# Retrieval of Cloud Ice Water Content and Effective Radius Using ARM Cloud Radar Reflectivity and Doppler Velocity

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## Introduction

Mace et al. (2002) and Matrosov et al. (2002) have published retrieval algorithms for cirrus microphysics (i.e., ice water content and particle size) based only on radar observed reflectivity (Z) and Doppler velocity (V). These ZV retrievals are attractive in that they do not require single layer or optically thin clouds and can therefore be applied during many periods when most other retrievals fail. In principle these retrievals can even be applied to the upper (ice only) portions of mixed phase clouds.

The results shown here are based on a modified form of the Mace et al. (2002) algorithm. It differs from the Mace algorithm in that:

- We permit the drop size distribution to be a gamma function of any chosen order rather than only an exponential function.
- We adopt the particle mass and area to fall speed model of Mitchell et al. (1996), rather than use an empirical velocity to maximum particle dimension power law relationship.
- We assume the radar scattering can be modeled as Rayleigh scattering and only depends on the particle mass, rather than use a radar cross section to maximum particle dimension power law approximation.
- We adopt volume and area relationships for individual ice particle types (habits) as given by Yang et al. (2000).
- We solve the resulting integral equations numerically using look-up tables.
- We use a different approach to estimate the particle fall velocities from the measured radar Doppler velocity which does not involve fitting to a regression relationship and includes an empirical maximum and minimum Z to Ice Water Content (IWC) constraint.

## Fall Velocity Estimation Scheme

One can think of the ZV retrieval as building a Z to IWC and Z to Re relationship for the observed cloud from the measured Doppler velocity. We conditionally average the measured Doppler velocity as a function of the measured reflectivity (in 2 dBZ x 500 m layer bins) to obtain the fall velocity. We require that each bin have a minimum of 100 samples and that the standard deviation be less than 2 cm/s. Any points which imply a Z to IWC ratio more than a factor of 10 above or below (dashed red lines in Figure 2) the expected results are rejected. Any empty bin is interpolated such that IWC = aZb with a fixed value of b. Figure 1 below depicts how the interpolation is accomplished. In this figure the circles represent locations (in layer/dBZ space) with good average Doppler fall velocities. The empty areas are locations without good values. The lines and dots show how nearby points are used to fill in the entire space. Figure 2 shows an example of the resulting Z to IWC relationship, which is derived using the reflectivity and Doppler velocities. In Figure 2 each line (with a symbol) represent one layer.

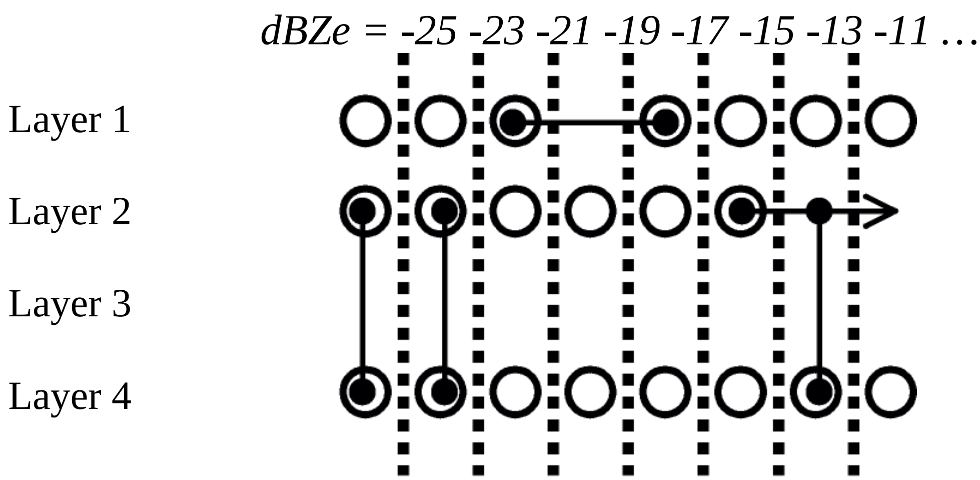


**Figure 1**.

## Drawbacks

The above technique suffer from a number of drawbacks including (1) one must estimate the particle fall velocity from the measured Doppler velocity, which includes effects due to updrafts and other air motions, (2) the relationship between the measurements (both reflectivity and fall velocity) and the particle microphysics depends on the crystal habit, which is not generally known, and (3) an error in the retrieved particle effective radius is strongly correlated with ice water content in such a manner that (for a given habit) the resulting error in optical depth (or extinction) is maximized.

