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Global climate change: a new type of environmental problem

1.1 The climate-change controversy

Of all the environmental issues that have emerged in the past few decades, global climate change is the most serious, and the most difficult to manage. It is the most serious because of the severity of harms it might bring. Many aspects of human society and well-being – where we live, how we build, how we move around, how we earn our livings, and what we do for recreation – still depend on a relatively benign and narrow range of climatic conditions, even though this dependence has been reduced and obscured in modern industrial societies by their wealth and technology. This dependence on climate can be seen in the economic harms and human suffering caused by the climate variations of the past century, such as the "El Niño" cycle and the multi-year droughts that occur in western North America every few decades. Climate changes projected this century are much larger than these twentieth-century variations, and their human impacts are likely to be correspondingly greater. Moreover, climate does not just affect people directly: it also affects all other environmental and ecological processes, including many whose connection to climate might not be immediately recognizable. Consequently, large or rapid climate change will represent an added threat to other environmental issues such as air and water quality, endangered ecosystems and biodiversity, and threats to coastal zones, wetlands, and the stratospheric ozone layer.

Projections of future climate change are uncertain, of course. Knowledge about climate change, like all scientific knowledge, is subject to uncertainty. We will discuss uncertainty, and how to make decisions about climate change under uncertainty, extensively in this book. But just because something is uncertain does not imply any particular advice on what to do about it. In particular, it does not necessarily mean the right course is to do nothing until we are certain. We do not wait to be certain the illness is life-threatening before calling the doctor, or wait to be certain we are going to drive into the tree before steering away from it. Sometimes we take action only when we are very confident it is the right course, but other times we take precautions against even rather unlikely risks. It depends on the particulars of each case.

For climate change, a key point about uncertainty is that it cuts both ways. Starting with some best estimate of climate change this century, making the estimate uncertain means that actual changes may turn out to be smaller than the current estimate, or bigger. Unless we prefer to run high-stakes risks – which people usually do not – this means uncertainty makes climate change more serious, not less. And the stakes are large. Present projections of climate change this century include, at the upper end of the uncertainty range, sustained rapid changes that appear to have few precedents in the history of the Earth, and whose impacts on human well-being and society could be catastrophic. This does not mean such extreme changes are certain, or even likely – but only that they are serious enough to be weighed in our decisions.

In addition to being the most serious environmental problem society has yet faced, climate change will also be the most difficult to manage. Environmental issues often carry difficult tradeoffs and political conflicts, because solving them requires limiting some economically productive activity or technology that is causing unintended environmental harm. Such changes are costly and generate opposition. But for previous environmental issues, technological advances and sensible policies have enabled large reductions in environmental harm at modest cost and disruption, so these tradeoffs and conflicts have turned out to be quite manageable. Controlling the sulfur emissions that contribute to acid rain in the United States provides an example. When coal containing high levels of sulfur is burned, in electric generating stations or other industrial facilities, sulfur dioxide (SO_2) in the smoke acidifies the rain that falls downwind of the smokestack, harming lakes, soils, and forests. Over the past 20 years, a combination of advances in technologies to remove sulfur from smokestack gases, and well-designed policies that give incentives to adopt these technologies, burn lower-sulfur coal, or switch to other fuels, have brought large reductions in sulfur emissions at a relatively small cost and with no disruption to electrical supply.

Climate change will be harder to address because the activities causing it – mainly burning fossil fuels for energy – are a more essential foundation of world economies, and are less amenable to simple technological correctives, than the causes of other environmental problems. Fossil fuels provide nearly 80 percent of world energy supply, and no alternatives now available could replace this huge energy source quickly or cheaply. Consequently, climate change carries higher stakes than other environmental issues, both in the severity of potential harms if the changes go unchecked, and in the apparent cost and difficulty of reducing the changes. In this sense, climate change is the first of a new generation of harder environmental problems that society will face this century, as the increasing scale of human activities puts pressure on ever more basic planetary-scale processes.

