Summary of 2010 Atlantic Tropical Cyclone Season and Verification of Authors' Seasonal Forecasts

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Summary

The 2010 North Atlantic hurricane season was remarkable. It was one of the most active seasons on record - experiencing even more storms than the NW Pacific in 2010 - but had little US landfalling activity. The TSR deterministic and probabilistic forecasts performed well for basin activity but overpredicted US landfalling activity. Basin activity was predicted to be in the top one-third of years to 62% probability in early December 2009 and to 96% certainty in early August 2010.

Tropical Storm Risk (TSR) presents a validation of their seasonal deterministic and probabilistic forecasts for North Atlantic tropical cyclone activity in 2010. These forecasts were issued on the 7th December 2009, 9th April 2010, 4th June 2010, 6th July 2010 and the 4th August 2010. 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 US landfalling outlook were skilful.

Features of the 2010 Atlantic Season

- One of the most active seasons since reliable records began in ~1950.
- Featured 19 tropical storms and 12 hurricanes (Figure 1). Only 2005 has seen more hurricanes (with 15) and only 2005 and 1933 have seen more tropical storms (with 28 and 21 respectively).
- No US landfalling hurricane. It is unprecedented for an Atlantic hurricane season with at least 10 hurricanes to have no hurricane strike on the US.
- Fifth year in a row with no major hurricane strike on the US. The only previous time this has happened was 1901-1905.
- Two hurricanes - Igor and Julia occurred simultaneously at Cat 4 intensity. This last happened in 1926.
- Hurricane Igor caused significant wind and flood damage on Newfoundland. 238 mm of rain fell on the Burin Peninsula making Igor the third wettest tropical cyclone to strike Canada.
- After two years without a hurricane landfall Mexico experienced two hurricanes strikes in 2010. Hurricane Alex was the strongest June hurricane to make landfall since Alma (1966) and caused US$ 1.5bn in total damage. Hurricane Karl struck in mid-September causing US$ 200 mn in total damage.

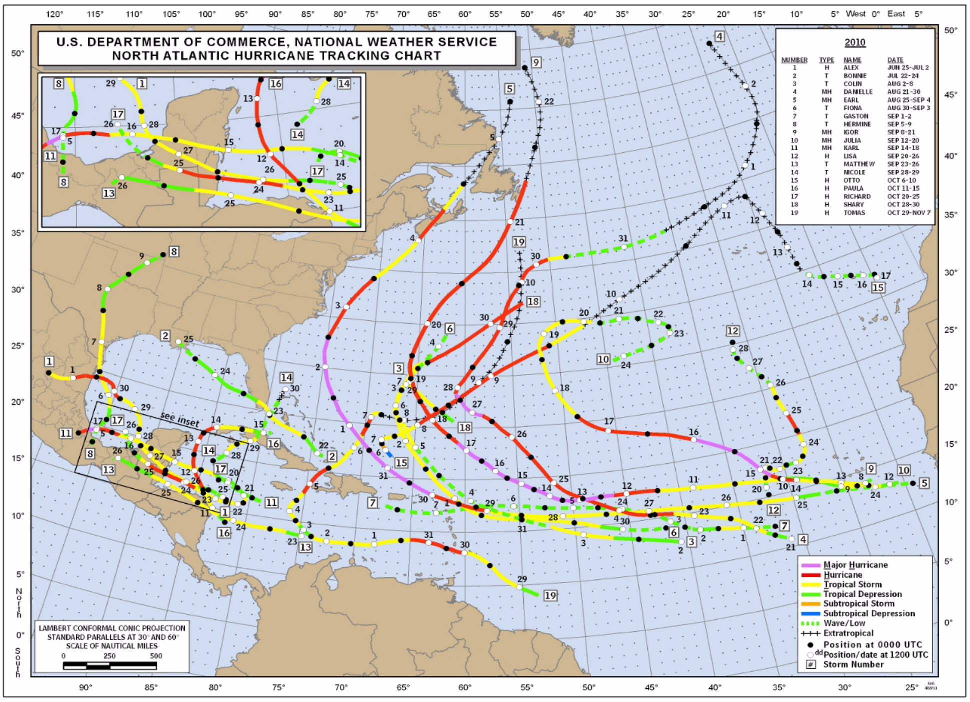

Figure 1. Tracks and intensities of North Atlantic named tropical storms in 2010. (Courtesy of U.S. Department of Commerce and National Weather Service).

