ELSEVIER

Coastal Engineering 41 (2000) 3–12

COASTAL ENGINEERING

www.elsevier.com/locate/coastaleng

Introduction
Operational oceanography in coastal waters

David Prandle *

Proudman Oceanographic Laboratory, Bidston Observatory, Birkenhead, CH43 7RA, UK

Abstract

Operational oceanography embraces hindcasting, nowcasting and forecasting of parameters from physics to ecology on scales from global to coastal. While coastal engineers are familiar with everyday requirements for forecasting tides, surges and waves, the wider linkages are less immediately evident. This introduction aims to articulate these linkages — highlighting both the common interests of oceanographers and engineers and the diversities in methodologies employed to address these on global to localised scales. The European Commission MAST III project, PROMISE (PRe-Operational Modelling In the Seas of Europe), aimed to expedite the development of operational oceanography. This introduction provides the background to this project, explaining the formulation of its objectives and indicating where descriptions of the related approaches are described in subsequent chapters. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Pre-operational oceanography; Surges; Suspended sediment; Tides; Waves; North Sea

1. Operational oceanography

Operational oceanography includes making, disseminating, and interpreting measurements of the seas and oceans in order to provide forecasts of future conditions. The related linkages involving transmission of observational data to computer models and dissemination of the results to the end-user are illustrated in Fig. 1. Operational modelling indicates real-time simulations and forecasts — analogous to daily weather forecasts. Pre-operational modelling infers model simulations similar to the latter (i.e., with synoptic specifications of initial, boundary and forcing conditions) but run subsequently.

* Fax: +44-151-653-6269.
E-mail address: d.prandle@pol.ac.uk (D. Prandle).

PII: S0378-3839(00)00024-7

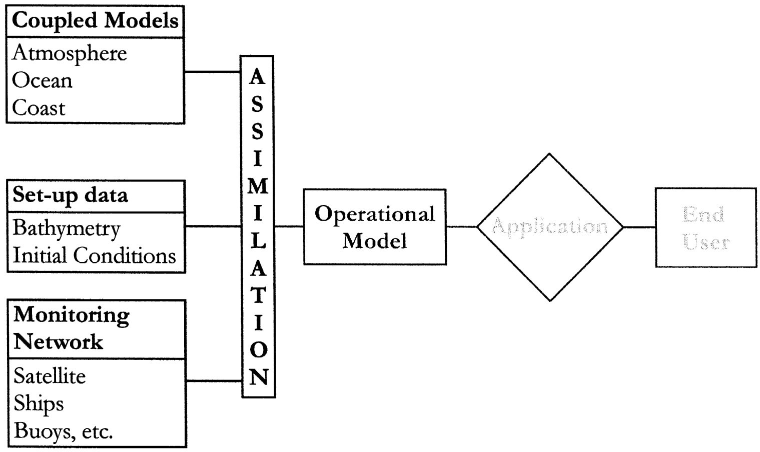

Fig. 1. Components of operational oceanography.

Forecasting involves short-term numerical prediction of processes such as storm surges, wave spectra, sea ice occurrence, and toxic algal blooms, as well as longer-term climatic statistical forecasts including seasonal and inter-annual variability. Thus, forecasts may extend forward for hours, days, months, or even years and decades on a climatic or statistical basis. The temporal and spatial resolutions of forecasts may be limited by the corresponding resolution of initial boundary and forcing conditions.

Nowcasting involves providing the best estimates of fields at the present time, by analyses via numerical models of observations. Typical applications are for daily or monthly descriptions of sea ice, sea surface temperature, or sea state.

Hindcasting involves assimilating observational data into a model to compile sets of historic fields and distributions (typically monthly or annually) of variables such as sea surface elevation, water temperature, salinity, nutrients, radionuclides, metals, etc.

Assimilation refers to techniques used to integrate model and observed information in an optimal way, taking into account the uncertainties or errors in the model and the observations. Thus, assimilation is used: (i) to validate and calibrate models and (ii) to determine the best representations of parameter fields for use as initial conditions in forecast runs, etc.

