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

Jennifer DeHart and Robert Houze

Atmospheric Physics and Chemistry Seminar
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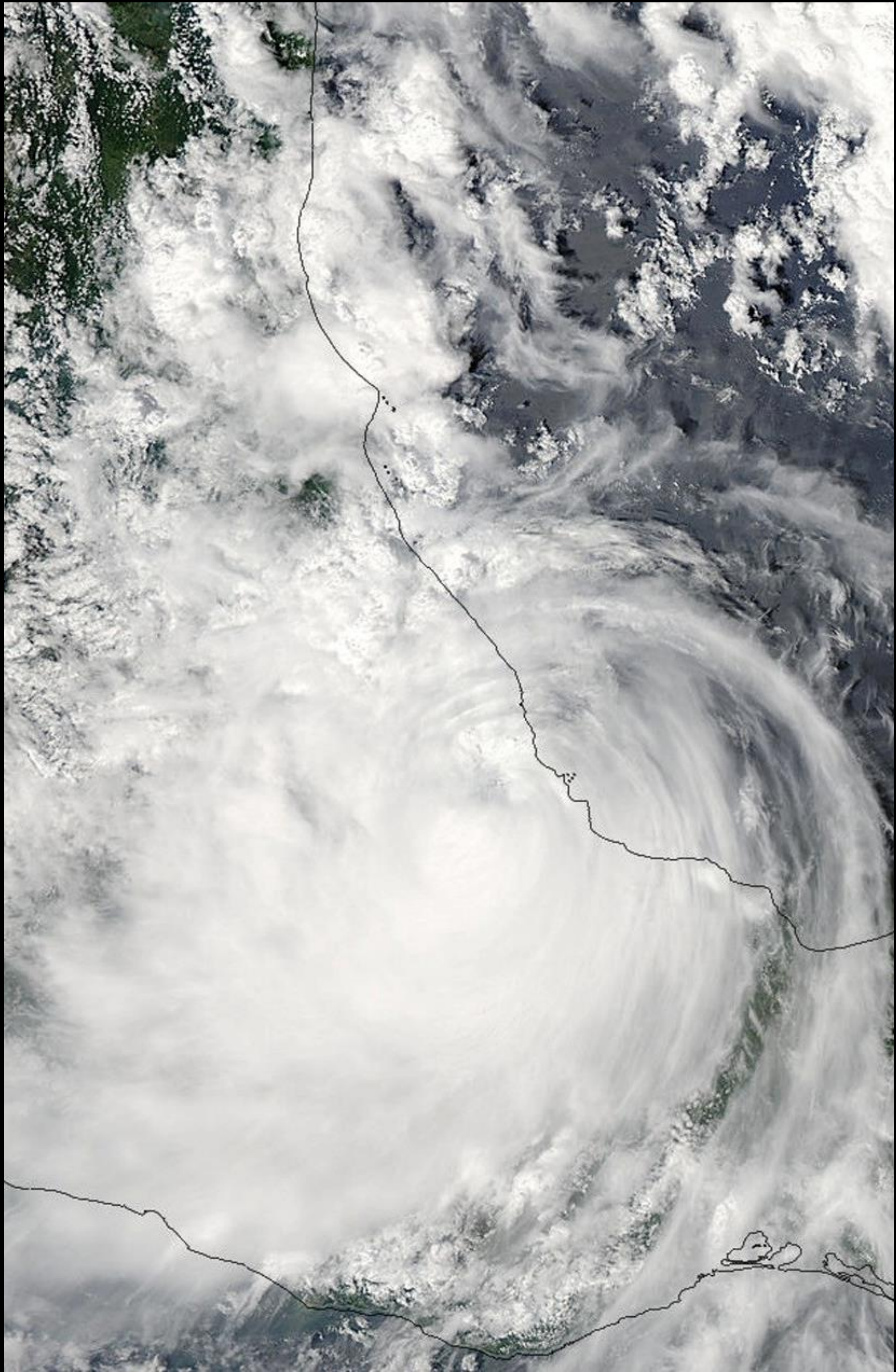


Orographic Modification of Clouds

- 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

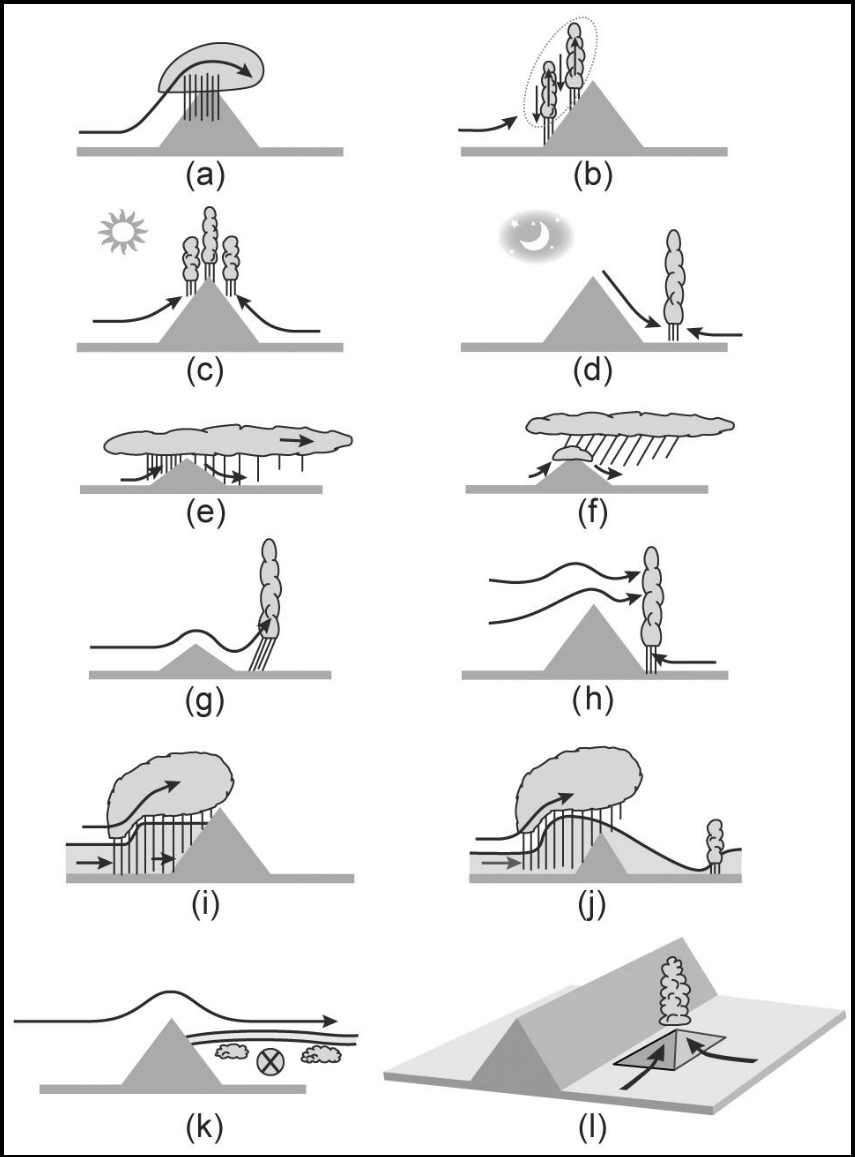
- Most research focuses on track deviations and intensity changes
  - Chang 1982, Bender et al. 1987, Roux et al. 2004, etc.

- 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~~

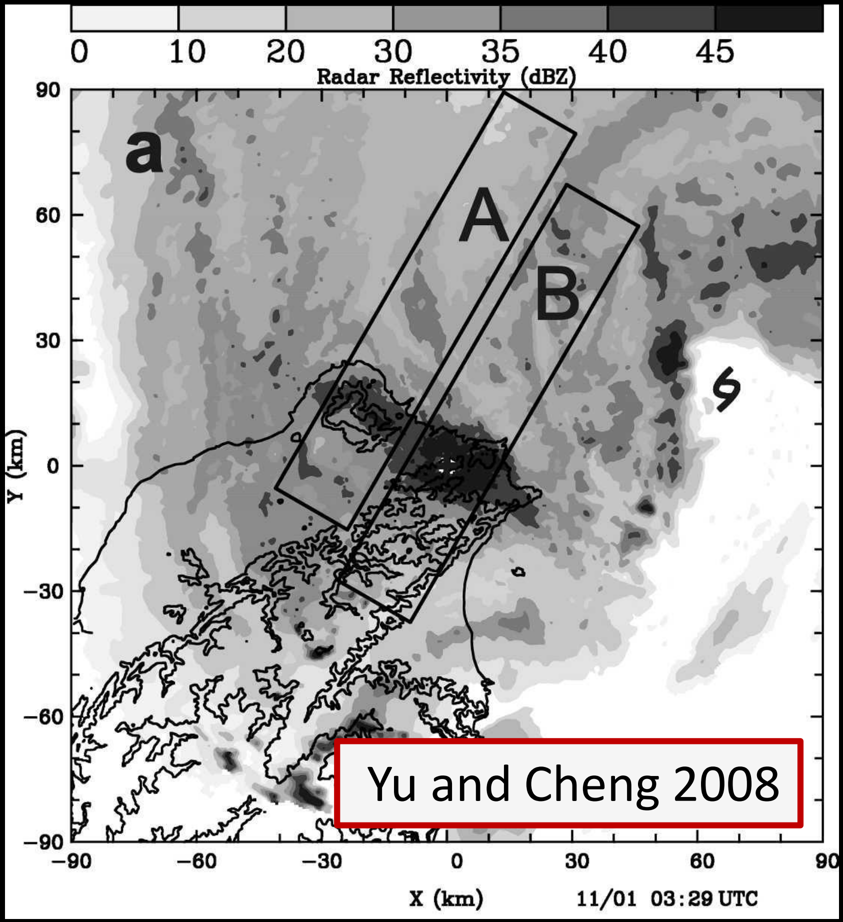
Orographic Enhancement Process

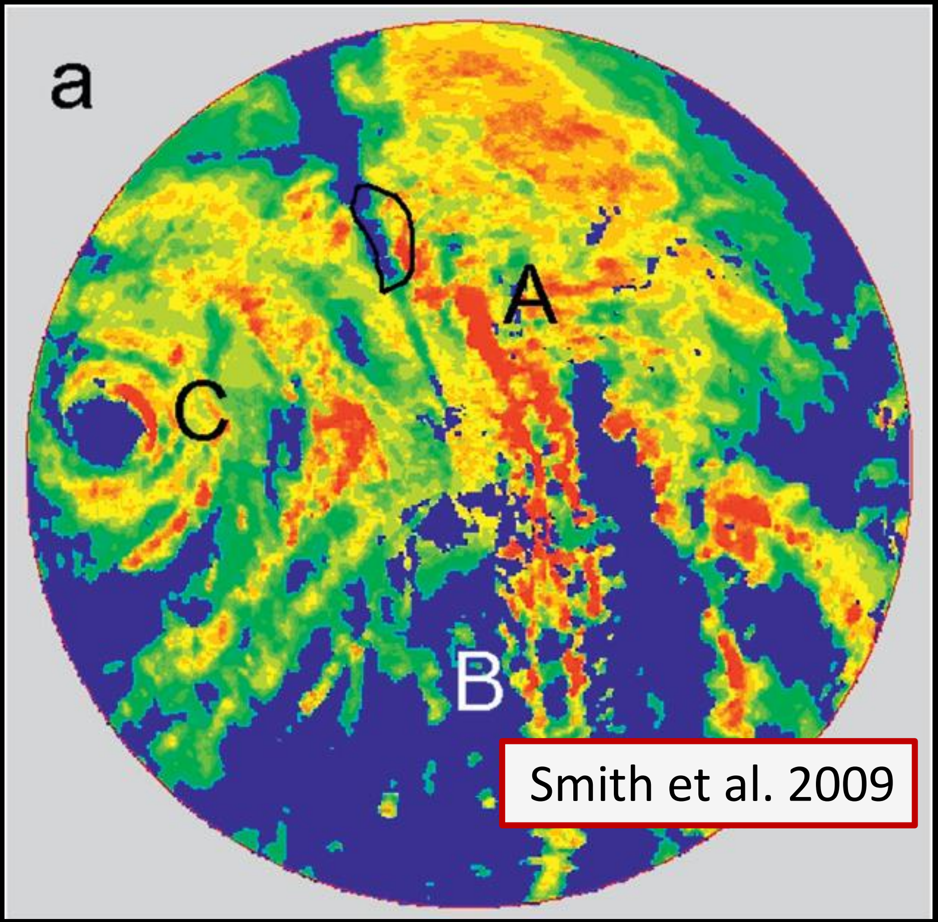


- Tied to underlying thermodynamic and kinematic characteristics
- Two sample mechanisms
  - Convection triggered by terrain
  - Seeder-feeder process

Image: Houze (2012)

