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Overview: The Exigencies That Drive Potential Causes of Action for Climate Change

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The implications of the crystallizing scientific understanding is that the planet is on the verge of dramatic climate change. It is still possible to avoid the most deleterious effects, but only if prompt actions are taken to stabilize global temperature close to its present value.[1]

INTRODUCTION

Over the course of the last few years, climate change litigation has been transformed from a creative lawyering strategy to a major force in transnational regulatory governance of greenhouse gas emissions. This book traces that journey and looks ahead to the future by considering a range of lawsuits and petitions filed in state, national, and international tribunals, as well as some potential causes of action. These actions cover an immense legal terrain but have in common their concern with more effective regulation of greenhouse gas emissions.

This introductory chapter frames the contributions in this book. It first provides an overview of climate change science, including both the current and the projected global impacts of climate change; second, it assesses current institutional responses to climate change and why they have been and likely will continue to be wholly inadequate to confront the looming threat of climate change in this century and beyond; third, it examines current efforts to open a new front to address climate change and climate change litigation; and finally, it provides a synopsis of the chapters that follow.

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[1] James E. Hansen, *Dangerous Human-Made Interference with Climate*, Testimony to the Select Committee on Energy Independence and Global Warming, U.S. House of Representatives, Apr. 26, 2007, *available at* http://www.columbia.edu/~jeh1/testimony_26april2007.pdf (last visited May 26, 2008).

1. OVERVIEW OF CLIMATE CHANGE SCIENCE

The most recent assessment by the Intergovernmental Panel on Climate Change (IPCC)[2] concludes that global average surface temperatures have increased by 0.8°C over the last century, with the linear warming trend over the past fifty years twice that of the past century.[3] Moreover, the assessment concluded that "[m]ost of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations."[4] This section provides an overview of the scientific understanding of the growth of these emissions and its impacts.

The surface of the Earth is heated by solar radiation emanating from the sun at short wavelengths between 0.15 and 5 μm. Each square meter of the Earth receives an average of 342 watts of solar radiation throughout the year.[5] Approximately 26% of this radiation is reflected or scattered back to space by clouds and other atmospheric particles, and another 19% is absorbed by clouds, gases, and atmospheric particles.[6] Fifty-five percent of incoming solar energy passes through the atmosphere. Four percent is reflected from the surface back to space, with the remaining 51% reaching the Earth's surface. The heating of Earth's surfaces results in reradiation of

[2] The IPCC was established by the World Meteorological Organization and the United Nations Environment Program in 1988 to review and assess the most recent scientific, technical, and socio-economic information related to the understanding of climate change, to evaluate proposals for reducing greenhouse gas emissions, and to assess the viability of response mechanisms. G.A. Res. 43/53, U.N. GAOR, 2d Comm., 43rd Sess., Supp. No. 49, at 133, U.N. Doc. A/43/49 (1989). The IPCC provides comprehensive Assessment Reports of the current knowledge and future projections of climate change at regular intervals. The reports are authored by teams of authors from throughout the world from universities, research centers, businesses, and nongovernmental organizations. There were more than 800 contributing authors to the latest report, and more than 2,500 scientific expert reviewers of the report. The First Assessment Report was published in 1990, the Second Assessment Report in 1995, the Third Assessment Report was released in 2001, and the Fourth Assessment Report (designated as "AR4") was released in four volumes throughout 2007. IPCC, *Fact Sheet* (2007), *available at* http://www.ipcc.ch/press/factsheet.htm (last visited May 10, 2007).

[3] *Technical Summary*, in CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS 5 (S. Solomon et al. eds., 2007), *available at* http://www.ipcc.ch/ipccreports.ar4-wg1.htm (last visited May 25, 2008) [hereinafter THE PHYSICAL SCIENCE BASIS]. Atmospheric temperatures have been rising at a rate of approximately 0.2°C per decade over the past thirty years. James E. Hansen, Green Mountain Chrysler-Plymouth-Dodge-Jeep v. Thomas W. Torti, Nos. 2:05-CV-302 & 2:05-CV-304 (Consolidated), *Declaration of James E. Hansen*, (Vt., 2007), *available at* http://www.columbia.edu/~jeh1/case_for_vermont.pdf (last visited May 25, 2008).

[4] THE PHYSICAL SCIENCE BASIS, *supra* note 3, at 10. *See also* R. Somerville et al., *Historical Overview of Climate Change*, in THE PHYSICAL SCIENCE BASIS, supra note 3, at 105 ("human activities have become a dominant force, and are responsible for most of the warming observed over the past 50 years"). The IPCC defines the term "very likely" as a greater than 90% likelihood of occurrence/outcome. *Id.* at 121.

