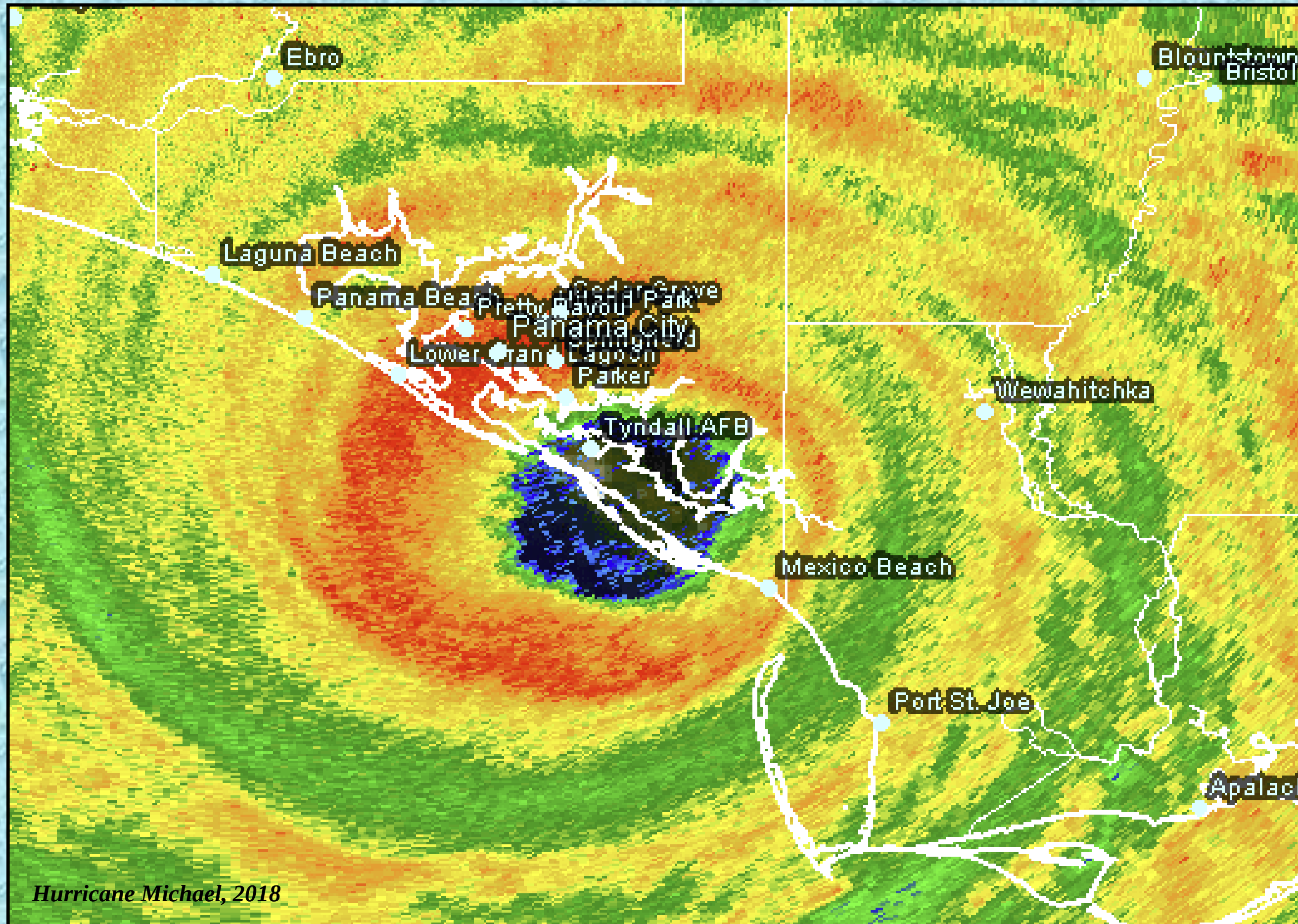
2019 RA-IV WMO Tropical Meteorology Course

WEATHER RADAR PRINCIPLES



Hurricane Michael, 2018

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COURSE OBJECTIVES

Part 1. Brief Review of Basic Radar Principles

1. Wavelengths suitable for weather surveillance
2. Beam height above the surface
3. Equivalent reflectivity or dBZ
4. Z-R (Reflectivity-Rainfall) relationships
5. Doppler velocities and the '*Doppler Dilemma*'

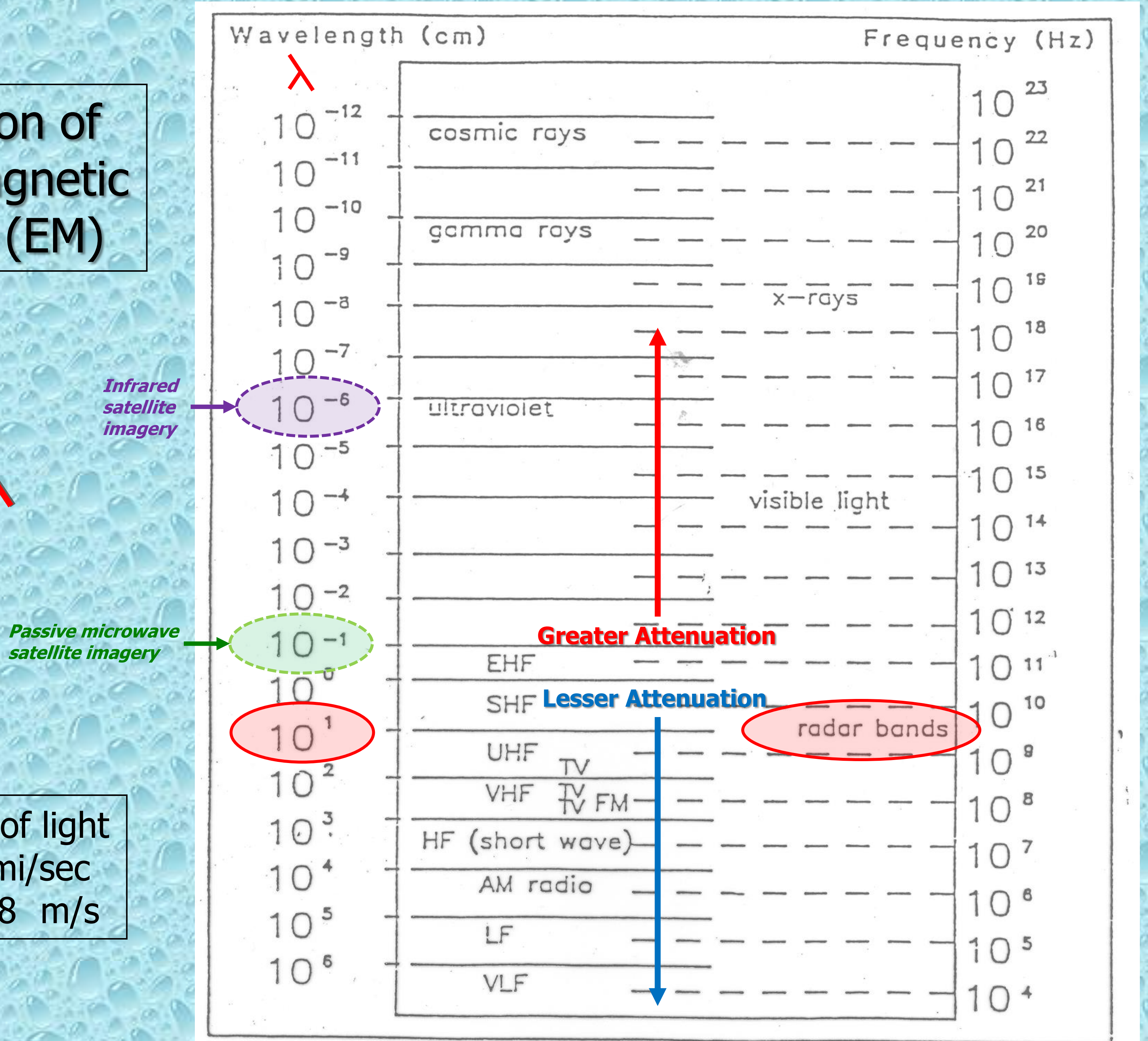
COURSE OBJECTIVES (cont’d)

Part 2. The NOAA WSR-88D Doppler Weather Radar

1. The operational system
2. A few practical examples
3. Interpretation of the data
4. Why we need algorithms
5. A glimpse into the future

Propagation of Electromagnetic Radiation (EM)

$V_{em} = f\lambda$



$V_{em} \simeq$ speed of light
= 186,000 smi/sec
= 299,792,458 m/s

Radar Operating Frequencies

Frequency (MHz)	Wavelength (cm)	Band
30,000	1	K (scatterometer)
10,000	3	X
6,000	5	C
3,000	10	S
1,500	20	L (air traffic control)

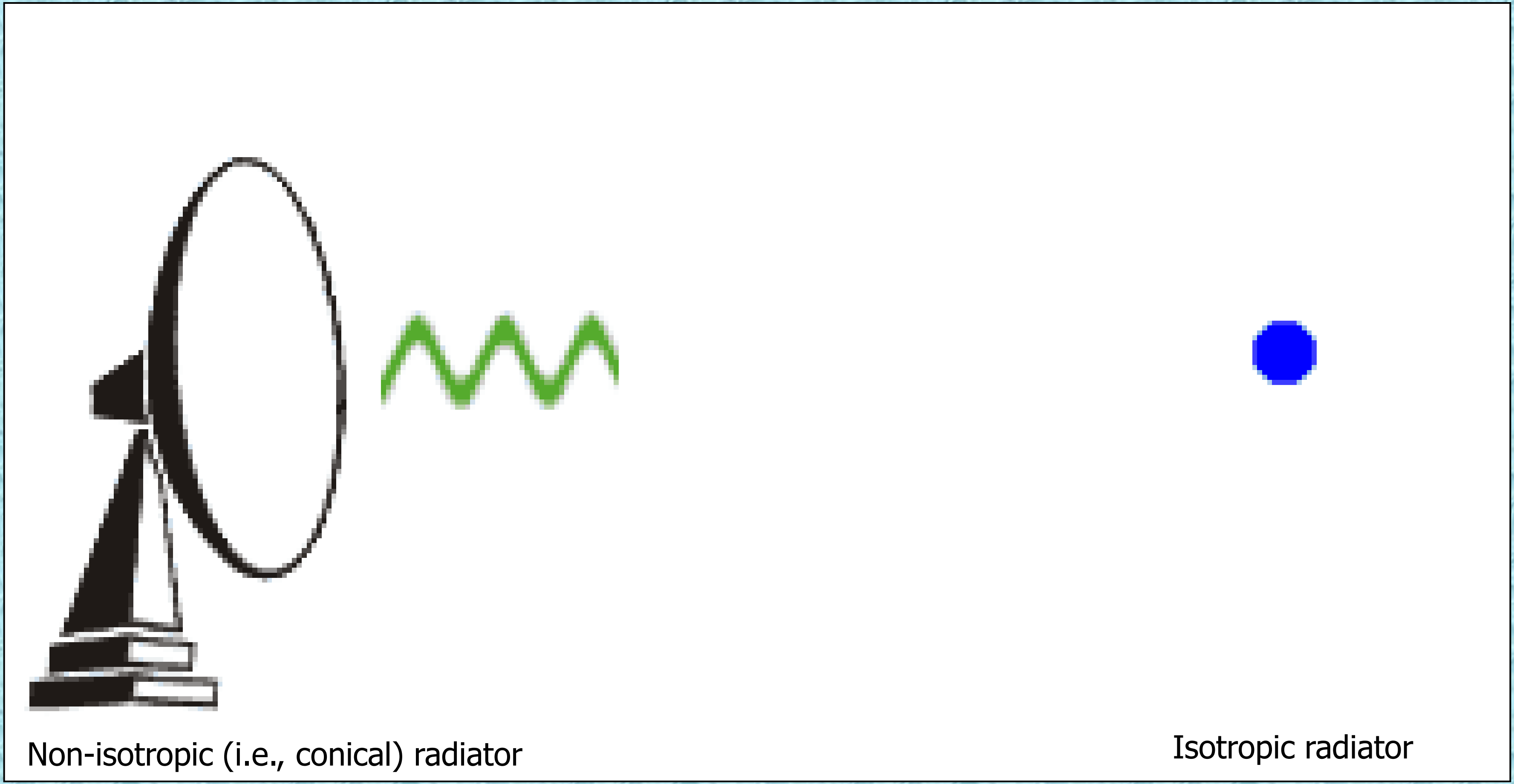
- **The longer (shorter) the wavelength, the larger (smaller) the precipitation-size particle that can be detected.**
- **The longer (shorter) the wavelength, the less (more) likely that precipitation attenuation of the radar signal will occur.**

WEATHER RADAR BANDS

10 cm	S-band
5 cm	C-band
1 cm	K-band

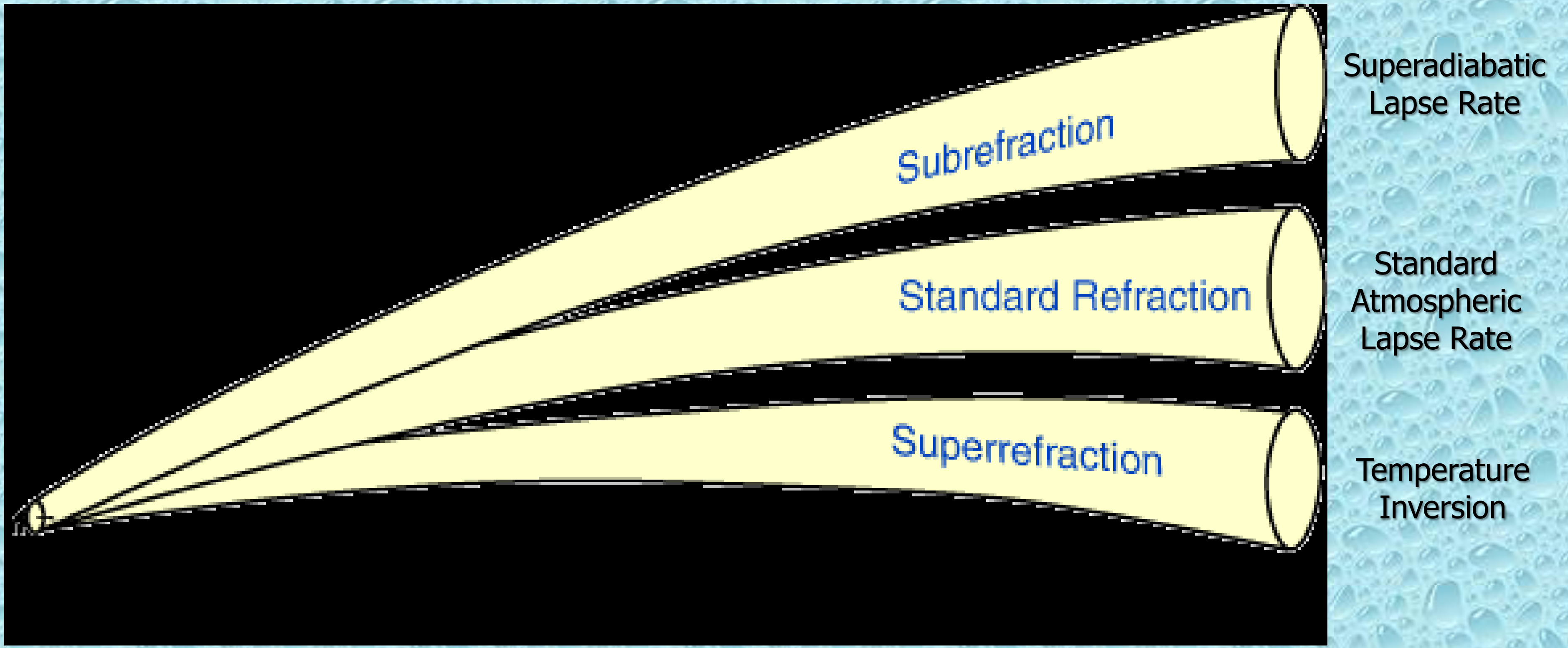
The NOAA National Weather Service WSR-88D Doppler radar is a 10-cm wavelength (S-band) weather detection radar that is excellent at sampling most precipitation particles *without encountering any significant signal loss due to precipitation attenuation*.

A large amount of horizontally polarized EM energy (~1,000,000 W) is transmitted…

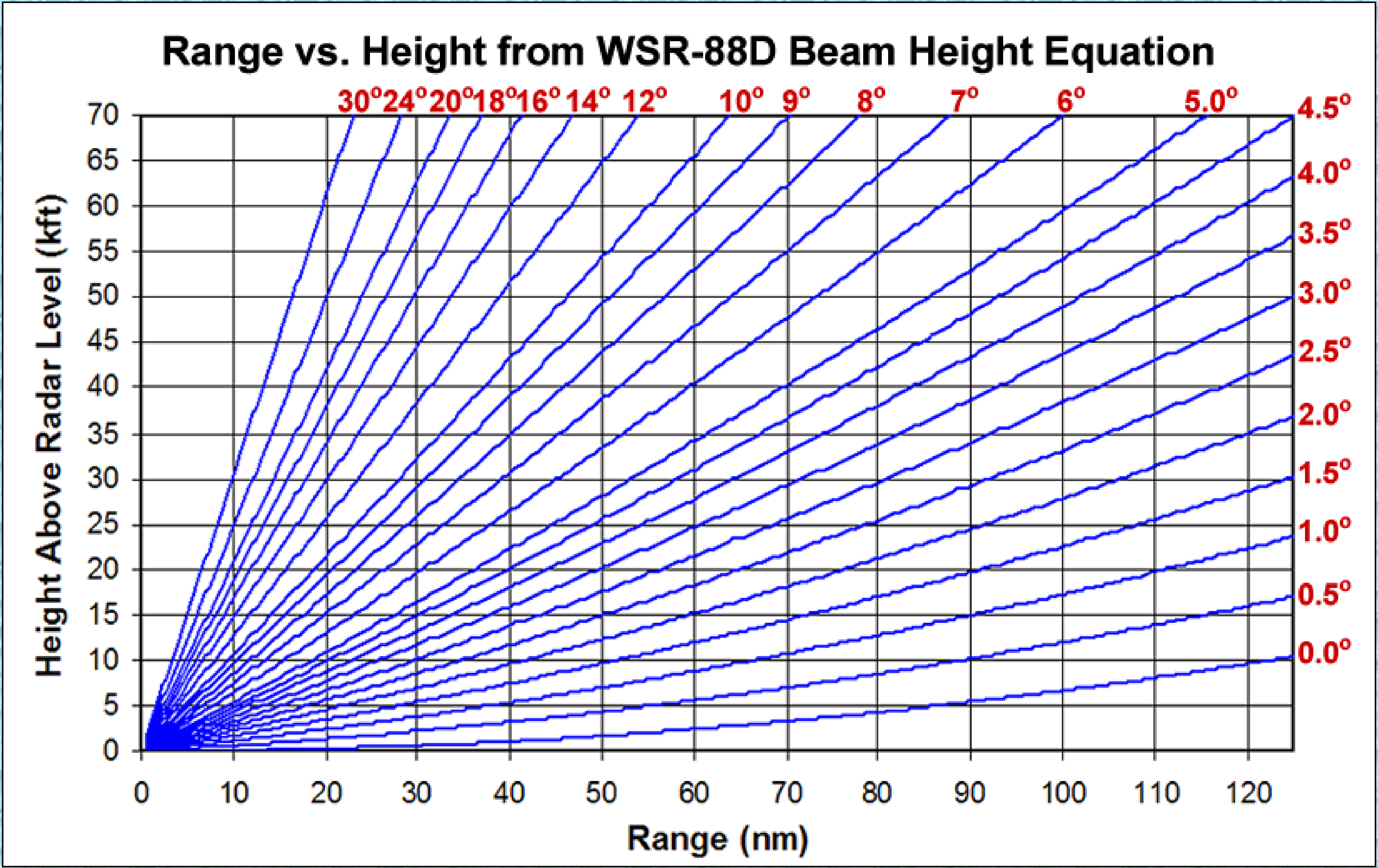


…but only a <u>fraction</u> of that energy (~0.000001 W) is 'reflected' (i.e., returned) back to the radar receiver.

Radar Beam Propagation



Differences in atmospheric density will cause the radar beam to 'bend' (i.e., refract) differently causing differences in beam centerline height from "standard".



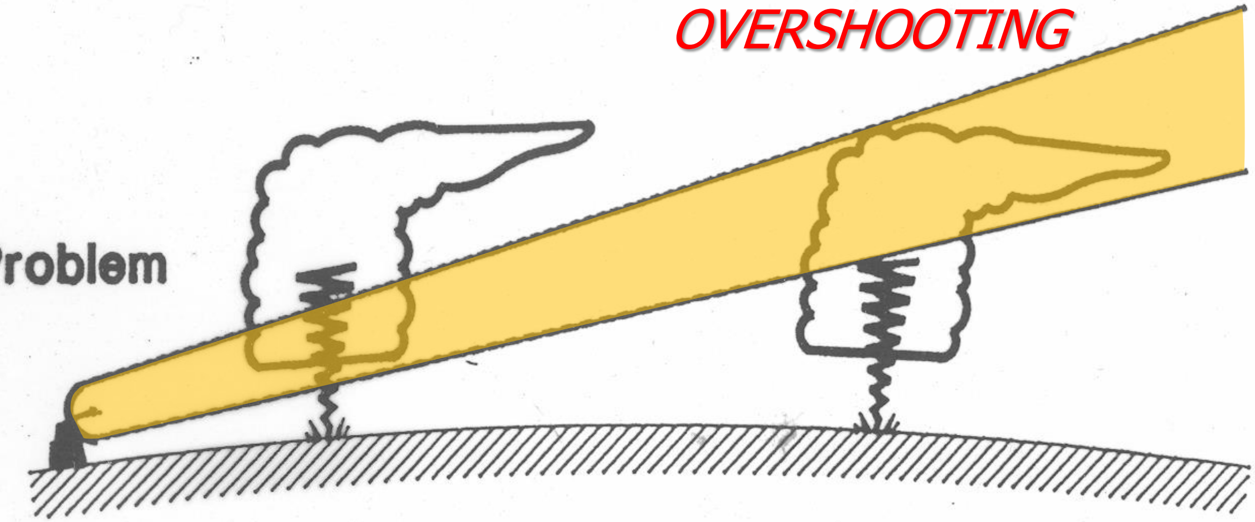
-- RHI diagrams assume standard refractivity index --

Radar Beamwidth Calculator

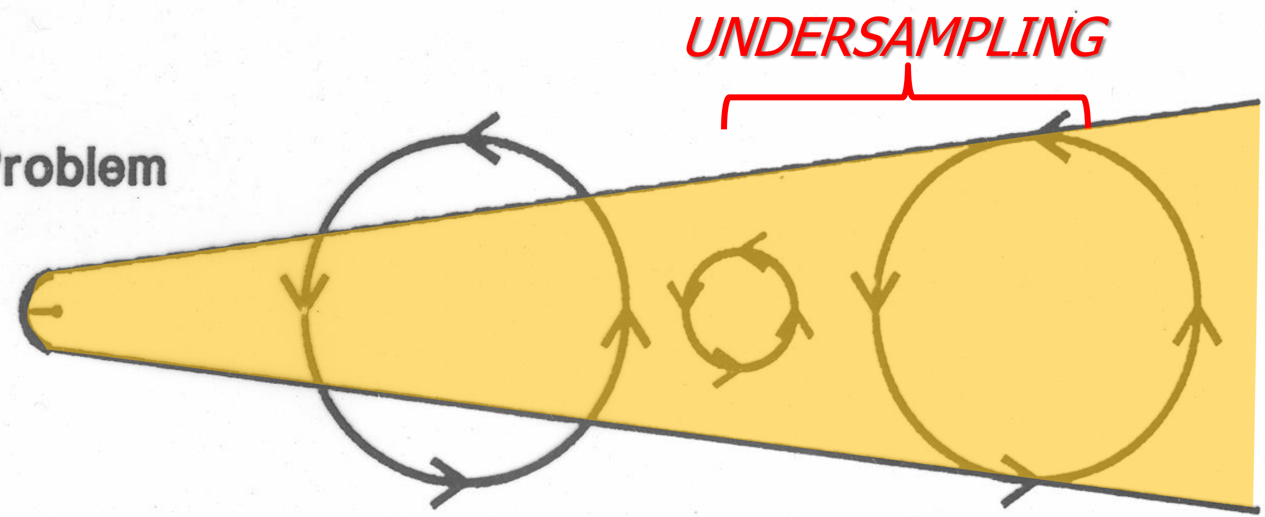
http://www.wdtb.noaa.gov/tools/misc/beamwidth/beamwidth.html

LIMITATIONS OF RADAR

1. Radar Horizon Problem



2. Aspect Ratio Problem



Radar Equation for Non-Isotropic Radiator

$$P_r \quad = \qquad\qquad\qquad \frac{Z}{R^2}$$

P_r = power returned to the radar from a target (watts)	P_t = peak transmitted power (watts)
G = antenna gain	θ = angular beamwidth
H = pulse length	π = pi (3.141592654)
K = physical constant (target character)	L = signal loss factors associated with attenuation and receiver detection
Z = target reflectivity	λ = transmitted energy wavelength
R = target range	

Everything inside the brackets is "known" and is, therefore, a "constant", which means that power returned to the radar by a target is *directly related to the reflectivity factor*, Z, and *indirectly related to the range*, R.

