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AN EVALUATION OF THE USE OF STREAM FUNCTION FITTING IN THE INTERPRETATION OF DATA COLLECTED FROM MOORED CURRENT METER NETWORKS

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ABSTRACT

A stream function has been fitted to JONSDAP 73 data and, after assessment of various approaches, flow patterns produced for each day of the exercise. A 12-day sample is shown. Comparisons have been made between these patterns and two numerical model results. Alternatives to the stream function technique are noted and some progress reported towards their use in shelf-sea environments.

INTRODUCTION

Hunter (Ref 1) pointed out that very often the current vectors produced from moored current meter networks were interpreted subjectively and that one consequence of this was that the magnitude of the vector was seldom given as much importance as the direction of flow. Objectively the two parameters are of equal importance. He felt that the application of a stream function to represent a set of velocity vectors from an irregularly spaced array would produce a more meaningful current field than the patterns of flow usually provided. In this paper we show the kind of results obtained from fitting a stream function to the JONSDAP 73 current meter data (Ref 2). A more detailed report has been produced (by D J Lawrence) and will be published in due course. For the moment we are aiming simply to show the main features of his results.

METHOD

a Data preparation and selection

The available JONSDAP 73 current meter data at the Fisheries Laboratory, in the form of raw 10-minute readings, were averaged over 24 hours 50 minutes to remove tides. Hourly tabulated data from two Dutch light vessels were also encoded and averaged over 25 hours. The averages were centred at 12 hours GMT of each day. This method produces an amplitude factor for the dominant M_2 tide of less than 0.0007, thus M_2 tidal streams of 150 cm/sec would be reduced to less than 0.1 cm/sec which was considered adequate as the expected wind driven currents would be of order 15 cm/sec (the median daily average wind speed, from the JONSDAP 73 report, was about 7cm/sec) and the residual drift of the order of 2-4 cm/sec.

From the available data set, 8 sites (Figure 1) were selected to give a long run of 41 days from 8 September to 18 October. The upper current meters from 6 moored rigs were used, with instruments ranging from 6 to 14 m below chart datum. At the two light vessels, Noord-Hinder and Texel, measurements were 6 m below the sea surface.

b Stream function fitting

Following Hunter (Ref 2) the stream function was fitted by a polynomial in x and y

$$\psi_n = \Sigma a_{ij} x^i y^j \qquad (1)$$

where $i \geq 0$

$j \geq 0$

$1 \leq (i + j) \leq n$

Thus n governs the order of the polynomial

The number of terms will be $(n + 1)(n + 2)/2 - 1$.

The transports for the Southern Bight are approximated by

$$\frac{\partial\psi}{\partial y} = T_x \simeq uh$$

$$-\frac{\partial\psi}{\partial x} = T_y \simeq vh \qquad (2)$$

where velocities (u, v) from the current meters are considered representative of the entire water column, the depths, h, are measured from chart datum at each site and T is the component of transport in each case.

Then, if there are m sites to be used, one gets from differentiating (1) and substituting in (2) a system of 2 m linear equations in $(n + 1)(n + 2)/2 - 1$ unknowns. This system is generally overdetermined and has to be solved in the least squares sense. A program to solve the exact case was also developed and verified using Hunter's drogue data.

The main work done was to solve the coefficients a_{ij} using daily data sets from the 8 sites for polynomials of order "n" = 2, 3, 4 and produce not only estimates of their standard deviations, but also the spatial variance of the transport before and after fitting, the residuals at the sites, the stream function values at rectangular grid points, and the vorticity evaluated at the mid-grid position.

RESULTS

Values of Ψ were printed out at rectangular grid positions to permit preliminary examination and contouring. A grid spacing of 25 km and 9 points along E-W and N-S axes were used to cover the Southern Bight. The x-y co-ordinate system origin was (0^{o} longitude, 52^{o}N). To facilitate contouring a mean was removed from each set to force the central point to zero. As hand contouring proved to be slow and inaccurate, the grid data points for each solution were stored for use by an interpolation program which used a 16-point bicubic spline and delineates the contours using symbols on the line printer. The scale chosen was 1:700,000 to match Admiralty Chart 2182, requiring 67 lines of 112 points each. These pictures then form the final product.

It was found that the Ψ_3 patterns gave the best fit as far as the data was concerned and some sample results of the daily transport fields are shown in Figure 2. Only contours relating to the "interior region" of Figure 1 are shown in this presentation.

