EARLY APRIL FORECAST OF ATLANTIC BASIN SEASONAL HURRICANE ACTIVITY FOR 1997

(Another year of expected above average hurricane activity)

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

[This forecast with figures and tables is available on the World Wide Web at this URL:
http://tropical.atmos.colostate.edu/forecasts/index.html] - also

Thomas Milligan and Carrie Schafer Colo. State Univ., Media Representatives (970-491-6432) are available to answer various questions about this forecast. A taped interview with William Gray can be obtained by calling 970-491-1525.

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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.

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

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 ($\triangle P$) and surface temperature ($\triangle T$) 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

Information obtained through March 1997 indicates that as during the previous two seasons the coming 1997 Atlantic hurricane season is again likely to have greater than average activity. We project that total season activity will include 11 named storms (average is 9.3), 55 named storm days (average 47), 7 hurricanes (average 5.8), 25 hurricane days (average 24), 3 intense (category 3-4-5) hurricanes (average 2.3), 5 intense hurricane days (average is 4.7) and a hurricane destruction potential (HDP) of 75 (average 71). Whereas net 1997 tropical cyclone activity is expected to be 110 percent of the long term average, conditions should be relatively quiet in comparison with the unusually active 1995 and 1996 seasons. Still, 1997 should be significantly more active than the average of the generally suppressed hurricane seasons during the last 25 years and especially in comparison to the particularly quiet seasons of 1991–1994. These early April predictions are identical to our early December (1996) forecast of 1997 hurricane activity. An important element entering this updated April forecast is the belief that a significant warm ENSO event will not occur before November. If this 1997 hurricane forecast is at least approximately correct, then the 3-year period of 1995-1997 will have been the most active consecutive three years on record. This in turn would suggest that we are entering a new era of generally greater Atlantic basin hurricane activity. Later forecasts updates for 1997 will be issued on 6 June and 6 August 1997. A verification of this forecast will be made in late November 1997.

These forecasts (as well as those of the past) are available on the World Wide Web at the access location given on the cover.

1. Introduction

Surprisingly strong long range predictive signals exist for Atlantic basin seasonal tropical cyclone activity. Our recent research indicates that a sizeable portion of the year-to-year variability of nine indices of Atlantic tropical cyclone activity can be skillfully hindcast as early as late November of the prior year. This late fall forecast can then be updated in early April, early June and early August. In this paper we present a spring update of our Atlantic tropical cyclone activity forecast for 1997, based on meteorological data available through the end of March 1997.

Forecasts were developed using 46 years (1950-1995) of historical data. We study this historical data to develop the best possible forecast regression equations from a variety of global wind, temperature, pressure, and rainfall features. Figures 1 and 2, below, show the various factors which are either used in our statistical models or to which we give additional considerations for the fine tuning of our forecasts.

These seasonal hurricane forecasts are based on the premise that the behavior of the atmosphere during the coming year will closely follow that of similar years in the past. In other words, we assume that those global environmental conditions which preceded active or inactive hurricane seasons in the past will be similarly

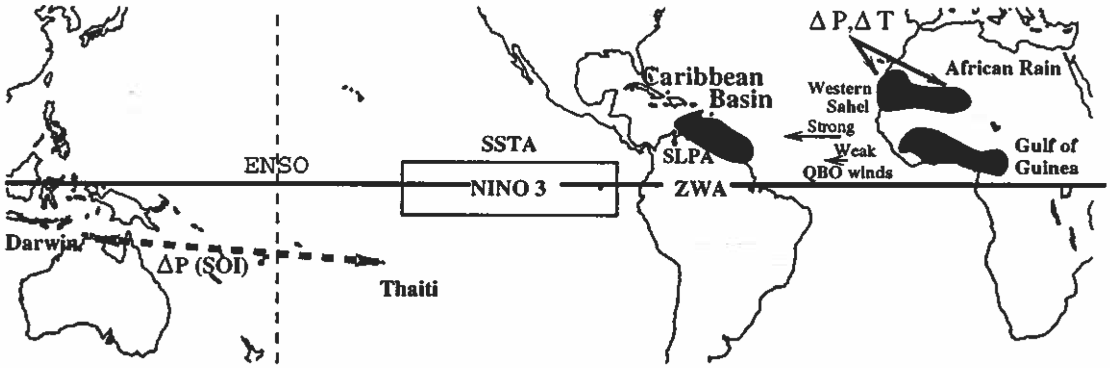

Figure 1: Meteorological parameters used in our late November, early April, early June and early August forecasts.

