FILE

INTERNAL DOCUMENT 163

I.O.S.

THE WEST COAST SURGE PREDICTION EXPERIMENT 1981 - 82

by

R. A. Flather and R. Proctor

IOS Internal Document No. 163
May 1982

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Wormley, Godalming,
Surrey GU8 5UB
(042-879-4141)

(Director: Dr. A. S. Laughton, FRS)

Bidston Observatory,
Birkenhead,
Merseyside L43 7RA
(051-653-8633)
(Assistant Director: Dr. D. E. Cartwright)

Crossway,
Taunton,
Somerset TA1 2DW
(0823-86211)
(Assistant Director: M. J. Tucker)

THE WEST COAST SURGE PREDICTION
EXPERIMENT 1981 - 82

by

R. A. Flather and R. Proctor

IOS Internal Document No. 163
May 1982

This report contributes to a project on the numerical prediction of west coast storm surges funded by the Ministry of Agriculture Fisheries and Food

Contents

1. Introduction

2. The operation of the scheme

3. The observational data set

4. Evaluation of the models

5. Conclusions and recommendations

1. INTRODUCTION

A scheme for storm surge prediction, developed at I.O.S., and based on numerical models of the atmosphere and of the sea has operated at the Meteorological Office during each winter season (September to April) since 1978-79. The original system (FLATHER 1979) was based on a sea model (CSM shown in Figure 1) covering the whole of the continental shelf and employed forecast wind and pressure data extracted from the fine - mesh 10 - level atmospheric model (grid points of which are also shown in Figure 1) run by the Meteorological Office.

Although it was originally intended only to provide basic information for the North Sea (later to be improved upon by results from additional models), the demand for surge forecasts for the West Coast, following storms and floods in 1976 and 1977, led to the establishment of an embryo West Coast Storm Tide Warning Service. Surge forecast information from the CSM for west coast ports was transmitted from the Storm Tide Warning Service (STWS) at Bracknell to the five Water Authorities with responsibilities for coastal protection, and, with the addition of warnings of potentially dangerous weather events as identified by LENNON (1963) from local Met. Offices, real - time measurements from water level recorders operated by the individual water authorities, and tidal predictions provided by I.O.S., has been used to activate the procedures for dealing with coastal flooding.

For North Sea surges, the CSM has been found to provide a useful supplement to the statistically based methods previously in use at STWS. For west coast surges, although some events have been well predicted, others certainly have not, and the general quality of the forecasts has not been satisfactory. Some poor forecasts were caused by inaccurate atmospheric model predictions - the wind and atmospheric pressure data determine to a very large extent the accuracy of the surge results - but it was felt that the poor resolution of important shallow areas of the west coast, such as the Bristol Channel and Morecambe Bay, provided by the CSM was also a significant factor. These considerations led, in the summer of 1979, to the proposal that a second 'West Coast' model (WCM shown in Figure 2), covering the Irish Sea and Bristol Channel with a grid 1/3 the size of the CSM, be introduced. The WCM was intended to run together with the CSM, taking the storm surge input along its open boundaries in the Celtic Sea and to the west of Scotland from the CSM forecasts, but giving improved predictions of the internally generated surge contribution and the important shallow - water interaction between surge and tide.

In the event, the financial constraints prevented the operational use of the WCM for the next two seasons, during which time the CSM continued to be used. Development work proceeded, leading to a modified operational system making use of meteorological observations to improve the accuracy of the surge forecasts (Figure 3) and to the establishment of a 'family' of sea models (Figure 4) giving increasing resolution of important shallow areas (FLATHER 1981).

In the summer of 1981 it was agreed that an operational test of the WCM be carried out over the period December 1981 to March 1982. The new operational system was introduced, and at the same time changes required to permit the running of additional models were incorporated. Minor changes were also made to the original WCM to improve the timing of tidal high water in the Bristol Channel and Morecambe Bay. The aim of the experiment was to evaluate the surge forecasts produced by the WCM by comparing them with the CSM forecasts and with observations. This report describes these comparisons and makes recommendations as to the requirements for improved predictions of west coast surges in the future.

2. THE OPERATION OF THE SCHEME

The new scheme of operation, shown in Figure 3b, was introduced before the 1981-82 season started. Both the CSM and the WCM were run under this new scheme. The individual steps in the procedure are as follows:

(i) Check the initial data time (IDT) of the new atmospheric model forecast against the last sea model data and set up the correct initial conditions and control data for the rest of the procedure accordingly.

(ii) For CSM :-
Process analysed and forecast wind and pressure fields covering the period -12 to +36 hours relative to IDT. Store the computed wind stress, pressure gradient and

open boundary surge input.

For WCM :-

a) Extract wind stress and pressure gradients from data stored for the CSM and assign to appropriate WCM grid points.

b) Extract surge elevation and current input from data arrays of CSM surge residuals and interpolate to WCM open boundary points.

(iii) Run the sea model to compute tide and surge together for -12 to +36 hours and store the results.

(iv) Run the sea model to compute the tide alone for the required period as determined in (i), normally +24 to +36 hours relative to IDT. Store the results.

(v) Merge the newly computed table of tide data for standard ports with the table saved from the previous forecast as required to give the output table covering -12 to +36 hours relative to IDT.

(vi) As for (v) but with model arrays of tidal elevation and current components instead of tables.

(vii) Subtract tide arrays and table from tide + surge arrays and table to give storm surge residuals and store the results. Print the surge table for STWS.

The complete procedure is run twice; first for the CSM, then for the WCM. The alternative for the WCM in part a) of step (ii) was introduced to save computer time.

Arrangements were made with the Meteorological Office to accumulate standard port data from both models in computer files. These files were accessed typically twice each week from I.O.S., the data they contained being transferred along a link using G.P.O. telephone lines to the computer at Bidston. After the first attempt, when some forecast information was lost, this data retrieval system worked satisfactorily.

Overall, the system proved to be quite reliable. Initial teething troubles associated with the installation of the WCM caused the morning forecast on 3rd December not to run. The WCM forecasts on the afternoon of 13th and the morning of 14th December were not run because power cuts caused by blizzards over the south of England affected the Met. Office computers. The CSM continued to operate and the WCM restarted with the afternoon forecast on 14th December.

Large oscillations in the surge residuals produced by the WCM in the North Channel of the Irish Sea were noticed after Christmas, and attempts were made to discover the cause. Before this could be done the oscillations were removed when the complete system re-started on the morning of New Years' Day. The re-start was caused by the failure of the initialisation procedure, step (i) described above, to recognise -12 hours relative to IDT 0000GMT on 1/1/82 as identical to 1200GMT on 31/12/81.

A computer breakdown at the Met. Office led to the loss of six successive forecasts on 28th, 29th and 30th January 1982, the longest interruption to have occurred in four seasons operation. Both models restarted with the morning forecast on 31st January.

In the course of investigating the Bristol Channel flooding of 13th December, an error was discovered affecting the atmospheric pressure distributions provided by the Met. Office for use in the surge hindcasts. This error, discovered in early February 1982 and present since the season started, will have affected all the model results up to that time, countering to some extent the improvement in accuracy hoped for as a result of adopting the new system of operation.

During spring tide conditions in the last week of February, the oscillations in surge residuals at Larne and Portpatrick on opposite sides of the North Channel reappeared in the WCM. Investigations revealed that they were associated with spatial oscillations of grid scale, suggesting that they were the result of a local instability. The fact that the deepest part of the WCM occurs in the North Channel and that the effect appeared during spring tide conditions when the water depths are greatest supports this. Consequently the timestep used in the WCM solution was reduced from 180 seconds, the value used in the CSM, to 150 seconds. Over the following few days the oscillations decreased in amplitude and disappeared, indicating that instability was indeed the likely cause, the cure being a small reduction in timestep.

The remaining period of the experiment passed without further interruption, the final WCM forecast being run on the morning of 30th March 1982.

3. THE OBSERVATIONAL DATA SET

Tide gauge records in the form of charts or digital data on paper or magnetic tape were received from the 21 sites listed in Table 1. Of these 11 belonged to the 'class A' tide gauge network and 2, those at Workington and Criccieth, were installed and maintained by I.O.S. for the purpose of the experiment.

The reduction of the data followed standard I.O.S. practice. Data on analogue charts were first digitised at hourly intervals, known errors being corrected wherever possible. Tidal predictions using the best available analyses were then carried out and the hourly values so obtained subtracted from the measured levels to give hourly values of the storm surge residual. These residuals were then examined critically for evidence of undetected errors, and whenever the source of these errors could be traced, they were corrected and fresh residuals derived. The process is subject to many possible errors, as discussed at length by FLATHER, DRAPER and PROCTOR (1982). Despite the great care and experience brought to bear on the problem, the resulting residuals should, therefore, be regarded as the best estimates possible with the information available. In some cases they are probably not very reliable.

With the available effort it was not possible to process all the data received. It was decided to concentrate on reducing data for the whole period from the gauges at Avonmouth and Heysham, key locations for surges on the west coast. Continuous data were also provided by the I.O.S. gauges at Criccieth and Workington and it subsequently became possible to produce almost continuous data for some other locations (see Table 1). The remaining effort was concentrated on reducing limited periods of data, typically of one or two weeks duration, covering periods of observed or forecast surge activity at as many ports as possible.

4. EVALUATION OF THE MODELS.

Since the aim of the experiment is the comparison of the sea models, it is desirable to examine the surges computed using the best available meteorological data. With this in view, the original intention was to take the hindcast surges produced by the two models for comparison purposes. However, the error in atmospheric pressure fields used for the hindcasts, mentioned earlier, introduces an uncertainty as to whether the meteorological data used in the hindcasts is in fact the most accurate. In the circumstances, it was decided to use forecast sea model data, hours 6 to 17 of each forecast being selected. Extracting 12 hours of data from the forecasts, produced twice each day, then gives continuous data coverage except, of course, when forecasts are lost.

For each of the 21 ports listed in Table 1, the forecast model data (hours 6 - 17) over the period 1 December 1981 to 30 March 1982 were extracted and plotted together with the available observations month by month. These plots are reproduced in Figures 5 to 25, giving a complete record of the performance of the two models. Nine of the ports, indicated in Table 1, are standard ports for both the CSM and the WCM. Newlyn is outside the WCM but gives a useful indication of the surges entering the WCM across its open boundary (as do St. Marys and Malin Head). Exceptionally, for Liverpool, data from the CSM grid element associated with Hilbre Island, which actually contains both tide gauges, are plotted with the WCM results and the observations. For the remaining ten ports WCM forecasts are compared with the observations.

In addition, results covering active surge periods at ports for which observations were available were plotted together. Figures 26 - 31 show the results, covering

(i) 11 - 14 December 1981 : the period of the Bristol Channel floods (Figure 26)

(ii) 18 - 21 December 1981 : the storm which caused the loss of the Penlee lifeboat (Figure 27)

(iii) 7 - 9 January 1982 : a negative surge in the eastern Irish Sea (Figure 28)

(iv) 6 - 13 February 1982 : containing three small positive surges in the Irish Sea (Figure 29)

(v) 28 February - 4 March 1982 : including two positive surges (Figure 30)

(vi) 11 - 13 March 1982 : large positive surge of short duration in Liverpool Bay (Figure 31)

Elementary statistical analyses were also carried out for ports with long time series of observations to determine an overall root - mean - square (RMS) error and coefficients in a linear regression between forecast and observed surges. The results are presented in Table 2.

As mentioned in the preceding section and discussed at length in FLATHER et. al. (1982), the observed residuals themselves should not necessarily be accepted as absolutely correct. An examination of the plotted observations reveals a number of questionable spans of data at several ports. In particular, tidal oscillations suddenly appear in previously smooth observed residuals at St. Marys (Figure 6) at 0900GMT on 14th December and at 1000GMT on 5th February. The first of these occasions corresponds to a chart change, suggesting that the new chart was perhaps not correctly located on the drum. In the two days preceding 5th February the pen was giving problems, providing a very faint trace on the chart. This problem was corrected and a strong line restored at 0930GMT on 5th February, immediately before the start of the second period of suspect data, suggesting that the corrective action introduced some error into the record. The large semi - diurnal oscillations at Ilfracombe (Figure 7) and peculiarities in the residuals at other shallow water ports in the Bristol Channel are thought to be due to poor or inadequate tidal predictions (see FLATHER et. al. 1982). Despite its location in Morecambe Bay, where a genuine tidal signal might be expected to occur due to shallow - water tide - surge interaction, the observed residuals at Heysham (Figure 18) are relatively free of such features except during the second week in December 1981. Examination of the corresponding chart showed a gap, at its worst exeeding 15 minutes, between 2400GMT and 0000GMT indicating that the chart had not been correctly located on the drum. The timing errors so introduced probably caused the oscillatory residuals. The large negative spikes on the Malin Head residuals (Figure 23) are thought to have been caused by an unknown gauge fault which led to tidal curves of peculiar shape during some periods.

Some aspects of the model results also require qualificaton. In particular, sharp changes in computed residuals occuring between 0500GMT and 0600GMT or 1700GMT and 1800GMT can be seen at many locations. A clear example occurs at Hilbre Island between 1700GMT and 1800GMT on 15th March (Figure 16). These are associated with the fact that the model data are extracted from separate forecasts such that there will, in general, be a discontinuity from one forecast to the next. Indeed a large jump at these times indicates that a substantial correction has been introduced in the intervening hindcast : the discontinuity should bring the computed surge into better agreement with the observations. The oscillations caused by the local instability of the WCM in the North Channel of the Irish Sea can be seen clearly at Portpatrick (Figure 21).

The season turned out to be quite an eventful one. Less than two weeks after the experiment started, flooding occured in the Bristol Channel on the evening of 13 December. Disappointingly, the models failed to predict the surge which approached 2m in magnitude (see Figure 26) probably to a large extent because of poor atmospheric model forecasts. The event is discussed in detail in FLATHER et. al. 1982. Less than a week later, on 19 December, the storm which caused the loss of the Penlee lifeboat produced a surge in excess of 1m in the Irish Sea which was well predicted by the models (Figure 27). January was a relatively quiet month with the only event, a negative surge on the 8th of 0.5m, being better predicted by the WCM in the eastern Irish Sea (Figure 28). A positive surge on 12 February (Figure 29) was reasonably well forecast with some tendency to overprediction. A surge on 2 and 3 March (Figure 30) was well predicted in the Irish Sea but not in the Bristol Channel. A substantial surge of short duration on 12 March in the eastern Irish Sea was badly underpredicted by the models (Figure 31).

Differences between the surges forecast by the two models can be expected to occur only during periods of surge activity, since only a differing response to local forcing or a different representation of shallow - water processes resulting from the higher resolution of the WCM can lead to surge residuals which deviate from those in the CSM. Examining Figures 5 - 25, this anticipated pattern of behaviour can be seen to have occured, with the model results being practically identical at most ports during periods of low surge activity.

A clear distinction can be seen in both the model forecasts and the observed surge behaviour between 'deep water' ports, such as Newlyn, Milford Haven, Holyhead and Portpatrick, and 'shallow water' ports, such as Avonmouth, Swansea, Hilbre Island and Heysham.

At deep water ports, the surges are characterised by smooth variations in time. Both models appear to be capable of reproducing the observed surges reasonably well. Differences between the model forecasts are not large, typically of order 10 to 20cm at most. Such differences as do occur between the model forecasts tend to be smaller than the discrepancies between either model and the observations. This suggests that no significant benefit is gained for these locations from the higher resolution of the WCM. The errors at deep water ports are most probably associated with either inaccuracies in the meteorological data or failure to represent properly surges generated off the shelf, problems which cannot be alleviated by the use of the WCM (unless it were practicable to introduce observed surge data in real time on its open boundaries to correct the surge entering from the CSM; see FLATHER and PROCTOR, 1982 for a description of how this might be achieved). Improvements in these aspects might result from the introduction of the new atmospheric model at the Met. Office next season, from a revision of the open boundary condition used in the CSM or possibly an extension of the CSM to include off-shelf areas.

At shallow water ports, the surges are much less smooth, with spikes, oscillations and other features related to the tidal period appearing in the observations, the WCM forecasts and, to a lesser extent, in the

CSM forecasts. The reliability of the residuals derived from observations at a few of these ports is questionable because of problems of measurement, tidal analysis and prediction, as mentioned earlier. In general, neither model appears capable of reproducing the details of the observations. Where the observations are reliable, it appears that some processes are not being represented properly in the models (for example, drying, local met. forcing, or shallow water interaction) or are simply not taken into account (e.g. set up due to surface waves). There are periods at some ports (e.g. the last three days in December 1981 at Avonmouth) when the WCM appears to simulate the observed behaviour quite well, but this is not the case overall. Quite large differences occur between the results from the two models, frequently of order 0.5m. However, the WCM surges in shallow water appear to be strongly influenced by drying, and despite its improved resolution compared with the CSM, this process is probably not simulated with sufficient accuracy. (There are, of course, fundamental problems of definition of surge residuals at points which dry out at low water, and it may not be realistic to attempt to predict residuals at such points). For shallow water ports there remains a problem. To achieve further progress, there is a requirement for improved observations, especially in the Bristol Channel, combined with better methods of analysis and tidal prediction such that reliable surge residuals can be derived. It may then be possible to identify with certainty the main sources of error. Further development of the surge modelling should then follow, probably involving the use of high resolution local models and improvements in the representation of shallow - water processes within them.

5. CONCLUSIONS AND RECOMMENDATIONS

The experiment has demonstrated that it is feasible to run more than one model within the operational system. Although for some places and for some events the WCM gives better results than the CSM, overall the WCM does not materially improve on the accuracy achieved by the CSM under the present scheme.

At deep water ports, the CSM and WCM give very similar results, differences between them being less than 30cm, with reasonably good agreement with the observations. The limitations on accuracy here are probably related to the meteorological forcing and to a lesser extent to the inclusion of externally generated surge effects. When these aspects have been improved, differences of the magnitude obtained between the CSM and WCM forecasts may become significant.

At shallow water ports, there are many uncertainties. Differences between the two models are greater, up to 50cm at times, due substantially to the effect of drying in the WCM. Yet the WCM does not have high enough resolution to simulate accurately this and other shallow-water processes. The result is that neither model agrees very well with the observations, which are also of doubtful accuracy in some instances. A priority here should be to provide the capability of measuring the surges accurately and consistently. This requires improved tide gauge installations and better methods of tidal analysis and prediction. Local surge generation can be of great importance as, for example, in the case of the Bristol Channel floods. The use of high resolution local models such as BCM and LBM should help to improve the reproduction of local generation, drying and tide-surge interaction.

In the immediate future, extensive changes must take place in order that a model based surge forecasting system can operate on the new computer at the Meteorological Office. These changes may extend to the sea model or models to be run for the 1982-83 season. Depending on the efficiency of the new computer programs, it may be possible to operate more than one sea model within existing financial constraints. In view of the results and conclusions presented above, the basic sea model must be of similar resolution to the CSM, possibly covering an increased area extending beyond the shelf edge. If it should prove possible to run additional models then they should be high resolution local models similar to BCM or LBM covering the most important shallow-water areas.

ACKNOWLEDGEMENTS

The authors are indebted to a number of authorities for the supply of tidal records and to the Meteorological Office for their continuing co-operation.

The tide gauge installations at Criccieth and Workington were the responsibility of D. L. Leighton.

Special thanks for their efforts in reducing the tide gauge records are extended to Mrs. Sheila Shaw, Mrs. Rose Maher, Mrs. Joyce Richards and Mrs. Margaret Davies.

Thanks are also due to R. A. Smith for preparing some of the diagrams.

The work was funded by the Ministry of Agriculture, Fisheries and Food.

REFERENCES

FLATHER, R.A., 1979. Recent results from a storm surge prediction scheme for the North Sea. pp. 385-409 in Marine Forecasting, Proceedings of the 10th Liege Colloquium on Ocean Hydrodynamics. (Ed. J.C.J. Nihoul). Elsevier (Oceanography Series, 25).

FLATHER, R.A., 1981. Practical surge prediction using numerical models. pp. 21-43 in Floods due to High Winds and Tides, (Ed. D.H. Peregrine). Academic Press (The Institute of Mathematics and its Applications, Conference Series).

FLATHER, R.A. and PROCTOR, R., 1982. Prediction of North Sea storm surges using numerical models: recent developments in the U.K.. Proceedings of the Symposium on North Sea Dynamics, Hamburg, 31 August - 4 September 1981. Springer - Verlag. (In press).

FLATHER, R.A., DRAPER, L. and PROCTOR, R., 1982. Coastal Flooding in the Bristol Channel and Severn Estuary on 13th December 1981. I.O.S. Internal Document No.162. (unpublished manuscript)

LENNON, G.W., 1963. The identification of weather conditions associated with the generation of major storm surges on the west coast of the British Isles. Q. J. R. met. Soc., 89, 381-394.

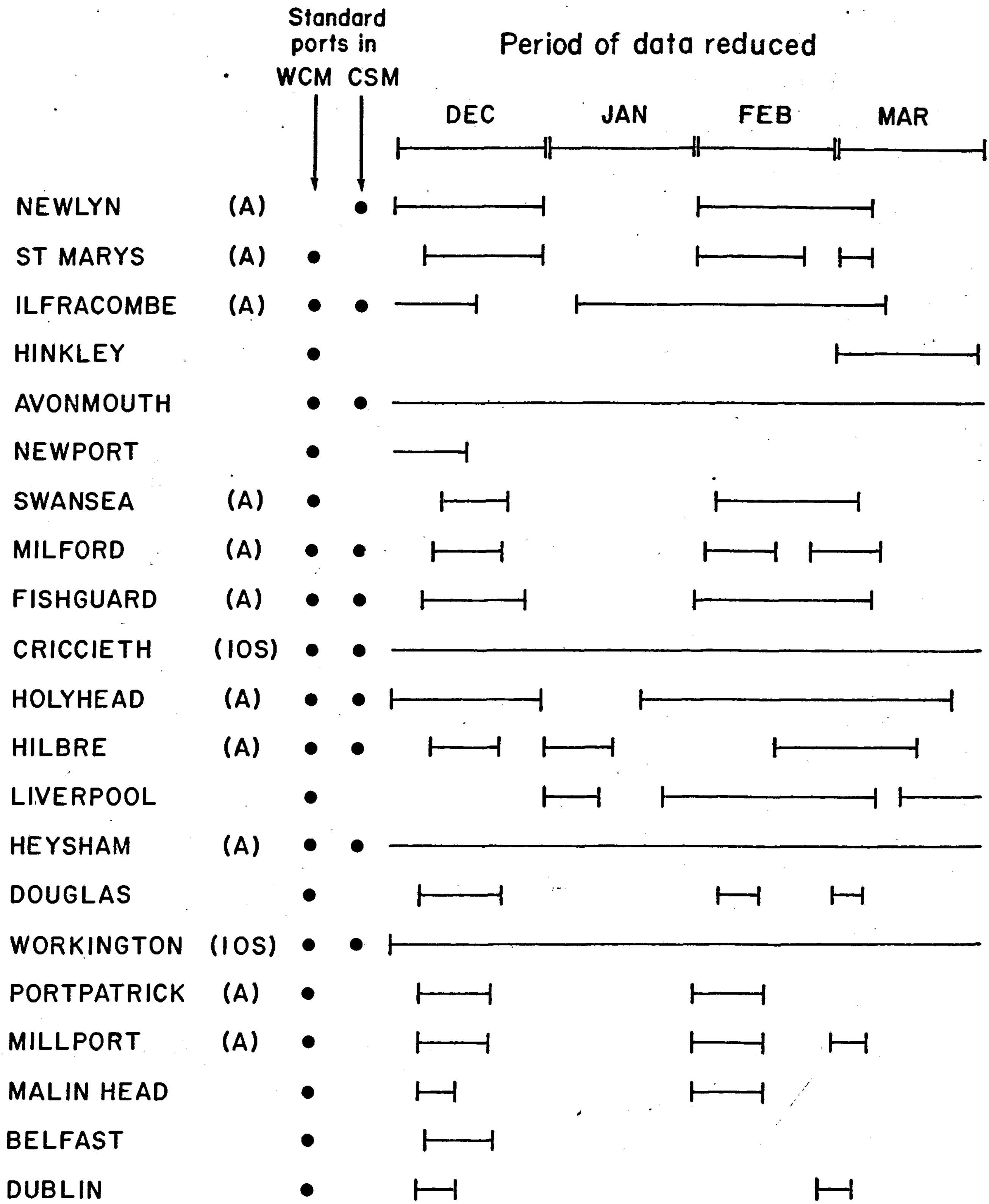


Table 1: Tide gauges from which records were received and periods for which surge residuals were derived. (A) indicates that a gauge belongs to the 'class A' network and (IOS) the gauges installed by I.O.S. for the experiment.

a) CSM

	Number of hourly values	R.M.S error (cm)	c_1	c_0 (cm)
Avonmouth	2743	29.6	0.88	-2.6
Criccieth	2754	14.5	0.85	-4.7
Holyhead	2076	10.9	0.95	-0.4
Heysham	2754	18.9	0.85	-3.0
Workington	2754	15.9	0.98	-1.6

b) WCM

Avonmouth	2700	30.7	0.72	-1.8
Criccieth	2700	15.1	0.79	-5.2
Holyhead	2052	11.2	0.88	-1.0
Heysham	2700	20.6	0.71	-2.6
Workington	2700	15.9	0.92	-1.6

Table 2: Root mean square errors (cm) and coefficients c_1 and c_0 (cm) in the linear regression equation ζ (observed) $= c_1 \zeta$(predicted) $+ c_0$ based on hourly comparisons between a) CSM and observed surge residuals, and b) WCM and observations.

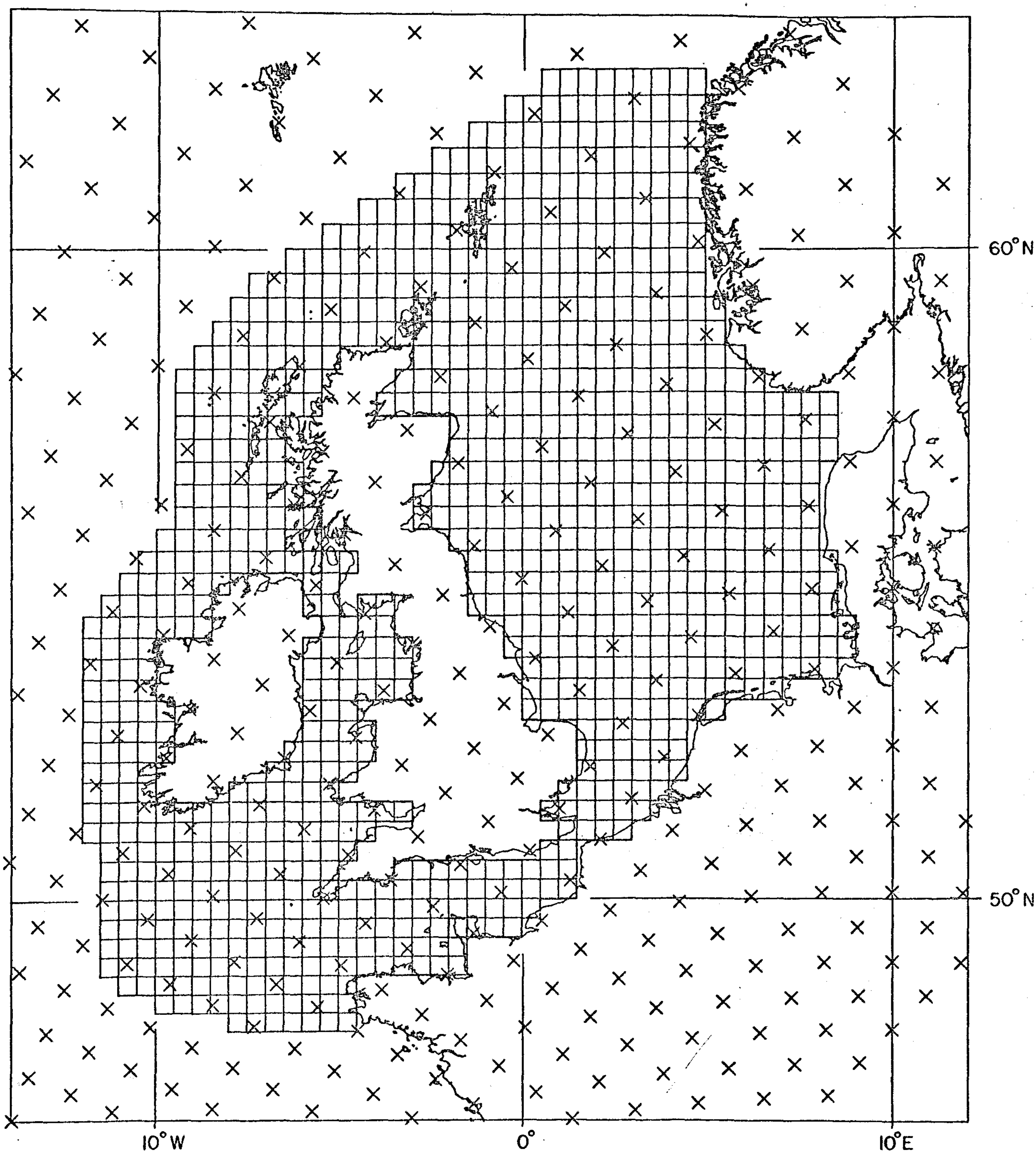


Figure 1: The continental shelf sea model (CSM) used as the basis for surge forecasts, with grid points (X) of the Met. Office's 10-level weather prediction model which supplies the required forecast winds and atmospheric pressures.

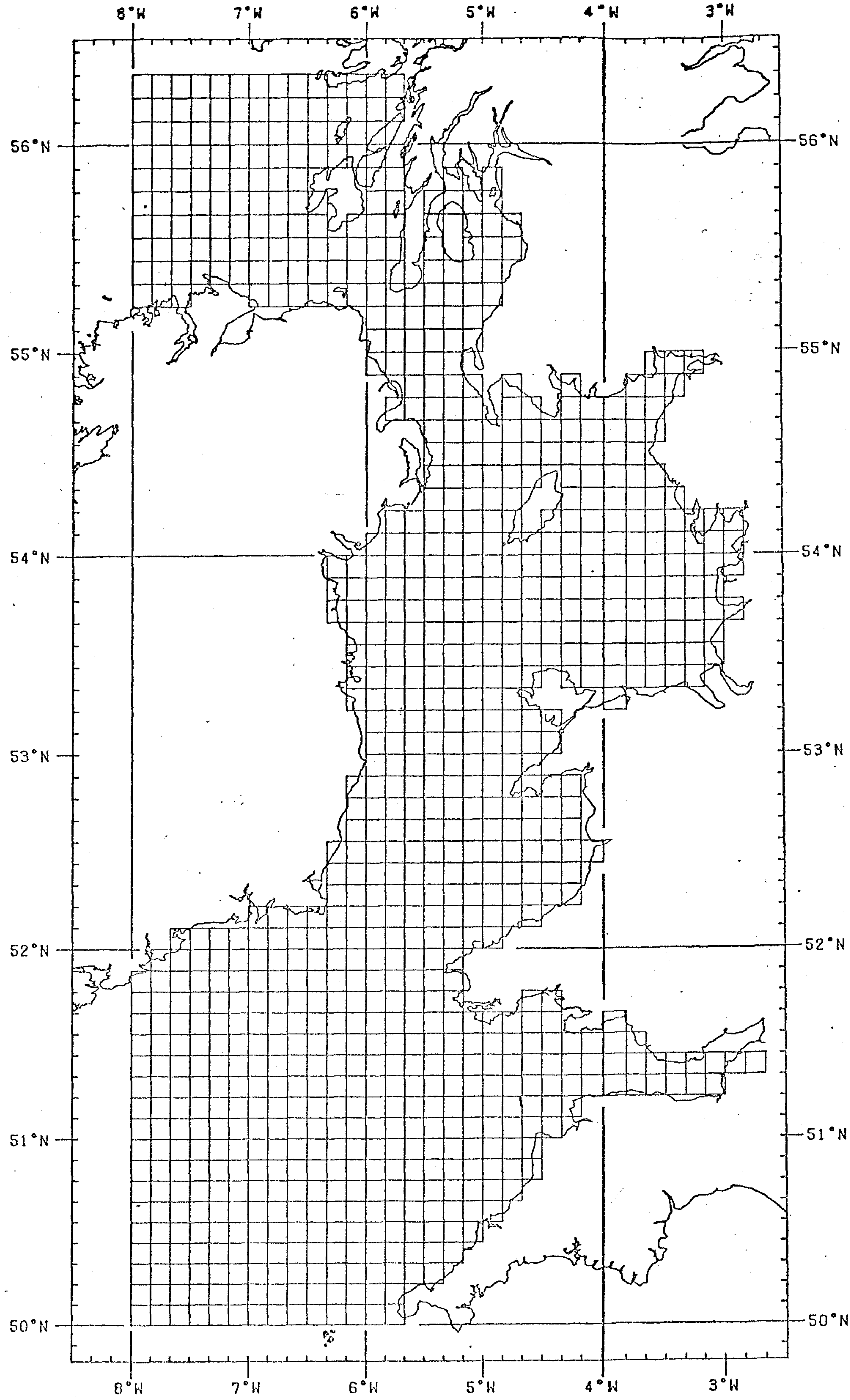


Figure 2: The experimental west coast sea model (WCM) under operational testing during the period December 1981 to March 1982.

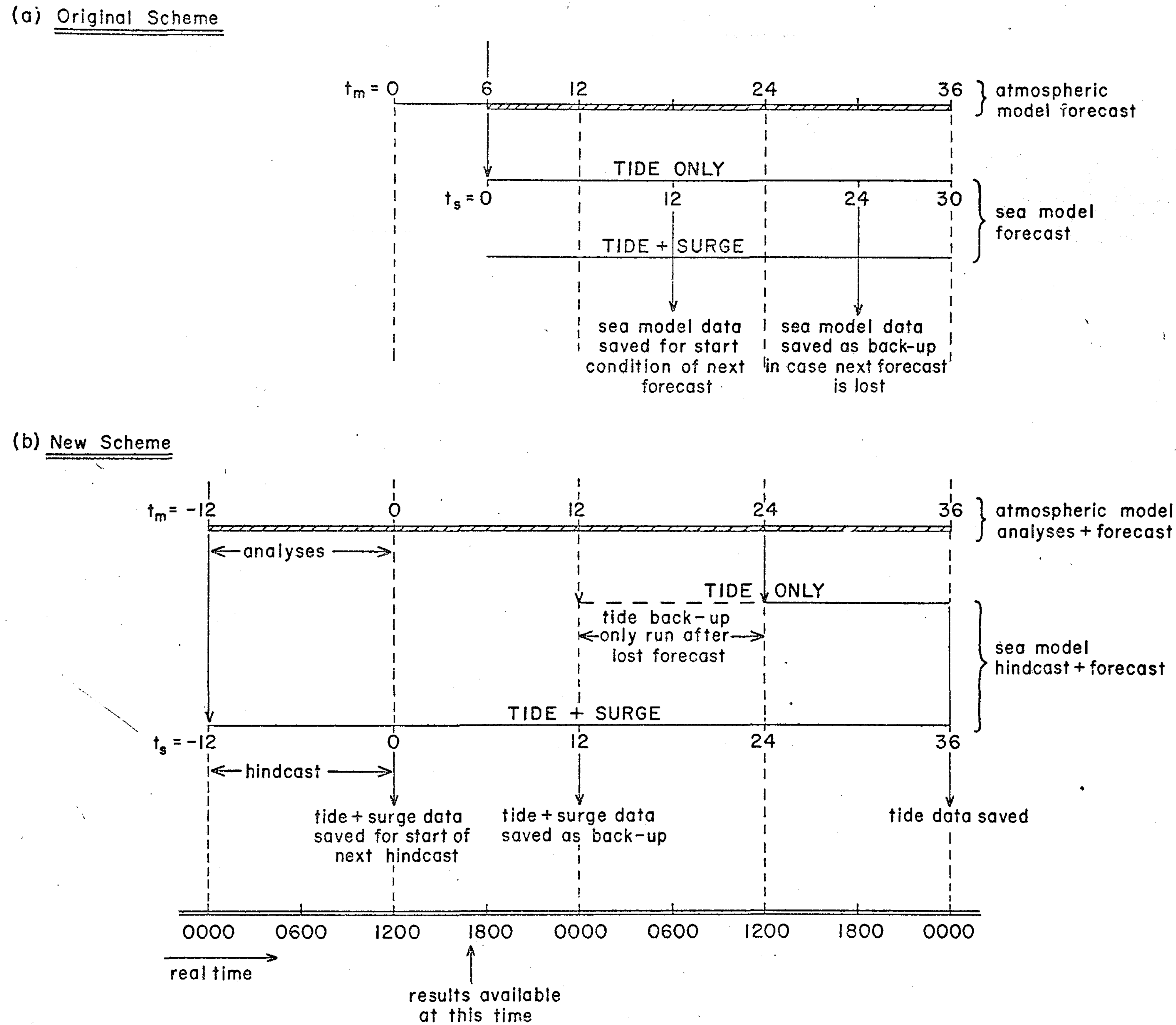


Figure 3: The original surge prediction scheme used from 1978 to 1981 and the new scheme introduced before the 1981-82 season.

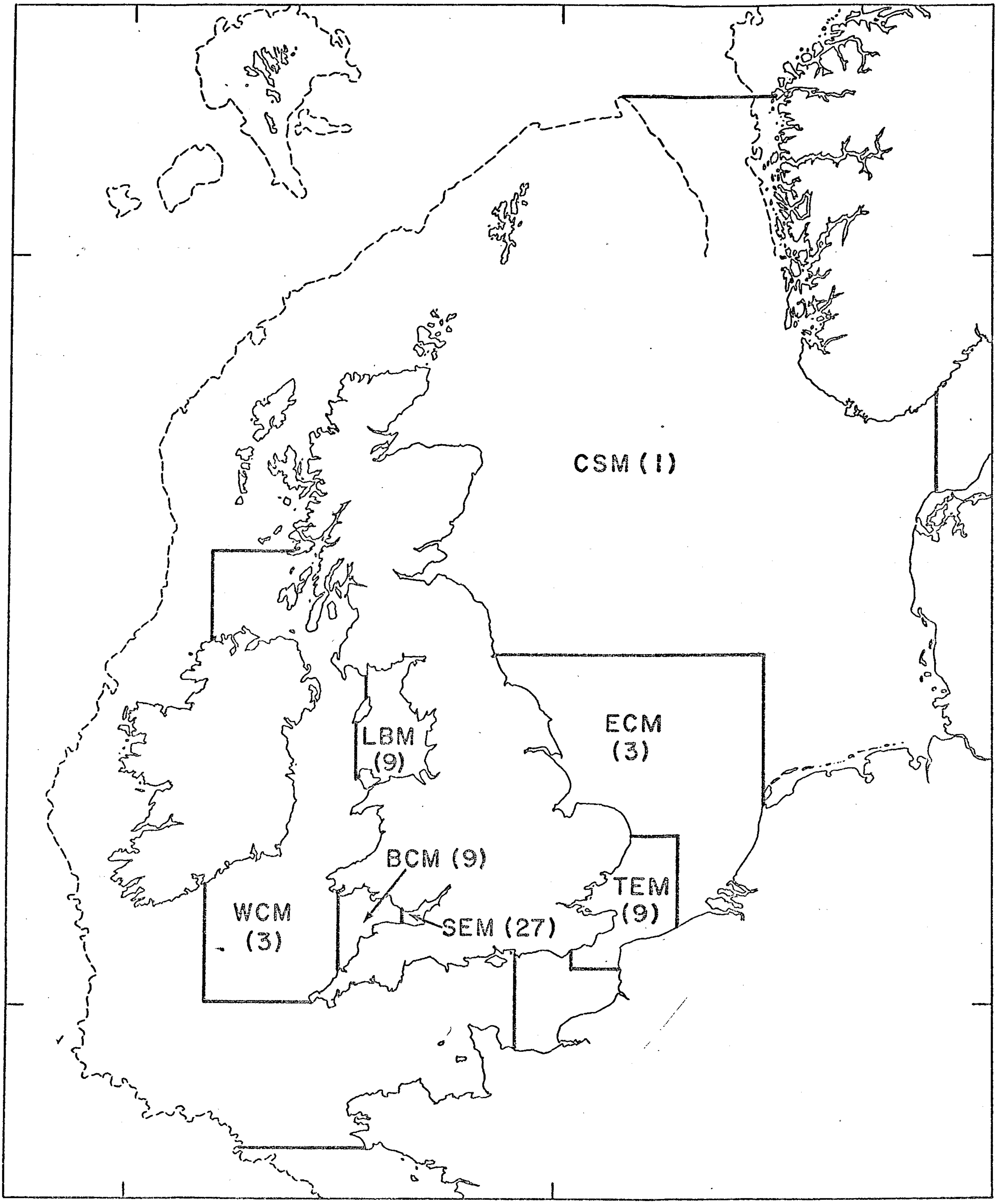
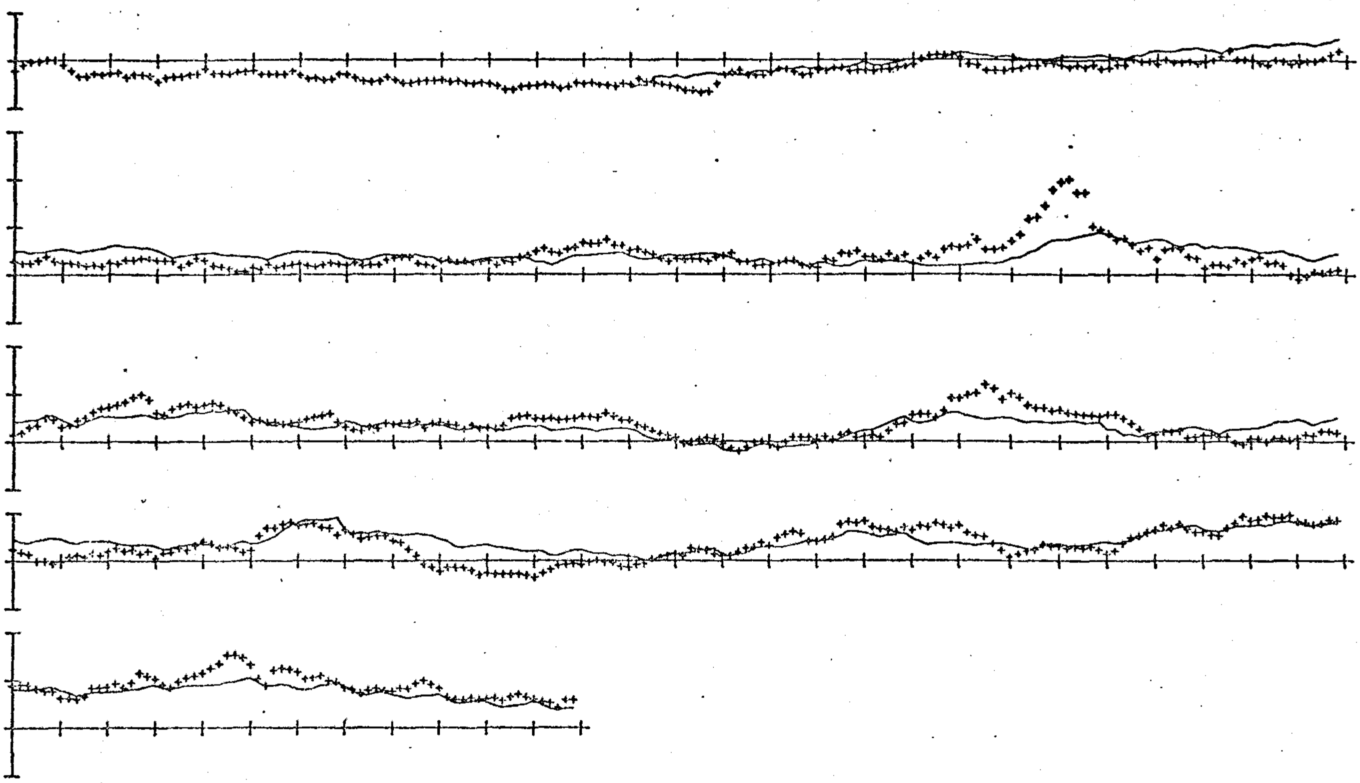


Figure 4: Proposed system of nested sea models for surge prediction with resolution factors, where for model X, the resolution factor is (grid size of CSM)/(grid size of X).

