UPDATED FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY FOR 1992

By

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(This update of the author's 26 November 1991 and 5 June 1992 seasonal forecasts of 1992 hurricane activity is based on new June–July meteorological conditions and recent studies by the author and his Colorado State University research colleagues)

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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 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.

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

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

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

Delta PT - A parameter which measures the west to east surface pressure (ΔP) and surface temperature (ΔT) gradient across the western Sahel region of Africa.

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

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

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

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

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

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

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

ABSTRACT

This paper presents details of the author's updated forecast of tropical cyclone activity for the Atlantic Ocean region including the Caribbean Sea and the Gulf of Mexico during 1992. This updated forecast includes meteorological data for June and July and is based on the author and his research colleagues ongoing research activities which relates the amount of seasonal Atlantic tropical cyclone activity to five factors: Namely, 1) three measures of the Quasi-Biennial Oscillation of equatorial stratospheric zonal wind (QBO) at 50 mb (20 km) and 30 mb (23 km) and the absolute value of the shear between these levels; 2) the El Niño (EN) as specified by the Equatorial East Pacific Sea Surface Temperature Anomaly (SSTA) and the value of the Southern Oscillation Index (SOI); 3) Caribbean basin Sea-Level Pressure Anomalies (SLPAs) and upper tropospheric 200 mb Zonal Wind Anomalies (ZWA); 4) two measures of West African Rainfall (AR) anomalies, one of June-July in the western Sahel region, and the other the previous year August through November precipitation in the Gulf of Guinea region and 5) the surface west to east pressure and temperature gradients across the western Sahel region of Africa.

Information received by the author through 4 August 1992 indicates that the 1992 hurricane season should be below average with about 4 hurricanes, 8 named storms of at least tropical storm intensity, about 15 hurricane days, a total of 35 named storm days and a Hurricane Destruction Potential of 35. Because the western Sahel is expected to be dry again this year, it is anticipated that there will be only one intense hurricane of Saffir/Simpson intensity category 3, 4 or 5 this season. This year's forecast is for the same amount of hurricane activity that was previously forecasted on 26 November 1991, an update assessment of 10 April and on 5 June 1992.

1 Introduction

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

2 Factors Known to be Associated With Atlantic Seasonal Hurricane Variability

The author's early August Atlantic seasonal hurricane forecast is based on the current values of indices derived from two global and four regional scale predictive factors which the author and his colleagues have previously shown to be statistically related to seasonal variations of hurricane activity. The current values of these predictive factors are available by late November of the previous year, by early June, the official start of the hurricane season, or by early August, before the start of the most active portion of the hurricane season. These predictive factors for early August are:

a) The direction of the east-west stratospheric Quasi-Biennial Oscillation (QBO) winds which circle the globe over the equator: On average, there is nearly twice as much intense Atlantic basin hurricane activity during seasons when equatorial winds at 30 mb and 50 mb (23 and 20 km altitude respectively) have a relatively westerly component as compared to periods when they have a relative easterly component. During the 1992 season, these QBO winds will be changing from an easterly to a westerly direction. Winds at 30 mb in September will be from a relative westerly direction and 50 mb will be from a relative easterly direction. The easterly component of the 50 mb winds is expected to render a modest inhibiting influence on this season's intense hurricane activity.

b) The presence or absence of a moderate or strong El Niño (warm water) event in the eastern equatorial Pacific: Atlantic hurricane seasons during moderate or strong El Niño events average only about 40 percent as much hurricane activity as occurs during non-El Niño seasons. These differences are related to the stronger upper tropospheric (200 mb or 12 km) westerly winds which typically occur over the Caribbean basin and western Atlantic during El Niño seasons. The moderately strong El Niño event of this past (1991-1992) winter and spring is now rapidly weakening and is expected to dissipate by October. This weakening warm event is expected to cause only a slight reduction on this year's hurricane activity. El Niño strength can be assessed from the Sea Surface Temperature Anomaly (SSTA) in the Nino 3 area of the Pacific and from the normalized surface pressure difference between Tahiti and Darwin, or Southern Oscillation Index (SOI) (see Fig. 1).

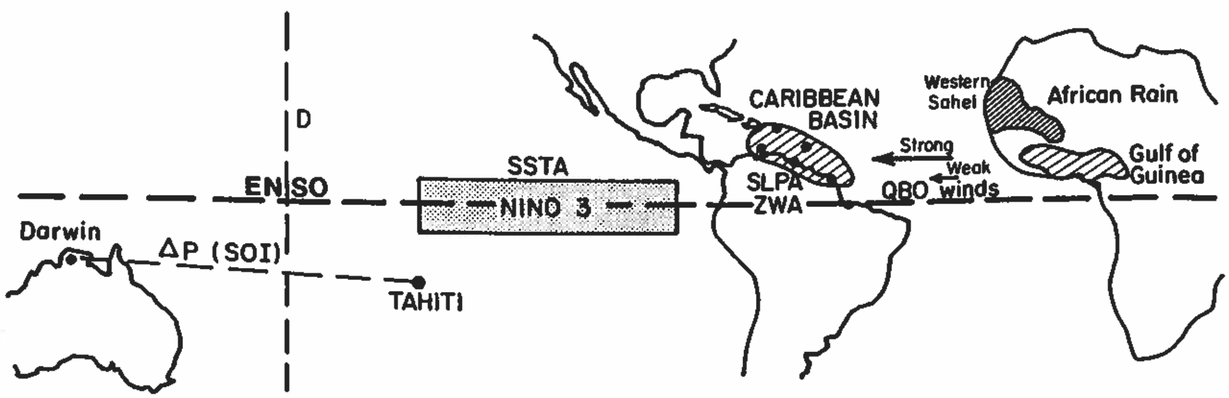

Figure 1: Locations of meteorological parameters used in 1 August Atlantic basin seasonal forecast.

