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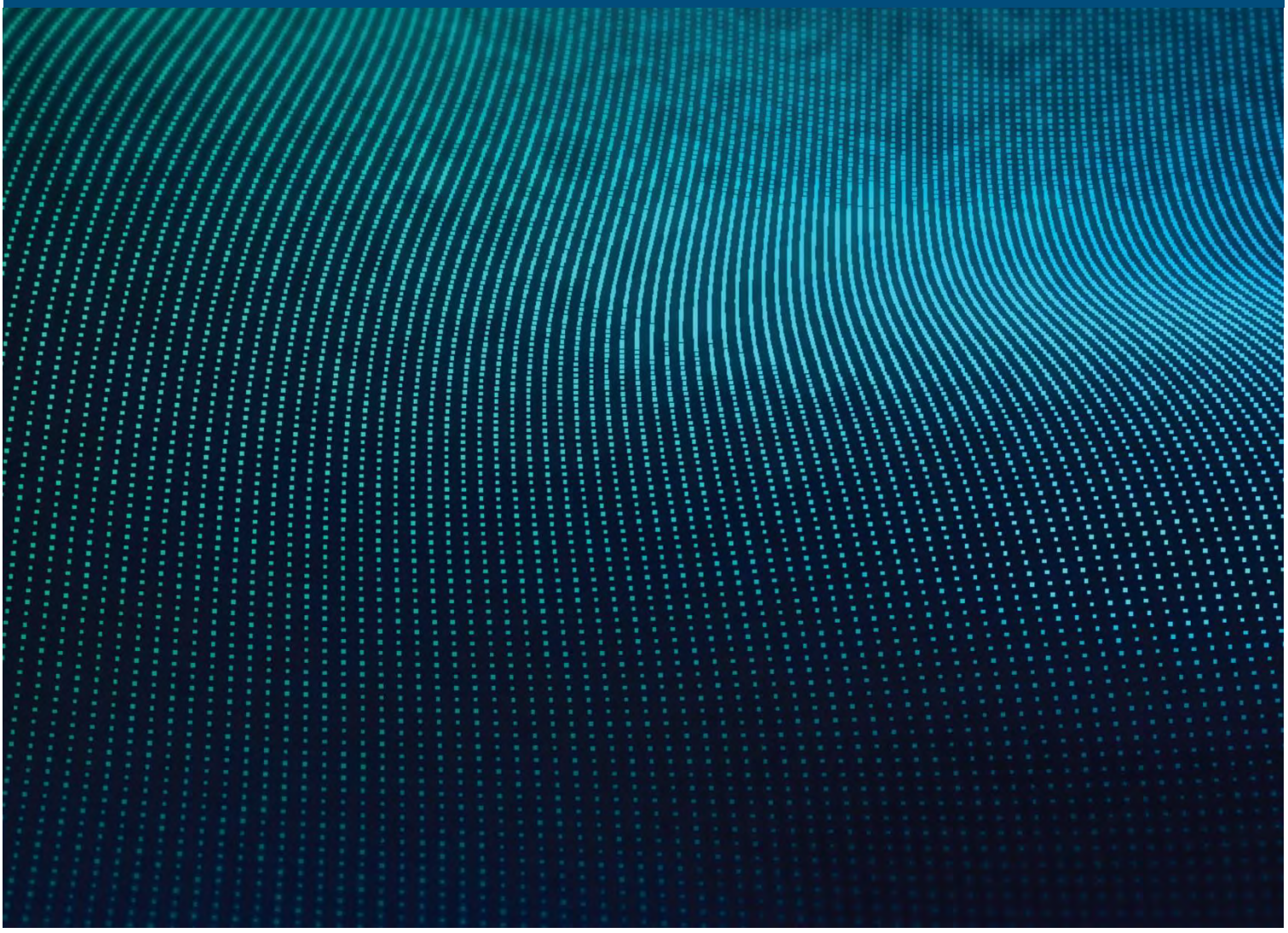
Climate, Weather and Environmental Sources for Actuaries



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Climate, Weather and Environmental Sources for Actuaries

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Climate, Weather and Environmental Sources for Actuaries

Foreword

This report was prepared for the Society of Actuaries in 2016, following its request for a set of data, analysis and discussion sources pertaining to climate change, environmental risks and weather. As both an actuary and environmental statistician, two broad research questions have interested me for years: how do scientists know, and what could actuaries do? This report is a collection of sources that deal with these two questions.

Decisions on what to include or highlight within each summary are my own and do not reflect the viewpoints of the agencies, institutions or authors of the sources themselves. Whenever possible, I used direct quotations from the sources. Although I am an academic, I have tried to shy away from sources published by academics in academic journals; instead, I have favored works written with practicing actuaries and the public in mind. Few sources are more public-oriented than those produced by governmental agencies, and here the reader will observe that nearly all governmental sources come from the United States. This does not imply that the governments of other nations are lacking in information related to climate risks. It only acknowledges that the Society of Actuaries is most heavily concentrated in North America, and the U.S. sources of data and analysis are most prevalent there.

I chose to limit summarizing a large number of sources from the same author, figuring that the curious reader could follow the thread given a few representative works. I also decided to avoid any specific mention of particular companies, but I did highlight associations individually. The latter exist in part to connect with the public, but individual companies need not be highlighted.

There was an inevitable tension between breadth and focus, which played out every time I asked myself if this report should include just one more source, just one more paper or just one more database. I make no claims that this report is complete. Even as I write this, I feel a tug to spend another afternoon researching, just to see if there's something else to be added. But I also feel the stronger tug to share what I have compiled, kick-starting research in directions I can't even anticipate at this time.

Thanks are due to the Society of Actuaries and in particular to the Climate and Environmental Sustainability Research Committee, Scott Lennox and Erika Schulty. All should be thanked for recognizing the importance of environmental risks to actuarial science, supporting research in this area and guiding projects along from conception to completion. Thanks also to Molly Keener of Wake Forest University for her expertise with image permissions and digital archiving. I owe a debt of gratitude to Hunter Miller, an undergraduate student at Wake Forest University. An aspiring actuary himself, Hunter provided time and a valuable second perspective. I wish him the very best as he prepares to graduate and embark on his career.

Rob Erhardt, April 2017

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Introduction

What Do We Know?

Most actuaries and risk managers do not fully understand climate science, just as most climate scientists do not fully understand insurance markets; however, actuaries and risk managers interested in climate risk must strive to achieve "climate literacy" to make the most informed business decisions. That is, they should become conversant in the major findings of climate science. They should understand the evidence for climate change and the pace and scale of projected changes. They should also understand the range of possible outcomes and have an intuitive grasp of both best-case and worst-case scenarios.

Many of the sources in this report were chosen to help actuaries achieve this literacy. The primary entry point is the Nobel Prize–winning Intergovernmental Panel on Climate Change. Its reports are exhaustive and full of references with full transparency in the true tradition of science, yet many are written with the nonscientific reader in mind. The language, graphics and explanations are all presented accordingly. The panel's summaries for policymakers are fully accessible to the curious actuary and should be considered required reading for risk managers working on climate risk.

This report also describes sources of high-quality data and the numerous agencies tasked with obtaining and storing such data. Most are managed by the U.S. government—more specifically, the National Centers for Environmental Information (housed within the National Oceanic and Atmospheric Administration, or NOAA). These sources form the backbone for measuring environmental risk and change. The "historical record" of global temperature data stretches from about 1880 to the present, but other high-quality data on precipitation, wind, natural disasters and other variables are available in abundance from the mid-twentieth century through the present. Data are most complete in the more economically developed regions of the world. Looking ahead, various scientific agencies build and maintain climate model projections. These are high-quality computer simulations of the earth's climate system run forward in time to demonstrate possible outcomes. This report highlights some North American climate models.

For more background information, a wealth of books and articles have been written on climate science. Some, such as *Introduction to Modern Climate Change*, focus purely on the science and assume little more background than high school chemistry and mathematics. Others discuss the relationship between the science and policy or economic implications, and they begin the transition from scientific literacy to informed decision making. *At War with the Weather* and *The Science and Politics of Global Climate Change: A Guide to the Debate* are two that are reviewed in this report.

Extensive work has been completed within the insurance industry on the state of climate risk disclosure and innovative climate risk solutions, some of which is highlighted in this report. The National Association of Insurance Commissioners, the Insurance Information Institute and the Geneva Association all contribute sources in this report. The United Nations Environment Programme Finance Initiative has also produced reports both on what *has* been done and what its partners say *should* be done next.

What Can Actuaries Do?

And then there is the matter of doing something about all this change. Reading the climate science literature, one learns that responses to climate change fall into three broad categories: mitigation, adaptation and geoengineering. Mitigation is about slowing or halting the change itself. Adaptation concerns actions that may help society build climate resilience to deal with climate changes. These actions may include strengthening seawalls, enhancing irrigation systems in drought-prone areas or changing building codes for coastal construction. Finally, geoengineering addresses efforts to intervene actively in the climate system. Risk management, insurance and associated regulations mostly fall into the category of adaptation, and it is here that actuaries may find they have the greatest potential impact.

Climate science is large in scale. One speaks of decades of time and continents of space. Our collective knowledge and confidence in global scientific results stubbornly resists being translated into confidence and knowledge of local impacts. Yes, the seas are rising and are projected to keep doing so, but what about coastal North Carolina and its booming real estate and tourism industries? Yes, the temperature is rising globally and changing rainfall patterns, but what about droughts in eastern Colorado? Yes, warmer waters in the Atlantic Ocean tend to give rise to North Atlantic hurricanes, but will we see an increase in hurricane landfalls? Will the ones that strike the coast be stronger? If so, by how much? And on and on.

Local outcomes are uncertain. But actuaries and risk managers have built companies and careers on how to make decisions given uncertainty. Sometimes the scientific sources mentioned in this report give way to probability models of outcomes, and one can apply the tools of probability to move forward. More commonly, reliable probability models cannot be constructed, but there are still ways forward.

This report contains a number of sources describing case studies—implemented responses to climate risks, with honest discussion of what worked and what didn't. Some examples include flood insurance in the Netherlands, index-based insurance in the Caribbean, crop insurance in Ethiopia and Pakistan and 11 case studies from the Geneva Association. The Munich Climate Insurance Initiative adds case studies that highlight its innovative and potentially transformative work.

The scope and scale of climate change necessitates government involvement through both regulation and coordination across borders and markets. The landmark 2015 United Nations Climate Change Conference (COP21) in Paris represented the largest-ever gathering of heads of state to discuss specific responses to climate change. Public-private partnerships are also necessary. Numerous sources describe the historical leadership that insurers have shown in creating building codes, fire safety codes, restrictions on construction in floodplains and so forth, and they ask if insurers can perform a similar role for climate risk mitigation.

This report contains detailed surveys and survey analysis on what the insurance industry is already doing and what it is disclosing to its investors and policyholders. The Geneva Association and scientist Evan Mills contribute exhaustive studies on the industry.

What becomes clear by the end of those industry-side surveys—and indeed by the end of this entire report—is that much still needs to be done. Governments, insurers, financial institutions, public-private partnerships and nonprofits all have a role to play in writing the next chapter of responses to climate change.

After finishing this report, all readers should ask themselves what they wish had made it into this report. Then they should write about that topic, and consider sharing their work widely. That's the way forward.

Section 1: Risk Management

Uncertainty about outcomes is fundamental to risk management. But often, one can specify the range of possible outcomes and their relative probabilities in advance; that is, one can build a probability model or distribution. Even in those cases where this isn't possible, sometimes one can estimate this distribution. Actuaries and risk managers have developed a wide range of tools to manage this risk. Lacking a probability model, the risk manager is faced with a restricted tool set. This necessitates the need for different approaches and increases the demand for reflective case studies in which risks were successfully (or even unsuccessfully) managed under similar conditions.

The first source "Risky Business" (1.1) is an initiative founded in 2013 by New York City Mayor Michael Bloomberg, former U.S. Secretary of the Treasury Hank Paulson and business leader and philanthropist Tom Steyer. It was designed to research and report on major trends in climate risk management efforts in the United States.

Next is "Risk Management and Climate Change" (1.2), a research article published in *Nature Climate Change*. It explores available risk management options under precisely the scenario presented by climate change—when both the full range of outcomes and their relative probabilities are unknown in advance.

"Climate Change and Risk Management: Challenges for Insurance, Adaptation, and Loss Estimation" (1.3), a research report from Resources for the Future, considers the portfolio risk of a set of individual risk management policies, such as insurance policies. The paper highlights three distinct features of climate change risk (micro-correlations, heavy tails and tail dependence), each of which increases total portfolio risk faster than one might expect.

"Climate Change Risk Management: An AMS Program Study" (1.4) is a 2014 report from the American Meteorological Society. It explores how different risk management approaches for greenhouse gas management aligned with economic principles.

The United Nations Framework Convention on Climate Change report "Mechanisms to Manage Financial Risks from Direct Impacts of Climate Change in Developing Countries" (1.5) explores the particulars of each financial tool used to manage climate risk in developing regions. Some of these tools are closely related to conventional insurance, though others are more flexible and directly target uninsurable risks.

Finally, the section closes with the case study "Climate Change and Increased Risk for the Insurance Sector: A Global Perspective and an Assessment for the Netherlands" (1.6), which takes a look at flood risk in a country that is vulnerable but also able to mitigate, adapt and geoengineer its way to flood risk management solutions.

Table 1.1

Major areas addressed in section 1

Source	Life insurance	Health insurance	Finance and microfinance	Property and casualty	Fundamentals of risk management
1.1				✓	✓
1.2					✓
1.3			✓	✓	✓
1.4					✓
1.5					✓
1.6				✓	✓

Table 1.2

Major areas addressed in section 1

Source	Government or public partnerships	Regulations	Developing nations	Public policy	Basic climate science
1.1	✓			✓	
1.2					
1.3					
1.4					
1.5	✓		✓	✓	
1.6	✓				

1.1 RISKY BUSINESS

https://riskybusiness.org/

Objective: An initiative founded in 2013 by New York City Mayor Michael Bloomberg, former U.S. Secretary of the Treasury Hank Paulson, and business leader and philanthropist Tom Steyer "to assess and publicize the economic risks to the U.S. associated with climate change."

Results and Potential Applications: Riskybusiness.org publishes a series of reports at the national, regional, and state levels. Currently, the five reports published are as follows:

1. From Risk to Return: Investing in a Clean Energy Economy

"This report examines the opportunities for American businesses and investors in a clean energy economy. It presents technology choices and outlines near- and medium-term investment opportunities across nine U.S. census regions. It finds that lowering climate risk by building a clean energy economy is technically and economically achievable using commercial or near-commercial technology."

2. The Economic Risks of Climate Change in the United States

"Damages from storms, flooding, and heat waves are already costing local economies billions of dollars—we saw that firsthand in New York City with Hurricane Sandy. With the oceans rising and the climate changing, the Risky Business report details the costs of inaction in ways that are easy to understand in dollars and cents—and impossible to ignore."

3. Heat in the Heartland: Climate Change and Economic Risk in the Midwest

"This report identifies the economic risks posed by a changing climate to the Midwestern U.S. The Midwest will likely be hit hard by impacts such as decreased labor productivity, increased energy demand, and increased heat-related mortality. This publication also includes a specific focus on the effects that climate change will have on agriculture and Midwestern cities."

4. Come Heat and High Water: Climate Risk in the Southeastern U.S. and Texas

"This report identifies the economic risks posed by a changing climate across 11 states in the Southeast, and Texas. The report also highlights the risks to manufacturing, a key driver of recent economic growth in this region."

5. From Boom to Bust? Climate Risk in the Golden State

"This report identifies the economic risks posed by a changing climate in the state of California. The report explains that California is likely to face economic challenges due to increasing temperatures and sea level rise exacerbated by climate change. The report includes analysis of the risks faced by different regions of the state."

In addition, the site posts news articles commenting on major developments.

1.2 RISK MANAGEMENT AND CLIMATE CHANGE

Kunreuther, H., Heal, G., Allen, M., Edenhofer, O., Field, C., Yohe, G. (2013). *Nature Climate Change*, *3*(5), 447–450.
http://www.nature.com/nclimate/journal/v3/n5/full/nclimate1740.html

Objective: "Studies of climate change and its impacts rarely yield consensus on the distribution of exposure, vulnerability, or possible outcomes. Hence policy analysis cannot effectively evaluate alternatives using standard approaches, such as expected utility theory and benefit-cost analysis." Acknowledging this, the authors describe a set of risk management options that do not require the full probability density function of outcomes.

Methodology: The authors describe four risk management methods that can be utilized in the cases where the full probability density function of possible outcomes and their relative likelihoods is unavailable. Each method is described in relation to a hypothetical example of whether or not to build a structure near the coastline given flood risks.

Results and Conclusions:

1. The first method deals with the case when the probability density function is generally well known for more common outcomes but is uncertain in the tail(s). If a value *x* can be determined where the cumulative probability in the density P($X > x$) is less than some very low threshold (termed a "safety level"), then the authors suggest these extreme outcomes can sometimes be disregarded, at least for the purposes of planning or policy design.

2. *Minimax regret* defines the *regret* of a policy choice, which is the difference in value between the optimal choice (had the risk manager known what outcome would occur) and a selected choice. Suppose the risk manager must make a policy choice *P* given one of several possible state outcomes *S*. Define *P*(S)* to be the best possible policy choice *had the manager known that state S would occur.* Define *V(S,P)* as the value of choosing policy *P,* given that state outcome *S* occurred. The policy choice selected by minimax regret is

$$\min_{p} \max_{s} (V(S, P^*(S)) - V(S, P))$$

That is, the policy selected is the one that minimizes the largest possible regret, taken over all state outcomes *S*. The relative probabilities of state outcomes do not enter into the decision—the decision is only how to minimize the largest possible regret.

3. The *maximin criterion* simply involves ranking all policies *P* by their worst-case outcomes and selecting the policy with the minimum—the "least worst-case scenario" policy choice.

4. *Robust decision making* does not seek to optimize over a range of uncertain outcomes (which would require the probability density function of those outcomes), but rather to select a policy choice based on some other quality intrinsic to the policy. An example might be selecting a policy based on the smallest difference between its best-case and worst-case outcome. This does not require any measure of the likelihood of those outcomes.

Potential Applications: Actuaries can apply each of the four methods outlined in this paper for climate risk management. A lack of detailed information on the probability density function of possible climate outcomes, exposure levels, or other quantities is precisely the scenario the actuary faces when looking at climate risks. The first method forgoes only part of the probability density function (the tail), but the other three methods can be applied without any use of the probability density function.

It goes without saying that the probability density function of outcomes contains a tremendous amount of information for risk management, and any method that can be applied without this full density function necessarily makes a decision based on less information. Actuaries should be fully aware of the added uncertainty from using any of these risk management decisions.

1.3 CLIMATE CHANGE AND RISK MANAGEMENT: CHALLENGES FOR INSURANCE, ADAPTATION, AND LOSS ESTIMATION

By Caroline Kousky and Roger Cooke, 2009. RFF DP 09-03.
Available at Resources for the Future

Objective: This research paper focuses on three risk phenomena, each of which serve to increase the total portfolio risk to insurers when writing multiple policies. There are micro-correlations, heavy tailed distributions and tail dependence. Climate risks exhibit all three phenomena, but beyond that, there is further evidence that climate change is exacerbating all three risks, so the total impact of these phenomena would be expected to grow.

Methodology: The paper first defines the three risk-related phenomena:

1. *Micro-correlation* is where any two risks X_i and X_j show such a small positive correlation in their losses that it is effectively imperceptible, and the two can reasonably be treated as independent random variables. However, when one builds a large portfolio of policies $T = \sum X_i$, then the variance of the total loss is

$$Var(T) = Var\left(\sum_{i=1}^{n} X_i\right) = \sum_{i=1}^{n} Var(X_i) + \sum_{i \neq j} Cov(X_i, X_j),$$

where the final sum of covariances is taken over all combinations of *i,j*. For example, a portfolio with *n* = 100 losses produces 4,950 covariance terms. While any single covariance term might be so small as to be negligible, the sum of 4,950 of these terms is far more of an issue. There even comes a point at which adding another policy to the portfolio might do more harm than good; ignoring micro-correlations amounts to ignoring the sum of the 2**n* covariance terms this additional policy adds to a portfolio of size *n*.

2. Heavy-tailed distributions are those whose tails decay at a sufficiently slow rate so as to leave substantial probability mass at values quite far from the expected value. It is often necessary to use such distributions when studying extreme events (low probability, high impact) such as those caused by rare natural disasters.

3. Tail dependence occurs when the dependence between two (or more) random variables *X* and *Y* is strongest for extreme values of each. That is, the variables exhibit little to no dependence for typical values, but extremes of one variable tend to come paired with extremes of the other. An example of this might be the dependence seen between the property and car insurance lines for one company in a region. In typical years, there is little relationship between the total property loss and total car loss. But if a large magnitude catastrophe such as a hurricane struck, one might expect unusually large magnitude losses for each line. Thus, the tails of these two lines might be more strongly dependent than the central portions of each.

