(1)

SUMMARY OF 1995 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHORS' SEASONAL PREDICTION

(A year of unusually high hurricane activity due to the combined effects of very low values of West Atlantic surface pressure, a westerly QBO, a return to cool ENSO conditions and very favorable Atlantic basin tropospheric wind shear conditions)

By
*William M. Gray**, *Christopher W. Landsea***
*Paul W. Mielke, Jr.**** and *Kenneth J. Berry* ***

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

(As of 30 November 1995)

* Professor of Atmospheric Science
** Post-doctoral position at NOAA/HRD Lab., Miami, FL
*** Professor of Statistics

(THE 1995 HURRICANE SEASON)

NATURE'S REVENGE

"The powerful and multiple physical forces of nature sometimes see fit to organize themselves in a unified and vicious plot to wreak havoc and revenge upon mortals who have the temerity to entertain thoughts that they may someday understand and perhaps forecast such onslaughts. What arrogance these mortals display!".

Unknown Source

Authors Rebuttal: NUTS

DEFINITIONS

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

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) Four 6-hour periods during which a tropical cyclone is observed or estimated to have hurricane intensity winds.

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.

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

Named Storm Day - (NSD) Four 6-hour periods during which a tropical cyclone is observed or estimated to have attained tropical storm or 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 reaching at some point in its lifetime a sustained low level wind of at least 111 mph (96 kt or 50 ms^{-1}). This constitutes a category 3 or higher on the Saffir/Simpson scale (a "major" hurricane).

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

Maximum Potential Destruction = (MPD) The seasonal sum of the square of the maximum wind in knots of each named storm in units of 10^3. MPD is different than HDP because MPD does not involve the time over which hurricane force winds exist.

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.

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.

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

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

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 12-16 months from the east, then reverse and blowing 12-16 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.

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

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

ZWA - Zonal Wind Anomaly - A measure of upper level (~ 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.

ABSTRACT

This paper summarizes the tropical cyclone (TC) activity which occurred in the Atlantic Basin during 1995 and verifies the authors' seasonal forecast of this activity which was initially issued on 30 November of last year, with updates on 5 June and 4 August of this year. The 1995 hurricane season was a year of near record hurricane activity. There was a total of 19 named storms (average 9.3) and 11 hurricanes (average 5.7) which persisted for a total of 62 days (average is 23). There were 5 major (intense) hurricanes of Saffir/Simpson category 3-4-5 (average is 2.1 intense hurricanes) with 11.5 intense storm days (average is 4.5). The seasonal total of named storm days was 121 or, 262 percent of average and net tropical cyclone (NTC) activity was 237 percent of the average for the last 45 years.

This unusually active hurricane season was the result of the concurrence of nearly all the physical factors known to enhance seasonal hurricane activity. This convergence of favorable factors typically occurs about once every 10-15 years. Of all these favorable factors, low values of surface pressure during 1995 were the most important. Our 1995 seasonal forecasts made on 30 November 1994, 5 June 1995 and 4 August 1995, all called for above average hurricane activity though not nearly as much hurricane activity as occurred.

1 Summary of 1995 Atlantic Tropical Cyclone Activity

The 1995 Atlantic hurricane season officially ends on 30 November. There were 11 hurricanes (maximum sustained wind >73 mph) and 62 hurricane days during the 1995 season. The total named storms (or, the sum of the number of hurricanes and tropical storms) was 19, yielding 121 named storm days. There were 5 major (intense) hurricanes this season. All designated tropical cyclone activity parameters were much above the long period average values. Figure 1 and Table 1 show the tracks and give statistical summaries, respectively of the 1995 season. Table 2 compares 1995 seasonal tropical cyclone activity as a percentage of the last 45-year climatology. Table 3 shows a comparison of the 1995 hurricane season with the last four seasons 1991-1994. Note the more active 1995 season in comparison with 1991 through 1994. In fact, in terms of number of Hurricane Days (HD), Intense Hurricanes (IH), Intense Hurricane Days (IHD), Hurricane Destruction Potential (HDP) and Net Tropical Cyclone Activity (NTC), 1995 values were higher than the total combined amount for these parameters during all of the four previous seasons (1991-1994). Clearly, 1995 represents a remarkable upsurge in hurricane activity.

Comparisons of the 1995 season with other active Atlantic Basin seasons vary depending on what seasonal parameters are examined. These may include the number of named storms, number of hurricanes, or number of major (category 3-4-5) storms as representative of seasonal activity. However, the number of named storm days, hurricane days, major hurricane days are also important representations of seasonal activity. We advocate use of a parameter termed the "Net Tropical Cyclone" (NTC) activity to characterize how active the season has been. NTC combines all six of the above mentioned measures of tropical cyclone activity. (See the Appendix for a more detailed definition of this parameter).

Table 1: Summary of information on named tropical cyclones occurring during the 1995 Atlantic tropical cyclone season. Information on Tropical Storm (TS), Hurricanes (H) and Intense Hurricanes (IH) with highest Saffir/Simpson category is shown. Information was supplied by courtesy of the National Hurricane Center.

	Named Storm	Max Category	Date	Max Winds kts	NSD	HD	IHD	HDP
1.	Allison	H-1	Jun 3-6	65kt	2.50	1.00	0	1.7
2.	Barry	TS	Jul 5-10	60	3.00	0	0	0
3.	Chantal	TS	Jul 13-22	60	6.75	0	0	0
4.	Dean	TS	Jul 28-Aug 3	40	0.50	0	0	0
5.	Erin	H-1	Jul 31-Aug4	75	4.25	2.00	0	4.0
6.	Felix	IH-4	Aug 8-25	120	14.00	9.25	1.75	24.2
7.	Gabrielle	TS	Aug 9-12	60	1.50	0	0	0
8.	Humberto	H-2	Aug 22-Sep 1	95	10.00	8.50	0	21.0
9.	Iris	H-2	Aug 22-Sep 4	95	12.75	7.50	0	17.6
10.	Jerry	TS	Aug 22-25	35	1.00	0	0	0
11.	Karen	TS	Aug 26-Sep 3	45	5.25	0	0	0
12.	Luis	IH-4	Aug 27-Sep 11	120	13.50	11.75	8.00	52.2
13.	Marilyn	IH-3	Sep 12-22	100	9.25	7.75	0.50	19.9
14.	Noel	H-1	Sep 27-Oct 7	65	9.50	3.00	0	5.1
15.	Opal	IH-4	Sep 30-Oct 5	130	5.00	2.75	1.00	8.8
16.	Pablo	TS	Oct 5-8	50	4.00	0	0	0
17.	Roxanne	IH-3	Oct 7-21	100	10.00	5.00	0.25	11.2
18.	Sebastien	TS	Oct 20-24	50	3.00	0	0	0
19.	Tanya	H-1	Oct 27-Nov 2	75	5.50	3.00	0	6.1
	Totals	19 NS, 11 H, 5 IH			121.00	62.00	11.50	172.0

Table 2: Summary of the 1995 seasonal hurricane and comparison with average conditions.