Radar Equation for Non-Isotropic Radiator

$$\overline{P}_r = \frac{P_t G^2 \theta^2 \pi^3 h |K|^2}{1024 \ln 2 R^2 \lambda^2} \sum_i D_i^6$$

$$\overline{P}_r = \frac{P_t G^2 \theta^2 \pi^3 |K|^2 Z}{1024 \ln 2 \lambda^2 R^2}$$

RETURNED POWER

Returned Power: $P_r \propto Diameter^6$

number of drops of diameter D

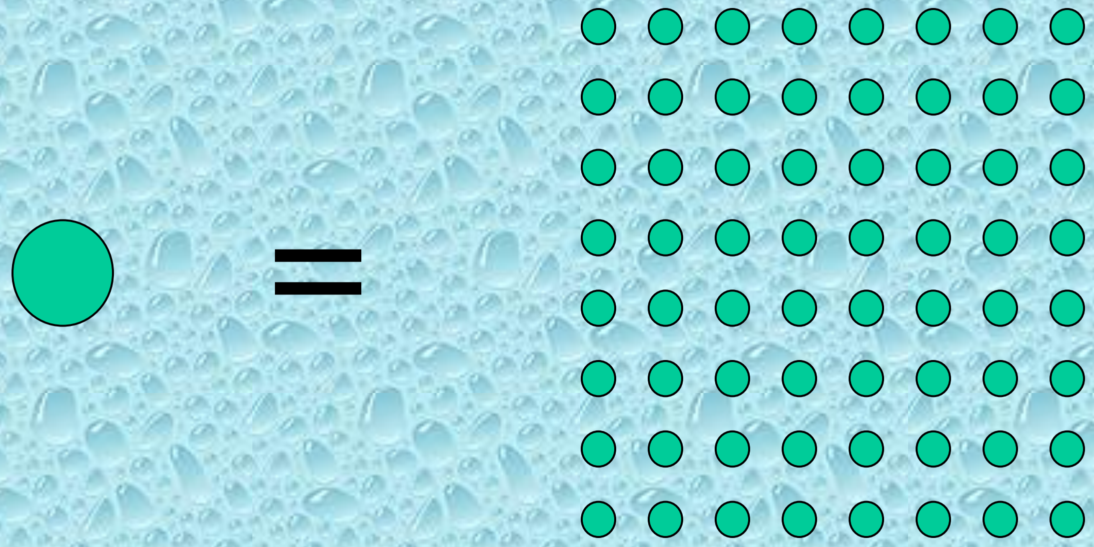
drop diameter(s)

Reflectivity factor: $Z = \sum n_i \times D_i^6$

(for Rayleigh scattering, D << λ)

- **Only a small increase in drop diameter can result in a large increase in reflectivity (Z).**
- **Large drops return the most power…but can contribute less total water mass!**

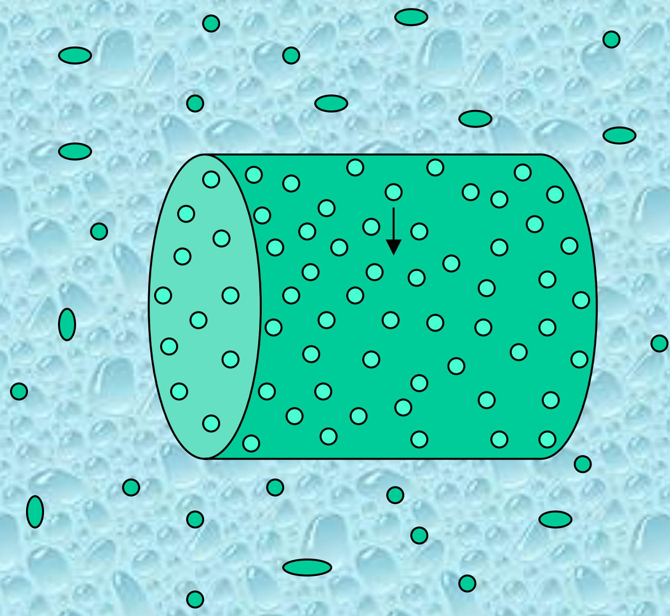
Effect of Drop Size on Reflectivity



One 1/4-inch diameter drop returns as much energy as 64 drops of 1/8-inch diameter.

However, one 1/4-inch diameter drop has a volume of only 0.065 in^3, whereas sixty-four 1/8-inch diameter drops yield a volume of 0.52 in^3 …or **8 times as much total water mass**!

What would Z be for 64 drops having a diameter of only 1 mm ?

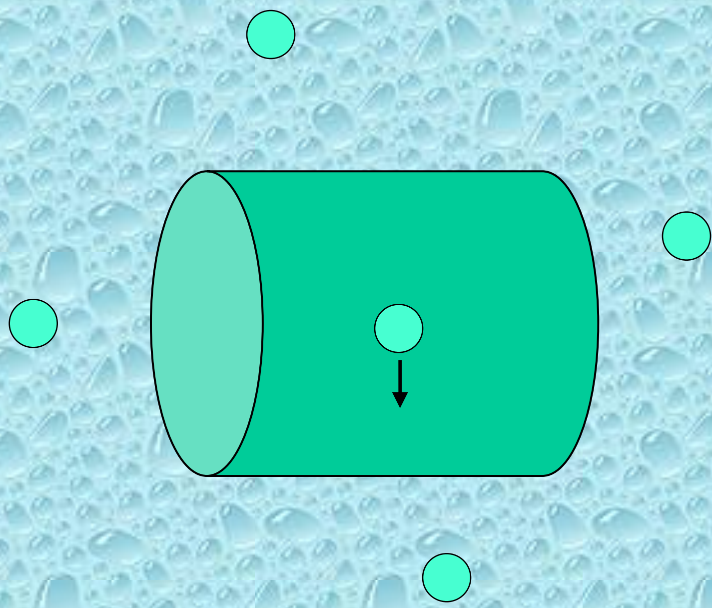


$$Z = \sum n_i \times D_i^6$$

$$Z = \sum 64 \times 1^6$$

$$Z = 64 \frac{mm^6}{m^3}$$

Now, what would *Z* be for only <u>one drop</u> having a diameter of 3 mm ?



$$Z = \sum n_i \times D_i^6$$

$$Z = \sum 1 \times 3^6$$

$$Z = 729 \frac{mm^6}{m^3}$$

REFLECTIVITY DILEMMA

The one 3-mm diameter rain drop returns more power and produces a larger reflectivity than the sixty-four 1-mm drops do… yet the one 3-mm diameter rain drop *contains less total water mass* than the sixty-four 1-mm rain drops!

Estimating Rainfall Rate Using Radar Reflectivity Data

$$Z = \sum n_i \times D_i^6$$

Since we do not know the actual drop size distribution in a radar volume sample, we use "*equivalent reflectivity*" instead of *actual reflectivity*.

$$Z_e = \frac{P_r \times R^2}{const}$$

where, Pr = power returned

R = target range

Equivalent reflectivity

$$dBZ_e = 10 \times \log(Z_e)$$

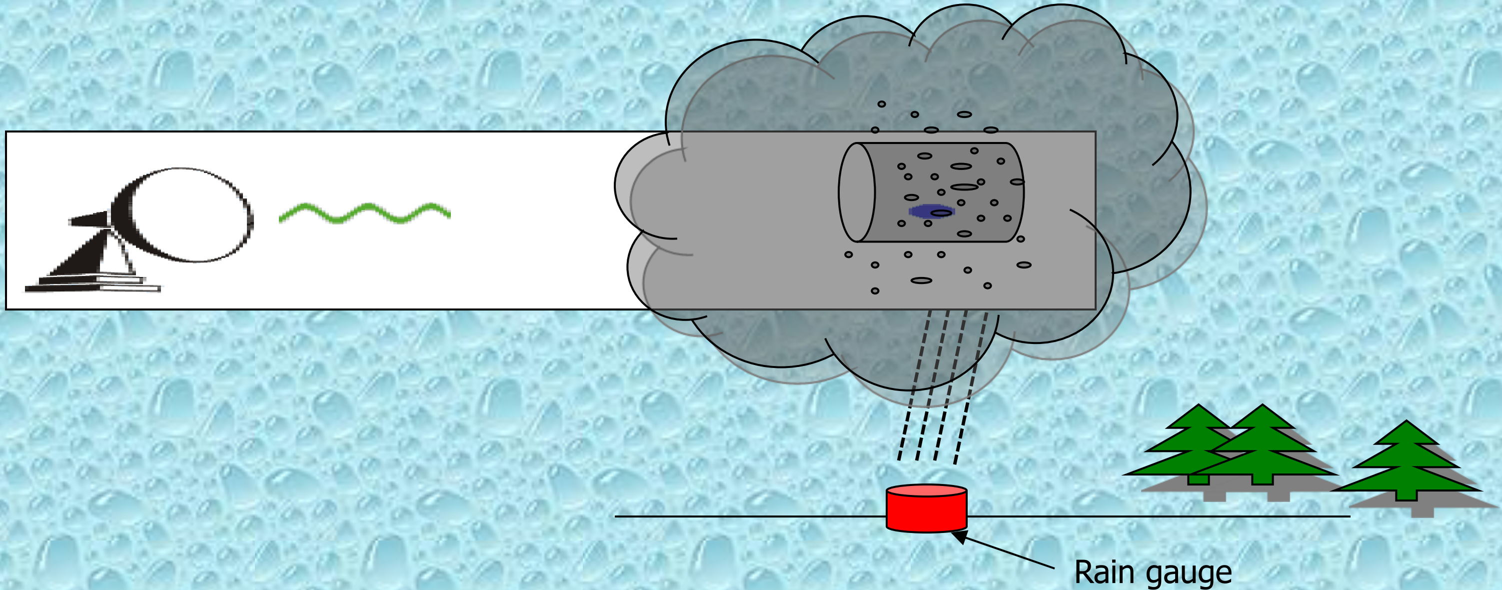
Using 10 times the logarithm of Z_e keeps the range of values of Z_e small, but still operationally useful.

$$dBZ_e = 10 \times \log(Z_e)$$

Z_e	Log Z_e	dBZ_e
10	1	10
100	2	20
1,000	3	30
10,000	4	40
100,000	5	50
1,000,000	6	60
10,000,000	7	70

Z-R or Reflectivity-Rainfall Relationships

we now have the input we need (i.e. Z_e)



Find an <u>empirical</u> relationship to estimate rainfall rate:

$$Z_e = a\,R^{\,b}$$

$$Z_e = 300\,R^{1.4}$$

Rainfall Rates (in\mm hr^{-1}) for Various *Z-R* Relationships

		WSR-88D	Conventional	Convective	Snowfall
	dBZ	$300R^{1.4}$	$200R^{1.6}$	$486R^{1.37}$	$2000R^{2}$
	20	0.02\0.05	0.03\0.76	0.01\0.25	0.01\0.25
	30	0.09\2.28	0.12\3.05	0.07\1.78	0.03\0.76
	40	0.48\12.2	0.47\11.9	0.36\9.14	0.09\2.29
	50	2.50\63.5	1.90\48.3	1.90\48.3	0.28\7.11
	55	**5.7\145**	**(55 dBZ = maximum reflectivity used for rainfall conversion by WSR-88D)**		
Probable Wet Hail Contamination	60	12.9\327	8.10\306	10.3\262	0.88\22.4
	70	67.0\1702	34.1\866	55.4\1407	2.78\70.7

Rainfall Rates (in\mm hr $^{-1}$) for WSR-88D Tropical *Z-R* Relationship

minimum radar reflectivity for determining eyewall diameter → 15

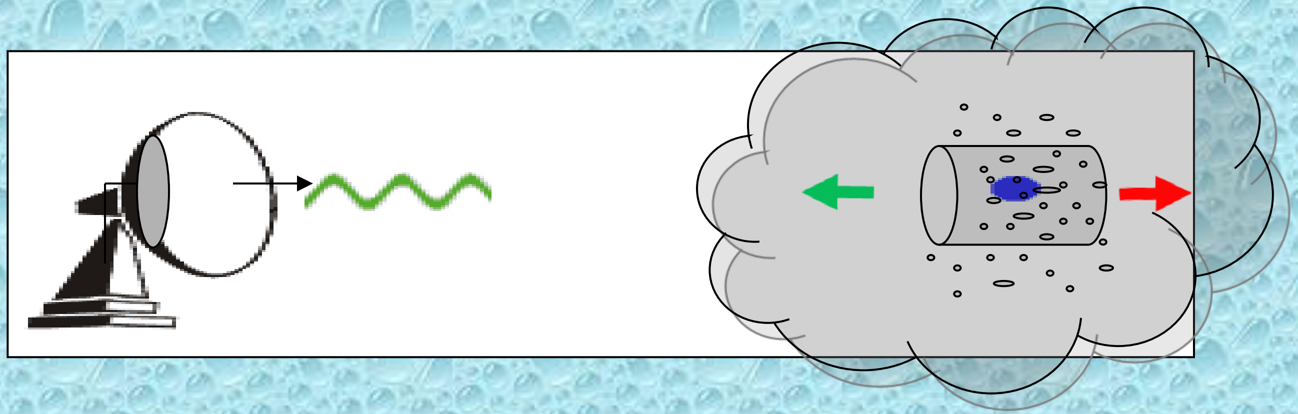
dBZ	Z	$250R^{1.2}$
15	31.6	0.01\0.18
20	100.0	0.02\0.47
25	316.2	0.05\1.22
30	1000.0	0.12\3.17
35	3162.3	0.33\8.28
40	10000.0	0.85\21.6
45	31622.8	2.22\56.5
50	100000.0	5.80\147.4
55	316227.8	15.14\384.6

$$R = \sqrt[1.2]{\frac{Z}{250}}$$

Radar Detection of Atmospheric Motion

or

Doppler Velocities



In addition to a measurement of power (reflectivity), we also have a measurement of particle <u>motion</u>.

A Doppler weather radar measures a single component of motion, but <u>only</u> ***<u>toward</u>*** or ***<u>away</u>*** from the radar.

The "Doppler Dilemma"

1. Speed of light — c
2. Wavelength — λ
3. PRF (pulse repetition frequency)

$$R_{max} = \frac{c}{2PRF}$$

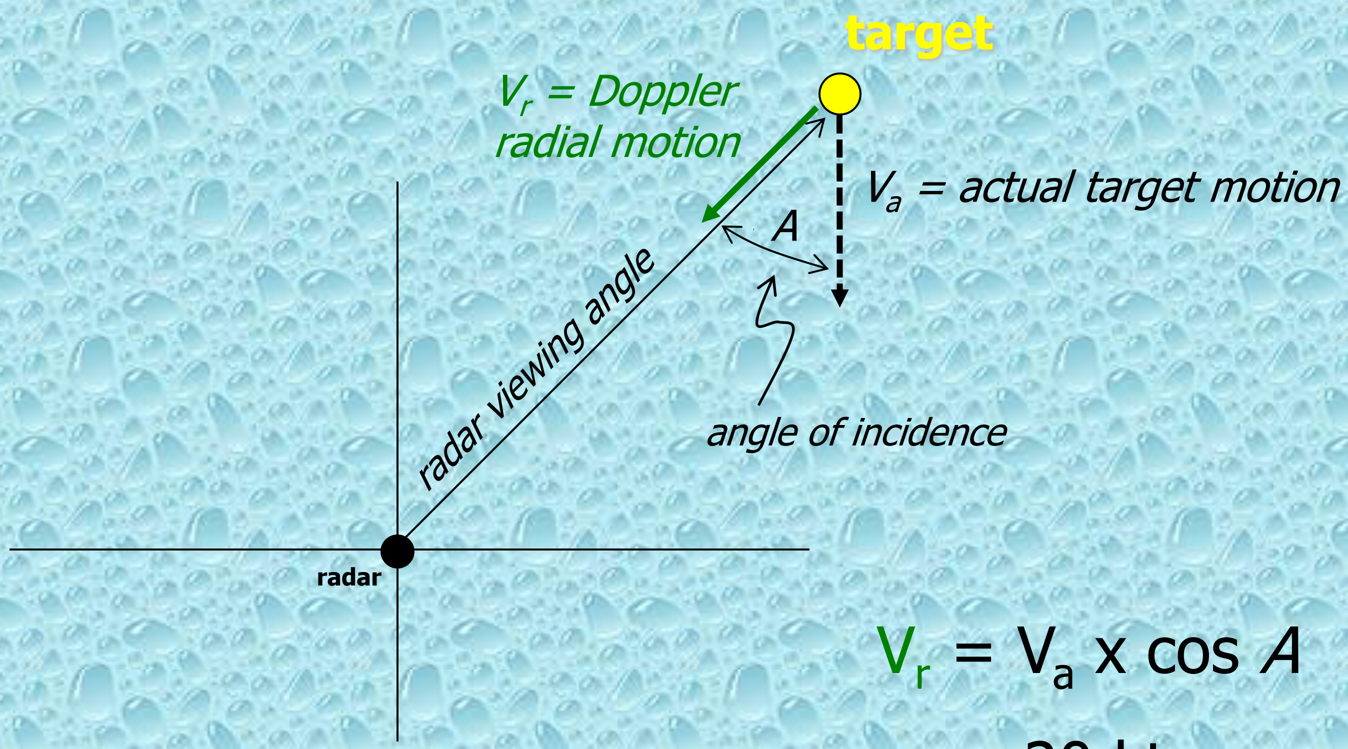
Maximum Unambiguous Range

but,

$$V_{max} = PRF\,\frac{\lambda}{4}$$

Maximum Unambiguous Velocity

Example of Actual Velocity => V_a = 20 kt



$V_r = V_a \times \cos A$

$= 20 \text{ kt} \times \cos 45^o$

$= 20 \times .707$

$V_r = 14.14$ kt

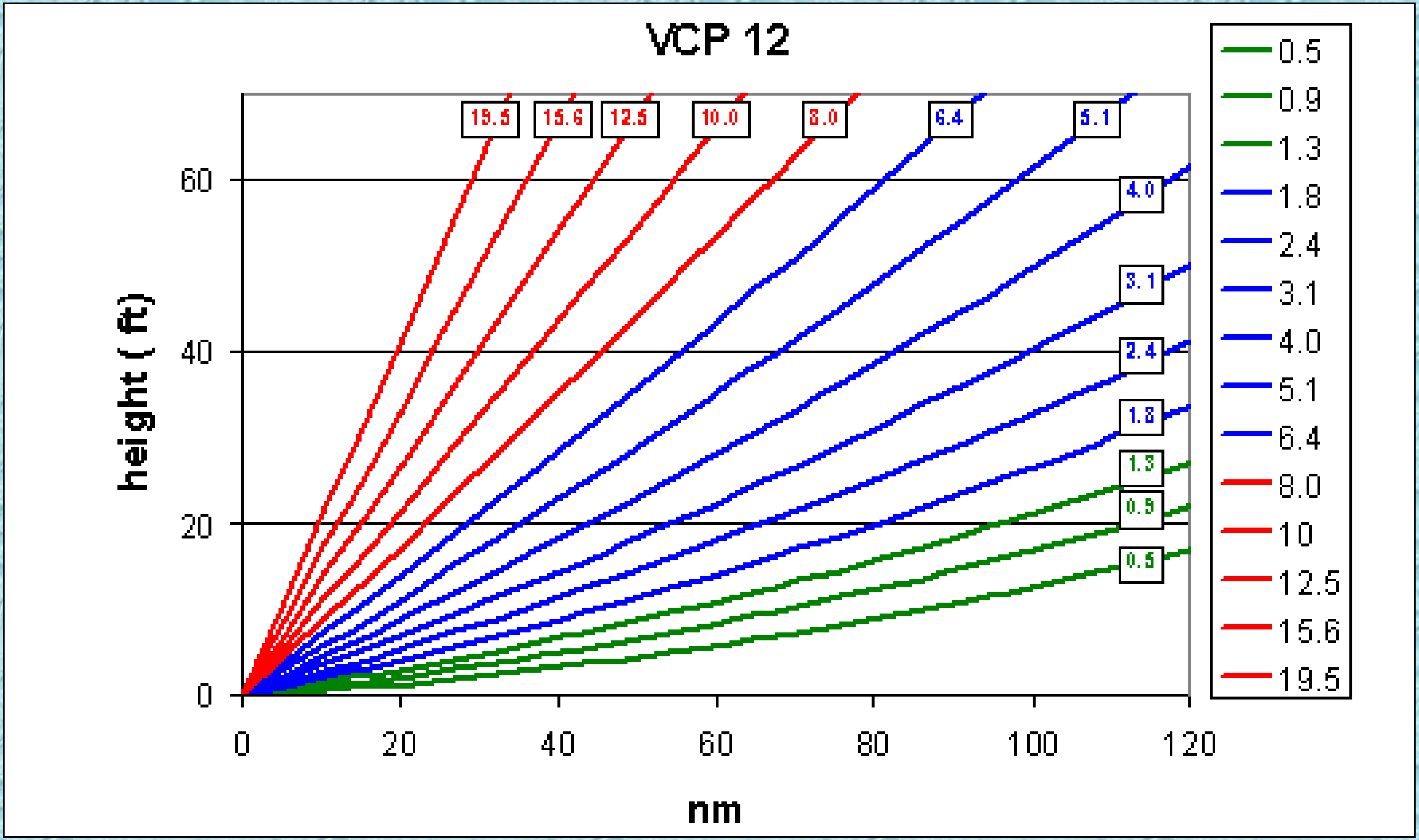
Part 2

NOAA WSR-88D Doppler Weather Radar

- Weather Surveillance Radar 1988-Doppler
- first working prototype installed in Norman, OK in 1988
- This is the radar used operationally by the U.S. National Weather Service
- NEXRAD is the name of the federal procurement program which developed the WSR-88D

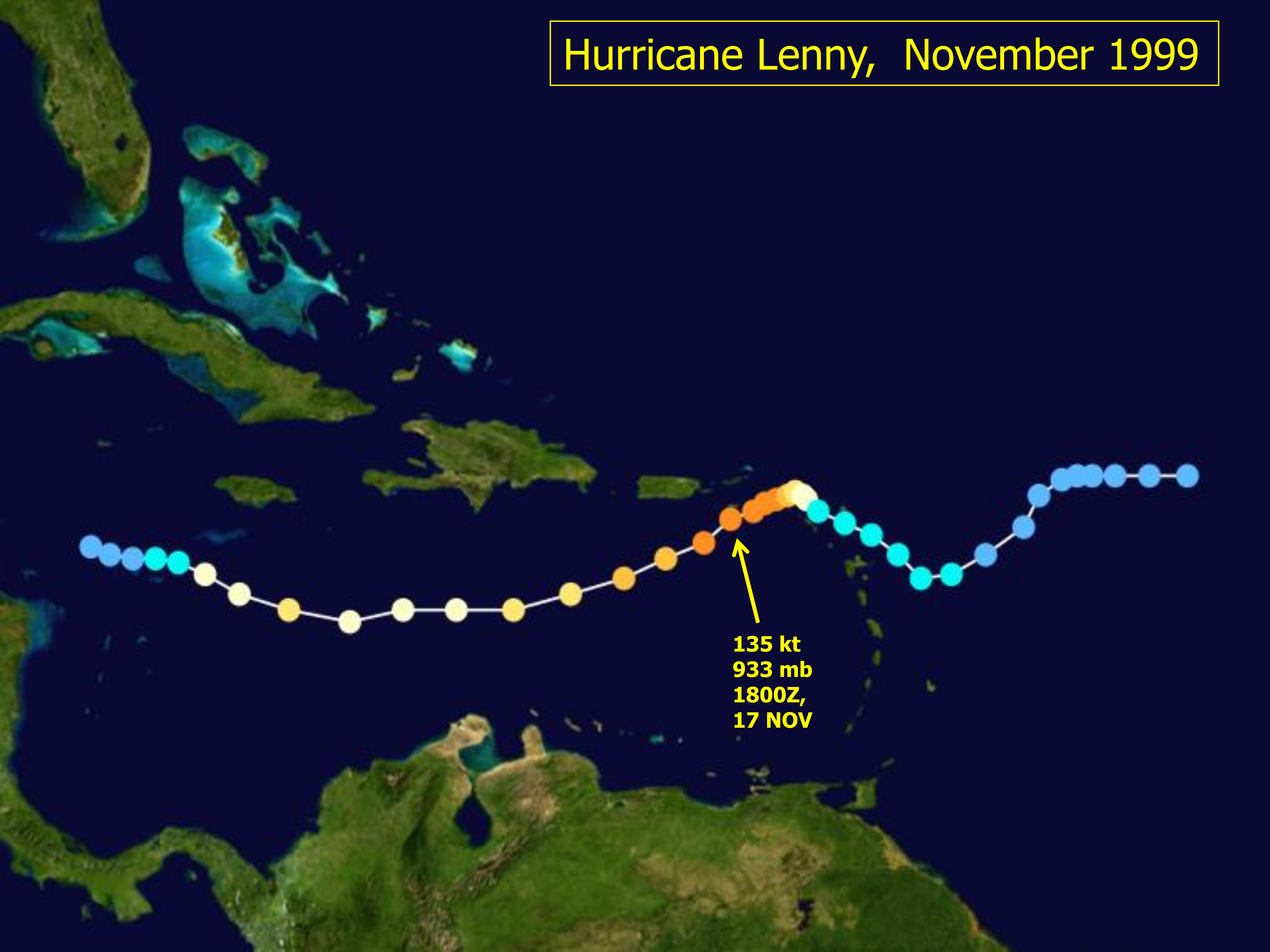

Andrew Hatzos NWS Cincinnatti OH

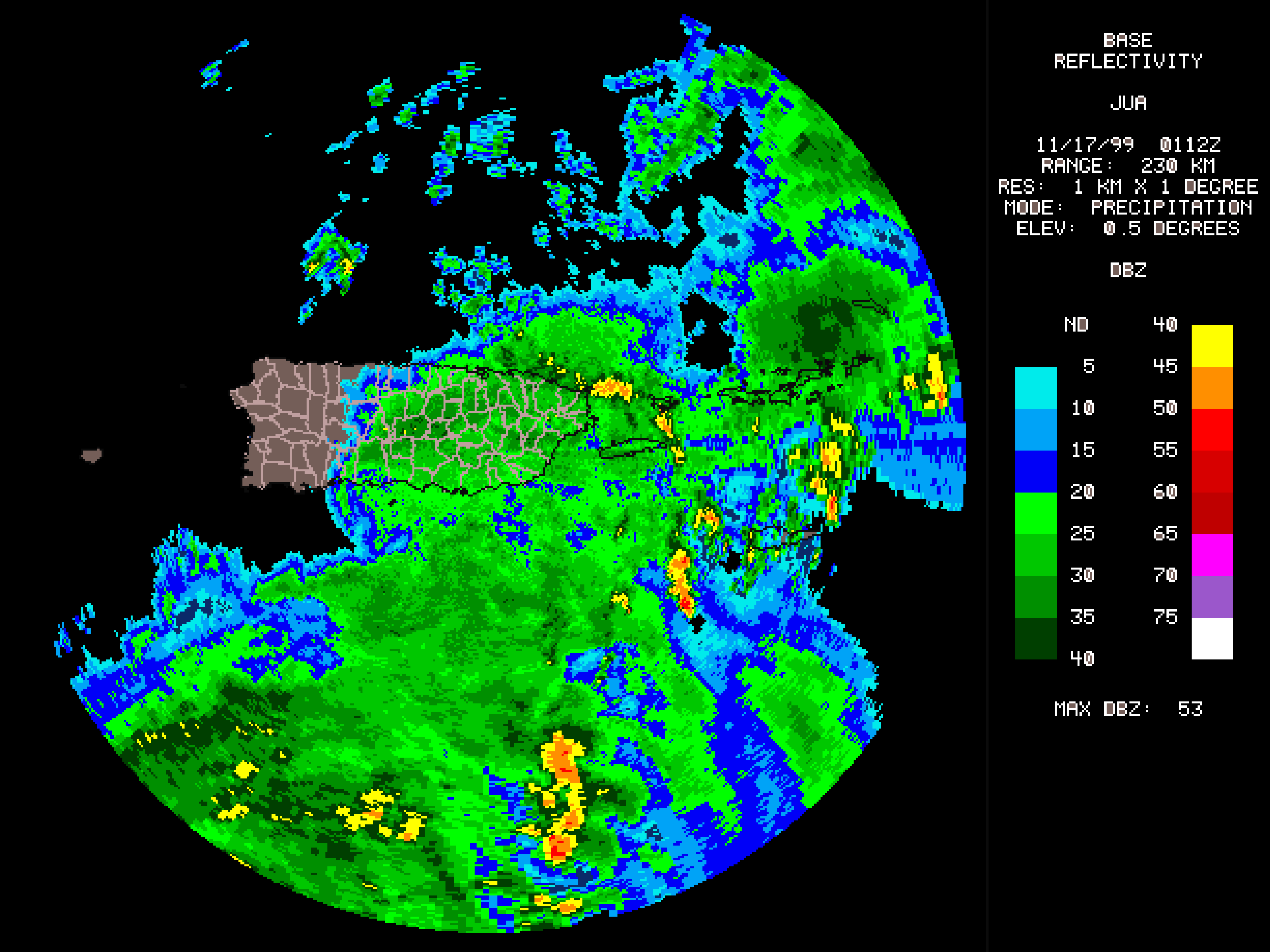
WSR-88D radar utilizes 9 different Volume Scans to collect reflectivity and Doppler velocity data



