The Hurricane Rainband and Intensity Change Experiment (RAINEX): Observations and Modeling of Katrina and Rita

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In the eye of Katrina

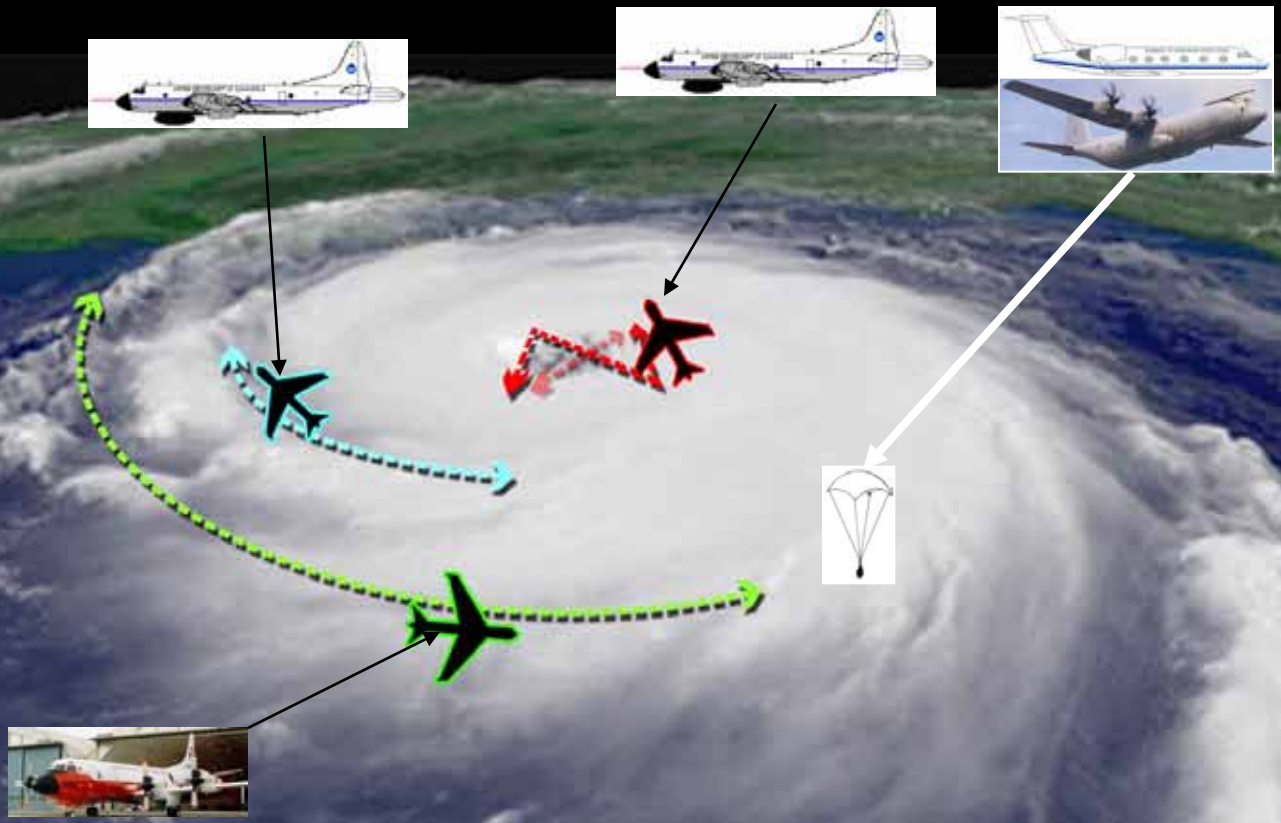
Factors Controlling Intensity Change

- Inner core (eye and eyewall) dynamics
- Environmental conditions, including vertical wind shear, moisture distribution, and sea surface temperature (upper ocean heat content), etc.

RAINEX Science Objectives

- **Use airborne observations to examine simultaneously the dynamic and thermodynamic *structures* of hurricane inner core and outer rainband regions where the positive potential vorticity associated with deep convective cores are located.**

- **Use numerical model to investigate the *interactions* of the rainbands and primary hurricane vortex circulation and their role in hurricane intensity change.**



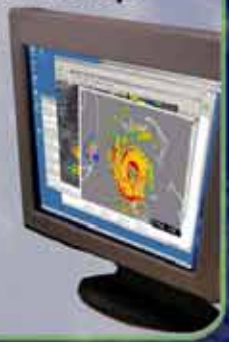
Collecting Data

Parachuting instruments called dropsondes are released from airplanes and record

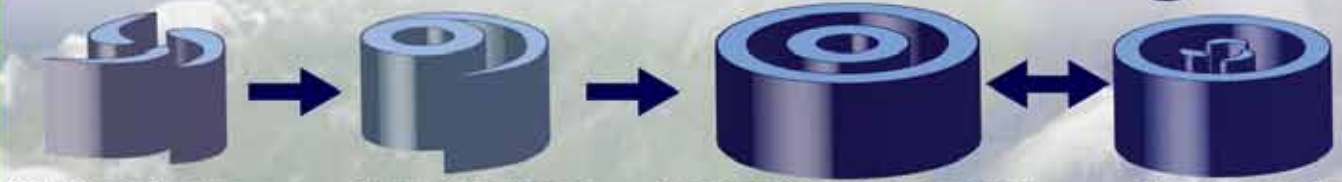
- air pressure
- temperature
- altitude
- humidity
- and more...

Analyzing Data

Gathered data will be used to develop models to better predict hurricane intensity.



How Hurricanes Gain Strength



Hurricane begins as tropical storm

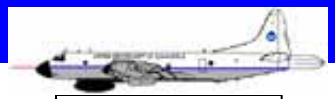
Eyewall forms as storm intensifies

Concentric eyewalls appear as the hurricane is the most intense

Inner eyewall breaks down and storm weakens

Simplified RAINEX Data Flow






C130 / G-IV

Piggy

Kermit

NRL/P3

air

ground

RSMAS
Science Operation Center

NHC

HRD

NCAR/ATD

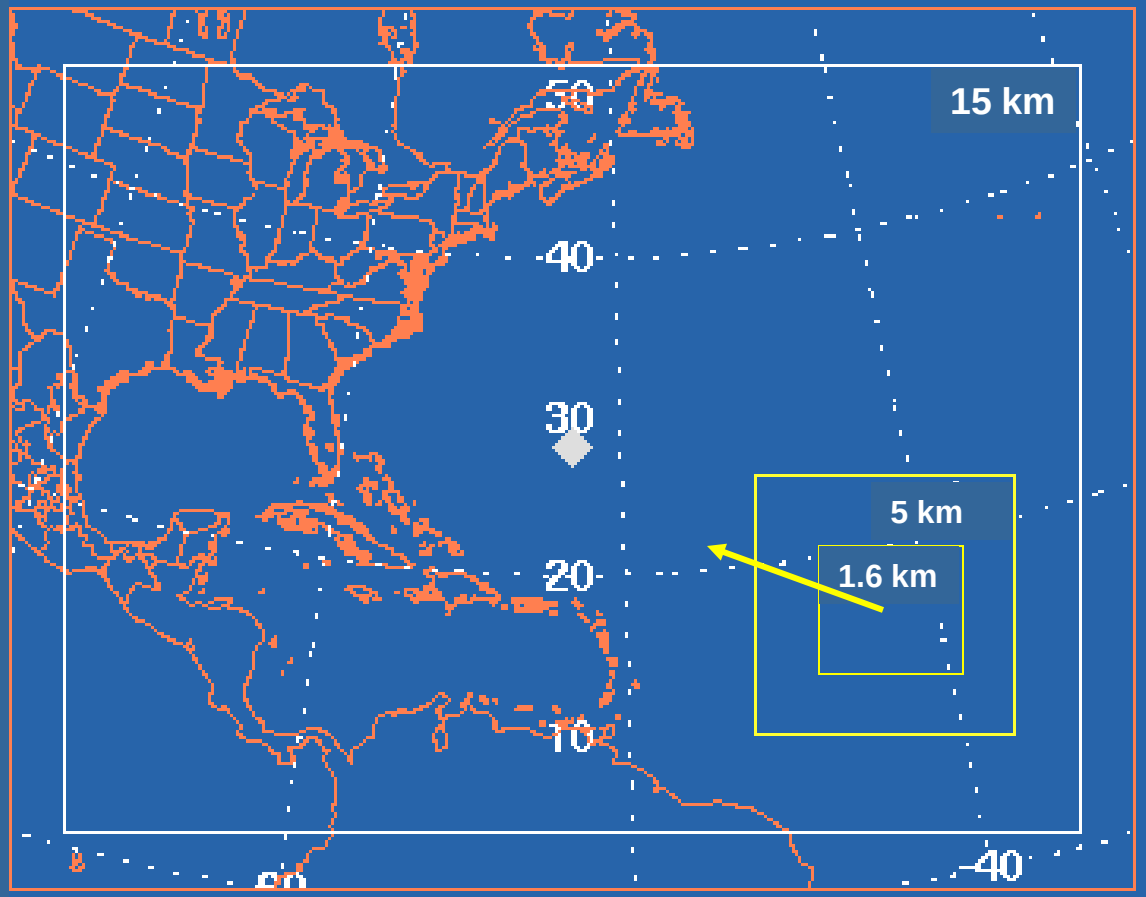
UCAR/JOSS

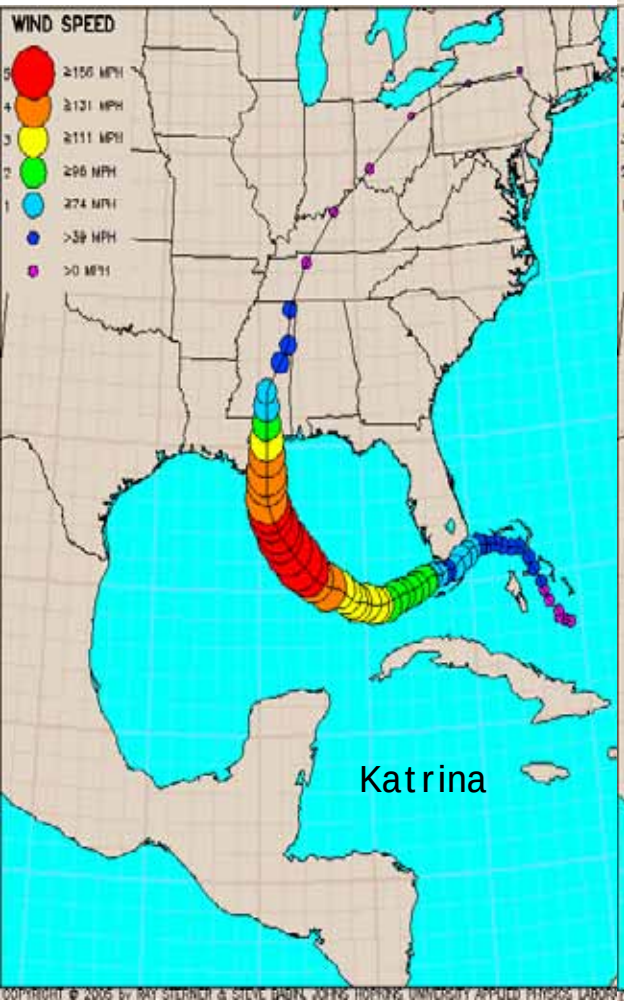
IOP: August-September 2005

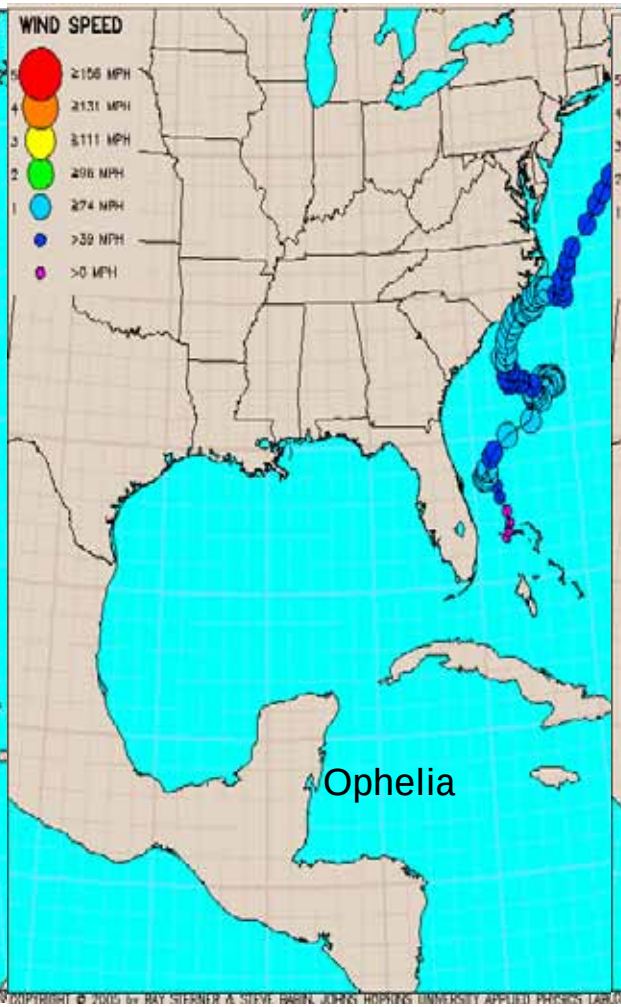
High-Resolution Multi-nested Vortex-Following Numerical Models at University of Miami:

