# Chapter 1
# THE SCIENCE OF CLIMATE CHANGE

**SYNOPSIS**



## I. INTRODUCTION

Human activity is changing the global climate with unpredictable and potentially profound consequences for global weather patterns, ecosystems, food security, and human health. Water vapor and gases such as carbon dioxide and methane allow energy from the sun to pass through the atmosphere to the earth's surface, and then trap a portion of that energy before it is radiated back into space. This so-called "greenhouse effect" is a natural process; without it the energy from the sun would be lost in space, leaving the earth cold and lifeless. It is also a homeostatic process, or a process tending toward equilibrium. The concentration of greenhouse gases in the atmosphere is kept relatively constant over time by complex natural cycles. Carbon dioxide ($CO_2$), for example, is absorbed by plants, released when the plants burn or decompose, and re-absorbed when new plants grow, only to be released again in an endless cycle.

Climate change refers to the response of the planet's climate system to altered concentrations of carbon dioxide and other "greenhouse gases" in the atmosphere. If all else is held constant (e.g., cloud cover, capacity of the oceans to absorb carbon dioxide, albedo, aerosols, etc.), increased concentrations of greenhouse gases lead to "global warming" — an increase in global average temperatures — and associated changes in the earth's climate patterns. Indeed, the basic mechanism of how carbon dioxide and other greenhouse gases warm the planet (i.e., the "greenhouse effect") has been well known since 1896, when the Swedish chemist Svante Arrhenius suggested that carbon dioxide emissions from combustion of coal would lead to global warming.

This chapter provides the scientific and factual basis for climate change. Although areas of uncertainty still exist with respect to the ultimate impacts of climate change, hundreds of scientific studies and real-time observations around the world clearly indicate that: (a) the earth's climate is changing; (b) the changes are the result of human activity; (c) the changes are happening at both a faster rate and with greater impacts than previously projected; and (d) immediate action is needed to reduce greenhouse gas emissions to avoid reaching more harmful levels. Indeed, a consensus has existed for decades within the international scientific community that we are witnessing discernible and serious impacts on our climate and natural systems due to human activities. Virtually every day, new observations solidify that consensus and confirm the increasing urgency of global climate change for predicting both global and regional impacts.

Despite the fact that virtually all of the world's atmospheric scientists have long agreed that climate change was a serious threat, debates over whether climate change is a "myth" or a "conspiracy of environmentalists" continue (although only in the United States). With the exception of a handful of "climate skeptics," no such debate now exists in the scientific community. The debate has moved from whether humans are causing climate change to what will be the magnitude and impacts of that change and, more importantly, how we should respond to it. In these latter issues, there remain significant areas of uncertainty, but over time the observed and predicted future impacts have almost all supported the conclusion that climate change is accelerating and impacts will be profound. Much of this chapter explores what is known and predicted about these impacts.

The world's ability to move beyond the question of whether climate change is occurring to how to respond to it owes much to the international community's deliberate attempt to organize and present climate science in a policy-relevant way. Anticipating the critical role that scientific consensus would play in building the political will to respond to climate change, the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) created the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC was initially charged with assessing the scientific, technical, and economic basis of climate change policy in preparation for the 1992 Earth Summit and the negotiations of the UN Framework Convention on Climate Change (discussed in Chapter 5). After the Convention entered into force, the IPCC continued to provide technical reports to the Parties and to the public. The IPCC's Second Assessment, for example, concluded in 1995 that the observed warming trend was "unlikely to be entirely natural in origin" and that the balance of evidence suggested a "discernible human influence" on the Earth's climate. IPCC, WORKING GROUP I, THE SCIENCE OF CLIMATE CHANGE, 3–5 (Second Assessment Report 1995). This conclusion informed negotiations of the 1997 Kyoto Protocol.

The IPCC issued its Fourth (and latest) Assessment in 2007 and found that "warming of the planet is unequivocal" and that "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely [i.e., more than 90% likely] due to the observed increase in anthropogenic greenhouse gas concentrations." IPCC WORKING GROUP I, THE PHYSICAL SCIENCE BASIS: SUMMARY FOR POLICYMAKERS (Fourth Assessment Report 2007). For this report and the public awareness its release raised, the IPCC shared the 2007 Nobel Peace Prize with former Vice President Al Gore. Since that report, continuing scientific evidence has mounted that the IPCC report largely underestimates the pace and intensity of climate change and the extent and severity of its impacts. The ensuing discussion of facts comes both from IPCC reports and subsequent findings of a variety of leading international scientific bodies. The next IPCC report is due out in 2014.

## QUESTIONS AND DISCUSSION

**1.** The IPCC is organized into three working groups: Working Group I concentrates on the science of the climate system, Working Group II on impacts of climate change and policy options for response, and Working Group III on the economic and social dimensions of climate change. The Working Groups' reports have been designed to inform the policy debate with thorough assessments every five years. The 1990 Assessment built momentum for the 1992 Framework Convention, and the 1995 Assessment's conclusion that climate change was already occurring helped to build the political commitment to establish clear targets and timetables in the Kyoto Protocol. The Fourth Assessment, which was released in November 2007, was used as the scientific basis for negotiations of the Copenhagen Accord and other post-Kyoto negotiations. It is no accident that the global community's next major deadline for trying to negotiate a universal climate change treaty is 2015, one year after the IPCC's Fifth Assessment is anticipated. As in the past, the hope is that the IPCC's scientific assessment will help to build political will and a sense of urgency for the negotiations.

**2.** The IPCC Assessments are intended to summarize the accepted state of the climate science at a given point in time, but the process of reviewing and summarizing the science and reaching consensus on the text necessarily takes several years. With the rate at which the climate is changing, the IPCC reports are arguably out of date by the time they are published. Given the slow nature of the IPCC, how safe are we in relying on its assessments? What other governance mechanisms could you design to ensure that the most accurate and timely science is available for policymakers, industry, and NGOs?

**3.** ***The Carbon Cycle***. To understand climate change, we must understand the global carbon cycle:

> The atmosphere is a critical part of two carbon cycles, which distribute a chemical raw material required by all living organisms. In the shorter cycle carbon is fixed in green plants and in certain microorganisms, such as algae, through the process of photosynthesis. This process takes place when sunlight is absorbed by chlorophyll, which powers a process that breaks down $CO_2$ from the atmosphere to form organic molecules, such as glucose and amino acids that accumulate in the biomass of the plants. Animals, which are not capable of photosynthesis, obtain the carbon they need to produce energy for maintaining their bodily processes by eating plants or other animals that are primary or secondary consumers of plants. Carbon is returned to the atmosphere in the form of $CO_2$ through the cellular respiration of living plants and animals and their decomposition upon death. The carbon in vegetation is also released to the atmosphere when it is burned, as in forest and range fires or slash-and-burn farming. The oceans absorb and release vast quantities of $CO_2$ and thus serve as a buffer that keeps the level of $CO_2$ in the atmosphere relatively stable.
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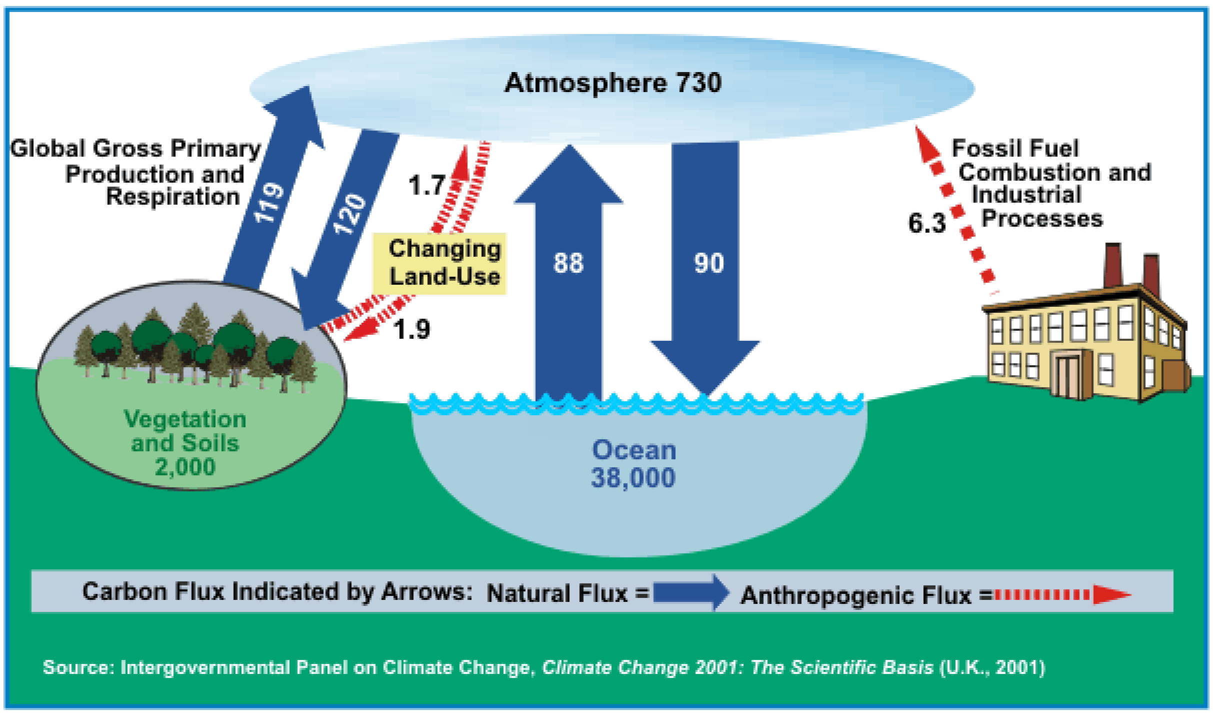
> There is also a geological carbon cycle that takes place naturally on a much

> longer scale of time. The cycle begins when organic material from plants and animals slowly becomes locked into sedimentary deposits, where it may remain for hundreds of millions of years in the form of either carbonates containing the shells of marine organisms or organic fossils, such as coal, oil, and natural gas. Some of the carbon is eventually released when the geological formations in which it is locked are exposed to weathering and erosion. Human beings have greatly accelerated the release of this carbon by mining and drilling large quantities of fossil fuels and burning them to produce energy while in the process emitting $CO_2$.

M. SOROOS, THE ENDANGERED ATMOSPHERE 31 (1997).

**Figure 1-1: The Carbon Cycle (in billions of tons)**



**4.** Although the phrase "greenhouse effect" derives its name from an analogy to greenhouses, the process by which gases warm the atmosphere is actually quite different from the way a greenhouse warms air. A greenhouse heats the air inside it primarily by allowing the sun's solar radiation to warm the ground inside it. The ground turns this solar radiation into heat which is reflected back into the atmosphere as waves of infrared radiation. Inside the greenhouse, this infrared radiation is absorbed by gases, thus warming the air. However, the glass of the greenhouse prevents the warmed air from escaping; that is, it prevents convection — the transfer of heat by motion. The temperature of a greenhouse will quickly drop if a window is opened. In contrast, the "greenhouse effect" reduces radiation loss, not convection. In other words, greenhouse gases are transparent to solar energy and thus allow solar radiation to warm the ground. As in a greenhouse, the ground releases heat as infrared radiation; instead of preventing convection, however, greenhouse gases absorb this infrared radiation. Unlike a greenhouse, the atmosphere has no window to open. Although the "greenhouse effect" may be an imperfect metaphor, it provides a useful way to describe this complex natural process.

**5.** Adding to the complexity of climate change is that not all the agents driving global warming are greenhouse gases. Most importantly, black carbon, or what we commonly think of as soot, may be the second leading cause of global warming — but is not a greenhouse gas. Black carbon is fine particulate matter categorized as an aerosol, and its primary mechanism for contributing to global warming is that it absorbs sunlight (as does any black surface), whereas greenhouse gases absorb infrared radiation reflected from the earth's surface. Thus, black carbon emissions and some of its warming impacts are localized, as opposed to the impacts of greenhouse gas emissions which are uniformly distributed.

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## II. THE CAUSES OF CLIMATE CHANGE

Since the beginning of the Industrial Revolution in the early 19th century, human activity has interfered with the homeostatic processes that make up the carbon cycle, releasing carbon dioxide and other greenhouse gases into the atmosphere more quickly than they are absorbed by natural "sinks," primarily oceans and forests. The result is that concentrations of these gases are increasing in the atmosphere. Due to the burning of fossil fuels, such as coal and oil, and the destruction of forests, the atmospheric concentration of carbon dioxide has increased by nearly 40 percent, from 280 parts per million (ppm) to 395 ppm, between 1750 and 2013, and, if current trends in fossil fuel use continue, concentrations would reach 600 to 700 ppm by the end of the 21st century. (One part per million of $CO_2$ means there is one molecule of $CO_2$ to every million molecules of air.) Concentrations of methane, nitrous oxide, and other greenhouse gases are rising as well, with methane increasing more than 250 percent from its 1750 level. As a result, an ever-greater proportion of the sun's energy is trapped within the atmosphere, causing the planet's atmosphere to warm.

## A. Increasing Greenhouse Gas Emissions

The seven man-made (or "anthropogenic") greenhouse gases currently regulated under the international climate regime are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride ($SF_6$), and nitrogen trifluoride ($NF_3$). Another category, chlorofluorocarbons (CFCs), are also greenhouse gases (GHGs), but are regulated under the Montreal Protocol on Substances that Deplete the Ozone Layer because of their ozone-depleting effects. These greenhouse gases collectively account for only three percent of the earth's atmosphere, but relatively small increases in their concentrations are altering the climate system. In addition, many land-use and agricultural practices directly contribute to GHG emissions or reduce the Earth's capacity to assimilate greenhouse gases. For example, forest loss both releases carbon stored in the felled trees and reduces the remaining forest's capacity to absorb carbon from the atmosphere. Also many substances not yet addressed internationally, such as black carbon (or soot), are also significant contributors to global warming. The primary drivers of global warming are discussed below.

*Sources of Greenhouse Gases.* Each of the seven major greenhouse gases currently regulated under the Kyoto Protocol (and CFCs, regulated under the Montreal Protocol) has different sources.

*Carbon dioxide*, composing over 70 percent of all anthropogenic greenhouse gases, is by far the most important. Two-thirds of all carbon dioxide is emitted by fossil fuel burning, in everything from large power plants to automobiles. Much of the remaining third of $CO_2$ emissions comes from cement manufacturing and deforestation. Despite growing calls for reducing $CO_2$ emissions, the U.S. Department of Energy predicts that global $CO_2$ emissions will increase 38 percent from 2010 to 2035. Contrast this prediction with the view by many climatologists that to avoid substantial climate impacts we need to cap global $CO_2$ emissions immediately and significantly reduce them by 2050.

*Methane* is produced by waste decomposition, the decay of plants, from certain agricultural practices (such as large-scale cattle and pork production, and the flooding of rice fields), and from coal mines. It also escapes from natural gas production sites and pipelines. Livestock production produces 30 percent of methane worldwide, and contributes more to global warming than the transportation sector. Solid waste landfills are also a significant source of methane. As temperatures rise, significant amounts of methane may also be seeping from the ocean floor and frozen lake beds.

*Nitrous oxide* ($N_2O$) is produced from automobile exhaust and other industrial processes, but the largest sources may be from livestock production and the poor management of manure.

*Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs)* are used in refrigerants, air conditioners, and other products. CFCs and more recently HCFCs are either phased out or scheduled for phase out under the Montreal Protocol treaty regime, aimed primarily at addressing ozone depletion. Unfortunately, among the most potent greenhouse gases are either alternatives to CFCs, such as HCFCs, or by-products associated with the production of alternatives, such as HFCs. Other fluorinated industrial gases, such as perfluorocarbons (PFCs), nitrogen trifluorite ($NF_3$), and sulphur hexafluoride ($SF_6$), are also potent greenhouse gases.

*Other gases*, such as sulfur dioxide ($SO_2$), nitrogen oxides (NOx) (not to be confused with nitrous oxide ($N_2O$)), carbon monoxide (CO), hydrogen sulfide ($H_2S$), ozone ($O_3$), and volatile organic compounds (VOCs) also contribute to global warming, either directly or indirectly, but are not yet covered by the Kyoto Protocol. The potential warming impacts of these non-Kyoto GHGs are not as well known. *See The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*, WORLD BUSINESS COUNCIL FOR SUSTAINABLE DEVELOPMENT AND WORLD RESOURCES INSTITUTE 46 (2001).

*Black Carbon.* Another significant cause of climate change is black carbon (i.e. soot), now suspected to be second only to $CO_2$ in its contribution to climate change. Recent studies suggest that preventing black carbon pollution may cut global warming by as much as 0.5° Celsius. Black carbon is produced by the incomplete combustion of coal, diesel, wood, and biomass fuels. It is technically a solid or "aerosol" that disperses locally. Not being a gas, black carbon is often ignored in policy discussions over greenhouse gases. Yet its impact is profound in some areas; for example, the accumulation of black carbon on ice sheets, which absorbs heat from sunlight that would otherwise be reflected back into space, is roughly twice as effective as $CO_2$ in thinning Arctic sea ice and melting land ice and permafrost. On a positive note, because black carbon has an average atmospheric lifetime of 5 to 8 days, implementing strategies to prevent black carbon pollution could have strong short term effects on mitigating global warming. William L. Chameides & Michael Bergin, *Soot Takes Center Stage*, 297 SCIENCE 2214 (Sept. 27, 2002); *see also* James Hansen & Larissa Nazarenko, *Soot Climate Forcing via Snow and Ice Albedos*, 101 PROC. NAT'L ACAD. OF SCIENCES 423 (January 13, 2004); Mark G. Flanner, Charles S. Zender, James T. Randerson, & Philip J. Rasch, *Present-Day Climate Forcing and Response from Black Carbon in Snow*, 112 J. GEOPHYS. RES., D11202 (2007); U.S. ENVTL. PROTECTION AGENCY, REPORT TO CONGRESS ON BLACK CARBON 17-66 (2012); T.C. Bond et al., *Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment*, J. GEOPHYS. RES. (forthcoming 2013) (DOI: 10.1002/jgrd.50171).

