Composite hurricanes affecting Puerto Rico, Hispaniola & Cuba

Mark R. Jury

Physics Department
University of Puerto Rico
Mayagüez Campus
Atlantic hurricane climatology

Timing and spatial distribution of hurricanes. A minimum occurs west of Hispaniola. Season peak - September 10\textsuperscript{th}. 
Here - cases are chosen when intense hurricanes affect Puerto Rico, Hispaniola and Cuba - on a westward track.
The **composite** features of hurricanes causing widespread impacts on Puerto Rico, Hispaniola and Cuba in the past 40 years are studied.

Individual cases have peculiar symptoms, averaging these together, common features are revealed.

**Aims:**

to analyze large-scale weather patterns and interaction between the hurricane and its surrounding circulation

to determine which factors relate to intensity and track, comparing local and remote (tropical and mid-latitude) signals.
Data and Methods:
obtain hurricane impact lists from the NWS of Puerto Rico and Dominican Rep. - 1950s+
obtain daily NCEP atmospheric variables and SST at low 2.5° resolution

find 8 overlapping cases
> H 3 intensity, winds > 50 m s⁻¹:

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Check for coherence; then calculate composite maps for days closest to PR / DR; analyze evolution and forcing
The timing of hurricanes

Probability max: 10 & 22 Sept, ~ 10 day intervals, phase-locked?

SST anomaly over the western Atlantic

Caribbean upper wind ~ 8 year cycle

Variations in $P_{\text{min}}$ intensity and position

Composite surface wind anomaly

8 case average
day 0

Subsequent N-S vertical section analysis
Vertical N-S section wind structure: link to upper easterlies

Observed average $V_T = 55 \text{ m s}^{-1}$!
Model interpolated winds are 25% of actual.
Vertical N-S section thermodynamic structure:

Geopotential’ on 70˚W day 0 T’ upper q’ lower

Pressure (height)

0 km

H +50

L -30

PR

moist

+2

??

8 case composite
Rain rate structure:

Observed average $R_R \sim 100$ mm/day!
Model interpolated rainfall is $\sim 20\%$ of actual.
The composite hurricane intensifies to day +2; track re-curves slowly: San Juan, Santo Domingo, Havana, and Key West are directly in the path!
Composite streamfunction anomaly

The cyclonic low circulation over the eastern mainland is of similar intensity to the hurricane near PR!
The hurricane is ‘attracted’ toward a moist region over the SE mainland, and comes from a region of higher SST as expected.
Remote mid-latitude effects:

Composite upper velocity potential and upper wind anomaly

The hurricane is pushed westward by the divergent circulation across the Atlantic.

An intense polar low and sub-tropical jet streak acts as an ‘attractor’.
Pulses of tropical wind are known to affect hurricanes in the western Atlantic.

Madden-Julian Oscillation

a 40-50 day alternation
Remote tropical effects

Composite hurricane score for tropical wind / convection

MJO forcing

5 case avg.

months
Summary:

A large-scale pattern for the composite hurricanes is evident.

Signal intensity is weakened by model averaging of low resolution data based on sparse observations. NCEP reanalysis hurricane $P_{\text{min}}$, wind and rain anomalies are $\sim 1/3$ of observed mean values. The lack of diabatic heating in the 500-400 hPa layer is the problem.

Major cities are impacted throughout the Caribbean:

$\sim 10^9$ damage and $\sim 10^3$ lives per hurricane!

Composite hurricane patterns indicate:

- Enhancement by warmer SSTs and favorable MJO, enabling development 7˚ further south than usual.
- Attraction by moist conditions and a jet streak over the eastern mainland induced by polar low.
- Tracks guided westward by upper divergent circulation, and link with upper tropical easterlies.

These preliminary findings deserve further attention by researchers at UPRM.
Caribbean climate variability and early summer rains

Mark R. Jury

Physics Department
University of Puerto Rico
Mayaguez Campus

With inputs from B Malmgren and A Winter
Methods:

Using monthly data:
- Obtain station rainfall for Caribbean since 1950
- Calculate geographical clusters: (factor analysis)
- Reconstruct the rainfall time series per cluster
- Analyze the annual cycle and residuals
- Compare year-to-year fluctuations with ENSO and NAO
- Analyze continuous and seasonal relationships

Using daily data:
- Analyze convective fluctuations occurring over DR-PR since 1980
- Perform a wavelet analysis on continuous data to determine important frequencies
- Analyze the recent March-April 2006 wet spell using composite NCEP data
  - thermodynamic and kinematic forcing
  - wave forcing at different latitudes
## Analysis of Caribbean rainfall data

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Cluster analysis of rainfall
annual cycles below

Cluster 1: Early
- Rainfall: 1402 mm

Cluster 2: Late
- Rainfall: 1411 mm

Cluster 3: Late
- Rainfall: 872 mm

Cluster 4: Early
- Rainfall: 1308 mm
Rainfall variability in time and space

Reconstructed cluster rainfall time series

wind climatology

strong

weak
8 year cycle in rainfall via regional SST and upper wind

SST anomaly

Caribbean upper wind
Cluster rainfall in the NW and SE relate to ENSO and NAO respectively.
ENSO influence positive and leading
NAO influence variable and lagging
What are the mechanisms underlying the relationships?

- **ENSO** correlation with precip. water
  - Humid air

- **ENSO** correlation with zonal winds
  - West winds → cyclonic vorticity
  - More rain

- Composite map of upper meridional winds in wet spell
  - Southerlies

- **NAO** correlation with geopotential height
  - Sinking motion
  - High pressure
  - Less rain
Dynamical forcing differs from early to late summer.
Higher frequency oscillations: What drives them?

- a. DR-PR
- b. Wavelet Power Spectrum
- c. Global Wavelet
Dynamics of the recent wet spell

Precip. water time series over western PR

~7 day cycle

2006 28 March 6 April 13 April

Composite maps for pulsed wet spell

Composite map – precip. water

Composite map – upper wind & height
Low level winds in the wet spell

- Westerly flow
- Caribbean SE flow
- Florida NE flow
- TROUGH
- ANDES
Influence of equatorial Kelvin Wave

Wavelength = 11 000 km  C = 1500 km / day  Period = 7 days
What triggered the wet spell?

Hovmoller analysis of upper V wind on 20 N and precip. water on equator (right). Diagonal lines show pulses of moisture moving up the Amazon, and interacting with upper flow over the Caribbean. Circles show wet spells over PR.
Conceptual model of early summer wet spells

- Flow steered by Andes
- Fast equatorial Kelvin waves
- Slow westward pulses of equatorial moisture
- Fast westward Pulses of equatorial moisture
- Evapo-transpiration from Amazon
- Deep anticyclonic circulation anomaly
- Fast eastward Rossby waves draw moisture
- Wet spell over Puerto Rico
Summary:

Puerto Rican rainfall clusters with Dominican (west) and Antilles (east) regions. There is an 8 year cycle and recent drying trend.

NW Caribbean rainfall is enhanced by El Nino in early summer, SE Caribbean rainfall is influenced by NAO.

High frequency oscillations are found that relate to MJO and Kelvin waves.

Early summer rainfall wet spells are driven by a combination of Amazon outflow and an upper jet stream wave. The conveyor belt is pulsed by Pacific Kelvin waves.

Further research is needed to create operational benefits.