EARLY AUGUST FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY FOR 1997

An expected season of near average hurricane activity

(Next page gives forecast numbers)

(6 August 1997)

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(This forecast is based on ongoing research by the authors, together with meteorological information through July 1997)

[This text is also available on the World Wide Web at the following URL: http://tropical.atmos.colostate.edu/forecasts/index.html] — also,

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Summary of the early August 1997 forecast of seasonal Atlantic hurricane activity.

Forecast Parameter	Observed to 1 Aug	Forecast Activity After 1 Aug	Total Seasonal Activity	Total Season 1950-1990 Average
Named Storms (NS)	4	7	11	9.3
Named Storm Days (NSD)	10	35	45	46.9
Hurricanes (H)	2	4	6	5.8
Hurricane Days (HD)	2	18	20	24
Intense Hurricanes (IH)	0	2	2	2.2
Intense Hurricane Days (IHD)	0	3	3	4.7
Hurricane Destruction Potential (HDP)	4	56	60	70.6
Net Tropical Cyclone Activity (NTC)	18	82	100	100
Maximum Potential Destruction (MPD)	12	48	60	61.7

ABSTRACT

This paper presents details of the authors' early August updated forecast of the amount of tropical cyclone activity expected in the Atlantic Ocean region (including the Caribbean Sea and the Gulf of Mexico) during the remainder of the 1997 hurricane season. Most Atlantic basin hurricane activity occurs after early August. This forecast is based on the authors' ongoing research relating the amount of seasonal Atlantic tropical cyclone activity to a number of regional and global atmospheric and oceanic conditions. We now have several new predictors not utilized in previous early August forecasts including Sea Surface Temperature Anomalies (SSTA) in three areas of the Atlantic plus the March Sea Level Pressure Anomaly (SLPA) in the eastern sub-tropical Atlantic. These new predictors are used in combination with our previous predictors which include the Quasi-Biennial Oscillation (QBO) of equatorial stratospheric winds; the El Niño-Southern Oscillation (ENSO); West African Gulf of Guinea rainfall anomalies during the previous August-November period, Western Sahel June-July rainfall, anomalous west to east gradient of temperature (ΔT) in West Africa during February through May, and Caribbean Basin June-July Sea Level Pressure and Upper Level Zonal Wind Anomalies (SLPA and ZWA).

Information received by the authors through 5 August 1997 indicates about an average amount of hurricane activity for this year. Because of above average early season activity (i.e., 4 named storms and 2 hurricanes) during June-July we expect the total 1997 hurricane activity to include about 6 hurricanes, hence 4 more after 6 August (total season average is 5.8), 11 named storms, or 7 more than we have had so far (total season average is 9.3), a seasonal total of about 20 hurricane days (average is 24), seasonal total of 45 named storm days (average is 47) and seasonal total Hurricane Destruction Potential (HDP) of 55 (average is 71). We also expect 2 more (hence, a total of 2) intense or major hurricanes of Saffir-Simpson intensity category 3, 4 or 5 (average is 2.2) and a total of 3 intense hurricane days (average is 4.7). These parameters represent an overall measure of total seasonal hurricane and tropical cyclone activity which is about 100 percent of the 41-year average between 1950–1990. This updated forecast is reduced by one hurricane and one intense hurricane from our prior early December, early April and early June forecast of 1997 hurricane activity. The reduction is due to the recent development of a strong El Niño event.

DEFINITIONS

Atlantic Basin - The area including the entire North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico.

El Niño - (EN) A 12-18 month period during which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Niño events occur irregularly, about once every 5-6 years or so on average.

Hurricane - (H) A tropical cyclone with sustained low level winds of 74 miles per hour (33 ms^{-1} or 64 knots) or greater.

Hurricane Day - (HD) A measure of hurricane activity, one unit of which occurs as four 6-hour periods during which a tropical cyclone is observed or estimated to have hurricane intensity winds.

Hurricane Destruction Potential - (HDP) A measure of a hurricane's potential for wind and storm surge destruction defined as the sum of the square of a hurricane's maximum wind speed (in 10^4 $knots^2$)for each 6-hour period of its existence.

Intense Hurricane - (IH) A hurricane which reaches a sustained low level wind of at least 111 mph (96 kt or 50 ms^{-1}) at some point in its lifetime. This constitutes a category 3 or higher on the Saffir/Simpson scale (also termed a "major" hurricane).

Intense Hurricane Day - (IHD) Four 6-hour periods during which a hurricane has intensity of Saffir/Simpson category 3 or higher.

MATL - May-June Sea Surface Temperature anomaly in the sub-tropical Atlantic between 30-50°, 10-30°W

Millibar - (mb) A measure of atmospheric pressure which is often used as a vertical height designator. Average surface values are about 1000 mb; the 200 mb level is about 12 kilometers and the 50 mb is about 20 kilometers altitude. Monthly averages of surface values in the tropics show maximum summertime variations of about $\pm$ 2 mb which are associated with variations in seasonal hurricane activity.

MPD - Maximum Potential Destruction - A measure of the net maximum destruction potential during the season compiled as the sum of the square of the maximum wind observed for each named storm.

Named Storm - (NS) A hurricane or a tropical storm.

Named Storm Day - (NSD) As in HD but for four 6-hour periods during which a tropical cyclone is observed (or is estimated) to have attained tropical storm intensity winds.

NTC - Net Tropical Cyclone Activity - Average seasonal percentage mean of NS, NSD, H, HD, IH, IHD. Gives overall indication of Atlantic basin seasonal hurricane activity (see Appendix B).

ONR - previous year October-November SLPA of subtropical Ridge in eastern Atlantic between 20-30°W.

QBO - Quasi-Biennial Oscillation - A stratospheric (16 to 35 km altitude) oscillation of equatorial east-west winds which vary with a period of about 26 to 30 months or roughly 2 years; typically blowing for 12-14 months from the east, then reverse and blowing 14-16 months from the west, then back to easterly again.

Saffir/Simpson (S-S) Category - A measurement scale ranging from 1 to 5 of hurricane wind and ocean surge intensity. One is a weak hurricane whereas 5 is the most intense hurricane.

SATL - May-June Sea Surface Temperature anomaly in the sub-tropical Atlantic between 22°S – 2°N and 35°W - 1°E

SLPA - Sea Level Pressure Anomaly - The deviation of Caribbean and Gulf of Mexico sea level pressure from observed long term average conditions.

SOI - Southern Oscillation Index - A normalized measure of the surface pressure difference between Tahiti and Darwin.

SST(s) - Sea Surface Temperature(s).

Tropical Cyclone - (TC) A large-scale circular flow occurring within the tropics and subtropics which has its strongest winds at low levels; including hurricanes, tropical storms, and other weaker rotating vortices.

Tropical Storm - (TS) A tropical cyclone with maximum sustained winds between 39 (18 ms^{-1} or 34 knots) and 73 (32 ms^{-1} or 63 knots) miles per hour.

Delta PT - A parameter which measures anomalous east to west surface pressure (ΔP) and west to east surface temperature (ΔT) gradients across West Africa.

