Simulating lidar depolarization by aerosols and clouds: Lessons learned from the M-PACE & SHEBA campaigns

Bastiaan van Diedenhoven
(Columbia University, NASA GISS)
Ann Fridlind, Andrew Ackerman (NASA GISS)

Thanks to Hugh Morrison and Paquita Zuidema for providing data

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

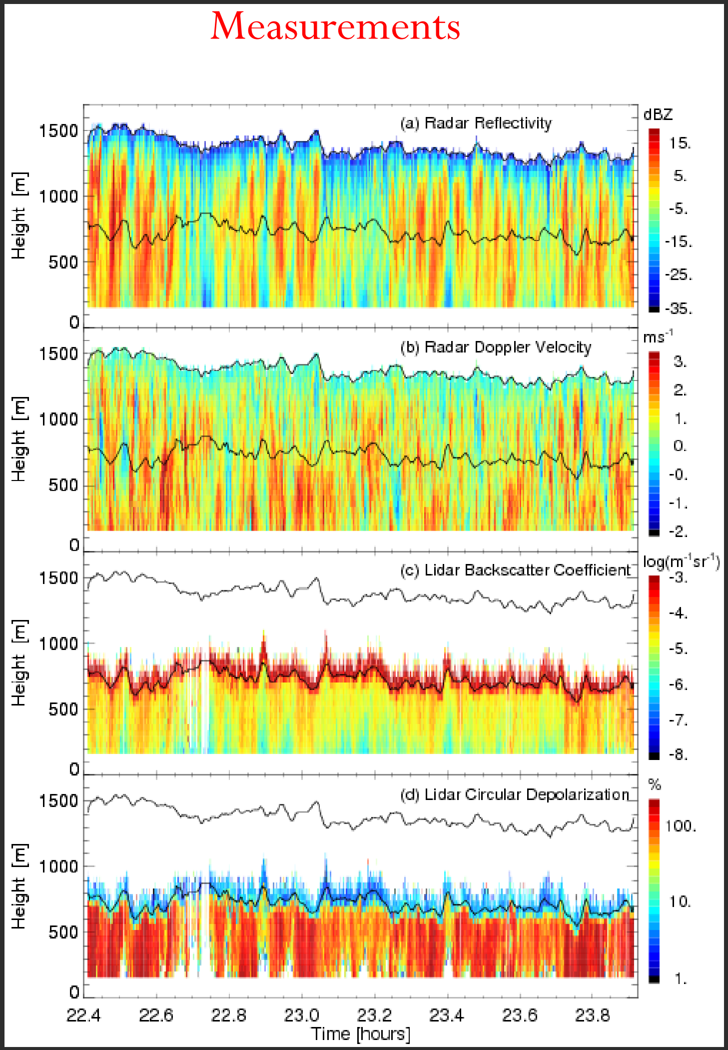
National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y. 10025

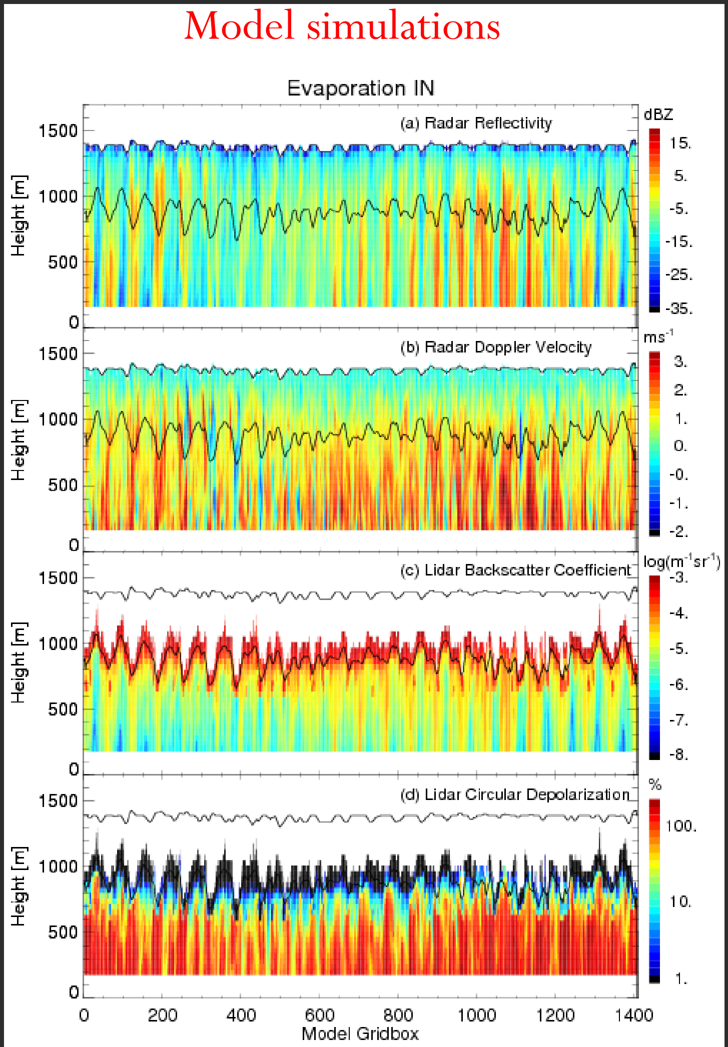
ARM CMWG meeting, Boulder, September 2009

Goals

- Understand lidar depolarization distribution under cloud base during M-PACE and SHEBA case studies
- Explore possibility of using simulated depolarization from model results to evaluate modeled liquid versus ice precipitation

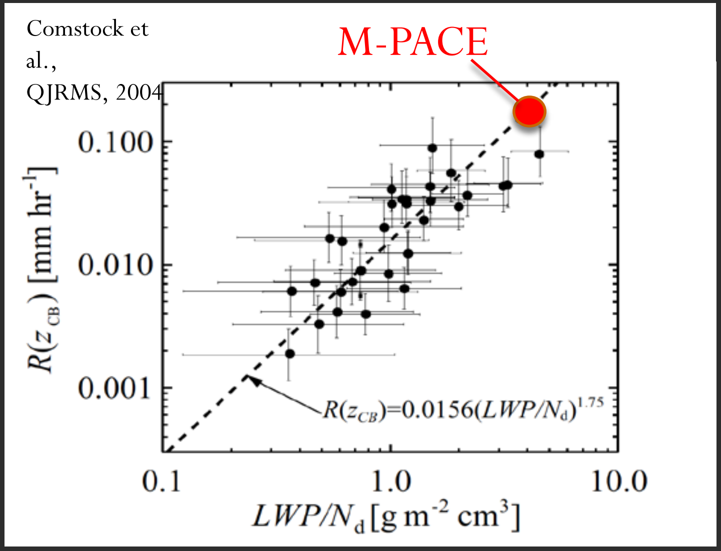
M-PACE 9 October 2004 MMCR Radar & HSRL Lidar study (van Diedenhoven et al., JGR, 2009)

