Retrieval of Cloud Phase and Ice Crystal Habit From Satellite Data

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Introduction

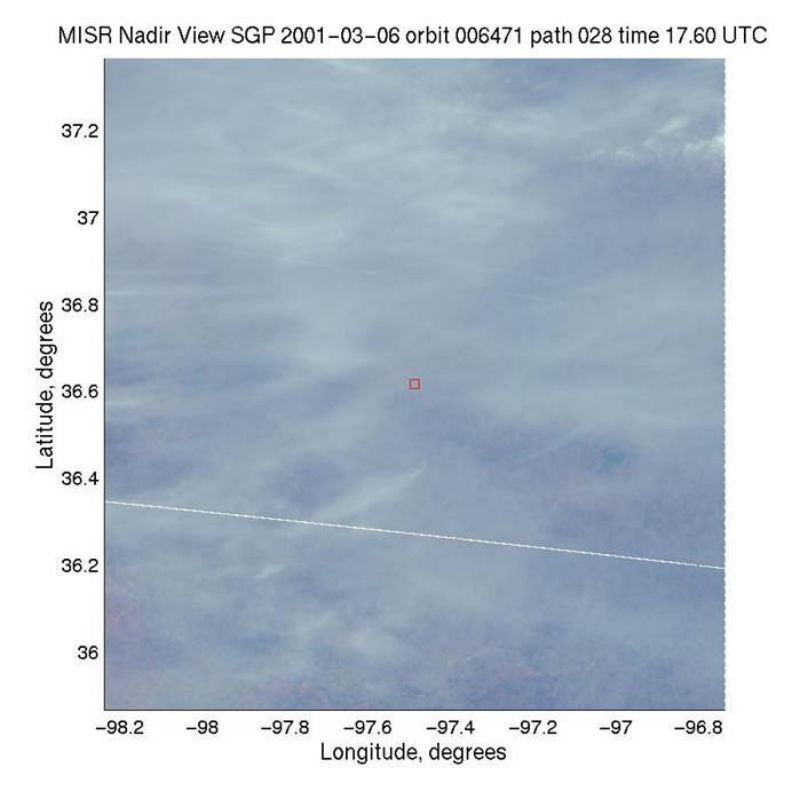
- Knowledge of cloud phase and crystal habit is fundamentally important to remote sensing and climate simulations
- The shape of a particle affects the scattering of light such that water droplets and ice crystals of various habits have different phase functions
- Multi-angle Imaging Spectro-Radiometer (MISR) measures radiances at 9 different angles – We can use this angular information to discern particle phase and habit, but must also consider the particle size.
- Particle size can be simultaneously determined using near-infrared radiance from the Moderate resolution Imaging Spectroradiometer (MODIS).

Retrieval

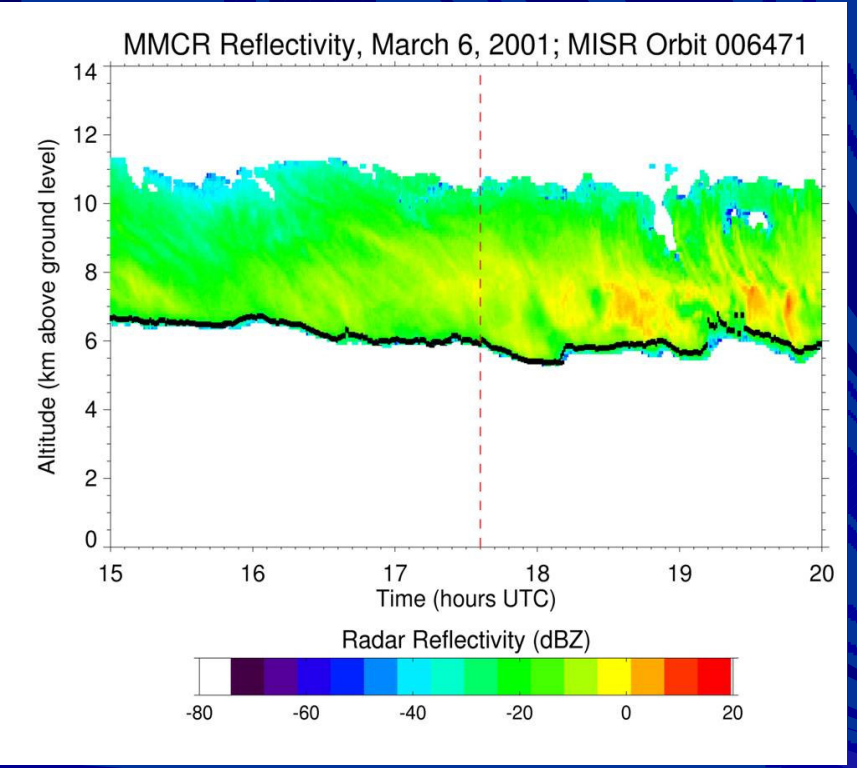
- Calculate radiance using state of the art radiative transfer model; ice scattering properties from Yang et al. (2000) database
- Retrieve best fit r_e, IWP, and crystal habit by minimizing deviation between modeled and measured reflectance over all cameras
- Currently assuming single layer cloud with one particle habit