When policy issues have high stakes, it is typical for policy debates to be contentious. Because the potential risks of climate change are so serious, and the fossil fuels that contribute to it are so important to the world economy, we would expect to hear strong opposing views over what to do about climate change – and we do. But even given the issue's high stakes, the number and intensity of contradictory claims advanced about climate change is extreme. The following published statements give a sense of the range of views about climate change.

Former US Vice-President Al Gore:

> "So today, we dumped another 70 million tons of global-warming pollution into the thin shell of atmosphere surrounding our planet, as if it were an open sewer. And tomorrow, we will dump a slightly larger amount, with the cumulative concentrations now trapping more and more heat from the Sun. As a result, the Earth has a fever. And the fever is rising. The experts have told us it is not a passing affliction that will heal by itself. We asked for a second opinion. And a third. And a fourth. And the consistent conclusion, restated with increasing alarm, is that something basic is wrong. We are what is wrong, and we must make it right.
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> "We, the human species, are confronting a planetary emergency – a threat to the survival of our civilization that is gathering ominous and destructive potential even as we gather here. But there is hopeful news as well: we have the ability to solve this crisis and avoid the worst – though not all – of its consequences, if we act boldly, decisively and quickly."[1]

United States Senator and former presidential candidate John McCain:

> "The burning of oil and other fossil fuels is contributing to the dangerous accumulation of greenhouse gases in the Earth's atmosphere, altering our climate with the potential for major social, economic and political upheaval. The world is already feeling the

[1] Nobel lecture, Oslo, December 10, 2007.

> powerful effects of global warming, and far more dire consequences are predicted if we let the growing deluge of greenhouse gas emissions continue, and wreak havoc with God's creation. A group of senior retired military officers recently warned about the potential upheaval caused by conflicts over water, arable land and other natural resources under strain from a warming planet. The problem isn't a Hollywood invention nor is doing something about it a vanity of Cassandra-like hysterics. It is a serious and urgent economic, environmental and national security challenge."[2]

Former UK Prime Minister Tony Blair and Netherlands Prime Minister Jan Peter Balkenende:

> "The science of climate change has never been clearer. Without further action, scientists now estimate we may be heading for temperature rises of at least 3–4 °C above pre-industrial levels. We have a window of only 10–15 years to take the steps we need to avoid crossing catastrophic tipping points. These would have serious consequences for our economic growth prospects, the safety of our people and the supply of resources, most notably energy. So we must act quickly."[3]

United Nations Secretary-General Ban Ki-moon:

> "We are gathered together in Bali to address the defining challenge of our age. We gather because the time for equivocation is over. The science is clear. Climate change is happening. The impact is real. The time to act is now."[4]

US Senator James Inhofe:

> "Anyone who pays even cursory attention to the issue understands that scientists vigorously disagree over whether human activities are responsible for global warming, or whether those activities will precipitate natural disasters. … With all of the hysteria, all of the fear, all of the phony science, could it be that man-made global warming is the greatest hoax ever perpetrated on the American people? It sure sounds like it."[5]

[2] Speech on Energy Policy, April 23, 2007.
[3] Letter to Matti Vanhanen (Prime Minister of Finland and President of the EU Council), October 20, 2006.
[4] Opening speech to Bali conference on climate change, December 12, 2007.
[5] "The Science of Climate Change," floor statement by Senator James M. Inhofe, July 28, 2003.

> "In addition, something that the media almost never addresses are the holes in the theory that CO_2 has been the driving force in global warming. Alarmists fail to adequately explain why temperatures began warming at the end of the Little Ice Age in about 1850, long before man-made CO_2 emissions could have impacted the climate. Then about 1940, just as man-made CO_2 emissions rose sharply, the temperatures began a decline that lasted until the 1970s, prompting the media and many scientists to fear a coming ice age. Let me repeat, temperatures got colder after CO_2 emissions exploded. If CO_2 is the driving force of global climate change, why do so many in the media ignore the many skeptical scientists who cite these rather obvious inconvenient truths?"[6]

