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SUMMARY OF 1994 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S SEASONAL PREDICTION

(A year of unusually light hurricane activity due to very high values of West Atlantic surface pressure, an easterly QBO and continuance of El Niño-like warm water conditions in the equatorial Pacific)

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HURRICANES, THE WORLD SERIES, AND THE FIELD OF DREAMS

The World Series was canceled this year.
It was also cancelled in 1904 when
John McGraw's Giants refused to play Boston.
Both years were very low in hurricanes
(2 in 1904, 3 this year) - as was 1901
(3 hurricanes) and 1902 (3 hurricanes)
the only other years that the series was
not played since the establishment of both
major leagues.

"Cancel it and they (Hurricanes) will go".

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.

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 ($\sim$ 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.

ABSTRACT

This paper summarizes the tropical cyclone (TC) activity which occurred in the Atlantic Basin during 1994 and verifies the author's seasonal forecast of this activity which was initially issued on 19 November of last year with updates on 5 June and 4 August of this year.

The 1994 hurricane season was unusual in view of (1) the very suppressed activity during the height of the season, between late August and early November, and (2) the very active November when two hurricanes formed. There were a total of seven named storms (average 9.3) and three hurricanes (average 5.7) which lasted a total of seven days (average is 23). There were no major (intense) hurricanes of Saffir/Simpson category 3-4-5 (average is 2.1 intense hurricanes with 4.5 average intense storm days). The seasonal total of named storm days was 28 or, 61 percent of average. Net tropical cyclone (NTC) activity was only 37 percent of the average of the last 45 years. Three systems, tropical storms Alberto, Beryl and Gordon, affected the US southeast coast; Alberto brought devastating floods to western central Georgia.

The author's extended range forecast, issued on 19 November of last year, called for a slightly above average hurricane season; this 9-11 month lead time forecast did not verify. The anticipated end of the unusually long running El Niño (since 1990) did not occur as expected. El Niño-like conditions persisted through the 1994 hurricane season and continued the suppression of hurricane activity as has occurred during each of the last four seasons. In addition, very high and unexpected surface pressure values developed over the western Atlantic during most of the 1994 season. The author's early June and early August updated forecasts, by contrast, showed considerable forecast skill. They accommodated the continuance of the El Niño and, in part, the higher surface pressure. They called for diminished overall hurricane conditions of only 70 and 50 percent of climatology. But hurricane activity was lighter yet. This lack of hurricane activity during 1994 was primarily the result of three factors: (1) strong and persistent high surface pressure conditions which occurred this year in the Caribbean basin and western Atlantic, (2) easterly lower stratospheric QBO winds, and (3) continued warm equatorial Pacific El Niño conditions. North Africa's West Sahel rainfall conditions were near average for this year and not thought to have been a significant factor in this year's diminished hurricane activity.

1 Summary of 1994 Atlantic Tropical Cyclone Activity

The 1994 Atlantic hurricane season officially ends on 30 November. There were three hurricanes (maximum sustained wind >73 mph) and seven hurricane days during the 1994 season. The total named storms (or the sum of the number of hurricanes and tropical storms) was seven, yielding 28 named storm days. There were no major or intense hurricanes this season and all designated tropical cyclone parameters were much below the long period average. Figure 1 and Table 1 show the tracks and statistical summaries, respectively, for all 1994 Atlantic named storms. Table 2 contrasts the tropical cyclone statistics for this season with recent past seasons and with climatology. During the last four hurricane seasons, only two hurricanes have formed equatorwards of 25°N; these were Hurricane Gert of 1993 and Hurricane Chris of this year. Long term climatology would have specified 14 hurricanes forming equatorwards of 25°N during this period.

This lack of low latitude hurricane activity during the last four years is a consequence of the combined influence of anomalously very high values of West Atlantic surface pressure and the continued mutli-year persistence of warm ENSO conditions and associated positive Caribbean basin 200 mb westerly wind anomalies during 1991-1994.

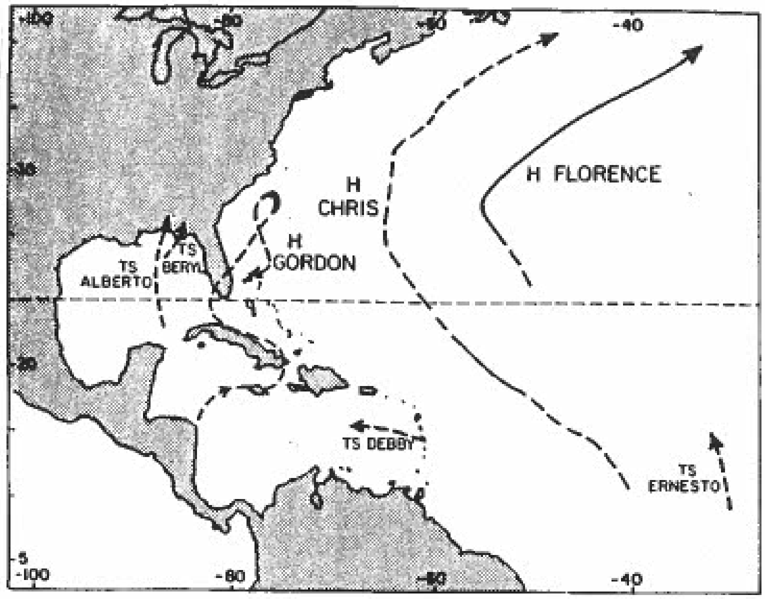

Figure 1: Tracks of Atlantic named storms for 1994. Dashed lines indicate periods of tropical storm intensity (maximum sustained winds with 39-73 mph), solid lines show the periods of hurricane intensity (maximum sustained winds greater than 73 mph).