We highlight these problem using an example cloud observed of the ARM SGP site on March 6, 2001.

Following Orr and Kropfli (1999), we used a 404 MHz radar wind profiler to estimate the vertical velocity in the regions just above and just below the cloud layer. This adjustment accounts for mesoscale atmospheric motion which, unlike smaller scale updrafts and downdrafts, can not be removed from the cloud radar Doppler velocity by averaging. For this case, the wind profiler data suggest about a 10 cm/s uplift, which we use as our best estimate (solid black line). The dashed lines in Figure 4 show results for +/- 10 cm/s uncertainty in this estimate.

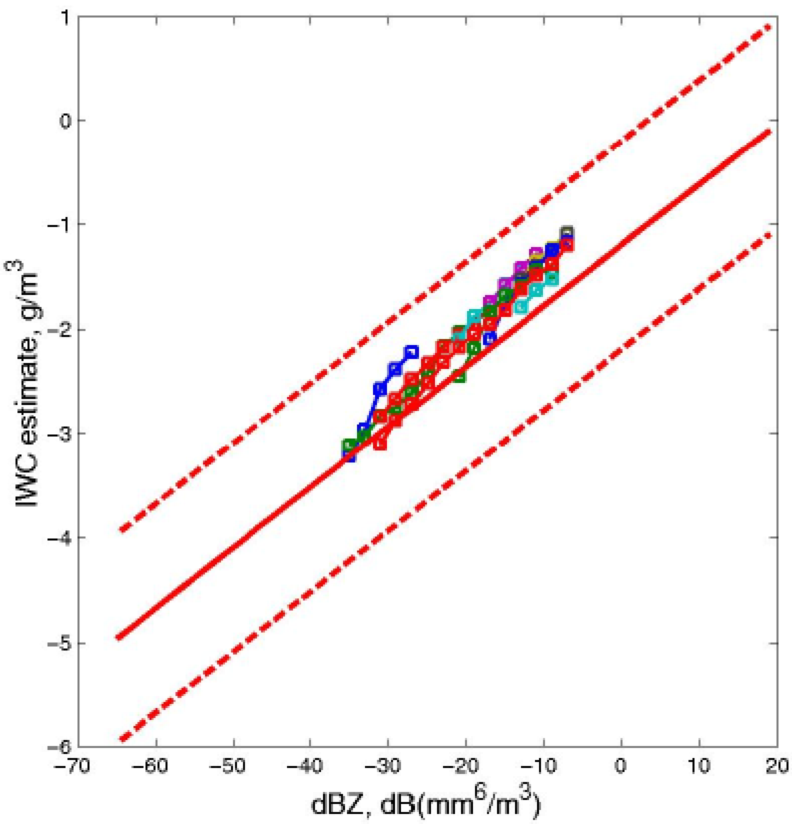


**Figure 2**.

The change in the retrieval solution due to variations in the mass and surface area of different ice crystal habits is also large (Figure 5). We are currently working on a retrieval for ice-crystal habit using multi-angle radiance data from the NASA MISR instrument.

Lastly, the error in IWC and Effective Radius (Re) is highly correlated. Optical Depth is proportional to IWC/Re. In the retrieval, any error in estimated fall velocity which causes the IWC to be overpredicted, ALSO causes the effective radius to be underpredicted (and vice versa). With the result that the error in the optical depth is magnified, as shown below in Figure 6.

# Comparison between ZV and Other retrieval techniques (summary of SGP cases)

We are currently running retrievals for optically thin clouds (tau < ~ 1) using a number of different techniques including lidar-radar (Donovan and van Lammeren 2001) and Zradiance (Mace et al. 1998), as well as raman-lidar and micropulse lidar-based estimates (Comstock and Sassen 2001). Drop-outs and scale inconsistency between the retrievals make comparison between the techniques difficult and are responsible for much of the scatter in the figure to the left. We are currently working to correct these problems. Nonetheless, even in this preliminary comparison we are finding that the ZV retrieval tends to produce the lowest optical depth estimates and the lidar-radar technique tends to produce the highest.

