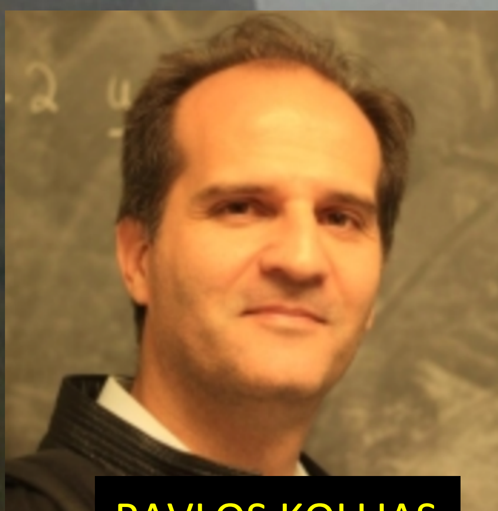
Detecting the Onset of Drizzle Using ARM Observations and a Steady-State 1-D Column Model



Outline

- Motivations
- Methods
- Modeling the onset of drizzle
- Observations of drizzle onset
- "Synergy" of Results
- Conclusions

Low, Drizzling Clouds

- Near-surface radiative properties (e.g. scattering, absorption, cloud "morphology").
- Drizzle affects aerosols' in/direct radiative effects.
- Classic references: Liou (2002), Shao and Liu (2004), Rosenfeld (2000), and many more!

Instruments

W-BAND ARM CLOUD RADAR (WACR)

CEILOMETER

Credit: www.arm.gov

1-D Steady State Model

- No dynamics
- Only microphysics processes (collision/coalescence, breakup, etc.)
- No sedimentation

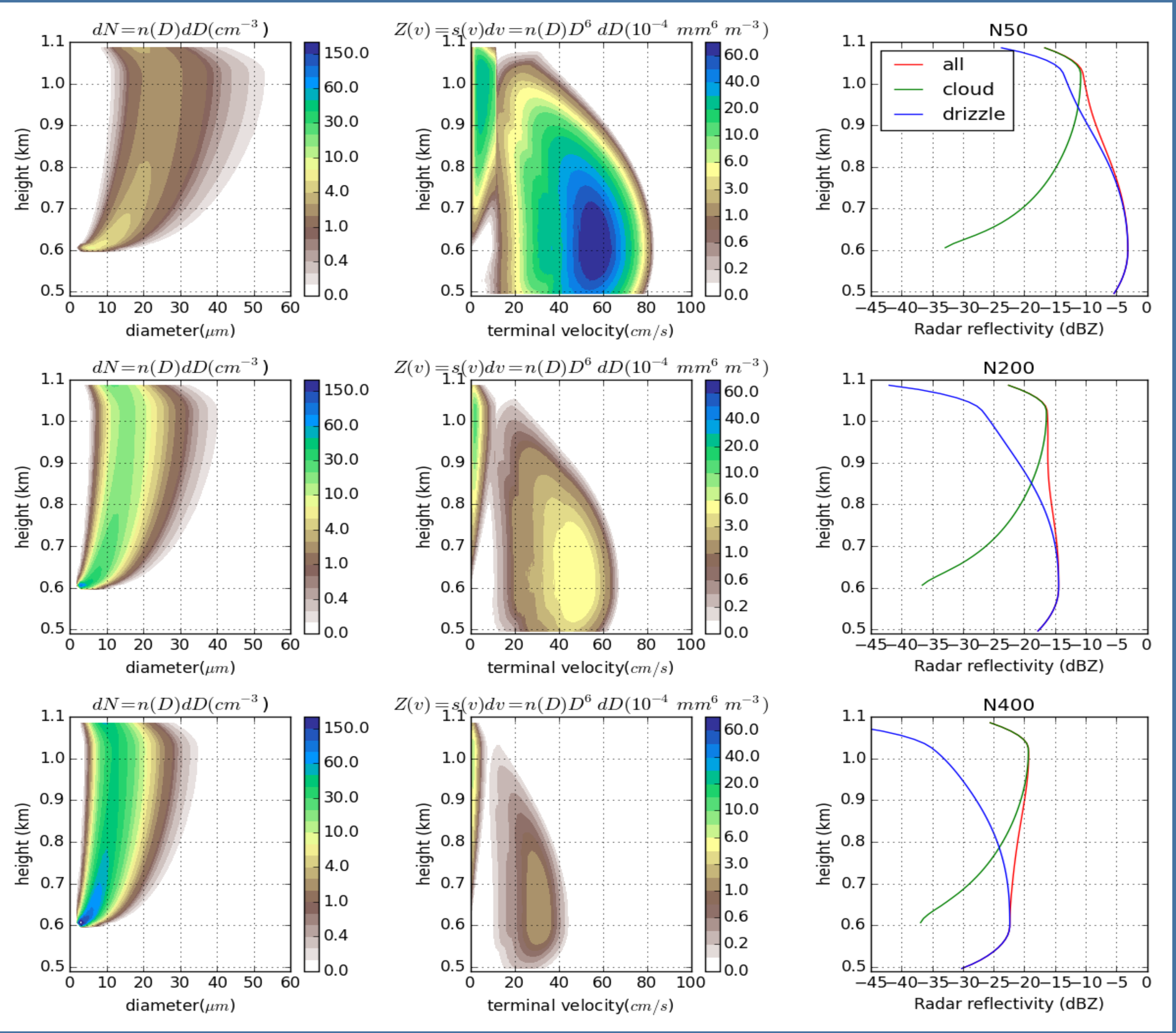
- **TEST CASE:**
  - Cloud depth is 500 meters
  - Cloud base @ 600 meters

But First... A Moment on Moments

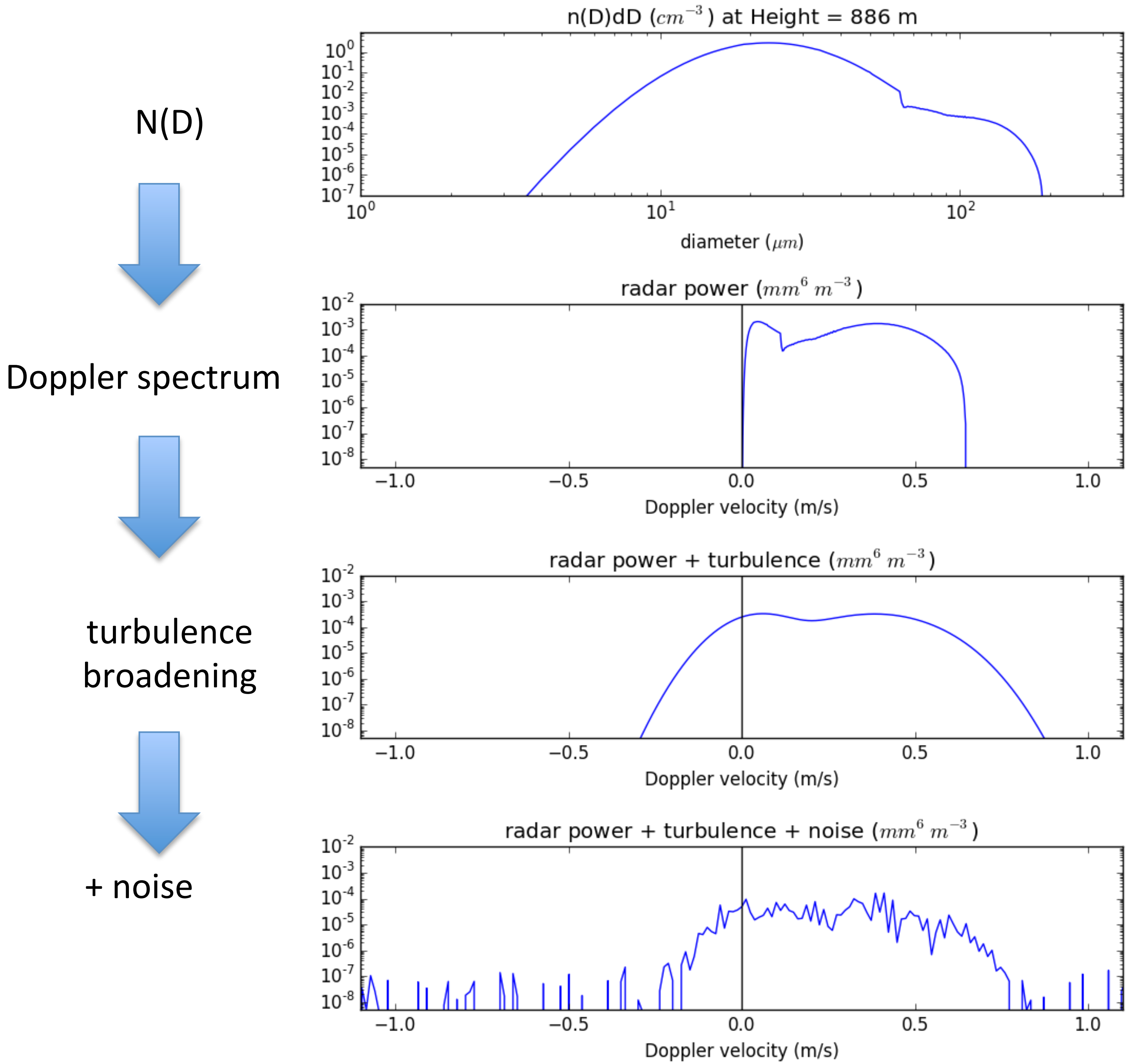
- Reflectivity Power → 0^{th} moment
  - How large the particles are.
- Doppler Velocity → 1^{st} moment
  - How fast the particles are moving in relation to the radar.
- Doppler Spectrum Width → 2^{nd} moment
  - Also the "standard deviation" of Doppler velocity
- Skewness → 3^{rd} moment
  - Positive skewed = biased toward smaller particles
  - Negative skewed = biased toward larger particles
  - Zero skewness = Symmetric distribution of the Doppler spectrum

Drizzle Onset

- When can we say that a “drizzle onset” happens?
  - Droplets’ size exceeds certain value? (arbitrary, and hard to measure)
  - Downward Doppler velocity? (air motion subtraction)
  - Drizzle dominates the radar echo signal? (maybe too late)
- How to detect the “drizzle onset”? (as early as possible)
  - (a) radar reflectivity threshold (Z_{th})
  - (b) slope of radar reflectivity profile (dZ/dz)
  - (c) Doppler spectra (Z ~ v): skewness etc.



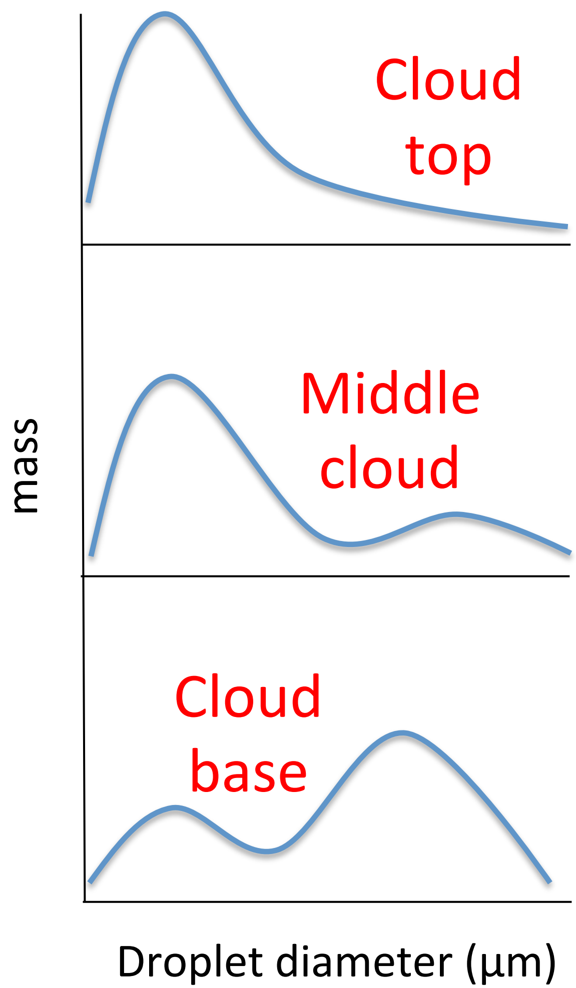
$dN = n(D)dD(cm^{-3})$
$Z(v) = s(v)dv = n(D)D^6\ dD(10^{-4}\ mm^6\ m^{-3})$
N50
N200
N400
all
cloud
drizzle
height (km)
diameter(μm)
terminal velocity(cm/s)
Radar reflectivity (dBZ)