2. Global–coastal teleconnections

Fig. 2 shows a schematic of elements involved in operational forecasts for coastal conditions. The open sea boundary provides reference to relative sea level change, i.e., the difference between the change in global sea levels and local land subsidence or uplift. However, such global impacts do not necessarily involve small, gradual coastal perturbations and consider the more immediate and first-order impacts of swell waves or tsunamis. Moreover, these impacts propagate in both directions; tidal power barriers designed for the head of Cumberland Basin were shown to significantly modify the tides throughout the Bay of Fundy and many global-scale marine pollutants originate from the

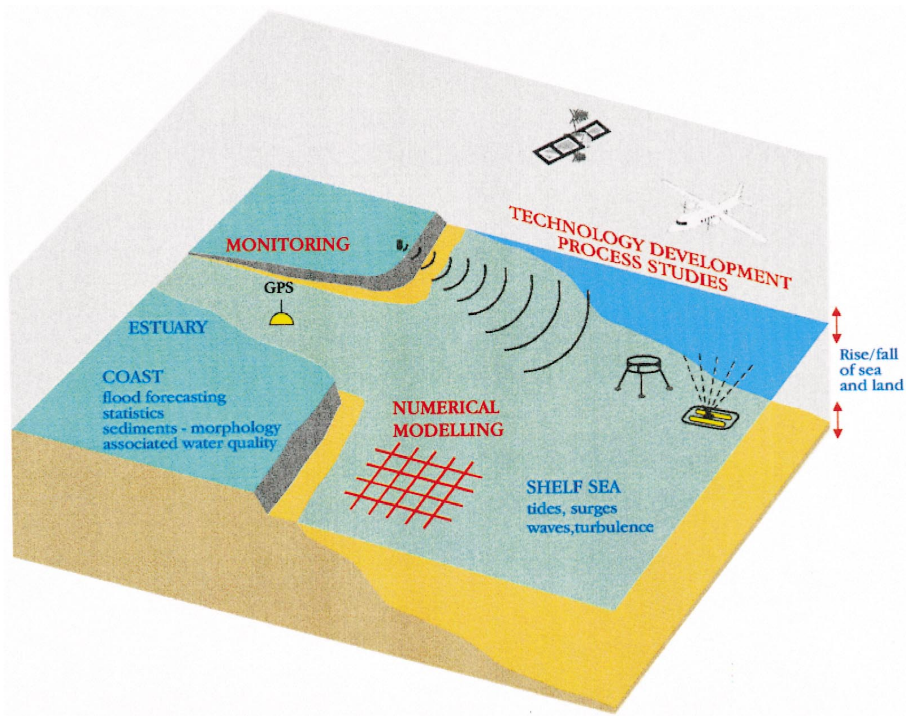

Fig. 2. Schematic of operational oceanography — coastal forecasting.

coastal zone. Generally, oceanic and atmospheric exchanges may constitute a source or a sink (or both) for mass, momentum or energy.

Fig. 3 illustrates these ocean–coast linkages and elaborates the interconnections between hindcasting, nowcasting and forecasting discussed Section 1. For coastal surge forecasts, the oceanic link may sometimes be neglected with only wind forcing at the sea surface together with tidal interactions considered. However, for coastal wave forecasts, the ocean swell generated several days earlier in some remote ocean may need to be specified at the ocean–shelf sea boundary. This specification will generally rely on the corresponding nowcast of ocean sea state.

For some parameters, such as storm surges and waves, their energy dissipates rapidly. This enables continuous long-term simulations to be made as a simple succession of shorter-term forecasts. Other parameters, such as temperature or salinity, have a longer memory and extended simulations may lead to accumulating errors requiring some technique for re-initialisation.

