CLIMATE CHANGE:
Indicators and Outlook

Major Indicators: Conditions

- Global Mean Temperatures
- Precipitation Trends
- Tropical Storm Activity
- Sea Ice Extent
- Sea Level

Major Indicators: Policy

- Ambient Greenhouse Gas Concentrations
- Greenhouse Gas Emissions
- Greenhouse Gas Intensity

PRIMARY SOURCES

National Oceanic and Atmospheric Administration

National Climatic Data Center

National Hurricane Center

National Snow and Ice Data Center

Energy Information Administration

University of Colorado at Boulder

Introduction

Because the controversy about climate change concerns the long-range future, it is difficult to construct definitive indicators (as opposed to endless computer models) of the present that do not get sucked into the acrimony about the models and theories of human-caused global warming. Too much of the public discourse on climate change is conducted through "signs and wonders" such as drowning polar bears, migrating armadillos, and unusual weather events—strong storms, heavy rainfall and/or drought, unseasonable temperatures. Such "signs and wonders" do not constitute data, and they can be misleading.

For example, the eastern United States basked in record warm temperatures in the winter of 2006–07—this after Buffalo experienced its sixth-heaviest snowfall in history, in *October.* Growers in California suffered $1 billion in citrus crop losses due to the coldest weather in 70 years. In the winter of 2009–10, this pattern reversed itself, with the eastern United States experiencing bitter cold with heavy snowfall, while the western U.S. enjoyed mild temperatures. A few months later, the pattern reversed again, with the eastern U.S. suffering a hot summer, while the Pacific Coast had one of its coldest summers in decades. Climate change, perhaps, but man-made global warming? It is useful to keep in mind that these often interchangeable terms are not necessarily co-terminous.

The earth's climate changes constantly, usually on time scales that are much longer than the average human lifespan but relatively short in geological terms. The historical record suggests that climate shifts can happen suddenly, for reasons that remain unclear. The argument that currently observable climate changes are outside the range of normal climate variability is a key tenet of the climate campaign, and despite the incessant refrain about the "consensus" that "the debate is over," this core question is far from settled. In an interview with the BBC, professor Phil Jones, the director of the Climatic Research Unit at the University of East Anglia, which was at the center of the "Climategate" controversy in late 2009, concurred:

> BBC: When scientists say "the debate on climate change is over," what exactly do they mean, and what don't they mean?

> JONES: It would be supposition on my behalf to know whether all scientists who say the debate is over are saying that for the same reason. *I don't believe the vast majority of climate scientists think this.* This is not my view. There is still much that needs to be undertaken to reduce uncertainties, not just for the future, but for the instrumental (and especially the paleoclimatic) past as well.[1] (emphasis added)

Also worth noting are the views of professor Judith Curry, head of the School of Earth and Atmospheric Sciences at Georgia Tech and one of the few scientists convinced of the potential for catastrophic global warming who are willing to engage skeptics seriously. Curry wrote last spring: "No one really believes that the 'science is settled' or that 'the debate is over.' Scientists and others that say this seem to want to advance a particular agenda. There is nothing more detrimental to public trust than such statements."[2] For her willingness to break from the enforced "consensus" of the climate campaign, Curry has been excoriated.

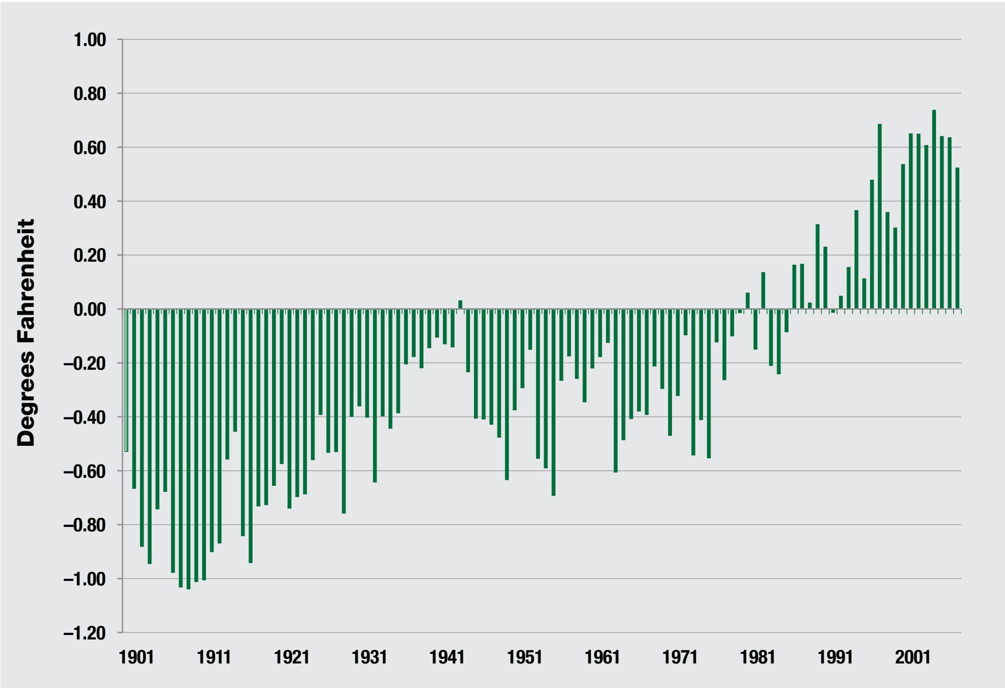
Meanwhile, the political campaign to have the United States adopt serious constraints on fossil fuel energy through an emissions trading scheme ("cap and trade") has come to an ignominious end, probably for good, while efforts to promote "green" energy are in retreat.

The controversy over both science and policy responses is not going to be resolved any time soon, if ever. Therefore, indicators of climate change should be divided into two categories that are largely (though not wholly) uncontroversial: direct indicators of observable changes in the global climate such as average temperature, changes in Arctic and Antarctic sea ice, and sea levels; and *policy* indicators, i.e., the factors that governments have chosen to track for purposes of affecting the human influences on climate change, chiefly ambient greenhouse gas (GHG) concentrations and human-caused greenhouse gas emissions. Data series are available for these variables, though significant methodological arguments remain about potential instrument errors or inaccuracies in the collection of raw data, and about the complex statistical techniques used to process and interpret the data.

Temperature

Bearing these caveats in mind, let's look at the data. Figure 1 displays the global average temperature anomaly—that is, the deviation from the average temperature of the period from 1971 to 2000—starting in 1901. The 1971–2000 period was chosen because it offered the most data points from which to calculate an average.

