PRACTICAL ASPECTS OF THE USE OF NUMERICAL MODELS FOR SURGE PREDICTION

by

R. A. FLATHER

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NATURAL ENVIRONMENT RESEARCH COUNCIL
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SCIENCES

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CONTENTS

Page

1. Introduction 1

2. The influence of length of warning on the error in the prediction. 3

3. A practical system for operational surge forecasts 6

4. Concluding remarks 12

References 14

Appendix 15

Tables 1 - 2 17

Figures 1 - 6

1. INTRODUCTION

This report deals with some practical aspects of the implementation of the storm surge prediction technique based on the use of numerical models introduced by FLATHER and DAVIES (1975, 1976). The essence of the proposed scheme is to take data from numerical weather predictions carried out by the Meteorological Office using a 10-level model of the atmosphere (BENWELL et al. 1971), then to process the data in order to determine the changing distribution of wind stresses and gradients of atmospheric pressure over the sea surface, and subsequently to use a sea model with the processed data as input to compute the storm surge. The original scheme, which employs a sea model covering the whole of the north-west European continental shelf, has been developed and improved as a result of recent experiments, culminating in a successful test run covering a continuous period of 44 days in November-December 1973 (FLATHER 1976). A second component consisting of a North Sea model giving better resolution of coastal areas and hence more accurate results (DAVIES 1976) has also been established. The quality of recent results suggests that the technique is now sufficiently developed to provide a useful supplement to existing surge forecasting methods. The present report discusses some of the questions which remain to be answered before operational predictions could be undertaken and describes a first practical system.

All previous experiments with the scheme have used either hours 6 to 18 or hours 7 to 19 of each meteorological forecast to produce surge predictions such that the end of one forecast coincides with the start of the following forecast, thereby giving a continuous record of the development of the surge. This procedure, if carried out operationally, would allow surge forecasts covering 12 hour periods to be issued twice a day; the time of issue being perhaps 1 to 2 hours before the start of the period covered. Although such forecasts could be useful in themselves, predictions covering an extended period and thus giving a surge warning further ahead of the event, with more time available to consider and take necessary action, would be more valuable. Since the 10-level model runs continue to 36 hours, there is no reason in principle why extended surge forecasts should not be produced simply by using, say, hours 7 to 36 of each meteorological prediction as data for sea model runs of 29 hours duration. The surge forecasts, still issued twice a day, would then overlap in much the same way as the numerical weather predictions and would warn of storm surges over the whole continental shelf up to 30 hours ahead. This basic system could later be extended by making use of the fine mesh North Sea model (DAVIES 1976) to improve the accuracy of predictions for shallow coastal waters. Further components giving shorter term more detailed results for localised areas or particular purposes might also be added. An example would be the Southern Bight - Thames Estuary model designed by PRANDLE (1974) to make surge predictions for the six hour period preceding high water at the site of the Thames flood prevention barrier.

It is well known that the precision of meteorological forecasts decreases with increasing length of warning, so that weather conditions more than a few days ahead can only be predicted with considerable uncertainty. Since the surge forecast depends largely on accurate meteorological data, it is necessary, before embarking on extended predictions, to demonstrate that surges can be forecast 30 hours in advance without suffering too great a loss in accuracy. This question of surge predictability is examined in section 2. It is shown that, although errors increase with the length of warning given, useful results can be obtained more than a day ahead of the event.

In section 3 details of the basic practical scheme providing overlapping predictions, as mentioned above, are presented together with some results obtained for surges during November 1973. In addition, the robustness of the scheme from the point of view of its ability to continue in case of computer breakdown or similar eventuality causing the loss of a forecast is demonstrated. It is intended that the system described here and embodied in the associated computer programs could be implemented on a trial basis at any time and that further refinement could then take place in the light of experience gained from using it to produce real-time predictions.

2. THE INFLUENCE OF LENGTH OF WARNING ON THE ERROR IN THE PREDICTION.

In order that experiments on the effect of length of warning on surge forecasts could be undertaken, additional data comprising hourly arrays of predicted 1000mb heights from hours 7 to 36 of 10-level model runs were obtained from the Meteorological Office. The data were supplied for the period beginning with the 0000 GMT forecast on 10 November and ending with the 1200 GMT forecast on 20 November 1973. With these data four surge predictions were carried out taking (i) hours 7 to 19 of each meteorological forecast as in earlier work (FLATHER 1976); (ii) hours 12 to 24; (iii) hours 18 to 30; and (iv) hours 24-36, to provide the required input to the continental shelf model. In all other respects the surges were calculated as before, in each case the duration of an individual forecast being 12 hours so that the end of one forecast coincided with the start of the subsequent forecast. From the experiment four continuous but distinct solutions for the surge development were obtained, corresponding to the runs (i) to (iv). The possible time of issue of individual predictions of sea level in case (i) might have been 1 to 2 hours before the start of the 12 hour period covered; in case (ii) 6 to 7 hours; in case (iii) 12 to 13 hours; and in case (iv) 18 to 19 hours.

Predicted surge residuals between 11 and 20 November 1973 at North Shields, Lowestoft, Southend, Ijmuiden and Cuxhaven obtained from solutions (i) to (iv) are plotted in Figure 1 together with hourly values derived from observations (denoted by +). It is clear from Figure 1 that the main surges are present in all solutions. There are occasions when the observed levels fall well outside the range of the forecasts, such as the negative surge on 12 November with the following positive surge along the English coast both of which are under-predicted, and the spurious positive surge also on the English coast on 16 November. At other times the observed levels lie within or close to the spread of those predicted. Another point of interest is that the range of predicted elevations at a given time varies considerably, from about 1.4 metres discrepancy between solutions (ii) and (iv) at Southend early on 20 November to almost complete agreement at Cuxhaven during the growth of the positive surge on 19 November. The magnitude of the differences between solutions presumably reflects the degree of uncertainty present in the meteorological forecasts.

Although it is not difficult to find times and places at which solution (iv), for example, appears to reproduce more closely the observations than does solution (i), it seems clear from Figure 1 that the earliest section of the atmospheric model prediction, used in (i), gives overall the most accurate results. This is confirmed by the root mean square errors given in Table 1. At most ports these errors increase when a later period of the 10-level model forecast is used to supply the input data for the surge calculation, as expected. However, the increase in error is not very large and taken with the evidence of Figure 1 suggests that useful surge information can be derived from the whole of the meteorological forecast. It should also be pointed out that the errors given for solutions (ii) to (iv) might be slightly larger than could be expected of operational results. In a practical scheme, such as that described in the following section, the initial state of the sea would be carried forward in time using the most accurate meteorological data available: usually hours 7 to 19 of a forecast. The initial conditions for each 12 hour sea model calculation in cases (ii) to (iv) were obtained from a sequence of earlier runs in each of which a later and hence less accurate section of the atmospheric model data was used. As a result, the initial state of the sea here could contain inessential errors which would influence the forecast in question. The errors given in Table 1 should therefore be considered as representative of the worst case likely to occur.

In order to obtain further insight into the nature of the errors, a linear regression analysis was carried out in which a relationship between predicted and observed elevations of the form

$$\zeta_{\text{observed}} = C_1 \, \zeta_{\text{predicted}} + C_0$$

was sought. The constants C_0 and C_1 were determined by standard least squares techniques from available hourly comparisons at individual ports in each of the four cases considered. The resulting values of C_0 and C_1 are given in Table 2. Noting that values of C_1 greater or less than unity indicate a tendency for surges to be respectively underestimated or overestimated by the prediction scheme, it is clear from Table 2 that an increase in the length of warning brings about a greater likelihood that a surge will be over-predicted. Thus, the earliest available forecast of a developing surge might be rather pessimistic. There appears to be no systematic variation of C_0 with length of warning.

3. A PRACTICAL SYSTEM FOR OPERATIONAL SURGE FORECASTS

In the light of the results presented in section 2, which suggest that useful surge predictions can be obtained using meteorological data from the whole of each 10-level model forecast, a practical system to provide extended overlapping predictions, as outlined earlier, has been implemented. The scheme is illustrated in Figure 2, to which the reader should refer in conjunction with the description which follows.

