Toward Improving Ice Water Content and Snow Rate Retrievals from Spaceborne Radars

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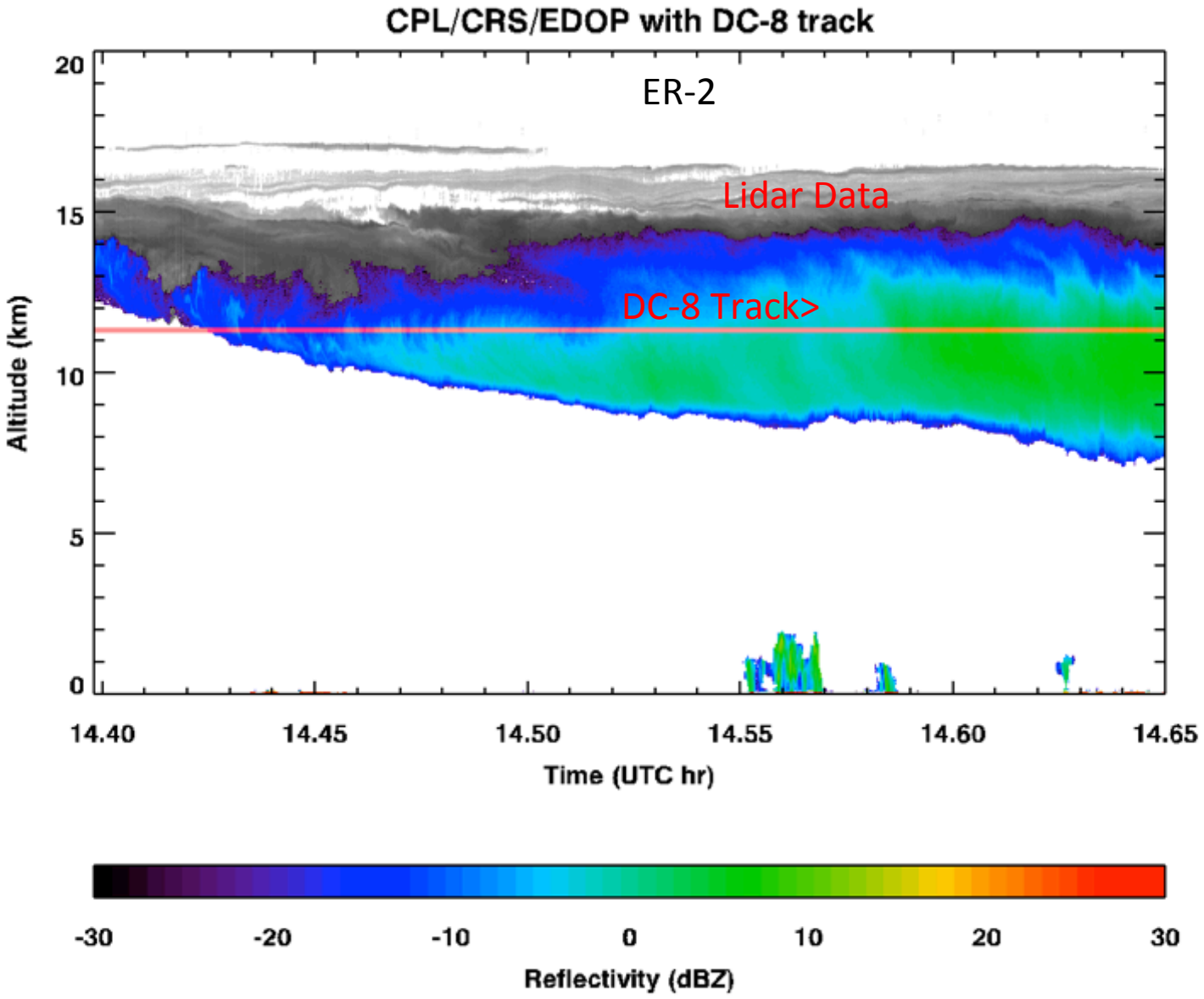
Approach

- Initially, we use NASA TC4 (Costa Rica, 2007) in-situ ice cloud observations and collocated ER-2 X and W-band radar measurements to develop Z_e-IWC and Z_e-S relationships for X and W-bands
- We plan on conducting a follow-on study to develop these relationships for Ku and Ka-band radars

Why did we choose the TC4 field program data set for our Initial Study?

