{Measurement uncertainties of} Vertical air motion in convective and stratiform rain from profiling radars during TWP-ICE

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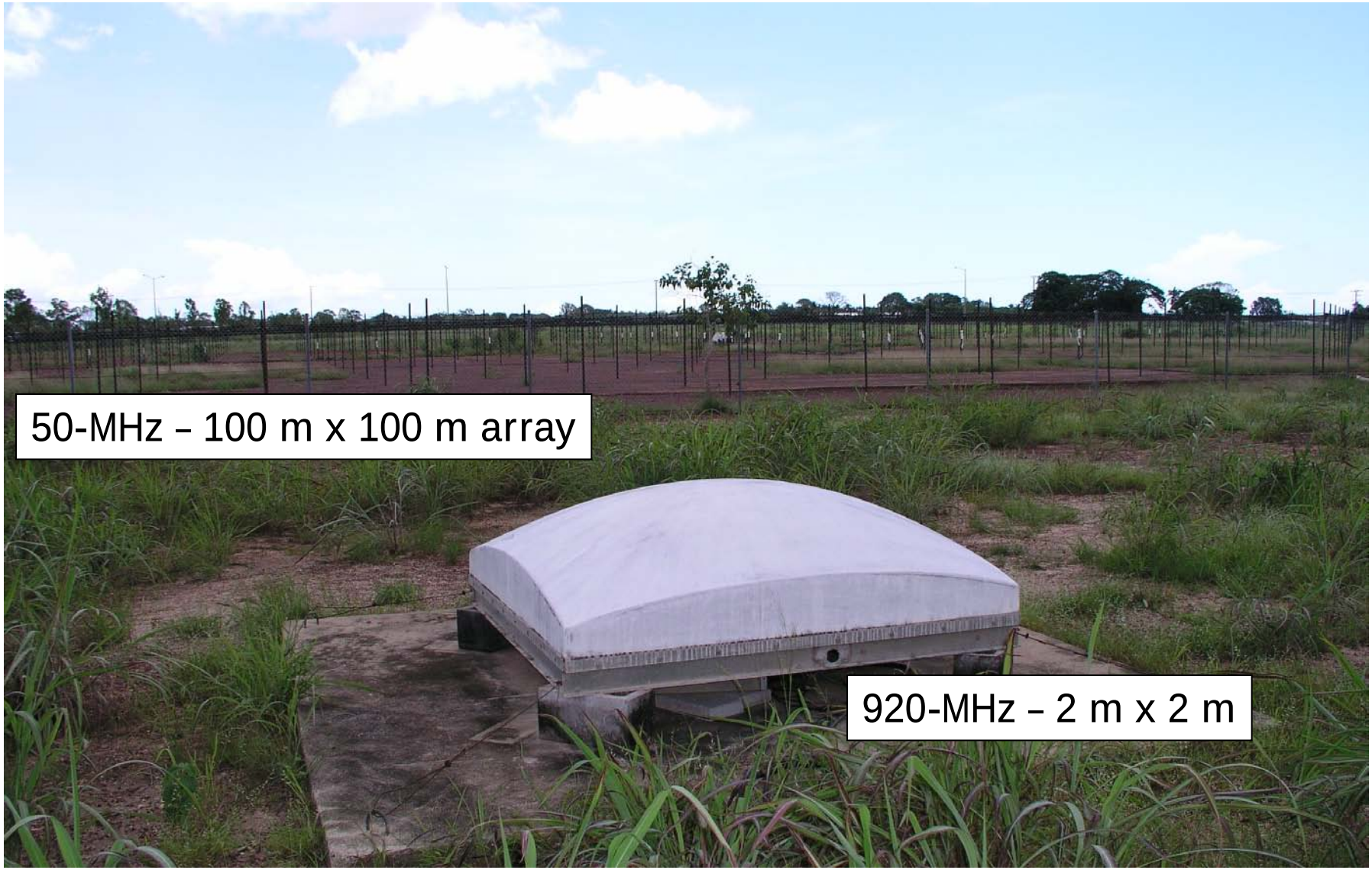
