14th AMOP Conference
Vancouver
June 12, '91

NEW CAPABILITIES IN REAL-TIME OIL SPILL AND FATE PREDICTION USING HF RADAR REMOTE SENSING

by

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1.0 INTRODUCTION

In times of emergency response to oil spills at sea, accurate prediction of the motion and fate of the floating slick is desirable. Over the continental shelves the surface circulation is notably variable, responding to tides, winds, density variations and low-frequency shelf waves. Much of this variability is not predictable with present numerical models or from available oceanographic data, and as a result slick motion projections tend to become quickly inaccurate. As with weather forecasting, ocean current prediction would benefit greatly from real-time data, either to be used directly in spill motion calculations, or for assimilation into circulation models.

At this time, HF radar remote sensing techniques provide the only practical means of obtaining surface current maps that cover enough of the shelf seas to be useful for spill motion modelling, at an acceptable accuracy and cost. Following a brief review of this measurement technique, some recent advances in new instrumentation and its use in emergency response to spills are discussed in this paper.

2.0 BACKGROUND TO HF RADAR

Over 35 years ago Crombie (1955) first explained the strong, distinctive symmetric peaks observed in HF sea-echo Doppler spectra in terms of Bragg scatter from surface waves. Crombie (1972) also suggested the use of these peaks to deduce surface currents, and devised an experiment utilizing a direction-finding two-element antenna pair to sense the magnitude and direction of the Gulf Stream flow off Cape Kennedy, Florida. The radial speed was related to bearing direction through the phase differences between the two antenna elements at each Doppler spectral frequency in the Bragg peak echoes.

In the absence of currents, the Bragg mechanism produces sea echo peaks that appear at Doppler positions proportional to the phase speed of waves whose lengths are exactly half the radar wavelength. For a given radar frequency, usually between 6 to 26 MHz, the wave length is known, and the reference position of these peaks can be precisely calculated. Any underlying radial component of current near the surface at the point of scatter will impart an additional shift from the reference position that is converted to speed through the Doppler relation.

The surface waves producing the echo are essentially tracers for the water current, analogous to turbulent scatterers in water that produce the return signal sensed by subsurface acoustic Doppler current profilers. Upper HF radar frequencies are selected since they scatter from short waves with periods of about 3 s; there is almost always some energy in these waves, even under the calmest conditions.

Under conditions of vertical current shear near the surface, waves are transported by the current at a mean depth equal to the radar wavelength divided by 8π. For example, at 12 MHz the mean depth is 1 m and the total layer thickness that influences the current is about 2 m. Thus the HF radar accurately measures horizontal currents in the uppermost layers, where other instruments such as current meters and acoustic doppler profilers become inoperable. For this reason, the HF measured currents are ideal for oil motion prediction.

The Bragg scatter mechanism yields information on current variations radial to the radar (i.e. pointing away from or toward the radar). Thus, two sites must view a point on the water in order to produce an unambiguous estimate of the total horizontal current vector. HF radar signal formats (pulse or linearly swept frequency) employ time delay to isolate the return from a annular segments of ocean at different radial distances from the coast (Fig. 1a). Two methods are generally employed to isolate the scattering patch in bearing: beam forming and direction finding (DF) methods.

HF current-sensing systems that employ DF methods have become known as CODARs (Lipa and Barrick, 1973), and feature compact antenna systems with three or four elements. The newest version, called SeaSonde, packages the entire receiving antenna system in a unit about 25 cm square containing a monopole and crossed-loopsticks (Fig. 1b).

In 1988 a CODAR system was used in a major demonstration project to map currents off the west coast of Vancouver Island (Dunbar et al., 1989) for the federal Department of Fisheries and Oceans. Current meter and drogue data, used to validate the radar measurements, demonstrated that the radar current maps were generally accurate to within 4-8 cm/s (Hardy et al., 1989). This level of accuracy meets the requirements for many oceanographic applications, and the spatial current maps yielded new and important information on surface current features never seen before, with important implications for fisheries research, oil spill response and maritime search and rescue.

