Institute on Science for Global Policy

The Coming Reality of Sea Level Rise: Too Fast Too Soon**

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Summary
The reality of accelerating rates of sea level rise as the result of human-induced global warming is becoming increasingly dire and urgently needs to be addressed. In 2012, the National Oceanic and Atmospheric Administration (NOAA) published the most recent United States Government sea level rise projections as a part of the National Climate Assessment. Those projections, which included anticipated acceleration in ice melt from Greenland and Antarctica, were for 4.1 to 6.6 feet of sea level rise by 2100. That could mean 2 feet by as early as 2048 and 3 feet by 2063. A 2 to 3 foot rise of sea level will make nearly all of the barrier islands of the world uninhabitable, result in inundation of a major portion of the world's deltas, and make low-lying coastal zones like south Florida increasingly challenging communities in which to maintain infrastructure and welfare and to assure protection of life and property during hurricanes and other extreme events.

Current realities
Most of the models projecting future sea level rise assume a gradual acceleration of sea level rise through this century and beyond as Greenland and Antarctic ice melt gradually accelerates. Our knowledge of how sea level rose out of the past ice age paints a very different picture of sea level response to climate change. At the depth of the last ice age, about 18,000 years ago, sea level was some 420 feet below present level as ice was taken up by large continental ice sheets. Subsequent ice melt and sea level rise was not a gradual acceleration and then deceleration. Rather it was a series of very rapid pulses of sea level rise followed by pauses. These rapid pulses of rise, from 3 to 30 feet probably within a century, were fast enough to leave drowned reefs, sandy barrier islands, tidal inlet deltas, and other coastal deposits abandoned across the continental shelf. That is what happens when the climate warms: It destabilizes some ice sheet sector which rapidly disintegrates, resulting in a rapid pulse of global sea level rise.

Our significantly warmed atmospheric climate is resulting in an accelerated ice melt of the surface of the Greenland Ice Sheet. Much of the surface of the Ice Sheet is darkening as the dust and black carbon in the ice concentrate on the melting surface. This accelerates heat absorption, further accelerating surface ice melt — one of many feedbacks not in current models. More importantly, warmed ocean water is accelerating ice melt in both Polar Regions. The warming North Atlantic Ocean and Arctic Ocean have been accelerating ice melt all around Greenland since about 1995 as this dense "warm" ocean water enters the deep outlet glacial fjords and penetrates far into and under the Ice Sheet. Warm ocean water is now also penetrating deeply into fjords under outlet glaciers and adjacent Ice Sheets of both West Antarctica and East Antarctica. Each of these warm waters is only 2 to 4 degrees Celsius, but they are causing a powerful amount of melting. We are creating a basically unlimited supply of warmth to the oceans for this to continue.

The beginnings of this polar Ice Sheet melt are showing numerous positive reinforcing feedbacks, which are rapidly accelerating the rate of melt far beyond anything being projected in current models. For example, because water on the melting ice surface absorbs more heat, surface melt is accelerated; this melt water percolates down through the ice and lubricates the base permitting faster motion, which results in more extensive fracturing. Water percolating through the fractured ice accelerates ice melt and warms the ice, which results in the softening of the ice and even further acceleration. With the rapid melting of the Arctic Ocean pack ice and warming of the Arctic Ocean, release of additional carbon dioxide and methane from decaying organics in the melted permafrost, and melting of methane hydrates on the Arctic continental shelf, the

accelerating melt of the adjacent Greenland Ice Sheet seems irreversible. We are most certainly witnessing the onset of a rapid pulse of sea level rise.

In the spring of 2014, NASA's Jet Propulsion Laboratory, Cal Tech, and the University of California-Irvine all came out with documentation showing that ice melt in from the margins of the West Antarctic Ice Sheet is much less constrained by underlying bathymetry than previously considered (i.e., bottom substrate is much deeper below the ice). The documentation also demonstrates that the numerous fjords penetrating in from the Greenland coast are deeper and extend much further in under the Ice Sheet than previously thought. In 2015, similarly accelerating ice melt has been documented under the East Antarctic Ice Sheet. Each of these findings means that warmed ocean water is now more easily penetrating further under these ice sheets, and accelerating ice melt will be happening significantly faster than previously thought.

In the summer of 2013, I had the opportunity to witness the melting ice sheets, flying about 50 miles onto the Greenland Ice Sheet following the deep channel below the Jacobshaven Icefjord in western Greenland to an elevation on the ice sheet of more than 6,000 feet. It was like flying up a large, meandering, fractured streambed in the ice surface. The channel was roughly 500 feet below the level of the ice sheet and dramatically fractured from the accelerated ice flow. This was created by melt at the base from deeply penetrating warmed ocean water. As a result of the fracturing and detachment from the bottom, the forward velocity of the ice has accelerated from a couple of miles to more than 20 miles per year. This witnessed event was a spectacular, but disturbing experience.