Table 1: Summary of information on named tropical cyclones occurring during the 1994 Atlantic tropical cyclone season. Hurricane (H) and Tropical Storm (TS) information was supplied by courtesy of the National Hurricane Center.

NAME and CATEGORY	DATES	TS DAYS	HUR. DAYS	INT. HUR. DAYS	HDP	MIN. CENTRAL PRESS. (mb)	MAX. WIND (mph)	MAX. S/S (Cat.)
1. TS Alberto	June 30-July 7	2.00	–	–	–	993	65	–
2. TS Beryl	Aug. 14-19	1.00	–	–	–	999	60	–
3. H Chris	Aug. 16-23	7.00	2.00	–	3.65	979	80	1
4. TS Debby	Sept. 9-11	1.25	–	–	–	1006	70	–
5. TS Ernesto	Sept. 21-26	2.00	–	–	–	997	60	–
6. H Florence	Nov. 4-9	5.00	4.00	–	8.91	972	110	2
7. H. Gordon	Nov. 10-20	9.50	1.00	–	2.00	980	85	1
TOTAL		28	7	0	15			
7 Named Storms; 3 Hurricanes								

Table 2: Comparison of 1994 hurricane activity forecast with activity in recent years.

	1994	As percent of 1950-93 Average Season	Last three seasons 1993	1992	1991	Long Term 1950-93 Ave.
Named Storms (NS)	7	75	8	6	8	9.3
Named Storm Days (NSD)	28	61	17	38	22	46
Hurricanes (H)	3	53	4	4	4	5.7
Hurricane Days (HD)	7	30	2	16	8	23
Intense Hurricanes (Cat. 3-4-5) (IH)	0	0	1	1	2	2.2
Intense Hurricane Days (IHD)	0	0	0.75	3.25	1.25	4.5
Hur. Dest. Pot. (HDP)	15	21	23	51	23	68
Net Tropical Cyclone Activity (NTC)	37	37	55	62	59	100

Expressing Seasonal Tropical Cyclone Activity in Terms of One Number: The Concept of Net Tropical Cyclone 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. 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 the long term mean. To this end, we have adopted 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 season's percentage departure values from long term means are used as the six measures of seasonal activity.

The NTC value is useful as a seasonal tropical cyclone measure because it combines most of the other tropical cyclone parameters of interest into a single number. There are many seasons during which a single parameter, say for example, the number of hurricanes, does not well represent the actual character of the overall tropical cyclone activity for that year. We propose the use of this single (NTC) index as a measure of tropical cyclone activity. This single index also has a higher forecast skill.

Table 3 lists the values of NTC for 1950-1994. Even with the inclusion of the two November hurricanes, 1994 seasonal hurricane activity was very low and ranked on a par with the recent very suppressed hurricane seasons of 1962 (33 percent), 1968 (41), 1972 (28), 1977 (46), 1982 (37), 1983 (32), 1986 (38) and 1987 (48). If the two November hurricanes had not formed, the NTC for 1994 would have been but 18 percent of the long term average - the lowest value since 1930.

Table 3: Listing of Seasonal Net Tropical Cyclone activity (NTC) values between 1950-1994.

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

2 Brief Summary of Characteristics for Individual 1994 Named Storms

1. Tropical Storm Alberto formed in late June just west of Cuba and moved northward, making landfall near Pensacola on the Florida Panhandle in early July when it was at its maximum intensity of 65 mph and minimum central pressure of 993 mb. Alberto then stalled over west central Georgia for four days while bringing unpredicted rainfall amounts and causing 28 deaths and estimated damage of $500 million.

2. Tropical Storm Beryl formed during mid-August in the northern Gulf of Mexico and rapidly moved inland on the Florida Panhandle, just to the east of where Alberto had made landfall a month-and-a-half earlier. But, in contrast to Alberto, Beryl's motion did not stall and it continued to move northeastward. Beryl's maximum wind at landfall was 60 mph with a minimum central pressure of 999 mb. A number of tornadoes were reported and flooding damage was also associated with Beryl, especially in South Carolina and Virginia.

3. Hurricane Chris formed in the low latitude central Atlantic region in mid-August. It moved northwestward towards Bermuda and then recurved towards the northeast before dissipating south of Newfoundland. Chris intensified into a weak hurricane when it was east of the Antilles. But upper level wind shearing conditions prevented Chris from holding its hurricane strength for more than two days. It reached a maximum intensity of 80 mph and a minimum central pressure of 979 mb.

4. Tropical Storm Debby formed from an Africa wave early on the 10th of September near the central Antilles. It then dissipated as it moved westward into the eastern Caribbean. Debby had maximum winds of 70 mph and had a minimum central pressure of 1006 mb.

5. Tropical Storm Ernesto formed in the eastern Atlantic in late September. It then moved northward in response to an upper level trough to its west and dissipated west of the Cape

Verde Islands. Estimated maximum winds were 60 mph and minimum central pressure was 997 mb. Ernesto never passed west of 31° longitude.

6. Hurricane Florence formed in early November in the central Atlantic. It then moved northwestward toward Bermuda and recurved into the westerly winds. Florence attained maximum winds of 110 mph and minimum central pressure 972 mb and was the first November hurricane since 1986. Florence reached category 2 intensity and was this season's most intense hurricane.

7. Hurricane Gordon. This second November hurricane first became a named storm in the Western Caribbean, off the Coast of Nicaragua, on the 10th of November. It then followed a very erratic and unusual track over the next 10 days. It first moved northward and then northeastward across Jamaica and then northward across eastern Cuba. Gordon then turned and moved WNW up the straight of Florida. Its track then turned east again, crossing the southern Florida Peninsula and then followed a NNE course along the Gulf Stream until it approached Cape Hattras, NC. At this point Gordon stalled, looped and then began a southward and then westward motion before gradually dissipating off the east coast of central Florida. Gordon was a named storm for 9 1/2 days, reaching hurricane intensity for one day as it was moving northward off the southeast US coast. Its maximum sustained winds never exceeded 85 mph and minimum central pressure was estimated to have never been below 980 mb. Gordon caused much rain induced flood damage in Jamaica and in south Florida and also shore damage off the outer banks in North Carolina.

