

Towards an integrated coastal simulator  
of the impact of sea level rise in East Anglia:

Part A- Coastal wave climate prediction  
and sandbanks for coastal protection

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**Part A**

**Coastal wave climate prediction and sandbanks for coastal protection:  
Towards a Regional Coastal Simulator**

**Overview and Technical Report**

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Note: the above Departments are combined as the School of Mechanical, Aerospace and Civil Engineering in the 'new' University of Manchester from October 2004. This report should be read in conjunction with Part B, covering coastal simulator and biodiversity.

### **1. Non-technical summary**

Many coastal regions around the UK are vulnerable to sea-level rise and climate change and the East Anglian coast is probably one of the most vulnerable. One aim of the Tyndall coastal simulator (see final report part B, Watkinson et al, 2005) is to predict coastline recession and flooding and this requires simulations of wave climate and tidal currents which determine morphodynamics and erosion. It is shown:

- (a) how computer simulations predict wave climate and larger-scale tidal motions quite efficiently and, importantly, how input data for bathymetry and tidal flow boundary conditions may be obtained;
- (b) how building up sandbanks may ameliorate inshore wave climate locally, reducing the impact of increasing wave height due to sea-level rise;
- (c) how available long-term histories of onshore wind data may be used to predict offshore wave climate and thence inshore wave climate very efficiently by generating data bases which may be curve-fitted and interpolated for each wind condition;
- (d) how long-time histories of inshore wave climate input into cliff erosion models may predict historical recession rates quite successfully.

### **2. Key research objectives**

- To test and validate as far as possible computer codes for predicting tidal flows and wave climate for the East Anglian coast. The finite-element codes TELEMAC-2D and TOMAWAC respectively were used as meshes and may readily be refined where necessary (e.g. where bathymetry is changing markedly).
- To assess the influence of sea-level rise on inshore wave heights.
- To assess the influence of building up sandbanks (e.g. with dredged material, on inshore wave heights with the view that the resulting local wave height decrease will ameliorate the effect of sea-level rise on coastal erosion, providing a potential component of an overall shoreline protection scheme).
- To develop methods for long-term inshore wave height prediction from long term onshore wind data, based on the above modelling capabilities. Historical wind data is available for many years for checking results and wind speed and direction are considered to be among the more reliable outputs from climate change models.

### **3. Work undertaken**

Initially work was concerned with setting up computational fluid dynamics simulations for tidal currents and wave propagation. The finite-element codes TELEMAC-2D and TOMAWAC respectively were used. Digitised bathymetry from Admiralty charts was obtained from METOC Ltd under licence. Computations were undertaken for a domain along the coast extending into deep water about 30-40 km offshore. For tidal currents, boundary conditions for this domain are required for time-dependent depth and velocity (flux) and these were acquired for a period of 216

hours in year 2000 from the continental shelf model CS3 of the Proudman Oceanographic Laboratory, again under licence. Results of inshore tidal level could be compared with BODC data for Lowestoft. Kinematics from TELEMAC were used to drive sediment transport and morphodynamics by the module SYSPHE. The TOMAWAC code for wave propagation has been quite widely tested although not for complex sandbank bathymetries of concern here. The physical mechanisms modelled are: shoaling and refraction due to bathymetries and currents, energy losses due to whitecapping and bottom friction, wave-wave interactions, and depth-induced breaking. Diffraction is not included. Preliminary tests were made for wave propagation over circular and elliptic shoals measured in (controlled) laboratory conditions. Diffraction effects are included in the code ARTEMIS and this was run for comparison. TOMAWAC was then applied to the East Anglia coastal domain to investigate changes in inshore wave climate due to sea level rise and due to increasing the height of sandbanks. Accretion or erosion of sandbanks due to tidal currents was then assessed. These effects due to wave action are difficult/impossible to predict. It was thought that sandbanks which accrete due to tidal action would also be good first choices to provide coastal protection.