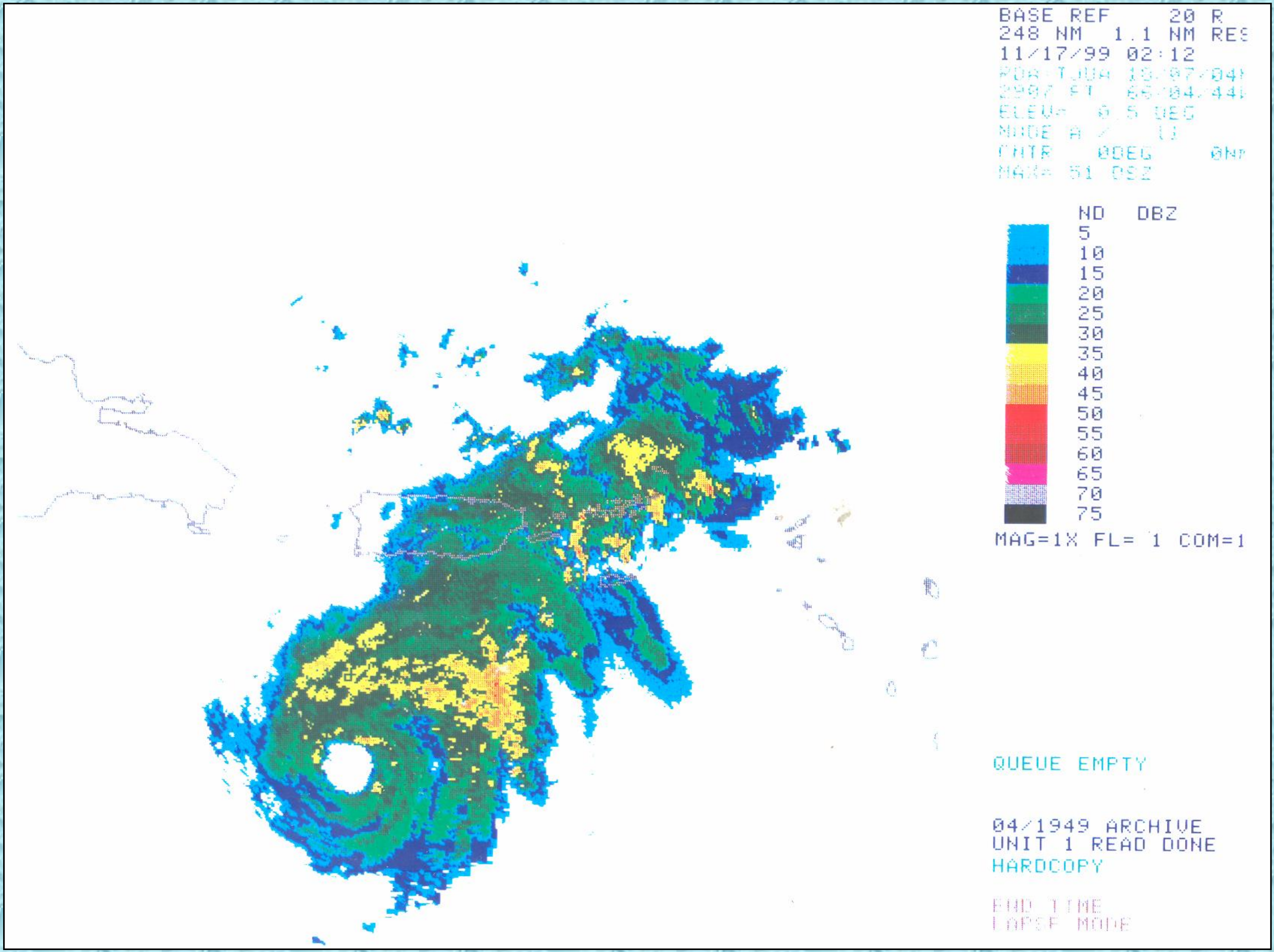
http://www.wdtb.noaa.gov/courses/dloc/topic2/rda/vcp.html

Hurricane Lenny, November 1999

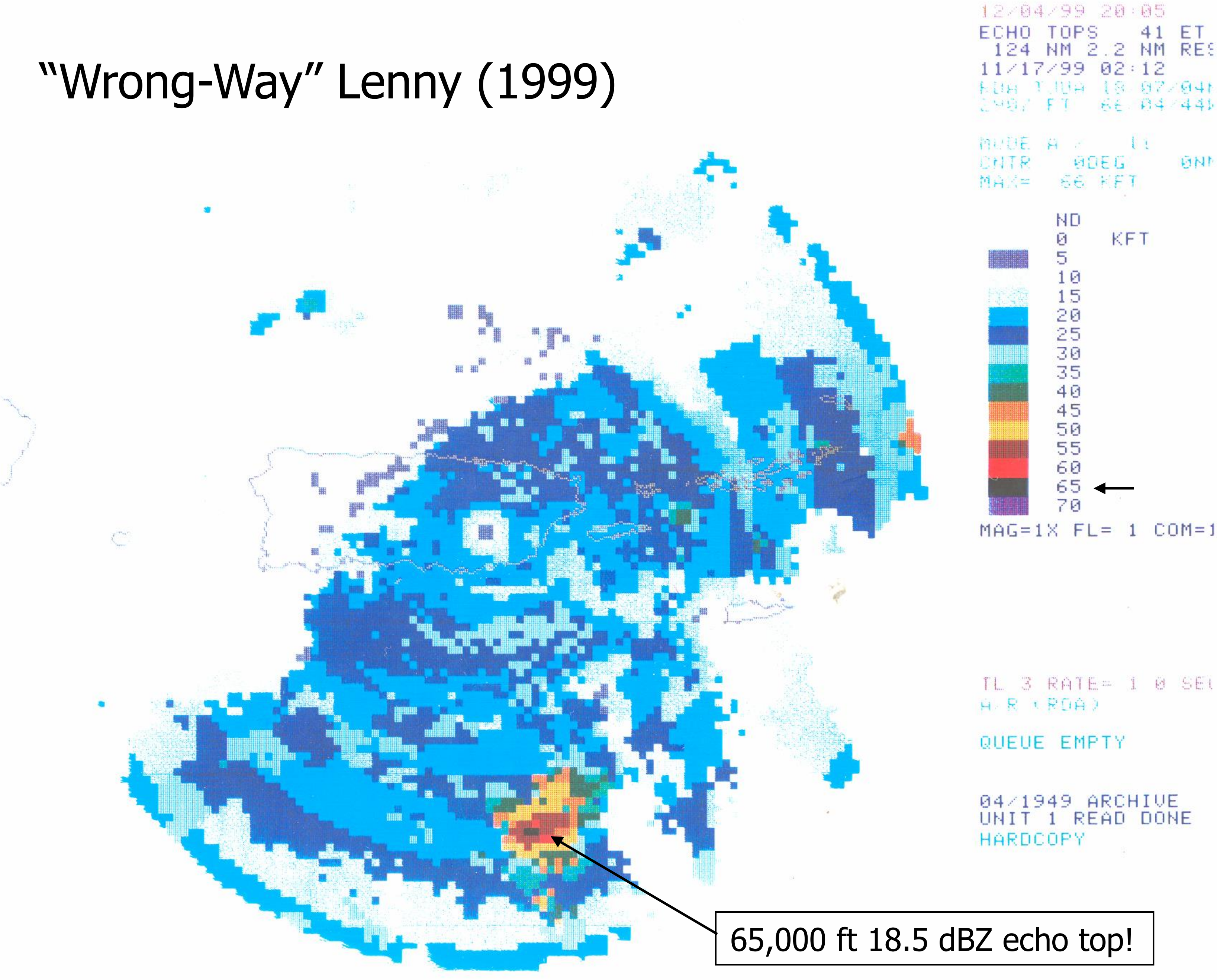



BASE
REFLECTIVITY
JUA
11/17/99 0112Z
RANGE: 230 KM
RES: 1 KM X 1 DEGREE
MODE: PRECIPITATION
ELEV: 0.5 DEGREES
DBZ
ND
5
10
15
20
25
30
35
40
40
45
50
55
60
65
70
75
MAX DBZ: 53

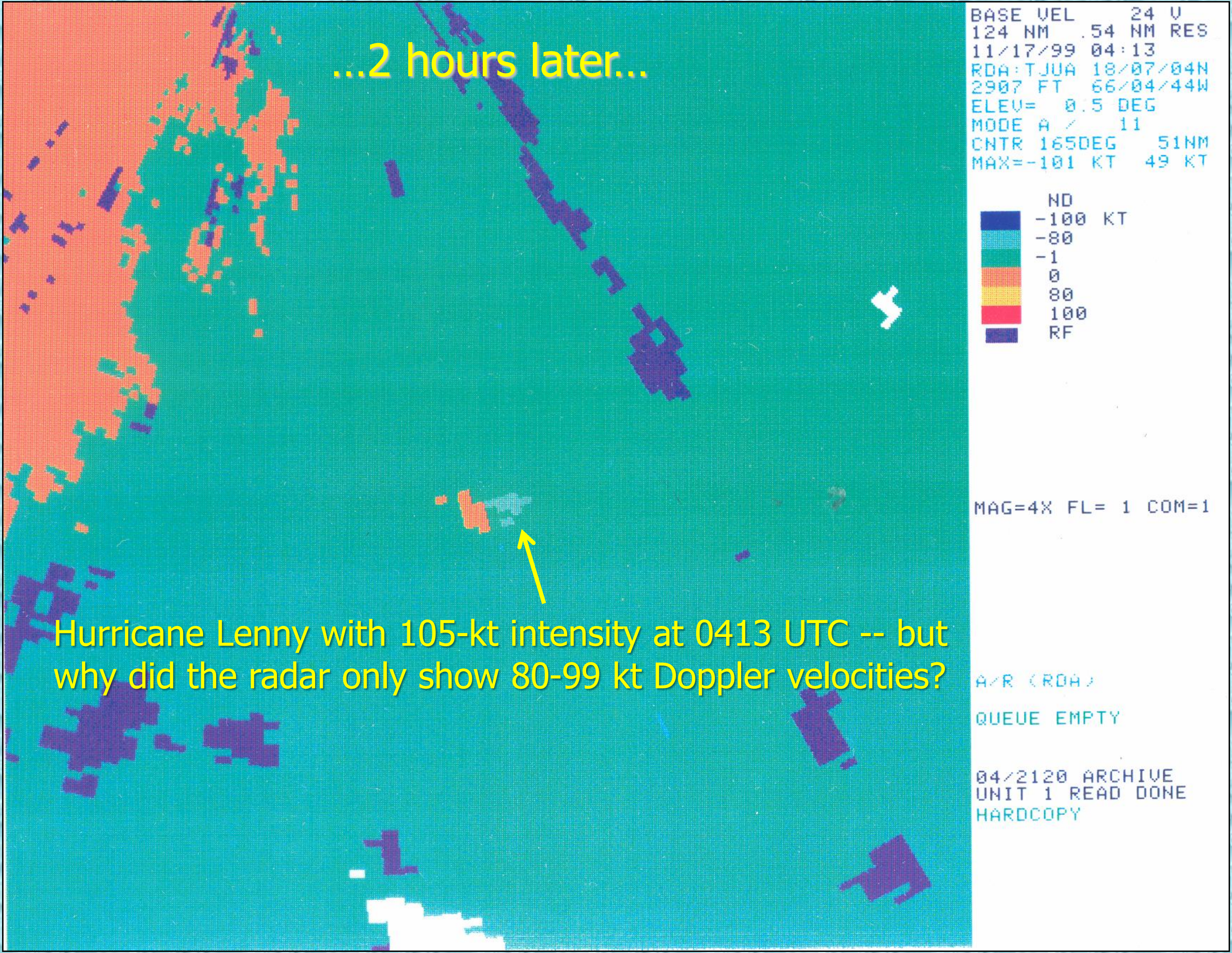
Hurricane Lenny (1999) – 100 kt intensity at 0212 UTC



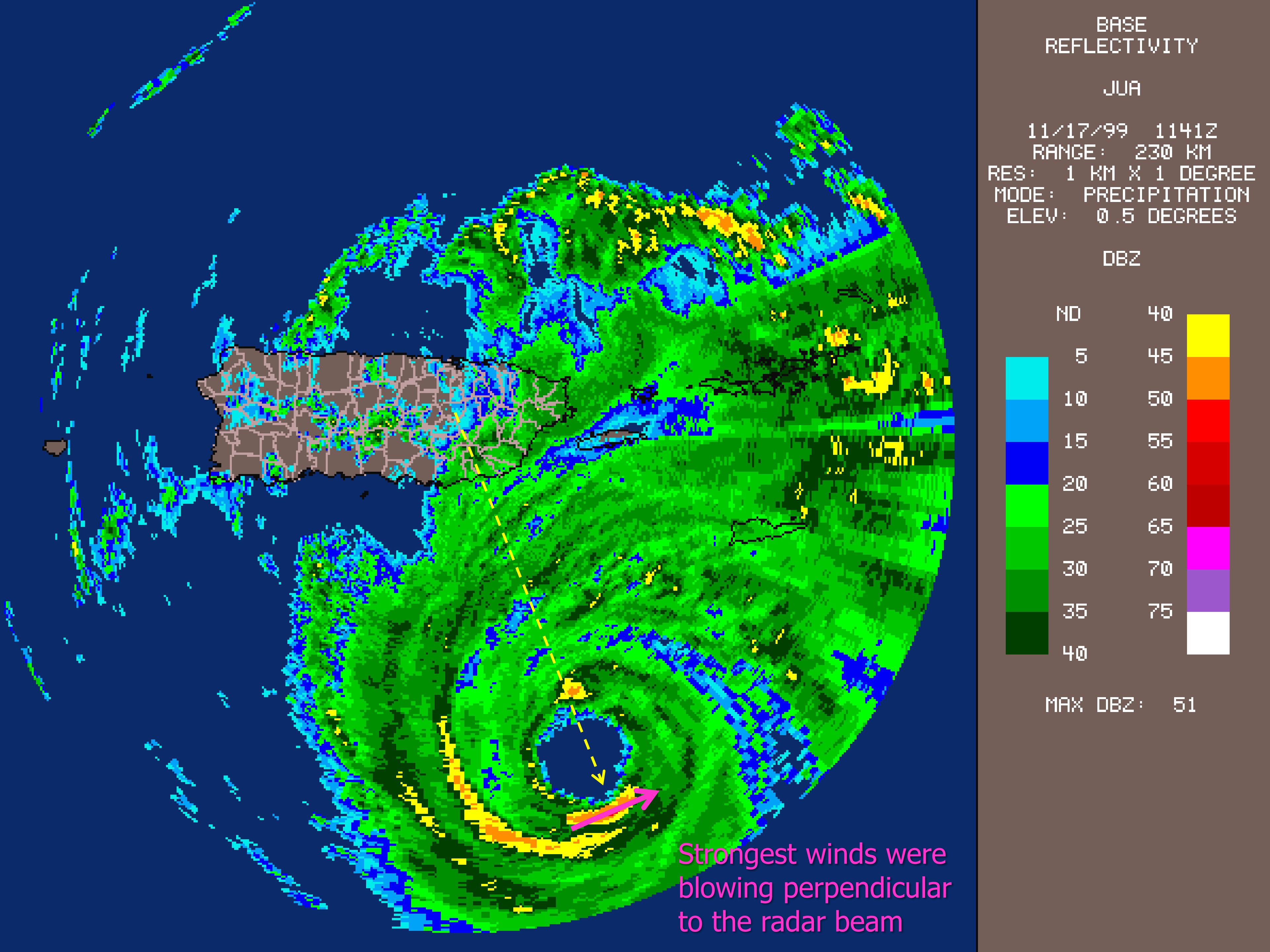
“Wrong-Way” Lenny (1999)

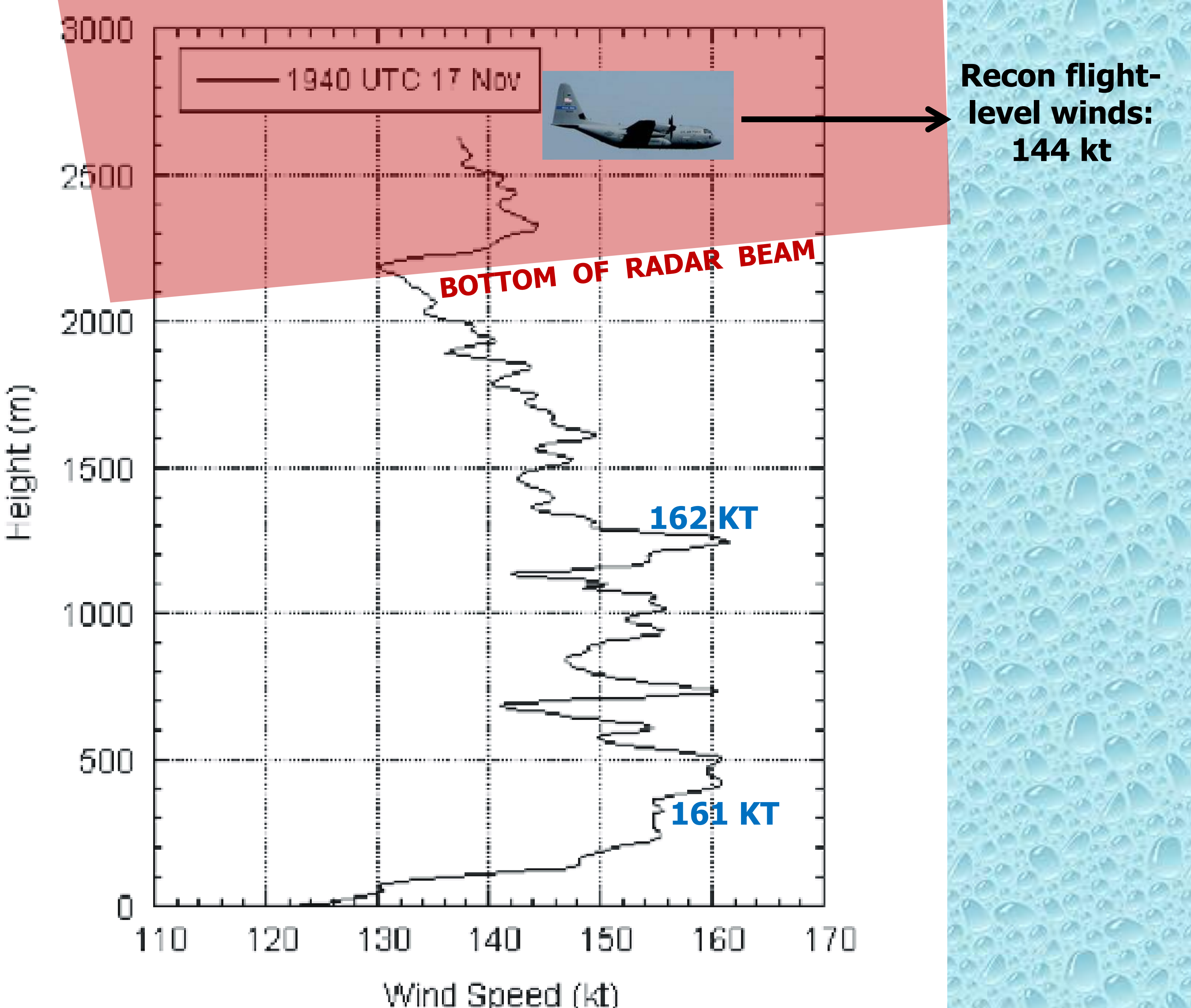


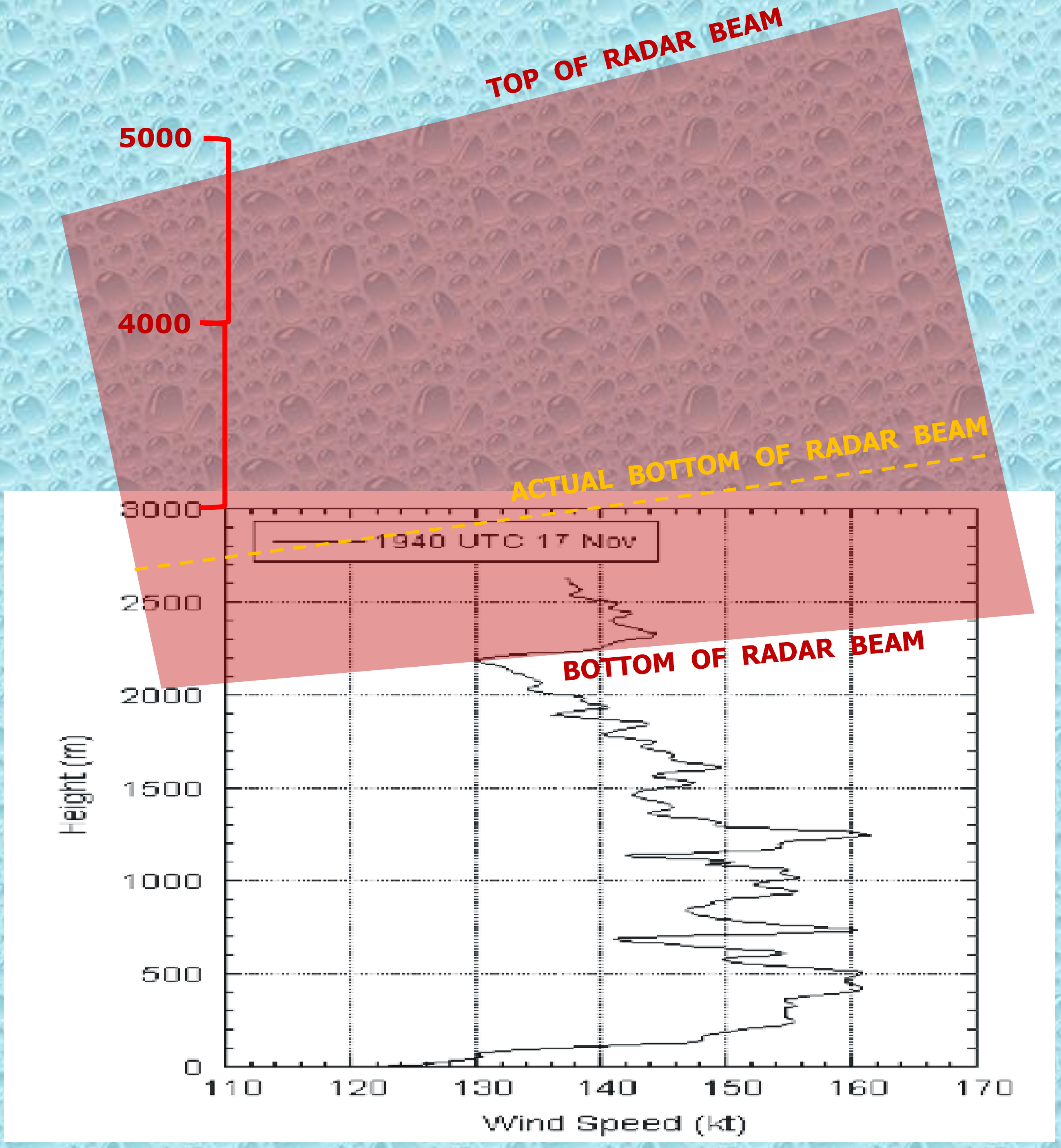
…2 hours later…



Hurricane Lenny with 105-kt intensity at 0413 UTC -- but why did the radar only show 80-99 kt Doppler velocities?