$$\xi(\mathrm{Re}, \mathrm{IWP}, \mathrm{H}) = \frac{1}{\mathrm{N}} \sum_{\mathrm{i}} \left[\frac{|\mathrm{Satellite}_{\mathrm{i}} - \mathrm{MODEL}_{\mathrm{i}}(\mathrm{Re}, \mathrm{IWP}, \mathrm{H})|}{\mathrm{Satellite}_{\mathrm{i}}} \right]$$

Case Study 1:
Cirrus at ARM SGP site

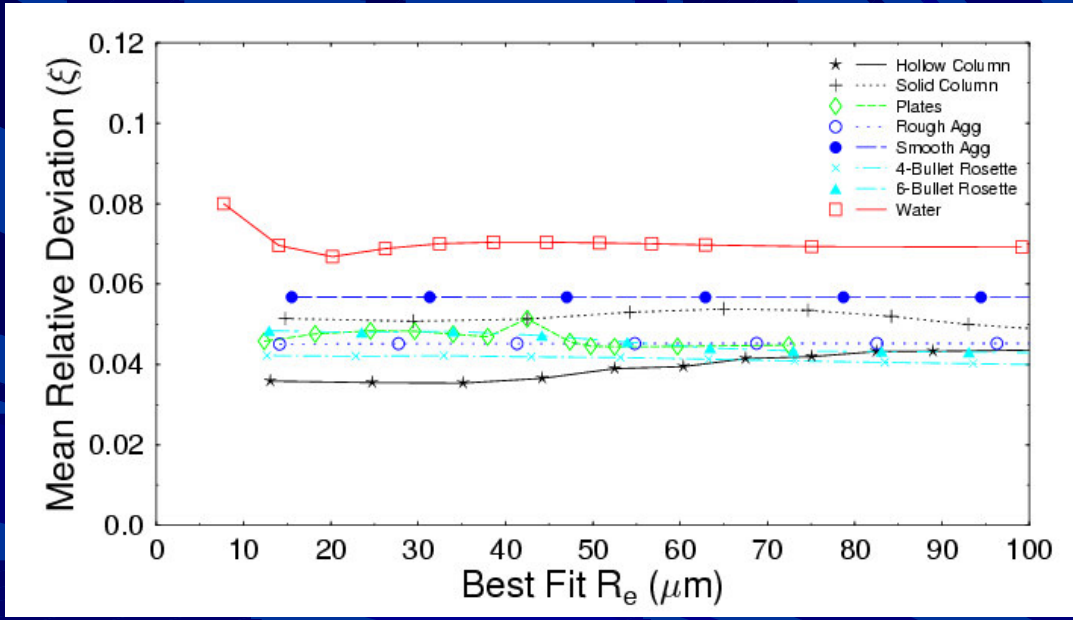


MISR nadir view image



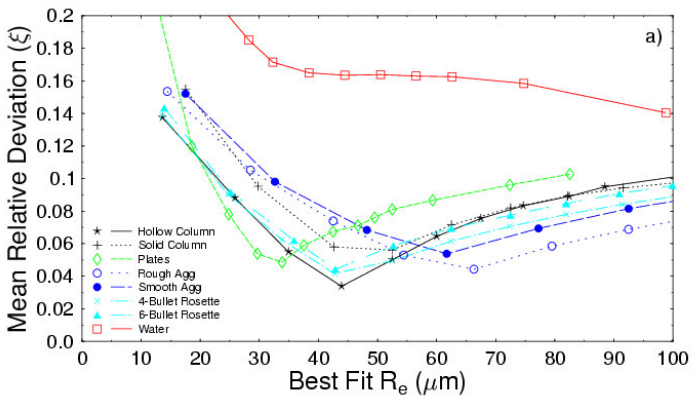
ARM millimeter wave radar reflectivity

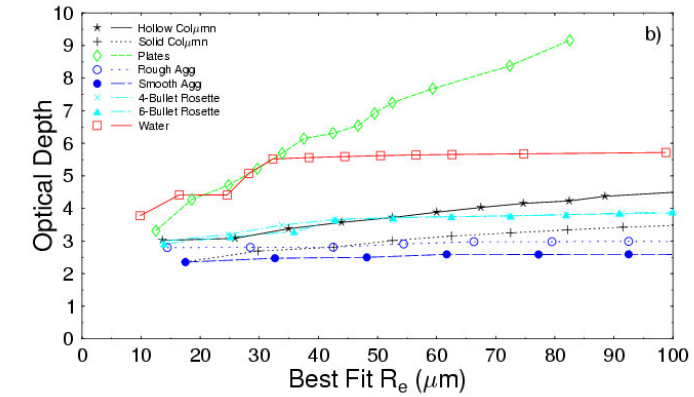
Case Study 1: MISR Only Retrieval Results



- Plot shows retrieval metric, ξ, as a function of best-fit effective radius for a range of IWP values for the March 6, 2001 cirrus case when only the MISR reflectances are used in the retrieval.
- Water is clearly the worst fit to the observed reflectances.
- Hollow columns are the best fit for R_e< 60 um; above 60 um several crystal habits appear equally valid.
- Little sensitivity to particle size using only the MISR visible wavelength.

Case Study 1: MISR and MODIS Retrieval Results





- Top panel shows retrieval metric, ξ, as a function of best-fit effective radius for a range of IWP values for the March 6, 2001 cirrus case using MISR and MODIS reflectances in the retrieval.
- Each particle type now shows a clear minimum in the metric as a function of particle size.
- Water is the worst fit; hollow columns are the best fit.
- Bottom panel shows retrieved optical depth as a function of best-fit effective radius for a range of optical depth.
- Wide range of optical depth with crystal type; relatively little variation in optical depth with crystal size.

