Sea Level Rise and Global Warming

An Infographic from the Union of Concerned Scientists

Methodology and Assumptions

Updated April 2014

The Sea Level Rise and Global Warming infographic is based on careful evaluations of data provided by the National Oceanic and Atmospheric Administration (NOAA), publications of scientific research, and publicly available data. What follows is an account of the data sources and assumptions for each of the four facts presented in the infographic.

Fact 1: *Sea levels in the U.S. are rising fastest along the East Coast and Gulf of Mexico.*

2014 Revision

Fact 1 of the infographic was revised in 2014 to show the most recent 50 years available of local sea level rise instead of the period since 1880, which was used in the original 2013 infographic. The original Fact 1 panel showed local sea level rise over the same time period as the global sea level rise – dating back to 1880, which is also presented in Facts 2 through 4. This was updated after learning that several of the original tide stations had too short a tide record to have confidence in the extrapolation back to 1880. A longer tide record is desirable because the longer the data set the more confidence one can have in its accuracy (see the confidence interval figure below). Since more tide stations around the U.S. have at least 50 years of record compared to the few tide stations with around 100 years of record, we chose to update Fact 1 panel with a 50-year fit provided by NOAA for the latest complete year of tide data available (2012) at the time of posting the revised April 2014 infographic.

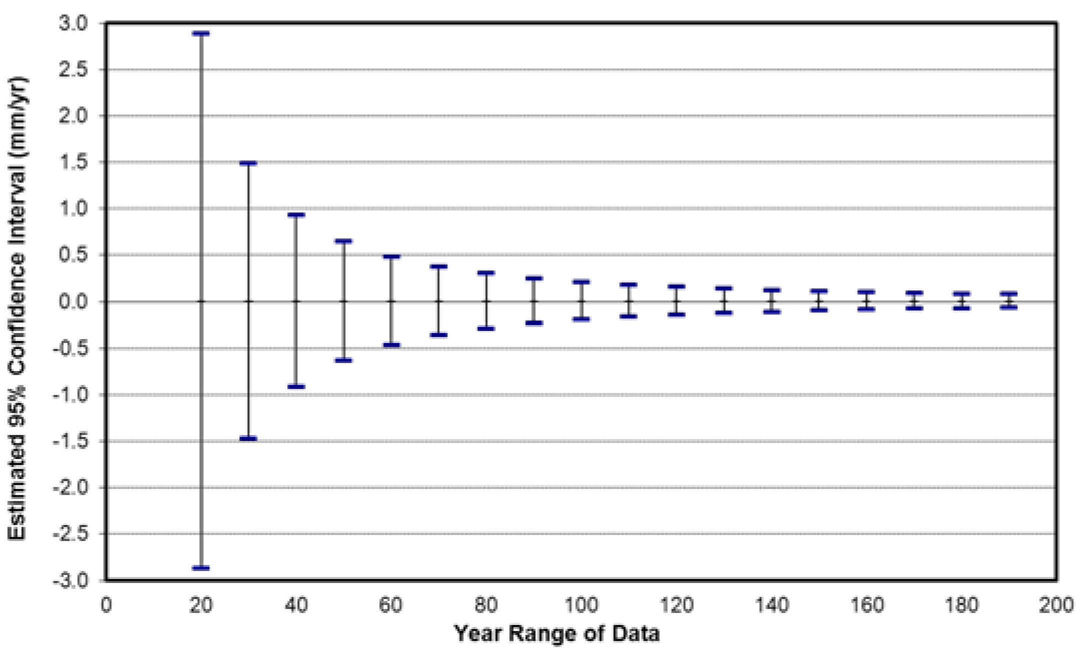

Figure 1: Confidence interval with period of record. Confidence interval improves for sea level rise rates for longer tide station records. Tide stations with more than 50 years of data are preferable for sea level rise trends. Image source: NOAA **(**available at **http://tidesandcurrents.noaa.gov/sltrends/sltrends_update.shtml?stnid=1612340)**

