Our Changing Climate: An Update on the Science

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Thank you for the opportunity to present the latest evidence for our changing climate in the U.S. Changing trends in severe weather are of special concern.

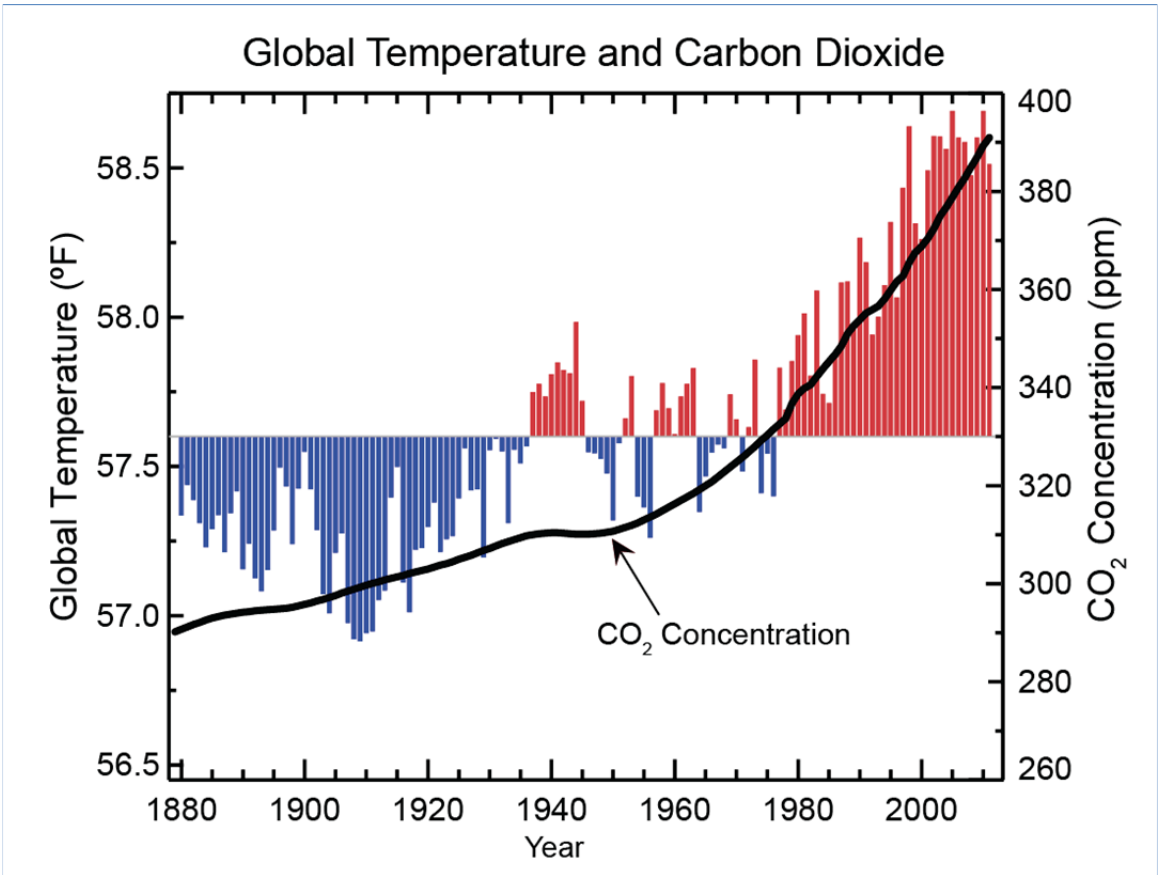
I am a professor and atmospheric scientist in the Department of Atmospheric Sciences at the University of Illinois. I am an expert in atmospheric physics and chemistry, and have authored over 400 scientific articles in peer reviewed journals, books, chapters of books, and in a number of national and international assessments related to concerns about ongoing changes in the Earth's climate and atmospheric chemistry. I co-lead the chapter on climate science for the U.S. National Climate Assessment. The assessment is currently under review by the National Academy of Sciences and the public at ncadac.globalchange.gov. I am also a member of the Executive Secretariat that oversees the assessment process and the Federal Advisory Committee for the assessment. In addition, I am a Coordinating Lead Author on the next major international IPCC assessment of climate change

