Calibration of KOUN Radar with Metal Spheres

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Outline

- Acknowledgements for team effort
- Definition of Z_{DR} and the Holy Grail: 0.1 dB
- Rationale for calibration effort
- Methods for calibration: Pros and Cons
- Calibration with metal spheres -- Theory
- Calibration with metal spheres -- Measurements with KOUN radar
- Summary of comparisons, theory versus experiment
- Conclusions

Acknowledgements for Team Effort

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• Walt Strong	Westheimer Airport Operations
• Tom Webster	FAA organization; illumination of balloon
• Dusan Zrnic	For giving thumbs up and for giving up thumbs

Differential Reflectivity (Z_{DR})

For radars equipped with two orthogonal receiver channels H and V

Definition: $Z_{DR} = 10 \log (Z_H / Z_V)$

But H and V channels must be carefully matched in overall gain!

The current Holy Grail: 0.1 dB accuracy in Z_{DR}
(A 2% difference in Z_H and Z_V)

Calibration Methods for Differential Reflectivity (Z_{DR})

'True' calibration:

1) Metal sphere calibration
2) 'Bird bath': vertically pointing observations on rain
3) Sun-pointing (RCVR check only)
4) NCAR cross-pol method
5) Drizzle

Pseudo calibration:

1) Hydrometeor calibration
2) Z-Z_{DR} asymptote method
3) Clear air backscatter
4) Natural ground clutter and towers
5) Use of the Moon

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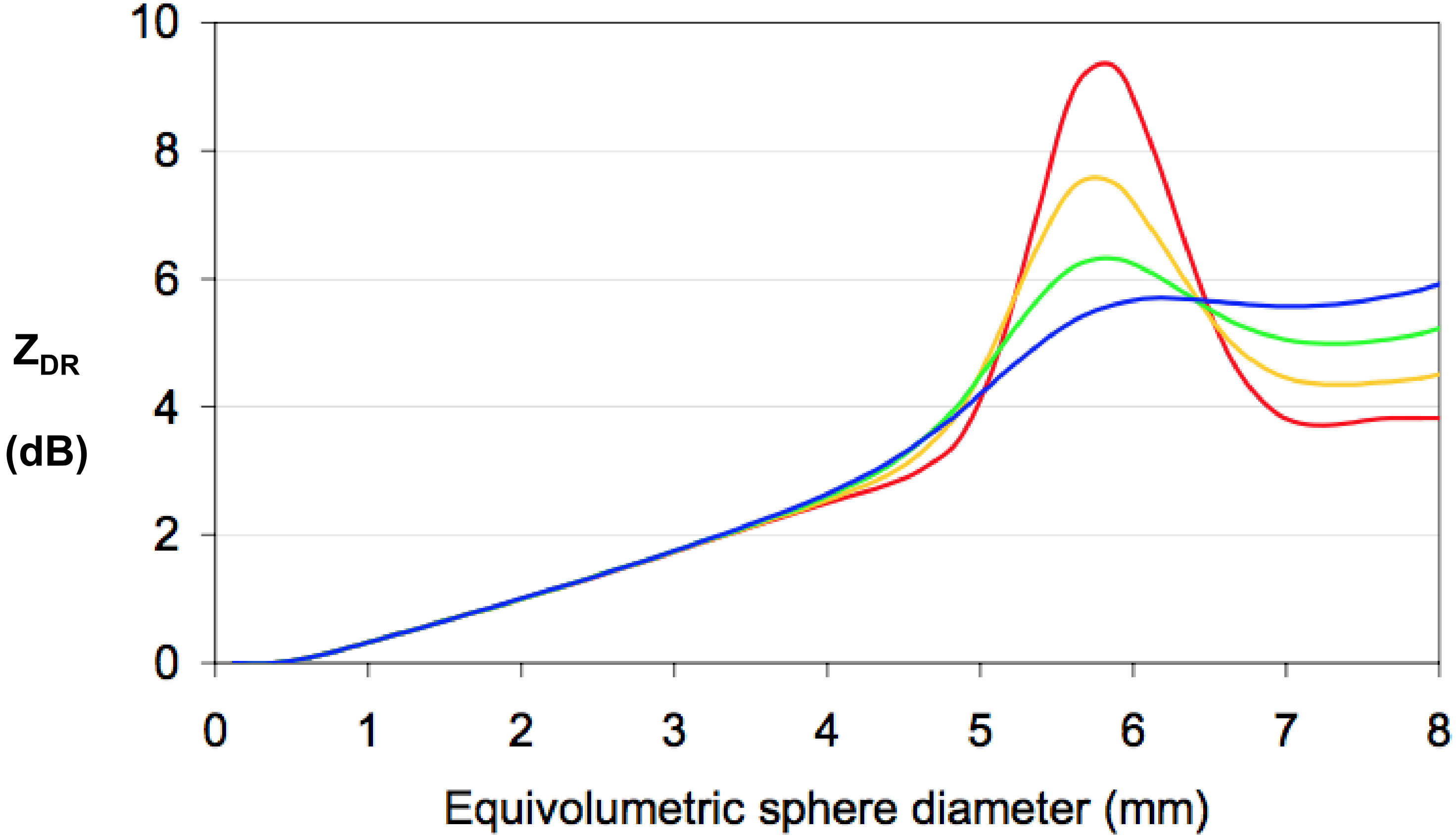
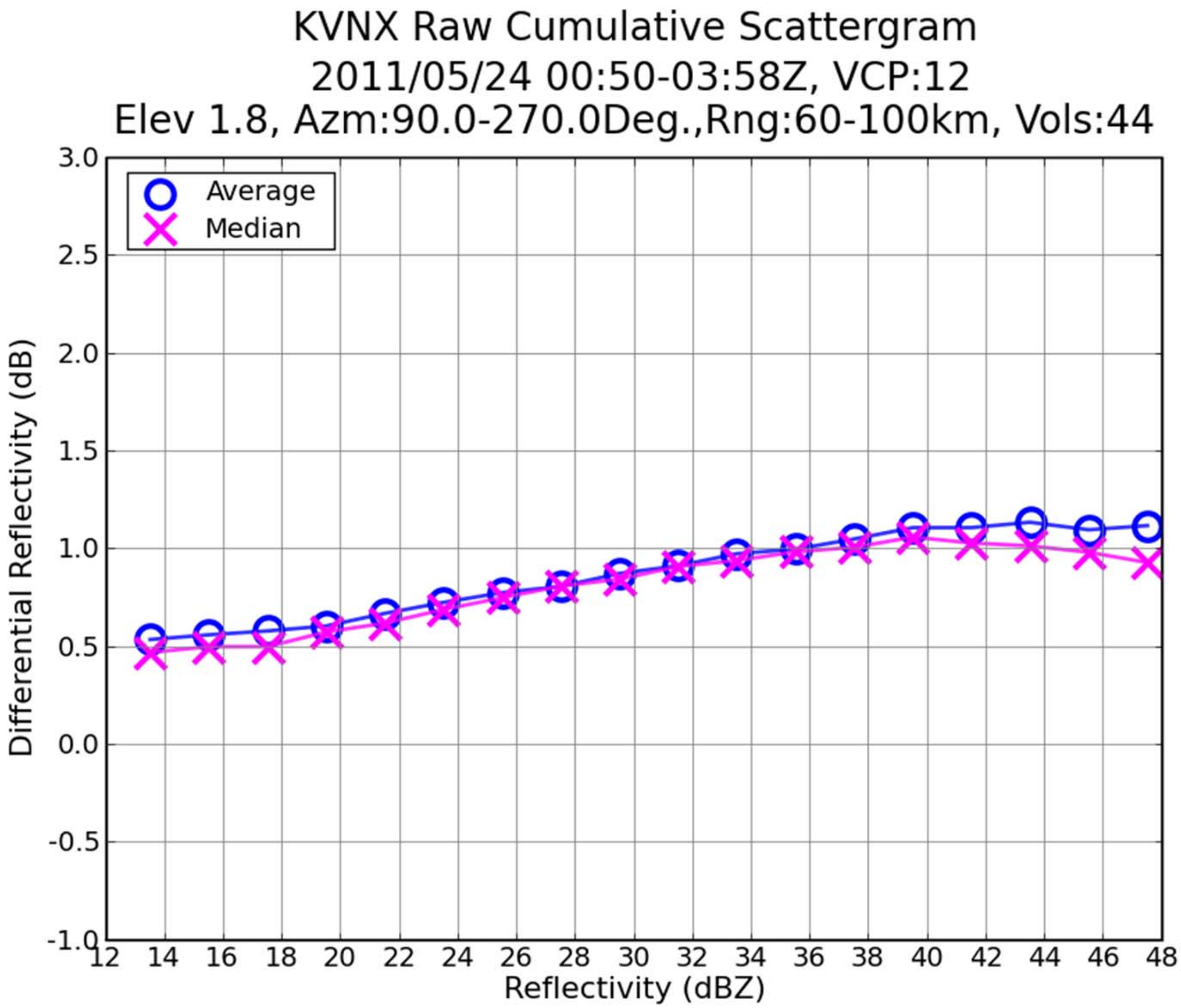
How small need a raindrop be to have a Z_{DR} return of 0.1 dB?



