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Science Briefs

Sea Level Rise, After the Ice Melted and Today

By Vivien Gornitz — January 2007

Climate warming is expected to result in rising sea level. Should this occur, coastal cities, ports, and wetlands would be threatened with more frequent flooding, increased beach erosion, and saltwater encroachment into coastal streams and aquifers. Global sea level has fluctuated widely in the recent geologic past. It stood 4-6 meters above the present during the last interglacial period, 125,000 years ago, but was 120 m lower at the peak of the last ice age, around 20,000 years ago. A study of past sea level fluctuations provides a longer-term geologic context, which can help us better anticipate future trends.

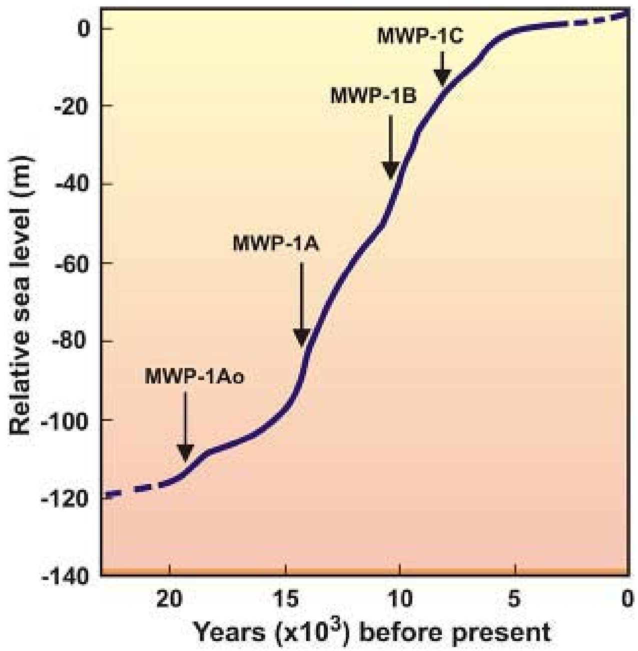


Figure at right: Generalized curve of sea level rise since the last ice age. Abbreviations: MWP = meltwater pulse. MWP-1A0, c. 19,000 years ago, MWP-1A, 14,600 to 13,500 years ago, MWP-1B, 11,500-11,000 years ago, MWP-1C, ~8,200-7,600 years ago.

Massive ice sheets covered parts of North America, northern Europe, and several other regions during the last ice age. This huge volume of ice lowered global sea level by around 120 meters as compared to today. After the ice sheets began to melt and retreat, sea level rose rapidly, with several periods of even faster spurts. The first such spurt may have started about 19,000 years ago, at which time ocean levels rose 10-15 m in less than 500 years. However, this event is not seen in all past sea level records and new evidence suggests that ice melting may have begun much earlier. A more clearly-defined accelerated phase of sea level rise occurred between 14,600 to 13,500 years before present (termed "meltwater pulse 1A" or "MWP-1A" by Fairbanks in 1989), when sea level increased by some 16 to 24 m (see Figure 1). Although the meltwater was previously believed to have come chiefly from Antarctica, a recent reconstruction by Tarasov and Peltier of ice sheet retreat using a glacial model calibrated by a variety of data points instead to a largely North American source. Furthermore, diatom fossils in sediments from fjords in East Antarctica show that ice melting there began perhaps 3000 years later, thus ruling out Antarctica as a likely source.

Image at left: Meltwater stream flowing into a large moulin in the ablation zone (area below the equilibrium line) of the Greenland ice sheet. (Image courtesy Roger J. Braithwaite, The University of Manchester, UK)

The rate of sea level rise slowed between 14,000 and 12,000 years ago during the Younger Dryas cold period and was