[5] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change 89 (2001) [hereinafter *Climate Change 2001-Scientific*].

[6] Physicalgeography.net, *The Greenhouse Effect*, http://www.physicalgeography.net/fundamentals/7h.html (last visited May 25, 2008).

approximately one-third of this energy, in the form of long-wave band (wavelengths of 3–50 μm) or infrared radiation.[7]

Some of the outgoing infrared radiation is absorbed by naturally occurring atmospheric gases – principally water vapor (H_2O), as well as carbon dioxide (CO_2), ozone (O_3), methane (CH_4), nitrous oxide (N_2O), and clouds.[8] This absorption is termed the "natural greenhouse effect" because these gases, which are termed "greenhouse gases," operate much like a greenhouse: they are "transparent" to incoming shortwave radiation, but "opaque" to outgoing infrared radiation, trapping a substantial portion of such radiation and reradiating much of this energy to the Earth's surface, increasing surface temperatures.[9] While greenhouse gases constitute only 1% of the atmosphere,[10] they are critical to the sustenance of life on Earth, elevating surface temperatures by about 33°C.[11]

Prior to the Industrial Revolution, atmospheric concentrations of naturally occurring greenhouse gases had been relatively stable for 10,000 years.[12] As a consequence, the net incoming solar radiation at the top of the atmosphere was roughly balanced by the net outgoing infrared radiation.[13] However, with the advent of fossil fuel–burning plants to support industry, automobiles, and the energy demands of modern consumers, as well as substantial expansion of other human activities, including agricultural production, "humans began to interfere seriously in the composition of the atmosphere"[14] by emitting large amounts of additional greenhouse gases. The human-driven buildup of greenhouse gases in the atmosphere has resulted in "radiative forcing"; that is, increased levels of these gases result in greater absorption of outgoing infrared radiation, and ultimately an increase in temperatures when a portion of this radiation is reradiated to the Earth's surface.[15]

The most important anthropogenic greenhouse gas over the past two centuries has been carbon dioxide, which is primarily attributable to fossil fuel

7 Somerville et al., *supra* note 3, at 96; Intergovernmental Panel on Climate Change, *Radiative Forcing of Climate Change* 7 (1994) [hereinafter *Radiative Forcing*].
8 Thomas R. Karl & Kevin E. Trenberth, *Modern Global Climate Change*, 302 Sci. 1719, 1719 (2003).
9 Stephen H. Schneider, *The Greenhouse Effect: Science and Policy*, 243 Sci. 771, 772 (1989).
10 UNFCCC Secretariat, *The Greenhouse Effect and the Carbon Cycle*, *available at* http://unfccc.int/essential_background/feeling_the_heat/items/2903.php (last visited May 25, 2008).
11 *Id.*
12 Haroon S. Kheshgi, Steven J. Smith & James A. Edmonds, *Emissions and Atmospheric CO_2 Stabilization*, in 10 Mitigation & Adaptation Strategies for Global Change 213, 214 (2005).
13 John R. Justus & Susan R. Fletcher, *Global Climate Change*, CRS Issue Brief for Congress 3 (Aug. 13, 2001), *available at* http://www.ncseonline.org/NLE/CRSreports/Climate/clim-2.cfm?&CFID=13638750&CFTOKEN=63020586 (last visited May 25, 2008).
14 Fred Pearce, *World Lays Odds on Global Catastrophe*, New Sci., Apr. 8, 1995, at 4.
15 UNEP, *Vital Climate Change Graphics* 10 (2005).

> The earth then is radiating less energy to space than it absorbs from the sun. This temporary planetary energy imbalance results in the earth's gradual warming . . . Because of the large capacity of the oceans to absorb heat, it takes the earth about a century to approach a new balance – that if, for it to once again receive the same amount of energy from the sun it radiates to space. And of course the balance is reset at a higher temperature.