Figure 1
Global Temperature Anomaly, 1901–2008



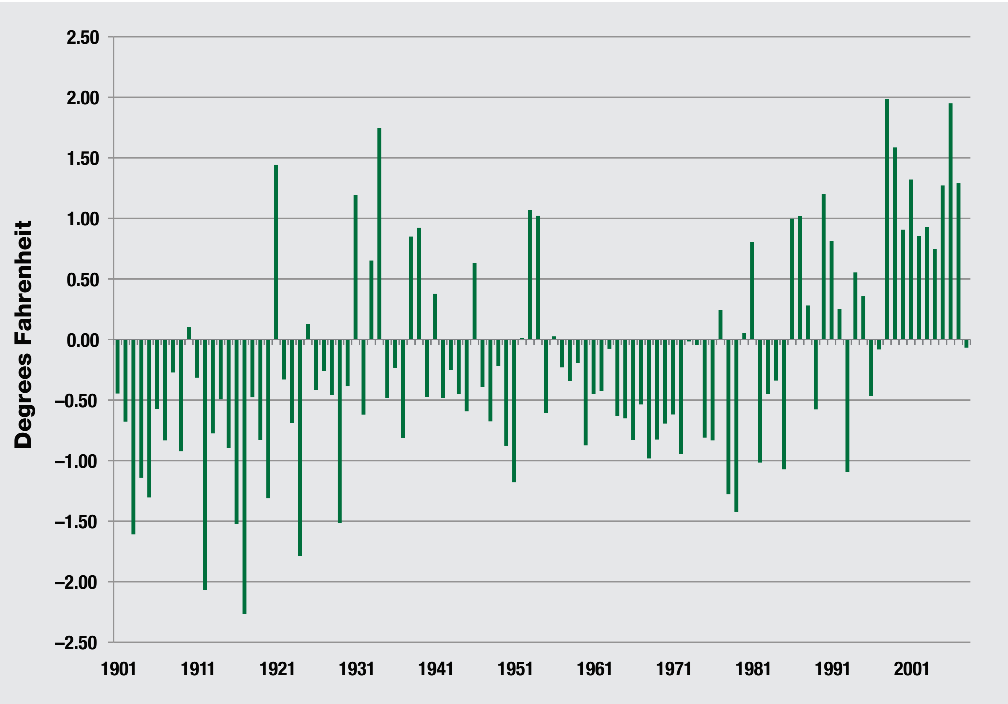
Source: National Climatic Data Center

Much is made of the period between 1980 and 1998, when the global average temperature rose by about 0.6 degrees Fahrenheit. But as Figure 1 shows, had the trend data from 1910 to 1940 been available in 1940, there might have been great worry about the sharp rise in global average temperature during that period, which preceded most of the increase in human-generated greenhouse gas emissions. In fact, there is thought to have been another period of sharp temperature rise between 1860 and 1880, but the raw data records are incomplete. Then between 1940 and 1980 global temperatures were flat or slightly declining, before resuming an upward trend from 1980 to 1998.

The picture begins to grow more complicated with Figure 2, which shows the temperature anomaly for the land area of the contiguous United States only. Here the long-term trend is of larger magnitude than that for the globe as a whole—not surprising, since temperatures over land are higher than temperatures over the oceans. It is much less consistent, however, as it shows a number of high temperatures in the 1930s. In the contiguous United States, 1934 may actually have been the hottest year of the 20th century—warmer than 1998, which is displayed in this series at the hottest year.

Figure 2

Contiguous United States Temperature Anomaly, 1901–2008

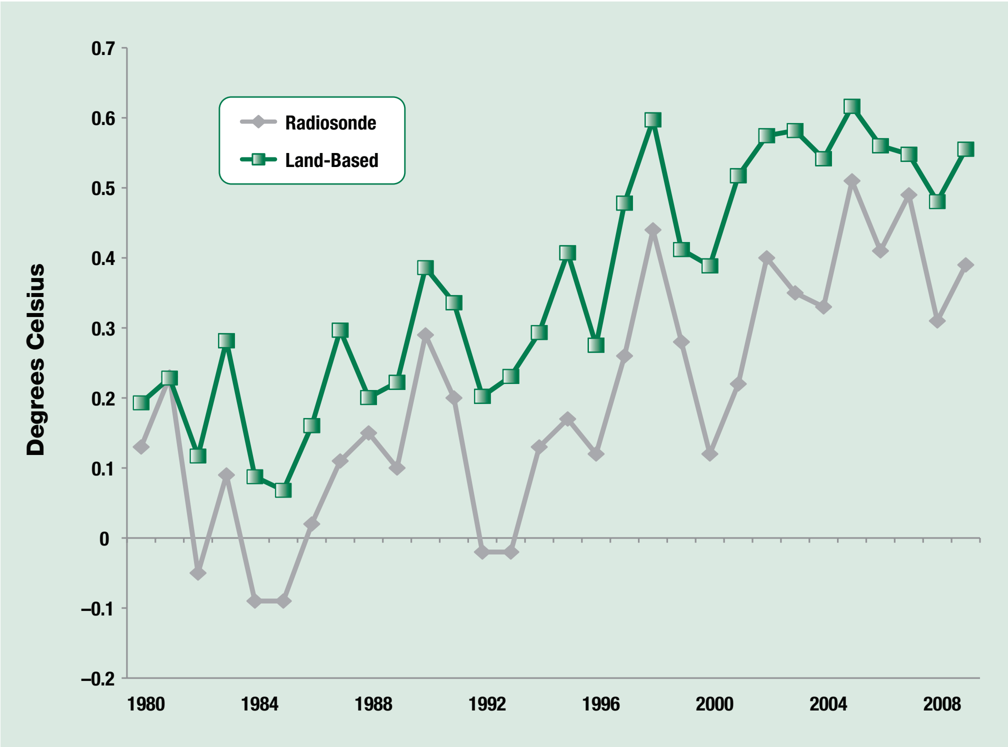


Source: National Climatic Data Center

One of the ongoing controversies concerns the discrepancy between ground-based thermometer data and satellite radiosonde data, considered more accurate. Both show a similar warming pattern, but the satellite data are consistently lower than the ground-based data, as shown in Figure 3.[3]

Figure 3

Ground-Based and Satellite Temperature Data Trends, 1980–2009



Source: NOAA

These comparisons provide the necessary backdrop for appreciating the controversy that arises from the global temperature trend of the last decade, shown in Figure 4. Temperatures were flat or slightly declining between 2002 and 2008, before ticking up slightly in 2009; 2010 is expected to rival 1998 as the hottest year of the last two decades, although we should note that 2010, like 1998, was an El Niño year, which is typically associated with higher temperatures. On the other hand, if one removes 1998 as an anomaly within the anomalies, then the long-term upward trend of temperatures would appear to be more intact. Observers should be cautious about drawing firm conclusions from the data of the last decade.