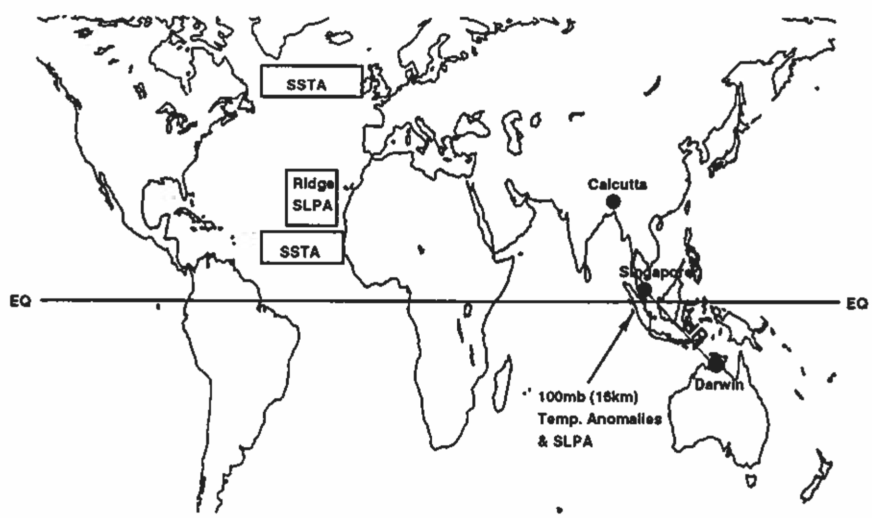

Figure 2: Other new predictors which have recently been found to be related to upcoming Atlantic hurricane activity.

related to future seasonal trends in hurricane activity. Allowing that the global atmosphere operates as a single entity, past observations provide insight on how the atmosphere-ocean-land system will likely operate in future months and seasons. Our forecast methodology and skill continues to evolve as we study new data and ideas to improve both our physical understanding and forecast skill.

2. Prediction Methodology

We prepare forecasts for nine measures of seasonal Atlantic basin tropical cyclone activity including the following: Number of Named Storms (NS), Number of Named Storm Days (NSD), Hurricanes (H), Hurricane Days (HD), Intense Hurricanes (IH), Intense Hurricane Days (IHD), Hurricane Destruction Potential (HDP), Net Tropical cyclone Activity (NTC), and Maximum Potential Destruction (MPD). (Definitions for these indices are given on page 2). For each of these activity parameters we choose the best six predictors (i.e., those resulting in optimum prediction skill) from a field of nine possible forecast parameters. The set of potential predictors currently in our early April forecast are shown in Table 1. The specific values of these parameters used in this year's forecast are shown in the right column. This is our "statistical" forecast. Additional forecast parameters representing conditions in the Pacific Ocean basin and the Asia-Australia regions (Figs. 1 and 2) are also consulted for further qualitative forecast adjustments. In this way, we use both quantitative and qualitative information to produce the final "adjusted" forecast.

Table 1: Pool of predictive parameters and their 1 April value for the early April 1997 prediction. Based on meteorological data through March 1997. See Figs. 1 and 2 for the locations of these predictors.

For 1 April Prediction (see Figs. 1 and 2 for location)	Specific 1 April Fcst Parameters
1 = QBO 30 mb 6 month extrapolation of zonal wind to Sept. 1977	-3 ms^{-1}
2 = QBO 50-30 mb 6 month extrapolation of absolute shear of zonal wind to Sept. 1977	1 ms^{-1}
3 = QBO 50 mb Balboa (Jun-Aug of 1996)	-26 knots
4 = Atlantic Ridge (Oct-Nov of 1996)	+1.45
5 = Atlantic Ridge (March 1997)	−0.85
6 = African rain - Sahel (Aug-Sept of 1996)	−0.21 SD
7 = African rain - Guinea (Aug-Nov of 1996)	−0.54 SD
8 = North Atlantic SSTA for 12N to 20N, 50W to 18W (Jan-Mar 1997)	+0.41°
9 = North Atlantic SSTA for 50N to 60N, 10W to 50W (Jan-Dec 1996)	+0.09°

Our predictions, developed from the 46-year data period of 1950–1995, explain about 47 to 66 percent of the past variance. Table 2 lists the predictions selected for each forecast parameter and gives their hindcast skill for the 46-year period of 1950–1995. In application to independent data (i.e., real forecast situations), we

Table 2: Listing of predictors chosen for each parameter forecast and the amount of hindcast variance explained by these six predictors for the 1 April forecast.

Forecast Parameter	Predictors Chosen from Table 1 in Order of Variance Explained	Variance Explained by Hindcast (1950-1995)
N	1,2,3,4,5,8	.555
NSD	2,3,4,5,6,7	.554
H	2,4,5,7,8, 9	.502
HD	1,3,4,6,7,8	.551
IH	1,2,3,4,5,6	.552
IHD	1,3,4,5,7,9	.474
HDP	1,3,4,5,6,7	.551
NTC	1,3,4,5,6,7	.574
MPD	1,3,4,5,6,7	.658

expect a net degradation of this hindcast skill of about 10-25 percent. Obviously, and by definition, it is impossible to specify the amount of degradation (if any) in an individual year. In some years, the forecast will do quite well, being very close to the observed values; while in other years the forecast will perform poorly.

