Summary of 2006 Atlantic Tropical Cyclone Season and Verification of Authors' Seasonal Forecasts

Issued: 22nd January 2007

by Professor Mark Saunders and Dr Adam Lea
Benfield Hazard Research Centre, UCL (University College London), UK.

Summary

In contrast to the hyperactive 2005 and 2004 hurricane seasons, 2006 was a relatively quiet hurricane year. Basin activity was at the 39th percentile and US landfalling activity at the 29th percentile of years between 1950 and 2005. The TSR forecasts were unsuccessful this year, predicting that activity would be in the upper tercile historically. The poor forecasts appear to be due to the suppressing effect of dry air and Saharan dust in August and to the unexpected and rapid onset of El Niño conditions in September.

The Tropical Storm Risk (TSR) consortium presents a validation of their seasonal probabilistic and deterministic forecasts for North Atlantic hurricane activity in 2006. These forecasts were issued monthly from the 6th December 2005 to the 4th August 2006. 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 greatly overpredicted the total and US landfalling activity.

Features of the 2006 Atlantic Season

- The 2006 Atlantic season saw 10 tropical storms, 5 hurricanes, 2 intense hurricanes and a total ACE index of 81. This is approximately 20% below the 1950-2005 climate norm, and is the quietest season since 2002.
- There were no hurricane landfalls in the US. This is only the 12th such occurrence since 1950.
- Three tropical storms made landfall in the US. Alberto struck 50 miles southeast of Tallahassee, Florida with 1 minute sustained winds of 40 kts and minimal damage. Beryl brushed Massachusetts as a 45 kt tropical storm. Ernesto made landfall first in Florida with sustained winds of 40 kts and again in North Carolina with sustained winds of 60 kts. Total damage from Ernesto was approximately US$ 100 million.
- 2006 is the first year since 1992 that no storms developed in the Gulf of Mexico.
- No storms developed in October or November. The last time this occurred was 2002. Since

1950 only 11 years have seen no named storm form after the 30th September.

- The ACE index for the main development region (MDR) was 62. This is almost as high as the MDR ACE index in 2005 which was 67; though 2005 saw a total ACE index over three times higher.

Individual Storm and Loss Summary 2006

No.	Name	Dates	Peak Wind (kts)	Minimum Pressure (mb)	Hurricane Category	Category at US Landfall	Estimated Insured Loss (US $ bn)*
1	Alberto	10-14 Jun	60	995	-	TS	-
2	Unnamed	17-18 Jul	45	998	-	-	-
3	Beryl	18-21 Jul	50	1000	-	TS	-
4	Chris	1-4 Aug	55	1001	-	-	-
5	Debby	21-26 Aug	45	999	-	-	-
6	Ernesto	24 Aug-1 Sep	65	985	1	TS	0.05
7	Florence	3-12 Sep	80	974	1	-	-
8	Gordon	10-20 Sep	105	955	3	-	-
9	Helene	12-24 Sep	105	955	3	-	-
10	Isaac	27 Sep-2 Oct	75	985	1	-	-

*Insurance Information Institute

Verification of Forecasts

1. North Atlantic Hurricane Activity

(a) Deterministic Forecasts: North Atlantic Hurricane Activity 2006					
		ACE Index	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (±SD) (1950-2005)		102 (±61)	2.7 (±2.0)	6.2 (±2.6)	10.3 (±4.0)
Actual Number 2006		81	2	5	10
TSR Forecasts (±SD)	4 Aug 2006	145 (±32)	3.5 (±1.2)	7.9 (±1.2)	15.9 (±2.3)
	5 Jul 2006	143 (±37)	3.4 (±1.5)	7.7 (±1.9)	14.1 (±3.6)
	6 Jun 2006	138 (±39)	3.4 (±1.5)	7.6 (±2.3)	13.9 (±3.7)
	5 May 2006	147 (±36)	3.6 (±1.5)	7.9 (±2.2)	14.6 (±3.7)
	4 Apr 2006	152 (±46)	3.8 (±1.7)	8.2 (±2.4)	15.4 (±3.9)
	6 Mar 2006	144 (±47)	3.5 (±1.7)	7.8 (±2.6)	14.6 (±4.1)
	6 Feb 2006	172 (±53)	4.1 (±1.7)	9.1 (±2.9)	16.4 (±4.5)
	4 Jan 2006	170 (±59)	4.0 (±1.8)	8.8 (±2.8)	16.2 (±4.3)
	6 Dec 2005	162 (±60)	3.9 (±1.8)	8.5 (±2.8)	15.7 (±4.5)
Gray Forecasts	3 Aug 2006	-	3	7	15
	28 May 2004	-	5	9	17
	2 Apr 2004	-	5	9	17
	5 Dec 2003	-	5	9	17
NOAA Forecasts	8 Aug 2006	96-149	3-4	7-9	12-15
	22 May 2006	118-179	4-6	8-10	13-16
Meteorological Institute, Cuba Forecasts	1 Aug 2006	-	-	9	15
	2 May 2006	-	-	9	15