As the son of an Illinois farmer, I am well aware of the importance of the climate to farmers and other Americans because of the effects of a changing climate on our economy and on our personal well-being. Our draft of the National Climate Assessment concludes that the evidence for a changing climate has strengthened considerably since the last assessment report written in 2009. Many more impacts of human-caused climate change have now also been observed. Corn producers in Iowa, oyster growers in Washington State, wine producers in California, and maple syrup producers in Vermont have all seen changes in their local climate that are outside of their experience. So too have coastal planners from Florida to Maine, water managers in the arid Southwest and parts of the southeast, and Native Americans on tribal lands across the nation. As we will discuss, there is also strong evidence of an increasing trend over recent decades in some types of severe weather. Scientific analyses suggest an increase in the likelihood of these events as our climate continues to change over this century. In today's testimony, I will focus on five main points about the changing climate in the U.S.

1. The U.S. and the global climate is changing now and this change is apparent across a wide range of observations. The evidence indicates that most of the climate change of the past 50 years is primarily due to human activities.

There is no debate within the science community, based on the peer-reviewed literature, about the large changes occurring in the Earth's climate and the fact that these changes are occurring as a response to human activities, mainly burning fossil fuels (e.g., see the current draft National Climate Assessment for a discussion of the evidence; the figure below shows the trend in global temperatures). Natural factors have always affected our climate in the past and continue to do so today; but now, the dominant influence is human activities. The science is clear and convincing that climate change is happening, happening rapidly, and happening primarily because of human activities.

A wide variety of independent observations give a consistent picture of a warming world. In the U.S., average temperatures have increased by 1.5°F since 1900 with more than 80% of the increase occurring since 1980. As a result of this warming, the growing season is lengthening, sea levels are rising, and glaciers and arctic sea ice are melting. Such multiple lines of evidence and the consistency of findings among many independent analyses form the basis for the conclusion that the "warming of the climate system is unequivocal."

