



Impacts of Weather, Climate and Sea Level-Related Extremes on Coastal Systems and Low-Lying Islands

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Weather and climate-related extremes have had disastrous impacts on coastal areas and low-lying islands. Cyclones (both tropical and extra-tropical), flooding from land, river and sea; drought; storm surges; rogue sea swell and waves; extreme low and high sea levels (including ‘king’ tides) have resulted in big changes in natural systems and massive destruction of settlements and infrastructure. There has been a long history of such impacts to littoral communities, and an equally long history of attempts to reduce potential impacts (through adaptation) from such extreme events. Indeed, it is probably true to say that both traditional and modern coastal communities have been more concerned with the risks, and with responses to the impacts of extreme events, than to the incremental changes associated with climate change and sea level rise. Thus, adaptation to extreme events in coastal and small island situations is nothing new. What is new is the potential for increases in both mean trends and extremes, and the need to understand the greater risk and vulnerability resulting from these extremes combined with the more intensive use of coastal zones and small islands.

Extreme events and the IPCC’s Fourth Assessment (AR4)

Extreme events figured prominently in both the coastal and small islands chapters of WG2’s assessment (chapter 6 and 16 respectively). Indeed, the first key messages in both chapters highlight the hazards and risks associated with extreme events. ‘Coasts are highly vulnerable to extreme events, such as storms, which impose substantial costs on coastal societies.’ Coasts are also ‘experiencing the adverse consequences of hazards related to climate and sea level rise’ and they ‘will be exposed to increasing risks, including coastal erosion, over coming decades...’. Similarly, ‘Small islands, whether located in the tropics or higher latitudes, have characteristics which make them especially vulnerable to the effects of climate change, sea-level rise and extreme events’.

Importantly, WG1 also recognised the significance of extreme events for coastal and island communities acknowledging that: ‘Societal impacts of sea level change primarily occur via the *extreme levels* rather than as a direct consequence of mean sea level changes’ (chapter 5). Several other points relating to sea level variability and extremes were noted:

- Sea level records contain a considerable amount of inter-annual and decadal variability such as ENSO and PDO;
- Sea level change has not been geographically uniform in the past; nor will it be in the future; and,
- There is evidence for a world-wide increase in extreme high sea levels since 1975.

However, they also point out that there have been far fewer studies of variations in extreme sea levels than of changes in mean sea level. Moreover, projections of sea level extremes in the 21st century were not considered in WG1 chapter 10, while in chapter 11 all three sample projections from regions within Australia, Europe and Bay of Bengal deal specifically with extreme sea levels associated with storm surges, the potential impacts of which are covered in WG2 chapter 6.

Mean sea level: not so meaningful

Virtually all global sea level projections deal exclusively with mean sea level. But paradoxically in very few coastal and island localities is mean sea level particularly meaningful. Few ecological or geomorphological phenomena or processes have thresholds around mean sea level. Rather these phenomena and processes change at the upper and lower limits of the tidal zone, that is around high tide level and low tide level. It is here, at these extreme levels, where major ecological and geomorphological transitions occur, and it is here that human uses and works change so abruptly, not at the mean level.

Clearly there is a requirement for more attention to be paid to the analysis of extremes in observational data (tide gauge and satellite) and to the inclusion of extremes in sea level projections. Thus far emphasis on extreme sea levels has focused primarily on two areas: sea levels associated with storm surges, and the comparison of the patterns and trends of extreme sea levels with the mean. In both cases prominence has been given to extreme high water levels, but it is appropriate to note here: (1) that storm surges are not the only weather-related sea-level extreme; and (2) that low sea levels also need to be given attention.

A plethora of impacts on coasts and low-lying islands

The combination of extreme events superimposed on incremental climate change (in this case sea-level rise) has already resulted in a range of biophysical impacts on coasts and low-lying islands and on the communities and settlements they support. Biophysical impacts include: increased levels of inundation and storm flooding; accelerated coastal erosion; sea water intrusion into fresh groundwater lenses; encroachment of tidal water into estuaries and river systems; elevated sea-surface and ground temperatures; altered tidal range in rivers and bays; and, reduced sea ice cover. And, socioeconomic impacts include: increased property loss and loss of coastal habitats; increased flood risk and loss of life; damage to coastal protection works and other infrastructure; increased disease risk; loss of renewable and subsistence resources; loss of tourism, recreation and transportation functions; loss of nonmonetary cultural resources and values; and, adverse impacts on agriculture and aquaculture through decline in soil fertility and water quality.

