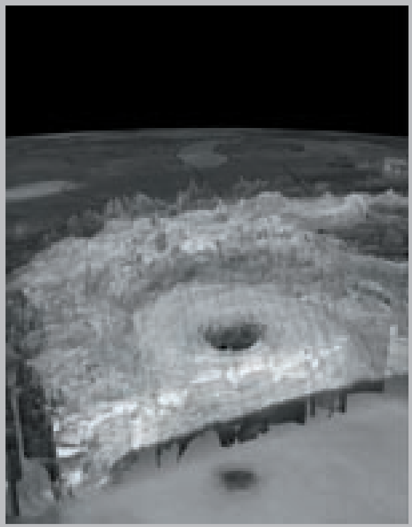
# THE WORST IS YET TO COME: HURRICANES AND GLOBAL WARMING



Gordon McBean

Twenty four-hour news saturation and the internet have made all of us witnesses to, if not victims of, all the planet's natural disasters. From the Southeast Asia tsunami on Boxing Day 2004 to Hurricane Katrina and her aftermath in the fall, the past year has also been devastating but it has also been a reminder of humanity's breathtaking capacity for empathy. We all looked at the faces of those devastated by Hurricane Katrina and knew it could have been us. And as the University of Western Ontario's Gordon McBean writes, if climate change patterns hold, one day, when Canada finds itself in the path of weather catastrophes we're used to watching from a distance, it will be.

L'information continue et l'Internet nous ont tous transformés en témoins sinon en victimes de toutes les catastrophes naturelles de la planète. Du tsunami survenu en Asie du Sud-Est en décembre dernier à l'ouragan Katrina de cet automne, l'année qui s'achève a été fertile en désastres qui ont toutefois révélé chez les gens d'étonnantes réserves d'empathie. En scrutant les visages défaits des victimes de l'ouragan Katrina, nous avons tous compris que leur drame aurait pu être le nôtre. Et comme l'écrit Gordon McBean, de l'Université Western Ontario, c'est ce qui arrivera si la progression des changements climatiques se maintient : ces catastrophes que nous observons aujourd'hui à distance frapperont tôt ou tard le Canada de plein fouet.

On August 23, 2005, meteorologists noted a storm developing off southeastern Bahamas. The next day, it reached tropical storm strength and was named Katrina. As it moved westward, it intensified and hit south Florida on August 25 as a category 1 hurricane, just two days after its initial detection. Then, Katrina left Florida and moved over the Gulf of Mexico, where atmospheric flow patterns and warm sea-surface temperatures led her to turn northward and intensify rapidly. By the morning of August 28, Katrina had reached category 5 and was also significantly larger than most hurricanes of her intensity. Katrina's widespread devastation along the central Gulf Coast states, including New Orleans, Mobile and Gulfport was bad enough, but the total damage was, of course, compounded by breaks in the levees that separated New Orleans from surrounding lakes. By the time the disaster at least stopped getting worse, the material, social and economic damage seemed overwhelming.

Considered separately, Katrina, Rita and Wilma may be innocuous women's names. But as a threesome, they're three hurricanes that have had a terrible human and socio-economic impact in North America. What has been happening? When this essay was first proposed, the topic was Katrina. Then we had to add Rita. Then Wilma...just after Vince became the first hurricane on record to make landfall in Spain. Then we had Alpha and Beta tracking through Central America, so named by the Hurricane Committee of the World Meteorological Organization, which had to resort to the Greek alphabet when they hit their limit at "W." Even before the end of hurricane season on November 30, 2005 was the busiest season since 1851, when we started keeping track. Hurricane Katrina has now entered the record books as causing the highest insurance loss in US history, estimated now to be about $US40 billion. The total costs have been estimated as high as $200 billion. Before Katrina, 1992's Andrew was the most expensive, with insured losses at $21 billion. Wilma, with sustained winds of more than 260 km/h, was the most intense Atlantic storm ever recorded and ranks 5$^{th}$ on the damage list, at $6.7 billion, and Rita, which tore through the Gulf states between them, ranks 8$^{th}$ on the all time list at over US$4 billion. In 2004, Florida reeled in the aftermath of an unprecedented four hurricanes in one season. Of the four, Charley, Ivan and Frances rank 3$^{rd}$, 4$^{th}$ and 7$^{th}$. So, six of the eight most damaging hurricanes ever to hit the US struck within a 14-month period (August 2004 to September 2005).

