The 2006 RMS Expert Elicitation and Atlantic Hurricane Activity Rates Update

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Risk Management Solutions

EXECUTIVE SUMMARY

In May 2006 RMS updated the underlying assumptions of landfalling hurricane frequency for modeling risk in the United States and the Caribbean. The new frequencies reflected a five-year forward looking view of risk, and were based on the latest scientific understanding on cycles and trends in hurricane landfall activity. This white paper provides a short review of the process RMS used to determine and implement the medium term (five-year forward looking) view of landfalling hurricane risk in version 6.0 that was based on an Expert Elicitation of hurricane climatologists held in October 2005. This is followed by a detailed review of the procedures and findings of the October 2006 Expert Elicitation that will provide the foundation for the RMS medium term view of frequency in version 7.0 to be released in spring 2007.

The October 2006 Expert Elicitation comprised an expanded panel of seven distinguished scientists in the field of Atlantic tropical meteorology and climatology. A range of statistical models were employed to present alternative perspectives on potential medium term hurricane activity in the Atlantic, after which the experts were requested to weigh the various models to provide their best estimate of the five-year period of landfalling hurricane risk in the United States and Caribbean from 2007-2011. The overall result of this year's expert elicitation is very similar to last year's conclusions, and as a result RiskLink and RiskBrowser 7.0 will retain the same medium term view of landfalling activity rates contained in version 6.0.

INTRODUCTION

Since 1995, the number of Atlantic basin hurricanes has surpassed the long term average every year, with the exceptions of 1997 and 2002, which were affected by warm conditions of the El Nino Southern Oscillation (ENSO). The 2006 hurricane season has also been under the influence of a warm ENSO event, with the projected basin activity to be near or just below normal at the end of the hurricane season. The basin has experienced five hurricanes in 2006, with two hurricanes reaching category 3 intensity on the Saffir Simpson Scale. Between 1995-2006[1], the elevated activity has been particularly apparent in the number of major hurricanes (classified as category 3 or higher) with an annual Atlantic basin average of 3.9 major hurricanes since 1995, compared to an annual average of 2.7 in the period from 1950 to 2006. The annual number of all hurricanes across the basin has also increased, to average 8.2 since 1995 compared with 6.1 annual hurricanes from 1950-2006. The increased activity in the Atlantic basin since 1995 is not, however, a unique feature of the historical record, as fluctuations in the numbers of past hurricanes have occurred over decadal time scales. For example, the period from 1970 to 1994 had lower activity levels than the long term historical baseline, while the 1950s and part of the 1960s showed increased levels of hurricane activity.

Changes in activity within the basin have also affected landfalling behavior, with reduced activity of at the US coastline with on average 1.2 hurricanes making landfall in the U.S. between 1970 and 1994 of which only 0.5 per year were major hurricanes. From the 1930s to the 1960s, those numbers were 1.8 and 0.8 respectively. Over the last 12 years they have risen to 2.2 and 0.85. In the Caribbean region, the average number of hurricanes between 1950 and 2006 was 1.0 per year, with about half reaching at least category 3 intensity. Those numbers have almost doubled since 1995, averaging 1.7 (category 1-5) and nearly 0.85 (category 3-5). Those figures are summarized in Tables 1 and 2.

Table 1: Activity Rates in the Atlantic Basin and in the Caribbean Region since 1950

	Atlantic Basin		Caribbean Region	
	category 1-5	category 3-5	category 1-5	category 3-5
1950-2006	6.10	2.70	1.00	0.50
1995-2006	8.20	3.90	1.70	0.85

1 The statistics in this section are computed with the 2006 season up to November 1st.

Table 2: Activity Rates in the U.S. in Different Periods of the Historical Record

	U.S. category 1-5	U.S. category 3-5
1930-1969	1.80	0.80
1970-1994	1.20	0.50
1995-2006	2.20	0.85

Based on this evidence for persistent raised activity, RMS undertook an extensive research effort into temporal variations of U.S. and Caribbean landfalling hurricane activity rates. This research led to the organization of the first annual expert elicitation, held in October 2005, to assess the expected hurricane activity in the Atlantic basin, specifically targeting the projected U.S. and Caribbean landfall frequencies over a five-year period (2006-2010). The results from this research and implementation effort were documented in a white paper published on the RMS website, as well as a manuscript submitted to Tellus for peer-review in August 2006.

REVIEW OF THE 2005 ELICITATION

As stated in *Elicitation of Expert Opinions for Uncertainty and Risks*, written by B. Ayyub, [CRC Press, NY, 2000]:

> "The primary reason for eliciting expert-opinion is to deal with uncertainty in selected technical issues related to a system of interest. Issues with significant uncertainty, issues that are controversial and/or contentious, issues that are complex, and/or issues that can have a significant effect on risk are most suited for expert-opinion elicitation."

