Protecting Your Community from Sea-Level Rise

Introduction:
Sea Level Rise **(SLR)** is a direct result of human-caused climate change; its dimensions are hard-wired into the earth's atmosphere. As the air envelope warms, the heat will be passed to ice volumes both floating (ice bergs and ice sheets) and grounded (glaciers). Floating ice does not change SLR if it melts but it does open large areas of the ocean to direct heating by sunlight. Increased heating of the water column can cause the Methane entrained deep at the sea bottom to be released to rise into the surface, adding to the Green House Gas **(GHG)** load and increasing atmospheric warming. In addition, floating ice-melt will expose coastal glaciers to attack by waves and storms. Clearly SLR is part of a profound climatic feedback loop.

Multi-year surface ice in Earth's polar regions have been a cyclic phenomenon within the Pleistocene for over 2.6 million years. The Arctic Ocean is a large open basin ringed by islands and continental shelves that has been largely covered by ice for most of the Pleistocene. This very long-term stability causes stable flow patterns in the continental jet streams with predictable changes in temperate zone weather. Only a few glaciers feed into the basin, therefore almost all of the ice is floating and when large portions of this ice melts most summers, SLR is not directly affected. As the atmosphere warms, more of the Arctic Ocean's ice melts every summer, arctic air becomes more humid, precipitation is affected, and jet streams become more erratic.

Global Climate Crisis and ice melt are closely linked, however, some profound differences are present — SLR will continue for hundreds or thousands of years, nothing that we do in the next 50 or 100 years will stop SLR. Even when GHGs and atmospheric warming return to pre-industrial levels, inertia of warm seas and locked-in feed-back cycles will continue to cause SLR. Like Cyclones and heat-domes, GHGs are the drive, nonetheless, SLR will not cause sudden, dangerous disasters to humans or nature. SLR is a slow process involving all the world's oceans at once. The information that follows will discuss the power and threats represented by SLR and gauge the risks of catastrophic disasters in vulnerable parts of the world.

Dimensions of the threat:
The extent of ice-melt is the subject of global research and computer modelling to gain knowledge about the speed of SLR. Following are summaries of currently published forecasts of SLR by the year 2100:

The IPCC's last word on the trend of SLR between now and 2100 was uttered in the **6th Assessment Report from Working Group I (6AR),** was released on August 9th, 2021; their trends were incorporated into the **NASA Sea Level Projection Tool** published on the same day. **6AR** did not include ice data from Antarctica since data was sketchy. Since that time accurate and reliable ice data has been gathered from the Southern Sea around Antarctica. **Figure 1** graphs the past five years' data plus the 1981 to 2010 median values for the Antarctic. The most obvious aspect is the little variation in ice data between the years 2019 and 2022 that graph very near the median line. 2023 has been a very different trend beginning in June 2023. The August 1, 2023 reading represents a loss of approximately 2.3 million sq. km ice from the median value.

