Satellite Measurements of the Surface Currents and the River Shannon Outflow Plume Movements off the West Coast of Ireland

A.P. Cracknell and W.G. Huang,
Department of Applied Physics and Electronic
& Manufacturing Engineering,
University of Dundee,
Dundee DD1 4HN, Scotland, UK.

Abstract

Thermal infrared (10.5-11.5 μm) images from NOAA polar orbiting satellites are used in this study. The surface currents off the west coast of Ireland have been mapped by using sequential images and elapsed time. The sea surface front in the Irish shelf and the outflow plume movements of the River Shannon have been studied. The results are compared with results of previous studies based on *in situ* measurements and an overall view of the surface currents off the west coast of Ireland is discussed.

1. Introduction

The sea region of this study includes the Irish shelf and the adjacent part of the north Atlantic ocean off the west coast of Ireland. As shown in Fig. 1, it extents from 8° W to 13° W longitude and from 51° N to 56° N latitude. The continental shelf edge defined as the 200 m isobath lies relatively close to the coast of Ireland. There are several rivers discharging fresh water into the sea, including the River Shannon which is the largest river in Ireland.

The surface water movements off the west coast of Ireland have been studied by many investigators (e.g., Monahan *et al.* 1984, Tulloch and Tait 1959). The branch of the north Atlantic drift approaching Ireland from the south-west divides into a north-going current flowing towards Rockall Bank and a southerly-going branch which, in turn, divides and gives a branch going towards the western Irish shelf (Edwards 1968). Over the shelf itself the currents are in general northerly, but there is a flow in an easterly direction around the north coast of Ireland to enter the north channel.

In reviewing the regional hydrographic literature the widely cited surface current charts are the atlas of the seas around the British Isles (Fig. 2) and the current chart (Fig. 3). Fig. 2 shows the general course of the current flow, but nothing about the sea surface front or eddies is mentioned. Although as a gross simplification, Fig. 2 is a good chart, it ignores some important temporary phenomena. Fig. 3 shows the general course of the current flow, a cyclonic eddy centred at 53°45′N 11°35′W and an anticyclonic eddy located at 55°07′N 11°29′W as well. It does present many details of sea surface currents. However, whether these eddies are permanent features still remained to be studied. Little is known about the sea surface front in this area.

The purpose of this study is to present new satellite-derived information useful in understanding the surface currents off the west coast of Ireland. In particular we address two problems, first the study of the currents in the vicinity of the shelf edge and secondly the transport and dispersion of the plume of river water emerging from the River Shannon. The synoptic data presented here are intended to confirm and consolidate the results of several previous non-synoptic studies and, consequently, tie these results together and give an overall view of the sea surface currents. It is based on an analysis of sea surface temperature patterns obtained from thermal infrared images. This includes the determination of flow vectors of surface currents derived from advective sea surface feature displacements and elapsed time.

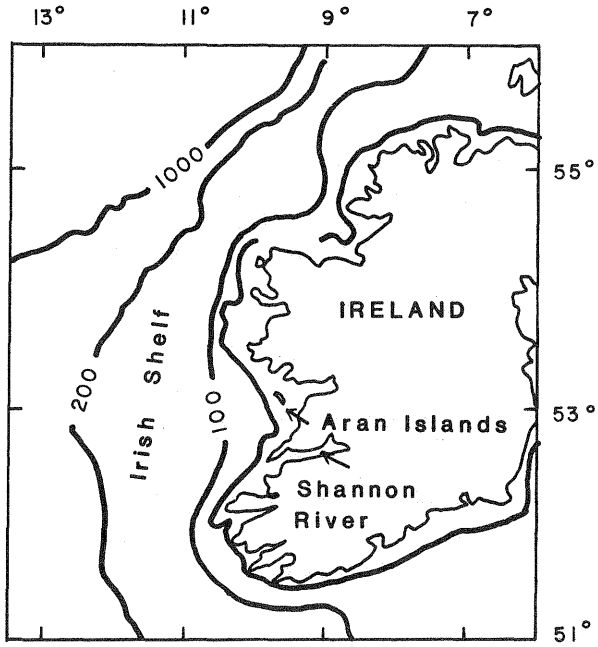


Figure 1: Location of study area (depth in metres).