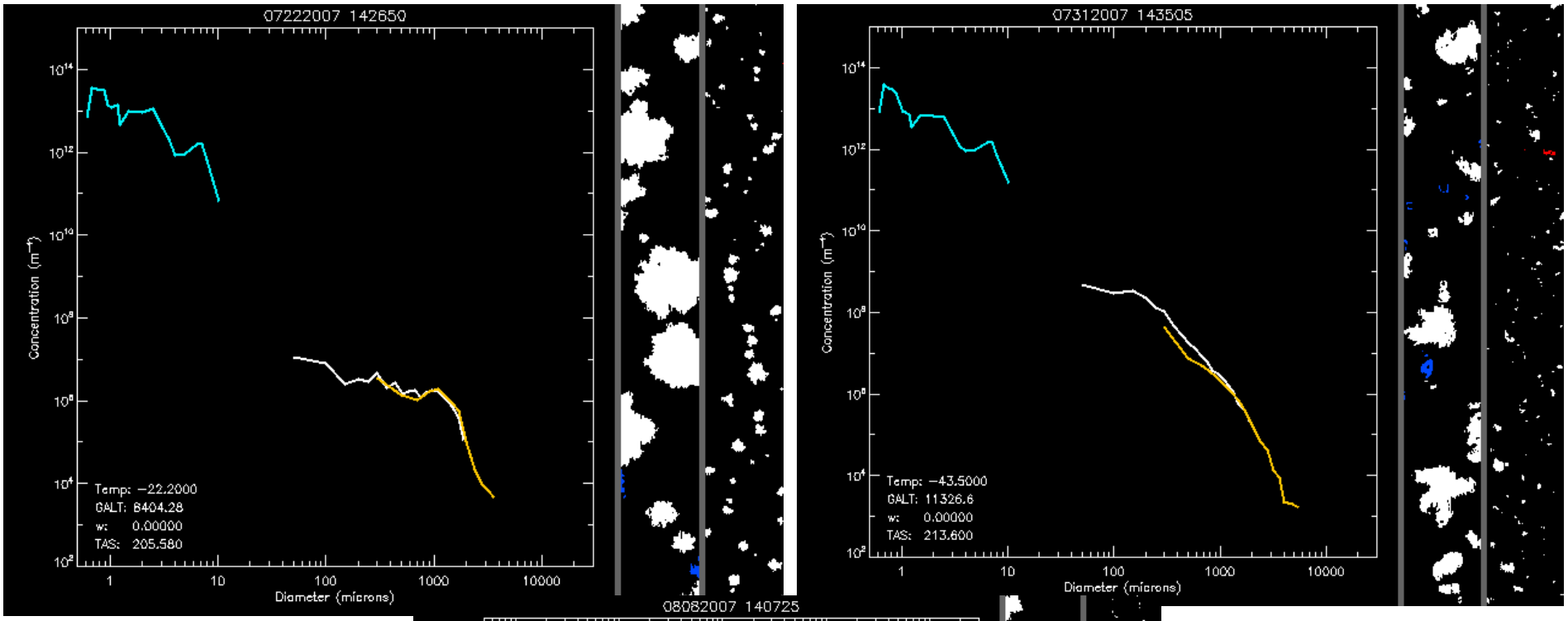
- More than 10,000 1-sec colocations of ER2 X and W-band radars with DC-8 in-situ observations on three days
  - (defined as within +/- 3 km horizontally and +/- 10 minutes)
- Size distributions and particle shapes/particle cross-sectional areas measured from 100 microns to >1 cm
- Direct**, reliable** measurements of the **ice water content**
- The direct ice water content measurements allows us to reliably derive/ test different mass dimensional relationships
- Using the particle size distributions and backscatter cross-sections developed from two backscatter models that employ the ice particle masses from the above, we can evaluate the ability to forward-model the radar reflectivity for two radar wavelengths
- We can derive reliable snowfall rates from the PSDs, masses, areas
- From direct measurements, derive(1) measured Ze-IWC relationships, quasi-directly (2) Ze-S, for two radar wavelengths



