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EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY FOR 1996

(A year of expected average hurricane activity)

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(This forecast is based on ongoing research by the author and his Colorado State University and NOAA/HRD research colleagues, together with meteorological information through late-November of 1995)

[Various long and short versions of this forecast with figures and tables are available on the Wide World Web at this URL
(http://typhoon.atmos.colostate.edu/forecasts/index.html)]

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Robert Fitzroy (Captain of HMS Beagle on which Charles Darwin sailed) became quickly and totally absorbed in his meteorological work, making available cheap barometers, setting up a telegraph station network and a system of storm warning cones in the ports, constructing weather charts and pioneering in the issue of daily weather forecasts. He summarized his meteorological views in a popular treatise, the *Weather Book* (1863). His forecasting service was successful with the public but was severely criticized by scientists. In the midst of the resulting controversy Fitzroy took his life.

(from The Thermal Theory of Cyclones, 1979
by Gisela Kutzback, p. 234)

Authors Comment: We intend to be around next year.

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 1996. This forecast is based on a forecast scheme developed previously by the authors with several new modifications. This allows estimates of seasonal Atlantic tropical cyclone activity to be made by late November of the prior year. Our ever evolving forecast schemes are based on 10-month forward extrapolations of the stratospheric Quasi-Biennial Oscillation (QBO) of equatorial zonal winds, two measures of Western Sahel rainfall through late November 1995, an extended range forecast of El Niño conditions in August to October 1996, an extended range forecast of Western Sahel rainfall amount for next summer, the November strength of the Northeast Atlantic subtropical ridge and other forecast parameters from the Pacific Ocean and from the Asia-Australia area.

Information obtained through late-November 1995 indicates that 1996 Atlantic hurricane activity is likely to be somewhat below the 1950 to 1995 average with 5 hurricanes (average 5.7), 8 named storms (average 9.3), 40 named storm days (average 46), 20 hurricane days (average 23), 2 intense (category 3-4-5) hurricanes (average 2.1), 5 intense hurricane days (average is 4.5) and a hurricane destruction potential (HDP) of 50 (average 68). Collectively, net tropical cyclone activity is expected to be 85 percent of the long period average. The 1996 season should be much less active active than the 1995 season but somewhat more active than the four recent inactive hurricane seasons 1991 through 1994.

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 and is expressed in units of 10^4knots squared.

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.

Maximum Potential Destruction = (MPD) The seasonal sum of the square of the maximum wind in knots of each named storm in units of 10^3. MPD is different than HDP because MPD gives only one value for each storm and does not contain information on the duration of the cyclone.

1 Introduction

Surprisingly strong long range predictive signals exist for Atlantic basin seasonal tropical cyclone activity. Our recent research indicates that a sizeable portion of the season-to-season variability of nine indices of Atlantic tropical cyclone activity can be skillfully hindcast by as early as late November of the prior year. We now have two separate prediction schemes for estimating hurricane activity in the following year. Information is developed from 46 years of past data (1950-1995). Our extended range predictive signals include two measures of Western Sahel rainfall during 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 similar extended range predictions for El Niño-Southern Oscillation (ENSO) variability and Western Sahel rainfall anomalies for the following summer. 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 anomalously westerly and, consequently, 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 QBO is in its 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 with moderate shear between the two levels. This should then be an inhibiting influence on next year's hurricane activity.

b) African Rainfall-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 rainfall data for Western Africa during the mid-summer to fall of prior year. 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 persistence of rainfall trends; that is, wet years tend to be 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). Since the rainfall in this region is positively related to Atlantic hurricane activity, persistence alone tends to provide a moderate amount of skill for forecasting next season's African rainfall as well as the associated Atlantic hurricane activity. But, there are other non-persistent features which make this a useful forecast parameter.

(2) August–November Rainfall in the Gulf of Guinea. Landsea (1991) and Gray and Landsea (1992) have documented an even stronger African rainfall - intense hurricane lag relationship using August through November rainfall along the Gulf of Guinea (see Fig. 1). Intense hurricane activity during seasons following the ten wettest August–November Gulf of Guinea years was <u>four</u> 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 relationship between the following season's hurricane activity and the August to November rainfall of the prior year. This year's rainfall for the West Sahel during August-September 1995 was -0.35 SD, somewhat dry. And the Gulf of Guinea August-November rainfall was somewhat above average (+0.14 SD). These trends and last years near average Sahelian rainfall indicate the long running Western Sahel drought conditions.