Operational services providing coastal forecasts of temperature and salinity already exist and can be used for scheduling of coastal power stations, feeding rates in fish farming, etc. Such forecasts should be extendable, in stochastic terms, to provide likelihood of monthly mean sea (and thereby ambient air) temperatures up to 6 months ahead. Such simulations are sensitive to initial distributions of temperature and salinity,

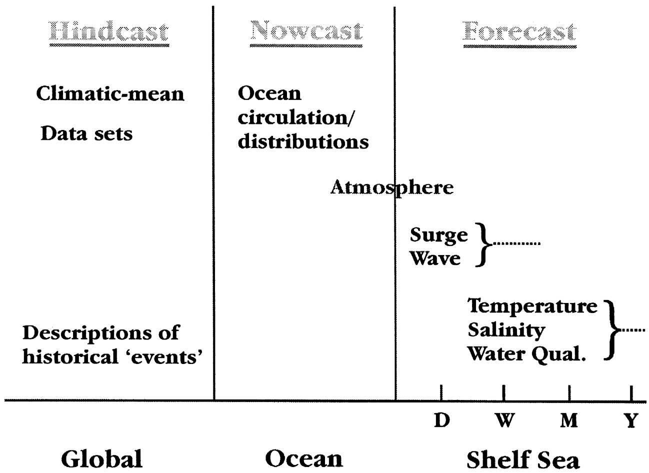

Fig. 3. Global–coastal teleconnections.

i.e., shelf sea nowcasts, and on climate mean prescriptions of ocean boundary conditions. The latter are derived from decadal simulations with shelf sea and ocean models, i.e., hindcasts. Deep ocean global forecasts models, incorporating data assimilation, are becoming available for operational use — an example is the global FOAM (Forecasting Ocean Atmosphere Model) model at the UK Meteorological Office.

Fig. 4 summarises the diversity between monitoring methodologies, time scales and applications for simulations in oceans to coasts. While this figure simplifies this diversity, there are many examples of closely overlapping interests, e.g., in the use of satellite altimetry for monitoring tide, surge and sea state in both oceans and shelf seas.

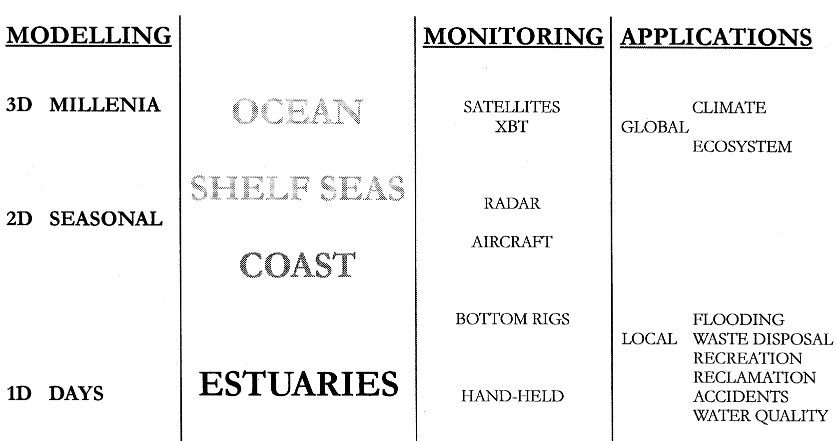

Fig. 4. Diversity in monitoring methodologies, time scales and applications in simulations in oceans to coast.

3. End-user interests

Fig. 1 shows the link between operational forecasting and end-user applications — often via an interface involving additional enhancement or tailoring of values for specific purposes. As part of the PROMISE (PRe-Operational Modelling In the Seas of Europe) project, a user meeting was held (London, June 13, 1997) to provide feedback on the adequacy of existing services, identify future requirements and gauge interests in developing engineering capabilities. The 60 participants from 10 countries represented the interests of coastal defence, flood warning, navigation, port and harbour operations, environmental regulation and management, defence, offshore oil and gas. There is a need, not only for optimised prediction values, but for associated error bars that can be incorporated into socio-economic risk analysis procedures, although sustainable development and accident avoidance are paramount. Derivation of such error bars may involve use of ensemble forecasts from either a range of models or for a range of 'scenarios' applied to a particular model.

