How Far into a Rain Shaft can mm-Wave Vertically Pointing Radars (VPR) Detect Raindrops?

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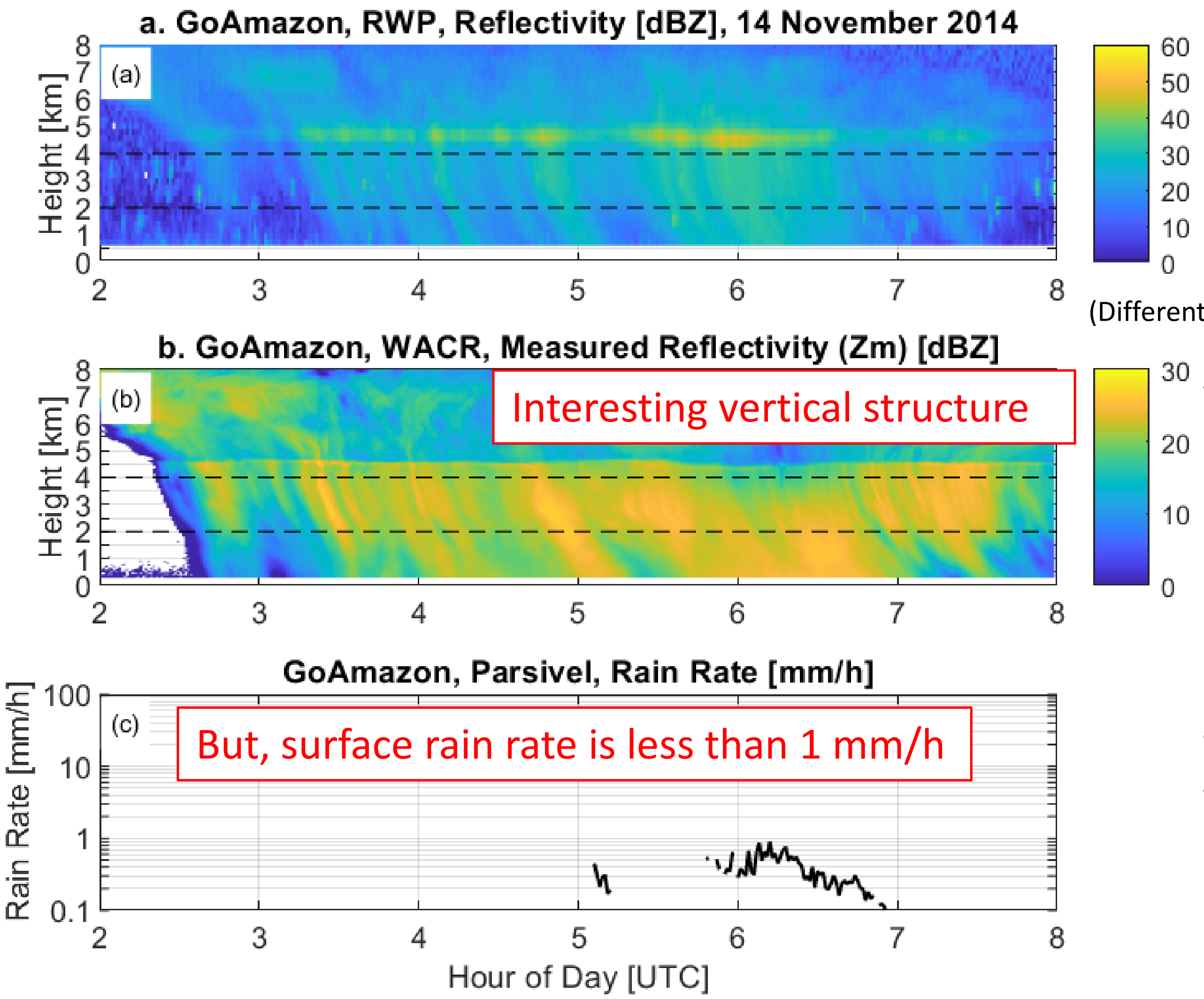
CCAR

Motivation: Want to study Vertical Evolution of DSD.



