

GLOBAL WARMING

IMPLICATIONS FOR CATASTROPHE RISK MANAGEMENT

The changes in the global climate in general and the increase in the frequency of intense storms in particular are of concern to not only the populations directly affected, they also hold wide ranging implications for the insurance industry. The worldwide insurance losses due to extreme weather events in 2005 were about \$80 billion¹, double of the 2004 losses, and more than three times the losses in 2002 and 2003 combined. Analysis of long-term hurricane loss record in the United States suggests that the average annual loss in the last decade is almost double than the average for the past 100 years. According to the Association of British Insurers (ABI 2005), annual losses from storms affecting the major insurance markets (U.S., Japan and Europe) could increase by two-thirds to \$27 billion by the 2080s. The significant increase, in recent years, in losses due to extreme weather events poses a challenge to the insurance industry of adjusting to a possibly changing catastrophe risk scenario.

The busy Atlantic hurricane seasons of the past two years and the ferocity of Hurricane Katrina last year have spawned a vigorous debate bringing forth the question whether the increased hurricane activity is due merely to cyclical trends or a sign that the phenomenon of global warming is beginning to have an impact on climate throughout the planet. Year 2005 saw several Atlantic hurricane season records broken – there were a record twenty seven named storms (windspeed 39 mph or higher) of which a record fifteen were hurricanes (windspeed 74 mph or higher) including four category 5 (windspeed 156 mph or higher) hurricanes (figure 1).

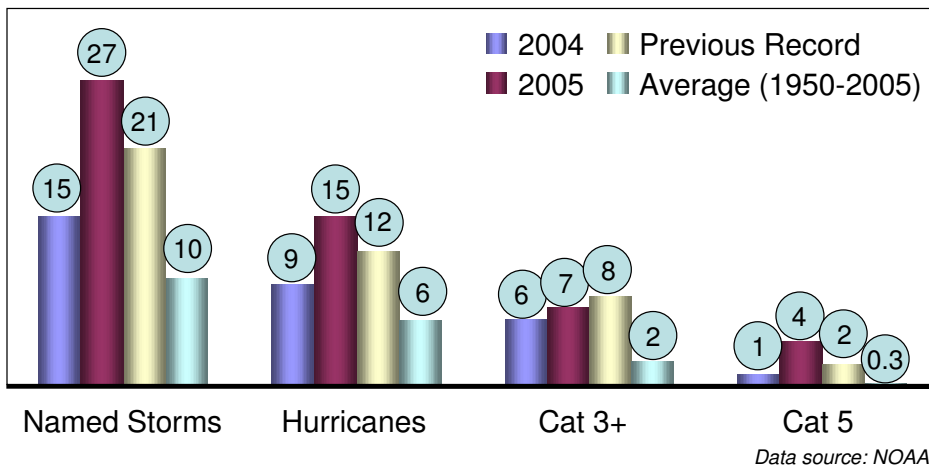


Figure 1. Tropical cyclone activity in the North Atlantic

¹ Swiss Re (Sigma 2003-2006)

Climate science is developing rapidly and scientists have been able to make significant advances in the understanding of the global warming and climate change phenomenon and its impact on the environment. They are also increasingly able to project some changes at the regional scale helping identify regional vulnerabilities and assess potential impacts. Science indicates that the Earth's climate has changed in the past and continues to change due to human-induced global warming (IPCC 2001). Sea surface temperature (SST), the dominant variable in hurricane formation, has been trending upward over the 20th century and is associated by some researchers (e.g. Emanuel 2005 and Trenberth 2005) with global warming while others (e.g. Goldenberg et al. 2001) have attributed these increases to natural climate cycles. An analysis of the historical record of SSTs and hurricane intensities by Emanuel (2005) suggests that the hurricane energy is highly correlated with tropical sea surface temperature, reflecting well-documented climate signals, including multidecadal oscillations in the North Atlantic and North Pacific, and global warming; and the hurricanes have also become significantly more destructive over the past three decades. Recent research also suggests that the duration and intensity of hurricanes worldwide has increased dramatically over the past half century, possibly due to increasing SSTs. Model results (Knutson and Tuleya 2004) show a shift in hurricane intensities toward extreme hurricanes. A statistical study by Webster et al. (2005) suggests that the number of stronger and more destructive hurricanes has almost doubled over the past 35 years.

