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Downward trends in the frequency of intense Atlantic hurricanes during the past five decades

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Abstract.
There is concern that the enhanced greenhouse effect may be affecting extreme weather events such as tropical cyclones. The North Atlantic basin offers a reliable, long–term record of tropical cyclone activity, though it may not be representative of tropical cyclones throughout the rest of the tropics. The most recent years of 1991 through 1994 have experienced the quietest tropical cyclone activity on record in terms of frequency of tropical storms, hurricanes, and intense hurricanes. This was followed by the 1995 hurricane season, one of the busiest in the past 50 years. Despite 1995's activity, a long-term (five decade) downward trend continues to be evident primarily in the frequency of intense hurricanes. In addition, the mean maximum intensity (i.e., averaged over all cyclones in a season) has decreased, while the maximum intensity attained by the strongest hurricane each year has not shown a significant change.

Introduction

Two hypothesized impacts of anthropogenic climate change due to increasing amounts of "greenhouse" gases that may occur [*Houghton et al.,* 1990] are increased tropical sea surface temperatures (moderate confidence) and increased tropical rainfall associated with a slightly stronger inter–tropical convergence zone (ITCZ) (moderate/low confidence). Because of these possible changes, there have been many suggestions based upon global circulation and theoretical modeling studies that increases may occur in tropical cyclone frequency [*AMS Council and UCAR Board of Trustees,* 1988; *Houghton et al.,* 1990; *Ryan et al.,* 1992; *Haarsma et al.,* 1993], area of occurrence [*Houghton et al.,* 1990; *Ryan et al.,* 1992], mean intensity [*AMS Council and UCAR Board of Trustees,* 1988; *Haarsma et al.,* 1993], and maximum intensity [*Emanuel,* 1987; *AMS Council and UCAR Board of Trustees,* 1988; *Houghton et al.,* 1990; *Haarsma et al.,* 1993; *Bengtsson et al.,* 1994]. In contrast, there have been some conclusions that decreases in frequency may result [*Broccoli and Manabe,* 1990; *Bengtsson et al.,* 1994] and that any man–made changes in tropical cyclones will likely be "swamped by natural variability" [*Lighthill et al.,* 1994]. One report [*Leggett,* 1994] has suggested that increased tropical cyclone incidence and severity have already taken place, but provided no quantitative evidence. Indeed, so pervasive is this idea that even the *U.S. Senatorial Bipartisan Task Force on Funding Disaster Relief* [1995] reported that "hurricanes...have become increasingly frequent and severe over the last four decades as climatic conditions have changed in the tropics." It is essential with such suggestions and pronouncements that there be a thorough analysis of what the climate record actually shows. This report provides such an analysis of the trends in Atlantic tropical cyclone frequency and intensity.

Five decade long trends

Tropical cyclone is the generic term which comprises hurricanes of the Atlantic and Northeast Pacific, typhoons of the Northwest Pacific, and cyclones of the Indian and Southwest Pacific. Most tropical cyclone basins have a very limited period (i.e. since the late 1960s) of reliable records to analyze for trends. However, the Atlantic basin, including the North Atlantic Ocean, Gulf of Mexico, and Caribbean Sea, has an accurate five decade long record of storms due to the use of aircraft reconnaissance [*Neumann et al.,* 1993; *Landsea,* 1993]. It is this dataset that is examined for recent changes of tropical storminess and for multi–decadal trends of frequency and intensity. This is not to suggest that the Atlantic basin is necessarily representative of global activity, but that it is useful for long–term analysis because of the unique reliable record of length.

On average, intense hurricanes (Atlantic basin tropical cyclones of category 3, 4, or 5 on the Saffir–Simpson hurricane scale [*Simpson,* 1974] with sustained near–surface winds of at least 50 ms^{-1}) have occurred at a rate of 2.2 times per year since aircraft reconnaissance began in 1944. Routine aircraft monitoring of the Atlantic basin has made it likely that even weak, short

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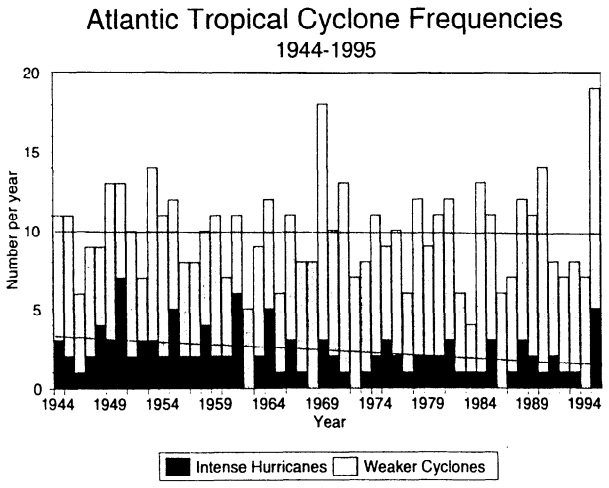