The scale of losses resulting from some of these impacts is illustrated in the WG2 assessment with examples of Hurricane Ivan and the island of Grenada (chapter 16) and Hurricane Katrina, New Orleans and the Mississippi delta (chapter 6). Those chapters also highlight a number of hotspots for risk and vulnerability, notably: coastal deltas, especially mega-deltas; the low coasts in high latitudes and polar regions; and the atolls and small low-lying islands in tropical and sub-tropical waters.

Future changes of relevance for coasts and small islands

Sea level is projected to rise between the present (1980–1999) and the end of this century (2090–2099) under the SRES scenarios by 0.18 to 0.59 m. During 2090 to 2099 under A1B, the central estimate of the rate of rise is 3.8 mm yr⁻¹ (AR4 WG1, chapter 10). Other anticipated climate-related changes include: a further rise in sea surface temperature; an intensification of tropical and extra-tropical cyclones; larger storm surges; increase in extreme wave heights; altered precipitation and runoff; and, ocean acidification. These phenomena will vary considerably at regional and local scales, but the impacts are virtually certain to be overwhelming negative on coastal systems and small islands. Indeed, it has been argued that the low-lying atoll states are particularly vulnerable. In fact two of those states, the Maldives in the Indian Ocean and Tuvalu in the Pacific, have long been identified as extreme examples of the potential negative impacts of climate change and sea-level rise. Key impacts of the latter include: accelerated coastal erosion; saline intrusion into freshwater lenses; increased inundation and sea flooding; and, the destruction of settlements and infrastructure from the higher reach of storm surges, swell and ‘king’ tides. Collectively such impacts could result in the islands becoming uninhabitable and some see island abandonment and resettlement as a realistic adaptation option. This has already happened in several atoll-island states.

Impact of extreme events on low-lying atolls: examples from Tuvalu and the Maldives

It is therefore important to assess the potential impact of climate change, sea-level rise and the related extremes on atoll islands. This is done in a series of case studies in which the author has been involved in the last three decades. The case studies, in the Maldives and Tuvalu, cover three types of extremes: weather-related extremes (hurricane, high swell waves); climate-related extremes (seasonal sea-level rise); and, a non-climate-related extreme (tsunami).

Weather-related extremes

Hurricane Bebe and Funafuti atoll, Tuvalu October 1972. Hurricane Bebe struck Funafuti atoll from the east on the night of 21 October 1972. In addition to destroying the settlement and several thousand coconut trees, killing several people and wrecking four ships, a massive coral rubble bank was thrown up on the ocean-side reef during the cyclone. This unusual and massive feature, as large as several islands, was 18 km long and 4 m high. Six weeks after the hurricane profiles were surveyed across the northern portion of the hurricane bank, and resurveys have been carried out episodically since then to monitor long term changes in the feature. Results of these surveys are summarised in the presentation.

Sea swell and high waves, Maldives, May 2007. In mid May 2007 unusually high

and strong waves reached the Maldives, causing severe flooding and sea water intrusion which resulted in damage to buildings, harbours, seawalls, trees, crops, fishing vessels, and eroded several beaches. The waves were not locally generated, but came from an extra-tropical deep low in the southern ocean over 5000 km away to the southwest of the Maldives. The swell waves approached the Maldives from the southwest and the most severely hit islands were located in the west and south of the archipelago. Although a rare event, the Maldives had experienced similar exceptional waves 20 years earlier in April 1987. These waves were caused by a near stationary mid- to high- latitude storm in the southern ocean near Australia, several thousand kilometers to the southeast. The flooding and destruction resulting from this event was the stimulus for President Gayoom of the Maldives to raise the issue of the potential impact of climate change and sea-level rise on small island states in international forums, including the UN General Assembly.