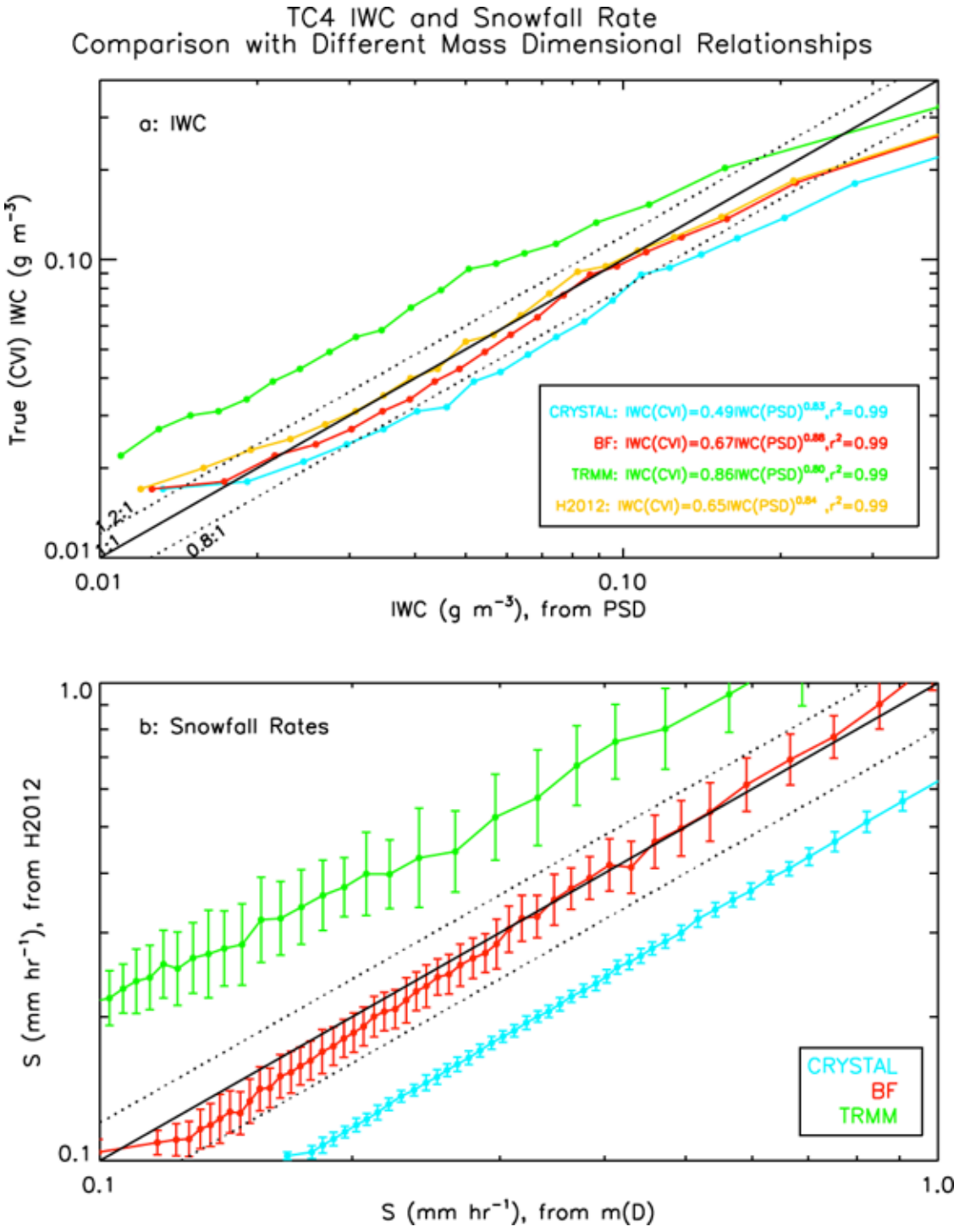
TC4

(Costa Rica)

Example of DC-8/ER-2 Colocation 31 July 2007



Evaluations are conducted for
22 July
31 July
8 August

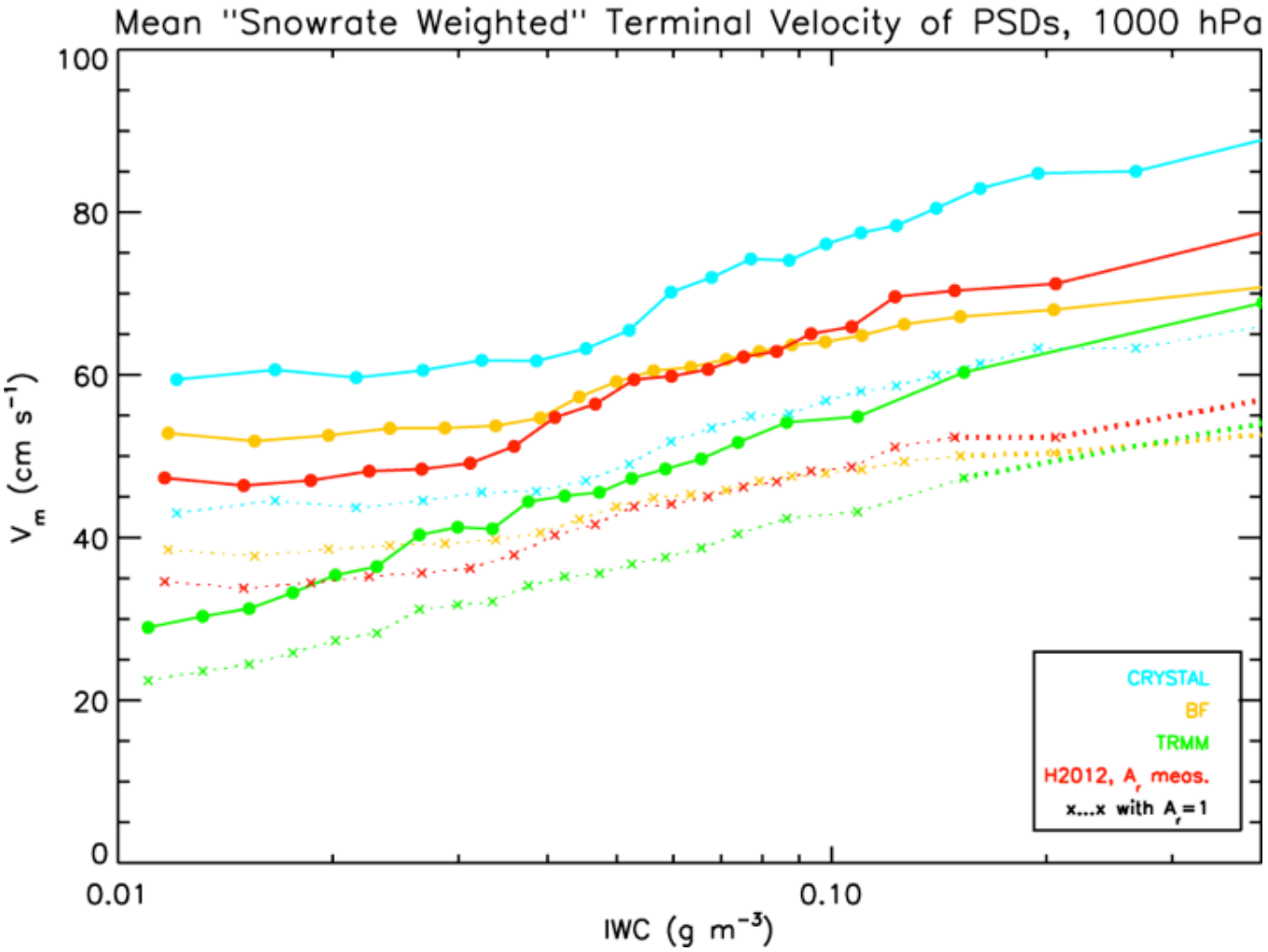


Compare measured and calculated IWCs from PSDs using the following 4 different m(D) relationships