RMS organized its first expert elicitation of hurricane activities in Bermuda on October 15, 2005, involving four experts: Prof. Jim Elsner (FSU), Prof. Kerry Emanuel (MIT), Tom Knutson (NOAA/GFDL), Prof. Mark Saunders (UCL). The elicitation focused on a series s of questions regarding the expected activity across the entire Atlantic basin, along the U.S. coastline and within the Caribbean region.

The experts were provided the time series of Atlantic basin activity of all hurricanes and those reaching category 3 (by windspeed) on the Saffir-Simpson scale. Additional analyses of storm activity using periods of activity defined by the work of Goldenberg at al. (Science, 2001) were also made available, as well as some basic information on how activities are employed within the RMS hurricane models.

Experts were first asked to consider the activity of category 1-5 and category 3-5 within the entire Atlantic basin. All experts agreed that the basin activity is currently above the long term average, and that the elevated levels of activity were expected to last for at least 10 to 15 years, a period significantly longer than the five-year medium term perspective that was the focus of the meeting. It was recognized that occasional years of reduced activity could also be expected, determined principally by the state of ENSO.

In order to assess hurricane activity over the entire Atlantic basin, the experts restricted the historical dataset to the period starting in 1950 due to concerns about data quality issues in the first half of the 20th Century. Experts agreed that a mixed baseline approach was a valid approach to quantify the expected medium term (2006-2010) basin activity, assigning a 90 % weight to the activity of the 1995 to 2005 period, and a 10 % weight to the long term post 1950 baseline. The 90%/10% mixed baseline approach yielded 8.2 hurricanes per year, 3.9 of those becoming category 3-5 hurricanes. The experts also agreed that a similar rule should be applied to the Caribbean (CB) region, as the islands are mostly affected by storms forming deep in the tropics from African Easterly Waves.

The experts were then asked to consider expectations around medium term activity rates at U.S. landfall. Two independent methods were employed: a direct assignment of probabilities of exceedance to various key activity rate measures for category 1-5 and category 3-5 hurricanes at landfall, including annual mean landfall rates derived from the 1900 to 2005 record and from the last 11 years. The second method involved converting the medium term activity of the Atlantic basin into expected U.S. landfall activity. In each method, individual opinions were obtained from each expert, and those were combined to form the overall U.S. activity rate targets.

Additional RMS research was conducted after the 2005 Expert Elicitation to address the question of regionalization in landfalling hurricane activity. The RMS track typology framework was utilized to identify stochastic events that originate over the tropical Atlantic. RMS found that in periods of heightened activity, the proportion of storms originating in the deep tropics (the region East of the Caribbean islands) increases. The experts confirmed that these storm tracks show the largest increases in numbers during periods of heightened activity. Investigating storms approaching the U.S. coastline, RMS further observed shifts in the regional activity of the most severe category 3-5 storms on multi-year time scales. Such shifts have also been discussed on the National Hurricane Center website.

RMS found that over the last 56 years, the activity of the most severe category 3-5 hurricanes also tends to persist in a given region for up to a decade at the time. This behavior seems to be only partially linked to changes in SSTs, as SSTs in the tropical Atlantic and the Gulf of Mexico have shown continuous increases over the last 30 years. In contrast to the early 1950s when high activity in the basin corresponded with a period when intense storms passed towards the Northeast, since 2000 category 3-5 hurricanes have almost exclusively occurred in the Gulf of Mexico and Florida. Hence this regionalization does not simply correspond with the phases of the AMO: and it would not be appropriate to employ the landfall regionalization of the 1950s to represent expected activities over the medium term.

The implementation of regionalization in the incremental activity produced the largest increase in medium term category 3-5 storms from eastern Florida to Cape Hatteras, North Carolina, as can be seen in the figure 1 below. This work and the general proceedings of the 2005 elicitation are summarized in a manuscript submitted to the journal Tellus in August 2006.

Figure 1: Regionalization of category 3-5 Landfall Rates. Percentages indicated increases relative to the 1900-2005 long-term historical baseline.

Scientific Developments Since October 2005

Since October 2005 there has been further debate in the scientific literature and at conferences concerning the causes of recent observed increases in both the number and intensity of tropical cyclones. There have been three main research questions that have emerged from this debate: whether increasing tropical sea surface temperatures (SSTs) are responsible for the increasing number and intensity of tropical cyclones; the relative contribution of global warming and natural variability within the climate system; and further investigations as to the reliability of the historical hurricane datasets.

