united nations
educational, scientific
and cultural
organization

international atomic
energy agency

the
abdus salam
international centre for theoretical physics

School on "Exploring the Atmosphere by Remote Sensing Techniques" 18 October - 5 November 1999

1151-14

"Vertical Distribution of Hydrometeors"

E. Clothiaux
Pennsylvania State University
University Park
USA

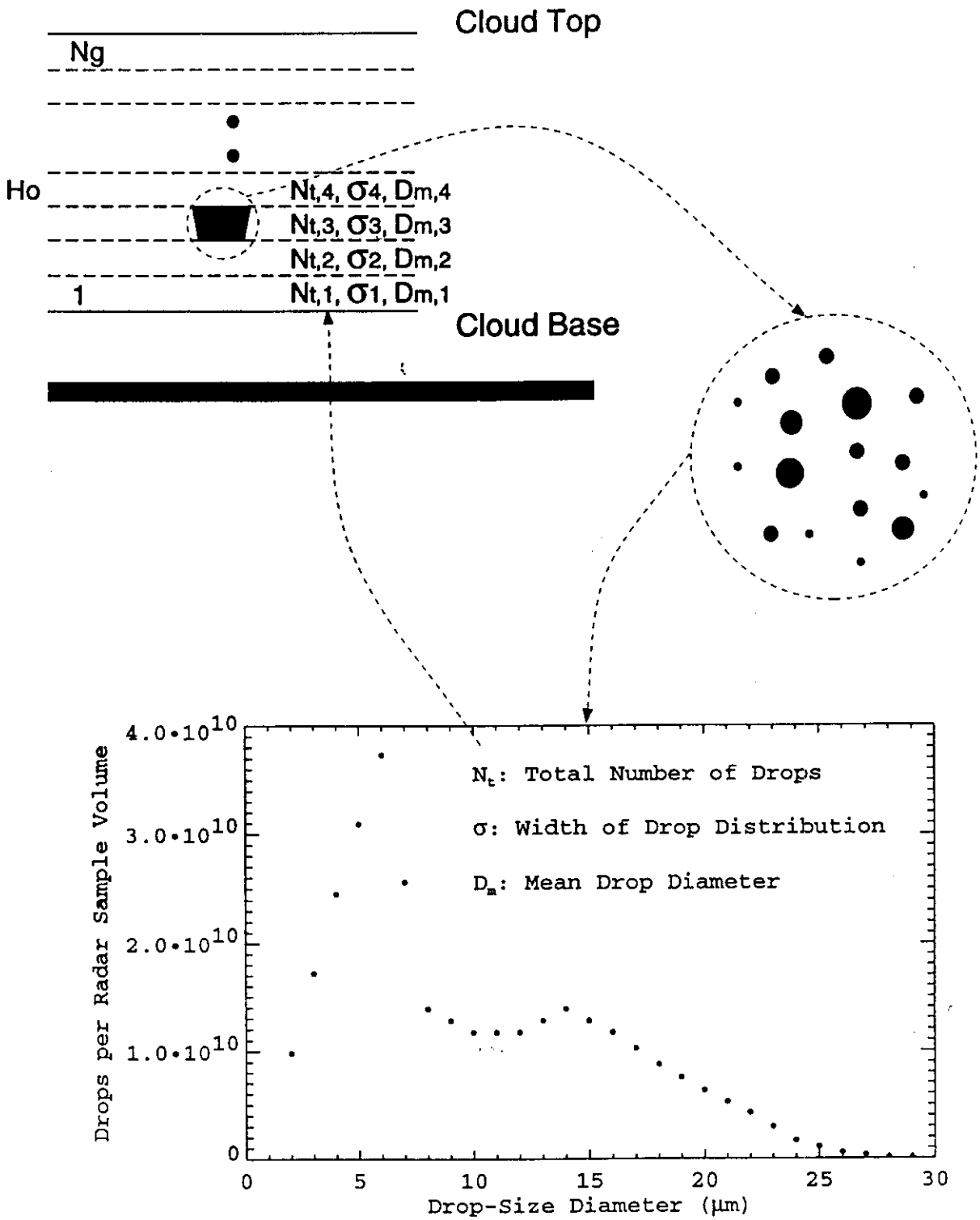
Vertical Distribution of Hydrometeors

Cloud Particles*
Precipitation Particles*

Stratus/Cirrus Cloud Properties

Cloud Particle Location*
Cloud Liquid Water Contents*
Cloud Particle Size Distributions*
Cloud Mean/Turbulent Motions

For radiation studies, the starred items are important. Consider stratus.


Cloud Top
Ng
Ho
Nt,4, σ4, Dm,4
Nt,3, σ3, Dm,3
Nt,2, σ2, Dm,2
1
Nt,1, σ1, Dm,1
Cloud Base
Drops per Radar Sample Volume
4.0•10^10
3.0•10^10
2.0•10^10
1.0•10^10
0
0
5
10
15
20
25
30
Drop-Size Diameter (μm)
N_t: Total Number of Drops
σ: Width of Drop Distribution
D_m: Mean Drop Diameter

Consider the Frisch et al. (1995) Algorithm

Cloud Liquid Water Path L_{wp} from Microwave Radiometer:

$$L_{wp} = \sum_{j=1}^{N_{\text{gates}}} L_{wc,j} = \sum_{j=1}^{N_{\text{gates}}} \sum_{i=1}^{N_{\text{bins}}} \rho_w \left[\frac{4}{3}\pi\left(\frac{D_i}{2}\right)^3\right] n_j(D_i)$$

Reflectivity Z_j from Radar

$$Z_j = \sum_{i=1}^{N_{\text{bins}}} D_i^6 n_j(D_i)$$

Assume $N_{t,j}$ is the same for all heights

$N_{t,j} = N_t$ (Constant with height and unknown)

Assume σ_j is the same for all heights

$\sigma_j = \sigma = 0.35$ (Constant with height and known)

together with a lognormal distribution,

With these assumptions, the effective diameter $D_{e,j}$ becomes

$$D_{e,j} = \left[\frac{\pi \rho_w H_o \sqrt{Z_j} (\sum_{k=1}^{N_{gates}} \sqrt{Z_k})}{6 L_{wp}}\right] e^{-2\sigma^2}$$

Z : No Ratio
6 : Present

and the liquid water content $L_{wc,j}$ becomes

$$L_{wc,j} = \left[\frac{\sqrt{Z_j}}{(\sum_{k=1}^{N_{gates}} \sqrt{Z_k}) H_o}\right] L_{wp}$$