BASE
REFLECTIVITY
JUA
11/17/99 1141Z
RANGE: 230 KM
RES: 1 KM X 1 DEGREE
MODE: PRECIPITATION
ELEV: 0.5 DEGREES
DBZ
ND
5
10
15
20
25
30
35
40
40
45
50
55
60
65
70
75
MAX DBZ: 51
Strongest winds were blowing perpendicular to the radar beam


1940 UTC 17 Nov
BOTTOM OF RADAR BEAM
162 KT
161 KT
Height (m)
Wind Speed (kt)
3000
2500
2000
1500
1000
500
0
110
120
130
140
150
160
170
Recon flight-level winds: 144 kt

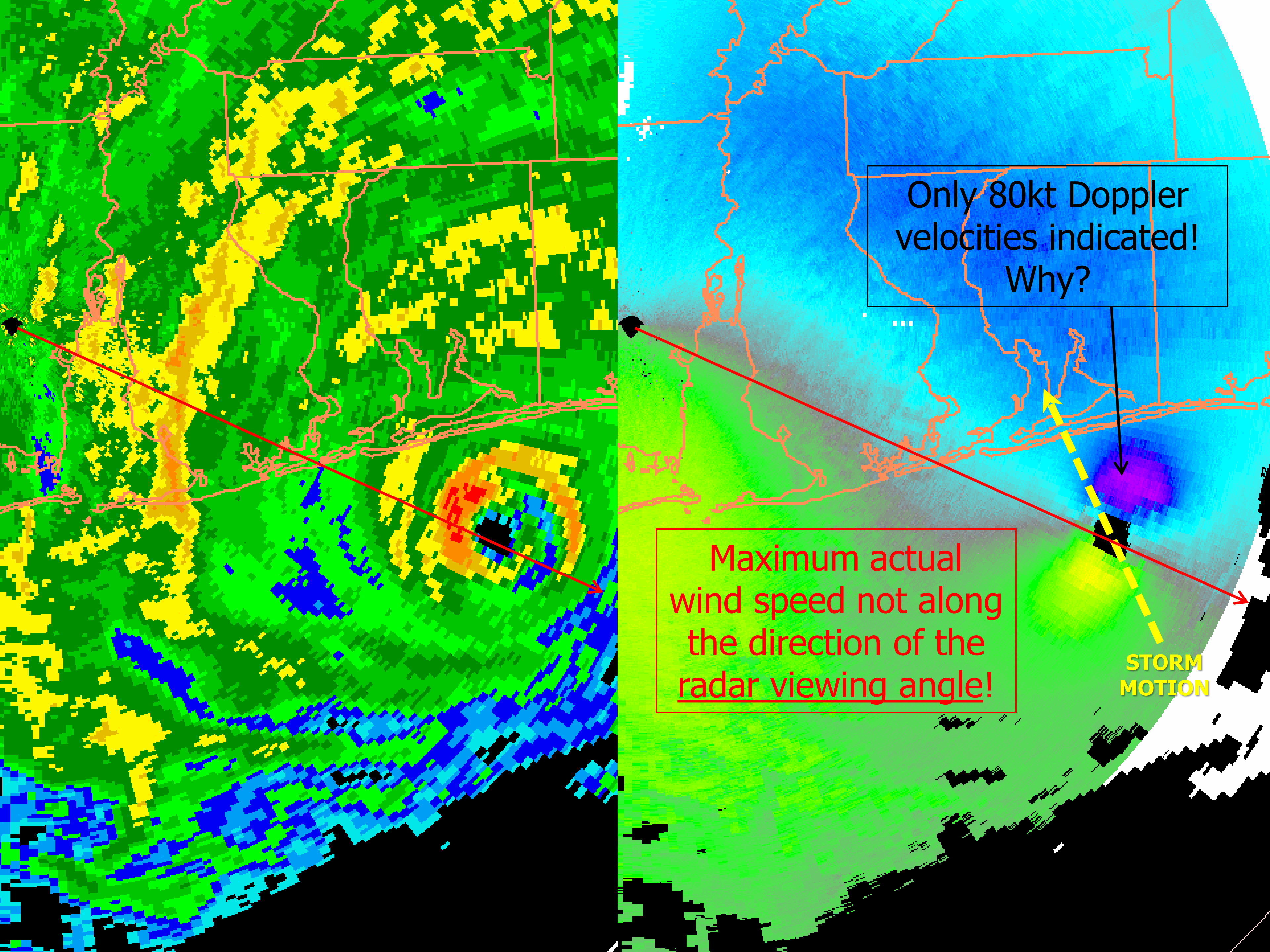


Radar beam is <u>overshooting and not sampling strongest winds</u> below 1,500 meters altitude at 0.5^o elevation angle and at sea-level.

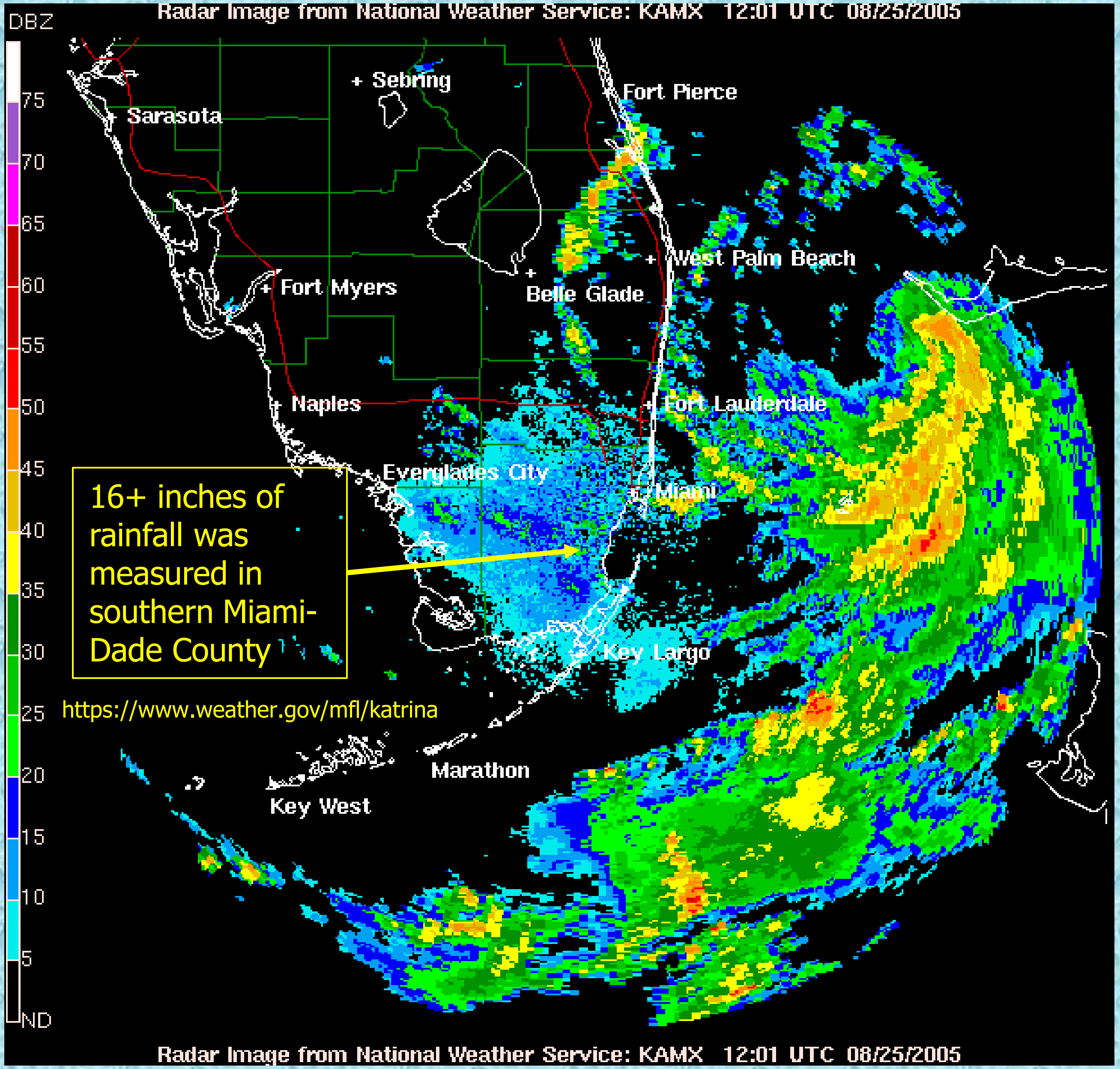
However, when San Juan radar antenna altitude of 860 meters is factored in, the bottom of the radar beam is <u>actually</u> at 3,000 meters ASL!

Example -- Hurricane Dennis (2005)

105 kt intensity at landfall in the Florida panhandle as determined by recon aircraft


Only 80kt Doppler velocities indicated! Why?
Maximum actual wind speed not along the direction of the radar viewing angle!
STORM MOTION

Hurricane Katrina (2005) making landfall near Broward & Miami-Dade County line and later moved over the NHC



Hurricane Katrina radar observations from NHC – 25 AUG 2005

2005,AUG,25,1700,26.18,79.51,F,CLOSED CIRCULATION WITH DRY SLOT TO N AND W.,RM,KAMX

2005,AUG,25,1728,26.19,79.50,F,MAX WND 65 KT S QUAD AT 4730 FT,RM,KAMX

2005,AUG,25,1801,26.16,79.54,F,MAX WND 77 KT S QUAD AT 5075 FT,RM,KAMX

2005,AUG,25,1829,26.16,79.63,F,WEAK REF NW SEMICIRCLE...MAX WND 75 KT SE QUAD,RM,KAMX

2005,AUG,25,1902,26.14,79.67,F,80 KTS S OF CTR AT 3900 FT,RM,KAMX

2005,AUG,25,1929,26.14,79.74,F,85 KT MAX S QUAD AT 3417 FT JUST S OF CTR,RM,KAMX

2005,AUG,25,2002,26.07,79.84,F,CENTER RAGGED CMA GOOD ZERO ISODOP,CJM,KAMX

2005,AUG,25,2030,26.00,79.90,G,INBOUND MAX OVER SE BROWARD 75 KT 2300',CJM,KAMX

2005,AUG,25,2058,25.98,79.95,G,STRONGEST CONV S EYEWALL KEY BISCAYNE AREA,CJM,KAMX

2005,AUG,25,2134,25.99,79.96,G,CENTRAL CONV BECOMING MORE SYMMETRICAL,CJM,KAMX

2005,AUG,25,2204,25.97,80.03,G,- -,CJM,KAMX

2005,AUG,25,2231,25.96,80.10,G, CENTER OVER COAST BROWARD-DADE COUNTY LINE,CJM,KAMX

2005,AUG,25,2304,25.96,80.16,G,HIGHEST WINDS OFFSHORE ABOUT 70 KT 1500',CJM,KAMX

2005,AUG,25,2332,25.89,80.24,G,- -,CJM,KAMX

2005,AUG,26,0000,25.88,80.31,G,- - ,CJM,KAMX

2005,AUG,26,0034,25.78,80.39,G,NHC IN EYE - CALM OUTSIDE,CJM,KAMX

2005,AUG,26,0101,25.73,80.46,G,75 KT INBOUND OVER CENTRAL DADE 700 FT ,CJM,KAMX

2005,AUG,26,0126,25.70,80.53,G,- - ,CJM, KAMX

2005,AUG,26,0201,25.64,80.60,G,TIGHT VELOCITY COUPLET STILL EVIDENT IN VEL ,CJM,KAMX

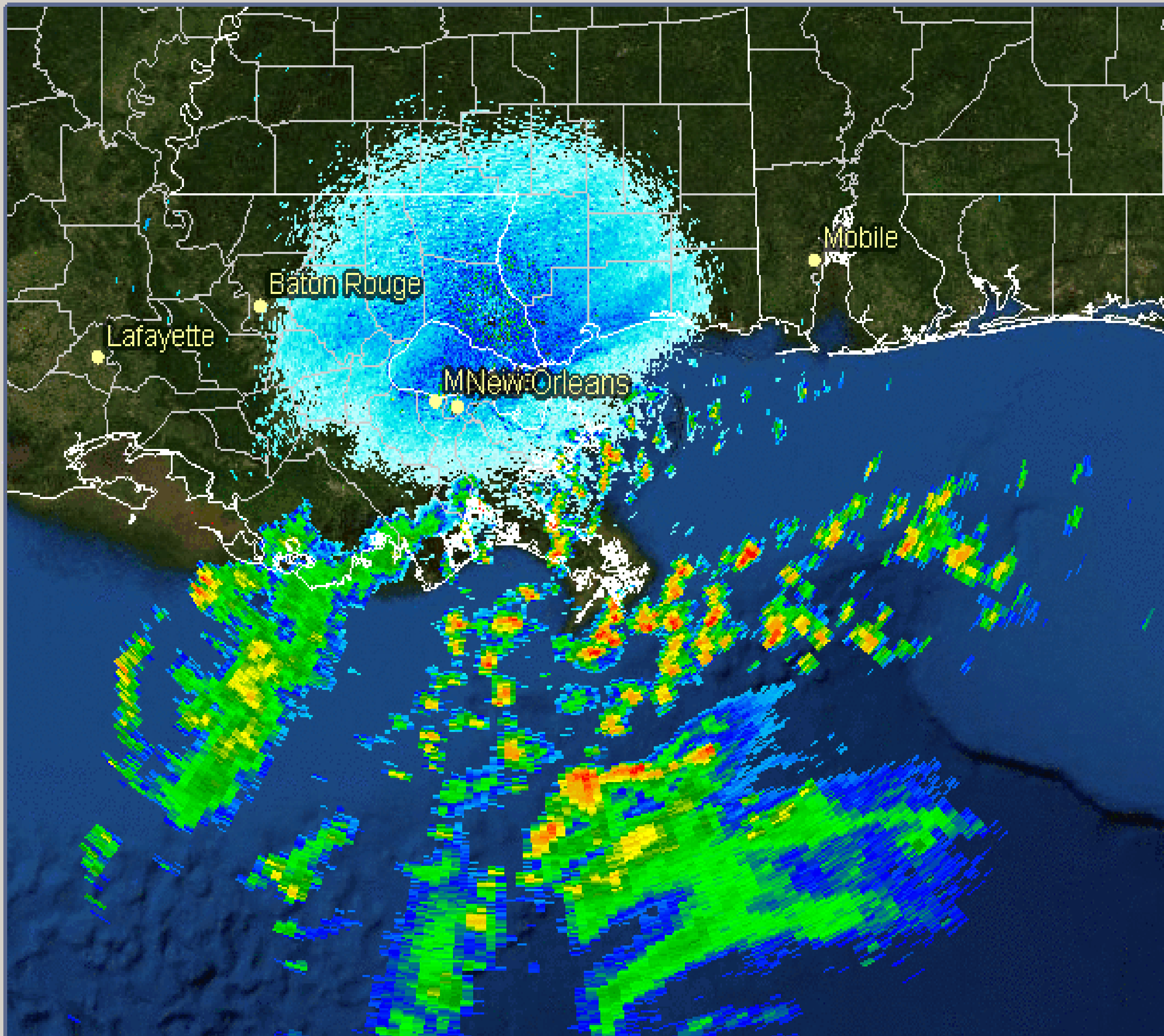
2005,AUG,26,0228,25.61,80.71,G,- - ,CJM,KAMX

2005,AUG,26,0301,25.58,80.82,G,80 KT AT 900 FT OUTBOUND,CJM,KAMX

2005,AUG,26,0326,25.56,80.93,G,74 KT AT 1600 FT,HDC,KAMX

Example -- Hurricane Katrina (2005)

Landfall along the southeast Louisiana coast



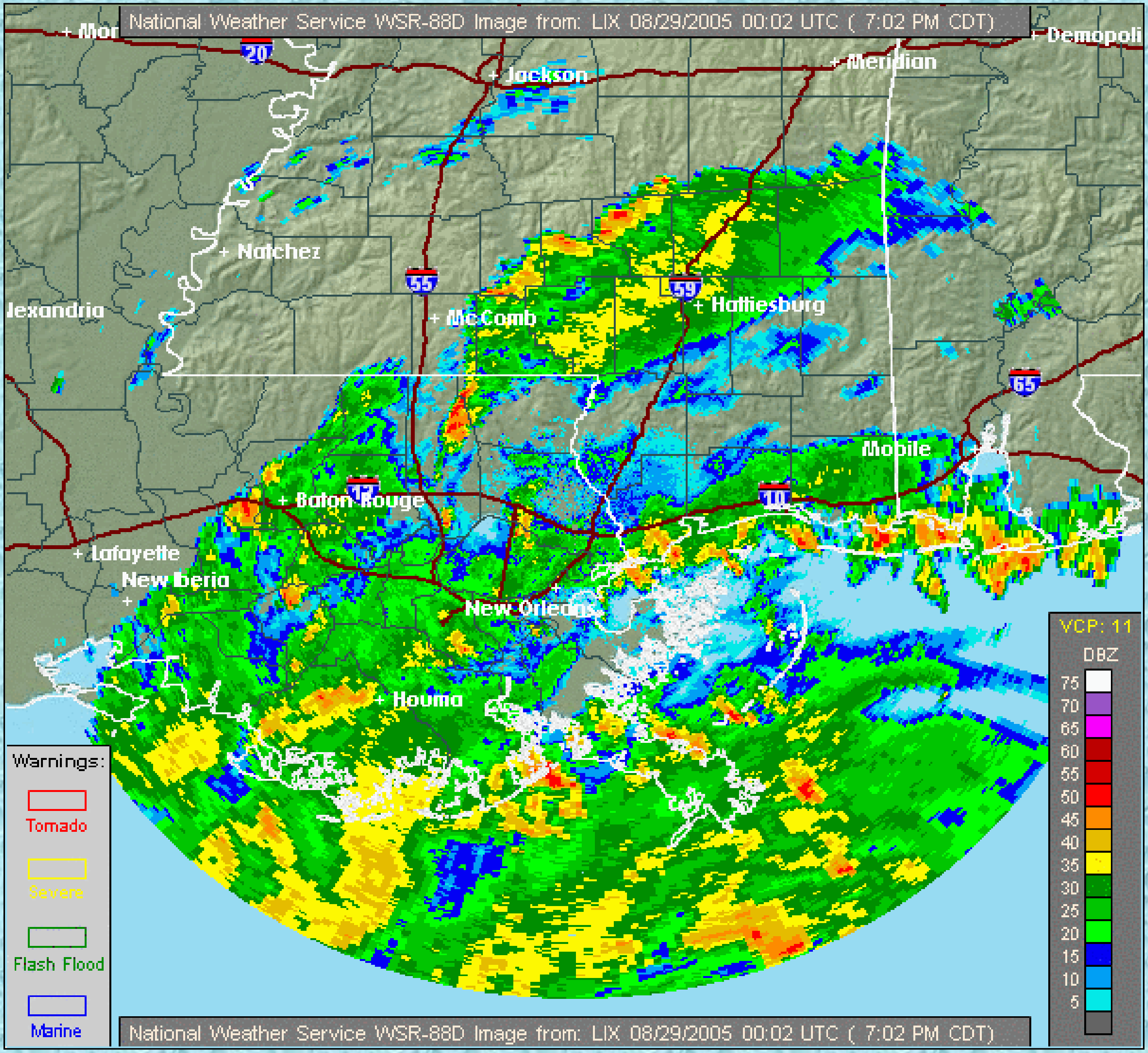
NEXRAD LEVEL-II
KLIX - NEW ORLEANS, LA
08/28/2005 17:04:58 GMT
LAT: 30/20/13 N
LON: 89/49/33 W
ELEV: 24 FT
VCP: 11

REFLECTIVITY
ELEV ANGLE: 0.38

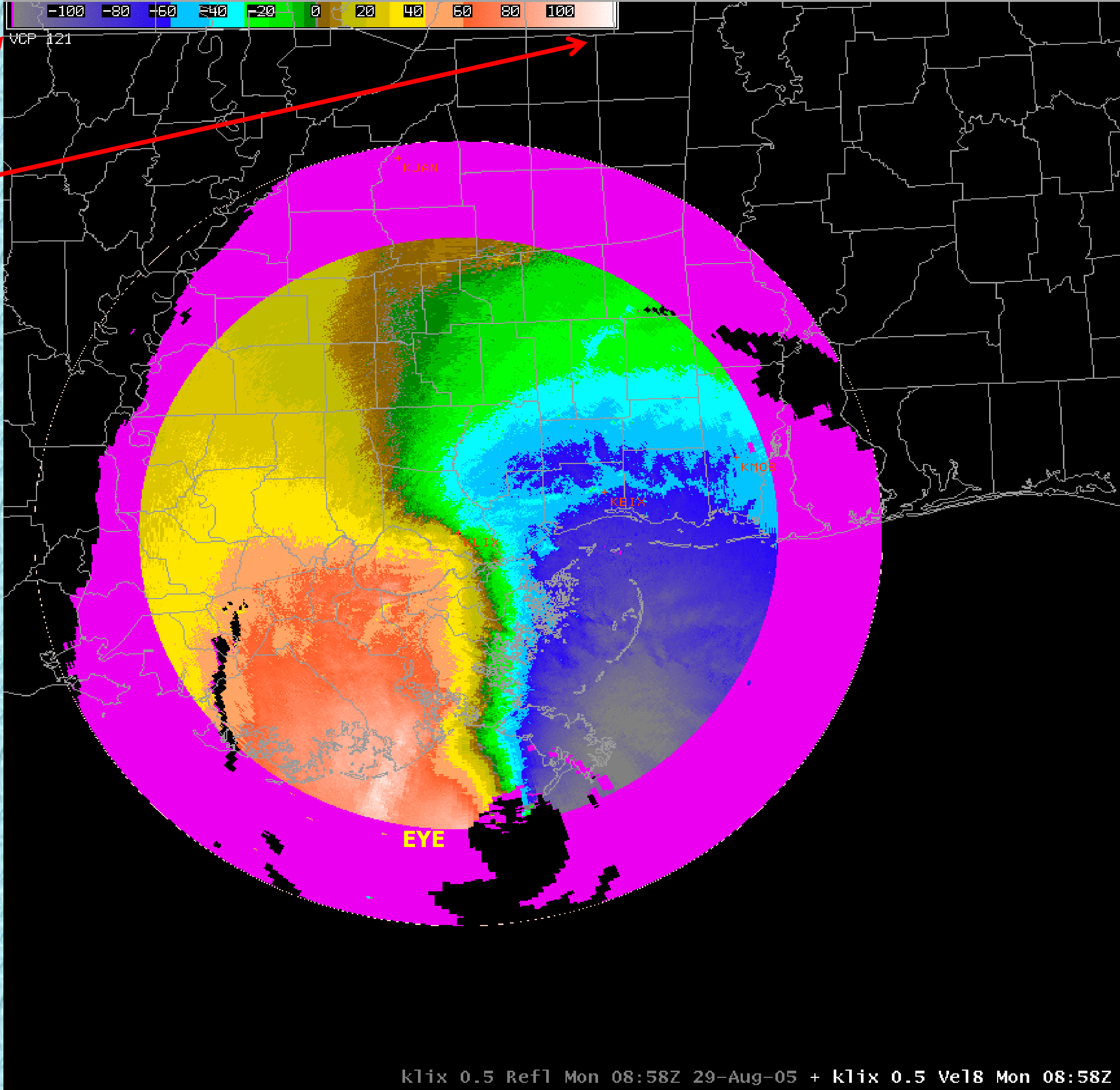
Legend: dBZ

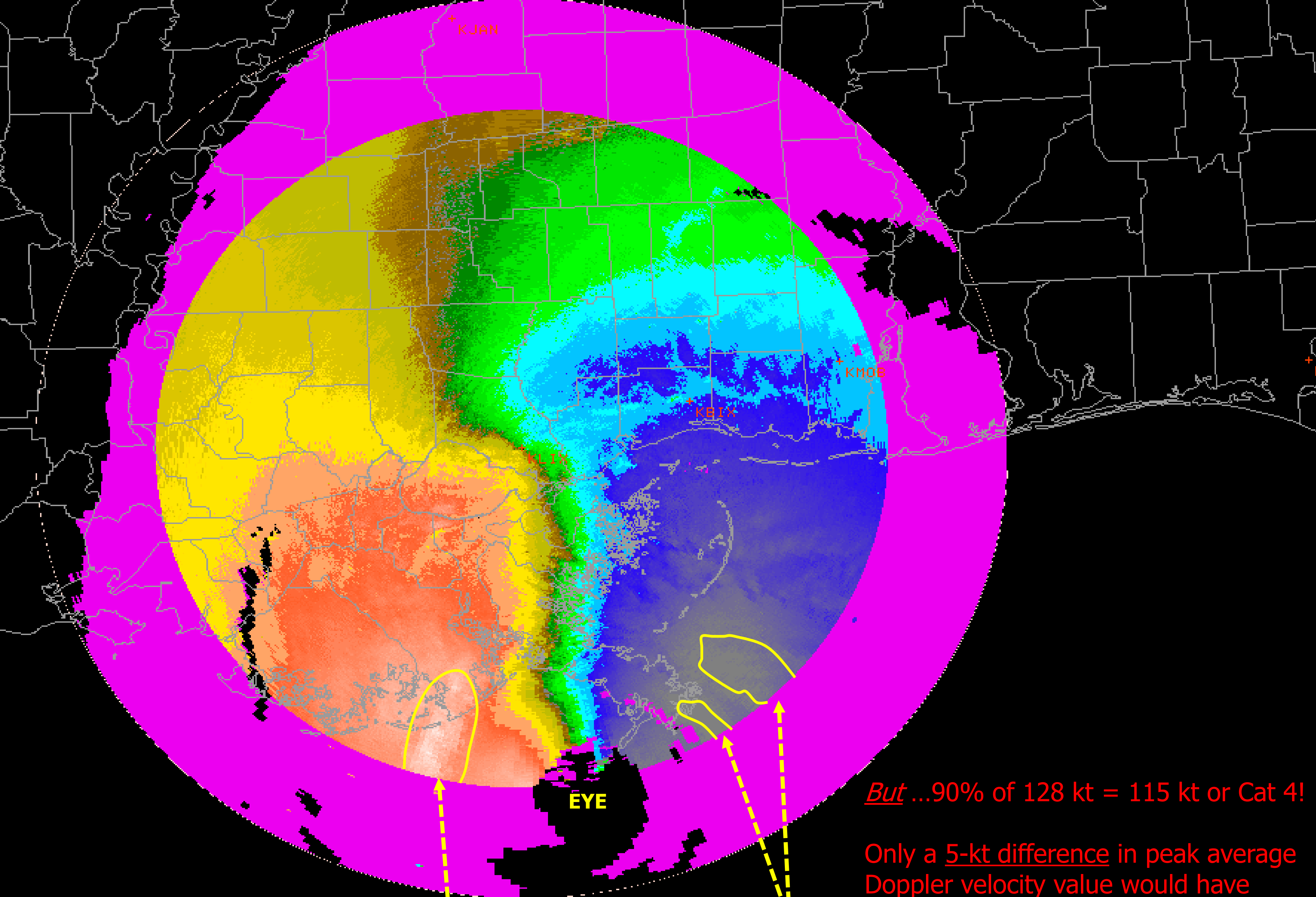
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25

RF


National Weather Service WSR-88D Image from: LIX 08/29/2005 00:02 UTC (7:02 PM CDT)
Jackson
Meridian
Demopoli
Natchez
McComb
Hattiesburg
lexandria
Mobile
Baton Rouge
Lafayette
New Iberia
New Orleans
Houma
20
55
59
65
12
10
VCP: 11
DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Warnings:
Tornado
Severe
Flash Flood
Marine
National Weather Service WSR-88D Image from: LIX 08/29/2005 00:02 UTC (7:02 PM CDT)

Maximum velocity Range is -123 kt to +123 kt due to not changing velocity increment to expand detectable velocity range to ±248 kt





But …90% of 128 kt = 115 kt or Cat 4!

