A PC BASED INSHORE WAVE FORECAST SYSTEM

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1. INTRODUCTION

Modern marine operations and coastal management are becoming increasingly sophisticated with a variety of tools available to assist decision making, risk assessment and planning. Forecasts of weather conditions are being used more widely, however, more detailed information is often required than is typically available at present. For example, parts of the UK coast are subject to coastal flooding and there is a need for real-time warning of such events. At present, however, the spatial resolution of global or regional wave models is too coarse to provide sufficiently detailed and accurate forecasts.

This paper describes the recent development of a flexible, easily configurable local area shallow water wave and associated response forecasting system. The real time control part of the system is based on the FloodWorks software package developed by Wallingford Software and CEH Wallingford. FloodWorks was originally developed for fluvial flood forecasting and combines hydrological and hydrodynamic modelling with real-time decision support and control.

The generic design of FloodWorks allows a wide range of computational wave and response models to be incorporated and linked in a straightforward manner. FloodWorks also includes the provision for in-situ and remote sensed data to be assimilated into the forecasts. This flexibility enables the system to be expanded for a range of decision support tools for coastal engineers.

A nearshore shallow water wave forecasting system has been set up within the FloodWorks framework as the first stage of development towards a coastal flood forecast system. This prototype system uses global or regional scale offshore forecast wave data provided by the UK Meteorological Office (Met Office) as boundary conditions to a shallow water wave transformation model. Corresponding inshore wave forecasts are provided in real time. The main features of the system are that it is based on established wave models, an existing real time control software technology and offshore wave forecasts from operational regional/global wave models.

2 THE FLOODWORKS SYSTEM

2.1 Overview

FloodWorks is a software facility that integrates hydrological and hydrodynamic modelling with real-time decision support and control. It is based on the River Flow Forecasting System (RFFS) software developed by CEH Wallingford and GIS & Database tools developed by Wallingford Software. It combines data assembly, validation and management, advanced hydrological and hydrodynamic simulation engines, geographical analysis and a relational database within a single environment. It also links real-time hydrological and meteorological time-series data sources with computational modelling.

Its main use allows managers and engineers to carry out fast, accurate simulations of the key elements of the future behaviour of hydrological and hydrodynamic systems to support mobilisation of emergency responses and provision of public warnings.

2.3 Operation

Whenever a new forecast is initiated, the FloodWorks data-gathering module collects the latest data from the available data sources (e.g. global wave model data, telemetry, radar, etc). This module matches up the data points from the telemetry and other systems to the model input data series and carries out data validation and conversion of data formats.

In automatic operation, or if the operator has no changes to make, these data pass directly to the FloodWorks Forecasting Module. This module feeds the data through a network of hydrological and hydrodynamic models to generate forecasts of the hydrological or hydrodynamic parameters over the selected forecast period.

The forecast time-series from the FloodWorks Forecasting Module are processed by the FloodWorks Analysis Module, which summarises and interprets the forecast time-series in relation to the warning levels defined for the various forecast points. The summary tables produced by this module contain geo-reference data for subsequent map-based display.

The complete set of input data, forecast time-series and forecast summary tables for each run of the Forecasting Module are stored in the FloodWorks Forecast Database. Through the FloodWorks Operator's Interface, operators can initiate additional runs, display the data from any of the completed runs in the form of maps, tables, graphs or reports, and construct fax or email bulletins based on the forecasts.

The FloodWorks runs forecasts automatically at regular intervals. Authorised operators are able to carry out 'special' runs in which they can select initial conditions for a run, initiate runs based on previous forecasts, produce forecasts only for selected parts of the network, choose between alternative meteorological forecasts, and edit any of the observed or forecast data to be used in the run.

For the prototype wave forecasting system FloodWorks was installed on a PC at the UK Met Office external to the operations room. FloodWorks was configured to trigger forecasts automatically on receipt of new input data. Met Office model output is sent to the FloodWorks server (as illustrated in Figure 1), via ftp, and its arrival triggers and automatic dataloading task to import the data and then a forecast run. As soon as the nearshore forecasts are computed these forecasts are sent via ftp to the Aberdeen Met Office from where the final wave forecasts were assembled and sent to the Client.

