NORTH ATLANTIC HURRICANE NEAR-TERM MODEL

April 29, 2010

EQECAT North Atlantic Hurricane Near-Term Model, April 29, 2010. Printed in the U.S.A.

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Preface

Introduction

In addition to our long-term model for estimating risk from North Atlantic hurricane activity, EQECAT has developed a near-term model based on the affects of the Atlantic Multi-decadal Oscillation (AMO).

Advances in climatology have led to great insights into understanding hurricane activity. The use of global circulation models has improved our understanding of the natural variability in climate and link the variability of these cycles with the variability of hurricane activity, specifically, landfalling hurricanes.

EQECAT research has identified a strong link between the cycles of the AMO and the risk of catastrophic hurricane winds onshore for the mainland US. Partitioning the historic data set into “warm” and “cold” years has enabled us to develop a conditional “near-term” model that reduces the uncertainty in the assessment of tropical storm risk.

This document provides a discussion of the AMO as the basis for EQECAT’s near-term model, the affect of the AMO on annual average losses, and gives an overview of the methodology used to develop the near-term model.

Background

Tropical cyclone activity over the Northern Atlantic Ocean has shown considerable variability in the last 110 years. Hurricanes occur more frequently in certain decades than others as a result of interannual variability, such as El Niño/Southern Oscillation (ENSO); and multidecadal variability, such as the AMO. Hurricane frequencies in catastrophe loss models have traditionally been based on a long-term view, e.g. uniform consideration of all historical data since 1900. Use of hurricane frequencies based on the long-term view is traditionally used for rate filings and for understanding the long term historical risk profile. However, many financial contracts tied to hurricane risk (e.g. reinsurance, catastrophe bonds, etc.) have lengths ranging from one to three years. Further, eras of heightened activity put a strain on the financial resources of re/insurers bearing hurricane risk, particularly due to the tendency of multiple active seasons to occur within decadal time scales. For these reasons, there is a need to better quantify the frequencies on these time scales. To meet this need, EQECAT has developed a near-term Atlantic hurricane frequency model, representing our best estimate of the risk over the next few years.

ENSO occurs on a time scale of two to seven years and can have considerable impact on hurricane activity due to increased vertical wind shear in the main development region of the Atlantic Basin during El Niño events. Because of the short time scale of the ENSO cycle and the possibility of onset of an El Niño event occurring midseason, use of ENSO in the near-term model is impractical.

The AMO is manifested in the variation of sea surface temperatures in the Atlantic Ocean. The warm phases of the AMO are believed to be associated with eras of hightened activity such as the extended period between 1926-1969 and the most recent period that began in 1995. EQECAT's current near-term hurricane frequencies are based on the historical events that occurred during the warm phases of the AMO. The near-term risk corresponding to the warm phases of the AMO produces an average annual loss (based on modeled losses from stochastic events) that is 37% higher than the long-term risk.

While the AMO is a very important component in hurricane risk, it is not the sole factor. EQECAT continues to evaluate all weather phenomenon as we seek new techniques to help us better reduce the uncertainty in catastrophe risk.

Rationale for a Near-Term Model

Tropical Cyclone activity over the North Atlantic Ocean has varied considerably over the last century. Some years have produced far more hurricanes than the long-term (1900-2008) seasonal average, while other years have minimal hurricane activity. Of most interest are stretches of many consecutive years where the hurricane activity tends to be high and similar periods where the activity is low.

The Atlantic Multidecadal Oscillation, or AMO, is an apparent long-term cycle of warm and cool periods of sea surface temperatures (SST) in the Atlantic Ocean. The AMO's warm phase is believed to be responsible for eras of active seasons such as the 1926-1969 period, as well as the recent period of higher hurricane activity that began in 1995 (Lepore 2005).

A hurricane season's activity can also be influenced by an El Niño/Southern Oscillation (ENSO) event. El Niño conditions occur when the surface waters of the equatorial eastern Pacific Ocean off the coast of Peru become much warmer than normal. The condition usually persists for only a year. However, a strong El Niño event during the hurricane season can produce wind shear in the tropical Atlantic, inhibiting hurricane development there even during warm/active AMO eras. Although the 2006 and 2009 Atlantic hurricane seasons occurred during the warm AMO period, El Niño events have inhibited hurricane activity during those years.

Warm El Niño conditions recur at irregular intervals of between two and seven years. Because they are difficult to predict, both in timing and intensity, it is not practical to incorporate ENSO into a near-term hurricane model.

