SUMMARY OF 2000 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHORS' SEASONAL ACTIVITY FORECAST

A Successful Forecast of an Active Hurricane Season – But (Fortunately) Below Average Cyclone Landfall and Destruction

(as of 21 November 2000)

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[This and past forecasts are available via the World Wide Web:
http://tropical.atmos.colostate.edu/forecasts/index.html] — also,

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SUMMARY OF 2000 SEASONAL FORECASTS AND VERIFICATION

Tropical Cyclone Seasonal Parameters (1950-90 Ave.)	Sequence of Forecast Updates: 8 Dec 99 Forecast	7 Apr 00 Forecast	7 Jun 00 Forecast	4 Aug 00 Forecast	Observed* 2000 Totals
Named Storms (NS) (9.3)	11	11	12	11	14
Named Storm Days (NSD) (46.9)	55	55	65	55	66
Hurricanes (H)(5.8)	7	7	8	7	8
Hurricane Days (HD)(23.7)	25	25	35	30	32
Intense Hurricanes (IH) (2.2)	3	3	4	3	3
Intense Hurricane Days (IHD)(4.7)	6	6	8	6	5.25
Hurricane Destruction Potential (HDP) (70.6)	85	85	100	90	85
Maximum Potential Destruction (MPD) (61.7)	70	70	75	70	78
Net Tropical Cyclone Activity (NTC)(100%)	125	125	160	130	134

*A few of the numbers may change slightly in the National Hurricane Center's final tabulation

VERIFICATION OF 2000 MAJOR HURRICANE LANDFALL

	Forecast Probability and Climatology for last 100 Years (in parentheses)	Observed
1. Entire United States Coastline	72% (50%)	0
2. Florida Peninsula and East Coast	54% (31%)	0
3. Gulf Coast	40% (30%)	0
4. Caribbean and Bahama Land Areas	72% (51%)	1
5. East Coast of Mexico	28% (18%)	0

VERIFICATION OF INITIAL AUGUST ONLY ATLANTIC BASIN HURRICANE FORECAST (ISSUED 4 AUGUST 2000)

Average August Tropical Cyclone Activity (1949–1999)	2000 August Forecast	2000 Verification
Named Storms (NS) (2.8)	3	4
Named Storm Days (NSD) (11.75)	14.25	25.00
Hurricanes (H)(1.6)	2	2
Hurricane Days (HD)(5.75)	8.25	13.25
Intense Hurricanes (IH) (0.6)	1	1
Intense Hurricane Days (IHD)(1.25)	1.25	1
Net Tropical Cyclone Activity (NTC)(26.1%)	33	42.2

DEFINITIONS

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

El Niño - (EN) A 12-18 month period during which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Niño events occur irregularly, about once every 3-7 years or so on average.

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

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

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

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

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

MATL - Sea surface temperature anomaly in the sub-tropical Atlantic between 30-50°N, 10-30°W

MPD - Maximum Potential Destruction - A measure of the net maximum destruction potential during the season compiled as the sum of the square of the maximum wind observed (in knots) for each named storm. Values expressed in 10^3kt.

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

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

NATL - Sea surface temperature anomaly in the Atlantic between 50-60°N, 10-50°W

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

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

QBO - Quasi-Biennial Oscillation - A stratospheric (16 to 35 km altitude) oscillation of equatorial east-west winds which vary with a period of about 26 to 30 months or roughly 2 years; typically blowing for 12-16 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 - The deviation of Caribbean and Gulf of Mexico sea level pressure from observed long term average conditions.

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

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

SSTA(s) - Sea Surface Temperature(s) Anomalies.

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.

TATL - Sea surface temperature anomaly in Atlantic between 6-22°N, 18-60°W.

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

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

ABSTRACT

This report summarizes tropical cyclone (TC) activity which occurred in the Atlantic basin during 2000 and verifies the authors' seasonal forecasts of this activity which were initially issued on 8 December 1999, with updates on 7 April, 4 June and 4 August of this year. The 4 August forecast also contained our first attempt at forecasting August-only tropical cyclone activity. All of these forecasts verified well. The 2000 hurricane season was characterized by enhanced levels of tropical cyclone activity but with no U.S. hurricane landfalls. A total of 14 named storms (average is 9.3) and 8 hurricanes (average is 5.8) occurred and persisted for a total of 32 hurricane days (average is 24). There were 3 major hurricanes of Saffir/Simpson intensity category 3-4-5 (average is 2.3) with 5.25 intense hurricane days (average is 4.7). The seasonal total of named storm days was 66 which is 141 percent of the long-term average. Net tropical cyclone (NTC) activity was 134 percent of the 1950–1990 average and 212 and 178 percent of average for the recent periods between 1990–94 and 1970–94, respectively. All of our forecast parameters were close to what occurred. We consider this to have been a successful forecast year.

1 Introduction

The Atlantic basin (including the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico) experiences more year-to-year hurricane variability than occurs in any of the other global tropical cyclone basins. The number of Atlantic basin hurricanes per season in recent years has ranged as high as 12 (as in 1969), 11 (as in 1950 and 1995), 10 (as in 1998), and as low as 2 (as in 1982) and 3 (as in 1997, 1994, 1987, 1983, 1972, 1962, 1957). Until the mid 1980s there were no objective methods for predicting whether forthcoming hurricane seasons were likely to be active, inactive, or near normal. Recent ongoing research by the authors (see Gray, 1984a, 1984b, 1990; Landsea, 1991; Gray *et al.*, 1992, 1993a, 1994) indicates that there are surprisingly skillful 3-to-11 month (in advance) predictive signals for Atlantic basin seasonal hurricane activity. This research now allows us to issue extended-range forecasts in early December for next year's Atlantic basin hurricane activity with updates in early April, early June, and early August. The purpose of this end-of-season report is to compare these forecasts with actual observed hurricane activity during the 2000 hurricane season.

2 Factors Known to be Associated With Atlantic Seasonal Hurricane Variability

Our forecasts, which are issued at several lead times prior to each hurricane season, are based on the current values of indices which are derived from various global and regional predictive factors which the authors have shown to be related to subsequent seasonal variations of Atlantic basin hurricane activity. Figures 1-3 provide a summary of the geographic locations from which the various forecast parameters are obtained. Our forecast methodology emphasizes the analysis of prior oceanic and atmospheric precursor conditions which are observed to be associated with the amount of hurricane activity during the following season. These predictors include the following:

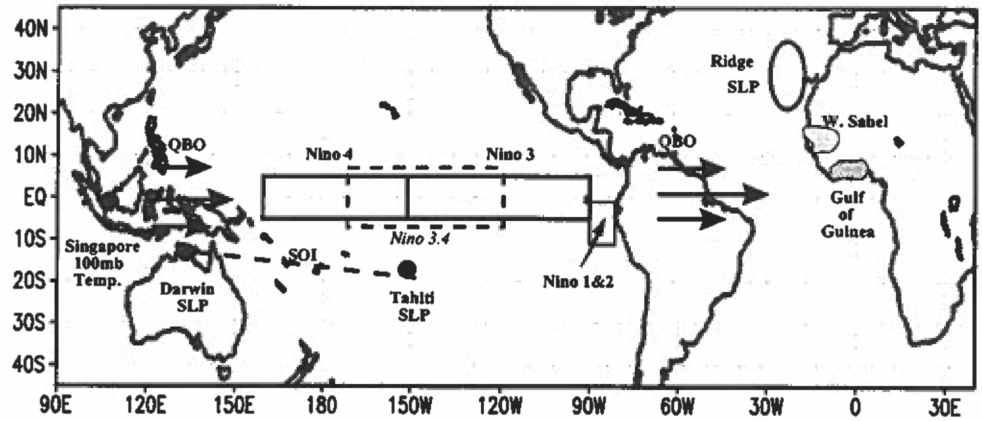

Figure 1: Areas from which specific oceanographic and meteorological parameters used as predictors in our seasonal forecasts are obtained.

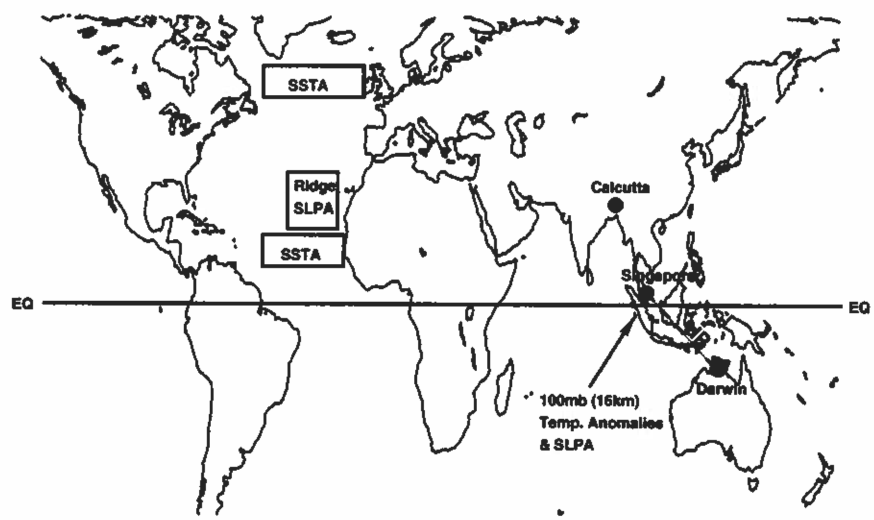

Figure 2: Additional predictor locations which are also considered in formulating our Atlantic season hurricane forecasts.

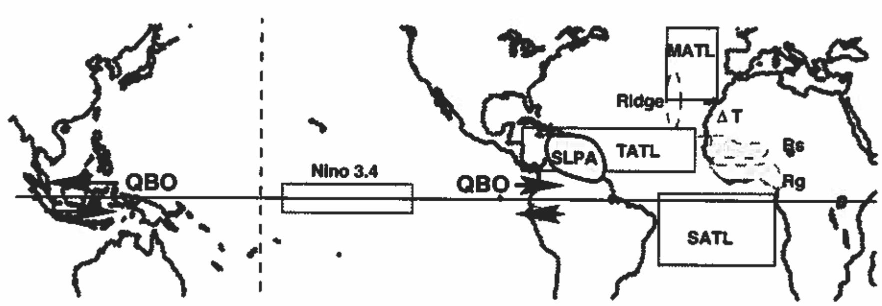

Figure 3: Additional meteorological parameters which are now used in our reformulated early June and early August forecast.

