WEATHER SIGNALS
Chapter 4

(Focus is on weather signals or echoes from radar resolution volumes filled with countless discrete scatterers---rain, insects, perturbations in atmospheric refractive index, etc.)

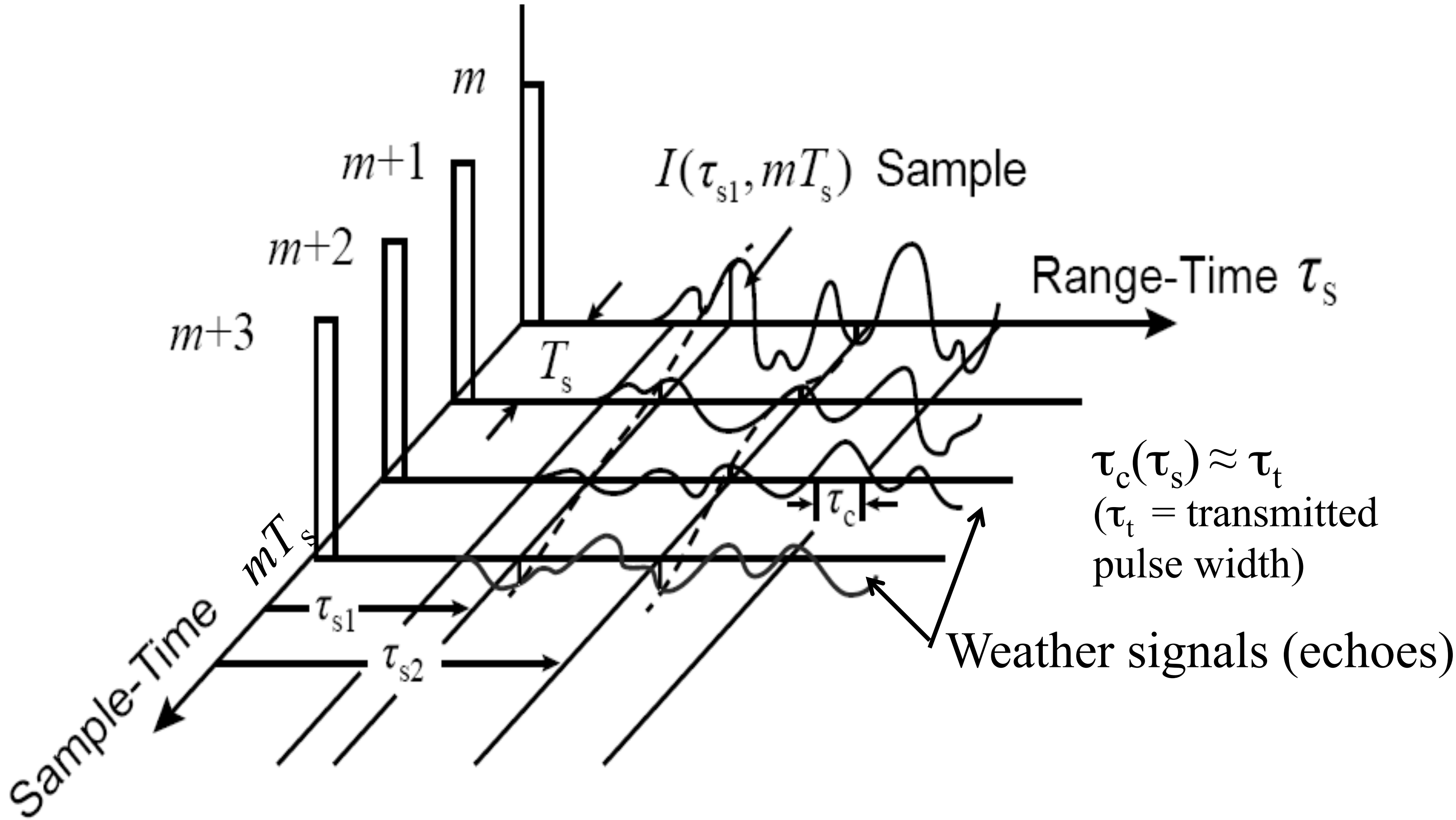
Weather Signal Characteristics

- Large dynamic range (100 million!)
- Signals are semi coherent
- Numerous scatterers in the radar resolution volume

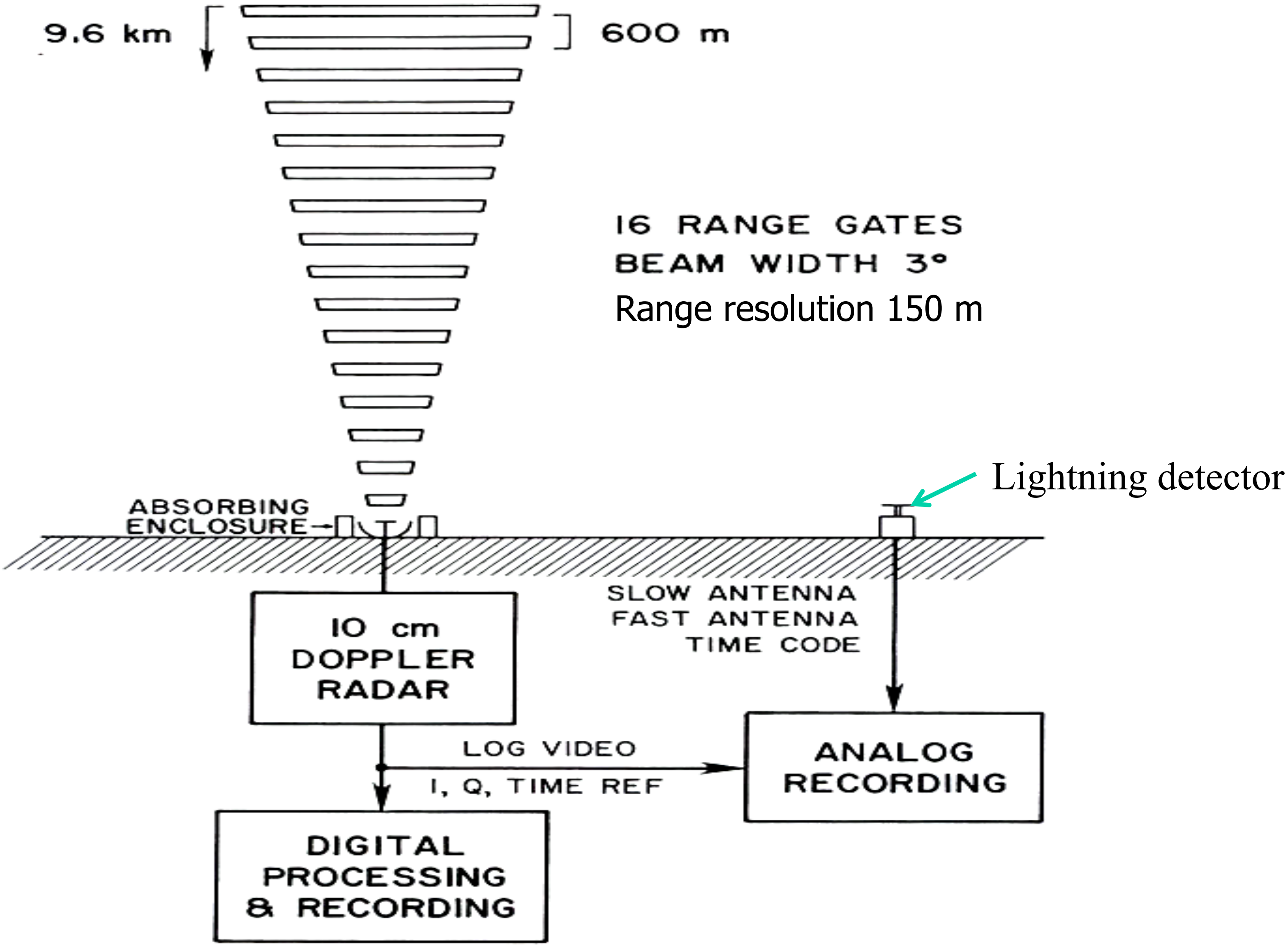
The choice instrument for weather surveillance is the pulsed polarimetric Doppler weather radar.

Extracting information (i.e., **fields** of echo H, V power, Doppler velocity, and correlation of H, V echoes) involves processing of echoes that randomly fluctuate.

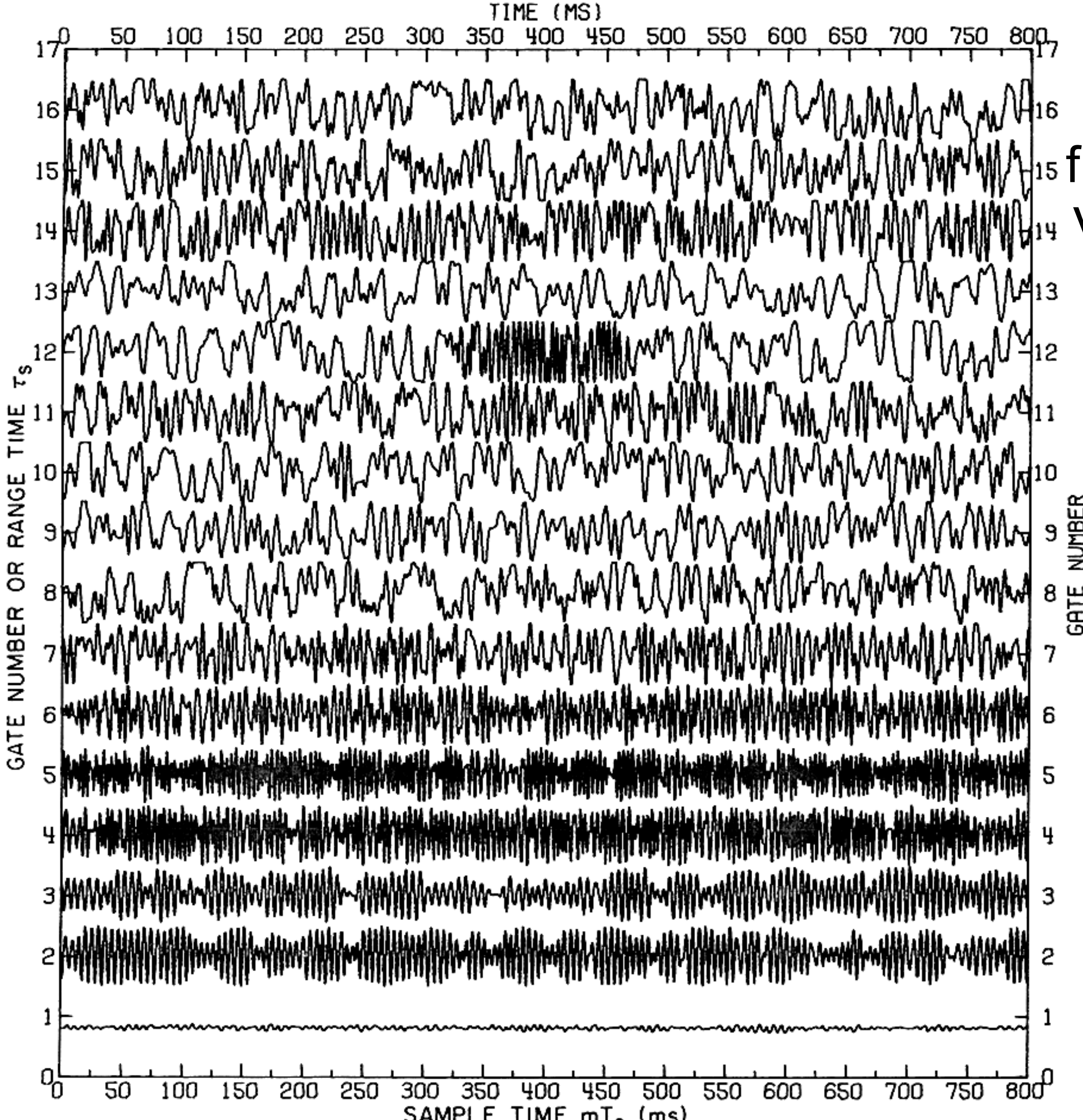
Echoes (I or Q) from Distributed Scatterers (Fig. 4.1)