Other sources of climate variability or change can influence hurricane activity over the Atlantic Basin. The North Atlantic Oscillation (NAO) can influence the tracks of tropical cyclones and may cause them to re-curve over the open Atlantic and not affect land. The phases of the NAO can last as little as a few weeks, so its use is not practical in the near-term model. Global warming is believed to be causing or will cause an increase in hurricane activity. Analysis of raw historical data favors an increase in hurricane activity; however, many hurricanes that have remained over the open ocean during the advent of satellites (before the 1960s) have not been observed and are not included in the raw historical data. Global circulation models (GCMs) have been used to project what hurricane activity could be like under conditions of increased atmospheric carbon dioxide concentrations, but results vary tremendously by the model employed. Due to a lack of a consensus on the part of the scientific community, global warming is not used in EQECAT's near-term model.

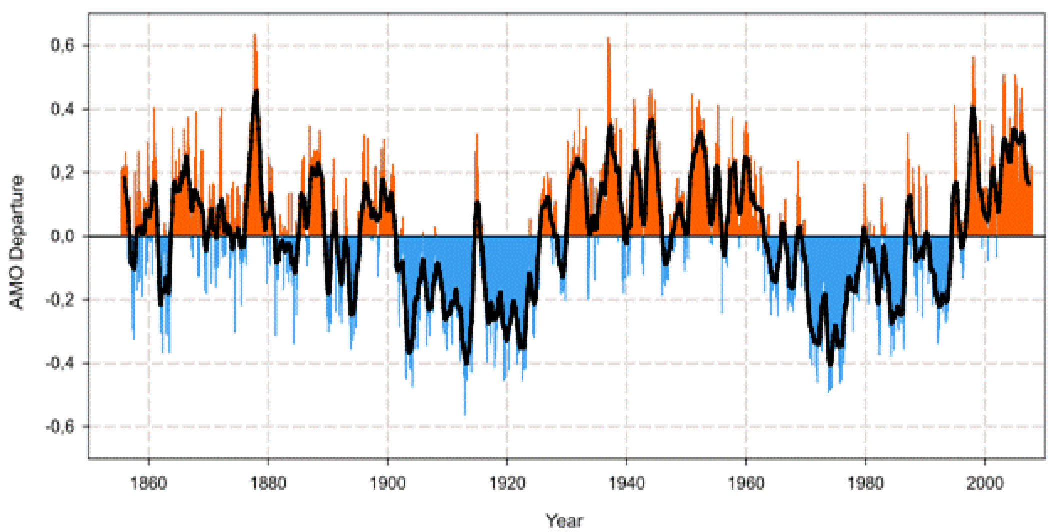
Average annual losses from tropical cyclones are higher during warm AMO periods than cold AMO periods. Although intense hurricanes such as Andrew can cause considerable damage within an era of low hurricane activity, devastating hurricanes have occurred more frequently during active, warm AMO periods. Many financial contracts tied to hurricane risk (e.g. reinsurance, catastrophe bonds, etc.) have lengths ranging from one to three years. Further, eras of active hurricane seasons can put a strain on the financial resources of insurance and reinsurance companies. If rates are based on the long-term average annual losses, these companies may not necessarily have adequate resources to cover loss costs associated with hurricanes that occur in consecutive active seasons. The near-term risk corresponding to the warm AMO phase can produce an average annual loss that is 37% higher than the long-term risk using EQECAT's 2008 EQEStock™ market exposure.

Due to the tendency of multiple active seasons to occur within decadal time-scales, it is essential for companies to consider the near-term risk as well as the standard long-term risk.

AMO: The Basis for EQECAT's Near-Term Model

EQECAT's near-term model is based on the AMO. The AMO is an approximately 70-year cycle (Figure 1) of the sea surface temperatures in the North Atlantic Ocean (Lepore 2005; Goldenberg et al. 2001). During the warm phase, sea surface temperatures in the tropics and subtropics are above average. Because tropical cyclones derive their energy from very warm and humid air, high sea surface temperatures are conducive for tropical cyclone development. According to Emanuel (1988), maximum potential intensity increases with increasing sea surface temperatures.

