Liquid Water Clouds

Zhien Wang
University of Wyoming

With contribution from Dave Turner and Andrew Vogelmann

Outline

- What do we have– CLOWD achievements
- What do we need– model evaluation and process study
- What can we do in the near future

CLOWD focus group

THIN LIQUID WATER CLOUDS

Their Importance and Our Challenge

BY D. D. TURNER, A. M. VOGELMANN, R. T. AUSTIN, J. C. BARNARD, K. CADY-PEREIRA, J. C. CHIU, S. A. CLOUGH, C. FLYNN, M. M. KHAIYER, J. LILJEGREN, K. JOHNSON, B. LIN, C. LONG, A. MARSHAK, S. Y. MATROSOV, S. A. MCFARLANE, M. MILLER, Q. MIN, P. MINNIS, W. O'HIROK, Z. WANG, AND W. WISCOMBE

Many clouds important to the Earth's energy balance contain small amounts of liquid water, yet despite many improvements, large differences in retrievals of their liquid water amount and particle size still must be resolved.

The CLOWD Accomplishments

1) the initial BAMS paper that illustrated the size of the problem (i.e., that the retrievals of liquid water cloud properties still have many uncertainties that need to be addressed)   2) that the 90 GHz frequency was critical to improving LWP retrievals when the LWP is small, and that it works in a wide range of conditions. (this work had started before CLOWD was formed, but we intensified the message)   3) the acquisition of the new 3-channel MWRs that include the 90 GHz frequency   4) the CLOWD-BBHRP efforts at Pt Reyes. We just need to finish that analysis through to a publication now   5) the RACORO long-term in-situ field experiment

6) The changing the AERIs to be fast-sampling

From Dave and Andy

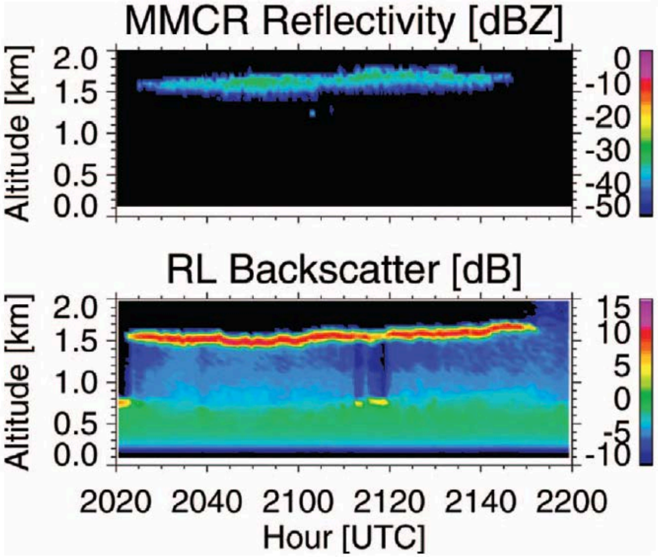
Many algorithms were involved!