See also James Hansen, *Defusing the Global Warming Time Bomb*, Sci. Am., Mar. 2004, at 71.

combustion,[16] cement production, and land-use change.[17] Carbon dioxide has accounted for 90% or more of the increased greenhouse gas climate forcing in recent years.[18] Since 1751, more than 297 billion metric tons of carbon have been released into the atmosphere from anthropogenic sources, with half of the emissions occurring since 1978.[19] Atmospheric concentrations of carbon dioxide were approximately 280 parts per million (ppm) at the start of the Industrial Revolution in the 1780s. While it took a century and a half to reach atmospheric concentrations of 315 ppm, the trend accelerated in the twentieth century, reaching 360 ppm by the 1990s, and 384 ppm currently,[20] which exceeds atmospheric levels for at least the last 650,000 years,[21] and most likely the last 20 million years.[22]

[16] Consumption of crude oil and coal account for almost 77% of fossil fuel carbon dioxide emissions. Climate Change Science Program & Subcommittee on Global Change Research, *Our Changing Planet: The U.S. Climate Change Science Program for Fiscal 2007* 117 (2007). Energy-related carbon dioxide emissions have risen 130-fold since 1850. Pew Center on Global Climate Change, *Climate Change 101: Understanding and Responding to Global Climate Change* 34 (2006), *available at* http://www.pewclimate.org/docUploads/Climate101-FULL_121406_065519.pdf (last visited May 25, 2008). "Worldwide use of coal, oil, and natural gas in 2005 led to the emission of about 7.5 gigatonnes of carbon (GtC) in CO2, an amount that continues to increase year by year." Rosina Bierbaum et al., *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable*, Scientific Expert Group Report on Climate Change and Sustainable Development 12 (2006), *available at* http://www.unfoundation.org/files/pdf/2007/SEG_Report.pdf (last visited May 25, 2008).

[17] "The additional release in recent years from deforestation and land-use change, mainly in tropical regions, has been estimated variously at between 0.7 GtC/year and 3.0 GtC/year in CO_2 . . . a mid-range value of 1.5 GtC/year is often cited." Bierbaum et al., *supra* note 16, at 12–13. This constitutes 20–25% of anthropogenic greenhouse gas emissions. Chatham House/Royal Society for the Protection of Birds, *Workshop on Reducing Emissions from Tropical Deforestation*, Summary Report 1 (2007), *available at* http://www.chathamhouse.org.uk/files/9165_160407workshop.pdf (last visited May 25, 2008); Raymond E. Gullison et al., *Tropical Forests and Climate Change*, 316 SCI. 985, 985 (2007). Deforestation also contributes to warming trends by eliminating possible increased storage of carbon and decreasing evapotranspiration. G. Bala et al., *Combined Climate and Carbon-Cycle Effects of Large-Scale Deforestation*, 104(16) PROC. NAT'L ACAD. SCI. 6550, 6550 (2007). However, deforestation exerts a cooling effect, particularly in seasonally snow-covered high latitudes, by decreasing the albedo (reflectivity) of surfaces. *Id.*

[18] James Hansen & Makiko Sato, *Greenhouse Gas Growth Rates*, 101(46) PROC. NAT'L ACAD. SCI. 16,109, 16,111 (2004).

[19] Climate Change Science Program & Subcommittee on Global Change Research, *Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Year 2007* 117 (2006).

[20] Eric Steig, *The Lag between Temperature and CO2*, RealClimate, Apr. 27, 2007, *available at* http://www.realclimate.org/index.php/archives/2007/04/the-lag-between-temp-and-co2/ (last visited on June 2, 2008). Approximately half of carbon dioxide emissions since 1751 have occurred since 1978. Climate Change Science Program & Subcommittee on Global Change Research, *supra* note 19, at 117. Carbon dioxide emissions grew 80% between 1970 and 2004. IPCC, Working Group III contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report, CLIMATE CHANGE 2007: MITIGATION OF CLIMATE CHANGE, SUMMARY FOR POLICYMAKERS 3 (2007), *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-spm.pdf (last visited May 25, 2008) [hereinafter MITIGATION OF CLIMATE CHANGE]. Between 2006 and 2007, carbon dioxide emissions rose a startling 20 percent. Malte Meinhaussen et al., *Greenhouse Gas Emissions Targets for Limiting Global Warming to 20°*, 458 NATURE 1158, 1160 (2009).

[21] THE PHYSICAL SCIENCE BASIS, *supra* note 3, at 4.

[22] CNA Corporation, *National Security and the Threat of Climate Change* 56 (2007), *available at* http://www.securityandclimate.cna.org/report/National%20Security%20and%20the%20Threat%20of%20Climate%20Change.pdf (last visited May 25, 2008).

