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Applying Numerical Modelling to the Prevention of Natural Disasters

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Introduction

Hong Kong occupies a coastal location in East Asia just south of the Tropic of Cancer. Its weather is subject to the vagaries of both tropical and extratropical weather systems as well as the monsoons. The presence of hilly terrain and long coast-line combine to give rise to complex small scale circulation patterns, which in turn lead to significant local variations within Hong Kong. This is illustrated by fig. 1 which shows the mean annual rainfall distribution. Therefore, to forecast weather in Hong Kong, it is necessary to take into consideration meteorological phenomena over a wide range of spatial scales, from the synoptic scale down to that of the local topography.

Hong Kong is a busy port with much marine transport activity. Within Hong Kong waters, there is also significant near-shore fishing and considerable recreational sailing. It is incumbent upon the meteorological service to safeguard all mariners from the threats of poor weather and rough seas.

Hazardous Weather in Hong Kong

Typhoons have always been the most feared weather system. High winds cause structural damage and casualties due to flying debris. Heavy rain, often occurring in association with active southwest monsoon, brings flooding in plains in the northern part of the territory, dangerously fast-flowing water on steep slopes (both natural streams and roads) and the failure of slopes in case rain is prolonged. On the close approach of typhoons, storm surge may occur especially in certain inlets and was the major killer in the past. 11 000 people were killed by the storm surge associated with a typhoon in 1937. Rough seas also cause problems for the fishing fleet, ships moored in the harbour and those traversing the sea lanes connecting Hong Kong and other ports.

Quasi-stationary troughs along the coast of southern China, the equivalent of Meiyu trough in China and Baiu front in Japan, occasionally bring prolonged periods of heavy rain. Floods and landslips occur as a result.

During the transition months of spring, copious supply of moisture from the South China Sea brings fog and extensive low cloud to the coastal areas. When this encounters southward advancing cold fronts, severe thunderstorms sometimes occur, bringing with them squalls and hail. Apart from causing disruptions to aviation and marine transport, lives are lost due to lightning strikes, damage to temporary structures, flying debris and accidents involving small boats at sea.

Monsoon winds, both in winter and summer, blow with force 6 strength or above from time to time and may even reach gale force on occasions when, for example, a tropical cyclone is situated nearby but not directly affecting Hong Kong. Some local sailors have been killed when they sailed from sheltered waters into the open sea, unaware of significant variations in wind strength and sea conditions within Hong Kong waters.

Warning Services

The Royal Observatory, Hong Kong, operates a forecasting and warning service for the general public, for aviation and for the marine community. A two-tier approach is adopted in which :

(a) routine weather bulletins are issued hourly for general dissemination, and

(b) special warnings covering specific hazardous weather phenomena are issued for radio broadcasts and speedy dissemination to a network of pre-determinated recipients.

The hourly weather bulletins normally give information on the state of sky, temperature, wind, precipitation and reduced visibility. The last two items are excluded when they are of no significance. For the public, these bulletins are the source of information on the forecast occurrence of heavy rain, thunderstorms, squalls and fog.

Whenever a tropical cyclone moves to within 800 km of Hong Kong and poses a threat, a system of local signals comes into effect and regular warning bulletins are issued for dissemination over the radio. These bulletins give information on the position and intensity of the tropical cyclone, its forecast movement, its impact on Hong Kong's weather conditions and precautionary actions to be taken. Great care is exercised in preparing the bulletins to make sure that the most important aspect of the tropical cyclone's impact on Hong Kong is clearly brought out, such as wind speed and direction, or rain, or storm surge, as the case may be. In certain situations, the focus is placed on the occurrence of rough seas, especially during public holidays when a considerable number of people travel among the outlying islands.

As a major port, Hong Kong broadcasts 3-hourly tropical cyclone warnings to international shipping in the area. Such warnings give information on present and forecast positions, wind and sea conditions around the centre and the intensity trend. In the past, it was difficult to issue these warnings so frequently because of data shortfalls. With the GMS in place, it has proved possible to provide the service with reasonable confidence with regard to consistency in tropical cyclone locations.

In respect of very short-range warnings, the Royal Observatory issues :

(a) thunderstorm warnings - to warn of the imminent occurrence of thunderstorms

(b) flood warnings - to warn of the occurrence of heavy rain which will lead to flash floods

(c) landslip warnings - to warn of the threat of slope failures under the influence of prolonged heavy rain

The nature of these warnings are often in the realm of nowcasting and their periods of validity are of the order of a few hours. In the operation of these warnings, forecasters typically draw heavily on data obtained from GMS imageries, radar, automatic weather stations and automatic-reporting rain-gauges.

Applying NWP to Weather Forecasting

Since 1985, prognostic products from ECMWF and U.K. Meteorological Office, transmitted to Hong Kong in GRID code via the Global Telecommunication System (GTS), are presented to forecasters in the form of isopleth and streamline charts. The resolution of the grid point data are in the range of '$5^{\circ} \times 5^{\circ}$' to '$2.5^{\circ} \times 2.5^{\circ}$'. It took a year or so before forecasters gained sufficient experience in interpreting the charts for the purpose of operational forecasting. The main impact of these products is in the form of guidance regarding the evolution of the synoptic background. These model outputs have been put to good use in forecasting surges of the winter monsoon arriving in Hong Kong. During summer, during which time Hong Kong's weather is tropical in nature, forecasters have yet to establish a good grasp of the relevant signals in these prognostic products for the forecasting of unsettled weather. Taken overall, the GRID code products are considered to be one of the two major information sources bringing about improvements in the forecast skill in Hong Kong, verified objectively, in the past few years (the other is the availability of GMS imageries).

One point of major interest is whether GRID products might help forecasters in the forecasting of tropical cyclone movement. Recent studies indicate that, when the environmental flow is quite well defined and when changes occur in the synoptic-scale flow, ECMWF model outputs at $1.125^{o} \times 1.125^{o}$ resolution can provide rather good forecasts of the flow and hence the movement of the embedded cyclone (Chan, 1988). But, in situations where the environmental flow is weak or where two tropical cyclones occur in close proximity, the model appears to encounter difficulties.

Figures 2 and 3 show how the ECMWF model performed vis-a-vis subjective forecasts issued in an operational environment. Both figures refer to Typhoon Wayne (8614), a most unusual typhoon which lasted for 21 days and made four major directional reversals during its lifetime. It was a severe test for both the model and the forecaster. Fig. 2 shows that ECMWF successfully captured the directional reversal of Wayne in response to changing background flow at the critical time of 12 UTC 22 August and the 72-hour forecast error was less than 200 km. This is in sharp contrast with errors exceeding 1000 km in the 48-hour forecasts issued by the Royal Observatory on 22nd and 23rd August. Fig. 3 shows a case in which the background flow was ill-defined and the subjective forecast issued on 31st August did better than ECMWF. These examples illustrate that ECMWF model outputs do have useful guidance value, especially when the synoptic flow exerts significant steering. However the GRID products now available on the GTS circuit do not have the resolution required to locate tropical cyclones down to within, say, 100 km. The performance of the GRID products in this respect therefore does not do full justice to the models themselves.

In the forecasting of heavy rain, operational experience suggests that GRID products give useful guidance regarding the general evolution of synoptic patterns (Chan, 1988). When it comes to the forecasting of times of rain commencement or cessation, it has been found necessary to examine fields of derived parameters e.g. vorticity at low levels. The relatively low resolution of existing GRID products is an obstacle to their application towards the forecasting of heavy rain which tends to occur on a rather small spatial scale.

