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Sea level in its many aspects

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Sea level is defined broadly as the mean level of the sea's surface and is used as the baseline for various measurements, including the height of land features (e.g., mountains) and the depth of the sea floor (e.g., submarine canyons). There are numerous complexities with this system, which has grown up piecemeal over many centuries across the world's coastal areas.

There is no one baseline, but many, for measuring sea level. Mean sea level is generally defined as an average level for the surface of the sea or ocean. Depths on nautical charts are measured from the chart datum. Many national charting agencies, including those of Australia and the United Kingdom, use the lowest astronomical tide (LAT) as the chart datum. This is the lowest tide that can be predicted under average meteorological conditions. The United States uses mean lower low water (MLLW) as the chart datum. MLLW is the average height of the lowest tide recorded at a tide station each day during the recording period. Other nations use their own chart datum.

Sea level calculation also depends on the point at which it is measured. In the UK, the Ordnance Datum is mean sea level measured at Newlyn in Cornwall. In France, sea level is referenced to the Marégraphe in Marseilles. The Netherlands utilizes the Amsterdam Peil elevation. In the United States, with its thousands of miles of coastline encompassing three oceans, there is the National Water Level Observation Network, comprised of 54 sites.

The lay person imagines that, since the entire world's oceans are interconnected, they must all be at the same height – sea level. While that assumption is true on the small scale, it is fallacious on the world-scale. Ignoring waves and tides, the oceans have different levels, and the levels vary within an ocean. The causes of these different levels are numerous. First, the earth is not a perfect sphere, or even a perfect ellipsoid. Rather, it is a lumpy rock. Dense material is not evenly distributed, resulting in variations in the effects of gravity. Ocean currents, such as the Gulf Stream, cause regional accumulations or diminishments of water. Thus, sea level in Bermuda (in the middle of the Gulf Stream) is almost three feet higher than sea level in Charleston, South Carolina (which is outside of the Gulf Stream's flow). Salinity is a significant factor. The higher salinity (and density) of the Atlantic Ocean is a major reason that its average level, on average, is eight inches lower than that of the Pacific Ocean. The height difference at the Isthmus of Panama is four inches, making a true "sea level" canal a physical impossibility.

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Temperature causes water to expand and become lighter. Sea water in warmer climes has a higher level (all other things being equal) than does water in cooler regions. As with many other subjects, on close examination sea level is much more complex than it first appears.

Another complicating factor is that the land against which sea level is measured is not static. It can rise or fall due to a number of factors. The 1964 Alaska earthquake tilted the island of Kodiak such that one end of the island was raised by 30 feet while the opposite end dropped about ten feet. It was years before the new depths in surrounding waters were recharted. Land can also subside. Some of the Louisiana levees failed during Hurricane Katrina because they were lower at the time the hurricane struck than they were when originally constructed, having lost altitude due to widespread land subsidence.

The major long-term issue with sea level is that it is rising worldwide. This is caused by two primary factors. Sea water, like the atmosphere, is getting warmer. Warm water occupies more space than cold water. This thermal expansion causes the sea level to rise, as the water has nowhere else to go than up. Secondly, the warmer atmosphere is causing naturally-occurring ice, such as found in glaciers and in the Antarctic and Greenland ice caps to melt faster than it is being replaced. Water from melting glaciers (whether in Alaska, Siberia, the Alps, or Mount Kilimanjaro) flows into the sea, as does water from the melting ice caps.

While estimates vary, experts calculate that thermal expansion will cause 45% of the projected sea level rise in the near future, while glacial melt will add 31%, melting of the Greenland ice cap will add 13%, and melting of the West Antarctic ice sheet will add 11%. The East Antarctic ice sheet appears to be currently relatively stable. These percentages can be expected to change over time, particularly as glaciers dwindle in size and if the melting rate of the Greenland ice cap increases as projected.

Experts estimate that sea level rose between 0.10 inch and 0.11 inch per year between 1993 and 2004 and that the rate of increase has accelerated since 2004. Projections vary, but the average estimate for sea level rise between now and the end of this century is 15 inches (estimates vary between 7 and 23 inches). A fifteen inch sea level rise will make numerous islands and coastal areas uninhabitable. Island nations like Tuvalu and the Maldives could disappear, and with them their legally-sanctioned territorial seas, exclusive economic zones, and continental shelves. Low-lying coastal lands, such as major portions of Bangladesh and Nigeria, will be at risk.

Finally, coastal/tidal cities, including Venice, New York, and London will be forced to relocate or adopt major remedial measures. The city of Miami Beach has already commenced planning a multimillion dollar project of sophisticated flood water pumps and conduits, as well as raising many of its streets and structures, in anticipation of higher sea levels. Superstorm Sandy awoke those living and working on Manhattan Island to the fact that much of the island, particularly Lower Manhattan, is only a foot or so above the current sea level. The Hampton Roads area of Virginia, home to one of the largest naval bases in the world and to a major commercial seaport, already experiences frequent flooding. An extensive system of levees and

sea walls has been proposed for much of the Louisiana Gulf coast, but plans and funding are currently not in sight.

Saint Mark's Square in Venice floods on a regular basis. Plans are being considered to construct a levee around all or most of the city. The Netherlands, with much of the nation below sea level and with the world's most sophisticated system of levees, dikes, and sea walls, is considering enhancement of that system. The Thames Barrier was built after the catastrophic North Sea Flood of 1953 to protect the London area from similar occurrences. When finished in 1984, it was estimated that closure would be required only two or three times each year. It is now closing at a rate of six to seven times annually. A more robust replacement has now been proposed. This listing merely scratches the surface of coastal locations at risk.

As a practical matter, it is impossible to protect all of these resources. Thus, it is incumbent upon society to select which at-risk resources are of the highest priority and then develop plans and funding to minimize the adverse impacts of sea level rise at those locations. For the locations that do not make the list, plans must be developed and implemented to minimize the adverse impacts upon the current inhabitants. Those individuals must be relocated and economically compensated at a fair and equitable level. Society cannot wait until the subways, streets, piers, and islands are flooded – it must act now to counter this known threat.

For those of us with ties to the sea, who know that the sea is ever-changing, it is disconcerting and somewhat sad to see changes coming so rapidly.