(a) El Niño-Southern Oscillation (ENSO): El Niño events are characterized by anomously warm sea surface temperature anomalies in the eastern equatorial Pacific areas termed Nino 1-2, 3, 3.4 and 4 (Fig. 1), a negative value of the Tahiti minus Darwin surface pressure gradient and enhanced equatorial deep convection near the Dateline. These conditions alter the global atmospheric circulation fields contributing to anomalous upper-level westerly winds over the Atlantic basin which typically reduce Atlantic basin hurricane activity. Conversely, during La Niña seasons, anomalously cold sea surface temperatures are present together with high values of Tahiti minus Darwin surface pressure difference and reduced deep equatorial convection near the Dateline are associated with enhanced Atlantic basin hurricane activity.

(b) The stratospheric Quasi-Biennial Oscillation (QBO). The QBO refers to the variable east–west oscillating stratospheric winds which encircle the globe near the equator. Other factors being equal, more intense (category 3-4-5) Atlantic basin hurricane activity occurs during seasons when equatorial stratospheric winds at 30 mb and 50 mb (23 and 20 km altitude, respectively) are from a westerly (versus easterly) direction.

(c) African Rainfall (AR): The incidence of intense Atlantic hurricane activity is enhanced when rainfall during years when prior August-September Western Sahel region is above average and when August-November Gulf of Guinea region during the prior year is also above average. The June-July rainfall is also a predictor for August through October hurricane activity. Other factors being equal, hurricane activity is typically suppressed if the rainfall in the prior year (or season) in these two regions is below average.

(d) Prior Year October-November and March northeast Atlantic Subtropical Ridge Strength (ONR). When this pressure ridge is anomalously weak during the prior autumn and spring periods, eastern Atlantic trade winds are weaker. A weak ridge condition is associated with decreased mid-latitude cold water upwelling and advection off the northwest African coast, as well as to decreased evaporative cooling rates in this area of the Atlantic. In this way, a weak ridge leads to warmer sea surface temperatures which typically persist into the following summer period and contribute (other factors being constant) to greater seasonal hurricane activity. Conversely, less hurricane activity occurs when the October-November and spring pressure ridge is anomalously strong.

(e) Atlantic Sea Surface Temperature Anomalies (SSTA) in the three regions [(MATL; 30-50°N, 10-30°N and TATL; 6-22°N, 18-60°W) during April through June] and [NATL; 50-60°N, 10-50°W and TATL during January through March]: [See Fig. 3 (bottom) for the location of these areas]. Warmer SSTAs in these areas enhance deep oceanic convection and, other factors aside, provide conditions more conducive for Atlantic tropical cyclone activity; cold water temperatures the reverse.

(f) Caribbean Basin Sea Level Pressure Anomaly (SLPA) and upper tropospheric (12 km) Zonal Wind Anomaly (ZWA): Spring and early summer SLPA and ZWA have moderate predictive potentials for hurricane activity occurring during the following August through October months (Fig. 3). Negative anomalies (i.e., low pressure and easterly zonal wind anomalies) imply enhanced seasonal hurricane activity (easterly 200 mb) while positive values imply suppressed hurricane activity (westerly 200 mb shear).

(g) Influence of West Africa west-to-east surface pressure and temperature gradients (Δ PT): Anomalously strong west-to-east surface pressure and temperature gradients across West Africa between February and May are typically correlated with the hurricane activity which follows later in the year.

Our various lead-time forecast schemes are created by maximizing the pre-season forecast skill from a combination of the above predictors, for the period 1950–1997. We also use an analog methodology whereby we look for those years with specific precursor climate signals strongly similar to the current forecast year whereby, the recurrence of similar TC activity is likely.

3 Statistical Summary of 2000 Atlantic Tropical Cyclone Activity

The 2000 Atlantic hurricane season officially ends on 30 November. To date, there have been eight hurricanes and 32 hurricane days during the 2000 season. The total named storms (i.e., the number of hurricanes plus tropical storms) was 14, yielding 66 named storm days. There were three intense or major (category 3-4-5) hurricanes this season. All designated tropical cyclone activity parameters exceeded the long-term average. Figure 4 and Table 1 show the tracks and give statistical summaries, respectively, for the 2000 season. Table 2 characterizes 2000 seasonal tropical cyclone activity in terms of long-term average annual percentages for the 1950-1990, 1970–94 and 1990–94 periods. Note that 2000 hurricane activity was much above the typical seasonal averages of 1970–1994 and of the more recent 1990–1994. The biggest changes have occurred for the most intense cyclones. Figure 5 shows the U.S. landfalling named storms of 2000.

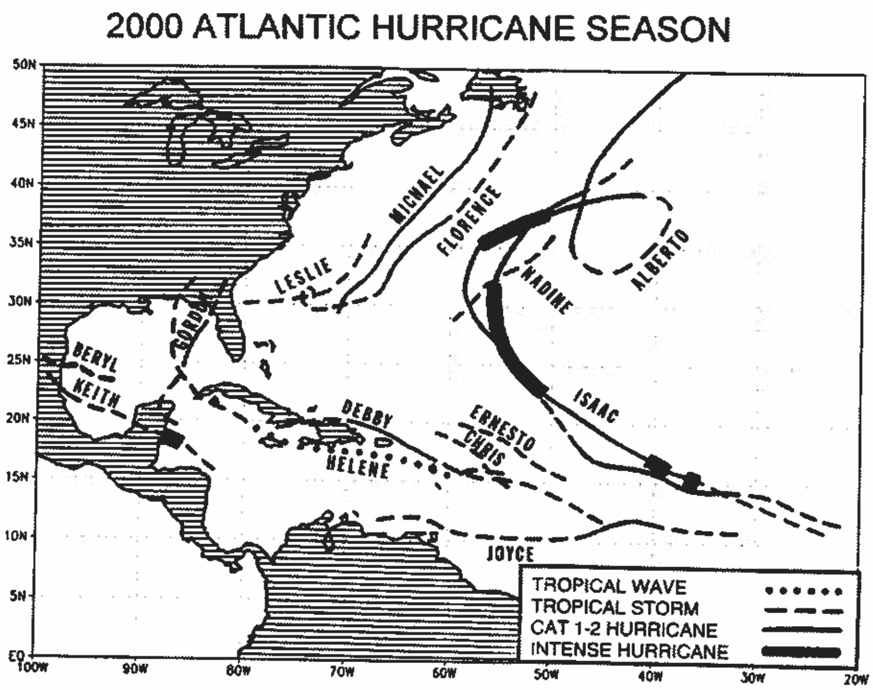

Figure 4: Tracks of the 14 named tropical cyclones of 2000. Dashed lines indicate the tropical storm intensity stage, thin solid lines indicate the Saffir/Simpson hurricane category 1-2 stage, and the thick lines show the intense (or major) hurricane category 3-4-5 hurricane stage.

By all measures, 2000 was a very active hurricane year. Only the number of U.S. hurricane landfall was below the long period average.

Table 1: Summary of information for named tropical cyclones occurring during the 2000 Atlantic season. Information on Tropical Storms (TS), Hurricanes (H) and Intense Hurricanes (IH) and the highest Saffir/Simpson category of each is shown. (Based on this information supplied by the National Hurricane Center).

Highest Category	Name	Dates of Named Storms	Peak Sustained Winds (kts)/ lowest SLP in mb	NSD	HD	IHD	HDP
IH-3	Alberto	Aug.4-23	110kt/950mb	19.25	12.50	1.00	30.30
TS	Beryl	Aug.13-15	45/1007	1.00			
TS	Chris	Aug.17-19	35/1008	0.25			
H-1	Debby	Aug.19-Aug.24	75/995	4.00	1.25		2.1
TS	Ernesto	Sep.2-3	35/1005	1.50			
H-1	Florence	Sep.9-17	70/985	6.50	2.00		3.0
H-1	Gordon	Sep.14-18	70/981	2.50	0.75		1.3
TS	Helene	Sep.15-22	60/986	3.00			
IH-4	Isaac	Sep.21-Oct.1	120/943	9.75	7.70	3.00	26.3
H-1	Joyce	Sep.25-Oct.2	80/976	5.75	2.00		4.6
IH-4	Keith	Sep.28-Oct.6	120/939	5.25	3.25	1.25	10.2
TS	Leslie	Oct.4-7	35/1006	1.25			
H-2	Michael	Oct.17-20	85/965	2.75	2.25		4.2
TS	Nadine	Oct.19-22	50/997	1.75			

Table 2: Summary of 2000 hurricane activity in comparison with long-term (1950–1990) and recent (1970–1994; 1990–1994) annual average conditions.

Forecast Parameter	1950–1990 Mean	Obs. 2000	2000 in percent as 1950-1990 Ave.	2000 in percent of ave. season between 1970-1994	2000 in percent of ave. season between 1990–94
Named Storms (NS)	9.3	14	151	163	166
Named Storm Days (NSD)	46.9	66	141	170	178
Hurricanes (H)	5.8	8	138	161	174
Hurricane Days (HD)	23.7	32	135	199	236
Intense Hurricanes (IH)	2.2	3	136	197	301
Intense Hurricane Days (IHD)	4.7	5.25	112	198	399
Hurricane Destruction Potential (HDP)	70.6	85	120	189	198
Maximum Potential Destruction (MPD)	61.7	77.9	126	197	237
Net Tropical Cyclone Activity (NTC)	100	134	132	178	247

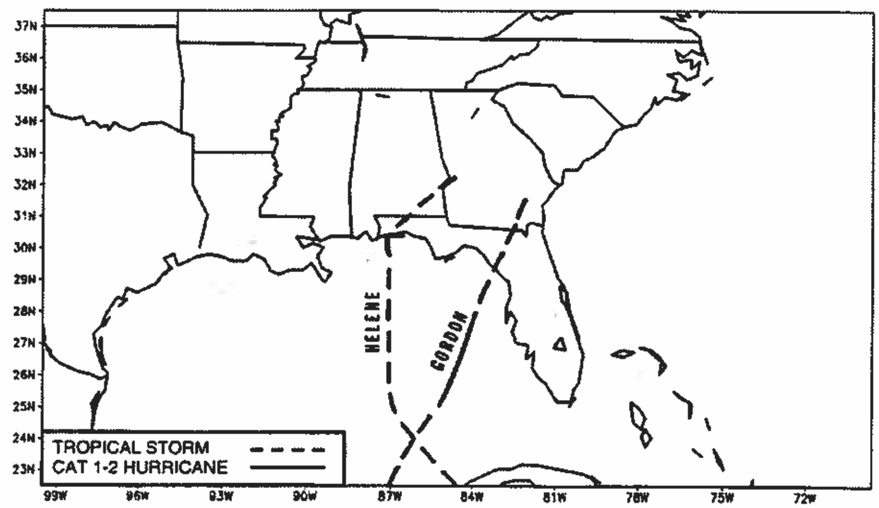

Figure 5: All 2000 U.S. landfalling tropical cyclones by intensity class.