Figure 1. Time series of Atlantic basin intense hurricanes (dark bars) and weaker cyclones (grey bars) for 1944–1995. Intense hurricanes are those cyclones that attain sustained surface winds of at least 50 ms^{-1} at some point in their life cycle. Weaker cyclones include all other remaining tropical storms, subtropical storms, and hurricanes. The superimposed lines are the linear best fits for the intense hurricanes (lower line) and for the total number of cyclones (upper line).

lived tropical cyclones have been detected [*Neumann et al.*, 1993], though a small overestimation on the order of 2.5 to 5 ms^{-1} of the intensity of strong hurricanes during the 1940s through the 1960s has been noted [*Landsea*, 1993]. Figure 1 is a time series of the numbers of intense hurricanes and the total number of Atlantic tropical cyclones since 1944 with the small overestimation bias removed. Intense hurricanes have shown a strong downward trend (–0.32 intense hurricanes per year per decade) significant at the 2% level, continuing the trend noted in *Landsea* [1993].

A large decrease in the incidence of intense hurricanes may seem surprising given the notoriety that strong hurricanes such as Hugo (1989) and Andrew (1992) have achieved with the incredible destruction they caused – \$8 billion and \$25 billion U.S. damage, respectively. A large portion of this immense toll is due to the property development and population increases along the U.S. coastal regions. As an example, southeast Florida including metropolitan Miami went 42 years (1950 to 1992) between strikes by intense hurricanes. During that time, the population increased by more than 600% [*Landsea*, 1993]. With no change of intense hurricane activity (or even a decrease as documented here), total property damage is likely to increase [*Pielke*, 1995]. Thus extreme caution is urged in the utilization of hurricane–related damage as a proxy for trends in hurricane incidence, given the numerous confounding societal factors.

However, as also seen in Fig. 1, the total number of tropical cyclones – including all hurricanes, tropical storms, and subtropical storms – has shown a much weaker and insignificant decrease. The number of weaker cyclones (tropical storms, subtropical storms, and those hurricanes which reach only Saffir–Simpson category 1 or 2) has actually slightly increased, although not significantly.

Time series in Fig. 2 show the mean peak intensities reached by all cyclones in each year and the maximum intensity reached by the most intense hurricane of the year. These results indicate that the mean intensity, which averages near 39 ms^{-1}, has decreased (–0.81 ms^{-1} per decade, significant at the 5% level). This is not surprising, given that the numbers of intense hurricanes has been declining, but not the total number of cyclones. The maximum intensity reached each year, however, has not exhibited any significant downward trend.

Record quiescent conditions: 1991–1994

The years 1991 through 1994 have been remarkably inactive. These four years averaged only 7.5 cyclones of at least tropical or subtropical storm strength, only 3.8 hurricanes, and only 1.0 intense hurricanes, all of which are the lowest frequencies for any four consecutive year period on record since reliable records began (i.e. 1944). (For comparison, the long term – 1944 to 1995 – averages are 9.8, 5.7, and 2.2, respectively.) However, the mean and maximum intensities, while being quite low, have not been unprecedented due to the occurrence of hurricane Andrew and two other relatively strong hurricanes in 1992 [*Mayfield et al.*, 1994].

Figure 3 demonstrates the differences in tropical cyclone activity between the years 1991 through 1994 versus that of the period 1987 through 1990, which experienced near average tropical cyclone conditions. Only one hurricane formed in the deep tropics, equatorward of 25°N excluding the entire Gulf of Mexico, in the latter years compared with 11 during 1987 through 1990 and 10.4 occurring during an average four year period. Note that, in contrast, the cyclone activity north of 25°N including the entire Gulf of Mexico had shown near average conditions: 14 hurricanes from 1991 through 1994,

