

sea. A hose-pump lightbuoy is undergoing pre-production tests, and evaluation of wave power plants in Ireland, Spain, Sweden and the USA have been carried out.

Variations on the systems mentioned above or new ideas are being developed in Denmark, the Netherlands, Norway, USA, Korea and Australia.

PREDICTED WAVE ENERGY COSTS

The predicted cost of electricity generated from wave power schemes is dropping as designs improve and as construction techniques are refined. To illustrate this, one of the OWC designs had a cost of US\$0.3 kWh⁻¹ in 1982. By 1993, OWC designs were costed at US\$0.11 kWh⁻¹ and projections suggest that costs will fall to US\$0.06 kWh⁻¹ by 2005 and lower still by 2010.

FURTHER READING

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Weather Extremes and Climate Impacts: a Case Study for the United States

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Weather events are among the most pervasive influences on human affairs. Good weather can enhance society's efforts, bad weather often reveals vulnerabilities and sometimes leads to human and environmental disasters. The degree to which society exploits good weather and reduces

its vulnerabilities to bad weather is a function of how society organizes and informs itself and its decision processes in the face of various typical and extreme weather events. This essay provides a perspective on the manner in which researchers acquire information about extreme weather impacts and how societies cope (and do not cope) with extreme weather. Such information and coping strategies are increasingly important as societies around the world see their economic and human vulnerabilities change and grow with increasing population and wealth.

What are weather impacts?

In the 1970s, climate became of increasing interest to many societies around the world. Events included the failed Peruvian anchovy harvests in 1971 and 1973; the 1972–1974 drought in the African Sahel; a severe 1972 winter freeze in the Soviet Union; and in 1974, floods, drought, and early frost in the US Midwest. The 1977 winter in the eastern US was the coldest ever recorded and summer was one of the three hottest in a century. As a consequence of these extreme events and their impacts, decision makers in influential national and international settings began paying significant attention to the relation of weather, climate, and human affairs (*see Climatic Extremes*, Volume 3).

The concept of weather impacts and related societal problems includes:

- extreme events, including droughts, hurricanes, floods, blizzards, tornadoes, thunderstorms (including hail), etc.;
- the benefits of good weather, meaning favorable conditions for a particular activity;
- routinely disruptive weather, defined as not extreme, but significant enough to warrant behavioral adjustments.

Most public and political attention focuses on disasters and extreme events, but the other types of weather are likely to have significant impacts on society as well. This essay focuses on extreme events.

THE CHALLENGE OF ASSESSING DAMAGES OF EXTREME WEATHER AND STORMS

In the aftermath of any extreme event such as a hurricane, there are many considerations in measuring its costs (of impacts). Any assessment of impacts resulting in an estimate of total damages associated with a disaster must pay explicit attention to assumptions guiding the analysis in order to facilitate interpretation of the estimate. The analyst needs to pay attention to five factors that can complicate damage assessment: contingency, quantification, attribution, aggregation, and comparison.

Contingency: The Problem of Multiple-order Impacts

When an extreme event strikes a community, it leaves an obvious path of destruction. For example, following a hurricane, as a result of high winds and water from a storm surge, homes, businesses, and crops may be destroyed or damaged, public infrastructure may also be compromised, and people may suffer injuries or loss of life. Such obvious impacts can be called direct impacts because of the close connection between event and damages. The costs associated with direct impacts are generally easiest to assess because they come in discrete quantities. In the US, federal insurance payouts are one measure of direct impacts, as are federal aid, public infrastructure reconstruction, and debris removal.

Secondary impacts are related to direct impacts. Generally, secondary impacts occur in the days and weeks following an event. For example, a flood may destroy a water treatment plant. The direct impact is the cost associated with rebuilding the plant; secondary impacts include the costs associated with providing fresh water for local citizens. In general, such secondary impacts are more difficult to assess because they require estimation and are part of an existing social process; e.g., estimating the costs of providing fresh water in lieu of the costs of normal operation of the plant without the disaster.

Other impacts on time scales of months and years occur and can easily be imagined but can be hard to quantify. For example, a flood may destroy a number of businesses in a community resulting in a decrease in tourist visits, which in turn leads to a shortfall in sales tax collection. As a result, community services that had been funded from sales tax revenues may suffer, leading to further social disruption and thus additional impacts. Estimation of the costs associated with such impacts is difficult because of numerous confounding factors. In short, an extreme event causes various impacts that reverberate through the social system for short and long periods. Separating the signal from the noise of ongoing social processes becomes increasingly difficult as the impact becomes further removed in time and in causation from the event's direct impacts.

