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Technical Briefing Paper (10): Coastal Zone Impacts and Utility Responses

Synopsis The pace of global mean sea level rise is accelerating, but local tidal levels depend on regional controls. These include thermal expansion and ocean currents, vertical land movements, changes in wind direction, and the frequency of intense storms. Adaptation measures include accommodation (by living with the risks), protection (by hard and soft structures), and retreat (by phased withdrawal or abandonment) from vulnerable areas. Detailed vulnerability assessments are only possible where there are high resolution topographic data.

Explanation One of the most unequivocal effects of global warming has been sea level rise. Global mean sea level has risen by an average rate of 1.8 mm/yr since 1961 and by 3.1 mm/yr since 1993 thanks to the thermal expansion of the ocean, and contributions from melting glaciers, ice caps and polar ice sheets (Figure 1, left panel). It is also likely that the incidence of extreme high sea levels (excluding tsunamis) has increased worldwide since 1975. However, global means conceal much variability in space and time. For example, during decades of strong westerly airflow over NW Europe associated with positive phases of the North Atlantic Oscillation (NAO) water piles up along the southeast coast of the North Sea causing a local sea level rise of ~20cm (Figure 1, right panel). Stormy weather and hurricanes increase wave heights and cause the ocean to 'bulge' under low pressure systems, raising water levels by several more meters on top of the tidal cycle. Flooding in estuaries may be further exacerbated by runoff from the land meeting these high tides.

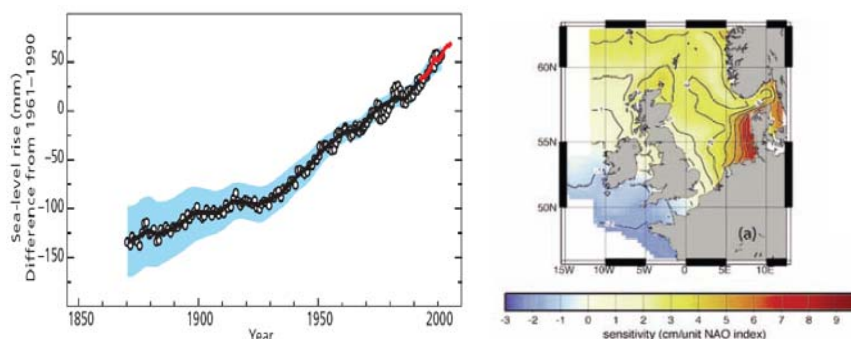


Figure 1 Sea level change

Left panel: Global mean sea level from tide gauge (blue) and satellite (red) data. Source: IPCC, 2007: Climate Change 2007 Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Figure 1.1 page 31

Right panel: Sensitivity of the sea level to winter-mean North Atlantic Oscillation index in cm/(unit NAO index) as calculated by a 2-d tide and surge model. Source: JRC (2006)

Looking forward, estimates range from a global mean sea level rise by the 2080s of 0.18 to 0.59m compared with 1980-1999, based on a range of climate models and emissions scenarios, up to a 1m rise by the end of the century. Thermal expansion is by far the largest component, but glacier, ice cap and Greenland ice melt are all expected to contribute positively to sea level over the 21st century. Conversely, increased snowfall over the Antarctic Ice Sheet contributes negatively to sea level. Spatial variations in modeled sea level rise are 0.08 m (one standard deviation) under A1B emissions due to local variations in ocean temperature, changing currents and water density. Local water levels must also be corrected for vertical land movements caused by isostatic adjustments following the last glacial period, and for subsidence of the land beneath some coastal developments.

Low-lying coastal systems, deltas, wetlands, lagoons and estuaries are clearly most vulnerable to sea level rise and increased storminess. Although there is a tendency to focus on the risk of inundation, changes in sediment transport, coastal erosion and recession also pose threats to unprotected infrastructure and ecosystems (e.g., salt marshes and mangrove swamps). Furthermore, sea level rise enables upstream migration of saline water into estuaries and intrusion into groundwater. This can cause interruptions to water supply in the short-term (as in the tidal Delaware River), but potentially degradation of freshwater sources and ecology over the long-term. These impacts are

further exacerbated by other pressures from fisheries, energy production, tourism and development, underlining the need for an integrated approach to coastal zone management.