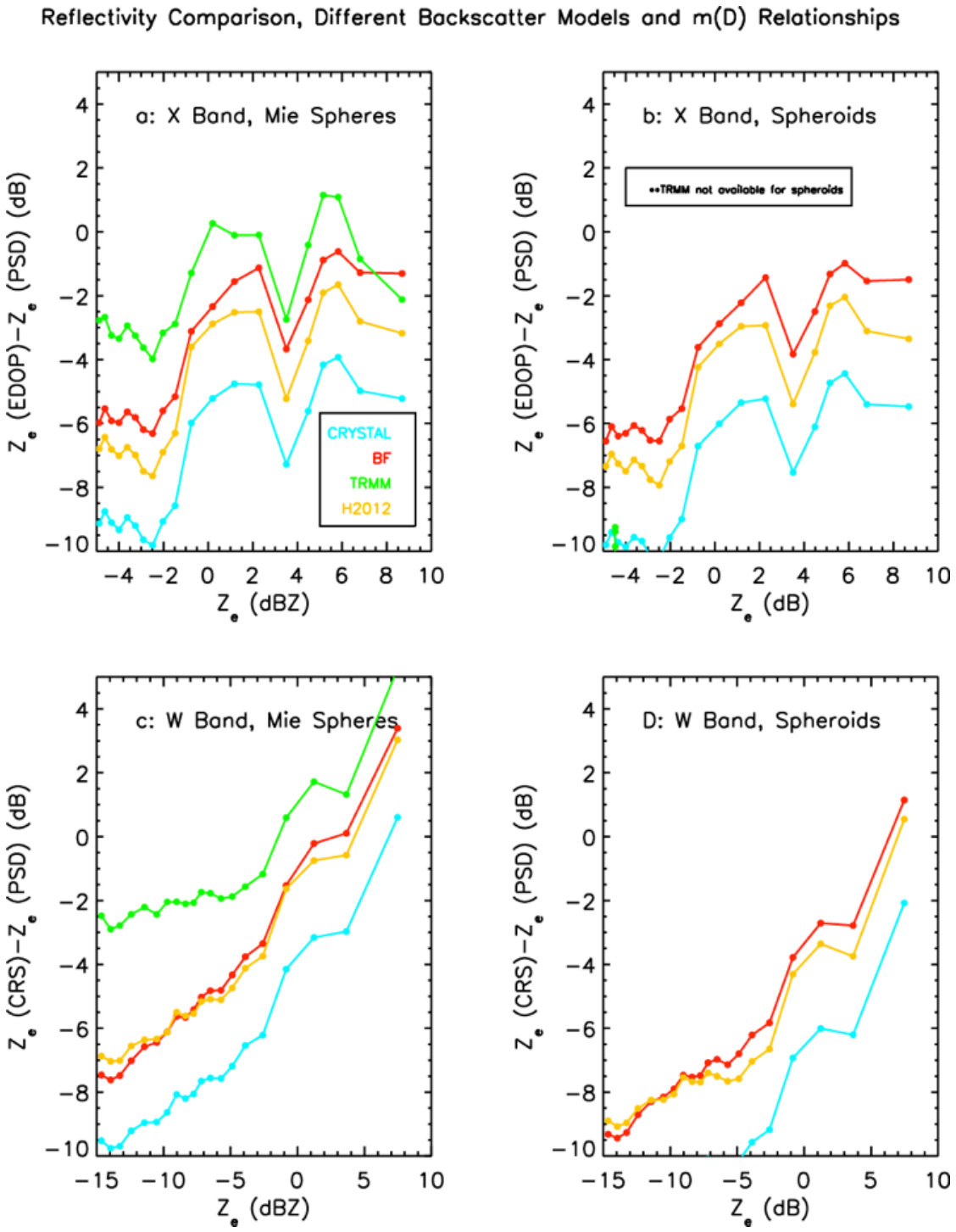
Heymsfield et al. (2012, H2012)
Brown and Francis (1994, BF)
CRYSTAL-FACE (CF), direct msts
KWAJEX (TRMM), fit w/radar data

Snowfall rates are derived using particle masses and calculated terminal velocities that re a function of the particle area ratio

