Summary of 2005 Atlantic Tropical Cyclone Season and Verification of Authors' Seasonal Forecasts

Issued: 16th January 2006
(Revised 20th March 2006)

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Summary

The 2005 hurricane season was the most active and destructive on record. Numerous seasonal, monthly and single storm records were set. The TSR probabilistic forecasts successfully predicted the above-average activity to high probability from December 2004. The 7th July and 5th August forecast updates predicted that basin hurricane activity in 2005 would be in the top one third of years historically to 97% and 100% probability, and U.S. landfalling hurricane activity would be in the highest one third of years historically to 82% and 85% probability.

The Tropical Storm Risk (TSR) consortium presents a summary of the record-breaking 2005 North Atlantic hurricane season and a validation of their seasonal probabilistic and deterministic forecasts for this activity. These forecasts were issued monthly from the 10th December 2004 to the 5th August 2005. 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, U.S. landfalling, and Caribbean Lesser Antilles landfalling. The tercile probability forecasts all proved highly skillful anticipating the above-average activity to high probability at all leads. The TSR deterministic forecasts were also all skillful (i.e. predicting activity well above the long term norm). However, with the exception of the early August forecast these greatly underestimated the extreme values for overall basin and U.S. landfalling hurricane activity.

Records Set by the 2005 Atlantic Hurricane Season

a) Seasonal records:

- Most tropical storms: 27. Previous record was 21 set in 1933.
- Most hurricanes: 15. Previous record was 12 set in 1969.
- Most category 5 hurricanes: 4 (Emily, Katrina, Rita and Wilma). Previous record was 2 set

in 1960 and 1961.

- Most major (Cat 3 or greater) hurricanes to strike the U.S.: 4. Previous record was 3 set in 1893, 1909, 1933, 1954 and 2004.
- Most U.S. insured damage in a hurricane season: US $ 50 billion. Previous record was approx US $ 29 billion (normalised to 2005 dollars) set in 1992 and 2004.
- Latest end to a hurricane season: January 6. Previous record was January 5 set in 1954/5.

b) Notable near seasonal records:

- Second highest number of tropical storms to strike the U.S.: 7. The record is 8 set in 1916 and 2004.
- Second highest number of hurricanes to kill 1000+ people: 2 (Katrina and Stan). The record is 3 set in 1780.
- Second most major (Cat 3 or greater) hurricanes: 7. The record is 8 set in 1950.

c) Monthly records:

- Most named tropical storms forming in July: 5.
- Most major hurricanes forming in July: 2.
- Most named tropical storms forming in November: 3.

d) Single storm records:

- Most damaging hurricane (and U.S. natural disaster) ever: Katrina - insured loss of approx US $ 38 billion. Previous record for a hurricane insured loss is US $ 29 billion (normalised to 2005 dollars) set by hurricane Andrew in 1992.
- Greatest storm surge from an Atlantic hurricane: 28-30 feet from Katrina in Gulfport, Mississippi. Previous record was 24.6 feet set by hurricane Camille in 1969.
- Most intense hurricane ever: Wilma had a central pressure of 882 mb. Previous record is 888 mb set by hurricane Gilbert in 1988.
- Dennis and Emily became the most intense hurricanes on record before August with central pressures of 930 mb and 929 mb respectively.
- Vince was the furthest north and east that a tropical cyclone has ever formed in the Atlantic. Vince was also the first tropical cyclone on record to strike the Iberian Peninsula.