TATL - May-June Sea Surface Temperature (SST) anomaly in Atlantic between 6-22°N, 18-80°W.

ZWA - Zonal Wind Anomaly - A measure of upper level ($\sim$ 200 mb) west to east wind strength. Positive anomaly values mean winds are stronger from the west or weaker from the east than normal.

1 knot = 1.15 miles per hour = .515 meters per second.

1 Introduction

The Atlantic basin, including the Atlantic Ocean, Caribbean Sea and Gulf of Mexico, experiences more season-to-season hurricane activity variations than any other global hurricane basin. The number of hurricanes per season in recent years has ranged as high as 12 (as in 1969), 11 (as in 1950 and 1995) and 9 (as in 1980, 1955, 1996), and as low as 2 (as in 1982) and 3 (1994, 1987, 1983, 1972, 1962, 1957). Until recent years there has been no objective method for determining whether a forthcoming hurricane season was likely to be active, inactive, or near normal. Recent and ongoing research by the authors (see Gray, 1984a, 1984b, 1990; Landsea, 1991; Gray *et al.*, 1992, 1993, 1994) indicates that there are surprisingly skillful 3-to-11 month (in advance) predictive signals for Atlantic basin seasonal hurricane activity.

2 Factors Known to be Associated With Atlantic Seasonal Hurricane Variability after 1 August

This early August seasonal forecast is based on the current values of indices derived from various global and regional scale predictive factors which the authors have previously shown to be statistically related to seasonal variations of hurricane activity. Figure 1 provides a summary of the locations of the various forecast parameters which go into the forecast. Successive sets of values of these predictive factors are obtained by the end of July. This is before the start of the active portion of the hurricane season. We statistically optimize the predictive signals from these forecast parameters. Our predictive factors include:

(a) The stratospheric Quasi-Biennial Oscillation (QBO). The QBO refers to variable east–west oscillating stratospheric winds which circle the globe near the equator. On average, there is nearly twice as much intense (category 3-4-5) Atlantic basin hurricane activity during seasons when equatorial stratospheric winds at 30 mb and 50 mb (23 and 20 km altitude, respectively) blow from a westerly as compared to an easterly direction.

(b) El Niño-Southern Oscillation (ENSO): ENSO characterizes the sea surface temperature anomalies in the Nino 3.4 region in the eastern equatorial Pacific (Fig. 1) and the value of Tahiti minus Darwin surface pressure gradient. The effects of a moderate or strong El Niño event with

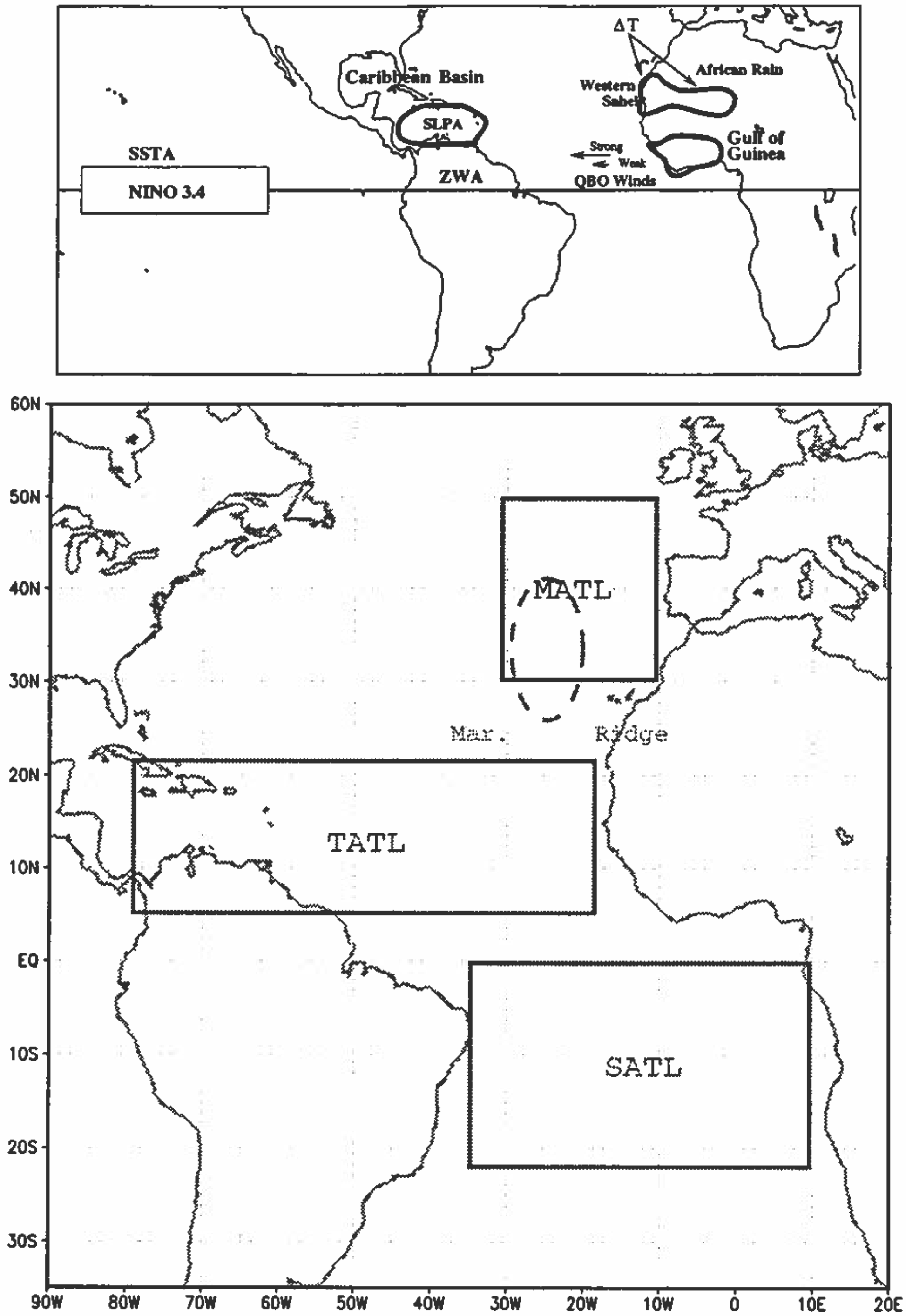

Figure 1: Locations of meteorological parameters used in the seasonal forecasts. Symbols are defined on the definitions pages (pages 3-4). The top diagram shows the locations of the global predictors. The bottom diagram shows the predictors in the Atlantic Ocean region.

warmer than usual SSTs in the eastern equatorial Pacific are to reduce Atlantic basin hurricane activity. By contrast, in those seasons with cold sea surface temperatures, and high values of Tahiti minus Darwin surface pressure occur (La Niña years) there is typically an enhancement of Atlantic basin hurricane activity. These differences are related to alterations of upper tropospheric (200 mb or 12 km) westerly winds and surface pressure over the Caribbean Sea and western Atlantic. Westerly upper-level winds are enhanced during El Niño seasons. This condition creates strong vertical wind shear over the tropical Atlantic which inhibits hurricane activity. During La Niña (or cold) years, westerly upper-level winds and the associated vertical wind shear are reduced and hurricane activity is typically greater.