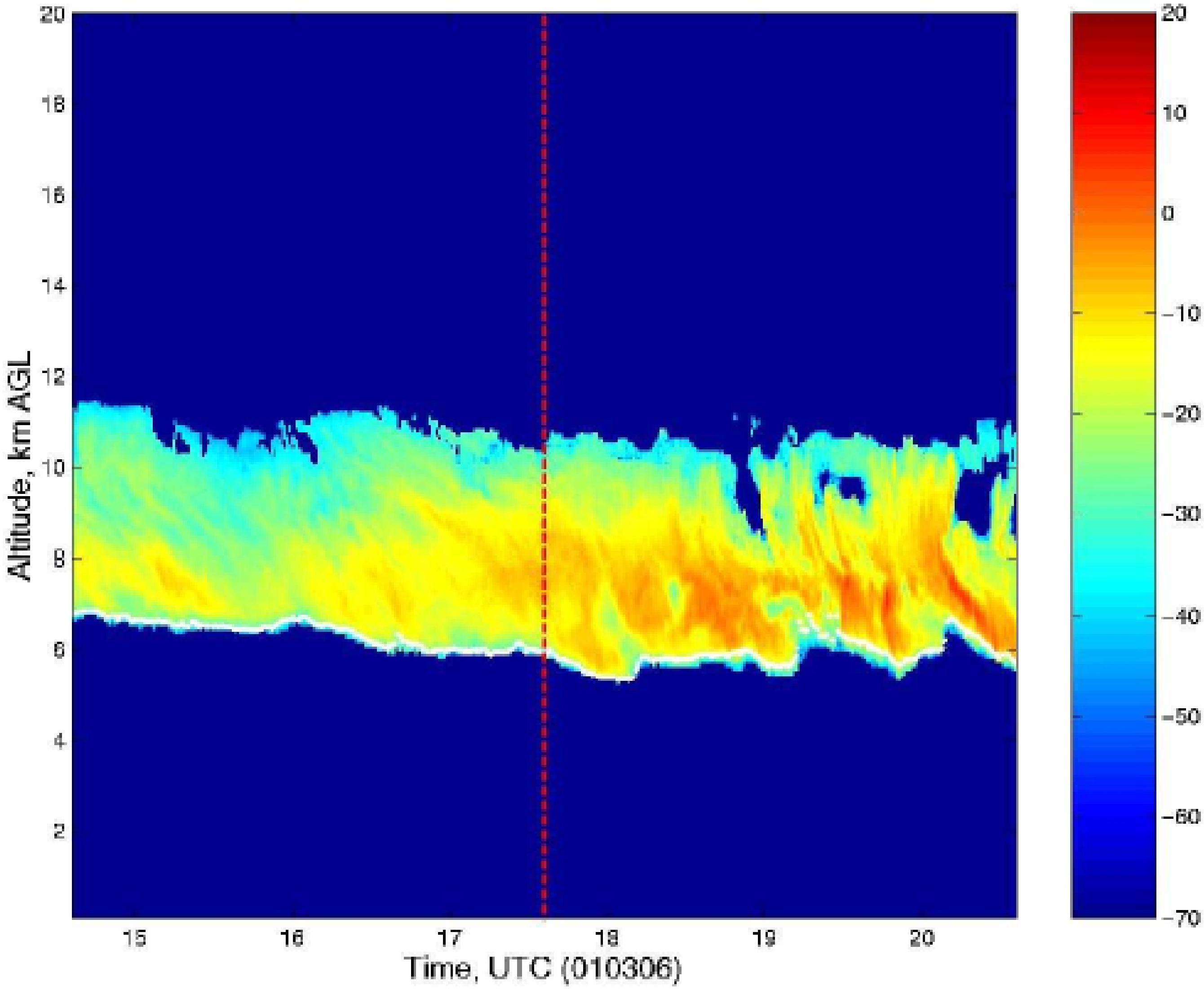


**Figure 3**.

## Summary/Future Directions

We have shown results of a cloud radar reflectivity and Doppler velocity (ZV) retrieval and highlighted some of the drawbacks to this approach. The retrieval algorithm is similar to that proposed by Mace et al. (2002) but with a number of modifications and (we hope) improvements. A preliminary comparison of ZV with other retrievals shows a large spread in the retrieved optical depth between the various techniques. We understand the source of some of these differences, but not enough. We