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GUY CARPENTER

GLOBAL WARMING: THE EVOLVING RISK LANDSCAPE

CLIMATE CHANGE
REPORT
SEPTEMBER 2013

MARSH & McLENNAN COMPANIES

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I. THE GLOBAL WARMING REALITY

A GREAT DEAL OF NOISE HAS CLOUDED THE NEED FOR OBJECTIVE DECISIONS ABOUT VERY REAL ATMOSPHERIC PERILS.

Global warming is an established scientific fact, and one that cannot be explained by statistical "noise" or natural variability alone. The single greatest threat under global warming is that of sea-level rise, which is expected to increase coastal flood frequency and severity under tropical cyclone, extratropical cyclone and tsunami events. The growing urban footprint and population density in coastal areas amplifies the financial and societal implications of such events. Changing weather patterns will lead to increased risk under flood and drought, with implications for agricultural, wildfire and water resources management. According to the Intergovernmental Panel on Climate Change (IPCC) (and consolidated scientific literature), tropical cyclone frequency is likely to decrease worldwide although the intensity of tropical cyclones could well increase. Adaptation measures to offset the impacts of these changes include water conservation and flood control efforts, together with sustainable agriculture and land use planning. Codes and standards play an essential role in climate adaptation and are particularly important in coastal areas. Diligent adjustment and modification of codes and standards can offset vulnerability in both developed and developing countries worldwide to reduce both the financial and social risks of climate change.

INTRODUCTION

Climate change, global warming and the resulting landscape shift for risk management has been a growing area of concern among governments, the general public, the private sector and of course the (re)insurance industry. The debate has been intensely polarized, very chaotic and intensely political, with numerous misrepresentations and misconceptions, resulting in a great deal of "noise" clouding the very real and emerging issues. To adapt to climate change and the changing landscape of atmospheric perils, it is essential to cut through the "noise" and focus on decisions made in full command of objective fact.

The Intergovernmental Panel on Climate Change has origins with the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The IPCC is a scientific body that reviews and assesses scientific evidence pertaining to the physics of climate change and technical and socioeconomic impacts. The IPCC reports integrate the work of thousands of scientists under a highly stringent review process from leaders in the field, with endorsements of governments on a worldwide basis. Objectivity, completeness and a policy-neutral approach are key criteria of all IPCC efforts.

The IPCC reports address the physical reality of climate change, its implications for weather and climate, the resulting impacts, the severe repercussions of sea-level rise and possible measures for adaptation and mitigation over the long term. The reports are a very detailed and robust body of work, of which key elements are discussed here.

THE REALITY OF GLOBAL WARMING

According to the IPCC Fourth Annual Assessment Report (AR4), the scientific consensus is that global warming is indeed an established scientific fact. The evidence is undeniable, and includes:

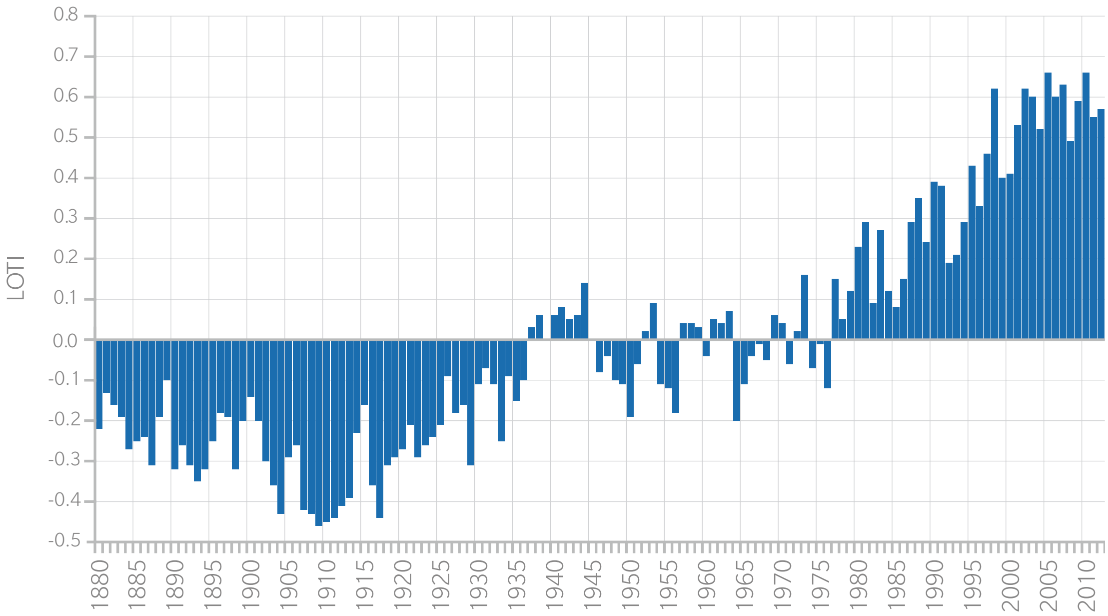
1. Increasing air temperatures
2. Increasing ocean water temperatures
3. Tree ring characteristics
4. Ice core sample chemical characteristics
5. Ice cap retreat

While climate variability has certainly been noted over past centuries, with supporting evidence over millennia, the rate of warming is believed to be unprecedented. The increase in the global mean air temperature as compared to the 1951 to 1980 average is depicted in Figure 1, and the increase in average oceanic heat content for depths of the 0-700 meter layer is depicted in Figure 2. The increase in oceanic heat content is notable because it takes a very large amount of energy to heat such a large volume of water.

Global warming is caused by what is known as the "greenhouse effect," where greenhouse gases such as carbon dioxide and methane absorb radiation emitted by the Earth, and re-emit that radiation back towards the surface, causing a warming effect. The process is very similar to how car windows work on a sunny day – the glass allows energy from the sun to heat the interior of a car but traps the heat before it escapes from the car. Greenhouse gases are responsible for the fact that the mean temperature of the Earth is 15 degrees (Celsius) instead of minus 18 degrees (Celsius). However, the increase in anthropogenic greenhouse gases since the industrial revolution is unprecedented in the Earth's history. According to the IPCC AR4 (2007), "most of the observed increase in global average temperatures is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. Greenhouse gas forcing alone would likely have resulted in a greater warming than observed if there had not been an offsetting cooling effect from aerosol and other forcings. It is extremely unlikely (less than five percent) that the global pattern of warming can be explained without external forcing, and very unlikely that it is due to known natural external causes alone."

As the Earth continues to warm, the air can hold more water vapor, which is a far more effective greenhouse gas than carbon dioxide. Water vapor can accelerate the warming process further.