Resolution Volumes

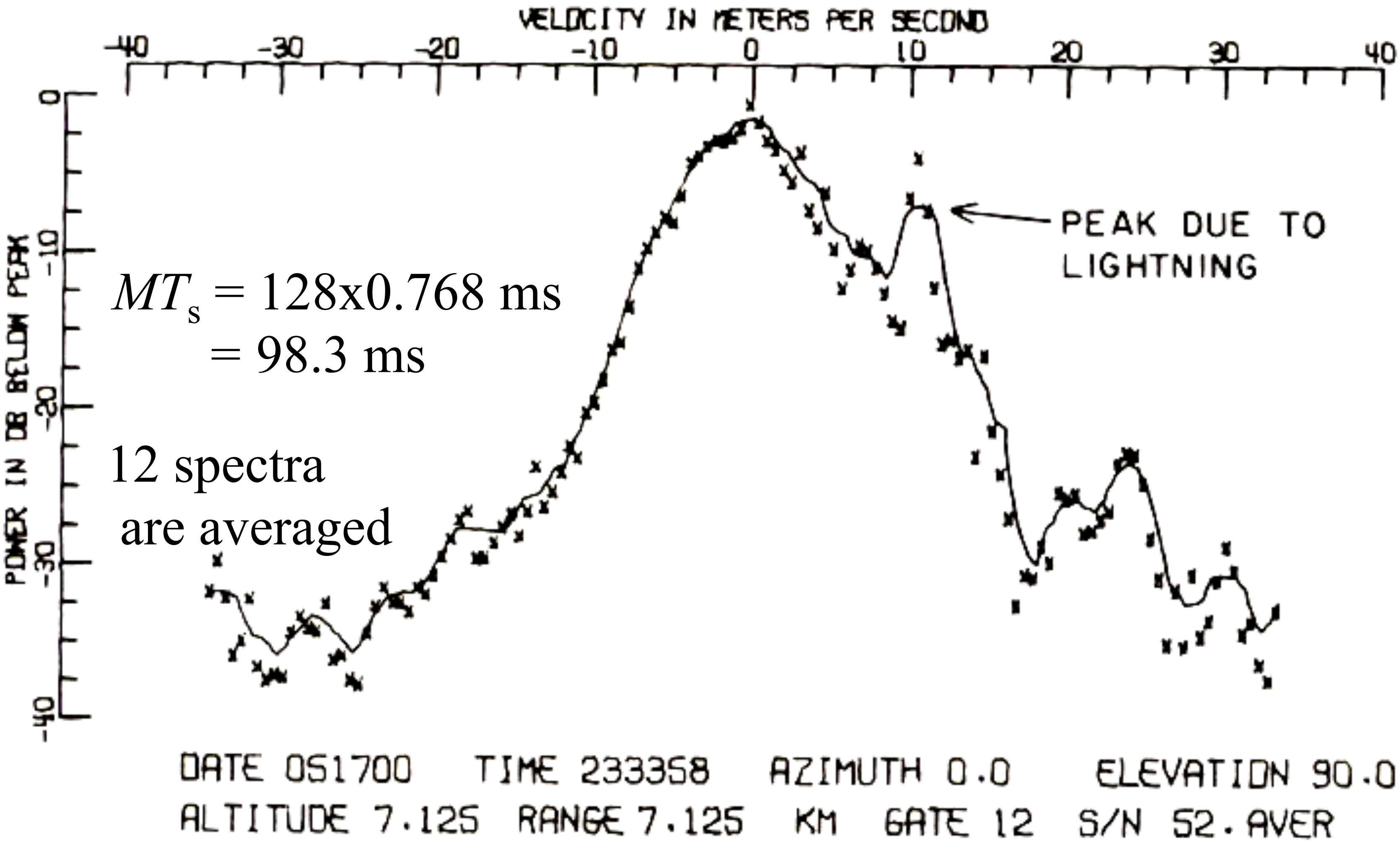


Echo samples from 16 Resolution Volumes (Fig. 4.3)



$T_s = 768$ ms

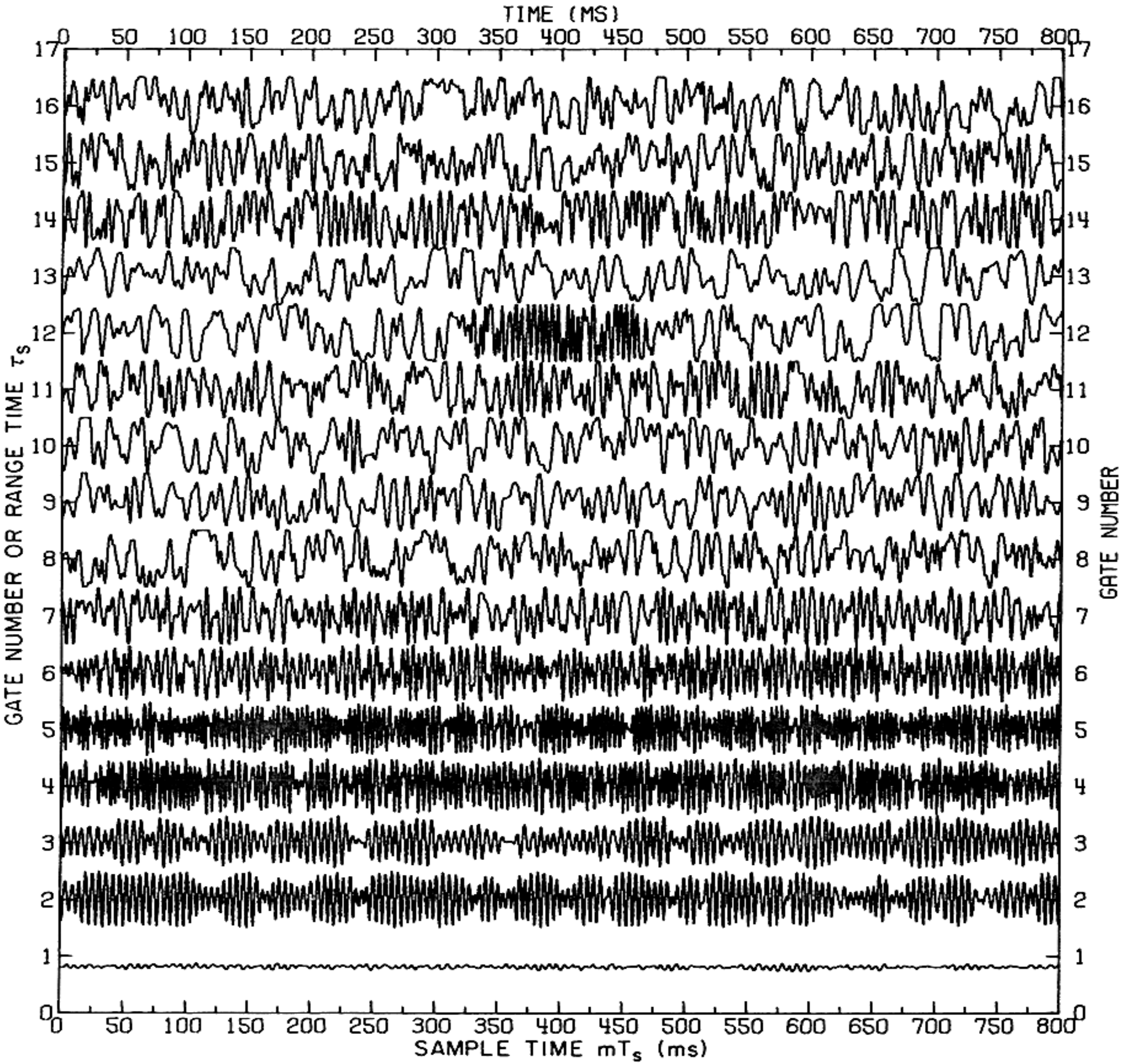
Gate 12 Signal Spectrum (Fig. 8.34)