The relationship between global warming and hurricane behavior is the subject of serious debate. Some scientists argue that links exist while others say warming influences are tiny when compared with natural swings. Scientists are divided on whether climate change, induced by global warming, is driving these statistics and the debate has researchers on both sides of the global warming fence. Although variability is large, trends associated with increasing global warming and correlations with SSTs and the consequent increasing hurricane intensities are evident in the environment in which hurricanes form, and our physical understanding and observations suggest that the intensity of and rainfalls from hurricanes are probably increasing, even if this increase cannot yet be conclusively proven with formal statistical tests.

Global Warming and Climate Change Research at Tokio Millennium Re

In order to respond to the growing volume of research and scientific evidence suggesting that global warming may be responsible for increasing losses related to severe weather events, Tokio Millennium Re (TMR) has devoted significant efforts to addressing and understanding the issues related to global warming and climate change and its consequent impacts on the environment. In addition to conducting internal research, TMR has developed and fostered dialog with a worldwide network of meteorologists and climate scientists. To this end, TMR brought together leading meteorologists, climate scientists and risk managers for a one-day seminar on May 2, 2006 in Bermuda to participate in discussions covering wide-ranging issues related to climate change and their potential impacts on the environment. While the general agreement was that global warming was for real and even greater future warming is anticipated due to anthropogenic forcing

(greenhouse gas emissions, etc.), uncertainty remains on the magnitude of the impacts of global warming on the increase in the frequency and intensity of tropical cyclones. There are question marks also on the quality of the data and models used for analyzing the impacts of climate change. TMR's First Summit on Climate Change is part of an ongoing effort to understand climate change and its implications for the insurance industry. The purpose of such meetings is to augment a process of research, analysis, and dialogue about the coming changes in climate, their potential impacts, and our best response to an uncertain and possibly continuously changing climate. Volatile and extreme weather will require changes to underwriting practices. We will need to focus more closely on current and likely future climate trends and, if needed, refine our view of risk globally while reconciling any future changes in the intensities of windstorms relative to the observed variability.

The research focus at TMR is on understanding and distilling the key issues facing the scientists and the end users of the scientific research and to develop practical solutions to address and adapt to a possibly changing climate risk landscape.

Global Warming Trends

Based on observed temperature trends (e.g. figure 2), scientists and climatologists are in general agreement regarding the recent warming of the earth; however, the reasons attributed to this warming are the subject of much debate. The global average surface temperature has increased by $0.6 \pm 0.2^\circ\text{C}$ since the late 19th century (IPCC 2001). The most recent period of warming (1976 to 1999) has been almost global, but the largest increases in temperature have occurred over the mid- and high latitudes of the continents in the Northern Hemisphere.

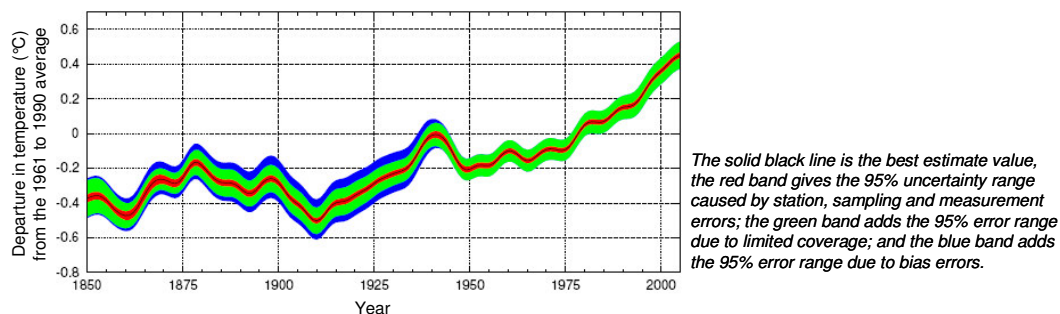


Figure 2. Global observed temperature smoothed deviations relative to 1961 to 1990 (adapted from Brohan et al. 2006)