(b) Probabilistic Forecasts: North Atlantic ACE Index 2006					
		Tercile Probabilities			RPSS
		below normal	normal	above normal	
Actual 2006		0	100	0	1
Climatology 1950-2005		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2006	1	15	84	-1.14
	5 Jul 2006	2	19	79	-0.92
	6 Jun 2006	4	22	74	-0.74
	5 May 2006	1	16	83	-1.09
	4 Apr 2006	3	17	80	-0.99
	6 Mar 2006	6	20	74	-0.79
	6 Feb 2006	6	18	76	-0.88
	4 Jan 2006	4	13	83	-1.17
	6 Dec 2005	6	15	79	-1.03
NOAA Forecasts	8 Aug 2006	5	20	75	-0.81
	22 May 2006	5	15	80	-1.05

2. MDR, Caribbean and Gulf of Mexico Hurricane Activity

(a) Deterministic Forecasts: MDR, Caribbean and Gulf Hurricane Activity 2006					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (±SD) (1950-2005)		79 (±60)	2.3 (±1.9)	4.3 (±2.5)	7.1 (±3.4)
Actual Number 2006		71	2	4	7
TSR Forecasts (±SD)	4 Aug 2006	118 (±50)	3.2 (±1.4)	5.5 (±1.5)	9.2 (±1.9)
	5 Jul 2006	116 (±44)	3.1 (±1.3)	5.5 (±1.5)	9.4 (±2.1)
	6 Jun 2006	112 (±39)	3.1 (±1.3)	5.4 (±1.6)	9.2 (±2.2)
	5 May 2006	121 (±35)	3.3 (±1.2)	5.7 (±1.5)	9.9 (±2.2)
	4 Apr 2006	125 (±44)	3.5 (±1.4)	6.0 (±1.8)	10.7 (±2.6)
	6 Mar 2006	117 (±43)	3.2 (±1.4)	5.7 (±2.0)	10.1 (±3.2)
	6 Feb 2006	146 (±47)	3.8 (±1.4)	7.0 (±2.3)	11.9 (±3.5)
	4 Jan 2006	144 (±59)	3.7 (±1.6)	6.7 (±2.6)	11.8 (±4.1)
	6 Dec 2005	136 (±60)	3.3 (±1.6)	6.4 (±2.7)	11.3 (±4.2)

The Atlantic Main Development Region (MDR) is the region 10°N - 20°N, 20°W - 60°W 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 2006					
		Tercile Probabilities			RPSS
		below normal	normal	above normal	
Actual 2006		0	100	0	1
Climatology 1950-2005		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2006	2	24	74	-0.69
	5 Jul 2006	3	25	72	-0.62
	6 Jun 2006	2	27	71	-0.56
	5 May 2006	1	19	80	-0.94
	4 Apr 2006	2	19	79	-0.92
	6 Mar 2006	3	24	73	-0.67
	6 Feb 2006	1	11	88	-1.35
	4 Jan 2006	3	15	82	-1.09
	6 Dec 2005	4	18	78	-0.92

TSR overpredicted tropical storm activity in the Atlantic in 2006. None of its deterministic or probabilistic forecasts showed any skill. The reason for the overprediction was a combination of unusually dry air over the tropical Atlantic which supressed activity during August, and the unexpected rapid onset of El Niño conditions during September which suppressed activity towards the end of the season. Sea surface temperatures in the Niño 3.4 region (5°S-5°N,

120°W-170°W warmed from 0.1°C to 0.7°C from August to September which is the largest percentage change in Niño 3.4 sea surface temperatures ever recorded.