Limited Area Model

With a view to obtaining prognostic fields at higher resolution, the Royal Observatory, Hong Kong, operates a limited area model which has been adapted from the very fine mesh limited area model VFM 65 with the assistance of the Japan Meteorological Agency. It is a primitive equation model with 13 sigma levels on a 51 x 36 one-degree latitude-longitude non-staggered (Arakawa A) horizontal grid (fig. 5). Parameterisation schemes for convection, radiation, turbulence and the boundary layer are included.

The initial analysis is based on optimal interpolation applied to ten standard levels (surface to 100 hPa), again at 1° resolution but over a wider domain (65-165°E, 0-65°N). Time-dependent lateral boundary conditions on seven standard pressure levels (fig. 5) are generated from the JMA Global Spectral Model and communicated to the Royal Observatory via the GTS link between Hong Kong and Tokyo. Owing to limitations of circuit capacity, outputs from two different runs of the JMA Global Spectral Model are utilized and are communicated to Hong Kong in two batches outside peak traffic hours on the circuit (fig. 6).

The model is run once a day to give 12-hourly prognostic charts up to 48 hours. By the time the charts are presented to the forecasters in the morning (local time), they have with them about 1 1/2 days of forecast value and give guidance up to the night of the following day. Fig. 4 shows part of a prognostic 850 hPa chart currently produced. Apart from streamlines (or isobars on the surface chart) for the identification of circulation systems, numerical values of the various parameters are also plotted to allow forecasters to examine any field relevant to the particular situation. Isopleths of vorticity are also plotted for their potential value in the forecasting of heavy rain.

To ease the workload on forecasters in the interpretation of prognostic charts for the purpose of local weather forecasting, other products are produced based on outputs from the model run. They include forecast time-cross-section (fig. 7) and vertical profiles (fig. 8). While the accuracy of the numerical values of forecasts temperature, R.H., etc., remains to be evaluated, operational experience indicates that these products are useful in giving guidance with regard to trends.

Local Winds Model

In order to improve the understanding of local variations in winds within Hong Kong, a model geared to investigations into this aspect has been adapted from one designed by the Meteorological Research Institute, Japan (Yeung, et al, 1989). It is a three-dimensional, prognostic, primitive equation model with Boussinesq approximation. The equations are written in terrain-following coordinates. In the surface layer, the vertical eddy diffusivities are obtained from flux profiles. Above the surface layer, turbulence is parameterised by a level 2 turbulence closure model.

The model has been run to investigate into both low and high wind speed situations. Figures 9 and 10 show the wind distribution in Hong Kong with background winds of 15 m/s from the northnortheast and from the northeast respectively. Although the background wind directions in the two cases differ by only 22.5°, significant differences in winds are indicated for the harbour area (middle part of low half of the figure). This kind of information is extremely relevant to the work of forecasters when issuing warnings for the local population and the marine community at times of tropical cyclone passage or strong winter monsoon.

Wave Models

A deep water wave model is currently operated to produce 48-hour wave and swell forecasts for the northern part of the South China Sea and the adjacent Pacific (domain : 5-35°N, 105-135°E). It is an adapted version of a model originated from the Meteorological Research Institute, Japan (Poon, 1988). The model is a coupled-discrete model which represents waves in 352 energy bins (22 frequencies and 16 directional components). Each component is allowed to grow according to a specified growth equation and energy exchange among components is allowed. The model is known to performed well in tropical cyclone situations. Fig. 11 shows a sample output chart from the model. To facilitate the formulation of forecasts, information on 'sea' and 'swell' are presented as separate items in the chart.

A shallow water wave model is run to give information on wave and swell conditions in Hong Kong waters (Poon, 1989). The computation domain consists of 15x17 grid points at 4.4 km resolution. Wind waves are computed using the SMB shallow water equations. As for swells, wave energy computed for a nearby grid point by the deep water wave model is advected into the model domain and subject to energy dissipation arising from dispersion, internal friction, etc. A sample forecast wave chart for Hong Kong waters is given in fig. 12. Sigificiant regional variations are clearly evident.

Information Dissemination

Routine hourly weather bulletins are sent to the media through an automated communication network operated by the Infomation Services Department of Hong Kong. Direct communication with radio and television stations are also set up. When tropical cyclones or heavy rain are of concern to the public, twice daily press conferences are held and special arrangements are made to ensure that the messages are conveyed to the public via television during the main news broadcasts.

Critical signals are distributed to government departments and relevant organisations required to take response actions through telephone calls. Major public utilities (e.g. power companies) and transport operators are linked to the Royal Observatory Hong Kong through direct teleprinter links. Warnings are also sent to various clients through the use of telex and telefax. Since 1988, weather information is kept in public databases which can be accessed using normal telex or telefax machines. This latest development has made it possible for warnings in written form to reach a much wider audience than before.

Looking Ahead

In the course of implementing the adapted version of VFM 65 in Hong Kong, it was found that the performance of the model was very sensitive to the lateral boundary conditions. Unfortunately, GTS circuit limitations prevent further enhancement of the transmission of lateral boundary conditions generated by the JMA global model. It is hoped that the planned use of GMS data transmission channel to transmit grid point value (GPV) data will eventually make it possible to strengthen this aspect of the operational running of the limited area model in Hong Kong.

The full potential of the operational limited area mode in Hong Kong has yet to be realised. Work is underway to generate more derived products based on the outputs of the model, with the specific objective of giving enhanced guidance to forecasters in respect of local weather forecasting. With the accumulation of experience with outputs from the model, it is hoped that more forecasting rules of a quantitative nature can be formulated.

A vital part of the forecasting process is to 'translate' outputs from the limited area model into weather conditions in various parts of Hong Kong. The 'local winds' model and wave model for Hong Kong waters are already making useful contributions in this direction. Some thoughts will be given to linking the 'local winds' model to the outputs of the limited area model. While existing computing capacity will not permit doing this in real-time, investigative studies will be carried out and hopefully the results will be sufficiently encouraging to support the case for expanded computer power.

<u>References</u>

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2. Chan, Y.K., 1988 : An analysis of the persistent heavy rain situation from 28 to 30 July 1987 and the revelation from using numerical model results to forecast this event (in Chinese). Presented at 3rd Guangdong - Hong Kong Joint Seminar on Hazardous Weather, April 1988.

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5. Yeung, K.K., Chang, W.L., Wan, B., Kimura, F., and Yoshikawa, T., 1989 : Simulation of boundary layer flow in Hong Kong. Submitted to <u>Atmospheric Environment</u>.