December 1981



January 1982

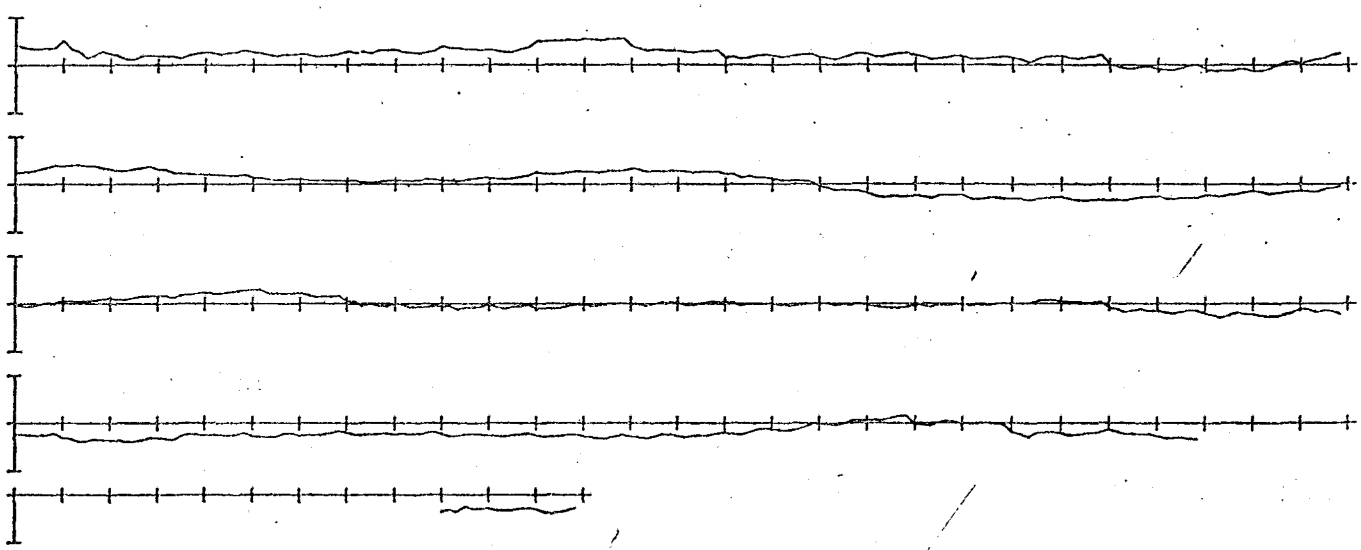
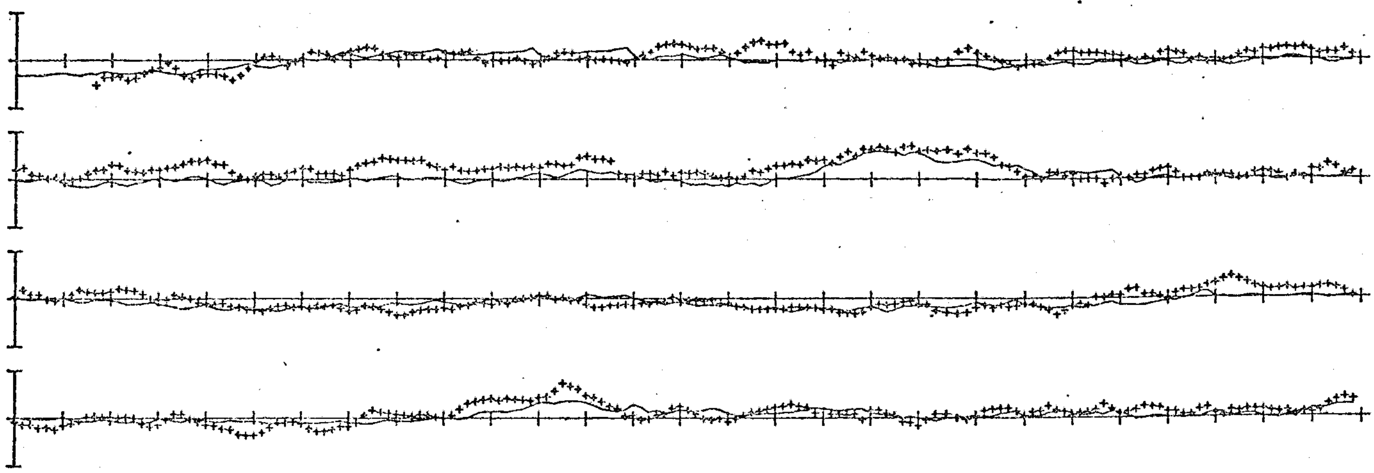


Figure 5 : Comparison of observed and computed surges at Newlyn
(+ + +) observations, continuous line CSM, no WCM data.
Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

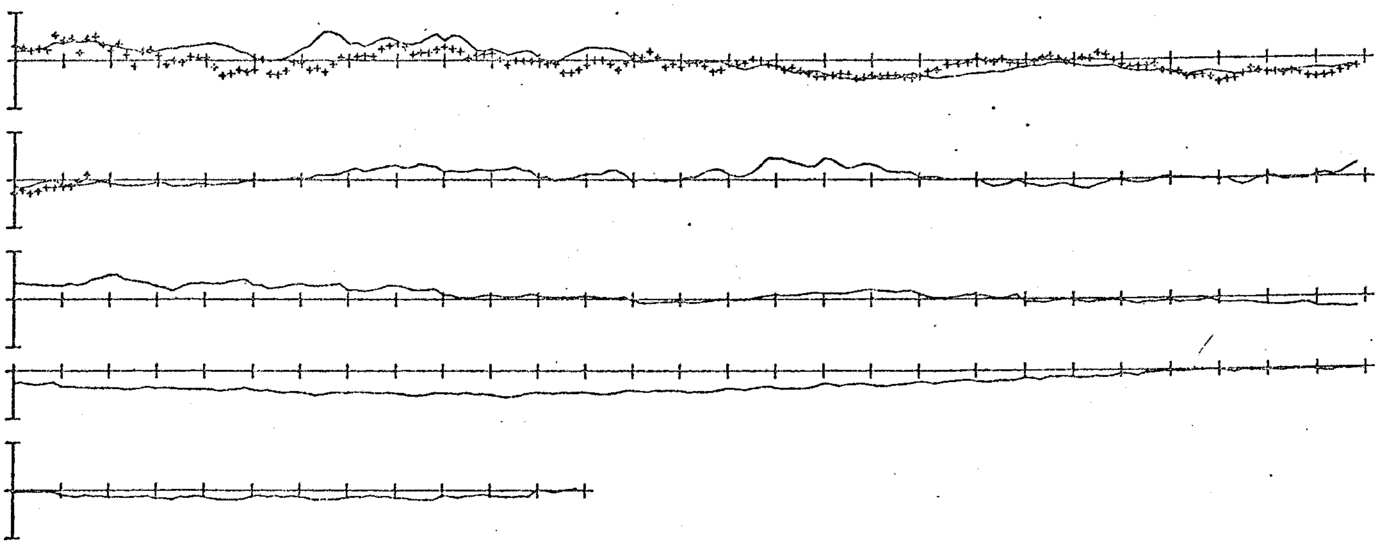
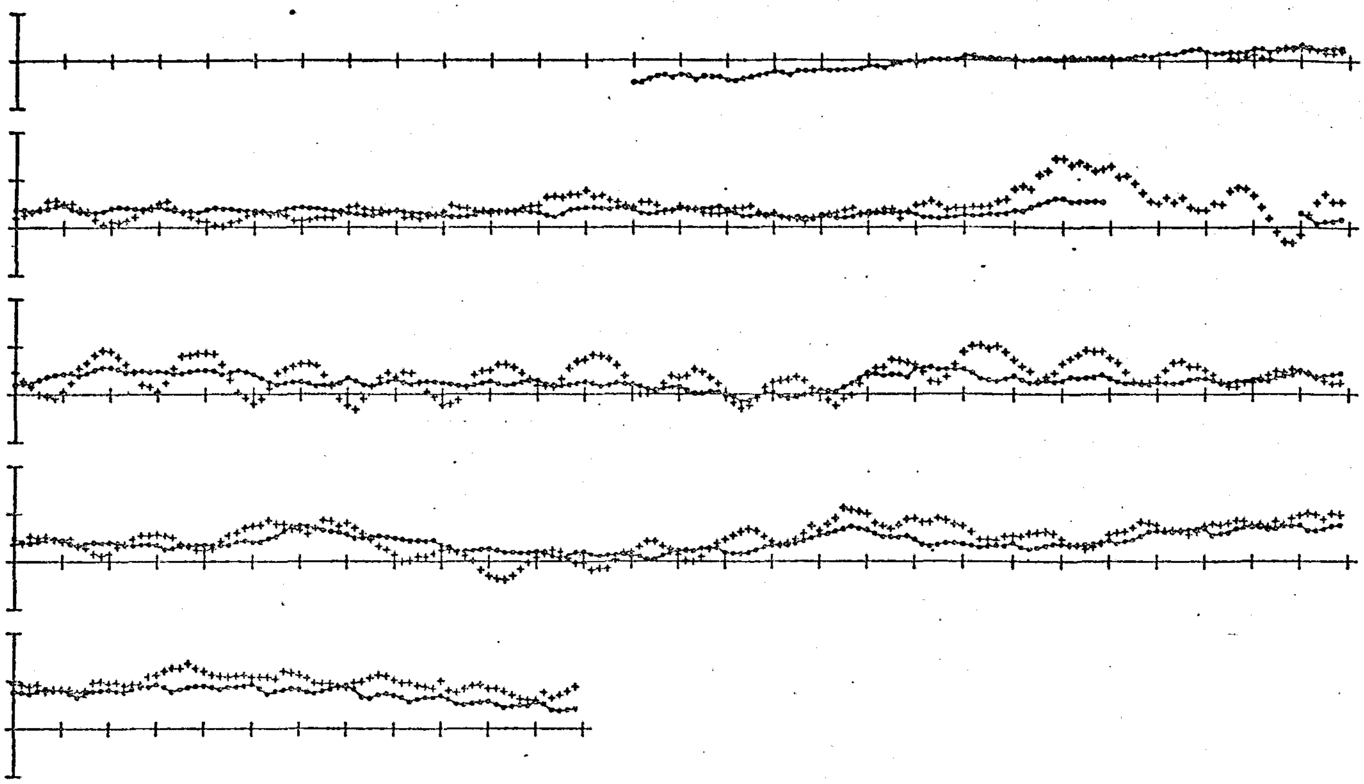


Figure 5 continued.

December 1981



January 1982

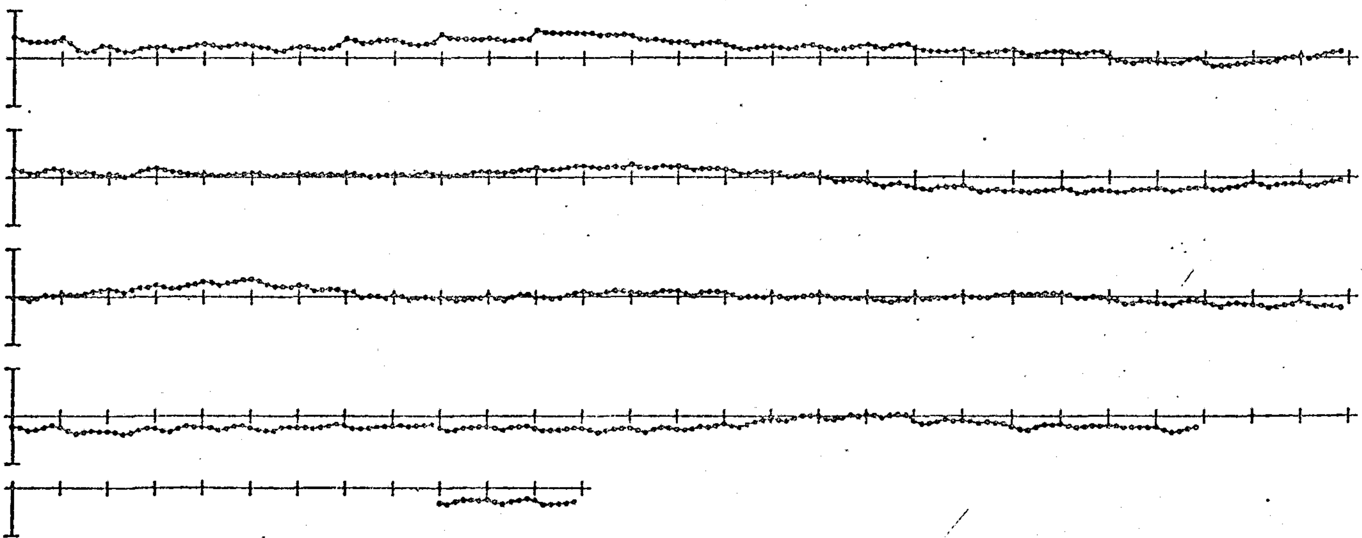
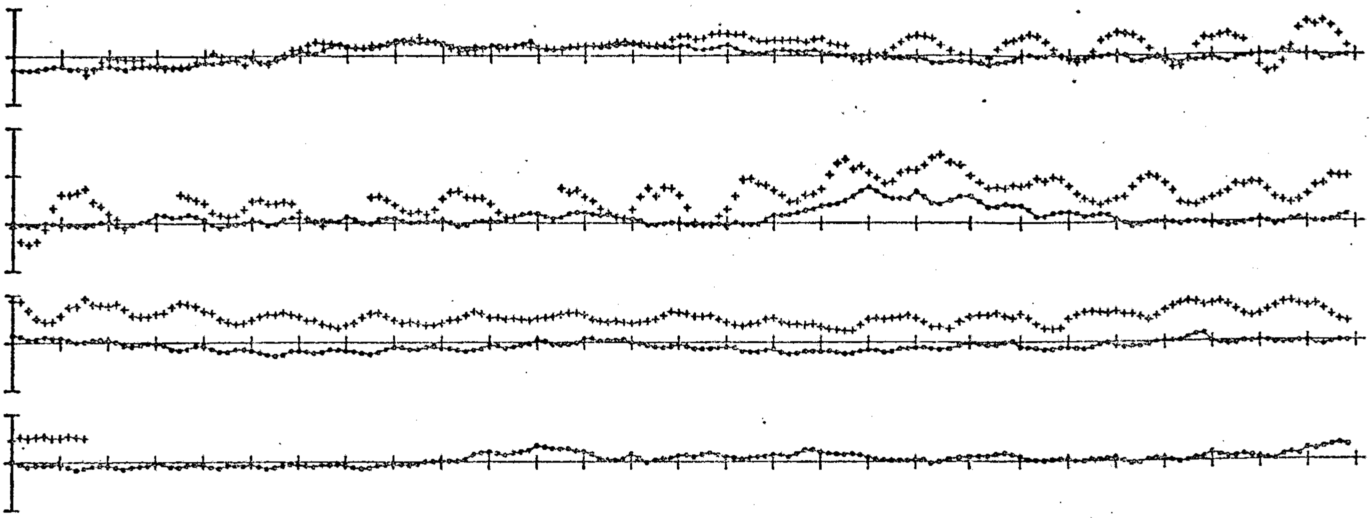


Figure 6 : Comparison of observed and computed surges at St Marys (+ + +) observations, continuous line with dots WCM, no CSM data. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

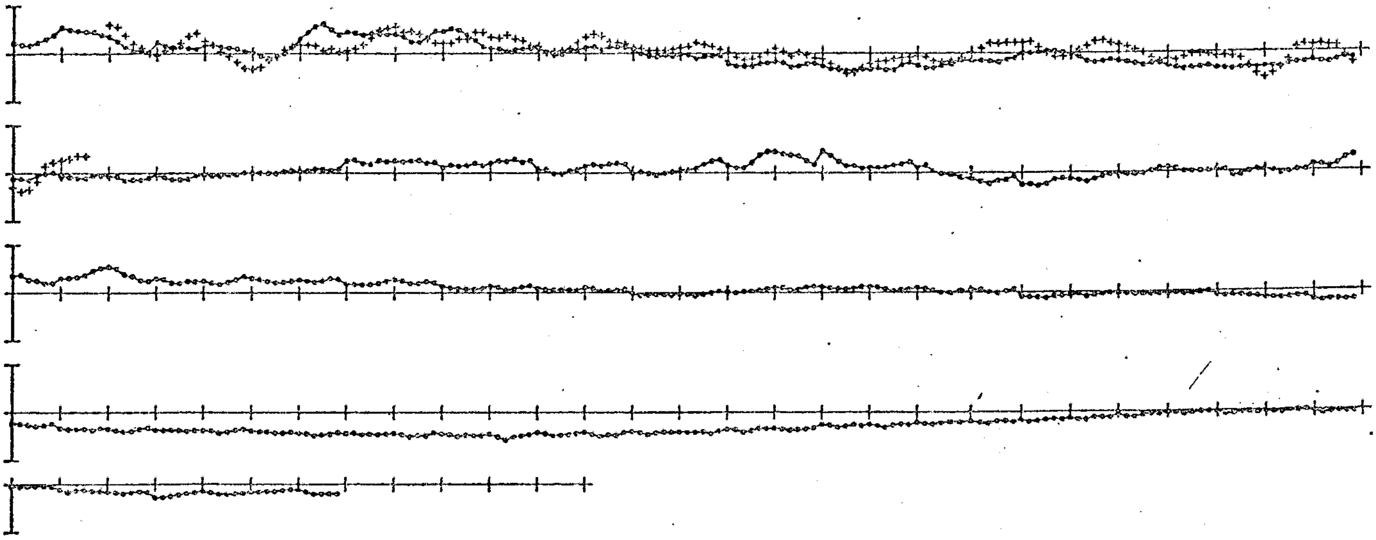
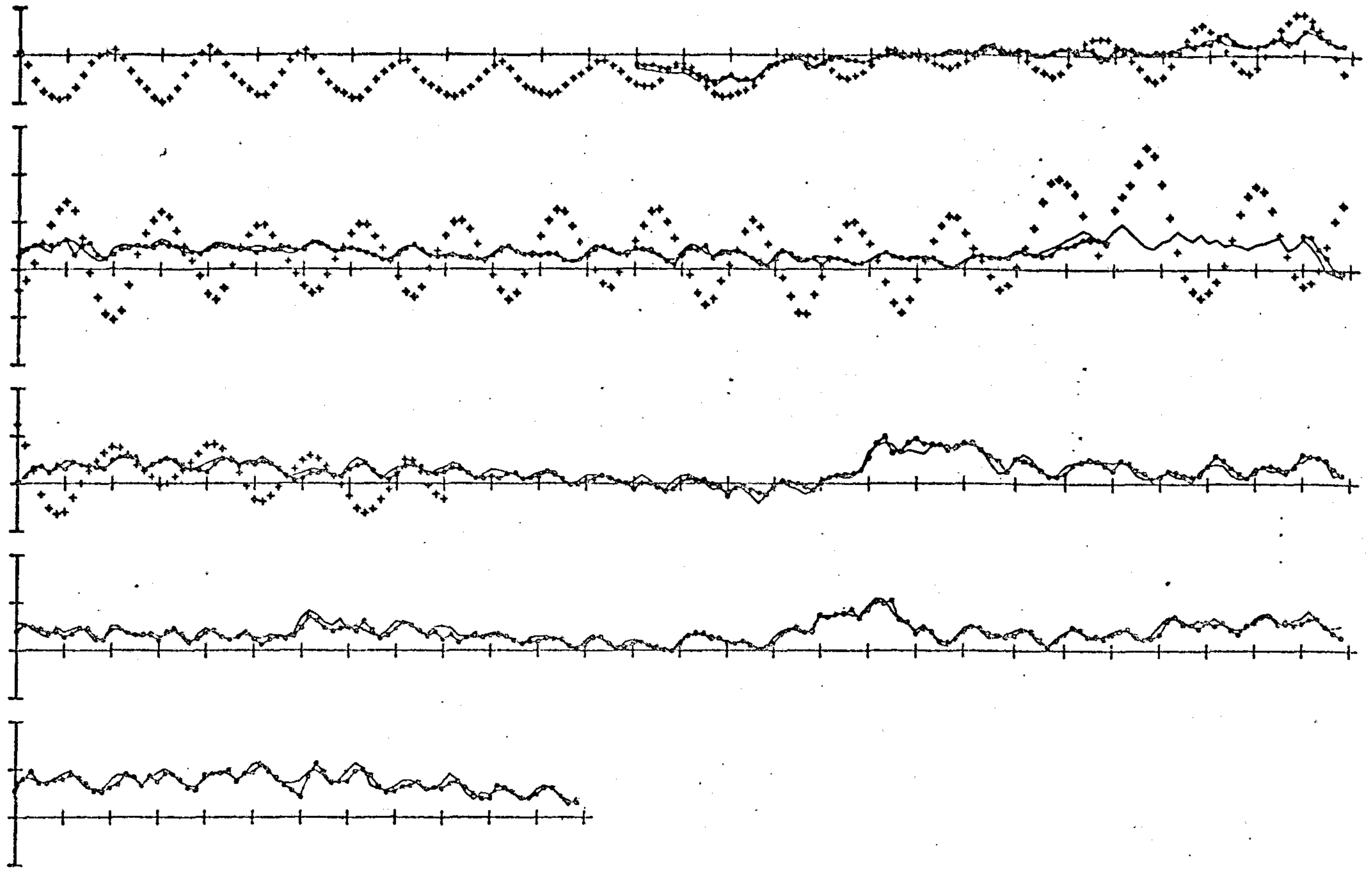


Figure 6 continued.

December 1981



January 1982

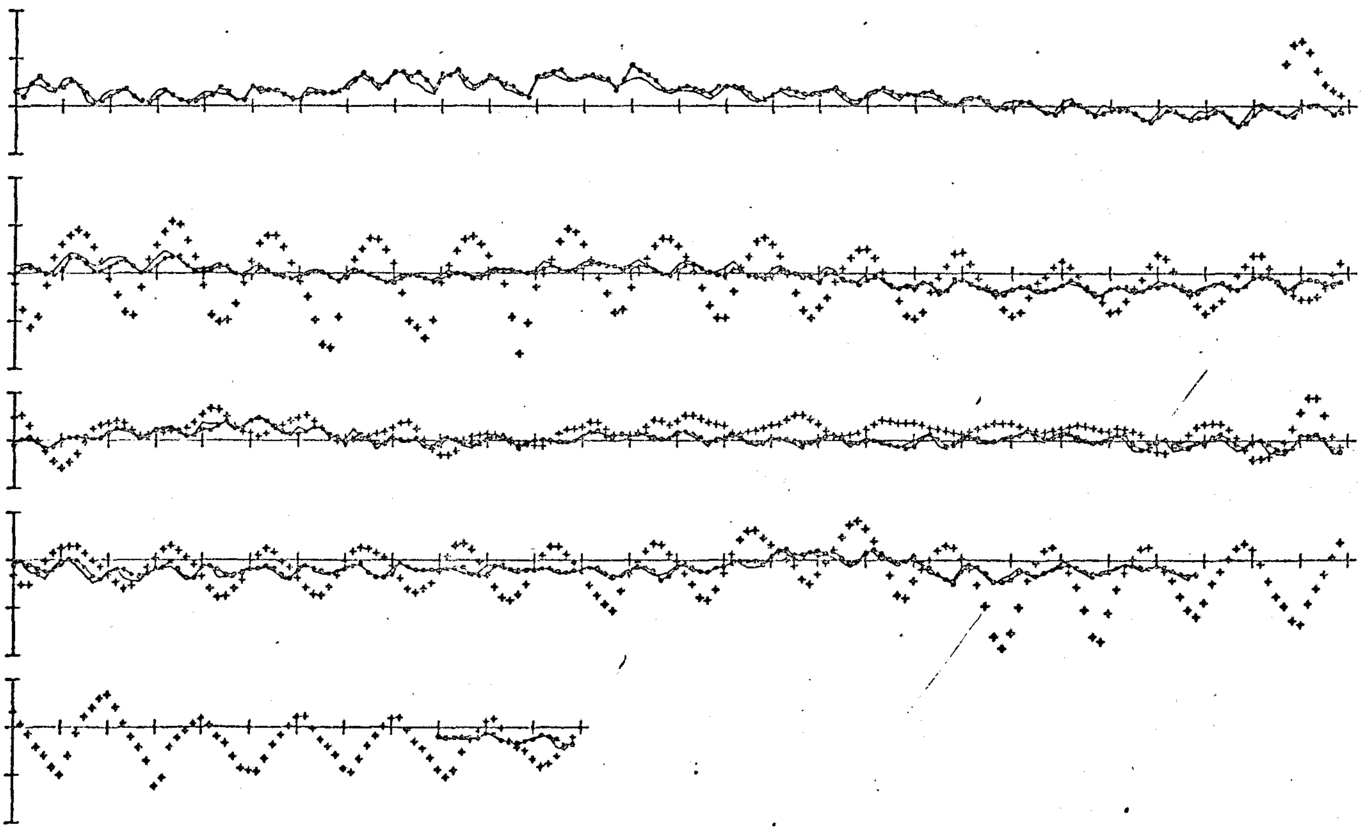
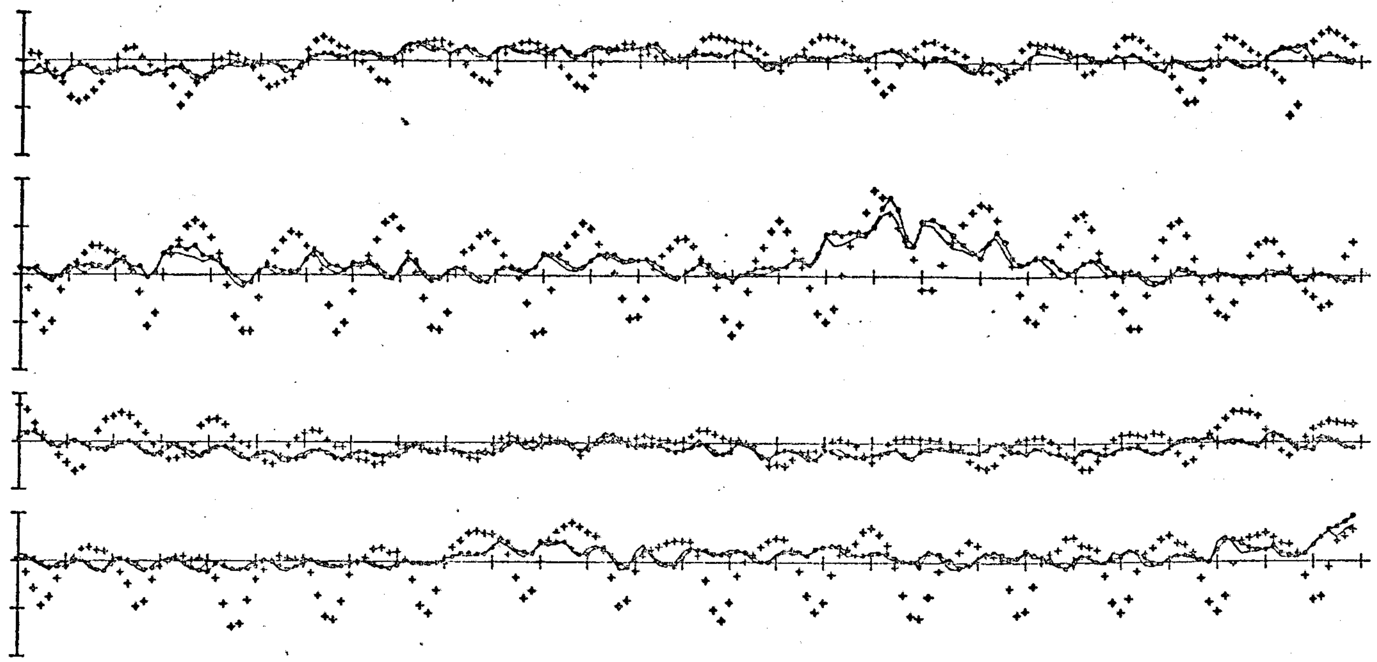


Figure 7 : Comparison of observed and computed surges at Ilfracombe
(+ + +) observations, continuous line CSM, line with dots WCM.
Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

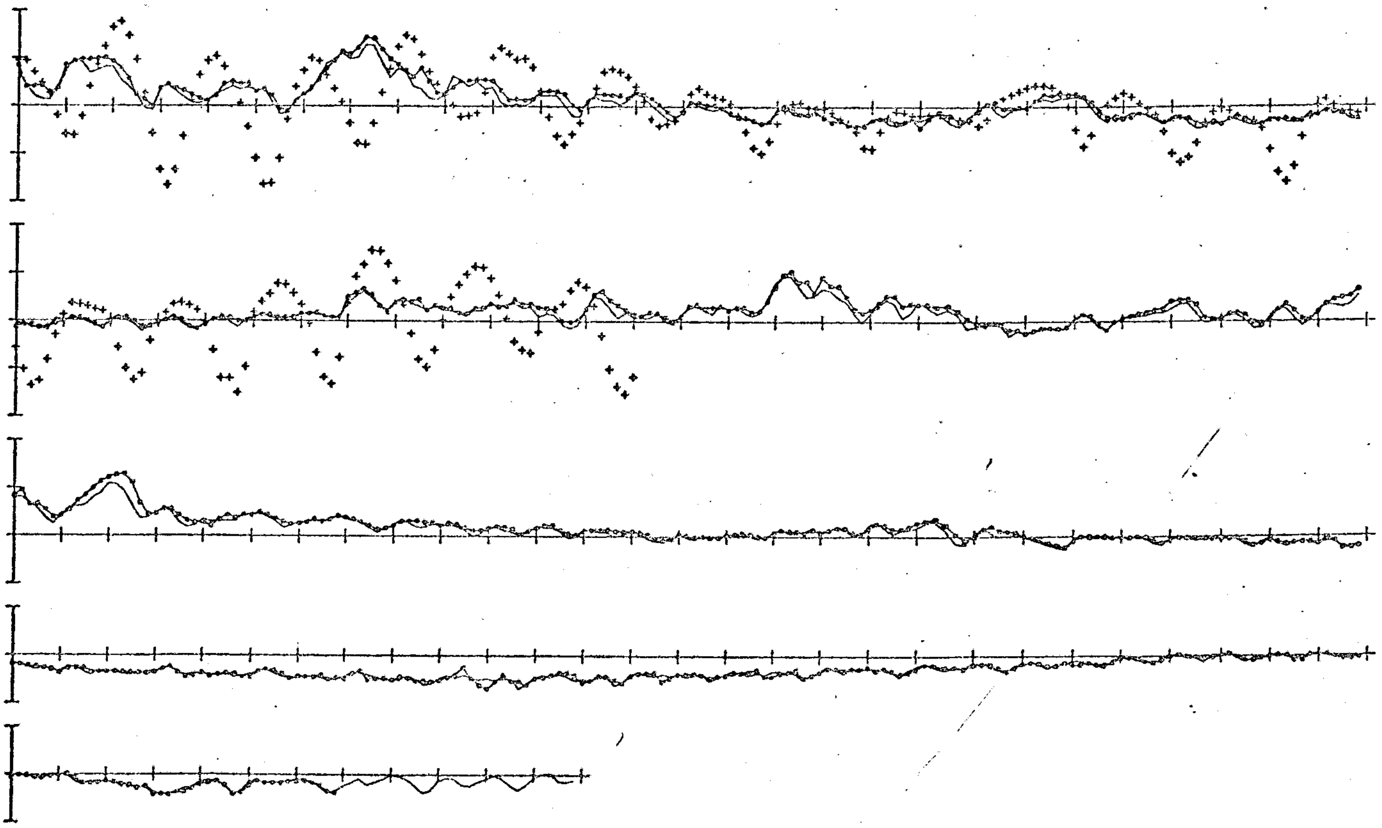
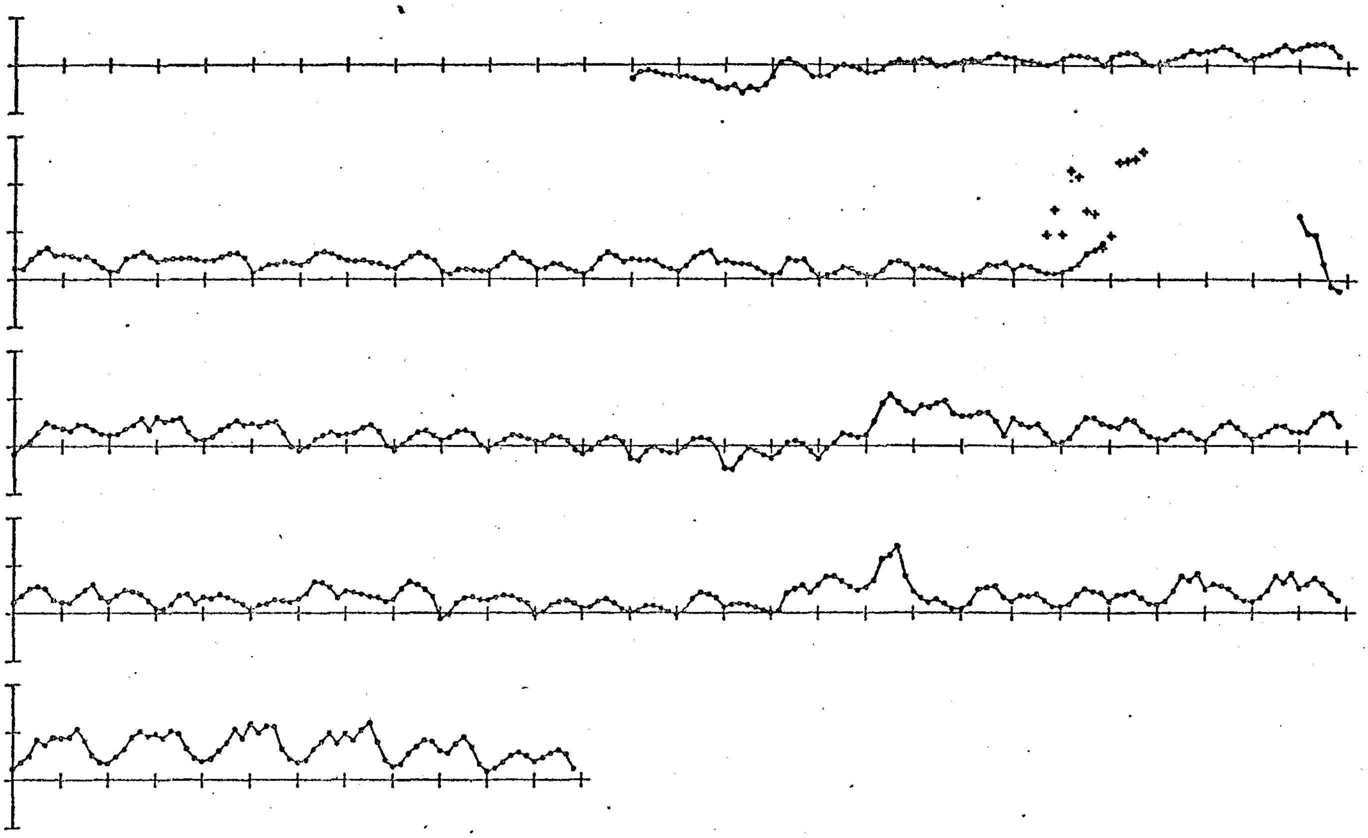


Figure 7 continued.

December 1981



January 1982

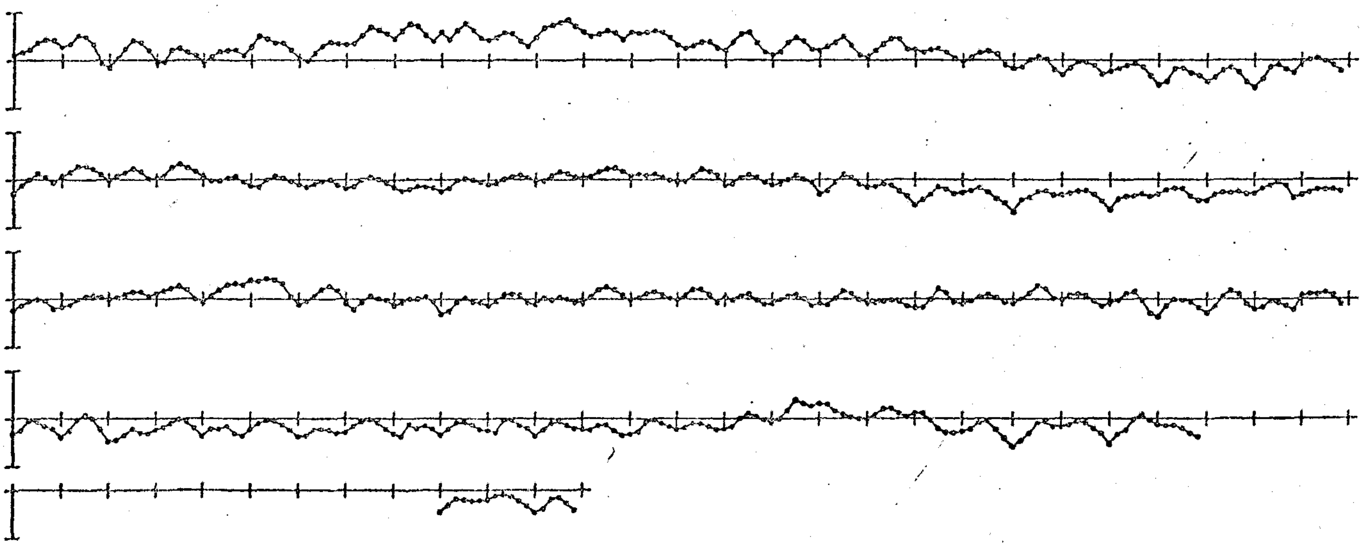
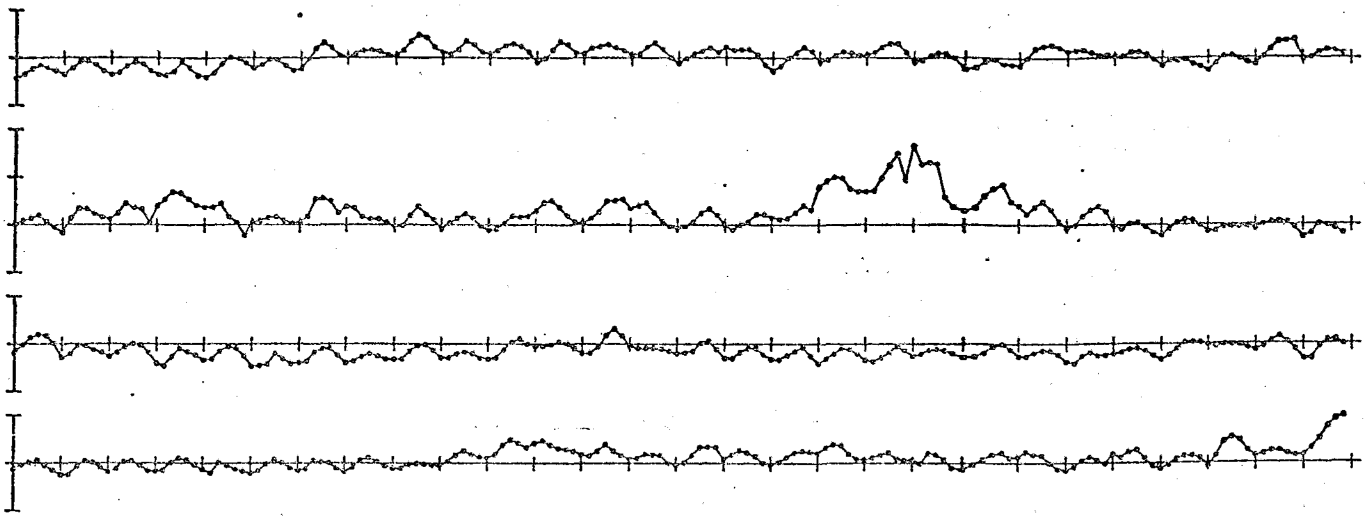


Figure 8 : Comparison of observed and computed surges at Hinkley Point (+ + +) observations, continuous line with dots WCM, no CSM data. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

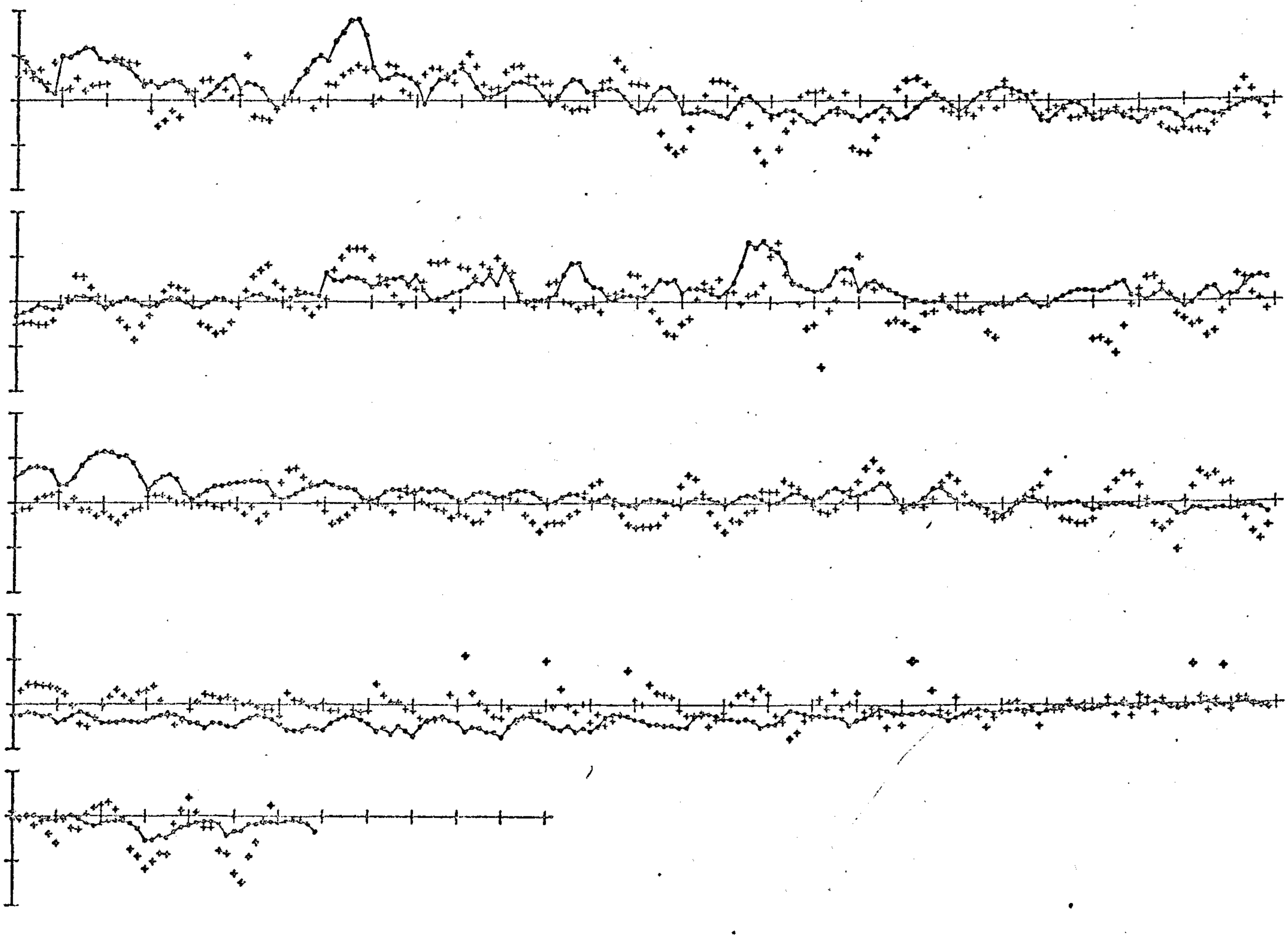


Figure 8 continued.