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## QUESTIONS AND DISCUSSION

**1.** ***Atmospheric Lifetimes and Global Warming Potential.*** Not all greenhouse gases are created equally; different gases have different warming impacts and different atmospheric lifetimes. The concept of "global warming potentials" (GWPs) was developed to reflect these differences and allow comparisons of the different impacts each gas has on the climate over a specific period of time. All GWPs are measured relative to $CO_2$, and the GWP for $CO_2$ over any timeframe is always 1. Over a 100-year timeframe, the GWP of methane is 25, which means that one unit of methane released into the atmosphere will have a warming impact 25 times greater than the same amount of $CO_2$ over 100 years. Each gas also has a different atmospheric lifetime. For example, methane's atmospheric lifetime is 12 years, while $CO_2$'s atmospheric lifetime is up to 200 years. As a result, a chemical's GWP changes when a different timeframe is used. Thus, because methane has a shorter atmospheric lifetime than $CO_2$, over a 20-year timeframe its GWP increases from 25 to 72. Policymakers and scientists rely on the different timeframes for different types of issues. For instance, the 20-year timeframe is useful when considering how much the earth's temperature might change as a result of near-term emissions of a gas, and the 100-year timeframe is useful when considering long-term effects of emissions, such as sea-level rise. Table 1-1 below shows the GWPs and atmospheric lifetimes for several of the major GHGs. Note that GWP is not a perfect measurement, as the warming impacts of substances with atmospheric lifetimes in the thousands of years, such as PFCs and sulfur hexafluoride, may not be accurately reflected over a 100-year timeframe.

**Table 1-1: Global Warming Potential of Major Climate Forcers**

| Substance | **$CO_2$** | **HFC-23** | **Methane** | **PFCs** | **$N_2O$** | **$SF_6$** | **CFC-11** | **Black Carbon** |
|---|---|---|---|---|---|---|---|---|

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Atmospheric Lifetime (yrs) | 5 - 200 | 270 | 12 | 10,000+ | 114 | 3,200 | 45 | < 1 |
| GWP over 20 years | 1 | 12,000 | 72 | 5230+ | 289 | 16,300 | 6730 | 2200 |
| GWP over 100 years | 1 | 14,800 | 25 | 7390+ | 298 | 22,800 | 4750 | 680 |

Review the GWPs in the above table. Why is establishing GWPs critical for policy setting?

**2.** ***Carbon Dioxide Equivalent ($CO_2$eq) Emissions.*** A gas's GWP provides a useful measure for comparing different greenhouse gases — a gas's radiative forcing equivalence compared to carbon dioxide. In the climate change context, radiative forcing measures the factors that affect the balance between incoming solar radiation and outgoing infrared radiation within the Earth's atmosphere. Positive forcing leads to global warming. Simplistically stated, radiative forcing for a greenhouse gas essentially boils down to a measure of how much infrared radiation is captured by a gas. A gas's carbon dioxide equivalence — abbreviated as either $CO_2$eq or $CO_2$e — is defined by the IPCC as:

> The amount of *carbon dioxide* emission that would cause the same integrated *radiative forcing*, over a given time horizon, as an emitted amount of a well mixed *greenhouse gas* or a mixture of well mixed greenhouse gases. The equivalent carbon dioxide emission is obtained by multiplying the emission of a well mixed greenhouse gas by its [GWP] for a given time horizon. For a mix of greenhouse gases, it is obtained by summing the equivalent carbon dioxide emissions of each gas.

IPCC, Glossary of Terms Used in the IPCC Fourth Assessment Report, at 945, *available at* http://www.ipcc.ch/glossary/index.htm (emphasis in original).

**3.** ***Banked Warming.*** Because most greenhouse gases, including $CO_2$, $NO_x$, PFCs, and HFCs, remain in the atmosphere and contribute to the greenhouse effect for many decades or centuries, we have already "banked" substantial amounts of greenhouse gases, and any emissions reductions taken today will not significantly reduce the overall impact until this bank is exhausted. As a result, anthropogenic warming and sea level rise are likely to continue for centuries due to the time scales associated with climate processes and feedbacks, even if the world stopped emitting GHGs today. For example, the IPCC concluded that even if $CO_2$

emissions were maintained at 1994 levels, they would lead to a nearly constant rate of increase in atmospheric $CO_2$ concentrations for at least two centuries. This means that even larger reductions in GHG emissions would be needed to avoid dangerous interference with the climate. It may even be necessary to pursue a "carbon negative" strategy, where the net amount of carbon taken out of the atmosphere through sequestration techniques exceeds what is added through annual emissions.

**4.** GHG emissions (and thus atmospheric concentrations) are expected to rise considerably in the next few decades. The U.S. Department of Energy's Energy Information Administration projects global $CO_2$ emissions will rise 38 percent from 2010 levels by 2035 (from 31.3 to 43.2 billion metric tons). North American emissions are estimated to reach 7.8 billion tons per year, while emissions from Asian developing countries, particularly China and India, are estimated to reach 19.7 billion tons per year by 2035. *See* U.S. Department of Energy, Energy Information Administration, International Energy Outlook 2011, Report #: DOE/EIA-0484 (2011).

## B. Declining Natural Carbon Sinks

As suggested by Figure 1-1, only about 40 percent of annual GHG emissions remain in the atmosphere, with the remainder being sequestered or absorbed by the earth's "carbon sinks." The oceans, forests, and soils are all critical carbon sinks and reservoirs. "Carbon reservoirs" currently store carbon *previously* removed from the atmosphere. Carbon sinks remove carbon from the atmosphere. If carbon reservoirs or sinks are disturbed they can release carbon and add to the atmospheric concentrations of greenhouse gases. Our understanding of carbon sinks and reservoirs is still incomplete. As the IPCC puts it:

> A sustainably managed forest comprising all stages of a stand life cycle operates as a functional system that maintains an overall carbon balance, retaining a part in the growing trees, transferring another part into the soils, and exporting carbon as forest products. Recently disturbed and regenerating areas lose carbon; young stands gain carbon rapidly, mature stands less so; and overmature stands may lose carbon[.] . . . During the early years of the life cycle, when trees are small, the area is likely to be a source of carbon; it becomes a sink when carbon assimilation exceeds soil respiration. * * *
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> Human activities modify carbon flows between the atmosphere, the land, and the oceans. Land use and land-use change are the main factors that affect

> terrestrial sources and sinks of carbon. Clearing of forests has resulted in a reduction of the global area of forests by almost 20 percent during the past 140 years. However, [improved] management practices can restore, maintain, and enlarge vegetation and soil carbon stocks. * * *
>
> Reducing the rate of forest clearing can reduce carbon losses from terrestrial ecosystems. Establishing forests on previously cleared land provides an opportunity to sequester carbon in tree biomass and forest soils, but it will take decades to centuries to restore carbon stocks that have been lost as a result of land-use change in the past.

IPCC, LAND USE, LAND-USE CHANGE, AND FORESTRY, at 26–27 [hereinafter IPCC SPECIAL REPORT ON LAND USE AND FORESTRY]. Thus, forests and soils can act as reservoirs (storing carbon), sinks (actively removing, or sequestering, carbon), or sources (emitting carbon), depending on the relative maturity of the forest as well as the human-caused interferences and uses of the land.

Other critical sinks are the oceans. Oceans have absorbed about one-quarter of all human-made $CO_2$ released since the industrial revolution, but recent studies suggest that their ability to absorb $CO_2$ may be declining significantly. A 10-year study by researchers from the University of East Anglia, for example, showed that the uptake of $CO_2$ by the North Atlantic Ocean halved between the mid-1990s and 2002–2005. Similarly, studies found in 2007 that the Southern Ocean's ability to absorb carbon has weakened considerably. *See, e.g.*, Paul Rincon, *Polar Ocean "Soaking up Less $CO_2$"*, BBC NEWS, May 17, 2007.

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## QUESTIONS AND DISCUSSION

**1.** As suggested by the above, deforestation and land-use changes play a complex and critical role in climate change. Over time, changes in forest cover, for example through deforestation and conversion to agriculture, have contributed significantly to the level of carbon in the atmosphere. From 1850 to 1998, approximately one-third of man-made GHG emissions into the atmosphere came from releases due to land-use changes, mostly through deforestation. For some countries, land-use practices comprise their primary contribution to climate change; fully three-quarters of Brazil's GHG emissions, for example, come from deforestation. For other countries, the contributions may be smaller but still significant; wildfires in the Western United States alone, for example, have been estimated to contribute emissions equal to 1.3 percent of 2010 fossil fuel emissions for the entire United States. Todd J. Hawbaker & Zhiliang Zhu, U.S. Dep't of Interior & US. Geo. Surv., *Baseline Wildland Fires and Emissions for the Western United States* in BASELINE AND PROJECTED FUTURE CARBON STORAGE AND GREENHOUSE-GAS FLUXES IN ECOSYSTEMS OF THE WESTERN UNITED STATES 29 (2012).

Not surprisingly, forest management has become a major issue in climate policy. Many carbon offset programs at both the national and international level involve reforestation initiatives. Conservationists and developing countries hope that they can be paid to conserve forests and avoid deforestation. This raises difficult questions for policy makers. The science is very complex for measuring the rates of forest sequestration and thus for measuring how many carbon "credits" should be awarded when a forest is conserved. It appears, for example, that droughts, which are likely to increase in severity with climate change, may reduce a forest's ability to sequester carbon by about 20 percent. Recent studies also suggest that while reforestation in tropical areas undoubtedly has a net positive impact in removing carbon, reforestation in some temperate areas may actually *add* to warming. Where dark leafy temperate forests replace lighter grasslands, the amount of light (and warmth) absorbed by the darker surface may actually offset the impact of the carbon sequestered from the atmosphere. These and other forest issues relevant for climate policy are discussed in Chapter 8.

**2.** In addition to the natural processes for removing and storing carbon, new technologies are being developed for creating and enhancing carbon sinks. These include carbon capture and sequestration (CCS) technologies that will capture and store carbon produced from the combustion of fossil fuels in geological formations. Other proposals include fertilizing the oceans to enhance algal blooms so they increase their $CO_2$ uptake, or "vacuuming" $CO_2$ directly from the atmosphere. Not all methods of sequestration rely on such modern approaches. Ancient land use practices among South America indigenous groups, for example, involve actually cooking wood underground instead of open to the air in a way that results in a high-carbon biochar; replacing "slash and burn" techniques of land-clearing with "slash and char" could sequester large amounts of carbon that would otherwise be released into the atmosphere. These proposals are explored further in Chapter 2's discussion of possible mitigation measures.

## C. The Relationship between GHG Concentrations and Temperature

Many aspects of climate change are well understood and relatively uncontroversial from a scientific perspective. Our use of fossil fuels and land-use practices are unlocking and releasing carbon dioxide taken out of the atmosphere over millennia and stored in fossil fuels, wood, or soil. According to the IPCC, global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70 percent since 1970. A bit more than half of the additional carbon emitted appears to be removed from the atmosphere and assimilated, either through plants and the soil or through increased absorption by the oceans. The remainder of the emissions remains in the atmosphere, significantly increasing atmospheric concentrations of greenhouse gases. Ice core samples taken from the Antarctic and Greenland ice caps show that atmospheric concentrations of anthropogenic greenhouse gases — carbon dioxide, methane, and nitrous oxide — have increased by about 40 percent, 250 percent, and 20 percent, respectively, in the industrial era.

*Increasing concentrations.* No one seriously questions that atmospheric concentrations of greenhouse gases have increased. The IPCC's Fourth Assessment issued in 2007 made the following conclusions regarding atmospheric concentrations of greenhouse gases:

> Global atmospheric concentrations of $CO_2$, methane ($CH_4$) and nitrous oxide ($N_2O$) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. Atmospheric concentrations of $CO_2$ (379 ppm) and $CH_4$ (1774 ppb) in 2005 exceed by far the natural range over the last 650,000 years. Global increases in $CO_2$ concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is very likely that the observed increase in $CH_4$ concentration is predominantly due to agriculture and fossil fuel use. Methane growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. The increase in $N_2O$ concentration is primarily due to agriculture.

IPCC, CLIMATE CHANGE 2007: SYNTHESIS REPORT, at 4 (Fourth Assessment Report 2007). As noted above, atmospheric concentrations of carbon dioxide in 2011 reached 390 ppm, an increase of nearly 40 percent from the pre-industrial era, and concentrations of methane and other greenhouse gases are rising at an even faster rate.

*Increasing Temperatures.* There is also no longer any significant question that average global temperatures have increased over the past century. The IPCC's Fourth Assessment concluded in language meant to put the debate over temperature to rest:

> [W]arming of the climate system is unequivocal, as is now evident from

> observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. . . . Eleven of the last twelve years (1995–2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906–2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901–2000) given in the Third Assessment Report (TAR). … The temperature increase is widespread over the globe, and is greater at higher northern latitudes. Land regions have warmed faster than the oceans.

*Id.* at 1. Thus, according to the IPCC, the global average surface temperature increased from 1906 to 2005 approximately 1.3° Fahrenheit (0.74° Celsius). Additionally, the last two decades have likely been the warmest decades in at least the past 1,000 years. The National Oceanic and Atmospheric Administration (NOAA) has determined that the first twelve years of the 21st century rank among the fourteen warmest on record. Further, 2012 was the warmest year recorded for the contiguous United States ever, eclipsing the former record by nearly 1° Fahrenheit.

Human influences will continue to change atmospheric composition throughout the 21st century. As a result, the IPCC estimates that global average surface temperature could increase by 2.5 to 5.6°F (1.8 to 4.0°C) by 2100 relative to 1990, depending on broad assumptions about future climate policy and economic growth. Many scientists believe the IPCC estimates are too low, and most recent studies suggest that actual global temperatures are more likely to approach the higher end of current predictions, with models predicting temperature increases of 8°F by 2100 as more likely than those with lower estimates. A 2012 review of climate science by the World Bank concluded that the world will face a 4.0°C increase by 2060 if significant mitigation efforts are not made. Compare this to the expressed desire of the global climate negotiations that avoiding catastrophic impacts requires temperature increases of less than 2°C (3.6° F). *Warm Still: Extreme Climate Predictions Appear Most Accurate, Report Says*, WASH. POST, Nov. 9, 2012, at A5. *See also* J. Hansen, R. Ruedy, M. Sato & K. Lo, *Global Temperature Trends: 2005 Summation*, NASA GODDARD INSTITUTE FOR SPACE STUDIES AND COLUMBIA UNIVERSITY EARTH INSTITUTE, Dec. 15, 2005; National Research Council, *Surface Temperature Reconstructions for the Last 2000 Years* (June 2006); H.J. Schellnhuber, et al., *Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided*, xiii–xviii (Nov. 2012) (A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics).

Global average temperatures only tell part of the story because regional variations will make many regions even hotter, and some colder. Temperatures over land and particularly over the northern hemisphere, for example, are anticipated to be higher than these global averages. In Alaska, Western Canada, and Eastern Russia, average winter temperatures have already risen by as much as 4–7°F (3–4°C) over the past 50 years and are projected to rise 7–13°F (4–7°C) over the next 100 years. *See* James Hansen, et al., *Global Temperature Trends: 2005 Summation* (NASA Goddard Institute for Space Studies & Columbia University Earth Institute: Dec. 15, 2005); *see also Arctic Climate Impact Assessment* (2004); James Hansen, et al., *Earth's Energy Imbalance: Confirmation and Implications*, 308 SCIENCE 1431 (June 5, 2005). By the end of the century, Northeastern U.S. winters are expected to warm by an average of 8–12°F, and summers by 6–14°F. More problematic than winter warming are the extreme heat waves that can be expected in the future. According to the 2012 World Bank study, tropical South America, central Africa, and all tropical islands in the Pacific are likely to experience regular, unprecedented heat waves of unprecedented magnitude and duration. In this new high-temperature climate regime, and in regions such as the Mediterranean, North Africa, the Middle East, and the Tibetan plateau, almost all summer months are likely to be warmer than the most extreme heat waves presently experienced. Such a rate of warming is without precedent for at least the last 10,000 years.

*The Causal Link between Concentrations and Temperature.* Any challenges by those opposed to addressing climate change cannot reasonably be based on questioning the increases either in GHG concentrations or in temperature; both of those are observable and well established. Harder to establish is the causal link between the two data sets. Is the observed increase in temperature due to the observed increase in GHG concentrations?

This question has been of primary concern to the IPCC, and over each successive report, evidence has mounted demonstrating that the observed warming was causally linked to increased GHG concentrations. By the 2007 Fourth Assessment, the IPCC could conclude:

> Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* [i.e., between 90–95% likely] due to the observed increase in anthropogenic greenhouse gas concentrations. This is an advance since the [Third Assessment Report's (TAR's)] conclusion that "most of the observed warming over the last 50 years is *likely* [i.e., greater than 66% likely] to have been due to the increase in greenhouse gas concentrations." Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns . . .

- It is *likely* that increases in greenhouse gas concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place.

- The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is *extremely unlikely* [less than 5%] that global climate change of the past fifty years can be explained without external forcing, and *very likely* that it is not due to known natural causes alone.

- Warming of the climate system has been detected in changes of surface and atmospheric temperatures, temperatures in the upper several hundred metres of the ocean and in contributions to sea level rise. Attribution studies have established anthropogenic contributions to all of these changes. The observed pattern of tropospheric warming and stratospheric cooling is *very likely* due to the combined influences of greenhouse gas increases and stratospheric ozone depletion.

- It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica. . . . The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are only simulated by models that include anthropogenic forcing. The ability of coupled climate models to simulate the observed temperature evolution on each of six continents provides stronger evidence of human influence on climate than was available in the TAR.

IPCC, Working Group I, at 10. Thus, the IPCC could conclude with "*very high confidence* [more than 90%] that the net effect of human activities since 1750 has been one of warming." The 2007 IPCC report has substantially quelled most serious questions about the causal link between observed warming trends and increased anthropogenic emissions of greenhouse gases.

Uncertainty still exists, however, as to the sensitivity of the relationship between greenhouse gas concentrations and temperature. *Climate sensitivity* refers to the temperature response of the climate system to a change in radiative forcing. It is usually expressed as the amount the planet would warm in response to doubling atmospheric $CO_2$ concentrations from pre-industrial times (i.e. to a level of 550 ppm). The IPCC Fourth Assessment estimates climate sensitivity to "be in the range 2ºC to 4.5ºC, with a best estimate value of about 3ºC. It is very unlikely to be less than

1.5ºC." IPCC WORKING GROUP I, TECHNICAL SUMMARY, THE PHYSICAL SCIENCE BASIS (Fourth Assessment Report 2007). Hansen et al. on the other hand calculate that the climate sensitivity is much larger, estimating an approximately 6°C increase in temperatures with a doubling of greenhouse gas concentrations. James Hansen *et al.*, *Target Atmospheric $CO_2$: Where Should Humanity Aim?*, 2 OPEN ATMOS. SCI. J. 217–231 (2008).

