CHAPTER 197

Surface currents remotely observed by means of RADAR

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INTRODUCTION

Surface currents normally are difficult to measure. Only a set of Lagrangian drifters observed from fixed stations or from an aircraft or by satellite can give adequate information. Beneath this there is a new and powerfull field measuring tool which functions with a decametre backscatter radiowave RADAR. Two (or more) such fixed RADAR stations on land or on islands can remotely measure the surface currents in front of them with high resolution in space and time.

This paper has two aims: first, to give a short explanation of the physical principles of the backscatter RADAR and to show its requirements and its limits, and secondly, to demonstrate the possibilities offered by this RADAR with an example of the coastal surface current off Norway.

PHYSICS OF OPERATION

A radio pulse or wave train of frequency 29.85 MHz is transmitted from a place near to the shore. The sea surface acts to the radio wave train as a scattering grid due to BRAGG scattering mechanism: if the wavelength of the transmitted electromagnetic wave is λ_{EL} (approximately 10 m) only those spectral parts of the seas gravity waves (surface waves) with wavelength

$$\lambda_{GR} = 0.5\,\lambda_{EL}$$

are responsible for the intense backscatter of electromagnetic waves. All other elevations of the sea surface act

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as scattering targets too, but their combined scattered total energy is some orders less due to destructive interference.

The received backscattered echo from the sea has a somewhat different frequency compared to the transmit signal. This is caused by the phase velocity v_{GR} of those ocean gravity waves which fulfill the BRAGG-condition: If the transmit frequency is f_{EL} and the phase velocity of the gravity waves is

$$v_{GR} = \sqrt{g \cdot \lambda_{GR} / 2\pi}$$

where g is the acceleration due to gravity, the DOPPLER shifted backscattered frequency $f_{EL,D}$ becomes

$$f_{EL,D} = f_{EL} \cdot \left(1 \pm \frac{v_{GR}}{c}\right)^2$$

where c is the speed of light.

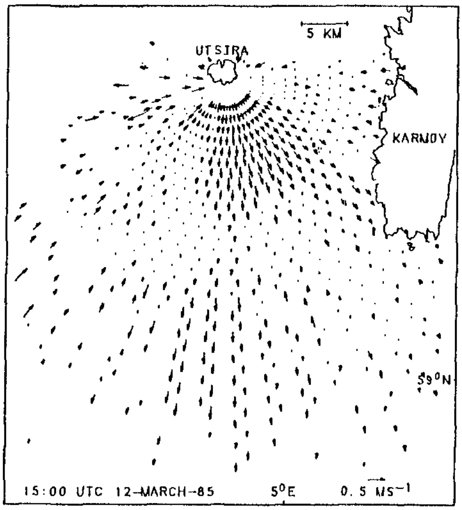
The difference in frequency between f_{EL} and the received DOPPLER-echo $f_{EL,D}$ is in the order of one Hertz. Because all variables are known, one can predict this difference. Early observations by D. D. Crombie (1955) turned out that there are differences between predicted and measured frequency shift values. He found, that underlying ocean current is increasing or decreasing the phase velocity of ocean gravity waves thus giving somewhat higher or lower echo frequency shifts. Later on Crombie and many other scientists, in particular D. E. Barrick (1977), B. J. Lipa (1977) and E. D. R. Shearman (1980) used HF-backscatter to remotely measure ocean surface current and wave hight, the latter from the strength of the echo.

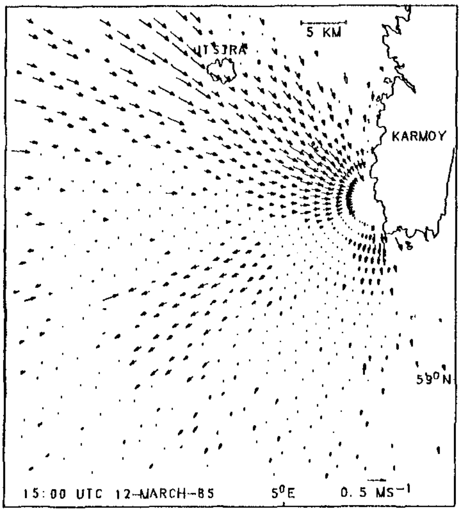
THE CODAR

The ocean current mapping HF-RADAR used by us is originally evolved by the U.S.-NOAA's Wave Propagation Laboratory (WPL) in Boulder, Colorado. D. E. Barrick, M. W. Evans and B. L. Weber (1977) and others there developed a RADAR for current mapping which they called CODAR, an acronym for Coastal Ocean Dynamics Application Radar.