We have reasons for believing that observations of both the Gulf of Guinea rainfall and the October-November ridge during 1996 were not representative of the general East Atlantic conditions of last Fall. Hence their uncritical acceptance might lead to an underestimate of the actual hurricane activity which will occur in 1997. Table 3 lists two different April statistical forecasts for the 1997 hurricane season and summarizes our final adjusted April 1997 forecast. Column 1 gives our full statistical forecast, and column 2 is our statistical forecast obtained using values which are half the observed Gulf of Guinea rainfall deviation (use of −0.27 SD rather than −0.54 SD, predictor 7 of Table 1) and for similar reasons, October-November 1996 pressure ridge (predictor 4 of Table 1) a value of +0.73 SD (rather than +1.56 SD). Column 3 gives our adjusted and final early April forecast.

In examining the data from last fall the synoptic circumstances associated with the establishment of these strong East Atlantic negative anomalies caused us to question their authenticity. SSTs in historical records are typically negatively correlated with the subtropical ridge anomaly; this was clearly not the case last Oct-Nov. The 500 mb height anomaly for October was associated with strong midlatitude trough in the central North Atlantic, and a very strong and stable subtropical ridge to its eastern side. We feel this anomalous configuration was not representative of the general ridge conditions of last fall.

Similar problems occurred with Gulf of Guinea rainfall. Early in the summer of 1996 SST anomalies south of the Guinea coast were much warmer than normal. This condition typically causes the monsoon trough over Africa to remain south of its normal position, and all evidence suggest that this occurred. However, in the middle of August these SSTs turned anomalously cool, and persisted for the rest of the year while, at the same time the Gulf of Guinea region was wet. These trends may be the cause of the rapid withdrawal of the monsoon trough from the Guinea coast in September through November and the reduced rainfall in this region.

In summary we suggest that both of these values, particularly of the October-November ridge, are not representative. Since the end of November conditions in the Atlantic have exhibited strong blocking (except for February), suggesting that the Atlantic subtropical ridge is much weaker than normal this year. And this borne out in the low March measurements. This is the rationale for reducing these anomalies in the statistical model to approximately half of their observed value. As noted before, statistical forecasts with these two restrictions are shown in column 2 of Table 3.

Table 3: Full April statistical forecast (column 1) along with adjusted statistical forecast (column 2) wherein all conditions remain the same except that Gulf of Guinea rain anomaly is assumed to be half (-0.27 rather than -0.54 SD) and the Oct-Nov ridge is also assumed half (+0.73 rather than 1.45) SD. See discussion for explanation of why we consider column 2 statistical results more representative than column 1. Column 3 is our final adjusted early April forecast.

Full Forecast Parameter	(1) Statistical Fcst	(2) Adjusted Statistical Fcst	(3) Adjusted Actual Fcst
Named Storms (NS)	9.7	10.50	11
Named Storm Days (NSD)	37.56	47.69	55
Hurricanes (H)	6.11	7.04	7
Hurricane Days (HD)	13.39	19.95	25
Intense Hurricanes (IH)	1.78	2.40	3
Intense Hurricane Days (IHD)	3.60	4.87	5
Hurricane Destruction Potential (HDP)	37.65	60.43	75
Net Tropical Cyclone Activity (NTC)	72.62	92.00	110
Maximum Potential Destruction (MPD)	47.20	60.99	75

3. Early April Atlantic Basin Hurricane Forecast for 1997

Table 4 gives the long period climatology and summarizes all 1997 hurricane season forecast values including the results obtained from our December 1996 forecast and the current early April forecast. Of primary interest is column 3 which gives our 4 April 1997 qualitatively adjusted, "actual" forecast for 1997. Both the early December (column 2) and early April (column 3) statistical forecasts have been adjusted upwards. As noted elsewhere this adjustment is the result of our analysis of additional global signals which though not explicitly included in the statistical forecast are nevertheless known to be linked to above average hurricane activity. These additional predictors indicate a somewhat more active hurricane season for 1997, warranting the upward adjustments in anticipation of a more active 1997 hurricane season.

Table 4: Updated statistical and adjusted Atlantic basin hurricane forecasts for 1997.

Forecast Parameter	(1) 1950-90 Average	(2) 6 Dec 96 Adjusted Forecast	(3) Early April 1997 Adjusted Forecast
Named Storms	9.3	11	11
Named Storm Days	46.6	55	55
Hurricanes	5.8	7	7
Hurricane Days	23.9	25	25
Intense Hurricanes	2.3	3	3
Intense Hurricane Days	4.7	5	5
Hurricane Destruction Potential	71.2	75	75
Net Tropical Cyclone Activity	100.0	110	110
Maximum Potential Destruction	66.0	70	70

Status of the Early April Predictors

As discussed in the foregoing pages, the forecast signals for 1997 are mixed. Of the nine potential predictors listed in Table 1, six indicate an above average season whereas three (Guinea and Sahel rain and the Atlantic Oct-Nov ridge) indicate below average activity in 1997. Reflecting on the prior discussions, we believe that the predictors indicating an above average hurricane season outweigh those indicating a below average season.