Figure 4
Global Temperature Anomaly, 1997–2009

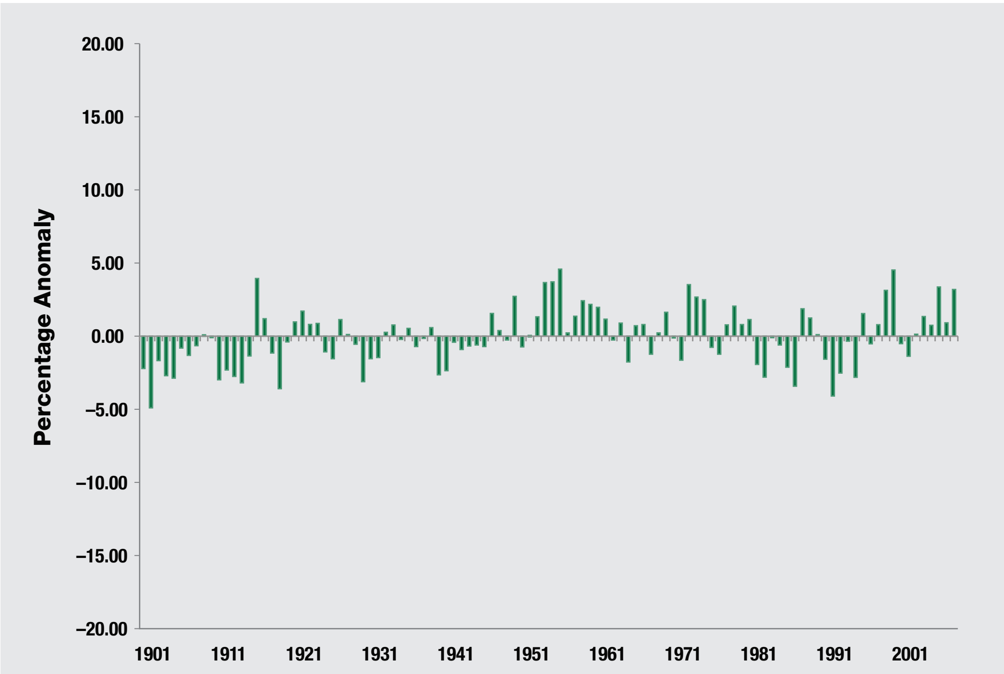
Source: NOAA

Precipitation

One of the most common misperceptions of global warming is that a warming planet will be a drier planet, with increasing drought conditions. While this may make intuitive sense to the layperson, it is exactly backwards: a warmer planet will see *increased* precipitation, as warmer temperatures will increase water evaporation and thus rainfall, though this will not be uniform, and changing weather patterns may result in droughts in some areas. Data from 1901 to the present show only a slight increase in global precipitation (1.9 percent) and no discernible correlation with the temperature record. Note in Figure 5 that global precipitation increased in the 1950s, when global temperatures were falling (compare with Figure 1).

Figure 5

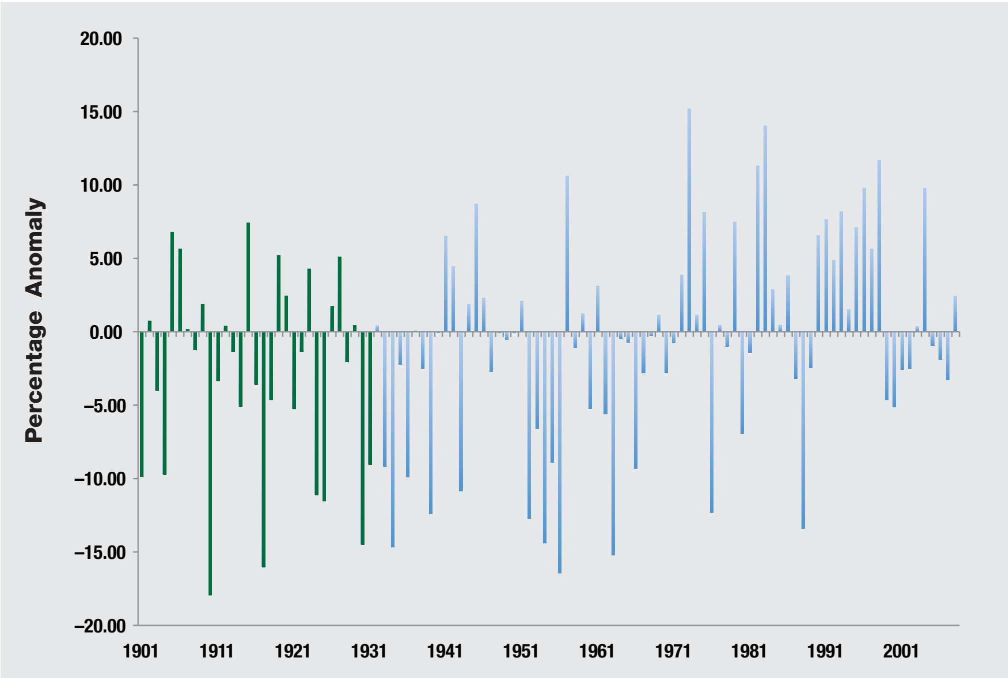
Global Precipitation Anomalies, 1901–2008



Source: NOAA

For the contiguous United States precipitation has increased 6.1 percent since 1901, as shown in Figure 6. There is considerable regional variability, however. The greatest increases came in the South (10.5 percent), the Northeast (9.8 percent), and the Eastern North Central climate region (9.6 percent). A few areas such as Hawaii and parts of the Southwest have seen a decrease.

Figure 6
Contiguous United States Precipitation Anomalies, 1901–2008



Source: NOAA

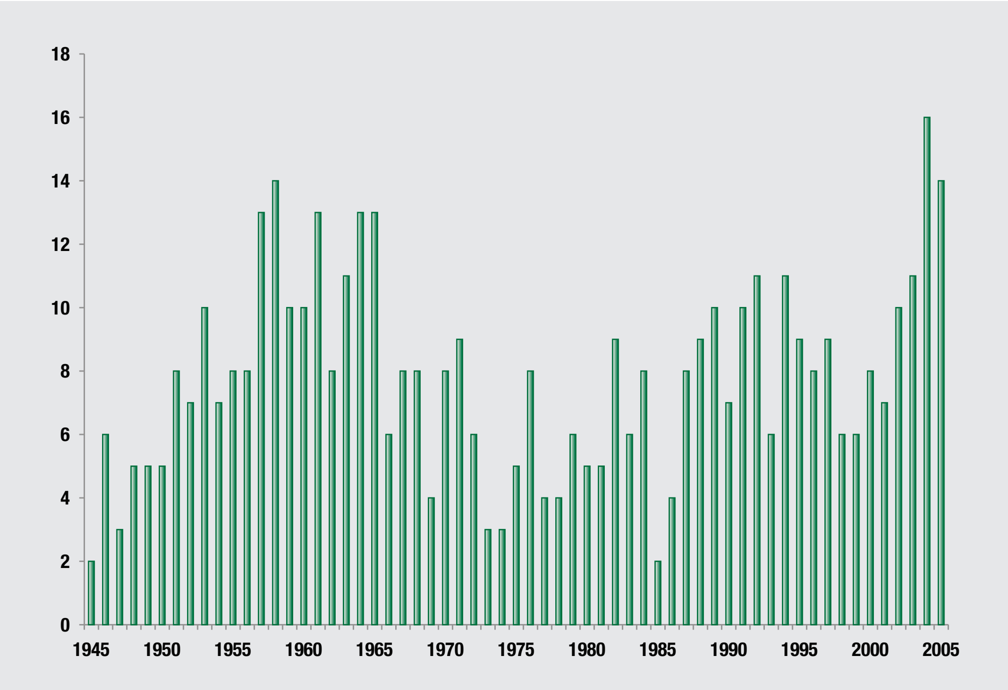
Tropical Storm Activity

Whether hurricanes and tropical storms are becoming more frequent and severe in intensity is highly contested at the moment, with leading scientists publishing studies on both sides of the issue. "Tempers Flare at Hurricane Meeting," *Nature* magazine reported in May 2006. Meanwhile, in November 2006 the World Meteorological Organization issued a "consensus statement" that reads: "Though there is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record to date, no firm conclusion can be made on this point."