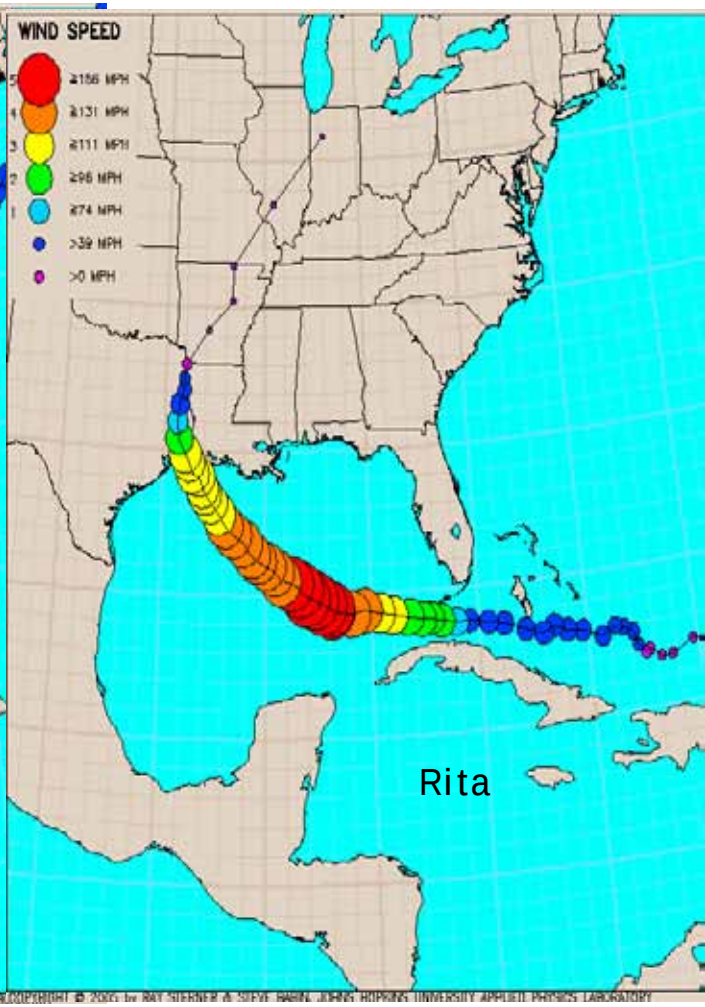
- UM/RSMAS Coupled Atmos-Wave-Ocean Model
- Weather Research and Forecast (WRF) Model

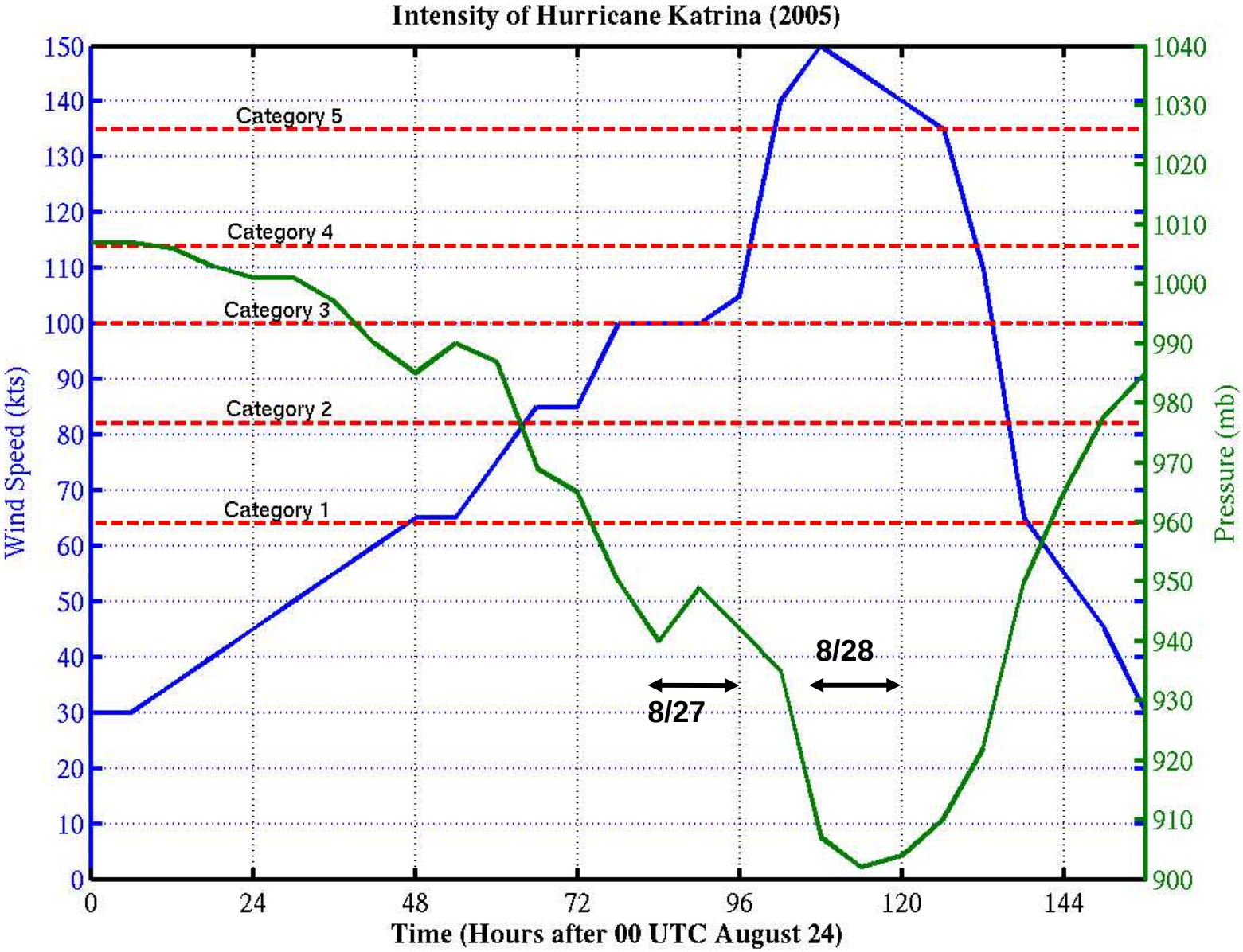
Mini ensemble MM5 and WRF forecasts using GFS, NOGAPS, CMC, and GFDL forecast fields as initial and lateral boundary conditions