Each of these three phenomena are important considerations when studying climate risks, but the authors further warn that there is evidence that climate change itself is increasing the magnitude of all three of these concerns.

Data and Sources: The data shown as examples of the three phenomena are a mix of randomly simulated variables meant to mimic what might be expected in the marketplace, as well as National Flood Insurance Program claims from St. Louis from 1991 to 1994 and Florida from 1978 to 2006.

Results and Potential Applications: The authors describe three precise risk management consequences to the climate risk phenomena they introduce:

1. *Limits to securitization.* The standard portfolio-based risk management argument is that by increasing the number of policies aggregated into a portfolio, the central limit guides the average loss toward a normal distribution with a decreasing variance. Securitization allows a large portfolio to be sliced into smaller, more liquid securities. The authors note that ignoring micro-correlations becomes an increasingly costly mistake as the size of a portfolio or the securitization process increases.

2. *Conditional indemnity.* In relation to tail dependence, the concern for insurers is that an extreme loss in one line of business may simultaneously occur with an extreme loss in another, despite the lack of a relationship between the lines during more typical times. Given this risk, one risk management option is to divide the space of total losses into two regions: Region 1 could be the one in which the two lines both exceed some high threshold, and Region 2 could cover all other cases (including an extreme in one line only or an extreme in neither). Insurers and the private markets can likely handle region 2, but region 1 can be addressed beyond the private insurance market, through excess-of-loss reinsurance, multiline contracts or a catastrophe bond triggered by simultaneous large losses across lines. Recognizing the tail dependence and estimating the bounds for regions 1 and 2 can inform the design of reinsurance or catastrophe bond solutions.

3. *Affordability and equity.* The report tells the story of Florida's residual market mechanism. After denying requested rate increases from insurers in the wake of hurricanes, the supply of insurance shrank, and the residual market in Florida grew. Over time, the state-run residual market insurer grew to be the largest in the state. With rates that are likely below market, the looming risk is that a catastrophic year of losses will cause the state insurer to recoup from the private insurers. But in the meantime, the availability of artificially low rate insurance fails to send the correct signal to the market and thus fails to use insurance as a mechanism for climate risk mitigation.

1.4 CLIMATE CHANGE RISK MANAGEMENT: AN AMERICAN METEOROLOGICAL SOCIETY PROGRAM STUDY

By P.A.T. Higgins, 2014. Available at Climate Policy Study

Objective: This American Meteorological Society (AMS) Policy Program study explores risk management responses to greenhouse gas emissions and climate change risks and discusses their strengths and weaknesses.

Results and Potential Applications: Perhaps the greatest value to actuaries is the section on risk management principles related to mitigation activities. Although the study focuses on the mitigation of climate change by reducing greenhouse gas emissions, the three economic principles underpinning the section on risk management approaches to mitigation are of broad value.

1. "Having less of something . . . almost certainly requires an increase in the price of those activities that cause it."

The study points out that a price increase in an activity encourages both *efficiency* and *frugality*, with only the latter leading to an overall decrease in the activity. Encouraging efficiency alone (without frugality) makes an activity cheaper and therefore encourages more of it, not less. When actuaries consider the use of risk management tools to mitigate risky but insured activities (construction in hurricane-, wildfire- or flood-prone areas, planting crops ill-suited to the climate and so on), increasing the price of such policies is necessary to achieve an overall reduction in the activity. Innovations in the efficiency of delivering insurance products to customers will itself only serve to increase the amount of risky activities.

2. Incorporating the costs associated with climate risks onto those who receive the benefits from the activity increases overall economic well-being.

Economic well-being is maximized when the entities that receive benefits from an activity directly pay the costs associated with that activity. Consider again the example of homeowners insurance in a hazard-prone area. The construction firm and homeowner are the primary beneficiaries of the activity itself, and this activity creates additional costs beyond the usual ones associated with homeowners insurance. Not only would proper risk pricing avoid warped incentives and discourage the activity itself, but it would maximize overall economic well-being.

3. Market mechanisms are the most economically efficient way to reduce undesirable activity. That is, the greatest reduction per unit cost is achieved with market-based approaches rather than regulatory approaches.

1.5 MECHANISMS TO MANAGE FINANCIAL RISKS FROM DIRECT IMPACTS OF CLIMATE CHANGE IN DEVELOPING COUNTRIES

United Nations Framework Convention on Climate Change.
Available at http://unfccc.int

Objective: "This technical paper provides information on the financial mechanisms used to manage risks from the direct impacts of climate change. The mechanisms described include both insurance mechanisms and other forms of risk spreading and sharing, referred to as non-insurance mechanisms. Developing countries require a portfolio of mechanisms, which may include insurance, to manage risks, as no one mechanism can meet the range of circumstances required by all countries. The paper considers hazards, assets and vulnerability in the context of climate change, and reviews several options for managing financial risks from impacts of climate change in developing countries. It also proposes three innovative financing schemes for this purpose."

Methodology: Chapter III explores hazards, assets and vulnerability. This includes categorizing the types of hazards resulting from climate change, exploring the impacts on various types of assets and providing some overview of risk-transfer mechanisms with discussion on how closely they match assets affected by particular hazards. Chapter IV explores insurance mechanisms for climate risks. This includes a detailed study of current insurance availability in developing countries and discussion of the major barriers to greater insurance coverage. Chapter V discusses potential financial solutions for developing countries, and Chapter VI explores potential noninsurance mechanisms for climate-related risks.

Results and Conclusions: The study shows that many insurance products have not been successful in developing countries. This is due, in part, to the high expense ratio of many insurance products and limited access to finance in rural, underdeveloped areas. However, recent advances in geographic information systems (GIS) may help insurance markets advance in rural areas. Further, index-based insurance has emerged as a low-cost alternative to traditional insurance, although the basis risk of a product is a concern. Microfinance and microinsurance are also products that may be economically viable once markets develop further.

The study describes three financial mechanisms (labeled A, B and C) designed for developing countries and depending on the specific circumstances. Table 1 summarizes the approaches.

Table 1. Overview of possible climate change related risk-transfer and risk-sharing schemes for developing countries, especially least developed countries, small island developing States and countries in Africa

Scheme A Single insurance policy (individual countries)	Scheme B Single insurance policy (for a group of countries)	Scheme C Climate change risk management mechanism
• Underlying risks are insurable • Applied per country • Short-term solution (renegotiated annually)	• Underlying risks are insurable • Applied to a set of countries • Short-term solution (renegotiated annually)	• Addresses uninsurable risks • Explicit risk reduction • Applied globally • Flexible term • Long-term solution
PURPOSE		
The aim of this scheme is to manage the financial impacts of climate change risks. These should be quantified in the risk assessment, which should detail the assets and the kind of hazards involved.	This scheme also aims to manage the financial impacts of climate change risks. The scheme entails support by external entities, like multilateral organizations and donors to support its establishment and the provision of technical advice.	One element involves coordination of international support by providing technical support in the area of climate risk management. A second element transfers financial risk by insurance or risk securitization in a very broad range of financial instruments.

Noninsurance risk management strategies discussed include informal risk sharing, intertemporal risk spreading and collective loss sharing, each of which are explored across the micro, meso, and macro scales.

Potential Applications: This detailed, informative study provides numerous examples of risk management applications around the globe, with particular attention to how well they scale up. The numerous reasons for the failure of insurance-based mechanisms to expand more fully in developing countries is described in excellent detail and sets the stage for the variety of insurance, financial and noninsurance risk management schemes described throughout the study.

1.6 CLIMATE CHANGE AND INCREASED RISK FOR THE INSURANCE SECTOR: A GLOBAL PERSPECTIVE AND AN ASSESSMENT FOR THE NETHERLANDS

Botzen, W. J. W., Van den Bergh, J. C. J. M., & Bouwer, L. M. (2010).
Natural hazards, *52*(3), 577-598.

Objective: This study explores the consequences of climate change and extreme weather events on the insurance sector in the Netherlands. By focusing on a single case study, the authors describe how the patchwork of private/public risk management strategies and division of hazards complicates the risk, and they suggest paths forward.

Methodology: The study uses output from a regional climate model to create four different warming scenarios (see the *Sources* summary on the North American Regional Climate Change Assessment Program website for more information on regional climate models). These then serve as inputs to an analysis of possible consequences. Extreme precipitation and flooding, wind, hail and extreme drought are specifically analyzed. For each risk, the various risk sharing arrangements between public and private institutions are analyzed, with discussion on how vulnerable the region might be to certain weather outcomes.

Data and Sources: The regional climate model is from the Royal Netherlands Meteorological Institute.

Results and Conclusions: One takeaway is how the patchwork of public/private insuring agencies, along with the subdivision of hazards, complicates the effective management of catastrophic weather events (Table 3, page 591). Consider floods: a distinction is drawn between a flood caused by a dam or dike failure and one caused by extreme precipitation; yet another distinction is made between a saltwater and freshwater flood (with different government approval processes for relief efforts). Private insurance enters the picture for personal automobiles damaged by flood, but otherwise the risks are covered by the public. The study also describes four main avenues for insurers to manage their exposure to increased hazards from climate change: limiting risk, adjusting premiums, controlling the damage from the hazards and transferring the risk. Though there is some possibility of premium increases, greater use of reinsurance, use of financial instruments or risk transfer through policy exclusions, the authors observe that each of these have drawbacks. These include issues of the availability and affordability of insurance, pushback from regulators, the cost and limitations of reinsurance and financial products and the social consequence of the decreased financial security of households. Echoing work by Evan Mills (Insurance in a Climate of Change and From Risk to Opportunity: Insurer Responses to Climate Change, both reviewed here in *Sources*), the authors conclude that industry-wide efforts to mitigate climate change and encourage adaptation strategies as loss controls would be cost-effective.

Potential Applications: Actuaries can use the case study to strengthen claims for reforms in the patchwork of risk management agencies and hazard distinctions, to consider how regional climate models offer future scenarios for case studies or stress testing and to consider the value of industry-led mitigation and loss controls as adaptations to climate change.

Section 2: Sources of Climate, Weather and Environmental Data

This section presents some of the major sources of climate, weather and environmental data that are freely available to risk managers. These data include both historical measurements overseen by leading scientific agencies in the United States and projections of future climate from computer models. A number of discussion papers and analyses of each are included, as are the recently unveiled Actuaries Climate Index and Actuaries Climate Risk Index, each developed specifically for the purpose of actuarial climate risk management.

The "Global Historical Climate Network (GHCN)" (2.1) is, in some sense, the most reliable and comprehensive land-based record of environmental data at the daily and monthly time scales. The National Centers for Environmental Information (NCEI) maintain "Climate Data Online" (2.2), a web portal that allows the user to easily search, access and download customizable datasets from the GHCN.

Beyond raw data, the NCEI publishes summary reports (2.3.1–2.3.4) on the state of the climate and key climate indicators. This section highlights the "State of the Climate," "North American Climate Extremes" and "North American Drought Monitor."

The tail of insurance losses is heavy, with only a few events accounting for many of the costs associated with natural disasters. The National Climate Data Center (NCDC) maintains a database of "Billion Dollar Weather and Climate Disasters" (2.4.1) and has published two discussion papers: "U.S. Billion-Dollar Weather and Climate Disasters: Data Sources, Trends, Accuracy and Biases" (2.4.2) and "Quantifying Uncertainty and Variable Sensitivity within the U.S. Billion-dollar Weather and Climate Disaster Cost Estimates" (2.4.3). All of these are summarized in this section.

Turning to the future, climate model projections are computer model runs that project forward several decades. When they are well designed and calibrated, they can provide insights into projected climate trends or shifts. Often, these models are built at a coarse spatial resolution due to limited computational power. The "North American Regional Climate Change Assessment Program (NARCCAP)" (2.5) contains a number of regional climate model projections for much of Canada and the continental United States. These are useful when one wishes to study more regional or localized projections of climate change.

The "Actuaries Climate Index" and companion "Actuaries Climate Risk Index" (2.6) were unveiled in 2016. They were designed to capture overall trends in climate change along with a measure of the associated actuarial risks of that change.

Finally, the "Chicago Mercantile Exchange" (2.7) summary describes a number of financial products known as weather derivatives, which link payments to certain weather outcomes and constitute one way firms can manage weather and temperature risk.

Table 2.1

Major areas addressed in section 2

Source	Life insurance	Health insurance	Finance and microfinance	Property and casualty	Fundamentals of risk management
2.1					
2.2					
2.3.1					
2.3.2					
2.3.3					
2.3.4					
2.4.1				✓	
2.4.2				✓	
2.4.3				✓	
2.5					
2.6					✓
2.7			✓		

Table 2.2

Major areas addressed in section 2

Source	Government or public partnerships	Regulations	Developing nations	Public policy	Basic climate science
2.1	✓			✓	✓
2.2	✓			✓	✓
2.3.1	✓			✓	
2.3.2	✓			✓	
2.3.3	✓			✓	
2.3.4	✓			✓	
2.4.1	✓				
2.4.2	✓				
2.4.3	✓				
2.5					✓
2.6					
2.7					

2.1 GLOBAL HISTORICAL CLIMATOLOGY NETWORK (GHCN) DAILY AND MONTHLY

https://www.ncdc.noaa.gov/oa/climate/ghcn-daily/
http://www.ncdc.noaa.gov/ghcnm/v3.php
ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/
tp://ftp.ncdc.noaa.gov/pub/data/ghcn/v3/

Objective: "GHCN (Global Historical Climatology Network)-Daily is an integrated database of daily climate summaries from land surface stations across the globe. Like its monthly counterpart GHCN-Monthly, GHCN-Daily is comprised of daily climate records from numerous sources that have been integrated and subjected to a common suite of quality assurance reviews" (http://bit.ly/2bdb23M).

Methodology: The daily dataset GHCN-D contains daily measurements from more than 75,000 land-based stations worldwide, representing more than 180 countries and territories. A series of rigorous quality control procedures is in place to ensure that each record is unique and passes several internal control checks. However, GHCN-D cannot and does not attempt to remedy any changes in reporting (systematic bias) at locations over time. Variables with the most complete coverage include daily maximum and minimum temperature (measured in tenths of °C) and daily total precipitation (measured in tenths of mm). Snowfall (mm) and snow depth (mm) join the temperature and precipitation measurements to form the core five variables, but a few dozen other variables make appearances at scattered stations, usually at those with the most thorough and complete records. The most recent dataset version is freely available through the GHCN-Daily website, and each previous version is archived at the NOAA/National Climatic Data Center in perpetuity. The Global Historical Climate Network-Monthly (GHCN-M) is a similar product but is developed at the monthly time scale.

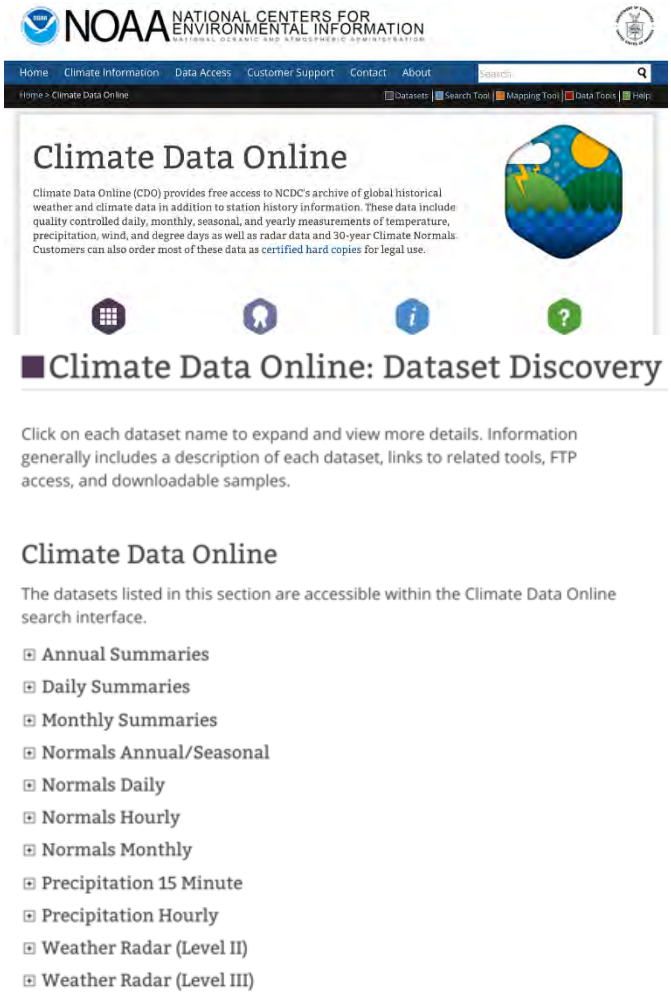
Data Sources: The primary article describing the construction of the database is as follows:
Menne, M.J., I. Durre, R.S. Vose, B.E. Gleason, and T.G. Houston. (2012): An overview of the Global Historical Climatology Network-Daily Database. *Journal of Atmospheric and Oceanic Technology*, 29, 897-910, doi:10.1175/JTECH-D-11-00103.1.

Results and Conclusions: The GHCN-D and GHCN-M databases are the end products.

Potential Applications: Actuaries should consider the GHCN-D a primary source of historical weather data for applications. The freely accessible, current version of GHCN-D may be obtained in one of two ways. For those comfortable with FTP (file transfer protocol) and working directly with data files, the FTP address at the top of this report gives complete access along with supporting documents. Most expert users flock to this source once they become comfortable moving and processing large quantities of data. Those seeking a more user-friendly, graphical interface to obtain data should access GHCN-D through the Climate Data Online (CDO) portal, also summarized in this report. Actuaries can quickly gain a sense of what is available through the CDO tool and will find that most regions in North America have stations with 100+ years of measurements on the core five variables (usually at airports or established monitoring stations). GHCN-M is primarily used to produce summary reports, such as the State of the Climate and Climate at a Glance tools, reviewed later in this report.

2.2 CLIMATE DATA ONLINE

https://www.ncdc.noaa.gov/cdo-web/



Objective: Climate Data Online (CDO) is a portal to the freely available source of historical weather data maintained by NOAA's National Centers for Environmental Information.

Data Sources: The data are obtained from the Global Historical Climate Network-Daily dataset. "The GHCN-D is an integrated database of climate summaries from land surface stations across the globe that have been subjected to a common suite of quality assurance reviews. The data are obtained from more than 20 sources. Some data are more than 175 years old while others are less than an hour old. GHCN is the official archived database" (http://bit.ly/1qufqhu).

Data are available at tens of thousands of stations worldwide. A majority of the stations are in the United States, and the coverage in terms of dates and variables varies tremendously among these stations. Commonly used variables include daily maximum and minimum temperature, daily precipitation, daily average wind speeds and wind gusts and others. In total, there are 55 daily variables, 18 monthly variables and 29 annual variables. Monthly, annual and other types of summaries are also available. Limited information on storm structure, hail index, mesocyclone identification, tornadic vortex signature and storm tracking information is also available. In general, the most complete data records for the longest periods of time are available at airports.

Methodology: We give a sense of the data available to actuaries through three examples, shown on the next few pages.

Potential Applications: All empirical studies performed by actuaries can use historical environmental data. For information on more data maintained by NOAA, see the following link:
https://www.ncdc.noaa.gov/wdcmet/data-access-search-viewer-tools

Figure 2.2.1

Example of the CDO search tool, with the four main categories shown on the left and the ability to select stations using the map tool on the right

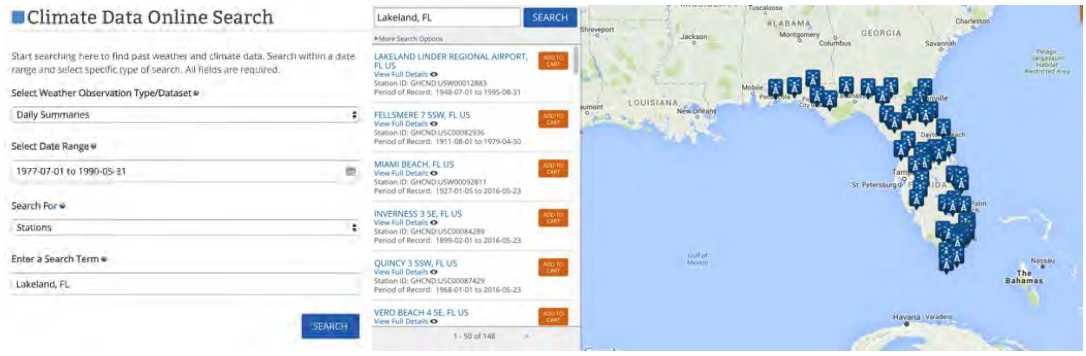


Figure 2.2.2

Left image: frost risk in a citrus-growing region. Photographer: Matt Stroshane/Bloomberg via Getty Images. Middle image: damage from wind and hurricanes. Photo credit: US Army Corps of Engineers. Right image: flood risk due to heavy precipitation. Photo Credit: US Army Corps of Engineers. All three types of weather risks can be analyzed using historical data available through the CDO.