Note that our April scheme presently includes no predictors based on data from the Pacific Ocean basin. However, it is likely that conditions in the tropical Pacific Ocean will significantly impact this summer Atlantic hurricane activity. These factors include the state of ENSO and the Singapore (far west Pacific) 100 mb Temperature Anomalies (TA). These Pacific Ocean processes are presently favorable for 1997 Atlantic basin hurricane activity. Other recent changes favorable for hurricane activity in the Atlantic basin which are not fully reflected in our objective April predictions include the following:

1. A large weakening of the Atlantic subtropical ridge since the October-November period of +1.45 SD to a March value of -0.85 SD. This suggests a reduced trend in ocean upwelling along Western Africa and South America, resulting in warmer tropical waters and lower sea level pressure in the tropical Atlantic for this summer.

2. Equatorial (Atlantic) SST anomalies in the area south of the West Africa bulge have become cold while the tropical Atlantic to the west of Africa (i.e., off the coast of Mauritania and Senegal) has become warm. If these SSTA patterns hold (as we expect them to), this should be an enhancing influence for both West African rainfall and (associated) hurricane activity this summer.

3. Broad scale North Atlantic SSTA patterns are warm, implying a multidecadal shift in North Atlantic SSTs which we believe is related to changes in the Atlantic Ocean thermohaline "conveyor" circulation.

Additional conditions which, since early December, have become more factorable for 1997 hurricane activity include:

1. More evidence (and hence, greater confidence) that significant El Niño warming will not occur during August through October 1997.

2. More evidence (and hence, greater confidence) that drought conditions will not occur in the Western Sahel region this coming summer.

3. Persistence of warm SST (anomaly) conditions over the far North Atlantic Ocean during the January–March 1997 period. This condition indicates persistence of a stronger Atlantic Ocean thermohaline circulation.

4. Middle latitude Atlantic wind patterns during the winter of 1997 have been more typical of the blocking conditions which were more prevalent during the late 1940s through the late 1960s; a time when the far North Atlantic also had similar warm SSTA conditions and Atlantic intense hurricane activity was more prevalent.

5. Low pressure anomalies in the Caribbean and weaker than normal Atlantic trade wind conditions are expected this summer. These conclusions are based upon recent work of co-author Knaff (1997b) who has developed a separate forecast of summertime Caribbean basin Sea Level Pressure Anomalies (SLPA) which is based upon the strength of the strength of the March Atlantic subtropical ridge, January through March SSTs in the North Atlantic (50-60°N, 10-50°W), and January through March Niño 3.4 (5°N–5°S, 120°W–170°W) SST anomalies. These factors forecast Caribbean SLP anomalies to be -0.1, -0.5, and -0.3 in June through July, June through September, and August through September, respectively. Lower than normal SLP in this region are related to increased hurricane activity (Shapiro 1982, Gray 1984, Knaff 1997a). These numbers are nearly identical to the pressure anomalies forecast scheme for last year's very active hurricane season.

In summary, data through the end of March indicate that 1997 will experience hurricane activity somewhat above the average for the last 47 years and distinctly more active than the recent inactive 1991-1994 and (longer) 1970–1994 periods.

4. Early April ENSO Prediction

Departing from the predictions of most other ENSO forecast groups, we do not foresee a significant Eastern Pacific El Niño warming this year. Rather, we expect neutral conditions (or at most, only weak warming (< 5°C) for NINO3 and NINO 3.4 during August through October this year. This assessment is based on the following information:

1. Our six parameter ENSO forecast of early December 1996 indicated a weak cooling event (-0.5°C) for this period of August through October (Gray et al. 1996b).

2. QBO westerly wind this summer at both 50 and 30 mb levels. El Niños typically do not occur or tend to rapidly weaken with the onset of the westerly QBO in the lower stratosphere. This is expected to occur in the early summer.

3. The lack of strong positive 100 mb temperature anomalies at Singapore during the last two years. [In the historic record (since 1957) all strong El Niños have been preceded by a notable sustained 100 mb warming at Singapore. Strong 100 mb warming at Singapore occur as a combined effect of the West phase of the QBO and a well established (cold SST) La Niña; these two conditions at times interact to strengthen the processes in the tropical Pacific that govern ocean heat storage, later released as a strong El Niño event. Hence, the lack of a strong 100 mb warming (since late 1993) in unfavorable for a moderate or strong 1997 El Niño event before November (see Sheaffer 1994, 1995a,b).]

4. El Niño conditions occur less frequently when North Atlantic SST anomaly conditions are positive, as they are this year.

5. After an extended, multi-year warm El Niño event as occurred during 1991–1994, there is historical precedent for the eastern equatorial Pacific to go 4–5 or more consecutive years without another significant warming event. Analogues illustrating this tendency occur after the extended El Niño events of 1939–1941, 1929–1931, 1911–1914, and 1899–1905 (except for 1903). It is likely that we will have to wait until at least next year (1998) before we experience our next significant El Niño warming. Conditions are much more favorable for a warming event next year than they are this year.