C O D A R

Coastal Ocean Dynamics Applications Radar

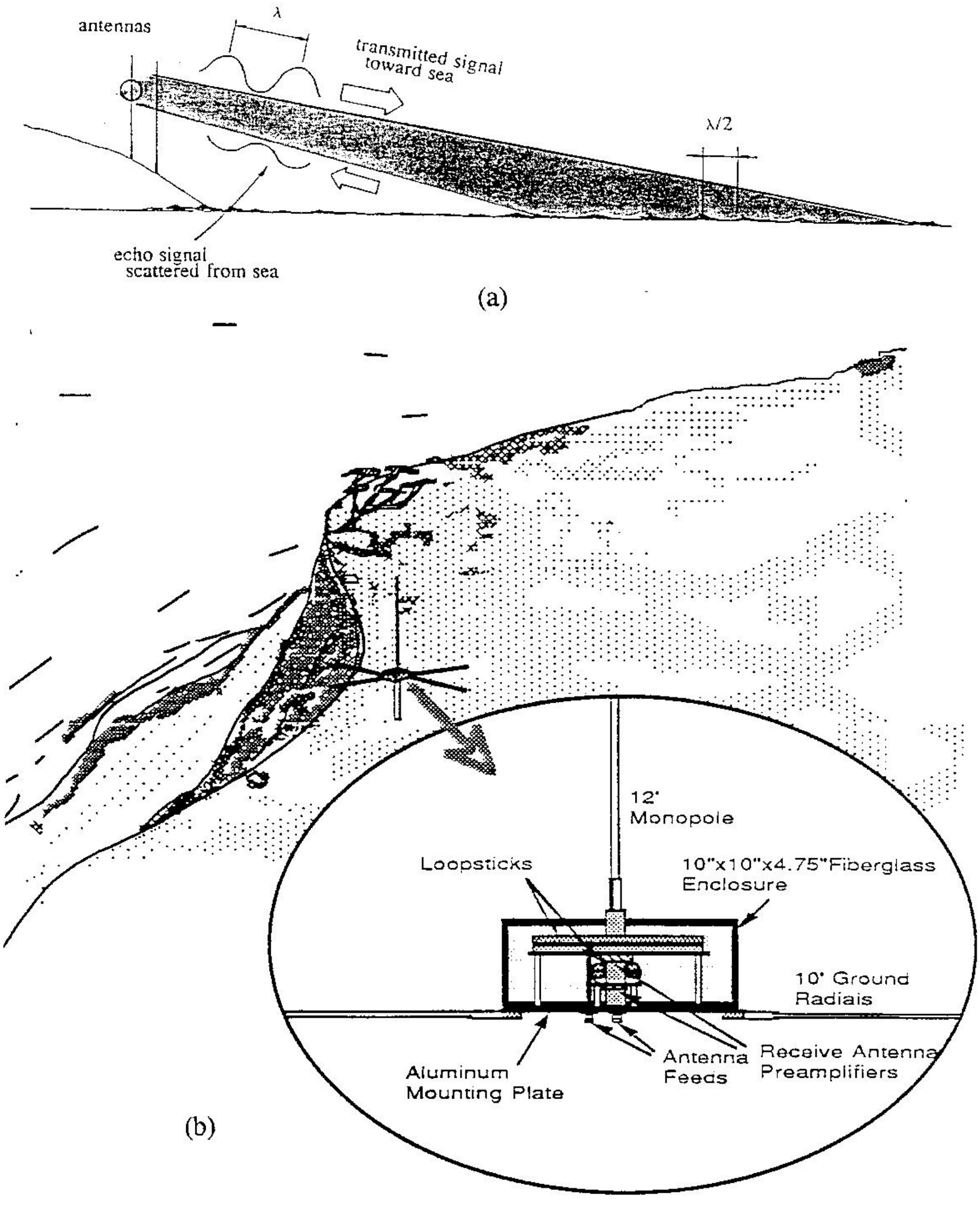

Figure 1 (a) Sketch of HF radar principles for measuring surface currents, (b) the crossed-loop receiving antenna system used at 12 MHz for the SeaSonde.

3.0 REAL-TIME SURFACE CURRENTS FOR OIL SPILL MODELLING

3.1 A Spill Hindcast Using HF-sensed Currents

Late in October and early November, 1988, two radar stations were established at Pachena and Carmanah Points, on Vancouver Island, to measure currents over Swiftsure Bank, at the entrance to Juan de Fuca Strait. These radars were the older form of CODAR employing a 4-element square receiving antenna. The transmit frequency was 25.4 MHz and the radial ring spacing was 1.2 km. A DF algorithm (Hardy et al., 1989) was used for deriving surface currents. Hourly surface current maps were obtained for several days.