3. US Landfalling Hurricane Activity

a) Deterministic Forecasts

US Landfalling Hurricane Activity 2006				
		ACE Index	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2005)		2.5 (±2.2)	1.5 (±1.3)	3.1 (±2.0)
Actual Number 2006		1.8	0	3
TSR Forecasts (±SD)	4 Aug 2006	3.2 (±1.5)	2.0 (±1.2)	4.2 (±1.9)
	5 Jul 2006	3.6 (±1.7)	2.0 (±1.4)	4.3 (±2.1)
	6 Jun 2006	3.5 (±1.7)	2.0 (±1.4)	4.3 (±2.1)
	5 May 2006	3.8 (±1.6)	2.1 (±1.4)	4.5 (±2.0)
	4 Apr 2006	4.0 (±1.7)	2.2 (±1.4)	4.8 (±2.0)
	6 Mar 2006	3.7 (±1.7)	2.1 (±1.5)	4.5 (±2.0)
	6 Feb 2006	4.5 (±1.9)	2.4 (±1.5)	5.2 (±2.0)
	4 Jan 2006	4.4 (±1.7)	2.4 (±1.3)	5.1 (±1.9)
	6 Dec 2005	4.2 (±1.8)	2.3 (±1.3)	4.9 (±1.9)

b) Probabilistic Forecasts

US Landfalling ACE Index 2006					
		Tercile Probabilities			RPSS
		above normal	normal	below normal	
Actual 2006		0	100	0	1
Climatology 1950-2005		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2006	59	30	11	-0.28
	5 Jul 2006	72	21	7	-0.72
	6 Jun 2006	70	22	8	-0.66
	5 May 2006	76	19	5	-0.85
	4 Apr 2006	78	17	5	-0.95
	6 Mar 2006	73	20	7	-0.77
	6 Feb 2006	84	12	4	-1.22
	4 Jan 2006	82	15	3	-1.09
	6 Dec 2005	81	15	4	-1.07

In contrast to 2004 and 2005, 2006 was near-average for tropical storm landfalls but below-average for hurricane landfalls with no hurricanes impacting the US. The US ACE index was about 30% below the long term climate norm but was still in the middle tercile. Most of the US ACE index was from tropical storm Ernesto which tracked up the US East Coast and made

landfall in South Florida and North Carolina. All deterministic forecasts overpredicted US landfalling activity and, as a consequence, no probabilistic forecast showed any skill.

4. Lesser Antilles Landfalling Numbers

Lesser Antilles Landfalling Hurricane Activity 2006					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2005)		1.4 (±2.0)	0.3 (±0.5)	0.4 (±0.7)	1.1 (±1.0)
Actual Number 2006		0.35	0	0	1
TSR Forecasts (±SD)	4 Aug 2006	2.2 (±1.5)	0.3 (±0.4)	0.6 (±0.6)	1.4 (±1.0)
	5 Jul 2006	2.0 (±2.3)	0.3 (±0.4)	0.6 (±0.6)	1.4 (±1.0)
	6 Jun 2006	1.7 (±2.3)	0.3 (±0.4)	0.6 (±0.6)	1.4 (±1.0)
	5 May 2006	2.1 (±2.4)	0.4 (±0.4)	0.6 (±0.6)	1.5 (±0.9)
	4 Apr 2006	2.3 (±2.6)	0.4 (±0.4)	0.7 (±0.6)	1.6 (±0.9)
	6 Mar 2006	2.1 (±2.7)	0.4 (±0.4)	0.7 (±0.6)	1.6 (±0.9)
	6 Feb 2006	2.5 (±2.7)	0.4 (±0.4)	0.8 (±0.6)	1.9 (±0.9)
	4 Jan 2006	2.3 (±2.7)	0.4 (±0.4)	0.8 (±0.6)	1.8 (±1.1)
	6 Dec 2005	2.3 (±2.7)	0.4 (±0.4)	0.7 (±0.6)	1.8 (±1.1)

One tropical storm and no hurricanes made landfall in the Lesser Antilles in 2006. The Lesser Antilles ACE index was well below the long term climate norm and was overpredicted at all leads.

Environmental Factors in 2006

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) 2006 trade wind speed over the Caribbean Sea and tropical North Atlantic, and the forecast August-September (AS) 2006 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, 40°W-110°W] (CAR U).
2. Aug-Sep SSTs in the Main Development Region [10°N-20°N, 10°W-60°W] (MDR SST).