4 Individual 2000 Tropical Cyclone Characteristics

Hurricane Alberto: Hurricane Alberto formed in the far eastern Atlantic on 3 August. Alberto briefly attained hurricane status on 5 August as it was moving west-northwestward. It weakened below hurricane strength for two days before turning to the north. Alberto reached a maximum intensity of 125 mph unusually far to the north (poleward of 35N) and took an eastward course across the North Atlantic, weakening to a tropical storm. It then unexpectedly executed a large clockwise loop between Bermuda and the Azores, re-strengthening into a hurricane before recurving out to sea. Alberto maintained tropical characteristics north of 52N, another unusual event. It will be remembered most for its longevity, becoming the longest-lived August named storm on record. It was a tropical storm for over 19 days, becoming the third longest-lasting tropical storm on record for any month in the Atlantic basin.

Tropical Storm Beryl: Tropical Storm Beryl formed in the southwestern Gulf of Mexico on the 13th of August. It was a large system with multiple centers, which may have inhibited its intensification. It drifted westward and made landfall in northeast Mexico on the 15th, reaching a peak intensity of 50 mph.

Tropical Storm Chris: Tropical Storm Chris developed from a tropical wave about 600 miles east of the Lesser Antilles on the 17th of August, briefly attaining tropical storm status on the 18th before dissipating the next day.

Hurricane Debby: Hurricane Debby formed from a large tropical wave on the 18th of August about eleven hundred miles east of the Windward Islands. It became a tropical storm the next day and a hurricane on the 21st before impacting the Lesser Antilles. The storm passed through the Northeast Caribbean Islands on the 22nd, reaching a maximum intensity of 85 mph. It then moved north of Puerto Rico and turned to the west, skirting the coast of the Dominican Republic while weakening back to a tropical storm. Debby dissipated after moving south of Eastern Cuba on the 24th. Debby was at one time predicted to reach category 4 status. It was temporarily viewed as a great threat to South Florida. Fortunately this did not materialize.

Tropical Storm Ernesto: Tropical Storm Ernesto developed from a tropical wave about

850 miles east of the Lesser Antilles on the 1st of September, attaining tropical storm intensity for about a day on the 2nd before dissipating a day later.

Hurricane Florence: Hurricane Florence formed from a mid-latitude baroclinic system about 375 miles south-southeast of Cape Hatteras on the 11th of September. It then moved very little over the next three days, briefly reaching hurricane status on the 12th. Florence then moved to the northeast and re-intensified into a hurricane on the 15th, bringing tropical storm force winds to Bermuda. The hurricane merged with an extratropical low on the 17th over the North Atlantic.

Hurricane Gordon: Hurricane Gordon was the first tropical cyclone of the year to affect the U.S. It formed just north of the Yucatan Channel from a tropical wave on the 14th of September. It drifted northward and became a hurricane about 300 miles south of Apalachicola on the 19th. Strong vertical wind shear then weakened Gordon into a tropical storm before it made landfall near Cedar Key, Florida on the evening of the 17th. It then merged with a cold front and dissipated shortly after landfall.

Tropical Storm Helene: Tropical Storm Helene was first observed as a tropical depression about 475 miles east of the Leeward Islands on the 15th of September. It then weakened into a tropical wave the next day and continued moving westward across the eastern Caribbean Sea. It then reformed as a tropical depression on the 19th just northeast of Grand Cayman Island. It then moved northwest toward the Gulf of Mexico and strengthened into a tropical storm shortly after exiting Cuba. Helene reached a maximum intensity of 70 mph on the 22nd. Helene weakened significantly before landfall as a minimal tropical storm near Fort Walton Beach, Florida on the morning of the 23rd. The remnants of Helene emerged into the Atlantic Ocean two days later, re-strengthening into a strong tropical storm before becoming extratropical in the North Atlantic.

Hurricane Isaac: Hurricane Isaac was the second major hurricane of the season. It developed from a tropical wave that was a couple hundred miles south of the Cape Verde Islands. It reached tropical storm strength on the 22nd of September as it was moving to the west-northwest. It rapidly increasing to major hurricane strength the next day. Isaac's peak intensity was 140 mph on the 28th as it was moving northward over the open ocean. Isaac was quite large as it recurved well east of Bermuda as a classic North Atlantic hurricane, transitioning into a strong extratropical storm that affected the British Isles.

Hurricane Joyce: Hurricane Joyce formed southwest of the Cape Verde Islands on the 25th of September. It became a hurricane a couple of days later, reaching a peak intensity of 90 mph on the 28th. Joyce weakened steadily as it progressed westward at a low latitude, affecting portions of the southern Windward Islands as a minimal tropical storm. The storm dissipated on the 2nd of October just north of the South American coast.

Hurricane Keith: Hurricane Keith developed over the northwest Caribbean Sea on the 28th of September and slowly moved northwest toward the Yucatan Peninsula, becoming a tropical storm the next day. The system rapidly intensified on the 30th into a major hurricane with sustained winds of 140 mph. Keith battered the coastal islands of Belize and the Yucatan as it slowly drifted westward into Central America. It weakened to a tropical depression while crossing the Yucatan Peninsula, re-strengthening into a tropical storm in the Bay of Campeche on the 4th of October. Keith reached an intensity of 90 mph shortly before making landfall just north of Tampico, Mexico. It then dissipated over the higher terrain of northeastern Mexico the next day.

Tropical Storm Leslie: Tropical Storm Leslie formed just off the east coast of Florida on the 4th of October from a subtropical depression. The precursor disturbance to Leslie caused extremely heavy rain over South Florida with flood damage estimated at 700 million dollars. Leslie gained tropical characteristics on the 5th but remained only a minimal tropical storm. It then became extratropical on the 7th while northwest of Bermuda.

Hurricane Michael: Hurricane Michael developed from a baroclinic low pressure system northeast of Bahamas. After the system moved northward for a few days, it quickly acquired tropical characteristics to become a hurricane on the 17th while racing north-northeast. It reached a maximum intensity of 100 mph east of Sable Island, Nova Scotia. Michael weakened slightly to a minimal hurricane before landfall along the southern coast of Newfoundland on the 19th and then was absorbed into an extratropical low pressure system.

Tropical Storm Nadine: Tropical Storm Nadine formed from a tropical wave a few hundred miles southeast of Bermuda on the 19th of October. It became a tropical storm the next day, reaching a peak intensity of 60 mph. Nadine then accelerated toward the northeast and merged with a mid-latitude system over the open ocean.

5 Variation of 2000 Forecast Parameters

Specific trends in the factors which we know to be associated with seasonal variation of hurricane activity during 2000 include the following:

a) ENSO Conditions. Equatorial Pacific SSTAs (in °C) in Niño-1-2, 3, 3.4 and 4 (see Fig. 1 for locations) are shown in Table 3. Cool water conditions were present throughout the season. In addition, the Tahiti minus Darwin surface pressure difference (the Southern Oscillation Index, SOI) was generally positive (as typical of cool ENSO conditions) while equatorial Outgoing Longwave Radiation (OLR) values near the Dateline were high, indicating diminished deep convection in that area. The forgoing were all favorable ENSO-linked conditions for the enhancement of this year's hurricane activity. Our ENSO forecast of early December 1999 for no El Niño during 2000 verified.

Table 3: April through October 2000 Niño sea surface temperature anomaly indices (in °C) and for Tahiti minus Darwin (SOI) surface pressure differences (in SD).

	April	May	June	July	August	September	October
Niño-1-2	0.6	0.1	–0.5	–0.9	–0.5	–0.3	–0.2
Niño-3	0.2	0.0	–0.4	–0.2	–0.3	–0.4	–0.3
Niño-3.4	–0.6	–0.5	–0.4	–0.3	–0.2	–0.4	–0.6
Niño-4	–1.0	–0.8	–0.5	–0.4	–0.1	0.0	–0.2
Normalized SOI in S.D.	1.2	0.2	–0.6	–0.4	0.4	1.0	1.0

b) Stratospheric QBO Winds

Table 4 shows both the absolute and relative (i.e., anomaly) values of 30 mb (23 km) and 50 mb (20 km) stratospheric QBO zonal winds near 12°N during March through October 2000. We had projected both 30 and 50 mb QBO winds to be from a relative easterly direction and, as such, would be an inhibiting feature for this year's activity. At the height of the 2000 season (in September), 50 mb QBO wind anomalies were westerly but were easterly at 30 mb, this increased the wind shear between the two levels. We judge this shear to have been a weak negative influence on this year's activity while the westerly winds at 50 mb were a positive influence, the net QBO influence likely neutral.

Table 4: Observed March through October 2000 values of stratospheric QBO zonal winds (U) in 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} (data supplied by James Angell and Colin McAdie).

OBSERVED WIND

Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	+1	−2	−13	−20	−25	−27	−27	−24
50 mb (20 km)	+7	+6	+4	−4	−10	−11	−7	−5

OBSERVED WIND ANOMALIES

Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	+6	+5	+1	−3	−7	−9	−11	−11
50 mb (20 km)	+7	+9	+10	+6	+4	+3	+3	+2

c) Sea-Level Pressure Anomaly (SLPA)

Table 5 gives information on regional Caribbean basin and Gulf of Mexico SLPA during the 2000 season. Caribbean SLPA was near neutral during the August through September period. The absence of high pressure prevented surface pressure from being an inhibiting influence on this season's conditions. Knaff's (1997) Atlantic SLPA forecast scheme predicted slightly below average SLPA for 2000. The forecast did not verify as well as last year. The base period of these pressure anomalies is 1950–1985.

Table 5: Lower Caribbean basin SLPA for 2000 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). Values in millibars (mb). Note: we use a SLP mean from 1950–1990 which is lower than the mean SLP during the last three decades.

	Jun	Jul	Aug	Sep	Oct
5-station Lower Caribbean Average SLPA	0.8	−0.5	+0.3	−0.3	+1.1
6-station Caribbean plus Gulf of Mexico Average SLPA	0.4	−0.3	+0.7	−0.5	+1.5

d) Zonal Wind Anomalies (ZWA)

Table 6 shows that the average upper tropospheric (12 km or 200 mb) ZWA during the critical months of August and September were slightly negative. Above average ZWA were present in October. The negative average August-September ZWA values reduce regional tropospheric vertical wind shear and were a factor in explaining the active 2000 season. Negative ZWA conditions allowed the westward moving easterly waves from Africa to experience less vertical wind shear and become better organized.