December 1981

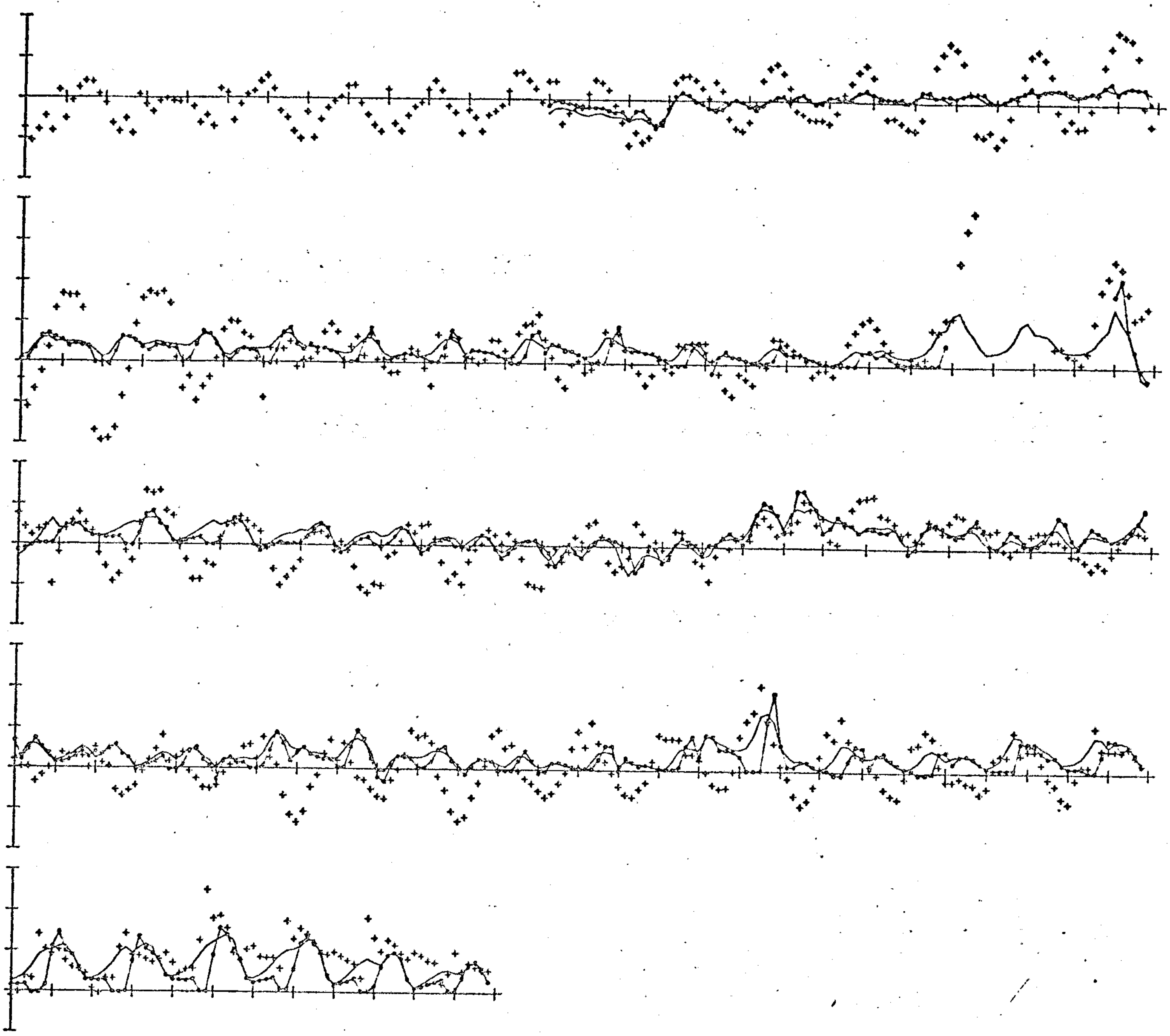


Figure 9 : Comparison of observed and computed surges at Avonmouth
(+ + +) observations, continuous line CSM, line with dots WCM.
Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

January 1982

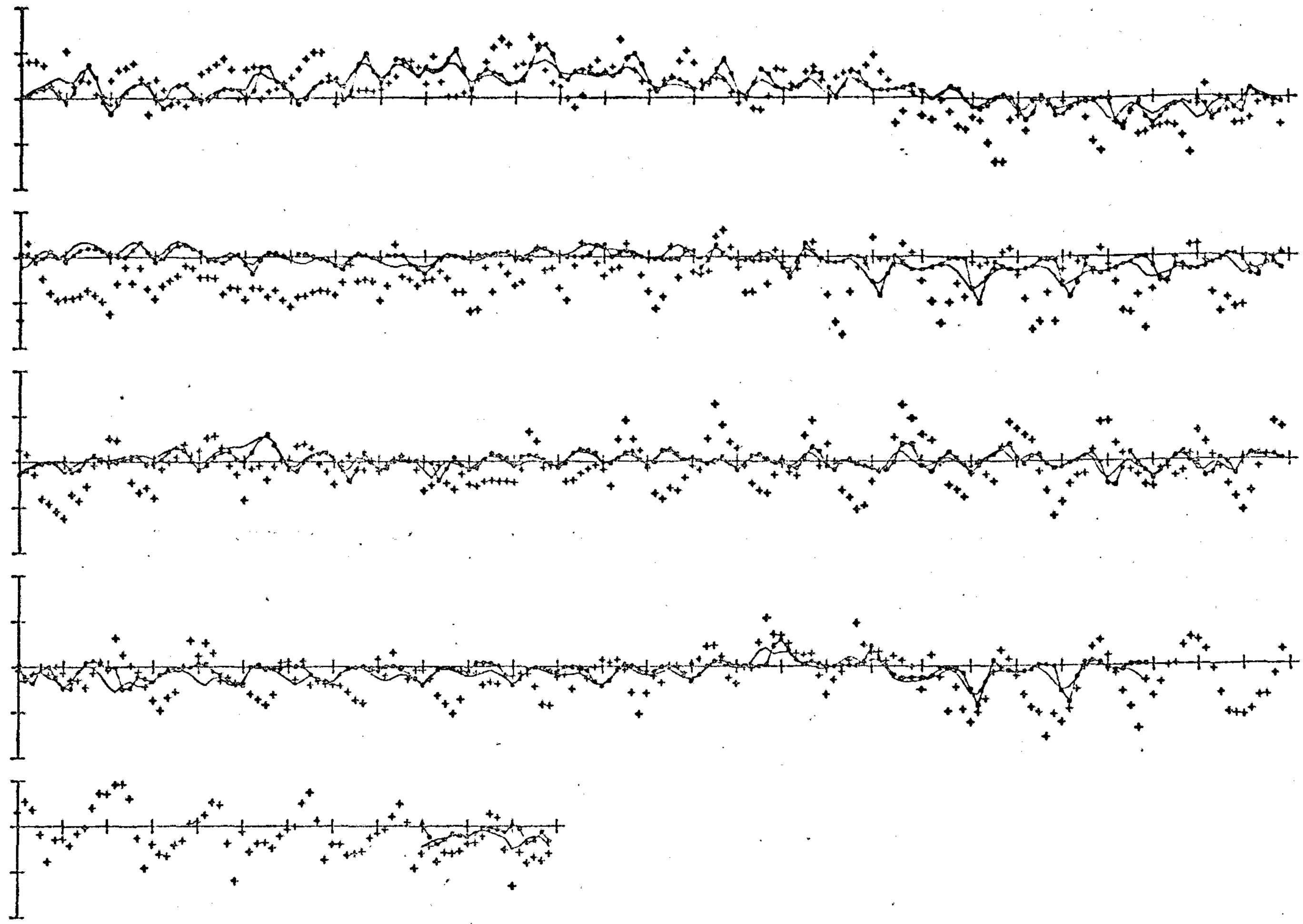
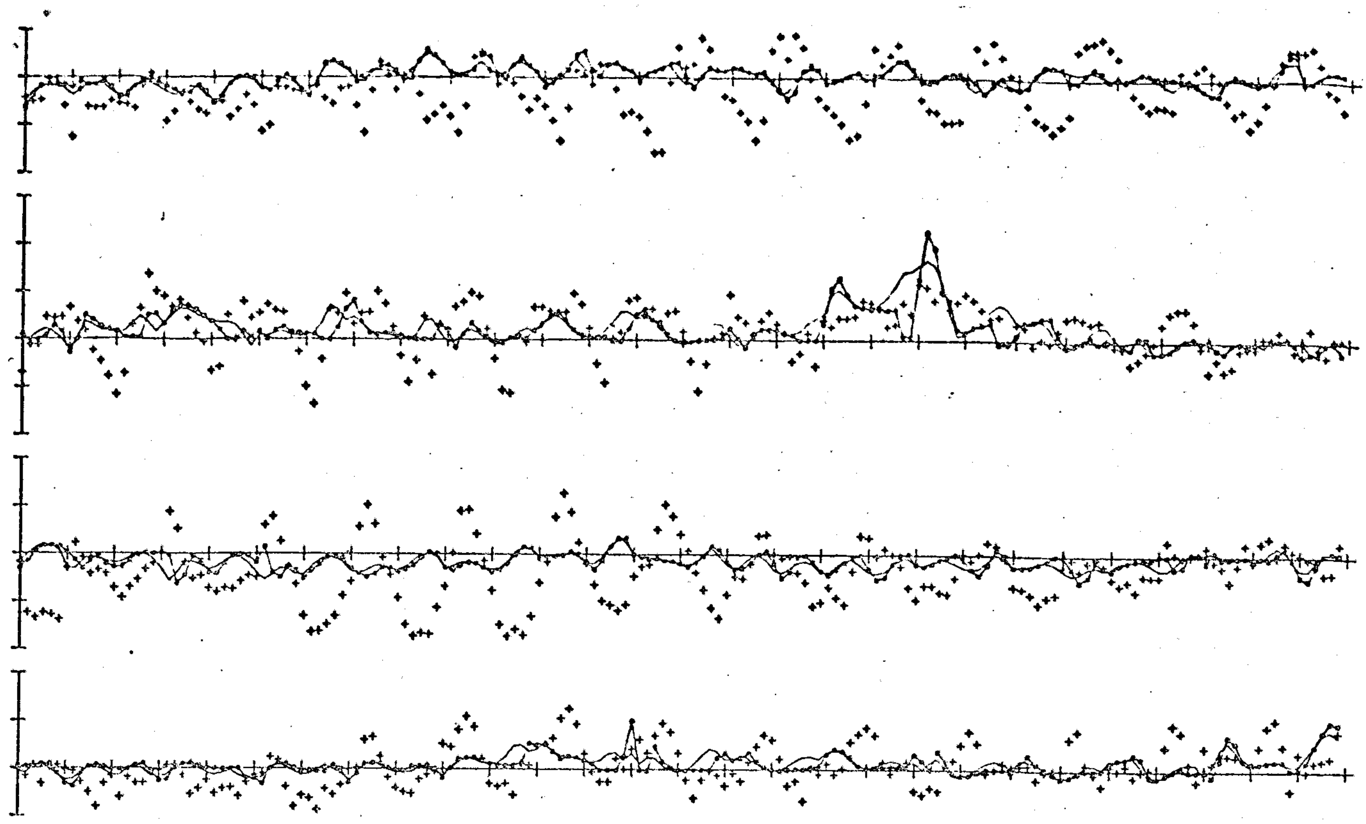


Figure 9 continued.

February 1982



March 1982

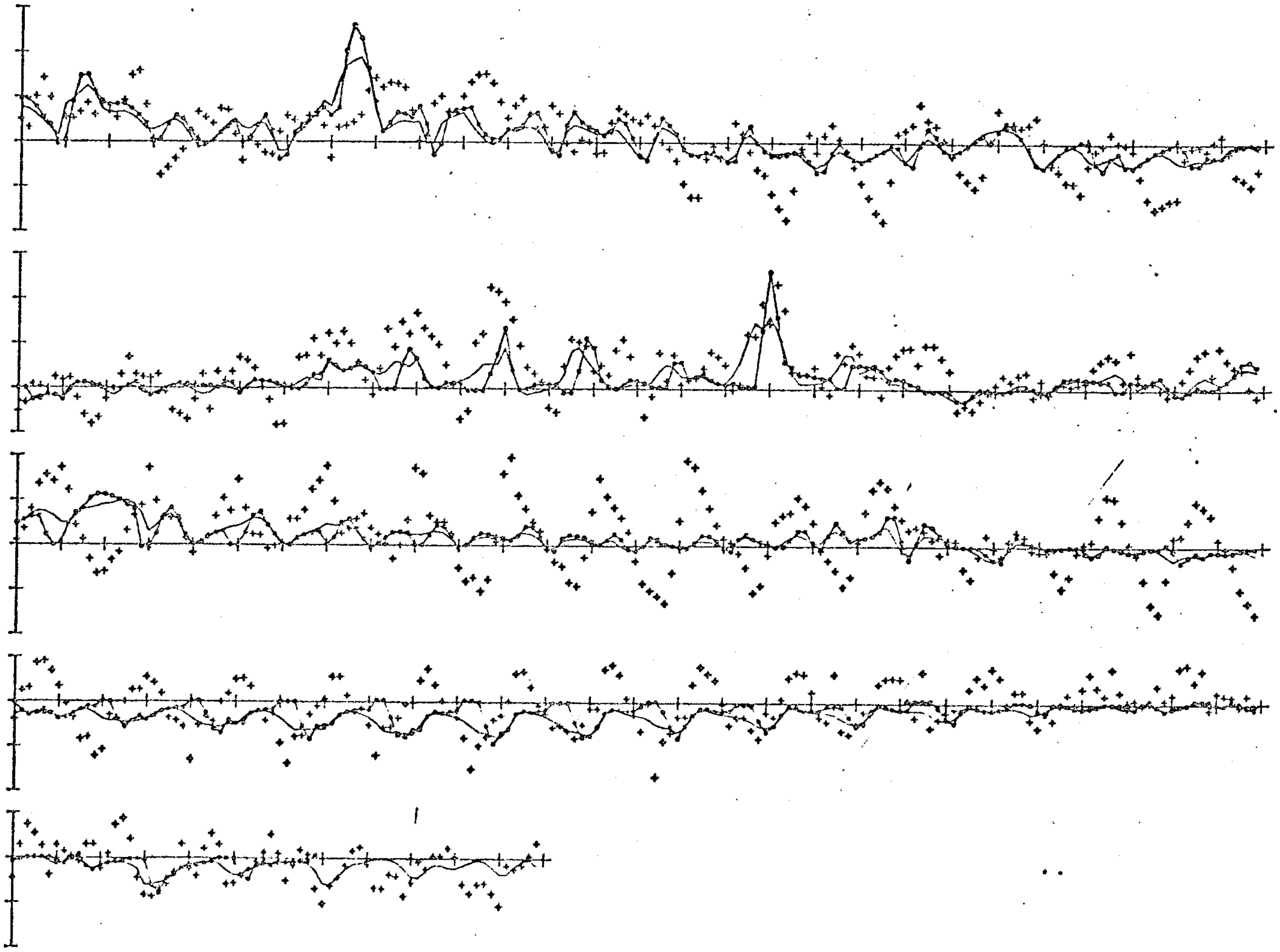
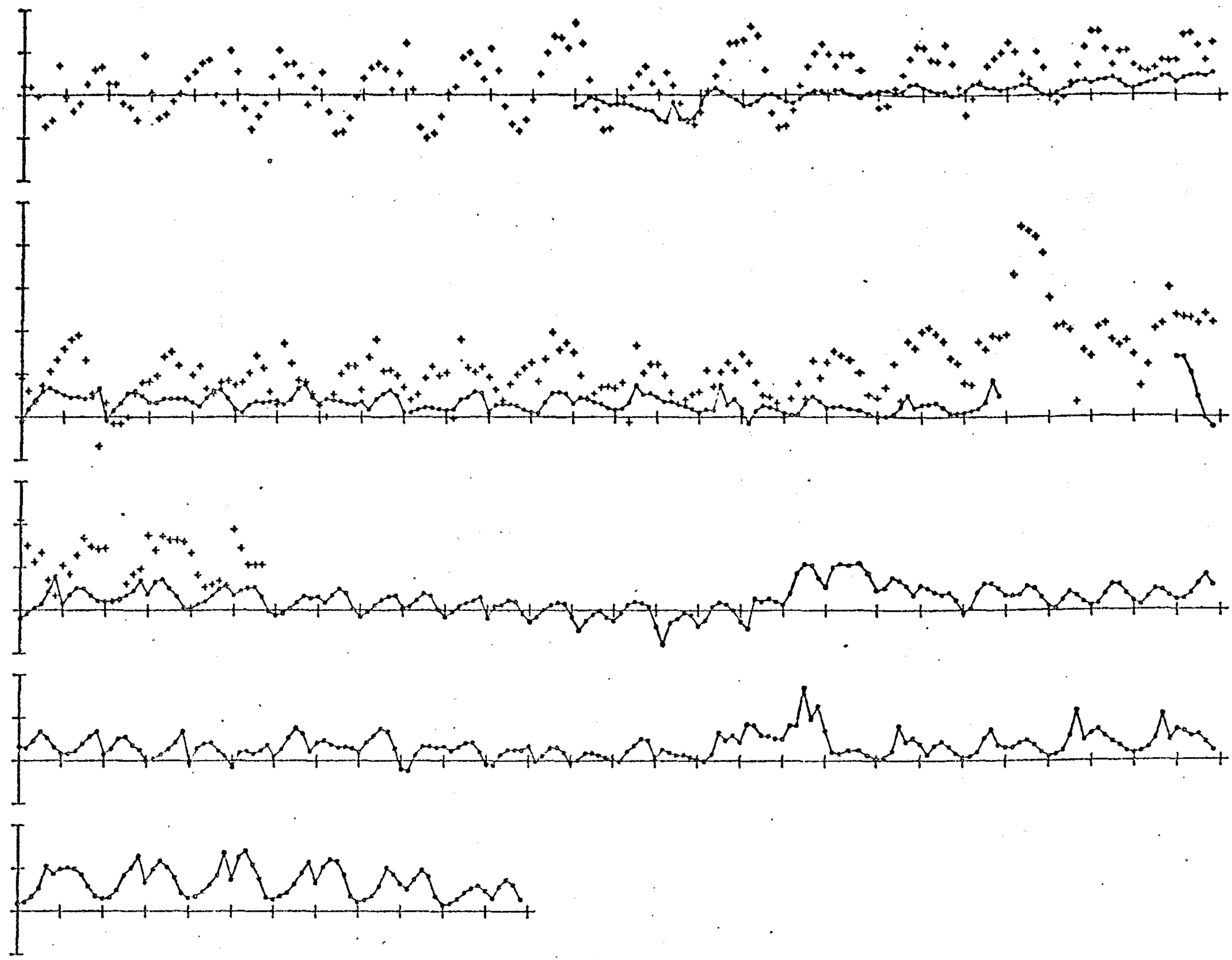


Figure 9 continued.

December 1981



January 1982

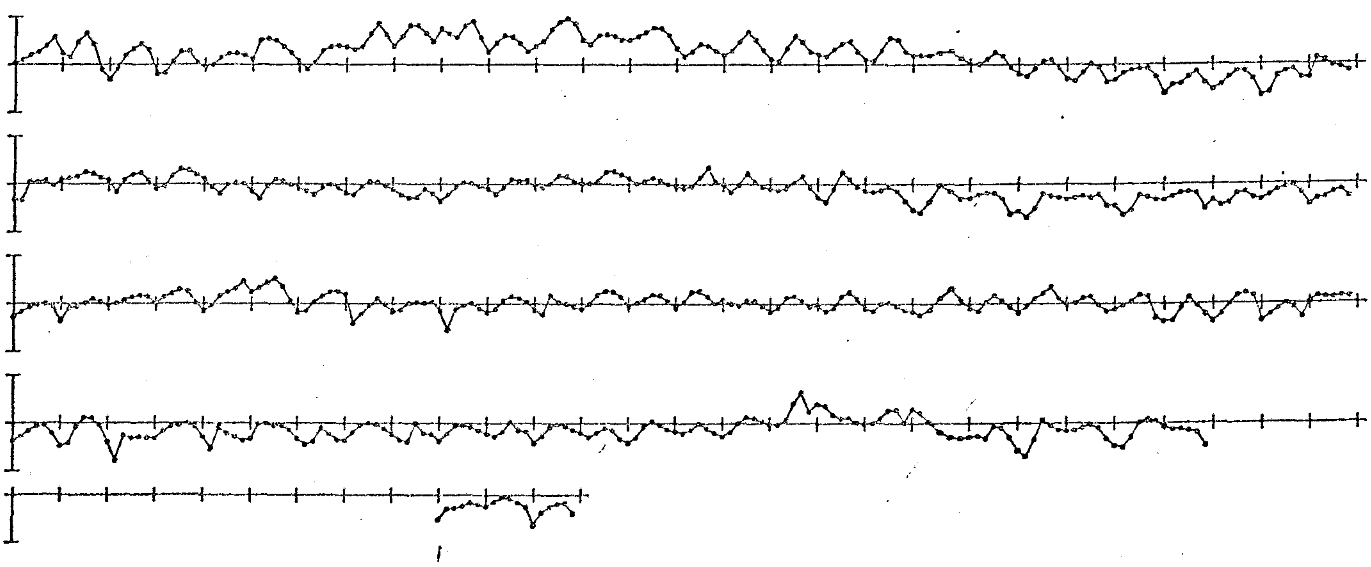
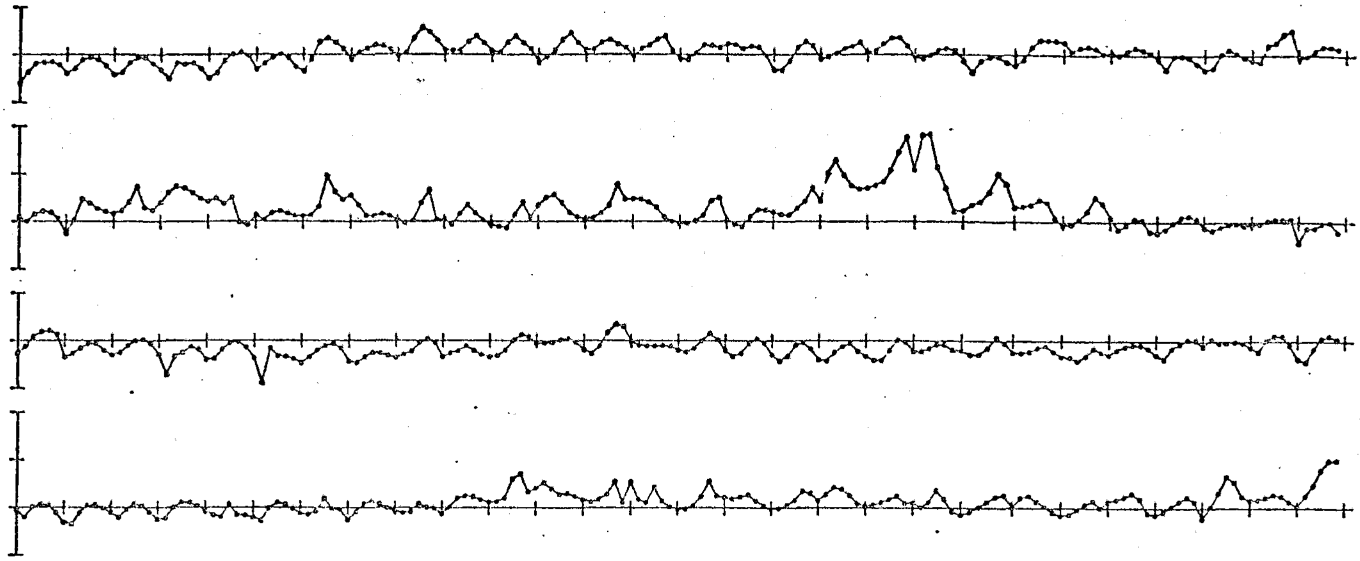


Figure 10 : Comparison of observed and computed surges at Newport (+ + +) observations, continuous line with dots WCM, no CSM data. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

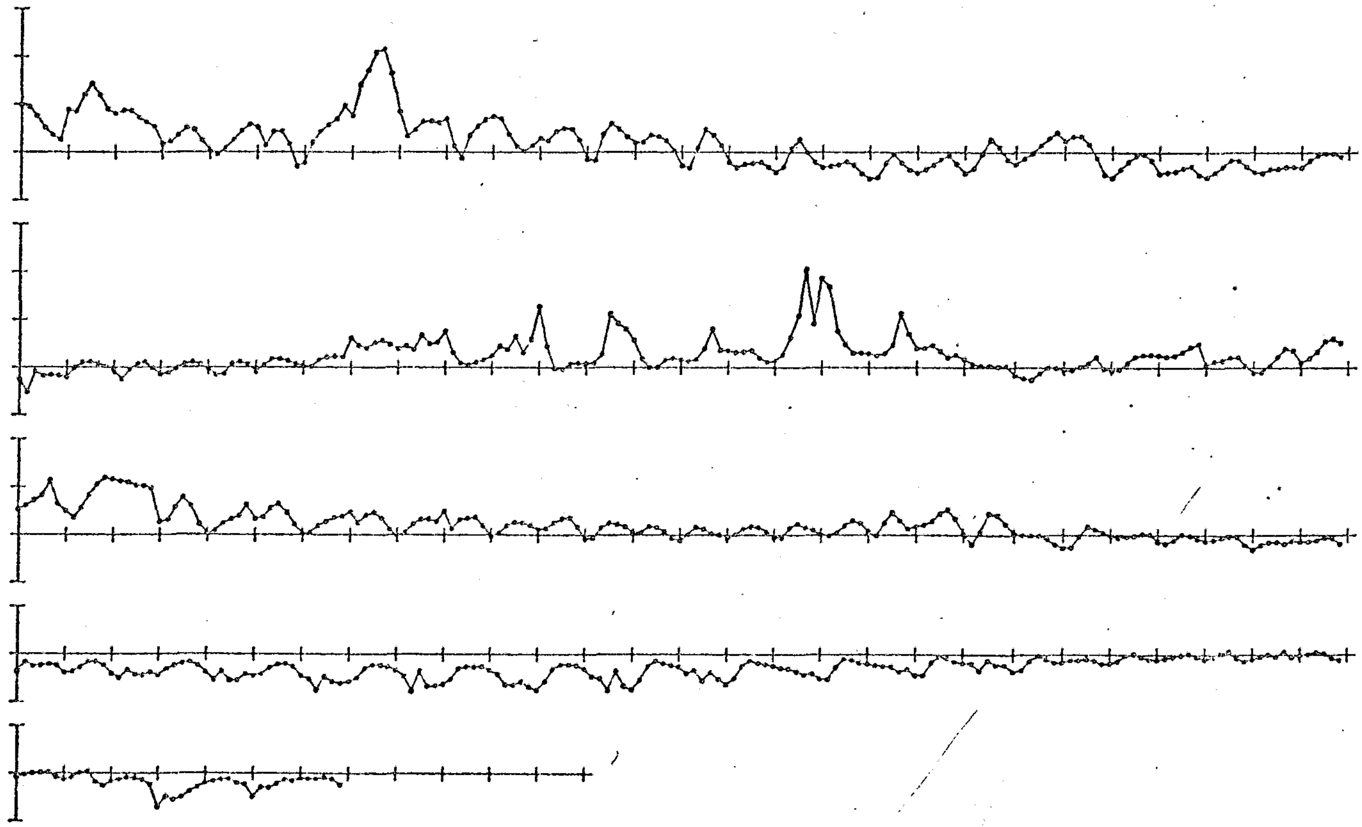
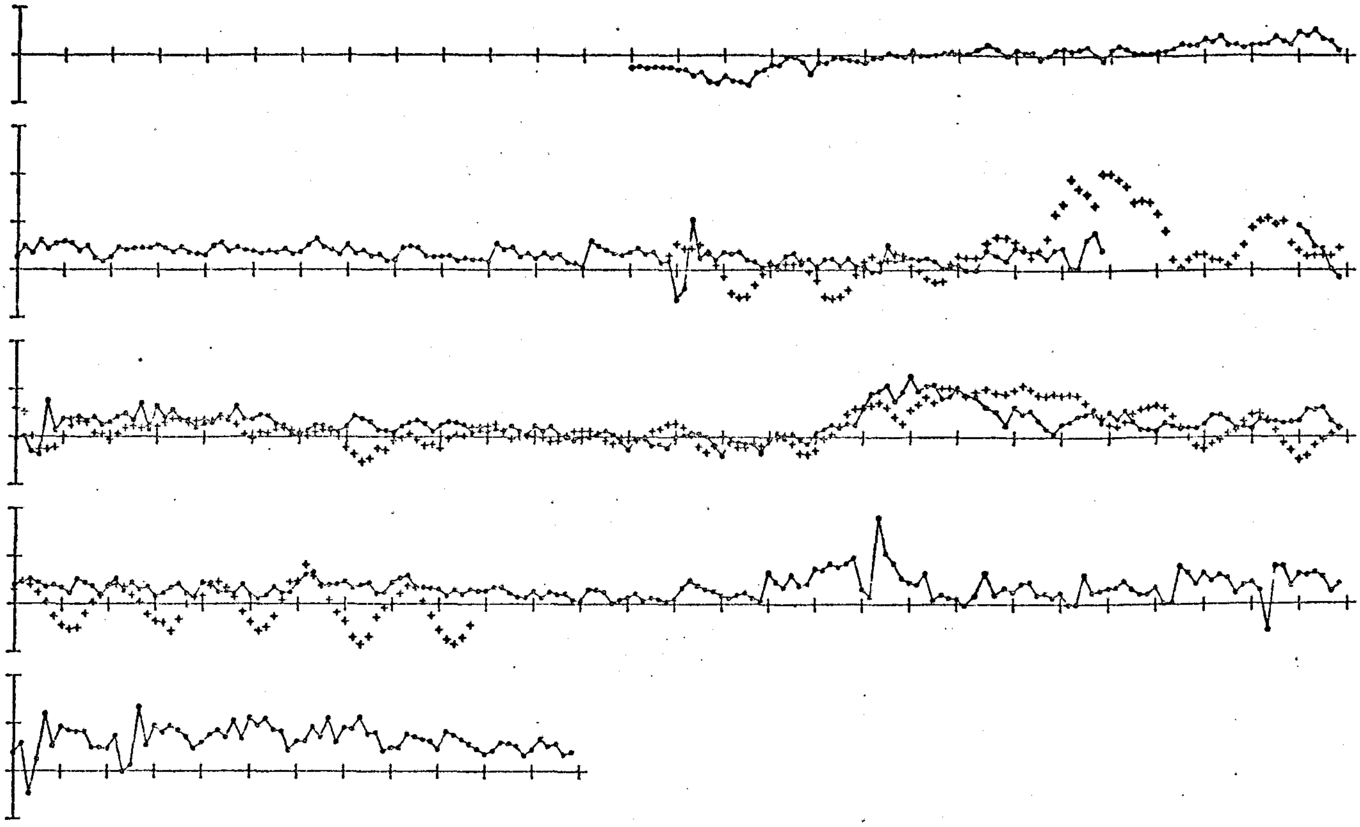


Figure 10 continued.

December 1981



January 1982

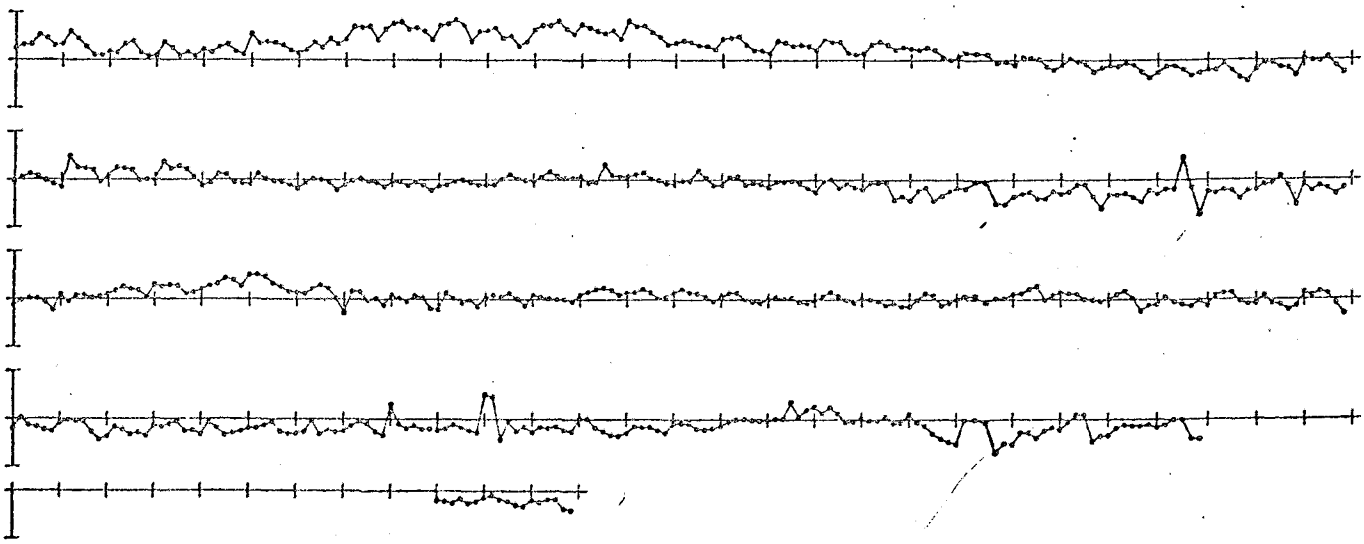
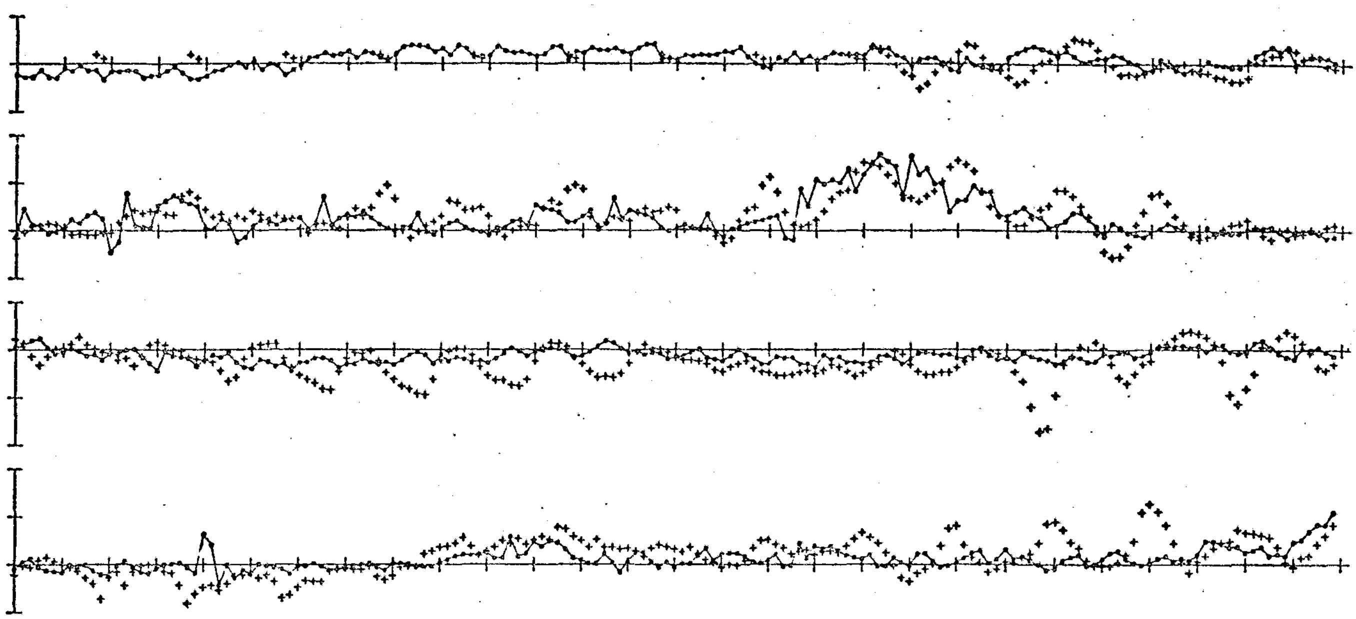


Figure 11 : Comparison of observed and computed surges at Swansea (+ + +) observations, continuous line with dots WCM, no CSM data. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

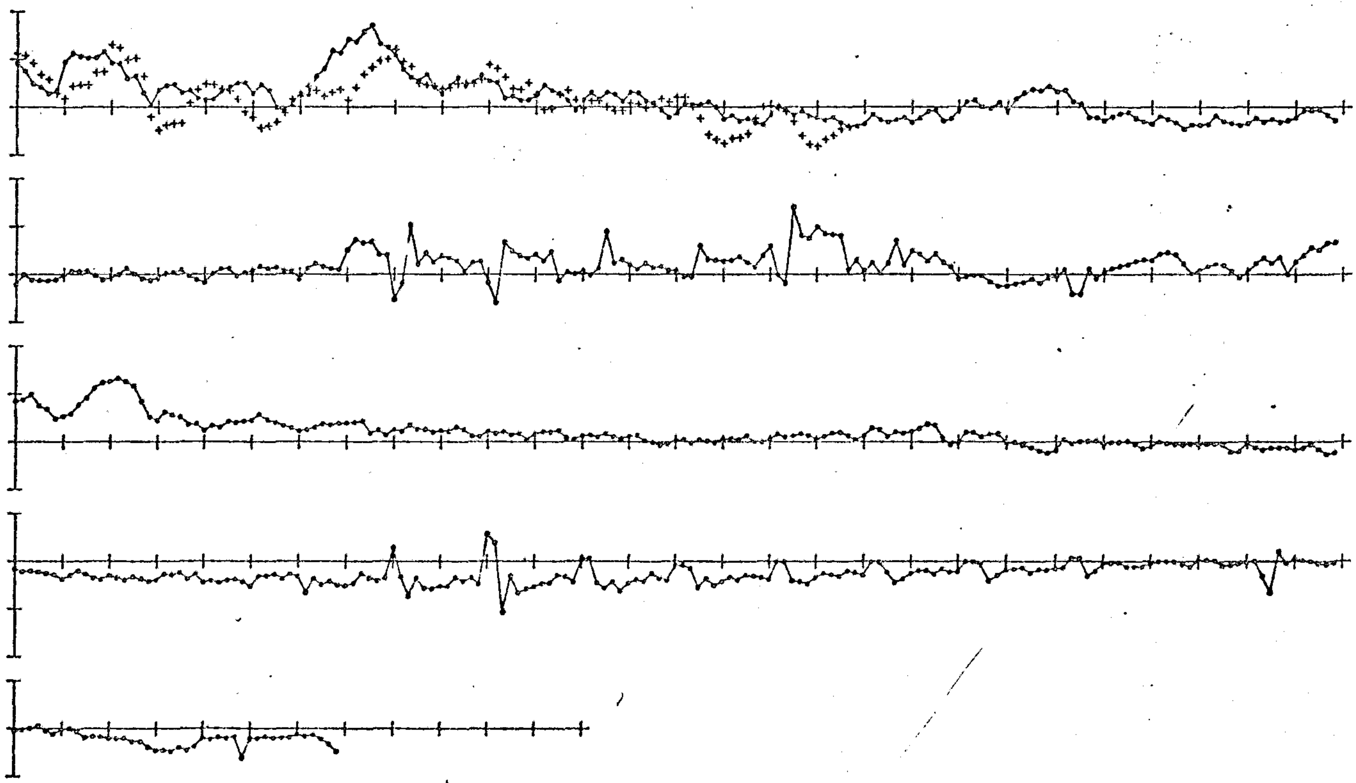
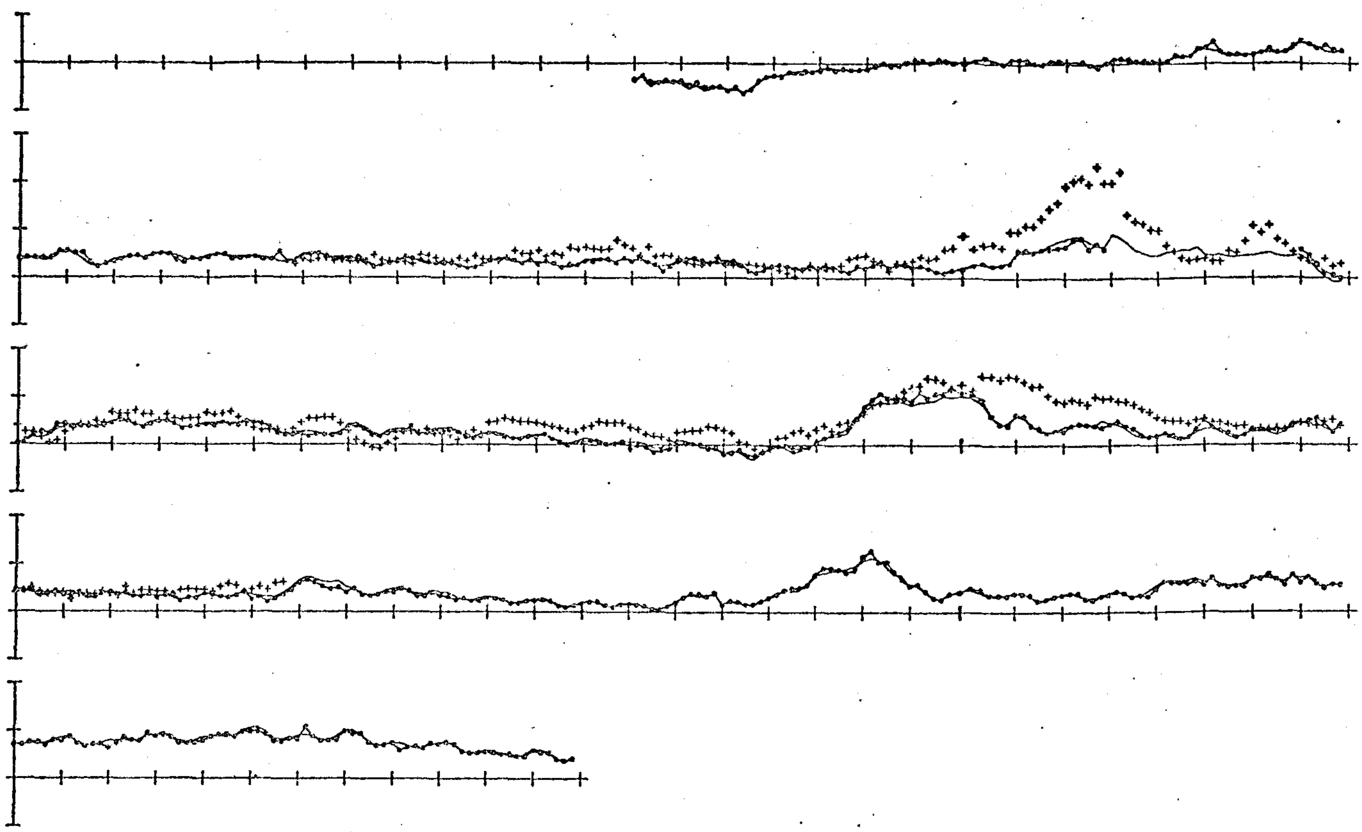


Figure 11 continued.

