Summary of 2008 Atlantic Tropical Cyclone Season and Verification of Authors' Seasonal Forecasts

Issued: 7th January 2009

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Summary

The 2008 North Atlantic hurricane season was active, damaging and deadly. The season saw basin tropical storm activity about 50% above the long-term (1950-2007) norm, US landfalling storm and hurricane activity 100% above-norm, and a basin total insured damage bill estimated at over US$ 20bn. Tropical storms in 2008 also caused over 800 fatalilties, mostly on Haiti. The year continued the current active hurricane era which has seen 10 of the last 14 years witness above-norm hurricane activity. The TSR deterministic and probabilistic forecasts performed well. The 2008 North Atlantic and U.S. landfalling hurricane seasons were predicted to have 'high activity' (i.e. within the top one third of years historically) to high (65-70%) probability from early December 2007. By early August 2008 TSR had raised these probabilities to 97% certainty that Atlantic basin hurricane activity would be in the top third of years historically and to 91% certainty that U.S. landfalling hurricane activity would be in the top third of years historically.

The Tropical Storm Risk (TSR) consortium presents a validation of their seasonal deterministic and probabilistic forecasts for North Atlantic tropical cyclone activity in 2008. These forecasts were issued on the 7th December 2007, 7th April 2008, 5th June 2008, 4th July 2008 and the 6th August 2008. They include separate predictions for tropical storms, hurricanes, intense hurricanes and the ACE (Accumulated Cyclone Energy) index, each given for the following regions: North Atlantic basin, tropical North Atlantic, US landfalling and Caribbean Lesser Antilles landfalling. All forecasts except for the Caribbean landfalling outlook were skilful.

Features of the 2008 Atlantic Season

- The 2008 North Atlantic tropical cyclone season saw 16 tropical storms, 8 hurricanes, 5 intense hurricanes and a total ACE index of 144. This compares to long-term norm values of 10.3, 6.2, 2.7 and 101 respectively. In terms of historical precedent, 2008 ranks - depending on which activity measure is used - between the 5th and 15th most active tropical cyclone season since reliable records began in 1944.
- Six tropical storms (Dolly, Edouard, Fay, Gustav, Hanna and Ike) struck the U.S. with three of these (Dolly, Gustav and Ike) striking at hurricane (category 2) strength. These strike

numbers compare to long-term norm values of 3.1 and 1.5 U.S. strikes per year respectively. The 2008 U.S. ACE index was 7.2. This was the highest U.S. ACE index since 1985 and the 4th highest since 1950.

- Hurricanes Dolly, Gustav and Ike all made landfall on the US Gulf coast. Dolly struck with 1-min sustained winds of 100mph, while Gustav and Ike struck with 1-min sustained winds of 110 mph, just short of category 3 intensity. Ike was the largest tropical cyclone ever observed with hurricane force winds extending 240 miles in diameter. Ike's large size brought a storm surge of over 12 feet from Galveston Island to southern Louisiana.
- Tropical storm Fay is the only tropical cyclone on record to make landfall four times in the US. Some parts of Florida received up to 25 inches of rain from Fay.
- The Greater Antilles was severly impacted by tropical cyclones in 2008. Cuba was struck by a record three major hurricanes (Gustav, Ike and Paloma). Over 800 people were killed in Haiti by four consecutive tropical cyclones (Fay, Gustav, Hanna and Ike).
- Paloma was the second strongest November hurricane on record, behind hurricane Lenny (1999). Paloma struck the Cayman Islands with 1-min sustained winds of 140 mph and later struck Cuba with 1-min sustained winds of 125 mph. Total damage in the Cayman Islands and Cuba is estimated at US$ 2bn.
- 2008 is the first year where six consecutive tropical cyclones struck the U.S. (Dolly, Edouard, Fay, Gustav, Hanna and Ike).
- 2008 is the first year where an intense hurricane developed in five different months of the season (July: Bertha, August: Gustav, September: Ike, October: Omar, November: Paloma).