> "While the dissenting scientists (…) hold a diverse range of views, they generally rally around several key points. 1) The Earth is currently well within natural climate variability. 2) Almost all climate fear is generated by unproven computer model predictions. 3) An abundance of peer-reviewed studies continue to debunk rising CO_2 fears, and 4) "Consensus" has been manufactured for political, not scientific purposes."[7]

Professor Richard Lindzen of the Massachusetts Institute of Technology:

> "Ambiguous scientific statements about climate are hyped by those with a vested interest in alarm, thus raising the political stakes for policy makers who provide funds for more science research to feed more alarm to increase the political stakes. After all, who puts money into science – whether for AIDS, or space, or climate – where there is nothing really alarming? Indeed, the success of climate alarmism can be counted in the increased federal spending on climate research from a few hundred million dollars pre-1990 to $1.7 billion today. It can also be seen in heightened spending on solar, wind, hydrogen, ethanol and clean coal technologies, as well as on other energy-investment decisions.

> "But there is a more sinister side to this feeding frenzy. Scientists who dissent from the alarmism have seen their grant funds disappear, their work derided, and themselves libeled as industry stooges, scientific

[6] "Hot & Cold Media Spin Cycle: A Challenge to Journalists Who Cover Global Warming." Senate Floor Speech, Sen. Inhofe, October 25, 2006.

[7] "Global Warming 'Consensus' in Freefall," Senate Floor speech, January 8, 2009.

> hacks or worse. Consequently, lies about climate change gain credence even when they fly in the face of the science that supposedly is their basis."[8]

Professor Roy Spencer of the University of Alabama:

> "For those scientists who value their scientific reputations, I would advise that they distance themselves from politically-motivated claims of a 'scientific consensus' on the causes of global warming – before it is too late. Don't let five Norwegians on the Nobel Prize committee be the arbiters of what is good science."[9]

And Vaclav Klaus, President of the Czech Republic:

> "As someone who lived under communism for most of his life, I feel obliged to say that I see the biggest threat to freedom, democracy, the market economy and prosperity now in ambitious environmentalism, not in communism. This ideology wants to replace the free and spontaneous evolution of mankind by a sort of central (now global) planning."[10]

One of the most striking aspects of this debate is the intensity of disagreements expressed over what we might expect to be simple matters of scientific fact, such as whether the Earth is warming and whether human emissions are responsible. Such heated public confrontation over the state of scientific knowledge and uncertainty – not just between political figures and policy advocates, but also between scientists – understandably leaves many concerned citizens confused.

Our goal in this book is to clarify the climate-change debate. We seek to help the concerned, non-expert citizen to understand what is known about climate change, and how confidently it is known, in order to develop an informed opinion of what should be done about the issue. We will summarize the state of knowledge and uncertainty on key points of climate science, and examine how some of the prominent claims being advanced in the policy debate – including some in the quotes above – stand up in light of present knowledge. Can we confidently state that some of these claims are simply right and others simply wrong, or are these points of genuine uncertainty or legitimate differences of interpretation?

[8] "Climate of Fear: Global warming alarmists intimidate dissenting scientists into silence," op-ed, *Wall Street Journal*, April 12, 2006.

[9] "Hey, Nobel prize winners, answer me this," Heartland Institute, March 15, 2008, at www.globalwarmingheartland.org/Article.cfm?artId=23004.

[10] "Freedom, not climate, at risk," op-ed, *Financial Times*, June 13, 2007.

We also summarize present understanding of the likely impacts of climate change and the technologies, policies, and other options available to deal with the issue. These are not purely scientific questions, although they can be informed by scientific knowledge. In addition, we examine how scientific argument and political controversy interact. This will help to illuminate why scientific arguments play such a prominent role in policy debate over climate change, and in particular how such extreme disagreements can arise on points that would appear to be matters of scientific knowledge. What do policy advocates hope to achieve by arguing in public over scientific points, when most of them – like most citizens – lack the knowledge and training to evaluate these claims? Why do senior political figures appear to disagree on basic scientific questions when they have ready access to scientific experts and advisors to clarify these for them? And finally, what are the effects of such blending of scientific and political arguments on the policy-making process?