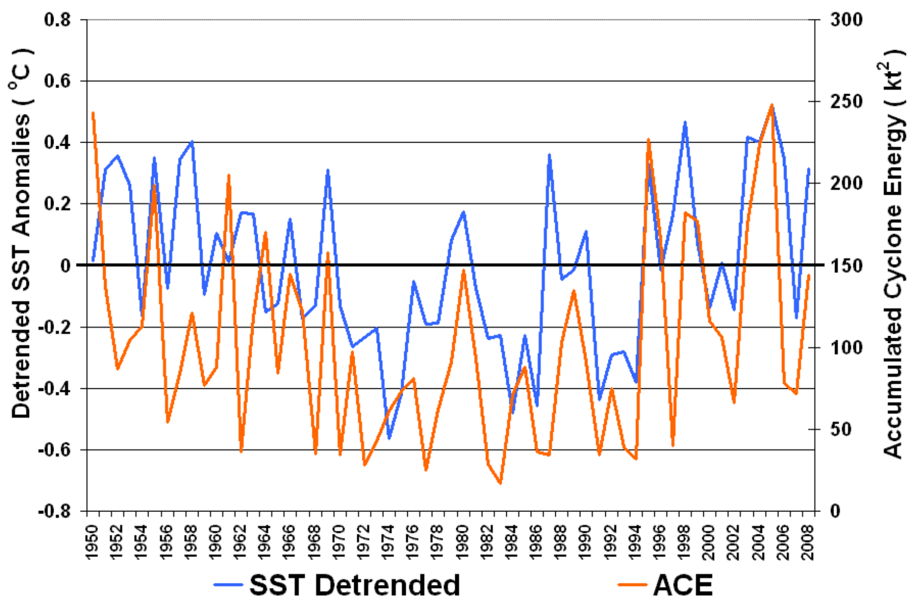
Figure 1: Monthly Values for the AMO Index, 1856-2008[1]



In addition to above average sea surface temperatures, wind shear is generally below average over the main development region of the tropical North Atlantic (Goldenberg et al. 2001). Both low wind shear and high sea surface temperatures provide conditions that are favorable for high hurricane activity during the warm AMO phase. Conversely, during the cold AMO phase, sea surface temperatures are below average and the wind shear is generally above average. Both these conditions dampen the development of tropical cyclones over the Atlantic Ocean.

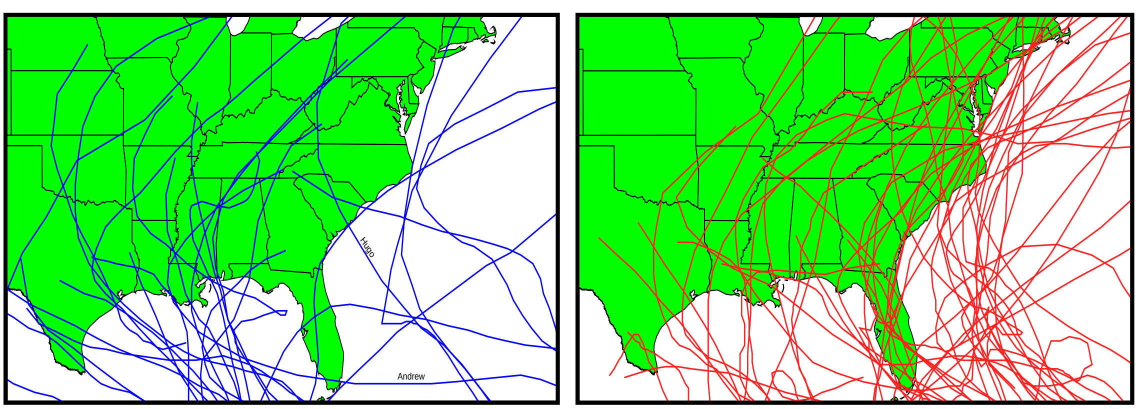
[1] Source: NOAA-ESRL (http://www.cdc.noaa.gov/data/timeseries/AMO/)

Figure 2: Tropical North Atlantic Sea Surface Temperature Anomalies (Aug.-Sept.) and North Atlantic Accumulated Cyclone Energy (1950-2008)



The accumulated cyclone energy (ACE) is a measure of a season's tropical cyclone activity, and is the summation of the squares of maximum sustained wind speeds of all storms every 6 hours. The ACE tends to increase with increasing SST as indicated in Figure 2. The multidecadal variation in the SST in Figure 2 resembles the variations in the AMO index in Figure 1. Years with positive SST anomalies tend to have high ACE. This especially occurs before 1970 and after 1995. Conversely, years with negative SST anomalies tend to have low ACE.