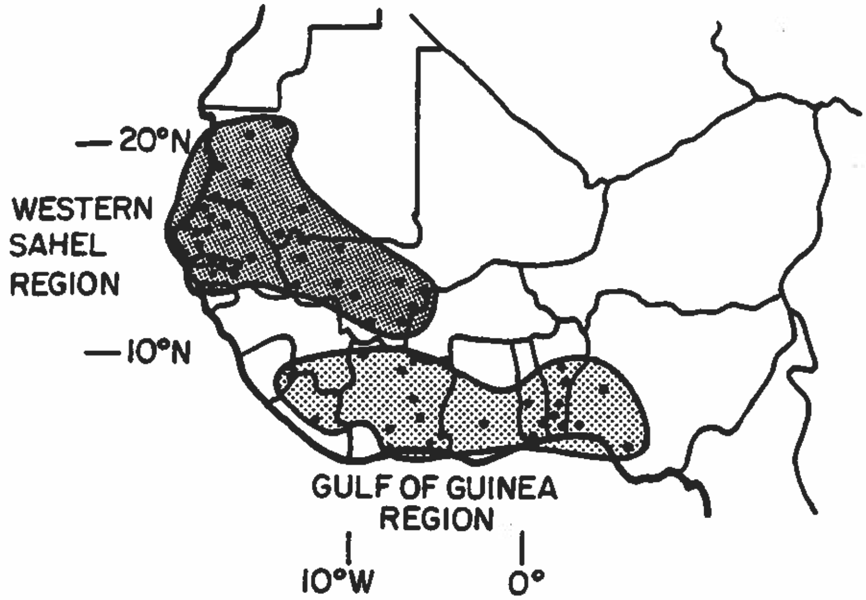

Figure 1: Locations of meteorological parameters used in 1 December Atlantic basin seasonal forecast.

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

ENSO is one of the principal global scale environmental factors affecting Atlantic seasonal hurricane activity. Hurricane activity is usually much suppressed during those seasons when anomalously warm water temperatures are present in the equatorial eastern and central Pacific. And, activity is usually enhanced during seasons with cold (or La Niña) water conditions. Hurricane activity during the four seasons (1991-1994) was much suppressed because of persistent, warm water conditions in the Nino-3 and NINO-4 regions of the equatorial Pacific and the associated negative values of the Southern Oscillation Index (SOI or Tahiti minus Darwin surface pressure).

We have recently devised a scheme for making extended range predictions of next summer's Nino-3 sea surface temperature anomaly (SSTA) conditions. This new ENSO prediction scheme (Gray et al. 1993) adds qualitative improvement to the extended range seasonal hurricane forecasts which Gray et al. (1992) developed previously but which lacked an ENSO prediction component. Nino-3 forecast for SSTA conditions for August through October 1996 is for cool water conditions. It appears that the four-year warm water event during 1991-1994 has definitely come to an end and we appear to be entering a new era of generally below normal eastern Pacific water temperatures (see attached ENSO prediction report). Cool ENSO conditions, much as was the case in 1995, should be an enhancing influence on next year's hurricane activity.

d) Strength of the November Atlantic Subtropical Ridge Between 20-30°W

The higher the surface pressure associated with this ridge, the stronger are the east Atlantic tradewinds which enhance upwelling of cold water off the northwest African coast. Colder surface water temperatures due to this enhanced ocean upwelling cause higher surface pressures and thus creates a positive feedback response. There is long term memory and feedback in this association. It is a useful parameter for predicting next year's seasonal hurricane activity. The ridge strength this November was near the 1950 to 1995 mean and therefore neither inhibits or enhances 1996 hurricane activity.

e) Other Potential Long Range Predictors

Our analyses have also shown that other global parameters have some value for extended range

Atlantic basin seasonal hurricane prediction and often improve our extended range forecasts. These include:

1. Singapore 100 mb temperature anomalies during July to November,
2. Sea-surface temperature anomalies in the Nino-3 region of the equatorial Pacific during the prior 27 months,
3. Darwin, Australia sea-level pressure anomaly (SLPA) in the prior May-July period,
4. Calcutta, India SLPA in the prior September through November period.

With these, we have a total pool of 12 forecast parameters. From this group we choose the best 5 to 7 predictors for each individual tropical cyclone predictors through a leaps and bounds regression methodology. Our extended range forecast schemes are based on an optimized combination of multiple lag relationships between these forecast parameters and nine seasonal indices of tropical cyclone activity. Our forecast specifies 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), net tropical cyclone activity (NTC), and Maximum Potential Destruction (MPD).