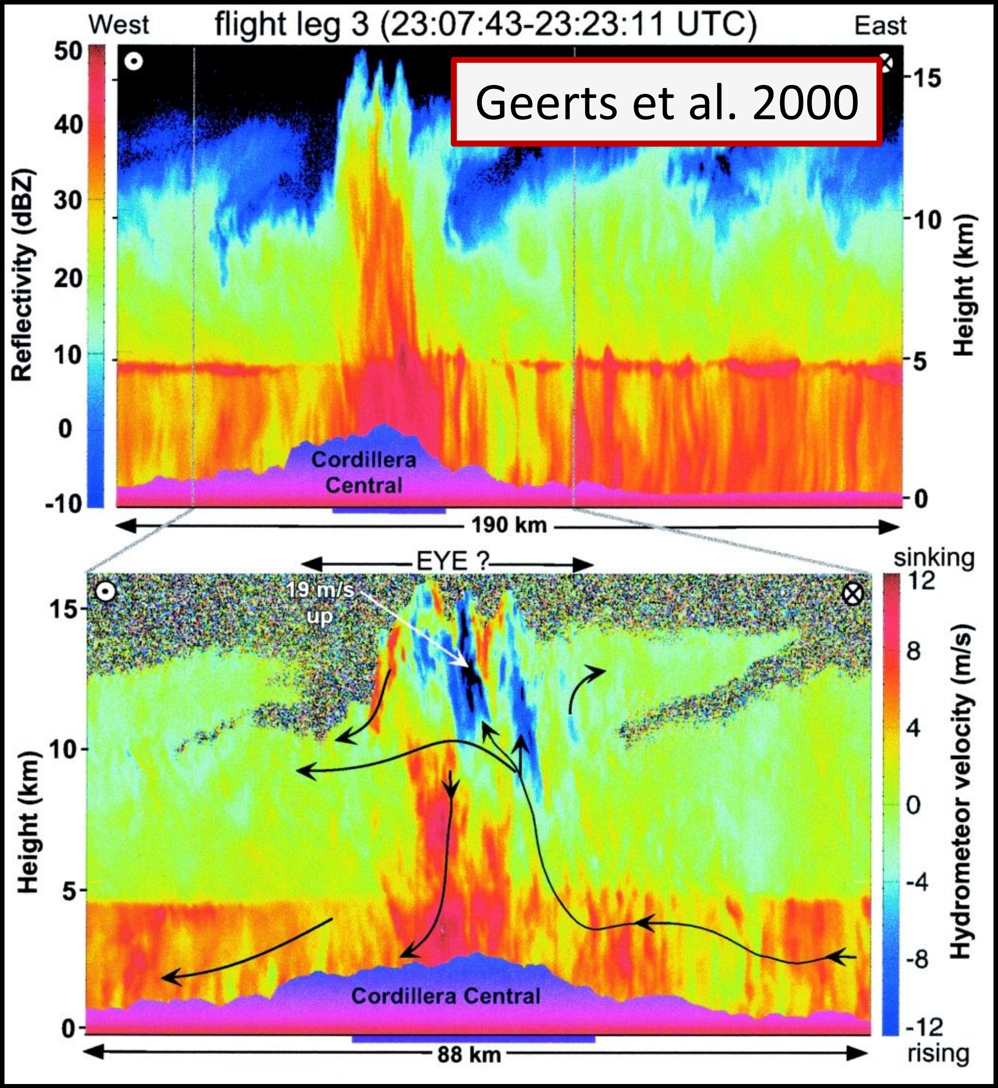
Cloud Water





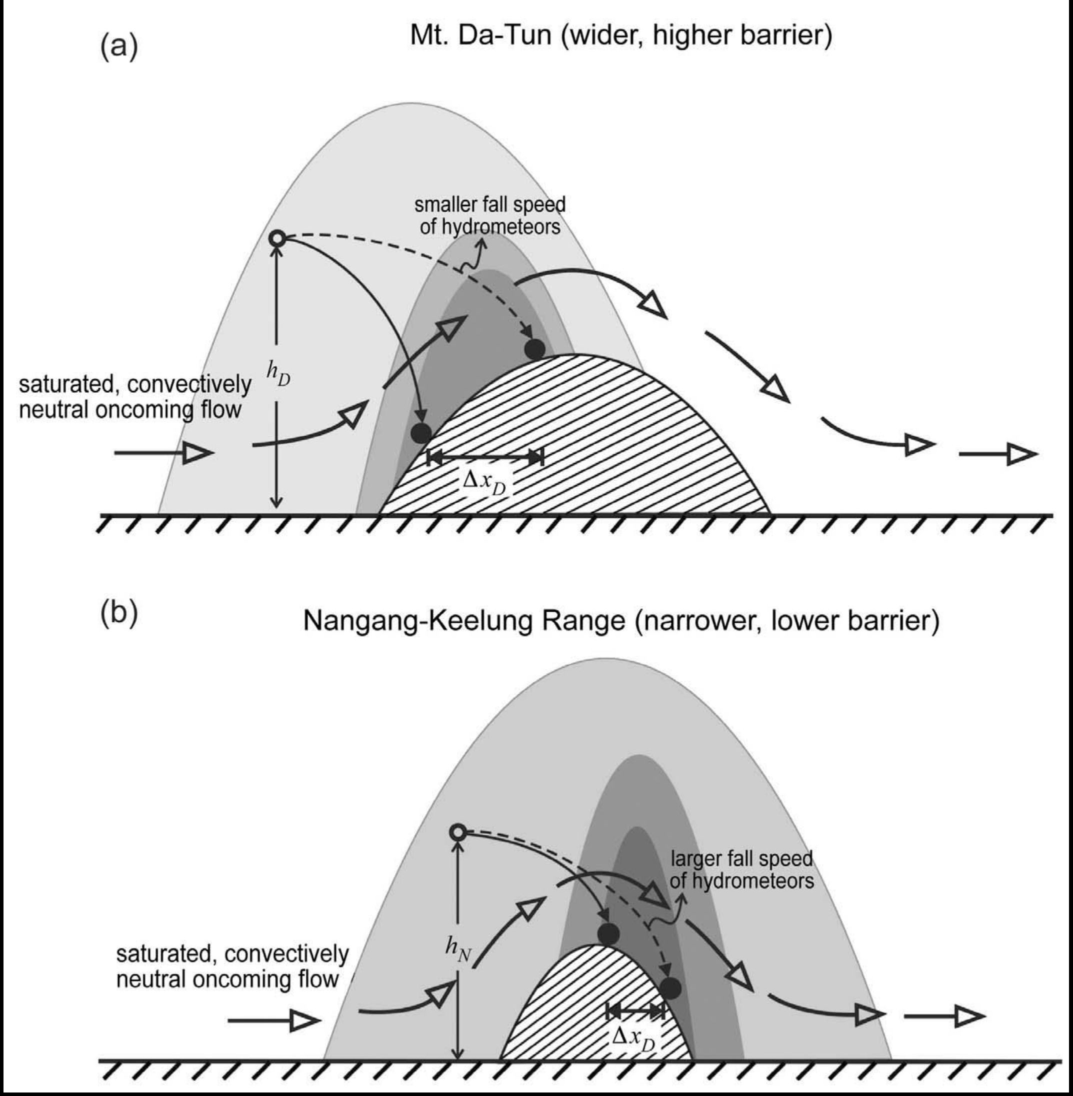
Warm-rain process – orographically generated cloud water
Diagnosed from horizontal reflectivity / thermodynamic profiles

Not so fast!



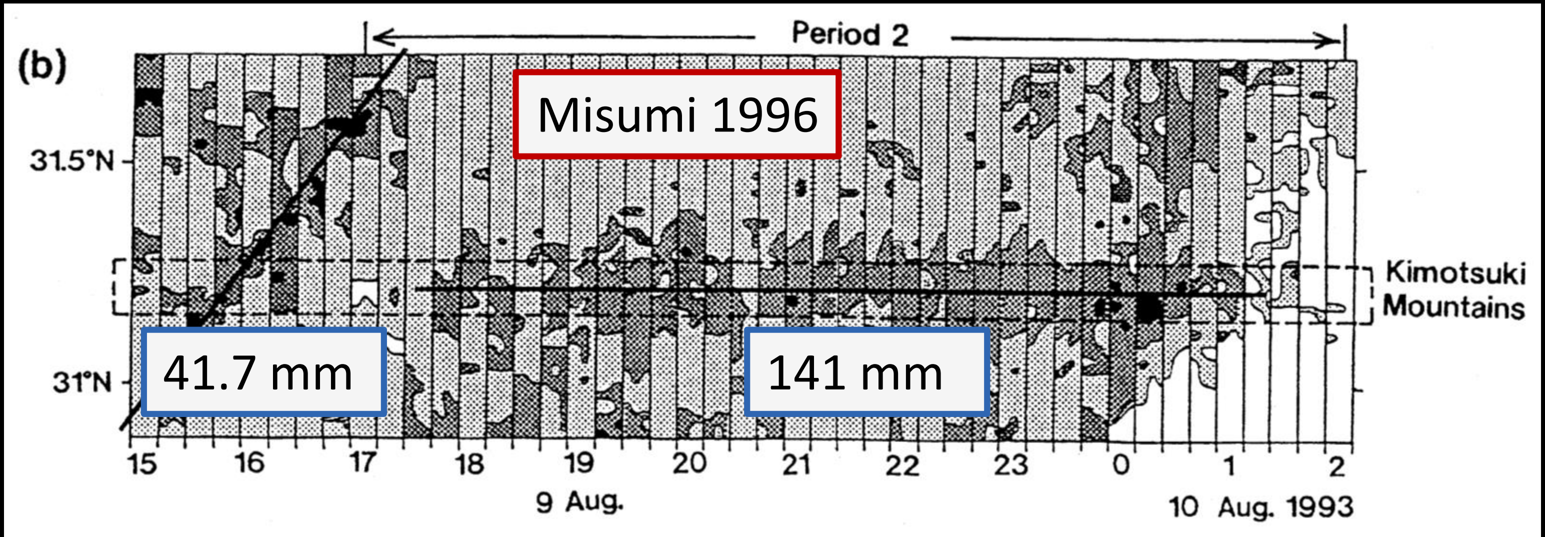
- Vertical radar measurements showed development of convection where the eye used to reside
  - release of potential instability within eye?

Where does the precipitation fall?



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

Precipitation Metrics



Precipitation = intensity · time
Precipitation does not have to be intense to cause devastating accumulation

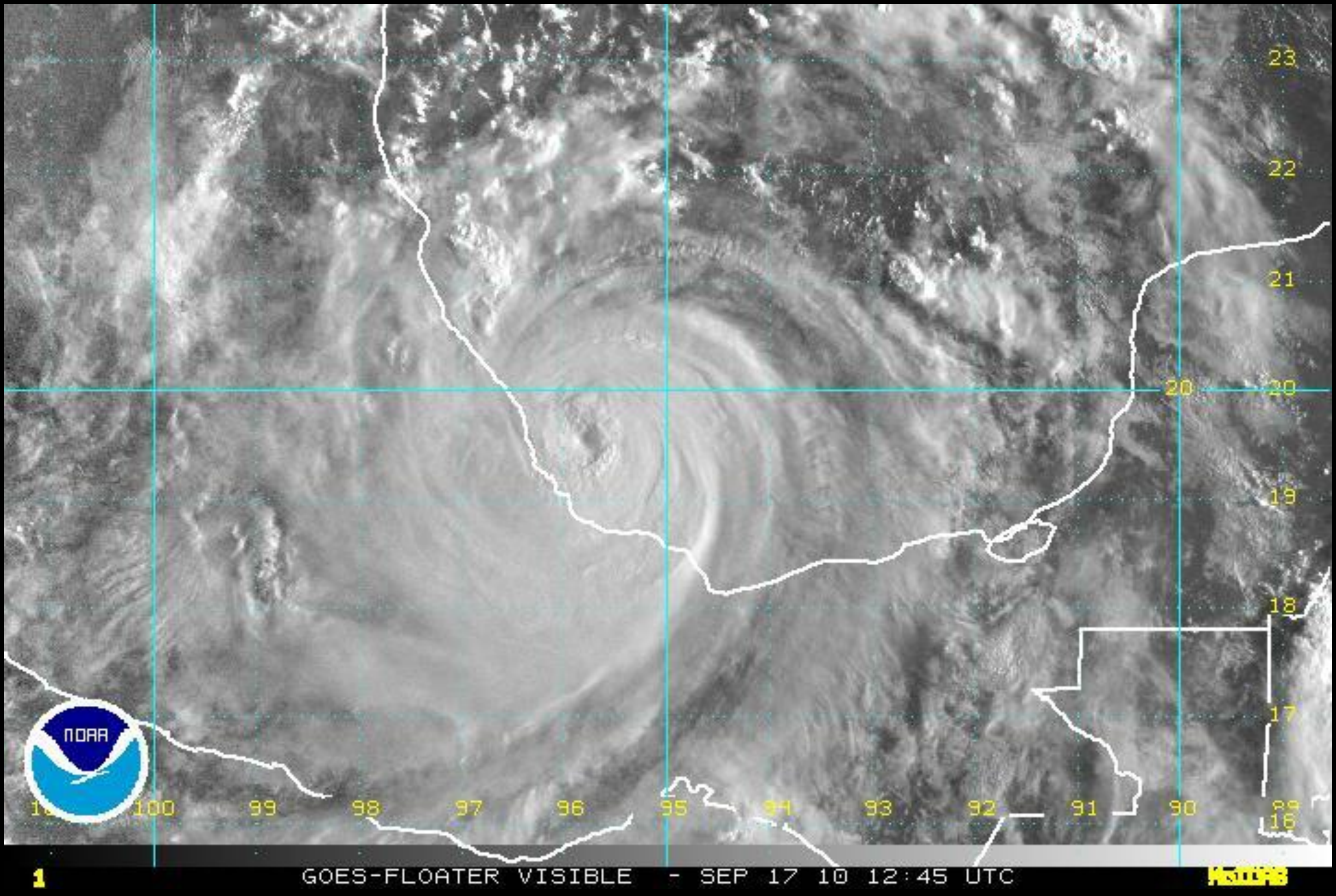
What does Karl bring?