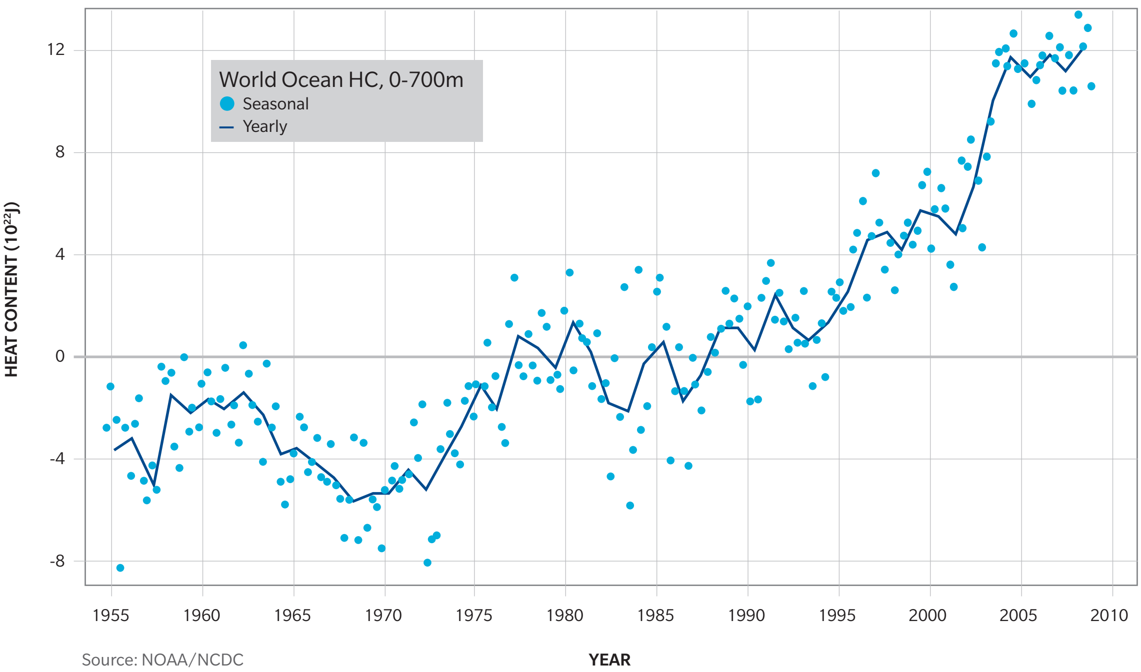
F-1 | GLOBAL LAND-OCEAN TEMPERATURE INDEX (LOTI) 1880-2012 (NASA/GISS)



(Source: NOAA/GISS 2013.)

(deg C, relative to the 1951-1980 mean)

F-2 | OCEAN HEAT CONTENT OF THE 0-700 METER LAYER SINCE 1955



Source: NOAA/NCDC

The IPCC has further concluded, based on consistent and scientifically defensible evidence, that "warming of the last half-century cannot be explained without external radiative forcing" (IPCC AR4, Working Group I, Section 9.7). So in essence, it is most unlikely that recent warming can be explained by natural variability alone.

A LOOK AT THE FUTURE

Scientists use a collection of global climate models (GCMs) to estimate the implications of global warming through the end of the century. While any single model demonstrates considerable error, the collection or ensemble of models has reasonably captured the climate change history of the past century. What is even more remarkable is that if greenhouse gas levels are held to pre-industrial levels in the GCMs, these models show a much colder climate between the Nineteenth Century and the present day than was actually observed. The same models are used for forward projections through the end of the century, under expected greenhouse gas concentrations.

Global climate model ensembles project a best estimate of a further two to four degree (Celsius) increase in the mean temperature of the Earth by the end of the century. This seems minor on an intuitive level. However the resulting impacts are of significant concern.

The hazard of greatest concern is coastal flooding.

Sea-level rise presents the most significant threat for coastal areas as a result of melting glaciers and thermal expansion of ocean waters. Apart from this threat, changing weather patterns will impose drought and inland flood threats for many areas. As a general principle of climate change, some modification to the mean of meteorological extreme value distributions can be expected, but with a more concerning increase in tail thickness (or variability). This change could amplify the effects of existing natural variability modes, such as the El Niño Southern Oscillation (ENSO), which already cause severe disruption due to flood, drought and hurricane frequency. The meteorological consequences of global warming are expected to be most severe in high latitudes and particularly in the polar regions.

II. THE CHANGING HAZARD LANDSCAPE

FLOODING IN COASTAL AREAS CAN PROPAGATE LARGE DISTANCES AND CAUSE DAMAGE TO INFRASTRUCTURES IN INLAND AREAS.