While there is plenty of room for honest, well-informed disagreement over what to do about global climate change, it is our view that the issue is made vastly more confused and contentious than it need be by misrepresentations of the state of scientific knowledge in policy debate, and by misunderstandings and misrepresentations of the extent of uncertainty on key scientific points about climate change and the significance of these uncertainties for action.

Before we can engage these questions, the next two sections of this chapter provide some necessary background. Section 1.2 provides a brief scientific background and primer on the Earth's climate, the greenhouse effect, climate models, and how human activities have increased greenhouse gases in the atmosphere. Section 1.3 provides a brief history of existing policy and institutions concerned with climate change, to provide the policy context for the present debate.

1.2 Climate and climate change: a scientific primer

1.2.1 What is climate?

The climate of a place, a region, or the Earth as a whole, is the average over time of the meteorological conditions that occur there – the average weather. For example, in the month of November between 1971 and 2000, the average daily high temperature in Washington, DC was 14°C, the average daily low was 1°C, and 0.3 cm of precipitation fell. These average values, along with averages of other meteorological quantities such as humidity, wind speed, cloudiness, and snow and ice coverage, define the November climate of Washington over this period.

While climate consists of average meteorological conditions, weather consists of meteorological conditions at a particular time. For example, on November 29, 1999, in Washington, DC, the high temperature was 5°C, the low was –3°C, and no precipitation fell. On this particular November day, the weather in Washington was somewhat colder and drier than Washington's average November climate.

Weather matters for short-term, day-to-day decisions. Should you take an umbrella when you go out tomorrow? Will frost kill plants left outdoors tonight? Is this a good weekend to go skiing in the mountains? Should you plan your party this weekend indoors or outdoors? In each of these cases, you care about conditions on a particular day, not long-term average conditions – the weather, not the climate.

Climate matters for longer-term decisions. If you run an electric utility, you care about the climate because if average summer temperatures increase, people will run their air conditioners more and you may need to build more generating plants to meet the increased electrical demand. If you are a city official, you care about the climate because urban water supplies usually come from reservoirs fed by rain or snow. Changes in average temperature or the timing or amount of precipitation could change both the supply and the demand for water. If the climate changes, the city may need to expand capacity to store or transport water, find new supplies, or develop policies to limit water use in times of scarcity. In Section 1.2.6 below, we will return to the difference between weather and climate, in discussing differences in their predictability.

1.2.2 Electromagnetic radiation

To understand how climate can change, we must first consider why the climate is the way it is, in particular places and for the Earth as a whole. Scientists have been studying these questions since the early nineteenth century, starting with the largest question of all: why is the Earth the temperature that it is?

The source of energy for the Earth's climate is sunlight, which is a form of *electromagnetic radiation*. Electromagnetic radiation includes all light that we can see, as well as other radiation, other light, that we cannot. Electromagnetic radiation consists of a stream of *photons*, tiny discrete packages of energy. Every photon has a size, or *wavelength*, that determines how it interacts with material in the world. Most photons emitted by the Sun have wavelength between about 0.3 and 0.8 microns.[11] This is also the range of wavelengths that are visible to

[11] A micron, or micrometer, is one one-millionth of a meter or one one-thousandth of a millimeter. A millimeter is about the width of one letter in this footnote.

human eyes. Our eyes, and those of other animals, have evolved to be sensitive to these wavelengths because of the survival advantages of being able to see the radiation that is most strongly present in the environment. Within the visible range, humans perceive different wavelengths as color. We see wavelengths near 0.3 microns as violet. As the wavelength increases, the perceived color changes to indigo, then blue, green, yellow, orange, and finally red at wavelengths around 0.8 microns. Photons with longer wavelengths, beyond red, are called *infrared* and are not visible to humans.

Most electromagnetic radiation in the universe comes from matter, through a process called *blackbody radiation*. Blackbody radiation is ubiquitous. Virtually everything in the universe, and all objects in everyday life, are constantly emitting photons. In fact, you are emitting photons right now, as is everything around you: the walls, your desk, your dog, this book. Everything is glowing.