DISCUSSION

a Daily mean flow

The most striking feature of the 41 daily field patterns is the lack of persistence of features from one day to the next. In the deep ocean features have been found with life times of tens of days (Ref 3) so that their development can be traced by means of techniques of this kind. In shallow seas where the response time of water circulation patterns to changes of the wind regime is of the order of hours or a day at the most, such an application does not seem to be possible. It is possible, however, to assess each daily field subjectively and to produce groups of basic shapes and/or basic mean flow directions and thus bring some order to the time series of daily flow patterns. For example, the majority of patterns (27 of 41 days) had mean flow direction north or north-west. Furthermore, a majority of these days (21 of 27) had patterns of either simple divergence or simple S-shaped curvature as one moves downstream. In Figure 2 the patterns for 10-12, 15, 17-18 September are part of these general populations. Such grouping allows proper perspectives to be gained between the overall mean pattern found and the occurrence of day-to-day variations in a spatial sense. Other interpretative techniques, that attempt to reduce the spatial patterns to daily vectors and relate these to the wind regimes (Figure 3) only reinforce conclusions reached by the simpler approach taken by, for example, Ramster, Medler and Jones (Reference 4).

It is interesting to note, incidentally, that a major feature of the JONSDAP 73 daily streamline patterns is the prevalence of a west or north-west component at least over that part of the Southern Bight being considered. The importance of such a trend was not really appreciated in the first general assessment of these data because most residual velocities in the central zone were small and variable (Neumann factors of < 30%, Ref. 4) and their relationship with the regimes on either side not clear in consequence (Reference 5). In fact this is exactly the type of situation it was hoped the application of the stream function technique would clarify and we feel that it has done so.

b 41-day mean flow

Figure 4(a) shows the streamline pattern (Ψ_3) together with the 41-day mean transports upon which it is based. For comparison, two other streamline patterns are shown, based on two-dimensional non-linear numerical models.

Figure 4(b) is taken from Prandle (Ref 6) and shows residual flows due to M_2 tidal forcing at the boundaries. Clearly the north-easterly drift in the north of the 'interior' region agrees with the ψ_3 mean pattern but to the south the streamlines generally show only a slight bending towards the west, the mean direction being NNE or north. Along the south-west boundary, of the interior region, there is a meander that has both west and east components and a closed gyre just above 52°N. The sense of the gyre is counter-clockwise whereas the mean ψ_3 pattern has clockwise curvature. Flow magnitudes are weak here, however. Across the entire interior region, the flow magnitude is about 5×10^4 m^3/sec in both northern and southern regions. This is only a factor of 2 lower than the present ψ_3 mean pattern so there is reasonable agreement.

Another model incorporating the non-linear effects of tidal forcing is due to Nihoul and Ronday (Ref 7). Their Figure 2 is reproduced here as Figure 4(c). Again the flow direction in the northern region is north-east. In the southern region, the streamlines show only very slight westward deviation from north-east. There is a gyre off the Anglian coast, counter-clockwise, in agreement with Prandle and opposite to the Ψ_3 pattern curvature. Across the entire interior region, the magnitude of flow is about 2×10^5 m^3/sec, which is a factor of 2 above the flow suggested by the ψ_3 flow pattern.

It may be suggested that comparisons of the numerical model outputs with either the 41-day ψ_3 regime or any of the daily stream function patterns is not very meaningful because by their very nature the models relate to those features of the circulation patterns that are instrinsically stable. Consequently only when a very long (> 100 day?) stream function mean field is taken will the results begin to approach the smoothness of the numerical model results. Unfortunately since both traditional field data sets and the modelling approach tend to smooth out short-period and small-scale variations that are potentially of great importance in both pure and applied aspects of marine biology, many workers only think in terms of such regimes. It seems to us that a time series of stream function flow charts provides a salutary warning to beware of such an attitude of mind.

c Future work

In the last 2-3 years there has been great interest in the problem of presenting irregularly spaced vector measurements in an objective fashion and various alternatives to the Hunter stream function approach have been developed. Freeland and Gould (Ref 3) "empirical orthogonal function" approach has been examined in detail and as a preliminary to the trial of this method away from the deep ocean where it is becoming popular, the correlation factors have been evaluated for the 8 sites used in the present work. Preliminary examination shows some consistency of these with distance, which is the first prerequisite for the adoption of the method (Figure 4). A problem to be faced is whether boundary conditions can be incorporated. Their incorporation might mean one would have to abandon the analytic solution and go to perhaps a Lagrangian multiplier type solution.

An important by-product of this preliminary work is the difference in character shown in Figure 5 between tidal stream data measured at light vessels and JONSDAP 73 moored current meter stations respectively. The differences are so great in fact that the light vessel data would have to be ignored in the drawing of any tentative curves. Investigation of the origins of these differences, which we think are due to more subtle factors than the differences in the position of the measurement and the sampling interval, would obviously be of considerable interest.

CONCLUSIONS

1 The use of stream function fitting and other related techniques to the data from moored current meter networks provides new perspectives for investigators.

2 As yet the rules for assessing a time series of stream function flow patterns are undefined but thought should be given to the development of objective guidelines and particularly to the comparison of such patterns with the output of numerical models at daily intervals.

