

THE INACTIVE 2009 HURRICANE SEASON IN THE NORTH ATLANTIC BASIN: AN ANALYSIS OF ENVIRONMENTAL CONDITIONS

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Abstract

The 2009 North Atlantic hurricane season was below normal when considering overall hurricane activity; however, activity was seen to vary sharply from month to month. All activity in 2009 occurred from August through early November with the highest activity in August, less activity in September and October, and only one tropical cyclone in November. Therefore, the 2009 hurricane season had a late start with no storms occurring in June and July. For the 2009 season, it is shown that large scale environmental factors forced by the El Niño event, such as increased vertical wind shear across the Caribbean and decreased mid-tropospheric relative humidity in the Main Development Region (10° N to 20° N and 20° W to 60° W), contributed strongly to the observed patterns of tropical cyclone activity across the basin. Lastly, the activity in the Atlantic in 2009 is compared to that in the Eastern North Pacific Western Development Region (10° N to 20° N and 116° W to 180°), and the potential for long-range seasonal forecasting of Atlantic tropical cyclones is noted.

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1. Introduction

The North Atlantic basin is one the most widely studied with regard to tropical cyclones. Given that the typical track of a tropical cyclone, forming in the Atlantic, often moves west-northwest towards the eastern and southeastern United States, there is a significant focus on hurricane activity in this basin.

There is considerable variation in the number of tropical cyclones each year. Several authors have contributed to identifying variables which are necessary for the formation of tropical cyclones. Palmén (1948) was the first to introduce the idea of a critical sea surface temperature for tropical cyclone development, relating it to atmospheric instability. Namias (1954) also emphasized the importance of instability. It was Riehl (1954) who originally formulated a set of conditions which are necessary for the formation of tropical cyclones; but these were a mixture of environmental factors, such as water vapor, and tropical cyclone characteristics, such as radial motion. However, Gray (1979) is widely quoted as the first person to list a set of local environmental variables which may affect seasonal tropical cyclone development. Gray quantified these six factors and divided them into two circulation factors and a geographic factor whose product gives the 'dynamical potential' for tropical cyclone formation (Gray 1979), and three thermodynamic parameters whose product gives the 'thermal potential' or 'potential for cumulonimbus convection' (Gray and Sheaffer 1991). More recently, African dust outbreaks have also been identified as a limiting factor in Atlantic tropical cyclone activity due to their association with low atmospheric moisture, high vertical wind shear, and stability (Evan et al. 2006).

In addition to these local factors which affect tropical cyclone activity, there are also non-local influences. The most well known teleconnection to have an effect on ocean basins is the El Niño – Southern Oscillation (ENSO). Most simply defined as a quasi-cyclic variation in equatorial Pacific oceanic sea surface temperatures (SSTs) and trade winds (Rasmusson and Carpenter 1982) resulting in changes to the intensity and location of the Walker circulation (Wang 2002), ENSO has long been the focus of intense study. However, due to its manifestation in multiple forms as a coupled oceanic-atmospheric phenomenon, there is no one universal definition for ENSO (Trenberth 1997); although classification by regional sea surface temperature anomalies is popular, specifically in the Niño regions 3, 4 and 3.4 which straddle the equator from 5° N to 5° S and extend across the Pacific Ocean from 90° W to 160° E. The current National Oceanic and Atmospheric Administration (NOAA) operational index, the Oceanic Niño Index (ONI), is one example of this type of index. The

Southern Oscillation Index (SOI, Allan et al. 1991) utilizes sea level pressure (SLP), and the Multivariate ENSO Index (MEI, Wolter and Timlin 1993) utilizes SLP and additional parameters to represent ENSO.

ENSO events vary in both intensity (Trenberth and Stepaniak 2001) and spatial location (Kim et al. 2009). The latter discovery of near equatorial Central Pacific warming events (termed Modoki El Niño events) that were found to be more predictable than typical eastern initiated El Niño warmings, holds significant potential for future study. Regardless of the definition used, it is understood that in addition to the direct link to changes in regional SSTs, ENSO also affects tropical cyclone variability by changing the critical atmospheric parameters necessary for tropical cyclogenesis, specifically vertical wind shear, mid-tropospheric relative humidity, SLP, and low-level vorticity.

In the Atlantic, the total number of tropical cyclones is usually below normal during an El Niño year (Knaff 1997) with an above-normal number of tropical cyclones in La Niña years (Lupo et al. 2008). ENSO also impacts hurricane maximum intensity (Landsea et al. 1999; Xie et al. 2005), genesis location (Elsner and Kara 1999), and landfall probabilities in the U.S. and Caribbean (O'Brien et al. 1996; Bove et al. 1998; Pielke and Landsea 1999; Tartaglione et al. 2003; Smith et al. 2007).

