Climate Change Management

Colleen Murphy · Paolo Gardoni
Robert McKim *Editors*

Climate Change and Its Impacts

Risks and Inequalities

Springer

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ISSN 1610-2002 ISSN 1610-2010 (electronic)
Climate Change Management
ISBN 978-3-319-77543-2 ISBN 978-3-319-77544-9 (eBook)
https://doi.org/10.1007/978-3-319-77544-9

Library of Congress Control Number: 2018938643

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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Introduction

Chapter 1
Risks and Values: New and Interconnected Challenges of Climate Change

Colleen Murphy, Paolo Gardoni and Robert McKim

Abstract This introductory chapter provides a brief summary of the main aims of the book. We also provide an overview of the structure of the volume as a whole and the main points of each chapter.

Introduction

Climate change is one of the most important and pressing contemporary global challenges for the international community. Climate change is modifying the likelihood and magnitude of natural hazards around the world and creating new vulnerabilities (Gardoni et al. 2016). These hazards include heat waves and their effects on wildfires and droughts; severe precipitation and its effects on floods and large snowfall events; and hurricanes. Climate change is also causing sea level rise that affects coastal communities where large and vulnerable populations often reside. It is estimated that $70–$100 billion will be needed by developing countries to adapt to the anticipated impacts of climate change. There is a clear need for a deeper understanding of the consequences of climate change, of the attendant natural hazards, and of their social impact.

Topics to which particular attention is paid in this book include:

1. Scientific understanding of the effects of climate change on the likelihood and magnitude of natural hazards;

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C. Murphy et al. (eds.), *Climate Change and Its Impacts*,
Climate Change Management, https://doi.org/10.1007/978-3-319-77544-9_1

2. Determination of the contribution that each person alive today is making to climate change;
3. Selection of the kind of ethical framework and lines of reasoning needed to evaluate behavior that contributes to climate change;
4. Assessment of civil infrastructure vulnerabilities as they are exacerbated by climate change as well as probabilistic predictions and stochastic formulations of intensified extreme load demands on infrastructure;
5. Development of new design criteria, codes and standards that can be put in place to help mitigate the impacts of climate change;
6. Identification of inequalities in vulnerability among communities and discussion of how these are exacerbated or diminished by climate change;
7. Resilience assessment for coastal communities exposed to hurricanes, storm surges and coastal floods affected by climate change;
8. Policies that can be put in place to help mitigate the impacts of climate change;
9. Cultural shifts and reevaluation of our priorities that might help humanity to respond adequately to climate change.

The basic premise of this book is that an appropriate and comprehensive response to climate change requires the technical expertise of engineers and scientists; the legal, cultural, political, environmental and economic expertise of social scientists and legal scholars; and the moral expertise of ethicists, including philosophers. In keeping with this premise, the book brings climate scientists, engineers, and urban planners into conversation with legal scholars, geographers, anthropologists and ethicists. The chapters provide a broad overview of how climate change is conceptualized by academics in all of these fields.

Structure and Overview of the Book

The book is organized into five parts. Part I consists in this introduction. Part II begins with an up to date account of what science is telling us about climate change and its consequences. Then the focus shifts to the moral implications of climate change in general and of the Paris Agreement in particular. The Paris Agreement entered into force on November 4, 2016, and to date 167 countries have ratified it. It "requires all Parties to put forward their best efforts through 'nationally determined contributions' (NDCs) and to strengthen these efforts in the years ahead. This includes requirements that all Parties report regularly on their emissions and on their implementation efforts" (United Nations 2015). Part III turns to a specific set of risks that are and will continue to be affected by climate change: risks from natural hazards. Part IV begins our discussion of responses to climate change, probing the issues of mitigation and adaptation. Also included here are analyses of how, where, and by whom mitigation as well as adaptation efforts should be made and prescriptions for ways to approach climate adaptation and mitigation. In Part V additional responses are considered. These include new perspectives on how to understand the problem and possible partial solutions to the problem, as well as some reflection about what motivates people to respond appropriately.

Part II: The Paris Agreement, Policy and Climate Justice

In Chap. 2, "Climate change in the 21st century: looking beyond the Paris Agreement," atmospheric scientist Donald J. Wuebbles provides a detailed and up to date summary of (a) the many lines of evidence that have led to the scientific consensus that the planet is warming due to human activity and especially because of the accumulation of CO_2 in the atmosphere, (b) the consequences of climate change such as sea-level rise and the increased frequency, intensity, and duration of severe weather events, (c) some projected consequences for the 21st century and beyond, and (d) an outline of the main options that humanity faces.

How should we think about the ways in which the behavior of individuals contributes to climate change? In Chap. 3, "Cumulative harm as a function of carbon emissions," philosopher John Nolt takes up the issue of the quantification of the harm associated with climate change. Establishing causal responsibility informs judgments of moral responsibility, but is not sufficient for moral responsibility (e.g., knowledge may matter too). Nolt focuses on the impact of cumulative emissions. He starts from the premise that global average temperature during any given future time period will increase directly and continuously with our cumulative emissions from the present through that period. Harm is also, he argues, going to increase directly and continuously with average global temperature increases. So harm increases directly and continuously with our cumulative emissions. What this means is that even small increases in emissions may cause significant harm.