In reviewing existing services, it was noted that storm surge forecasting systems are operated by many European nations and collaboration is well developed. Scope for development exists, especially in complex, localised regions where strong wave–tide–surge interactions arise. A range of assimilation techniques are used, generally involving shore-based tide gauge observations. Scope for wider usage of satellite altimeter data and current observations (H.F. Radar at strategic Straits) was recognised. Sea state forecasting (using spectral wave models) is also in widespread operational use — a range of wave models (both second and third generation) is applied both globally and regionally. For coastal waters, the SWAN model is available (public domain) and has been adopted by the US Navy ONR for transforming forecasts of sea state from offshore up to the surf zone. The accuracy and resolution of wind data is recognised as a limiting factor in almost all O.O. systems. The increasing trend towards coupled models (tide wave, physics–chemistry–biology) dictates the need for major modelling centres, providing communication links and data processing to support both operational and pre-operational modelling.

Since the bathymetry in dredged channels is often highly mobile, near-continuous high-accuracy bathymetric surveying techniques are important. The scope for SAR, HF and X-band radar and LIDAR imagery to provide the latter is developing rapidly. Forecasts of temperature in shelf seas use satellite images for initialisation, and there is urgent need for sea bed and undulator data to complement these sea surface values. Such satellite images and related aircraft surveillance were also stimulating the development of chlorophyll and algal bloom forecasting systems.

The oil and gas industries have pressing requirements for forecasts/statistics of wave and current (profiles) data in deeper water (> 200–2000 m) worldwide — involving appreciable investment into high-resolution baroclinic models. The performance of such models depends on links with larger area (ocean) models and associated monitoring networks.

For naval needs, communications are a high priority. The influences of density fronts and turbidity zones on sonar transmissions are overwhelming and hence, there is a need for the development of eddy-resolving baroclinic models and predictions of suspended particulate matter.

Reports of the paucity of historical data in many areas, outside of ship routes, etc., highlight the need for internationally coordinated survey programmes. By contrast, the need to make better use of existing data and facilities (instruments on oil platforms, navigational buoys) was emphasised including collection, processing and banking of observational data. Despite past initiatives to this effect, knowledge of the existence, accessibility and exchange (formats) of such data is unsatisfactory.

The need for a concerted European approach in developing existing O.O. services is universally recognised. Exciting opportunities are presented by the rapid advances in computational power, monitoring technology and systems, scientific understanding and numerical methods (for both modelling and assimilation). Initiatives are needed to develop structured research, development and evaluation programmes to parallel the GOOS plans for the period 2000–2005. There is a well-defined need for greater accuracy, resolution and reliability of existing services and a requirement for expanded services relating to coupled models and in complex regions (deep water).

4. Formulation of the PROMISE project — the need for international collaboration

Although the user meeting described in Section 3 occurred mid-way in the project, many of the requirements had long been widely acknowledged and formed the determinants in establishing the goals of PROMISE.

Operational oceanography is expanding rapidly to embrace dynamically coupled atmosphere–ocean–shelf sea–coastal models (or modules) involving simulations over a range of time scales. Likewise, the scope is extending from essentially physical parameters such as tides, surges, waves, temperature and salinity to chemical parameters related to water quality, through ultimately biological/ecological parameters indicative of ecosystem variability. The associated range of sensors, instruments and their platforms shows corresponding diversity — from microprobes to wave buoys and from satellite sensors to ROVs.

Recognising the above, it follows that this range of activities cannot be supported by any single engineering or scientific research centre. Clearly, existing centres must select their areas of expertise and must collaborate in ‘total system’ simulations. Moreover, this collaboration must be international and the associated communications must mirror those developed over the last 20 years by the meteorological operational community.

Thus, the PROMISE partners were drawn from a number of leading modelling and monitoring centres in Europe. The North Sea was selected as a focus since it is the most intensively studied shelf sea worldwide, with the widest range of advanced operational forecasting services. One aim involved rationalising some of the existing ranges of forecasting models; an associated aim was to examine the challenges in dynamically coupling these. A parallel EU initiative (EU MAST Workshop, Bergen, August 8–10, 1996) focusing on rationalisation of turbulence modelling provided a starting point for associated goals within PROMISE.

Coastal engineers have traditionally focused on the response of beaches to waves. Concerns arising from climate change (sea level and storminess), offshore aggregate extraction, steepening of cross-shore slopes, adoption of soft-defence strategies (including beach nourishment) require this focus to be extended to consider coastal–nearshore sediment exchange. Thus, the goal selected was to evaluate existing North Sea wave, tide, surge, turbulence and sediment (suspension) models and to explore how these could be developed to accommodate coupled applications in localised coastal zones. Extensive data sets were then required to develop and assess the various modules.

