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Operational oceanography — a view ahead

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Abstract

This Special Volume aimed to provide a description of the existing state-of-the-art in Operational Oceanography in coastal waters, this concluding chapter reviews recent progress and includes a look forward to future developments. Preceding chapters reviewed user-needs, described states of development in tidal, surge, wave, turbulence and sediment models and assessed observational data requirements.

Whilst future development depends on a wide spectrum of incremental developments (such as described in this volume), the need for international collaboration is crucial to ensure obstacles are recognised ahead of time allowing these to be addressed with the appropriate scale of resources. Likewise the trend towards coupled sea-ocean-atmosphere forecasting models is likely to accelerate, introducing significant 'operational' and 'coupling' issues. Meanwhile the steady assemblage of the GOOS (Global Ocean Observing System) provides opportunities to impact on its planning to ensure optimal benefits-both economic and environmental. © 2000 Elsevier Science B.V. All rights reserved.

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1. Aims of the Pre-Operational Modelling In the Seas of Europe (PROMISE) project

The underlying aim of the PROMISE project was to expedite Operational Oceanography in Europe. User-requirements surveys highlighted the need for enhanced accuracy, reliability, resolution and increased forecast period together with an extension of the parameter range from existing physical parameters to incorporate chemical, biological and ecological aspects. Participants included a number of the major European modelling centres. The selected focus of quantifying sediment fluxes in the North Sea (Gerritsen et

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al., 2000) conveniently embraced tidal, surge and wave dynamics, i.e., the most well-established existing operational forecasting services.

The approach adopted was first to assemble comprehensive test-bed observational data sets for both local coastal zones and for the entire North Sea, thence, to develop generic models for tide, surge, wave, turbulence and suspended particulate matter (SPM) simulations. The final stage involved evaluation of these generic models in simulations against the test-bed data sets.

The specific developments within PROMISE might be contrasted with the wider vision for advances in Operational Oceanography presented by Woods et al. (1996) and an accompanying implementation strategy by Prandle and Flemming (1998).

2. Achievements

As perhaps the first ever attempt to report the wide-ranging, inter-related aspects of developing Operational Forecasting systems, this special issue constitutes a definable initial milestone. Paper authors were encouraged (and referees accepted!) to provide a balance between the customary concentration on state-of-the-art progress alongside clear statements of long-standing underlying difficulties. The range of information, including references ranging from latest publications back to the original primary papers, over a wide but coherent field should enable readers to gain a balanced perspective of this topic.

2.1. Generic modules

The development of generic modules and the ready availability of public domain model codes have removed much of the mystique that traditionally surrounded marine modelling. The diversity of marine systems makes it unlikely that a single integrated model will evolve as for weather forecasting. However, rationalisation of modules within modelling systems is a recognised goal, together with standardisation of prescribed inputs such as bathymetry, tidal boundary conditions, etc. Such enhanced rationalisation will enable the essential characteristics of various types of models to be elucidated including the inherent limits to predictability.

The WAM wave modelling community has been an outstanding example of the value of such public domain generic codes. The further developments of this code for faster application on finer spatial resolutions required in shallow water is reported here by Monbaliu et al. (2000) Release, during the PROMISE programme, of the somewhat similar SWAN code has stimulated interest. Likewise, the application of the K-model, reported here by Schneggenburger et al. (2000), extends the capability of such modelling into shallow embayments.

The generic single-point k-ε turbulence model developed in PROMISE by Baumert et al. (2000) makes a corresponding valuable addition to the availability of generic modules. In particular, the incorporation of sediment erosion and deposition under the combined influences of both tidal currents and surface waves will be widely utilised. Subsequent testing of the WAM wave model is described here for Holderness by

Prandle et al. (2000). The turbulence is evaluated both at Holderness and in the Dover Strait (Chapalain and Thais, 2000), providing useful feedback on performance.

The challenges of coupling such modules was addressed by Ozer et al. (2000). Addressing both the broad philosophy and practical difficulties, this paper provides insight into future problems to be considered in progressing towards ecological models. Likewise, the success of existing surge wave forecasting models, described by Flather (2000) for the North Sea, is usefully contrasted by Carretero Albiach et al. (2000) when applied to the vastly different shelf conditions encountered off Spain.