Figure 2.2.3

Time series plot of minimum temperatures from July 1, 1977, to May 31, 1990, at Lakeland Linder Regional Airport, Florida. The first gray area highlights a freeze in Florida on December 24–25, 1983, that caused nearly $1 billion in damage and killed trees on 120,000 acres. The second gray area highlights a freeze in Florida on January 20–22, 1985, that damaged 90% of Florida's orange and grapefruit crops. The final gray area highlights a freeze in Florida on December 22–26, 1989, that did more than $1 billion in damage.

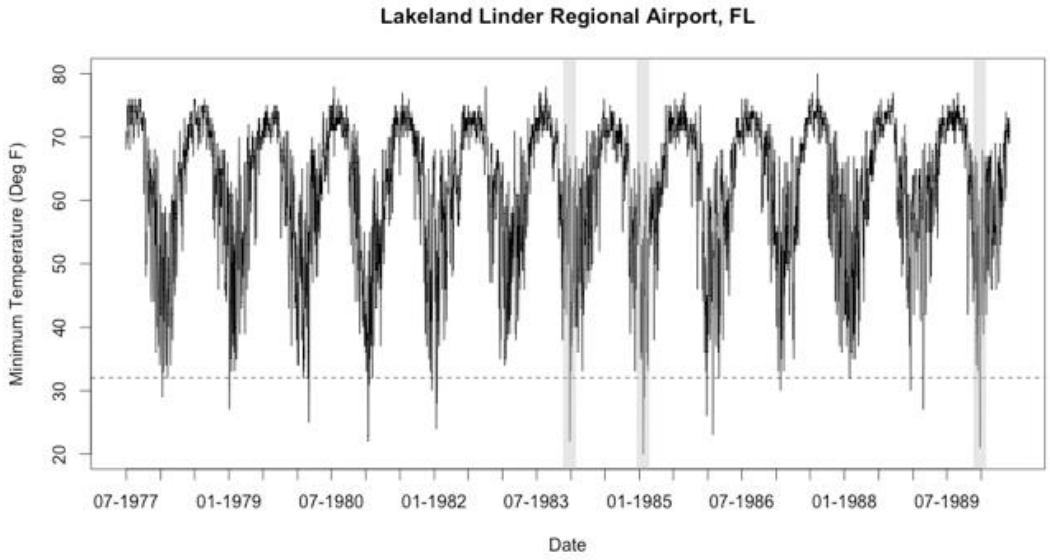


Figure 2.2.4

Time series plot of average wind speed from January 1, 2012, to May 30, 2013, at Mount Holly South Jersey Regional Airport, New Jersey. The greatest average wind speed occurred at the time of Hurricane Sandy, which caused an estimated $36.8 billion in damage in New Jersey and damaged or destroyed about 72,000 homes and businesses.

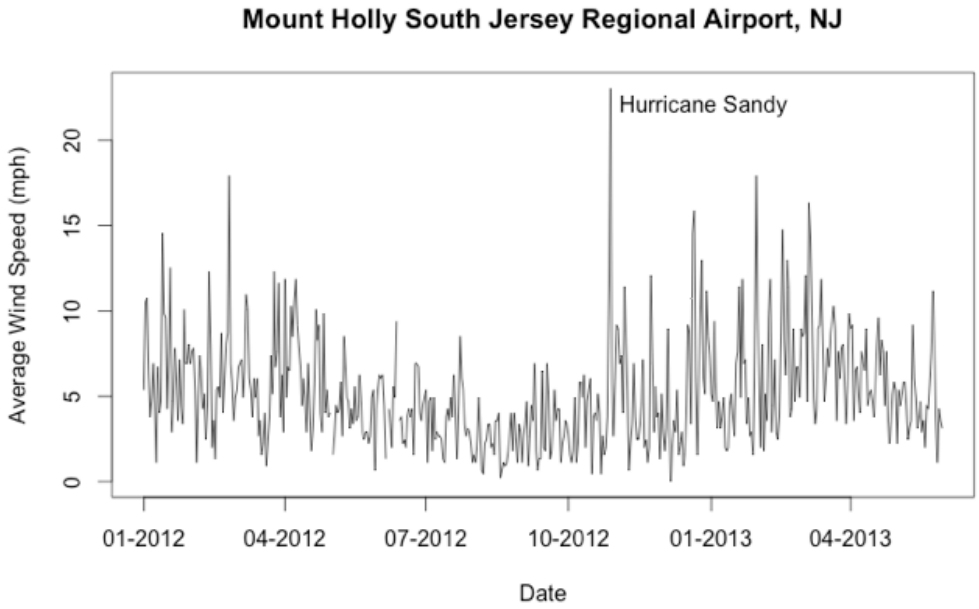
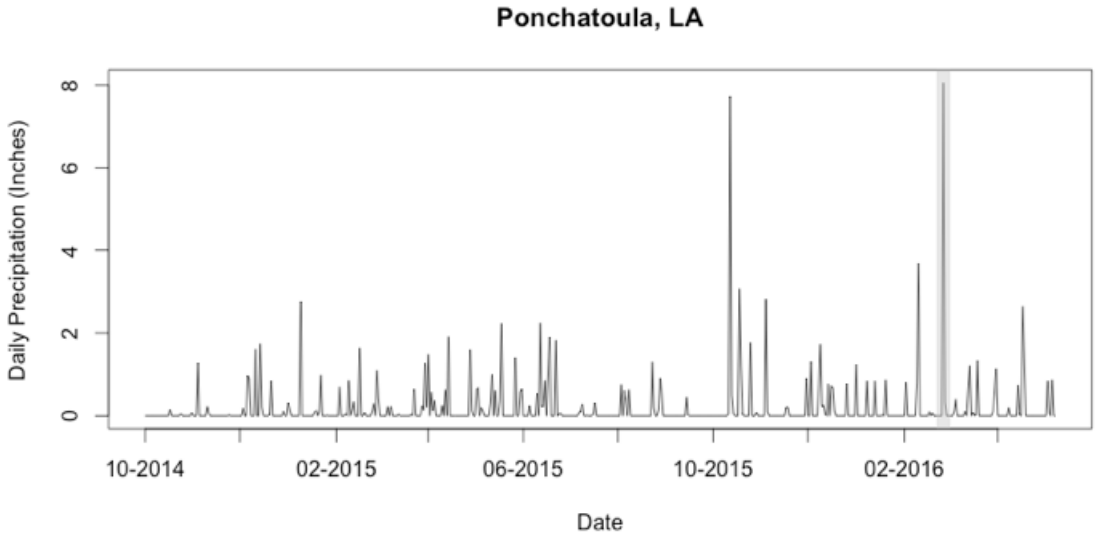


Figure 2.2.5

Time series plot of daily precipitation from October 14, 2014, to May 21, 2016, in Ponchatoula, Louisiana. The gray area highlights the flood in Louisiana from March 10, 2016, to March 12, 2016, where some locations received up to 10 inches of rain with damage to nearly 5,000 homes.



2.3 NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION

2.3.1 CLIMATE MONITORING

http://www.ncdc.noaa.gov/climate-monitoring/

Objective: "To monitor and assess the state of the Earth's climate in near real-time, providing decision-makers at all levels of the public and private sectors with data and information on climate trends and variability including perspectives on how the climate of today compares to the past" (http://bit.ly/1zWS8D0).

Methodology: The Climate Monitoring tools are subdivided into a number of smaller, focused tools designed to quickly display the state of the current climate and how that state compares to previous states since 1895. The tool categories are shown in the image on the right. In general, these tools display data with a time resolution of one month (or larger), or they display/construct indices meant to capture overall trends within the weather and climate system. Some of these indices are purely meteorological (such as those found under Teleconnections), while others are designed to link the state of the climate to human impacts (such as those found under Societal Impacts).

Data Sources: Climate Monitoring ultimately relies on the Global Historical Climate Network, reviewed earlier in this report. The Monitoring References link contains detailed geographic maps of various climate and census regions of the United States, entry-level explanations and answers to frequently asked questions, and explanations regarding how the climate is monitored and with what uncertainty.

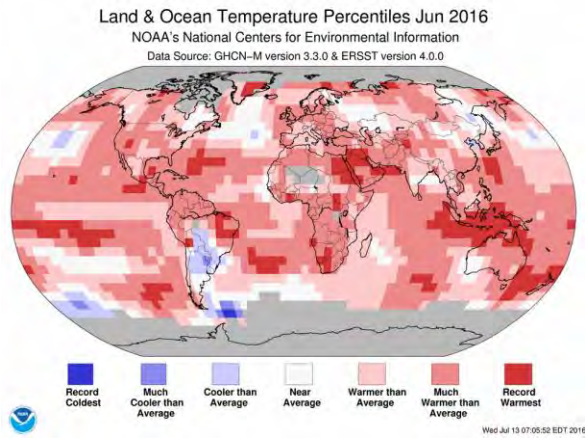
Results, Conclusions and Potential Applications: Many of these reports have an eye toward studying impacts of weather and climate on humans, and these are stored under the Societal Impacts tab. For example, Crop Moisture Stress Index (CMSI) fuses measurements of droughts from the Palmer Z index (itself found under Temperature, Precipitation, and Drought on this page) with soybean and corn yields to form an index that tracks crop stress due to water abundance or shortfall. This index could assist actuaries with crop or farm insurance. The Residential Energy Demand Temperature Index (REDTI) "provides quantitative information on the impact of seasonal temperatures on residential energy demand" and could serve as useful input for work with temperature derivatives. Maps of snow depth (Snow and Ice) help to serve as predictors of which river systems are at risk of drying, with clear links to crop stress.

As examples, three comprehensive tools from the Climate Monitoring set are highlighted in the next few pages. These are the State of the Climate/Climate at a Glance, North American Climate Extremes Monitoring (NACEM), and North American Drought Monitor (NADM).

2.3.2 CLIMATE MONITORING: STATE OF THE CLIMATE AND CLIMATE AT A GLANCE

http://www.ncdc.noaa.gov/sotc/ http://www.ncdc.noaa.gov/cag/

Objective: The State of the Climate is a collection of monthly summaries recapping climate-related occurrences on both a global and national scale. The Climate at a Glance tool is an interactive time series and mapping tool that allows users to form their own visualizations of the state of the current climate for regions or time periods of particular interest.



Methodology: The global summary gives a highlight of selected climate events and anomalies. The monthly blended land and sea surface temperature percentiles (shown to the left for June 2016) gives a sense of which regions of the earth were warmer (red) or cooler (blue) than their 30-year average. The global summary also includes information on hazards, snow and ice, upper atmosphere temperatures and El Niño. The national summary includes detailed information on the state of the climate in the United States. This summary includes discussion of recent tornadoes, snow and ice, droughts, wildfires and hurricanes and tropical storms. Summaries are both monthly and year-to-date.

The Climate at a Glance tool allows users to display monthly data from the national to the climate divisional level, either as high-quality spatial maps or as time series plots.

Data Sources: The reports and figures are all based on the GHCN-M (monthly) data product.

Results and Conclusions: The results are the set of monthly and year-to-date summary reports. Of particular interest to actuaries may be the NOAA Climate Monthly Briefings, which are "summaries of these summaries." This briefing highlights, in about 15 slides, what NOAA scientists have deemed the most important findings from the extensive monthly State of The Climate summaries.

Potential Applications: Perhaps the greatest value of this tool is to place the current state of the climate into historical or global context. Actuaries can easily investigate if a regional anomaly, such as a heat wave, is spatially isolated or representative of what is happening globally. They can similarly place a current set of climate events, such as acres burned to wildfires, into historical context by quickly checking how the current state compares to decades of data. These comparisons can help to protect against any tendency to overreact to a current climate event; they also help to demonstrate in what ways current climate events fall well outside the historical norm of climate events. For example, unprecedented heat waves could be an early warning sign of an increase in mortality in certain regions, which is of interest to life and health actuaries.

2.3.3 CLIMATE MONITORING: NORTH AMERICAN CLIMATE EXTREMES MONITORING (NACEM)

http://www.ncdc.noaa.gov/extremes/nacem/

Objective: "The North American Climate Extremes Monitoring (NACEM) product was developed to provide an accessible analysis tool that will help improve the understanding of observed changes in extreme climate conditions by providing users the ability to examine trends and occurrences of certain types of extreme or threshold events at the station-by-station level. The NACEM currently provides data and analysis for eight indices that have been defined by the World Meteorological Organization (WMO) Commission for Climatology/CLIVAR Expert Team on Climate Change Detection Monitoring and Indices (ETCCDM)" (http://bit.ly/2b9qAlc).

Methodology: The eight indices comprise the following: number of frost days (minimum temperature less than 0°C); number of summer days (maximum temperature greater than 25°C); number of icing days (maximum temperature less than 0°C); number of tropical nights (minimum temperature greater than 20°C); and the percentage of days whose minimum (or maximum) temperature is below the corresponding 10th percentile or above the corresponding 90th percentile. The index is computed at the station level and provides corresponding anomalies, data permitting, with respect to the 1961–1990 long-term average. Further information on these definitions can be found at the description of the methodology.

An interactive mapping tool allows users to select a time period (a given month, season or year after 1955) to view a specific index across North America or to view time series graphics for a specific station of interest.

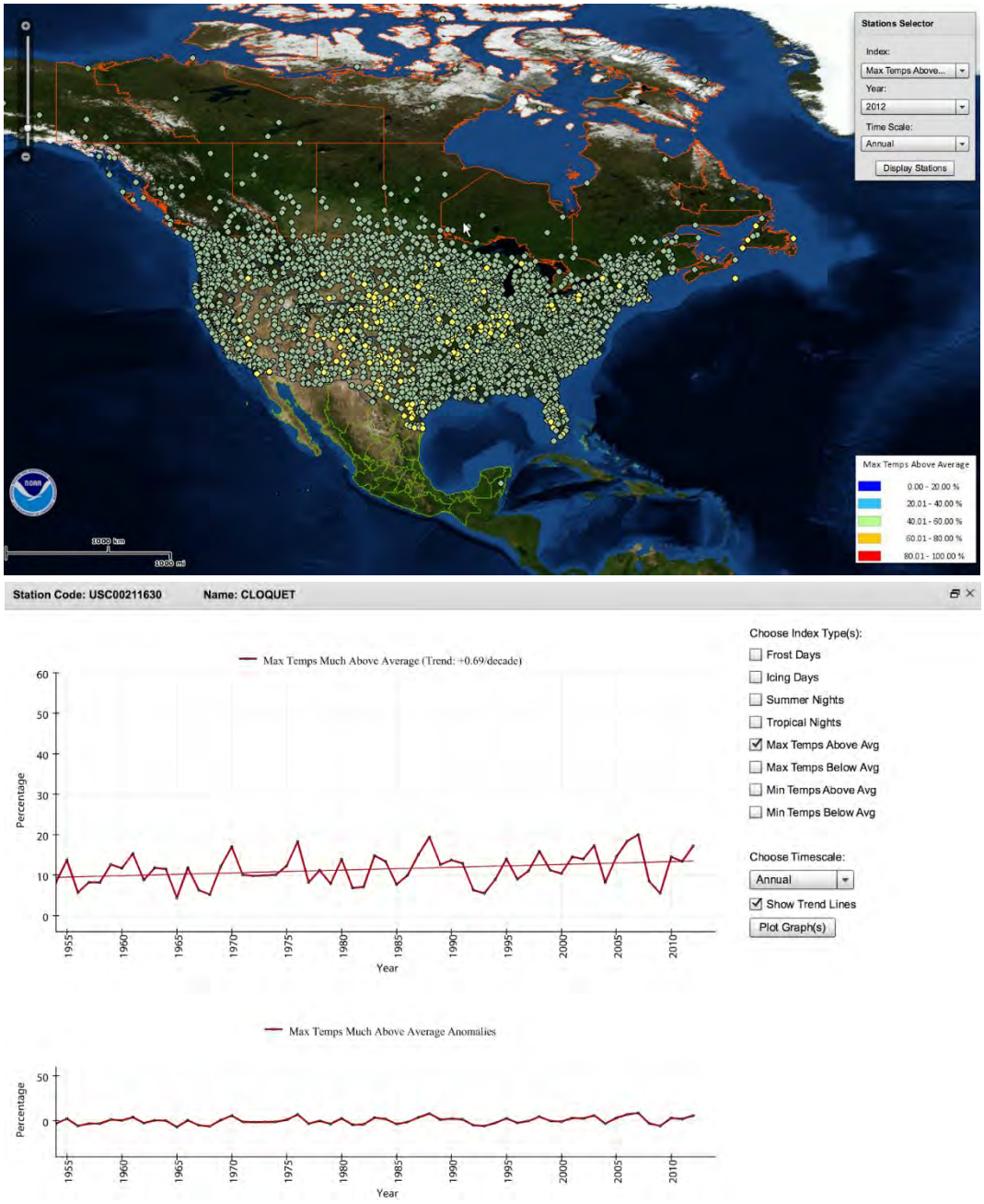
Data sources: The data underlying the indices are obtained from the Global Historical Climate Network-Daily (GHCN-D), also reviewed in this report.

Results and Conclusions: This source draws no conclusions from the data.

Potential Applications: Actuaries working in agricultural or crop insurance would be well served to explore regional trends in excessive heat, cold, frost and icing days. Actuaries exploring topics relating to temperature derivatives or other weather derivatives will also find data here. More generally, the source provides insight into the trends of extremes in climate and weather.

Figure 2.3.3.1

Example of the mapping tool, along with time series plots of the percentage of days whose maximum temperature is well above the average (maximum daily temperature greater than the 90th percentile) for Cloquet, Minnesota.



2.3.4 NORTH AMERICAN DROUGHT MONITOR (NADM)

http://www.ncdc.noaa.gov/temp-and-precip/drought/nadm/

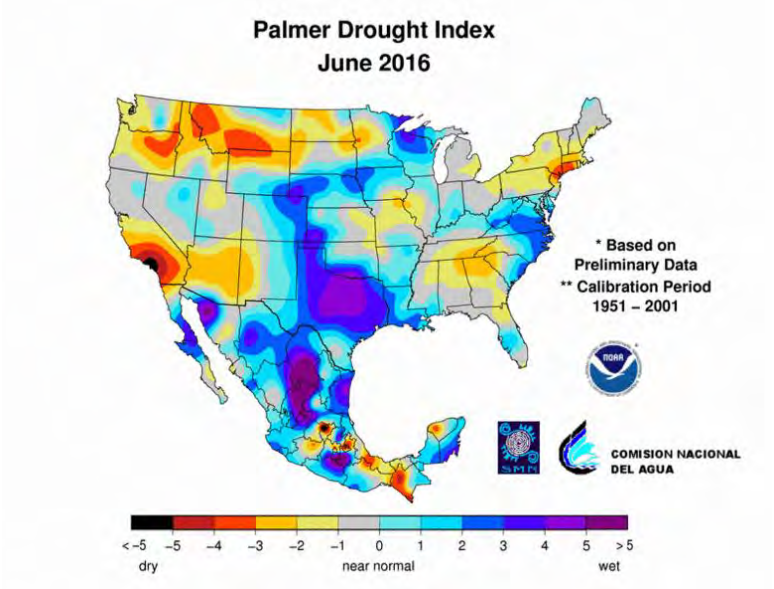
Objective: The Drought Monitor "synthesizes multiple indices, outlooks and local impacts, into an assessment that best represents current drought conditions. The final outcome of each Drought Monitor is a consensus of federal, state and academic scientists" (http://bit.ly/2aMRTk3).

Methodology: The NADM extends the successful U.S. Drought Monitor to cover all of North America. Described as blending science with art, the NADM incorporates several indices to measure and track drought, with input from scientific agencies. Maps are produced monthly from 2002 to present, and all previous values are archived.

In addition to the monthly map itself, a brief text supplement elaborates on the state of drought in North America, with specific subsections for Canada, the United States, and Mexico.

Data Sources: The monitor is based on a variety of datasets and expert opinions. Datasets and indices include the percentage of long-term average (1951–2001) precipitation, standardized precipitation index (SPI) values, the Modified Palmer Drought Index (PMDI), Palmer Hydrological Drought Index (PHDI), and Palmer Z Index (ZNDX) values. All of these data are available as monthly raw data files at NADM.

Figure 2.3.4.1
Example of the Palmer Drought Index.