3 Unusual Nature of the 1994 Season

The most unusual aspect of the 1994 hurricane season was the lack of any hurricane activity between the 20th of August, when Chris was downgraded from a hurricane to a tropical storm, until the 5th of November when Tropical Storm Florence was upgraded to a hurricane. This 77 day period with no hurricane activity during what is the traditional height of the hurricane season (when climatologically, about 80 percent of all hurricane activity occurs) was quite special. Climatology would have specified 6.4 named storms and 4.2 hurricanes during this period; the actual numbers were 2 and 0.

Since 1886 there have been only three previous years (1907, 1914, and 1925) wherein there was no reported hurricane activity between the 20th of August and the 5th of November. Although two named storms (Debby and Ernesto) formed during this 77 day period, these were weak and short lived tropical storms. For instance, Debby was a named storm in the eastern Caribbean for only 1 1/4 days and Ernesto, which formed in the far eastern Atlantic, was also only a weak tropical storm and was so classified for only two days.

Another special feature of the 1994 season was the late season formation of two hurricanes (Florence and Gordon), after the first of November. It is unprecedented to have two-thirds of any season's hurricanes occur after the first of November. On average only about five-and-one-half percent of all named storms and somewhat less than four percent of all hurricanes form after 1 November. There have been only three previous seasons during the last 109 years wherein two hurricanes have occurred after 1 November (1886, 1980, and 1984). During the last 124 years there have been only nine years when two named storms occurred after 1 November (1887, 1888, 1953, 1954, 1961, 1969, 1980, 1984, 1994). In only one year has there ever been more than two named storms after the 1st of November, this was 1887 when two hurricanes and one named storm formed.

In all previous years during which two named storms occurred after 1 November, the hurricane season as a whole had been active. This further underscores the very unusual character of 1994, not only because two hurricanes occurred after 1 November, but also because these two November hurricanes occurred in a season in which the overall cyclone activity through October was very low. Records back to 1871 show no other season like 1994. Of those 33 hurricane seasons since 1886 in which three or less hurricanes formed during the entire season, only one year (1925) had a hurricane after 1 November. Of those 16 seasons since 1886 in which 8 or more hurricanes formed during the entire season, there were 9 hurricanes which formed after 1 November. Thus, the probability of getting a hurricane after 1 November is roughly 20 times greater during a very active season ($\geq$ 8 hurricanes) as compared to an inactive ($\leq$ 3 hurricanes) season.

Expressed in terms of named storms, the association between post 1 November named storm numbers and seasonal named storm frequency is similar. Since 1871 there have been 31 seasons with 11 or more total named storms. During these 31 active years, 33 named storms formed after 1 November. By contrast, there have been 29 hurricane seasons with 5 or less total named storms. Of these 29 suppressed activity seasons (since 1871), a total of only two named storms formed after 1 November; just seven percent per year as many as occurred during the active seasons.

There can be no question but that those hurricane seasons with above average incidence of named storms and hurricanes through October have a much higher probability of having additional named storms and hurricanes after 1 November. This is another way that 1994 tropical cyclone activity was so anomalous. The weak hurricane activity through October was not at all indicative of the forthcoming very active November. We have no explanation as to why two hurricanes formed in November.

4 Factors Known to be Associated With Atlantic Seasonal Hurricane Variability

The 1994 seasonal hurricane forecast was based on past research by the author and colleagues (Gray, 1984a, 1984b); Gray (1990); Landsea and Gray (1992); Landsea et al. (1992); Gray et al. (1992, 1993a,b)) which relates seasonal Atlantic hurricane activity to six climate indices including: (a) the El Niño (EN); (b) the Quasi-Biennial Oscillation (QBO) of equatorial 30 mb and 50 mb stratospheric winds; (c) Caribbean Basin-Gulf of Mexico Sea-Level Pressure Anomaly (SLPA) in spring and early summer; (d) lower latitude Caribbean Basin 200 mb (12 km altitude) zonal wind anomaly in early summer, (e) Western Sahel rainfall and, (f) a parameter expressing the trend in west to east surface pressure and surface temperature gradients in February through May in West Africa. Figure 2 shows the geographical distribution of the data source areas for these forecasts. These six factors have all been shown to be strongly related to seasonal variations in Atlantic tropical cyclone activity.

The author's seasonal forecast scheme has the following form:

$$\begin{array}{c} (Predicted\ Amount \\ of\ TC\ Activity \\ Per\ Season) \end{array} = Ave.\ Season + \overbrace{(EN + QBO + SLPA + ZWA + AR + PT)}^{Adjustment\ Terms}$$

where

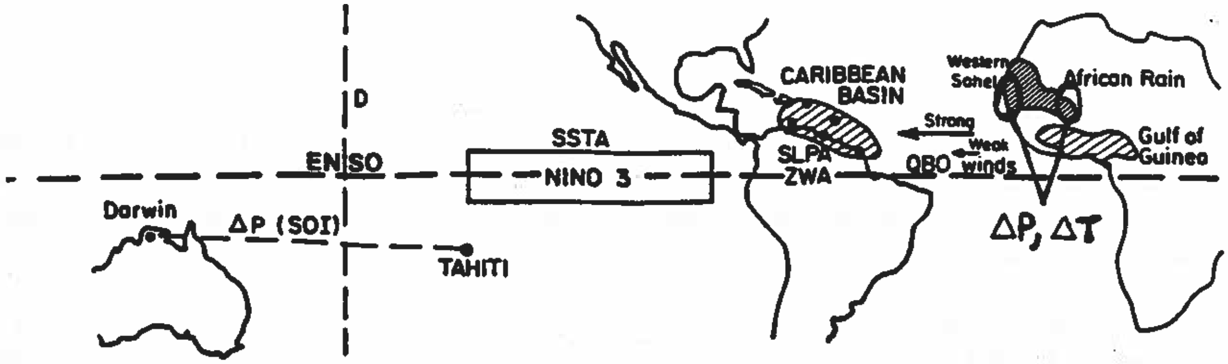

Figure 2: Data source locations for the meteorological parameters used in the early August Atlantic basin seasonal forecast.