An example of one current map is shown in Fig. 2, indicating the strong tidal flows along the coast out of the strait. It also shows a distinct front over the edge of the shelf where the outflowing brackish water merges with the oceanic water. The offshore range of this radar was about 35 km, and the data are shown here on a 2 x 2 km Cartesian grid oriented EW-NS. An oil spill model (Hodgins et al., 1991) was implemented on the 500-m Cartesian grid shown in Fig. 3, and a hypothetical spill of about 20,000 m^3 was released over 6 hours off the mouth of Juan de Fuca Strait.

The hourly radar surface current maps were used to drive the oil spill model. In order to extend the radar coverage area to the total model grid domain, a simple interpolation and filling algorithm was applied to the radar data (Fig. 4). These fields were subsequently interpolated onto the 500-m grid for the oil spill model using bilinear interpolation.

The evolution of the spill at 1, 2, 3 and 6 hours after release is shown in Fig. 5. The currents at 5 and 11 hours after the spill are plotted in Fig. 6. As can be seen here the tidal influence is strong in this area, producing a constantly changing flow pattern. The distinct zone of convergence at 11 hours is a characteristic tidally-induced feature recurring in the maps over several days. The spill is mapped at 9 and 12 hours in Fig. 7; the convergence in surface flow between these times has resulted in a reduction of the area occupied by the spill.

3.2 Real-time Spill Motion Prediction

The second-generation CODAR systems, called SeaSondes offer several significant improvements over the older units, the most important of which are increased range (up to 70 km); compact, solid-state RF electronics for greater reliability; compact, easily deployed antenna systems; VHF data communications between sites and real-time vector map processing; PC-based data acquisition and processing; and a user-friendly graphical user interface for data display and manipulation. The entire RF and data acquisition system is packaged as shown in Fig. 8, and the equipment is suitable for rapid deployment during emergency response. A data-link

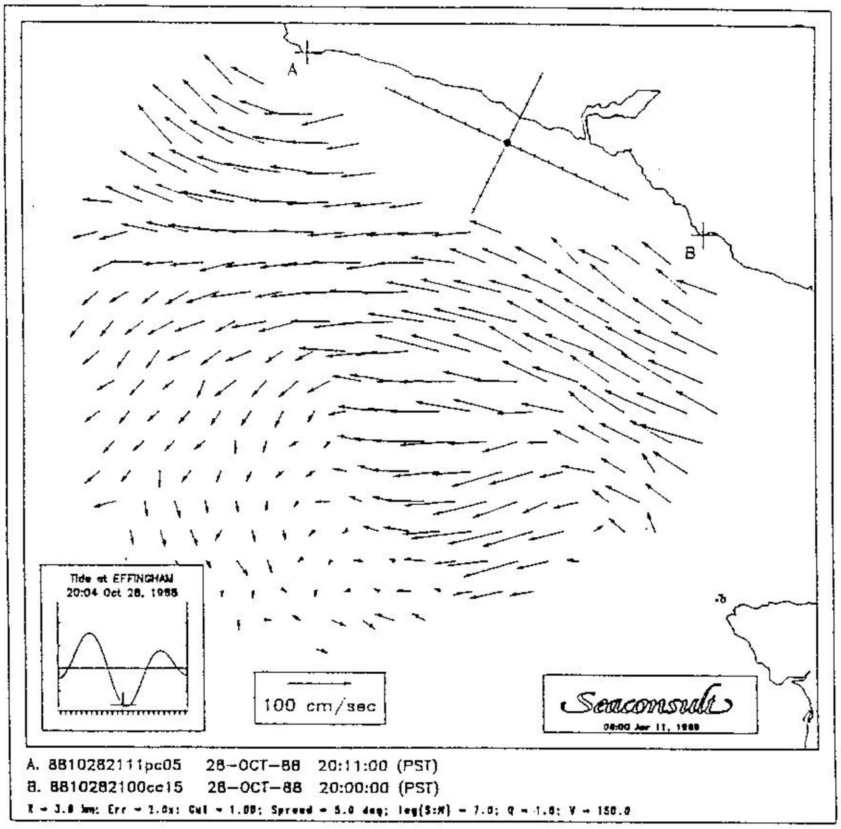

Figure 2 Surface currents over Swiftsure Bank off Vancouver Island measured using HF radar.