There are atmospheric pressure changes related to ENSO which affect tropical cyclone numbers. The combination of the proximity of the North Atlantic to the Pacific El Niño area and to the atmospheric circulation anomalies associated with El Niño is such that the upper tropospheric climate in the Atlantic-Caribbean region is strongly affected by El Niño events (Gray and Sheaffer 1991). The association between ENSO and North Atlantic hurricanes is due to the position of the Atlantic-Caribbean region being directly downwind (in terms of the upper level winds) from the area of the major Pacific El Niño warming. It can be physically explained by the alteration of the flow patterns in the upper troposphere, which is a result of large changes in the Walker and Hadley cells (Philander 1989) and results in changes of the vertical wind shear profile. During an El Niño, upper level shearing is increased over the Caribbean Sea and strengthened trades necessitate that there will be increased evaporation which will lead to an increased net heat flux out of the ocean leading to cooling there (Klein et al. 1999). In addition, more recently it has been suggested (Tang and Neelin 2004) that the anomalous tropospheric temperatures communicated from the Pacific by atmospheric wave dynamics during an El Niño, which affect column stability relative to equilibrium with North Atlantic sea surface temperature, inhibits tropical cyclone formation in the North Atlantic. These findings have been supported by

Camargo et al. (2007) who constructed composites of a tropical cyclone genesis potential index with regard to ENSO, and noted in El Niño years that mid-tropospheric relative humidity (at the 600 hPa level) and vertical wind shear (850 to 200 hPa) are important for the reduction in genesis seen in the Atlantic basin.

The recent work of Zhao et al. (2009) showed significant negative relationships between seasonal Eastern North Pacific and North Atlantic basin tropical cyclone activity. It was previously found beneficial by Collins and Mason (2000) to split the Eastern North Pacific basin into two tropical cyclone development regions at 116° W named the Eastern Development Region (EDR: 10° N to 20° N, North American coastline to 115.9° W) and Western Development Region (WDR: 10° N to 20° N and 116° W to 180°). Collins (2010) specifically linked activity between the WDR and the North Atlantic basin, observing a significant negative relationship between the two, driven in part by ENSO through its impact on mid-tropospheric relative humidity in the WDR (Collins and Mason 2007), vertical wind shear (Gray and Sheaffer 1991), and mid-tropospheric relative humidity in the North Atlantic (Camargo et al. 2007). A significant relationship was not evident between the EDR and the North Atlantic basin. The purpose of this paper is to detail the large-scale environmental factors associated with the variations in tropical cyclone activity throughout the North Atlantic basin in 2009 and to consider forecasting potential with the environmental conditions and hurricane activity in the Eastern North Pacific WDR. Wang and Lee (2009) found interannual and multidecadal links between the two basins, and observed that seasonal hurricane forecasting could be improved by consideration of both basins together. Specific attention in this paper is given to ENSO.

2. Data and Methodology

The source for the tropical cyclone indices used in this study is the official historical tropical cyclone database obtained from the Tropical Prediction Center/ National Hurricane Center (TPC/NHC) best track file for the North Atlantic basin (Jarvinen et al. 1984; TPC 1998). These data represent the most complete and reliable source of all North Atlantic tropical cyclones. The best track data records were compiled from various publications and represent a rigorous, post season analysis of all tropical cyclone intensities and tracks every six hours. Categories of tropical cyclone development considered include tropical storm (17 m s^{-1}), hurricane (33 m s^{-1}), and intense hurricane ($\geq 50 \text{ m s}^{-1}$). As a measure of overall activity, Net Tropical Cyclone activity (NTC) is considered. NTC is

defined by Gray et al. (1994) as

$$\text{NTC} = (\% \text{NS} + \% \text{H} + \% \text{IH} + \% \text{NSD} + \% \text{HD} + \% \text{IHD}) / 6 \quad (1)$$

where each season's percentage values from the long period mean (1971–2000) is used for the six measures of seasonal activity: Named Storms (NS), Named Storm Days (NSD), Hurricanes (H), Hurricane Days (HD), Intense Hurricanes (IH), and Intense Hurricane Days (IHD). In addition, monthly NTCs are calculated where these measures are also compared to the monthly climatologies over the same time period. As such, the 1971–2000 average value of this parameter is 100 for both monthly and seasonal measures. In addition, we calculate the Accumulated Cyclone Energy (ACE) defined as the sum of the squares of the maximum sustained surface wind speed (knots) measured every six hours for all named systems while they are at least tropical storm strength and not extratropical in phase (Bell et al. 2000).