The basic theory—that warmer ocean waters lead to stronger storms—seems intuitively sensible; the difficulty is a lack of reliable data to confirm both long-term ocean temperature trends and tropical storm intensity. Various proxy techniques to estimate storm dynamics decades ago are vulnerable to the usual statistical critiques. Even estimating the *number* of tropical storms beyond 25 years ago is subject to uncertainties, as we did not have satellite coverage of the entire ocean area; without such coverage, many tropical storms form and then dissipate before detection.

The series displayed in Figure 7, from the National Hurricane Center, shows only a modest rise—if any—in tropical storm activity in recent decades. Figure 8, also from data reported by the National Hurricane Center, displays tropical storms that made landfall in the U.S.; these data suggest no trend of increasing storm activity affecting the United States.

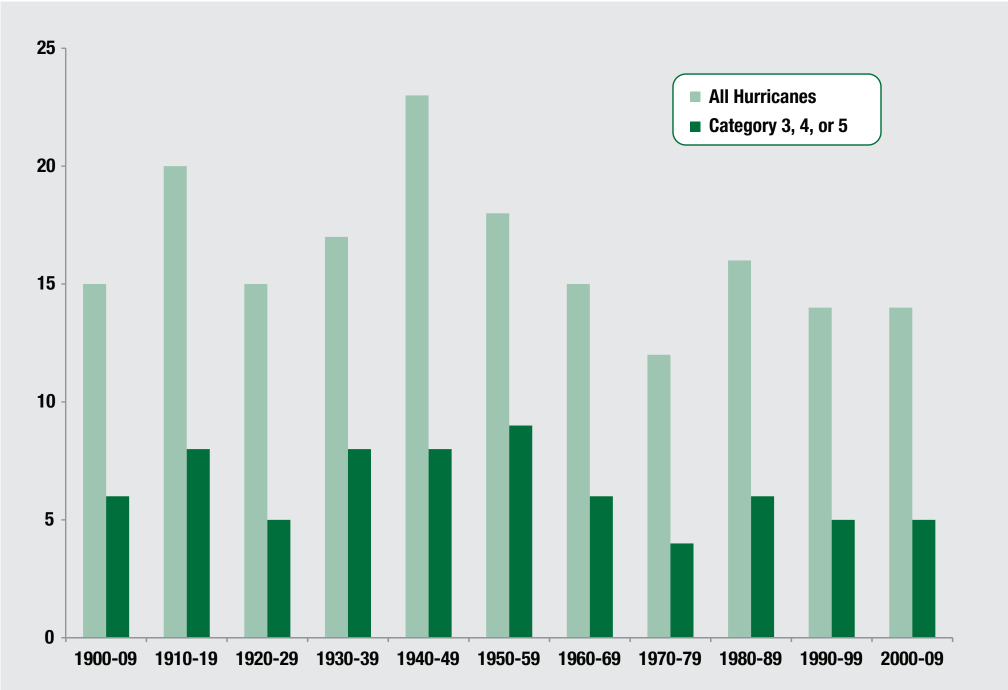
Figure 7
Atlantic and Pacific Hurricane Activity, 1945–2005



Source: National Hurricane Center

Figure 8

Tropical Storms Making Landfall in the U.S. by Decade



Source: National Hurricane Center

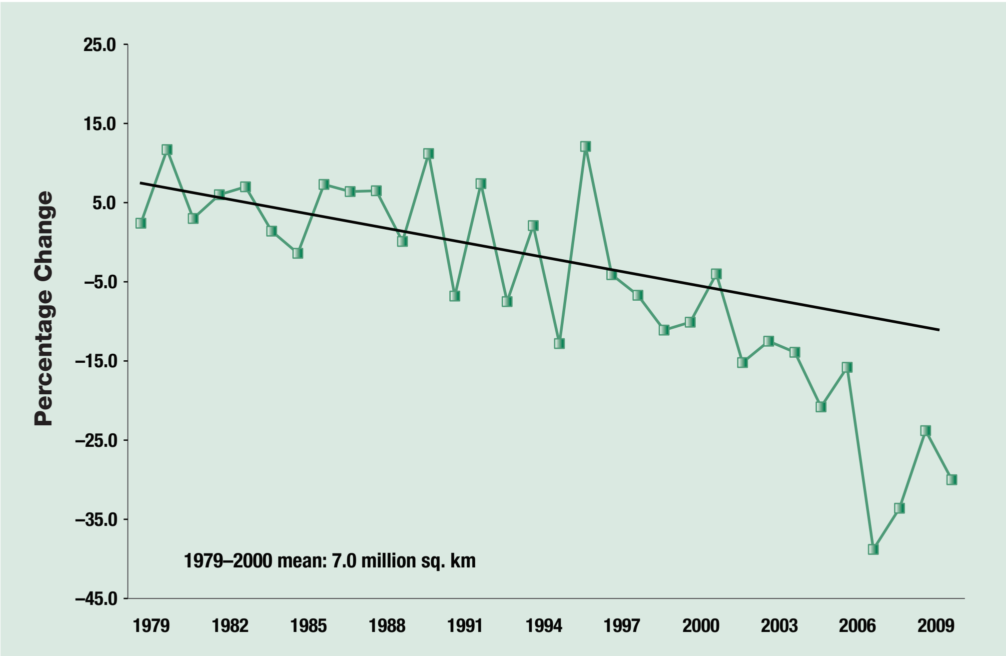
Sea Ice

In addition to air and ocean temperatures, the other real-time climate indicator that receives a lot of attention is the vexing question of the size of ice masses at the North and South Poles (and Greenland)—vexing because multiple datasets evoke contradictory interpretations. (Go to the National Snow and Ice Data Center's website for a roundup of sea ice datasets.[4]) Most climate specialists like to focus on Arctic ice extent for the month of September, which is when the Arctic ice cap reaches its late-summer minimum.