Local Sea Level Rise: Over the Last Fifty Years (1963-2012)						
Station Name	**Infographic Name**	**NOAA Trend 1963-2012 (mm/yr)**	**NOAA Trend 1963-2012 Standard Error (mm/yr)**	**NOAA total 1963-2012 (mm)**	**NOAA total 1963-2012 (in)**	**NOAA total 1963-2012 Rounding to nearest 0.5 (in)**
GALVESTON	Galveston, TX	6.413	0.376	320.66	12.62	12.5
SEWELLS POINT	Norfolk, VA	5.318	0.319	265.89	10.47	10.5
ATLANTIC CITY	Atlantic City, NJ	4.848	0.283	242.38	9.54	9.5
WASHINGTON	Washington, DC	3.596	0.382	179.78	7.08	7
THE BATTERY	New York, NY	3.452	0.266	172.58	6.79	7
CHARLESTON	Charleston, SC	3.099	0.283	154.93	6.10	6
BOSTON	Boston, MA	3.004	0.238	150.18	5.91	6
KEY WEST	Key West, FL	2.766	0.218	138.30	5.44	5.5
PENSACOLA	Pensacola, FL	2.444	0.282	122.21	4.81	5
SAN DIEGO	San Diego, CA	2.009	0.351	100.43	3.95	4
SEATTLE	Seattle, WA	1.780	0.310	89.00	3.50	3.5
SAN FRANCISCO	San Francisco, CA	1.484	0.405	74.18	2.92	3
LOS ANGELES	Los Angeles, CA	1.162	0.309	58.11	2.29	2.5

Table 1: NOAA 50-year fit of tide station data. The latest 50-year trend (1963-2012) available at time of revised infographic (April 2014)
NOAA Data: co-ops.userservices@noaa.gov and updated annually at
http://tidesandcurrents.noaa.gov/sltrends/50yr.shtml?stnid=1612340

Local sea level trends are a combination of both the global trend and local factors such as vertical land movement and changes in the path or strength of coastal ocean currents (see Table 2). Sea levels have risen more in Atlantic City, N.J.; Sewells Point, near Norfolk, Va; and Galveston, Texas in the most recently recorded 50-year period (between 1963 and 2012) than they have risen globally since 1880.

We extend appreciation to Forbes Tompkins, World Resources Institute, and Leonard Barry, Director of the Florida Center for Environmental Studies, for advice on tide stations. We thank Chris Zervas, NOAA, for his helpful review of the use of NOAA fifty year fit for tide station data. For more information and to obtain data, please contact NOAA via the email co-ops.userservices@noaa.gov.

Fact 2: *Global Warming is the primary cause of current sea level rise.*

Between 1880 and 2010, average global surface temperatures rose by 0.8 °C (1.4 °F) (Hansen et al. 2010). This warming has caused an expansion of seawater and a shrinking of land-based ice—glaciers, ice caps, and ice sheets. These two processes have been largely responsible for the observed rise in global sea level since 1880 (Church et al. 2011).

Global sea level rose by 8 inches (210 mm) between 1880 and 2009 (Church and White 2011). This estimate is based on tide gauge measurements—available between 1880 and 2009—and satellite altimeter data—available from 1993 to 2009.

To calculate the relative contributions of ice loss, thermal expansion, and other factors to the total observed global sea level rise from 1972 to 2008, we relied on the accounting of sea level rise components presented by Church et al. 2011 (See Table 2).

Component	**Linear trend and uncertainty* (mm/year)**	**Notes**
Total observed global sea level rise	2.10 ± 0.16	Includes both tide gauge data (available for entire time period) and satellite data (available after 1993).
Thermal expansion	0.80 ± 0.15	Includes entire water column
Land ice loss	1.09 ± 0.26	
Groundwater depletion	0.26 ± 0.07	
Other terrestrial water storage factors	-0.37 ± 0.25	Includes dam retention and natural terrestrial storage
Total of known contributions	1.78 ± 0.36	
Residual	0.32 ± 0.39	

**Error estimates are one standard deviation*

Table 2: Contributions to sea level rise; Adapted from Church et al. 2011

We calculated the contributions of land ice loss and thermal expansion as percentages of the total observed global rise in sea level. Together, these two components account for 90% (or 1.89 mm/yr) of the total observed rise. All of the known contributions, however, add up to less than the total observed rise, meaning that the sea level rise budget is not closed. Therefore the remaining 10% is attributed to a combination of known and unknown factors.

Fact 3: *Sea level rise is accelerating.*

Sea level rise projections for 2050 are drawn from NOAA's Global Sea Level Rise Scenarios report (NOAA 2012a). The report does not specifically report data for the year 2050, so we have estimated data for 2050 based upon their Figure 10, which shows projections out to 2100. Our estimates for the year 2050, rounded to the nearest whole number for the infographic, are as follows:

Lowest scenario: 10 cm (3.94 in)
Intermediate-low scenario: 15 cm (5.90 in)
Intermediate-high scenario: 40 cm (15.75 in)
Highest scenario: 60 cm (23.62 in)

For the "most likely range," we show the range between the intermediate-low and intermediate-high scenarios. The lowest-end scenario is considered less likely because it is a simple extension of the historical sea level rise rate without accounting for the observed acceleration since the 1990s (Church and White 2011). The highest scenario, while possible, assumes much more rapid loss of land ice (See Table 3 below).