c) African Rainfall (AR). Atlantic intense hurricane activity is typically enhanced in those seasons when the western Sahel region of West Africa has had above average June-July rainfall and the Gulf of Guinea region (Fig. 2) has had above average late summer and fall precipitation during the previous year (i.e., in this case, during the fall of 1991). Hurricane activity is typically suppressed if the prior period rainfall in these two regions has been below average. Last year (1991) conditions were dry and this trend has prevailed through June and July of this year. These trends indicate that western Sahel precipitation will again have below normal rainfall for the rest of this year. This should act to reduce intense hurricane activity for this year. Figure 3 demonstrates the strong modulation of intense hurricane tracks in those years of wet versus dry western Sahel rainfall years.

d) Sea Level Pressure Anomaly (SLPA) in the eastern Caribbean basin. Other factors aside, negative pressure anomalies in the eastern Caribbean basin in late spring and early summer are typically associated with active hurricane seasons and vice-versa. Pressure anomaly values for June and July of this year have been somewhat above normal. This is judged to be a weak inhibiting influence on this season's hurricane activity.

e) Lower latitude Caribbean basin upper tropospheric ($\sim$ 200 mb or 12 km altitude) west to east or zonal wind anomalies (ZWA): Stronger 200 mb zonal wind anomalies are associated with a suppression and negative anomalies with an enhancement of seasonal hurricane activity. June-July ZWA values for this year were weakly positive. This is judged to be a weak suppressing influence on this season's hurricane activity.

f) Western Sahel west to east surface pressure and temperature gradients (or Delta PT). Our recent research is showing that west to east surface pressure and surface temperature gradients across the western Sahel region of Africa from February through May are well correlated with the hurricane activity which follows later in the year. As shown in Fig. 4, we find that Atlantic hurricane activity is enhanced

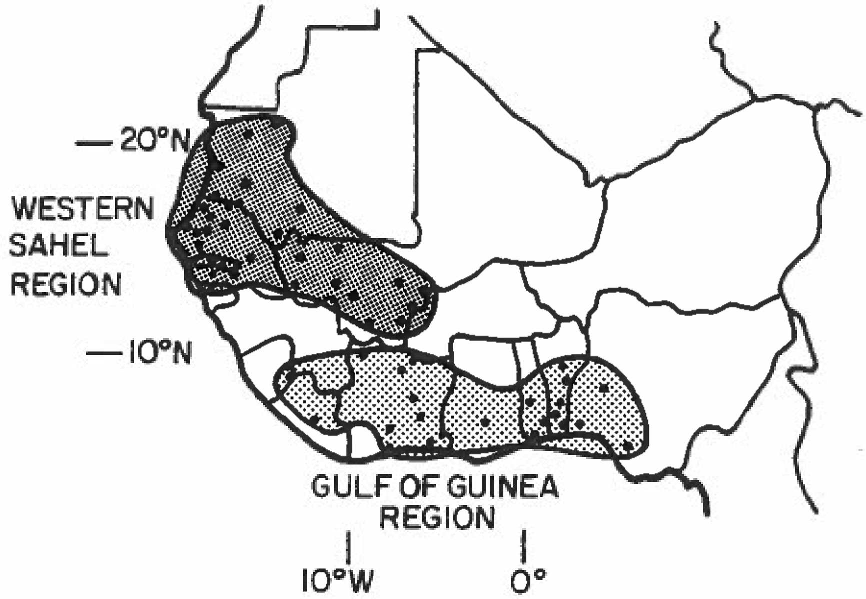

Figure 2: Locations of rainfall stations which make up the 38-station western Sahel precipitation index and the 24-station Gulf of Guinea precipitation index. August to November rainfall within the Gulf of Guinea region provides a predictive signal for the following year's hurricane activity while June to July rainfall in the western Sahel provides a predictive signal for the upcoming Atlantic hurricane season (see Landsea, 1991; and Gray *et al.*, 1992a,b, 1993).

