Synoptic-scale Environments and Dynamical Mechanisms Associated with Predecessor Rain Events Ahead of Tropical Cyclones

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Master’s Thesis Seminar
8 July 2010
NOAA/CSTAR Grant NA07NWS4680001
Outline

• Overview of a PRE
• PRE-vious research
• Data and Methods
• PRE-relative composite analysis
• PRE associated with TC Rita (2005)
• Concluding remarks
Predecessor Rain Events Ahead of Tropical Cyclones

• Defined by Cote (2007) as distinct mesoscale regions of heavy rainfall [~100 mm (24 h)^{-1}] ~1000 km downstream of landfalling and recurving tropical cyclones (TCs)

• Develop as a poleward stream of moisture from a TC interacts with a region of forcing for ascent

• Pose a substantial flash-flooding risk due to:
  – Prolonged high precipitation rates
  – High precipitation efficiencies

PRE ahead of TC Rita
06Z 25 Sep 2005
Previous Work on PREs

Bosart and Carr (1978): PRE ahead of TC Agnes (1972)

- > 200 mm of rain fell
  ~1000 km ahead of poleward-moving TC Agnes
- Moisture transported by the outer circulation of Agnes toward a region of QG forcing for ascent associated with short-wave trough
- Distinction between TC rainfall and PRE rainfall
Previous Work on PREs

Cote (2007):
• PREs tend to form in a region of confluence downstream of short-wave trough, within the equatorward entrance region of an upper-level jet streak
• Precipitation focused along low-level baroclinic zones and along elevated terrain

Galarneau et al. (2010):
• Low-level thermal advection and frontogenesis along a baroclinic zone important for PRE development
• Ridging associated with diabatic outflow from TC intensifies jet streak
Favorable Environments for Heavy Rain

Maddox et al. (1979): “Frontal” type flash flood pattern
Role of the TC: Linkage to Extratropical Transition

- Moisture transport on eastern flank of TC circulation

- Forcing associated with frontogenesis and warm-air advection as TC circulation interacts with baroclinic zone (e.g., Klein et al. 2000; Harr and Elsberry 2000; Atallah and Bosart 2003)

- Diabatic outflow associated with TC strengthens jet streak and enhance upper-level vorticity gradients (e.g., Bosart and Lackmann 1995; Atallah and Bosart 2003; Atallah et al. 2007)

Source: Klein et al. (2000)
Data and Methods

• PRE identification criteria:
  – Deep tropical moisture associated with the TC advected from the TC by the lower-/middle-tropospheric flow into PRE region
  – Radar reflectivity values $\geq 35 \text{ dBZ}$ for at least 6 h.
  – Average rainfall rate $\geq 100 \text{ mm (24 h)}^{-1}$ over duration of the PRE
  – Must be a clear horizontal separation between the PRE and the TC rain shield.

• PREs during 1988–2008 identified using:
  – National base reflectivity radar mosaics (cases during 1995–2008)
  – 1° GFS analyses and 2.5° NCEP–NCAR reanalysis data
  – NCDC Hourly Precipitation Dataset
  – NPVU quantitative precipitation estimates (QPE)
  – Unified Precipitation Dataset
PRE Stratification Scheme

“Jet in Ridge”

“Southwesterly Jet”

“Downstream Confluence”
Summary of PREs 1988–2008

- **Southwesterly Jet**
- **Jet in Ridge**
- **Downstream Confluence**
- **Unclassifiable**

**Graph 1:**
- **Y-axis:** Frequency of Occurrence (%)
- **X-axis:** TC Genesis Month
- **Legend:**
  - All TCs (N=273)
  - PP TCs (N=38)

**Graph 2:**
- **Y-axis:** Number of TCs (N=38)
- **X-axis:** PRE Category
- **Legend:**
  - Number of TCs (N=38)
  - Number of PREs (N=56)
PRE-relative Composites

“Jet in Ridge” Category

200 hPa

925 hPa

Z (dam, black), wind speed (m s⁻¹, shaded)