Late in 2007 and at the beginning of 2008, the climate community was in full cry about the sharply lower level of Arctic ice in September 2007. There were predictions that 2008 might see the first totally ice-free Arctic, though some cautious voices suggested that the drop in 2007 might be a one-year anomaly rather than evidence of accelerating ice loss. The cautious voices were probably correct. Arctic sea ice data for September 2008 and 2009 show upticks from 2007; there was another slight downtick in 2010, as shown in Figure 9. It should be noted that polar and sea ice in Antarctica has increased over the last 30 years, though this is actually consistent with most global warming computer models.

Figure 9

September Arctic Sea Ice Anomaly, 1979–2010



Source: National Snow and Ice Data Center

Climate scientists dispute whether greenhouse gases are the cause of the Arctic warming observed over the last 30 years. Findings in the peer-reviewed scientific literature continue to suggest that wind patterns and ocean currents play a larger role than greenhouse gases. In a complicated 2008 article in *Nature*, "Vertical Structure of Recent Arctic Warming," five scientists at the University of Stockholm noted a number of anomalies in the pattern of warming in the Arctic atmosphere, and ruled out greenhouse-gas-induced amplifying feedbacks as the cause of Arctic warming. The authors instead identify changing wind patterns at high altitudes as the chief driver of recent Arctic warming; these winds were measurably lighter in 2008. "Our results do not imply," the authors were careful to hedge, "that studies based on models forced by anticipated future CO_2 levels are misleading when they point to the importance of snow and ice feedbacks. . . . Much of the present warming, however, appears to be linked to other processes, such as atmospheric energy transports."[5]

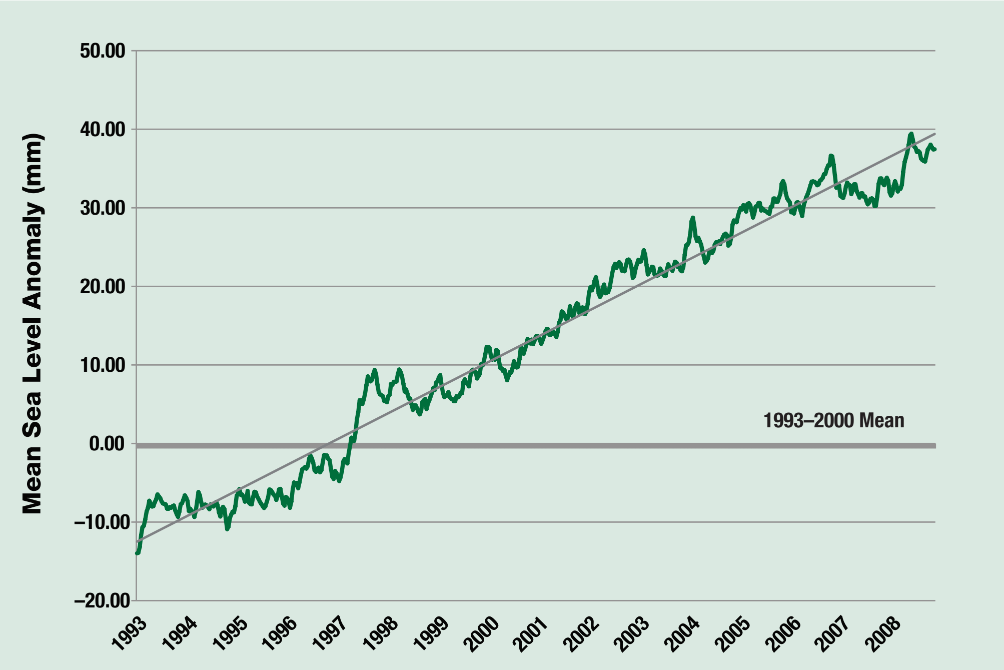
Sea Level

The sea level has been rising at a steady rate since reliable tidal gauges have been generating data—about 200 years. In fact, the sea level is thought to have been steadily rising since the end of the last Ice Age 10,000 years ago. Measuring sea level is not simple, as subsidence and geological movement of the continental plates will corrupt data from tidal gauges. High-quality satellite data has been available only since the early 1990s—not a very long record for a time series. For a good discussion of the issue and the methodological difficulties, see http://tidesandcurrents.noaa.gov/sltrends/mtsparker.html.

Figure 10 displays average global sea level relative to a mean period from 1993 to 2000, as calculated from satellite data by climate researchers at the University of Colorado at Boulder. While this slope looks alarming because of the short x-axis, it represents an average increase of about three millimeters a year, or about one foot per century.

Figure 10

Global Mean Sea Level Anomaly, 1993–2008

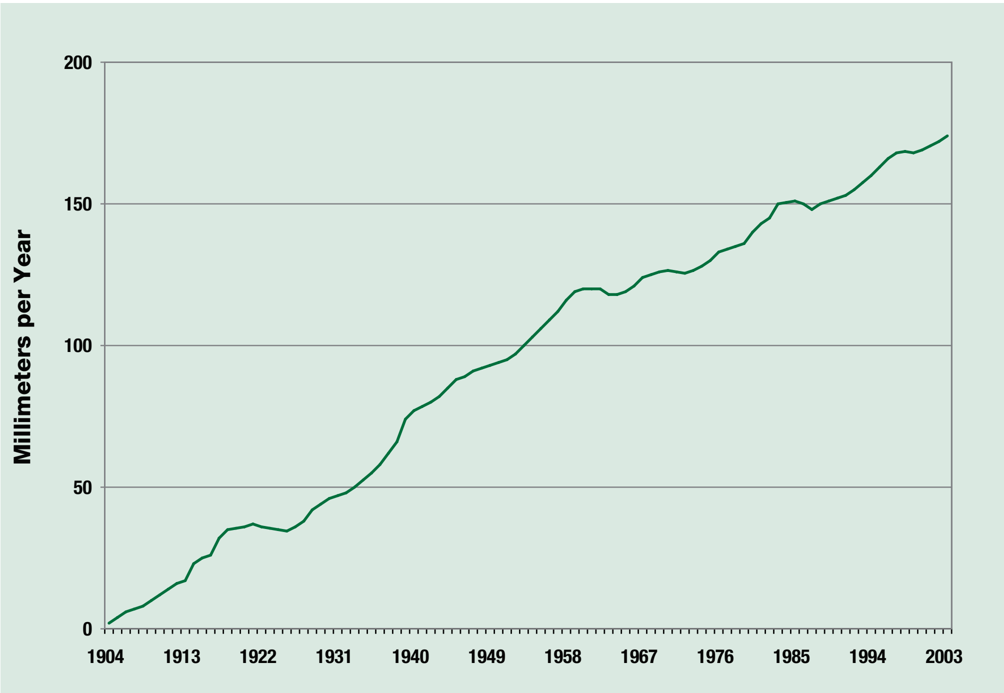


Source: University of Colorado at Boulder

Is there evidence that the rate of sea-level rise is currently accelerating on account of climate change? Some recently published research indicates that it is not. In a 2007 article in *Geophysical Research Letters*, S. J. Holgate of the Proudman Oceanographic Laboratory in Liverpool, England, examined tidal records from nine gauges thought to have consistent and reliable data going back to 1904.[6] (Three of the nine gauges are located in the United States.) Holgate concluded that "the high variability in the rates of sea level change observed over the past 20 years [was] not particularly unusual. The rate of sea level change was found to be larger in the early part of last century (2.03 ± 0.35 mm/yr 1904–1953), in comparison with the latter part (1.45 ± 0.34 mm/yr 1954–2003). . . . Over the entire century the mean rate of change was 1.74 ± 0.16 mm/yr." Holgate's finding, it should be noted, is at odds with the conclusion of the 2007 report of the Intergovernmental Panel on Climate Change (IPCC), which found that sea level rise had accelerated substantially in recent decades. Holgate's findings for the amount of sea level rise and the rate of sea level rise are shown in Figures 11 and 12.