(c) African Rainfall (AR): The incidence of intense Atlantic hurricane activity is strongly enhanced during those seasons when West Africa June-July Western Sahel rainfall and previous year August-November Gulf of Guinea region rainfall (shaded area in Fig. 2) have above average precipitation. Hurricane activity is typically suppressed if the rainfall in these two regions was below average.

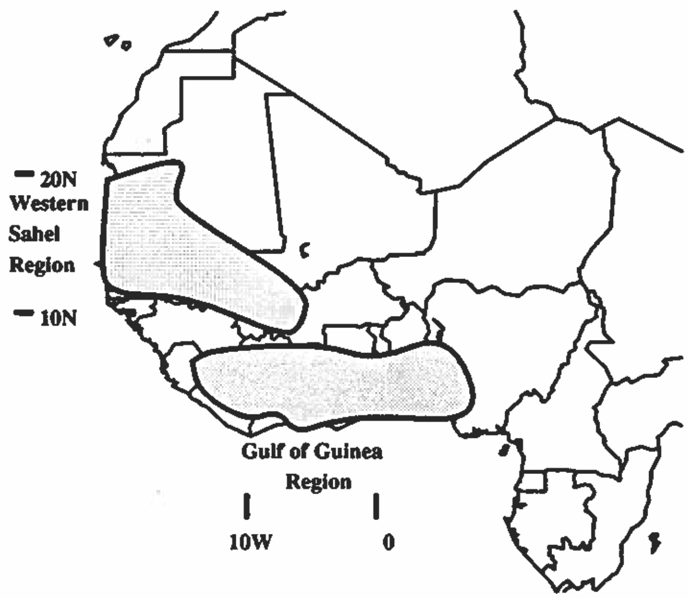

Figure 2: Regions which are used to create a 38-station Western Sahel precipitation index and a 24-station Gulf of Guinea precipitation index. August to November rainfall within the Gulf of Guinea region provides a predictive signal for the following years hurricane activity as does the early season June-July rainfall in the Western Sahel for the current season (see Landsea 1991; and Gray et al. 1993).

(d) Previous March Northeast Atlantic Subtropical Ridge Strength (R-M).
When this pressure ridge is anomalously weak during the prior spring, the eastern Atlantic trade winds during the following August–October period are typically weaker. Weaker trade winds reduce cold water advection and upwelling off the northwest African coast as well as the evaporative cooling in this area of the Atlantic. This leads to warmer sea surface temperatures and promote increased season hurricane activity. Weaker hurricane activity occurs when the March Ridge (R–M) has anomalously high pressure.

(e) Atlantic Sea Surface Temperature Anomalies (SSTA) in the three regions
(MATL; 30-50°N, 10-30°N, TATL; 6-22°N, 18-82°W and SATL; 22°S to 2°N, 35°W to 10°E)

during May through June: See Fig. 1 (bottom) for the location of these areas. Higher SSTAs enhance deep oceanic convection and, other factors aside, provide conditions more conducive for tropical cyclone activity, while cold water reduces activity.

(f) Caribbean Basin Sea Level Pressure Anomaly (SLPA) and upper tropospheric (12 km) Zonal Wind Anomaly (ZWA): June-July values of SLPA and ZWA have a moderate predictive potential for hurricane activity occurring during the following August through October months. Negative anomalies (i.e., low pressure and easterly zonal wind anomalies) imply enhanced seasonal hurricane activity while positive values imply suppressed hurricane activity.

(g) Influence of West Africa west-to-east temperature gradients (Δ T): Project research has shown that anomalous west-to-east temperature gradients across West Africa from February through May are well correlated with the hurricane activity which follows later in the year (see Gray et al. 1994). We find that Atlantic hurricane activity is enhanced when the February to May east (Region B – in Fig. 3) minus west (Region A) temperature gradient anomaly is below average.

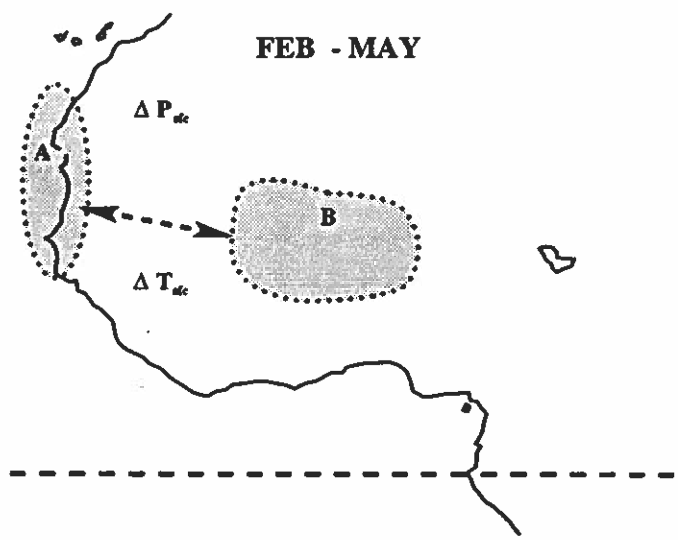

Figure 3: Map showing of the two West African regions—west (Area A) and east (Area B)—from which multi-station surface pressure and temperature values are computed to form combined west-to-east pressure and temperature gradients or ΔT parameter. (Gray et al. 1994).

3 Forecast Methodology

Our early August seasonal forecast scheme has the following general form:

$$\begin{matrix} \textit{(Predicted Amount} \\ \textit{of TC Activity} \\ \textit{Per Season)} \end{matrix} = Ave.\ Season + \overbrace{(QBO+EN+AR+ONR+MATL,\ TATL\ etc.)}^{Adjustment\ Terms} \quad (1)$$

Each adjustment term has a weighted coefficient associated with it. We statistically test for the best individual predictor, the best two-predictor combination, the best three-predictor combinations, etc. For each predictor added, we require that the predictor improve the hindcast by at least five percent of the remaining variance. Unless such an improvement occurs, we stop adding new predictors. The number of predictors accepted under this criterion is typically four to seven. In one case we use only three predictors, in another case we use eight predictors.

We use the above factors to make predictions for nine separate measures of seasonal hurricane activity. These include separate predictions of the seasonal number of

NS	–	Named Storms
NSD	–	Named Storm Days
H	–	Hurricanes
HD	–	Hurricane Days
IH	–	Intense Hurricanes
IHD	–	Intense Hurricane Days
HDP	–	Hurricane Destruction Potential
NTC	–	Net Tropical Cyclone Activity
MPD	–	Maximum Potential Destruction

Research has shown that those prior atmospheric and oceanic conditions which are associated with active seasons have different characteristics than those factors associated with inactive seasons. Hurricanes forming from African waves typically have longer tracks and more days of activity than do hurricanes forming at higher latitudes. As the damage a hurricane does typically increases with the square, cube, or higher power of its wind speed, we have developed specific parameters such as HDP and MPD which better reflect this exponential damage rise with wind speed. Consequently, we make separate multi-parameter forecasts for each of these measures of Atlantic basin seasonal activity.

