International Council for the Exploration of the Sea

CM 1971/C:22
Hydrography Committee

A computer simulation of surface drifter returns

by

H. W. Hill and J. W. Horwood
Fisheries Laboratory, Lowestoft

INTRODUCTION

There have been many investigations reported in the literature concerned with establishing a simple empirical relationship between the wind velocity, W, and the speed, u, of the surface current induced. Most of the investigations between the work of Ekman (1905) and Tomczak (1964) have been reviewed by Lee and Ramster (1968), and nearly all have assumed a linear relationship of the form suggested by Ekman

$$u = KW$$

where K is a wind stress factor which Ekman suggested was of the order of

$$K = 1.43$$

in North Sea latitudes. In fact estimates of K have ranged in value from almost zero to 4.3 (Tomczak 1964), the lowest values found by Harvey (1968) in a series of surface drifter experiments in the Irish Sea which showed values of K between 0.2 and 3.2 although he concluded that the most probable range for K was between 1.5 and 2.0. Several other studies have been carried out since Lee and Ramster reported, including those by Neumann (1968) and Smith (1968), the latter being related to the drift of oil from the TORREY CANYON incident where oil was found to drift at 3.3 per cent of the wind velocity.

Ekman also suggested that the surface current was deflected at angle θ to the right of the wind direction, θ increasing with depth. Many authors have assumed that θ approximates zero for the surface layer as normally represented by the drift of surface bottles, cards and drifters, including Neumann, although he introduced into his calculations an element of drift due to the underlying residual current system, as did Tomczak in a rather more limited fashion. Smith (1968) obtained his value of 3.3 per cent by omitting the residual current systems in the Western Approaches. Alternatively Brusson (1967) using a value of 2.5 per cent explained the discrepancy between observed and expected drifts of the TORREY CANYON oil by a residual current system. Haug (1970), referring to transport of surface pollutants, concluded that residual drift was necessary in the computation, and calculated K as lying between 1.5 per cent and 4.5 per cent with a best fit of 2.7 per cent for an oil patch. The exclusion of a residual current system and the means whereby it may be included in the estimation of K and θ have seemed to us the most serious limitations of the previous work. An attempt to progress along these lines was made during two research cruises of RV CLIONE and RV ERNEST HOLT in November 1968 and November/December 1969 respectively, when arrays of current meters were moored in the Irish Sea and surface drifters were released within the arrays.

METHOD

Between 1 and 17 November 1968, 9 current meter stations were moored in the western Irish Sea with 3 Plessey MO21 recording current meters at each station, readings being taken every 10 minutes. The meters were positioned 12 m from the surface at low water, 4 m above the bottom and in the middle of the water column. The 12 hour 25 minute mean residuals for each of the meters which produced reliable records have already been published by Hill and Ramster (1969). On 9 and 10 November 1969 a similar current meter array of 11 stations, with a total of 29 meters was moored on the positions shown in Fig. 1, which also includes the 12 hour 25 min residual vectors over the total period of 30 days for which this array was in position. These two sets of results, together with the mean surface current circulation deduced by Ramster and Hill (1969), formed the basis of the current meter input to the computer simulation for the 1968 and 1969 drifter release experiments. In those cases where the time from drifter release to drifter recovery exceeded the total length of the current meter record, the current system acting on the drifter after the end of the meter record was assumed to be the mean current over the period of the current meter observations in that sector.

Three types of surface drifters were used in the 1968 experiment. 250 drift envelopes, as used by the UK National Institute of Oceanography, were released at Station C (Fig. 1) on 5 November, together with 250 yellow surface drifters of similar construction to the Woodhead seabed drifter, but weighted to give a specific gravity of 0.96 g/cc (similar to that of the crude oil released by TORREY CANYON). It had been found in tank experiments in the laboratory before the cruise that this would cause the mushroom-shaped top of the drifter to float in the top 2-3 cm of water. To represent the surface drift of the top 50 cm of water, 50 red surface drogue-type drifters were released at each of the 9 current meter stations in 1968, and at each of the 11 current meter stations in 1969.