Eight of the last ten years have seen above-average hurricane seasons in the Atlantic. The year 2004 also marked the first time Japan was hit by 10 typhoons (as hurricanes are called in the western Pacific or Indian Oceans) in a single season. The classification of hurricanes by name is a fairly recent practice. It was only in 1950 that the World Meteorological Organization began naming hurricanes, using such names as "able," "baker," and "charlie" — the military codes for letters. In 1953, women's names were assigned, starting with Alice and Barbara. In October, 1954, there was Hurricane Hazel, the most intense hurricane to strike Ontario.

It was not until 1979 that male names were included, the first being Bob, and the first Hispanic one being Jose, in 1981. But before they're named, several factors need to conspire to create a hurricane. Sea surface temperature needs to be at least 26ºC to provide the energy and for moisture to evaporate from the ocean. They cannot form very near or at the equator, because the Coriolis force (due to the Earth's spin around its poles) is too small to create a rotating flow. So, the hurricane creation zone is over the tropical oceans away from the equator, but bounded on the north and south by the 26ºC isotherm. Given those and some other atmospheric conditions, a pre-existing disturbance, such as a storm off the African continent, can trigger a rotating storm. The ocean then provides the energy to spin it up. When sustained surface winds reach 88 km/h it is called a tropical storm. When the winds exceed 119 km/h it is called a hurricane. According to the official Saffir-Simpson scale, named after two famous hurricane meteorologists, hurricanes are classified as category 1 (winds 119-153 km/h), 2 (154-177 km/h), 3 (178-209 km/h), 4 (210-251 km/h) or 5 (winds greater than 251 km/h). When Wilma and Katrina were category 4 or 5 hurricanes, their winds exceeded more than twice the legal speed limit on Canadian highways.

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The devastation of Katrina was an enormous tragedy for people, property and the environment. How did it happen? In fact, this event was entirely predictable, predicted and preventable, if the right things had been done. The October 2001 issue of *Scientific American* carried a story titled "Drowning New Orleans." This was the lead: "A major hurricane could swamp New Orleans under 20 feet of water, killing thousands. Human activities along the Mississippi River have dramatically increased the risk, and now only massive reengineering of southeastern Louisiana can save the city." It went on to say, describing local preparations: "The boxes are stacked eight feet high and line the walls of the large, windowless room. Inside them are new body bags, 10,000 in all. If a big, slow-moving hurricane crossed the Gulf of Mexico on the right track, it would drive a sea surge that would drown New Orleans under 20 feet of water. 'As the water recedes,' says Walter Maestri, a local emergency management director, 'we expect to find a lot of dead bodies.' New Orleans is a disaster waiting to happen."

It is eerie to read this article, not in an obscure technical journal but in a publication mainstream enough that it should have brought attention to the danger. It was highlighted in the local press. Yet nothing much happened. Over the longer term, the disaster could have been prevented by an active program of land-use planning and control. Municipal and other levels of government must learn to say "no" to certain developments. In the New Orleans area, the activities of humans have dramatically increased the rate of land loss by altering certain natural processes and accelerating the Mississippi Delta's natural subsidence, increasing the area's vulnerability to hurricanes. As the city expanded from its original location, it spread into low-lying areas. To prevent flooding in New Orleans, a system of dikes and levees was constructed, but only to the standards of a category 3 hurricane. In the end, much of the city was below sea level. Because of studies like the one in *Scientific American*, the US Army Corp of Engineers, which has responsibility for the levees, proposed additional work on them. Then the federal government allocated one-sixth of the funding requested. Obviously, governments seem reluctant to invest in disaster mitigation. In the case of Katrina, the impact was compounded by the slow pace of relief and evacuation. With proper investment in all phases of emergency and disaster management — mitigation/prevention, preparedness, response and recovery — natural hazards do not have to become natural disasters.

