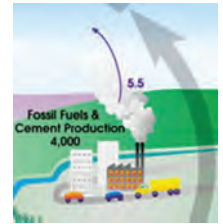


Carbon, climate change, and controversy

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Implications

- Carbon dioxide levels do show natural variability, but only since the industrial revolution have values moved beyond the “natural bound” of 270 to 280 ppm. Current levels are approximately 390 ppm.
- Global livestock production 1) appropriates around 3% of global net primary productivity, 2) leads to collateral carbon flows such as losses to the atmosphere by tropical deforestation for pasture and croplands, and 3) is a significant source of carbon dioxide emissions.
- Globally, livestock is the largest methane source emitter (third in the United States). Atmospheric methane is increasing, can linger in the atmosphere for ~9 to 15 years, and is more than 20 times more effective at trapping heat than carbon dioxide.
- Carbon losses associated with grazing systems could be reduced through proactive management to conserve vegetation cover/soil carbon storage and integration of climate fluctuations in livestock production systems.
- Human-related activities are a clear contributor to climate change, and changes are happening on time scales much shorter than natural climate changes.
- Humans may not perceive that average temperatures are warmer in 2100, but they will notice when coastal cities are facing sea level rise, days exceeding 100 degrees Fahrenheit increase, food prices fluctuate because of changing crop yields or livestock productivity, or diseases appear in new latitudes because of a more favorable climate.
- The apparent controversy over climate change is rooted in a campaign by special interests to create reasonable doubt (e.g., tobacco industry and smoking) or basic lack of understanding of simple climate, science, and statistical principles.
- Climate change will also affect livestock production and practices.
- Sustainable pathways exist to reduce atmospheric carbon loading.

Key words: carbon, carbon cycle, carbon footprint, climate change, methane

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Introduction

This article provides a contemporary discussion on carbon and climate change. The primary goals are to provide 1) a current description of carbon cycle processes, 2) insight on the relative contribution of natural and human sources, with a particular emphasis on implications for livestock communities, 3) an understanding of linkages between atmospheric carbon and climate change, 4) perspective on apparent controversies related to the climate change discussion, and 5) thoughts on pathways forward.

What Are Carbon and the Carbon Cycle?

Nitrogen is the most abundant element in Earth’s atmosphere, and oxygen is the most important element for human life because we need it for respiration. Carbon, the fourth most abundant element in the universe, is also critical to life on Earth. In the form of diamonds, carbon is one of the strongest materials on the planet, but it is a building block of fragile life. Some basic characteristics of carbon include

- Chemical element with symbol C
- Atomic number 6
- Nonmetallic, tetravalent (4 electrons are available to form covalent chemical bonds)
- Three naturally occurring isotopes
- Molecular variants (allotropes) include diamonds, graphite, and amorphous carbon.

Carbon, like water, cycles continuously within the Earth system. One atom may need millions of years to traverse this complex circuit (Figure 1). Carbon travels through the atmosphere, lithosphere, hydrosphere, and biosphere and thus represents one of Earth’s primary biogeochemical cycles. Two categories of the carbon cycle are known: 1) the geological category, which accounts for time scales on the order of millions of years and 2) the biological-physical category, which operates at time scales ranging from days to thousands of years. Herein, the discussion will primarily refer to the biological-physical carbon cycle and its exchanges with the atmosphere (i.e., exchanges of carbon dioxide, methane, carbon monoxide, volatile organic compounds, and so on). Canadell et al. (2010) provided a review of the carbon cycle, human activity, and the climate system, and this review is a recommended starting point for key areas of emphasis related to the carbon-climate-human system and future needs.

Through photosynthesis, vegetation absorbs the energy of the sun and removes carbon dioxide (i.e., a “sink”) from the atmosphere. The amount of solar energy converted is characterized as net primary productivity (NPP). Net primary productivity is a representation of the primary source of food for organisms on Earth that require preformed organic compounds for food and energy (Imhoff et al., 2004). Imhoff and colleagues have called NPP “a common currency” for accounting for the impact of land

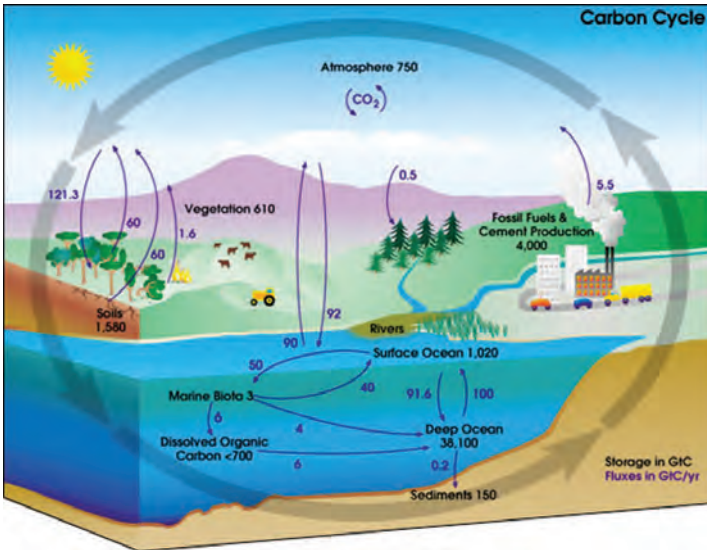


Figure 1. The carbon cycle. Storage terms (GtC) are in black, and fluxes (GtC/yr) are in purple. GtC is gigatons of carbon (source: NASA).

transformation on the climate system. Figure 2 indicates that humans are consuming an increasing quantity of the planet’s land plant production for food, biofuels, and other human activities.