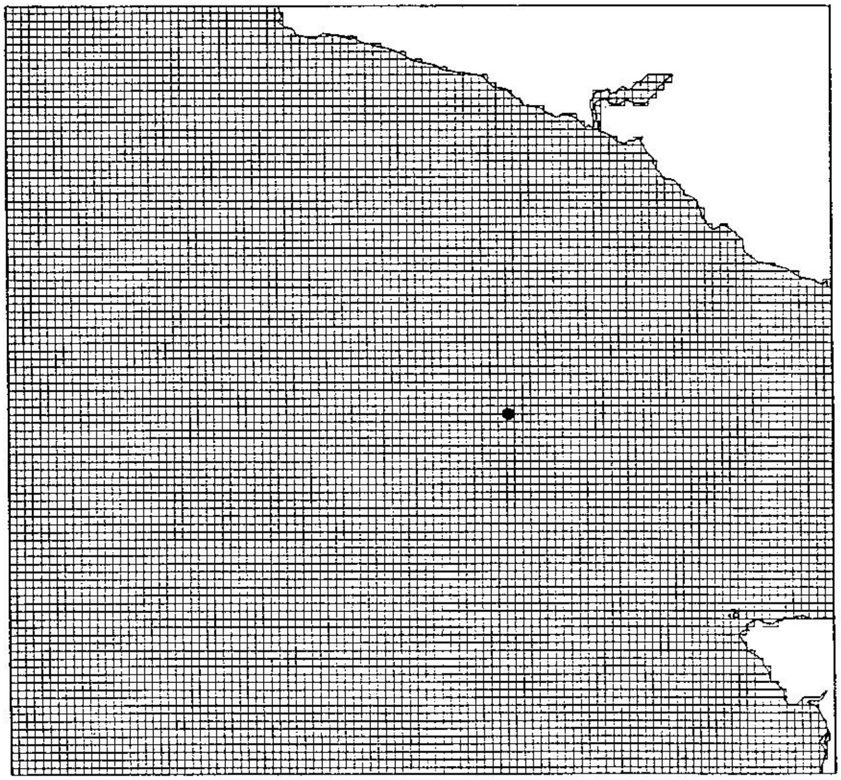

Figure 3 Model grid with a 500-m spacing for oil spill modelling off the mouth of Juan de Fuca Strait.