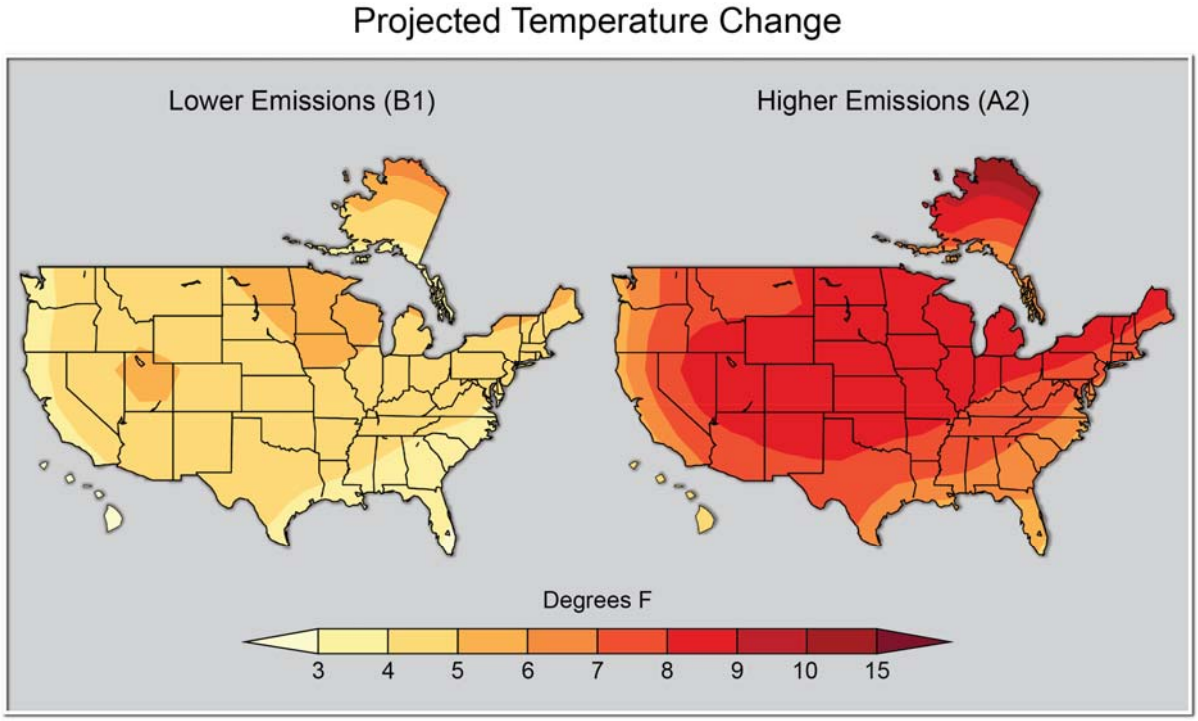


Caption. Global annual average temperature (as measured over both land and oceans; scale on left) has increased by more than 1.4°F since 1880. Red bars show temperatures above the long-term average, and blue bars indicate temperatures below the long-term average. The black line shows atmospheric carbon dioxide (CO_2) concentration in parts per million (ppm); scale on right. While there is a clear long-term global warming trend, some years do not show a temperature increase relative to the previous year, and some years show greater changes than others. These year-to-year fluctuations in temperature are due to natural processes, such as the effects of El Niños, La Niñas, and the eruption of large volcanoes. (Source: Temperature data from NOAA NCDC 2012, CO_2 data from NOAA ESRL 2012)

Natural drivers of climate cannot explain the observed warming over the last five decades; the majority of the warming can only be explained by the effects of human influences.

Our confidence in projections of future climate change has increased. Choices made now and in the next few decades will determine the amount of additional future warming (see figure below).

Lower levels of heat-trapping gas emissions will lead to noticeably less warming beyond the middle of this century. Higher emissions levels will result in more warming, and thus more severe impacts on many aspects of human society and the natural world. Emissions produced today will continue to affect our climate for decades and even centuries to come.



Caption: Maps show projected change in average surface air temperature in the later part of this century (2070-2100) relative to the early part of the last century (1901-1960) under a scenario that assumes substantial reductions in heat trapping gases (B1, left) and a higher emissions scenario that assumes continued increases in global emissions (A2, right). Projected changes are averages from 15 global climate models. In the low emissions scenario B1, CO_2 emissions increase by a small amount to 2050 and then decrease by 50% relative to 2010 emissions. In the high emissions scenario A2, which largely assumes continued heavy energy and transportation reliance on fossil fuels, CO_2 emissions increase throughout the century, by almost a factor of 3 in 2100 relative to 2010.

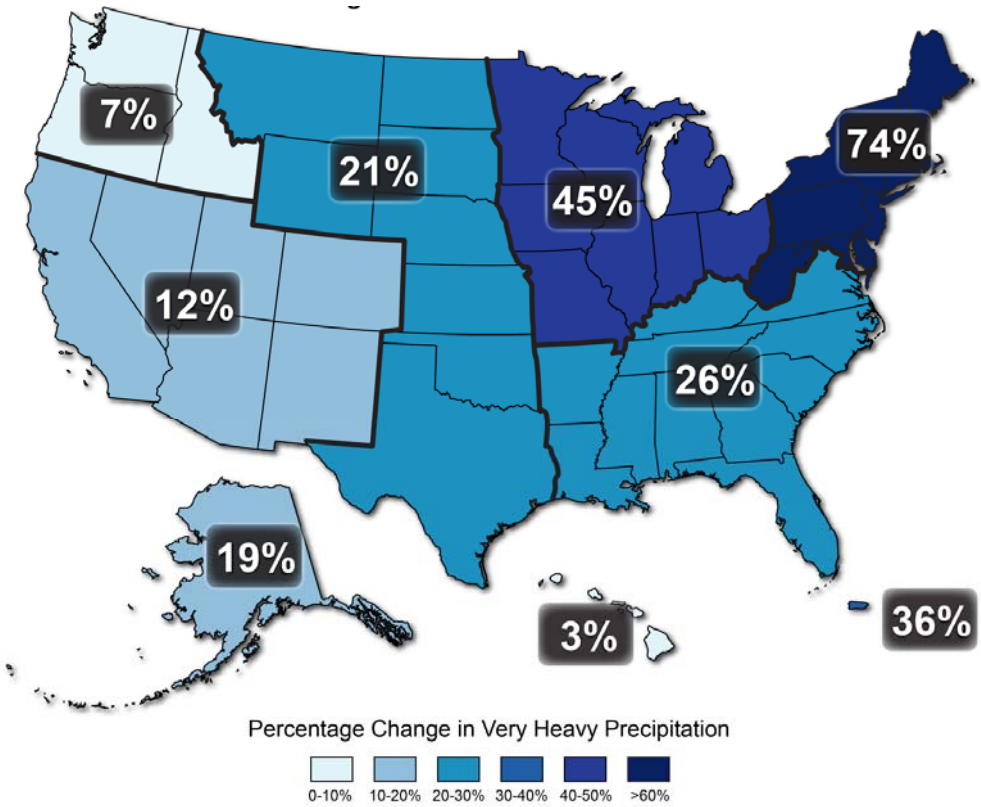
2. Heavy downpours are increasing in most regions of the U.S., especially over the last three to five decades. Certain types of other extreme weather events, including heat waves, and floods and droughts in some regions have become more frequent and intense. The trends are projected to continue.