Recent research has been directed towards improving our 1 August forecast methodology. This work has involved the addition of new predictors and changing of statistical procedures. Our earlier 1 August forecast scheme (Gray et al. 1993) was developed on hindcast information for the 41-year period of 1950-1990. It used the same nine predictors for each forecast parameter, did not distinguish between hurricane activity occurring before and after 1 August, and did not predict Maximum Potential Destruction (MPD). Table 1 shows the nine forecast parameters we used and the estimated amount of hindcast variance explained by this earlier 1 August scheme. Our hindcast skill for most parameters was between 50-60 percent.

Newer analyses have shown that this nine parameter scheme leads to an exaggeration of our true forecast skill when applied to future (and independent) data sets. This forecast degradation made it desirable that we make new studies of ways in which we might reduce our number of predictors and still retain or improve our hindcast skill.

Newer Forecast Scheme. We have recently developed a second and likely improved 1 August forecast scheme which includes three important new physical predictors. This scheme distinguishes between hurricane activity before and after 1 August activity and a scheme which forecasts MPD. This new 1 August forecast scheme employs an improved statistical approach which chooses the best predictors from a large pool of known precursor signals. We order our predictors by the amount of added forecast skill which each contributes. This new scheme adopts a regression procedure which chooses the best 1, then 2, then 3, etc. predictors from a pool of 14 potential predictors shown in Table 2. This new prediction scheme has allowed us to reduce the number of predictors from a fixed set of nine to a variable selection of four to seven and thus reduces the forecast true skill shrinkage when applied to independent data. Other improvements involve the optimizing of our forecasts to include hurricane activity occurring only after 1 August and using 46 rather than 41 years in the developmental data set. We are confident that this newer prediction scheme is superior to our earlier scheme which we developed four years ago.

Table 3 provides details of the various predictors chosen for each of the different forecast measures of activity (NS, NSD, H, etc.). Some predictors (such as Gulf of Guinea rainfall or 30 mb

Table 1: List of nine predictors and amount of hindcast variance explained in our earlier (Gray et al. 1993 1994) 1 August seasonal forecast scheme.

Predictors	Predictants	Hindcast Amount of Variability Explained	Expected Independent Forecast Skill
1. QBO 50 mb U	NS	0.447	0.152
2. QBO 30 mb U	NSD	0.608	0.419
3. Ab. Shear of 50-30 mb U	H	0.472	0.199
4. Western Sahelian Rainfall (June-July)	HD	0.505	0.255
5. Gulf of Guinea (Aug-Nov of previous year)	IH	0.586	0.387
6. SLPA - June-July	IHD	0.540	0.316
7. ZWA - June-July	HDP	0.549	0.330
8. SOI - June-July	NTC	0.581	0.379
9. SSTA - June-July for Nino 3			

Table 2: Listing and descriptions of 14 potential 1 August predictors.

Forecast Parameters
1 = U_{50} July extrapolated to September near 10°N in m/s
2 = U_{30} July extrapolated to September near 10°N in m/s
3 = Absolute shear (AS) (July extrapolated to September) in m/s
4 = August to November Guinea Coast Rain (Rg) Standard Deviation (S.D.)
5 = June to July Western Sahel Rain of previous year (Rs) Standard Deviation (S.D.)
6 = Del–Temp (February to May) in West Africa (Fig. 3) in Standard Deviation (S.D.)
7 = SLPA (June to July) in mb
8 = ZWA (June to July) in m/s
9 = SST 3.4 (June to July) in °C $\times 10^{-2}$
10 = D-SST 3.4 (June to July minus April to May) in °C $\times 10^{-2}$
11 = MATL (May to June) 30-50°N, 10-30°W in °C $\times 10^{-2}$
12 = TATL (May to June) 6-22°N, 18-80°W in °C $\times 10^{-2}$
13 = SATL (May to June) 22°S to 2°N, 35°W to 1°E in °C $\times 10^{-2}$
14 = Ridge (March) in Standard Deviation (S.D.)

zonal winds) are selected for nearly every measure of activity, while other predictors (such as SLPA or ΔT) are selected by only one or two of our forecast equations. Table 3 also lists the hindcast measure of agreement or amount of variance explained. Note that for HDP, NTC and MPD we are able to explain over two-thirds of the hindcast variance.

Table 3: Details of our new 1 August forecast scheme utilizing a variable number of predictors in order to maximize the forecast skill or measure of hindcast variance explained while limiting the number of predictors. See Figs. 1-3 for the location of the predictors. The period of 1950–1995 was used to develop these equations.

Forecast Parameter	No. of Predictors	Hindcast Measure of Agreement	Expected Independent Fcst Skill	Predictors
(NS)	3	.466	.360	U_{50} R_g MATL
(NSD)	6	.634	.415	U_{50} U_{30} R_g SLPA MATL DDST3.4
(H)	4	.513	.366	U_{50} U_{30} R_g D–T
(HD)	7	.685	.482	U_{30} Shear R_g ZWA SLPA MATL DDST3.4
(IH)	6	.638	.499	U_{50} U_{30} R_s R_g D–T Ridge
(IHD)	4	.582	.475	U_{50} R_g D–T MATL
(HDP)	8	.719	.543	U_{30} Shear R_g SST3.4 SLPA D–T MATL DDST3.4
(NTC)	7	.714	.536	U_{50} U_{30} R_g SLPA D–T MATL DDST3.4
(MPD)	7	.678	.526	U_{30} R_g SST3.4 SLPA MATL SATL DSST3.4

A new aspect of our research is a thorough study of the anticipated statistical forecast skill reduction which occurs when a dependent data sample (such as the historical hurricane information of 1950-1995 used to develop our hindcast equations) is applied to independent data sets such as the forthcoming 1997 season. This process has been discussed in recent papers by Mielke et al. (1996, 1997). We plan future research on this topic. Anticipated forecast skill reduction (or "degradation") from that obtained in the developmental data set is known to be more of a problem when the number of predictors is large and the number of years of developmental data is small.

Table 3 also presents the expected forecast skill degradation due to the application of our scheme to independent data. As we gain more years of developmental data sets (now 46) and, as we reduce the number of variables, the amount of estimated real forecast skill, although impossible to determine in an individual year, should likely not undergo undue degradation.

4 Forecast Parameters for 1 August 1997 Prediction

The following values are our parameter measurements which go into our new 1 August forecast scheme. These are derived from meteorological data through July.

4.1 QBO

Tables 4 and 5 show the absolute and relative (anomalous) values of the current and extrapolated 30 mb (23 km) and 50 mb (20 km) stratospheric QBO zonal winds near 11 to 13°N latitude during the primary hurricane period of August through October 1997. These estimates are based on a combination of the current trends in the QBO winds plus the annual wind cycle variations for the low latitude stations of Curacao (12°N), Trinidad (11°N), and Barbados (13°N). Note that during the primary August through October hurricane season, 30 mb and 50 mb zonal winds will be from a relative westerly direction and hence will be a enhancing influence upon this year's hurricane activity.