3 At the time-scale of one day the circulation of the Southern Bight during JONSDAP 73 contained significant west and north-west-going components of drift not fully recognized before.

4 Light ship tidal stream data is very different in character to moored recording current meter data.

ACKNOWLEDGEMENTS

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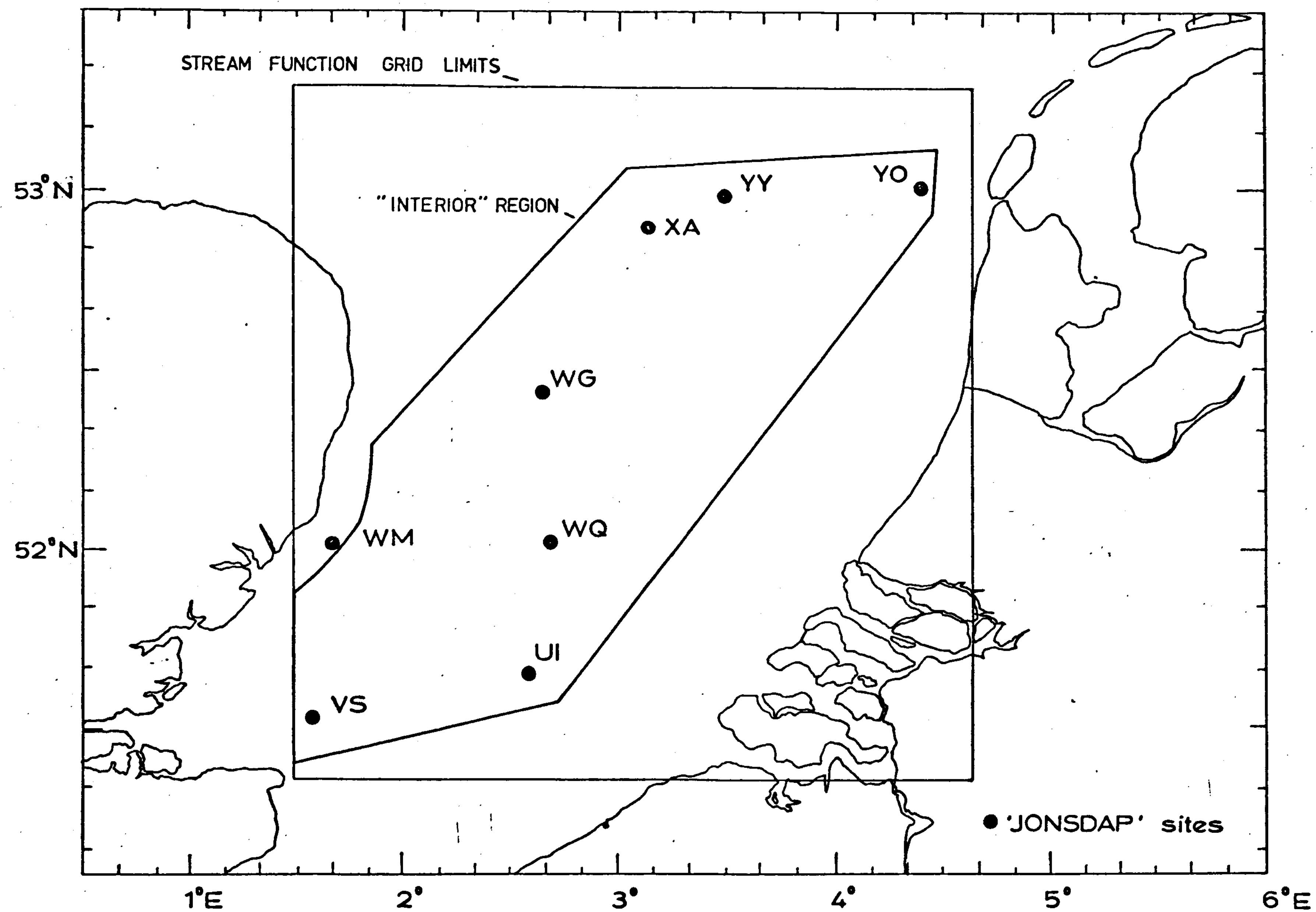

Figure 1 The Southern Bight showing the 8 JONSDAP '73 stations used, the limits of the stream function grid, and the 'interior' region over which the stream function was judged valid.

