EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY FOR 1994

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(This forecast is based on ongoing research by the author and his Colorado State University research colleagues, together with meteorological information through mid-November of 1993)

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ABSTRACT

This paper presents details of a 6–11 month extended range seasonal forecast of the tropical cyclone activity likely to occur in the Atlantic Ocean basin during 1994. This forecast is based on new research by the author and his colleagues which allows estimates of next season's Atlantic tropical cyclone activity to be made by November of the prior year. The forecast scheme is based on a 10-month forward extrapolation of the Quasi-Biennial Oscillation (QBO) of equatorial stratospheric zonal wind, two measures of West African rainfall through mid-November 1993 and an extended range forecast of El Niño conditions for August to October 1994.

Information through mid-November 1993 indicates that the 1994 Atlantic hurricane activity is likely to be somewhat above average with about 6 hurricanes (average 5.7), 10 named storms (average 9.3), 25 hurricane days (average 23), 2 intense hurricanes (average 2.2) and a hurricane destruction potential of 85 (average 68). The 1994 season should be more active than the three recent 1991, 1992 and 1993 hurricane seasons and, in particular, more active in the tropical regions (at latitudes south of 25°N) where only one short lived hurricane has occurred during the last three years. The 1994 season should be more like the hurricane seasons of 1988 and 1989 which produced a total of five major hurricanes. The probability of hurricane destruction along the US East Coast, Peninsula Florida, and within the Caribbean basin for 1994 is projected to be somewhat greater than the mean probability for the last 40 years and is distinctly higher than the probabilities for the last three years.

It is expected that the long running 1990-1993 El Niño-like warm water conditions will finally dissipate by the next hurricane season and that comparatively cool surface water conditions will be present in the east and central equatorial Pacific; this trend should enhance hurricane activity. It is also expected that West African Sahel drought will abate somewhat next season. This upward rainfall trend should also diminish the inhibiting influences on hurricane activity than have occurred in recent years. Stratosphere QBO conditions will be in the easterly phase which will tend to inhibit tropical cyclone activity. But in the net hurricane activity should be enhanced over recent years.

DEFINITIONS AND ABBREVIATIONS

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

Named Storm Day (NSD) - Four consecutive six–hour periods during which a tropical cyclone is observed or estimated to have attained tropical storm or hurricane intensity winds.

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

Intense or Major Hurricane (IH) - A hurricane reaching sustained low level winds of at least 111 mph (96 kt or $50ms^{-1}$) at some point in its lifetime. This constitutes a category three or higher storm intensity rating on the Saffir/Simpson scale.

Intense or Major Hurricane Day (IHD) - Four six-hour periods during which a hurricane has Saffir/Simpson category three intensity or higher.

Hurricane Destruction Potential (HDP) - A measure of a hurricane's potential for wind and storm surge destruction. HDP is defined as the sum of the square of a hurricane's maximum wind speed during each six-hour period of its existence. This value is summed for the season.

Net Tropical Cyclone Activity (NTC) - A combined measure of the average seasonal percentage of NS, NSD, H, HD, IH, and IHD to their long term mean.

1 Introduction

Surprisingly strong long range predictive signals exist for Atlantic basin seasonal tropical cyclone activity. Recent research by the author and research colleagues Chris Landsea, Paul Mielke and Ken Berry indicates that between 45 and 67 percent of the season-to-season variability of eight indices of Atlantic tropical cyclone activity can be independently hindcast by as early as mid-November of the prior year. These predictive signals include two measures of West African rainfall in the prior year, the phase of the stratospheric Quasi-Biennial Oscillation of zonal winds at 30 mb and 50 mb (which can be extrapolated ten months into the future) and an extended range prediction for El Niño-Southern Oscillation (ENSO) conditions during the summer-fall period of 1994. These predictors which have been tested on 34 years of hindcasts between 1959-1992, are available by mid-November of the prior year. Hence, they can be utilized to make skillful forecasts of Atlantic tropical cyclone activity during the following year. A brief summary of these predictor indices is as follows:

a) QBO–Tropical Cyclone Lag Relationship

The easterly and westerly modes of stratospheric QBO zonal winds which circle the globe over the equatorial regions have a substantial influence on Atlantic tropical cyclone activity (Gray, 1984a; Shapiro, 1989). Typically, there is 50 to 75 percent more hurricane activity (depending on the specific activity index considered) during those seasons when stratospheric QBO winds between 30 and 50 mb are from the westerly phase (direction) and when the vertical wind shear (ie., the variation of wind speed with height) between these two levels is small. Conversely, seasonal hurricane activity is typically reduced when stratospheric winds are in the easterly phase and the wind shear between 30 and 50 mb is large. We project that 50 and 30 mb winds will be strongly from the east next year.

b) African Rainfall and Tropical Cyclone Lag Relationship

As discussed by Landsea (1991), Gray and Landsea (1992) and Gray et al. 1992, surprising strong predictive signals for seasonal hurricane activity can be obtained from mid-summer to fall West African prior year rainfall data. These include:

(1) August–September Western Sahel Rainfall. During the last four decades, the Western Sahel area (see Fig. 1) has experienced large year to year rainfall persistence; that is, wet years have been followed by wet years (e.g., in the 1950s and 1960s) while dry years are typically followed by dry years (e.g., in the 1970s, 1980s and 1990s). This persistence tendency provides a moderate amount of skill for forecasting next season's African rainfall and the associated Atlantic hurricane activity.

(2) August–November Rainfall in the Gulf of Guinea. Landsea (1991) and Gray and Landsea (1992) have documented an even stronger rainfall - intense hurricane lag relationship in August through November rainfall along the Gulf of Guinea (see Fig. 1). Intense hurricane activity in seasons following the ten wettest August–November Gulf of Guinea years was four times greater than that which occurred during those hurricane seasons following the ten driest August-November periods in the Gulf of Guinea. This association suggests a very strong modulation of the following season's rainfall activity by rainfall in the prior year. This year's rainfall for the West Sahel during August-September 1993 was not as dry as observed in previous years (-0.25 S.D.) and the Gulf of Guinea August-mid-November rainfall has been slightly above average (+0.10). These trends indicate the potential for a break in West Sahel drought conditions for next year.

c) The El Niño-Southern Oscillation (ENSO) Relationship

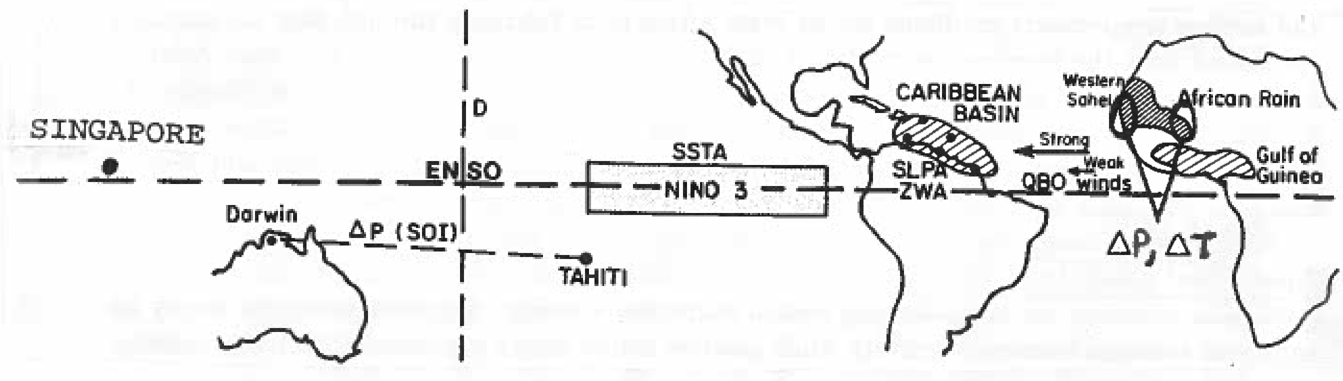

Figure 1: Locations of meteorological parameters used in early August Atlantic basin seasonal forecast.