Non-climate- related extremes

Impact of the Sumatran tsunami on the Maldives, December 2004. The tsunami of 26th December 2004 was generated by a magnitude Mw 9.3 earthquake off the northwest coast of Sumatra, Indonesia. The Maldives, situated 2,500 km. west of Sumatra, were in the direct path of the tsunami in its westward propagation across the Indian Ocean. The first tsunami waves reached the archipelago 3.5 hours after the earthquake and lasted for about 6 hours. The highest waves were coincident with a neap tide and combined with ambient southerly swell resulted in water levels of sufficient height and reach to inundate and overtop many islands with catastrophic consequences. Over 80 lives were lost and 53 of the 198 inhabited islands suffered severe damage to buildings, houses and infrastructure, with several of the worst affected islands being abandoned. The results of the effects of the tsunami, based on several pre- and post-tsunami topographic surveys of 13 islands in South Maalhosmadulu atoll, central Maldives are included in the presentation.

Climate-related (?) extremes

Sea level rise, Maldives, January to June 2007. Between January and June 2007 tide gauge records at Male show that mean monthly sea level rose nearly 20 cm. In fact during June sea level reached the highest levels ever recorded at Male. The cause of this sea level rise has not been determined, but may be a combination of astronomic, oceanographic and climatologic process, rather than just a climate-related extreme (hence the above (?)). Beach, reef and island surveys were carried out in February and October 2007 to determine the impact of this medium-term sea-level rise and results are reviewed in the presentation.

These examples provide analogues of the potential impacts of a range of extreme events on atoll islands. They also demonstrate that the effects of extreme events should not be measured only a short time after the occurrence, but rather on a longer term basis. The importance of longitudinal studies that include on-going monitoring is emphasized. One critical conclusion from these studies is the scale of the differential impacts on 'natural' systems and human systems, works and resources. And that conclusion has implications for adaptation responses.

Needs in science, impacts and adaptation studies for coasts and low-lying islands

A review of the literature on the impacts of weather, climate and sea level-related extremes on coastal systems and low-lying islands shows a number of significant gaps, some of which have been alluded to in the above. These gaps are in the scientific focus as well as the understanding of impacts and adaptation to extreme events. Both ‘scientific’ and impacts/adaptation studies need some expansion and redirection to satisfy the challenges associated with extreme events.

For instance with reference to the ‘science’, three examples can be cited. First, much greater attention needs to be given to the analysis of extreme sea levels, for it is these extremes that coastal systems and communities have to adapt to. Analysis should not only include higher water levels associated with storm surges, but those that are more predictable such as ‘king’ tides. Extreme low tides and water levels also need to be analysed. Projections of extreme sea levels into the future are required. Second, in addition to sea level, wave action is a critical coastal change driver. Changes in wave climate, not only wave height but also wave direction and period, require investigation and greater efforts are needed to develop wave climate scenarios and projections. Similarly with sea surface temperature extremes, so important in understanding coral bleaching. Third, and at a more generalized scale, is the need to develop regional and/or localized scenarios of extreme events that can be used as a basis for impact and vulnerability analyses and forward planning for adaptation actions.

For impact and adaptation studies, relevant to coasts and small islands, a number of gaps and issues have arisen in the present review. Four needs are summarized below. There is a need:

- To identify which extreme events are important for particular coastal regions and islands and for local communities. Obviously these will differ greatly even amongst the most vulnerable environments, atoll islands, mega-deltas and low polar coasts.
- To undertake longitudinal studies of the impacts of extreme events on both ‘natural’ systems and human use systems. How the latter have responded in the past to extreme events could help to determine which adaptive measures have worked over the long-term and which have not.
- To recognize that while some coastal and island communities and institutions find it difficult to appreciate and respond to the slow incremental changes associated with climate change and mean sea level rise, they often do have experience in understanding and coping with extreme events. This experience could be capitalized on.
- To focus on the positive and not just negative aspects of weather and climate-related extremes.

Finally, there is the need to recognize that extreme events, superimposed on incremental long-term sea-level and climate change projections, means that risk in coastal areas and low-lying islands will grow for many generations to come, unless there is a substantial and ongoing investment in adaptation.