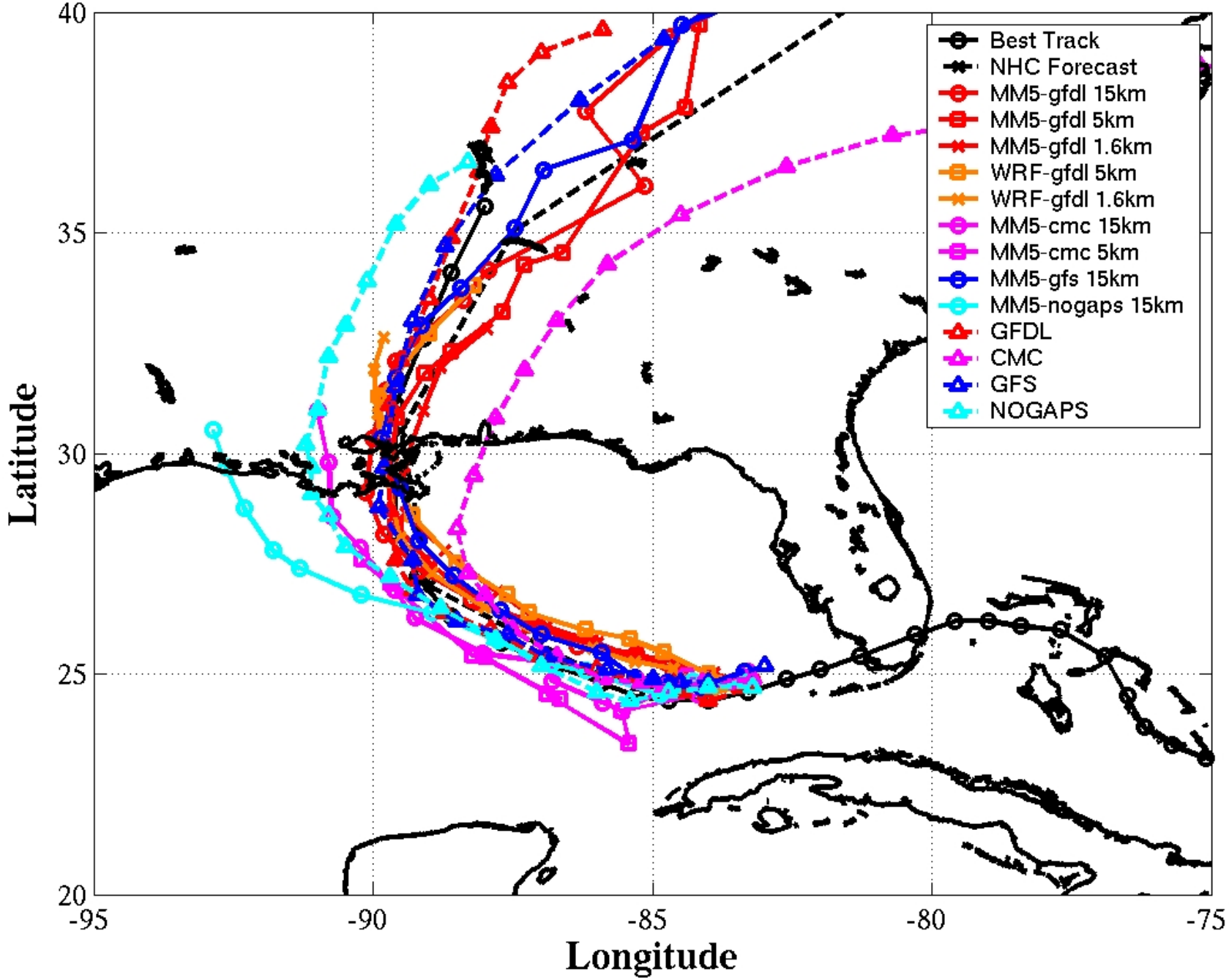


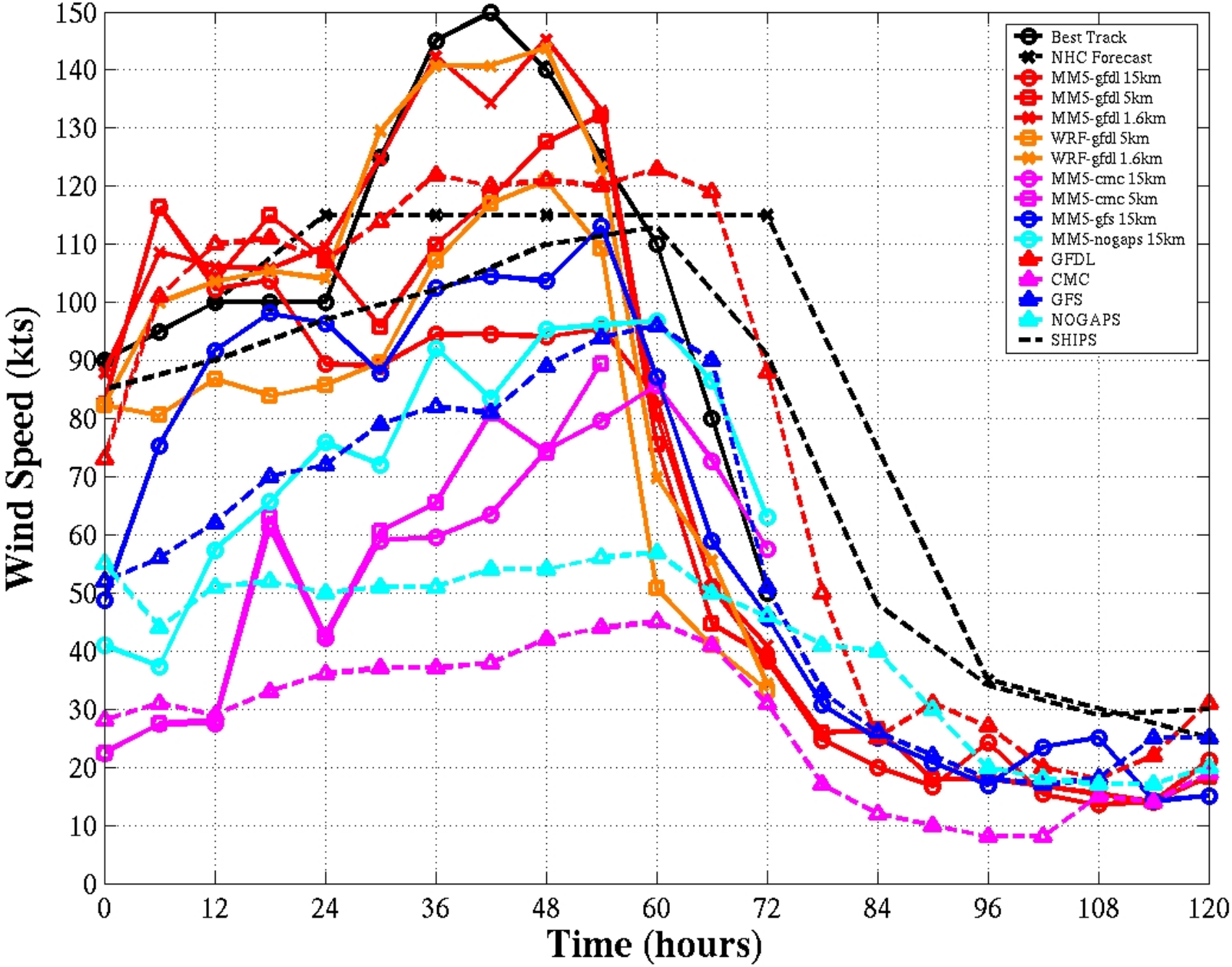

WIND SPEED
≥156 MPH
≥131 MPH
≥111 MPH
≥96 MPH
≥74 MPH
>39 MPH
>0 MPH
Katrina

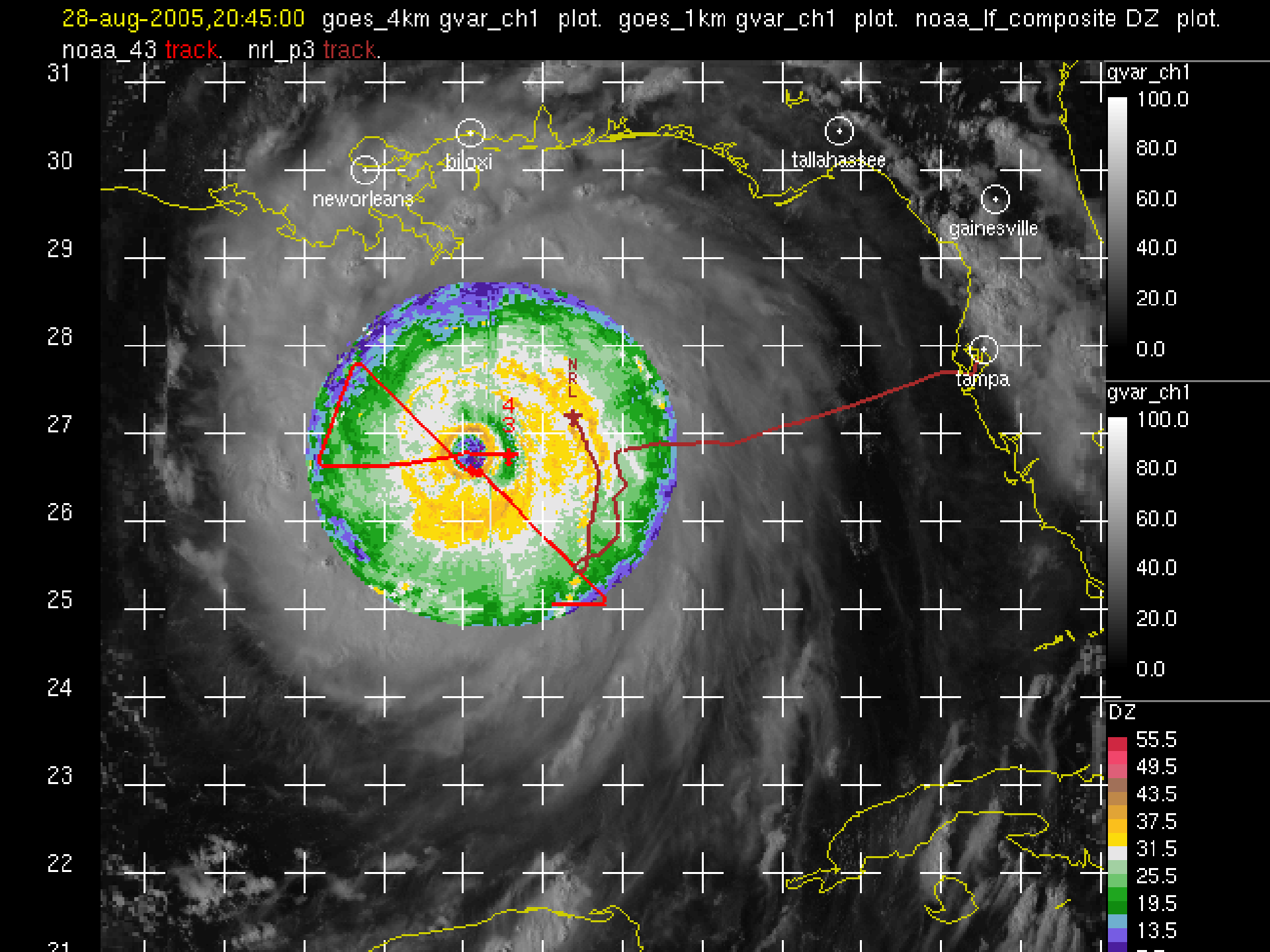

WIND SPEED
≥156 MPH
≥131 MPH
≥111 MPH
≥96 MPH
≥74 MPH
>39 MPH
>0 MPH
Ophelia

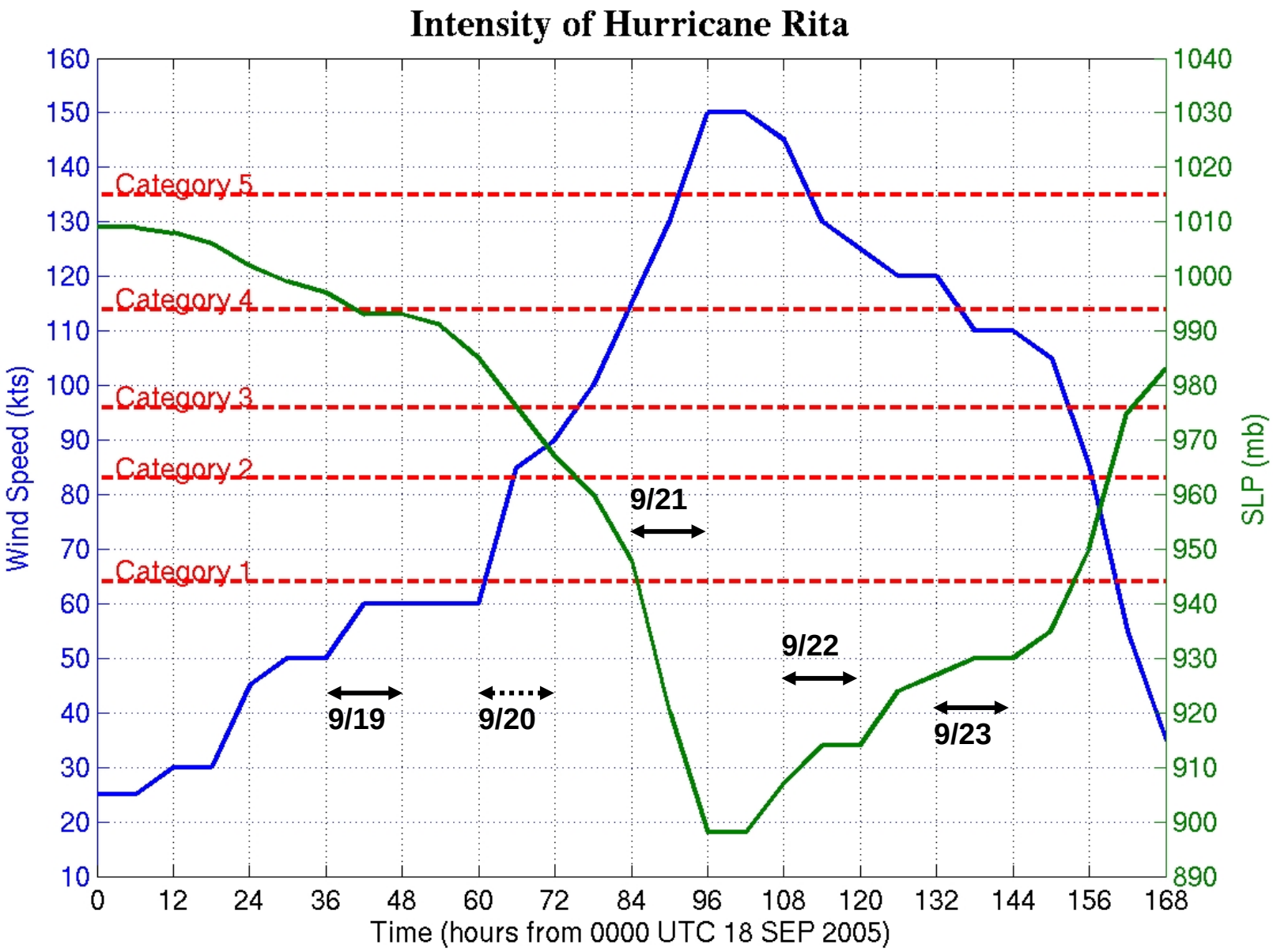

WIND SPEED
≥156 MPH
≥131 MPH
≥111 MPH
≥96 MPH
≥74 MPH
>39 MPH
>0 MPH
Rita

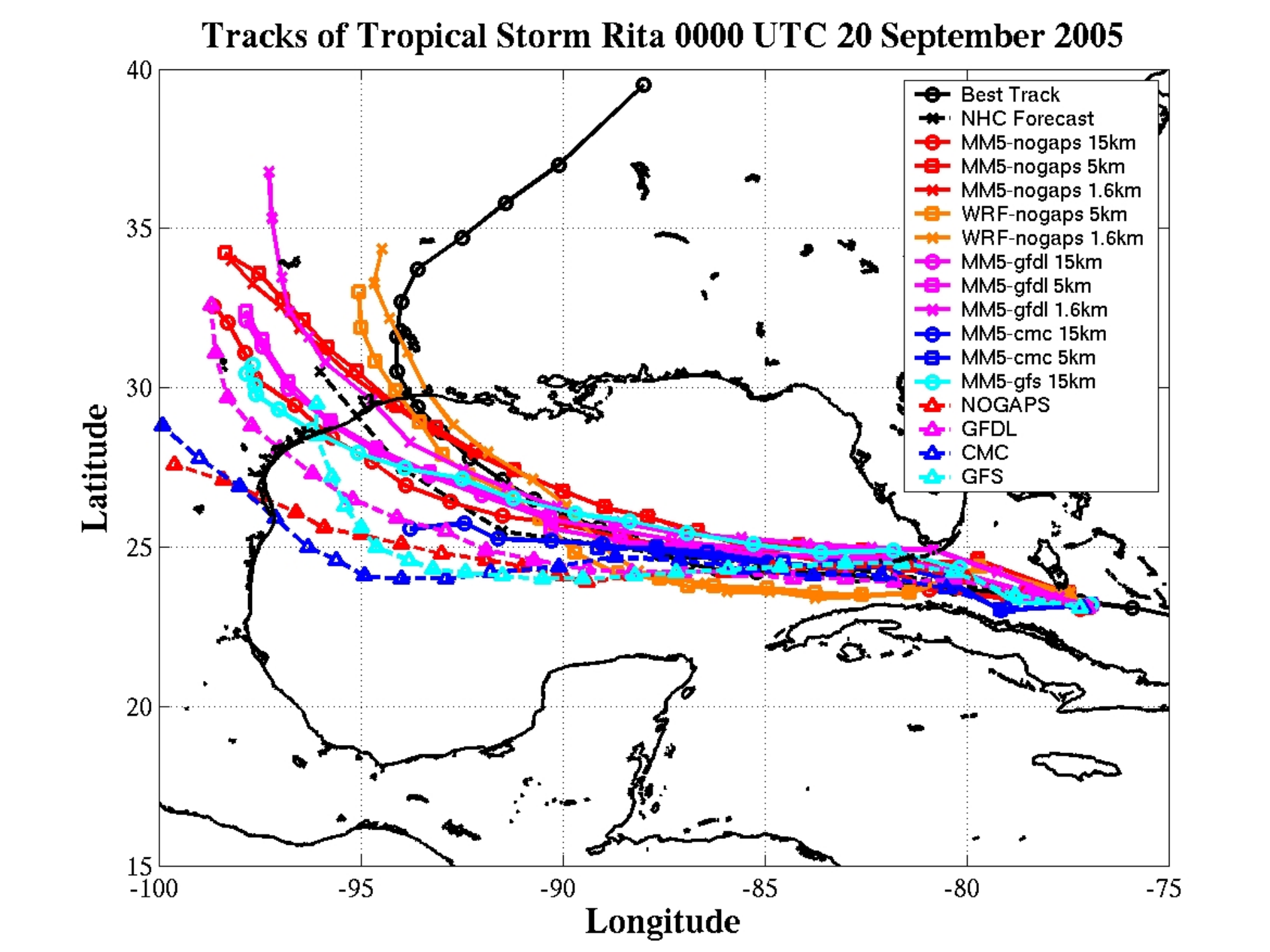

Intensity of Hurricane Katrina (2005)
Wind Speed (kts)
Pressure (mb)
Time (Hours after 00 UTC August 24)
Category 5
Category 4
Category 3
Category 2
Category 1
8/27
8/28
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
900
910
920
930
940
950
960
970
980
990
1000
1010
1020
1030
1040
0
24
48
72
96
120
144

