Understanding Differences in Current ARM Ground-based Cloud Retrievals

Chuanfeng Zhao[1*](zhao6@llnl.gov), Shaocheng Xie[1], Stephen A. Klein[1], Renata McCoy[1],
Jennifer Comstock[2], Min Deng[3], Maureen Dunn[4], Robin Hogan[5], Dong Huang[4], Michael Jensen[4],
Jay Mace[6], Sally McFarlane[2], Ewan Oconnor[5], Matthew Shupe[7], Dave Turner[8], Zhien Wang[3]

1. Lawrence Livermore National Lab, CA, USA
2. Pacific Northwest National Lab, WA, USA
3. University of Wyoming, WY, USA
4. Brookhaven National Lab, NY, USA
5. University of Reading, Reading, UK
6. University of Utah, UT, USA
7. University of Colorado, CO, USA
8. NOAA National Severe Storms Lab, OK, USA

Motivation

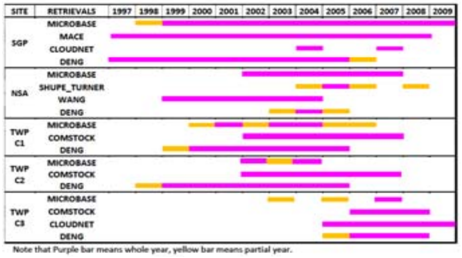
The representation of clouds remains one of the largest uncertainties in current climate prediction. Cloud properties retrieved from ARM ground-based measurements provide an opportunity for better understanding cloud microphysical processes and improving cloud parameterizations in climate models. However, uncertainties in various retrievals, pose a severe restriction on using these retrieval products in cloud modeling studies.

Understanding the cloud retrieval uncertainties helps climate modelers better constrain climate models. An in-depth analysis of the existing cloud retrievals helps explore issues and provides insights for scientists to further improve their cloud retrieval products. It also helps users to better use the data.

In this study, 7 ARM ground-based cloud retrievals are combined into a cloud retrieval ensemble dataset (CRED); and are used to understand the retrieval differences.

7 ARM Ground-based Cloud Retrievals

- MICROBASE: ARM baseline cloud retrieval product (led by Dr. Michael Jensen at BNL)
- MACE: More physically based cloud retrievals (Prof. Jay Mace of Univ. of Utah)
- CLOUDNET: improved parameterization estimate (Prof. Robin Hogan of Univ. of Reading)
- DENG: physically based cloud retrievals for cirrus (Dr. Min Deng of Univ. of Wyoming)
- SHUPE_TURNER: Physically based (thin mixed) and parameterization method (Other clouds) (Dr. Matthew Shupe of Univ. of Colorado; Dr. David Turner of NOAA Nation. Severe Storms Lab)
- WANG: Arctic Mixed Phase clouds (Physically based) (Prof. Zhien Wang of Univ. of Wyoming)
- COMSTOCK: Case-dependent parameterization at TWP (Dr. Jennifer Comstock at PNNL)



Note that Purple bar means whole year, yellow bar means partial year.