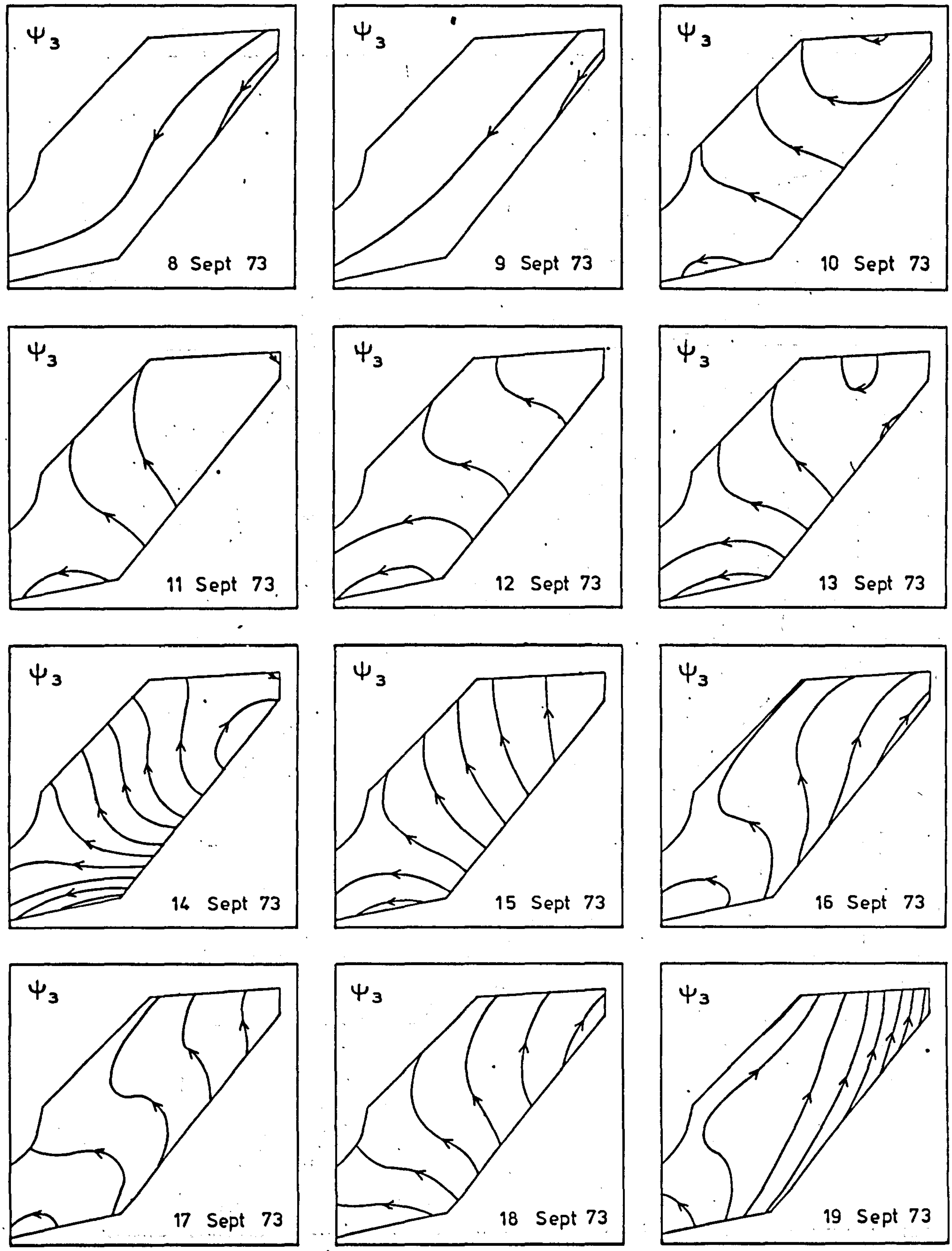

Figure 2 Stream function contours for polynomial of order 3 over 'interior' region only (see Figure 1). Daily averaged transports. Transport between adjacent contours = 0.5 x 105 m^3/sec.

