Summary of 2011 Atlantic Tropical Cyclone Season and Verification of Authors' Seasonal Forecasts

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Summary

The 2011 North Atlantic hurricane season was unusual in having the equal third-highest number of tropical storms on record yet in having hurricane numbers and an ACE index that were only slightly above-average. The most notable event of the season was hurricane Irene which struck the Bahamas followed by impacts on a large swathe of the US East Coast causing a total insured loss close to US$ 4bn. Irene was the first hurricane to strike the US in three years. The TSR deterministic and probabilistic forecasts performed well for basin activity but overpredicted US landfalling activity.

Tropical Storm Risk (TSR) presents a validation of their seasonal deterministic and probabilistic forecasts for North Atlantic tropical cyclone activity in 2011. These forecasts were issued on the 6th December 2010, 4th April 2011, 23rd May 2011, 6th June 2011, 4th July 2011 and the 4th August 2011. 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 2011 Atlantic Season

- Featured 19 tropical storms, 7 hurricanes and 3 intense hurricanes (Figure 1). Only 1933 and 2005 recorded more tropical storms (with 21 and 28 respectively) than 2011. It is likely that some of the weaker and more short-lived 2011 tropical storms would not have been documented prior to the start of satellite monitoring that began in the mid 1960's.
- Hurricane Irene became the first hurricane since Ike (2008) to strike the US. If Irene had not struck the US in 2011 the three-year period 2009-2011 would have become the first three-year period on record without a single US hurricane strike. Irene made landfall on the Outer Banks of North Carolina on the 27th August with 1-minute sustained winds of 75 kts (85 mph) followed by a second landfall at Little Egg Inlet, New Jersey with 1-minute sustained winds of 60 kts (70 mph). The US insured damage bill from Irene is estimated at US $3.5 bn. Before striking the US Irene impacted the Bahamas with 1-minute sustained winds of 105 kts (120 mph) causing US $200-400 mn in insured loss.
- The US has now had six consecutive years (2006-2011) without an intense hurricane landfall. This breaks the previous longest sequence of 5 years with no US intense hurricane landfall set in 1900-1905.

- Eight consecutive tropical storms formed before the first hurricane, Irene, developed. This broke the previous longest opening sequence of six consecutive tropical storms prior to a hurricane development set in 2002.