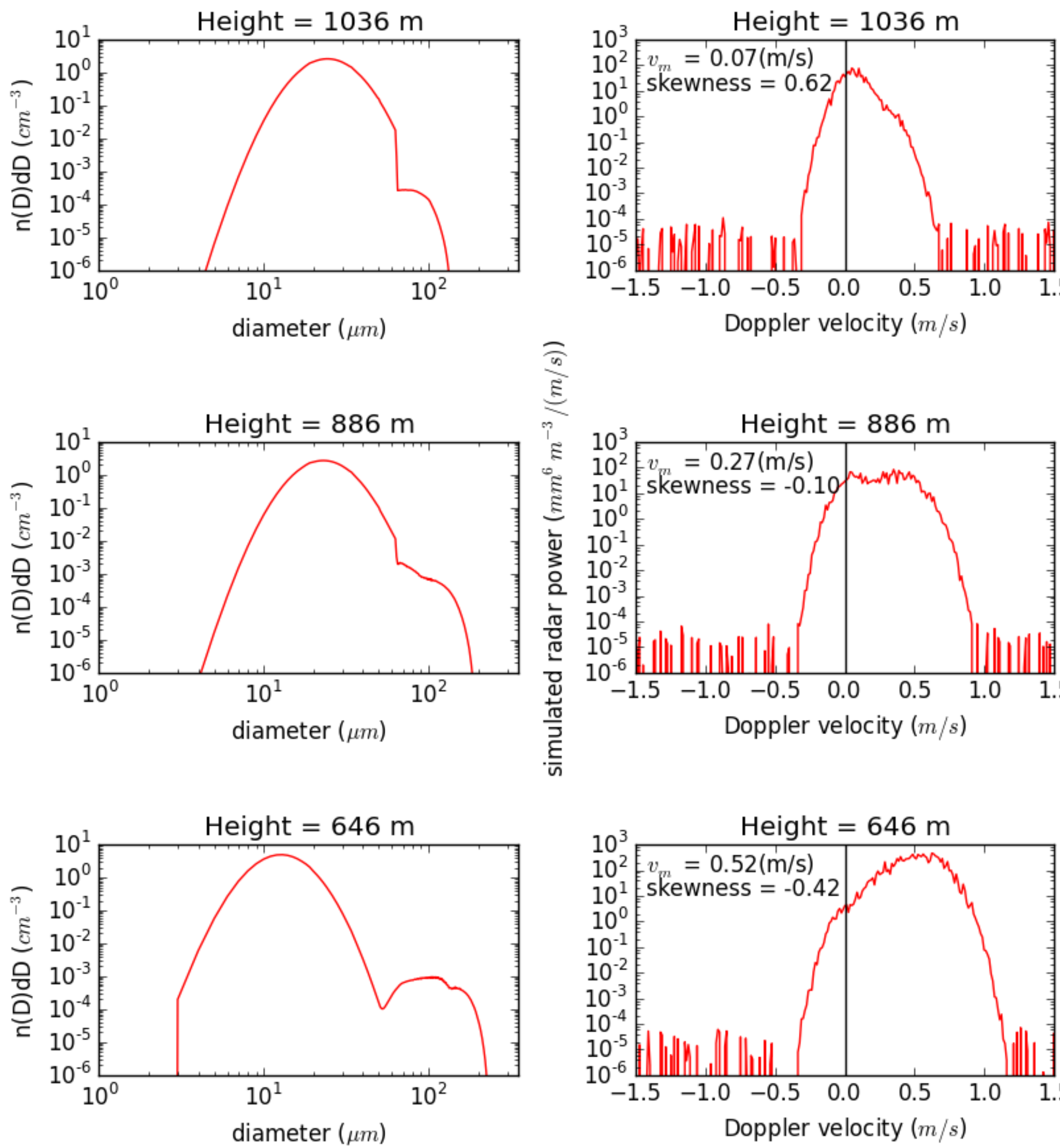


N(D)
Doppler spectrum
turbulence broadening
+ noise
n(D)dD (cm^{-3}) at Height = 886 m
diameter (μm)
radar power ($mm^6\,m^{-3}$)
Doppler velocity (m/s)
radar power + turbulence ($mm^6\,m^{-3}$)
Doppler velocity (m/s)
radar power + turbulence + noise ($mm^6\,m^{-3}$)
Doppler velocity (m/s)

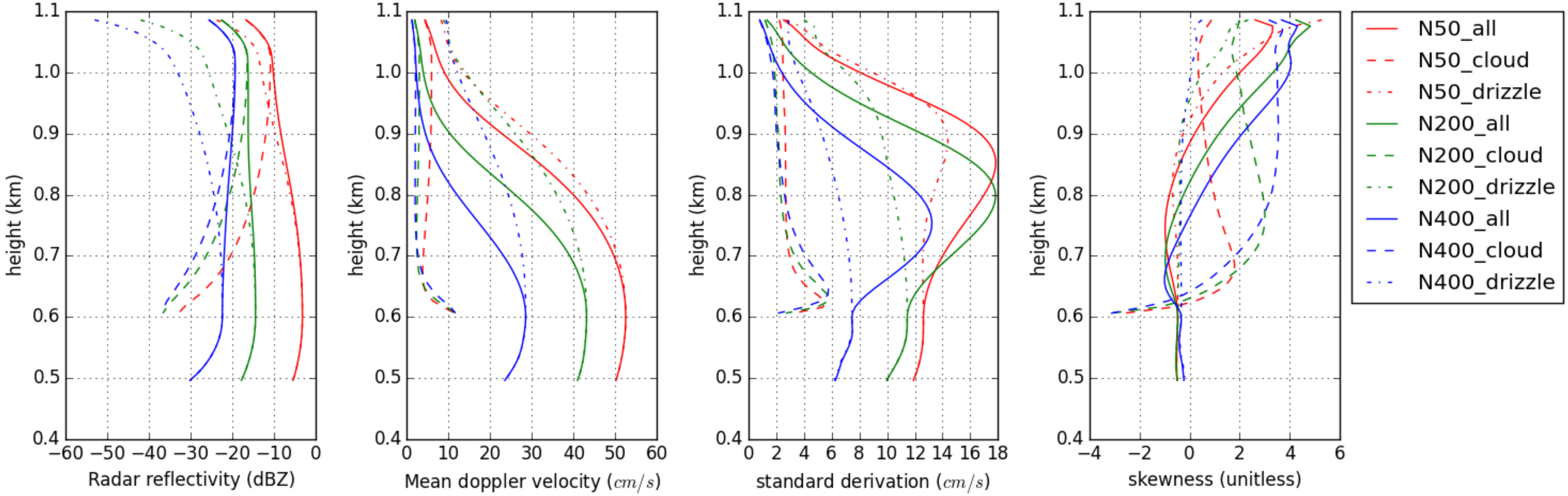
Our forward model simulations:

Why using forward model?





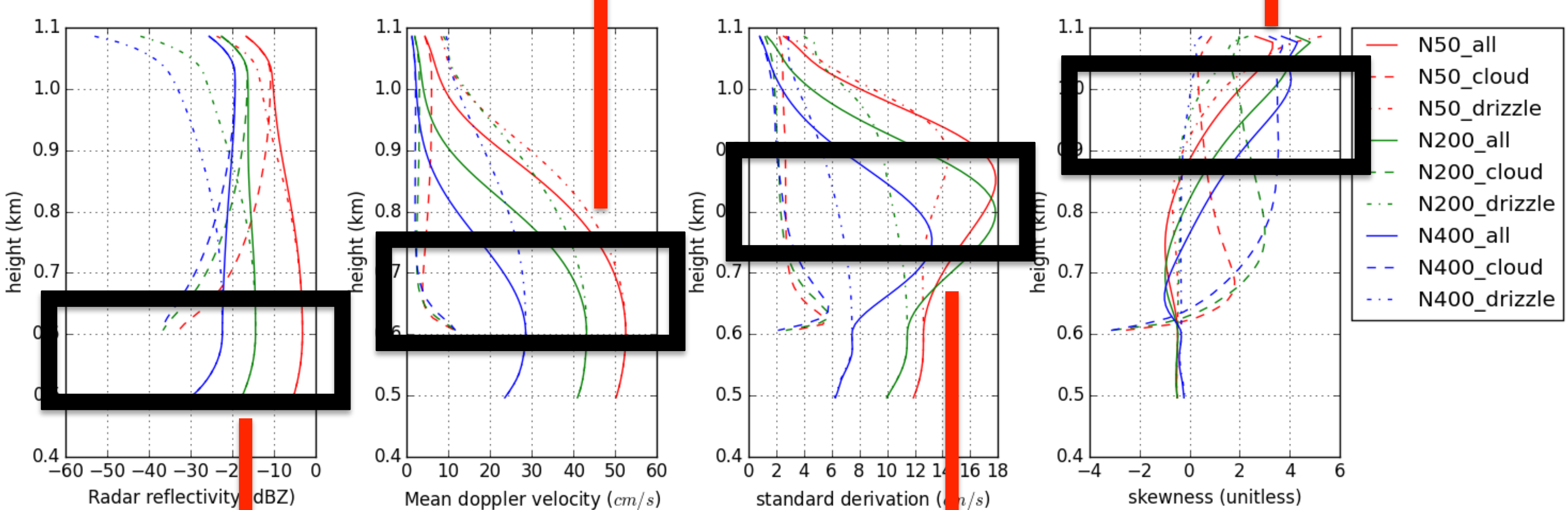
Reflectivity: Cloud Only vs. Drizzle Only



0th	**1st**	**2nd**	**3rd**	**Moment**
Total reflectivity	Mean v	Spectrum width	skewness	

DOPPLER VELOCITY: maximum near cloud base from falling drizzle

SKEWNESS: left-skewed means there's more (faster) falling drizzle drops!



0th 1st 2nd 3rd **Moment**

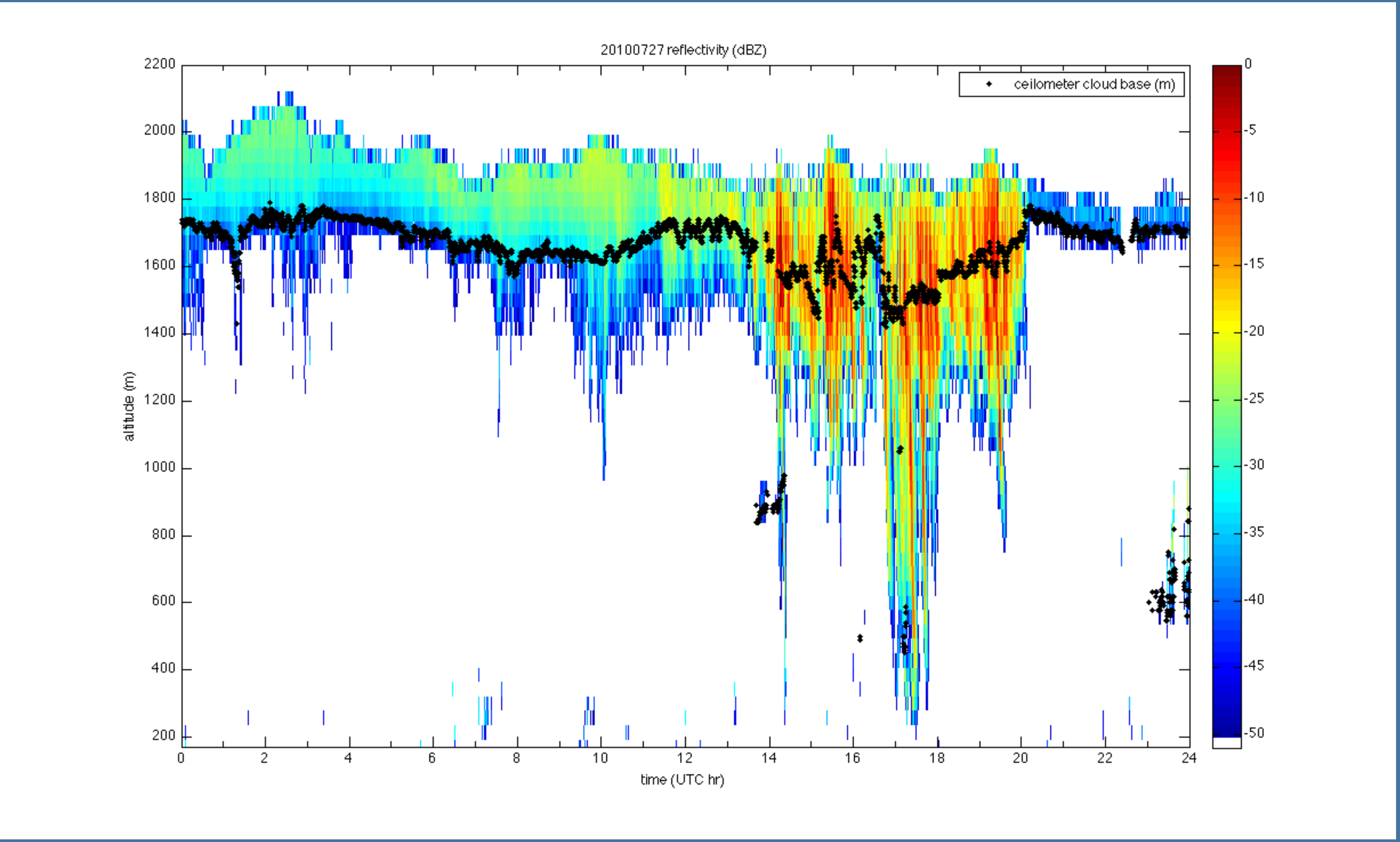
REFLECTIVITY: local min near cloud base and cloud top