$MT_s = 128 \times 0.768$ ms
$= 98.3$ ms

12 spectra are averaged

Repeat of Fig. 4.3

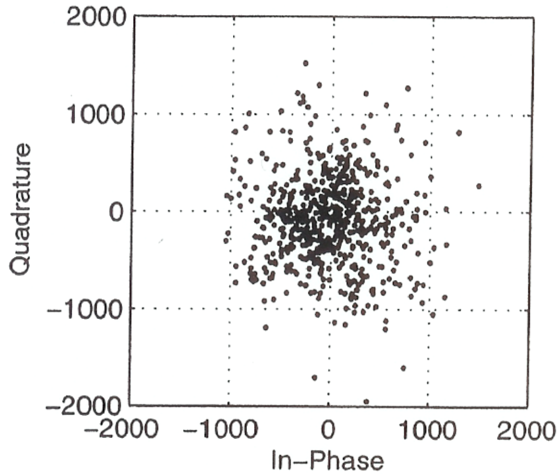


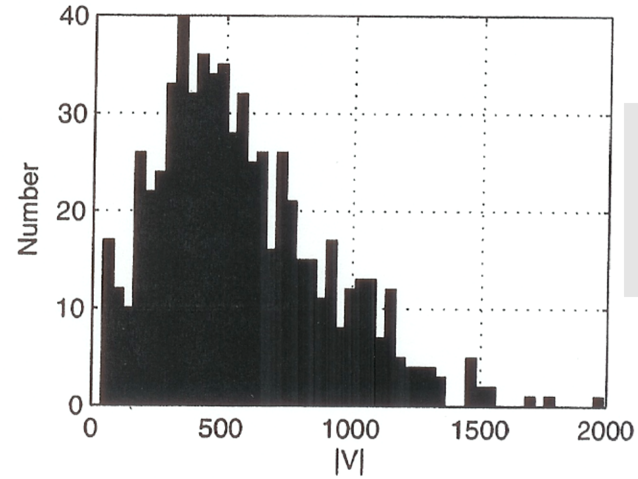
randomness

$\tau_c(mT_s) \approx$ 2-4 ms

Statistics of Weather Signals

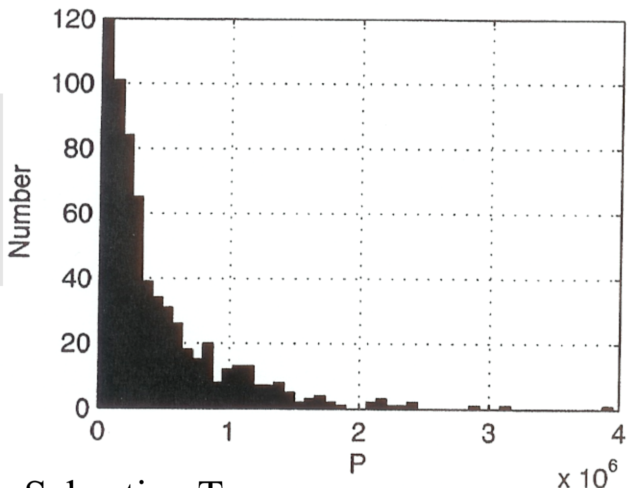
I and ***Q*** are uncorrelated zero mean random variables with Gaussian probability density function (pdf)

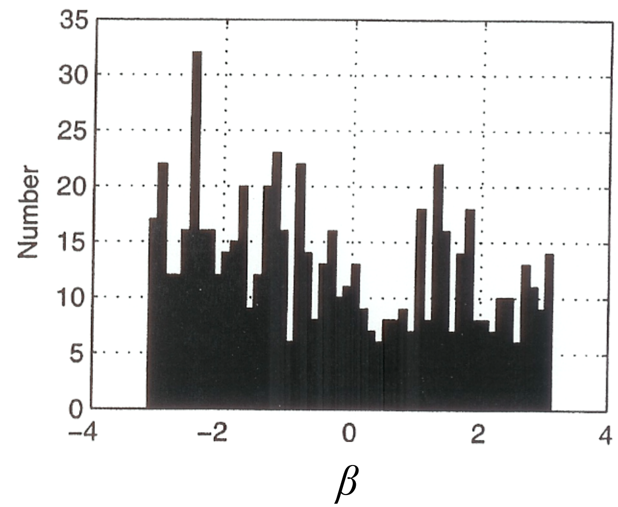




Amplitude |*V*| has a Rayleigh pdf

P has an exponential pdf

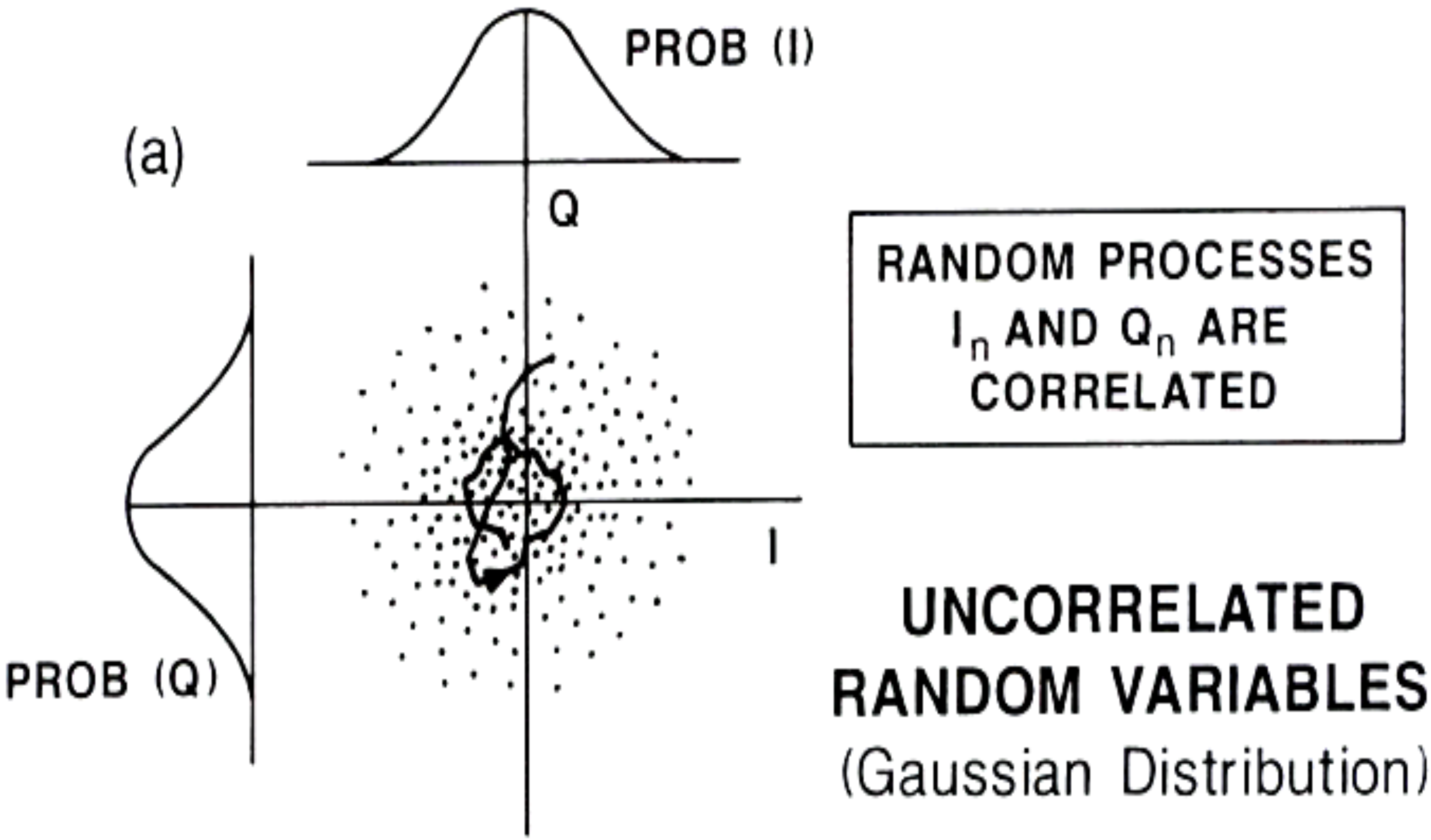




β has a uniform pdf

Thanks to Dr. Sebastian Torres

Weather Echo Statistics (Fig. 4.4)



Weighting Functions for Scatterers and the Weather Radar Equation

$$\overline{P_r}(r_o) \approx \frac{P_t g^2 \lambda^2 \eta(r_o)}{(4\pi)^3 r_o^2 \mathrm{l}^2(r_o)} \int_0^{r_o} |W_s(r)|^2 \, dr \int_0^{\pi} d\theta \int_0^{2\pi} f^4(\theta,\varphi) \sin\theta \, d\varphi \qquad (4.12)$$

where η is the reflectivity (i.e., backscatter cross section per unit volume-- assumed spatially uniform):

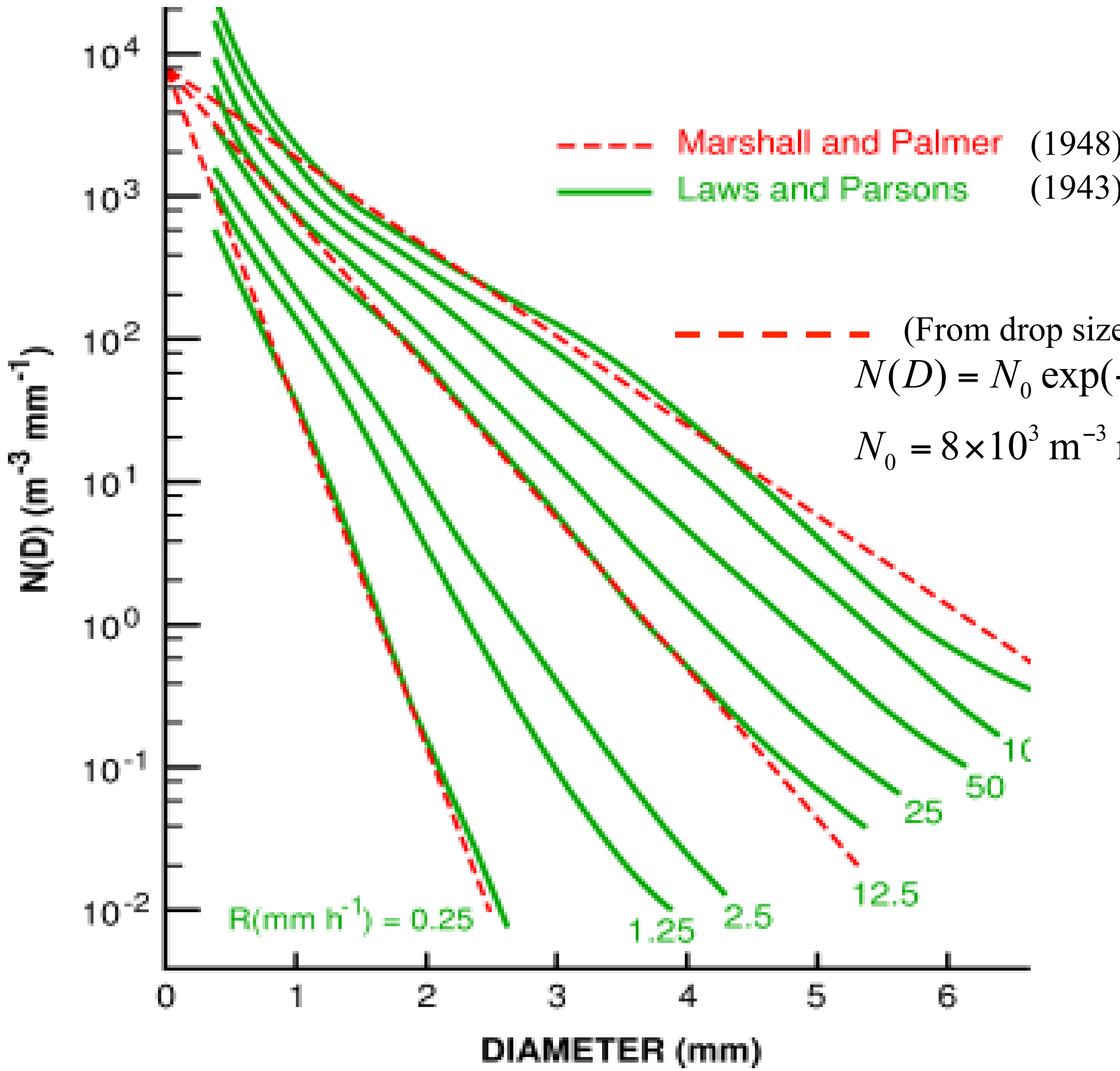
$$\eta(\boldsymbol{r}) = \int_0^{\infty} \sigma_b(D) N(D,\boldsymbol{r}) dD \quad (m^2 m^{-3}) \qquad (4.10)$$