Individual Storm and Loss Summary 2010							
No.	Name	Dates	Peak Wind (kts)	Minimum Pressure (mb)	Hurricane Category	Category at US Landfall	Estimated Insured Loss (US $ bn)
1	Alex	25 Jun-2 Jul	95	946	2	-	0.75
2	Bonnie	22-24 Jul	40	1005	-	TS	minimal
3	Colin	2-8 Aug	50	1005	-	-	-
4	Danielle	21-30 Aug	115	942	4	-	-
5	Earl	25 Aug-4 Sep	125	927	4	-	0.023
6	Fiona	30 Aug-3 Sep	50	998	-	-	-
7	Gaston	1-2 Sep	35	1005	-	-	-
8	Hermine	5-9 Sep	60	989	-	TS	0.12
9	Igor	8-21 Sep	135	924	4	-	0.1
10	Julia	12-20 Sep	120	948	4	-	-
11	Karl	14-18 Sep	110	956	3	-	0.1
12	Lisa	20-26 Sep	75	982	1	-	-
13	Matthew	23-26 Sep	50	998	-	-	unknown
14	Nicole	28-29 Sep	40	995	-	-	-
15	Otto	6-10 Oct	75	976	1	-	-
16	Paula	11-15 Oct	90	981	2	-	-
17	Richard	20-25 Oct	85	977	2	-	0.09
18	Sharry	28-30 Oct	65	989	1	-	-
19	Tomas	26 Oct-7 Nov	85	983	2	-	0.25

Verification of Forecasts

1. North Atlantic Hurricane Activity

(a) Deterministic Forecasts: North Atlantic Hurricane Activity 2010					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (±SD) (1950-2009)		101 (±60)	2.7 (±1.9)	6.1 (±2.6)	10.4 (±4.0)
Actual Number 2010		169	5	12	19
TSR Forecasts (±SD)	4 Aug 2010	183 (±39)	4.5 (±1.2)	9.7 (±1.7)	17.8 (±2.8)
	6 Jul 2010	203 (±45)	4.8 (±1.5)	10.4 (±2.2)	19.1 (±3.3)
	4 Jun 2010	182 (±48)	4.4 (±1.5)	9.5 (±2.5)	17.7 (±3.5)
	25 May 2010	-	4	8	16
	9 Apr 2010	159 (±58)	4.0 (±1.7)	8.5 (±2.8)	16.3 (±4.1)
	7 Dec 2009	135 (±59)	3.4 (±1.8)	7.4 (±3.1)	13.9 (±4.9)
Gray Forecasts	4 Aug 2010	185	5	10	18
	2 Jun 2010	185	5	10	18
	7 Apr 2010	150	4	8	15
	7 Dec 2009	100-162	3-5	6-8	11-16
NOAA Forecasts	5 Aug 2010	149-228	4-6	8-12	14-20
	27 May 2010	136-236	3-7	8-14	14-23
Met Office Forecast	17 Jun 2010	204 (±114)	-	-	20 (±7)

(b) Probabilistic Forecasts: North Atlantic ACE Index 2010					
		Tercile Probabilities			*RPSS*
		below normal	normal	above normal	
Actual 2010		0	0	100	1
Climatology 1950-2009		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2010	0	4	96	0.997
	6 Jul 2010	0	3	97	0.998
	4 Jun 2010	1	8	91	0.985
	25 May 2010	5	18	77	0.900
	9 Apr 2010	6	17	77	0.898
	7 Dec 2009	14	24	62	0.705
NOAA Forecasts	5 Aug 2010	0	10	90	0.982
	27 May 2010	5	10	85	0.955

The TSR forecasts correctly predicted an above-average season although the December forecast underpredicted the overall activity. Forecast performance was similar for all forecast agencies with the forecasts from June onwards slightly overpredicting total activity. This overprediction may have arisen because activity during the first half of August was unusually quiet. If this period had been more active then it is likely the forecasts from June onwards would have performed even better. The TSR probabilistic forecasts were all very skilful, as were the NOAA forecasts. The TSR July forecast performed best overall.

2. MDR, Caribbean and Gulf of Mexico Hurricane Activity

(a) Deterministic Forecasts: MDR, Caribbean and Gulf Hurricane Activity 2010		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (±SD) (1950-2009)		79 (±58)	2.4 (±1.8)	4.3 (±2.4)	7.1 (±3.3)
Actual Number 2010		160	5	10	16
TSR Forecasts (±SD)	4 Aug 2010	159 (±42)	4.2 (±1.1)	7.6 (±1.5)	12.8 (±2.4)
	6 Jul 2010	179 (±43)	4.5 (±1.3)	8.3 (±1.8)	14.1 (±2.4)
	4 Jun 2010	157 (±45)	4.1 (±1.3)	7.4 (±2.0)	12.7 (±2.6)
	9 Apr 2010	134 (±54)	3.7 (±1.5)	6.4 (±2.4)	11.3 (±3.3)
	7 Dec 2009	110 (±55)	3.1 (±1.6)	5.3 (±2.6)	9.1 (±3.9)