2 8-11 Month Extended Range Prediction Schemes

2.1 Outline of Basic (Gray et al. 1992) Scheme

Our original extended range forecast scheme had the following form:

$$(Seasonal\ Forecast) = \beta_o(1 + a_1 U_{50} + a_2 U_{30} + a_3|U_{50} - U_{30}|$$

$$+ a_4 R_s + a_5 R_G \qquad (1)$$

where

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. $\lvert U_{50} - U_{30}\rvert$	=10 month extrapolated 50 mb minus 30 mb September QBO zonal wind shear
4. R_s	= Measured standard deviation of previous year August-September Western Sahel rainfall
5. R_G	= Measured standard deviation of previous year August-November Gulf of Guinea rainfall

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. These equations were developed on data from the 41 years of 1950-1990. They explain about 40-50 percent of the variance of each of the nine forecast parameters in non-independent hindcasts.

Values of the forecast parameters used for prediction of the next year's Atlantic hurricane activity are given in Table 1. Substitution of the forecast predictors in Table 1 into Eq. 1 yields the forecast for the amount of next year's Atlantic basin seasonal hurricane activity shown in Table 2. This forecast indicates somewhat below average hurricane activity during 1996. Table 2 also gives the hindcast skill associated with each prediction.

Table 1: Values of the five (input) parameters for 1995 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) = –0.35 S.D.
5. Gulf of Guinea (R_G) = + 0.14 S.D.

Table 2: Statistical prediction for the 1996 season as obtained with Eq. 1 and the final amount of undegraded variance explained in the 41-year hindcast developmental data set.

Forecast Parameter	Gray et al. 1992 Statistical Forecast	Amount of Undegraded Variance Explained in the Developmental Data Set
Named Storms (NS)	7.8	.44
Named Storm Days (NSD)	30.7	.51
Hurricanes (H)	6.2	.45
Hurricane Days (HD)	17.5	.49
Intense Hurricanes (IH)	2.0	.50
Intense Hurricane Days (IHD)	6.4	.45
Hurricane Destruction Potential (HDP)	52.6	.45
Net Tropical Cyclone Activity (NTC)	88.7	.53

2.2 New and Improved Extended Range Forecast Scheme

A new version of our extended range forecasting scheme differs from the original scheme in that it involves a pool of predictors on which we employ a leaps and bounds regression method which successively chooses the best two predictors, the best three predictors, etc. up to ten predictors. Variance explained typical increases as we add predictors but at an ever decreasing rate of improvement. Given the limited pool of hindcast years (46) from which to develop our scheme, degradation occurs when the scheme is applied to independent data if too many predictors are used (i.e., over curve-fitting). Consequently, we optimize the number of predictors, in this case we limit the number of 1996 predictors to six.

Table 3 shows the pool of ten potential predictors, their numerical value for this year's forecast and the six predictors which are chosen for each forecast of our nine forecast hurricane activity parameters. Table 4 shows the prediction for the 1996 hurricane season with this new extended range forecast scheme along with the amount of undegraded variance explained within the 46-year developmental data sets. This newer forecast scheme also indicates a somewhat below average 1996 hurricane season.

Real Forecast Skill. Application of these forecast schemes to future independent data will occasion a forecast skill degradation such that the amount of variance explained will decrease by 10-25 percent. We estimate that our newer 1 December extended range real forecast skill to range between about 35-45 percent. We consider this a skillful forecast, particularly in consideration of the extended range nature of the forecast.

Table 5 provides a comparison of both of these hurricane prediction schemes, our qualitative adjustment and the actual 1996 seasonal forecast. The 1996 forecast hurricane activity expressed as percent of the average season activity is given on the right column. Net tropical cyclone activity is expected to be about 85 percent of the average of the last 45 seasons. Though the overall activity

Table 3: Predictor values for 1996 forecast.

Predictor No.	Predictor	Predictor Values for 1996 Fcst
Pool of 10 Potential Predictors		
1 =	U_{50}	–20 m/s
2 =	U_{30}	–24 m/s
3 =	$\|U_{50} - U_{30}\|$	4 m/s
4 =	Guinea Rain (Aug-Nov)	+0.14 SD
5 =	Sahel rainfall 4-year Average	–0.62 SD
6 =	Atlantic Ridge	0.00 SD
7 =	Singapore 100 mb TA (Jul-Nov)	–0.6 $\times 10^{-1} oC$
8 =	Nino-3 (Prior 27 months)	+17.4 $\times 10^{-2} oC$
9 =	Darwin SLPA (May-July)	+4.3 $\times 10^{-1}$ mb
10 =	Calcutta SLPA (Aug-Nov)	–0.2 mb

Top six predictors chosen for each forecast variable

Predictors	1	2	3	4	5	6	7	8	9	10
NS	1	2			5	6	7	8		
NSD		2		4	5	6	7	8		
H	1	2	3	4		6			9	
HD		2	3	4	5	6			9	
IH	1		3	4		6			9	10
IHD		2	3	4	5	6			9	
HDP		2	3	4	5	6		8		
NTC			3	4	5	6		8	9	
MPD	1		3	4	5	6				10

Table 4: 1996 tropical cyclone activity prediction using our new extended range forecast scheme and with the amount of undegraded variance explained in the 46-year hindcast developmental data set.