The climate system varies both through natural processes (e.g. solar and volcanic) as well as in response to variations in external "forcing" from human-induced causes (e.g. greenhouse gases and sulphate aerosols). A model-based assessment (figure 3) suggests that that Global warming may contain a significant contribution from anthropogenic or human-induced forcing. The inclusion of anthropogenic forcings may provide a plausible explanation for a substantial part of the observed temperature changes over the past century (figure 3(b)), but a good match with observations is obtained when both natural and anthropogenic factors are included (figure 3(c)) (IPCC 2001).

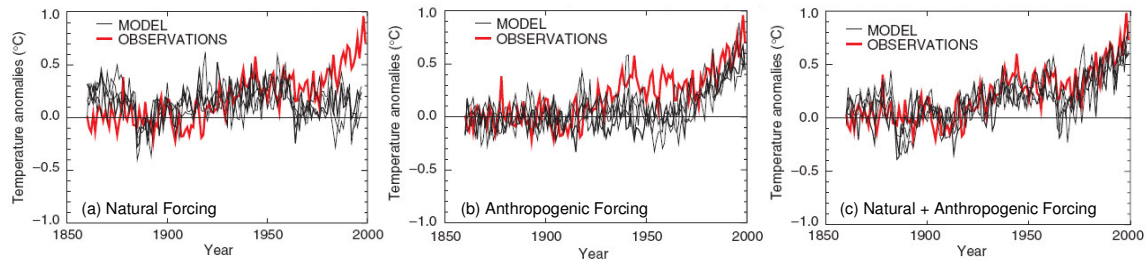


Figure 3. Modeled and observed variations in surface temperature changes relative to 1880-1920 mean (IPCC 2001)

Effects of Global Warming on Sea Surface Temperature

Sea surface temperatures (SSTs) in the tropical Atlantic appear to have a century-scale warming trend similar to the global temperature trend, but with additional multi-decadal variability superimposed. Warming trends are also evident in other tropical basins, particularly the Indian Ocean/western Pacific warm pool. Figure 4 shows the SST trends for the tropical cyclone season in various ocean basins (Webster et al. 2005) indicating that tropical ocean SSTs increased on average by approximately 0.5°C between 1970 and 2004.

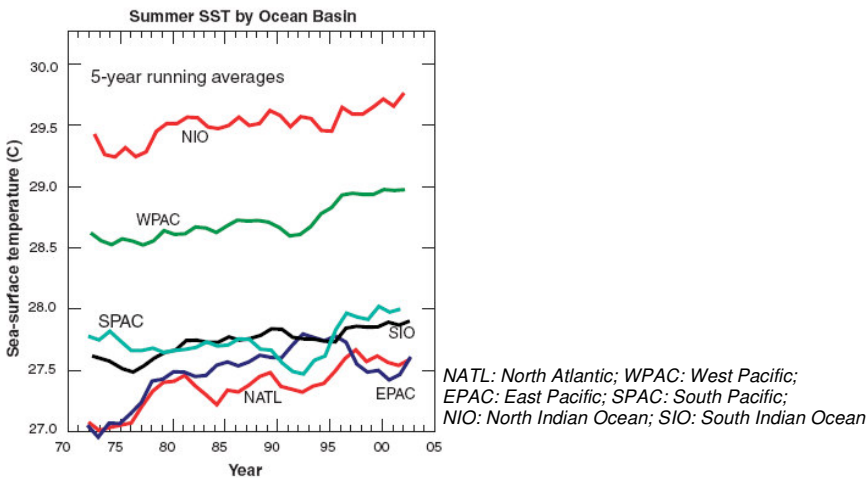


Figure 4. Running 5-year mean of SST during the respective hurricane seasons for the principal ocean basins (Webster et al. 2005)