DOPPLER SPECTRUM WIDTH: maximum in middle of cloud due to varying particle sizes

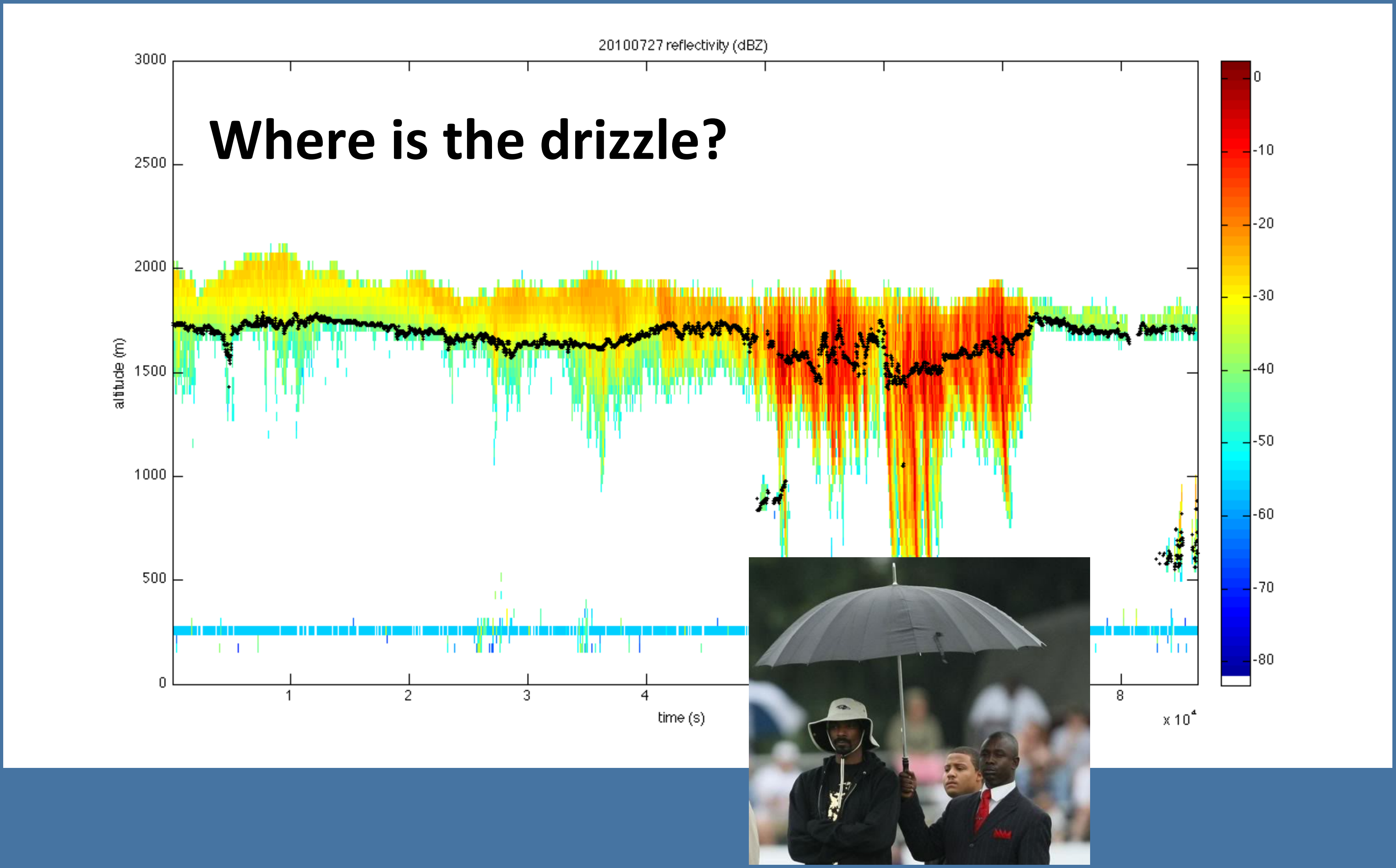
Comparing Model Results with Observations

- Ceilometer & WACR Data
- How do we determine cloud base in a drizzling cloud?
  - Ceilometer: sees thru (heavier) drizzle drops
  - WACR: measures cloud properties (reflectivity, etc.)

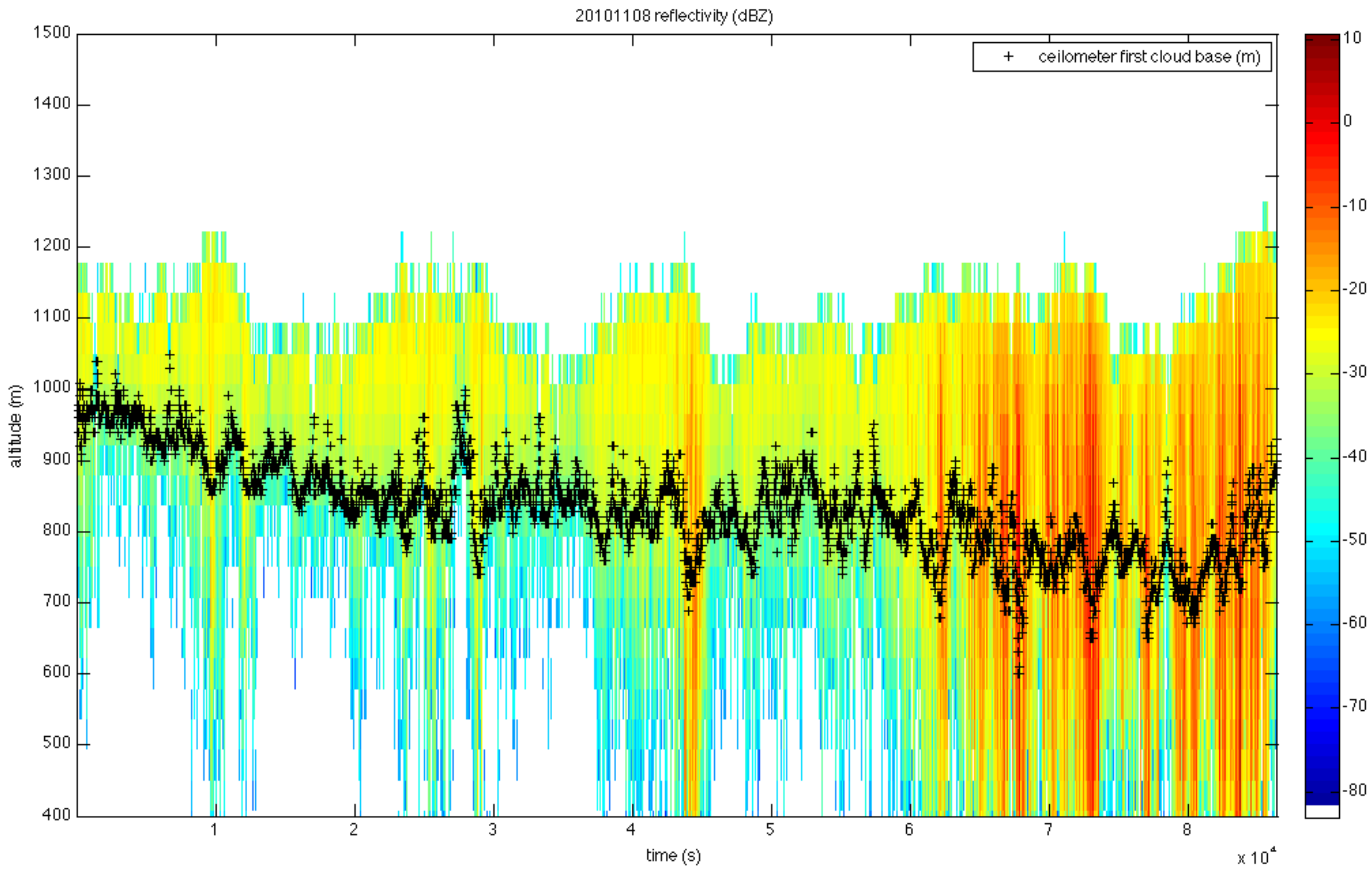
Ceilometer vs. Radar Reflectivity: Case 1



Ceilometer vs. Radar Reflectivity: Case 1



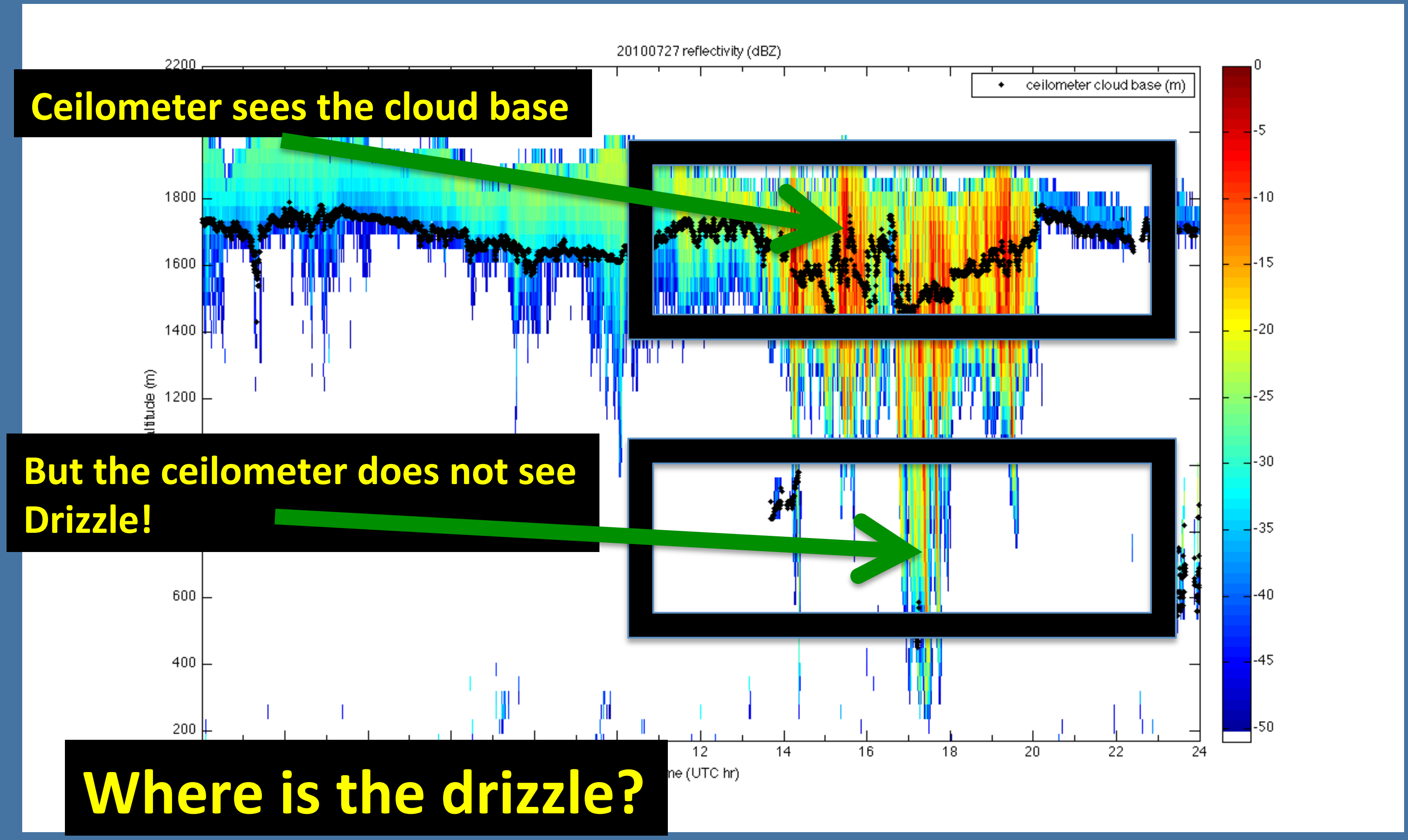
Ceilometer vs. Radar Reflectivity: Case 2



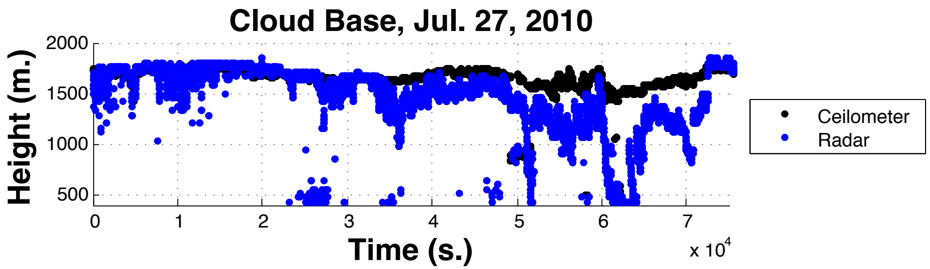
Deriving Drizzle Onset Empirically

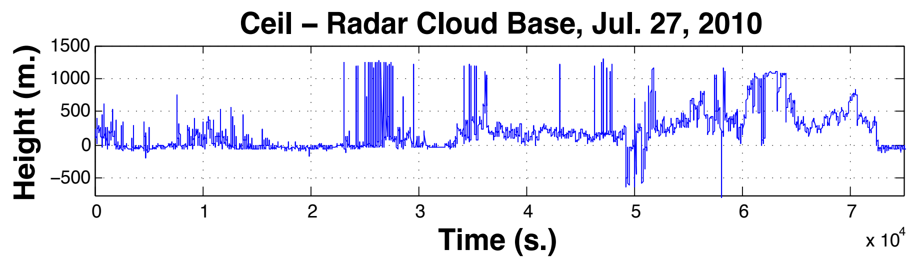
- Mikael/Jingjing/Andy – fill in this part
- Andy – talk about smoothing results and their application
- Mikael/Jingjing – talk about deriving thresholds

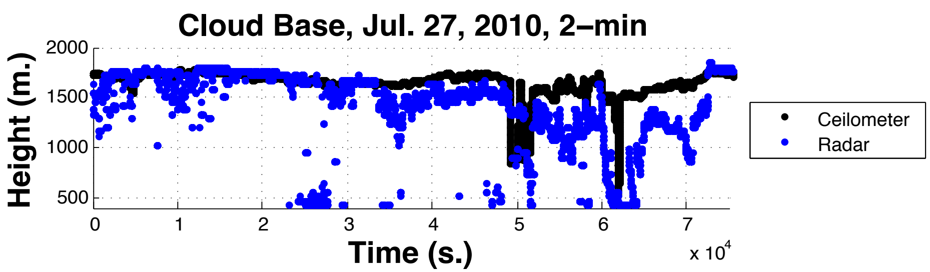
Ceilometer vs. Radar Reflectivity: Case 1