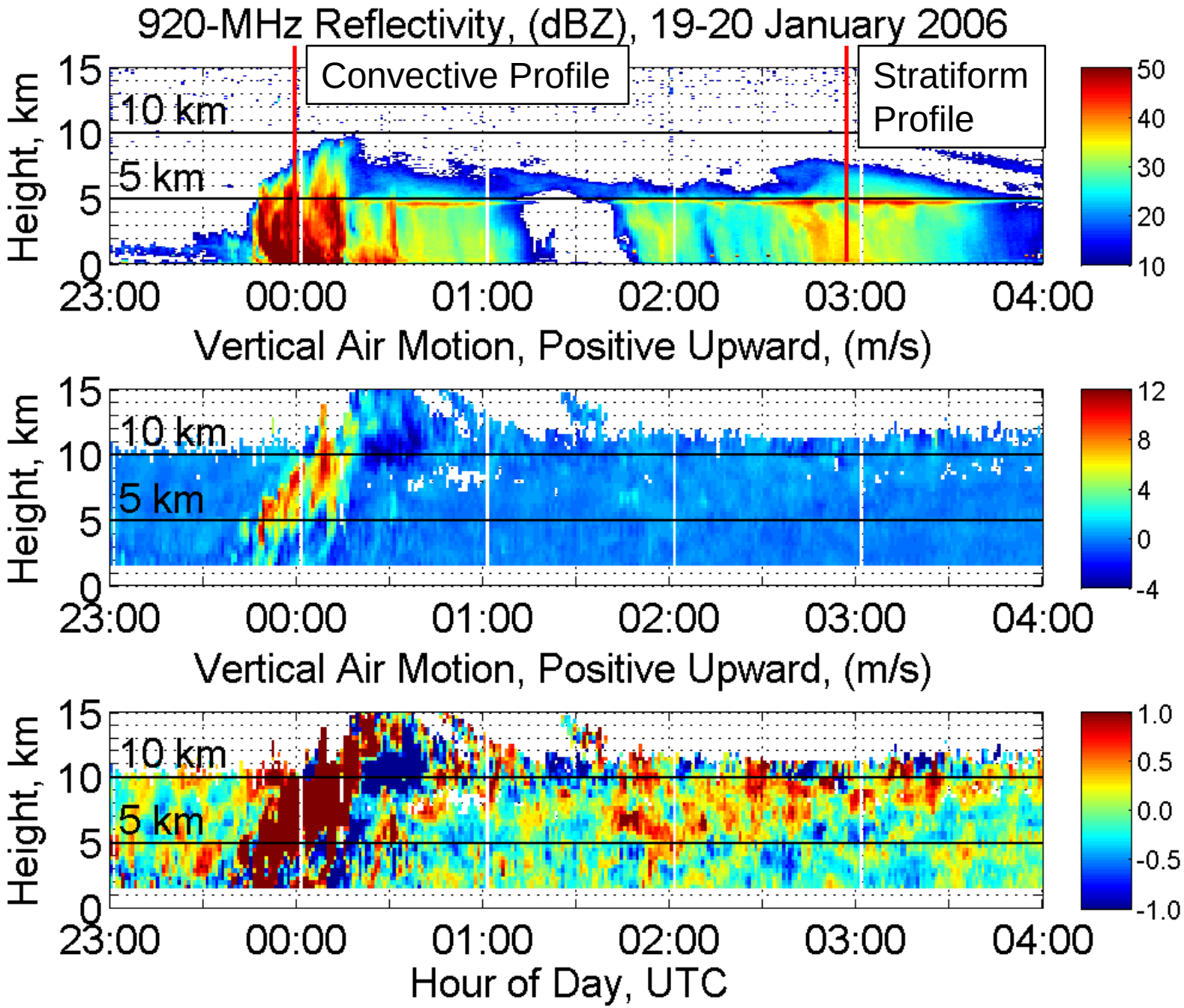
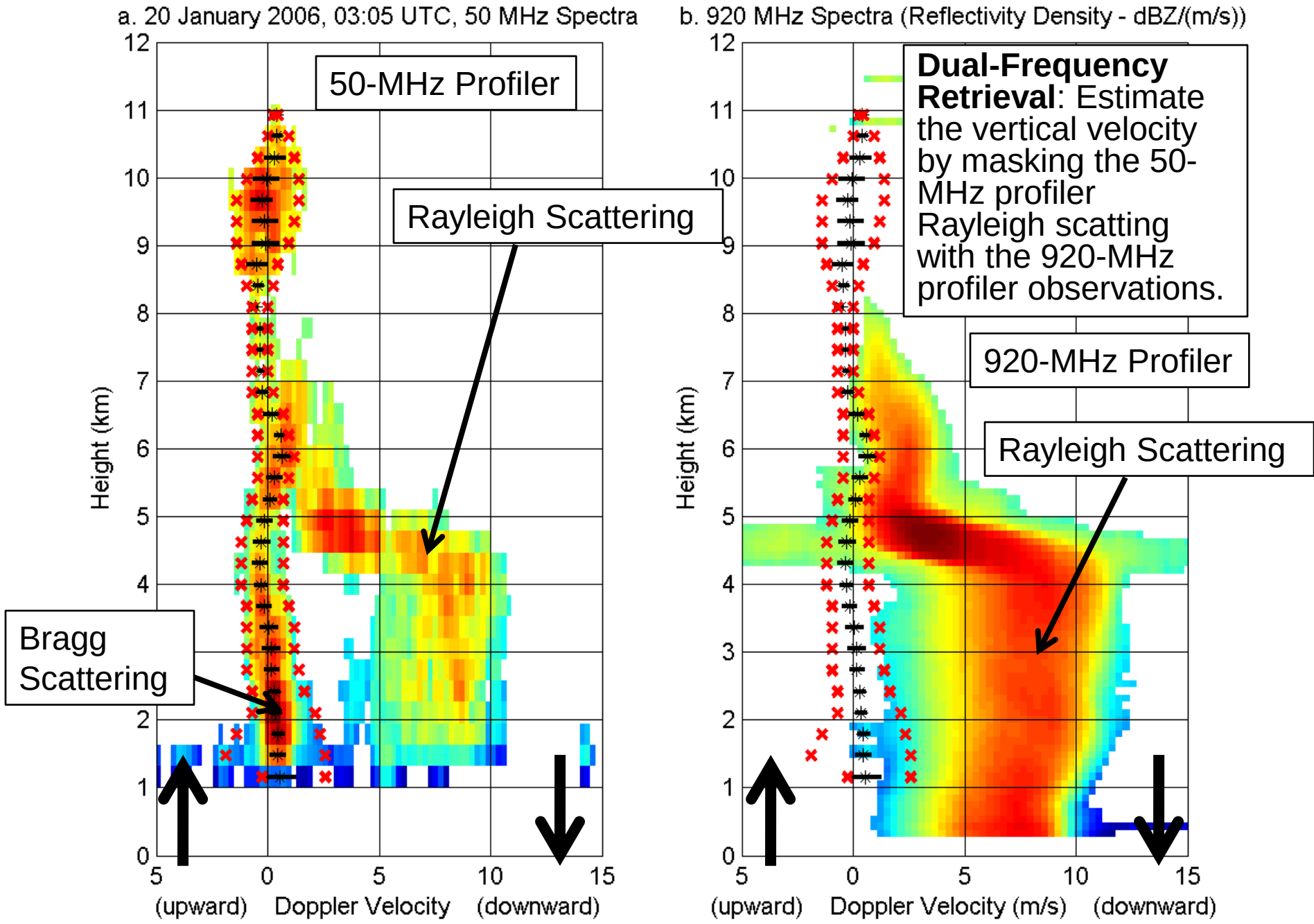
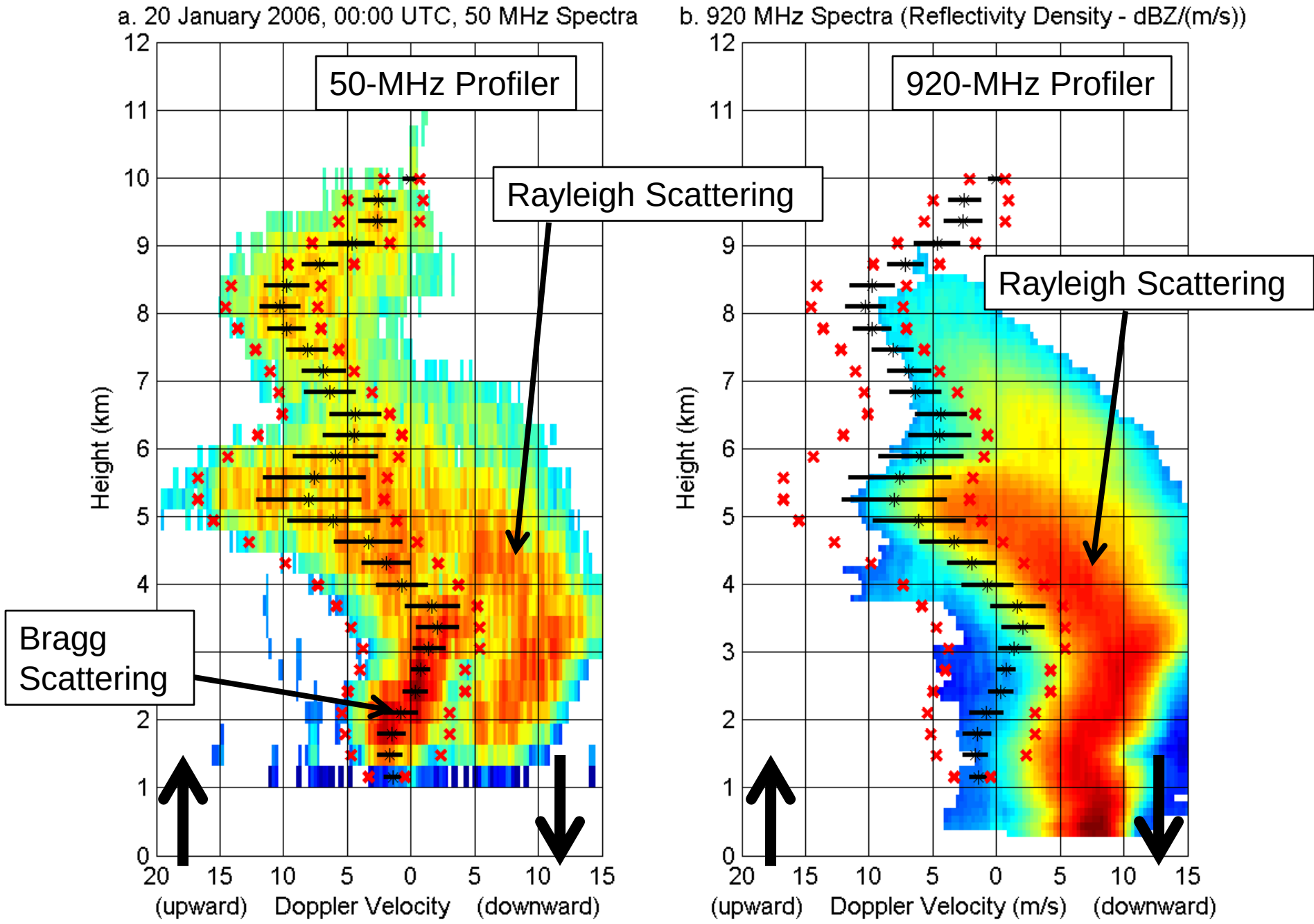
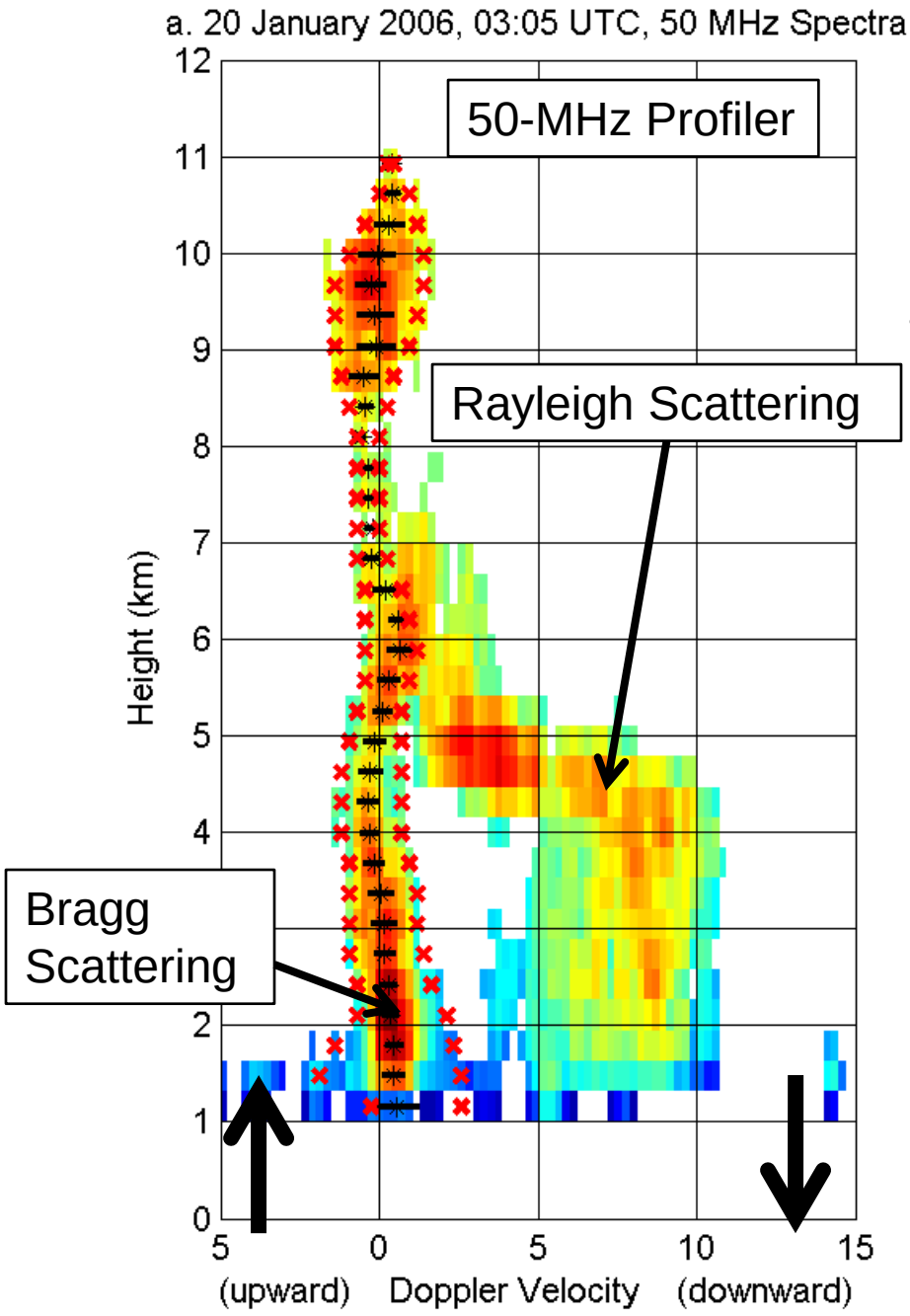
50-and 920-MHz Wind Profilers near Darwin, Australia