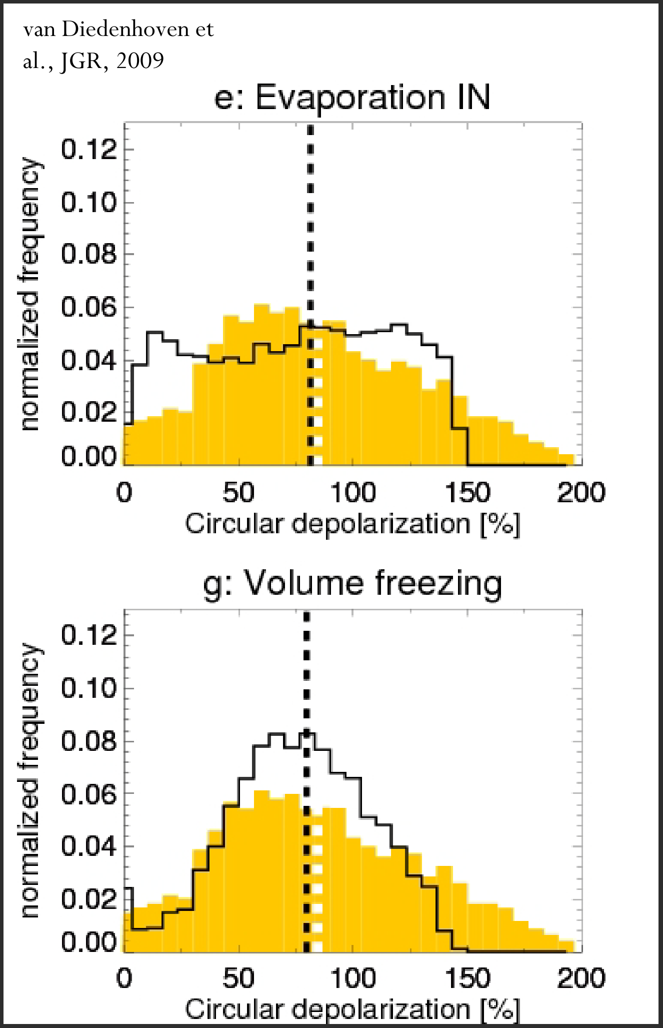




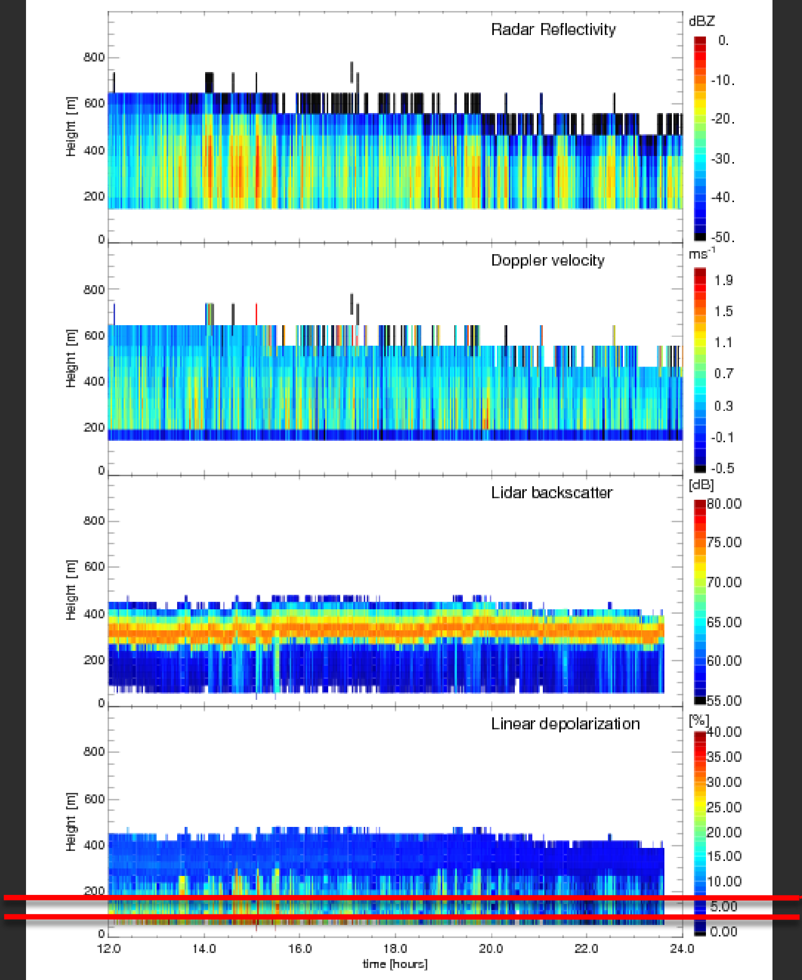
Depolarization under cloud base during M-PACE

- Simulating depolarization distribution helped identifying model runs with realistic relative amount of ice and drizzle under cloud
- Simple lidar simulations based on DHARMA simulations assume
  - Spherical drizzle drops ➔ 0% depolarization
  - Ice aggregates with optical properties similar to rough columns with AR=0.6 ➔ 150% circular depolarization



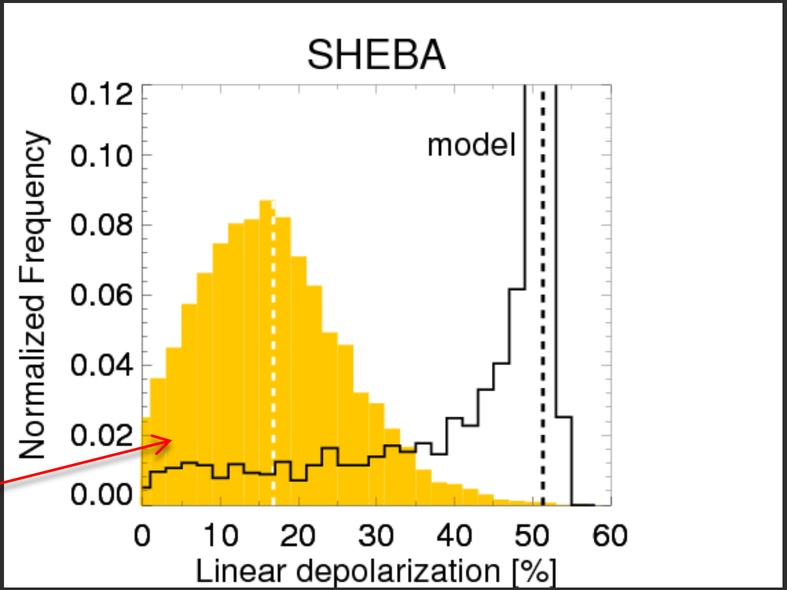


SHEBA 7 May 1998
MMCR radar and DABUL lidar

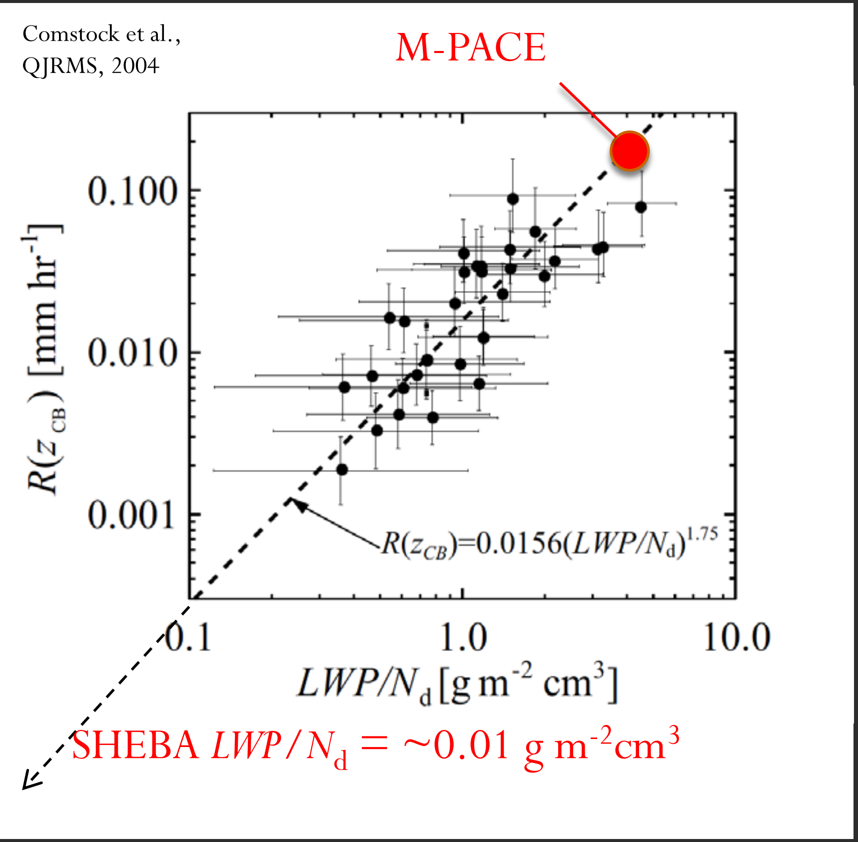


Thanks to Paquita Zuidema and Janet Intrieri for lidar data

- Low depolarization values under cloud base but no drizzle modeled (as expected)