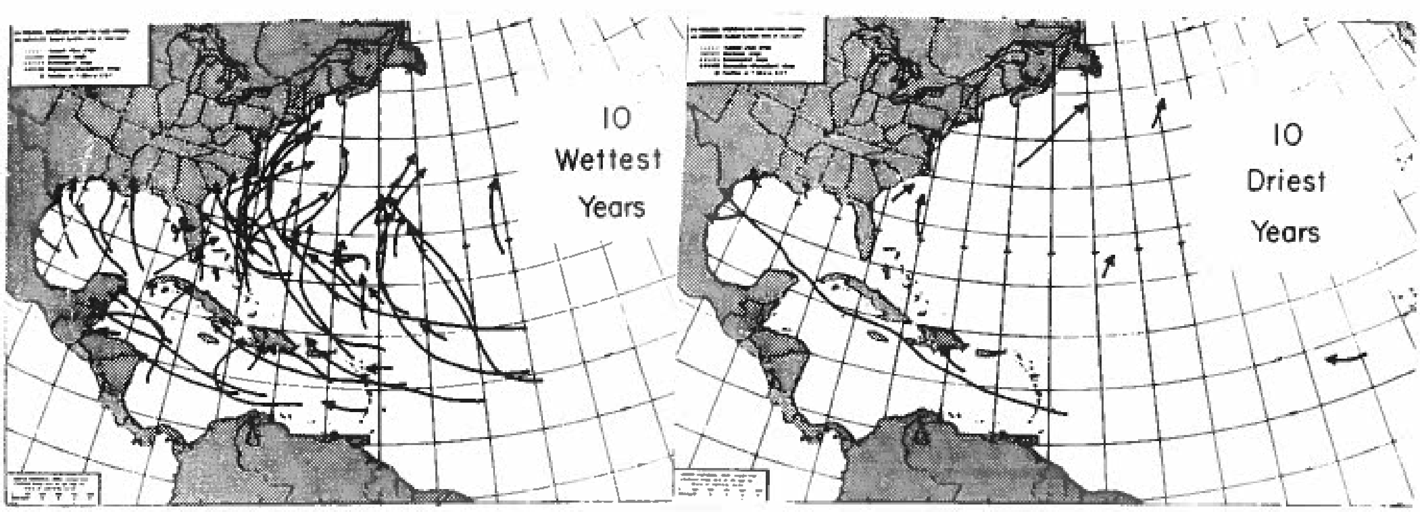

Figure 3: Comparison of intense hurricane storm tracks during the 10 wettest and 10 driest western Sahel rainfall seasons during the 43-year (1949–91) period.

when the surface pressure difference between the east (Region B) minus the west (Region A) is greater than normal and/or when the east minus west temperature difference is below average. These pressure and temperature gradients between February and May of this year have been configured so as to indicate below average hurricane conditions for this season.

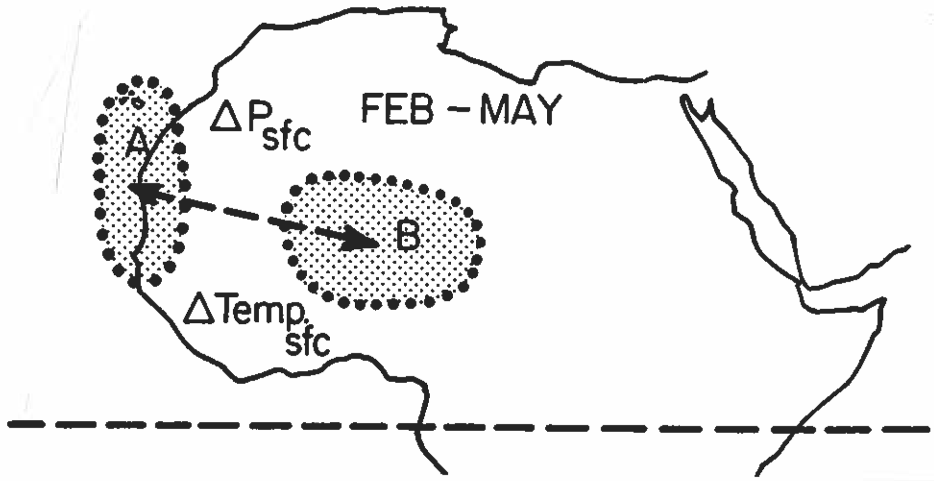

Figure 4: Locations of the two West African regions—west (Area A) and east (Area B)—from which the means of normalized multi-station surface pressure and temperature data are computed to form a combined west-to-east pressure and temperature gradient or Delta PT parameter.

3 Current Characteristics and Further Discussion of the Early August Predictors of the 1992 Hurricane Season

3.1 QBO

Tables 1 and 2 show absolute and relative values for the current and extrapolated 30 mb (23 km) and 50 mb (20 km) stratospheric QBO zonal winds near 11 to 13°N during the primary hurricane period of August through October, 1992. These estimates are based on a combination of the current trends in the QBO winds, combined with the annual cycle of wind variations at low latitude stations including Curacao (12°N), Trinidad (11°N), and Barbados (13°N). Note that during the primary August through October hurricane season, 30 mb zonal winds are expected to have shifted to a westerly phase but that 50 mb zonal winds are anticipated to persist from an easterly direction.

Stratospheric QBO wind conditions for this year are expected to be in an intermediate or transitional stage, changing from easterly to westerly phase conditions. We suspect that such change-over conditions will cause a slight negative deviation on this season's hurricane activity. There should also be a generally inhibiting influence on intense hurricane activity due to the easterly phase of the QBO below 50 mb. Over the last 42 years there have been only about half as many intense Atlantic hurricanes (category 3-4-5) in those seasons when 50 mb QBO absolute value of zonal winds were strongly from the east (as they are expected to be this year) than when they are weakly from the east (westerly phase).

3.2 ENSO

El Niño events cause the upper tropospheric westerly winds in the Caribbean basin and easterly tropical Atlantic to be stronger than normal. These upper level westerly winds cause vertical shearing (i.e., strong variations of the horizontal wind with height) of the westward moving Atlantic easterly wave systems which emanate from Africa. These shearing influences prevent the easterly waves from

Table 1: April through July (observed) and August through October (extrapolated) absolute values of stratospheric QBO zonal winds (U) in the (critical) latitude belt between 11-13°N, as obtained from lower Caribbean basin stations Curacao (12°N), Barbados (13°N), and Trinidad (11°N). Values are in ms^{-1} (as supplied by James Angell, Colin McAdie, and from our direct GTS network).

	Observed				Extrapolated		
Level	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	–18	–21	–23	–20	–15	–9	–4
50 mb (20 km)	–6	–13	–20	–24	–25	–24	–18

Table 2: As in Table 1 but for the "relative" (or anomalous) zonal wind values where the annual wind cycle has been removed. Values are in ms^{-1}.