Nitrous oxide emissions, primarily generated through fertilizer production and industrial processes, account for approximately 5% of greenhouse gas forcing in recent years.[23] Atmospheric concentrations of nitrous oxides rose from a preindustrial value of 270 parts per billion (ppb) to 319 ppb in 2005.[24]

Methane emissions, generated primarily through rice cultivation, ruminants, energy production, and landfills, account for approximately 4% of greenhouse gas forcing in recent years.[25] Atmospheric concentrations of methane have increased 153% from preindustrial levels, reaching 1,774 ppb in 2005. This far exceeds the natural range of the last 650,000 years.[26] Overall, the global emissions of the six primary anthropogenic greenhouse gases rose 70% between 1970 and 2004.[27]

The increasing emissions translate into tangible human impacts. The World Health Organization has estimated that warming and precipitation trends over the past thirty years associated with anthropogenic climate change have claimed 150,000 lives annually, primarily attributable to human disease and malnutrition.[28] Recent studies have linked the significant increase in violent weather events over the past several decades to increases in sea surface temperature associated with climate change.[29] Other expressions of climate change include "increasing ground instability of permafrost regions . . . shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans . . . [and] poleward and upward shifts in ranges in plant and animal species. . . ."[30]

Overall, warming is undoubtedly exerting a substantial and pervasive influence on the globe. As the IPCC recently concluded, "[o]f the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming."[31] Physical system responses to climate change

[23] Hansen & Sato, *supra* note 18, at 16,111.
[24] Intergovernmental Panel on Climate Change, *supra* note 5, at 4.
[25] Hansen & Sato, *supra* note 18, at 16,111.
[26] Intergovernmental Panel on Climate Change, *supra* note 7, at 4. Overall, emissions of the six primary greenhouse gases generated by anthropogenic sources increased 75% between 1970 and 2004. Netherlands Environmental Assessment Agency, *Global Greenhouse Gas Emissions Increased 75% since 1970* (Nov. 13, 2006), *available at* http://www.mnp.nl/en (last visited May 25, 2008).
[27] *Climate Change 2001-Scientific*, *supra* note 5, at 3.
[28] Jonathan A. Patz et al., *Impact of Regional Climate Change on Human Health*, 438 NATURE 310, 310 (2005).
[29] Greg J. Holland & Peter J. Webster, *Heightened Tropical Cyclone Activity in the North Atlantic: Natural Variability or Climate Trend?*, 365 PHIL. TRANSACTIONS ROYAL SOC'Y A 2695 (2007); K. Emanuel, *Increasing Destructiveness of Tropical Cyclones over the Past 30 Years*, 436 NATURE 686–88 (2005).
[30] Intergovernmental Panel on Climate Change, CLIMATE CHANGE 2007: IMPACTS, ADAPTATION AND VULNERABILITY, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report, Summary for Policymakers 2, *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-spm.pdf (last visited on June 2, 2008) [hereinafter IMPACTS, ADAPTATION AND VULNERABILITY].
[31] *Id.* at 2. *See also* Cynthia Rosenzweig et al., *Attributing Physical and Biological Impacts to Anthropogenic Climate Change*, 453 NATURE 353, 353–54 (May 2008) (stating that in a study of 29,500 data series "[n]inety-five per cent of the 829 documented physical changes have been in directions consistent with warming").

over the past three decades include shrinking glaciers on every continent, melting permafrost, shifts in the spring peaks of river discharge, and coastal erosion. Biological effects include phonological changes (such as the timing of blooming of fauna, species' migration and reproduction), and changes in community structure.[32]

However, the greatest trepidation of climate scientists lies in the outlook for this century and beyond, as atmospheric concentrations of greenhouse gases continue to rise. Absent aggressive global efforts to reduce greenhouse gas emissions, atmospheric concentrations of carbon dioxide may reach twice preindustrial levels by as early as 2050,[33] and perhaps triple by the end of the century.[34] The latest assessment by the IPCC projects that a doubling of atmospheric concentrations of carbon dioxide from preindustrial levels is likely to result in temperature increases in the range of 2°–4.5°C, with a best estimate of 3°C.[35] This projection is remarkably consistent with paleoclimatic evidence. "[E]mpirical data climate change over the past 700,000 years yields a climate sensitivity of ¾°C for each W/m² of forcing, or 3°C for a 4 W/m² forcing.[36] However, the time line for these projections may prove to be far too sanguine given a "shocking" rise in global energy demand in the past few years, according to the International Energy Agency (IEA) in its most recent *World Energy Outlook*.[37] The IEA report concludes that world energy demand has accelerated rapidly during this decade, primarily attributable to breakneck economic growth in China and India, and that world energy needs could be 50% higher in 2030 than today.[38] As a consequence, the IEA projects that atmospheric concentrations

[32] Rosenzweig et al., *supra* note 31 at 353.