The Paris Agreement and climate change more generally raise foundational questions of policy and of ethics. In Chap. 4, "Justice in mitigation after Paris," philosopher Darrel Moellendorf invokes a distinction between international justice, which deals with how burdens are distributed among states, and intergenerational justice, which deals with how burdens are distributed across generations. Because the Paris Agreement involved a decentralized approach in which states decided what climate change mitigation steps to undertake, pledges made by states can be assumed to be consistent with their own development and poverty eradication objectives. Consequently, adherence to the Paris Agreement probably is consistent with the requirements of international justice, at least in the short term. In the long term, however, an intergenerational collective action problem looms. It arises from the increasingly ambitious pledges that the Paris Agreement requires. If the cost of renewable energy does not fall rapidly enough, or if it is not understood to do so by the public, international cooperation is threatened. Moellendorf considers how this collective action problem is best understood and mechanisms to solve it.

Intergenerational justice and international justice are not the only two lens that may be used to evaluate the ethics of the Paris Agreement and policies enacted to fulfill it. In Chap. 5, “Prioritarianism and climate change,” legal scholar Matthew Adler presents a comparative analysis of prioritarianism and utilitarianism as frameworks for evaluating climate change mitigation policies. Prioritarianism gives special consideration to the impact of policies on the well-being of the worse-off and does not engage in discounting. Utilitarianism considers the impact of a policy on well-being overall, discounting impacts that are farther into the future. Utilitarianism remains the prevailing framework for climate economics. However, Adler argues that prioritarianism is a more ethically defensible framework although more work needs to be done in modeling from a prioritiarian perspective.

Part III: Natural Hazards, Resilience and Mitigation

As Wuebbles’ chapter (Chap. 2) explains, the consequences of climate change are many. These include exacerbating natural hazards such as hurricanes and flooding. As the global community prepares for climate change and its consequences, it is important to determine how these hazards will be affected by climate change and how best to mitigate, and be resilient in the face of, such hazards.

Chapters 6, 7, and 8 focus on the impact of climate change on particular hazards. In Chap. 6, “Assessing climate change impacts on hurricane hazards,” civil engineer and risk analyst David V. Rosowsky addresses the question of whether the predicted climate change scenarios will have a tangible effect on the hurricane hazard. The chapter conclusively shows that the worst-case scenario in climate change will have a clear effect on the hurricane hazard on the US coastline. The results from this chapter can be used by decision and policy makers as well as insurers/re-insurers and risk portfolio managers. They can also be used to develop optimal mitigation strategies that make best use of resources and properly balance the risks faced by communities.

In Chap. 7, “Climate change, heavy precipitation and flood risk in the western United States,” climate scientists Eric Salathé and Guillaume Mauger examine the role of climate change in flood risk. Instead of developing predictions and risk assessments based on historical data, the occurrence of climate change requires deriving such predictions and assessments from climate models and downscaling methods. Downscaling methods are used to obtain local flood predictions that are needed for community risk and resilience analysis. The chapter discusses both statistical and dynamical downscaling and their implications for flood predictions. The chapter ends by presenting a case study that shows the impact on a flood plain of sea level rise, reduced snowpack and higher intensity precipitation extremes.

In the United States the flooding of rivers has long been the cause of significant damage to the built and natural environments and has resulted in much social harm. In Chap. 8, “The impact of climate change on resilience of communities vulnerable to riverine flooding,” an interdisciplinary team consisting of civil engineers, risk analysts and an atmospheric scientist considers riverine flooding, which is caused by a river exceeding its capacity due to excessive rainfall or significant snow melt over a short period of time. Xianwu Xue, Naiyu Wang, Bruce R. Ellingwood, and Ke Zhang develop a new modeling framework for flood hazard analysis that incorporates the effects of climate change. This framework uses a hydrological model within a hydraulic analysis. The hydrological model is used to simulate hydrological processes at a course spatial resolution. The hydraulic analysis is used to compute flood variables (like localized flood depths, velocities and inundated areas) considering a finer spatial resolution. The new framework is calibrated and validated using the Wolf River Basin in Shelby County, Tennessee.

In Chap. 9, “Planning for community resilience under climate uncertainty,” civil engineer and risk analyst Ross B. Corotis challenges the probabilistic models used in risk analysis of future hazards. The premise of his challenge is that such probabilistic models have been traditionally calibrated using historical data. However, the changes brought by climate change in the likelihood of occurrence and magnitude of the stressors to a community call for a reevaluation of such models. The chapter also notes the importance of considering communities as a whole in contrast to single structures considered in isolation. To promote community resilience, the chapter puts forward the concept of adaptive management and defines the participatory methods by which community mitigation actions can be developed.

Part IV: Responding to Climate Change: Mitigation and Adaptation

Fulfilling the aspirations of the Paris Agreement requires countries to take specific actions. Part IV includes chapters that consider the policies and strategies that are being, will be, and should be adopted to aid communities at all scales from the local to the national and beyond in both mitigating and adapting to the consequences of climate change.

In Chap. 10, “Climate change governance and local democracy: synergy or dissonance,” geographer Emmanuel Nuesiri focuses on the question of local governance in climate change mitigation and adaptation programs and policies. He looks specifically at programs targeting emissions reductions stemming from efforts to prevent deforestation, to encourage reforestation and sustainable management of forests specifically in developing countries, known as the (REDD+) initiative. Priority in such programs should be given to local democratic participation as a way of ensuring that REDD+ programs benefit local people. However, Nuesiri offers a cautionary tale of the UN-REDD funded Nigeria-REDD program. He highlights its failure to ensure robust local democratic participation and its insufficient engagement with local government authorities. The chapter ends by recommending that UN-REDD programs not only interact with NGOs but also with local authorities.