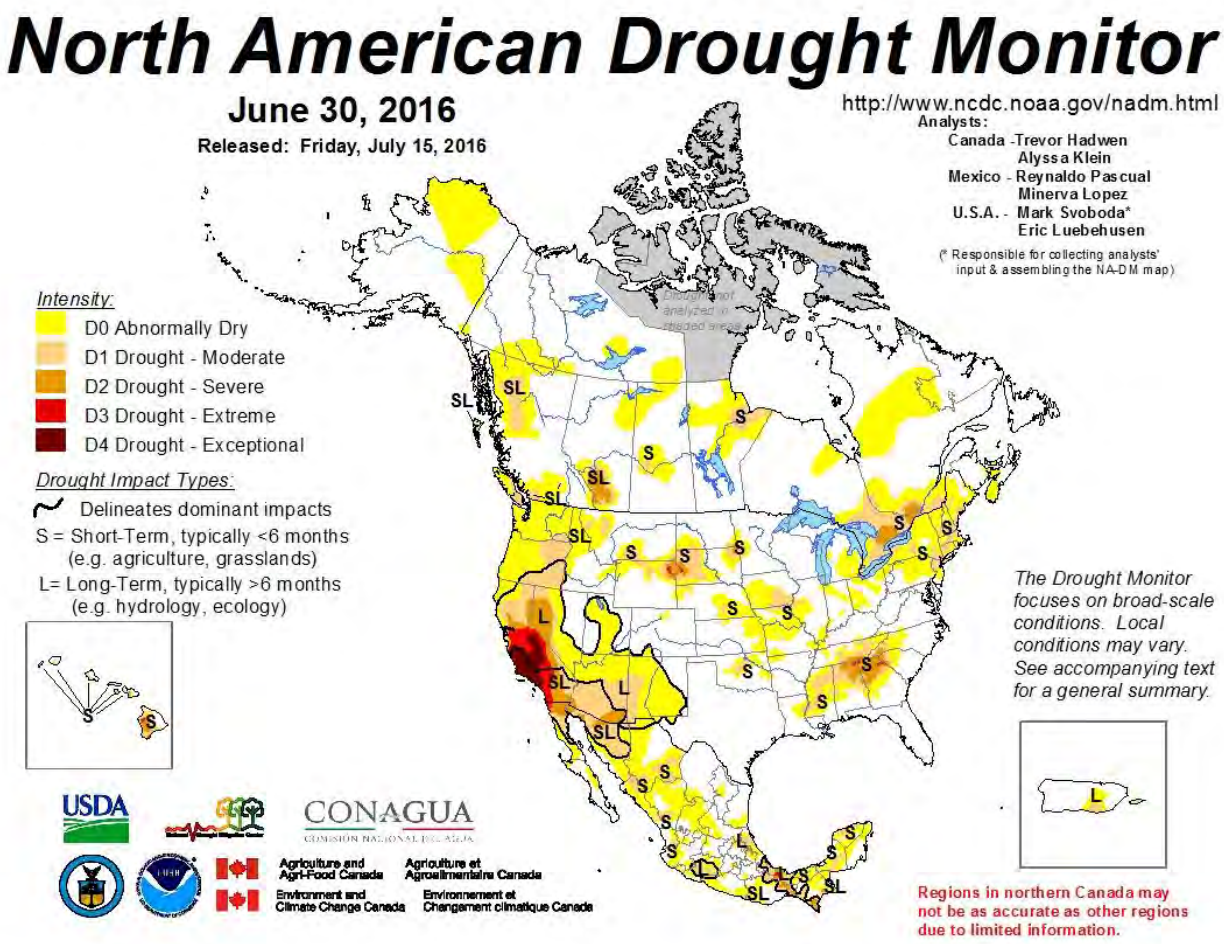


Results and Conclusions: An example of the result from the NADM is shown on the next page.

Potential Applications: A central value to this product is the blending of several indices and agency observations into both a spatially varied map and a supplemental text document. The link between this product and crop insurance is strongest and could serve as an early warning indicator for farm and crop claims.

Figure 2.3.4.2

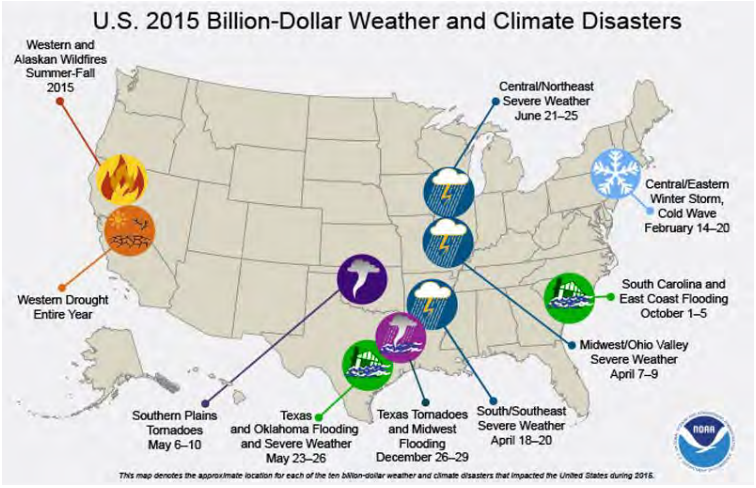
Map result of NADM for June 30, 2016, for all of North America.



2.4 U.S. BILLION-DOLLAR WEATHER AND CLIMATE DISASTERS

2.4.1 DATABASE AND ONLINE TOOLS

https://www.ncdc.noaa.gov/billions/



Objective: This report records all U.S. weather and climate events since 1980 that have caused at least $1 billion in damages from total direct losses. This summary briefly describes the online data tool useful for mapping, exploring trends and summarizing subsets of the full database of billion-dollar events.

Mapping: The mapping tool allows users to pick a specific time period between 1980 and 2015, a particular disaster type and a cost display (unadjusted or adjusted for Consumer Price Index). The resulting interactive map of the United States displays the number of events of that type for each state, and using the shading, users can explore the spatial distribution of events.

Time Series: The time series tool allows users to pick a specific time period between 1980 and 2015, a particular disaster type and a cost display (unadjusted or adjusted for Consumer Price Index). The resulting time series plot displays the number of events over time, along with a smoothed estimate of five-year costs and a corresponding confidence interval.

Summary Statistics: This is a convenient tool to aggregate information on the frequency and total cost of different disaster types over a prespecified time period, without regard to where or when within the time period they occurred.

Table of Events: The raw data of each disaster include the following:

- The date range of the event, along with a hyperlink that gives detailed information on the state of the U.S. climate at that time
- A description of the event itself, including which states were impacted
- The estimated total direct loss and number of deaths resulting from the event

Potential Applications: The primary value of the database is to allow actuaries to focus on those most extreme events that jointly constitute the vast majority of all weather-related losses. Actuaries who wish to try to improve on the frequency trend estimation or severity estimation of any type of disaster will find the raw data here, along with information to point to further research. Actuaries can use the online tools to explore the data and identify specific events, regions, or time periods of interest for rate-making purposes. Actuaries can further use the tool to generate high-quality visualizations of billion-dollar events for presentations.

Figure 2.4.4.1

An example taken from the mapping tool. Here we see that the southeastern United States tends to have more events, with Texas in particular experiencing an unusually large number.

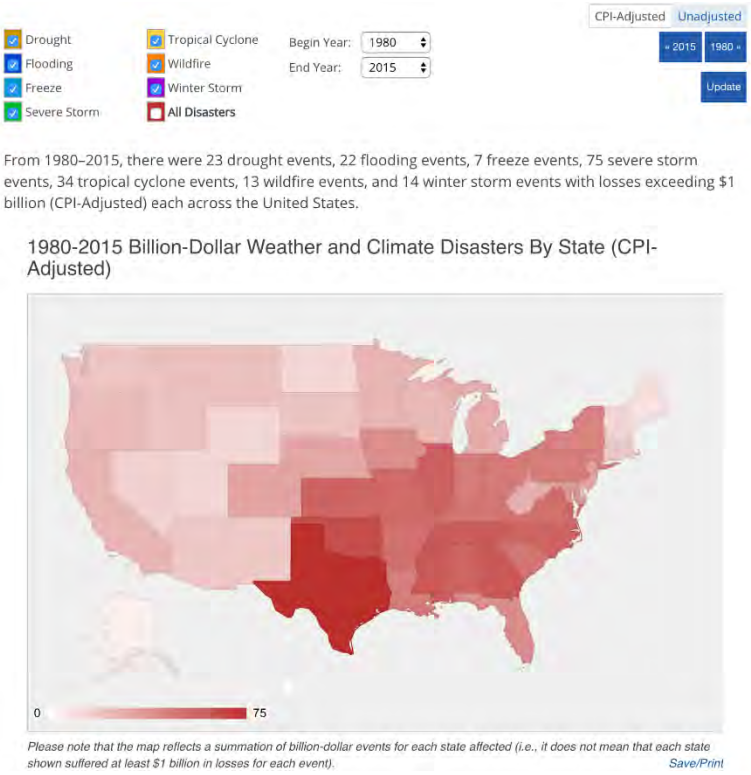


Figure 2.4.4.2

An example taken from the time series tool, showing both the variability from year to year and the general upward trend in the number of billion-dollar disasters.

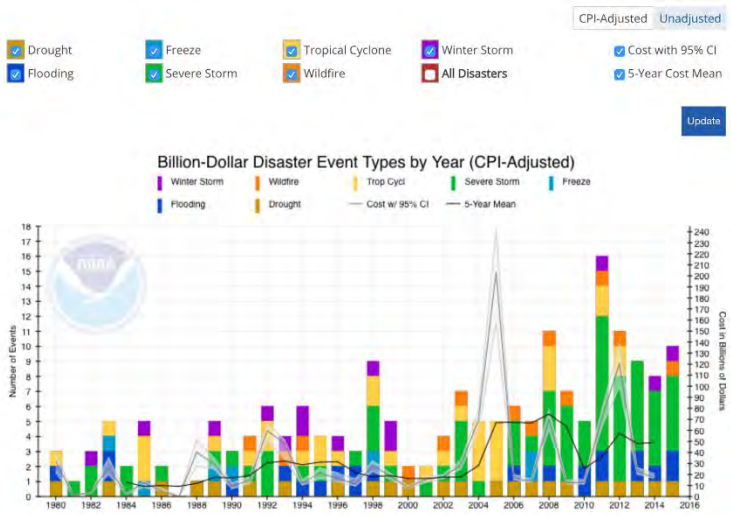
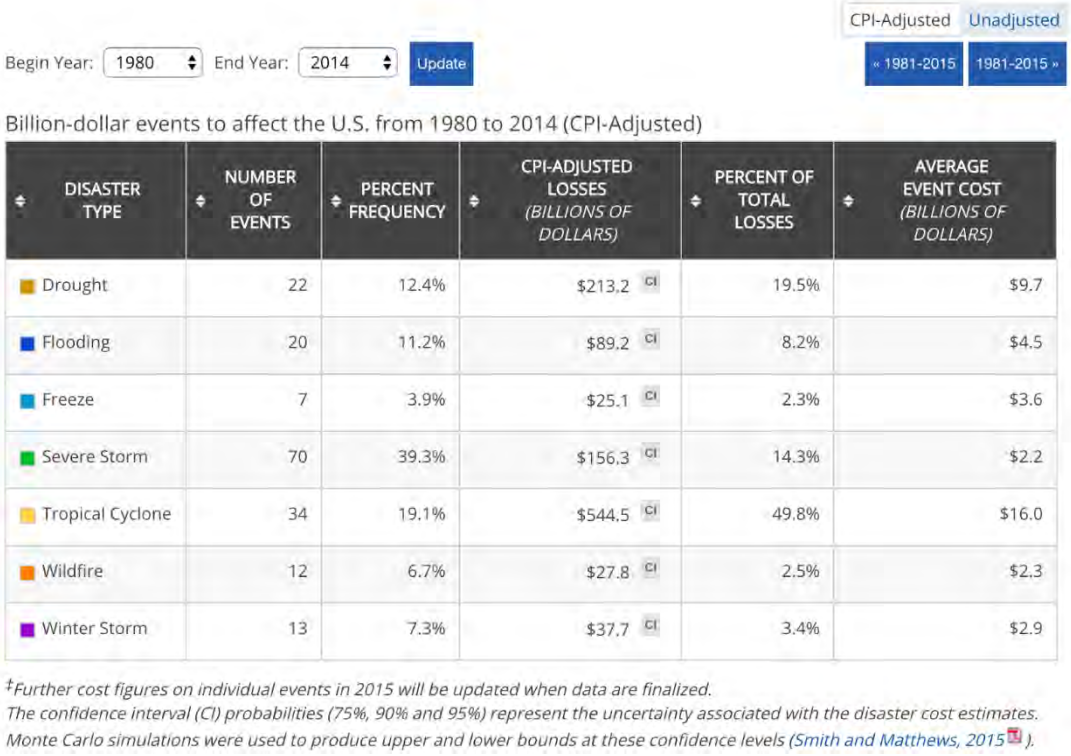


Figure 2.4.4.3

An example from the summary statistics tool.



CPI-Adjusted Unadjusted

Begin Year: 1980 End Year: 2014 Update

« 1981-2015 1981-2015 »

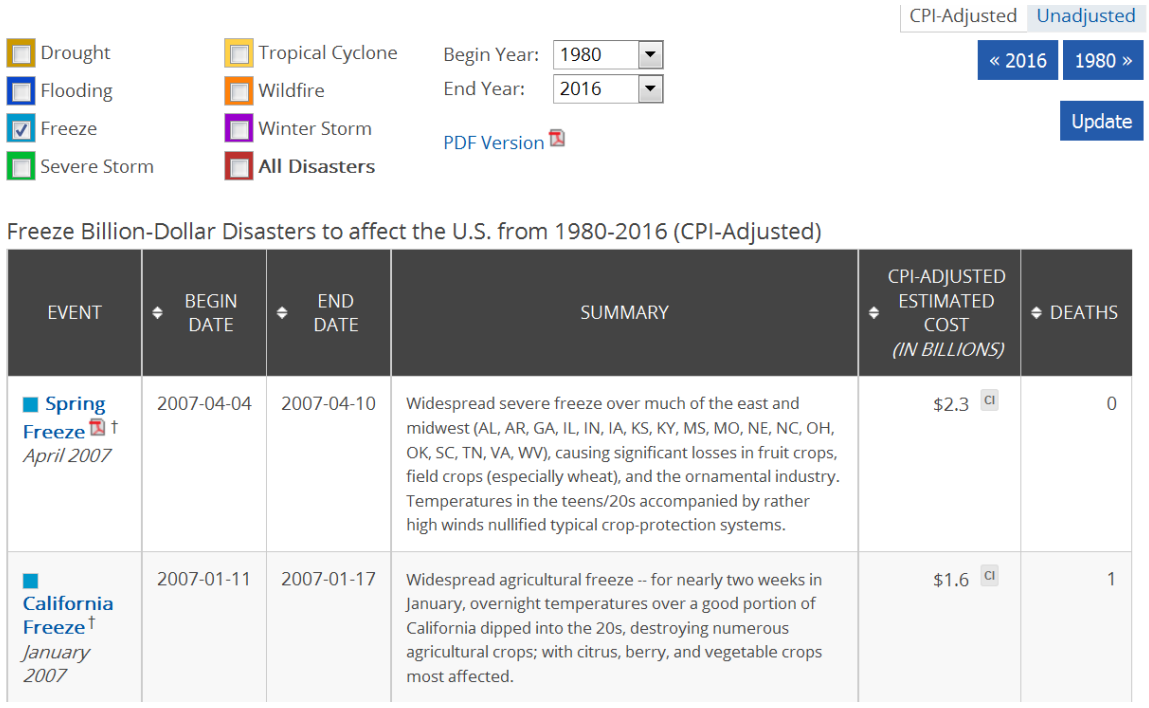
Billion-dollar events to affect the U.S. from 1980 to 2014 (CPI-Adjusted)

DISASTER TYPE	NUMBER OF EVENTS	PERCENT FREQUENCY	CPI-ADJUSTED LOSSES (BILLIONS OF DOLLARS)	PERCENT OF TOTAL LOSSES	AVERAGE EVENT COST (BILLIONS OF DOLLARS)
Drought	22	12.4%	$213.2 CI	19.5%	$9.7
Flooding	20	11.2%	$89.2 CI	8.2%	$4.5
Freeze	7	3.9%	$25.1 CI	2.3%	$3.6
Severe Storm	70	39.3%	$156.3 CI	14.3%	$2.2
Tropical Cyclone	34	19.1%	$544.5 CI	49.8%	$16.0
Wildfire	12	6.7%	$27.8 CI	2.5%	$2.3
Winter Storm	13	7.3%	$37.7 CI	3.4%	$2.9

‡*Further cost figures on individual events in 2015 will be updated when data are finalized.*
The confidence interval (CI) probabilities (75%, 90% and 95%) represent the uncertainty associated with the disaster cost estimates. Monte Carlo simulations were used to produce upper and lower bounds at these confidence levels (Smith and Matthews, 2015).

Figure 2.4.4.4

An example from the Table of Events tool showing summaries on a few freeze events.



CPI-Adjusted Unadjusted

« 2016 1980 »

Drought Tropical Cyclone Begin Year: 1980

Flooding Wildfire End Year: 2016

Freeze Winter Storm

Severe Storm All Disasters

PDF Version

Update

Freeze Billion-Dollar Disasters to affect the U.S. from 1980-2016 (CPI-Adjusted)

EVENT	BEGIN DATE	END DATE	SUMMARY	CPI-ADJUSTED ESTIMATED COST (IN BILLIONS)	DEATHS
Spring Freeze † *April 2007*	2007-04-04	2007-04-10	Widespread severe freeze over much of the east and midwest (AL, AR, GA, IL, IN, IA, KS, KY, MS, MO, NE, NC, OH, OK, SC, TN, VA, WV), causing significant losses in fruit crops, field crops (especially wheat), and the ornamental industry. Temperatures in the teens/20s accompanied by rather high winds nullified typical crop-protection systems.	$2.3 CI	0
California Freeze † *January 2007*	2007-01-11	2007-01-17	Widespread agricultural freeze -- for nearly two weeks in January, overnight temperatures over a good portion of California dipped into the 20s, destroying numerous agricultural crops; with citrus, berry, and vegetable crops most affected.	$1.6 CI	1

2.4.2 DATA SOURCES, TRENDS, ACCURACY AND BIASES

Adam Smith (NOAA NCDC) and Richard Katz (NCAR)
https://www.ncdc.noaa.gov/billions/docs/smith-and-katz-2013.pdf

Objective: The U.S. Billion-dollar Weather and Climate Disasters report records all U.S. weather and climate events since 1980 that have caused at least $1 billion in damages from total direct losses. This study helped identify and correct biases in the report.

Methodology: The report includes disasters whose *total direct loss* exceeds $1 billion (adjusted to 2011). *Total* loss refers to the sum of insured and uninsured losses. *Direct* loss refers to physical damage to buildings and material assets, time costs, public and private infrastructure and agricultural assets. Deliberately excluded are *indirect* losses, such as health care costs, costs associated with loss of life and losses to natural capital. Weather and climate disasters are categorized by disaster type: tropical cyclones, droughts/heatwaves, severe local storms, nontropical floods, winter storms, wildfires and freezes. This categorization reflects the different administrative agencies tasked with monitoring and maintaining data for each type of disaster. For each category, the two primary quantities needed to estimate the total direct loss are (1) an estimate of the total insured loss, and (2) an estimate of the insurance participation rate. Total direct losses are estimated as

$$\text{Estimated total direct loss} = \text{Estimated insured loss} \,/\, \text{Estimated insurance participation rate}$$

Data Sources: Table 2 of the paper shows all data sources used for the report, which include ISO/Property Claim Services, FEMA/National Flood Insurance Program, USDA/Risk Management Agency, the Army Corps, the National Fire Information Council and other state agencies.

Results and Conclusions: The report concludes that there is a statistically significant increase in the frequency of billion-dollar disaster events, and the magnitude is around +5% per year. This trend accounts for inflation but does not account for changes in exposure (population or wealth shifts).

The report also concluded that there was likely an *underestimation* of the average loss of each disaster by around 10–15% and attributed this underestimation to the factor approach used by the report. Calling *TL* the total loss, *IL* the insured loss and *p* the insurance participation rate, and assuming independence between *IL* and *p*, we have the expected total loss of

$$\mathrm{E(TL)} \;=\; \mathrm{E(IL\,/\,p)} = \mathrm{E(IL)} \cdot \mathrm{E}(1/\mathrm{p}) \;\geq \mathrm{E(IL)} \cdot 1/\mathrm{E(p)},$$

by Jensen's inequality. As the quantity on the right-hand side is what the NCDC report actually computes, the expected total loss on the left-hand side should be larger. The estimated 10–15% underestimation results from simple simulation studies performed by the authors. Reports issued since 2014 have corrected for this underestimation bias.

Potential Applications: By studying the method for producing the report and correcting for the underestimation bias, actuaries can repeat this analysis for any subtype of losses (crop only, property and so on) while properly accounting for random variation in the quantities *IL* and *R*. The procedure for aggregating insured losses and participation rates (obtaining data by state but aggregating to estimate total loss) is described, but it can either be improved on or be used in other settings. Further, actuaries can explore methods for removing the effects of exposure shifts from the trend estimation of +5% in the frequency of billion-dollar disasters to obtain more accurate frequency trend estimates.

2.4.3 QUANTIFYING UNCERTAINTY AND VARIABLE SENSITIVITY WITHIN THE U.S. BILLION-DOLLAR WEATHER AND CLIMATE DISASTER COST ESTIMATES

Adam Smith (NOAA NCDC) and Jessica Matthews (NC State and NOAA NCDC)
https://www.ncdc.noaa.gov/billions/docs/smith-and-matthews-2015.pdf

Objective: To provide (ex post facto) estimates of the uncertainty in the total direct losses estimated in the U.S. billion-dollar events database by varying input parameters, and to provide a framework to identify the most influential input parameters for these types of estimated total direct losses.