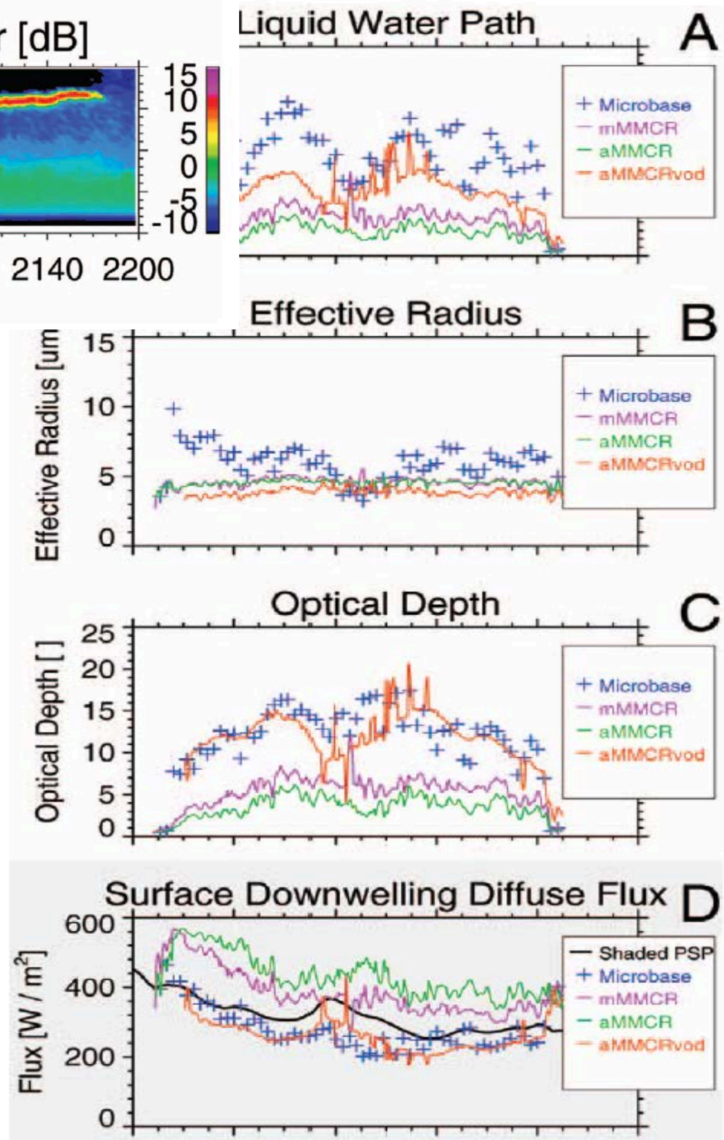
Table 2. Algorithms and participants in the first CLOWD intercomparison.