According to IPCC (2001), it is very likely that the 20th century warming has contributed significantly to the increase in ocean-heat content as well as the observed rise in global average sea level through thermal expansion of seawater and widespread loss of land ice. The average annual rise, based on tide gauge records, was in the range of 1 to 2 mm during the 20th century. Analyses indicate that global ocean heat content has increased significantly since the late 1950s and more than half of the increase in heat content has occurred in the upper 300 m of the ocean, equivalent to a rate of temperature increase in this layer of about 0.04°C/decade (IPCC 2001).

Effects of Increasing Sea Surface Temperature on Tropical Cyclone Activity

Ocean heat is the key ingredient for hurricane formation. As climate change causes seas to warm, the oceans store more energy resulting in intensification of tropical cyclones. Recent observational studies suggest strong correlation between long-term variations in tropical SSTs and measures of tropical cyclone intensities. Based on an analysis of the historical record of tropical cyclones in the north Atlantic, Emanuel (2005) found that the potential destructiveness of hurricanes, described by a “power dissipation index²”, has doubled since the mid-1970s, correlating closely with Atlantic SST (figure 5). Similar trends were found in the western North Pacific basin. Emanuel attributes this trend to both longer storm lifetimes and greater storm intensities reflecting climate signals, including multidecadal oscillations in the North Atlantic and North Pacific, and global warming. Emanuel also suggests that future warming may lead to an upward trend in tropical cyclone destructive potential.

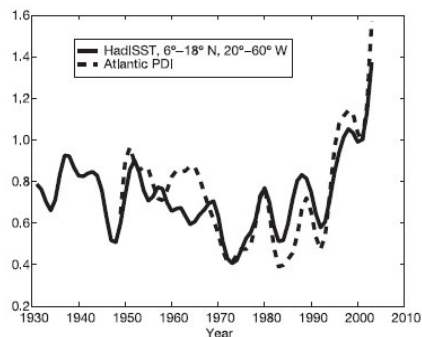


Figure 5. Correlations between long-term variations in Atlantic SST and Atlantic Power Dissipation Index (PDI) (Emanuel 2005)

Webster et al. (2005) examined the number of tropical cyclones and cyclone days as well as tropical cyclone intensity since 1970. It was seen that globally, the number of storms that reached the highest categories 4 and 5 on the Saffir-Simpson Scale³, which have wind speeds greater than 130 mph, has almost doubled over the past 35 years while storms in categories 1 to 3 reduced (figure 6). The largest increase occurred in the North Pacific, Indian, and Southwest Pacific Oceans, and the smallest percentage increase occurred in the North Atlantic Ocean.

² Power Dissipation Index is the cube of maximum windspeed (correlates well with hurricane damage) during the lifetime of the systems while they are of at least tropical-storm strength (windspeed of 39 mph) summed up for all the storms in a year.

³ Saffir-Simpson Hurricane Scale is a 1 (minimal damage) to 5 (catastrophic damage) rating based on a hurricane's intensity, used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall.

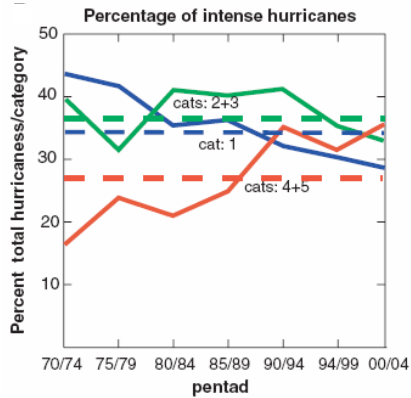


Figure 6. Historical trends in hurricane intensities (Webster et al. 2005)