"from Teschl et al., (2008)"

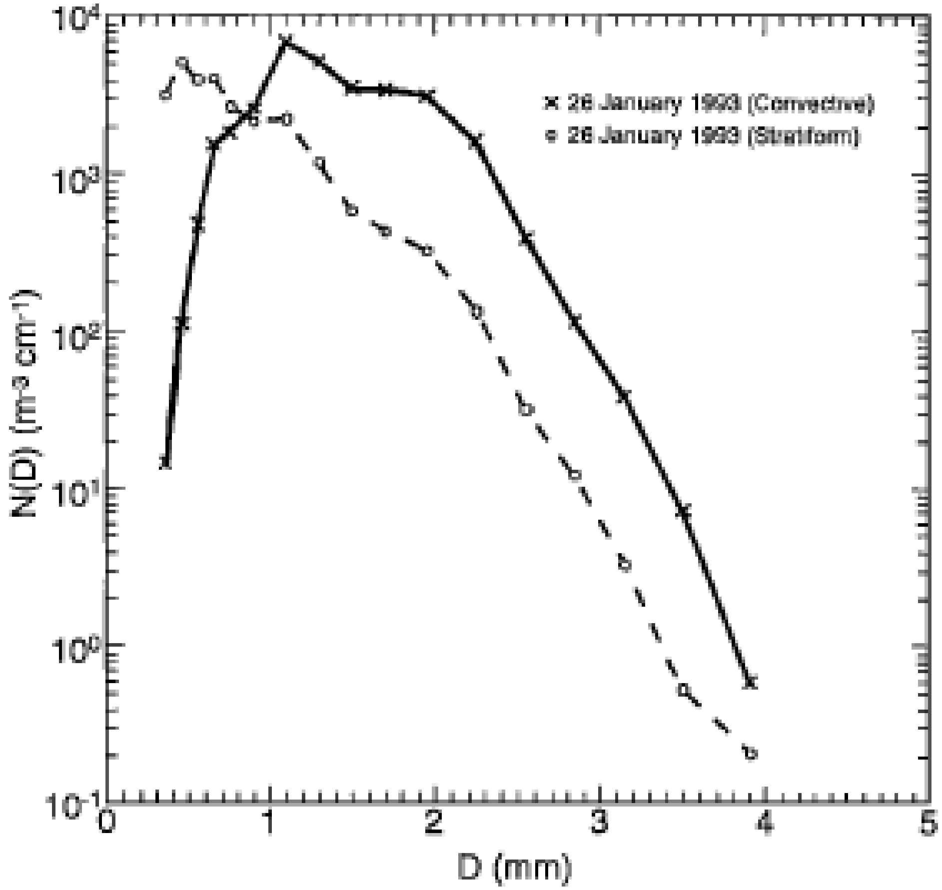
'Calibration' by Z_{DR} Asymptote Method

Is the small Z asymptote 0 dB?



From NEXRAD Data Quality Committee

Drop Size Distribution in Stratiform Rain Contains Oblate Raindrops



"from Atlas et al. (1999)"

Drop Size Distributions in Convective, Transition, and Stratiform Conditions

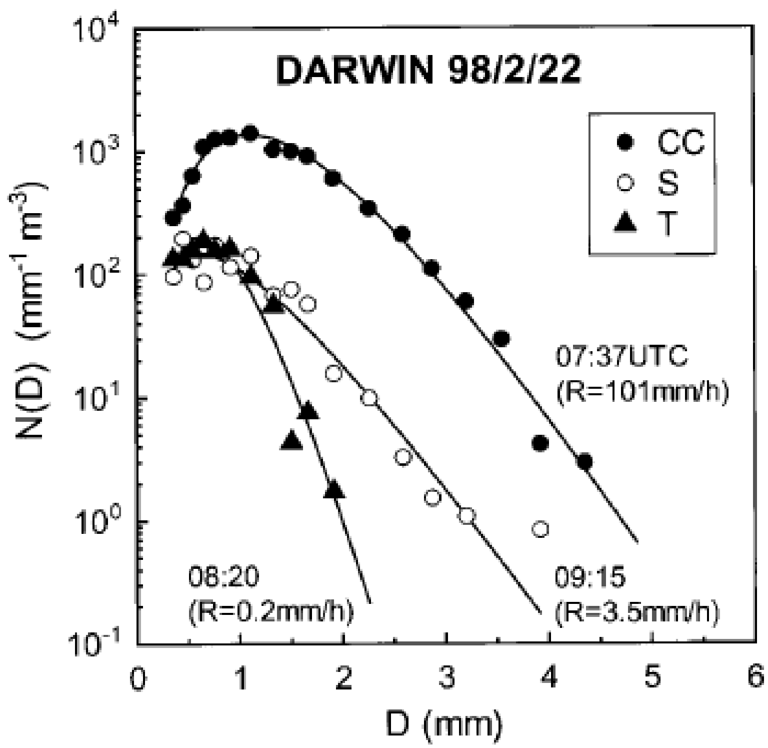


FIG. 4. DSD of different parts of the continental squall line of 22 Feb 1998 observed in Darwin, Australia. Values of DSD parameters (N_0, Λ, μ) in the convective-center (0737 UTC), reflectivity-trough (0820 UTC), and stratiform (0915 UTC) regions are (4.89×10^4, 3.57, 3.87), (4.08×10^6, 8.27, 5.19), and (2.35×10^3, 3.06, 1.81), respectively. The values of N_0 are modal values.

"From Maki et al. (2000)"

Z_{DR} Calibration on Drizzle

- **By definition: drizzle drops have diameters in range 200 - 500 microns, with rainfall rate < 0.5 mm/hr**
- **Drizzle drops are 0 Z_{DR} targets from all incident angles**
- **BUT, 1000 droplets per cubic meter, with D = 200 microns has $Z = ND^6$ which is -12 dBZ**
- **Too weak for detection by most radars**
- **LITTLE JOY WITH THIS APPROACH**

What targets are suitable for Z_{DR} calibration, relative to 0.1 dB 'Holy Grail' criterion?

Target	Differential Reflectivity	Suitability?
Raindrops	> 3 dB	No
Stratiform raindrops	> 0.5 dB	No
Dry snow	0.5 - 2 dB	No
Drizzle drops	< 0.1 dB	Yes
Metal spheres	< 0.01 dB	Yes

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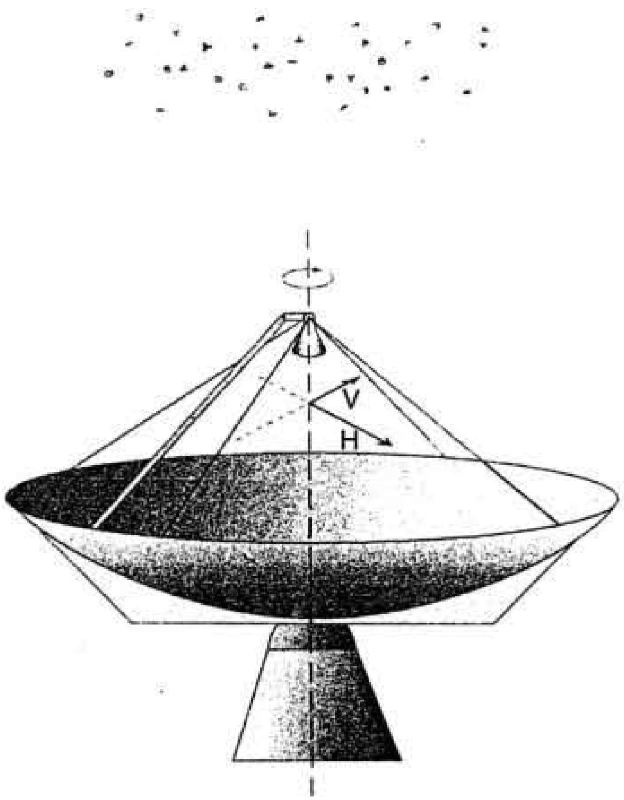
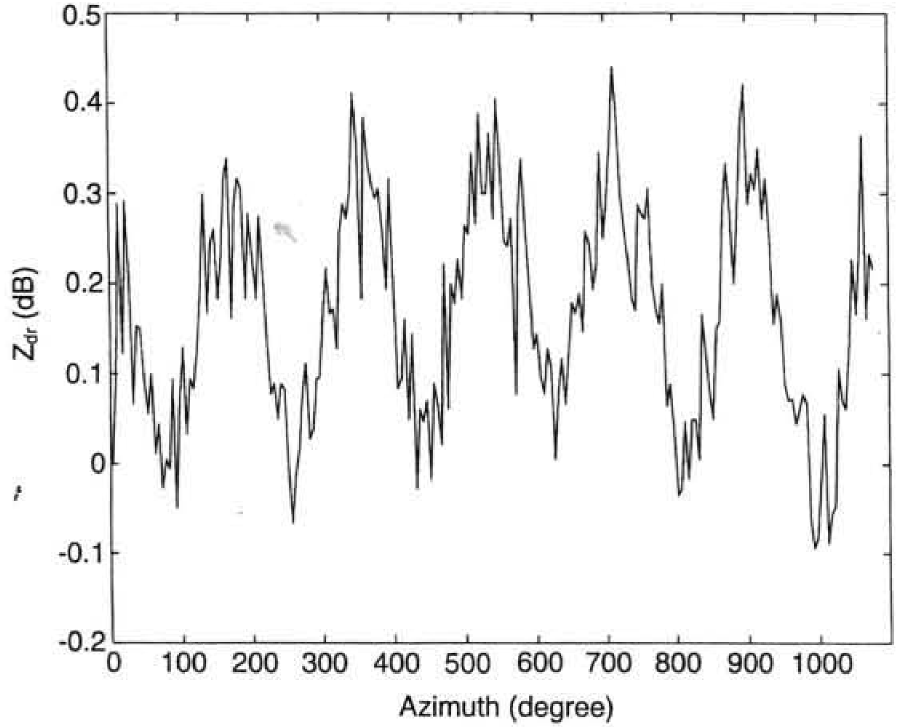
'Bird Bath' Method: Z_{DR} Calibration at Vertical Incidence



(a)

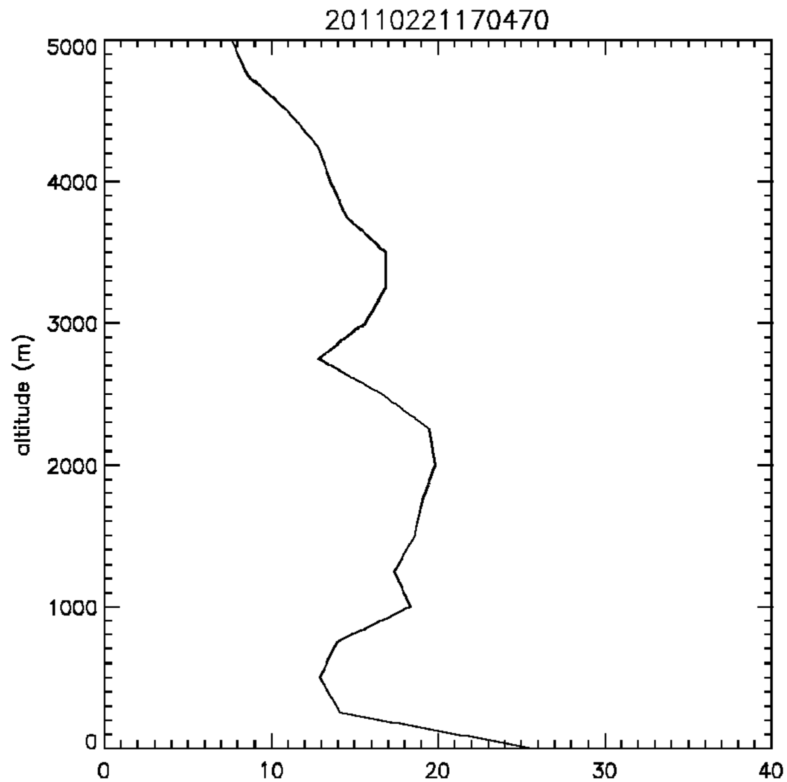


(b)