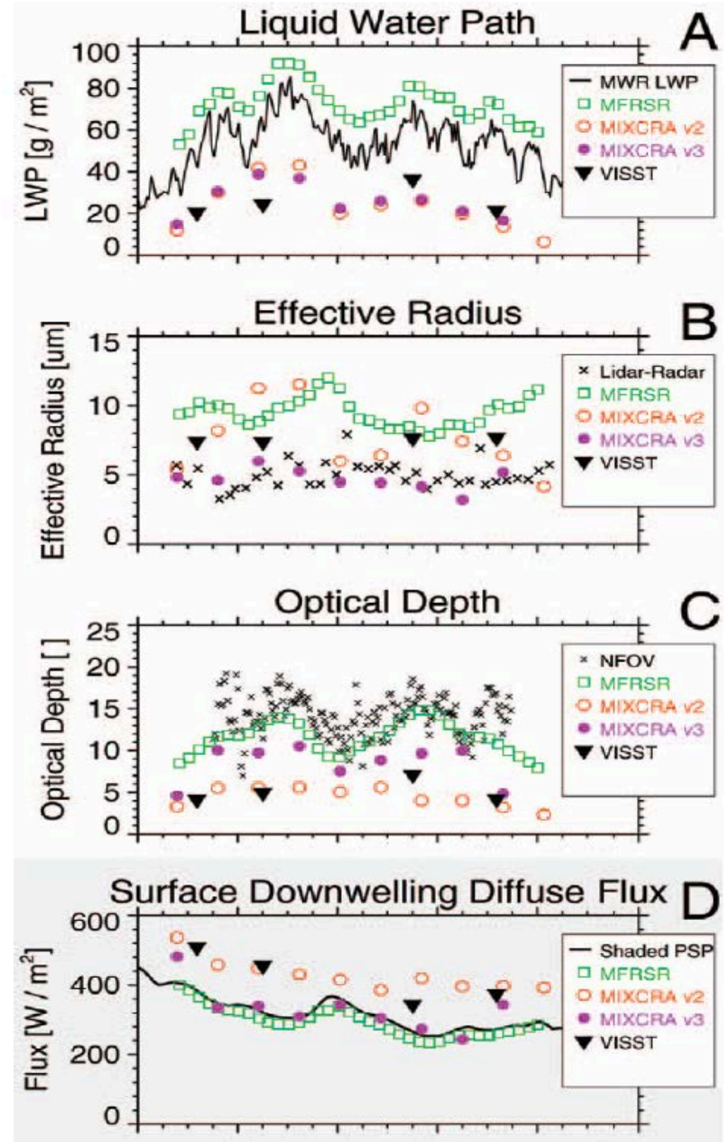
Type	Key name	Contributor	Comments and reference
MICROWAVE	ARM Stat	N/a	MWR LWP, standard ARM product, uses monthly retrieval coefficients determined from Liebe and Layton (1987) (dry air and water vapor) and Grant et al. (1957) (liquid water) absorption model (Liljegren and Lesht 1996)
	Clough Phys	Clough, Cady-Pereira, and Turner	MWR LWP, physical iterative method using optimal estimation, absorption model is monoRTM (Marchand et al. 2003; Turner et al. 2004)
	Lilj Stat2	Liljegren and Turner	MWR LWP, "variable coefficient" method where retrieval coefficients are predicted from surface meteorological observations; absorption model is Rosenkranz (1998) (Liljegren et al. 2001; Turner et al. 2004)
	Lin Phys	Lin	MWR LWP, physical iterative method using the absorption model Liebe and Layton (1987) for dry air and water vapor and Ray (1972) for liquid water (Lin et al. 2001)
CLOUD RADAR	MICROBASE	Miller and Johnson	MMCR LWC and r_e profiles, using the Liao and Sassen (1994) parameterization of Z–LWC and scaling the LWC profile to match the MWR's LWP (Lilj Stat2) (Miller et al. 2003)
	aMMCR	Austin	MMCR-only retrievals of LWC and r_e profiles for nondrizzling clouds, assuming a column-constant value for the droplet number density [an improved algorithm derived from Austin and Stephens (2001)]
	aMMCRvod	Austin	Retrieval of LWC and r_e profiles for nondrizzling clouds, assuming a column-constant value for the droplet number density, from MMCR reflectivities and MFRSR-derived visible optical depths [an improved algorithm derived from Austin and Stephens (2001)]
	mMMCR	Matrosov	MMCR-only retrievals of LWC and r_e profiles, where drizzle regions are identified by simple thresholds (Matrosov et al. 2004)
VISIBLE	MFRSR	Min	MFRSR-derived τ, and when MWR LWP (ARM Stat) is included, r_e is also retrieved and more accurate retrievals of τ are realized (Min and Harrison (1996)
	NFOV	Marshak and Chiu	Retrievals of τ from the narrow field-of-view zenith radiometer (870 nm) [a one-channel approach similar to Marshak et al. (2004); Chiu et al. (2006)]
	Not shown*	Long	Broadband shortwave retrievals of τ using an empirical relationship derived from Min and Harrison (1996), effective radius is assumed to be 10 μm (Barnard and Long 2004)
INFRARED	MIXCRA v2	Turner	AERI-derived τ and r_e, and hence LWP, using radiance observations from 8 to 13 μm (Turner 2005)
	MIXCRA v3	Turner	AERI-derived τ and r_e, and hence LWP, using radiance observations from 8–13 to 3–5 μm (Turner and Holz 2005)
SATELLITE	VISST	Minnis and Khaiyer	*GOES-8* visible infrared solar split-window technique applied to 10-km-diameter footprint centered on the SGP site, providing τ, r_e, and LWP (Minnis et al. 1995)
	Not shown*	Minnis	*Terra* Moderate Resolution Imaging Spectroradiometer (MODIS)-retrieved cloud properties (Minnis et al. 1995)
LIDAR	Lidar–radar	McFarlane	Lidar–radar retrievals of τ and r_e profiles, for cloud elements seen simultaneously by the lidar (MPL) and radar (Donovan and van Lammeren 2001)
	Not shown*	Wang	Raman lidar retrievals of τ
	Not shown*	Flynn	MPL retrievals of τ

*These datasets were not shown in this manuscript in order to maintain some clarity in Figs. 4, 5, and 6.