In addition to the above observational evidence connecting SST with increase in tropical cyclone intensity, high-resolution climate models have been developed and used to assess the relation between greenhouse warming and hurricane intensity. Knutson and Tuleya (2004) used a suite of general circulation models to investigate prospective changes in tropical cyclone activity in a warmer world. Figure 7 shows comparison of simulated hurricane intensities for present-day (thin line) and future (thick line) climate conditions assuming an 80-year build-up of atmospheric CO₂ (i.e. the greenhouse gas considered responsible for global warming) at 1%/yr compounded. The results are aggregated from sets of experiments using nine different global climate model projections and four different versions of a high-resolution hurricane prediction model. The results show that a near century of warming, from the atmospheric buildup of greenhouse gases, simulated by an 80-year build-up of CO₂ at 1%/yr compounded, would result in tropical cyclones with 14% increase in central pressure fall, 6% increase in the peak surface wind, and 18% increase in the average rate of precipitation within about 100 km of the storm center. These increases are shown to primarily result from a strong association, within the models employed, between sea surface temperatures (SSTs) in the tropical cyclone formation regions and maximum storm intensity.

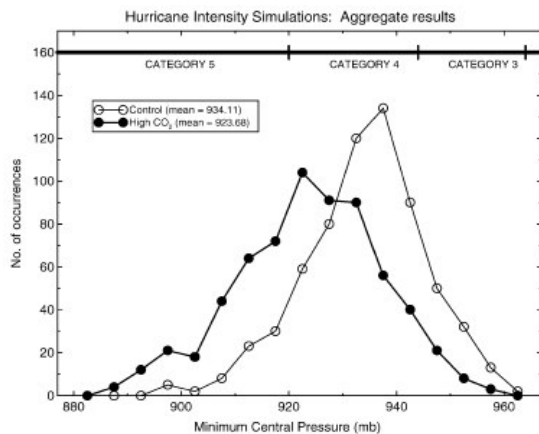


Figure 7. Comparison of simulated hurricane intensities for present-day (thin line) and future (thick line) climate conditions assuming an 80-year build-up of atmospheric CO₂ at 1%/yr compounded (Knutson and Tuleya 2004)

Reconciling Between Models and Observations

There have been questions raised regarding the validity of “idealized” models which fail to consider “real world” conditions like weather noise, wind shear effects and other factors that can prevent storms from reaching their full intensity. A related question for the modeling and statistical studies is the quality of the weather, temperature and historical tropical cyclone data used and whether the reported long-term trends represent real changes or are merely artifacts of modeling or data problems. A recent report by The U.S. Climate Change Science Program (CCSP 2006) claims to have addressed and reduced some of the discrepancies between the data sets (satellite data and other temperature observations) and the models thus increasing our understanding of observed climate changes and their causes. The report also states that research continues to support evidence of human influences on the climate system and global temperature increases due to changes in greenhouse gases, aerosols, and stratospheric ozone.

However, question remains on whether the observed trends can be reconciled with theories or simulations of the sensitivity of hurricane intensity to changes in climate conditions. The SST changes due to increased CO₂ in the Global Fluid Dynamics Laboratory experiments (Knutson and Tuleya 2004) averaged 1.75 °C, which is substantially greater than the 0.5 °C warming experienced in the tropical Atlantic and other basins during the period covered by the observational hurricane intensity studies mentioned earlier. Model-based studies by Knutson and Tuleya (2004) suggest a 4% to 5% increase, whereas statistical analysis of observational data by Emanuel (2005) shows a 30% increase, in tropical cyclone windspeed per °C increase in SST. Thus, there seems to be a significant discrepancy in modeled and observed analyses results which remains unresolved at this time.

Historical Atlantic Tropical Cyclone Activity

Figure 8 shows the 5-year moving average plots of the number Atlantic tropical cyclones and U.S. landfalling hurricanes. While the Atlantic tropical cyclone activity shows an increasing trend, especially after 1995, there is no such clear trend evident in the U.S. landfall activity although the two datasets show a moderate degree of correlation. This observation is important in that landfalling hurricanes are the primary drivers of insured property losses.