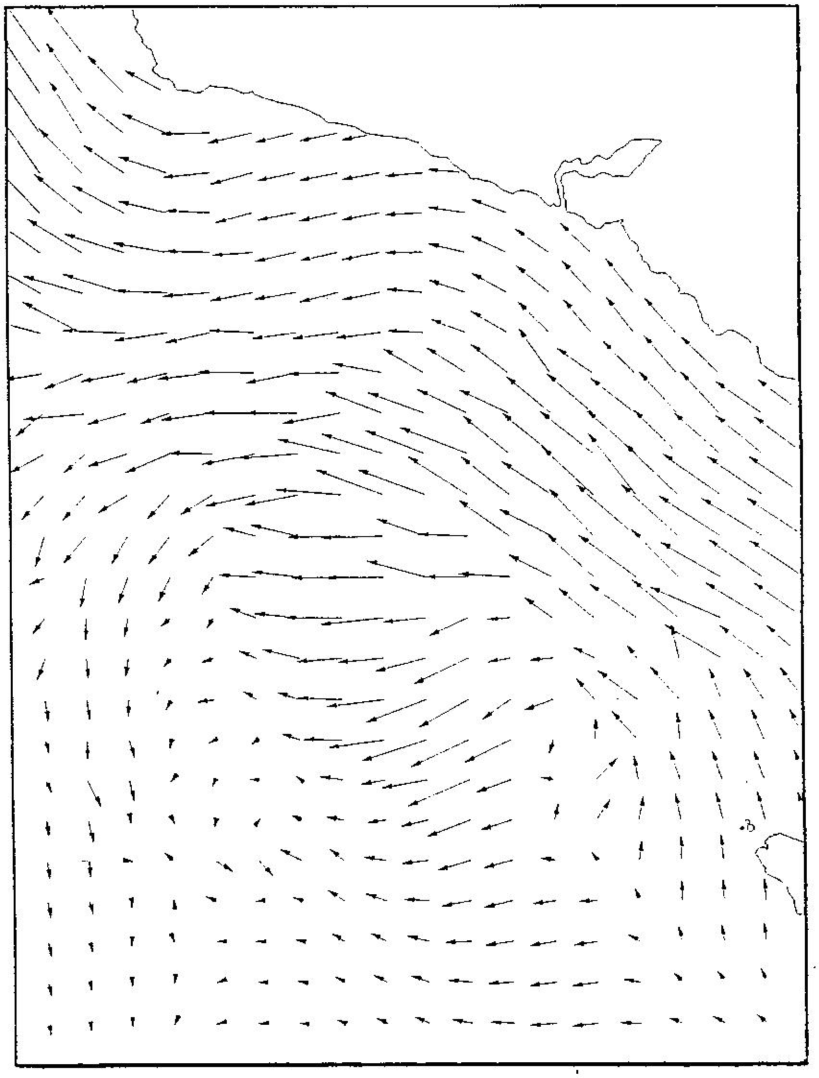

Figure 4 Extended surface current field incorporating the HF radar sensed currents.