The computer simulation

For the purpose of the simulation the northern Irish Sea was divided into 11 current sectors and 5 wind sectors as shown on Fig. 2. At all points within a current sector it was assumed that the current could be represented by the near-surface current meter in that sector, or if this meter did not produce reliable records, by the mid-depth meter. If a current meter station had/not provided reasonable results, the current system was inferred or interpolated from nearby sectors in line with the surface circulation given by Ramster and Hill (1969). The five wind sectors were assumed to have a similar wind at all points within the sector as recorded at the five meteorological stations at Valley, Squires Gate, Ronaldsway, Mull of Galloway and Dublin.

The central point of the drifter distribution (x', y') is determined from the position six hours previously (x, y) from the equations

$$x' = x + 6FC(x) + 6FK(W(x)\cos\theta + W(y)\sin\theta)$$

$$y' = y + 6FC(y) + 6FK(W(y)\cos\theta - W(x)\sin\theta),$$

where C(x), C(y), W(x), W(y) are the hourly mean current and wind speeds in the north and east directions respectively for the appropriate sector and time, and F is a unit conversion factor. The spread of the drifter distribution about the central point is estimated by a time dependent, symetric, bivariate normal distribution with variance σ^2 increasing as

$$\sigma^2 = 2\epsilon T,$$

where $\epsilon = 1.6 \times 10^{-5}$ Km^2/sec is a value of the diffusion coefficient obtained in dye release experiments in the northern Irish Sea by Talbot (pers. comm.) and T is the time after release in secs.

Thus, at each 6 hourly step of the computation, the centre of the patch of drifters and its spread are determined until the centre comes within σ of a coastline. At this stage, the drifter distribution is integrated to find the percentage of the drifters which would have landed and the distribution recentred offshore and allowed to continue movement under the influence of the wind and current. The simulation was normally continued until 95 per cent of the drifters had beached or until the centre of the drifter patch passed out of the model area. Output is by line printer and paper tape, the latter being fed to an off-line graph plotter to produce the course of each drifter track as shown in the example at Fig. 3.

The parameters K and θ, in which we were particularly interested, were varied for each simulation run, K ranging from 1.0 to 4.5 in steps of 0.1, and θ from 0 to 25 degrees in steps of 5 degrees, although it was not necessary to use the complete range of each parameter for all types of drifter.

RESULTS

The drift envelopes

The positions from which the drift envelopes released at Station C were returned are shown in Table 1 together with the time to recovery. It can be seen that a total of 198 were recovered out of the 250 released, the majority landing by 10 November with scattered returns in both time and space after 12 November. In order to obtain the best estimate of K and θ for the batch of landings centred at 53°30'N we have excluded those landed later than 12 November, and consider the approximately normal distribution up to that date totalling 165 drifters. Of these 11 or 6.7 per cent landed at distances greater than $3\frac{1}{2}$ miles from the centre of landings from which we can calculate that the standard deviation of the observed landings was

$$\sigma = 1.9 \text{ n. miles.}$$

The computer simulation produces a standard deviation σ^1 after $4\frac{1}{2}$ days of $\sigma^1 = 1.93$ n. miles; hence there is good agreement between the observed and simulated returns in so far as the dispersion of drift envelopes is concerned.

Time, within the computer simulation, is reckoned from 0600 hours GMT on 5 November so that the envelopes were released within the first 6 hourly period at 0810 hours GMT, the simulation permitting the correct proportion of the 6 hourly period for the drift of the envelopes. Thus "days-out" from 0600 hours GMT on 5 November are also given under the dates in Table 1 in $\frac{1}{4}$ days. In order to compare the best fit of K and θ to the observed returns, the values of these parameters relative to the 50 per cent return point have been shown in Table 2, tabulated against the number of days in the sea and the distance of the centre of the simulated distribution from the central point of the observed distribution of envelopes. From Table 1 it is clear that 50 per cent of the 165 envelopes returned in the initial distribution were returned between $4\frac{1}{2}$ and $4\frac{3}{4}$ days. Since we are working in $\frac{1}{4}$ day units we would therefore expect the best fit of K and θ to correspond to a time in Table 2 between $4\frac{1}{4}$ and 5 days and these are marked by a cross. Theoretically the best fit of K and θ should also correspond to N = 0 but we have an inherent inaccuracy in the current and wind inputs due to the positioning and density of the measuring stations, which reflects in the irregularity of N in the columns of Table 2. However, by drawing a line around all cells of the table marked by a cross for which N is less than 5 n. miles, we arrive at an envelope of values for K and θ, from which we can deduce that K probably lies between 3.4 per cent and 3.8 per cent and θ probably lies between 5 degrees and 10 degrees.