Z : Ratio
6 : Not Present

E H

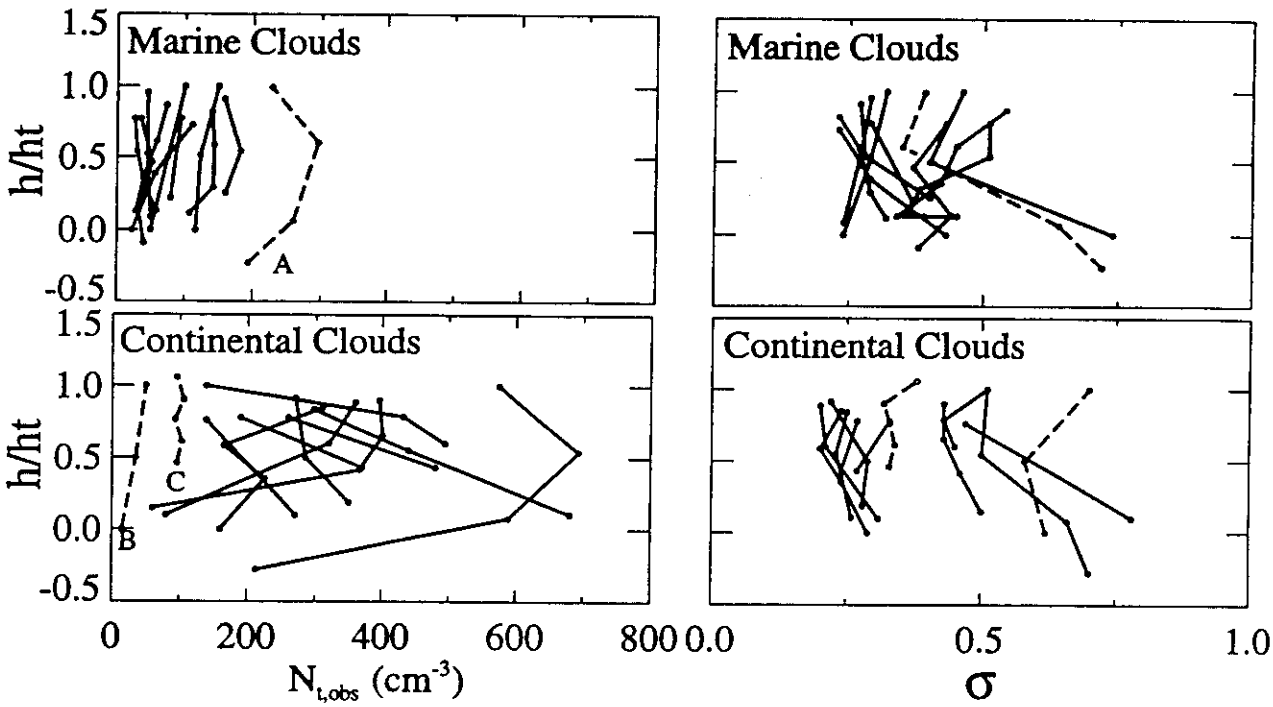
Are the assumptions any good?

Constant value of Nt
Constant value of σ=0.35
No drizzle
Parametric form for the size distribution

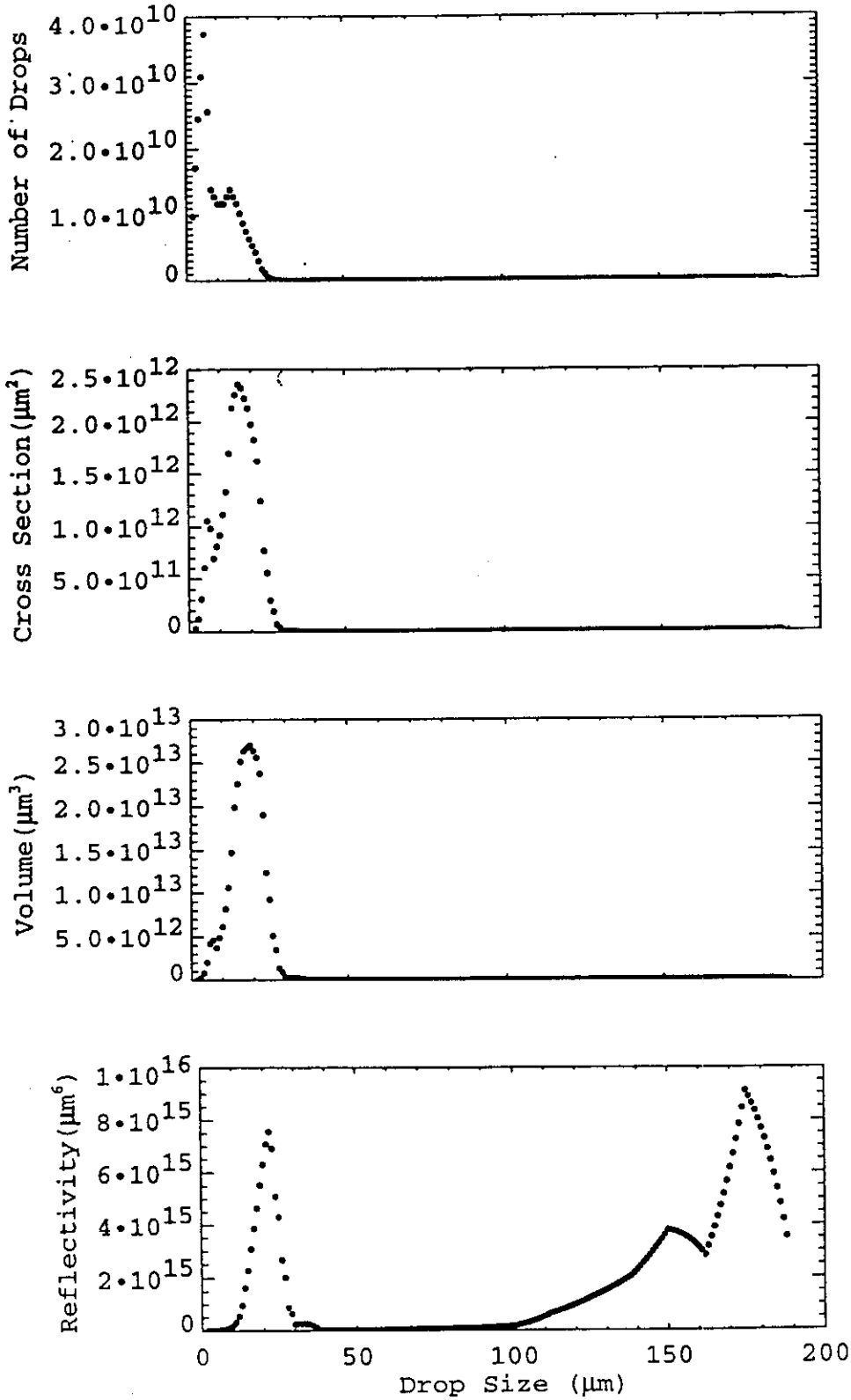
Are the measurements sufficiently accurate?

