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Science Briefs

The Great Ice Meltdown and Rising Seas: Lessons for Tomorrow

By Vivien Gornitz — June 2012

***CharacterTowns.org** occasionally gets carried away with "wonkish" stuff. So be it with this article but the history is useful and the discussion is impressive. The motivation to slog through this is the seriousness of the problem and the extent to which NASA is going to monitor the situation. Part of the data base necessary for Arctic Council action.*

As accumulating atmospheric greenhouse gases lead to further climate warming, sea level rise will accelerate, endangering coastal communities by more frequent flooding, exacerbated beach erosion, and saltwater penetration into streams and aquifers. Twentieth century global sea level rise has averaged 1.7 mm/yr, increasing to around 3 mm/yr since 1993, as measured by TOPEX/Poseidon and Jason satellite altimetry. Current trends exceed those of the last few millennia by 1 to 2 mm/yr, based on saltmarsh data from many localities.

However, sea level varied substantially in the past, ranging from 4-6 m (or more) above present during the last interglacial, 125,000 years ago, to 120 m below present at the peak of the last ice age, around 21,000-20,000 years ago. The subsequent great ice meltdown spanned 12,000 years, nudging sea level ever upward at an average rate of ~10 mm/yr. But several more rapid jumps punctuated the marine incursion (Fig. 1). A closer examination of these rapid sea level changes may help us better plan for the future.

In the first significant jump (meltwater pulse 1Ao, or MWP 1Ao), 19,600-18,800 years ago, ocean levels climbed at least 10 m within 800 years. However, not all sea level proxies register this event. A faster rise began 14,600 years ago during the comparatively mild Bølling-Allerød interstadial, accelerated about 300 years later and peaked about 13,800 years ago (meltwater pulse 1A, or MWP 1A) (Stanford et al., 2011). Sea level rose ~16 m during this event at rates of 26-53 mm/yr. Computer models that "fingerprint" spatial patterns of sea level rise attribute much of the meltwater to Antarctica. Different sources of ice melt leave geographically distinctive sea level fingerprints, because their ice unloading histories and gravitational pull between shrinking ice masses and ocean vary. On the other hand, geological data indicate significant deglaciation in Antarctica starting only toward the end of MWP 1A, which suggests that most of the meltwater originated from the breakup of Northern Hemisphere ice sheets.

During the Younger Dryas cold period, between 12,900 and 11,800 years ago, the encroaching oceans slowed their upward pace. A heavy freshwater influx via the Mackenzie River into the Arctic Sea and ultimately the eastern North Atlantic may have triggered this cold episode. Once the warmth returned, rates of sea level rise averaged 13 to 15 mm/yr during meltwater pulse 1B, 11,000-9,000 years ago, an event recorded in Barbados, but not in Pacific corals. This difference may arise from glacial isostatic or gravitational effects; alternatively, the increase at Barbados may have been overestimated.

