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ATLANTIC TROPICAL CYCLOGENESIS – SATELLITE ANALYSIS

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1. INTRODUCTION

The Best Track data provide a good documentation of where and when Atlantic hurricanes and tropical storms originate, according to the initial positions. Either the first designation as a tropical storm or as a tropical depression can be used. Typically, the first tropical storm classification follows the first tropical depression position by 12 to 36 hours, however this can vary greatly. Satellite image analysis of the one to 2-day period prior to first tropical storm designation can reveal a wealth of additional information on a particular tropical cyclogenesis event. Animation of high resolution visible images can be used to track the tropical cyclone center back in time. However, it may be difficult to pinpoint this circulation center's point of origin. This is because it originates in association with a pre-existing disturbance or easterly wave which has its own broad circulation center and may also have one or more pre-existing mesoscale circulation centers. Additionally, active deep convective clouds and mesoscale convective systems (MCS) are closely associated with this center, making it difficult to track. Using infrared (IR) images, the MCS's can be objectively identified by the centroid of IR temperature defined cold cloud areas at their maximum extent. Typically, an easterly wave's lower level circulation can be tracked with visible images for many days prior to initiation of a tropical storm. At times, upper level lows and troughs are present during cyclogenesis. Subtropical cyclones may transition to tropical cyclones. Water vapor image animations are used to track those features.

A thorough description of a tropical cyclogenesis event requires a careful, detailed analysis with animations of high resolution multi-spectral geostationary images covering a period of several days. The purpose of this paper is to describe a systematic approach to an analysis of this type and show some examples. The analyses with a large sample of cases will show the wide variety of meteorological conditions associated with tropical cyclogenesis as well as an evaluation of the common features. These studies have the potential to not only increase our understanding of how tropical cyclones form, but also provide the basis for evaluation of conceptual models and operational model numerical model forecasts.

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2. SYSTEMATIC APPROACH – GENESIS BEST TRACKS

For lack of a better term, the analysis process is called a "Genesis Best Track". It is analogous to the "Best Track", except that it is a post-analysis of the pre-tropical storm weather system. The objective of a "Genesis Best Track" is to document the time and location of: 1) the pre-tropical storm center, 2) the broad center of the pre-existing tropical disturbance (easterly wave), 3) convective maxima associated with MCSs, 4) upper level lows. To do this, the following step-by-step procedure is proposed.

1. Plot date/time and lat/lon of first tropical storm (TS) and tropical depression (TD) classifications using Best Track data or operational advisories.
2. Using animations of visible images, along with 3.9-micrometer images at night, track the center back in time to either its origin or where it is no longer well-defined, and note this time and location (Point A).
3. Extrapolate that center back an additional 24 h.
4. Beginning at Point A, using animations of visible images, along with 3.9-micrometer images at night, track the broader scale circulation center (i.e. trough axis, vorticity center) of the tropical wave or tropical disturbance, back in time up to 5 days or to where it is no longer identifiable.
5. Using IR or water vapor images, plot the location and time of convective maxima within 5 degrees latitude of the combined track from Steps 1-4.
6. Using water vapor image animations, plot the location of upper level vorticity centers at regular 24-h intervals within 10 degrees latitude of the combined track from Steps 1-4.

An example of a "Genesis Best Track" is shown in Fig.1 for Hurricane Rita. The pre-tropical storm center can be tracked back through the tropical depression stage to a location near 21N 65W. The pre-existing tropical wave's broad circulation center is tracked back to 12 September. It is notably devoid of deep convection until 16 September. Several convective maxima are identified and plotted on 16-18 September. On 15 September, an upper level circulation center formed to the northwest of the tropical wave. Its track to the west is shown and it became poorly defined on 18 September.

