Summary of 2004 Atlantic Tropical Cyclone Season and Verification of Authors' Seasonal Forecasts

Issued: 31st January 2005

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

Summary

An exceptionally active year with five US landfalling hurricanes causing an estimated total insured loss of US $ 20.5bn (a one in 35 year event). 2004 recorded the second highest total ACE index and the highest main development region ACE index since 1950. The TSR probabilistic forecasts successfully predicted the above-average activity to high probability from December 2003; the 4th August update giving probabilities of 86% and 70% for basin and US landfalling hurricane activity in 2004 being in the upper tercile historically. However, the TSR deterministic forecasts - while all skillful - greatly underpredicted the extreme values for overall basin and US landfalling hurricane activity.

The Tropical Storm Risk (TSR) consortium presents a summary of the 2004 North Atlantic tropical cyclone season and a validation of their seasonal probabilistic and deterministic forecasts for this activity. These forecasts were issued monthly from the 5th December 2003 to the 4th August 2004 and include separate predictions for tropical storms, hurricanes, intense hurricanes and the ACE (Accumulated Cyclone Energy) index. The latter is given for each of the following regions: North Atlantic basin, tropical North Atlantic, USA landfalling, and Caribbean Lesser Antilles landfalling.

Features of the 2004 Atlantic Season

- The 2004 Atlantic season was an exceptionally active season, with a total ACE index of 228. This is the second highest ACE index since 1950. 2004 is the only year since 1950 where the ACE index from the hurricane main development region has exceeded 200.
- A very active year for US landfalling storms. Four hurricanes (three of which were intense) struck Florida. This is the first time since 1886 that four hurricanes have hit the same state. The US landfalling ACE index was the fourth highest since 1950 and the eighth highest since 1900. We attribute this to an unusually strong and persistent ridge of high pressure over the US east coast which prevented many of the storms which formed in the MDR from recurving and remaining at sea in the North Atlantic.
- 2003 and 2004 together hold the highest total ACE index (401) since 1950 for two

consecutive Atlantic hurricane seasons.

- Hurricane Ivan's ACE index (70) is the highest from a single tropical cyclone anywhere in the world since reliable records began. Ivan also holds the record for the longest duration at Category 4 (>115kts) intensity. This was due to its long track through the deep tropics during conditions of very favourable sea surface temperature and low vertical wind shear.
- Hurricane Charley was the most intense hurricane to strike the US since Andrew in 1992. It came ashore at Charlotte Harbour, Florida with 145mph winds and caused US $6.8bn in insured damage. This was the second most damaging US hurricane strike in the last 53 years. An unusual feature of Charley was its rapid intensification and change in direction a few hours prior to landfall.
- Most activity was concentrated into August and September (with only three weak tropical storms occurring outside these months). August 2004 was the most active August since 1950 having a total ACE index of 65, eight tropical storms, four hurricanes and three intense hurricanes. Although September saw near average numbers of named storms, it had the highest North Atlantic total ACE index (155) during any month since 1950.
- Hurricanes Frances and Jeanne struck the Florida coastline within 5 km of each other. Frances was a Category 2 hurricane with winds of 105mph and Jeanne was a Category 3 storm with winds of 120mph. Jeanne had earlier killed over 2000 people in Haiti where it struck as a tropical storm causing massive flooding and mudslides.

Individual Storm and Loss Summary 2004

No.	Name	Dates	Peak Wind (kts)	Minimum Pressure (mb)	Hurricane Category	Category at US Landfall	Estimated US Insured Loss (US $ bn)**
1	Alex	31 Jul - 6 Aug	105	957	3	-	0.0025
2	Bonnie	9-12 Aug	55	1001	-	TS	-
3	Charley	9-15 Aug	125	941	4	4	6.8
4	Danielle	13-21 Aug	90	970	2	-	-
5	Earl	13-15 Aug	45	1009	-	-	-
6	Frances	25 Aug - 9 Sep	125	935	4	2	4.4
7	Gaston	27 Aug - 1 Sep	65	986	1	1	0.065
8	Hermine	29 - 31 Aug	50	1002	-	TS	-
9	Ivan	2 - 24 Sep	145	910	5	3	6.0
10	Jeanne	13 - 28 Sep	105	950	3	3	3.25
11	Karl	16 - 24 Sep	120	938	4	-	-
12	Lisa	19 Sep - 3 Oct	65	987	1	-	-
13	Matthew	8 - 10 Oct	40	997	-	TS	
14	Nicole*	10 - 11 Oct	45	988	-	-	-
15	Otto	29 Nov - 3 Dec	45	995	-	-	-