EN = El Niño influence. (Warm East Pacific water reduces hurricane activity, cold water enhances it.)

QBO = 30 mb and 50 mb Quasi-Biennial Oscillation zonal wind anomaly correction. (Increased hurricane activity for westerly or positive phase, reduced hurricane activity for easterly or negative zonal wind.)

SLPA = Average Caribbean SLPA for Spring and early Summer. (Reduce hurricane activity if SLPA is significantly above average, add activity if significantly below average.)

ZWA = Zonal Wind Anomaly at 200 mb (12 km) for five low latitude upper air Caribbean stations. (Reduce hurricane activity if positive, increase hurricane activity if negative.)

AR = Western Sahel rainfall. (Increase activity if wet, reduce it if dry.)

PT = West Africa west-to-east gradients of surface pressure and surface temperature during February through May. More activity when pressure decreases going west and temperature increases going west.

4.1 Specific Values of 1994 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 have persisted in a complicated and mixed way ever since. But these long lasting El Niño conditions are not expected to continue beyond the spring of 1995. For the fifth straight year these El Niño like conditions have exerted an inhibiting influence on Atlantic seasonal hurricane activity and particularly the development of intense or major hurricane activity from systems forming at latitudes below 25°N. Table 4 shows how NINO-3 and NINO-4 positive sea surface temperature anomaly (SSTA) has persisted over the years of 1990 through 1994. It is unusual to have El Niño like conditions to last through five consecutive summers. This has not happened in the historical records going back 140 years. The majority of El Niños do not last more than one to two years. We must go back more than 50 years to find warming events lasting longer than two years. Wright's (1989) data indicate that there have been prior periods wherein warm El Niño events tended to persist for three or four consecutive years. The years of 1939-41 were generally warm as were 1911-14, 1899-1903, and likely 1865-1869. On average there is only about 40 percent as much hurricane activity during these warm periods in comparison with non-El Niño years.

Table 5 gives monthly values of the Southern Oscillation Index (SOI) since January 1990. Although monthly SOI values are known to be a little erratic from one month to the next, nearly

Table 4: Sea surface temperature anomalies (SSTA) (°C) in the equatorial Pacific of NINO-3 and NINO-4 regions during the years of 1990-1994 and anticipated SSTA conditions (after vertical dotted lines) through November 1995. Transection period from warm to cold SSTA conditions is shown by vertical dashed line. Figure 2 shows the location of NINO-3. NINO-4 is to its west.

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:	COLD	
1995	WARM			⟶ |	Transition ⟶		|		COLD ⟶			

NINO4 (5°N to 5°S, 150°E to 150°W)

Year	J	F	M	A	M	J	J	A	S	O	N	D
1990	0.7	0.6	0.6	0.6	0.4	0.4	0.6	0.7	0.8	0.8	0.8	1.0
1991	0.8	0.7	0.5	0.8	0.9	0.8	0.9	0.9	0.8	1.2	1.1	1.2
1992	0.7	0.9	1.0	0.9	0.8	0.9	0.9	0.7	0.7	0.6	0.5	0.7
1993	0.5	0.4	0.5	0.5	0.6	0.6	0.8	0.6	0.9	0.5	0.8	0.7
1994	0.4	0.0	0.2	0.3	0.6	0.6	1.0	1.0	1.0	1.1:		
1995	WARM			⟶ |	Transition ⟶		|		COLD ⟶			

all monthly SOI values have been negative since late in 1989. And it is likely that negative values will persist into the late spring of 1995. If this occurs then the SOI, in conformity with the NINO-3 and NINO-4 warm water temperatures will have been continuously negative for 5 1/2 years. According to SOI data which extends back to the 1850s (Wright, 1989), there has not been a previous period wherein negative SOI conditions and associated positive equatorial eastern Pacific surface water temperatures have been continuously of one sign for such a long period.

Table 5: Monthly values of the SOI as measured by the standardized Tahiti minus Darwin SLPA with anticipated changes for 1995.

Year	J	F	M	A	M	J	J	A	S	O	N	D	Yearly Mean	Mean A-S-O Values
1990	−0.2	−2.4	−1.2	0.0	1.1	0.0	0.5	−0.6	−0.8	0.1	−0.7	−0.5	−0.4	−0.4
1991	0.6	−0.1	−1.4	−1.0	−1.5	−0.5	−0.2	−0.9	−1.8	−1.5	−0.8	−2.3	−1.0	−1.4
1992	−3.4	−1.4	−3.0	−1.4	0.0	−1.2	−0.8	0.0	0.0	−1.9	−0.9	−0.9	−1.2	−0.6
1993	−1.2	−1.3	−1.1	−1.6	−0.6	−1.4	−1.1	−1.5	−0.8	−1.5	−0.2	0.0	−1.0	−1.3
1994	−0.3	−0.1	−1.4	−1.8	−1.0	−0.9	−1.8	−1.8	−1.8	−1.3:	Negative		−1.1	−1.6
1995	Negative			⟶ |	Transition ⟶		|		Positive ⟶					