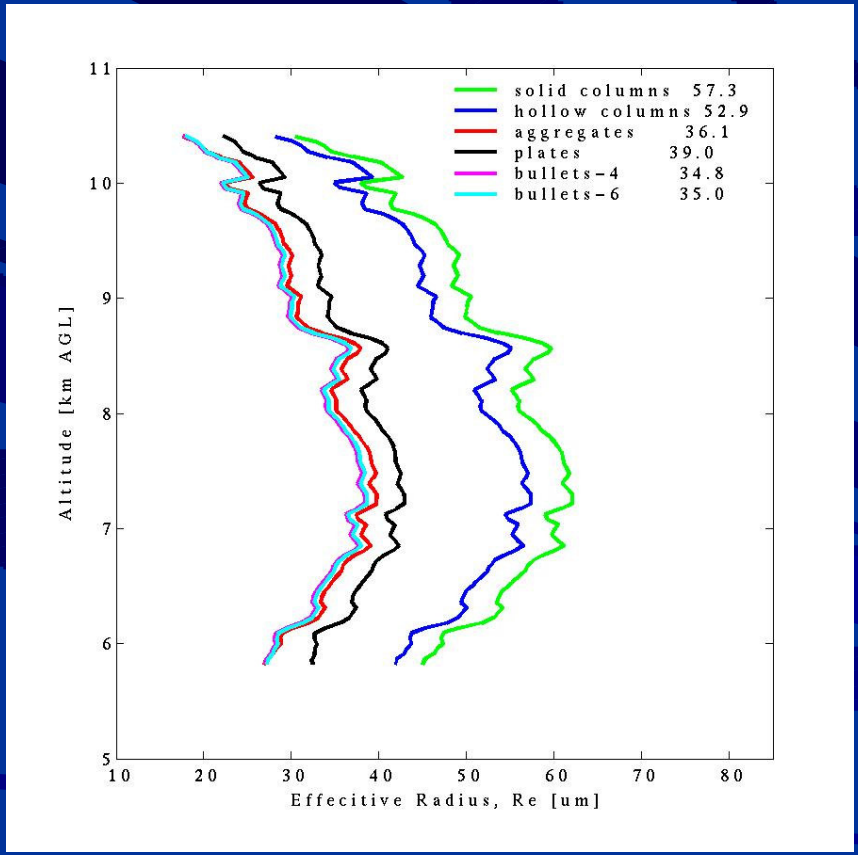
Case Study 1: Effect of crystal habit on retrieved optical depth

Habit	Metric(ξ)	Reff	IWP	τ
Hollow Columns	.033	43.2 μm	88.3 g/m^2	3.6
4-Bullet Rosettes	.038	45.1 μm	95.3 g/m^2	3.7
Rough Aggregates	.041	62.7 μm	103.0 g/m^2	2.9
Plates	.047	32.5 μm	107.6 g/m^2	5.7
Water	.143	100 μm	360 g/m^2	5.7
MODIS		**29.7 μm**	**77.0 g/m^2**	**3.5**
Radar Retrieval		**53.9 μm (48 – 58)**	**110.3 g/m^2 (82.6-149.5)**	**3.4 (2.4-5.1)**