ENSO is the principal global scale environmental influence affecting Atlantic seasonal hurricane activity. Hurricane activity is usually much suppressed during those seasons with anomalously warm equatorial eastern and central Pacific water temperatures are present. And, activity is usually enhanced during seasons with cold (or La Niña) water conditions. Hurricane activity during the last three seasons has been much suppressed because of the persistent, continuous warm water conditions which have been present in the NINO-3 and NINO-4 (see Fig. 2) regions of the equatorial Pacific and the continuous drought conditions which have been present in the Western Sahel region of Africa.

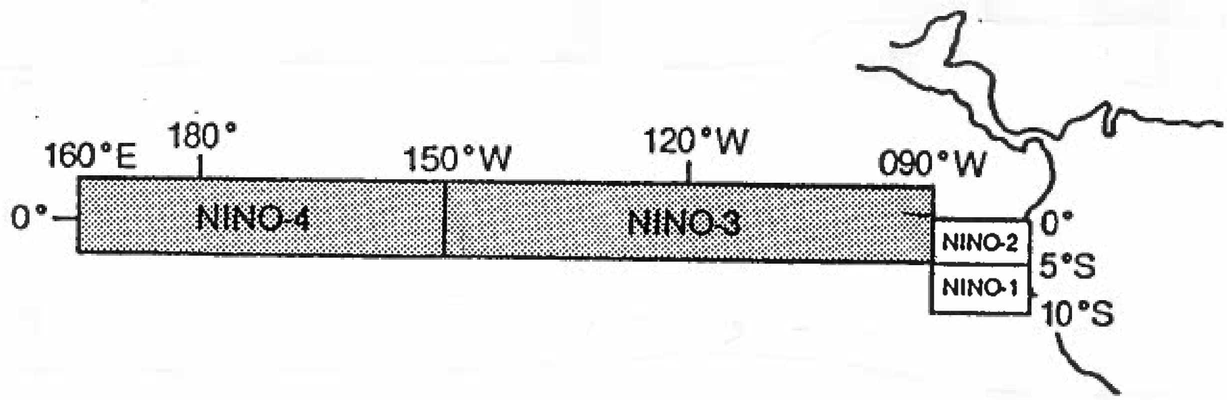

Figure 2: Equatorial Pacific sea surface temperature anomaly indices (°C) for the areas indicated.

We have recently devised a scheme for making extended range predictions of next summer's NINO-3 sea surface temperature anomaly (SSTA) conditions using the past two years of global climate data. This new ENSO prediction scheme (Gray et al. 1993) adds improvement to the extended range seasonal hurricane forecasts which Gray et al. 1992 developed previously but which lacked an ENSO component. Table 1 compares the amount of seasonal hurricane variability (as determined by ρ – a measure of agreement) that can be explained from our original hindcast studies using the years 1950-1990 and the amount of variance with our new forecast scheme while utilizes an ENSO prediction. This latter forecast scheme was recently devised on hindcasts for the 34 year period of 1959-1992. Our NINO-3 forecast for SSTA conditions for next August through October 1994 is for cool water anomaly of –0.33°C. It appears that the 4-year warm water period will finally come to an end in the spring and early summer of 1994.

2 Basis for Extended Range Forecasts

This extended range forecast scheme is based on an optimized combination of multiple lag relationships observed between Atlantic hurricane activity and the climate indices described in the prior section. There are three forecast predictors for QBO [extrapolated U_{30}, U_{50}, $|U_{30} - U_{50}|$], two predictors for African rain [August–September Western Sahel rainfall (R_s) and August–November Gulf of Guinea (R_G) rainfall] and four predictors representing our extended range ENSO prediction. These nine forecast parameters are employed to specify the likely number of named storms (NS), named storm days (NSD), hurricanes (H), hurricane days (HD), intense hurricanes (IH), intense hurricane days (IHD), Hurricane Destruction Potential (HDP), and net tropical cyclone activity (NTC) expected to occur next season.