- 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

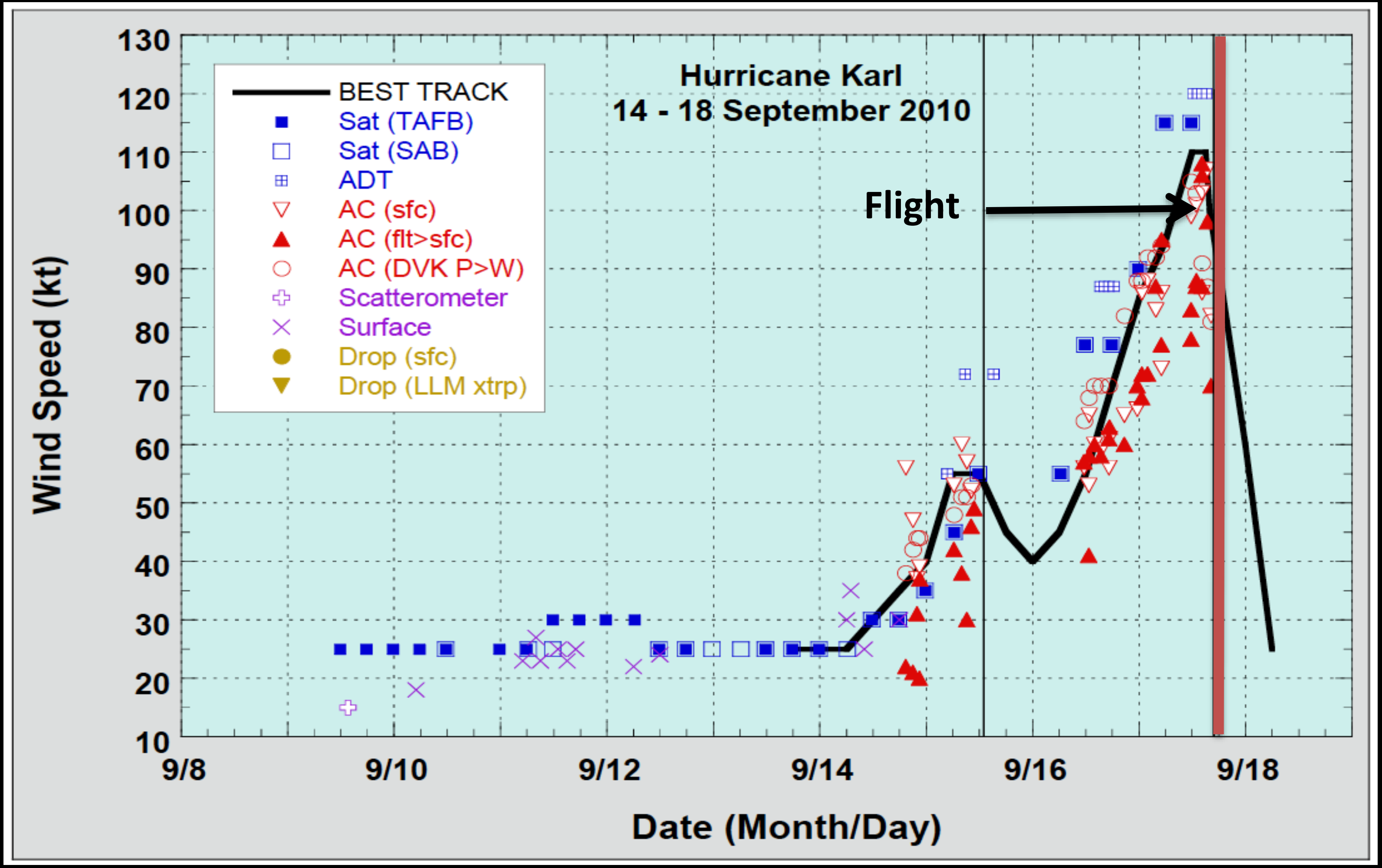
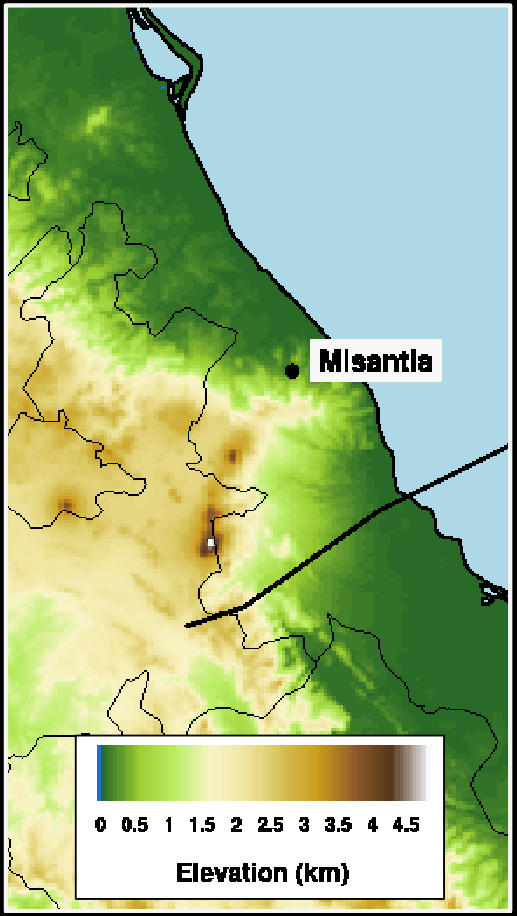
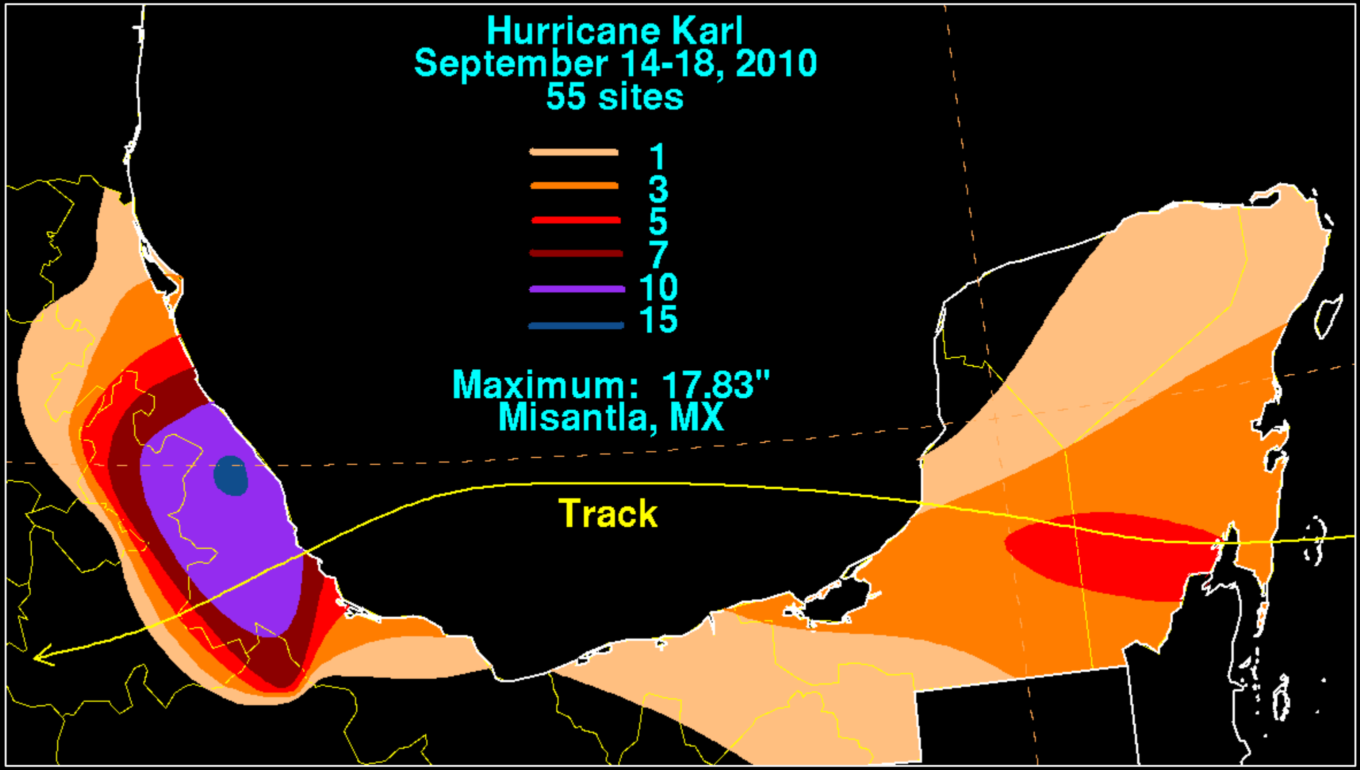


Image: NHC

Rainfall and Mexican Terrain

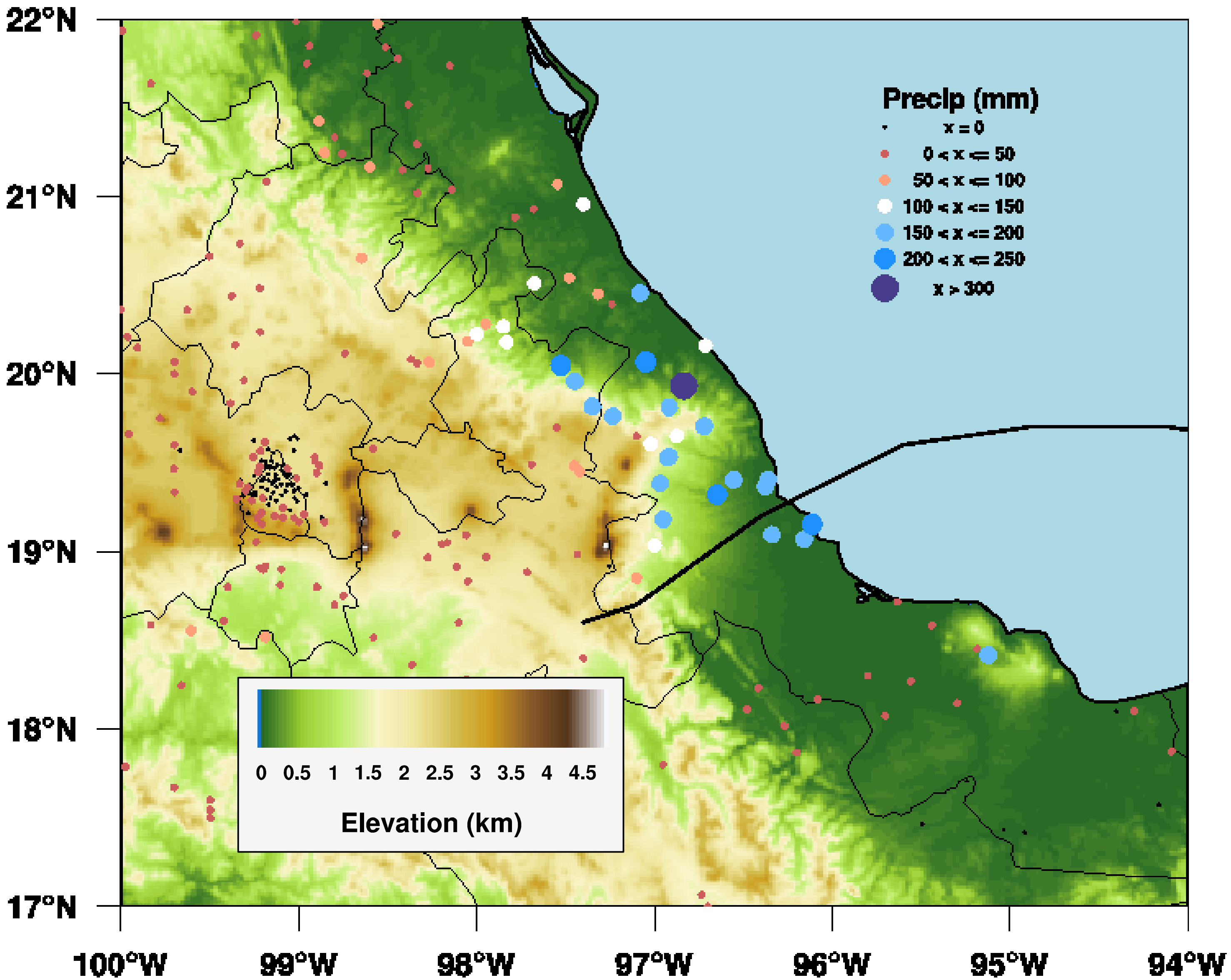




- Intense rainfall collocated with eastern edge of Mexican terrain
- Maximum rainfall measured near Misantla