Raindrops at vertical incidence are 0 dB Z_{DR} targets

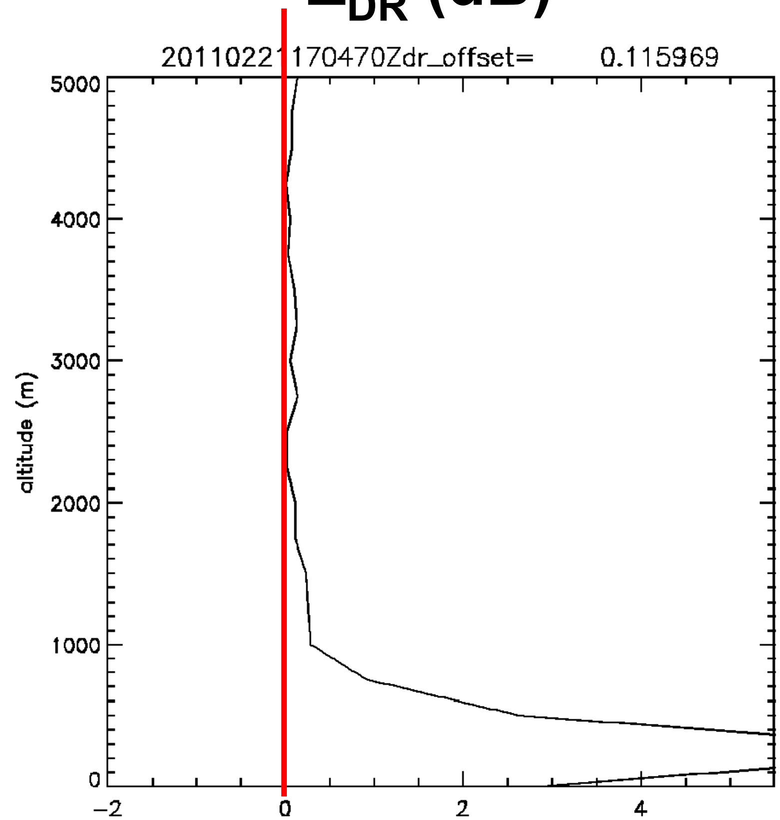
Valparaiso ‘Bird Bath’ Z_{DR} Bias Check

Reflectivity (dBZ)



Reflectivity (dBZ)

Z_{DR} (dB)



Differential Reflectivity (dB)

NEXRAD Radars Can Point Vertically

Procedure:

- Remove some mechanical stops (bolts)
- Elevation angle encoder functions to 90°
- Software modification could be needed to record data

Recommendation:

- Make measurements on rain at vertical incidence during polarimetric upgrade

Radar Calibration with Metal Spheres

Two calibrations for the price of one

- **Calibrate differential reflectivity end-to-end**
  - A sphere is isotropic and a 0 dB target
- **Calibrate reflectivity end-to-end**
  - The radar cross section of a metal sphere is the geometrical cross section πr^2 when the sphere is large in comparison to a radar wavelength

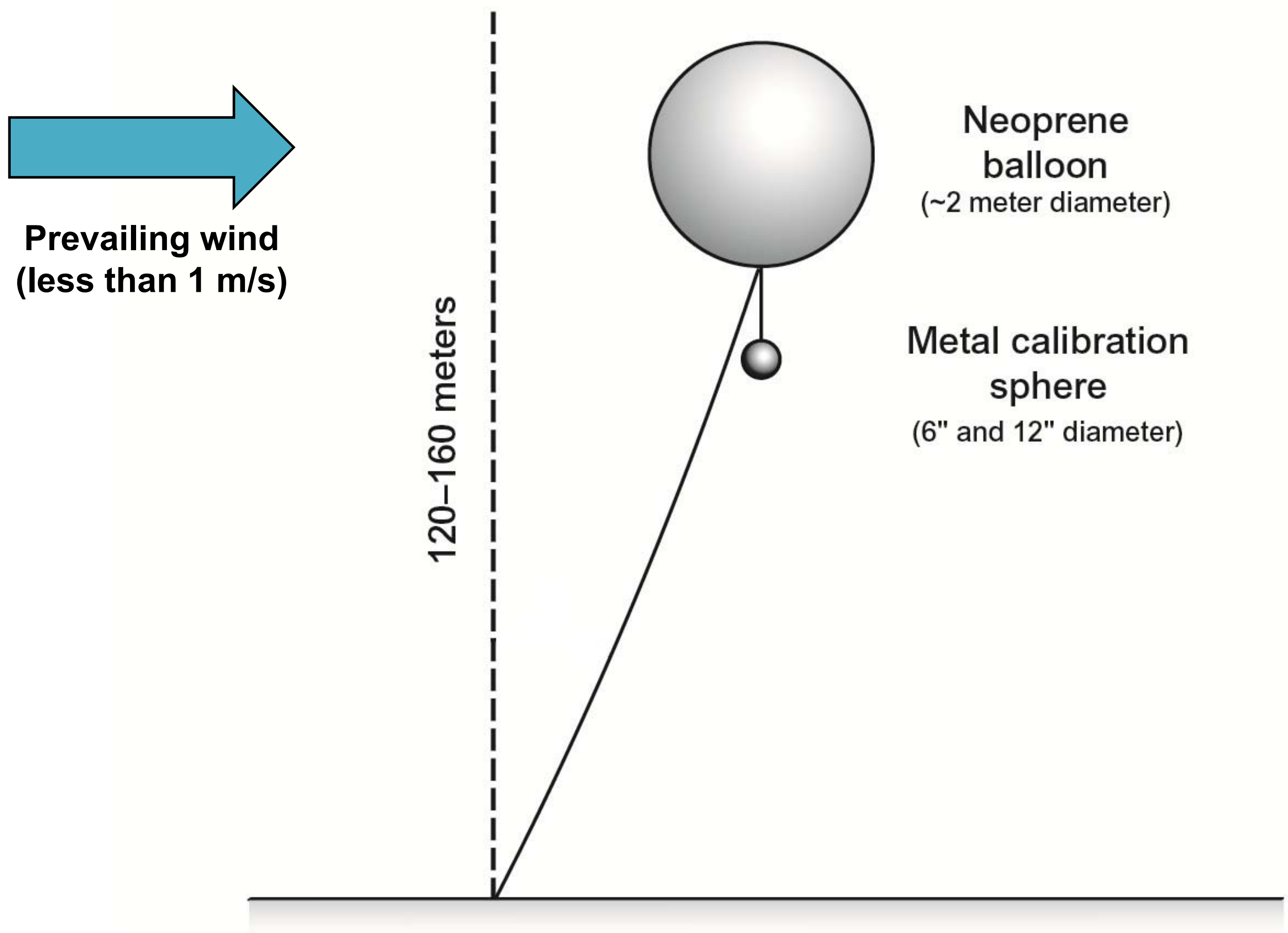
Metal Sphere Specifications

Metal Calibration Spheres					
Diameter	**Composition**	**Manufacturer**	**Cost**	**Sphericity**	**Maximum Z_{DR}**
6”	aluminum	Century Metal Spinning Co.	$400	0.005” in 6”	< 0.007 dB
12”	aluminum	Trimillenium Corp.	$722	0.5%	< 0.043 dB

6” Metal Sphere for Calibration

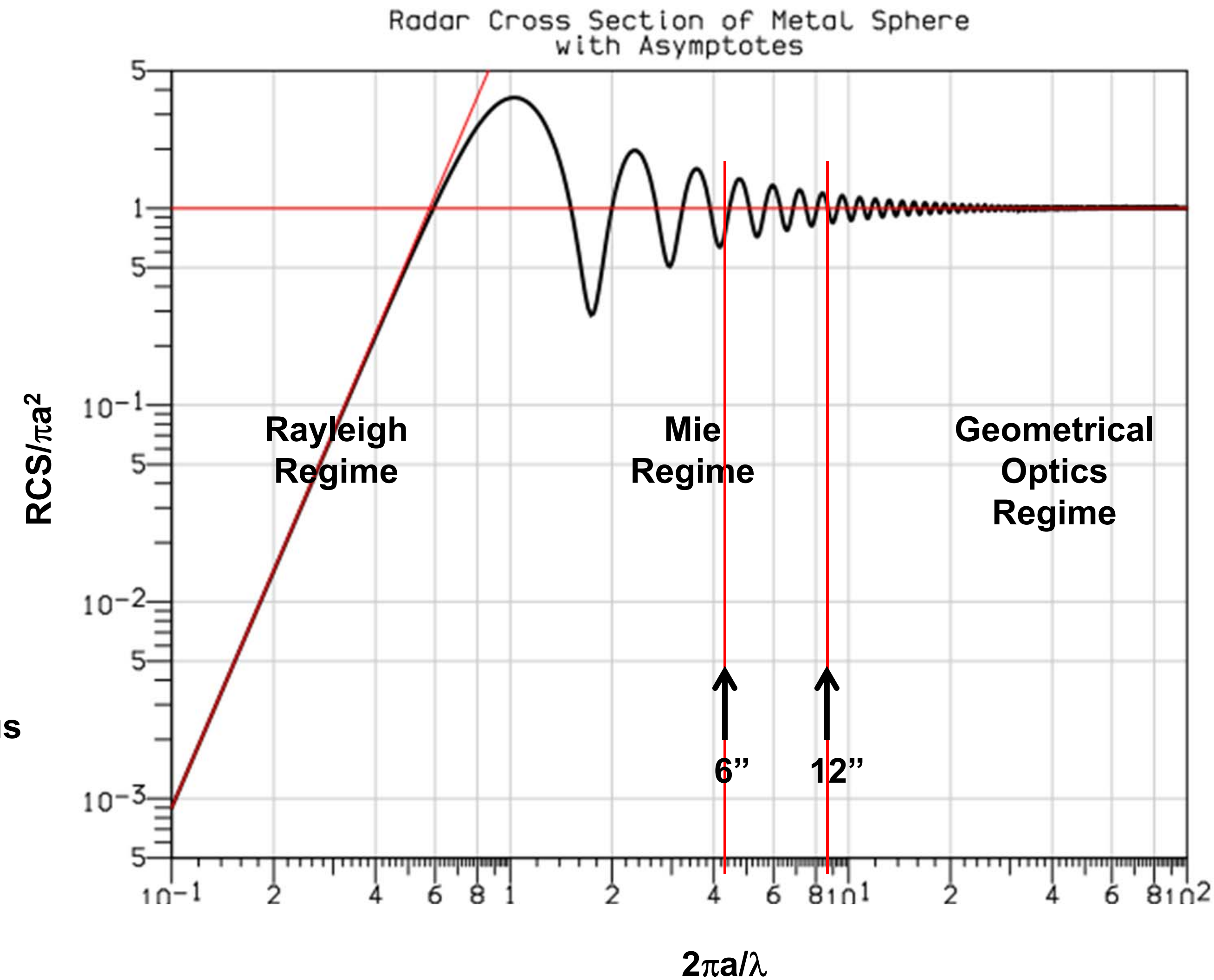
Attachment of the 6” Calibration Sphere to the Base of the Tethered Neoprene Balloon