This unusually long El Niño like period should not be taken as an indication of man-induced climate change but only as an example of the wide variety of naturally occurring multi-year ENSO conditions which are possible. Professor Colin Ramage (formerly of the University of Hawaii) has made the point that one would likely have to observe the ENSO for 500-600 years before most of the wide variety of possible multi-year ENSO events can be measured. Because such a long period warm event has not been previously recorded in our historical data (which goes back about 140 years) does not mean that such long El Niño-like warm periods are not within the range of natural

Table 6: March through October 1994 observed absolute value 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)	–16	–20	–24	–29	–31	–30	–28	–18
50 mb (20 km)	+3	-3	-9	–18	–24	–25	-25	–21

Table 7: As in Table 6, but for the "relative" (or anomalous) zonal wind values where 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)	–11	–12	–11	–12	–13	–12	–11	–6
50 mb (20 km)	+3	–2	–3	–8	–10	–15	–15	–14

events.

b) Stratospheric QBO Winds

Tables 6 and 7 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 the 1994 period of March through October 1994. Note that during all of the 1994 season, the QBO winds were strongly from the east. These QBO winds were a suppressing influence on this year's hurricane activity.

c) Sea-Level Pressure Anomaly (SLPA)

Table 8 gives information on regional Caribbean basin and Gulf of Mexico SLPA during the 1994 season. Note that all stations had quite high SLPA during the months of August through October. During the crucial August-September 1994 period, observed surface pressure values were the second highest during the last 45 years. These unusually high August-September surface pressure anomalies are consistent with the very low amount of tropical cyclone activity which occurred this year. Since 1950, only 1991 had comparably high average Caribbean basin SLPA during June through September. And 1991 was also a very inactive hurricane season.

Except for October, eastern Caribbean basin SLPA was unusally high throughout the 1994 hurricane season. June-July SLPA averaged 1.0 mb above normal and August-September was 1.2 mb above normal. These are exceptionally high pressure anomalies, especially when one realizes that the standard deviation of sea level pressure at these low latitudes during these summer months is but 0.5 mb.

Of all the parameters which modify Atlantic seasonal hurricane activity, variations of Caribbean SLPA are one of, if not the strongest. 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. We are making progress. It appears that there are ways to predict seasonal Caribbean basin SLPA with skill from precursor pressure anomalies in other parts of the globe.

Table 8: Lower Caribbean basin SLPA for 1994 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	+0.8	+1.0	+1.2	+1.2	-0.4
6-station Caribbean plus Gulf of Mexico Ave. SLPA	+0.7	+1.0	+1.0	+1.5	-0.3

The reduction of hurricane activity due to high pressure appears to occur in two ways. High Caribbean pressure indicates an equatorial 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 an indication of enhanced Caribbean basin and West Atlantic subsidence and drying. Higher pressure drives stronger subsidence which lowers the height of the moist layer and sharpens the trade-wind inversion. As Fig. 3 indicates, such subsidence makes it more difficult for easterly waves to intensify into named storms. The upper Caribbean basin experienced very strong drought conditions during the summer of 1994.

d) Zonal Wind Anomalies (ZWA)

Table 9 shows that the upper tropospheric Zonal Wind Anomalies (ZWA) were generally positive at the peak of the hurricane season during September 1994 but were not a primary inhibiting factor during the rest of the season. (Surface pressure was the most dominant feature). These zonal wind anomalies do not fully portray the adverse conditions in the Atlantic between the 20th of August and the end of October. There was a strong upper tropospheric trough (TUTT) present much of this period that produced significant upper level westerly wind shearing for many of the waves coming off Africa.

Table 9: 1994 Caribbean basin 200 mb (12 km) Zonal Wind Anomaly (ZWA) in ms^{-1} (as supplied by Colin McAdie of NHC; analyses 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	+1.2	-1.0	-1.2	+3.6	+0.7

e) African Western Sahel Rainfall in 1994

African Western Sahel rainfall is a very powerful modulator of Atlantic hurricane activity, particularly for intense or major (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 no category 3-4-5 hurricanes forms (as in 1994) the Western Sahel would be expected to be quite dry. This was not the case this year. Overall, the African Sahel had above average rainfall and our Western Sahel (see Fig. 4) stations reported a rainfall deficiency during June through September of only -0.05 SD. This year the Western Sahel was the wettest that