3 Statistical Forecast

Professors Paul Mielke and Ken Berry of the CSU Statistics Department have made extensive statistical analyses of these November predictors and of the eight (following season) predictants for the 34-year base period of 1959-1992. Their analyses have yielded optimized regression equations for the most skillful extended range hindcasts. The statistical methodology for these analyses consists of four distinct, but interrelated steps as follows: (1) Least-absolute deviation regression which provides prediction values for each of the hindcast years. (2) A cross-validation (jackknife) procedure ensures that the prediction for any year is independent of the observations for that year. (3) The predicted values and observed values for all forecast years are compared by calculating a measure of agreement. (4) The probability of the measure of agreement is obtained under the null hypothesis (see Gray et al. 1992).

Our forecast equations take the following form:

$$\begin{aligned} &\text{(QBO terms)} \\ (Seasonal\ Forecast) = \beta_o(1 + a_1U_{50} + a_2U_{30} + a_3|U_{50} - U_{30}| \\ &\text{(African Rainfall Terms)} \\ &+ a_4R_s + a_5R_G \qquad (1) \\ &\text{(ENSO Terms)} \\ &+a_6DSLPA + a_7Sing1 + a_8Sing.2 + a_9N3 \end{aligned}$$

Definitions of the Predictor Terms in Eq. (1) are as follows

1. U_{50} = 10 month extrapolated 50 mb September QBO zonal wind near 10°N
2. U_{30} = 10 month extrapolated 30 mb September QBO zonal wind near 10°N
3. $|U_{50} - U_{30}|$ =10 month extrapolated 50 mb minus 30 mb September QBO zonal wind shear
4. R_s = Measured standard deviation of 1993 August-September Western Sahel rainfall
5. R_G = Measured standard deviation of previous year August-November Gulf of Guinea rainfall
6. D-SLPA = The May-July Darwin Sea Level Pressure Anomaly.
7. Sing.1 = The previous September to February Singapore 100 mb temperature anomaly
8. Sing.2 = The previous March to August Singapore 100 mb temperature anomaly
9. N3 = The NINO-3 sea surface temperature anomaly for the prior 27 months.

The β_o and "a" coefficients are determined to maximize the hindcast predictive signals. Different β_o and "a" coefficients are determined for each predictor (see the appendix). Table 1 shows the amount of hindcast variance (or measure of agreement) that can be explained from this new forecast equation for the 34 years of 1959-1992 (column 2). The hindcast skill of our older forecast (which does not include a prediction of ENSO) is shown in Column 1.

Table 1: Agreement coefficient (ρ; or, the amount of variability explained) for different hurricane parameters obtained in a cross-validation (or jackknife) test statistical relationship. The first column lists the Gray et al. (1992) statistical hindcast skill for the 41-year period of 1950-1990. The second column lists the corresponding values for our newest hindcast scheme which uses an extended range ENSO prediction for the 34-year period of 1959-1992. The P-value of no relationship (last column) is shown for the newest scheme. Note that we are able to hindcast more than 50 percent of the variability for more parameters and as much as two-thirds of the variability of NTC.

Forecast Parameter	Gray et al. 1992 Statistical Forecast	Newest Scheme ρ	P
Named Storms (NS)	.440	0.628	$.174 \times 10^{-7}$
Named Storm Days (NSD)	.514	0.568	$.180 \times 10^{-6}$
Hurricanes (H)	.447	0.560	$.817 \times 10^{-7}$
Hurricane Days (HD)	.491	0.549	$.538 \times 10^{-6}$
Intense Hurricanes (IH)	.498	0.448	$.608 \times 10^{-5}$
Intense Hurricane Days (IHD)	.451	0.491	$.646 \times 10^{-6}$
Hurricane Destruction Potential (HDP)	.447	0.543	$.470 \times 10^{-6}$
Net Tropical Cyclone Activity (NTC)	NOT MADE	0.673	$.291 \times 10^{-8}$