Tethered Metal Sphere



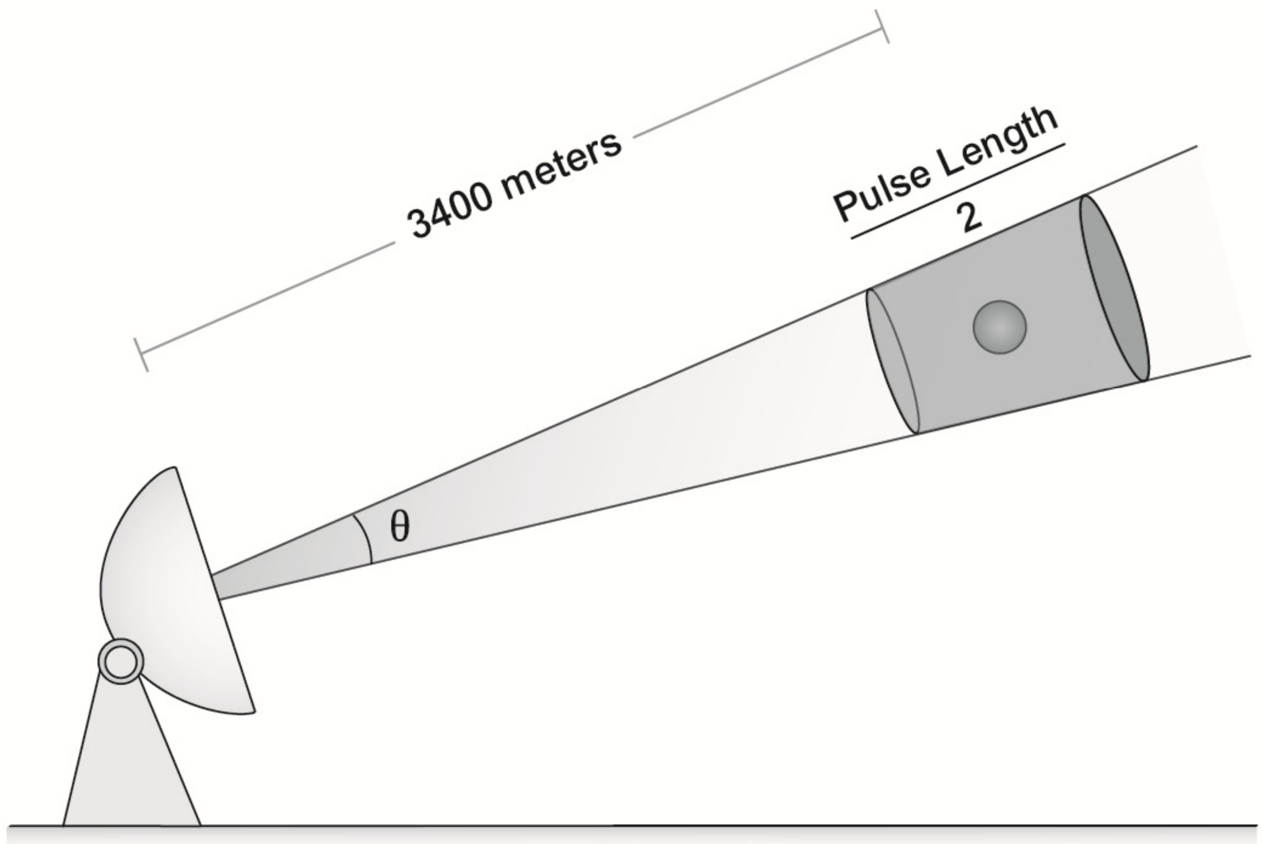
Floodlight Illumination of the Tethered Balloon Following FAA Requirements

Radar Cross Section of Metal Sphere versus Scattering Parameter



a – radius

Sphere Centered in Pulse Resolution Volume



Theory Based Primarily on Geometry

Volume reflectivity (with units of area per unit volume)

$$\eta = \pi^5 |k|^2 Z / \lambda^4 \qquad m^2/m^3 \qquad (1)$$

The radar pulse resolution volume (PRV) is the volume occupied by the metal sphere with radar cross section σ.
Accordingly, the sphere effective volume reflectivity is then:

$$\eta = \sigma/PRV \qquad m^2/m^3 \qquad (2)$$

where $\sigma = \pi r^2$ for a metal sphere large compared to a λ and where $PRV = \pi \theta \varphi h R^2/8$ m^3,

Equating (1) and (2) and solving for radar reflectivity Z gives

$$Z = (8 \lambda^4 / \theta \varphi h \pi^5 |k|^2) r^2/R^2 \qquad mm^6/m^3 \qquad (3)$$

Use (3) to compute reflectivity expected for metal spheres versus radar range R

Plugging in the Numbers for KOUN

Theory: $Z = (8\,\lambda^4 / \theta\,\varphi\,h\,\pi^5\,|k|^2)\,r^2/R^2$ mm^6/m^3

