Unsettled

What Climate Science Tells Us, What It Doesn’t, and Why It Matters

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In this language, a statement that is *virtually certain* has at most a 1 percent likelihood of being incorrect, while a statement that’s *likely* has about a two-thirds chance of being true, and a *very unlikely* statement has at most a 10 percent chance of being true.

Because climate science is complex, uncertainties aren’t always easy to quantify in terms of probabilities. The United Nations’ Intergovernmental Panel on Climate Change (IPCC) has therefore established a second set of calibrated terms to indicate confidence in a given finding. Confidence is a qualitative judgment that depends upon the number, quality, and agreement of different lines of evidence. The five levels of confidence are *Very high*, *High*, *Medium*, *Low*, and *Very low*, as illustrated in the IPCC chart below.

The IPCC reports make many explicit confidence assessments.
Figure 1.1 Annual global surface temperature anomalies as determined by four independent analyses. Anomalies are the deviation of temperatures from a baseline (average) value. Though there are minor differences among them, all four analyses show similar trends and fluctuate in sync. Typical uncertainties in the data points are ± 0.1°C.\(^1\) The inset shows global average temperatures, rather than anomalies. Differences among the four data sets are too small to display there.
Figure 1.2 A climate record with fluctuations and trends. The annual minimum depth of the Nile River near Cairo over more than 650 years from 622 to 1284 AD. The data, measured in meters, shows a characteristic pattern of year-to-year fluctuations around longer-term trends.
Figure 1.3 County-by-county changes in US surface temperatures between 1895 and 2018. Created from NOAA data and published in the Washington Post on August 13, 2019, under the headline “Extreme climate change has arrived in America.”
Figure 1.4 Annual average temperatures from 1910 to 2013 for New York City (top) and West Point, NY (bottom), 42 miles to the north. The gray lines are the annual values while the black lines are the ten-year trailing averages. The West Point data has been shifted downward by 1.5°C for clarity.
**Surface Temperature Change (1901–2015)**

**Figure 1.5** Surface temperature change (in °F) for the period 1986–2015 relative to 1901–1960. Changes are generally significant over most land and ocean areas. Changes are not significant in parts of the North Atlantic Ocean, the South Pacific Ocean, and the southeastern United States. There is insufficient data in the Arctic Ocean and Antarctica to compute long-term changes there. (Adapted from CSSR Figure 1.3.)

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**Change in Temperature (°F)**

-1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0
**Figure 1.6** *Ocean heat content from 1960 to 2019.* The anomalies are related to a 1958–1962 baseline, and the time series are smoothed over twenty-four months. The gray dashed lines are the 95 percent confidence interval of the total ocean heat budget."
Figure 1.7 Global average surface temperature anomalies during the last fifteen hundred years as reconstructed by different proxy methods, together with the modern instrumental record (black line). Anomalies are relative to an 1881–1980 baseline and have been smoothed to reduce variations on timescales shorter than about fifty years.
Figure 1.8 Global average surface temperature anomaly as determined by various geological proxies for five periods extending to five hundred million years ago.
Figure 2.1 Earthshine and sunshine visible on a crescent moon.

The upper-right portion of the image shows the thin lunar crescent illuminated by sunshine, easily visible to the naked eye. A strong filter placed over that region (causing the line through the lower part of the image), makes the earthshine visible on the rest of the lunar disk.
Figure 2.2 Flows of sunlight and heat through the earth’s climate system. About 30 percent of the incoming solar radiation is reflected, while the atmosphere intercepts more than 80 percent of the infrared radiation emitted from the surface.
Figure 2.3 The spectrum of heat leaving the top of the atmosphere.