Numerical weather predictions using the 10-level model are carried out twice a day by the Meteorological Office. Each prediction run covers the period $0 \leqslant t_m \leqslant 36$ hours, where t_m denotes meteorological model time and $t_m = 0$ corresponds to either 0000 GMT or 1200 GMT on the day. The collection of observational information and preparation of initial fields describing the state of the atmosphere at $t_m = 0$ takes about 5 hours of real time, so that the model computation, which requires approximately 14 minutes on an IBM 360/195 computer, can begin at say 0500 GMT or 1700 GMT. Data required for the surge calculation is then extracted from the output of the 10-level model and stored on a magnetic tape. In the present case these data comprise hourly arrays for $7 \leq t_m \leq 36$ hours of geopotential heights of the 1000mb pressure surface from a 24 x 26 rectangular subset of grid points of the atmospheric model covering the north-west European continental shelf (FLATHER and DAVIES 1975, 1976). At this point the data would, if necessary, be transferred from the magnetic tape on the computer at the Meteorological Office to a similar magnetic tape on the computer at the Institute of Oceanographic Sciences or wherever the surge prediction part of the process was to be carried out. This transfer of data using telephone lines, a procedure in routine use, is the only major aspect of the proposed scheme which has not yet been tested. The time required for data transmission would be of the order of 20 minutes so that the surge computation could begin at say 0545 GMT or 1745 GMT.

Each sea model prediction run covers a period $0 \leq t_s \leq 29$ hours, where t_s denotes sea model time and $t_s = 0$ corresponds to $t_m = 7$, being either 0700 GMT or 1900 GMT on the day. The initial state of the sea is taken directly from fields computed in the previous forecast with no input of observational information. Thus, referring to Figure 2, the situation at time $t_s = 0$ in forecast 3, say, is identified with that at time $t_s = 12$ in forecast 2, stored in the preceding run. If, for some reason, forecast 2 were unavailable then fields from $t_s = 24$ in forecast 1 would be used as initial conditions for forecast 3. Thus by storing data twice, at $t_s = 12$ and $t_s = 24$, during each sea model run, a degree of robustness sufficient to survive the loss of one meteorological forecast is embodied in the scheme.

In the tests completed so far, the surge computation was carried out on an IBM 370/165 computer at the Science Research Council's Daresbury Nuclear Physics Laboratory, requiring in all less than 6 minutes processing time. The necessary programs were submitted and the output returned through a telephone link from the Institute of Oceanographic Sciences. Assuming no delays in gaining access to the computer, the prediction might thus be available for issue by about 0600 GMT or 1800 GMT. Clearly these times are dependent on the speed of the computer employed and could be set back by perhaps 1 hour if a less powerful machine had to be used. Details of the individual steps carried out in the surge computation are given in an appendix.

The scheme has been tested, as far as is possible without facilities for real time transmission of meteorological data and the necessary priority in accessing computers, by carrying out overlapping predictions for the period 10-21 November 1973. In contrast with the results of section 2, which were obtained from sea model runs of 12 hours duration, the whole of the available meteorological data was used in each of the present forecasts as input for sea model runs lasting for 29 hours. Results for the storm surge of 18-20 November are plotted in Figure 3. Here, in each forecast, the earliest section, $0 \leq t_s \leq 12$ hours, is drawn with a continuous line; the next section, $12 \leq t_s \leq 24$ hours, with a dashed line; and the remaining period $24 \leq t_s \leq 29$ hours with a dotted line: '+' indicates an observed value and 'o' is the starting point, $t_s = 0$, of a sea model forecast. Note also that an expanded time scale is used as compared with Figure 1. It can be seen in Figure 3 that, for a given time, the system produces two and sometimes three predictions each originating from a different forecast. Figure 4 shows how the predicted spatial distribution of surge for the same time, 2100 GMT 19 November, varies from one forecast to the next. The distribution given in Figure 4a originates from the weather forecast beginning at 1200 GMT on 18 November, which might have been issued more than a day ahead, while Figure 4b and 4c show later predictions. The overall features of the distribution of surge are remarkably similar. Later forecasts suggest higher levels in the Southern Bight and the German Bight with a corresponding reduction in elevation in the extreme north of the North Sea, as compared with Figure 4a. Also the surge peak on the English coast which appears at Lowestoft in the earliest prediction (Figure 4a) is placed further north in both later forecasts. The height of this peak is also increased. Referring back to Figure 3, it is clear that, in fact, the prediction shown in Figure 4a was generally in better agreement with observations at this time than were both later forecasts. Indeed, the increased elevations indicated on the English coast in Figures 4b and 4c can be identified with the anomalously high levels which appear at Inner Dowsing, Lowestoft, Southend and Ijmuiden between 1800 GMT on 19 November and 0600 GMT on 20 November (see Figure 3).

Tests were also carried out to simulate the effect on the surge predictions of the loss of one meteorological forecast at various times during the period 18-20 November. Following the interruption, sea model calculations were continued as described earlier, using as initial conditions data from t_s = 24 hours of the forecast before the one presumed lost (see Figure 2). Figure 5 shows, as an example, a comparison between the normal prediction starting at 0700 GMT on 19 November and the corresponding prediction obtained assuming that the forecast beginning at 1900 GMT on 18 November was not available. Essentially, two results starting from different initial conditions are shown. Unlike the situation in the atmosphere in which the comparative absence of frictional damping makes the initial situation all important, it is clear from Figure 5 that the two sea model solutions converge very rapidly. Although there are significant differences during the first few hours, the results are practically identical during the latter part of the forecast period. Subsequent predictions should, therefore, be little affected by the loss of one set of meteorological data.

Predicted spatial distributions of surge elevation and depth mean current for 2100 GMT on 19 November, corresponding to those shown in Figure 4 but assuming in each case that the previous forecast was lost, are given in Figure 6. Thus, differences between Figure 6a and Figure 4a are due to the loss of the 0000 GMT 18 November weather forecast. These differences can be seen to be small, as would be expected since the results illustrated come from time t_s = 26 hours; i.e. late in the sea model calculation beginning at 1900 GMT on 18 November. Differences, due to the loss of 1200 GMT 18 November weather forecast, between Figures 6b and 4b (t_s = 14 hours of the calculation starting at 0700 GMT 19 November) are rather more apparent but still not large. There are, however, marked differences between Figures 6c and 4c; t_s = 2 hours in the calculation beginning at 1900 GMT on 19 November. In this case, as a result of omitting the 0000 GMT forecast on 19 November, levels in the Wash are reduced by 50 cm, those in the Southern Bight by as much as 25 cm, while in the centre of the northern North Sea levels are raised by more than 25 cm. These findings are consistent with the rapid convergence of solutions shown in Figure 5.

It is interesting to note, here, that the surge distributions shown in Figures 4 and 6 appear to fall into two distinct groups. First, there is a strong similarity between Figures 4a, 6a and 6c, each of which places the surge peak on the English coast in the neighbourhood of Lowestoft with a maximum level of less than 175 cm. Second, Figures 4b, 4c and 6b also closely resemble each other, having a surge exceeding 200 cm on the north coast of East Anglia. In seeking to explain this dichotomy, the one distinguishing factor which emerges is that the computation of the distributions in the second group employed data from the 0000 GMT weather forecast on 19 November, while the computation of the distributions in the first group did not. It seems probable, therefore, that the overpredicted surge appearing at Inner Dowsing, Lowestoft, Southend and Ijmuiden between 1800 GMT on 19 November and 0600 GMT on 20 November (see Figure 3) was caused by too high an estimate of the northerly wind component over the western North Sea during this forecast.

4. CONCLUDING REMARKS

As the next stage in the development of a prediction technique for storm surges based on the use of numerical models, some practical questions relating to their operational use have been examined.

Experiments, described in section 2, to determine how the accuracy of the results depends on the length of warning provided have been carried out by making four distinct predictions for the period 11-20 November 1973, each using a different section of the 10-level model forecasts. It was found that, although errors increase when predicting further ahead, useful results can be obtained with meteorological data taken from the whole of each 36 hour numerical weather forecast. Worthwhile predictions of developing surges up to 30 hours in advance are therefore possible. A linear regression analysis of the results showed some tendency for the earliest warning to overestimate surge magnitudes.

The operational procedure for a first practical system was described in section 3. The proposed scheme, which employs weather forecasts but requires no sea level measurements, can be considered as the basic component of what could become a more comprehensive system, with additional components for specific purposes being included later. In its initial form it would give overlapping surge predictions for the whole continental shelf covering 29 hour periods. The forecasts would be issued twice a day perhaps one hour before the start of the period covered.