Only a 5-kt difference in peak average Doppler velocity value would have resulted in a Cat 4 instead of a Cat 3 hurricane at landfall!

90% of 123 kt = 111 kt or Cat 3

≥123 kt @ 8-10 Kft

Example -- Tropical Storm Erika (Aug 2015): Heavy Rainfall Event

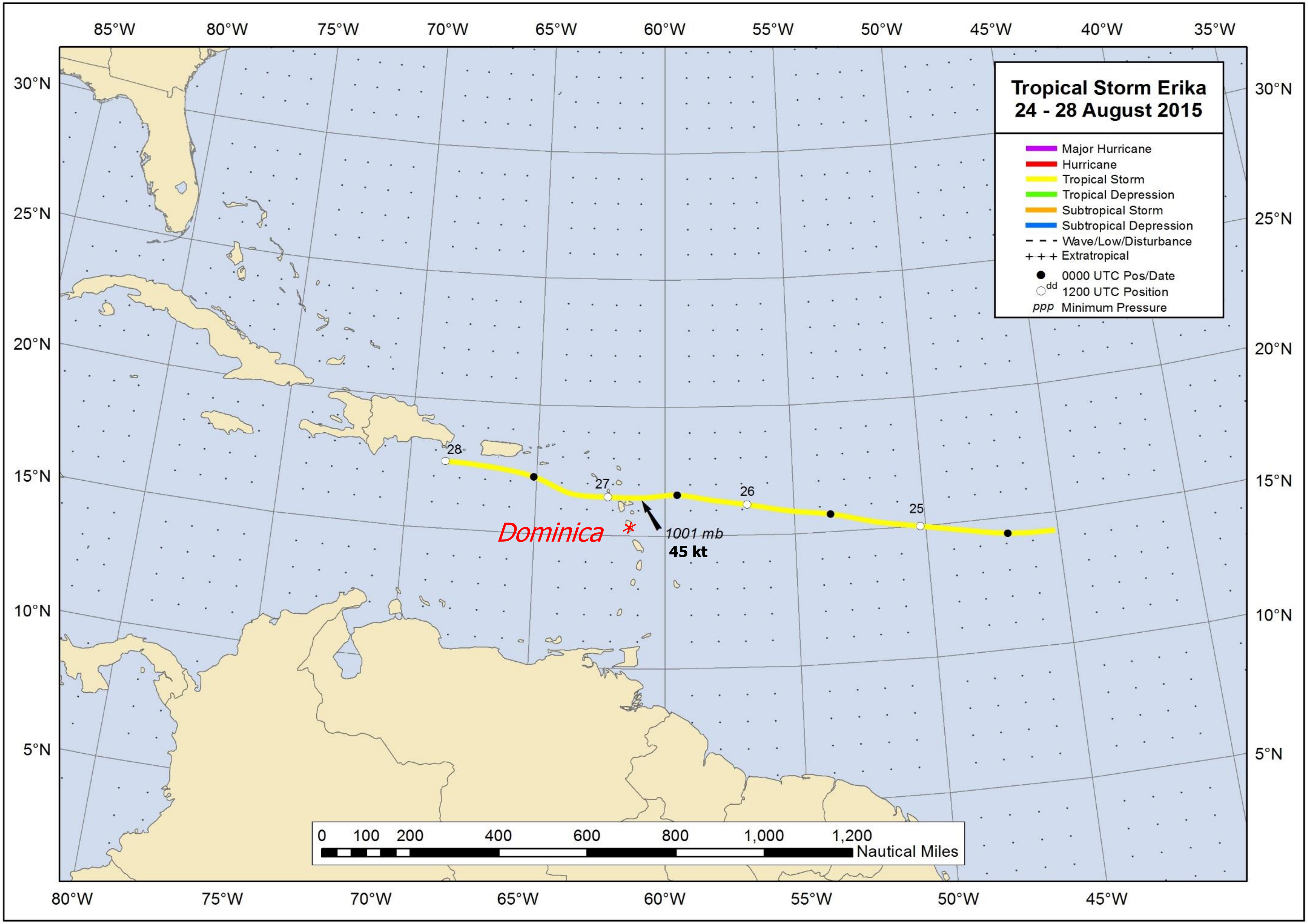
- Cyclone passed through the northern Leeward Islands on 27 August 2015 with only 40-45 kt winds.

- Produced 12.62 inches (320 mm) of rainfall in ~12 hours (0600-1800 UTC) measured at Canefield Airport (TDCF) on southwestern coast of Dominica.

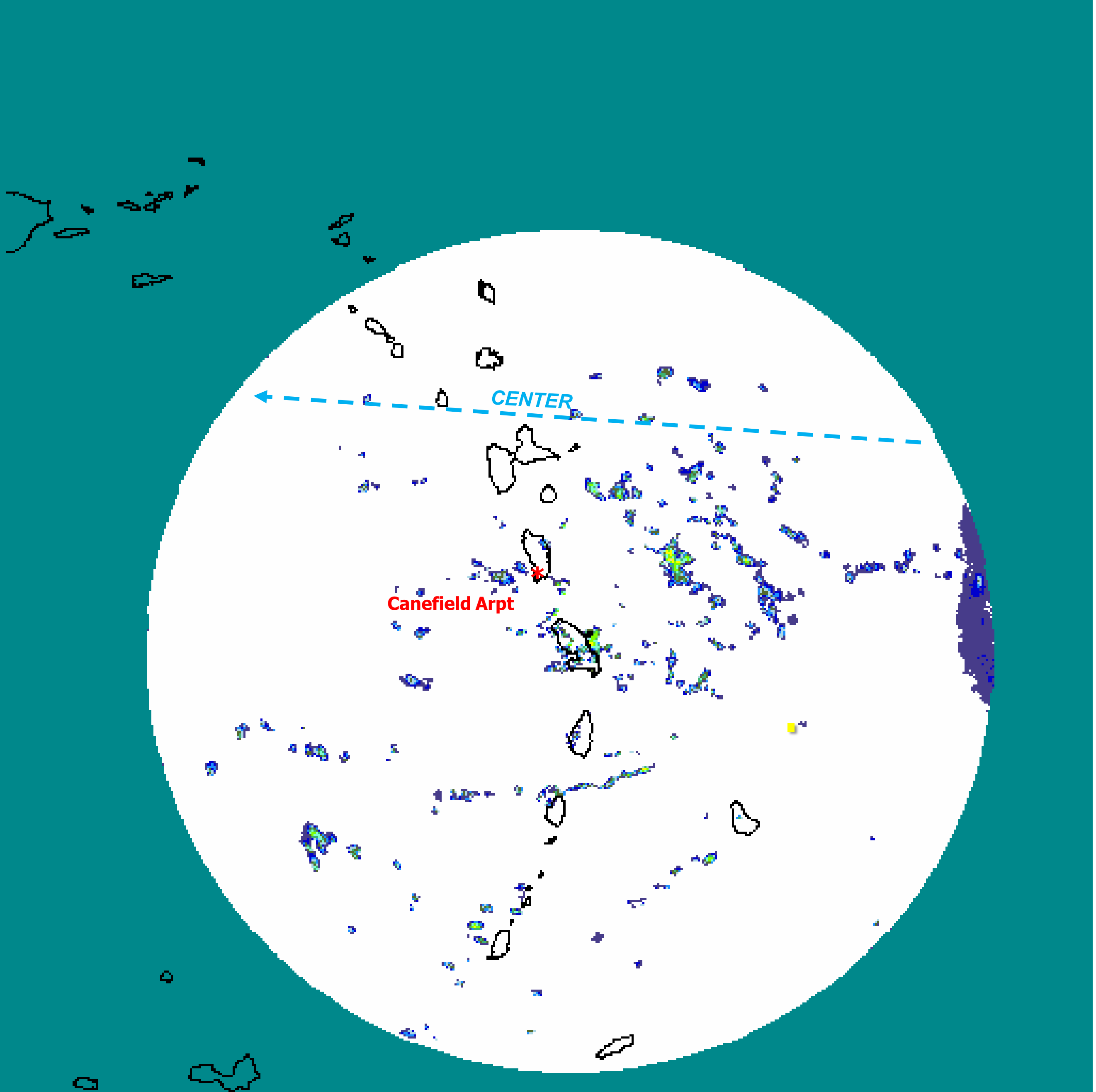
- Caused flash flooding and mudslides on Dominica, damaged or destroyed 271 houses, and caused major damage to roads, bridges and other infrastructure.

- Damage estimated to be to US$500 million on Dominica.

- 30 people killed and 574 persons left homeless.



Tropical Storm Erika
24 - 28 August 2015
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low/Disturbance
Extratropical
0000 UTC Pos/Date
dd 1200 UTC Position
ppp Minimum Pressure
85°W
80°W
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
35°W
30°N
25°N
20°N
15°N
10°N
5°N
28
27
26
25
Dominica *
1001 mb
45 kt
0 100 200 400 600 800 1,000 1,200
Nautical Miles



Mosaïque radar
Guadeloupe / Martinique

26 / 08 / 2015
14H00 UTC

REFLECTIVITY

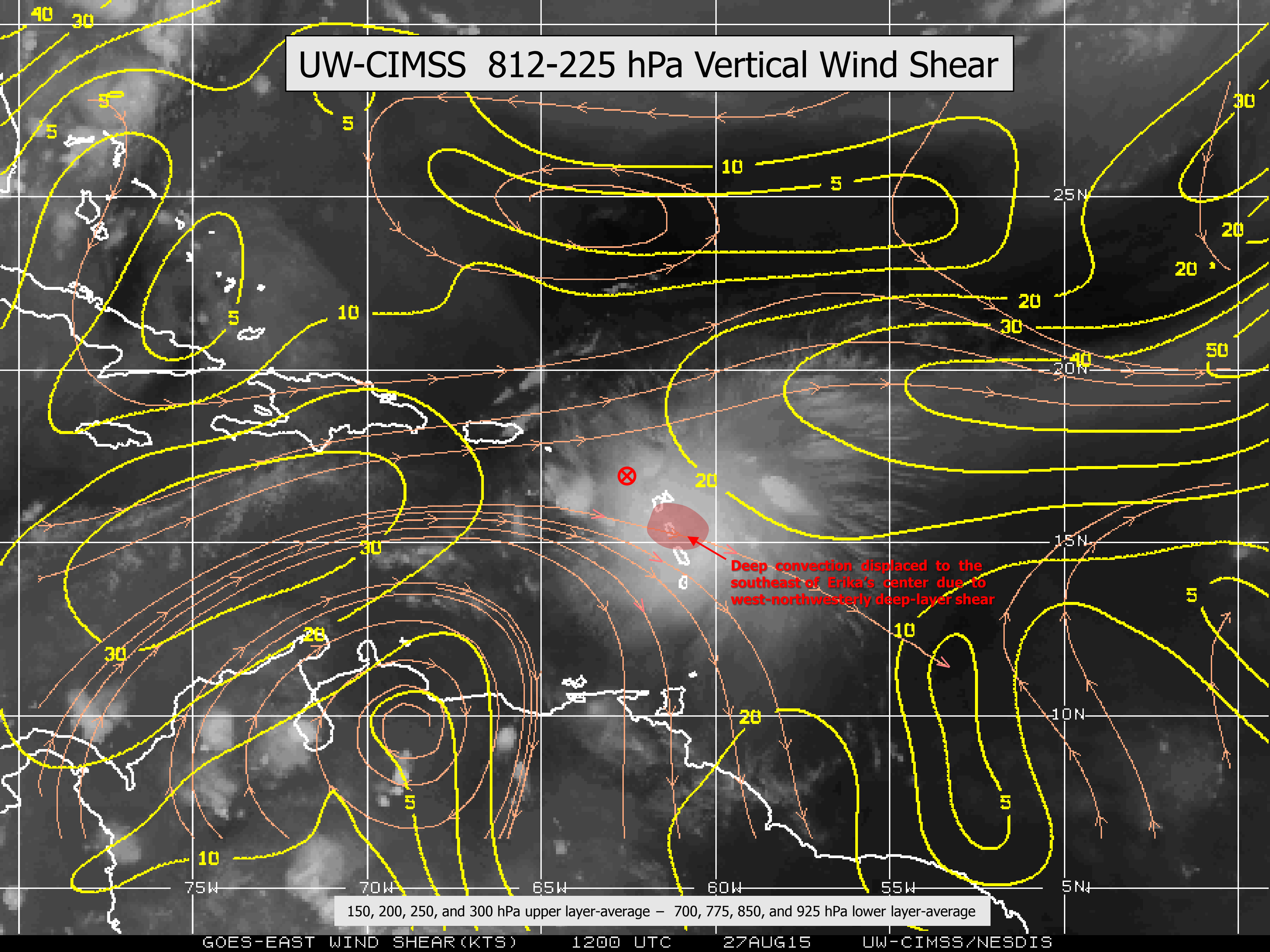
62.0- 66.0+>
58.5- 62.0
55.0- 58.5
51.5- 55.0
48.0- 51.5
44.5- 48.0
41.0- 44.5
37.5- 41.0
34.0- 37.5
30.5- 34.0
27.0- 30.5
23.5- 27.0
20.0- 23.5
16.5- 20.0
13.0- 16.5

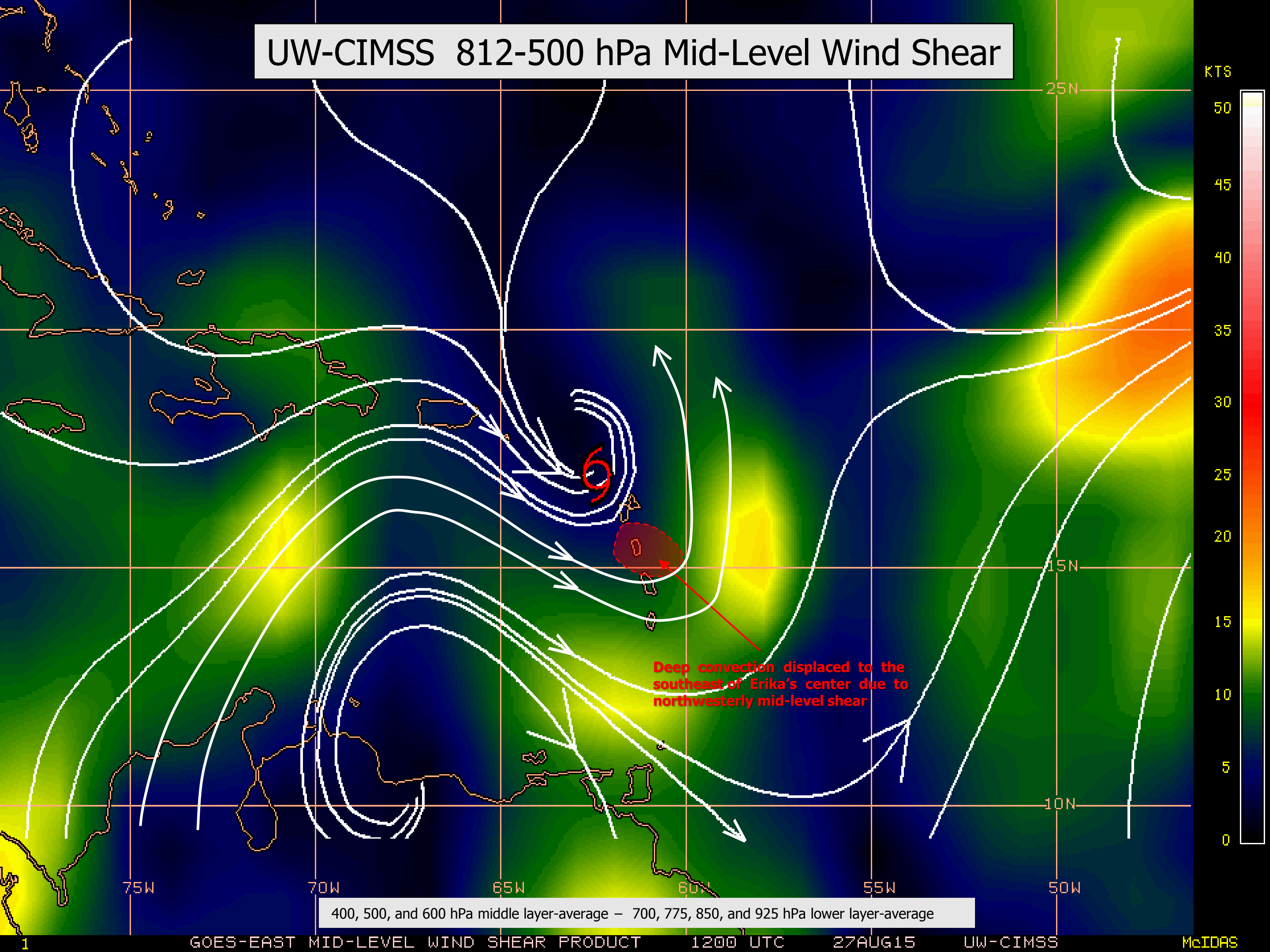
dBZ

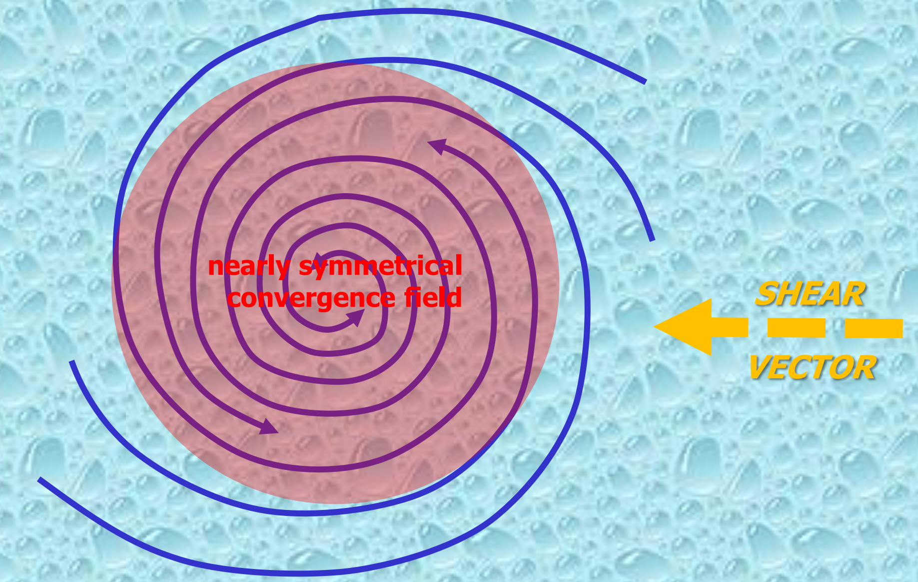
RANGE : 400 km

METEO FRANCE
Toujours un temps d'avance

https://www.youtube.com/watch?v=NsizGHCWslc

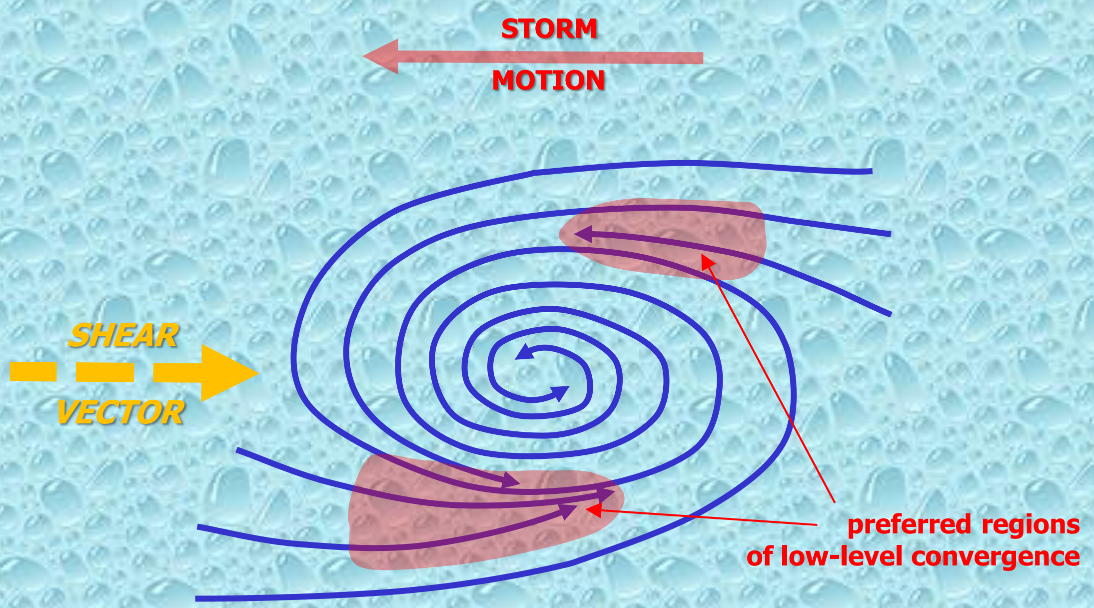

UW-CIMSS 812-225 hPa Vertical Wind Shear
Deep convection displaced to the southeast of Erika's center due to west-northwesterly deep-layer shear
25N
20N
15N
10N
5N
75W
70W
65W
60W
55W
150, 200, 250, and 300 hPa upper layer-average – 700, 775, 850, and 925 hPa lower layer-average
GOES-EAST WIND SHEAR(KTS) 1200 UTC 27AUG15 UW-CIMSS/NESDIS


UW-CIMSS 812-500 hPa Mid-Level Wind Shear
KTS
50
45
40
35
30
25
20
15
10
5
0
25N
20N
15N
10N
75W
70W
65W
60W
55W
50W
Deep convection displaced to the southeast of Erika's center due to northwesterly mid-level shear
400, 500, and 600 hPa middle layer-average – 700, 775, 850, and 925 hPa lower layer-average
1 GOES-EAST MID-LEVEL WIND SHEAR PRODUCT 1200 UTC 27AUG15 UW-CIMSS McIDAS



Typical symmetrical TC

- Low shear
- Shear vector in same direction as TC motion
- Balanced low-level convergence field



Sheared TC

- Moderate to strong shear
- Shear vector in opposite direction as TC motion
- Causes asymmetry of surface pressure/wind fields
- Creates unbalanced low-level convergence field

Cause of the heavy rainfall on Dominica

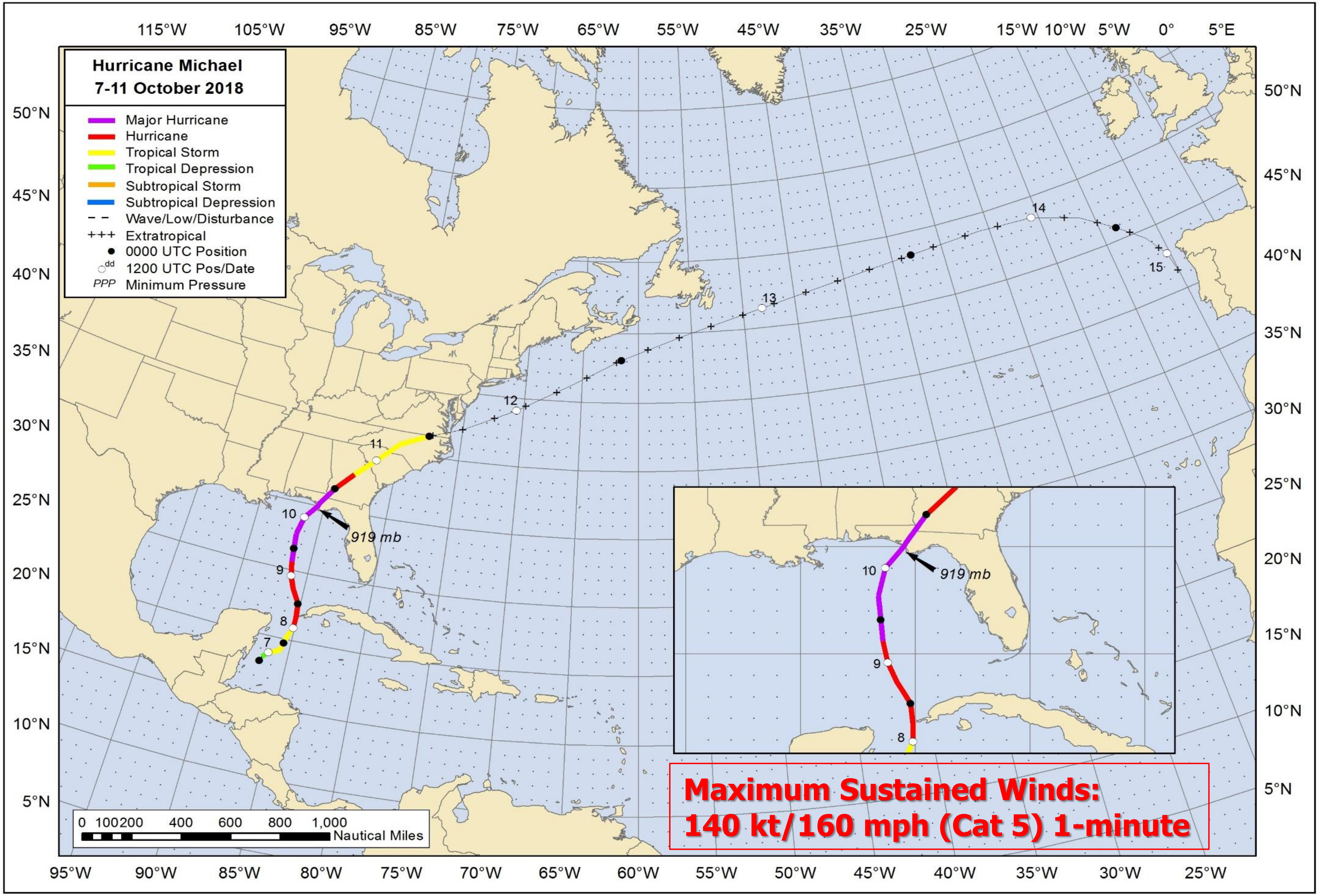
- Localized storm-scale forcing caused by development of low-level convergence zone over/near island.