Long-term prediction of wave climate requires an efficient solver for wave propagation and also an assessment of the relevance of various effects. The sensitivity of TOMAWAC predictions to tidal currents, inshore wind forcing and directional spread was thus tested. It was found that inshore wave climate was primarily dependent only on offshore wave height and direction and not the above effects. This enabled a number of runs covering the possible parameter range for offshore wave height and direction to be made establishing a data base which, through curve fitting and interpolation, may predict wave climate at specified inshore sites for each offshore condition extremely efficiently. The offshore wave condition was determined from onshore wind data using standard formulae. The resulting algorithms and relevant data sets were supplied to Bristol University to input long time series of wind data to produce nearshore wave climate for their cliff erosion models.

Towards the end of the project recent inshore wave data for the East Anglia coast became available from the Environment Agency. These data together with Wavenet buoy data further offshore have enabled some preliminary analysis and comparisons to be made. However the buoy positions do not coincide with positions already used and the coastal wave climate calibration needs to be repeated.

#### **4. Results**

- a. TELEMAC-2D with appropriate bathymetry and boundary conditions predicts measured tidal levels well and generally may be expected to predict larger-scale flow features well. However smaller scale features associated with sandbank wakes will not be reliably reproduced (from related EPSRC project).
- b. TOMAWAC generally predicts wave propagation over shoals well for waves with broad directional spread. Effects of diffraction appear negligible,

although this is not the case with narrow directional spread. In coastal conditions effects due to currents, inshore wind forcing and directional spread are generally small. Inshore wave climate may thus be defined by offshore wave height, direction and tidal level through the application of TOMAWAC. Although TOMAWAC was chosen for this study, the same conclusions will apply to the widely used finite-difference code SWAN.

- c. Building up sandbanks (e.g. through dredged material) will reduce inshore wave heights locally and may be considered as part of a coastal protection strategy. This would help to ameliorate increases in inshore wave height due to sea level rise. Certain sandbanks appear to accrete naturally due to tidal action.
- d. Onshore wind data has been used to define offshore wave climate which is then converted to inshore wave climate through TOMAWAC. By running TOMAWAC over relevant parameter ranges, inshore wave data may be curve fitted and interpolated to define inshore wave climate from onshore wind data very efficiently. This enables long-time series of wind data to be input in order to output long-time series of wave climate at pre-defined locations. This has been fed into the Bristol University cliff erosion model giving good historical predictions of cliff recession (undertaken by Bristol University).

## **5. Relevance to Tyndall Centre research strategy and overall Centre objectives**

The Regional Coastal Simulator of Theme 4 is an important component of the Tyndall research strategy. Wave climate determines coastal erosion and flooding with obvious economic and social implications. It also provides an interface with tidal inlets with their associated exchange processes. Implications for biodiversity may be explored (see final report part B, Watkinson et al, 2005) .

## **6. Potential for further work**

This is being investigated through a scoping study run by Bristol University with Manchester and Southampton Universities, due to report in October 2004. There is clearly potential to integrate efficient wave modelling into all aspects of the Regional Coastal Simulator, including aspects associated with flooding which have yet to be explored. An important ongoing specific aspect (presently part-time) is to compare with inshore wave buoy data collected since 2002 by the Environment Agency (EA). Indeed interaction with the EA concerning future deployment is to be investigated. A further exciting possibility is to develop these methods for the prediction of sandbank evolution, making some basic hypotheses about the driving excitation and transport mechanisms. Such a scheme may be calibrated against bathymetries available from the British Geological Survey (BGS) by running time 'backwards'. Sandbanks are important to the Coastal Simulator as they are a vital element in wave dissipation and hence coastal protection.

## 7. Publications

Tyndall working papers:

Stansby,P.K., Kuang,C-P. Launder,B.E. and Laurence,D.R. (2005) Sandbanks for Coastal protection: Implications of sea-level rise

Part 1: Application to East Anglia, TWP86

Part 2: Current and morphological modelling, TWP87

Part 3: Wave modelling, TWP88.