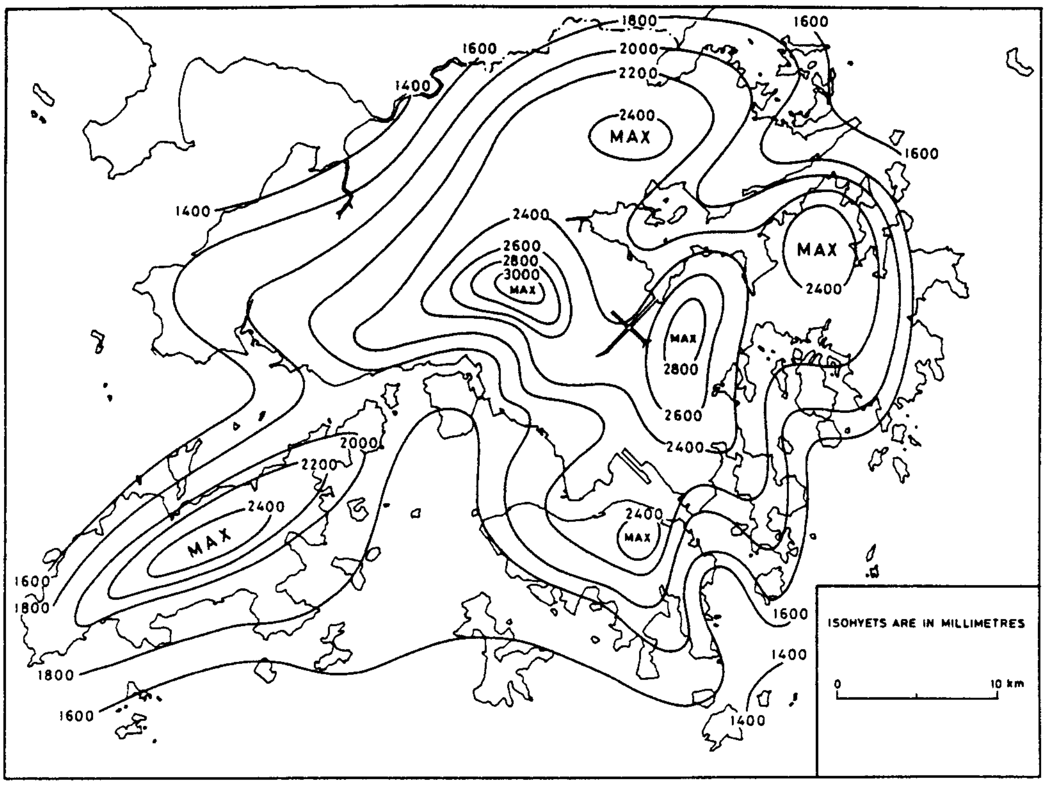


Fig. 1 Annual rainfall distribution in Hong Kong.

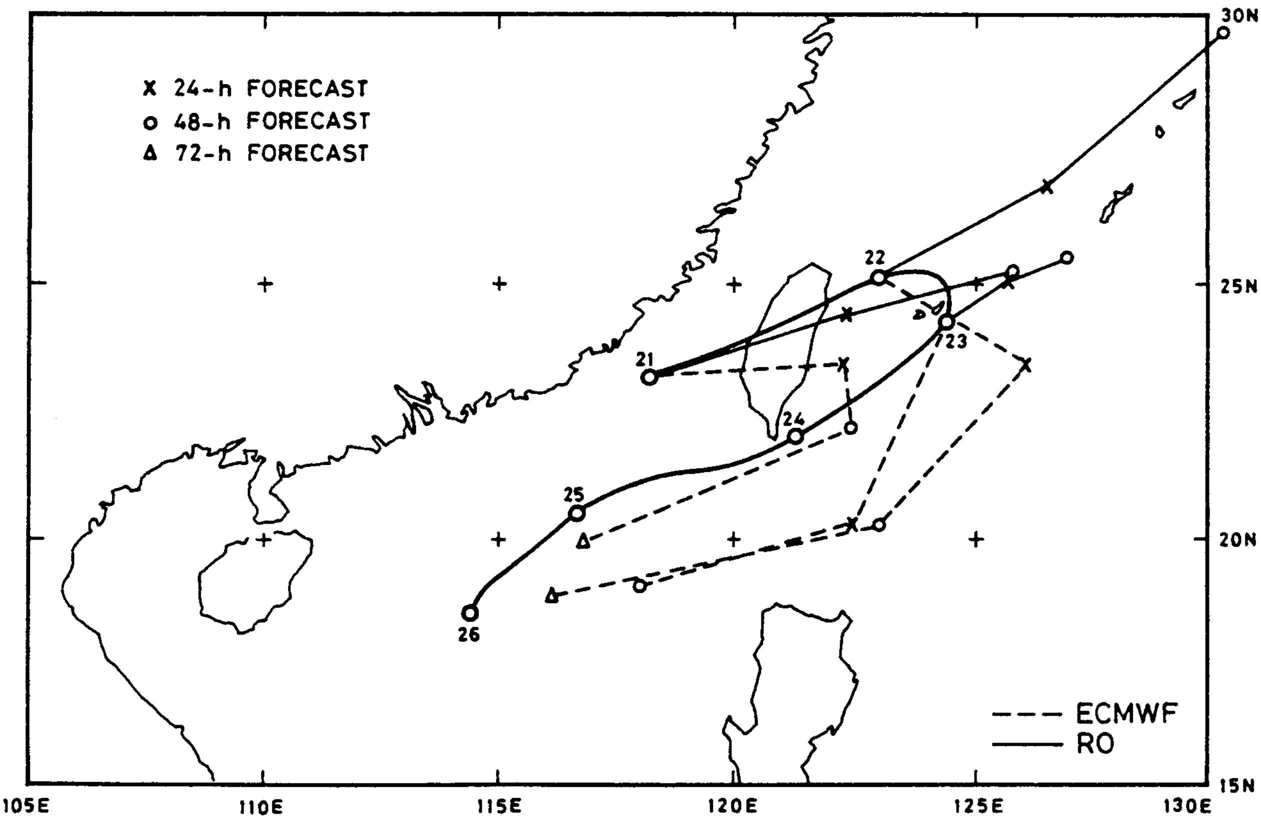


Fig. 2 Forecast tracks, Typhoon Wayne (8614), August 1986.
Best-track positions for 12UTC on the dates indicated.

