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POSITION OF THE MINIMUM-SURGE AREA IN THE NORTH SEA RELATING TO QUASI UNIFORM STEADY WIND/PRESSURE FIELDS

S. Ishiguro

1980

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

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Contents

Abstract

The response of the water-level in the semi-closed shallow sea to each of the orthogonal quasi uniform steady wind/pressure fields generally contains an undisturbed water-level line (zero line). The surge height under such a field in an arbitrary direction is minimum in an area near the cross point of the zero lines. This is called a minimum-surge area by the author. This area characterizes the response of the water-level to the field irrespective of its direction. The relationship between the position of the minimum-surge area in the sea and the area to which the field is applied is examined in this paper.

The position changes considerably with the size of the field chosen. Examples of the response of the water level in the North Sea to a small field (which just covers the North Sea), a large field (which covers all the on-shelf seas around the British Isles), and a few intermediate cases (simulated) are shown.

When a quasi uniform steady wind/pressure field is applied to the prediction of an extreme surge height, it is recommended that the sea be divided into some sections (e.g. the North Sea, the English Channel) so that an independent field is applied to one of the sections at a time. The response to this field should be obtained at each point in all the sections. After repeating this process for all the sections, then the largest surge value at each point in the sea should be selected.

1. Introduction

The author introduced a method of high storm surge prediction in 1966, and improved it in 1976. Further improvements are now being carried out.

This method is based on an assumption (which has now been well proven) that a high storm surge is generated by a quasi uniform steady wind/pressure field over the sea for a considerable duration. Such a field can be represented by only three parameters: wind speed, wind direction and duration. Parameters for the associated pressure field can be derived from the parameters of the wind field.

Therefore, if a set of surge heights, at each point in the sea, generated by a set of two wind fields (which have a normalized wind speed, orthogonal directions and a certain duration) is once obtained, the surge height at the point can be determined. The set of orthogonal surge heights can be obtained by computing the surge dynamic equations, and the set can be used repeatedly for many different cases. Fig. 1 shows an example of a set of the orthogonal surge height diagrams.

A surge diagram for an arbitrary wind direction can be obtained by making a vector sum of the two orthogonal surge diagrams.

The maximum surge height, at each point in the sea, can also be determined from a set of orthogonal surge diagrams, by choosing the wind direction which makes the surge height maximum. Fig. 2 shows an example of maximum surge-height diagram produced in this way. In fact, this diagram involves an associated pressure field, the duration of the field, and the response time of water level.

Nevertheless, a conspicuous area can be seen, near the centre of the sea, in which the surge height is minimum* (not necessarily zero). The author calls this area a minimum-surge area.

In a high storm surge in the North Sea, the wind-generated surge is generally dominant over a pressure-generated surge. Therefore, the position of the minimum surge area is almost determined by the cross point of the undisturbed water-level lines (zero lines) in a set of the orthogonal wind-generated surge diagrams.

Described in this paper is the relationship between the position of a minimum-surge area and the area to which a quasi uniform steady wind field is applied.

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*The surge height in this area has been discussed in Ref. 3.