The devastating effects of the December 2004 Indian Ocean tsunami, Hurricane Katrina, the Kashmir earthquake and other events are vivid reminders that natural disasters are a global concern that can result in great loss of human lives, livelihoods and economic assets in both developed and developing countries. Although earthquakes and tsunamis can have horrific impacts, most disaster losses — in terms of number of events, lives lost or material destruction — stem from extreme weather-related events such as hurricanes, cyclones, other major storms, floods, landslides, wildfires and drought. In the last 10 years, about three-quarters (by number) of all natural disasters were triggered by weather-related events (figure 1). While catastrophic events are, fortunately, fairly rare, the frequency of recorded natural disasters has been rising rapidly. From about 100 per decade in the period 1900-40, to 650 per decade in the 1960s, and 2,000 per decade in the 1980s, it reached almost 2,800 per decade in the 1990s. Most of this increase is for weather-related events. Millions of people are killed, injured or displaced each year because of natural disasters, and property damage has been doubling about every seven years over the past forty years.

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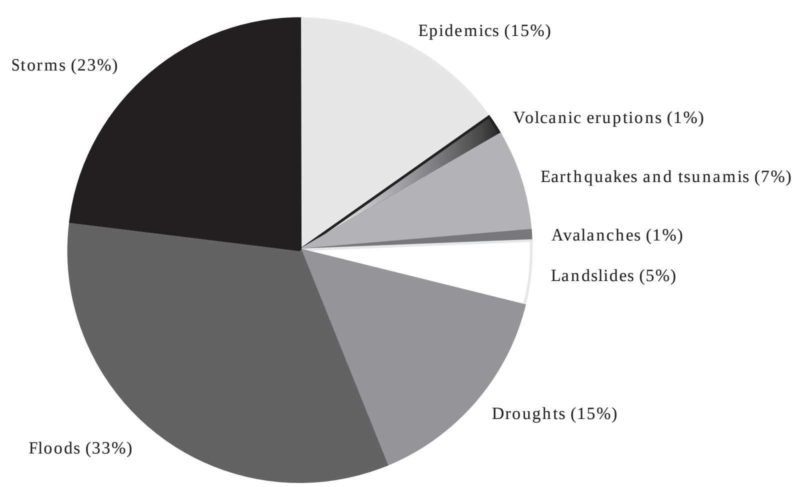
Around the globe, population growth in hazardous areas means more people and communities are at risk. People are also living by choice or circumstances in more hazardous zones — along coasts, river banks and mountain slopes. There is more and more expensive infrastructure, so when damage occurs it is more expensive. In urban regions (and particularly in very large cities), the complex infrastructure systems that make life and economic activity possible also increase the vulnerability of populations to disruptions caused by natural hazards. Human intervention in the environment can also increase vulnerability to natural hazards. Examples include changes in land cover that increase the risk of landslides or flooding, destruction of mangroves that increases the susceptibility of coastal areas to storm damage, and the emission of pollutants and greenhouse gases into the atmosphere, which changes the climate and can increase the frequency of extreme weather events.

Was Katrina due to global warming? Since the US government is on record as saying it will rebuild New Orleans and other areas, the more urgent question is: what hurricane and other storm criteria will be used in the redesign? Clearly, the pre-Katrina design of levees and protective systems was inadequate. What would be adequate? Should the design for rebuilding be based on the climate of the past, the last 30 years, or on the best estimates of the climate of the future?

Although we often hear about the overall warming of 0.6°C over the past century, it is more relevant to talk about the 0.5°C warming since 1950. Climate statistics have changed over the past few decades. The question of what has caused these changes hasn't been easy to answer. Climate scientists fully recognize that the climate system varies naturally due to the coupling between the ocean and the atmosphere (as with *El Nino*), and that it also responds to external forcing — factors outside the natural climate system, such as variations in the sun's emissions and in the orbit of the Earth around the sun, volcanoes, asteroid impacts and human activities.