plan to continue research in this area over the coming year. All of the thin cloud cases selected in this study occurred during overpasses of the MODIS, MISR, and CERES instruments. We plan to include data and retrievals from these instruments in future research, including retrievals of Crystal Habit from the MISR instrument.

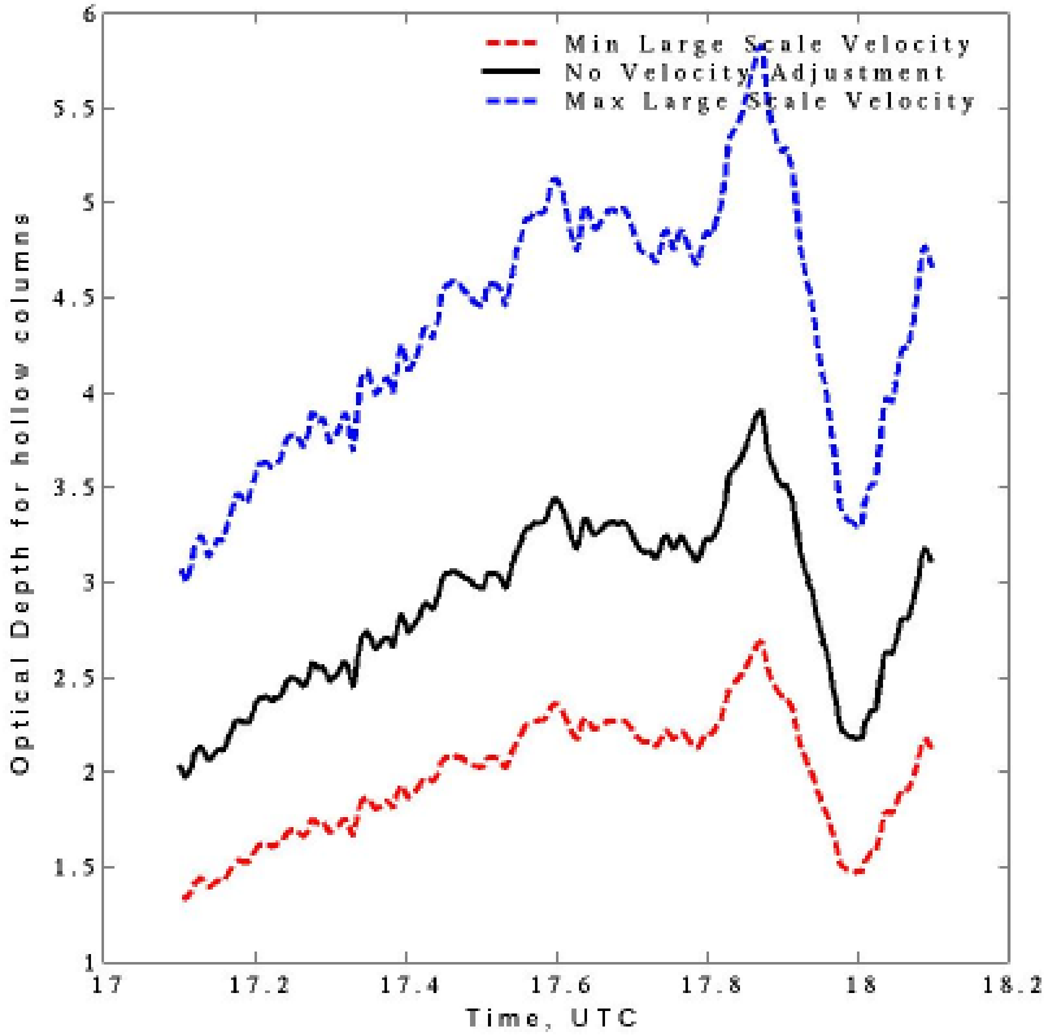
Min Large Scale Velocity
No Velocity Adjustment
Max Large Scale Velocity
Optical Depth for hollow columns
Time, UTC
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
17
17.2
17.4
17.6
17.8
18
18.2