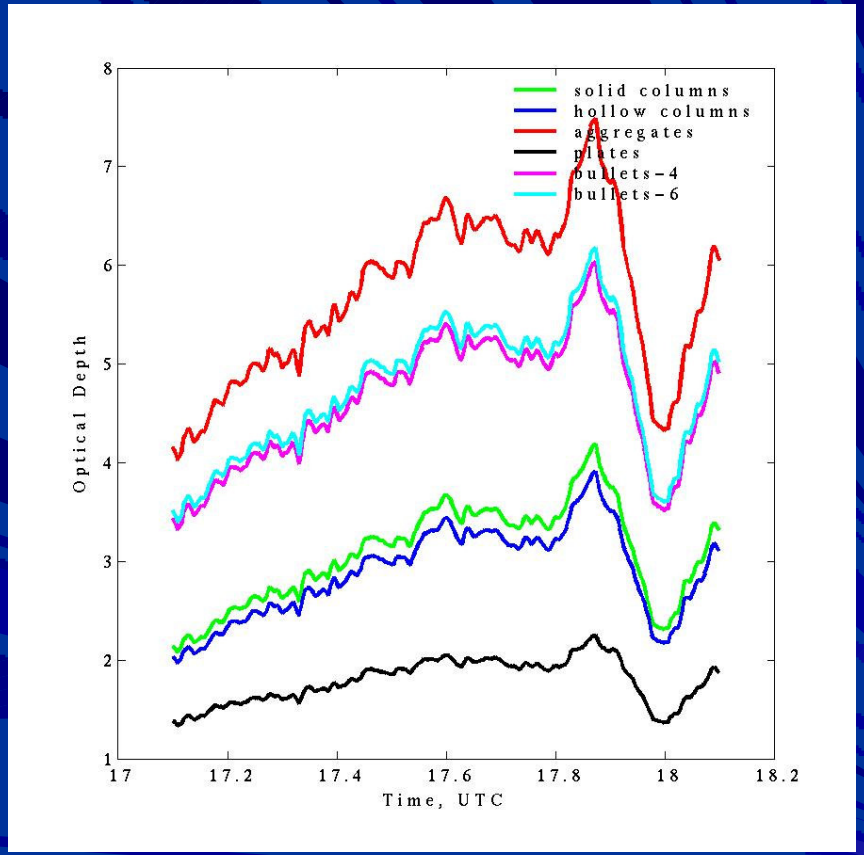
Case Study 1: Radar Z-V Algorithms

- New radar retrieval algorithms, which use reflectivity (Z) and Doppler velocity (V), can retrieve vertical profiles of particle size and IWC
- Retrievals are sensitive to crystal habit due to dependence of particle fall speed and effective density on habit
- Constraining the particle habit reduces the uncertainty in the radar retrievals