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 2010		Tercile Probabilities			*RPSS*
		below normal	normal	above normal	
Actual 2010		0	0	100	1
Climatology 1950-2009		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2010	0	6	94	0.994
	6 Jul 2010	0	2	98	0.999
	4 Jun 2010	1	6	93	0.991
	9 Apr 2010	5	17	78	0.900
	7 Dec 2009	11	26	63	0.732

The MDR, Caribbean and Gulf in 2010 was very active with activity double the long term climate norm. The MDR had its highest ACE index since 2004, and its sixth highest ACE index since 1950. The TSR deterministic forecasts correctly predicted the high activity from early December with the June and August forecasts predicting an ACE index withn three units of the observed ACE. Tropical storm and hurricane numbers were underpredicted at all lead times, with the July forecast performing best for these parameters. The August forecast performed best for the ACE index. The probabilistic forecasts were all very skilful with the July probabilistic forecast almost perfect.

3. US Landfalling Hurricane Activity

a) Deterministic Forecasts

US Landfalling Hurricane Activity 2010					
		US ACE Index ($x10^4kts^2$)	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2009)		2.5 (±2.2)	1.5 (±1.3)	3.2 (±2.0)
Actual Number 2010		0.6	0	2
TSR Forecasts (±SD)	4 Aug 2010	4.6 (±1.6)	2.6 (±1.4)	5.7 (±1.9)
	6 Jul 2010	5.4 (±1.9)	2.8 (±1.4)	6.2 (±2.0)
	4 Jun 2010	4.8 (±2.0)	2.5 (±1.5)	5.7 (±2.0)
	25 May 2010	-	2	5
	9 Apr 2010	4.1 (±2.1)	2.3 (±1.5)	5.1 (±2.1)
	7 Dec 2009	3.5 (±2.1)	1.9 (±1.5)	4.4 (±2.2)

b) Probabilistic Forecasts

US ACE Index 2010					
		Tercile Probabilities			*RPSS*
		below normal	normal	above normal	
Actual 2010		100	0	0	1
Climatology 1950-2009		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2010	1	10	89	-2.19
	6 Jul 2010	1	7	92	-2.29
	4 Jun 2010	3	12	85	-1.99
	25 May 2010	7	19	74	-1.54
	9 Apr 2010	6	18	76	-1.63
	7 Dec 2009	12	24	64	-1.13

No hurricanes made landfall in the US in 2010. Historically no year with at least 10 hurricanes has had no US landfalling hurricanes. None of the TSR forecasts anticipated such a quiet year for US landfalling hurricanes and thus showed no skill. The lack of US hurricane landfalls was likely caused by an anomalous trough over the US East coast during August and September (Figure 2(b)), which acted to steer Atlantic hurricanes away from the US East coast. In contrast, during July, an anomalous ridge was present over the US East coast (Figure 2(a)), which, had it persisted, through August-September, would have favoured high US landfalling activity. This sudden change in the sign of mid-level geopotential height anomalies between July and August-September is why the early August forecast (which relies on the persistence of July steering winds over the Atlantic as a predictor (Saunders and Lea (2005)) failed to predict the observed extremely low US landfalling activity.

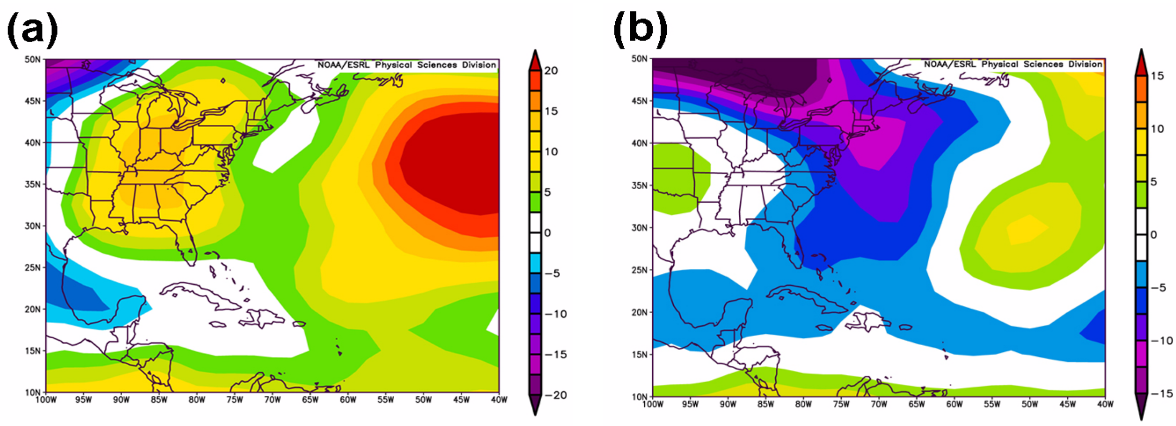

Figure 2. 700mb geopotential height anomalies (based on 1968-1996 climate norm); (a) in July 2010; (b) in August-September 2010. Note the anomalously high geopotential height (ridging) over the US East Coast during July was replaced by an anomalously low geopotential height (troughing) during August-September.