920-MHz Reflectivity, (dBZ), 19-20 January 2006
Convective Profile
Stratiform Profile
10 km
5 km
Height, km
15
10
5
0
23:00
00:00
01:00
02:00
03:00
04:00
50
40
30
20
10
Vertical Air Motion, Positive Upward, (m/s)
12
8
4
0
-4
Vertical Air Motion, Positive Upward, (m/s)
1.0
0.5
0.0
-0.5
-1.0
Hour of Day, UTC


a. 20 January 2006, 03:05 UTC, 50 MHz Spectra
b. 920 MHz Spectra (Reflectivity Density - dBZ/(m/s))
50-MHz Profiler
Rayleigh Scattering
Bragg Scattering
Dual-Frequency Retrieval: Estimate the vertical velocity by masking the 50-MHz profiler Rayleigh scatting with the 920-MHz profiler observations.
920-MHz Profiler
Rayleigh Scattering
Height (km)
(upward) Doppler Velocity (downward)
(upward) Doppler Velocity (m/s) (downward)


a. 20 January 2006, 00:00 UTC, 50 MHz Spectra
b. 920 MHz Spectra (Reflectivity Density - dBZ/(m/s))
50-MHz Profiler
920-MHz Profiler
Rayleigh Scattering
Rayleigh Scattering
Bragg Scattering
Height (km)
Height (km)
0
1
2
3
4
5
6
7
8
9
10
11
12
20
15
10
5
0
5
10
15
(upward)
Doppler Velocity
(downward)
(upward)
Doppler Velocity (m/s)
(downward)



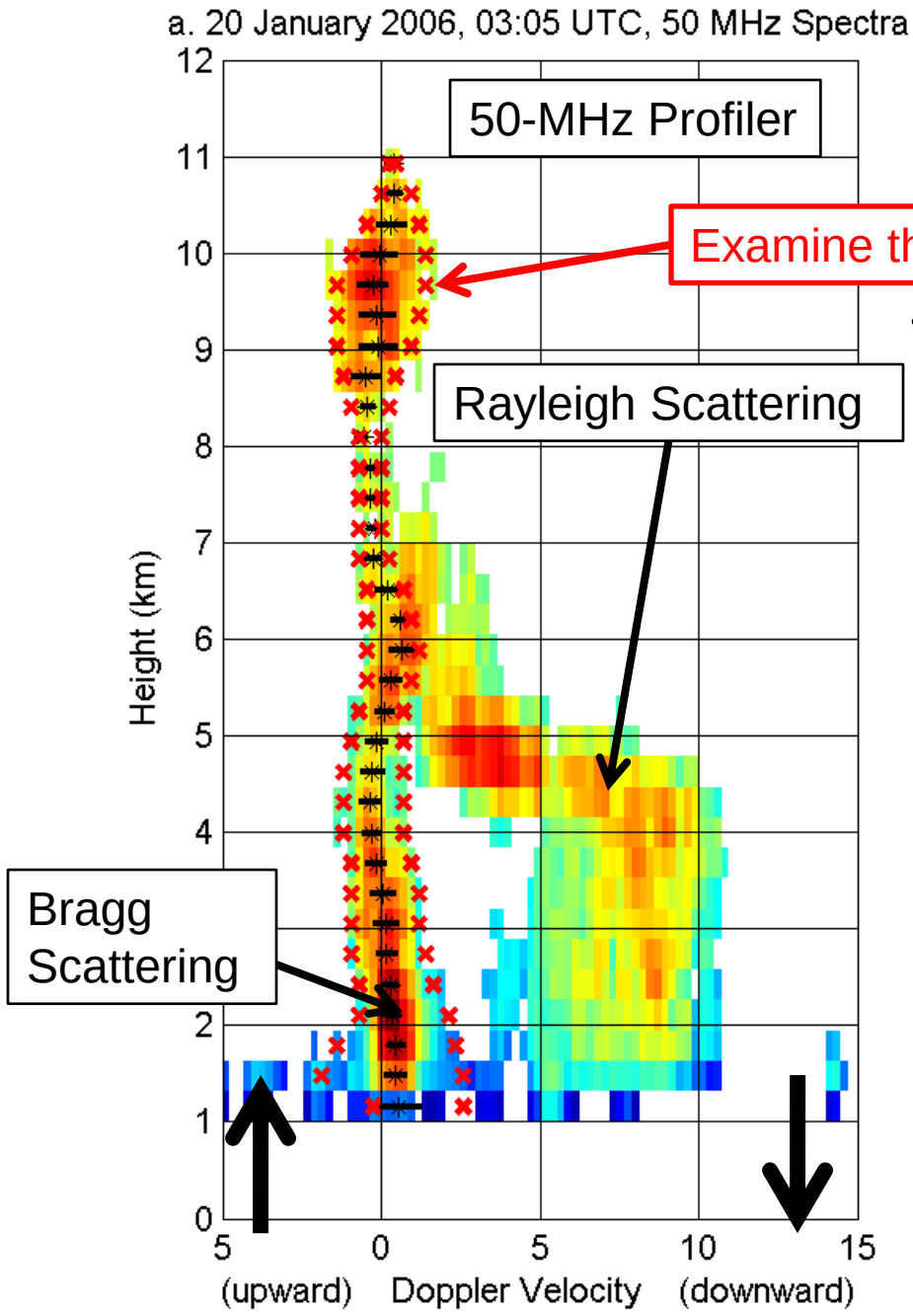
What are the vertical air motion ***uncertainties***?

Types of uncertainties:

- Measurement
- Representativeness
- Model
- Sampling

Profiler Parameters

- 45 second dwell period



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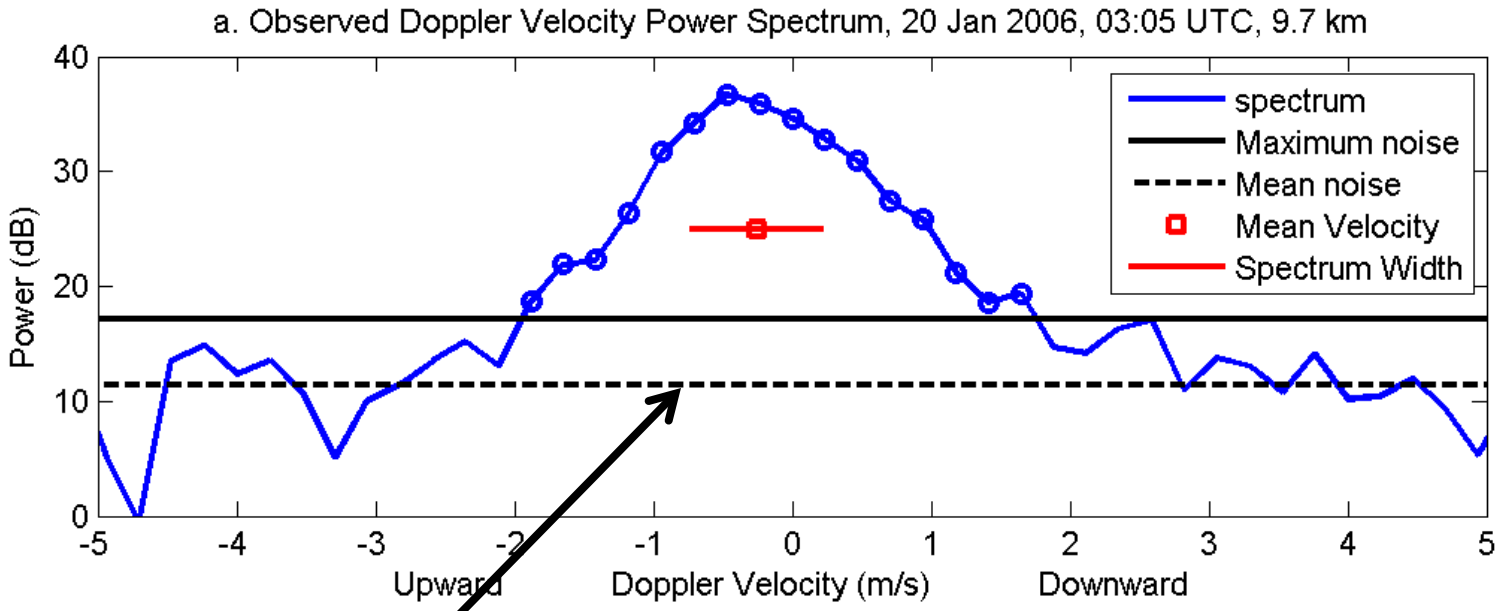


