Characterizing the Structure of Hurricane Karl (2010): Doppler Radar and WRF

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Orographic Modification of Clouds

• Subject of numerous studies
  – Peter Hobbs, Ron Smith, Dale, Bob
  – Cascade Project, DOMEX, IMPROVE, OLYMPEX
  – Dynamics, precipitation processes, etc

• Tropical cyclones less of a focus
Orographic Modification of TCs

• Most research focuses on track deviations and intensity changes
  – Chang 1982, Bender et al. 1987, Roux et al. 2004, etc.

• TCs under examination generally interact with an island (e.g., Taiwan)
  – Exceptions: Bender et al. 1987 and Zehnder 1993(a)
How does orographic modification occur?

- Type of cloud processes that occur
- Characteristics
  - Intensity, duration, location
- Enhancement vs. redistribution
Orographic Enhancement Process

• Tied to underlying thermodynamic and kinematic characteristics

• Two sample mechanisms
  – Convection triggered by terrain
  – Seeder-feeder process

Image: Houze (2012)
Cloud Water

Warm-rain process – orographically generated cloud water
Diagnosed from horizontal reflectivity / thermodynamic profiles
Not so fast!

- Vertical radar measurements showed development of convection where the eye used to reside
  - release of potential instability within eye?
Where does the precipitation fall?

- Background wind speed and orography geometry both determine location of maximum precipitation.
Precipitation Metrics

Precipitation = intensity \cdot time
Precipitation does not have to be intense to cause devastating accumulation
What does Karl bring?

• Mexico is not an island
  – large horizontal extent, slightly higher peak elevations (> 3 km)
• Airborne radar data provides glimpse at vertical dimension
Science Questions

• What do airborne radar measurements indicate about the nature of the precipitation during landfall over the mountainous terrain of Mexico?
• What can WRF simulations tell us about the underlying processes?
Hurricane Karl (2010)
Karl Best Track and Flights

Hurricane Karl
14 - 18 September 2010

Flight

Image: NHC
Rainfall and Mexican Terrain

- Intense rainfall collocated with eastern edge of Mexican terrain
- Maximum rainfall measured near Misantla, MX

Image: David Roth, NOAA
NASA GRIP

DC 8 Flight Track – 09/17/2010

Aug./Sept. 2010

Key instrument: APR-2 radar on DC8
- 10 km flight level
- Ku / Ka band
- high resolution
- downward pointing
- cross-track scan
Upstream Sounding
Karl Circulation at 19Z
Upslope Segment

Minutes after 1800 Z

Low-level enhancement present in reflectivity data
Warm-rain process
Jalapa
Orizaba

3-hour Rainfall Totals

Rainfall (mm)

Orizaba

~210 mm

Jalapa

~212 mm

data from NCDC/NHC
Minutes after 1900 Z

Low-level enhancement not present
Fall streaks from melting ice aggregates
Cumulative Rainfall

data c/o Michel Rosengaus

- Alvarado
- CD Aleman
- Cordoba
- UT de Tecamachalco
- Huamantla
- Huauchinango

Cordoba

mm

12Z 9/17 00Z 12Z 9/18 00Z 12Z

0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800 1920 2040 2160 2280 2400
Compare reflectivity profiles for upslope and downslope flight legs

Removed surface and beams likely to have suffered attenuation
Mean profile shows strong enhancement in upslope segments, downslope segments remain fairly constant towards surface.
Distributions consistent with the mean profile
0530Z Convection
Terrain Modification Experiments
WRF Details

- WRF 3.4.1
- Initialized at 00Z on 9/15/2010
- 4 domains: 54, 18, 6, 2 km
  - 2, 6 km domains follow vortex
- Microphysics: Goddard
- Boundary Layer: MYJ
- Levels: 70
- Two runs: control and reduced terrain
Control run: traces observed track (storm motion too fast).
Flat terrain run: track shifts northward.
Modeled Intensity

Karl’s intensity is underestimated, but general trend is captured.

Modified terrain run reaches deeper intensity and does not drop off as quickly.
Accumulated Precipitation
Relative Humidity and Streamlines

![Relative Humidity and Streamlines Diagram](image-url)
CONCLUSIONS

- Upslope flow produces enhanced near-surface reflectivity in Karl
  - cloud water collected by drops or shallow convection
- Downslope flow does not have the low-level signature
- Mixture of gentle ascent + deeper convection
- WRF simulations consistent
  - enhanced cloud water / rain trace terrain
  - vertical distributions shift towards greater hydrometeor mixing ratios
Background precipitation important to determining enhancement

Landfall complicates matters by removing energy source