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CITATION

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Sea Level

An Introduction to the Special Issue

If you listen closely to the current public discourse on climate change, you will frequently hear the refrain "Global Warming ***and*** Sea Level Rise." Although global warming is likely to have many serious consequences, it is the specter of sea level rise that seems to attract the most attention. Perhaps this focus is because sea level rise lends itself to graphic (though inaccurate) portrayals, such as tsunami waves crashing onshore. Indeed, at the current global rate of ~ 3 mm yr^{-1}, one might be tempted to dismiss sea level rise as a minor consequence of climate change. But, the current rate is expected to grow, possibly resulting in 1–2 m (3–6 ft) of sea level rise over the next 100 years. This increase will directly threaten the 146 million people worldwide who currently live within 1 meter of mean high water. Entire island nations may be inundated, and roughly 3.5 trillion dollars of property are at risk along the east coast of the United States alone. There are also a number of near-term threats, including the slow, ongoing inundation of ecologically sensitive marshlands, and increasing vulnerability to storm surge (see cover photo). It is against this backdrop that we present this special issue of *Oceanography*.

There is no shortage of excellent publications on the topic of sea level rise. In his book *Sea Level Rise: History and Consequences* (Academic Press, 2000), Bruce Douglas provided a thorough review of the literature at the end of the 1990s, and Church et al. in *Understanding Sea-Level Rise and Variability* (Wiley-Blackwell, 2010; reviewed in this issue, p. 214) updated these findings for the last decade. Also, there have been many national and international sea level rise assessments, culminating in the first four reports of the Intergovernmental Panel on Climate Change (see Pfeffer's article on land ice in this issue for a stroll through the history of these and other efforts, p. 94). Given all of this recent literature, one may question the need for a special issue of *Oceanography* on the topic.

It is often stated that global sea level rise is one of the most important consequences of human-caused climate change. Indeed, the article by Nicholls (see p. 144) suggests that the impacts of rising sea levels in the next century will be profound and the costs will be high. Despite the obvious significance, scientific literature on the subject seems perennially intractable, leaving many readers unsure of where to begin. In one sense, sea level rise seems like one of the easiest aspects of global warming to understand: warming seawater expands to take up more room, and meltwater from land ice eventually makes its way back to the ocean. How complicated can it be? As you peruse the articles in this special issue, we think you will be surprised to discover the complexity of the subject area and the many important questions that remain to be answered.

For example, we often think of the ocean as a bathtub, where the level simply rises as water flows in. In our first article, Tamisiea and Mitrovica (p. 24) remind us that the ocean is more akin to a child's inflatable pool where the sides and bottom bend and sink as we add water (and rambunctious children). These effects are often dismissed as small

This special issue of *Oceanography* was conceived by Stan Wilson, NOAA/NESDIS Senior Scientist, and jointly supported by NOAA, NASA, and NSF. Stan is retiring this June, after 40 years of government service, first at the Office of Naval Research, next at NASA Headquarters, and finally with NOAA where he served as Assistant Administrator of the National Ocean Service, among other positions. Stan helped pioneer the modern era of sea level science through his work on the TOPEX/POSEIDON altimeter mission and more recently through his leadership of the Committee on Earth Observation Satellites (CEOS) Ocean Surface Topography Constellation. He also provided important support for the Argo array of profiling floats during the early stages of its development. Stan has been an incredibly strong advocate for all of the ocean sciences and we will sorely miss his energy and enthusiasm.

— The Special Issue Guest Editors

and unimportant for modern-day sea level rise, but Tamisiea and Mitrovica show that, coupled with changes in Earth's rotation and gravity field, they will play a critical role in the rate of regional and local sea level change as ice loss increases over the next century.

Much of the rest of the issue is devoted to measuring sea level throughout Earth's history. The first three articles consider the geologic evidence. Miller et al. (p. 40) show that changes in global sea level have been caused by several processes, have been active for the last several 100 million years, and have had a major impact on the geologic record. Yokoyama and Esat (p. 54) note that while orbital forcing explains much of the variability in Earth's climate and sea level for the last 150,000 years, fossil corals point to abrupt climate changes on millennial time scales (and possibly shorter); it is expected that future analysis will confirm that changes in sea level were equally abrupt. Engelhart et al. (p. 70) summarize records from salt marshes along the east coast of the United States, documenting the changing rate of sea level rise during the last 10,000 years after carefully accounting for local deformations of Earth's crust.

There is no sea level equivalent to the now famous "hockey-stick" curve showing modern warming in the context of the last several thousand years. Nevertheless, there is increasing evidence to support the idea that the rate of sea level rise accelerated sometime during the last century or two. The article by Woodworth et al. (p. 80) describes the modern instrumental record of sea level rise and the evidence for acceleration in light of the recent efforts to use salt marshes (see also Engelhart et al., p. 70) as sea level indicators prior to the advent of tide gauges.

The causes of modern-day sea level rise are laid out in the next three articles. Pfeffer (p. 94) covers the evolution of our ability to observe and understand ice loss from the world's glaciers and ice sheets. Johnson and Wijffels (p. 112) explain how changes in the density of seawater drive changes in sea level and chart our ability to observe them; and Leuliette and Willis (p. 122) discuss the modern systems for measuring global sea level rise and the additions of water and heat that drive it.

One of the thorniest topics is the prediction of future rates and magnitudes of sea level rise. Of course, prediction is the elusive aim of many scientific endeavors, but for sea level rise, the problem remains especially vexing. Ice sheets in a warming climate interact with everything from the atmosphere to the land to the ocean. The lack of realistic physical models that can explain their complicated behavior has so far stymied our ability to narrow the window of possible future scenarios to one that could be useful for policymakers and planners. In their article on p. 130, Church et al. cover the delicate issue of projecting future sea level rise and provide a sobering assessment of our ability to see into the future.

The last article concerns the impacts of sea level rise and our ability (or lack thereof) to adapt to it. While the complexities of understanding past, present, and future sea level change are numerous, the coastal zone is ripe with subtleties of its own. Here, Nicholls (p. 144) reminds us that the academic study of sea level rise bears directly on real life choices that must be faced by many in the coming decades, both in coastal communities and in society at large. The choice between addressing the causes of sea level rise, adapting to its impacts, or retreating from its gradual advance is not as obvious as it may seem.

So, why the special issue? Like the Hydra of Greek mythology, sea level science is a many-headed beast—each head having its own discipline, its own language, and its own set of scientific priorities. Our hope with this issue is to spark the embers of discussion across these disciplines by providing a jumping-off point for those bold enough to explore the others. We hope, too, that young researchers will be inspired to follow the threads of these scientific challenges and close some of the major gaps in our ability to predict sea level rise. As the realities of global warming sink in, the urgent need for organization and leadership in sea level science becomes ever more apparent. We may never tame the Hydra, but success will come if we can at least coax all the heads to look in the same direction—toward the future.

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— *Laury Miller, National Oceanic and Atmospheric Administration*

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