Individual Storm and US Insured Loss Summary 2005							
No.	Name	Dates	Peak Wind (kts)	Minimum Pressure (mb)	Hurricane Category	Category at US Landfall	Estimated Insured Loss (US $ bn)*
1	Arlene	8-13 Jun	60	989	-	TS	-
2	Bret	28-30 Jun	35	1002	-	-	-
3	Cindy	3-7 Jul	65	992	1	TS	-
4	Dennis	5-13 Jul	130	930	4	3	1.1
5	Emily	11-21 Jul	140	929	5	-	-
6	Franklin	21-29 Jul	60	997	-	-	-
7	Gert	23-25 Jul	40	1005	-	-	-
8	Harvey	2-8 Aug	55	994	-	-	-
9	Irene	4-18 Aug	90	975	2	-	-
10	Jose	22-23 Aug	45	1001	-	-	-
11	Katrina	23-31 Aug	150	902	5	3	38.1
12	Lee	28 Aug - 2 Sep	35	1007	-	-	-
13	Maria	1-10 Sep	100	960	3	-	-
14	Nate	5-10 Sep	80	979	1	-	-
15	Ophelia	6-18 Sep	75	979	1	-	0.8
16	Philippe	17-24 Sep	70	985	1	-	-
17	Rita	18-26 Sep	155	897	5	3	4.7
18	Stan	1-5 Oct	70	979	1	-	-
19	Tammy	5-6 Oct	45	1001	-	TS	-
20	Vince	9-11 Oct	65	987	1	-	-
21	Wilma	15-25 Oct	160	882	5	3	6.1
22	Alpha	22-24 Oct	45	998	-	-	-
23	Beta	27-31 Oct	100	960	3	-	-
24	Gamma	18-21 Nov	45	1004	-	-	-
25	Delta	23-28 Nov	60	980	-	-	-
26	Epsilon	29 Nov - 8 Dec	75	979	1	-	-
27	Zeta	30 Dec - 6 Jan	55	994	-	-	-

*Insurance Information Institute (http://www.iii.org)

Verification of Forecasts

1. North Atlantic Hurricane Activity

(a) Deterministic Forecasts: North Atlantic Hurricane Activity 2005					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2004)		98 (±57)	2.6 (±1.8)	6.0 (±2.4)	9.9 (±3.3)
Actual Number 2005		250	7	15	27
TSR Forecasts (±SD)	5 Aug 2005	249 (±36)	6.6 (±1.2)	11.4 (±1.5)	22.1 (±2.3)
	7 Jul 2005	190 (±42)	4.1 (±1.5)	8.8 (±1.9)	15.3 (±2.4)
	7 Jun 2005	159 (±42)	3.5 (±1.4)	7.8 (±1.9)	13.8 (±2.2)
	5 May 2005	158 (±44)	3.6 (±1.4)	7.8 (±2.1)	13.9 (±2.6)
	5 Apr 2005	155 (±50)	3.6 (±1.5)	7.8 (±2.1)	13.9 (±2.9)
	7 Mar 2005	156 (±52)	3.6 (±1.6)	7.9 (±2.3)	14.0 (±3.2)
	9 Feb 2005	151 (±53)	3.5 (±1.6)	7.7 (±2.3)	13.6 (±3.3)
	5 Jan 2005	157 (±56)	3.6 (±1.6)	7.8 (±2.4)	13.9 (±3.5)
	10 Dec 2004	145 (±56)	3.4 (±1.6)	7.5 (±2.5)	13.4 (±3.6)
Gray Forecasts	5 Aug 2005	-	6	10	20
	31 May 2005	-	4	8	15
	1 Apr 2005	-	3	7	13
	3 Dec 2004	-	3	6	11
NOAA Forecasts	2 Aug 2005	158-236	5-7	9-11	18-21
	16 May 2005	105-166	3-5	7-9	12-15
Meteorological Institute, Cuba Forecasts	1 Aug 2005	-	-	9	20
	2 May 2005	-	-	7	13

(b) Probabilistic Forecasts: North Atlantic Total ACE Index 2005					
		Tercile Probabilities			RPSS
		below	normal	above	
Actual 2005		0	0	100	1
Climatology 1950-2004		33.3	33.3	33.3	0
TSR Forecasts	5 Aug 2005	0	0	100	1
	7 Jul 2005	0	3	97	0.997
	7 Jun 2005	2	12	86	0.948
	5 May 2005	2	13	85	0.940
	5 Apr 2005	4	16	80	0.899
	7 Mar 2005	4	16	80	0.899
	9 Feb 2005	6	18	76	0.860
	5 Jan 2005	6	16	78	0.884
	10 Dec 2004	8	20	72	0.813
NOAA Forecasts	2 Aug 2005	0	2.5	97.5	0.998
	16 May 2005	10	20	70	0.790