December 1981



January 1982

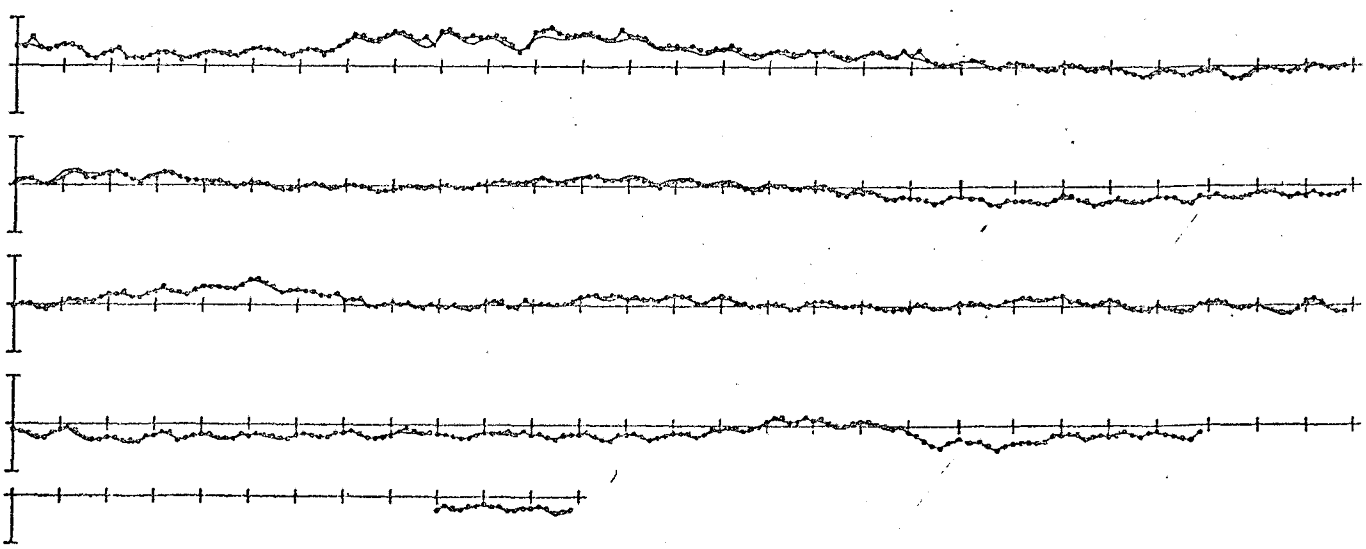
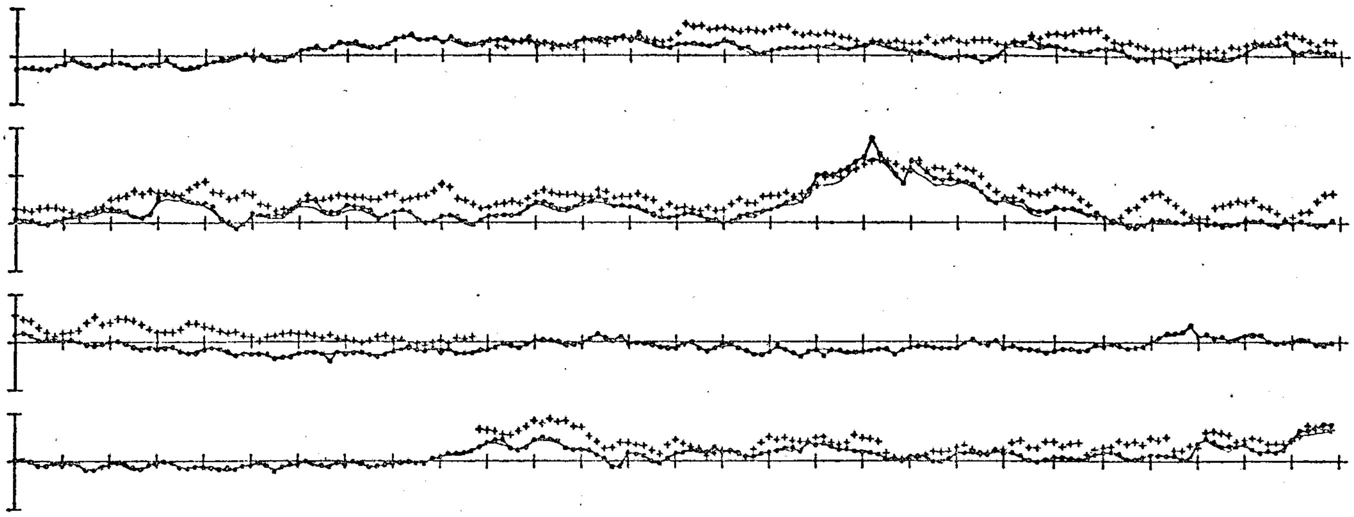


Figure 12 : Comparison of observed and computed surges at Milford Haven (+ + +) observations, continuous line CSM, line with dots WCM.
Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

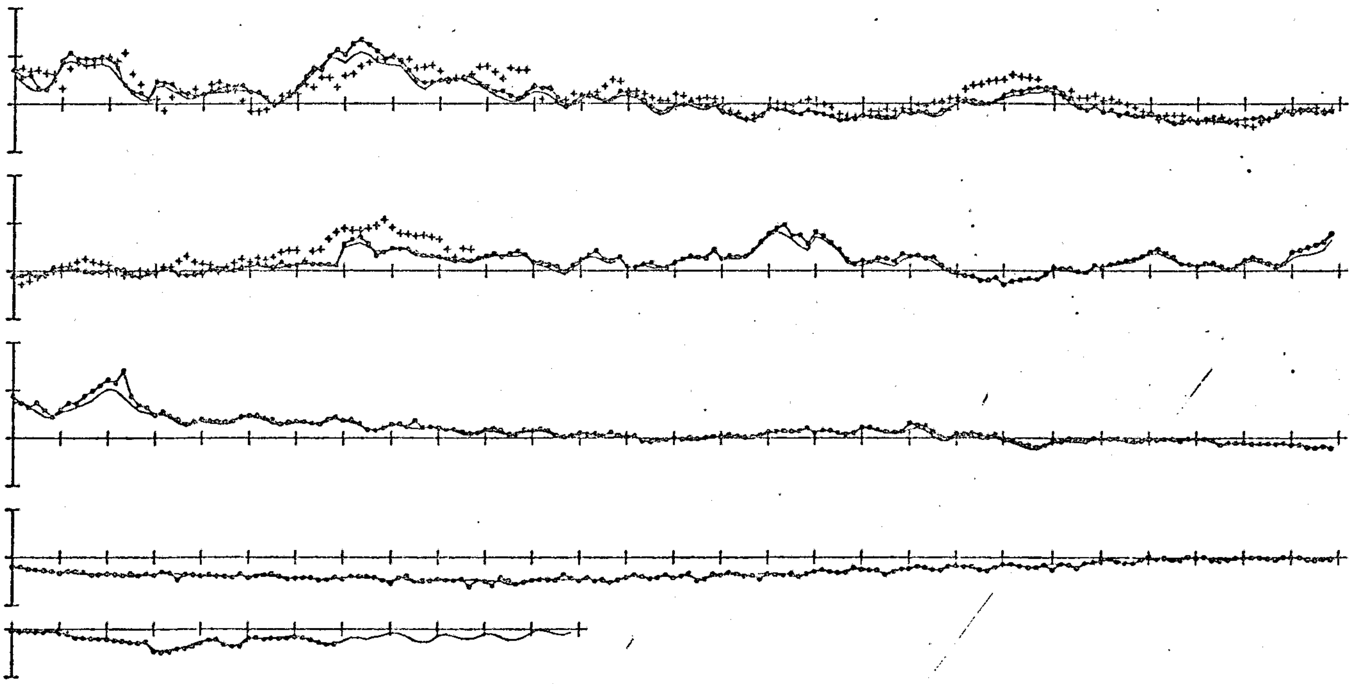
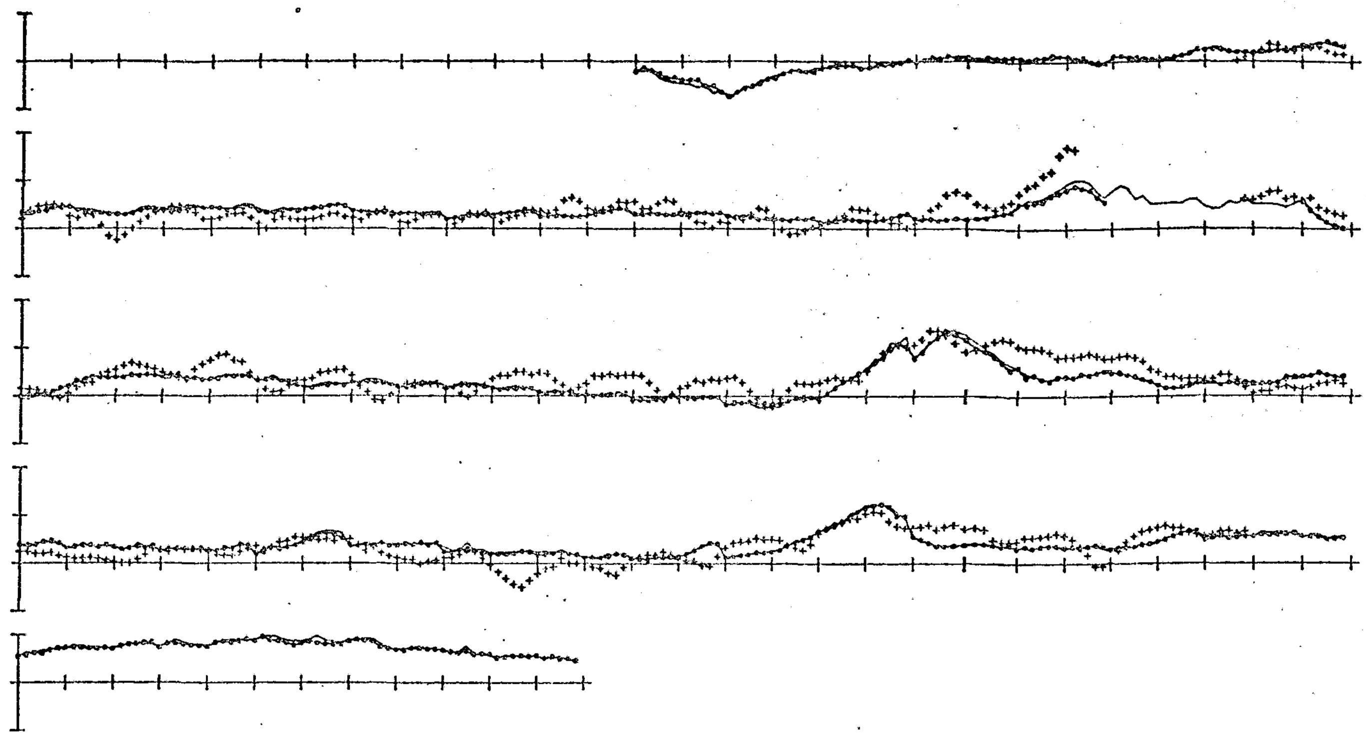


Figure 12 continued.

December 1981



January 1982

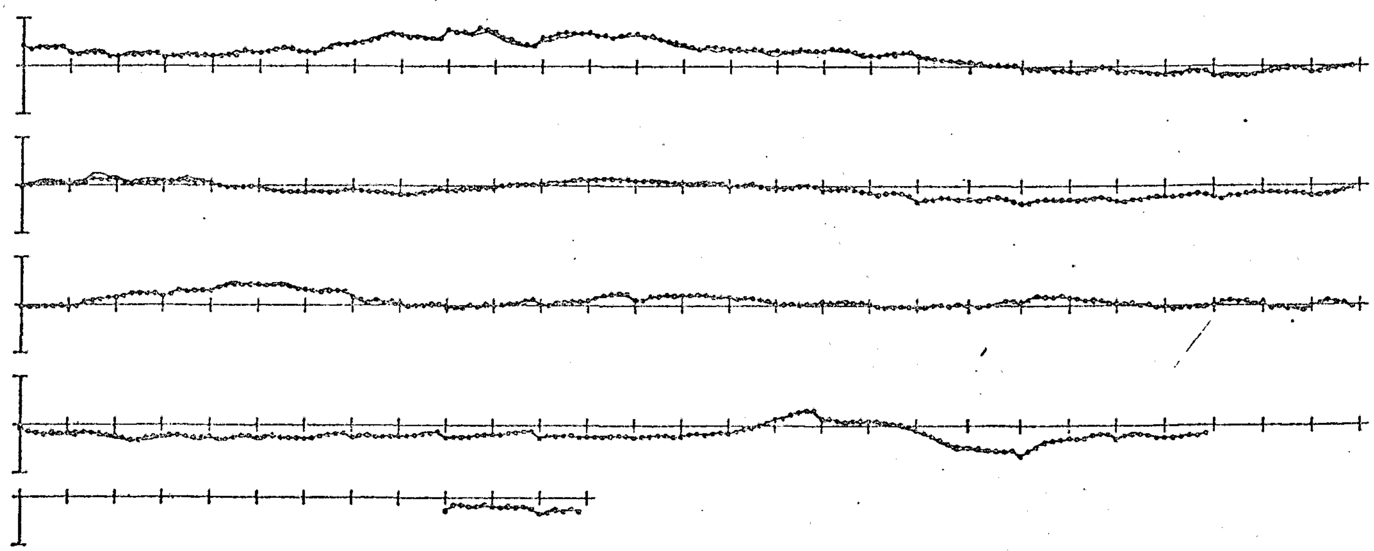
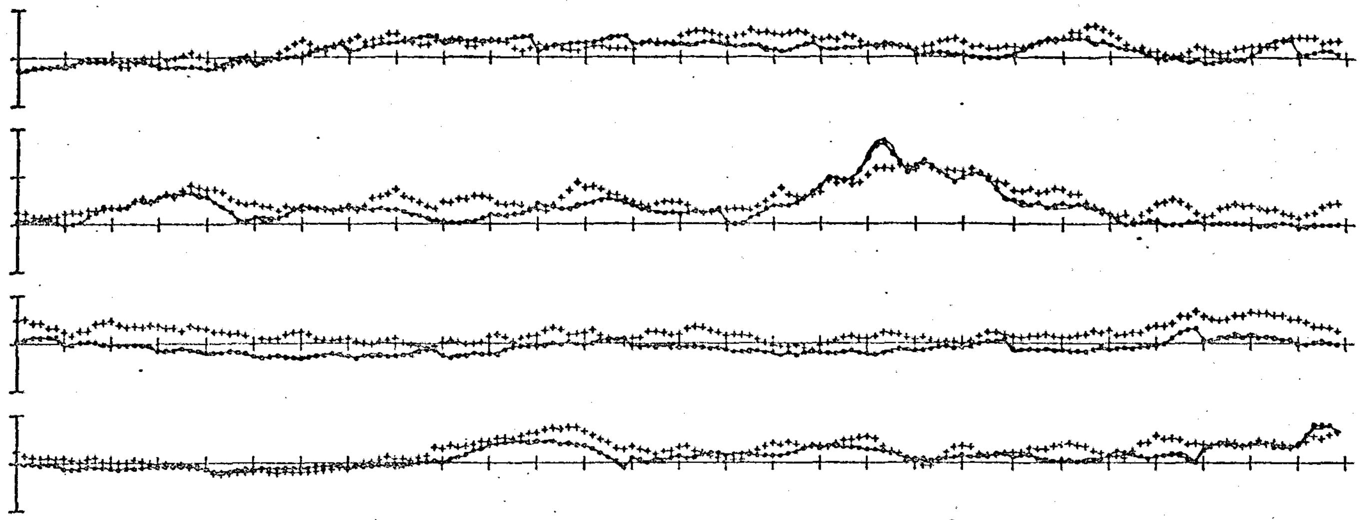


Figure 13 : Comparison of observed and computed surges at Fishguard (+ + +) observations, continuous line CSM, line with dots WCM. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

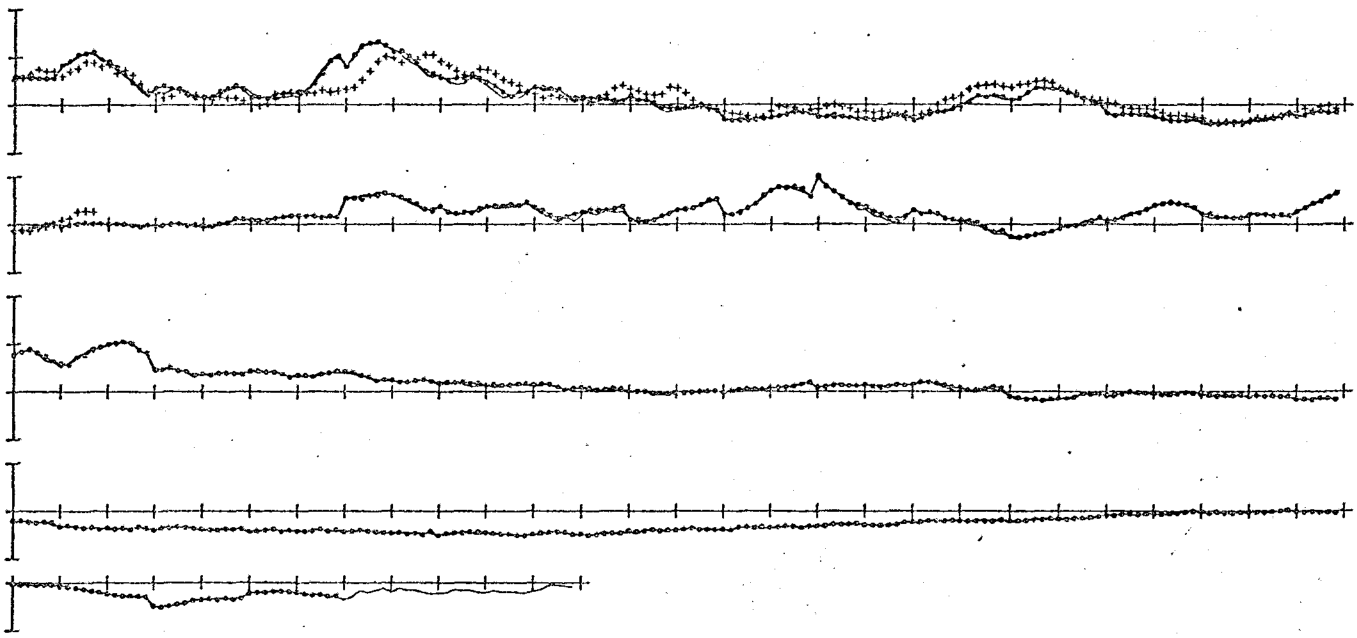


Figure 13 continued.

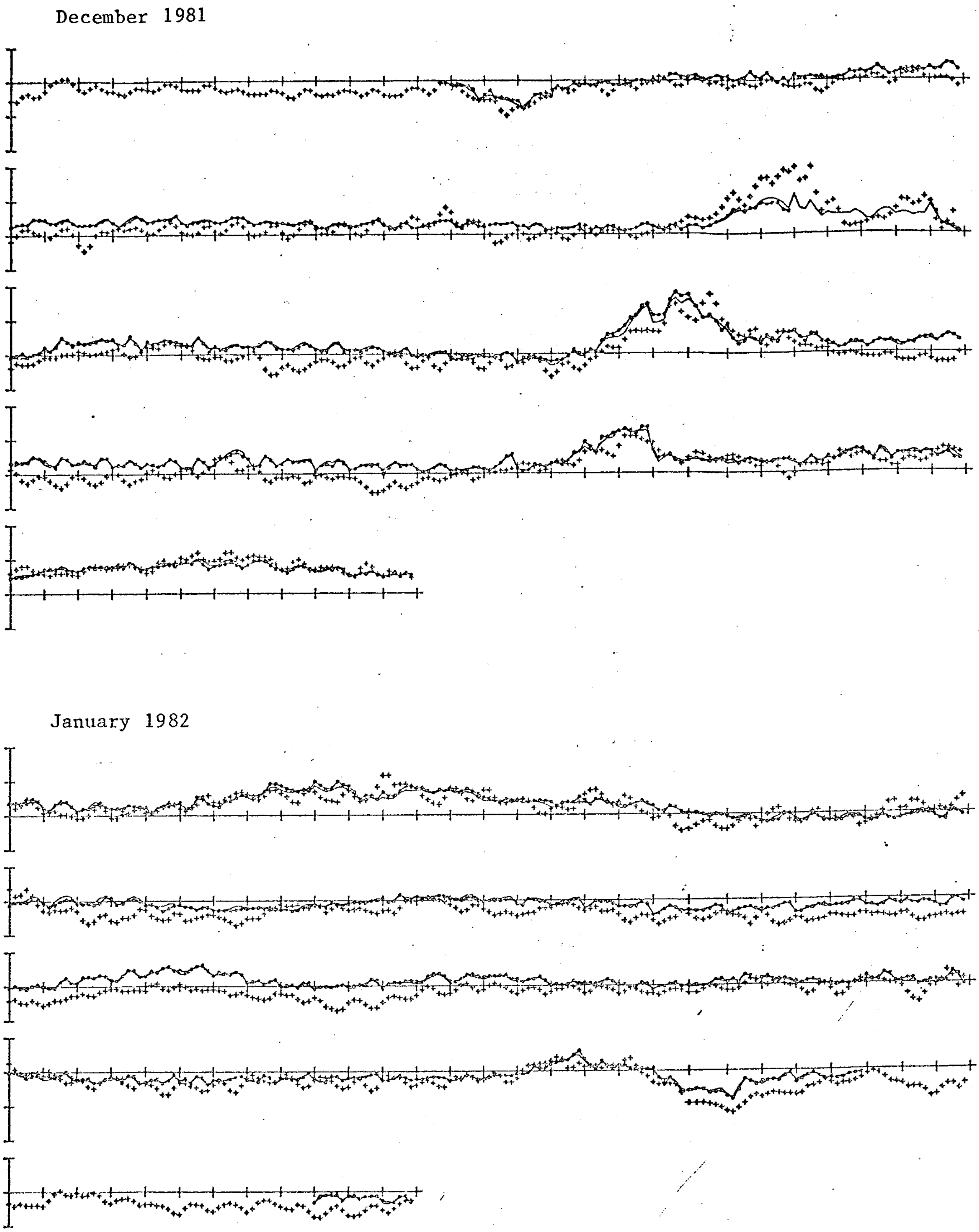
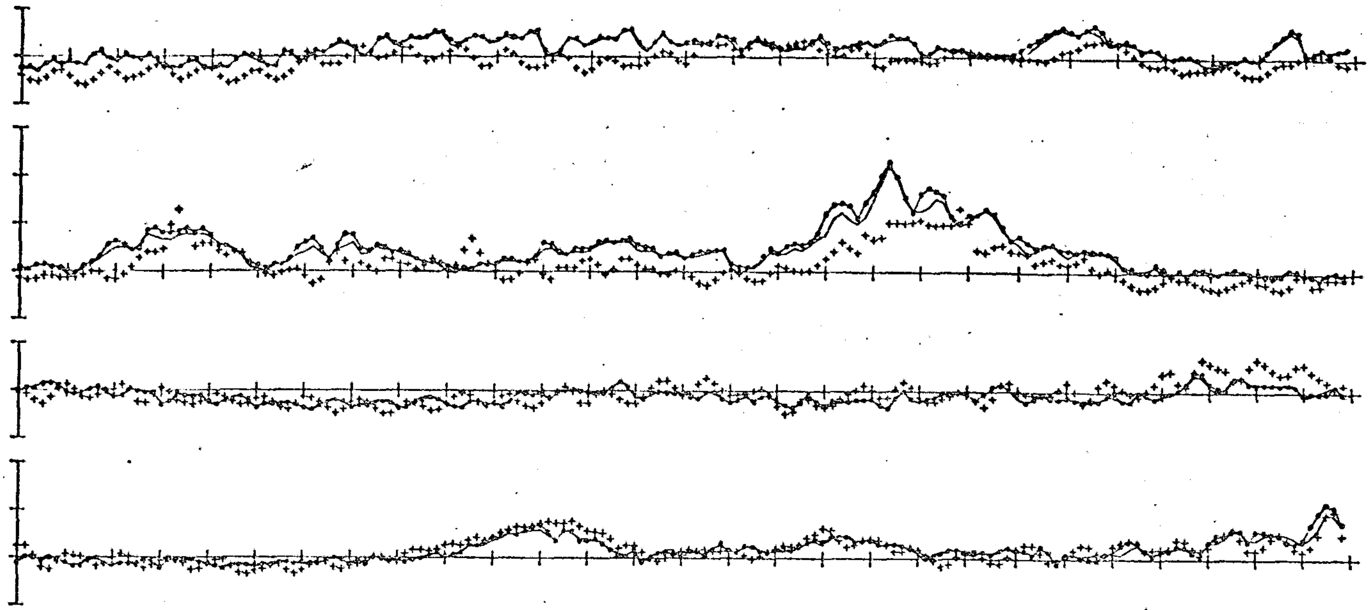


Figure 14 : Comparison of observed and computed surges at Criccieth (+ + +) observations, continuous line CSM, line with dots WCM. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

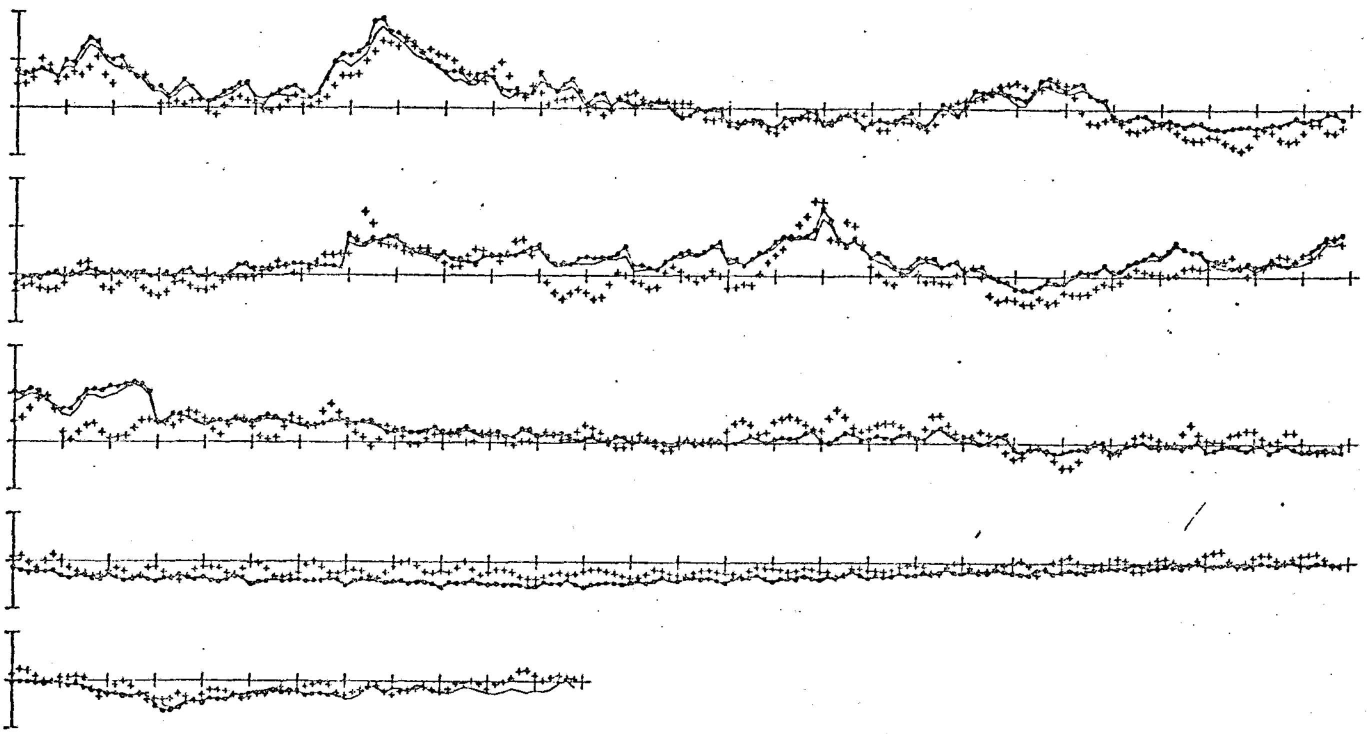
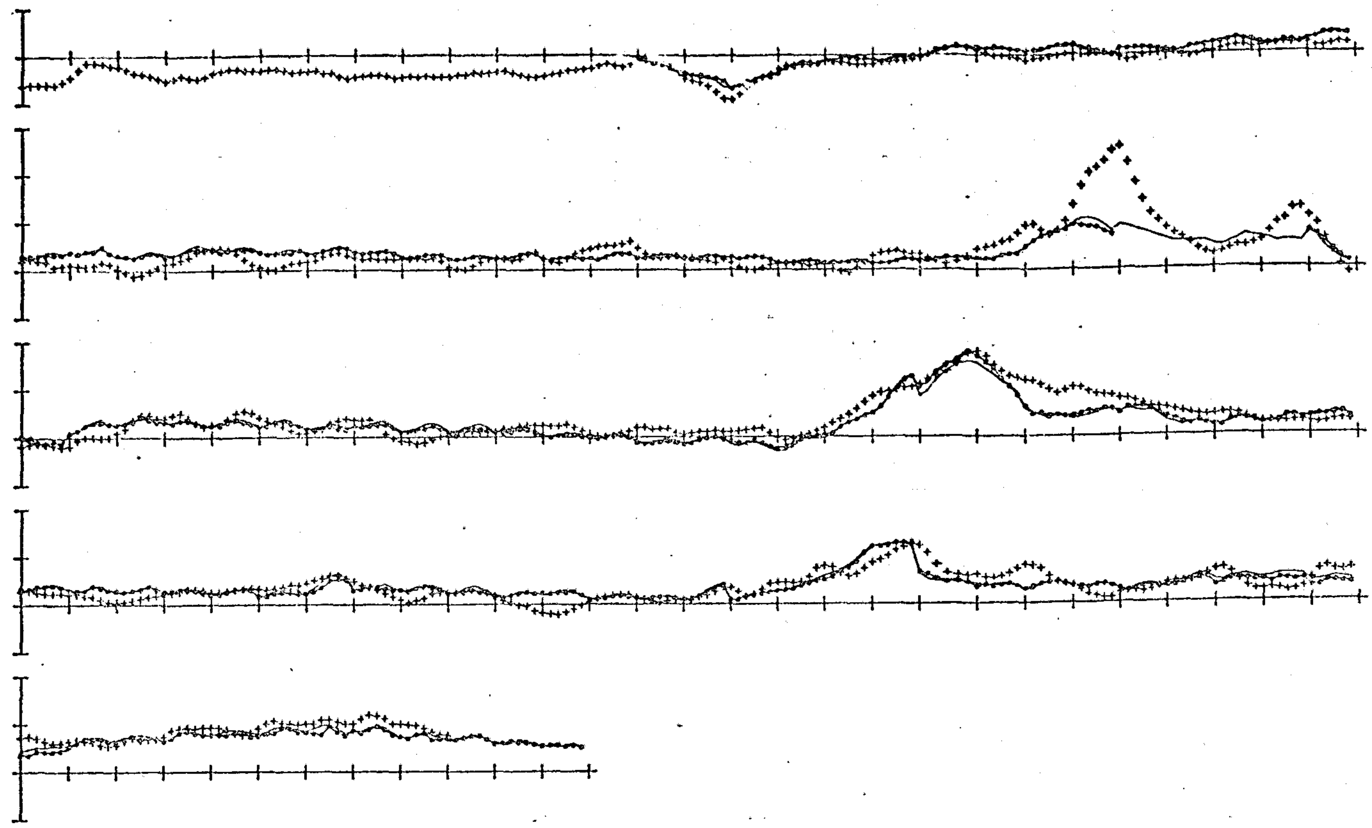


Figure 14 continued.

December 1981



January 1982

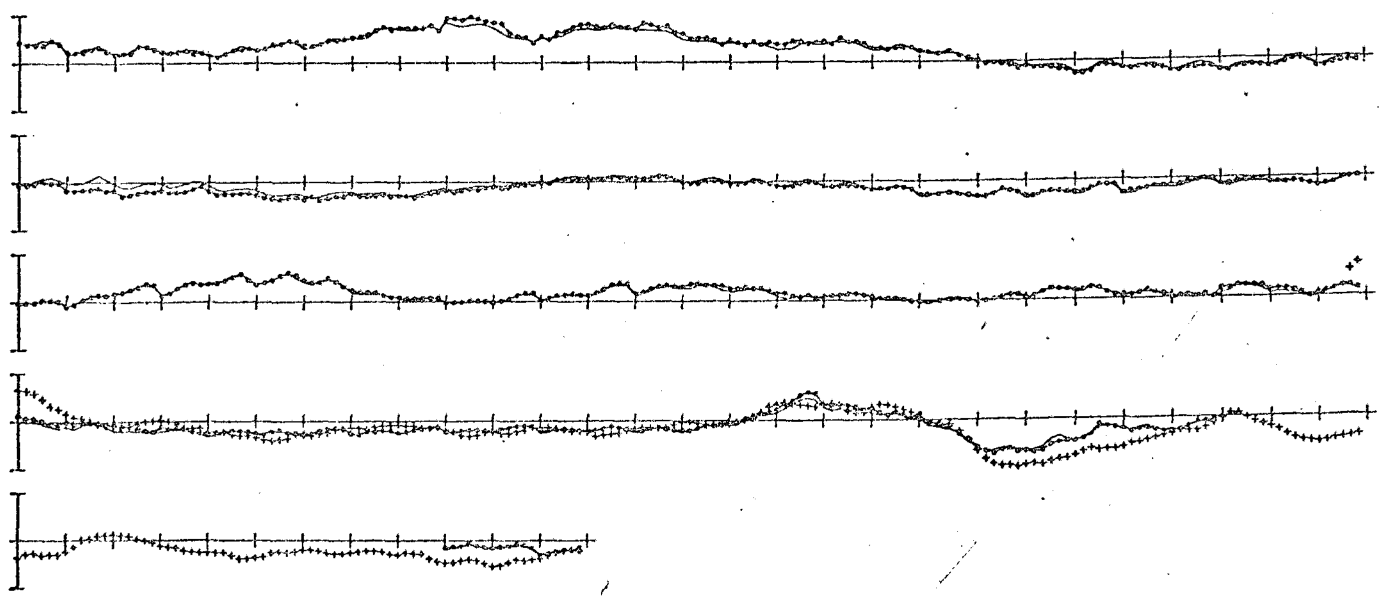
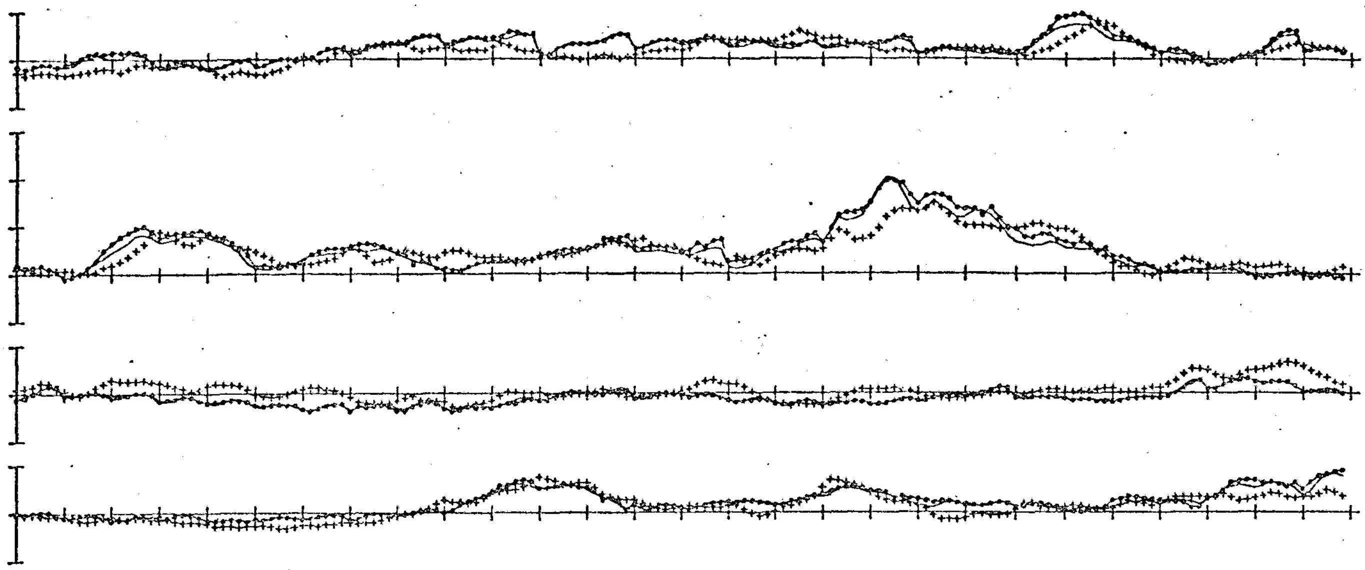


Figure 15 : Comparison of observed and computed surges at Holyhead (+ + +) observations, continuous line CSM, line with dots WCM. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

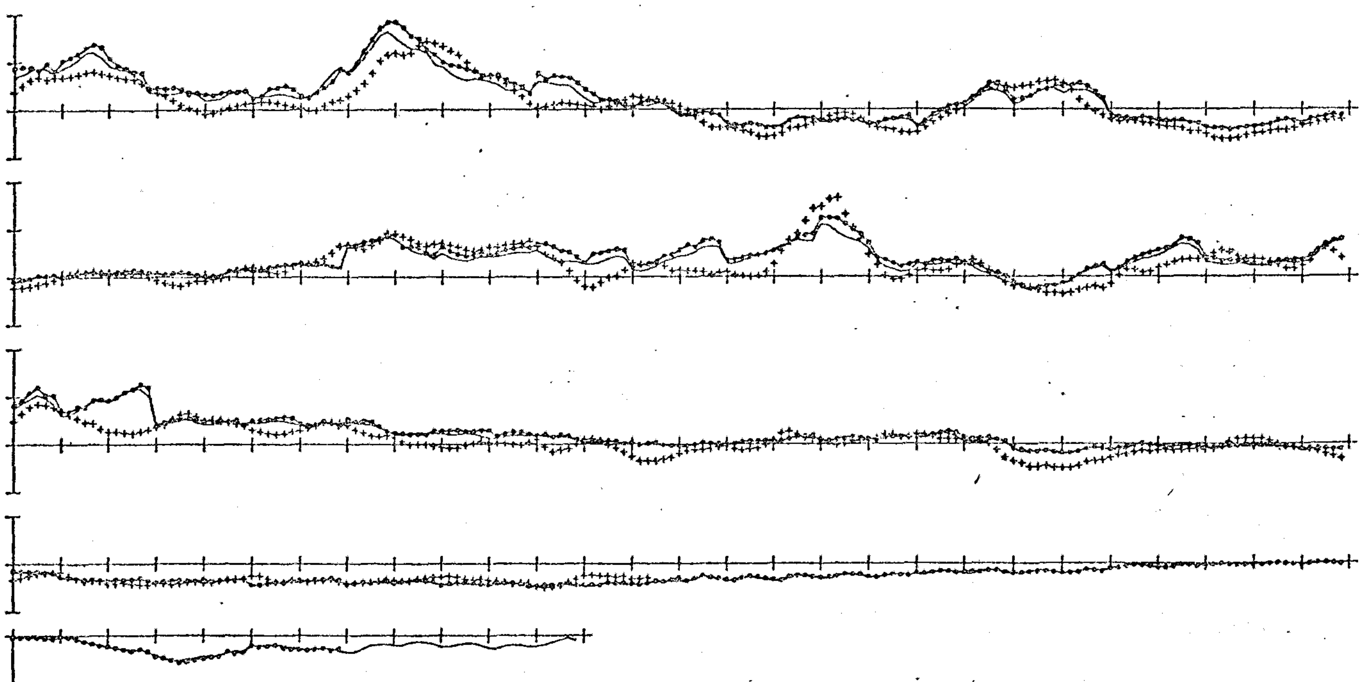
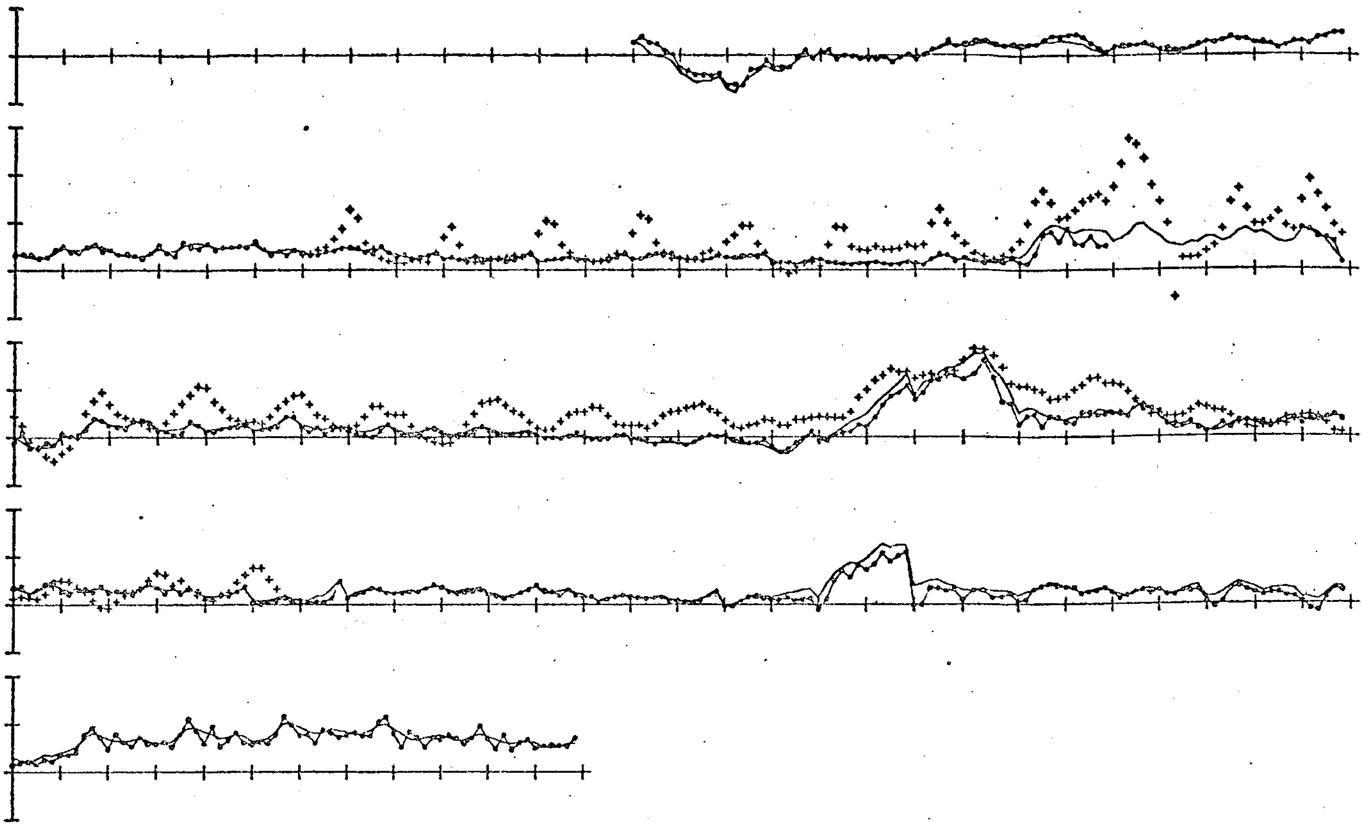


Figure 15 continued.