* Subtropical storm. **Insurance Information Institute

Verification of Forecasts

1. North Atlantic Hurricane Activity

(a) Deterministic Forecasts: North Atlantic Hurricane Activity 2004					
		Total ACE Index	Named Storms	Hurricanes	Intense Hurricanes
Average Number (±SD) (1950-2003)		95 (±54)	9.9 (±3.3)	6.0 (±2.3)	2.5 (±1.9)
Actual Number 2004		228	15	9	6
TSR Forecasts (±SD)	4 Aug 2004	145 (±36)	14.0 (±2.4)	7.6 (±1.1)	3.1 (±1.3)
	5 Jul 2004	114 (±36)	12.3 (±2.4)	6.6 (±1.3)	2.6 (±1.4)
	4 Jun 2004	101 (±34)	11.7 (±2.1)	6.1 (±1.5)	2.4 (±1.3)
	11 May 2004	120 (±40)	12.6 (±2.6)	6.8 (±1.8)	2.7 (±1.3)
	6 Apr 2004	128 (±50)	13.1 (±3.2)	7.2 (±2.1)	2.9 (±1.5)
	5 Mar 2004	122 (±53)	12.8 (±3.6)	7.0 (±2.4)	2.8 (±1.5)
	5 Feb 2004	139 (±53)	13.7 (±3.5)	7.6 (±2.4)	3.1 (±1.5)
	6 Jan 2004	132 (±59)	13.3 (±3.9)	7.2 (±2.6)	2.9 (±1.6)
	5 Dec 2003	132 (±59)	13.0 (±4.0)	7.2 (±2.7)	2.9 (±1.6)
Gray Forecasts	6 Aug 2004	-	13	7	3
	28 May 2004	-	14	8	3
	2 Apr 2004	-	14	8	3
	5 Dec 2003	-	13	7	3
NOAA Forecasts	7 Aug 2004	103-146	12-15	7-9	3-4
	19 May 2004	95-155	11-15	6-8	2-4
Meteorological Institute, Cuba Forecasts	1 Aug 2004	-	12	8	-
	2 May 2004	-	10	6	-

(b) Probabilistic Forecasts: North Atlantic Total ACE Index 2004					
		Tercile Probabilities			RPSS
		Below normal	Normal	Above normal	
Actual 2004		0	0	100	1
Climatology 1950-2003		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2004	1	13	86	0.95
	5 Jul 2004	7	38	55	0.47
	4 Jun 2004	13	46	41	0.13
	11 May 2004	7	32	61	0.61
	6 Apr 2004	9	26	65	0.70
	5 Mar 2004	13	27	60	0.62
	5 Feb 2004	7	21	72	0.81
	6 Jan 2004	12	23	65	0.72
	5 Dec 2003	12	23	65	0.72
NOAA Forecasts	7 Aug 2004	10	45	45	0.23
	19 May 2004	10	40	50	0.37

2. MDR, Caribbean Sea and Gulf of Mexico Hurricane Activity

(a) Deterministic Forecasts: MDR, Caribbean and Gulf Hurricane Activity 2004					
		Total ACE Index ($x10^4 kts^2$)	Named Tropical Storms	Hurricanes	Intense Hurricanes
Average Number (±SD) (1950-2003)		73 (±55)	6.8 (±3.1)	4.1 (±2.4)	2.2 (±1.8)
Actual Number 2004		209	10	7	5
TSR Forecasts (±SD)	4 Aug 2004	129 (±42)	10.4 (±2.5)	5.9 (±1.7)	3.1 (±1.3)
	5 Jul 2004	97 (±39)	8.7 (±2.3)	4.9 (±1.6)	2.6 (±1.4)
	4 Jun 2004	85 (±37)	8.1 (±2.5)	4.4 (±1.7)	2.4 (±1.3)
	11 May 2004	103 (±42)	9.0 (±2.8)	5.1 (±2.0)	2.7 (±1.3)
	6 Apr 2004	112 (±53)	9.5 (±3.4)	5.5 (±2.4)	2.9 (±1.6)
	5 Mar 2004	106 (±57)	9.2 (±3.9)	5.3 (±2.6)	2.8 (±1.6)
	5 Feb 2004	123 (±57)	10.1 (±3.8)	5.9 (±2.6)	3.1 (±1.6)
	6 Jan 2004	115 (±62)	9.7 (±4.1)	5.5 (±2.8)	2.9 (±1.7)
	5 Dec 2003	115 (±63)	9.5 (±4.2)	5.5 (±2.8)	2.9 (±1.7)