In 2005, publications by Emanuel and Webster et al. developed independent statistical analyses that utilized different measures of historical hurricanes to infer trends in the number and intensity of tropical cyclones. Emanuel (2005) utilizes the power dissipation index, based on the sum of the windspeeds cubed throughout the life of a storm, to demonstrate that the North Atlantic has observed a 30-year upward trend towards more powerful and intense hurricanes. Webster et al., (2005) found the number of category 4-5 hurricanes appeared to have significantly increased in all ocean basins since 1970, while the total number of global hurricanes has not significantly changed. In the wake of those agenda setting publications, numerous additional publications have been generated, advancing or challenging the debate.

Several studies (Landsea, 2005; Emanuel, 2005b; Landsea et al., 2006; Klotzbach, 2006) have raised doubts to the completeness and accuracy of the Atlantic and global records of tropical cyclones. Landsea (2005 & 2006) criticize the findings of Emanuel (2005) by highlighting the need for a reanalysis of the historical Atlantic hurricane database. Highlighting a lack of confidence in the older record, Klotzbach (2006) only utilizes hurricane datasets back to 1986 and observes only a small increase in global category 4-5 hurricanes, which he attributes to improved observational technology.

Other studies have discussed the relative impacts of global warming and natural climate variability on tropical cyclones (Anthes et al., 2006; Hoyos et al., 2006; Mann and Emanuel, 2006; Trenberth and Shea, 2006; Webster et al., 2006; Pielke et al., 2005; Trenberth, 2005). Anthes et al. (2006) identify that global warming, is changing the potential relationships between climate change and tropical cyclone frequency and intensity. Likewise, (Elsner, 2006; Hoyos et al., 2006) find that as sea surface temperatures (SSTs) increase, the ocean can store more energy that can be converted to hurricane intensity. However, Pielke et al. (2005) warn that linking global warming to hurricane impacts is premature. Another group of researchers focus on changes in tropical North Atlantic SSTs that are associated with a pattern of natural variation called the Atlantic Multi-Decadal Oscillation (Trenberth and Shea, 2006). Other climate forcing mechanisms, such as aerosols, have been linked to the reduced activity in hurricane activity in the 1970s through the 1980s rather than a multi-decadal SST oscillation (Mann and Emanuel, 2006). Although new science has emerged over the last 12 months, and it is clear that a greater number of climatologists are sympathetic to the idea that global warming is affecting hurricane activity, the impact of climate change on the number and intensity of tropical cyclones still remains a matter of some debate. However in the recent climatological literature there is little doubt that we live in a period of raised hurricane activity.

2006 Atlantic Hurricane Season

Although the U.S. experienced several tropical storm landfalls in the early part of 2006 Season, with Tropical Storm (TS) Alberto making landfall in the Florida panhandle, followed by Tropical Storm Beryl near Cape Cod, the nearest there came to a U.S. landfall was when Hurricane Ernesto weakened while approaching South Florida. Subsequently the western part of the Atlantic basin experienced quiet conditions for the rest of the season. While activity in the Caribbean and the U.S. has been below average, the activity across the entire basin has been near the long term average, with nine named storms, five hurricanes, and two of those becoming major storms. Activity in the second half of the season has shifted towards the eastern part of the basin, reminiscent of past years affected by El Niño conditions.

On September 10 2006, scientists at the NOAA Climate Prediction Center reported that El Niño conditions have developed in the tropical Pacific and are likely to continue into early 2007. Currently, weak El Niño conditions exist, but there is a potential for this event to strengthen into a moderate event over the winter. It is very difficult to determine if El Niño will affect the 2007 season, as predictive models for ENSO have little skill beyond the months of March or April, a period often described in the literature as the Spring Barrier. El Niño typically acts to suppress hurricane activity in the year prior to the peak Pacific SST anomalies, by increasing the vertical wind shear over the Caribbean Sea region, and, on average, tends to increase hurricane activity in the year after the peak of the Pacific SST anomalies, by causing a weakening of the Atlantic trade winds and a resultant warming of the MDR SSTs. For more information regarding the current El Niño cycle and its impact on the medium term view of landfalling hurricane risk, RMS has published the document "The 2006 El Niño Cycle – Implications for the RMS View of Hurricane Activity", available on the RMS website.