Mean Noise, n_{mean}

The Spectrum Moments

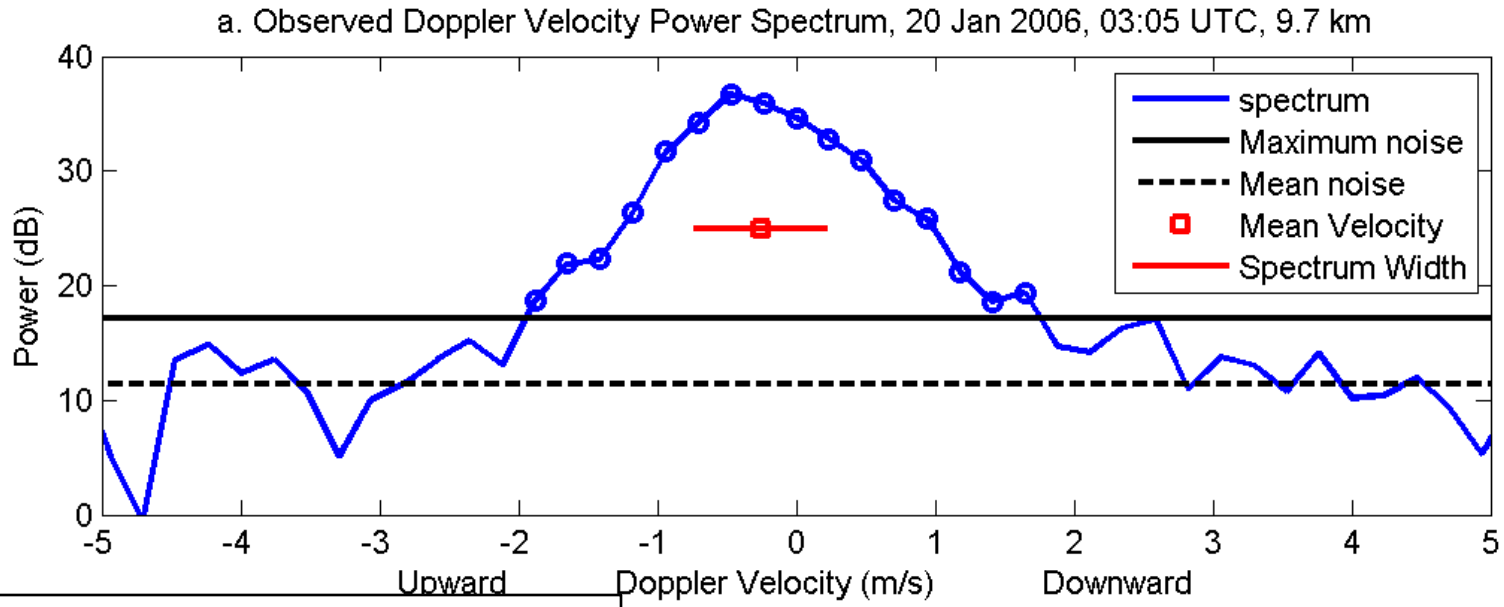
SNR = 7.6 dB

Signal to Noise Ratio $SNR = \frac{Signal\ Power}{Noise\ Power} = \frac{\sum_i (S(v_i - n_{\text{mean}})dv}{N_{\text{pts}} n_{\text{mean}}}$

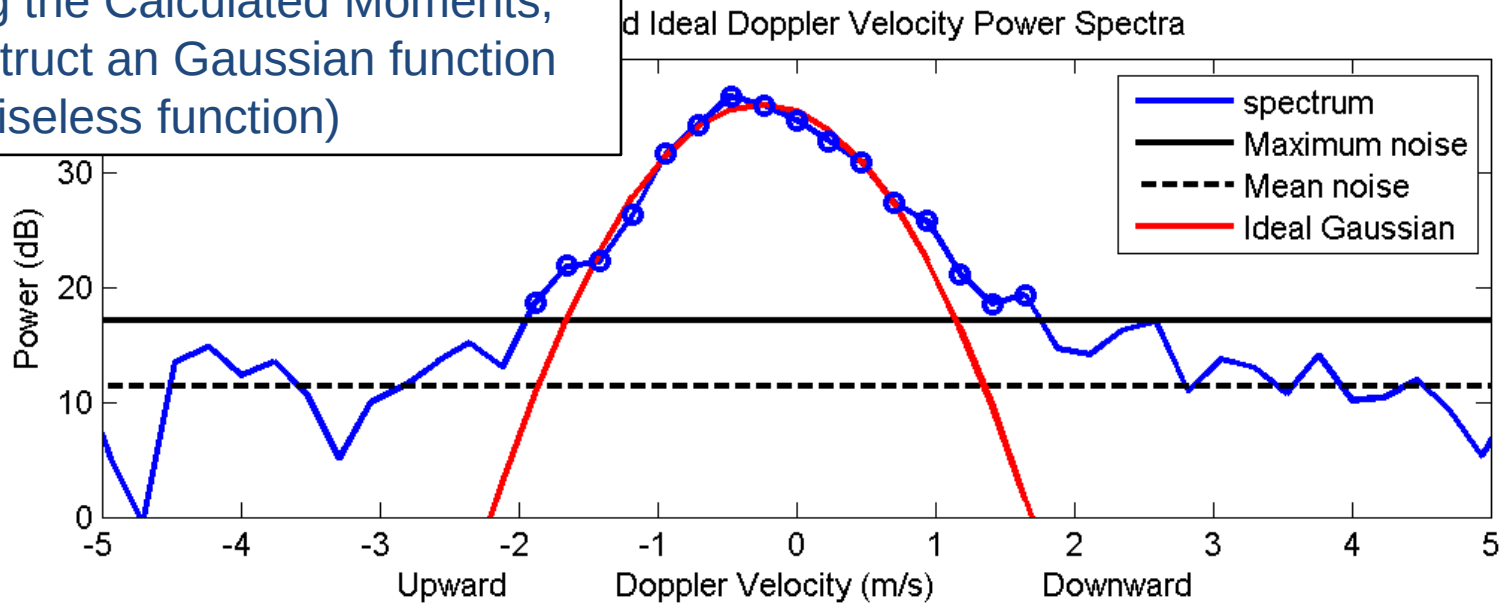
Mean Velocity $\bar{V} = \frac{\sum_i v_i S(v_i) dv}{\sum_i S(v_i) dv}$

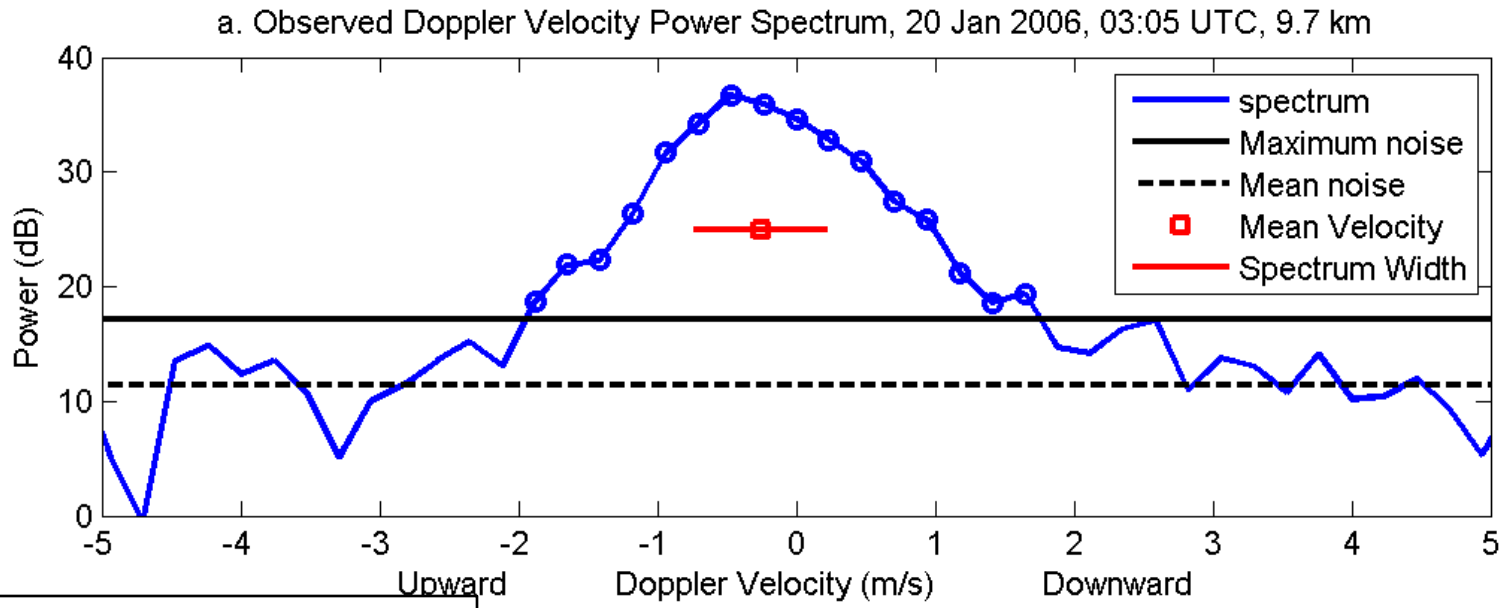
Spectrum Width $W = 2\sigma = 2\left[\frac{\sum_i (v_i - \bar{V})^2 S(v_i) dv}{\sum_i S(v_i) dv}\right]^{1/2}$