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: MDR, Caribbean Sea and Gulf ACE Index 2004					
		Tercile Probabilities			RPSS
		Below normal	Normal	Above normal	
Actual 2004		0	0	100	1
Climatology 1950-2003		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2004	1	11	88	0.96
	5 Jul 2004	5	28	67	0.72
	4 Jun 2004	8	37	55	0.48
	11 May 2004	5	24	71	0.78
	6 Apr 2004	7	21	72	0.81
	5 Mar 2004	10	23	67	0.74
	5 Feb 2004	5	17	78	0.88
	6 Jan 2004	9	20	71	0.80
	5 Dec 2003	9	20	71	0.80

The 2004 season was exceptionally active in the MDR, Caribbean Sea and Gulf of Mexico. The ACE index, at almost three times the long term average, was the highest on record and is the only year with an MDR ACE index greater than 200. Hurricane Ivan, which formed in the MDR, contributed an ACE index of 70, which is the highest ACE index from a single tropical cyclone recorded anywhere in the world to date. Almost all the ACE index from the 'MDR, Caribbean Sea and Gulf of Mexico' combined region came from the MDR. The Caribbean Sea

and Gulf of Mexico together contributed an ACE index of just 3.6 (the tenth lowest since 1950). The TSR forecasts correctly predicted the number of named storms but underpredicted the number of hurricanes, intense hurricanes and the ACE index. This large underprediction of the ACE index was due, in part, to the intense hurricanes having long westward tracks through the deep tropics, thereby maintaining hurricane intensity for a long time.

All probabilistic forecasts showed significant positive skill. The August forecast performed best overall and was close to perfect.

3. US Landfalling Hurricane Activity

(a) Deterministic Forecasts: US Landfalling Hurricane Activity 2004				
		US ACE Index	Named Tropical Storms	Hurricanes
Average Number (±SD) (1950-2003)		2.2 (±2.0)	3.0 (±1.9)	1.4 (±1.2)
Actual Number 2004		6.6	8	5
TSR Forecasts (±SD)	4 Aug 2004	3.1 (±1.4)	4.2 (±1.7)	2.0 (±0.9)
	5 Jul 2004	2.6 (±1.3)	3.6 (±1.7)	1.6 (±0.9)
	4 Jun 2004	2.4 (±1.2)	3.4 (±1.7)	1.5 (±0.9)
	11 May 2004	2.8 (±1.2)	3.8 (±1.7)	1.7 (±0.9)
	6 Apr 2004	3.0 (±1.3)	3.9 (±1.7)	1.8 (±1.0)
	5 Mar 2004	2.9 (±1.3)	3.8 (±1.7)	1.7 (±1.0)
	5 Feb 2004	3.3 (±1.3)	4.1 (±1.7)	1.9 (±0.9)
	6 Jan 2004	3.1 (±1.4)	3.9 (±1.9)	1.7 (±1.1)
	5 Dec 2003	3.1 (±1.4)	3.9 (±1.9)	1.7 (±1.1)

(b) Probabilistic Forecasts: US ACE Index 2004					
		Tercile Probabilities			RPSS
		Below normal	Normal	Above normal	
Actual 2004		0	0	100	1
Climatology 1950-2003		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2004	5	25	70	0.77
	5 Jul 2004	8	34	57	0.54
	4 Jun 2004	11	40	49	0.35
	11 May 2004	6	31	63	0.65
	6 Apr 2004	6	27	67	0.72
	5 Mar 2004	6	30	64	0.67
	5 Feb 2004	3	22	75	0.83
	6 Jan 2004	6	26	68	0.74
	5 Dec 2003	6	26	68	0.74

The 2004 season was a very active year with five hurricanes making US landfall. In addition,

hurricane Alex passed 10 miles from Cape Hatteras bringing hurricane force winds to the outer banks. The US ACE index of 6.6 is the eighth highest since 1900. Four hurricanes and one tropical storm affected Florida. The last time one state suffered so many hurricane landfalls was Texas in 1886. The TSR forecasts all predicted above average landfalling activity but underpredicted the magnitude by a factor of two. The February and August forecasts performed best overall.