	Observed				Extrapolated		
Level	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	–12	–9	–5	–1	+6	+10	+12
50 mb (20 km)	–5	–7	–8	–9	–11	–12	–10

developing into named storms or, if they do develop, prevent them from becoming as intense as they might otherwise become without such shearing influences.

The Central and Eastern tropical Pacific experienced a moderate to strong El Niño event earlier this year. This warming event is now in a rapid weakening phase. The strength of this ENSO event is best represented by the SSTA anomaly in the Nino 3 (5°N–5°S, 90–150°W) region of the equatorial Pacific and by the normalized SOI index – see Fig. 1. Table 3 indicates the values of this parameter from March through July, 1992; note the weakening trend. It is expected that this El Niño event will be fully dissipated by late in the year and it is likely that cold SST (or La Niña) condition will occur during the next hurricane season. Because the current El Niño is expected to be significantly weaker by September than it is at present, this factor is anticipated to pose only a modest suppressing influence on this season's Atlantic seasonal hurricane activity.

Table 3: Nino 3 SST anomaly and Southern Oscillation Index.

	March	April	May	June	July
SSTA (°C)	1.3	1.4	1.6	0.7	0.1
SOI (S.D.)	–3.0	–1.4	0.0	–1.2	–0.7

3.3 West African Rainfall (AR)

Work by Gray (1990), Landsea (1991), and Landsea and Gray (1992) have demonstrated that substantially more intense Atlantic hurricane activity occurs when June through September western Sahel rainfall is above average as compared to those seasons when this rainfall is below average (see Fig.

3). The long running West African drought of 1970-87 was associated with a great suppression of intense hurricane activity during that 18 year period. A temporary (two year) interruption of African drought conditions occurred in 1988–89 when there was also a substantial increase in intense hurricane activity including five Saffir/Simpson category 4-5 hurricanes. However, drought conditions returned again in 1990 and 1991 (see Fig. 5). The assessment for 1992 (as of the end of July) is that we will again see below average western Sahel rainfall this year. It is expected that precipitation amounts will be more in line with the reduced values of 1970-87 and 1990-91. West African rainfall is thus judged to be an inhibiting influence for Atlantic intense hurricane activity for 1992.

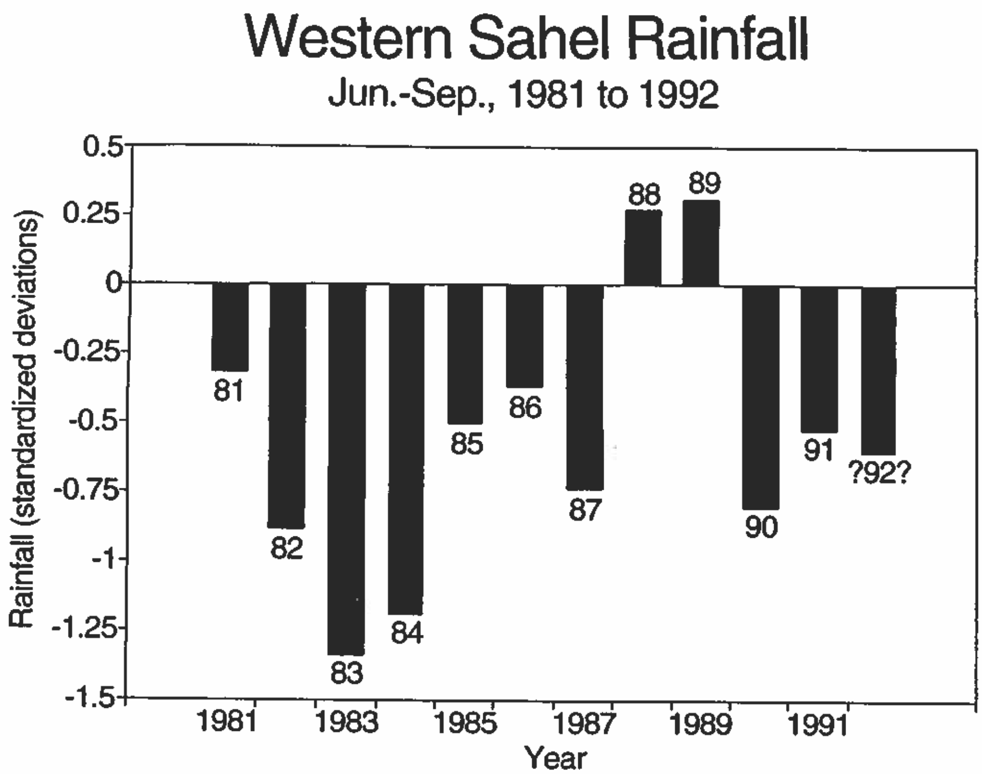

Figure 5: Recent variations of the standard deviation of June through September rainfall (right diagram) in the western Sahel region. Note the break in drought conditions during 1988 and 1989.

The assessment that 1992 will have below average precipitation in the Sahel is based upon the following considerations:

1. Below normal measured and inferred western Sahel rainfall conditions during June and July of this year. From NOAA-CAC information (Richard Tinker) for 23 western Sahel stations and from the assessments of the Department of Agriculture (Douglas LeComte) and U.S. Department of State AID FEWS program (Graham Farmer) is to be approximately −0.40 standardized deviations below normal. Noting that last year's August through November Gulf of Guinea rainfall was quite dry (−0.79 S.D.), we obtain a combined "early season" net rainfall amount of −0.53 S.D. As discussed by Landsea (1991) these "early season" rainfall deficiencies translate into a distinctly lower probability of intense hurricane activity for this year (about one intense hurricane).