Figure 3: Tracks of Hurricanes, by AMO Phase, that Made Landfall in the United States at Category 3 Intensity or Higher

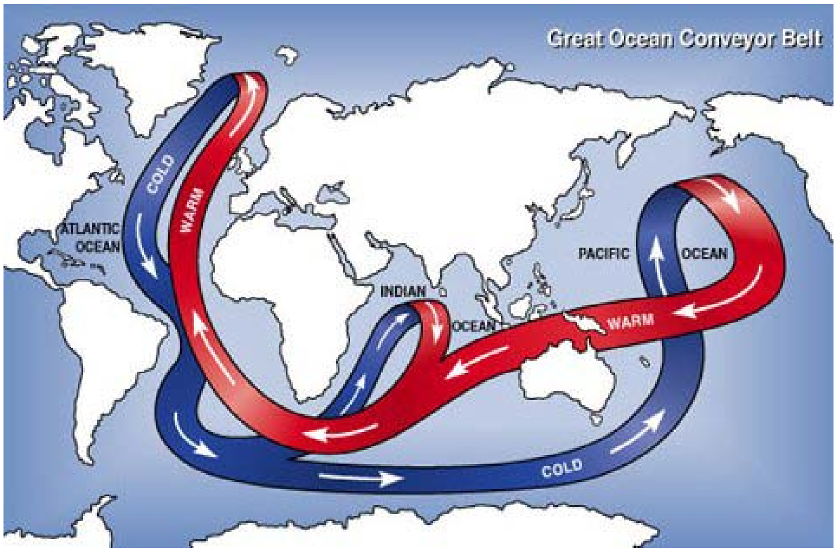


Cool AMO: 28 CAT 3+ events in 51 years. Frequency 0.55 per year

Warm AMO: 49 CAT 3+ events in 59 years. Frequency 0.83 per year

In addition to high ACE values, warm AMO years, collectively, have more intense U.S. hurricane landfalls than cool AMO years, as seen in Figure 3. The frequency of intense hurricane landfalls is 0.83 per year during warm AMO years which is about 50% higher than cool AMO years. Because the majority of losses are caused by intense hurricanes, a higher frequency in landfalls of intense storms would indicate the AMO's importance in the insurance community.

Figure 4: Schematic Depiction of the Thermohaline Circulation[2]



Some scientists believe that multidecadal variations in the Atlantic Ocean are the result of large-scale variations in sea water salinity and the Thermohaline Circulation. Gray (2008) noted variations in salinity as a primary driver in multi-decadal variations in Atlantic Ocean currents. Salinity affects the density of sea water, which in turn causes changes in the vertical motions of sea water. These vertical motions would then influence the speed and positions of horizontal currents, which will impact sea surface temperatures.

The AMO is used as a basis for developing near-term frequencies in the EQECAT North Atlantic Hurricane Model. Its timescale and impact are sufficient to justify its use in the development of the near-term model. While other factors can influence a season's hurricane activity, such as ENSO, the North Atlantic Oscillation, and the strength of the Saharan Dust Layer, their effect is on shorter time scales, and their occurrence less predictable than the AMO.

[2] Source: University Corporation for Atmospheric Research

Other Climate Aspects Affecting Hurricane Activity

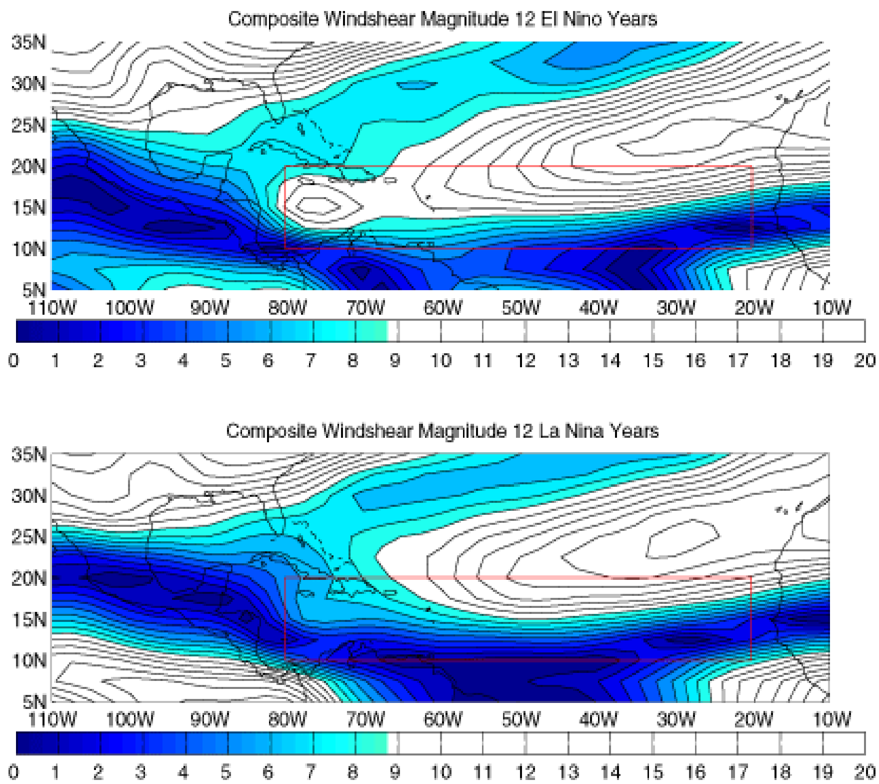
This section includes information on additional sources of climate variability or change that influence Atlantic Basin hurricane activity, as well as an explanation as to why direct inclusion of these aspects in EQECAT's near-term hurricane model is not practical.