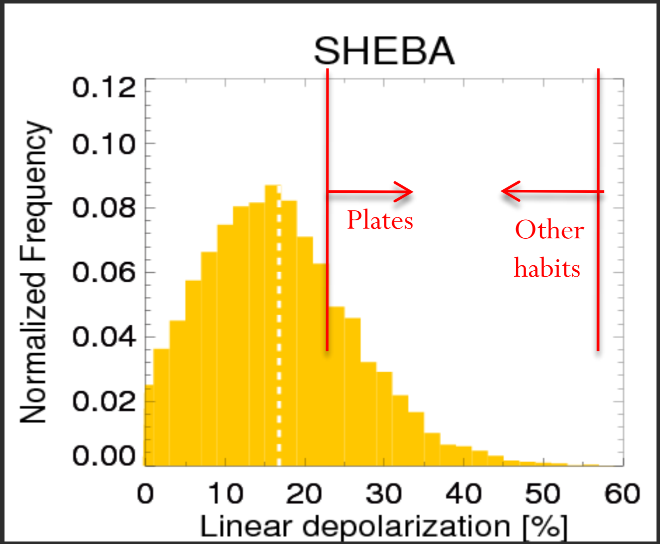
No drizzle during SHEBA

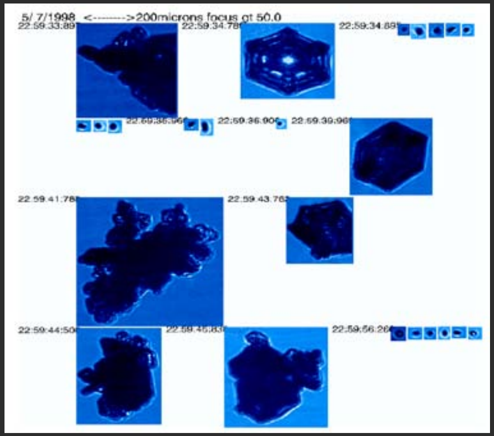


Variation in crystal habit cannot explain depolarization distribution

Particle shape	Linear depolarization
Spheres	0%
Aggregates	58%
Bullets/rosettes	50%
Droxtals	55%
Columns	40%--55% depending on aspect ratio
Plates	23%--40% depending on aspect ratio

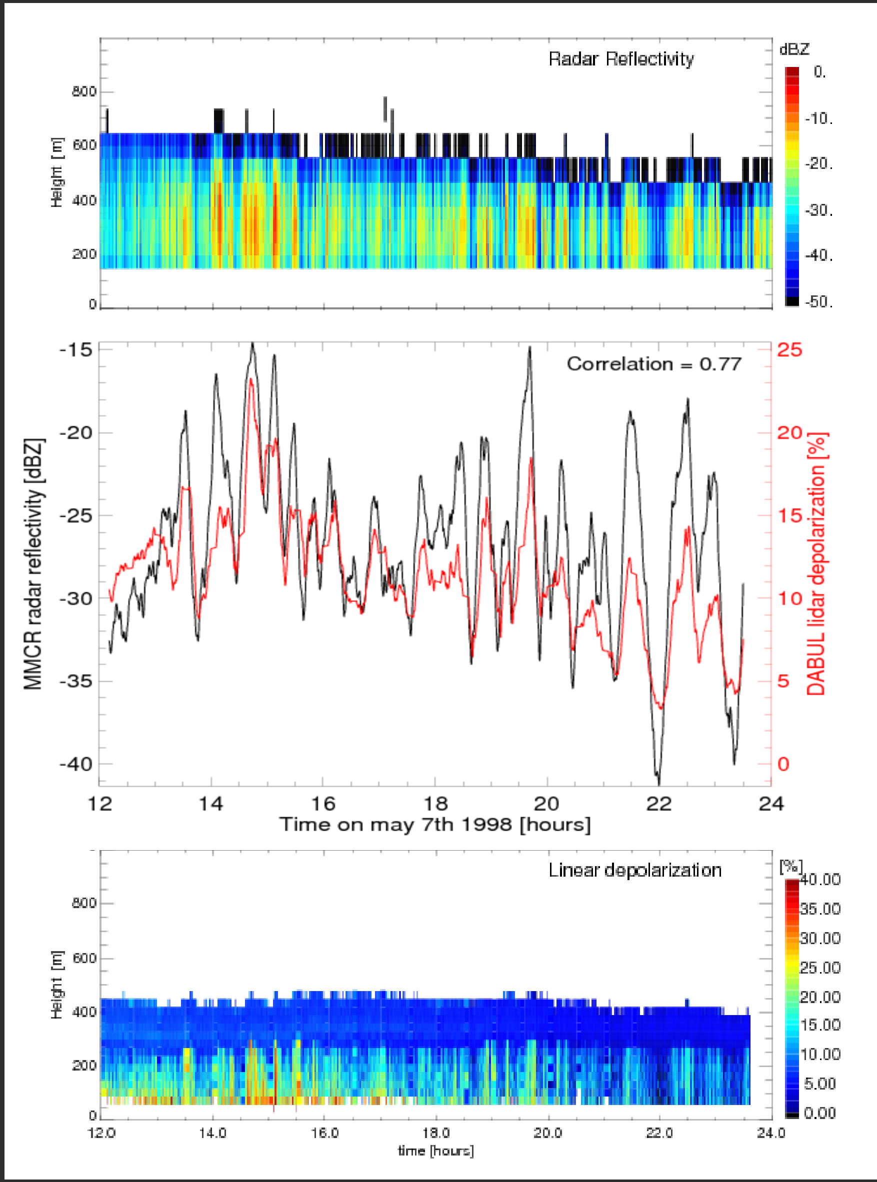
See for example You et al. JQSRT 2006, Yang et al. JQSRT 2009, Sassen & Benson JAS 2000





Reflectivity and depolarization

- Strong correlation with Radar reflectivity suggests that variation in depolarization is related to variation in IWC
- Spherical particles must be present ➔ aerosols



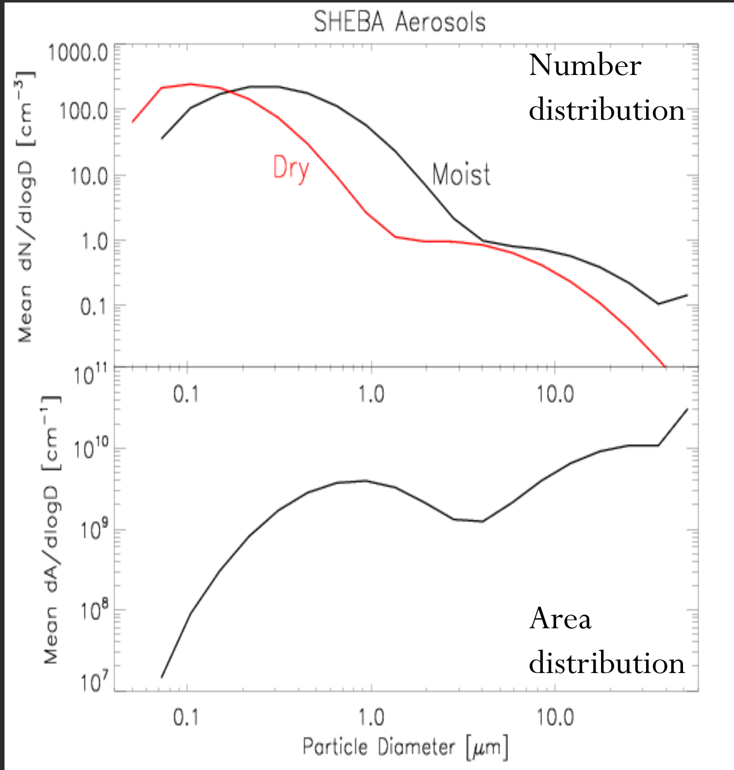
Including humidified aerosols in the simulations

- No aerosol measurements during SHEBA
- Dry aerosol distributions are based on M-PACE HHPC-6 measurements scaled for polluted SHEBA conditions (Hugh Morrison)

30 September Update:

Aerosol distribution documented as dry was actually measured at ambient RH!!