In Chap. 11, “Sea level rise and social justice: the ethics of climate change driven migration,” anthropologist Elizabeth Marino draws on case studies from the United States to illustrate the way existing social policies and colonial legacies influence who is vulnerable to displacement from climate change. She discusses how the social, political and legal context shape which natural events become disasters. Marino outlines the criteria used to determine who counts as a climate refugee, the legal and political consequences that follow from being excluded or included, and the environmental techniques for protecting communities from rising sea levels. She then focuses on the decisions that will shape which individuals and communities living in coastal areas will be displaced from rising sea levels.

Next the discussion moves from displacement to adaptation with a focus on the case of sea level rise. In Chap. 12, “Recovery after disasters: how adaptation to climate change will occur,” urban planner Robert B. Olshansky argues that, in most cases, communities will notice changes in the sea level on the occasion of particular events such as coastal storms and storm surges rather than on account of a continuous background increase in the sea level. The fact that sea level rise will come to people's attention in this way will shape the adaptation process, which will be part of the long-term post-disaster recovery. Given this feature of the adaptation process, this chapter describes the phases and players in the post-disaster recovery along with its challenges and the disruptions it will bring. In keeping with themes raised by both Nuesiri and Marino, Olshansky argues that a successful recovery requires involvement of the affected citizens.

Part V: Responding to Climate Change: Priorities, Perspectives, and Solutions

The final set of chapters introduces some new perspectives on how to understand climate change and how to respond to it, some reflection about what motivates people to respond, and some proposals about steps that would contribute to finding a solution.

In Chap. 13, “The climate-change challenge to human-drawn boundaries,” legal scholar Eric T. Freyfogle proposes that the best way to approach climate change and its consequences is in terms of a comprehensive goal of ensuring that the landscapes around us are healthy, diverse, and resilient, while also facilitating human flourishing. Pursuing this goal requires the modification of core elements of our culture. Instead of an emphasis on the rights of individuals, including individual landowners, we ought to focus on the common good of the land community. And we should rethink the institution of private property, conceiving of it as having the purpose of promoting the welfare of the land community. These changes in turn require that we rethink human-drawn boundaries at all levels. In some respects boundaries are less relevant today. After all, the consequences of climate change do not conform to our boundaries. But in other respects boundaries are more relevant: in particular, establishing and preserving healthy, diverse, and resilient landscapes may sometimes require local control and territorial autonomy.

How are people moved by the harms that climate change is generating and will generate? In Chap. 14, "Neoliberal (mis)management of Earth-time and the ethics of climate justice," moral theologian Michael S. Northcott argues that the main reasons that people of faith are concerned about climate change include their compassion for the vulnerable, their concern about people who are already being harmed by climate change, and their concern for their own children and grandchildren. These are among the findings derived from interviews with congregation members in Scottish churches that have a record of promoting ecological responsibility. The interviewees were accordingly less impressed by a neo-liberal emphasis on what is economically most attractive or by what course of action a utilitarian summing up of costs and benefits would dictate or by short-term performance targets.

In Chap. 15, "Human capital in a climate-changed world," legal scholar Shi-Ling Hsu examines the issue of economic development in an era of climate change. Hsu argues that it is a mistake to see increased fossil fuel use as necessary to development. He contends that economic development can proceed in conjunction with efforts to remove fossil fuel subsidies. Moreover, resources that would otherwise not be available due to such subsidies can instead be used to focus on what will be necessary to maintain development in the midst of climate change: education. This shift would have the extra benefit of compensating those most likely to be harmed by climate change.

Finally, in Chap. 16, "A wild solution for climate change," conservation biologist Thomas E. Lovejoy begins by providing an up to date account of the consequences of climate change for biodiversity. He summarizes various changes on land and in the oceans that are already occurring. These include flowering plants blossoming earlier and earlier animal migrations. He outlines what the best research leads us to expect given the likely effects of climate change on habitat, especially when this is combined with heavy human use of landscapes. We can expect dislocations and extinctions and unpleasant surprises when poorly understood thresholds are crossed. Lovejoy considers solutions including the obvious one of moving away as quickly as possible from fossil fuels. At the end of his paper he mentions some research that supports the "wild solution" mentioned in the title of his chapter. The key idea is that ecosystem restoration might pull enough CO_2 out of the atmosphere to combat climate change.

Closing Reflections

Responding adequately to climate change requires a collective effort of society. It requires integrating and synthesizing the scientific understanding of climate change, models to predict the impact of climate change on the natural and built environments, an understanding of the implications of climate change for individuals' well-being and the way vulnerability shapes these implications, the formulation of public policies, and the existence of political will. As the chapters in this volume illustrate, interdisciplinary research and discussions among the different stakeholders should aim to develop successful strategies that are technically sound and that promote international justice, intergenerational justice and environmental justice.

Chapters in this volume point to the areas where further research is needed for our collective success in responding to climate change. Adaptation and mitigation are the dominant strategies for responding to climate change. It remains to be seen where the limits of each strategy lie, and whether the source of such limits is technical in nature or social or both (Adger et al. 2009). It also remains to be seen whether there will be the political will to respond to the crisis of climate change, and if there are ideas and principles that might move and inspire people and that have not yet been articulated. Furthermore, it remains to be seen whether political institutions will be able to prioritize these problems that are global in character and intergenerational in temporal scope (Gardiner 2011).

Finally, climate change raises important questions of trade-offs and potential moral conflicts. Laudato Si', Pope Francis' impressive recent encyclical on the environment, asks us to hear both "the cry of the poor" and "the cry of the earth" (Francis 2015, Sect. 49). On the one hand, it seems that we can simultaneously respond to both cries. The poor are among the most vulnerable to climate change; hence steps to address climate change that emphasize the most vulnerable will at a minimum be compatible with contributing to solving both problems at once (Thomas and Twyman 2005). On the other hand, steps to ameliorate the problems of the poor may be bad for the earth. As more poor people become better off there is characteristically more consumption and increased greenhouse gas emissions. Those of us who are better off can consume less, giving others a chance to make their way out of poverty without making things worse in terms of total emissions and total human impact. But a failure on the part of people who have options may force everyone into a tragic situation in which efforts to combat inequality will continue to exacerbate climate change. It remains to be seen whether a way forward that does justice to both of these fundamentally important concerns—the plight of the poor and climate change—will be found.