2. Anticipated continuation of weak El Niño warm water conditions in the equatorial Pacific during the next few months. Warm SST conditions are typically associated with below normal western Sahel rainfall conditions.

3. The present configuration of global and Atlantic SSTA conditions which in past years have been associated with African drought conditions. These SSTA conditions include positive southwest Atlantic SSTA and negative SSTA anomalies off the coast of West Africa plus SSTA conditions in the Pacific and Indian oceans. The UK Meteorological Office (1992) is also forecasting dry Sahel region rainfall conditions for this year. Meteorological office forecasts are based on global SSTA patterns through June.

4. Negative values of February through May east-to-west anomaly gradients of surface pressure and west-to-east anomaly gradients of surface temperature (Delta PT) in West Africa. Such conditions are associated with later season dry conditions for the western Sahel.

3.4 SLPA

Table 4 shows June–July 1992 average Sea Level Pressure Anomaly (SLPA) values for the five most relevant low latitude tropical Atlantic stations. June–July SLPA values have been somewhat above (+0.4 mb S.D.) the long term average in this special 5-station low latitude area (see Fig. 1). Pressure anomalies are based on deviations from the last 42–year average. This indicates a modest reduction in this year's hurricane activity. These low latitude stations have been found to be more relevant to variations in seasonal hurricane activity than have these values in combination with the higher latitude Gulf of Mexico pressure anomalies previously used in the author's forecasts.

Table 4: Lower Caribbean basin Sea-Level Pressure Anomalies (SLPA) for 1992 in mb (as kindly supplied by Colin McAdie of NHC and from our CSU analysis).

Low Latitude SLPA for June–July, 1992 (mb)	
San Juan (19.5°N, 66°W)	-0.1
Curacao (12°N, 69°W)	+0.8
Barbados (13.5°N, 60°W)	-0.1
Trinidad (11°N, 62°W)	+0.8
Cayenne (5°N, 52.5°W)	+0.6
Average	+0.4

3.5 ZWA

The June–July Lower Caribbean basin 200 mb (12 km) zonal wind anomalies (ZWA) usually gives good indications of future tropospheric wind shear conditions for this region and over the tropical Atlantic during the later more active part of the hurricane season. ZWA conditions also act as a monitor for the influences of tropical Pacific El Niño warm water events on Caribbean basin upper tropospheric wind conditions. The data of Table 5 show that the upper tropospheric ZWAs for June and July were weakly positive. This indicates a modest reduction in this season's hurricane activity.

3.6 Western Sahel West to East Gradients of Surface Pressure and Surface Temperature

New project research by C. Landsea and R. Taft is showing that west-to-east surface pressure and temperature gradients which become established across West Africa during February through May are good indicators of the intense hurricane activity to be expected in the coming months. Figure 4 showed the west-and-east areas of West Africa from which these surface pressure and temperature gradients are taken. Pressure and temperature are expressed as deviations from the 1950–1991 average. Hurricane activity is highest when the east (Region B) minus west (Region A) deviational pressure gradients are

Table 5: April-May 1992 lower Caribbean basin 200 mb Zonal Wind Anomaly (ZWA) in ms^{-1} (as supplied by Colin McAdie of NHC and from our CSU analysis).

Station	April-May	June-July
Kingston (18°N, 77°W)	0	−2.0
Curacao (12°N, 69°W)	−1	+1.0
Barbados (13.5°N, 60°W)	+1	+2.0
Trinidad (11°N, 62°W)	+1	+4.0
Average	0	+1.2

most positive and/or when the east region minus west region temperature gradient is most negative. Thus, seasonal Atlantic hurricane is a function of Delta *PT or* $(\Delta P_{sfc(B-A)} - \Delta T_{sfc(B-A)})$. It is surprising how well these West African February through May surface pressure and temperature gradients are associated with seasonal hurricane activity in the following months. Pressure and temperature gradients that establish themselves in spring have a conservatism, tending to persist into summer and early fall. The combination of these west to east ΔP and ΔT gradients between 1950-1991 explained 46 percent (r = 0.68) of the variance of seasonal number of intense (category 3-4-5) hurricane days (see Fig. 6).

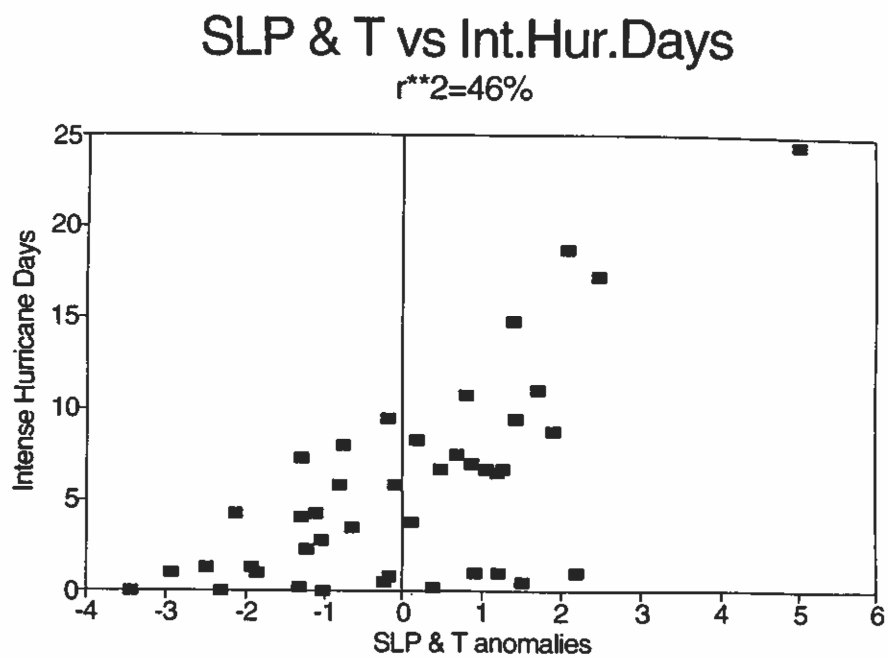

Figure 6: Scatter diagram of the seasonal number of intense hurricane days versus the combined west to east surface pressure and temperature gradient anomalies (Delta PT) during February through May during the years 1950–1991.