Forecast Parameter	45-year Ave. (1950-94	1995	1995 in % of last 45-yr. Ave.
Named Storms (NS)	9.3	19	204
Named Storm Days (NSD)	46.1	121	262
Hurricanes (H)	5.7	11	193
Hurricane Days (HD)	23.0	62	270
Intense Hurricanes (IH)	2.1	5	238
Intense Hurricane Days (IHD)	4.5	12	267
Hurricane Destruction Potential (HDP)	68.1	172	253
Net Tropical Cyclone Activity (NTC)	100	237	237
Maximum Potential Destruction (MPD)	61.6	127	206

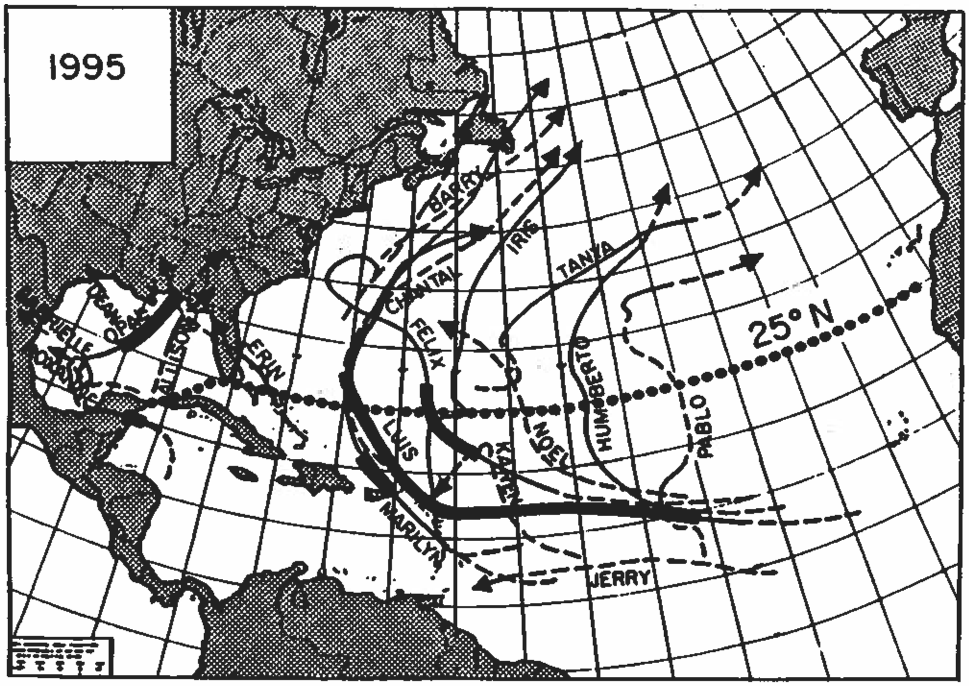

Figure 1: Tracks of 1995 named tropical cyclones. Dashed lines indicate the tropical storm intensity stage, thin solid lines indicate the Saffir/Simpson hurricane category 1-2 stage, and thick lines show the intense hurricane category 3-4-5 hurricane stage.

Table 3: Comparison of 1995 seasonal hurricane activity (through 31 October 1995) with the 1991-1994 seasons.

		Observed				Four-year Total
	'95	'94	'93	'92	'91	for 1991-1994
Hurricanes (H)	11	3	4	4	4	15
Named Storms	19	7	8	6	8	29
Hurricane Days (HD)	62	7	10	16	8	41
Named Storm Days (NSD)	121	28	30	38	22	118
Hurr. Dest. Pot. (HDP)	172	15	23	51	23	112
Intense Hurricanes (Cat. 3-4-5) (IH)	5	0	1	1	2	4
Intense Hurricane Days (IHD)	12	0	0.75	3.25	1.25	5.25
Net Tropical Cyclone Activity (NTC)	237%	37%	55%	62%	59%	213%

2 Comparison of 1995 With Other Active Hurricane Seasons of the Past

Going back 120 years we find 10 other hurricane seasons with hurricane activity comparable to 1995. These years are listed in Table 4. These very active years occur on average about every 10-15 years. It is on this scale that a large percentage of the global atmospheric conditions associated with active hurricane seasons combine in a favorable mode to produce very active hurricane seasons.

Table 4: Comparison of 1995 hurricane activity with the ten most active hurricane seasons during the last 120 years. Numbers of hurricane , intense days, HDP and NTC are less reliable before the mid 1940s. Circled values show years when seasonal totals were greater than 1995.

Forecast Parameter	1995	1969	1961	1955	1950	1933	1926	1916	1906	1893	1887
Named Storms (NS)	19	18	11	12	13	21	11	14	11	12	17
Named Storm Days (NSD)	121	84	71	82	98	136	87	88	89	111	106
Hurricanes (H)	11	12	8	9	11	7	8	11	6	10	10
Hurricane Days (HD)	62	40	48	47	60	50	55	47	44	72	55
Intense Hurricanes (IH)	5	3	6	5	7	5	6	6	4	3	2
Intense Hurricane Days (IHD)	12	3	21	14	16	11	23	11	11	25	8
Hurricane Destruction Potential (HDP)	172	110	170	158	200	152	197	143	137	230	158
Net Tropical Cyclone Activity (NTC)	237	157	222	198	262	273	287	255	203	286	210

The 1995 active hurricane season is not unprecedented. In terms of total Named Storms (NS), 1933 had two more than this year (21 total), 1969 two less (17), 1887 two less (17), and 1936 two less (17). In terms of the total number of Hurricanes (H), the 1995 value of 11 was exceeded only in 1969 (12), was equaled in 1950 and 1916 (11 each) and there was only one less hurricane in 1933, 1893 and 1887 (10 each). In terms of Net Tropical Cyclone Activity (NTC) the value of 237 for 1995 was exceeded in 1950 (262), 1933 (273), 1926 (287), 1916 (255), and 1893 (286). And NTC was only somewhat less in 1961 (222) and 1955 (198). The 1995 Hurricane Destruction Potential (HDP) value of 172 was exceeded in 1950 (200), 1926 (197) and 1893 (230). The total of 5 Intense or Major Hurricane (IH) activity in 1995 was exceeded in 1950 (7) and 1961, 1926 and 1916 with 6 each. The 1995 Named Storm Days (NSD) value of 121 exceeds all previous years except 1933 (136). Thus, although 1995 was a very active year for hurricanes, a number of other seasons during the last 120 years were as active or nearly as active as this year.

3 Low latitude formation and track recurvature

In contrast with the previous four years (1991-1994) there was a sharp increase in the amount of low latitude hurricane formation events during 1995. Only two hurricanes formed equatorwards of 25°N during the four years 1991-1994. In contrast, no less than nine hurricanes formed equatorward of 25°N during 1995 - a 18 fold increase. Typically, it is hurricanes which form at low latitudes that cause the majority of the hurricane spawned destruction. In this regard, the US was very fortunate during the unusually active 1995 hurricane season. The location of a persistent mid- and upper-tropospheric trough along the US East Coast imposed mean upper level cyclone steering winds which were more from the south than usual. This circulation feature caused the majority of this season's hurricanes and tropical cyclones to turn more northward and then northeastward into the westerly winds before they had a chance to reach the US mainland. This trend is nicely illustrated in the multiple cyclone track map in Figure 1. Although hurricanes Allison and Erin made landfall on the US, it was only hurricane Opal which brought major damage and destruction to the US mainland. In other, less active hurricane seasons a similar East Coast trough pattern may not be present and the possibility of hurricane damage may be much higher. The West Indies and Mexico were much less fortunate than the US mainland. Intense hurricanes, Luis, Marilyn and Roxanne caused a great deal of destruction, particularly to the US Virgin Islands.

4 Timing of 1995 Seasonal Activity

Tropical cyclone formation during the very active 1995 hurricane season can be seen to have occurred in two active 30 day periods (28 July - 29 August and 27 September - 27 October) strattling an inactive 30-day (29 August - 27 September) period at the very climatological center of the hurricane season when only one named storm (intense hurricane Marilyn; September 12-22) formed. Figure 2 shows these two active periods of tropical cyclone formation with the lull of activity in between.

