# Accurately Determining the Risks of Rising Sea Level

PAGES 441–442

With the highest density of people and the greatest concentration of economic activity located in the coastal regions, sea level rise is an important concern as the climate continues to warm. Subsequent flooding may potentially disrupt industries, populations, and livelihoods, particularly in the long term if the climate is not quickly stabilized [*McGranahan et al.*, 2007; *Tol et al.*, 2006]. To help policy makers understand these risks, a more accurate description of hazards posed by rising sea levels is needed at the global scale, even though the impacts in specific regions are better known.

Several maps illustrating threatened coastal zones have been presented to a wide audience (e.g., at http://flood.firetree.net at the global scale or by *Marbaix and van Ypersele* [2004] for Belgium). Often, though, the area at risk is identified on the basis of mean sea level, ignoring tides. *Rowley et al.* [2007] (see also http://www.cresis.ku.edu/research/data/sea_level_rise) followed that approach, presenting new maps of areas lying at a given altitude above mean sea level and data on the associated population count. While that work includes technical refinements and adds population data providing an estimate of the number of people at risk, it relies on fixed increases in mean sea level and static population. This brief report reviews the limitations of the approach by Rowley et al. and others, and discusses other aspects involved with human vulnerability to sea level rise.

### *Mean Sea Level Versus High Water Level*

Natural coastal zones include intertidal areas with mudflats, salt marshes, and mangroves. If people live at these intertidal elevations, they rely on adaptation measures comprising various forms of protection, in particular dikes, or sometimes elevating structures above the flood levels.

The use of only mean sea level to determine flood risk is a significant limitation to risk analyses primarily because the actual flooding process involves the level of high water, which is linked to tides and storms. Depending on the region, the highest level reached by water can be many meters above mean sea level. Thus, a large fraction of the land within a few meters above mean sea level is currently at risk of flooding, and large populations can be threatened when protection fails.

Such a case was tragically shown in New Orleans, La., and surrounding areas in 2005. Though much of the flooded regions were below sea level, they were protected from the sea by dikes that were breached, resulting in lowland flooding. Under current climate conditions, there is a significant probability of flooding in many coastal regions, associated with the return period of high water levels that exceed the design level of adaptation measures. Therefore, while maps based on mean sea level are illustrative, their limitations need to be appreciated and the results should not be overinterpreted in coastal or climate policy making.

### *Improving the Methodology to Compute Flood Risk*

To locate risk areas, simple methods mark all the pixels under a given level as "potentially flooded" and use a mask specifically prepared to exclude regions, such as the Caspian Sea, that cannot be reached by ocean water although they are partly below sea level. By contrast, the refined global information system (GIS) methodology presented by *Rowley et al.* [2007] consists of "spreading" the flooded area from pixel to pixel starting from the ocean, reminiscent of an actual flooding process. However, because of the limited horizontal and vertical resolution of global data sets, some propagation of flooding occurs at smaller scales than is available in the data. It would be interesting to verify whether the methodology presented by Rowley et al. is more representative of the actual area at risk than is a map of the area under the selected water level, although the two methods seem to provide similar evaluations of the area at risk, suggesting that other limitations of these methods are more important.

As a first step toward a more complete view of the impacts of sea level rise, maps can be produced for the area under local mean high water level, as presented by *Anthoff et al.* [2006]. As sea level rise is added to the current high water level rather than mean sea level, the results take into account the risk of flooding the currently protected area due to astronomical tides.

Besides, capturing more aspects of sea level rise impacts is a difficult task, particularly for global coverage, as it needs additional local-scale data. Computing flood risk requires data for the high water level for different return periods associated with sea depth, tides, waves, winds, and atmospheric pressure during storms [*Hoozemans et al.*, 1993]. Ultimately, when investigating the impacts of future sea level rise, data should also include regional changes in mean sea level [*Gregory et al.*, 2001], possible changes in extreme sea levels [*Lowe and Gregory*, 2005], and local changes in land level (e.g., postglacial rebound or subsidence following groundwater extraction).

### *Flood Risk and Adaptation*

Accurately determining the consequences of sea level rise not only involves a solid understanding of what might happen, but also requires projections for the adaptation that will take place in different scenarios and regions. Adaptation includes protection (dykes, beach nourishment), restoration of wetlands and associated natural protection, and so forth, and is now considered more effective when taking place in an integrated coastal zone management context. The level of protection taking place is expected to increase in response to increased sea level [*Nicholls and Tol*, 2006], and in response to local economic growth, as wealthy people tend to prioritize risk protection because they can afford to be cautious [*Nicholls*, 2004].

Current global-scale modeling of adaptation involves uncertain data at the regional scale and simplified hypotheses about the mechanisms and levels of action against flooding. However, conclusions are emerging that suggest that widespread flood protection from anticipated sea level rise would be economically rational, especially for the moderate increases in the sea level (less than a meter) expected during the 21st century [*Nicholls and Tol*, 2006]. This requires further investigation, but it suggests that coastal societies will have more choice in their response to sea level rise than might be assumed.