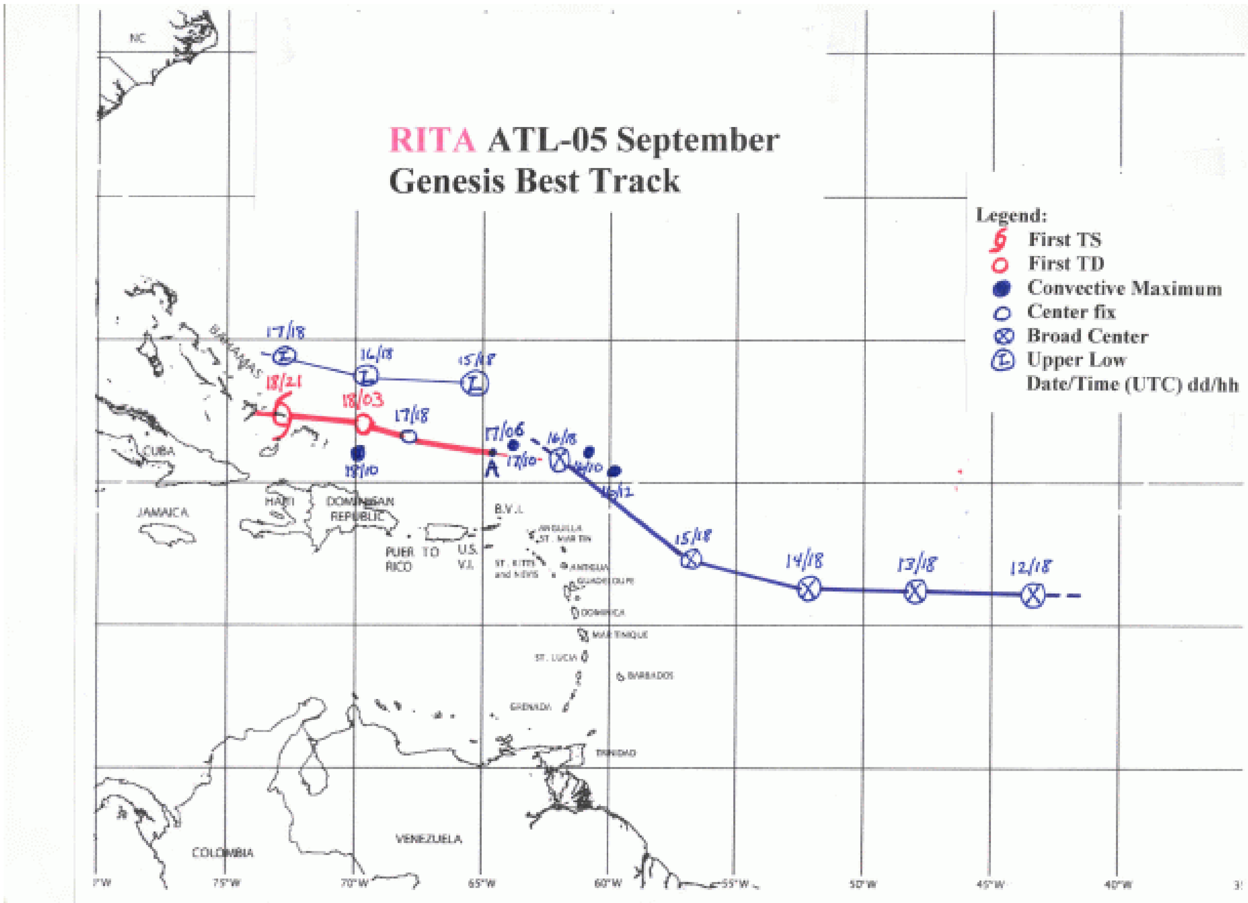

Fig. 1. "Genesis Best Track" for Hurricane Rita.

3. CONVECTIVE MAXIMA

It seems clear that deep convection plays an important role in tropical cyclogenesis. IR image data can be used along with a -60C threshold and a contiguous size (~4-5 x 10^4 km^2) requirement to objectively identify and locate MCSs. Fig. 1 depicts the time and location of convective maxima, i.e. MCSs at their maximum extent of cold (<-60C) cloud area.

A large sample of this type of MCS data with respect to tracks of pre-tropical storm circulation centers may likely provide insight as to their role in tropical cyclogenesis.

Fig. 2 shows the IR image of a convective maximum during the cyclogenesis period of Hurricane Katrina, with the subsequent positions of the Best Track initial classifications as Tropical Storm (~27 h after the Fig. 2 image time) and Tropical Depression (~9 h). Aircraft reconnaissance fixed a low-level (1500 ft, 457 m) center with 1008 hPa minimum sea-level pressure at 2015 UTC / 23 August. Fig. 3 shows the visible image and the location of the aircraft center fix along with locations of the Best Track positions.