The environmental variables were chosen to consider thermodynamic as well as dynamic factors which have been shown to have an important influence on hurricane frequency (Palmén 1948; Namias 1954; Riehl 1954; Gray 1979). The National Centers for Environmental Research/ National Center for Atmospheric Research (NCEP/NCAR) reanalysis project (Kalnay et al. 1996) provides the data for most of the environmental variables investigated including relative humidity at 500 hPa, omega at 500 hPa (the vertical velocity in a pressure vertical coordinate system which is a measure of convection/subsidence), column total precipitable water, vertical wind shear between 200 and 850 hPa (calculated by time averaging the wind vectors and then calculating the magnitude of the difference between the time averaged 200 and 850 hPa winds), relative vorticity at 850 hPa, and SLP. The NCEP/NCAR reanalysis project has two unique characteristics, the length of the period covered and the assembly of a very comprehensive observational database. These factors make the data ideal for this study. The global data are now available on a $2.5^\circ \times 2.5^\circ$ latitude/longitude grid for many vertical levels (the number of which depends on the variable in question), and have a six-hourly and monthly time resolution. Confidence in these data has been addressed by Collins and Mason (2000) and Kalnay et al. (1996). Sea surface temperature anomalies were calculated using the NOAA extended reanalysis dataset (version 3b; Smith et al. 2008). Climatology statistics for all datasets were calculated for the period 1971 – 2000. The monthly environmental data are averaged over the months August to October to correspond with peak tropical cyclone activity in the North Atlantic. In addition, conditions during individual months over the peak

season are examined in the Main Development Region (MDR: 10° N to 20° N and 20° W to 60° W). Anomalies are calculated as standard deviation departures from the 1971–2000 climatological mean. For the purpose of comparison to prior seasons, the rank of each parameter is also calculated from the entire NCEP/NCAR reanalysis period of 1948–2009. Rank order is defined by anomaly values conducive to tropical cyclone activity – hence, 1 would be the season most favorable for tropical cyclone activity (negative anomalies for vertical wind shear, positive for relative humidity) and 62 the least favorable for tropical activity. African dust activity was also examined utilizing aerosol optical thickness data (Evan and Mukhopadhyay 2010) from the Advanced Very High Resolution Radiometer (AVHRR) and Moderate resolution Imaging Spectroradiometer (MODIS) onboard the NOAA and NASA AQUA satellites, respectively.

3. Results

a. 2009 North Atlantic tropical cyclone activity

Individual storm details of duration, genesis location and peak intensity can be found in Table 1, with storm tracks seen in Fig. 1. An examination of Table 1 shows that overall in 2009, nine named storms formed in the North Atlantic basin, with three reaching hurricane strength and two becoming intense hurricanes (though none reached category 5). While five named storms formed in the Atlantic MDR, above the median three per year for the region, only Bill could be considered a classic long track Cape Verde tropical cyclone. Three of the other four were weak (not reaching hurricane strength) and all were short in duration. Only one tropical storm, Claudette, made landfall, though the extratropical cyclone that was formerly Ida impacted the Gulf of Mexico coast. Overall, no systems made landfall on the United States at hurricane intensity. There was a late start to the 2009 season with Ana being named on August 12th (though followed quickly by Bill and Claudette within a 33 hour period). This late start is nearly six weeks after the median onset date (since 1971) of July 4th, though similarly late seasons have occurred in the recent past. For example, the devastating Hurricane Andrew was named on August 17th, 1992. More recently, Tropical Storm Alex was

named on August 1st in 2004.

Tropical cyclone statistics are further detailed in Table 2. Total ACE was only 52.58 for the season, far below normal (compared to a 1971–2000 climatological value of 83.00). Despite the overall lull in activity, the concentrated timing of the storms that did form was unprecedented. The storms in August accounted for an ACE of 30.06 (57.17% of the season total). Considering all months of August from 1950 to 2009, August 2009 constituted the highest percentage of its season total ACE (a mean August being only 23.73% of season total ACE). Activity was seen to vary sharply from month to month in the 2009 season with periods of higher activity in August and to a lesser degree September, October and early November. No activity was observed during the remainder of the official Atlantic hurricane season, considered to be June 1 to November 30th. 2009 saw a large decrease in activity compared to the recent active period largely observed since 1995, where the NTC values for each year were all above the 2009 value of 76.71 (except the strong El Nino year of 1997 where the NTC was 57.00 and the number of tropical cyclones in the basin was 7). Named storms, hurricanes and intense hurricanes averaged 14.5, 8.0 and 3.9, respectively with a mean NTC of 175.9 between 1995 and 2008.

b. North Atlantic peak season environmental conditions

Considering the peak season between August and October 2009, there was a lack of some of the key features of the tropical North Atlantic that favor tropical cyclone development. In particular, there was very low relative

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Name	Duration of Cyclone	Location of Tropical Cyclogenesis	Region	Degree of Tornado Production
Ana	11-16 AUG	14.4, 27.9	TS	35
Bill	15-24 AUG	11.8, 32.0	H4	115
Claudette	16-17 AUG	27.0, 83.4	TS	50
Danny	26-29 AUG	24.3, 69.6	TS	50
Erika	01-03 SEPT	16.7, 57.3	TS	45
Fred	07-12 SEPT	11.8, 24.0	H3	105
Grace	04-06 OCT	38.5, 29.5	TS	55
Henri	06-08 OCT	15.1, 49.2	TS	45
Ida	04-10 NOV	11.0, 81.3	H2	90

Table 1. Tropical cyclones which formed in the North Atlantic during the 2009 season. Category refers to maximum intensity reached on the Saffir – Simpson scale (e.g., H2: Category 2 hurricane). Duration of Cyclone refers to the dates during which the cyclone was tropical in nature and of at least tropical storm intensity. Maximum Intensity is the maximum 1-minute sustained wind speed.