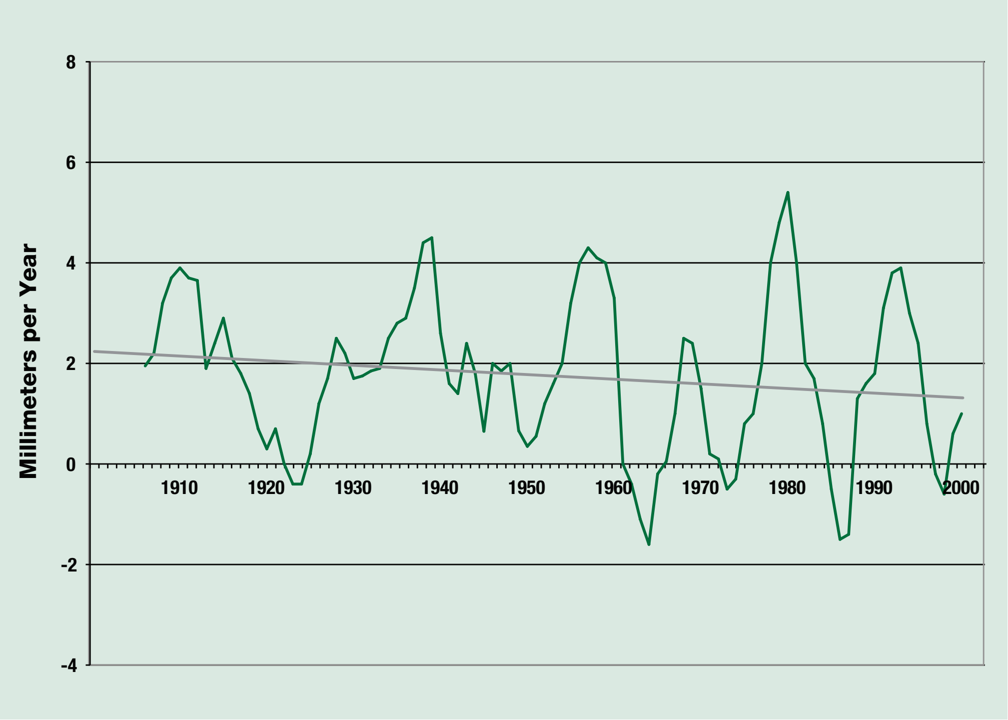
Figure 11

Cumulative Sea Level Rise, 1904–2003



Source: Holgate

Figure 12:
Global Average Rates of Sea Level Change, 1904–2000



Source: Holgate

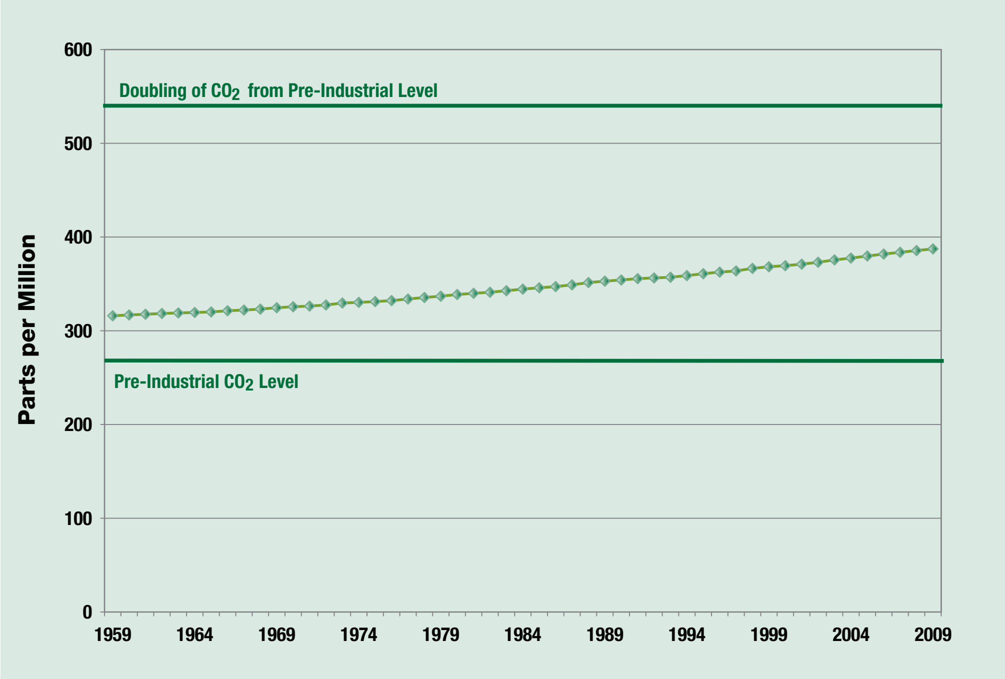
Climate Policy Indicators

Scientists and commentators point to nearly everything as an indicator of climate change. Starting with the 12th edition, the *Index of Leading Environmental Indicators*, the *Almanac*'s predecessor, tracked three main *policy-relevant* indicators for climate change. They are: levels of ambient global greenhouse gases (principally carbon dioxide and methane), greenhouse gas emissions, and greenhouse gas intensity (i.e., the amount of greenhouse gases emitted per dollar of GDP). This latter metric, a measure of the change in energy efficiency relative to economic growth, is arguably the most important for policy purposes.

Figure 13 displays the trend in global CO_2 concentrations in the atmosphere, taken from the monitoring series of the Mauna Loa Observatory in Hawaii. The global CO_2 concentration increased by 1.78 parts per million in 2009, an increase of 0.46 percent over 2008. This is a slight decrease over the rate at which CO_2 has been accumulating for the last 20 years. This time series is often shown on a narrow x-axis scale, such that the increase in CO_2 appears steep and rapid—"alarming" even. Sometimes very long-term CO_2 levels are depicted on a logarithmic x-axis scale that produces even more dramatic but misleading imagery. Here the trend is displayed on a wider x-axis scale with two benchmarks to note: the pre-industrial level of atmospheric CO_2, and the level representing a doubling of CO_2 (about 550 ppm), which has become the arbitrary benchmark target for carbon stabilization at some future point, beyond which it is presumed—though far from proven—that dramatic harm to the planet will occur.