Lwp
Z j

Miles et al.: Cloud Droplet Size Distributions
in Low-level Stratiform Clouds



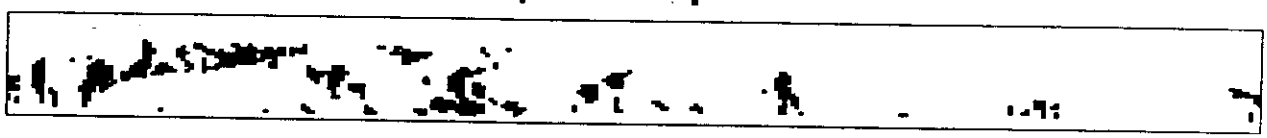
E 6


Number of Drops
4.0•10^10
3.0•10^10
2.0•10^10
1.0•10^10
0
Cross Section (μm^2)
2.5•10^12
2.0•10^12
1.5•10^12
1.0•10^12
5.0•10^11
0
Volume (μm^3)
3.0•10^13
2.5•10^13
2.0•10^13
1.5•10^13
1.0•10^13
5.0•10^12
0
Reflectivity (μm^6)
1•10^16
8•10^15
6•10^15
4•10^15
2•10^15
0
0
50
100
150
200
Drop Size (μm)

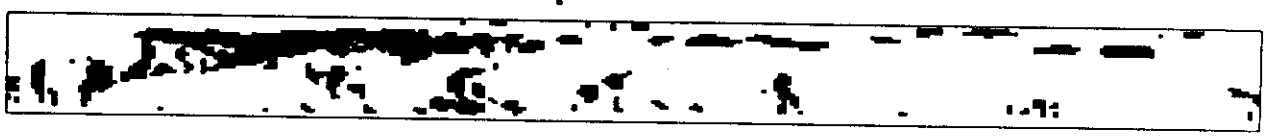
E 7

Barker et al., Overlapping Cloud: What Radars Give and What Models Require

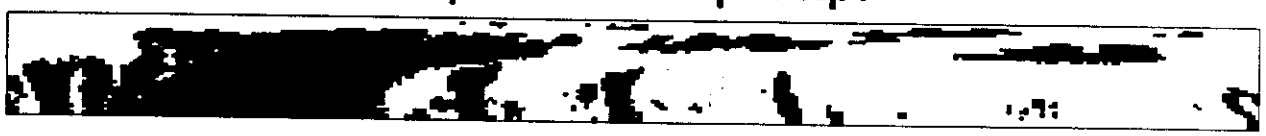
liquid droplets



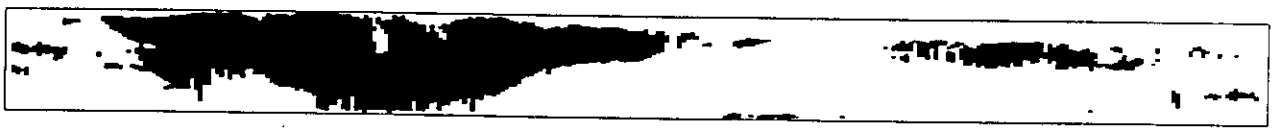
liquid + ice



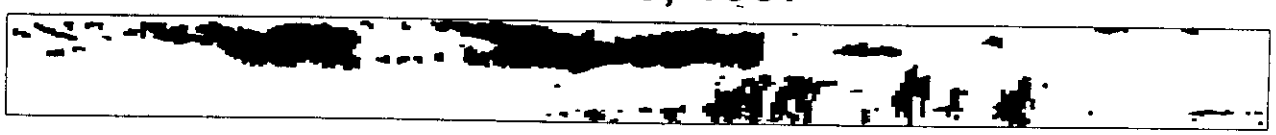
liquid + ice + precip.