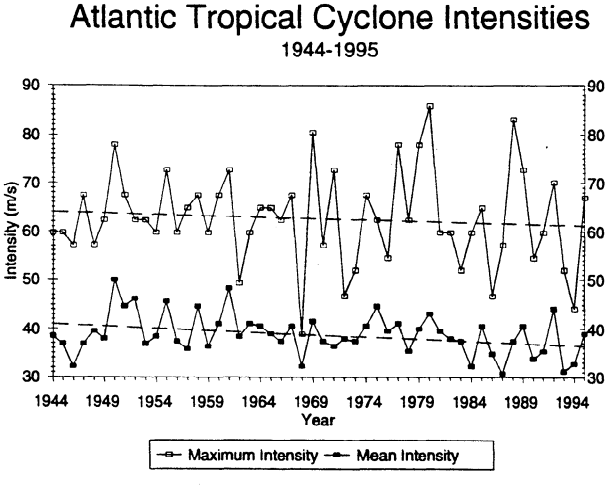

Figure 2. Time series of the Atlantic basin maximum intensity (open symbols) and mean intensity (solid symbols). The maximum intensity is the highest sustained surface winds for the strongest hurricane for each year. The mean intensity is the average of highest sustained surface winds achieved by all of the storms for each year. The superimposed lines are the linear best fits for the maximum intensity (upper line) and for the mean intensity (lower line).

12 from 1987 through 1990, and 12.4 during an average four year period. Since 1991, the cyclones equatorward of 25°N were all spawned by African easterly waves [*Avila and Pasch,* 1995], while the majority of those poleward of 25° N had their genesis in non–tropical wave mechanisms.

This lack of low latitude hurricane activity had allowed the Caribbean Sea and the surrounding countries to remain hurricane–free for five consecutive (1990–1994) years, which is unprecedented since the turn of the century. During this period, a larger than usual number of tropical storms in the deep tropics failed to intensify further. These storms had the potential for developing to hurricane strength but were disrupted by strong tropospheric vertical wind shear (which advects away the central convection necessary for maintenance and development of the tropical cyclone) [e.g., *Gray,* 1968; *DeMaria et al.,* 1993].

The drop in the numbers of low latitude hurricanes is related to changes in the circulation of the troposphere over the tropical Atlantic. These four years have seen the combination of numerous El Niño episodes (1991/92, 1993, and 1994/95) and continuing drought conditions in the African West Sahel (the driest quintile – within the driest 20% of occurrences – was reported in 1991 and 1992, dry quintile – within the next 20% of occurrences – in 1993, and neutral quintile – within the middle 20% of occurrences – in 1994). Both of these factors have been shown [*Gray,* 1990; *Landsea and Gray,* 1992] to increase the tropospheric vertical shear by accelerating both the low level tradewind easterlies and the upper tropospheric westerlies over the tropical Atlantic Ocean. In addition, the August to October sea level pressures over the Caribbean Sea has also been much higher than average (+0.8 mb – higher than any other four year period), suggesting a weaker and/or equatorially depressed ITCZ. These higher than normal pressures have come in conjunction with slightly cooler than average sea surface temperatures (a couple tenth's of a degree) in the Caribbean Sea and tropical North Atlantic Ocean, though these slight temperature changes are secondary to the large atmospheric circulation variations that have been observed. While these features appear to be responsible for the lack of low latitude hurricanes, the question remains as to what is responsible for the recurring El Niño events, the long–running drought in the Sahel, the very high pressures over the Caribbean, and the slightly cooler than average sea surface temperatures. It has been hypothesized that they may be due to a weakened North Atlantic deep water formation and resultant thermohaline circulation [*Landsea et al.,* 1994].