The system has been tested, in so far as this is possible at present, by simulating real time operation for the period 10-20 November 1973. Results for the storm surge of 18-20 November were examined in some detail. In particular, it was shown that useful long-term predictions of the spatial distribution of surge elevations and currents are possible; an important asset provided by the method. Further, the robustness of the scheme, in the sense of its ability to continue despite the loss of one set of meteorological data, was also demonstrated. The indications are that the influence of such an interruption is unlikely to extend beyond the first few hours of the following forecast.

The procedure described here could be implemented on a trial basis at any time. Further refinement could then take place with the benefit of experience of real-time operation.

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APPENDIX

A summary of the individual steps carried out in a single surge prediction is given here. The relevant formulae may be found in FLATHER and DAVIES (1975,1976) and FLATHER (1976).

(i) East and north components of wind stress on the sea surface and of the gradient of atmospheric pressure are estimated from the 10-level model data by means of the relations described in FLATHER and DAVIES (1975) with some subsequent modifications (FLATHER 1976). Arrays of values of stress and pressure gradient components at appropriate grid points of the sea model for hours $t_s = 0(1)29$ hours are stored on magnetic disc.

(ii) Using the hydrostatic law, estimates of surge elevation at each point on the open boundary of the sea model are made at intervals of one hour and the data stored on magnetic disc.

(iii) A sea model run is carried out for $0 \leq t_s \leq 29$ hours to predict the tide during the forecast period. The tide is generated from input of the two largest harmonic constituents, M_2 and S_2, along the open sea boundaries with the initial state taken as that at time $t_s = 12$ in the preceding tidal run. Hourly arrays of elevation and horizontal components of depth averaged currents are stored on magnetic disc together with time series comprising 15 minute values from up to 30 chosen ports. A selection of the output may be printed if necessary.

(iv) A second sea model run is carried out for $0 \leq t_s \leq 29$ hours to predict the total water level due to tide and meteorological effects during the forecast period. The tide is generated as in (iii), while the surge component comes from the influence on the sea model of wind stress and pressure gradient estimated in (i) with the addition of a surge component, estimated in (ii), entering across the open boundary. By computing tide and surge together in this step, account is taken of the interaction between them. Hourly arrays of elevation and current are stored on magnetic disc with time series from the chosen ports as in step (iii).

(v) Storm surge residuals, including interaction effects, are computed by subtracting the tidal solution, stored in step (iii), from the complete solution, stored in step (iv). The resulting prediction is printed and hourly arrays of residual elevation and current and time series of surge at points of interest are stored on magnetic disc for subsequent plotting.

(vi) Time series of predicted surge elevation at chosen points, stored in (v), are plotted. The computer program causes plotting instructions to be written onto a magnetic tape and the actual diagrams are produced on a Calcomp 925/936 off-line plotting system. This step may be omitted if the printed results from step (v) show that no event of interest occurred.

(vii) Contour plots showing the spatial distribution of surge elevation and/or plots showing the distribution of storm surge currents at selected times, as required, are drawn using the data stored in (v). The plotting is carried out on an off-line system as in (vi) but line printer elevation contours are produced for immediate inspection.

(viii) All data placed on magnetic disc in steps (iii), (iv) and (v) is transferred to magnetic tape for permanent storage.

Port	(i) 7-19 h	(ii) 12-24 h	(iii) 18-30 h	(iv) 24-36 h
Stornoway	18.5	17.2	18.1	16.9
Lerwick	10.6	10.7	12.0	12.1
Wick	21.5	22.1	22.7	22.2
Aberdeen	20.1	22.5	24.2	25.6
North Shields	19.0	23.9	25.9	27.3
Immingham	25.5	33.3	38.8	40.5
Inner Dowsing	24.8	33.3	40.3	41.6
Lowestoft	21.4	29.7	36.7	39.3
Walton-on-Naze	26.1	35.2	41.2	43.7
Southend	29.5	36.7	41.9	45.7
Dover	20.7	25.5	30.3	32.6
Ostende	32.7	36.2	38.2	39.7
Ijmuiden	27.9	35.0	39.6	39.7
Terschelling	26.0	29.8	34.8	36.7
Cuxhaven	38.4	39.6	43.1	49.0
Esbjerg	30.0	36.6	42.9	48.3
Bergen	11.2	12.9	13.7	15.4
All ports	24.8	29.5	33.7	35.9

Table 1 : RMS errors (cm) for the period 11-20 November 1973 based on hourly comparisons of observed surge residuals and values predicted using different sections of the meteorological forecast.

Port	(i) 7-19 h		(ii) 12-24 h		(iii) 18-30 h		(iv) 24-36 h	
Stornoway	0.91	-12.9	0.95	-12.4	0.87	-10.9	0.87	- 9.1
Lerwick	1.17	- 3.2	1.33	- 5.4	1.15	- 2.6	0.94	0.1
Wick	0.97	-18.1	0.99	-18.0	0.94	-16.7	0.85	-13.1
Aberdeen	0.92	-12.2	0.84	-11.8	0.77	-11.4	0.69	- 9.1
North Shields	0.91	- 1.6	0.78	- 1.4	0.74	- 2.2	0.74	- 1.4
Immingham	0.85	- 8.9	0.73	- 9.2	0.66	- 9.6	0.65	- 9.3
Inner Dowsing	0.88	- 0.7	0.75	- 0.7	0.67	- 0.8	0.67	- 0.9
Lowestoft	0.98	- 2.9	0.83	- 2.0	0.76	- 3.1	0.75	- 3.2
Walton-on-Naze	0.91	- 2.4	0.77	- 1.3	0.72	- 1.6	0.69	0.7
Southend	0.88	- 0.5	0.77	- 0.6	0.72	- 0.9	0.69	1.9
Dover	0.99	- 7.5	0.87	- 7.7	0.80	- 9.1	0.78	- 8.7
Ostende	0.91	24.5	0.76	25.9	0.70	24.3	0.69	24.0
Ijmuiden	1.03	- 1.6	0.86	1.7	0.81	- 0.6	0.86	- 4.4
Terschelling	1.10	- 5.4	0.98	- 3.1	0.92	- 5.8	0.97	- 9.6
Cuxhaven	1.14	6.6	1.05	9.7	0.99	7.7	0.96	5.5
Esbjerg	1.03	-11.6	0.95	- 8.8	0.92	-10.6	0.88	- 8.3
Bergen	0.89	- 1.8	0.75	- 0.1	0.71	0.9	0.55	4.1

Table 2 : Regression coefficients C_1, C_0, where $\zeta_{\text{observed}} = C_1 \zeta_{\text{predicted}} + C_0$, from analysis of the results for 11-20 November 1973 obtained using different sections of the meteorological forecast.