Figure 13

Atmospheric CO_2 Concentration, 1959–2009



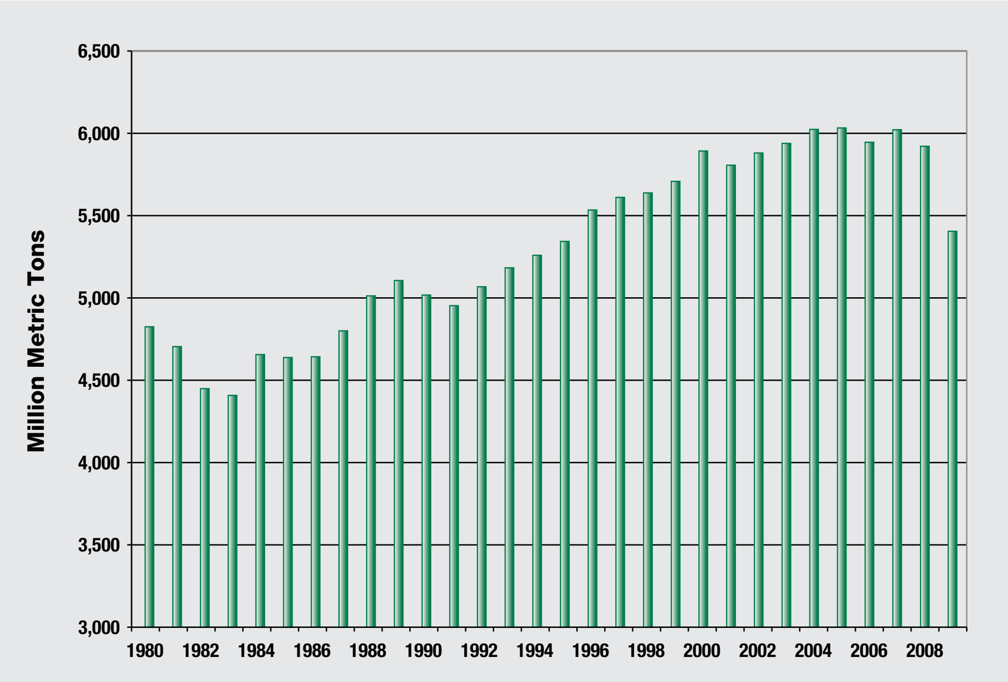
Source: NOAA/Mauna Loa Observatory

Figure 13 makes evident an important fact typically left out of discussion: It has taken 200 years to go a little more than one-third of the way toward a doubling of CO_2 levels in the atmosphere. The rate has increased only slightly since global economic growth started accelerating in the 1980s. At these rates, it will be well into the 22nd century before the CO_2 level reaches twice its pre-industrial level. Most of the IPCC projections of high temperature increase from greenhouse gases assume that this trend will break sharply upward very soon—that the rate at which CO_2 is accumulating in the atmosphere will more than double from the long-term historical trend. Intense controversy followed these projections, as discussed extensively in the *Index* starting with the ninth edition in 2004. Numerous economists and energy experts suggest that future emissions are being vastly overestimated because of faulty economic analysis.

Roger Pielke Jr., Tom Wigley, and Christopher Green offered a notable contribution to this ongoing debate in the spring of 2008 with an analysis arguing that the IPCC forecasts significantly *underestimate* future greenhouse gas emissions; the authors point to data showing that the rise in GHG emissions in the first half of this decade came in far above the existing high-end projections.[7] They argue that this makes the IPCC's chief policy prescription—steep reductions in future GHG emissions—*less* likely to be attained, because the IPCC's policy analysis has underestimated the technological challenge involved. In one sentence, Pielke and his team believe the IPCC's emissions goals are not achievable. This is not a new critique. NYU physicist Martin Hoffert and a large number of colleagues published a challenging critique of the IPCC's energy assumptions in *Science* magazine in 2002, igniting an earlier chapter of this controversy.[8]

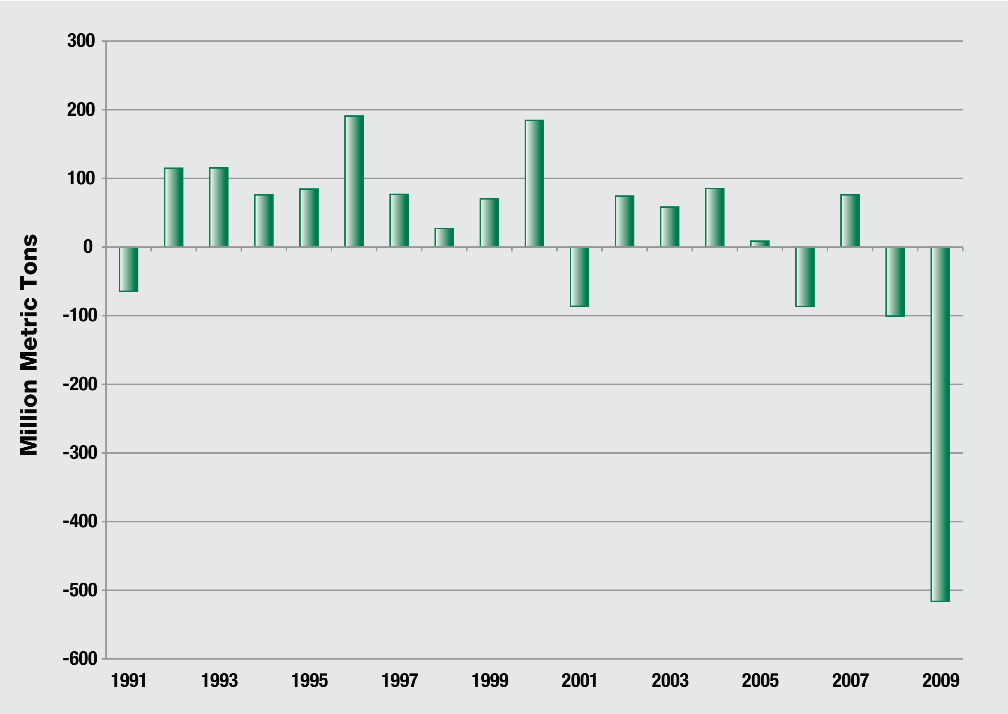
Figure 14 displays U.S. CO_2 emissions from 1980 to 2009, while Figure 15 displays the year-over-year change. One aspect to note in Figure 14 is that growth in CO_2 emissions was slow in the last decade even before the recession. CO_2 emissions grew by 13 percent over the course of the Clinton Administration and about 3 percent during the Bush years before the recession began. Figure 15 in particular shows the effect of the severe recession of 2008–09 on emissions: U.S. CO_2 emissions fell back to a level last seen in 1995.