The landfalling activity is driven by several factors that have large uncertainty. There are at least three complex mechanisms within earth’s environment correlated with a variety of climate signals that affect hurricane landfall activity. They are:

Atlantic Multidecadal Oscillation (AMO): The AMO is a series of long-duration changes in the SST of the North Atlantic Ocean, with cool and warm phases that may last for 20-40 years at a time. These changes are natural and have been occurring for at least the last 1,000 years. Tropical cyclone development is favored when the Atlantic SST is warm and is reduced when it is cool. Currently the North Atlantic has been in a warm phase since the mid-1990s.

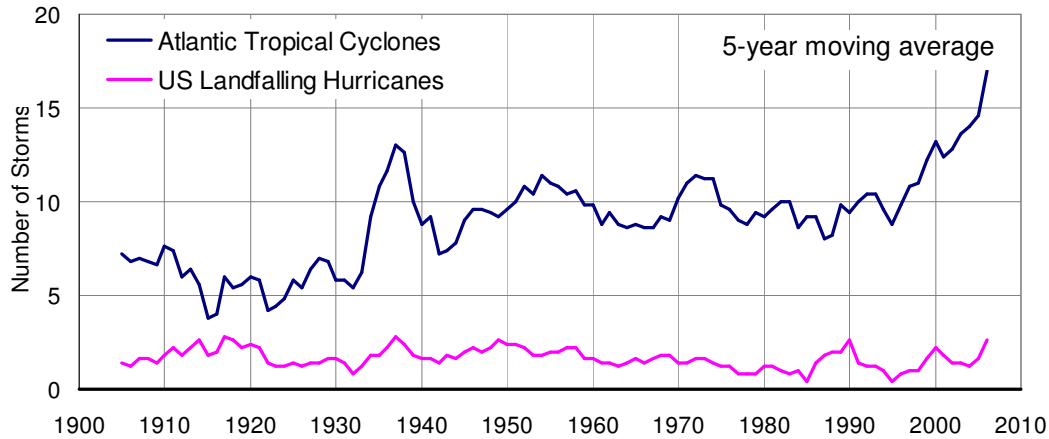


Figure 8. Atlantic tropical cyclone and U.S. landfalling hurricane activity (Data source: NOAA)

El Niño Southern Oscillation (ENSO): ENSO represents a significant change in SST over the eastern and central equatorial Pacific that occurs at irregular intervals, generally ranging between two and seven years. These changes in SST result in changes in large-scale atmospheric convection that affect wind patterns around the globe. During El Niño events (ENSO warm phase), an increase in tropospheric vertical shear (the difference between the upper-level and near-surface winds) inhibits tropical cyclone genesis and intensification. During La Niña events (ENSO cold phase), a reduction in tropospheric wind shear enhances tropical cyclone activity.

North Atlantic Oscillation (NAO): NAO refers to large-scale fluctuations in atmospheric pressure in the Atlantic Ocean between the high-pressure system near the Azores and the low pressure system near Iceland. The pressure difference between these two locations is a measure of the westerly winds across the Atlantic basin. Scientists view the NAO as a measure of the strength and location of the high pressure system over the central Atlantic Ocean, commonly referred to as the Bermuda High – important in defining the most prominent tropical cyclone pathways in the Atlantic. Thus, NAO has a significant impact on atmospheric steering currents and hence hurricane landfalls, especially in the U.S. However, the NAO varies in response to the atmospheric pressure distribution over the Atlantic, which changes on a very short time scale (weeks to months).

Historical Atlantic tropical cyclone activity vis-à-vis the AMO

Of the three climate signals most closely correlated with hurricane activity, recent scientific research has focused on the AMO because it is the only signal with a relatively long period spanning 20 to 40 years. Based on an analysis of multidecadal relationships of Atlantic tropical cyclones to Atlantic SSTs, Landsea et al. (1999) divided the AMO phases as follows: 1869 to 1893: Warm; 1894 to 1925: Cool; 1926 to 1970: Warm and 1971 to 1994: Cool. Recent research suggests that we are currently in a warm phase since around the mid-nineties.