The ice ages of the past were mainly due to orbital variations, and volcanoes inject massive amounts of dust into the stratosphere that reflects the sun's rays and cool the climate. Comprehensive global climate models, used to investigate climate, can replicate the variations of the past. But when we examine the last hundred years using only known natural factors (solar variability and volcanic activity), natural factors explain global mean temperature up to at least the 1930s and fairly close-

FIGURE 1. NATURAL DISASTERS BY TRIGGERING HAZARD, AVERAGED ACROSS THE WORLD, 1994-2003

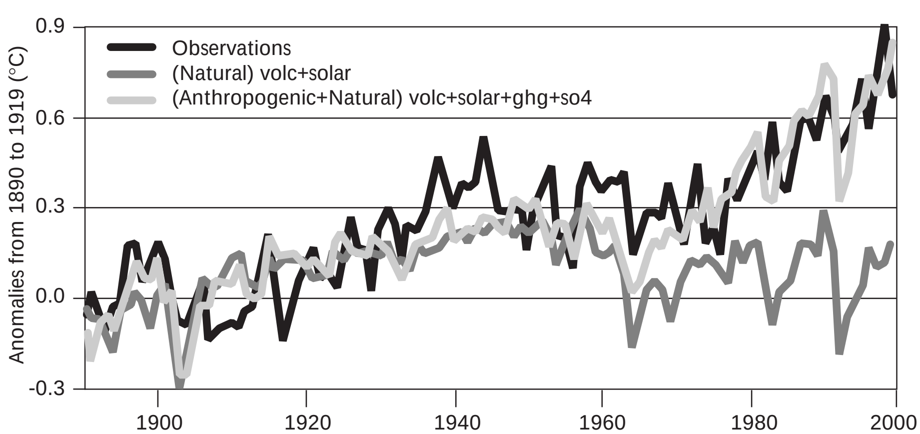



Source: EM-DAT: The OFDA/CRED International Disaster Database.

ly until about 1950 (figure 2). However, for the past 50 years, natural factors alone would have resulted in cooling, while in fact our climate has been warming. Only when we incorporate the human or anthropogenic factors (greenhouse gas concentrations and human-caused sulphate aerosols) do the model simulations closely approximate the past 50 years. It is on this scientific basis that scientists attribute the warming to human activities.

The Intergovernmental Panel on Climate Change (IPCC), which submitted to governments its Third Assessment Report in 2001, stated it this way: "In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." And it said that "Concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities." In drawing on these two conclusions, the IPCC *Summary for Policy Makers* stated that: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." A recent scientific review, published in May 2005 in the prestigious *Journal of Climate* states, "Thus, the recent research supports and strengthens the IPCC Third Assessment Report conclusion that 'most of the global warming over the past 50 years is likely due to the increase in greenhouse gases.'"

FIGURE 2. COMPARISON OF OBSERVATIONS OF GLOBAL AVERAGE TEMPERATURE WITH MODEL SIMULATIONS WITH ONLY NATURAL FORCING (VOLCANOES, SOLAR) AND NATURAL PLUS ANTHROPOGENIC FORCING (INCLUDING GREENHOUSE GASES AND AEROSOLS)[1]




[1] Only when changes in anthropogenic greenhouse gases and sulfate aerosols are included are models able to reasonably reproduce observed warming after about 1970.
Source: G.A. Meehl, W.M. Washington, C.M. Ammann, J.M. Arblaster, T.M.L. Wigley and C. Tebaldi: "Combinations of Natural and Anthropogenic Forcings in Twentieth-Century Climate." *Journal of Climate,* 2004 17: 3721-3727.

A recent statement issued by the International Joint Science Academies summarizes well the issue of climate change and its significance for the global community. The statement, titled "Global Response to Climate Change," (Joint Science Academies' Statement, 2005), is signed by the presidents of the academies of science of all of the G8 countries (Canada's signatory was the president of the Royal Society of Canada), as well as by those of China, India and Brazil. It says that "climate change is real," and that actions must be taken to "reduce the causes [and] prepare for the consequences of climate change."

In other words, nations must work together to stabilize the amount of greenhouse gases in the atmosphere in order to mitigate climate change, all the while adapting to what will inevitably be a changing climate. Similarly, the Gleneagles G-8 summit communiqué of 2005 states "Climate change is a serious and long-term challenge that has the potential to affect every part of the globe."