Table 6: 2000 Caribbean basin 200 mb (12 km) Zonal Wind Anomaly (ZWA) in ms^{-1} (as supplied by Colin McAdie of NHC, in combination with CSU data) for the four stations including Kingston (18°N), Curacao (12°N), Barbados (13.5°N), and Trinidad (11°N).

	June	July	August	September	October
Average ZWA	+1.8	+1.1	+0.4	–1.4	+4.2

e) African Western Sahel Rainfall in 2000

Summer rainfall in the Western Sahel region of Africa turned out to be significantly below average during June through September (–0.75 SD) despite the generally active hurricane season. Watching daily satellite loops of infrared (deep convective storms) imagery, one tended to conclude that the western Sahel ITCZ cloudiness and rainfall were not below average. But, as recently pointed out by S. Nicholson (1999), satellite estimates of rainfall appear to overestimate rainfall (wet bias) as compared with the available rain gauge data (such as it is!).

We have, so far, been unable to explain this lack of positive Sahel rainfall and major hurricane association since 1995. Our previous research has shown (Gray 1990, Landsea 1991, Landsea and Gray 1992, Landsea et al. 1992) a strong relationship between western Sahel rainfall and Atlantic basin major hurricane activity. Clearly, this topic requires further study.

6 Special Characteristics of the 2000 Season

The 2000 season included the following special features:

1. Three major hurricanes. This year saw the persistence of the recent strong upturn in major hurricane activity which began in 1995. The years 1995-2000 are the most active six-year period on record and 1998-2000 constitute the most active three-year period in terms of total hurricanes (26). It must be pointed out, however, that pre-World War II records are less reliable for weaker cyclone systems and those in the Central Atlantic.

2. An exceptional outbreak of tropical cyclone activity occurred during September. Six tropical cyclones formed within a 19-day period during this month.

3. No U.S. hurricane landfall events occurred. Only two tropical storms (Gordon and Helene) made landfall on the U.S. coast (Fig. 5). This was the first year since 1994 when a hurricane has not crossed the U.S. coastline.

4. This season saw no named storms form during June, July or November.

5. Seven named storms formed in September. Only four prior months have had this many named storms in a month and 1995 and 1933 (for August) and 1998 and 1949 (for September).

6. There was quite an enhancing high latitude hurricane activity in the central Atlantic (Alberto, Florence, Isaac, Leslie, Michael and Nadine).
7. Several African origin named storms that progressed westward at low latitudes did not intensify into significant hurricanes. This is not typical. Those weakening and dying in the low latitudes over tropical Atlantic included Chris, Debbie, Ernesto and Joyce. The weakening of these low latitude storms was due to the persistence of a strong Tropical Upper Tropospheric Trough (TUTT) in the West Atlantic.
8. The Madden-Julian Oscillation (MJO) appeared to exercise a stronger than usual intraseasonal influence on this season's activity. This can be inferred from the concentration of named storm formation in the seven days between August 13-19 (four systems), in the 19 days between 9-28 September (six systems), and the three days of 17-19 October (two systems). This approximate monthly time-scale, up-and-down variation can also be found in the monthly variation in SLPA and ZWA (Tables 5 and 6).

7 Verification of Individual 2000 Lead Time Forecasts

Table 7 shows our forecasts for 2000 at four different lead times with this year's observed numbers. Note that we consistently forecast an active 2000 hurricane season. Beginning on 4 December 1999, we held to this forecast in our subsequent 7 April, 4 June and 6 August updates. We consider this year to have been one of our better Atlantic basin seasonal forecasts.

Our forecast of an above average probability of U.S. hurricane landfall did not materialize however. Landfall probability is a different type of forecast, which is not expected to verify well in individual years. It must be judged over periods of 4-5 years. Whereby, there are almost always higher numbers of landfalling hurricanes during 4-5 active seasons in comparison with 4-5 inactive seasons.

Table 7: Verification of our 2000 total seasonal hurricane predictions.

Tropical Cyclone Parameter (1950–1990 Ave. in Parenthesis)	8 Dec 1999 Fcst.	7 Apr 2000 Fcst.	7 Jun 2000 Fcst.	4 Aug 2000 Fcst.	Actual 2000 Total
Named Storms (NS)(9.3)	11	11	12	11	14
Named Storm Days (NSD) (46.9)	55	55	65	60	66
Hurricanes (H) (5.8)	7	7	8	7	8
Hurricane Days (HD) (23.7)	25	25	35	30	32
Intense Hurricanes (IH) (2.2)	3	3	4	3	3
Intense Hurricane Days (IHD) (4.7)	6	6	8	6	5
Hurricane Destruction Potential (HDP) (70.6)	85	85	100	90	85
Maximum Potential Destruction (MPD)(61.7)	70	70	75	70	78
Net Tropical Cyclone Activity (NTC) (100) in percent	125	125	160	130	134

The following are quotes from our initial and updated 2000 seasonal forecasts, all of which verified.

From our initial 8 December 1999 forecast:

"we are predicting that there will be no El Niño event next year (i.e., 2000). Rather, the current La Niña, or cool surface temperatures in the eastern equatorial Pacific should continue through next hurricane season, though possibly in a diminished state from the very cold conditions presently observed .... We predict yet another year of above average hurricane activity though less active than the recent very busy years of 1995, 1996, 1998 and 1999."

Our 7 April 2000 updated forecast
Same statements as our 8 December 1999

Our 7 June 2000 updated forecast
Same statements as the two earlier forecasts:

Our 4 August 2000 updated forecast:

"Information obtained through July 2000 indicates that the Atlantic hurricane season in 2000 is likely to be less active than the four recent very busy years of 1995, 1996, 1998 and 1999. However, total activity is expected to exceed the long term average and is anticipated to be considerably more active than the mean for the recent period of 1970 through 1994 ......"

"The observation of no named storms through the 4th of August 2000 is judged to have little or no bearing on whether we will have an overall active or inactive hurricane season."

"We expect August to have hurricane activity above that (a net NTC of 33/26.1 or 126 percent) of the long period August mean. In round numbers the August forecast is for three named storms, two hurricanes, and one intense or major hurricane."

[Our August only verification values were 4 NS, 2 H, 1 IH – very close to what we observed.]

We consider our Atlantic basin seasonal forecast for 2000 to have been a success. Our probability of 88 percent of a U.S. landfalling hurricane and 72 percent chance of a landfalling major hurricane did (fortunately) not verify. A continuation of the fortuitous trend (or luck) where the U.S. has been spared an increase in major landfall activity despite the strong up turn of major hurricane activity since 1995 should not be expected. We have experienced only three U.S. landfalling major hurricanes the last six years, when by the standards of last century ratio of U.S. landfall to Atlantic basin major hurricanes we should have experienced seven or eight events between 1995–2000.

8 Initial Prediction and Verification of Individual Monthly Hurricane Activity

Background. Periods within variously active or inactive Atlantic basin hurricane seasons do not conform to the overall trend of the season as a whole. For example, although 1961 was a very active hurricane season there was no tropical cyclone activity of any kind during the entire month of August. In 1995, 19 named storms formed in the Atlantic but only one new named storm developed during the 30-day period spanning the statistical peak of the hurricane season between 27 August and 26 September. Conversely, the inactive season of 1941 had only six named storms (average 9.3) but four of these storms developed during September (average September activity is 3.4). During the inactive hurricane season of 1968, three of the eight named storms that year formed during June (average is 0.5).

We are studying how well various sub-season and/or individual monthly trends can be forecast in efforts being spearheaded by Eric Blake of our project.

It is, in general, more difficult to predict shorter periods of hurricane activity than to predict the entire yearly activity. [Signals vary more from climatology on a monthly than on a seasonal basis.] Despite these inherent difficulties, we have, nevertheless devised a quite skillful forecast scheme (as determined by 51 years of hindcast testing using a seasonal independent jackknife approach) for the prediction of August-only activity. This technique involves searching June and July global reanalysis data for potential predictors associated with active versus inactive August periods. We predict the same activity parameters (NS, NSD, H, HD, etc.) as in our seasonal scheme. This monthly forecast methodology will be fully documented in a forthcoming paper.

Verification. Table 8 summarizes our forecast of TC activity for August 2000, along with a jackknife estimate of hindcast skill for the 51-year period of 1949–1999, long period August mean values, and final adjusted August 2000 forecast numbers (Table 8).

Table 8: Prediction of August 2000 Atlantic basin seasonal hurricane activity, 51-year hindcast variance (r^2) explained (skill) and the August climatology.

Forecast Parameter	Statistical Forecast	Jackknife Hindcast Skill	August Climatology	2000 Final Adjusted Forecast Values
NS	2.29	.49	2.76	3
NSD	14.21	.61	11.80	14.25
H	1.77	.53	1.55	2
HD	8.27	.62	5.67	8.25
IH	1.13	.58	0.57	1
IHD	1.04	.70	1.18	1.25
NTC	32.2	.73	26.1	33

Table 9 shows the best July analog years for 2000 which were used as an aid in fine tuning the final August 2000 forecast values. These six analog years averaged slightly less activity than the current forecast. Table 9 also shows the August verification. Note that the above average 4 August forecast was made despite a total absence of tropical cyclone activity prior to issuing the forecast.

August was characterized by Caribbean basin ZWA and SLPA values which were slightly unfavorable. But other global June-July circulation features were favorable for August activity. Four named tropical storms formed with two reaching hurricane strength and one reaching major hurricane status. It is notable that three of the named storms were very short-lived, largely due to the higher than average local vertical shear. In fact, two of the storms dissipated completely over the open ocean due to strong shear in the deep tropics, an unusual occurrence for the deep tropics in an otherwise active hurricane season.

Alberto was the one storm that thrived during August. It persisted as a hurricane for a long period. However, Alberto did not intensify greatly until it reached higher latitudes, where the

Table 9: Analog years selected for August 2000 forecast on the basis of climatological qualities most similar to June and July (mainly) TC-linked global climate signals for year 2000.