December 1981



January 1982

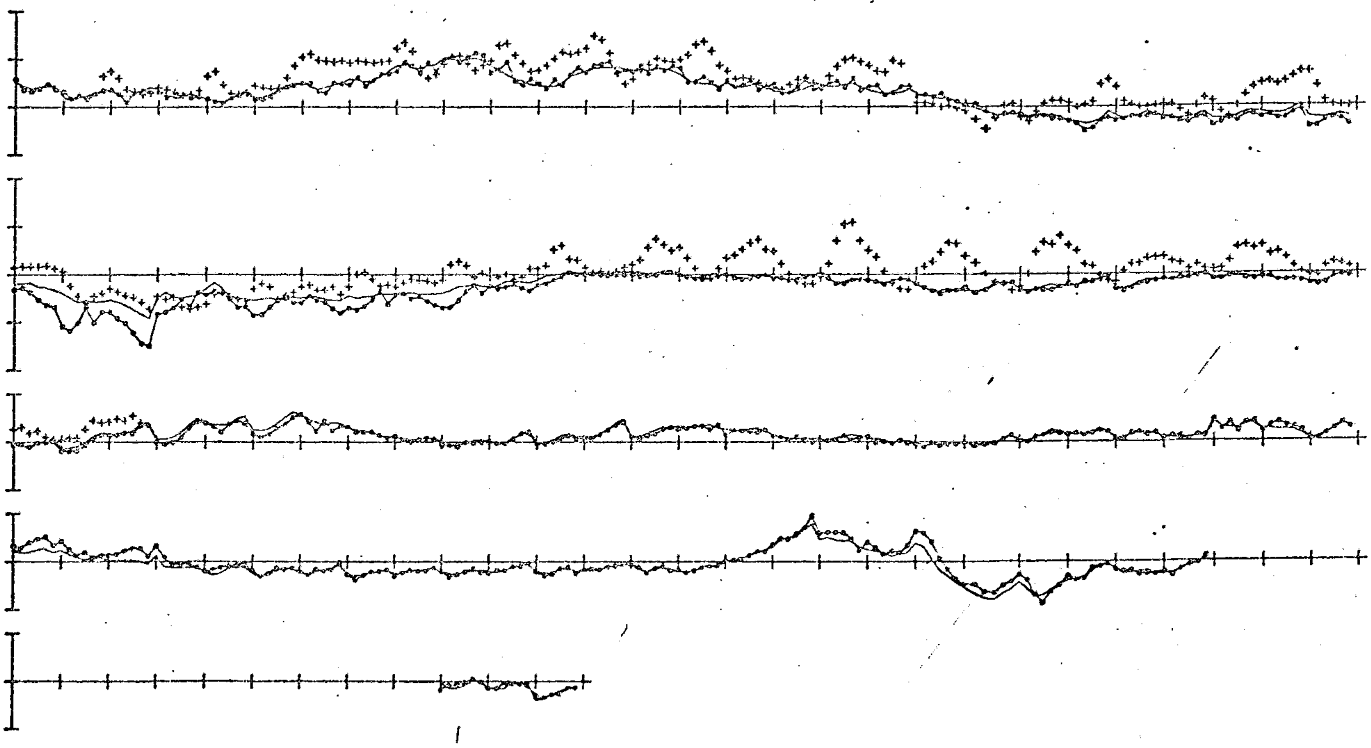
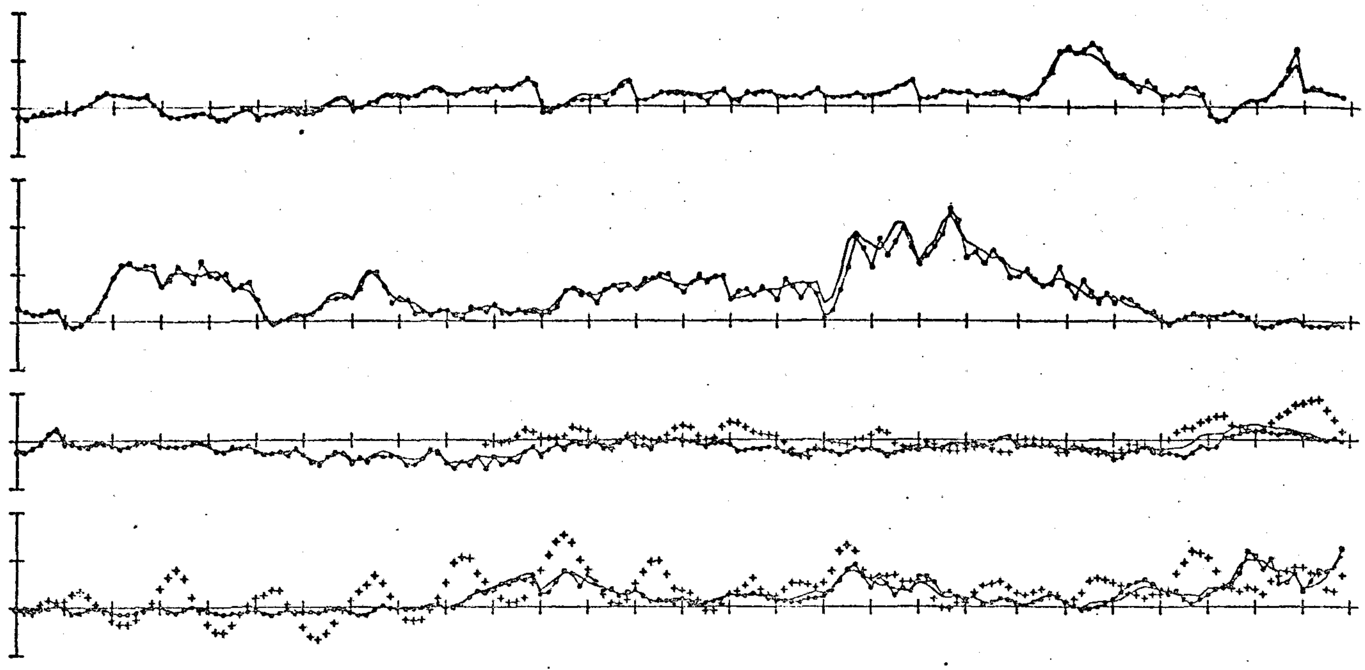


Figure 16 : Comparison of observed and computed surges at Hilbre Island (+ + +) observations, continuous line CSM, line with dots WCM.
Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

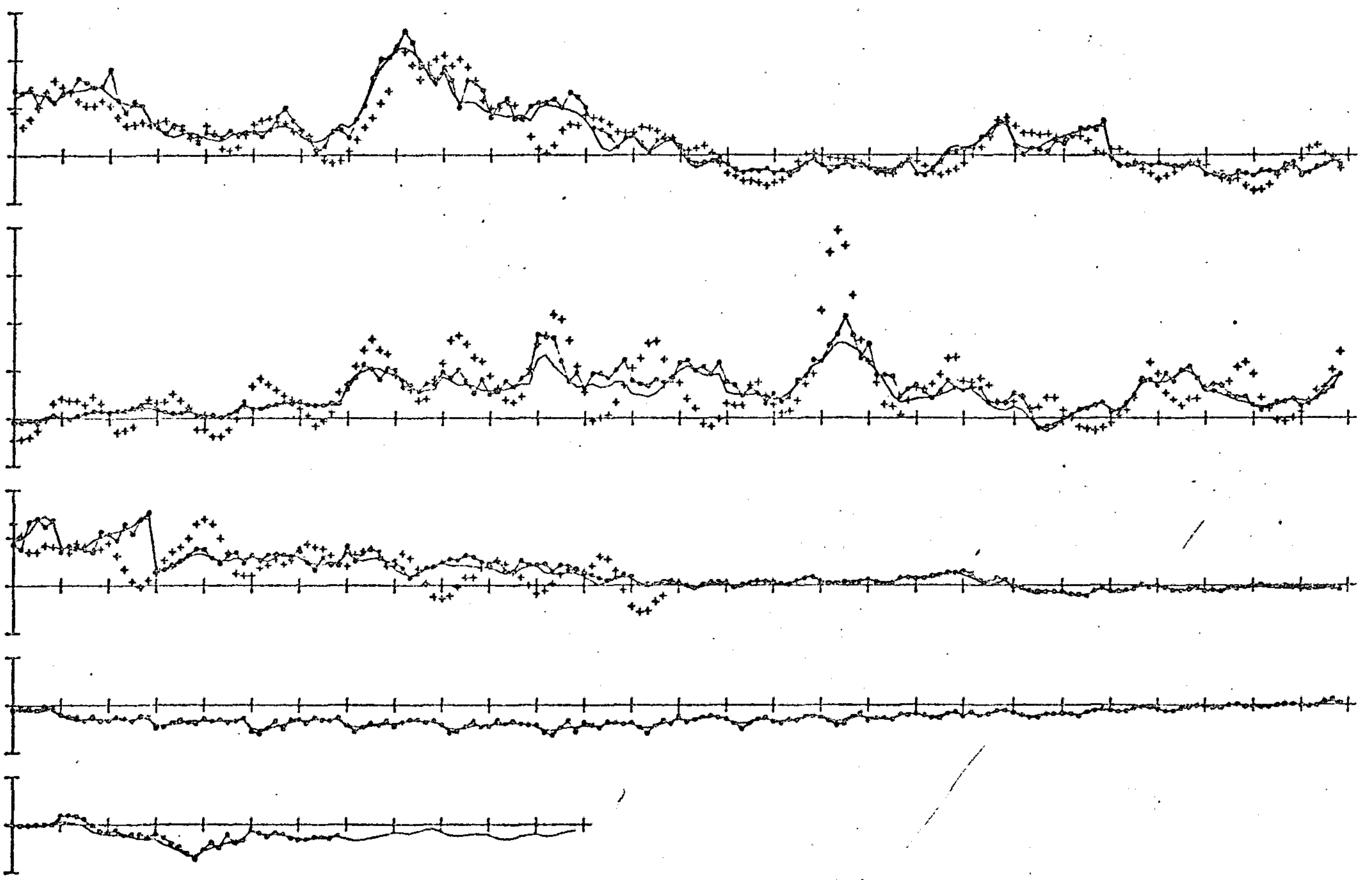


Figure 16 continued.

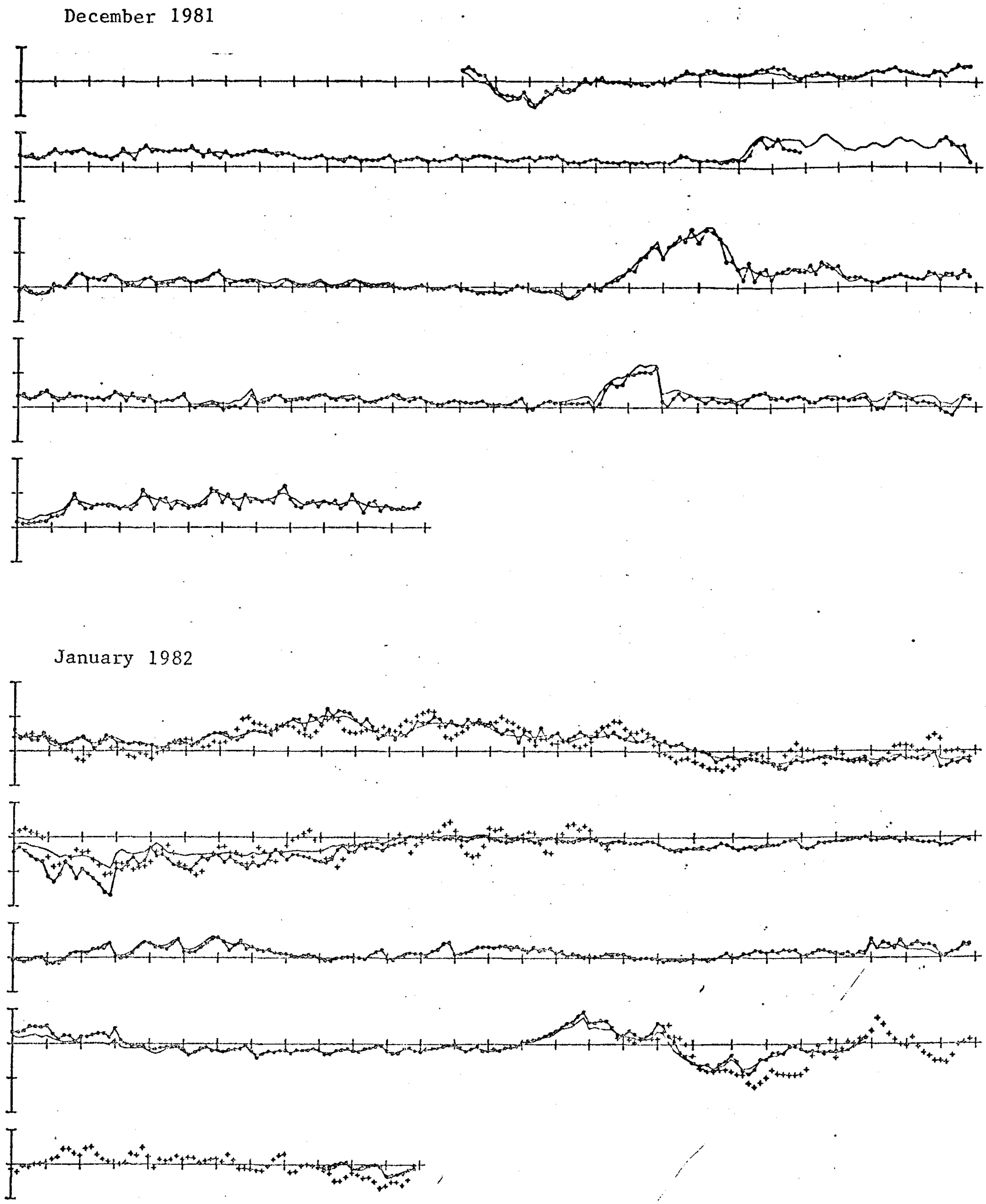
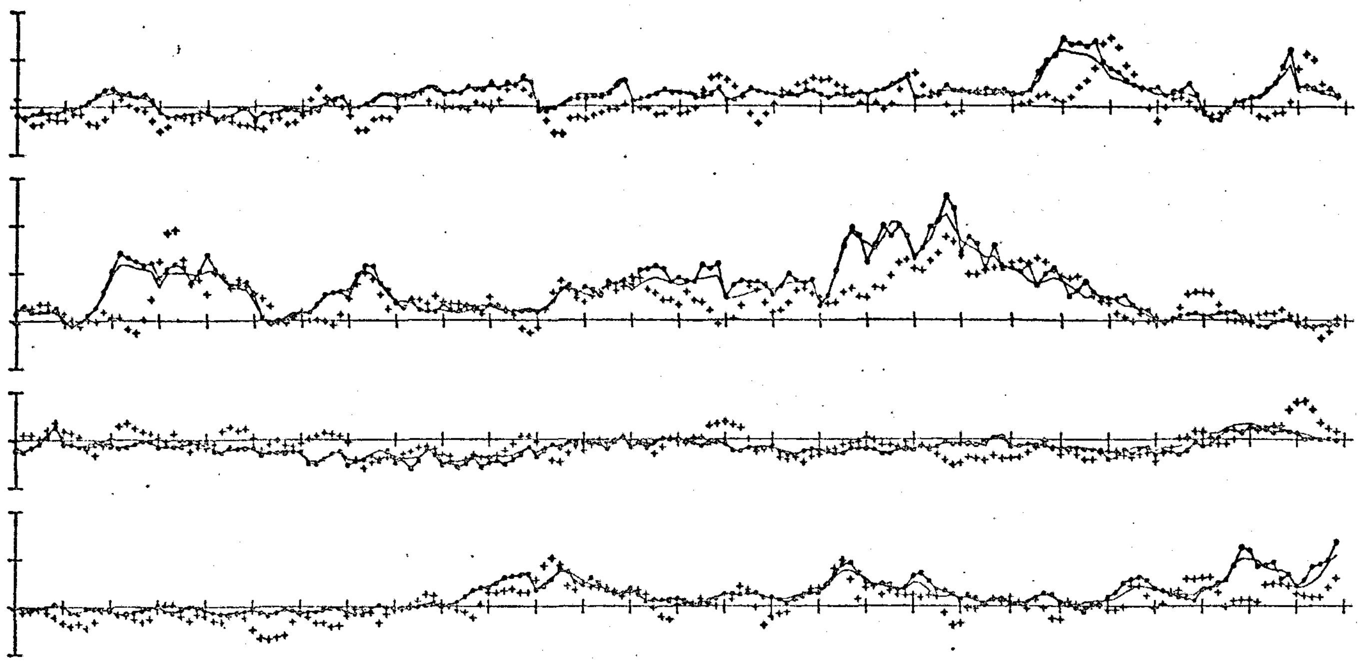


Figure 17 : Comparison of observed and computed surges at Liverpool (+ + +) observations, continuous line CSM, line with dots WCM. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

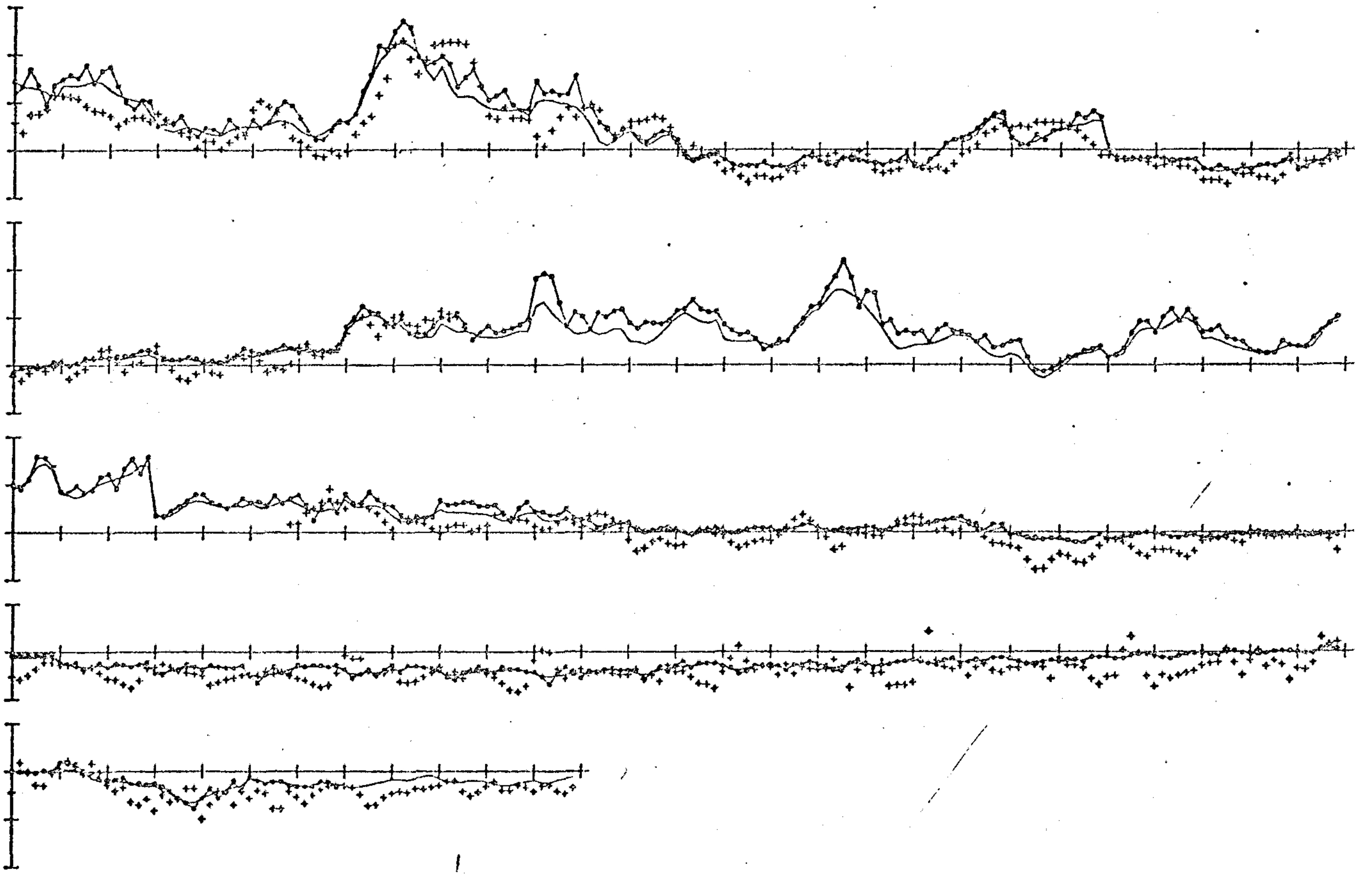
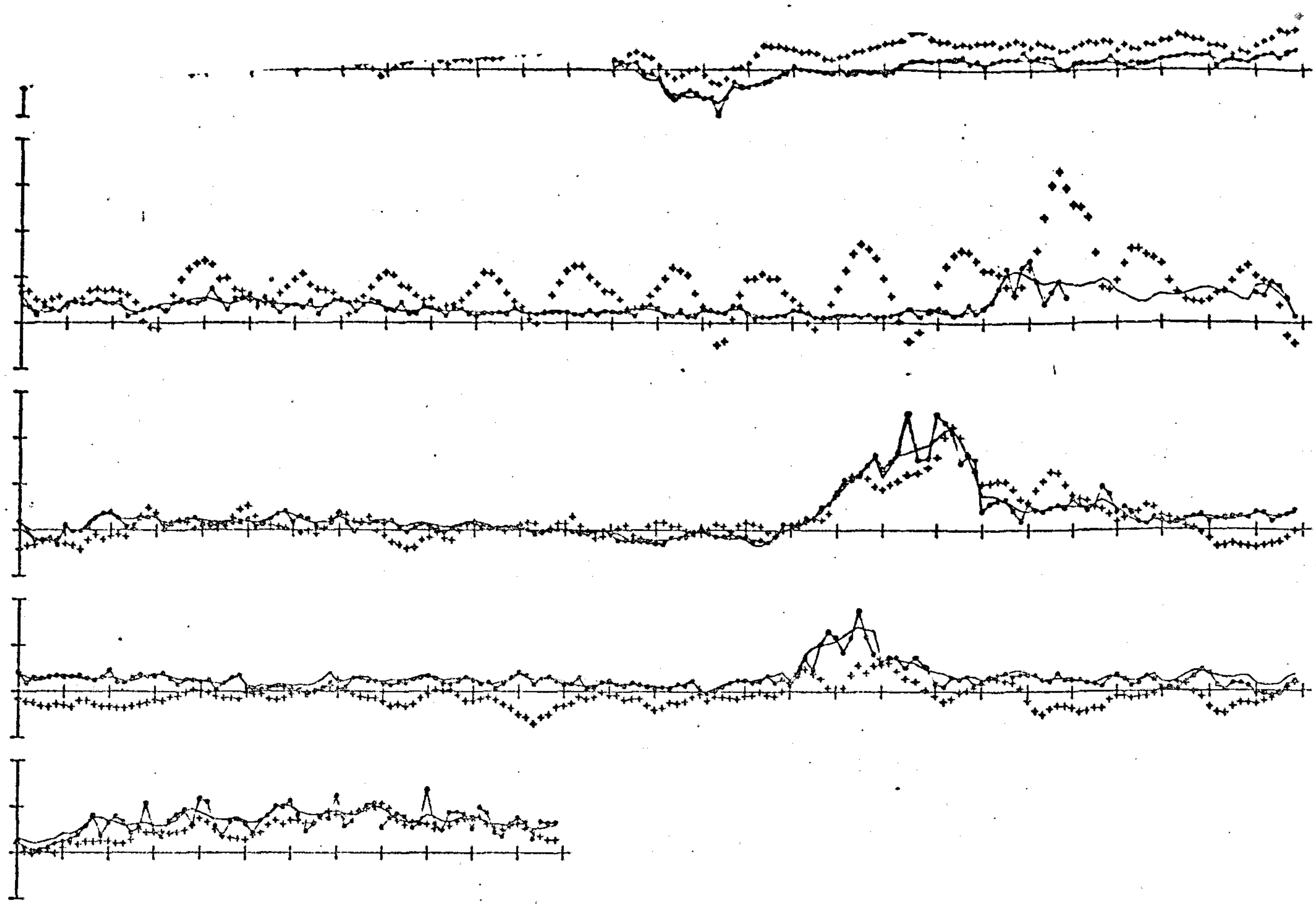


Figure 17 continued.



January 1982

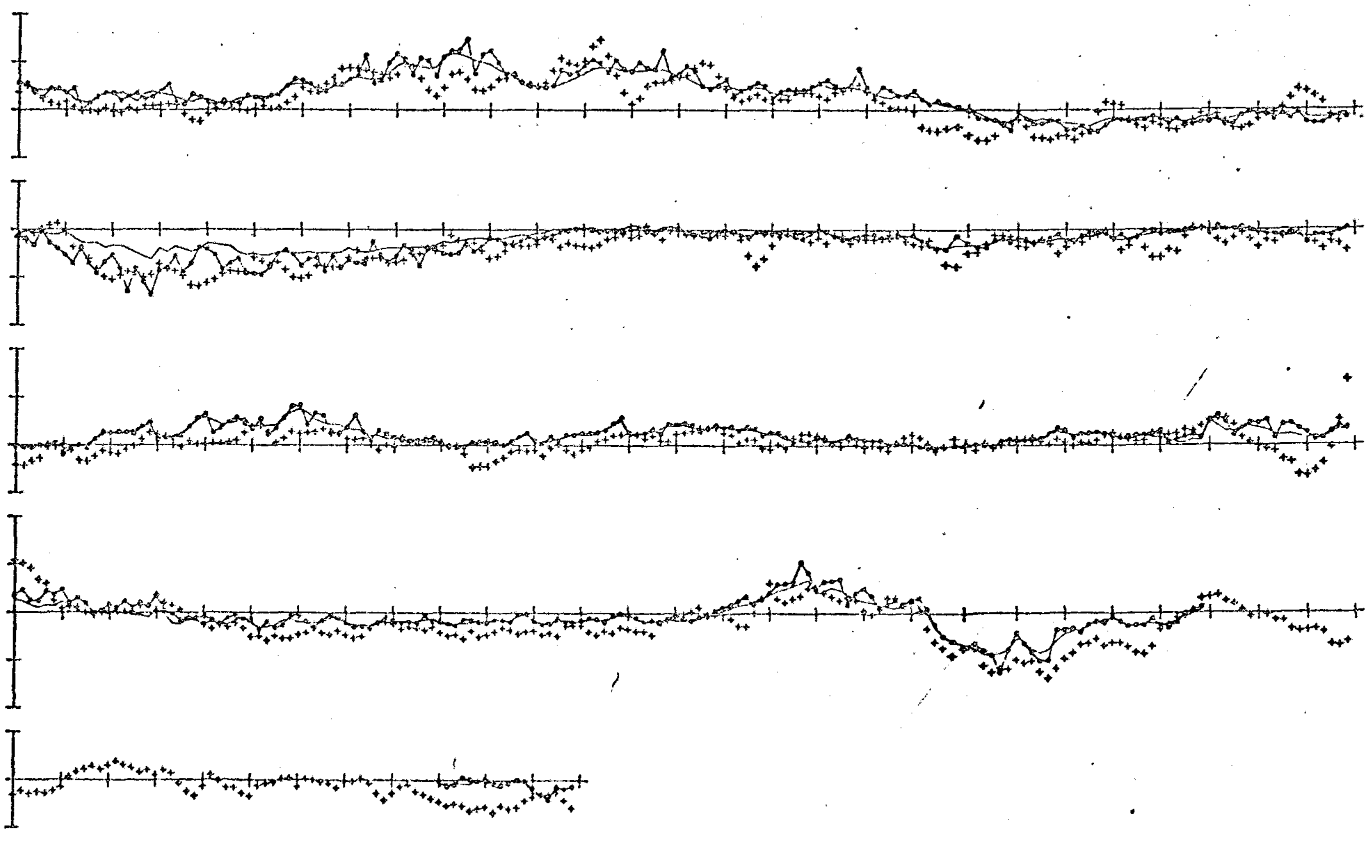
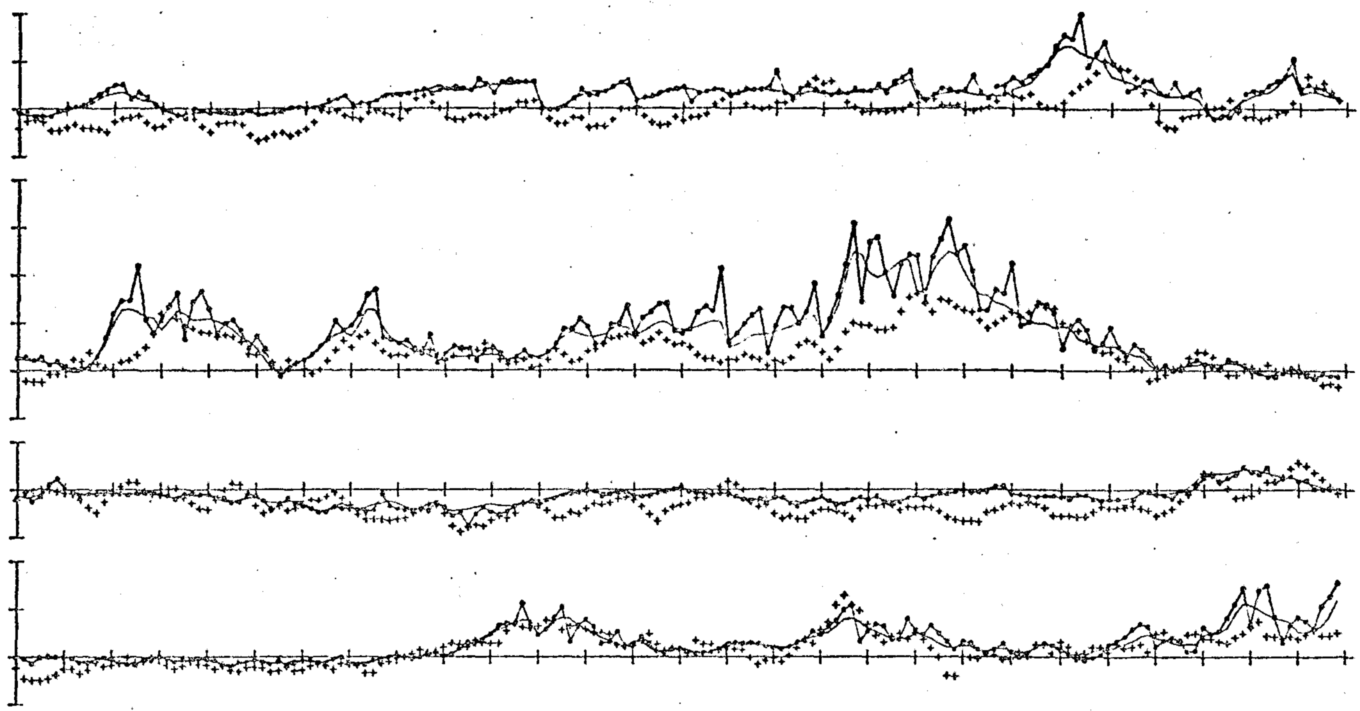


Figure 18 : Comparison of observed and computed surges at Heysham (+ + +) observations, continuous line CSM, line with dots WCM. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

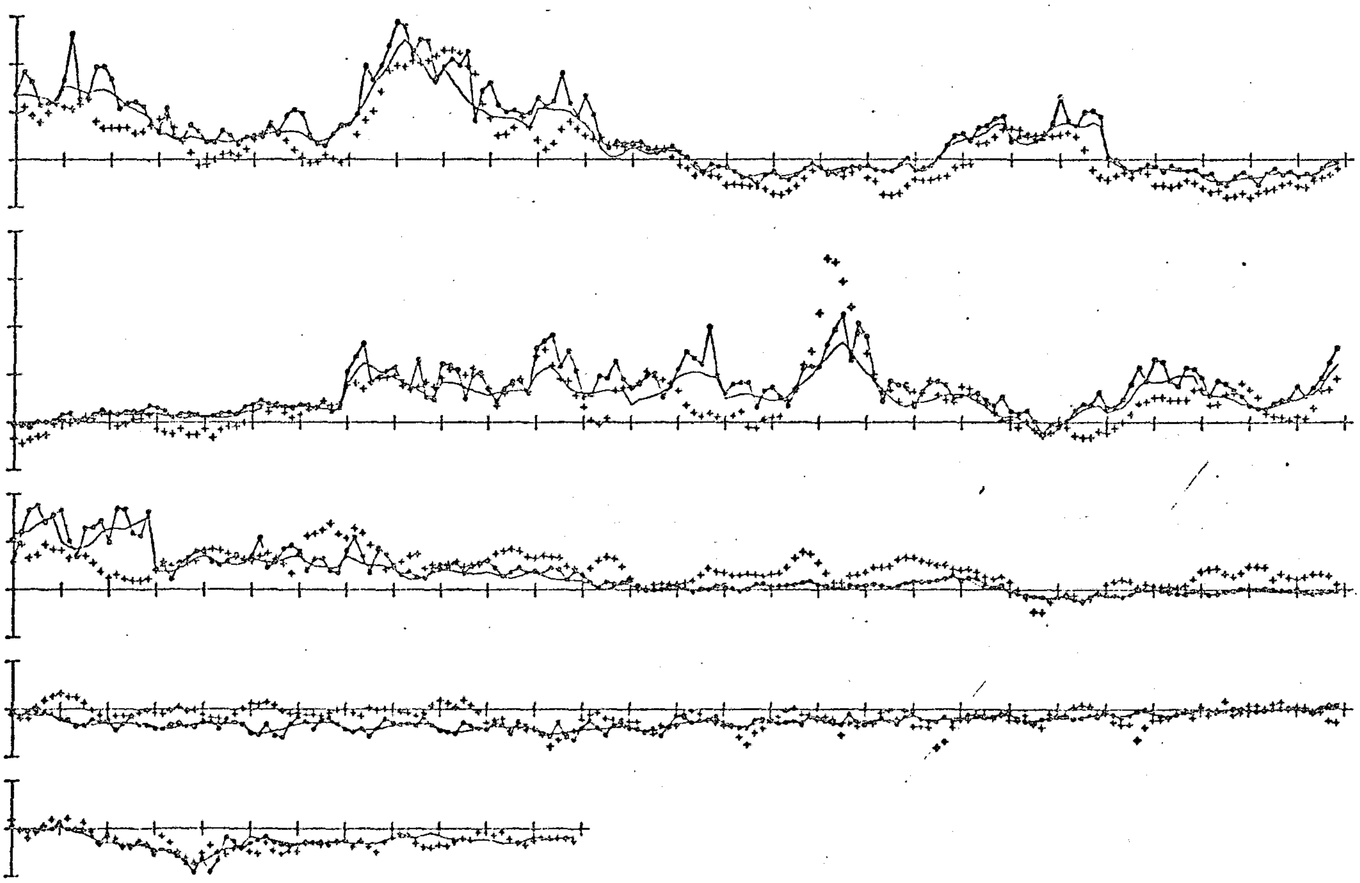
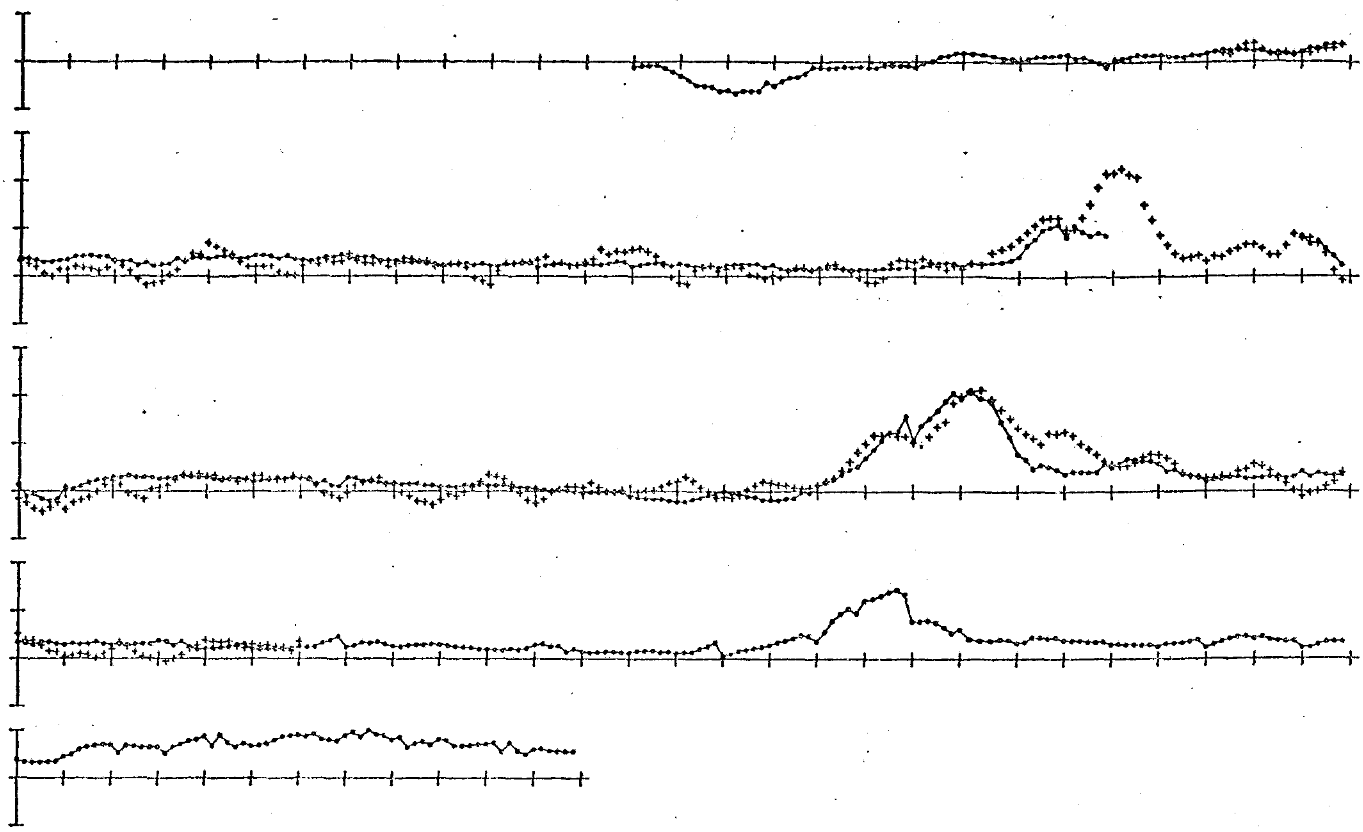


Figure 18 continued.