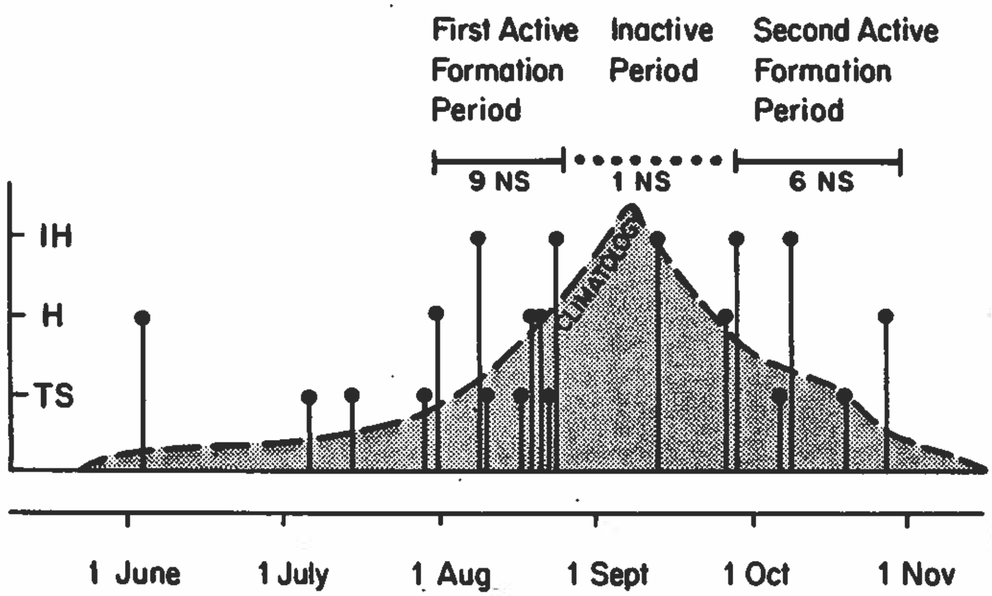

Figure 2: Time line showing the dates when the 19 named storms of 1995 were first named. The development of these storms tended to occur during two active periods (28 July-28 August, and 27 September-27 October), on either side of a relatively inactive period between 29 August and 26 September.

Tropical cyclone activity in 1995 began early when hurricane Allison formed in the Eastern Gulf of Mexico during early June. Two named storms (Barry and Chantal) formed during the first half of July. But what was most distinctive about the 1995 hurricane season was the nine named storms (Dean, Erin, Felix, Gabrielle, Humberto, Iris, Jerry, Karen and Luis) which formed during the 28 day period between 31 July and 27 August. This is equivalent to a new named storm formation about every three days. Of these nine named storms, five became hurricanes (Erin, Felix, Humberto, Iris and Luis) and two became intense category 4 hurricanes (Felix and Luis).

It was during this August period when the West Atlantic environmental conditions became ideal for tropical cyclone formation. Sea level pressure and tropospheric wind shear conditions in the Western Atlantic were both about two standard deviations below August average conditions (see Tables 9 and 10). After 27 August there was a sharp 30-day downturn in new name storm formation. Between August 27, when Luis was named, and September 27 when Noel and Opal were named, only one new system - intense hurricane, Marilyn, formed. Such a sharp 30-day downturn in new formations is typical of active hurricane seasons. It is common to have a clustering of tropical cyclone activity over 20-30 day periods interspersed with similar 20-30 day periods when new tropical cyclone formation becomes much less frequent. It is to be noted that the downturn of hurricane activity during the 1995 season occurred during the climatological height of the hurricane season in September. September is the month usually experiencing the largest numbers of tropical cyclone formations; the peak of the hurricane season being September 10th. The general September downturn in new name storm formation is well associated with changes to less favorable environmental conditions. Higher sea level pressure anomalies and increased Western Tropical Atlantic wind shear conditions developed during much of September 1995.

The second burst of new name storm formation occurred between 27 September and 27 October when six additional new name storms formed. Of these new storms four became hurricanes and two became intense hurricanes (Noel - H, Opal - IH, Pablo - TS, Roxanne - IH, Sebastien - TS and Tanya - H). It was in late September and October when western Atlantic sea level pressure and tropospheric vertical wind shear were again reduced.

5 Factors Known to be Associated With Atlantic Seasonal Hurricane Variability

Seasonal hurricane forecasts are 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 3 provides a summary of the locations of the various parameters which go into our seasonal forecast. Successive sets of values of these predictive factors are obtained, first during late November of the previous year and then updated during early June of the concurrent year (the official start of the hurricane season) and during early August (just before the start of the active portion of the hurricane season). These predictive factors include the following:

(a) The stratospheric Quasi-Biennial Oscillation (QBO) influence. 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 the equatorial stratospheric winds at 30 mb and 50 mb (23 and 20 km altitude, respectively) are more westerly as compared to when they are from a more easterly direction. During the 1995 season, these QBO winds were from a relative westerly direction. This was an enhancing influence for this season's hurricane activity.

(b) El Niño-Southern Oscillation (ENSO) influence: ENSO characterizes the sea surface temperature anomalies in the eastern equatorial Pacific and the value of Tahiti minus Darwin (Fig. 3) surface pressure gradient. The effects of a moderate or strong El Niño (warm Nino-3 water and low values of Tahiti minus Darwin sea level pressure difference) event in the eastern equatorial Pacific are to reduce Atlantic basin hurricane activity. By contrast, in those seasons with cold Nino-3 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

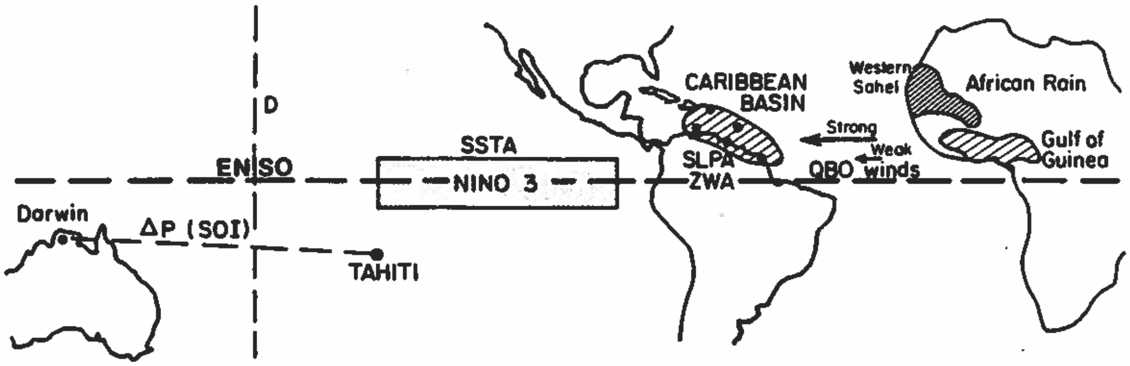

Figure 3: Locations of meteorological parameters used in the seasonal hurricane forecasts.

related to alterations of upper tropospheric (200 mb or 12 km) westerly winds and surface pressure over the Caribbean Basin and western Atlantic. Westerly winds are enhanced during El Niño seasons and this condition creates strong vertical wind shear over the Atlantic, inhibiting hurricane activity. During La Niña (or cold) years, westerly upper-tropospheric winds and the associated vertical wind shear are reduced and hurricane activity is typically greater. The unusually persistent 1991-94 El Niño-like conditions finally ran their course and neutral to cold water conditions settled into the equatorial Pacific during August and September of this year, thereby becoming an enhancing influence on this year's Atlantic basin hurricane activity.

(c) African Rainfall (AR) influence: The incidence of intense Atlantic hurricane activity is strongly enhanced during those seasons when rainfall during June-July in the Western Sahel is above average and when August-November rainfall in Gulf of Guinea region during the prior year (shaded area in Fig. 4) is above average. Hurricane activity is typically suppressed if the rainfall in these two regions was below average. Rainfall amounts for both the Western Sahel and the Gulf of Guinea were near average for 1995. This did not cause a suppression of this year's hurricane activity as has occurred in most of the last 25 hurricane seasons.

(d) Influence of West Africa west-to-east surface pressure and temperature gradients (Δ PT). We find that Atlantic hurricane activity is enhanced when the February to May east minus west (Region B minus Region A in Fig. 5) pressure gradient in West Africa is higher than normal and/or when the east minus west temperature gradient anomaly is below average. These February through May 1995 pressure and temperature gradients indicated a forthcoming average North African monsoon with a near average amount of seasonal hurricane activity – not the distinctly below average conditions as occurred during most of the last quarter century.