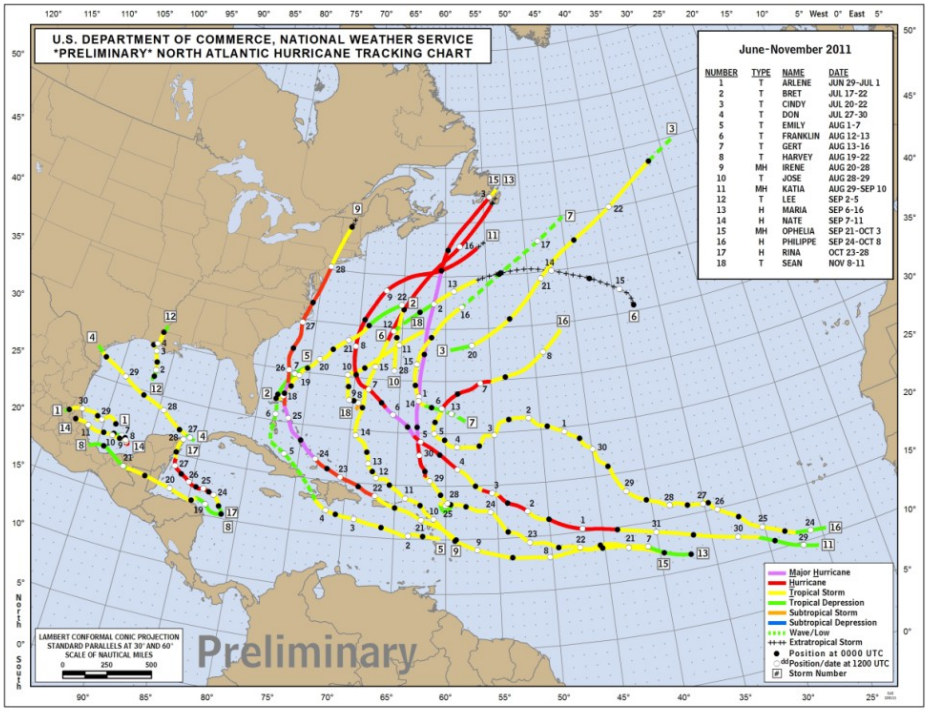

Figure 1. Tracks and intensities of North Atlantic named tropical storms in 2011. The map is preliminary based on end-of-season data and may be updated (Courtesy of U.S. Department of Commerce and National Weather Service).

Individual Storm and Loss Summary 2011

No.	Name	Dates	Peak 1-min Sustained Wind (kts)	Minimum Pressure (mb)	Hurricane Category	Category at US Landfall	Estimated US Insured Loss (US $bn)
1	Arlene	28 Jun-1 Jul	55	993	-	-	-
2	Bret	17-22 Jul	55	996	-	-	-
3	Cindy	20-22 Jul	60	994	-	-	-
4	Don	27-30 Jul	45	997	-	-	-
5	Emily	1-7 Aug	45	1003	-	-	-
6	Franklin	12-13 Aug	40	1004	-	-	-
7	Gert	13-16 Aug	55	1000	-	-	-
8	Harvey	19-22 Aug	55	994	-	-	-
9	Irene	20-29 Aug	105	942	3	1	3.5*
10	Jose	28-29 Aug	40	1007	-	-	-
11	Katia	29 Aug-10 Sep	115	946	4	-	-
12	Unnamed	1-2 Sep	40	1002	-	-	-
13	Lee	2-5 Sep	50	986	-	TS	0.315*
14	Maria	6-16 Sep	70	979	1	-	-
15	Nate	7-11 Sep	65	994	1	-	-
16	Ophelia	20 Sep-3 Oct	120	940	4	-	-
17	Philippe	24 Sep-8 Oct	80	976	1	-	-
18	Rina	23-28 Oct	95	966	2	-	-
19	Sean	8-11 Nov	55	983	-	-	-

*National Hurricane Center tropical cyclone reports

Verification of Forecasts

1. North Atlantic Hurricane Activity

a) Deterministic Forecasts

North Atlantic Hurricane Activity 2011					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (±SD) (1950-2010)		102 (±60)	2.7 (±1.9)	6.2 (±2.7)	10.5 (±4.2)
Actual Number 2011		123	3	7	19
TSR Forecasts (±SD)	4 Aug 2011	146 (±39)	4.2 (±1.2)	8.5 (±1.7)	16.1 (±2.8)
	4 Jul 2011	127 (±45)	3.6 (±1.5)	7.8 (±2.2)	14.4 (±3.3)
	6 Jun 2011	123 (±48)	3.5 (±1.5)	7.6 (±2.4)	14.1 (±3.4)
	23 May 2011	124 (±52)	3.6 (±1.5)	7.6 (±2.7)	14.2 (±3.7)
	4 Apr 2011	124 (±56)	3.6 (±1.6)	7.5 (±2.8)	14.2 (±3.9)
	6 Dec 2010	141 (±58)	4.0 (±1.7)	8.4 (±3.0)	15.6 (±4.3)
CSU Forecasts	3 Aug 2011	160	5	9	16
	1 Jun 2011	160	5	9	16
	6 Apr 2011	160	5	9	16
	8 Dec 2010	165	5	9	17
NOAA Forecasts	4 Aug 2011	126-200	3-5	7-10	14-19
	19 May 2011	96-186	3-6	6-10	12-18
Met Office Forecast	26 May 2011	151 (±61)	-	-	13 (±4)

b) Probabilistic Forecasts

North Atlantic ACE Index 2011					
		Tercile Probabilities			*RPSS*
		below normal	normal	above normal	
Actual 2011		0	0	100	1
Climatology 1950-2010		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2011	3	20	77	0.90
	4 Jul 2011	10	31	59	0.68
	6 Jun 2011	14	31	55	0.40
	23 May 2011	16	29	55	0.59
	4 Apr 2011	17	28	55	0.59
	6 Dec 2010	12	22	66	0.77
NOAA Forecasts	4 Aug 2011	0	15	85	0.96
	19 May 2011	10	25	65	0.76

