RMS WHITE PAPER

2013 ATLANTIC HURRICANE SEASON OUTLOOK

June 2013 - RMS Cat Response

Season Outlook

At the start of the 2013 Atlantic hurricane season, which officially runs from June 1 to November 30, seasonal forecasts are calling for an above-average hurricane season in terms of the number of tropical storms, hurricanes, and major hurricanes[1] expected in the Atlantic Basin compared to the 1950-2012 average of 11.2 tropical storms, 6.3 hurricanes, and 2.7 major hurricanes.[2,3] For example, the Colorado State University (CSU) forecast calls for 18 tropical storms, 9 hurricanes, and 4 major hurricanes. The majority of forecasts indicate however, that the number of tropical storms and hurricanes is on par with the more recent period of heightened activity since 1995, which has seen an average of 15.2 tropical storms and 8 hurricanes. The number of major hurricanes forecast is, however, notably above both the 1950-2012 average of 2.7 and the 1995-2012 average of 3.7.

The seasonal forecasts therefore indicate the potential for an active Atlantic Basin hurricane season, although it is important to note that high activity does not necessarily translate to an increase in the number of landfalls.[4]

Seasonal Forecasts

The most recent 2013 seasonal forecasts, including those from the three main forecasting groups: Colorado State University (CSU), National Oceanic and Atmospheric Administration Climate Prediction Center (NOAA CPC), and Tropical Storm Risk (TSR), are shown in Table 1.

Table 1: Summary of the 2013 Atlantic Basin seasonal forecasts, average seasonal activity, and 2012 season storm totals

Forecast Group	Date Issued	Tropical Storms	Hurricanes	Major Hurricanes	ACE Index (10^4kt^2)
CSU*	June 2013	18 (14.3-21.7)	9 (6.9-11.1)	4 (2.4-5.6)	165 (117-213)
NOAA CPC**	May 2013	13-20	7-11	3-6	-
TSR	May 2013	15.3 (±3.9)	7.5 (±2.7)	3.4 (±1.5)	130 (±51)
FSU COAPS**	May 2013	15 (12-17)	8 (5-10)	-	135
U.K. Met Office**	May 2013	14 (10-18)	9 (4-14)	-	130 (76-184)
Penn State University	May 2013	16 (+/- 4)	-	-	-
WSI	April 2013	16	9	5	-
Accuweather	April 2013	16	8	4	-
1900 – 2012 Average[5]	-	10.0	5.5	2.3	91.6
1950 – 2012 Average	-	11.2	6.3	2.7	102.9
1995 – 2012 Average	-	15.2	8	3.7	138.1
2012	-	19	10	2	128

* CSU forecast ranges have a 67% probability of occurrence; ** Forecast ranges have a 70% probability of occurrence.

[1] Category 3 or higher on the Saffir-Simpson Hurricane Wind Scale.
[2] The historical database for landfalling hurricanes is generally agreed to be complete since 1900. However, the record of hurricane activity in the Atlantic Basin itself is generally agreed to be complete only from 1950 onward, due to the onset of satellite technology.
[3] 1950–2012 and 1995-2012 hurricane averages from HURDAT http://www.aoml.noaa.gov/hrd/hurdat.
[4] Wang, C., H. Liu, S-K. Lee, and Atlas, R., (2011), Impact of the Atlantic warm pool on United States landfalling hurricanes, Geophys. Res. Lett., 38,
[5] 1900-2012 hurricane average from HURDAT http://www.aoml.noaa.gov/hrd/hurdat.

The groups' most recent forecasts predict tropical storm figures similar to the 1995-2012 average of 15.2, but above the 1950-2012 average of 11.2. Compared to the preceding 2012 Atlantic hurricane season, which closed with 19 tropical storms and 10 hurricanes, forecasters are calling for lower numbers of tropical storms and hurricanes. However, forecasters are calling for more major hurricanes to develop this season, which is in contrast to 2012, which saw just 2 major hurricanes.[6]

The forecast groups are also calling for accumulated cyclone energy (ACE)[7] values above the 1950-2012 average of 102.9, suggesting that we can expect strong, long-lived storms, which is also reflected by the high major hurricane forecast figures.