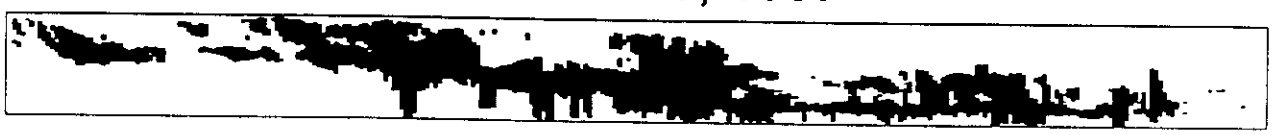
April 22, 1997



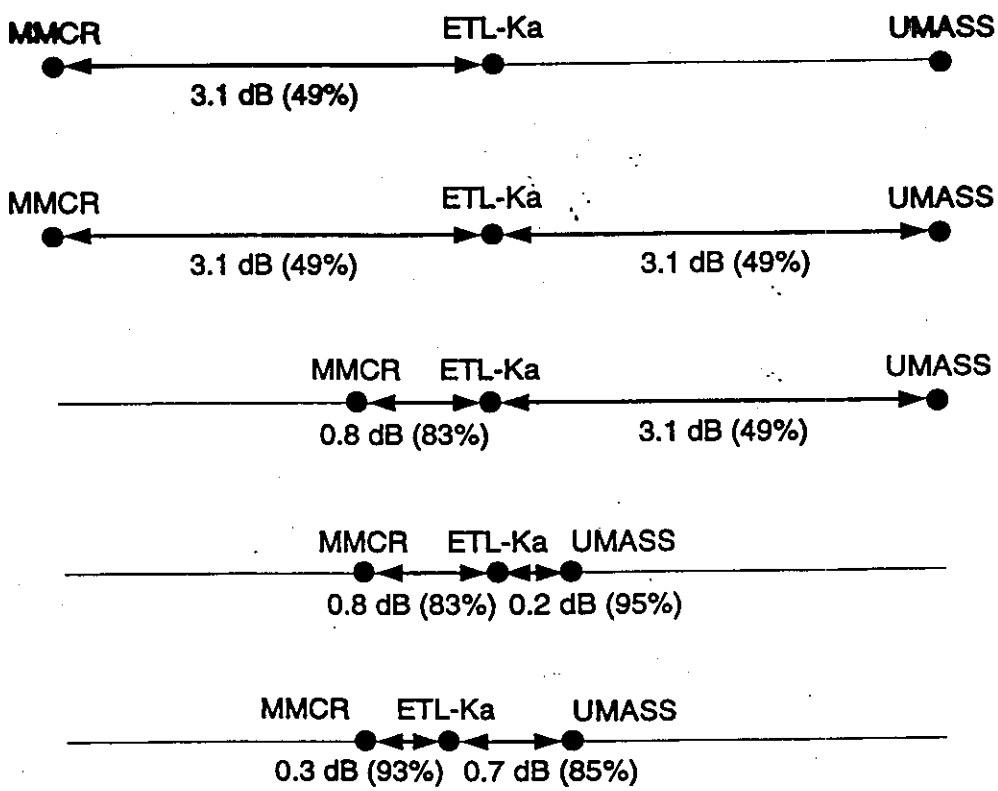
June 23, 1997



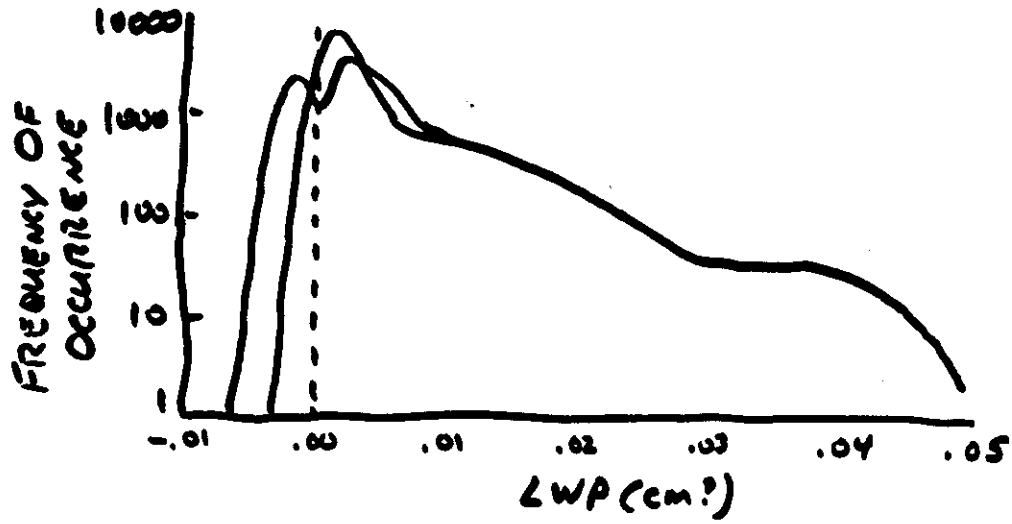
October 10, 1997

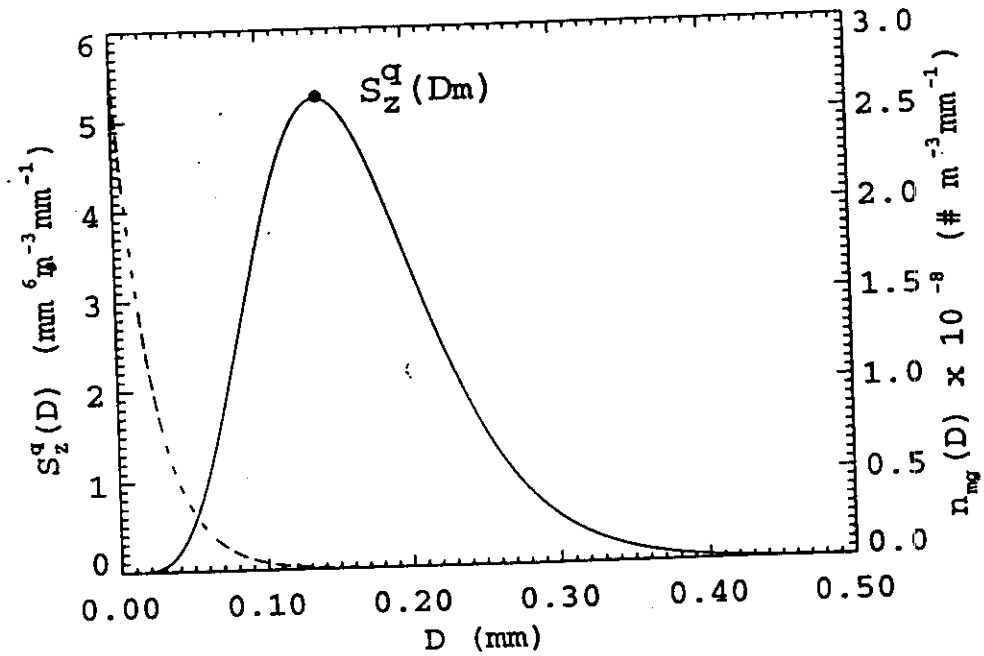


ARM Millimeter-Wave Cloud Radar Calibration History

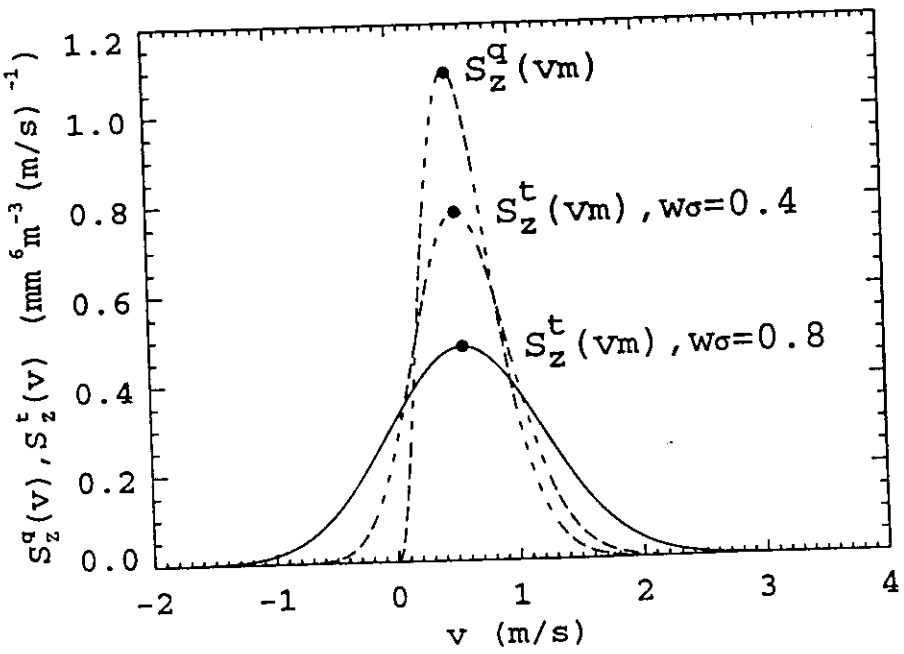


JIM LILJEGREN




$S_z^q(Dm)$