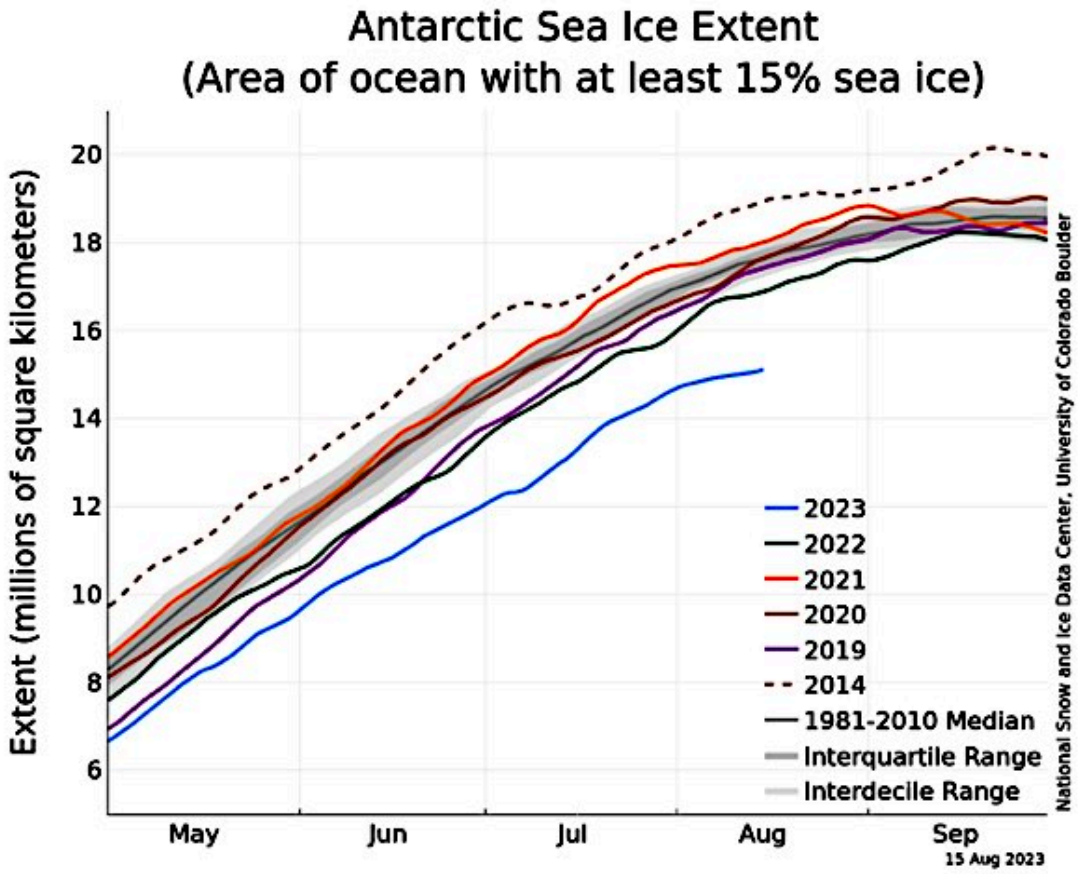

Figure 1: Absolute area of sea ice around Antarctica on a daily basis.

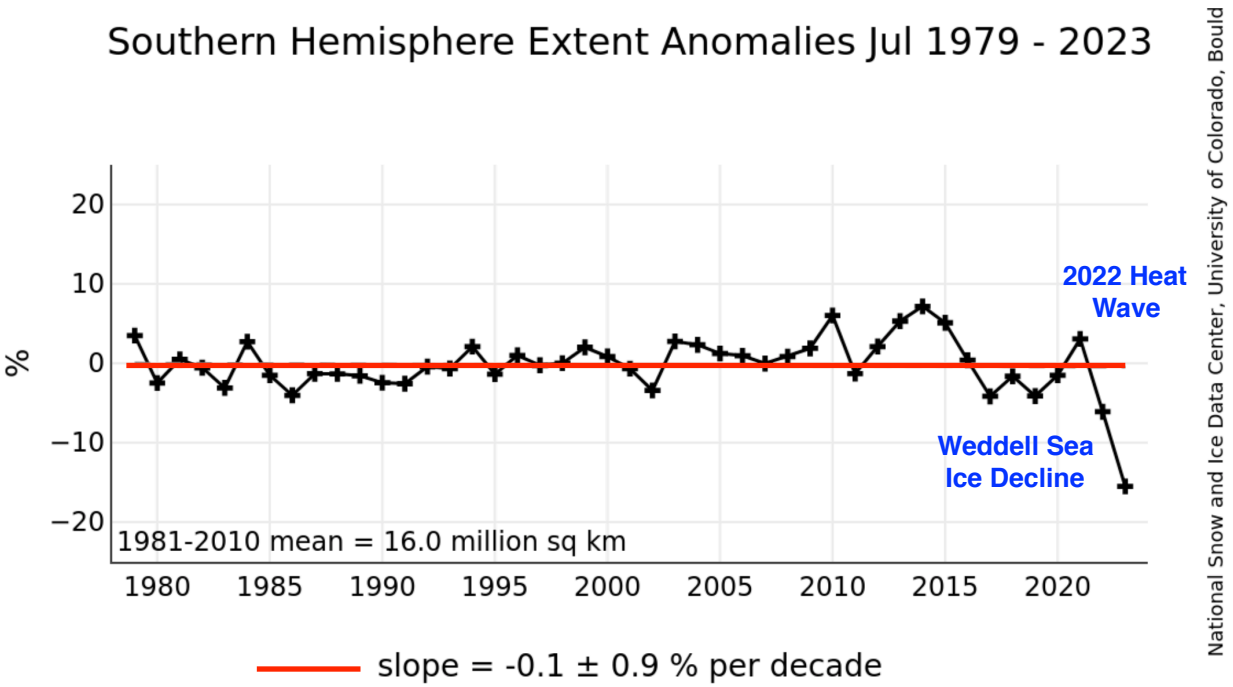

Figure 2: Antarctic ice extent expressed as deviations from the 1980 - 2021 mean.