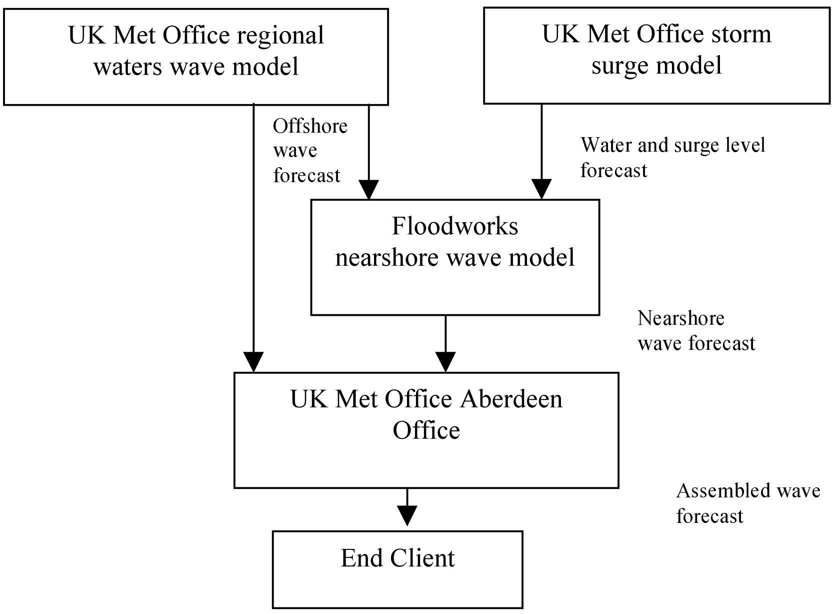

Figure 1 Overview of prototype service network

3. DESCRIPTION OF THE WAVE AND SURGE MODELS

3.1 Offshore waves (Regional wave model)

The UK waters wave model covers the north-west European continental shelf from 12° W, between 48° N and 63° N at a resolution of 1/9° longitude by 1/6° latitude (approximately 12 km). The UK waters model includes the effect of time-varying currents on the waves, using currents forecast by the operational storm surge model (described in Section 3.2). The model runs four times daily from taking hourly surface winds from mesoscale NWP (Numerical Weather Prediction) to give a 48-hour forecast. A second run of the UK waters wave model is also made to give a 5-day forecast, this takes hourly winds from global NWP but does not include the effects of currents.

Waves in the tidal waters around the UK can be a combination of locally generated wind waves and remotely generated swell, both can be modified by tidal or storm-surge currents which affect both wave height and wave period. Waves around the UK are important for prediction of coastal flooding and the breaching of sea defences, and for fast ferry operations (which cannot operate if the wave height is expected to exceed 3.5 m).

3.2 Tide and surge water levels

Water levels used in the forecast are provided by the UK Met Office's storm surge model that is primarily used by the Storm Tide Warning Service. The model is owned and developed by the Proudman Oceanographic Laboratory. Winds and surface pressure fields are used as forcing data as well as tide data to provide hindcast and forecast total water levels. The model itself is run twice: in the first instance, the computation is for the tides only; in the second, the tides and the meteorological effects are computed together. The storm surge residuals are obtained by subtracting the results of the first run from those of the second. The model covers the European Continental Shelf, North Sea, Skagerrak and Kattegat with an average grid length of approximately 12km.

3.3 Transformation of waves from offshore to nearshore

The HR Wallingford TELURAY wave refraction model (Abernethy and Gilbert, 1975), predicts wave activity at coastal sites, given a spectral description of offshore wave conditions. The model uses the concept of wave rays, which are lines everywhere perpendicular to the wave crest. These rays are followed or tracked seawards, from a selected inshore point to the offshore edge of the grid system using Snell's law to calculate changes in ray path due to refraction effects. Since the ray paths are reversible, each ray then gives information on how wave energy travels between the seaward edge of the grid system and the inshore point of interest.