W = 0.95 m/s



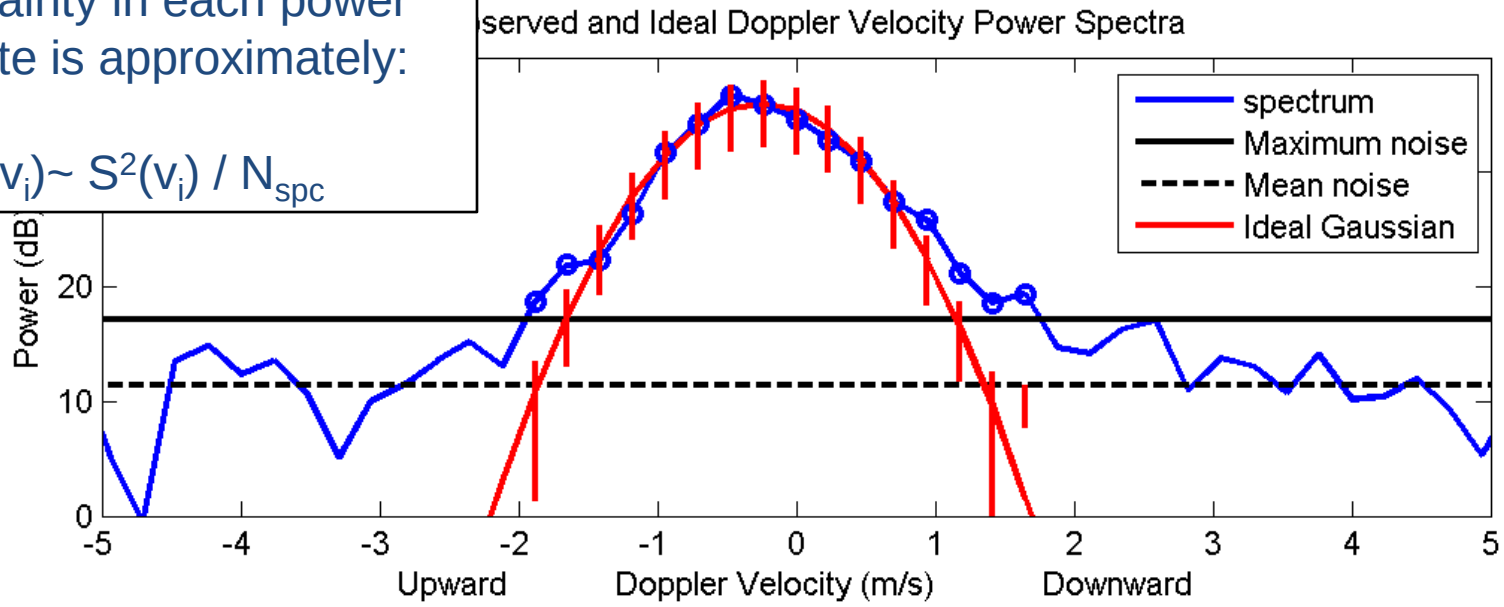
Using the Calculated Moments, Construct an Gaussian function (a noiseless function)

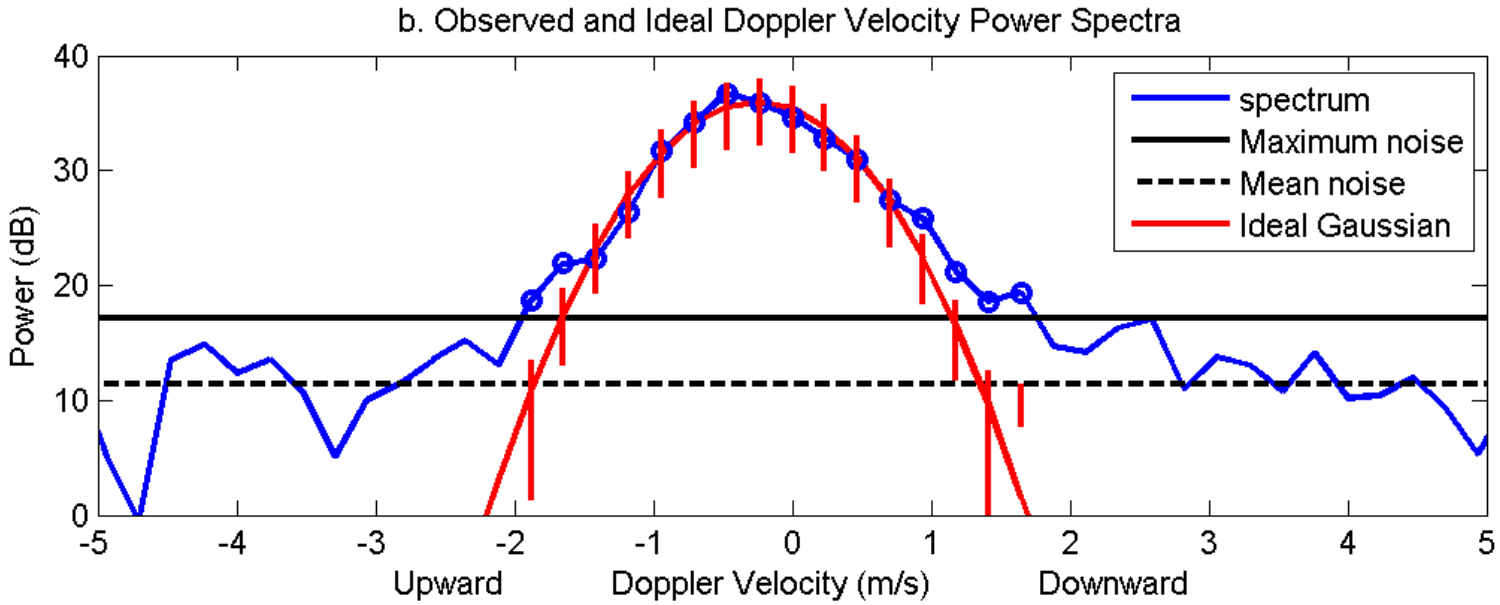




Uncertainty in each power estimate is approximately:

$\sigma^2(v_i) \sim S^2(v_i) / N_{spc}$





Velocity Moment with Uncertainty in $S(v_i)$

Uncertainty pulled from a pdf of expected power estimates.

Mean Velocity

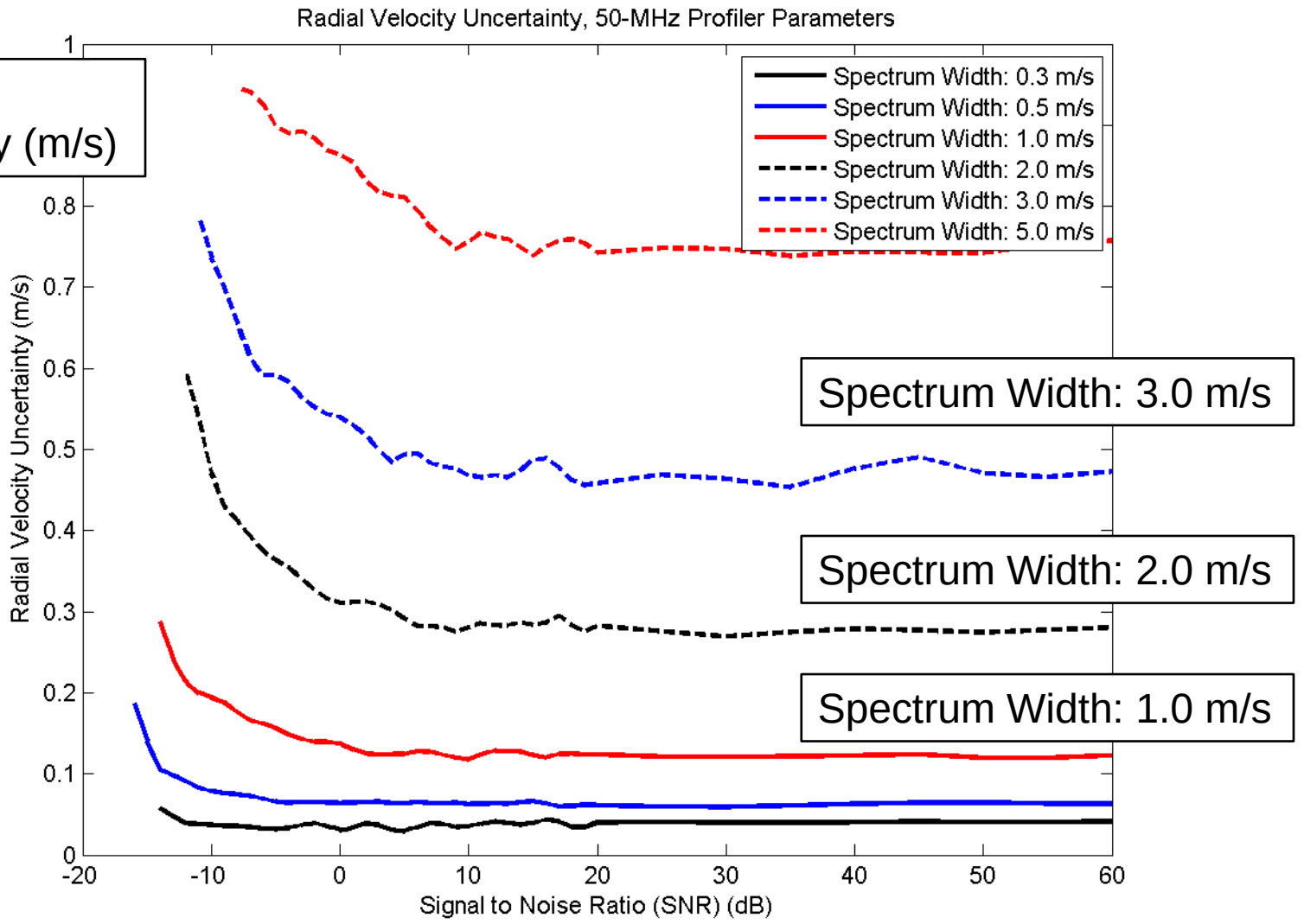
$$\bar{V} = \frac{\sum_i v\left(S(v_i) + \delta S(v_i)\right)dv}{\sum_i (S(v_i) + \delta S(v_i))dv}$$