Acknowledgements This book builds upon the presentations, discussions, and related outcomes from the workshop *Climate Change and Its Impact: Risks and Inequalities* that took place at the University of Illinois at Urbana-Champaign on March 10–11, 2016. This workshop was made possible through grants from the Department of Civil and Environmental Engineering (CEE)—Research Thrust Development Program, the College of Liberal Arts and Sciences Conference

Support Program, and the Illinois International Conference Grant Program. The Women and Gender in Global Perspectives Program (WGGP), the College of Law and the MAE Center: Creating a Multi-hazard Approach to Engineering provided additional support. The opinions and findings presented in this book are those of the authors of each chapter and do not necessarily reflect the views of the sponsors or the editors.

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Part II
The Paris Agreement, Policy and Climate Justice

Chapter 2
Climate Change in the 21st Century: Looking Beyond the Paris Agreement

Donald J. Wuebbles

Abstract The science is clear that the Earth's climate, including that of the United States, is changing, changing much more rapidly than generally occurs naturally, and it is happening primarily because of human activities. This chapter discusses the science underlying climate change and the current understanding of how our planet is being affected. In addition to the global analysis, there is special attention given to the findings for the United States. Humanity is already feeling the effects from increasing intensity of certain types of extreme weather and from sea level rise that are fueled by the changing climate. Climate change affects many sectors of our society, including threats on human health and well-being. Climate change will, absent other factors, amplify some of the existing threats we now face. The effects on humanity are already significant, costing us many billions of dollars each year along with the effects on human lives and health. Policy to respond to climate change is imperative—we have three choices, mitigation, adaptation, or suffering. Right now we are doing some of all three. The Paris Agreement begins the process internationally of really doing something to slow down change. But the current agreement is just the beginning and we will need to do much more.

Introduction

The science is clear: the Earth's climate is changing, it is changing extremely rapidly, and the evidence shows it is happening primarily because of human activities (IPCC 2013, 2014; Melillo et al. 2014; UKRS-NAS 2014; and the thousands of papers referenced in these assessments). Climate change is happening now—it is not just a problem for the future—and it is happening throughout the world. There are many indicators of the changing climate. Surface temperature is just one of them. Trends in the severity of certain types of severe weather events are

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C. Murphy et al. (eds.), *Climate Change and Its Impacts*,
Climate Change Management, https://doi.org/10.1007/978-3-319-77544-9_2

increasing. Sea levels are also rising because of the warming oceans and because of the melting land ice. Observations show that the climate is changing extremely rapidly, about ten times more rapidly than natural changes in climate based on paleoclimatic observations of the changes that occurred since the end of the last ice age. And the evidence clearly points to climate changes over the last half century as being primarily due to human activities, especially the burning of fossil fuels and also land use change, especially through deforestation. As a result, it is not surprising that many national and world leaders have concluded that climate change, often referred to as global warming in the media, has become one of the most important issues facing humanity.

There is essentially no debate in the peer-reviewed scientific literature (or in the national and international assessments of the science prepared by hundreds of scientists) about the large changes occurring in the Earth's climate and the fact that these changes are occurring as a response to human activities. Natural factors such as changes in the energy output of the Sun have always affected our climate in the past and continue to do so today; but over the last century, human activities have become the dominant influence in producing many, if not most, of the observed changes occurring in our current climate.

People throughout the world are already feeling the effects from increasing intensity of certain types of extreme weather and from sea level rise that are fueled by the changing climate. Prolonged periods of heat and heavy downpours, and in some regions, floods and in others, drought, are affecting our health, agriculture, water resources, energy and transportation infrastructure, and much more.

The harsh reality is that the present amount of climate change is already dangerous and will become far more dangerous in the coming decades. Climate change is itself likely to increase the risks for impacts on human society and on ecosystems, and the more intense extreme events associated with a changing climate pose a serious risk to human health.

The chapter begins with a discussion of the changes happening and projected to happen in the climate system and a summary of the underlying scientific basis for the human cause for these changes. Much more on each of these topics, and the projections of future changes in climate, can be found in the international (IPCC 2013, 2014) and U.S. National Climate (Melillo et al. 2014) assessments of the science mentioned earlier. The connections between potential impacts and the changing climate are then examined, with a special focus on the United States based on discussion in the 3rd National Climate Assessment (NCA: Melillo et al. 2014). Issues associated with mitigation and adaptation policy, including the effects of the Paris Agreement are then assessed.