Given the typical inverse relationship between land surface temperature and surface pressure, positive west-to-east pressure gradients are typically associated with negative west-to-east temperature gradients and vice versa. A positive value of Delta PT would act to enhance southerly moist deviational flow over West Africa. More African rain and Atlantic hurricane activity would result. When these two west to east ΔP and ΔT gradients are of opposite sign (negative for ΔP and positive for ΔT) this would cause

West Africa to have northerly and dry deviational winds. This is conducive to dry conditions and fewer Atlantic seasonal hurricanes. February through May west-to-east pressure (Δ P) and temperature (Δ T) gradients for 1992 were such as to lead to reduced Atlantic basin hurricane activity Δ P = -1.5 S.D., Δ T = +0.8 S.D.

4 Statistical Forecast for 1992

The author and his research colleagues Paul Mielke, Ken Berry, and Chris Landsea are developing improved quantitative forecast schemes for the prediction of Atlantic seasonal hurricane activity from the periods of early December, early June, and early August (see papers by Gray, Landsea, Mielke, and Berry: 1992a, 1992b, and 1993). These collaborative research activities with CSU statistics professors Paul Mielke and Kenneth Berry has yielded new quantitative prediction equations which better refine and maximize our early August predictions. Mielke and Berry find that the best early August predictive equations take the form of

$$\tilde{y} = b_o + b_1 \left[a_1 U_{50} + a_2 U_{30} + a_3 |U_{50} - U_{30}|\right]$$

$$+ b_2 \left[a_4 R_S + a_5 R_G\right]$$

$$+ b_3 \left[a_6 (SOI) + a_7 (SSTA) + a_8 (SLPA) + a_9 (ZWA)\right] \quad (1)$$

where

$\tilde{y}$ is the predictant (NS, NSD, H, etc.),
a's and b's are empirically derived coefficients,
U_{50}, U_{30} are extrapolated September QBO zonal winds at 30 and 50 mb at 10°N (Table 1),
$|U_{50} - U_{30}|$ absolute value of the extrapolated vertical wind shear between 50 and 30 mb,
R_S is the western Sahel June–July precipitation,
R_G is the previous year August to November precipitation in the Gulf of Guinea region,
SOI is the normalized Tahiti minus Darwin Sea Level Pressure differences for June–July (Table 3),
SSTA is the Sea Surface Temperature Anomaly in Nino 3 in June and July (Table 3),
SLPA is the Sea Level Pressure Anomaly in the lower Caribbean basin in June–July (Table 4),
ZWA is the Zonal Wind Anomaly in the Caribbean basin in June–July (Table 5).

The a and b coefficients vary for each forecast parameter and are given in Table 6.

The amount of independent (jackknife) hindcast variance which this forecast scheme was able to explain for the years 1950–1990 is given in Table 7. Note that the early August forecast is able to explain more than 60% of the year-to-year variance of intense hurricane activity and name storm days. A forthcoming paper (Gray, Landsea, Mielke, and Berry, 1992b) gives the details of this 1 August forecast scheme.

Table 6: Constants and coefficients for 1 August statistical forecasts.

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
NS	1.000	0.711	−0.082	1.000	−1.260	1.000	0.106	−0.275	0.046
NSD	1.000	0.560	−0.358	1.000	1.109	1.000	0.096	−0.864	−1.489
H	1.000	1.928	0.284	1.000	17.876	1.000	−1.172	−1.966	−0.025
HD	1.000	0.894	0.266	1.000	0.613	1.000	0.182	−0.050	−0.075
IH	1.000	0.614	−0.467	1.000	0.591	1.000	0.051	0.474	0.630
IHD	1.000	0.730	2.777	1.000	0.248	1.000	−0.019	1.272	0.567
HDP	1.000	0.608	0.629	1.000	0.256	1.000	0.169	0.705	0.312

	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$
NS	11.228	0.100	−0.757	−0.931
NSD	68.890	1.029	5.106	−5.309
H	7.410	0.046	0.050	0.239
HD	33.509	0.493	4.503	−4.318
IH	3.459	0.041	1.142	−0.677
IHD	5.023	0.055	6.370	−1.217
HDP	93.364	1.756	31.814	−14.372

Table 7: Amount of independent (jackknife) seasonal hindcast skill between 1950–1990 from application of Equation 1.

Forecast Parameter	Percent of Explained Variance
No. of Name Storm (NS)	45
No. of Name Storm Days (NSD)	61
No. of Hurricanes (H)	47
No. of Hurricane Days (HD)	51
No. of Intense Hurricanes (IH)	62
No. of Intense Hurricane Days (IHD)	61
Hurricane Destruction Potential (HDP)	58

The nine predictor variables for the 1992 early August forecast are as follows:

U_{50}	=	–24 m/s
U_{30}	=	–9 m/s
$\|U_{50} - U_{30}\|$	=	15 m/s
R_S	=	–0.40 S.D.
R_G	=	–0.79 S.D.
SLPA	=	+0.40 mb
SOI	=	–0.90 S.D.
SSTA	=	+0.4°C
ZWA	=	+1.2 m/s

Table 8 shows both the statistical guidance provided by Mielke and Berry's jackknife analysis technique and the author's qualitative adjusted forecast numbers for the early August prediction. It is expected that the 1992 hurricane season will be below average with the incidence of the seven forecast parameters being at about 58% of the average of these values of the last 42 years. Intense hurricane activity is expected to be more reduced.