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## QUESTIONS AND DISCUSSION

**1.** ***Feedback Loops.*** Among the important factors for predicting the ultimate ramifications of climate change are a series of "feedback loops" in the planet's climate system. Some of these feedback loops may intensify the global warming impact of climate change (positive feedback loops), while others may tend to minimize the impacts of global warming (negative feedback loops). For example, as the atmosphere warms, it should hold more water vapor, which in turn will cause an increase in temperature. More clouds are also expected to form, but their effect on temperature will depend on whether they are low cumulus clouds, which tend to reflect sunlight, or high cirrus clouds, which tend to trap heat. The reduction in ice and snow cover because of an increase in temperature will provide a positive feedback, as the so-called albedo effect (the earth's reflectivity) will decrease, reflecting less sunlight away from the earth's surface. Melting permafrost is another example of a positive feedback loop, where the thawing soil releases massive quantities of methane into the atmosphere. So is forest die-off. On the other hand, $CO_2$ can spur the growth of plants (all other factors being equal), which in turn increases the amount of carbon removed from the atmosphere by photosynthesis. This latter negative feedback loop is often emphasized by those who argue that climate change will not be significant. And the possible shut-down of the thermohaline circulation (the Atlantic ocean current that brings warm water from the gulf to northern Europe) is expected to lead to a much cooler northern Europe (although the shut-down also will slow the ocean current that carries $CO_2$ to the deep ocean, which will be another positive feedback).

**2.** ***Sulfates and Global Cooling.*** In the past, the role of sulfate particulate emissions in the global climate system caused confusion among policymakers and the public. Sulfate particulates (also called sulfate aerosols) are emitted from the combustion of fossil fuels and biomass. Unlike $CO_2$, however, sulfate particulates have a cooling effect on the planet because they reflect sunlight away from the earth's surface. The relative magnitude of this cooling effect was not well understood until recently. Indeed, in the 1970s the relative effect of aerosol cooling was thought by some scientists to be greater than the global warming effect of fossil fuel combustion. As a result, some scientists were for a short time worried about a global cooling, and global cooling was one of the major concerns in the early 1970s.

Since then, our understanding of the effect of aerosols has increased. The net effect of sulfate aerosols from fossil fuel emissions is now recognized to be less than the warming effect of associated emissions of carbon dioxide and other greenhouse gases, although locally the cooling from sulfate aerosol emissions can completely mask or offset the warming effect due to greenhouse gases. While the cooling is typically focused in particular regions, it can have impacts on a continent's or hemisphere's overall climate patterns. Moreover, anthropogenic sulfate aerosols are short-lived in the atmosphere (a matter of weeks as compared to decades for $CO_2$ and $N_2O$). As a result, the cooling effect of sulfate aerosols on climate adjusts rapidly to increases or decreases in emissions. Thus, as we reduce sulfate emissions, the masking effect of the aerosols will end sooner than the warming effects of most greenhouse gases. The cooling effect of sulfate aerosols has led some scientists to consider how aerosols could be used to counter-act the impact of global warming. They are now researching whether we should deliberately seed the upper atmosphere with massive amounts of aerosol particles in an effort to cool the planet. These and other "geoengineering" proposals are discussed in Chapter 19.

**3.** Although uncertainty surely exists on the extent and scale of impacts and, particularly, on what levels of greenhouse gas concentrations will lead to what impacts, no significant doubt exists among scientists that climate change is happening, is serious, is caused by human activity, and demands real attention at all levels. The few remaining "climate skeptics" typically try to obscure the basic understanding and consensus that exists. Some of these efforts have received substantial press, including Michael Crichton's 2004 fictional novel *State of Fear* and the continued publications from conservative think tanks such as the Cato Institute and the American Enterprise Institute. But the uncertainty portrayed in the press or in popular culture is not reflected in the scientific community — at least about the basic consensus that greenhouse gas concentrations are increasing due to human activities and having a discernible impact on global average temperature. In the United States alone, the National Academy of Sciences, the American Meteorological Society, the American Geophysical Union, and the American Association for the Advancement of Science have all issued statements in recent years stating that the evidence of human-induced climate change is compelling. To determine whether a significant minority opinion was being ignored, Naomi Oreskes surveyed the abstracts of every published article in refereed scientific journals from 1993 to 2003. Of the over 600 journal articles that addressed contemporary issues of climate change, *not one* of them challenged the basic consensus that the climate is changing due to human-made increases in greenhouse gases.

*See* Naomi Oreskes, *Beyond the Ivory Tower: The Scientific Consensus on Climate Change*, 306 SCIENCE, Dec. 3, 2004, at 1686.

**4.** Until recently, climate skeptics raised three basic arguments against the link between greenhouse gas concentrations and temperature increases: (1) that long-term temperature trends of the earth's surface do not show a meaningful increase, (2) that discrepancies between satellite and ground-level data disproved climate models, and (3) that variations in the changes in solar activity can account for the observed warming. As pointed out in the following excerpt, all three of these arguments have effectively been rebutted in peer-reviewed scientific literature in the past few years:

## THOMAS HOMER-DIXON, POSITIVE FEEDBACKS, DYNAMIC ICE SHEETS, AND THE RECARBONIZATION OF THE GLOBAL FUEL SUPPLY: THE NEW SENSE OF URGENCY ABOUT GLOBAL WARMING

*in* STEVEN BERNSTEIN, ET AL., A GLOBALLY INTEGRATED CLIMATE POLICY FOR CANADA 39–40 (2007)[*]

The first argument concerns the long-term trend of Earth's average surface temperature. In 1999, Mann, Bradley, and Hughes released a paper that estimated average global temperature for the last millennium. This work was subsequently updated by Mann and Jones in 2003 to provide a temperature record from the years 200 to 2000 AD. M. Mann, R. Bradley, & M. Hughes, *Northern Hemisphere Temperatures during the Past Millennium: Inferences, Uncertainties, and Limitations*, 26(6) GEOPHYSICAL RESEARCH LETTERS 759 (1999); M. Mann & P. Jones, *Global Surface Temperatures over the Past Two Millennia*, 30(15) GEOPHYSICAL RESEARCH LETTERS (2003). These researchers combined a number of different paleoclimatological records — like tree rings and coral growth rates — that are "proxy" measures of atmospheric temperature during various historical epochs. They cobbled these proxy measures together to get a long-term record of the planet's temperature. Their graph famously showed a sharp uptick over the last half century, which is why it was widely labeled the "hockey stick" graph. It has been one of the most contentious pieces of evidence used to support the claim that we are experiencing an abnormally warm period.

. . . In response to criticism of the statistical methodology used to cobble these records together, the National Academy of Sciences in the United States created a panel to examine the Mann et al. methodology. The panel released its results last year, saying that, overall, while some questions remained about the methodology, the original study's conclusions were largely correct: the warming of the last 40 years very likely made Earth hotter than anytime in the last 1000 years, and it certainly made Earth hotter than anytime in the last 400 years. I think the National Academy of Sciences report dealt with the hockey stick issue; it's off the table now . . . *See* National Research Council of the National Academies, Committee on Surface Temperature Reconstructions for the Last 2,000 Years, Board on Atmospheric Sciences and Climate, Division on Earth and Life Sciences, *Surface Temperature Reconstructions for the Last 2,000 Years* (National Academies Press: 2006).

The second argument concerns satellite data. There has been an enormous debate about an apparent discrepancy between data from satellites that show no warming in the troposphere and data from ground level instruments that show warming. The argument was originally made by John Christy of the University of Alabama in Huntsville. R.W. Spencer & J.R. Christy, *Precise Monitoring of Global Temperature Trends from Satellites*, 247 SCIENCE 1558 (1990). But recent studies have looked very carefully at this apparent discrepancy between satellite and ground-level data and have shown that Christy and his colleagues made a number of methodological and statistical errors. Once these errors are corrected, the discrepancy disappears. [*See* B.D. Santer et al., *Influence of Satellite Data Uncertainties on the Detection of Externally Forced Climate Change*, 300 SCIENCE 1280 (23 May 2003); C. Mears & F. Wentz, *The Effect of Diurnal Correction on Satellite-Derived Lower Tropospheric Temperature*, 309 SCIENCE 1548 (2 Sept. 2005). On errors in interpreting weather balloon data, see S. Sherwood, J. Lazante, and C. Meyer, *Radiosonde Daytime Biases and Late-20th-Century Warming*, 309 Science 1556 (2 Sept. 2005).] The satellite record actually shows tropospheric warming — in fact, it shows both tropospheric warming and, as we would expect from global warming theory, stratospheric cooling.

The third argument concerns radiation from the sun. The most common argument now put forward by climate skeptics is that the recent warming is a result of changes in the intensity of the sun's radiation. But a major review article last year in the journal *Nature* showed that it's virtually impossible to explain the warming we've seen in the last 40 years through changes in solar radiation. [See P. Foukal et al., *Variations in Solar Luminosity and Their Effect on the Earth's Climate*, 443 NATURE 161 (Sept. 14, 2006).] This research is pretty well definitive, too.

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Most of the remaining climate skeptics focus on the "uncertainty" of climate modeling, but no current alternative theory for the observed global warming has any significant following. The more important debate over science is no longer *whether* increased concentrations of greenhouse gases are causing global warming, but what is the *rate* of that warming, what will be the short-term and long-term *impacts* of the warming, and *when* will they occur.

**5.** Despite the broad scientific consensus relating to climate change, climate skeptics nonetheless continue to gain headlines that overstate uncertainties in the underlying science. Two well-publicized examples from 2009 illustrate these developments. First, climate skeptics publicized an error in the IPCC's Working Group II report related to the melting of Himalayan glaciers, claiming that this reflected systemic problems with the IPCC process and undermined the entire report. The IPCC's response put the error into perspective:

> The Synthesis Report, the concluding document of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change . . . stated: "Climate change is expected to exacerbate current stresses on water resources from population growth and economic and land-use change, including urbanisation. On a regional scale, mountain snow pack, glaciers and small ice caps play a crucial role in freshwater availability. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st century, reducing water availability, hydropower potential, and changing seasonality of flows in regions supplied by meltwater from major mountain ranges (e.g. Hindu–Kush, Himalaya, Andes), where more than one-sixth of the world population currently lives."
>
> This conclusion is robust, appropriate, and entirely consistent with the underlying science and the broader IPCC assessment. It has, however, recently come to our attention that a paragraph in the 938-page Working Group II contribution to the underlying assessment refers to poorly substantiated estimates of rate of recession and date for the disappearance of Himalayan glaciers. In drafting the paragraph in question, the clear and well-established standards of evidence, required by the IPCC procedures, were not applied properly.

IPCC, STATEMENT ON THE MELTING OF HIMALAYAN GLACIERS (2010). The IPCC thus admitted to the error, but noted that it had no impact on the general conclusions of the report. Many IPCC supporters thought the IPCC's response was too little and too late, particularly given that there is little doubt that the Hindu-Kush-Himalaya-Tibetan Glaciers are melting and endangering the fresh water supply and food security of billions of people. Mats Eriksson *et al.*, *The Changing*

*Himalayas: Impact of Climate Change on Water Resources and Livelihoods in the Greater Himalayas*, 1 The International Centre for Integrated Mountain Development (2009); *see also* Jeffrey S. Kargel *et al.*, *Satellite-era Glacier Changes in High Asia* (Dec. 14, 2009) (Presentation at NASA "Black Carbon and Aerosols" press conference). Since the 1950s, warming in excess of 1ºC on the Tibetan side of the Himalayas has contributed to retreat of more than 80 percent of the glaciers, and the degradation of 10 percent of its permafrost in the past ten years. Jane Qiu, *The Third Pole*, 454 NATURE 393 (2008). *See generally* Bidisha Banerjee & George Collins, *Undoing 'The Curse' of a Chain of Errors: Anatomy of IPCC's Mistake on Himalayan Glaciers and Year 2035* (Feb. 4, 2010) (presentation at the Yale Forum on Climate Change and the Media).

In the second controversy, which became known as "climate-gate," thousands of emails of climate scientists at the University of East Anglia were hacked and released to the public in November 2009. Climate skeptics claimed that these emails showed that the data had been manipulated and certain key facts hidden. The emails were released just prior to the Copenhagen climate conference, and the resulting media frenzy fueled skepticism regarding the validity of climate change.

Independent investigations subsequently exonerated the scientists of all accusations that they had manipulated their results. The investigations found only that the scientists had not been sufficiently transparent in their research. Although the scientific data and the reports published based on this data, including the IPCC's Fourth Assessment, were found to be scientifically accurate, the scandal had a negative effect on public opinion, particularly "among individuals with a strongly individualistic worldview or politically conservative ideology." *See* A. A. Leiserowitz, *et al.*, *Climategate, Public Opinion, and the Loss of Trust*, Working Paper (2010).

**6.** The strategy of climate skeptics shows that small groups of scientists or interest groups with deep political and industrial connections can raise public doubt. This is the case on issues ranging from the safety of tobacco smoke to the validity of climate change. These countervailing interest groups use doubt or the lack of absolute certainty to discredit valid scientific research. By casting doubt on the science, the policy making process can be slowed if not halted. For example, Frederick Seitz, a former president of the U.S. National Academy of Sciences, directed over $43.3 million in research money from the R.J. Reynolds tobacco company to scientific efforts to prove cigarettes were not dangerous. Later in his career Seitz founded the George C. Marshall Institute, which in the late 1980s published the first report attacking climate science. Seitz and followers fought the fact that tobacco kills and also fueled the idea that global warming was not as serious as scientists claim. *See* NAOMI ORESKES & ERIK M. CONWAY, MERCHANTS OF

DOUBT, HOW A HANDFUL OF SCIENTISTS OBSCURED THE TRUTH ON ISSUES FROM TOBACCO SMOKE TO GLOBAL WARMING, 10–11, 27–29, 186–89 (2010); *see also* ERIC POOLEY, THE CLIMATE WAR, TRUE BELIEVERS, POWER BROKERS, AND THE FIGHT TO SAVE THE EARTH, (2010). For a critique of MERCHANTS OF DOUBT, see William O'Keefe, & Jeff Kueter *Clouding the Truth: A Critique of Merchants of Doubt* (George C. Marshall Institute: June 20, 2010). What is the difference between those who purposely mislead by casting doubt on climate science, and those with genuine questions? Are not climate skeptics simply part of the give-and-take of science? Is it relevant whether scientists are funded by the potentially regulated industry?

## III. THE ENVIRONMENTAL IMPACTS OF CLIMATE CHANGE

So what if the planet's temperature increases? Understanding the ultimate impact of climate change on human health and the environment is of course critical for policymaking. As early as 2001, the third IPCC Assessment found that climate change was *already* having a discernible impact on many different environmental systems. The evidence of impacts caused by global warming has increased substantially since 2001. In fact, the IPCC Fourth Assessment found that, based on a "review of more than 29,000 observational data series, from 75 studies that show significant change in many physical and biological systems, more than 89 percent are consistent with the direction of change expected as a response to warming." The Fourth Assessment further concluded:

> **Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.**
>
> With regard to changes in snow, ice and frozen ground (including permafrost), there is high confidence [about 8 out of 10 chance of being correct] that natural systems are affected. Examples are:
>
> - enlargement and increased numbers of glacial lakes;
> - increasing ground instability in permafrost regions, and rock avalanches in mountain regions;
> - changes in some Arctic and Antarctic ecosystems, including those in sea-ice biomes, and also predators high in the food chain [such as polar bears].

Based on growing evidence, there is high confidence that the following types of hydrological systems are being affected around the world:

- increased run-off and earlier spring peak discharge in many glacier- and snow-fed rivers;

- warming of lakes and rivers in many regions, with effects on thermal structure and water quality.

There is very high confidence [about 9 out of 10 chance of being correct], based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems, including such changes as:

- earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying;

- poleward and upward shifts in ranges in plant and animal species.

Based on satellite observations since the early 1980s, there is high confidence that there has been a trend in many regions towards earlier "greening' " of vegetation in the spring linked to longer thermal growing seasons due to recent warming.

There is high confidence, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. These include:

- shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans;

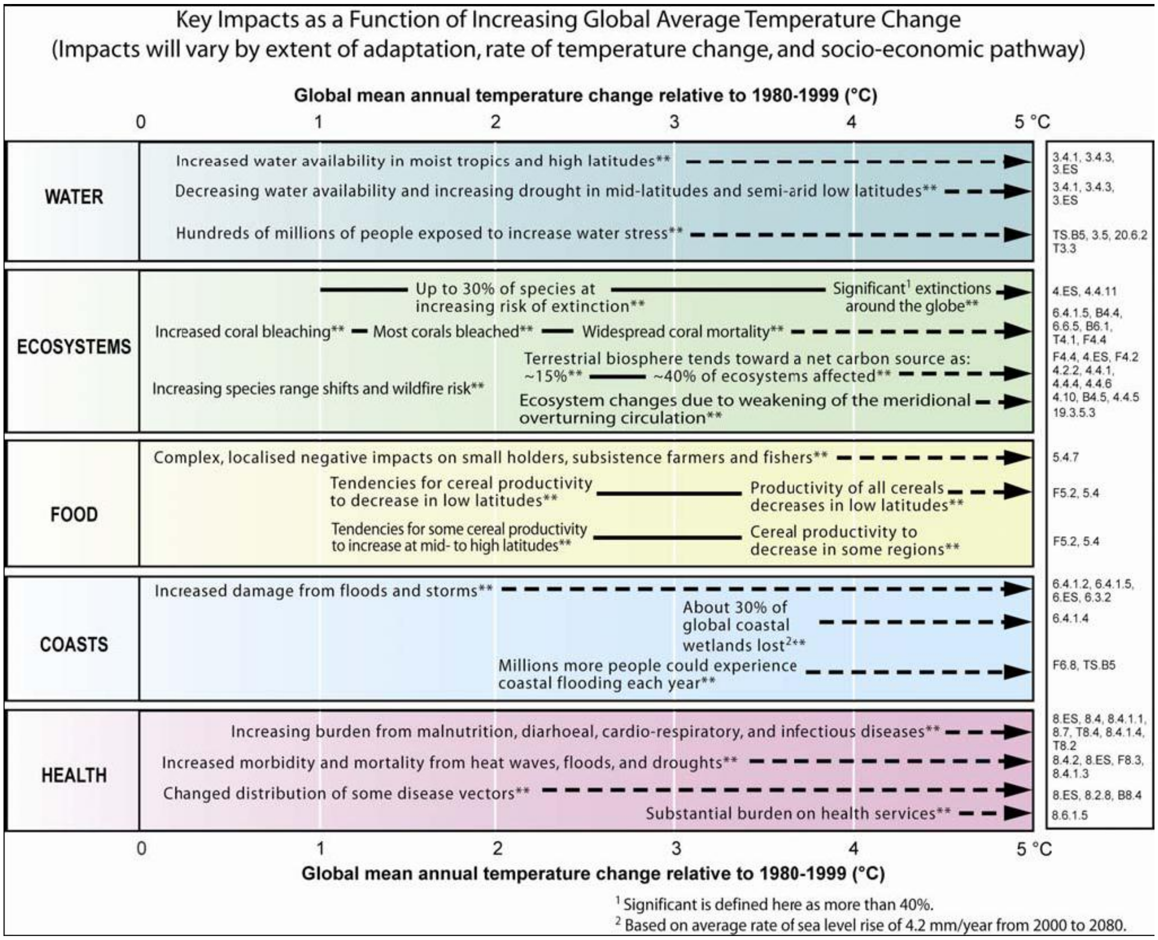
- increases in algal and zooplankton abundance in high-latitude and high-altitude lakes;

- range changes and earlier migrations of fish in rivers.