Q. How do we estimate the uncertainty of this summation?
A. We simulate it using Monte Carlo simulations.

Monte Carlo Simulation

1) Find moments of spectrum
2) Construct ideal (noiseless) Gaussian spectrum
3) Replicate realistic spectrum:
   a) Add uncertainty to the noiseless Gaussian spectrum
   b) Construct N_{spc} separate noisy spectra ($N_{spc} = 3$)
   c) Average spectra to generate realistic spectrum
4) Calculate moments of realistic spectrum
5) Repeat steps 3) and 4) 1000 times
6) Calculate the mean & STD of moments
7) Mean represents measurement bias
8) STD represents measurement uncertainties

Velocity Uncertainty is defined as Standard Deviation (STD) of mean velocity moments from 1000 simulations with the same (SNR, Spectrum Width) pair



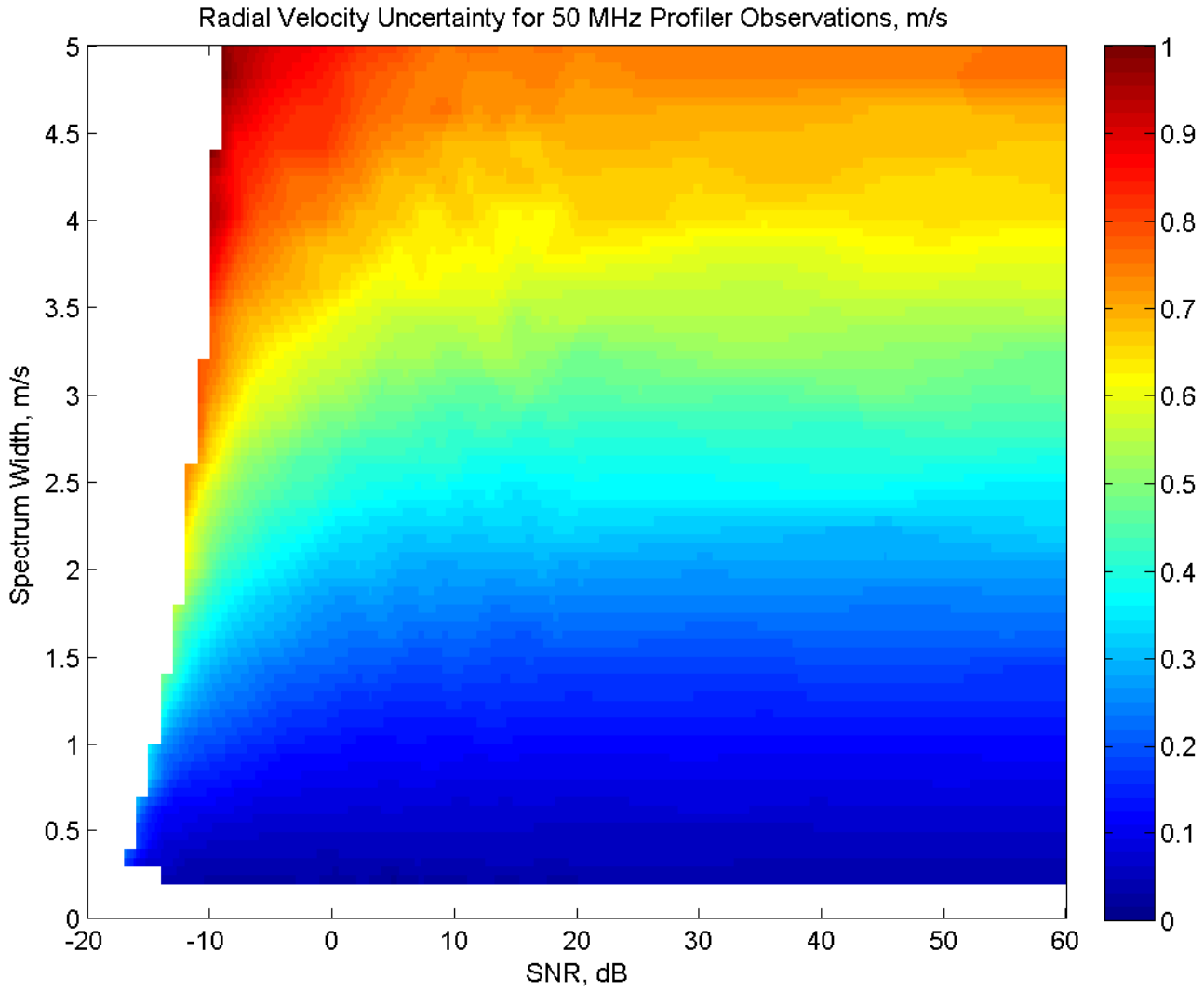
Velocity Uncertainty (m/s)

