

Global sea-level rise and coastal vulnerability

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Global sea-level has fluctuated through geological time but the sea-level oscillations during the Quaternary and especially the last Ice Age were particularly important in shaping our modern coastline. At the last glacial maximum of 20,000 years ago, the sea level was around 120 m lower than today. It then rose rapidly to reach its current position around 6–7,000 years ago. During this period, there were times when the sea level was rising at rates in excess of 20 mm year^{-1} , although the pattern, timing and rates of this major sea-level rise event vary around the world, as does the time when sea level stabilised near its present position (Harvey 2006). After a few millennia of relative stability, geological and tide-gauge data provide evidence of sea-level rise during the 19th and 20th centuries, reaching an average rate of 1.7 mm year^{-1} during the 20th century (Church and White 2006). This modern sea-level rise raised concerns about the vulnerability of the significant population living near the coast, for which there are various global and sub-global estimates (Mimura 2001; Small and Nicholls 2003; Ericson et al. 2006; Woodroffe et al. 2006; McGranahan et al. 2007; Nicholls et al. 2007). Recent satellite data, combined with tide-gauge data, provide evidence of an increased sea-level rise of over 3 mm year^{-1} (see Church et al.; this volume).

The need to better understand the causes of sea-level rise, provide accurate predictions of the future rate of sea-

level rise and to assess coastal vulnerability has been the subject of numerous scientific articles in the global change literature, which have recently been reviewed and synthesised in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (Parry et al. 2007; Solomon et al. 2007). The feature articles in this issue of Sustainability Science provide a useful contribution to this continuing debate. The idea for this issue arose from discussions following a special session on sea-level rise, held at the Open Science Conference of the ESSP (Earth Systems Science Partnership) in November 2006, Beijing, China. The ESSP comprises a partnership of the world's four leading global change scientific research organisations: (1) DIVERSITAS (International Program for Biodiversity Science); (2) IGBP (International Geosphere-Biosphere Programme); (3) IHDP (International Human Dimensions Project); and (4) WCRP (World Climate Research Program).

The co-chairs of the special conference session on sea-level rise (Wilson and Harvey) brought scientists together from different global change research programs (largely the WCRP and IGBP) to present different perspectives on sea-level rise. This followed recent research efforts from the WCRP, which held a workshop in 2006 on sea-level rise and vulnerability (see Church et al.; this volume) and the IGBP and its coastal program LOICZ (Land–Ocean Interactions in the Coastal Zone), which recently published a 10-year research synthesis (Crossland et al. 2005). Four of the speakers from the ESSP conference (Church, Harvey, Nicholls and von Storch) have contributed articles to this issue of Sustainability Science with the additional help of a number of their fellow researchers. A further two papers (Syvitski and Torresan et al.) have been included to broaden the scope of the debate. The first three papers focus on physical aspects of sea-level rise, whereas the last

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three papers examine different approaches to coastal vulnerability assessment.

The first paper by Church et al. provides a background to historical sea-level rise and gives a detailed account of the various contributions to sea-level rise in the 20th century, including ocean-thermal expansion, glaciers and ice caps, Greenland and Antarctica ice sheets, and terrestrial water storage. The paper outlines the observational requirements needed to inform a better understanding of sea-level rise and comments on some of the impacts of sea-level rise. The latter part of the paper looks to the future and provides an up-to-date comment on the projections of 21st century sea-level rise and longer-term implications. In particular, the paper comments on the recent satellite-based sea-level observations and the increasing concern about the stability of ice sheets. In their conclusion, Church et al. note the need for further research in closing the sea-level budget and in better understanding ice-sheet dynamics in order to reduce some of the uncertainties in sea-level projections.

The second paper by Syvitski provides a terrestrial perspective to illustrate the importance of coastal dynamics in affecting relative sea-level rise on deltaic coasts. The significance of environmental change for Asian megadeltas has been illustrated by Woodroffe et al. (2006), who note that these low-lying coastal regions support enormous populations, including many of the world's megacities. Syvitski provides an analysis of the world's populated deltas to show that their long-term sustainability is often more affected by large-scale engineering projects than by climate change-induced sea-level rise, but, nonetheless, both changes will act synergistically to increase coastal vulnerability (see Nicholls et al. 2007). The engineering projects include dam construction, channel control and petroleum or groundwater extraction. Syvitski demonstrates that the rate of eustatic sea-level rise is often similar to the rate of natural sediment compaction and is often smaller than the rate of isostatic-controlled subsidence. He points out that deltaic coasts affected by large-scale engineering works are even more vulnerable to sea-level rise.

The paper by von Storch and Woth examines the issue of possible future changes to storm surges and, hence, extreme sea levels. They note that climate change-induced sea-level rise and changed storm tracks will alter the regional distribution of storm surges, but stress the importance of regional and local data, such as modifications to local bathymetry. von Storch and Woth present a three-step methodology using a downscaling concept to model predicted changes to storm surges in European marginal seas. They incorporate historic data into their models and then derive scenarios of future conditions which, in the case of the North Sea, shows moderately higher surges. Their third step incorporates local data for

harbours and near-shore areas, which allows them to factor in bathymetric and coastline alterations. While their methodology has been tested for European data, it is still under development for other parts of the world and they acknowledge a major challenge will be in the simulation of tropical storms, which are widely expected to intensify in a warming world (Solomon et al. 2007).

The next three papers all examine coastal vulnerability assessment (CVA). The first of these (Torresan et al.) uses a European example to compare the use of global and regional scales in CVA. They propose a set of regional vulnerability indicators and compare these with a group of parameters and variables from the DIVA (Dynamic Interactive Vulnerability Assessment) database and its broader scale approach. Torresan et al. demonstrate the applicability of their GIS-based decision support system for CVA at the regional level using the Veneto shoreline in Italy as a case study. The paper discusses the value of the higher spatial resolution of the regional approach and its greater analytical detail, but acknowledges constraints created by the quantity of data and the geometric complexity of the modelling.

The paper by Harvey and Woodroffe examines Australian approaches to CVA. Although Australian scientists had a significant involvement in the development of global approaches to CVA through the IPCC, Harvey and Woodroffe note that, until recently, there has not been a co-ordinated national approach. An attempt to do this in the mid-1990s resulted in a series of different approaches by the various state and territory governments. Since then, there have been some quite sophisticated CVA approaches developed in different areas, but they are not co-ordinated at a national level. Harvey and Woodroffe identify six key approaches developed in different regions: (1) wetland mapping; (2) geomorphic unit mapping; (3) storm surge vulnerability modelling; (4) probabilistic approaches to beach erosion; (5) indicative mapping of potential coastal retreat; and (6) Great Barrier reef vulnerability studies. They then outline recent attempts to produce a national government-based approach to CVA.

The final paper by Nicholls et al. provides an important perspective to the CVA debate by placing the climate-change drivers of coastal vulnerability in the context of non climate-change drivers. They stress the danger of ignoring these other drivers, which may lead to overstating the importance of climate change (as illustrated by Syvitski; this volume). Nicholls et al. demonstrate that the integrated use of all coastal vulnerability drivers is possible within a scenario framework (using the SRES framework as an example), and consider relevant impacts and adaptation. They acknowledge the importance of sea-level rise, but attempt to provide a balanced approach, where it is one of a number of coastal vulnerability drivers and the relative

importance of the drivers needs to be assessed, as well as recognising how adverse drivers may reinforce negative impacts. They conclude that there is a need to make assumptions about the future more explicit in CVA and argue for more systematic efforts on coastal scenario development.

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