The hurricane landfall data can be analyzed to develop correlations between AMO phases and hurricane activity. Figure 9 is similar to figure 8, but with cool and warm AMO phases overlaid on the data.

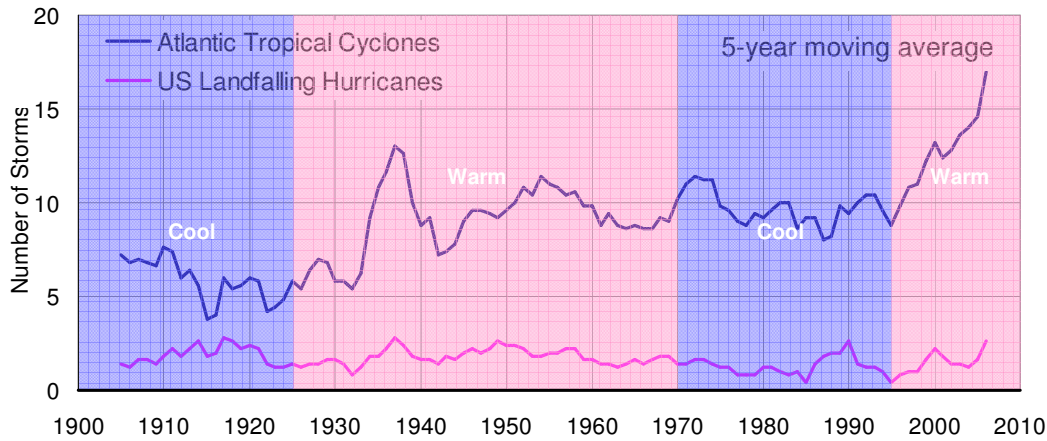


Figure 9. Frequency of U.S. landfalling hurricanes relative to AMO (Data source: NOAA)

The analysis shows that while there is a general increase, relative to the long-term average, in the average number of tropical cyclones in the warm phases and decrease in the cool phases, the increases are more pronounced for the current warm phase. For example, the average number of U.S. landfalling hurricanes and the average number of U.S. landfalling major (category 3 and above) hurricanes have increased by about 30% and 50%, respectively, for the recent warm phase (1995 to present).

Historical Hurricane Insured Losses in the U.S.

As discussed above, the coastal U.S., historically, has experienced more major hurricane onslaughts during the AMO warm phases relative to the cold phases and the long-term average. The insured losses, therefore, show a similar trend as well. Figure 10 shows U.S. hurricane annual insured losses since 1900. The losses have been normalized to 2006, accounting for the changes in property values, population, inflation and wealth (Collins and Lowe 2001). The historical loss record shows no apparent long-term trend. However, seen in conjunction with the AMO phases, there is an increase in average losses during the warm phases and decrease during the cool phases relative to the long-term historical average of about \$4.7 billion. For example, average annual losses in the recent warm phase (past decade) are almost double of the long-term average whereas they are about half of the long-term average for the last cool phase (1971 to 1994).