Individual Storm and Loss Summary 2008

No.	Name	Dates	Peak Wind (kts)	Minimum Pressure (mb)	Hurricane Category	Category at US Landfall	Estimated Insured Loss (US $ bn)
1	Arthur	31 May-2 Jun	35	1005	-	-	-
2	Bertha	3-20 Jul	105	948	3	-	-
3	Cristobal	19-23 Jul	55	-	-	-	-
4	Dolly	20-25 Jul	85	964	2	2	0.525
5	Edouard	3-6 Aug	55	-	-	TS	minimal
6	Fay	15-26 Aug	55	-	-	TS	0.18
7	Gustav	25 Aug-4 Sep	130	941	4	2	5*
8	Hanna	28 Aug-7 Sep	70	978	1	TS	0.1
9	Ike	1-14 Sep	125	935	4	2	15*
10	Josephine	2-6 Sep	55	994	-	-	-
11	Kyle	25-29 Sep	70	984	1	-	-
12	Laura	29 Sep-1 Oct	50	993	-	-	-
13	Marco	6-8 Oct	55	998	-	-	-
14	Nana	12-14 Oct	35	1005	-	-	-
15	Omar	13-18 Oct	110	959	3	-	unknown
16	Paloma	5-10 Nov	125	943	4	-	unknown

*Munich Re press release 29th December 2008.

Verification of Forecasts

1. North Atlantic Hurricane Activity

(a) Deterministic Forecasts: North Atlantic Hurricane Activity 2008					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (±SD) (1950-2007)		101 (±60)	2.7 (±1.9)	6.2 (±2.6)	10.3 (±4.0)
Actual Number 2008		144	5	8	16
TSR Forecasts (±SD)	5 Aug 2008	191 (±42)	4.5 (±1.4)	9.7 (±1.7)	18.2 (±2.9)
	4 Jul 2008	136 (±48)	3.5 (±1.6)	7.9 (±2.2)	14.6 (±3.4)
	5 Jun 2008	131 (±52)	3.4 (±1.6)	7.7 (±2.4)	14.4 (±3.4)
	7 Apr 2008	136 (±61)	3.5 (±1.8)	7.8 (±2.7)	14.8 (±4.1)
	10 Dec 2007	149 (±66)	3.7 (±1.8)	8.3 (±3.0)	15.4 (±4.7)
Gray Forecasts	5 Aug 2008	175	5	9	17
	3 Jun 2008	150	4	8	15
	9 Apr 2008	150	4	8	15
	7 Dec 2007	125	3	7	13
NOAA Forecasts	7 Aug 2008	123-201	3-6	7-10	14-18
	22 May 2008	88-184	2-5	6-9	12-16
Met Office Forecast	18 Jun 2008	-	-	-	16 (±5)

(b) Probabilistic Forecasts: North Atlantic ACE Index 2008					
		Tercile Probabilities			*RPSS*
		below normal	normal	above normal	
Actual 2008		0	0	100	1
Climatology 1950-2007		33.3	33.3	33.3	0
TSR Forecasts	5 Aug 2008	0	3	97	0.998
	4 Jul 2008	8	25	67	0.793
	5 Jun 2008	4	16	80	0.925
	7 Apr 2008	14	23	63	0.719
	10 Dec 2007	11	19	70	0.817
NOAA Forecasts	7 Aug 2008	5	10	85	0.955
	22 May 2008	10	25	65	0.762

With the exception of the August forecast the TSR deterministic forecasts all performed very well with skill comparable to the other competing forecasts. TSR raised its forecast in August on the expectation that the trade wind speed would be more favourable than thought previously. The trade wind forecast verified but activity levels were lower than expected. A possible reason for this was the supression of activity during the first half of August and the second half of September due to a stronger than normal Madden Julian Oscillation influence on hurricane activity this year. All probabilistic forecasts showed excellent skill and the August and June forecasts outperformed the corresponding NOAA August and May forecasts.