2. MDR, Caribbean and Gulf of Mexico Hurricane Activity

(a) Deterministic Forecasts: MDR, Caribbean and Gulf Hurricane Activity 2005					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2004)		76 (±58)	2.3 (±1.8)	4.2 (±2.4)	6.9 (±3.2)
Actual Number 2005		141	5	9	16
TSR Forecasts (±SD)	5 Aug 2005	227 (±40)	6.5 (±1.1)	9.9 (±1.7)	18.1 (±2.1)
	7 Jul 2005	172 (±44)	4.0 (±1.4)	7.0 (±1.8)	11.5 (±2.2)
	7 Jun 2005	141 (±43)	3.4 (±1.3)	6.0 (±1.9)	10.0 (±2.3)
	5 May 2005	140 (±45)	3.5 (±1.3)	6.0 (±2.0)	10.1 (±2.7)
	5 Apr 2005	138 (±51)	3.5 (±1.5)	6.0 (±2.2)	10.1 (±3.1)
	7 Mar 2005	138 (±55)	3.5 (±1.5)	6.1 (±2.4)	10.2 (±3.5)
	9 Feb 2005	133 (±56)	3.4 (±1.5)	5.9 (±2.4)	9.8 (±3.6)
	5 Jan 2005	139 (±59)	3.5 (±1.6)	6.0 (±2.5)	10.1 (±3.7)
	10 Dec 2004	128 (±59)	3.3 (±1.6)	5.7 (±2.6)	9.6 (±3.8)

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: MDR, Caribbean and Gulf ACE Index 2005					
		Tercile Probabilities			RPSS
		below	normal	above	
Actual 2005		0	0	100	1
Climatology 1950-2004		33.3	33.3	33.3	0
TSR Forecasts	5 Aug 2005	0	0	100	1
	7 Jul 2005	0	3	97	0.997
	7 Jun 2005	1	11	88	0.960
	5 May 2005	1	13	86	0.945
	5 Apr 2005	2	16	82	0.912
	7 Mar 2005	3	16	81	0.906
	9 Feb 2005	4	18	78	0.876
	5 Jan 2005	4	17	79	0.888
	10 Dec 2004	6	20	74	0.833

TSR successfully predicted that tropical storm activity in the Atlantic would be well above the long term average at all leads. The TSR August forecast performed best overall, although the ACE index was slightly overpredicted. The August forecast outperformed all other competing forecasts and the December and April forecasts outperformed Gray's December and April forecasts. For more details on Gray's forecasts see http://typhoon.atmos.colostate.edu/forecasts/.

In terms of the rank probability skill score (*RPSS*) all TSR forecasts outperformed NOAA's

May forecast. All of the TSR forecasts had very high skill with a *RPSS* of at least 0.8 at all leads. The August forecast performed best overall and had perfect skill. The July forecast had near perfect skill and was comparable to NOAA's August forecast skill.

All probabilistic forecasts showed high positive skill with the August forecast showing perfect skill and the July forecast showing near perfect skill. For all leads the *RPSS* was above 0.8 and from March onwards it was above 0.9.