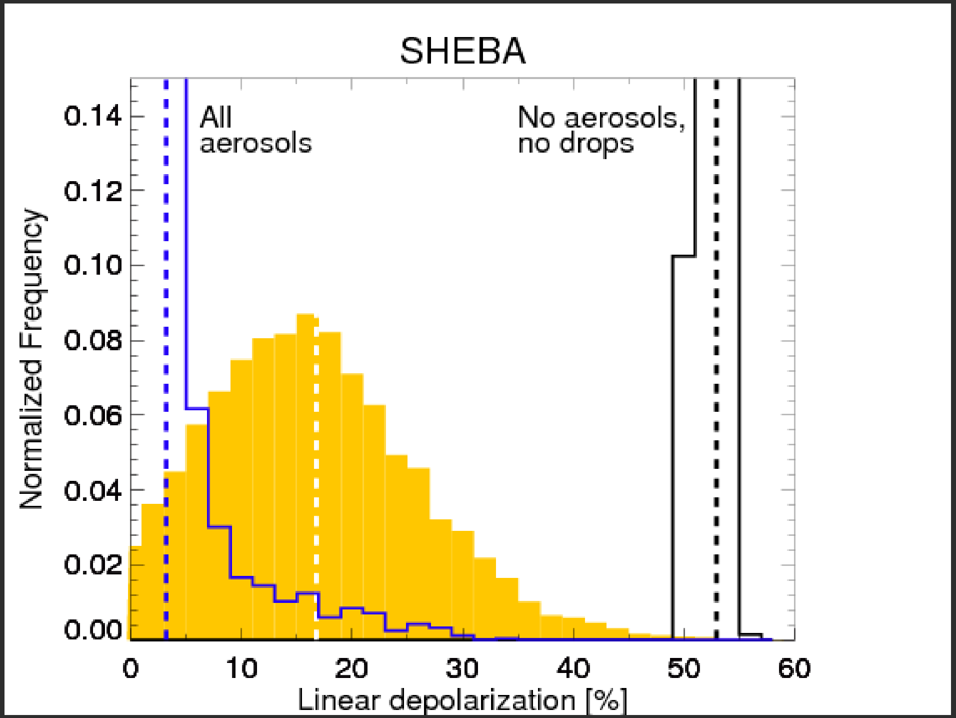
So consider presented effects of aerosols overestimated!



Dry aerosol distribution:
$N1=350\ cm^{-3}$, $r1=0.052\ \mu m$, $\sigma1=2.04$
$N2=1.8\ cm^{-3}$, $r2=1.3\ \mu m$, $\sigma2=2.5$

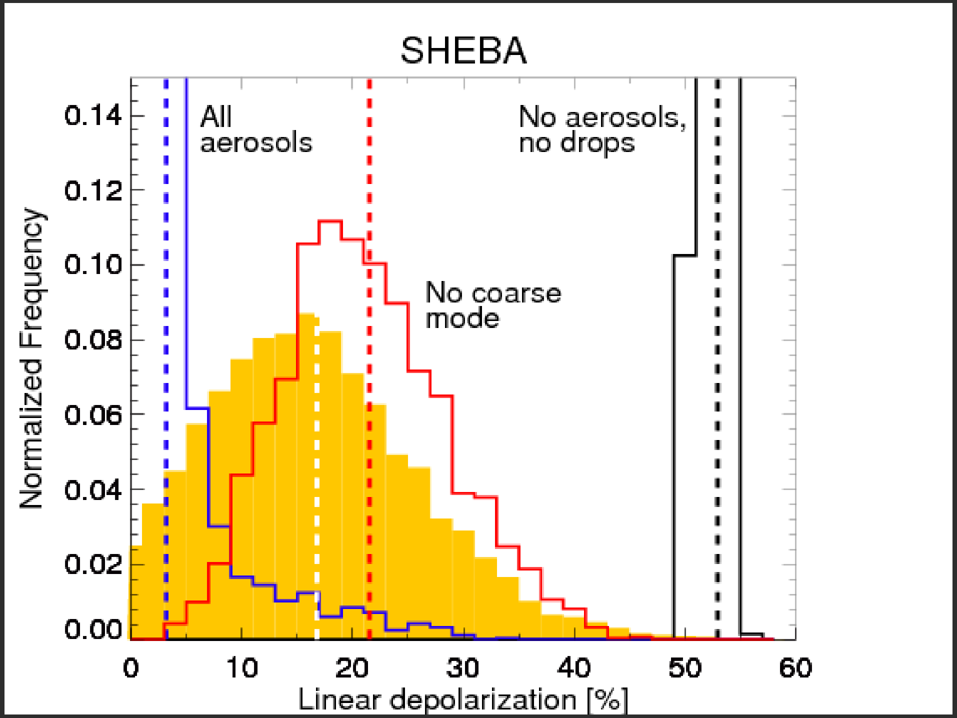
SHEBA results including aerosols

- Lidar simulation based on DHARMA results with
  - Activated drops removed
  - Spherical humidified aerosols included ➔0% depolarization
  - Ice aggregates with scattering properties as rough columns with AR=0.6 ➔55% depolarization
- Including aerosols leads to very low mean depolarization values



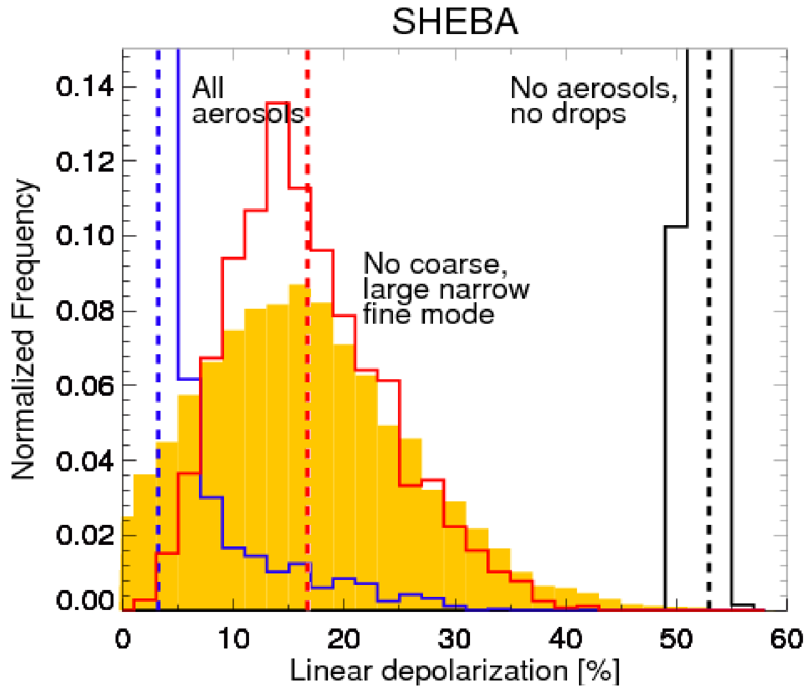
SHEBA results including aerosols

- Large mode consist of sea salt from marine air sampled during M-PACE
- SHEBA measurements above frozen ice pack
- Removing large mode leads to slightly higher depolarization than measured