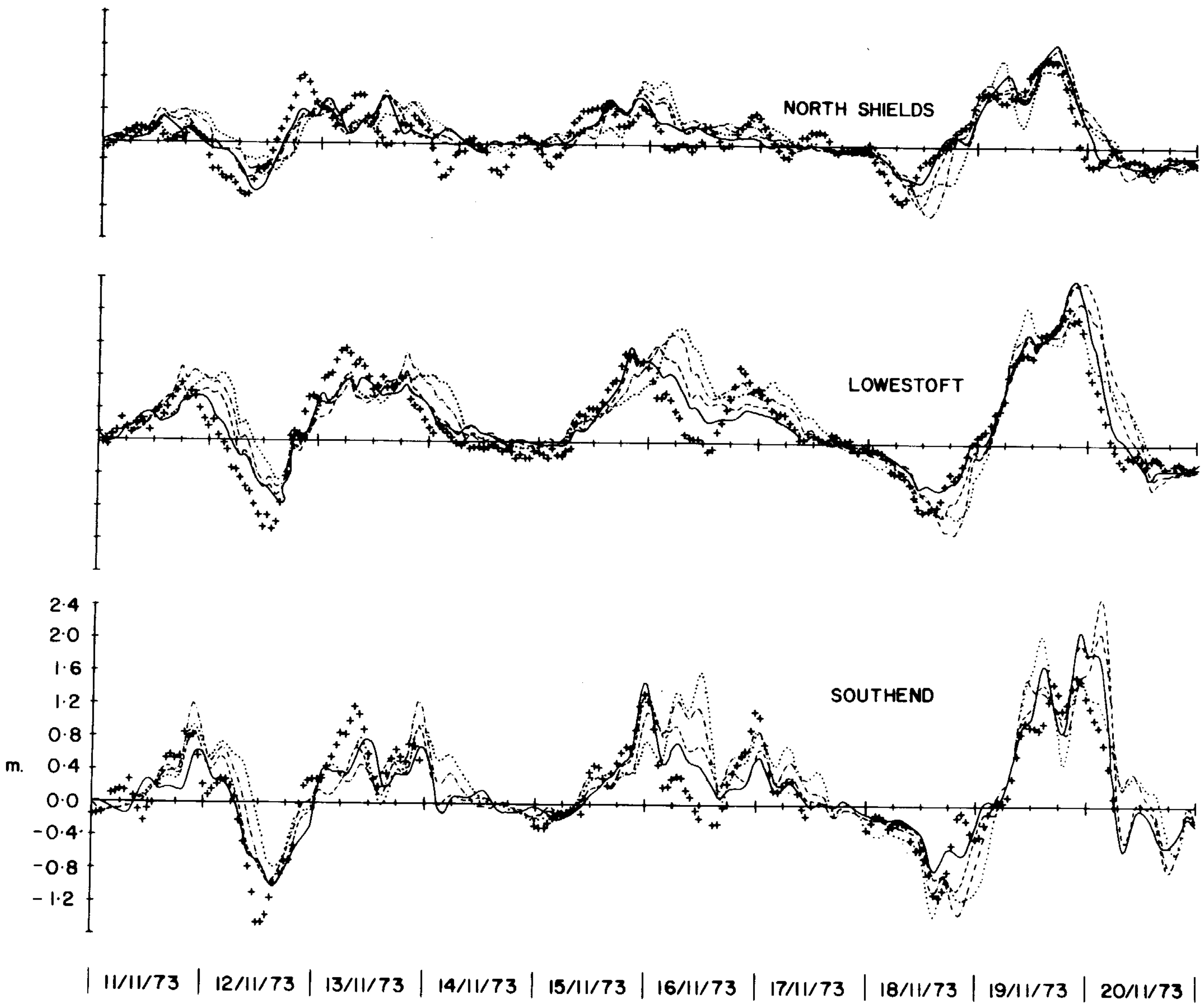

Figure 1a: Predicted surge levels obtained using different sections of the meteorological model forecasts compared with observed levels, illustrating the dependance of the prediction on the length of warning possible.

——— hours 7-19 ; - - - - - - - - hours 12-24 ; -·-·-·-·- hours 18-30 ; ··············· hours 24-36.

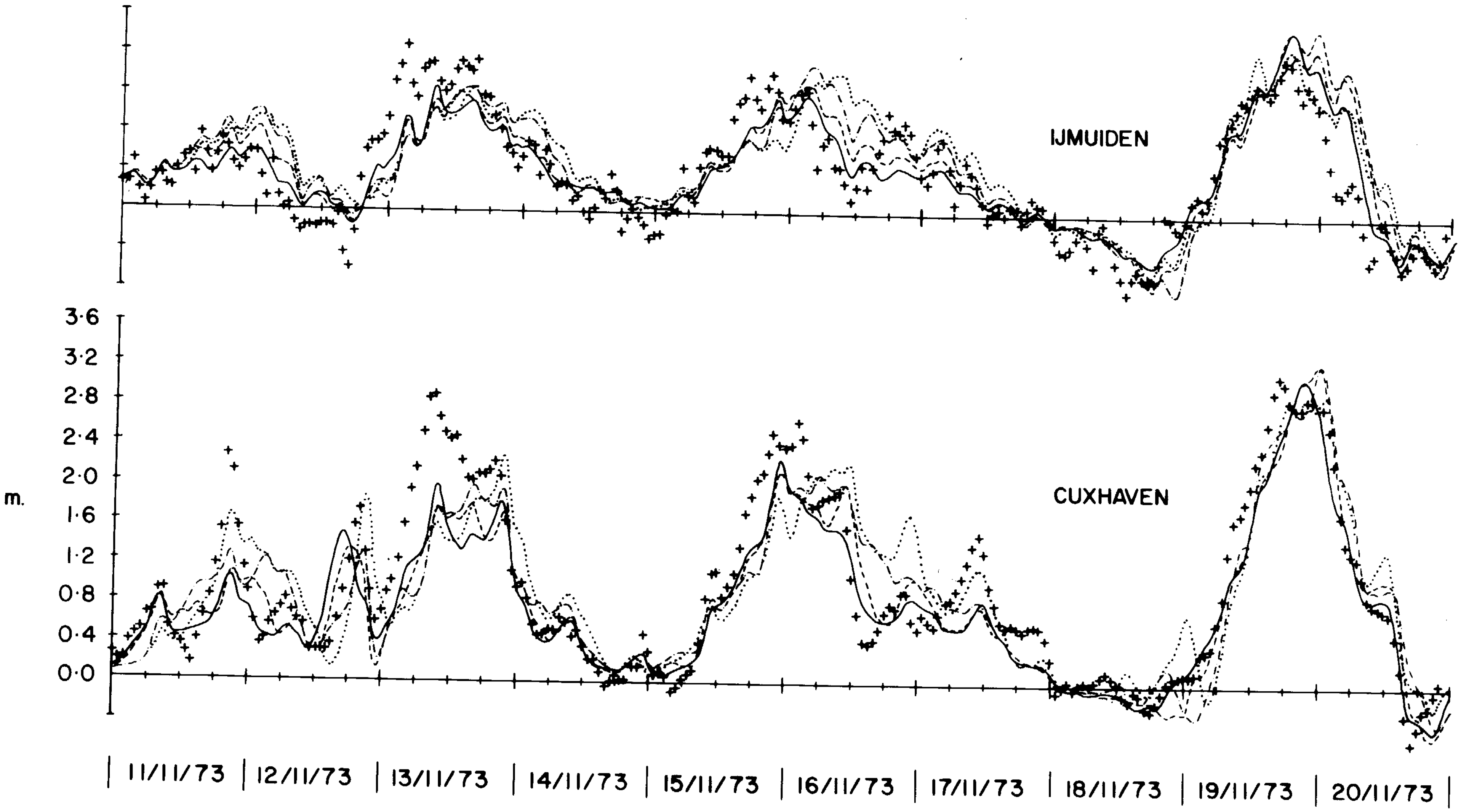

Figure Ib : Predicted surge levels obtained using different sections of the meterological model forecasts compared with observed levels, illustrating the dependance of the prediction on the length of warning possible.

——— hours 7-19 ; ------ hours 12-24 ; -·-·-·- hours 18-30 ; ··········· hours 24-36.