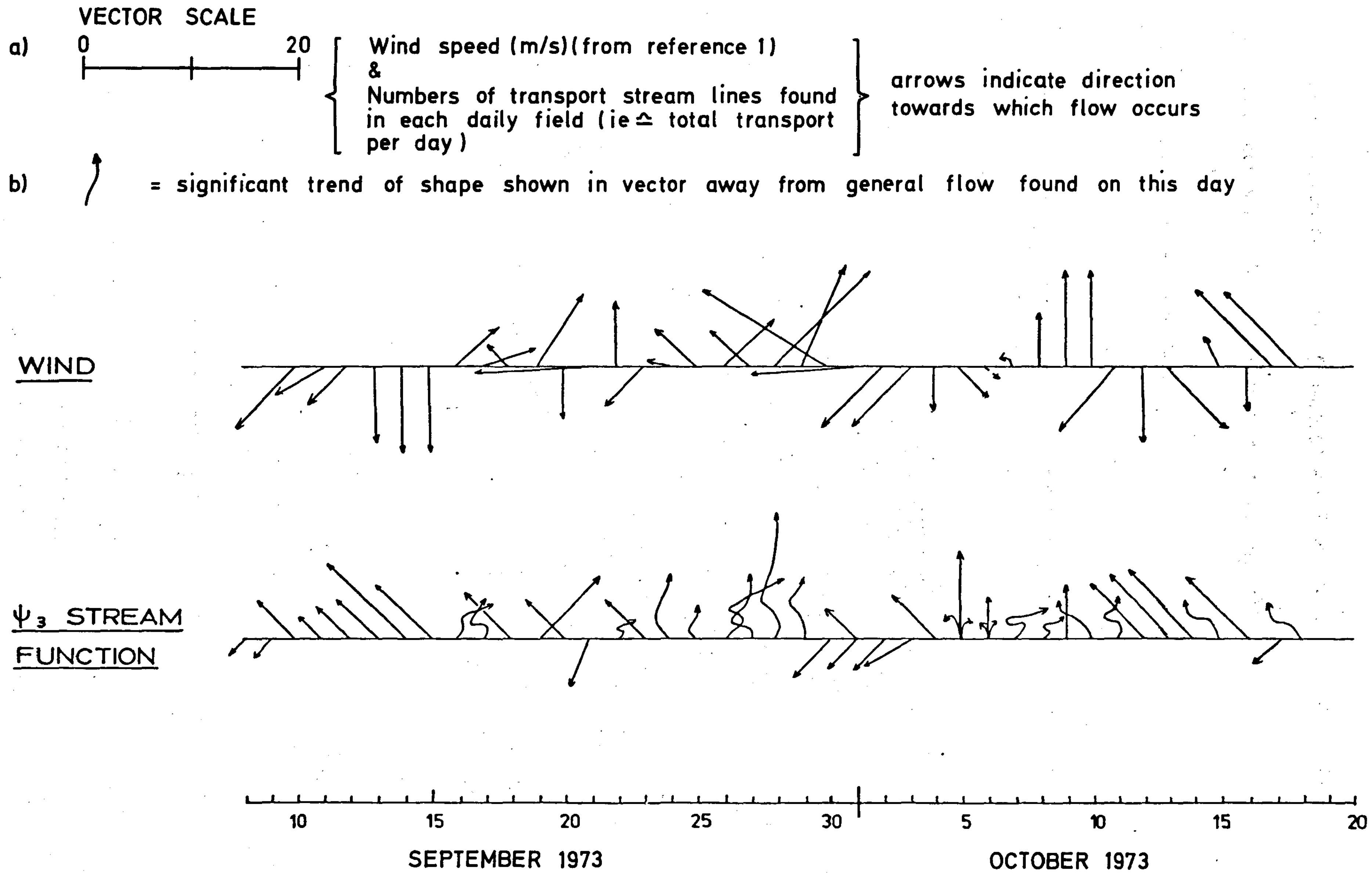

Fig 3. Vector time series of wind and stream function fields

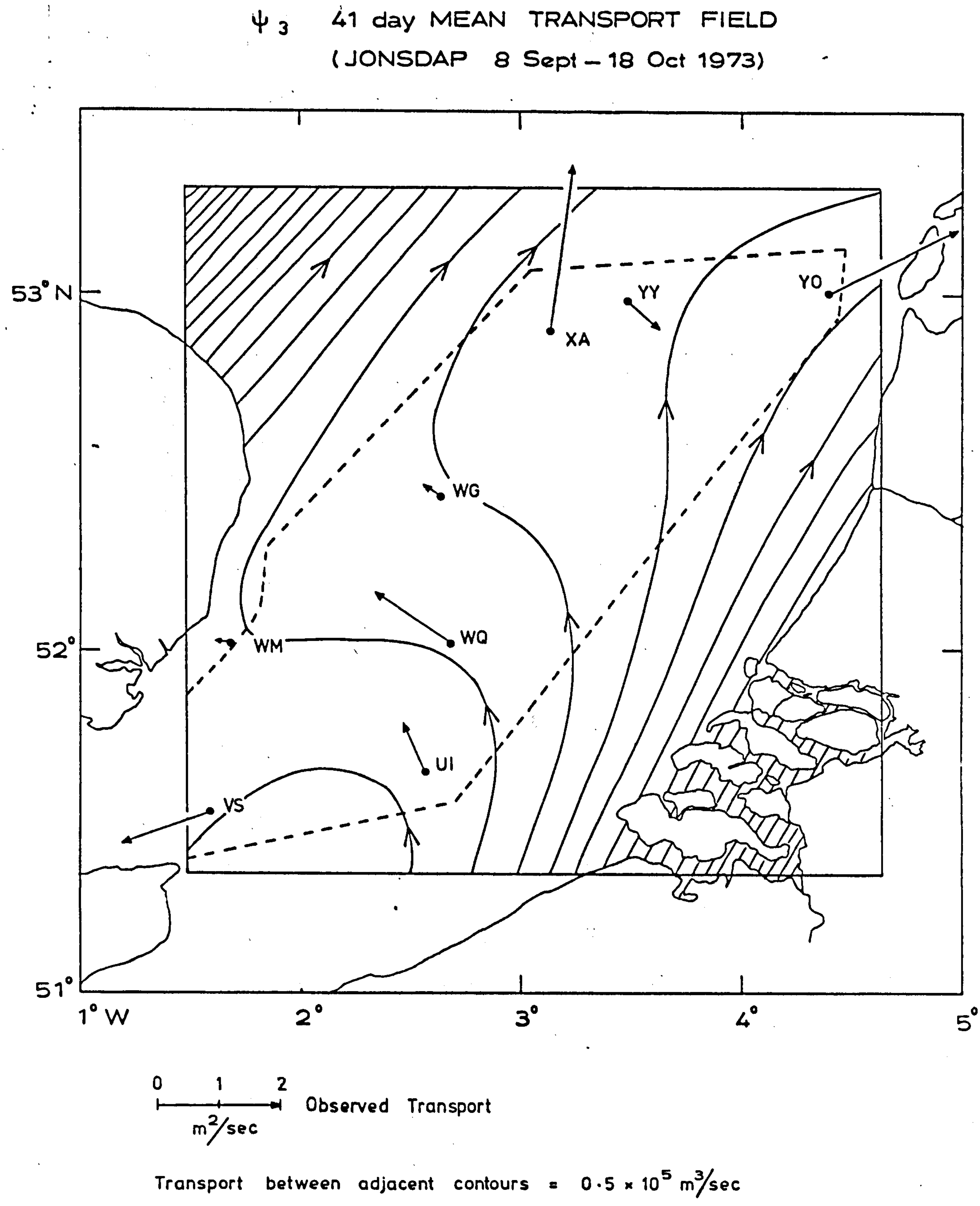

Figure 4a 41 day mean transport field (JONSDAP, 8 September–18 October 1973).