December 1981



January 1982

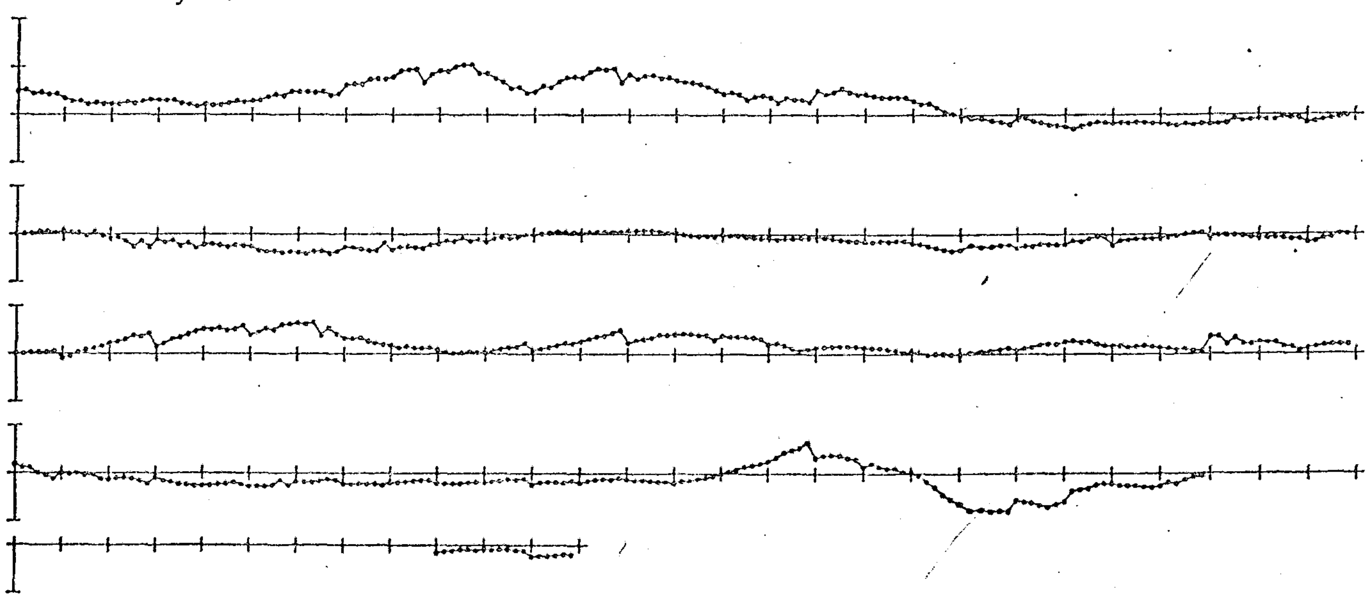
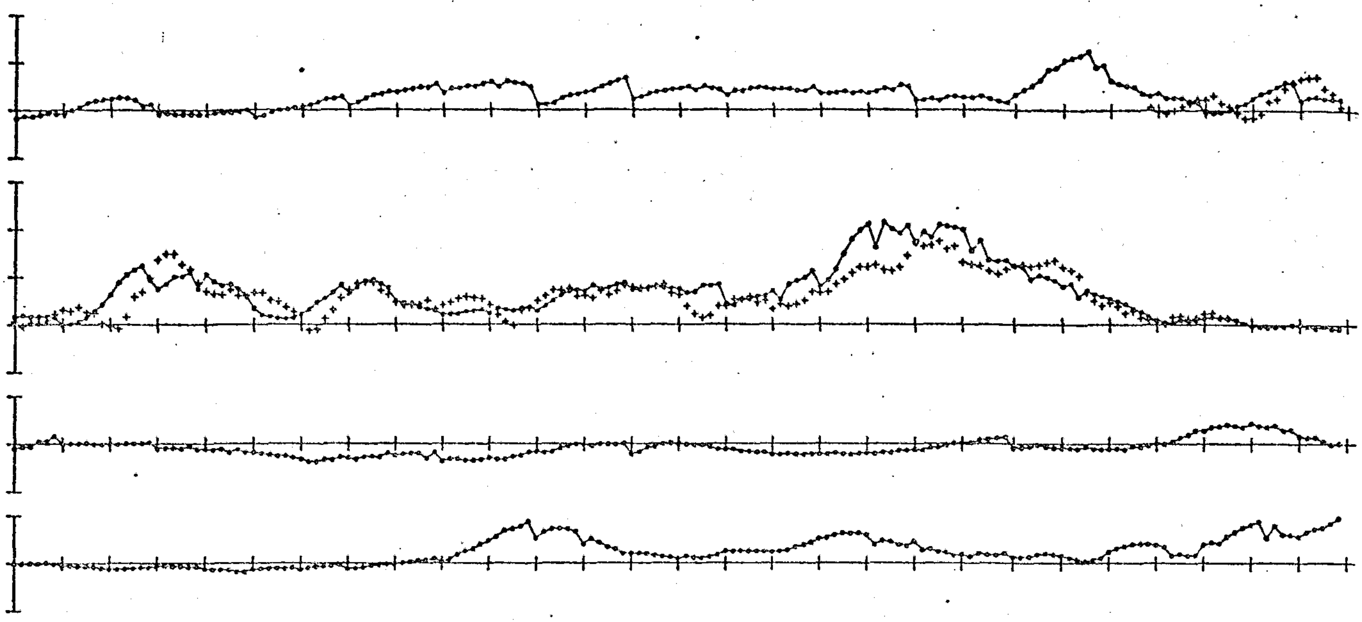


Figure 19 : Comparison of observed and computed surges at Douglas
(+ + +) observations, continuous line with dots WCM, no CSM data.
Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

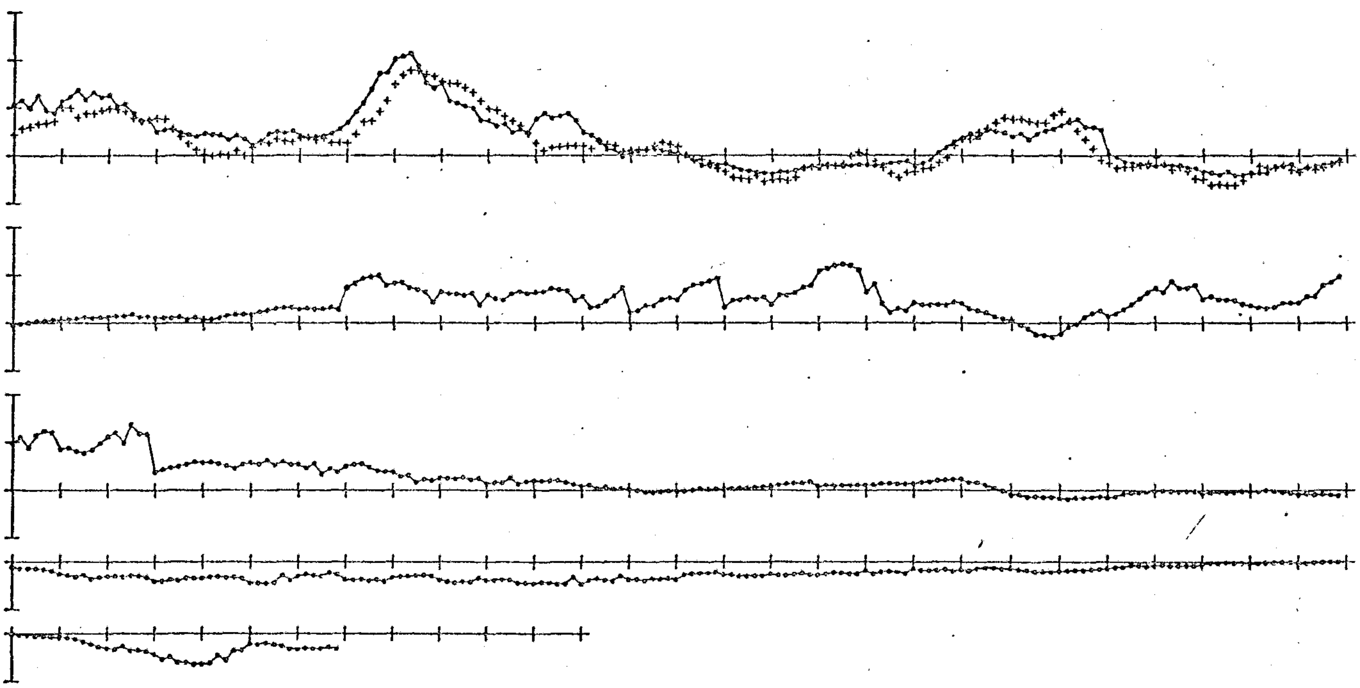
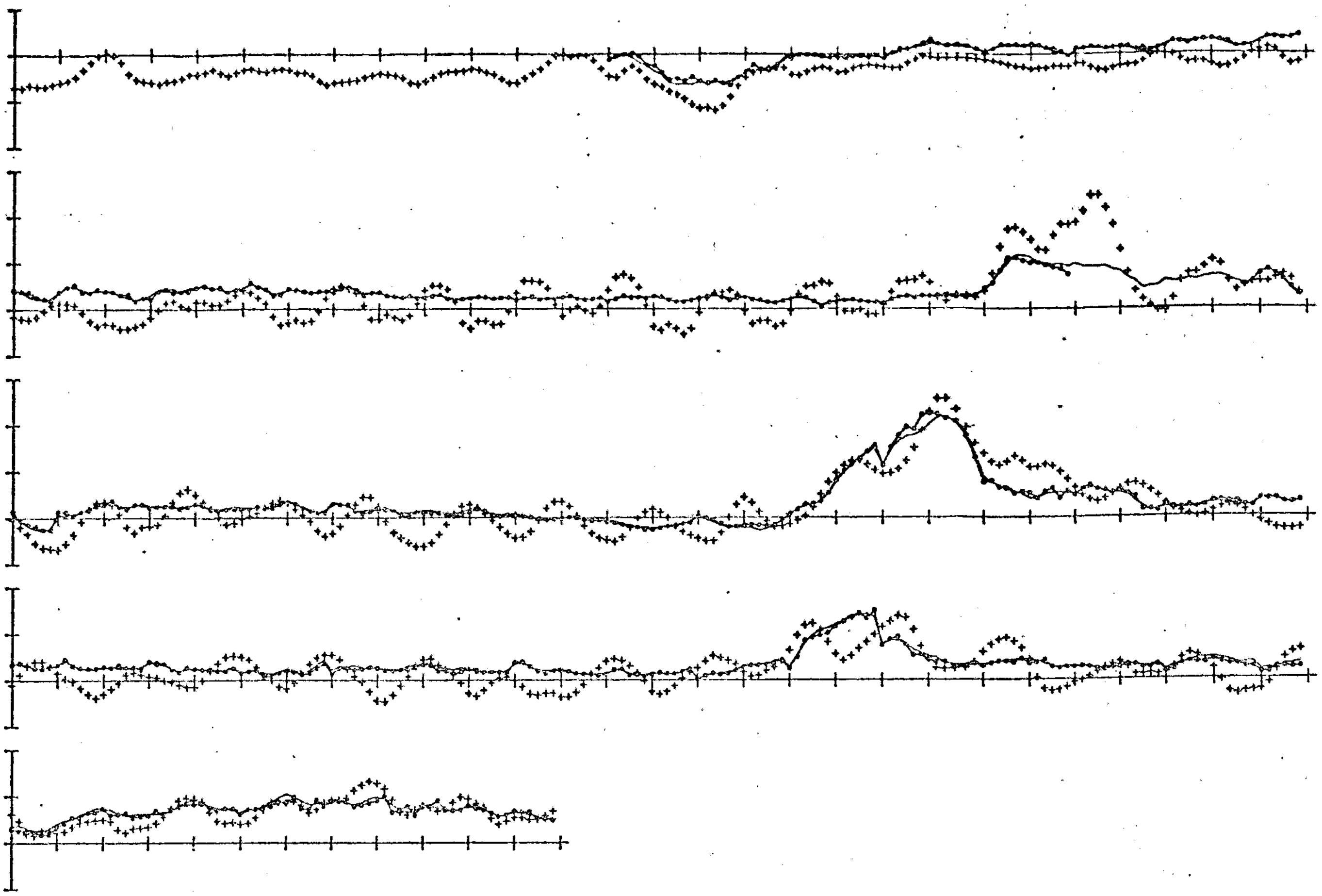


Figure 19 continued.

December 1981



January 1982

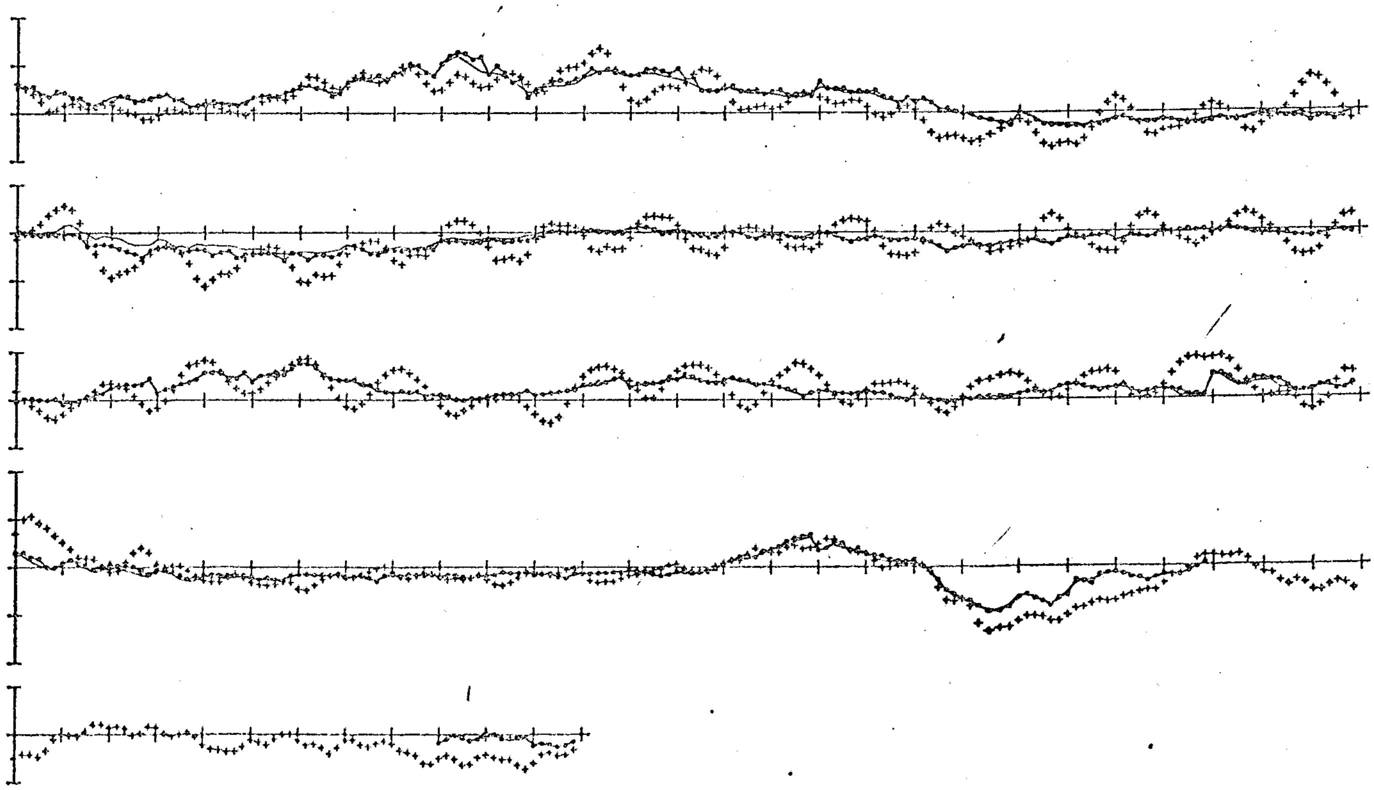
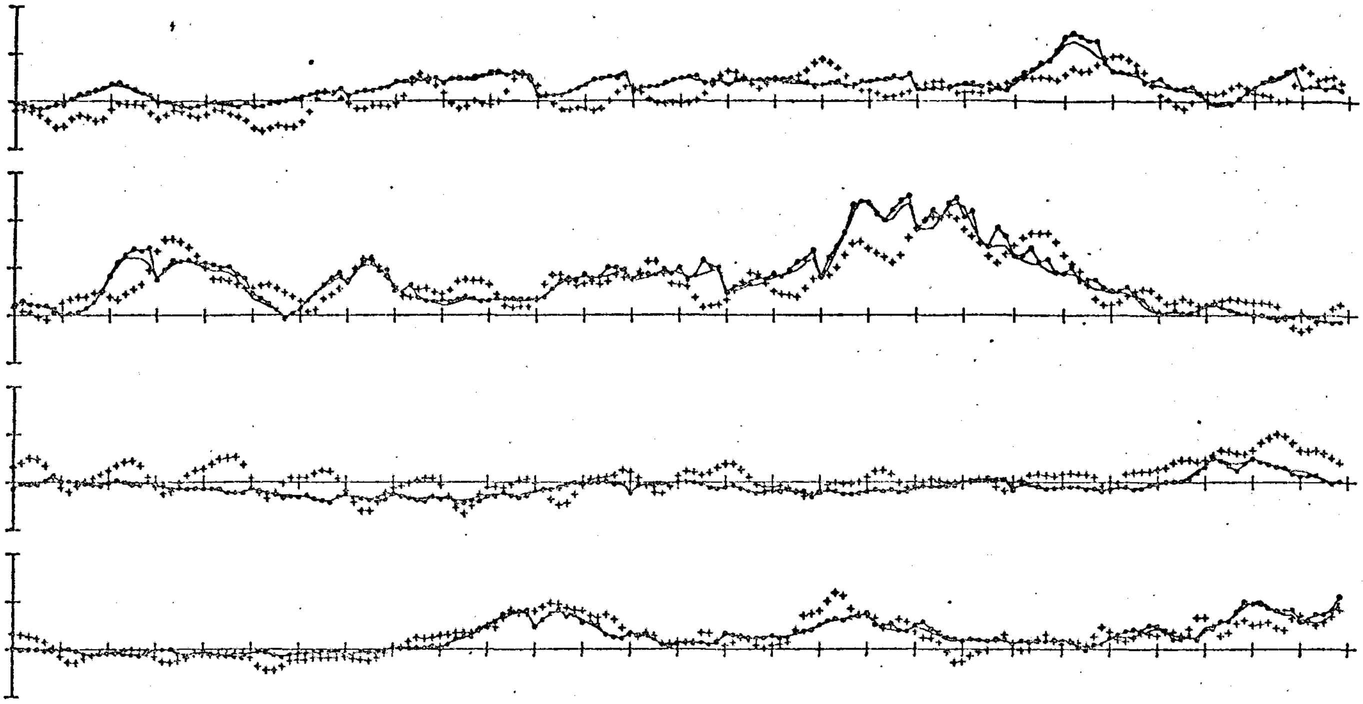


Figure 20 : Comparison of observed and computed surges at Workington (+ + +) observations, continuous line CSM, line with dots WCM. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

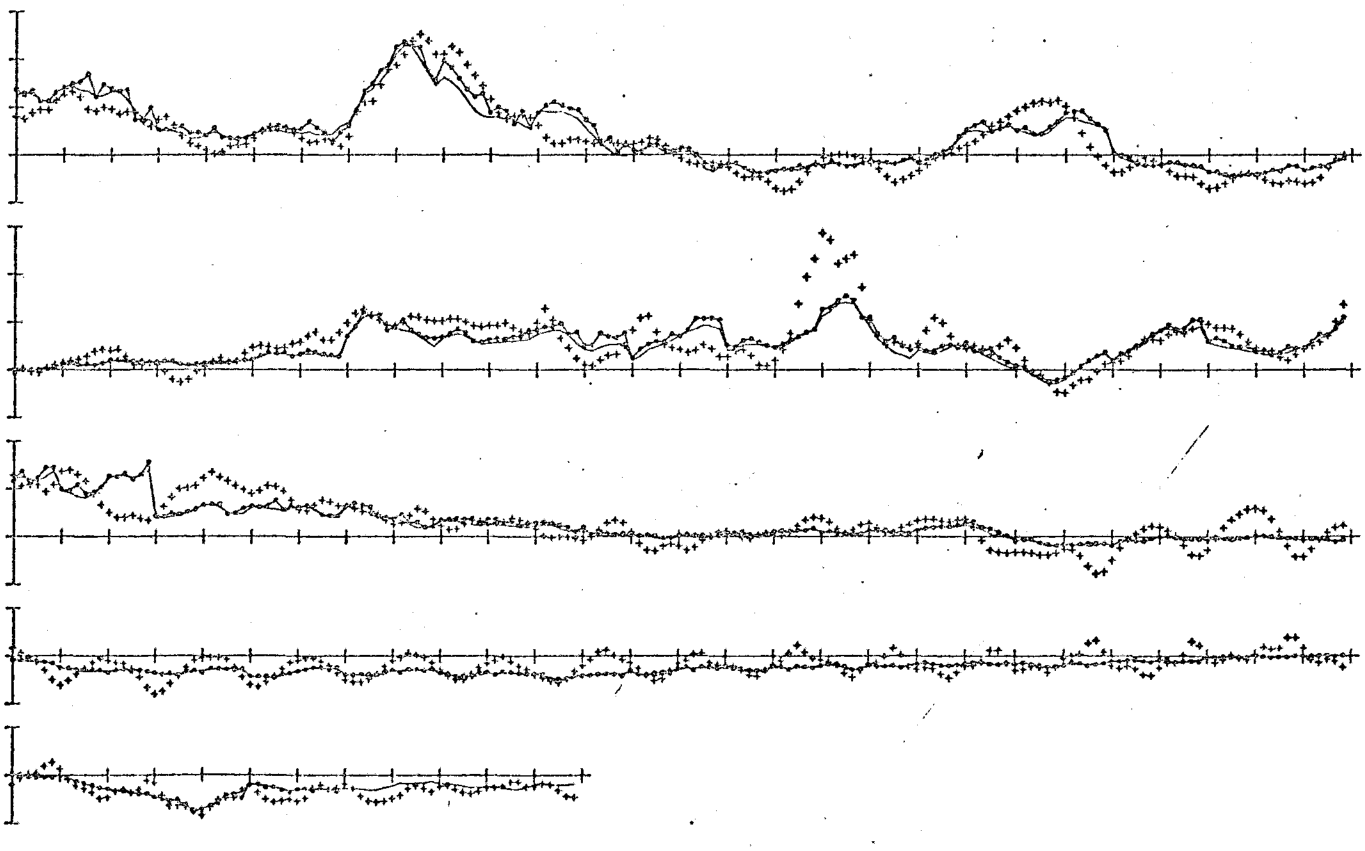
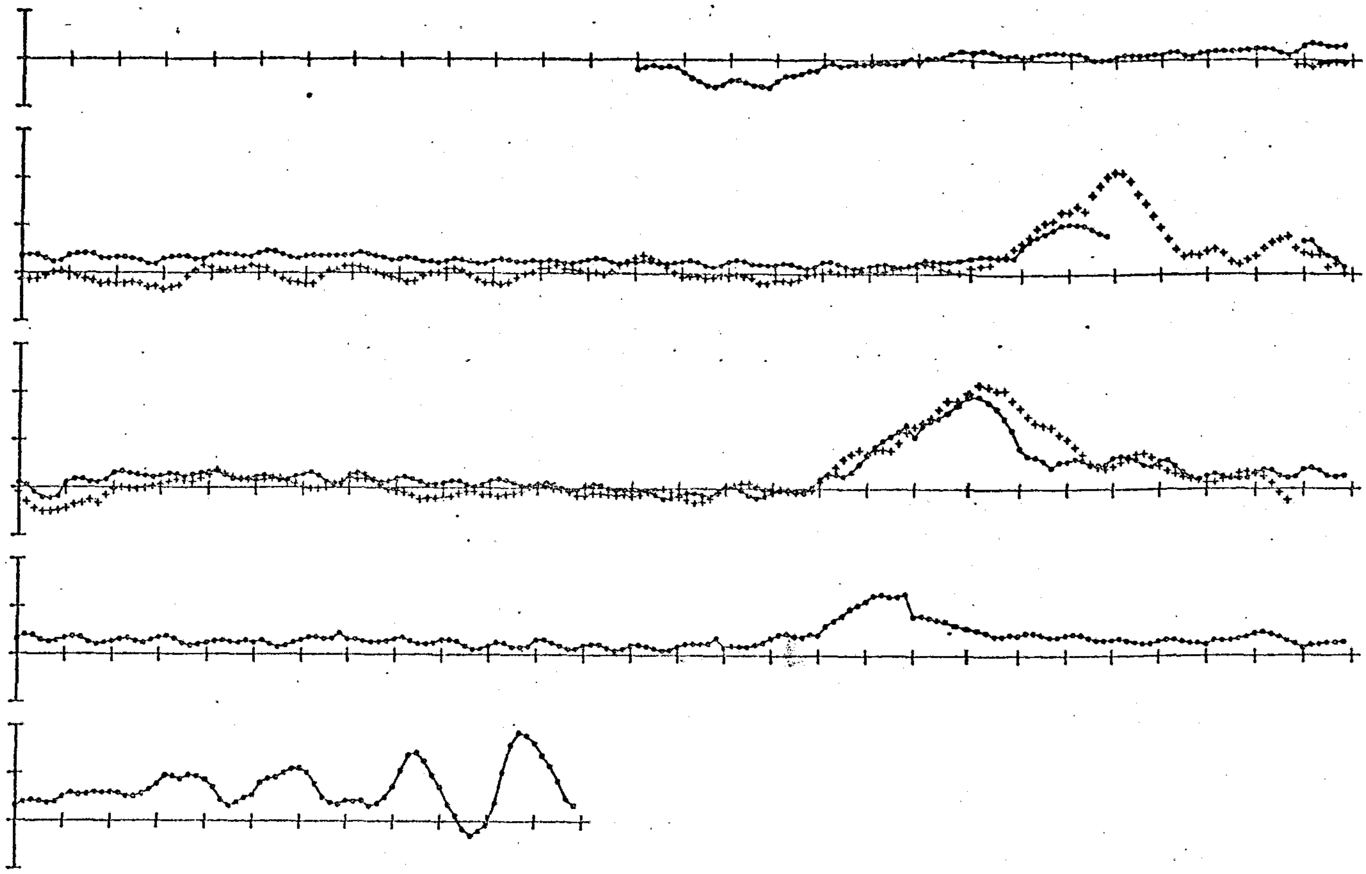


Figure 20 continued.

December 1981



January 1982

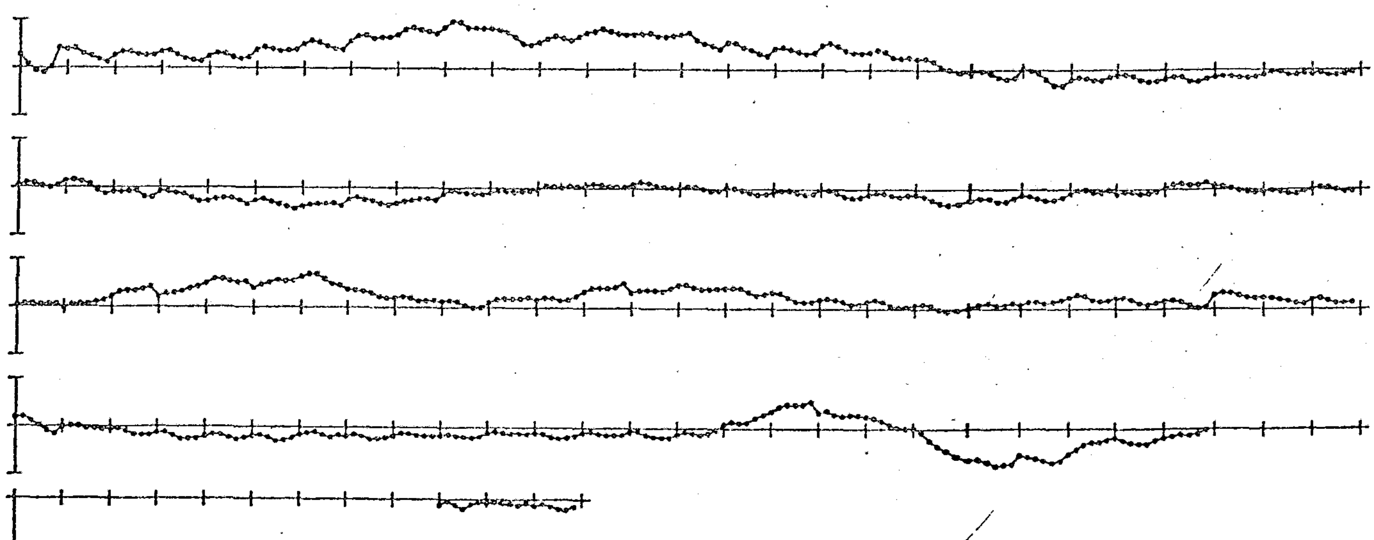


Figure 21 : Comparison of observed and computed surges at Portpatrick (+ + +) observations, continuous line with dots WCM, no CSM data.
Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982

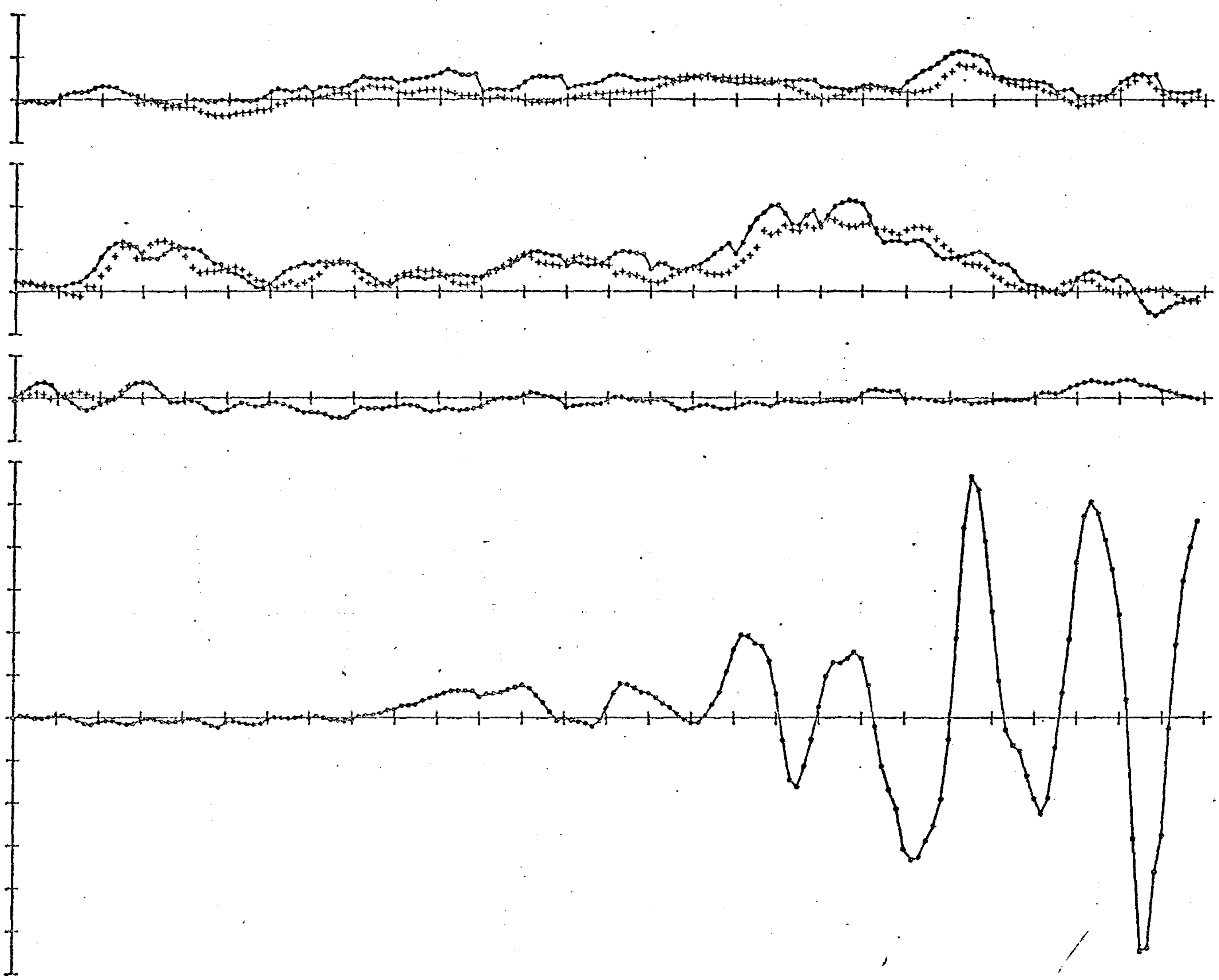


Figure 21 continued.

March 1982

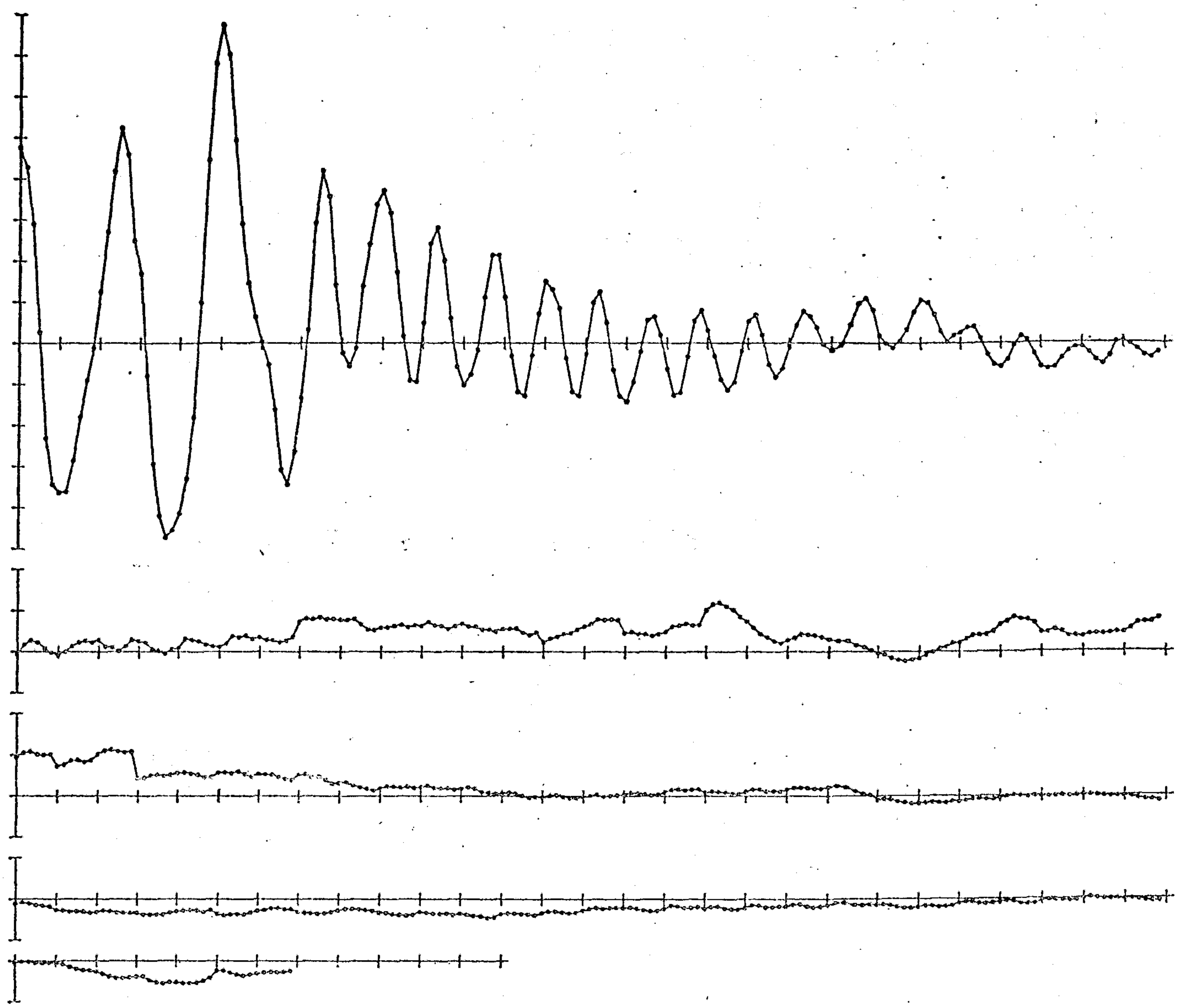
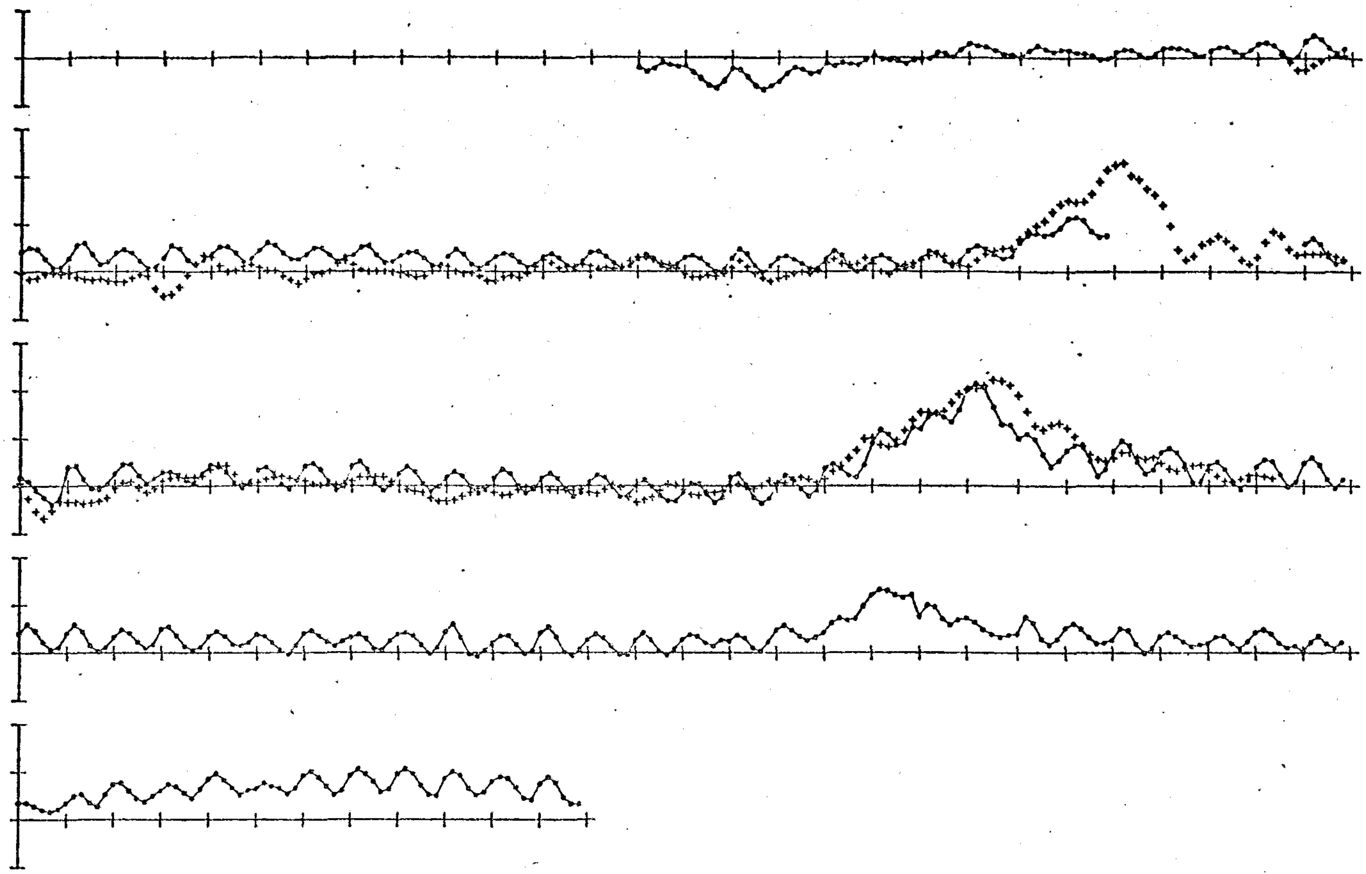


Figure 21 continued.