The climatology for CAR U is $-6.4 ms^{-1}$ (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 2006			
		JAS CAR U (ms^{-1})	AS MDR SST (^{o} C)
Actual Value 2006 (1976-2005 Anomaly)		0.51	0.46
TSR Forecasts (±SD)	4 Aug 2006	0.30 (±0.43)	0.40 (±0.13)
	5 Jul 2006	0.34 (±0.51)	0.27 (±0.17)
	6 Jun 2006	0.31 (±0.53)	0.21 (±0.22)
	5 May 2006	0.46 (±0.59)	0.18 (±0.24)
	4 Apr 2006	0.61 (±0.67)	0.03 (±0.27)
	6 Mar 2006	0.46 (±0.75)	0.09 (±0.28)
	6 Feb 2006	0.83 (±0.74)	0.22 (±0.28)
	4 Jan 2006	0.79 (±0.79)	0.25 (±0.30)
	6 Dec 2005	0.68 (±0.80)	0.24 (±0.30)

All the TSR forecasts for CAR U and MDR SST showed positive skill and anticipated the correct anomaly sign. The early August forecasts proved the most skillful for AS MDR SST whereas the March and May forecasts were the most skilful for JAS CARU. The magnitude of the AS MDR SST anomaly was underpredicted in all forecasts.

Given that the JAS CAR U and AS MDR SST were both moderately enhancing for hurricane activity in 2006 it is surprising that activity was below the long term climate norm. The values for the two predictors during August/September 2006 were comparable to their values in the three previous years (2003-2005), all of which were extremely active. This is illustrated in Figure 1.

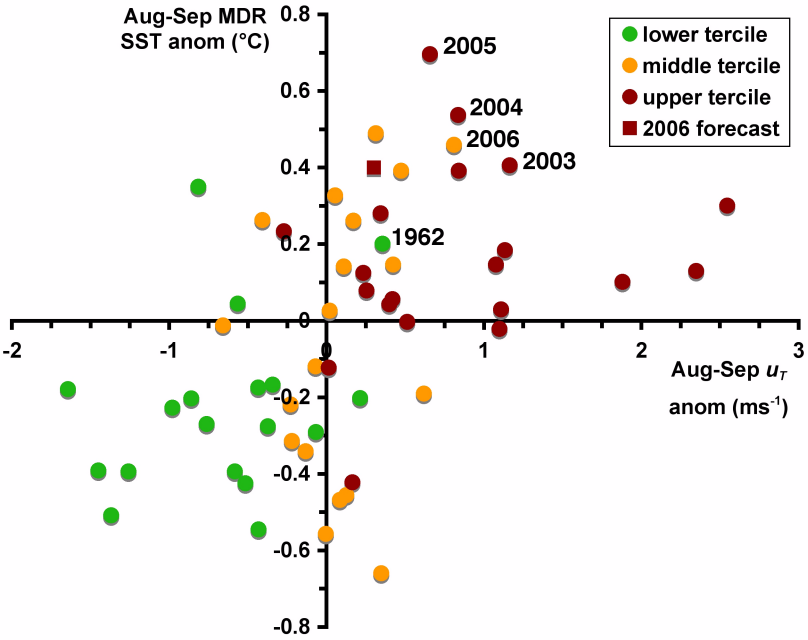

Figure1: The unusual and atypical nature of seasonal hurricane activity in 2006.

The Figure shows that based on historical data back to 1950, upper tercile hurricane activity would be expected for the JAS CAR U and AS MDR SST predictor values observed in 2006. Furthermore, the values for the predictors were well predicted in 2006 as demonstrated by the 2006 forecast point. So why was 2006 so inactive?

The explanation appears likely due to a combination of two factors. The first is the suppressing effect of considerable African dry air and Saharan dust over the hurricane main development region during August. This dry air would have increased atmospheric stability and decreased mid-level relative humidity thereby suppressing thunderstorm formation and tropical storm development. A further key factor was the sudden onset and development of El Niño conditions from mid September. This resulted in increased vertical wind shear over the Caribbean and tropical Atlantic and suppressed storm activity in October and November.

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 for deducing 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:

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).

References

Epstein, E. S., 1969: A scoring system for probability forecasts of ranked categories. *J. Appl. Meteor.*, **8**, 985-987.

Goddard, L., A. G. Barnston, and S. J. Mason, 2003: Evaluation of the IRI's "net assessment" seasonal climate forecasts. *Bull. Amer. Meteor. Soc*., **84**, 1761-1781.

Wilks, D. S., 2006: *Statistical Methods in the Atmospheric Sciences (2nd Edition)*, Academic Press, 627pp.

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 Benfield, the world's leading independent reinsurance and risk intermediary, 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 three 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 (Benfield), Alan Fowler (Royal & SunAlliance) and Jonathan Clark (Crawford & Company) for industrial liaison. We acknowledge web-site assistance by Peter Yuen (UCL).