and $N(D,\boldsymbol{r}) \equiv$ size distribution ($\mathrm{m}^{-3}\mathrm{mm}^{-1}$)

$|W_\mathrm{s}(r)|^2 \equiv$ the range weighting function;

$f^4(\theta,\varphi) \equiv$ the angular weighting function.

Drop Size Distributions (Fig. 8.3b)



(From drop sizes between 1 and 3 mm)

$$N(D) = N_0 \exp(-\Lambda D) \ (\text{EXP.DSD})$$

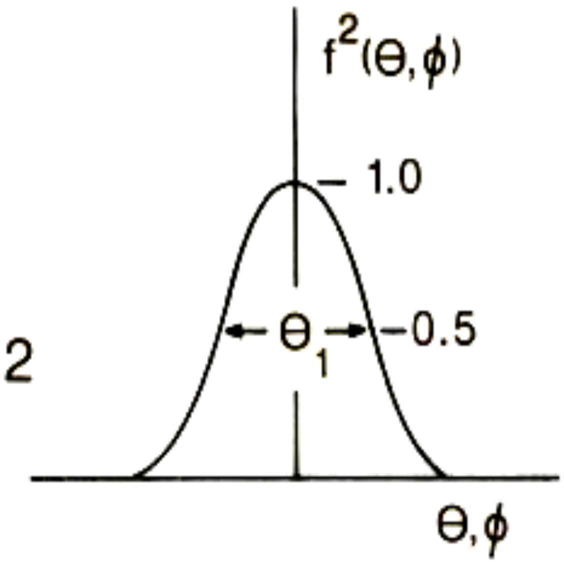
$$N_0 = 8 \times 10^3 \ \text{m}^{-3} \ \text{mm}^{-1} \ (\text{MP DSD})$$

The Angular Weighting Function

THE WEIGHTING FUNCTIONS

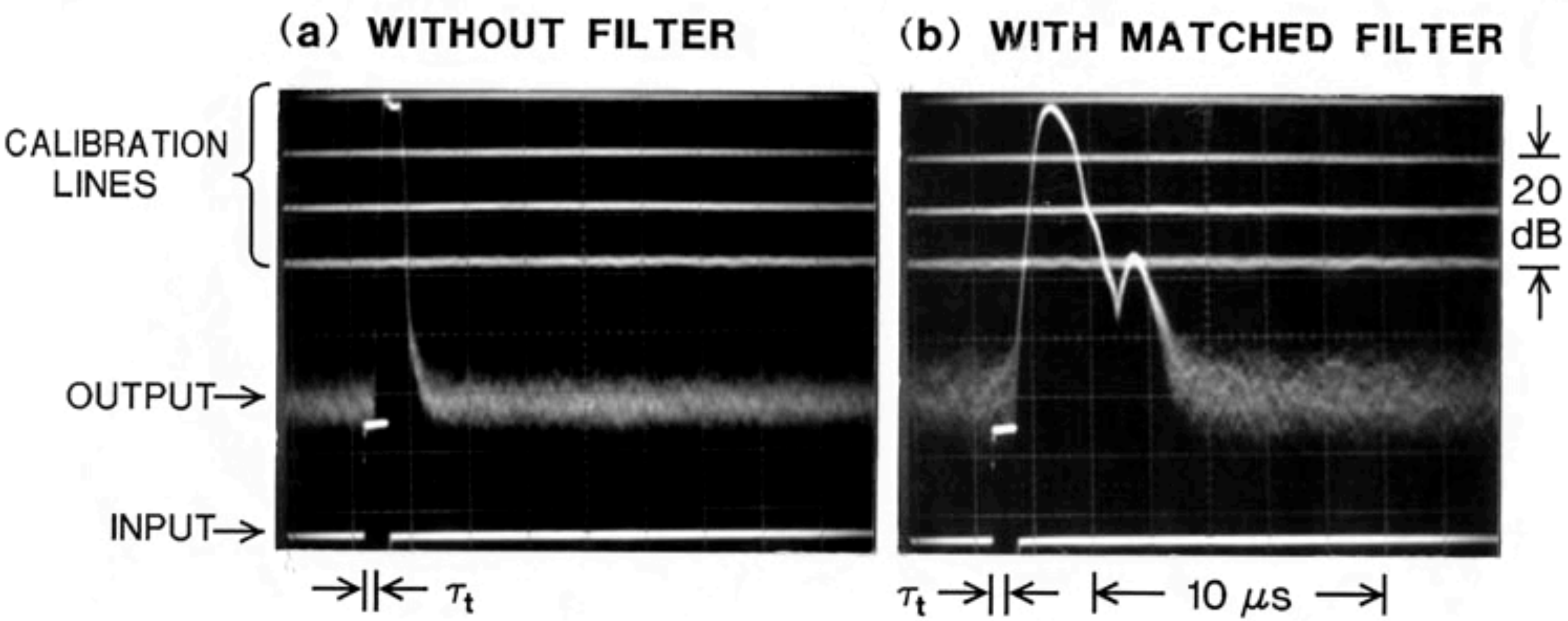
ANGULAR:

(4.13) $$\int_0^{\pi}\int_0^{2\pi} f^4(\Theta,\phi)\sin\Theta\, d\Theta\, d\phi = \pi\Theta_1^2/8\ln 2$$



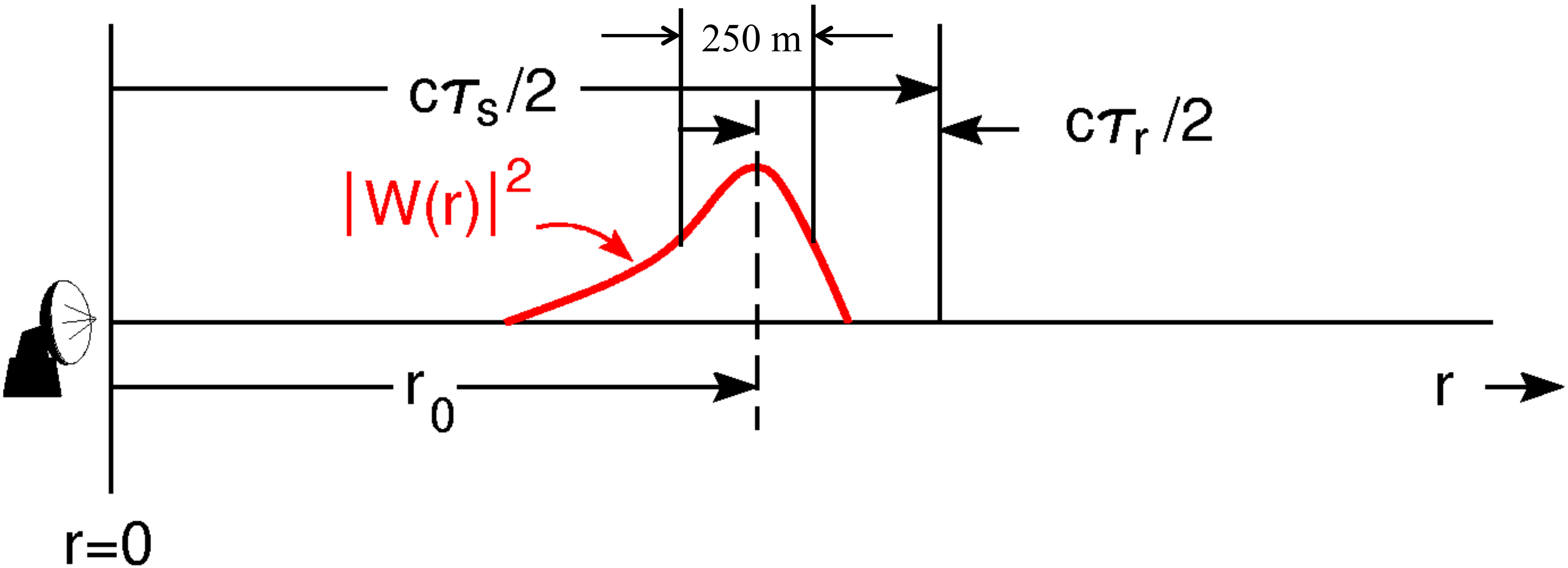
for circularly symmetric Gaussian pattern

The Measured Range Weighting Function for two Receiver Bandwidths (Fig. 4.6)



