Climate Change Science: What We Know

by Lydia Olander, Rob Jackson, Gabi Hegerl, and Nicole St.Clair
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NICHOLAS INSTITUTE FOR ENVIRONMENTAL POLICY SOLUTIONS
DUKE UNIVERSITY

What We Know

1. Scientists first described how accumulating carbon dioxide levels would raise Earth's temperatures, in the early 1800s.
2. The Earth is warming.
3. It is very likely current warming is due to human activity
4. The main uncertainty in predicting future climate change comes from uncertainty in projecting future demography and economics.
5. In addition to warming, there are numerous other impacts of climate change already being observed.
6. We can reduce future warming and its impacts through our actions.

1. Our Knowledge of Climate Change Is Not New

Our understanding of how the Earth's atmosphere traps heat began in the 19^{th} century and soon led to predictions of increased warming from human production of carbon dioxide (CO_2). In 1827, French mathematician Jean-Baptiste Fourier first used the greenhouse analogy to describe how the Earth's atmosphere stays warmer than the surrounding space by trapping infrared radiation. In the 1890s, the Nobel Prize-winning Swedish chemist Svante Arrhenius and American Scientist P.C. Chamberlain independently proposed that increasing CO_2 levels in the atmosphere from the burning of fossil fuels would warm the planet[i].

Direct measurements of atmospheric CO_2 began in 1958 on the top of Mauna Loa volcano in Hawaii, where the air is free of most pollution. Preindustrial (1700s) atmospheric levels of CO_2 were around 280 parts per million (ppm), by 1959 at Mauna Loa they were 316ppm and by 2003 they had reached 375ppm. Since 1958, the Mauna Loa measurements show that the concentration of CO_2 has increased over 18% and the rate of increase has accelerated from around ½% per year to 1% per year.[ii]

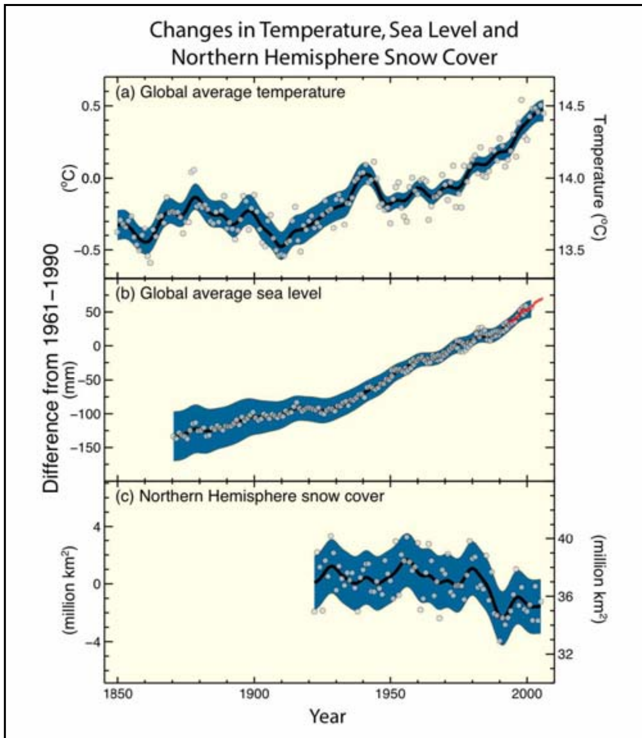

Figure 1. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated.

2. The Earth Is Warming

Direct observations show (a) increasing global average air and ocean temperature, (b) rising global sea level, and (c) widespread reductions in snow cover (Figure 1)[iii]. Extensive data also show changes in wind patterns, storm tracks, and the temperatures of extreme hot and cold periods. For every continent except Antarctica, where data are insufficient for an assessment, warming in the last 50 years has already occurred and is continuing.

Our understanding of the Earth's atmosphere and climate in the distant past relies on the remarkable ice-core record from Antarctica and Greenland as well as a wide variety of proxy data, such as tree rings, ice cores, fossil pollen, ocean sediments, corals and historical data. The ice-core record allows scientists to study actual bubbles of the Earth's atmosphere a million years into the past. In conjunction with these direct measurements of CO_2, the proxy data show consistent records of temperature across multiple proxies in different parts of the world. The IPCC states that the last time the polar regions were significantly warmer than they are now for an extended period, which was about 125,000 years ago, melting of polar ice led to 13 to 20 feet of sea level rise.