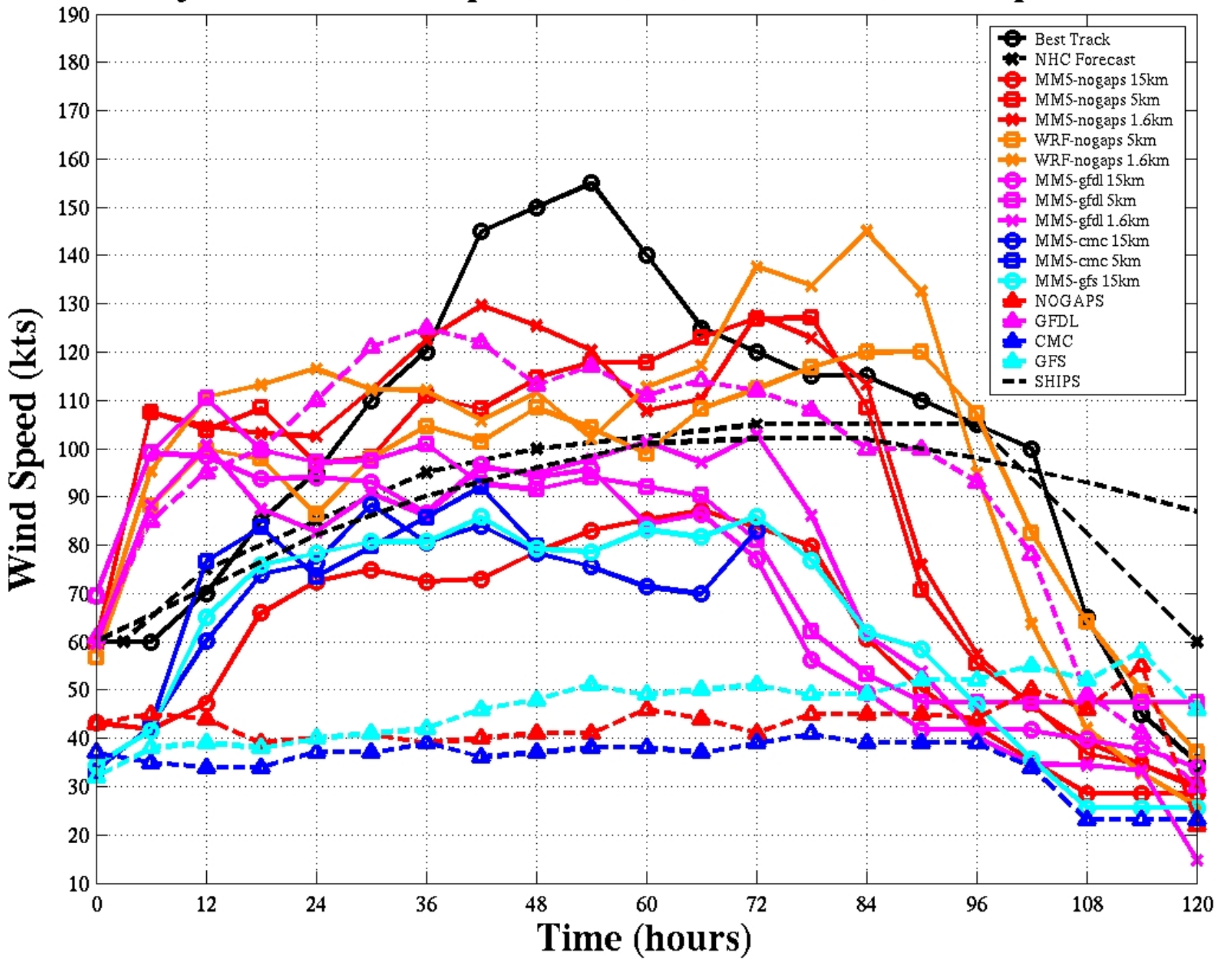

Track Forecast of Hurricane Katrina 0000 UTC 27 August 2005
Best Track
NHC Forecast
MM5-gfdl 15km
MM5-gfdl 5km
MM5-gfdl 1.6km
WRF-gfdl 5km
WRF-gfdl 1.6km
MM5-cmc 15km
MM5-cmc 5km
MM5-gfs 15km
MM5-nogaps 15km
GFDL
CMC
GFS
NOGAPS
Latitude
Longitude
40
35
30
25
20
-95
-90
-85
-80
-75


Intensity Forecast of Hurricane Katrina 0000 UTC 27 August 2005
Wind Speed (kts)
Time (hours)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
12
24
36
48
60
72
84
96
108
120
Best Track
NHC Forecast
MM5-gfdl 15km
MM5-gfdl 5km
MM5-gfdl 1.6km
WRF-gfdl 5km
WRF-gfdl 1.6km
MM5-cmc 15km
MM5-cmc 5km
MM5-gfs 15km
MM5-nogaps 15km
GFDL
CMC
GFS
NOGAPS
SHIPS

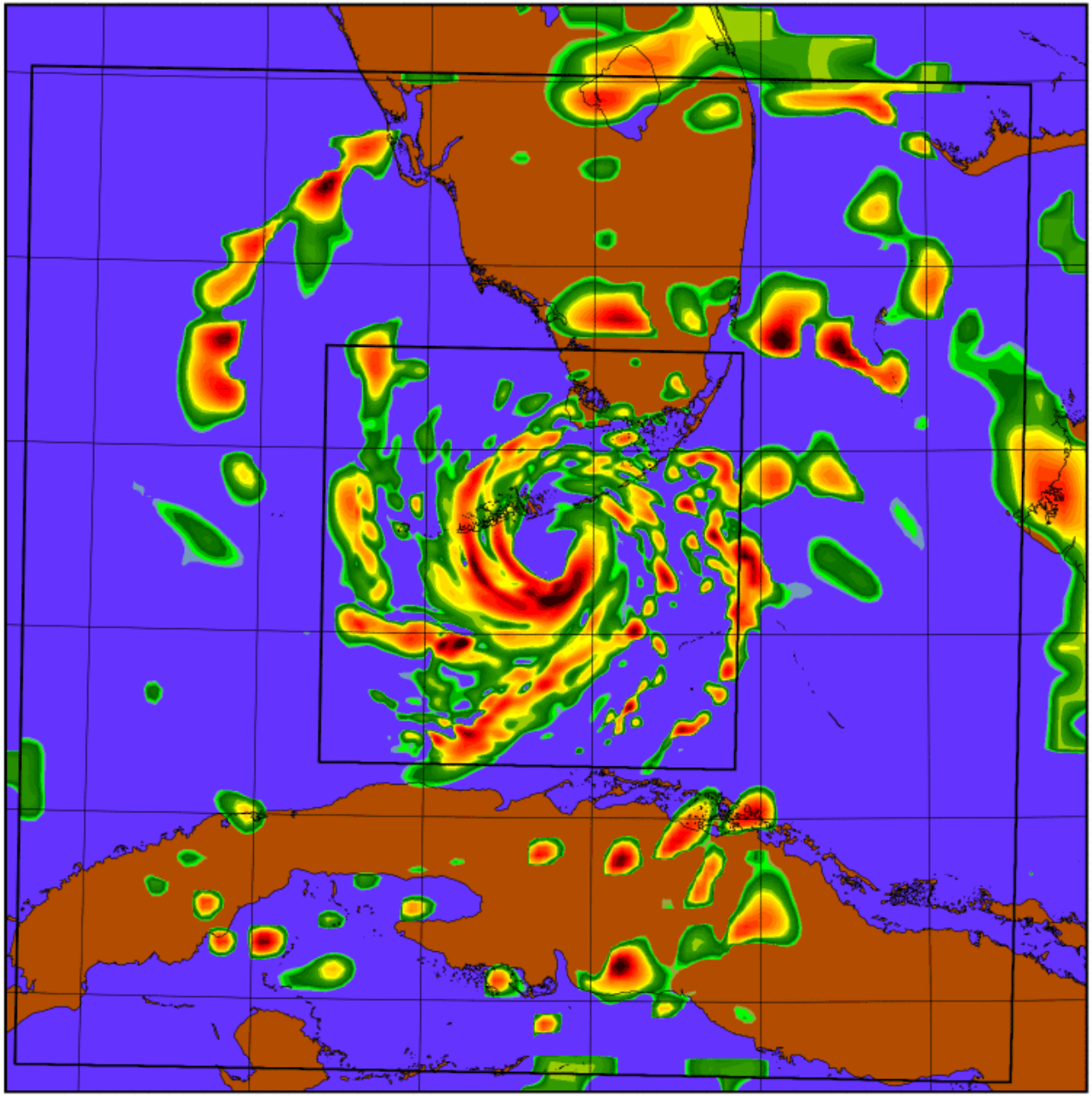

28-aug-2005,20:45:00 goes_4km gvar_ch1 plot. goes_1km gvar_ch1 plot. noaa_lf_composite DZ plot.
noaa_43 track. nrl_p3 track.
31
30
29
28
27
26
25
24
23
22
21
biloxi
tallahassee
neworleans
gainesville
tampa
NRL
43
gvar_ch1
100.0
80.0
60.0
40.0
20.0
0.0
gvar_ch1
100.0
80.0
60.0
40.0
20.0
0.0
DZ
55.5
49.5
43.5
37.5
31.5
25.5
19.5
13.5

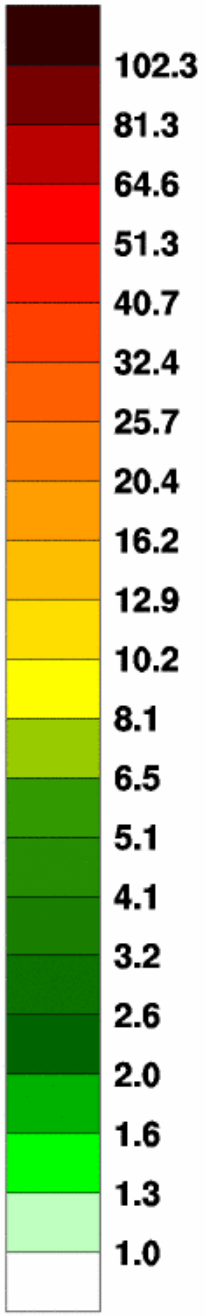

Intensity of Hurricane Rita
Wind Speed (kts)
SLP (mb)
Time (hours from 0000 UTC 18 SEP 2005)
Category 5
Category 4
Category 3
Category 2
Category 1
9/19
9/20
9/21
9/22
9/23
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
1040
1030
1020
1010
1000
990
980
970
960
950
940
930
920
910
900
890
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168