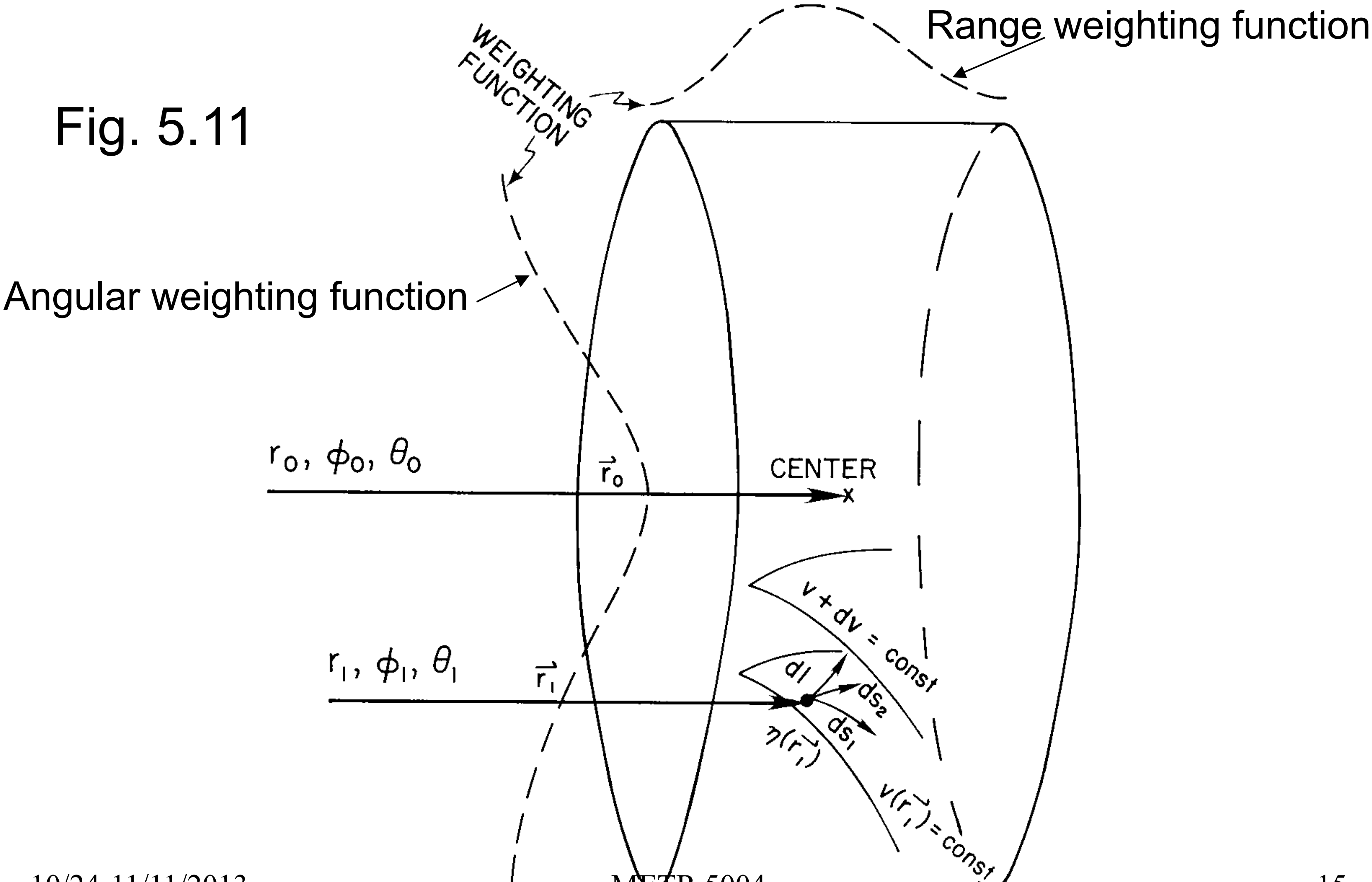
Range Weighting Function for Echoes Samples at Range Time τ_s

(Fig.4.7)

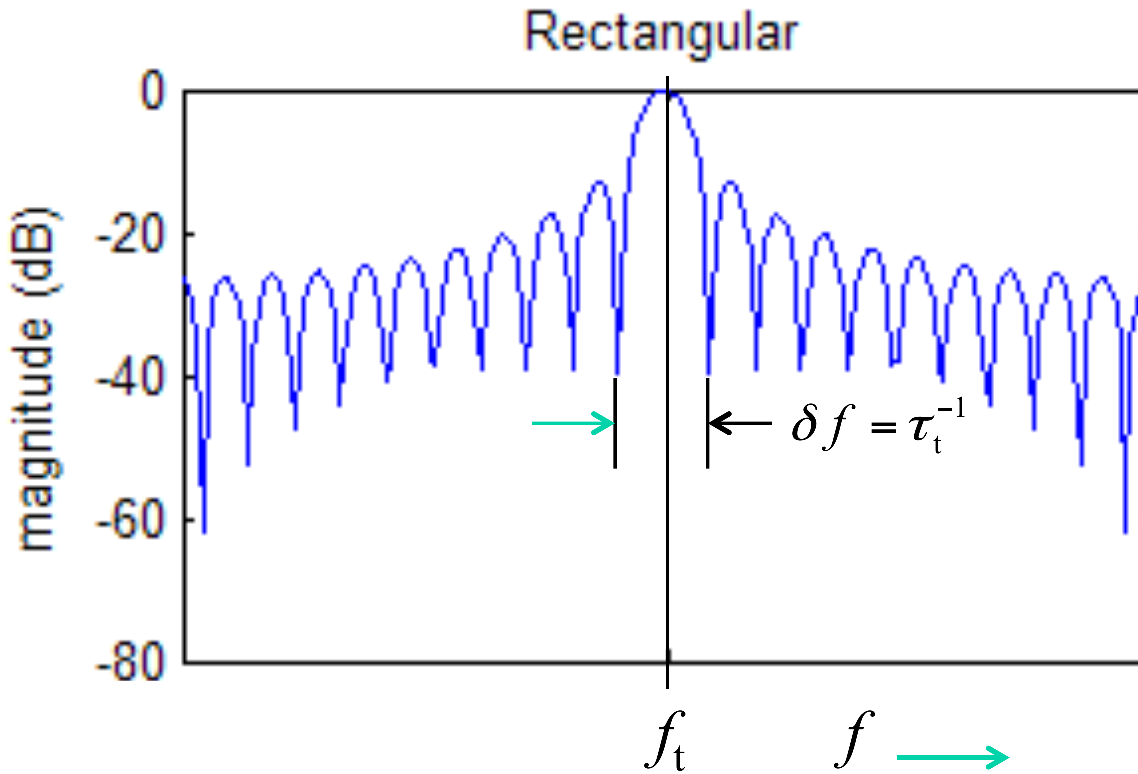


The Resolution Volume V_6

Fig. 5.11

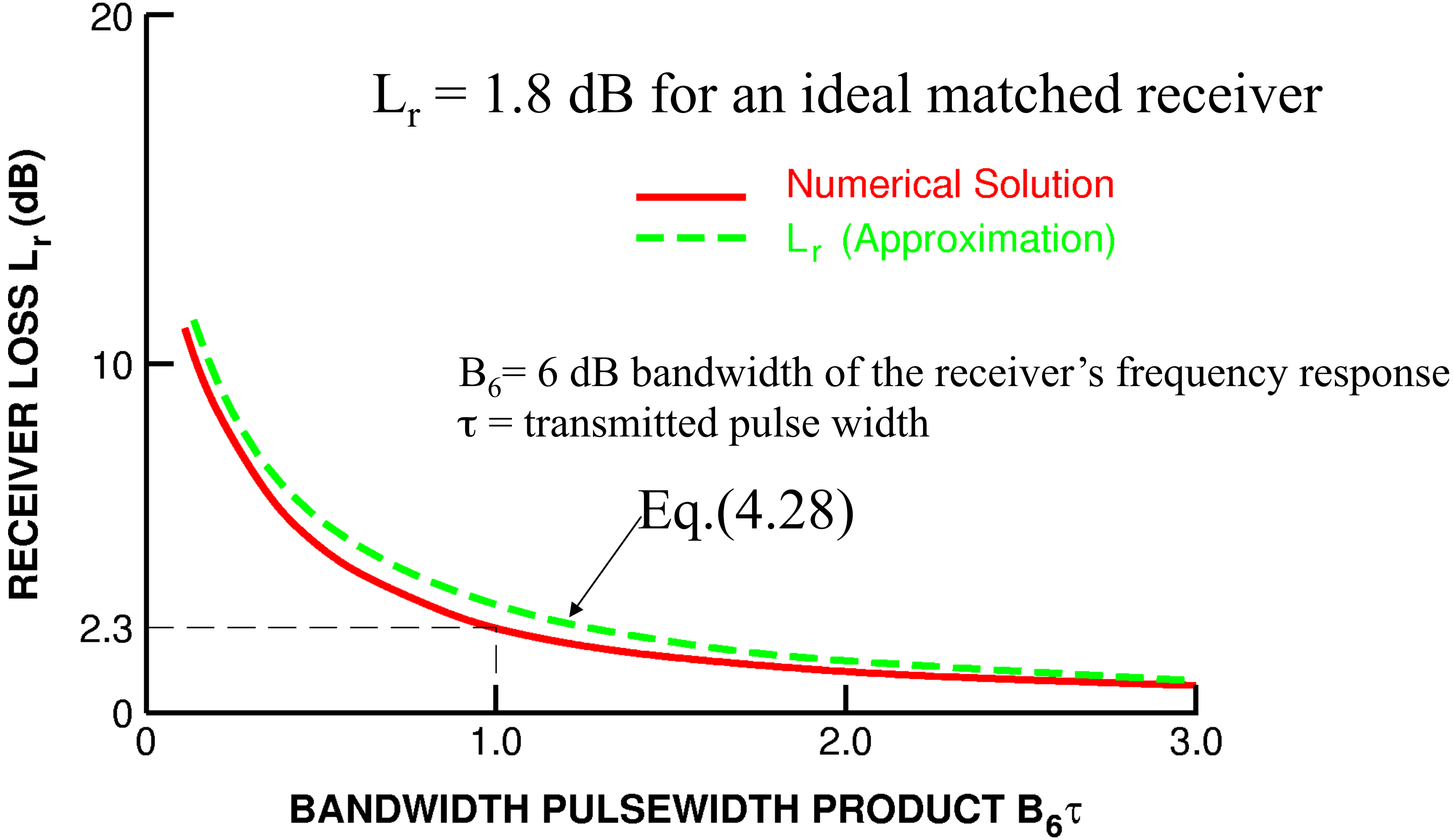


Spectrum of a transmitted rectangular pulse



If receiver frequency response is matched to the spectrum of the transmitted pulse (an ideal matched filter receiver), some echo power will be lost. This is called the finite bandwidth receiver loss L_r. For and ideal matched filter L_r = 1.8 dB.