$\lambda = 11.08$ cm

$\theta = \varphi = 0.95$ deg $= 1.66 \times 10^{-2}$ rad

$h = 1.50\ \mu s$

6" sphere

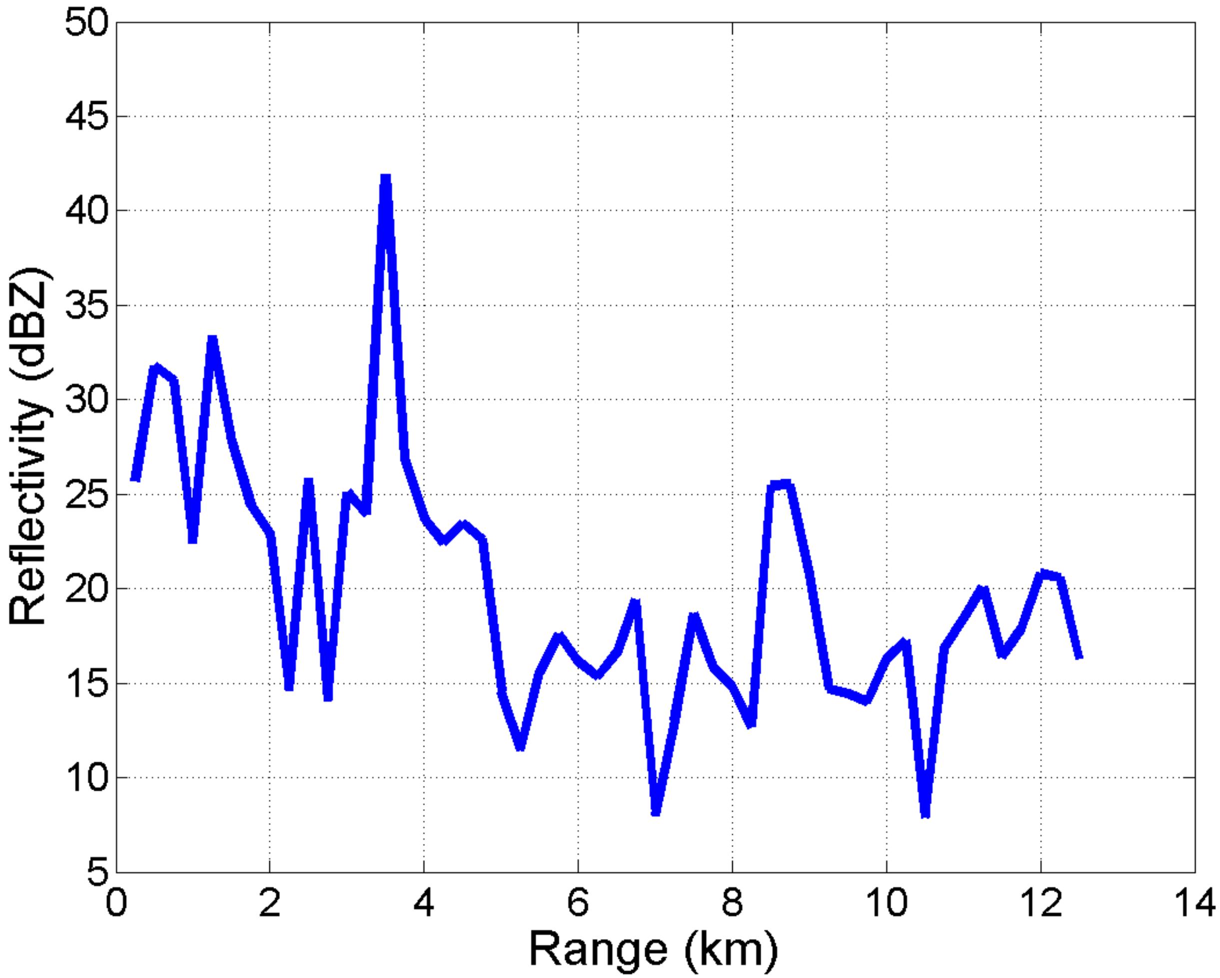
$|k|^2 = 0.93$

$R = 3400$ meters

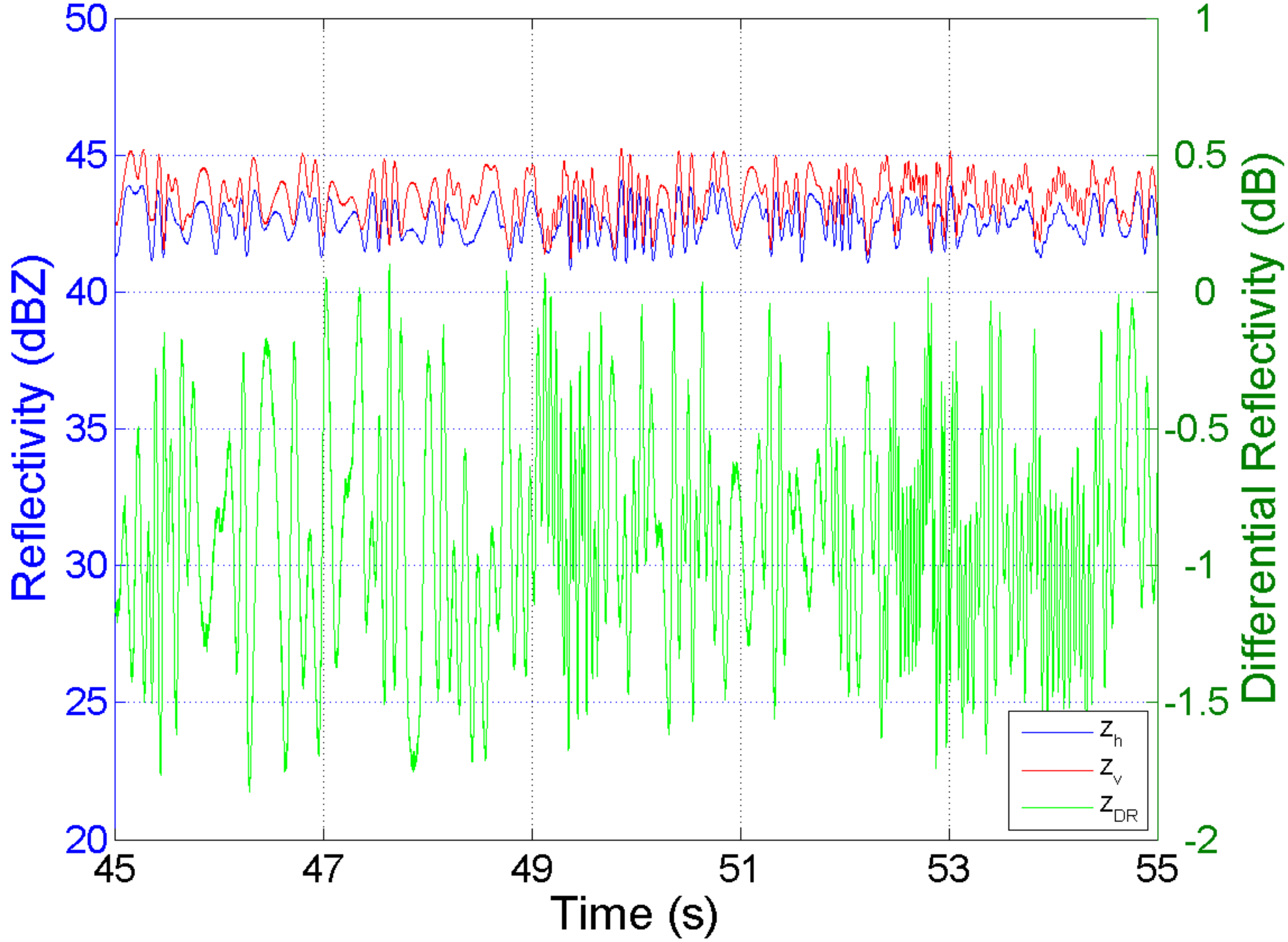
$Z = 17200\ mm^6/m^3$

$10 \log Z = 42.3$ dBZ

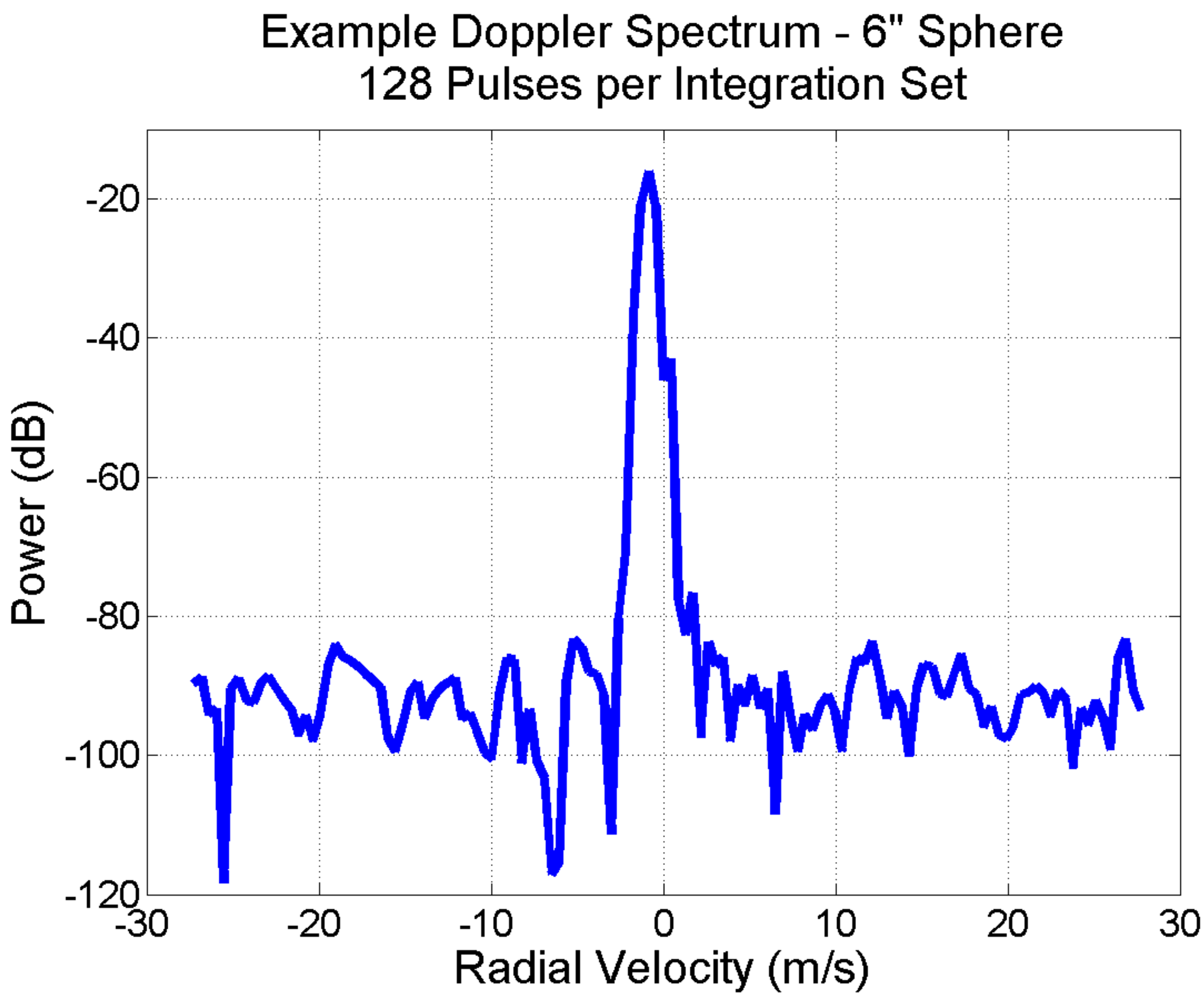
6” Sphere Signal versus Slant Range



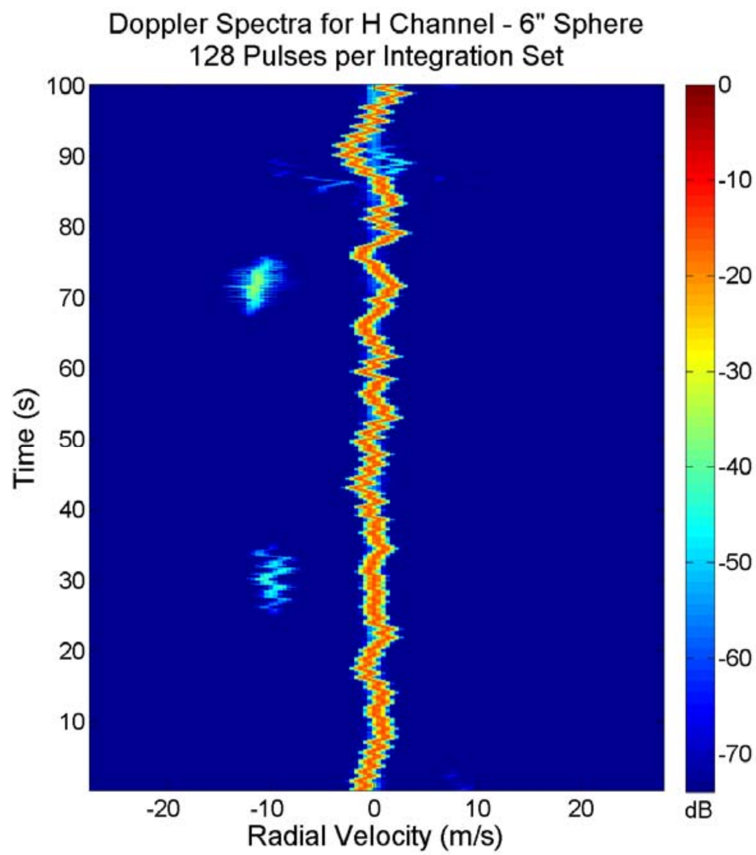
Z_H, Z_V, and Z_{DR} (Pulse-to-Pulse) for 6" Sphere