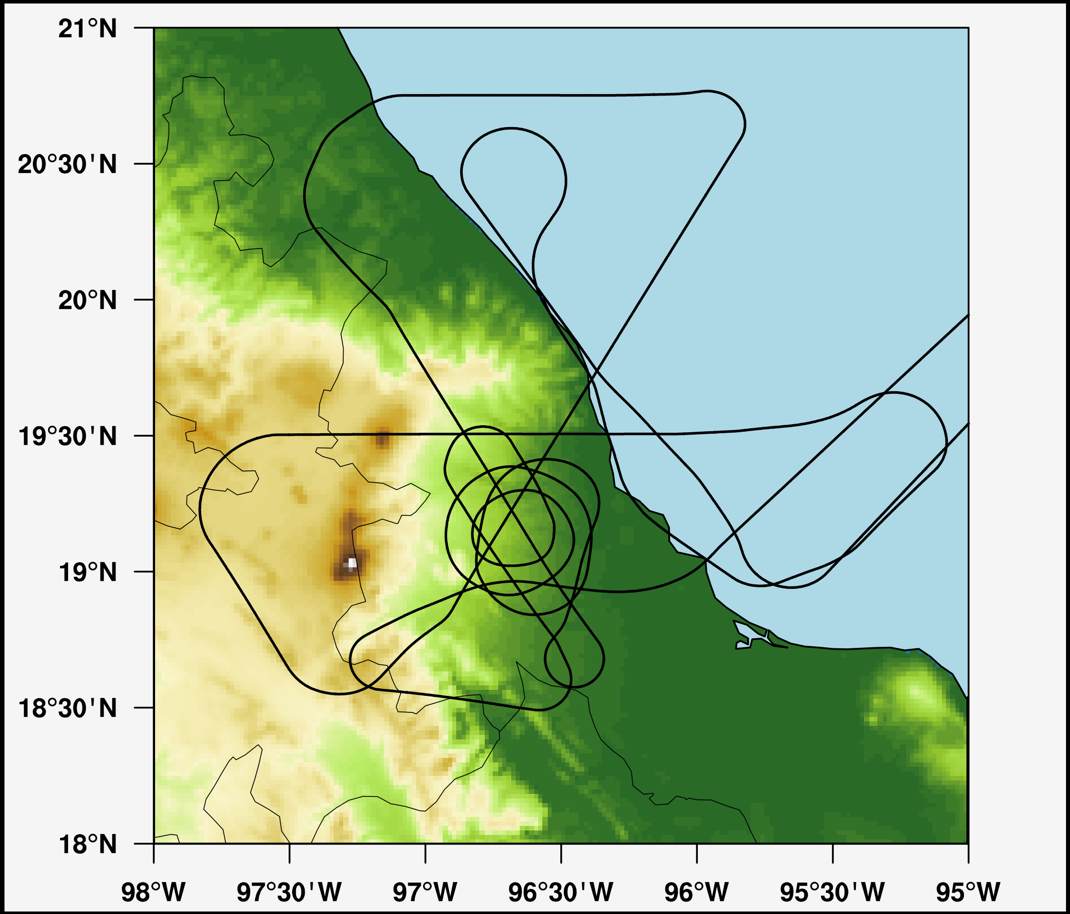
Image: David Roth, NOAA

24 Hour Precip ending 13Z on 9/18/10



NASA GRIP

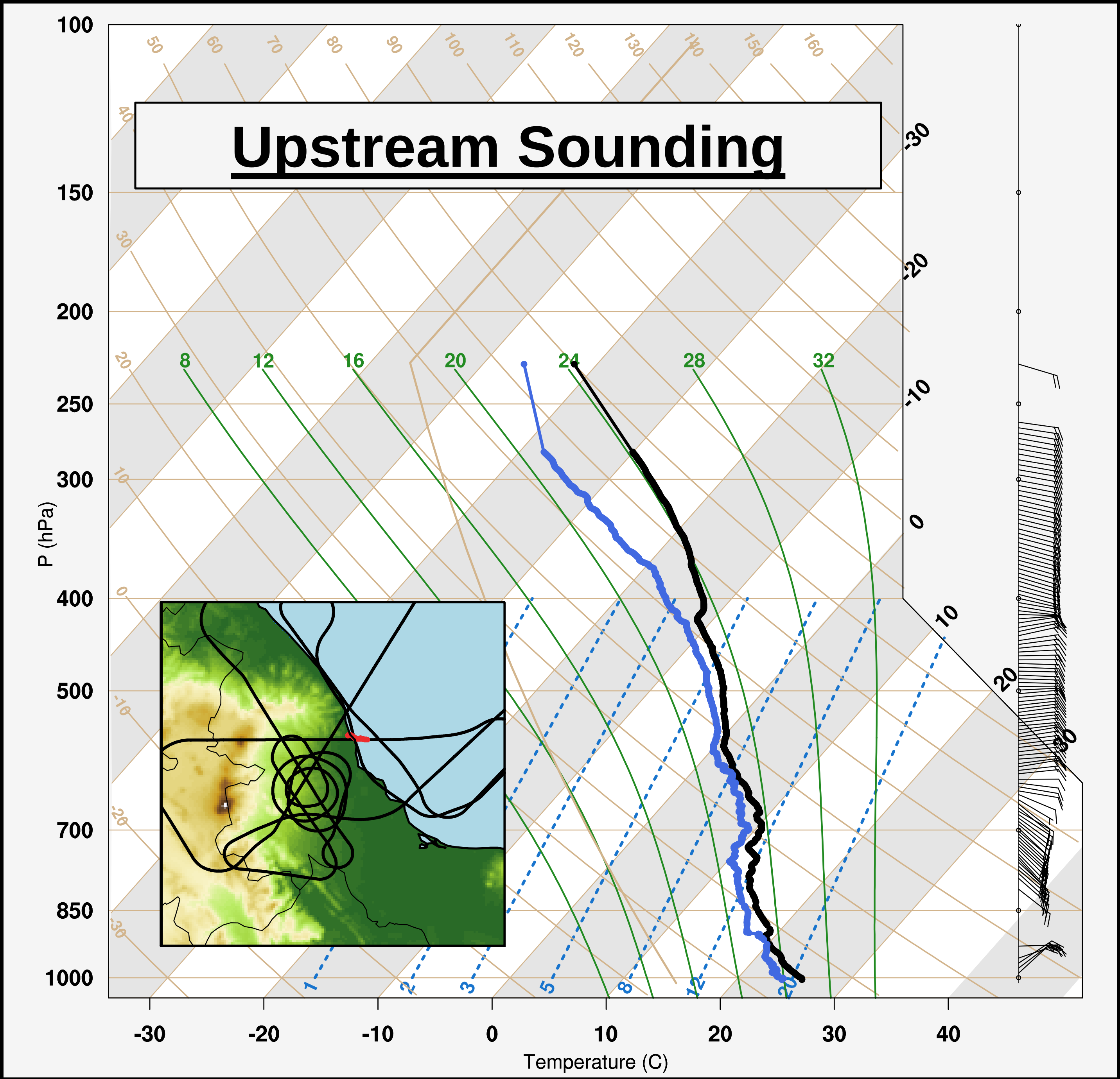
DC 8 Flight Track – 09/17/2010

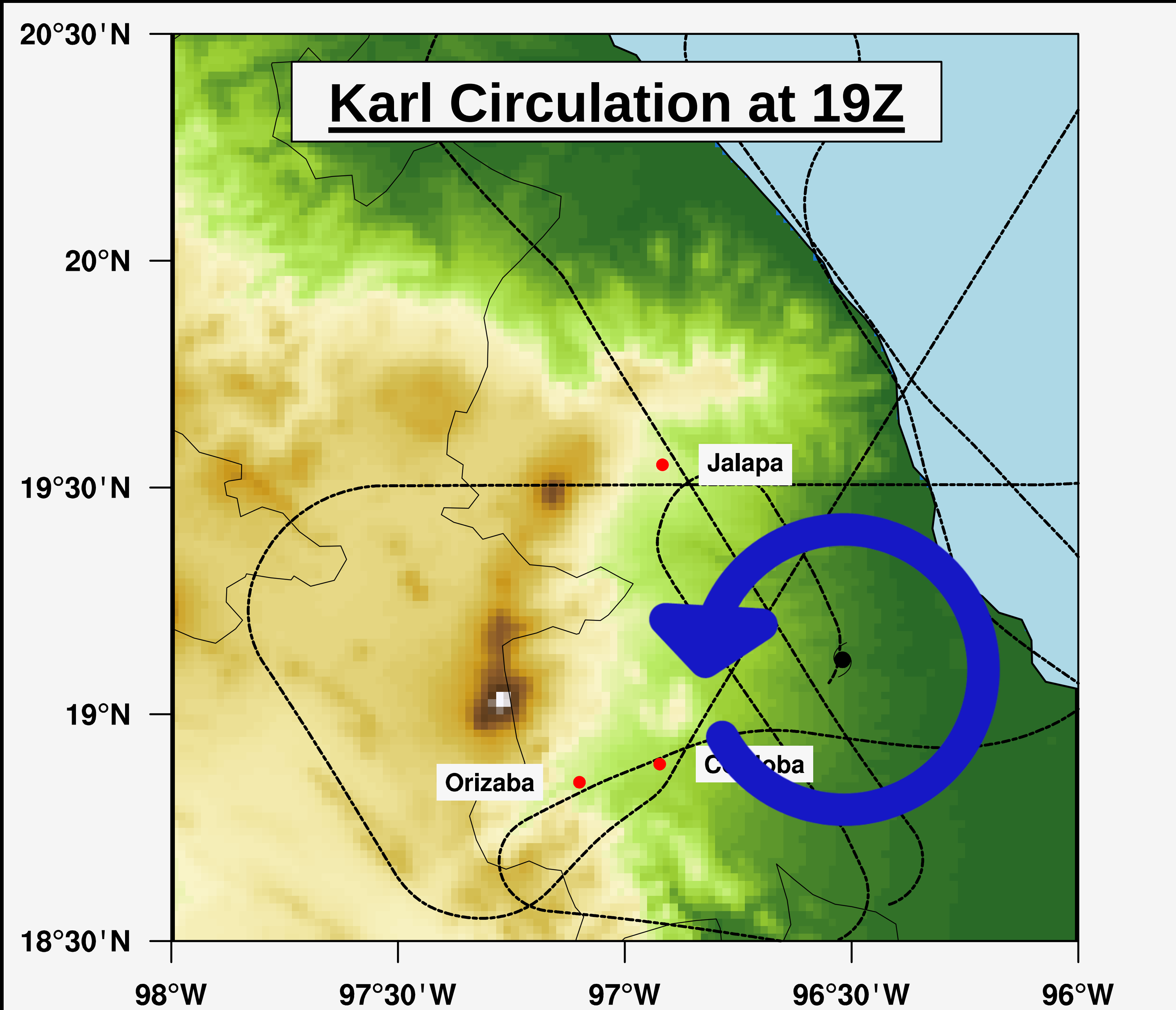


<u>Aug. / Sept. 2010</u>

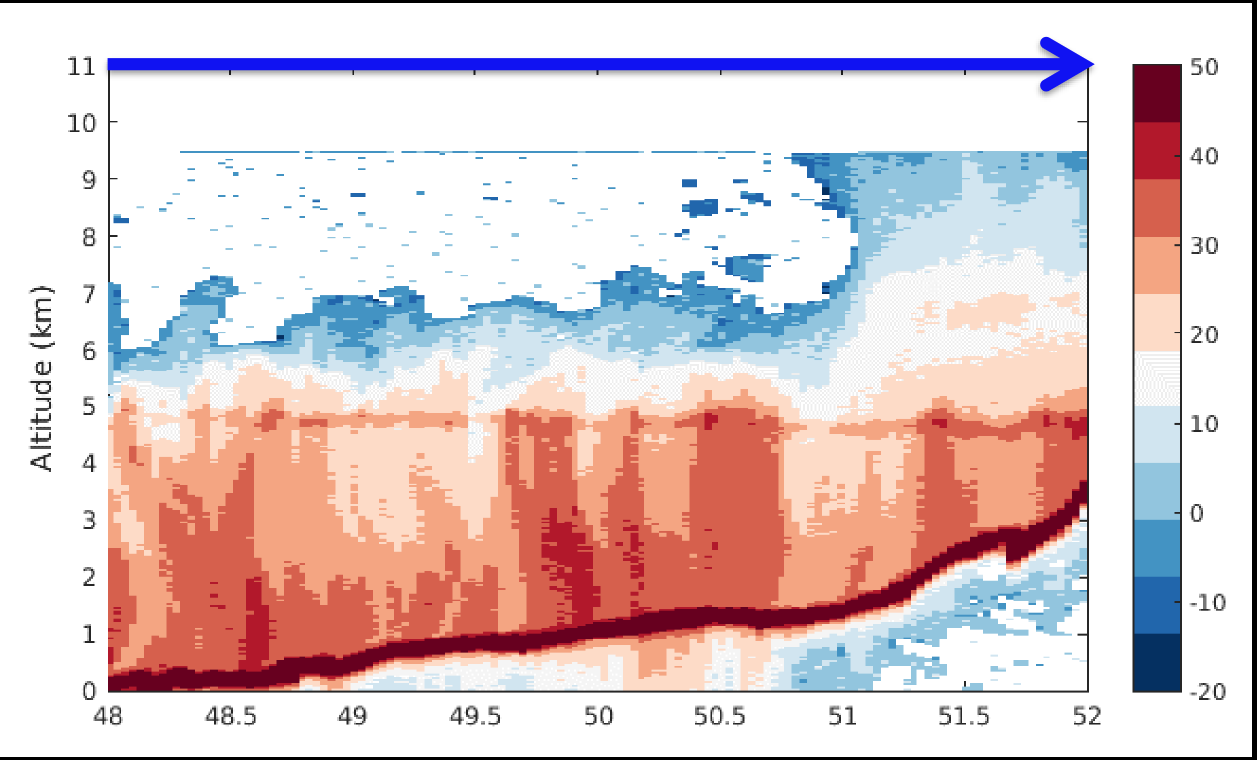
Key instrument: APR-2 radar on DC8

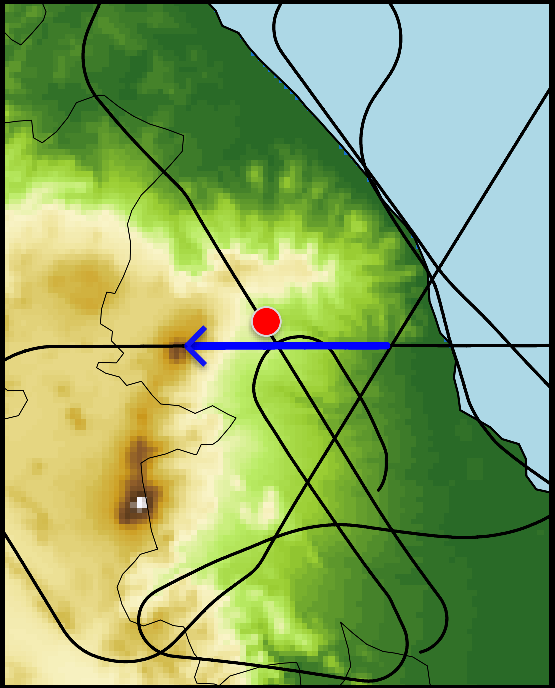
- -10 km flight level
- -Ku / Ka band
- -high resolution
- -downward pointing
- -cross-track scan


Upstream Sounding
P (hPa)
Temperature (C)
100
150
200
250
300
400
500
700
850
1000
-30
-20
-10
0
10
20
30
40
8
12
16
20
24
28
32


Karl Circulation at 19Z
Jalapa
Orizaba
20°30'N
20°N
19°30'N
19°N
18°30'N
98°W
97°30'W
97°W
96°30'W
96°W