- Localized mesoscale forcing caused by development of leeside vortex west of and over island.

- Persistent orographic lifting of very moist and unstable air mass caused by low-level westerly winds on south side of TS Erika.

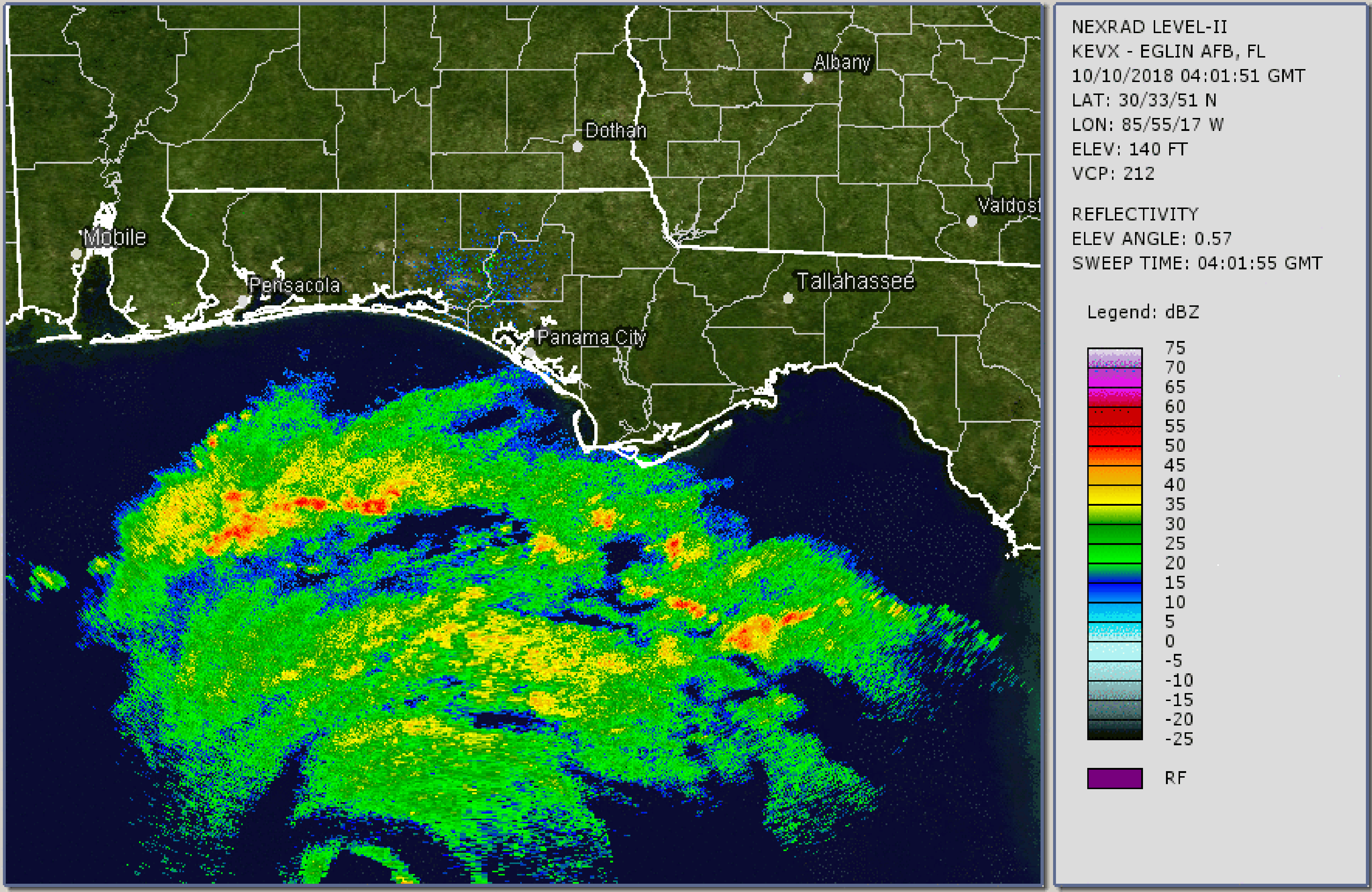
- Strong west-northwesterly 850-200 mb vertical wind shear of 23-33 kt (SHIPS model) displaced convective mass toward the south and east side of Erika's circulation.

Category 5 Hurricane Michael, 7 - 11 October 2018

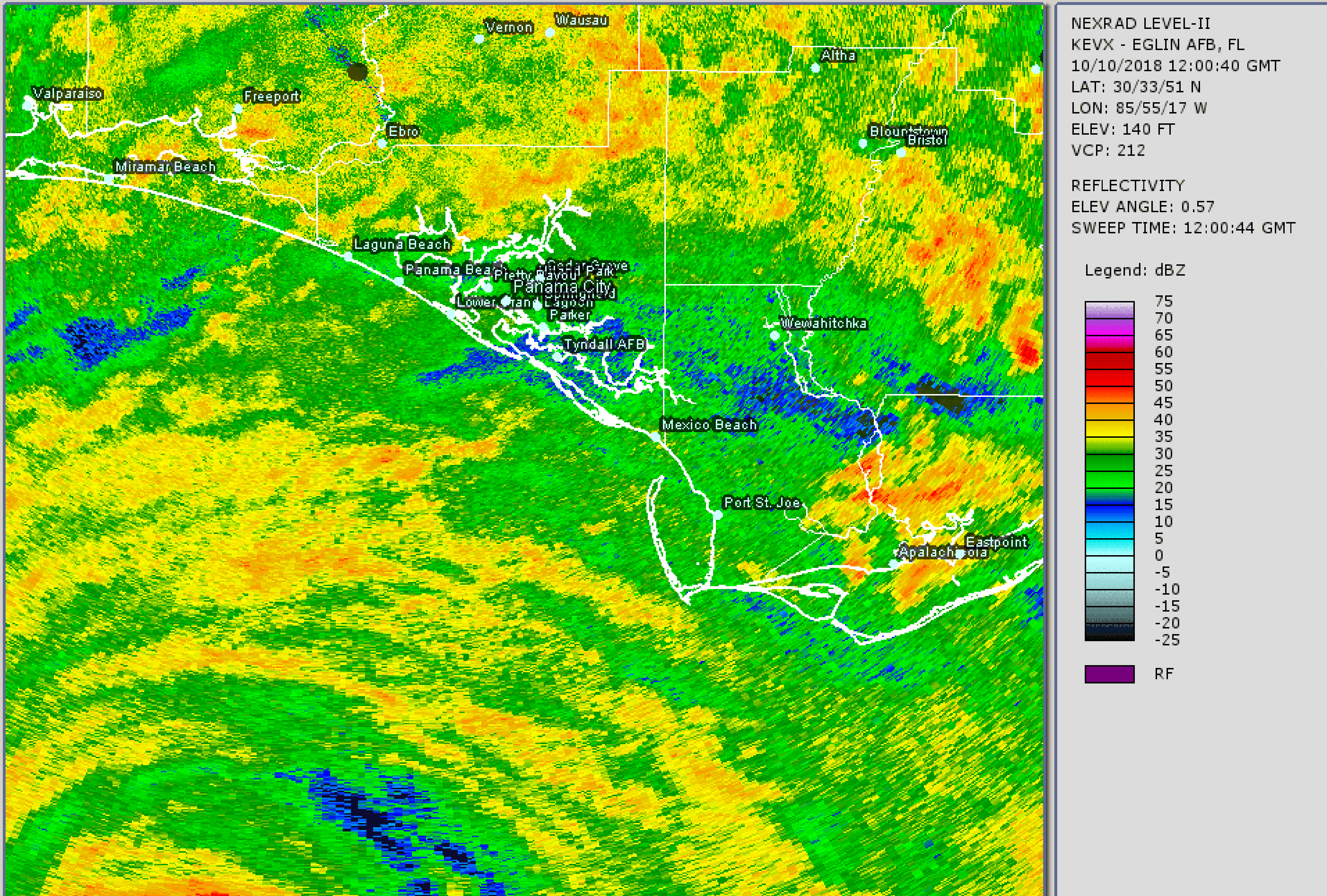


Maximum Sustained Winds:
140 kt/160 mph (Cat 5) 1-minute

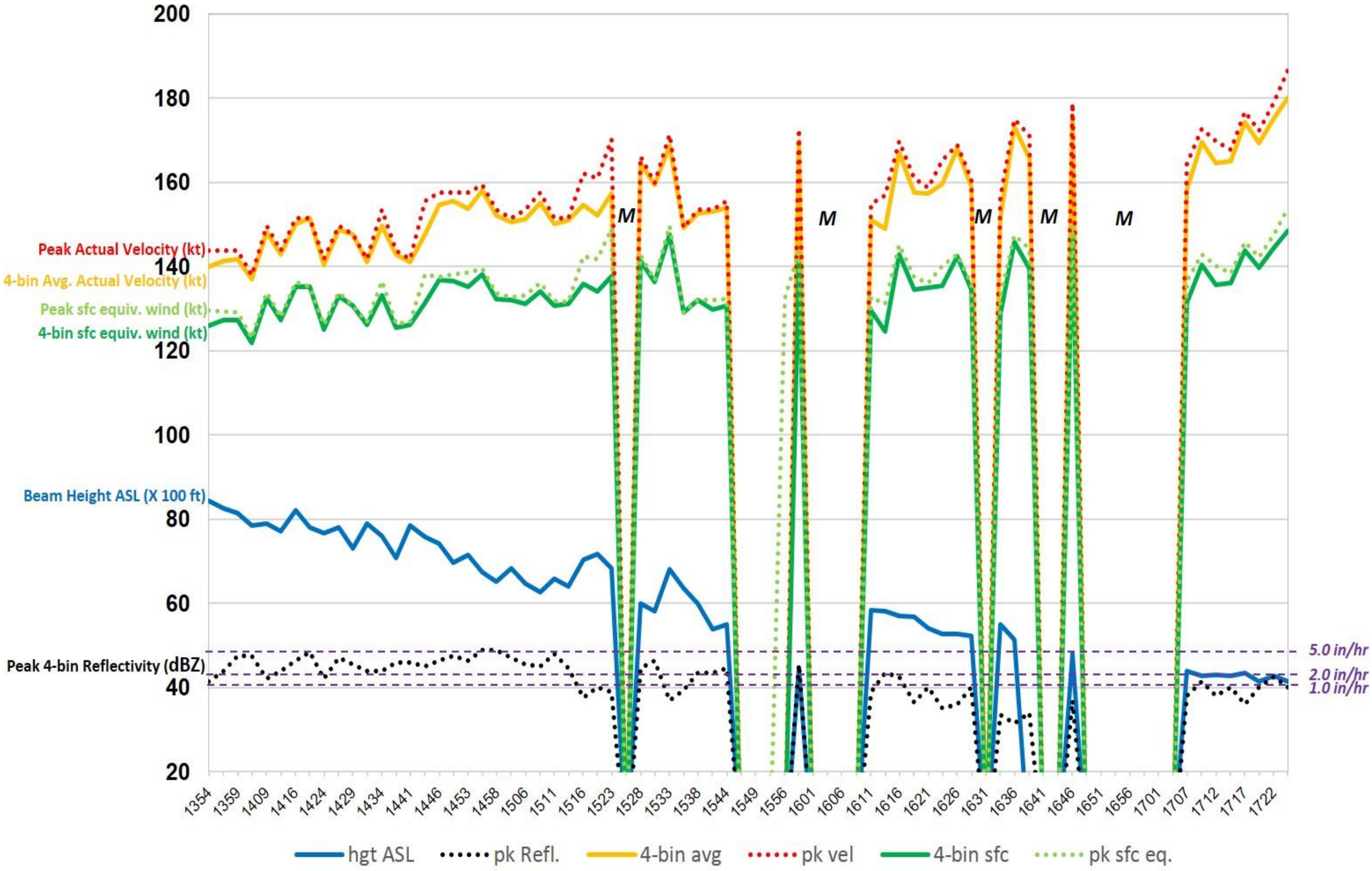
Hurricane Michael, 10 October 2018 (long range)



Hurricane Michael, 10 October 2018 (short range)



H. Michael -- KEVX 0.5 deg elev. pre-landfall Doppler radar analysis, 10 OCT 2018 – se quadrant



WSR-88D tropical Z-R relationship

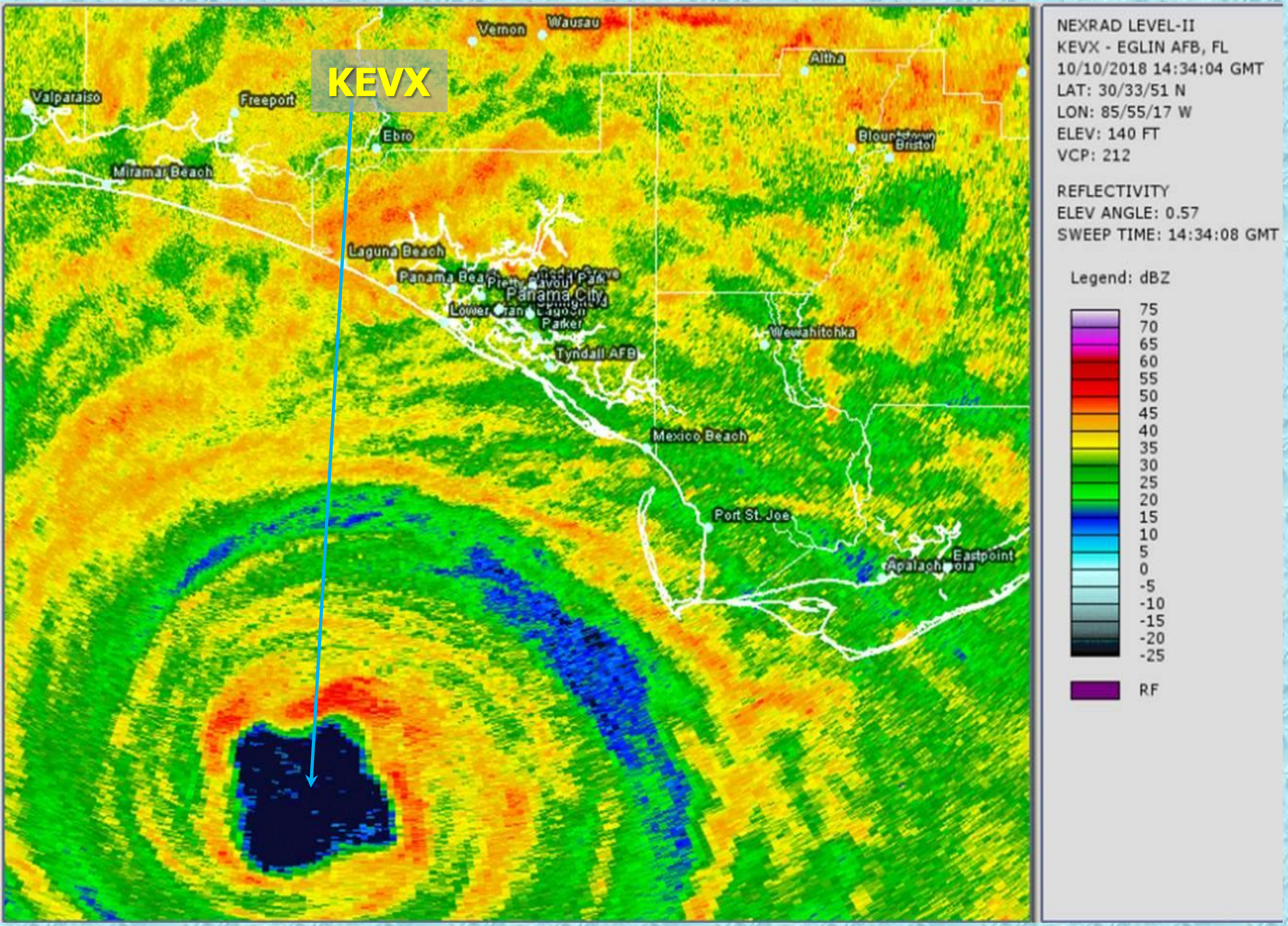
$Z = 250\ R^{1.2}$

The KEVX WSR-88D Doppler radar data analysis and associated equivalent surface wind speed conversions of the *undisturbed tangential wind flow* in the southeastern quadrant (090-150^{o} true) leading up to landfall indicate that Hurricane Michael was strengthening right up until landfall occurred at approximately 1730 UTC 10 OCT 2018.

The red-shaded area indicates the time period where original $V_{Doppler}$ values were not converted to V_{actual} values due to AWIPS-II data ingest and display issues; this time period will eventually be converted in the future. However, the wind speeds shown will *likely be lower than* the converted V_{actual} values.

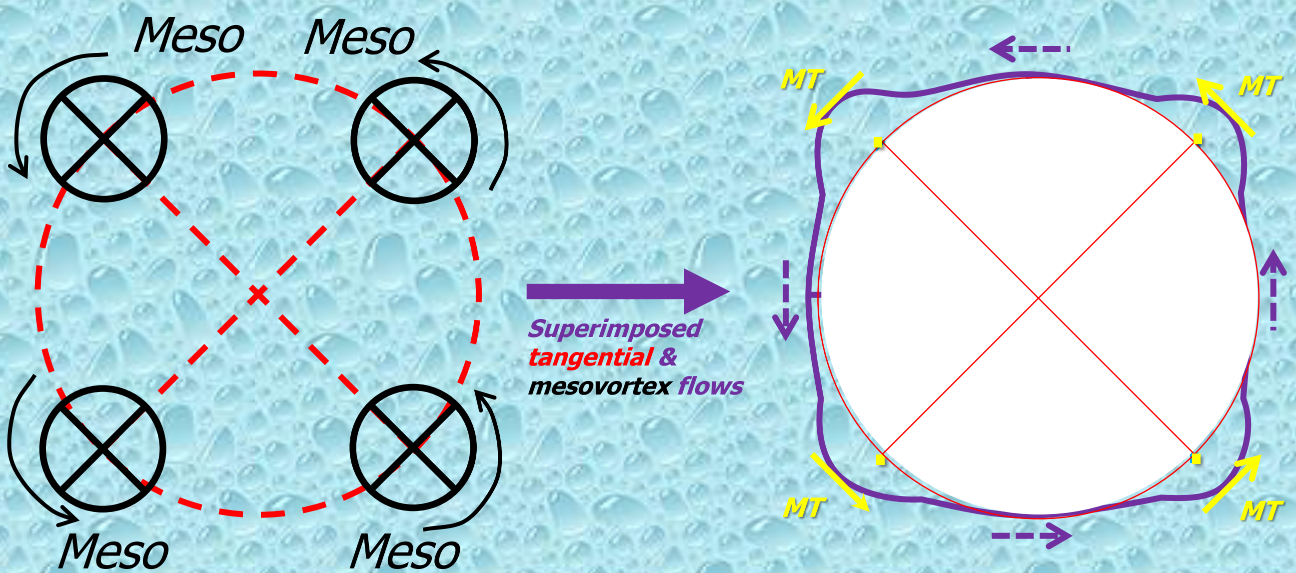
No $V_{Doppler}$ and V_{actual} values were obtained time periods where the tangential wind flow was perturbed by eyewall mesovortices (labeled "M") and, thus, making the values there unrepresentative.

The V_{actual} values over the last ~1 h prior to landfall suggest that Michael had sustained surface wind speeds of at least ***140 kt***.



Real-Time example of the combined tangential and four mesovortex flows (MT) associated with Hurricane Michael at 1434:04 UTC 10 OCT.

Some of the MT flows indicated V_{actual} values of 180-200 kt, which corresponds to an ***equivalent surface wind speed of 153-165 kt*** using recon adjustment values ranging from 0.825 to 0.850 for the corresponding altitudes of the $V_{Doppler}$ radar bins.



The tangential & mesovortex combined flows can only be accurately assessed at locations ***MT*** where both flows directions *exactly* coincide, thus allowing for symmetrical/circular flow to be assumed at those points.

This allows for an accurate assessment of the Cosine of the Radar Viewing Angle (RVA) and, therefore, V_{actual} to be calculated.

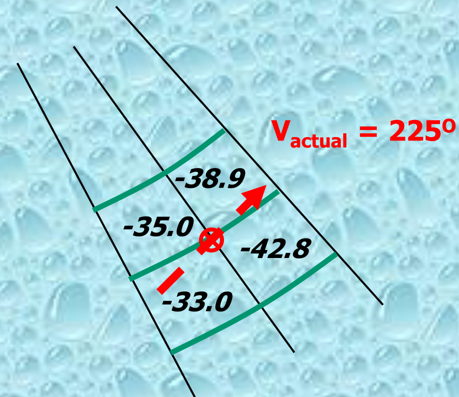
Eyewall mesovortex wind speed data *were not included* in the computation of V_{actual} values.

However, there were at least 5 cases where the wind direction of the tangential winds and the mesovortex winds coincided, allowing for the calculation of peak combined flows and V_{actual} values, which ranged from ~180-200 kt, resulting in equivalent surface wind speed estimates of 153-165 kt.

Some consideration and weight should be given to the equivalent surface wind speeds associated with the eyewall mesovortices (eddy flow) since the temporal and spatial scales of those features were very similar to scale of the undisturbed eyewall tangential flow between the mesovortices.