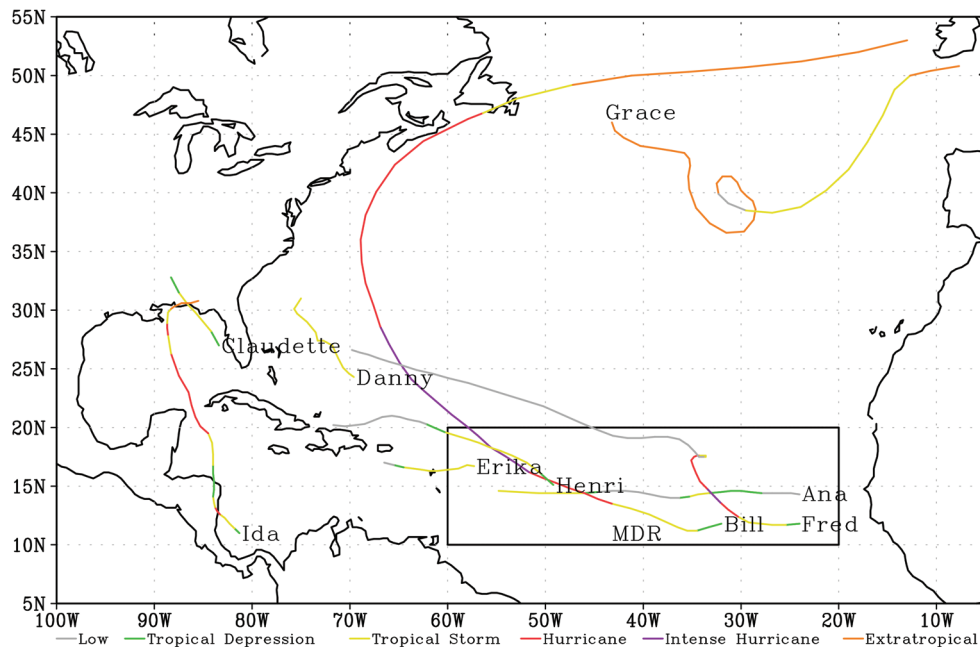


Fig. 1. 2009 North Atlantic basin tropical cyclone tracks. Main Development Region (MDR) is denoted.

	Year	NS	NSD	H	HD	IH	IHD	ACE	NTC
June	2009	0	0.00	0	0.00	0	0.00	0.00	0.00
	Climo	0.40	0.91	0.13	0.13	0.00	0.00	0.89	100
July	2009	0	0.00	0	0.00	0	0.00	0.00	0.00
	Climo	0.93	2.58	0.30	0.53	0.03	0.02	2.85	100
Aug	2009	4	14.25	1	7.00	1	3.00	30.06	144.85
	Climo	3.10	12.53	1.73	5.67	0.53	1.17	22.63	100
Sept	2009	2	6.75	1	2.75	1	0.50	11.22	40.87
	Climo	4.30	21.02	2.73	10.97	1.20	2.32	41.53	100
Oct	2009	2	4.00	0	0.00	0	0.00	3.19	26.96
	Climo	1.93	6.88	1.03	2.67	0.23	0.33	10.72	100
Nov	2009	1	5.00	1	2.25	0	0.00	8.12	133.51
	Climo	0.67	2.67	0.43	0.97	0.07	0.10	4.05	100
Year	2009	9	30.00	3	12.00	2	3.50	52.58	76.71
	Climo	9.47	46.88	5.60	21.03	1.97	3.93	83.00	100

Table 2. 2009 Tropical cyclone statistics for North Atlantic basin by month. Number of Named Storms (NS), Named Storm Days (NSD), Hurricanes (H), Hurricane Days (HD), Intense Hurricanes (IH), Intense Hurricane Days (IHD), Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone activity (NTC). All climatology figures from a 1971 – 2000 mean.

humidity, particularly over the MDR, and positive values of omega and high vertical wind shear, particularly over the Caribbean (Fig. 2). Favorable conditions for development were the below normal values of sea level pressure, positive relative vorticity, and slightly high precipitable water over some of the MDR (Fig. 3). Incidentally, sea surface temperatures (Fig. 4) were near normal and hence were not an explanatory factor to the inactive season, unlike results of Namias (1969), who found this a large explanatory factor for the inactive season of 1968. Seasonal mean African dust activity was observed to be near normal in 2009 (0.21 units of optical depth compared to a mean of 0.23) and thus not a primary forcing factor on tropical cyclone activity this season (not shown).