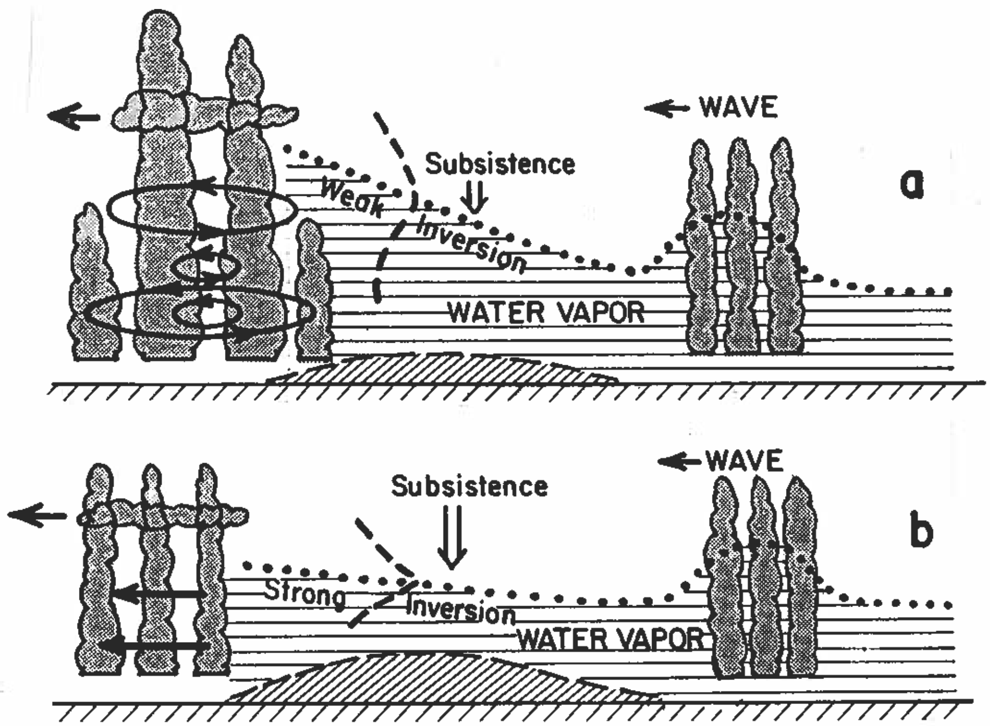

Figure 3: Idealized schematic of an Atlantic easterly wave disturbance moving westward from Africa into the central and western Atlantic Ocean near 15°N latitude during late summer. In the top diagram (a) only moderate high surface pressure and enhanced subsidence drying conditions exist and only a weak 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. 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.

it has been since 1989 and overall, the 4th wettest year since 1970. Rainfall amounts in the central and eastern Sahel were measured to be +0.62 SD and +0.39 SD And there was good easterly wave activity coming off of West Africa this year. The early June Western Sahel rainfall forecast of Landsea, Gray, Mielke, and Berry (1994) had predicted that the Sahel would not be as dry this year as in previous years.

f) Discussion

The easterly waves coming out of West Africa appeared as strong this year as those waves in the years when many tropical storms and hurricanes form. But these waves were not able to transform themselves into tropical cyclones in the western Atlantic locations where this typically takes place.

The very high West Atlantic and Caribbean basin sea level pressure which was present until early October acted to displace the Intertropical Convergence Zone (ITCZ) in the Western Atlantic and to a more southerly position over South America. This trend established much stronger than normal subsidence in the areas of the West Atlantic, where such transformation transformation from easterly waves to named storms typically takes place. This year's easterly waves were not able to overcome the strong middle level drying and the stronger trade inversion that this enhanced subsidence induced. This in combination with persistent, regional TUTT generated upper level western winds over the primary area where the eastern-wave-to-tropical-storm transformation takes place appears to have been the primary factor for the plausity of this year's tropical cyclone activity.

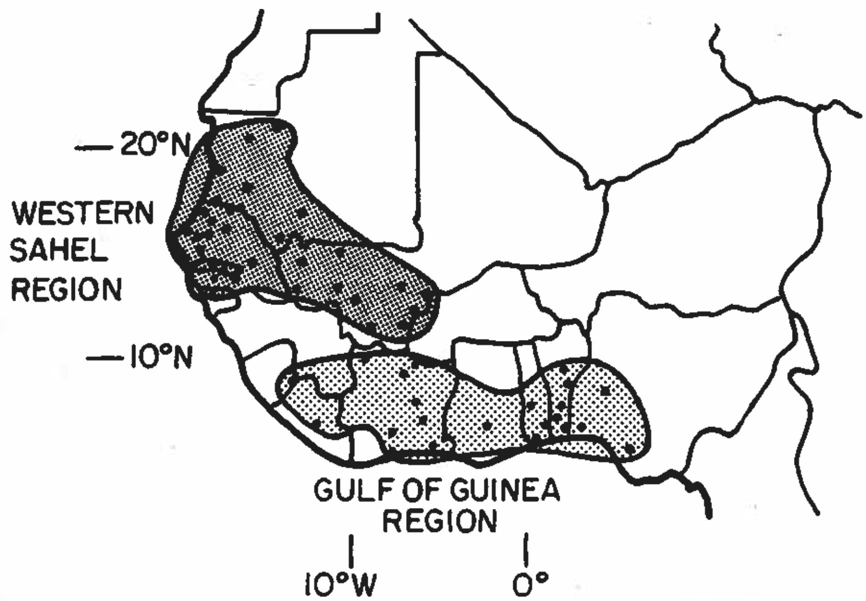

Figure 4: Locations of rainfall stations which make up the 38-station Western Sahel precipitation index and the 24-station Gulf of Guinea precipitation index.

5 Verification of Author's 1994 Forecast

Table 2 summarized statistical information for the 1994 hurricane season. Table 10 summarizes verification statistics for each of the author's three lead time 1994 seasonal forecasts . Note that the extended range (nine month lead) forecast, made on 19 November 1993, did not verify. Whereas overall hurricane activity in this forecast was projected to be 110 percent of the long term average, only 37 percent actually occurred. This failure of the 9-11 month extended range forecast was due to effects of the unexpected continuation of El Niño-like conditions through the 1994 season and to the very high sea level pressures which developed over the West Atlantic which could not be foreseen. It had been anticipated in November 1993 that the long running El Niño event would likely dissipate by the beginning of the most active portion of the hurricane season in August 1994. This did not occur. As most El Niños last only 1-2 years, this was difficult to anticipate. The author was not alone in his inability to forecast the unprecedented continuance of El Niño conditions through a fifth consecutive year. Most El Niño experts have been surprised by the continuation of this remarkably long lasting warm water event. There is no precedent for such a long lasting El Niño event in historical data going back to the 1850s. This failure to anticipate the continuance of the El Niño during 1994 was the primary reason for the poor performance of this extended range forecast. These warm equatorial water conditions are expected to finally terminate by the late summer of next year.

