSRAD system is finding scientific application in calibrating the value of the eddy diffusion coefficient in 3D numerical currents (Hearn et al, 1987).

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