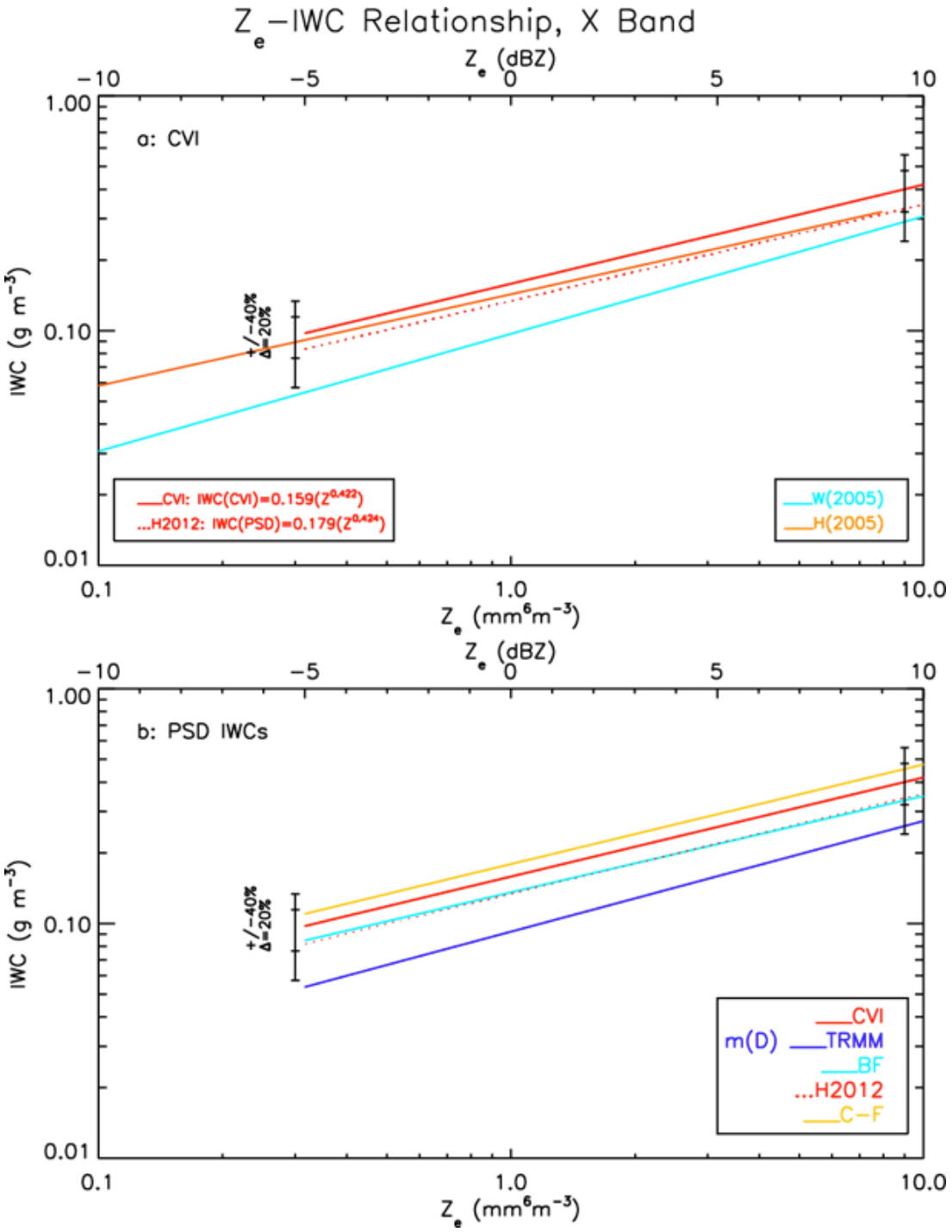
How does the particle mass affect the terminal velocity and thus snowfall rate?