Methodologies: The authors use a factor approach to estimate total (that is, insured plus uninsured) direct losses by aggregating estimated direct insured losses L_i; using an example based on the 50 states, we have

$$\text{Estimated total direct loss} = \sum_{i=1}^{50} m_i L_i;\ m_i = \frac{1}{p_i};\ L_i = \text{Direct insured loss for state } i,$$

where the multiplier m_i is based on p_i, the estimated insurance participation rate for state *i*. Obtaining estimates for the p_i and L_i was described in the U.S. Billion-Dollar Weather and Climate Disasters: Data Sources, Trends, Accuracy and Biases report (hereafter referred to as DSTAB). In this follow-up study, the authors vary those obtained estimates p_i and L_i in four scenarios:

- +/- 3% based on uniform perturbations
- +/- 5% based on uniform perturbations
- +/- 3% based on normally distributed perturbations
- +/- 5% based on normally distributed perturbations

(Note it is not clear from the paper if "+/- 3% normal perturbations" refers to adding mean-zero random variable with a standard deviation of 3% or a different standard deviation, but this is a minor issue.) That is, the single point estimate from the DSTAB report is perturbed slightly, and a resulting estimated direct total loss is computed. This is repeated 10,000 times, yielding a distribution of 10,000 estimates. Using this distribution, the authors construct confidence intervals for estimates using appropriate quantiles, and they also investigate where within this range the reported single estimate from the DSTAB paper falls. Additionally, the authors demonstrate an easily implemented approach to identify which of the parameters, p_i or L_i, most influence the final total direct loss calculation.

Data Sources: The data used in this study match the data sources used in the original DSTAB (also summarized in this report).

Results and Conclusions: As a demonstration, the method described is applied to three billion-dollar events: the 2012 U.S. drought, the tornado super outbreak of April 25–28, 2011, and Hurricane Ike in 2008. In each case, 75%, 90% and 95% confidence intervals of total direct losses are estimated under the four perturbation scenarios. The uncertainty in these estimates is on the order of billions of dollars and highlights the importance of incorporating uncertainty into estimates.

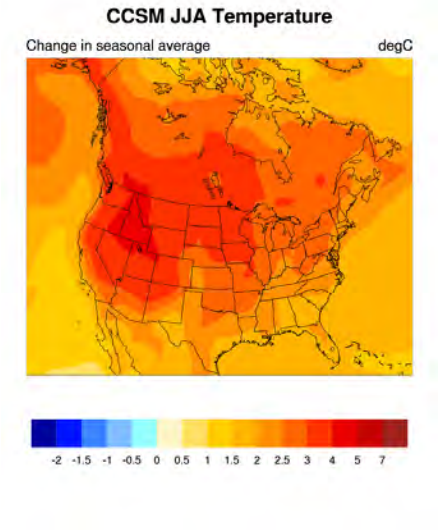
Potential Applications: The primary value to actuaries is in repeating the perturbation-based approach to estimating total direct losses when aggregating a collection of individually estimated losses. The authors demonstrate that minor uncertainties in input parameters can have a large collective impact on estimated total direct loss. Incorporating parameter uncertainty through simulations, bootstrapping or Bayesian statistical approaches adds tremendous value, as quantifying the uncertainty in estimates is an essential role of actuarial science.

2.5 NORTH AMERICAN REGIONAL CLIMATE CHANGE ASSESSMENT PROGRAM (NARCCAP)

http://www.narccap.ucar.edu/index.html

Figure 2.4.1

Source: UCAR



Objective: "The North American Regional Climate Change Assessment Program (NARCCAP) is an international program to produce high resolution climate change simulations in order to investigate uncertainties in regional scale projections of future climate and generate climate change scenarios for use in impacts research" (http://bit.ly/2bkX1BP).

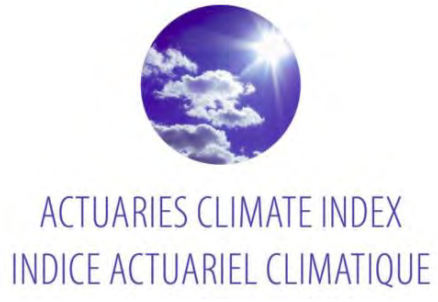
Methodology: General circulation models (GCMs) are computer experiments that project climate variables (temperature, precipitation, wind speeds, pressure and so on) into the future on a grid of locations across the globe. The spatial resolution is too coarse to make regional conclusions. As a partial remedy, one option is to nest a regional climate model (RCM), defined over a limited area, inside a global GCM. The GCM sets the boundary conditions, and the RCM runs the projections at a much finer spatial resolution, allowing users to make regional conclusions. This procedure is known as *dynamic downscaling*. The result is a set of higher resolution regional climate projections.

Data and Sources: NARCCAP uses global climate model output from CMIP3, under the SRES A2 emissions scenario. A variety of regional climate models are nested within a variety of general circulation models. The RCMs are run for both the future period of 2041–2070 and the current period 1971–2000 (useful for checking how well a GCM/RCM replicates the observed past climate). In addition, a number of regional projections for the period 1979–2004 are provided using the National Centers for Environmental Prediction (NCEP) Reanalysis as the driver (essentially, using the observed past climate as the GCM).

Results and Conclusions: The results from NARCCAP are regional climate model projections for 2041–2070 over most of North America at a spatial resolution that makes it possible to draw regional conclusions. In addition, NARCCAP provides model runs for the past (1971–2000), which are useful for checking how well RCMs can replicate the historical climate.

Potential Applications: The NARCCAP project provides a set of regional climate projections, and one stated goal is for "those who want to use the results as climate scenarios for performing impacts studies (e.g. on agriculture, water resources)" (http://bit.ly/2aHCHcA). But actuaries who are interested in this subject should plan to invest substantial time in understanding the climate models, how to access and manipulate the data and, *perhaps most importantly*, the limitations of regional climate modeling. While using climate scenarios for regional impacts is within the domain of NARCCAP, it is likely that actuaries will need to partner with experienced NARCCAP users before undertaking consequential projects.

2.6 ACTUARIES CLIMATE INDEX



http://www.actuariesclimateindex.org/

Objective: To create an index that measures changes in climate extremes and another index that relates those changes to actuarial risks. These indices should be objective, transparent, educational and useful as tools for actuaries.

Methodology: The Actuaries Climate Index (ACI) is constructed using a combination of six "frequency of severity" indices. These include high and low daily temperatures, heavy precipitation, lengthy drought, high winds and coastal sea levels. Using historical daily data drawn from a number of governmental and scientific sources, the researchers set a baseline (expected) for each of these six variables using the time period 1961–1990. Standardized anomalies of each variable are computed by comparing a quarterly value to its expected value and standard deviation, for instance as

$$\Delta S = \frac{(S_{actual} - S_{expected})}{\sigma_{S_{expected}}},$$

where S refers to the sea level measurement, and ΔS refers to the sea level anomaly—that is, the number of standard deviations a measurement is above or below its expected value. The six anomalies are dimensionless and can be averaged as

$$ACI = \frac{\Delta T_H + \Delta T_C + \Delta P + \Delta D + \Delta W + \Delta S}{6},$$

where the six items are high temperature, low temperature, precipitation, drought, wind and sea level, respectively. The ACI is computed quarterly for 2.5-degree grid cells across the United States and Canada, then rolled up into 12 regions, the country level and a single North American aggregate index.

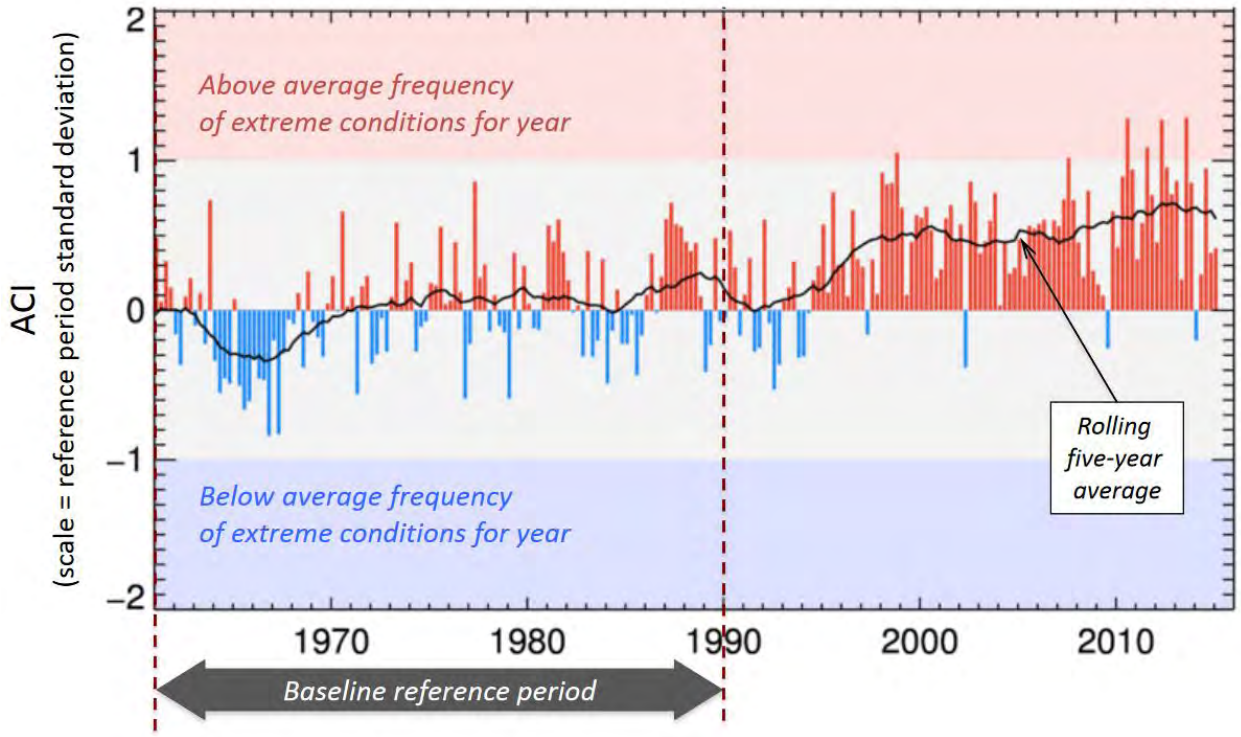
The Actuarial Climate Risk Index (ACRI) relates the ACI to economic losses, mortality and morbidity. It then uses a weighted average based on population to create an index that more closely tracks climate change in areas of people and property.

Data and Sources: Temperature data and precipitation data used to construct ΔT_H, ΔT_C, ΔP and ΔD come from CLIMDEX, which is itself based on the Global Historical Climate Network-Daily (also summarized in this report). Wind data for ΔW comes from NOAA Earth Systems Research Laboratory. Sea level data for ΔS comes from the Permanent Service for Mean Sea Level (PSMSL) at the U.K. National Oceanography Center. Economic data are obtained from the Spatial Hazard Events and Losses Database for the United States (SHELDUS) and the Canadian Disaster Database.

Results and Conclusion: The resulting indices are published quarterly. Shown below is the ACI for all of North America, along with a five-year moving average shown in black. The ACI is clearly up from its baseline in 1961–1990, measuring the increasing prevalence of extreme events (in relation to the baseline period).

Figure 2.6.1

The ACI for all of North America, along with a five-year moving average shown in black.



Potential Applications: The research team for the ACI and ACRI envisions these two indices as useful educational tools for actuaries and as potential input quantities for risk management decisions and products. Possible expansions include other regions, deeper analysis of subcomponents of the indices and research on the statistical connections between the ACI/ACRI and quantities of interest to the insurance world (claims, exposures and so on).

2.7 CHICAGO MERCANTILE EXCHANGE GROUP WEATHER PRODUCTS

http://www.cmegroup.com/trading/weather/

Objective: Weather products are financial contracts whose payments are determined by outcomes in the weather. Institutions may buy these to protect against weather risks or to use as financial investments. Major weather products include those with payments based on temperature (specifically heating and cooling degree days) and precipitation, though contracts are based on other weather variables as well. Some are sold at the CME Group, while others are more specialized or sold over the counter.

Methodology: The largest class of weather derivatives are based on cooling degree days (*CDD*s) and heating degree days (*HDD*s), defined using average daily temperature *T* as

$$CDD = max(T - 65, 0) \text{ and } HDD = max(65 - T, 0).$$

These quantities are then summed up over all days $d \in D$ into *cumulative cooling degree days* (and *cumulative heating degree days*), as

$$cCDD = \sum_{d \in D} CDD_d.$$

The resulting quantity is a measure for the overall demand for cooling (or heating) within time period *D,* without regard to specifically how that demand was distributed. Products based on *cCDD*s and *cHDD*s are traded for several North American cities at the CME, generally for monthly, seasonal and annual time periods.

Data and Sources: U.S.-based MDA EarthSat and UK-based Speedwell provide much of the data used to determine weather derivative settlements, as well as short-term forecasts and other specialized services. Historical settlement data on weather derivatives is available at the CME, which allows a *burn analysis* as an entry point for exploring the actuarial behavior of possible contracts.

Potential Applications: Weather derivatives are closely related to index-based insurance products and can be used as a tool sold by insurers to allow clients to manage weather risk. They also form investment opportunities for insurers, as their performance is driven by the weather and is therefore largely unrelated to the performance of financial markets.

The Industry Links section of the CME Weather Products website connects to multiple sources of historical weather data, short-term weather predictions and agencies and groups that work in the weather derivative and weather risk sector. Several of these data sources can be used to study possible index-based insurance products.

Section 3: Reports and Books on Climate Risk

The climate is big and complicated. The politics and possible responses to climate change make the issue even larger and more complex. Risk managers, scientists, policymakers and citizens encounter material they need to understand to make the best decisions. This section provides excellent sources on the basic science, policy, adaptation strategies and current trends—the background necessary for determining how best to manage climate risk.

The section begins with three reports from the Nobel Prize-winning Intergovernmental Panel on Climate Change, undoubtedly the agency that most captures the "scientific consensus" on climate change. These reports include the high-level "Synthesis Report Summary for Policymakers" (3.1.1), which was written to convey basic climate science and climate trends to a nonscientific audience. In addition, this section describes "Impacts, Adaptation and Vulnerability: Summary for Policymakers" (3.1.2), looking specifically at the consequences of climate change and possible responses to those consequences. There is also the "IPCC Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX): Chapter 9 Case Studies" (3.1.3), which provides a risk management perspective.

Many excellent books on climate science, climate adaptation and climate risk management have been written, but this section focuses on just four of these works. The first, *An Introduction to Modern Climate Change* (3.2), focuses on basic climate science and is perfect for risk managers seeking basic scientific literacy on the subject. The second, *The Science and Politics of Global Climate Change: A Guide to the Debate*, second edition (3.3), transitions to how the science shapes (or fails to shape) public discussion about and policies concerning climate change. Two books that delve more directly into risk management are *Weather Derivative Valuation* (3.4) and *At War with the Weather: Managing Large-Scale Risks in a New Era of Catastrophes* (3.5).

The 2015 United Nations Climate Change Conference, or COP21 (3.6), made history with a new framework to synchronize efforts to mitigate climate change and adapt to its unavoidable consequences. Finally, the nonprofit news website Climate Central (3.7) has distinguished itself as a valuable source for developments in both the science of and responses to climate change.

Table 3.1

Major areas addressed in section 3

Source	Life insurance	Health insurance	Finance and microfinance	Property and casualty	Fundamentals of risk management
3.1.1					
3.1.2					✓
3.1.3			✓		✓
3.2					
3.3					
3.4			✓		✓
3.5			✓	✓	✓
3.6			✓		
3.7					

Table 3.2

Major areas addressed in section 3

Source	Government or public partnerships	Regulations	Developing nations	Public policy	Basic climate science
3.1.1	✓			✓	✓
3.1.2	✓		✓	✓	
3.1.3	✓		✓	✓	
3.2				✓	✓
3.3	✓	✓		✓	✓
3.4					
3.5	✓	✓			
3.6	✓	✓	✓	✓	✓
3.7				✓	✓

3.1 THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

3.1.1 SYNTHESIS REPORT SUMMARY FOR POLICYMAKERS

https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

Objective: "The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation" (http://bit.ly/2aNbjVL).

The IPCC was awarded half of the 2007 Nobel Peace Prize. The summary for policymakers—published roughly every five years along with each new assessment report—is designed to convey the broad scientific consensus to the community of leaders in non-scientific settings.

Methodology: Roughly every five years, the IPCC oversees the publication of a comprehensive assessment report that reviews the latest scientific understanding of the climate. The most recent was the Fifth Assessment Report, released in 2014, just before the 2015 United Nations Climate Change Conference in Paris. Written by more than 800 authors and reviewing 9,200 scientific papers on the subject, the Fifth Assessment Report is comprehensive but not well suited as a summary document for nonscientists. To fill this need, the IPCC also publishes a synthesis report summary for policymakers alongside the full-length report. The 2014 summary is a 32-page document highlighting the most significant findings, graphics and statements of scientific consensus. This report is approved by governmental members of the IPCC, with negotiations over how best to convey the degree of certainty and clarity.

Data and Sources: It is not a stretch to say that the data and sources underlying the full IPCC assessment reports comprise nearly "everything scientific" on the subject. More than 9,200 scientific papers, along with all of the data analyzed within these papers, went into the IPCC Fifth Assessment Report "Climate Change 2014: Mitigation of Climate Change." The summary, "Climate Change 2014: Synthesis Report Summary for Policymakers," is based on the full assessment report. Citations are available for the full Assessment Report for working Groups One, Two and Three.

Results and Conclusions: The report provides a series of very simple, high-quality images that demonstrate the historic nature of the shifts in the climate system. In addition, it provides clear and precise statements of the scientific consensus of climate change at the time of publication. Three of the strongest headlines from the 2014 summary are from pages 2 and 4:

"Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems."

"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen."

"Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last

800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century."

Potential Applications: Actuaries should see the "Synthesis Report Summary for Policymakers" as the point of entry into the massive world of the IPCC and its reports. It is customary to cite precise statements (such as the three shown above) or images from the IPCC. Therefore, the primary value of this source is to allow actuaries to understand and state the scientific consensus surrounding climate changes and impacts and to use key statements and figures in their own presentations. Images and statements from the IPCC may be reproduced according to the following policy:

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IPCC Secretariat,
World Meteorological Organization, 7bis
Avenue de la Paix, P.O. Box No. 2300, CH-1211
Geneva 2, Switzerland.

3.1.2 IMPACTS, ADAPTATION AND VULNERABILITY: SUMMARY FOR POLICYMAKERS

http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf

Objective: Part of the IPCC Fifth Assessment Report, the "Impacts, Adaptation and Vulnerability Summary for Policymakers" moves beyond the basic physical science and focuses on projected consequences of climate change, including both risks and opportunities for policymakers.

Methodology: The summary is organized into three main sections: Observed Impacts, Future Risks and Opportunities and Managing Future Risks and Building Resilience. In addition to observed changes in the climate itself (largely summarized in the synthesis report for policymakers), the Observed Impacts section points out that *consequences of the observed changes in the climate have also been observed*. With a "high" or greater level of confidence, the report discusses species' shifts in migration, territory and abundance; changes in crop yields; impacts from climate-related extreme weather events; and stressors for people living in poverty. Some results from the future risks and managing risks sections are shown on the following page.

Data and Sources: The full list of citations and sources is available here: http://www.ipcc.ch/report/ar5/wg2/docs/WG2AR5_Citations.pdf.

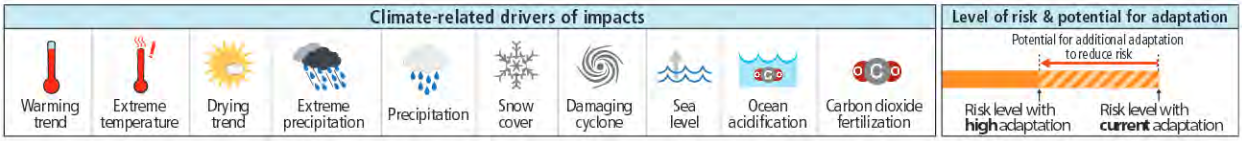
Results and Conclusions: Page 12 of the IPCC summary identifies eight key risks that span sectors and regions with high confidence (reprinted verbatim):

1. Risk of death, injury, ill-health, or disrupted livelihoods in low-lying coastal zones and small island developing states and other small islands, due to storm surges, coastal flooding, and sea level rise.
2. Risk of severe ill-health and disrupted livelihoods for large urban populations due to inland flooding in some regions.
3. Systemic risks due to extreme weather events leading to breakdown of infrastructure networks and critical services such as electricity, water supply, and health and emergency services.
4. Risk of mortality and morbidity during periods of extreme heat, particularly for vulnerable urban populations and those working outdoors in urban or rural areas.
5. Risk of food insecurity and the breakdown of food systems linked to warming, drought, flooding, and precipitation variability and extremes, particularly for poorer populations in urban and rural settings.
6. Risk of loss of rural livelihoods and income due to insufficient access to drinking and irrigation water and reduced agricultural productivity, particularly for farmers and pastoralists with minimal capital in semi-arid regions.
7. Risk of loss of marine and coastal ecosystems, biodiversity, and the ecosystem goods, functions, and services they provide for coastal livelihoods, especially for fishing communities in the tropics and the Arctic.
8. Risk of loss of terrestrial and inland water ecosystems, biodiversity, and the ecosystem goods, functions, and services they provide for livelihoods.