$S_z^q(D)$ (mm ^{6}m^{-3}mm^{-1})
$n_{mg}(D)$ x 10^{-8} (# m^{-3}mm^{-1})
D (mm)
0.00
0.10
0.20
0.30
0.40
0.50
0
1
2
3
4
5
6
0.0
0.5
1.0
1.5
2.0
2.5
3.0

(a)

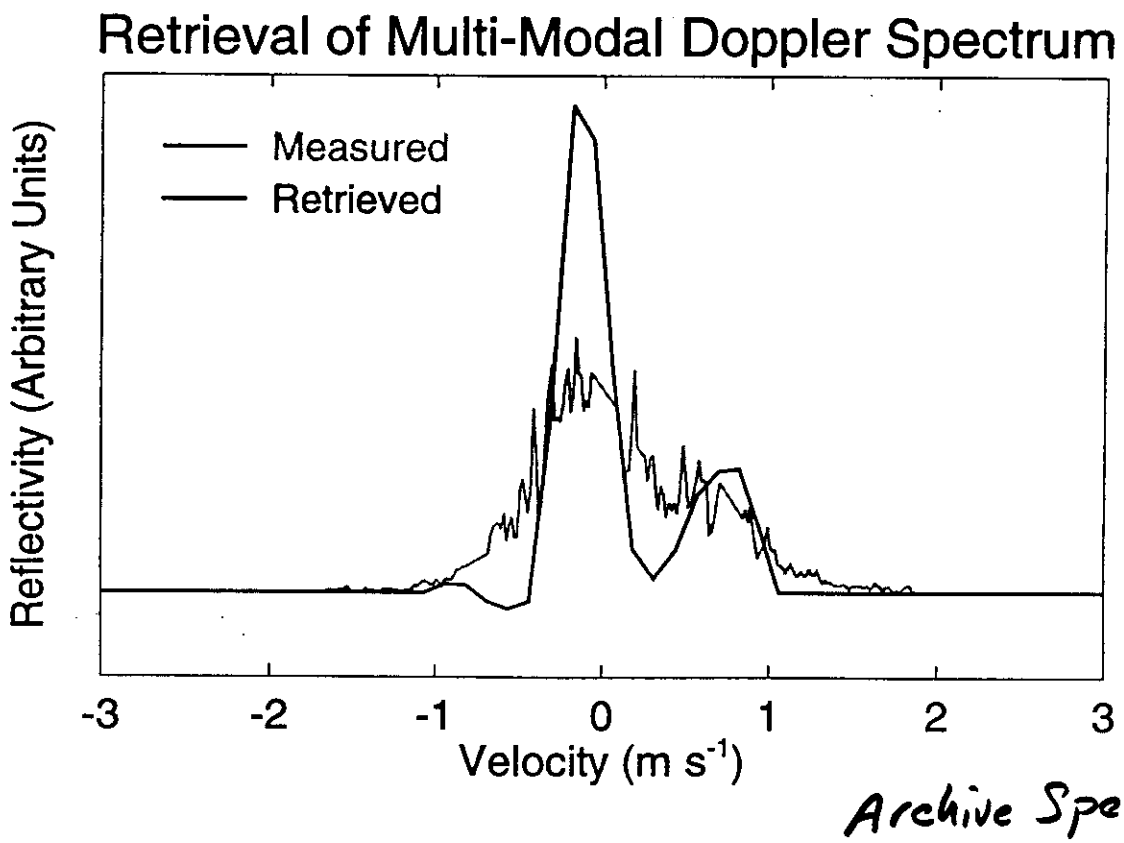

$S_z^q(vm)$
$S_z^t(vm)$, wσ=0.4
$S_z^t(vm)$, wσ=0.8
$S_z^q(v)$, $S_z^t(v)$ (mm ^{6}m^{-3} (m/s)$^{-1}$)
v (m/s)
-2
-1
0
1
2
3
4
0.0
0.2
0.4
0.6
0.8
1.0
1.2

(b)