Participation of a Spanish partner provided useful perspective on the applicability of these models, developed for an enclosed sea, to an exposed coast.

5. Volume contents

The broad PROMISE goals described above were translated into subprogrammes concerned with:

- rationalising generic models (for waves, turbulence and suspended sediments);
- assembling bench-test data sets; and
- intercomparisons/evaluation of applications.

This volume is subdivided into three corresponding parts, namely, forecast models, observational data sets, and case study applications in the coastal regions shown in Fig. 5.

5.1. Forecast models

The dynamic processes involved in the erosion, deposition and transport of sediments occur over time scales of seconds (turbulent motions and waves), hours (tidal oscillations), months and years (seasonal cycle) to inter-annual variability with corresponding space scales from millimetres to thousands of kilometres; thus, a range of models is required.

The first paper by Flather describes existing Operational Services, providing a useful starting point for the developments described in subsequent sections.

The influence of waves relative to tidal currents on sediment erosion increases dramatically in shallower water. The initial goal for wave modelling in PROMISE was to achieve a common implementation of the third-generation spectral wave model WAM-Cycle4 — suitable for dissemination. Subsequent goals were: (i) to extend this ‘deep water’ version for high spatial resolution application in shallow water and (ii) dynamic coupling to a tide surge model to satisfy the requirements for sediment transport modelling. The paper by Monbaliu et al. includes both an evaluation of existing versions of the WAM-Cycle4 code on the North Sea scale together with a multitude of developments for application on fine resolution in shallow waters.

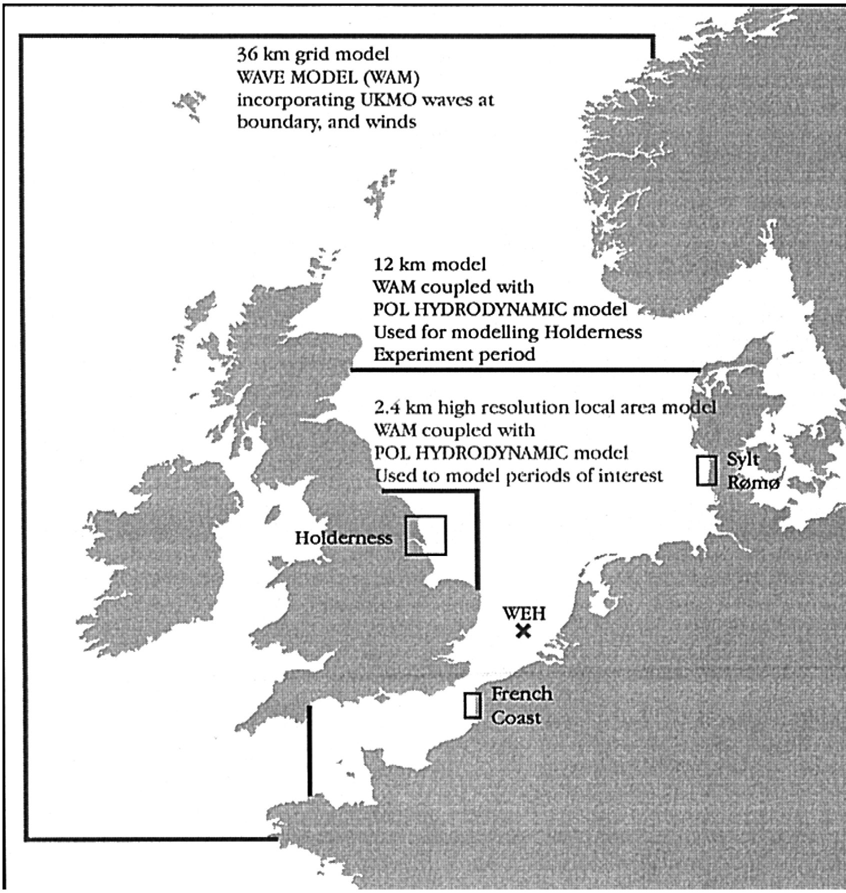

Fig. 5. Coastal zones for bench-test data sets.

