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ATLANTIC INTENSE HURRICANES, 1995-2003 – CHARACTERISTICS BASED ON BEST TRACK, AIRCRAFT, AND IR IMAGES

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1. INTRODUCTION

During the nine-year period 1995-2003, there have been **32** intense hurricanes in the Atlantic basin. Intense hurricanes are those that attain Saffir-Simpson Category 3 or higher (i.e. >100 kt wind maximum). A distinct upturn in the frequency of intense hurricanes has occurred since 1995, with an annual average of **3.6** intense hurricanes, compared with the long-term (1950-2000) average of **2.3**. This change has been documented and discussed by Goldenberg, et al, (2001).

Using "Best Track" data (Jarvinen and Neumann, 1979), ordered lists of various parameters associated with each of the 32 intense hurricanes have been compiled. For example, the lowest minimum sea-level pressure (MSLP) with each hurricane ranges from 905 hPa with Mitch (1998) to 968 hPa with Erin (2001).

Aircraft reconnaissance center fix sea-level pressure observations, geostationary satellite infrared (IR) temperature, and wind radii estimates from Tropical Prediction Center advisories have also been used to compile parameters to describe characteristics of this set of hurricanes. **Table 1** lists the average, maximum, and minimum values of some of the key parameters.

Table 1. Average, maximum, and minimum values of parameters for 1995-2003 Atlantic intense hurricanes.

Parameter	Units	Ave.	Max.	Hurricane	Min.	Hurr.
BestTrack						
MSLP	hPa	941.0	968	Erin	905	Mitch
Vmax	knots	118.1	155	Mitch	100	-----
Vmax	m/s	60.7	79.7	Mitch	51.4	-----
IH-days	days	2.5	8.0	Luis/Isabel	0.25	-----
-dMSLP24	hPa/day	32.3	54	Mitch	15	-----
dVmax-24	knots/day	39.2	65	Keith	20	-----
dVmax-24	(m/s)/day	20.1	33.4	Keith	10.3	-----
Aircraft						
-dMSLP12	hPa/day	51.2	80	Opal	34	-----
Satellite						
T-No-6	Dvorak	6.5	7.2	Mitch/Keith	5.6	Felix01
T-max	Dvorak	6.8	7.5	Mitch/Keith	6.0	Erin
Surr-T	C	-71.0	-58.2	Erin	-79.	Opal
R-coldest	km	64.0	100	Alberto	28	Iris
Eye-T	C	2.1	18.8	Floyd	-60.	Opal
TPC Advisory						
R-34	n.mi.	141.5	231	Cindy	69	Iris
R-50	n.mi.	82.4	150	Luis	23	Iris
RMW	n.mi.	19.7	30	-----	5	Lili/Iris
R-34	km	261.8	427	Cindy	128	Iris
R-50	km	152.4	278	Luis	42.5	Iris
RMW	km	36.5	56	-----	9.3	Lili/Iris

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2. INTENSITY

Hurricane intensity is expressed as the associated maximum surface wind speed or as the minimum sea level pressure, which is inversely related to the wind speed. The lowest minimum sea level pressure (**MSLP**) is given in Table 1 along with the highest maximum surface wind speed (**Vmax**) in both knots and standard units of m/s. It should be noted that Best Track files give intensity measurements at 6-hour intervals, which may not capture the maximum intensity. However, Tropical Prediction Center archives also include an estimate of maximum intensity and its time of occurrence. Hurricane Mitch (1998) was clearly the most intense Atlantic hurricane since 1995 with 905 hPa and 155 kt, while the more typical Atlantic intense hurricane has **MSLP** and **Vmax** of about 940 hPa and 120 kt.

3. INTENSE HURRICANE DURATION

The Best Track data provide a measurement of the duration of 100 kt or greater intensity (**IH-days** in Table 1) in increments of 0.25 days (6 h). While Hurricane Opal (1995) is third most intense in terms of **MSLP** with 919 hPa, it ranks a very modest 23rd in terms of **IH-days**. Hurricanes Luis (1995) and Isabel (2003) tied for the maximum **IH-days** value of 8.0 while the average for the 32 cases is 2.5.

4. INTENSIFICATION RATE

It is important to know the rate at which hurricanes can intensify, and the Best Track parameters in Table 1 are **–dMSLP-24**, the largest 24-h decrease of MSLP, and **dVmax-24,** the largest 24-h increase in maximum wind speed. The standard "Best Track" times of 00, 06, 12, and 18 UTC are used for these computations. 32 hPa/day and 39 knots/day are the average intensification rates for the 32 Atlantic intense hurricanes, while the extreme values are 54 hPa/day for Hurricane Mitch (1998) and 65 kt/day for Hurricane Keith (2000). A more extensive study of Atlantic tropical cyclone intensification rates by Kaplan and DeMaria (2003) documented that "rapid intensification" defined by the 95th percentile of all observed intensity changes, is associated with 83% of intense hurricanes and all hurricanes of Saffir-Simpson Category 4 or 5. That result is duplicated almost exactly by this limited data set of maximum intensification rates with each of the 32 intense hurricanes since 1995. Of the 19 hurricanes that are Category 4 or higher, the maximum intensification rates are at least 29 hPa/day and 30 kt/day.