c. North Atlantic MDR environmental conditions

Mean values of environmental variables from August to October over the MDR are provided in Table 3. Assessing 2009, it can be seen that while vertical wind shear and precipitable water values are moderately favorable, neither result is remarkable or significant when compared to the long term record in the MDR. Regarding vertical wind shear, this is to be expected as the El Niño induced shear maximum is centered over the Caribbean,

which is not included in this regional subset. Sea level pressure (1.60 standard deviations below normal) and relative vorticity (2.56 standard deviations above normal) were both strongly positive for increased tropical cyclone activity in the MDR during the peak of the 2009 season and rated in the upper quadrant of historical seasons for both of these parameters. This corresponds well to the formation of five named storms in the area, cited previously as an above normal total. However, both 500 hPa omega (1.44 standard deviations above normal) and 500 hPa relative humidity (3.12 standard deviations below normal) were extremely unfavorable for tropical cyclone activity in the MDR. These mid-tropospheric levels of subsidence and dryness were both historically significant. In fact, 2009 was the driest season ever observed in the MDR at this level in the entire NCEP/NCAR reanalysis dataset. These extreme conditions correspond well to the short duration and minimal intensity of the storms that managed to form in the region in 2009.

d. Comparison to similar past El Niño events

Since 1950, four years (1957, 1986, 1991, 1994) have exhibited a similar equatorial Pacific SST evolution to 2009 with the presence of a moderate and intensifying

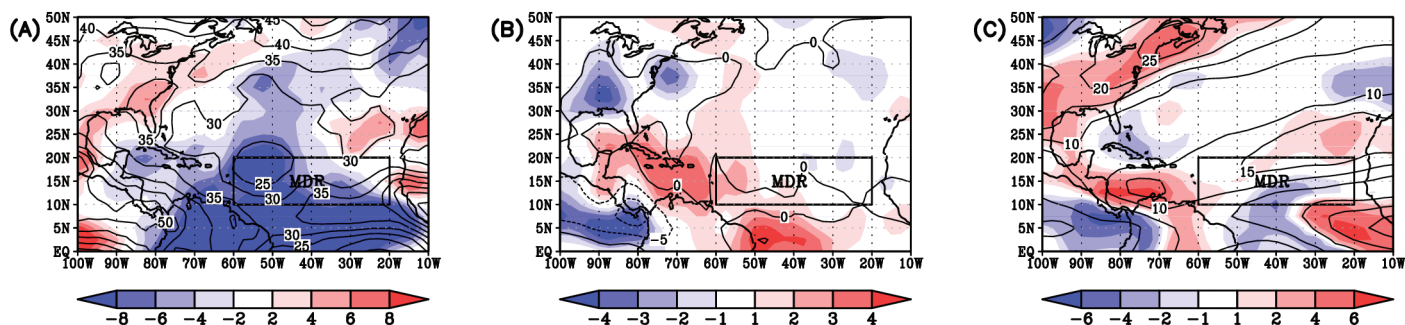


Fig. 2. (a.) August – October 500 hPa relative humidity means (contours) and anomalies (shading) in %. (b.) August – October 500 hPa omega means (contours) and anomalies (shading) in 10^{-2} m s^{-1} . (c.) August – October 850 – 200 hPa vertical wind shear means (contours) and anomalies (shading) in m s^{-1} . MDR as in Fig. 1.

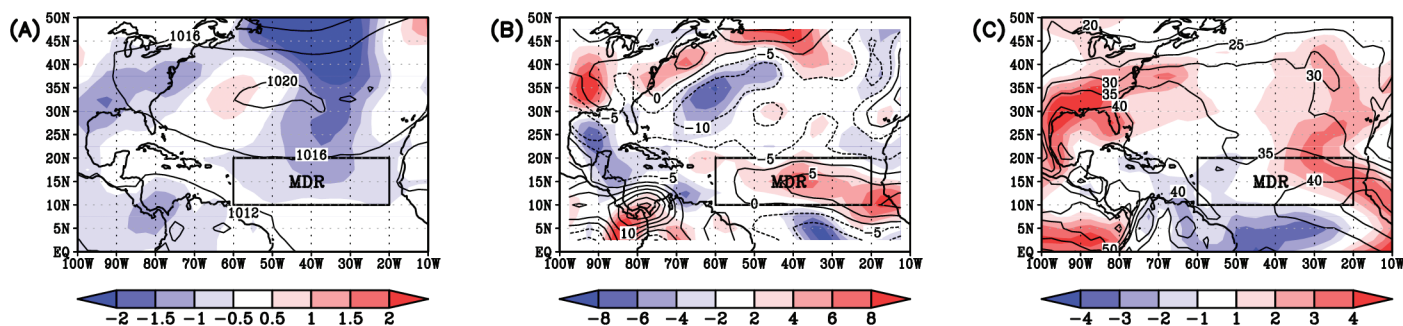


Fig. 3. (A) August – October sea level pressure means (contours) and anomalies (shading) in hPa. (B) August – October 850 hPa vorticity means (contours) and anomalies (shading) in 10^{-6} s^{-1} . (C) August – October precipitable water means (contours) and anomalies (shading) in mm. MDR as in Fig. 1.