[33] Hansen, *supra* note 1, at 4.

[34] David Talbot, *The Dirty Secret*, Tech. Rev. (July/Aug. 2006), *available at* http://www.technologyreview.com/Energy/17054 (last visited May 25, 2008); Stephen F. Lincoln, *Fossil Fuels in the 21st Century*, 34(8) Ambio 621, 621 (2005).

[35] Intergovernmental Panel on Climate Change, *supra* note 7, at 12. *See also* Bierbaum et al., *supra* note 16, at x:

> If CO2 emissions and concentrations grow according to mid-range projections, moreover, the global average surface temperature is expected to rise by 0.2°C to 0.4°C per decade throughout the 21st century and would continue to rise thereafter. The cumulative warming by 2100 would be approximately 3°C to 5°C over preindustrial conditions.

[36] Hansen, *supra* note 3, at 7. As Hansen notes, paleoclimatic data is particularly compelling because it also includes any cloud feedbacks that may exist. Cloud feedbacks are recognized by most climatologists as the largest source of uncertainty in climatic modeling. Intergovernmental Panel on Climate Change, *supra* note 7, at 4; Richard A. Kerr, *Three Degrees of Consensus*, 305 Sci. 932, 933 (2004).

[37] *IEA Predicts 'Shocking' Rise in Global Energy Demand*, Environmental Finance Online News, Nov. 8, 2007, *available at* http://www.environmental-finance.com/onlinews/1108iea.html (last visited May 25, 2008). *See also* Josep G. Canadell, *Contributions to Accelerating Atmospheric CO_2 Growth from Economic Activity, Carbon Intensity, and Efficiency of Natural Sinks*, Proc. Nat'l Acad. Sci. Early Ed., Nov. 13, 2007, http://www.pnas.org/cgi/doi/10.1073/pnas.0702737104 (last visited May 25, 2008) (global carbon dioxide emissions rate increased from 1.3% in the 1990s to 3.3% annually in 2000–2006).

[38] International Energy Agency, World Energy Outlook 2007: China and India Insights 41 (2007), http://www.iea.org/npsum/weo2007sum.pdf (last visited Nov. 15, 2007). The United States, China, and India are slated to construct an additional 850 coal-fired plants by 2012. These plants are projected to produce an additional 2.7 billion tons of carbon dioxide, while the Kyoto Protocol only requires its Parties to reduce their emissions by about 483 million tons. Mark Clayton, *New Coal Plants Bury 'Kyoto,'*

of carbon dioxide could rise to levels that would produce a 6°C increase in global temperatures by 2030.[39]

Moreover, the IPCC's most recent assessment's midrange scenario projects that sea levels will rise between 18 and 59 centimeters (7–23 inches) during the remainder of this century as a consequence of projected warming.[40] However, there is a very real possibility that sea levels will rise much more than this given potential dynamical responses of ice sheets in Greenland and West Antarctica,[41] which may exert substantial positive feedbacks on sea level rise over the next century and beyond.[42]

A recent study that incorporates ice dynamics projects that sea levels will rise between 0.8 and 2.0 meters,[43] "the highest estimates of sea level rise by 2100 that has been published in the literature to date."[44] In the longer term, if annual temperatures increase by more than 3°C in the Antarctic region, which is highly likely by the end of this century, one study projects that globally averaged sea levels could increase by 7 *meters* over a period of 1,000 years or more.[45]

Consistent scientific evidence predicts that climate change will have dire implications for both natural systems and human institutions. In the context of natural systems, the IPCC's most recent assessment concluded that "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, overexploitation of resources)."[46] For example, coral reefs have extremely narrow temperature tolerances of between 25 and 29°C, with some species in Pacific

Christian Sci. Monitor, Dec. 23, 2004, *available at* http://www.csmonitor.com/2004/1223/p01s04-sten.html (last visited May 25, 2008).

39 *IEA Predicts 'Shocking' Rise in Global Energy Demand*, *supra* note 37.

40 G. A. Meehl, et al., *Global Climate Change Projections*, in IPCC Fourth Assessment Report, The Physical Science Basis (2007), at 820, http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Ch10.pdf (last visited May 20, 2007). Rising sea levels associated with climate change are attributable primarily to thermal expansion of ocean waters due to warming and glacial melting. Hansen, *supra* note 1, at 16.