COASTAL FLOODING

The hazard of greatest concern under global warming is coastal flooding. According to the IPCC, a sea-level rise of at least one to two feet (25 to 50 centimeters) can be expected by the end of the century (with the understanding that a wide range of sea-level rise scenarios exist). This is of great significance for all coastal cities and communities. This is of even greater significance to fishing and agriculture communities located on the Asian coasts, many of which are situated on low-lying and flat geographical areas. The recent consequences of Cyclone Nilam for Eastern India and the impacts of Sandy (2012) for the coastal United States are grave examples of such impacts, and under sea-level rise, such impacts will come with greater frequency and severity. Tropical cyclone, extratropical cyclone and tsunami coastal impacts will all come with greater frequency and severity under the projected sea-level rise. This poses a significant human and economic concern for these areas, and is a significant concern to the (re)insurance industry.

The recent consequences of Cyclone Nilam for Eastern India and the impacts of Sandy for the coastal United States are examples of impacts which will come with greater frequency and severity.

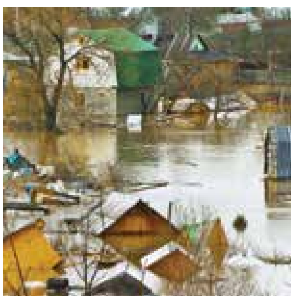
The IPCC identifies a number of possible long-term adaptation measures. Such measures include the development and improvement of building codes and standards for coastal flood resilience in vulnerable areas – important both for developing and developed countries. With the possible rise in sea levels, coastal management, including a re-examination of coastal defense structures such as dykes and seawalls, should be a priority. Flooding in coastal areas can propagate large distances inland to cause damage to infrastructures in inland areas, such as subway transportation systems. As another measure, land use strategies that shift unnecessary development away from coastal areas may also be beneficial as a means of mitigating the coastal flood threat to life, property and capital.

CHANGING WEATHER PATTERNS – DROUGHT

Changing weather patterns will cause changes to precipitation characteristics worldwide. According to the IPCC (IPCC SREX, 2012), “there is medium confidence that some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions, droughts have become less frequent, less intense, or shorter, for example, in central North America and northwestern Australia.”

Areas of the Colorado Basin in the United States and some Himalayan watersheds are already facing water shortage issues.

By the end of the century, GCM projections indicate that the number of days between precipitation events will



By the end of the century, GCM projections indicate that the number of days between precipitation events will increase for the broader areas of:

- Southern Australia
- Southeast Asia and India
- Asia Minor
- Southern Europe
- Northern, west-coastal and southern Africa
- Northeastern South America and coastal west South America
- Central America and western North America

The effects on soil moisture could be particularly acute in the U.S. south central plains as well as southern Europe, raising significant issues for agricultural interests in these areas by the 2050s. Increasing periods between rainfall events places stress on soils, limiting the capacity for agricultural activity. In extreme cases, affected areas can essentially become deserts.

Areas that see diminished annual precipitation will face water shortages. Other areas with water supply mainly from glacial sources will face the same problem to a greater severity due to glacial retreat. This has impacts for water resources management. For example, areas of the Colorado Basin in the United States and some Himalayan watersheds are already facing water shortage issues. For urban and suburban areas, the increasing footprint of the built landscape reduces the area of groundwater recharge zones, limiting the replenishment of aquifers. This compounds the problem for areas affected by decreasing annual precipitation.

Another hazard imposed by drought conditions is that of wildfire. With a longer growing season, diminished snowpacks and diminished precipitation, the wildfire hazard will increase. Fire probability is enhanced by warmer temperatures, lower relative humidities and greater wait times between rainfall events. As vegetation becomes dry under these conditions, it is more prone to ignition by random sources and more likely to spread with an increase in surrounding dry fuels. The wildfire hazard in areas already facing such a threat will see an increase in severity of this threat under global warming. In fact, the IPCC has noted that in the last three decades, the wildfire season in the western United States has increased by about 78 days (IPCC AR4, 2007 – Working Group II, Section 14.2.2).

Long-term adaptation strategies for the drought hazard include land-use planning that permits rainwater catchment, and preserves groundwater recharge zones and the deployment of sustainable agricultural practices. Under extreme cases, agricultural interests may be forced to relocate if soils no longer permit a viable growing season. The wildfire threat can be reduced by housing modification, increased separation distance between the home and adjacent forests and thinning of fuels on the property itself.