The yellow drifters

A similar technique was employed to obtain the best fit for K and θ in respect of the 250 yellow mushroom drifters released simultaneously with the drift envelopes. Table 3 shows that the total returns numbered 208 and as before we have curtailed the distribution at 17 November so that of the 181 returns of the initial landing, 35 or 19 per cent were outside a distance of $3\frac{1}{2}$ miles from the centre of landings 54°15'N, 05°37'W. From this σ can be estimated as

$$\sigma = 2.7 \text{ n. miles},$$

and from the simulation after $9\frac{1}{4}$ days, $\sigma^1 = 2.77$ n. miles, which again shows good agreement. In this case 50 per cent of the drifters landed between $9\frac{1}{4}$ and $9\frac{1}{2}$ days after the simulation zero. Hence we mark a cross against all cells in Table 4 for which D lies between 9 and $9\frac{3}{4}$, and ring those where N is less than some arbitrary level, say 6 n. miles. In fact, in Table 4, there is rather less variability of N and D within the columns and we might well restrict D to $9\frac{1}{4}$ or $9\frac{1}{2}$ days and N to less than 3 miles which suggests that the best estimates of K and θ are

$$1.9\% \leq K \leq 2.2\%,$$

$$\theta = 15^\circ.$$

The red drogue drifters

Only 50 red drogue-type drifters were released at each station so that the return distributions were less well defined. However, an indication of the ranges of K and θ for this type of drifter, can be obtained from those releases in 1968 and 1969 from which recoveries were not scattered too widely, as is shown in Table 5.

Table 5 Ranges of K and θ for red drogue-type drifters

	Station	K%	θ deg
1968	19 (G)	1.1-1.2	5-15
	13 (B)	1.3-1.4	15-25
	12 (A)	1.0-1.3	15-25
	18 (H)	1.0-1.4	15-25
1969	12 (L)	1.6-1.9	15-25
	13 (K)	1.6-1.7	15-25

Although K and θ are not so well defined as for the drift envelopes and the yellow drifters it seems clear that K lies between 1.0 per cent and 1.9 per cent and θ probably lies between 15° and 25°.

In conclusion it is of interest to note that the estimates for K and θ are consistent with the Ekman hypothesis of the water velocity being to the right of the wind direction and deflecting further to the right with decreasing velocity as the water depth represented by the drifter increases.

SUMMARY

A computer simulation which included a residual current system was used to estimate the wind-water factor, K, and deflection of the surface waters to the right of the wind direction, θ, for three types of surface drifter on two current meter cruises in the Irish Sea. The best estimates for K were found to be from 3.4 per cent to 3.8 per cent for drift envelopes, representing the top 1-2 cm of water, from 1.9 per cent to 2.2 per cent for yellow mushroom drifters, with a specific gravity similar to oil released from the TORREY CANYON and designed to float in the top 2-3 cm of water, and from 1.0 per cent to 1.9 per cent for red drogue-type drifters, representing the top 50 cm of water; the angle of deflection θ was estimated as 5-10°, 15° and 15-25° respectively for the three types of drifter.

REFERENCES

BRUSSON, Cdt, 1967. Le pétrole du 'Torrey Canyon' en mer. Penn Ar Bed., Vol. 6, No. 50.

EKMAN, V. W., 1905. On the influence of the earth's rotation on ocean currents. Ark. Mat. Astr. Fys., Vol. 2, 1-52.

HARVEY, J., 1968. The movements of seabed and sea-surface drifters in the Irish Sea, 1965-67. Sarsia, No. 34, 227-42.

HAUG, O., 1970. Transport of Pollution in the Sea. GESCAMP/24

HILL, H. W. and RAMSTER, J. W., 1969. Variability in current meter records in the Irish Sea. ICES Symposium on Physical Variability in the N. Atlantic, Cont. No. 44.

