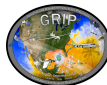


# Necessary and Sufficient Conditions for Tropical Cyclogenesis: Evidence from Recent Field Programs



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## 1. Introduction

This study seeks to advance our understanding of the necessary and sufficient conditions for tropical cyclogenesis; specifically those environmental, convective and thermodynamic properties that may determine the fate of disturbances with apparent genesis potential.

The following questions are addressed through synthesizing data from multiple aircraft and satellite platforms for 12 developing and 4 non-developing disturbances:

- What is the thermodynamic evolution of the developing inner core?
- What properties of wave organization are important for genesis? Does a mid-level circulation in a near-saturated environment precede genesis?
- Which of the following convective properties are most important for genesis?
  - Fractional coverage / proximity of rainfall around the center
  - Convective intensity
  - Timing of intense convective bursts
  - Duration

## 2. Data and Methodology

### DEV CASES INCLUDED:

PREDICT/GRIP/IFEX (P-G-I) 2010:

- TD2: 6 July – 9 July (genesis: 8 July 00Z)
- Bonnie: 18 July – 25 July (22 July 06Z)
- Earl: 23 Aug. – 4 Sept. (25 Aug. 06Z)
- Fiona: 27 Aug. – 4 Sept. (30 Aug. 12Z)
- Gaston: 29 Aug. – 11 Sept. (1 Sept. 06Z)
- Karl: 9 Sept. – 18 Sept. (14 Sept. 12Z)
- Matthew: 20 Sept. – 25 Sept. (23 Sept. 12Z)

IFEX 2009:

- Danny: 24 Aug. – 29 Aug. (26 Aug. 09Z)

IFEX 2008:

- Fay: 10 Aug. – 24 Aug. (15 Aug. 12Z)
- Kyle: 20 Sept. – 29 Sept. (25 Sept. 00Z)

TCS-08:

- Nuri: 14 Aug. – 23 Aug. (16 Aug. 18Z)

IFEX/TCSP 2005:

- Gert: 21 July – 25 July (23 July 18Z)

### NONDEV CASES INCLUDED:

P-G-I (2010):

- Gaston
- PGI-27
- PGI-30
- PGI-48

• For each disturbance, the "center" is defined by the vorticity maximum (VM) manually tracked in the 6-hourly, 1x1° NCEP FNL MODEL ANALYSIS. VM are identified at 925, 850, 700, 600 hPa.

• Tracks begin when VM is identified consistently for at least 24 hrs after initial time, and end after landfall, or when re-curving north of 45°

• Statistics shown are computed for 0-3° from the 850 hPa VM center

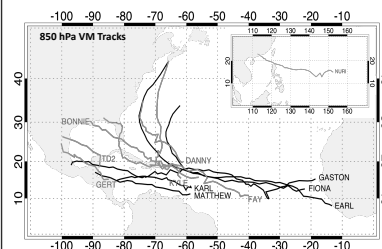
• Genesis - Tropical Depression (TD) classification by NHC

### SATELLITE DATA:

- Infrared (IR) every 30 min. at 3 km resolution
- Passive Microwave (PMW)  $T_b$  from AMSR-E\*, TRMM TMI, SSM/I(S) 15, 16, 17\*
- Derived Total Precipitable Water (TPW)\* from AMSR-E, TMI, SSM/I(S)
- AIRS
- TRMM merged-IR rain rate (3B42)

### DROPSONDE DATA:

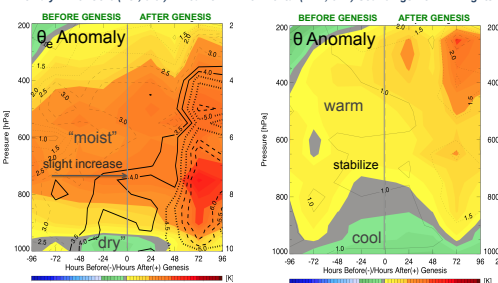
- 245 Non-developing dropsondes
- 667 pre-genesis
- 1537 post-genesis



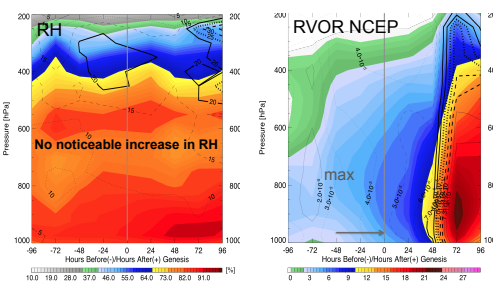
Black lines:  
P-G-I (Aug. - Sept. 2010)  
cases  
Gray lines: all other  
disturbances

## 3. Results: Thermodynamic

Composite time series of dropsondes within INNER CORE (3°) of DEVELOPING disturbances  
Anomaly: Inner Core (I.C.; 0-3°) - Mean of Environmental (ENV; 3-7°) Soundings from All Flights