(e) Caribbean Basin Sea Level Pressure Anomaly (SLPA) and upper tropospheric (12 km) Zonal Wind Anomaly (ZWA) influence. SLPA and ZWA have a strong association with Atlantic Basin hurricane activity. Values of SLPA and ZWA for 1995 were both below average, indicating an enhancing influence on this season's hurricane activity.

6 Why 1995 was Such an Active Hurricane Season

Nearly all of the climate forecast parameters which we use to forecast Atlantic Basin hurricane activity took on positive (for hurricane activity) values during 1995, thereby contributing to the

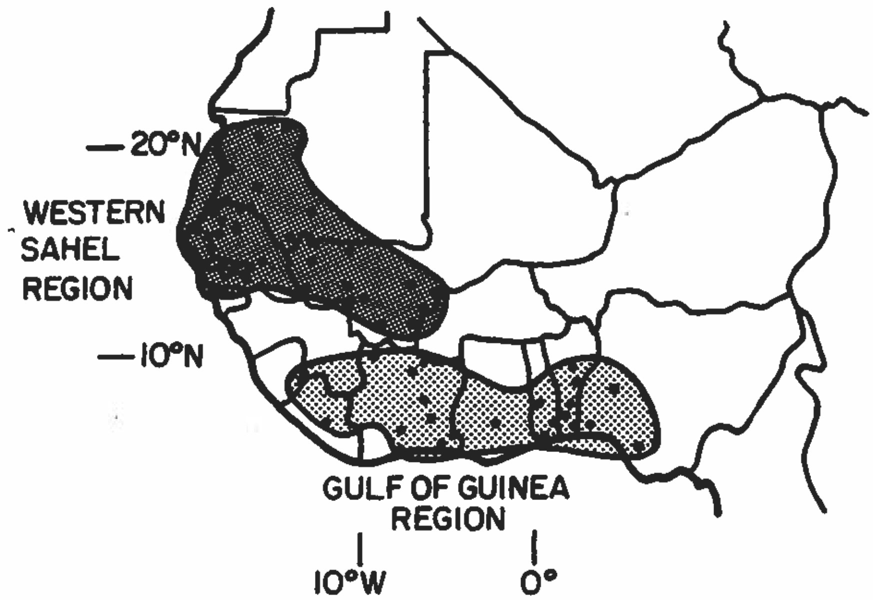

Figure 4: Locations of rainfall stations which make up the 38–station Western Sahel precipitation index and the 24-station Gulf of Guinea precipitation index. August to November rainfall within the Gulf of Guinea region provides a predictive signal for the following years hurricane activity as does prior year August-September rainfall in the Western Sahel.

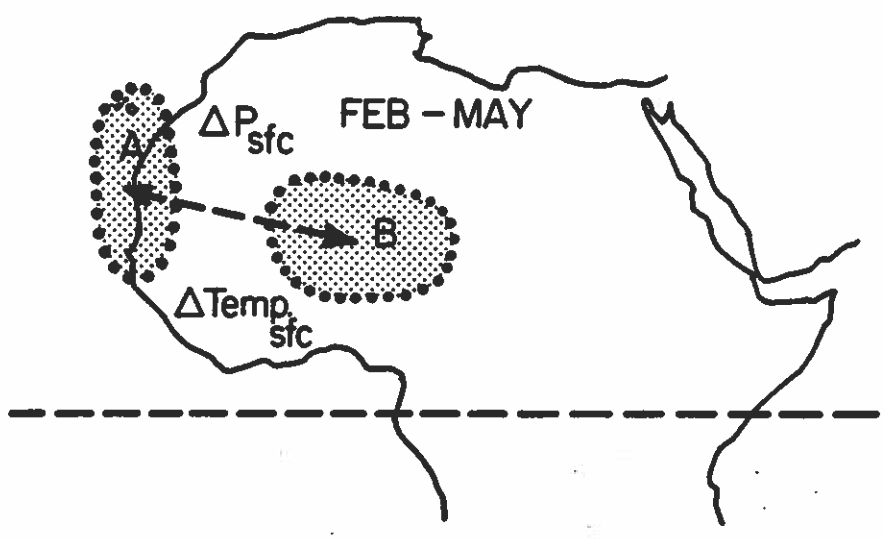

Figure 5: Map showing the two West African regions—west (Area A) and east (Area B)—from which multi-station surface pressure and temperature values are obtained to assess the west-to-east pressure and temperature gradients or Δ PT parameter.

unusually active hurricane season. These are listed in Table 5. The favorable factors for hurricane enhancing climate were:

1. The westerly stratospheric QBO
2. Dissipation of a persistent El Niño and the return of cooler East Pacific sea surface temperature conditions.
3. Lack of a drought in the Western Sahel region.
4. Much below average sea-level pressure in the Caribbean Basin.
5. Eastern 200 mb zonal wind anomalies over the tropical Atlantic.

Table 5: Listing and specific values for 1995 environmental conditions during August and September 1995 which contributed to very high hurricane activity.

1. QBO Relative Winds at 10-15°N	30 mb 50 mb	+10 m/s +11 m/s
2. Nino-3 SSTA		−0.57°C
3. June-Sept Western Sahel rainfall		−0.48 SD
4. Caribbean Basin Sea-level Pressure Anomaly (SLPA)		−1.5 mb
5. Caribbean Basin 200 mb Zonal Wind Anomaly		−4.0 m/s

Other Predictive Factors Which Indicated an Active Hurricane Season for 1995

Besides these major climate factors there were other factors not explicitly included in our forecast which also indicated that an active hurricane season was in store for 1995. This included:

1. The usually warm SSTA conditions off of the Northwestern African coastline which extended far westward to near Bermuda.
2. Lower Atlantic sub-tropical pressure anomaly and weaker than normal Atlantic tradewind conditions.
3. A stronger than normal 200 mb tropical easterly jet extending westward across the Atlantic from Africa.
4. Stronger than normal tropical wave activity coming out of West Africa.
5. Higher surface layer salinity contents in the far North Atlantic, indicating a possible speed-up of the Atlantic Ocean thermohaline circulation.
6. High amount of India, Indonesia, and general Asian monsoon rainfall indicating that a return to cooler ENSO conditions was likely in progress.
7. Lower than normal Singapore 100 mb temperature anomalies during the summer and fall of 1994.

   These additional factors added support for further justification as to why 1995 was such an active hurricane season.

7 Details and Specific Values for the 1995 Seasonal Hurricane Predictors

a) ENSO

An El Niño like warm water event began forming in the tropical Pacific in late 1989 and El Niño-like conditions persisted in a complicated and somewhat variable mode until the spring of 1995 at which time, an ongoing cooling finally began to emerge. Table 6 provides a tabular summary of Nino-3 sea surface temperature anomaly (SSTA) conditions for the last six years. It is unusual to have El Niño like conditions persist through five consecutive summers. These warm ENSO conditions, as shown in Table 6, have finally dissipated.

Table 6: Sea surface temperature anomalies (SSTA) (°C) in the equatorial Pacific of NINO-3 during the years of 1990-1995 and anticipated SSTA conditions through November 1996. Note cooling has been present since April 1995.