In terms of carbon and perhaps relevant to this readership community, Asner and Archer (2010) reported that global terrestrial NPP is about 57 billion metric tons. They also noted that “global livestock production (1) appropriates around 2 petagrams (Pg) C, or 3% of global NPP, (2) leads to collateral carbon flows like losses to the atmosphere by tropical deforestation for pasture and croplands, and (3) is a significant source of carbon dioxide emissions.” Asner and Archer (2010) further stated that

carbon losses associated with grazing systems could be reduced through proactive management to conserve vegetation cover/soil carbon storage and integration of climate fluctuations in livestock production systems.

During photosynthetic exchanges, carbohydrates are created. Plants, humans, and animals, through respiration, consume carbohydrates for metabolism, and this releases carbon dioxide (i.e., a source) to the atmosphere. Decomposition of organic matter also cycles carbon to the lithosphere and the atmosphere. Figure 3 is an illustration of a Keeling curve, where the seasonal cycle of the aforementioned processes is evident in the oscillating time series of atmospheric carbon dioxide (Keeling et al., 1995). One might consider this process an analogue to the Earth “breathing.” Another land process that contributes carbon is fire, which produces carbon dioxide, methane, and black carbon particulate matter through the consumption of biomass and organic material. van der Werf et al. (2010) reported that during the period 2001 to 2009, “most fire carbon emissions were from fires in grasslands and savannas (44%) with smaller contributions from tropical deforestation and degradation fires (20%), woodland fires (mostly confined to the tropics, 16%), forest fires (mostly in the extratropics, 15%), agricultural waste burning (3%), and tropical peat fires (3%).” van der Werf et al. (2010) also suggested that in the case of reduced trace gases (e.g., CO and CH₄), processes like deforestation, degradation, and peat fires were likely more important contributors.

The ocean is also a major component of the carbon cycle. Oceans are major sinks for carbon because carbon dioxide dissolves quite easily into water, depending on its temperature and current carbon storage. Interestingly, cold ocean waters will take in more carbon dioxide from the atmosphere, whereas warm ocean waters will release carbon dioxide to the atmosphere. One can easily envision a “positive feedback” if a carbon dioxide-enriched atmosphere is causing both atmospheric and oceanic warming. Additionally, cold, downward currents redistribute carbon dioxide to the deep ocean. Warm, upward currents carry carbon dioxide to

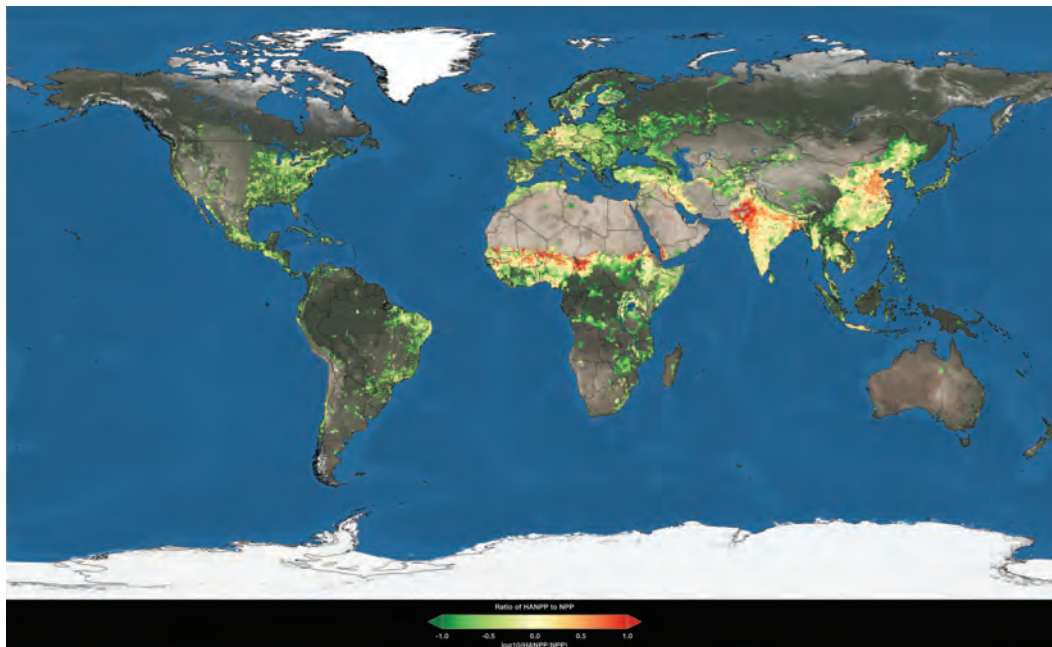


Figure 2. Total consumption by region of photosynthetic plant material as a percentage of the plant material grown by region. The plant “supply” is net primary production (NPP), and the “demand” is Human Appropriation of Net Primary Production (HANPP). (Credit: Trent Schindler, Scientific Visualization Studio, NASA’s Goddard Space Flight Center).