Figure 3.1.1.1

Reproduced below is the portion of Assessment Box SPM.2 Table 1 (page 23), that focuses on three key risks for North America.

Assessment Box SPM.2 Table 1 | Key regional risks from climate change and the potential for reducing risks through adaptation and mitigation. Each key risk is characterized as very low to very high for three timeframes: the present, near term (here, assessed over 2030–2040), and longer term (here, assessed over 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially for different emission scenarios. For the longer term, risk levels are presented for two scenarios of global mean temperature increase (2°C and 4°C above preindustrial levels). These scenarios illustrate the potential for mitigation and adaptation to reduce the risks related to climate change. Climate-related drivers of impacts are indicated by icons.



North America

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation (Very low / Medium / Very high)
Wildfire-induced loss of ecosystem integrity, property loss, human morbidity, and mortality as a result of increased drying trend and temperature trend (*high confidence*) [26.4, 26.8, Box 26-2]	• Some ecosystems are more fire-adapted than others. Forest managers and municipal planners are increasingly incorporating fire protection measures (e.g., prescribed burning, introduction of resilient vegetation). Institutional capacity to support ecosystem adaptation is limited. • Adaptation of human settlements is constrained by rapid private property development in high-risk areas and by limited household-level adaptive capacity. • Agroforestry can be an effective strategy for reduction of slash and burn practices in Mexico.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Heat-related human mortality (*high confidence*) [26.6, 26.8]	• Residential air conditioning (A/C) can effectively reduce risk. However, availability and usage of A/C is highly variable and is subject to complete loss during power failures. Vulnerable populations include athletes and outdoor workers for whom A/C is not available. • Community- and household-scale adaptations have the potential to reduce exposure to heat extremes via family support, early heat warning systems, cooling centers, greening, and high-albedo surfaces.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Urban floods in riverine and coastal areas, inducing property and infrastructure damage; supply chain, ecosystem, and social system disruption; public health impacts; and water quality impairment, due to sea level rise, extreme precipitation, and cyclones (*high confidence*) [26.2-4, 26.8]	• Implementing management of urban drainage is expensive and disruptive to urban areas. • Low-regret strategies with co-benefits include less impervious surfaces leading to more groundwater recharge, green infrastructure, and rooftop gardens. • Sea level rise increases water elevations in coastal outfalls, which impedes drainage. In many cases, older rainfall design standards are being used that need to be updated to reflect current climate conditions. • Conservation of wetlands, including mangroves, and land-use planning strategies can reduce the intensity of flood events.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	

Potential Applications: In the section Managing Future Risks and Building Resilience (page 26), one item of particular interest to actuaries is as follows: "Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts (medium confidence). Instruments include public-private finance partnerships, loans, payments for environmental services, improved resource pricing, charges and subsidies, norms and regulations, and risk sharing and transfer mechanisms. Risk financing mechanisms in the public and private sector, such as insurance and risk pools, can contribute to increasing resilience, but without attention to major design challenges, they can also provide disincentives, cause market failure, and decrease equity. Governments often play key roles as regulators, providers, or insurers of last resort."

3.1.3 IPCC SPECIAL REPORT: MANAGING THE RISKS OF EXTREME EVENTS AND DISASTERS TO ADVANCE CLIMATE CHANGE ADAPTATION (SREX)—CHAPTER 9 CASE STUDIES

https://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf

Objective: "To frame the challenge of dealing with extreme weather and climate events as an issue in decision-making under uncertainty, analyzing response in the context of risk management."

Methodology: Risk-financing mechanisms are described across three scales: the local (households and farmers), national (governments) and international (development organizations, nongovernment organizations). This is shown in Table 9-3 from page 523 of the report, reproduced below:

Figure 3.1.3.1

Reproduced table from the IPCC special report.

Table 9-3 | Examples of risk financing mechanisms (shaded cells) at different scales. Source: adapted from Linnerooth-Bayer and Mechler, 2009.

	Local *Households, Farmers, SMEs*	***National*** *Governments*	***International*** *Development organizations, donors, NGOs*
Solidarity	Help from neighbors and local organizations	Government post-disaster assistance; government guarantees/bailouts	Bilateral and multilateral assistance, regional solidarity funds
Informal risk transfer (sharing)	Kinship and other reciprocity obligations, semi-formal micro-finance, rotating savings and credit arrangements, remittances		
Savings, credit, and storage (inter-temporal risk spreading)	Savings; micro-savings; fungible assets; food storage; money lenders; micro-credit	Reserve funds; domestic bonds	Contingent credit; emergency liquidity funds
Insurance instruments	Property insurance; crop and livestock insurance; micro-insurance	National insurance programs; sovereign risk transfer	Re-insurance; regional catastrophe insurance pools
Alternative risk transfer	Weather derivatives	Catastrophe bonds	Catastrophe bonds; risk swaps, options, and loss warranties

The shaded cells and items indicate those that involve a risk-financing mechanism and are therefore areas of opportunity for insurers and actuaries. Three examples that span the three scales are described.

Data and Sources: This summary focuses in particular on Section 9.2.13 "Risk Transfer: The Role of Insurance and Other Instruments in Disaster Risk Management and Climate Change Adaptation in Developing Countries."

Results and Conclusions: The first case study describes the 2003 implementation of micro index-based crop insurance in Andhra Pradesh, India. Insurance payments were triggered by outcomes in rainfall measured at a local rainfall gauge. This eliminated moral hazard as well as the transaction costs of claims handling and helped farmers gain access to credit. The second case study describes how the World Food Programme (WFP) set up a capital program based on the Ethiopia Drought Index; this case study serves as a powerful example of the success of drought indices. The third case study describes a catastrophe insurance pool set up by sixteen Caribbean governments.

Potential Applications: The section ends with four broadly described outcomes (presented here verbatim):

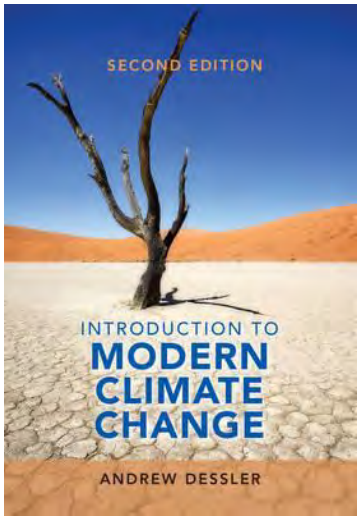
- Because risk transfer instruments require detailed analysis of risk, they can both raise awareness and provide valuable information for its response and reduction.
- By pricing risk, insurance can provide incentives for investments and behavior that reduce vulnerability and exposure, especially if premium discounts are awarded.
- Insurers and other providers can make risk reduction a contractual stipulation.

> Providers can partner with government and communities to establish appropriate regulatory frameworks and promote, for instance, land use planning, building codes, emergency response, and other types of risk-reducing policies." (page 525, http://bit.ly/1WN0vsO)

Actuaries will find success stories in the developing world for innovative products, the creation of new markets for risk-sharing mechanisms and information on how this work ties into greater global goals for climate risk management.

3.2 AN INTRODUCTION TO MODERN CLIMAGE CHANGE, SECOND EDITION

Andrew Dessler, Texas A&M University
Cambridge University Press, 2015



An Introduction to Modern Climate Change is an excellent introductory textbook, covering both the underlying science and the policy implications of changes to the earth's climate system. The second edition reflects information presented in the the IPCC Fifth Assessment Report. In the introduction, the author explains, "The goal of the book is to cover the human-induced climate change problem from stem to stern, covering not just the physics of climate change but also the economic, policy, and moral dimensions of the problem" (page ix).

The scientific material assumes only high school–level quantitative skills, and no particular background in science is required. Indeed, the book is used in Climate Literacy courses at colleges and universities, so curious actuaries should not encounter much technical difficulty. Chapters 1–7 cover various aspects of the science of the climate and climate change in a broadly accessible way, culminating with future climate predictions in Chapter 8.

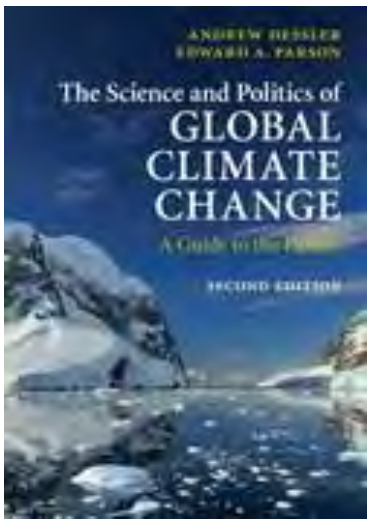
Then the book delves into chapters on the impacts of climate change, exponential growth, fundamentals of climate change policy, mitigation policies, a brief history of climate science and politics and putting everything together for a long-term policy to address climate change. These later chapters encourage big thinking on the proper responses to climate change. They ask to what degree should our responses be based on *mitigation* (dealing with the causes of climate change), *adaptation* (making adjustments to deal with the impacts of climate change) or *geoengineering* (actively trying to intervene in the climate)?

Actuaries should find the discussion of adaptation to be particularly exciting. Adaptation led by actuaries might include new insurance products and new methods for managing crop risks, droughts, flood risk, catastrophe reinsurance and bonds and so forth. It could also include efforts to advocate for new insurance regulations, private-public partnerships or government-backed risk pools.

Actuaries less familiar with climate change should also appreciate the tone of this book. Dessler writes, "This is not a book of advocacy . . . my strategy in this book is to just explain the science and then lay out the possible solutions and trade-offs among them" (page xi). By including some discussion of the costs and trade-offs, Dessler fuses the economic with the scientific. The result points to a place where actuaries should find that their skills of quantifying risks and placing dollar figures on uncertain outcomes are in demand.

3.3 THE SCIENCE AND POLITICS OF GLOBAL CLIMATE CHANGE: A GUIDE TO THE DEBATE, SECOND EDITION

Andrew Dessler and Edward Parson
Cambridge University Press, March 2010



Coauthored by an atmospheric scientist and a public policy expert, the second edition of *The Science and Politics of Global Climate Change: A Guide to the Debate* explores the intersection of the science of, politics surrounding and policy responses to climate change. The title of Chapter 2, "Science, Politics, and Science in Politics" captures the overall arc of this short book, which discusses some basics of climate science and public policy with regard to climate change and then explores the intersection of the two.

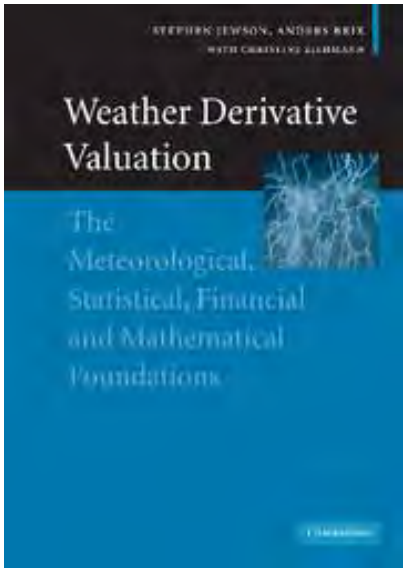
While the science is covered and does not assume any scientific background on the part of the reader, the coverage is less complete than what would be found in a source devoted entirely to the science. Chapters 1 and 3 of the book guide the reader through some of the basics of climate science and scientific evidence for climate change. This scientific foundation is more or less an answer to the question, what scientific literacy would be needed to understand the public policy debates? Contrarian claims are also analyzed alongside the relevant scientific facts.

Chapter 2 describes the foundations for the different types of arguments advanced in the climate change policy debate, including which arguments relate to testable scientific principles and therefore which types of arguments can be framed in scientific terms. Chapter 4 broadly discusses some policy responses, and these fall largely into the categories of mitigation (addressing the causes of climate change), adaptation (addressing the impacts of climate change) and the less-discussed geoengineering (actively modifying the climate system). Chapter 5 is admittedly political, addressing head-on the political positions and actions of powerful leaders and offering suggestions from the authors on paths forward.

Since most actuaries are neither scientific experts nor public policy experts, the entirety of this book should serve as a good resource about the basic foundations of how climate science informs and supports particular public policy responses. In particular, seeing how the insurance industry as a whole and its constituent pieces individually (insurers, consultants, regulators and so on) can take actions in mitigation or adaptation is a useful way of seeing the connections between actuarial science and climate change. This book can also serve a valuable educational role in teaching actuaries about how to form a private-public partnership to manage climate risks.

3.4 WEATHER DERIVATIVE VALUATION: THE METEOROLOGICAL, STATISTICAL, FINANCIAL, AND MATHEMATICAL FOUNDATIONS

Jewson, Stephen and Brix, Anders, with Ziehmann, Christine.
Cambridge Press, 2005



Hailed as the first book to cover the breadth of mathematical, statistical, financial and meteorological considerations for the pricing of weather derivatives, *Weather Derivative Valuation* persists as a highly readable yet comprehensive text on the subject of weather derivatives. For many actuaries, this text will serve as an accessible starting point to their reading on the subject.

Weather derivatives are financial contracts whose payments are determined by observed weather outcomes. Specifying a set of locations, time periods and particular weather outcomes in advance, businesses and other institutions can use weather derivatives as financial protection against adverse weather outcomes. Financial institutions can serve as a counterparty, with the aim of making a profit through premiums or of diversifying a financial portfolio with holdings.

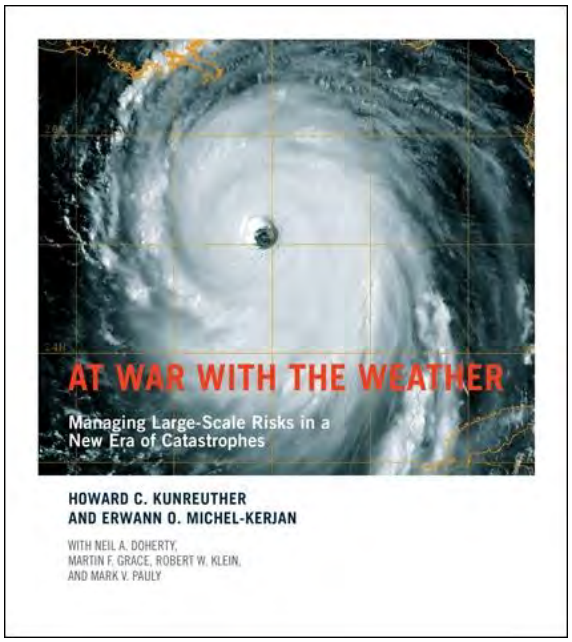
Opening with an accessible introduction to the motivation for and definitions of different types of weather derivatives, this book does an excellent job of balancing the presentation of two fundamentally different methods for pricing: *actuarial* and *financial*. Actuarial pricing focuses on estimating the range of possible outcomes and their relative likelihoods; that is, developing a probability model. Financial pricing is concerned with utilizing market prices and financial theory such as arbitrage pricing. The depth of material on the actuarial method includes a discussion of data sources and cleaning, the distinction between modeling weather at the daily level versus modeling at the index level, considerations for moving from a single contract to a portfolio and how meteorological forecasts are constructed and can be used. This material, at well over half the book, is the most directly applicable for the actuary. But for those actuaries with experience in financial theory, the chapters on connections between weather derivatives and Black-Scholes, arbitrage and the mathematical considerations of the "Greeks" are enlightening. In particular, the absence of an underlying tradable asset makes these financial instruments fundamentally different from other financial derivatives.

The authors combine several decades of experience in senior leadership positions in the insurance and risk management industries with a clear, expository writing style aimed at practicing actuaries. It may well be impossible to read this and not come away with new insights into the connections between weather risk and actuarial science.

3.5 AT WAR WITH THE WEATHER: MANAGING LARGE-SCALE RISKS IN A NEW ERA OF CATASTROPHES

Howard Kunreuther and
Erwann Michel-Kerjan
https://mitpress.mit.edu/node/195563

Figure 3.5.1
Cover of *At War with the Weather: Managing Large-Scale Risks in a New Era of Catastrophes*, edited by Howard Kunreuther et al, published by The MIT Press.



At War with the Weather proclaims that we have entered a "new era" in weather catastrophes, a result of concentration of population, infrastructure and assets along the nation's coast. The focus is on hurricanes, but the book maintains enough generality that the discussion applies to other natural disasters as well.

The two guiding principles that form the basis of the exposition are that (1) premiums should reflect risk, properly signaling to the marketplace what the true cost is, and 2) subsidies or assistance to the underinsured and uninsured should come from public sources rather than from insurance cross-subsidies. These two, when taken together, advocate for an open, free and transparent marketplace for disaster insurance, in which the insurance industry helps to steer coastal development toward lower risk outcomes.

The book offers a comprehensive treatment on disaster insurance, achieved by blending specific case studies with general discussion and analysis. The case studies are Miami-Dade, Florida; New York City; Charleston, South Carolina; and Houston, Texas, providing four distinct regions and four distinct states that manage and regulate hurricane risk differently. The book is divided into four broad themes: cause for concern, understanding the demand and supply for disaster insurance, protecting homeowners against natural disasters and creating innovative solutions. The first set of chapters describes the confluence of forces that have led to the "new era" of risk. The second set deals with how homeowners demand and purchase insurance and how insurers supply and finance it. The book provides evidence that homeowners appear to underestimate the risks, and insurers are at risk as well. The third theme explores the homeowner's insurance market in further detail by analyzing affordability, risk-reduction measures and possible alternatives to the status quo. Finally, the fourth theme discusses how to "win" the war against weather.

Actuaries interested in the subject of weather and climate risks will not be disappointed. The text is simultaneously complete and gripping. The authors presume the reader is a sophisticated professional but not necessarily an expert. Mathematical expressions, data visualizations and precise terms taken from economics, finance or the law are used throughout, but these always serve to strengthen the point being made. In short, this book should be considered required reading for any actuary working in catastrophe modeling.

3.6 OUTCOMES OF THE 2015 U.N. CLIMATE CHANGE CONFERENCE IN PARIS

http://www.c2es.org/docUploads/cop-21-paris-summary-02-2016-final.pdf

Background: The 2015 United Nations Climate Change Conference (sometimes written as COP21 or CMP11) was held in Paris in late 2015. One hundred and ninety-five nations were represented, and more than 150 presidents and prime ministers were in attendance, setting a record for the most heads of state gathered in a single day. The major result is known as the Paris Agreement. This agreement is widely reported as a "hybrid" approach and is thus different from—but still a successor to—the Kyoto Protocol. From the top down, the agreement imposes requirements that nations transparently develop plans to reduce emissions, openly improve those plans and report all progress. From the bottom up, nations are given flexibility as to how they implement and achieve these plans. Global targets, standards for reporting and accounting and mechanisms to assist developing nations were also part of the agreement.

Results: With respect to mitigation (dealing with the causes of climate change), the agreement set a global goal to limit global temperature increase to 2°C above preindustrial levels, while urging additional effort to limit the increase to only 1.5°C. All nations must also develop *nationally determined contributions* (NDCs), which are expected net greenhouse gas contributions. Each country must publicize its NDC, along with all the information needed to evaluate how successfully it is implementing that contribution. An expert panel will review each nation's progress in a "facilitative" manner, and countries must update their NDCs every five years with a clear progression.

The precise means by which countries achieve reductions is flexible. The Paris Agreement sets accounting standards to accurately track "carbon transfers," whereby one country's excess reductions may be counted toward another country's balance. Naturally, there are strict rules against double-counting.

For adaptation (dealing with the consequences of climate change), the agreement sets global goals and transparency standards to extend adaptation efforts. These extend support for vulnerable nations dealing with unavoidable impacts (such as those at immediate risk of sea level rise) but explicitly do not allow for liability of compensation. Collectively, nations pledged $19 billion to assist developing nations with mitigation and adaptation.

As of late 2016, the legal process of nations ratifying the agreement was unfolding. The agreement called for stocktaking in 2023.

3.7 CLIMATE CENTRAL

http://www.climatecentral.org/

Objective: "To communicate the science and effects of climate change to the public and decision-makers" (http://bit.ly/2aREwkj).

Methodology: The organization describes itself this way: "An independent organization of leading scientists and journalists researching and reporting the facts about our changing climate and its impact on the public. Climate Central surveys and conducts scientific research on climate change and informs the public of key findings. Our scientists publish and our journalists report on climate science, energy, sea level rise, wildfires, drought, and related topics. Climate Central is not an advocacy organization. We do not lobby, and we do not support any specific legislation, policy or bill. Climate Central is a qualified 501(c)3 tax-exempt organization" (http://bit.ly/2aREwkj).