El Niño event over the course of the Atlantic hurricane season. Examining tropical cyclone activity statistics for these years (Table 4), it can be seen that the mean storm counts, durations and activity totals for these years are very similar to those observed in the 2009 season. These seasons, like 2009, also feature depressed activity in both storm frequency and intensity. A composite mean of peak season (August – October) vertical wind shear for these four years is shown in Fig.5a. This shear pattern is nearly identical to that observed in 2009 (Fig. 2c). The difference between 2009 and the El Niño composite for shear is

shown in Fig. 5b.

e. Teleconnections and relationship between the North Atlantic and Eastern North Pacific Western Development Region (WDR).

The La Niña conditions from early 2009 quickly waned and were replaced by a developing El Niño regime. Reaching moderate intensity by October, Niño region

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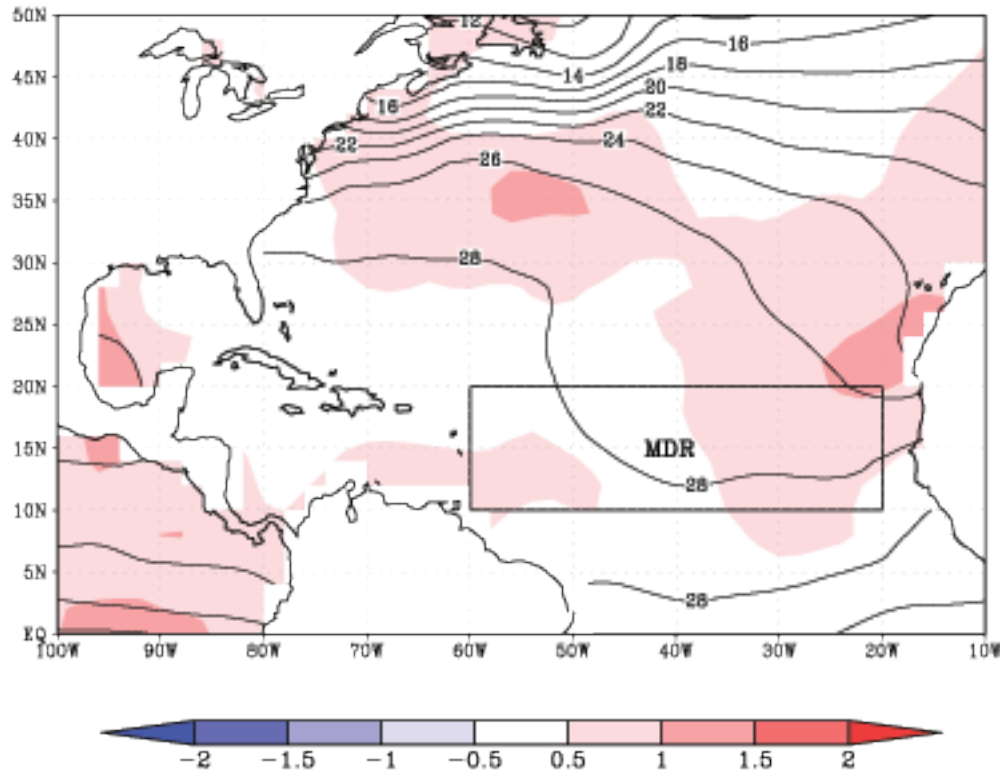


Fig. 4. August – October sea surface temperature means (contours) and anomalies (shading) in degrees C. MDR as in Fig. 1.

Parameter	Mean	Anom	Rank
500 hPa Relative Humidity (%)	29.44	-3.12	62
500 hPa Omega (10^{-2} m s^{-1})	0.41	1.44	57
850-200 hPa Vertical Wind Shear (m s^{-1})	9.66	-0.28	41
Sea Level Pressure (hPa)	1013.73	-1.60	14
850 hPa Relative Vorticity (10^{-6} s^{-1})	3.91	2.56	8
Precipitable Water (mm)	38.36	0.53	31

Table 3. August – October mean atmospheric parameters in the Main Development Region for 2009. Anomalies are calculated from standard deviation departure from the 1971–2000 mean conditions in the region. Ranks indicate the ordinal value of data in the 62 year (1948–2009) NCEP/NCAR reanalysis (where 1 is most favorable for tropical cyclone activity and 62 is least).