Attribution: The Problem of Causation

Related to contingency is attribution. In the aftermath of a natural disaster, people are quick to place blame on nature, e.g., the flood caused billions of dollars in damages. However, it is often the case that natural disasters are a consequence of human failures. Damage is often a result of poor decisions of the past and inadequate preparation, rather than simply the overwhelming forces of nature. It is often at the intersection of extreme events and poor preparation that a disaster occurs. An important aspect of

learning from a disaster is to understand what damages and casualties might have been preventable and which were not. Gross tabulations of damages neglect the question of why damage occurred, and often implicitly blame nature rather than society.

Quantification: The Problem of Measurement

How much is a life worth? Or put in practical terms, how much public money are people willing to pay to save one more life in the face of an environmental hazard? According to one review, the public assigns between \$2.0 million and \$10.9 million as the value of a human life. The difficulty associated with assigning an economic value to a human life is representative of the more general problem of assessing many of the costs associated with weather impacts. Similar questions might include: what is the value of a lost ecosystem, park, or unrecoverable time in school, etc.? What are the costs associated with psychological trauma?

Often, an extreme event impacts many aspects of society that are not explicitly associated with an economic measure (e.g., well-being). As a consequence, any comprehensive economic measurement of an extreme event's impact necessitates the quantification of costs associated with subjective losses. Therefore, the assumptions that one brings to assessment of value can affect the bottom line. Care must be taken to make such assumptions explicit in the analysis.

Aggregation: The Problem of Benefits and Spatial Scale

Estimates of impacts from disasters rarely consider benefits. Consider the following example: following a hurricane that severely damages agricultural productivity in a region, commodity prices rise nationwide. Thus, while farmers in the affected region may lose money, farmers outside of the region may actually incur significant benefits. At a national level the hurricane may thus lead to net economic benefits. Even in the immediate vicinity of the storm track, the rainfall may be beneficial in replenishing depleted reservoirs and groundwater.

The above example points to two sorts of issues: benefits and spatial scale. Arguably, following every disaster some individuals and groups realize benefits in some way from the event. Should such benefits be subtracted from a hurricane's total impact? Further, the picture of damages depends upon the scale of the analysis. For the same event a county may experience complete devastation, the state only moderate impacts, and the nation positive benefits. Transfers of wealth through disaster aid further complicate the picture. Since there are multiple valid spatial scales from which to view a hurricane's impacts, careful attention must be paid to the purposes of loss estimates. Furthermore, it is important to remember that impacts go beyond those things

that can be expressed in dollars – suffering and hardship are losses independent of scale.

Comparison: The Problem of Demographic Change

As a consequence of the challenges facing meaningful impact assessment, comparing impacts across time and space is problematic. In many settings, past extreme events would certainly leave a greater legacy had they occurred in more recent years. Yet, damage statistics often go into the historical record noting only the event and economic damage (usually adjusted only for inflation). Such statistics can lead to mistaken conclusions about the significance of damage trends. Since population and property at risk to extremes have changed dramatically in recent decades, such statistics may grossly underestimate vulnerability. Therefore, care must be taken in the use of bottom-line damage estimates to reach policy conclusions.

The Bottom Line: Apples with Apples, Oranges with Oranges

There are many ways to measure the costs associated with a weather or climate impact. There is no one right way. The method chosen for measurement of the costs of damages depends upon the purposes for which the measurement is made, and therefore must be determined on a case-by-case basis. No matter what method is employed when assessing or using the costs associated with an impact, the analyst needs to ensure at least two things. First, the analyst needs to explicitly describe the assumptions that guide the assessment: what is being measured, how, and why. Second, apples should be compared with apples and oranges with oranges. If the purpose is to compare the impacts of a recent event with one in the past or a weather disaster with an earthquake, the methods employed ought to result in conclusions that are meaningful in a comparative setting.

IMPACTS TREND DATA

Following the discussion above, a three-tiered sequence is useful for assessing weather and climate impacts. Direct impacts are those most closely related to the event, such as property losses associated with wind damage. Secondary impacts are those resulting later from the direct impacts. For example, an increase in medical problems or disease following a hurricane would be a secondary impact. Tertiary impacts are those that follow long after the storm has passed. A change in property tax revenues collected in the years following a storm is an example of a tertiary impact. The impacts discussed below are direct impacts.

Hurricanes

In the US, after adjusting only for inflation, hurricanes were responsible for an annual average of \$1.6 billion for the period 1950–1989, \$2.2 billion over 1950–1995, and \$6.2 billion over 1989–1995. For comparison, China suffered an average of \$1.3 billion (unadjusted) in damage related to typhoons over the period 1986–1994. Significant tropical cyclone damage is also experienced by other countries including those in south-east Asia, along the Indian Ocean (including Australia), islands of the Caribbean and Pacific, and in Central America (including Mexico). While a full accounting of these damages has yet to be documented and made accessible, it is surely in the billions of dollars, with a reasonable estimate of about \$10–20 billion annually (1995 \$).