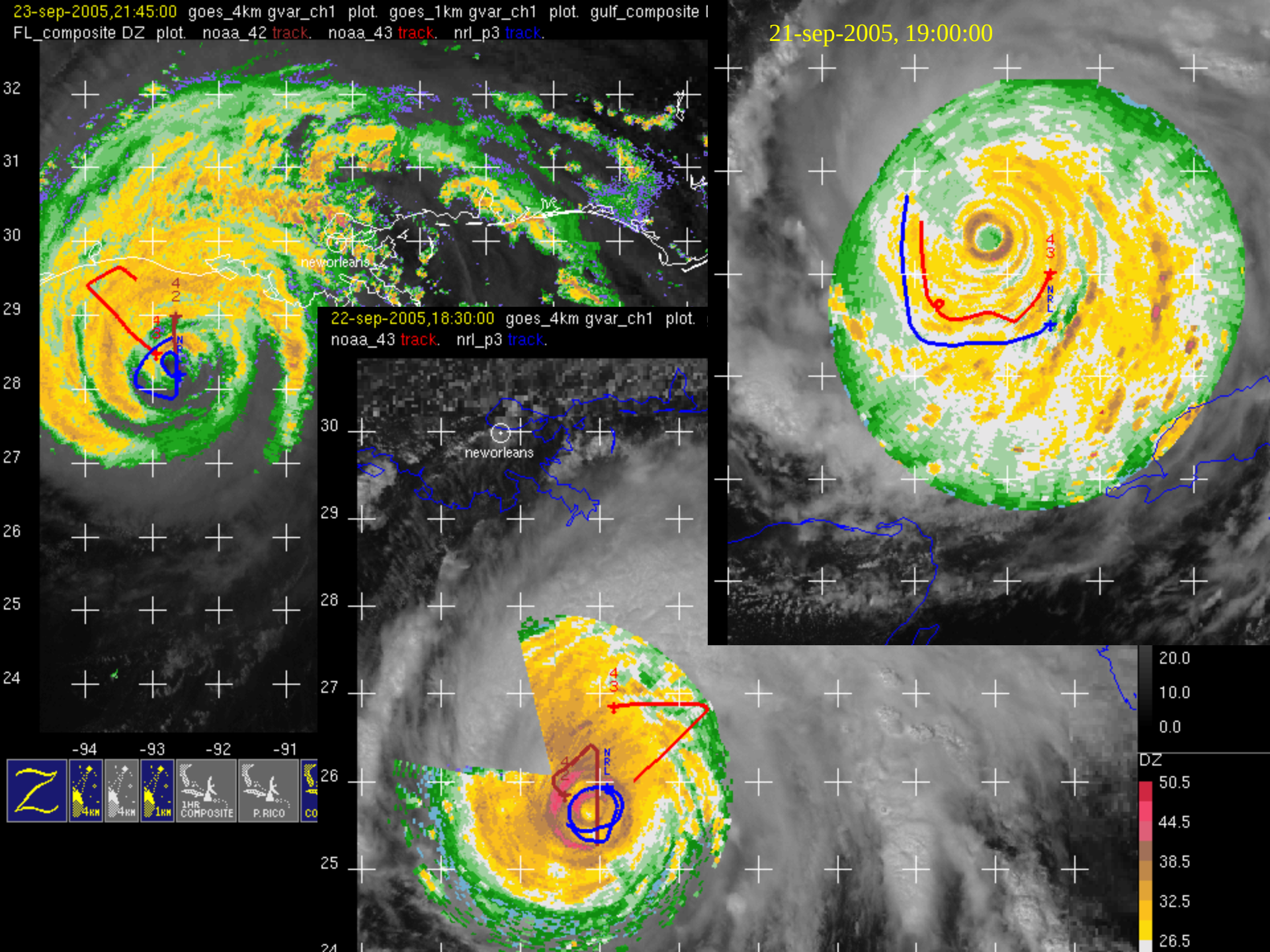

Tracks of Tropical Storm Rita 0000 UTC 20 September 2005
Best Track
NHC Forecast
MM5-nogaps 15km
MM5-nogaps 5km
MM5-nogaps 1.6km
WRF-nogaps 5km
WRF-nogaps 1.6km
MM5-gfdl 15km
MM5-gfdl 5km
MM5-gfdl 1.6km
MM5-cmc 15km
MM5-cmc 5km
MM5-gfs 15km
NOGAPS
GFDL
CMC
GFS
Latitude
Longitude
40
35
30
25
20
15
-100
-95
-90
-85
-80
-75

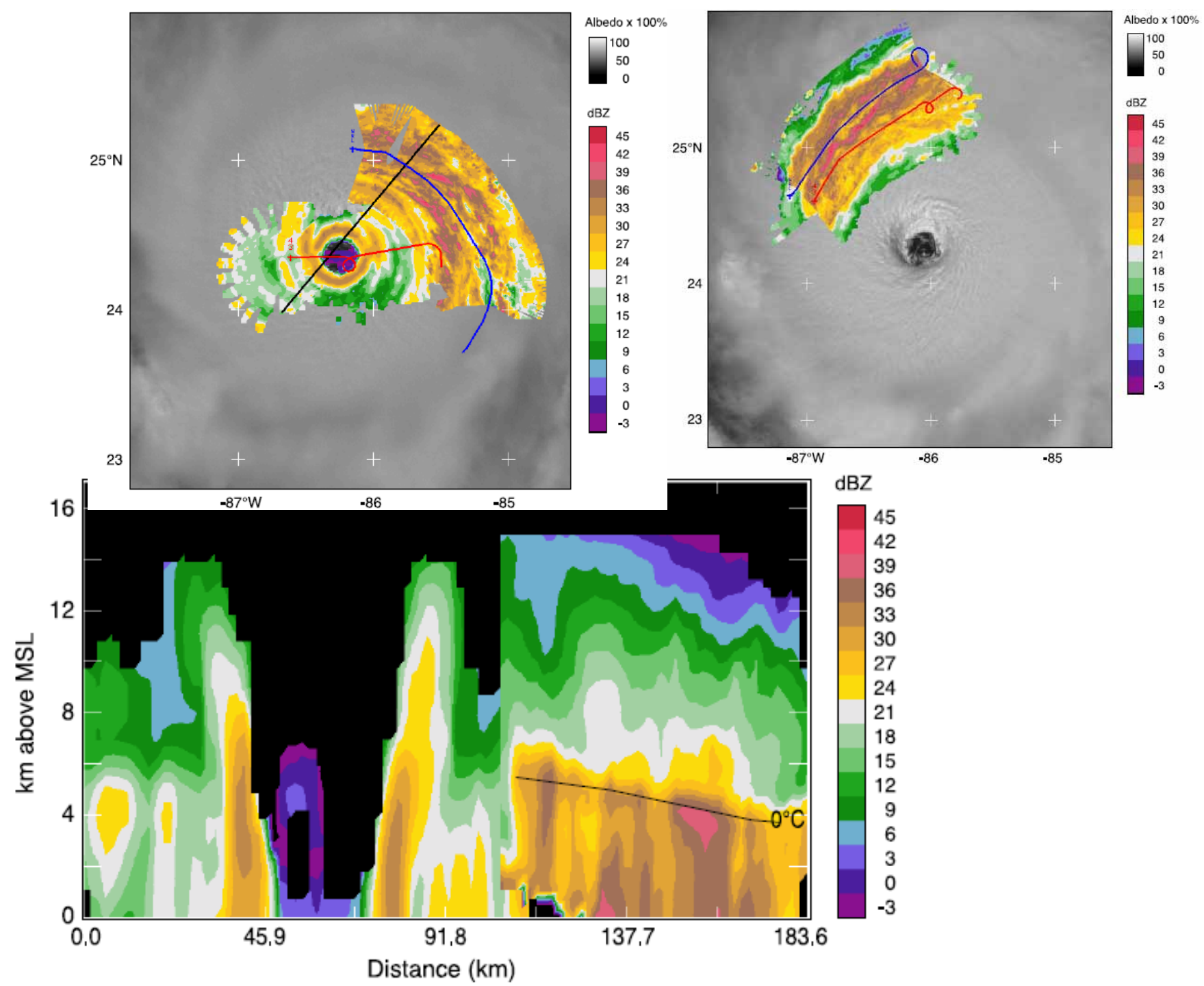

Intensity Forecast of Tropical Storm Rita 0000 UTC 20 September 2005
Wind Speed (kts)
Time (hours)
Best Track
NHC Forecast
MM5-nogaps 15km
MM5-nogaps 5km
MM5-nogaps 1.6km
WRF-nogaps 5km
WRF-nogaps 1.6km
MM5-gfdl 15km
MM5-gfdl 5km
MM5-gfdl 1.6km
MM5-cmc 15km
MM5-cmc 5km
MM5-gfs 15km
NOGAPS
GFDL
CMC
GFS
SHIPS

Rita MM5-NOGAPS Rain Rate (mm/h) 1800 UTC 20 Sep 2005

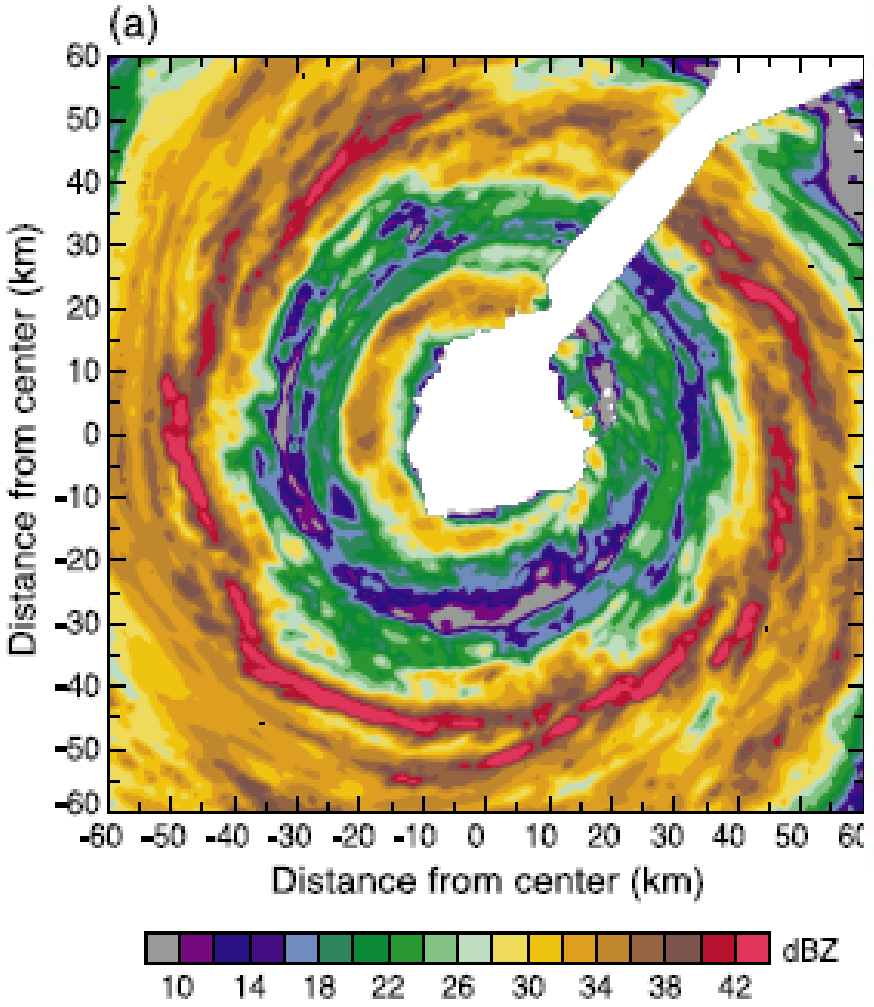




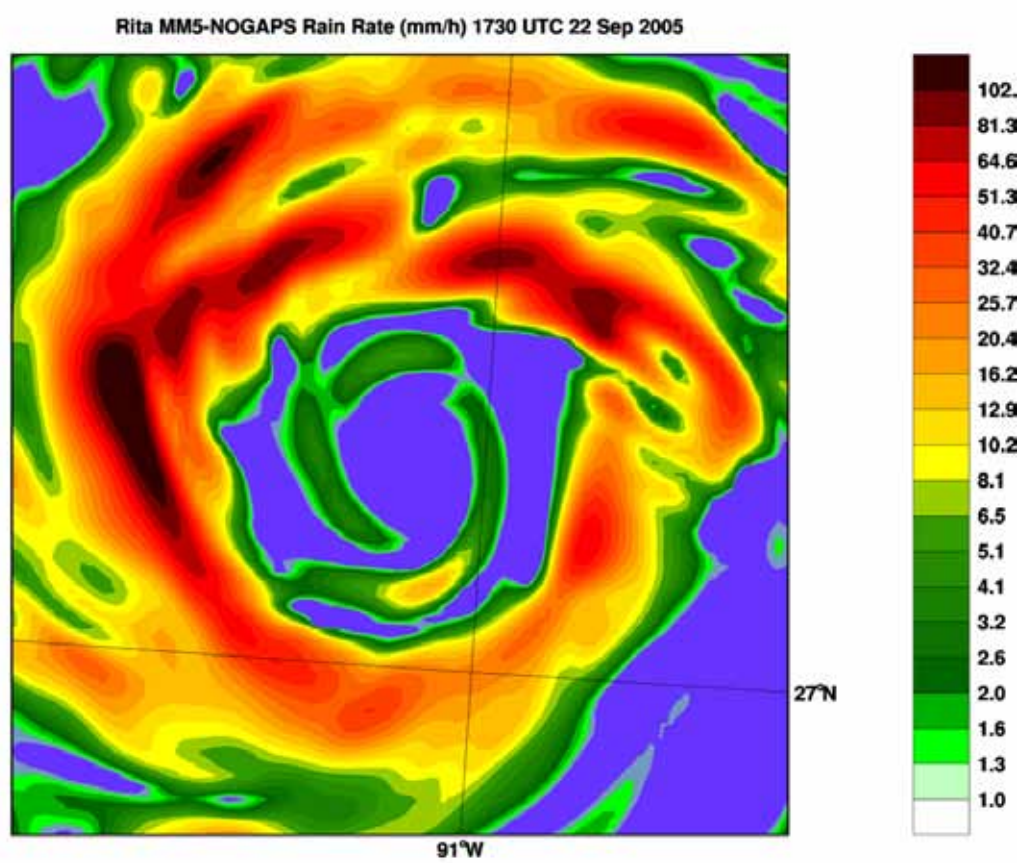

23-sep-2005,21:45:00 goes_4km gvar_ch1 plot. goes_1km gvar_ch1 plot. gulf_composite
FL_composite DZ plot. noaa_42 track. noaa_43 track. nrl_p3 track.
21-sep-2005, 19:00:00
22-sep-2005,18:30:00 goes_4km gvar_ch1 plot.
noaa_43 track. nrl_p3 track.
neworleans
neworleans
32
31
30
29
28
27
26
25
24
-94
-93
-92
-91
4KM
4KM
1KM
1HR COMPOSITE
P.RICO
20.0
10.0
0.0
DZ
50.5
44.5
38.5
32.5
26.5