41 A persuasive case is made by Hansen that the IPCC in its Fourth Assessment Report failed to adequately take into account multiple positive feedbacks that could occur in Greenland and West Antarctica should temperatures rise by 2–3°C. These include "reduced surface albedo, loss of buttressing ice shelves, dynamical response of ice streams to increased melt-water and lower sea surface ice altitude," all of which result in massive rises in sea level within a few centuries. James Hansen et al., *Global Temperature Change*, 103(39) Proc. Nat'l Acad. Sci. 14,288, 14,292 (2006).

42 J.E. Hansen, *Scientific Reticence and Sea Level Rise*, 3 Envtl. Res. Letters 1, 4 (2007); James Hansen et al., *Climate Change and Trace Gases*, 365 Phil. Transactions Royal Soc'y A 1925, 1936 (2007); Michael Oppenheimer et al., *The Limits of Consensus*, 317 Sci. 1505, 1505 (2007).

43 W.T. Pfeffer, et al., *Kinematic Constraints on Glacier Contributions to 21st Century Sea-Level Rise*, 321 Sci. 1340, 1342 (2008).

44 *How Much Will Sea Level Rise?*, RealClimate.org, Sept. 4, 2008, http://www.realclimate.org/index.php?p=598 (last visited Sept. 5, 2008).

45 Jonathan M. Gregory, Philippe Huybrechts & Sarah C.B. Raper, *Threatened Loss of the Greenland Ice-Sheet*, 428 Nature 616, 616 (2004). *See also* Julian A. Dowdeswell, *The Greenland Ice Sheet and Global Sea-Level Rise*, 311 Sci. 963, 963 (2006). Hansen also concluded that a 2–3°C increase in temperatures could ultimately result in sea level rise of 25 *meters* over the course of the next few hundred years. *Id.* at 21.

46 Impacts, Adaptation and Vulnerability, *supra* note 30, at 5.

island developing countries (PIDCs) currently living near their threshold of thermal tolerance.[47] Projected sea temperature rises in the Pacific region over the next century are likely to result in a "catastrophic decline" in coral cover.[48] Loss of coral reefs could have similar implications in other regions, including the Indian Ocean and Caribbean Sea.[49] Overall, the World Bank has estimated that 50% of the subsistence and artisanal fisheries will be lost in regions where coral reefs die due to coral bleaching attributable to climate change.[50] The massive infusion of carbon dioxide into the world's oceans associated with the growth of anthropogenic emissions also may result in serious declines in coral reef calcification rates, further contributing to their destruction.[51]

In addition, forest ecosystems may be negatively impacted by climate change. Climate change may drive changes in floristic composition in some regions, resulting in changes in forest composition. This could result in the decline of species that sustain assemblages of pollinators, herbivores, symbiotic fungi, and other important species in regions such as the Amazon.[52] In some cases, the loss of key tree species could result in the collapse of entire forest ecosystems.[53]

Climate change may adversely impact a wide array of species through, inter alia, habitat alteration and destruction, changes in phenology (the relationship between climate and periodic biological phenomena, such as hibernation or migration), and direct temperature effects.[54] The IPCC in its Fourth Assessment Report concluded

47 William C.G. Burns, *The Potential Impacts of Climate Change on Pacific Island State Ecosystems*, Occasional Paper of the Pacific Institute for Studies in Development, Environment, and Security, at 4 (Mar. 2000).

48 Brian C. O'Neill & Michael Oppenheimer, *Climate Change Impacts Are Sensitive to the Concentration Stabilization Path*, 101(47) Proc. Nat'l Acad. Sci. 16,411, 16,414 (2004) ("Model studies suggest that Earth may enter an era of sustained bleaching and widespread demise of reefs if global mean temperature increases by >1°C from recent levels").

49 John P. McWilliams et al., *Accelerating Impacts of Temperature-Induced Coral Bleaching in the Caribbean*, 86(8) Ecology 2055, 2059 (2005) (projected warming in the Caribbean could result in "maximum bleaching extent (i.e., 100% of coral-bearing cells) and maximum bleaching intensity (100% of coral colonies)"; Simon D. Donner et al., *Global Assessment of Coral Bleaching and Required Rates of Adaptation Under Climate Change*, 11 Global Climate Change Biology 2251, 2256–57 (2005) (severe coral bleaching events could occur every three to five years by 2030 in the majority of the world's coral reefs, and become a biannual event by 2050); Charles R.C. Sheppard, *Coral Decline and Weather Patterns over 20 Years in the Chagos Archipelago, Indian Ocean*, 28(6) Ambio 472, 475 (1999).