> The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units [IPCC Working Group I Fourth Assessment]. However, the effects of observed ocean acidification on the marine biosphere are as yet undocumented.

IPCC, WORKING GROUP II, SUMMARY FOR POLICYMAKERS, CLIMATE CHANGE 2007: IMPACTS, ADAPTATION, AND VULNERABILITY 1-2 (Fourth Assessment Review 2007). Think carefully about what is being said in the IPCC report. Behind the stilted language, the IPCC is confirming that summer river flows are declining, polar bears are threatened, and natural ecosystems and migration patterns are already disrupted by climate change. The impacts already observed from climate change are widespread and significant; the future, anticipated impacts even more so. The IPCC presented the expected impacts as a function of potential temperature increases, reproduced in Table 1-2. Note that we have already increased greenhouse gas concentrations sufficiently as to essentially lock in a 1°C (1.8°F) increase over pre-industrial times, and a 2°C (3.6°F) increase will be very difficult to avoid without substantial reductions in greenhouse gas emissions by 2020.

**Table 1-2: Key Impacts as a Function of Temperature Increases**




Selected potential environmental impacts from climate change are discussed further below, followed by sections on regional impacts and socio-economic impacts.

## A. Melting Ice

In the past few years, scientists have had to re-assess their predictions about melting polar ice as evidence is emerging that current melting in both the Antarctic and Arctic is more extensive and more rapid than previously predicted.

*Melting Arctic Ice.* In 2004, the Arctic Climate Impact Assessment (ACIA) found that the

Arctic was warming much more rapidly than anticipated — at nearly twice the rate of the rest of the planet. The ACIA reported that temperatures in the region will increase by 4–7°C (7–13°F) by 2100, melting half of the Arctic's summer sea ice and a significant portion of the Greenland Ice Sheet. The report also suggested that it was possible for the Arctic to lose all its summer sea ice by 2100.

But even these estimates may have been too benign. On September 16, 2012, Arctic sea ice was the smallest it has been since satellite monitoring began in 1979. At 1.32 million square miles, the extent of sea ice was an amazing 293,000 square miles below the 2007 record. The six lowest extents of sea ice occurred in the past six years (up to 2012). Ice loss in August 2012 was the greatest on record at an astonishing 35,400 square miles a day. *Arctic Sea Ice Shrank to New Low This Month*, WASH. POST, Sept. 20, 2012, at A5. The summer sea ice is now less than half as extensive as 50 years ago. Just as alarming, the Arctic sea ice is not recovering during the winter, reaching new lows almost every year. *See* National Snow and Ice Data Center, *Arctic Sea Ice Extent Remains Low; 2009 Sees Third-Lowest Mark* (Oct. 6, 2009); *see also* Petr Chylek *et al.*, *Arctic Air Temperature Change Amplification and the Atlantic Multidecadal Oscillation*, 36 GEOPHYS. RES. LETTERS (July 16, 2009).

In the past decade, Arctic sea ice has melted much faster than climate models predicted and is about 30 years ahead of predictions made by the IPCC. If these current rates continue, the Arctic Ocean could be ice-free in the summers by 2020. *Arctic Ice May Melt 30 Years Sooner*, REUTERS, May 3, 2007. Dr. Walt Meier, a researcher at the U.S. National Snow and Ice Data Center (NSIDC) in Colorado, puts this into perspective:

> For 800,000 to a million years, at least some of the Arctic has been covered by ice throughout the year. That's an indication that, if we are heading for an ice-free Arctic, it's a really dramatic change and something that is unprecedented almost within the entire record of human species. Having four years [now ten years] in a row with such low ice extents has never been seen before in the satellite record. It clearly indicates a downward trend, not just a short-term anomaly.

David Adam, *Meltdown Fear as Arctic Ice Cover Falls to Record Winter Low*, GUARDIAN, May 15, 2006; *see also* INTERNATIONAL ARCTIC SCIENCE COMMITTEE (IASC) & THE ARCTIC COUNCIL, ARCTIC CLIMATE IMPACT ASSESSMENT (Nov. 2004). Loss of Arctic sea ice will likely have significant, but still unknown, impacts on global weather patterns with initial research showing it may slow down the jet stream which, in turn, will lead to extreme weather patterns being more persistent.

*Greenland.* The situation is similar with Greenland's large ice fields, with a 2006 study suggesting that the large glaciers are disintegrating at a rate that has nearly doubled in the last ten years. In August 2010, an "ice island" four times the size of Manhattan calved from Greenland's Petermann Glacier. Andrew C. Revkin, *Vast Ice 'Island' Breaks Free of Greenland Glacier*, N.Y. TIMES, Aug. 7, 2010. The accelerated net loss of ice from the Greenland ice sheet since the mid-1990s is contributing as much as 0.7 millimeters per year to sea level rise due to both increased melting and accelerated ice flow. I. Allison et al., *The Copenhagen Diagnosis: Updating the World on the Latest Climate Science (2009)*.

*Antarctica.* The Antarctic region appears to be in similar condition. The air over the western Antarctic peninsula has warmed by nearly 6°F since 1950. Although for many years scientists thought global warming might cause Antarctica to gain mass, as warmer temperatures would increase precipitation in Antarctica's center, recent studies demonstrate that it, like the Arctic, is already melting significantly. *See* Eric Rignot et al., *Recent Antarctic Ice Mass Loss from Radar Interferometry and Regional Climate Modeling,* NATURE GEOSCIENCE, Jan. 13, 2008; Andrew Shepherd et al., *A Reconciled Estimate of Ice-Sheet Mass Balance,* SCIENCE, Nov. 2012, at 1183–89. From early 2002 to early 2009, the Antarctic ice sheet is estimated to have lost approximately 143 Gt ice per year. Markku Rummukainen *et al.*, PHYSICAL CLIMATE SCIENCE SINCE IPCC AR4, A BRIEF UPDATE ON NEW FINDINGS BETWEEN 2007 AND APRIL 2010 (2010). According to a recent study, the Antarctic ice sheets are melting at a rate of approximately 150 cubic kilometers per year (+/- 80), which is roughly the total U.S. water consumption over three months and is projected to result in a 0.4 millimeter (mm) rise in sea level each year. Most scientists believe that Antarctica's annual ice loss is the result of warmer oceans and ocean breezes that have changed ocean currents around the continent, bringing warmer water into contact with the ice. *See* Andrew C. Revkin, *Antarctica Surveys Show Melting Ice Is Causing Rising Sea Levels*, N.Y. TIMES, Mar. 3, 2006; Eric Rignot, et al., *Recent Antarctic Ice Mass Loss from Radar Interferometry and Regional Climate Modeling*, NATURE GEOSCIENCE, Jan. 13, 2008. Melting in the Antarctic also could release significant amounts of methane believed to be frozen underneath the ice sheets.

*Declining Glaciers and Permafrost.* Virtually all of the world's glaciers are receding due to global warming. Around the world, there are significant observed and predicted declines in glaciers, with significant implications for long-term availability of freshwater as well as for biodiversity. Recent estimates include, for example, that Europe's Alps could lose 80 percent of their glaciers by the end of the century, Glacier National Park is likely to have no glaciers by 2030, and Nepali glaciers are shrinking at a rate of 30 to 60 meters per decade. In addition, warming in excess of 1°C on the Tibetan side of the Himalayas since the 1950's has contributed to retreat of more than 80 percent of the glaciers, and the degradation of 10 percent of its permafrost in the past ten years. Jane Qiu, *The Third Pole*, 454 NATURE 393 (2008); James Owen, *Alps Could Be Ice Free by 2100, Study Warns*, NAT'L GEOG. NEWS, July 11, 2006; *Glaciers Melting In Montana Park: U.N. Is Asked To Declare Park An Endangered World Heritage Site*, CBS NEWS, Mar. 13, 2006; David Cyranoski, *Climate Change: The Long-Range Forecast*, 438 NATURE 275–76 (Nov. 17, 2005).

The impact of receding glaciers can be significant on downstream users. Consider for example that 500 million people use water from the Ganges River, and yet 70 percent of the Ganges' low summer flows comes from just one massive glacier which is receding at 40 meters a year. Emily Wax, *A Sacred River Endangered by Global Warming: Glacial Source of Ganges Is Receding*, WASH. POST, June 17, 2007, at A14. Melting glaciers and mountain ice-caps are also estimated to be contributing more than 1 millimeter per year to sea level rise. I. Allison *et al.*, *The Copenhagen Diagnosis*, *supra*.

Of perhaps greater concern is the loss of permafrost across vast reaches of Alaska, Canada, and Russia. Warming temperatures could thaw the top ten or more feet of permafrost across the Northern Hemisphere by 2050, and as much as 90 percent by 2100. Such a thawing would alter ecosystems and substantially damage buildings and roads. It would also release massive amounts of $CO_2$ (doubling current atmospheric levels) and methane into the atmosphere, as permafrost is estimated to hold 30 percent or more of all carbon stored in soils worldwide. This positive feedback will further amplify climate change. However, none of the IPCC projections account for this. I. Allison *et al.*, *The Copenhagen Diagnosis*, *supra*; *see also* Edward A.G. Schuur *et al.*, *Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle*, BIOSCIENCE (Sept. 2008). The circumpolar permafrost regions, which include peatlands, contain about twice the carbon contained in the atmosphere. If 10 percent of permafrost thawed by the end of the century, atmospheric concentrations of $CO_2$ could increase by as much as 80 ppm (from today's 389 ppm) and temperatures could increase by an additional 1.0°F. C. Taurnocai, et al., *Soil Organic Carbon Pools in the Northern Circumpolar Permafrost*, 23 GLOBAL BIOGEOCHEMICAL CYCLES 2023 (2009).

## B. Rising Sea Levels

According to the IPCC's Fourth Assessment, global average sea level rose at an average rate of 1.8 mm per year from 1961 to 2003. The rate was faster from 1993 to 2003, about 3.1 mm per year. Total sea level rise in the last century is estimated at a modest 0.17 meters. Moreover, under a range of future scenarios, the IPCC estimates a maximum 21st century sea level rise of no more than an additional 0.59 meters.

More recent studies suggest that the IPCC's Fourth Assessment significantly underestimated sea level rise and its impacts on coastal countries and landowners. First, data released since the Fourth Assessment suggests that the rate of sea level rise is more than previously calculated, and will lead to as much as 1.4 meters by the end of the century. *See* Susan Solomon, *et al.*, *A Closer Look at the IPCC Report*, 319 SCIENCE 409–10 (Jan. 25, 2008); J.T. Overpeck & J.L. Weiss, *Projections of Future Sea Level Becoming More Dire*, 106 PROC. NAT'L ACAD. SCI. 21461–62 (2009); *see also* Anny Cazenave & William Llovel, *Contemporary Sea Level Rise*, 2 ANN. REV. MARINE SCI. 145 (2010). According to the World Bank, sea-level rise would likely be held to less than 2 meters only if warming were kept well below 1.5°C.

Sea-level rise will vary regionally with the tropics expecting to experience as much as 20 percent higher sea level rise than higher latitudes. Many islands around the world will disappear; Assateague Island off Virginia's coast, for example, may disappear by the turn of the century. Storm surges, like one from Hurricane Sandy that devastated lower Manhattan and New Jersey in 2012, will be more frequent and higher in the future.

The IPCC's Fourth Assessment only considered sea level rise assuming a linear relationship between temperature increases and ice melting As the discussion of polar ice melts above suggests, many scientists are re-assessing the likelihood of even more significant sea-level rise due to the rapid disintegration of either the Greenland or West Antarctic Ice sheets, or both. Indeed, the primary variable in accurately modeling future sea level rise, at least over the long term, is the stability of the ice sheets. The U.S. Geological Survey, for example, projects that a complete melting of the current Greenland ice sheet would raise sea levels by about 6.5 meters, and a melting of the West Antarctic ice sheet, or a release of the ice sheet from its mooring on the ocean floor, would raise sea levels by about 8 meters. Adding the East Antarctic Ice Sheet could raise sea levels by 80 meters! To put this in perspective, a 10-meter rise in sea levels would flood about 25 percent of the U.S. population, including most of southern Florida, lower Manhattan and portions of southern California. U.S. GEOLOGICAL SURVEY, SEA LEVEL AND CLIMATE (2000). Increasing concern over rapid melting led Rajendra Pachauri, head of the IPCC, to announce that "future reports from the IPCC should look at the 'frightening' possibility that ice sheets in Greenland and Antarctica could both begin melting rapidly. . . . If, through a process of melting, they collapse and are submerged in the sea, then we really are talking about sea-level rises of several meters." *U.N. Climate Chief: World Should Watch Poles: Previous Reports*

*Didn't Factor in "Frightening" Possibility of Significant Melt*, ASSOC. PRESS, Jan. 8, 2008.

## C. Changing Ocean Ecology

Sea level rise gets a lot of attention because of its impacts on coastal settlements, but other significant impacts on the oceans arise from increased concentrations of atmospheric greenhouse gases. These include changes in ocean temperature, salinity, acidity, and currents.

*Ocean Acidification.* Increased atmospheric concentrations of $CO_2$ and other greenhouse gases in the atmosphere are altering ocean chemistry in ways that threaten corals and other marine organisms. The oceans have absorbed as much as one-third of anthropogenic $CO_2$ emissions, creating carbonic acid and increasing ocean acidity by 30 percent.. This ocean acidification makes it more difficult for corals, plankton, and tiny marine snails to form their body parts because the more acidic waters dissolve the calcium carbonate skeletons and shells. Moreover, the productivity of plankton, krill, and marine snails, which compose the base of the ocean food chain, declines as the ocean acidifies. Reductions in their productivity will affect populations of everything from whales to salmon. Joan A. Kleypas, *Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers*, NAT'L CENTER FOR ATMOS. RES. (June 2006). In 2009, Congress passed the Federal Ocean Acidification Research and Monitoring Act, creating the first federal program explicitly designed to address ocean acidification.

Worldwide, we may be approaching irreversible damage to coral reefs from mass coral bleaching, disease, and now acidification. Some scientists predict that all ocean corals may be dissolving by the year 2050, at which time $CO_2$ concentrations are expected to reach 560 ppm. J. Silverman, *et al*., *Coral Reefs May Start Dissolving When Atmospheric $CO_2$ Doubles*, 36 GEOPHYS. RES. LETT. (2009). The effects of ocean acidification are irreversible on a time scale of tens of thousands of years. Even if emission cuts begin immediately, there is no known way to reverse the effects of ocean acidification. Inter-Academy Panel on International Issues, STATEMENT ON OCEAN ACIDIFICATION (2009). Scott C. Doney, et al., *Ocean Acidification—Present Conditions and Future Changes in a High $CO_2$ World*, 22 OCEANOGRAPHY 36–47 (2009).

*Ocean Warming.* Measuring average ocean temperature over time is complex, particularly given that the limited historical data that do exist were not gathered for the purpose of monitoring climate change. Nonetheless, most recent studies conclude that surface temperature of the oceans has increased over the past decades, which is consistent with climate modeling.

*See, e.g.*, Catia M. Dominguez, et al., *Improved Estimate of Upper-Ocean Warming and Multi-Decade Sea Level Rise*, 450 NATURE 1090–93 (June 19, 2008). Warming of the ocean contributes to sea level rise (through thermal expansion) and could significantly alter ocean ecology. A 2012 study suggested that ocean animals (including sharks, whales, and sea turtles) could lose up to 35 percent of their habitat and as much as 20 percent of species diversity in the North Pacific due to warmer temperatures caused by climate change. *Study: Climate Change Will Alter Marine Habitat*, WASH. POST, Sept. 24, 2012, at A4.

*Ocean Currents.* Even slight changes in ocean temperature and salinity (due, for example, to ice melt) may alter ocean circulation and vertical mixing in the ocean, which threatens nutrient availability, biological productivity, and the functions of marine ecosystems. According to one recent study, the Walker Circulation, which drives the trade winds and guides ocean behavior across the tropical Pacific, has weakened 3.5 percent since the mid-1800s and may weaken another 10 percent by 2100. These Pacific currents supply important nutrients to ocean ecosystems across the equatorial Pacific, a vital fishing region. Perhaps most important for climate change are the currents of the Southern Ocean around Antarctica. Although significant uncertainty still exists about how the Southern Ocean is responding to global warming, the ocean is responsible for absorbing a significant amount of carbon (perhaps as much as 15 percent of the earth's total carbon sink). Changes in winds and currents in the Southern Ocean could thus have a significant impact on the overall rate of warming. For another important potential impact on ocean currents, see the discussion, *infra*, regarding the Atlantic Ocean's thermohaline circulation.

## D. Intensifying Weather Events

Climate is of course different from weather, and among the most hotly debated questions in the current climate debate is the extent to which extreme weather events are caused or exacerbated by global warming. The IPCC's 2007 Fourth Assessment noted that the intensity and frequency of hurricanes, floods, droughts, storms, and other extreme climate events are likely to increase as temperatures rise. An increasing number of studies have begun to show the impact generally of climate change on intensifying extreme weather, including droughts, floods, and hurricanes. *See, e.g.*, U.S. CLIMATE CHANGE SCIENCE PROGRAM, WEATHER AND CLIMATE EXTREMES IN A CHANGING CLIMATE. REGIONS OF FOCUS: NORTH AMERICA, HAWAII, CARIBBEAN, AND U.S. PACIFIC ISLANDS (June 2008). It is still difficult, however, to attribute all or part of a particular weather event to anthropogenic climate change, although the methodologies for doing so are improving all the time.