Our Changing Climate

The fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC 2013, 2014) is the most comprehensive analysis to date of the science of climate change and how it is affecting our planet. Over 800 scientists and other experts were involved in the four volumes of this assessment. Similarly, the 3rd U.S. National Climate Assessment (Melillo et al. 2014) is the most comprehensive analysis to date of how climate change is affecting the United States now and how it could affect it in the future. A team of more than 300 scientists and other experts (see complete list online at http://nca2014.globalchange.gov), guided by a 60-member National Climate Assessment and Development Advisory Committee, produced the assessment. Stakeholders involved in the development of the assessment included decision-makers from the public and private sectors, resource and environmental managers, researchers, representatives from businesses and non-governmental organizations, and the general public. The resulting report went through extensive peer and public review before publication, including two sets of reviews by the National Academy of Sciences. The NCA collects, integrates, and assesses observations and research from around the country, helping us to see what is actually happening and understand what it means for our lives, our livelihoods, and our future. The report includes analyses of impacts on seven sectors—human health, water, energy, transportation, agriculture, forests, and ecosystems—and the interactions among sectors at the national level. The report also assesses key impacts on all parts of the United States and evaluated for specific regions: Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, Hawaii and Pacific Islands, as well as the country's coastal areas, oceans, and marine resources. By being so comprehensive, the NCA aim is to help inform Americans' choices and decisions about investments, where to build and where to live, how to create safer communities and secure our own and our children's future. The 4th National Climate Assessment is now underway and will be published in 2018.

Climate is defined as long-term averages and variations in weather measured over multiple decades. The Earth's climate system includes the land surface, atmosphere, oceans, and ice. Scientists from around the world have compiled the evidence that the climate is changing, changing much more rapidly than tends to occur naturally (by a factor of ten or more relative to the natural changes that occurred following the end of the last ice age 20,000 years ago), and that it is changing because of human activities; these conclusions are based on observations from satellites, weather balloons, thermometers at surface stations, ice cores, and many other types of observing systems that monitor the Earth's weather and climate. A wide variety of independent observations give a consistent picture of a warming world. There are many indicators of this change, not just atmospheric surface temperature. For example, ocean temperatures are also rising, sea level is rising, Arctic sea ice is decreasing, most glaciers are decreasing, Greenland and Antarctic land ice is decreasing, and atmospheric humidity is increasing.

Climate Change Effects on Temperature

Temperatures at the surface, in the troposphere [the active weather layer extending from the ground to about 8–16 km (5–10 miles altitude)], and in the oceans have all increased over recent decades. Consistent with our scientific understanding, the largest increases in temperature are occurring closer to the poles, especially in the Arctic (this is especially related to ice-albedo feedback, which, as snow and ice decrease, indicates that the exposed surface will absorb more solar radiation rather than reflect it back to space). Snow and ice cover have decreased in most areas on Earth. Atmospheric water vapor (H_2O) is increasing in the lower atmosphere, because a warmer atmosphere can hold more water (the basic physics is captured by the Clausius–Clapeyron equation, which provides the relationship between temperature and available water vapor). Sea levels are also increasing. All of these findings are based on observations.

As seen in Fig. 1, global annual average temperature (as measured over both land and oceans) has increased by more than 0.8 °C (1.5 °F) since 1880 (through 2012). Since then, 2014 was the warmest year on record, but this was greatly eclipsed by 2015, when a strong El Niño event (unusually warm water in the eastern portion of the Pacific Ocean) added to the effects of climate change. So far, it looks like 2016 will be warmer still. While there is a clear long-term global warming trend, some years do not show a temperature increase relative to the previous year, and some years show greater changes than others. These year-to-year fluctuations in temperature are related to natural processes, such as the effects of ocean events like El Niños and La Niñas, and the cooling effects of atmospheric emissions from volcanic eruptions. At the local to regional scale, changes in climate can be influenced by natural variability for a few decades (Deser et al. 2012). Globally, natural variations can be as large as human-induced climate change over

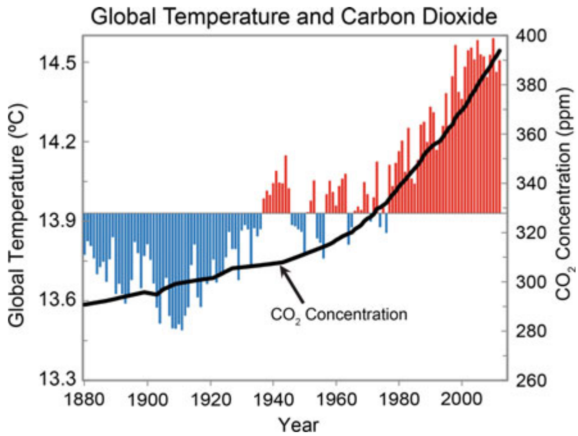

Fig. 1 Changes in observed globally-averaged temperature since 1880. Red bars show temperatures above the long-term average, and blue bars indicate temperatures below the long-term average. The black line shows the changes in atmospheric carbon dioxide (CO_2) concentration in parts per million (ppm) over the same time period (Melillo et al. 2014; temperature data from NOAA National Climate Data Center)

timescales of up to a decade (Karl et al. 2015). However, changes in climate at the global scale observed over the past 50 years are far larger than can be accounted for by natural variability (IPCC 2013).

While there has been widespread warming over the past century, not every region has warmed at the same pace (Fig. 2). A few regions, such as the North Atlantic Ocean and some parts of the U.S. Southeast, have even experienced cooling over the last century as a whole, though the U.S. Southeast has warmed over recent decades. This is due to the stronger influence of internal variability over smaller geographic regions and shorter time scales. Warming during the first half of the last century occurred mostly in the Northern Hemisphere. The last three decades have seen greater warming in response to accelerating increases in heat-trapping gas concentrations, particularly at high northern latitudes, and over land as compared to the oceans. These findings are not surprising given the larger heat capacity of the oceans leading to land-ocean differences in warming and the ice-albedo feedback