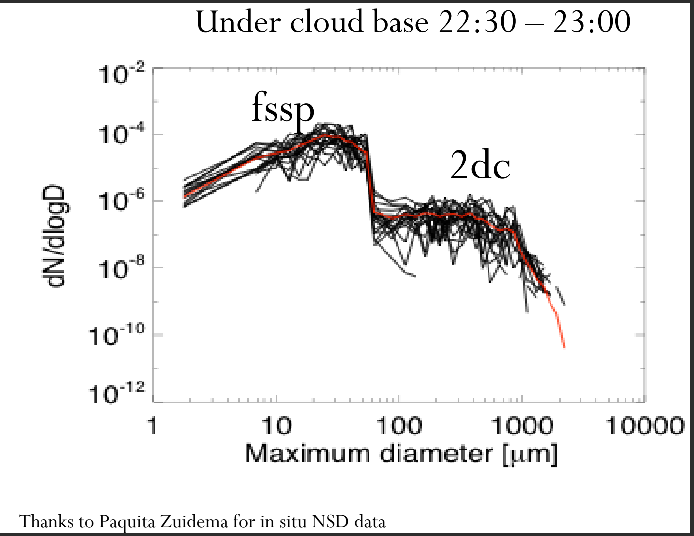
SHEBA results including aerosols

- SHEBA conditions are polluted while M-PACE was clean
- Increasing fine mode sizes while narrowing distribution brings depolarization into even better agreement with measurements

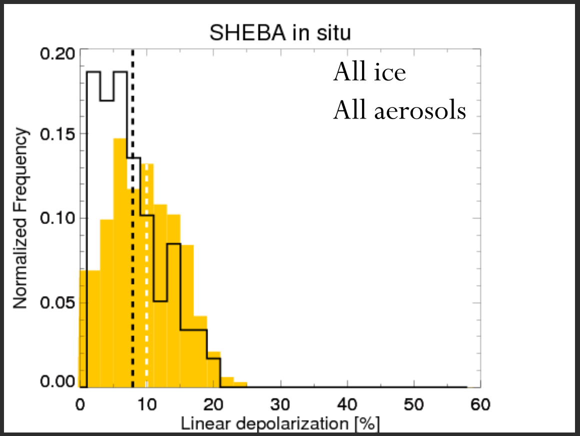


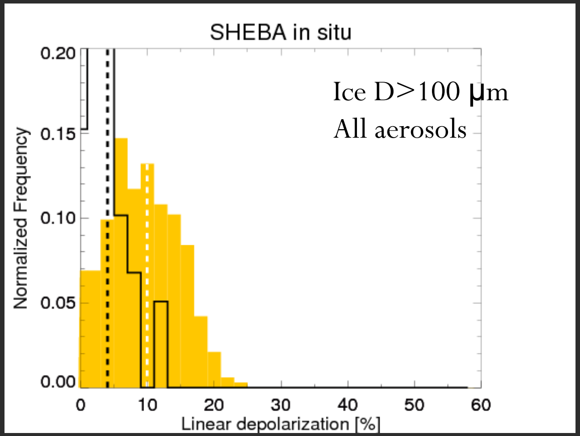
Dry aerosol distribution:
N1=350 cm^{-3}, r1=0.1 μm, σ1=1.5

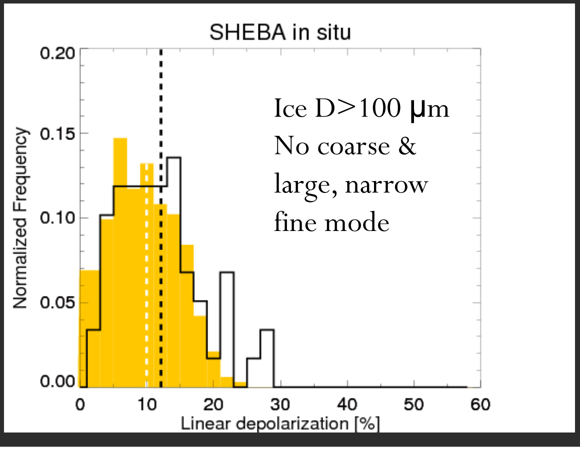
Depolarization from in situ size distributions



- Lidar simulation based on in situ number size distributions with
  - Average humidified aerosols from simulations
  - Ice scattering properties as rough columns with AR=0.6

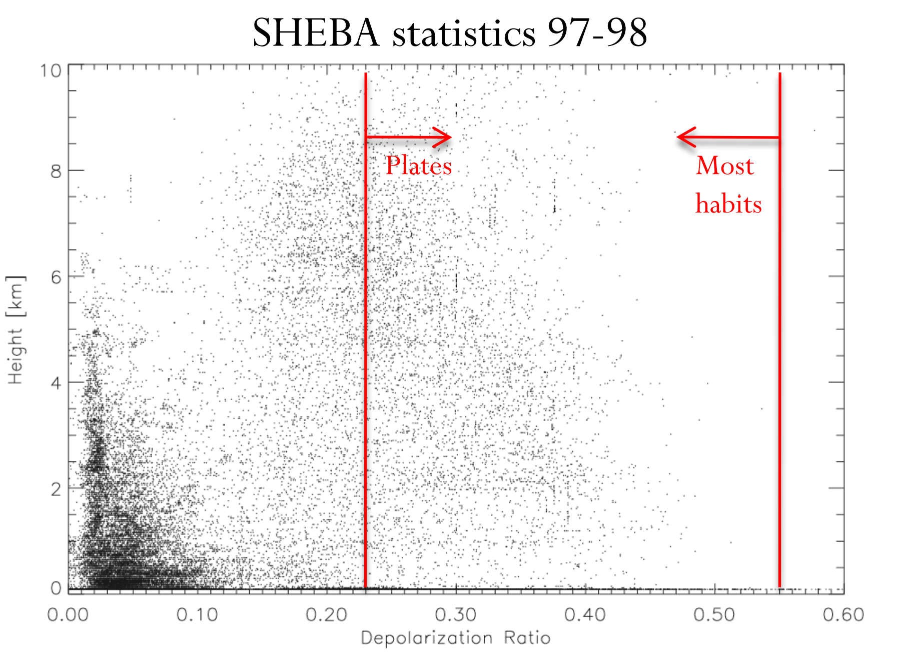






Depolarization statistics

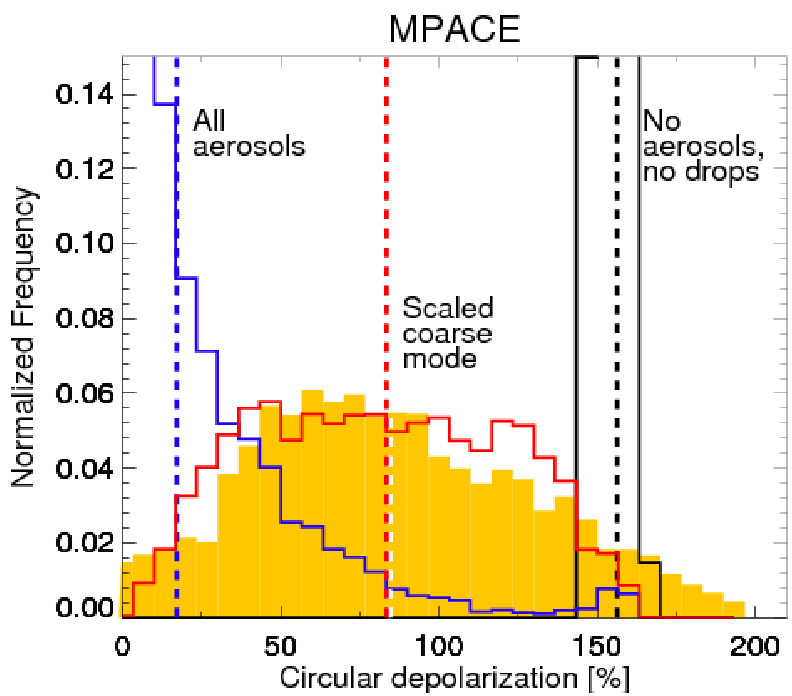
- How prevalent is effect of humidified aerosol on lidar depolarization?
- Statistics indicate pervasive contribution of low depolarization to distribution



Intrieri et al.,JGR, 2002

What about aerosols during M-PACE?