NINO3 (5°N to 5°S, 90-150°W)

Year	J	F	M	A	M	J	J	A	S	O	N	D
1990	0.4	0.3	0.5	0.6	0.3	0.0	0.1	0.2	0.2	0.0	0.2	0.4
1991	0.4	0.2	0.3	0.4	1.0	1.3	1.0	0.5	0.6	0.8	1.1	1.2
1992	1.5	1.4	1.3	1.4	1.6	0.7	0.1	–0.2	0.1	–0.1	0.0	0.0
1993	0.1	0.3	0.8	1.2	1.7	0.8	0.3	0.0	0.3	0.4	0.3	0.3
1994	0.4	0.0	0.1	0.2	0.4	0.4	-0.2	–0.1	0.2	0.7	1.1	1.2
1995	1.0	0.7	0.2	–0.2	–0.4	–0.1	0.0	–0.5	–0.5	–0.6	(–0.7) est.	—
1996	⟵		Expected to continue on the cool side								⟶	

b) Stratospheric QBO Winds

Tables 7 and 8 show both the absolute and relative (i.e., anomaly) values for 30 mb (23 km) and 50 mb (20 km) stratospheric QBO zonal winds near 12°N during March through October 1995. During all of the 1995 hurricane season, QBO winds were from the relatively westerly direction. These QBO wind conditions were an enhancing influence on this year's hurricane activity.

c) Sea-Level Pressure Anomaly (SLPA)

Table 9 gives information on regional Caribbean basin and Gulf of Mexico SLPA during the 1995 season. Note that all stations had quite low SLPA during the months of August through October. During the crucial August-September 1995 period, observed surface pressure values were close to the lowest values observed during the last 45 years. These unusually low August-September surface pressure anomalies for all hurricane months are very consistent with the large amount of tropical cyclone activity which occurred this year.

Of all the parameters which modify Atlantic seasonal hurricane activity, variations of Caribbean SLPA is one of the strongest. Only tropospheric vertical wind shear is more important. Observations show that summertime Caribbean basin variations in SLPA are independent of ENSO and the QBO. Although SLPA is typically inversely related to western Sahel rainfall, this relationship explains only a small portion of the SLPA variations. We are presently attempting to develop independent methods for making separate predictions of SLPA at both the extended and short range lead times. There appears to be methods for predicting seasonal Caribbean basin SLPA with skill from precursor pressure anomalies in other parts of the globe.

Table 7: Observed March through October 1995 absolute values of stratospheric QBO zonal winds (U) in the (critical) latitude belts between 11-13°N, as obtained from Caribbean stations at Curacao (12°N), Barbados (13°N), and Trinidad (11°N). Values are in ms^{-1} (as supplied by James Angell and Colin McAdie).

	Observed							
Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	+6	+5	0	−6	−7	−5	−6	−7
50 mb (20 km)	+4	+4	+2	−3	−5	−3	+2	+4

Table 8: As in Table 7, but for the "relative" (or anomalous) zonal wind values wherein the annual wind cycle has been removed. Values are in ms^{-1}.

	Observed							
Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	+10	+13	+14	+11	+14	+13	+10	+6
50 mb (20 km)	+3	+5	+8	+10	+11	+10	+12	+11

Table 9: Lower Caribbean basin SLPA for 1995 in mb (for San Juan, Barbados, Trinidad, Curacao and Cayenne) - top row and for the Caribbean-Gulf of Mexico. Brownsville, Miami, Merida (Mexico), San Juan, Curacao and Barbados - bottom row (as kindly supplied by Colin McAdie of NHC in combination with our CSU analysis).

	April	May	June	July	August	September	October
5-station Lower Caribbean Ave. SLPA	−0.9	+0.5	−0.2	−1.2	−1.3	+0.3	−0.2
6-station Caribbean plus Gulf of Mexico Ave. SLPA	−1.4	−0.4	−0.8	−1.2	−2.9	−0.3	−1.4

The reduction of hurricane activity due to high pressure in the tropical Atlantic appears to occur in two ways. High Caribbean pressure indicates an equatorward (i.e., southward) shift of the Intertropical Convergence Zone (ITCZ). This condition in turn causes greater subsidence in those Western Atlantic areas into which easterly waves move. Higher pressure also is associated with stronger upper tropospheric zonal winds which act to adversely shear potentially developing systems. It is noted that movement of cloud clusters and easterly waves to a more southerly latitude is less favorable for hurricane formation.

High pressure is also indicative of enhanced Caribbean basin and West Atlantic subsidence and drying. Higher pressure drives stronger low-level divergence and subsidence. This lowers the height of the moist layer and sharpens the trade-wind inversion. Figure 6 indicates how such subsidence makes it more difficult for easterly waves to intensify into named storms. This year subsidence in the western Atlantic was weaker than normal. The upper Caribbean basin and Florida experienced very heavy rain conditions during the summer of 1995, in large measure because of the low-pressure anomaly conditions. High surface pressure is related to greater rates of tropospheric subsidence and low-level divergence. Such large rates of subsidence lead to enhanced tropospheric drying and humidity decrease. A stronger ~ 2-3 km high tradewind inversion also develops during high pressure periods. These responses to higher pressure conditions make the development of pre-cyclone weather systems and/or the intensification of already developed systems more difficult. Stronger synoptic forcing influences such as easterly wave induced upward vertical motion is required to overcome these more adverse higher subsidence and higher pressure influences. When surface pressure is lower, the opposite influences are present and cyclone development and cyclone enhancement can occur with less synoptic scale and easterly wave vertical motion forcing.

d) Zonal Wind Anomalies (ZWA)

Table 10 shows that the upper tropospheric Zonal Wind Anomalies (ZWA) were very negative and hence comparatively favorable for 1995 seasonal hurricane activity.

Table 10: 1995 Caribbean basin 200 mb (12 km) Zonal Wind Anomaly (ZWA) in ms^{-1} (as supplied by Colin McAdie of NHC and in combination with CSU data) for the four stations of Kingston (18°N), Curacao (12°N), Barbados (13.5°N), and Trinidad (11°N).

	April	May	June	July	August	September	October
Average ZWA	–2.5	–0.5	–1.6	–4.3	–7.0	–4.1	–0.8

e) African Western Sahel Rainfall in 1995

African Western Sahel rainfall is a very powerful modulator of Atlantic hurricane activity, particularly for intense category 3-4-5 hurricane activity. This direct relationship between Western Sahel rainfall and intense hurricane activity is one of the most powerful of the climate relationships. Typically, when many category 3-4-5 hurricanes form (as in 1995) the Western Sahel would be expected to be wet. This was not the case this year. Overall, the African Sahel had slightly below average rainfall in the Western Sahel.