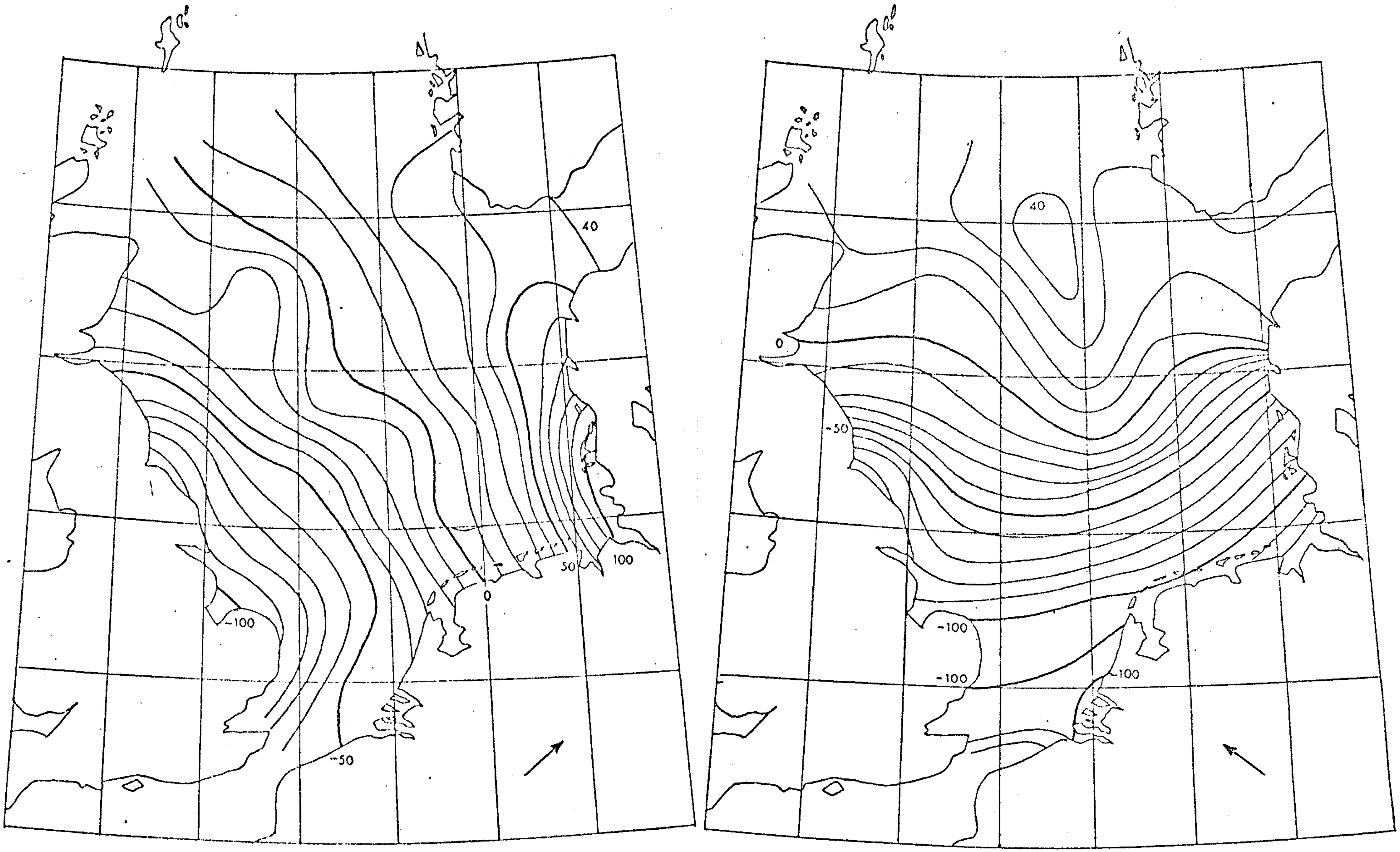

Fig. 1 Example of a set of orthogonal wind-generated surge diagrams for the North Sea.

Each diagram is obtained by solving the surge dynamic equations with a suddenly applied uniform steady wind field over the sea. The value of $(U/20)^2$ should be multiplied to a line value, to obtain a surge height (cm), where U is the hourly mean wind speed (m/s).