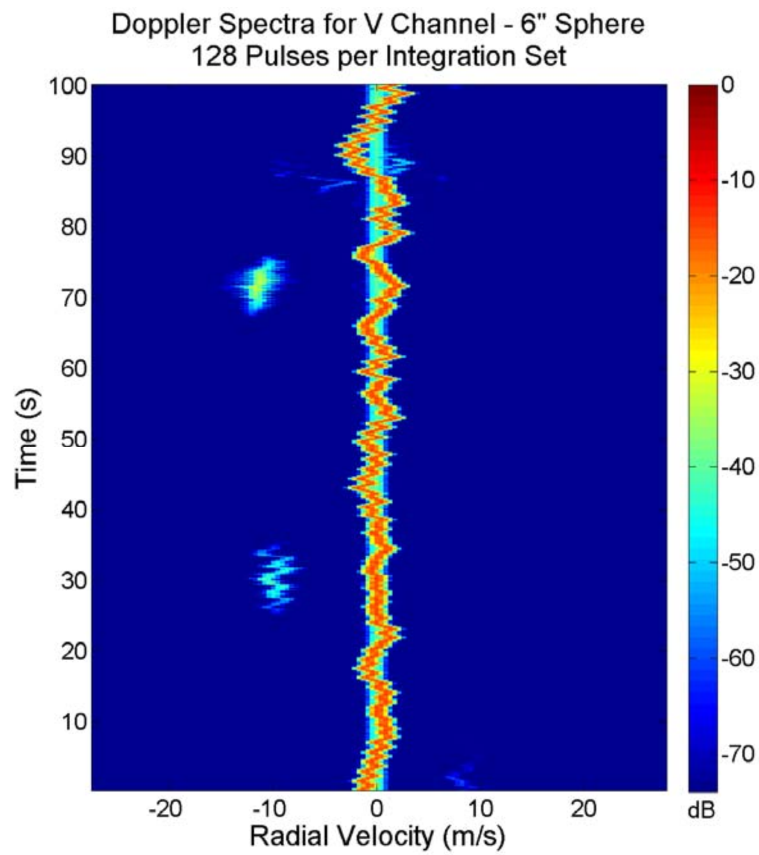


6” Sphere Narrow Spectral Width



6” Sphere Time-Frequency Spectral Plot



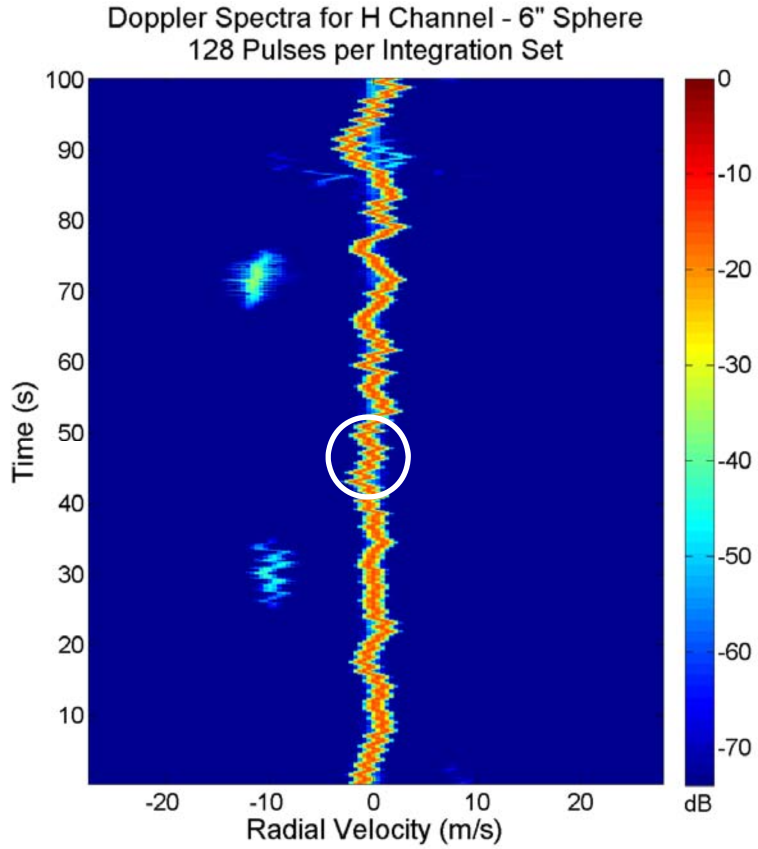


Pendulum Oscillation

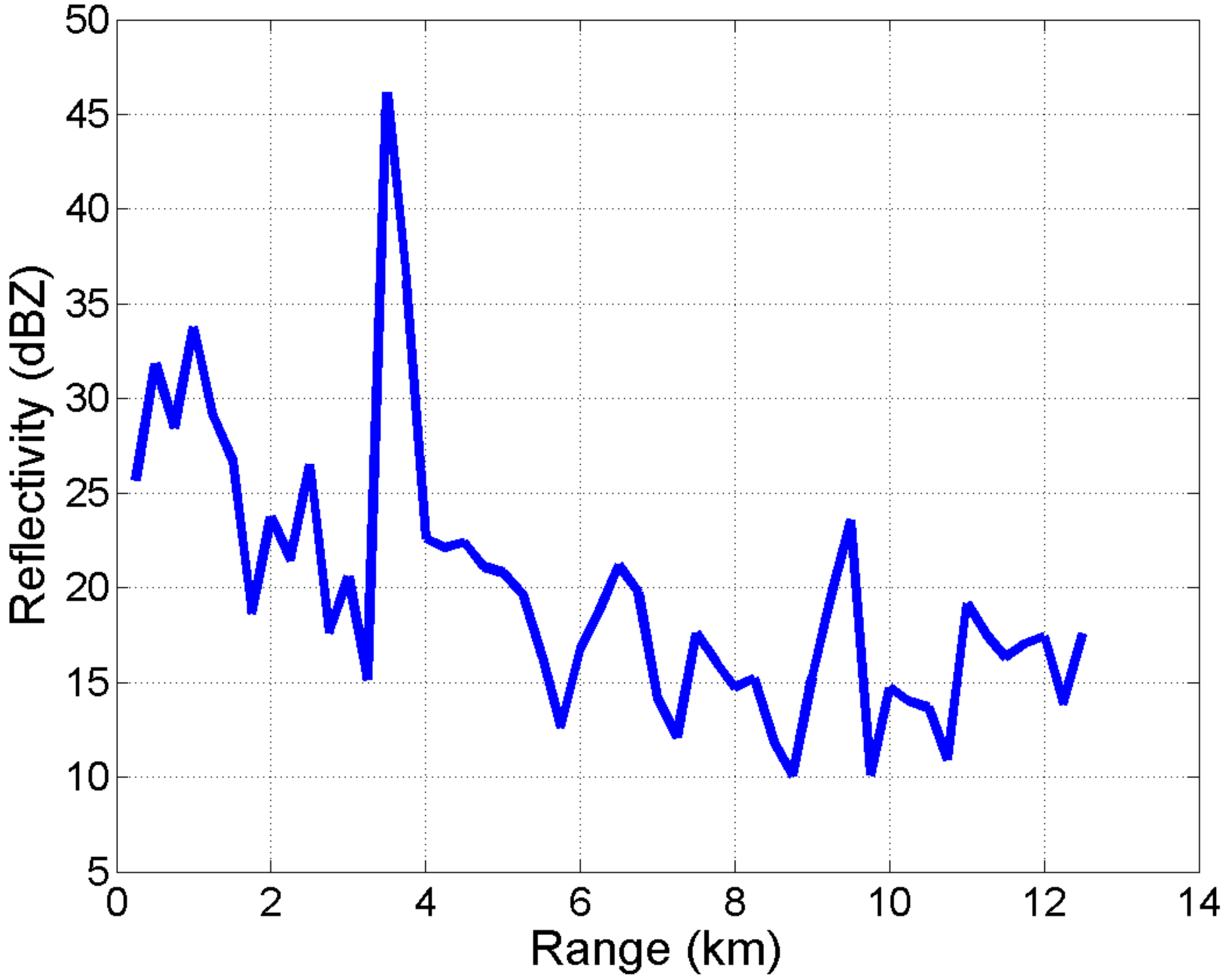
Period for a simple pendulum of length L is:

$$T = 2\pi\sqrt{\frac{L}{g}} = 1.3 \text{ seconds}$$

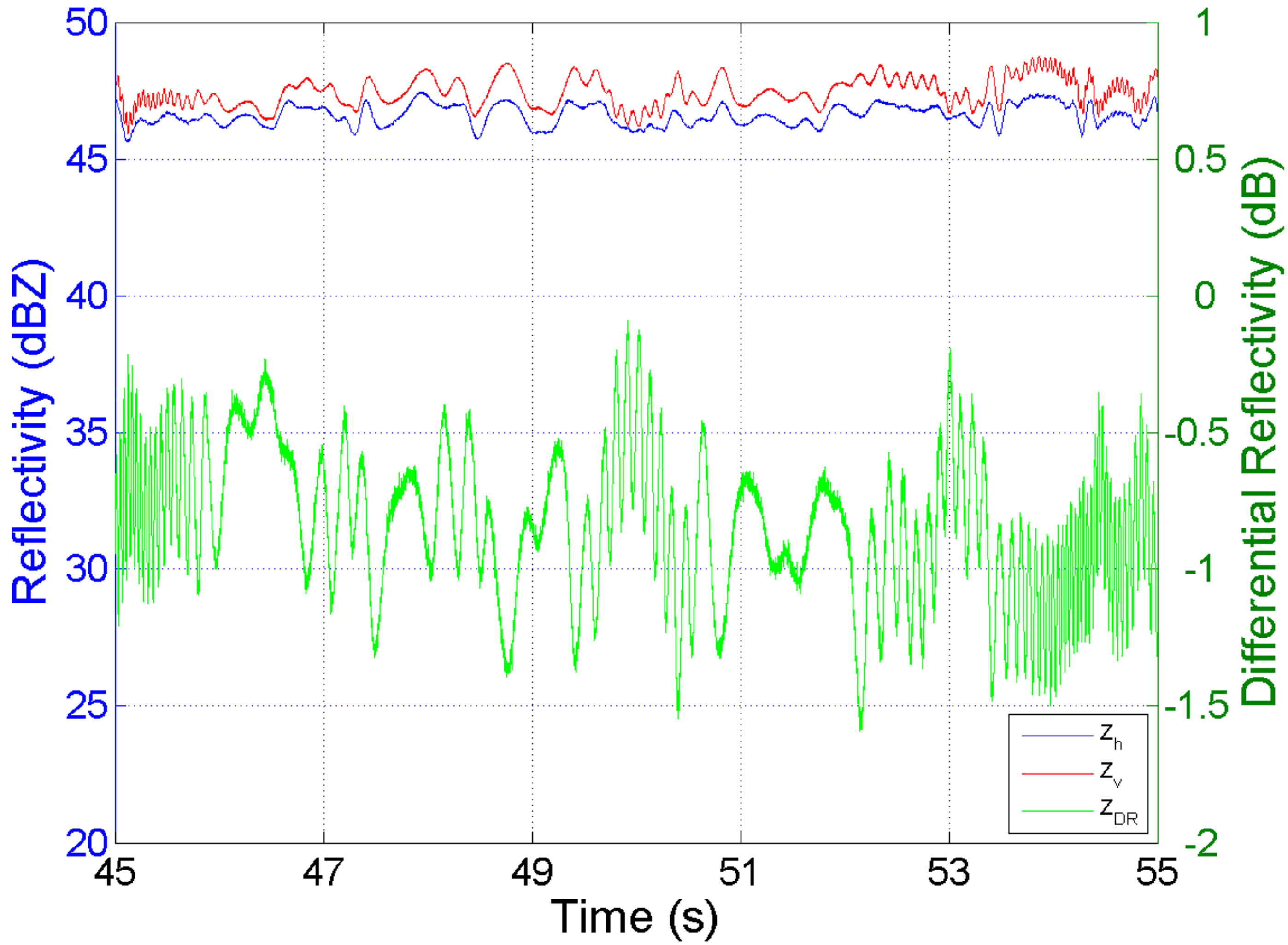
Solve for L = 42 cm



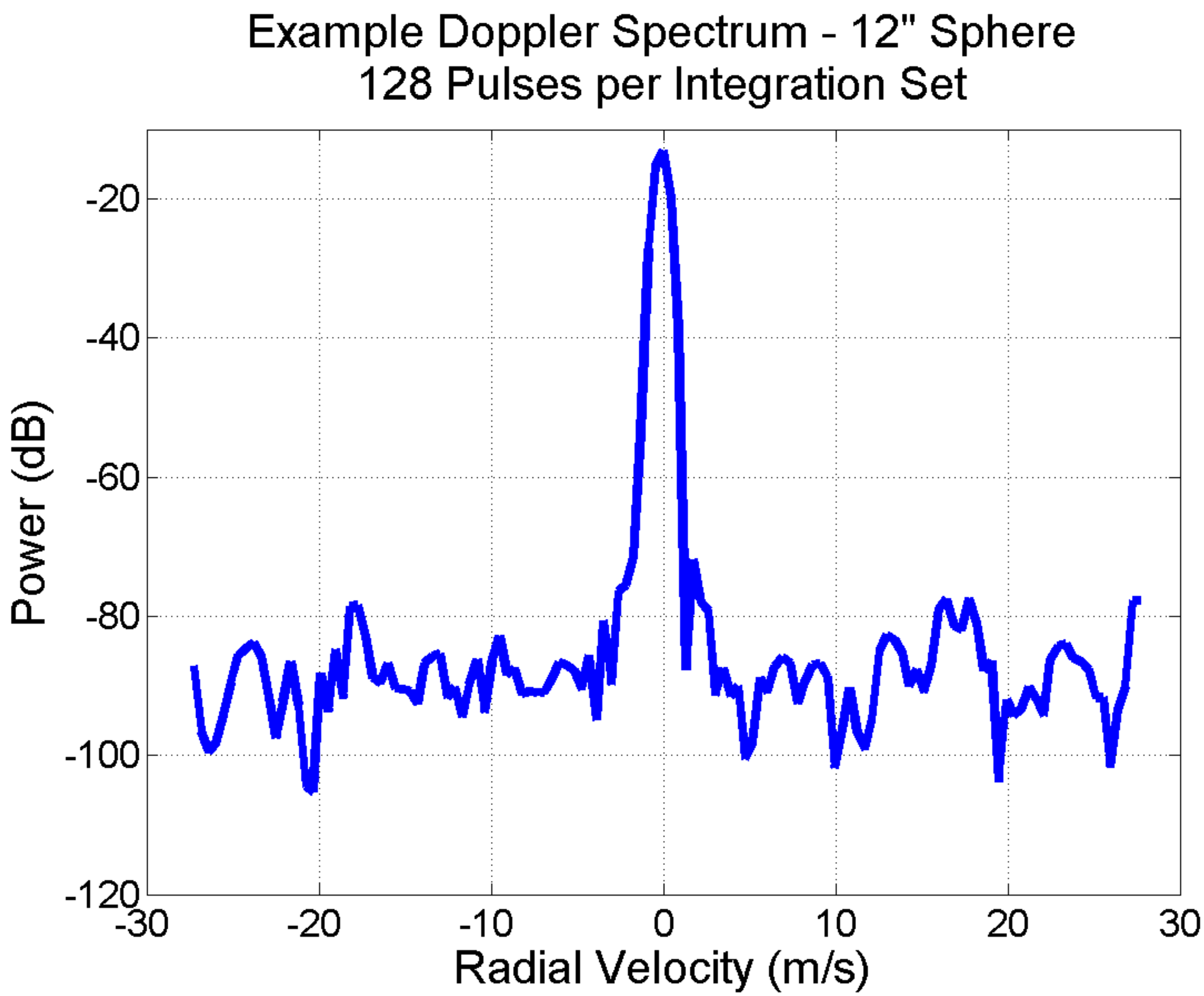
12” Sphere Signal versus Slant Range



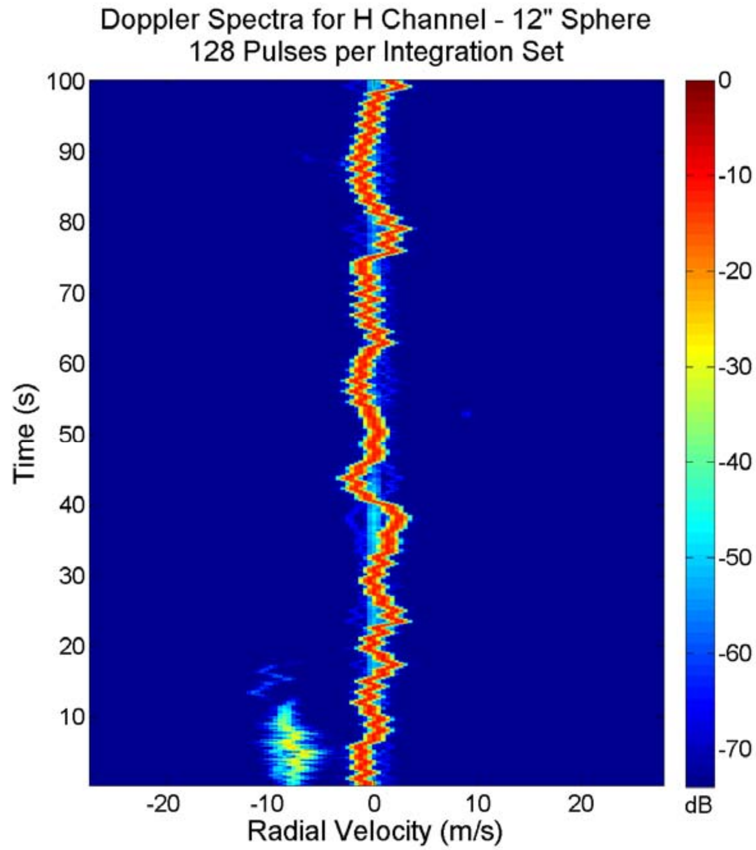
Z_H, Z_V, and Z_{DR} (Pulse-to-Pulse) for 12” Sphere