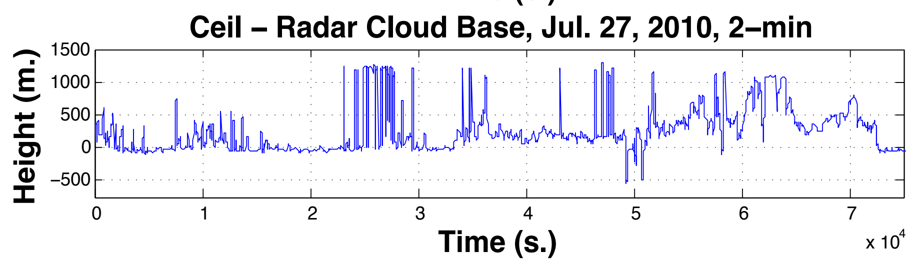


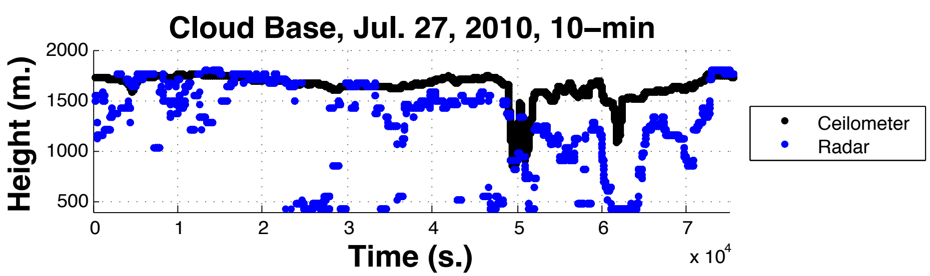
Smoothing the Observations: July

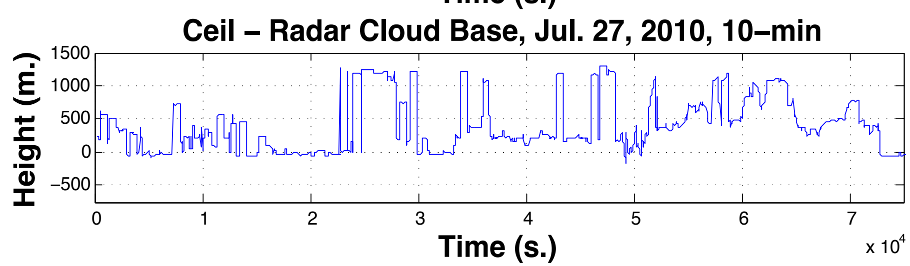






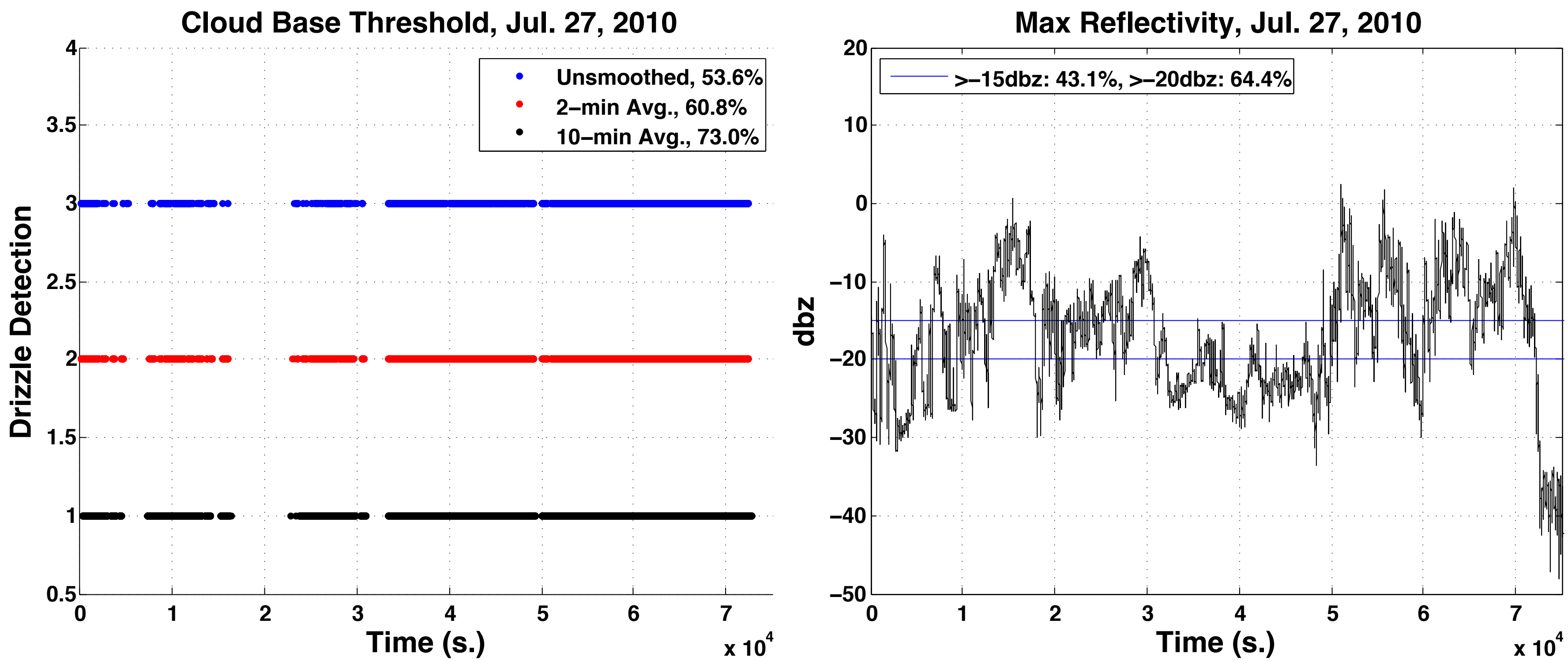






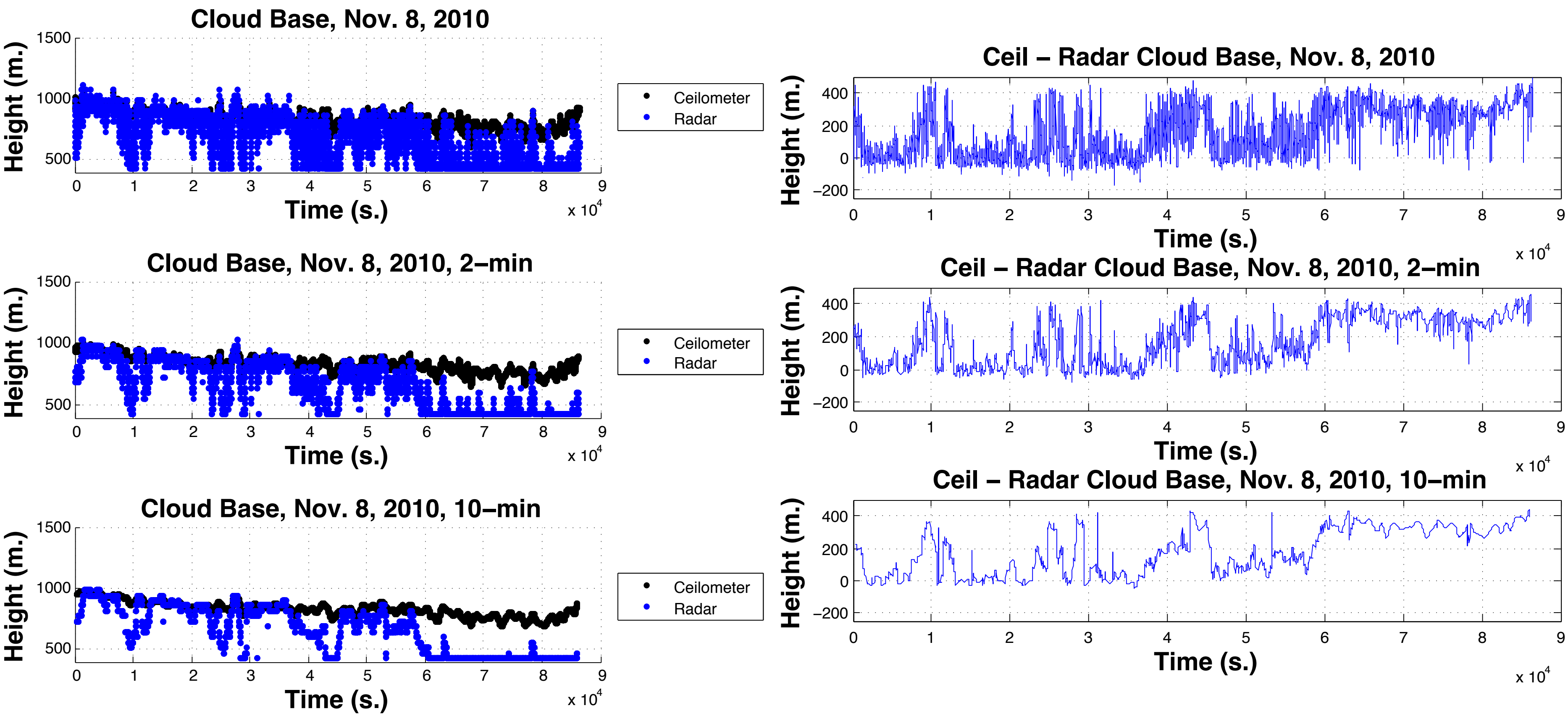
$CBHeight_{CEIL\text{-}RADAR} > 100$ m

Smoothing the Observations: July



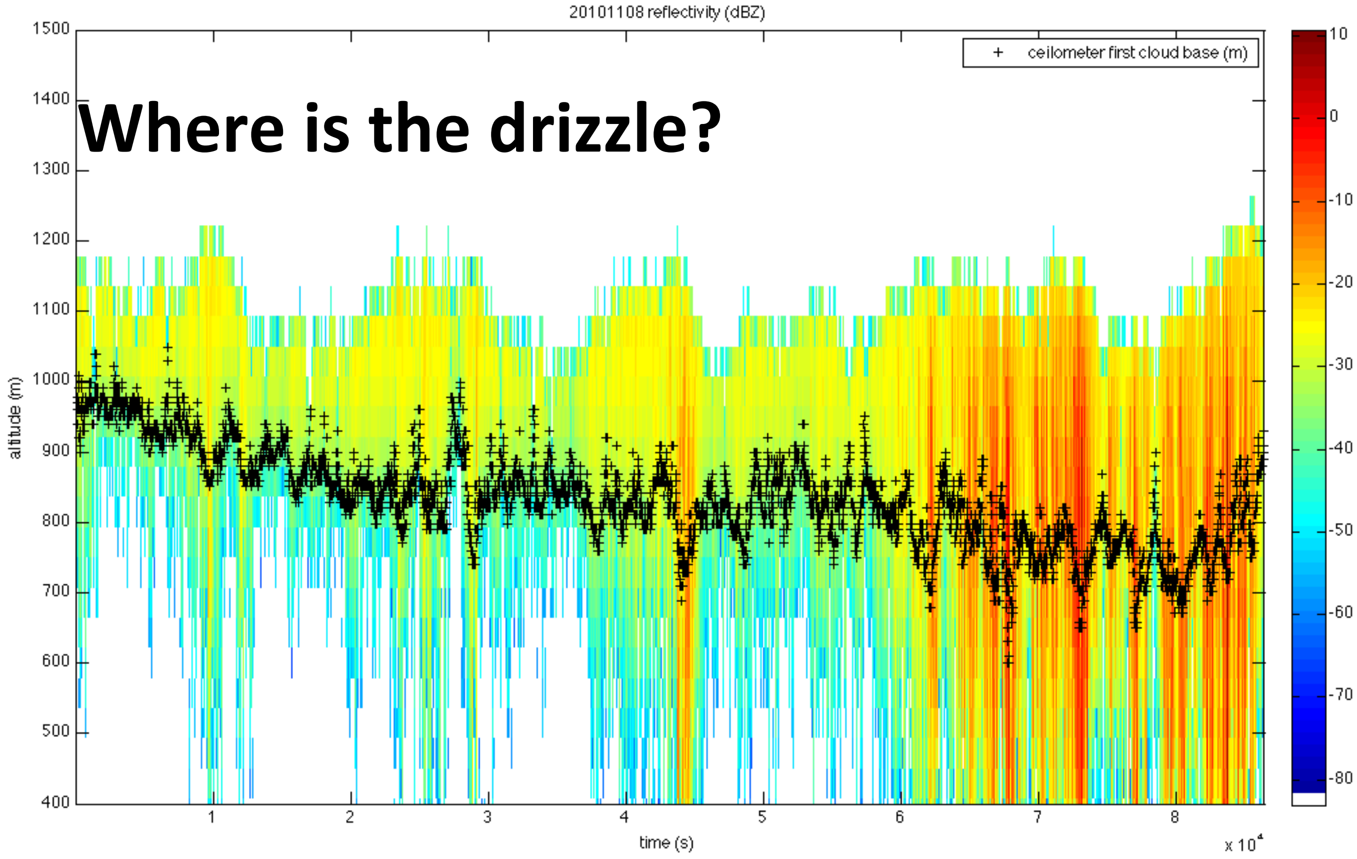
$CBHeight_{CEIL\text{-}RADAR} > 100$ m

Smoothing the Observations: November

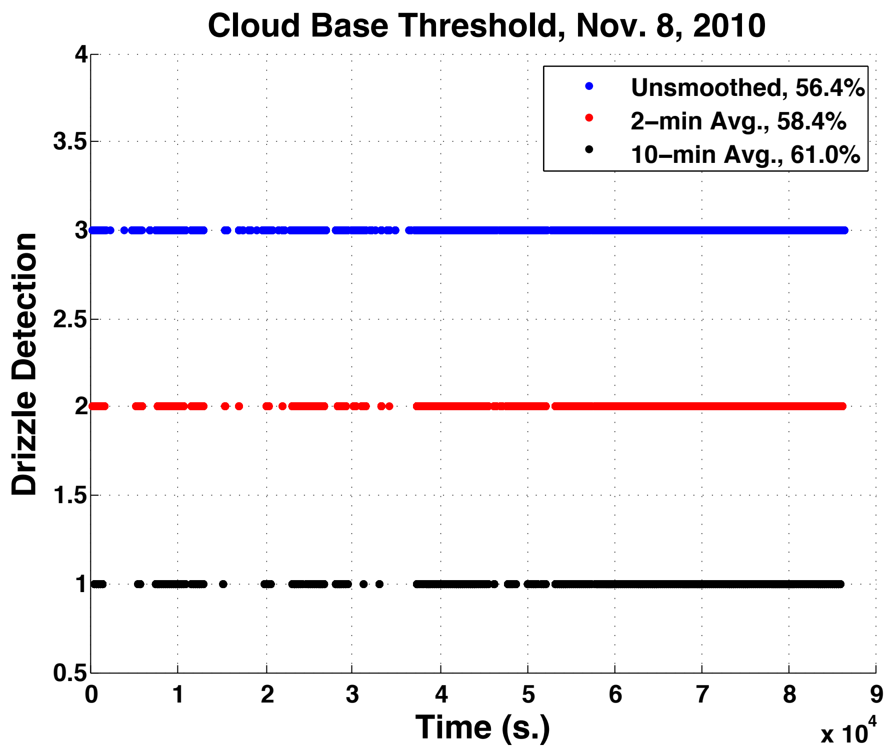


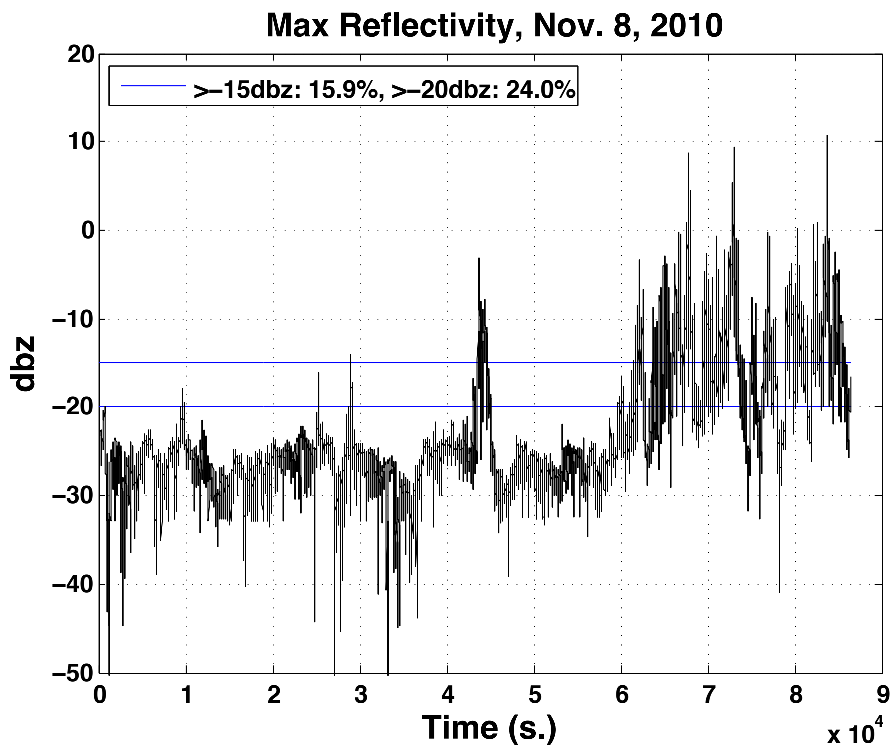
$$\textbf{CBHeight}_{\textbf{CEIL-RADAR}} > \textbf{100 m}$$

Ceilometer vs. Radar Reflectivity: Case 2

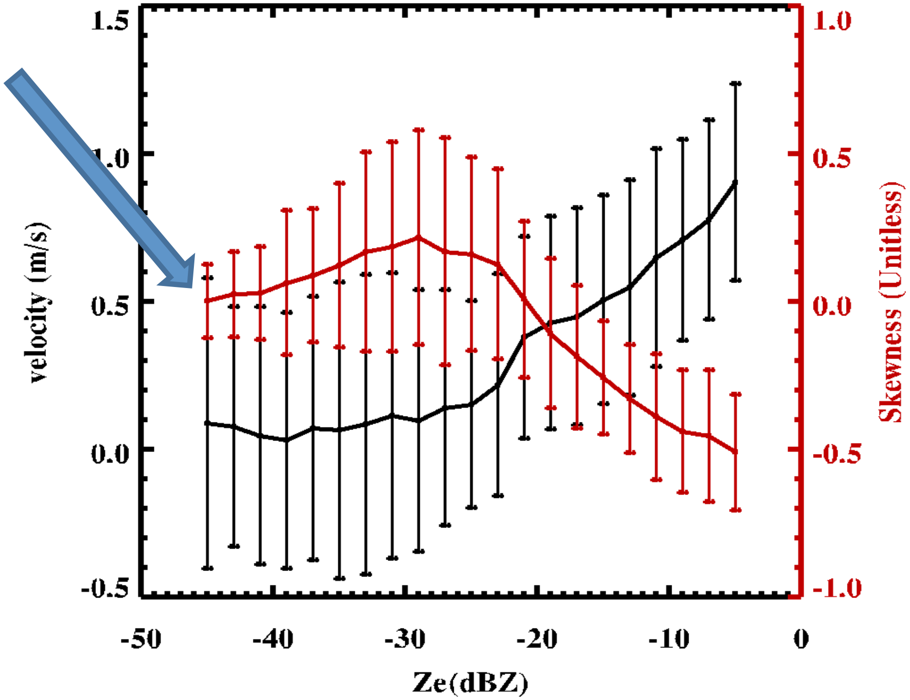


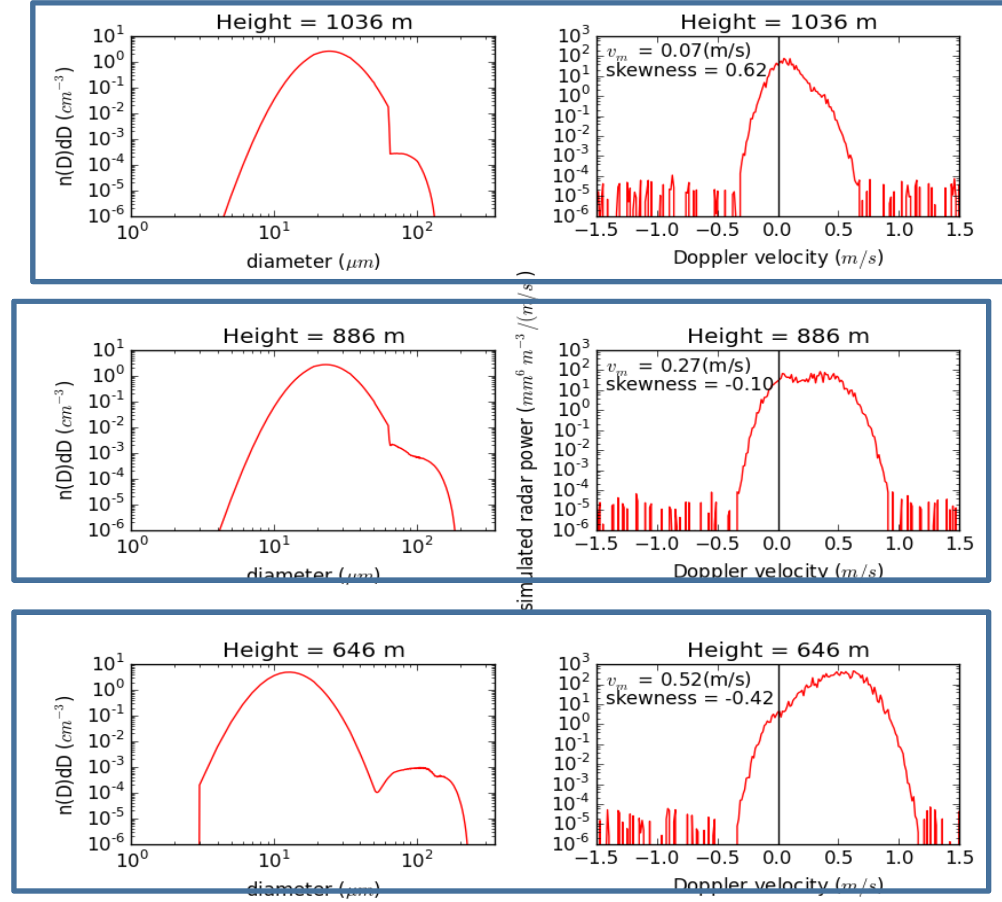