Application Faced with accelerating sea level rise and changes in storm surge frequency there are essentially three adaptation strategies:

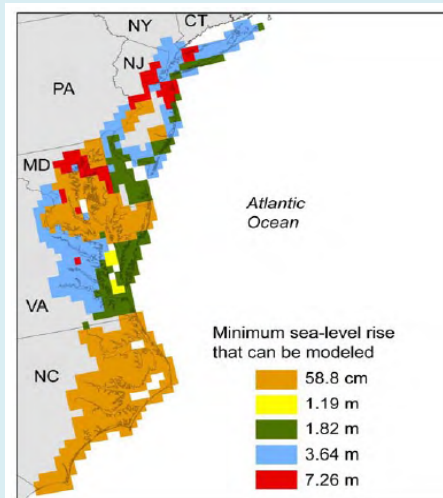
Accommodation – involves living with the hazard but taking steps to avoid further development in vulnerable locations through planning controls and zoning. Accommodation also includes the use of forecasts to prepare for storms, and shelters to protect people and property already at risk;

Protection – involves traditional hard engineering such as sea defenses, dykes and beach nourishment to reduce the *probability* of damage in vulnerable areas. Salt marsh creation is increasingly seen as a more cost-effective and ecologically desirable soft engineering solution;

Retreat – involves withdrawing key activities and infrastructure from particularly vulnerable areas. More controversially sea defenses may be dismantled allowing inundation of some low-lying sections of coast to help buffer others.

High resolution topographic data and models of shoreline erosion and accretion (e.g., Tyndall Centre Coastal Simulator, see: http://www.tyndall.ac.uk/publications/briefing_notes/bn18.pdf) are helping to identify areas most vulnerable to sea level rise and expansion of flood risk zones. Unfortunately, global elevation data sets (e.g., GTOPO30 and SRTM) are poorly suited for detailed inundation mapping because of low vertical resolution (typically whole meter intervals) and accuracy (see below). Other survey products such as LIDAR have accuracies of $\pm 0.3\text{m}$ but are not universally available. There may also be a lack of consistency in the tidal datum against which the sea level rise is measured, or site specific conditions that affect tidal dynamics and/or short-term shore levels. Other mapping techniques such as photogrammetry and ground survey can produce high-quality elevation data for detailed vulnerability assessment, but this is only feasible over small areas.

Case Study Feasibility of sea-level vulnerability mapping along the mid-Atlantic US coastline



The current USGS holdings of the best available elevation data include LIDAR for North Carolina, parts of Maryland, and parts of New Jersey (orange areas on the map). Elsewhere elevation data are not suitable for detailed assessments of sub-meter increments of sea-level rise and hence the production of spatially explicit local planning maps. Given an upper limit sea level rise projection of 59 cm under A1B emissions, it is evident that existing data are unable to delineate areas vulnerable to inundation within the 21st century. Nonetheless, earlier analyses suggest that $\sim 58\,000\text{ km}^2$ of land on the Atlantic and Gulf coasts lies below the 1.5 m contour. The most vulnerable states are Louisiana, Florida, Texas, and North Carolina.

Figure 2 Estimated minimum sea-level rise scenarios that can be resolved in the mid-Atlantic region given the best available elevation data (August 2008). Source: Gesch et al (2009)

Supporting materials and links

- Bindoff, N.L., Willebrand, J., Artale, V. et al. 2007: Observations: Oceanic Climate Change and Sea Level. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., Qin, D., Manning, M. et al. (eds.)]. Cambridge University Press, Cambridge, UK
- European Commission, 2006. *Marine and coastal dimension of climate change in Europe: A report to the European Water Directors*. A report by the Institute for Environment and Sustainability, Joint Research Centre, European Commission http://ies.jrc.ec.europa.eu/uploads/fileadmin/Documentation/Reports/Varie/cc_marine_report_optimized2_01.pdf
- Gesch, D.B., B.T. Gutierrez, and S.K. Gill, 2009: Coastal elevations. In: *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. U.S. Environmental Protection Agency, Washington DC, pp. 25-42.
- Grinsted, Aslak, J. C. Moore, and S. Jevrejeva, 2009. Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD. *Climate Dynamics*, DOI 10.1007/s00382-008-0507-2. Published online, January 6, 2009.
- Titus, J.G. and Richman, C. 2001. Maps of lands vulnerable to sea level rise: modelled elevations along the US Atlantic and Gulf coasts. *Climate Research*, **18**, 206-228.