In the last three decades, the wildfire season in the western United States has increased by about 78 days.

CHANGING WEATHER PATTERNS – FLOOD

Under global warming, weather patterns will change, leading to increased precipitation for some areas. Even for some areas that see less precipitation on an annual basis, the rainfall may come in more intense bursts. According to the IPCC, "there is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scales because the available instrumental records of floods at gauge stations are limited in space and time, and because of confounding effects of changes in land use and engineering."

However, "there have been statistically significant trends in the number of heavy precipitation events in some regions. It is likely that more of these regions have experienced increases than decreases, although there are strong regional and subregional variations in these trends" (IPCC SREX, 2012).

Storm water management systems, particularly those of older design, are sometimes not equipped to handle intense rainfall events, and urban flooding is certainly an issue as a result. Flooding caused by the landfall of tropical cyclones along coastal areas will be exacerbated by the increase in precipitation as well as sea-level rise. Moreover, stormwater management systems often become overwhelmed by coastal flooding, preventing proper drainage under excessive rainfall that comes with tropical cyclones. This hazard is projected to increase in severity under global warming.

Rapid development in urban areas without due attention to increasing flood risks can increase the risk of severe impacts under urban flooding.

Adaptation strategies over the long term include attention to stormwater management infrastructure to accommodate larger rainwater volumes, upgrading codes and standards for civil infrastructure and land use that permits rainwater catchment basins. Rapid development in urban areas without due attention to increasing flood risks can increase the risk of severe impacts under urban flooding.

SEVERE CONVECTIVE STORMS

No observable trends have been detected in the United States with either tornado or hail climatology, according to the scientific literature at large and the IPCC. The tornado events of the very active 2011 season are not unprecedented in history (Doswell et al., 2012). Such outbreaks have occurred before – in 1974, for example, and such outbreaks will occur again.

The incidence of severe convective storms is not expected to change under global warming. However, a recent study by Trapp et al. (2007) concluded that the number of days in which severe weather could occur may increase under global warming. More research is required in this regard. Flooding under intense rainfall events has been shown to increase and will increase further under global warming, as noted above.

In the absence of a detectable trend in severe convective events of tornadoes or hail, significant headway can still be made through adaptation of tornado and hail resilience measures of existing building codes and standards and recommendations of the Institute for Business and Home Safety (IBHS). Tornado resilience measures in particular can save thousands of dollars under weaker tornadoes, and save lives under stronger ones. Such measures attain greater importance given the expanding population footprints, increasing population densities and increasing property values in the United States.

Tornado resilience measures in particular can save thousands of dollars under weaker tornadoes, and save lives under stronger ones.