Analyses from the NOAA National Climate Data Center indicate that the last two years, 2011 and 2012, have had some of the most extreme, and most costly, weather events in the history of our country. These two years have had the largest number of billion dollar events. Both years have had over $60 Billion in damages from severe events. The events include major droughts and heat waves, severe storms, tornadoes, floods, hurricanes, and wildfires.

These recent events are just part of the picture, however. Overall, there has been an increase in some key types of extreme weather events since about 1960. Widespread changes in temperature extremes have been observed over the last 50 years. In particular, the number of heat waves globally has increased, and there have been widespread increases in the numbers of very warm nights. Numbers of very cold days, cold nights, and days with frost have decreased.

Overall, we're seeing more extreme heat and less extreme cold, as you'd expect in a warming climate. Heat waves have generally become more frequent across the U.S. in recent decades, with western regions (including Alaska) setting records for numbers of these events in the 2000s. Recent prolonged (multi-month) extreme heat has been unprecedented. The 2011 and 2012 events in the central U.S. set records for highest monthly average temperatures, including the highest monthly temperature on record; for the spring and summer months, 2012 had the largest area of record-setting high monthly average daytime high and nighttime low temperatures combined. Corresponding with this increase in extreme heat, the number of cold waves has reached the lowest levels on record.

Since the 1950s, there has been an increase in the amount of rain falling in the heaviest events (the top 1%) across the U.S. (see figure below), with an increase of 45% in the Midwest and 74% in the Northeast. Over the U.S. as a whole, there's been about a 20% increase in the amount of precipitation falling in the heaviest events. More intense rainfall means an increased likelihood of floods. In general, the national tendency for more precipitation coming as larger events is projected to further increase because as the atmosphere warms it holds more moisture.



Caption: The map shows percent increases in the amount of precipitation falling in very heavy precipitation events (defined as the heaviest 1% of all daily events) from 1958 to 2011 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest. Based on data from NOAA NCDC. From the 2013 draft U.S. National Climate Assessment.

The general pattern of precipitation change is one of increases at higher northern latitudes and decreases in the tropics and subtropics over land. Essentially, the wet areas are getting wetter and the dry areas are getting drier, and this pattern is expected to continue.

For some severe weather events, such as tornadoes, lightning, hail and strong winds, uncertainties in data collection make it difficult to determine statistically significant trends.

3. Scientific analyses are now indicating a strong link between changing trends in severe weather events and the changing climate.

Every weather event that happens nowadays takes place in the context of a changed background climate. Globally, the temperatures are higher, the sea level is higher, and there is more water vapor in the atmosphere, which energizes storms. So nothing is entirely "natural" anymore. The background atmosphere has changed and continues to change due to human activity.

It's a fallacy to think that individual events are caused entirely by any one thing, either natural variation or human-induced climate change. Every event is influenced by many factors. Human-induced warming is now a contributing factor in all weather events.

We're seeing more heat waves and they are hotter and they last longer. And while a particular heat wave may still have occurred in the absence of human-induced warming, it would not have been as hot, or lasted as long, and such events would not occur as frequently. For example, an analysis of the Texas heat wave of 2011 found it was 20 times more likely due to human-induced warming than it would have been otherwise. And in the future, summers that hot will be commonplace, if we continue on our current path of increasing emissions of heat-trapping gases.

The changes occurring in precipitation are also consistent with our understanding of our changing climate. For extreme precipitation, we know why more precipitation is falling in very heavy events: Warmer air holds more water vapor, and so when any given weather system moves through, all that extra water dumps out in a heavy downpour. And in between these downpours there are longer periods without rain. So you get this cycle of very wet and very dry conditions. And we're seeing this happening now, just as climate studies indicated it would. The same is true for heavy snowfall events.