Table 4: Observed and extrapolated March through October 1997 absolute values of stratospheric QBO zonal winds (U) in the critical latitude belts between 11-13°N as obtained from Caribbean stations of Curacao (12°N), Barbados (13°N), and Trinidad (11°N). Values are in ms^{-1} (data supplied by James Angell and Colin McAdie).

	Observed					Extrapolated		
Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	+3	+2	-3	-5	-5	-5	-4	-1
50 mb (20 km)	-4	-6	-6	-2	-2	-1	-1	+1

Table 5: As in Table 4 but for the "relative" (or anomalous) stratospheric zonal wind values wherein the annual wind cycle has been removed. Values are in ms^{-1}.

	Observed					Extrapolated		
Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	+8	+9	+11	+12	+13	+13	+12	+12
50 mb (20 km)	-4	-2	0	+4	+6	+8	+9	+10

4.2 ENSO

Sea surface temperature anomaly (SSTA) conditions (in °C) in Nino-1-2, 3, 3.4 and 4 (see Fig. 4), as well as the SOI values since April 1997 are shown in Table 6. Very warm water El Niño conditions are present. These conditions should be a rather strong suppressing influence for this year's hurricane activity. Our earlier 1997 forecasts did not anticipate such a strong El Niño event. This is the primary factor causing us to trim our 1 August forecast values from earlier estimates.

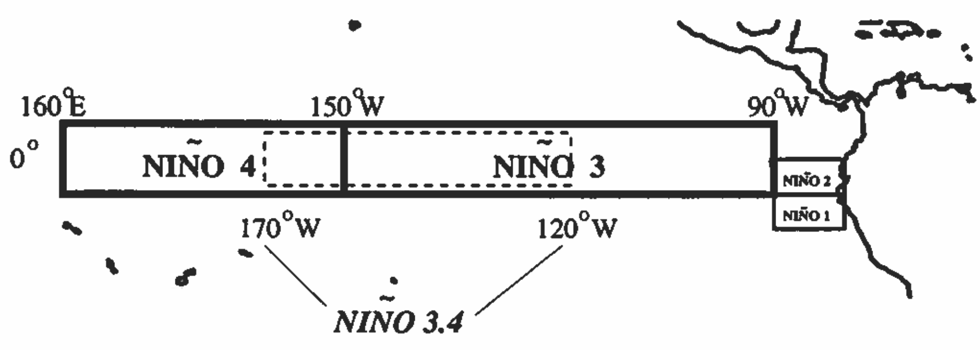

Figure 4: Equatorial Pacific sea surface temperature anomaly indices (°C) for the areas indicated.

4.3 West African Rainfall (AR)

Western Sahel June-July rainfall conditions (-0.40 SD) indicate drought conditions so far this season, but we expect near normal rainfall in August and September. Last year's August through November 1997 Gulf of Guinea's rainfall was measured as -0.40 SD. We expect that in the net, these

Table 6: April through July values of various Niño sea surface temperature anomalies (in °C) and Tahiti minus Darwin (SOI) surface pressure difference (in S.D.)

	Apr	May	June	July
Nino-1-2	1.3	2.9	3.9	4.5
Nino-3	0.4	1.4	2.1	2.7
Nino-3.4	0.5	1.1	1.6	2.0
Nino-4	1.0	0.9	0.9	1.0
SOI	−1.3	−1.8	−2.0	−1.8

prior drought conditions will be an inhibiting influence on Atlantic intense (or major) hurricane activity during 1997.

4.4 West African ΔT

There has been no change in these conditions since our early June forecast wherein a value of +0.60 SD was noted. A positive value for this index is an enhancing influence for the year's hurricane activity.

4.5 SLPA and ZWA

Two Caribbean basin parameters which contribute to the early August hurricane forecast are the Caribbean Basin Sea Level Pressure Anomalies (SLPA) and 200 mb (12 km) Zonal Wind Anomalies (ZWA). The June-July 1997 five-station tropical (Trinidad, Barbados, Curacao, San Juan and Cayenne) SLPA's were just at the 1950–1995 average (i.e., zero). A second six-station surface pressure average, made up of Brownsville, Miami, Merida (Yucatan), San Juan, Barbados, and Trinidad, gives a pressure anomaly for June-July of –0.1 mb.

The five-station June-July (Trinidad, Curacao, Barbados, Kingston and Balboa) ZWA values are also positive, +1.5 m/s. These two June-July measurements indicate a moderate suppressing influence on this year's hurricane activity. But since 10 July both the SLPA and ZWA have been rising to higher than the June-July average. This is becoming more of a negative influence for this season's hurricane activity. Table 7 lists all of these values.

4.6 Atlantic Ocean Predictors

March Ridge (MR). The March 1997 SLPA between 20-30°W of the northeast Atlantic subtropical anticyclone (see Fig. 1b) was low, –0.85 S.D. This indicates the likelihood of more hurricane activity this year.

Middle ATLantic SSTA (MATL). May through June 1997 SSTA for this area is +0.76°C. This also indicates enhancement of this season's hurricane activity.

Tropical ATLantic SSTA (TATL). May through June 1997 SSTA for this area was +0.30°C, indicating an enhancing influence for this season's activity.

South ATLantic SSTA (SATL). May through June 1997 SSTA for this area was –0.50°C, indicating an enhancing influence for this season's activity.

4.7 Summary of 1 August Predictors

Table 8 provides information on the current values of the pool of fourteen 1 August predictors from which we choose our best predictors for both the older and newer schemes. This forecast

Table 7: April through July 1997 Sea Level Pressure Anomaly (SLPA) and Zonal Wind Anomaly (ZWA).

	April–May	June–July
5-Station SLPA of Tropical Average (mb)	+1.2	0
6-Station SLPA of Tropical and Sub-Tropical Average (mb)	+0.7	–0.1
5-Station Tropical Zonal Wind Anomaly (ZWA) (m/s)	+ 1.0	+1.5

parameter indicates mixed signals for this year's activity. The parameters of U_{50}, U_{30}, AS, ΔT, MATL, TATL, SATL and Ridge indicate enhanced 1997 hurricane activity while the parameters of R_s, R_g , ZWA, SSTA(3.4) and DSSTA(3.4) indicate reduced activity. This is a difficult forecast because there is nothing in our past data set back to1950 which has a similar mix of variables. We did not anticipate such a strong El Niño event as is presently in place.

Table 8: Listing of 1 August 1996 predictors.