In the author's updated, early June 1994 and early August 1994 forecasts, the amount of 1994 hurricane activity was greatly reduced from what had been forecast in November 1993. The early June forecast anticipated about half of the observed reduction of this years hurricane activity from climatology and the early August forecast anticipated about two-thirds of the observed reduction from climatology. The author judges the early June and early August forecasts to have been generally successful. Figures 5 and 6 show how each forecast parameter for each of the three different lead period forecasts compared with what actually occurred in 1994 and with what one would expect from 1950-93 average climatology. Figure 5 shows data for our three lead times (19 November 1993, 5 January 1994, and 4 August 1994) in comparison with what occurred and with climatology while Fig. 6 shows similar forecast comparisons of these three lead time forecasts with climatology, but for the forecasts we would have obtained had we used only our formal equation

Table 10: Statistics for the author's three different lead time seasonal forecasts of 1994 hurricane acticity and how these forecasts verified.

Mean Seasonal Activity for 1950-1993 Climatology	1994 Fcst made on 19 Nov 1993	1994 Fcst as of 5 June	1994 Fcst as of 4 Aug	1994 Verifi-cation
Named Storms (NS) - 9.3	10	9	7	7
Named Storm Days (NSD)	60	35	30	28
Hurricanes (H) - 5.7	6	5	4	3
Hurricane Days (HD) - 23	25	15	12	7
Intense Hurricanes (IH) - 2.1	2	1	1	0
Intense Hurricane Days (IHD) - 4.5	7	1	1	0
Hurricane Destruction Potential (HDP) - 68	85	40	35	15
Net Tropical Cyclone Activity (NTC) - 100	110	70	55	37

without any adjustments. Both figures show that the 5 June on 4 August forecasts had considerable skill.

Table 11 compares the straight (unadjusted) statistical prediction obtained from our forecast equations at each lead time with our actual prediction and to the final 1994 seasonal verification data. Note in the 19 November 1993 forecast that six of the eight forecast parameters were better than the qualitatively adjusted prediction. In the 5 June forecast the statistical prediction is superior for all prediction parameter and was especially close for the predictions of Hurricane Days and Intense Hurricane activity (0.60 and 0.15 versus 0 and 0). The 5 June forecast appears to have been quite skillful. The author should have stuck with his unadjusted statistical predictions as the majority of adjustments went the wrong way. All statistical forecast parameters in the 5 June and 4 August forecast predicted a substantial reduction of 1994 activity which would have been specified by climatology.

6 Great Suppression of 1991-1994 Hurricane Activity - Especially for Latitudes South of 25°N

There has been an unusually large suppression of hurricane activity during the last four years (1991-94). Figure 7 shows the 1991-94 average of the eight seasonal hurricane parameters expressed as percentages in comparison with the long term 1950-1993 climatology. Overall, hurricane activity during the last four years has only averaged about half of the average seasonal climatology.

This large decrease in hurricane activity during the last four years has occurred exclusively in lower latitudes south of 25°N. Higher latitude ($>$ 25°N) hurricane activity has increased slightly over the long period average. Figure 8 gives percentage comparisons of the number of named storms, hurricanes, and intense category 3-4-5 hurricanes which formed both North and South of 25°N during this four year period. This net downturn in named storms and hurricane activity has been exclusively a function of the greater suppression in the normal activity that one would expect at the lower latitudes. Note that no category 3-4-5 hurricanes formed equatorwards of 25°N when climatology would have specified six. Only two hurricanes formed equatorwards of 25°N when climatology would have specified 10. This strong low latitude downturn is related to the continuous El Niño-like conditions which have persisted, strong African drought conditions in three of the last four years, and higher than average values of West Atlantic and Caribbean basin surface pressure in all four years. It is well known that these three climate parameters have a much greater influence

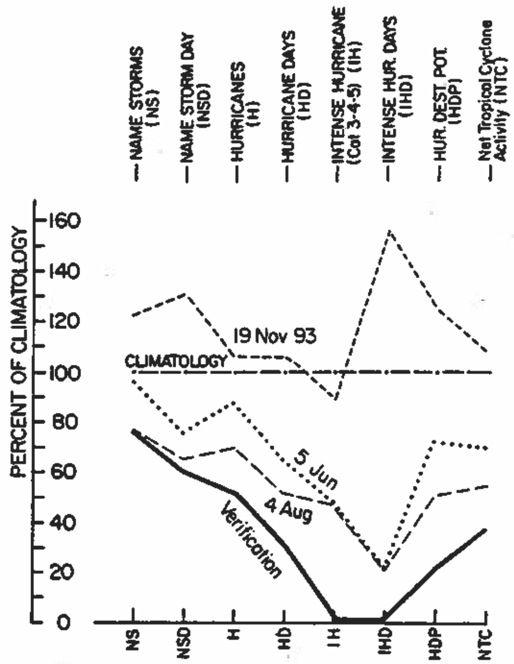

Figure 5: Comparison of 1994 actual verification parameter values (thick line), the 1950-1993 climatology values and forecast values at each of the three different lead times for the eight different forecast parameters of NS, NSD, H, HD, IH, IHD, HDP, and NTC.

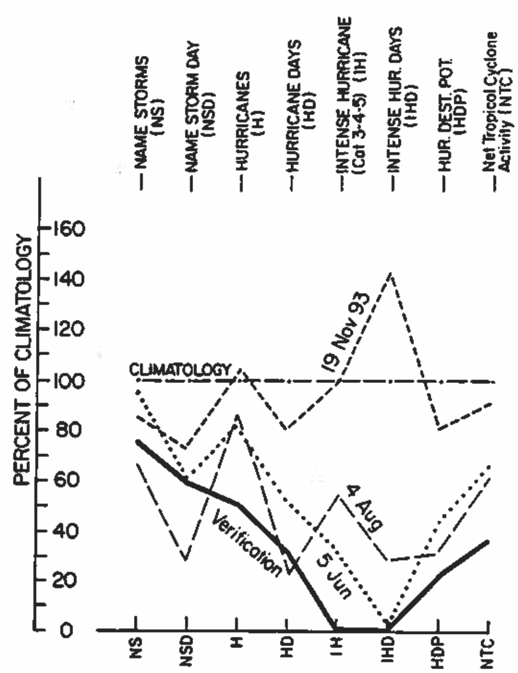

Figure 6: Same as Fig. 5, but a comparison of actual 1994 verification values (thick line) with the 1950-93 climatology and the unadjusted statistical forecast values at each of the different lead times (from our prediction equations without any qualitative adjustments).