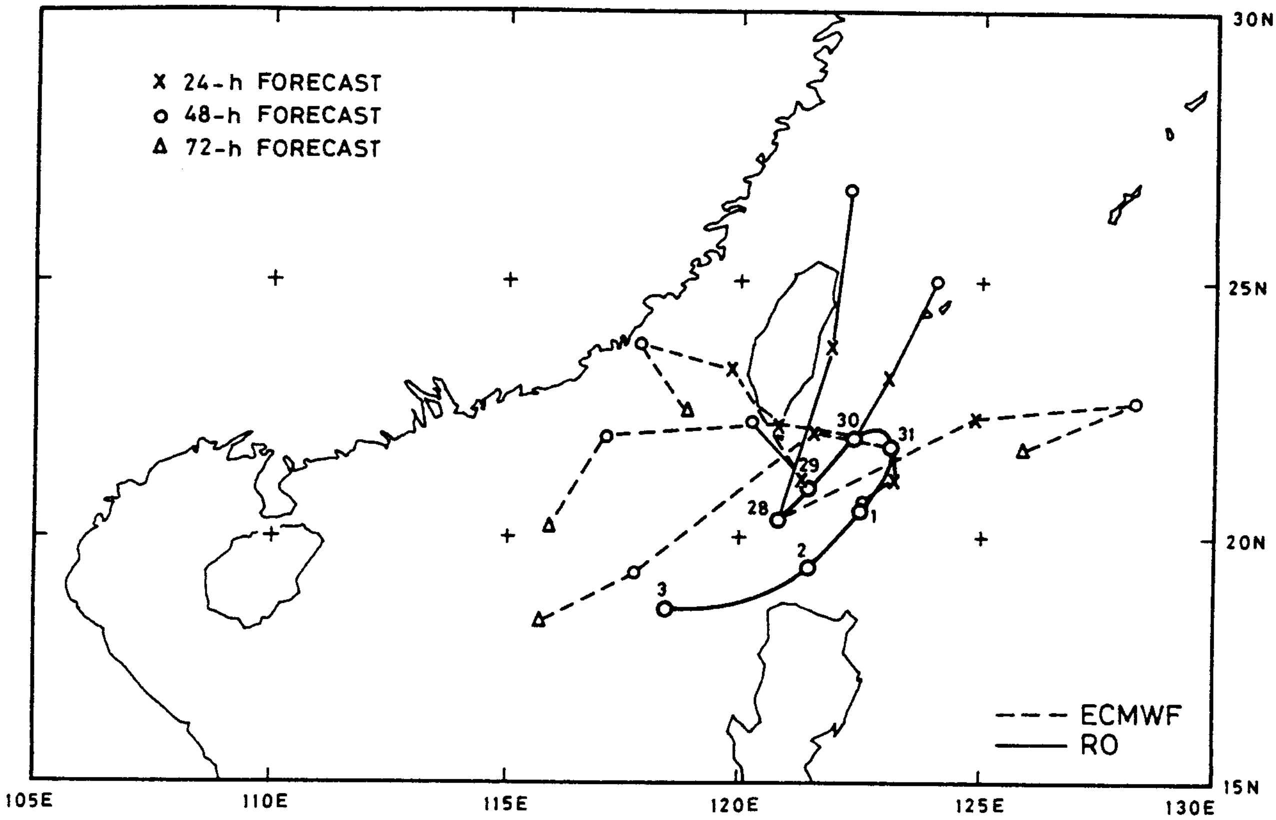


Fig. 3 Forecast tracks, Typhoon Wayne (8614), August 1986. Best-track positions for 12UTC on the dates indicated.

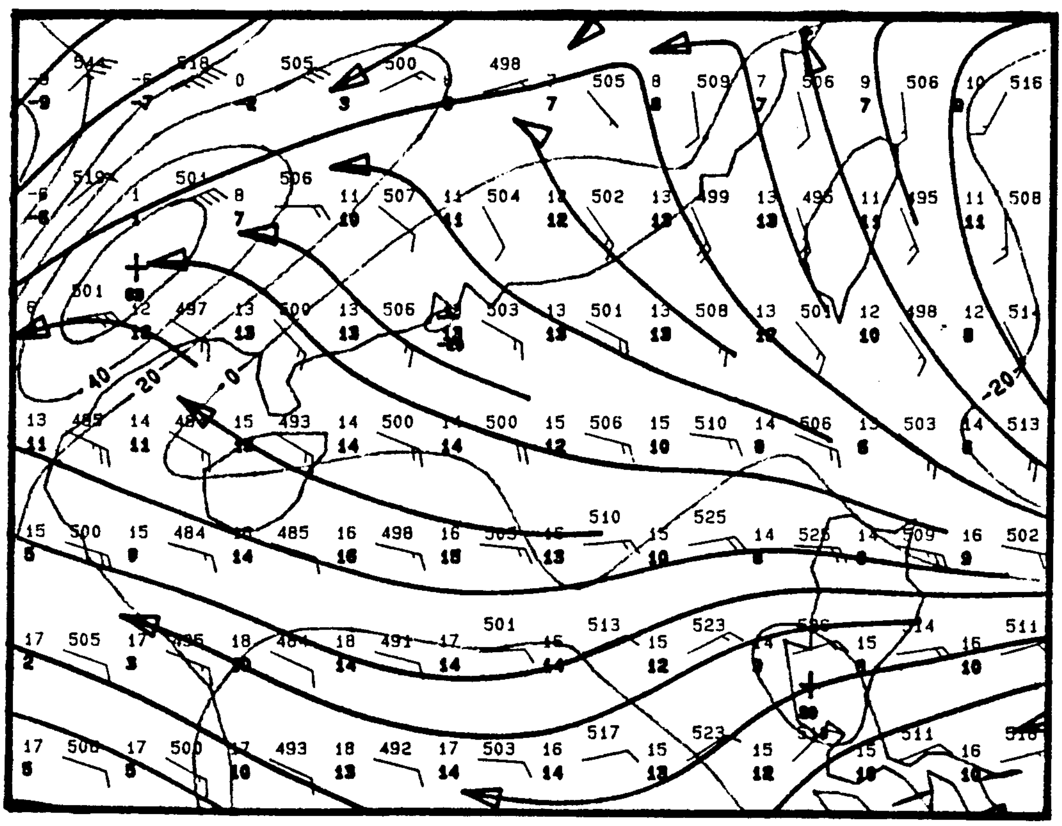
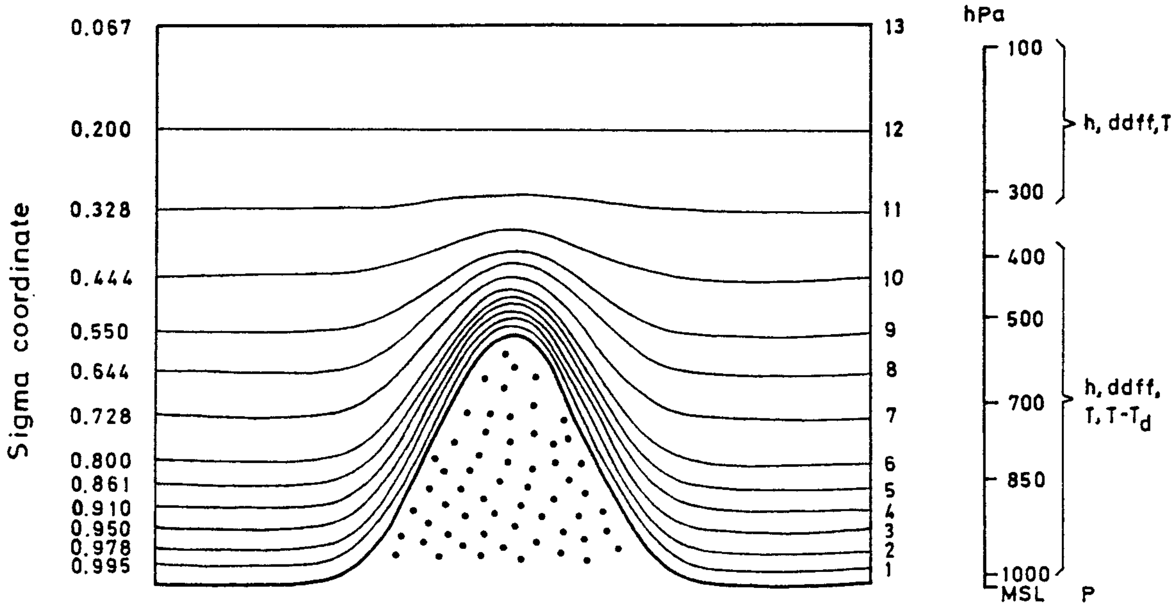
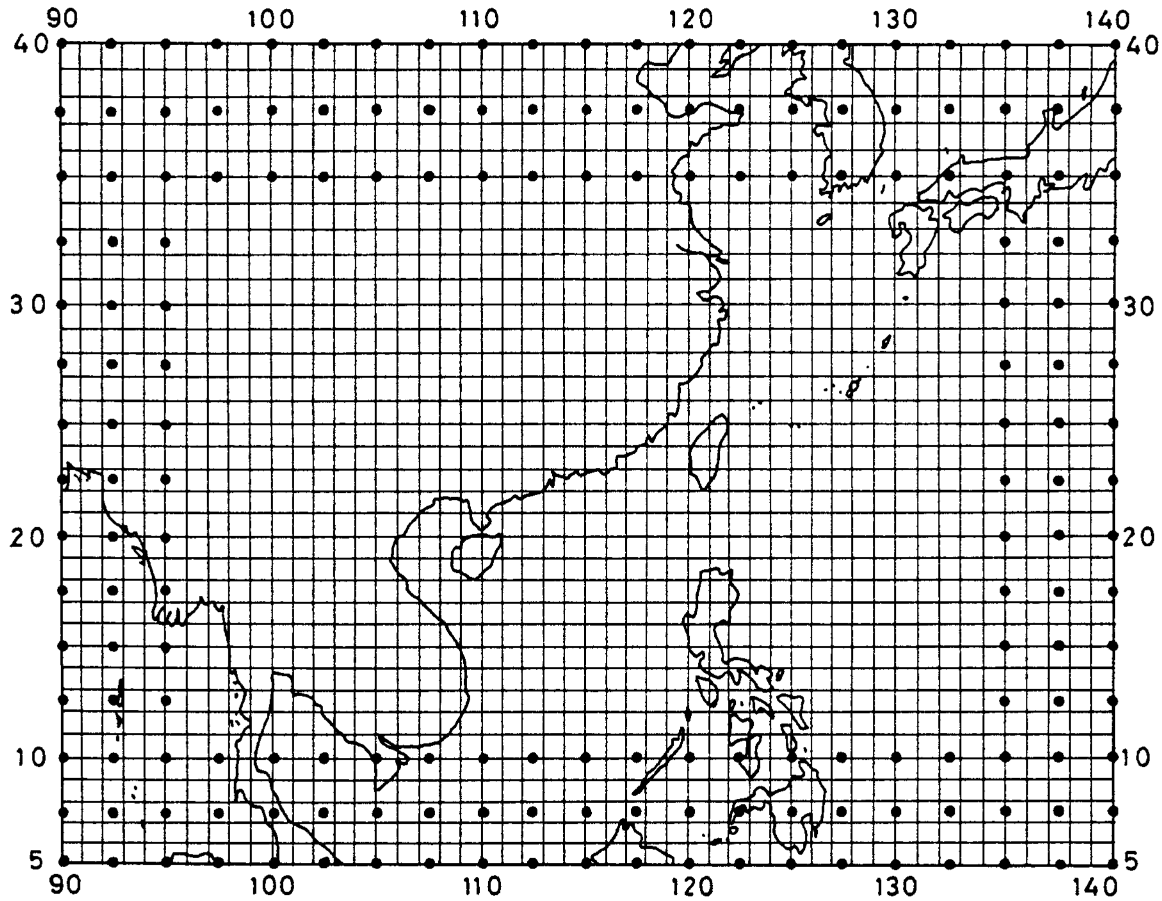