All probabilistic forecasts showed significant positive skill. The August and February forecasts performed best overall, closely followed by the December and January forecasts.

4. Lesser Antilles Landfalling Numbers

Lesser Antilles Landfalling Hurricane Activity 2004					
		ACE Index ($x10^4 kts^2$)	Named Tropical Storms	Hurricanes	Intense Hurricanes
Average Number (±±SD) (1950-2003)		1.4 (±2.1)	1.1 (±1.0)	0.4 (±0.7)	0.2 (±0.5)
Actual Number 2004		2.5	2	1	1
TSR Forecasts (±SD)	4 Aug 2004	2.6 (±2.1)	1.8 (±0.8)	0.8 (±0.5)	0.4 (±0.4)
	5 Jul 2004	2.0 (±2.3)	1.5 (±1.0)	0.6 (±0.6)	0.3 (±0.4)
	4 Jun 2004	1.7 (±2.3)	1.4 (±1.0)	0.6 (±0.6)	0.3 (±0.4)
	11 May 2004	2.1 (±2.4)	1.6 (±1.0)	0.7 (±0.6)	0.3 (±0.4)
	6 Apr 2004	2.3 (±2.6)	1.6 (±1.1)	0.7 (±0.7)	0.4 (±0.4)
	5 Mar 2004	2.1 (±2.7)	1.6 (±1.1)	0.7 (±0.7)	0.4 (±0.4)
	5 Feb 2004	2.5 (±2.7)	1.7 (±1.1)	0.7 (±0.7)	0.4 (±0.4)
	6 Jan 2004	2.3 (±2.7)	1.7 (±1.1)	0.7 (±0.7)	0.4 (±0.4)
	5 Dec 2003	2.3 (±2.7)	1.7 (±1.1)	0.7 (±0.7)	0.4 (±0.4)

Two tropical storms and one hurricane made landfall in the Lesser Antilles. Hurricane Ivan made landfall in Grenada as a Category 3 hurricane causing great destruction. The TSR August forecast correctly predicted the number of tropical storms and hurricanes, but slightly overpredicted the ACE index. All forecasts, except those for intense hurricane strikes, were correct to within one standard error.

Environmental Factors in 2004

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 2004 trade wind speed over the Caribbean Sea and tropical North Atlantic, and the forecast August-September 2004 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 -6.4ms^{-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 2004			
		JAS CAR U (ms^{-1})	AS MDR SST (°°C)
Actual Value 2004 (1974-2003 Anomaly)		0.83	0.61
TSR Forecasts (±SD)	4 Aug 2004	0.73 (±0.44)	0.29 (±0.13)
	5 Jul 2004	0.25 (±0.45)	0.18 (±0.16)
	4 Jun 2004	0.16 (±0.45)	0.02 (±0.20)
	11 May 2004	0.35 (±0.55)	0.17 (±0.25)
	6 Apr 2004	0.48 (±0.72)	0.17 (±0.27)
	5 Mar 2004	0.39 (±0.78)	0.16 (±0.25)
	5 Feb 2004	0.60 (±0.76)	0.27 (±0.26)
	6 Jan 2004	0.50 (±0.85)	0.24 (±0.27)
	5 Dec 2003	0.49 (±0.86)	0.25 (±0.27)

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. However, the magnitude of the JAS trade wind speed anomaly was underpredicted in all forecasts. The magnitude of the MDR SST anomaly was even more underpredicted. The MDR SST anomaly warmed rapidly from early August and was the highest since 1950. If both the JAS CAR U and AS MDR SST predictors had been predicted perfectly the total ACE index would have been forecast to be 167. The remaining underprediction arises partly because the magnitude of the 2004 JAS CAR U anomaly (0.83 ms^{-1}) was lower than what would be expected historically for such a high total ACE index. The other two years with a total ACE index of over 200 (1950 and 1995) both had trade wind anomalies of at least 1 ms^{-1}.

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; Wilks 1995; Goddard et al 2003). Computation of *RPSS* begins with the rank probability score (RPS) which is defined as:

$$RPS = \sum_{m=1}^{N_{cat}} \left(CP_{F\,m} - CP_{O\,m} \right)^2$$

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

The total ACE (Accumulated Cyclone Energy) index is the sum of the squares of all 6-hourly maximum sustained wind speeds (in units of knots) for all North Atlantic systems while they are at least tropical storm in 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 in 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 in strength and within the boxed region (10°N-18°N, 60°W-63°W) (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 (1950-2003).
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).