Computations in the TELURAY program can be split into two parts. The first stage involves consideration a large number of ray paths, representing a wide range of offshore wave periods and directions, to generate a set of matrices, known as transfer functions. These transfer functions provide a description of the transformation of wave energy between the edge of the refraction grid and the inshore point of interest. The second stage uses these transfer functions to modify each of the offshore spectra into a corresponding inshore spectrum at the specified inshore point.

TELURAY represents the effects of depth and current refraction and shoaling. The model has recently been extended to include the effects of non-linear shoaling and wave breaking using the empirical formulation described in Goda (1984).

4. OPERATIONAL WAVE FORECASTS FOR THE SCOTTISH COAST

4.1 Background

Forecasts of wave conditions were required for a towing operation in the North Sea during the summer months of 2002. Typically most North Sea operations rely on deep water wave forecasts provided by wave generation models that ignore shallow water wave processes. However, due the length and type of the object being towed nearshore wave conditions were considered to be a critical part of the operation.

4.2 Location

The tow route starts in a large open bay north of Wick (Scotland) which is predominately exposed to waves from the northeast, though east to southeast. The seabed is gently sloping, but includes a sandbank within 1km from the coast which tends to shift in position and level over the duration of years.

4.3 Application of the TELURAY wave transformation model

A TELURAY wave transformation model was set up for an area extending offshore to the location of the nearest Met Office UK waters wave model point. An unstructured triangular mesh was generated to cover the area of interest with high resolution along the tow route (see Figure 2). The mesh spacing varied between 50m and 200m in the shallow areas and along the tow route and 500m in the outer areas.

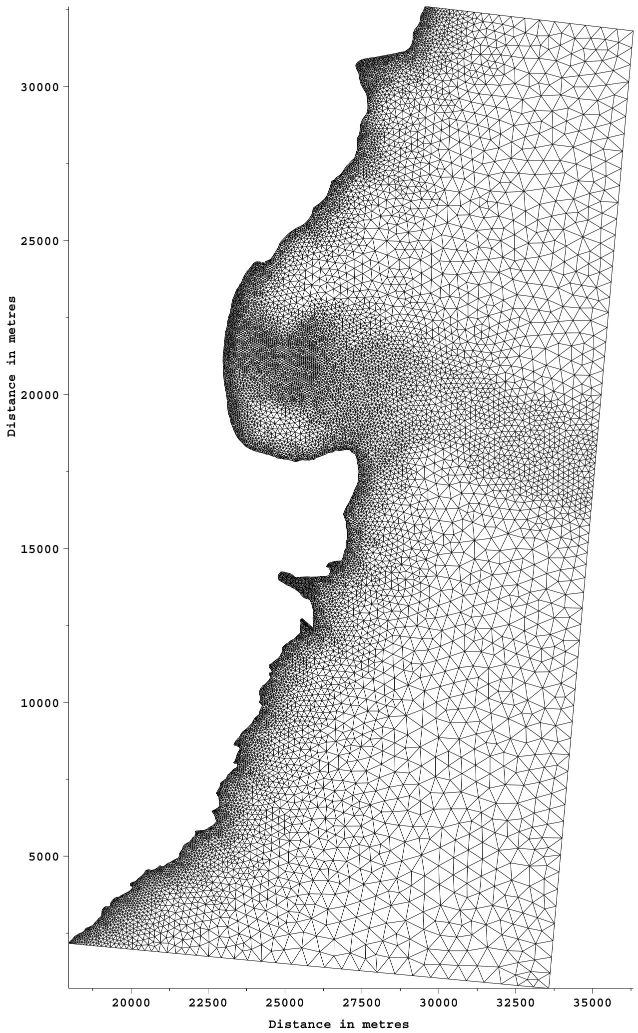

Figure 2 TELURAY model mesh

Model depths were interpolated from the UK Admiralty Charts of the area and recent surveys of depths provided by the Client. Figure 3 shows a contour plot of depths in the model.