925 hPa Z (dam, black), \( \theta \) (K, red), frontogenesis \([10^{-1} \text{ K} (100 \text{ km})^{-1} (3 \text{ h})^{-1}]\), white); PW (mm, shaded)

2.5° NCEP–NCAR Reanalysis

N = 7
PRE-relative Composites

"Southwesterly Jet" Category

200 hPa

N = 17

2.5° NCEP–NCAR Reanalysis

925 hPa Z (dam, black), θ (K, red), frontogenesis \([10^{-1} \text{ K (100 km)}^{-1} (3 \text{ h})^{-1}, \text{white}]; \text{PW (mm, shaded)}

200 hPa Z (dam, black), wind speed (m s\(^{-1}\), shaded)
PRE-relative Composites

“Downstream Confluence” Category

200 hPa Z (dam, black), wind speed (m s⁻¹, shaded)

925 hPa Z (dam, black), θ (K, red), frontogenesis [10⁻¹ K (100 km)⁻¹ (3 h)⁻¹, white]; PW (mm, shaded)

2.5° NCEP–NCAR Reanalysis
“Jet in Ridge” PRE associated with TC Rita
24–25 Sep 2005

1200 UTC 24 Sep – 0000 UTC 26 Sep 2005 total precipitation (mm, shaded)
generated from the NPVU QPE dataset
Synoptic Environment

0600 UTC 25 Sep 2005

200 hPa

- Z (dam, black)
- wind barbs (≥ 25 m s\(^{-1}\), barbs)
- wind speed (m s\(^{-1}\), shaded)

925 hPa

- Z (dam, black)
- θ (K, red)
- wind barbs (≥ 10 m s\(^{-1}\), barbs)
- PW (mm, shaded)

1° GFS Analysis
Mechanisms for Heavy Rainfall

WSI NOWRAD reflectivity (dBZ);
925-hPa wind barbs (≥ 10 m s⁻¹),
θ (K, black),
frontogenesis [K (100 km)⁻¹ (3 h)⁻¹, red]

1000–700-hPa PW (mm, shaded),
vertically integrated WV flux vectors (kg m⁻¹ s⁻¹),
WV flux convergence (10⁻³ kg m⁻² s⁻¹, blue),
Mechanisms for Heavy Rainfall

0300 UTC 25 Sep

WSI NOWRAD reflectivity (dBZ);
925-hPa wind barbs ($\geq 10$ m s$^{-1}$),
$\theta$ (K, black),
frontogenesis [K (100 km)$^{-1}$ (3 h)$^{-1}$, red]

1000–700-hPa PW (mm, shaded),
vertically integrated WV
flux vectors (kg m$^{-1}$ s$^{-1}$),
WV flux convergence ($10^{-3}$ kg m$^{-2}$ s$^{-1}$, blue),

20 km RUC Analysis
Mechanisms for Heavy Rainfall

0600 UTC 25 Sep

WSI NOWRAD reflectivity (dBZ);
925-hPa wind barbs (≥ 10 m s⁻¹),
θ (K, black),
frontogenesis [K (100 km)⁻¹ (3 h)⁻¹, red]

1000–700-hPa PW (mm, shaded),
vertically integrated WV
flux vectors (kg m⁻¹ s⁻¹),
WV flux convergence (10⁻³ kg m⁻² s⁻¹, blue),

Midlevel shear

20 km RUC Analysis
Mechanisms for Heavy Rainfall

1200 UTC 25 Sep

WSI NOWRAD reflectivity (dBZ);
925-hPa wind barbs (≥ 10 m s⁻¹),
θ (K, black),
frontogenesis [K (100 km)⁻¹ (3 h)⁻¹, red]

1000–700-hPa PW (mm, shaded),
vertically integrated WV
flux vectors (kg m⁻¹ s⁻¹),
WV flux convergence (10⁻³ kg m⁻² s⁻¹, blue),

20 km RUC Analysis
Linkage to Extreme-rain-producing MCSs

PRE associated with TC Rita

“Training line/adjoining stratiform” MCS from Schumacher and Johnson (2005)
Cross-section View
0600 UTC 25 Sep