E 11

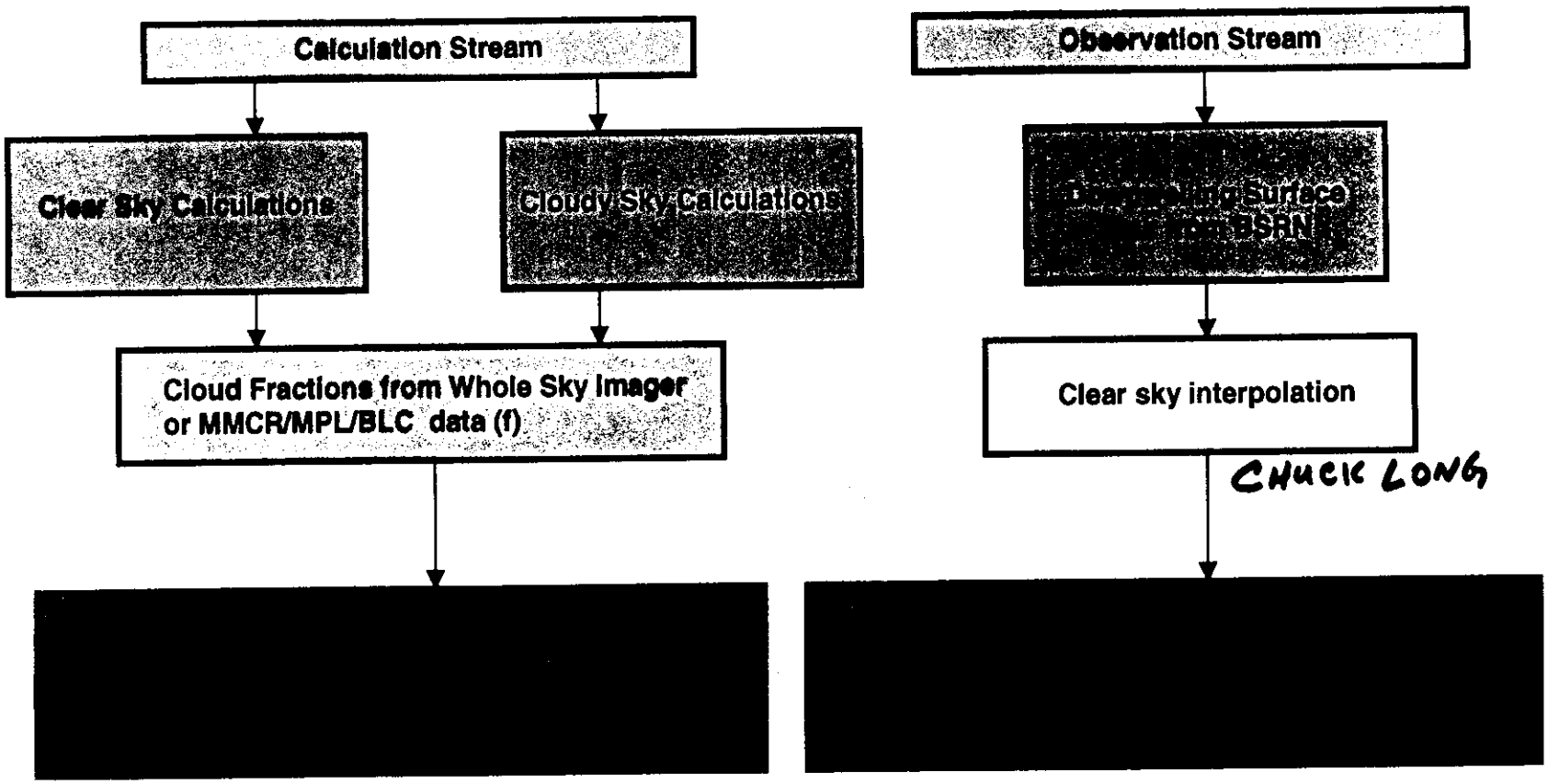
David Babb and Hans Verlinde:
Deconvolving Spectra

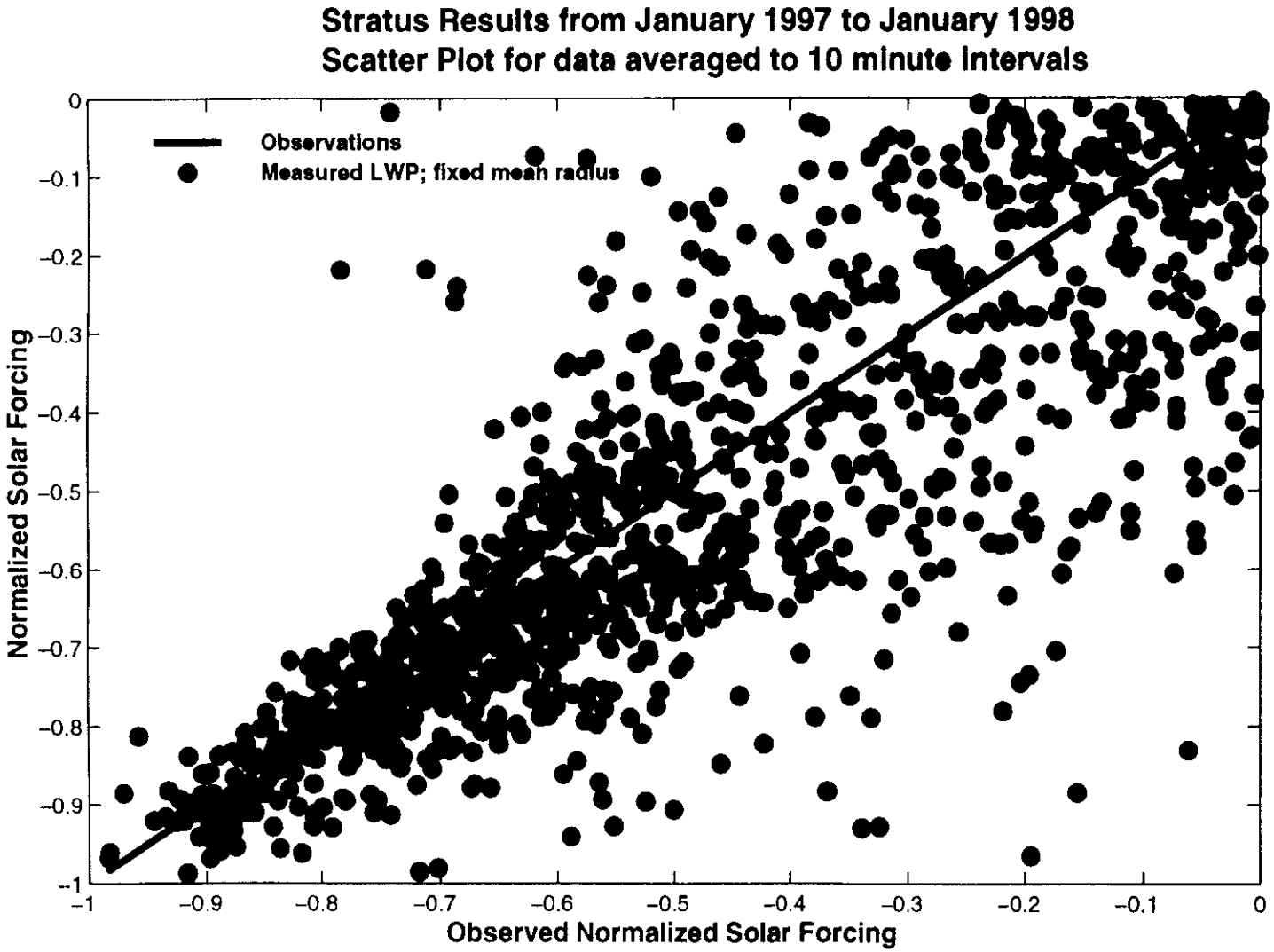
Miles, et al.: Particle and Turbulent Vertical Velocities from Doppler Cloud Radar Measurements