Albedo x 100%
100
50
0
dBZ
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
0
-3
25°N
24
23
-87°W
-86
-85
km above MSL
16
12
8
4
0
0,0
45,9
91,8
137,7
183,6
Distance (km)
0°C

ELDORA composite reflectivity in Rita on 22 Sept 05

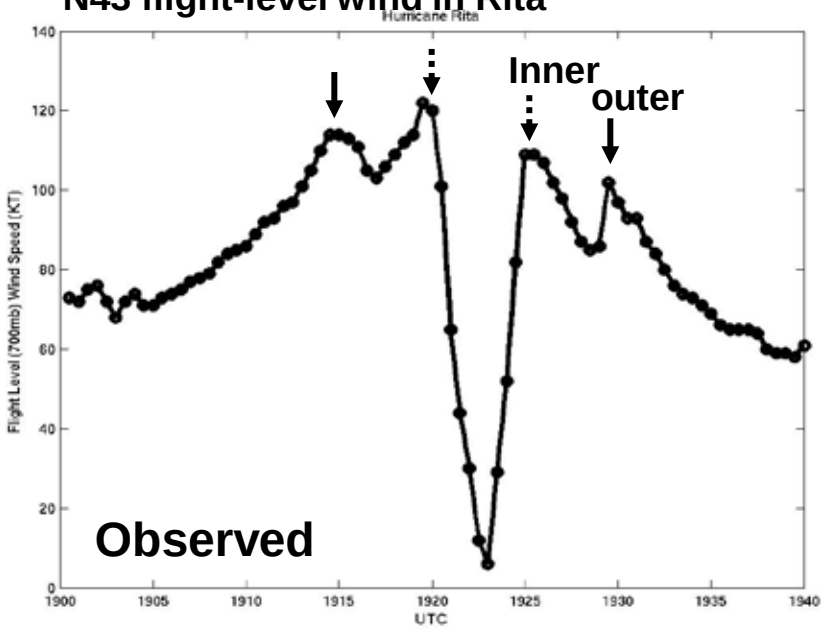


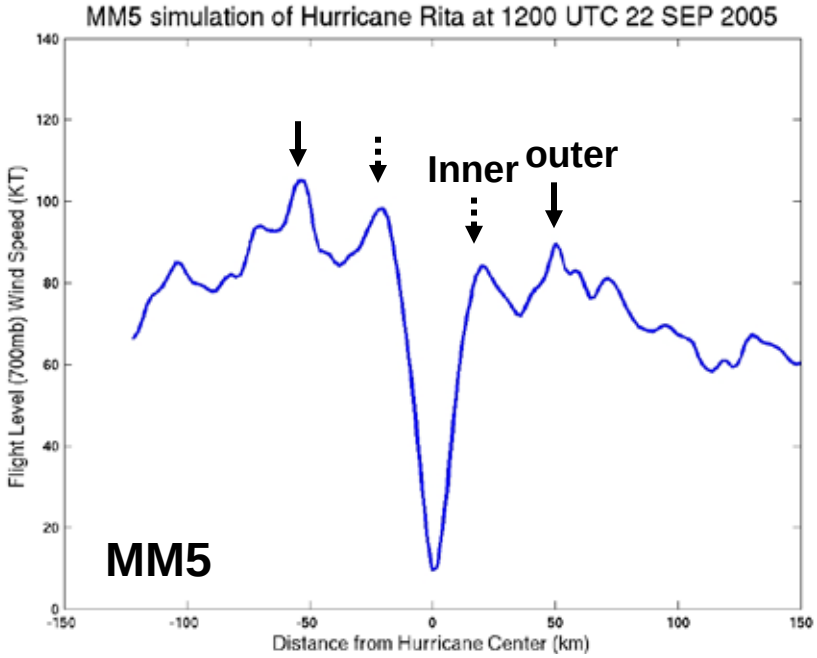
MM5 Rainrate in Rita on 22 Sept 05



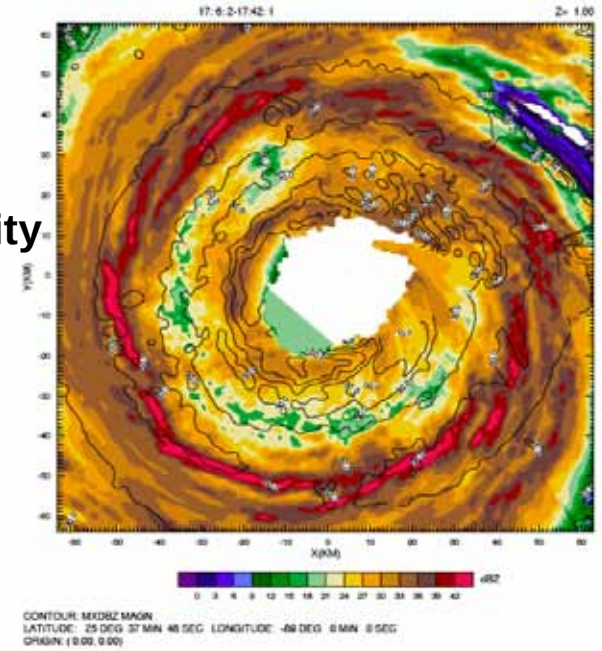
Eyewall Replacement in Hurricane Rita (2005)