Changes in the global climate have altered and will continue to alter the risk associated with natural hazards. As the IPCC noted in 2001:

> *The vulnerability of human societies and natural systems to climate extremes is demonstrated by the damage, hardship, and death caused by events such as droughts, floods, heat waves, avalanches, and windstorms. While there are uncertainties attached to estimates of such changes, some extreme events are projected to increase in frequency and/or severity during the 21st century due to changes in the mean and/or variability of climate, so it can be expected that the severity of their impacts will also increase in concert with global warming.*

Our climate is now fundamentally changed and our future will be different in important ways from the past.

The scientific case for hurricanes has been more controversial — until recently. In their 2001 assessment, the IPCC examined the evidence on the observed changes in the last half-century and concluded that the data were insufficient to make any assessment of changes in hurricane wind or precipitation intensities. However, in examining the projected changes during the 21st century, they did conclude that, based on understanding of the physics of hurricanes, that increases in both wind and precipitation intensities were "likely, over some areas." The IPCC defined "likely" to mean there is a 66-90 percent probability. Over the past six months, a series of scientific papers and presentations have clarified the issue, starting with Dr. Kevin Trenberth (a leading US climate scientist) in "Science" in June 2005. Professor Kerry Emanuel of MIT, in a paper in *Nature* of July 2005, showed that the destructive power of hurricanes has increased by 50 percent over the last 50 years. In the

September issue of *Science*, Professors P. Webster, G. Holland, J. Curry and H. Chang published the systematic analysis of hurricanes in all ocean basins from 1970 to the present — a period of consistent global satellite data.

Both studies showed that although the number of hurricanes has remained about constant, the number of category 4 and 5 hurricanes worldwide has nearly doubled in the last 35 years, and the increase is consistent with the observed warming of the sea surface temperatures. For example, comparing the periods 1975-89 and 1990-2004, the number of category 4 and 5 hurricanes increased from 16 to 25 in the North Atlantic and 85 to 116 in the West Pacific.

At a seminar by the American Meteorological Society in Washington, DC, on October 25, 2005, Drs. Kevin Trenberth, Kerry Emanuel and Judith Curry shared the conclusion that anthropogenic climate change is causing increased hurricane intensity. Since there are still those who claim that there is no trend, Curry explained that most US hurricane specialists focus only on Atlantic hurricanes that actually hit the United States. She noted that only 11 percent of hurricanes worldwide occur in the North Atlantic, and only 2 percent of all hurricanes make landfall in the US. She argued that this sample size is not large enough to enable scientists to spot the effects of climate change on storm activity. Some also argue that variations are just natural on time scales of a few decades, but since the global climate has been significantly changed over the past 50 years, cycles of 20 years seem to be irrelevant. Further, reliance on past storm data for forecasting is now more problematic because in a new climate the old relationships will not be valid. This increases the risk of storms being more unpredictable in the near term as forecasters adjust their methods.

From a strictly Canadian perspective, why does all this matter? There are the social and economic factors, including the connections of global insurance costs. And hurricanes do impact directly on Canada. According to a recent report of the Nova Scotia-based Canadian Hurricane Centre, between one and nine tropical storms per year pass through the Hurricane Centre's response zone, which extends from Ontario eastward to the waters off Nova Scotia and Newfoundland. Ginny, Gerda and Juan are the named category

**As a category 4 and 5 storm, Hurricane Katrina struck the Gulf Coast at 240 km per hour, or more than twice the speed limit on Canadian highways. Studies find that cat. 4 and 5 storms have nearly doubled in the last 35 years, coinciding with a warming of oceans due to global warming.**

2 hurricanes that have made landfall in Atlantic Canada since 1950. When Hurricane Juan hit Nova Scotia on September 29, 2003, it was the strongest hurricane in over 100 years. Juan's maximum sustained wind speed was 160 km/h, with gusts up to 230 km/h. Waves in excess of 20 metres occurred, and there was much erosion, particularly in the Bedford Basin.