*Hurricanes, Cyclones, and Tornadoes.* Hurricanes Katrina, Rita, and most recently Sandy each brought significant public attention to the connection between climate change and hurricanes. Although it is impossible to determine for certain that any specific hurricane or other weather event was caused or intensified by climate change, many recent studies confirm that climate change will generally add to the frequency and intensity of hurricanes and similar weather events. The IPCC's 2007 Fourth Assessment, for example, noted that the intensity and frequency of hurricanes, floods, droughts, storms, and other extreme climate events are likely to increase as temperatures increase. The U.S. Climate Change Science Program concluded that more intense hurricanes in the Atlantic are "likely" because of climate change. *Id.* According to the National Center for Atmospheric Research, "[g]lobal warming accounted for around half of the extra hurricane-fueling warmth in the waters of the tropical North Atlantic in 2005," the year that brought $100 billion in damage from 28 named storms, including both Hurricanes Katrina and Rita. National Center for Atmos. Res., *Global Warming Surpassed Natural Cycles in Fueling 2005 Hurricane Season, NCAR Scientists Conclude* (Press Release, June 22, 2006). Another study suggested the number of Category 4 and 5 hurricanes worldwide has nearly doubled over the past 35 years, even though the total number of hurricanes has dropped since the 1990s. P. J. Webster, et al, *Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment*, 309 SCIENCE 1844–46 (Sept. 16, 2005).

*Freshwater, Floods, and Droughts.* Climate change will likely intensify the global hydrological cycle, which could affect the magnitude and timing of floods and droughts. Some areas, including northern Europe, North America and Siberia, are expected to get significantly wetter. Seasonal flooding in many other areas will be worsened because of more intense storms. Increased flooding along rivers alone (as opposed to coast lines) is predicted to affect 330 million people worldwide.

Many already dry areas will see increased water shortages. Climate change is expected to exacerbate water shortages particularly in northern and eastern Africa, the Middle East, southern Europe and South Asia. A warmer climate could decrease the proportion of precipitation falling as snow, reducing spring runoffs available for the growing season. Average annual runoff is projected to decrease by 20 to 40 percent in the Danube, Mississippi, Amazon, and Murray Darling river basins, but increase by roughly 20 percent in the Nile and the Ganges basins. In China's Yellow River, continued rising temperatures are projected to decrease water availability 20 to 40 percent by 2040 and reduce total agricultural output 10 percent by 2030 to 2050. Overall, Africa's available surface water is expected to be reduced 25 percent by 2100.

Several regions of the United States now regularly suffer from significant droughts, which may be exacerbated by climate change. One study found that the declining snowpack in the western United States is primarily attributable to human-made climate change. According to the report, since 1950 the water content of the snowpack in the western United States has decreased in eight of nine mountain regions, ranging from 10 percent in the Colorado Rockies to 40 percent in the Oregon Cascades, and this decline cannot be explained by natural variability. *See* Marc Kaufman, *Decline in Snowpack Is Blamed On Warming: Water Supplies In West Affected*, WASH. POST, Feb. 1, 2008, at A01. A 2007 study found that the Great Lakes will suffer significant declines primarily due to increased evaporation because the lakes do not freeze as much as before. The study estimates that water levels in Lake Erie could drop more than 6 feet by 2066. *See* DETROIT RIVER-WESTERN LAKE ERIE BASIN INDICATOR PROJECT, STATE OF THE STRAIT, STATUS AND TRENDS OF KEY INDICATORS (2007). A recent U.S. government scientific assessment concluded that North America was "very likely" to experience more frequent heat waves and more frequent and intense rainstorms, and that the Southwest was "likely" to see increased drought conditions. U.S. CLIMATE CHANGE SCIENCE PROGRAM, WEATHER AND CLIMATE EXTREMES, *supra.*

## E. Declining Forests and Increasing Desertification

*Changing Forests.* Sustained climate change is expected to lead to substantial regional changes in the extent and type of forest cover, with some regions gaining and some losing forest productivity. For example, forests from central Europe to Siberia and to a lesser extent in North America have been growing more vigorously during the past two decades, presumably because warmer temperatures have lengthened the growing season by nearly three weeks. Long-term forest trends are hard to predict. Essentially, warmer temperatures will shift climate zones northward, with more southern species being able to tolerate more northern regions. Of course, this assumes that soil, precipitation, and other factors allow for the orderly spread of forest species.

But an orderly transition is doubtful; other forces are likely to limit forest productivity. In 2003, for example, forest fires in Europe, the United States, Australia, and Canada accounted for more global emissions than any other source, and at least one study by the Scripps Institute has suggested that warmer springs and summers may be increasing the number and severity of fires in the western United States. NASA scientists have observed significant browning in Arctic boreal forests, thought to be due to drier and warmer conditions. Even if GHG emissions stopped today, Eurasia, eastern China, Canada, Central America, and Amazonia are estimated to be at a

30 to 60 percent risk of forest loss. One recent study suggests that if left unchecked, increasing temperatures and declining rainfall could transform Brazil's entire Amazon Rainforest into a grassy savannah by the end of the century. Michael Astor, *Researchers: Warming May Change Amazon*, WASH. POST, Dec. 29, 2006.

Diseases may also spread to new areas. As a result of warmer average temperatures in British Columbia, for example, the mountain pine beetle extended its range north and has destroyed an area of soft-wood forest three times the size of Maryland, killing 411 million cubic feet of trees — double the annual take by all loggers in Canada. Alaska has also lost up to three million acres of old growth forest to the pine beetle. Forests and their implications for climate policy are discussed further in Chapter 8.

*Increasing Desertification.* Deserts, covering nearly a fourth of the world's land mass and home to more than 500 million people, are expected to be among the hardest hit areas from climate change. Temperatures in desert regions have increased 0.5° to 2°C over the period 1976–2000, which was higher than the average global rise of 0.45°C. In general, deserts are likely to become more extreme and larger; with few exceptions, they are projected to become hotter but not significantly wetter. Shifts in temperature and precipitation in temperate rangelands may result in altered growing seasons and boundary shifts between deserts, grasslands, and shrublands. UNEP's 2006 GLOBAL DESERTS OUTLOOK described the impact of climate change on deserts this way:

> Because deserts are driven more by climatic pulses than by average conditions, even moderate changes in precipitation and temperature may create severe impacts by shifting the intensity and frequency of extreme periods, and subsequently creating catastrophic effects on plants, animals, and human livelihoods.
>
> Climate change is expected to affect less the total amount of available water, and more the overall water regime and the timing of water availability in deserts. Deserts and desert margins are particularly vulnerable to soil moisture deficits resulting from droughts, which have increased in severity in recent decades and are projected to become even more intense and frequent in the future. Conversely, flood events are expected to be fewer but more intense, in which case less moisture would infiltrate into soils, and run-off and eroded sediment would concentrate in depressions, reinforcing the patchiness of desert ecosystems.

> Deserts fed by melting snow or ice, such as the deserts of Central Asia and the Andean foothills, will be particularly vulnerable to a changing climate. As the volume of snowpack diminishes, river regimes will change from glacial to pluvial and, as a result, total run-off is expected to increase temporarily and then to decline. Peak discharges will shift from the summer months, when the demand is highest, to the spring and winter, with potentially severe implications for local agriculture.

UNEP, GLOBAL DESERTS OUTLOOK x (2006).

## F. Impacts on Ecosystems and Wildlife

As suggested by the impacts described above on different ecosystems, including forests, freshwater, deserts, and oceans, it should be no surprise that climate change is likely to have profound and sweeping impacts on the world's biological diversity. In 2001, the IPCC concluded that:

> Distributions, population sizes, population density, and behavior of wildlife have been, and will continue to be, affected directly by changes in global or regional climate and indirectly through changes in vegetation. Climate change will lead to poleward movement of the boundaries of freshwater fish distributions along with loss of habitat for cold- and cool-water fishes and gain in habitat for warm-water fishes. . . . Many species and populations are already at high risk, and are expected to be placed at greater risk by the synergy between climate change rendering portions of current habitat unsuitable for many species, and land-use change fragmenting habitats and raising obstacles to species migration. Without appropriate management, these pressures will cause some species currently classified as "critically endangered" to become extinct and the majority of those labeled "endangered or vulnerable" to become rarer, and thereby closer to extinction, in the 21st century.

IPCC, WORKING GROUP II, SUMMARY FOR POLICYMAKERS 11 (Third Assessment Report 2001).

In the past six years, theory has become reality; climate change impacts have already had significant impacts on a wide variety of animal behavior, with scientists reporting changes in populations, migration patterns, hibernation, and reproduction as animals adapt to earlier spring temperatures. Dr. William E. Bradshaw and Dr. Christina M. Holzapfel of the Center for Ecology and Evolutionary Biology have noted that climate change effects penetrate to the genetic level in a wide variety of organisms, with heritable genetic changes in populations such as birds, squirrels, and mosquitoes. Long term, they project that:

> small animals with short lifecycles and large population sizes will probably adapt to longer growing seasons and be able to persist; however, populations of many large animals with longer life cycles and smaller population sizes will experience a decline in population size or be replaced by more southern species. . . . [W]hile questions remain about the relative rates of environmental and evolutionary change . . . it is clear that unless the long-term magnitude of rapid climate change is widely acknowledged and effective steps are taken to mitigate its effects, natural communities with which we are familiar will cease to exist.

William E. Bradshaw & Christina M. Holzapfel, *Evolutionary Response to Rapid Climate Change*, 312 SCIENCE1477–78 (June 9, 2006). Not only are smaller animal species expected to adapt better, but a warmer climate will lead to the evolution of smaller individuals within species. This "dwarfism" will lead to smaller wild animals, smaller farm animals and perhaps even smaller humans as a natural response to climate change. *See Mass Extinction Forecast with 6$^o$C Temperature Rise,* CLIMATE NEWS NETWORK, Jan. 7, 2013.

Although by no means the only impact on wildlife, extinctions from climate change are expected to be significant and widespread. The IPCC's Fourth Assessment found that "[a]pproximately 20–30 percent of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5–2.5 degrees Celsius." IPCC, WORKING GROUP II, SUMMARY FOR POLICYMAKERS 8 (Fourth Assessment Report 2007). This suggests that roughly a quarter of all biological diversity may go extinct at temperatures that may be hard to avoid. Several currently rare (and not so rare) species may go extinct if they are unable to evolve or adapt to rapidly changing conditions.

Many examples of climate change impacts on biodiversity exist, reflecting the varied threats facing the planet's biodiversity. Between the 1980s and 1990s, almost two-thirds of the 110 known species of frogs in Central America became extinct. The direct cause of many of the extinctions appears to be a fungus now able to multiply due to warmer, cloudier nighttime weather. A 70-mile wide area off of Oregon's coast has become a dead zone due to low levels of oxygen linked to global warming. Bears in northern Spain have stopped hibernating. The U.S.

Geological Survey predicts that as Arctic sea ice loss increases in the coming years, polar bear populations could decline by two-thirds by 2050. Other recent studies have linked global warming to declines in such disparate species as pikas, blue crabs, penguins, gray whales, salmon, walruses, and ringed seals. Bird extinction rates are predicted to be as high as 38 percent in Europe and 72 percent in northeastern Australia, if global warming exceeds 2°C above pre-industrial levels.

In sum, it is hard to comprehend the breadth and gravity of impacts on wildlife and natural ecosystems due to climate change, particularly when other ecological stresses are considered. As the IPCC's Fourth Assessment puts it: "the resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (e.g., land-use change, pollution, over-exploitation of resources)." IPCC, WORKING GROUP II, SUMMARY FOR POLICYMAKERS 8 (Fourth Assessment Report 2007). According to the World Bank, in a 4°C warmer world "climate change seems likely to become the dominant driver of ecosystem shifts, surpassing habitat destruction as the greatest threat to biodiversity" and "driving a transition of the Earth's ecosystems into a state unknown in human experience." *Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided,* at xvi.

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## G. Regional Impacts

The impacts from climate change are expected to be significantly different across regions. Indeed, regional variability is already being seen in the relatively higher temperature increases experienced in the Arctic, for example. Moreover, an increasing amount of time is now being spent refining climate models to predict regional or local impacts. To help understand some of the differences across regions, the IPCC collected and published the following table that provides some examples.

**Table 1-3: Climate Change Impacts by Region, reprinted from IPCC, SYNTHESIS REPORT, SUMMARY FOR POLICYMAKERS**
10–11 (Fourth Assessment Report 2007)

| | |
|---|---|
| **Africa** | • By 2020, between 75 and 250 million people are projected to be exposed to increased water stress due to climate change.<br>• By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely |

| | |
|---|---|
| | compromised. This would further adversely affect food security and exacerbate malnutrition.<br>• Towards the end of the 21st century, projected sea-level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5-10% of Gross Domestic Product (GDP).<br>• By 2080, an increase of 5-8% of arid and semi-arid land in Africa is projected under a range of climate scenarios. |
| **Asia** | • By the 2050s, freshwater availability in Central, South, East and South-EastAsia, particularly in large river basins, is projected to decrease.<br>• Coastal areas, especially heavily-populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers.<br>• Climate change is projected to compound the pressures on natural resources and the environment, associated with rapid urbanization, industrialization and economic development.<br>• Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle |
| **Australia and New Zealand** | • By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites including the Great Barrier Reef and Queensland Wet Tropics.<br>• By 2030, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions.<br>• By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions.<br>• By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding. |
| **Europe** | • Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods, and more frequent coastal flooding and increased erosion (due to storminess and sea-level rise).<br>• Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60% under high emissions scenarios by 2080).<br>• In Southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity.<br>• Climate change is also projected to increase the health risks due to heat-waves, and the frequency of wildfires |

| | |
|---|---|
| **Latin America** | • By mid century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation.<br>• There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America.<br>• Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase.<br>• Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation. |
| **North America** | • Warming in western mountains is projected to cause decreased snowpack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources.<br>• In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5-20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilized water resources.<br>• During the course of this century, cities that currently experience heatwaves are expected to be further challenged by an increased number, intensity and duration of heatwaves during the course of the century, with potential for adverse health impacts. Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution. |
| **Polar Regions** | • The main projected biophysical effects are reductions in thickness and extent of glaciers and ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators.<br>• For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions are projected to be mixed.<br>• Detrimental impacts would include those on infrastructure and traditional indigenous ways of life.<br>• In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered. |
| **Small Islands** | • Sea-level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities.<br>• Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching is expected to affect local resources.<br>• By mid-century, climate change is expected to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods.<br>• With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands. |

## QUESTIONS AND DISCUSSION

**1.** Regional variations are particularly important because some regions, particularly in developing countries, do not have the capacity to adapt well to the changes and impacts that are coming.

> The ability of human systems to adapt to and cope with climate change depends on such factors as wealth, technology, education, information, skills, infrastructure, access to resources, and management capabilities. There is potential for developed and developing countries to enhance and/or acquire adaptive capabilities. Populations and communities are highly variable in their endowments with these attributes, and the developing countries, particularly the least developed countries, are generally poorest in this regard. As a result, they have lesser capacity to adapt and are more vulnerable to climate change damages, just as they are more vulnerable to other stresses. This condition is most extreme among the poorest people. * * *
>
> The effects of climate change are expected to be greatest in developing countries in terms of loss of life and relative effects on investment and the economy. For example, the relative percentage damages to GDP from climate extremes have been substantially greater in developing countries than in developed countries.

IPCC WORKING GROUP II, SUMMARY FOR POLICYMAKERS, at 8. For more on adaptation responses to climate change, see Chapter 3.

**2.** For a good recitation of some potential local and regional impacts from climate change, see the complaint filed in *State of Connecticut v. American Electric Power, Inc.*, Civ. No. 04-5669 (S.D.N.Y.); *see also* the Arctic Climate Impact Assessment, *supra*. As another example, a 2004 California study projected the potential impacts of climate change under two scenarios: one where emissions reduction policies are implemented and temperatures only increase by 2.3 to 3.3°C (4 to 5.9°F) by the end of the century, and the "business-as-usual" scenario, which projects a temperature increase of 3.8 to 5.8°C (6.8 to 10.4°F). Under the first scenario, the report predicts that heat waves become four times more frequent, increasing heat-related deaths by two or three times current rates. It also predicts the Sierra Nevada snow pack, which is a large source of water for municipal and agricultural areas in the state, decreases by 30 to 70 percent. Under the second scenario, heat waves and extreme heat in Los Angeles are projected to be six to eight times more frequent, with heat-related mortality increasing by five to seven times the current rate. Snow pack reduction ranges from 73 to 90 percent, causing "devastating impacts" throughout California as already tight water resources are strained beyond capacity. The higher temperatures in both scenarios would also shorten the ripening period for grapes, significantly degrading the state's ability to produce world class wine. Higher temperatures are also expected to cause a reduction in milk production by as much as 7 to 10 percent. *See* Katharine Hayhoe, *et al*., *Emissions Pathways, Climate Change, and Impacts on California*, PROC. OF THE NAT'L ACAD. OF SCIENCES (August 2004). What steps can the State of California take to respond to climate change — either to reduce the effects of climate change or to prepare for a different future? How do scenarios help to shape climate policy?

**3. *Weather and Climate Change.*** Often the media and others confuse weather with climate. Weather refers to meteorological conditions at a specific place and time, including temperature, humidity, wind, precipitation, and barometric pressure. Climate refers to weather patterns that prevail over extended periods of time, including both average and extreme weather. The variability that is inherent in weather masks the long-term trends of climate, making it even more difficult to actually measure changes in climate. Climate change often receives front-page media coverage only during droughts or floods, even though it is impossible to say that any single weather event was caused by climate change. Moreover, as soon as the weather breaks or appears to go back to normal, media coverage wanes, and many people are left believing that the climate change stories were a false alarm.

Consider the remarkable weather of the summer of 2010. Wildfires ripped through Russia. Summer temperatures were 15ºC above average — the highest in 130 years of record keeping. The extreme temperatures sparked fires that left thousands homeless, and caused a doubling in the death rate in and around Moscow. Although the heat wave alone does not prove that climate change is occurring, it was a wake-up call for Russian leaders. Russian President Dmitri Medvedev attributed the extreme heat and fires to climate change, a stance he had not taken previously. *See* John Collins Rudolf, *Has a Warming Russia Outpaced the World?* N.Y. TIMES, Aug. 6, 2010; Dina Fine Maron, *When the Smoke Clears in Russia, Will Climate Policy Change?*, N.Y. TIMES, Aug. 11, 2010. As Russia faced a scorching heat wave, Pakistan faced massive flooding and China was devastated by mudslides. In Pakistan, approximately one in ten people were affected by the flooding, 1,600 people were killed, and 6 million people were in need of humanitarian aid. *UN Launches $429m Pakistan Flood Appeal*, BBC NEWS, Aug. 11,

2010. The flooding was caused by massive monsoons and was the worst flooding in 80 years. And in China, torrential rains and flash floods resulted in landslides that killed almost one thousand people. The combination of severe weather events along with significant floods and summer heat waves in the United States, though difficult to attribute definitively to climate change, are all consistent with predicted weather patterns expected in a warmer world. *See* Justin Gillis, *In Weather Chaos, a Case for Global Warming*, N.Y. TIMES, Aug. 15, 2010.