Forecast Parameter	1966 Statistical Forecast Values	Amount of Undegraded Variance Explained
Named Storms (NS)	8.3	50.8
Named Storm Days (NSD)	39.5	55.2
Hurricanes (H)	5.4	48.3
Hurricane Days (HD)	21.2	54.6
Intense Hurricanes (IH)	2.1	56.1
Intense Hurricane Days (IHD)	6.2	46.9
Hurricane Destruction Potential (HDP)	42.0	50.8
Net Tropical Cyclone Activity (NTC)	85.2	55.9
Maximum Potential Destruction (MPD)	59.3	62.5

is expected to be below average is is important to note that the intense hurricane activity next year would be greater than in most years in the last couple of decades.

Table 5:

Forecast Parameter	Older 1 Dec Fcst Scheme	Newer 1 Dec Fcst Scheme	Quality Adjusted 1966 Fcst	Percent of Last 46-year Average
Named Storms (NS)	7.8	8.3	8	86
Named Storm Days (NSD)	30.7	39.5	40	87
Hurricanes (H)	6.2	5.4	5	88
Hurricane Days (HD)	17.5	21.2	20	87
Intense Hurricanes (IH)	2.0	2.1	2	95
Intense Hurricane Days (IHD)	6.4	6.2	5	111
Hurricane Destruction Potential (HDP)	52.6	42.0	50	73
Net Tropical Cyclone Activity (NTC)	88.7	85.2	85	85
Maximum Potential Destruction (MPD)	—	59.3	55	89

3 Atlantic Basin Hurricane Activity in Years Following Extremely Active Seasons

There have been ten previous hurricane seasons (1887, 1893, 1906, 1916, 1926, 1933, 1950, 1955, 1961, 1969) with activity comparable to 1995. In attempting to assess how active the 1996 may be, it is instructive to note the level of activity during hurricane seasons following these other ten unusually active hurricane seasons. The years following unusually active seasons tend to experience somewhat below average hurricane activity. Table 6 provides a comparison of seasonal averages during the ten most active hurricane seasons (top line) versus average activity in the subsequent ten seasons (1888, 1894, 1907, 1917, 1927, 1934, 1951, 1956, 1962 and 1970) following usually active years. Also listed is the ratio of activity during the active years to that in the subsequent years. Some striking features are to be noted include the following:

1. Years following unusually active hurricane seasons tend to be suppressed in hurricane activity, particularly for intense hurricane activity.
2. Tropical cyclone activity during unusually active seasons is typically 2 to 4 times higher during the subsequent seasons, depending on the specific index of activity considered. The seasonal number of intense hurricane days, is nearly 6.5 times greater during active seasons than in following years. The net tropical cyclone activity (or NTC) is three times greater.
3. Only two of the ten "subsequent" seasons (1894 and 1951) had above average hurricane activity and only two others (1934 and 1951) had a total of more than five hurricanes in the subsequent season.

This trend suggests that the 1996 hurricane season will likely be a great deal less active than has been the 1995 season.

Table 6: Average seasonal totals of named storms (NS), named storm days (NSD), Hurricanes (H), Hurricane Days (HD), Intense Hurricanes (IH), Intense Hurricane Days (IHD), Hurricane Destruction Potential (HDP), and Net Tropical Cyclone (NTC) activity during the ten previous most active hurricane seasons during the last 125 years (top line) versus the same average seasonal totals during the ten subsequent seasons (line 2). The ratio of active year to subsequent year activity is on the third line.

	NS	NSD	H	HD	IH	IHD	HDP	NTC
Ave. of Ten Most Active Seasons	13.9	95	9.5	52	4.7	14.2	166	251
Ave. of Ten Years Following Ten Most Active Seasons	7.3	38	4.2	17	1.2	2.2	49	83
Ratio Active Yr/Following Yr	1.9	2.5	2.3	3.0	3.9	6.4	3.4	3.0

It is observed that the year preceding an unusually active hurricane season also has below average activity. For example, the average number of NS, H and IH during ten years before unusually active hurricane seasons was 7.3, 4.2, and 1.4, below the last 45-year average values of 9.3, 5.7 and 2.1. Such weak prior season activity was dramatically illustrated in 1994, one of the most inactive seasons during this century.