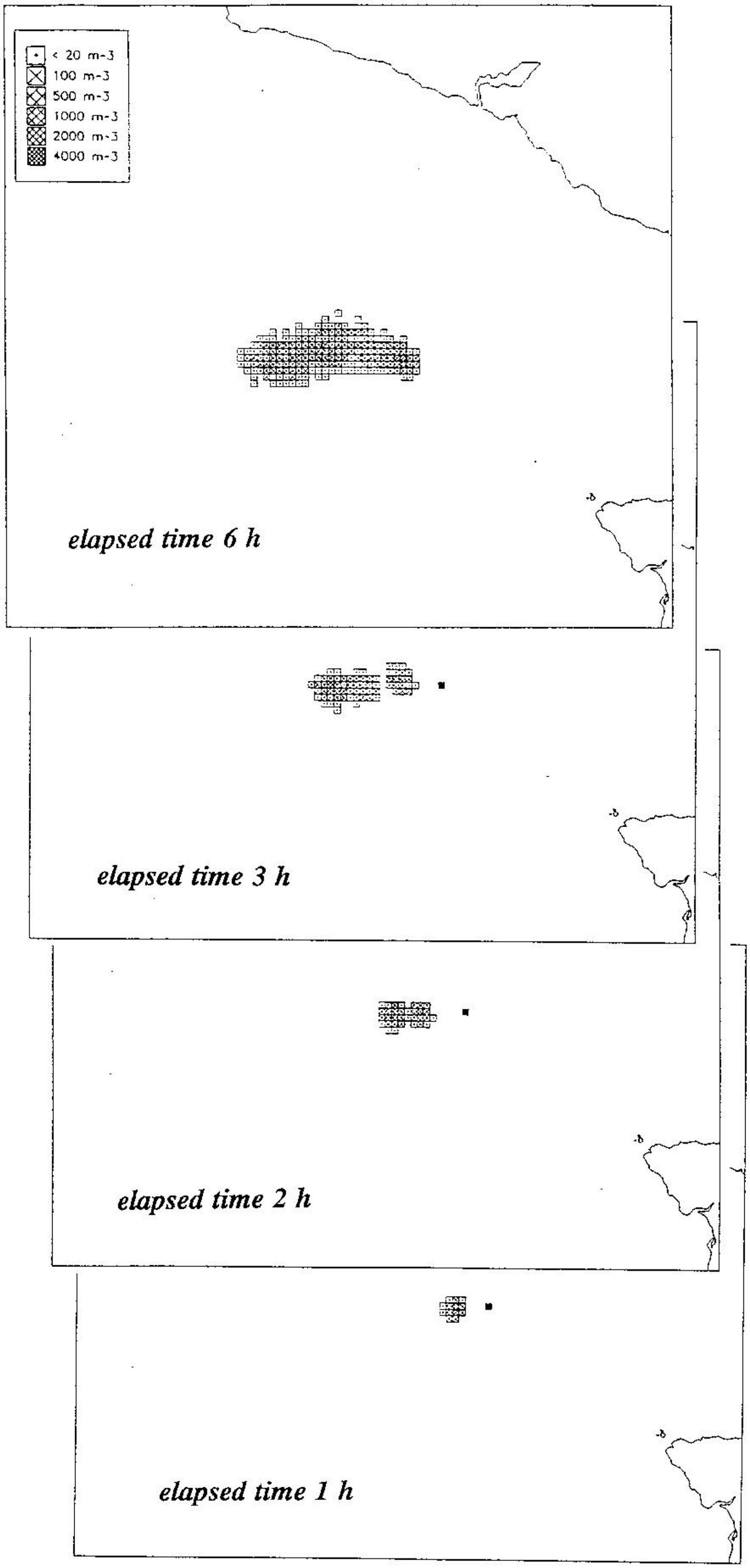

Figure 5 Evolution of a 20,000 m^3 crude oil spill using measured surface currents to calculate the motion.

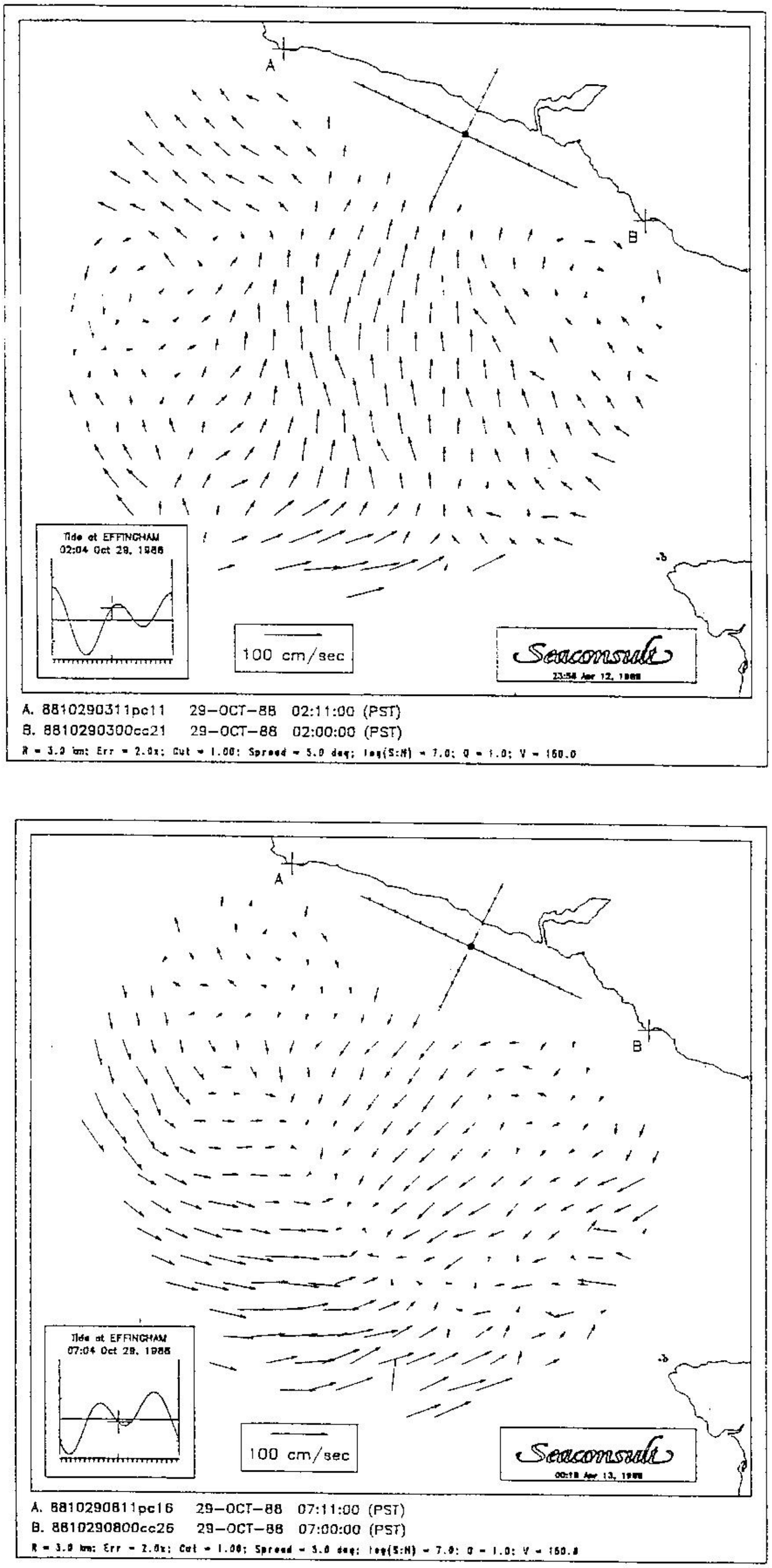

Figure 6 Surface currents measured with HF radar at elapsed times of 5 and 11 hours after the spill started.