December 1981



January 1982

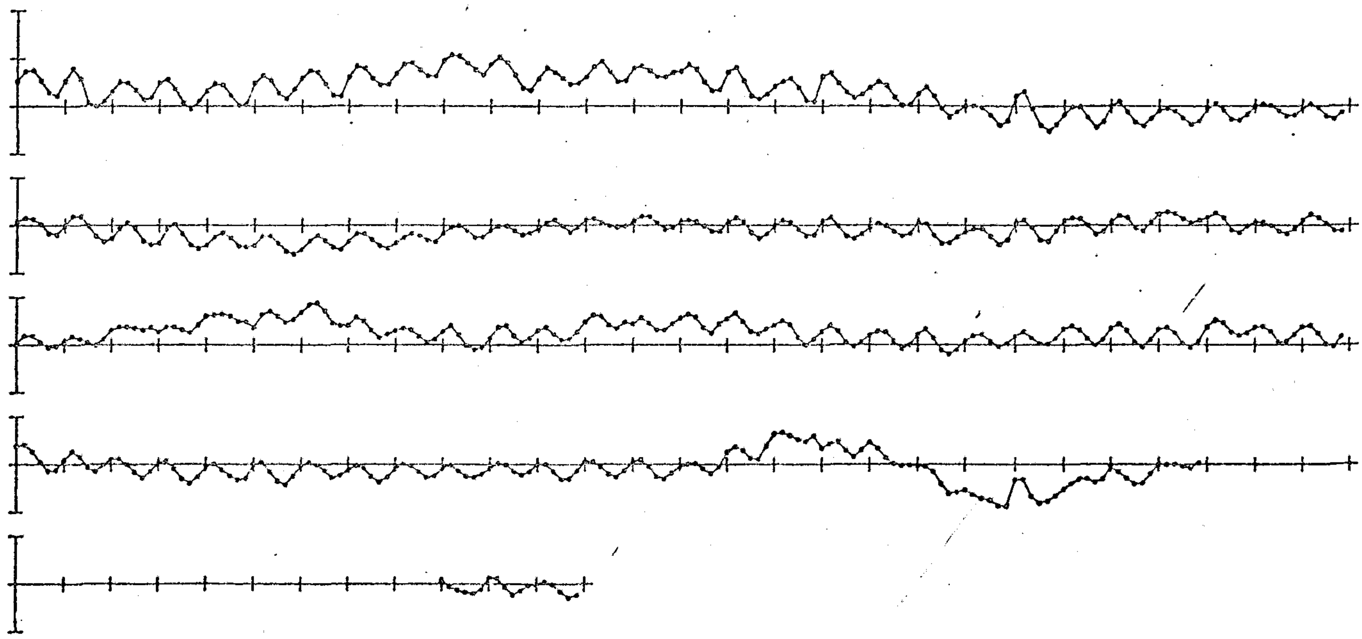
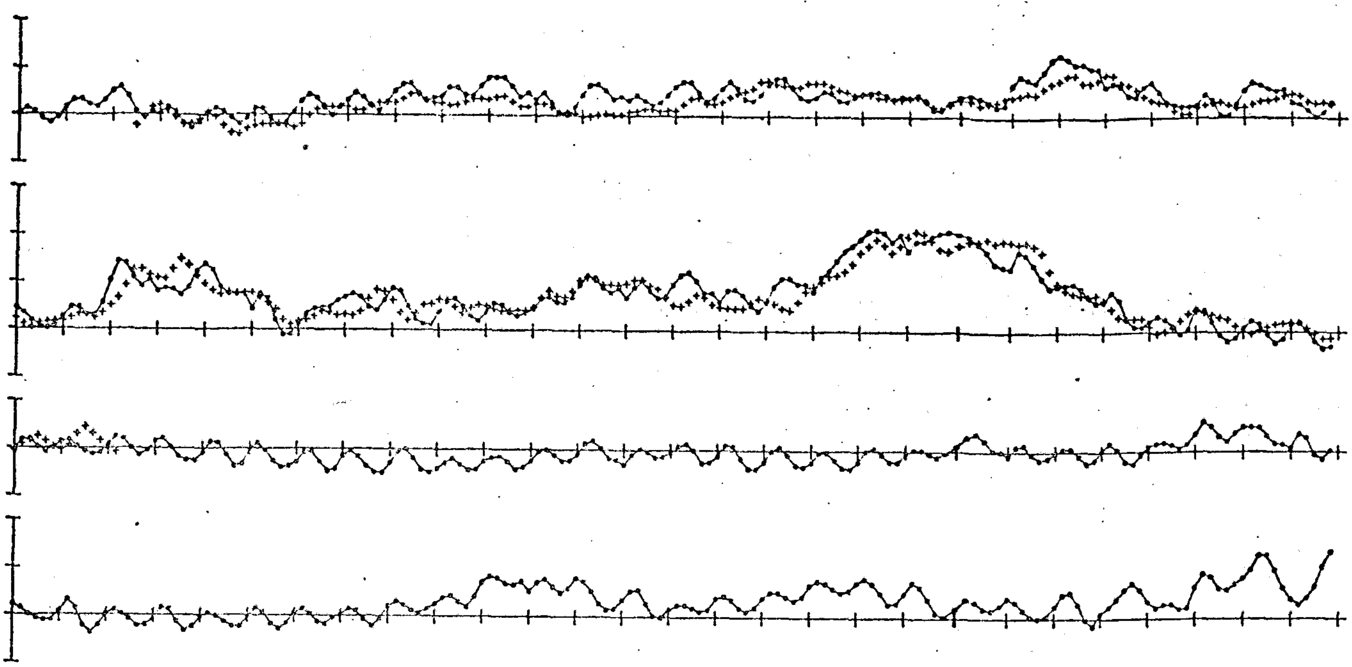


Figure 22 : Comparison of observed and computed surges at Millport
(+ + +) observations, continuous line with dots WCM, no CSM data.
Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

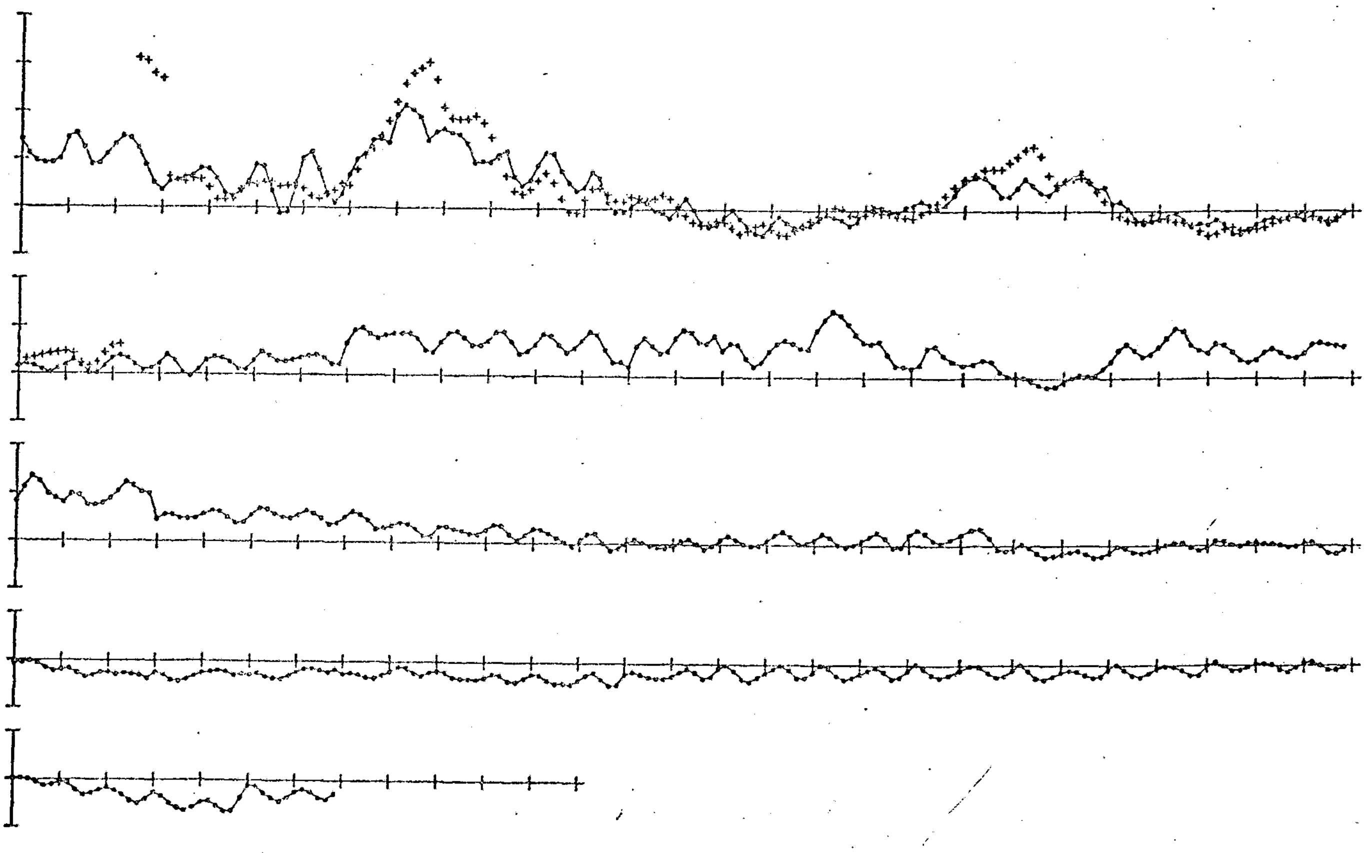
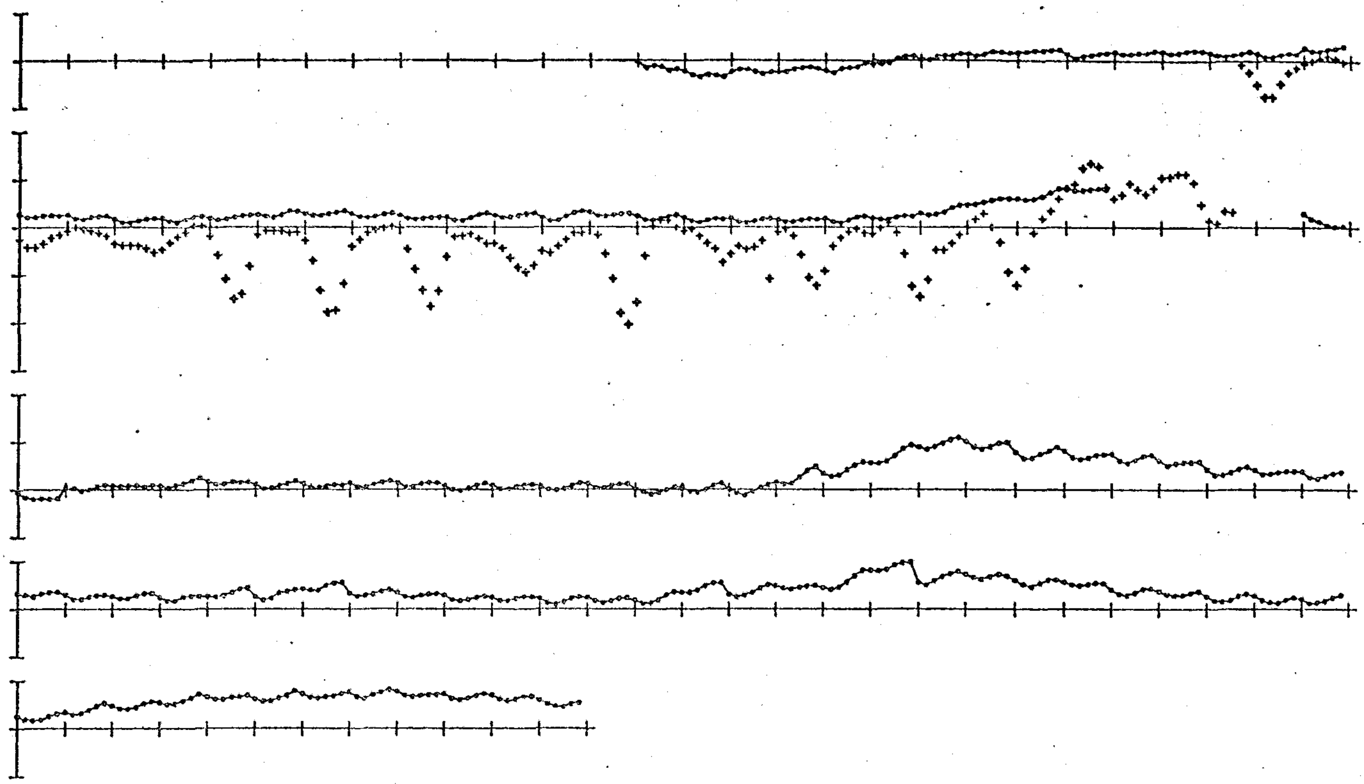


Figure 22 continued.

December 1981



January 1982

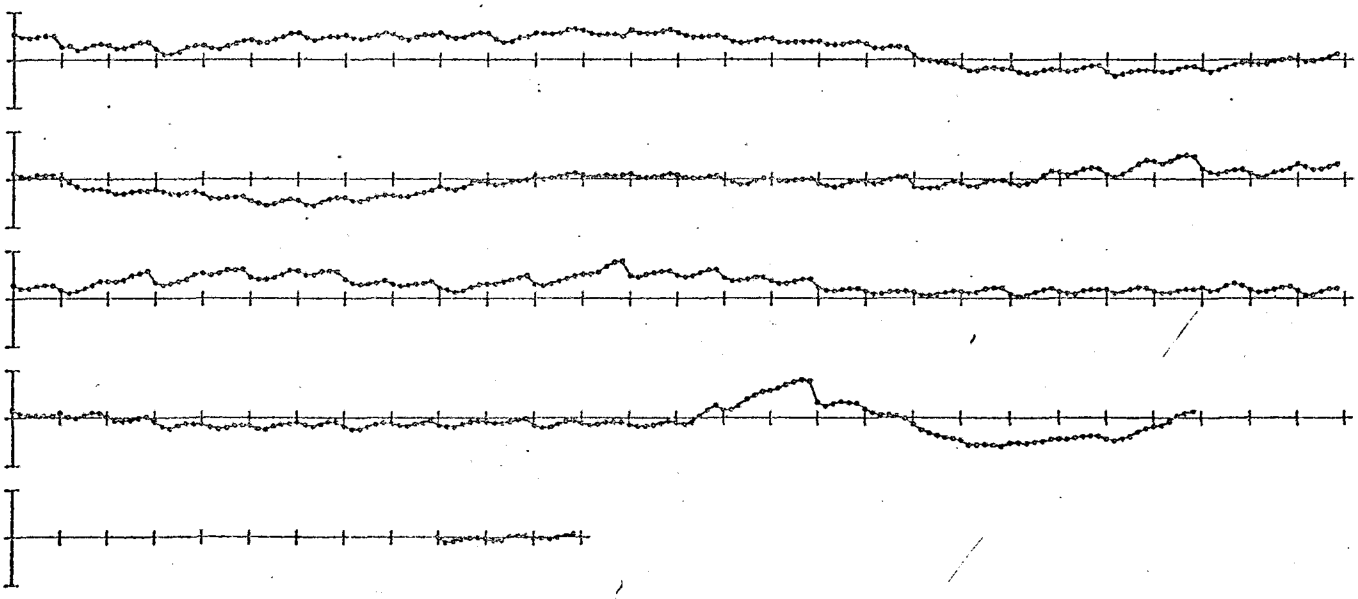
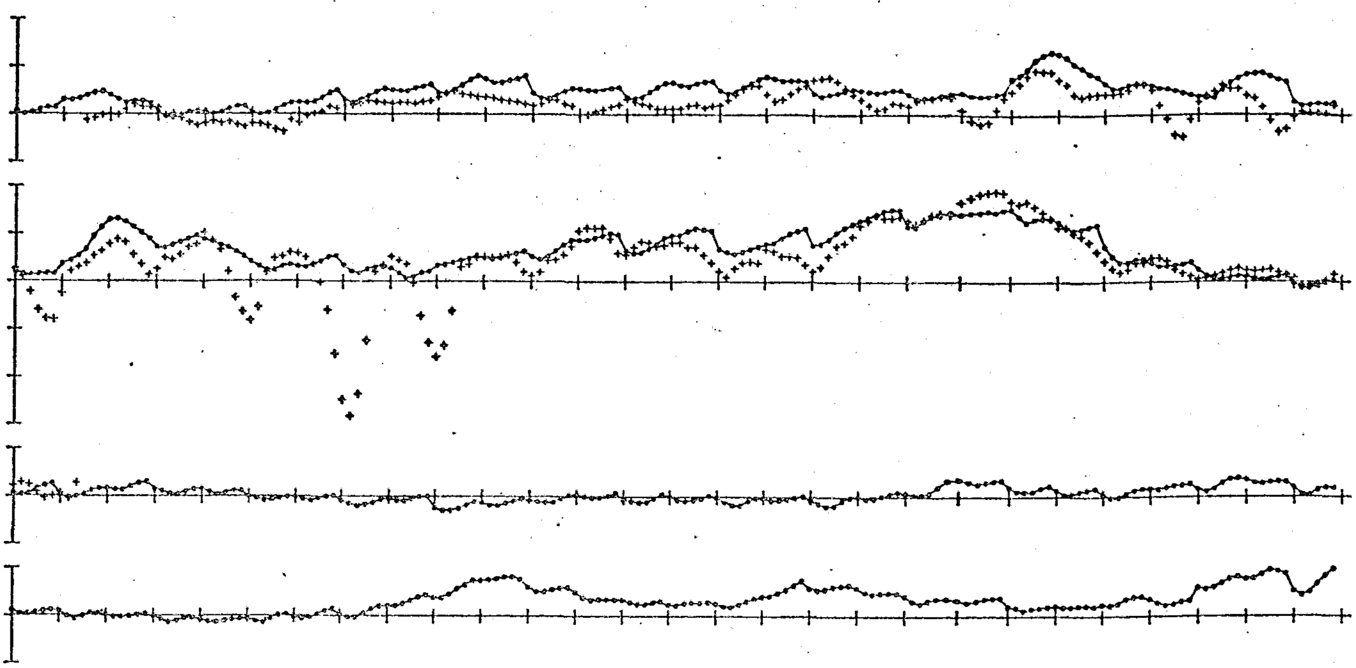


Figure 23 : Comparison of observed and computed surges at Malin Head (+ + +) observations, continuous line with dots WCM, no CSM data. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

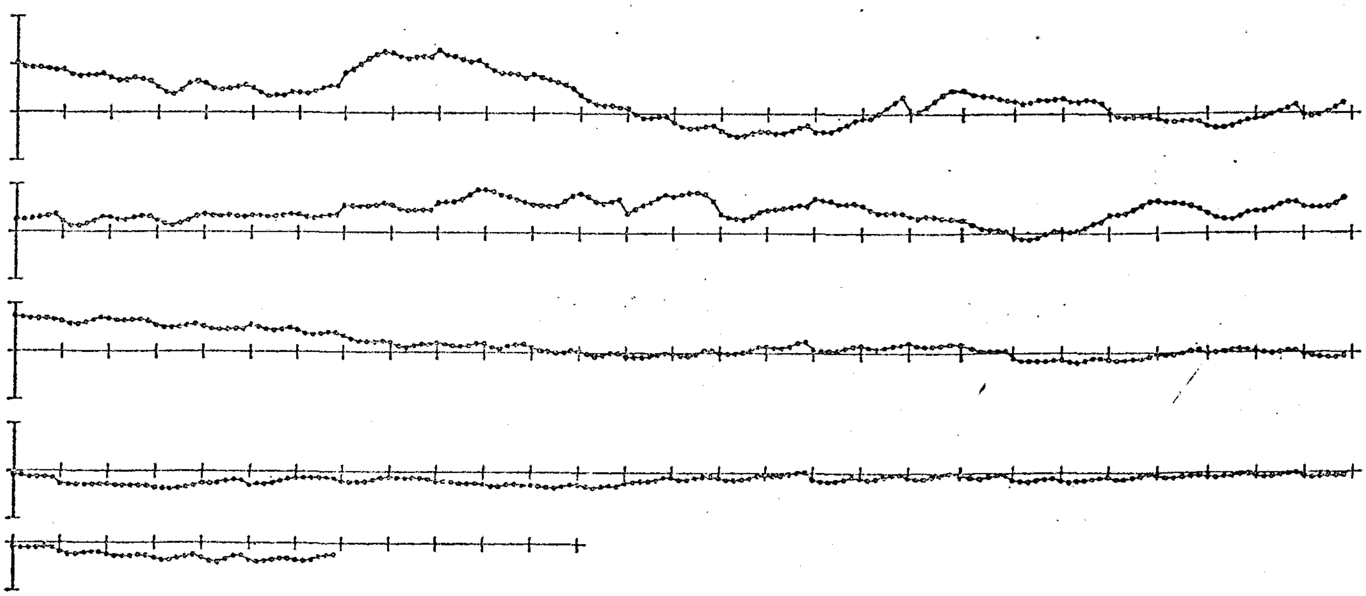
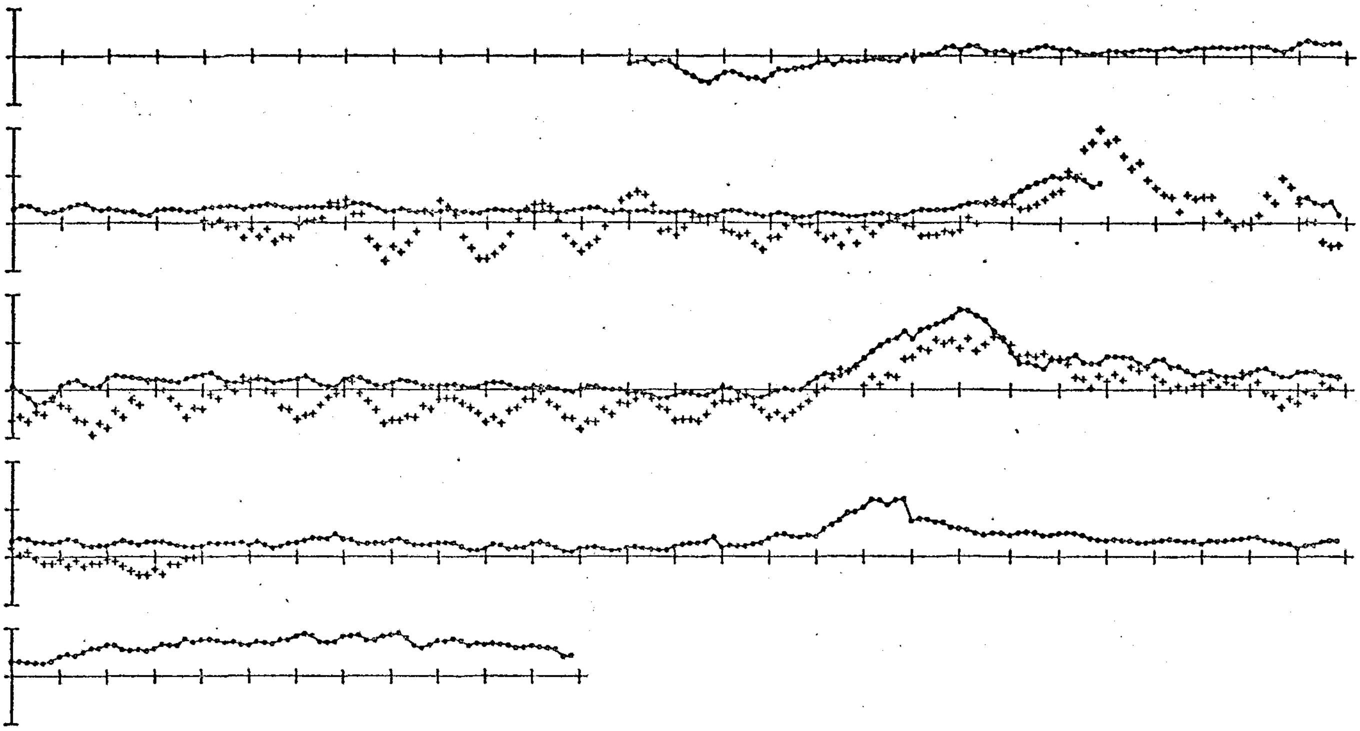


Figure 23 continued.

December 1981



January 1982

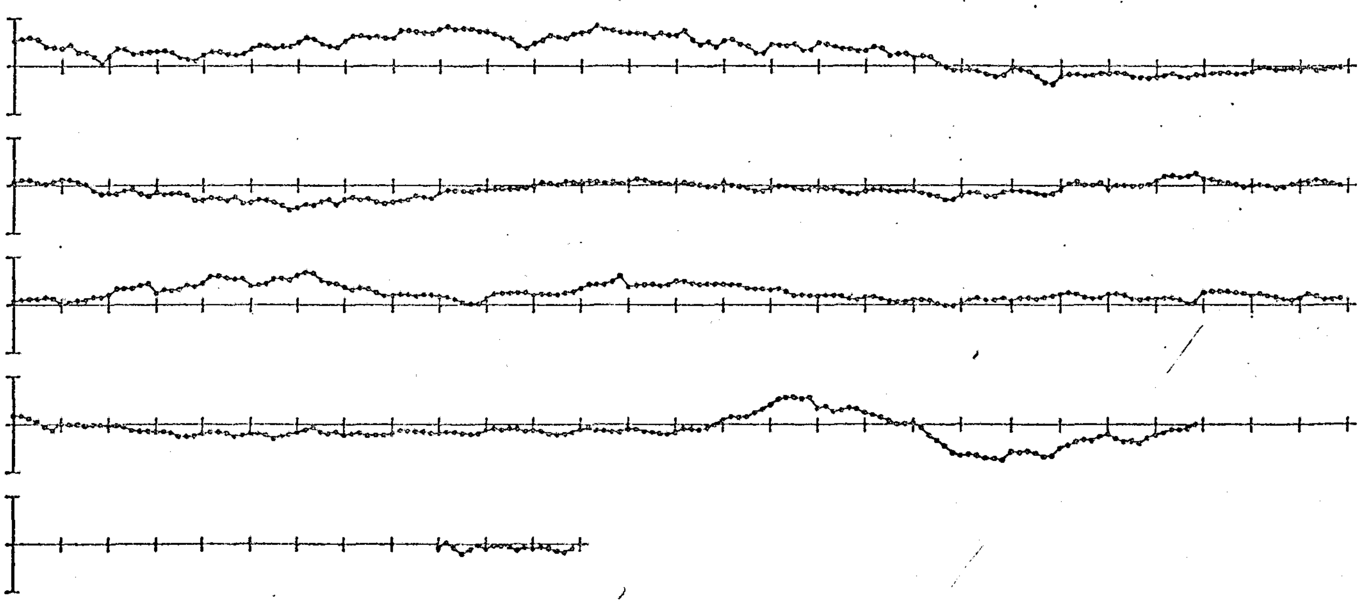
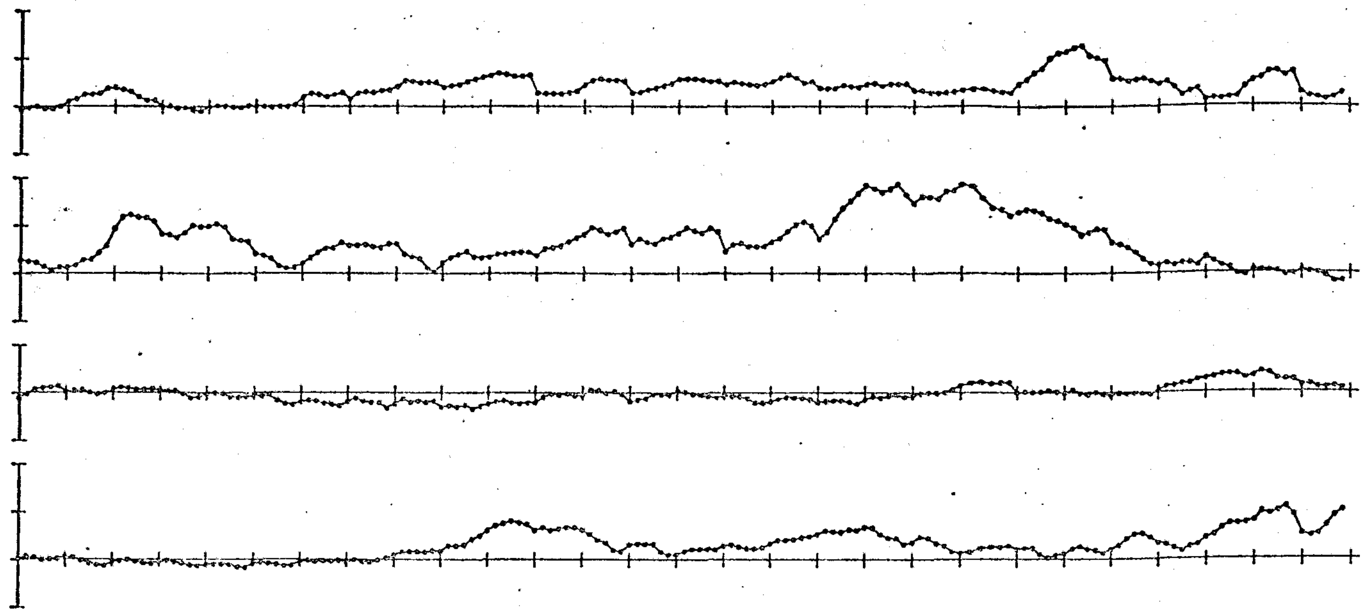


Figure 24 : Comparison of observed and computed surges at Belfast (+ + +) observations, continuous line with dots WCM, no CSM data. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

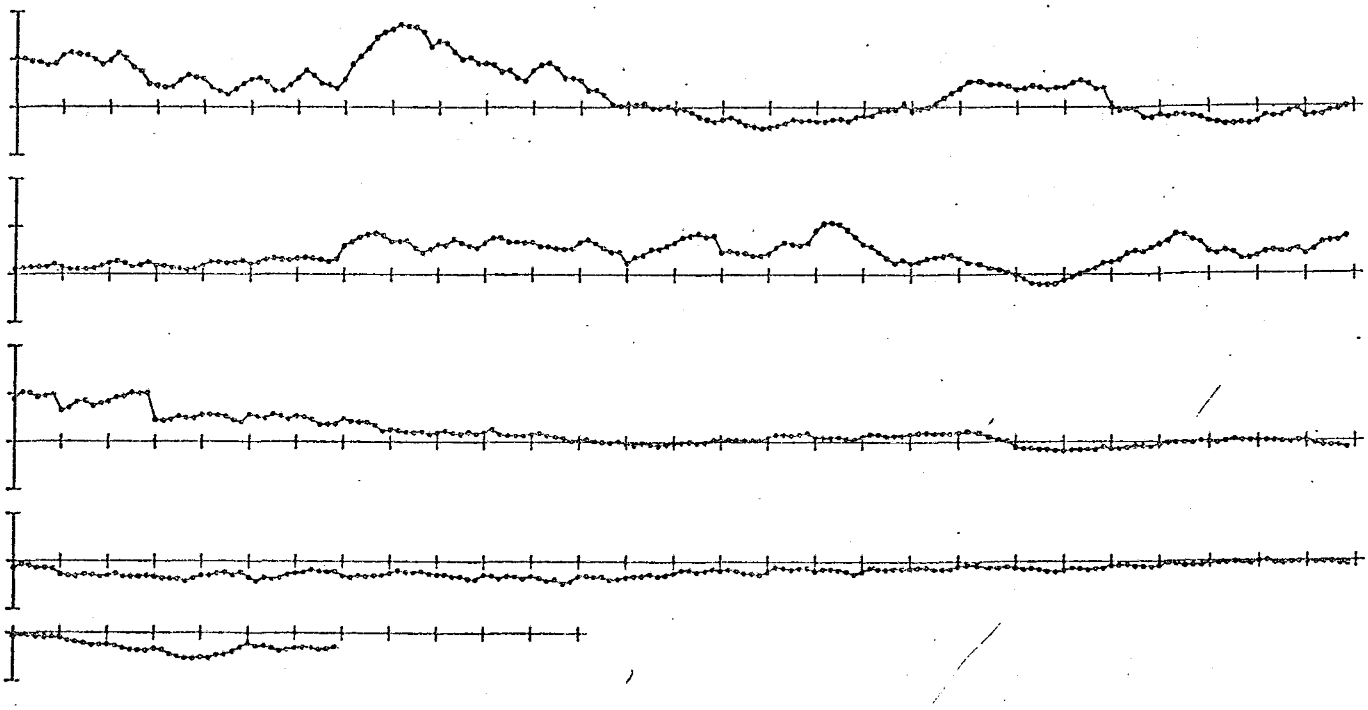
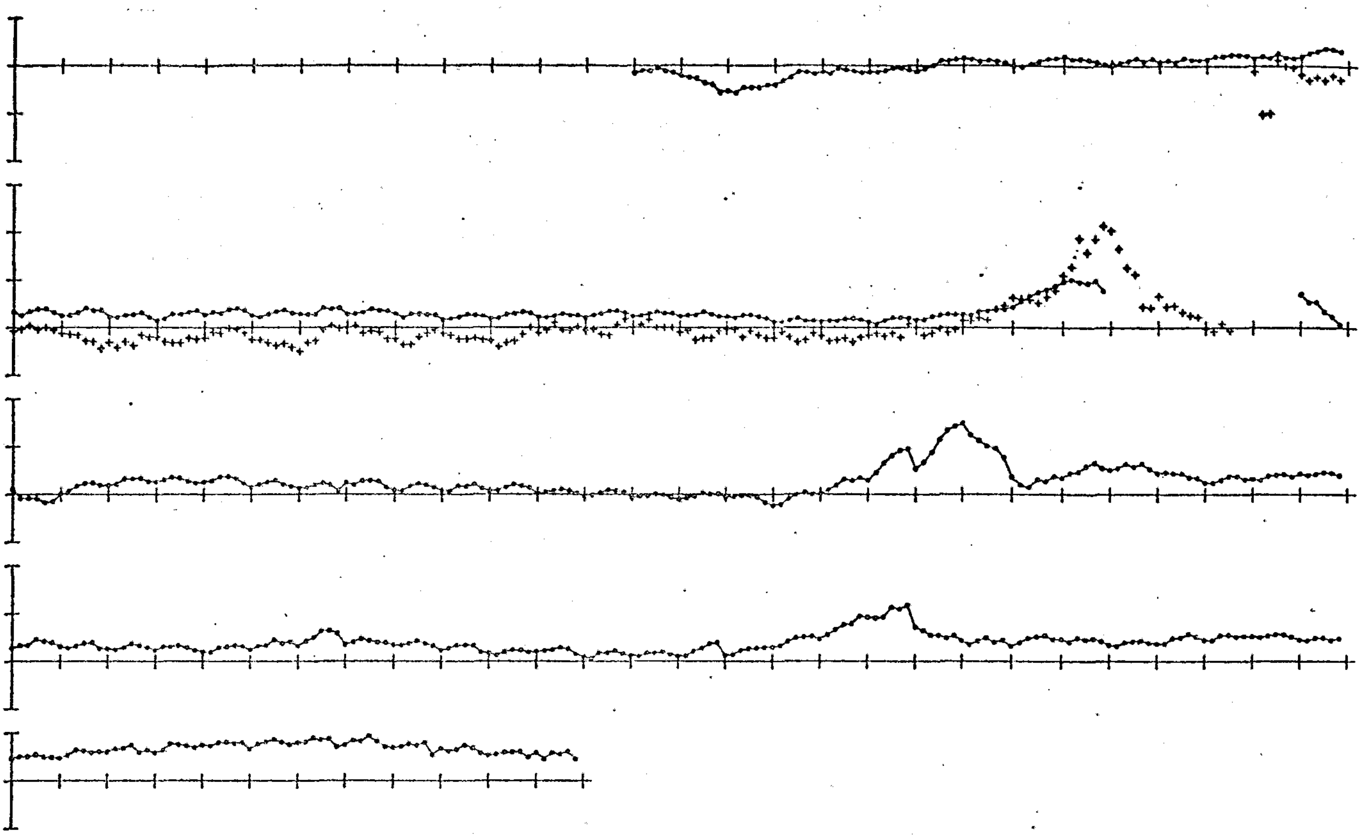


Figure 24 continued.

December 1981



January 1982

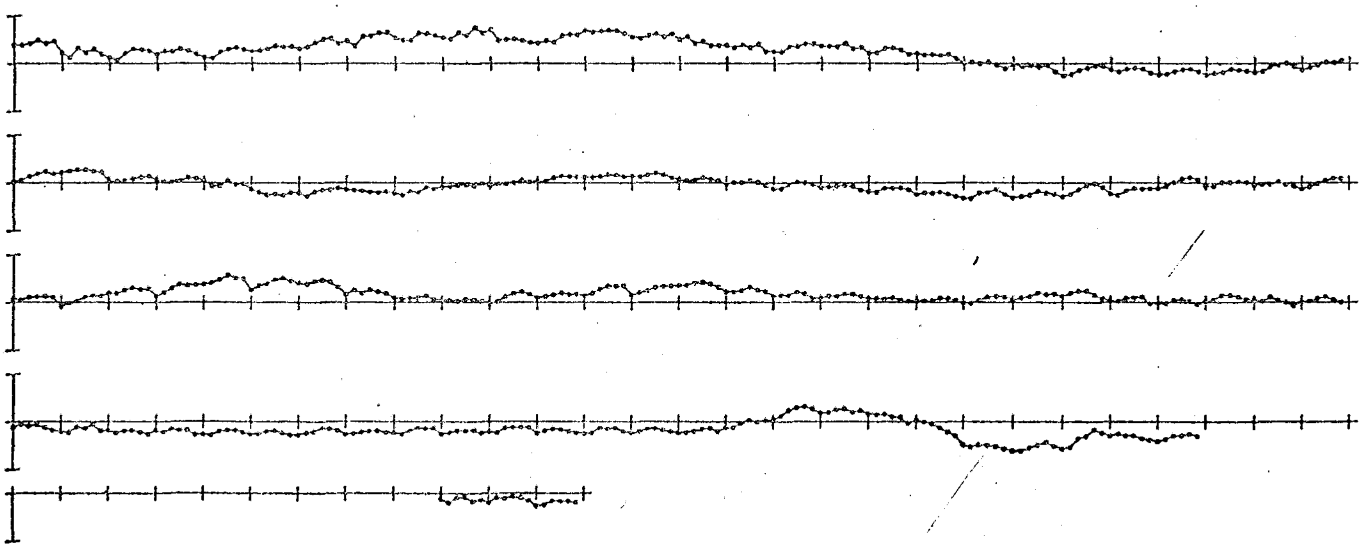
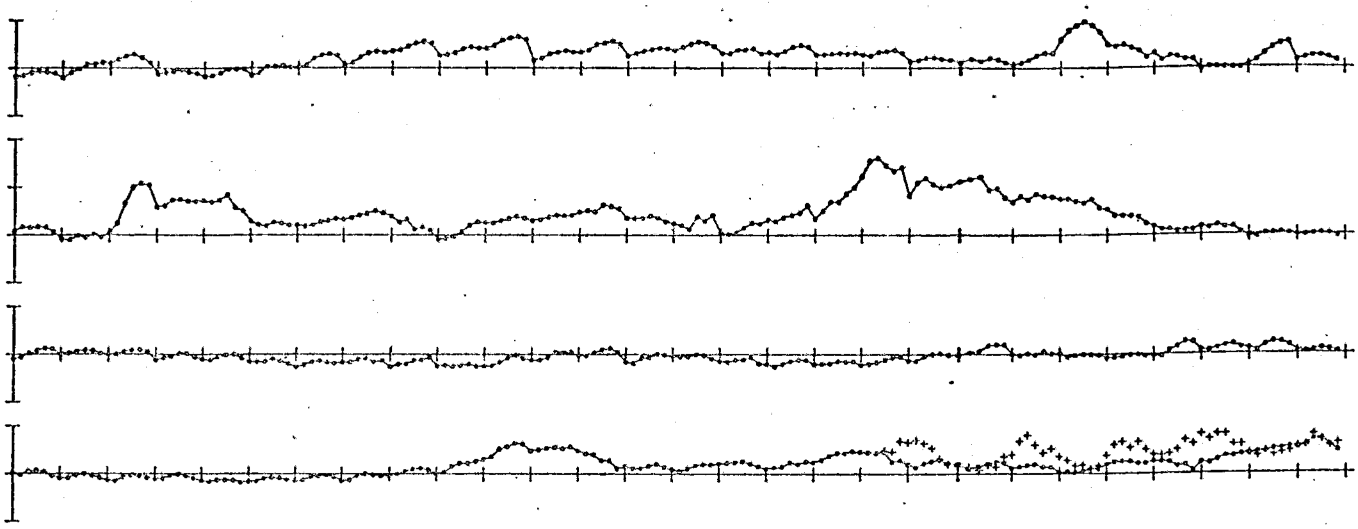


Figure 25 : Comparison of observed and computed surges at Dublin (+ + +) observations, continuous line with dots WCM, no CSM data. Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

February 1982



March 1982

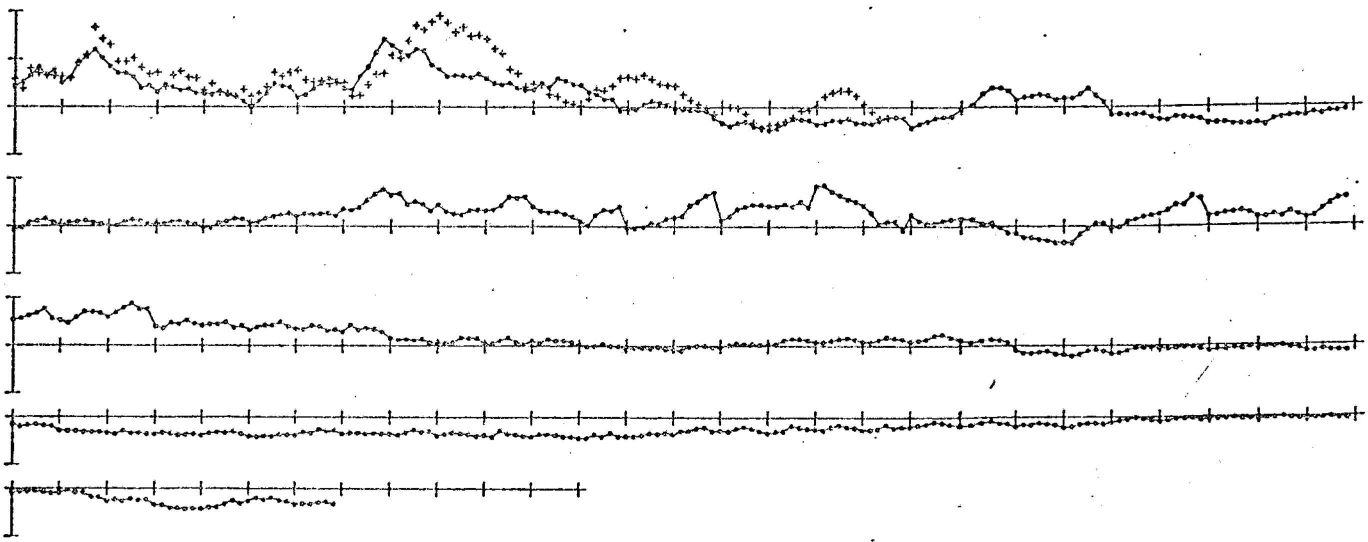


Figure 25 continued.

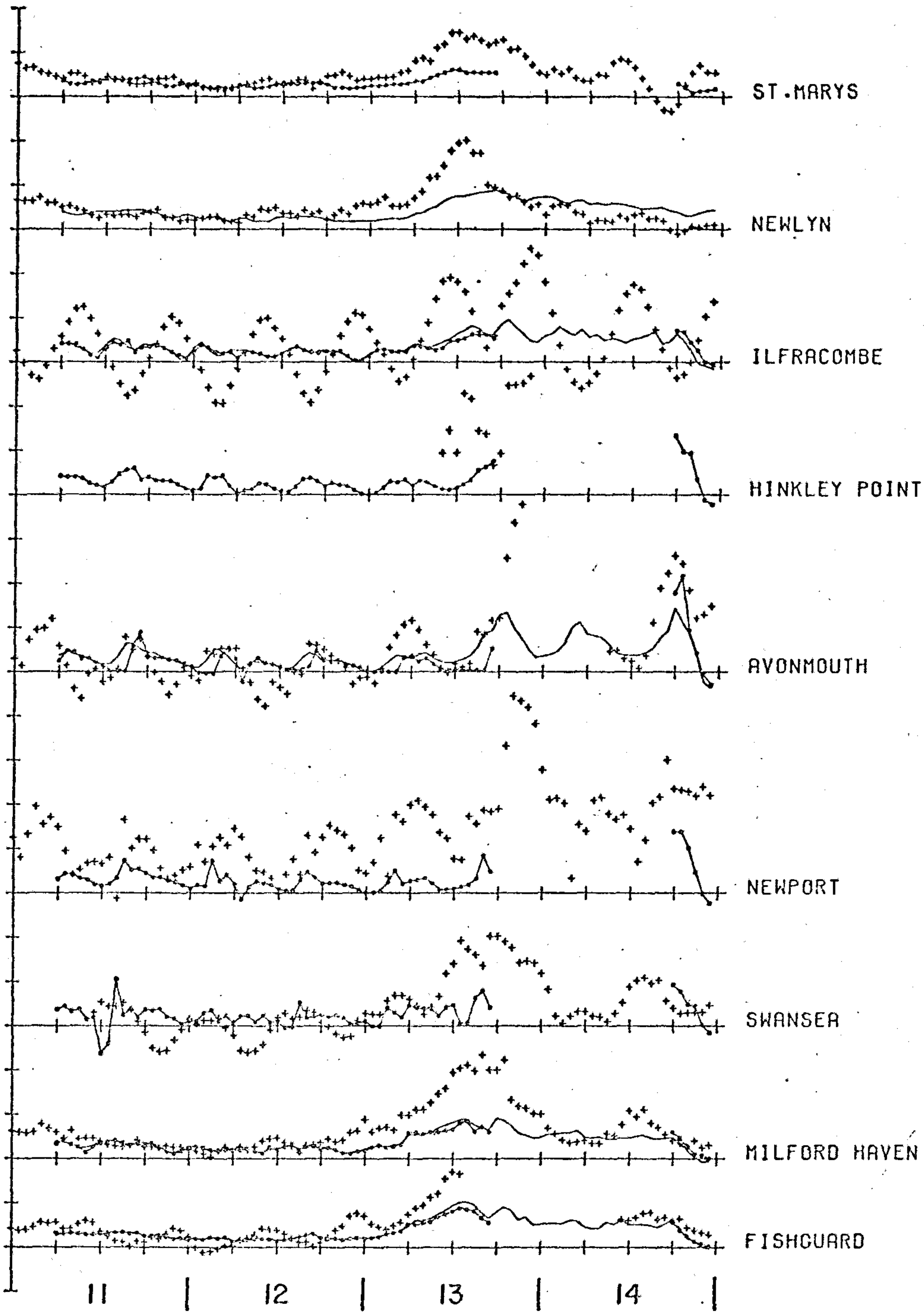


Figure 26 : Observed and computed surges for 11 - 14 December 1981.
(+ + +) obsevations, continuous line CSM, line with dots WCM.
Scale : vertical tick marks 0.5m, horizontal marks 6 hours.