Upslope Segment

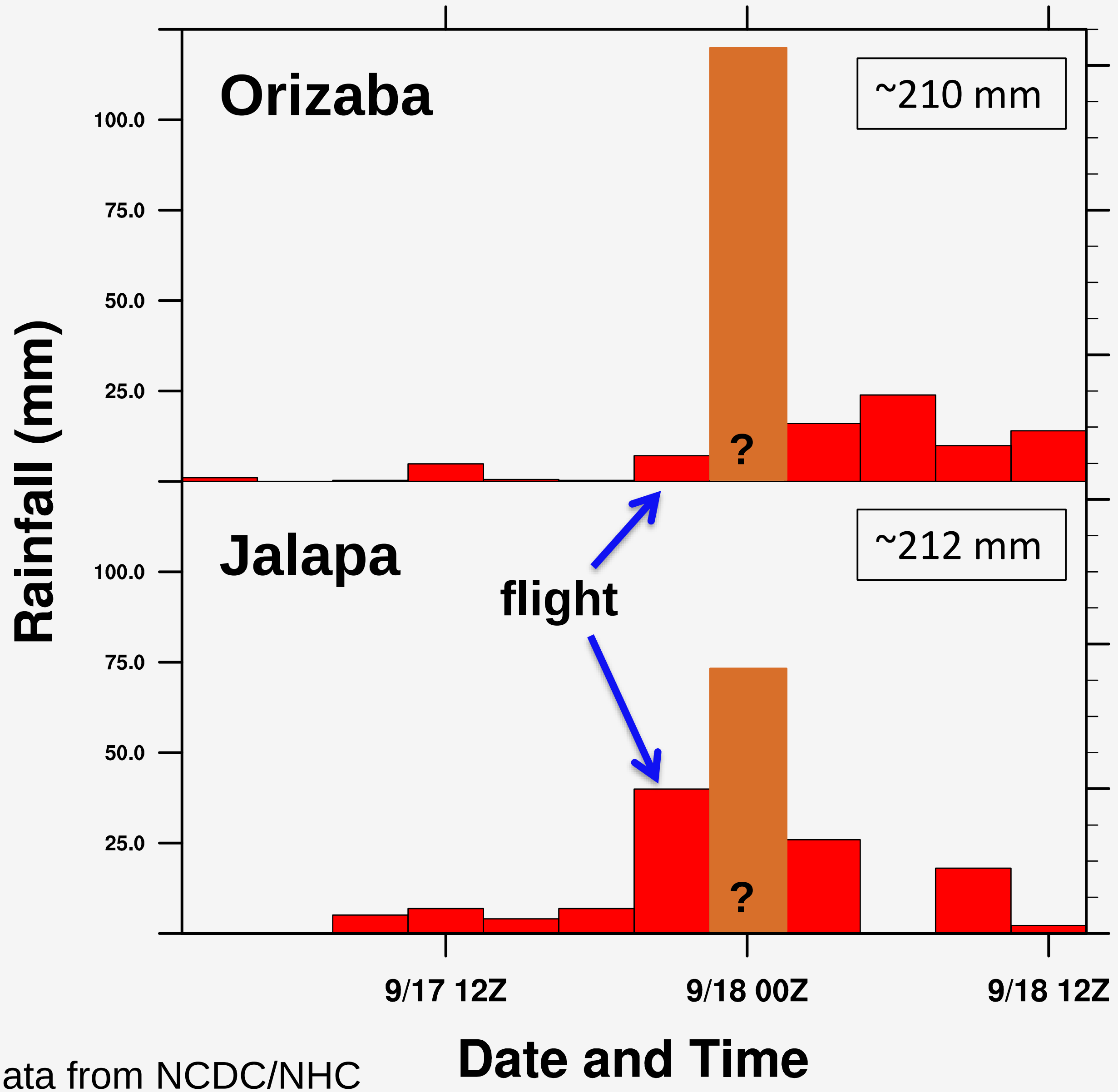




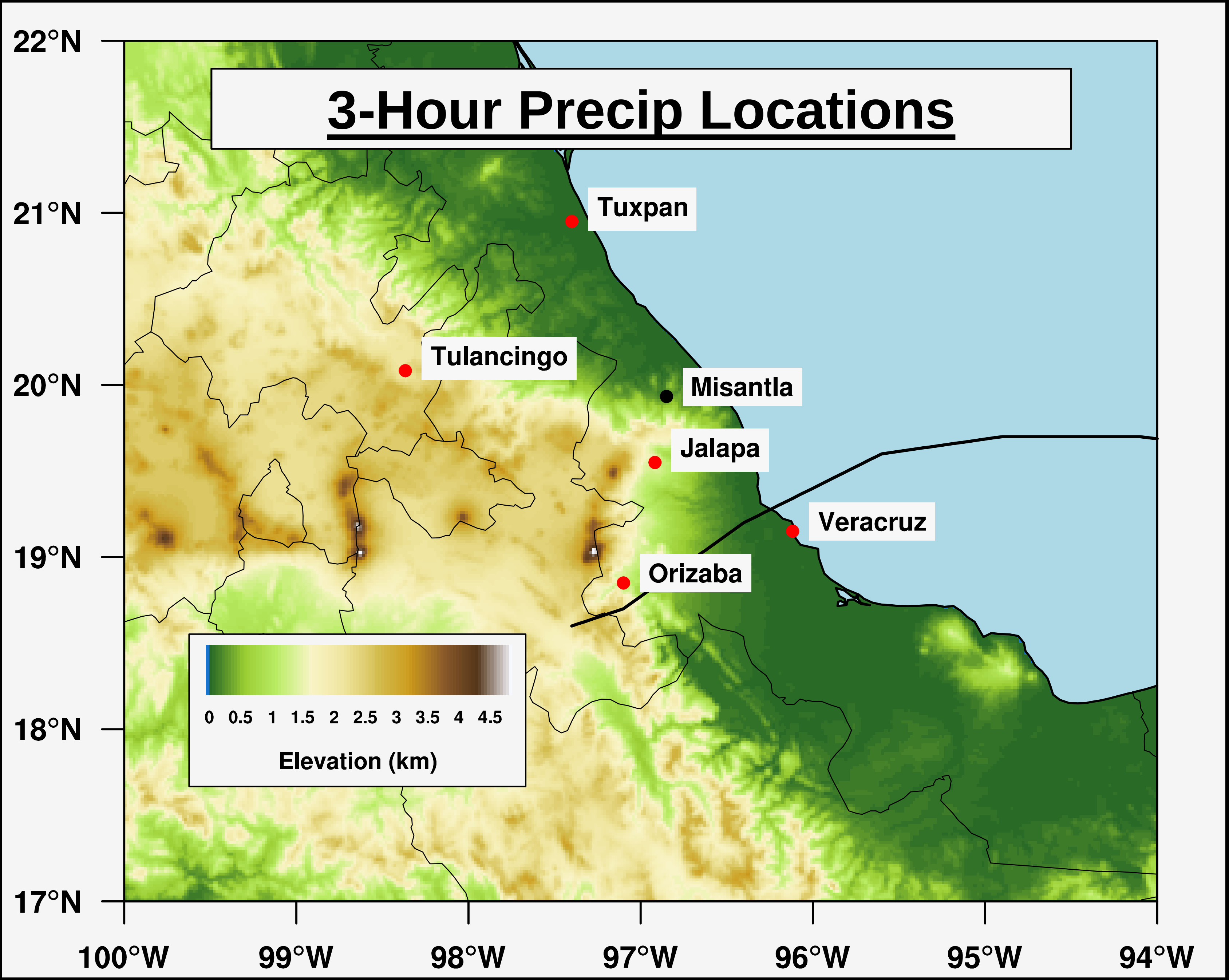
Minutes after 1800 Z

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

3-hour Rainfall Totals

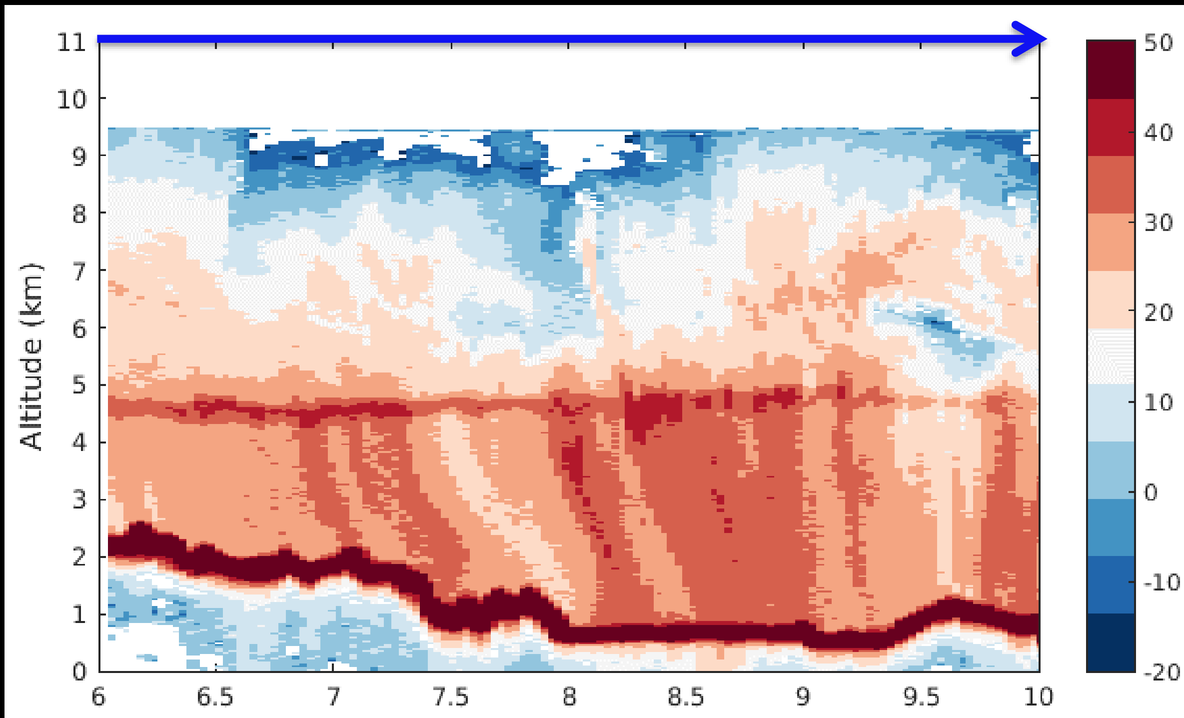


data from NCDC/NHC

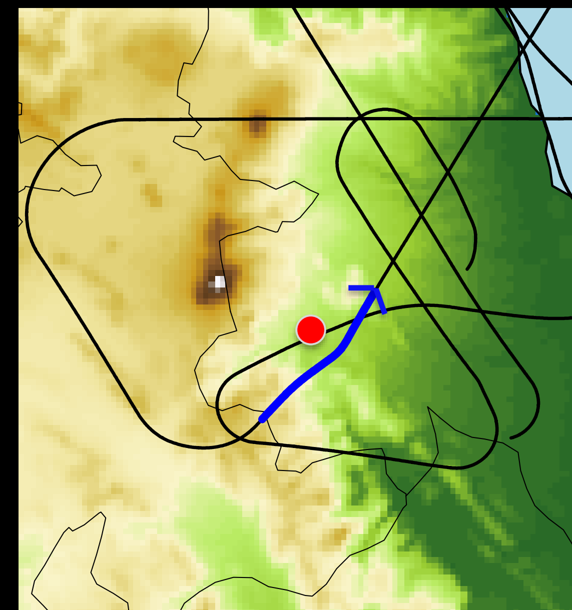


3-Hour Precip Locations
Tuxpan
Tulancingo
Misantla
Jalapa
Veracruz
Orizaba
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Elevation (km)
22°N
21°N
20°N
19°N
18°N
17°N
100°W
99°W
98°W
97°W
96°W
95°W
94°W

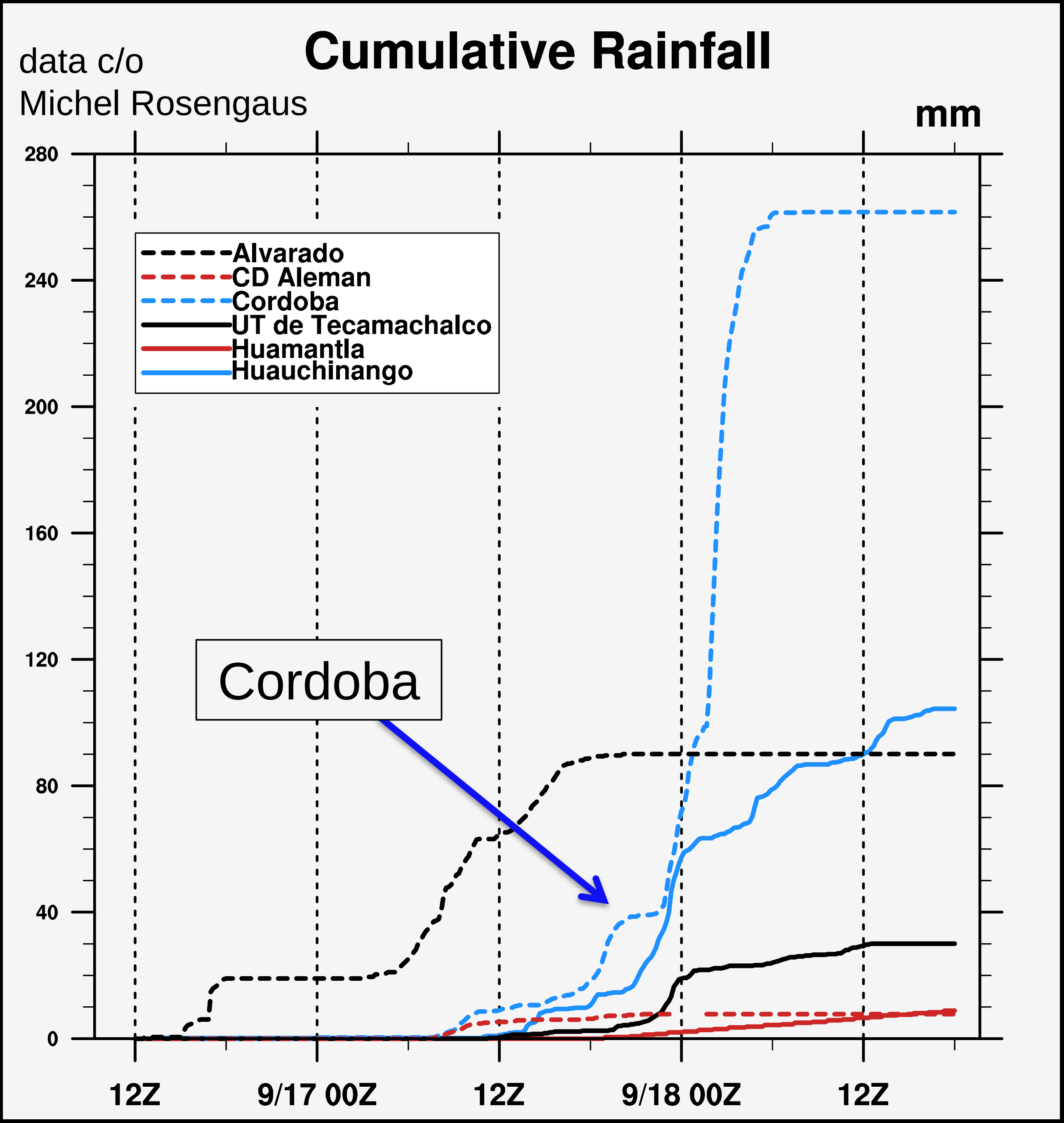
Downslope Segment



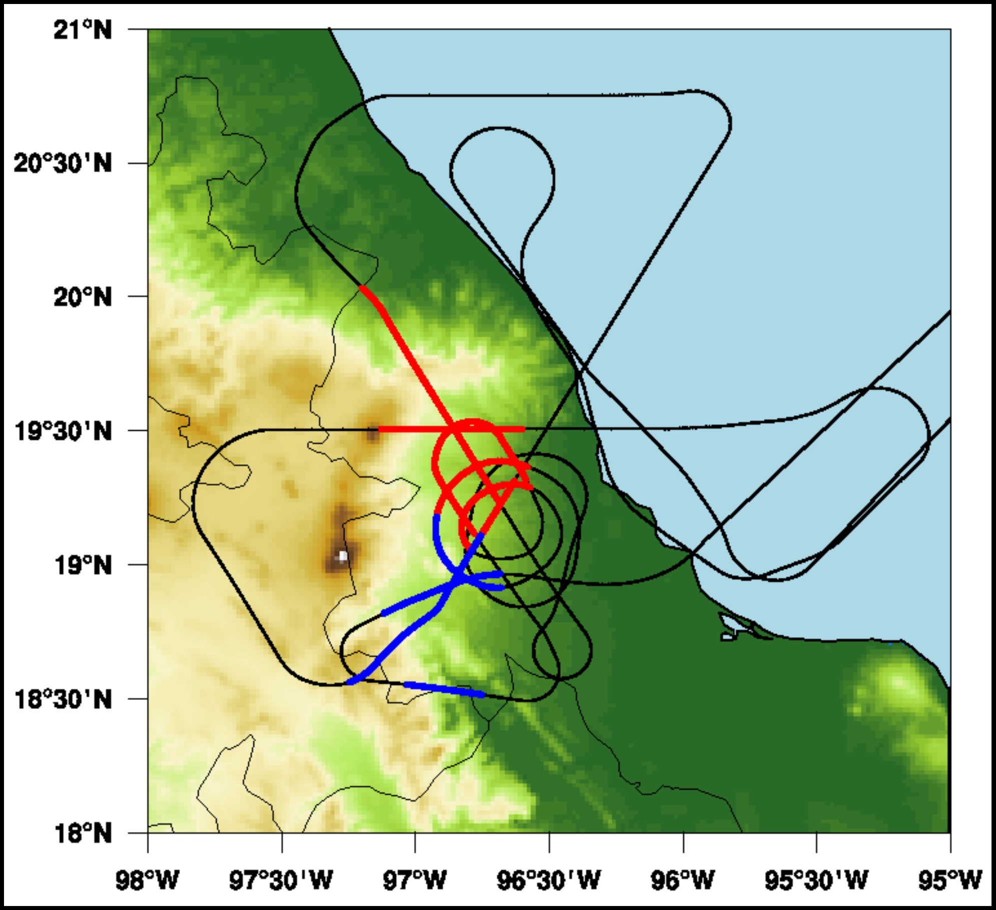
Minutes after 1900 Z



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

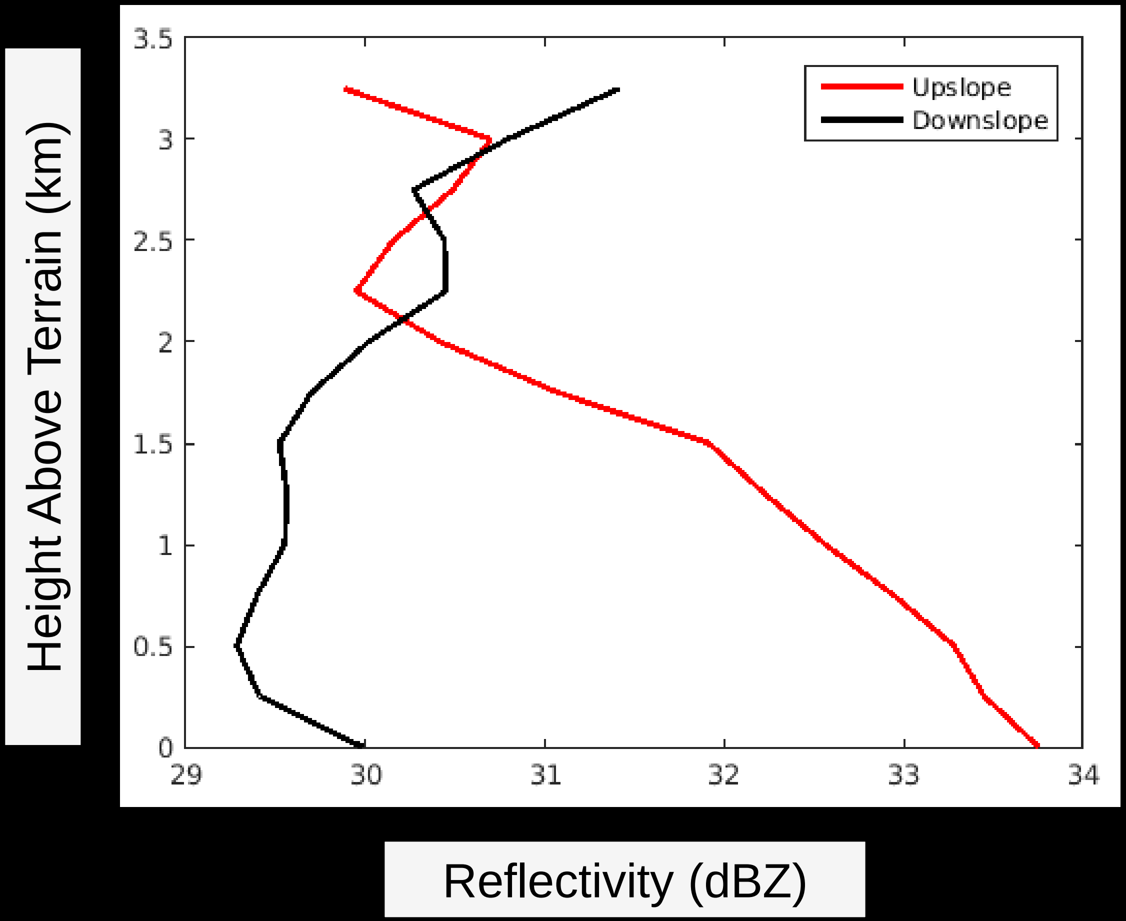

Cumulative Rainfall
data c/o
Michel Rosengaus
mm
280
240
200
160
120
80
40
0
Alvarado
CD Aleman
Cordoba
UT de Tecamachalco
Huamantla
Huauchinango
Cordoba
12Z
9/17 00Z
12Z
9/18 00Z
12Z