- Lidar simulation based on DHARMA results with
  - Drizzle removed
  - Humidified aerosols included
  - Ice properties as rough columns with AR=0.6
- Agrees well when course mode is reduced by factor 8
- What are the relative contributions to depolarization from aerosols versus drizzle?



Dry aerosol distribution:
N1=72 cm^{-3}, r1=0.052 μm, σ1=2.04
N2=1.8 cm^{-3}, r2=1.3 μm, σ2=2.5

Conclusions

- Variation in relative ice and drizzle amounts could explain depolarization during M-PACE but not during SHEBA
- Including realistic humidified aerosols in simulations can explain depolarization during SHEBA
- What are the relative contributions to depolarization during M-PACE from aerosols versus drizzle?
- Effect of aerosols complicates the use of depolarization for evaluation of modeled precipitation phase
- 30 Sept. Update: Effects of aerosols shown here overestimated due to assumption that measured size distribution is for dry aerosol!
- ISDAC high quality continuous aerosol measurements will provide excellent data to further explore

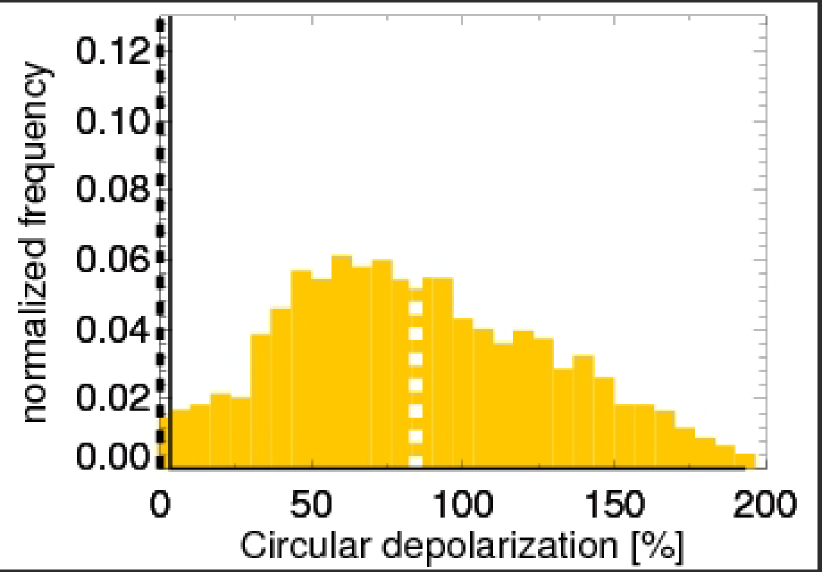
Thanks

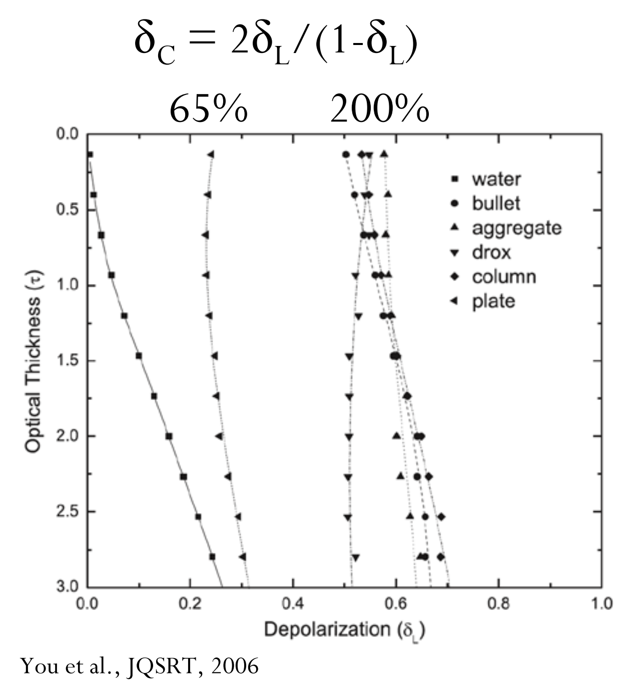
See results with updated dry aerosol size distribution at our AGU talk/poster (Fridlind et al.)

Extra slides

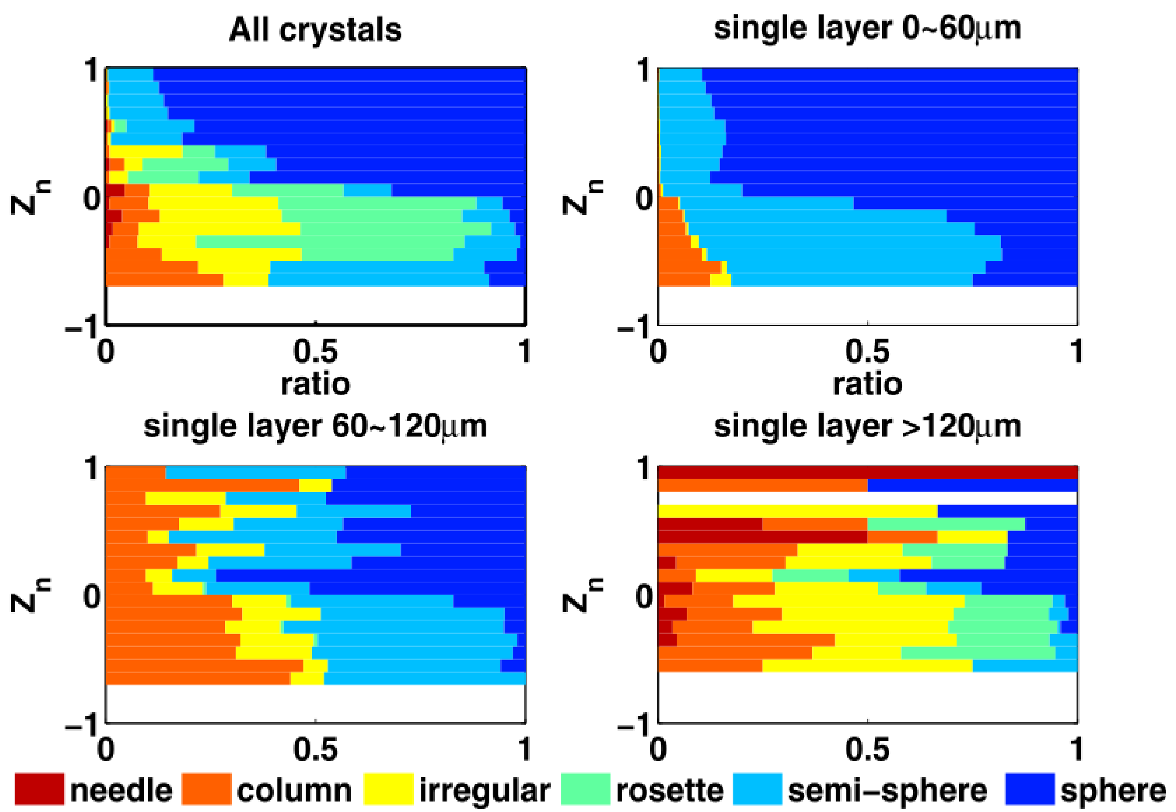
Depolarization during MPACE

- Distribution of low depolarization values cannot be explained by ice habit variations