5. Singapore 100 mb Temperature Anomaly (TA) as a Hurricane Predictor

In active hurricane years, it is observed that Singapore 100 mb temperature anomalies (TA) tend to be negative during the nine month period extending from July of the previous year through March of the forecast year. Table 5 shows Singapore 100 mb temperature anomaly values prior to 10 active hurricane seasons since 1957 (the year when Singapore data became available) versus 10 temperature values prior to inactive seasons. Note that in all 10 active years, Singapore 100 mb temperatures during the prior July to March period were substantially negative whereas they were positive preceding 9 of 10 inactive hurricane years. The 100 mb TA value for 1997 is –15.4°C (× 10) which is typical of the active years. Although these Singapore TA measurements are not explicitly incorporated into our early April quantitative forecast scheme, they provide qualitative evidence for support of the upward adjustment of our statistical forecast.

Table 5: Singapore 100 mb temperature anomaly (TA) in degrees C (x 10) during the 9-month July to March period preceding 10 active versus 10 inactive hurricane years. Note the consistently large differences. The value of TA for 1997 (–15.4), is typical of an active year.

Active Years	TA	Inactive Years	TA
1958	–9.8	1962	3.2
1961	–16.5	1972	10.3
1964	–11.3	1977	-1.4
1966	–2.0	1982	22.2
1969	–11.0	1983	9.7
1985	–8.4	1986	9.9
1988	–7.7	1987	2.4
1989	–5.1	1991	8.1
1995	–10.0	1992	5.4
1996	–2.8	1994	6.8
Ave	–8.5	Ave	7.7
1997	–15.4		

6. Singapore TA Values Prior to El Niño Years

Since 1957 there have been 12 years (1965, 1972, 1976, 1977, 1982, 1983, 1986, 1987, 1991, 1992, 1993, and 1994) with moderate or strong El Niños accompanied by major suppression of hurricane activity. Table 6 lists values for Singapore 100 mb TA during the prior July through March period during these 12 events. Note that 11 of these 12 El Niño years were associated with positive Singapore TA values. An observed very cold July 1996 to March 1997 value of –15.4 is evidence that a significant warm El Niño in 1997 is unlikely. Additional perspectives on these associations are provided in Table 7 which contrasts seasonal hurricane activity during 10 years when prior July through March Singapore TA were most below average (1961, 1963, 1964, 1969, 1973, 1974, 1975, 1985, 1988, 1995) versus 10 years when these TA values were most above average (1972, 1981, 1982, 1983, 1984, 1986, 1991, 1994). Note the large ratio of difference.

Table 6: Singapore 100 mb temperature anomaly in degrees C (x 10) during the 9-month July to March period preceding 12 El Niño years when hurricane activity was greatly suppressed. Note the consistent positive values whereby the 1997 TA value of (–15.4) is not typical of suppressed activity.

Year	July Through March Singapore 100 mb TA in 10^{-1} deg C
1965	8.3
1972	10.3
1976	0.2
1977	–0.4
1982	22.2
1983	9.7
1986	9.9
1987	2.4
1991	8.1
1992	5.4
1993	0.1
1994	6.8
AVE	6.9
1997	–15.4

Table 7: Listing of average measures of hurricane activity and the ratio for 10 seasons following the coldest July to March 100 mb TAs at Singapore versus 10 years with warm TA values.

Season	NS	NSD	H	HD	IH	IHD	HDP	NTC
10 Active Years	12.7	70.8	7.9	38.4	4.0	9.6	119.1	162.7
10 Inactive Years	6.2	26.6	3.8	10.7	0.9	1.3	28.6	50.4
Ratio Active/Inactive	2.0	3.0	2.1	3.6	4.4	7.4	4.2	2.6

7. Hurricane Activity and Stratospheric QBO

Since the early 1950s (when stratospheric QBO data became available) there have been six years with QBO conditions between 70 mb to 10 mb are near identical to those occurring this year. These prior "near identical" years are 1957, 1961, 1969, 1973, 1980, 1985 and 1990. There have also been seven "fairly similar" QBO years (1955, 1964, 1971, 1975, 1978 and 1993) during which QBO conditions were close to the conditions of 1997. Thirteen years can be characterized as having distinctly 'dissimilar' QBO conditions, including 1954, 1956, 1958, 1960, 1965, 1958, 1970, 1972

1974, 1979, 1982, 1984, and 1987. Table 8 presents summaries of the yearly hurricane activity in each of these QBO linked categories. Note that hurricane activity during the six "near identical" and seven "fairly similar" QBO years most like 1997 had comparable hurricane activity to the amounts of activity we are predicting for 1997.

Table 8: Average hurricane activity during (1) those six years when the stratospheric QBO from 70 mb to 10 mb was 'near identical' to that of 1997; during seven years when the stratosphere was "fairly similar" and 13 other years when stratospheric QBO conditions were distinctly 'dissimilar' to this year. Our 1997 forecast, on the bottom line, is close to both the 'near' identical and "fairly similar" QBO years.