Year	NS	NSD	H	HD	IH	IHD	ACE	NTC
1957	8	38.00	3	21.00	2	6.50	83.75	81.49
1986	6	23.50	4	10.50	0	0.00	35.79	36.64
1991	8	22.25	4	8.25	2	1.25	33.97	55.12
1994	7	27.75	3	7.25	0	0.00	31.53	34.88
Mean	7.25	27.81	3.50	11.75	1.00	1.94	46.26	52.03
2009	9	30.00	3	12.00	2	3.50	52.58	65.72

Table 4. Tropical cyclone activity data for similar past El Niño events. Number of Named Storms (NS), Named Storm Days (NSD), Hurricanes (H), Hurricane Days (HD), Intense Hurricanes (IH), Intense Hurricane Days (IHD), Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone activity (NTC).

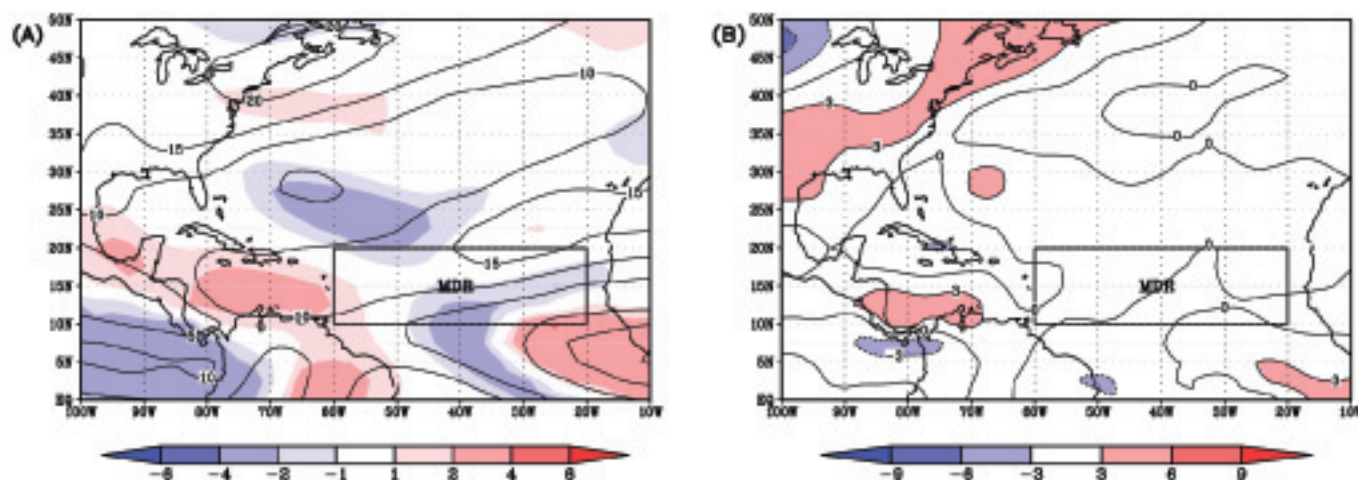


Fig. 5. (A) August – October 850 – 200 hPa vertical wind shear means (contours) and anomalies (shading) in m s^{-1} for the El Niño composite (1957, 1986, 1991, and 1994). (B) Difference between 2009 and El Niño composite vertical wind shear (m s^{-1}). MDR as in Fig. 1.

	Jan	Feb	Mar	Apr	May	Jun
Niño 3.4	-0.97	-0.65	-0.48	-0.18	0.27	0.62
Niño 3	-0.59	-0.51	-0.64	-0.01	0.35	0.74
Niño 4	-0.73	-0.64	-0.30	-0.04	0.33	0.57
	Jul	Aug	Sep	Oct	Nov	Dec
Niño 3.4	0.86	0.82	0.83	1.04	1.67	1.82
Niño 3	0.99	0.98	0.82	0.83	1.28	1.58
Niño 4	0.63	0.76	0.79	1.24	1.52	1.40

Table 5. Niño region sea surface temperature anomalies ($^{\circ}\text{C}$) by month for 2009. The regions extend latitudinally from 5°N to 5°S . Longitudinal extents: Niño 3: 90°W - 150°W , Niño 3.4: 120°W - 170°W , Niño 4: 150°W - 160°E .

statistics can be found in Table 5 with El Niño conditions observed in SST's near the end of the hurricane season in Fig. 6. While seasonal activity was found to be below normal in the North Atlantic, in the Eastern North Pacific WDR activity had returned to near normal conditions after a lull in activity from 2002-2008. Despite seasonal totals being near normal, there was much more monthly variation in activity there, compared to the Atlantic. In the WDR, activity was concentrated into two hyperactive months (August and October) with NTC values in excess of 200, over twice the normal amount of activity during those periods. Relative humidity, a feature previously linked to ENSO and WDR activity (Collins and Mason 2003), spiked in both active months well above normal values. Fig. 7 shows the dipole in August-October mid-tropospheric relative humidity between the two basins. This can be explained by the relationship with ENSO found in the Eastern North Pacific WDR by Collins and Mason (2003) and the relationship in the North Atlantic found by Tang and Neelin (2004). Based on the negative relationship noted in the past by authors (Zhao et al. 2009; Collins 2010), and confirmed with the 2009 season; the conditions in the Eastern North Pacific WDR may help with North Atlantic long-range seasonal tropical cyclone forecasting. Incidentally, while seasonal vertical wind shear (affected by ENSO) has been shown to relate to tropical cyclone frequency in the North Atlantic, it has not shown any significant relationships with seasonal tropical cyclone frequency in the Eastern North Pacific (Collins and Mason 2003). However, it should be emphasized that this study considered seasonal activity and not intraseasonal activity where the MJO, operating via the vertical wind shear, is strongly related to tropical cyclone frequency (Maloney and Hartmann 2000).