Although forecast groups expect an active season, an increased number of storms in the Atlantic Basin does not always translate to a higher probability of landfalling storms in the U.S.. Complex factors control the development and steering of storms in the basin. As an example, research suggests that during periods of high sea surface temperatures (SSTs) in the Atlantic Basin, storms have a tendency to form farther east in the Atlantic, reducing the possibility for a hurricane to make landfall in the U.S.[4]

Key Drivers of the Seasonal Forecasts

The 2013 forecasts anticipate an above-average season in the Atlantic Basin in relation to the 1950-2012 average due to a combination of interrelated atmospheric and oceanic conditions that have contributed to high hurricane activity in the basin since 1995,[8,9] including:

1. Above-average sea surface temperatures (SSTs) observed in the Atlantic Main Development Region (MDR[10]) during the first half of 2013 and the expected continuation of above-average SSTs throughout the 2013 season.
2. The expected continuation of neutral El Niño-Southern Oscillation (ENSO) conditions through the Atlantic hurricane season, notably during the August to October peak, with a low likelihood of El Niño, which typically suppresses hurricane activity in the Atlantic Basin.

Role of the Atmosphere and Ocean in the 2013 Atlantic Hurricane Season

Sea Surface Temperatures

Warm Atlantic SSTs in combination with low levels of wind shear are essential for hurricane formation and development. SSTs higher than 80°F (26.5°C)[11] are required for hurricane development and for sustained hurricane activity. Since early spring 2013, CSU has reported significant anomalous warming across the tropical Atlantic, with the eastern tropical Atlantic exhibiting significantly above-average temperatures. Forecast groups have attributed this anomalous warming to a negative phase of the North Atlantic Oscillation (NAO) which is associated with weakened Atlantic subtropical high pressure and anomalously

[6] Hurricane Sandy was upgraded to major hurricane status in a post-season storm analysis in February 2013.
[7] ACE is calculated as the square of the sum of the maximum sustained wind speed (in knots) at 6-hour intervals for the duration of the storm at tropical storm status or greater (sustained wind speeds of 35 knots or higher).
[8] Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nuñez, and W. M. Gray, 2001: The recent increase in Atlantic hurricane activity: Causes and implications. Science, 293, 474-479
[9] Bell, G. D., and M. Chelliah, 2006: Leading tropical modes associated with interannual and multi-decadal fluctuations in North Atlantic hurricane activity. J. of Climate. 19, 590-612
[10] The Main Development Region spans the tropical Atlantic Ocean and the Caribbean Sea between 10-20°N, 20-70°W
[11] As indicated by NOAA Hurricane Research Division http://www.aoml.noaa.gov/hrd/tcfaq/A15.html

weak trade winds across the MDR. Weak trade winds can result in a reduction of ocean mixing (with deeper colder water), causing an anomalous warming of SSTs.

Figure 1: April to May 2013 SST anomalies (°C) in the tropical Atlantic (against 1981 to 2010 climatology)[12]

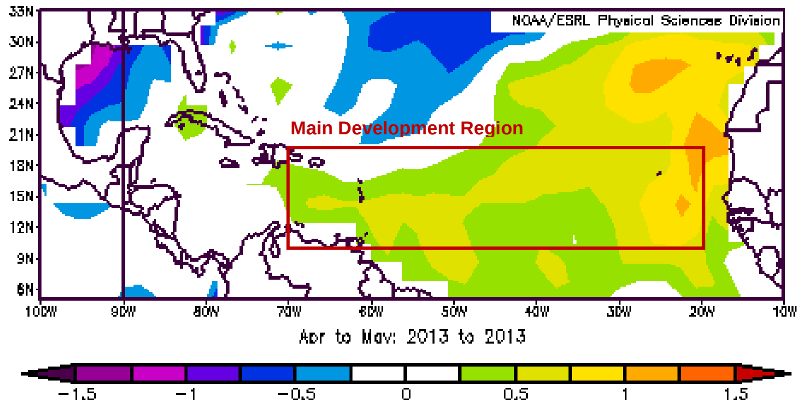
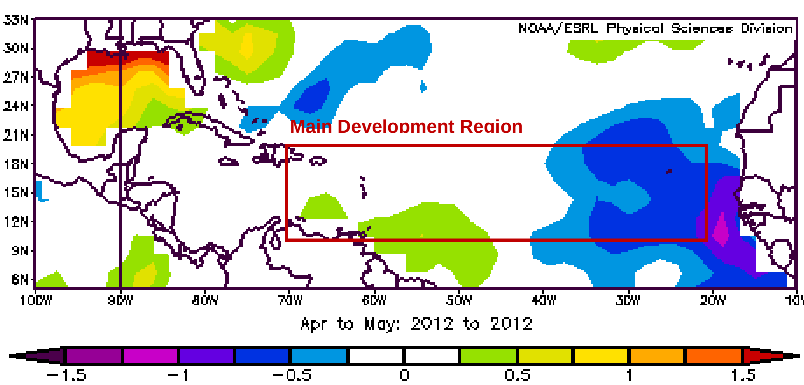


Figure 1 shows the SST anomalies (°C) for April to May 2013, highlighting regions where SSTs deviate from the 1981 to 2010 climatological base period. The figure illustrates that SSTs measured over the entire MDR were around 0.5°C above average, with temperatures in the eastern MDR reaching around 1°C above average. Conversely, SSTs in the far northern Gulf of Mexico and along the U.S. Atlantic Coast fall slightly below the 1981 to 2010 climatological average.