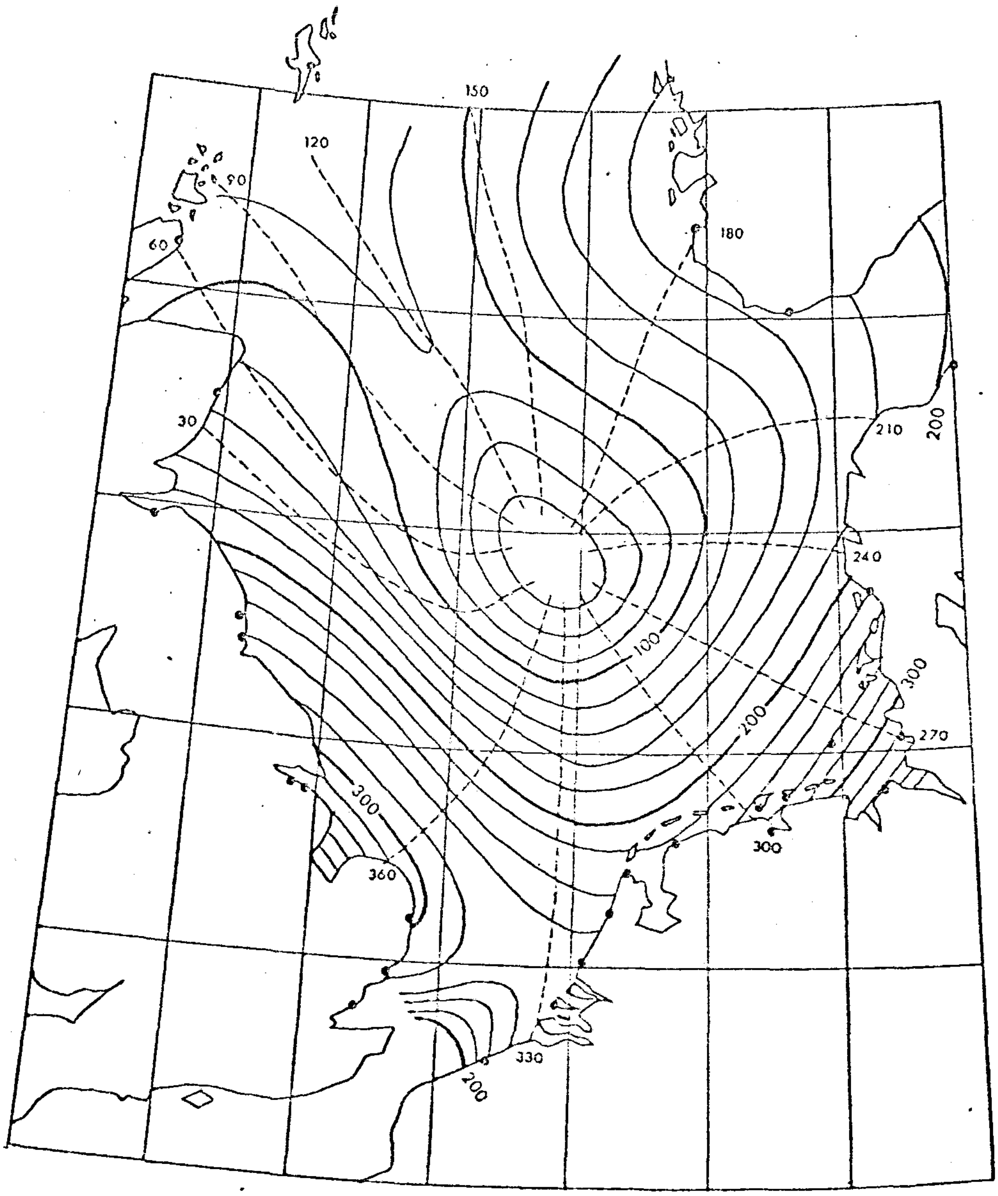

Fig. 2 Example of a maximum surge height diagram which includes the minimum-surge area near the centre of the sea.

The maximum surge height at each point in the sea is determined by a wind speed, wind direction, pressure gradient, pressure-gradient direction, duration and the water-level response time, each of which is different from point to point.

The effective wind speed over the duration is considerably less than the hourly mean wind speed. This diagram has been designed for the hourly mean speed of 36 m/s, and the automatic adjustment for a duration is included in the equations used for the diagram.

The value of a solid line gives the maximum surge height (cm), and a dotted line a wind direction (degrees) which generates this height.

This diagram indicates internal surges only at their fully developed state. Other types of surge, and internal surges other than the fully developed state, are not included.

An external surge enters into the sea any time, and increases or decreases the internal surge heights, depending on their combinations. An external surge and other type of surges might exceed the maximum internal surge height around the minimum surge area.