Spectrum Width: 3.0 m/s

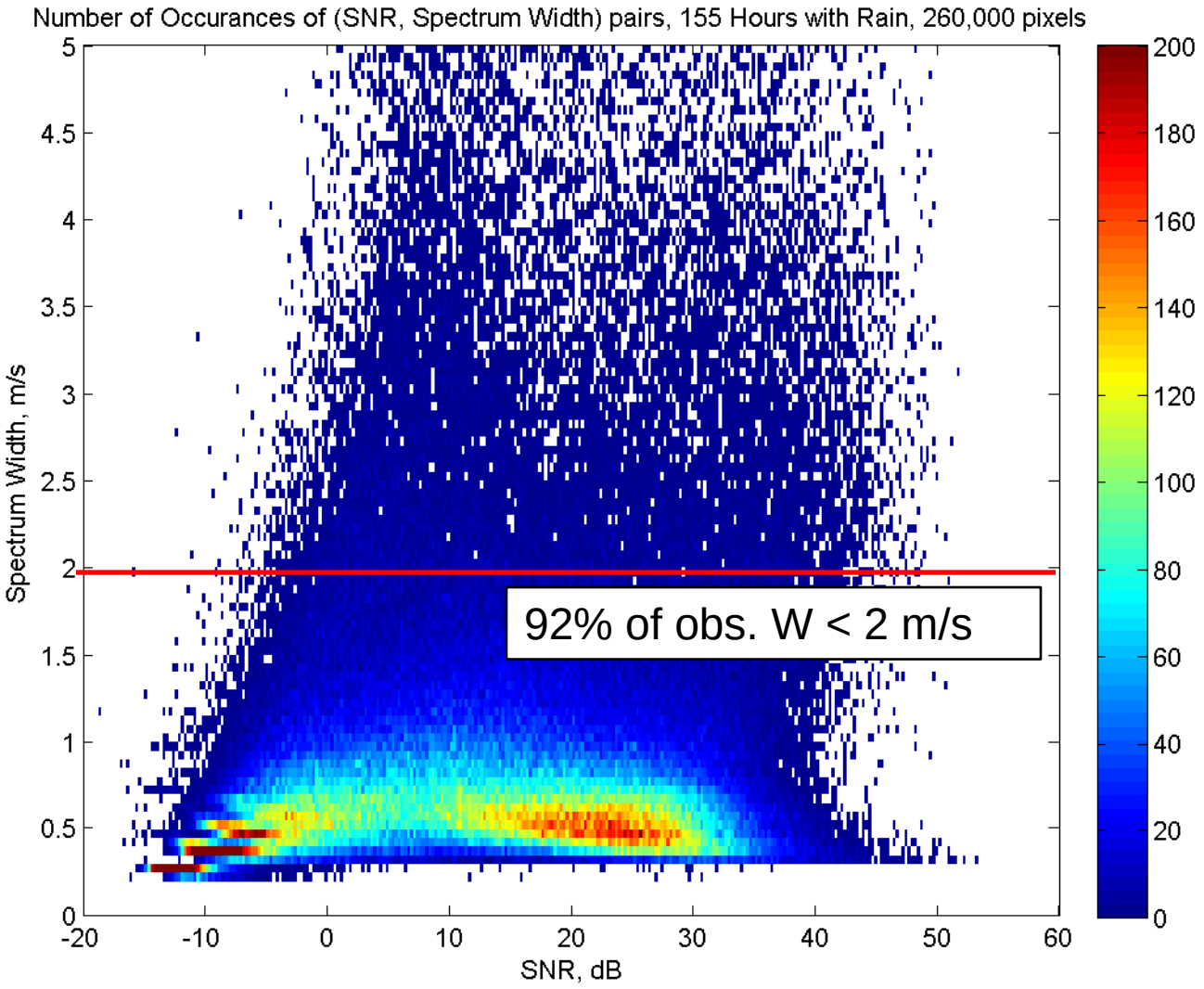
Spectrum Width: 2.0 m/s

Spectrum Width: 1.0 m/s

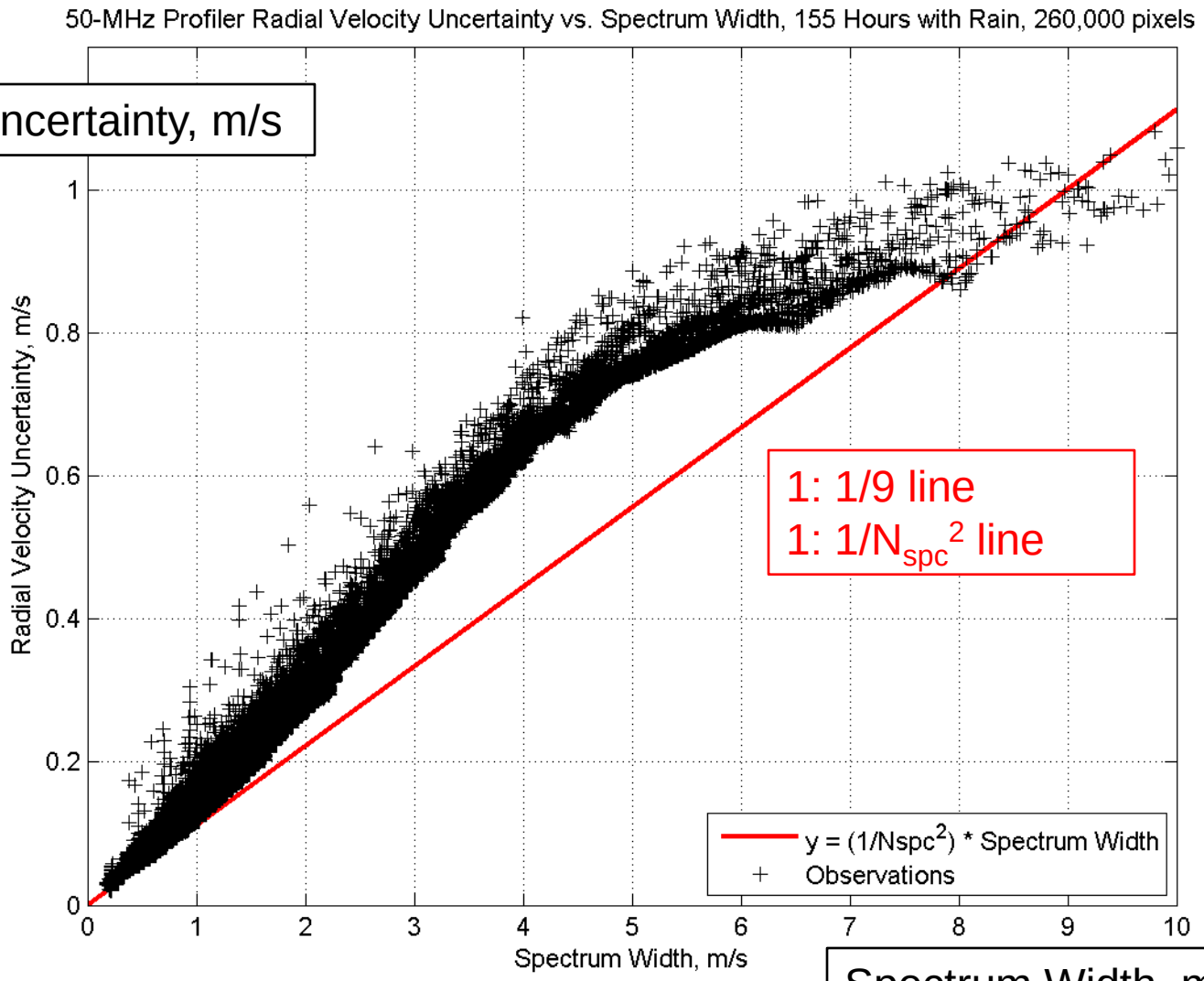
Construct a look-up table:
For each (SNR, Spectrum width) pair, look-up the radial velocity uncertainty



Distribution of Observed SNR and Spectrum Width Pairs



Velocity Uncertainty vs. Spectrum Width: 50-MHz Profiler



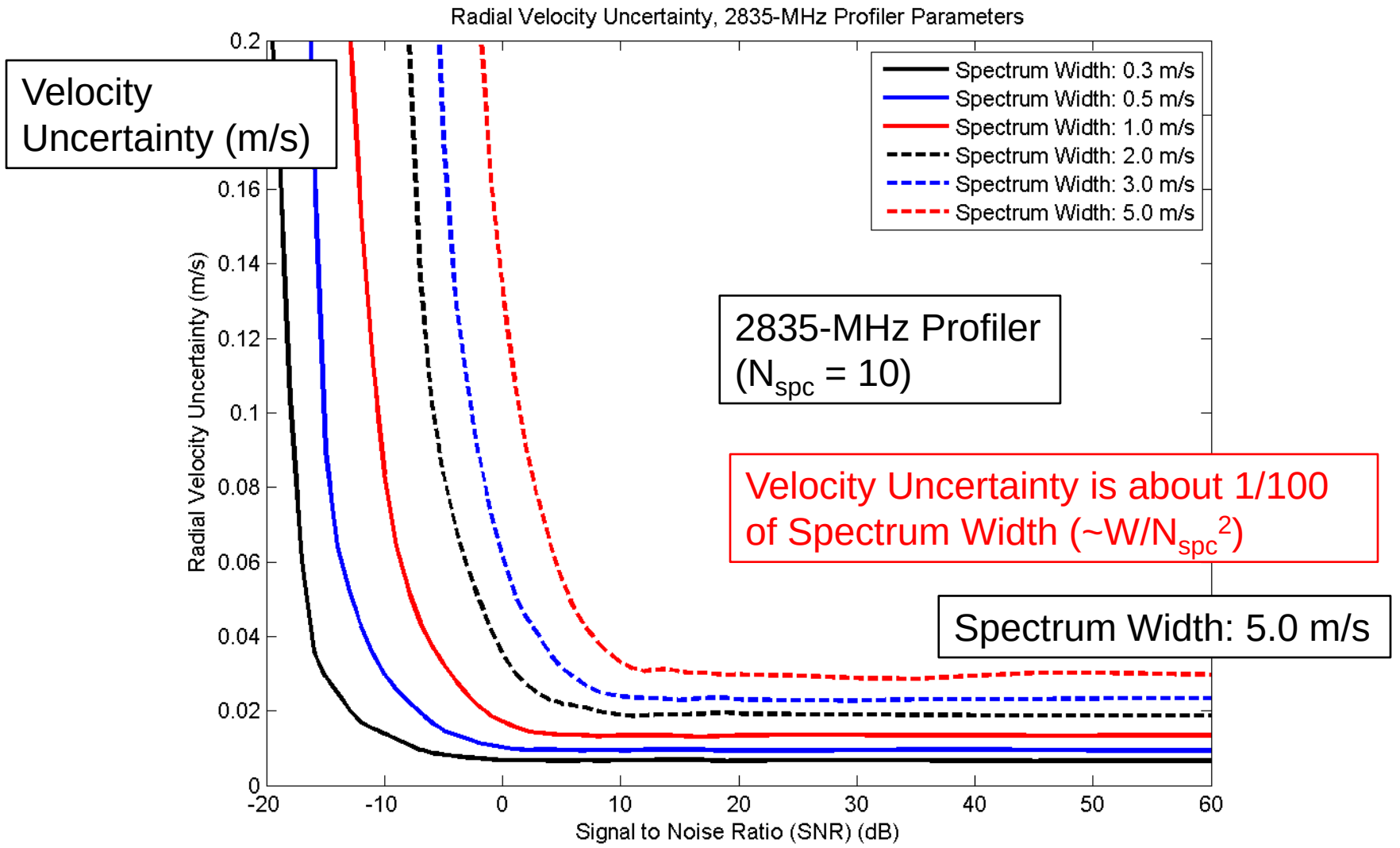
Velocity Uncertainty, m/s

1: 1/9 line

1: $1/N_{spc}^2$ line

Spectrum Width, m/s

Velocity Uncertainty can be estimated for all radars collecting Doppler velocity power spectra. This plot is for the 2835-MHz profiler that had N_{spc} = 10.