Retrieval Techniques

Retrievals	Clouds	Refs	Assumptions		Theory Based Functions/Models/parameters …	Major Inputs	Direct output	Method
			PSD	Habit				
MICROBASE	Liquid	Liao and Sassen 1994; Frisch et al. 1995	Log-normal (σ=0.35)	spherical	LWC=F(Z); re=F(Z); N~200 cm^{-3}	Z, LWP	re, LWC	EPM
	Ice	Liu & Illingworth 2001; Ivanova et al. 2001	Exponential	Planar polycrystals	IWC=F(Z); re=F(T)	Z, T	re, IWC	EPM
	Mixed	All above	See above	See above	f_{ice}=-T/16; $Z_{liquid}=(1-f_{ice})*Z$; $Z_{ice}=f_{ice}*Z$	Z, LWP, T	re, WC	EPM
MACE	Boundary stratus	Dong et al. 1998 (Layer Average)	log-normal (σ=0.35)	Spherical	Thick: re=F(LWP, γ, μ0); Thin: δ-2 stream model	LWP, R, γ, μ0	re	EPM; optimal
		Dong and Mace 2001 (Vertical Profile)	Log-normal	Spherical	LWC=F(LWP, Z); re=F(re_D98, Z); re=F(Z)	Z	re, LWC	EPM
	Other Liquid	Frisch et al. 1998 (Vertical profile of LWC)	-	spherical	LWC=F(LWP, Z); $\langle r^6\rangle=\langle r^3\rangle^2$	LWP, Z	LWC	EPM
	Cirrus	Mace et al. 1998 (Layer Average)	Modified Gamma (α=1)	Spherical	MODTRAN3 model (optical thin)	Z, R	re, N, IWC	Optimal
		Mace et al. 2002 (Vertical Profile)	Exponential	Bullet Rosette	Z_e=F(L, n(L)); Vd=F(L, n(L), V(L)); σ_d^2=F(L, n(L), V(L))	Z, V	re, N, IWC	Forward
	Other Ice	Liu and Illingworth 2001	Exponential	-	IWC = aZ_e^b , a, b are constants	Z	IWC	EPM
CLOUDNET	Liquid part	-	-	-	LWP-scaled adiabatic assumption using T, P	T, P; LWP	LWC	Forward
	Ice part	Hogan et al. 2006	Gamma	-	IWC=F(Z, T)	T, P; Z	IWC	EPM
DENG	Cirrus	Deng and Mace 2006	Exponential	Spherical	$Z_e=F(\lambda, N_0)$; $V_d=F(\lambda, W_m)$; $\sigma_d=F(\lambda, W_q)$; $W_q=F(\sigma_d, Z_e)$;	Z, V, σ_d	re, IWC	Forward
SHUPE_TURNER		Shupe 2007	Cloud Phase Determination					
	Liquid only	Frisch et al. 1995; Turner et al. 2007	Log-normal (σ=0.30)	Spherical	re=F(Z, N) with Adjusted N; LWC from LWP with adiabatic gradient	Z, LWP	re, LWC	Forward
	Liquid in thin mixed	Turner 2005 MIXCRA Turner et al. 2007	Gamma	Any	LBLRTM and DISORT; LWC from LWP-scaled adiabatic assumption	R; LWP	re, tau, lwp, lwc	Optimal
	Ice part	Shupe et al. 2005	exponential		IWC=aZ_e^b; $D_0=143a^{-0.53}Z_e^{0.53(1-b)}$; a=a($T_{IR}$), b=0.63	Ze	re, IWC	EPM
WANG	Mixed	Wang et al. 2004; Wang and Sassen 2002	Modified gamma log-normal	hexagonal	ice part (Wang and Sassen 2002); Liquid part: DISORT;	LWP, R, Z	re, WC	EPM Optimal
COMSTOCK		Shupe 2007	Cloud Phase Determination					
	Liquid part	Same as MICROBASE; LWP from MWR RET (Turner et al. 2007; Turner 2007)						
	Ice (Z & σ_{ext} exist)	Wang and Sassen 2002	Modified Gamma	hexagonal	IWC=F(σ, D_{ge}); D_{ge}=F(IWC, Z_e); ρ_i=0.92g/cm^3	Ze, σ_{ext}	re, IWC	EPM
	Ice (Z or σ_{ext} exist)	Hogan et al. 2006; -	Fitting Gamma	-	iwc=f(Z, T); iwc/ σ_{ext} =f(T); D_{ge}=(IWC/σ_{ext})(2.3/ρ_i) [Fu 1996]	Z, T or σ_{ext}, T	re, IWC	EPM
	Drizzle and Rain	-	Marshall-Palmer type	-	R=F(Z); N(r)=F(R, r); r_e=volume/area; N_0 ~ 0.8 cm^{-4}	Z	re, R, N	EPM

EPM means empirical parameterization method ; optimal means AERI-based optimal iteration method

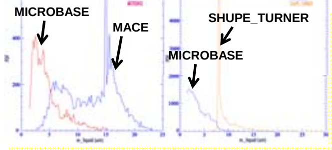
Understanding Cloud Retrieval Differences

Differences in retrieval algorithms

• Boundary Layer Stratus

-Difference in Theories (AERI-based, radar-based; T-based, etc.)
- Difference in Assumptions (e.g. PSD)

Large Discrepancies in liquid re (2004/10)



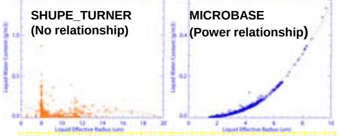
• re difference:

MICROBASE
<<
MACE
SHUPE_TURNER

Because:

MICROBASE use water vapor/droplet competition mechanism, limiting large particle size; MACE/SHUPE_TURNER are AERI based (part MACE products are Z based).