The TSR deterministic forecasts performed very well. In general they outperformed forecasts from other agencies for all parameters except tropical storm numbers. The June TSR forecast correctly predicted the ACE index and the April, May and July TSR forecasts were correct to within five ACE units. Hurricane and intense hurricane numbers were well forecast but tropical storm

numbers were under-predicted. The under-prediction of tropical storm numbers was due to a high number of weak, short lived storms which developed in the sub-tropics. The TSR tercile probabilistic forecasts were all skilful, as were the NOAA forecasts, which slightly outperformed the TSR forecasts. The TSR June forecast performed best overall.

2. MDR, Caribbean and Gulf of Mexico Hurricane Activity

a) Deterministic Forecasts

MDR, Caribbean and Gulf Hurricane Activity 2011					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (±SD) (1950-2010)		80 (±59)	2.4 (±1.8)	4.4 (±2.5)	7.3 (±3.5)
Actual Number 2011		110	3	7	12
TSR Forecasts (±SD)	4 Aug 2011	122 (±42)	3.9 (±1.1)	6.4 (±1.5)	11.2 (±2.4)
	4 Jul 2011	103 (±43)	3.3 (±1.3)	5.7 (±1.8)	9.5 (±2.4)
	6 Jun 2011	99 (±45)	3.2 (±1.3)	5.5 (±2.0)	9.2 (±2.7)
	23 May 2011	100 (±49)	3.3 (±1.4)	5.5 (±2.2)	9.3 (±3.1)
	4 Apr 2011	100 (±53)	3.3 (±1.5)	5.4 (±2.4)	9.3 (±3.3)
	6 Dec 2010	117 (±55)	3.7 (±1.5)	6.3 (±2.6)	10.7(±3.7)

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 and Gulf ACE Index 2011					
		Tercile Probabilities			*RPSS*
		below normal	normal	above normal	
Actual 2011		0	0	100	1
Climatology 1950-2010		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2011	3	21	76	0.90
	4 Jul 2011	8	32	60	0.70
	6 Jun 2011	10	34	56	0.63
	23 May 2011	12	31	57	0.64
	4 Apr 2011	14	30	56	0.62
	6 Dec 2010	10	23	67	0.79

The MDR, Caribbean and Gulf registered an ACE index nearly 40% above the long term climate norm in 2011. The TSR deterministic forecasts performed well with all ACE predictions within 11% of the observed ACE index. Tropical storm and hurricane numbers were under-predicted at all lead times, with the August forecast performing best for these parameters. Intense hurricane numbers were correctly predicted at all lead times except December and August which slightly

over-predicted intense hurricane numbers. The probabilistic forecasts were all skilful with the August probabilistic forecast the most skilful.

3. US Landfalling Hurricane Activity

a) Deterministic Forecasts

US Landfalling Hurricane Activity 2011				
		US ACE Index ($x10^4 kts^2$)	Hurricanes	Named Tropical Storms
Average Number (±SD) (1950-2010)		2.4 (±2.2)	1.5 (±1.3)	3.1 (±2.0)
Actual Number 2011		1.61	1	2
TSR Forecasts (±SD)	4 Aug 2011	3.4 (±1.8)	2.2 (±1.5)	5.2 (±2.1)
	4 Jul 2011	3.2 (±2.1)	1.9 (±1.5)	4.4 (±2.2)
	6 Jun 2011	3.1 (±2.1)	1.9 (±1.5)	4.3 (±2.2)
	23 May 2011	3.1 (±2.1)	1.9 (±1.5)	4.4 (±2.1)
	4 Apr 2011	3.1 (±2.1)	1.9 (±1.5)	4.4 (±2.2)
	6 Dec 2010	3.6 (±2.1)	2.1 (±1.6)	4.9 (±2.2)