Issues


MMCR Reflectivity [dBZ]
Altitude [km]
RL Backscatter [dB]
Altitude [km]
2020 2040 2100 2120 2140 2200
Hour [UTC]


Liquid Water Path
A
Microbase
mMMCR
aMMCR
aMMCRvod
Effective Radius
B
Effective Radius [um]
Optical Depth
C
Optical Depth [ ]
Surface Downwelling Diffuse Flux
D
Flux [W / m2]
Shaded PSP


Liquid Water Path
A
LWP [g / m2]
MWR LWP
MFRSR
MIXCRA v2
MIXCRA v3
VISST
Effective Radius
B
Effective Radius [um]
Lidar-Radar
Optical Depth
C
Optical Depth [ ]
NFOV
Surface Downwelling Diffuse Flux
D
Flux [W / m2]
Shaded PSP

What do we need?

- **For cloud climatology**: -- need small mean biases, day-night, and long-term, can have relative large random errors

- **For model evaluation**:

- **For processes study**: need more parameters with high accuracies

What do cloud modelers want?

ARM
Atmospheric Radiation Measurement

- There is no single answer to this…the diversity of cloud types and models governs this
- Quantities of interest:
  - cloud boundaries
  - cloud particle sizes
  - cloud optical depth
  - cloud water contents
  - integrated water contents
- Need more continuous (at all ARM sites, all the time) vs. IOP (quite good at)
- Why continuous?
  - Statistical comparison to models (to alleviate the sampling issue)
  - Look for relationships in the data between meteorology, aero Klein2009 properties

What do we need?

- Be able to deal with all kind of water clouds: Day-night, multi-layer, precipitating
- Be able to cover long-time ACRF data streams
- Take advantages of new instrumentation.

These algorithms were are important!

Single-sensor approaches!

Not enough!

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	[illegible]	[illegible]	… method using the absorption model Liebe and … water vapor and Ray (1972) for liquid water
	[illegible]	[illegible]	… ing the Liao and Sassen (1994) parameterization … C profile to match the MWR's LWP (Lilj Stat2)
	[illegible]	[illegible]	… and r_e profiles for nondrizzling clouds, assum- … r the droplet number density [an improved … and Stephens (2001)]
	[illegible]	[illegible]	… s for nondrizzling clouds, assuming a column- … number density, from MMCR reflectivities and … depths [an improved algorithm derived from
	[illegible]	[illegible]	… and r_e profiles, where drizzle regions are identified by simple thresholds (Matrosov et al. 2004)
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Future
Operational multi-sensor algorithms

- Stratiform water clouds: MWR+MMCR+MPL
  - It can be applied to the most of ARCF data
- Convective water clouds: multi-frequency radar (Hogan 2005; Huang et al. 2009)
  - After new radar
- Can add radiation measurements to further constrain stratiform water cloud retrieval.

Multi-sensor water cloud study—we started this long-time ago!

Measurement of Stratus Cloud and Drizzle Parameters in ASTEX with a K_a-Band Doppler Radar and a Microwave Radiometer

A. S. FRISCH, C. W. FAIRALL, AND J. B. SNIDER

NOAA Environmental Technology Laboratory, Boulder, Colorado

(Manuscript received 1 June 1994, in final form 28 September 1994)

1995

MMCR+MWR

Continental Stratus Clouds: A Case Study Using Coordinated Remote Sensing and Aircraft Measurements

KENNETH SASSEN, GERALD G. MACE, AND ZHIEN WANG

Department of Meteorology, University of Utah, Salt Lake City, Utah

MICHAEL R. POELLOT

Atmospheric Sciences Department, University of North Dakota, Grand Forks, North Dakota

STEPHEN M. SEKELSKY AND ROBERT E. MCINTOSH*

Microwave Remote Sensing Laboratory, University of Massachusetts–Amherst, Amherst, Massachusetts

1999

(Manuscript received 12 December 1997, in final form 11 August 1998)