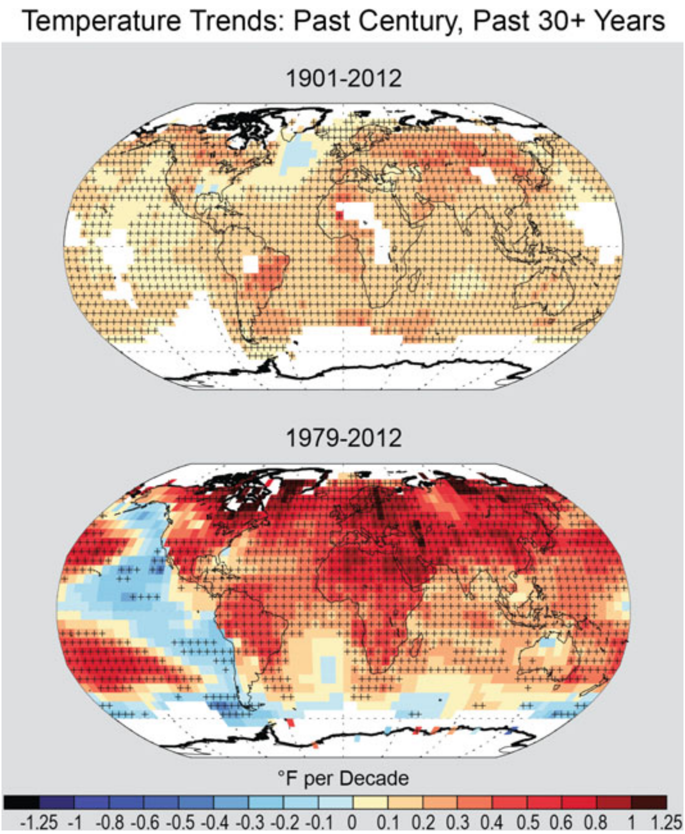

Fig. 2 Surface temperature trends for the period 1901–2012 (top) and 1979–2012 (bottom) from NOAA National Climate Data Center's surface temperature product. Updated from Vose et al. (2012). From Melillo et al. (2014)

leading to larger warming at higher latitudes. As a result, land areas can respond to the changes in climate much more rapidly than the ocean areas even though the forcing driving a change in climate occurs equally over land and the oceans.

Even if the surface temperature had never been measured, scientists could still conclude with high confidence that the global temperature has been increasing because multiple lines of evidence all support this conclusion. Figure 3 shows a number of examples of the indicators that show the climate on Earth is changing very rapidly over the last century. Temperatures in the lower atmosphere and oceans have increased, as have sea level and near-surface humidity. Basic physics tells us that a warmer atmosphere can hold more water vapor; this is exactly what is measured from the satellite data showing that humidity is increasing. Arctic sea ice,

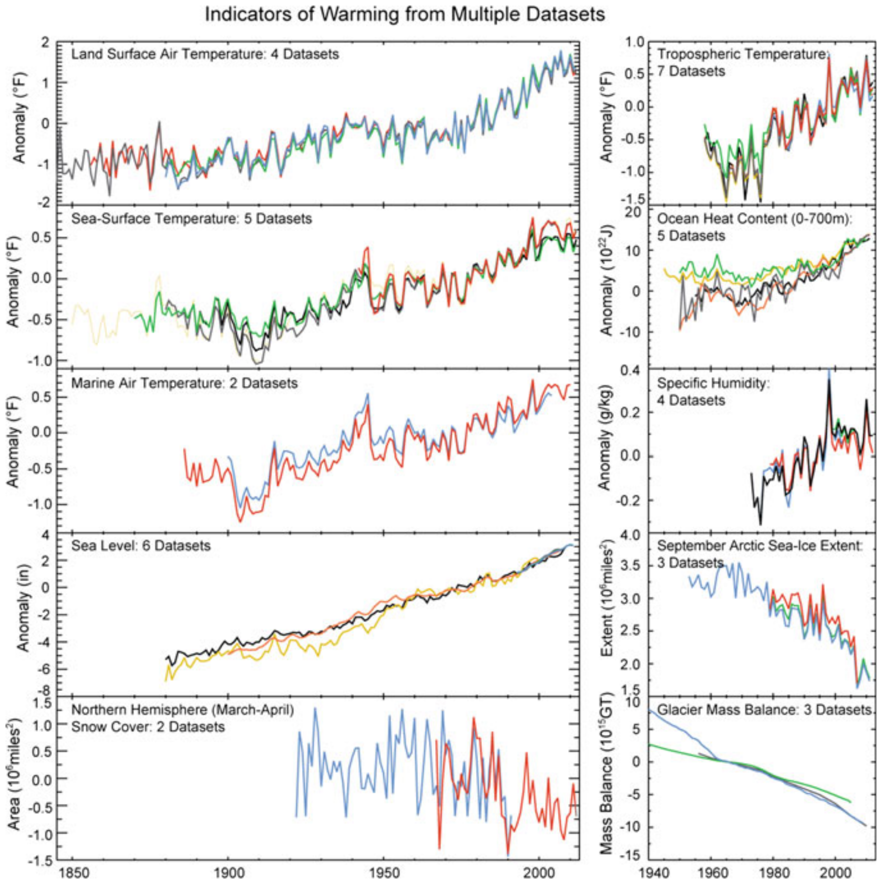

Fig. 3 Observed changes, as analyzed by many independent groups in different ways, of a range of climate indicators. All of these are in fact changing as expected in a warming world. Further details underpinning this diagram can be found at http://www.ncdc.noaa.gov/bams-state-of-the-climate/. From Melillo et al. (2014)

mountain glaciers, and Northern Hemisphere spring snow cover have all decreased. Over 90% of the glaciers in the world are decreasing at very significant rates. The amount of ice on the largest masses of ice on our planet, on Greenland and Antarctica, are decreasing. As with temperature, many scientists and associated research groups have analyzed each of these indicators and come to the same conclusion: all of these changes paint a consistent and compelling picture of a warming planet.