**Figure 4**.

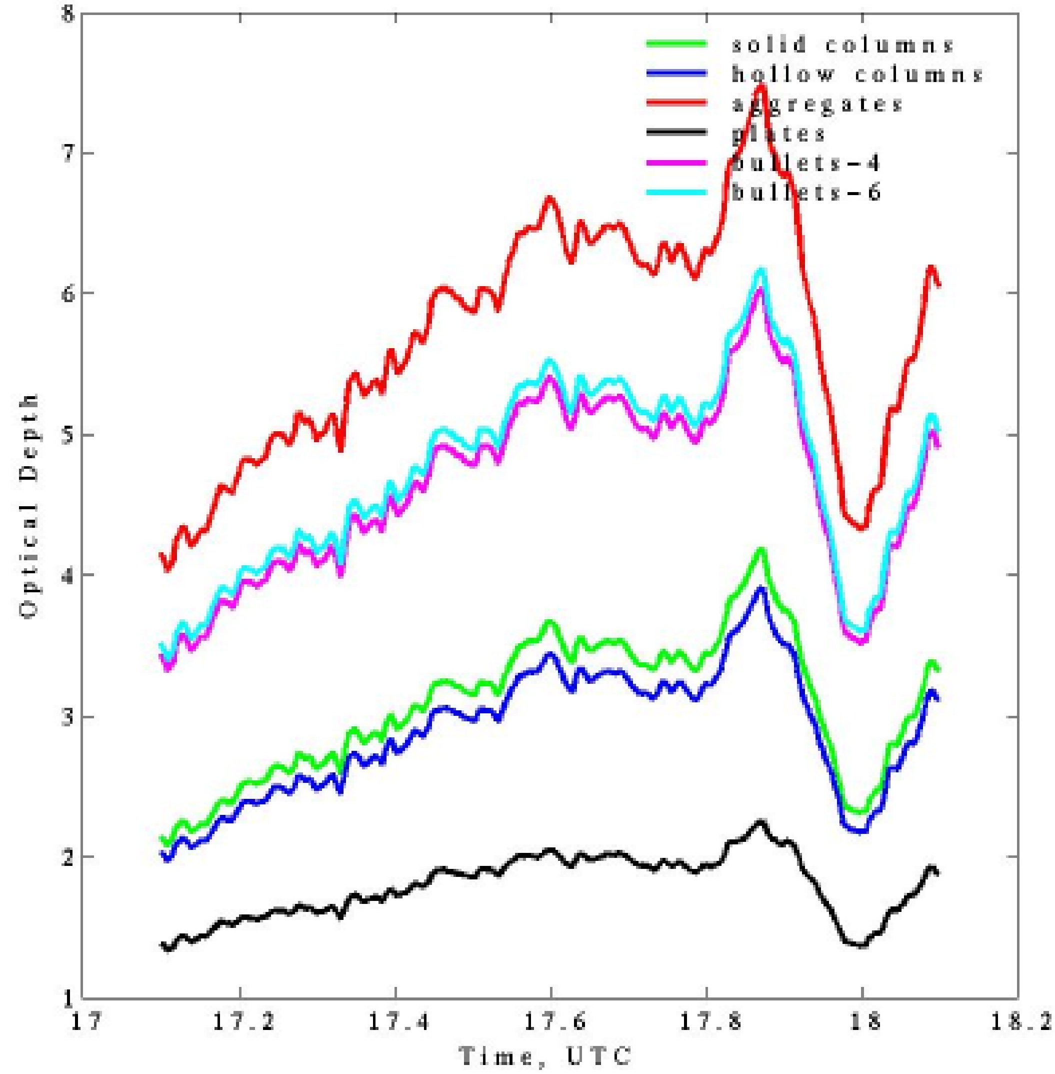
solid columns
hollow columns
aggregates
plates
bullets-4
bullets-6
Optical Depth
Time, UTC
1
2
3
4
5
6
7
8
17
17.2
17.4
17.6
17.8
18
18.2