This alternating active-inactive tendency for seasonal hurricane activity is not a complete mystery but appears to be associated with the strong biennial nature of the atmosphere and ocean variability. The stratospheric Quasi-biennial Oscillation (QBO) is well known and the strong tendency for the troposphere to have a biennial oscillation has also been well established in observational and modeling studies. ENSO has a significant biennial mode, as do most other tropospheric phenomena including tropical cyclones.

4 Discussion

This extended range seasonal hurricane forecast is based on the premise that the atmosphere will behave in 1996 as it has in the past; that those global environmental conditions which proceed active or inactive hurricane seasons of the past give meaningful information on the future. This hurricane forecast has also benefited from our separate and independent 1996 forecasts of ENSO conditions and of African Sahel rainfall. The atmosphere operates as a single entity and hence, each separate forecast aids our physical interpretation of the complete atmosphere-ocean-land system and in the making of other forecasts.

5 Schedule of Atlantic Basin Seasonal Hurricane Forecasts for 1996

Thus seasonal forecast for the 1996 hurricane season issued on 30 November 1995 will be updated on 5 April 1996, 6 June 1996 and 7 August 1996. A 1996 seasonal verification and a forecast for 1997 hurricane activity will be issued in late November 1996. In addition, seasonal forecasts of late summer and fall 1997 ENSO conditions, the anticipated 1997 Sahel rainfall conditions will also be issued in late November, 1996.

6 Cautionary Note

It is important that the reader appreciate that these seasonal forecasts are based on statistical schemes which will fail in some years. These forecasts also do not specifically predict where within the Atlantic basin storms will strike. Even if 1996 should prove to be a somewhat average hurricane season, there are no assurances that many hurricanes will strike along the US or Caribbean Basin coastline and do much damage.

7 Likely Increase of Landfalling Major Hurricanes in Coming Decades

There has been a great lull in the incidence of intense category 3-4-5 hurricanes striking the US East Coast, Florida and Caribbean Basin during the last 25 years. We see this trend as a natural consequence of the slowdown in the Atlantic Ocean (thermohaline) Conveyor Belt circulation which appears to be responsible for a long list of concurrent global circulation and rainfall pattern changes (see Gray and Sheaffer, 1996). These include the Sahel drought, increased El Nino activity, Pacific and Atlantic middle latitude zonal wind increases among numerous others.

Both actual historical observations and geological (proxy) records indicate that this lull in major hurricane activity will not continue indefinitely. A return of increased major landfalling hurricane activity should be expected within the next decade or two. When this happens, the upshot of large coastal development during the last 25-30 years will very likely include hurricane destruction as never before experienced. More research on the causes and the likely timing of this change-over to increased intense hurricane activity is desperately needed. Increased intense hurricane activity striking US coastal areas is a more assured and immediate threat to the US than that of greenhouse gas warming and other environmental problems which are receiving comparatively much greater attention.

Changes in the North Atlantic. We may be seeing the early stages of the beginning speed-up of the Atlantic thermohaline (Conveyor Belt) circulation from its three decades long slow down. Aagaard (1995) has recently reported on a large decrease in ice flow through the Fram Strait (the North Atlantic passage between Greenland and Spitzbergen). This decreased ice flow reduces the introduction of fresh water and, thereby, increases surface salinity values in the North Atlantic. Recent observations report surface water salinity increases in the deep water formation areas of the North Atlantic during the last few years. Increased salinity greatly increases water density. Chilling of high salinity surface water then creates very dense water which is able to sink to great depth, thereby engendering a northward flow of warm replacement water; hence - the Atlantic conveyor.

Recent deep water observations in the North Atlantic reveal fairly stagnant water a decade or more old. The surface salinity increases that are now being measured in the North Atlantic will likely result in a speed-up of the Atlantic Ocean thermohaline circulation in the next few years. If this does occur, then we anticipate a general increase in West African Sahel rainfall, a decrease in Atlantic summertime upper tropospheric westerly winds and, regarding the issue at hand, a decade long increase of Atlantic basin intense hurricane activity. These new regional North Atlantic measurements may thereby be an ominous sign of future increases in US and Caribbean basin landfalling hurricane activity. Regardless, the quarter century lull which we have enjoyed cannot be expected to continue indefinitely into the future.

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