Comparison with 1997 QBO	NS	NSD	H	HD	IH	IHD	HDP	NTC
6 "Near Identical" Yrs	11.3	57.4	7.3	29.3	2.6	5.9	87.4	122.3
7 "Farily Similar" Yrs	10.7	55.2	6.0	27.3	2.8	5.2	79.7	114.5
13 Dissimilar Yrs	7.8	35.3	4.5	16.0	1.5	3.7	46.8	75.4
1997 Early Apr Fcst	11	55	7	25	3	5	75	110

8. Combination of Singapore TA and QBO Data

We have observed a strong tendency for easterly QBO conditions and positive Singapore TA values to occur during hurricane seasons which are suppressed and/or during El Niño years. The opposite conditions occur during active hurricane seasons. These are typically westerly QBO years with negative Singapore anomalies. For the Singapore-QBO data record, available back to 1957 (40 prior years), all those hurricane seasons which experienced westerly QBO conditions and cold Singapore TA conditions during the prior July through March period were active. Moreover, there has never been a year (since 1957) when this same combination of QBO and Singapore TA conditions was accompanied by a significant El Niño event and an inactive season. Hence, this combination of indicators (through March 1997) is another qualitative assessment lending support to our upward adjustment of our statistical forecast and the belief that we are in line for an active 1997 hurricane season.

9. Hurricane Activity During Weak Eastern Pacific Warm Water Years

The 12 strong El Niño years listed in Table 6 are generally associated with notably suppressed Atlantic basin hurricane activity. But the five weaker eastern Pacific warm events occurring in 1951, 1953, 1958, 1969, and 1979 experienced little or no hurricane suppression. August through October NINO-3 SSTA anomalies during these years were 1951 (0.95), 1953 (0.45), 1958 (0.30), 1969 (0.80), and 1979 (0.50)); an average of +0.6°C. Meanwhile, net tropical cyclone (NTC) activity during these years was 120, 120, 139, 155, and 95 percent of average (mean 126). Our early 1997 April NTC forecast value is 110. Thus, if a weak warming event of perhaps 0.3 to 0.6°C should develop in the NINO-3 or NINO-3.4 region this year (as a number of ENSO watches anticipate), there is good evidence that this warm event will not be effective in suppressing this year's hurricane activity.

10. Prior Analog Year

It is prudent to consider the climatology of comparable prior years with similar early April predictors as we have this year. A comparative study of the April predictors (Table 1) for the past 50 years yields five prior years with predictors which are in total similar to the current April 1997 conditions. These analog years in decreasing similarity to 1997 are 1969, 1964, 1951, 1980 and 1961. Table 9 compares hurricane activity in these analog years to our 1997 forecast of activity. All five analog years had generally above average hurricane activity and nearly all individual categories of activity were higher than that being forecast for 1997. These analog years also suggest an active hurricane season for 1997.

Table 9: Hurricane activity occurring during the best 1 April predictor analogs to 1997 and comparison with 1997 forecast.

Analog Year	NS	NSD	H	HD	IH	IHD	HDP	NTC
1969 (1)	17	83	12	40	3	2.75	110	155
1964 (2)	12	71	6	43	5	9.75	139	167
1951 (3)	10	58	8	36	2	5.00	113	120
1980 (4)	11	60	9	38	2	7.25	126	134
1961 (5)	11	71	8	48	6	20.75	170	220
Ave	12.2	68.6	8.6	41	3.6	9.1	131.6	159.2
1997 Fcst	11	55	7	25	3	5	75	110

11. Prior Three-Year Periods of Above Normal Activity

If the actual 1997 hurricane activity turns out to be only average (or greater), then the three seasons of 1995–1997 will represent the most active three consecutive hurricane seasons since records became available. But how frequently do runs of three consecutive active hurricane seasons occur? The historical hurricane record shows several such consecutive three-year periods. These include 1886–1888, 1891–1893, 1932–1934, 1943-1945, 1949–1951, 1953–1955, and 1988–1990. A climatology of these three-year periods (noting that the hurricane data prior to aircraft observations are less reliable), is given in Table 10. Average values for measures of tropical cyclone activity during these three year periods are shown along with averages for the third year (only). Note that on average, the third year of these three-year periods is typically as active as the previous two years and notably more active than the 1950–1990 average. Our 1997 forecast, shown on the bottom line of Table 10, is consistent with the average level of hurricane activity occurring during the third year of a three-year active cycle.

The occurrence of consecutive three-year periods of above average activity was more common during the 1930 through 1950 period and during the 1880s and 1890s. What else was different during these periods? Figure 3 shows time series of North

Table 10: Average seasonal totals of named storms (NS), named storm days (NSD), Hurricanes (H), Hurricane Days (HD), Intense Hurricanes (IH), Intense Hurricane Days (IHD), Hurricane Destruction Potential (HDP), and Net Tropical Cyclone (NTC) activity during the seven previous three year active hurricane periods during the last 125 years (top line) versus the same average seasonal totals during the third year of these three year periods (line 2). The 1950–1990 average is shown in the third line for comparison.