El Niño Southern Oscillation (ENSO)

ENSO is the variation of sea surface temperatures in the equatorial Pacific Ocean. During the El Niño phase, sea surface temperatures in the eastern and/or central Pacific are above average. During the La Niña phase, sea surface temperatures are below average in these same regions. ENSO alters the position of the Walker Circulation, a zonal atmospheric pattern that occurs over the tropics in both low and high altitudes (Holton 1992). The Walker Circulation is driven by areas of ascent (typically over land and warm oceans) and descent (typically over cool oceans). The shift of the Walker Circulation causes changes in the upper-level winds and changes in the vertical wind shear over the Atlantic Ocean.

Arkin (1982) has noted winds in the upper atmosphere are stronger than normal over the tropical Atlantic Ocean during El Niño events. This causes higher vertical wind shear over the main tropical cyclone development regions than during La Niña years, seen in Figure 5 (International Research Institute for Climate and Society 2007). The red boxes in Figure 5 denote the main tropical development region in the North Atlantic. White contoured areas indicate higher wind shear, which inhibits hurricane formation and intensification. During El Niño years, there has been an average of 1.13 US Mainland hurricane landfalls per year. La Niña years have an average of 2.28 US Mainland hurricane landfalls per year (Smith et al. 2007).

Figure 5: Monthly Composite Wind Shear (m/s) During El Niño Years (top) and La Niña Years (bottom)[3]



Although ENSO impacts hurricane activity in the Atlantic Ocean, its cycles are irregular and relatively short (2-7 years) and accurately predicting the onset and strength of its phases is difficult. The 2006 El Niño event started in August, midway through the hurricane season. Even at the start of the 2009 hurricane season, it was still unclear how the extent of the newly developing El Niño would affect the upcoming season. As it turned out, the 2009 El Niño strengthened, and this greatly suppressed hurricane activity for the season.

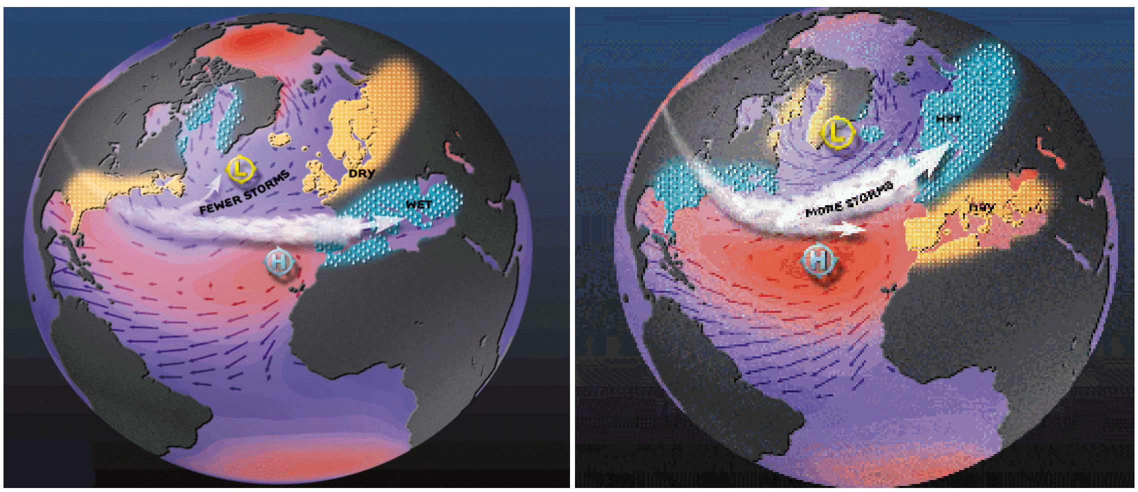
Thus, without reliable knowledge of the near-term (3 year) future state of ENSO, its direct use in near-term modeling is not practical for in the estimation of losses for one-year reinsurance contracts or a multi-year securitization. While a predicted state of ENSO is not directly used in the EQECAT near-term model, the interannual variability it causes is incorporated into the EQECAT near-term model.

[3] Source: The International Research Institute for Climate and Society (http://iri.columbia.edu/climate/ENSO/globalimpact/TC/Atlantic/ windshear.html).