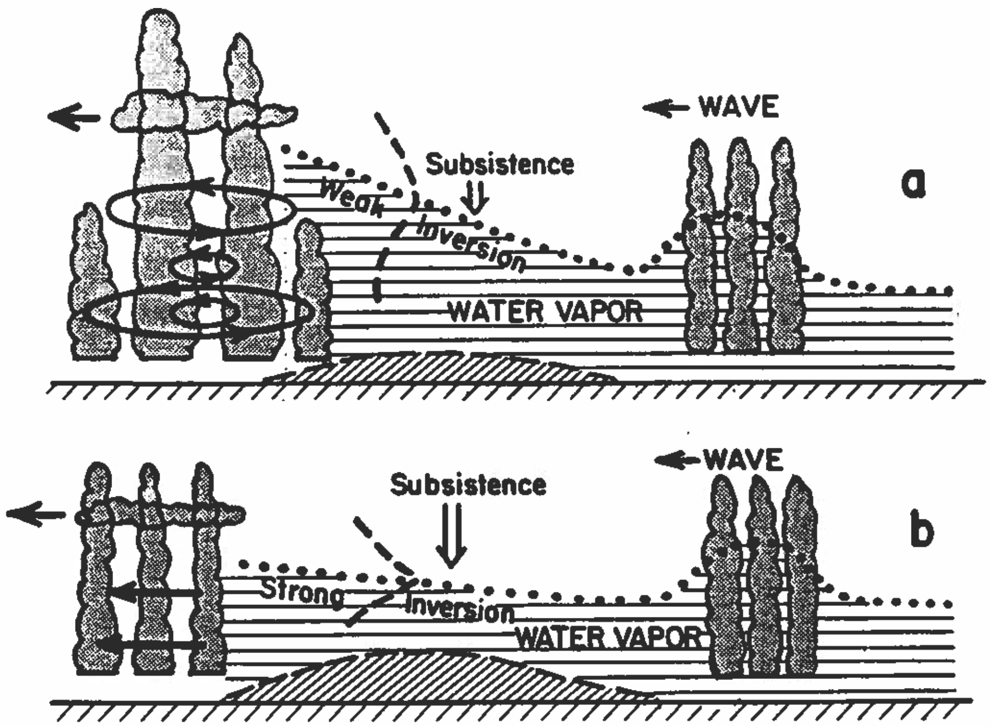

Figure 6: Idealized schematic of an Atlantic easterly wave disturbance moving westward from Africa into the central and western Atlantic Ocean near 15°N latitude during late summer. In the top diagram (a) only weak surface pressure and weak subsidence drying conditions exist. A weak trade wind inversion is present. The top of the moisture level is high enough such that the wave's upward vertical motion is able to overcome the subsidence drying and a hurricane is able to form. The top diagram was typical of 1995. In the bottom diagram (b) surface pressure and subsidence are stronger than normal, the height of the moist level is lower than normal and the trade wind inversion is stronger. The wave's upward vertical motion cannot overcome these adverse influences. The westward moving easterly wave disturbance of diagram (b) is not able to transform itself into a tropical storm or hurricane and continues to move to the west as a cloud cluster. The bottom diagram is more typical of 1994.

8 Unity of Forecast Parameters for Tropospheric Vertical Wind Shear

The most fundamental requirement for active hurricane seasons is that there be little change (shearing) of wind direction and speed between the 1 km (~ 3000 ft) and 12 km (~40,000 ft) levels. Most of the global and regional factors (just discussed) associated with either active or inactive Atlantic basin hurricane seasons can be related directly or indirectly to physical processes which govern deep western tropical Atlantic vertical wind shear. For example,

1. cold or La Niña surface ocean temperature conditions in the equatorial east Pacific are associated with small values of western tropical Atlantic vertical wind shear.
2. Above average rainfall in West Africa is associated with weaker Western Atlantic 1-12 km wind shear and below average rainfall conditions with higher values of tropospheric wind

shear.

3. Lower than normal West Atlantic surface pressure is also well related to weaker values of vertical wind shear, higher than normal pressure to larger vertical wind shear.

4. Warm values of sea surface temperature off the west coast off Africa are well related to weaker tradewinds and indirectly to weaker values of tropospheric vertical wind shear and with cold SST conditions, the opposite occurs.

5. Other global circulation parameters including the Singapore 100 mb (16 km altitude) Temperature Anomaly (TA), the stratospheric Quasi-biennial Oscillation (QBO) wind changes, Calcutta, India surface pressure anomaly, Western African east-west surface temperature and pressure gradients during February through May (and other parameters variations) have less direct but nevertheless meaningful associations with tropical western Atlantic 1 to 12 km vertical wind shear.

During 1995, nearly all of the above factors which influence West Atlantic tropospheric vertical wind shear were in place so as to bring about favorable reduction of vertical wind shear conditions allowing frequent western Atlantic tropical cyclone formation. Some of these favorable environmental associations were not included in our 1995 forecast equations and this may be the main reason that our forecast equations fell short of specifying the full extent of this season's extremely active hurricane season.

9 Contrast of 1994 and 1995 Hurricane Seasons

There could not be two hurricane seasons more different than 1994 and 1995. During 1994 there were no hurricanes at all for 77 consecutive days during the height of the hurricane season. And, two of the three hurricanes that did form in 1994 did so during November, a month with typically little or no activity. No hurricanes formed during November 1995. The contrast of environmental conditions during these two seasons offers a good explanation as to why these two seasons were so different. Table 11 shows the contrasts in western Atlantic surface pressure and 200 mb ($\sim$ 40,000 ft) zonal wind differences between these two seasons. Note in the top panel that persistent easterly 200 mb wind anomalies during 1995 replaced the westerly anomalies that occurred throughout most of 1994. The 1994 pressure conditions were the highest of the last 50 years whereas the 1995 surface pressure was close to being the lowest of the last 50 years. That tropical cyclone conditions would be so different between these two seasons is no accident.

It has been known for many years that sea level pressure is associated with powerful modifications of seasonal hurricane activity. The very active hurricane years of 1969, 1961, 1955, 1950 and 1933 were also years of very low western tropical Atlantic surface pressure. Much of the influence of surface pressure is associated with vertical wind shear, tropospheric moisture and low-level divergence.

Some may argue that the August-October surface pressure differences were a result of the cyclones themselves and not environmental differences. This is not true as tropical cyclones neither cover a large enough area nor last long enough to be responsible for the very low surface pressures observed during the 1995 hurricane season - only a small portion of this pressure drop may be so explained. No tropical cyclones came close to the measurement stations of Trinidad, Curacao, and Cayenne.

Table 11: (a) Differences in ZWA and (b) Caribbean basin-Gulf of Mexico SLPA between 1994 and 1995.

a.

Lower Caribbean Zonal Wind Anomalies
Trinidad, Barbados, Curacao, Kingston, Balboa

	April	May	June	July	August	September	October
1994	+1.2	+1.3	+1.0	−1.0	−1.2	+3.8	+0.6
1995	−2.5	−0.5	−1.6	−4.3	−7.0	−4.1	−0.8
Differences 1994 Minus 1995	+3.7	+1.8	+2.6	+3.3	+5.8	+7.9	+1.4

b.

SLPA (6-station — Brownsville, Miami, Merida, San Juan, Barbados, Curacao

	April	May	June	July	August	September	October
1994	+0.7	+0.6	+1.0	+1.0	+1.0	+1.5	−0.3
1995	−1.4	−0.4	−0.8	−1.2	−2.9	−0.3	−1.4
Differences 1994 Minus 1995	+2.1	+1.0	+1.8	+2.2	+3.9	+1.8	+0.9

10 The 1995 Hurricane Season and Global Warming

Some individuals will interpret the great upswing in 1995 hurricane activity as related in some way to increased man-induced greenhouse gases like carbon dioxide (CO_2). Such individuals are sometimes driven more from a political than a scientific agenda. There is no reasonable way that such an interpretation can be made. Man-induced greenhouse gas warming, even if a physically valid hypothesis, is a very slow and gradual process that, at best would only be expected to bring about small changes in global circulation over periods of 50 to 100 years. Not the abrupt and dramatic one year upturn in hurricane activity as occurred between 1994 and 1995. And, even if man induced greenhouse increases over the last 25 years were to be interpreted as causing global mean temperature increase over the last 25 years, there is no way to relate such small global temperature increases to intense Atlantic basin hurricane activity during this period. Atlantic intense (or category 3-4-5 hurricane activity) has shown a substantial decrease to only about 40 percent of the amount of intense hurricane activity which occurred 25-50 years ago. Intense hurricane activity in the Atlantic basin has shown a significant decrease while the globe has undergone a small mean temperature increase. We interpret most of this global mean temperature increase as resulting from natural and not from man-induced influences. The large increase in 1995 Atlantic hurricane activity is no mystery. It was the results of natural variations in global circulation patterns and we were able to predict a portion of this increase without invoking global warming or greenhouse gas increases. Therefore, **there is no plausible way that increases in man-induced greenhouse gases can be even remotely related to this year's extremely active Atlantic basin hurricane season.**

11 Verification of Authors' Forecast of the 1996 Hurricane Season

All of our 1995 hurricane forecasts were for an above average season. Our forecast of named storm days, hurricane days, and intense or major hurricane days, although calling for an above average season of all parameters, did not well specify how unusually active this season would become. Tables 12 and 13 show our 1995 hurricane forecasts for total seasonal activity which were issued on 30 November 1994, and 7 June 1995. Table 14 shows how our 4 August 1995 forecast of hurricane activity after 1 August 1995 has verified (see Gray et al. 1995a, 1995b). The first author made a qualitative adjustment to the 30 November 1994 forecast at the National Hurricane Conference in Atlantic City on April 14, 1995. This was based on a then false assessment of March ENSO and Atlantic sea surface temperature conditions. This qualitative downward adjustment of the 30 November 1994 forecast is also shown in Table 12. This was a mistake that will not be repeated; no qualitative adjustments to our forecasts will henceforth be made in the future. We are now planning to make a new seasonal hurricane forecast in early April which will be quantitatively based on meteorological data through March.