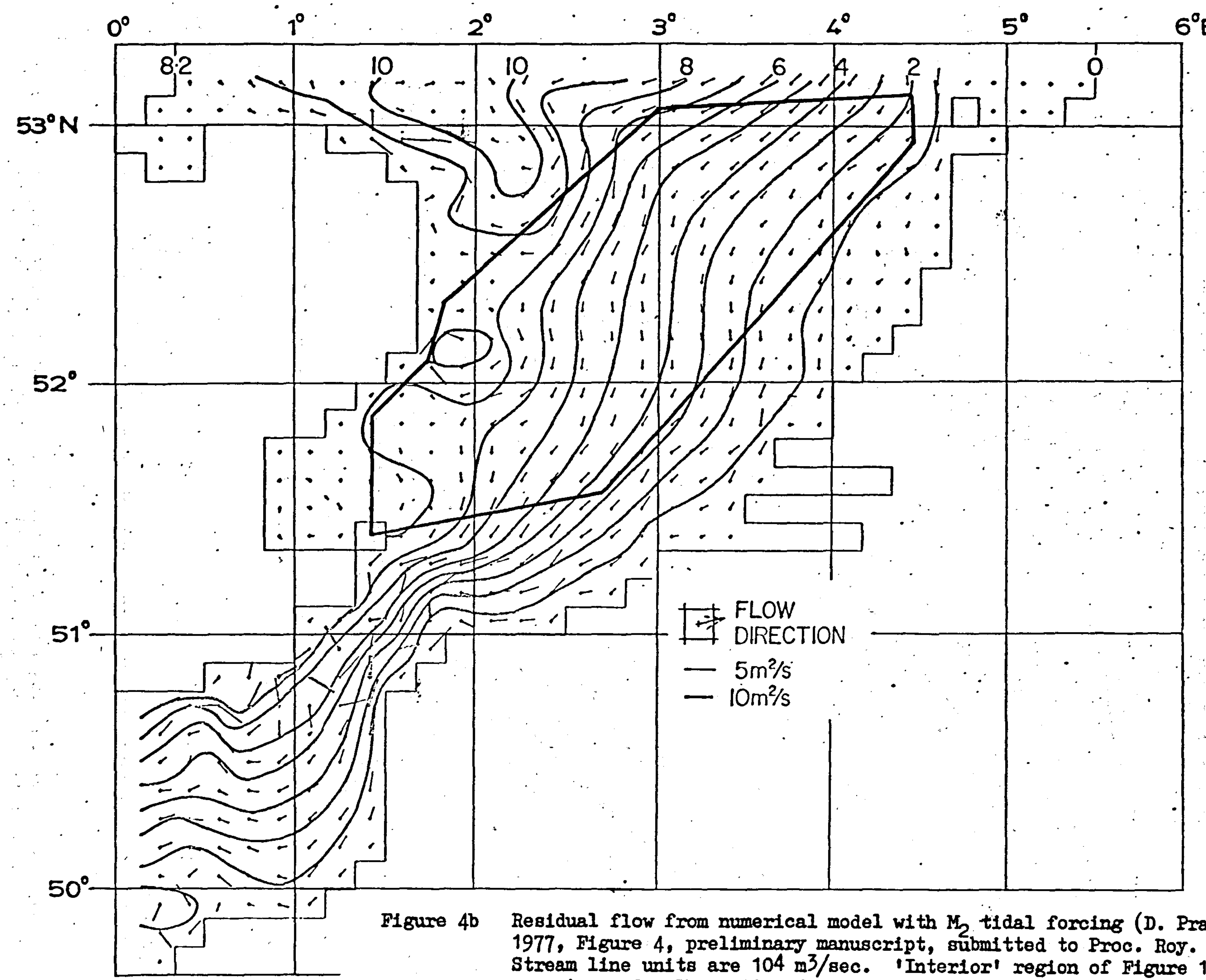

Figure 4b Residual flow from numerical model with M_2 tidal forcing (D. Prandle, 1977, Figure 4, preliminary manuscript, submitted to Proc. Roy. Soc.). Stream line units are 10^4 m^3/sec. 'Interior' region of Figure 1 is superimposed. The ratio of x to y scales is about 9:10.