Obtaining projections of sea level rise impacts that provide accurate regional assessments and global coverage is not an easy task. It will take time to progressively include better local data and improve the modeling of key physical and human aspects. A recent improvement in this regard is the DIVA tool [*DINAS-Coast Consortium*, 2006]. However, accounting for the actual level of high water, better analysis methods, and adaptation will provide a view on sea level risks that has more policy relevance. As sea level rise is expected to continue over a long period after greenhouse gas emissions are reduced, and uncertainties remain regarding the possibility of accelerated ice melting, the impacts and responses to long-term and/or large sea level rise are also topics worthy of more research. These investigations will contribute to place the effects of sea level rise in perspective in the broader context of climate change impacts on natural and human systems, and could possibly help to contain damages.

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By P. Marbaix and R. J. Nicholls

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# NEWS

## Conference Marks Fiftieth Anniversary of Global $CO_2$ Record

PAGE 443

The fiftieth anniversary of the global $CO_2$ record, begun by Charles David Keeling at the South Pole and in Hawaii during the International Geophysical Year (IGY; 1957–1958), will be celebrated at a symposium in Kona, Hawaii, near the Mauna Loa Observatory, on 28–30 November 2007.

At the time of Keeling's initial efforts, little was known about $CO_2$ in the atmosphere and no reliable atmospheric record existed. Indeed, many scientists were not certain that one could detect meaningful patterns such as seasonal changes, hemispheric differences, and fossil fuel emissions with measurements of such a low-concentration constituent of the atmosphere. The early measurements by Keeling began what was to become a coordinated global monitoring network involving scientists and agencies from countries around the world. Information derived from this network—which now includes many greenhouse gases, isotopes, and other tracers—has been crucial for informing national and international assessments of global climate change, not the least of which are the Intergovernmental Panel on Climate Change (IPCC) assessment reports.

This conference will bring together leaders of business, government, and science to discuss the global $CO_2$ record, climate change, and what is needed from future $CO_2$ measurement systems to monitor the efficacy of mitigation efforts. The conference will include a keynote speech by U.S. National Academy of Sciences president Ralph Cicerone and presentations and panels focusing on a range of concerns. A session on what has been learned from the $CO_2$ measurement record will be chaired by Ralph Keeling of the Scripps Institution of Oceanography and Pieter Tans of the NOAA Earth System Research Laboratory. A panel addressing impacts and urgency includes Vice Admiral Paul Gaffney II, coauthor of the Military Advisory Board's *National Security and the Threat of Climate Change,* and Richard Somerville, a coordinating lead author for IPCC assessment reports.

Among other conference highlights: IPCC Working Group I cochair Susan Solomon, senior scientist at the NOAA Earth System Research Laboratory, will focus on the global climate–related problem of reducing emissions of ozone-depleting substances, noting how this effort underscores useful approaches for addressing $CO_2$ emissions; Robert Socolow of Princeton University, N. J., will chair a session on mitigation options; former California State Assembly member Fran Pavley, coauthor of California's AB 32 tailpipe emission reduction bill, will lead a session on regional efforts to reduce greenhouse gas emissions; and Michael Walsh, executive vice president of the Chicago Climate Exchange, will discuss economic tools and financial incentives to reduce emissions.

For more information, visit the Web site: http://www.co2conference.org.

—James Butler and Melinda Marquis, NOAA Earth System Research Laboratory, Boulder, Colo.

## In Brief

PAGE 443

**Large-scale carbon sequestration projects** The U.S. Department of Energy (DOE) announced on 9 October the first three large-scale carbon sequestration projects in the United States. The three projects—Plains Carbon Dioxide Reduction Partnership, Southeast Regional Carbon Sequestration Partnership, and Southwest Regional Partnership for Carbon Sequestration—double the number of large-volume carbon storage demonstrations in operation worldwide. DOE plans to invest $197 million over 10 years, subject to annual appropriations from Congress, for the projects, which are the first of several sequestration demonstration projects planned through DOE's Regional Carbon Sequestration Partnerships. These projects will demonstrate the entire carbon dioxide ($CO_2$) injection process—preinjection characterization, injection process monitoring, and postinjection monitoring—at large volumes to determine the ability of different geologic settings to permanently store $CO_2$. The program earlier had identified more than 3000 billion metric tons of potential storage capacity in promising sinks, with the potential to represent more than 1000 years of storage capacity from point sources in North America.

**Improving Mississippi River water quality** If water quality in the Mississippi River and the northern Gulf of Mexico is to improve, the U.S. Environmental Protection Agency (EPA) needs to take a stronger leadership role in implementing the federal Clean Water Act, according to a 16 October report from the U.S. National Research Council. The report notes that EPA has failed to use its authority to coordinate and oversee activities along the river. In addition, river states need to be more proactive and cooperative in efforts to monitor and improve water quality, and the river should be monitored and evaluated as a single system, the report indicates. Currently, the 10 states along the river conduct separate and widely varying water quality monitoring programs. "The limited attention being given to monitoring and managing the Mississippi's water quality does not match the river's significant economic, ecological, and cultural importance," said committee chair David A. Dzombak, director of the Steinbrenner Institute for Environmental Education and Research at Carnegie Mellon University, Pittsburgh, Pa. The report notes that while measures taken under the Clean Water Act have successfully reduced much point source pollution, nutrient and sediment loads from nonpoint sources continue to be significant problems. For more information, visit the Web site: http://books.nap.edu/catalog.php?record_id=12051.

—Randy Showstack, Staff Writer