Fig. 4 Part of a sample 850 hPa chart generated by the Royal Observatory limited area model.



(a)



(b)

Fig. 5 Royal Observatory limited area model

(a) Vertical structure of model and variables carried at lateral boundary points.

(b) Horizontal domain. Boundary points are represented by black dots.

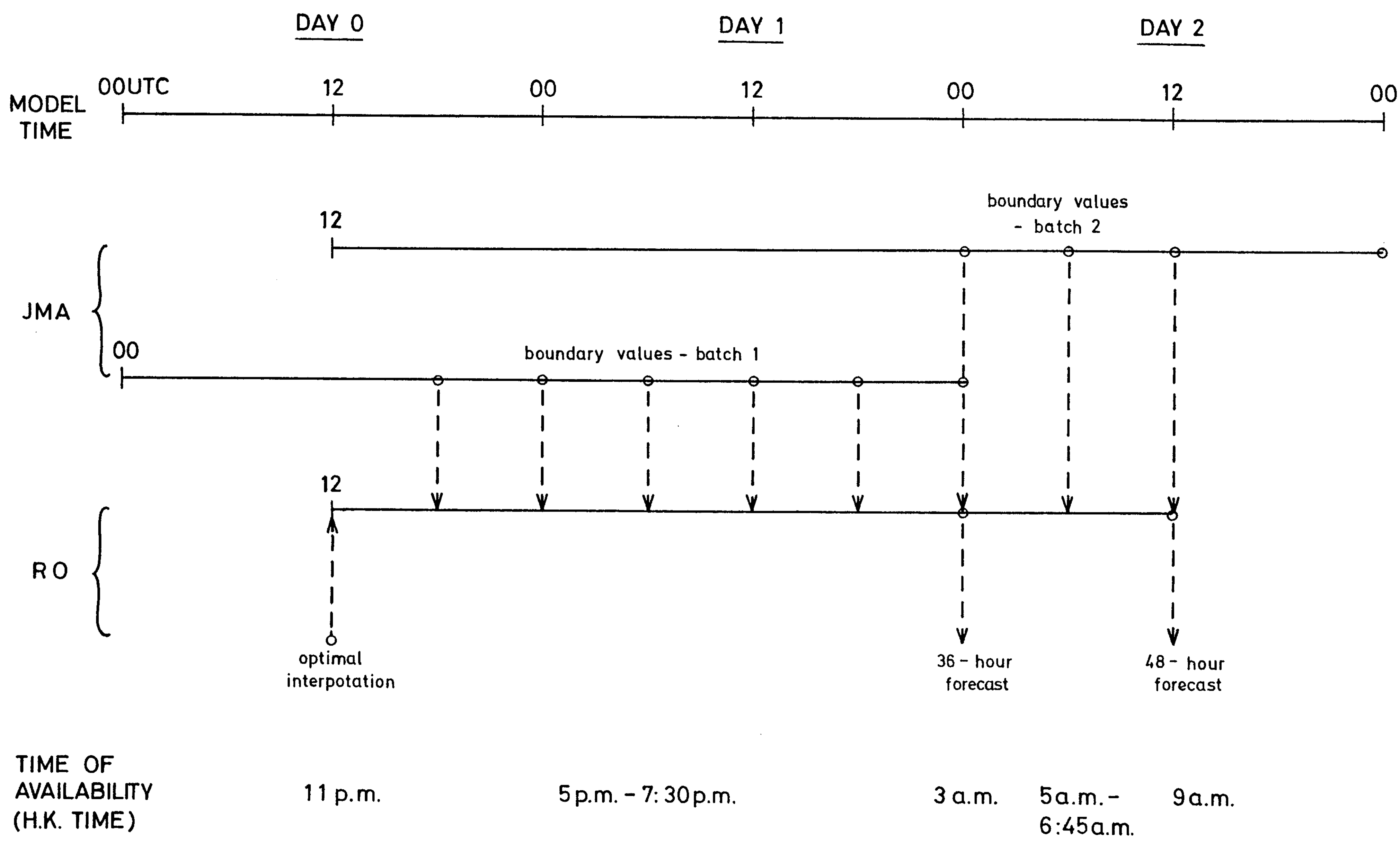


Fig. 6 Operational schedule of the Royal Observatory limited area model.