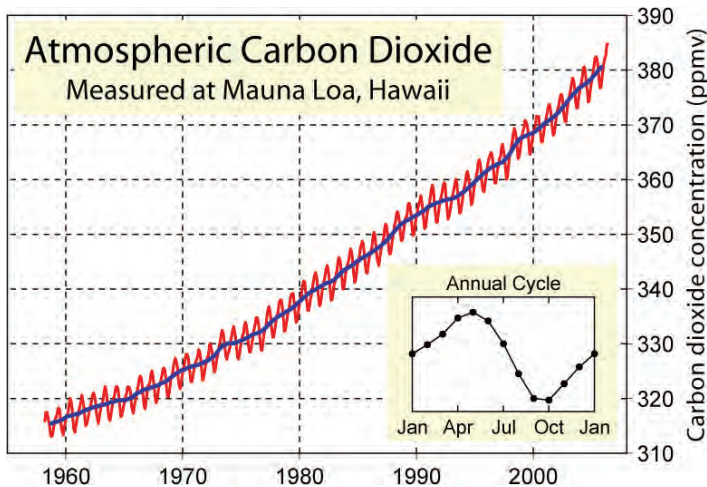


Figure 3. The Keeling curve illustrating trends in atmospheric carbon dioxide in parts per million by volume (ppmv; source: <http://mydasdata.larc.nasa.gov>).

the surface and eventually to the atmosphere. Phytoplankton in the ocean are also a source for carbon dioxide but unlike more stable land-based carbon storage systems (e.g. trees), there is rapid variation in the ocean. Phytoplankton are consumed by respiring zooplankton in days (rather than years) and a small residual of carbon is left at the ocean bottom. Still, over time, this process can result in significant carbon removal (NASA; <http://earthobservatory.nasa.gov/Features/CarbonCycle/>).

The Human Footprint on the Carbon Cycle

The carbon cycle is a delicate part of the Earth system, and increasingly the human or anthropogenic footprint is apparent. In the contemporary discussion of climate change, one fact is very clear and not debatable; human activities have altered the carbon cycle, particularly the atmospheric component. According to data from the National Oceanic and Atmospheric Administration (NOAA) Paleoclimatology and Earth System Research Laboratory, both carbon dioxide and methane levels have increased by 38 and 148%, respectively, as of 2009, above preindustrial levels. Researchers in Purdue University's Vulcan project (with NASA and the Department of Energy funding through the North American Carbon Program, <http://www.nacarbon.org/nacp/>) have developed the capacity to display greenhouse gas emissions hourly and for different geographic regions. Figure 4 clearly illustrates the strong influence of human activity (e.g., urbanization, transportation corridors) on carbon dioxide emissions. The interested reader can also use NOAA's Carbon Tracker (<http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/>) to monitor carbon.

Widespread use of fossil fuels began around 1750 with the Industrial Revolution, and the trajectory has been upward since then. Other human activities affecting the atmospheric part of the carbon cycle include deforestation, agricultural and livestock activities, and urbanization. Burning fossil fuels accelerates the flux of carbon dioxide into the atmosphere such that natural processes like sedimentation are not able to serve as an offset. Likewise, removal of natural carbon sinks through land clearing, deforestation, and urbanization also contributes to increased atmospheric carbon. Figure 5 represents the approximate budget of carbon exchanges in the Earth's system.

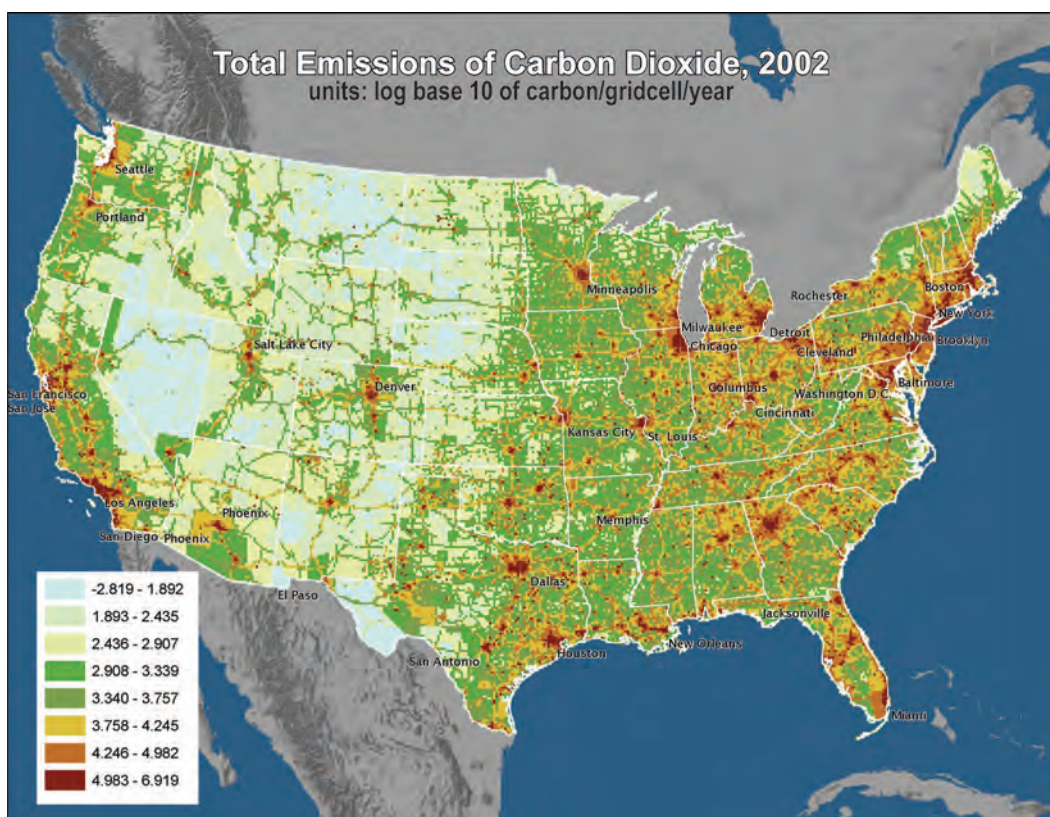


Figure 4. Carbon dioxide emissions for 2002 in the United States (source: NASA, Purdue University, and Department of Energy, Vulcan Project). Courtesy of Kevin Gurney and the Vulcan Project (Credit: C. C. Miller), Purdue University. Support provided by NASA (CARBON/04-0325-0167) and USDOE (DE-AC02-05CH11231).