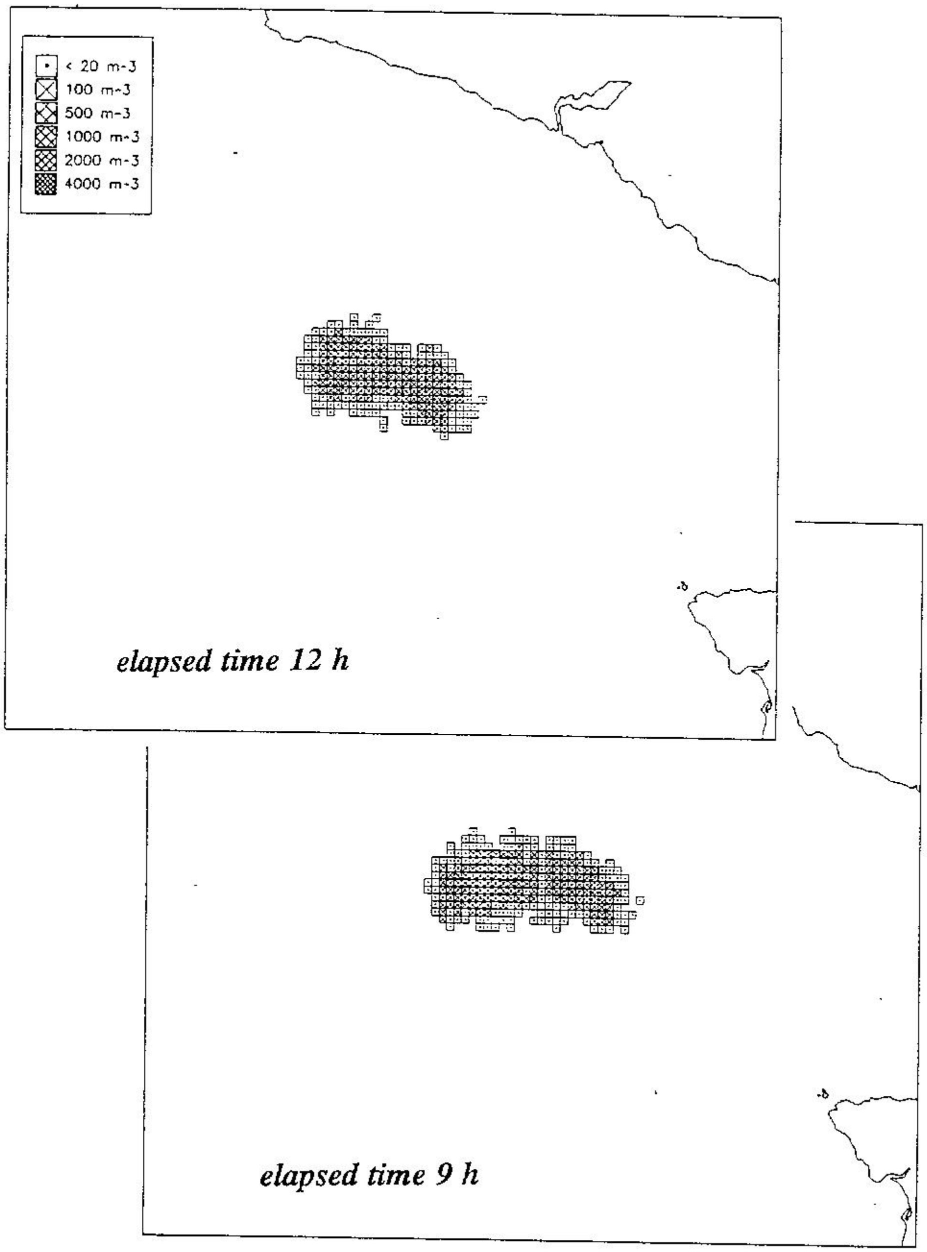

Figure 7 Modelled slicks 9 h and 12 h after the spill time, showing the reduction in slick size resulting from convergent flows.