THE 2006 ELICITATION OF EXPERT OPINIONS

Given the need to continue to support the rolling five year risk horizon, a second annual elicitation of expert opinion on medium term hurricane activities was conducted in New York City, on October 13, 2006. The principal goals of this year's elicitation were again to assess hurricane activity in the Atlantic, along the U.S. coastline and Caribbean islands over a five-year time horizon spanning 2007 to 2011. The list of invited experts was extended to comprise the following seven scientists:

- Dr. Suzana Camargo (IRI/Columbia University),
- Professor Kerry Emanuel (MIT),
- Dr. John Knaff (CIRA/Colorado State University),
- Thomas Knutson (NOAA/GFDL),
- Dr. James Kossin (University of Wisconsin),
- Professor Mark Saunders (UCL), and
- Dr. Frédéric Vitart (ECMWF).

These scientists represent a broad cross-section of expertise ranging from real time hurricane forecasting, seasonal forecasting, and involvement in research studies at longer time scales in hurricane climatology. The following additional scientists were also invited but could not join because of other commitments: Dr. Gerald Bell (NOAA/GFDL), Professor James Elsner (Florida Sate University), Stanley Goldenberg (NOAA/HRD), Philip Klotzbach (Colorado State University), and Dr. Christopher Landsea (NOAA/NHC).

The agenda of the 2nd annual elicitation was expanded to cover three rounds of questions, addressing key aspects of relevance to the assessment of hurricane activity in the Atlantic basin. Those three rounds were:

- Round 1: Assessment of the expected hurricane activity across the entire Atlantic and along the U.S. coastline over the next five years (2007-2011)
- Round 2: Considerations around the regionalization of activity across the Western Atlantic (including the Caribbean region) over the next five years (2007-2011)
- Round 3: Considerations around the expected activity in the Atlantic basin over longer time scales

The majority of time at the meeting was however focused around addressing the first Round of questions.

Round 1: Atlantic and U.S. Hurricanes: Expected Activity During the Next Five Years

The first round of questions was aimed at quantitatively addressing the following questions on the activity of Atlantic and U.S. hurricanes:

- What is the expected activity of all hurricanes (category 1-5) and the most severe category 3-5 in the Atlantic basin over the next five years (2007-2011)?
- What is the expected activity of all hurricanes (category 1-5) and the most severe category 3-5 across the U.S. coastline as a whole over the next five years (2007-2011)?

Statistical Models of Atlantic Hurricane Activity

In preparation for the elicitation proceedings, multiple statistical models were developed by RMS as an ongoing effort to continue to research and assess hurricane activity across the Atlantic basin and at U.S. landfall, as well as provide more information around the uncertainty associated with the use of such tools in forecasting. Results from those models were distributed to the experts prior to October 13th and and discussed in detail during the course of the meeting. The following classes of predictive models were provided to the expert panel:

- Models based only on historical hurricane numbers
- Models based on SST predictions, including expected trends in SSTs

In addition to the statistical models, the expert panel was provided with the long term historical baseline statistics as measured over the 1950 to 2005 period for both the basin and U.S. activity as well as from 1900 to 2005 period for the U.S. The 2006 hurricane season was still active at the time of the elicitation, and thus statistics were provided to the experts with and without the 2006 season as of the date of the elicitation.

Round 2: Regionalization of Activity

The second round of questions discussed the regionalization of basin activity, i.e. how the activity across the entire basin translates into activity in the Western Atlantic (including the Caribbean region). Regionalization may occur as a result of changes in the distribution of storm genesis and/or in the conditions that govern storm tracks. The following questions were raised during this phase of the meeting:

- Do you accept that a period of elevated activity comprises incremental storms (i.e., in addition to those that would have formed in the Atlantic Main Development Region (MDR)? (The MDR is a region in the tropical Atlantic where SSTs tend to be warmer than normal in active hurricane seasons.)
- Can we state that the activity in the Caribbean region follows similar patterns to those described for the entire Atlantic Basin?
- Do you consider there is auto-correlation in the regional distribution of hurricane tracks within the Atlantic Basin over multiple years (and what could be the underlying climatological explanation)?

Round 3: Activity at Longer Time Scales

The last round of questions discussed the impacts of climate change on hurricane activity within the Atlantic Basin, and therefore addressed the expected number of hurricanes over longer time periods. The following questions were discussed in succession with the panel of experts:

- How long are the current heightened levels of activity expected to last for?
- If the 2005 hurricane season has a 100-year return period in 2005, what return period do you think it would have in 2045?
- Can we expect a larger increase in the frequency of the most severe storms, compared to the overall hurricane population?

All experts agreed that the heightened levels of activity should last for more than five years. In fact, all experts weighed the likelihood of the basin to remain active for more than 10 years at 80% or higher. Opinions diverged beyond 15-20 years into the future, with some experts believing the current levels of activity will last for more than 20 years, while others assigned a larger likelihood for the activity to converge back onto the long-term levels within 10 to 20 years.