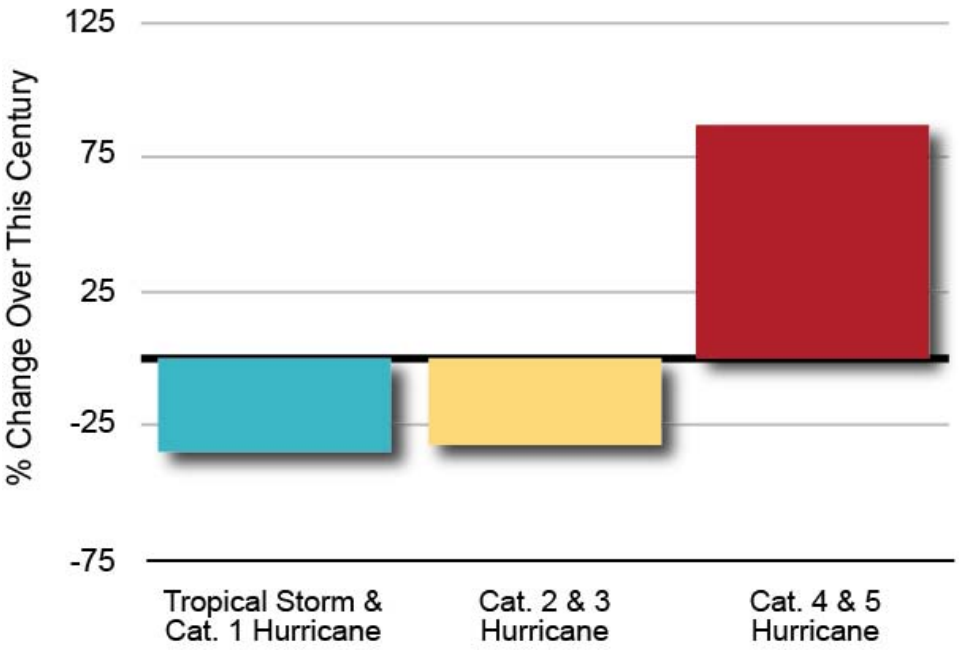
At the same time, droughts like we have been seeing in recent years in the Southwest and Midwest are projected to become stronger and more frequent as climate change continues.

4. There has been an increase in the overall strength of hurricanes and in the number of strong (Category 4 and 5) hurricanes in the North Atlantic since the early 1980s. The intensity of the strongest hurricanes is projected to continue to increase as the oceans continue to warm.

There has been a substantial increase in virtually every measure of hurricane activity in the Atlantic since the 1970s. These increases are linked, in part, to higher sea surface temperatures in the region in which Atlantic hurricanes form in and move through.

Climate models that incorporate the best understanding of all the factors affecting hurricanes project further increases in the frequency and intensity of the strongest Atlantic hurricanes, as well as increased rainfall rates in response to continued warming of the tropical oceans.

Hurricane activity in other ocean basins like the Pacific has not shown such clear increases as those found in the Atlantic, but there is a lack of sufficient historical data in these regions.



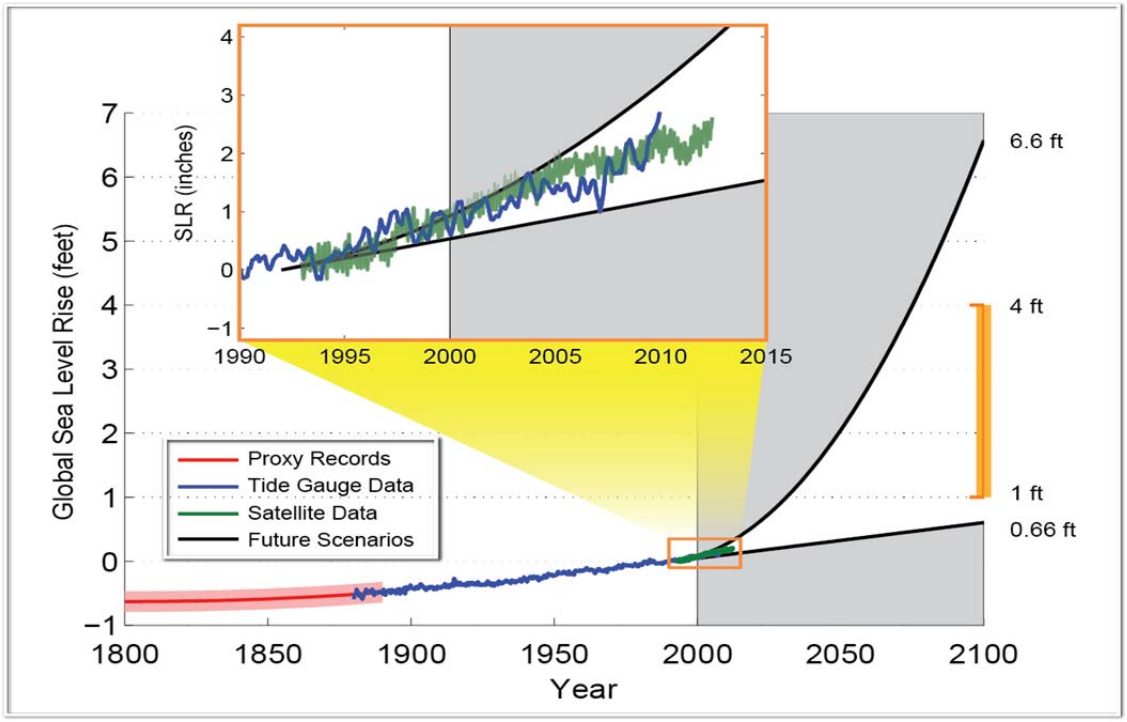
Caption. Model projections of percentage changes in Atlantic hurricane and tropical storm frequencies for different storm categories, by the late this century, showing that intensity is likely to increase. Projected changes are for the period 2081-2100 compared with the period 2001-2020.