Case Study 1: Z-V Results

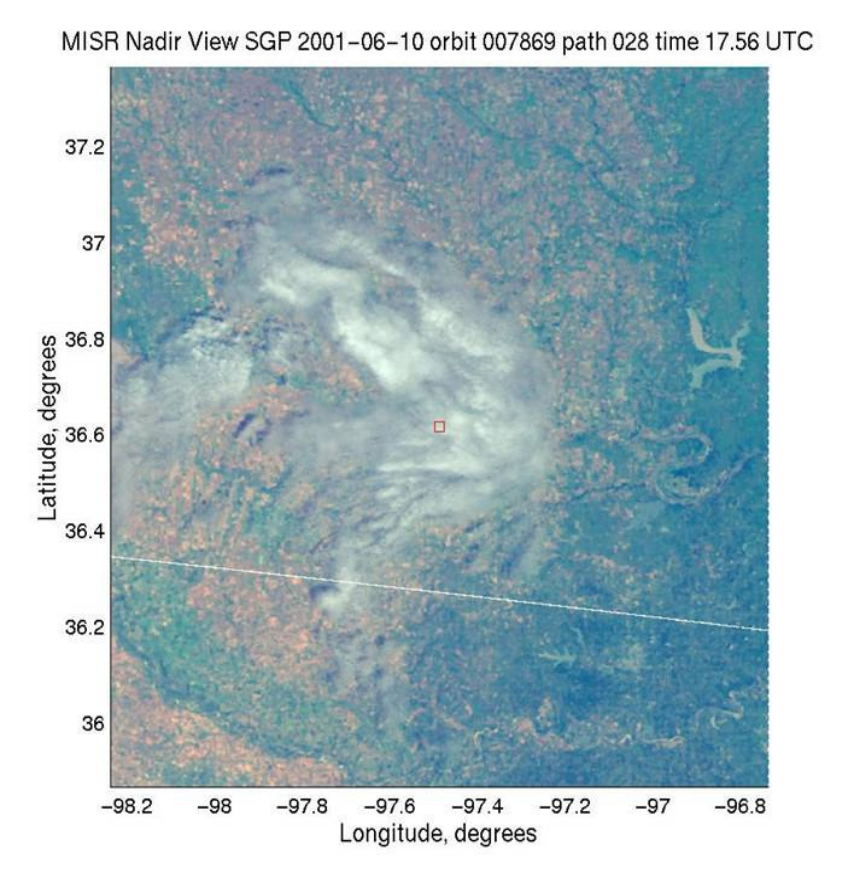


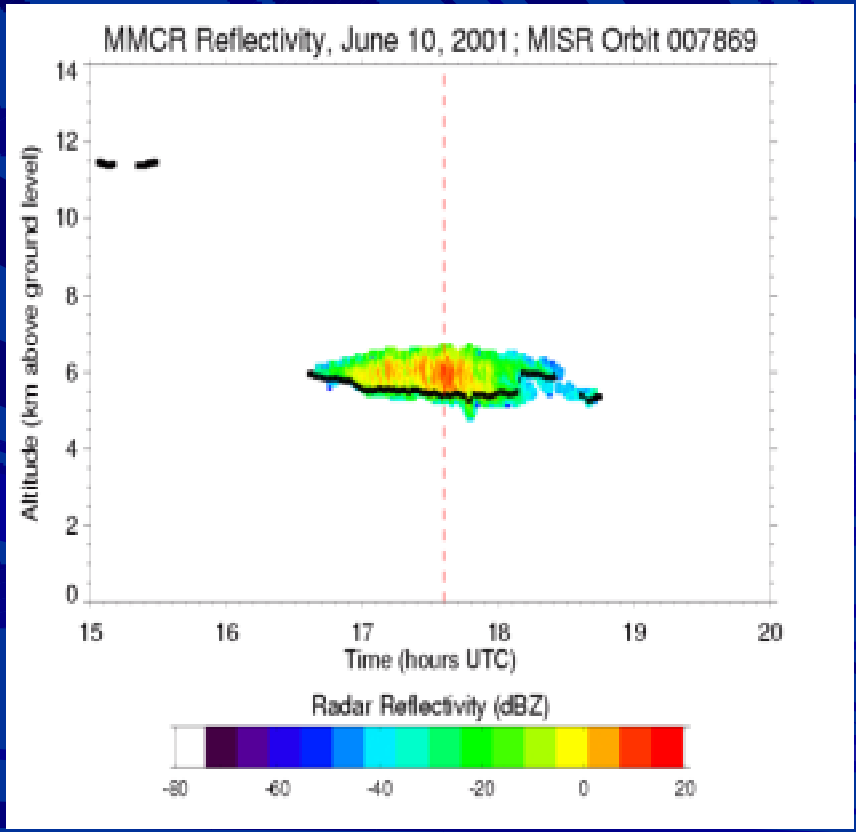
Profiles of effective radius retrieved from radar Z-V