Recon Wind Data vs. WSR-88D ($V_{Doppler}$) & V_{actual} Direction

```
AF301 1514A MICHAEL          HDOB 27 20181010
171930 3000N 08534W 6970 02432 9177 +191 +097 194027 030 053 002 03
172000 2959N 08532W 6960 02446 9181 +191 +100 193030 031  ///  /// 03
172030 2958N 08532W 6968 02435 9173 +197 +105 208032 033 049 002 00
172100 2956N 08531W 6963 02446 9171 +205 +121 229049 065 083 001 03
172130 2955N 08530W 6981 02466 9242 +168 +135 238107 122 099 001 00
172200 2954N 08528W 6967 02555 9327 +140 +139 231142 149 121 002 05
172230 2953N 08527W 6973 02621 9437 +137 +136 225150 152 123 005 03
172300 2952N 08525W 6977 02684 9527 +124  ////  218141 148 132 007 05
172330 2951N 08524W 6971 02747 ////  +114  ////  219140 146 133 006 05
172400 2951N 08522W 6976 02789 9613 +128 +118 217132 136 101 002 03
172430 2950N 08521W 6971 02819 9641 +130 +106 219124 128 092 001 00
172500 2949N 08522W 6971 02829 9654 +126 +109 222122 123 092 001 00
172530 2948N 08522W 6967 02844 9667 +125 +109 224119 120 091 001 00
172600 2947N 08522W 6970 02853 9679 +123 +114 226116 118 088 003 00
172630 2946N 08522W 6968 02866 9699 +119 +117 229112 115 085 006 00
172700 2945N 08523W 6967 02875 9719 +118 +118 233108 110 085 007 00
```



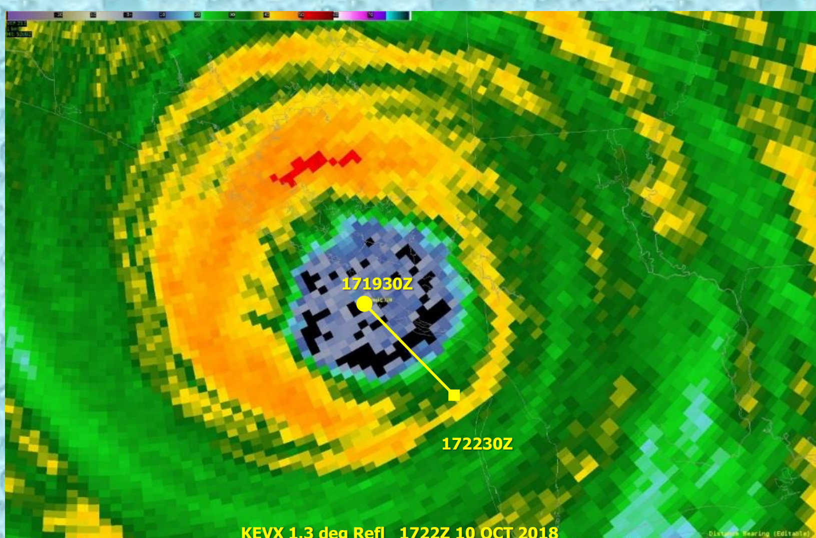
Radar beam height = 8337 ft ASL
Aircraft altitude/height = 8599 ft ASL

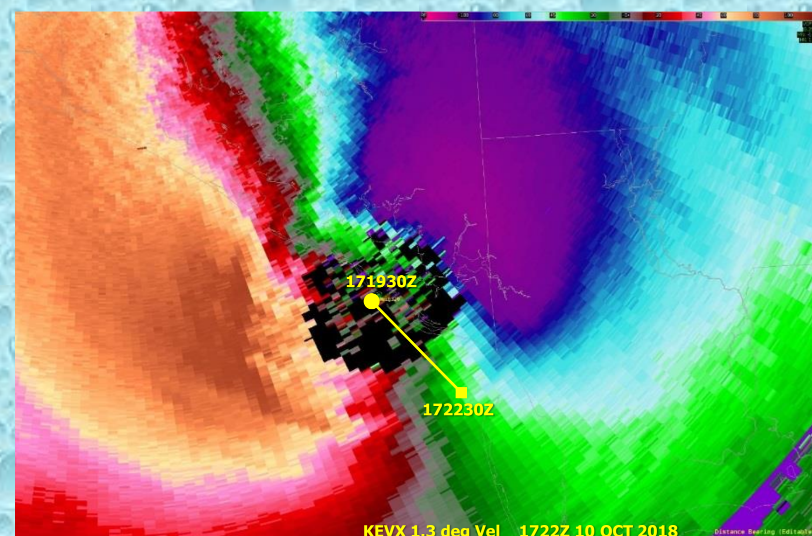
Recon actual wind direction = 225°
Radar radial = 149°
Radar viewing angle = 76°
Cosine 76° = 0.2419

$V_{actual} = V_{Doppler}$ / Cosine of angle

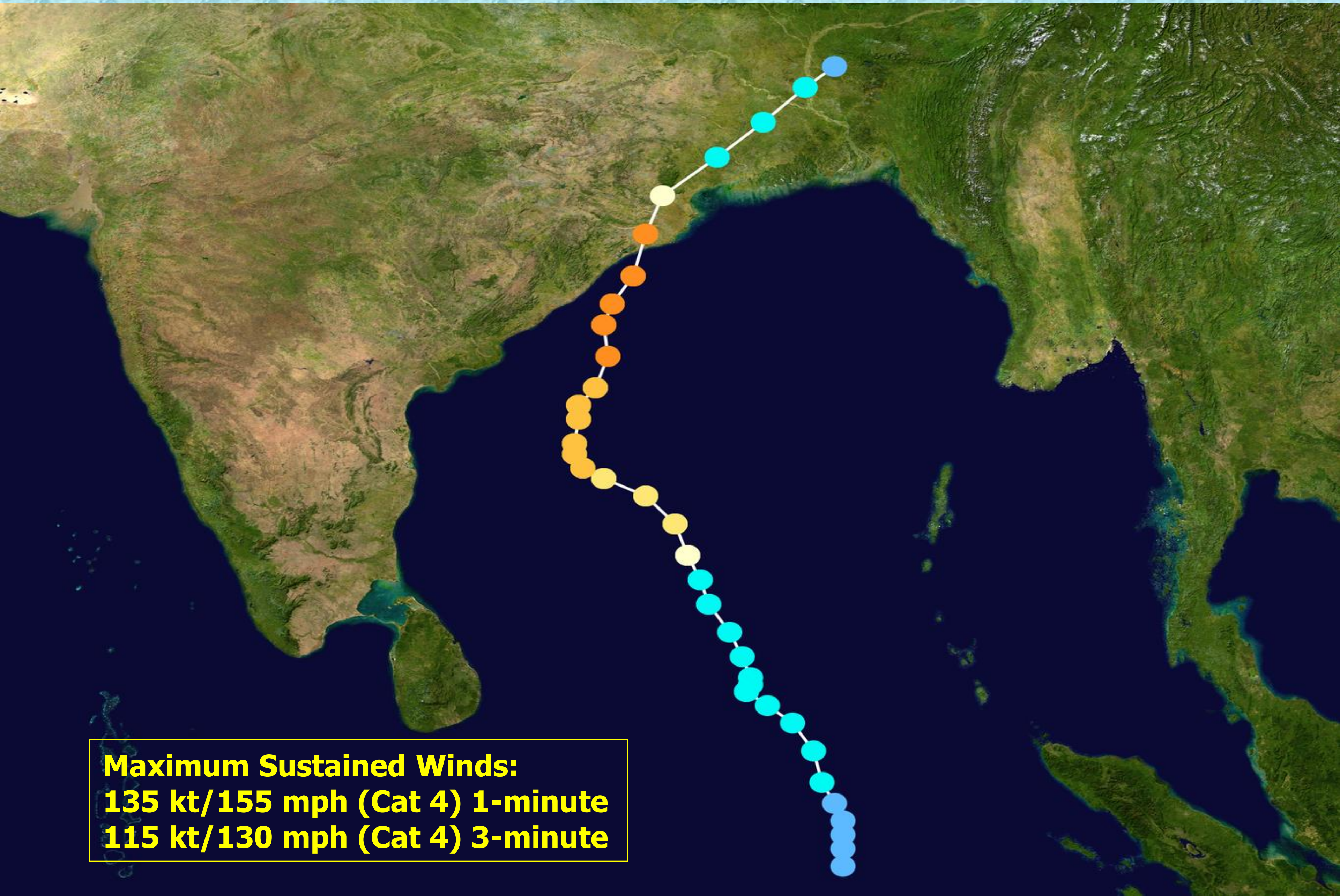
$V_{Doppler}$ 33.0 kt => V_{actual} = 136.0 kt
$V_{Doppler}$ 35.0 kt => V_{actual} = 144.7 kt
$V_{Doppler}$ 38.9 kt => V_{actual} = 160.8 kt
$V_{Doppler}$ 42.8 kt => V_{actual} = 176.9 kt

4-bin V_{actual} average = 154.6 kt
Recon V_{actual} = 152.0 kt

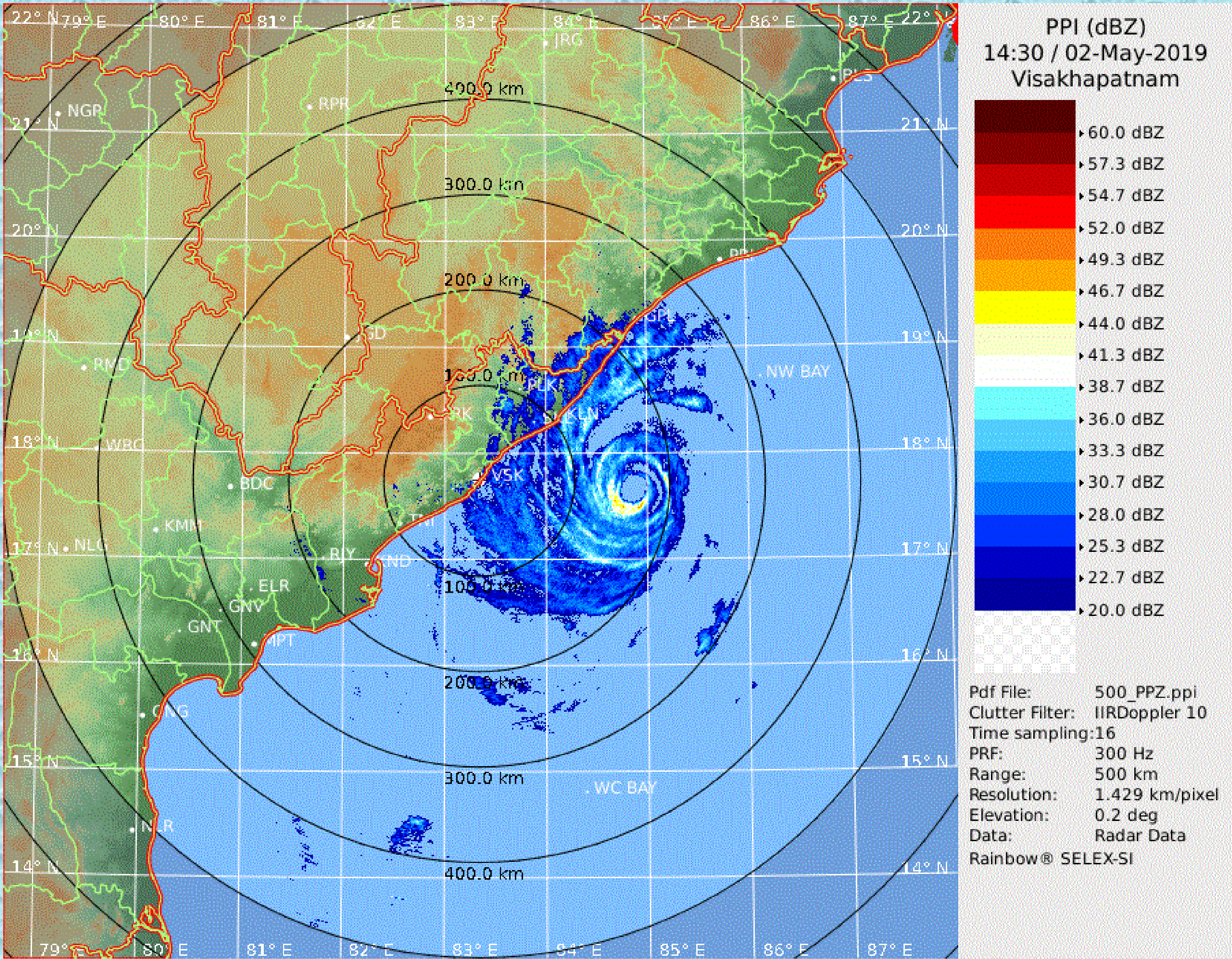




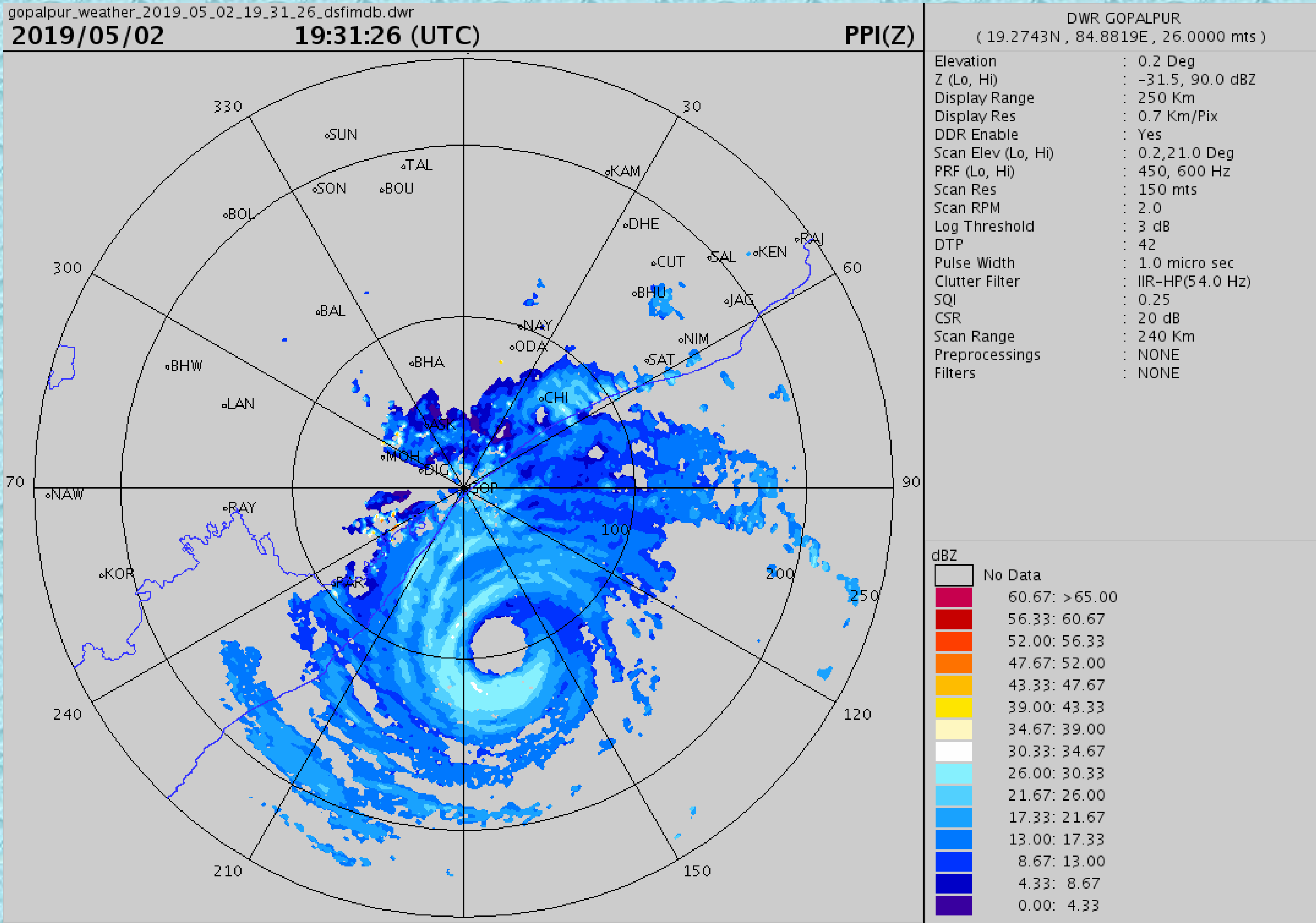
Extremely Severe Tropical Cyclone Fani, 26 April – 5 May 2019



Tropical Cyclone Fani, 02-03 May 2019 (long range)

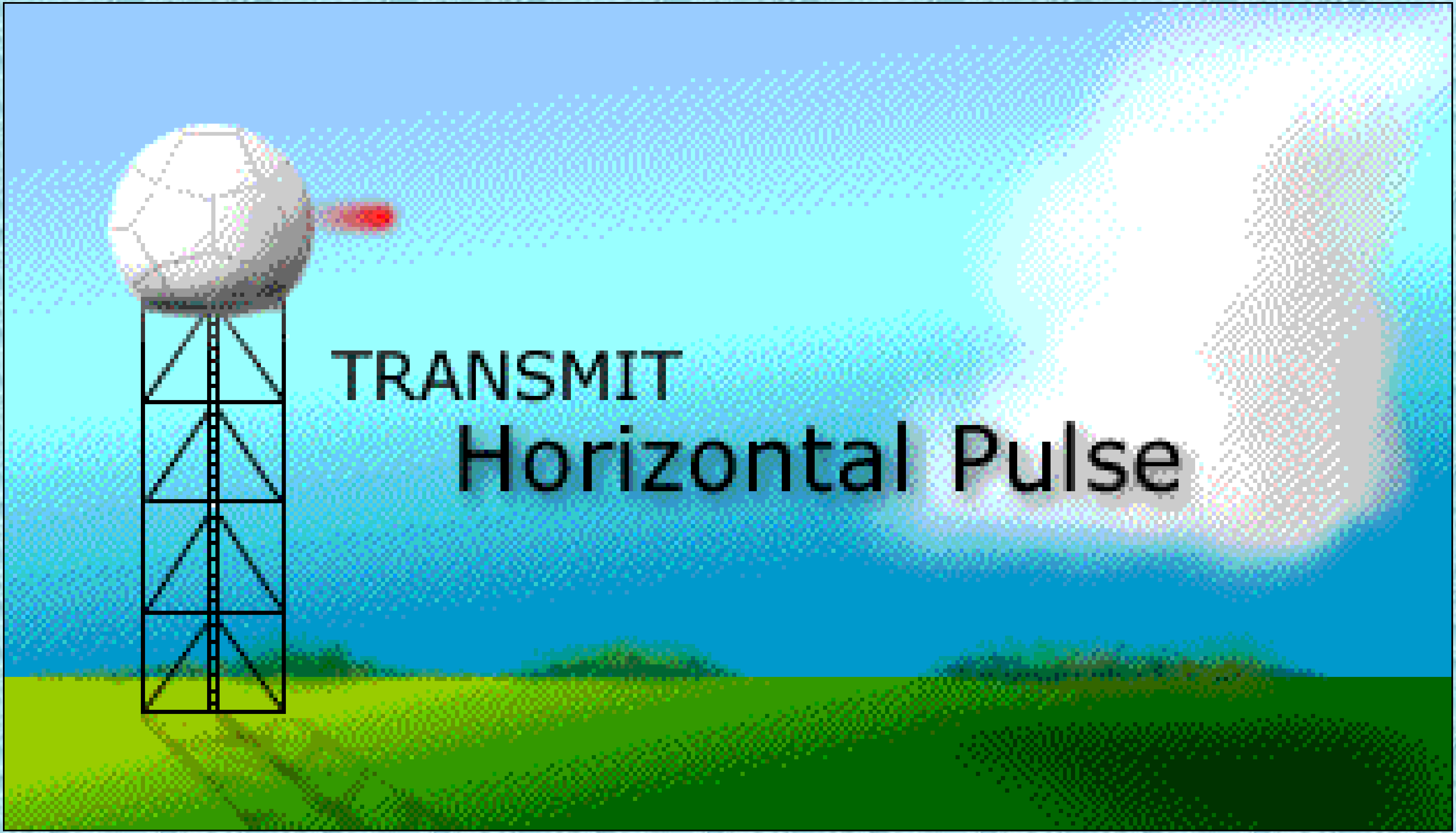


Tropical Cyclone Fani, 02-03 May 2019 (short range)



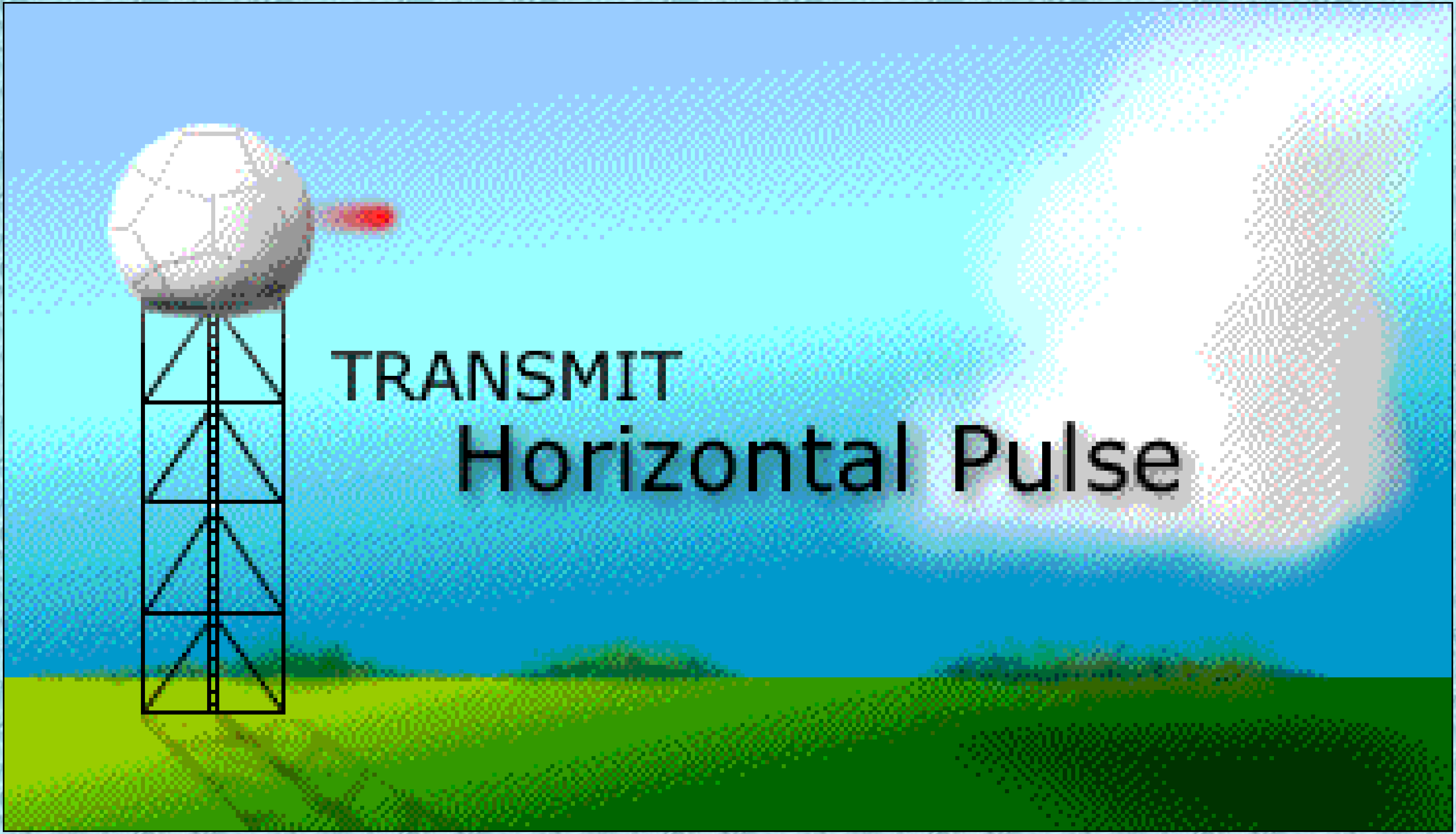
Dual-Polarization Doppler Weather Radars

Conventional Horizontal-Polarized Radar



Typical rain drop is a 'flat', oblate spheroid with a <u>wider horizontal axis</u> that returns more energy in the horizontal plane

Dual-Polarized Radar



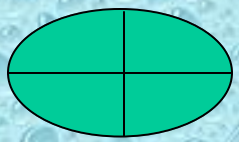
Provides betters Z-R relationship and rainfall estimates by determining *precipitation type*

New parameter called "Differential Reflectivity" or "Z_{DR}" helps to determine precipitation type

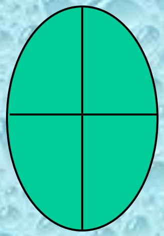
Z_h = horizontal polarized reflectivity

Z_v = vertical polarized reflectivity

$Z_h > Z_v$ for raindrops



$Z_h < Z_v$ for large wet hailstones



$$dBZ_{dr} = 10 \times \log (Z_h / Z_v)$$

Z_{DR} values for meteorological echoes typically range between -2 dB and 6 dB

- Values of Z_{DR} well above zero indicate the hydrometeors in the volume are horizontally oriented (e.g., rain) -- meaning their horizontal axis is longer than their vertical axis ($P_h > P_v$).

- Values of Z_{DR} well below zero indicate the hydrometeors in the volume are vertically oriented (e.g., large hail) -- meaning their vertical axis is longer than their horizontal axis ($P_h < P_v$).

- Values of Z_{DR} near zero indicate the hydrometeors in the volume have a nearly spherical shape (e.g., snow, giant hail), in the mean ($P_h \sim P_v$).

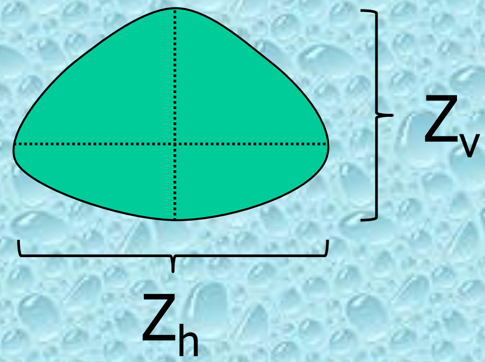
http://www.wdtb.noaa.gov/courses/dualpol/outreach/DualPol-Flipchart.pdf

Example: Consider a field of large, falling raindrops.
The drops tend to fall with an oblate, horizontal orientation.
The field of drops, as a whole, will have a larger cross-section of water in the horizontal plane compared to the vertical.

A horizontally-polarized radar pulse will, therefore, backscatter more energy/power in this field of drops than a vertically-polarized pulse will, resulting in more radar return for the horizontal pulse than the vertical pulse.

In this case, $Power_{hor} > Power_{vert} \Rightarrow Z_h > Z_v$, thus $Z_{DR} > 0$.