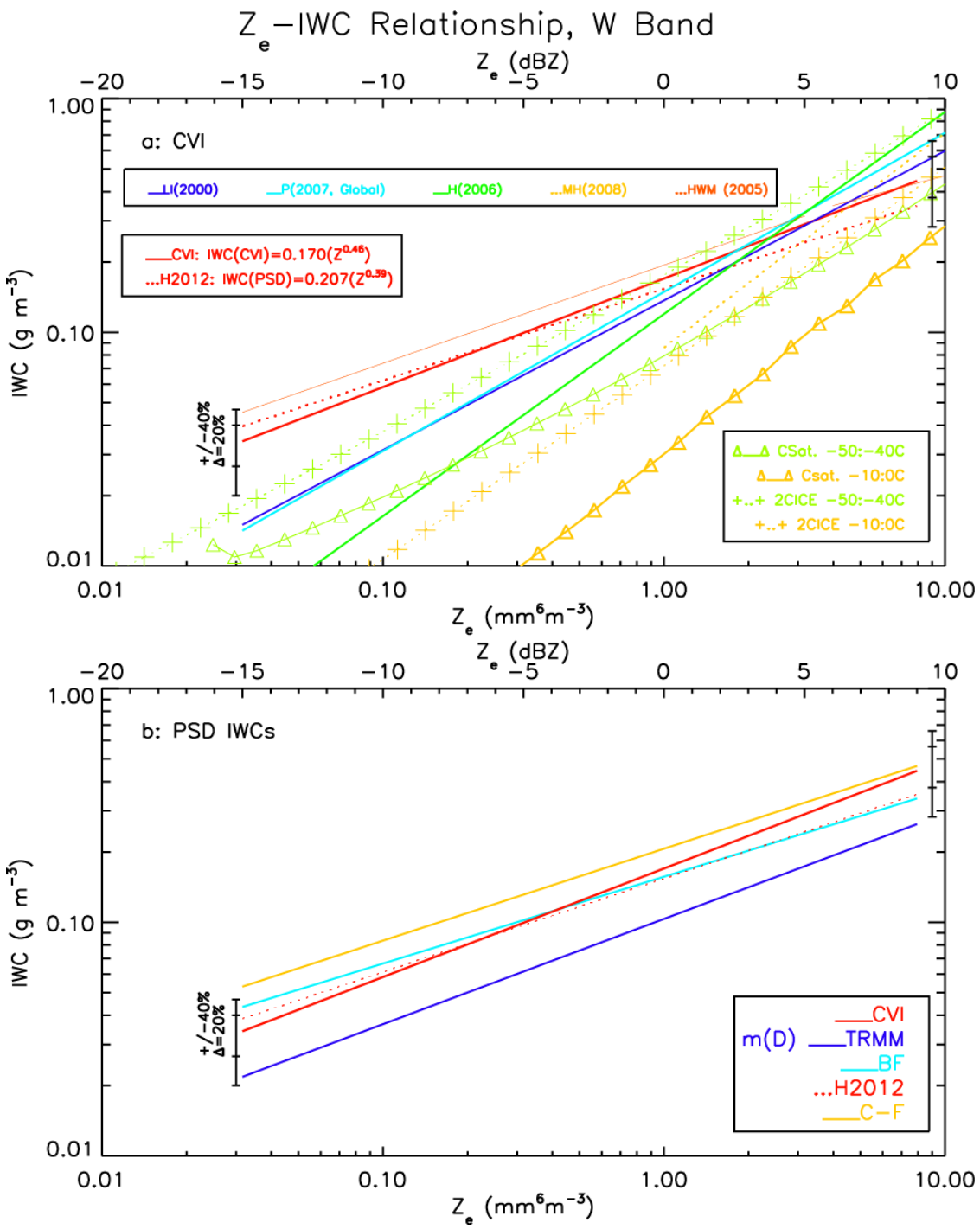
V_m=S/IWC*0.036

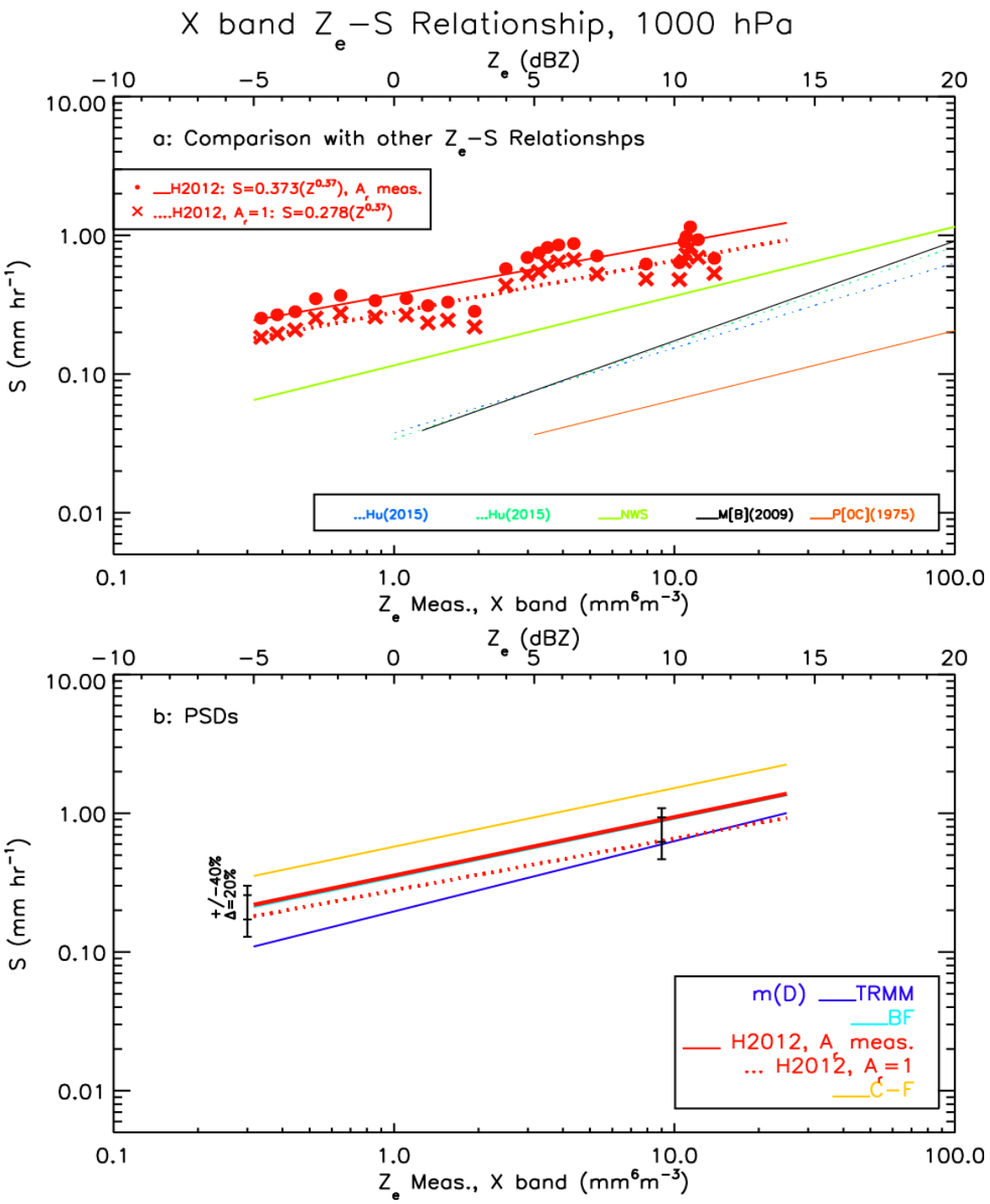


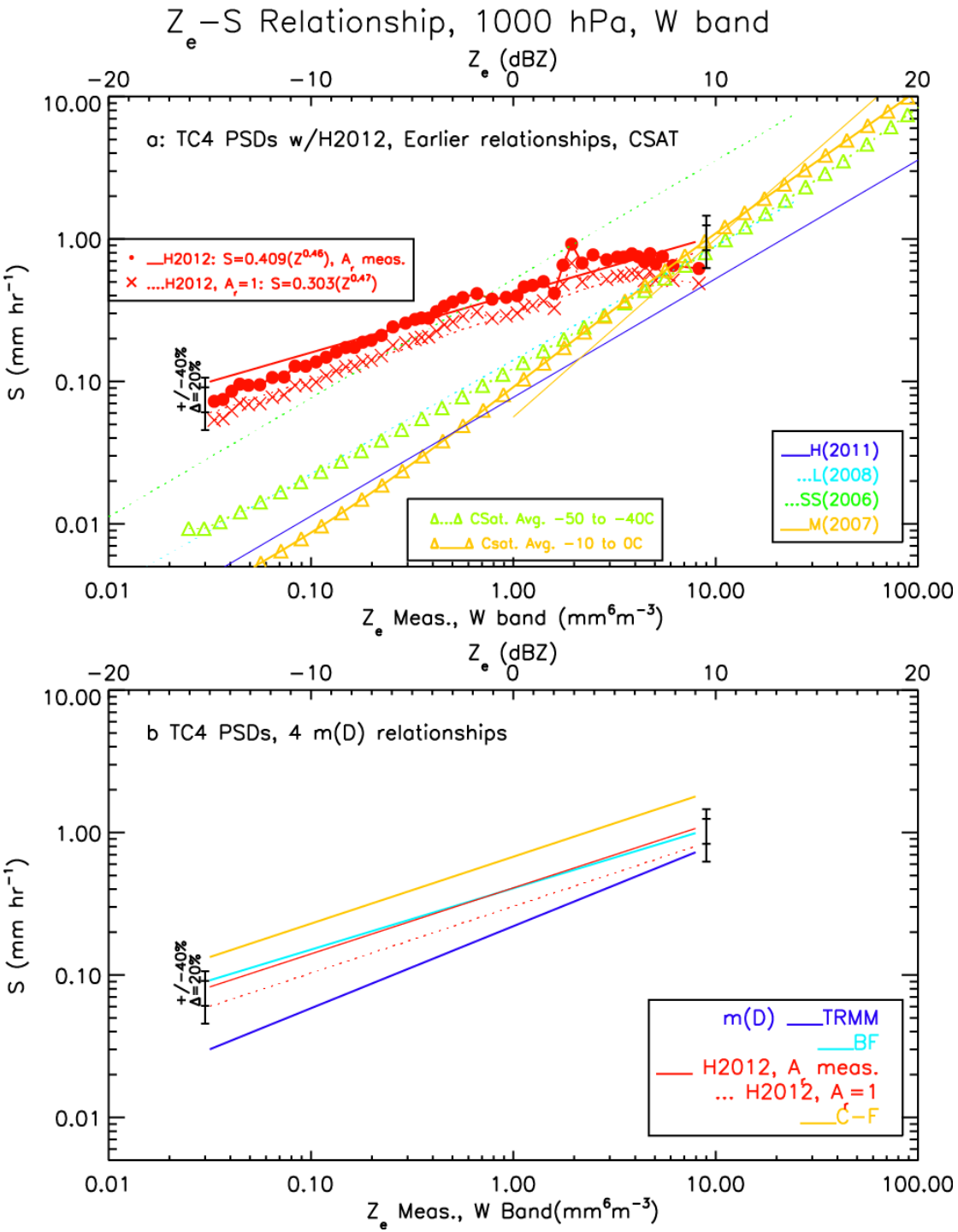
These results argue for an approach that develops