Despite our underprediction of the unusually high amounts of 1995 tropical cyclone activity, we were quite correct in anticipating a great upswing in 1995 activity from the very inactive 1991-94 seasons. We also correctly forecast the 1995 dissipation of the El Niño in November 1994. This was contrary to most El Niño forecasts of the time and most of those into the winter and spring of 1995. Here are a few excerpts from our forecast write-up of the 1995 season.

- From our 30 November 1994 forecast.

Table 12: Verification of our 1995 total seasonal hurricane predictions.

Forecast Parameter	30 Nov. 1994 Fcst	14 April Qualitative Adjustment	7 June Fcst	Verification
Named Storms (NS)	12	10	12	19
Named Storm Days (NSD)	65	50	65	121
Hurricanes (H)	8	6	8	11
Hurricane Days (HD)	35	25	35	62
Intense Hurricanes (IH)	3	2	3	5
Intense Hurricane Days (IHD)	8	5	6	12
Hurricane Destruction Potential (HDP)	100	75	110	172
Net Tropical Cyclone Activity (NTC)	140%	100%	140%	237%

Table 13: Verification of 4 August 1995 forecast for hurricane activity after 1 August.

Forecast Parameter	Climatology After 1 Aug	Forecast Activity After 1 Aug	After 1 Aug Verification
Named Storms (NS)	7.8	11	14
Named Storm Days (NSD)	41.4	49	105
Hurricanes (H)	5.1	7	9
Hurricane Days (HD)	21.4	27	59
Intense Hurricanes (IH)	2.0	3	5
Intense Hurricane Days (IHD)	4.4	5	12
Hurricane Destruction Potential (HDP)	64.4	84	166
Net Tropical Cyclone Activity (NTC)	86.0%	107%	214%

Table 14: Verification of 4 August 1995 forecast for total 1995 seasonal activity.

Forecast Parameter	Last 45-Year Average	Forecast Total Seasonal Activity	Verification
Named Storms (NS)	9.3	16	19
Named Storm Days (NSD)	46.1	65	121
Hurricanes (H)	5.7	9	11
Hurricane Days (HD)	23.0	30	62
Intense Hurricanes (IH)	2.1	3	5
Intense Hurricane Days (IHD)	4.5	5	12
Hurricane Destruction Potential (HDP)	68.1	90	172
Net Tropical Cyclone Activity (NTC)	100	130	237

"The 1995 season should be much more active than the four recent 1991 through 1994 hurricane seasons, and especially in the tropical regions at latitudes south of 25N where only two short lived hurricane have occurred during the last four years. The character of 1995 season should tend toward that of the two recent hurricane seasons of 1988 and 1989 which produced a total of five intense or major hurricanes and 19 intense hurricane days."

"Implicit in this forecast is the anticipated dissipation of the long running equatorial Pacific warm water event which has now persisted for over four consecutive years. Our extended range ENSO prediction scheme forecasts a NINO-3 sea surface temperature anomaly of –0.74°C for the August-October 1995 period. The inhibiting influence on hurricane activity of warm equatorial Pacific water temperatures for next year is thus felt to be very low. Consequently, hurricane activity should be higher."

(The Nino-3 water temperature were only slightly warmer than our forecast).

- From our 5 June 1995 forecast.

  "Past records indicate that it is typical to have a number of suppressed or somewhat below normal years in a row which are then followed by a year of greatly increased hurricane activity. It appears that 1995 will be one of those seasons wherein a large upsurge in hurricane activity occurs.

  The El Niño, stratospheric QBO, West African rainfall, and Atlantic sea surface temperature anomalies are all coming together to promote the large-scale wind and thermal-moisture conditions which are associated with an active season.

  The probability of hurricane activity within the Gulf of Mexico will be higher during 1995 than it has been since 1989.

  There has been no hurricane activity at all within the Caribbean during the last five years. This is a consequence of the long lasting El Niño event of 1991-94, Western Sahel drought conditions during 1990-93 and higher than average Caribbean basin surface pressures during the last five years. These inhibiting influences are not expected to be present during the 1995 season. Consequently, the probability of Caribbean basin hurricane activity will be greater this year than any of the last five years."

- From our 4 August 1995 forecast.

  "Most of those global and regional meteorological features which in the past have been associated with active Atlantic hurricane seasons are coming together this summer. There is a very high statistical probability that 1995 will experience a very active hurricane season."

12 Schedule of Atlantic Basin Seasonal Hurricane Forecasts for 1996

A seasonal forecast for the 1996 hurricane season will be issued on 30 November 1995 with regular updates coming on 5 April 1996, 6 June 1996, and 7 August 1996. A 1996 seasonal verification and a forecast of 1997 hurricane activity will be issued in late November 1996. In addition seasonal forecasts of late summer and fall 1997 ENSO conditions, the anticipated 1997 Sahel rainfall conditions will also be issued in late November, 1996.

13 Verification of Past Seasonal Forecasts

The first author has now issued seasonal hurricane forecasts for the last 12 years. In most of the prior forecasts, predictions have been superior to climatology, which was previously the only way to estimate future hurricane activity (see Table 15). The seven late May and early June seasonal forecasts for 1985, 1986, 1987, 1988, 1991, 1992 and 1994 were more accurate than climatology. The forecasts for 1984 and 1990 were only marginally successful and the two seasonal forecasts for 1989 and 1993 were failures. The 1989 forecast was a failure because of processes associated with the excessive amounts of rainfall which fell in the Western Sahel that year. Prior to 1990, our seasonal forecast did not include African rainfall as a predictor. We have corrected this important omission and forecasts since 1990 have incorporated Western Sahel rainfall estimates and we have developed a new Sahel rainfall prediction scheme by Landsea et al., 1994. The failure of the 1993 seasonal forecast is attributed to our failure to anticipate the resurgence and continuation of El Niño conditions through the whole of the 1993 hurricane season. In particular, the first author failed to anticipate the re-emergence of stronger El Niño conditions after the middle of August 1993. It is very unusual to have an El Niño last so long as the recent 1991-94 event. This failure motivated us to develop a new extended range ENSO prediction scheme (Gray et al., 1994b,c).

Acknowledgements

The authors are indebted to a number of meteorological experts who have furnished us with the data necessary to make this forecast or who have given us valuable assessments of the current state of global atmospheric and oceanic conditions. We are particularly grateful to John Sheaffer and John Knaff for their very penetrating climate discussions and data inputs. We are also grateful to Colin McAdie who has furnished much data necessary to make this forecast and to Vern Kousky, Gerry Bell, James Angell and Richard Larson for helpful discussion. The authors have also profited from indepth interchange with his project colleagues Ray Zehr, Patrick Fitzpatrick and James Kossin. William Thorson and Richard Taft have provided valuable computer assistance. We wish to thank Tom Ross of NCDC, Wassila Thiao and Vadlamani Kumar of the African Desk of CPC who provided us with West African and other meteorological information. Douglas LeCompte of USDA has provided us with continuous African rainfall summaries. Barbara Brumit and Amie Hedstrom have provided manuscript and data reduction assistance. We appreciate receiving the UK Meteorological Office experimental forecasts of this summer's Sahel precipitation. We have profited over the years from many indepth discussions with most of the current NHC hurricane forecasters. These include Lixion Avila, Miles Lawrence, Max Mayfield, Richard Pasch and Edward Rappaport. The first author would further like to acknowledge the encouragement he has received over recent years for this type of forecasting research applications from Neil Frank and Robert Sheets, the former directors of the National Hurricane Center (NHC) and from Jerry Jarrell, Deputy NHC director. We look forward to a beneficial association with the new director, Robert Burpee.