2. MDR, Caribbean and Gulf of Mexico Hurricane Activity

(a) Deterministic Forecasts: MDR, Caribbean and Gulf Hurricane Activity 2008					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (±SD) (1950-2007)		78 (±59)	2.3 (±1.8)	4.3 (±2.5)	7.1 (±3.3)
Actual Number 2008		135	5	7	13
TSR Forecasts (±SD)	5 Aug 2008	164 (±46)	4.2 (±1.2)	7.5 (±1.5)	13.4 (±2.3)
	4 Jul 2008	109 (±47)	3.2 (±1.4)	5.7 (±1.7)	9.8 (±2.3)
	5 Jun 2008	104 (±47)	3.1 (±1.4)	5.5 (±1.8)	9.6 (±2.6)
	7 Apr 2008	109 (±57)	3.2 (±1.6)	5.6 (±2.3)	10.0 (±3.4)
	10 Dec 2007	122 (±62)	3.4 (±1.7)	6.1 (±2.6)	10.6 (±4.0)

The Atlantic Main Development Region (MDR) is the region 10^oN - 20^oN, 20^oW - 60^oW between the Cape Verde Islands and the Caribbean. A storm is defined as having formed within this region if it reached at least tropical depression status while in the area. Most of the infamous Atlantic basin hurricanes formed within the MDR, Caribbean Sea and Gulf of Mexico.

b) Probabilistic Forecasts

(b) Probabilistic Forecasts: MDR, Caribbean and Gulf ACE Index 2008					
		Tercile Probabilities			*RPSS*
		below normal	normal	above normal	
Actual 2008		0	0	100	1
Climatology 1950-2007		33.3	33.3	33.3	0
TSR Forecasts	5 Aug 2008	0	6	94	0.994
	4 Jul 2008	7	28	65	0.772
	5 Jun 2008	9	30	61	0.713
	7 Apr 2008	11	26	63	0.733
	10 Dec 2007	9	21	70	0.824

Overall activity in the MDR, Caribbean and Gulf in 2008 was about 55% above the 1950-2007 climate norm. The TSR deterministic forecasts performed very well although major hurricane numbers were underestimated. The TSR August forecast overpredicted the ACE index and hurricane numbers but performed well for storm numbers and major hurricane numbers. The TSR December forecast performed best overall. All probabilistic forecasts showed excellent skill with respect to climatology.

3. US Landfalling Hurricane Activity

a) Deterministic Forecasts

US Landfalling Hurricane Activity 2008				
		US ACE Index ($x10^4 kts^2$)	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2007)		2.4 (±2.2)	1.5 (±1.3)	3.1 (±2.0)
Actual Number 2008		7.2	3	6
TSR Forecasts (±SD)	5 Aug 2008	4.5 (±1.4)	2.0 (±0.9)	4.6 (±1.3)
	4 Jul 2008	2.9 (±1.1)	1.7 (±0.9)	4.0 (±1.3)
	5 Jun 2008	2.9 (±1.2)	1.7 (±1.0)	4.0 (±1.3)
	7 Apr 2008	2.9 (±1.2)	1.7 (±1.0)	4.0 (±1.4)
	10 Dec 2007	3.1 (±1.3)	1.8 (±1.0)	4.1 (±1.4)

b) Probabilistic Forecasts

US ACE Index 2008					
		Tercile Probabilities			*RPSS*
		below normal	normal	above normal	
Actual 2008		0	0	100	1
Climatology 1950-2007		33.3	33.3	33.3	0
TSR Forecasts	5 Aug 2008	1	8	91	0.985
	4 Jul 2008	6	32	62	0.735
	5 Jun 2008	7	33	60	0.704
	7 Apr 2008	7	31	62	0.732
	10 Dec 2007	7	28	65	0.772

2008 was a very destructive hurricane season for the US. Although no intense (category 3 or higher) hurricane made landfall two of the three landfalling hurricanes were just short of category 3 intensity. The US ACE index is the 4th highest since 1950, and is the highest ever for a season with no major hurricane landfall. The ACE index was enhanced by both the erratic track of tropical storm Fay which made landfall four times and which also strengthened whilst over Florida, and by hurricane Hanna which tracked along a large portion of the US East coast as a tropical storm. These two storms alone contributed 39% of the US ACE index. The August forecast (Saunders and Lea, 2005) performed best overall. All forecasts predicted correctly that US landfalling activity would be above norm although the magnitude was underpredicted. All probabilistic forecasts performed well showing significant positive skill with respect to climatology.