[http://www.tyndall.ac.uk/publications/working\\_papers/working\\_papers.shtml](http://www.tyndall.ac.uk/publications/working_papers/working_papers.shtml)

Kuang,C-P. and Stansby,P.K.(2004) Modelling directional random wave propagation inshore *ICE Journal of Maritime Engineering*, 157(3), 123-131.

Stansby,P.K., Kuang,C-P. Launder,B.E. and Laurence,D.R. Stability of dumped sediment on sandbanks due to tidal currents off the East Anglia coast, UK, International Symposium of Environmental Hydraulics, Hong Kong, December 2004.

Stansby,P.K., Kuang,C-P. Launder,B.E. and Laurence,D.R. (2004) Sandbanks for coastal protection, in preparation for *ICE Journal of Maritime Engineering*.

Stansby,P.K. Keynote lecture on 'Coastal waves and long-term prediction' at 1<sup>st</sup> IMA Conference on Flood Risk Analysis, Bath, September 2004.

Nicholls,R.J., Hall,J.W. and Stansby,P.K. Special session proposed for Coastal Dynamics, Barcelona 2005 on 'Long-term coastal prediction', with contribution 'Long-term coastal wave climate from onshore wind data' by Stansby,P.K. and Zhou,J.G.

The inter-disciplinary Tyndall Centre for Climate Change Research undertakes integrated research into the long-term consequences of climate change for society and into the development of sustainable responses that governments, business-leaders and decision-makers can evaluate and implement. Achieving these objectives brings together UK climate scientists, social scientists, engineers and economists in a unique collaborative research effort.

The Tyndall Centre is named after the 19th century UK scientist John Tyndall, who was the first to prove the Earth's natural greenhouse effect and suggested that slight changes in atmospheric composition could bring about climate variations. In addition, he was committed to improving the quality of science education and knowledge.

The Tyndall Centre is a partnership of the following institutions:

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- Stansby, P., Launder B., Laurence, D., Kuang, C., and Zhou, J., (2006) **Towards an integrated coastal simulator of the impact of sea level rise in East Anglia: Part A- Coastal wave climate prediction and sandbanks for coastal protection** Tyndall Centre Technical Report 42A
- Lenton, T. M., Loutre, M. F, Williamson, M. S., Warren, R., Goodess, C., Swann, M., Cameron, D. R., Hankin, R., Marsh, R. and Shepherd, J. G., (2006) **Climate change on the millennial timescale**, Tyndall Centre Technical Report 41
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- Pearson, S., Rees, J., Poulton, C., Dickson, M., Walkden, M., Hall, J., Nicholls, R., Mokrech, M., Koukoulas, S. and Spencer, T. (2005) **Towards an integrated coastal sediment dynamics and shoreline response simulator**, Tyndall Centre Technical Report 38
- Sorrell, S. (2005) **The contribution of energy service contracting to a low carbon economy**, Tyndall Centre Technical Report 37
- Tratalos, J. A., Gill, J. A., Jones, A., Showler, D., Bateman, A., Watkinson, A., Sugden, R., and Sutherland, W. (2005) **Interactions between tourism, breeding birds and climate change across a regional scale**, Tyndall Centre Technical Report 36
- Thomas, D., Osbahr, H., Twyman, C., Adger, W. N. and Hewitson, B., (2005) **ADAPTIVE: Adaptations to climate change amongst natural resource-dependant societies in the developing world: across the Southern African climate gradient**, Tyndall Centre Technical Report 35
- Arnell, N. W., Tompkins, E. L., Adger, W. N. and Delany, K. (2005) **Vulnerability to abrupt climate change in Europe**, Tyndall Centre Technical Report 34
- Shackley, S. and Anderson, K. et al. (2005) **Decarbonising the UK: Energy for a climate conscious future**, Tyndall Technical Report 33
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- Haxeltine, A., Turnpenny, J., O’Riordan, T., and Warren, R (2005) **The creation of a pilot phase Interactive Integrated Assessment Process for managing climate futures**, Tyndall Centre Technical Report 31
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- Shepherd, J., Challenor, P., Marsh, B., Williamson, M., Yool, W., Lenton, T., Huntingford, C., Ridgwell, A and Raper, S. (2005) **Planning and Prototyping a Climate Module for the Tyndall Integrated Assessment Model**, Tyndall Centre Technical Report 29
- Lorenzoni, I., Lowe, T. and Pidgeon, N. (2005) **A strategic assessment of scientific and behavioural perspectives on ‘dangerous’ climate change**, Tyndall Centre Technical Report 28
- Boardman, B., Killip, G., Darby S. and Sinden, G, (2005) **Lower Carbon Futures: the 40% House Project**, Tyndall Centre Technical Report 27
- Dearing, J.A., Plater, A.J., Richmond, N., Prandle, D. and Wolf, J. (2005) **Towards a high resolution cellular model for coastal simulation (CEMCOS)**, Tyndall Centre Technical Report 26
- Timms, P., Kelly, C., and Hodgson, F., (2005) **World transport scenarios project**, Tyndall Centre Technical Report 25
- Brown, K., Few, R., Tompkins, E. L., Tsimplis, M. and Sortti, (2005) **Responding to climate change: inclusive and integrated coastal analysis**, Tyndall Centre Technical Report 24
- Anderson, D., Barker, T., Ekins, P., Green, K., Köhler, J., Warren, R., Agnolucci, P., Dewick, P., Foxon, T., Pan, H. and Winne, S. (2005) **ETech+: Technology policy and technical change, a dynamic global and UK approach**, Tyndall Centre Technical Report 23
- Abu-Sharkh, S., Li, R., Markqvart, T., Ross, N., Wilson, P., Yao, R., Steemers, K., Kohler, J. and Arnold, R. (2005) **Microgrids: distributed on-site generation**, Tyndall Centre Technical Report 22
- Shepherd, D., Jickells, T., Andrews, J., Cave, R., Ledoux, L, Turner, R., Watkinson, A., Aldridge, J. Malcolm, S, Parker, R., Young, E., Nedwell, D. (2005) **Integrated modelling of an estuarine environment: an assessment of managed realignment options**, Tyndall Centre Technical Report 21
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- Dutton, A. G., Bristow, A. L., Page, M. W., Kelly, C. E., Watson, J. and Tetteh, A. (2005) **The Hydrogen energy economy: its long term role in greenhouse gas reduction**, Tyndall Centre Technical Report 18
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- Brown, K., Boyd, E., Corbera-Elizalde, E., Adger, W. N. and Shackley, S (2004) **How do CDM projects contribute to sustainable development?** Tyndall Centre Technical Report 16

- Levermore, G, Chow, D., Jones, P. and Lister, D. (2004) **Accuracy of modelled extremes of temperature and climate change and its implications for the built environment in the UK**, Tyndall Centre Technical Report 14
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- Tsimplis, S. et al (2004) **Towards a vulnerability assessment for the UK coastline**, Tyndall Centre Technical Report 10
- Gill, J., Watkinson, A. and Côté, I (2004). **Linking sea level rise, coastal biodiversity and economic activity in Caribbean island states: towards the development of a coastal island simulator**, Tyndall Centre Technical Report 9
- Skinner, I., Fergusson, M., Kröger, K., Kelly, C. and Bristow, A. (2004) **Critical Issues in Decarbonising Transport**, Tyndall Centre Technical Report 8
- Adger W. N., Brooks, N., Kelly, M., Bentham, S. and Eriksen, S. (2004) **New indicators of vulnerability and adaptive capacity**, Tyndall Centre Technical Report 7
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- Goodess, C.M. Osborn, T. J. and Hulme, M. (2003) **The identification and evaluation of suitable scenario development methods for the estimation of future probabilities of extreme weather events**, Tyndall Centre Technical Report 4
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