This research analysis and forecast has been supported by research grants from the National Science Foundation (NSF) and National Atmospheric and Oceanic Administration (NOAA) National Weather Service and Climate Prediction Center.

14 References

Aagaad, K., 1995: The fresh water flux through Fram Strait: A variable control on the thermohaline circulation. NOAA sponsored Atlantic climate conveyor belt project meeting, 2-4 May, Miami, FL.

Gray, W. M., 1984a: Atlantic seasonal hurricane frequency: Part I: El Niño and 30 mb quasi-biennial oscillation influences. *Mon. Wea. Rev.*, 112, 1649-1668.

Gray, W. M., 1984b: Atlantic seasonal hurricane frequency: Part II: Forecasting its variability. *Mon. Wea. Rev.*, 112, 1669-1683.

Gray, W. M., 1990: Strong association between West African rainfall and US landfall of intense hurricanes. *Science*, 249, 1251–1256.

Gray, W. M., 1994a: Summary of 1994 Atlantic tropical cyclone activity and verification of author's seasonal prediction. Dept. of Atmos. Sci. Report, Colo. State Univ., Ft. Collins, CO, 21 pp.

Gray, W. M., 1994b: Extended range forecast of Atlantic hurricane activity for 1995. Dept. of Atmos. Sci. Report, Colo. State Univ., Ft. Collins, CO, 9 pp.

Gray, W. M., 1995: Early April 1995 assessment of the forecast of Atlantic basin seasonal hurricane activity for 1995 (which was issued 30 November 1994). Report for the 17th National Hurricane Conference, Atlantic City, NJ, 11-14 April.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1992: Predicting Atlantic seasonal hurricane activity 6–11 months in advance. *Wea. Forecasting*, 7, 440-455.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1993: Predicting Atlantic basin seasonal tropical cyclone activity by 1 August. *Wea. Forecasting*, 8, 73-86.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1994a: Predicting Atlantic basin seasonal tropical cyclone activity by 1 June. *Wea. Forecasting*, 9, 103-115.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1995: Forecast of Atlantic seasonal hurricane activity for 1995 (as of 7 June 1995). Dept. of Atmos. Sci., Colo. State Univ., Ft. Collins, CO, 23 pp.

Landsea, C. W., 1991: West African monsoonal rainfall and intense hurricane associations. Dept. of Atmos. Sci. Paper, Colo. State Univ., Ft. Collins, CO, 272 pp.

Landsea, C. W., 1993: A climatology of intense (or major) Atlantic hurricanes. *Mon. Wea. Rev.*, 121, 1703-1713.

Landsea, C. W. and W. M. Gray, 1992: The strong association between Western Sahel monsoon rainfall and intense Atlantic hurricanes. *J. Climate*, 5, 435–453.

Landsea, C. W., W. M. Gray, P. W. Mielke, Jr., and K. J. Berry, 1992: Long-term variations of Western Sahelian monsoon rainfall and intense U.S. landfalling hurricanes. *J. Climate*, 5, 1528–1534.

Landsea, C. W., W. M. Gray, P. W. Mielke, Jr., and K. J. Berry, 1994: Extended range prediction of West African Sahel rainfall for June-September 1995. Dept. of Atmos. Sci. Report, Colo. State Univ., Ft. Collins, CO, 9 pp.

Mielke, P., K. Berry, C. Landsea and W. Gray, 1995: Artificial skill and validation in meteorological forecasting. Conditionally accepted to *Wea. Forecasting*, 10.

UK Meteorological Office, 1995: Preliminary experimental forecast of 1995 seasonal rainfall in the Sahel and other regions of tropical North Africa. May 1994, 4 pp.

Table 15: Verification of the authors' previous seasonal predictions of Atlantic tropical cyclone activity for 1984-1994.

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	10
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		24
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	68
Hurr. Destruction Potential(HDP)	90	75	57
Major Hurricanes (Cat. 3-4-5)	3	2	1
Major Hurr. Days	Not Fcst.	5	1.00

Table 15: Continued.

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	23
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	38
Hurr. Destruction Potential(HDP)	35	35	35	51
Major Hurricanes (Cat. 3-4-5)	1	1	1	1
Major Hurr. Days	2.0	2.0	2.0	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)	85	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	37

APPENDIX A

DERIVED MEASURES OF SEASONAL HURRICANE ACTIVITY

Measures of seasonal tropical cyclone activity include the seasonal total number of named storms (NS), hurricanes (H), intense (or major) hurricanes (IH), named storm days (NSD), hurricane days (HD), intense hurricane days (IHD), and hurricane destruction potential (HDP). Definitions of these hurricane indices are given at the beginning of this report. More detailed information is contained in Gray et al. (1992, 1994) and in Landsea (1993). In view of this complexity, it is desirable to define a single number which provides a simple but comprehensive expression of net season tropical cyclone activity in terms of a percentage difference from a long term mean. To this end, we propose a new parameter of seasonal activity termed the "Net Tropical Cyclone activity" (NTC) which is defined as:

$$NTC = (\%NS + \%H + \%IH + \%NSD + \%HD + \%IHD)/6$$

where each of six of the percentage departure values from the long term means are used as measures of seasonal activity. The NTC value is useful as a measure of seasonal tropical cyclone activity because it combines most of the other tropical cyclone parameters of interest into a single index. There are many seasons during which a single parameter, say for example, the number of hurricanes, is not well representative of the actual character of the overall tropical cyclone activity for that year. This single index has the highest forecast skill. Table 16 lists the values of NTC for 1950-1994.

Table 16: Listing of Seasonal Net Tropical Cyclone activity (NTC) values between 1950-1995.

Year	NTC (%)	Year	NTC (%)	Year	NTC (%)
1950	243	1965	86	1980	135
1951	121	1966	140	1981	114
1952	97	1967	97	1982	37
1953	121	1968	41	1983	32
1954	127	1969	157	1984	77
1955	198	1970	65	1985	110
1956	69	1971	95	1986	38
1957	86	1972	28	1987	48
1958	140	1973	52	1988	121
1959	99	1974	76	1989	140
1960	101	1975	92	1990	104
1961	222	1976	85	1991	59
1962	33	1977	46	1992	62
1963	116	1978	86	1993	55
1964	168	1979	96	1994	37
				1995	237

Other measures of seasonal tropical cyclone activities include Hurricane Destruction Potential (HDP) and Maximum Potential Destruction (MPD). HDP in 10^4 knots^2, MPD in 10^3 knots^2. Table 17 includes these values over the last 46-year period.

Table 17: Hurricane Destruction Potential (HDP) and Maximum Potential Destruction (MPD) between 1950-1995.

Year	HDP	MPD	Year	HDP	MPD	Year	HDP	MPD
1950	200	130	1965	73	38	1980	126	86
1951	113	80	1966	121	65	1981	18	29
1952	70	59	1967	98	54	1982	18	29
1953	59	81	1968	18	28	1983	8	22
1954	91	66	1969	110	120	1984	42	53
1955	158	103	1970	18	57	1985	61	73
1956	39	46	1971	65	72	1986	23	29
1957	66	46	1972	14	22	1987	11	28
1958	94	82	1973	24	39	1988	81	82
1959	60	59	1974	46	49	1989	108	77
1960	72	53	1975	54	65	1990	57	65
1961	170	106	1976	65	51	1991	23	43
1962	26	30	1977	18	44	1992	51	48
1963	103	61	1978	40	60	1993	23	33
1964	139	88	1979	73	59	1994	15	27
						1995	158	1247