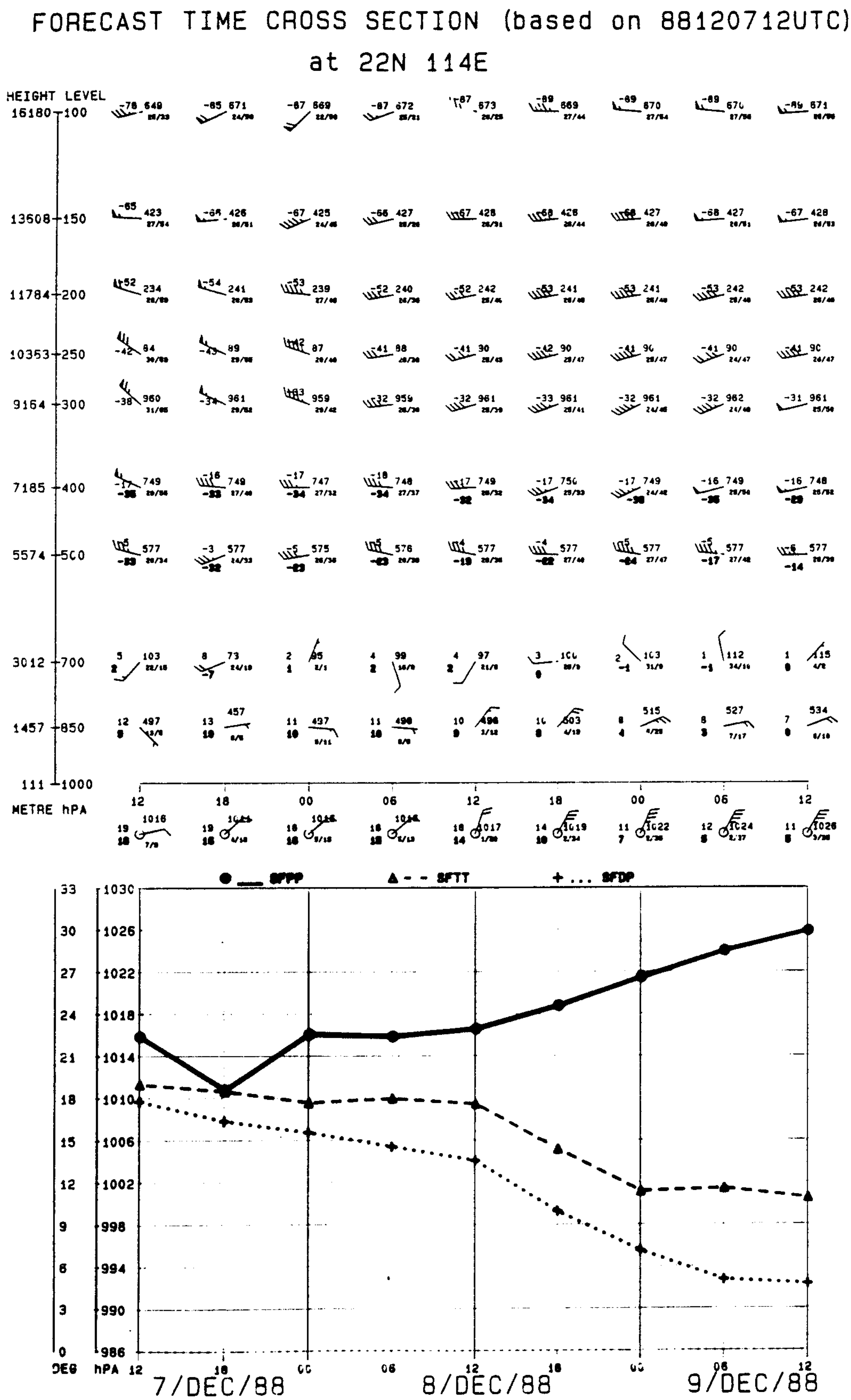


Fig. 7 Forecast time cross-section based on outputs of the Royal Observatory limited area model

FORECAST VERTICAL PROFILE (based on 88120712UTC)
at 22N 114E

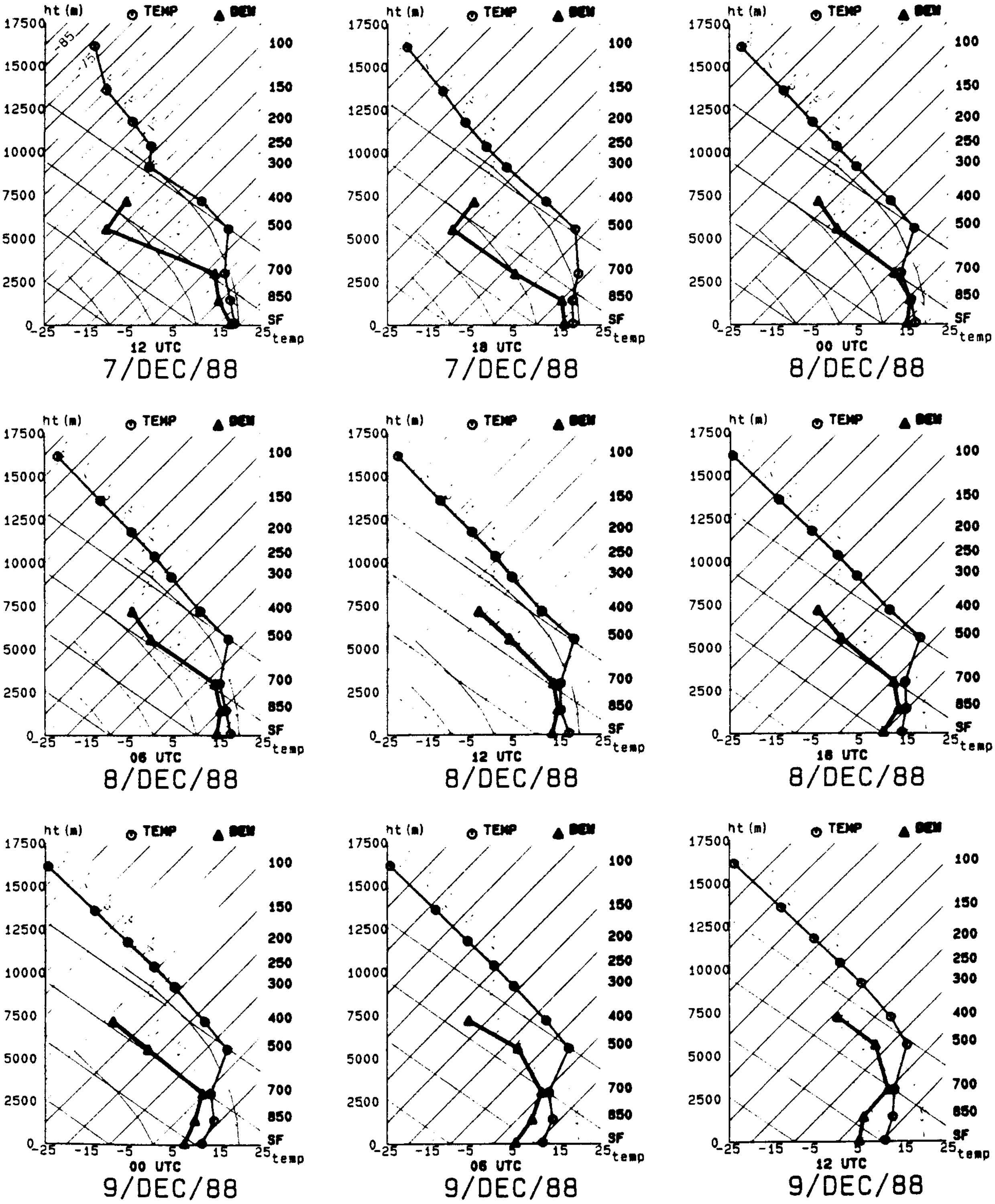


Fig. 8 Forecast vertical profiles based on outputs of the Royal Observatory limited area model