	NS	NSD	H	HD	IH	IHD	NTC
1949	3	15	2	7.5	1	.75	31.9
1951	3	10.75	1	7.25	1	1.75	30.9
1954	2	7.75	1	5	0	0	12.3
1963	2	13.75	2	10.5	1	0.5	30.9
1980	3	19.50	3	13	1	6.5	60.6
1981	2	11	1	0.5	0	0	10.7
Average	2.5	13	1.7	7.25	0.5	1.5	29.6
2000 Aug. Forecast	3	14.25	2	8.25	1	1.25	33
2000 Aug. Verification	4	25.00	2	13.25	1	1.00	42.2

ZWA was actually negative due to the presence of a strong TUTT. Alberto became an intense hurricane north of 35N, a rare occurrence. As noted earlier, it was the longest-lasting tropical cyclone on record in August, which caused the extremely large number of named storm and hurricane days.

This was our first monthly forecast. We will be working to develop monthly forecasts for other individual months and for the crucial 30-day period of mid-August to mid-September.

9 Seasonal Forecast Methodology

Table 10 provides a comparison of the statistical forecast values versus our final adjusted forecasts at different lead times. Note that all of the statistical forecasts consistently underestimated 2000 year cyclone activity and that we made an upward adjustment of our actual forecast. Our statistical regression based predictions have been consistently less skillful than our actual forecasts since 1995, when we entered what we believe will be a new multi-decadal era of altered global atmosphere and ocean circulation features which enhance Atlantic basin hurricane activity. Our previous statistical forecast methodology was based on training data from 1950 through to 1990 and, as such, has proven less robust for predictions in the period since 1995. We do not know the specific reason(s) for the sudden fall-off of skill. However, the unexpected break down of the association between major hurricane activity and West African rainfall may be implicated. The ENSO-hurricane relationship appears to have been stronger the last six years.

In consideration of this fall off in statistical regression reliability we chose to base our 2000 seasonal forecast on analog prediction methodology which involves identifying past years with atmosphere and ocean conditions similar to those of the year being forecast.

Since 1949, there were five years with 3 to 12 month precursor ocean and atmosphere conditions fairly similar to 2000: 1949, 1956, 1981, 1989 and 1996. Table 11 lists these precursor properties for these analog years. Properties considered in selecting these years include the following:

1. The QBO relative wind conditions at 30 mb are from the east.

Table 10: Comparison of 2000 statistical and final forecasts for the four lead time periods. Note that in each forecast we chose to increase our actual forecast values over those specified by our statistical model. These alterations were based primarily on our analog methodology which consistently suggested that greater amounts of activity were likely.

Forecast Parameter	1 Dec 99 Statistical Scheme	Final 8 Dec 99 Fcst	1 Apr 00 Statistical Scheme	Final 7 Apr 00 Fcst
Named Storms (NS)	7.2	11	7.5	11
Named Storm Days (NSD)	29.4	55	54.2	55
Hurricanes (H)	4.8	7	5.2	7
Hurricane Days (HD)	13.6	25	16.2	25
Intense Hurricanes (IH)	1.3	3	1.5	3
Intense Hurricane Days (IHD)	2.1	6	3.6	6
Hurricane Destruction Potential (HDP)	41.3	85	46.1	85
Maximum Potential Destruction (MPD)	49.4	70	62.1	70
Net Tropical Cyclone Activity (NTC)	73.3	125	47.8	125

Forecast Parameter	1 Jun 00 Statistical Scheme	Final 7 Jun 00 Fcst	1 Aug 00 Statistical Scheme	Final 4 Aug 00 Fcst
Named Storms (NS)	7.6	12	6.6	11
Named Storm Days (NSD)	22.7	65	32.3	60
Hurricanes (H)	1.8	8	4.1	7
Hurricane Days (HD)	25.0	35	14.4	30
Intense Hurricanes (IH)	2.3	4	1.8	3
Intense Hurricane Days (IHD)	5.0	8	2.6	6
Hurricane Destruction Potential (HDP)	83.0	100	35.4	90
Maximum Potential Destruction (MPD)	42.4	75	48.6	70
Net Tropical Cyclone Activity (NTC)	109.0	150	59.6	130

2. An active multi-decadal period for hurricanes which is characterized by a comparatively strong Atlantic thermohaline circulation as gauged by measurements of SSTA in the North Atlantic (50-60°N, 10-50°W) during the prior 11 to 19-month period. Warm SSTA's in this location indicate a stronger than average conveyor; cold anomalies a below average Atlantic Ocean conveyor. A century of evidence indicates that hurricane activity (particulaly intense or major hurricane activity) is enhanced when a strong Atlantic conveyor circulation is present and suppressed when a weaker circulation is present. All 1999 and 2000 early SSTA information indicated a strong conveyor for 2000.

3. Projected below average SSTA for August-October in the Pacific Nino 3.4 area which occurred.

4. Projected negative Caribbean basin 200 mb ZWA conditions for August through October. This occurred during the average of the two critical months of August and September but not for October.

5. Projected negative Caribbean basin SLPA conditions for August through October. These values were neutral for August and September. October had relatively high pressure, however.

6. Projected above average Western Sahel for June through September 2000 did not occur wherein actual rainfall amounts were -0.75 SD below average.

Table 11: Global atmosphere/ocean conditions during the five analog years which we choose as having similar precursor signals for the 2000 hurricane season.

Year	Extrapolated 30 mb Sept QBO	Inferred Strong Atlantic Ocean Conveyor Circulation from N. Atl. SSTA	Below Normal Cold Aug-Oct Nino 3.4 SSTA	Negative Aug-Sept ZWA	Negative Aug-Sept SLPA (mb)	Western Sahel June-Sept Rainfall Anomaly
1949	East	yes	Yes	Yes	Yes	Wet
1956	East	yes	Yes	Yes	Yes	Wet
1981	East	yes	Yes	Yes	Yes	Wet
1989	East	yes	Yes	Yes	Yes	Wet
1996	East	yes	Yes	Yes	Yes	Dry
Observed Aug-Oct 2000 Conditions	East	yes	Yes	Yes	Neutral	Dry (Not as expected)

Table 12 compares the seasonal hurricane activity during the five analog years versus observed 2000 conditions. Note that the observed seasonal tropical cyclone parameters for 2000 were generally similar to the average of the five analog years excepting western African rainfall. Clearly, the methodology of consulting prior years wherein similar global atmosphere and ocean conditions occur (ie - the analog approach) appears quite promising. We hope to spend the next few years in further development of this forecast methodology.

Note in Table 12 that our forecast was very similar to the average of the five analog years. Given the similarity of 2000 precursor conditions to the average of the precursor conditions of the analog years we were wise to have issued a seasonal forecast similar to the average of the hurricane activity that occurred in these years.

This analog methodology does not require detailed understanding of all the complex processes behind such associations and is a great advantage over initial value numerical modeling approaches which depends on accurately simulating most of the complex physical processes of the atmosphere-ocean system.

Table 12: Atlantic basin tropical cyclone activity (during analog seasons for the year 2000).

	NS	NSD	H	HD	IH	IHD	HDP	NTC
1949	13	62	7	22	3	3	64	115
1956	8	30	4	13	2	2.25	39	69
1981	11	60	7	22	3	3.75	63	114
1989	11	66	7	32	2	9.75	108	135
1996	13	78	9	45	6	6.00	135	204
Average	11.2	59	6.8	27	3.2	5.5	82	127
4 Aug Fcst	11	55	7	30	3	6	90	130
2000 Verification	14	62	8	32	3	5	85	134

10 Comparison of Statistical and Analog Forecasts

We are presently trying to provide an explanation for the recent (since 1995) decrease in the skill of our seasonal statistical regression forecasts. The best measure of forecast skill is for NTC activity which is a percentage composite measure of the six seasonal activity parameters (NS, NSD, H, HD, IH, IHD). Comparisons of our various lead time forecasts of NTC for 2000 are given in Table 13. Note that our analog forecast technique predicted NTC one-and-a-half to two times greater than that of our statistical scheme (column a). Knowing that our recent year statistical forecasts were underestimating hurricane activity we opted to use our analog techniques. This proved to be a wise decision. Column (b) of Table 13 shows that the ratio of the 2000 observed value of NTC (134) to our analog forecast of NTC was quite close. Observed values of NTC were a very good match for our analog forecasts. Table 14 shows the ratio of each of our four lead time adjusted forecasts to that of our statistical forecasts (column c). Note that our four lead time forecasts were about 1.8 times higher than our statistical regression forecasts. By contrast, the observed NTC to our forecast NTC (column d) was very close.

This same relationship of analog to statistical regression forecasts occurred for our forecast of the active Atlantic hurricane seasons during 1998 and 1999. Table 15 is similar to Tables 13 and 14. They show the average of the four lead time forecasts for each of the last three seasons. All three years of analog forecasts were superior to our statistical forecasts – compare columns (1) and (2). The average three-year verification errors were only seven percent by the analog forecast technique whereas there was a 80 percent underforecast by our statistical regression method (column 2). The average of our actual final forecasts during these three years were somewhat less skillful than our three-year average analog forecasts – underforecast of 28 percent (column 4).

Our actual 1998 NTC forecast was a significant underestimate of that year's actual NTC activity (compare columns 1 versus 4). We would have been closer if we had relied only on our analog information. Our forecasting for both the 1999 and 2000 seasons used the analog

Table 13: Comparisons of the ratio of 2000 NTC analog to statistical forecasts and of the ratio of observed 2000 NTC to the analog NTC forecasts.

Forecast Period	(a) Ratio Analog Fcst NTC/Statistical Fcst NTC	(b) Ratio Observed NTC/Analog Fcst N'
1 December	119/73.3 = 1.62	134/119 = 1.13
1 April	144/47.8 = 3.01	134/144 = 0.93
1 June	131/109 = 1.20	134/131 = 1.02
1 August	127/59.6 = 2.13	134/127 = 1.06
Mean	130.25/72.42 = 1.80	134/130.25 = 1.03
Percent Fcst. Underestimate	80	3

Table 14: Comparison of final 2000 NTC forecast to statistical forecasts and of observed NTC to final forecasts.

Forecast Period	(c) Ratio Final Fcst NTC/Statistical Fcst NTC	(d) Ratio Observed NTC/Fcst NTC
1 December	125/73.3 = 1.71	134/125 = 1.07
1 April	125/47.8 = 2.61	134/125 = 1.07
1 June	150/109 = 1.38	134/150 = 1.12
1 August	130/59.6 = 2.18	134/130 = 0.97
4-season Mean Percent	132.5/72.4 = 1.83	134/132.5 = 1.01
Percent Underestimated	83	1

Table 15: Comparison of NTC ratios (observed/forecast) for the average of the four different lead time (analog and statistical) forecasts during the last three years.