Smoothing the Observations: November





$\text{CBHeight}_{\text{CEIL-RADAR}}$ > 100 m





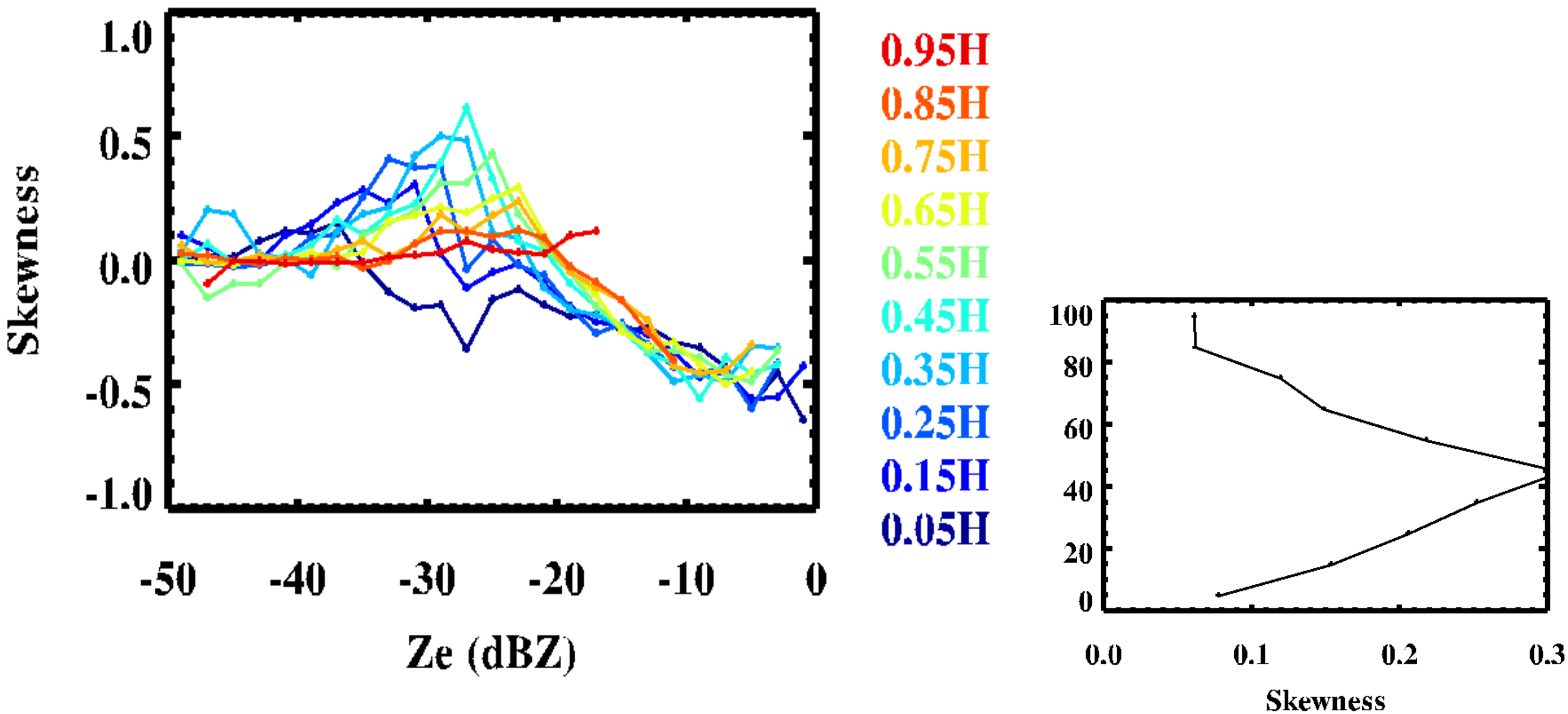
1. At very low reflectivity, the skewness is near zero.

2. increase fall velocities → a positive tail develops in the observed Doppler velocity spectra → a positive increase in the average skewness. With the increase of Ze, the skewness reaches a positive max (but cloud-size droplets still dominate)

3. Skewness starts to decrease as the drizzle spectral peaks grow relative to the cloud peak. Skewness crosses zero (Symmetric).

4. Skewness becomes negative when the drizzle peak is dominant

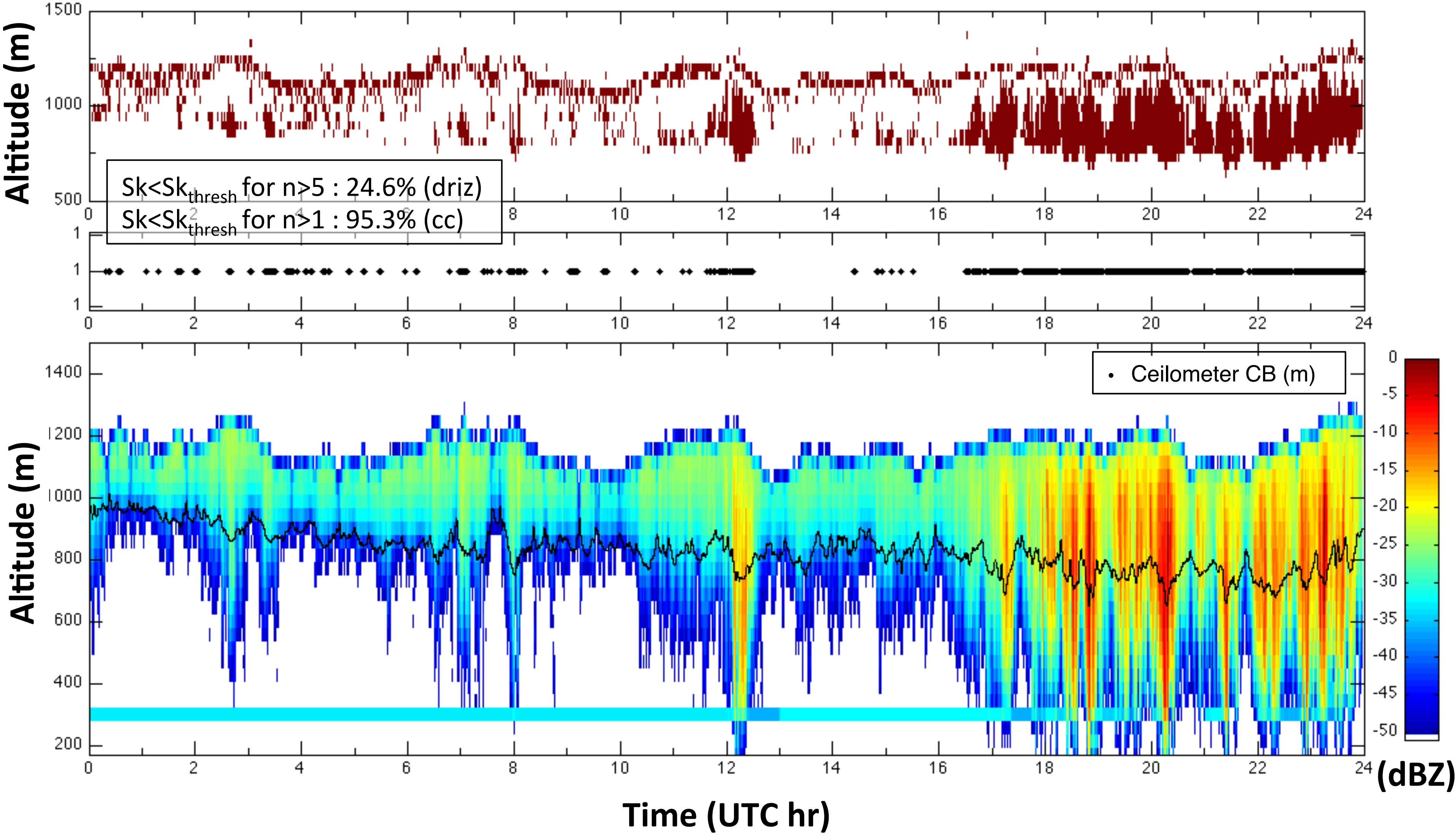
Deriving a Skewness Threshold from Observations