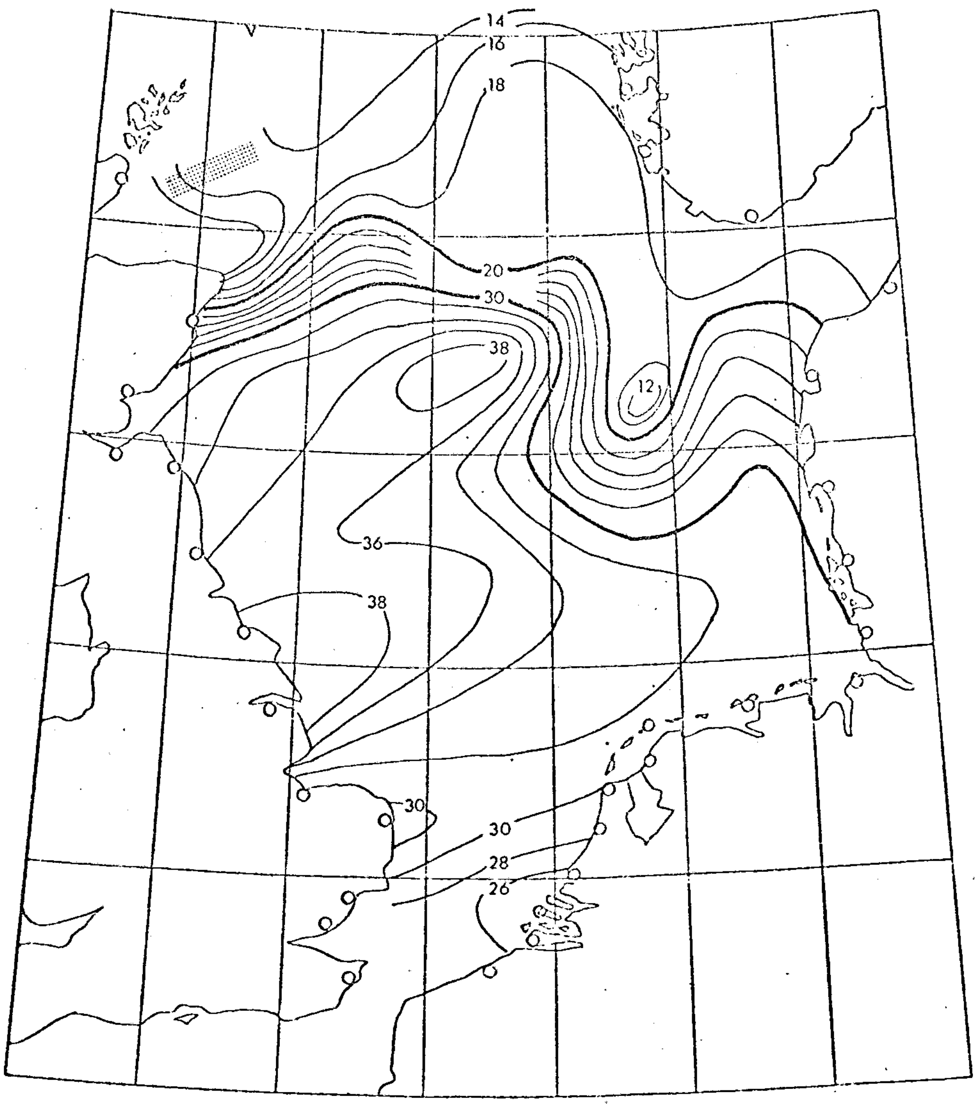

Fig. 3 An external surge entered into the undisturbed North Sea (computed).

The initial pattern of the surge is a square pulse (height 15 cm, width 40 hr, front length 100 km), and this is injected into the sea through an area (shown by a shaded area) off Wick. Line values indicate the surge heights (cm).

2. Position of the undisturbed water-level line in the sea

Taking a model of the North Sea, which is terminated by artificially decided boundaries (Wick-Bergen, Margate-Calais, and Frederikshaven-Göteberg), the effect of a wind field area on the position of the minimum surge is examined.

Each boundary in the model has been designed so that it represents the hydrodynamic conditions (seen from the inside of the North Sea) as closely as possible to the natural conditions (i.e. no boundary).

Fig. 3 shows the response of the water level to an external surge entered into the undisturbed North Sea, through a part of the boundary line connecting Wick and Bergen (shown by a shaded area, 100 km). The external surge is represented by a square pulse (height 15 cm, width 40 hours). Note, an extended wind field beyond the boundary line is simulated by this external surge.

Fig. 4 shows the response of the water level to a suddenly applied uniform steady wind field (wind speed 20 m/s, direction 255^{o}) over the sea area limited by the above-mentioned boundaries.

Fig. 5 has been obtained by superimposing Fig. 3 on Fig. 4. Therefore, Fig. 5 represents a state where the area of the wind field in Fig. 4 is slightly extended beyond the boundary. It can be seen that the zero line (undisturbed water-level line) in Fig. 5 is shifted towards the British coast, compared with Fig. 4.

Fig. 6 shows a similar diagram to Fig. 5, but with a higher external surge (height 30 cm, width 40 hours). It can be seen that the zero line is shifted further towards the British coast.

Fig. 7 shows the response of the water level to a uniform steady wind field (wind speed 20 m/s, direction 255^{o}, and duration 60 hours) over all the on-shelf seas around the British Isles. The model used for obtaining Figs. 1 to 6, and the model for Fig. 7 are different. Despite this fact, the positions of the zero line in Fig. 6 and Fig. 7 are similar. A systematic change of the position of the zero line with the increase of the area of the uniform steady wind field can be seen in Figs. 4 through 6, and Fig. 7.