algorithm, assuming different crystal habits



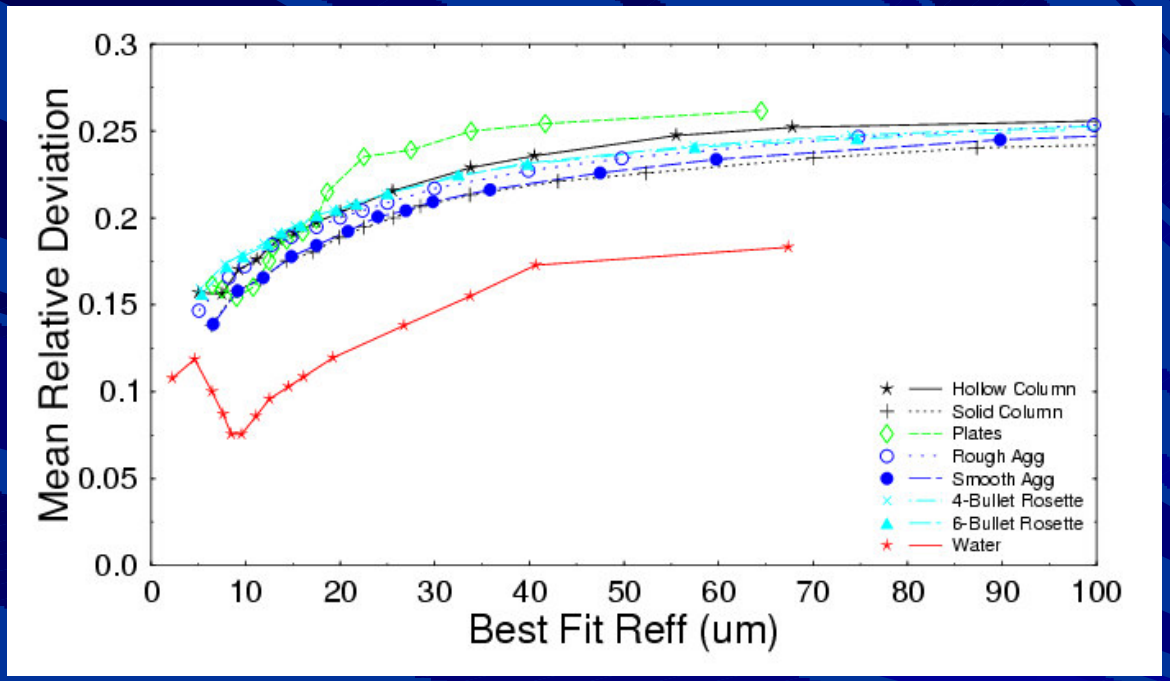
Optical depth retrieved from radar Z-V algorithm, assuming different crystal habits.