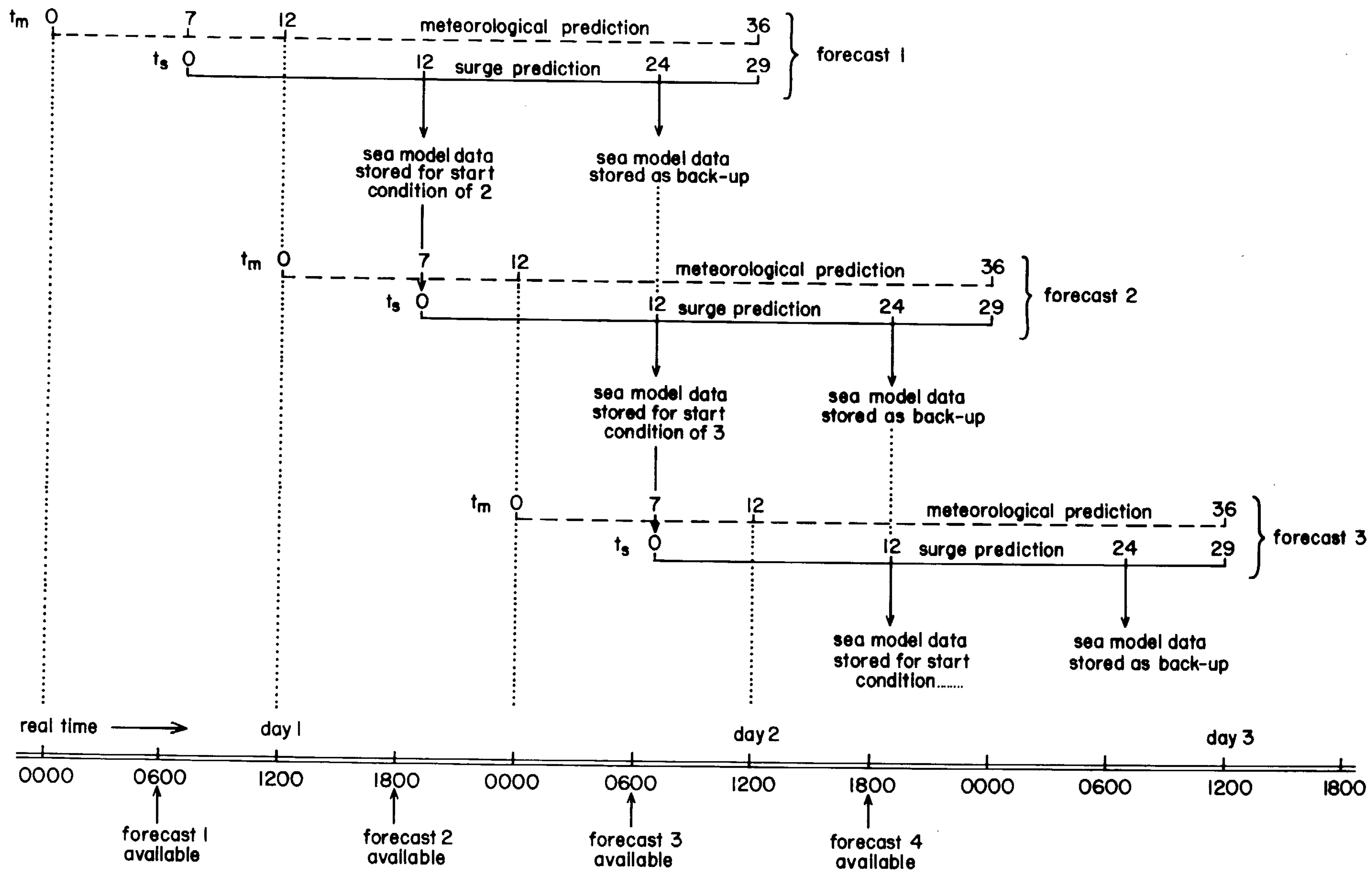

Figure 2 : Scheme for operational surge forecasting providing overlapping predictions up to 30 hours ahead

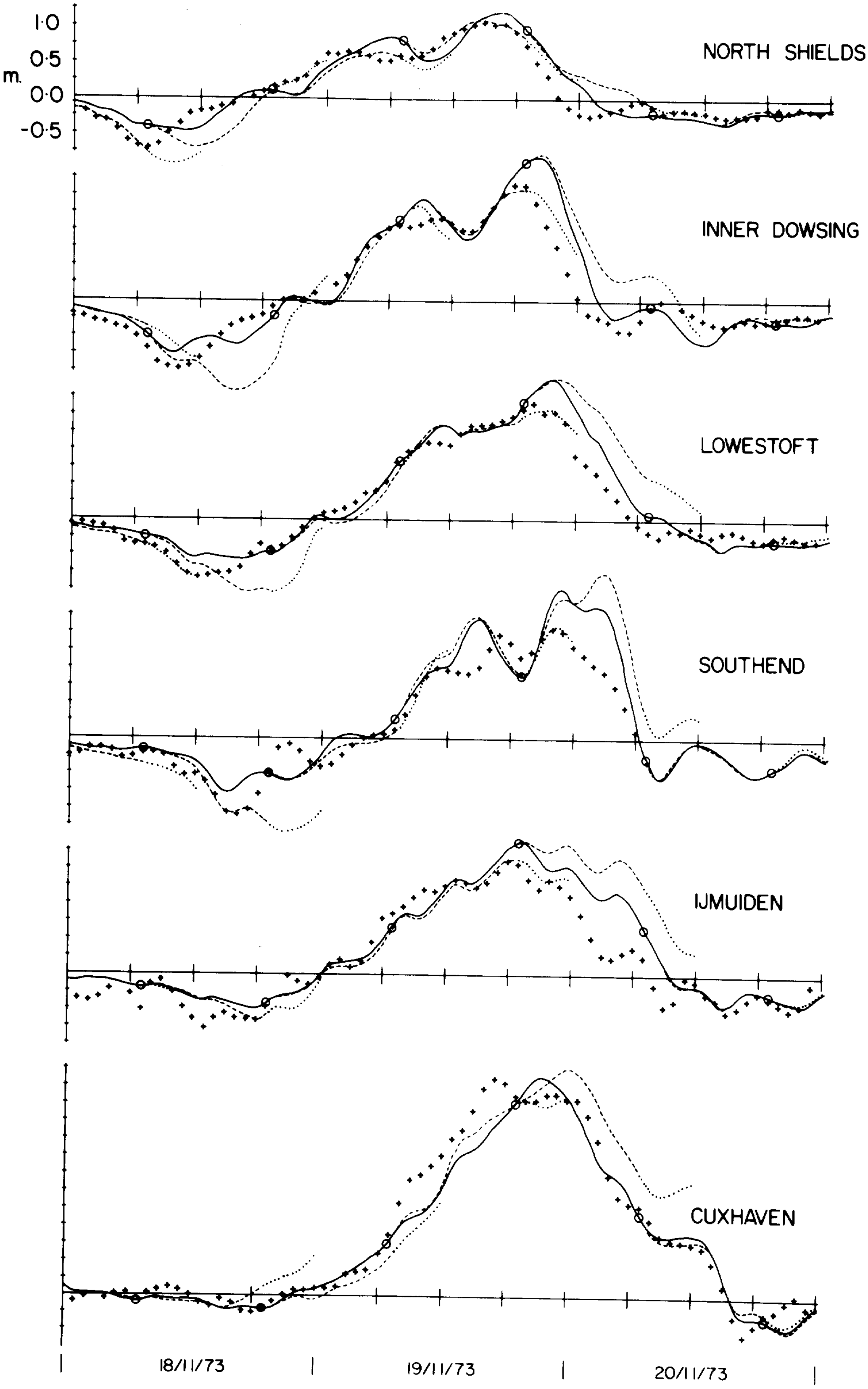

Figure 3 : Overlapping predictions for the period 18-20/11/73 obtained by running the forecasting scheme in an operational mode.

o - start of sea model prediction ; ——— hours 0-12 ; -------- hours 12-24 ; ·········· hours 24-29.