The CODAR consists of a transmit antenna near to the shore and a set of four receiving antennas for direction finding of the HF-echos from the sea. The transmitted (and received) electromagnetic wave is a ground wave which follows the curvature of the earth. The water in this case be electric conductive salt water. In the case of fresh water or of sea ice no ground wave is generated.

A single CODAR station can only measure the radial component of the surface current at each point of the sea in front of it. So a minimum of two stations separated by





igure 1: The radial portion of the total current field, as seen at the same time from a CODAR station on the island UTSIRA and a second one on the island KARMOY off Norway.

some ten kilometres is capable to give complete information about the two dimensional surface current field. During recent years we developed further both the hardware and the software of our original CODAR transceivers. One of the technical inventors of CODAR, M. W. Evans, founded a company offering CODAR's for sale +). Modern CODAR stations are lightweight and need only some kilowatts electric power.

As a first step each CODAR station is generating a map of measured radial current vectors as shown in figure 1. The azimutal resolution here is 6 degrees while the radial extension is staggered into range cells of 1.2 km depth each. Every radial current vector in fig. 1 is an average over 18 minutes of observation.

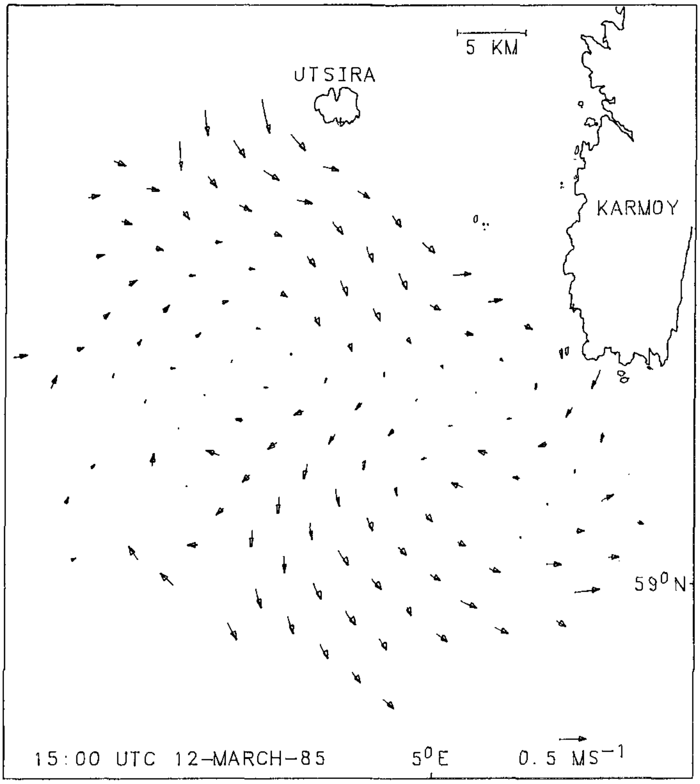


Figure 2: Total surface current field by combination from figures 1.

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From two - or more - sets of radial current vectors a final vector map of the total 2-dimensional surface current is produced by combining the radial shares. This is done at each point of a rectangular grid which is adjusted to the observation area. The result of this step is shown in figure 2.

The maximum range we obtained up to now is 50 km, depending on sea state, salinity of water and the place for erection of the antennas. Sometimes there is interference by strange transmitters, but the CODAR can change its own operation frequency.