LEE, A. J. and RAMSTER, J. W., 1968. The hydrography of the North Sea. A review of our knowledge of pollution problems. Helgoländer wiss. Meeresunters., Vol. 17, pp. 44-63.

NEUMANN, H., 1968. The drift of pollutants at the surface of the North Sea. Helgoländer wiss. Meeresunters., Vol. 17, pp. 81-93.

RAMSTER, J. W. and HILL, H. W., 1969. Current system in the northern Irish Sea. Nature, Lond., Vol. 224, No. 5214, pp. 59-61.

SMITH, J. E., 1968. 'Torrey Canyon' Pollution and Marine Life. A report by the Plymouth lab. of the MBA of the UK. Camrbidge University Press.

TOMCZAK, G., 1964. Investigations with drift cards to determine the influence of the wind on surface currents. Studies on Oceanography Ed. by K. Yoshida, Tokyo University Press.

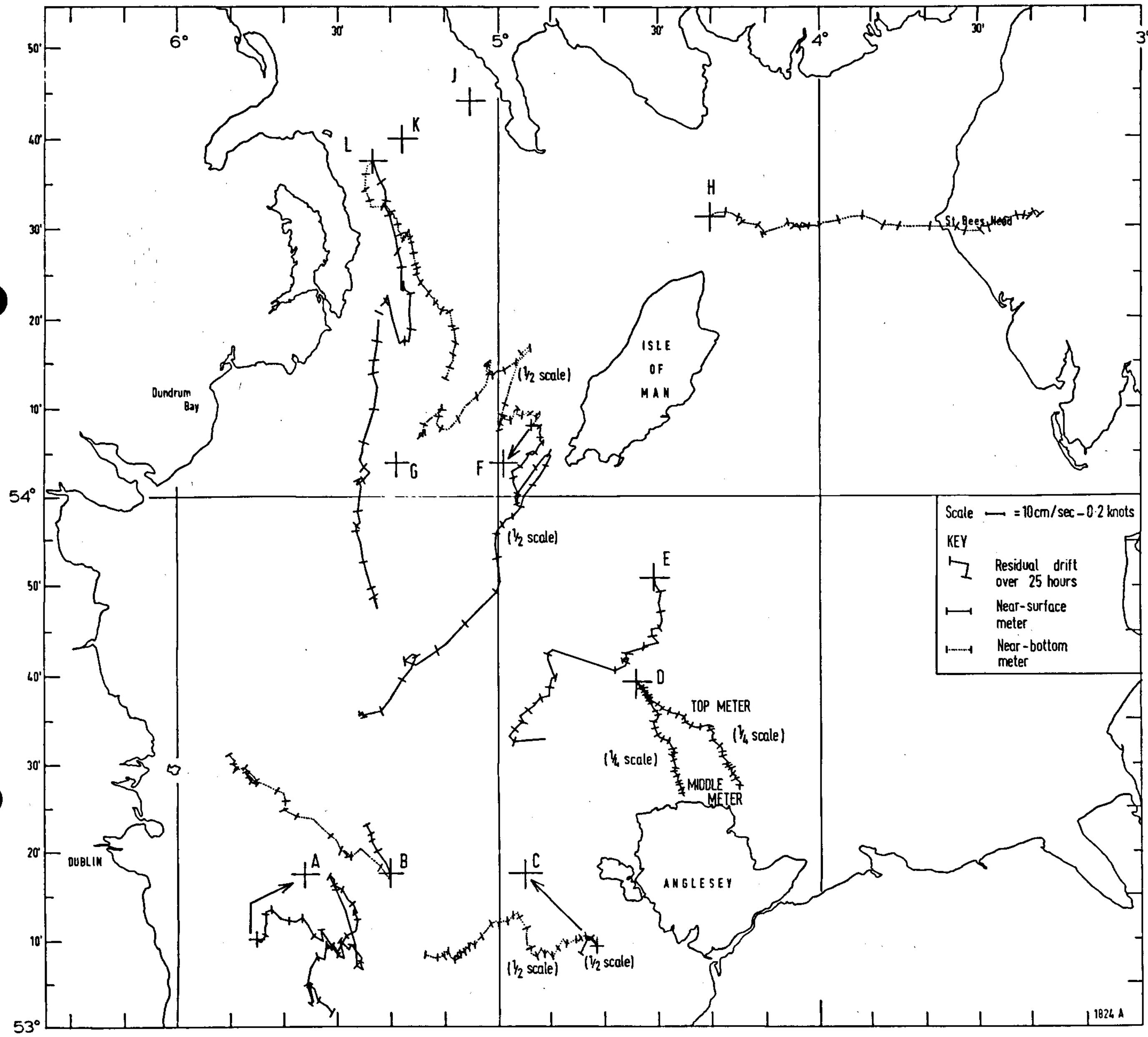

Fig.1 24 hour 50 minute mean current meter vectors, 9 November - 10 December 1969