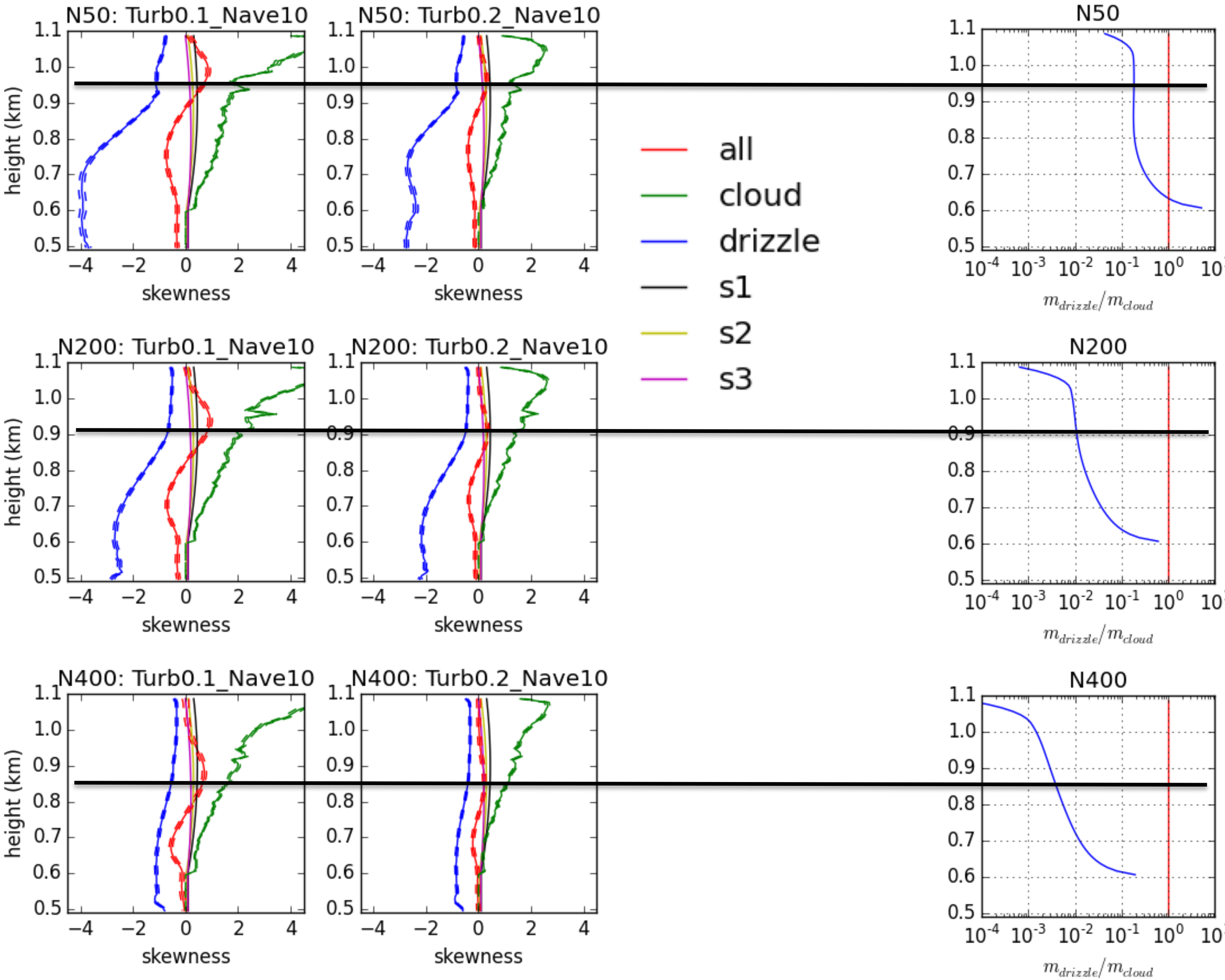


$$Sk_{thresh}(z^*) = -1\text{x}10^{-3}(z^*)^2 + 0.012(z^*) + 0.089$$

$$r^2 = 0.79$$

Skewness diagnoses both collision-coalescence and in-cloud drizzle (!!!!!)





N50: Turb0.1_Nave10
N50: Turb0.2_Nave10
N50
N200: Turb0.1_Nave10
N200: Turb0.2_Nave10
N200
N400: Turb0.1_Nave10
N400: Turb0.2_Nave10
N400
height (km)
skewness
$m_{drizzle}/m_{cloud}$
all
cloud
drizzle
s1
s2
s3

Summary

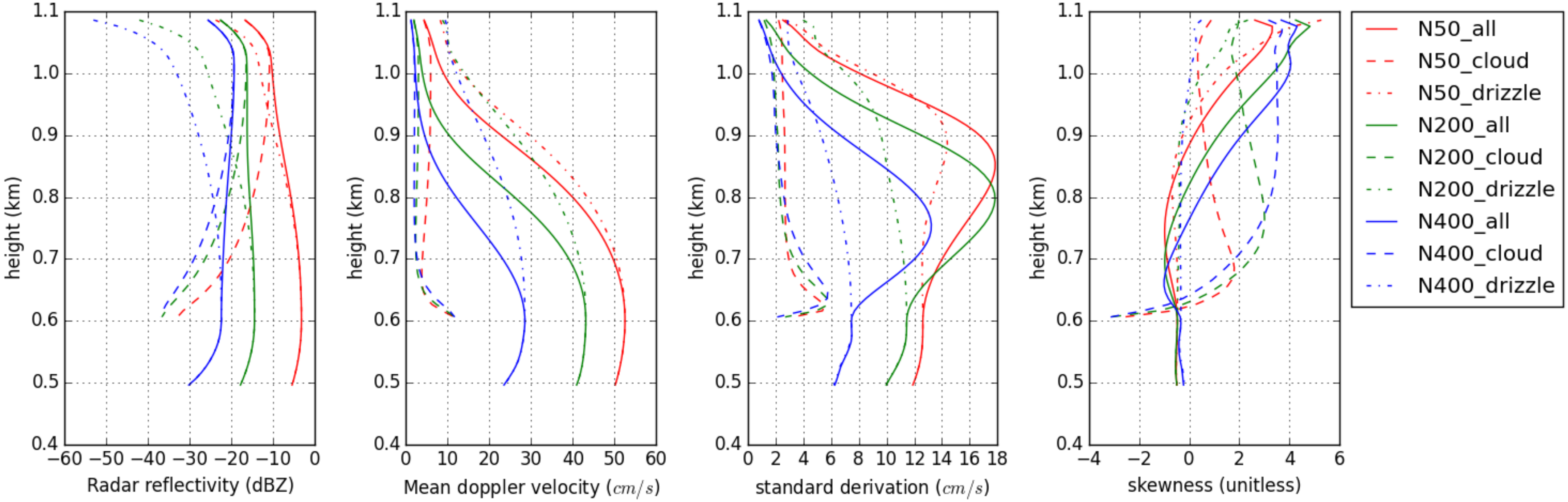
- Existing threshold techniques can identify drizzle, but miss the onset

- Doppler velocity spectrum skewness more accurately detects the onset of drizzle
  - Positive skewness can also be thought of a fingerprint of collision-coalescence

Questions?

THANKS FOR LISTENING!

Appendix



1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
height (km)
−60 −50 −40 −30 −20 −10 0
Radar reflectivity (dBZ)
0 10 20 30 40 50 60
Mean doppler velocity (cm/s)
0 2 4 6 8 10 12 14 16 18
standard derivation (cm/s)
−4 −2 0 2 4 6
skewness (unitless)
N50_all
N50_cloud
N50_drizzle
N200_all
N200_cloud
N200_drizzle
N400_all
N400_cloud
N400_drizzle

What we want to know

What we observe

Microphysics

Forward model

observation

$$n(D)$$

$$N = \int n(D)\,dD$$

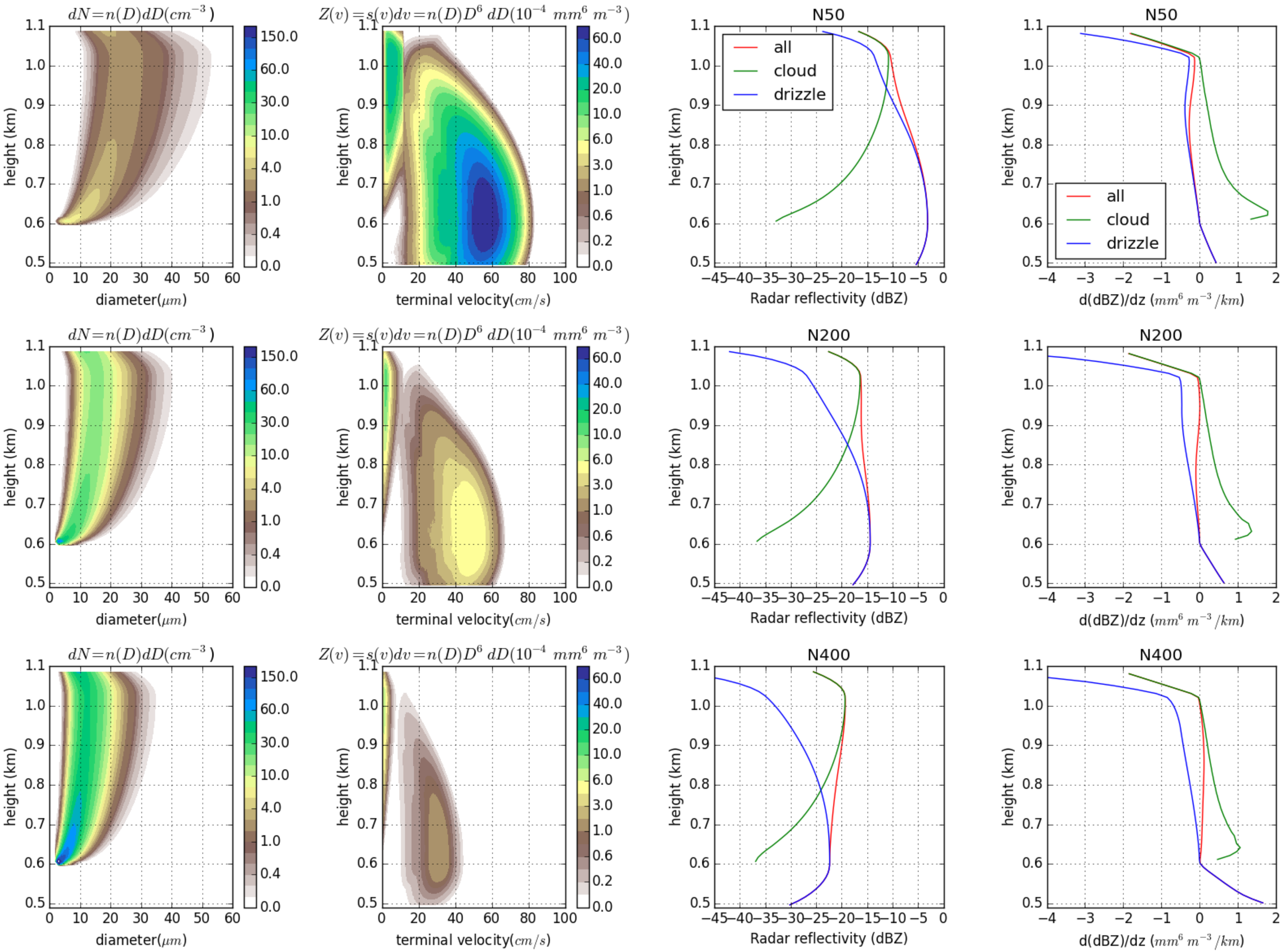
$$LWC = \rho_w \frac{\pi}{6} \int n(D) D^3\,dD$$