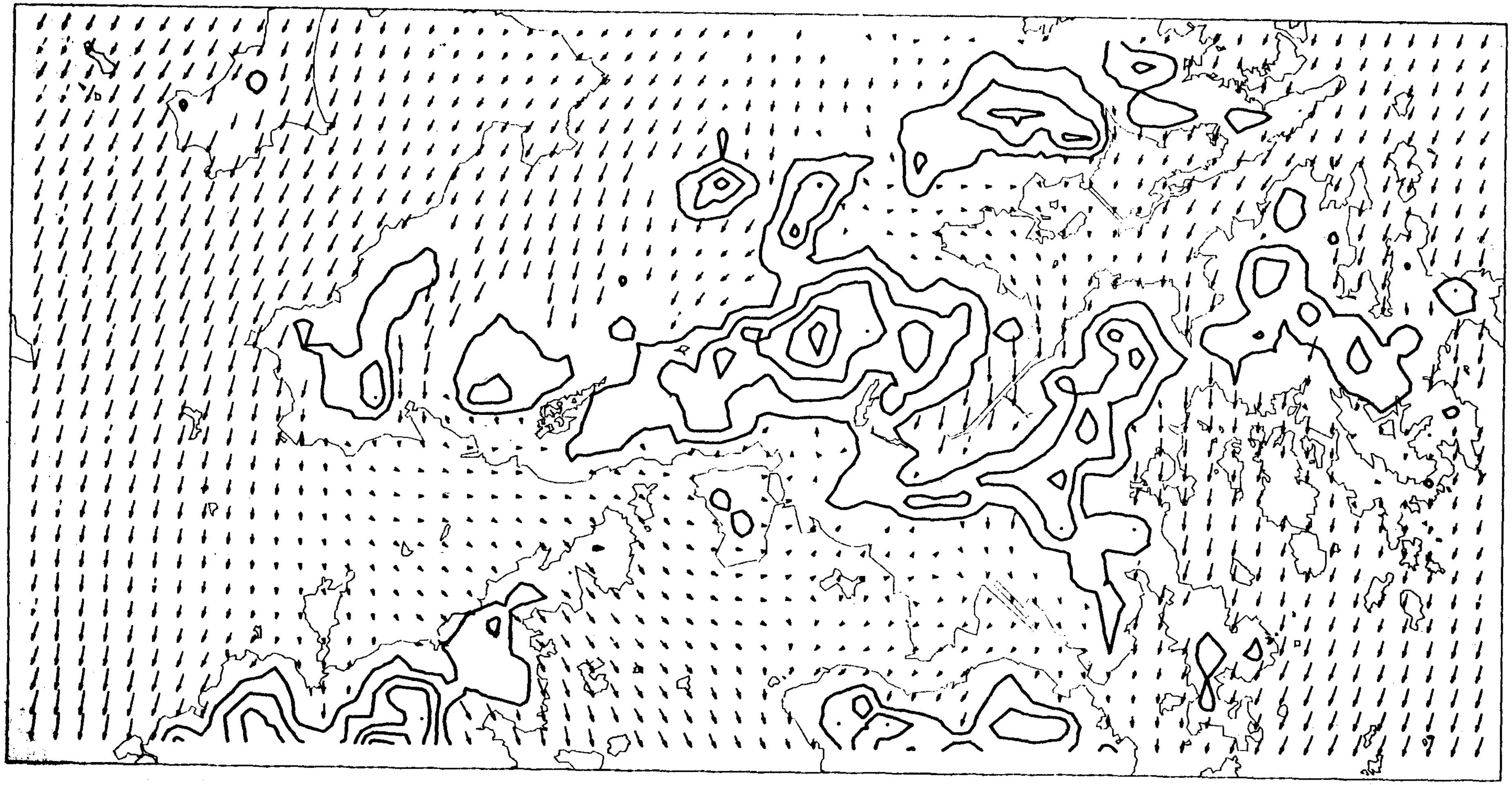


Fig. 9 Output from local winds model for a background wind of 15 m/s from NNE. Scale of wind vector : → equals 10 m/s. Contours at 150 m intervals.

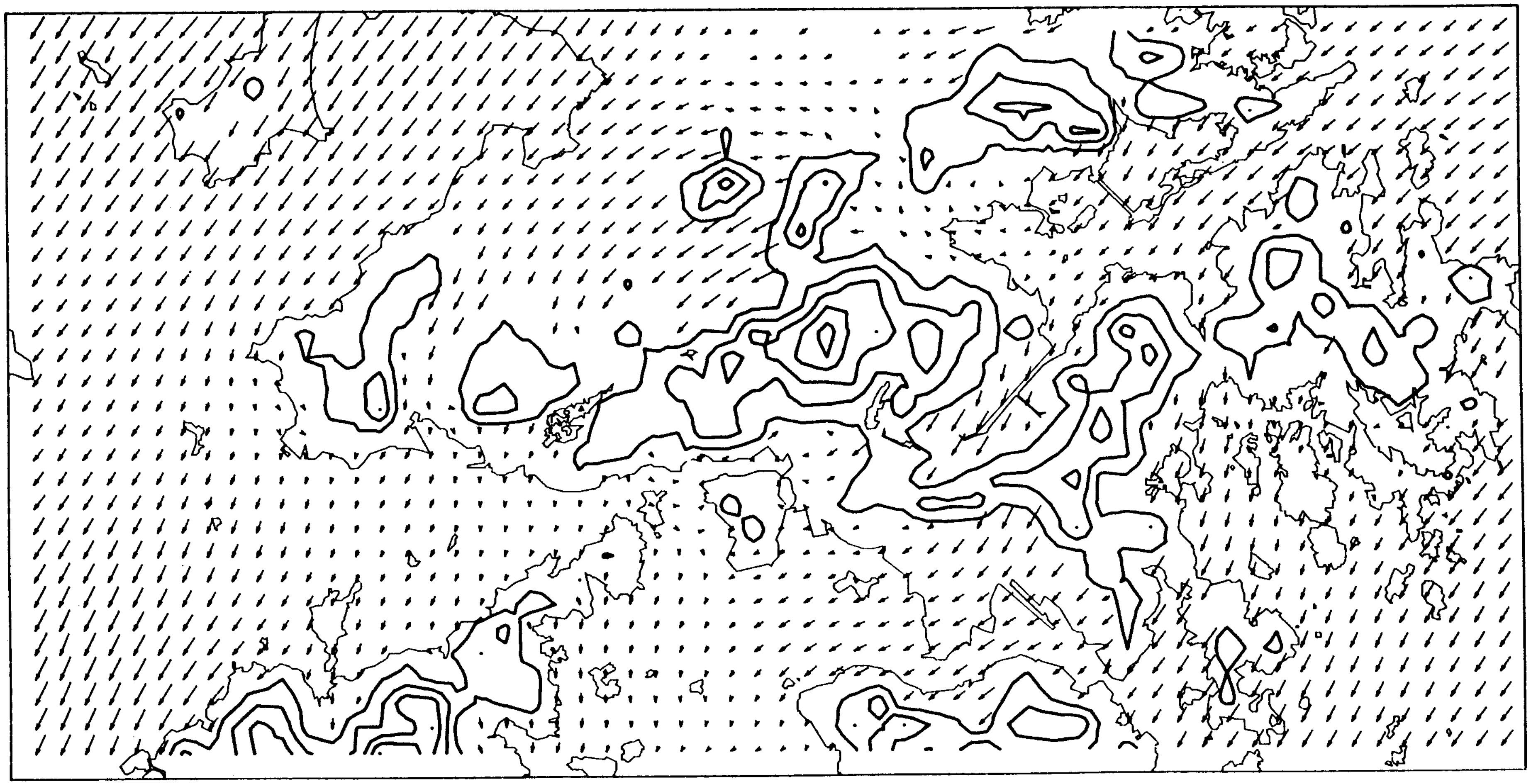


Fig. 10 Output from local winds model for a background wind of 15 m/s from NE. Scale of wind vector : → equals 10 m/s. Contours at 150 m intervals.