Climate Central is the fusion of scientific research and nonpartisan climate journalism.

Its research group publishes scientific, peer-reviewed research on climate science and its projected impacts. The research focus is divided into four programs: climate science, energy, sea level rise and meteorology. In addition to research, each program produces data analysis, visualizations, interactive tools and reports aimed at "decision-makers."

An internally independent news group publishes daily news pieces on issues relating to climate change, as well as the surrounding social, political and impacts landscape.

In addition to scientific studies and news pieces, the website offers free supplemental materials, including several galleries of images and infographics, videos, special reports, data visualization tools and a tool called States of Change, which collects stories and research on climate change at a local level.

Potential Applications: Climate Central produces a wide range of high-quality, technically sophisticated materials designed to educate and inspire nonscientists. They similarly produce a range of data analysis, visualization and exploration tools relating to climate risks. Actuaries who follow this site will keep themselves up-to-date on news on climate science and its projected impacts.

Section 4: Industry-wide Viewpoints, Statements and Reports

In this section, we take a step back from specific databases, companies or books, and ask what the insurance industry as a whole is doing. Specifically, we ask what the industry is measuring and disclosing about climate risks, what information it collects or feels is needed, what changes it feels should be made to regulations and what innovative experiments from large-scale partnerships are being implemented.

This section begins with a comprehensive introduction to "The Geneva Association" (4.1), which presents itself as the world's leading international insurance think tank. We focus on just two of its many reports: "Insurance Industry and Climate Change" and "Insurers' Contribution to Disaster Reduction—11 Case Studies."

Lawrence Berkeley National Laboratory scientist Evan Mills put together a comprehensive research program in the 1990s titled "Insurance in a Climate of Change" (4.2), in which he painstakingly detailed major trends within the insurance industry in response to climate change. His first publication in the prestigious journal *Science* is summarized in this section, along with his industry survey results in "A Global Review of Insurance Industry Responses to Climate Change" (4.3).

One of the few papers written specifically on the topic of insurance regulation, "The Potential Impact of Climate Change on Insurance Regulation" (4.4) presents the findings from the National Association of Insurance Commissioners (NAIC) from a multiyear study that examined how climate change would strain existing insurance regulations. The NAIC then teamed up with Ceres in "Insurer Climate Risk Disclosure Survey Report & Scorecard: 2014 Findings & Recommendations" (4.5) to conduct an industry-wide survey exploring the degree to which insurers are measuring and disclosing climate risks.

The NAIC/Ceres survey, along with Evan Mills's survey analysis, makes clear that the insurance industry has a way to go before it is fully measuring and disclosing climate risks. To help identify the hurdles, we have "Advancing Adaptation through Climate Information Services" (4.6) from the United Nations Environment Programme Finance Initiative (UNEPFI), which asks its members what they need to better link their services to climate risk management. The authors also analyze possible roles for the private finance industry in "Adaptation and Vulnerability to Climate Change: The Role of the Financial Sector" (4.7).

The "Insurance Information Institute" (4.8) remains a reliable source of industry-wide information and research, and this work increasingly covers climate and weather risk. And finally, this section and the entire report closes with a summary of the "Munich Climate Insurance Initiative" (4.9). This group is an ambitious "laboratory on climate change and insurance," leading the way on innovative programs designed to manage rising climate risks across the globe.

Table 4.1

Major areas addressed in section 4

Source	Life insurance	Health insurance	Finance and microfinance	Property and casualty	Fundamentals of risk management
4.1			✓	✓	✓
4.2	✓	✓			✓
4.3					✓
4.4					
4.5	✓	✓	✓	✓	
4.6			✓		✓
4.7			✓		
4.8	✓	✓	✓	✓	✓
4.9			✓		✓

Table 4.2

Major areas addressed in section 4

Source	Government or public partnerships	Regulations	Developing nations	Public policy	Basic climate science
4.1	✓		✓		
4.2				✓	✓
4.3					
4.4		✓			
4.5					
4.6	✓				
4.7					
4.8		✓		✓	
4.9	✓	✓	✓	✓	

4.1 THE GENEVA ASSOCIATION

https://www.genevaassociation.org/

Objective: The Geneva Association describes itself as "the leading international think tank of the insurance industry" (https://www.genevaassociation.org/). It consists of the CEOs of 80 of the world's largest insurers and reinsurers. One of its three major research programs is Extreme Events and Climate Risk, and this program publishes a wide range of research reports and news releases.

This summary will highlight just two of these comprehensive reports.

The Insurance Industry and Climate Change—Contribution to the Global Debate

Methodology: The report simultaneously targets insurers, regulators and the public, with the internal goal of exploring future claims costs and possible scenarios and the external goal of identifying challenges that will require integrated leadership with political, educational or social action. The report is internally complete and covers basics in climate change science, projections and responses, all from the perspective of the insurance industry. But what makes this report (and other materials from the Geneva Association) stand out is the emphasis on *leadership from the insurance industry* throughout. The Geneva Association views the insurance and reinsurance industries as true leaders, fully capable of developing best business practices within and, more importantly, of *leading* public-private partnerships, *leading* emerging economies to new risk management practices and *leading* society toward climate resilience. The tone is optimistic and forward-looking.

Results and Conclusions: Defining five levels of sustainable development—level 1, inactive; level 2, reactive; level 3, proactive; level 4, developed; and level 5, integrated—the report determines that the industry was (as of 2009) in level 1 and needed to get to level 3 as quickly as possible. Entire chapters on opportunities in emerging markets, public-private partnerships and industry best practices expand on the path from reaction to action.

Insurers' Contribution to Disaster Reduction—A Series of Case Studies

Methodology: This report explores 11 specific case studies across four broad areas: floods, earthquakes, resilient communities and liability litigation. Flooding is explored through the oscillating growth in floodplain development and then flood disaster management, the National Flood Insurance Program, the 2011 Thai floods and an analysis of The Netherlands (70% of whose GDP is produced in a floodplain). Earthquakes are explored with case studies from the Tohoku earthquake in Japan, the California Earthquake Authority and the Norwegian Natural Perils Pool. The notion of climate-resilient community development is explored with the R4 Rural Resilience Initiative and a case study of Chinese catastrophe insurance. Finally, liability litigation stemming from disasters is explored through the stories of Bhopal, India, and liability surrounding oil claims in Ecuador.

Results and Conclusions: In addition to specific results and conclusions from each of the 11 case studies, six summative "key findings" are provided (page 7, http://bit.ly/2aQBPnh) that stretch beyond specific cases. They are quoted directly here:

1. Risk-based, actuarially sound pricing is an essential mechanism for insurance to mitigate risk.
2. Public policy issues can facilitate insurance's effectiveness or distort the incentives it provides.

3. Knowledge-building about insurance is essential.
4. Insurance has relevant expertise in risk reduction and claims compensation so that liquidity is effectively injected into catastrophe-affected economies.
5. The role of capital markets and packaging risk in such a way as to attract financial players is key.
6. Post-disaster liability litigation can be either an effective means of compensation for victims or a formidable obstacle to victim recovery.

Potential Applications: The 11 case studies in particular should be studied to inform innovative new products, policies or market expansions for climate risk management. Specifics can be hard to come by with the study of climate risk, and these 11 cases help remedy that problem. The Geneva Association also maintains an Environmental Extremes + Climate Risk (EE+CR) Working Group, which publishes a wide range reports and news announcements on the topic, with events and conferences organized around the theme.

4.2 INSURANCE IN A CLIMATE OF CHANGE

Mills, E. (2005). *Science*, *309*(5737), 1040-1044.
http://evanmills.lbl.gov/pubs/pdf/insurance_and_climate.pdf

Objective: This *Science* article is included here to serve as a gateway to the project Insurance in a Climate of Change, created by Dr. Evan Mills at the Lawrence Berkeley National Laboratory in the 1990s. Actuaries should know that the journal *Science* is widely recognized as one of the most influential scientific journals in the world.

Methodology: The wider Insurance in a Climate of Change project has been a multidecade effort to research the connection between the insurance industry and climate change risks. The data and sources used for this *Science* paper span the set of sources used in the wider project.

Results and Conclusions: When looking at catastrophe property losses from 1980 to 2004, the weather-dependent share of insured losses was 90%, whereas it was only 75% for total (insured plus noninsured) property losses. This is primarily a consequence of market penetration of different forms of property insurance, selection preferences of insurers and consumers and the role of public entities. The result is that the insurance industry is in some sense *more* exposed to how climate change risks might impact weather-driven catastrophe losses than the wider society is.

Mills describes "a new classes of losses" within life and health insurance lines as a result of climate change. These are "driven by thermal extremes, reduced water quality and availability, elevated rates of vector-borne disease, air pollution, food poisoning, and injuries and mortalities from disasters and their associated mental health impacts" (page 1042). The section goes on to discuss the possible rise in livestock disease, decreased food production and how CO_2-linked aerosols and allergens may exacerbate asthma and respiratory disease.

Potential Applications: Climate scientists discuss mitigation versus adaptation—broadly, the difference between addressing the *causes* of climate change versus addressing the *consequences* (see, for example, any of the IPCC sources also summarized in the current report). In this study, Mills notes that "insurance is a form of adaptive capacity for the impacts of climate change." He further asks, "Can insurers extend their self-chosen historical role in addressing root causes (as founders of the first fire departments, building codes, and auto safety testing protocols) to one preventing losses at a much larger scale, namely, the global climate?" (page 1043).

Insurer-led efforts to help reduce losses—obtained through public policy leadership, direct financing of disaster-resilient infrastructure and technologies, nudging consumer behavior through premium discounts or other means—would not only help insurers manage risk, but would play a powerful role in global climate change adaptation.

4.3 A GLOBAL REVIEW OF INSURANCE INDUSTRY RESPONSES TO CLIMATE CHANGE

Mills, E. (2009). *The Geneva Papers on Risk and Insurance—Issues and Practice*, *34*(3), 323-359. http://evanmills.lbl.gov/pubs/pdf/gpp200914a.pdf

Objective: This paper is a summary of the much longer 2009 CERES report. The review captures the state of the global insurance industry response (as of 2009) to climate change and offers a set of best practices and next steps to encourage the industry as a whole to take a more active leadership role on climate risks.

Methodology, Data and Sources: The report takes the view of "climate change as the ultimate [Enterprise Risk Management] challenge" and first documents and then encourages more industry leadership on this issue. Mills reviewed more than 300 source documents gathered from 1999 to 2008. These were taken from company press releases, company websites, corporate social responsibility reports, and other places. A web-based direct survey to several hundred global insurance companies, insurance trade organizations and journals also formed a primary dataset.

Results and Conclusions: The report categorizes 643 climate-related activities of insurers into 10 distinct categories, with specific examples and discussion of each category. These categories are promoting loss prevention, aligning terms and conditions with risk-reducing behavior, crafting innovative insurance products and services, offering carbon risk management and carbon reduction services, financing climate protection improvements, investing directly in climate change solutions. building awareness and participating in the formation of public policy, leading by example and disclosing climate risk.

Mills describes the growing connection between climate change and liability losses, noting that "it is becoming increasingly clear that losses arising from the causes and impacts of climate change, as well as the emerging response to it, will also pierce the liability lines" (page 346).

The connection between the insurability of climate disasters and the notion of sustainability is explored in a manner that should serve as a strong motivation for the insurance industry. Quoting a paper by Patton, Mills writes, "Loss-prone infrastructure cannot be truly 'sustainable,'" reminding the reader of the necessary role of the insurance industry in the wider goal of sustainability.

Potential Applications: Mills repeatedly makes the argument that just as the insurance industry led the way with the formation of fire departments and building codes to reduce physical losses, so too should it lead the way to help reduce climate-based losses. This goal touches many of the categories described above and can be delivered through terms and conditions of policies, direct financial investment (as the industry collectively controls trillions of dollars in financial assets), formation of public policy and so forth.

The report ends with ten "best practices" for the industry and ten "initial steps" that can be taken by individual insurance companies. The best practices (reprinted verbatim from page 351) are as follows:

1. Improve the quality of climate risk modeling, with particular attention to stress-testing of plausible scenarios
2. Maintain the insurability of extreme weather events
3. Utilize terms and conditions of policies to drive consumer behavior towards climate friendly actions
4. Design new products and services which help customers become more aware of climate-friendly technologies and practices
5. Utilize the power of financial reserves and investment choices
6. Participate in carbon markets as both an investor and manager

7. Strive for carbon neutrality
8. Promote education and training in the area of climate risks and opportunities
9. Engage in public policy
10. Engage in traditional risk reduction (withdrawal from markets, premium increases, stricter underwriting) only when actions on the preceding nine items is insufficient.

The ten initial steps can be summarized into the suggestion of creating and maintaining a company culture around climate risks. The steps include recognizing climate risks as part of ERM; developing employees, positions, relationships and reports around the issue; and so forth.

Given the rapid rise in attention devoted to the issues of sustainability, the following assertion (on page 355) should be taken as an opportunity for the insurance industry to lead:

One of several "elephants in the room" is the failure to link sustainability and disaster-resilience. In fact, one cannot exist without the other. Insurers are perfectly placed to make the case for unifying "green" and "disaster-resilient" practices.

Readers looking for more depth on this survey and the ten best practices will find the full study described in From Risk to Opportunity: Insurer Responses to Climate Change.

4.4 THE POTENTIAL IMPACT OF CLIMATE CHANGE ON INSURANCE REGULATION

The National Association of Insurance Commissioners, 2008.
http://www.naic.org/

"*Declining to write coverage or reducing coverage should be a last option*" (page 3).

Objective: This white paper explores broad consequences of climate change on the regulation of insurance across practice areas.

Methodology: The NAIC held scientific presentations on climate change in February 2005, which led to a public hearing on the topic in December of that year. As a result, the NAIC Climate Change and Global Warming Task Force was created to write this white paper with a period of public comment that lasted until May 2008. This process continues today, with the NAIC Climate Change and Global Warming (C) Working Group.

Results and Conclusions: A central result that cuts across all areas of insurance is solvency. Insurance portfolios hold direct and indirect investments in real estate, mortgage-backed securities and financial instruments attached to firms with substantial exposure to climate risks. Given the essential role of surplus in the industry, all insurers are attached to climate risks.

With the property and casualty areas, the NAIC encourages regulators to verify that insurers have a contingency plan in response to catastrophic losses and the ensuing strain in surplus and cash outflows—a *stress test*. This necessitates the collection and dissemination of information relating to catastrophe scenarios and the resulting ability of the insurer to handle them.

A substantial portion of the white paper is concerned with the joint effort by insurers, regulators and governments to engage in loss prevention measures. This section discusses how regulators can influence education for consumers, changes in building codes and land-use planning, the creation of policy incentives to encourage consumers to reduce exposure, tiered rating and other mechanisms—all of which result in less exposure to risk. Parallels are drawn between climate risks and the historical role the insurance industry played in developing building codes and fire responses.

The white paper ends with a section titled "Encourage or Mandate Enhanced Disclosure," in which regulators are urged to ask themselves four questions (page 15):

1. Are insurers adequately including climate risk, and climate risk changes, in their internal risk assessment process?
2. Are insurers adequately informing and incentivizing policyholders as to their risks?
3. Are the insurers' governance structures sufficient to keep board members informed about climate risk?
4. Are insurers taking adequate steps to mitigate their own risks and to foster policyholder mitigation?

It should be clear from the above that, whether by legal mandate or regulatory pressure, insurers will increasingly be expected to measure, discuss, report and work to reduce their climate risks. And as page 3 in this white paper states, "Declining to write coverage or reducing coverage should be a last option."

Potential Impacts: The NAIC formed the Climate Change and Global Warming (C) Working Group to carry this work forward (their survey Insurer Climate Risk Disclosure Survey Report & Scorecard: 2014 Findings & Recommendations is described in the next section).

While much of the regulation and reporting for insurance falls outside the scope of the actuarial division at companies, actuaries can play an active role in creating discounts, credits or other policy incentives to encourage consumers to reduce exposure. They can develop tiered rating plans to reflect better and worse climate risks. Nudging consumer behavior decisions to reduce climate risk without reducing coverage availability or affordability will be an essential undertaking for the entire insurance industry, and actuaries should play a leading role.

4.5 INSURER CLIMATE RISK DISCLOSURE SURVEY REPORT & SCORECARD: 2014 FINDINGS & RECOMMENDATIONS

Ceres Report on NAIC Survey

Objective: Following the formation of the NAIC Climate Change and Global Warming (C) Working Group, a survey was distributed in 2014 to gauge the degree to which the insurance industry is measuring and disclosing climate risks.

Methodology: Ceres asked a series of questions relating to the culture of climate change at a company, assigned a point value to each question and set amounts so that a 100-point scale resulted. Defining four categories (Leading is 75 points or more; Developing is between 50 and 75 points; Beginning is between 25 and 50 points; and Minimal is less than 25 points), Ceres placed individual companies into these categories for both distinct themes and an overall aggregate. The ensuing analysis mostly counts the number of companies that achieve different levels of distinction. Particularly high-scoring companies that stand out are highlighted in the report as examples to emulate.

Data and Sources: Responses were received from 330 insurers to a 2014 survey administered by the National Association of Insurance Commissioners. These insurers cover 87% of U.S. direct premiums. The full lists of questions, subquestions and respondents are included in the report as appendices. Questions were categorized into six themes: Climate Risk Governance, Enterprise-Wide Climate Risk Management, Climate Modeling and Analytics, Stakeholder Engagement, Internal Greenhouse Gas Management and Climate Risk Disclosure and Reporting.

Results and Conclusions: "In general, most of the companies responding to the survey reported a profound lack of preparedness in addressing climate-related risks and opportunities" (http://bit.ly/1uAKfeY). Larger companies and property and casualty companies tended to receive higher designations than smaller and nonproperty and casualty companies.

Life/annuity and health insurers showed widespread survey evidence of limited engagement on climate issues. Overall, 79% of life and annuity companies and 89% of health insurers earned the bottom Minimal designation. The report echoes the NAIC when observing that life and annuity insurers control around two thirds of the insurance industry's total cash and invested assets, and many of these investments are in companies or holdings that face climate risk. This is also true for health insurers, though to a lesser degree.

For property and casualty insurers, the report observed a sector-wide trend to withdraw and limit coverage in disaster-prone coastal areas. The NAIC itself wrote, "Declining to write coverage or reducing coverage should be a last option" (page 3, NAIC Potential Impact of Climate Change on Insurance Regulation), so this trend is troubling and not in the long-run interest for building climate change resiliency. Property and casualty insurers on the whole had companies with overall Leading or Developing ratings (4% and 20%, respectively). A number of property and casualty companies received higher ratings for advancing climate change modeling and analytics (26% Leading, 21% Developing).

The particular scoring system and arbitrary cutoffs for designations should not detract from the overall message that wide variability of managing climate risks exists across insurers, and opportunities abound for companies to increase their involvement.

Potential Applications: The survey ends with a list of recommendations for insurers as well as regulators. For insurers, they are to (page 10):
1. Develop climate risk oversight at the board and senior executive level

2. Issue a comprehensive public statement on climate risk
3. Integrate climate risk into ERM
4. Improve climate change scenarios and impact assessments
5. Evaluate climate risks and opportunities in investments
6. Engage stakeholders
7. Provide comprehensive climate disclosures to regulators
8. Participate in industry initiatives on climate risk

For regulators, the four recommendations are to mandate climate risk disclosure in all 50 states, improve the climate risk disclosure survey, advocate for rating agency evaluations of climate risk management and provide insurers with climate science resources.

4.6 ADVANCING ADAPTATION THROUGH CLIMATE INFORMATION SERVICES

UNEP Finance Initiative and Sustainable Business Institute

Objective: This source contains results from a survey of global member institutions of the United Nations Environment Programme Finance Initiative administered to determine precisely what types of information these institutions require to link their services of risk management with broader climate adaptation.

Methodology: "The United Nations Environment Programme Finance Initiative (UNEPFI) is a global partnership between UNEP and the financial sector. Over 200 institutions, including banks, insurers and fund managers, work with UNEP to bring about systemic change in finance to support a sustainable world" (http://www.unepfi.org/).

Data and Sources: Roughly one third of UNEPFI member institutions (65 responses) were surveyed between February 2010 and April 2010. These included 11 insurers and reinsurers, 35 lenders, and 19 asset managers. The full list of respondents is available in the report.

Results and Conclusions: Around 80% of respondents requested "advice on the reliability of predictions," making it the single most commonly requested item from the survey. It is clear that a lack of understanding about climate projections themselves is preventing the financial industry from utilizing these projections more. The importance, availability and accessibility of historical data were frequently mentioned, with respondents saying that historical data were almost as important as climate projections and 43% admitting that they did not feel adequately informed about sources of historical weather data.

The time and geographic scale of climate predictions were frequently brought up in responses. Respondents requested more information on *regional and local* climate projections. Preference was also shown for projections over the *next 10 to 30 years*. The report summarized this by saying that "predictions and analyses will have to be customized to the type, location, and customer base of the financial institution concerned" (page 10).