**Figure 5.**

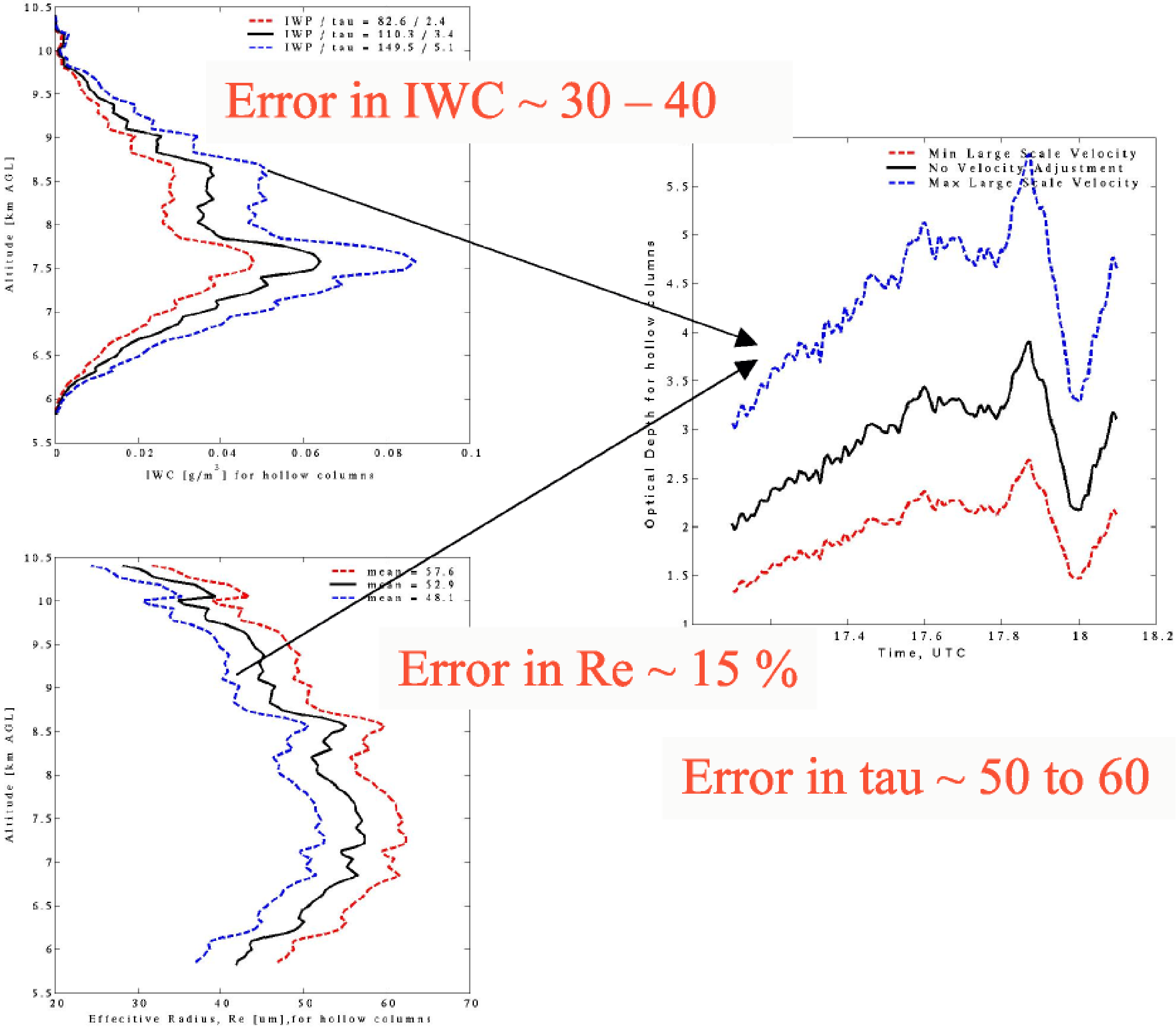
IWP / tau = 82.6 / 2.4
IWP / tau = 110.3 / 3.4
IWP / tau = 149.5 / 5.1
Error in IWC ~ 30 – 40
Altitude [km AGL]
IWC [g/m3] for hollow columns
Min Large Scale Velocity
No Velocity Adjustment
Max Large Scale Velocity
Optical Depth for hollow columns
Time, UTC
mean = 57.6
mean = 52.9
mean = 48.1
Error in Re ~ 15 %
Effecitive Radius, Re [um],for hollow columns
Error in tau ~ 50 to 60