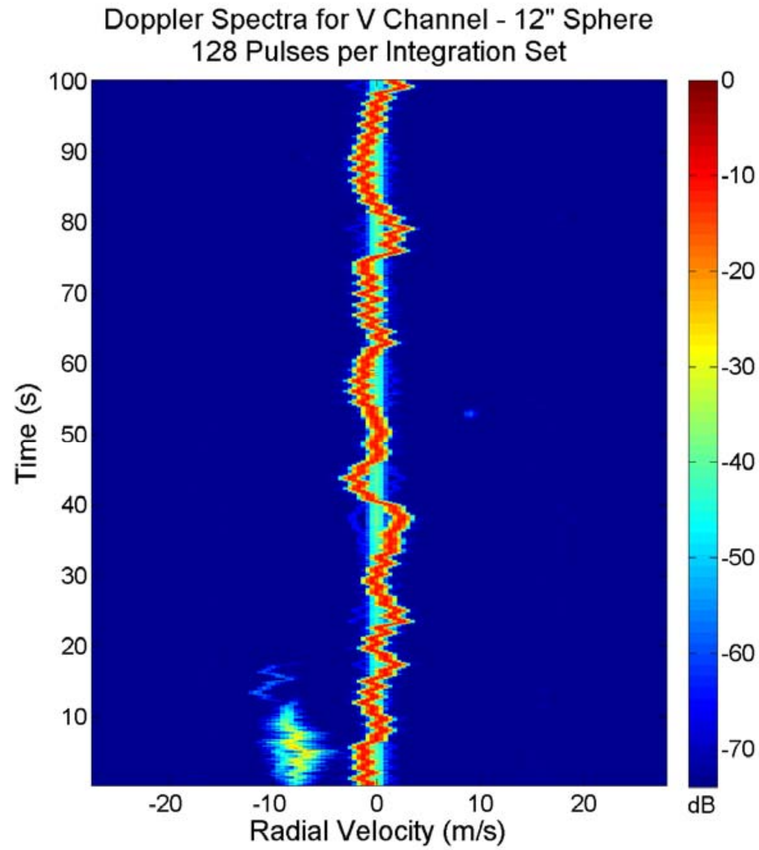


12" Sphere Narrow Spectral Width



12” Sphere Time-Frequency Spectral Plot

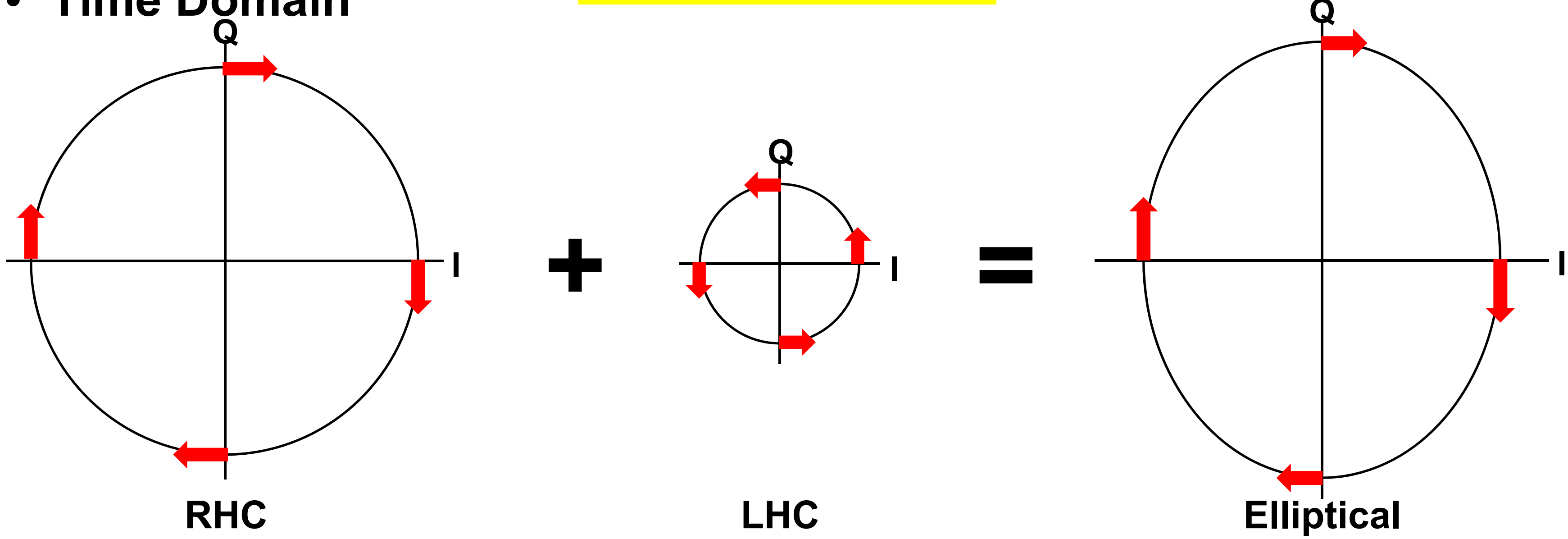




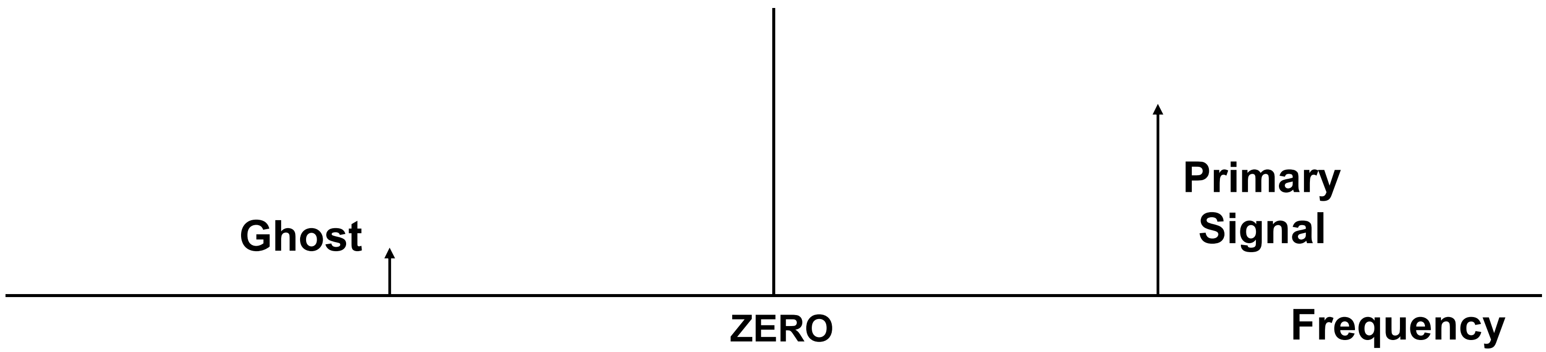
I and Q Mismatch Explains 'Ghosting'

- Time Domain

Not drawn to scale



- Frequency Domain



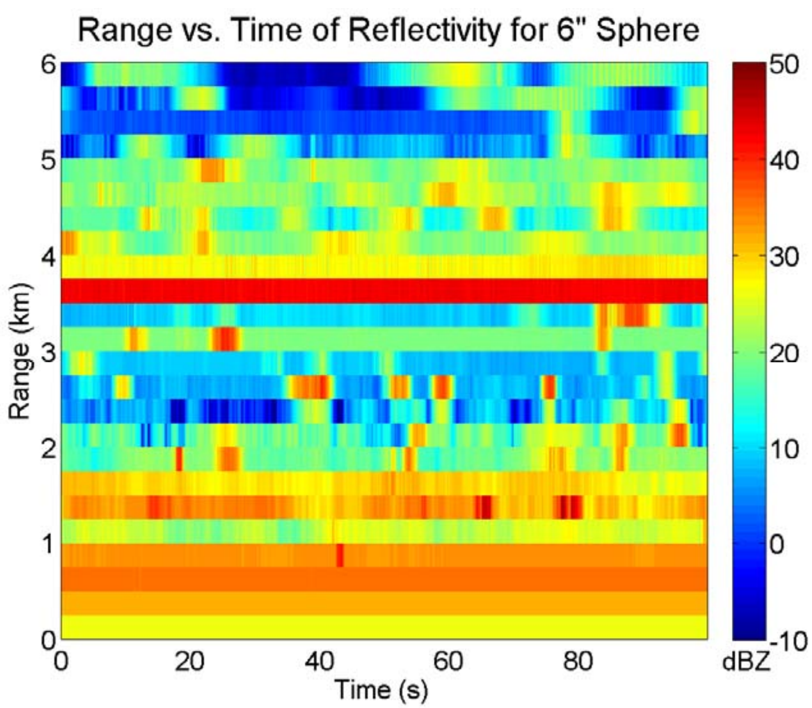
Results

	Predicted Z (dBZ)	Measured Z (dBZ)	Std. Dev. Z (dB)	Predicted Z_{DR} (dB)	Measured Z_{DR} (dB)	Std. Dev. Z_{DR} (dB)
6" Sphere	42.3	42.5	0.47	0	-0.90	0.25
12" Sphere	48.3	46.7	0.36	0	-0.87	0.20

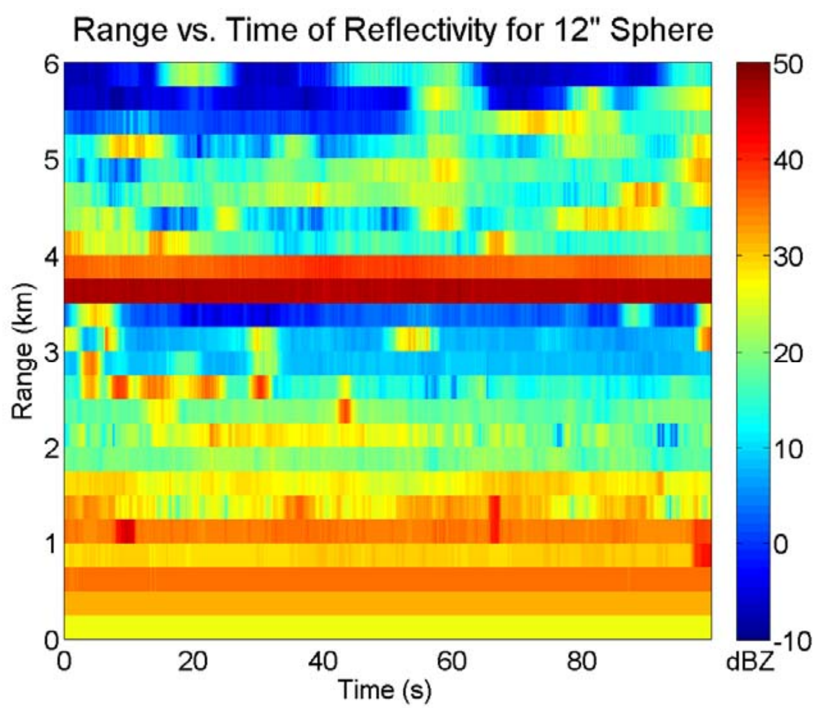
- **Z_{DR} offset biased negative**
- **Standard deviation based on 128 samples**
- **0.43 dB standard deviation on Z_{DR} pulse-to-pulse for 6" sphere**
- **0.33 dB standard deviation on Z_{DR} pulse-to-pulse for 12" sphere**

Centering Problem of Sphere within PRV

6” Sphere Centered



12” Sphere Drifted



Conclusions

- **The KOUN radar is well calibrated in reflectivity Z**
  - **Difference between theory and experiment is ~0.3 dB**
- **The KOUN radar is not well calibrated in differential reflectivity Z_{DR}**
  - **The Z_{DR} offset from zero is of order -0.9 dB for both metal spheres**
- **Use of standard metal sphere targets provides a practical, accurate, and inexpensive means to calibrate NEXRAD dual pol radars in both reflectivity and differential reflectivity**
  - **Worthwhile to spot check additional NEXRADs**
- **Remaining puzzle: Why is the pulse-to-pulse measurement of Z_{DR} on a presumed single scatterer as variable as it is?**

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