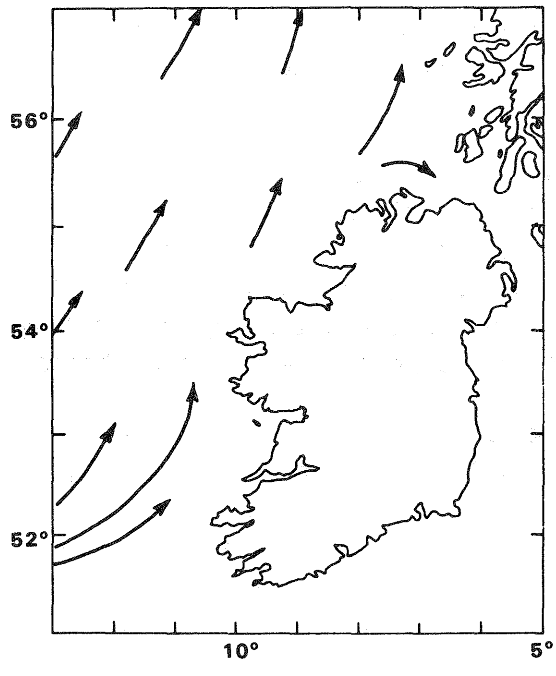


Figure 2: Sea surface current off the west coast of Ireland from the atlas (after Lee and Ramster, 1979)

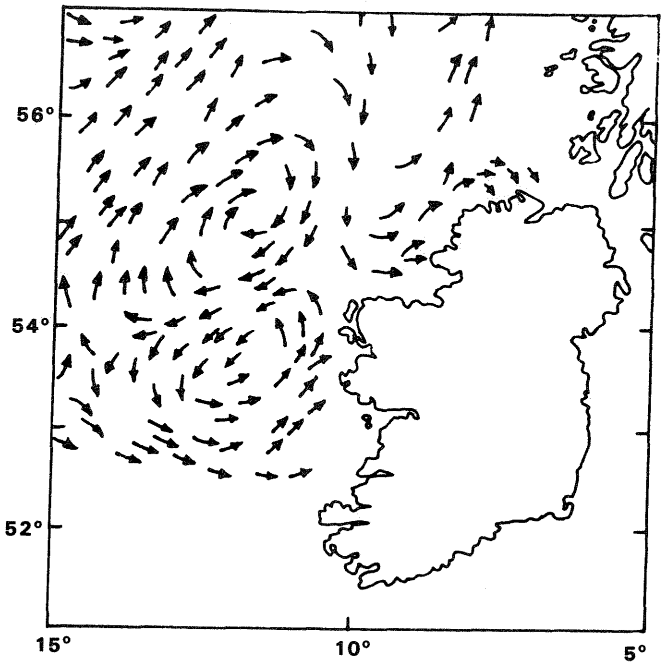


Figure 3: Schematic diagram of the current system of the uppermost waters off the west coast of Ireland (after Tulloch and Tait, 1959)

2. Data and Methods

The data used in this study are from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA polar orbiting satellites. Thermal infrared (channel 4) images are used with peak spectral responses from 10.5-11.5 µm and a spatial resolution of about 1.1 km at nadir. To determine current vectors three sequential images obtained from orbits 5596, 5610 and 5627 during the period 25-27 April 1984 have been selected to derive surface current vectors and a further 18 images were used for qualitative study of the shelf front and for the study of the plume from the Shannon estuary.

The images are geometrically distorted because of the method of data acquisition and the curvature and rotation of the Earth. An important consideration in the study of surface velocity distribution is the availability of surface features which are presented in the same geometric perspective to allow a sequence of images to be compared. It is necessary to carry out a geometrical rectification of images, that is to determine the coefficients in the mathematical relationships between the addresses of pixels in the image and the corresponding coordinates of those points on a map. The images used to compute flow vectors are geometrically rectified and an accuracy of ± 0.8 km in the location of each pixel was achieved.