For a series of diagrams shown in Figs. 4 through 7, the wind direction is chosen to be 255^{o}. This wind direction, with a considerable wind speed and duration, generates a large positive surge along the Danish coast, and a large negative surge along the British coast. At the same time, a large positive surge is generated along the north-west coast of Scotland (Ishiguro, 1980), and this enters into the North Sea as an external surge. This external surge tends to cancel the negative internal surge along the British coast, resulting in an almost undisturbed water level around Aberdeen (Fig. 7). Note, in the diagram for the other component (315^{o}) of the orthogonal surge heights (Fig. 5 of Pingree & Griffiths' paper, 1980), the zero line is again near Aberdeen; i.e. the minimum-surge area under this very large wind field (covering all the on-shelf seas around the British Isles) is near Aberdeen.

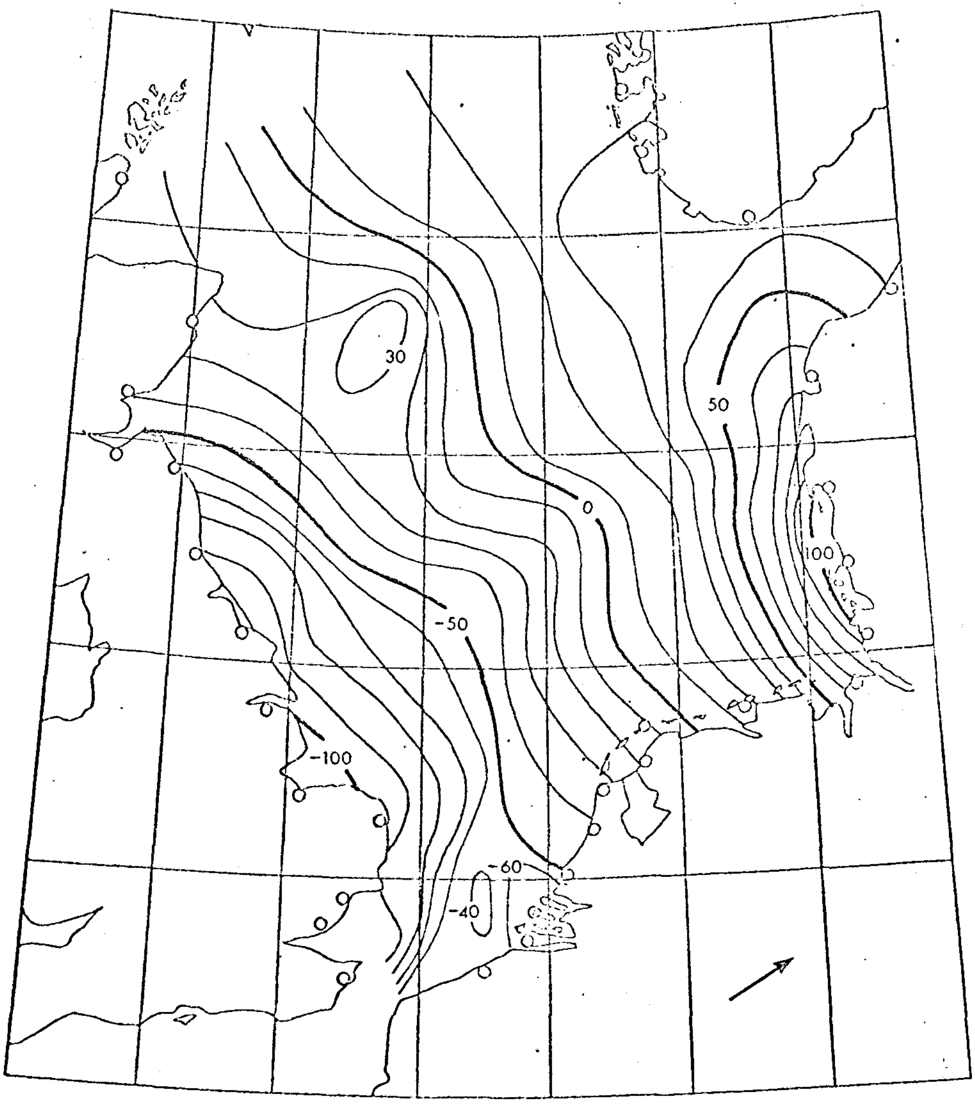

Fig. 4 Internal surge generated by a suddenly applied uniform steady wind field over the North Sea (computed).

Wind speed 20 m/s, direction 255°. The state after 40 hours is shown. Line values indicate the surge heights (cm).