A complete forecast is plotted as

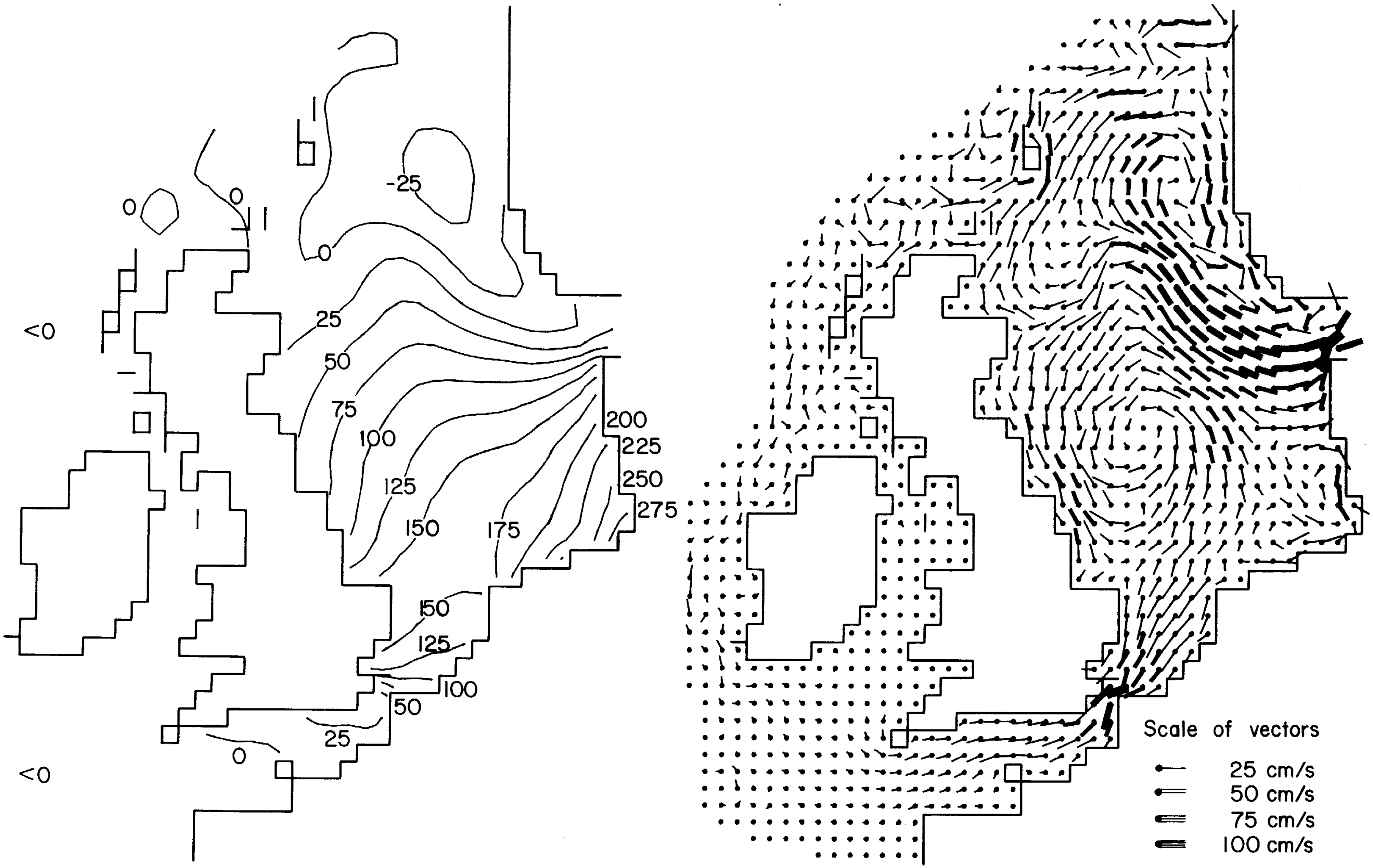

Figure 4 : The predicted distribution of surge elevation (cm) and depth mean current at 2100 GMT 19/11/73 obtained from different forecasts.