Since in this study surface temperature differences, rather than absolute surface temperatures, are important the thermal infrared data have not been converted to temperature and no corrections have been made for radiometric calibration and atmospheric contamination. A density slicing technique has been applied to enhance the surface temperature patterns by using the SIGMA image processing system at the University of Dundee. Fig. 4(a)-4(d) show some examples of processed images.

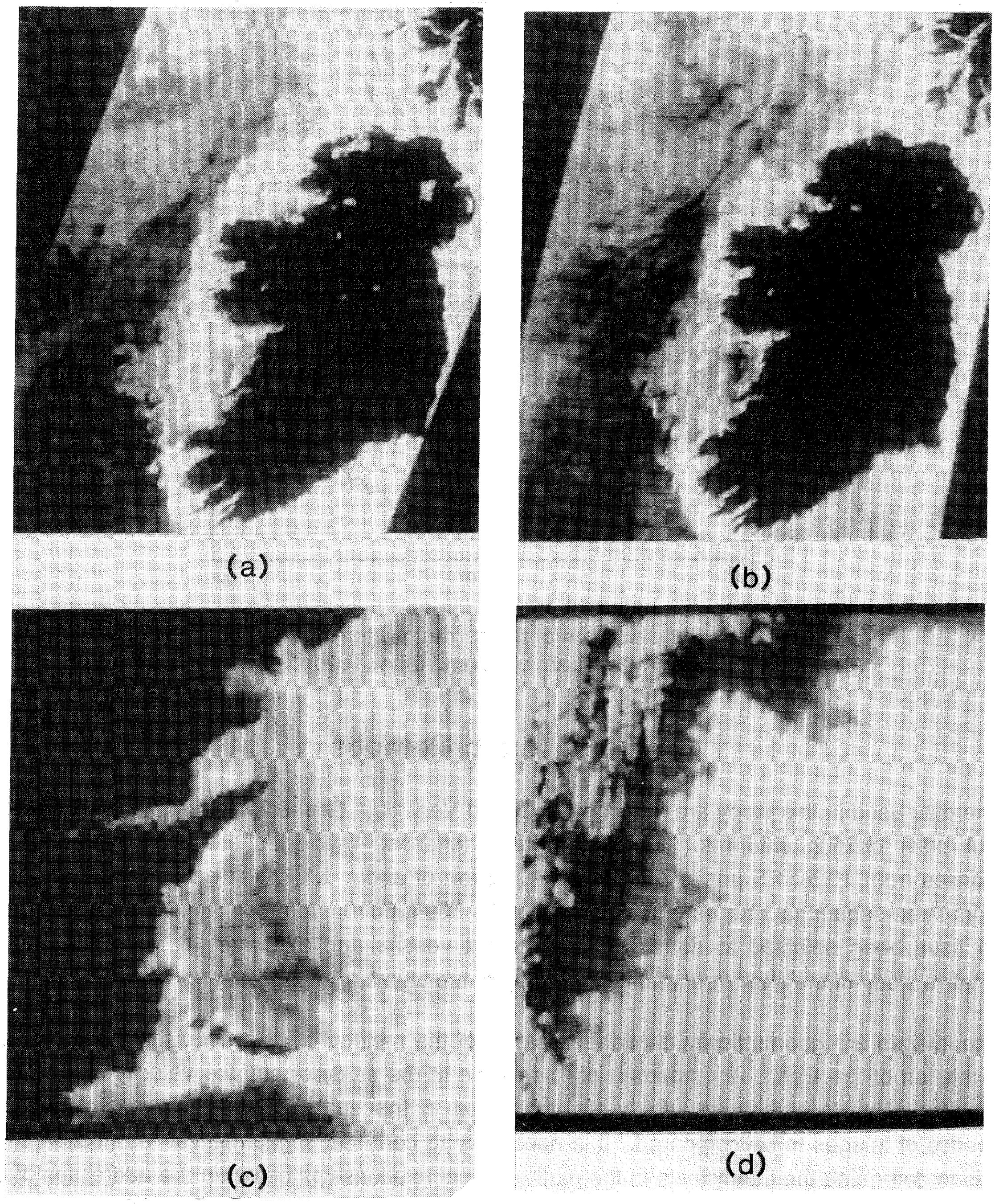


Figure 4: Examples of processed thermal infrared images from NOAA AVHRR.
(a) 25 April, 1984, NOAA-8; (b) 27 April, 1984, NOAA-8;
(c) 27 April, 1984, NOAA-8; (d) 11 January, 1985, NOAA-8.