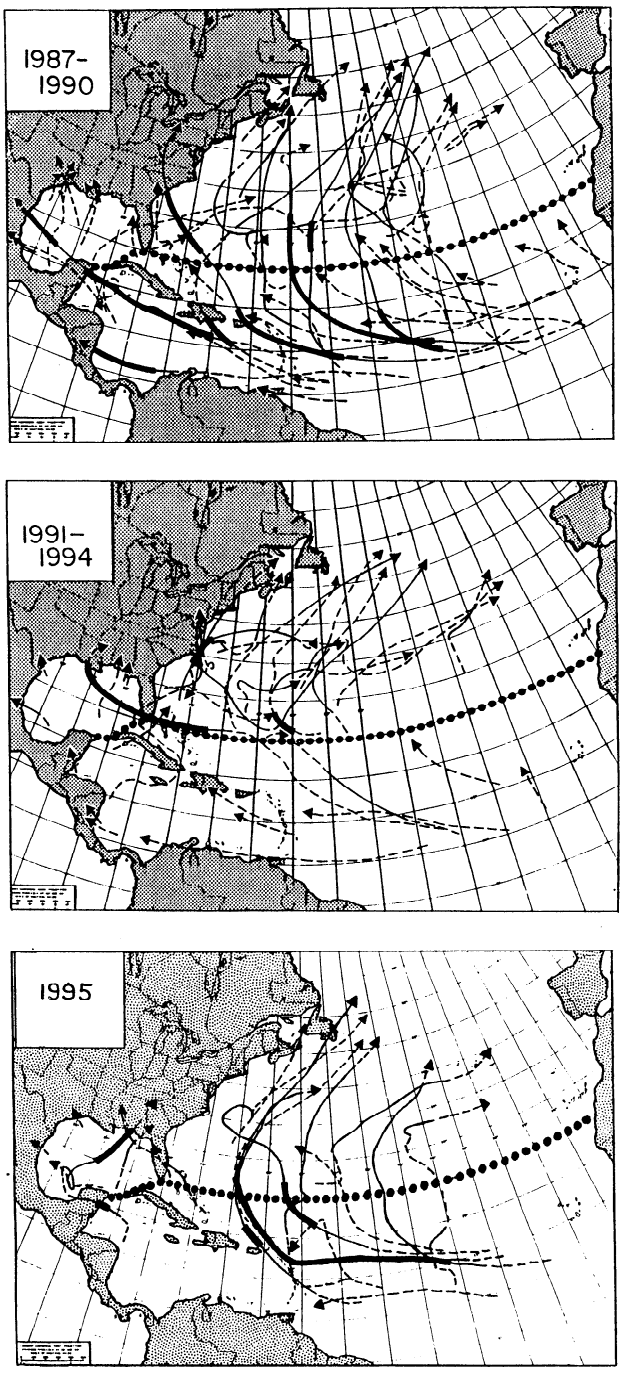

Figure 3. Depiction of tracks of all cyclones of at least tropical or subtropical storm strength during 1987–1990 (top panel), 1991–1994 (middle panel), and 1995 (bottom panel). Tropical and subtropical storm stages are designated by dashed lines. Hurricane stages are shown with solid lines. Intense hurricane stages are indicated with the heavy solid lines. The large dotted line denotes the separation point (approximately 25 °N) between cyclones in the deep tropics and those in subtropical latitudes.

1995: A near record active season

The quiet conditions of the previous four years have been, at least temporarily, ended with the near record season of 1995. This year saw 19 tropical storms and hurricanes, 11 of which reached hurricane status, and five of those obtained at least 50 ms^{-1} sustained winds of the intense hurricanes. Those numbers are the largest since 1933, 1969, and 1964, respectively. As seen in the bottom panel of Fig. 3, seven of the 11 hurricanes reached hurricane status while in the deep tropics, south of 25°N - compared with just one total in the previous four years. The environmental conditions, in strong contrast to the previous years, included an end to the El Niño events, lower sea level pressures, higher than average sea surface temperatures, and extremely low vertical wind shear. At least for 1995, the tropical Atlantic

has returned to the favorable conditions for tropical cyclone activity that was previously seen in the late 1940s to late 1960s.

Conclusions

In summary, contrary to many expectations that globally tropical cyclones may be becoming more frequent and/or more intense due to increasing concentrations of greenhouse gases, regionally the Atlantic basin has in recent decades seen a significant trend of fewer intense hurricanes and weaker cyclones overall. In addition, the maximum intensity reached in each year has shown no appreciable change. These trends have been accentuated in recent hurricane seasons – 1991 to 1994 – with the lowest frequencies recorded of tropical storms, hurricanes, and intense hurricanes in the 50 year period of accurate counts. These decreases have primarily been manifested in the deep tropical latitudes (i.e. equatorward of 25°N excluding all of the Gulf of Mexico) and the countries surrounding the Caribbean Sea have particularly benefited as five years with no hurricanes in the region is the longest hurricane–free span since the turn of the century.

However, 1995 has, at least temporarily, heralded the return of Atlantic basin hurricanes. Most of the regional and global factors which previous research has shown to be related to active Atlantic hurricane seasons were present during 1995. It is possible that this sharp increase of activity was a consequence of an increase in the strength of the oceanic thermohaline circulation. It will likely take several more years before it can be established whether 1995 was simply a single year anomaly in continued quiet conditions or whether it was the beginning of a regime of active hurricane seasons.

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