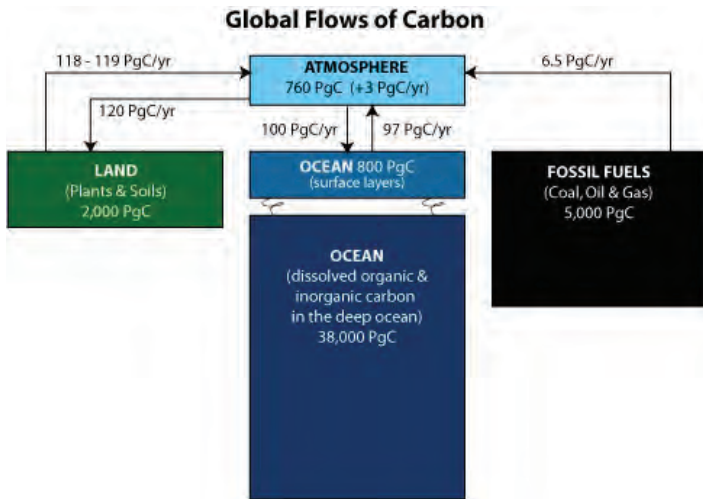


Figure 5. Carbon flows in the Earth system (Source: NASA). Note: 1 Pg = 1 petagram = 1×10^{15} g = 1 billion metric tons; 1 kg of carbon (C) = 3.67 kg of carbon dioxide (CO₂).

The global carbon stock in Figure 5 is estimated and will exhibit annual variability but certainly indicates the role of fossil fuels. Interestingly, scientists have become accountants, but rather than trying to balance monetary accounts, they have tried to solve the mystery of the “missing” carbon. When accounting for carbon sources, sinks, natural process, and anthropogenic contributions, the carbon budget does not balance.

In fact, there is an excess of carbon. Contemporary debate centers on locating regions or pathways for the missing carbon flux. Some have speculated that reforestation in the Northern Hemisphere over the last century could explain the missing carbon (Sedjo, 1993). Others have noted that climate change could cause greater uptake than carbon release. Even more challenging is the fact that predictions of greenhouse gas emissions (from the IPCC Special Report on Emission Scenarios, <http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf>) vary from a level that is over 5 times larger than the current flow to a reduction by 2100 (Melenberg et al., 2011).

Additionally, it is quite evident from Figure 6 and Figure 3 that although carbon dioxide levels do show natural variability, only since the industrial revolution have values moved beyond the “natural bound” of 270 to 280 ppm. In December 2009, the global atmospheric carbon dioxide concentration was ~390 ppm, according to Tans and Conway (2010), which exceeds the level in Figure 6. The Global Carbon Project (<http://www.globalcarbonproject.org>) issues periodic assessments of the carbon budget. Friedlingstein et al. (2010) noted that the global atmospheric carbon dioxide growth rate over the period 2000 to 2009 was 2.5% per year compared with 1% per year from 1990 to 1999 (Figure 7).

Le Quéré et al. (2009) note that increased atmospheric carbon dioxide emissions are likely due to increased contributions from emerging economies, production and international trade of goods and services, and continued use of coal as a fuel source. Studies also indicate that emissions from land use change have remained fairly constant over the past decade or perhaps even declined (Friedlingstein et al., 2010).

Methane Versus Carbon Dioxide

Although carbon dioxide and water vapor are likely the most important greenhouse gases in the atmosphere, methane is also increasing. The

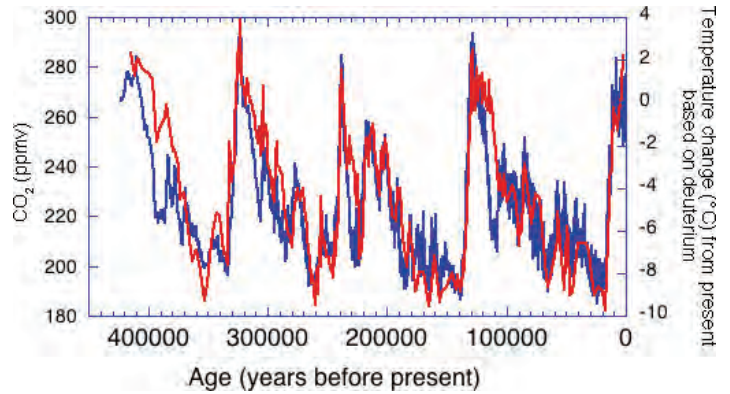


Figure 6. Carbon dioxide levels over the past 350,000 years (source: NOAA NCDC). Red represents CO₂, and blue represents temperature variation.

problem with methane is that it can linger in the atmosphere for approximately 9 to 15 years and is more than 20 times more effective at trapping heat than carbon dioxide (CO₂). There is likely a human component as approximately 50% of methane emissions are attributed to “fossil fuel production, animal husbandry (enteric fermentation in livestock and manure management), rice cultivation, biomass burning, and waste management,” according to the US Environmental Protection Agency (EPA, <http://www.epa.gov/outreach/sources.html>). About 40% of methane sources are natural (Heimann, 2010). The major natural emission sources include anaerobic decomposition of organic carbon in wetlands, termites, wild and domesticated animals, wildfires, and geological sources. Additionally, McGuire et al. (2010) is a comprehensive source for current assessments of how methane hydrates in permafrost may be contributing to the atmospheric carbon load due to thawing at high latitudes. Figure 8 provides an excellent summary of emission sources over the past 2 decades.