1. U_{50}	–1.0 m/s
2. U_{30}	–4.0 m/s
3. AS	+3 m/s
4. R_s	–0.40 SD
5. R_g	–0.57 SD
6. ΔT	+0.60 SD
7. SLPA	0 mb
8. ZWA	+1.5 m/s
9. SSTA(3.4)	1.8 SD
10. DSSTA(3.4)	1.0°C
11. MATL	+0.76 SD
12. TATL	+0.30°C
13. SATL	–0.50°C
14. Ridge	–0.85 SD

5 Forecast of 1997 Total Hurricane Activity and Activity Likely to Occur After 1 August and Total Season Amount

Table 9 lists both our original and newer quantitative forecasts for post 1 August hurricane activity. Our forecast for the remainder of the hurricane season (August through November) is for below average tropical storm and hurricane activity to occur. During June and July 1997, the Atlantic basin experienced a large amount of tropical cyclone activity with 4 named storms and 2 hurricanes compared with 1.5 and 0.7 on average. (During average seasons, approximately 84 percent of named storms, 88 percent of hurricanes and 95 percent of intense hurricanes occur after 1 August.) Thus, with an observed very active early (June-July) season combined with an anticipated quieter than usual August through November, we act to make the overall 1997 hurricane season near normal. The last column on the right of Table 9 gives our qualitatively adjusted post 1 August forecast. Note that our new post 1 August forecast scheme is very close to that specified by climatology (Table 10).

Table 9: Summary of older (for the entire season) and newer scheme (after 1 August activity) forecasts of after 1 August activity.

Forecast Parameter	Original (Gray et al. 1993) Whole Season Forecast	New Scheme All Season	Post 1 Aug Newer Statistical Scheme	After 1 Aug Climatology	Qualitative Adjusted After 1 Aug Forecast	Forecast Total Season Activity
(NS)	10.07	11.81	8.53	7.8	7	11
(NSD)	70.96	63.04	51.24	41.1	35	45
(H)	6.98	7.37	6.63	5.1	4	6
(HD)	27.97	30.93	26.39	21.4	18	20
(IH)	1.44	3.09	2.67	2.0	2	2
(IHD)	3.29	8.22	8.22	4.4	3	3
(HDP)	46.57	90.82	87.68	64.4	56	60
(NTC)	86.39	150.89	96.32	86.0	82	100
(MPD)	—	62.38	58.47	57.1	51	60

Discussion. Our earlier forecast scheme did not include the three new predictors which utilize SSTA at various locations in the Atlantic and March surface pressure anomalies in the eastern Atlantic subtropical ridge. Values of these important new predictors were all positive for 1997. Table 11 shows the activity before 1 August and our forecast of after 1 August activity. The last column gives our total seasonal forecast which are very close to climatology as seen in Table 10.

Table 10: After 1 August forecast of hurricane activity based on a variable number of predictors, the activity which occurred before 1 August and total seasonal hurricane activity we expect in 1997.

Forecast Parameter	Activity Before 1 August	After 1 August Adjusted Forecast	1997 Total Seasonal Forecast	Seasonal Average 1950–1990
Named Storms (NS)	4	7	11	9.3
Named Storm Days (NSD)	10	35	45	46.9
Hurricanes (H)	2	4	6	5.8
Hurricane Days (HD)	2	18	20	23.7
Intense Hurricanes (IH)	0	2	2	2.2
Intense Hurricane Days (IHD)	0	3	3	4.7
Hurricane Destruction Potential (HDP)	4	56	60	70.6
Net Tropical Cyclone Activity (NTC)	18	82	100	100%
Maximum Potential Destruction (MPD)	12	48	60	61.7

Table 11 compares our early August forecast with our earlier 30 November 1996, 4 April 1997 and 6 June 1997 forecasts. All three of our previous forecasts anticipated an above average 1997 hurricane season. We have now reduced our earlier numbers due to the strong developed El Niño.

Table 12 compares this year's 1 August forecast seasonal activity with the amount of hurricane activity which occurred during 1995-1996 and the average of the 1991–94 season.. The 1997 season is expected to be much less active than the 1995 and 1996 seasons but significantly more active than the earlier four hurricane seasons of 1991-1994.

Table 11: Comparison of the current early August total seasonal predictions versus climatology as well as the three forecasts made for 1997 issued 30 November 1996, 4 April 1997 and 6 June 1997.

Forecast Parameter	Earlier Forecasts 6 Dec 96 Fcst	4 Apr 97 Fcst	6 Jun 96 Fcst	Current Total Season 6 August Fcst
Named Storms (NS)	11	11	11	11
Named Storm Days (NSD)	55	55	55	45
Hurricanes (H)	7	7	7	6
Hurricane Days (HD)	25	25	25	20
Intense Hurricanes (IH)	3	3	3	2
Intense Hurricane Days (IHD)	5	5	5	3
Hurricane Destruction Potential (HDP)	75	75	75	60
Net Tropical Cyclone Activity (NTC)	110%	110%	110%	100%
Maximum Potential Destruction (MPD)	70	70	70	60

Table 12: Comparison of total season early August 1997 seasonal prediction with activity in previous years.

	6 Aug Entire Season Forecast 1997	Observed 1996	1995	Average of 1991–1994 Season	Ave. (1950-90)
Hurricanes (H)	6	9	11	3.8	5.8
Named Storms (NS)	11	13	19	7.2	9.3
Hurricane Days (HD)	18	45	62	10.2	23.7
Named Storm Days (NSD)	45	78	121	29.8	46.9
Hurr. Dest. Pot. (HDP)	60	135	172	27.8	68.1
Intense Hurricanes (Cat. 3-4-5) (IH)	2	6	5	1.0	2.2
Intense Hurricane Days (IHD)	3	13	11	1.3	4.7
Net Tropical Cyclone Activity (NTC)	100%	198%	243%	54%	100%

5.1 Location of 1997 Hurricanes

It is to be expected that low latitude (< 25°N) hurricane formation will be suppressed this year due to the presence of stronger vertical wind shear which is typical in the Atlantic low latitude regions during El Niño years. But higher latitude (> 25°N) tropical cyclone formation activity, which is more common in El Niño years when tropical upper tropospheric troughs (TUTTs) are present, should be enhanced. The latter are a result of the expected weaker vertical wind shears at higher latitudes which typically occur in El Niño years. It is to be noted that all four 1997 named storm formations thus far (before 1 August of this year) have occurred at higher (> 25°N) latitudes.

6 Analog Years for 1997

The three best analog years to 1997 are 1953, 1957 and 1969. These were the only three years between 1950–1996 wherein overall general global conditions were similar to 1997. These include:

1. QBO conditions between 70 mb to 10 mb which were very close to this year's activity.
2. Positive North Atlantic and North Pacific SST anomalies during the prior October through March (as this year).
3. Positive Eastern Tropical Pacific SST anomalies and negative values of the SOI as is present this year.

The hurricane activity after 1 August in these years were as follows:

	NS	NSD	H	HD	IH	IHD	HDP	NTC	MPD
1953	13	52	6	18	3	5.5	59	113	78
1957	6	33	2	19	1	4.75	59	66	30
1969	16	78	12	40	3	2.75	110	150	118
Ave	12.8	55	6.7	26	2.1	4.2	76	108	75
1997 After 1 Aug Fcst	7	35	4	18	2	3	56	82	48

Our forecast is thus below the average of these three broadscale analog years but higher than in 1957, a strong El Niño year like this year. However, our confidence in this year's forecast is less than that of most of our forecasts.