a) 1200 GMT forecast on 18/11/73, available at ~ 1800 GMT 18/11/73

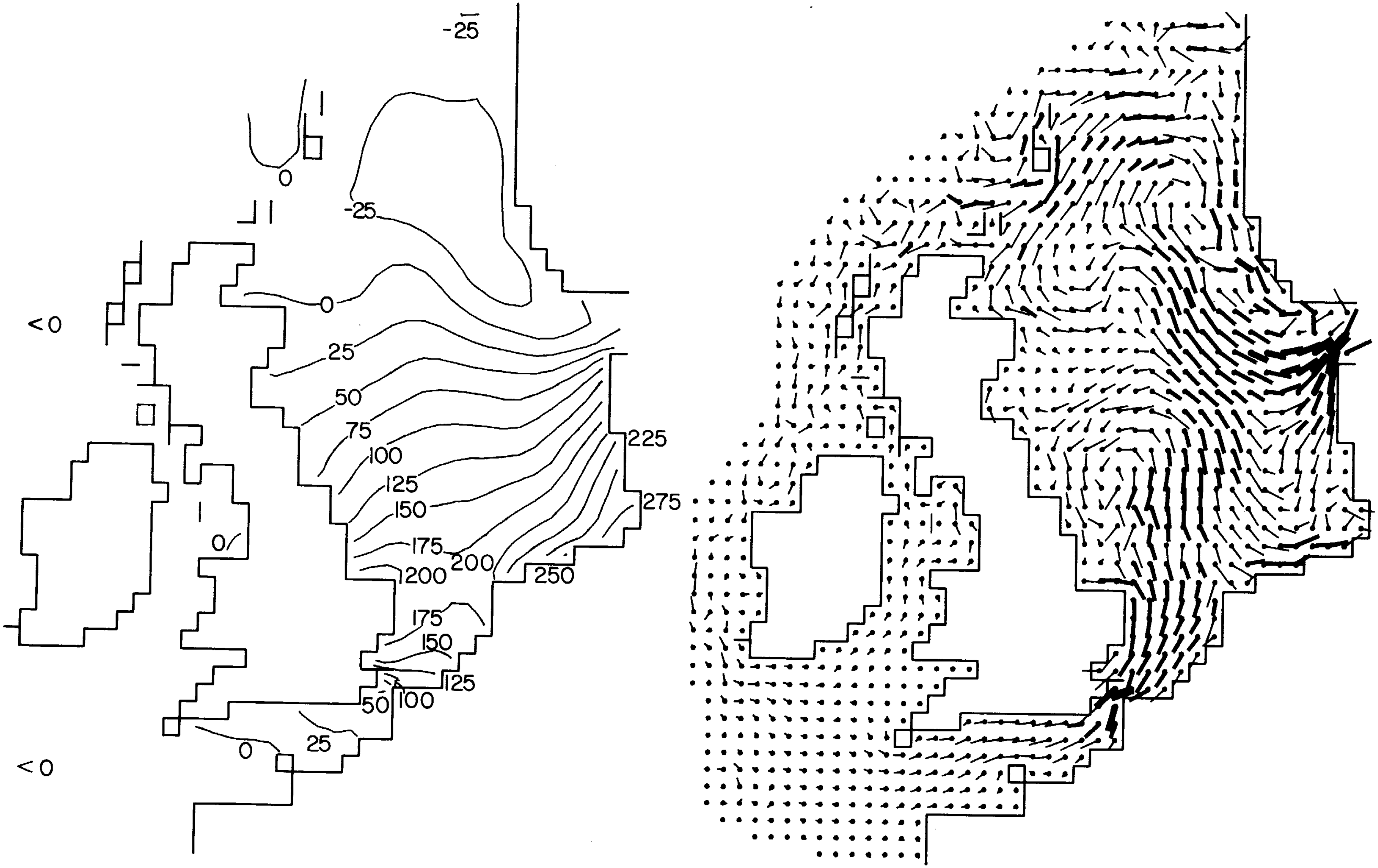

Figure 4: b) 0000 GMT forecast on 19/11/73, available at ~ 0600 GMT 19/11/73

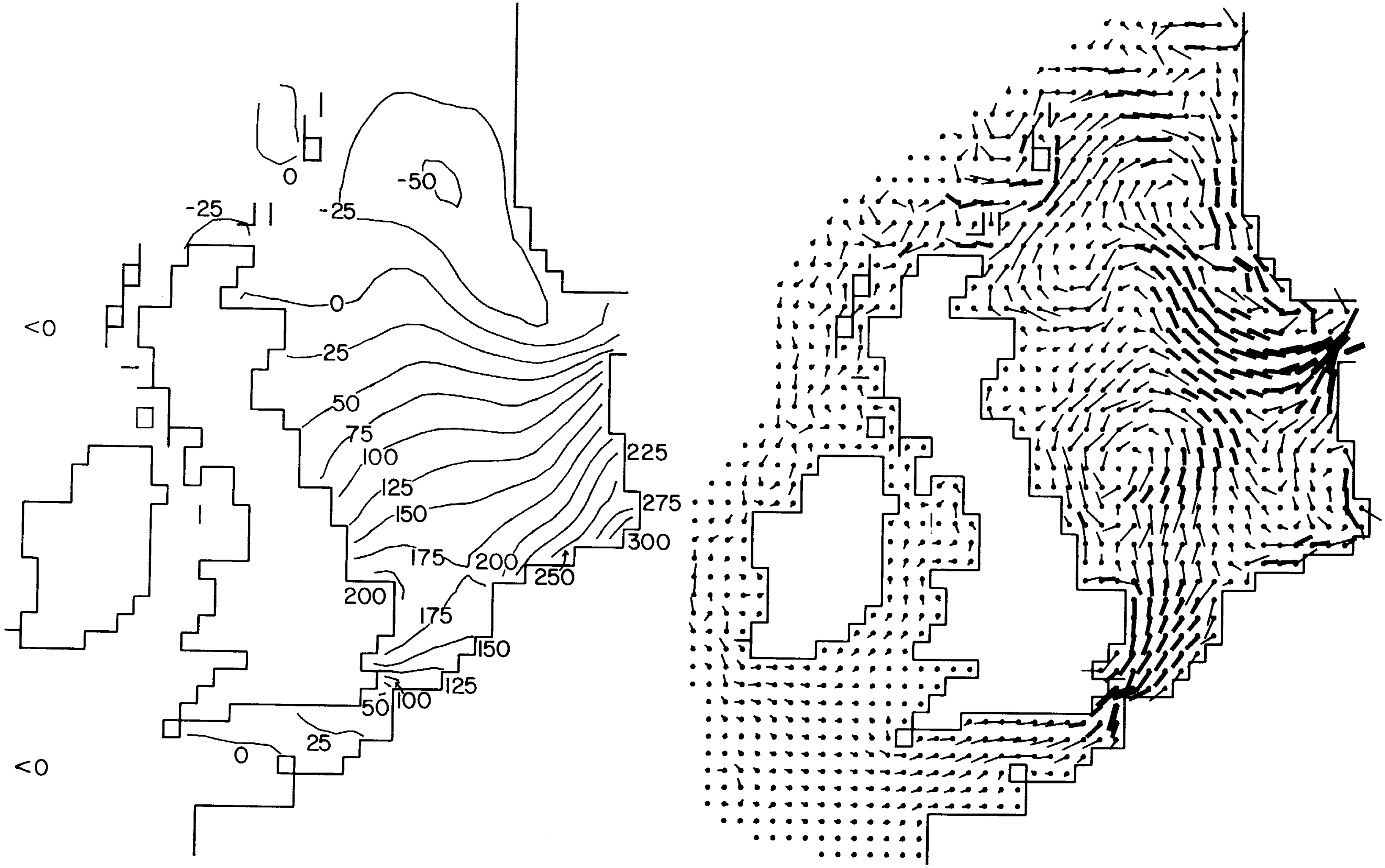

Figure 4: c) 1200 GMT forecast on 19/11/73, available at ~ 1800 GMT 19/11/73

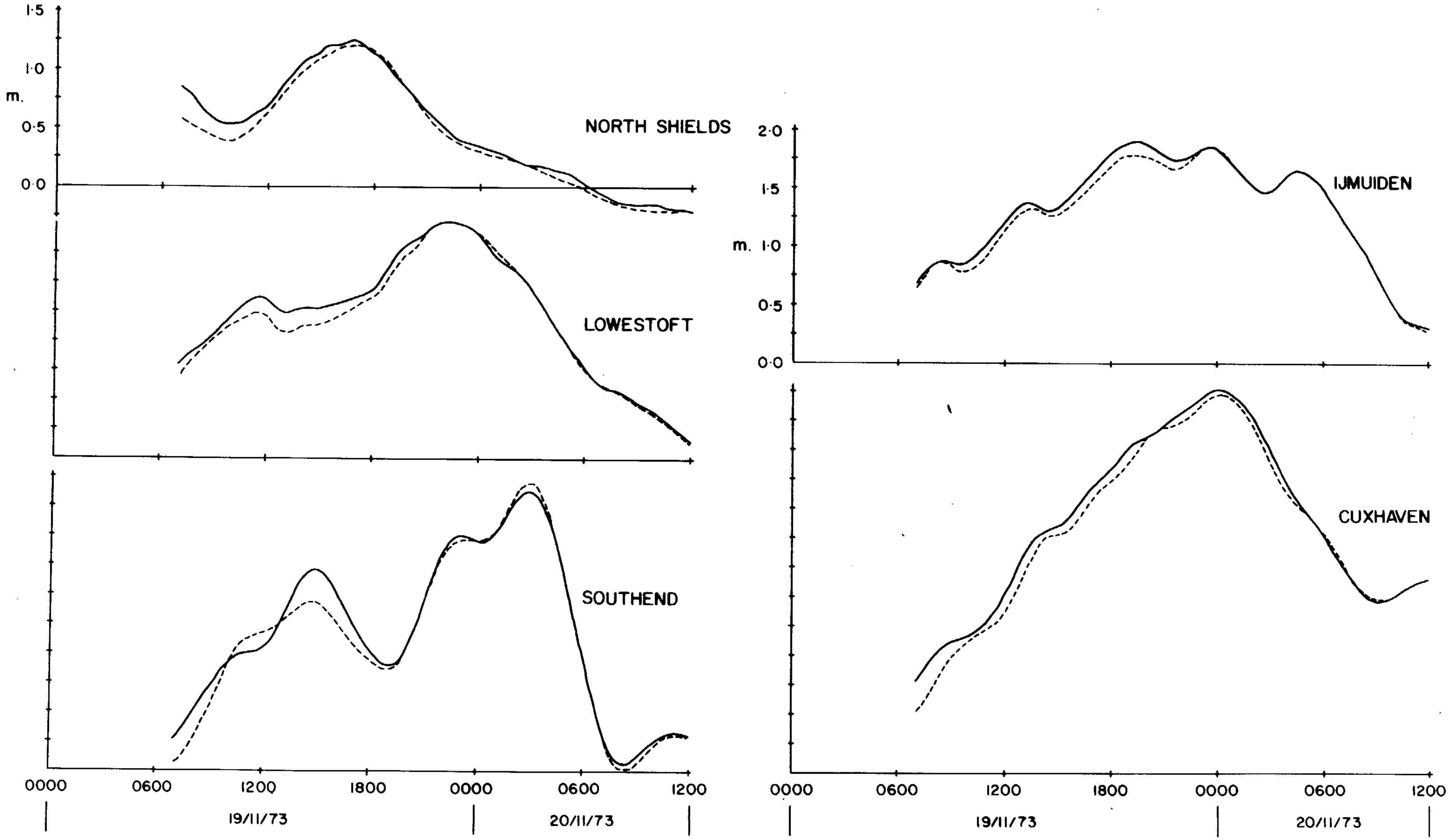

Figure 5: The effect of missing the preceding forecast on the prediction beginning at 0700 19/11/73.
——— normal prediction ; -------- prediction assuming 1900 18/11/73 forecast not available

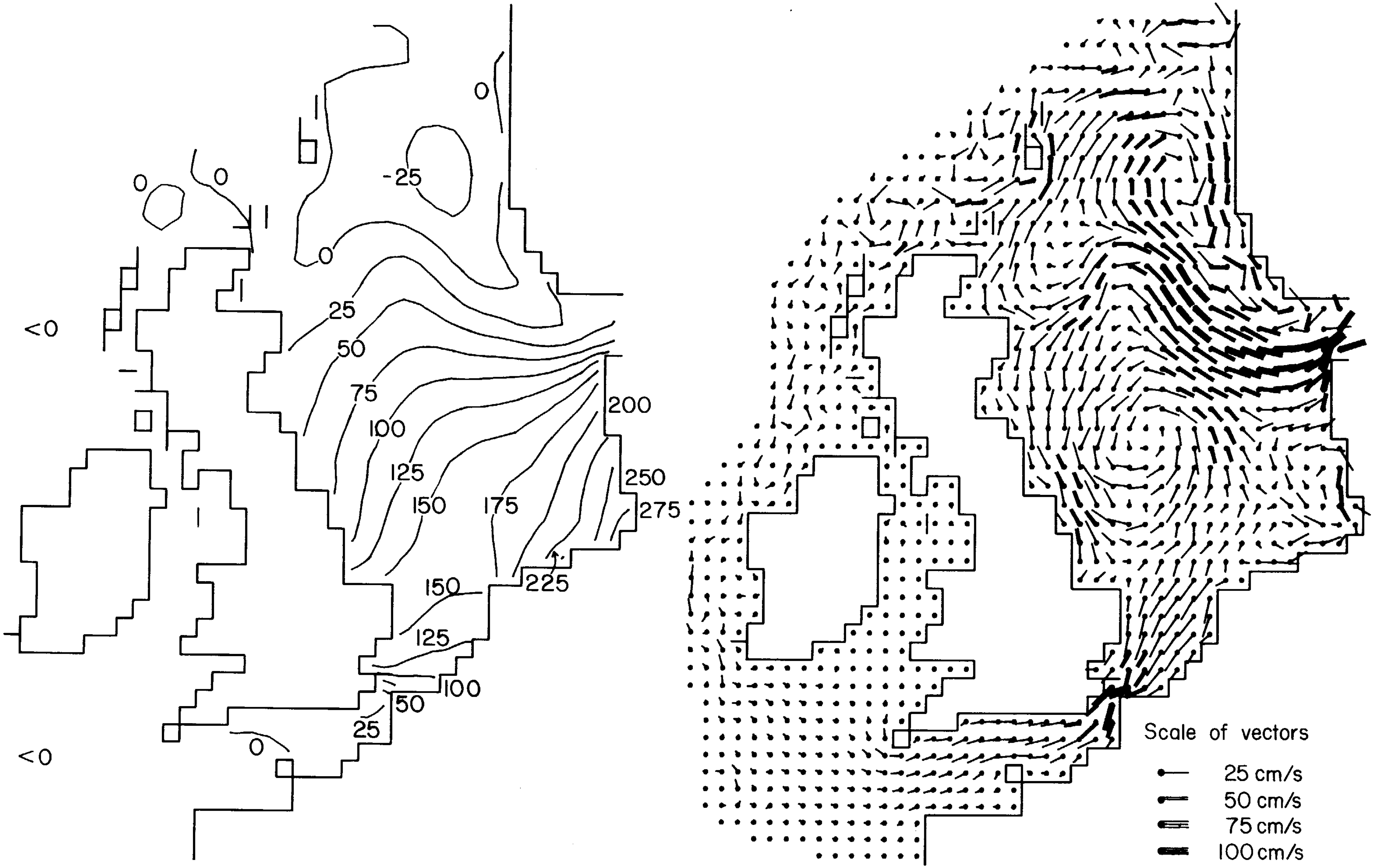

Figure 6 : Predicted spatial distribution of the surge at 2100 GMT 19/11/73 obtained from different forecasts assuming, in each case that the preceding forecast was not available.