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# IV. SOCIO-ECONOMIC IMPACTS

The breadth and magnitude of the environmental and physical impacts from climate change described above come into clearer focus when one analyzes the socio-economic impacts that will inevitably follow. Consider, for example, the effect that changing climates will have on food production or increasing temperatures could have on public health in urban “heat islands.” These impacts are compounded further when viewed in light of expected global population and urbanization trends.

## A. Agriculture, Drought, and Famine

Existing models suggest that global agricultural production could remain relatively stable in the face of anticipated climate change, but crop yields and changes in productivity could vary considerably across regions and among localities. Severe hardships could occur in specific regions, unless agricultural methodologies and distribution chains adapt successfully to relatively rapid and unpredicted changes in climate patterns.

According to three reports published in the December 2007 Proceedings of the National Academies of Science, such smooth transitions should not be assumed; the studies estimate that 1 to 5°C warming could result in “catastrophic” impacts on agriculture due to seasonal extremes of heat, drought or rain, the multiplier effects of spreading diseases or weeds, and other ecological upsets. *Toll of Climate Change on World Food Supply Could Be Worse than Thought*, SCIENCEDAILY, Dec. 4, 2007. Supporting this are recent studies showing significant nonlinear effects on corn and soybean productivity in the United States when local temperatures reach 29°C and 30°C, respectively. The challenge for food security is even more acute in light of the need to double grain production by 2100 just to keep up with expected population and demographic changes.

Already some observations tend to support the position that productivity in many regions may decline. A 2007 report found that rising temperatures between 1981 and 2002 caused an estimated loss in production of wheat, corn, and barley of approximately 40 million tons a year worth about $5 billion (over what would otherwise have been produced). Although relatively modest compared to global production, it does suggest that global warming is already having a negative impact on agriculture. Steve Connor, *World's Most Important Crops Hit by Global Warming Effects*, THE INDEPENDENT, March 19, 2007. Recent studies have also linked global warming to shortened growing seasons and exacerbated drought conditions with significant negative impacts on rice farmers in Bangladesh, cotton farmers in Africa, ranchers in Australia, and dairy producers in California. Lower food productivity, in turn, will add to the possibilities of famine and more widespread malnutrition, particularly in the poorest developing countries. In 2012, for example, the World Health Organization predicted that reduced food productivity due to climate change could lead to 100 million more women and children being undernourished in developing countries within a decade.

Lower productivity over the long term is not the only impact on food security. Extreme temperatures and weather events also lead to short-term disruptions in food supplies and food prices. Food prices have always been sensitive to extreme weather events, but such events are expected to be more common and more severe in a warming world. The 2008 food crisis may provide a window into how climate change coupled with other factors can disrupt access to food. In 2008, the world suffered a severe food crisis, due to a combination of low harvests due to severe weather, rising fuel costs, growing demand for beef, and increased demand for biofuels. The World Bank reported that food prices had risen 75 percent since 2000, with wheat prices increasing by 200 percent. The cost of rice hit record highs, and corn prices were the highest in more than a decade. Food-related riots or civil unrest erupted in several countries, including Indonesia and Haiti. Some countries were accused of hoarding rice from the international markets. The situation prompted the UN Food and Agricultural Organization to hold a "high level conference" on food security, which was attended by more than 180 countries and focused on the challenges posed by climate change and the demand for biofuels. *See Declaration of the High Level Conference on Food Security: Challenges from Climate Change and Bioenergy*, June 5, 2008. As bad as 2008 was, prices went even higher in 2011. Prices continue to fluctuate more than in the past, in part due to extreme weather fluctuations. For example, food prices increased 8 percent in the first quarter of 2012 in part because of extreme cold in Europe affecting wheat prices and extreme heat and drought in South America affecting sugar, corn, and soybeans. *See* World Bank, *Food Price Watch,* 2 (April 2012).

Future impacts are anticipated to be even worse. For example, by 2080 the FAO predicts a 5 to 8 percent increase in the amount of arid lands in sub-Saharan Africa, resulting in a loss of about 280 million tons of cereal production (16 percent of their agricultural output). According to some estimates, areas of extreme drought (where virtually no farming will be possible), which currently encompass 1 percent of land area at any given time, could increase to 30 percent of land area by 2100. Against this backdrop of lowering productivity, the world's food supplies will be more vulnerable to short-term disruptions due to extreme weather events. According to scenarios offered by Oxfam America, by 2030 drought and flooding in southern Africa could increase the consumer price of corn and other coarse grains by as much as 120 percent. "Price spikes of this magnitude today would mean the cost of a 55lb bag of corn meal — a staple which feeds poor families across Africa for about two weeks — would rocket from around \$18 to \$40." Similar weather events hitting across South East Asia could see the world market price of rice increase by 22 percent and spikes of more than 40 percent in rice-importing countries such as Nigeria. *See* Oxfam America, *Extreme Weather, Extreme Prices* (Sept. 5, 2012).

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## B. Public Health Impacts

A variety of public health impacts have also been linked to current and future climate change, including generally: increased illnesses and deaths from heat waves and air pollution; increased outbreaks of some insect-borne infectious diseases, most notably malaria; increased cases of diarrhea and other water-borne diseases from increased flooding; and increased malnutrition due to reduced agricultural yields in drought-ridden areas. The ultimate impacts of climate change on health will vary widely from region to region. Indeed, we might expect fewer people to freeze to death (even while more die from heat exposure), but we can also expect that the areas hardest hit by climate change (tropical and subtropical developing countries) are also areas with generally poor health care or sanitation and thus the least likely to be able to treat the increased health impacts.

The World Bank, in anticipating a world that is 4°C warmer, noted the following health impacts:

> Large-scale extreme events, such as major floods that interfere with food production, could also induce nutritional deficits and the increased incidence of epidemic diseases. Flooding can introduce contaminants and diseases into healthy water supplies and increase the incidence of diarrheal and respiratory illnesses. The effects of climate change on agricultural production may exacerbate under-nutrition and malnutrition in many regions — already major contributors to child mortality in developing countries. Whilst economic growth is projected to

> significantly reduce childhood stunting, climate change is projected to reverse these gains in a number of regions: substantial increases in stunting due to malnutrition are projected to occur with warming of 2°C to 2.5°C, especially in Sub-Saharan Africa and South Asia, and this is likely to get worse at 4°C. . . . Changes in temperature, precipitation rates, and humidity influence vector-borne diseases (for example, malaria and dengue fever) as well as hantaviruses, leishmaniasis, Lyme disease, and schistosomiasis.
>
> Further health impacts of climate change could include injuries and deaths due to extreme weather events. Heat-amplified levels of smog could exacerbate respiratory disorders and heart and blood vessel diseases, while in some regions climate change–induced increases in concentrations of aeroallergens (pollens, spores) could amplify rates of allergic respiratory disorders.

*Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided*, at xvii.

Nor are public health impacts only a concern for the future. The World Health Organization (WHO) reports that anthropogenic climate change *already* result in approximately 140,000 additional deaths each year. The World Health Organization, *Climate Change and Health*, FACT SHEET NO. 266 (Oct. 2012)). Anecdotal evidence also now links public health threats specifically to global warming. In the winter of 2007, more than 3,000 cases of infections caused by the rat-transmitted hanta virus were reported in Russian cities and towns, attributed to an unusually warm winter and the presence of rats that should have been hibernating. Italy is now experiencing outbreaks of dengue, a tropical disease from the tropical tiger mosquito, now thriving in southern Europe and spreading to France and Switzerland. In the United States, the National Environmental Trust reported that heat-related deaths may double due to climate change by 2050.

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## C. Climate Migration and Refugees

Climate change is expected to be a major driver for population migration in the future, with millions of people forced to leave their homes due in part to conditions caused or exacerbated by climate change. As early as 1993, Oxford Visiting Fellow Dr. Norman Myers estimated that by 2050 approximately 150 million "climate" refugees would be forced from their homes due to agricultural changes and sea level rise brought about by global warming. *See* N. Myers, *Environmental Refugees in a Globally Warmed World*, 43 BIOSCIENCE 752 (1993). Current estimates range from 25 million to 1 billion refugees who will be displaced by climate change-related impacts by 2050, with the most frequently cited estimate being 200 million. Nor are the impacts all in the future; an estimated 20 million people were displaced in 2008, alone, because of rising seas, desertification, and flooding. The following excerpt explores some of the current issues relating to climate change, migration and refugees.

## TERESITA PEREZ, CLIMATE REFUGEES: THE HUMAN TOLL OF GLOBAL WARMING

(Center for American Progress, Dec. 7, 2006)*

The number of people affected [by climate change] is uncertain since these "climate refugees" are not granted official refugee status under the Geneva Convention, and the United Nations therefore keeps no central tally. According to the International Federation of Red Cross [and Red Crescent Societies], however, climate change disasters are currently a bigger cause of population displacement than war and persecution. Estimates of climate refugees currently range from 25 to 50 million, compared to the official refugee population of 20.8 million. Rising sea levels, increasing desertification, weather-induced flooding, and other environmental changes, will likely displace many more hundreds of millions of people.

Accidents of geography have caused the countries least able to prevent climate change to become the most vulnerable to its earliest effects. Developing countries bear minimal responsibility for climate change because they have little industry and produce relatively small amounts of pollution. But their populations — often the poorest of the world's poor — are more likely to occupy dangerous locations, such as coast lines, flood plains, steep slopes, and settlements of flimsy shanty homes. The governments of these poor countries therefore carry the largest burden associated with climate refugees though they are already failing to meet the basic needs of their citizens and are ill-equipped to recover from disasters.

We can already see the effects that global warming has on some island nations. The inhabitants of the Carteret Islands were the first climate refugees forced to relocate due to sea level rise attributed to global warming. The Papua New Guinean government authorized a total evacuation of the islands in 2005 — the evacuation is expected to be complete by 2007. Estimates show that by 2015 Carteret will be largely submerged and entirely uninhabitable.

Floods and other weather-related disasters have also caused nearly 10 million people to migrate from Bangladesh to India over the past two decades, creating immense population pressures. A one-meter rise in sea level will, in turn, inundate three million hectares in Bangladesh, and displace another 15–20 million people. * * *

Of course, not all climate refugees are due to anthropogenic climate changes; some refugees would need to leave their homes for "natural" weather events as well. But the long-term impacts of climate change are clearly going to increase the number of such refugees and stretch the international community's ability to deal with them.

## QUESTIONS AND DISCUSSION

**1.** One particularly dramatic localized impact from climate change is the potential of glacial lake outburst floods or "GLOFs." Freshwater lakes often form at the base of many glaciers, held back by naturally occurring earthen dams or moraines. As glaciers recede more rapidly from climate change, the amount of water in these lakes can expand significantly, as does the pressure resulting on the earthen dam. GLOFs occur when the soil moraine holding back the lake bursts. As with any sudden dam burst, significant damage can occur in a short period of time. GLOFs are not a new phenomenon, but UNEP and other international agencies are concerned that many glacial lakes may now be filling too rapidly due to climate change. A UNEP study identified 20 glacial lakes in Nepal and 24 in Bhutan that they believe are at "high risk" of bursting within the next decade. The impact of a GLOF can be significant; in August 1985, a sudden outburst flood from the Dig Tsho glacial lake in Nepal killed four people, destroyed fourteen bridges and caused $1.5 million in damage to a nearly completed hydropower plant. What policy measures could Nepal and Bhutan implement to protect against such floods? Who should pay for such measures? U.N. Chronicle, *Global Warming Triggers Glacial Lakes Flood Threat*, UNITED NATIONS ENVIRONMENT PROGRAMME, Nov. 3, 2002, at 48.

**2.** Food security issues will not only be limited to changes in agricultural production. Fish production may also decline due to climate change. A December 2006 report in Nature showed that as climate warms, phytoplankton production declines. Not only does this mean that less phytoplankton is available to remove carbon from the atmosphere (producing a warming feedback loop), but phytoplankton is also the base of the ocean food chain. Less phytoplankton production inevitably means less fish production. Scott C. Doney, *Oceanography: Plankton in a*

*Warmer World*, 444 NATURE 695 (Dec. 7, 2006); NASA, *Climate Warming Reduces Ocean Food Supply*, Dec. 6, 2006.

**3.** The connections between climate change and public health may not always be apparent. One 2008 study linked higher temperatures to kidney stones and estimated that climate change could cause at least 1.6 million new kidney stone cases by 2050. *Kidney Stones Linked to Warming*, RENO GAZETTE J., July 15, 2008 at B1.

**4.** For many types of impacts, the portion attributable to global warming cannot easily be separated from the interactions with other causes. For example, global warming will be exacerbated in many cities by the urban heat island effect, where the cumulative impact of few trees and dark pavements can cause temperatures during heat waves to be 6–7° C higher in cities than in surrounding areas. Similarly, higher carbon dioxide levels in already polluted areas are expected to lead to as much as 20,000 more air pollution deaths annually due to the chemical and meteorological effects of $CO_2$. In part, this is due to synergistic impacts between increased temperatures and asthma and other air pollutant-related health effects.

**5.** As you consider the plight of climate refugees, consider whether a moral responsibility exists for wealthier countries, particularly those that have contributed disproportionately to climate change, to provide support or even citizenship to displaced communities. Is there any argument for a legal responsibility? In this regard, think of the differing responses to Tuvalu's plight from New Zealand and Australia, as depicted in the following excerpt from Friends of the Earth-Australia:

> Tuvalu is the first country in which residents have been forced to evacuate because of rising sea levels. Nearly 3000 Tuvaluans have already left their homelands. In support of their crisis, the New Zealand government has established an immigration programme called the Pacific Access Category, which currently sees seventy-five residents migrate to NZ each year. . . .
>
> The Pacific Access Category (PAC) is an immigration deal that was formed in 2001 between the governments of Tuvalu, Fiji, Kiribati, Tonga and New Zealand, to enable environmental refugees who are displaced from their homes by the effects of climate change to move to a less vulnerable environment. Each country has been allocated a set quota of citizens who can be granted residency in New Zealand each year. The PAC allows 75 residents each from Tuvalu and Kiribati, whereas Tonga and Fiji have a quota of 250.

> Following the Australian government's refusal to accept any Tuvaluan environmental refugees, New Zealand agreed to accept the entire Tuvaluan population of 11,000. Although New Zealand's immigration policies are far more supportive towards environmental refugees than Australia's policies, Pacific Islanders still face a number of impediments to reaching safer ground. Principal applicants must meet set requirements before being eligible to enter the PAC ballot.
>
> These requirements exclude part of the Tuvaluan population by stipulating that: applicants possess citizenship status for Kiribati, Tuvalu, Tonga or Fiji; are aged between 18 and 45; have an acceptable offer of employment in New Zealand; have a minimum level of skills in English language; have a minimum income requirement if the applicant has a dependant; exhibit certain health and character requirements; and have no history of unlawful entry into New Zealand since July 1, 2002.
>
> In short, this means that the elderly and the poor — those most vulnerable — may have trouble being accepted as principal applicants. Furthermore, an "acceptable" offer of employment is defined as "permanent, full-time, genuine, and paid by a salary or wages". Considering their location and level of access to required resources, Tuvaluans may have difficulty gaining employment in New Zealand before they arrive in the country, thereby excluding them from access to the program. . . .
>
> In 2000, the Tuvaluan government appealed to both Australia and New Zealand to take in Tuvaluan residents if rising sea levels reached the point where evacuation would be essential. The Australian government refused to implement a program to grant Tuvaluan environmental refugees residency in Australia. In response to Tuvalu's crisis, Immigration Minister Phillip Ruddock stated that accepting environmental refugees from Tuvalu would be "discriminatory".
>
> With regard to Australia's response, Senior Tuvalu official, Mr Paani Laupepa expressed that while New Zealand has helped out their neighbours, "Australia on the other hand has slammed the door in our face".

FRIENDS OF THE EARTH AUSTRALIA, A CITIZEN'S GUIDE TO CLIMATE REFUGEES, 6–7. In light of its concern that the number of climate refugees may be increasing, New Zealand recently created a climate ambassador. For a popular depiction of the issues presented by climate refugees, see the 2010 award-winning documentary *Climate Refugees,* available through www.climaterefugees.com/. For a comprehensive look at issues confronting climate and other environmental refugees, see FORESIGHT: MIGRATION AND GLOBAL ENVIRONMENTAL CHANGE: FUTURE CHALLENGES AND OPPORTUNITIES (2011).

**6.** When we think of environmental refugees generally or climate refugees more specifically, we almost always think of the poor from developing countries such as Bangladesh or island States such as Tuvalu. But the United States has also struggled to support recent climate-related refugees — 250,000 people were permanently displaced from Hurricane Katrina and the official response to support these refugees was heavily criticized. *See, e.g.,* Lester R. Brown, *Global Warming Forcing U.S. Coastal Population to Move Inland: An Estimated 250,000 Katrina Evacuees are Now Climate Refugees*, ECO-ECONOMY UPDATE (Aug. 16, 2006). More recently, Hurricane Sandy in 2012 displaced thousands of residents and small businesses in New York and New Jersey. Their recovery will take months, if not years, and resulted in highly politicized debates over the role of federal assistance. *Recovery Remains Spotty 3 Months after Hurricane,* NYTIMES.COM, Jan. 21, 2013. What does the U.S. experience suggest about the ability of other countries to respond to people internally displaced by an increasing number of natural disasters?

**7.** ***Problem Exercise on Impacts.*** Any recitation of general impacts from climate change can seem sterile and largely divorced from the reality of law students. But in recent years, an increasing number of studies are being done to identify potential climate change impacts for virtually all regions or states of the United States. Research the potential impacts of climate change on the location where you are attending law school.