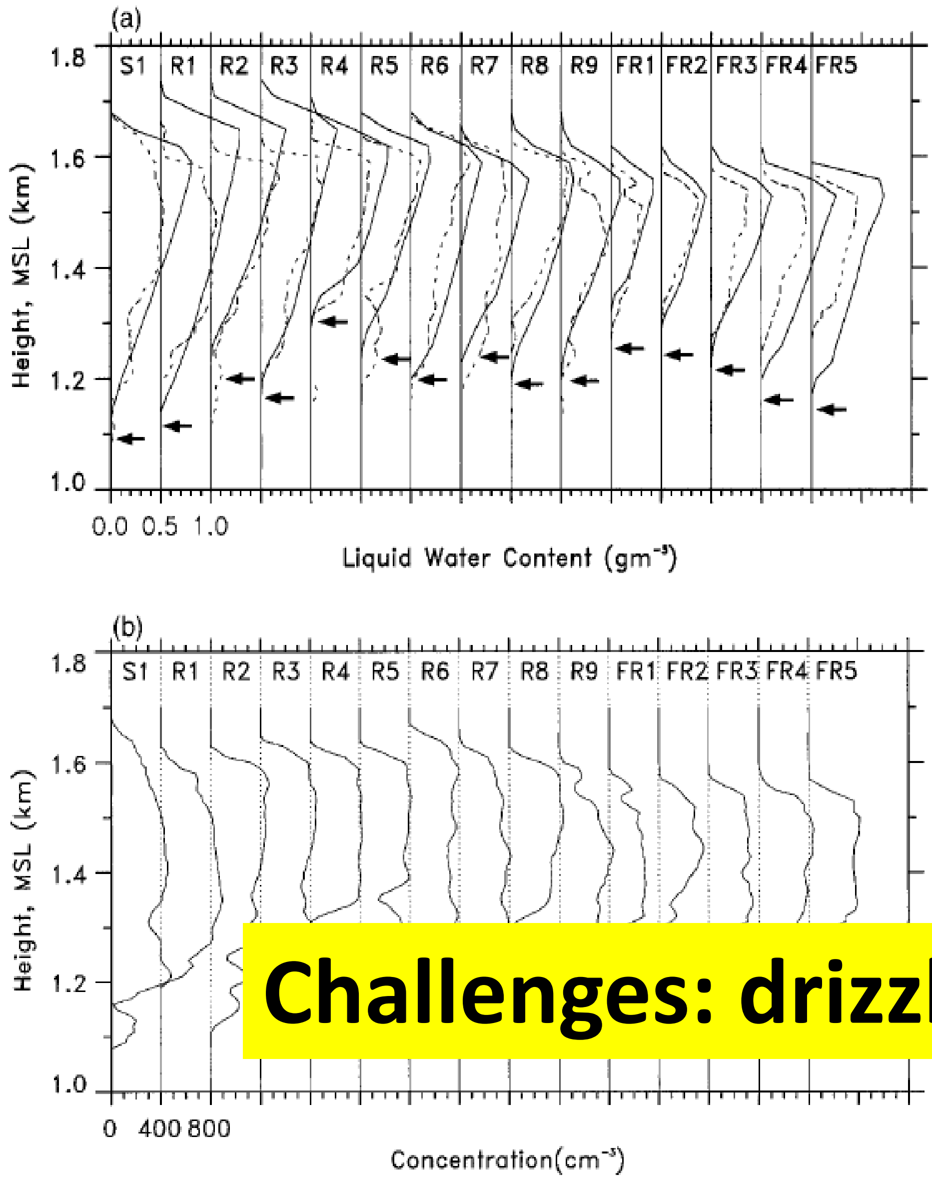


FIG. 3. Comparison of vertical profiles of (a) LWC derived from the FSSP (dotted) and the radar algorithm (solid) using the average in situ measured N_d, with arrows indicating the lidar cloud-base height; (b) the FSSP-derived droplet number concentration. Each set of profiles in (a) [or (b)] is shifted to the right by 0.5 gm^{-3} (400 cm^{-3}) and is based on the 30-m K$_a$-band radar resolution.