3. Current Warming Is Very Likely Due to Human Activity

The Earth's climate is affected by any change in the radiation (heat) entering or leaving the climate system. These changes may include:

- the amount of sunlight reaching Earth, as influenced by changes in the Earth's orbit relative to the sun or solar activity,
- the reflectance of the earth surface, as influenced by changes in ice and snow cover and land cover,
- the reflectance of the atmosphere, as influenced by changes in clouds or aerosols, and
- the amounts of atmospheric gases that absorb radiation (including carbon dioxide, methane, nitrous oxide, and ozone).

Although all of these factors, except the amount of sunlight reaching Earth, have been altered by human activity, the largest impact on climate by far in recent decades has been the increase in greenhouse gases. Since the start of the industrial revolution, carbon dioxide concentrations in the atmosphere have risen by almost 40%, methane concentrations have more than doubled, and nitrous oxide concentrations have increased ~15%. Carbon dioxide and nitrous oxide are long-lived gases, typically remaining in the atmosphere for more than a century once they are released; methane stays in the atmosphere for about a decade. Based on the ice core record, global atmospheric concentrations of carbon dioxide, methane and nitrous oxide today far exceed those seen for at least hundreds of thousands (~650,000 thousand) of years, possibly millions (~20 million), with most of the increase coming since industrialization[iv,v].

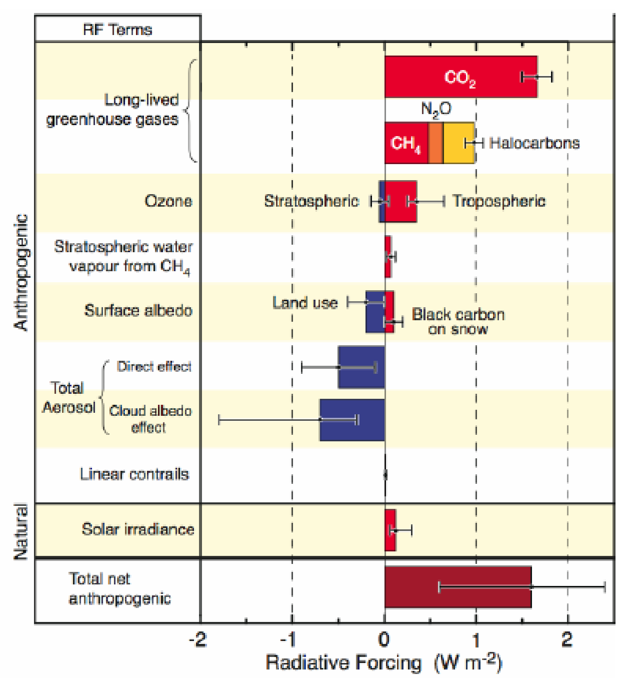

Figure 2. Global-average warming influence or "radiative forcing" (RF) estimates and ranges in 2005. The red to yellow, positive forcings lead to warming, while the blue, negative forcings lead to cooling. The only natural forcing is the small positive warming from solar irradiance. The final row shows the cumulative effect of the positive and negative forcing caused by human activities (anthropogenic).

The scientific consensus is that most of the observed increase in globally averaged temperature caused by increased production of greenhouse gases attributable to human activity. It is extremely unlikely that the recent warming can be explained by natural climate variability or natural influences on climate such as changes in solar variation or volcanic eruptions alone. The combined observations of widespread warming of the atmosphere and ocean, the observed global patterns of warming, and the observed loss of ice mass can only be simulated by including human activities.

4. Confidence in Models and Projections

Confidence in models has grown considerably. Results from all the main global models are converging and accurately describe the climate and atmospheric chemistry patterns both historically and today, including the recent warming trend as verified by measurements over the last 50 years and the data recorded in the ice cores and proxies. Uncertainties in predictions arise primarily from uncertainty in our future demographics and energy path.