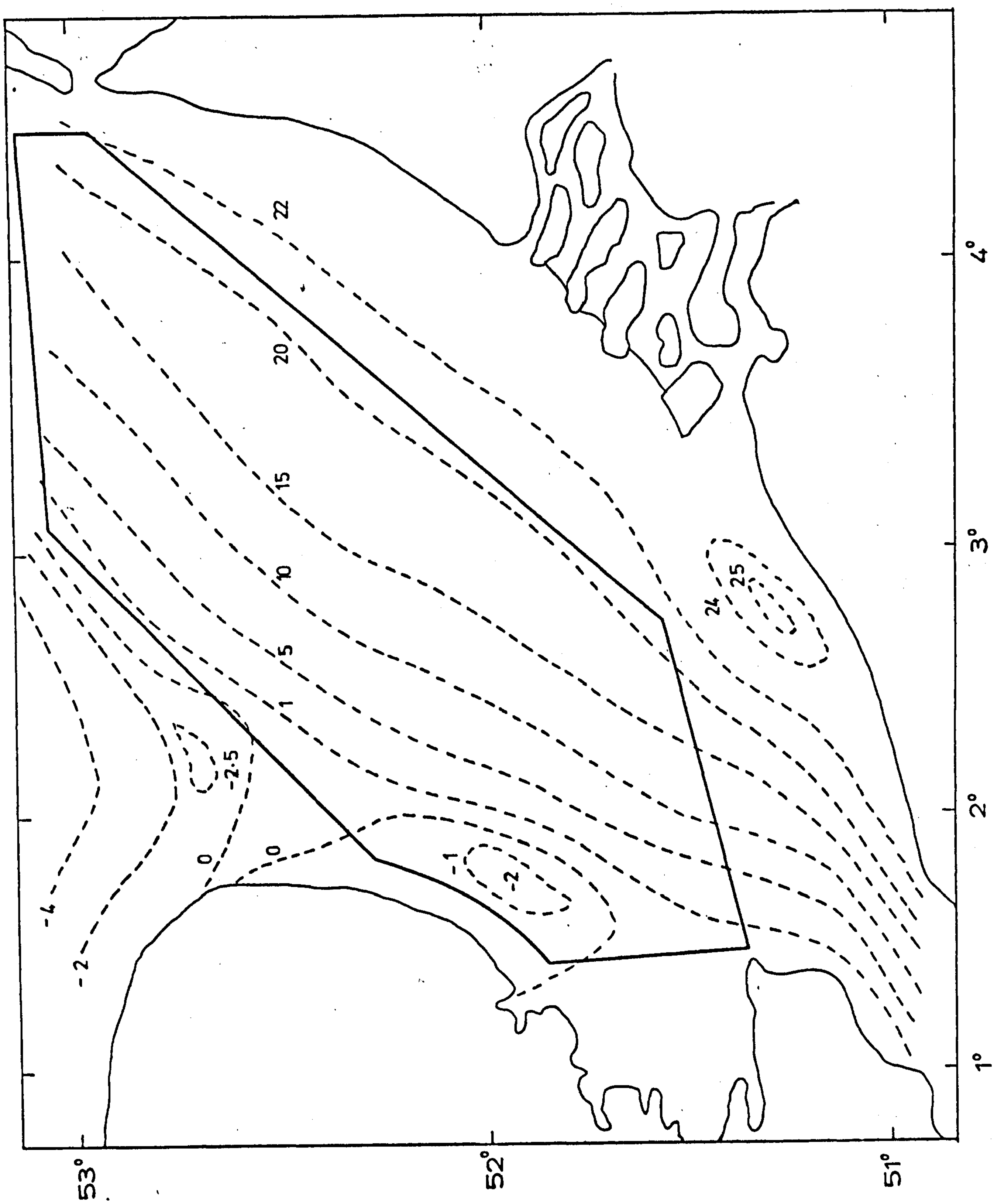

Figure 4c Residual flow from numerical model with M_2 tidal forcing and river inflow. [Due to Nihoul and Ronday (1975), Figure 2. Copied from D. Prandle, 1977, preliminary manuscript, submitted to Proc. Roy. Soc., Figure 5.] Stream line units are 10^4 m^3/sec. 