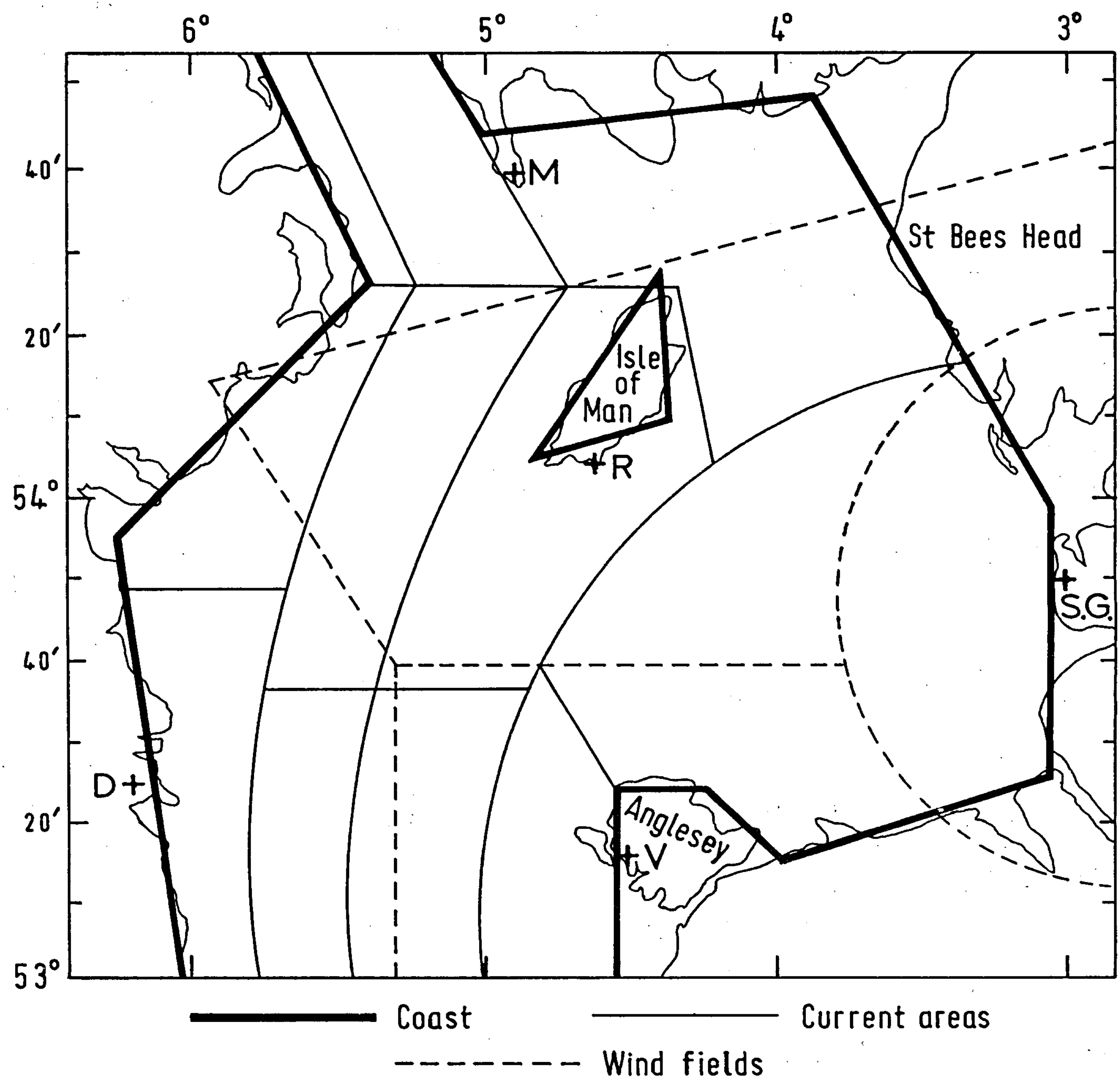

Figure 2 Grid used for computer simulation of drifter returns in the Irish Sea. Weather stations: V - Valley, S. G. - Squires Gate, R - Ronaldsway, M - Mull of Galloway, D - Dublin.