3. Results

The satellite thermal infrared images (Fig. 4) reveal both spatial and temporal sea surface temperature patterns which imply circulation patterns off the west coast of Ireland. Three distinctive hydrographic domains can be defined from the images: 1) the outer domain with depths between 130 m and the shelf break where the north Atlantic flow is approaching Ireland, 2) the middle domain with depths between 50 m and 130 m in which there occurs the mixed colder surface temperature and sea surface front and 3) the coastal domain inshore of 50 m where the outflow plumes of rivers are active.

3.1 Surface Currents

The images in Fig. 4(a) and 4(b) show many commonly identified features in two of the three scenes that we have used. Seven sea features have been used to compute the movement along the front. A total of twenty-nine sea features, including these seven, have been selected and twenty-nine current vectors have been obtained by applying the feature-tracking method which uses sequential images and elapsed time to compute flow vectors from them. The image-derived surface current map is given in Fig. 5. The map presents the current pattern in the spring of 1984 off the west coast of Ireland.

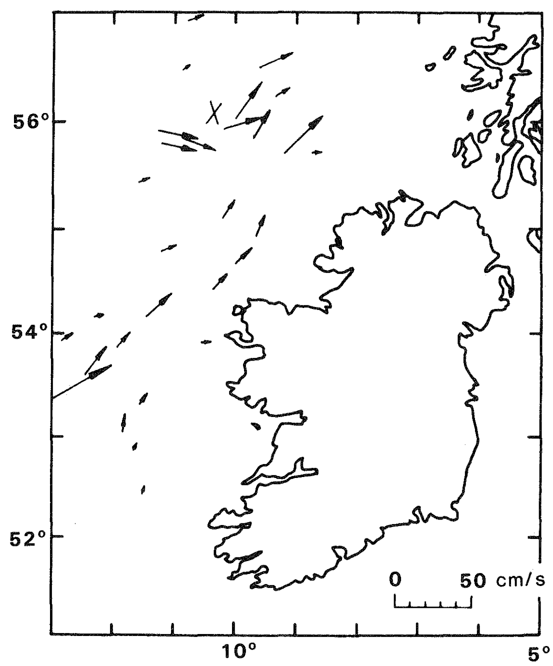


Figure 5: Current map off the west coast of Ireland derived from sequential satellite thermal infrared images.

3.2 Surface Front

Fig. 4(a) and 4(b) clearly show the Irish shelf front between mixed coastal water and stratified Atlantic water. The front is characterized by cyclonic and anticyclonic eddies. The front forms in April and disappears in July along the whole west coast of Ireland. It meanders around the depth of 130 m. The difference in temperature between the coastal water and Atlantic water is about 1.6 degC. Some characteristics for the Irish shelf front are obtained from the images (table 1).

Table 1: Characteristics for the Irish shelf front

Name	Symbol	Order of Magnitude Value
Coriolis parameter	f	10^{-4} s^{-1}
Frontal length	L	500 km
Frontal time scale	T	90 days
Eddy length scale	l	20 - 40 km
Eddy velocity	υ	3.5 cm s^{-1}
Eddy circulation	c	4.4×10^3 m^2 s^{-1}
Vorticity	ω	7.5×10^3 rad s^{-1}
Eddy Rossby number	$R_0 = 2\Pi\upsilon / lf$	0.02
Eddy time scale	$t \sim l / \upsilon$	1 - 7 days