North Atlantic Oscillation

The North Atlantic Oscillation (NAO) is an atmospheric condition manifested by the variation of difference in sea level pressure between the Atlantic subtropical high pressure system and the Icelandic Low pressure system (Murnane 2004). During the positive NAO phase, sea level pressure difference is above average and the mid-latitude westerly winds occurring between the Subtropical High and Icelandic Low are amplified due to the increase in the pressure gradient force (Holton 1992). The pressure gradient force is manifested in the tendency for air to flow from high pressure to low pressure. The amplified pressure difference allows for more frequent and stronger middle latitude storms to cross the Atlantic Ocean and impact Europe.

Figure 6: General Circulation Patterns over the North Atlantic Ocean During Negative (left) and Positive (right) NAO[4]



Due to its impact on European storm systems, the NAO has important implications in EQECAT's Eurowind Model. The subtropical high pressure system is displaced eastward during positive NAO, and this would increase the likelihood of Atlantic hurricanes to re-curve northward before impacting the United States. During negative NAO, the subtropical high is displaced westward, and this would cause hurricanes to more likely impact land rather than an early northward re-curvature into the colder waters of the North Atlantic. Elsner and Jagger (2006) have found that the probability of the United States experiencing a hurricane landfall is higher during weak or negative NAO than positive NAO. The NAO varies intraseasonally and has a time scale as short as a few weeks. Due to the short duration of the NAO phases within a hurricane season, its direct inclusion in our near-term hurricane model is not practical.

[4] Source: Martin Visbeck and Columbia University (http://www.ldeo.columbia.edu/res/ pi/NAO/)

Global Warming

The effects of the rise in anthropogenic (man-made) carbon dioxide on the Earth's climate have been researched extensively by the scientific community. Studies on the effects of an increase in atmospheric carbon dioxide concentrations on Earth's climate include investigations on the frequency and intensity of tropical cyclones. These effects are studied by the examination of recent historical storm records and projections from global circulation models.

Examination of the historical tropical cyclone record support an increase in the number of tropical storms and hurricanes, but this increase is mostly attributed to improvements in storm detection resulting from advances in technology. Before the use of aircraft reconnaissance and satellites, ship and land observations are the only sources of storm detection. These limitations would cause many tropical cyclones which remained at sea to be absent in the records. Landsea (2007) compares the abundance of tropical cyclone tracks over the central North Atlantic in 2005, which was the most active hurricane season on record, with the absence of similar tracks in 1933, which was the most active season prior to 2005. Due to detection issues and missed storms in the early, pre-satellite years of the hurricane record, Landsea determined a needed adjustment, increasing storm counts by 3.2 tropical cyclones per year before 1966. Analyzing the adjusted (corrected) tropical cyclone counts resulted in no significant long-term trend beyond the expected fluctuations of active/warm and quiet/cool AMO periods. Thus, no long-term increase in activity was found which could be attributed to global warming.

The effects of increased carbon dioxide on hurricane activity have been examined by the use of global circulation models (GCMs). The GCMs allow scientists to examine simulated climates under various conditions that have not been observed historically such as the doubling of atmospheric carbon dioxide concentrations. Some of these "What if" studies, such as Knutson and Tuleya (2004), favor an increase in tropical cyclone activity over the Atlantic Basin due to primarily increased SSTs. SSTs increase the maximum potential intensity of tropical cyclones (Emanuel 1988) allowing for more frequent and or more intense storms to occur with the assumption that all other variables remain constant. Other studies such as Vecchi and Soden (2007), favor a decrease in hurricane activity over the Atlantic Basin due to increased vertical wind shear. Although models can project conditions that have not been observed in the real world, models are subject to limitations such as choice of input variables, resolution, methodology, and implementation. Due to the variation in the outcomes of such studies, there is no consensus in forecast trends in hurricane activity decades into the future with the assumptions of continued increase in atmospheric carbon dioxide.

Near-Term Model Methodology

EQECAT's near-term model is identical to the long-term model except for the frequencies of stochastic storms. The stochastic storm frequencies are based on historical data and are derived by use of statistical smoothing methods that compute frequencies as a function of landfall location and intensities.