Ze-IWC and Ze-S relationships directly or quasi-directly



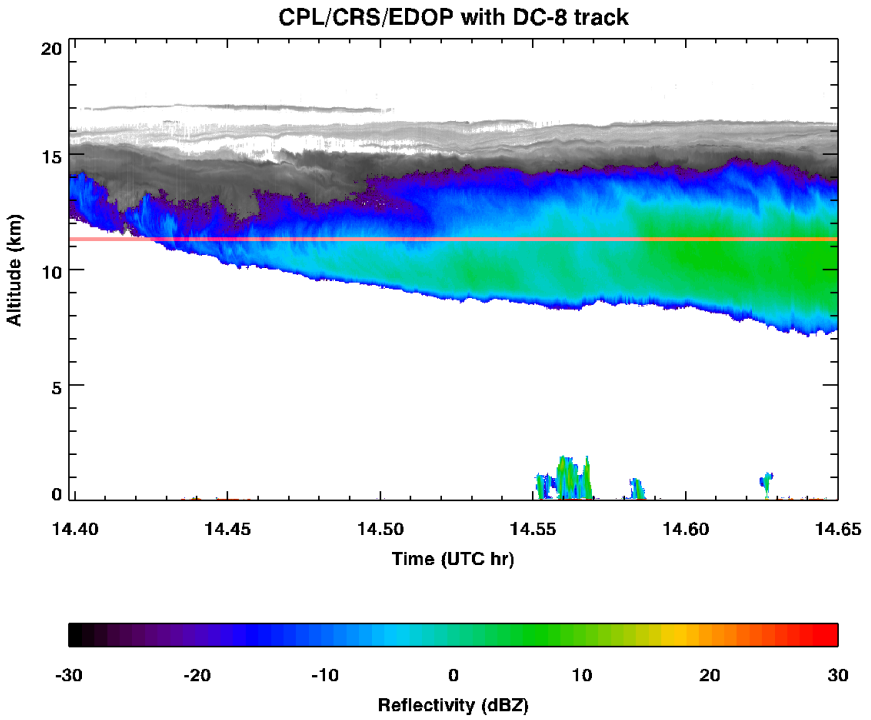
W: Wang (2005)
H: Heymsfield (2005, CF) quasi-direct
(too much mass in the larger sizes?)