Values of the forecast parameters used in forecasting next year's Atlantic hurricane activity with both forecast schemes are given in Table 2. Substitution of the forecast predictors of Table 2 into Eq. 1 gives both our earlier forecast (see Gray et al. 1993, Eq. 4, page 452) and our most recent scheme forecast (Table 3). We consider the values in the second column of Table 3 to be the best estimates that can be made of next year's Atlantic hurricane activity at this time. Through inclusion of the ENSO predictors, we have been able to obtain a higher level of predictive skill than was possible with our previous extended range forecast scheme (Gray et al., 1992) which did not include ENSO. The final forecast is only a small qualitative adjustment (rounding off) of our most recent statistical forecast and is given in the third column of this table. The percentage, expressed in terms of the long term mean, is given in the right column of this table.

Table 2: Values of the nine (input) parameters for 1994 forecast are as follows:

1. U_{50} = –20 m/s
2. U_{30} = –24 m/s
3. $|U_{50} - U_{30}|$ = 4 m/s
4. Sahel (R_s) = –0.25 S.D.
5. Gulf of Guinea (R_G) = + 0.10 S.D.
6. Darwin SLPA = + 12.7 x 10^{-1} mb
7. Singapore 100 mb TA (Sept-Feb) = –6.78 x 10^{-1} °C
8. Singapore 100 mb TA (Mar-Aug) = + 3.75 x 10^{-1} °C
9. NINO3 past 27 mo. SSTA = + 66.67 x 10^{-2} °C

Table 3: Statistical prediction as obtained with Eq. 1 and the final adjusted forecast.

Forecast Parameter	Gray et al. 1992 Previous Statistical Forecast	Newest Statistical Forecast	Qualitative Adjusted Actual Forecast	Forecast in Percentage of last 43 year Mean
Named Storms (NS)	7.87	9.72	10	108
Named Storm Days (NSD)	31.58	60.56	60	130
Hurricanes (H)	6.28	6.40	6	105
Hurricane Days (HD)	18.40	24.95	25	107
Intense Hurricanes (IH)	2.04	1.92	2	92
Intense Hurricane Days (IHD)	6.48	7.19	7	150
Hurricane Destruction Potential (HDP)	54.94	84.83	85	122
Net Tropical Cyclone Activity (NTC)	91.08	109.10	110	110

The nine predictor equation (1) is our most skillful extended range prediction scheme at this time. We believe that it is our best forecast because of its demonstrated hindcast skill for data from the last 34 years. However, this is by no means our final extended range forecast scheme. Next year's forecast scheme will likely be different. We are in the process of developing more refined schemes wherein we hope to reduce the ENSO influence in the prediction to only one variable (rather than the current four). We also hope to reduce the two prior year West African rainfall predictors by using a newly developed scheme for extended range prediction of Western Sahel rainfall (see Landsea et al. 1993). This would reduce the rainfall predictors from two to one.

4 Discussion

Implicit in this forecast is the anticipated dissipation of the long running equatorial Pacific warm water event which has now persisted for nearly four consecutive years. Historical records going back to the 1850s (see Wright, 1989) indicate that above average water temperatures in the equatorial Pacific have never persisted for more than four consecutive years and that three and four year warm events of the sort we have just had are very rare. Our extended range ENSO prediction scheme forecasts a NINO-3 sea surface temperature anomaly of −0.33°C for the August-October 1994 period. This also supports an end to the long running El Niño-like warm water conditions. The inhibiting influence on hurricane activity of warm equatorial Pacific water temperature for next year is believed to be very low. Consequently, hurricane activity should be higher. In addition, our extended range estimate of West African precipitation for next year gives slight positive precipitation values (+0.012 S.D.). This West Sahel rainfall forecast has a measure of agreement of 0.67 (or two-thirds of the variability) in 34 years of cross-validated hindcast forecast tests for the years of 1959-1992. This indicates that we should likely see a break in the long running Western Sahel drought for next year. Rainfall amounts should be higher than have occurred during most of the last 25 years. Recent August to mid-November 1993 Gulf of Guinea rainfall has been slightly above average for the first time since 1988. This is another indication that next year's seasonal hurricane activity should be above what has been observed for the last three years. Thus, of our three primary extended range predictor, two, (ENSO and West African rainfall) appear favorable for enhanced hurricane activity with only the QBO as an unfavorable indicator for increased activity. Next year's hurricane activity should be enhanced over that of the last three years, at least.