In the long-term model, all historical hurricanes dating back to 1900 that have made landfall in the United States are used in the calculation of storm frequencies. In the near-term model, historical storms in only specific subsets of years are used in the calculation of frequencies. These subsets of years are based on the warm or cool phases of the AMO, provided by NOAA (http://www.magazine.noaa.gov/stories/mag184.htm), and are shown in the following table:

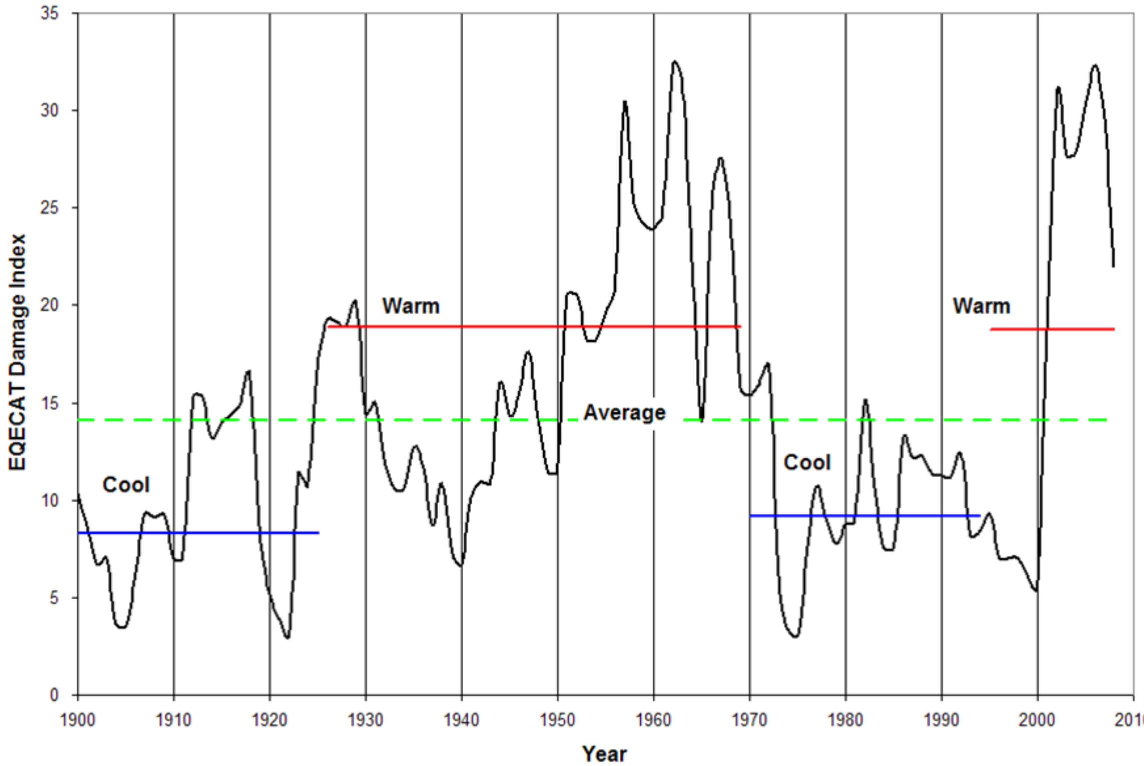
Table 1: List of Cool and Warm AMO Years

AMO Phase	Years
Cool	1900-1925
Warm	1926-1969
Cool	1970-1994
Warm	1995-2008

Since we are currently in the warm AMO phase, historical storms from 1926-1969 and 1995-2008 (a total of 58 years) were used in the calculation of near-term frequencies for WORLDCATenterprise.Because there is above average hurricane activity during the warm phase, the EQECAT near-term model produces average annual losses and exceedance curves that are higher than those produced by the long-term model.

The 109-year history of hurricanes provides a good, but incomplete, data set. The limited number of events combined with the very non-homogeneous concentration of coastal property values in cities does not provide compelling evidence of a trend. To reduce the sensitivity of the results to "direct hits" and "misses" in urban areas, EQECAT developed the EQECAT Damage Index. This index is based on the damage to a portfolio of uniformly spaced residential buildings throughout all of the US and provides a score of the on-shore damage potential of a storm without the bias of hitting or missing an urban area. This index is plotted in the following figure.

Figure 7: Trended EQECAT Damage Index by Year (7-year averaging)



Overlaying the trended EQECAT Damage Index with the AMO cycles highlighted reveals a strong correlation with the AMO phases. Because the index values can be compared on a year-by-year basis, the individual sets (warm AMO indices, cool AMO indices) can be hypothesis tested for correlation to the AMO phases. A simple student's T test on this data shows the probability that the index scores is unrelated to the AMO is less than 2%, or conversely, 98% probability that the index scores are related to AMO.