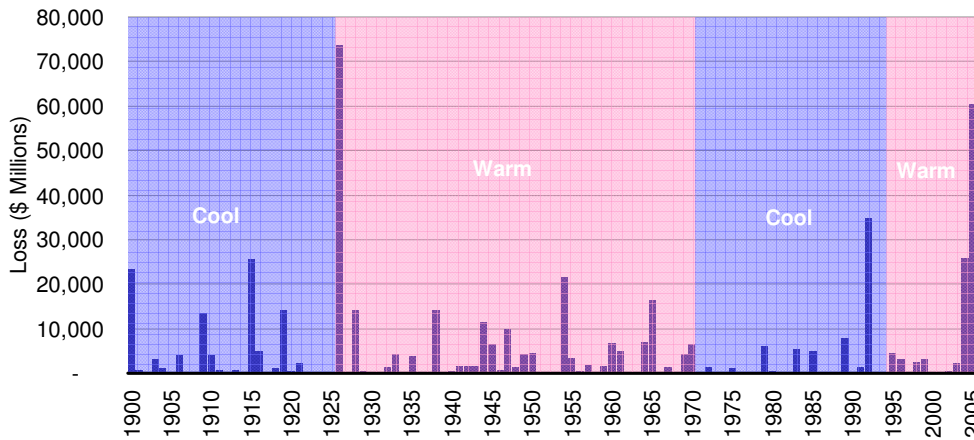


Figure 10. U.S. hurricane historical insured losses vis-à-vis the AMO phases

Scientists have suggested that the current warm phase will continue for another decade or so. Current and near-future catastrophe risk management models should therefore incorporate the effects on losses due to the increased tropical cyclone activity during the AMO warm phase. One way to achieve this would be by adjusting the long-term loss distributions by increases attributed to the AMO warm phase. This is a significant departure from the traditional long-term view of tropical cyclone risk used in the catastrophe models. The loss distributions in catastrophe modeling are expressed as Exceedence Probability (EP) curves, which are cumulative distributions showing the probability that losses will exceed a certain amount, from either single or multiple occurrences. The EP curves can also be expressed in terms of return period losses wherein, for example, a 100 year return period loss means that there is a 1% annual probability of exceeding that size loss. Analysis of the historical losses since 1900, incorporating the overall effects of the past two AMO warm phases (1926 to 1970 and 1995 to present), suggests an average increase in the losses in the AMO warm phase in the range of 20% to 30% over the long-term. Figure 11 shows the long-term and AMO warm phase historical maximum yearly occurrence insured hurricane loss distributions for the U.S. Note that these loss distributions are based on analysis of limited sample of historical data; a more thorough analysis should consider the impacts on the stochastic loss distributions used in the catastrophe models which provide a more robust representation of risk.

Conclusions and Future Directions

A growing body of expert opinion now agrees that Global warming is for real and even greater future warming is anticipated due to anthropogenic forcing (greenhouse gas emissions, etc.). The scientific and statistical evidence calls for storms that will be more severe and last longer. It is becoming increasingly clear that volatile and extreme weather will require changes to underwriting practices. Despite the issues facing the commercial catastrophe modelers of sorting out short-term prediction from long-term trends, they



Figure 11. U.S. hurricane historical insured loss distributions – long-term and AMO warm phase

have begun incorporating the short-term impacts of climate change in the models and the industry has generally been accepting of the changes. However, given the issues with the methodologies used to model and assess the impacts of climate change, as well as the data quality and the uncertainty in the magnitude of the impacts of climate change, a thorough examination and validation of the scientific results is needed, including a statistically rigorous analysis of the climate-hurricane connection and associated volatility in the impacts.

The insurance industry is at the forefront of research related to understanding the impacts of climate change on the environment and, as the widespread losses in the past couple of years have demonstrated, it is the insurance industry that will have to deal with most of its consequences. There are many steps that the industry could take to understand and adapt to this change, beginning with a forward-looking view, i.e. taking a more pragmatic approach to underwriting that plans ahead as opposed to merely reacting to catastrophic events or basing decisions on historical patterns. Some other steps the industry needs to consider in order to move forward effectively to resolving the issues related to global warming and providing realistic financial assessment of the impacts are: a) raise pertinent questions about global warming and climate change relevant to insurance and reinsurance; b) increase knowledge and awareness of the complex issues surrounding the problem of global warming and climate change and the potential impacts on the environment; c) identify and reconcile the uncertainties around the various models and data used to measure the impacts of climate change; and e) pave the way for an effective and continuous dialogue and collaboration with the research community.

We need to focus more closely on current and likely future climate trends and, if needed, refine the view of risk globally while reconciling any future changes in hurricane intensities relative to the observed variability. Finally, since the climate change phenomenon is global in scale the investigation needs to consider activity across all basins.

We are at an early stage in our understanding of the opportunities and challenges presented by climate change. Further studies are needed on climate change impacts where there is limited scientific evidence at present. This will enable better and more realistic modeling of the financial risks arising from the effects of global warming and climate change.

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