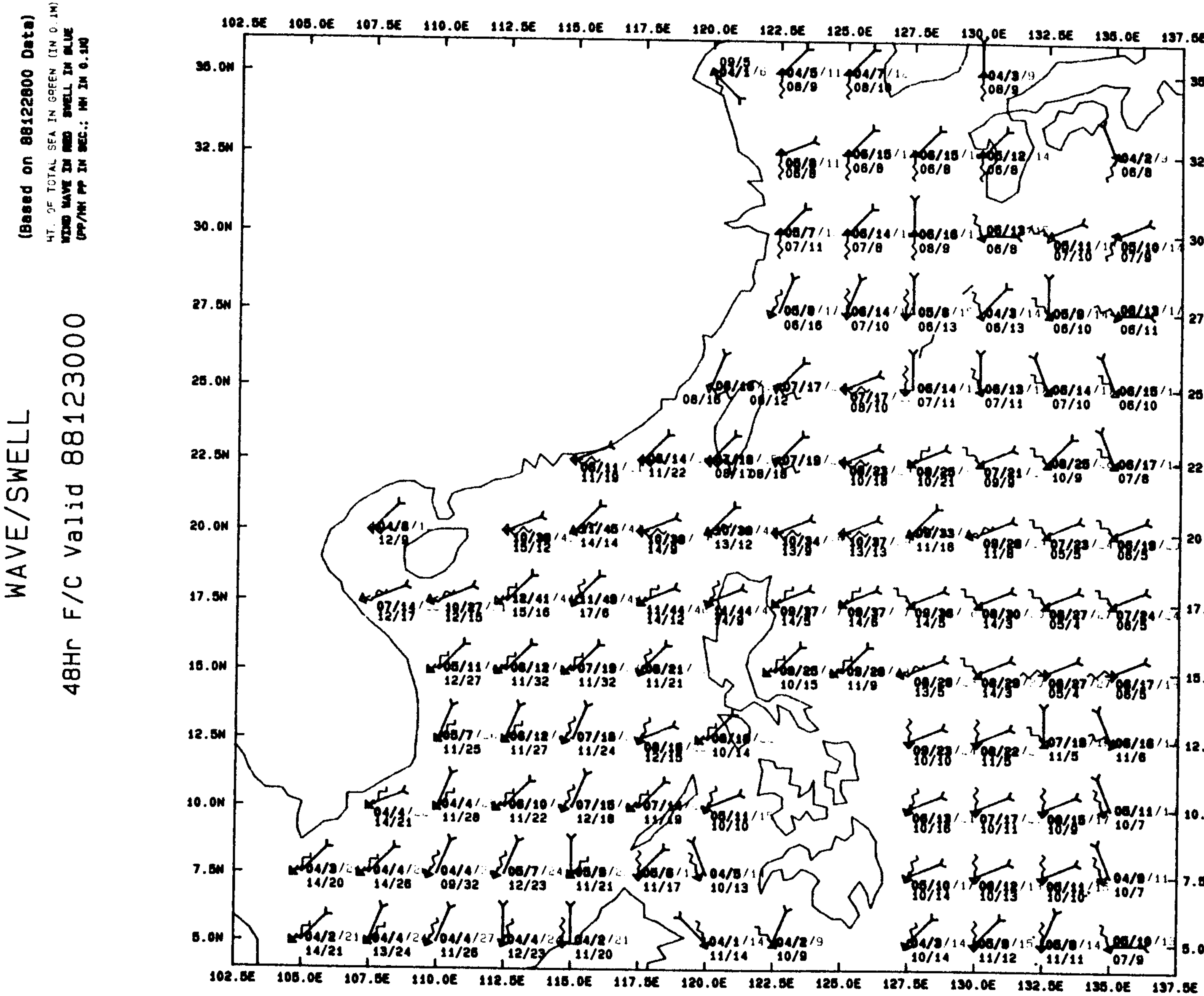


Fig. 11 Sample product of Royal Observatory deep water wave model.

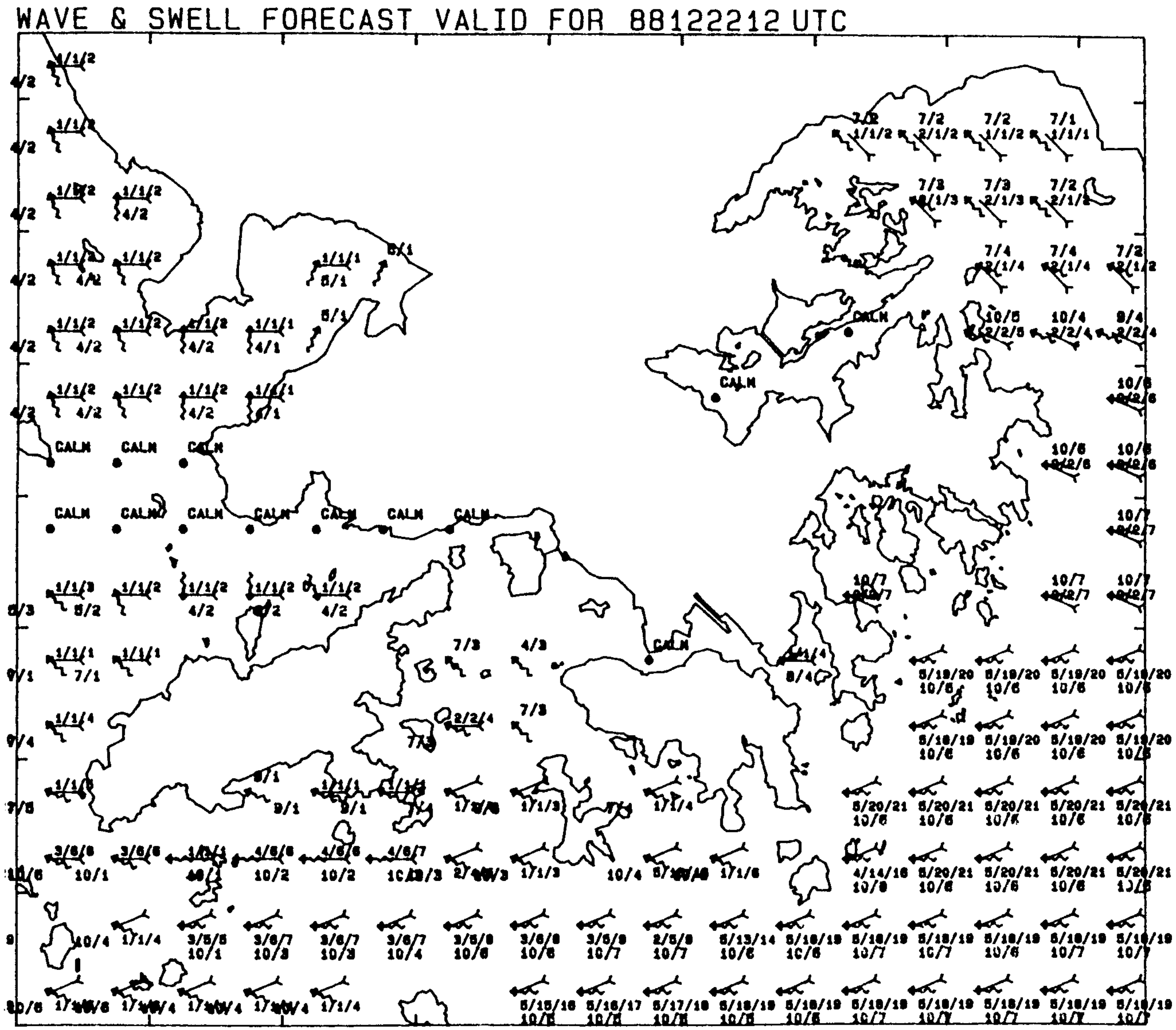


Fig. 12 Sample product of Royal Observatory shallow water wave model.