## V. RAPID CLIMATE CHANGE EVENTS AND LIVING WITH UNCERTAINTY

Most of the impacts described above, significant as they may be, are relatively straightforward and linear results from increasing temperatures due to climate change. Even more disturbing is the increasing evidence that climate change may be leading us toward a non-linear "environmental cliff," where climate change triggers rapid, irreversible, and unpredictable results. Such abrupt or rapid climate change events could occur suddenly, and drastically, when certain thresholds are crossed, tipping the climate into a new state of equilibrium — one that could change the planet's global ecology and create millions of climate refugees. As a 2007 study on the implications of climate change for national security explained:

> Abrupt climate changes present the most worrisome scenario for human societies because of the inherent difficulties in adapting to sudden changes. Abrupt sea level rise is particularly worrisome. The great ice sheets along the edges of Greenland and the West Antarctic are vulnerable to sudden breakup: as the edges of the sheet thaw and meltwater seeps to the ice-ground boundary, the meltwater will act as a lubricant and facilitate a slippage into the sea. This physical phenomenon is an example of a positive feedback mechanism that, once started, is difficult to reverse. Melting of these ice sheets would be catastrophic. The Greenland Ice Sheet could raise sea levels by twenty-three feet over a millennium; the West Antarctic Ice Sheet would have a more immediate impact, raising sea levels more than three feet per century for five centuries. The probability of a collapse of the West Antarctic Ice Sheet before 2100 is estimated to be between 5 and 10 percent.
>
> None of these abrupt climate changes are projected by the climate models driven by the IPCC's 2007 future scenarios. However, if temperature increases were at the high end of the ranges projected by the models, abrupt climate changes such as those discussed above are more likely to occur. Such abrupt climate changes could make future adaptation extremely difficult, even for the most developed countries.

The CNA Corporation, *National Security and the Threat of Climate Change* 60 (2007). Although substantial sea level rise is the best known possible form of abrupt climate change, it is not the only one that concerns scientists. Of potentially equal concern is the way in which changes in ocean temperatures and salinity may alter major ocean currents, most notably the ocean's thermohaline circulation. The following excerpt from the Union of Concerned Scientists describes how global warming might weaken or shut down the thermohaline circulation.

> Thermohaline circulation is a global ocean circulation pattern that distributes water and heat both vertically, through the water column, and horizontally across the globe. As cold, salty water sinks at high latitudes, it pulls warmer water from lower latitudes to replace it. Water that sinks in the North Atlantic flows down to the southern hemisphere, skirts the Antarctic continent, where it is joined by more sinking water, and then crosses south of the Indian Ocean to enter the Pacific

> Ocean basin. There, the cold deep water rises to the surface, where heat from the tropical sun warms the water at the ocean's surface and drives evaporation, leaving behind saltier water. This warm, salty water flows northward to join the Gulf Stream, traveling up the Eastern coast of the United States and across the Atlantic Ocean into the North Atlantic region. There, heat is released to the atmosphere, warming parts of Western Europe. Once this warm, salty water reaches the North Atlantic and releases its heat, it again becomes very cold and dense, and sinks to the deep ocean. * * *
>
> Thermohaline circulation is [thus] driven by the sinking of cold, salty water at high latitudes. Fresh water flowing into the North Atlantic Ocean from rainfall or the melting of ice and permafrost can make the ocean water less salty, and therefore less dense. If it becomes "light" enough, it will not sink any more, possibly slowing or shutting down global thermohaline circulation. Indeed, during some of the abrupt events in Earth's past climate, scientists find evidence of large catastrophic flows of fresh water into the North Atlantic from the melting of glaciers and ice caps, and due to flooding from glacier-dammed lakes. Without the large-scale sinking of salty water in the North Atlantic the influx of warm water to replace it from the tropics would not occur, effectively switching off the thermohaline circulation.
>
> Past changes in thermohaline circulation have occurred during periods of relatively rapid climate change, such as transitions in and out of glaciations. Similarly, the rapid warming we are currently experiencing could trigger an abrupt thermohaline shutdown and subsequent regional cooling. While a shutdown of thermohaline circulation is unlikely to occur in the next century, scientists have recently found that freshwater inputs have already caused measurable "freshening" of North Atlantic surface waters over the past 40 years. Human activities may be driving the climate system toward a threshold and thus increasing the chance of abrupt climate changes occurring.

Union of Concerned Scientists, *Abrupt Climate Change FAQ, available at* www.ucsusa.org. The following excerpt is from a National Academies of Science report on the potential reduction of the thermohaline circulation (THC). As you read it, consider how much is still unknown about the THC and what the appropriate policy response should be in the face of such uncertainty.

# NATIONAL RESEARCH COUNCIL, ABRUPT CLIMATE CHANGE: INEVITABLE SURPRISES

(2002)*

[In the past,] abrupt climate changes were especially common when the climate system was being forced to change most rapidly. Thus, greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events. The abrupt changes of the past are not fully explained yet, and climate models typically underestimate the size, speed, and extent of those changes. Hence, future abrupt changes cannot be predicted with confidence, and climate surprises are to be expected. * * *

If the increase in atmospheric greenhouse gas concentration leads to a collapse of the Atlantic THC, the result will not be global cooling. However, there might be regional cooling over and around the North Atlantic, relative to a hypothetical global-warming scenario with unchanged THC. By itself, this reduced warming might not be detrimental. However, we cannot rule out the possibility of net cooling over the North Atlantic if the THC decrease is very fast. Such rapid cooling would exert a large strain on natural and societal systems. The probability of this occurring is unknown but presumably much smaller than that of any of the more gradual scenarios included in the Intergovernmental Panel on Climate Change report. The probability is not, however, zero. Obtaining rational estimates of the probability of such a low-probability/high-impact event is crucial. It is worth remembering that models such as those used in the Intergovernmental Panel on Climate Change report consistently underestimate the size and extent of anomalies associated with past changes of the THC. * * *

Even if no net cooling results from a substantial, abrupt change in the Atlantic THC, the changes in water properties and regional circulation are expected to be large, with possibly large effects on ecosystems, fisheries, and sea level. There are no credible scenarios of these consequences, largely because the models showing abrupt change in the THC have too crude spatial resolution to be used in regional analyses. To develop these scenarios would require the combination of physical and biological models to investigate the effects on ecosystems. . . .

If we are to develop the ability to predict changes in the THC, we must observe its strength and structure as a fundamental requirement, akin to the necessity to observe the equatorial

Pacific if one wants to forecast El Niño. So far, however, no observational network exists to observe the THC on a continuous basis. * * *

Arctic sea-ice volume appears to have shrunk dramatically in recent decades. . . . The influence of that decline on the freshwater budget of the Atlantic THC is unknown but could be critical. It is crucial to know the net freshwater flux from the Arctic Ocean to the Nordic Seas, in the form of both sea ice and low-salinity surface water. . . . Given the importance of freshwater forcing for the stability of the THC, such events might presage change in the circulation.

## QUESTIONS AND DISCUSSION

**1.** Given the large gaps identified above in our understanding of the THC, what should the appropriate policy response be? In general, how should policy makers address low probability/high impact risks? Moreover, not only is the probability low, but we also know so little about the underlying mechanism of the THC that we have little confidence in our analysis of the probability. In this respect, consider how the precautionary principle, discussed further in Chapter 4, could guide policymakers. Under the precautionary principle, policymakers are encouraged to take cost-effective measures to prevent potential irreversible impacts even if there is less than full scientific certainty about the probability and scale of the impacts. Can you see how this approach differs from the normal regulatory approach taken in the United States, where we must demonstrate that an impact will, or is at least likely to, occur before we regulate to prevent the impact? How does the precautionary principle help us, if at all, in addressing rapid climate change events like those described above?

**2.** As noted above in the discussions of sea level rise, the latest IPCC reports and supportive modeling do not include estimates based on rapid polar ice melting or the shutdown of the thermohaline circulation. Does such an approach properly inform policymakers of the known potential risks from climate change? How should they report on low probability/high impact possibilities?

**3.** It is not just the potential for rapid climate change events that lends uncertainty to discussions of climate change, but also the enormous uncertainty surrounding how or even whether our societies can adapt to so many changes to our ecological, economic, and social fabric in such a short time. The World Bank highlighted these synergistic and interactive impacts in the following excerpt after surveying the many discrete changes that would occur in 4°C (3.6°F) warmer world:

## H.J. SCHELLNHUBER, ET AL., TURN DOWN THE HEAT: WHY A 4°C WARMER WORLD MUST BE AVOIDED

xvii–xviii (Nov. 2012)

Climate change will not occur in a vacuum. Economic growth and population increases over the 21st century will likely add to human welfare and increase adaptive capacity in many, if not most, regions. At the same time, however, there will also be increasing stresses and demands on a planetary ecosystem already approaching critical limits and boundaries. The resilience of many natural and managed ecosystems is likely to be undermined by these pressures and the projected consequences of climate change. * * *

The cumulative and interacting effects of such wide-ranging impacts, many of which are likely to be felt well before 4°C warming, are not well understood. For instance, there has not been a study published in the scientific literature on the full ecological, human, and economic consequences of a collapse of coral reef ecosystems, much less when combined with the likely concomitant loss of marine production due to rising ocean temperatures and increasing acidification, and the large-scale impacts on human settlements and infrastructure in low-lying fringe coastal zones that would result from sea-level rise of a meter or more this century and beyond.

As the scale and number of impacts grow with increasing global mean temperature, interactions between them might increasingly occur, compounding overall impact. For example, a large shock to agricultural production due to extreme temperatures across many regions, along with substantial pressure on water resources and changes in the hydrological cycle, would likely impact both human health and livelihoods. This could, in turn, cascade into effects on economic development by reducing a population´s work capacity, which would then hinder growth in GDP.

With pressures increasing as warming progresses toward 4°C and combining with nonclimate-related social, economic, and population stresses, the risk of crossing critical social system thresholds will grow. At such thresholds existing institutions that would have supported adaptation actions would likely become much less effective or even collapse. One example is a risk that sea-level rise in atoll countries exceeds the capabilities of controlled, adaptive migration, resulting in the need for complete abandonment of an island or region. Similarly, stresses on human health, such as heat waves, malnutrition, and decreasing quality of drinking water due to seawater intrusion, have the potential to overburden health-care systems to a point where adaptation is no longer possible, and dislocation is forced.

Thus, given that uncertainty remains about the full nature and scale of impacts, there is also no certainty that adaptation to a 4°C world is possible. A 4°C world is likely to be one in which communities, cities and countries would experience severe disruptions, damage, and dislocation, with many of these risks spread unequally. It is likely that the poor will suffer most and the global community could become more fractured, and unequal than today. The projected 4°C warming simply must not be allowed to occur — the heat must be turned down. Only early, cooperative, international actions can make that happen.

## VI. NATIONAL SECURITY AND CLIMATE CHANGE

In recent years as the potential impacts from climate change have become clearer, many people are viewing climate change in terms of national security. Partly this is because efforts to address climate change by, for example, shifting to renewable energy or energy conservation will reduce our oil dependency and strengthen our national security at the same time. But the national security discussion also recognizes that climate change may lead to significant instability in the economies and societies of strategically important regions of the world.

The discussion of climate refugees, above, is just one dimension of the instability that can trigger security concerns. Consider in this regard the findings from a 2007 report issued by an independent research organization advised by former U.S. military officials:

### THE CNA CORPORATION, NATIONAL SECURITY AND THE THREAT OF CLIMATE CHANGE

6–7 (2007)

*Projected climate change poses a serious threat to America's national security.* The predicted effects of climate change over the coming decades include extreme weather events, drought, flooding, sea level rise, retreating glaciers, habitat shifts, and the increased spread of life-threatening diseases. These conditions have the potential to disrupt our way of life and to force changes in the way we keep ourselves safe and secure.

In the national and international security environment, climate change threatens to add new hostile and stressing factors. On the simplest level, it has the potential to create sustained natural and humanitarian disasters on a scale far beyond those we see today. The consequences will likely foster political instability where societal demands exceed the capacity of governments to cope.

*Climate change acts as a threat multiplier for instability in some of the most volatile regions of the world.* Projected climate change will seriously exacerbate already marginal living standards in many Asian, African, and Middle Eastern nations, causing widespread political instability and the likelihood of failed states.

Unlike most conventional security threats that involve a single entity acting in specific ways and points in time, climate change has the potential to result in multiple chronic conditions, occurring globally within the same time frame. Economic and environmental conditions in already fragile areas will further erode as food production declines, diseases increase, clean water becomes increasingly scarce, and large populations move in search of resources. Weakened and failing governments, with an already thin margin for survival, foster the conditions for internal conflicts, extremism, and movement toward increased authoritarianism and radical ideologies.

The U.S. may be drawn more frequently into these situations, either alone or with allies, to help provide stability before conditions worsen and are exploited by extremists. The U.S. may also be called upon to undertake stability and reconstruction efforts once a conflict has begun, to avert further disaster and reconstitute a stable environment.

*Projected climate change will add to tensions even in stable regions of the world.* The U.S. and Europe may experience mounting pressure to accept large numbers of immigrant and refugee populations as drought increases and food production declines in Latin America and Africa. Extreme weather events and natural disasters, as the U.S. experienced with Hurricane Katrina, may lead to increased missions for a number of U.S. agencies, including state and local governments, the Department of Homeland Security, and our already stretched military, including our Guard and Reserve forces.

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The connection between climate change and national security has not been lost on the U.S. military. At the same time that the Bush Administration was denying the scientific evidence for climate change, the military was basing its strategic planning for the coming century in part on scenarios premised on substantial climate impacts. A 2003 Pentagon scenario described national security threats posed by abrupt climate changes, which could dramatically disrupt the world's natural, social, and economic capacity to support the human population and could trigger worldwide military conflicts over food, water, and energy supplies.

> Violence and disruption stemming from the stresses created by abrupt changes in the climate pose a different type of threat to national security than we are accustomed to today. Military confrontation may be triggered by a desperate need for natural resources such as energy, food, and water rather than by conflicts over ideology, religion, or national honor. The shifting motivation for confrontation would alter which countries are most vulnerable and the existing warning signs for security threats.

PETER SCHWARTZ & DOUG RANDALL, AN ABRUPT CLIMATE CHANGE SCENARIO AND ITS IMPLICATIONS FOR U.S. NATIONAL SECURITY 14 (2003). As one journalist observed: "as abrupt climate change hits home, warfare may again come to define human life." David Stipp, *The Pentagon's Weather Nightmare*, FORTUNE (Feb. 9, 2004). In 2010 the Pentagon listed climate impacts as a key issue that will affect U.S. national security, calling it an "accelerant of instability or conflict":

> Climate change and energy are two key issues that will play a significant role in shaping the future security environment. . . . First, climate change will shape the operating environment, roles, and missions that we undertake. . . . Assessments conducted by the intelligence community indicate that climate change could have significant geopolitical impacts around the world, contributing to poverty, environmental degradation, and the further weakening of fragile governments. Climate change will contribute to food and water scarcity, will increase the spread of disease, and may spur or exacerbate mass migration. While climate change alone does not cause conflict, it may act as an accelerant of instability or conflict, placing a burden to respond on civilian institutions and militaries around the world. . . . In some nations, the military is the only institution with the capacity to respond to a large-scale natural disaster. . . .
>
> Second, [the Department of Defense (DoD)] will need to adjust to the impacts of climate change on our facilities and military capabilities. . . . In 2008, the National Intelligence Council judged that more than 30 U.S. military installations were already facing elevated levels of risk from rising sea levels. DoD's operational readiness hinges on continued access to land, air, and sea training and

test space. . . .

Department of Defense, Quadrennial Defense Review Report 83–88 (Feb. 2010); *see also* National Academy of Sciences, National Security Implications of Climate Change for U.S. Naval Forces (April 26, 2010) (assessing the implications of climate change for the U.S. Naval Services).

## QUESTIONS AND DISCUSSION

**1.** The 2003 Pentagon report received significant attention in the press, in part because the military appeared to be taking the threat of climate change more seriously than officials in the Bush Administration's Environmental Protection Agency. What do you think led to the different approaches of these agencies? Is it consistent to prepare for a rapid climate change event militarily (perhaps as a precautionary step), while at the same time denying that the risk of such an event warrants taking any steps to curb climate change?

**2.** On April 17, 2007, the United Kingdom, sitting as President of the UN Security Council, held the first-ever discussion of climate change at the Security Council. Although the decision to use that forum to discuss climate change was controversial, over fifty delegations spoke at the hearing with many supporting the Security Council's attention on climate change as a long-term risk to international security. The following excerpt from the UN's official summary of the meeting provides a flavor of the controversy:

> The session was chaired by British Foreign Secretary, Margaret Beckett[.] . . . She said that recent scientific evidence reinforced, or even exceeded, the worst fears about climate change, as she warned of migration on an unprecedented scale because of flooding, disease and famine. She also said that drought and crop failure could cause intensified competition for food, water and energy.
>
> She said that climate change was a security issue, but it was not a matter of narrow national security — it was about "our collective security in a fragile and increasingly interdependent world". By holding today's debate, the Council was not seeking to pre-empt the authority of other bodies, including the General Assembly and the Economic and Social Council. The decisions that they came to, and action taken, in all those bodies required the fullest possible understanding of

> the issues involved. "[So] climate change can bring us together, if we have the wisdom to prevent it from driving us apart," she declared.
>
> China's representative was among those who argued that the Council was not the proper forum for a debate on climate change. "The developing countries believe that the Security Council has neither the professional competence in handling climate change — nor is it the right decision-making place for extensive participation leading up to widely acceptable proposals," he said. . . . The issue could have certain security implications, but, generally speaking, it was, in essence, an issue of sustainable development. * * *
>
> But Papua New Guinea's representative, who spoke on behalf of the Pacific Islands Forum, said that the impact of climate change on small islands was no less threatening than the dangers guns and bombs posed to large nations. Pacific island countries were likely to face massive dislocations of people, similar to population flows sparked by conflict. The impact on identity and social cohesion were likely to cause as much resentment, hatred and alienation as any refugee crisis.
>
> . . . The Forum did not expect the Council to get involved in Climate Change Convention negotiations, but it did expect the 15-member body to keep the issue of climate change under continuous review, to ensure that all countries contributed to solving the problem and that those efforts were commensurate with their resources and capacities. It also expected the Council to review sensitive issues, such as implications for sovereignty and international legal rights from the loss of land, resources and people.
>
> Singapore's speaker said that . . . [w]hile it might be difficult to quantify the relationship between climate change and international peace and security, there should be no doubt that climate change was an immediate global challenge, whose effects were transboundary and multifaceted. He was not advocating that the Security Council play a key role on climate change, but neither could he deny that body "some sort of a role, because it seems obvious to all but the wilfully blind that climate change must, if not now, then eventually have some impact on international peace and security."