Aircraft reconnaissance center fix sea-level pressure observations provide additional insight on intensification rates due to the reliability of more direct measurements and typical observation intervals less than 6-12 h. With the 1995-2003 Category 4-5 Atlantic hurricanes, 11 had rapid intensification periods that were well observed by aircraft. The largest 12 h MSLP decrease using linear interpolation with available aircraft

observations **(-dMSLP-12**) is included in Table 1. The 12 h computation interval results in faster intensification rates. The average of the 11 cases was 51 hPa/day, while Hurricane Opal (1995) had a remarkable 80 hPa/day intensification rate over a 12 h period.

5. IR IMAGE MEASUREMENTS

Dvorak (1984) proposed a method for estimating intensity based on IR pixel temperatures. The same method has been applied to 30-minute interval IR images with all 32 Atlantic intense hurricanes since 1995, except that multiple radius measurements were employed. For intense hurricanes, the algorithm is nearly identical to the Objective Dvorak Technique (ODT) described in Velden et al (1998). The objective Dvorak intensity estimates are summarized in Table 1 by **T-No-6** (the 6 h running mean of the Dvorak intensity) and **T-max** (the maximum single image Dvorak intensity number). Results give Dvorak intensities (T-numbers) to the nearest 0.1. The T-number conversion to maximum surface winds for the range of values in Table 1 are: T6.0=115 kt, T6.5=127kt, T7.0=140kt, T7.5-155kt. Work is underway to perform a thorough validation of the objective Dvorak intensities, including characteristics such as timing of maximum intensity, the timing of rapid intensification, and biases as a function of intensity.

The IR measurements comprising the objective intensity estimates are also summarized in Table 1. **Surr-T** is the "surrounding temperature" defined as the warmest IR pixel temperature on the coldest circle, and it ranges from –58C to –79C, averaging –71C. The **Eye-T** is the warmest IR pixel temperature in the eye. Cloud free eyes have temperatures in the 15-18C range, a few degrees cooler than the ocean surface due to water vapor attenuation. Average **Eye-T** is 2C and the median 11C, occurring with the presence of very shallow clouds. A few intense hurricanes have colder **Eye-T** values. With weaker hurricanes this is common with high clouds covering the eye, but with intense hurricanes it is likely due to a very small eye limiting the capability of the IR sensor to view directly down to the surface, as with Hurricane Opal (1995). **R-coldest** is the radius of the circle with the coldest surrounding temperature. The radii are defined in increments of 4 km corresponding to the approximate resolution of the IR sensor. The inner radius is used when multiple radii have the same surrounding temperature. **R-coldest** averaged 64 km, with a broad range from 28 km for Hurricane Iris (2001), a very small hurricane, to 100 km for Hurricane Alberto (2000), which had a large eye.

6. WIND RADII AND SIZE

Each IR image from which **T-max** was measured, was archived in a common hurricane centered format. Those images show large differences in the deep convection and high cloud coverage associated with some hurricanes at comparable intensities. For example, Hurricane Floyd's overall cloud shield is much larger than the clouds associated with Hurricane Iris, while the Vmax is 135 kt with Floyd and 125 kt with Iris.

The advisories issued by the Tropical Prediction Center include estimates of the radial extent of winds greater than 34 kt and 50 kt in quadrants. The quadrant values were averaged and included in Table 1 as **R-34** and **R-50** along with estimates of the radius of maximum winds (**RMW**), both in nautical miles and kilometers. The observed size differences that can occur among intense hurricanes can be seen by comparing the wind radii values of large hurricanes, Luis (1995) and Cindy (1999) to the small values associated with Hurricane Iris (2001).

Additional work is underway to evaluate the capability of IR derived quantities to provide reliable estimates of wind radii and radius of maximum wind.

7. LANDFALLS

Loss of life and property damage are closely related to hurricane intensity at time of landfall. Landfall Vmax and MSLP have been compiled for the 1995-2003 Atlantic intense hurricanes. **21** of the **32** hurricanes made landfall with at least hurricane intensity, **12** of which were intense hurricanes at landfall. Only **three** of those **12** were U.S. landfalls. Opal (1995), Fran (1996), and Bret (1999), each made landfall on the U.S. coast with Vmax of 100 kt. The highest landfall Vmax was 125 kt with Hurricane Iris (2001) in Belize, and the lowest landfall MSLP was 930 hPa with Hurricane Floyd (1999) in the Bahamas.

ACKNOWLEDGMENTS:

This work is supported by NOAA Grants NA90RAH00077 and NA17RJ1228. The views, opinions, and findings in this report are those of the authors and should not be construed as an official NOAA and or U.S. Government position, policy, or decision.

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