For comparison, April to May 2012 SSTs were around average in the central and western waters of the Atlantic MDR, and slightly below average in the eastern waters, with a pool of noticeably (1.35°F/0.75°C below average) cool water in the extreme eastern region (Figure 2). Conversely, temperatures in the Gulf of Mexico were abnormally warm in 2012. Across the MDR, April and May 2013 SSTs were much higher than in 2012.

Figure 2: April to May 2012 SST anomalies (°C) in the tropical Atlantic (against 1981 to 2010 climatology) [11]



[12] Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado http://www.esrl.noaa.gov/psd/. Data provided by Kalnay et al., (2006). Red box denotes the main development region

A continuation of above-average SSTs in the tropical Atlantic is forecast through the season, which is anticipated to have an enhancing effect on Atlantic Basin hurricane activity in 2013. Model forecasts of Atlantic SSTs from organizations such as the National Center for Environmental Prediction Coupled Forecast System (NCEP CFS), the European Center for Medium-Range Weather Forecasts (ECMWF), and the International Research Institute for Climate and Society (IRI), are predicting above-average temperatures across the tropical Atlantic through the 2013 hurricane season. There is, however, uncertainty associated with predicting SSTs at this lead time, though an active season appears likely.

The El Niño-Southern Oscillation (ENSO) and Atlantic Wind Shear

The El Niño-Southern Oscillation (ENSO) is a climate fluctuation over the tropical Pacific Ocean that transitions from a warm phase (El Niño) to a cold phase (La Niña) over a 3–7 year cycle. ENSO can cause large inter-annual fluctuations in Atlantic hurricane activity through its impacts on the upper level atmospheric circulation and vertical wind shear in the Atlantic MDR.[13] El Niño episodes are associated with strong vertical wind shear across the tropical Atlantic, creating conditions that inhibit hurricane activity by spreading the latent heat needed for hurricane development. The reverse is true for La Niña.

The Niño3.4 index, which indicates the departure in monthly SSTs from the long-term mean averaged over the Niño3.4 region (5–5°S, 170–120°W), is commonly used to define an El Niño, or La Niña event. We have been experiencing ENSO-neutral conditions since October 2012 and we are currently (as of June 2013) in an ENSO-neutral phase.

Figure 3 shows the mid-May ENSO forecasts from various dynamical and statistical models of the likely progression of the Nino3.4 SST anomaly throughout the Atlantic hurricane season, provided by the International Research for Climate and Society (IRI). Most models call for the continuation of ENSO-neutral conditions into the Northern Hemisphere winter, although some statistical models indicate the development of weak La Niña conditions at this time.

The May probabilistic ENSO forecasts for the Nino3.4 region, also provided by IRI, are shown in Table 2. The May forecast for August-September-October, which represents the climatological peak of the hurricane season, indicates a 17% probability of El Niño, a 56% probability of ENSO-neutral conditions, and a 27% probability of La Niña.

The forecasts for the 2013 Atlantic hurricane season to remain in ENSO-neutral conditions indicate that enhanced vertical wind shear, which is the main mechanism responsible for inhibiting hurricane activity, is unlikely to play a major role in suppressing hurricane activity in the Atlantic Basin. If La Niña conditions develop, reducing vertical wind shear across the tropical Atlantic, then there may be an even higher level of hurricane activity in the Atlantic Basin during the 2013 season although, again, this does may not necessarily translate to an increase in the number of landfalls.