Of particular interest to this readership community is animal and livestock impacts. Globally, livestock is the largest methane source emitter (third in the United States). Gill et al. (2010) argued that livestock contribute directly [i.e., as methane and nitrous oxide (N₂O)] to about 9% of global anthropogenic greenhouse gas emissions. The EPA states that

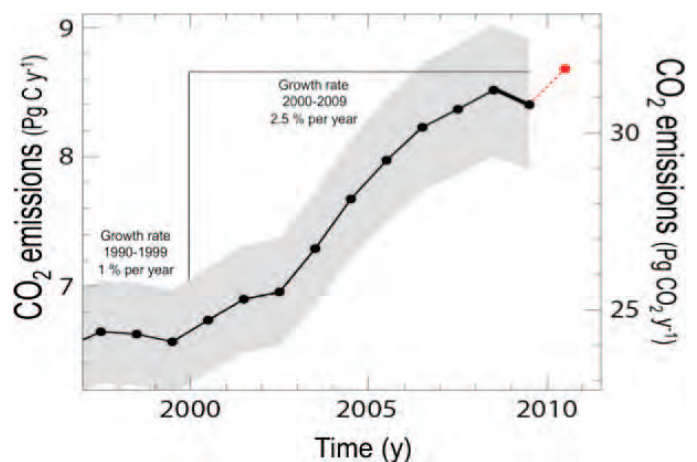


Figure 7. Carbon dioxide growth rates and variance (shading) (1997 to 2009). Source: Friedlingstein et al. (2010).

Table 1 U.S. Methane Emissions by Source (TgCO₂ Equivalents)

Source Category	1990	2000	2005	2006	2007	2008	2009
Natural gas systems	189.8	209.3	190.4	217.7	205.2	211.8	221.2
Enteric fermentation	132.1	136.5	136.5	138.8	141	140.6	139.8
Landfills	147.4	111.7	112.5	111.7	111.3	115.9	117.5
Coal mining	84.1	60.4	56.9	58.2	57.9	67.1	71
Manure management	31.7	42.4	46.6	46.7	50.7	49.4	49.5
Petroleum systems	35.4	31.5	29.4	29.4	30	30.2	30.9
Wastewater treatment	23.5	25.2	24.3	24.5	24.4	24.5	24.5
Forest land remaining forest land	3.2	14.3	9.8	21.6	20	11.9	7.8
Rice cultivation	7.1	7.5	6.8	5.9	6.2	7.2	7.3
Stationary combustion	7.4	6.6	6.6	6.2	6.5	6.5	6.2
Abandoned underground coal mines	6	7.4	5.5	5.5	5.6	5.9	5.5
Mobile combustion	4.7	3.4	2.5	2.3	2.2	2	2
Composting	0.3	1.3	1.6	1.6	1.7	1.7	1.7
Petrochemical production	0.9	1.2	1.1	1	1	0.9	0.8
Iron and steel production & metallurgical coke production	1	0.9	0.7	0.7	0.7	0.6	0.4
Field burning of agricultural residue	0.3	0.3	0.2	0.2	0.2	0.3	0.2
Ferroalloy production	+	+	+	+	+	+	+
Silicon carbide production and consumption	+	+	+	+	+	+	+
Incineration of waste	+	+	+	+	+	+	+
International bunker fuels	0.2	0.1	0.1	0.2	0.2	0.2	0.1

Figure 8. United States methane emissions by source (TgCO₂ equivalent). Source: http://www.epa.gov/climatechange/emissions/downloads11/US-GHG-Inventory-2011-Complete_Report.pdf.

“among domesticated livestock, ruminant animals (cattle, buffalo, sheep, goats, and camels) produce significant amounts of methane as part of their normal digestive processes. In the rumen, or large forestomach, of these animals, microbial fermentation converts feed into products that can be digested and utilized by the animal. This microbial fermentation process, referred to as enteric fermentation, produces methane as a by-product, which can be exhaled by the animal.”

The website <http://epa.gov/climatechange/emissions/usinventoryreport.html> has a wealth of information on methane emissions from livestock enteric fermentation and how they are estimated (i.e., the chapter titled “Agriculture”). Additionally, options for reducing methane emissions from enteric fermentation and potentially useful resources/tools can be found at <http://www.epa.gov/outreach/rlep/index.html>.

Livestock manure management, through anaerobic (i.e., without oxygen) decomposition of organic material in livestock manure management systems, is a significant source as well. Lagoons and holding tanks commonly used in large dairy and swine facilities are known sources of methane, along with manure used on fields and pastures. Pasture and field applications tend to be insignificant sources in dry form. The US inventory report (link above) provides more information on these sources. Readers may also be interested in the EPA AgSTAR Program, which according to its website, “encourages adoption of anaerobic digestion technologies that recover and combust biogas (methane) for odor control or as an on-farm energy resource, <http://www.epa.gov/agstar/>.”