The smooth gray curve corresponds to having no atmosphere, while the spiky gray curve (0 ppm) corresponds to having all of the major greenhouse gases except CO₂ (water vapor, methane, ozone, and nitrous oxide). The solid black and dotted black lines show how the spectrum changes when CO₂ is included at concentrations of 400 and 800 ppm, respectively. Where only one curve is visible, all curves coincide.
Figure 2.4 Human and natural influences on the climate, 1850–2018. Human-caused CO$_2$ and other greenhouse gases (including methane, halocarbons, ozone, and oxides of nitrogen) exert a warming influence, while human-caused aerosols and changes in land albedo exert a cooling one. Episodic natural cooling by large volcanic eruptions and small variations in the sun’s intensity complete the picture. The bars at right show 2σ uncertainties in each forcing today, and also for the total of all forcings.$^{15}$
Figure 3.1 Monthly average concentration of carbon dioxide as measured in Mauna Loa, Hawaii, from 1958 through 2020. The inset shows the average seasonal variation.
Figure 3.2 Annual global greenhouse gas emissions from 1970 to 2018. Emissions of non-CO₂ gases are expressed as CO₂-equivalent amounts.
Figure 3.3 Atmospheric concentration of carbon dioxide beginning at 550 million years ago. Values determined from the isotopic ratio in carbonate sediments and fossilized soils are relative to the average over the past few million years; today’s concentration would be about 1.3 on this scale, down in the lower right-hand corner.5
Figure 3.4 Atmospheric methane concentrations from 1983 to 2020. Monthly average values are shown in parts per billion (ppb). The solid line is the 12-month trailing average.
Figure 3.5 Sources of global methane emissions due to human activities in 2010.
Figure 3.6 The global population and real global GDP assumed in four different Representative Concentration Pathways (RCPs) used to describe future emissions.
Figure 3.7 Projected global human emissions of CO₂ (upper panel), concentration of CO₂ in the atmosphere (middle panel), and total human-caused forcings (lower panel). The latter include all greenhouse gases and aerosols.¹³
Figure 4.1  Schematic of the grid used in computer models of the atmosphere.
Figure 4.2 Clouds are much smaller than model grid boxes and so require that modelers make subgrid assumptions. Note that this figure is misleading in that the actual grid boxes are much thinner than what's shown.
Figure 4.3 The global average surface temperature anomaly as simulated in the CMIP3 and CMIP5 model ensembles. The solid gray lines show the ensemble averages, while the corresponding dotted lines show the ensemble spreads. The black line shows the observed anomalies.
Figure 4.4 The Atlantic Multidecadal Oscillation (AMO) index, constructed from sea surface temperatures in the North Atlantic. The black line is the ten-year trailing average of the annual values.¹⁵
Figure 4.5  Global mean surface temperature anomalies from twenty-six CMIP6 models. Individual model runs are shown as light gray traces, while the dark lines are three different observational data sets. Anomalies are relative to an 1880–1910 baseline, and the curves are smoothed over eleven-year intervals.
Figure 4.6 Equilibrium climate sensitivities of forty models from the CMIP6 ensemble. Models are arranged in order of decreasing sensitivity. Those shown in black are more sensitive than the likely upper limit given in AR5.23
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Headlines about record highs (often accompanied by visuals of red thermometers and barren desert vistas) don’t come out of nowhere, however. The US government’s most recent assessment report, the 2017 Climate Science Special Report (CSSR), is not just misleading on this point—it’s wrong. I say that, to use the assessment reports’ lingo, with Very High Confidence because of some sleuthing I did in the spring of 2019. What emerged is a disturbing illustration of how non-experts are misled and science is spun to persuade, not inform. In fact, page 19 of the CSSR’s Executive Summary says (prominently and with Very High Confidence):

There have been marked changes in temperature extremes across the contiguous United States. The number of high temperature records set in the past two decades far exceeds the number of low temperature records.

It offers Figure 5.1 (their Figure ES.5) in support:

**Figure 5.1** The ratio of the number of daily record high temperatures to daily record low temperatures for stations across the forty-eight contiguous states from 1930 to 2017.11 (CSSR Figure ES.5.)
Figure 5.2 The coldest (left) and warmest (right) temperatures of the year since 1900, averaged across the forty-eight contiguous US states. The spiky light lines show the year-by-year values, while the darker lines show the smoothed behavior. (CSSR Figure 6.3.)
Figure 5.3  The difference between running records and the absolute record, illustrated for daily high temperatures at a single station. Each of the running records is higher than all years before it, while the sole absolute record is the highest of all years.
Figure 5.4 Numbers of record US daily temperature extremes calculated by the “running” method used in the CSSR. The dots show the incidence of record temperatures (highs in the left panel, lows in the right panel), while the gray line is the eleven-year running average. The black line shows the expected decline if there were no trend in temperatures.
Figure 5.5  Numbers of record US daily temperature extremes for 725 US stations from 1895 until 2018, calculated by the “absolute” method. The upper panel shows the numbers of record high temperatures (per 100,000 observations) for each year, while the lower panel shows the numbers of record lows.
Figure 6.1  Annual number of hurricanes (upper) and Accumulated Cyclone Energy (middle) in the North Atlantic for each year from 1851 to 2020. The lower panel shows the AMO index from Figure 4.4. In each panel, light lines show the year-to-year variation, while the black line is the ten-year trailing average.
NORTH ATLANTIC HURRICANE ACTIVITY AND SEA SURFACE TEMPERATURE (1949–2015)

Figure 6.2 Variation of the annual sea surface temperature and Power Dissipation Index in the North Atlantic from 1949 to 2015. The data is smoothed over 5-year intervals.
Figure 6.3  Power Dissipation Index in the North Atlantic Ocean. Two different analyses of the data are shown, along with straight lines indicating the trend in each. (NCA2014, Figure 2.23.)
Figure 6.4 Power Dissipation Index in the North Atlantic from 1949 to 2019. The black data and trend line were highlighted in NCA2014 (our Figure 6.3), while the gray data shows years prior to 1971 and after 2009.
US ANNUAL TORNADO COUNT (1950-2019)

Figure 6.5 Number of tornadoes recorded by NOAA each year from 1950 to 2019 in the contiguous forty-eight states.25
Figure 6.6  Number of tornadoes recorded by NOAA each year from 1954 through 2014 in the forty-eight contiguous states. The upper panel shows tornadoes in category EF1 or stronger, while the lower panel shows only the strongest tornadoes, which have strengths EF3 or greater.\textsuperscript{59}
Figure 6.7  Annual tornado activity in the contiguous United States. The black dots indicate the number of days per year with at least one tornado rated EF1 or greater, and the larger black circles and line show the decadal averages of such tornado days. The gray dots indicate the number of days per year with more than thirty tornadoes rated EF1 or greater, and the corresponding larger circles and line show the decadal averages of these tornado outbreaks. (Adapted from CSSR Figure 9.3.)
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Figure 7.7 Changes in the size of flooding events in rivers and streams in the United States between 1965 and 2015. Upward-pointing symbols show locations where floods have become larger; downward-pointing symbols show locations where floods have become smaller. The larger, solid symbols represent stations where the change was statistically significant.¹⁶
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Figure 8.3 Changes in Global Mean Sea Level relative to 1880 as estimated from tide gauge data. The solid curve indicates the average value and the dashed lines the uncertainty.
Figure 8.4 Changes in Global Mean Sea Level as measured by satellite altimetry. A seasonal cycle of about 7 mm (0.2 inches) is superimposed on a trend of $3.0 \pm 0.4$ mm/yr ($0.12 \pm 0.02$ in/yr).
Figure 8.5  Eighteen-year leading trends in Global Mean Sea Level since 1900. Estimates from three different tide gauge analyses are shown, together with a single value from satellite altimetry. Uncertainties are 90 percent confidence levels; that is, there is only a 10 percent chance that the true values lie outside the shaded area. (AR5 WGI Figure 3.14.)
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ESTIMATES OF TOTAL IMPACT OF CLIMATE CHANGE

Figure 9.4 Estimates of the net global economic impact in 2100 from rising global temperatures.
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PER CAPITA ENERGY VS. GDP (1980–2017)

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PARIS AGREEMENT AND GLOBAL EMISSIONS

Figure 12.4 Global annual greenhouse gas emissions from 2000 to 2030. The historical record and IPCC AR5 projections from 2015 are shown, as are projections under both current policies and assuming all Paris targets and pledges are met. Future emissions paths thought to be compatible with global temperature increases of 1.5°C and 2°C are also shown. The vertical bars show the uncertainties in projections at 2030. Disruptions due to COVID-19 are evident in 2020.13,14
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