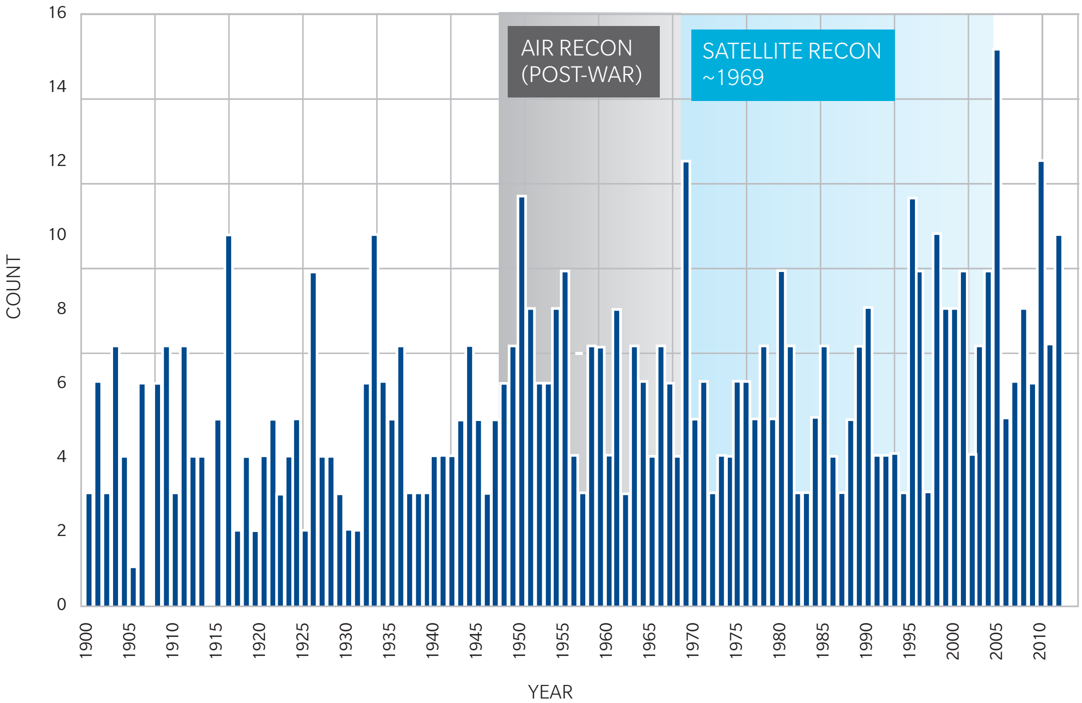
TROPICAL CYCLONES

One of the more controversial discussions of the climate change question has been the subject of tropical cyclones, historical trends and expected shifts under global warming. The questions cannot be easily answered with either observations or climate models, and the subject has been one of heated debate in both scientific and political arenas.

Observational Record – Atlantic Basin

It is tempting to conclude that hurricane counts in the Atlantic Basin constitute a trend, but post-war aircraft reconnaissance and satellite technology must be considered before making such a bold statement. Basin detection capabilities in the Atlantic improved significantly in the post-war era with aircraft reconnaissance, yet only became truly robust around the year 1970 with satellite technology (Figure 3). Furthermore, any possible long-term trend in the Atlantic Basin is masked by large interseasonal variability due to natural effects such as the Atlantic Multidecadal Oscillation (regardless of the cause) on the timescale of decades and ENSO on the timescale of three to five years.

F-3 | ATLANTIC BASIN HURRICANES (1900-2012)



Source: Guy Carpenter

Note:Post-war and satellite-era periods resulting in improved detection. Significant variability from year to year

Observational Record – Pacific Basin

In the western North Pacific, analyses of past observations do not show any increasing trend in tropical cyclone activity. Like the Atlantic Basin, activity undergoes large variations on multi-decadal time scales. If there is indeed a trend, it is actually a downward trend during the last 60 years, with the number of tropical cyclones in 2010 being the lowest during this period (Liu and Chan 2013). This latest study clearly shows that tropical cyclone activity in this ocean basin goes through large variations on multi-decadal time scales.

Observational Record - General

According to the IPCC (IPCC SREX, 2012), "there is low confidence in any observed long-term (40 years or more) increases in tropical cyclone activity (intensity, frequency and duration), after accounting for past changes in observing capabilities."

In terms of intensity trends, changes in observation technologies (aircraft, satellite) in recent years have resulted in more accurate estimates of intensities. Landsea et al. (2006) have demonstrated that such changes can account for most of the perceived increases in the frequency of intense hurricanes in the Atlantic. In the western North Pacific, the frequency of occurrence of intense typhoons also undergoes large amplitude multi-decadal variations with no discernible trends (Chan, 2006, 2008). The "trend" discussed in Emanuel (2005) and Webster et al. (2005) is actually an upward branch of this multi-decadal signal.