a) 1200 GMT forecast on 18/11/73

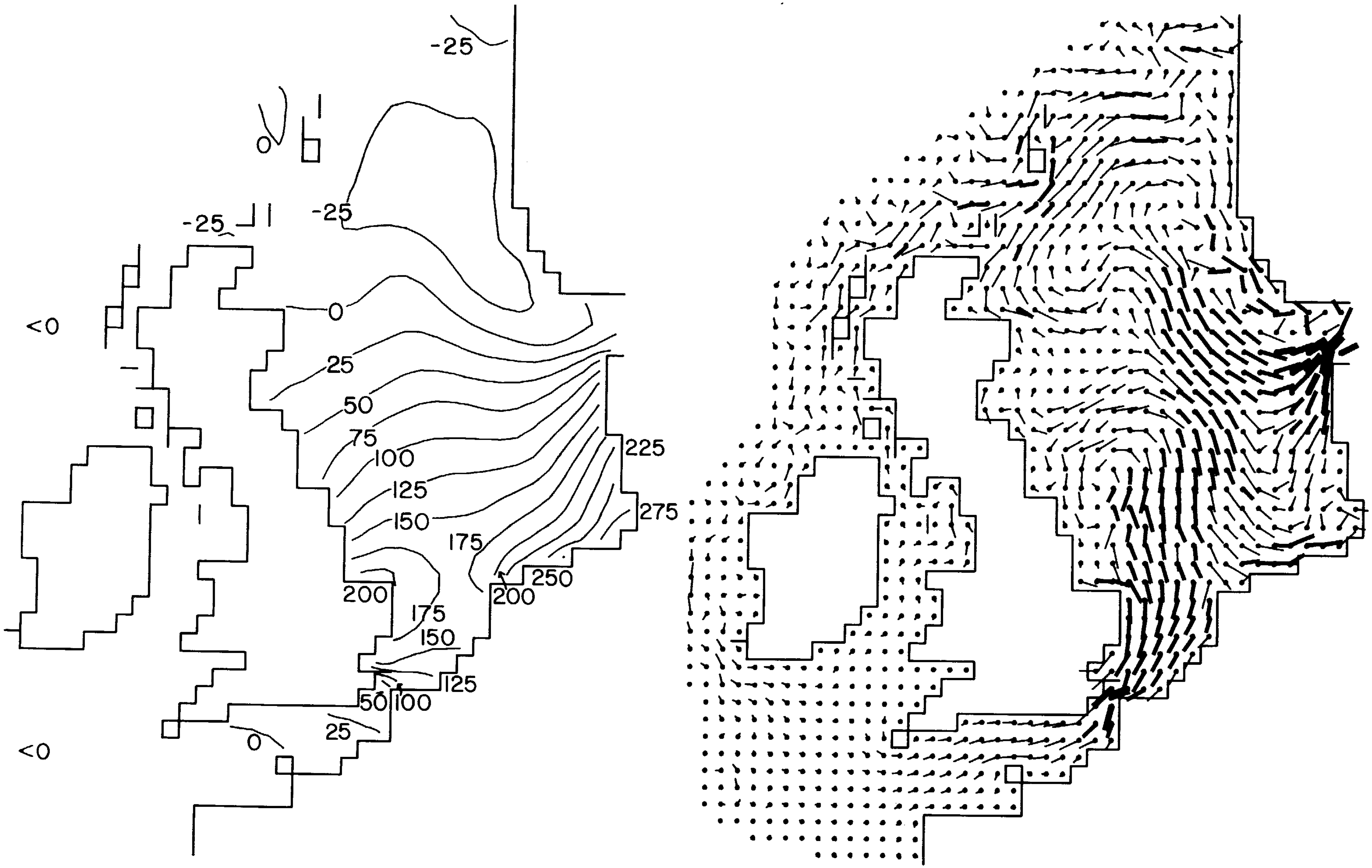

Figure 6: b) 0000 GMT forecast on 19/11/73

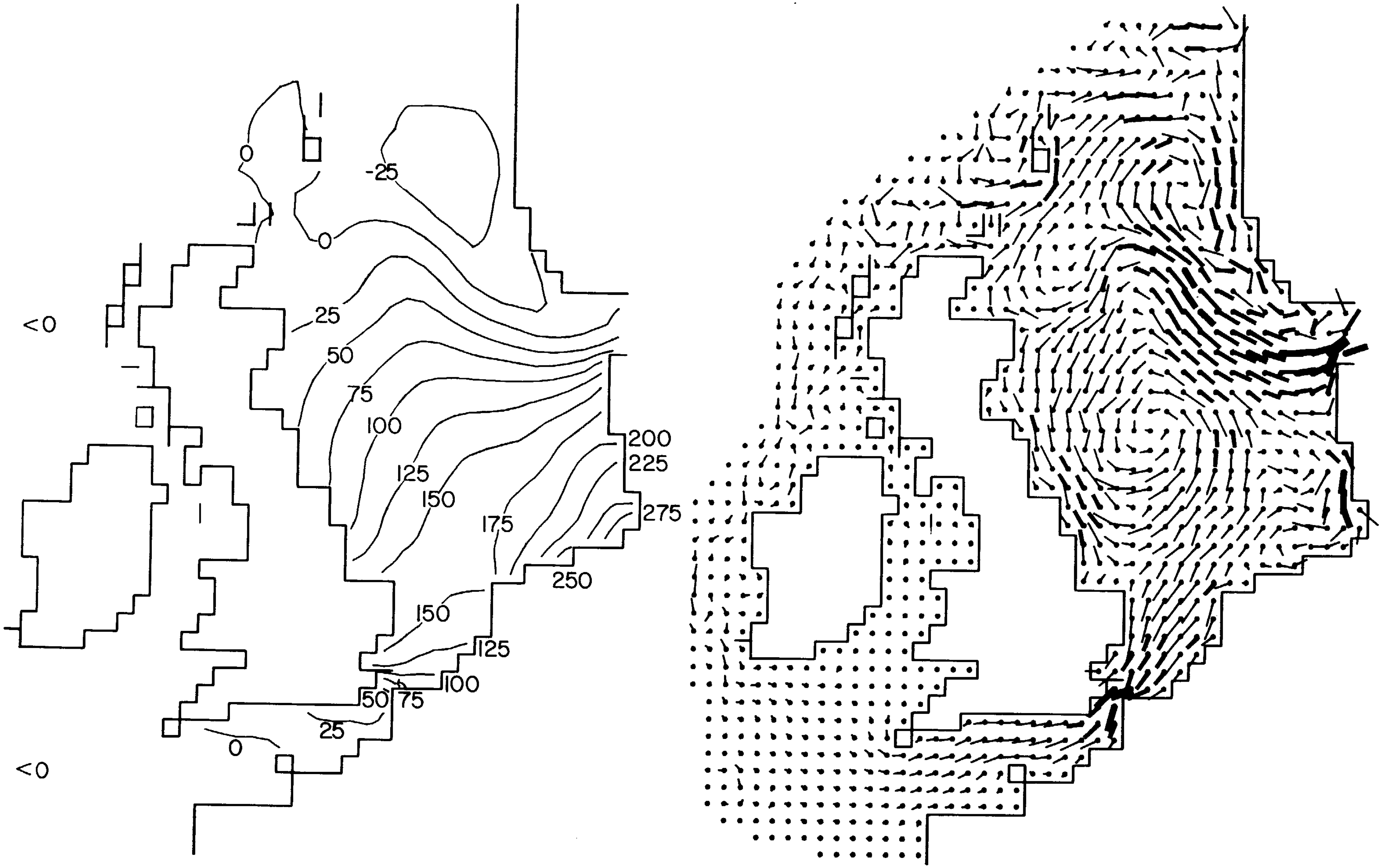

Figure 6: c) 1200 GMT forecast on 19/11/73