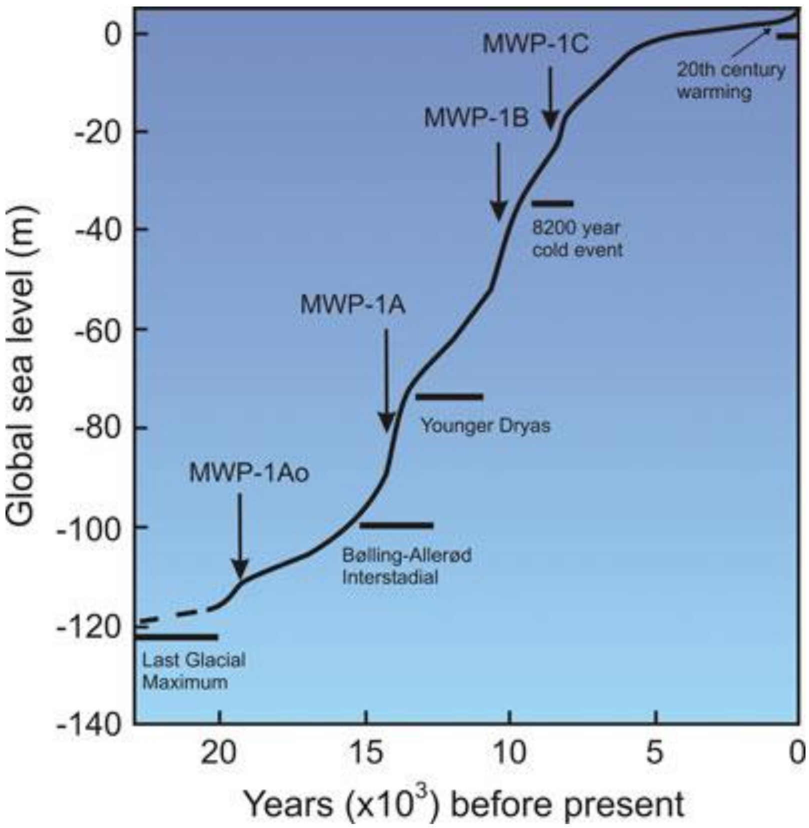

Figure 1. Generalized sea level rise since the last ice age showing several meltwater pulses (MWP). MWP-1A0, c. 19,600-18,800 years ago; MWP-1A, 14,600 to 13,800 years ago; MWP-1B, 11,000-8,800 years ago; and MWP-1C, ~8,200-7,600 years ago.

Around 9,300 years ago, a glacial dam burst at the southeastern end of Lake Superior, provoking pervasive Northern Hemisphere cooling, followed by a minor meltwater pulse about 9,000 years ago. However, meltwater pulse 1C (8,200-7,600 years ago) left traces at numerous locations in the United States, northwestern Europe, and China. It occurred soon after the 8200 year cold event, which resulted from the final catastrophic drainage of glacial Lakes Agassiz and Ojibway around 8400 years ago. The torrent of around 100,000 cubic kilometers unleashed within a few years or less amounted to barely a meter rise in global sea level, if evenly spread across the world's oceans (note 1). Yet the stratigraphic record preserves vestiges of this relatively minor pulse.

Most glacial melting ended by about 7,000-6,000 years ago. Because of slowly diminishing adjustments of Earth's lithosphere to ice sheet removal, sea level falls near formerly ice-covered regions and rises along the margins of the vanished ice sheets. Since the mid-Holocene, ~6,000 to 4,000 years ago, sea level has receded at many coastal sites and tropical ocean islands far from glacial influences, as water is "siphoned" away from the central equatorial ocean basins into depressions peripheral to former ice sheets. The weight of glacial meltwater added to the oceans also depresses far-field continental shelves, pushing the shoreline upward while lowering local sea level. While rates of sea level rise have generally remained fairly stable over the past few thousand years, high resolution proxy sea level records detect subtle changes related to the Medieval Warm Period and Little Ice Age (Kemp et al., 2011).

What have we learned from our excursion into the last deglaciation? Could polar ice sheets collapse catastrophically, as in the past? The much more extensive ice sheets were weakened by prolonged multi-century melting. Major meltwater pulses occurred either during periods of warming (i.e., MWP 1A) or once warmth returned (i.e., MWP 1B or MWP 1C). But the temperature rise of the last few decades is unprecedented within the past millennium. More disconcertingly, within the last 10-15 years, meltwater from glaciers and ice sheets accounts for two thirds to nearly four fifths of the total observed rise in sea level (which includes ocean thermal expansion).