Projections of future climate change depend upon many factors, including population and economic growth, as well as the trajectory of the world's energy choices. Multiple scenarios are run to cover the range of possible futures; each of these incorporate uncertainties inherent in the models. The latest projections for the 21st century show an additional increase in global temperature between 2.0 to 11.5 Fahrenheit (1.1 to 6.4 degrees Celsius)[vi]. Even if atmospheric concentrations of greenhouse gases were frozen at today's level, some warming would still occur in the next few decades due to the gases that have already accumulated and the slow rate by which natural processes remove them, but it is substantially less than projected if emissions continue to increase (see figure 3).

Projections of Future Warming

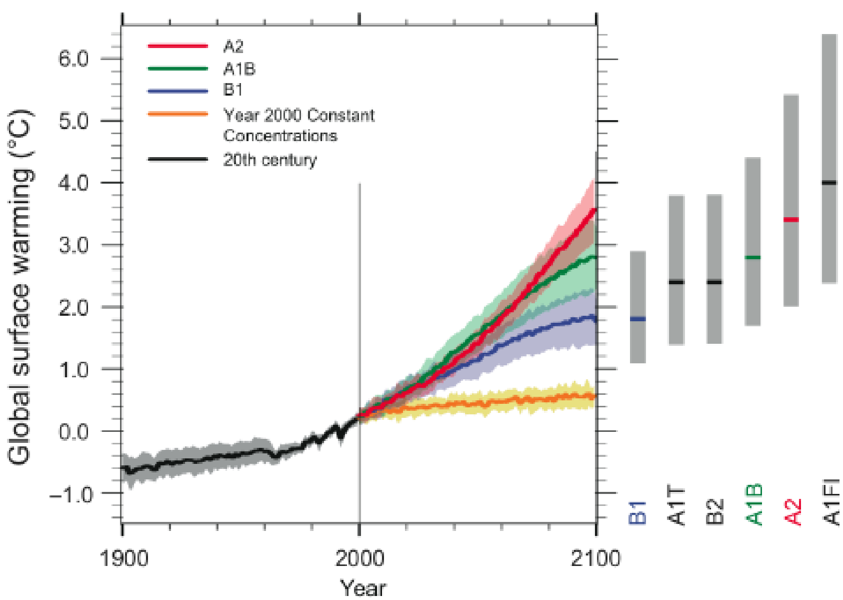

Figure 3. The orange line represents warming if atmospheric concentration were held constant at year 2000 levels. The others are projections of various scenarios:
A2 – population grows continuously, fragmented regional economies
A1B - rapid economic growth, population peaks mid century, rapid use of new efficient technology
B1 – population peaks mid century, rapid shift toward service and information economy, clean and efficient technologies
The gray bars on the right, represent the likely temperature ranges for these 3 scenarios plus 3 others run by IPCC.

The other sources of uncertainty are unforeseen thresholds in our climate system that may lead to abrupt changes and large feedbacks from initial warming, which are likely to further accelerate warming. Including feedbacks such as:

- the reduction in sea ice, a major reflective surface, causing the Earth to absorb more solar energy and increases warming and melting, and
- the melting and consequent decomposition of carbon rich permafrost soils resulting in large releases of carbon dioxide and methane (a powerful greenhouse gas, which causes 23x more warming than CO_2).

5. Observed and Predicted Climate Change Impacts

Climate change has numerous impacts, including sea level rise, increased fire frequencies, changes in storm patterns, and acidification of the world's oceans, which can degrade corals and the marine food web. Models predicting these responses to climate change are based on natural cycles and well known physical laws. They model changes we are already observing well and are being used to estimate possible changes in this century (table 1).

Table 1: Selected Impacts – Observations, Predictions, and Why it Matters[vii]