**Figure 6**.

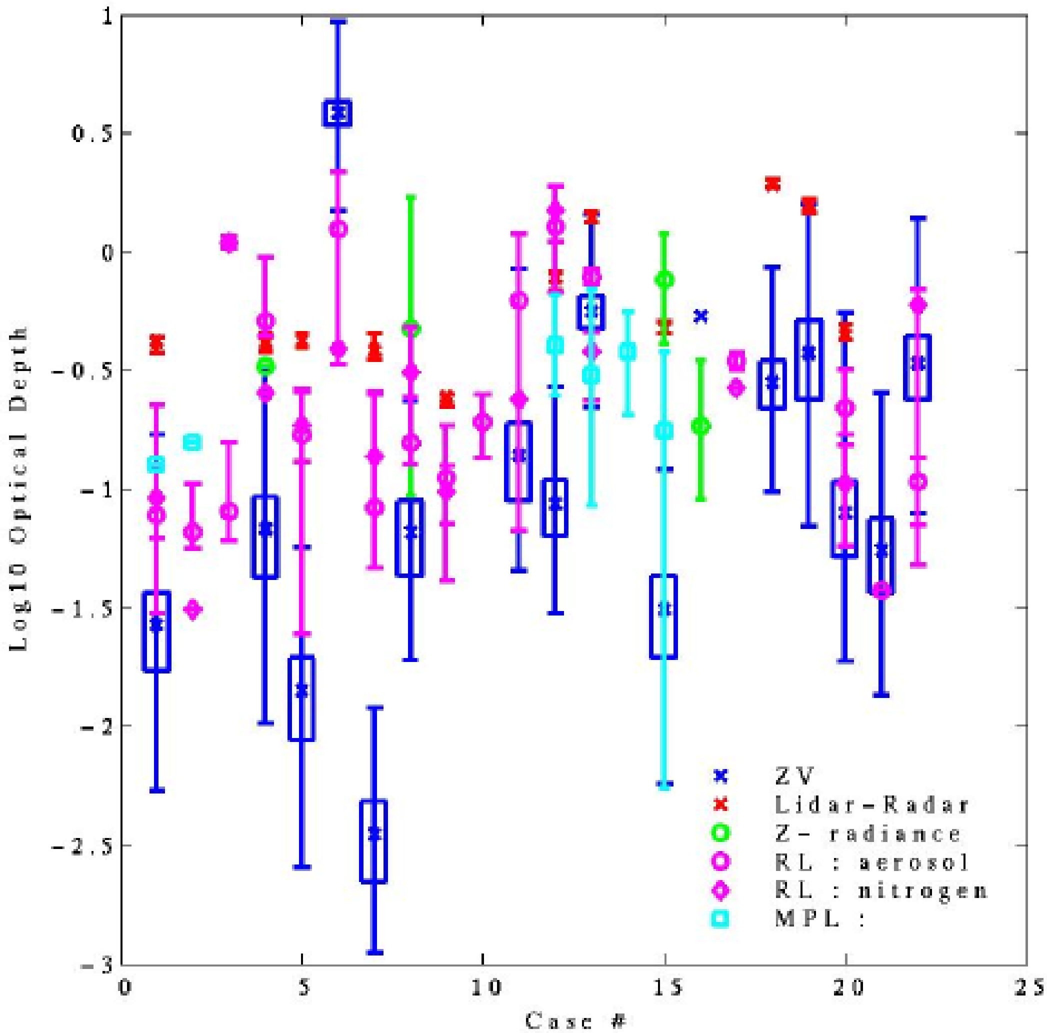
Log10 Optical Depth
Case #
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
0
5
10
15
20
25
ZV
Lidar-Radar
Z- radiance
RL : aerosol
RL : nitrogen
MPL :

**Figure 7**.