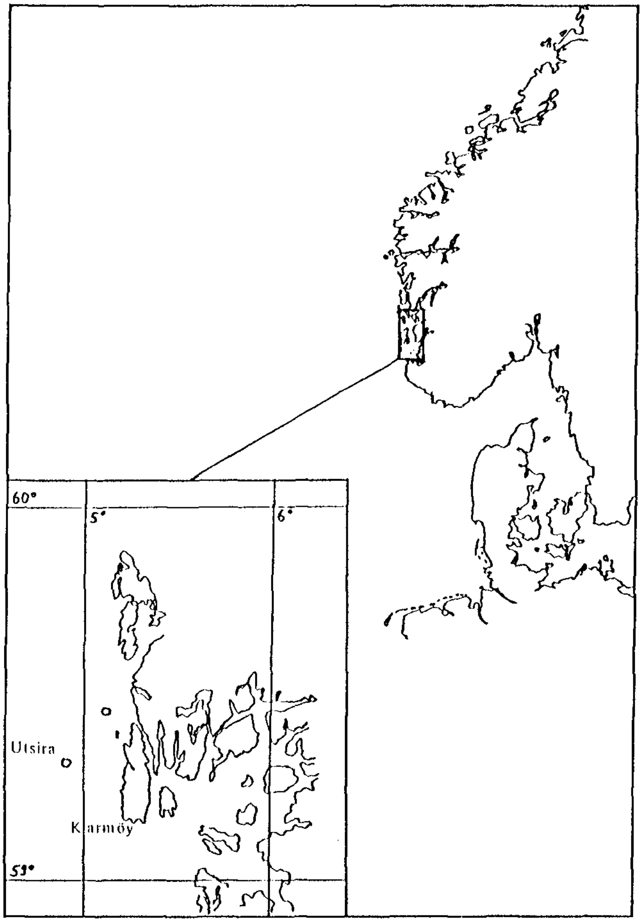

Figure 3, 4: Observation area off Norway. Distance between stations UTSIRA and KARMOY is 21 km.

SURFACE CURRENT MAPS

As an example some measurement results off Norway in 1985 are given here. The area under observation is shown in fig. 3 and enlarged in fig. 4. Two CODAR stations have been installed on the rocks of the coast: one on the island Utsira, the other on the island Karmoy, both sites belonging to Norway.

From satellite pictures it is known that eddies with radii from 10 to 50 km are generated here. Strong tidal and residual currents are typically. It is supposed that a sea bottom topography - given in fig. 5 - which is rich in contrasts is responsible for the generation of eddies. The

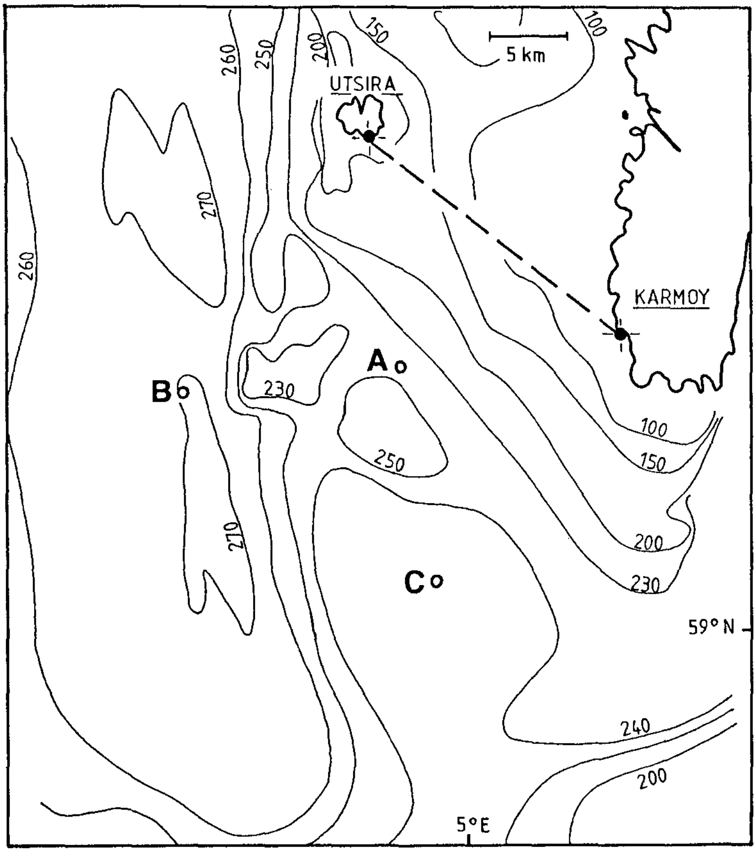

Figure 5: Sea bottom topography; depth given in meters.

consecutive pictures in figure 6, taken during 8 hours of observation, are an example from a set of 150 CODAR observations there.