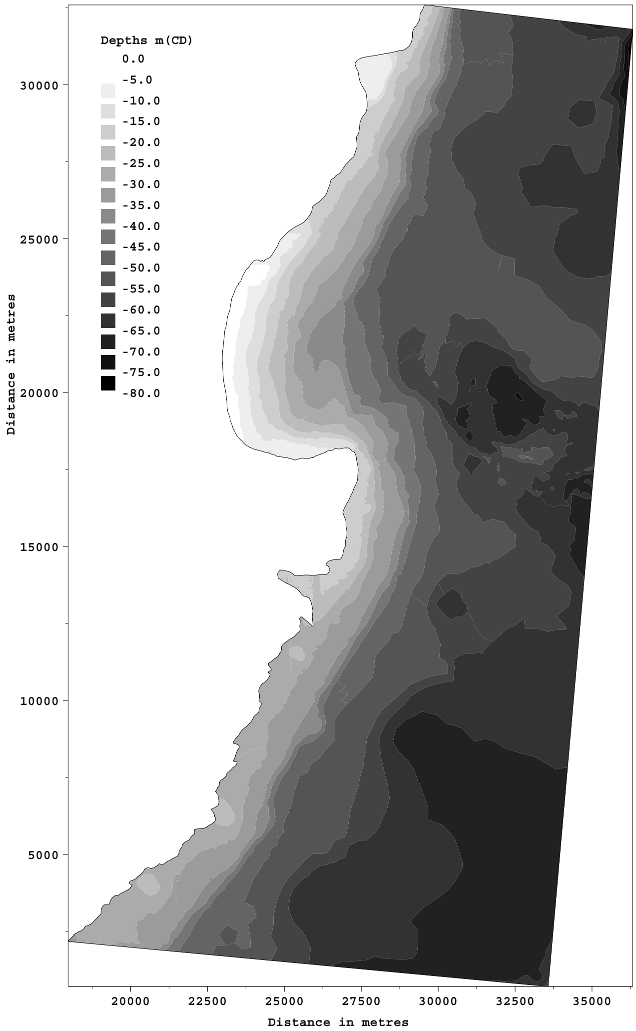

Figure 3 TELURAY model depths

4.4 Treatment of wind sea and swell

For operational purposes the TELURAY model is run at several water levels within the expected tidal and surge level range. Transfer functions relating wave conditions at each inshore location are then used as input to the second stage of TELURAY to compute corresponding nearshore wave conditions for a given set of offshore wave forecasts in real time.

For the prototype system wind sea and swell are treated independently and assumed to remain stationary between each forecast period (3 hours). In addition, only the integrated offshore parameters of significant wave height, H_{m0}, mean wave period, T_z and mean direction θ_m and peak wave period, T_p, are used as boundary conditions in the nearshore TELURAY wave transformation model. For each forecast condition 2D wave spectra are re-assembled based on the assumption of a JONSWAP frequency distribution and a symmetric $\cos^{2n}(\theta - \theta_m)$ directional distribution. In the present case study this is acceptable, but future enhancement to the system will include direct application of the forecast offshore spectra as boundary conditions in the TELURAY model.

4.5 Output from the model

Output from the TELURAY model consists of wave spectra and the associated integrated parameters of H_{m0}, T_z, T_p and θ_m for both wind sea and swell. The integrated parameters can be viewed in the FloodWorks interface. Figure 4 gives an example of a view of FloodWorks interface. Summary output in textual form can also be produced.