3. US Landfalling Hurricane Activity

a) Deterministic Forecasts

US Landfalling Hurricane Activity 2005				
		ACE Index ($x10^4kt^2$)	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2004)		2.3 (±2.1)	1.5 (±1.3)	3.1 (±2.0)
Actual Number 2005		5.0	4	7
TSR Forecasts (±SD)	5 Aug 2005	4.4 (±1.7)	3.4 (±1.5)	7.4 (±2.3)
	7 Jul 2005	4.3 (±1.9)	2.2 (±1.5)	5.7 (±2.1)
	7 Jun 2005	3.6 (±1.9)	2.0 (±1.6)	4.2 (±2.1)
	5 May 2005	3.6 (±1.8)	2.0 (±1.5)	4.2 (±2.0)
	5 Apr 2005	3.6 (±1.8)	2.0 (±1.6)	4.3 (±2.0)
	7 Mar 2005	3.6 (±1.9)	2.0 (±1.6)	4.3 (±2.1)
	9 Feb 2005	3.5 (±1.9)	2.0 (±1.6)	4.2 (±2.2)
	5 Jan 2005	3.6 (±2.0)	2.0 (±1.7)	4.3 (±1.9)
	10 Dec 2004	3.4 (±2.0)	1.9 (±1.7)	4.1 (±2.2)

b) Probabilistic Forecasts

US Landfalling ACE Index 2005					
		Tercile Probabilities			RPSS
		below	normal	above	
Actual 2005		0	0	100	1
Climatology 1950-2004		33.3	33.3	33.3	0
TSR Forecasts	5 Aug 2005	0	15	85	0.933
	7 Jul 2005	4	14	82	0.920
	7 Jun 2005	9	21	70	0.787
	5 May 2005	8	21	71	0.798
	5 Apr 2005	9	21	70	0.787
	7 Mar 2005	9	20	71	0.802
	9 Feb 2005	11	22	67	0.746
	5 Jan 2005	10	20	70	0.790
	10 Dec 2004	13	22	65	0.718

The 2005 season was another very active year for US landfalling tropical storms. Seven storms and four hurricanes struck the U.S.. All the hurricanes which impacted the U.S. were intense setting a new record. In addition, hurricane Ophelia passed just 15 miles from the North Carolina coastline bringing hurricane force winds onshore. The US ACE index of 5.8 is the fifth highest since 1950. All the hurricanes made landfall along the US Gulf coast, severely affecting oil and gas production. The TSR forecasts all predicted above average landfalling activity but underpredicted the magnitude. The August forecast (Saunders and Lea, 2005) performed best overall correctly predicting the number of tropical storm landfalls.

All probabilistic forecasts showed significant positive skill with an *RPSS* skill score of at least 0.7. The July and August landfalling forecasts performed best overall with a *RPSS* above 0.9.

4. Lesser Antilles Landfalling Numbers

Lesser Antilles Landfalling Hurricane Activity 2005					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2004)		1.4 (±2.1)	0.3 (±0.5)	0.5 (±0.7)	1.4 (±2.1)
Actual Number 2005		1.3	0	1	1
TSR Forecasts (±SD)	5 Aug 2005	5.4 (±1.9)	0.6 (±0.4)	2.0 (±0.6)	3.2 (±0.7)
	7 Jul 2005	3.5 (±2.1)	0.5 (±0.4)	0.9 (±0.6)	2.1 (±0.9)
	7 Jun 2005	2.9 (±2.0)	0.4 (±0.4)	0.8 (±0.6)	1.8 (±0.9)
	5 May 2005	2.8 (±2.2)	0.4 (±0.4)	0.8 (±0.6)	1.8 (±0.9)
	5 Apr 2005	2.8 (±2.3)	0.4 (±0.4)	0.8 (±0.6)	1.8 (±1.0)
	7 Mar 2005	2.8 (±2.4)	0.4 (±0.4)	0.8 (±0.6)	1.8 (±1.0)
	9 Feb 2005	2.7 (±2.4)	0.4 (±0.4)	0.7 (±0.6)	1.8 (±1.0)
	5 Jan 2005	2.8 (±2.4)	0.4 (±0.4)	0.8 (±0.6)	1.8 (±1.0)
	10 Dec 2004	2.6 (±2.4)	0.4 (±0.4)	0.7 (±0.6)	1.7 (±1.0)

Despite the overall unprecedented activity, landfalling activity in the Lesser Antilles was only average. One hurricane, Emily, made landfall near Grenada, the island devestated by hurricane Ivan in 2004. The lower than expected Lesser Antilles landfalling activity was due to the relatively low MDR activity for such an active year and because most hurricanes did not develop until they had tracked beyond or well away from the Lesser Antilles. The TSR August forecast correctly predicted the number of hurricanes at all leads except August, but overpredicted the ACE index. In general forecasts at earlier lead times performed best overall.