Figure 2 casts Antarctic sea ice data as departures from the 1979 to 2010 mean value; the mean value is shown as a red trendline that is very nearly flat. The ice decline at 2016-2019 is the decline in ice within the Weddell Sea caused by storms. Also marked is the catastrophic heatwave that began in March 2022 when the average temperatures were 38C higher than normal. This appears to be the cause of the loss of sea ice tallied in **Figures 1 & 2** . As described above, sea ice actually floats on tide-water and so does not affect global sea level although sea ice can entrain small masses of grounded ice that is pulled offshore. This is why sea ice fluctuations in the Arctic Ocean has no direct affect on global sea level. Loss of sea ice in the Arctic and Antarctic does, however, cause heating of ocean waters because it allows warm air and sunlight to warm open water to a much greater extent than has happened in the past. Also the sea ice protects the grounded ice from storms and wave action, this is especially important for the mouths of active glaciers; wholesale melting of sea ice is destructive of grounded glacier ice which will lead to global SLR.

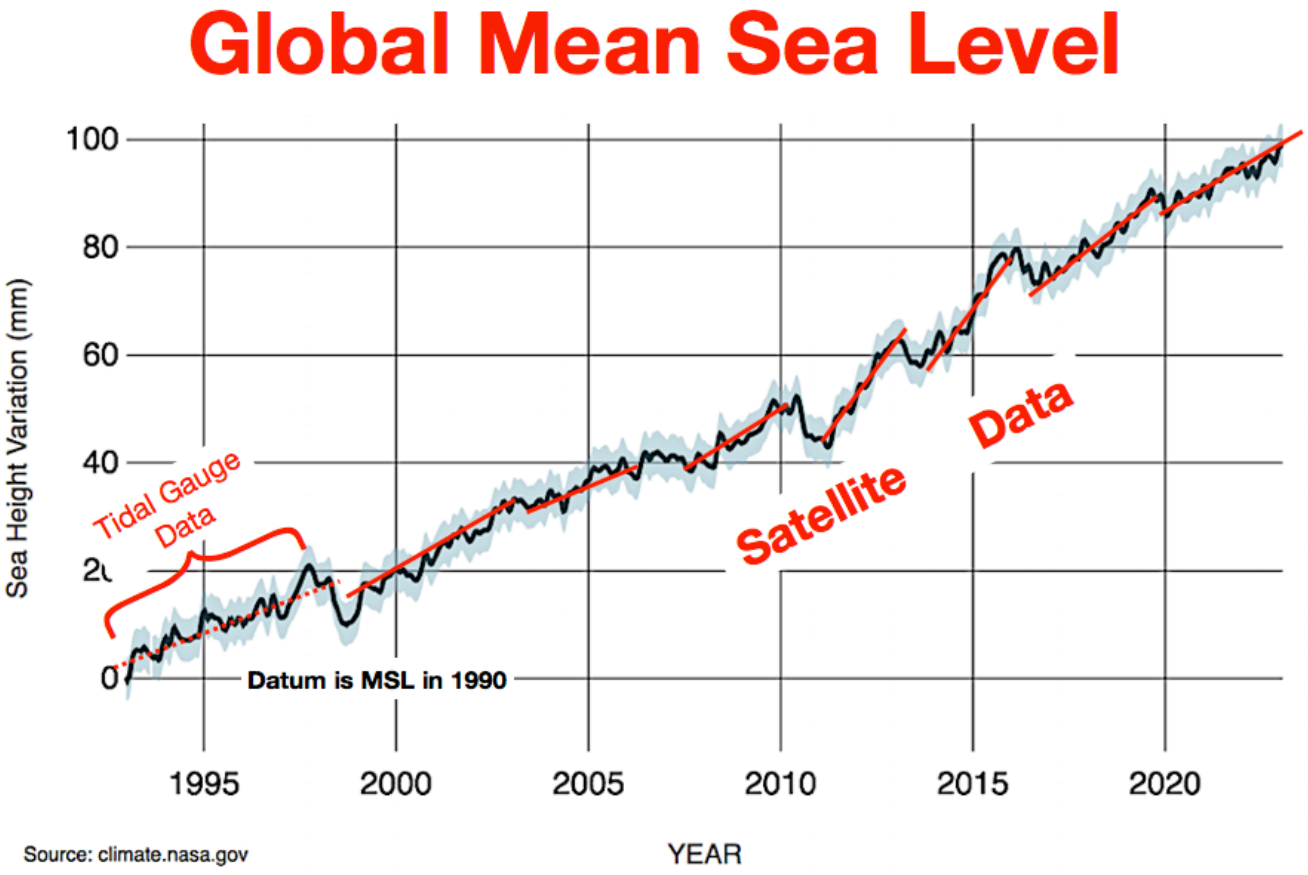

Figure 3: Global Average Sea Level 1991 to 2023 with transition from physical tide-gauge date to satellite data. *(Source:* **https://climate.nasa.gov/vital-signs/sea-level/***)*

On the other hand, Greenland has only a small volume of sea ice but a vast volume of actively melting grounded glacial ice that certainly does drive SLR. **Figure 3** is the latest compilation of SLR data showing changes in shoreline elevation and in overall trendlines. It is clear that not only is sea level rising but the rate at which it is rising is also increasing.