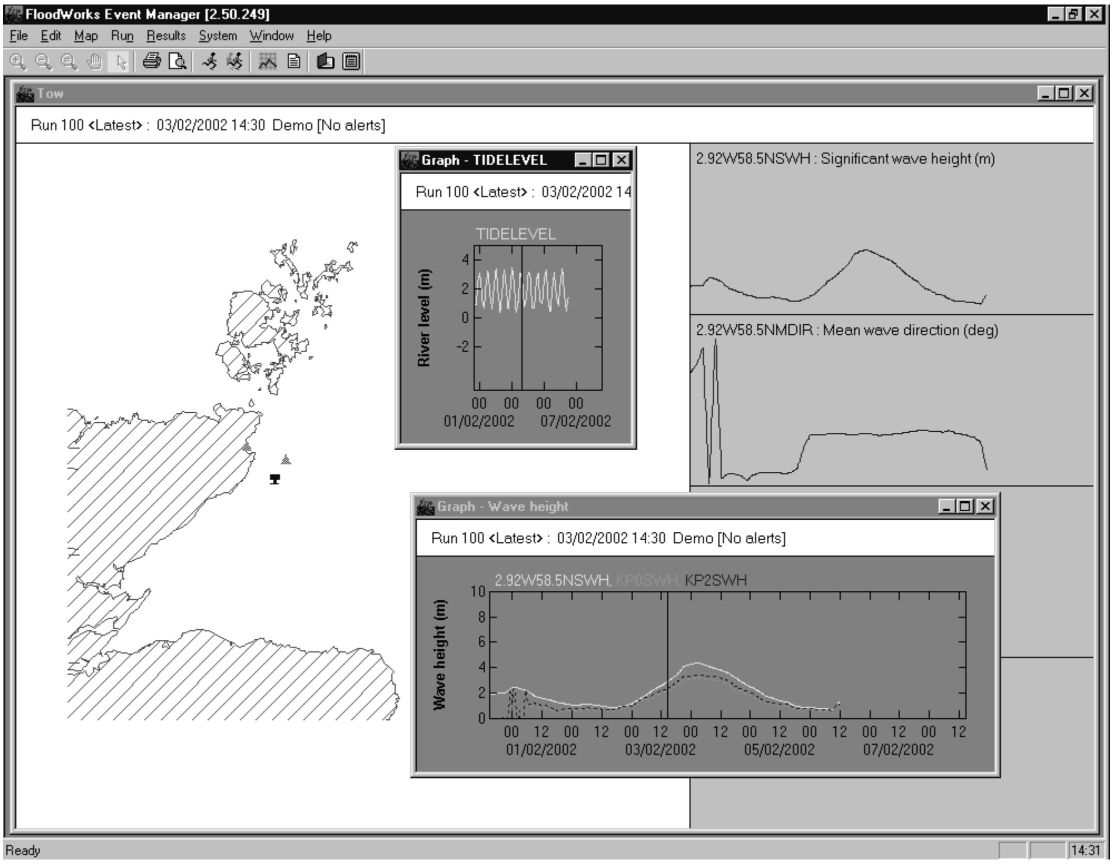

Figure 4 FloodWorks forecast run interface

5. CONCLUSIONS AND FUTURE WORK

A shallow water wave transformation model has been incorporated into an existing real time support system for nearshore wave forecasting in open sea coasts. Offshore wave forecasts from a regional wave model are provided in real time as boundary conditions from which corresponding nearshore wave conditions are computed. The prototype has been applied to a coastal site in Scotland and is presently under review. It is anticipated that as part of this review the forecasts will be compared with measured data at the site.

Future developments of the system will be driven by customer requirements, but the flexible approach of FloodWorks will allow the system to expand to include forecasts of, for example, vessel response, underkeel clearance and overtopping. Ongoing research into the complicated processes that affect coastal flooding, for example breach prediction, is hoped to lead to the possibility of reliable coastal flooding forecasting.

6. REFERENCES

1. Abernethy, C. L. and G. Gilbert, 1975: Refraction of wave spectra. Report IT117, Hydraulics Research Limited.
2. Goda, Y. 1984: Random seas and design of maritime structures. University of Tokyo Press.

7. ACKNOWLEDGEMENTS

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