This experience indicates that whilst standardised, generic modules are perceived as the requisite building blocks of future interdisciplinary, international forecast models — the likely requirement for multiple versions is a reality. Moreover, retention of flexibility at the module level is both necessary and desirable to accommodate a wide range of applications and to provide ensemble forecasts.

2.2. Observational data sets

Observational data sets always include components of variable or uncertain accuracy and gaps in temporal/spatial coverage. Thus, a major challenge in using such data sets to evaluate model performance is to balance their mutual deficiencies. The strategy for assembling such data sets, described by Lane et al. (2000) recognises this difficulty. The PROMISE data sets are accessible via three discrete stages. The first stage involves a general text/pictorial description of the observational programme — indicating prevailing weather conditions, recurrent instrument or platform problems, etc. The second stage contains 'quick-look' illustrations of the processed/calibrated data, e.g., time series of currents or SPM. The final stage contains the original raw data. Thus, a ready appreciation of observational shortcomings is provided together with the possibility of reprocessing where appropriate.

3. Ways forward

3.1. Formulating observational modelling strategies

Fig. 1 (van Ruiten, personal communication) provides a generalised indication of the resolution practicable with existing computing power for baroclinic circulation models of oceans, seas and bays. Real-time forecasting requires simulation times of order 100 times faster than real time. The corresponding estimates for spectral wave modelling are broadly similar. Fig. 1 also provides a representation of the comparable resolution provided by various monitoring systems — remote sensing, ship-borne and fixed networks. Rigorous model evaluation or effective assimilation of observational data into models requires broad compatibility between resolution and accuracy in models and observations — temporally, spatially (horizontal and vertical) and in parameter range.

The continuous increase in computing power experienced over the last few decades seems likely to continue for the next decade or more. To take full advantage of this in

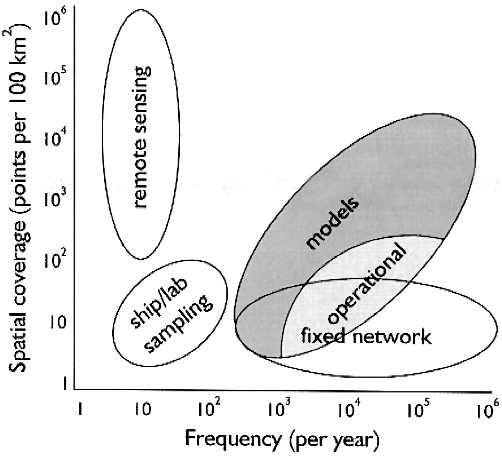

Fig. 1. Spatial and temporal coverage of various observational/monitoring systems (van Ruiten, personal communication).

Operational Oceanography, we need clearer recognition of the necessary related requirements in our planning of monitoring systems. Development of new sensors, commercial production of prototype instruments, international agreements on new satellite programmes and international ship experiments all involve lead times of the order of a decade. There is a pressing urgency to articulate the roles of and synergy between satellite, aircraft, ship, sea surface, seabed and coastal (radar) instrumentation and, likewise, how new assimilation techniques may contribute to bridging gaps in monitoring capabilities. Observer Systems Sensitivity Experiments, wherein the effect of the existence or omission of specific components in a (hypothetical) monitoring system can be identified, are more discussed than implemented.

3.2. Recommendations of PROMISE

The experience gained in PROMISE has highlighted the many challenges faced in rationalising the existing plethora of operational models and in providing appropriate test-bed data sets for evaluating these. However, perversely, this experience has further strengthened the conviction that the full potential of Operational Oceanography can only be attained by international collaboration amongst both system operators (meteorological agencies) and system developers (marine modelling centres). Oceanographers need to gain from the prior experience of meteorologists in quality assurance/evaluation of models and in assimilation of observational data. Realisation of the above within the PROMISE project has run parallel with the simultaneous development of EuroGOOS. A joint PROMISE–EuroGOOS workshop (Rome, March 1999) derived the following list of ‘ways forward’ in relation to the problems of forecasting dynamics and sediment movement in the coastal zone.