The combined effects of tides and waves induce stresses at the sea bed which simultaneously generate turbulent eddies and sediment erosion. The subsequent pathway of any eroded particle depends on a balance between its settling rate (excess density) and its movement via current components associated with tides, waves and turbulence. Baumert et al. describe the fundamental equations governing the generation and decay of turbulence associated with wave and tidal forcing. Numerical techniques for practical solution of these equations are also described and applications illustrated. These generic models are well validated against microstructure measurements from free-falling sensors; however, some difficulties remain in the reproduction of the background levels which determine layer exchange rates in stratified conditions.

In deep water, the spectral gap between tides and waves enables their simulations to be entirely independent. In shallower water, their non-linear interactions become of first-order importance. Incorporation of interactive coupling requires a minimum level of accuracy in each of the dynamical processes. Ozer et al. describe numerical techniques and associated impacts of wave–tide coupling on a North Sea scale.

5.2. Observational data

Data from recent national monitoring experiments off the coasts of the UK, Germany, France and Spain were assembled in readily accessible form for model development and assessment. The earlier ZISCH and (UK) North Sea Project data sets were extensively used in PROMISE — illustrating the longer-term value of such data sets. More recent comprehensive coastal data sets from Holderness and Sylt–Rømø were also used together with more limited data sets from the French and Spanish coasts. Lane et al. describe the development of a generalised format for assembling and disseminating such bench-test data sets. Johannessen et al. provide a review of satellite remote sensing capabilities. While satellite data offer the greatest long-term prospect in operational oceanography, there is generally a trade-off between the spatial resolution of satellite data and its available temporal coverage. Continuous, near-global coverage is afforded by geostationary meteorological satellites, and coverage several times daily is available for NOAA/AVHRR. At mid-latitudes, the limitations introduced by cloud cover restrict the applicability for continuous operational services.

5.3. Case studies — model evaluations

Given models and observations, data assimilation (being the interface between them) is the third essential component of marine forecasting systems. Assimilation is used to transfer observed information to update the model state, the model forcing and/or model coefficients. The challenge is to take advantage of the complementary character of models and observations: the generic, dynamically continuous character of process knowledge embedded in models vs. the specific, quantitative character of observed data. Specification of the sources and sinks in SPM (suspended particulate matter) simulations is severely complicated; in particular, availability of sea bed sources depends on the chronology of previous deposition and associated consolidation rates. Vos et al. illustrate how satellite images of (surface) SPM concentrations can be used in conjunction with model simulations to infer the magnitude of discrete sediment sources. Aircraft surveillance using multi-wavelength imagery promises to differentiate between the reflectance associated with chlorophyll and various sediment fractions and allow model verifications. However, the need for atmospheric corrections is likely to involve continued reliance on in situ calibrations.

Schneggenburger et al. employ an alternative shallow-water wave approach, applying the *K*-model to an enclosed bay. Prandle et al. combine the application of the new shallow-water 'PROMISE-WAM' code to the exposed UK east coast. Results from this wave model are used in an associated tidal model to simulate the patterns of erosion from a rapidly retreating coast. Carretero-Albiach et al. review the application of both tide surge and wave models to the exposed Atlantic coast of Spain. The contrasts with the semi-enclosed North Sea are evident; thus, in surge forecasting, the influence of atmospheric pressure, negligible in the North Sea, tends to predominate over wind forcing. Chapalain and Thais examine the application of single-point turbulence/SPM models (as described in the paper by Baumert et al.) to a coast within a highly energetic tidal strait. Gerritsen et al. indicate how, for finer-grained sediment, these coastal simulations must be coupled with sediment fluxes over the scale of the adjacent sea — for both import and export of material.

In the final paper, Prandle summarises the major conclusions drawn from PROMISE (as described in the preceding sections) and presents these against the background of ongoing and planned future development in international programmes such as GOOS — the global ocean observing system.

Acknowledgements

This work was carried out as part of PROMISE, MAS3-CT9500025, supported by the European Union.