Potential Applications: Members overwhelmingly favored participating with research institutes to share information and form usable databases of information. This was truer for the insurers and reinsurers of the group. Specifically, the companies mentioned their interest in collaborating on the following topics (listed in the order of preference: sectoral analyses, regional scenarios, project databases, databases of weather/extreme events, loss and catastrophe models, and loss databases.

A majority of respondents expressed strong interest in periodic reports on the effects of climate change, best practices, reports on regional effects of climate change and training.

4.7 ADAPTATION AND VULNERABILITY TO CLIMATE CHANGE: THE ROLE OF THE FINANCE SECTOR

United Nations Environment Programme Finance Initiative CCWG, 2006
http://www.unepfi.org/fileadmin/documents/CEO_briefing_adaptation_vulnerability_2006.pdf

Objective: In November 2006, the UNEPFI Climate Change Working Group issued a briefing to explore and encourage the role of the private financial sector in climate change adaptation.

Methodology, Data and Sources: The report is based on scientific, government and business research and includes 72 direct citations and endnotes. The methodology might best be described as distilling broad trends and opportunities for the finance sector as a whole.

Results and Conclusions: The briefing describes the escalating anticipated consequences to the insurance industry with rising carbon dioxide levels over time, assuming that no adaptive steps are taken. Looking forward from 2016, the briefing anticipates market withdrawal through 2025 and increasing difficulty maintaining returns to investors and rising costs of reinsurance through 2035. Before 2045, the report predicts that the costs of climatic extremes will pierce $1 trillion (2005 values), with possible insolvencies.

The optimistic side of the report notes a number of opportunities for the insurance industry across sectors, most notably increased demand for its services (as risk grows). There are also opportunities to play a role in financing and encouraging climate-resilient infrastructure, exploring catastrophe bonds and weather derivatives and offering consulting expertise and administration based on experience. The briefing notes that "the sums required for comprehensive adaptation are very large. The private sector can provide a portion if the conditions are right. But, more importantly, it can apply the skills it has honed in commercial markets to complement the public sector and other stakeholders in areas of vulnerability" (page 21, http://bit.ly/2aHIUFj). Public-private partnership opportunities are explored across ten issues, with insurers and financial institutions able to play a role in all ten.

The briefing ends with case studies exploring index-based insurance and microfinance in Ethiopia, problems with disaster management in the wake of Hurricane Katrina, simplified insurance products and public-private partnerships with U.K. flood insurance.

Potential Applications: Four ending recommendations to the financial sector are to "mainstream" climate change into their business practices, supply innovative new products and services for adaptation, prepare contingency plans for scenarios (including so-called worst-case scenarios) and engage with policymakers in public-private partnerships to build adaptive capacity.

4.8 INSURANCE INFORMATION INSTITUTE (III)

http://www.iii.org/

Objective: "To improve public understanding of insurance—what it does and how it works" (http://www.iii.org/).

Methodology: The III serves to promote public understanding of all sectors of insurance, and this includes the public understanding of climate change risks. In 2014, it published an article on the topic, which highlighted a few initiatives within the industry.

Data and Sources Provided: The III provides a page that serves as a database of disasters. It also serves as a public-oriented educational tool in how disasters are insured and how consumers can take steps to reduce their exposure. The material includes a mixture of articles, white papers, videos and fact sheets on disaster insurance, and the material covers general topics such as the role of the Federal Emergency Management Agency; specific high-profile disaster events such as Hurricane Katrina; and hazard-specific materials on tornadoes, earthquakes, hurricanes, floods and other weather hazards.

Potential Applications: Given the frequent calls, described throughout the current report, for insurers to engage in loss-control measures and build adaptive capacity, the Insurance Information Institute could serve as one of the industry's most effective channels at communicating the importance of these measures to the public. This could be particularly helpful if the loss control measures ask for some sort of sacrifice or concession from consumers, such as tightened building codes or land-use restrictions.

4.9 MUNICH CLIMATE INSURANCE INITIATIVE

http://www.climate-insurance.org/home/

Objective: "MCII brings together insurers, experts on climate change and adaptation, NGOs, and researchers intent on finding effective and fair solutions to the risks posed by climate change. MCII, through its unique setup, provides a forum and gathering point for insurance-related expertise on climate change impacts and explores ways how to create sustainable approaches that create incentive structures for risk and poverty reduction" (MCII Mission Statement).

Methodology: As the self-styled "leading innovation laboratory on climate change and insurance" (http://www.climate-insurance.org/about/), the Munich Climate Insurance Initiative (MCII) focuses on uninsured vulnerable populations at risk of climate change. The guiding objectives are to promote loss-reduction strategies, develop affordable insurance-related solutions, conduct pilot projects for insurance-related solutions, promote insurance-related approaches with public sector organizations and associations and support mechanisms to protect disaster victims fairly. The repeated use of the phrase "insurance-related" is telling and indicates that the MCII seeks to expand beyond the range of traditional insurance products and markets.

Results and Conclusions: Five large-scale projects are described, with multiple reports, news updates and conference announcements available for each. Many of these projects form an excellent set of *implemented* case studies and therefore have already bridged the gap between conceptual need and action.

The report Countries Addressing Climate Change Using Innovative Insurance Solutions imagines three hypothetical countries. Country A is a lower-middle-income Asian country primarily concerned with agricultural risks and looking to use risk-transfer as part of climate change protection. Country B is an upper-middle-income Caribbean island country looking to protect the government's surplus against wild fluctuations caused by weather disasters. Country C is a low-income African country exposed to weather extremes that is looking primarily at risk pooling at the subnational and national levels. For each hypothetical country, a three-phase sequence for developing a "comprehensive climate risk management approach" is described. The phases are (1) an assessment of risks and needs, (2) a design of strategy and (3) implementation. The varied needs and constraints of these three hypothetical countries greatly impacts the particular way the three phases are carried out.

While it often seems that sources on climate risk are theoretical, conceptual and/or speculative, some document on-the-ground solutions that were put in place. One such solution is Climate Risk Adaptation and Insurance in the Caribbean, a program that "intends to overcome barriers in extending access to risk management solutions including insurance and risk reduction to low-income communities in the Caribbean" (http://bit.ly/2aKIrgP). Specifically, from 2011 to 2014, this program was deployed in Jamaica, St. Lucia, Grenada, Belize and Guyana. Goals were to deploy weather-related risk insurance, support the development of public-private solutions and demonstrate the value of risk pooling in climate change adaptation and risk management.

The two specific tools deployed were the Livelihood Protection Policy for individuals and the Loan Portfolio Cover for financial institutions. Both tools are index-based insurance products. Individuals or institutions pay a premium up front for the coverage and receive a payment triggered by the recording of excessive wind or excessive rainfall—whether or not the policyholder experienced an actual loss as a result of the

weather extreme. The MCII materials detail these two policies, along with "lessons learned" regarding financial literacy, regulatory frameworks and technology.

The MCII highlighted four other projects as well:

1. MCII's Contribution to a G7 Initiative on Climate Risk Insurance: "As a risk transfer instrument, climate risk insurance is able to mitigate adverse consequences of climate-change related extreme weather events and can minimize the cost and optimize the timing of meeting post-disaster funding needs without compromising development goals, fiscal stability and help to alleviate human suffering while decreasing the loss of livelihoods."

2. Loss and Damage in Vulnerable Country Initiative: "The 'Loss and Damage in Vulnerable Countries Initiative' supports the Government of Bangladesh and the Least Developed Countries Group to voice their call for action to the international community in the UNFCCC climate negotiations process."

3. Innovative Insurance Solutions for Adaptation to Climate Change: The purpose of this report is "to develop a strategic framework for low income countries and emerging economies in finding ways to implement climate risk insurance solutions in an integrated climate risk management approach." (http://mcii.webseiten.cc/projects/)

4. Designing a Disaster Risk Insurance Framework for Pakistan: This project aims to "support the Government of Pakistan in designing a national disaster insurance fund to serve vulnerable people."

Potential Applications: The ability to study specific, tested and implemented insurance-related solutions to manage climate risks is an excellent resource for actuaries. The MCII has done the insurance industry a true service by experimenting with innovative insurance-related solutions and providing test cases for future solutions.

Conclusion

The preceding 36 sources cover topics as varied as basic climate science, insurance regulation, public-private partnerships, fundamentals of climate risk management and much that's in between. Hopefully, all reader found that several sources spoke to their needs. One purpose of this report was to provide concise summaries of excellent sources that could be just the thing a company or risk manager needed to address a current business problem.

If, however, readers found that their fundamental question about managing some type of climate risk wasn't fully answered by this report, then they have fulfilled its main purpose—more than anything else, this report was designed to spur additional research and writing on the various topics contained within.

A few areas in particular seem poised for exciting developments in the short term. The recently unveiled Actuaries Climate Index and Actuaries Climate Risk Index have the potential to reshape how companies manage climate risks. External, transparent and scientifically guided, these indices may create a common reference point for companies on how to measure and manage climate risks. Early work utilizing these tools could shed light on ways to upgrade either the ACI or ACRI, and hopefully, these indices will become more refined and more widely used over time.

Many sources discussed the historical role insurers played with crafting regulations designed to minimize risk. The creation of fire departments, building codes, floodplain designations and similar regulatory enhancements all came with substantial insurance industry leadership. Turning an eye toward climate and weather risks, insurers can once again choose to lead the charge by using their market position to help create regulations that mitigate climate risks up front. Individual companies and their trade associations should consider how to be leaders in this regard.

Several sources on finance, as well as some surveys of industry disclosure, have highlighted that much remains to be done regarding the measurement and disclosure of climate risks. We've seen that climate risks are often direct business risks, but they are also financial investment risks, since many financial assets held by insurers are themselves exposed to climate risk. As the saying goes, "What gets measured gets managed." Sometimes the mere act of measuring and disclosing certain risks is all it takes to turn a company's creative energies toward effective ways of managing that risk.

For many readers, the case studies summarized in this report will provide some of the most valuable reading. There is simply no substitute for the knowledge of how a particular innovative insurance or microfinance experiment turned out and what lessons were learned. This is particularly true for innovative work in the developing world, where exposure to climate risk is often higher due to lower adaptive capacity and climate resilience. To those readers who did not find a specific case study in their area of business or geographic region of concern, simply ask yourselves if you might be able to run the experiment on behalf of the industry, writing the case study for others.

The climate science sources, databases and climate models described in this report were brief, but hopefully they conveyed how important it is to have basic climate change literacy. Having in-house or consulting expertise on climate modeling or environmental statistics can be a valuable use of resources for any company dealing with climate risk. Statisticians, climate scientists, environmental scientists and IT professionals with "big data" skills can provide much of that needed new perspective and skill set.

Many sources highlighted in this report also focused on unique partnerships, whether between for-profit companies, public-private partnerships or partnerships with development agencies such as the United

Nations. Given the scale of climate risks, particularly in the developing world, partnering with agencies may be a necessity. Local agencies, local governments and nonprofit institutions often have the expertise to help with the dissemination of information and assist with the distribution channels for insurance and financial products. Partnerships with large-scale international development groups, such as the United Nations, can be one way to ensure that resources in new markets are put to the best use. And for-profit companies might consider joining existing groups dedicated to furthering the industry as a whole on the issue of climate risk.

These are just a few possible next steps for the industry. The climate is big, and climate risks are diffuse. All innovative approaches will represent real progress for the insurance industry. Hopefully, this report has helped lay the foundation for dozens of high-quality sources being written right now and bound for the next summary report.

References

Actuaries Climate Index. http://www.actuariesclimateindex.org/

Botzen, W. J. W., J. C. J. M. Van den Bergh, and L. M. Bouwer. (2010). "Climate Change and Increased Risk for the Insurance Sector: A Global Perspective and an Assessment for the Netherlands." *Natural Hazards* 52(3): 577–598.

Center for Climate and Energy Solutions. (2015) "Outcomes of the 2015 U.N. Climate Change Conference in Paris." Arlington, VA: C2ES. http://www.c2es.org/docUploads/cop-21-paris-summary-02-2016-final.pdf.

Climate Central. http://www.climatecentral.org/.

Climate Monitoring: North American Climate Extremes Monitoring (NACEM). http://www.ncdc.noaa.gov/extremes/nacem/.

CME Group Weather Products. http://www.cmegroup.com/trading/weather/.

Dessler, Andrew. (2015) *An Introduction to Modern Climate Change*, 2nd ed. New York City: Cambridge University Press.

Dessler, Andrew, and Edward Parson. (2010) *The Science and Politics of Global Climate Change: A Guide to the Debate*, 2nd ed. New York City: Cambridge University Press.

The Geneva Association. https://www.genevaassociation.org/

Higgins, P. A. T. (2014) "Climate Change Risk Management: An American Meteorological Society Policy Program Study." Washington, DC: The American Meteorological Society. https://www.ametsoc.org/ams/assets/File/Climate_Policy_Study_final.pdf.

The Insurance Information Institute. http://www.iii.org/.

Messervy, M., C. McHale, and R. Spivey. (2014) Insurer Climate "Risk Disclosure Survey Report & Scorecard: 2014 Findings & Recommendations." http://bit.ly/1uAKfeY.

IPCC. (2012) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Chapter 9. Cambridge, UK, and New York City: Cambridge University Press. https://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf.

IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf.

IPCC. (2014) "Summary for Policymakers," in *Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK, and New York City: Cambridge University Press. http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf

Jewson, Stephen, and Anders Brix., with Christine Ziehmann. (2005) *Weather Derivative Valuation: The Meteorological, Statistical, Financial, and Mathematical Foundations*. Cambridge, UK: Cambridge Press.

Kousky, Caroline, and Roger Cooke. (2009) Climate Change and Risk Management: Challenges for Insurance, Adaptation, and Loss Estimation (RFF DP 09-03). Washington, DC: Resources for the Future. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-09-03.pdf.

Kunreuther, Howard, and Erwann Michel-Kerjan. (2011) *At War with the Weather: Managing Large-Scale Risks in a New Era of Catastrophes*. Cambridge, MA: MIT Press. https://mitpress.mit.edu/node/195563.

Kunreuther, Howard, Geoffrey Heal, Myles Allen, Ottmar Edenhofer, Christopher B. Field, and Gary Yohe. (2013) "Risk Management and Climate Change." *Nature Climate Change* 3(5): 447–450. http://www.nature.com/nclimate/journal/v3/n5/full/nclimate1740.html

Mills, Evan. (2005) "Insurance in a Climate of Change." *Science* 309(5737): 1040–1044. http://evanmills.lbl.gov/pubs/pdf/insurance_and_climate.pdf.

Mills, Evan. (2009) *From Risk to Opportunity: Insurer Responses to Climate Change*. Boston, MA: Ceres. https://www.ceres.org/resources/reports/insurer-responses-to-climate-change-2009.

Mills, Evan. (2009) "A Global Review of Insurance Industry Responses to Climate Change." *The Geneva Papers* 34(3): 323–359. http://evanmills.lbl.gov/pubs/pdf/gpp200914a.pdf.

Munich Climate Insurance Initiative. http://www.climate-insurance.org/home/.

National Association of Insurance Commissioners. (2008) "The Potential Impact on Climate Change Insurance Regulation." Kansas City, MO: NAIC. http://www.naic.org/documents/cipr_potential_impact_climate_change.pdf.

National Oceanic and Atomospheric Administration, National Centers for Environmental Information. https://www.ncei.noaa.gov/

Climate Data Online. https://www.ncdc.noaa.gov/cdo-web/.
Climate Monitoring. http://www.ncdc.noaa.gov/climate-monitoring/.
Climate Monitoring: Climate at a Glance. http://www.ncdc.noaa.gov/cag/
Climate Monitoring: State of the Climate. http://www.ncdc.noaa.gov/sotc/
Global Climate Historical Network (GHCN) Daily and Monthly
https://www.ncdc.noaa.gov/oa/climate/ghcn-daily/
http://www.ncdc.noaa.gov/ghcnm/v3.php
ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/
ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/v3/
North American Drought Monitor (NADM). http://www.ncdc.noaa.gov/temp-and-precip/drought/nadm/.
U.S. Billion-Dollar Weather and Climate Disasters: Database and Online Tools.
https://www.ncdc.noaa.gov/billions/.

North American Climate Change Assessment Program (NARCCAP). http://www.narccap.ucar.edu/index.html.

Risky Business. http://riskybusiness.org/.

Smith, Adam B., and Richard Katz. (2013) "U.S. Billion-Dollar Weather and Climate Disasters: Data Sources, Trends, Accuracy and Biases." https://www.ncdc.noaa.gov/billions/docs/smith-and-katz-2013.pdf.

Smith, Adam B., and Jessica Matthews. (2014) "Quantifying Uncertainty and Variable Sensitivity within the U.S. Billion-Dollar Weather and Climate Disaster Cost Estimates." https://www.ncdc.noaa.gov/billions/docs/smith-and-matthews-2015.pdf.

United Nations Environment Programme Finance Initiative. (2006) "Adaptation and Vulnerability to Climate Change: The Role of the Finance Sector," CEO Briefing. http://www.unepfi.org/fileadmin/documents/CEO_briefing_adaptation_vulnerability_2006.pdf.

United Nations Environment Programme Finance Initiative and Sustainable Business Institute. (2011) "Advancing Adaptation through Climate Information Services." http://www.unepfi.org/fileadmin/documents/advancing_adaptation.pdf.

United Nations Framework Convention on Climate Change "Mechanisms to manage financial risks from direct impacts of climate change in developing countries." http://unfccc.int/resource/docs/2008/tp/09.pdf

Appendix A: Areas Covered in Each Source

LIFE INSURANCE
4.2, 4.5, 4.8

HEALTH INSURANCE
4.2, 4.5, 4.8

FINANCE AND MICROFINANCE
1.3, 2.7, 3.1.3, 3.4, 3.5, 3.6, 4.1, 4.5, 4.6, 4.7, 4.8, 4.9

PROPERTY AND CASUALTY INSURANCE
1.1, 1.3, 1.6, 2.4.1, 2.4.2, 2.4.3, 3.5, 4.1, 4.5, 4.8

FUNDAMENTAL PRINCIPLES OF RISK MANAGEMENT
1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 2.6, 3.1.2, 3.1.3, 3.4, 3.5, 4.1, 4.2, 4.3, 4.6, 4.8, 4.9

GOVERNMENT OR PUBLIC PARTNERSHIPS
1.1, 1.5, 1.6, 2.1, 2.2, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.4.1, 2.4.2, 2.4.3, 3.1.1, 3.1.2, 3.1.3, 3.3, 3.5, 3.6, 4.1, 4.6, 4.9

REGULATIONS
3.3, 3.5, 3.6, 4.4, 4.8, 4.9

DEVELOPING NATIONS
1.5, 3.1.2, 3.1.3, 3.6, 4.1, 4.9

PUBLIC POLICY
1.1, 1.5, 2.1, 2.2, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 3.1.1, 3.1.2, 3.1.3, 3.2, 3.3, 3.6, 3.7, 4.2, 4.8, 4.9

BASIC CLIMATE SCIENCE
2.1, 2.2, 2.5, 3.1.1, 3.2, 3.3, 3.6, 3.7, 4.2

About The Society of Actuaries

The Society of Actuaries (SOA), formed in 1949, is one of the largest actuarial professional organizations in the world dedicated to serving more than 27,000 actuarial members and the public in the United States, Canada and worldwide. In line with the SOA Vision Statement, actuaries act as business leaders who develop and use mathematical models to measure and manage risk in support of financial security for individuals, organizations and the public.

The SOA supports actuaries and advances knowledge through research and education. As part of its work, the SOA seeks to inform public policy development and public understanding through research. The SOA aspires to be a trusted source of objective, data-driven research and analysis with an actuarial perspective for its members, industry, policymakers and the public. This distinct perspective comes from the SOA as an association of actuaries, who have a rigorous formal education and direct experience as practitioners as they perform applied research. The SOA also welcomes the opportunity to partner with other organizations in our work where appropriate.

The SOA has a history of working with public policymakers and regulators in developing historical experience studies and projection techniques as well as individual reports on health care, retirement and other topics. The SOA's research is intended to aid the work of policymakers and regulators and follow certain core principles:

Objectivity: The SOA's research informs and provides analysis that can be relied upon by other individuals or organizations involved in public policy discussions. The SOA does not take advocacy positions or lobby specific policy proposals.

Quality: The SOA aspires to the highest ethical and quality standards in all of its research and analysis. Our research process is overseen by experienced actuaries and nonactuaries from a range of industry sectors and organizations. A rigorous peer-review process ensures the quality and integrity of our work.

Relevance: The SOA provides timely research on public policy issues. Our research advances actuarial knowledge while providing critical insights on key policy issues, and thereby provides value to stakeholders and decision makers.

Quantification: The SOA leverages the diverse skill sets of actuaries to provide research and findings that are driven by the best available data and methods. Actuaries use detailed modeling to analyze financial risk and provide distinct insight and quantification. Further, actuarial standards require transparency and the disclosure of the assumptions and analytic approach underlying the work.

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