5. Global sea level has risen by about 8 inches since 1880. It is projected to rise another 1 to 4 feet by 2100. Many coastal areas of the U.S. will be increasingly affected.

After at least two thousand years of little change, sea level rose by roughly 8 inches over the last century, and satellite data provide evidence that the rate of rise over the past 20 years has roughly doubled. In the U.S., millions of people and many of the nation's assets related to military readiness, energy, transportation, commerce, and ecosystems are located in areas at risk of coastal flooding because of sea level rise and storm surge.

Sea level is rising because ocean water expands as it heats up and because water is added to the oceans from melting glaciers and ice sheets. Sea level is projected to rise an additional 1 to 4 feet in this century. Scientists are unable to narrow this range at present because the processes affecting the loss of ice mass from the large ice sheets are dynamic and still the subject of intense study. Some impact assessments consider sea level rise as high as 6.6 feet by 2100.

Nearly 5 million people in the U.S. live within 4 feet of the local high-tide level. In the next several decades, storm surges and high tides could combine with sea level rise and land subsidence to further increase flooding in many of these regions.



Caption. Estimated, observed and possible amounts of global sea level rise from 1800 to 2100. Proxy estimates (Kemp et al. 2012) (for example, based on sediment records) are shown in red (pink band shows uncertainty), tide gauge data in blue (Church and White 2011), and satellite observations are shown in green (Nerem et al. 2010). Future scenarios range from 0.66 feet to 6.6 feet in 2100 (Parris 2012). Higher or lower amounts of sea level rise are considered implausible, as represented by the grey shading. The orange line shows the currently projected range of sea level rise of 1 to 4 feet by 2100. The large projected range reflects uncertainty about how glaciers and ice sheets will react to the warming ocean, the warming atmosphere and changing winds and currents. As seen in the observations, there are year-to-year variations within the long-term upward trend.

Conclusions

In conclusion, while we are already seeing the climatic effects of our emissions of heat-trapping gases, it is important to recognize that the future lies largely in our hands. Will we reduce our emissions, and have a future with less warming and less severe impacts, or will we continue to increase our emissions and have a future with more warming and more severe impacts, including more extreme weather events? The choice is ours.

Addendum: Addressing some of the Commonly Asked Questions about climate change

Below I address just a few questions that might be of interest to the members of the Senate. Many other Commonly Asked Questions are addressed in an Appendix of the draft National Climate Assessment (go to http://ncadac.globalchange.gov and select Appendix 1).

Should we trust computer models of the Earth's climate?