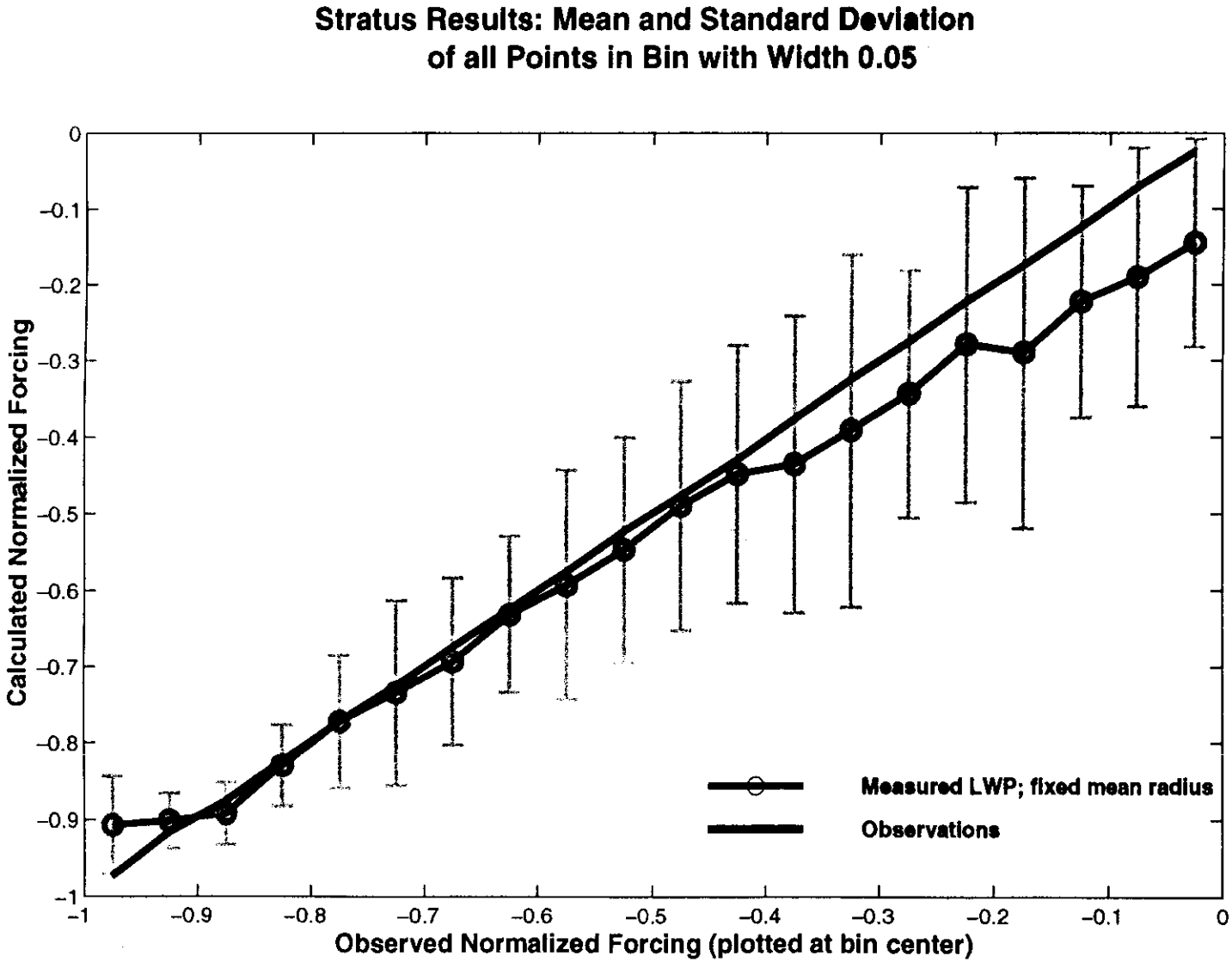
Archive Spectra!

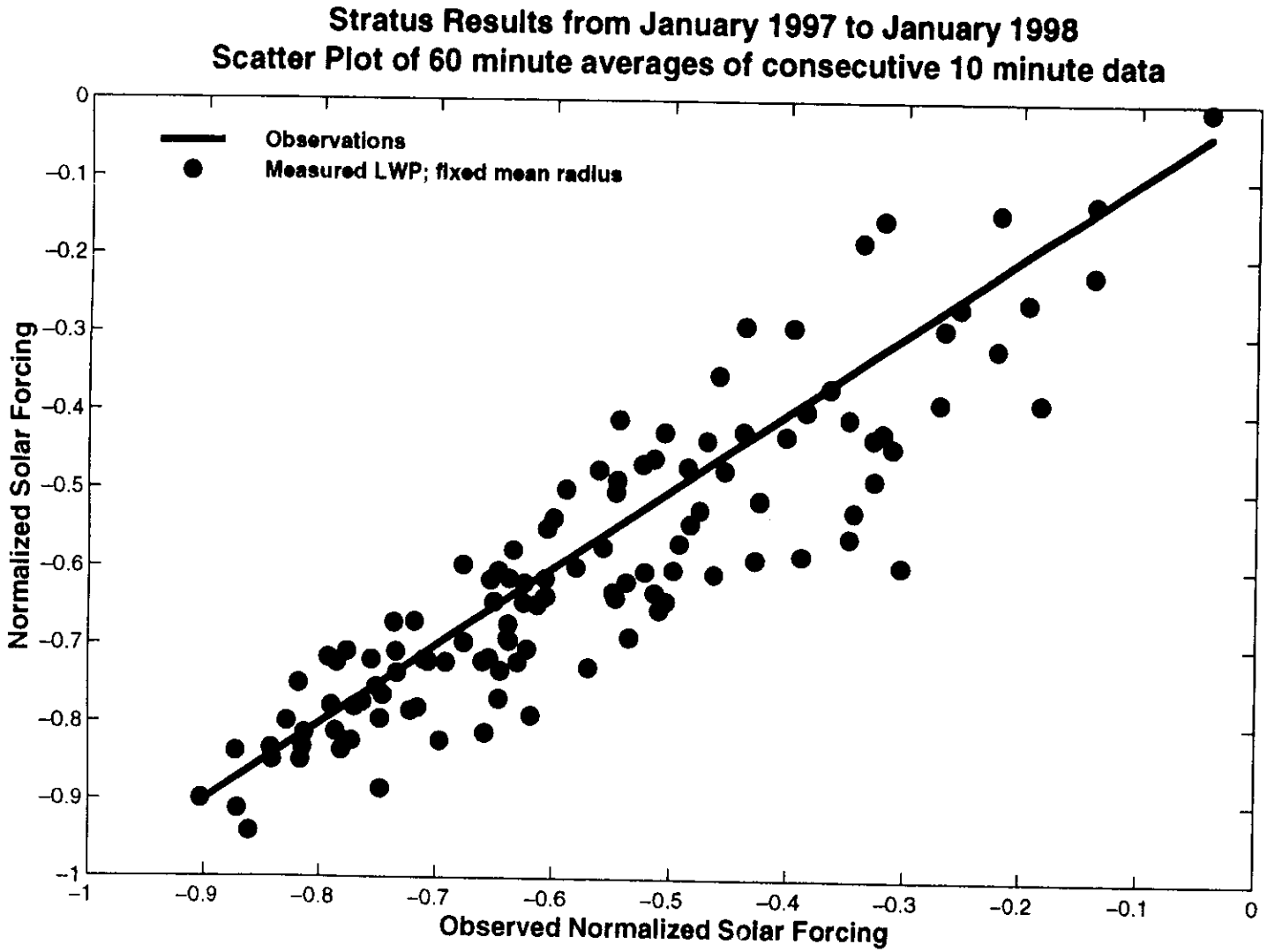
Normalized Cloud Forcing for Downwelling Surface Solar Flux