Impact	Observed	Predicted	Why it Matters
Sea level rise	Rate is increasing 1.8mm/yr 1962-2003 3.1mm/yr 1993-2003	200-600 mm rise in 21st century (by 2100)[viii]	Risk to coastal populations and infrastructure.
Ocean acidification[ix]	pH increase 0.1 units (30% increase in Hydrogen ions) in last 200 years	Ph increase up to 0.5 units (300% increase in H ions) by 2100. Greater than has been observed in hundreds of thousands of years.	Calcifying organisms like corals and plankton can be damaged and may decline. They are crucial in the ocean food web. Acidification will take tens of thousands of years to reverse once atmospheric levels of CO2 decline.
Ocean circulation (Atlantic-conveyor belt)		Likely to slow, but not very likely to have abrupt transition	Abrupt cooling in Europe less likely.
Sea ice in Arctic	Arctic sea ice extent shrunk 2.7% per decade (since 1978).	Arctic late summer sea ice in some projections disappears almost entirely by the latter part of the 21st century. Antarctic sea ice also declines.	• Increased coastal storm impact with no ice to block storms[x] • Improved navigation near poles, access to coastal resources (oil and gas) • Decline of polar bears and other species that depend on ice
Extreme temperatures	Extreme cold less common, extreme hot (heat waves) more frequent	Hot extremes become more frequent	Increased mortality in vulnerable population.
Precipitation and Droughts	Frequency of heavy precipitation events increased in most areas; More intense and longer droughts over wider areas, particularly in tropics and subtropics.	Heavy storms become even more frequent, particularly in high-latitudes, decreases in subtropical areas.	
Cyclones	Some observational evidence for increase in intensity (but not number) of tropical cyclone activity in N. Atlantic since 1970s, correlated with increased sea surface temperatures.[xi]	Cyclones become more intense, larger peak wind speeds and more precipitation associated	

6. The Worst Scenarios Can Still be Avoided

Climate change can be mitigated by reducing global emissions of greenhouse gases, by improving energy efficiency, and developing new energy technologies that either lower or eliminate emissions (e.g., clean coal with sequestration or renewables, such as wind, solar, and biofuels). There are many near-term (next 20 years) options that, if adopted globally, could help stabilize concentrations of greenhouse gases in the atmosphere [xii]. In addition to helping stabilize the climate, these options could dramatically improve air and water quality in the U.S. and the health of millions of people by reducing other pollutants.

We also need to adapt to the climate change already locked-in by current emissions levels. Already we have to relocate coastal communities in Alaska and Louisiana; and other actions will soon be needed.

[i] Jackson, R. 2002. The Earth Remains Forever: Generations at a Crossroads. University of Texas Press, Austin TX, pp.94,95.

[ii] Ibid and updated Mauna Loa data from http://cdiac.ornl.gov/ftp/ndp001/maunaloa.co2

[iii] Page 6. http://www.ipcc.ch/SPM2feb07.pdf IPCC (2007). Climate Change 2007: The Physical Science Basis: Summary for Policymakers.

[iv] Chaprter 8. Intergovernmental Panel on Climate Change. Climate Change 2001: The Scientific Basis. http://www.grida.no/climate/ipcc_tar/wg1/index.htm.
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Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.M. Barnola, I. Basile, M. Bender, J. Chappellaz, J. Davis, G. Delaygue, M. Delmotte, V.M. Kotyakov, M. Legrand, V.Y. Lipenkov, C. Lorius, L. Pepin, C. Ritz, E. Saltzman and M. Stievenard (1999). Climate and Atmospheric History of the Past 420,000 years from the Vostok Ice Core, Antarctica. *Nature*, **399**, 429-436.

[v] Page 3-4. http://www.ipcc.ch/SPM2feb07.pdf IPCC(2007). Climate Change 2007: The Physical Science Basis: Summary for Policymakers.

[vi] http://www.ipcc.ch/SPM2feb07.pdf IPCC(2007). Climate Change 2007: The Physical Science Basis: Summary for Policymakers.

[vii] All information from 2007 IPCC Summary unless noted. http://www.ipcc.ch/SPM2feb07.pdf
IPCC (2007). Climate Change 2007: The Physical Science Basis: Summary for Policymakers.

[viii] Prediction uses current rate of ice sheet melting, which may change, but cannot yet be well modeled.

[ix] Raven, J.A. et al. 2005. Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide. Royal Society, London, UK.

[x] All of these impacts detailed in The Arctic Climate Impacts Assessment 2004 http://www.acia.uaf.edu/

[xi] Multi-decadal variability complicates detection of trends over short time period of observations.

[xii] Pacala, S. and R.Socolow (2004). Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science*, **305**, 968 - 972
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Wigley, T.M.L., R. Richels, and J.A. Edmonds (1996). Economic and environmental choices in the stabilization of atmospheric CO2 concentrations. *Nature*, **379**, 240-243