Five out of seven experts believe that increases in activity will impact the frequency of major category 3-5 more heavily than that of the overall population of storms. The two remaining experts had no strong opinion on this subject.

Key Results from the 2006 Elicitation of Expert Opinions

After the models were presented and experts given time to discuss their outcomes, they were asked to weigh them according to which were considered to provide the best predictors of the medium-term's 2007-2011 activities. The experts were assigned 100 units of probability to be assigned to the models, allocating the units according to which models they considered gave the most credible results. For Atlantic Basin predictions, there were 10 different models available, including several variations of the mixed baseline and sea surface temperature predictor approaches. For the assessment of U.S. landfall, the experts were provided with two variants of each of the 10 models (making a total of 20 in all), as the U.S. activity can be assessed directly from the U.S. landfall time series or by first estimating the basin activity and then converting the basin numbers into numbers of landfalling storms.

After each expert individually weighed how much probability to assign to the different models, the results were generated in the form of a mean activity rate for each expert as well as a probability density distribution over all the individual model results. The results of the individual expert activity rate forecasts were then circled back to all the experts at the meeting. Individuals with outlying opinions were then asked to discuss and explain their reasoning to the group, generating a new round of discussions around issues that were potentially overlooked.

The process was conducted separately for the assessment of activities across the whole Atlantic Basin and for U.S. landfalling category 1-5 and category 3-5 activities. Experts had the option to weigh models differently for the major (category 3-5) hurricanes than for all hurricanes, but the majority used similar weights for both sets, particularly when it came to the assessment of the U.S. landfall activity. In setting their weights, experts were asked to account for the 2006 Atlantic and U.S. activity, and the current El Nino conditions.

After the second round of discussion, experts were then given a final chance to refine their weights according to what had been learned, but most experts were confident in their initial assessment and kept their initial responses. None of the experts adjusted their U.S. landfall estimates after the first round of weight assignment.

The averages across the seven experts were between +/-2% of the October 2005 first RMS expert elicitation activity rate estimates, for the entire Atlantic Basin and the U.S. activity for both category 1-5 and category 3-5 hurricanes. A sensitivity test was performed as to the impact of these global changes in activity rates on U.S. hurricane losses using the RiskLink® 6.0 U.S. Hurricane Model and the latest vintage 2006 industry exposure datasets. After implementing the change from the 2005 expert elicitation to the 2006 expert elicitation medium-term activity rates, it was found that losses for an industry portfolio changed by less than 1% across return periods.

CONCLUSIONS

RMS held a second annual elicitation of expert opinions on the five–year, medium-term view of hurricane activity in New York on October 13, 2006. This year, the process was expanded in terms of the number of experts invited, as well as in the material that RMS developed as additional research into the topic, all of which served to support the elicitation proceedings. The number of participating experts increased from four to seven. Professor Kerry Emanuel, Tom Knutson, and Professor Mark Saunders, who were members of our 2005 panel, agreed to participate again. Additionally, four other individuals participated in this year's panel, representing a broad spectrum of opinions across the hurricane community: Dr. Suzana Camargo, Dr. John Knaff, Dr. Jim Kossin, and Dr. Frédéric Vitart.

The results of the 2006 elicitation of activity rates at U.S. landfall were very similar to those implemented in version 6.0. In fact, for measures of category 1-5 and category 3-5 activities across the basin and at U.S. landfall, changes in rates compared to last year's analysis were 2% or less. Also, the meeting provided support for arguments concerning the regionalization of the increment of activity implemented in version 6.0.

Despite the low activity observed at U.S. landfall and throughout the western half of the Atlantic hurricane basin in 2006, the level of expected medium-term risk for the U.S. remains significantly above the long-term average. The possible occurrence of an El Niño event reducing hurricane activities was included in the forecasts delivered by the experts covering the 2007-2011 period, including any potential influence of the current 2006 El Niño event. In fact, historically, the occurrence of an El Niño during the winter tends to slightly increase the expected activity over the following year.

RMS will release an update to the U.S. Hurricane Model in version 7.0 in spring 2007, reflecting any changes in knowledge relevant to expected hurricane losses. However, the medium-term, five-year view of activity rates implemented in version 7.0 will remain unchanged from RiskLink 6.0 as a result of the 2006 expert elicitation. The long-term historical baseline activity rates that are available in the model will be updated to incorporate the 2006 season.

RMS plans to publish the 2006 elicitation methodology and results described in this document in one or more peer-reviewed journal articles within the next 12 months.