Gill et al. (2010) noted that “If all parts of the livestock production lifecycle are included (fossil fuels used to produce mineral fertilizers used in feed production and nitrogen emissions from fertilizer use; methane

release from the breakdown of fertilizers and from animal manure; land-use changes for feed production and for grazing; land degradation; fossil fuel use during feed and animal production; fossil fuel use in production and transport of processed and refrigerated animal products), livestock are estimated to account for 18% of global anthropogenic emissions.” Pitesky et al. (2011) has challenged the 18% number, which was based on a full life-cycle analysis for livestock even though the same analysis was not conducted for other greenhouse gas sources. It is important to clarify this point because, as Crystal Powers from the University of Nebraska–Lincoln states, “we do not want to perpetuate the myth that eating a hamburger is worse for the environment than driving an over-sized sports utility vehicle, when the comparisons were not done equally.”

Whereas much of the aforementioned discussion considers the impact of livestock on climate change, Reynolds et al. (2010) discussed the impacts of climate change on livestock production. They discussed implications such as impacts on forage yields, feedstuff quality, availability and cost, water availability, thermal stress and related welfare issues, plus disease spread and control. Reynolds et al. (2010) particularly mentioned how changing climate would affect 1) the suitability of land, 2) availability of land due to sea level rise, 3) water availability and quality, and 4) production efficiencies under drought conditions. Such carbon-climate-human systems feedbacks are equally important as the physical climate changes.

Atmospheric Carbon and Changing Climate

It is increasingly clear that loss in efficacy of natural carbon sinks and increased human activity is accelerating atmospheric accumulations of carbon (Canadell et al., 2007; Raupach et al., 2008; Le Quéré et al., 2009). The looming question is how the increasing greenhouse gas stock in the atmosphere will affect the Earth’s climate. Climate change can be defined as any change in some statistical property of atmospheric variables or phenomena. Examples might include, but are not limited to, increased mean global temperatures, changes in the frequency/intensity of floods or droughts, urban heat islands, or volcanic-induced cooling. It should be noted that, in the aforementioned examples, greenhouse gases were the source of attribution. Climate changes on many different scales ranging from billions of years to sub-decadal and varies spatially across the globe. In the state of Georgia (United States), Assistant State Climatologist Pam Knox stated that “during the last Ice Age, Georgia probably experienced a climate somewhat wetter and cooler than we have today.” She went on to say that “models indicate that average annual rainfall was about 63 inches and the annual average temperature was 56.3°F, compared with modern values of 51 inches and 63.5°F.” The Earth’s climate changes because of a variety of factors: solar variability, orbital changes, atmospheric turbidity, changes in land configuration/surface characteristics, and changes in radiation-absorbing gases.

The major ice ages, for example, can be strongly linked to variations in Earth’s orbital mechanics: eccentricity, precession, and tilt (so-called Milankovitch cycles, Bennett, 1990). Additionally, solar activity varies in 11-year intervals but does not adequately explain recent trends in temperature over the past 150 years (IPCC, 2007). So, when someone asks the question, “Doesn’t climate change naturally?” the answer is “Well, of course it does.” The more salient question is whether current changes (and the rate of change) can be linked to increased loading of atmospheric carbon due to humans. Figure 6 suggests that atmospheric temperature

is associated with atmospheric carbon dioxide, and simple extrapolation would point toward a globally warming climate.

Climate has changed in the past, but the fundamental issue that has been somewhat muted is that the rate of change of atmospheric carbon and warming is alarming. The planet’s atmosphere warms because of positive radiative forcing (i.e., more energy is entering or remaining in the climate system than leaving it). Increased concentrations of greenhouse gases lead to greater positive forcing. A good analogy is the excessive warming on Venus, which has an atmosphere composed of ~97% carbon dioxide. Former NASA-Goddard Director of Earth Sciences Franco Einaudi has spoken about the following fundamental concerns:

- “The forcing that triggered the transition from glacial to interglacial periods was of the order 0.25 watts per square meter (a measure of power per unit area, W/m²).
- The forcing applied since 1750 is about 1.5 W/m² which is larger than 0.25 W/m².
- Forcing since 1750 has been acting over time scales of decades, not tens of thousands of years.
- The temperature already has values close to the maxima on record in the last thousands of millennia.
- The rate of temperature increase since the beginning of the industrial revolution is unprecedented.”

Figure 9 indicates that without anthropogenic forcing, climate models cannot reproduce current trends in observed temperature. This finding is evidence that both natural and human processes are driving the warming trend. As such, IPCC (2007) stated unequivocally that most of the global warming in the past 5 decades is very likely (odds 9 out of 10) due to human increases in greenhouse gases.

But Are We Missing the Point?

It is evident that our atmosphere is warming in response to natural and human forcings, but I argue that we miss the point by focusing on “global warming.” The Earth’s response to the warming now is a more compelling discussion. Too much emphasis is placed on the degree of

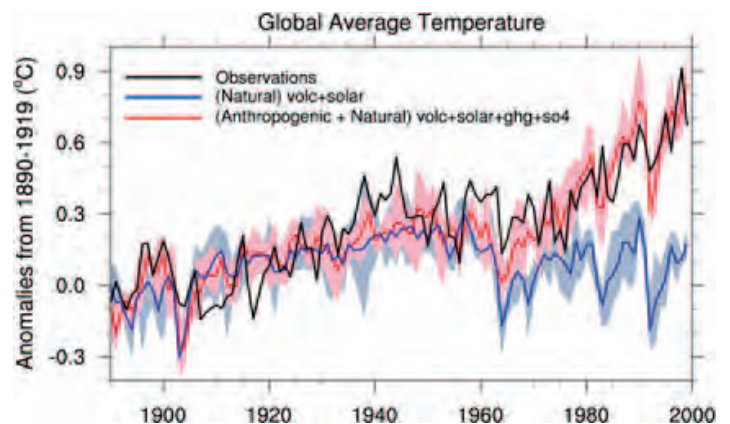


Figure 9. Model output of natural and human climate forcing and the observed trend [figure courtesy of University Corporation for Atmospheric Research (UCAR) as adapted from the IPCC, 2007].