3.2.1. Observational data sets

- Assemble complete, consistent, documented, accessible bench-test observational data sets for model validation
- Articulate monitoring strategies, elaborating synergistic values of the range of systems and sensors
- Improve the accuracy and resolution of bathymetric data

3.2.2. Technology

- Exploit the potential of shore-based radar for measuring winds, waves, surface currents and bathymetry
- Develop vertical profiling capabilities
- Enhance accuracy and extend the range of parameters measurable by remote sensing (salinity)

H.F. and X-band Radar offer a convenient way of measuring, in real time, the diverse adjustment of the spectra as waves propagate into shallower water. These monitoring developments allied to shallow water development of the existing deep water wave models provide exciting opportunities for studying rapidly evolving near-shore bathymetry.

Evaluation of the generic turbulence model, developed in PROMISE, is restricted by the availability of direct measurements of turbulent intensity. Likewise, evaluation of the associated SPM model is restricted by both the accuracy and spatial resolution of observations. The accuracy is restricted by the varying sensitivity of optical and acoustic sensors to the pertaining spectrum of particle diameters. The spatial resolution is limited to single points (or limited profiles) in OBS and ABS sensors and to surface values from satellite or aircraft sensors. Techniques to circumvent these shortcomings are described by Vos et al. (2000) whereby the spatial patterns of surface imagery are used to validate models.

The more general strategy to overcome these difficulties in providing observational data sets to evaluate SPM models is illustrated by Prandle et al. (2000). This Holderness Experiment employed duplication of sensors (transmissometers, OBS, ABS) and rigs (along parallel adjacent cross-shore profiles) and utilised ships, aircraft, satellite and radar alongside such in situ observations. Progress in satellite remote sensing (Johannessen et al., 2000) will dictate the rate of development of Operational Oceanography for many parameters. Moreover, remotely sensed data must be processed in hours to days, if it is to be useful in operational forecasting. The design of new, comprehensive networks exploiting synergistic aspects of a range of instruments/platforms integrally linked to modelling requirements/capabilities is a major challenge.

3.3. Forecast systems

3.3.1. Forecast systems

- Develop finer resolution meteorological models
- Address ocean–sea–atmosphere coupling, physics-computer protocols

The need for enhanced information from atmospheric models is a high-priority item in Operational Forecasting. Accuracy and extent, in time ahead, of wind forecasts are the primary limiting factors for sea-state and surge forecasting. The need for dynamically coupled ocean–atmosphere models is an essential element to improve 'atmospheric forcing'. Coupling of regional sea and ocean models is a prerequisite for longer-term simulations (especially hindcasting and nowcasting) in shelf seas. A hierarchy of coupling is envisaged, beginning with limited exchange of selected parameters in a 'filtered' format, e.g., heat flux or contaminant exchange, with complete dynamic coupling likely to be a distant prospect.

4. Summary

There is a well-defined need for greater accuracy, resolution and reliability of existing services. A major objective of Operational Oceanography is to minimise damage from future events (from storms on a short-scale to longer-term sea level change) by reducing the uncertainties in related forecasting. More positively, Operational Oceanography is central to sustainable exploitation and management of our marine resources.

Ocean forecasting involves processes from physics to ecology on scales from micro-turbulence to global ocean circulation with a similarly wide spectra of technologies. 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). Nonetheless, investment and the associated progress will depend on demonstrable benefits to end users. The pace will be dictated by our ability to collaborate in maximising the potential of past investments as well as careful planning for the future. Initiatives are needed to develop structured research, development and evaluation programmes to parallel the GOOS plans for the period 2000–2005. The ultimate goal is a fusion of environmental data and knowledge, utilising fully the communications and computational capacities.

Subsequent development of comprehensive ecological forecasting in the coastal zone may not necessarily proceed by direct extension of the methods outlined above. More innovative methodologies may be appropriate for such fundamental challenges. The stimulus provided in the USA by the open 'public domain' philosophy adopted for both observational data and model codes should serve as a challenge in Europe.

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