Table 8: Raw Atlantic basin statistical seasonal forecast for 1992 (Column A), the author's adjusted forecast (column B) and a comparison (percent) of the adjusted forecast for 1992 versus average values for the last 42-years (column C).

Forecast Parameter	A Statistical Prediction for 1992	B Author's Adjusted Forecast for 1992	C 1992 Forecast as a Percent of the last 42 Year Ave.
Named Storms (N)	6.86	8	81
Named Storm Days (NS)	23.26	35	74
Hurricanes (H)	5.16	4	68
Hurricane Days (HD)	12.96	15	63
Intense Hurricanes (IH)	0.78	1	40
Intense Hurricane Days (IHD)	2.49	2	35
Hurricane Destruction Potential (HDP)	37.67	35	47
Mean			58

Table 9 provides a more objective comparison of this season's Atlantic hurricane forecast with the observed hurricane activity of recent years. Note that the 1992 season is expected to be significantly less active than the three hurricane seasons of 1988–89–90 but more active than 1991. It is expected that the 1992 hurricane season will be more typical of the average hurricane season during 1970–87. This early August forecast gives identical values to my extended range forecast of seasonal Atlantic hurricane activity which was issued on 26 November 1991, and to my 5 June forecast update.

The best past season analogue to this year (for data through July) was 1977 which experienced a quite inactive season with but 14 name storm days, 7 hurricane days, and only one intense hurricane which lasted for one day.

5 Forecast for the Gulf of Mexico

Our studies have shown that, in general, Gulf of Mexico hurricane activity seems to be less closely related to the seasonal prediction factors for hurricane activity variations in the Atlantic basin as a

Table 9: Comparison of 1992 Hurricane Activity Forecast With Activity in Previous Years.

	5 Aug Fcst. 1992	5 June Fcst. 1992	26 Nov Fcst. 1991	Observed 1991	1990	1989	1988	Ave. Season 1970-87	Ave. Season 1950-69	42 Year Ave.
Hurricanes	4	4	4	4	8	7	5	4.9	6.5	5.9
Named Storms	8	8	8	8	14	11	12	8.3	9.8	9.9
Hurricane Days	15	15	15	8	28	32	24	15.5	30.7	23.8
Named Storm Days	35	35	35	22	68	66	47	37.3	53.4	47.2
Hurr. Dest. Pot. (HDP)	35	35	35	23	57	108	81	42.7	100.0	74.5
Major Hurricanes (Cat. 3-4-5)	1	1	1	2	1	2	3	1.6	3.4	2.5
Major Hurricane Days	2.0	2.0	2.0	1.25	1.00	10.75	8.00	2.1	8.8	5.5

whole. The Gulf of Mexico is removed from the tropical Atlantic belt and is further downwind from Africa. Only a small percentage of hurricanes track into the Gulf of Mexico from the open Atlantic. Hurricanes in the Gulf occur earlier in the season and the hurricane season therein typically terminates earlier. Intense hurricanes (category 3-4-5) Alicia (1983), Allen (1980), Celia (1970), and Elena (1985) all made landfall along the Gulf Coast in deficient West African rainfall years. This is atypical of the rest of the Atlantic basin.

6 Verification of Previous Forecasts

Table 10 gives verification data for the author's eight previous seasonal hurricane forecasts. The late July forecasts have been superior to the early June forecasts and the forecasts of named storm activity have been the most skillful. Last year's forecast was quite successful. Except for 1989, these forecasts have been an improvement over climatology - the only objective seasonal prediction that had previously been available. The lack of accuracy for the 1989 forecast is attributed to conditions accompanying the heavy rainfall which fell in West Africa that year. Prior to 1990, African rainfall was not explicitly included in the author's forecast scheme. African rainfall influences are now becoming better understood and are now included in the forecast. We have also recently added the western Sahel west-east surface pressure and surface temperature gradient as a new independent forecast parameter.

A report verifying this year's forecast will be issued in late November.

7 Discussion

It is expected that the suppressing effects of the El Niño, western Sahel drought conditions, the QBO, and negative ΔP and ΔT influences will contribute to a below normal hurricane season for this year. Although it is expected that hurricane activity during the 1992 season will be below average, there should be slightly more hurricane activity than occurred in 1991, particularly in the tropical regions (i.e., at latitudes south of 25°N), the Caribbean, and the Gulf of Mexico. These regions were devoid of hurricanes in 1991. It is expected that there will be less tropical cyclone formation at higher latitudes in 1992 as compared with the large number of tropical cyclone formations at high latitudes during 1990 and 1991.

The projection for drought conditions in the western Sahel for this year implies that there will likely be a below average amounts of intense hurricane (category 3-4-5) activity. The probability for major hurricane destruction along the US East Coast and over Peninsula Florida is below that of the last 45 year average and is more comparable to the East Coast hurricane threat for the last 20 years. As hurricane damage along the US Gulf Coast is not closely related to trends in western Sahel rainfall, little can be said as to the probability of Gulf Coast intense hurricane related damage for this year.