Impact of AMO on Average Annual Losses and Return Period Losses

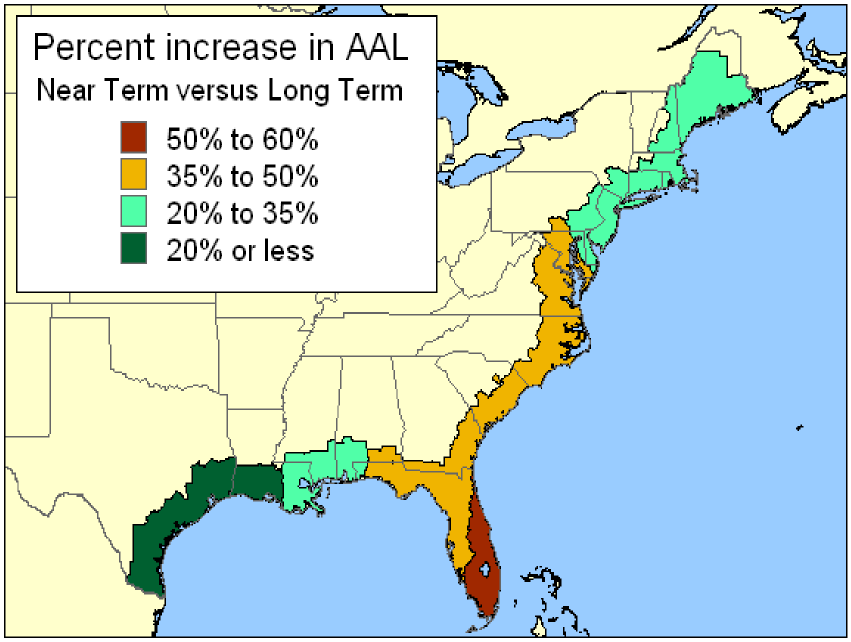
The AMO has an impact on average annual loss costs. Using our EQESTOCK portfolio, EQECAT has computed average annual loss costs and exceedance curves for the near-term and long-term models. Our EQESTOCK portfolio serves as a proxy for market exposures in 2008 and applies to modeled losses for all storms. Using this portfolio, modeled losses from a historical storm (for example, the 1926 Miami Hurricane) would reflect loss costs under 2008 market exposure. Loss costs from an early event would therefore be higher than their original losses due to increases in values, exposure, and construction costs.

Table 2: AAL from Stochastic Events using EQESTOCK Portfolio

Period	AAL (in billions)	100-Year Per Occurrence (in billions)
Long-Term Model	$12.7	$118.3
Near-Term Model	$17.4	$142.1

According to the modeled losses in Table 2, the near-term model (corresponding to the warm AMO phase) has an AAL that is 37% higher than the long-term AAL. The 100-year per occurrence loss is 20% higher in the near-term model than the long-term model. Although these differences are large, it is important to note that the AAL are driven by landfalls of intense storms (category 3 and above). These storms occurred in both warm AMO and cool AMO years; however, influential storms occur more often during the warm AMO. Due to the importance of influential storms, it is important for insurers and reinsurers to examine the exceedance curves in addition to the AAL in making financial decisions.

Figure 8: Percent Increase in AAL Losses from the Long-Term Model to the Near-Term Model for Coastal Counties



The impact of the near-term model has greater influences in some regions than in others (Figure 8). The southeastern states have near-term AAL that are more than 50% higher than the long-term model. The southeastern Atlantic states had frequent landfalls of intense hurricanes during the 1950s (all occurring during the warm AMO phase). Florida had landfalls of intense hurricanes during the 1940s, 1960s, and in 2004 (all occurring during the warm AMO phase). The near-term model has only resulted in increases of AAL that are less than 20% in Texas and western Louisiana. The small increases in losses are due to the high frequency of landfalls of intense hurricanes during both cool and warm AMO as indicated in Figure 3. The Northeast has modest increases (between 20% and 35%) in losses resulting from the use of the near-term model (Figure 8). Although the 1938 New England Hurricane and Hurricane Donna (both events occurring during warm AMO), have caused considerable damage, notable storms, such as Hurricane Bob and Hurricane Gloria, occurred during the cool AMO. The near-term model has the greatest impact in the southeastern Atlantic coast followed by the Northeast and the western Gulf of Mexico.

The geographical pattern of increased AAL along the coastal states computed by EQECAT's Near-Term Model (Figure 8) is a strong reflection of those areas most affected by the warm phase of the AMO. As shown in Figure 3, the Gulf of Mexico exhibited only slight changes in activity between warm and cool AMO phases. Many Gulf hurricanes actually form within the Gulf itself and are thus little affected by AMO phase. In contrast, Figure 3 showed the US Atlantic coast exhibiting a huge increase in major hurricanes during warm AMO phases. The strong increase in major Atlantic storms that are formed and supported by the warm AMO phase preferentially affect the U.S. Atlantic Coast, most notably, Florida, the Southeast, and Mid-Atlantic states.

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