Climate Change Effects on Precipitation

Precipitation is perhaps the most societally relevant aspect of the hydrological cycle and has been observed over global land areas for over a century. However, spatial scales of precipitation are small (e.g., it can rain several inches in Washington, DC, but not a drop in nearby Baltimore) and this makes interpretation of the point-measurements difficult. Based upon a range of efforts to create global averages, there does not appear to have been significant changes in globally averaged precipitation since 1900 (although as we will discuss later there has been a significant trend for an increase in precipitation coming as larger events). However, in looking at total precipitation there are strong geographic trends including a likely increase in precipitation in Northern Hemisphere mid-latitude regions taken as a whole (see Fig. 4). Stronger trends are generally found over the last four decades. In general, the findings are that wet areas are getting wetter and dry areas are getting drier, consistent with an overall intensification of the hydrological cycle in response to the warming climate (IPCC 2013).

As mentioned earlier, it is well known that warmer air can contain more water vapor than cooler air. Global analyses show that the amount of water vapor in the atmosphere has in fact increased over both land and oceans. Climate change also alters dynamical characteristics of the atmosphere that in turn affect weather patterns and storms. At mid-latitudes, there is an upward trend in extreme precipitation in the vicinity of fronts associated with mid-latitude storms. Locally, natural variations can also be important. In contrast, the subtropics are generally tending to have less overall rainfall and more droughts. Nonetheless, many areas show an increasing tendency for larger rainfall events when it does rain (Janssen et al. 2014; Melillo et al. 2014; IPCC 2013).

Climate Change Effects on Severe Weather

Along with the overall changes in climate, there is strong evidence of an increasing trend over recent decades in some types of extreme weather events, including their frequency, intensity, and duration, with resulting impacts on our society. The changing trends in severe weather resulting from climate change are already

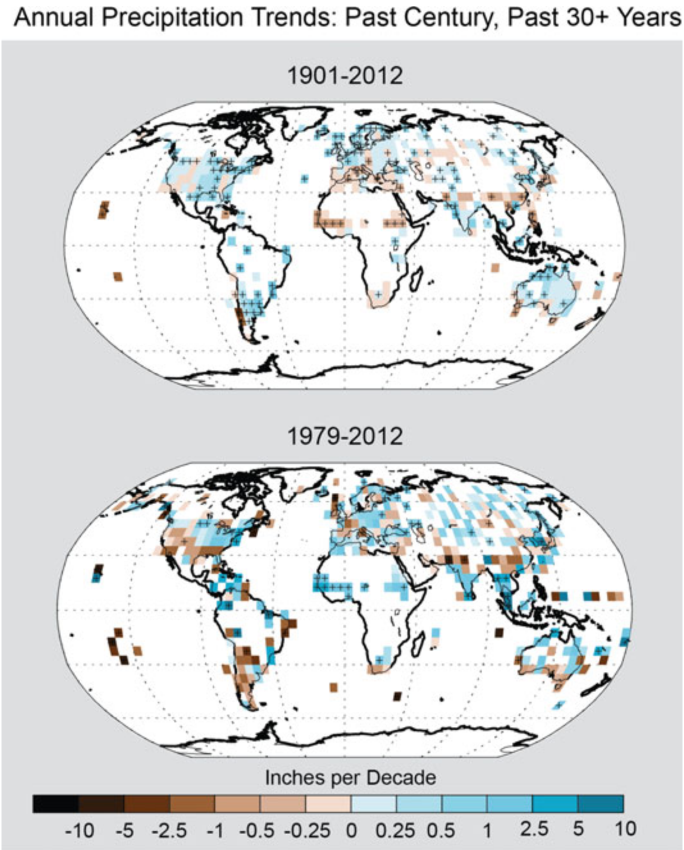

Fig. 4 Global precipitation trends for the period 1901–2012 (top) and 1979–2012 (bottom). Based on date from NOAA NCDC. From Melillo et al. (2014)

affecting the world, including the United States. The United States has sustained over 178 weather/climate disasters since 1980 where damages/costs reached or exceeded $1 billion per event (including CPI adjustment to 2013), with an overall increasing trend (http://www.ncdc.noaa.gov/billions/; also Smith and Katz 2013). The total cost of the 178 events through 2014 is over $1 trillion. In the years 2011 and 2012, there were more such weather events than previously experienced in any given year, with 14 events in 2011 and 11 in 2012, with costs greater than $60 billion in 2011 and greater than $110 Billion during 2012. There were 8 billion dollar plus events in the United States in 2014. The events in these analyses include major heat waves, severe storms, tornadoes, droughts, floods, hurricanes, and wildfires. A portion of these increased costs can be attributed to the increase in population and infrastructure near coastal regions. However, even if hurricanes and their large, mostly coastal, impacts were excluded, there still would be an overall increase in the number of billion dollar events over the last 34 years. Similar analyses by Munich Re and other organizations show that there are growing numbers of severe weather events worldwide causing extensive damage and loss of lives. Figure 5 shows the overall increase in the number of severe events since 1980 through 2015. Even though geophysical events like earthquakes are included in Fig. 5, they are roughly a constant number each year, while the number of severe climate and weather related events has increased dramatically. In summary, there is a clear trend in the impacts of severe weather events on human society not only in the United States, but throughout the world.