Table 11: Comparison of our statistical predictions with the actual forecast at the three specified lead times.

Forecast Parameter Mean Seasonal Activity for 1950-1993 Climatology	19 NOV 1993 Forecast Statistical	Actual	5 JUN 1994 Forecast Satistical	Actual	4 AUG 1994 Forecast Statistical	Actual	1994 Verification
Name Storms (NS) - 9.3	7.87	10	8.85	9	6.1	7	7
Name Storm Days (NSD)	31.58	60	28.03	35	12.6	30	28
Hurricanes (H) -5.7	6.28	6	4.73	5	4.9	4	3
Hurricane Days (HD) -23	18.40	25	12.20	15	3.9	12	7
Intense Hurricanes (IH) Cat. 3-4-5 2.1	2.04	2	0.60	1	1.2	1	0
Intense Hurricane Days (IHD)- 4.5	6.48	7	0.15	1	1.3	1	0
Hur. Destruction Potential (HDP) -68.1	54.94	85	30.18	40	22	35	15
Net Tropical Cyclone Activity (NTC) - 100	91.08	110	64.78	70	60.2	55	37

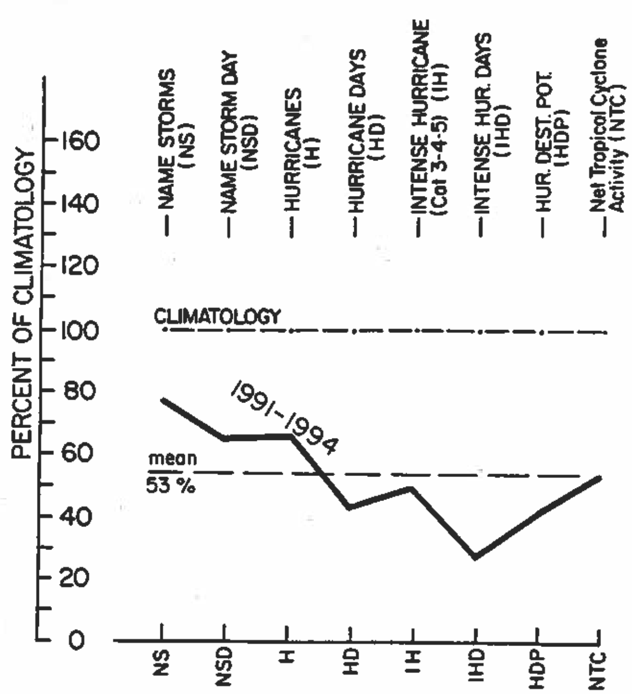

Figure 7: Comparison of mean hurricane parameters for the four years of 1991-94 with 1950-93 climatology.

on the modulation of lower than higher latitude hurricane activity.

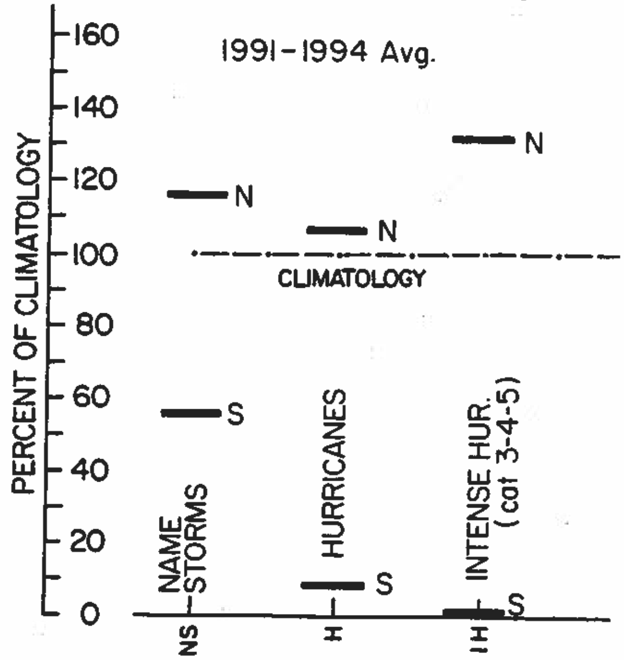

Figure 8: Comparison of the four season 1991-1994 average number of named storms, hurricanes and intense (category 3-4-5) hurricanes forming north (N) of 25°N latitude and south (S) of 25°N latitude in comparison with what one would expect from the 1950-93 climatology. There was more formation than climatology would specify in the north and many, many fewer formation events to the south than would be expected from climatology.

7 Summary Verification of Ten Previous Seasonal Hurricane Forecasts and General Potential for Seasonal Prediction

The author has now issued seasonal forecasts of Atlantic hurricane activity for 11 years including 1994. A summary of the first 10 years of forecasts and their verifications is given in Table 12. The author's forecasts have evolved during these ten years to where we now have a much superior forecast scheme to that which was used during the first six years. When applied in hindcast trials over this same ten-year period, or over the longer 43-year of our developmental data period, our current forecast scheme is superior to climatology, the only other method tjat was available to forecast forthcoming hurricane season activity. Regardless of how one might interpret these seasonal forecasts over the last 11 years, we are confident that the physical parameters we use will stand the test of time and will demonstrate ever improving skill in future forecasts, particularly if we keep working to improve them.

8 Acknowledgements

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Table 12: Verification of the author's previous seasonal predictions of Atlantic tropical cyclone activity for 1984-1992.

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 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
1991		**Prediction 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**	**Prediction 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**	**Prediction 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