Tangential circulation vectors, $\theta$ (K, blue contours), frontogenesis [K (100 km)$^{-1}$ (3 h)$^{-1}$, red contours], mixing ratio (g kg$^{-1}$, gray shading)
Impact of Diabatic Heating on the Upper-level Flow
0000 UTC 25 Sep

200-hPa irrotational wind (m s$^{-1}$), wind speed (m s$^{-1}$, shaded); 250–200-hPa hPa potential vorticity (PVU, black); 700-hPa ascent (10$^{-3}$ hPa s$^{-1}$, red)
Impact of Diabatic Heating on the Upper-level Flow

0600 UTC 25 Sep

200-hPa irrotational wind (m s\(^{-1}\)), wind speed (m s\(^{-1}\), shaded); 250–200-hPa hPa potential vorticity (PVU, black); 700-hPa ascent (10\(^{-3}\) hPa s\(^{-1}\), red)
Impact of Diabatic Heating on the Upper-level Flow

1200 UTC 25 Sep

200-hPa irrotational wind (m s$^{-1}$), wind speed (m s$^{-1}$, shaded); 250–200-hPa hPa potential vorticity (PVU, black); 700-hPa ascent (10$^{-3}$ hPa s$^{-1}$, red)
Cross-section view
0000 UTC 25 Sep

Upward vertical velocity (10^{-3} hPa s^{-1}, red), wind speed (m s^{-1}, black), PV (PVU, shaded), \theta (K, gray),

1° GFS Analysis
Cross-section view
1200 UTC 25 Sep

Upward vertical velocity ($10^{-3}$ hPa s$^{-1}$, red), wind speed (m s$^{-1}$, black), PV (PVU, shaded), $\theta$ (K, gray),

1° GFS Analysis
Concluding Remarks

Rita case summary

- PRE developed as a continuous, strong poleward moisture surge from Rita impinged upon a quasi-stationary baroclinic zone
- Low-level convergence and deformation at the terminus of the southerly low-level jet likely enhanced frontogenesis along baroclinic zone
Concluding Remarks

Rita case summary

• Upper-/middle-level diabatic heating in the mature PRE likely eroded PV aloft, promoted frontogenesis, and contributed to the strengthening of upper-level jet

• Long-lived PRE was likely due to a combination of:
  1. Continuous moisture transport towards and moisture convergence within PRE region
  2. Quasi-stationary region of low-level frontogenesis
  3. Diabatically enhanced ageostrophic circulation within upper-level jet entrance region
Key features of composites

- PREs preferentially develop in the equatorward entrance region of an upper-level jet streak
- Strong low-level flow downstream of TC oriented perpendicular to baroclinic zone → warm-air advection, frontogenesis, moisture transport from the TC
- Categories differ with regard to:
  - Position of TC relative to key features (i.e., trough, jet, ridge, baroclinic zone)
  - Amplitude and configuration of upper-/middle-tropospheric flow
  - Degree of the interaction between the TC and the midlatitude flow
Synoptic-scale Environment of “Jet in Ridge” PREs
Synoptic-scale Environment of “Southwesterly Jet” PREs
Synoptic-scale Environment of “Downstream Confluence” PREs
Schematic Cross Section

Moist low-level flow
PREs in the Context of the Maddox et al. (1979) “Frontal” Pattern

“Jet in Ridge” PRE

Surface

500 hPa

Low Level Jet >20 m s⁻¹

PW >50 mm

H

L

Φ₂₀₀ trough axis

Φ₂₀₀

Cool And Moist

Hot And Dry

Warm And Moist

T₂ = 60°F

T₂ = 70°F

T₂ = 70°F

120 n.m.

120 n.m.
PREs in the Context of the Maddox et al. (1979) “Frontal” Pattern

“Southwesterly Jet” PRE

Surface

500 hPa
PREs in the Context of the Maddox et al. (1979) “Frontal” Pattern

“Southwesterly Jet” PRE

Transformation stage of ET (Klein et al. 2000)