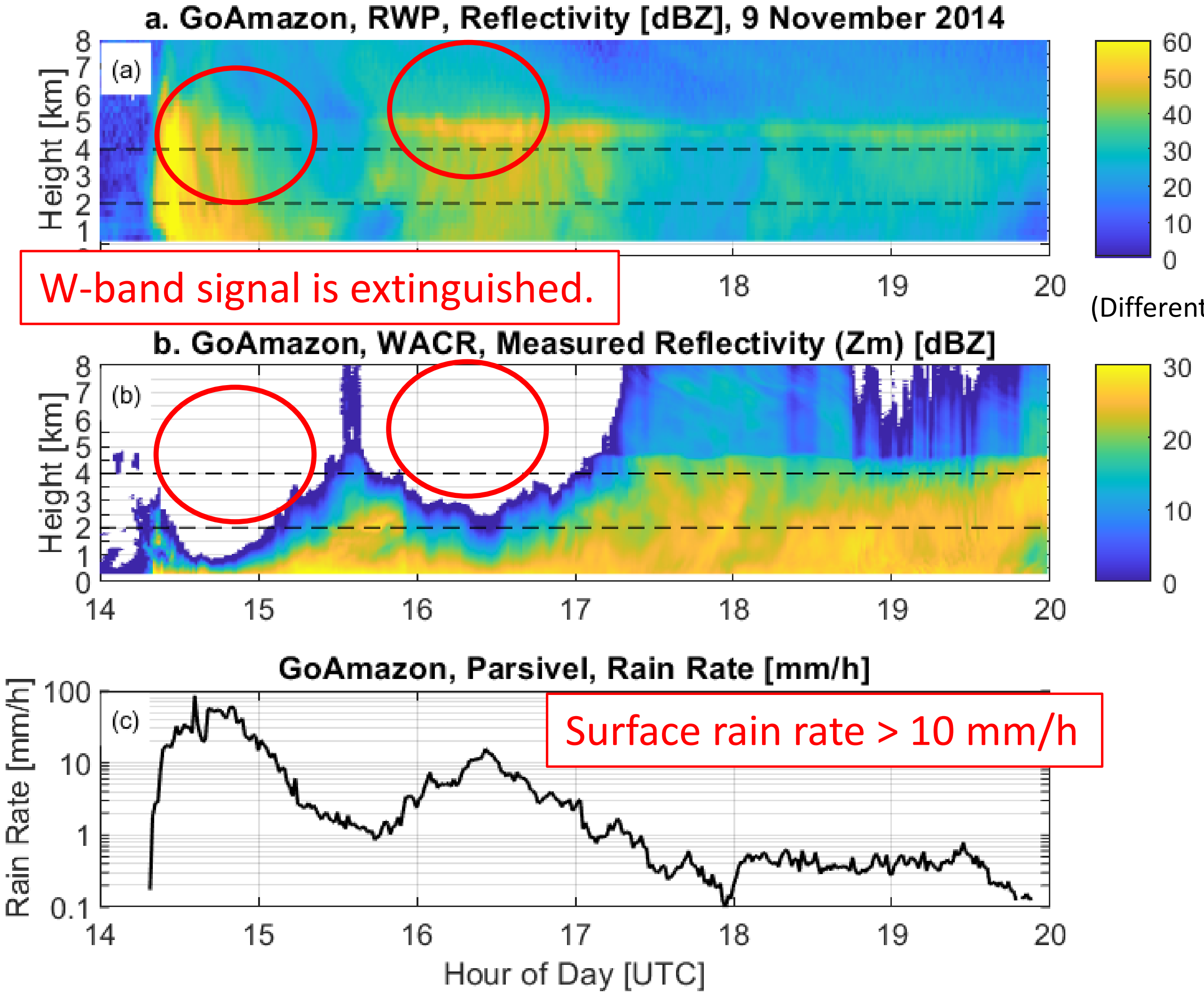
(Different color scales)

Radar Wind Profiler (RWP)
1.2 GHz (Rayleigh scattering)
Reflectivity [dBZ]

W-band ARM Cloud Radar (WACR)
94 GHz (non-Rayleigh scattering)
Measured Reflectivity [dBZ]
No attenuation adjustment

Surface PARSIVEL
Surface Disdrometer
Rain Rate [mm/h]

Motivation: But W-band signal is extinguished @ R> 10 mm/h



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How far into a rain shaft should a W-band (95 GHz) radar observe before the signal is extinguished?