	NS	NSD	H	HD	IH	IHD	HDP	NTC
Ave. of Seven Most Active 3 Year Periods	12.1	72	7.3	34	2.3	6.6	104	132
Ave. of Third Year of These Active Periods	11.3	69	7.3	34	1.9	6.9	98	128
1950–1990 Average	9.3	47	5.8	24	2.3	4.7	71	100
1997 Forecast	11	55	7	25	3	5	75	110

Atlantic (50-60°N, 10-50°W) SST anomalies and the June to September rainfall in the Sahel in relation to these three-year periods of above normal hurricane activity. In general, the active three-year periods occurred in association with near or greater than normal West Sahel June to September rainfall and warmer than normal SST conditions in the North Atlantic. We believe the latter (SST conditions) are related to multi-decadal variations in the North Atlantic thermohaline circulation. The upshot of these analyses of three-year runs of enhanced activity suggests that the 1997 hurricane season will likely again bring greater than normal amounts of activity.

12. Relationships Between Hurricanes and West African Rainfall

Whereas a strong season to season correlation exists in historical between increased Atlantic hurricane activity and above average West (Northwest Africa) Sahel rainfall, this relationship failed during the last two seasons. Sahel rainfall activity was only near normal (–0.20 and –.21 SD) despite the two unusually active hurricane seasons. Another very active hurricane season, 1926, also experience below average rainfall in the western Sahel. A possible explanation of this recent disparity may lie in the unusual configuration of SST anomalies enveloping much of West Africa during June through August of these three years. SST anomalies south of the Guinea coast during these years were warmer than normal as was the tropical North Atlantic. Typically, warm SSTs off West Africa are associated with cool SST anomalies in the equatorial regions of the Atlantic and vice versa. Normally, this alternating "dipole" like SSTA pattern is strongly related to West African rainfall but not so during 1995 and 1996. Apparently, the warm conditions south of the Guinea coast played a role in keeping the Sahel region rain near normal, while at

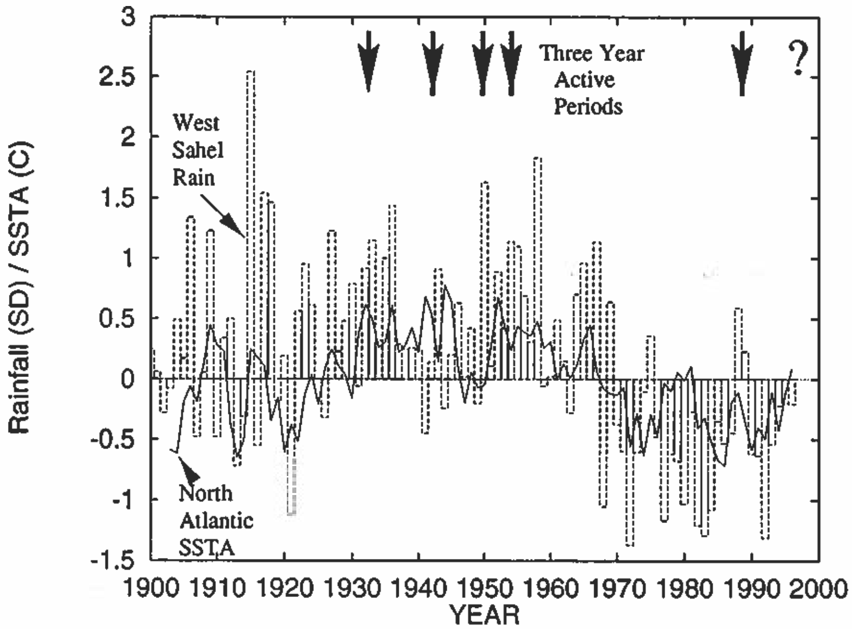

Figure 3: Time series of the North Atlantic SST anomalies (solid line) and the standardized amount of West Sahel June to September rainfall. In the upper portion of this figure are arrows depicting the seven three year periods of increased Atlantic hurricane activity.

the same time, providing very warm SST conditions extending across the tropical Atlantic which were favorable for increased hurricane activity.

The 1995 and 1996 Hurricane Seasons and Global Warming. Some individuals will interpret the recent upswing in hurricane activity during 1995 and 1996 and the expected above normal activity in 1997 as evidence of climate changes due to increased man-made greenhouse gases such as carbon dioxide (CO_2). This may be a logical interpretation, given all the media hype on this topic. But this speculation cannot be accepted. There is no reasonable way that such an interpretation can be accepted. Anthropogenic greenhouse gas warming, 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. This would not result in the abrupt and dramatic one year upturn in hurricane activity as occurred between 1994 and 1995. And, if man induced greenhouse increases were to be interpreted as causing global mean temperature increase over the last 25 years, there is no way to relate such a small global temperature increases to more intense Atlantic basin hurricane activity during this same period. Intense Atlantic category 3-4-5 hurricane activity experienced a substantial decrease over the period of 1970–1994. This downturn in intense hurricane activity occurred while the global surface temperatures were increasing.