Receiver Loss Factor (Fig. 4.8) for a Gaussian receiver response and rectangular pulse (in general a matched condition is when $B_6\tau = 1$)



Reflectivity Factor Z

(Spherical scatterers; Rayleigh condition: $D \leq \lambda/16$)

$$\eta(\boldsymbol{r}) = \frac{\pi^5}{\lambda^4} |K_{\mathrm{m}}|^2 Z(\boldsymbol{r}) \qquad (4.31)$$

where

$$Z(\boldsymbol{r}) \equiv \frac{1}{\Delta V} \sum_i D_i^6 = \int_0^\infty N(D,\boldsymbol{r}) D^6 dD \qquad (4.32)$$

$$\eta(\boldsymbol{r}) = \frac{\pi^5}{\lambda^4} |K_{\mathrm{w}}|^2 Z_{\mathrm{e}}(\boldsymbol{r}) \qquad (4.33)$$

for water drops: $|K_{\mathrm{w}}|^2 \approx 0.93$ independent of $\mathrm{T}(^{\mathrm{o}}\mathrm{C})$;

for ice particles: $|K_{\mathrm{i}}|^2 \approx 0.16$ dependent on T and ice density.

Reflectivity Factor of Spheroids (Horizontally Polarized Waves)

$$Z_h = \frac{\lambda^4 N_o}{\pi^5 |K|^2} \int_0^{\infty} \int_{\xi} \int_{e} p[D_e, e, \xi] \sigma_h [D_e, e, \xi] dD_e d\xi de$$

S K I P ?

$p[D_e, e, \xi]$ = probability density

$\sigma_h[D_e, e, \xi]$ = backscatter cross section for H pol.

D_e = equivalent volume diameter

e = eccentricity of the spheroid scatterer

ξ = angle between the symmetry axis and the electric field direction

N_0 = the number density per unit diameter (m^{-4})

Differential Reflectivity

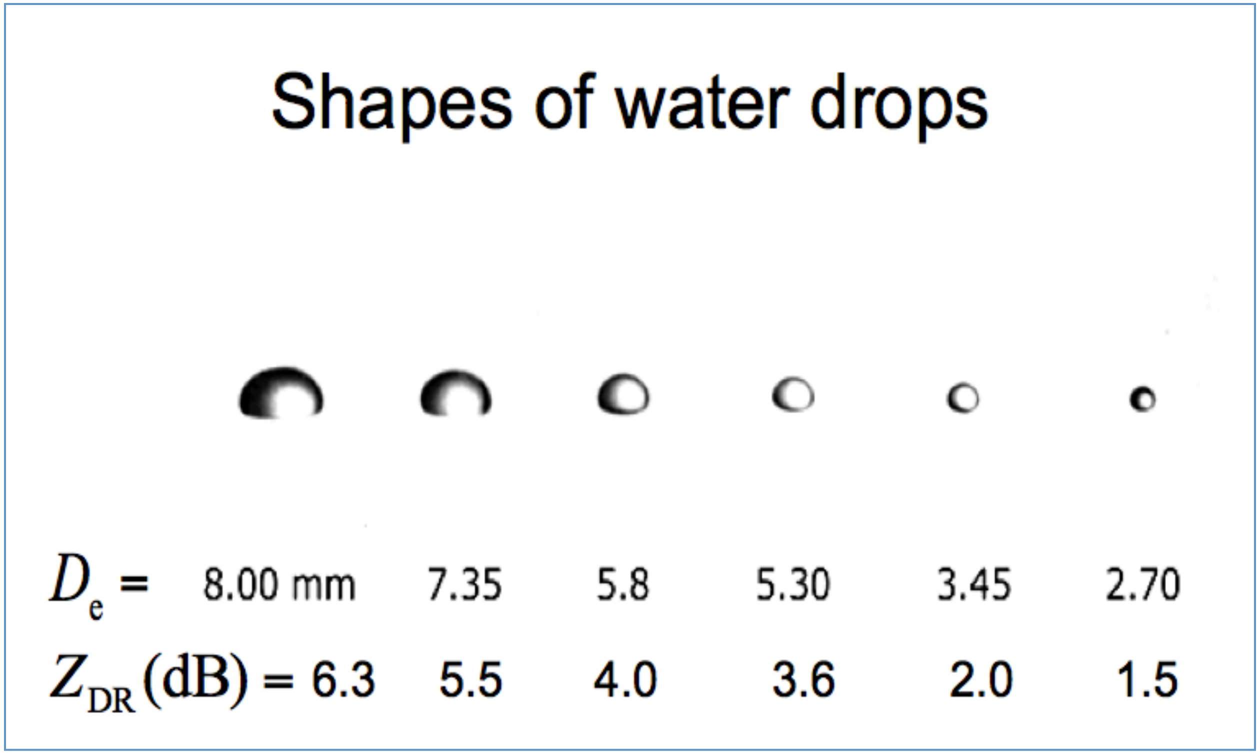
in dB units:

Z_{DR}(dB) = Z_h(dBZ) - Z_v(dBZ)

in linear units:

$Z_{dr} = Z_h(\text{mm}^6\text{m}^{-3})/Z_v(\text{mm}^6\text{m}^{-3})$

- is independent of drop concentration N_0
- depends on the shape of scatterers



Shapes of raindrops falling in still air and experiencing drag force deformation.

D_e is the equivalent diameter of a spherical drop. Z_{DR} (dB) is the differential reflectivity in decibels (Rayleigh condition is assumed). Adapted from Pruppacher and Beard (1970)

The Weather Radar Equation

A form of the weather radar equation for echo power from rain is:

$$E\left[P(\boldsymbol{r}_0)\right](\text{mW}) = \frac{\pi^5 10^{-17} P_t(\text{W}) g^2 g_s \tau(\mu\text{s}) \theta_1^2(\text{deg.}) \, |K_w|^2 \, Z_w(\text{mm}^6\,\text{m}^{-3})}{6.75 \times 2^{14} (\ln 2) r_0^2(\text{km}) \lambda^2(\text{cm}) l^2 l_r} \qquad (4.35)$$

$E\left[P(\boldsymbol{r}_0)\right] \equiv$ Expected peak weather signal power in milliwatts;

$P_t \equiv$ Peak transmitted pulse power (typically 500 kW)

$g_s \equiv$ net power gain of the echo in going from the antenna to the radar output. τ = pulse width

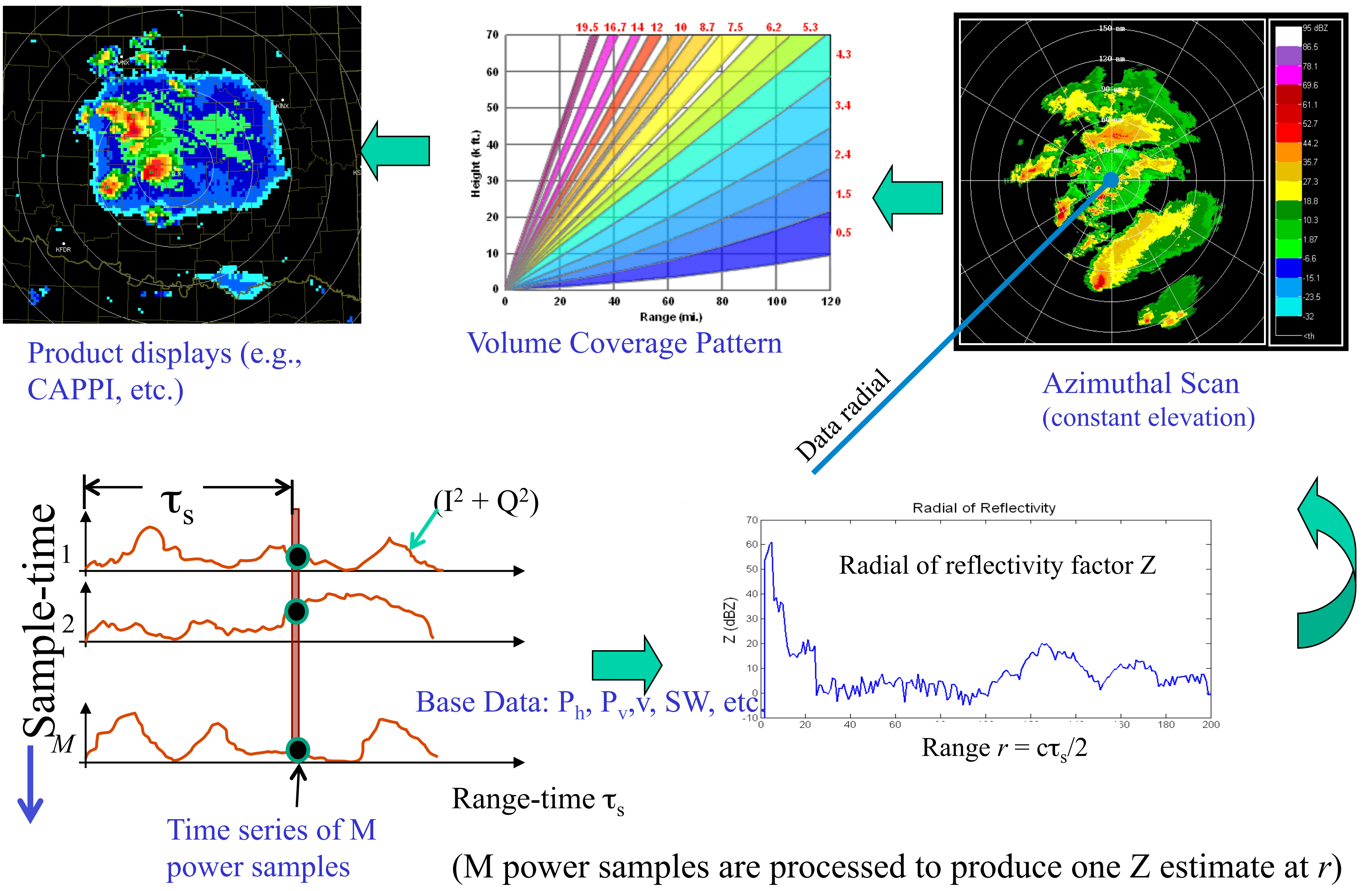
$\theta_1 \equiv$ one-way half-power beamwidth; $|K_w|^2 \equiv$ dielectric factor of water

$Z_w \equiv$ reflectivity factor for water spheres; $r_0 \equiv$ range (in km) to the center of the resolution volume V_6

$l \equiv$ one-way loss factor (a number $\geq$ 1) incurred for propagation through a rain filled atmosphere.