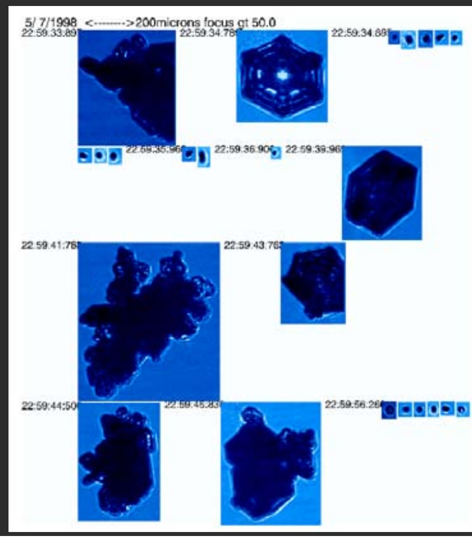


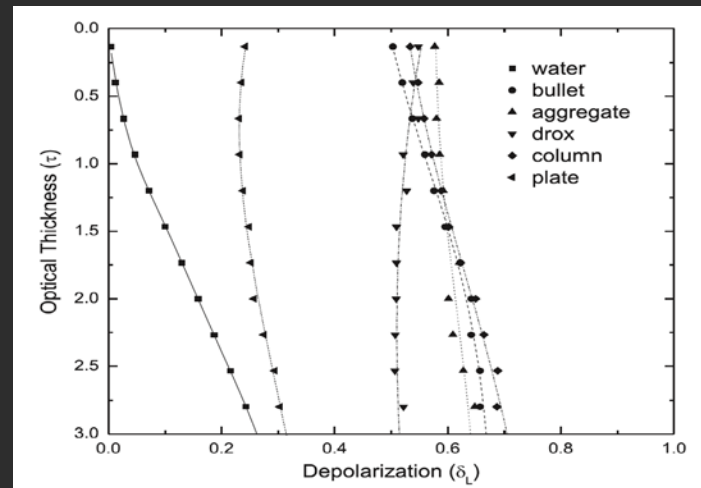
M-PACE habits



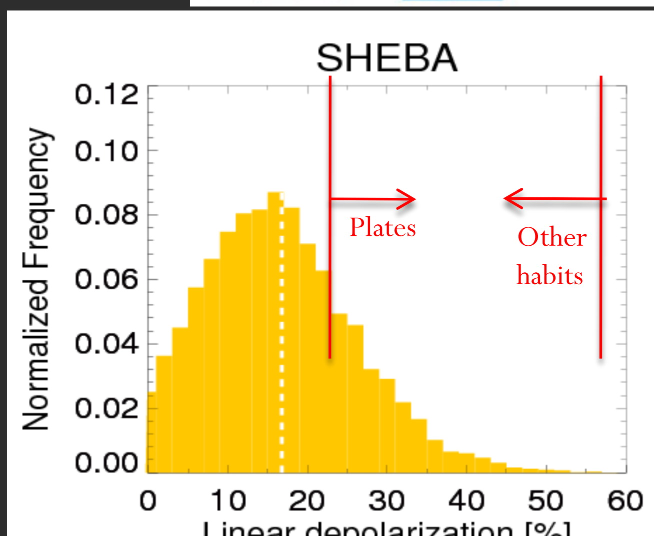
McFarquhar et al., JGR, 2007

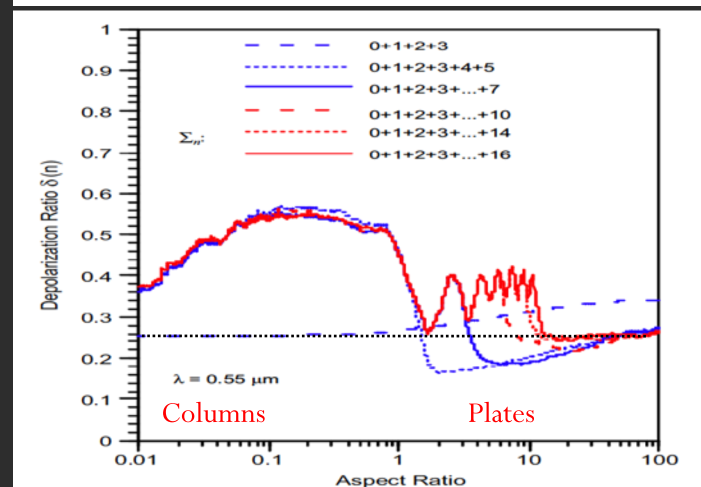
Variation in crystal habit cannot explain depolarization distribution