b) Probabilistic Forecasts

US ACE Index 2011					
		Tercile Probabilities			*RPSS*
		below normal	normal	above normal	
Actual 2011		0	100	0	1
Climatology 1950-2010		33.3	33.3	33.3	0
TSR Forecasts	4 Aug 2011	8	25	67	-1.09
	4 Jul 2011	14	26	60	-0.74
	6 Jun 2011	16	26	58	-0.66
	23 May 2011	15	26	59	-0.70
	4 Apr 2011	15	26	59	-0.70
	6 Dec 2010	11	22	67	-1.12

Just one hurricane and two tropical storms made US landfall in 2011. 2011 is the third consecutive year that landfalling storm and hurricane numbers have been below the 1950-2010 climate norm. All forecasts over-predicted US landfalling with the probabilistic forecasts showing no skill. The lack of skill in the US landfall forecasts is because these forecasts, with the exception of the August forecast, are generated by thinning from the total basin activity, and high basin activity this year did not translate into high US landfalling activity. The failure of the August forecast is, like in 2010, due to a lack of persistence between July and Aug-Sep steering winds (Figure 2).

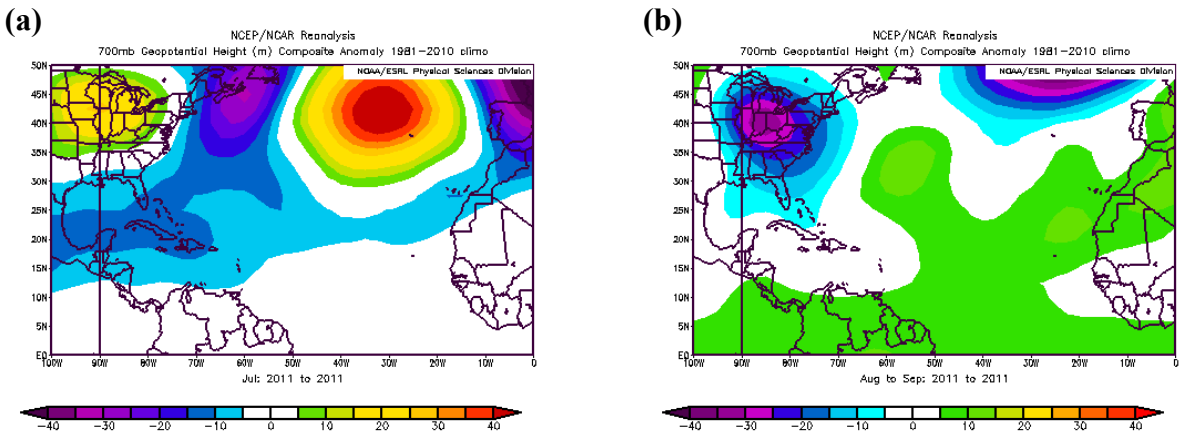

Figure 2. 700mb geopotential height anomalies for (a) July 2011 and (b) August-September 2011 over the North Atlantic. The geopotential height pattern reverses between July and August-September.

4. Lesser Antilles Landfalling Numbers

Lesser Antilles Landfalling Hurricane Activity 2011					
		ACE Index ($x10^4 kts^2$)	Intense Hurricanes	Hurricanes	Tropical Storms
Average Number (±SD) (1950-2010)		1.4 (±2.0)	0.2 (±0.5)	0.5 (±0.7)	1.1 (±1.0)
Actual Number 2011		0.37	0	0	2
TSR Forecasts	4 Aug 2011	2.1 (±1.7)	0.3 (±0.4)	0.7 (±0.5)	1.5 (±0.8)
	4 Jul 2011	1.8 (±1.8)	0.3 (±0.4)	0.6 (±0.6)	1.4 (±0.8)
	6 Jun 2011	1.7 (±1.8)	0.3 (±0.4)	0.6 (±0.6)	1.3 (±0.8)
	23 May 2011	1.7 (±1.9)	0.3 (±0.4)	0.6 (±0.6)	1.3 (±0.9)
	4 Apr 2011	1.7 (±2.0)	0.3 (±0.4)	0.6 (±0.6)	1.3 (±0.9)
	6 Dec 2010	2.0 (±2.0)	0.3 (±0.4)	0.7 (±0.6)	1.5 (±0.9)