Year	(1) NTC Obs./Analog Fcst	(2) NTC Obs./Statistical Fcst.	(3) NTC Analog/Statistical	(4) NTC Obs./Act. Fcst
1998	1.24	1.69	1.36	1.74
1999	0.92	1.85	2.02	1.21
2000	1.06	1.85	1.75	1.01
Mean of three years	1.07	1.80	1.71	1.28

approach and were quite close to the actual NTC values which occurred.

10.1 Conjecture on Possible Causes for the Recent Failure of Statistical Regression Scheme

Since 1995 we have had a major change in the basic global atmospheric and oceanic circulation features including (among others):

1. Atlantic Sea Surface Temperature (SST) and surface pressure patterns
2. Trend in the North Atlantic Oscillation
3. Alteration in Pacific SST and Circulation Features

The global atmosphere-ocean system has been functioning differently since mid-1995 and, it appears, that our statistical schemes have missed the influence of these altered physical factors which affect Atlantic tropical cyclone activity. As our statistical schemes were developed on training data from the 1950–1990 period, it appears that since 1995 the atmosphere-ocean is functioning differently than it had in the earlier period, it is possible that cause of the break down of our statistical regression scheme may have the same origin as the recent changes in the western Sahel and major hurricane relationship and the appearing stronger relationship between ENSO and Atlantic hurricane activity.

10.2 Current Superiority of Analog Forecast Methods

At present the analog forecast technique, when property applied, appears to have distinct advantages over the typical statistical regression schemes that we have used for many years.

Typically, there are at least a few prior years wherein a number of similar global precursor relationships such as the El Niño Southern Oscillation (ENSO), the stratospheric QBO, the global arrangement of surface pressure anomaly (SLPA) and sea surface temperature anomaly (SSTA), etc. are generally similar to the current year's pre-season conditions. Selecting analogs allow us to immediately focus on the few prior years likely to be more representative of current conditions.

The atmosphere and ocean, in combination, have a strong and long multi-month to multi-season memory. It is reasonable to infer that global precursor signals of past years that are associated with specific levels of hurricane activity would be similarly indicative of the same level of hurricane activity for a coming season. As no prior year can ever be expected to be a perfect analog to current year conditions, it is likely that an ensemble average of the four or five closely similar multi-parameter precursor analog years may be the best estimate of the forthcoming season. This is an area which we plan to conduct further research.

11 Increased Level of Atlantic Basin Hurricane Activity (Including U.S. Landfall) During the Last Six Years

A major rearrangement of Atlantic Ocean SST features began in mid-1995 and has continued through October 2000 (Fig. 6). This change is well associated with increased Atlantic basin intense or major (cat. 3-4-5) hurricane activity during the last six years. We hypothesize that these strong, broadscale SST changes are due to basic changes in the strength of various components of the Atlantic Ocean thermohaline ("conveyor belt") circulation. This interpretation is consistent with changes in a long list of global atmospheric circulation features during the last six years which conform to a prominent shift towards a stronger Atlantic Ocean thermohaline circulation and Atlantic SSTAs (see Fig. 6). This change occurred between 1994 and 1995. Such changes in Atlantic multi-decadal thermohaline circulation shifts appear to occur on periods of 25–50 years. If this interpretation is correct, then increased Atlantic basin intense (category 3-4-5) hurricane activity may be expected to persist through the early decades of the 21st century, which will be in contrast with the greatly diminished activity during the later decades of the 20th century.

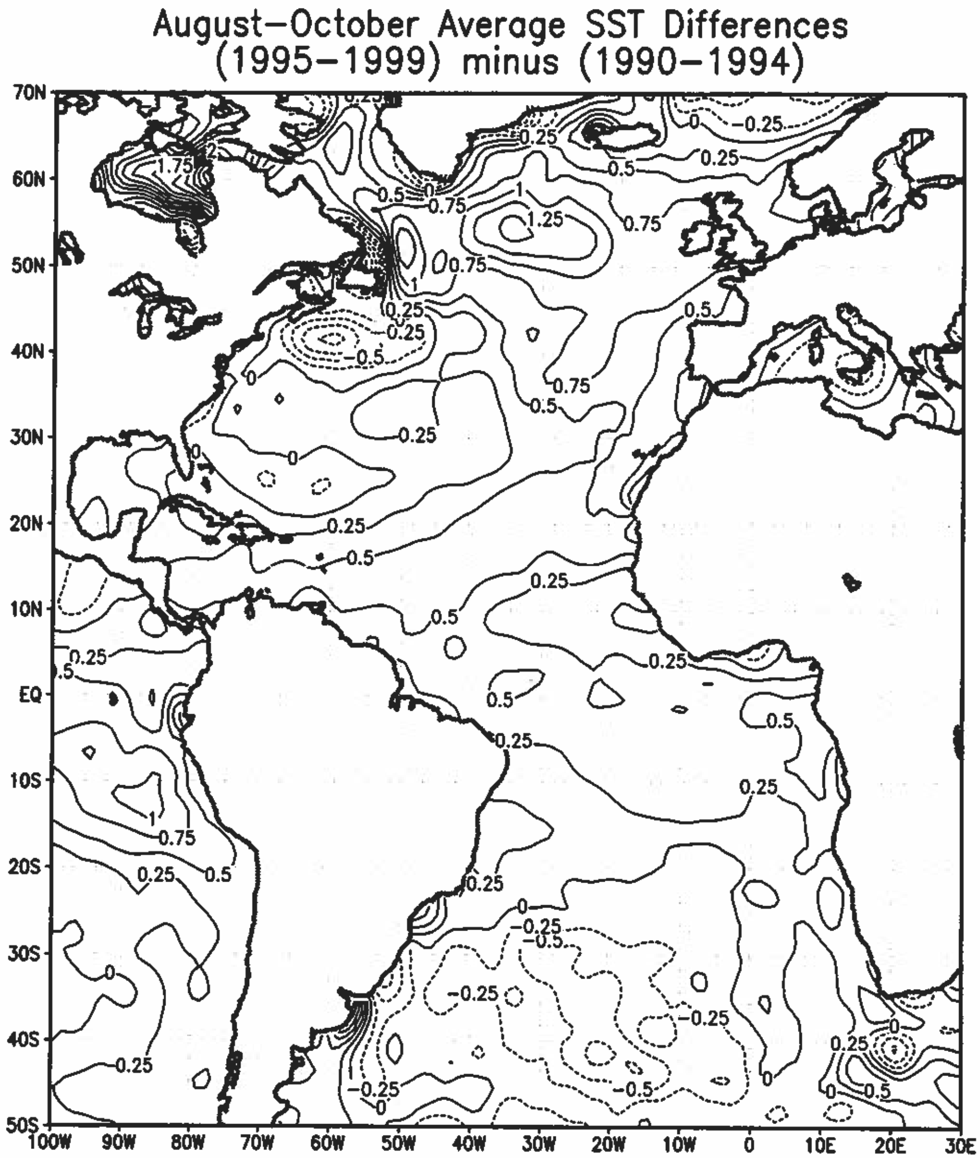

Figure 6: August through October SST differences (in °C) for the two five-year periods of 1995 to 1999 minus 1990 to 1994.

Despite El Niño-linked reduced hurricane activity of 1997, the last six years (1995–2000) are together the most active six consecutive hurricane years on record. Table 16 lists the total number of named storms (79), hurricanes (49), major hurricanes (category 3-4-5) (23), major hurricane days (56.25) and Net Tropical Cyclone (976) which occurred during 1995–2000. Note that despite the inactive 1997 season, the annual average NS, H, IH, IHD and NTC during these six years was 146, 163, 239, 329, 331 and 214 percent of the NS, H, HD, IH, IHD, and NTC hurricane activity of the prior (1989–94) six-year period. Note also that NS, H, HD, IH, IHD and NTC during the last six years are 153, 165, 247, 250, 373 and 217 percent of the average for the prior 25-year (1970-1994) period; the greatest increase having occurred for IH and IHD activity. Figure 7 portrays differences in H and IH tracks during these periods. These trends to increased hurricane activity give strong support to the suggestion that we have indeed entered a new era of greatly increased major hurricane activity. Despite the large El Niño-linked reductions in NTC during 1997 (55), NTC activity of the six-year period of 1995-2000 has averaged 165 or 165 percent of the 1950-1999 average. Excluding 1997 average NTC for the five years of 1995, 1996, 1998, 1999, and 2000 have had a mean NTC of 187.

Table 16: Comparison of recent five-year period (1995–2000) hurricane activity with prior five-year period (1990–1994) and the recent quarter century period of 1989–1994.

Year	Named Storms (NS)	Hurricanes (H)	Hurricane Days (HD)	Cat 3-4-5 Hurricanes (IH)	Cat 3-4-5 Hurricane Days (IHD)	Net Tropical Cyclone Activity (NTC)
1995	19	11	60	5	11.50	229
1996	13	9	45	6	13.00	198
1997	7	3	10	1	2.25	54
1998	14	10	49	3	9.25	168
1999	12	8	43	5	15.00	193
2000	14	8	32	3	5.25	134
TOTAL	79	49	239	23	56.25	976
Six-year Ave. 1995-2000	13.2	8.2	39.8	3.80	9.4	163
1989	11	7	32	2	10.75	140
1990	14	8	27	1	1.00	104
1991	8	4	8	2	1.25	59
1992	6	4	16	1	3.25	62
1993	8	4	10	1	0.75	55
1994	7	3	7	0	0	37
TOTAL	54	30	100	7	17.00	457
Six-year ave.	9.0	5.0	16.7	1.2	2.8	76
Ratio 1995-00/1989-94 in percent	146	163	239	329	331	214
Annual Ave. Ratio 1995–00/1970–94 in percent	153	165	247	250	373	217

For some years we have suggested that the era of greatly reduced intense Atlantic category 3-4-5 hurricane activity between the late 1960s to early 1990s would end and that the U.S. and Caribbean coastal regions should be expected to see an increase in landfalling major hurricanes

