Simulating Decadal Coastal Morphodynamics

Coastal geomorphic systems provide many services of key importance to humankind, including protection from flood and erosion hazards, diverse habitats and amenity values (Agardy et al., 2005; Jones et al., 2011). However, these systems are widely undergoing degradation that can be substantially attributed to the cumulative direct and indirect effects of human interference. Declining sediment inputs and throughputs are frequently a factor driving a shift towards progressive coastal erosion (Valiela, 2006; Nicholls et al., 2007). Such sediment starved systems have reduced resilience and are further threatened by human-induced climate change, not only due to accelerated sea-level rise, but also through possible shifts in wave and surge climate (Wong et al., 2014).

At the same time, society is starting to plan more strategically to protect and sustain growing coastal populations and economies, as well as to counter habitat decline (Nicholls et al., 2013). This inevitably leads to the challenge of predicting coastal geomorphic behaviour at what we term here the mesoscale (of the order of 10^1 to 10^2 km length scales and 10^1 to 10^2 year timescales). Geomorphic evolution at this scale involves a broad range of drivers that govern the functioning of coastal systems and determine how they will respond to external disturbances. As well as natural processes, the role of human intervention needs to be considered, including the pervasive legacy of engineering interventions over the preceding decades and even longer.

Alongside traditional engineering, geomorphological science now plays a central role in the management of both open coasts and estuaries. Geomorphological assessments of coastal behaviour, vulnerability and resilience are often based on analyses of historic shoreline change tempered by expert judgement. However, mesoscale prediction of coastal change is fundamentally a modelling problem, given the complexity and non-linearity of many of the linkages between hydrodynamics, sediment transport and landforms (French and Burningham, 2009). Critical aspects of geomorphic behaviour emerge at a system level from feedbacks between a multitude of landform components and the constraining effects of antecedent landscape setting, geology, sediment sources, as well as both structural and non-structural interventions. Analysis of historical datasets can be combined with traditional 'bottom-up' process-based modelling of contemporary processes to synthesize an understanding of landform dynamics at increasingly broad spatial scales. However, the largely insurmountable problem of predicting both general and detailed aspects of complex system behaviour beyond the timescales at which we can tightly specify governing physics and boundary conditions remains. Hence, we still lack the ability to quantify likely coastal morphological changes at the timescales that are crucial in a climate change and coastal management context. Encouragingly, geomorphology is well placed to take a lead on predicting the impacts of alternative climate (and management) futures given that it can draw on a range of alternative modelling approaches that allow us to focus on the mesoscale problem in multiple complementary ways. This leads to the proposal for a new hybrid approach that is able to translate our understanding of coastal processes into models that retain a sound physical basis, whilst at the same time demonstrating useful predictive skill.

In the UK, these challenges are being addressed by the Integrating COAstal Sediment SysTems (iCOASST) project. Funded by NERC from 2012 to 2016 and in a partnership with the Environment Agency, iCOASST has developed and applied new conceptual frameworks and models for mesoscale coastal simulation that will be able to support the management of coastal geomorphic systems. The papers contained in this special issue emerge from a discussion of the iCOASST vision at a small International Workshop held in Southampton in October 2013. The iCOASST vision has several key aspects. The first of these is the use of formal systems analysis as a means of conceptualising a broader set of open coast, estuary and inner shelf dynamic interactions than is possible using existing management frameworks. As French et al. (a) argue, this is hampered by the lack of a clear theoretical basis for specifying the most appropriate scale and complexity at which to approach coastal morphodynamic problems. Moreover, understanding and mitigating climate change impacts at the coast require a framework that embraces the connectivity of open coasts with estuaries and the inner shelf at broader scales and that also acknowledges the extent of anthropogenic control. French et al. (b) present a novel ontology of landforms and interventions that is partly inspired by the coastal tract concept (Cowell et al, 1993) and its temporal hierarchy of sediment sharing systems, but places greater emphasis on a spatial hierarchy, from coastal regions, through landform complexes, to individual landforms and human interventions. Systems analysis can also help specify the fundamental feedbacks and behaviours that need to be modelled. Payo et al. demonstrate Causal Loop Analysis as a means of bridging the gap between purely conceptual and more quantitative mechanistic geomorphic models. Causal Loop Diagrams are shown to be especially useful as a means of revealing, in advance of more quantitative modelling, the existence of multiple response pathways and outcomes. This allows modellers to assess whether the critical feedbacks necessary to generate observed landform behaviours have been adequately captured.

The three subsequent papers describe more quantitative approaches to the problem of mesoscale coastal prediction. Coastal datasets have traditionally been used to test process-based models. However, as discussed by Reeve et al., the extent of some of these datasets now opens up possibilities for sophisticated statistical analyses and machine-learning methods that can be used to reveal causal linkages and to make predictions of future morphological change. Whilst the geographical scope of data-driven models may presently be rather limited, analyses undertaken at data-rich locations can be extremely valuable in guiding coastal monitoring programmes to ensure that their sampling schemes are adequate to resolve the landform behaviours that are most important in driving progressive shoreline evolution at a mesoscale.

A key aspect of iCOASST, outlined by van Maanen et al., is the creation of a modelling framework that exploits the complementary insights from diverse modelling techniques. Central to this framework are the reduced complexity models that are built upon the strategy of representing the critical processes at scales that are not much smaller than those of interest. It is also argued that the process of coupling sets of reduced complexity models, within a framework defined by conceptual models, coastal area models and data-driven techniques, can lead to new insights into mesoscale coastal evolution. This concept is fundamental to the iCOASST vision.

In the last paper of this special issue, Lazarus et al. discuss a relatively new area of research, which explores the coupling between physical processes and human activities. The dynamic feedbacks between natural and anthropogenic processes are likely to give rise to interesting and complex behaviour and increasingly shape the evolution of coastal areas in the long term. The study of these feedbacks is inherently a multi-disciplinary task that requires engagement with social science and policy disciplines and deserves particular attention for future research.

This collection of papers also demonstrates the commitment of the iCOASST consortium to change the relationship between modellers, consultants and stakeholders from the present expert-led one to a more participatory approach. This reflects the need to engage stakeholders not only in terms of understanding their problems but also through engaging and capturing their understanding in ways that make the model outcomes more relevant, transparent and useful. This is partly accomplished through the participatory two-way knowledge formalisation made possible by the system mapping approach (French et al., b), and which finds its way through to the more quantitative models being refined and developed in iCOASST (French et al., a). It is also founded on a transition to open source community models (van Maanen et al.) and the growing awareness that geomorphic change and human action are intrinsically linked (Lazarus et al.). As the repeated winter storms that battered the UK coast in 2013/14 remind us, our coasts evolve in a complex socio-political context. The iCOASST project's delivery of a science-based framework that allows for a more participatory approach and facilitates a more constructive dialogue between science, stakeholders and policy makers is thus of the utmost importance.

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