As Juan was undergoing a transition from a hurricane, with its symmetric structure, to an extra-tropical storm (with typically strong winds on one side and strong rain on the other), it caused damage more akin to a category 3 hurricane, although the average winds did not justify that ranking. In a sense it was fortunate that the storm surge happened at night, so there were fewer people exposed. There was widespread damage in central Nova Scotia and Prince Edward Island, and at least eight lives were lost. More than 300,000 people were without power for up to a week and a half. Unusually warm ocean surface temperatures, about 3ºC warmer than usual, are one reason that Juan was much stronger than usual. Another is that the storm accelerated so that it was moving quickly and the winds relative to the ground, the sum of the winds around the storm and the speed of the storm, had more impact. So, as the climate warms, the occurrence of these warmer waters will be more prevalent in the future, boding ill for hurricanes.

Because of its impact, the Meteorological Service of Canada specifically requested, for the first time, that a hurricane name be retired. So Juan will not hit Atlantic Canada again. A more positive result of Juan is that it was the Canadian Katrina of its day, in terms of alerting governments, utilities, emergency management agencies and people in general to be better prepared.

Fifty-one years ago Hurricane Hazel blasted through Ontario. Hazel originated in early October 1954 in the tropical Atlantic, and created havoc in Haiti and the Bahamas as it moved north to hit the Carolinas as a category 4 hurricane. Its storm surge of 4.4 m wiped out much of Garden City, South Carolina. As it passed inland over the Carolinas it transformed into a mid-latitude cyclone with winds equivalent to a category 3 hurricane. In the United States there were 95 deaths and about $250 million in property damage. As Hazel moved into Ontario, it merged into a cold frontal system, and the result was torrential rain. The river basins in the Toronto area received over 2m of rain, causing flash flooding. Bridges were destroyed and 81 people were killed. Although the flooding caused most of the damage, wind gusts of over 150 km/h were recorded; it still carried hurricane status despite its long overland path. Hazel was the most intense hurricane of the year and the most intense to ever hit this far into Canada. Because of Hazel, policies were implemented to prohibit development along the rivers or in the floodplains of the greater Toronto area, and conservation authorities were created across southern Ontario, which have restricted development in flood prone areas and provided excellent recreational opportunities.

Both Hazel and Juan were hurricanes undergoing transition to mid-latitude storms. As with Hazel, when a hurricane merges into a pre-existing mid-latitude storm, there can be particularly horrendous consequences. As our climate warms, three factors will make the impacts of hurricanes and their mid-latitude transitions potentially much more damaging. First, the aforementioned projections of more high-intensity hurricanes in the tropical regions which, as they move north, will be stronger. Second, as the climate warms, the sea surface temperatures will warm through all latitude bands and provide energy so that storms will maintain their intensity over the oceans to higher latitudes. Third, more intense mid-latitude storms are expected. The IPCC has projected that more intense precipitation events are very likely to occur. So, we can expect a combination of strong hurricanes in the tropics that do not lose as much strength as they move north, and the possibility that they will merge with more intense storms at our latitudes. This is all a major cause for concern.

Storm surges — ocean waters driven by marine winds — have already shown their impacts on places like Charlottetown and Halifax. As the climate warms, the sea level will also rise. A one-half metre — up to a possible full metre — rise is projected by the end of this century. Imagine, then, a major storm, with a resulting storm surge of a several metres of water, coming onshore, with the sea already a metre higher than it is now. The risk to low-lying coastal communities is incalculable.

There is a strong connection between weather on the day-to-day basis — hurricanes, storms of all kinds, the ocean — and climate. The integrated provision of information to Canadians on the time scale of events from the tornado in the next 10 minutes to the storm/hurricane of tomorrow and the day after, through the weekly to seasonal predictions, to the climate change scenarios on decadal and to century times scales needs to be a key part of Canada's response to climate change and central to an adaptation strategy. Integration across time and space scales and across a broader range of parameters, such as air quality, floods, storm surges and ice conditions, must be fostered as a comprehensive prediction system within a science-service organization. A critical part of the predictions must be information advising Canadians as to what these events mean to them and how they can or should respond. This is nothing more or less than the ultimate role of government — to protect its citizens.

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