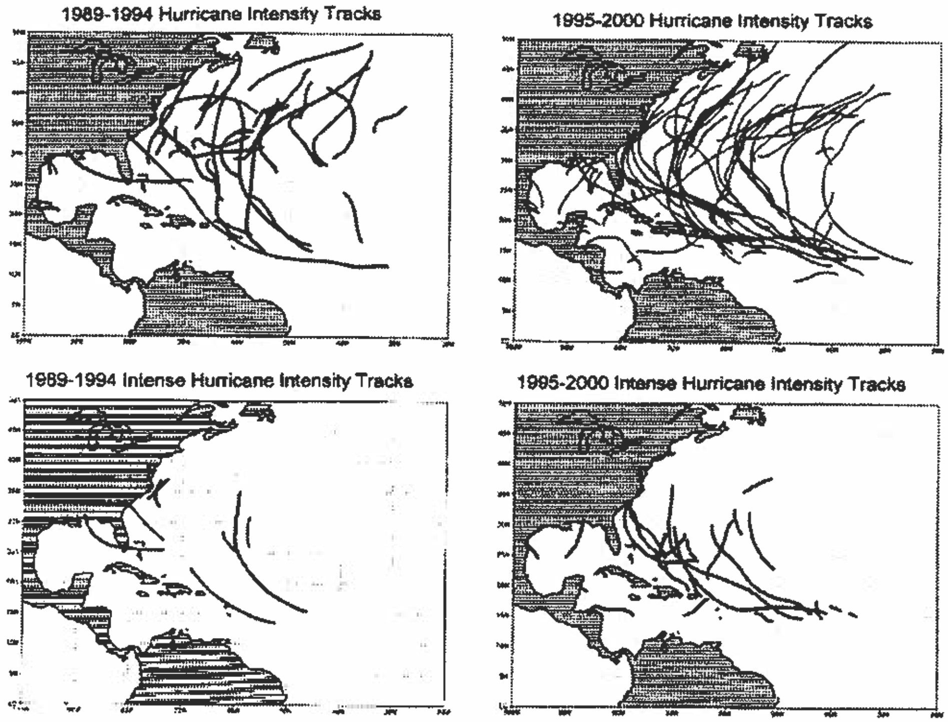

Figure 7: Comparison of cyclone tracks of hurricane intensity (top diagrams) and of category 3-4-5 hurricane intensity (bottom) during two six-year periods, 1989–94 (left) and 1995–00 (right).

(Gray 1990). This outlook is ominous because of the increases in U.S. ssoutheastern population and the new realization that when hurricane destruction is normalized for coastal population, inflation, and wealth per capita [see Pielke and Landsea (1998)] that major hurricanes (on a statistical basis) cause about 85 percent of all U.S. tropical cyclone linked destruction.

Recent Upswing of U.S. Landfalling Tropical Cyclones but Decrease in Major Hurricane Landfall. In comparison to Atlantic basin major hurricane activity Table 17 lists the number of U.S. landfall named storms during the two most recent six-year periods, 1989–1994 versus 1995–2000. Note the increase from 8 to 13 in U.S. hurricane landfall during the last six years from the previous six-year period. This increase is consistent with the overall increase in net Atlantic basin hurricane activity as shown in Table 16. Table 18 gives ratios of 1995–00 versus 1989–94 incidence of landfalling tropical cyclones and two categories of hurricanes. Overall, hurricane landfall activity increased 163 percent between the earlier and later period.

However, the foregoing is deceiving, particularly in comparison to the differences in major landfall events between these two periods. Official records indicate that over the last century (1900–1999) there have been 218 major hurricanes in the Atlantic basin and of these category 3-4-5 storms, about one-third (73) have come ashore along the U.S. coastline. In the last six years (1995–2000) there have been 23 major hurricanes within the Atlantic basin but only three (Opal, 1995; Fran, 1996; and Bret, 1999) have come ashore. If the typical one out of three ratio of major hurricane landfall events of the last six years had taken place, then we should have experienced 7-8 major hurricane landfall events, not just three that did come ashore.

Table 17: Comparison of U.S. landfalling tropical cyclones of various intensity class TS, Cat 1-2, and Cat 3-4-5 hurricanes during 1989–1994 versus 1995–2000.

1989–1994	NAMED STORMS
1989	3 (Chantal – Cat 1), (Hugo – Cat4), (Jerry – Cat 1)
1990	1 (Marco – TS)
1991	1 (Bob – Cat 2)
1992	2 (Andrew – Cat 4; Cat 3), (Danielle – TS)
1993	1 (Arlene – TS), (Emily – Cat 3)
1994	3 (Alberto –TS), (Beryl –TS), (Gordon –TS)
1989–1994	11 TOTAL
1995–2000	NAMED STORMS
1995	5(Allison –TS), (Dean – TS), (Erin – Cat 1; Cat 2), (Jerry –TS), (Opal – Cat 3)
1996	3 (Bertha – Cat 2), (Fran – Cat 3), (Josephine –TS)
1997	1 (Danny – Cat 1)
1998	7 (Bonnie - Cat 2), (Charlie –TS), (Earl – Cat 1), (Frances –TS) (Georges – FL Cat 2; MS Cat 2), (Hermine – TS), (Mitch –TS)
1999	5(Bret – Cat 3), (Dennis –TS), (Floyd – Cat 2), (Harvey –TS), (Irene – Cat 1)
2000	2 (Gordon – TS), (Helene – TS)
1995–2000	23 TOTAL

Table 18: Comparison of U.S. landfalling of named storms and hurricanes of various intensity during the prior six-year period of 1989–1994 versus the more recent 1995–2000 period. (If a cyclone comes inland at two different locations it is counted twice).

	1989–1994	1995–2000	Ratio 1995-00/1989–94
TS Only	6.00	12.00	2.00
Cat. 1-2 Hurricanes	4.00	10.00	2.50
Cat. 3-4-5 Hurricanes	4.00	3.00	0.75
TOTAL	14.00	25.00	1.79
Landfall as a Ratio to Mean NTC Activity 100 NTC is taken as one.			
TS Only	8.00	7.25	0.91
Cat. 1-2 Hurricanes	5.33	6.06	1.14
Cat. 3-4-5 Hurricanes	5.33	1.82	0.34
TOTAL	18.67	15.15	0.81

We have been fortunate that an upper-air trough has been located along the U.S. East Coast during a high percentage of time during the last six hurricane seasons. The fortuitous frequent location of this upper-level East Coast trough has caused a large portion of otherwise northwest moving major hurricanes to be recurved to the north before they reach the U.S. coastline. Thus, we have been lucky. But this luck can not be expected to continue. Very few residents of the southeastern U.S. coastline are likely aware of how fortunate they have been over the last 3-4 decades.

Given the U.S. major hurricane landfall numbers of the last century, our luck at beating climatology has now extended about four decades. For example, in the 30-year period of 1971–2000, the U.S. experienced 15 major landfall events, or 0.50 per year. This is only 62 percent the annual incidence of major hurricane landfall events which occurred in the previous 72 years of 1900–1971.

With regard to the Florida Peninsula and the U.S. East Coast, the situation is even more skewed. In the last 40 years (1961–2000), there have been only six landfalling major hurricanes (average 0.15 per year) along the Florida Peninsula and U.S. East Coast. Between 1900–1960 there were 31 major landfall events along this same coastline (or 0.51 per year). The first six decades of the 20th century had 3.4 times more landfall major hurricanes along the Florida Peninsula and East Coast than occurred in the last four decades. This long downturn in U.S. major hurricane landfall events along the Florida Peninsula and East Coast is unlikely to continue. Climatology will eventually right itself and we must expect a great increase in landfalling major hurricanes in the coming few decades.

12 Landfall Probabilities for 2000

A new aspect of our research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline. Whereas individual hurricane landfall events can not be accurately forecast for an individual year, the net yearly probability of landfall can be forecast with statistical skill. With the premise that landfall is a function of varying climate signals, a probability specification has been accomplished through a statistical analysis of all U.S. hurricane landfalls of named storms during the last 100 years (1900–1999). Specific landfall probabilities can be given for all cyclone intensity classes for a set of distinct U.S. coastal regions. Net landfall probability is statistically related to the overall Atlantic basin Net Tropical Cyclone Activity (NTC) and to climate trends linked to multi-decadal variations of the Atlantic Ocean thermohaline circulation (as measured by recent past years of North Atlantic SSTA*). Table 19 gives verification of our landfall predictions for 2000. These landfall probabilities did not materialize.

Active research is in progress on this technique. Full documentation of the methodology for estimating hurricane landfall probability study is being prepared and will, hopefully, be available in the next few months. Landfall probabilities include specific forecast of the probability for landfalling tropical storms (TS) and hurricanes of category 1, 2, 3, and 4-5 is being developed for each of 11 units of the U.S. coastline (Fig. 8). These 11 units are further being subdivided by coastal population into 96 regions based on coastal population. Statistics are being developed for each 100 km (65 mile) segment of the entire U.S. coastline.

Figure 9 gives a general outline of this methodology. These forecast probabilities will be supplemented with probability values for each 100 km coastal segment receiving gale force winds

Table 19: Estimated probability (percent) of one or more U.S. landfalling Tropical Storms (TS), category 1-2 hurricanes, and category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (region 1-4), and along the Florida and the East coastline (Regions 5-11) for 2000. The mean annual number of one or more landfalling systems during the last 100 years is given in parentheses. The actual landfall numbers for 2000 follow the dash "–" symbol.

Coastal Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	82% (80)–2	73% (68)–0	60% (52)–0	89% (84)–0	98% (97)–2
Gulf Coast (Regions 1-4)	67% (59)–2	46% (42)–0	34% (30)–0	62% (61)–0	87% (83)–2
Florida plus East Coast (5-11)	47% (51)–0	52% (45)–0	39% (31)–0	72% (62)–0	86% (81)–0

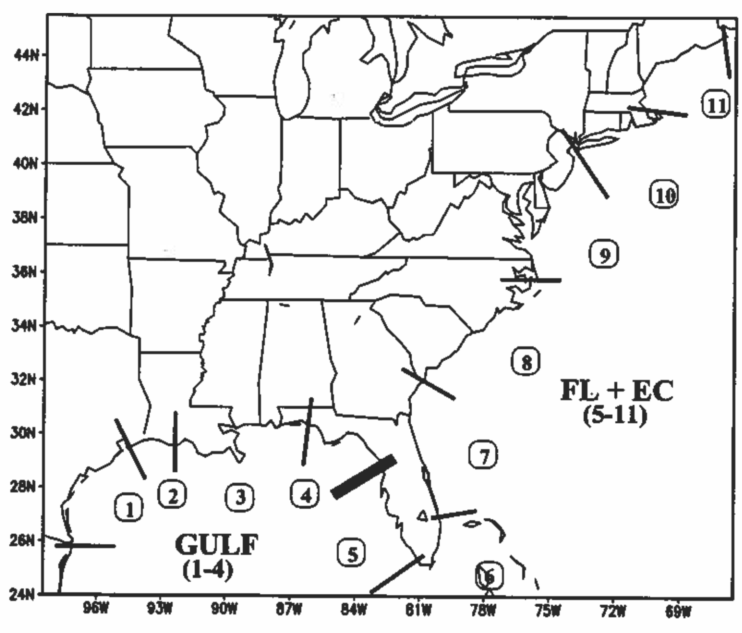

Figure 8: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made.