4. Conclusions

The inactivity of the 2009 North Atlantic hurricane season was due to multiple local factors, but primarily

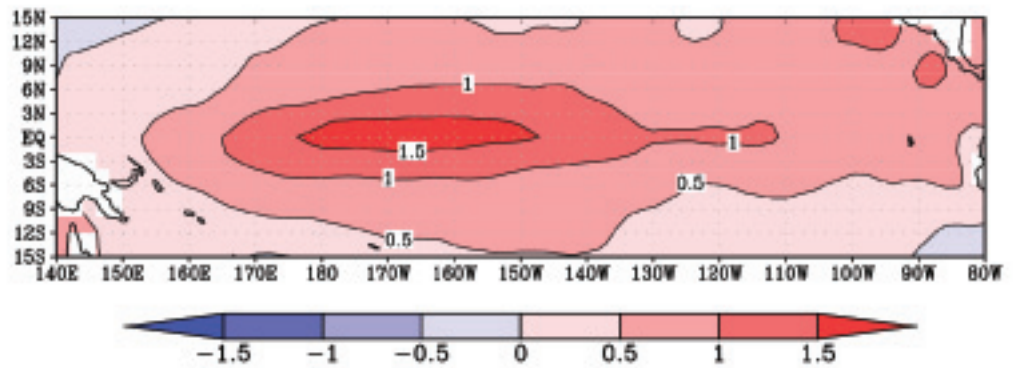


Fig. 6. October 2009 equatorial Pacific sea surface temperature (°C) anomalies.

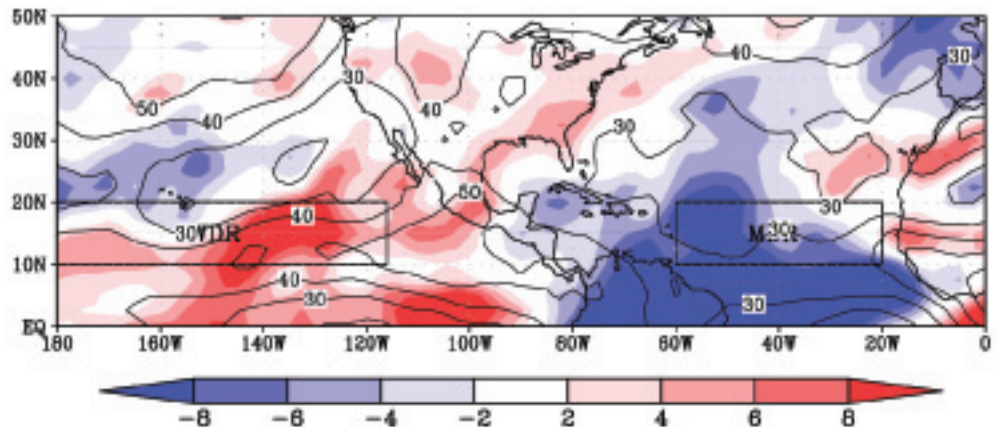


Fig. 7. August – October 2009 500 hPa relative humidity (%) in the Eastern North Pacific and the North Atlantic. MDR as in Fig 1., Eastern North Pacific Western Development Region (WDR) is denoted.

driven by the El Niño. The development of a moderate El Niño resulted in a large decrease in mid-level relative humidity for the whole season. Despite the presence of some favorable conditions in the MDR resulting in above normal storm counts in the area, the lifespan and intensity of those cyclones were largely limited by the dry mid-tropospheric conditions. In particular, the 2009 season was observed to behave very closely to a composite of past seasons with similar El Niño events in both tropical cyclone activity and large scale environmental conditions.

The North Atlantic activity was compared to activity in the Eastern North Pacific Western Development Region and a dipole in some of the forcing factors was observed between the two basins. Opposite values of relative humidity in the two basins in particular relate to El Niño and accounts for the 2009 Eastern North Pacific Western Development Region seeing higher activity than was observed there in the last few years. This negative relationship between the two basins has significance for North Atlantic tropical cyclone seasonal forecasting potential using environmental conditions in the Eastern North Pacific Western Development Region as possible parameters to be included in a forecasting model.

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