Throughout the world, the trends in extreme events are changing; these include increases in the number of extremely hot days, less extreme cold days, more precipitation events coming as unusually large precipitation, and more floods in some regions and more drought in others (Min et al. 2011; IPCC 2012, 2013; Zwiers et al. 2013; Melillo et al. 2014; Wuebbles et al. 2014a, b). For the United States, analyses of atmospheric observations (e.g., Kunkel et al. 2013; Peterson et al. 2013; Vose et al. 2014; Wuebbles et al. 2014a), have shown a pattern of responses in weather extremes relative to the changing climate. These analyses have shown that there are some events, especially those relating to temperature and precipitation extremes, where there is strong understanding of the trends in extreme weather and also of the underlying causes of the observed changes. For some other extremes, the detection of trends in floods, droughts, and extratropical cyclones is also high, but there is less

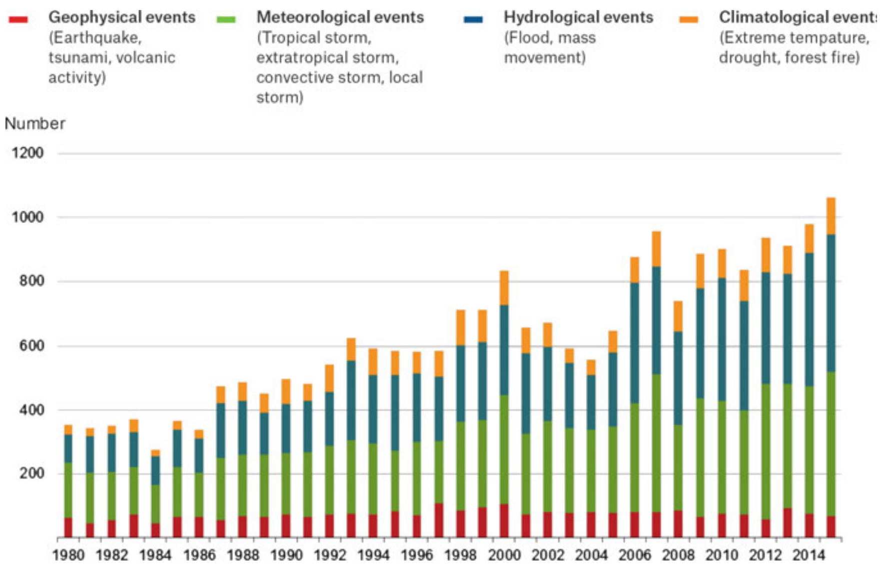

Fig. 5 The number of severe loss events from natural catastrophes per year since 1980 through 2015 as evaluated by Munich Re. Overall losses totaled $90 billion dollars (2015 was not a high year in terms of total costs; the previous year was $110 billion), of which roughly $27 billion was insured. In 2015, natural catastrophes claimed 23,000 lives (average over the last 30 years was 54,000). Figure from Munich Re (https://www.munichre.com/us/weather-resilience-and-protection/media-relations/news/160104-natcatstats2015/index.html)

(only medium) understanding of the underlying cause of the trends. Similarly, there is medium understanding of the observed trends and cause of changes in hurricanes and also in snow events. There is insufficient data to accurately determine trends in strong winds, hail, ice storms, and tornadoes, so there response to a changing climate are not as well understood. Findings for the United States correlate well with analyses of climate extremes globally (IPCC 2012, 2013).

Modeling studies of the changes in climate are generally consistent with the observed trends in extreme weather events over recent decades. Extreme weather events obviously occur naturally. However, the overall changes in climate occurring globally are also altering the frequency and/or severity of many of these extreme events. Trends in extreme weather events, especially in more hot days, less cold days, and more precipitation coming as extreme events, are expected to continue and to intensify over the coming decades.

In most of the United States over the four decades or so, the heaviest rainfall events have become more frequent (e.g., see Fig. 6) and the amount of rain falling in very heavy precipitation events has been significantly above average. This increase has been greatest in the Northeast, Midwest, and upper Great Plains (Melillo et al. 2014).

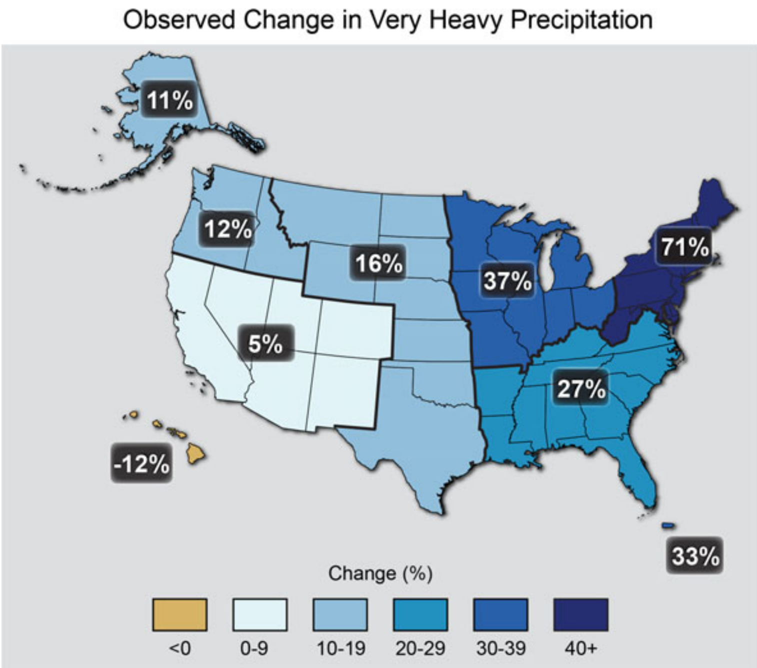

Fig. 6 Percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental U.S. These trends are larger than natural variations for the Northeast, Midwest, Puerto Rico, Southeast, Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawaii, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012. From Melillo et al. (2014)