In light of our improving understanding of ice melt, we probably should be anticipating at least 7 to 30 feet of global sea level rise by the end of the century regardless of what we do. Even if we stopped burning fossil fuels tomorrow, the greenhouse gasses in the atmosphere will keep warming the atmosphere for at least another 30 years. More than 90% of this global warming heat is ending up in the oceans, which have the capacity to capture and store and use this heat for centuries. As a result, ice melt and sea level rise will continue for centuries. Most projections recognize that sea level rise will be accelerating through this century and the next. When we are talking about a 4 to 6 feet rise by the end of the century, this will not be a new fixed sea level. This level will be a single point during a period of continued acceleration of sea level rise, because of the continuing acceleration of ice melt. If we encounter a 5-feet increase at the end of the century, sea level will be rising at a foot per decade.

There is currently a very aggressive building boom underway in south Florida (i.e., on the barrier islands and throughout downtown and in the low western areas bordering the Everglades, presently 230 new condominiums are under construction in Miami-Dade County). South Florida is building without considering the viability of construction or challenge of maintaining a low coastal infrastructure anywhere with that level of sea level increase. There are already areas that will be unlivable and properties that will be unsellable within a 30-year mortgage cycle.

Scientific opportunities and challenges

Several recent papers, including one from the National Research Council, have pointed out that we now have greenhouse gas levels sufficient to cause a 79-foot sea level rise. Our recorded history does not have direct observations as to how fast destabilized ice sheet sectors can disintegrate. Indications from the past and the present are that pulses of sea level rise happen very fast (e.g., 3 to 30 feet per century).

Even with the current projection of 6.6 feet in sea level rise by the end of the century, it is beyond sobering to consider the risk in the present investments. With a further 2 feet of sea level rise (possibly before 2048) most of the barrier islands (of south Florida and the world) will become abandoned and the people relocated; at the same time low areas (e.g., Sweetwater and Hialeah

bordering the Everglades) will become flooded more frequently and therefore become increasingly difficult places to live. Citizens in these areas will lose their freshwater resources, be living in a community with a failing and disconnected infrastructure, and be at increasing risk from catastrophic storm surges, flooding from hurricanes, and failing sewage treatment plants.

Many renowned scientists have concluded that global sea level may rise 15 to 30 feet by the end of the century. However, communities should begin planning using the 2012 NOAA projections for planning (4.1 to 6.6 feet by 2100). With that, they will quickly realize that very serious problems will be occurring very soon. With accelerating sea levels projected through this century and beyond, there is a need to refocus on realistic plans to maintain community stability during relocation and environmental quality during inundation. South Florida cannot consider the option of living below sea level with levees and dikes because the limestone and sand substrate is much too porous and permeable. With planning, using the NOAA projections, it will be easy to adapt to higher and faster rates of sea level rise.

Policy issues

- Counties must aggressively and transparently plan for their future, integrating high-resolution elevation, storm surge, flood risk, and infrastructure elevation maps to determine the timing, costs and economic feasibility for maintaining a functional infrastructure, viable insurance, and human health and safety.

- Maps need to be produced for each 6 inches of sea level rise. With these, intelligent planning can be done to determine what areas and infrastructures are currently at unacceptable risk, and at what thresholds and costs infrastructure will have to be modified to maintain functionality and acceptable risk. These maps can also determine infrastructure services that will have to be discontinued from certain sectors because of unacceptable risk or cost.

- We must act within the framework of the reality before us. As there is little possibility that these sea level rise projections will diminish, it is imperative to:
  (a) Terminate long-term, infrastructure-intensive development of barrier islands and low-lying coastlines.
  (b) Divert public money from hard or soft shore-protection measures into funds to be used for relocation assistance, cleaning low-lying polluted lands, and removing storm-damaged development and infrastructure.
  (c) Establish firm sea-level-rise thresholds for termination of infrastructure services and for permission to rebuild following storm destruction.
  (d) Establish preplanned sea-level-rise thresholds that stage insurance withdrawal through cooperative public-private agreements.
  (e) Implement the Southeast Florida Regional Climate Change Compact, which has some 1,200 action items to help insure the stability of affected individuals and communities.
  (f) Initiate intensive education for the affected public.

Without planning, there will come a point where society and civilization as we know it will collapse into chaos. We can only prevent this scenario with serious planning and effort. Our children and future civilization deserve much better than we are presently doing.

Maps provided by Peter Harlem, Florida international University, 2014