Upslope and Downslope Segments

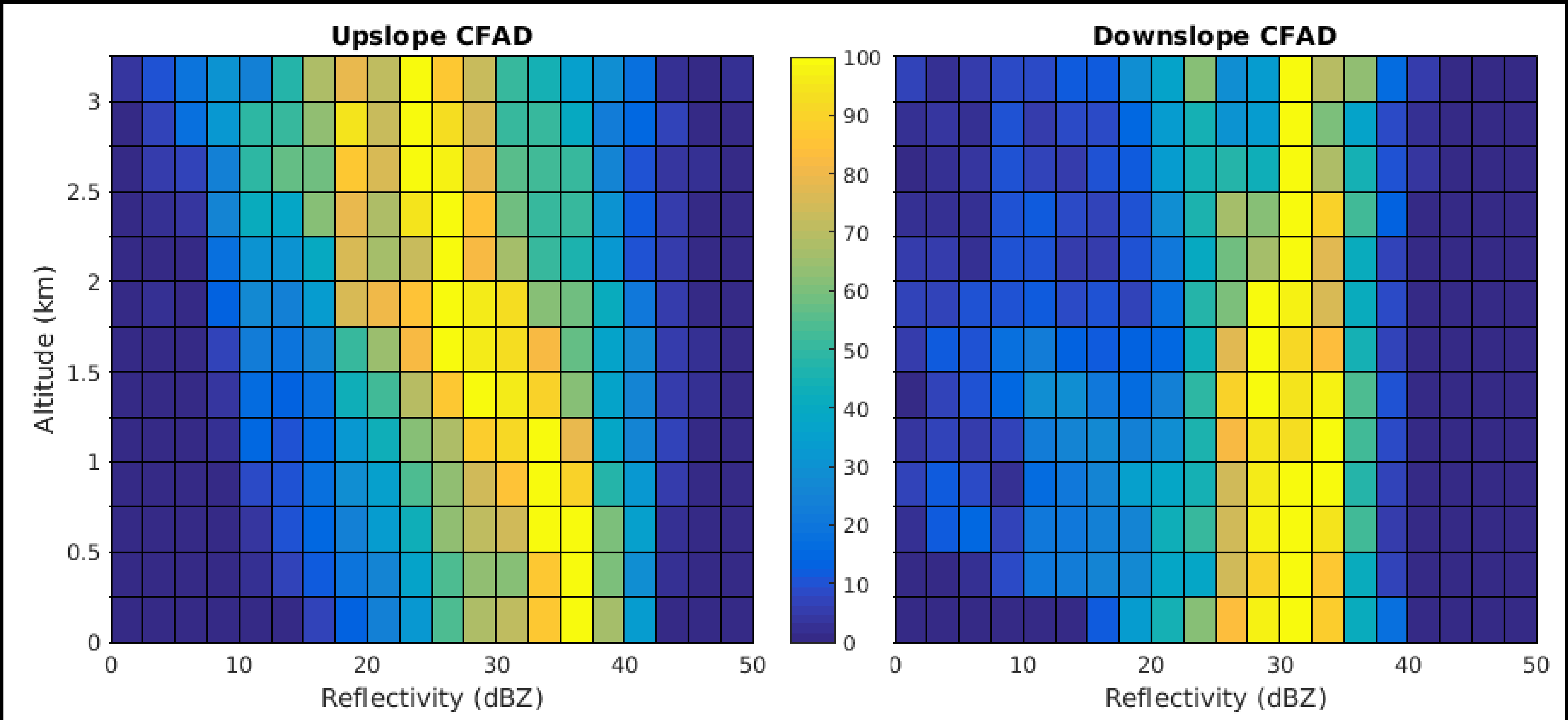


Compare reflectivity profiles for upslope and downslope flight legs

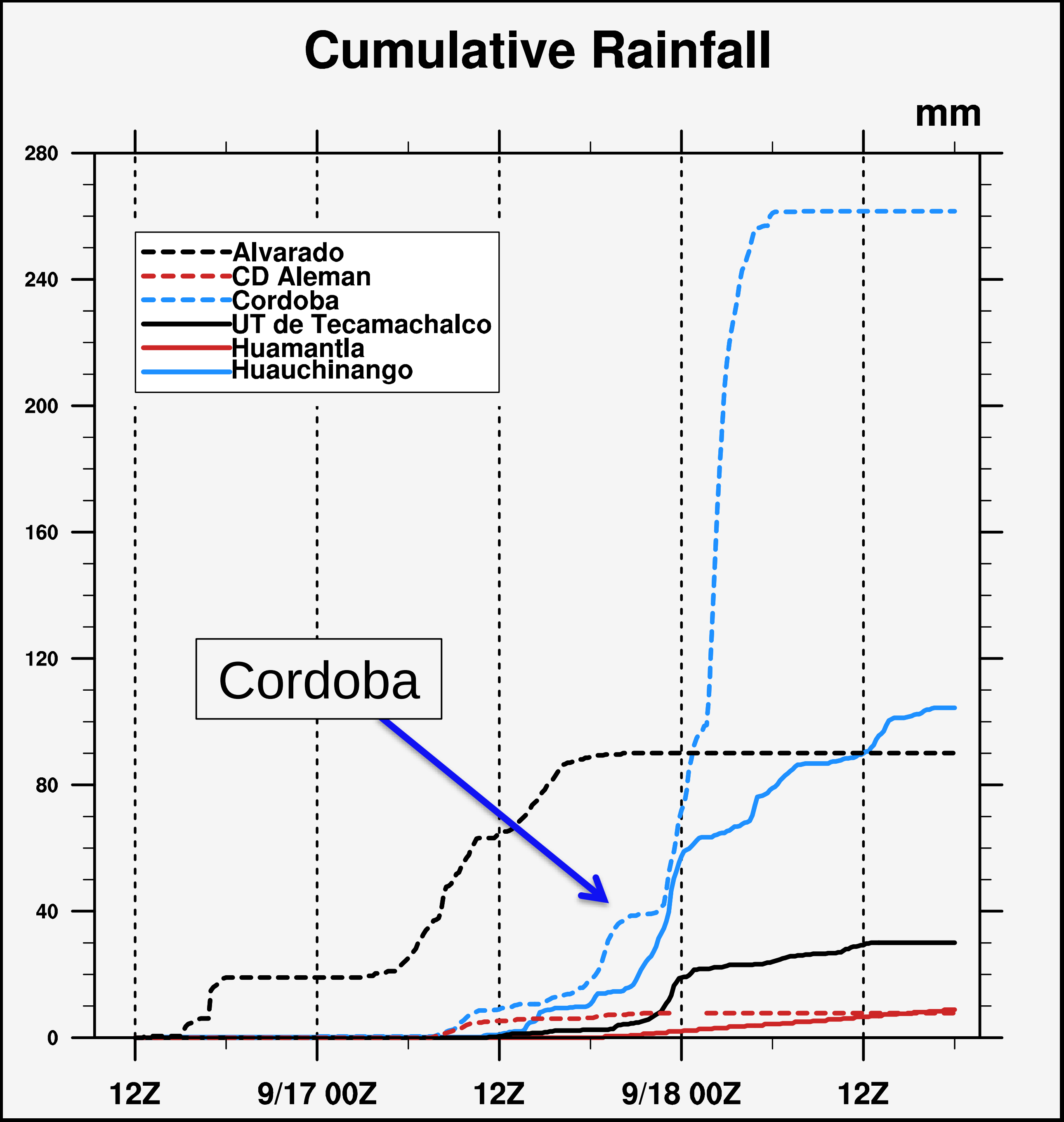
Removed surface and beams likely to have suffered attenuation



Mean profile shows strong enhancement in upslope segments, downslope segments remain fairly constant towards surface

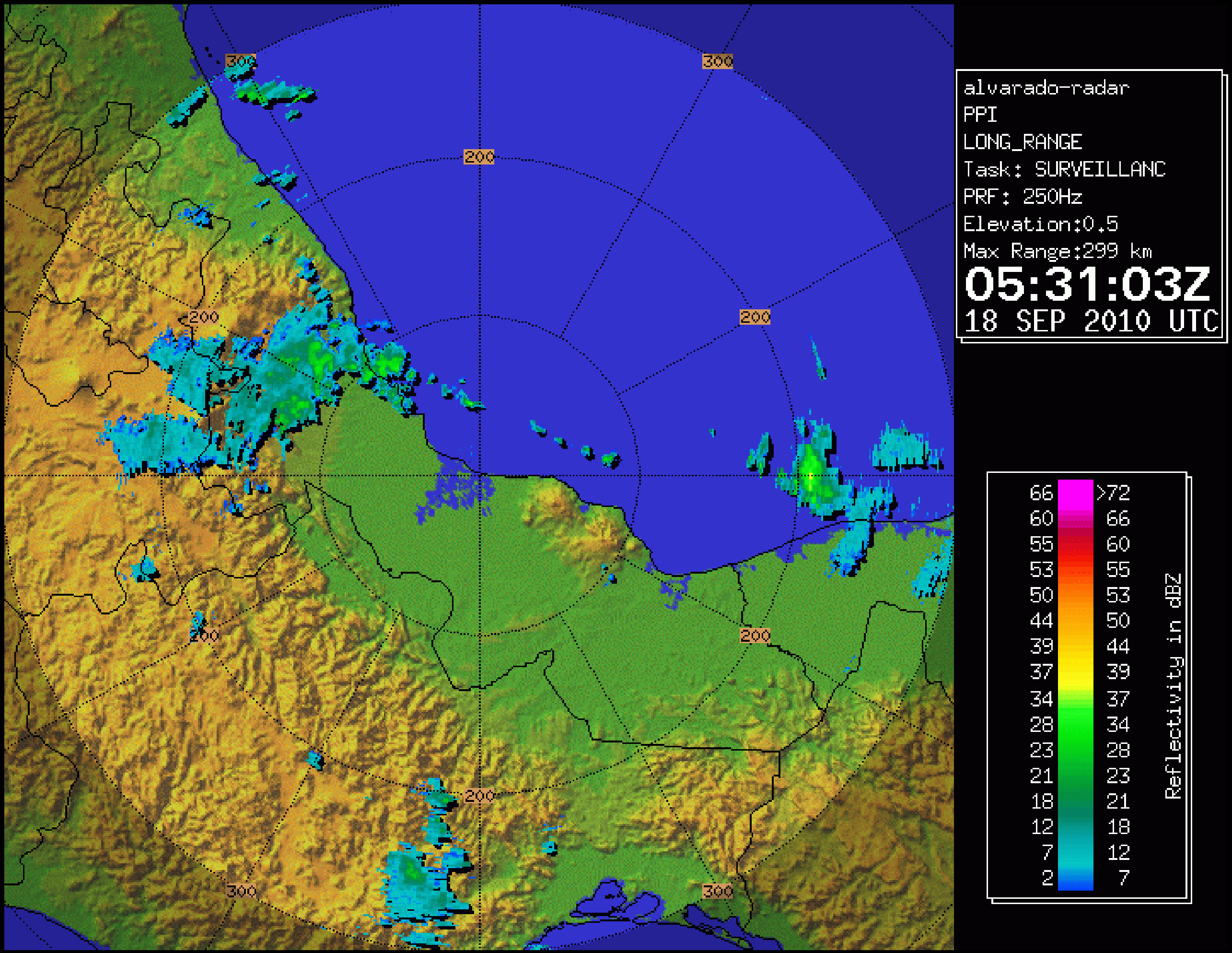


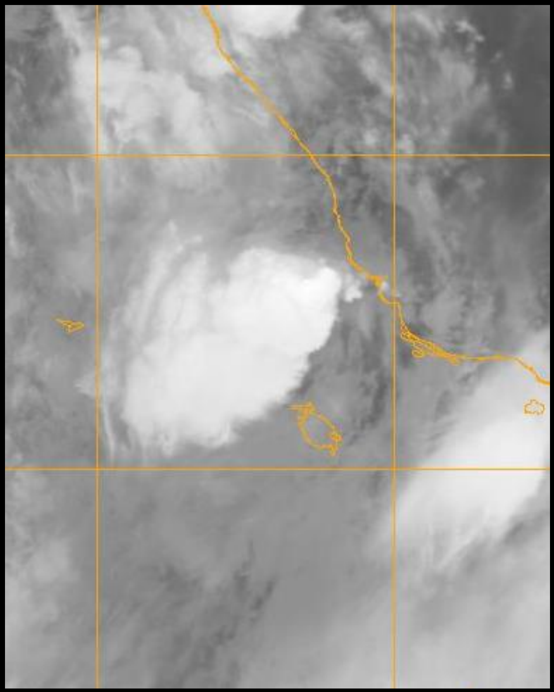
Distributions consistent with the mean profile