*See* UN Division of Public Information, *Security Council Holds First-Ever Debate on Impact of Climate Change on Peace, Security, Hearing over 50 Speakers* (April 17, 2007). The Security

Council revisited the link between climate change and international security when the Pacific small island States sought formal recognition that climate change was a threat to international peace and security. Not willing to go that far, the Security Council recognized climate change as potentially important "contextual information" for understanding certain international conflicts and asked the Secretary General to ensure that his reporting to the Council included such contextual information. What difference could it make if the Security Council were to recognize climate change as a formal threat to security, as suggested by the Pacific Island Forum? Why are China and the other developing countries insistent that this should remain an issue of sustainable development? The excerpt also provides some initial insights into the conflicts that occur in global negotiations over climate change. The global politics of climate are discussed further in Chapters 4, 5, and 6.

**4.** The unprecedented melting of the Arctic Ocean's summer ice has sparked an international land grab between Russia, Denmark, the United States, and Canada. At stake are claims to potentially vast natural resources that may now (due to receding polar ice) be economically feasible to exploit. In 2007, Russia took the remarkable step of sending a submarine to plant a Russian flag under the North Pole to stake its claim to vast parts of the territory. This has prompted renewed focus on the rules for claiming territorial areas of the continental shelf, which are set by the UN Convention on the Law of the Sea. In addition to raising diplomatic concerns, Russia's move also led for further calls for the United States to ratify the UN Convention on the Law of the Sea. *See generally* Duncan Currie, *Sovereignty and Conflict in the Arctic Due to Climate Change: Climate Change and the Legal Status of the Arctic Ocean* (Aug. 5, 2007); *see also* discussion of the law of the sea in Chapter 9.

**5.** For a readable and interesting account of how past variations in climate played a role in history, see BRIAN FAGAN, THE LITTLE ICE AGE: HOW CLIMATE MADE HISTORY: 1350–1800 (2000). Although the book's description of this era in Europe is interesting for showing how climate affects human development, it is addressing a period of regional climate variability in Europe and has little direct relationship to today's global climate change.

**6.** In June 2008, the National Intelligence Council provided a report to Congress identifying the national security threats to the United States and the world posed by climate change. The report, which was the first formal report of its kind in the United States, warned that climate change could threaten U.S. security by leading to political instability, mass movements of refugees, terrorism, and conflicts over water and other resources. The report was based in part on assessments conducted by Columbia University's Center for International Earth Science Information Network (CIESIN), which ranked countries by looking at their relative vulnerability to sea-level rise, increased water scarcity, and higher temperatures, compared with their ability to adapt. *See, e.g., Climate Change May Challenge National Security, Classified Report Warns*, SCIENCE DAILY, June 26, 2008.

## VII. KEEPING OUR EYE ON THE BALL: LONG-TERM STABILIZATION TARGETS TO AVOID THE WORST CLIMATE IMPACTS

As should now be readily apparent, climate change science is complex and laden with considerable uncertainties. Climate change cannot easily be seen or perceived directly; many of its impacts are decades in the future and result from multiple causes. These characteristics have significant implications for policymakers and the public seeking to address climate threats, as suggested by the following excerpt:

### NATIONAL ACADEMY OF SCIENCES, ADVANCING THE SCIENCE OF CLIMATE CHANGE

61 (2010)

*Future climate will be unlike the climate of the recent past.* For roughly the past 10,000 years, the climate has been relatively stable. Exceptional years, decades, and even centuries have occurred, of course, occasionally creating havoc for civilizations in some regions of the world. However, human societies have generally been well-served by assuming that the climate fluctuates around a relatively constant average state, with no long-term trends towards warmer or cooler temperatures, more or less precipitation, or more or fewer extreme events. This is changing, as Earth's climate system — from GHG concentrations to temperatures, ice cover, precipitation, and a host of other inter-related changes — moves outside the range within which it has fluctuated throughout the 10,000 years of recorded human history. As a result, many of our conventional practices for including climate and climate-related uncertainty in decision making — such as using historical records to plan for the "100-year flood" or the "100-year drought" — will need to be revisited, and new ways of thinking about preparing and adapting to change will need to emerge. Conventional practices may even heighten risks by encouraging us to continue planting vulnerable crop varieties, harvesting threatened resources at unsustainable levels, or building homes and communities in areas at growing risk from fires, floods, or rising sea levels. * * *

*Climate change processes have considerable inertia and long time lags.* Until GHG emissions are brought below the rate of their removal from the atmosphere, atmospheric concentrations will continue to rise. The most important GHGs remain in the atmosphere for years to centuries and continue to affect Earth's heat balance throughout their atmospheric lifetimes. Other climate change processes also exhibit considerable inertia, which results in delays between GHG emissions and the impacts of climate change. The oceans, for example, warm much more slowly than the atmosphere in response to the buildup of heat-trapping gases. Additionally, many of the sources of GHG emissions, such as power plants and automobiles, have lifetimes of years to decades. Thus, our decisions now will shape the world for generations to come. Research has shown that individuals and organizations have trouble perceiving risks and taking action on such long-lead time problems.

*The sensitivity of the climate system is somewhat uncertain.* [S]cientists have learned a great deal about the response of the climate system to GHGs and other climate forcing agents through a combination of direct observations of recent climate change, indirect evidence of historical climate variations, and climate modeling studies. However, Earth's climate sensitivity — which dictates how much warming would be expected if future emissions were known exactly — remains somewhat uncertain. . . .

*There may be tipping points or thresholds that, once crossed, lead to irreversible events.* Some of the physical and biological feedbacks triggered by climate change can become irreversible when they pass a certain threshold or tipping point. . . . Human systems can also experience tipping points, such as the collapse of an economy or political system. Because of the possibility of crossing such thresholds, simple extrapolations of recent trends may underestimate future climate change impacts. Given the complexity of coupled human-environment systems, it is difficult to forecast when a tipping point might be approaching, but the probability of crossing one increases as the climate system moves outside the range of natural variability.

*Analyses of impacts resulting from higher levels of climate change are limited.* Most scientific analyses of climate change have focused on the impacts associated with global temperature change of between 3.6ºF to 5.4ºF (2 to 3ºC) by the end of the 21st century, relative to pre-industrial conditions. Yet model-based projections of future global temperature change range from 2ºF to more than 11ºF, and even larger changes are possible. For comparison, the higher end of the expected range of future temperature change is comparable to the temperature difference between the present climate and the climate at the height of the last ice age, when glaciers covered the sites presently occupied by New York, Chicago, and Seattle and ecosystems around the world were radically different. Although there have been some recent efforts to estimate the impacts that might be associated with global temperature changes of greater than 9 or 10ºF (5 or 6ºC) over the next century relatively little scientific information is available regarding the potential risks posed by such extreme changes in global climate.

*Climate change does not act in isolation.* [C]limate change is just one of many stressors affecting human and environmental systems. For example, estuaries and coral reefs are being affected by warming ocean temperatures, ocean acidification, sea level rise, and changes in runoff from precipitation, and these climate-driven impacts interact with other ongoing threats such as pollution, invasive species, coastal development, and overfishing. The impacts of these multiple stresses and interacting environmental changes on food production, water management, energy production, and other critical human activities are associated with important risks in terms of meeting human needs. The prevalence of multiple stresses and the interconnected nature of many climate-related processes also raise significant scientific and management challenges.

Individually and collectively, these complexities make it challenging to address the risks posed by climate change. Indeed, it is easy to get lost (and depressed) in the details of GHG concentrations, carbon dioxide emission levels, parts per million, surface air temperatures, sea level rise, and all the other climate impacts. But thinking about climate change impacts and policy can be simplified — by working backwards from the world in which we want to live to the current policies necessary to get there. We can break this down into a series of five questions:

***First***, what impacts must we avoid to ensure a livable planet for future generations?

***Second***, what is the maximum average temperature increase that is allowable to ensure that we avoid the worst climate impacts?

***Third***, what is the maximum atmospheric concentration of greenhouse gases that is allowable to ensure that we do not exceed the average temperature increase identified in Question 2?

***Fourth***, what is the amount of net greenhouse gas emissions into the atmosphere that is allowable to stabilize atmospheric concentrations below the level identified in Question 3?

***Fifth***, what policies will be required to achieve the necessary reductions in greenhouse gas emissions identified in Question 4?

***What impacts must we avoid to ensure a livable planet?*** Although policymakers can differ over what modest impacts are tolerable from climate change, almost everyone would agree that we must avoid the worst potential impacts. As discussed in the previous sections of this chapter, many impacts are already occurring and cannot be reasonably avoided in the future (for example, extensive glacier melting and many changes in natural ecosystems). Compared to the anticipated future impacts from a "business-as-usual" scenario, however, today's impacts are relatively modest. Although we will necessarily incur some costs from climate change, we can still avoid the most significant impacts — for example, the wholesale crash of food production or of natural ecosystems, the melting of the Greenland or West Antarctic ice sheets, or the shutdown of the thermohaline circulation.

***What is the maximum level of temperature increase that can occur without the risk of massive climate impacts?*** Some scientists recommend a limit of 1°C beyond 1990 temperatures to protect coral reefs, 2°C to protect the Greenland and West Antarctic ice sheets, and 3°C to protect the thermohaline circulation. B.C. O'Neill & M. Oppenheimer, *Climate Change — Dangerous Climate Impacts and the Kyoto Protocol*, 296 SCIENCE 1971–72 (2002). Similarly, NASA's Dr. James Hansen originally set his long-term temperature target at a 1°C increase above 2005 temperatures (roughly equivalent to a 2°C total increase), based on an estimate of how much more warming the planet could tolerate before triggering a 1.5 m sea level rise. *See* James A. Hansen, *Defusing the Global Warming Time Bomb*, 290 SCI. AM. 68–77 (2004); James Hansen, *A Slippery Slope: How Much Global Warming Constitutes 'Dangerous Anthropogenic Interference', An Editorial Essay*, 68 CLIMATE CHANGE 269 (2005). Although there is obviously some uncertainty over this question, many scientists agree with this assessment that we must limit our total temperature increase to at most 2°C (approximately 1°C more than current warming), to have confidence that we can avoid significant negative change. *See also, e.g.*, Christan Azar & Henning Rodhe, *Targets for Stabilization of Atmospheric $CO_2$*, 276 SCIENCE 1818–19 (1997) (calling for global warming not to exceed 2°C); H. Grassl, J. Kokott, et al., *Climate Protection Strategies for the 21st Century: Kyoto and Beyond*, (German Advisory Council on Global Change 2003) (calling for a maximum 2°C warming as "acceptable").

This position comports as well with what we know of historical temperatures. A recent study shows that current warming has made global average temperatures higher than any since the end of the last ice age 12,000 years ago, and we are now within 1.0°C (1.8°F) of the highest temperatures in the past million years. In reporting on the study, NASA's Dr. James Hansen, said:

> That means that further global warming of 1°C defines a critical level. If warming is kept less than that, effects of global warming may be relatively

> manageable. During the warmest interglacial periods the Earth was reasonably similar to today. But if further global warming reaches 2–3°C, we will likely see changes that make Earth a different planet than the one we know. The last time it was that warm was in the middle Pliocene, about three million years ago, when sea level was estimated to have been about 25 meters (80 feet) higher than today. . . . This evidence implies that we are getting close to dangerous levels of human-made (anthropogenic) pollution.

NASA, Press Release, *NASA Study Finds World Warmth Edging Ancient Levels*, Sept. 25, 2006. The study reached its conclusion by focusing on two specific impacts — sea level rise and widespread species extinctions — and concluded that avoiding these would require limiting global warming to a 2°C increase. *See* James A. Hansen, et al., *Global Temperature Change*, PROC. NAT'L ACAD. SCI., Sept. 25, 2006.

The goal of limiting warming to no more than 2°C has influenced global negotiations with the post-2012 negotiations often supporting this goal. The Copenhagen Accord, for example, endorsed the "scientific view that the increase in global temperature should be below 2 degrees." Still, significant uncertainty exists regarding a "safe" level of temperature increase, and some leading scientists (including James Hansen) have begun to call for a lower target of 1.5°C. The post-2012 negotiations have left open the potential need to review and strengthen the long-term temperature goal. *See, e.g.*, Copenhagen Accord, para. 12.

***At what level must we stabilize atmospheric GHG concentrations to limit warming to a total of 2°C?*** Assuming for the moment that we have settled on the long-term goal of limiting temperature increase to below 2 degrees, the question becomes what level of GHG concentrations is permitted. Here, too, there is some bounded uncertainty in the relationship between atmospheric greenhouse gas concentrations and temperature rise.

Studies of ice cores in Antarctica show that levels of $CO_2$, as well as other GHGs, including methane and nitrous oxide, are higher than at any time in the past 800,000 years, with $CO_2$ increasing at a rate 200 times faster than at any time over that span. The amount of $CO_2$ in the atmosphere has increased from its preindustrial level of approximately 280 ppm in 1750 to more than 395 ppm in 2013 , and, if current trends continue unabated, concentrations would reach 600–700 ppm by the end of the 21st century.

The IPCC's Fourth Assessment aimed at stabilizing $CO_2$ concentrations at 450-550 ppm by 2100. In recent years, however, knowledge about climate change impacts has moved the goal.

Most observers now recognize that the risks from doubling greenhouse gas concentrations (i.e., a goal of 550 ppm) are unacceptably high. A study in 2004 found that stabilization at the equivalent of 550 ppm $CO_2$ provides only a 10–20 percent chance of limiting global average temperature rise to 2°C, while stabilizing atmospheric concentrations to 400 ppm $CO_2$ would yield an 80 percent chance of limiting global average temperature rise to 2°C above preindustrial levels. Paul Baer, *Probabilistic Analysis of Climate Stabilization Targets and the Implications for Precautionary Policy*, presented at the Am. Geo. Union Ann. Mtg., Dec. 17, 2004. More recently, UNEP concluded that "Limiting long-term global temperature increase to below 2°C with a likely (greater than 66%) chance would imply greenhouse gas concentrations at equilibrium to be around 415 ppm $CO_{2e}$." UNEP, BRIDGING THE EMISSIONS GAP 17 (2011). NASA's lead climate scientist, Dr. James Hansen, by contrast, believes that temperature is much more sensitive to greenhouse gas concentrations and has argued for a lower $CO_2$ target of 350 ppm—a *decrease* from the 2011 levels of 390 ppm. This debate is important because it sets the broad parameters for the speed, extent and scale of the needed policy and technological responses. But to some extent, consensus over a precise concentration level is not necessary; we know that we must cut emissions much more than we have, and we must do so quickly.

***What level of greenhouse gas emissions reductions is necessary to reach the desired stabilization levels?*** Here again, a general consensus has emerged around the goal of 50 percent reductions worldwide by 2050 (involving 80 percent reductions for industrialized countries) and significant interim reduction targets by 2020 or 2030. In 2003, the German Advisory Council on Global Change found that worldwide carbon dioxide emissions must be cut globally by 45–60 percent by the year 2050 relative to 1990. This means that industrialized countries must reduce their greenhouse gas emissions by at least 20 percent by 2020 and make substantially higher cuts (around 80 percent) by 2050. Review again the data about emissions level presented previously in this chapter. How well are we doing?

***What policies and measures will allow us to attain the reductions identified above?*** This is the subject of the next chapter.

## QUESTIONS AND DISCUSSION

**1.** The objective adopted by the UN Framework Convention on Climate Change (UNFCCC) is to stabilize atmospheric greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system." *See* UNFCCC, Article 2; *see also* Chapter 4 discussing this objective. The International Climate Task Force calls for an international objective that would limit temperatures from "rising more than 2°C (3.6°F) above the pre-industrial level." Are these two objectives consistent? Given the unprecedented scope of the linear and non-linear impacts from climate change, what should the ultimate objective of climate policy be? Put another way, what risks should be considered as the baseline for setting international policy? A rapid climate change event such as the shutdown of the thermohaline circulation? Or the more linear risks associated with polar ice melt, drought, or coral loss?

**2.** Meeting this long-term stabilization target means unprecedented reductions in greenhouse gas emissions over the next 50 years, with consensus estimates focusing on a 60 to 80 percent reduction from 1990 levels by 2050, followed by a near-complete transition to a carbon-free economy by 2100. By comparison, the Kyoto Protocol, discussed in Chapter 5, aimed at a 5.2 percent reduction from 1990 levels in most developed countries (excluding the United States) by 2012. It was acknowledged to be only the first step, and many world leaders have called for the more ambitious reductions suggested by the above analysis. The European Union proposed cuts of up to 80 percent by 2050. Tony Blair, *Global Warming: "We Must Do More to Beat Climate Change,"* THE INDEPENDENT, Nov. 19, 2005; *see also* State of California Executive Order S-3-05 (June 1, 2005) (setting emissions target at 80 percent below 1990 levels by 2050); State of New Mexico Executive Order 05-033 (June, 2005) (setting emissions target at 75 percent below 2000 level by 2050). Such deep reductions will not be easy and presume a massive investment in a "new energy economy." The policies to get us there are discussed in Chapter 2.

**3.** Talking about the potential impacts from climate change poses significant challenges for environmentalists and policymakers, particularly with respect to complex and potentially catastrophic impacts like the shutdown of the thermohaline current. The first challenge is not to make policymakers or the public feel as if any action is hopeless. In fact, the worst climate impacts happen only at higher temperatures and higher concentrations. The "business-as-usual" scenario is a bleak one — but humans are adaptive and innovative, and we should be able to move significantly away from the business-as-usual future if we have the will to do so. We are essentially in a fight over degrees — at what level of warming will we finally stabilize before bringing greenhouse gas concentrations down? In such a fight, every small step that policymakers (or individuals) take contributes to the solution.

The second challenge is how to sound the alarm about climate change without sounding like an alarmist. Because the worse predicted impacts from climate change are still decades away, the public can be inured over time to warnings and begin to believe that "chicken little is simply announcing that the sky is falling again." On the other hand, severe weather events often bring public attention back on climate change even if the scientific links between climate change and specific weather events are not always clear. Given these factors, if you were advising a U.S. environmental organization on its communications policy, what advice would you give them?

**4.** Many organizations, publications, and websites regularly report on developments in climate science. *See, e.g.*, www.climatescience.gov (information provided by the U.S. government's Climate Science Program, an integrated effort of several government agencies); http://www.c2es.org/ (the Center for Energy and Climate Solutions); www.ucsusa.org/global_warming/ (the Union of Concerned Scientists); *see also* the online publications of *Science* or *Nature*, which frequently publish articles on climate change. For an informative explanation of, and commentary on, current climate science, see www.realclimate.org. An engaging and readable (although ultimately disturbing) depiction of the impacts from climate change can be found in MARK LYNAS, SIX DEGREES: OUR FUTURE ON A HOTTER PLANET (2006).