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Climate and Catastrophic Weather Events

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Abstract

The impacts of global climate change are conventionally discussed in terms of changes in the temperature averaged over the year and over the globe. Much less emphasis has been placed on anticipated changes in weather variability. Of particular interest are extreme events such as windstorms, hurricanes, floods, droughts, hailstorms, tornadoes, etc. In the last decade, the number of catastrophic weather events is three times as great, and the cost to the world economies, eight times higher than the decade of the 1960s. In part, the higher cost in the last decade is due to greater vulnerability of society as a result of increasing urbanization. In 1997, a year with exceptionally few natural disasters, 13,000 deaths could be attributed to weather-related events, and the economic losses were $30 billion, as compared to $60 billion in 1996. The most frequent natural catastrophes in 1997 were windstorms and floods, which accounted for 82% of the economic losses and no less than 97% of the insured losses. Floods devastated large areas of China, Latin America and the United States. As in 1996 Central Europe, experienced a flood when the heaviest precipitation ever recorded inundated areas in Poland, Germany, the Czech Republic and Austria.

Whether the frequency and intensity of extremes will increase or decrease in a warmer world is not known; the spatial scales of most extreme events are much too small to be captured in current climate models. However, a small increase in the surface temperature of the oceans will undoubtedly lead to increased water content of the atmosphere, since the vapor pressure of water rises exponentially with temperature. Thus, it is highly likely that at least some regions of the globe will experience higher precipitation and more frequent flooding in a warmer world.

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The customary discussions of climate change involve the increase in temperature averaged over the globe and over the year. The mean changes in temperature are estimated to be on the order of 1-3^{o} C in the next 50 – 100 years. Far less attention has been paid to changes in the variability of weather as a result of global warming. The variability will of course be a function of geographical region. The most important elements of variability are the frequency and intensity of extreme events.

Weather-related catastrophes are those that affect an extended geographical region and a significant population. The economic loss related to such a catastrophe depends on the severity or intensity of the event. For example, a hurricane can have maximum wind speeds that vary by a factor of 2. The extent of damage can be expected to vary with the square of the maximum wind speeds.

The economic and social implications of the catastrophic weather event will also depend on the area affected by the event. Weather extremes in urban regions are likely to have a much greater impact on both population and economic losses than extremes that affect rural, less populated areas.

The impact of an event will of course depend strongly on what sort of protective measures have been executed. A flood for which no protective measures have been taken will cause significantly greater damage than one in which dykes have been built and maintained.

In examining the economic consequences of extreme events one needs to look both at the total cost, which can only be estimated approximately, and at the losses incurred by the insurance firms. The insured losses are accurately tracked by the insurance companies and re-insurance companies. In general, for the industrialized world, the insured losses range from 10-70% of the total losses. In the developing world there is very little insurance coverage and in general economic losses can only be approximated very loosely.

When discussing weather-related catastrophes, it is helpful to use a simple classification. Floods are those events in which the water in a river or lake covers a much larger geographical region than the normal conditions. Storms are events with strong winds. In the western world, they are designated as *hurricanes* in tropical regions or as *gales* in the more northern regions. In the eastern part of the globe, hurricane-like storms are called *typhoons*. Much of the damage associated with these wind storms results from the ocean surges in which the normal tides are greatly increased and the ocean intrudes inland.

Dry events—precipitation below normal—can lead to droughts, which may be accompanied by bush or forest fires that cause extensive damage to both people and property. Droughts are also often accompanied by heat waves and have a direct effect on the health of the population.

Cold events include unseasonable heavy frost, leading to widespread agricultural damage, snow storms and ice storms. The latter two events can lead to not only property damage but to fatalities.

Finally, there are classic events such as hailstorms, which occur mostly in the summer time, but also occasionally in winter; and avalanches, which are the result of heavy precipitation. In winter the avalanches are snow avalanches, while in summer they are more likely to be mud avalanches.

The losses associated with catastrophic weather events have been increasing in the last two decades, but still are a relatively small fraction of the gross domestic product (GDP) of the nations affected. For example, in 1996 total insured losses were approximately 8 billion US$, while the total cost to society was on the order of 60 billion US$. The highest fraction of losses is associated with wind storms of various sorts. The number of floods approximately equaled the number of storms, but a relatively small fraction of flood damage is covered by insurance.