The Lesser Antilles was fortunate in 2011 in experiencing no hurricane landfalls. Two weak tropical storms (Irene and Maria) affected the islands but the ACE index was well below-norm. The TSR forecasts over-predicted Lesser-Antiles landfalling hurricane numbers and the ACE index but slightly under-predicted tropical storm landfalling numbers. The over-prediction of the ACE index was due to the majority of storms forming in the MDR tracking west-northwest and missing the islands to the north.

Environmental Factors in 2011

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) 2010 trade wind speed, u_T, over the Caribbean Sea and tropical North Atlantic, and the forecast August-September (AS) 2011 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, 45°W-85°W] (JAS u_T).
2. Aug-Sep SSTs in the Main Development Region [10°N-20°N, 20°W-60°W] (AS MDR SST).

The 1981-2010 climatology for JAS u_T is -5.6ms^{-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 2011			
		JAS u_T (ms^{-1})	AS MDR SST (°C)
Actual Value 2011 (1981-2010 Anomaly)		1.31	0.24
TSR Forecasts (±SD)	4 Aug 2011	1.07 (±0.48)	0.22 (±0.16)
	4 Jul 2011	0.25 (±0.61)	0.20 (±0.17)
	6 Jun 2011	0.14 (±0.67)	0.12 (±0.23)
	23 May 2011	0.19 (±0.80)	0.11 (±0.26)
	4 Apr 2011	0.20 (±0.83)	0.08 (±0.27)
	6 Dec 2010	0.70 (±0.83)	0.27 (±0.29)

All the TSR forecasts for u_T and MDR SST showed positive skill and anticipated the correct anomaly sign. The early August forecast proved the most skilful for both predictors. Although forecasts under-predicted 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. A factor suppressing the favourable trade wind and SST influences leading to storms being short-lived and weaker than one would otherwise expect was vertical instability. Vertical instability refers to the ability of an air mass to undergo vertical motion. Thunderstorms – the seeds of tropical storms – occur more readily when vertical instability is higher than normal. Throughout the 2011 hurricane season vertical instability was persistently below normal over the tropical North Atlantic, Caribbean Sea and Gulf of Mexico (see Figure 3).

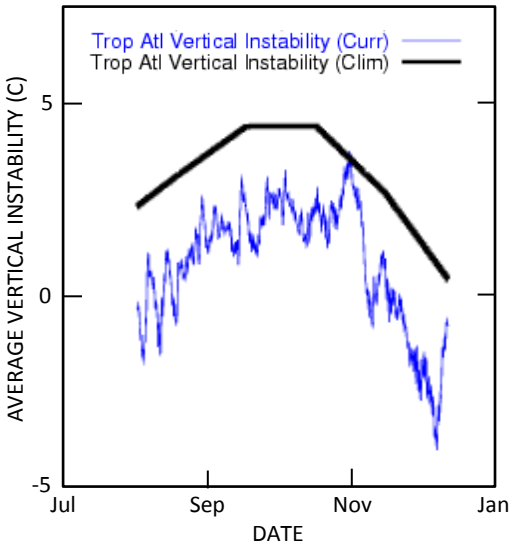

Figure 3. Vertical instability over the tropical North Atlantic during 2011 compared to climatology (Image courtesy of NOAA).

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:

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

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 (1950-2010).

Forecasts for 2012

TSR outlooks for 2012 North Atlantic hurricane activity are being issued on the 7th December 2011, 5th April 2012, 25th May 2012, 5th June 2012, 5th July 2012 and 6th August 2012.

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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.