Tropical Cyclones – A Look at the Future

It is tempting to conclude that because of global warming, tropical cyclone frequency will increase. The evidence suggests otherwise, however. Under global warming ocean temperatures should increase, but shear in the Atlantic Basin should also increase – the two factors have competing impacts on tropical cyclone frequency in the Atlantic Basin.

According to the latest climate model projections, global tropical cyclone activity in the future is likely to decrease although significant variations will still exist in individual ocean basins (Knutson et al., 2010). Despite a possible decrease in frequency of occurrence, the number of intense tropical cyclones will likely increase by about ten percent. Again, the extent of such an increase differs from basin to basin.

There is indeed a trend in raw losses under tropical cyclones. However, correcting for population density and inflation, these trends become indistinguishable. The increasing population density and property value concentrations in coastal areas implicate higher risk (Pielke et al., 2008). Furthermore, IPCC AR4 states that "failing to adjust for time-variant economic factors yields loss amounts that are not directly comparable and a pronounced upward trend through time for purely economic reasons."

Hurricane impacts, notwithstanding any trends, are projected to become more severe with more frequent intense precipitation events and sea-level rise. The growing population density and escalating property values in coastal areas are cause for even greater concern.

Long-term adaptation strategies include development and improvement of codes and standards and land-use strategies that dissuade development in flood-prone coastal regions, as noted in the discussion above. Wind resilience measures of existing codes and standards for hurricane-prone regions such as the State of Florida have demonstrated their effectiveness under events such as Hurricane Charley (2004).

EXTRATROPICAL CYCLONES

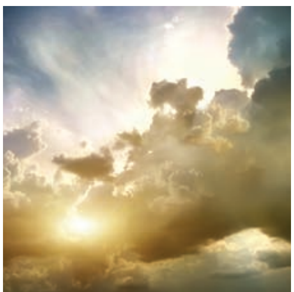
Extratropical cyclones pose a hazard primarily due to wind and flooding. They can also bring storm surge impacts in coastal regions. Portions of Europe are particularly prone to extratropical cyclone occurrence and these higher counts will naturally include some stronger events by nature of their underlying intensity distributions.

Under global warming, the number of extratropical cyclones is expected to decrease. However the intensity of these cyclones is expected to increase.

There is evidence that the Northern Hemisphere mean storm tracks have already moved towards the poles (Ulbrich et al., 2009; IPCC AR4, 2007).

On a regional basis, despite a net disposition of the storm tracks towards the poles, recent scientific evidence demonstrates an association of the reduced ice cap with negative phases of the North Atlantic Oscillation (NAO). In deep winter this would bend the Europe portion of the storm track southwards to reside over France and Spain, increasing extratropical cyclone transits over the area and increasing the number of excessive cold outbreaks over Northern Europe and the United Kingdom (Jaiser et al., 2012).

Adaptation strategies again include development and improvement of codes and standards for structural resilience under wind loads and control of urban flooding. Coastal flood mitigation strategies include development and adherence to codes and standards and land use strategies discussed previously. Such strategies should prove valuable over the long term.



III. ADAPTATION MEASURES

ADAPTATION MEASURES FOR THE HAZARDS POSED BY GLOBAL WARMING INCLUDE THE DEVELOPMENT AND IMPROVEMENT OF CODES AND STANDARDS FOR WIND AND FLOOD RESILIENCE IN VULNERABLE AREAS. THIS IS ESPECIALLY IMPORTANT FOR DEVELOPING COUNTRIES WHERE OVER 95 PERCENT OF WEATHER-RELATED FATALITIES OCCUR.

LOSS IMPLICATIONS AND ADAPTATION MEASURES

Economic losses resulting from natural disasters increased from USD75.5 Billion in the 1960s to USD659.9 Billion in the 1990s (IPCC AR4, 2007 – Working Group II, Section 1.2.8.4). Insured losses have also increased, and "the dominant signal is of significant increase in the values of exposure" (IPCC AR4, 2007 – Working Group II, Section 1.3.8.4). Furthermore, the IPCC states that "failure to adjust for time-variant economic factors yields loss amounts that are not directly comparable and a pronounced upward trend for purely economic reasons." As an example, the recent "trend" in hurricane losses for the coastal United States becomes indistinguishable when normalized by inflation and population density (Pielke et al., 2008).