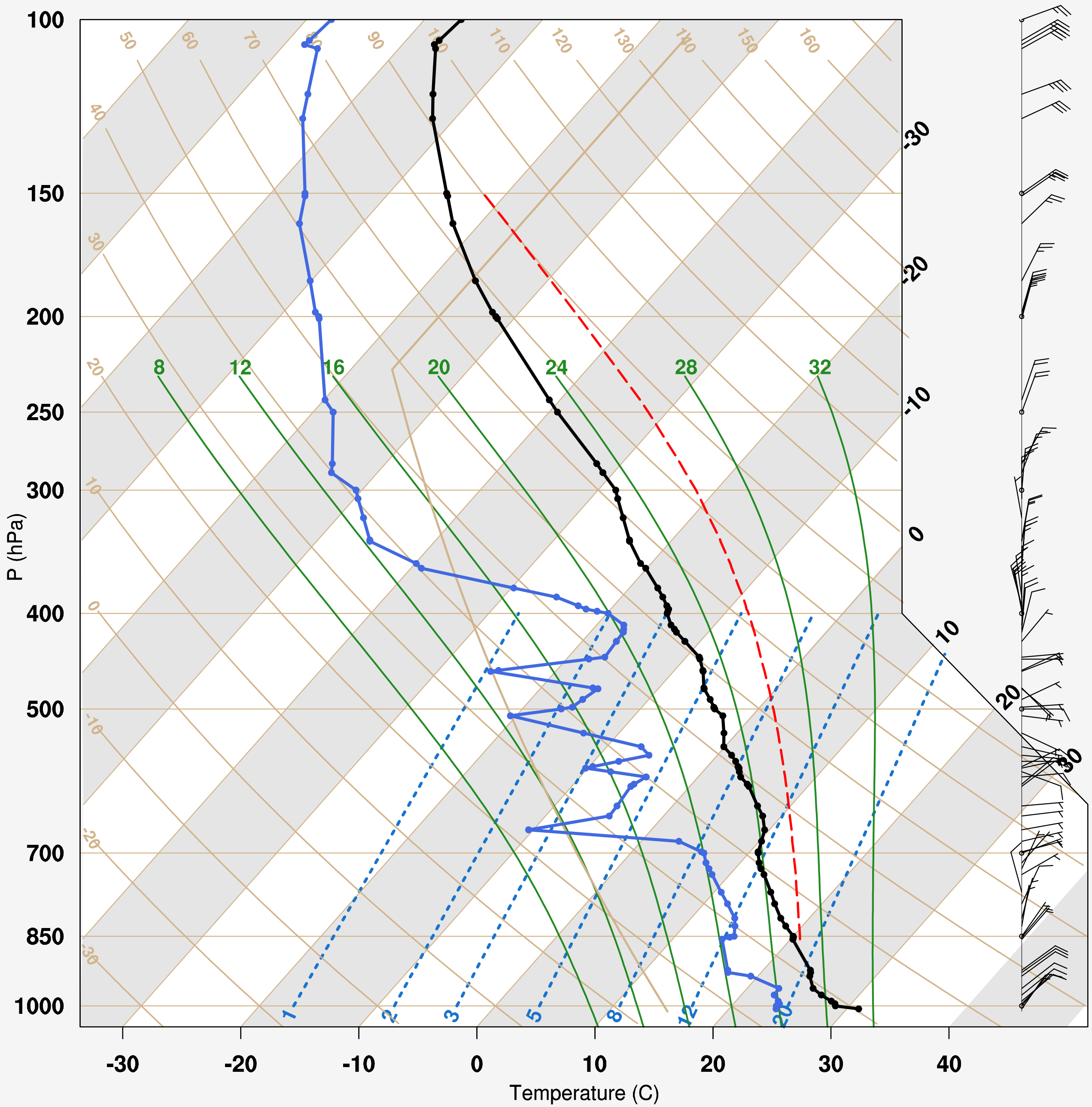
Cumulative Rainfall
mm
280
240
200
160
120
80
40
0
Alvarado
CD Aleman
Cordoba
UT de Tecamachalco
Huamantla
Huauchinango
Cordoba
12Z
9/17 00Z
12Z
9/18 00Z
12Z

0530Z Convection





Veracruz 9/18 00Z

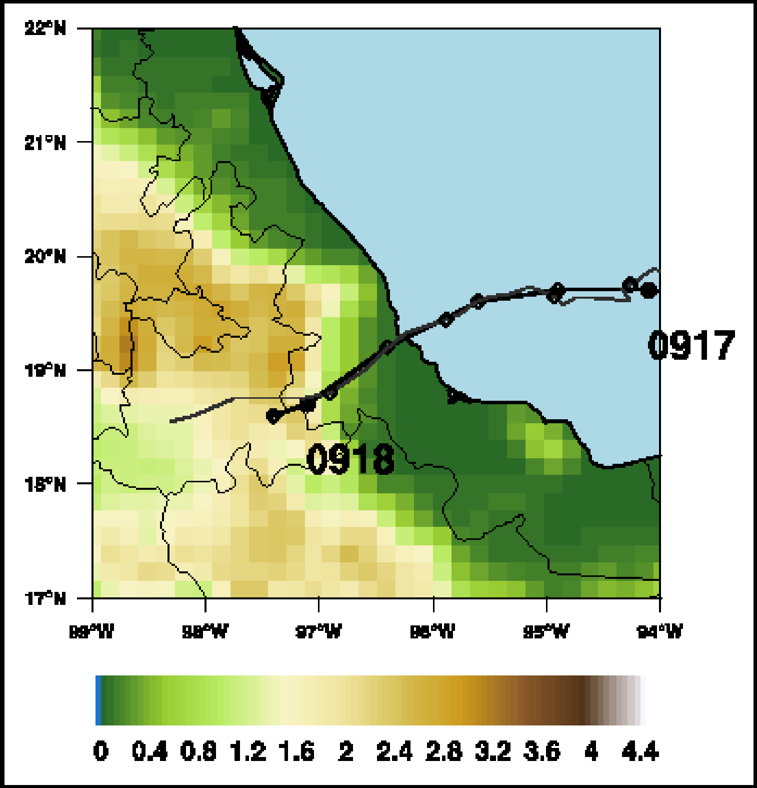


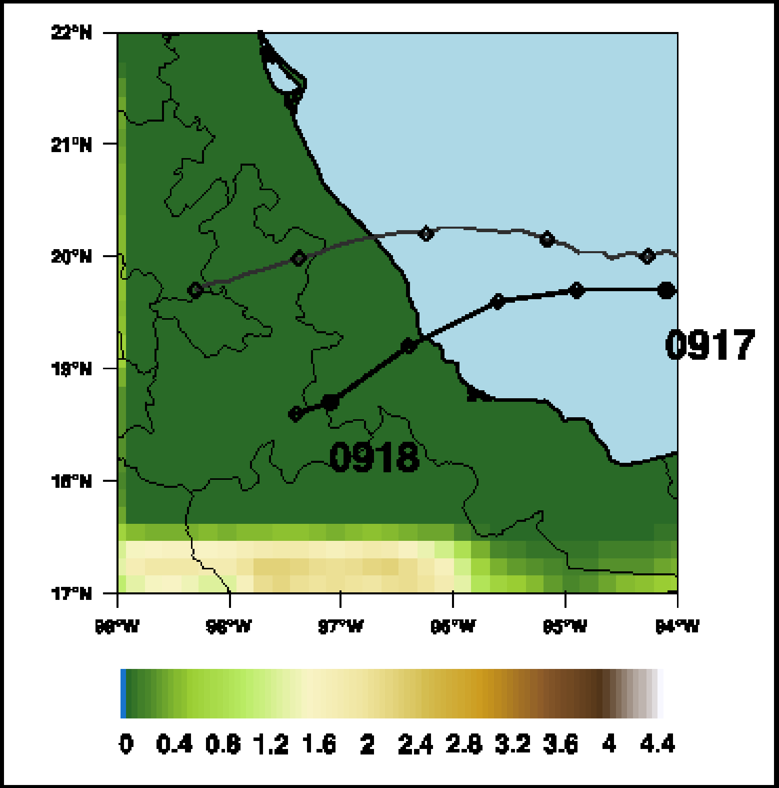
Terrain Modification Experiments

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

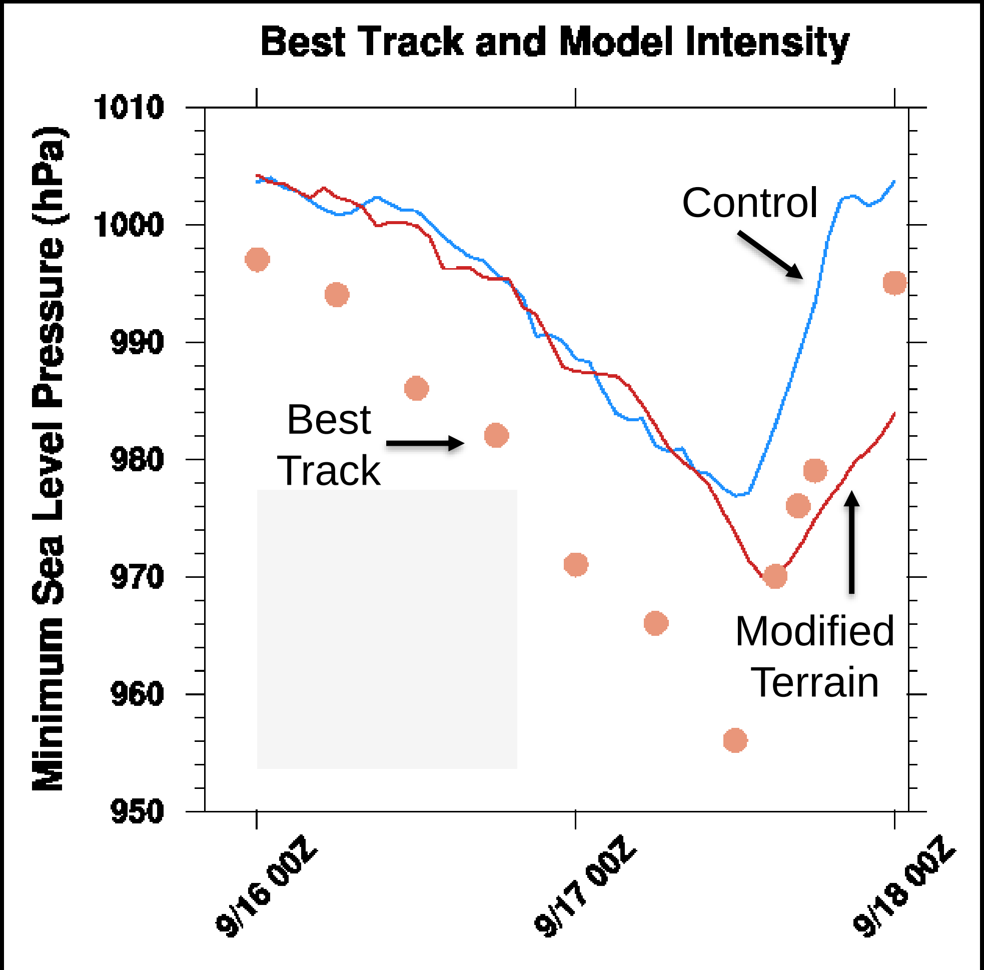
Observed and Simulated Tracks





Control run: traces observed track (storm motion too fast).
Flat terrain run: track shifts northward.

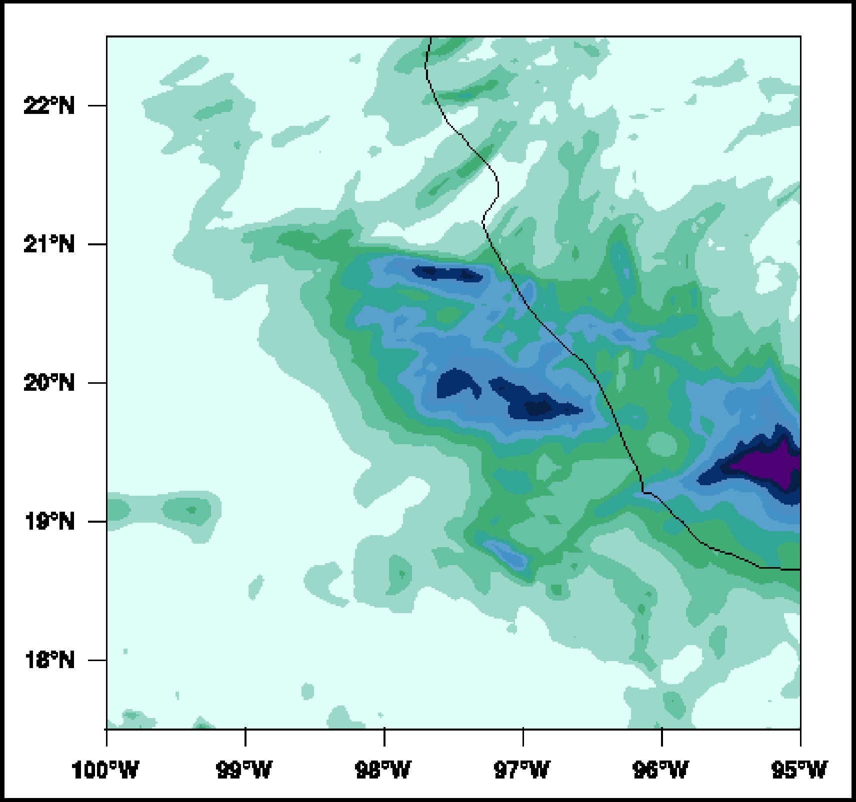
Modeled Intensity

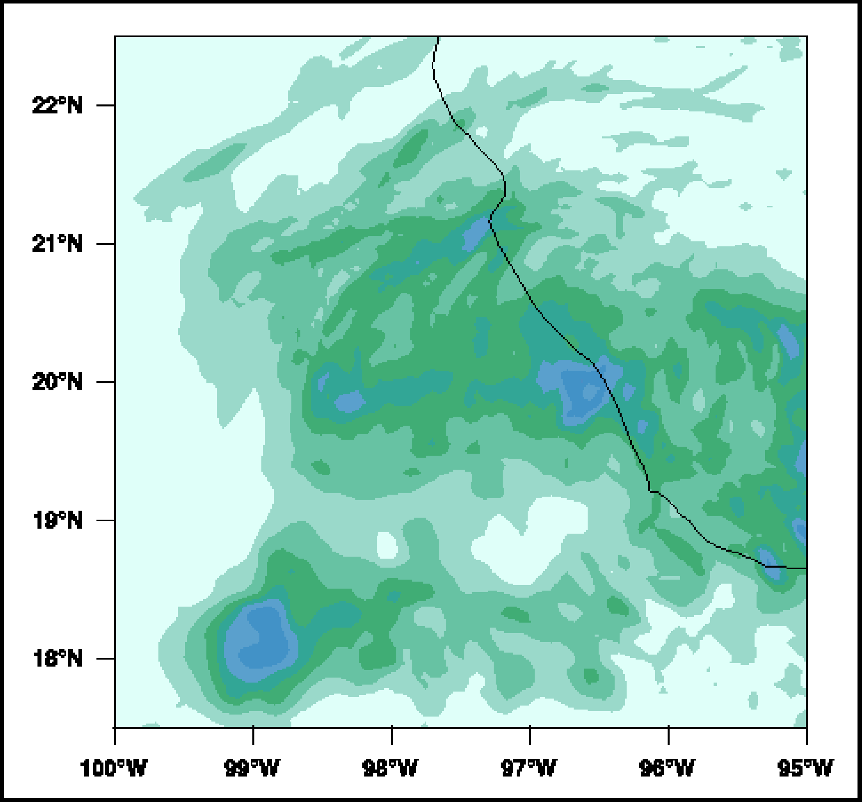


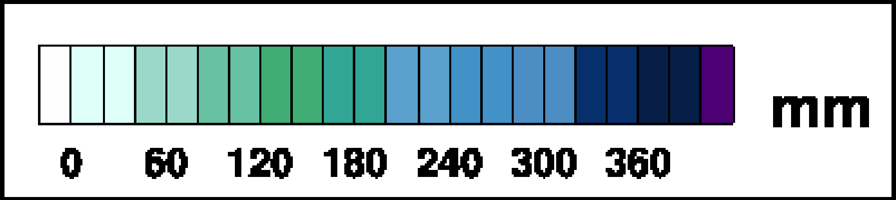
Karl's intensity is underestimated, but general trend is captured