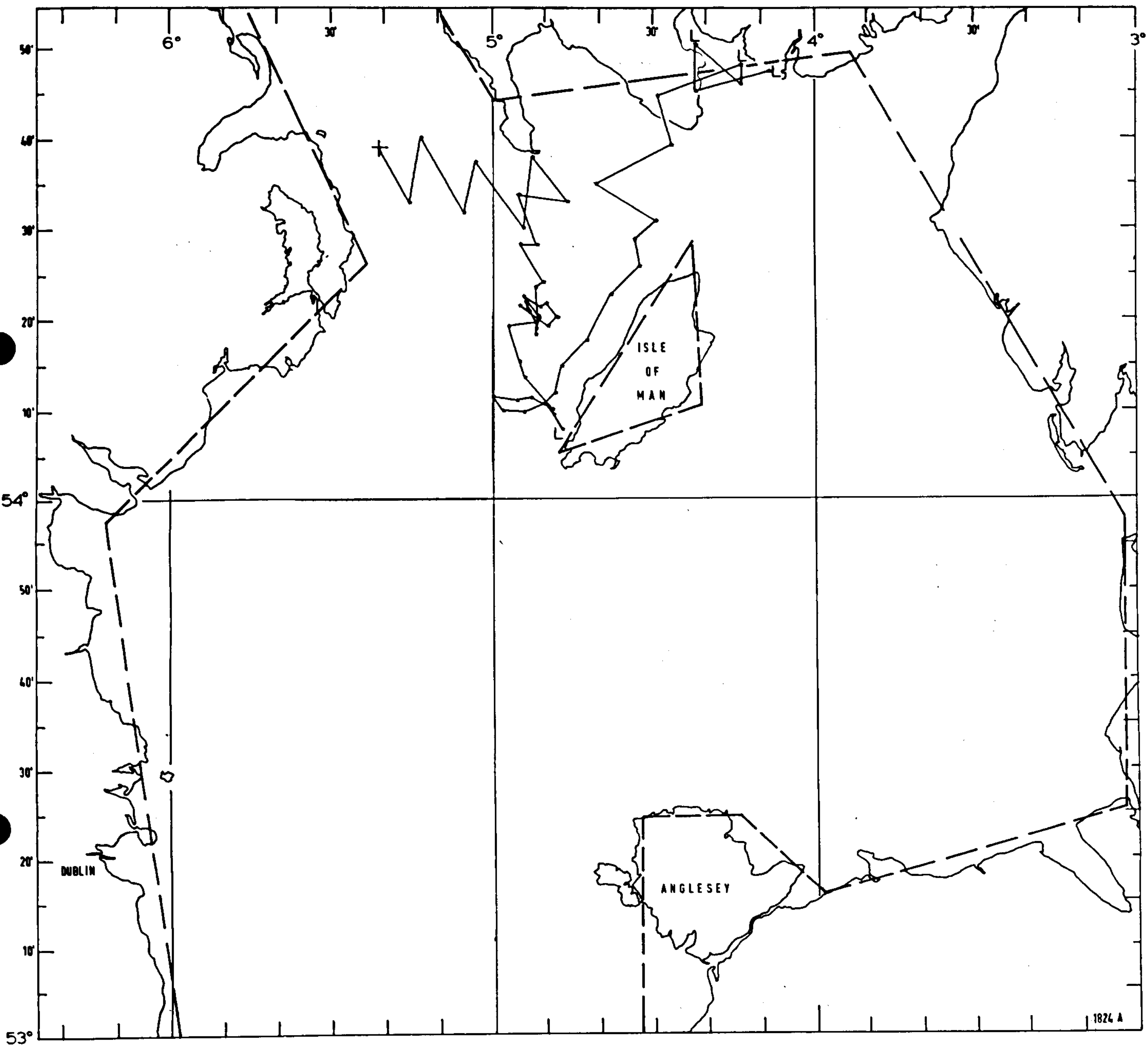

Figure 3 A typical drifter simulation showing release and landing points. — — — computerised coastline, -x-x-x- simulated drifter path, + release point, L landing point. (Station K, 1969; $\theta = 5^{o}$; K = 2.0%.)

Table 1 Returns of drift envelopes released at Station C at 0810 GMT on 5 November 1968

Date (November)		7	8	9	10	11	12	>12	Totals	Section totals
Computed days out		$1\frac{3}{4}$	$2\frac{3}{4}$	$3\frac{3}{4}$	$4\frac{3}{4}$	$5\frac{3}{4}$	$6\frac{3}{4}$	$7\frac{3}{4}$		
Position										
53°22'N	06°10'W							1	1	
25'	04'							3	3	15
25'	07'				3	1	-	7	11	
53°27'	06°09'	-	2	9	16	-	-	3	30	
28'	09'	-	-	12	4	-	-	1	17	
28'	12'	-	-	-	-	-	-	1	1	
29'	01'	-	-	-	-	-	-	1	1	167
29'	06'	1	-	10	25	-	2	1	39	
32'	06'	-	9	33	20	-	-	1	63	
33'	05'	-	1	7	3	-	-	5	16	
35'	06'	-	-	-	6	1	-	1	8	
53°45'	06°15'							1	1	
48'	14'							1	1	
54°04'	06°00'							3	3	16
16'	05°53'							1	1	
10'	52'							1	1	
23'	04°22'							1	1	
Total		1	12	71	77	2	2	33	198	

Table 2 Variation of K and θ against days out (D) and distance in nautical miles (N) from central point of observed drift envelope recoveries

K	θ											