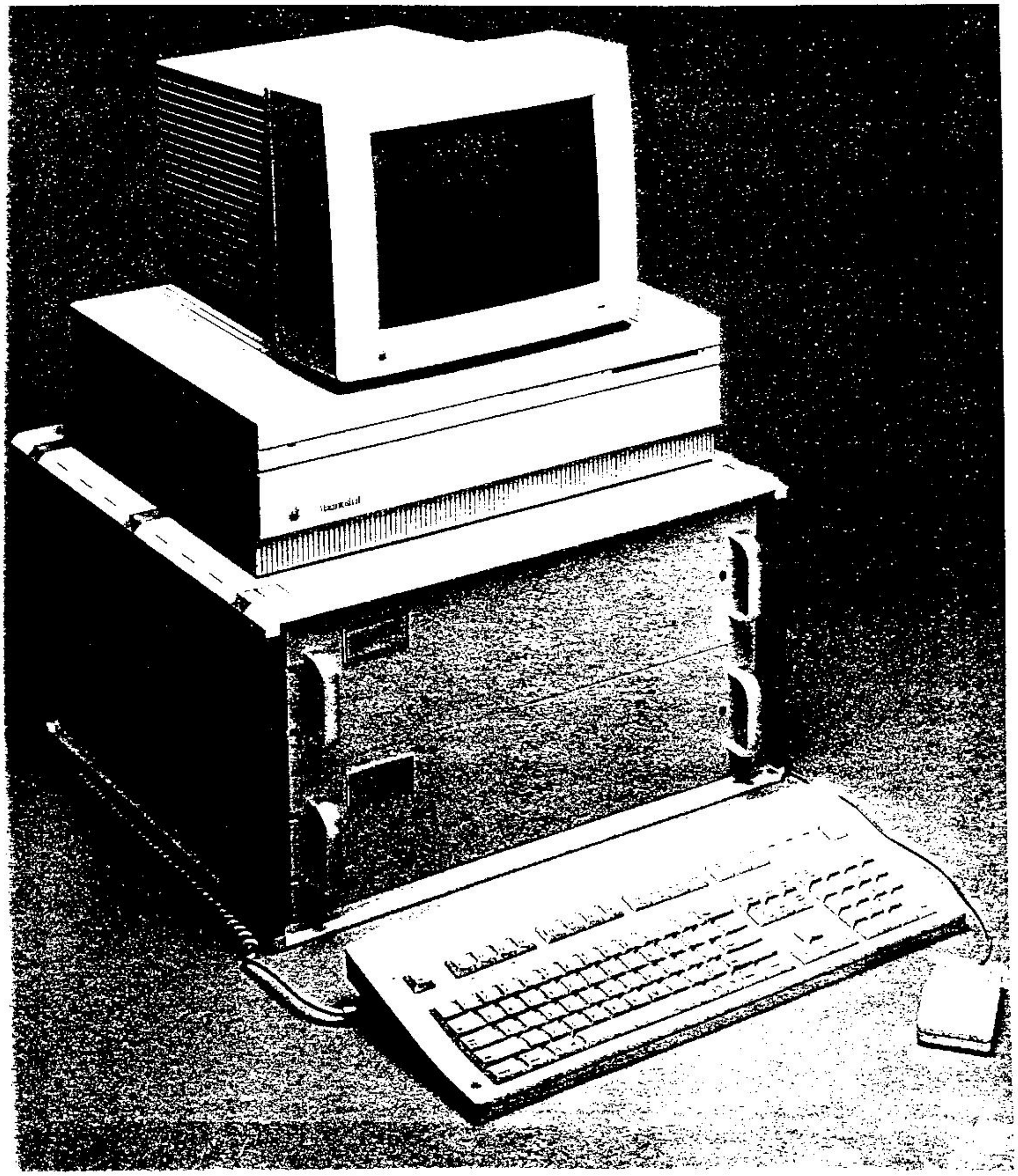

Figure 8 Photograph of the SeaSonde system for coastal current mapping out to 70 km range. All radar hardware except the antenna is contained in the lower box. The data acquisition and processing is performed by the Macintosh II computer.