Image animations suggest that Katrina's tropical cyclone center either originated with the MCS in Fig. 2 or that a pre-existing mesovortex intensified in association with the MCS, leading to the subsequent tropical depression. While these events were occurring, a distinct upper level circulation can be seen in water vapor image animations about 500 km north of the low level center. It is not clear as to how the pre-existing broad scale circulation (tropical wave), the MCS, and the upper level circulation interact, and provide the combined forcing, that results in a Tropical Storm Katrina forming at its observed time and location.

The Tropical Prediction Center / National Hurricane Center Tropical Cyclone Report on Hurricane Katrina (Knabb et al, 2005) gives an excellent description of the genesis period of Hurricane Katrina beginning with the statement, "The complex genesis of Katrina involved the interaction of a tropical wave, the middle tropospheric remnants of Tropical Depression Ten, and an upper tropospheric trough."

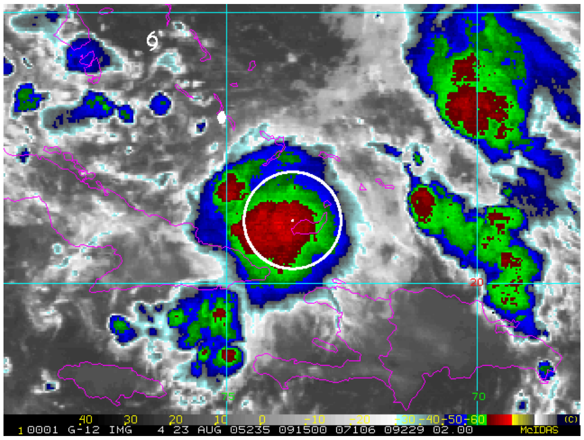

Fig. 2. GOES-12 IR image, 0915 UTC, 23 August, 2005. The locations of the first designations as TD and TS are marked to the northwest of the MCS.

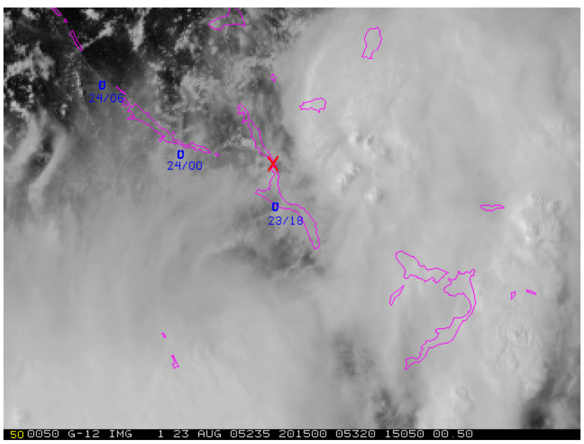

Fig. 3. GOES-12 visible image, 2015 UTC 23 August 2005. X marks the location of the aircraft center fix, and the 6-hourly Best Track positions are shown for 23 Aug / 18 UTC and 24 Aug/ 00 and 06 UTC.

4. BLENDED TOTAL PRECIPITABLE WATER (TPW) PRODUCT

The microwave sounder channels aboard the NOAA and DMSP polar orbiting satellites provide the capability of retrieving total precipitable water over the oceans. A composite of 3 NOAA and 3 DMSP satellites are used at CIRA, to produce a global analysis of TPW (Kidder and Jones, 2005). This blended TPW product is very useful in tracking easterly waves. An example covering the Atlantic is shown in Fig. 4. Initial tropical storm positions have been plotted on the animations of this product with analyses at 6-hour intervals during the period 16 August – 17 October. Tropical cyclogenesis generally occurs with pre-existing disturbances that are identifiable by the TPW patterns, and have increasing TPW exceeding a value of 62.5 mm.

5. DISCUSSION

Recently, some interesting ideas, conceptual models, and research findings on tropical cyclogenesis have emerged. The satellite analysis procedures and products illustrated in this paper seem well suited for testing the application and validity of conceptual models with individual cases studies. The following remarks on some of those studies are not meant to be a thorough review of pertinent research.

Holland and Webster have proposed a “wave accumulation” mechanism, following the initial study of Holland (1995), as a tropical cyclogenesis conceptual model. Animations of the CIRA TPW product, at times, appear to depict this process.

Frank and Roundy (2004) have analyzed the relationships of different dynamical wave types and deep convective activity as quantified by outgoing longwave radiation (OLR) data.

Montgomery, et al (2006) have demonstrated the critical role that small intense cumulonimbus (hot towers) in the tropical cyclogenesis process. The satellite images show the overshooting tops and small convective cores that are nearly always present along with the mesoscale convective systems, during the genesis period.