Methodology: Step 1. Estimate $Z_{measured}$

Estimate Attenuated Reflectivity factor profiles (Measured Reflectivity)

k: Specific Attenuation [dB/km]

$$Z_{measured}(r) = Z_e(r) - 2\int_0^r (k)ds$$

Effective Reflectivity Factor

2-way attenuation to range r

Expressing Z_e and k with power laws:

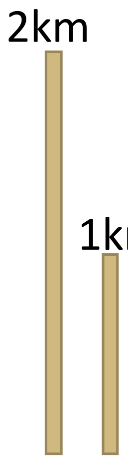
$$Z_e = 10log\left(aR^b\right) \qquad \text{[dBZ]}$$

$$k = cR^d \qquad \text{[dB]}$$

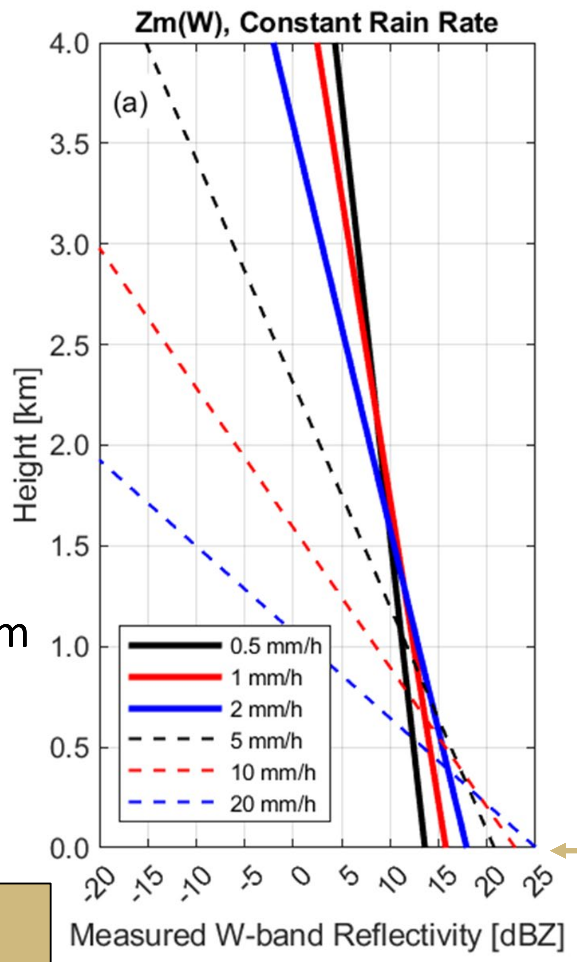
For constant rain rate cores R with path length r:

$$Z_{measured}(r) = 10log\left(aR^b\right) - 2\left(cR^d\right)r$$

(Attenuated Reflectivity)



Rain cores (path length)