The year 1997 had the least insured losses of the past 10 years. The total insured losses were 4.5 billion US$. The highest losses were associated with flooding, particularly the flood of Central Europe in July 1997. The heaviest recorded precipitation in June and July led to record flood stages in the Oder, Nysa and Mozara rivers. The maximum discharge in these rivers exceeded the discharges that would be expected once in 1,000 years. The economic cost of the floods was significant. In Poland, it amounted to 2.9 billion US$, or approximately 3% of Poland's GDP, while the total losses associated with the floods in Poland, the Czech Republic, Germany and Austria amounted to 5.3 Billion US$. Only 800 million US$ were insured, mainly in Germany and Austria.

Beginning in the spring of 1997, the waters of the Eastern Pacific became abnormally warm. The pile up of warm waters along the Western coast of South America set off the strongest El Niño in the 50 year record covering instrumented regions. The El Niño conditions have persisted into 1998. The 1997-98 El Niño contained many features common to previous El Niños. There was extreme precipitation, floods and windstorms occurred along the Pacific Coast of North and South America. While the Western Pacific had excess precipitation, the Eastern Pacific was extraordinarily dry. The dry areas led to forest fires and droughts in the Western Pacific from Australia to Indonesia and Taiwan. The forest fires in Indonesia were accompanied by extraordinarily smoky conditions through much of South East Asia, including Malaysia and Singapore.

The El Niño of 1997-98, however, generated a new and somewhat unexpected catastrophic event. The warm Eastern Pacific waters pumped sufficient energy and moisture into the atmosphere to create huge thunderstorms in the Gulf of Mexico and the southeastern United States. In the period January 4th to January 10th, 1998, this warm moist air collided with arctic cold air in Eastern Canada and northeastern United States to cause the most severe ice storm in history. The ice storm dumped as much as 100 millimeters of freezing rain into the province of Quebec, Canada. The deposition of 15 millimeters of freezing rain is considered a once-in-a-100-year event.

The ice storm damage trees, power lines, and buildings, and led to numerous accidents on ice-covered streets and highways. At one time, more than 3 million residents in Eastern Canada were without electricity. The Canadian maple syrup industry was totally decimated. The total cost of the ice storm was about 3 billion US$, while the insured losses were 1.6 billion US$. This is the first time in history that a catastrophic weather event in Canada caused losses greater than 1 billion US $.

During the period 1970 through 1996, 17 weather catastrophes caused insured losses of greater than a billion US$. Geographically, the losses were concentrated in the United States, where a larger proportion of properties are covered by insurance. But Europe and Japan also suffered losses greater than a billion dollars to weather events in this period. The temporal distribution of the losses shows that they were concentrated in the last 10 years of the 26-year period.

Since 1970, the number of weather-related catastrophes affecting the insurance industry has constantly risen, with the greatest increase since 1982. The rising losses to the insurance industry come from a number of causes. Population density has increased as people move into urban areas. There has been a tendency to site high-cost industries in hazardous areas. There is a much higher concentration of insured assets in the industrialized countries.

Finally, one must examine the issue of whether the increasing losses might reflect changes in climate. Climate change remains a somewhat scientifically controversial subject, despite the conclusions of the Inter-governmental Panel on Climate Change (IPCC). This Panel, convened by the World Meteorological Organization (WMO) and the United National Environmental Program (UNEP), came to the conclusion that the atmosphere is indeed warming and that that warming can be linked to emission of greenhouse gases by a variety of human activities. However, a large group of scientists conducting the IPCC activities could come to no firm conclusions as to the impact of global warming on extreme weather events. There are a number of reasons for this failure. Far more attention has been given to changes in the mean than to changes in the variability of weather. The spatial scale of many extreme events is too small to be captured in the relatively coarse grid of large computer models of climate. Furthermore, extreme weather events have their origins in the linkages between atmosphere and ocean. These linkages remain poorly understood and are difficult to represent in climate models.

Despite the poor understanding of the impact of climate change on the frequency and intensity of extreme weather events, some general statements can be made. Warming of the oceans will increase the water vapor content of the atmosphere. Because of the exponential dependence of vapor pressure of water on temperature, relatively small increases in temperature will lead to significant changes in that water vapor.