In the US, 196 people lost their lives as a result of hurricanes over the period 1986–1995. Experts have estimated that world wide, tropical cyclones result in approximately 12 000–23 000 deaths. Tropical cyclones have been responsible for the largest losses of life due to a natural disaster. For instance, in April 1991, a cyclone made landfall in Bangladesh resulting in the loss of more than 140 000 lives and disrupting more than 10 million people (and leading to \$2 billion in damages). A similar storm resulted in the loss of more than 250 000 lives in November 1970. Similarly, thousands of lives have been lost in China, India, Thailand, Honduras, and the Philippines in recent years.

Society has become more vulnerable to hurricane impacts. The trend of increasing losses during a relatively quiet period of hurricane frequencies should be taken as an important warning. When hurricane frequencies and intensities return to levels observed earlier in the 20th century, then losses are likely to increase to record levels unless actions are taken to reduce vulnerability.

Inhabitants along the US Atlantic and Gulf Coasts are fortunate in that hurricane watches and warnings are readily available, as are shelters and well-conceived evacuation routes. However, this should not give reason for complacency – the hurricane problem cannot be said to be solved. Disaster planners have developed a number of scenarios that might result in a large loss of life in the US. For instance, imagine a situation of gridlock as evacuees seek to flee the Florida Keys on the only available road. Or imagine New Orleans, with much of the city below sea level, suffering the brunt of a powerful storm, resulting in tremendous flooding. Scenarios such as these highlight the need for constant attention to saving lives. Since the nature of the hurricane problem is constantly changing as society changes, the hurricane problem can never be said to be solved.

Floods

By any measure, floods have a significant impact on society. The Red Cross estimates that, worldwide, more than

1.5 billion people over the 25-year period ending in 1995 have felt the impact of floods. Of that total, they estimate that more than 318 000 people were killed and more than 81 million were made homeless. In addition, over the period 1991–1995 flood-related damages totaled more than US\$200 billion (not inflation adjusted) worldwide, representing close to 40% of all economic damages attributed to natural disasters in this 5-year period. In the 1990s, significant flood damage occurred in eastern Europe (1997, damages totaling US\$4–6 billion), US and Canada (1997, US\$1.75 billion), China (1996, US\$26.5 billion), central Europe (1993 and 1995, US\$4 billion), and the US Midwest (1993, US\$16 billion).

Reliable and accurate knowledge of flood impacts is important because decision makers allocate scarce resources to flood-related concerns based on their interpretation of past trends in and expectations for the future of the magnitude and causes of flood impacts. In addition, local actions taken to reduce vulnerability to floods are based on public and decision-makers' perceptions of the past and expectations for the future. Regrettably, implementation of policies in response to floods is hampered by a lack of specific knowledge of past trends in flood impacts on society and, more importantly, the factors that underlie those trends. Indeed, the International Federation of Red Cross and Red Crescent Societies has written:

The lack of systematic and standardized data collection from disasters, man-made or natural, in the past is now revealing itself as a major weakness for any developmental planning. Cost–benefit analysis, impact analysis of disasters or rationalization of preventative actions are severely compromised by unavailability and inaccuracy of data or even field methods for such data collection.

Some have speculated that the steady increase in the average annual economic damages related to floods in the US indicates a change in climate; some blame population growth and development; others place the blame on federal policies; and still others suggest that the trend distracts from the larger success of the nation's flood policies. Empirical evidence from a number of cases clearly shows that climate, population growth and development, and flawed policy all play a role in trends in the costs of flooding in the US, but the state of knowledge is such that the relative contribution of each factor is poorly understood. The US case seems typical: policy makers face difficulties in assessing the magnitudes and causes of floods and in evaluating the effectiveness of past responses.

A consequence of the lack of data on the spatial extent of floodplains in the US is the difficulty in assessing trends in flood frequencies and current levels of population at risk to floods. Trends in population at risk to flood events are important in any determination as to whether societal vulnerability to floods is decreasing, increasing, or remaining relatively constant. One can easily hypothesize

that increasing population and urbanization in the US has led to a commensurate increase in population at risk. Yet, one can also hypothesize that the various societal responses to floods may have more than compensated for population growth and, in fact, fewer people are today at risk to flood events. Currently, reliable data to assess trends in populations at risk from flood events are lacking.

Accurate determination of property at risk to flooding faces many of the same obstacles. Differences in estimates of people and property at risk to floods are attributable to actual demographic changes, but also to differences in floodplain definitions, and to the lack of reliable data. The data that do exist allow for only gross generalizations.