(≥ 40 mph), sustained hurricane force winds (≥ 75 mph), and major hurricane (category 3-4-5) winds (≥ 115 mph). There will also be a discussion of potential tropical cyclone spawned hurricane destruction within each of the 96 different U.S. coastal locations.

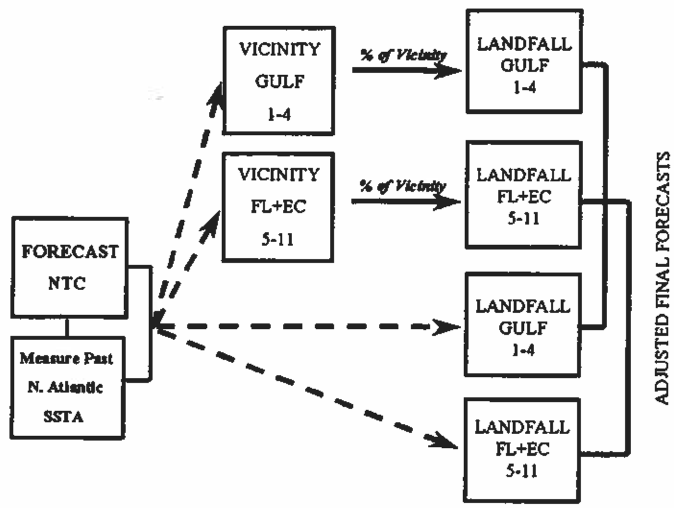

Figure 9: General flow diagram illustrating how forecasts of U.S. hurricane landfall probabilities are made. We forecast NTC and use an observed measure of the last few years of North Atlantic (50-60°N, 10-50°W) SSTA*. Regression equations are then developed from the combinations of forecast NTC and measured SSTA* values. A regression is then developed from U.S. hurricane landfall measurements of the last 100 years and separate equations are derived for the Gulf and for Florida and the East Coast (FL+EC).

13 The 1995–2000 Upswing in Atlantic Hurricanes and Global Warming

Some may interpret the recent large upswing in Atlantic hurricane activity (since 1995) as being in some way related to increased man-made greenhouse gases such as carbon dioxide (CO_2). There is no scientifically reasonable way that such an interpretation of this recent upward shift can be made. Anthropogenic greenhouse gas warming, even if a physically valid hypothesis, is a very slow and gradual process that, at best, might only be expected to bring about small changes in global circulation over periods of 50 to 100 years and could not cause the abrupt and dramatic upturn in hurricane activity as occurred between 1994 and 1995. Also, the large downturn in Atlantic basin major hurricane activity between 1970–1994 would need to be reconciled with proposed global warming scenarios during this period. Atlantic intense (or category 3-4-5) hurricane activity showed a substantial decrease during 1970–1994 to levels about 40 percent of the amount which occurred during the 1950–1969 or the 1995–2000 periods. There were 78 Atlantic basin major hurricanes in the 26 years of 1950–1969, 1995–2000 versus 38 in the 25 years of 1970–1994. This is an annual ratio differences of two to one. And, even if man induced greenhouse increases were shown to be causing global temperature increases over the last 25 years, there is no way to relate such a small global temperature increase to more hurricane activity.

In contrast with the large increase in Atlantic basin major hurricane activity during the last five years, total hurricane and typhoon activity in the (East and West) North Pacific region during the period 1995–2000 has decreased. When we combine Atlantic and North Pacific tropical cyclone activity, we see a net downward trend for the recent 1995–2000 period (Table 20). Hence, we should not interpret the recent enhancement of major hurricanes in the Atlantic as indicative of the changes of hurricane activity around the globe. It is only in the Atlantic where hurricane activity has shown a sharp rise and this rise is in conformity with the changes in Atlantic sea surface temperature patterns and the diagnosed increase in the thermohaline circulation. Such up and down multi-decadal changes in Atlantic intense sea surface temperature and tropical cyclone activity have been observed to take place many times in the past and are considered to be naturally occurring modes of multi-decadal variability.

Table 20: Comparison of North Pacific and Atlantic tropical cyclone activity during 1989–1994 versus 1995–2000.

(1989–1994)	No. of Systems $\geq$ TS Intensity	No. of Systems $\geq$ HUR. Intensity	No. of Major Hurricane
North Pacific (East and West)	301	230	100
Atlantic	54	30	7
Total	355	250	107
(1995–2000)			
North Pacific (East and West)	252	183	73
Atlantic	79	49	23
Total	331	232	96
Ratio of Total North Pacific + Atlantic 1995–2000/1989–1994	0.93	0.93	0.90

14 Forthcoming Early December Forecasts for 2001 Hurricane Activity

We will be issuing a seasonal forecast for 2001 Atlantic basin hurricane activity on 8 December 2000. A separate forecast will also be attempted for the month of August 2001. These forecasts will be based on data available to us through November 2000. These forecasts will be disseminated on the World Wide Web. Updates to the 2001 seasonal forecast will be issued in early April, early June, and early August 2001 as will a separate forecast for August 2001 with our late update.

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The financial backing for the issuing and verification of these forecasts has, in part, been supported by the National Science Foundation. But this NSF support is insufficient. Recently, the Research Foundation of the United Services Automobile Association (USAA) and State Farm insurance companies have made contributions to the first author's project. It is this support which is allowing our seasonal predictions to continue.

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APPENDIX A: Verification of Past Seasonal Forecasts

The first author has now issued seasonal hurricane forecasts for 16 consecutive years (1984–1999). In the majority of these forecasts, the predictions were superior to climatology (i.e., long-term averages), particularly for named storms. Figures 8 and 9 offer comparisons of our 1 August forecasts of named storms and hurricanes versus climatology and actual year-to-year variability. Overall, there is predictive skill greater than climatology.

We have issued forecasts for intense or major (category 3-4-5) hurricanes since 1990. The 1 August forecast correlation for these 11 years has been r = .73.

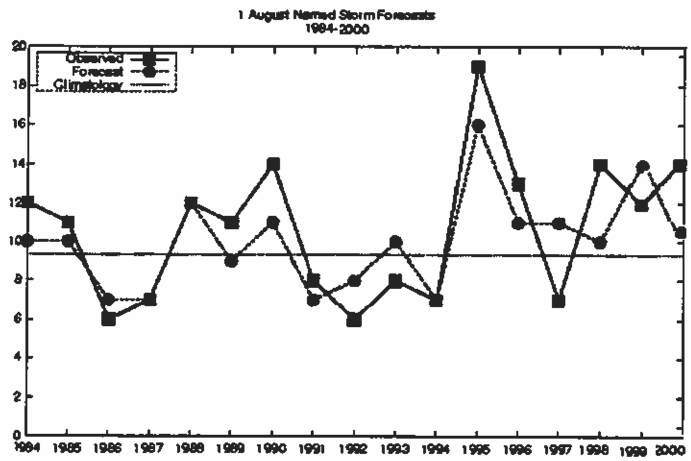

Figure 10: 1 August prediction of total named storms versus the number of actually observed versus long-term climatological mean (r = 0.80) for period 1984–2000.

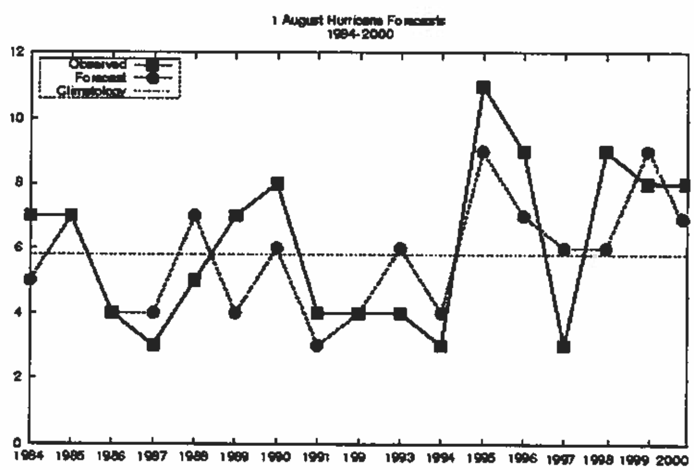

Figure 11: 1 August prediction of total hurricanes versus the number of actually observed versus climatological long-term mean (r = 0.64) for period 1984–2000.

Table 21: Summary verifications of the author's prior seasonal forecasts of Atlantic TC activity between 1984-1999.

	Prediction Dates		Observed
1984	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	of 28 May	Update 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	29 May	Update 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	26 May	Update 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	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	26 May	Update 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	5 June	Update 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	5 June	Update 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	26 Nov 1991	Update 5 June	Update 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	24 Nov 1992	Update 4 June	Update 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	19 Nov 1993	Update 5 June	Update 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	30 Nov 1994	Update 14 April	Update 7 June	Update 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	30 Nov 1995	Update 4 April	Update 7 June	Update 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

1997	30 Nov 1996	Update 4 April	Update 6 June	Update 5 August	Obs.
No. of Hurricanes	7	7	7	6	3
No. of Named Storms	11	11	11	11	7
No. of Hurricane Days	25	25	25	20	10
No. of Named Storm Days	55	55	55	45	28
Hurr. Destruction Potential(HDP)	75	75	75	60	26
Major Hurricanes (Cat. 3-4-5)	3	3	3	2	1
Major Hurr. Days	5	5	5	4	2.2
Net Trop. Cyclone Activity	110	110	110	100	54

1998	6 Dec 1997	Update 7 April	Update 5 June	Update 6 August	Obs.
No. of Hurricanes	5	6	6	6	10
No. of Named Storms	9	10	10	10	14
No. of Hurricane Days	20	20	25	25	49
No. of Named Storm Days	40	50	50	50	80
Hurr. Destruction Potential(HDP)	50	65	70	75	145
Major Hurricanes (Cat. 3-4-5)	2	2	2	2	3
Major Hurr. Days	4	4	5	5	9.2
Net Trop. Cyclone Activity	90	95	100	110	173

1999	5 Dec 1998	Update 7 April	Update 4 June	Update 6 August	Obs.
No. of Hurricanes	9	9	9	9	8
No. of Named Storms	14	14	14	14	12
No. of Hurricane Days	40	40	40	40	43
No. of Named Storm Days	65	65	75	75	77
Hurr. Destruction Potential(HDP)	130	130	130	130	145
Major Hurricanes (Cat. 3-4-5)	4	4	4	4	5
Major Hurr. Days	10	10	10	10	15
Net Trop. Cyclone Activity	160	160	160	160	193