I.C.  $\theta_e$  and  $\theta$  greater than ENV at mid-levels (above 850 hPa) - **warmer** and **"more moist"**  
**Cool, dry** anomaly develops **low-levels** (below 850 hPa) **within 2 days of genesis**

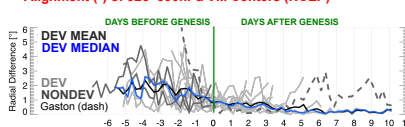


Within 2 days of genesis, RVOR increases more rapidly at low-levels

An initially stronger mid-level circulation in a favorable thermodynamic environment (moisture/saturation) supports primarily low-level convergence and spin-up right before genesis (Davis and Ahijevych 2012; Raymond et al. 2011; Nolan 2007)

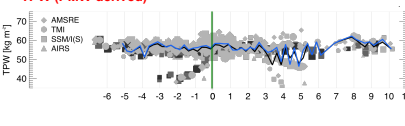
## 4. Results: Environment

Alignment (°) of 925-600hPa VM Centers (NCEP)



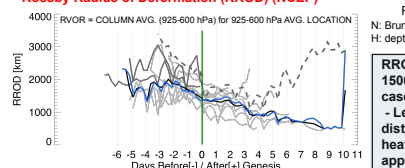
Vertical alignment  
of the VM at low-  
and mid-levels is a  
requirement for  
formation  
- within 1°

TPW (PMW-derived)



Little progressive  
moistening  
observed; TPW  
identical before  
and after genesis  
TPW must be at least  
50 mm for formation?

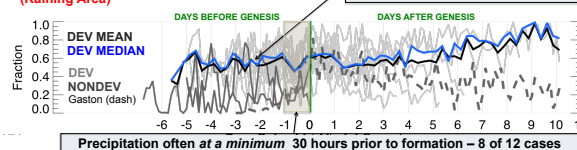
Rosby Radius of Deformation (RRD) (NCEP)



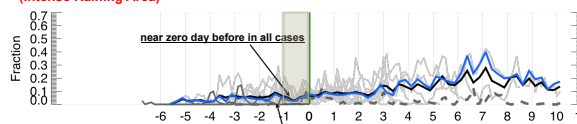
RRD is approximately  
1500 km by genesis in all  
cases  
- Length scale of  
disturbance (latent  
heating) must also  
approach 1500 km

## 5. Results: Convection

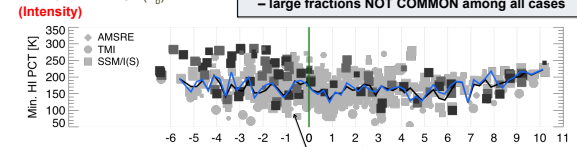
Fractional Coverage of Rainfall within 3°  
(Raining Area)



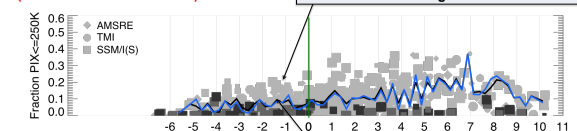
Precipitation often at a minimum 30 hours prior to formation - 8 of 12 cases



Minimum PMW PCT ( $T_b$ )  
(Intensity)



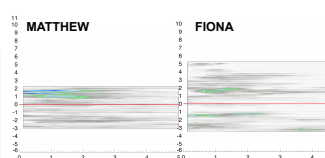
Fraction of pixels with PCT ( $T_b$ ) ≤ 250 K  
(Area of Intense Convection)



Fraction of 'intense convection' shows a slight increase before genesis

Azimuthally Averaged Rain Rate  
(Proximity)

- In some cases such as Matthew, persistent rainfall occurs near the center in the 1-2 days prior to genesis
- In cases such as Fiona, a noticeable lack of rainfall anywhere near the center within a day of genesis



## 6. Conclusions

- For genesis, wave vorticity must be predominantly from curvature, the VM/pouch must be vertically aligned at low- and mid-levels, and disturbance length scale must approach the RRD
- Though some "progressive moistening" observed (mixing ratio ~ 0.5 kg kg⁻¹ day⁻¹), inner core moisture content/RH often already primed for formation days in advance
- Pre-genesis convective episodes exhibit no common, distinguishing characteristics in the days leading up to formation.
  - Although a slight increasing trend is observed in proxies for 'intense convection', some cases exhibit no intense convection within 24-36 hours of genesis
- The most favorable convective burst (in terms of area, proximity to center, and intensity) does not necessarily occur within a day of formation; some are observed as many as 3-4 days in advance.
- Given the variability in convective properties, within the context of the wave organization, there are likely multiple pathways to formation

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