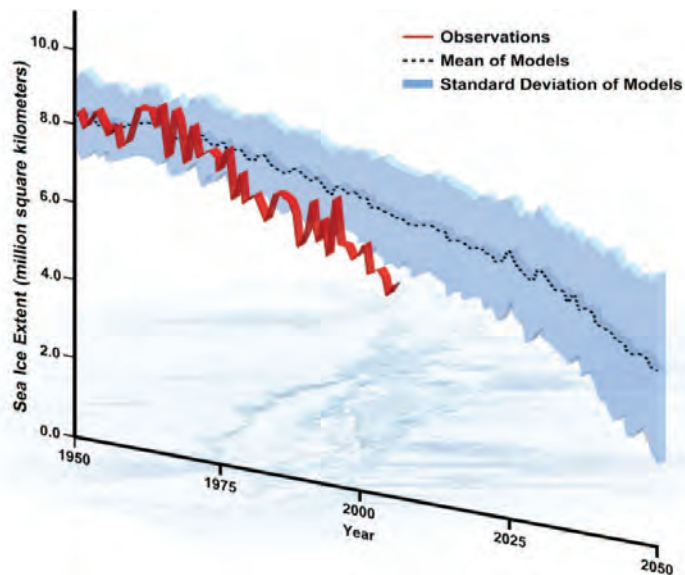


Figure 10. Observed and modeled sea ice extent [source: National Center for Atmospheric Research (NCAR)].

warming. *I am still seeking a person that will “perceive” that the average global temperature is 3 degrees warmer in 2100, but they will certainly notice when coastal cities are facing sea level rise, cereal prices fluctuate due to changing crop yields, or diseases appear in new latitudes because of more favorable climate.*

Mote (2007) reported dramatic melt rates in Greenland. Extreme hydroclimate events (i.e., floods, droughts, hurricanes, winter storms, thunderstorms) are increasing in intensity and frequency (Del Genio et al., 2007; Shepherd and Knutson, 2007; Shepherd et al., 2010; Knutson et al., 2010). Seasonal sea ice losses (red line) are exceeding worst-case scenario trends (Figure 10) such that merchant ships recently sailed from Japan to Europe via the Northeast Passage of the Arctic Ocean.

Such changes have caused many climate scientists to move beyond the “if climate change is occurring due to humans” argument to “have we reached or surpassed a tipping point” argument. *A tipping point is essentially an irreversible, on practical time scales, climate impact* (e.g., the melting of Greenland or thawing of permafrost). A critical question is whether we have surpassed a tipping point, or is there some atmospheric carbon dioxide threshold yet to be exceeded (e.g., 450 ppm)? Additionally, numerous broader impacts in agricultural, public health, ecosystems, and national security sectors among others are directly affected by a changing climate. A few examples should suffice. Ainsworth and Ort (2010) discussed recent associations among crop yields, atmospheric carbon dioxide, and climate change. The US National Research Council Committee on National Security Implications of Climate Change for U.S. Naval Forces (2011) recently issued a report on the national security implications of climate change for US naval forces. It found clear concerns related to declining Arctic sea ice, sea level rise, humanitarian relief, and political instability, among many other topics of interest. The report is available at http://www.nap.edu/catalog.php?record_id=12914. The American Meteorological Society recently initiated a new scholarly journal called *Weather, Climate, and Society* (<http://www.ametsoc.org/pubs/journals/wcs/index.html>).

So Why the Controversy?

Clearly, the Earth’s climate system is responding to increased rates of carbon loading in the atmosphere. Yet, there appears to be controversy. Before offering my concluding remarks, I would like to personally reflect on the controversy because it will influence scientific, public, and political action on carbon and climate in the future.

Consensus

Oreskes (2007) established that peer-reviewed literature publications on this topic are in consensus. Yet, the non-peer-reviewed material on blogs, websites, and other media outlets has created the impression of vast disagreement. The peer review process allows scientific findings to be vetted and challenged in a forum so that error-filled, biased, or tainted studies do not get published. A very small percentage of peer-reviewed literature has provided a serious challenge to the consensus of evidence that has been published. However, some misinformation that has proliferated comes from so-called experts that, in some cases, are not publishing or current in climate science. There are also efforts by certain industries to create doubt using official-looking studies from “experts” that are not rigorously peer-reviewed. Here, it is important to remember what noted author Upton Sinclair said: “It is difficult to get a man [or industry] to understand something, when his salary depends upon his not understanding it (Sinclair, 1935).”

Climate Versus Weather

It is amusing how often someone asks me, “Why is it cold? Where is all of this snow coming from? What about the NE blizzard? What happened to global warming?” In a warmer climate, we will still have winter and cold weather, even snowstorms. Further, weather represents a realization of day-to-day, week-to-week variability in atmospheric conditions, whereas climate represents statistical properties of atmospheric conditions for a location or time period (e.g. average, extremes, variability). Paul Dirmeyer, a scientist at the Center for Ocean-Land-Atmosphere Studies (Calverton, MD), put it nicely: “Picture a bell curve for daily temperatures, cold on left tail, hot on right tail, most values in the middle. All indications from climate change projections are that the cold tail pretty much stays put while the hot tail stretches out to hotter values. That moves the mean/median (average) a bit warmer/milder, increases the variability (spreads out the curve wider), yet we still get cold snaps and winter weather about as severe as ever.”