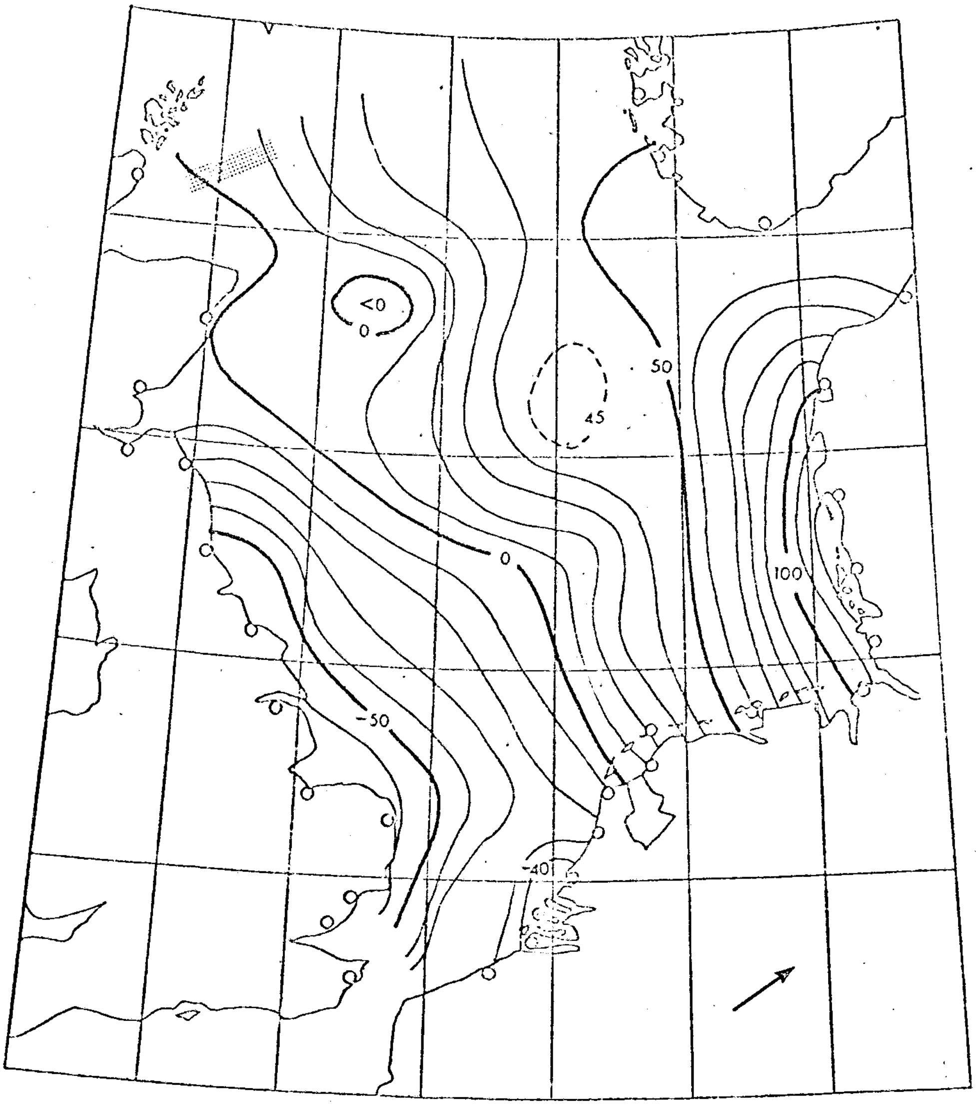

Fig. 5 Resultant of the external surge shown in Fig. 3 and the internal surge shown in Fig. 4. This is equivalent to extending the wind field.

Line values indicate the surge heights (cm). The shaded area shows the area through which the external surge is entered.