Data from **Figure 3** demonstrates an overall rate of SLR of 90 mm/3.5 inch in the 30 years from 1990 to 2020 (3mm/year). Detailed rate of rise as shown in the Satellite Data which vary up to 10mm/yr or 0.10m per decade. This rate could be extrapolated to a SLR of 0.90m by 2100. This is the source of the estimated SLR published by IPCC in 2019 *(IPCC 2019: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report)*. But the IPCC estimate could not make use of more recent research in Antarctica like the ice loss documented for 2016 to 2019, 2021, 2022, and 2023 in **Figure 2.** Such an extrapolation (0.90m by 2100) has a good deal of uncertainty due to the shortage of long-term SLR data; even the range of high-quality satellite sea level measurements show a wide range of rise rates, making extrapolations

difficult. Average SLR during the next 70 years (until 2100) could be similar to rates averaged between 1990 and 2020 although the most recent information show the rate of rise has been increasing because of increasing rates of global warming.

Scientists at NASA have researched the SLR data for the last Ice Age which began 125,000 years ago and had its peak (Last Glacial Maximum)at about 20,000 BP. **Figure 4** casts the rates of SLR during the past 20,000 years extending from the Last Glacial Maximum **(LGM)** to the present. Melting and subsequent SLR has been rapid although in tune with similar SLR periodically throughout the Pleistocene (2.6 million years to 10,000 years BP).

The most rapid rate of rise since the LGM was between 8200 BP and 7600 BP (Melt Water Pulse 1B) during which the mean sea level rose 35 meters, a rate of 0.58 meters or 1.91 feet per decade. This rate would equal a SLR of 4.0 m above the current level averaged across the globe at 2100. It is reasonable to assume that present day SLR because of anthropogenic global heating would be similar. *(NASA Science Briefs, Sea Level Rise, After the Ice Melted and Today, by V. Gornitz, January 2007).*