7 Comparison of of 1997 with 1982–83 Hurricane Seasons

The emerging strong El Niño of this year is being compared to the 1982–83 El Niño event which was the strongest of this century. In the years of 1982 and 1983 Atlantic hurricane activity was greatly reduced. NTC of these years was only 37 and 32 percent of the long term average. We do not find the overall climatological conditions associated with the strong emerging El Niño event of this year to be comparable to those of 1982. Major climate feature differences include a westerly QBO in 1997 versus an easterly one in 1982, warmer Atlantic basin SST conditions this year in comparison with cool Atlantic basin SST conditions in 1982–83. Also, it is likely we have entered a new era of enhanced hurricane activity as evidenced by general warming of Northern Hemisphere SST conditions versus those of the Southern Hemisphere SST conditions that were not present in 1982–83.

8 Verification of 1997 Forecasts

We will issue a verification of this year's 1997 seasonal hurricane forecast via the World Wide Web and e-mail on 25 November 1997.

9 Prospects for Increased Landfalling Major Hurricanes in Coming Decades

There has been a significant lull in the overall incidence of intense category 3-4-5 hurricanes striking the US East Coast, Florida and Caribbean basin (except for 1995 - 1996) during the last 25 years. We see this trend as a natural consequence of slowing of the Atlantic Ocean thermohaline (Conveyor Belt) circulation which also appears to be associated with a long list of concurrent global circulation changes during the last quarter century. The latter include the Sahel drought, increased

El Nino activity, Pacific and Atlantic middle latitude zonal wind increases, among numerous other changes. Both historical and geological (proxy) records indicate that this lull in major hurricane activity will not continue indefinitely; the return of increased major landfalling hurricane activity should be expected within the next decade or so. More research on the causes and the likely timing of this change-over to a decade long period of increased intense hurricane activity is much needed. Increased intense hurricane activity striking US coastal areas is an assured threat to the US much more so than earthquakes, greenhouse gas warming and other environmental problems which are receiving disproportionately greater attention.

Changes in the North Atlantic. We may now be seeing the early stages of a transition to enhanced Atlantic thermohaline (Conveyor Belt) circulation from a recent three decade long slowing. There are reports of decreased ice flow through the Fram Strait (the North Atlantic passage between Greenland and Spitzbergen) which thereby, reduces the introduction of fresh water and leading to increased surface salinity values in the North Atlantic. Recent observations report increased surface water salinity in the deep water formation areas of the North Atlantic during the recent years. Rising salinity increases water density. Chilling of high salinity surface water then creates very dense water which is able to sink to great depth, thereby causing increased equatorward flow of deep water and engendering a northward flow of warm near surface replacement water; hence - the Atlantic Ocean "conveyor". A strong conveyor increases North Atlantic water temperatures and thus transports more heat to high latitudes, a condition favorable to increased hurricane activity.

The salinity values in the North Atlantic have been steadily rising over the last 15 years and recent deep water observations in the North Atlantic reveal that fairly stagnant water has been present for a decade or more. The surface salinity increases that are now being measured in the North Atlantic will likely lead to greater Atlantic Ocean thermohaline circulation in the next few years. Presuming this occurs, we anticipate a concurrent general increase in West African Sahel rainfall, a decrease in Atlantic summertime upper tropospheric westerly winds over the tropical Atlantic and, regarding the issue at hand, a likely multi-decadal long increase of Atlantic basin intense hurricane activity. These new regional North Atlantic measurements may thereby be an ominous sign of forthcoming increases of US and Caribbean basin hurricane landfalling activity.

Outlook for 1998. We expect the current El Niño event to be dissipated by the August through October 1998 period and the beginning of cool (La Niña) ENSO conditions will likely be in place. It is likely that we will be in a mixed QBO pool of 10 and 30 mb relative wind from the east and 50 mb relative winds from the west. We anticipate that warm North Atlantic SST anomaly conditions will persist, indicating that we will be continuing in a new multi-decadal era of enhanced Atlantic basin hurricane activity which began in 1995. We expect for now that the 1998 hurricane season of about average hurricane activity.

10 Forthcoming Early December Forecasts of 1998 Hurricane, West African Sahel and ENSO Variability

We will issue an extended range forecast for the expected 1998 Atlantic basin hurricane activity, West African rainfall and the ENSO on 5 December 1997. These forecasts will be based on data through November 1997. Recent research has shown that considerable extended range forecast skill is available in early December of the prior year.

11 Cautionary Note

It is important that the reader appreciate that these seasonal forecasts are based on statistical schemes which, owing to their probabilistic nature, must fail in some years. Moreover, these forecasts do not specifically predict where within the Atlantic basin storms will strike. Regardless of whether 1997 should prove to be active or inactive, the probability always exists that one or more hurricanes may strike along the US or Caribbean Basin coastline and do much damage.

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14 APPENDIX: Verification of All Past Seasonal Forecasts

The first author has now issued seasonal hurricane forecasts for 13 consecutive years. In most of these prior forecasts, predictions have been superior to climatology (i.e., long-term averages), particularly for named storms. Figures 5 and 6 offer a comparison of our 1 August forecasts of named storms and hurricanes versus climatology and actual year-by-year variability. Note that a large portion of the negative and positive deviations from climatology were anticipated. The 13 season correlation for named storms is r = 0.93 (86% of variance) and for hurricanes r = 0.72 (52% of variance). During the seven years (1990–1996) in which we have made forecasts of intense (or major) hurricane activity, our correlation has been r = 0.69, or nearly half of the variance.

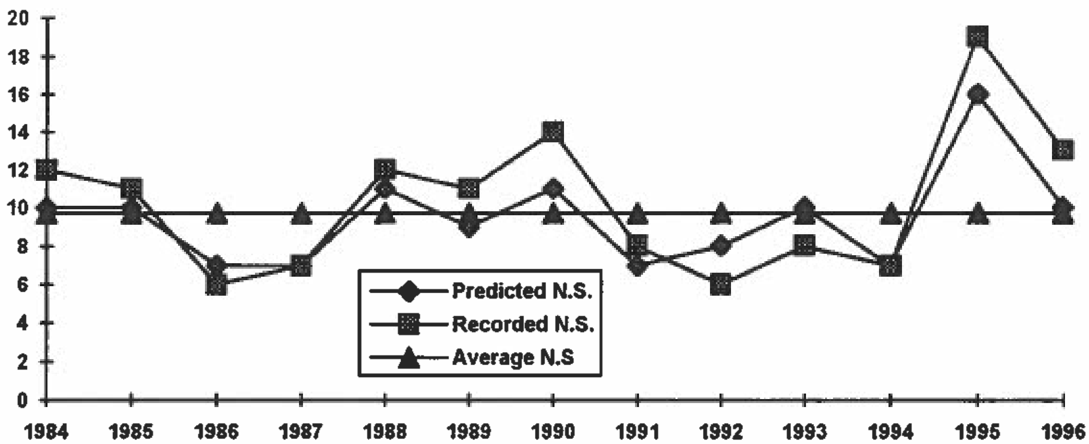

Figure 5: 1 August prediction of total named storms versus the number of actually observed versus long-term climatological mean (r = 0.93) (Graph by Cliff Nielson).