4. Lesser Antilles Landfalling Numbers

Lesser Antilles Landfalling Hurricane Activity 2008					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2007)		1.4 (±2.0)	0.2 (±0.5)	0.5 (±0.7)	1.1 (±1.0)
Actual Number 2008		0	0	0	0
TSR Forecasts (±SD)	5 Aug 2008	2.9 (±2.0)	0.5 (±0.4)	0.9 (±0.5)	2.1 (±0.8)
	4 Jul 2008	1.9 (±2.1)	0.3 (±0.4)	0.7 (±0.6)	1.5 (±0.9)
	5 Jun 2008	1.8 (±2.1)	0.3 (±0.4)	0.6 (±0.6)	1.5 (±1.0)
	7 Apr 2008	1.9 (±2.4)	0.3 (±0.4)	0.7 (±0.6)	1.5 (±1.1)
	10 Dec 2007	2.2 (±2.4)	0.4 (±0.4)	0.7 (±0.6)	1.6 (±1.0)

No tropical storm made landfall on the Lesser Antilles in 2008 which is unusual for such an active season. Of the 23 other years with a total ACE index above the 1950-2007 climatology only two of these years saw no tropical storm make landfall on the Lesser Antilles. The reasons for this were that few storms formed east of the Lesser Antilles in 2008 and those that did either tracked northward towards the Bahamas or recurved at sea. As a result, the TSR forecasts overpredicted Lesser Antilles landfalling activity this year.

Environmental Factors in 2008

1. Contemporaneous Influences

The basic tenet of sound seasonal hurricane forecasting is to forecast the key environmental conditions at the height of the Atlantic hurricane season in August and September. TSR's two predictors are the forecast July-September (JAS) 2008 trade wind speed, u_T, over the Caribbean Sea and tropical North Atlantic, and the forecast August-September (AS) 2008 sea surface temperature in the hurricane main development region. The former influences cyclonic vorticity (the spinning up of storms) in the main hurricane track region, while the latter provides heat and moisture to power incipient storms in the main track region. The specific predictor values and regions are:

1. Jul-Sep Caribbean 925hPa u-winds [7.5°N-17.5°N, 30°W-100°W] (JAS u_T).
2. Aug-Sep SSTs in the Main Development Region [10°N-20°N, 10°W-60°W] (AS MDR SST).

The climatology for JAS u_T is $-6.4 ms^{-1}$ (with the -ve sign indicating an easterly wind). When the trade wind speed is lighter than average (+ve u_T anomaly), cyclonic vorticity within and to the immediate north of the u_T region is enhanced. The primary factor controlling anomalies in summer trade wind speed (u_T) is the anomaly in the zonal SST gradient between the east Pacific (ENSO region) and the Caribbean Sea.

2. Predictor Verification

Predictor Verification 2008			
		JAS u_T (ms^{-1})	AS MDR SST (^oC)
Actual Value 2008 (1978-2007 Anomaly)		2.28	0.38
TSR Forecasts (±SD)	5 Aug 2008	1.32 (±0.43)	0.15 (±0.15)
	4 Jul 2008	0.35 (±0.42)	0.17 (±0.18)
	5 Jun 2008	0.31 (±0.43)	0.08 (±0.22)
	7 Apr 2008	0.40 (±0.64)	0.06 (±0.28)
	10 Dec 2007	0.55 (±0.75)	0.19 (±0.29)

All the TSR forecasts for u_T showed positive skill and anticipated the correct anomaly sign. The early August forecast proved the most skillful for the trade wind anomaly whereas the early December forecast was the most skilful for SST. The TSR forecasts all underpredicted the magnitude of both the SST and trade wind anomalies. Despite this however, the total hurricane activity this year was well below what would be expected for such favourable wind and SST anomalies and this resulted in good forecasts for the 2008 Atlantic hurricane season despite underpredicting the SST and trade wind anomalies. Had TSR predicted the trade wind and SST anomalies perfectly the forecast ACE index would have been around 240 and the forecast number of tropical storms 21.