4. Lesser Antilles Landfalling Numbers

Lesser Antilles Landfalling Hurricane Activity 2010					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2009)		1.4 (±2.0)	0.2 (±0.5)	0.5 (±0.7)	1.1 (±1.0)
Actual Number 2010		3.3	0	2	2
TSR Forecasts (±SD)	4 Aug 2010	2.7 (±1.7)	0.4 (±0.4)	0.8 (±0.5)	1.8 (±0.8)
	6 Jul 2010	3.0 (±1.8)	0.4 (±0.4)	0.9 (±0.5)	2.0 (±0.9)
	4 Jun 2010	2.7 (±1.8)	0.4 (±0.4)	0.8 (±0.5)	1.8 (±0.9)
	9 Apr 2010	1.9 (±2.4)	0.3 (±0.4)	0.7 (±0.6)	1.5 (±1.1)
	7 Dec 2009	2.2 (±2.4)	0.4 (±0.4)	0.7 (±0.6)	1.6 (±1.0)

The Lesser Antilles experienced 2010 landfalling activity approximately double the 1950-2009 climate norm. This is the highest Lesser Antilles landfalling activity since 1999. The TSR forecasts correctly predicted above-norm landfalling activity at all lead times but underpredicted the magnitude. The July forecast performed best overall.

Environmental Factors in 2010

1. Contemporaneous Influences

Without doubt the high North Atlantic hurricane activity in 2010 is linked to one of the strongest La Niña events on record and to exceptionally warm August-September MDR SSTs. La Niña began in May 2010 and persisted and intensified throughout the 2010 hurricane season. The Aug-Sep MDR SSTs were the warmest on record in 2010.

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) 2010 trade wind speed, u_T, over the Caribbean Sea and tropical North Atlantic, and the forecast August-September (AS) 2010 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 -6.4ms^{-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 2010			
		JAS u_T (ms^{-1})	AS MDR SST (°C)
Actual Value 2010 (1980-2009 Anomaly)		2.88*	0.78
TSR Forecasts (±SD)	4 Aug 2010	1.35 (±0.49)*	0.63 (±0.13)
	6 Jul 2010	1.63 (±0.59)	0.71 (±0.17)
	4 Jun 2010	1.21 (±0.64)	0.61 (±0.23)
	9 Apr 2010	0.81 (±0.79)	0.42 (±0.27)
	7 Dec 2009	0.40 (±0.74)	0.20 (±0.29)

* JAS u_T region was changed from 7.5°-17.5°N, 100°-30°W to 7.5°-17.5°N, 85°W-45°W in the August forecast because it was judged that the forecast u_T anomaly for the former region (which is based on observed July u_T) was too high due to extreme westerly anomalies present in the region from 100°W-85°W heavily biasing the forecast. The observed value for JAS 7.5°-17.5°N, 85°W-45°W region was 1.90 ms^{-1}).

All the TSR forecasts for u_T and MDR SST showed positive skill and anticipated the correct anomaly sign. The observed AS MDR SST anomaly and JAS trade wind anomaly were the highest since reliable records began in 1950. The early July forecast proved the most skillful for both predictors. Although forecasts underpredicted the magnitude of the trade wind anomaly, the total Atlantic hurricane activity was below what would be expected for such high positive trade wind and SST anomalies. This resulted in the total Atlantic hurricane activity predictions performing very well. One reason for total hurricane activity being less than suggested by the observed magnitude of the trade wind predictor is that hurricane activity during the first half of August was very low, due to a combination of dry air, reduced vertical instability and increased vertical wind shear caused by upper level lows.

Definitions and Verification Data

The verification is made using best 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:

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

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^{o}N-18^{o}N,60^{o}W-63^{o}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.
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 (1950-2009).

Forecasts for 2011

TSR outlooks for 2011 North Atlantic hurricane activity are being issued on the 6th December 2010, 4th April 2011, 24th May 2011, 6th June 2011, 5th July 2011 and 4th August 2011.

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Tropical Storm Risk.com (TSR)

Tropical Storm Risk (TSR) offers a leading resource for predicting and mapping tropical storm activity worldwide. The public TSR website provides forecasts and information to benefit basic risk awareness and decision making from tropical storms. The new TSR Business service and web site offers real-time products of unrivalled accuracy for the detailed mapping and prediction of tropical storm windfields worldwide. The TSR consortium is co-sponsored by Aon Benfield, the leading reinsurance intermediary and capital advisor, RSA Insurance Group, the global insurance group, and Crawford & Company, a global claims management solutions company.

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