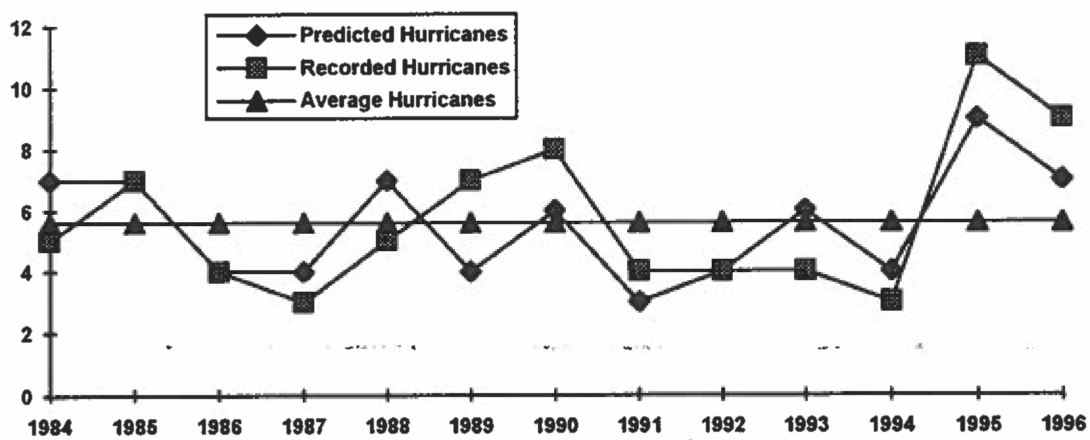

Figure 6: 1 August prediction of total hurricanes versus the number of actually observed versus climatological long-term mean (r = 0.72) (Graph by Cliff Nielson).

Table 13: Verification of the authors' previous seasonal predictions of Atlantic tropical cyclone activity for 1984-1996.

1984	Prediction of 24 May and 30 July Update		Observed
No. of Hurricanes	7		5
No. of Named Storms	10		12
No. of Hurricane Days	30		18
No. of Named Storm Days	45		51

1985	Prediction of 28 May	Updated Prediction of 27 July	Observed
No. of Hurricanes	8	7	7
No. of Named Storms	11	10	11
No. of Hurricane Days	35	30	21
No. of Named Storm Days	55	50	51

1986	Prediction of 29 May	Updated Prediction of 28 July	Observed
No. of Hurricanes	4	4	4
No. of Named Storms	8	7	6
No. of Hurricane Days	15	10	11
No. of Named Storm Days	35	25	23

1987	Prediction of 26 May	Updated Prediction of 28 July	Observed
No. of Hurricanes	5	4	3
No. of Named Storms	8	7	7
No. of Hurricane Days	20	15	5
No. of Named Storm Days	40	35	37

1988	Prediction of 26 May and 28 July Update		Observed
No. of Hurricanes	7		5
No. of Named Storms	11		12
No. of Hurricane Days	30		21
No. of Named Storm Days	50		47
Hurr. Destruction Potential(HDP)	75		81

1989	Prediction of 26 May	Updated Prediction of 27 July	Observed
No. of Hurricanes	4	4	7
No. of Named Storms	7	9	11
No. of Hurricane Days	15	15	32
No. of Named Storm Days	30	35	66
Hurr. Destruction Potential(HDP)	40	40	108

1990	Prediction of 5 June	Updated Prediction of 3 August	Observed
No. of Hurricanes	7	6	8
No. of Named Storms	11	11	14
No. of Hurricane Days	30	25	27
No. of Named Storm Days	55	50	66
Hurr. Destruction Potential(HDP)	90	75	57
Major Hurricanes (Cat. 3-4-5)	3	2	1
Major Hurr. Days	Not Fcst.	5	1.00

1991	Prediction of 5 June	Updated Prediction of 2 August	Observed
No. of Hurricanes	4	3	4
No. of Named Storms	8	7	8
No. of Hurricane Days	15	10	8
No. of Named Storm Days	35	30	22
Hurr. Destruction Potential(HDP)	40	25	22
Major Hurricanes (Cat. 3-4-5)	1	0	2
Major Hurr. Days	2	0	1.25

1992	Prediction of 26 Nov 1991	Updated Prediction of 5 June	Updated Prediction of 5 August	Observed
No. of Hurricanes	4	4	4	4
No. of Named Storms	8	8	8	6
No. of Hurricane Days	15	15	15	16
No. of Named Storm Days	35	35	35	39
Hurr. Destruction Potential(HDP)	35	35	35	51
Major Hurricanes (Cat. 3-4-5)	1	1	1	1
Major Hurr. Days	2	2	2	3.25

1993	Prediction of 24 Nov 1992	Updated Prediction of 4 June	Updated Prediction of 5 August	Observed
No. of Hurricanes	6	7	6	4
No. of Named Storms	11	11	10	8
No. of Hurricane Days	25	25	25	10
No. of Named Storm Days	55	55	50	30
Hurr. Destruction Potential(HDP)	75	65	55	23
Major Hurricanes (Cat. 3-4-5)	3	2	2	1
Major Hurr. Days	7	3	2	0.75

1994	Prediction of 19 Nov 1993	Updated Prediction of 5 June	Updated Prediction of 4 August	Observed
No. of Hurricanes	6	5	4	3
No. of Named Storms	10	9	7	7
No. of Hurricane Days	25	15	12	7
No. of Named Storm Days	60	35	30	28
Hurr. Destruction Potential(HDP)	[illegible]	40	35	15
Major Hurricanes (Cat. 3-4-5)	2	1	1	0
Major Hurr. Days	7	1	1	0
Net Trop. Cyclone Activity	110	70	55	36

1995	Prediction of 30 Nov 1994	14 April Qualit. Adjust.	Updated Prediction of 7 June	Updated Prediction 4 August	Obs.
No. of Hurricanes	8	6	8	9	11
No. of Named Storms	12	10	12	16	19
No. of Hurricane Days	35	25	35	30	62
No. of Named Storm Days	65	50	65	65	121
Hurr. Destruction Potential(HDP)	100	75	110	90	173
Major Hurricanes (Cat. 3-4-5)	3	2	3	3	5
Major Hurr. Days	8	5	6	5	11.5
Net Trop. Cyclone Activity	140	100	140	130	229

1996	Prediction of 30 Nov 1995	Updated 14 April	Updated Prediction of 7 June	Updated Prediction 4 August	Obs.
No. of Hurricanes	5	7	6	7	9
No. of Named Storms	8	11	10	11	13
No. of Hurricane Days	20	25	20	25	45
No. of Named Storm Days	40	55	45	50	78
Hurr. Destruction Potential(HDP)	50	75	60	70	135
Major Hurricanes (Cat. 3-4-5)	2	2	2	3	6
Major Hurr. Days	5	5	5	4	13
Net Trop. Cyclone Activity	85	105	95	105	198