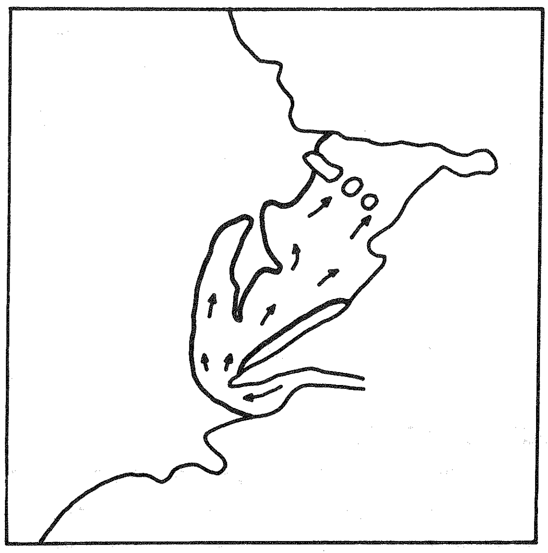
3.3 Plume movements

The river outflow plume from a river is likely to differ from seawater in its temperature, salinity and colour. For example, a river outflow plume is found from satellite thermal infrared images to be warmer in summer and colder in winter than the seawater, which exhibits much less thermal variation. Thus, the pattern of a river outflow plume can be determined from images and the transport and dispersion of the outflow plume can be deduced.

From the images (Fig. 4), it can be seen that outflow plumes of several rivers are active along the coast. The outflow plumes are darker on summer images, which corresponds to higher surface temperatures, and are whiter on winter images, which corresponds to lower surface temperatures. Here only the outflow plume from the River Shannon is discussed because it is the largest outflow plume along the coast. It should provide some information about the surface flow movements near the coast.

The summer and winter outflow plume patterns of the River Shannon from the images are given in Fig. 6. Both summer and winter patterns show that the outflow plume turns through nearly 90° and spreads towards the north after it leaves the river mouth. When approaching the Aran Islands, the outflow plume divides into a north-easterly-going part towards Galway Bay and a north-westerly part meeting seawater. The movements of the outflow plume suggest that the current flow near the coast is northerly going.

(a)



(b)

Figure 6: (a) Summer outflow plume movement pattern of the River Shannon; (b) winter outflow plume movement pattern of the River Shannon.

4. Discussions

From the image-derived current map (Fig. 5) and the outflow plume movements of the River Shannon (Fig. 6) we can obtain the general course of sea surface currents off the west coast of Ireland. The current flow from the Atlantic drift approaches the western Irish shelf and goes north-east. Near the coast the currents are in general northerly. There is a flow going into the north channel around the north coast of Ireland. The average surface current speed for the twenty-nine vectors we derived from the images was 17 cm s^{-1}. The general course of the currents obtained by analysing satellite images confirms the description made previously on the basis of sea measurements. The image-derived current speed is numerically in good agreement with the typical value, 15 cm s^{-1}, given in the atlas of the seas around the Irish shelf (Lee and Ramster 1979).

From the satellite images (Fig. 4), it is obvious that there exists a sea surface front on the Irish shelf during the summer season. Until now, few papers have reported about it. It is not surprising that such an important oceanographic phenomenon has not been caught by ship observations, because 1) the interval of the stations are usually 10-30 miles, 2) the difference in temperature between the coastal water and Atlantic water is relatively small, and 3) the sea surface front is a temporary feature. However, we are confident that an oceanographic cruise deliberately designed to study this front could do so successfully.

From the satellite images we have not found any eddies in the locations identified by Tulloch and Tait (1959). On the other hand a cyclonic eddy located at 57°04′N 10°50′W was detected, but it had disappeared and was not apparent in the images from one month later. It is not clear how long the eddy exists because we do not have enough sequential cloud-free images to follow the eddy. It is certain that the eddy is not a permanent feature.

References

Edwards, C., 1968, Water movements and the distribution of hydromedusae in British and adjacent waters. SARSIA, 34, 331-346.

Lee, A. J. and Ramster, J. W., 1979, Atlas of the seas around the British Isles. Ministry of Agriculture, Fisheries and Food, Fisheries Research Technical Report, 20, (HMSO, London).

Monahan, E. C., Spillane, M. C. and Murphy, E. M., 1984, Surface currents off the northwest coast of Ireland. Rapp. P.-V. Reun. Cons. int. Explor. Mer., 185, 67-77.

Tulloch, D. S. and Tait, J. B., 1959, Hydrography of the north-western approaches to the British Isles. Marine Research, Scottish Home Department 1959, No. 1, 1-32.