Modified terrain run reaches deeper intensity and does not drop off as quickly

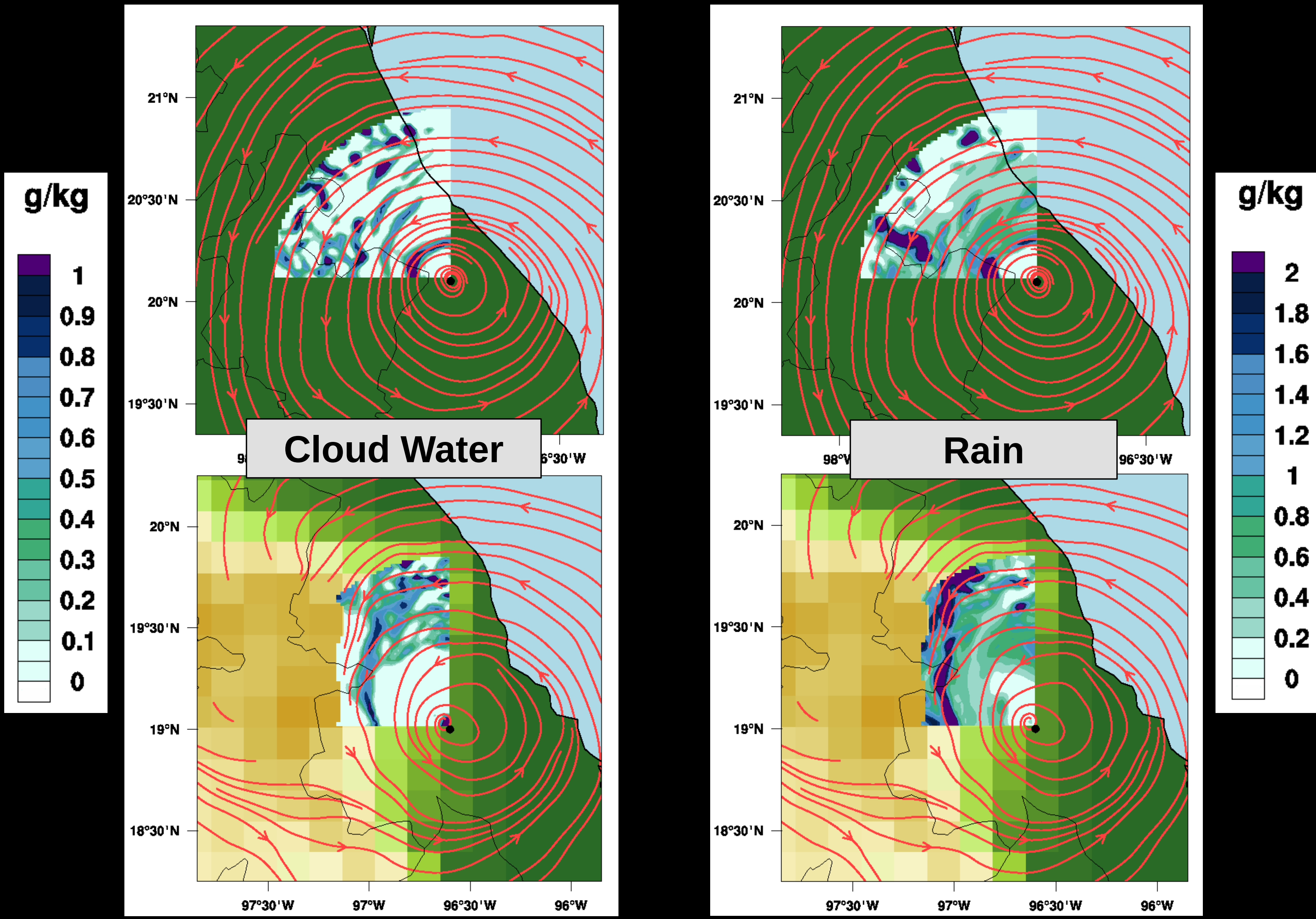
Accumulated Precipitation



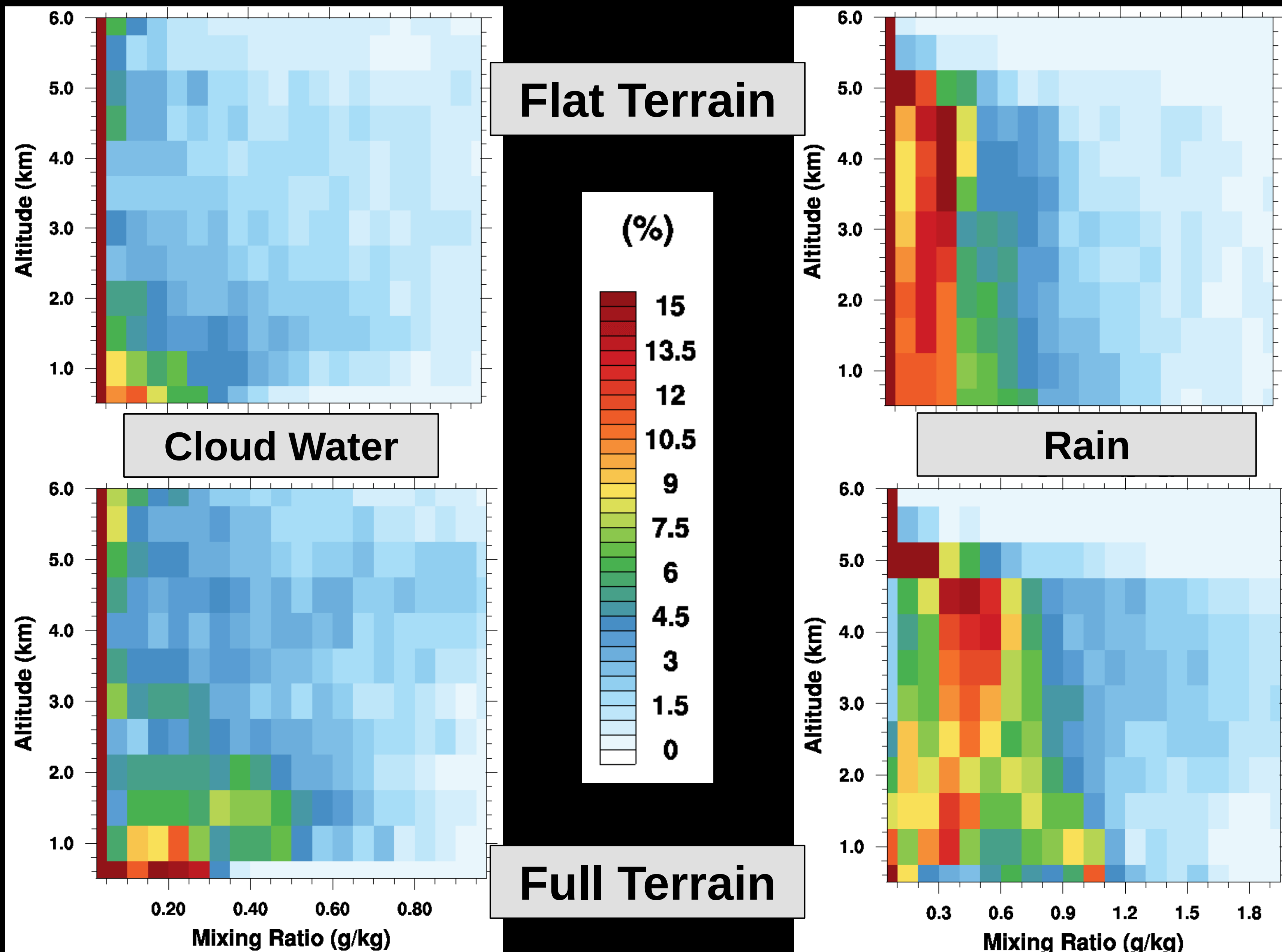




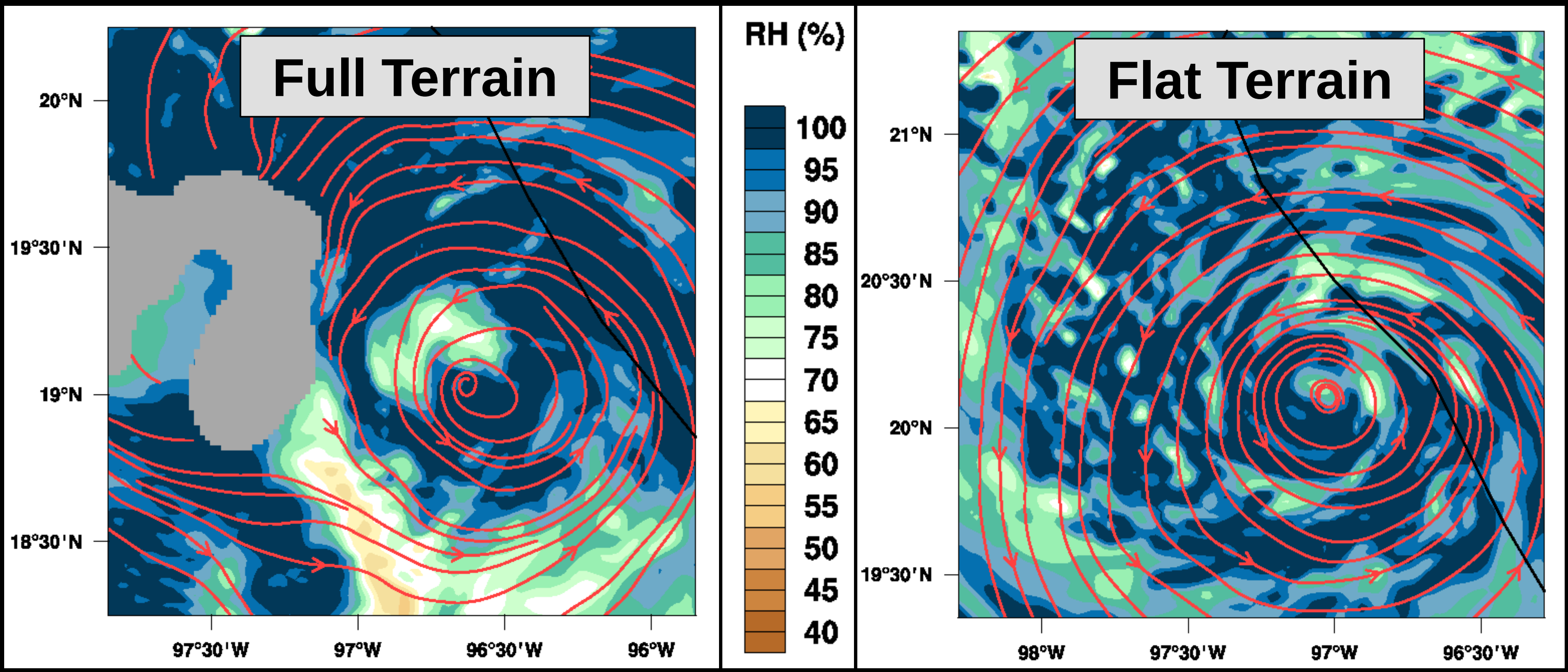
2.5 km Mixing Ratio and Streamlines



Mixing Ratio Frequencies



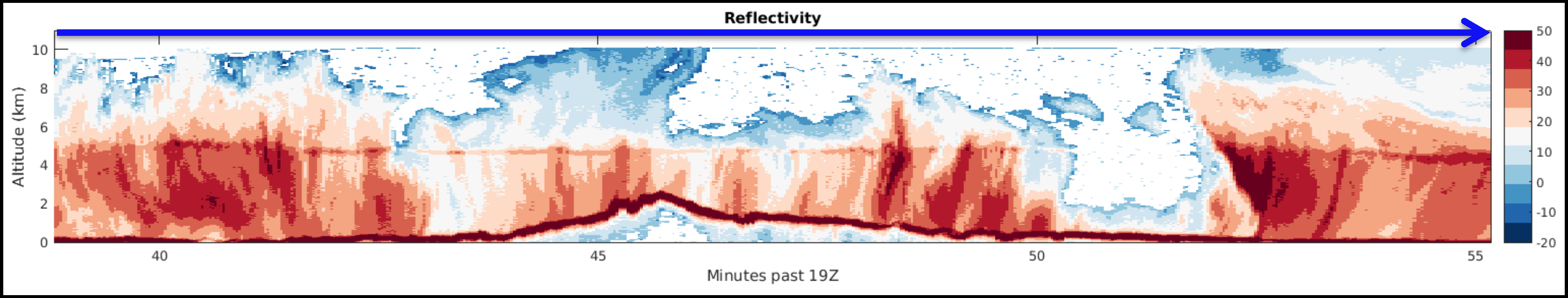
Relative Humidity and Streamlines

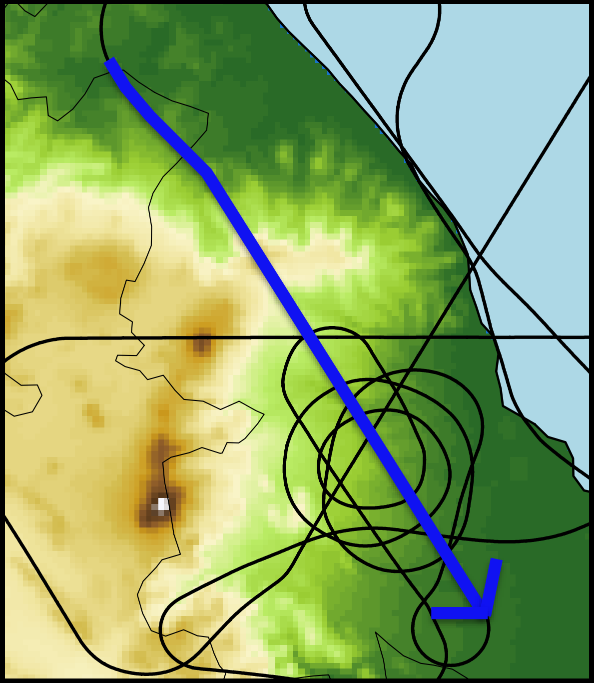


CONCLUSIONS

- 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

A larger view...





Background precipitation important to determining enhancement

Landfall complicates matters by removing energy source