13. Likely Increase of Landfalling Major Hurricanes in Coming Decades

Excepting the last two (1995 and 1996) seasons, there has been a marked decrease in the incidence of intense category 3-4-5 hurricanes striking the US East Coast, Florida and Caribbean region during the last 25 years. This quarter-century lull is likely a consequence of alterations the slowdown in the Atlantic Ocean's thermohaline circulation which appears to be responsible for a long list of concurrent global climate trends including the Sahel drought, increased El Niño activity, Pacific and Atlantic middle latitude zonal wind increases, among numerous others.

Both historical and geological (proxy) records indicate that this extended lull in major hurricane activity will not continue. A new era of major hurricane activity appears to have begun with the usually active 1995 and 1996 seasons. As a consequence of the exploding US and Caribbean coastal development during the last 25-30 years we should begin to see a large upturn in hurricane spawned destruction.

Long Term Changes in the North Atlantic. The Atlantic thermohaline circulation may now be recovering from an inferred three decade long slowing. Evidence of this includes recent reports of decreased ice flow (hence fresh water) through the Fram Strait between Greenland and Spitsbergen as well as increased water salinity in the deep water formation areas of the North Atlantic during the last three years. Chilling of this comparatively dense high salinity surface water creates very dense water which can sink to great depth and more south, out of the basin and engendering a northward flow of warm near surface replacement water, this process is often termed "Atlantic (Ocean) Conveyor". Among other considerations, a strong conveyor, as hypothesized, increases North Atlantic SST anomalies which are useful as a proxy for the strength of the conveyor belt and an indication of enhanced Atlantic basin hurricane activity.

14. Forthcoming Forecast Updates

Updated 1997 forecasts will be issued on the following dates:

- Friday 6 June 1997, just after the official start of the hurricane season and on
- Wednesday 6 August 1997, just prior to the most active portion of the hurricane season.

These later forecasts will utilize data which is closer in time to the hurricane season and therefore, should be somewhat more reliable than our late November and (this) early April forecasts. Verification of all our forecasts will be issued in late November 1997.

15. Cautionary Note

It is important that the reader appreciate that these seasonal forecasts are based on statistical schemes and forecasting judgements which will fail in some years.

These forecasts also do not specifically predict where within the Atlantic basin storms will strike. Even if 1997 should prove to be an above average hurricane season, there are no assurances that many hurricanes will strike along the US or Caribbean Basin coastline and do much damage.

16. Acknowledgments

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APPENDIX: Verification of All 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 6). 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. The failure of the 1993 seasonal forecast is attributed to our failure to anticipate the resurgence of El Niño conditions. 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, which is used as a quantitative first guess as to upcoming El Niño conditions. We have no explanation for my large underprediction of the 1996 hurricane activity.

Table 11: Verification of the authors' previous seasonal predictions of Atlantic tropical cyclone activity for 1984-1995.

1984	Prediction of 24 May and 30 July Update		Observed
No. of Hurricanes	7		5
No. of Named Storms	10		12
No. of Hurricane Days	30		18
No. of Named Storm Days	45		51
1985	**Prediction of 28 May**	**Updated Prediction of 27 July**	**Observed**
No. of Hurricanes	8	7	7
No. of Named Storms	11	10	11
No. of Hurricane Days	35	30	21
No. of Named Storm Days	55	50	51
1986	**Prediction of 29 May**	**Updated Prediction of 28 July**	**Observed**
No. of Hurricanes	4	4	4
No. of Named Storms	8	7	6
No. of Hurricane Days	15	10	11
No. of Named Storm Days	35	25	23
1987	**Prediction of 26 May**	**Updated Prediction of 28 July**	**Observed**
No. of Hurricanes	5	4	3
No. of Named Storms	8	7	7
No. of Hurricane Days	20	15	5
No. of Named Storm Days	40	35	37
1988	**Prediction of 26 May and 28 July Update**		**Observed**
No. of Hurricanes	7		5
No. of Named Storms	11		12
No. of Hurricane Days	30		21
No. of Named Storm Days	50		47
Hurr. Destruction Potential(HDP)	75		81
1989	**Prediction of 26 May**	**Updated Prediction of 27 July**	**Observed**
No. of Hurricanes	4	4	7
No. of Named Storms	7	9	11
No. of Hurricane Days	15	15	32
No. of Named Storm Days	30	35	66
Hurr. Destruction Potential(HDP)	40	40	108
1990	**Prediction of 5 June**	**Updated Prediction of 3 August**	**Observed**
No. of Hurricanes	7	6	8
No. of Named Storms	11	11	14
No. of Hurricane Days	30	25	27
No. of Named Storm Days	55	50	66
Hurr. Destruction Potential(HDP)	90	75	57
Major Hurricanes (Cat. 3-4-5)	3	2	1
Major Hurr. Days	Not Fcst.	5	1.00

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

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

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

1994	Prediction of 19 Nov 1993	Updated Prediction of 5 June	Updated Prediction of 4 August	Observed
No. of Hurricanes	6	5	4	3
No. of Named Storms	10	9	7	7
No. of Hurricane Days	25	15	12	7
No. of Named Storm Days	60	35	30	28
Hurr. Destruction Potential(HDP)	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	36

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

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