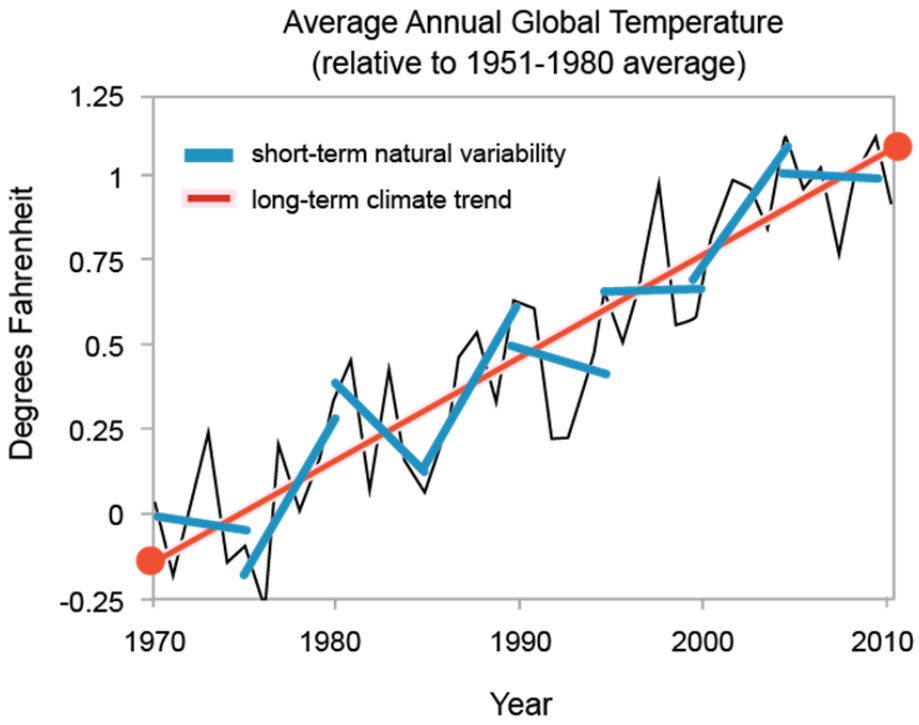
Some people wonder if they should trust computer climate models. While no model is perfect, climate models have proven remarkably accurate in forecasting the climate change we've experienced to date. In a few cases, model projections have been overly conservative, for example, in projecting how quickly Arctic sea ice would decline. It has in fact declined more rapidly than the models forecast.

Today's climate models encapsulate the great expanse of current understanding of the physical processes involved in the climate system, their interactions, and the performance of the climate system as a whole. They are extensively tested relative to observations and are able to reproduce the key features found in the climate of the past century.

Because models differ in their representation of certain processes, we make use of these differences by examining suites of models in climate assessments. However, they all give the same basic story Also, despite the tremendous improvements in the climate modeling capabilities over my 40 years as a scientist, the basic response of a significant effect on the climate system from human activities continues to be about the same as the models were finding 40 year ago. These models are the only crystal balls we have – and although not perfect, they are very useful tools.

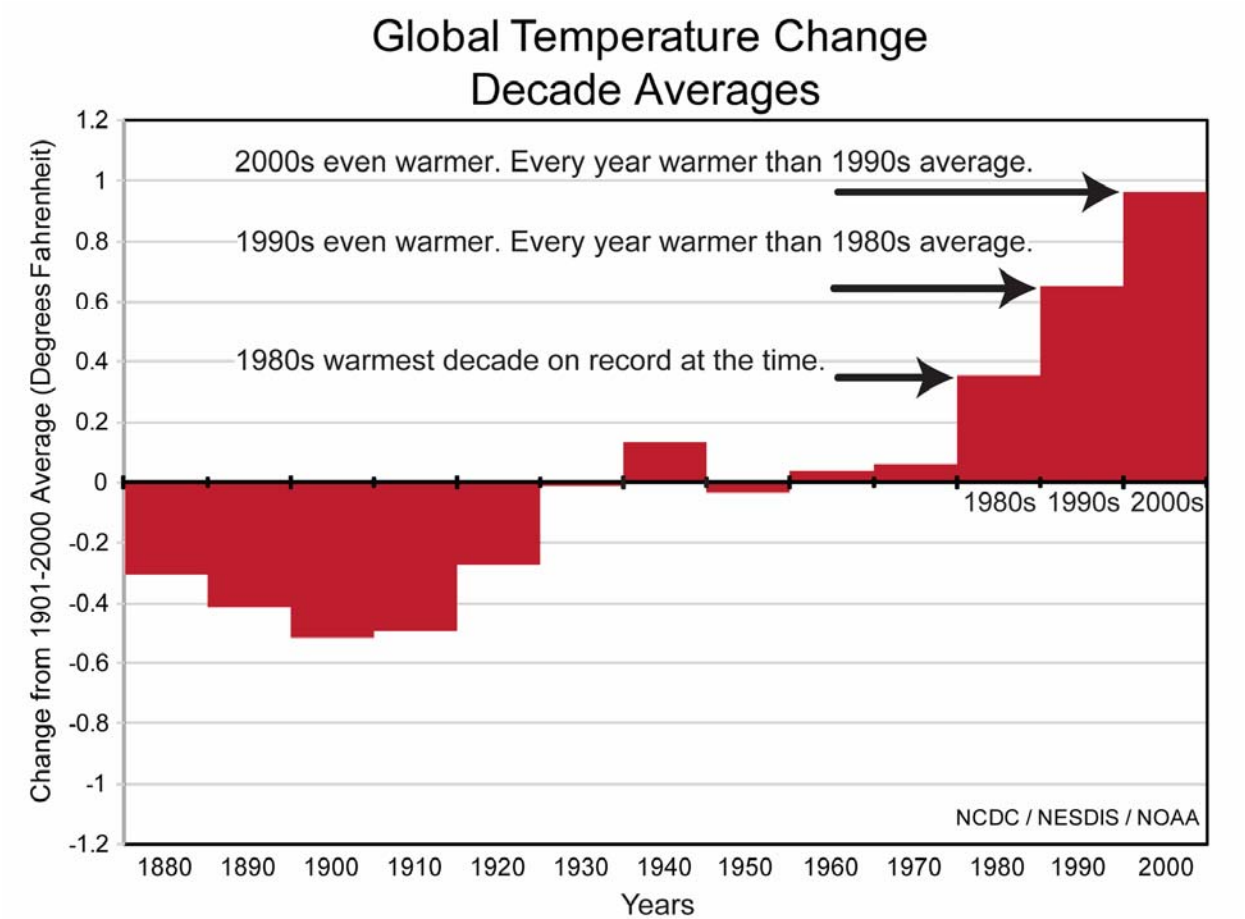
Is the global temperature still increasing? Isn't there recent evidence that it is actually cooling?