	0°			5°			10°			15°		
	D		N	D		N	D		N	D		N
0.031	5¼		1	5½		6	7¾		30	7¾		33
0.032	5¼		1	5¼		4	7¾		30	7¾		56
0.033	5	x	-4	5¼		3	5½		12	6		35
0.034	4¾	x	-7	5	x	-2	5¼		8	6¼		29
0.035	4¾	x	-7	4¾	x	-3	5	x	6	6		17
0.036	4½	x	-9	4¾	x	-5	5	x	5	5¼		14
0.037	4¼	x	-10	4½	x	-5	4¾	x	2	5	x	11
0.038	4¾	x	-6	4¼	x	0	4½	x	5	5½		29
0.039	3¼		-9	3½		-5	4½	x	2	5½		30
0.040	3¼		-9	3¼		-5	5	x	17	5½		37
0.041	3¼		-8	3¼		-4	3½		0	5½		37
0.042	3		-7	3¼		-4	3¼		0	5¼		37
0.043	3		-7	3		-3	3¼		1	4½	x	19
0.044	3		-7	3		-3	3¼		1	4½	x	19
0.045	3		-7	3		-2	3		2			

+ N = Northerly deviation

– N = Southerly deviation

Table 3 Return of yellow surface drifters released from Station C at 0810 hours GMT on 5 November 1968

Date (November)	13	14	15	16	17	18	>18	Section Total
Computed days out	$7\frac{3}{4}$	$8\frac{3}{4}$	$9\frac{3}{4}$	$10\frac{3}{4}$	$11\frac{3}{4}$	$12\frac{3}{4}$	$13\frac{3}{4}$	
Position								
54°05'N 05°49'W							1	
12' 53'	-	18						34
13' 52'	-	-	13					
15' 52'	-	2						
14' 38'	-	-	-	1	-	1	3	
14' 40'	-	1						
15' 37'	1	27	-	35	-	-	16	166
15' 41'	-	24						
16' 35'	-	53						
18' 33'	-	4						
20' 30'	-	1						
22' 29'	-	1						8
24' 27'						2	4	
Total	1	131	13	36	-	3	24	208