Case Study 2: Altocumulus at SGP





Case Study 2: Results



Retrieval metric as a function of best-fit effective radius for a range of IWP values for the June 10 altocumulus case at SGP. Both MISR and MODIS reflectances are used in the retrieval for this case.

- Water is best fit; MODIS retrievals indicate mixed phase cloud; ARM microwave radiometer shows LWP of 40-80 g/m^2
- Altocumulus actively growing as it moved over the ARM site; likely to have water at top of cloud
- Need sensitivity studies to determine depth in cloud to which retrieval is sensitive

Case Study 3:
Cirrus cloud over FARS

(Facility for Atmospheric Remote Sensing, U. of Utah)

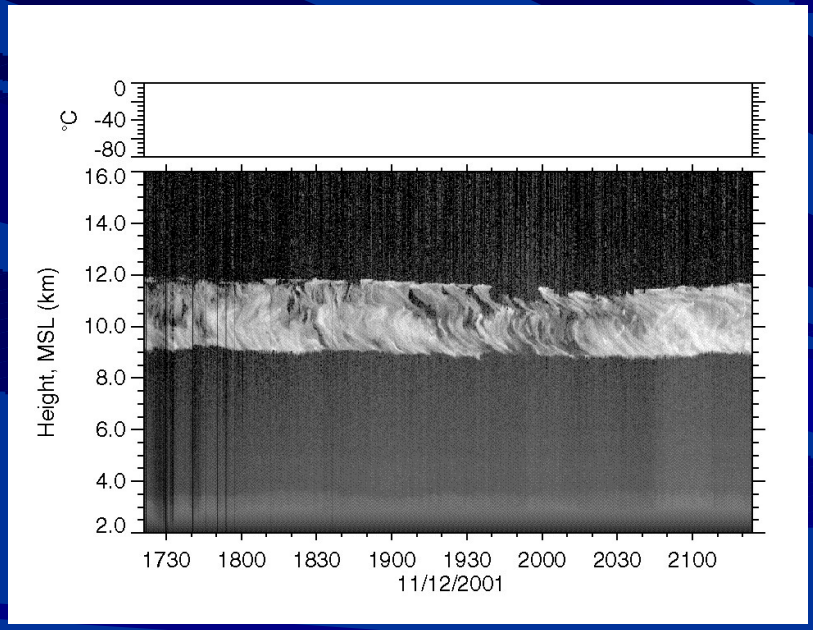
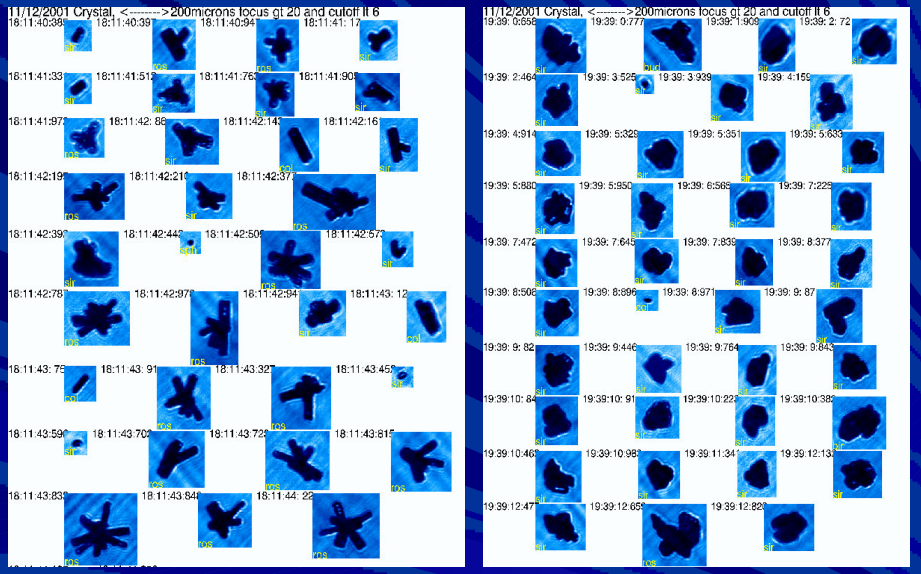
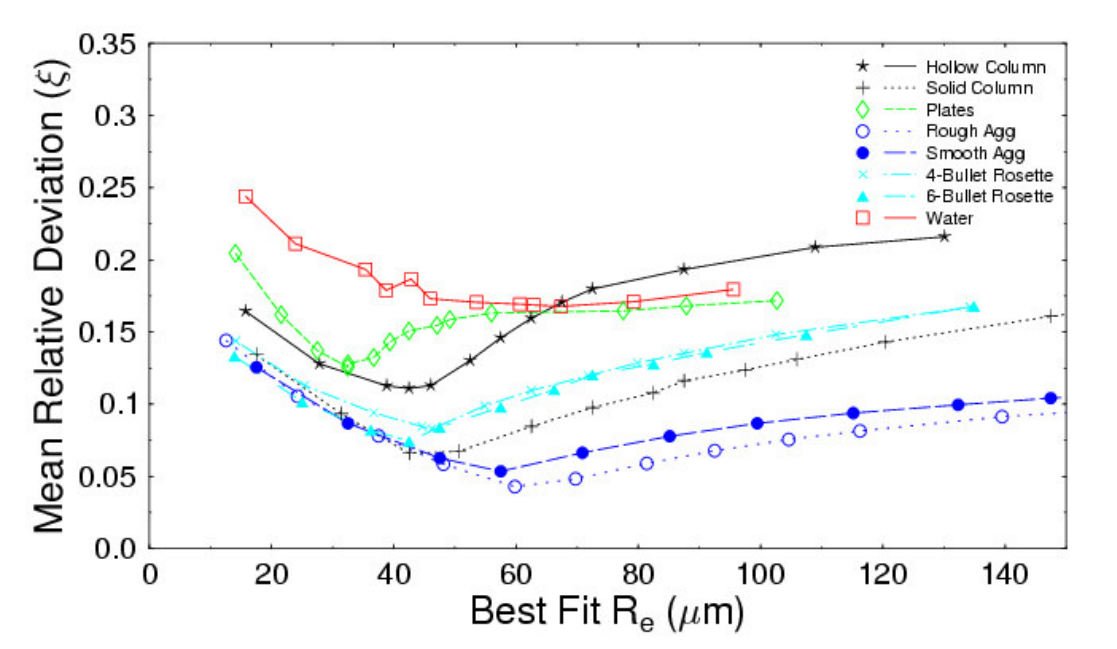


Image from FARS lidar



Images from cloud particle imager (CPI)on in situ aircraft above FARS; crystals are primarily bullet rosettes and aggregates

Case Study 3: Retrieval Results



Retrieval results for FARS case using MISR and MODIS observations.

- In situ measurements were made within the same cloud system; roughly 180 miles away
- In situ measurements show bullet rosettes and aggregates; retrieval shows aggregates as best fit
- Need to study effects of habit mixtures in retrieval

Conclusions

- Initial results show ability to discriminate cloud phase and crystal habit
- Need case studies with coincident in situ measurements of crystal habit for validation.
- Need to perform sensitivity studies to understand effects of habit mixtures; sensitivity to vertical structure; depth to which retrievals are valid
- Knowledge of crystal habit can constrain radar Z-V retrieval algorithms