But if everything around you is emitting radiation, why don't you see it glowing? The answer can be seen in Figure 1.1, which shows the distribution of wavelengths of the photons emitted by objects at three different temperatures. For an object at room temperature, about 20°C, almost all photons are emitted at wavelengths longer than 4 microns. These infrared photons are detectable by infrared cameras and night-vision goggles, but cannot be seen by human eyes.[12]

As an object's temperature increases, the amount of energy it emits as blackbody radiation increases. The relation between temperature and total radiated energy, known as the Stefan-Boltzmann Law,[13] states that energy emitted is proportional to the fourth power of temperature. So if the temperature of an object doubles, the rate of energy emitted increases by a factor of 2^4 or 16. This means that an object at 5600°C, like the Sun, radiates energy more than a hundred thousand times faster than an object at 20°C.

But as Figure 1.1 shows, this higher rate of radiation does not just come from emitting more photons of the same wavelengths: as an object warms up, the mix of photons it emits also shifts toward shorter wavelengths. For an object at 2200°C (middle panel, Figure 1.1), about the temperature of a piece of iron being worked by a blacksmith, most emitted photons have wavelengths too long for human eyes to see, but a few fall in the visible range. These visible photons are

[12] This explains the term "blackbody." A blackbody is an idealized object that absorbs all photons that fall on it, and emits photons with wavelengths that are determined by its temperature. At room temperature, such an object would appear to be black to the human eye.

[13] Power radiated (energy per second) per unit area is equal to σT^4, where σ is a constant (5.67×10^{-8} W/m^2/K^4) and temperature is measured in degrees Kelvin, degrees above absolute zero, which is equal to the Celsius temperature plus 273.15.

at the red end of the visible range, so the iron has a faint red glow: it has become "red hot." Blacksmiths use this to tell when a piece of metal has become hot enough to work, and the need to see this faint red glow is one reason blacksmiths often work in dim light. The Sun is, to a good approximation, a 5600°C blackbody. The bottom panel of Figure 1.1 shows that most photons emitted by a body at this temperature lie in the range that is visible to humans.

When you see a room-temperature object like this book, you are *not* seeing blackbody photons emitted by the book, because those photons are outside the visible range in the infrared. Rather, you are seeing photons that were emitted by some much hotter blackbody, the Sun or a light bulb filament (~2700°C), which have hit the page and reflected to your eye.

1.2.3 The Earth's energy balance

Photons of any wavelength are little bundles of energy. So when an object emits a photon, the photon carries a tiny bit of energy away from the object. And when a photon falls on an object and is absorbed, the object gains the photon's tiny bit of energy. Most objects – including you and everything around you – are continuously emitting photons by blackbody radiation, and at the same time absorbing photons that were emitted by other objects.

If an object is losing more energy by emitting photons than it is receiving by absorbing photons, its energy must be decreasing. Since temperature is a measure of an object's energy, this imbalance in energy emitted and absorbed causes the object's temperature to fall. Similarly, if an object is gaining more energy by absorbing photons than it is losing by emitting them, its temperature must rise. If the rates of energy gain from absorption and loss from emission are equal, the object's temperature is constant: it is in equilibrium, or steady-state.

Nearly all the photons striking the Earth come from the Sun. The amount of solar energy striking the Earth per second is truly awesome: 154 thousand trillion watts, or an average of 342 watts per square meter averaged over the whole Earth's surface. Of this, about 30 percent is reflected back to space by clouds, ice, snow, and other light-colored surfaces, so about 240 watts per square meter is absorbed by the Earth's surface and atmosphere.

In the early nineteenth century, mathematician Joseph Fourier asked a seemingly simple question: since the Earth is always absorbing energy from the Sun, why does it not heat up until it is as hot as the Sun? Blackbody radiation provides the answer to Fourier's question: the Earth and atmosphere (a rather large blackbody) radiate energy out to space, also at a rate of about 240 watts per square meter, precisely offsetting the energy absorbed from sunlight. We can use this equilibrium to estimate what the surface temperature of the