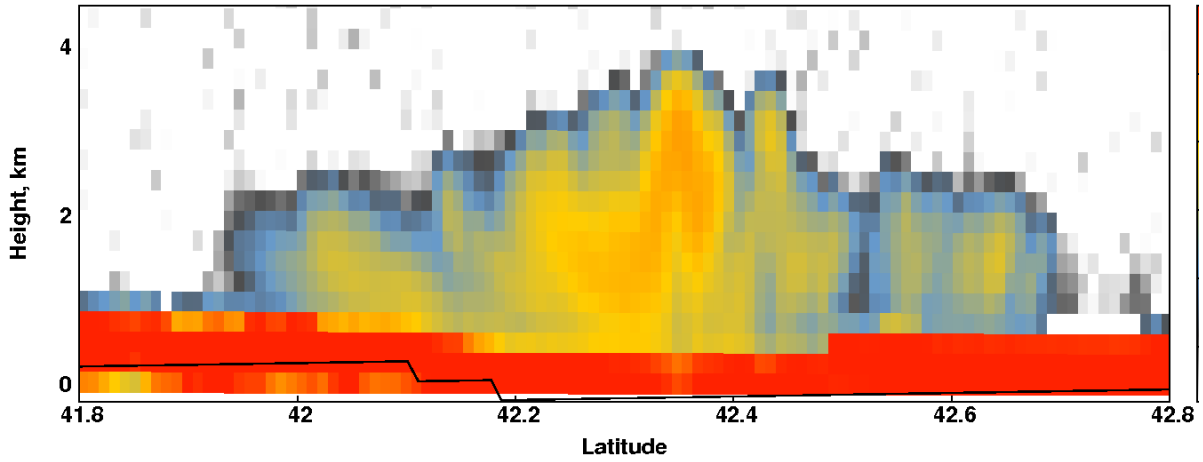

Z_e – IWC Relationship, W Band
Z_e (dBZ)
−20
−15
−10
−5
0
5
10
1.00
0.10
0.01
IWC (g m^-3)
a: CVI
LI(2000)
P(2007, Global)
H(2006)
MH(2008)
HWM (2005)
CVI: IWC(CVI)=0.170(Z^0.46)
H2012: IWC(PSD)=0.207(Z^0.39)
+/−40%
Δ=20%
ΔΔ CSat. −50:−40C
ΔΔ Csat. −10:0C
+..+ 2CICE −50:−40C
+..+ 2CICE −10:0C
0.01
0.10
1.00
10.00
Z_e (mm^6m^-3)
b: PSD IWCs
m(D)
CVI
TRMM
BF
H2012
C−F


X band Z_e–S Relationship, 1000 hPa
Z_e (dBZ)
−10
−5
0
5
10
15
20
10.00
1.00
0.10
0.01
S (mm hr^{-1})
a: Comparison with other Z_e–S Relationshps
H2012: S=0.373(Z$^{0.37}$), A_r meas.
....H2012, A_r=1: S=0.278(Z$^{0.37}$)
...Hu(2015)
...Hu(2015)
NWS
M[B](2009)
P[0C](1975)
0.1
1.0
10.0
100.0
Z_e Meas., X band (mm^{6}m^{-3})
b: PSDs
+/−40%
Δ=20%
m(D)
TRMM
BF
H2012, A_r meas.
H2012, A_r=1
C−F


Z_e −S Relationship, 1000 hPa, W band
Z_e (dBZ)
−20
−10
0
10
20
a: TC4 PSDs w/H2012, Earlier relationships, CSAT
H2012: S=0.409(Z^0.46), A_r meas.
H2012, A_r=1: S=0.303(Z^0.47)
+/−40%
Δ=20%
H(2011)
L(2008)
SS(2006)
M(2007)
ΔCSat. Avg. −50 to −40C
ΔCsat. Avg. −10 to 0C
S (mm hr^−1)
10.00
1.00
0.10
0.01
0.01
0.10
1.00
10.00
100.00
Z_e Meas., W band (mm^6m^−3)
b TC4 PSDs, 4 m(D) relationships
m(D) TRMM
BF
H2012, A_r meas.
H2012, A_r=1
C−F
Z_e Meas., W Band(mm^6m^−3)

1) the TC4 observations were taken within stratiform/anvil cloud formed by tropical convection and the anvils themselves were not producing precipitation in the general sense of snow or rain reaching the surface, although larger snow particles were being created.
2) the existing CloudSat snowfall retrievals have primarily focused on systems producing precipitation at the surface such as the one in the lower figure (it's from the major Buffalo, NY snowstorm in 2014).
3) the CloudSat 2C-SNOW-PROFILE retrieval product does extend its estimates for snowfall aloft, but at this point only for systems which are producing snowfall at the surface.





Summary

- The goal of this study was to test the ability to forward-model particle size distributions to yield IWC and S as a function of radar reflectivity at X and W-bands, where the particle mass could be derived accurately using direct measurements of the IWC and particle size distributions/shapes, and the reflectivity at these wavelengths were measured directly with collocated remote sensing and in-situ observations.
- The specific goal was not to develop Z_e-IWC and Z_e-S relationships at X and W-bands that are universally applicable to clouds and precipitation remote sensing from satellite-borne radars.
- A limitation is that the range of reflectivities was only in the range of about -15 (-5) and 10 dB, and temperatures from about -15 to -50C.

Specific Findings

- Even with knowledge of the particle mass, forward-modeled reflectivities, using Mie-spheres and T-matrix approximations yielded reflectivities that were 2 or more dB too high
- The Heymsfield et al. (2012) and Brown and Francis (1994) m(D) relationships, together with the particle size distributions, yielded IWCs that were accurate to better than 20% over the range 0.01 to about 0.5 g m^{-3}.
- Errors in the m(D) relationship when forward-modeling PSDs to yield IWC and *S* and their relationship to Z_e yield larger errors for *S* than for IWC.
- The CloudSat 2C-Ice algorithm yielded a Ze-IWC relationship that fit the relationship developed from the TC4 data quite well, for similar temperatures.
- The CloudSat 2C-Snow-Profile algorithm might underpredict the IWCs and snowfall rates
  - I have a good understanding of the differences between the mass and terminal velocity algorithms used here and other those of other studies

Concluding Remarks

- More such studies are needed, factoring in Ku and Ka-band data
- Use of the in-situ condensed water content data-especially in ice, is problematic because the accuracy of the instrument(s) is questionable, especially for the larger particles which dominate the radar reflectivity.