50 O. Hoegh-Guldberg et al., *Pacific in Peril*, Greenpeace 54 (Oct. 2000), *available at* http://www.greenpeace.org/raw/content/australia/resources/reports/climate-change/coral-bleaching-pacific-in-pe.pdf (last visited May 26, 2008).

51 See William C.G. Burns, *Potential Causes of Action for Climate Change Impacts under the United Nations Fish Stocks Agreement*, in this volume.

52 William F. Laurance et al., *Pervasive Alteration of Tree Communities in Undisturbed Amazonian Forests*, 428 Nature 171, 174–75 (2004).

53 Frank Ackerman & Elizabeth Stanton, *Climate Change: The Costs of Inaction*, Report to Friends of the Earth England, Wales and Northern Ireland 23 (2006), *available at* http://www.foe.co.uk/resource/reports/econ_costs_cc.pdf (last visited May 25, 2008).

54 *See* James Battin, *Projected Impacts of Climate Change on Salmon Habitat Restoration*, 104 Proc. Nat'l Acad. Sci. 6720–25 (2007); Mark B. Bush, Miles R. Silman & Dunia H. Urrego, *48,000 Years of Climate and Forest Change in a Biodiversity Hotspot*, 303 Sci. 827, 829 (2004); Andrew R. Blaustein et al., *Amphibian Breeding and Climate Change*, 15(6) Conservation Biology 1804–09 (2001).

that 20–30% of species would likely face an increased risk of extinction if globally averaged temperatures rise 1.5–2.5°C above 1980–1999 levels, and that 40–70% of species could be rendered extinct should temperature increases exceed 3.5°C.[55] Thus, climate change may pose the greatest global threat to biodiversity in most regions of the world by the middle or latter part of this century.[56]

In terms of human impacts, 100 million people may be imperiled by coastal flooding even under the middle range of projections,[57] with the very future of many small island nations potentially hanging in the balance.[58] Should sea level ultimately rise 4–6 meters, the results would be "globally catastrophic,"[59] resulting in the inundation of large parts of many major cities, including New York, London, Sydney, Vancouver, Mumbai, and Tokyo.[60] "In Florida, Louisiana, the Netherlands, Bangladesh and elsewhere, whole regions and cities may vanish. China's economic powerhouse, Shanghai, has an average elevation of just 4 metres."[61]

There is also likely to be a substantial increase in the incidence of a wide array of deadly diseases. This includes vector-borne infectious diseases such as malaria and dengue fever,[62] as well as water-borne diseases such as cholera and hepatitis A.[63] A 2°C increase in temperature, for example, could lead to 40–60 million additional cases of malaria in Africa and millions of additional deaths.[64]

Global food production potential is anticipated to rise over a range of 1–3°C temperature increases.[65] However, increased temperatures and regional declines in precipitation could exacerbate conditions in arid and semiarid regions,[66] resulting

55 T. Flannery, The Weather Makers 116 (2005); Craig D. Thomas et al., *Extinction Risk from Climate Change*, 427 Nature 145, 146–47 (2004).

56 Thomas et al., *supra* note 55, at 146–47.

57 Climate Action Network, *Preventing Dangerous Climate Change* 6 (2002).

58 William C.G. Burns, *Potential Implications of Climate Change for the Coastal Resources of Pacific Island Developing Countries and Potential Legal and Policy Responses*, 8(1) Harv. Asia-Pac. Rev. 1–8 (2005); William C.G. Burns, *The Possible Impacts of Climate Change on Pacific Island State Ecosystems*, Occasional Paper of the Pacific Institute for Studies in Development, Environment & Security 1–19 (Mar. 2000).

59 Richard A. Kerr, *Global Warming Is Changing the World*, 316 Sci. 188, 190 (2007).

60 James Hansen, *Climate Catastrophe*, New Sci. 33, July 30, 2007, *available at* http://pubs.giss.nasa.gov/docs/2007/2007_Hansen_2.pdf (last visited May 25, 2008).

61 *Id.* Sea level rise of several meters could compel more than one billion inhabitants to retreat inland "or face exile." *See also* Sujatha Byravan & Sudhir Chella Rajan, *Providing New Homes for Climate Change Exiles*, 6 Climate Pol'y 247, 247 (2006).