Humans Cannot Change the Climate

Numerous examples refute the skeptic’s claim that humans cannot alter climate. Among these are that 1) cities are warmer than rural areas because of manmade materials like asphalt and other heat-storing materials (i.e., urban heat island), 2) the ozone hole can be attributed to chlorofluorocarbons in refrigerants and spray cans used in previous decades, and 3) high pollution or “photochemical” smog days are directly linked to human activities.

Climate Change Consequences and Solutions Are Not on 2-, 4-, or 6-Year Cycles

Political systems are often configured for rapid solutions so there is often no perceived political capital in acting on climate change, which is often thought to be distant in time or space. Interestingly, a recent

study (Spence et al., 2011) indicated that people's perception of climate change is modified when they experience a weather-related disaster. This is consistent with the notion that people understand things that are easily perceptible to them. For example, most people can identify with someone carrying symptoms of the flu virus, perhaps even the H1N1 virus. Thus, the public health problem is perceived to be clear, and public health warnings may not readily be challenged. Climate change attribution is not always so easy to achieve.

Uncertainty

It is imperative that the public understands that words like “uncertainty” or “probability” are not bad. It is unlikely that models will ever produce perfect projections, yet some skeptics have used the word “uncertainty” to cast doubt on climate models, data, or scientific credibility. Global climate models (GCM) have known deficiencies but are still capable of reproducing past, present, and future climate states (Smith et al., 2007). Global climate models are fundamentally different from weather prediction models, which attempt to produce realizations of the atmosphere on 1- to 10-day time frames. Because GCM are projecting climate states, the following statement is also not well-informed: “Weather models degrade in skill beyond 2 weeks, so how can we trust 50- to 100-year projections?” Additionally, each day the public consumes data that contain uncertainty. For example, when a hurricane is approaching landfall, there is usually a cone of uncertainty placed around the point of expected landfall. Another example is the percent chance of rainfall. If the meteorologist says “there is an 80% chance of rain,” most people will probably grab an umbrella.

Trends

Assessing climate trends requires long-term records. There are inevitably peaks and valleys in any data series over short periods of time, even as the overall trend has a clear tendency. Intermittent periods of “level-off” or decline in the data records (see previous figures) do not refute that an increasing trend may be evident, so we must be careful not to focus on short time spans to draw a conclusion. For example, in any given 2-week period, the Dow Jones Index (a major stock market index in the United States) may trend downward. Yet, any good investor or analyst knows that the market, for the year, has a very good chance of finishing much higher than that 2-week period.

Consilience

Oreskes (2007) speaks about the word “consilience.” In an era of “climategate e-mail scandals” and targeted campaigns to “create reasonable doubt,” consilience is a powerful term. Consilience is essentially the notion that different research groups, methodologies, or datasets from around the world arrive at similar conclusions. This suggests that even if one study or scientist is questionable, a large body of peer-reviewed, public research still supports the notion of anthropogenic climate change and its consequences.

What Do We Do Now?

At this point, the natural question is “What next?” In order to achieve reductions in the rate of accumulation of atmospheric carbon dioxide, Canadell et al. (2010) argued for “the delivery of routine updates

of global and regional carbon budgets, including its attribution of variability and trends to underlying drivers; secondly, the assessment of the magnitude of the carbon–climate feedback; and thirdly, the exploration of pathways to climate stabilization and their uncertainties.” It is particularly important to understand the uncertainties associated with various wedges that have been proposed to populate the so-called stabilization triangle (Pacala and Socolow, 2004) required to halt or reverse current emission trends. Such wedges might include carbon capture and sequestration, renewable energy, high-efficiency appliances, nuclear energy, altered land use practices, and others. As Canadell et al. (2010) also noted, “underpinning much of this research is the optimal deployment of a global carbon monitoring system that includes biophysical and socio-economic components.”

Further, a larger degree of uncertainty exists concerning carbon pools and processes. Many are poorly understood or not represented in current earth/climate modeling systems. This is likely a primary driver of model spread in climate projections (Huntingford et al., 2009). Some unresolved issues are related to decomposition processes, vulnerability of methane hydrates to temperature change and resource extraction, climate-ozone-ocean interactions, and drought-deforestation associations with land emissions (Cochrane and Laurence, 2008; Schuur et al., 2009; Lenton et al., 2009).

Even with such improvements, is it too late? Zeke Hausfather, a contributor to the Yale Forum on Climate Change (<http://www.yaleclimatemediaforum.org/2010/12/common-climate-misconceptions-atmospheric-carbon-dioxide/>) recently wrote an intriguing discussion noting that “while much of the ‘pulse’ of extra CO₂ accumulating in the atmosphere would be absorbed over the next century if emissions miraculously were to end today, about 20% of that CO₂ would remain for at least tens of thousands of years.” He went on to remark that “while a good portion of warming attributable to carbon and other greenhouse gas emissions would be removed from the atmosphere in a few decades if emissions were somehow ceased immediately, about 10% will continue warming Earth for eons to come. This 10% is significant, because even a small increase in atmospheric greenhouse gases can have a large impact on things like ice sheets and sea level if it persists over the millennia. So, is it too late?” For our sake, let us hope not.

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