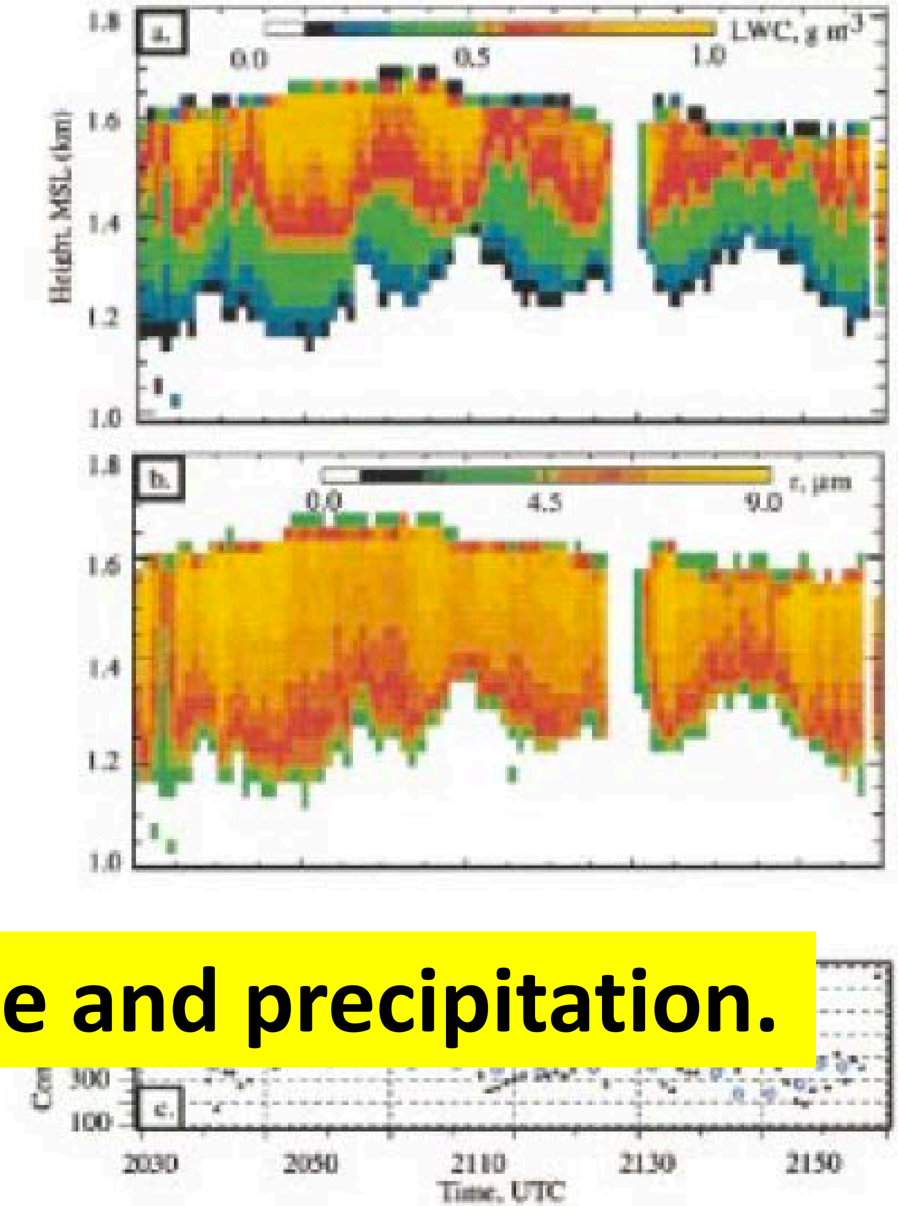


FIG. 8. Comparison of 1-min resolution (a) stratus LWC field using the variable N_d radar algorithm method, (b) radar-derived $\bar{r}$, and (c) a plot of radar-derived (*) and in situ ramp-averaged (○) N_d.

Challenges: drizzle and precipitation.