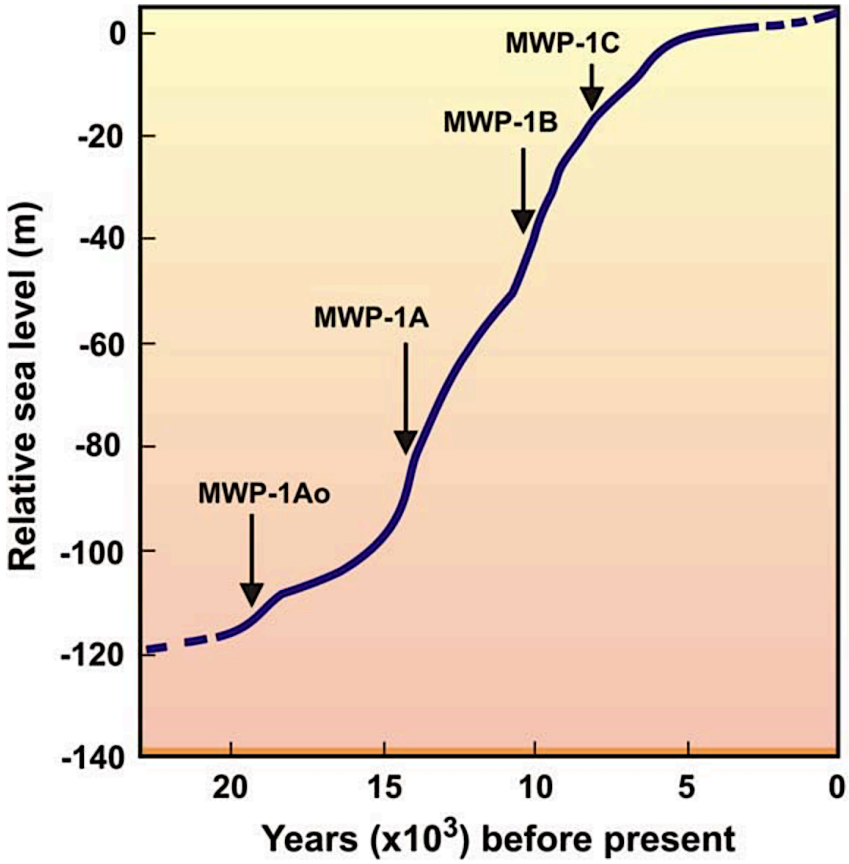

Figure 4: Relative sea level elevations since the end of the Last Glacial Maximum at approximately 25,000 BP.

Several governments are using much higher estimates for sea level in 2100 than the 0.90m estimate coming from IPCC. Several of these are quoted in a recent book **Moving to Higher Ground,** by J. Englander 2021.

- US Department of Defence in 2016 adopted a planning figure of 2.0 meters of SLR by 2100 plus a locally appropriate "safety margin" for all of their facilities.

- The UK Environmental Agency plans for 0.90m SLR by 2100 "but the plan is adaptable to differing rates of sea-level rise up to 2.7 m by 2100." *(***https://metro.co.uk/2021/11/02/what-parts-of-the-uk-will-be-underwater-if-sea-levels-keep-rising-15525633/***)*.

- Coastal China plans on SLR reaching from 3m to 5m by 2100. (**Antiquity , Volume 96 , Issue 386 , April 2022 , pp. 406 - 421 DOI: https://doi.org/10.15184/aqy.2022.1).**
- Tokyo forecasts SLR up to 2.8m by 2100 **(https://earth.org/data_visualization/2021-wrap-up-tokyo-sea-level-rise-map/).**

- Netherlands now (2023) forecasts that the North Sea will rise up to 2.9m by 2100 **(https://www.vn.nl/rising-sea-levels-netherlands/).**

Summary:

It is clear that SLR poses a serious threat to all the coastal nations of the world. Even if climate changing fighting strategies in the next 75 years, SLR rates will continue and will continue to accelerate. Recycling will not abate SLR. Electric transportation will not stop SLR. Carbon taxes will have no affect on global SLR. We see the direction this is going. By 2100 the world's average shoreline will to 2.8 to 4.0 meters above the current point. This is easy to plot on a modern map. What to do with the built environment currently situated between 0.0m and 4.0m? This is a question for government planners and home owners. This forecast elevation for SLR **DOES NOT** include cyclone storm surge or "King Tides" or a margin of safety.

Local planning is a very complex issue for engineers, political leaders, and citizens. Despite the intricacies and unknowns it must be pursued to avoid catastrophe in the second half of the 21st Century. If planners do not consider all the evidence for accelerating CLR, their plans may well prove inadequate. Building highways, bridges, and government buildings must be safe from SLR. If planners ignore polar ice melt, they will have failed at their jobs and been negligent in performing climate threat due diligence. You cannot ignore the past six years of Antarctic ice loss.