Molinari, et al (2006) have analyzed a case study of the formation and intensification of a new tropical cyclone center associated with a pre-existing tropical storm’s asymmetric distribution of deep convective clouds.

Lin, et al (2005) have used Meteosat satellite imagery to show that 23 of 34 eastern Atlantic tropical cyclones originated from the Ethiopian Highlands, during the period 1990-2001.

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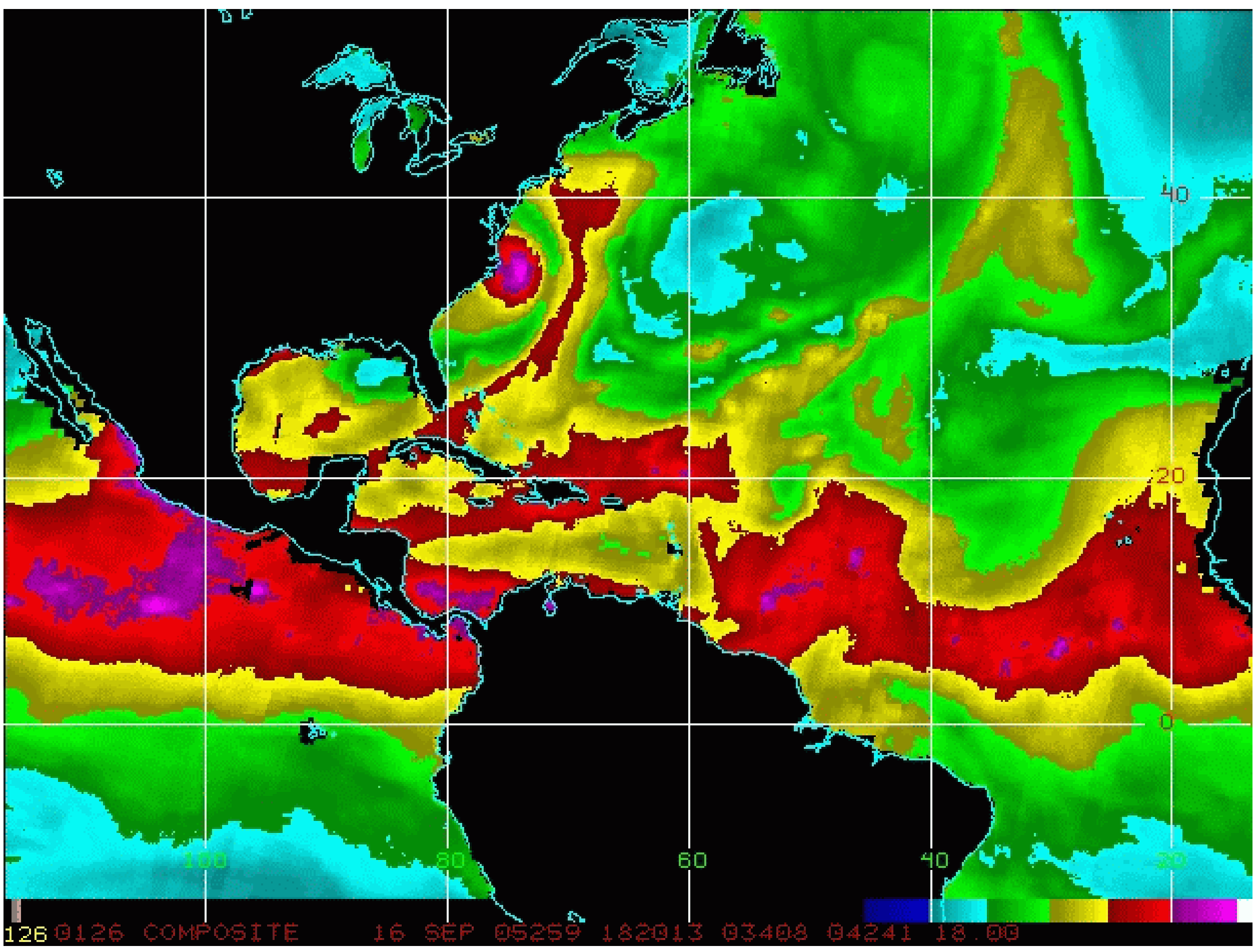

Fig. 4. CIRA Blended TPW product, 1820 UTC, 16 September 2005. (Kidder and Jones, 2005)