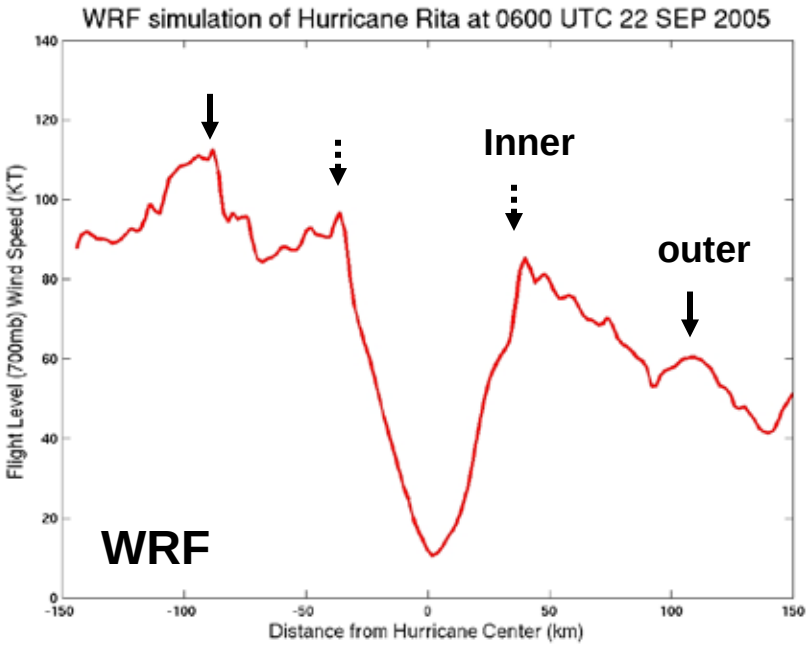
N43 flight-level wind in Rita

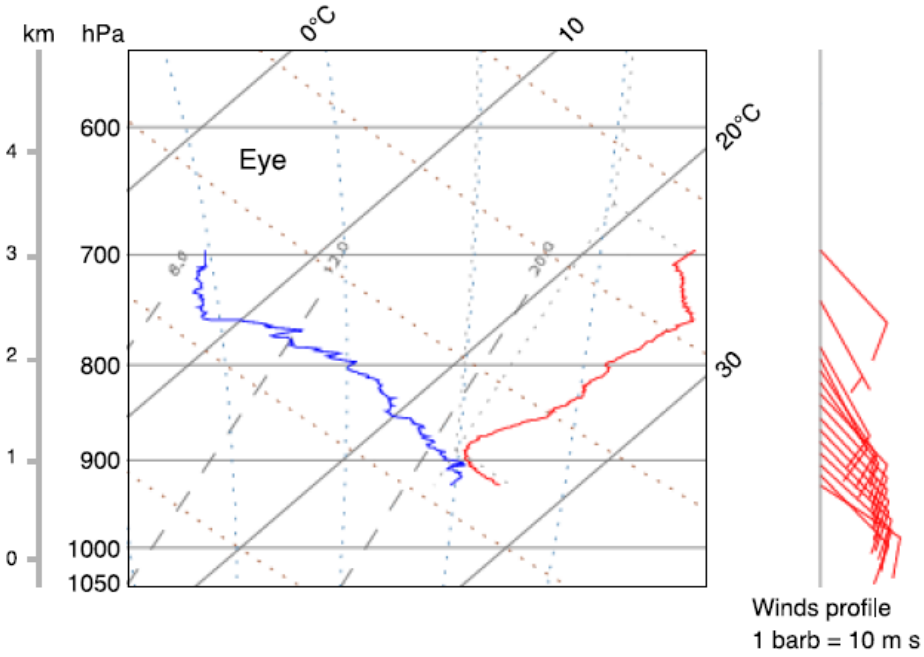


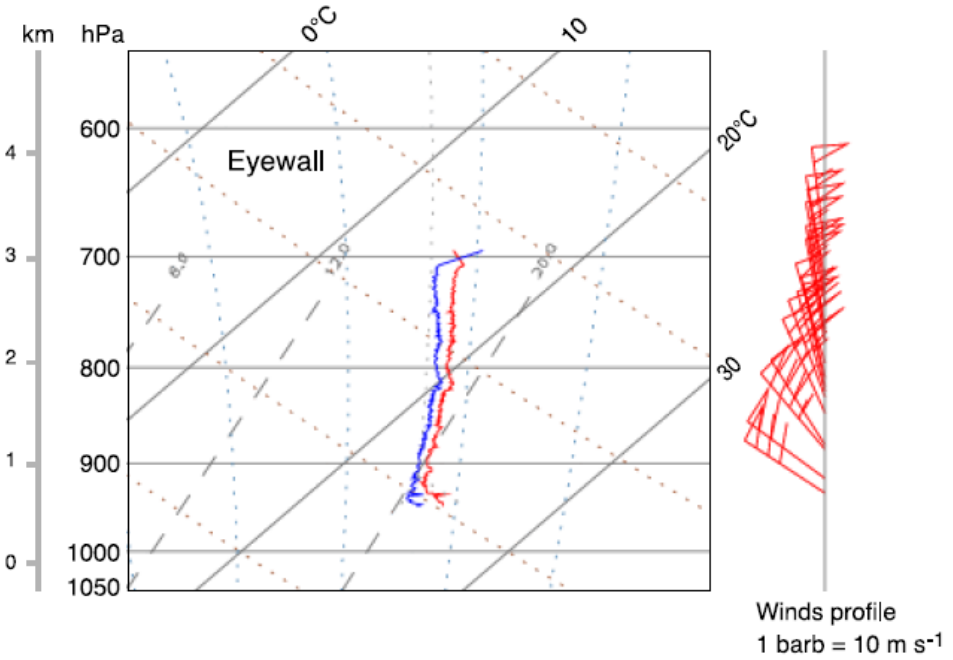


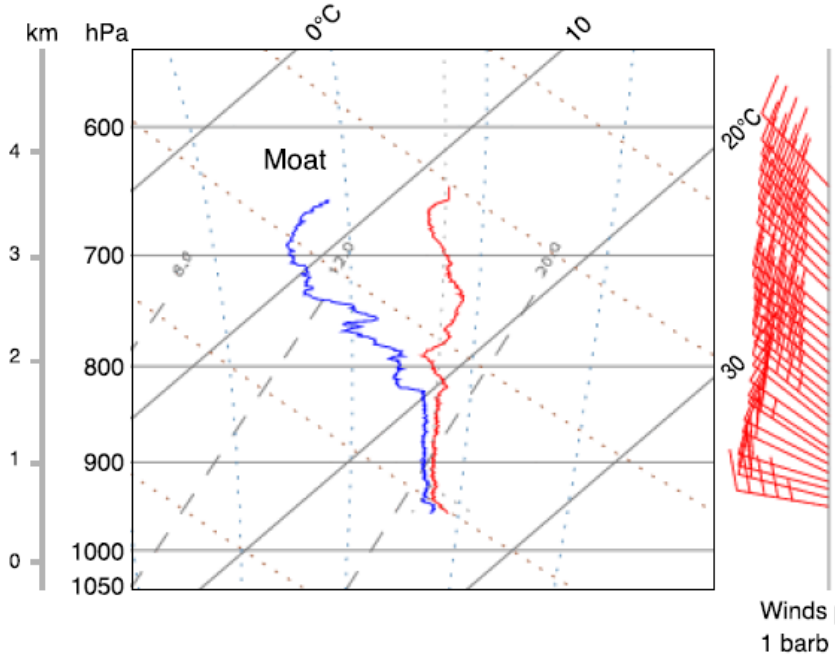
Radar Reflectivity

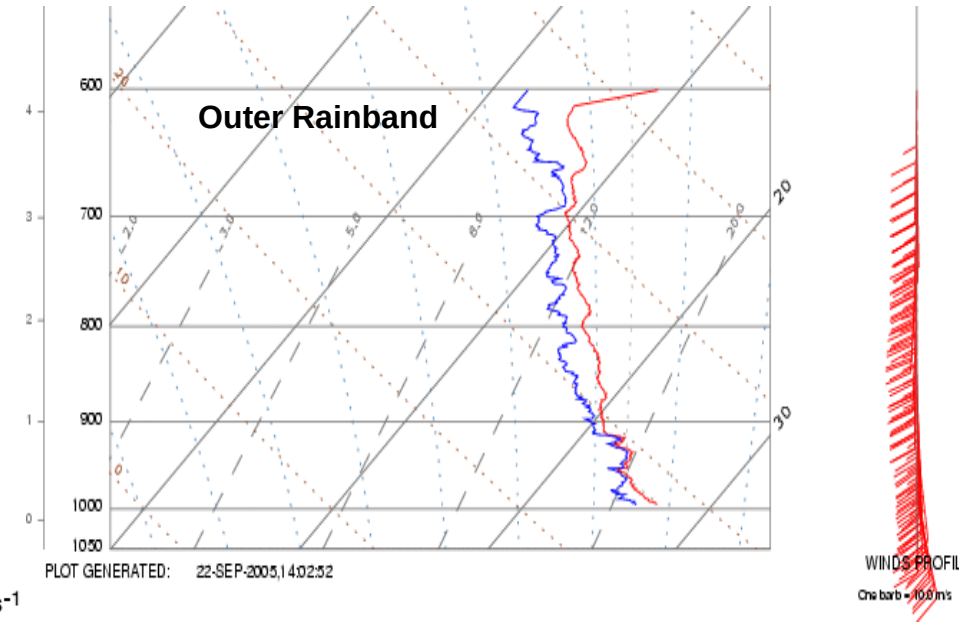




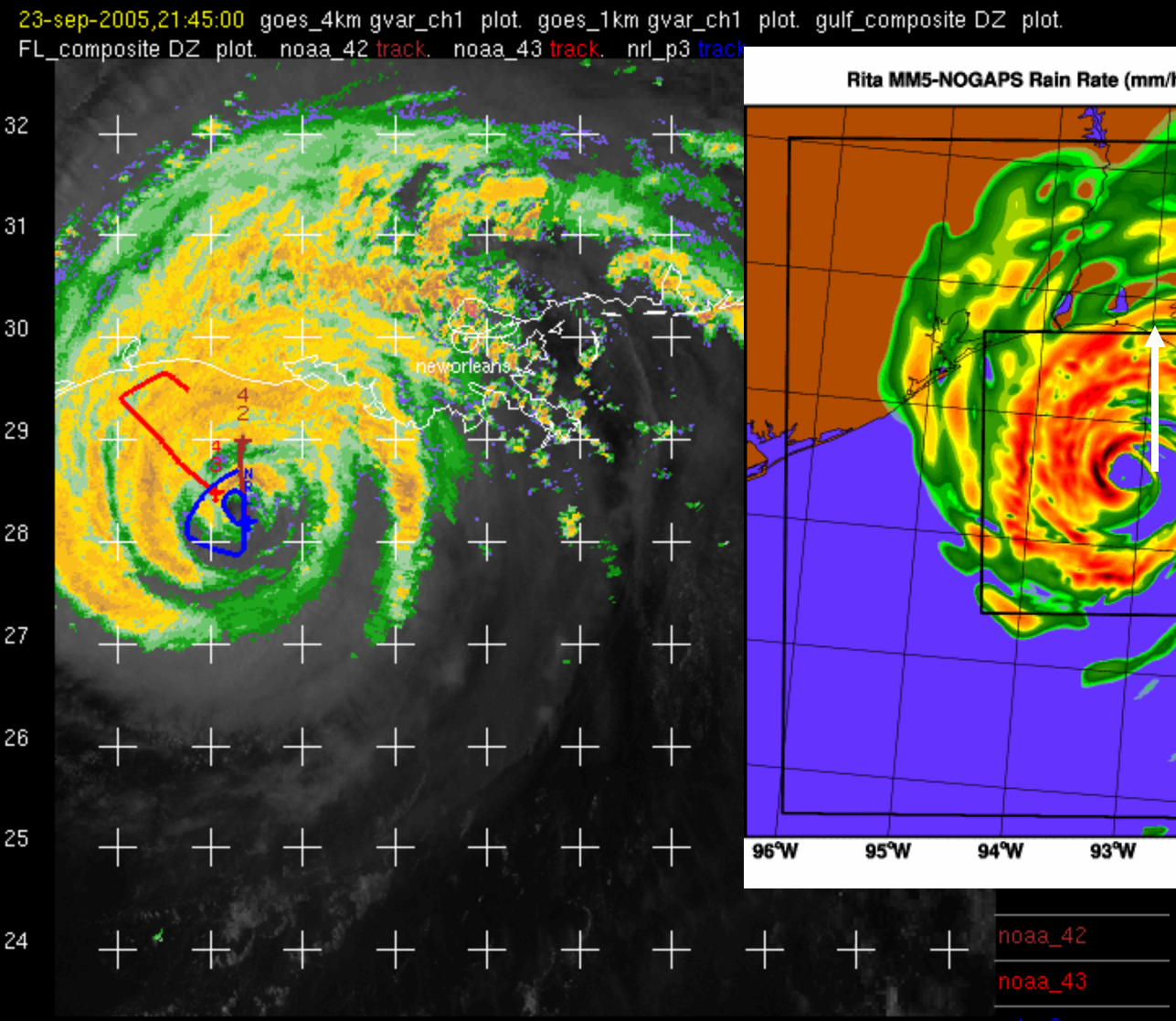

km
hPa
0°C
10
Eye
600
700
800
900
1000
1050
20°C
30
Winds profile
1 barb = 10 m s

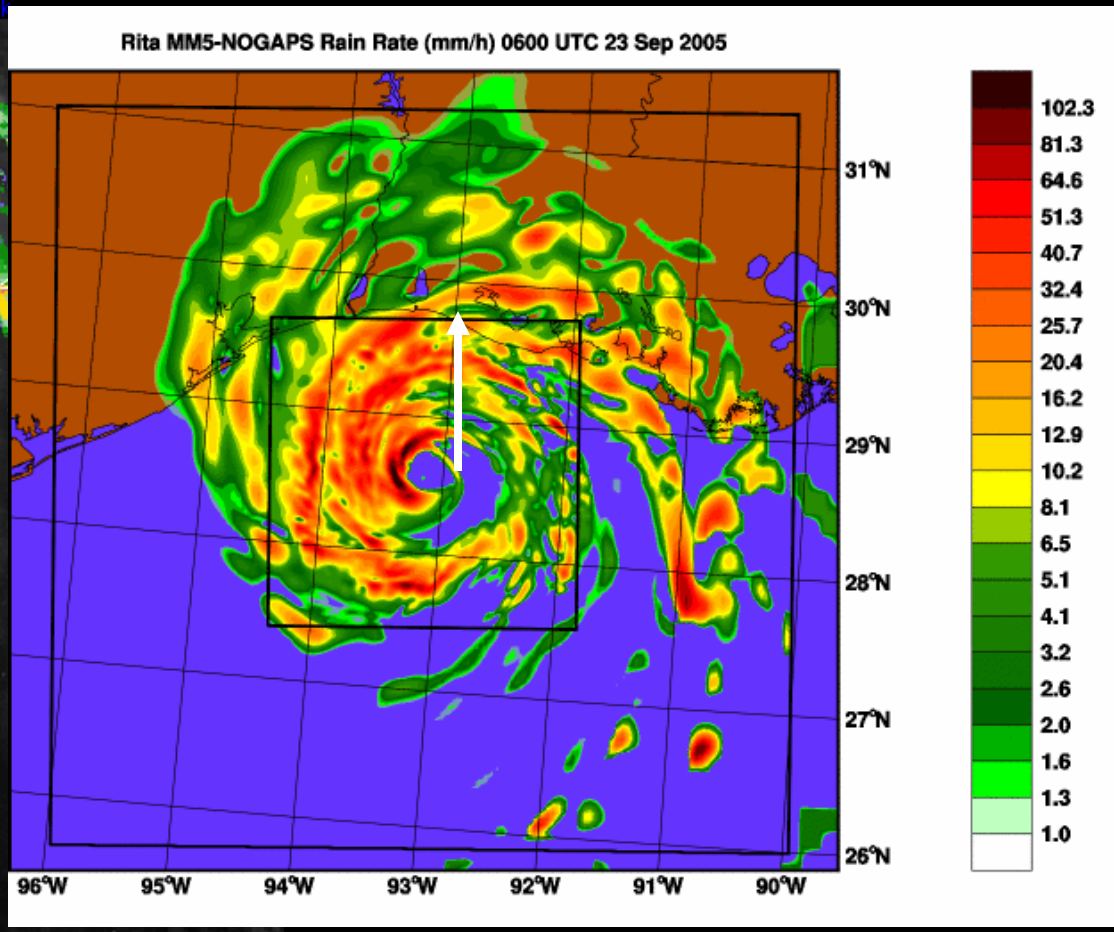

km
hPa
0°C
10
Eyewall
600
700
800
900
1000
1050
20°C
30
Winds profile
1 barb = 10 m s-1


km
hPa
0°C
10
Moat
600
700
800
900
1000
1050
20°C
30
Winds profile
1 barb = 10 m s-1


Outer Rainband
600
700
800
900
1000
1050
20
30
PLOT GENERATED: 22-SEP-2005,14:02:52
WINDS PROFILE

Effect of vertical wind shear on Hurricane Rita structure and intensity





Model 5-day forecast

Conclusions

- **RAINEX conducted 9 multi-aircraft missions in Hurricanes Katrina, Ophelia, and Rita, and collected data in all stages from Tropical Depression to Category 5 hurricanes.**

- **RAINEX provided an unique, comprehensive dataset for evaluating and improving high-resolution models.**

- **High-resolution (~1 km, resolving the inner core and rainbands) forecasts in real-time are extremely valuable for mission planning and overall understanding of the storm structure, evolution, and intensity change.**