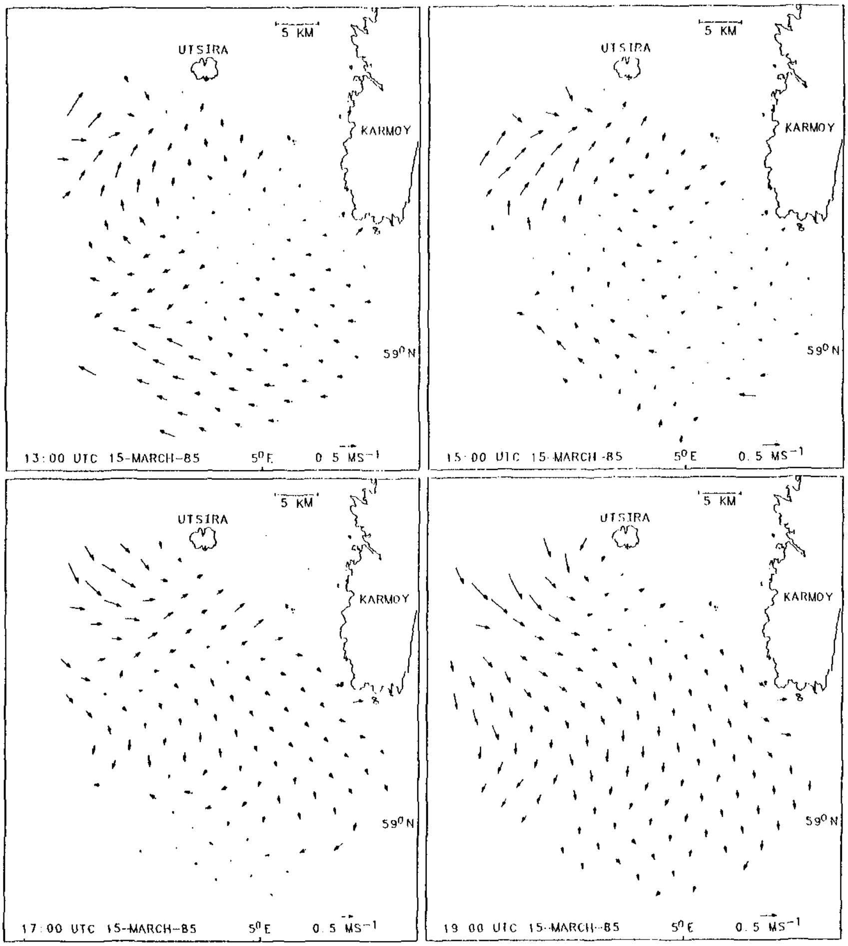

Figure 6: Four consecutive surface current patterns as observed every 2 hours.

TIME SERIES OF SURFACE CURRENT

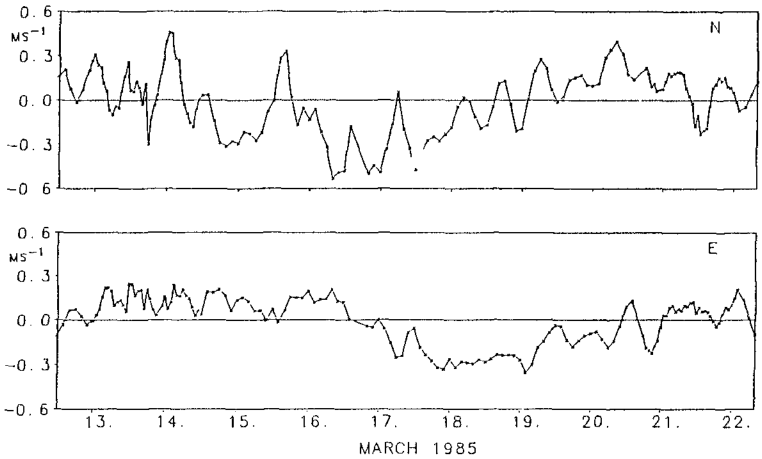

Figure 7: Current velocities at place C versus time.