Large Raindrops



Example: Z_h = 317,000 and Z_v = 100,000

(i.e. 55 dBZ) (i.e. 50 dBZ)

Therefore, $Z_{DR} = 10 \log (Z_h/Z_v)$

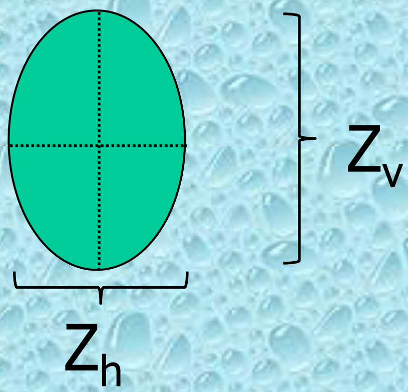
$= 10 \log (317000/100000)$

$= 10 \log (3.17)$

$= 10 \times 0.501$

$Z_{DR} = +5.01$

Large Wet Hailstones



Example: Z_h = 100,000 and Z_v = 317,000

(i.e. 50 dBZ) (i.e. 55 dBZ)

Therefore, $Z_{DR} = 10 \log (Z_h/Z_v)$

$= 10 \log (100000/317000)$

$= 10 \log (0.315)$

$= 10 \times -0.501$

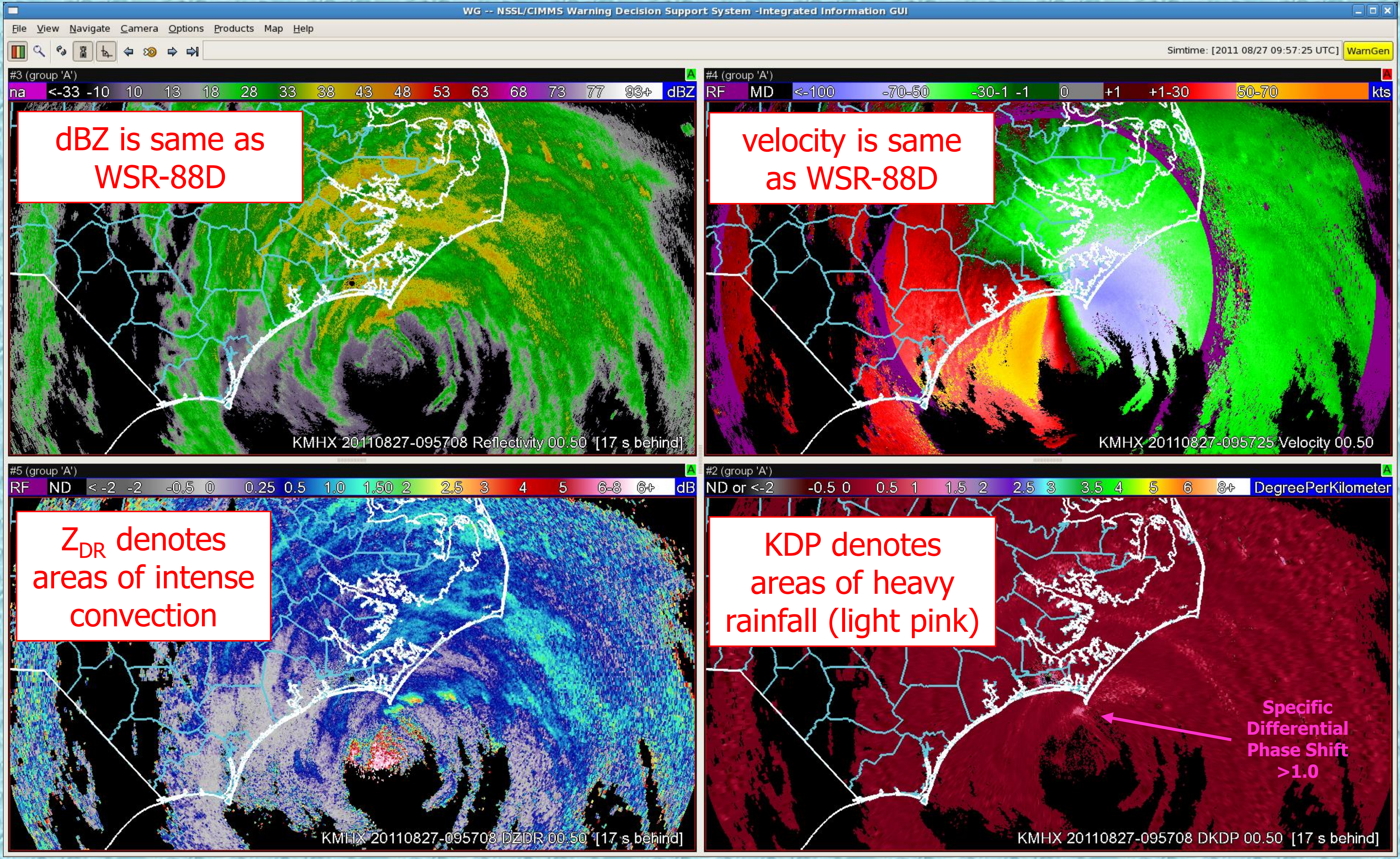
$Z_{DR} = -5.01$

- Differential reflectivity values above 2 dB are commonly observed in rain.

- Although hailstones are not necessarily spherical, studies have shown that they fall with a tumbling motion -- meaning a field of falling hailstones within the radar resolution volume will "appear" to consist of nearly spherical hydrometeors. Therefore, the value of dBZ_{DR} for hail is usually close to zero.

- Some graupel and hail hydrometeors with a conical shape can fall with their major axes oriented in the vertical. In these cases, the dBZ_{DR} will be found to be negative.

Dual-Pol Radar Example -- Hurricane Irene (2011)



Provides betters Z-R relationship and rainfall estimates by determining precipitation type

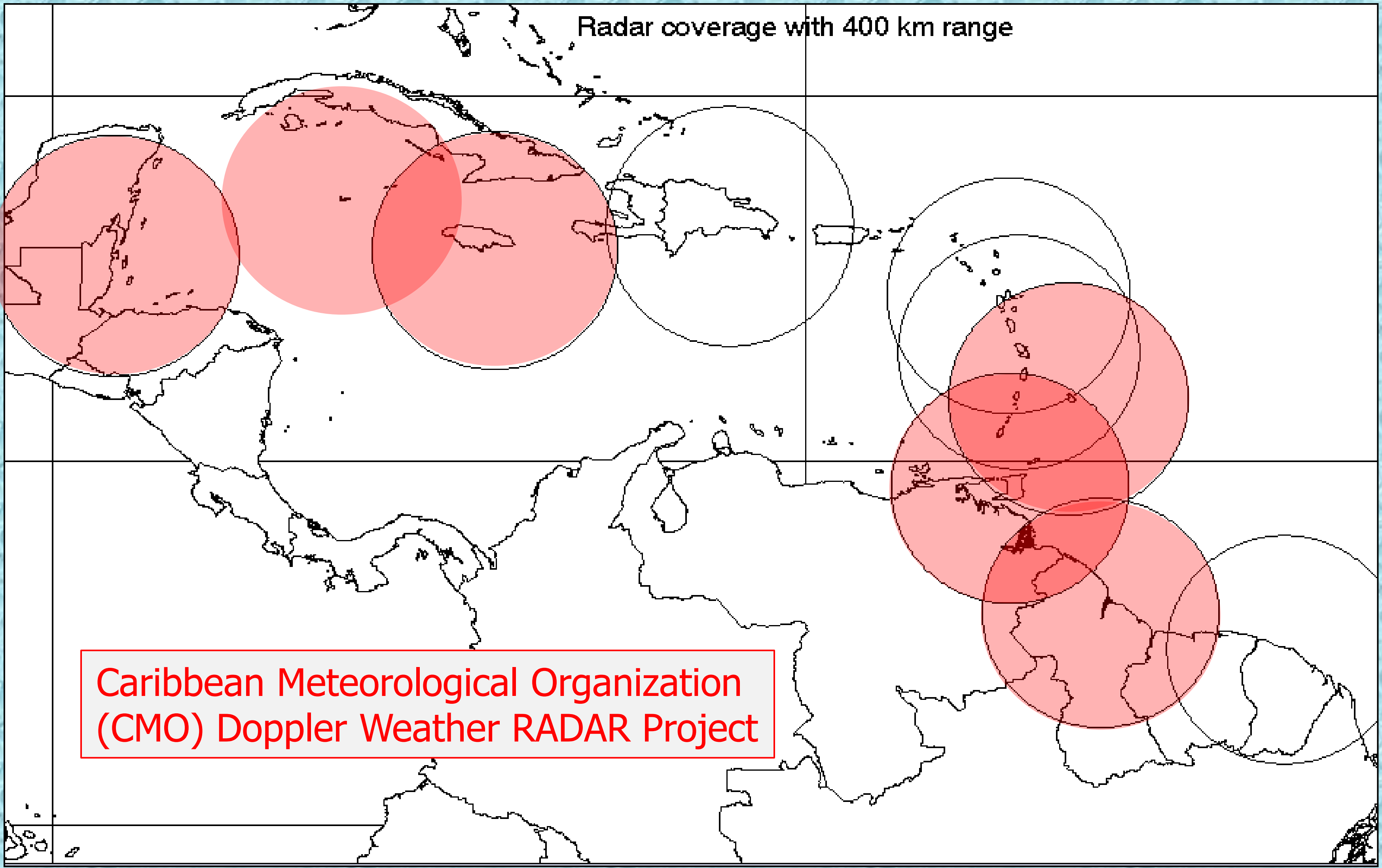
http://www.nws.noaa.gov/com/weatherreadynation/news/121311_irene.html

Caribbean Meteorological Organization (CMO) Doppler Weather RADAR Project

- €13-million (Euro) project that aims to replace old radars with new Doppler radars.
- Goal: provide improved awareness of approaching tropical cyclones and heavy rainfall events.
- New radars installed in Barbados, Belize, Guyana, and Trinidad.


Barbados

http://www.cmo.org.tt/radar.html
http://www.cmo.org.tt/management.html
http://www.cdera.org/workshop/un-spider/day2/LAYNE-CMO_Presentation.pdf
www.cmo.org.tt/docs/CMC46/CMC46_Docs/CMC46_Doc_8.doc



Caribbean Meteorological Organization (CMO) Doppler Weather RADAR Project

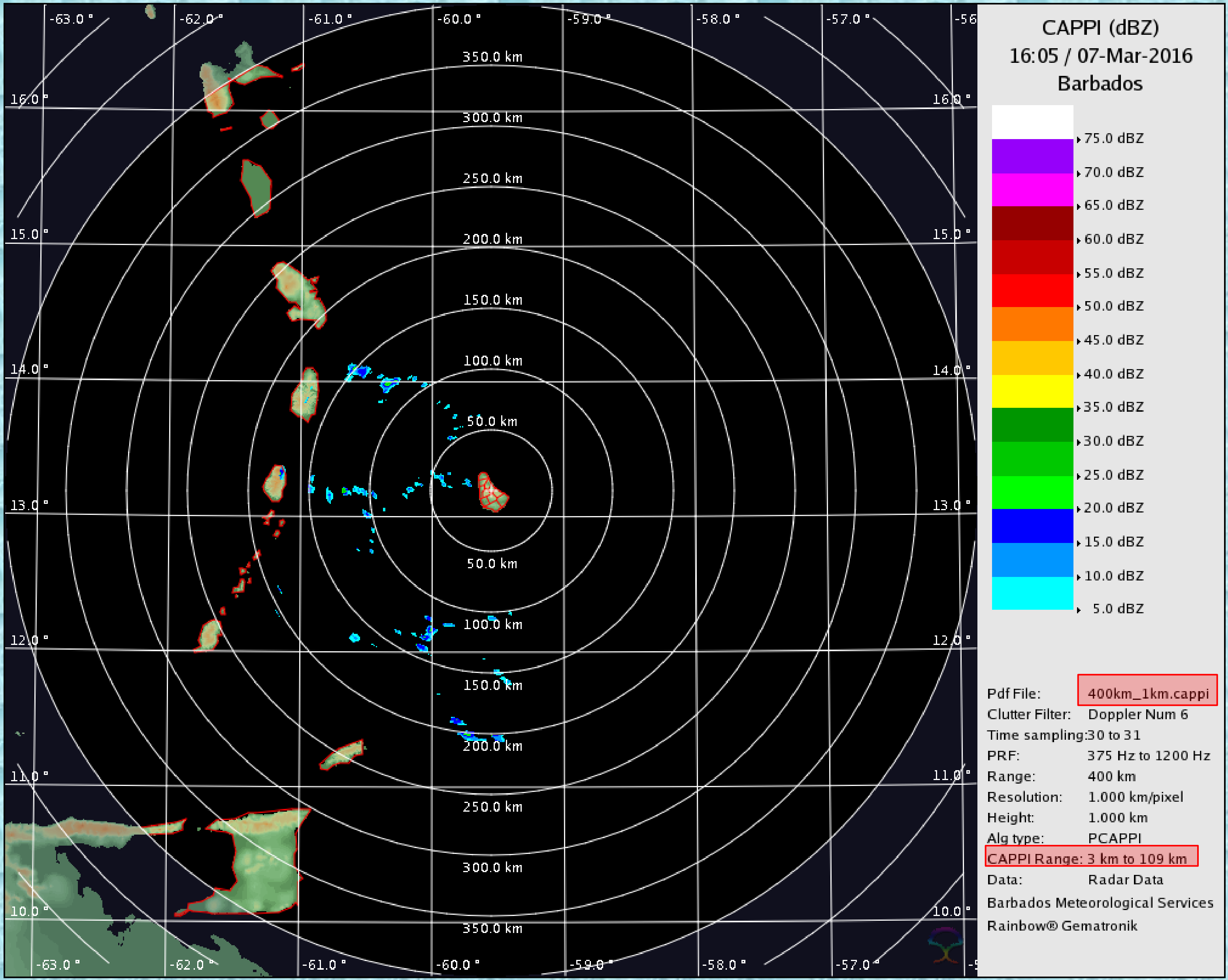
SELEX-Gematronik was awarded the contract for the four METEOR 500S S-Band weather radar systems

- S-band/10 cm wavelength for maximizing precipitation detection

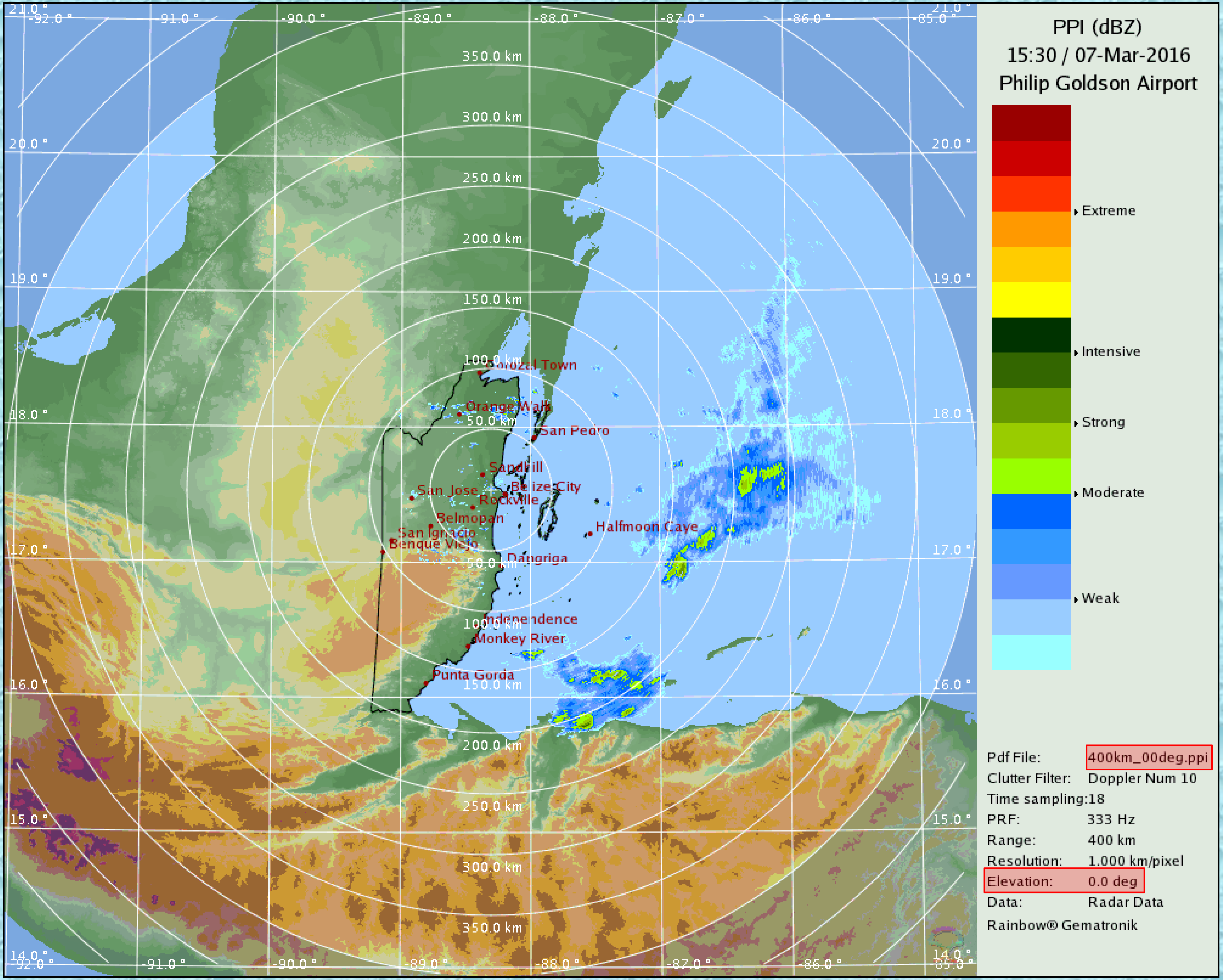
- 8.5-meter diameter parabolic antenna dish

- Not dual-polarization capable
(NOTE: 700S model does have dual-polarization capability)

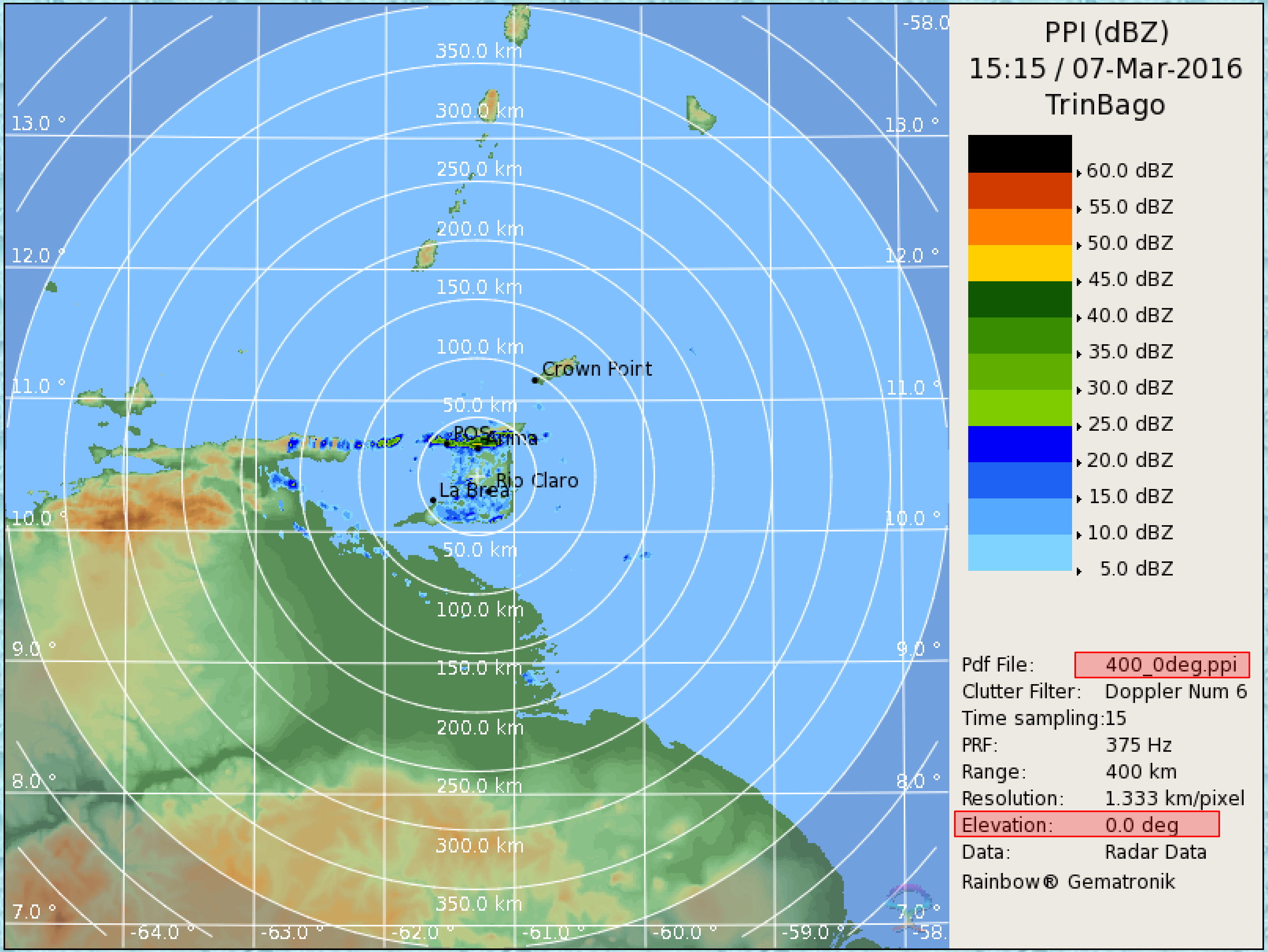
- $\leq 1.0^{O}$ beamwidth



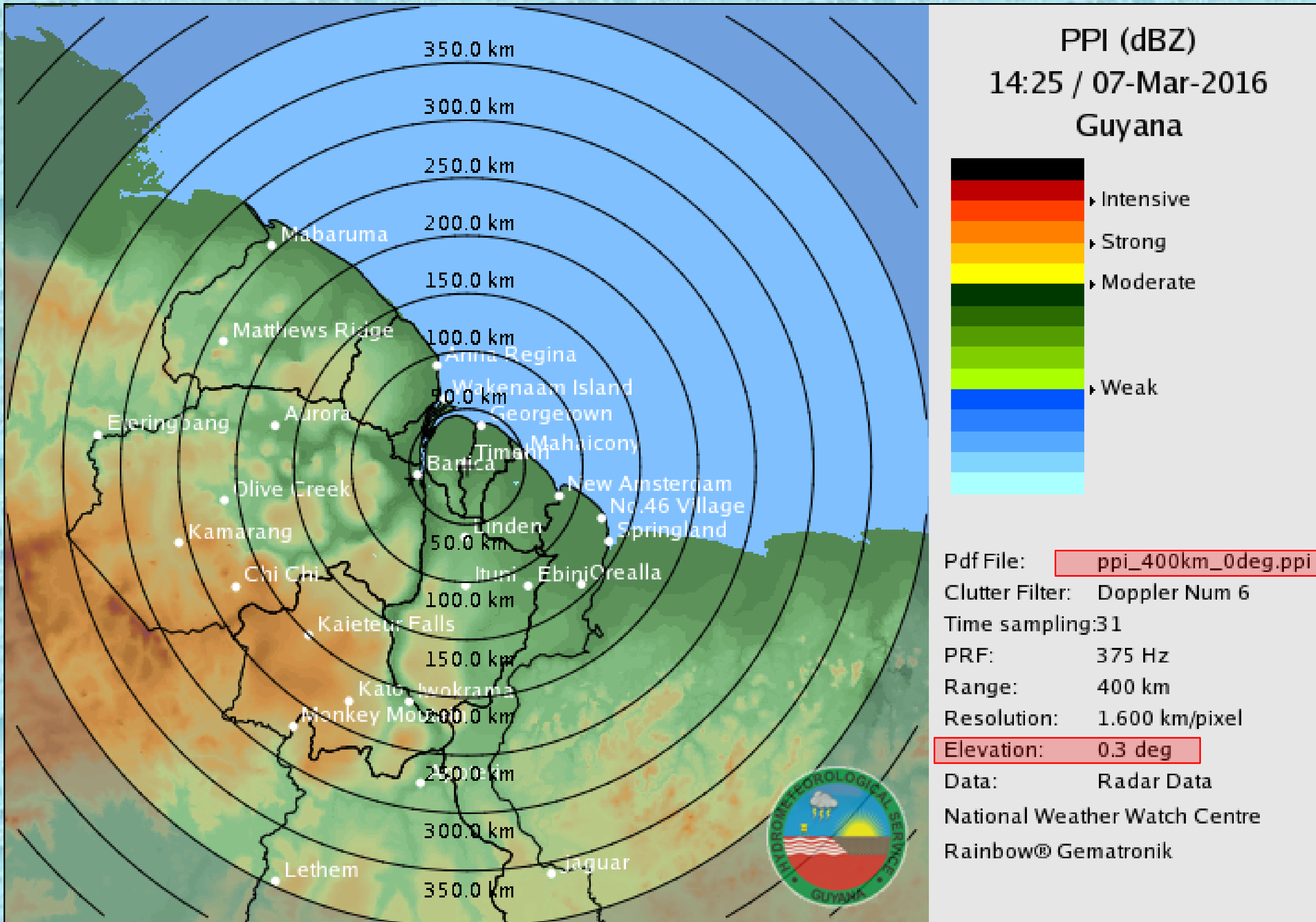
Barbados Doppler Weather Radar



Belize Doppler Weather Radar



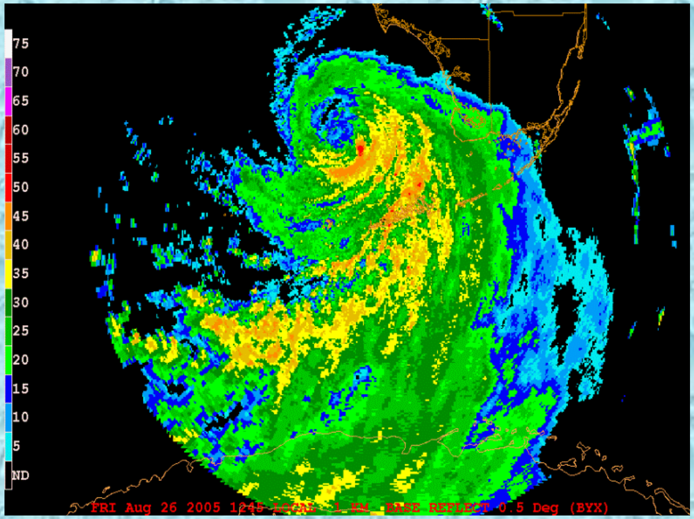
Trinidad & Tobago Doppler Weather Radar



Guyana Doppler Weather Radar

Conclusions

• Wavelength is a key design consideration for weather radar (WSR-88D uses 10 cm)



• Doppler velocity is an effective tool in determining tropical cyclone intensity, and detecting rapid intensification.

• Future – dual polarization will give better precipitation estimates.

•NEXRAD-in-space will generate radar data for the entire Atlantic basin.