Definitions and Verification Data

The verification is made using track data obtained from the US National Hurricane Center (http://www.nhc.noaa.gov) and the Unisys Weather (http://weather.unisys.com) websites. Position and maximum windspeeds are supplied at 6-hour time intervals. We interpolate these to 1 hour intervals to deduce the landfalling ACE indices.

Rank Probability Skill Score

The probabilistic skill measure employed is the rank probability skill score (*RPSS*) (Epstein 1969; Goddard et al 2003; Wilks, 2006). Computation of *RPSS* begins with the rank probability score (RPS) which is defined as:

$$\sum_{m=1}^{N_{cat}} (CP_{Fm} - CP_{Om})^2$$

where $N_{cat} = 3$ for tercile forecasts. The vector CP_{Fm} represents the cumulative probability of the forecast up to category m, and CP_{Om} is the cumulative observed probability up to category m. The probability distribution of the observation is 100% for the category that was observed and is zero for the other two categories. For a perfect forecast $RPS = 0$. The *RPS* is referenced to climatology to give the *RPSS* which is defined as:

$$RPSS = 1 - \frac{RPS_{fcst}}{RPS_{ref}}$$

where RPS_{fcst} is the *RPS* of the forecast and RPS_{ref} ($=RPS_{cl}$) is the *RPS* of the climatology forecast. The maximum *RPSS* is 1; a negative *RPSS* indicates skill worse than climatology.

Total ACE Index = Accumulated Cyclone Energy Index = Sum of the Squares of 6-hourly Maximum Sustained Wind Speeds (in units of knots) for all Systems while they are at least Tropical Storm Strength. ACE Unit = $x10^4$ $knots^2$.

US ACE Index = Sum of the Squares of hourly Maximum Sustained Wind Speeds (in units of knots) for all Systems while they are at least Tropical Storm Strength and over the USA Mainland (reduced by a factor of 6). ACE Unit = $x10^4$ $knots^2$.

Lesser Antilles ACE Index = Sum of the Squares of hourly Maximum Sustained Wind Speeds (in units of knots) for all Systems while they are at least Tropical Storm Strength and within the boxed region (10^oN-18^oN,60^oW-63^oW) (reduced by a factor of 6). ACE Unit = $x10^4$ $knots^2$.

Intense Hurricane	=	1 minute sustained winds > 95kts (110mph).
Hurricane	=	1 minute sustained winds > 63kts (73mph).
Tropical Storm	=	1 minute sustained winds > 33kts (38mph).
SD	=	Standard Deviation.
USA Mainland	=	Brownsville (Texas) to Maine.
Lesser Antilles	=	Island Arc from Anguilla to Trinidad inclusive.
Terciles	=	Data groupings of equal (33.3%) probability corresponding to the upper, middle and lower one-third of values historically (1950-2005).

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Tropical Storm Risk.com (TSR)

Founded in 2000, *Tropical Storm Risk* (TSR) offers a leading resource for forecasting the risk from tropical storms worldwide. The venture provides innovative forecast products to increase risk awareness and to help decision making within the (re)insurance industry, other business sectors, government and society. The TSR consortium is co-sponsored by Aon Benfield, the leading reinsurance intermediary and capital advisor, Royal & Sun Alliance, the global insurance group, and Crawford & Company, a global claims management solutions company. The TSR scientific grouping brings together climate physicists, meteorologists and statisticians at University College London and the Met Office.

Tropical Storm Risk has won two major insurance industry awards during the past four years. In 2006 TSR was awarded the prestigious Risk Management Award at the British Insurance Awards, and in 2004 won the British Insurance Award for London Market Innovation of the Year.

Acknowledgements

We thank David Simmons (Aon Benfield), Alan Fowler (Royal & SunAlliance) and Andries Willemse (Crawford & Company) for industrial liaison. We acknowledge web-site assistance by Alan Muir (UCL).