Our past emissions of greenhouse gases have committed us to continued warming even in the face of reduced or stabilized emissions in the future. The magnitude of this so-called "committed warming" is on the order of 0.5°C by the end of the century if atmospheric concentrations of greenhouse gases are maintained at current levels and less if emissions are rapidly reduced to zero (Meehl et al. 2005; Wigley 2005; Matthews and Zickfield 2012).

As the oceans and land ice respond to continued warming, sea level will continue to rise. The greatest uncertainty in estimating future sea level rise is the rate of ice loss, primarily from Greenland and Antarctica (NOAA 2012a).

Fact 4: *The choices we make today will determine how high sea level rises this century, how fast it occurs, and how much time we have to protect our communities.*

Scientists have developed a range of scenarios for future sea level rise based on estimates of growth in heat-trapping emissions and the potential responses of oceans and land ice. The latest scenarios suggest a 90 percent certainty that the increase in global sea level will range from 8 inches to 6.6 feet above 1992 levels by 2100 (NOAA 2012a).

The lowest end of this range is a simple extension of historic sea-level rise—and recent data indicate that this rate has nearly doubled in recent years.[1] Three other scenarios show a more likely range of 1.6 to 6.6 feet of sea level rise by 2100 (See Table 3 below). The rate and magnitude of the loss of ice sheets—primarily in Greenland and West Antarctica—account for much of the difference in the projections of sea-level rise by the end of the century (NOAA 2012a).

The lowest-end scenario is considered less likely because it is a simple extension of the historical sea level rise rate without accounting for the observed acceleration since the 1990s (Church and White 2011). The highest scenario, while possible, assumes much more rapid loss of land ice.

The "most likely range" is what was considered most likely by the draft report of the National Climate Assessment (NCA 2013). Given the lowest emissions scenarios, thermal expansion of ocean waters, and melting of small mountain glaciers without any additional ice loss from Greenland or Antarctica, sea level is projected to rise by 11 inches by 2100 (NCA 2013; Marzeion et al. 2012; Yin 2012). Recent work also suggests that 4 feet of sea level rise by 2100 is plausible (NCA 2013 and references therein).

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[1] Satellite altimetry recorded a global sea-level rise of 0.13 inches per year from 1993 to 2009—nearly twice the 20th century average rate measured by tide gauges (Church and White 2011). The National Oceanic and Atmospheric Administration (NOAA) recommends using the lowest scenario only where there is a "great tolerance for risk" (NOAA 2012a).

Scenario	Global average SLR by 2100 (meters)	Global average SLR by 2100 (feet)	Scenario assumptions			
			Emissions Scenario	**Ice**	**Oceans**	**Notes**
Highest	2.0	6.6	A1B	Maximum loss of land ice as modeled by Pfeffer et al. 2008	Warm as projected by IPCC AR4	This scenario combines maximum ice loss and a level of ocean warming associated with a middle-of-the-road emissions scenario (A1B) to calculate future SLR.
Intermediate-High	1.2	3.9	Models employ a range of IPCC AR4 SRES scenarios (Vermeer and Rahmstorf 2009 and Jevrejeva et al. 2010).	Ice loss increases throughout the 21st century comes to dominate total sea level rise. Ice loss is simulated as a response within climate models.	Thermal expansion is simulated as a response within climate models. Its contribution to total sea level rise over the 21st century gradually declines.	This scenario represents the average of the high end of semi-empirical models that use observed data to extrapolate into the future (i.e. Vermeer and Rahmstorf 2009; Horton et al. 2008; Jevrejeva et al. 2010). Models rely on the existing observed relationships between global temperature and the rate of sea level rise, ice loss, and thermal expansion.
Intermediate-Low	0.5	1.6	B1	Minimal ice sheet loss	Warming as per IPCC AR4 B1	This scenario assumes aggressive decreases in GHG emissions. SLR is primarily driven by thermal expansion
Lowest	0.2	0.7	n/a	n/a	n/a	Linear continuation of historical SLR rate since 1900. NOAA gives no emissions information.

Table 3: Sea level rise scenarios. Adapted from NOAA 2012a.

While past emissions will largely dictate sea level rise through 2050, our present and future emissions will have a great bearing on sea level rise from 2050 to 2100 and beyond (Schaeffer et al. 2012; Zecca and Chiari 2012; Jevrejeva et al. 2010).

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