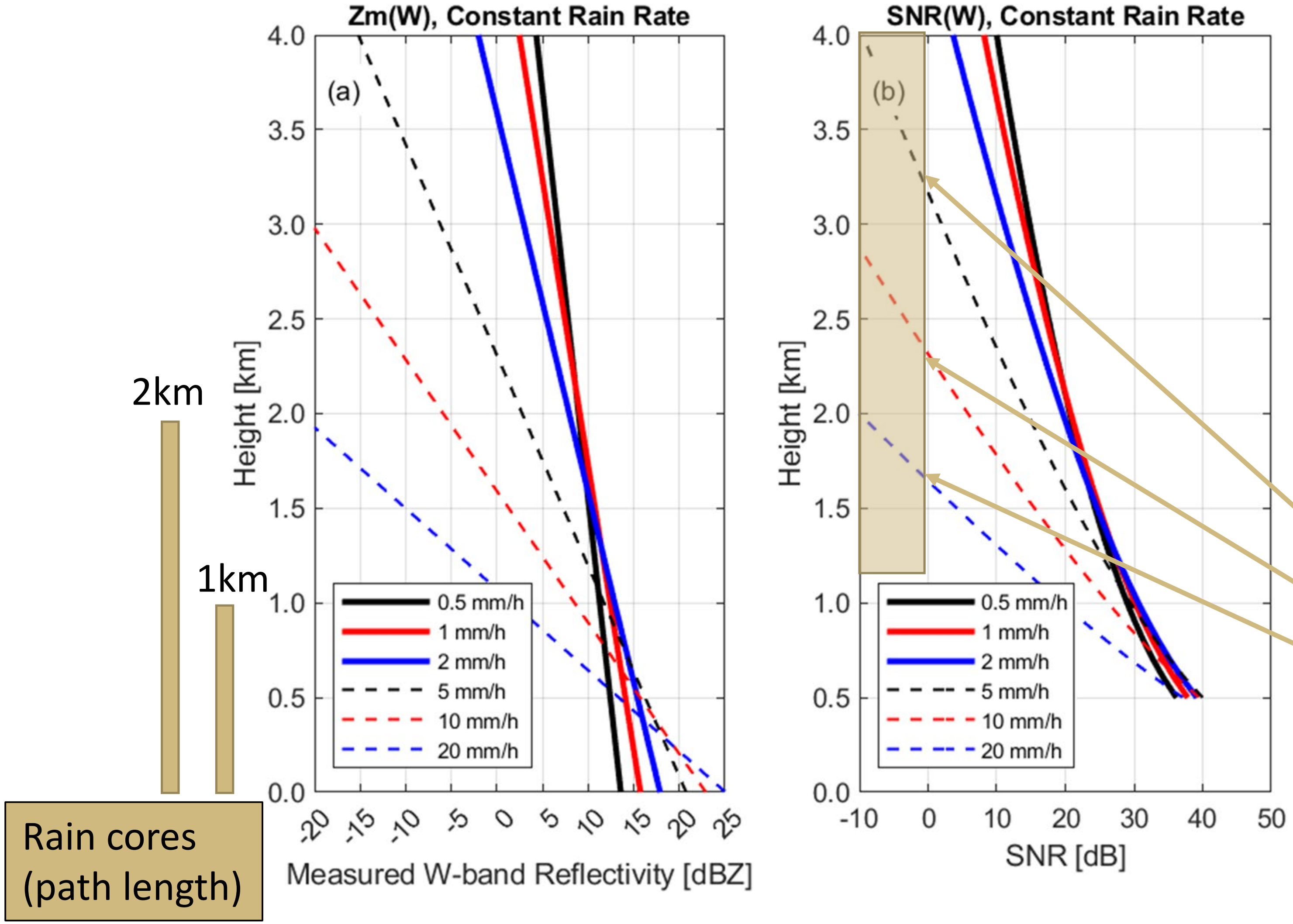


Z_e

(Attenuated Reflectivity)

Step 2. Convert Z_m profiles into SNR profiles

Express $Z_m^\lambda(r)$ as radar Signal-to-Noise Ratio: $SNR(r) = \underbrace{C_{radar}^\lambda}_{\text{Calibration Constant}} + Z_m^\lambda(r) - \underbrace{20log(r)}_{r^2 \text{ term}}$



Maximum range through rain shaft is when SNR drops below radar's minimum SNR detection limit.

With $SNR_{minimum} = 0$ dB, maximum ranges are about:

R = 5 mm/h -> 3.2 km
R = 10 mm/h -> 2.4 km
R = 20 mm/h -> 1.6 km

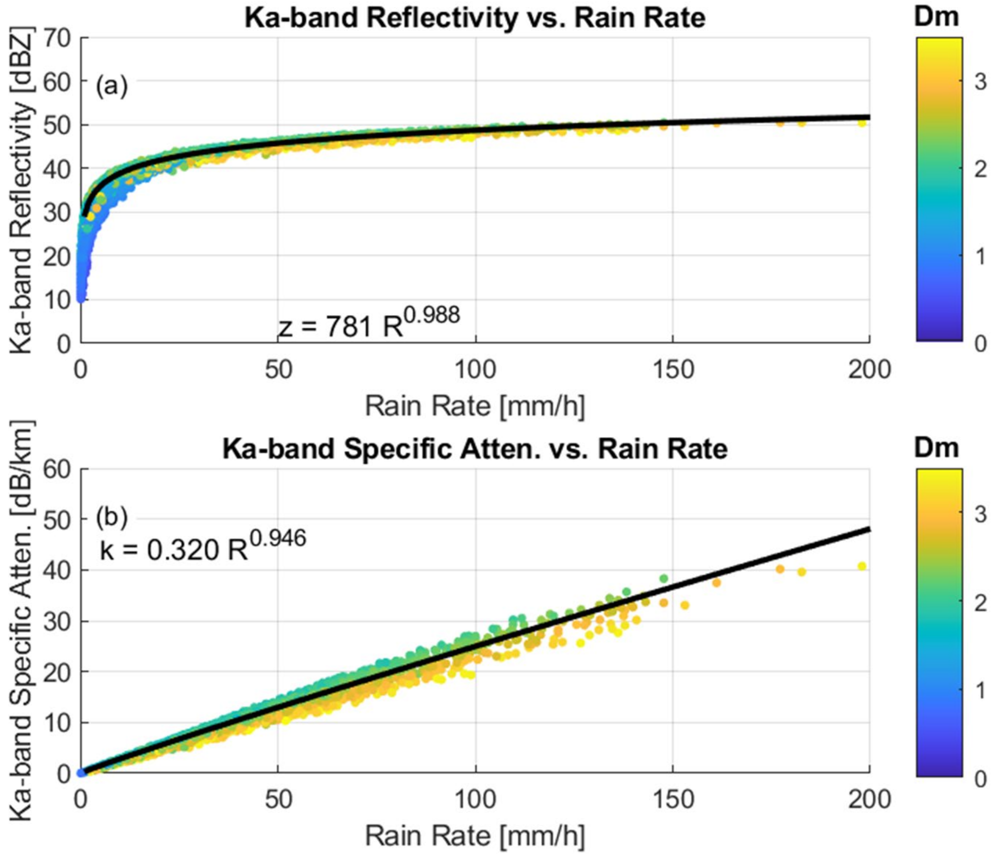
Step 3. Develop k-R and Z-R relationships

Estimate R, Z_e, and k for each 1-minute Parsivel GoAmazon obs. (~20,300 samples)

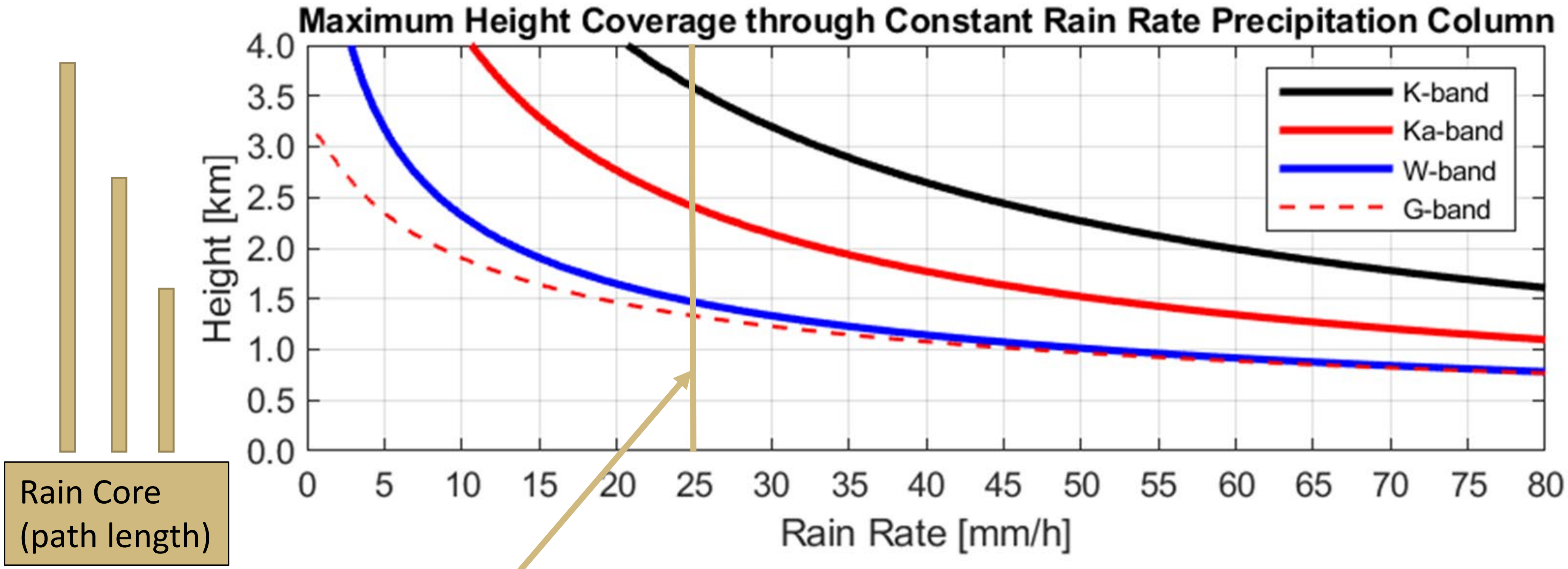
1. PyTmatrix Python module (Leinonen: github.com/jleinonen/pytmatrix/)
2. Backscattering & extinction cross-sections for each Parsivel raindrop diameter
3. Full details in Williams 2022, *Remote Sensing*, doi.org/10.3390/rs14061305