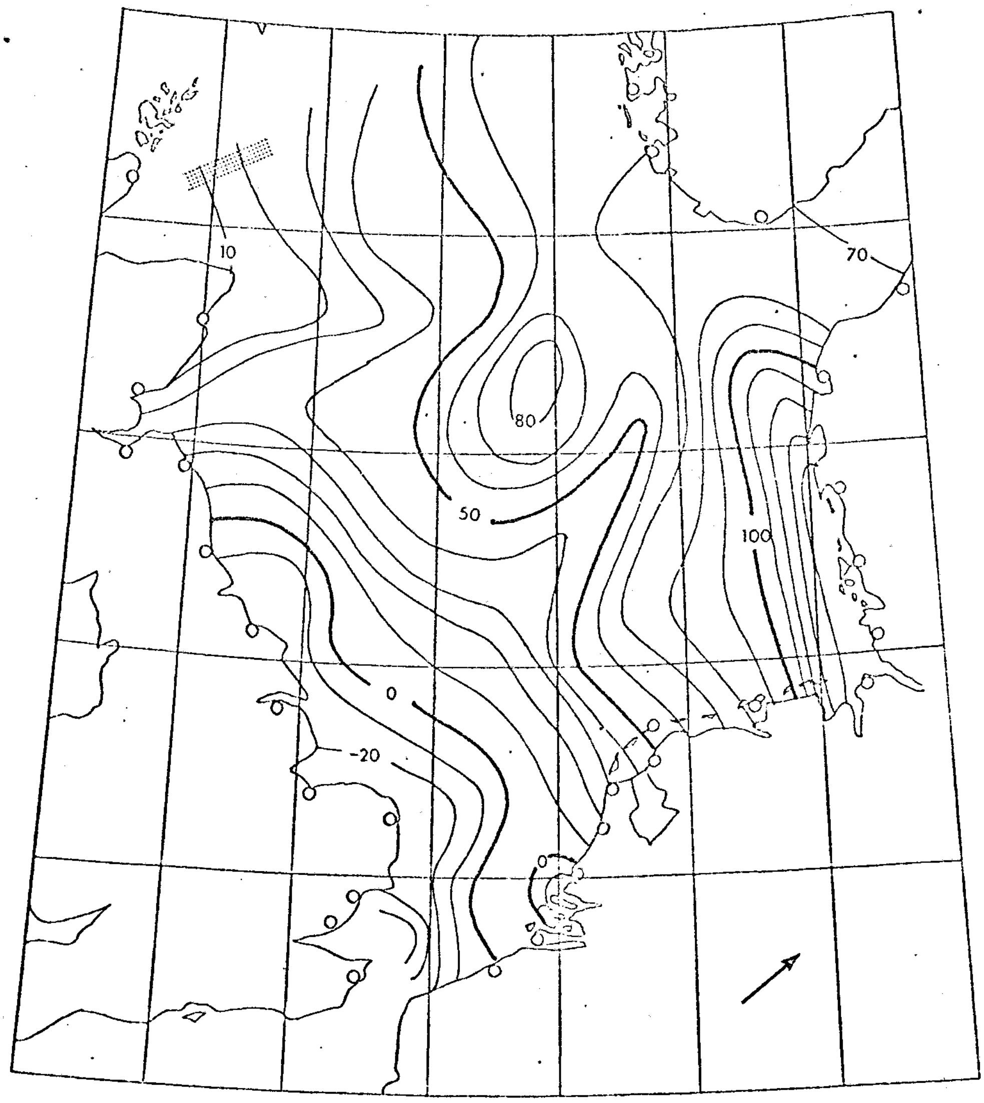

Fig. 6 Resultant of an external surge (similar to Fig. 3, but pulse height 30 cm) and the internal surge shown in Fig. 4. This is equivalent to extending the wind field.

Line values indicate the surge heights (cm). The shaded area shows an area through which the external surge is entered.