Climate change is defined as a change in the average conditions over periods of 30 years or more. On these time scales, global temperature continues to increase. Over shorter time scales, however, natural variability (due to the effects of El Niño and La Niña events in the Pacific Ocean, for example, or volcanic eruptions or changes in energy from the Sun) can reduce the rate of warming or even create a short-term cooling. We do not expect every single year to be warmer than the previous year, because there are still natural variations in climate. The long-term trend is very clearly an upward one, but not in a straight line.



Caption. Short-term trends in global temperature (here, the blue lines that show temperature trends at five-year intervals from 1970 to 2010) can range from negative to sharply positive. The evidence of climate change is based on long-term trends over 20-30 years or more (red line). Measurement data from NASA-GISS.

As shown below, every decade in the last 50 years has been warmer than the one before it. The decade of the 2000s was the warmest globally.



Caption: The last 5 decades have seen a progressive warming of the Earth. Measurement data from NOAA NCDC.

Climate is always changing. How is recent change different than in the past?

The Earth has experienced large climate changes in the past. However, current changes in climate are unusual for two reasons: first, these changes are occurring faster and second, these changes are primarily the result of human activities.

In the past, climate change was driven exclusively by natural forcings: explosive volcanic eruptions that inject reflective particles into the upper atmosphere and cool climate on short time scales, or periodic variations in the Earth's orbit that change climate on longer timescales.

Natural factors are still affecting the planet's climate today. The difference is that, since the beginning of the Industrial Revolution, humans have been adding increasing amounts of heat-trapping gases to the atmosphere at a much faster rate than can occur naturally as we dig up billion year old carbon in the form of coal, oil and gas and release that carbon to the atmosphere in the geological blink of an eye. Records from ice cores, tree rings, and other forms of "natural thermometers" reveal three important findings. First, recent climate change is unusually rapid. After a glacial maximum, the Earth typically warms by about 7 to 13°F over thousands of years. The current rate of warming is about 8 times faster.

Second, global temperatures in the last 100 years are unusually warm when compared to temperatures over the last several thousand years. And third, carbon dioxide levels are currently higher than any time in at least the last 800,000 years. Paleoclimate studies indicate that temperature and carbon dioxide levels have been higher in the distant past, millions of years ago, when the world was very different than it is today. But never before have such rapid, global-scale changes occurred during the history of human civilization.

Our societies have not been built to withstand the changes that are anticipated in the relatively near future, and many are already experiencing the effects of failure to anticipate higher temperatures, sea level rise, and other climate-related impacts.