D ~ v

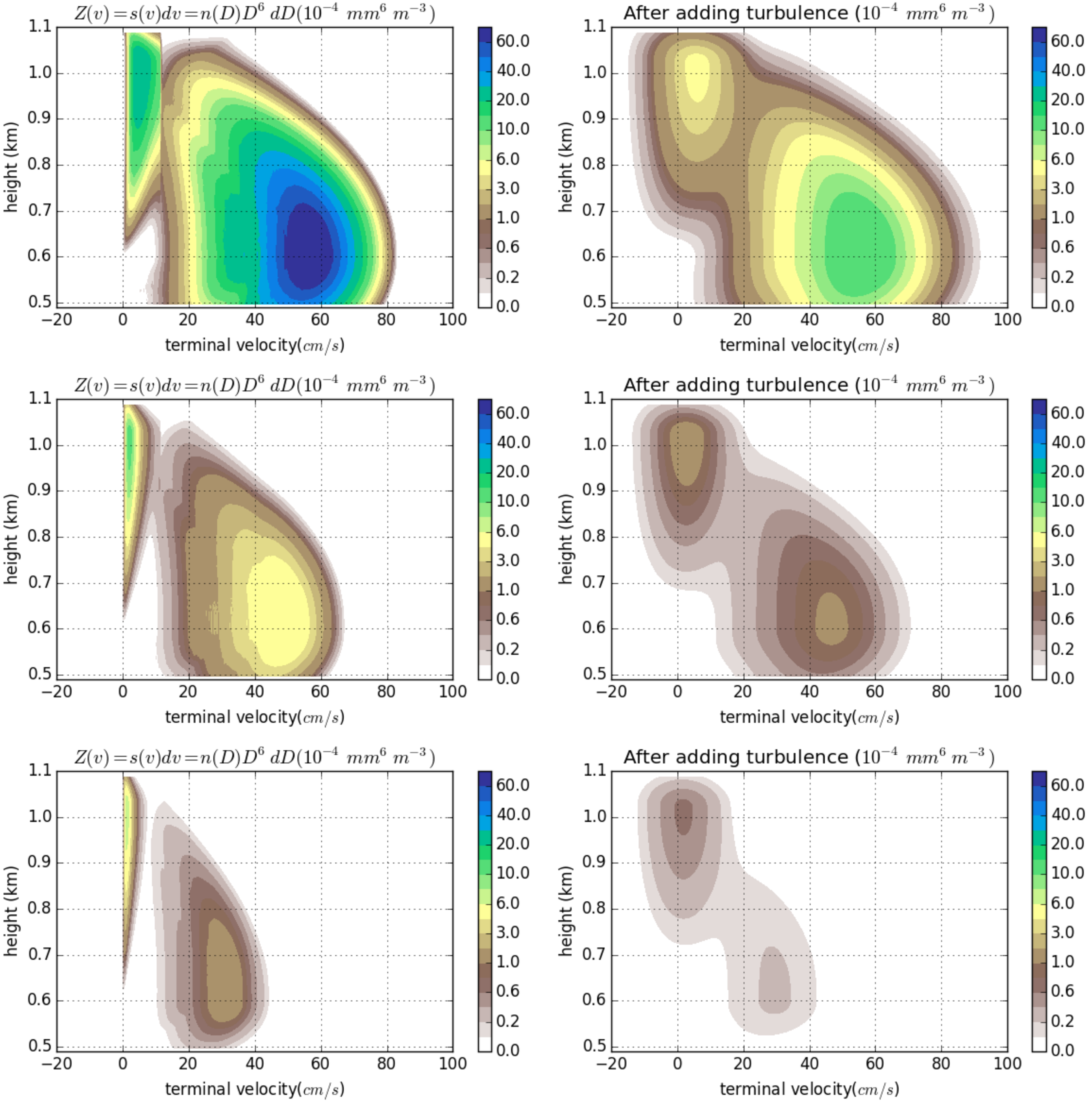
$$s(v)\,dv \sim dZ(v) = n(D) D^6\,dD$$

retrieval

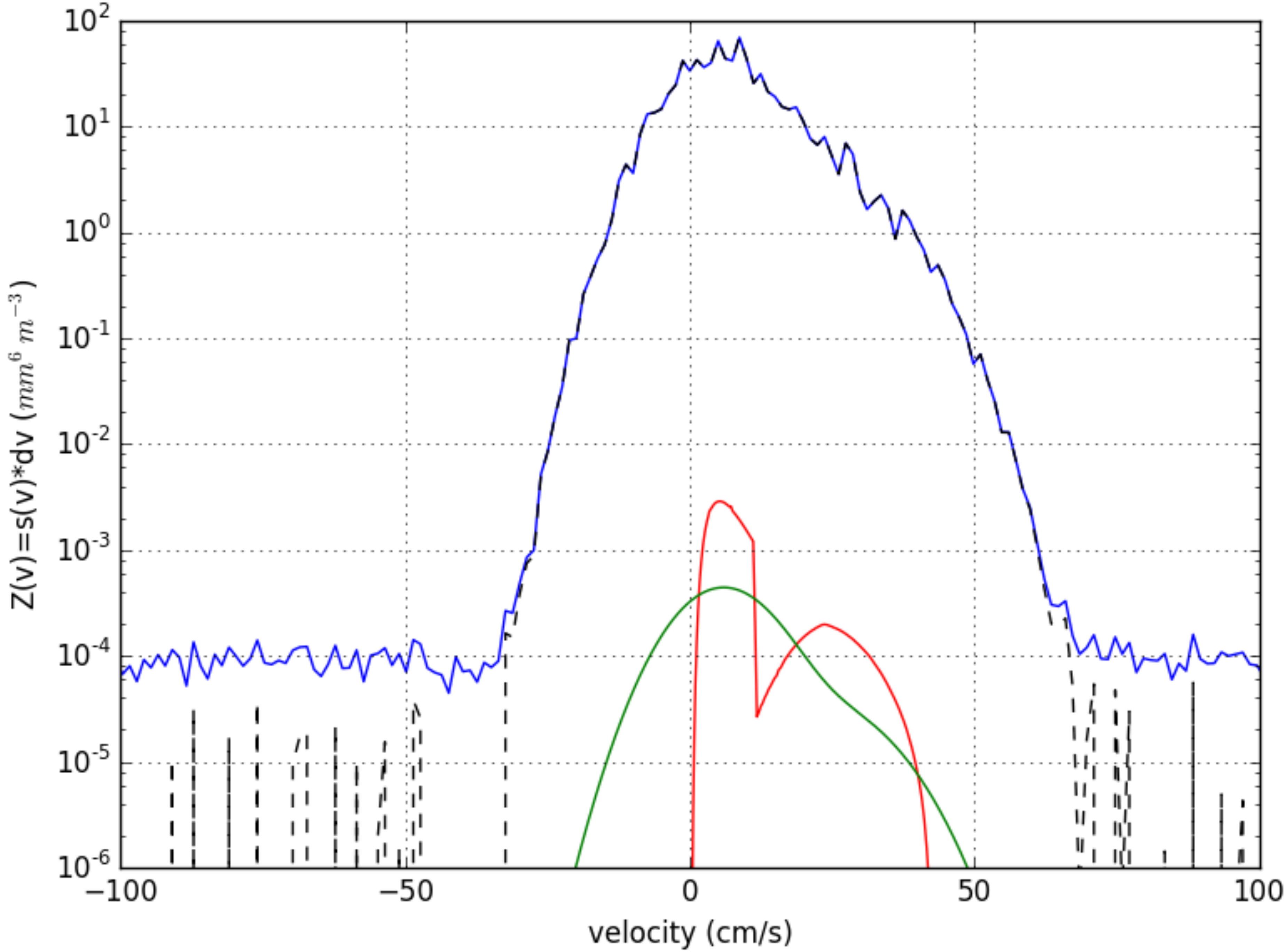
Air attenuation: reduce the signal
Turbulence: broaden the spectra width
Noise: white noise (broad spectra), sensitivity



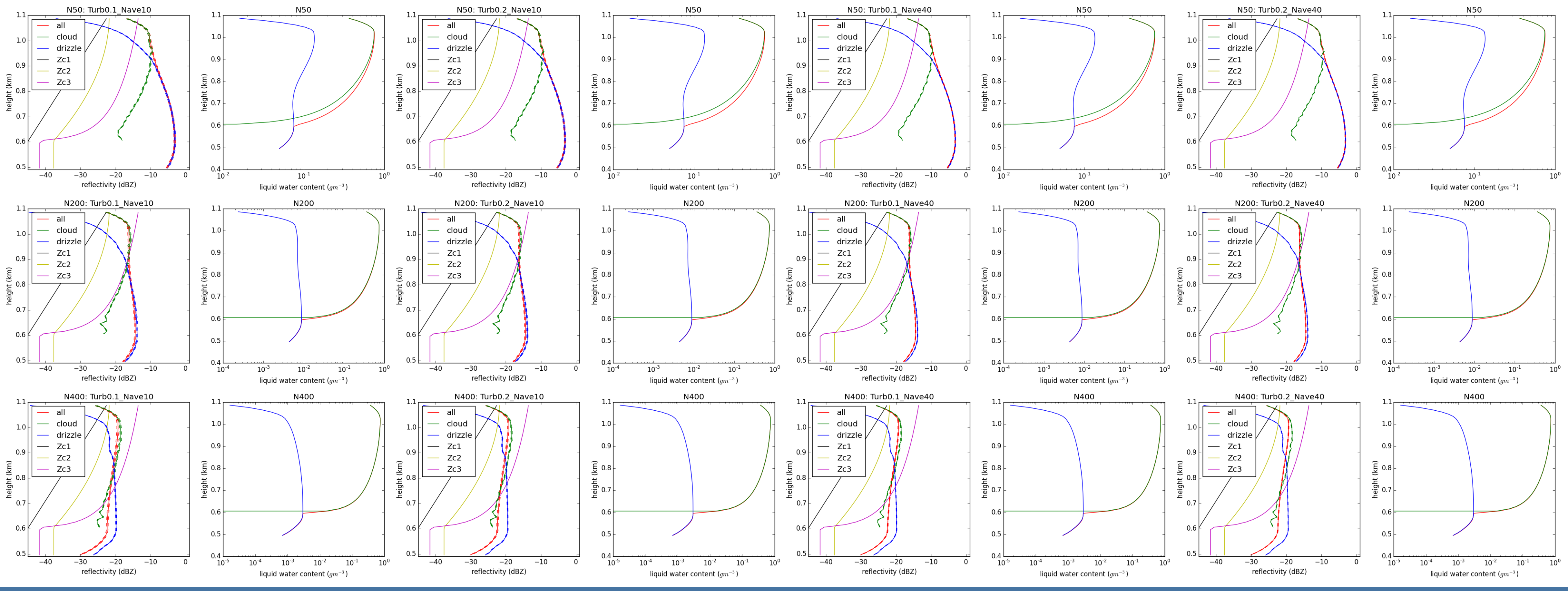
$dN=n(D)dD(cm^{-3})$
$Z(v)=s(v)dv=n(D)D^6\ dD(10^{-4}\ mm^6\ m^{-3})$
N50
N200
N400
all
cloud
drizzle
height (km)
diameter(μm)
terminal velocity(cm/s)
Radar reflectivity (dBZ)
d(dBZ)/dz ($mm^6\ m^{-3}/km$)



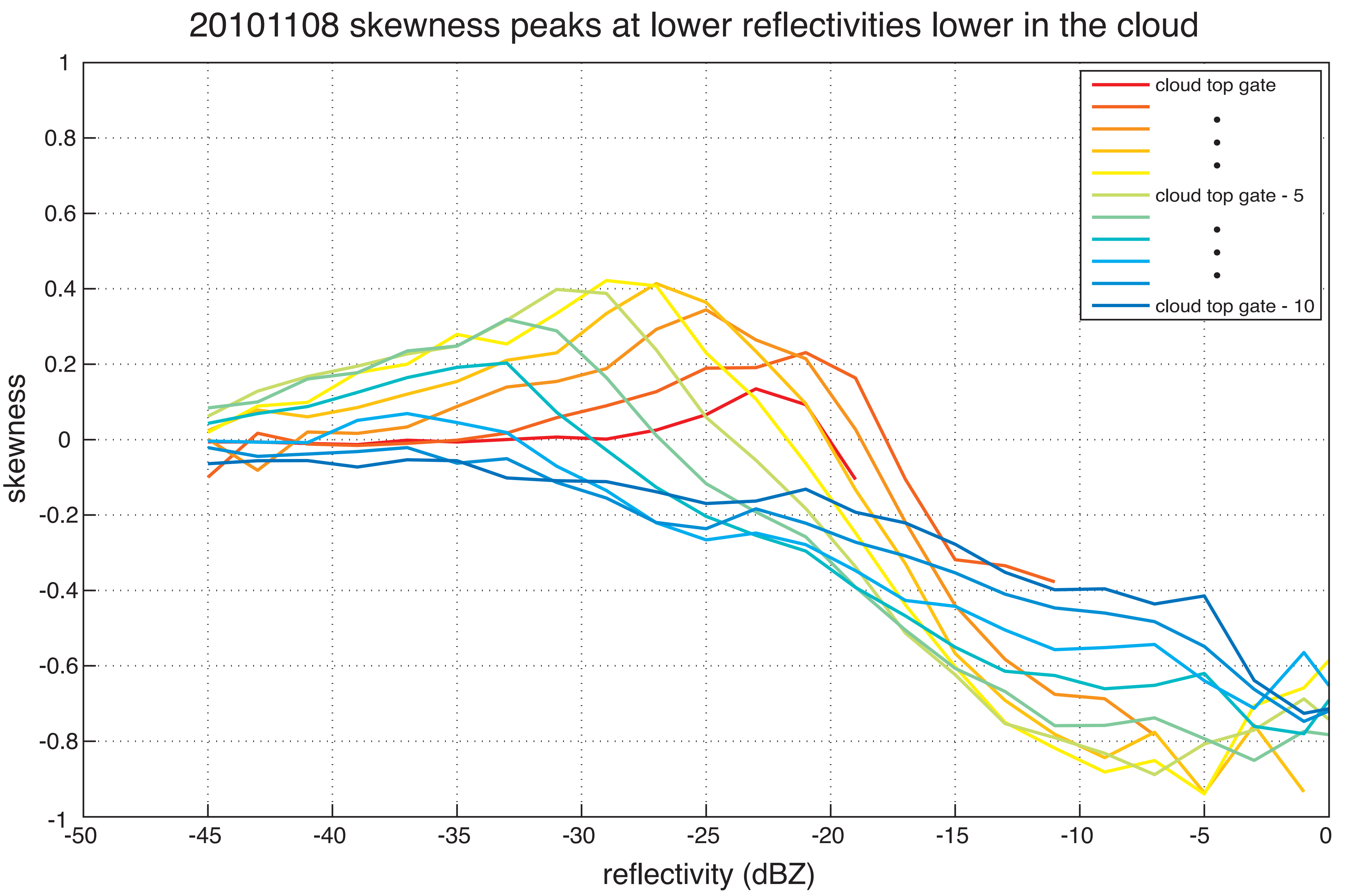
$Z(v)=s(v)dv=n(D)D^6\ dD(10^{-4}\ mm^6\ m^{-3})$
After adding turbulence $(10^{-4}\ mm^6\ m^{-3})$
height (km)
terminal velocity(cm/s)
0.0
0.2
0.6
1.0
3.0
6.0
10.0
20.0
40.0
60.0