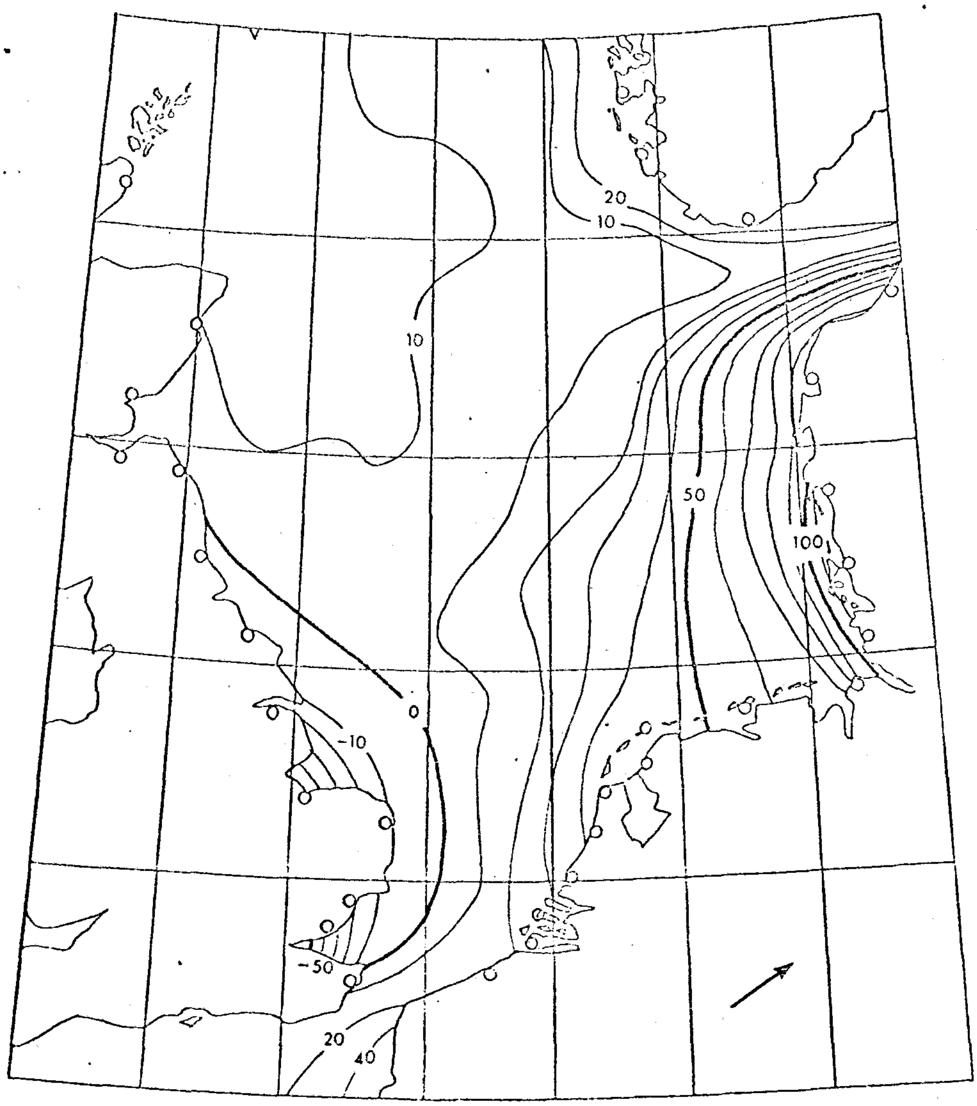

Fig. 7 Response of the water level in the North Sea to a suddenly applied uniform steady wind field over all the on-shelf seas around the British Isles.

Wind speed 20 m/s, direction 255°. Line values indicate the surge heights, 60 hours after the application of the wind field.

This diagram has been obtained (by the author) by applying the wind speed to the wind-stress diagram computed by Pingree & Griffiths (1980) which was not originally intended to be used for storm surge problems.

3. Conclusions

The investigation in the preceding chapter has been carried out for only one of the orthogonal surge components, but a similar result would be obtained for the other component.

When the sea is modelled with a limited area to which a quasi uniform steady wind/pressure field is applied, the result of the water-level response to this field is, of course, affected by the limited area of the field.

The minimum-surge area (see the abstract of this paper for the definition) characterizes the response of the water level to the field, irrespective of its direction.

In the first example (Fig. 2), the field covers just the North Sea, and the minimum-surge area appears in the centre of the sea. In the second example (Fig. 7 of this paper, or Fig. 3 and Fig. 5 of Pingree & Griffiths' paper, 1980), the field covers all the on-shelf seas around the British Isles, and the minimum-surge area with an almost zero water level appears around Aberdeen. Fig. 5 and Fig. 6 show intermediate cases.

It is important to realize that the minimum-surge area is a particular area appearing only in the fully developed state of the sea under a uniform steady wind/pressure field. In other words, the water-level is not necessarily minimum in the area in other states.

The first example shows internal surges in the North Sea only. An external surge (or surges) might exceed the water-level indicated in the minimum-surge area. An internal surge at a not fully developed stage again might exceed the water-level in the area. An external surge occurring at the same time as the internal surge might affect the resultant surge height.

In the second example, the water level around Aberdeen would be almost zero, if all the on-shelf seas around the British Isles are covered by a single quasi uniform steady field, although this meteorological condition is quite rare. From the first example, the largest surge height around Aberdeen is about 1.2 m which is derived from the field covering just the North Sea. Most positive surge heights around Aberdeen will be between zero and 1.2 m. Note, external surges do not have to be considered for the second example. They are included in the area to which the field is applied.

When a quasi uniform steady wind/pressure field is applied to the prediction of an extreme surge, it is recommended that the sea be divided into some sections (e.g. the North Sea, the on-shelf sea around the north-west of Scotland, the English Channel), so that an independent field (with specific values) is applied to one of the sections at a time. The response to this field should be obtained at each point in all the sections. After repeating this process for all the sections, then the largest surge value (height or current) at each point in the sea should be selected.

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