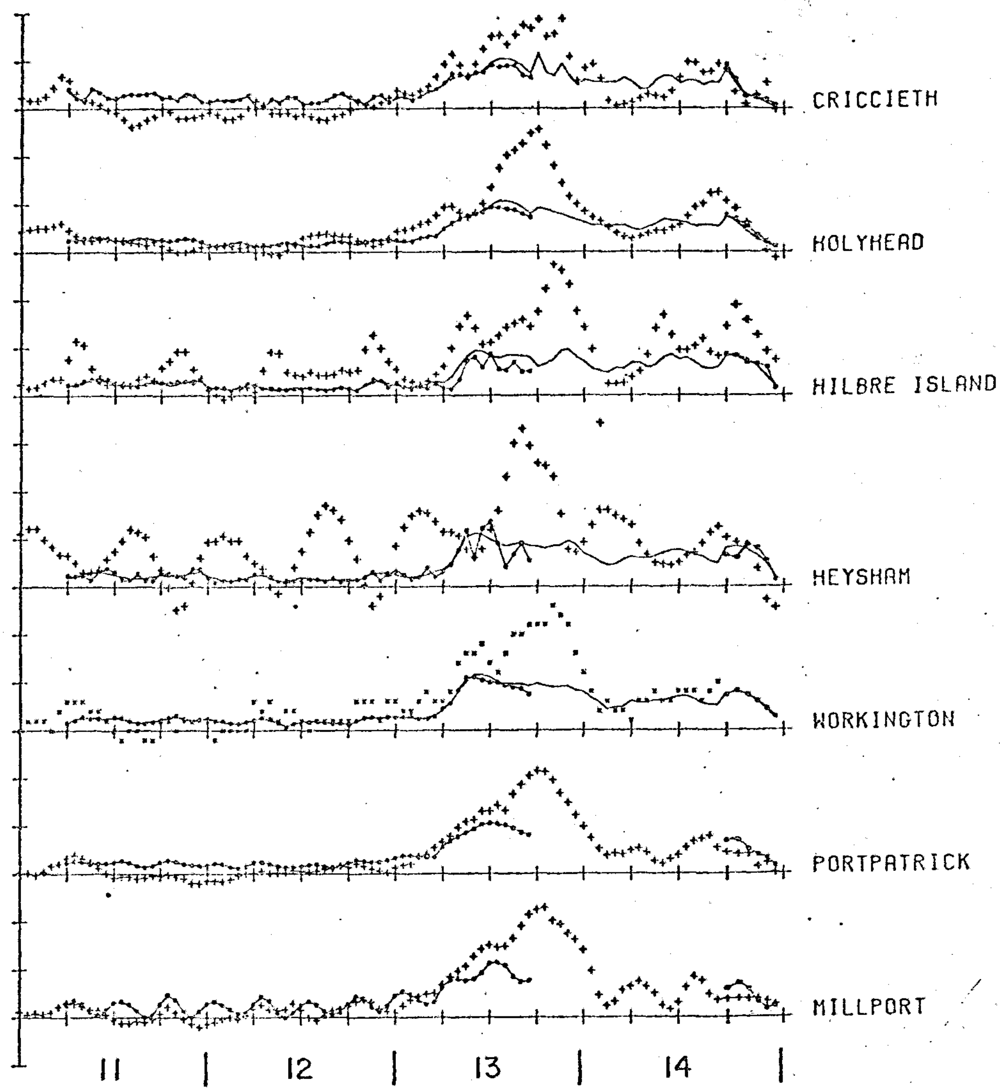


Figure 26 continued :

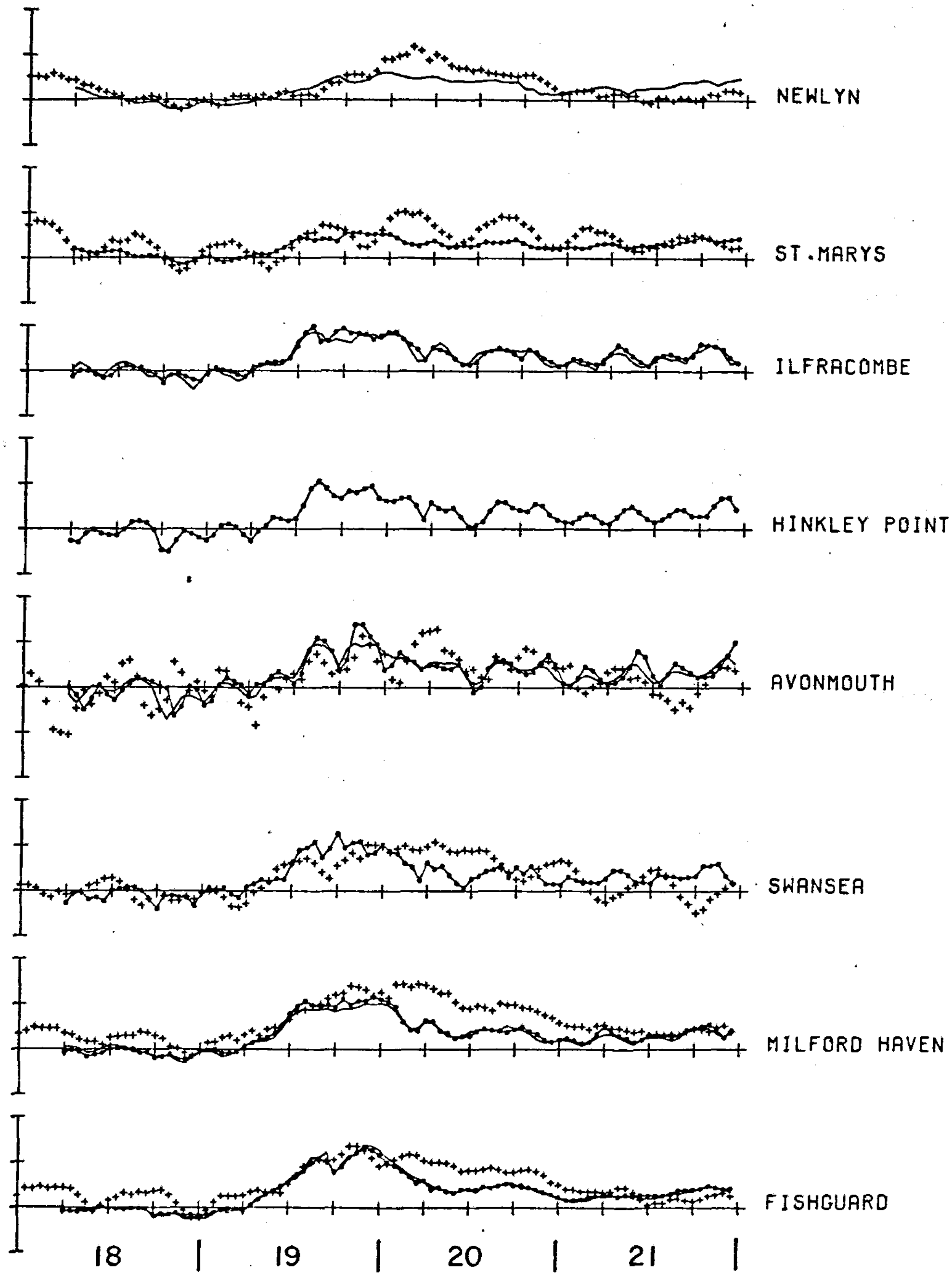


Figure 27 : As Figure 26 but for 18 - 21 December 1981.

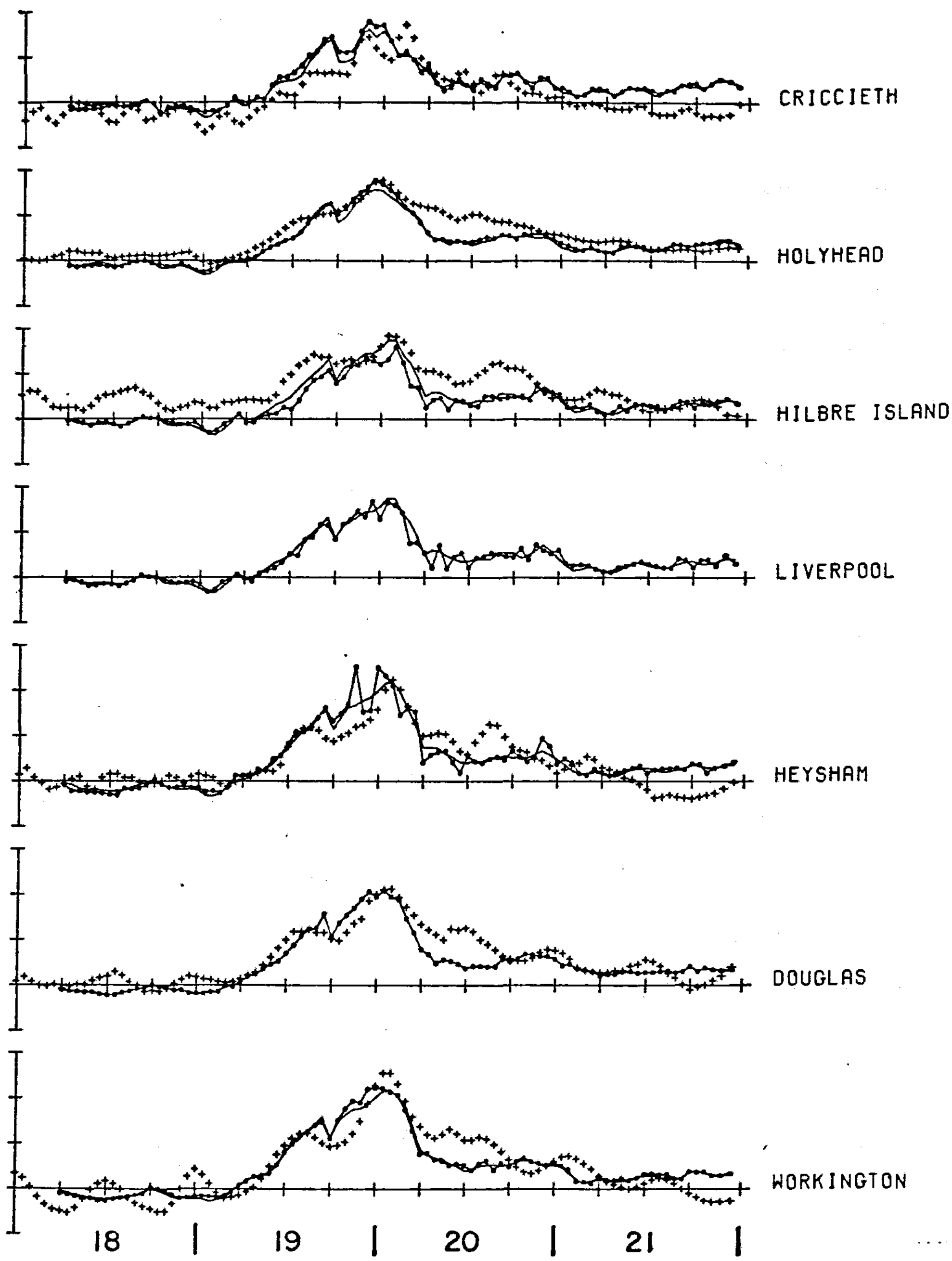


Figure 27 continued :

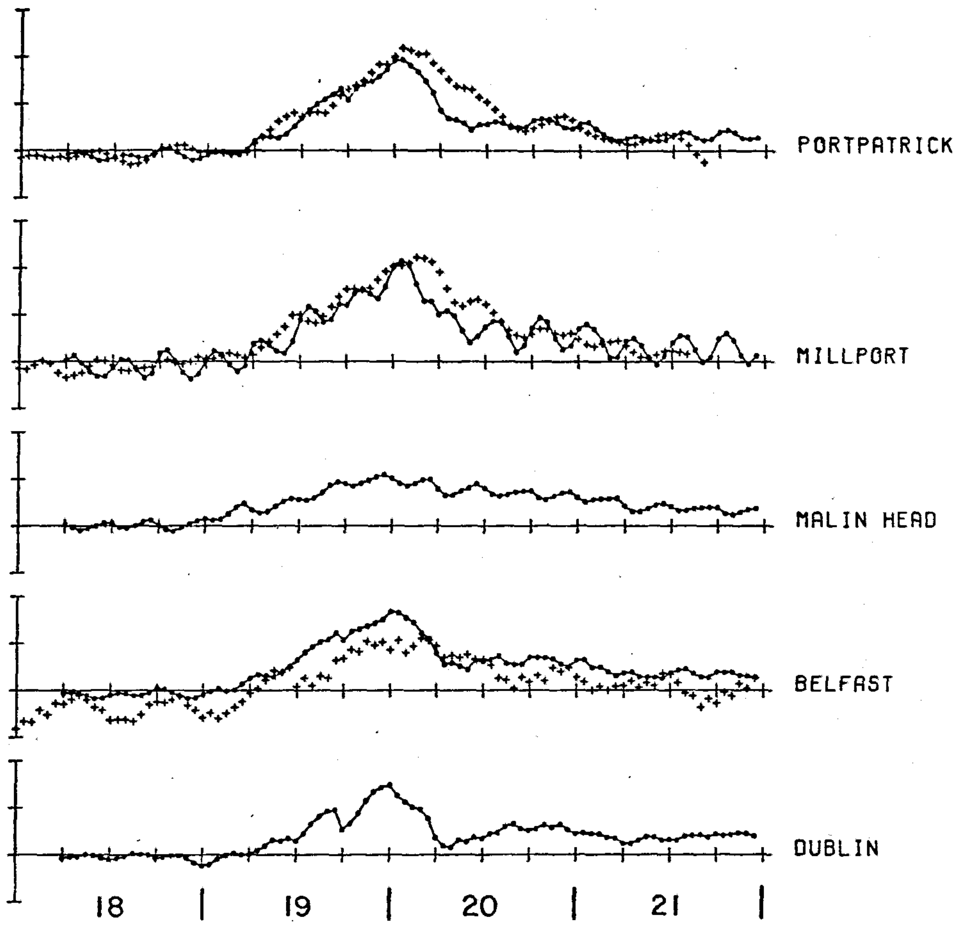


Figure 27 continued :

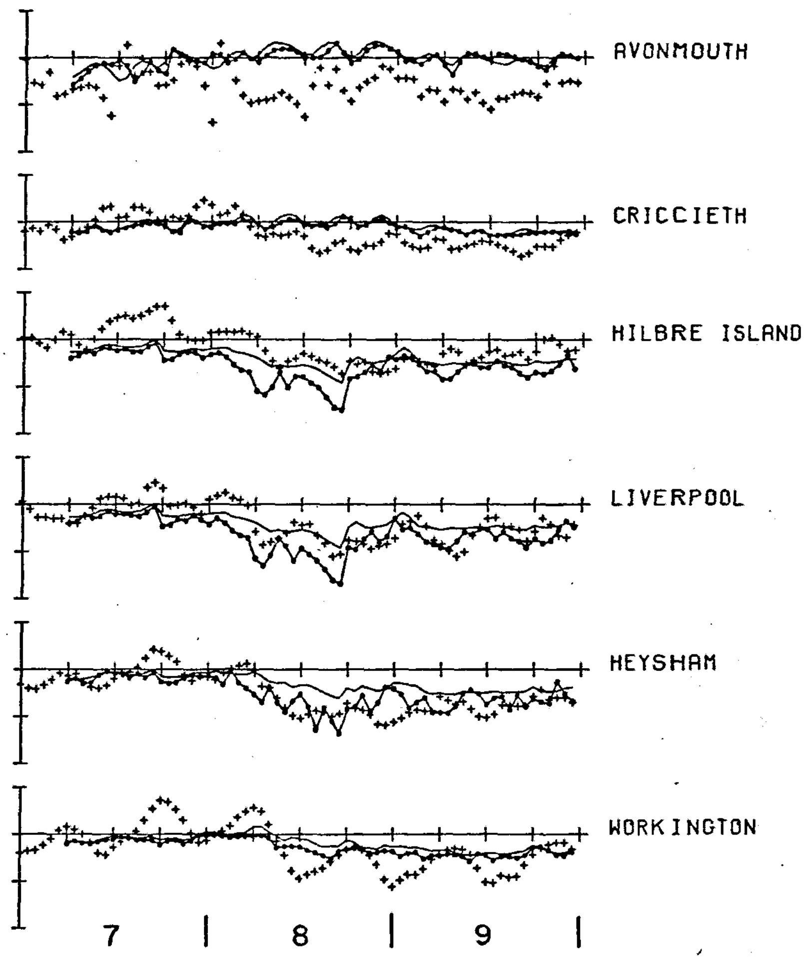


Figure 28 : As Figure 26 but for 7 - 9 January 1982.

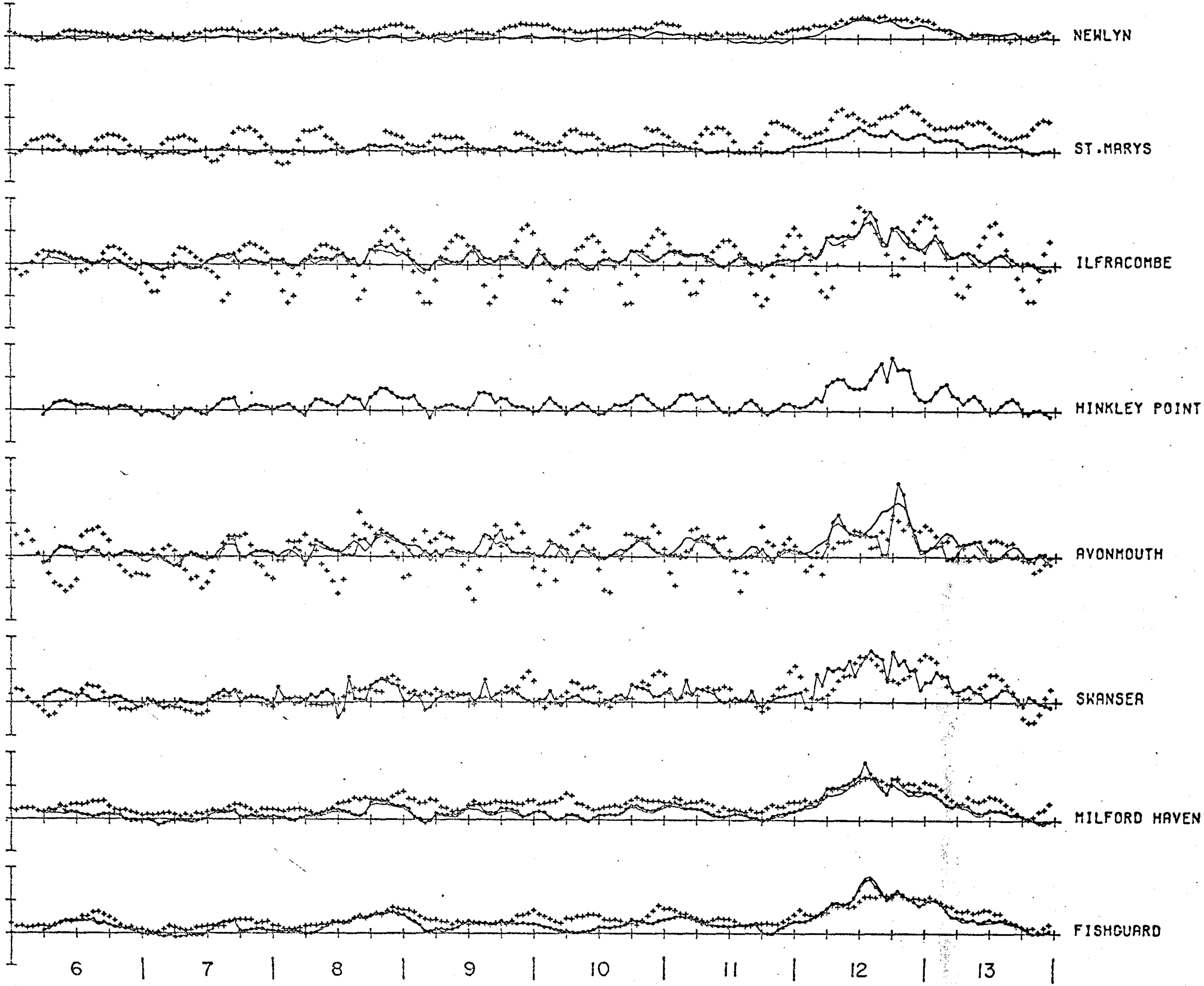


Figure 29 : As Figure 26 but for 6 - 13 February 1982.

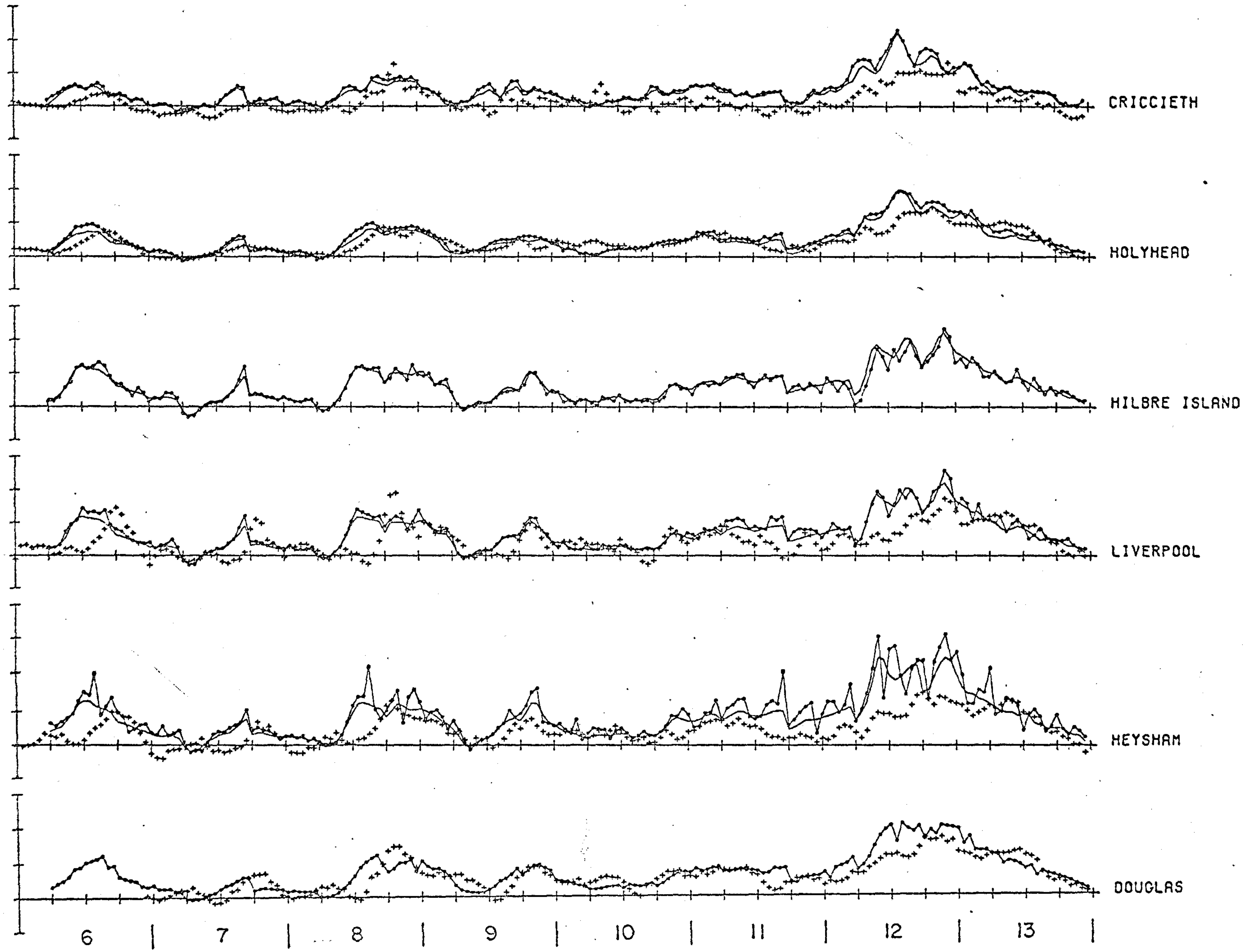


Figure 29 continued :

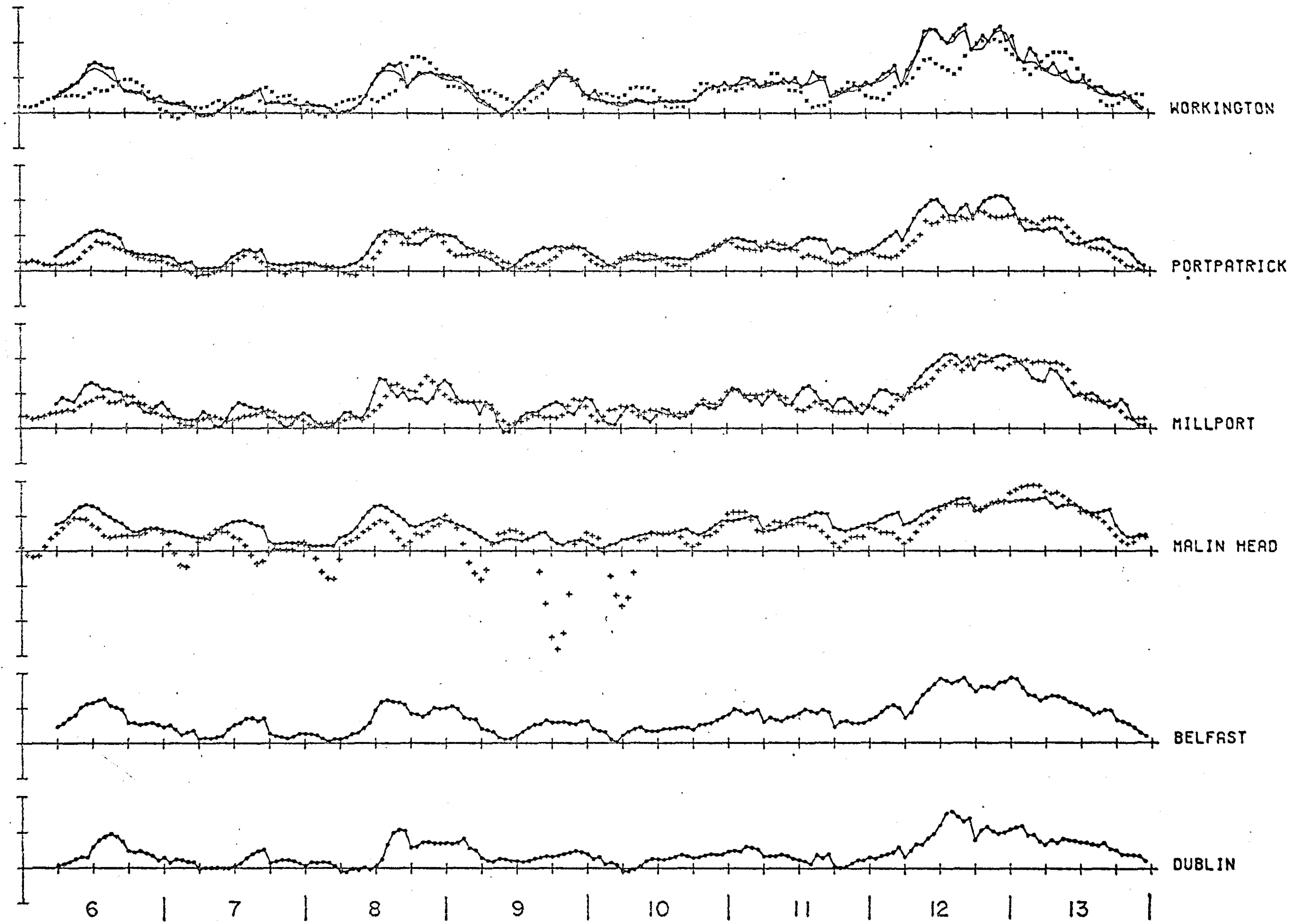


Figure 29 continued :

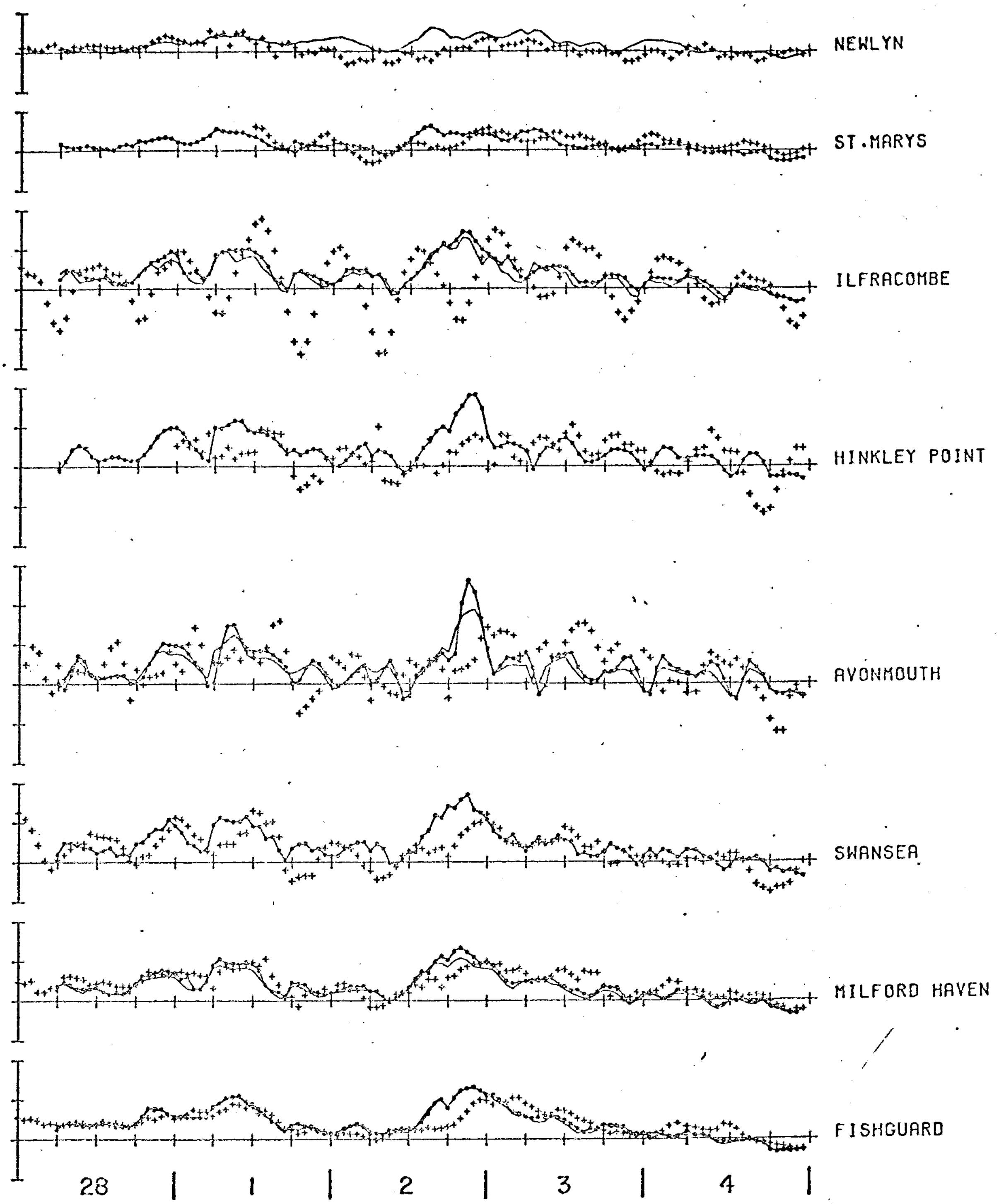


Figure 30 : As Figure 26 but for 28 February - 4 March 1982.

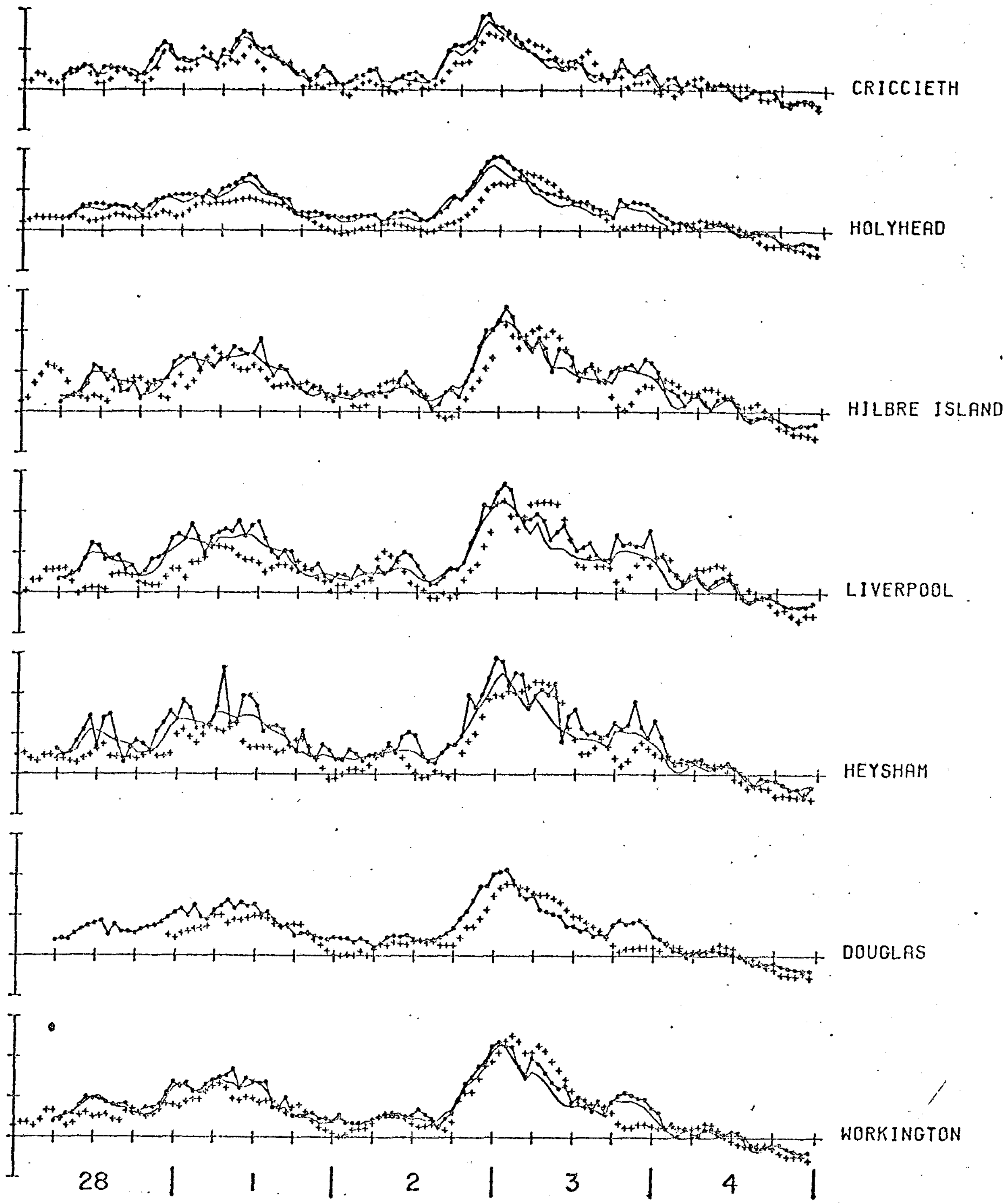


Figure 30 continued :

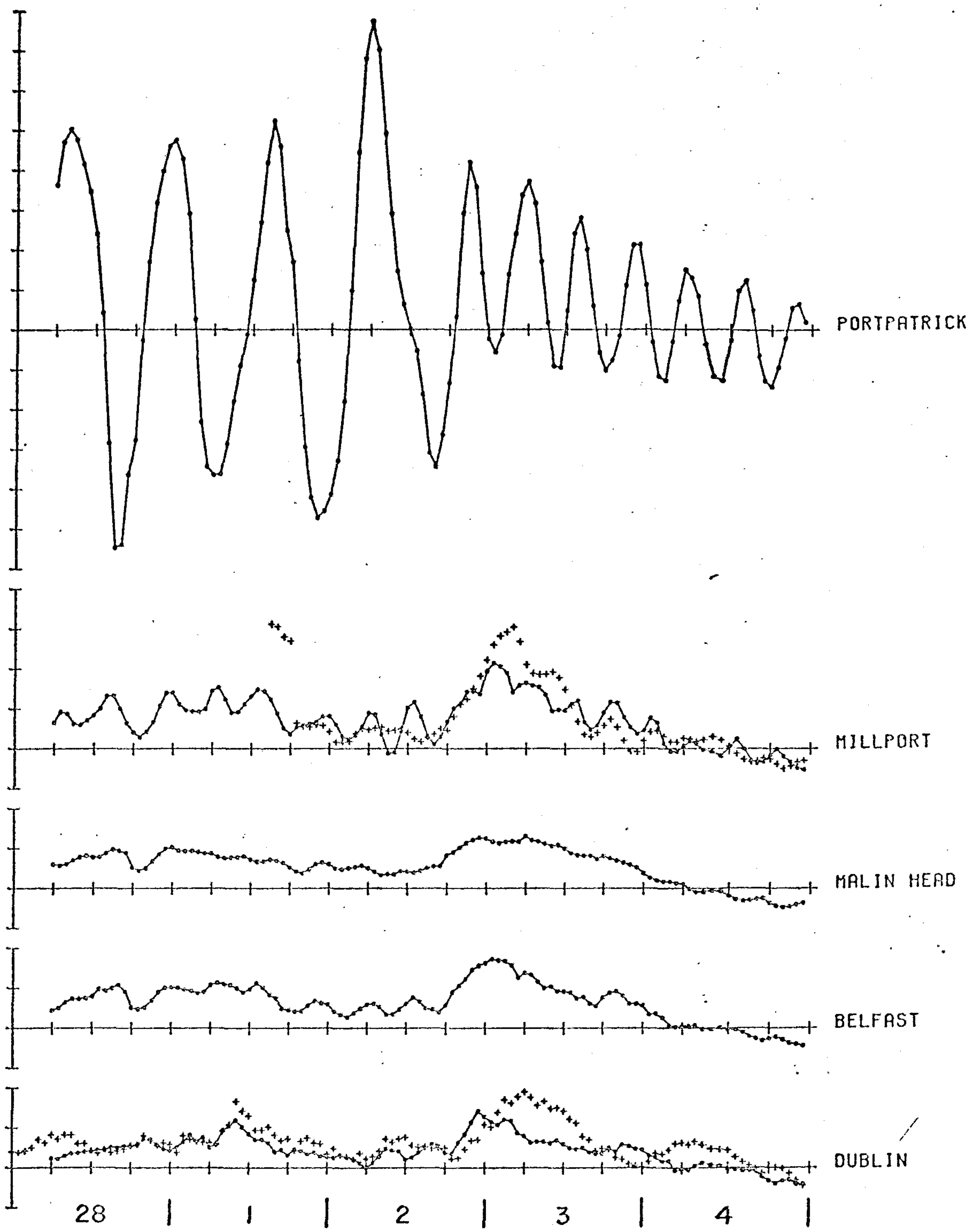


Figure 30 continued :

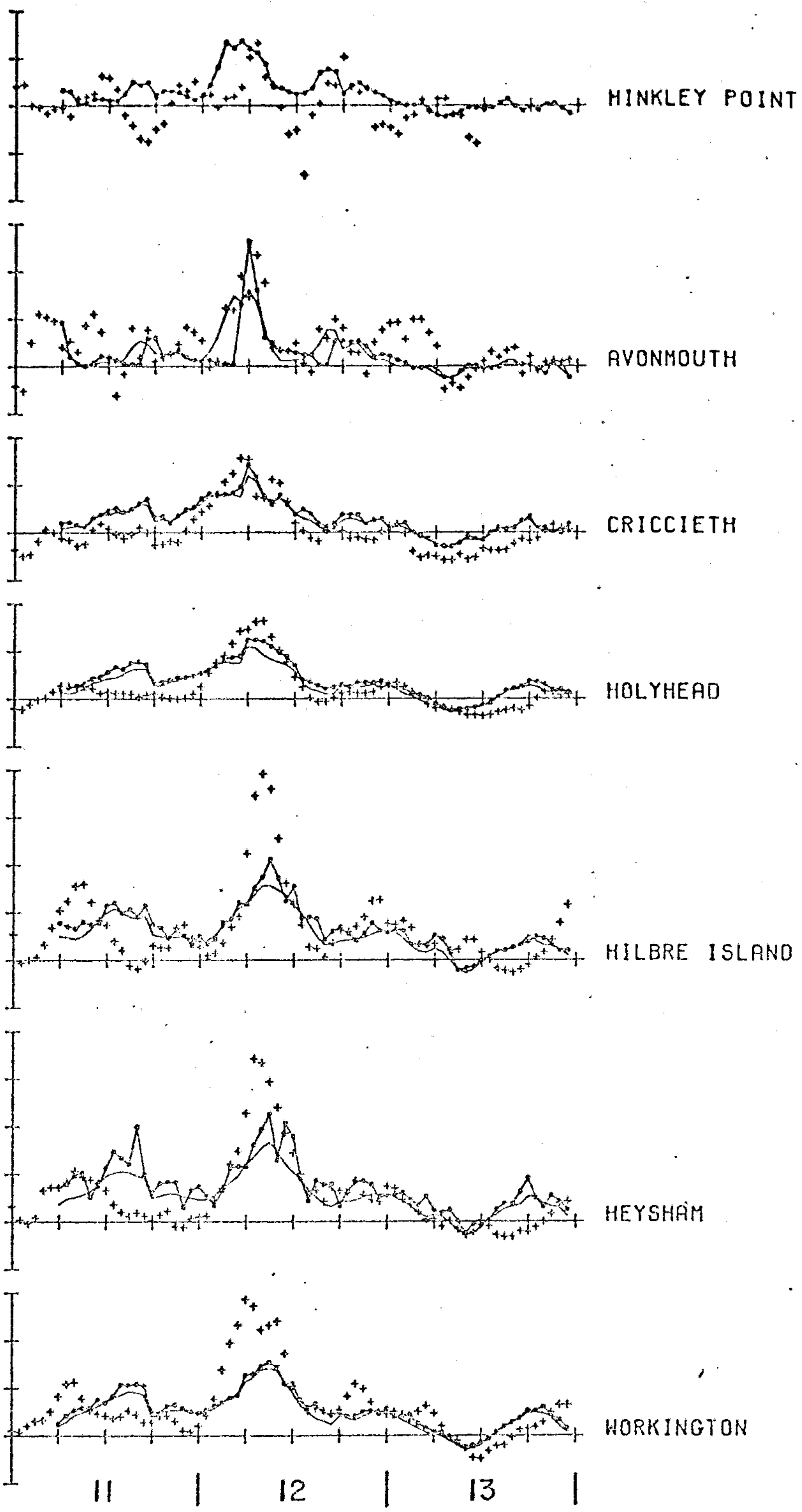


Figure 31 : As Figure 26 but for 11 - 13 March 1982.