Table 10: Verification of the author's eight previous seasonal predictions of Atlantic tropical cyclone activity for 1984-1991.

1984	Prediction of 24 May and 30 July Update		Observed
No. of Hurricanes	7		5
No. of Named Storms	10		12
No. of Hurricane Days	30		18
No. of Named Storm Days	45		51
1985	**Prediction of 28 May**	**Updated Prediction of 27 July**	**Observed**
No. of Hurricanes	8	7	7
No. of Named Storms	11	10	11
No. of Hurricane Days	35	30	21
No. of Named Storm Days	55	50	51
1986	**Prediction of 29 May**	**Updated Prediction of 28 July**	**Observed**
No. of Hurricanes	4	4	4
No. of Named Storms	8	7	6
No. of Hurricane Days	15	10	10
No. of Named Storm Days	35	25	23
1987	**Prediction of 26 May**	**Updated Prediction of 28 July**	**Observed**
No. of Hurricanes	5	4	3
No. of Named Storms	8	7	7
No. of Hurricane Days	20	15	5
No. of Named Storm Days	40	35	37
1988	**Prediction of 26 May and 28 July Update**		**Observed**
No. of Hurricanes	7		5
No. of Named Storms	11		12
No. of Hurricane Days	30		24
No. of Named Storm Days	50		47
Hurr. Destruction Potential(HDP)	75		81
1989	**Prediction of 26 May**	**Updated Prediction of 27 July**	**Observed**
No. of Hurricanes	4	4	7
No. of Named Storms	7	9	11
No. of Hurricane Days	15	15	32
No. of Named Storm Days	30	35	66
Hurr. Destruction Potential(HDP)	40	40	108
1990	**Prediction of 5 June**	**Updated Prediction of 3 Aug**	**Observed**
No. of Hurricanes	7	6	8
No. of Named Storms	11	11	14
No. of Hurricane Days	30	25	27
No. of Named Storm Days	55	50	68
Hurr. Destruction Potential(HDP)	90	70	57
Category 3-4-5 Hurricanes (IH)	3	2	1
Category 3-4-5 Hurricane Days (IHD)	Not fcst.	5	1.00
1991	**Prediction of 5 June**	**Updated Prediction of 2 Aug**	**Observed**
No. of Hurricanes	4	3	4
No. of Named Storms	8	7	8
No. of Hurricane Days	15	10	8
No. of Named Storm Days	35	30	22
Hurr. Destruction Potential(HDP)	40	25	23
Category 3-4-5 Hurricanes (IH)	1	0	2
Category 3-4-5 Hurricane Days (IHD)	2	0	1.25

8 Outlook for 1993

There is a good possibility that Atlantic basin hurricane activity in 1993 will be considerably greater than that which occurred last year or is expected this year. This assessment is based on considerations relating to the three primary forecast factors (El Niño, QBO, and African rain) which indicate the likelihood of an above average season. Specifically,

1) there is a high probability that a moderate or strong La Niña (or cold water) event will be in progress in the tropical Pacific during the 1993 season. This condition should act as an enhancing influence on hurricane activity analogous (but likely weaker) to the very cold La Niña event of 1988-89 which was associated with very active hurricane seasons during these two years;

2) it is expected that the stratospheric QBO will be in a westerly and hence hurricane-enhancing phase at both 50 mb and 30 mb levels during next year's hurricane season; and

3) La Niña conditions will favor a lessening of western Sahel drought conditions.

The author will be issuing a forecast of the seasonal hurricane activity for 1993 in late November at the time of the verification of this year's forecast.

9 Cautionary Note

It is important that the reader realize that this seasonal forecast is based on a statistical scheme which will fail in some years. This forecast also does not specifically predict which portion of the hurricane season will be most active or where within the Atlantic basin storms will strike. Even if 1992 should prove to be a below average hurricane season, there are no assurances that several hurricanes will not strike along the US or Caribbean basin coastline and do much damage.

10 References

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

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

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

Gray, W. M., 1991: Extended range forecast of Atlantic seasonal hurricane activity for 1992. Colo. State Univ., Dept. of Atmos. Sci., (informal report), 11 pp.

Gray, W. M., 1992: 5 June forecast of Atlantic seasonal hurricane activity for 1992. Dept. of Atmos. Sci., Colo. State Univ., Ft. Collins, CO, 17 pp.

Gray, W. M., C. W. Landsea, and J. D. Sheaffer, 1992: Long period variations in African rainfall and hurricane related destruction along the US East Coast. For presentation at the 14th Annual National Hurricane Conference, Norfolk, VA, April 10, 37 pp.

Gray, W. M., C. W. Landsea, P. Mielke and K. Berry, 1992a: Predicting Atlantic seasonal hurricane activity 6–11 months in advance. *Wea. and Forecasting*, 7, September issue.

Gray, W. M., C. W. Landsea, P. Mielke, and K. Berry, 1992b: Predicting Atlantic basin seasonal tropical cyclone activity by 1 August. In press *Weather and Forecasting.*

Gray, W. M., C. W. Landsea, P. Mielke, and K. Berry, 1993: Predicting Atlantic basin seasonal tropical cyclone activity by 1 June. To be submitted to *Weather and Forecasting.*

Landsea, C. W., 1991: West African monsoonal rainfall and intense hurricane associations. Forthcoming Dept. of Atmos. Sci. Paper, Colo. State Univ., Ft. Collins, CO, 270 pp.

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

UK Meteorological Service, 1992: Preliminary experiment forecast of 1992 seasonal rainfall in the Sahel and other regions of tropical North Africa. May, 1992, 3 pp.

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