CONCLUSIONS

The information presented above is consistent with the findings of the Intergovernmental Panel on Climate Change (IPCC). Even on a global scale it is difficult for scientists to discern trends in extreme events. As the IPCC (1996, 173) notes:

Overall, there is no evidence that extreme weather events, or climate variability, have increased, in a global sense, through the 20th century, although data and analyses are poor and not comprehensive. On regional scales there is clear evidence of changes in some extremes and climate variability indicators. Some of these changes have been toward greater variability; some have been toward lower variability.

For many years, decision-makers have assumed that climate remains constant, at least over the relevant period of record. So it was possible to estimate statistical return periods from historical time series. In recent years, however, scientists and policy makers have come to realize that we live in a climate that is changing in ways that are difficult to assess and predict. In other words, both the distribution of events and the central tendency may be changing. A consequence is that climate change or variability may be responsible for some of the variance in weather-related deaths and damages.

However, it is difficult to attribute the documented recent increases in economic impacts in the US to fluctuations in climate. This is primarily due to the fact that the strongest signal in the impacts record is increased societal vulnerability.

In this context, studies of extreme events have often called for greater emphasis to be placed on the following areas:

Vulnerability Mapping

Communities would benefit from a greater understanding of exposure and risk. Many countries, particularly developing countries, lack the resources to undertake such studies. Even some US communities have never been evaluated for

flood risk. In addition to mapping where natural hazards could occur, community planners could map the neighborhoods where highly vulnerable groups such as the disabled, poor, and elderly reside. This information can provide a tool for targeting education and other mitigation programs, evacuation plans, distribution of relief supplies, and other response services to where they are most needed.

Land Use

Much development around the world occurs in the most vulnerable locations, including low-lying shorelines and inland flood-prone areas. Land use planning is typically in a rudimentary stage in those regions. For example, coastal areas of parts of the southeastern US have experienced explosive growth over recent years. In 1990, Dade and Broward Counties in south Florida had larger populations than all 109 counties from Texas through Virginia on the Gulf and Atlantic coasts in 1930. Some policies for managing land in vulnerable areas include zoning, regulation, taxing, creating special property districts in which governments may exercise eminent domain, and public acquisition of land at risk.

Promulgation and Effective Enforcement of Building Codes

Building codes are an important component in strengthening housing stock and reducing vulnerability. In disaster-prone areas, effective building codes should address factors such as the ability of structures to withstand high wind velocities. For example, South Florida's building code requires structures to be able to withstand wind velocities not less than 120 mph (53.2 m s^{-1}) at a height of 10 m above the ground. Many engineers maintain that using steel or composite fasteners to hold on a roof would save homes. However, even the best codes will not reduce vulnerability without adequate enforcement. One study comparing damage from two hurricanes of roughly equal size and intensity found that building code enforcement was a primary factor in reducing structural damage to buildings during hurricanes. Other strategies are necessary in those parts of the developing world where much of the construction of homes occurs informally and does not go through a code review and inspection process.

Improved Forecasts, Warnings, and Evacuations

While major improvements in weather forecast accuracy have been made, thanks to advances in technology, considerable opportunity exists for further improvement in both the technical production of forecasts and their use by decision-makers. In addition, some countries need better national communications systems to disseminate warnings.

Dissemination of effective warnings can be a challenge in countries such as India where warnings need to be translated into several languages. It is likely that those who suffered the greatest impacts of Hurricane Mitch in Central America had little or no warning of its approach and little opportunity to evacuate even if warned.

For evacuation to be effective, communities must develop data banks on various factors including: what areas need to be evacuated, how many people need to be evacuated, how will the public respond to an evacuation, what roads will be used, and where will evacuees be sheltered? Improvements to the evacuation process can range from widening roads, to building new causeways, to limiting population growth in areas most at risk.

Reduce Environmental Degradation

Deforestation is occurring at alarming rates in some parts of the world. Loss of natural vegetation reduces the soil's ability to absorb rainwater, and contributes to the instability of hill slopes. These factors can lead to highly dangerous landslides that result in hundreds of deaths. Development of wetlands and beaches interferes with the ability of these natural environmental features to absorb floodwaters and act as seawalls. Poor land use and natural resource management, while a reflection of poverty, is also caused by government policies that subsidize unsustainable activities and practices. These policies often result from conscious decisions and trade-offs made by government officials. If the decision-making processes are opaque and corrupt, there is little that people can do to exert pressure to correct these environmentally harmful practices.

Addressing Poverty and Poor Health

Many factors that increase societal vulnerability to extreme weather, particularly in the developing world, will not be solved without a concurrent focus on alleviating poverty, improving public health and provision of secure land tenure in safe sites. Poor people frequently build homes through the informal housing sector, making building codes and land use restrictions meaningless. They often settle on marginal lands such as steep slopes and flood-prone areas. Poverty is also a factor in environmental degradation practices such as deforestation. Vulnerability reduction has clear links with economic development and public health.

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