From a set of consecutive current maps one can compute time series of the current velocity for each place of interest. An example for place C in fig. 5 is given in fig. 7. More detailed analysis of time series obtained from CODAR-results is given by Essen, Gurgel and Schirmer (1983) and by Essen, Freygang, Gurgel and Schirmer (1984).

TIDAL ELLIPSES

Given a set of consecutive CODAR-observations it is possible to compute the tidal ellipses for any place of interest in the current field. In figure 8 a set of 12 of such ellipses is given. Using a frequency filter according to Fourier, only the semi diurnal tidal components are left in this example. In a somewhat similar manner one can extract the residual current only.

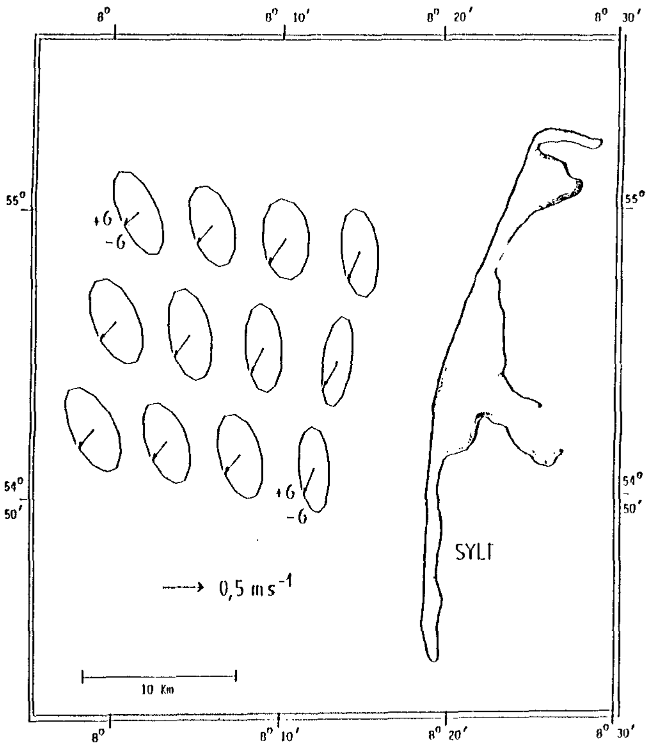

Figure 8: Tidal ellipses in front of the German island SYLT - only the semidiurnal component is given -.

UPWELLING AND DOWNWELLING

From an extensive set of surface current vectors the amount of upwelling or downwelling can be computed. If this is done separately with each snapshot of the surface current field, a time series of upwelling and/or down-welling can be gained. In figure 9 this divergence, taken from the vector fields, is plotted against time for the place A in fig. 5.

In the case of very low current velocities (less than 10 cm/s) the uncertainty becomes to large because diffe-rences between small numbers with random noise are to be computed.

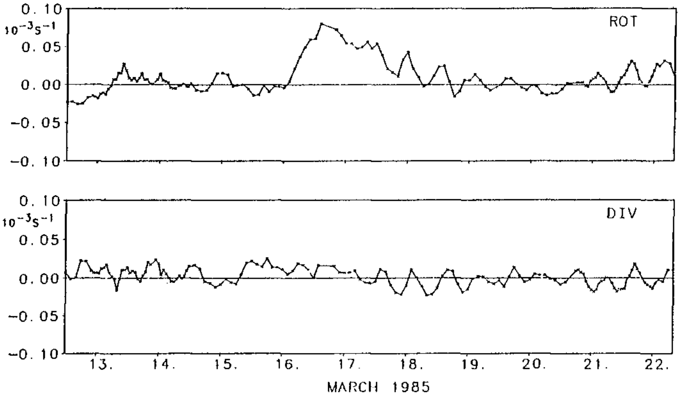

Figure 9 lower part: DIVergence - or upwelling and downwelling respectively - at place A in fig. 5 as a function of time.

upper part: The amount of ROTation at place A in fig. 5.

ROTATION

Finally the amount of rotation can be computed from the vector field of measured surface current. Again this is done - as an example - for place A in fig. 5. The amount of rotation as a function of time is given too in figure 9 - lower curve.

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