Environmental Factors in 2005

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 2005 trade wind speed over the Caribbean Sea and tropical North Atlantic, and the forecast August-September 2005 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^{o}N-17.5^{o}N, 30^{o}W-100^{o}W] (CAR U).
2. Aug-Sep SSTs in the Main Development Region [10^{o}N-20^{o}N, 10^{o}W-60^{o}W] (MDR SST).

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

2. Predictor Verification

Predictor Verification 2005			
		JAS CAR U (ms^{-1})	AS MDR SST (^{o} C)
Actual Value 2005 (1975-2004 Anomaly)		0.93	0.73
TSR Forecasts (±SD)	5 Aug 2005	1.44 (±0.41)	0.57 (±0.13)
	7 Jul 2005	0.83 (±0.54)	0.60 (±0.17)
	7 Jun 2005	0.52 (±0.53)	0.43 (±0.22)
	5 May 2005	0.56 (±0.60)	0.35 (±0.24)
	5 Apr 2005	0.62 (±0.68)	0.24 (±0.25)
	7 Mar 2005	0.66 (±0.75)	0.20 (±0.26)
	9 Feb 2005	0.54 (±0.74)	0.26 (±0.27)
	5 Jan 2005	0.62 (±0.79)	0.27 (±0.28)
	10 Dec 2004	0.49 (±0.79)	0.24 (±0.28)

All the TSR forecasts for CAR U and MDR SST showed positive skill and anticipated the correct anomaly sign. The early July forecasts proved the most skillful for both predictors with the early August forecast overpredicting the trade wind anomaly. The MDR SST anomaly this year was the highest since reliable records began in 1950; a factor behind why the magnitude of the SST anomaly was underpredicted especially at earlier leads. Despite the very favourable predictors the MDR activity this year was only average and major storms tended to form further west in the Caribbean, Gulf of Mexico or Bahamas region. As a result, the MDR, Caribbean and Gulf activity was well predicted at longer leads despite the SST and trade wind anomalies being underpredicted.

Definitions and Verification Data

The verification is made using track and intensity data obtained from the US National Hurricane Center (http://www.nhc.noaa.gov) and from 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 for deducing the landfalling ACE indices.

Rank Probability Skill Score

The probabilistic skill measure employed is the rank probability skill score (*RPSS*) (Epstein 1969; Wilks 1995; Goddard et al 2003). 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.
Terciles = Data groupings of equal (33.3%) probability corresponding to the upper, middle and lower one-third of values historically (1950-2004).
USA Mainland = Brownsville (Texas) to Maine.
Lesser Antilles = Island Arc from Anguilla to Trinidad Inclusive.

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Tropical Storm Risk.com (TSR)

Tropical Storm Risk.com (TSR) is a venture which has developed from the UK government-supported TSUNAMI initiative project on seasonal tropical cyclone prediction. The TSR consortium comprises experts on insurance, risk management and seasonal climate forecasting. The TSR industry expertise is drawn from *Benfield*, the leading independent reinsurance intermediary, *Royal & SunAlliance*, the global insurance group, and from *Crawford & Company*, a global claims management solutions company. The TSR scientific grouping brings together climate physicists, meteorologists and statisticians at *UCL* (University College London) and the *Met Office*. TSR forecasts are available from http://tropicalstormrisk.com.

Acknowledgements

We thank David Simmons (Benfield), Alan Fowler (Royal & SunAlliance) and Jonathan Clark (Crawford & Company) for industrial liaison. We acknowledge web-site assistance by Peter Yuen (UCL).