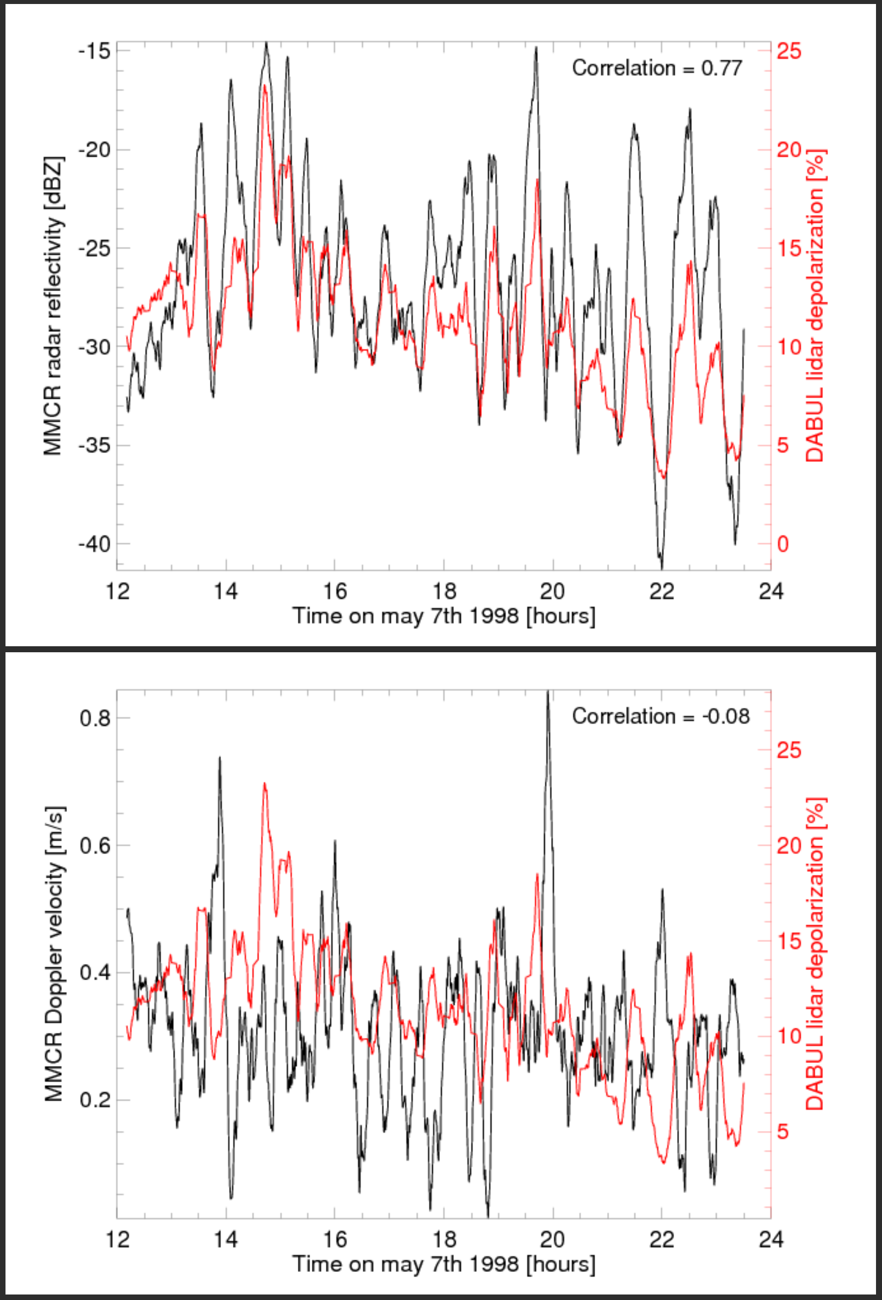
You et al., JQSRT, 2006





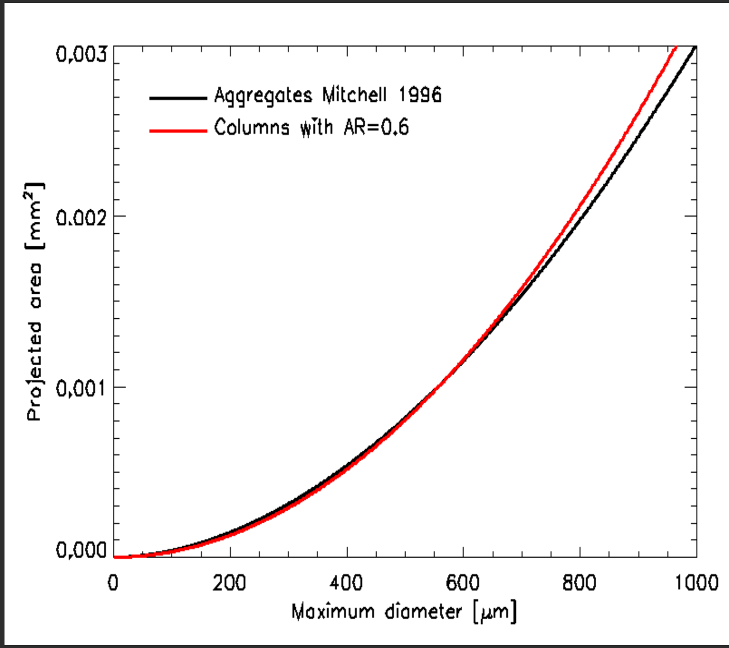
Yang et al., JQSRT , 2009

Correlation reflectivity and Doppler velocity and lidar depolarization under cloud base



Ice scattering properties model

- Scattering properties of aggregates are simulated using hexagonal columns with AR=0.6
- Such columns have projected area - diameter relation similar to aggregates
- Scattering properties obtained by ray tracing (Macke et al 1996)
- 10% 'Roughness' of surface reduces g and backscattering
- Particles with rough surfaces all have similar phase functions (e.g. Macke et al 1996)



Definition of linear depolarization

Linear depolarization: $\delta_L = (\beta - \beta_L)/(\beta + \beta_L) * 100\%$

Backscatter coefficient: $\beta(z) = \sum n_i(z)\sigma_i P_{11}(180^o)_I$

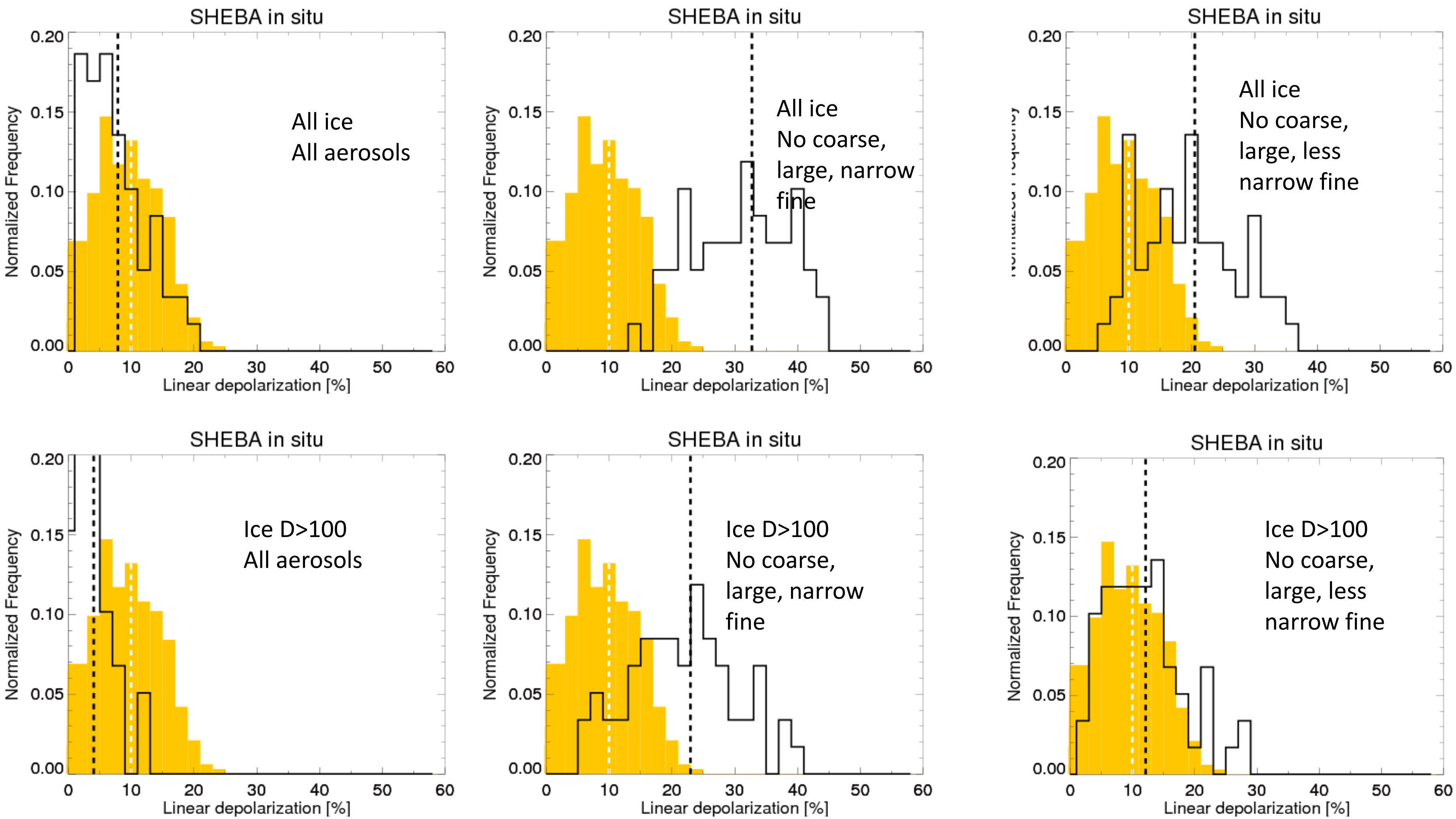
Equivalent backscatter coefficient for linear polarized light:

$\beta_L(z) = \sum n_i(z)\sigma_i P_{22}(180^o)_i$

Where $n_i(z)$ = number density of particle size/type i

σ= scattering cross section of particle size/type I

$P_{11}(180^o)_I$ = normalized phase function in backscattering direction


SHEBA in situ
All ice
All aerosols
SHEBA in situ
All ice
No coarse,
large, narrow
fine
SHEBA in situ
All ice
No coarse,
large, less
narrow fine
SHEBA in situ
Ice D>100
All aerosols
SHEBA in situ
Ice D>100
No coarse,
large, narrow
fine
SHEBA in situ
Ice D>100
No coarse,
large, less
narrow fine
Normalized Frequency
Linear depolarization [%]