$l_r \equiv$ loss factor due to the finite bandwidth of the receiver; $\lambda \equiv$ wavelength of the transmitted radiation

Acquisition, Processing and Display of Weather radar data

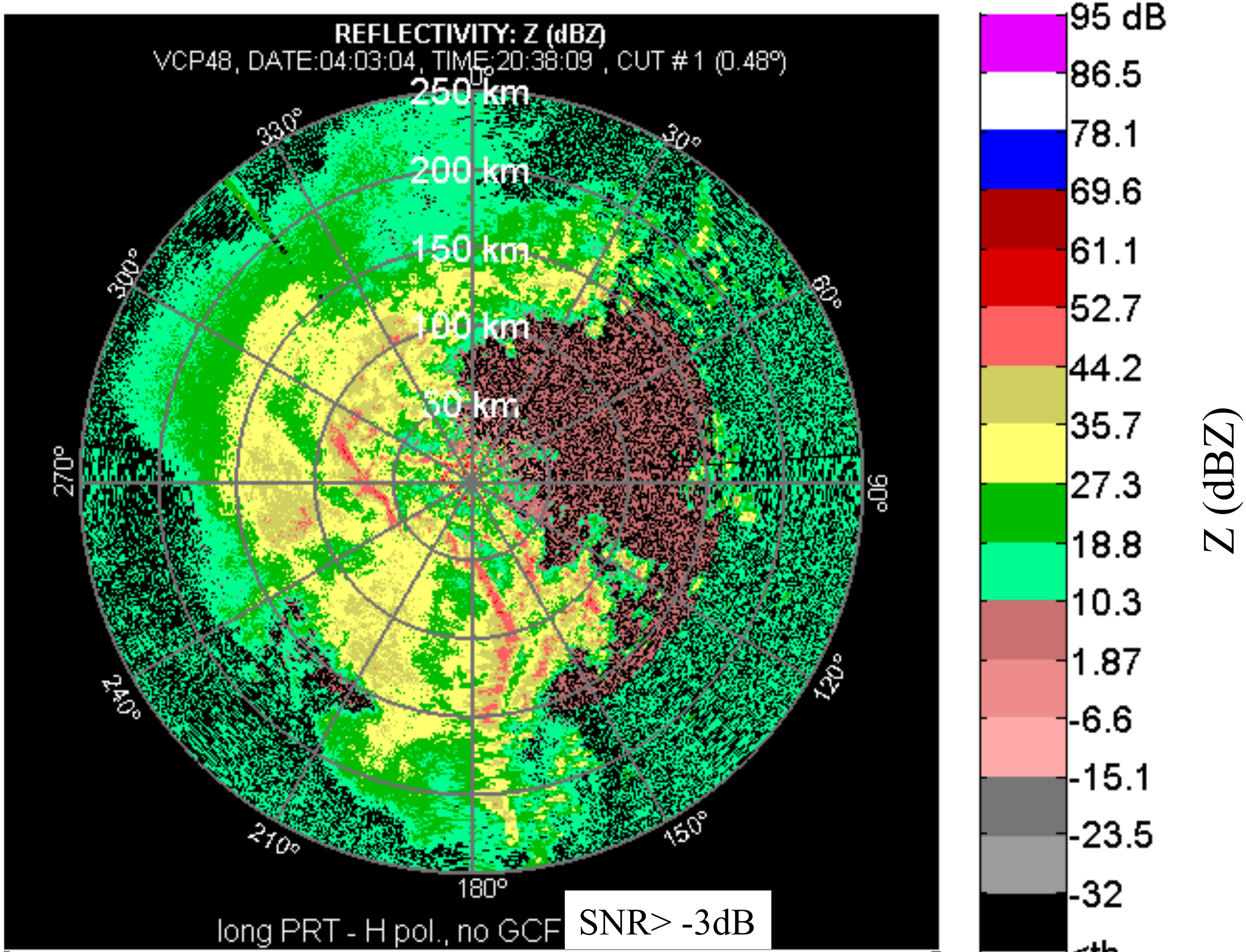


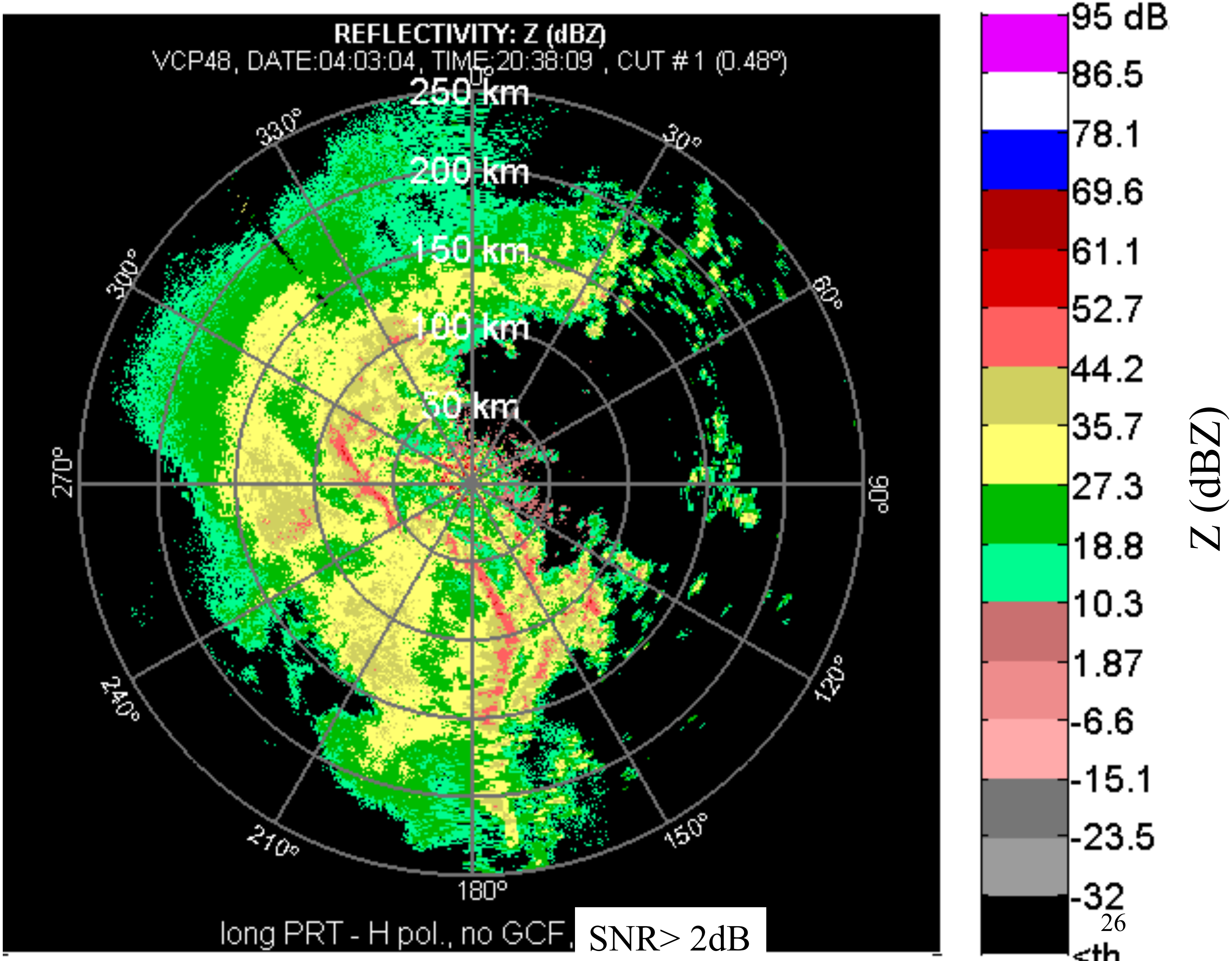
WSR-88D Thresholding Data Fields based on Signal to Noise Ratios

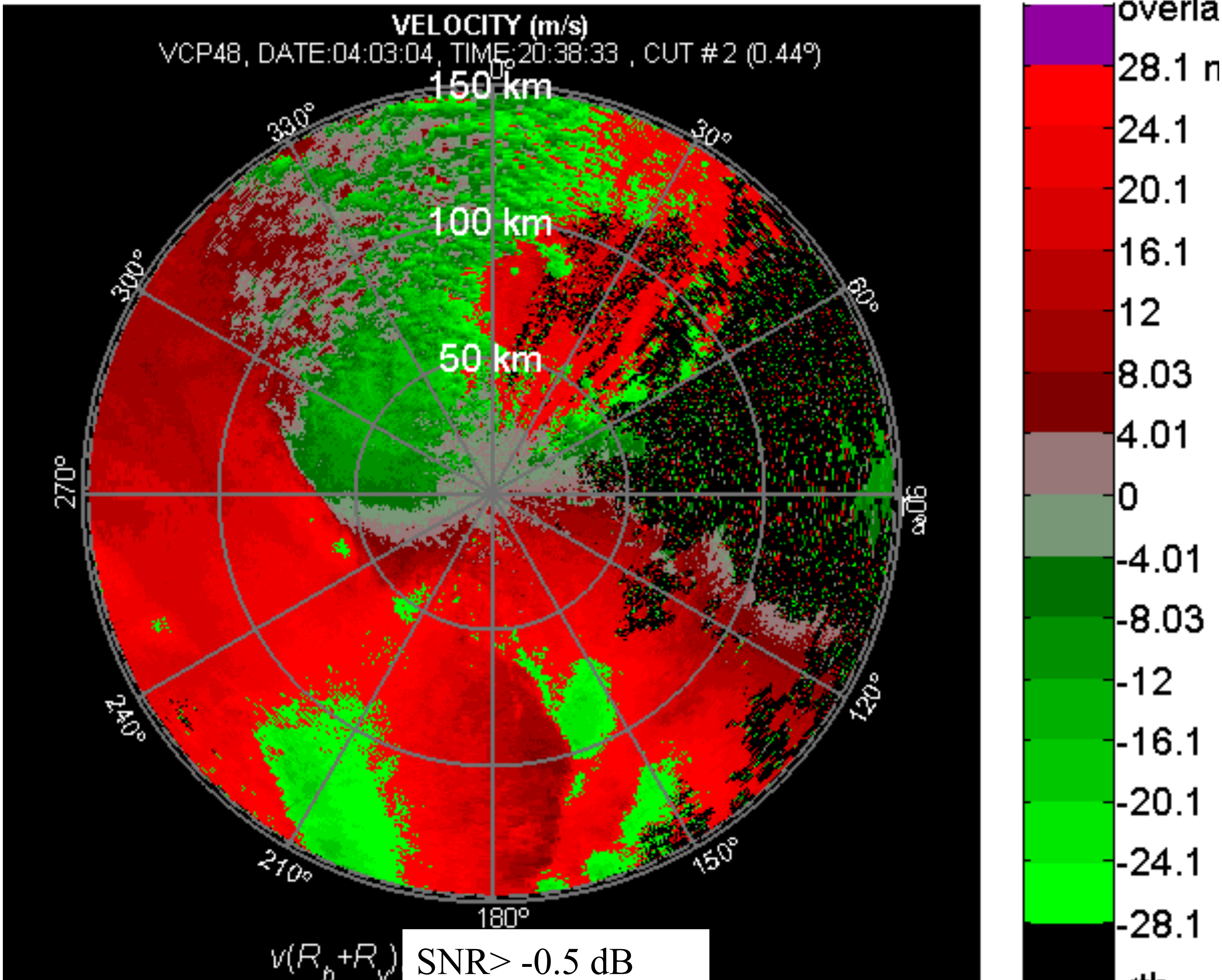
Locations with non-significant powers are censored:

-Non significant
returns have a SNR below a user-defined threshold

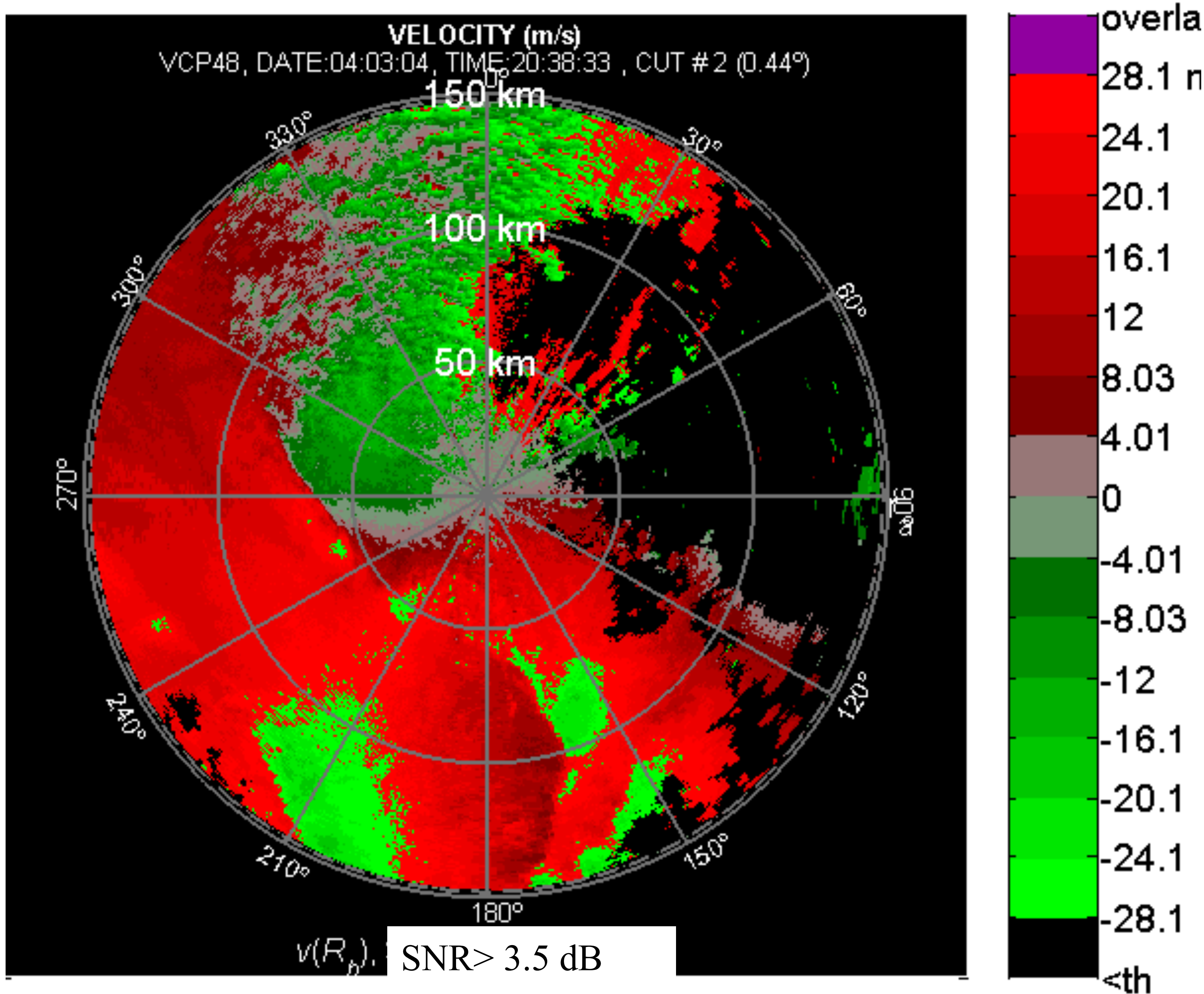
-The system allows a different threshold
for each spectral moment


REFLECTIVITY: Z (dBZ)
VCP48, DATE:04:03:04, TIME:20:38:09 , CUT # 1 (0.48°)
250 km
200 km
150 km
100 km
50 km
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
long PRT - H pol., no GCF
SNR> -3dB
95 dB
86.5
78.1
69.6
61.1
52.7
44.2
35.7
27.3
18.8
10.3
1.87
-6.6
-15.1
-23.5
-32
<th
Z (dBZ)

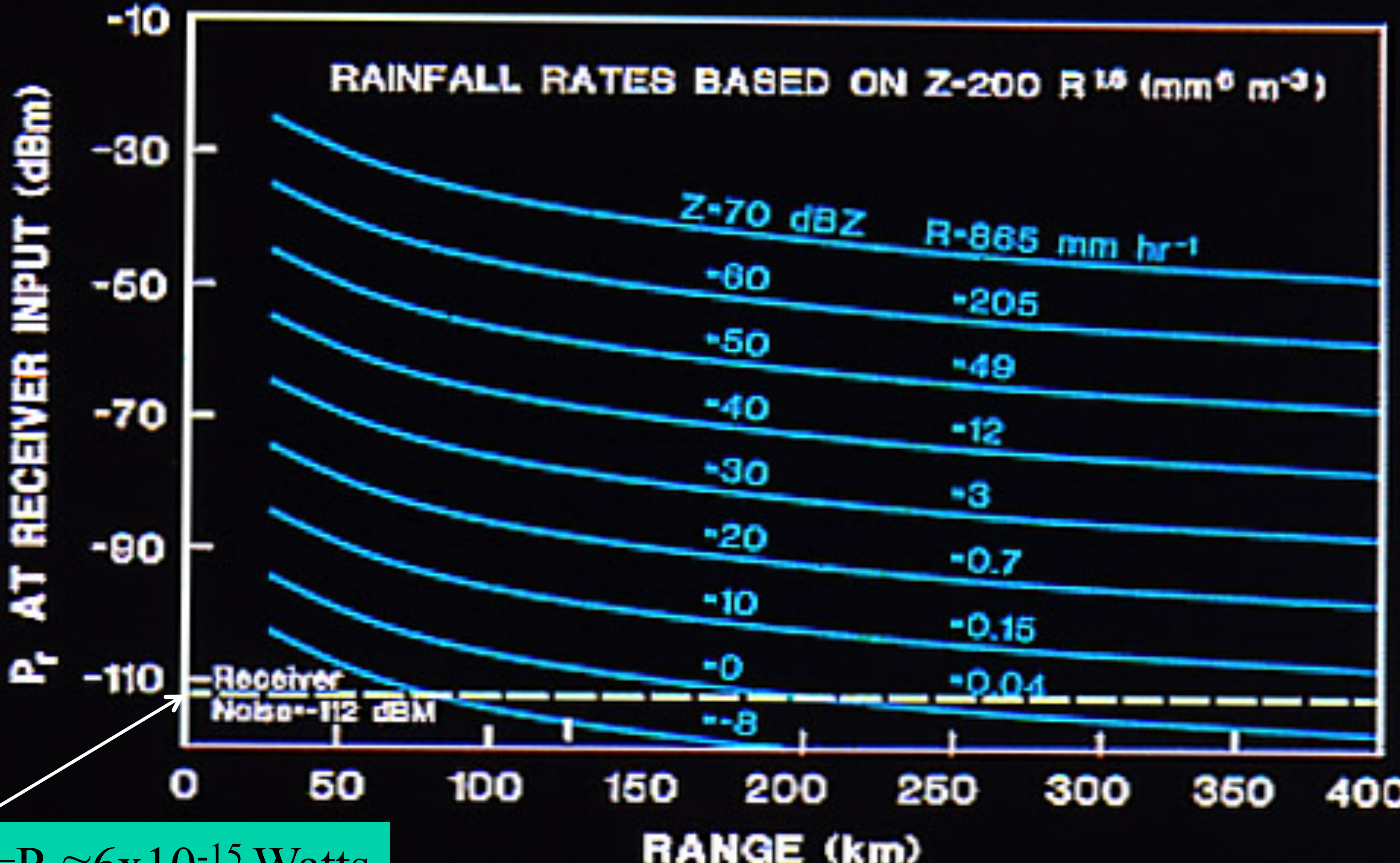

REFLECTIVITY: Z (dBZ)
VCP48, DATE:04:03:04, TIME:20:38:09 , CUT #1 (0.48°)
0°
250 km
200 km
150 km
100 km
50 km
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
long PRT - H pol., no GCF,
SNR> 2dB
95 dB
86.5
78.1
69.6
61.1
52.7
44.2
35.7
27.3
18.8
10.3
1.87
-6.6
-15.1
-23.5
-32
<th
Z (dBZ)



VELOCITY (m/s)
VCP48, DATE:04:03:04, TIME:20:38:33 , CUT # 2 (0.44°)
150 km
100 km
50 km
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
SNR> -0.5 dB
overla
28.1 m
24.1
20.1
16.1
12
8.03
4.01
0
-4.01
-8.03
-12
-16.1
-20.1
-24.1
-28.1
<th


VELOCITY (m/s)
VCP48, DATE:04:03:04, TIME:20:38:33 , CUT # 2 (0.44°)
150 km
100 km
50 km
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
overla
28.1 n
24.1
20.1
16.1
12
8.03
4.01
0
-4.01
-8.03
-12
-16.1
-20.1
-24.1
-28.1
<th
SNR> 3.5 dB

Weather Echo Power vs Range (WSR-88D)



$P_r = P_n \approx 6 \times 10^{-15}$ Watts