$$Z_e^{\lambda} = 10log\left(a^{\lambda}R^{b^{\lambda}}\right) \qquad k_{rain}^{\lambda} = c^{\lambda}R^{d^{\lambda}}$$

Band	Wavelength [mm]	a^{λ}	b^{λ}	c^{λ}	d^{λ}
S (2.7 GHz)	111	150	1.610	2.28E-04	1.038
C (5.6 GHz)	53.6	144	1.599	7.88E-04	1.349
X (9 GHz)	33.3	64.5	1.884	4.18E-03	1.380
Ku (13.6 GHz)	22.1	139	1.749	2.35E-02	1.203
K (24 GHz)	12.5	489	1.340	0.110	1.075
Ka (35.6 GHz)	8.4	781	0.988	0.320	0.946
W (94 GHz)	3.1	37.5	0.716	1.26	0.732
G (200 GHz)	1.5	1.06	0.756	1.32	0.723



Results: How Far Can mm-Waves Observe into Rain Shafts?



Interpretation:

For a 25 mm/h rain shaft:

G-band (200 GHz) radar would be extinguished by 1.4 km
W-band (94 GHz) radar would be extinguished by 1.5 km
Ka-band (36 GHz) radar would be extinguished by 2.4 km
K-band (24 GHz) radar would be extinguished by 3.6 km

Results: How Far Can mm-Waves Observe into Rain Shafts?

Rain rates that extinguish radar signals for fixed path lengths.

Path Length	X-band	Ku-band	K-band	Ka-band	W-band	G-band
4.0 km	116	55	21	11	3	*
3.5 km	138	67	26	14	4	*
3.0 km	166	84	33	18	6	1
2.5 km	>200	107	44	24	9	4
2.0 km	>200	142	60	33	14	9

* Return signal completely extinguished due to atmospheric gas attenuation.

To observe through a 3 km rain shaft

The rain rate must be less than:

Concluding Remarks

- While high frequency radars provide unique observations of precipitation, their signal attenuation through rain must be understood.
- This study provides a repeatable methodology to estimate the path length needed to extinguish a radar signal through (constant rain rate) rain shafts.
- More details of this analysis are provided in:
  - Williams, C.R., 2022: How much Attenuation Extinguishes mm-Wave Vertically Pointing Radar Return Signals?, *Remote Sensing*, doi.org/10.3390/rs14061305.

Future Work

- These analyzes must be performed with your radar's sensitivity.
- Repeat analysis using aircraft mounted downward pointing radars (where there is more distance from radar to the near-surface high rain rate cores).