The IPCC identifies a number of possible adaptation measures for the hazards posed by global warming. Such measures again include the development and improvement of codes and standards for wind and flood resilience in vulnerable areas. This is especially important for developing countries where over 95 percent of weather-related fatalities occur. Land use strategies again are identified for flood-prone areas to shift unnecessary development to less vulnerable areas or to improve flood control measures where such developments exist. Such resilience measures can help to curtail long-term weather and climate losses under global warming.

The coastal flood threat is particularly acute under global warming, and emphasizes the need for a flood risk transfer strategy that is actuarially sound and also meets the complex network of regional, physical, economic and political constraints in force for such areas.

CLOSURE

The IPCC publications represent scientific consensus among many of the world's top scientists (and scientific consensus is difficult to achieve). Their findings are generally consistent with the broader scientific literature.

Global warming is an established scientific fact, with an association with human activity that cannot be explained away as statistical "noise". It is expected that global warming will continue through the end of the century. Coastal flooding under sea-level rise is the single greatest threat, followed by inland flooding and drought. The societal and economic impacts of these hazards, particularly for coastal areas, can be quite severe. These impacts are summarized in Table 1.

T-1 | SUMMARY OF HAZARDS, IMPACTS AND POSSIBLE LONG TERM MITIGATION MEASURES UNDER GLOBAL WARMING

HAZARD	PROJECTED IMPACT	ADAPTATION MEASURES
Sea-Level Rise	Increased severity and frequency of coastal flooding under tsunami, tropical cyclone and extratropical cyclone.	Codes and standards, land-use strategies, re-examination of coastal defense structures. Risk transfer strategies that are actuarially sound and fulfill political, economic and other practical constraints.
Diminished rainfall	Increased water resources and agricultural threats. Increased risk of wildfire.	Land use strategies that allow rainwater catchment and aquifer recharge. Building codes and land use strategies to mitigate against wildfire threat.
Increased rainfall intensity	Increased severity of inland flooding.	Implement stormwater management infrastructure appropriate for the hazard.
Severe convective storm including tornado and hail	No projected change in the hazard.	Implement existing measures in the building code, and those proposed by agencies such as the IBHS for tornadoes and hail.
Tropical Cyclone	Possible increase in intensity. Increased threat under coastal flood and inland heavy rain.	Codes and standards for coastal flood, land-use strategies. Risk transfer strategies that are actuarially sound and fulfill political, economic and other practical constraints.
Extratropical Cyclone	Projected decrease in frequency. Projected increase in severity. Net Poleward shift, but bent further south over southern Europe.	Codes and standards for wind resilience.

With the exception of coastal flood, inland flood and drought, the wholesale attribution of increasing financial losses to an increase in natural hazard frequency misrepresents the issues. Statements concerning loss trends under natural disaster would be better served if normalized by factors including (per capita) gross domestic product, total insured value, population density and annualized property value. Such statements should also be in cognizance of the scientific literature. The impacts of meteorological hazards, of course, depend on the frequency and severity of the events, but also on the vulnerability, population density, local infrastructure and the property values of affected areas.

Codes and standards and land-use strategies are accepted adaptation measures to improve resilience against flood, wind and fire impacts under global warming. Such measures can build resilience for life, property and capital especially in developing countries. Catastrophe modeling strategies under global warming, particularly with respect to the coastal flood threat, would be particularly valuable. Risk transfer strategies that make use of such measures are more likely to prevail over the long term.

Since the publication of the IPCC AR4 (2007), new advances in the science are available and under appraisal and will be consolidated into the Fifth Assessment Report to be released in 2013-2014. Guy Carpenter will closely follow these new developments.

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