[13] Gray, W.M., 1984: Atlantic seasonal hurricane frequency. Part I: El Niño and the 30 mb quasi-biennial oscillation influences. Monthly Weather Review, 112,1649-1668

Figure 3: Mid-May 2013 ENSO Model forecasts of 3-month SST anomalies in the Nino3.4 region based on the 1971-2000 climatological base period[14]

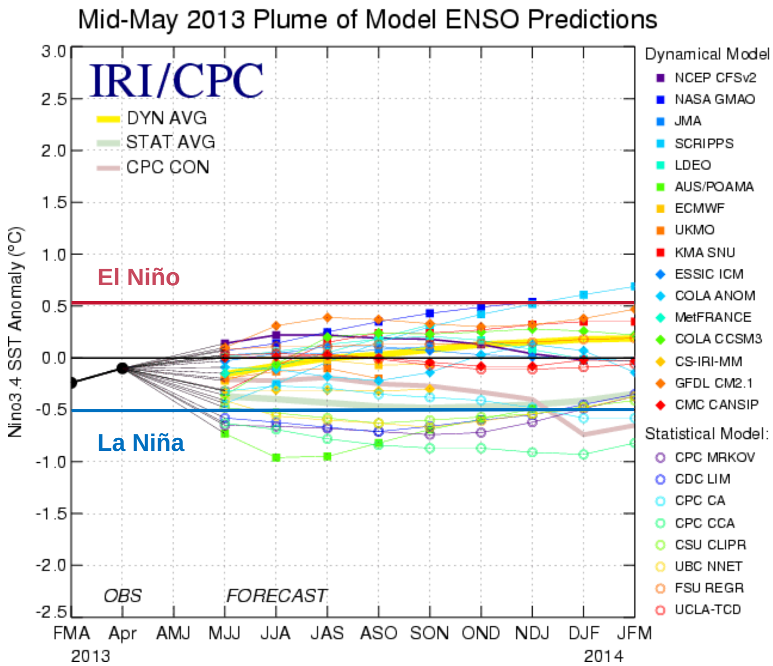


Table 2: The IRI probabilistic ENSO forecast for the NINO3.4 region as released in May 2013[15]

Season	La Niña (%)	Neutral (%)	El Niño (%)
April-May-June 2013	09%	88%	03%
May-June-July 2013	12%	82%	06%
June-July-August 2013	18%	73%	09%
July-August-September 2013	23%	64%	13%
August-September-October 2013	27%	56%	17%
September-October-November 2013	29%	51%	20%
October-November-December 2013	31%	46%	23%
November-December-January 2014	33%	44%	23%
December-January-February 2014	33%	44%	23%

[14] Image provided by the International Research for Climate and Society (IRI) http://portal.iri.columbia.edu/
[15] Data provided by the IRI http://portal.iri.columbia.edu/portal/server.pt

Understanding the Skill Level of Seasonal Forecasts

Seasonal Forecast Implications

There are many uncertainties associated with seasonal forecasts, particularly as they are based on the status of a variety of atmospheric and oceanic factors that are challenging to quantify and predict. The success of seasonal hurricane forecasts is dependent on, among other factors, the successful prediction of relevant climatological factors such as ENSO, and the relationship between such factors and hurricane activity. For this reason, RMS recommends treating seasonal hurricane activity forecasts with a level of caution.

Seasonal forecast skill for predicting the number of North Atlantic hurricanes is relatively low in the months prior to the season. The 2012 seasonal forecasts released in May and June underestimated the number of tropical storms and number of hurricanes that occurred in the season. For example, the June 2012 CSU called for 13 tropical storms and 5 hurricanes when in fact the season ended with 19 tropical storms and 10 hurricanes, although the CSU predicted correctly the number of major hurricanes (2). As the hurricane season progresses, however, statistical and dynamical models incorporate information about the ocean's observed subsurface thermal structure, which generally increases the accuracy and predictive skill of subsequent forecasts.

Landfalling Hurricanes

Forecast groups, including the Colorado State University (CSU) and Tropical Storm Risk (TSR), anticipate an above-average probability of hurricane landfall over the U.S. and Caribbean. The June CSU forecast calls for a 72% probability of one or more major hurricanes making landfall along the entire U.S. coastline, which is far above the 52% average for the last century. In comparison, the June 2012 CSU forecast called for a 48% probability of hurricane landfall along the U.S. coastline. The CSU landfall probability is calculated based on the overall Atlantic Basin Net Tropical Cyclone Activity (NTC).

There is greater uncertainty associated with forecasting hurricane landfalls than forecasting hurricane development in the Atlantic Basin, as landfall forecasts are difficult to predict more than a few weeks in advance. This is due to the forecast uncertainty of steering currents (or steering winds) that influence storm direction. Steering currents are synoptic scale systems (large-scale weather systems), which can be highly changeable and difficult to predict far in advance. Steering current patterns observed during the 2011 and 2012 Atlantic hurricane seasons played a role in keeping storms away from the U.S, while in 2004 and to a lesser extent in 2005, steering currents were influential in directing a number of storms toward the U.S..