5 Cautionary Note

It is important for the reader to realize that this seasonal forecast is a statistical procedure which will fail in some years. Even though a remarkable degree (45 to 67 percent) of independent extended range skill has been obtained from the analysis of hindcasts of 34 years of prior data, there remains from 33 to 55% of variability which is not explained. This forecast also does not specifically predict where within the Atlantic basin storms will strike. Even if 1994 should prove to be an active hurricane season, there are no assurances that hurricanes will strike along the US or Caribbean coastlines or do much damage. However, we reiterate that the probability of damage for 1994 is slightly higher than the average for the last 40 years and is especially higher than it has been during the last three years and somewhat higher than the average of the last 25 years. The last 25-year activity has been suppressed compared with average hurricane activity of the last 60 years.

6 Acknowledgements

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Appendix A

β and a coefficients for the predictants of Eq. 1

NS		NSD
= .10970958D+02	BETA	.57243956D+02
-.92650358D-02	50 mb Winds	-.11194679D-01
+.14689379D-01	30 mb Winds	+.77753930D-02
-.60760436D-02	Absolute U50-U30 Shear	-.15745414D-01
-.18752912D+00	Sahel Rainfall	-.17707576D+00
+.14565801D+00	Gulf of Guinea Rainfall	+.28374274D+00
+.38345796D-03	Darwin SLPA May-July	-.22092016D-02
-.23911767D-01	Singapore 100 mb September-February	-.21387117D-01
-.61018284D-02	Singapore 100 mb March-August	-.49398952D-02
+.29286172D-02	Previous 27 Months	+.16309021D-02

H		HD
.68479308D+01	BETA	.29351853D+02
-.10346260D-03	50 mb Winds	-.15293454D-02
+.13649601D-02	30 mb Winds	+.66312734D-02
-.20491404D-01	Absolute U50-U30 Shear	-.16145595D-01
-.75472872D-01	Sahel Rainfall	-.51594216D-01
+.15286739D+00	Gulf of Guinea Rainfall	+.25912513D+00
-.16588256D-02	Darwin SLPA May-July	-.86457445D-02
-.18885493D-01	Singapore 100 mb September-February	-.21904245D-01
+.30454801D-02	Singapore 100 mb March-August	-.66415050D-02
+.15785321D-02	Previous 27 Months	+.45538937D-02

IH		IHD
.25969818D+01	BETA	.38784669D+01
+.91441706D-02	50 mb Winds	-.17663042D-01
+.34034544D-02	30 mb Winds	-.32794445D-01
-.15473338D-01	Absolute U50-U30 Shear	-.68065159D-01
-.14067756D+00	Sahel Rainfall	+.38471095D+00
+.33596863D+00	Gulf of Guinea Rainfall	+.10125728D+01
-.14234157D-01	Darwin SLPA May-July	-.14044734D-01
-.13173851D-01	Singapore 100 mb September-February	+.14623537D-01
+.81848514D-02	Singapore 100 mb March-August	+.15104992D-01
+.21368574D-02	Previous 27 Months	+.55327368D-02

HDP		NTC
.74091418D+02	BETA	.10295008D+03
-.11879441D-01	50 mb Winds	-.81856550D-02
+.14046997D-02	30 mb Winds	+.50465229D-02
-.22908169D-01	Absolute U50-U30 Shear	-.13373284D-01
+.70978702D-01	Sahel Rainfall	-.51577046D-01
+.50672193D+00	Gulf of Guinea Rainfall	+.47969504D+00
-.78520471D-02	Darwin SLPA May-July	-.16710655D-02
-.12797386D-01	Singapore 100 mb September-February	-.13867887D-01
-.40051799D-02	Singapore 100 mb March-August	-.19747704D-02
+.39264889D-02	Previous 27 Months	+.48351103D-02