MMCR+MWR+ MPL (lidar) (3M) for stratiform water clouds

Radar

Lidar

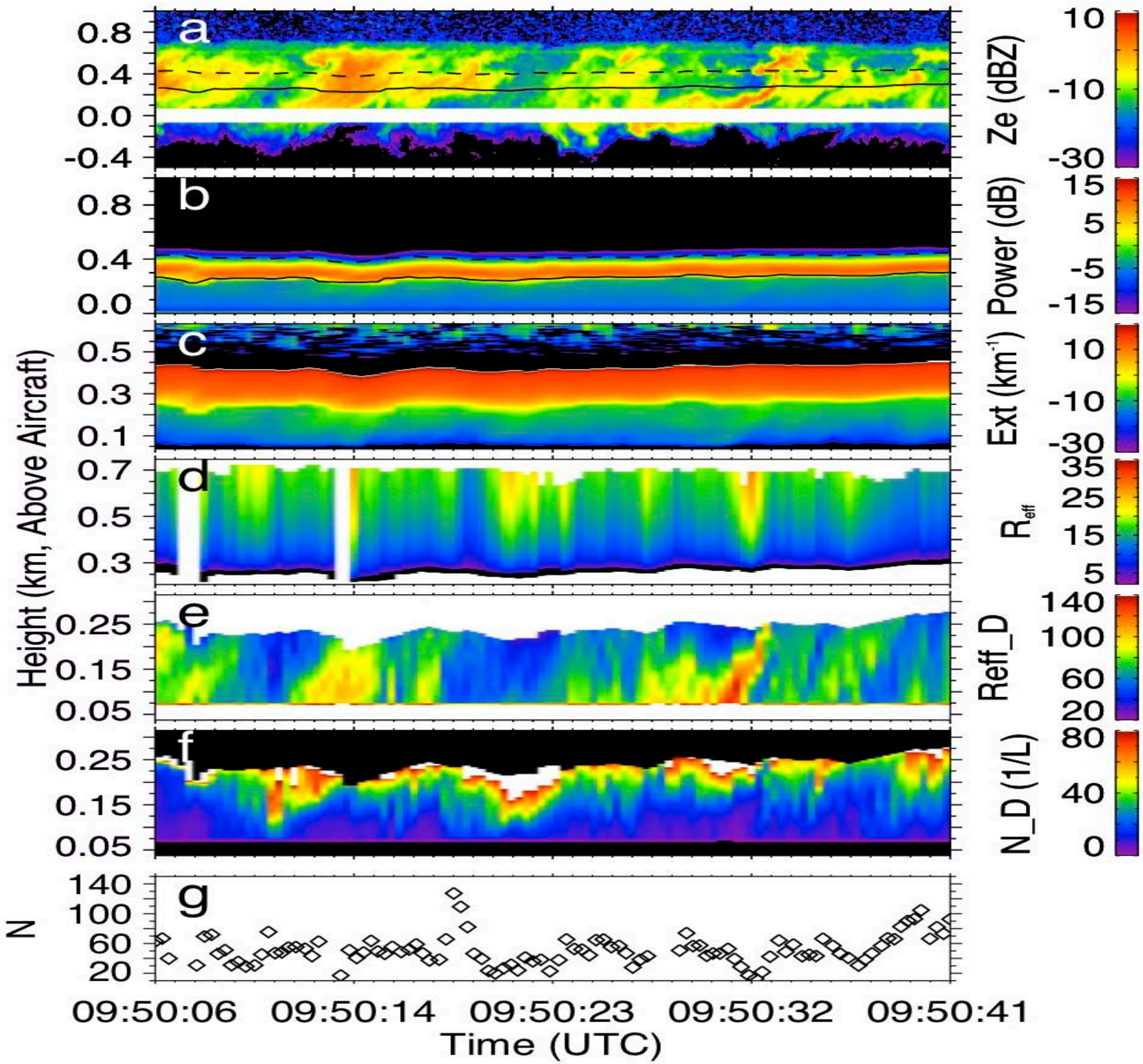
Lidar extinction

Cloud r_{eff}

Drizzle r_{eff}

Drizzle N

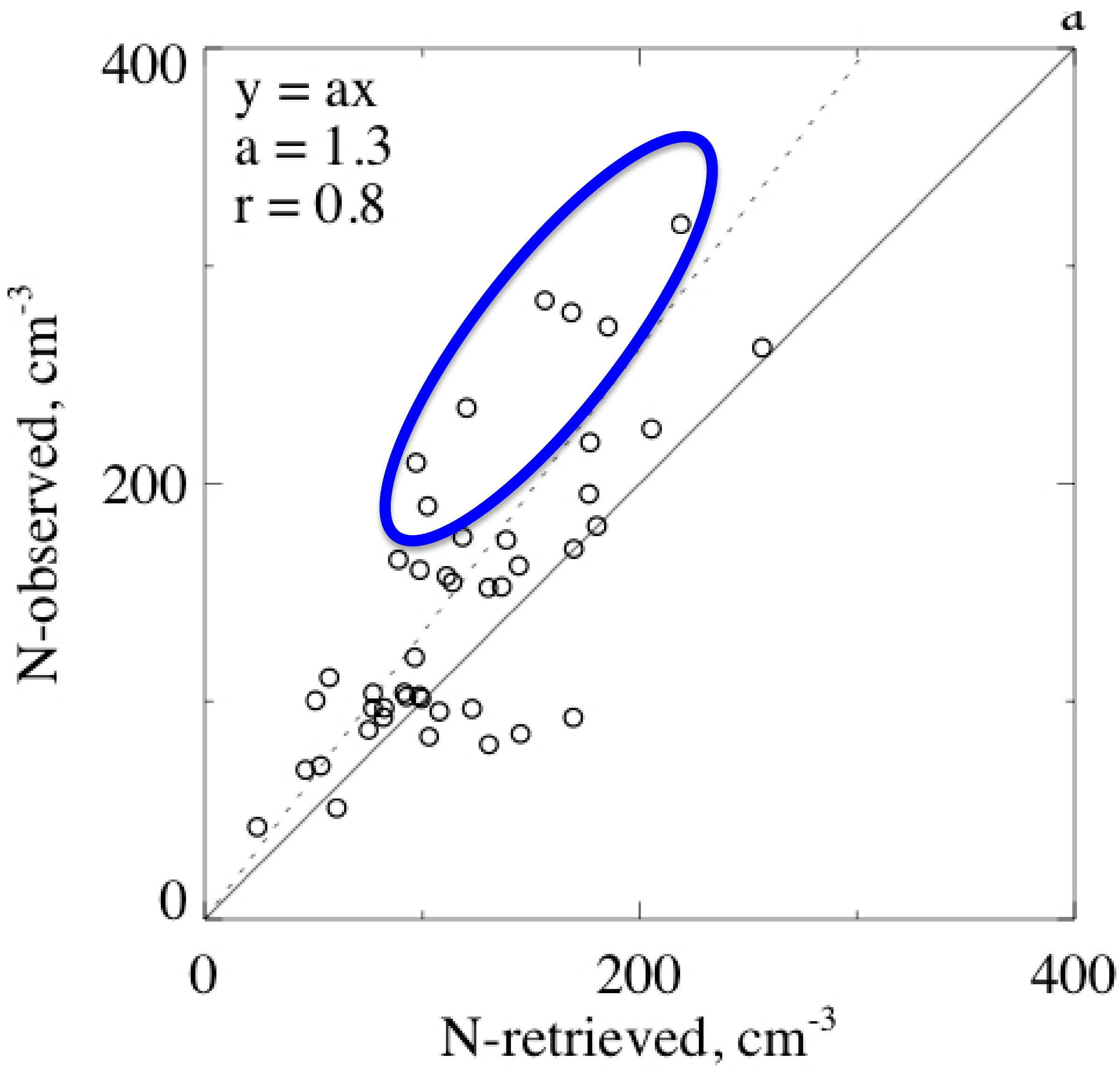
Cloud N



A VOCALS case

Water droplet concentration evaluation

In-situ



Remote Sensing

Key measurements
1. LWP

- Take advantage the new 90 GHz data (Dave and Maria working on this).
- Deal with "difficult" situations such as mixed-phase and broken cloud (e.g., cumulus) conditions.
- Maintain instrumentation stability.
- Using clear sky measurements as reference points to improve the retrievals (Wang 2007).

Key measurements

2. Radar
- Calibration
- Pointing for Doppler measurements

3. Lidar
- Avoiding signal saturations

Measurement Issues

- Calibrations: instrumentation side and data processing
- Be able to cover required signal range
  - MPL signal saturations in water clouds
- Smart sampling and averaging–
  - cloud–type dependent signal intensity.
  - Changing clouds -- signals are non-linearly dependent on cloud properties.