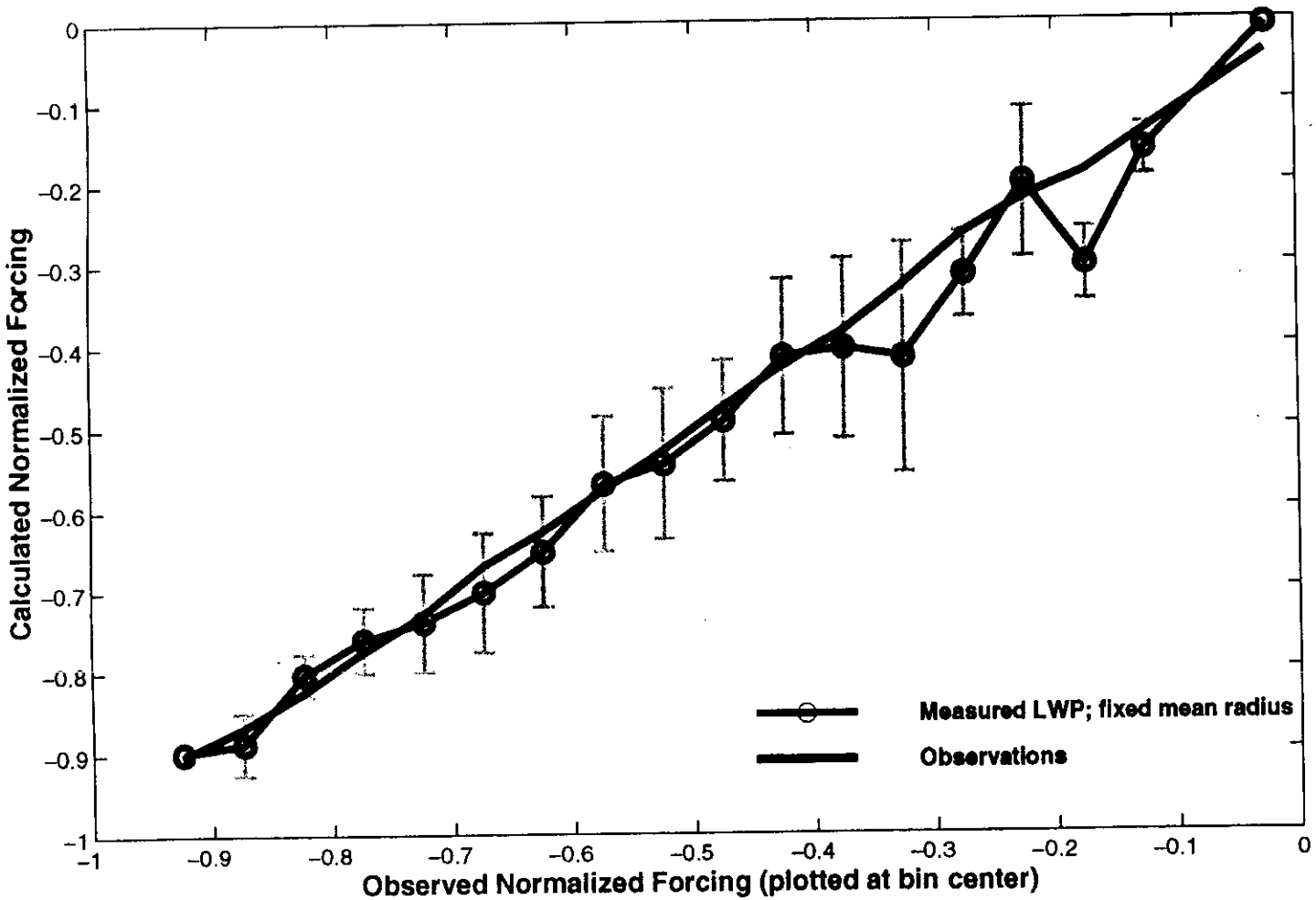


RMSD = 0.16
AVGD = -0.04


Stratus Results: Mean and Standard Deviation
of all Points in Bin with Width 0.05
Calculated Normalized Forcing
Observed Normalized Forcing (plotted at bin center)
0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
−1
−1
−0.9
−0.8
−0.7
−0.6
−0.5
−0.4
−0.3
−0.2
−0.1
0
Measured LWP; fixed mean radius
Observations


Stratus Results from January 1997 to January 1998
Scatter Plot of 60 minute averages of consecutive 10 minute data
Observations
Measured LWP; fixed mean radius
Normalized Solar Forcing
Observed Normalized Solar Forcing
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0

Stratus Results: Mean and Standard Deviation of all Points in Bin with Width 0.05 [60 minute averages of consecutive 10 minute data]



Conclusions

Microphysical Retrievals:

1) Does value depend upon absolute calibration of the radar?

~10%

2) Does value depend upon LWP? Are the values reasonable?

* Must emphasize uncertainties in retrieved values and calibration!

Cloud Overlap:

1) Cloud particles versus precipitation

* Spectra about 6-12 months away. Hefty data load

A clean ARM Data Record:

1) Reprocessing data through the ARM infrastructure

* Microwave radiometer retrievals
* Active remote sensors