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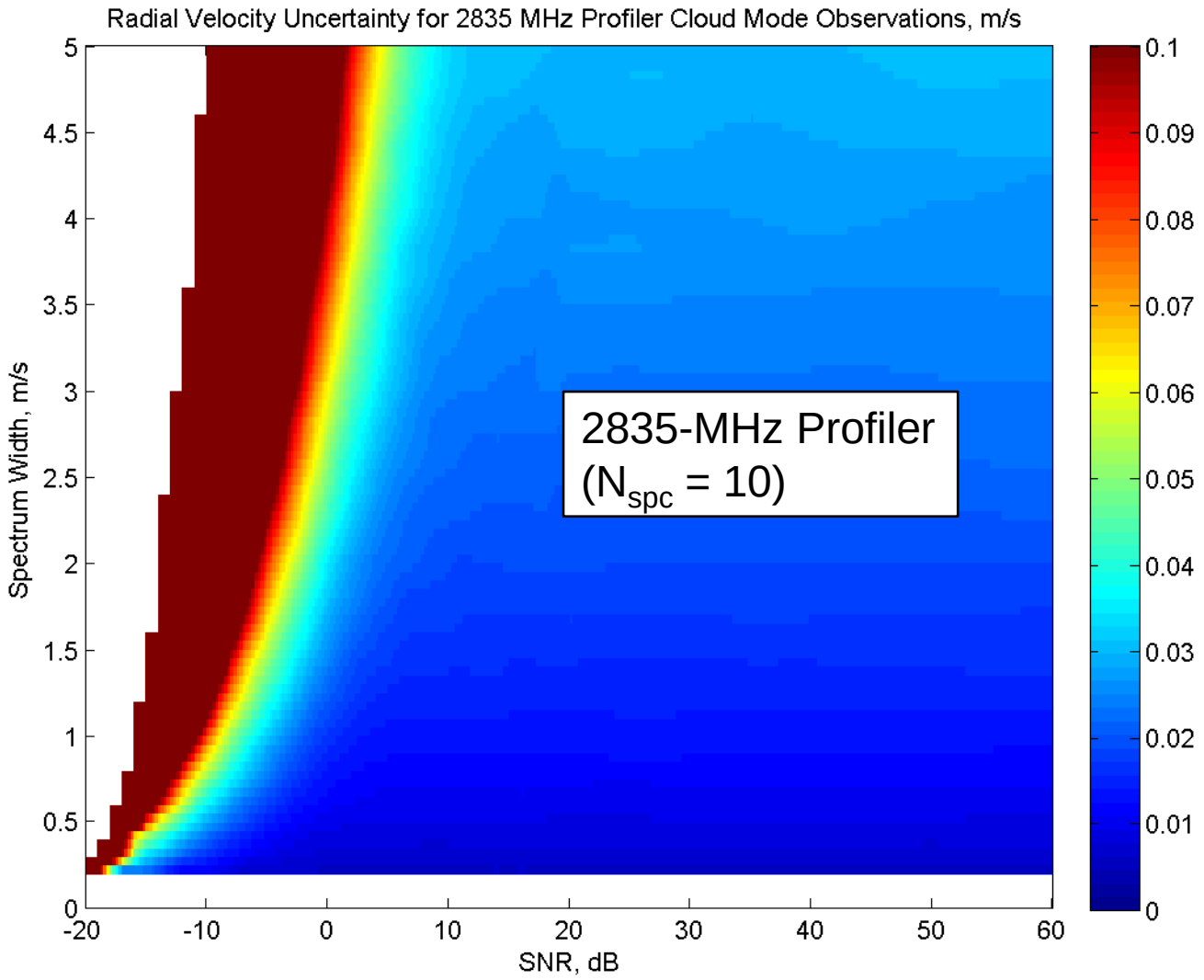

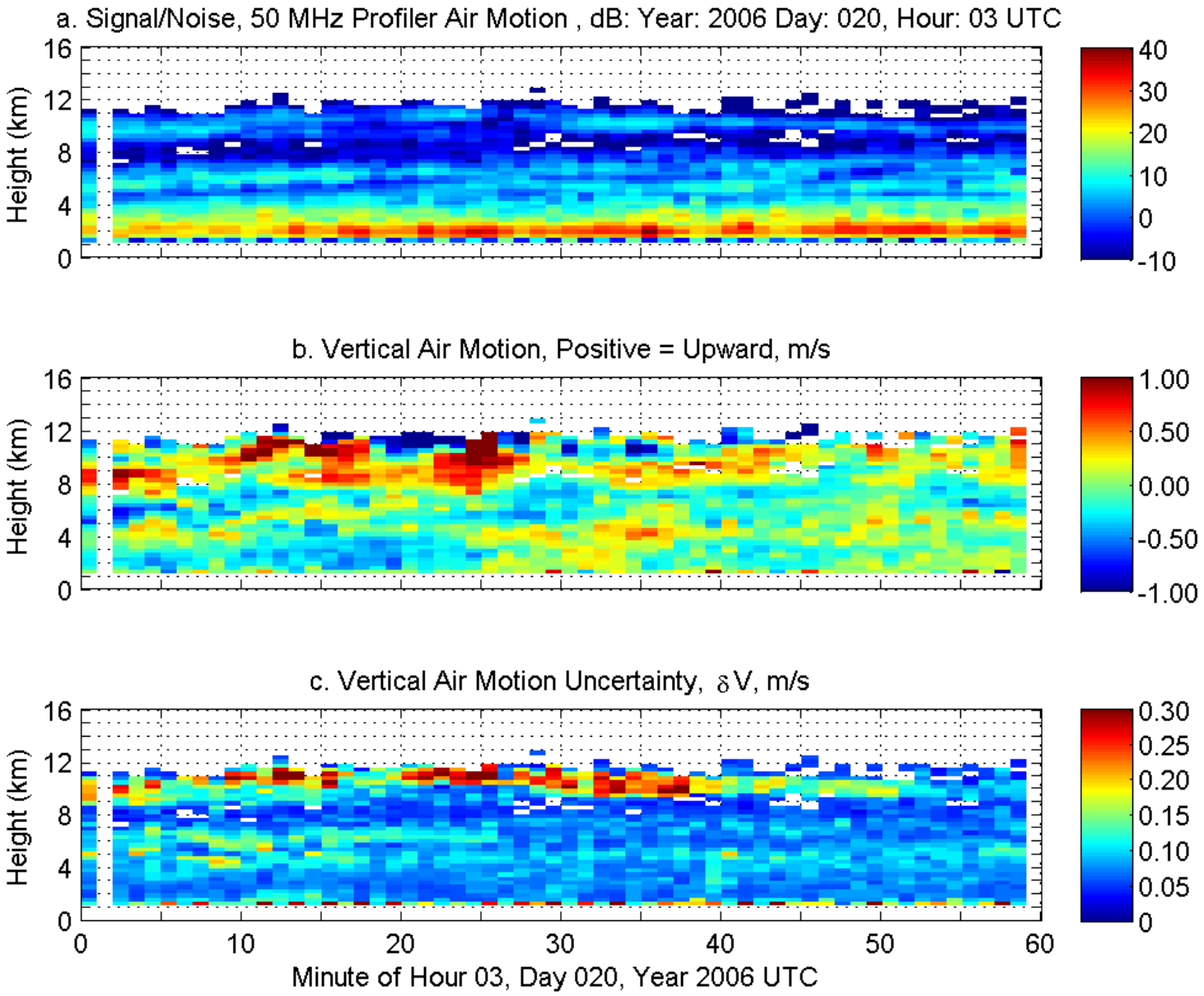
a. Signal/Noise, 50 MHz Profiler Air Motion , dB: Year: 2006 Day: 020, Hour: 03 UTC
Height (km)
16
12
8
4
0
40
30
20
10
0
-10
b. Vertical Air Motion, Positive = Upward, m/s
Height (km)
16
12
8
4
0
1.00
0.50
0.00
-0.50
-1.00
c. Vertical Air Motion Uncertainty, δV, m/s
Height (km)
16
12
8
4
0
0.30
0.25
0.20
0.15
0.10
0.05
0
0
10
20
30
40
50
60
Minute of Hour 03, Day 020, Year 2006 UTC

Summary Comments

- Monte Carlo Simulation used to construct many realistic Doppler velocity power spectra
- Moments are estimated for each spectra
- Standard deviation of moments represent the measurement uncertainty
- Velocity uncertainty dependent on SNR and spectrum width
- Velocity uncertainty ~1/10 of spectrum width (W) for 50-MHz profiler vertical air motion estimates (~W/N_{spc}^2)
- Velocity uncertainty ~1/100 of spectrum width (W) for 2835-MHz profiler vertical air motion estimates (~W/N_{spc}^2)
- TWP-ICE vertical air motion data files will contain both estimate and the measurement uncertainty
- Monte Carlo Simulation can be used to develop a look-up table for all future observations
- Technique can be applied to any radar that uses spectral processing