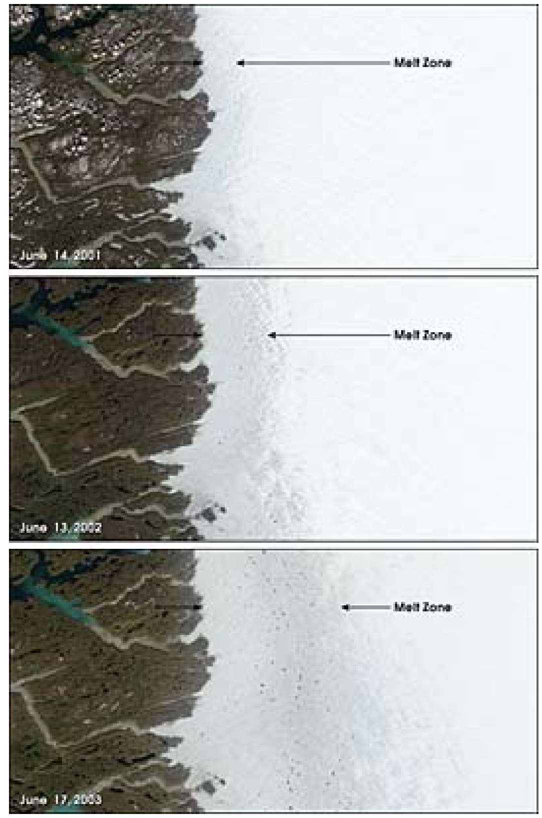
succeeded by another surge, "meltwater pulse 1B", 11,500-11,000 years ago, when sea level may have jumped by 28 m according to Fairbanks, although subsequent studies indicate it may have been much less. Meltwater from glacial Lake Agassiz (southwest of Hudson Bay) draining catastrophically into the North Atlantic via Lake Superior and the St. Laurence seaway was once thought to have initiated ocean circulation changes leading to the Younger Dryas cold period. Regional removal of ice sheets, however, occurred nearly 1000 years later, and hence draining of Lake Agassiz could not likely have caused the Younger Dryas cold reversal. This cold spell may have instead been triggered by increased outflow into the Arctic Ocean, the Fram Strait east of Greenland, and ultimately the eastern North Atlantic, between 12,900 and 12,800 years before present, as suggested by the glacial model of Tarasov and Peltier. On the other hand, Leventer et al. indicate that the timing of deglaciation in eastern Antarctica roughly coincides with the onset of meltwater pulse 1B.

A fourth interval of rapid sea level rise 8200-7600 years ago was first identified by a hiatus in coral growth in the Caribbean about 7600 years ago. Although less firmly established than the other such intervals, it is supported by stratigraphic data from elsewhere including Chesapeake Bay; the Mississippi River delta; the Yellow River in China; coastal Lancashire, England; and Limfjord, northwestern Denmark. This spurt has been linked to a cold event 8200 year ago, which apparently resulted from the catastrophic drainage of glacial Lakes Agassiz and Ojibway around 8400 yrs ago, releasing a volume of about 105 cubic kilometers within a few years or even less. But it only produced about 1 meter of global sea level rise, assuming an even spread of this volume spread across the world's oceans. Yet even this minor increase in sea level left an imprint in the stratigraphic record.

By the mid-Holocene period, 6000-5000 years ago, glacial melting had essentially ceased, while ongoing adjustments of Earth's lithosphere due to removal of the ice sheets gradually decreased over time. Thus, sea level continued to drop in formerly glaciated regions and rise in areas peripheral to the former ice sheets. At many low-latitude ocean islands and coastal sites distant from the effects of glaciation, sea level stood several meters higher than present during the mid-Holocene and has been falling ever since. This phenomenon is due to lithospheric responses to changes in ice and water loading. Water is "siphoned" away from the central equatorial ocean basins into depressed areas peripheral to long-gone ice sheets. Loading by meltwater that has been added to the oceans also depresses far-field continental shelves, tilting the shoreline upward and thus lowering local sea level. Over the past few thousand years, the rate of sea level rise remained fairly low, probably not exceeding a few tenths of a millimeter per year.

Figure at right: Three successive images of an area on the west edge of the Greenland ice sheet taken in June of 2001, 2002, and 2003. Although the sheet's edge has not visibly moved, the extent of the "melt zone" — the translucent area dotted with meltwater ponds — along the edge is greatly expanded. Ice loss by glaciers in Greenland doubled between 1996 and 2005. (Images courtesy Jacques Descloitres, MODIS Land Rapid Response Team, NASA/GSFC.)

Twentieth century sea level trends, however, are substantially higher that those of the last few thousand years. The current phase of accelerated sea level rise appears to have begun in the mid/late 19th century to early 20th century, based on coastal sediments from a number of localities. Twentieth century global sea level, as determined from tide gauges in coastal harbors, has been increasing by 1.7-1.8 mm/yr, apparently related to the recent climatic warming trend. Most of this rise comes from warming of the world's oceans and melting of mountain glaciers, which have receded dramatically in many places especially during the last few decades. Since 1993, an even higher sea level trend of about 2.8 mm/yr has been measured from the TOPEX/POSEIDON satellite altimeter. Analysis of longer tide-gauge records (1870-2004) also suggests a possible late 20th century acceleration in global sea level.



Recent observations of Greenland and the West Antarctic Ice Sheet raise concerns for the future. Satellites detect a thinning of parts of the Greenland Ice Sheet at lower elevations, and glaciers are disgorging ice into the ocean more rapidly, adding 0.23 to 0.57 mm/yr to the sea within the last decade. The West Antarctic Ice Sheet is also showing some signs of thinning. Either ice sheet, if melted completely, contains enough ice to raise sea level by 5-7 m. A global temperature rise of 2-5°C might destabilize Greenland irreversibly. Such a temperature rise lies within the range of several future climate projections for the 21st century. However, any significant meltdown would take many centuries. Furthermore, even with possible future accelerated discharge from the West Antarctic Ice Sheet, it highly unlikely that annual rates of sea level rise would exceed those of the major post-glacial meltwater pulses.

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Reference

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Additional references may be found in Gornitz (2007).

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