Z(v)=s(v)*dv ($mm^6\ m^{-3}$)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
−100
−50
0
50
100
velocity (cm/s)

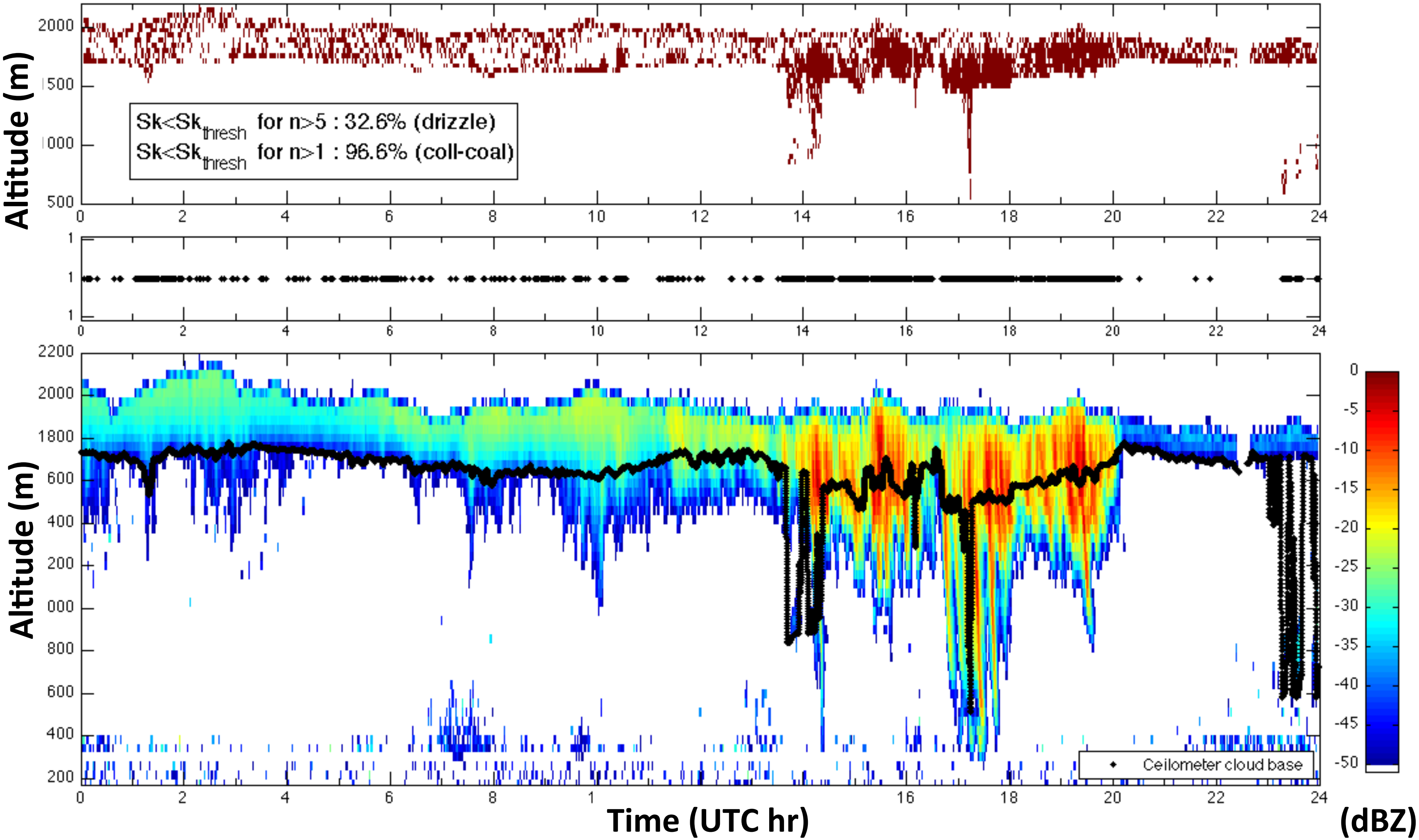


N50: Turb0.1_Nave10
N50
N50: Turb0.2_Nave10
N50
N50: Turb0.1_Nave40
N50
N50: Turb0.2_Nave40
N50
N200: Turb0.1_Nave10
N200
N200: Turb0.2_Nave10
N200
N200: Turb0.1_Nave40
N200
N200: Turb0.2_Nave40
N200
N400: Turb0.1_Nave10
N400
N400: Turb0.2_Nave10
N400
N400: Turb0.1_Nave40
N400
N400: Turb0.2_Nave40
N400
all
cloud
drizzle
Zc1
Zc2
Zc3
height (km)
reflectivity (dBZ)
liquid water content (gm^{-3})



20101108 skewness peaks at lower reflectivities lower in the cloud
cloud top gate
cloud top gate - 5
cloud top gate - 10
skewness
reflectivity (dBZ)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
0

Skewness diagnoses both collision-coalescence and in-cloud drizzle (!!!!!)



Several studies have proposed a threshold in radar reflectivity as the basis of discrimination between nonprecipitating and precipitating clouds.

- -15 dBZ (Chin et al.,[2000])
- -20 dBZ (Kato et al. [2001])
- -17 dBZ (Kogan et al. [2005])

- The threshold reflectivity for drizzle is dependent on height.

The threshold profile is

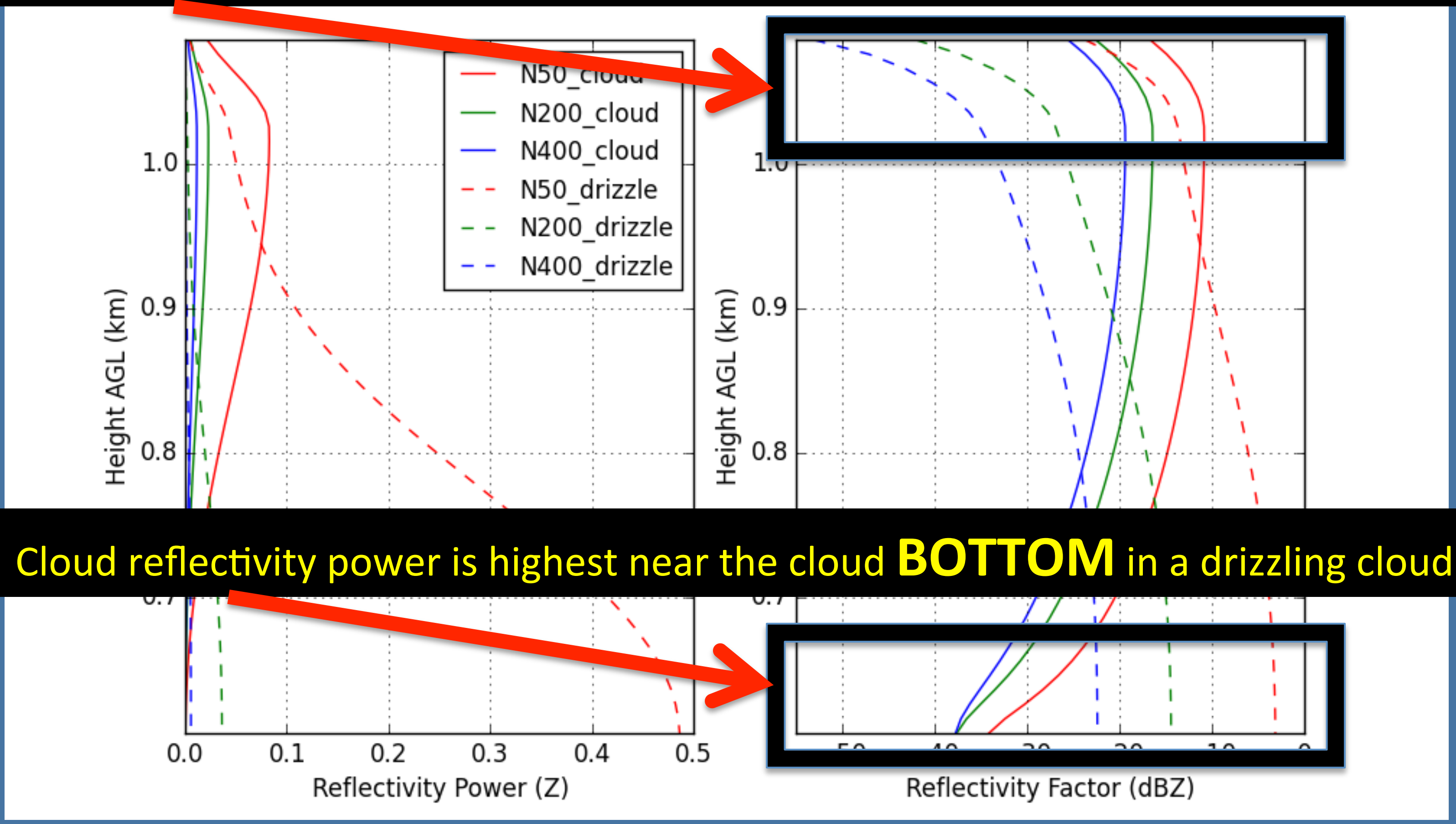
$$Z_{e\ (thres)}(mm^6/m^3)=0.046(X)^{1.413}$$

where X is the normalized cloud height.

(Wang 2002 Master thesis: Identifying drizzle within marine stratus with W-band radar reflectivity profiles)

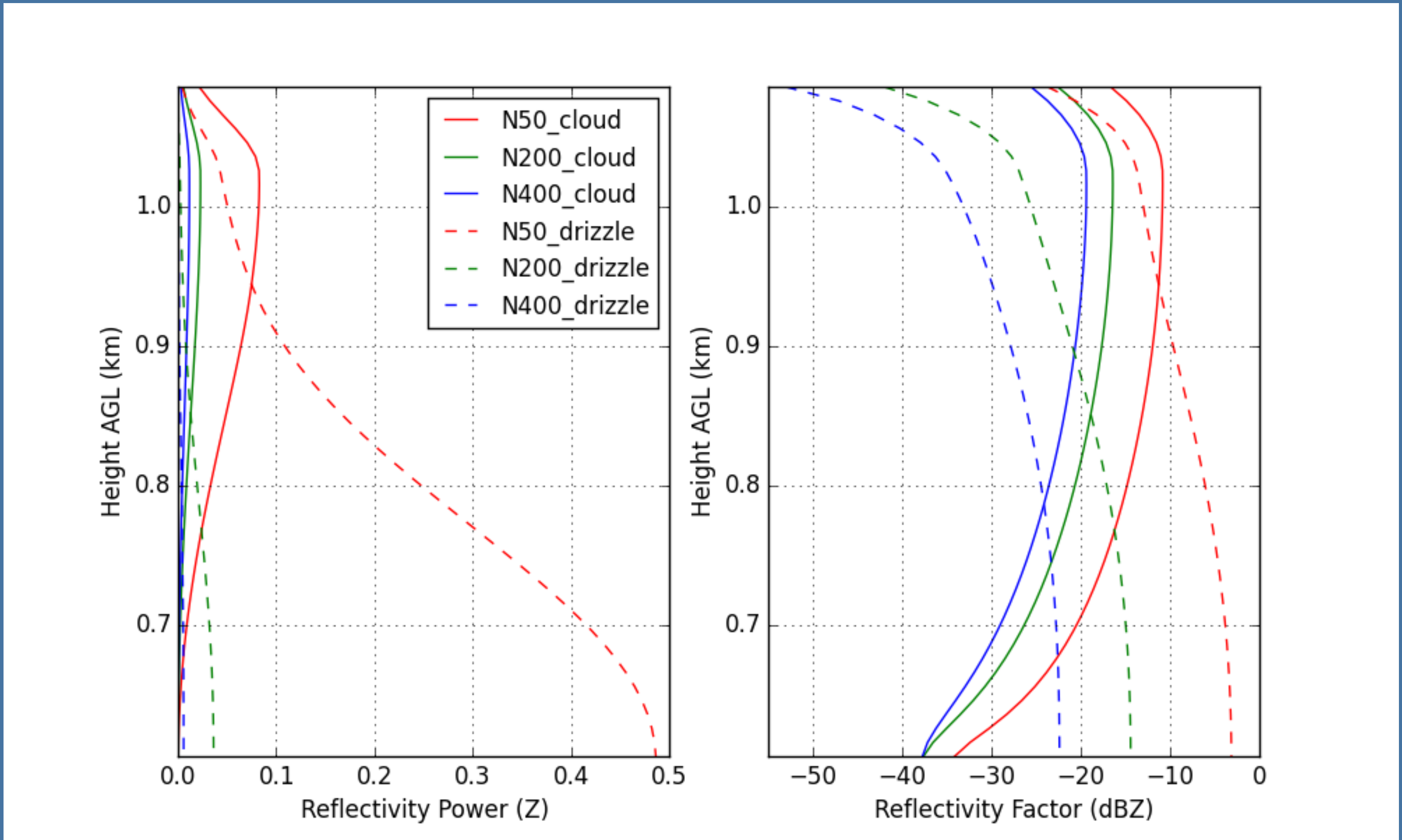
Reflectivity: Cloud Only vs. Drizzle Only

Cloud reflectivity power is highest near the cloud **TOP** in non-precipitating cloud



Cloud reflectivity power is highest near the cloud **BOTTOM** in a drizzling cloud

Reflectivity: Cloud Only vs. Drizzle Only



Skewness as a Prognostic Variable

- Reflectivity alone is not enough...
- "Skewness is a parameter very sensitive to early drizzle generation" – Kollias et al. (2011)

$$s_{PSD} = \frac{\langle V^3 \rangle_D - 3\langle V \rangle_D \langle V^2 \rangle_D + 2\langle V \rangle_D^3}{\sigma_{PSD}^3}$$