'Interior' region of Figure 1 is superimposed. The ratio of x to y scales is about 9:10.

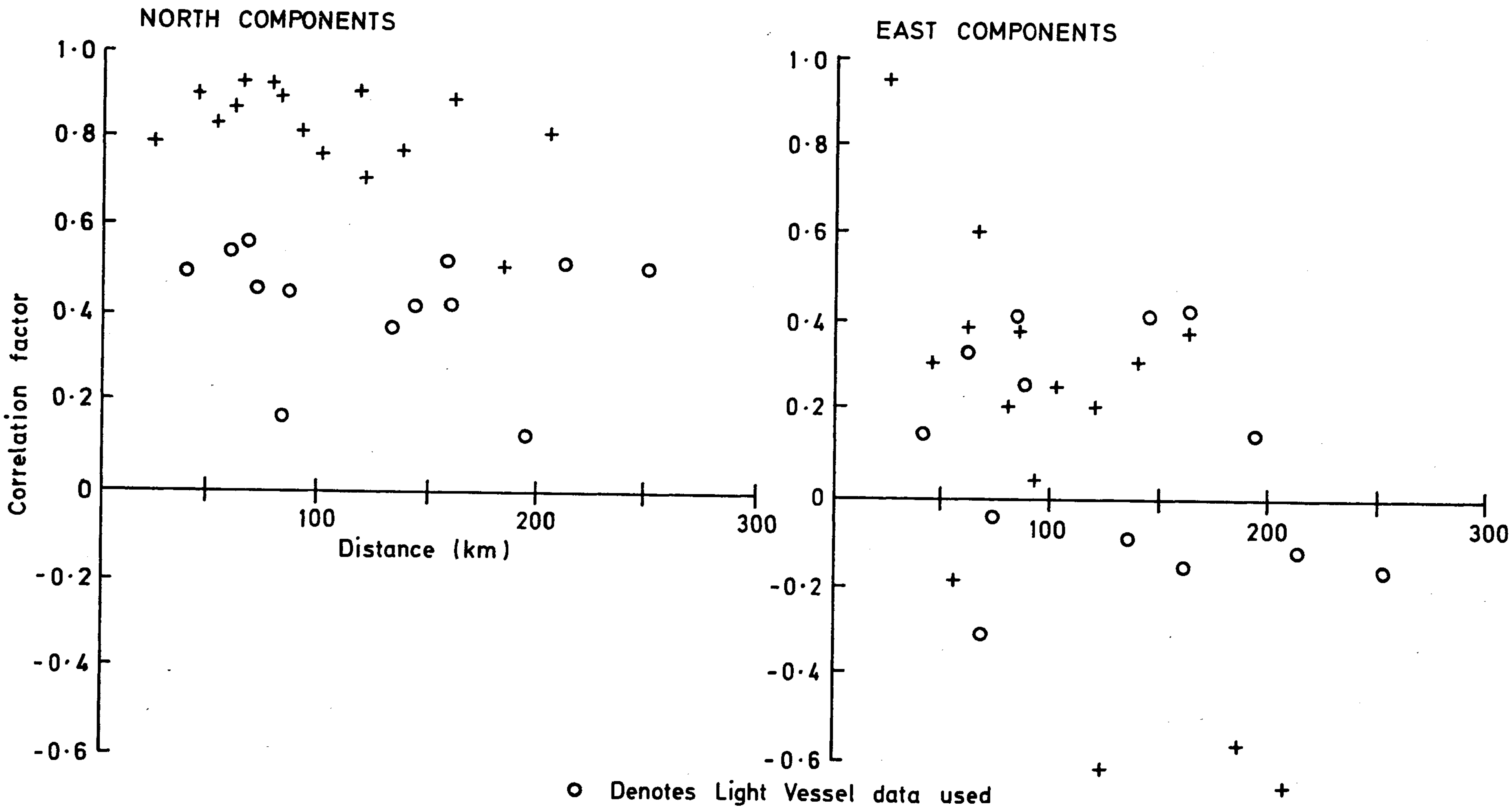

Figure 5 Correlation factor for components of transport from 8 JONSDAP '73 sites against site separation distance. Data are daily averages from 8 September to 19 October 1973.