Figure 14
U.S. CO_2 Emissions, 1980–2009



Source: Energy Information Administration, Emissions of Greenhouse Gases in the U.S. 2008 and Monthly Energy Review

Figure 15
Annual Change in U.S. CO_2 Emissions, 1991–2009

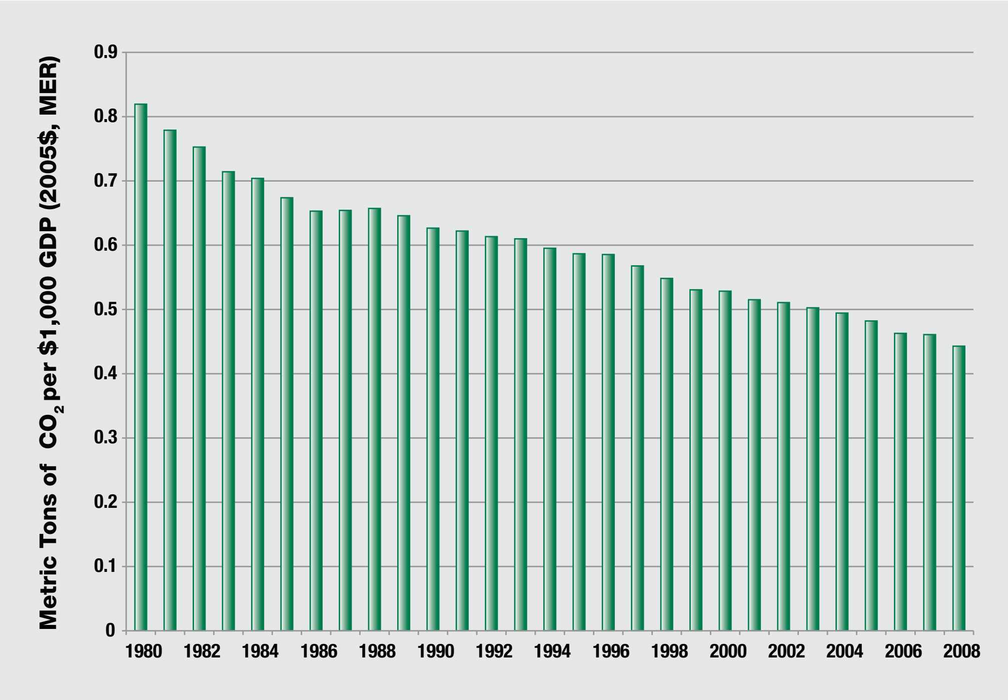


Source: EIA, Emissions of Greenhouse Gases in the U.S. 2009 and Monthly Energy Review

The next level of refinement in this analysis is to consider measures of greenhouse gas intensity; that is, the amount of greenhouse gases emitted per dollar of economic output. Whether to measure and compare energy and economic output on a purchasing power parity (PPP) basis or by market exchange rates (MER) is a subject of controversy among climate economists. Most lean toward using PPP, although Figure 16 uses MER. In any case, the figure shows that U.S. CO_2 intensity, which is really a proxy for energy intensity, has declined 46 percent since 1980.

Figure 16

U.S. Greenhouse Gas Emissions Intensity, 1980–2008

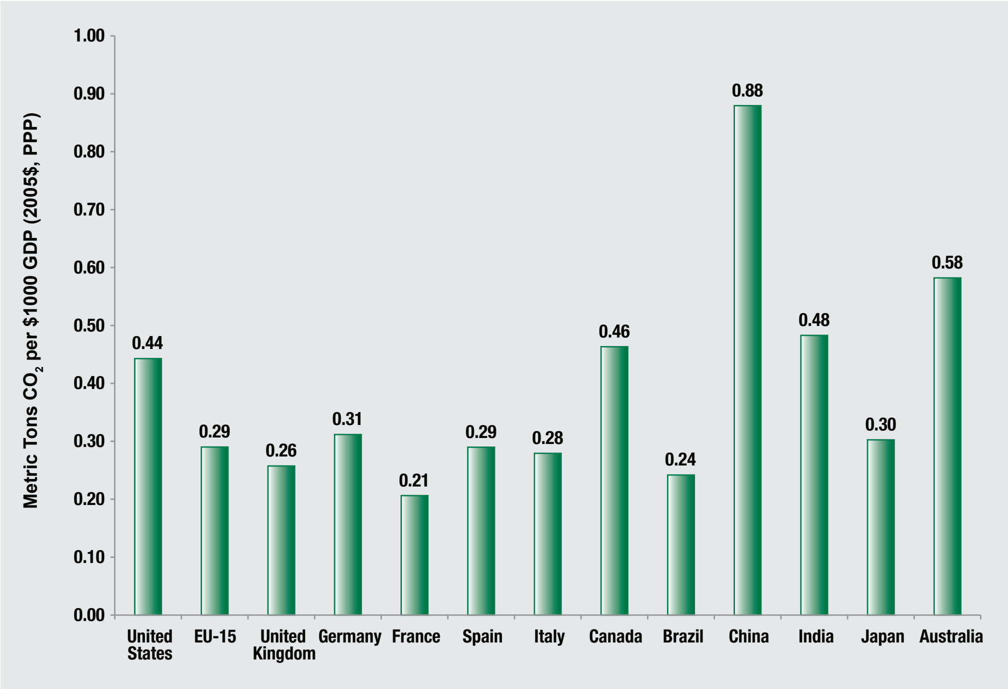


Source: EIA

The common but misleading view is that the United States is vastly less energy efficient than European nations. Figure 17 indicates that U.S. CO_2 emissions intensity is about one-third higher than EU-15 emissions intensity. In fact, when measured on an output-adjusted basis, American GHG intensity is only slightly higher than the figures for the wealthy EU-15 nations. The American climate is warmer than Europe's, and the larger geographical size of the U.S. requires us to use more energy transporting goods and people. When these differences are normalized, American and European energy use is more nearly equal.

Figure 17

CO_2 Emissions Intensity, 2008



Source: EIA

Going forward, the most useful metric to watch will be the rate of change in CO_2 emissions intensity. Here, the record of the United States is enviable. Since 1991—the year after the Kyoto Protocol benchmark was set—U.S. GHG intensity has declined by 28.8 percent, compared to 28.9 percent for the EU-15. (See Figure 18) Over the last five years, the improvement in U.S. GHG intensity appears to have been accelerating. The improvements in GHG intensity that Germany and the UK experienced are due partly to one-time extraordinary circumstances; in the case of the UK, decisions made prior to 1990 to make a transition from coal to natural gas for electricity generation accounts for much of the improvement, while Germany owes much of its improvement to the expedient of shutting down old inefficient facilities in the former East Germany after unification in 1991. By contrast, the comparable U.S. performance represents continuous improvements in efficiency.