As the water vapor content of the atmosphere increases, one can anticipate enhanced precipitation. Indeed, careful studies carried out at the US National Oceanographic and Atmospheric Agency (NOAA) show that total precipitation in the United States has increased by about 10% in the period 1910-1995. Precipitation shows high irregularities, but nonetheless the trend is quite clear, with larger areas of the United States being affected by heavy precipitation events. An interesting feature of the increase in average precipitation is that more precipitation falls during episodes of high rain or snow fall, and involve larger amounts of precipitation than during similar events in the past. As a result of the heavier precipitation the frequency of flooding has increased in many parts of the United States. This increased flooding and the damage associated with these floods did not show up in insurance statistics because there is little insurance coverage for flooding in the United States. Instead, governments at both local and state levels have in the past assumed the role of the insurance industry, enabling flood victims to recover part of their losses through very low-cost loans to rebuild or rehabilitate damaged property.

The impact of climate change on extreme weather events may be reflected in the apparent increase in intensity and frequency of El Niño. The historical records on El Niño go back some 200 years, but careful instrumented observations are available only since 1950. Periods of El Niño, with the accumulation of warm waters off the western coast of South America, are interrupted by periods of La Niña, in which the waters are colder than normal. Since 1975 periods of La Niña have become statistically less frequent.

In addition, the two strongest El Niños on record are those of 1983 and of 1977-78. Whether these observations are a result of climate change or not is still a matter of controversy. However, if the periods increase in the future, then various extreme weather events associated with El Niño can be anticipated to increase. It has long been known that the oceans interact with the atmosphere in very significant ways. As indicated above, the ocean is a major source of water vapor and energy. As a result, this interaction can influence the nature of catastrophic weather events.

A most important point is that the time scales for the ocean and atmosphere differ greatly. In the atmosphere the time scales are measured in days, while in the ocean the characteristic time scales are on the order of months to many years. For example, in the atmosphere, a particular high pressure area moving across Europe in the summertime will maintain spatial coherence for several days to maybe as long as a week. During that time, a prediction that the weather the next day will be very much like the weather of today is likely to be correct. In the oceans, on the other hand, the slower time scales mean that predictions over months and perhaps years are possible.

The long time scales associated with oceanic motions mean that the combined system has a memory. Atmospheric behavior of today may be influenced by ocean events that occurred a number of years ago. For example, observations indicate that during the hurricane season off the coast of the southeastern United States, strong winds expose a deeper layer of the ocean to the warming sun. Once the storm subsides, cooler waters cover the warm, deep layer, which then migrates with the time scale of 10 years along the coast of Europe. Wintertime storms can once again expose the warm water, which then can lead to greater precipitation as a result of evaporation controlled by the temperature.

The longer time scales for the oceans imply that it may be possible to make longer-term predictions of atmospheric behavior. What is required, of course, are detailed observations of the ocean. Of particular importance is the temperature structure in the upper few hundred meters of the ocean. Warmer or colder waters can change the behavior of the overlying atmosphere.

In addition to possible enhanced predictability, the longer-term memory of the ocean-atmosphere systems means that extreme weather events cannot be treated as statistically independent events governed by an exponential distribution. Indeed, observations show that extreme events can be clustered in time. The clustering in time has important implications for the analysis of risk. In a typical risk analysis, the total capital is a sum of the initial capital plus a constant depending on the insurance rate, multiplied by time, with losses subtracted from that sum. The losses have some distribution that tends to be heavy-tailed in terms of magnitude. Typically, losses are assumed to be independent in time. The total capitalization can then be viewed as increasing linearly in time with the insurance rate, punctuated by a few losses occurring randomly.

An alternative model, taking into explicit account the possibility of clustering in time, can lead to a distinctly different picture. Clustering implies that losses over a shorter interval can lead to ruin even though the individual losses are relatively small.

In summary, catastrophic weather events can cause severe local and regional economic losses as well as serious social disruption. For the industrialized world, these losses are still small compared with GDP. For developing countries and for countries in transition, the losses can amount to several percent of GDP, as illustrated by the losses suffered in Poland as a result of the 1997 summer floods.

Catastrophic weather-related losses have increased so that over the last decade they have been 8 times as great as those of the decade of the 1960s. This increase in losses can be understood in part as being due to urbanization and to the centralization of industries and vulnerable regions, such as coastal areas and river basins. Increased losses, however, may be influenced by a phenomenon related to global warming.

Global warming will lead to increased precipitation, particularly in some regions of the world, since the vapor pressure of water depends exponentially on temperature. Increased precipitation can lead to increased flood frequency. It may also be true that El Niño events will intensify and become more frequent as the ocean warms. However, the overall impact of global warming on the frequency and intensity of catastrophic weather events remains a subject for future research.