Difference in LWC and re relationship (2004/10)



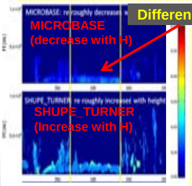
• re and LWC relationship

As left figures show

Results Explain:

SHUPE_TURNER: LWC (Adiabatic gradient with LWP scale) and re (AERI-based) are independent; MICROBASE: both re and LWC are Z based parameterization (3rd power law relationship used)

Difference in r_e vertical structure (M-PACE period)



For Mixed Phase clouds

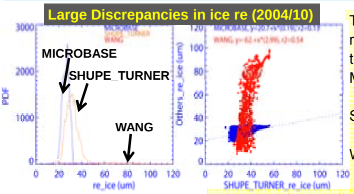
MICROBASE liquid re is both Z and T based, the decrease of T with height makes re decrease with height, inconsistent with in-situ aircraft measurements

SHUPE_TURNER is AERI-based physically derived layer averaged re, hourly average shows a roughly increasing feature with H.

• High Level Ice Clouds

-Difference in Theories
(Z-V-σ based; Z-based; T-based; Z-T based; Z-σ_{ext} based)
- Difference in Assumptions (PSD, Ice Crystal Habit, etc.)
- Difference in Parameters for same theory
(e.g. IWC=aZ^b; SHUPE_TURNER (b=0.63), MICROBASE/MACE (b=0.59)

Large Discrepancies in ice re (2004/10)



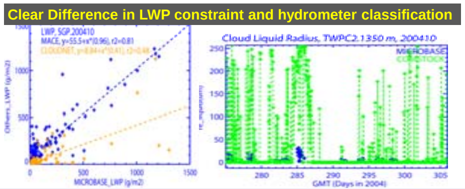
The difference in ice re is associated with their retrieval basis:
MICROBASE:
T based;
SHUPE_TURNER:
Z based;
WANG:
Z- σ_{ext} based

Note: WANG has different definition in re

Differences in retrieval inputs and constraints

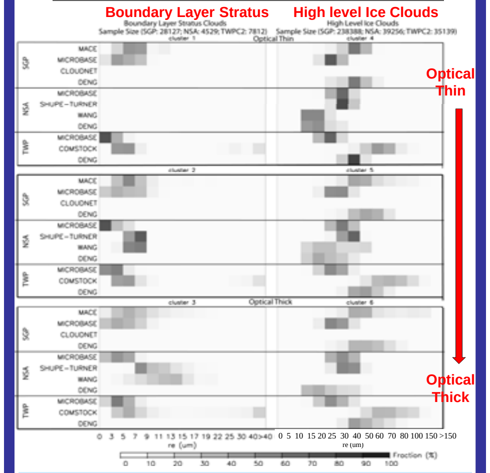
Boundaries; Phases; Detection/classification; MWR LWP; Other Measure

Clear Difference in LWP constraint and hydrometer classification



Statistical Analysis

Systematic Difference in re for same clouds (2002-2007)



- large or systematic differences exist between retrievals, although most cloud liquid re< 20 um and ice re <150 um:

	Liquid re	Ice re
SGP:	MICROBASE<MACE	MICROBASE<MACE/DENG
NSA:	MICROBASE<SHUPE_TURNER <WANG	DENG<MICROBASE<SHUPE_TURNER
TWP:	MICROBASE<COMSTOCK	MICROBASE<DENG<COMSTOCK

- Systematic errors can, at least partly be expected from retrieval algorithms
  - Small MICROBASE liquid re
    (water vapor/droplet competition: Z-based);
  - Small MICROBASE ice re with limited range
    (T-based);
  - large MACE/SHUPE_TURNER/WANG liquid re
    (AERI or Z-based)
  - Large COMSTOCK ice re with broad range
    (Z-σ_{ext} based; different definition);

Conclusions

- Large systematic discrepancies are seen in cloud retrievals.
- The differences among retrieval products are largely associated with the retrieval techniques, including the retrieval theory based and assumptions used, and cloud retrieval inputs and constraints.
- The discrepancies, at least partly, can be expected from their technique details; the retrieval theoretical nature provides useful information to understand and use current retrievals.

Future Work

- Improve accuracy of the retrieval input & constraints, make them uniform.
- Systematic validation of the retrievals using in-situ aircraft measurements and ground-based flux closure calculation (like BBHRP)
- Implement advanced statistical methods to better quantify data uncertainty - e.g. Bayesian approach

Reference

Comstock et al. (2007): An Intercomparison of microphysical retrieval algorithms for upper-tropospheric ice clouds. *BAMS, 88*, 191-204.

Turner et al. (2007): Thin liquid water clouds: Their importance and our challenge. *BAMS, 88*, 177-190.

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