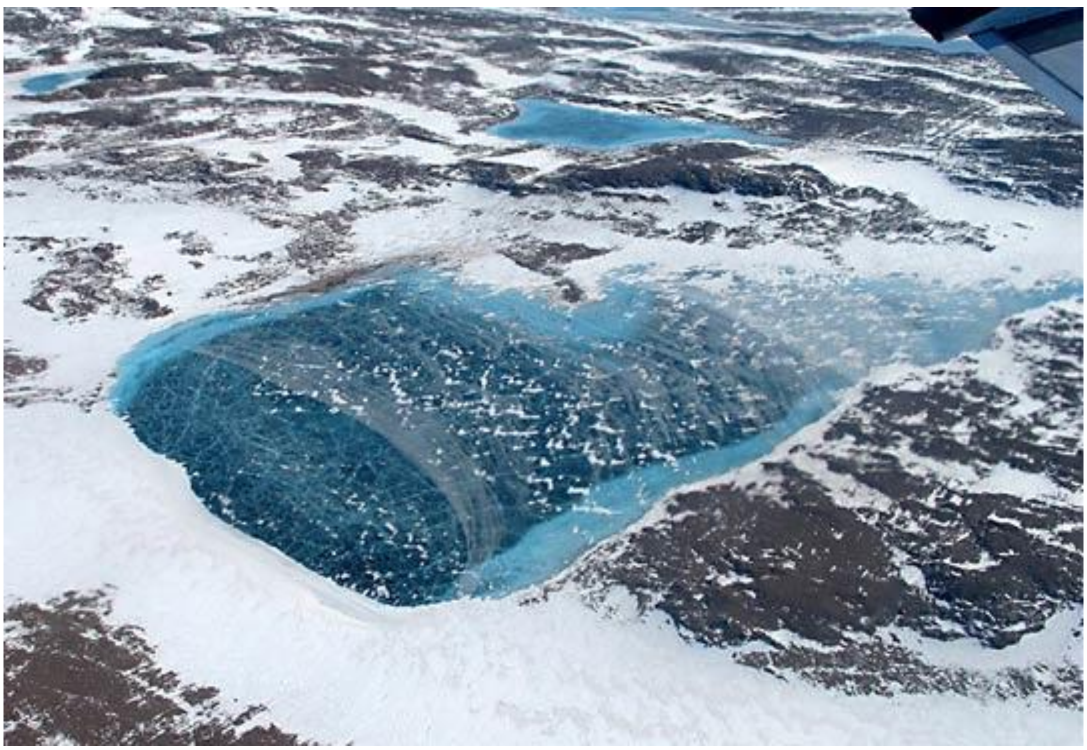

Figure 2. Meltwater ponds near the eastern coast of Greenland (76.84°N 22.07°W) as seen from a NASA aircraft during the Ice Bridge. (Photo: NASA/WFF/Jim Yungel)

If melted completely, the Greenland and West Antarctic ice sheets could raise sea level by 10 m. A global temperature rise of 0.8°-3.2°C, projected by several climate models for 2100, could eventually destabilize Greenland irreversibly. Still, any significant meltdown would take at least a few centuries because of the sluggish response time of ice sheets and constraints on how fast they can shed their ice. Should global warming continue unabated, the sea level speedup would probably become quite noticeable later in this century and beyond, inducing a current sense of complacency, as rates still remain relatively low. A plausible upper bound estimate lies near 1 meter of ice melt by 2100, assuming an average deglacial rate — roughly 3 times the current global rate (note 2).

The story does not end in 2100. Increasing atmospheric greenhouse gases not only guarantee a much warmer world, but one that stays hot long after new inputs of these gases have ended. Surface heat penetrates slowly to the seafloor because of the ocean's high thermal inertia, assuring centuries of sea level rise. A substantial fraction of anthropogenic carbon dioxide, unlike methane or nitrous oxide, lingers in the atmosphere for thousands of years after fossil fuel combustion ceases, maintaining higher air temperatures for centuries, possibly millennia, before equilibrium is restored. The extended warmth gives the remaining ice sheets ample time to generate new meltwater pulses.

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Footnotes

[1] Melting of Antarctic ice may have also added to sea level rise at that time. (Back to text)

[2] The local sea level trend could be much higher due to glacial isostatic adjustments, land subsidence, subsurface fluid extraction, and/or neotectonics, in addition to the contribution from thermal expansion. (Back to text)

References

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Additional references are cited in Gornitz (2012).

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