62 Impacts, Adaptation and Vulnerability, *supra* note 30, ch. 9, Human Health, at sec. 9.7.1.1 (Number of people living in potential transmission zone of malaria may increase by 260–320 million by 2080); John E. Hay et al., *Climate Variability and Change and Sea-Level Rise in the Pacific Islands Region*, South Pacific Regional Environment 69 (2003), *available at* http://www.sprep.org/climate/documents/webi.pdf (last visited May 25, 2008); William C.G. Burns, *Climate Change and Human Health, The Critical Policy Agenda*, 287(17) J. Am. Med. Ass'n 287, 287 (2002).

63 IPCC, *supra* note 7, at sec. 9.5.1.

64 Paul Reiter, *Climate Change and Mosquito-Borne Disease*, 109 Envtl. Health Persp. 1, 1 (2001).

65 Impacts, Adaptation and Vulnerability, *supra* note 30, at 8.

66 Papua New Guinea & Pacific Island County Unit, The World Bank, *Cities, Seas, and Storms*, *in* 4 Adapting to Climate Change 13, Nov. 13, 2000; UNEP Information Unit On Climate Change, *Climate Change Scenarios: Why the Poor Are the Most Vulnerable*, Fact Sheet No. 111 (May 1993).

in substantial declines in crop production in many developing nations.[67] This could be especially disastrous in Africa, where close to half of the currently 800 million undernourished people reside.[68] The IPCC in its most recent assessment indicates that yields from rain-fed agriculture could decline by up to 50% by 2020.[69]

The economic implications of climate change could also be extremely serious. A 2005 study for the European Commission projected that the cost of climate change could be more than $100 trillion by the end of this century.[70] Other studies project even potentially direr economic impacts. For example, the German Institute for Economic Research projects that economic damage could reach $20 trillion annually by 2100 under a business-as-usual scenario for greenhouse gas emissions, reducing global economic output by 6–8%.[71] The Stern Review on the Economics of Climate Change for the U.K. government concluded that warming on the higher end of projections could result in a 5–10% loss of GDP, with poorer countries suffering losses in excess of 10%.[72]

2. INTERNATIONAL LEGAL RESPONSES TO CLIMATE CHANGE

The primary international legal response to climate change to date is the United Nations Framework Convention on Climate Change (UNFCCC),[73] which entered into force in 1994 and has been ratified by 189 countries and the European Economic Community.[74] Unfortunately, resistance by several nations, most prominently, the United States and OPEC States, to mandatory reduction targets for greenhouse gas emissions led the drafters to resort instead to "constructive ambiguities" and "guidelines, rather than a legal commitment."[75] Thus, the UNFCCC merely calls

[67] Drew T. Shindell et al., *Solar and Anthropogenic Forcing of Tropical Hydrology*, 33 Geophysical Res. Letters L24706 1, 5 (2006), *available at* http://pubs.giss.nasa.gov/docs/2006/2006_Shindell_etal_4.pdf (last visited May 25, 2008); Mark Spalding, Stephen Grady & Christoph Zöckler, *Changes in Tropical Regions*, *in* Impacts of Climate Change on Wildlife 28 (Rys E. Green et al. eds., 2002).

[68] CNA Corporation, National Security and the Threat of Climate Change 15 (2007), *available at* http://securityandclimate.cna.org (last visited May 25, 2008).

[69] Impacts, Adaptation and Vulnerability, *supra* note 30, at 10.

[70] Paul Watkiss et al., The Impacts and Costs of Climate Change iv (2005), Commissioned by the European Commission DG Environment, *available at* http://ec.europa.eu/environment/climat/pdf/final_report2.pdf (last visited May 25, 2008).

[71] Ackerman & Stanton, *supra* note 53, at 22.

[72] Nicholas Stern, The Economics of Climate Change, Executive Summary ix (2006), *available at* http://www.hm-treasury.gov.uk./media/4/3/Executive_Summary.pdf (last visited May 25, 2008).

[73] United Nations Framework Convention on Climate Change, 31 I.L.M. 849 (May 9, 1992) [hereinafter UNFCCC].

[74] United Nations Framework Convention on Climate Change Secretariat, *UNFCCC: Status of Ratifications*, *available at* http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php (last visited May 25, 2008) [hereinafter *Status of Ratifications*].

[75] Ranee Khooshie Lai Panjabi, *Can International Law Improve the Climate? An Analysis of the United Nations Framework Convention on Climate Change Signed at the Rio Summit in 1992*, 18 N.C. J. Int'l L. & Com. Reg. 401, 404 (1993).