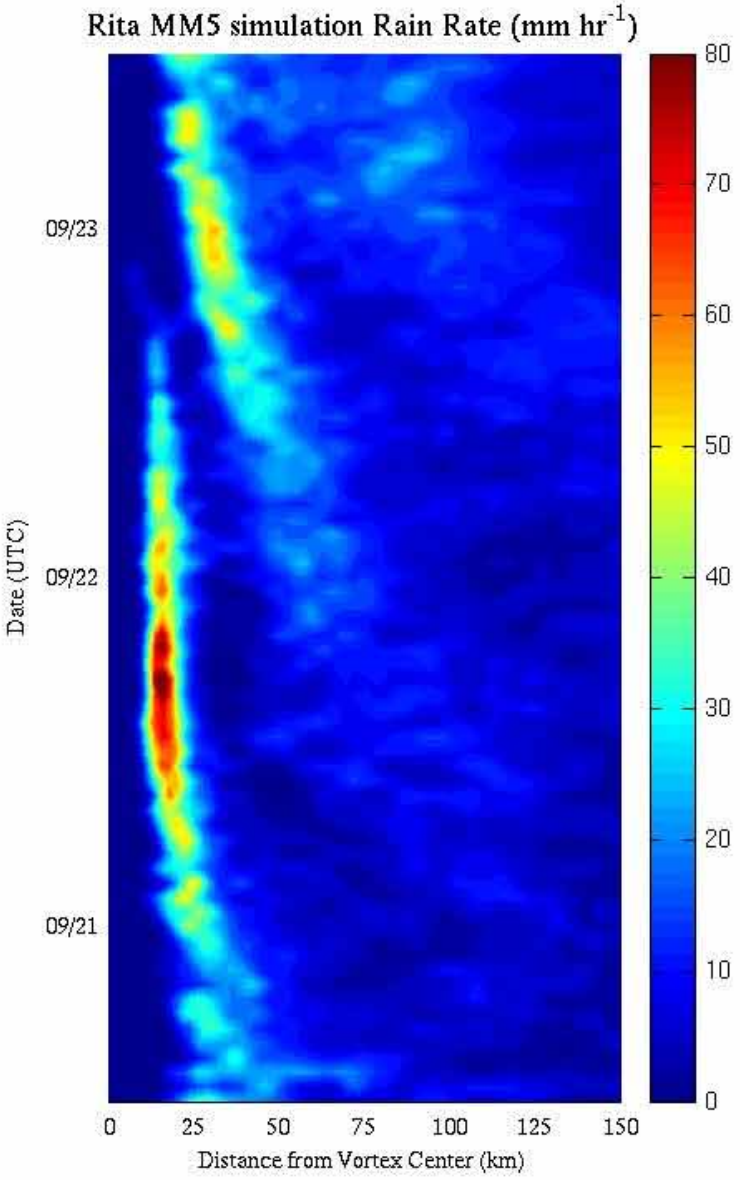
- **Accurate initial and lateral boundary conditions for high-res models are needed.**

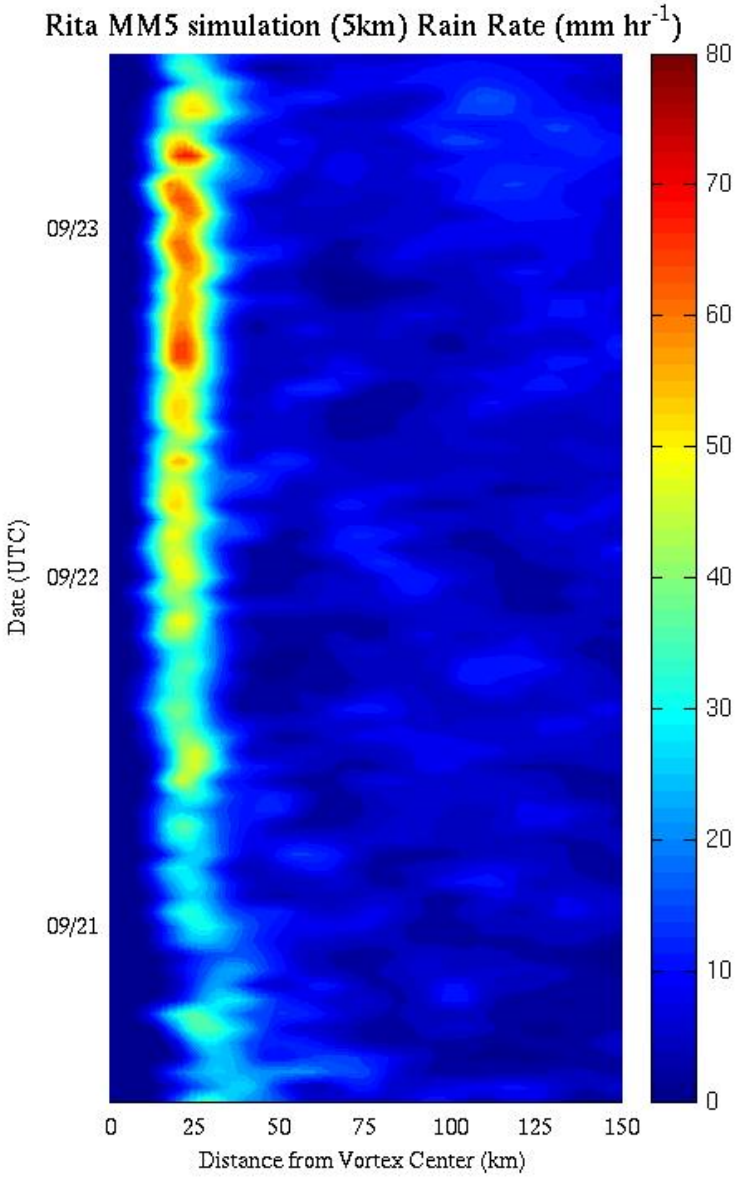
Acknowledgments

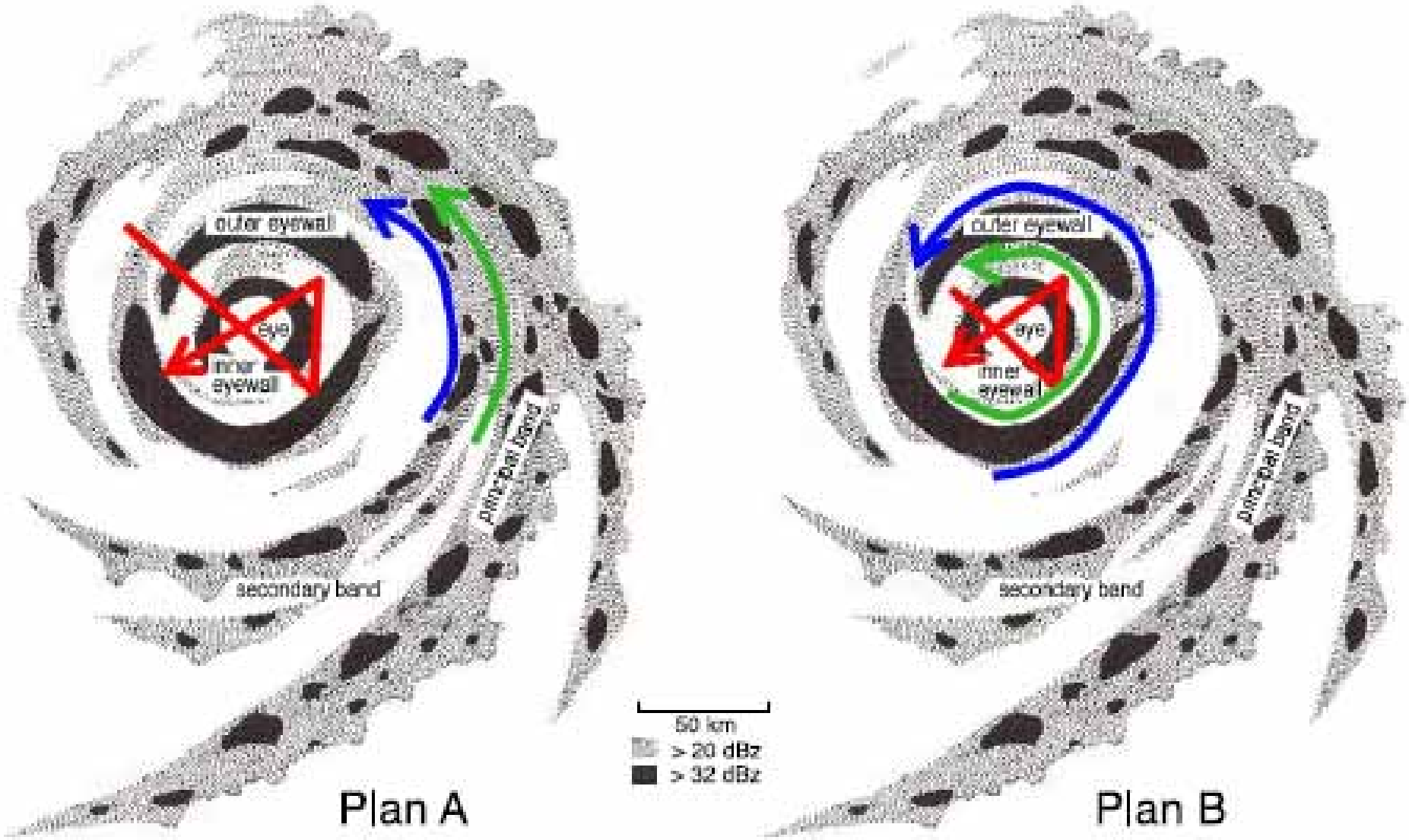
- **Support from the NRL P3 crew, UCAR/JOSS, NOAA AOC, HRD, NSSL, NESDIS, and RSS is critical to the success of RAINEX field program.**

- **RAINEX is support by NSF research grants ATM-0432623 and ATM-0432717.**

Hurricane


Rita MM5 simulation Rain Rate (mm hr-1)
Date (UTC)
09/23
09/22
09/21
0
25
50
75
100
125
150
Distance from Vortex Center (km)
80
70
60
50
40
30
20
10
0


Rita MM5 simulation (5km) Rain Rate (mm hr-1)
Date (UTC)
09/23
09/22
09/21
0
25
50
75
100
125
150
Distance from Vortex Center (km)
80
70
60
50
40
30
20
10
0


outer eyewall
eye
inner eyewall
secondary band
outer rain band
50 km
> 20 dBz
> 32 dBz
Plan A
outer eyewall
eye
inner eyewall
secondary band
outer rain band
Plan B

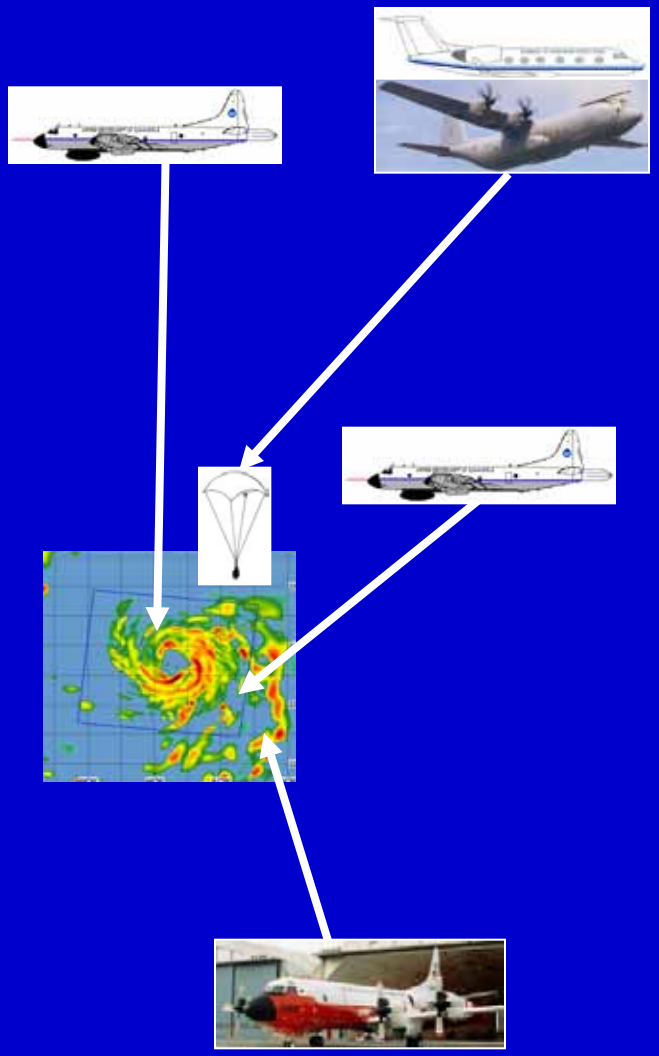
Hurricane Internal Dynmaics

- Inner core and rainband interactions
- Concentric eyewalls and eyewall replacement cycle

Environment ⟶ **Rainbands** ⟷ **Inner Core**

- Vertical wind shear
- Moisture distribution

Hurricane Rainband and Intensity Change Experiment (RAINEX)
Houze et al. (2006, BAMS)



RAINEX is the first experiment using three-Doppler-aircraft flying in hurricanes.

Approach:

- Use airborne Doppler radar to observe **both** eyewall and rainband internal vorticity structures **simultaneously**
- Use intensive **dropsondes** for thermodynamic environment of hurricane rainbands and eyewall to support both **analysis and modeling/forecasting**
- Use model to determine how the vorticity features evolve and storm **intensity changes**


Boulder
SATELLITE
COMMS
2005
RAINEX
Tampa
Miami