Karhunen-Loève Expansion Analysis of Uncertainties in Cloud Microphysical Property Retrievals

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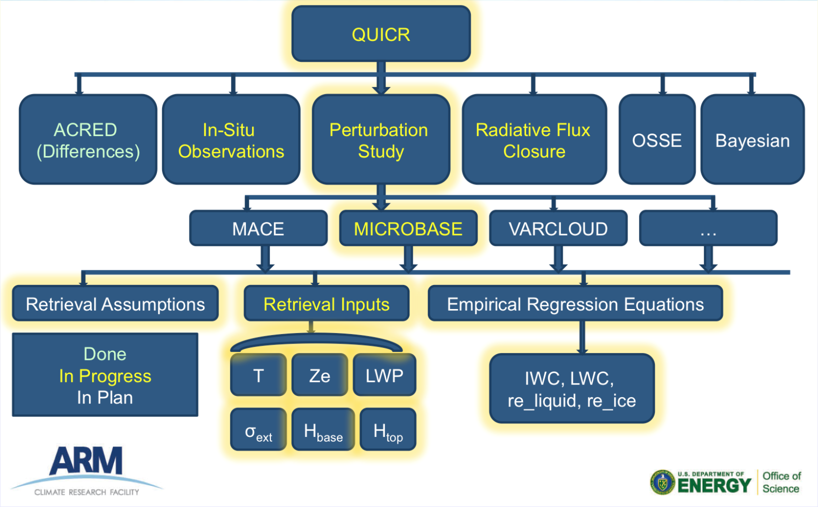
Overview


QUICR
ACRED (Differences)
In-Situ Observations
Perturbation Study
Radiative Flux Closure
OSSE
Bayesian
MACE
MICROBASE
VARCLOUD
...
Retrieval Assumptions
Retrieval Inputs
Empirical Regression Equations
Done
In Progress
In Plan
T
Ze
LWP
σ_{ext}
H_{base}
H_{top}
IWC, LWC, re_liquid, re_ice
ARM
CLIMATE RESEARCH FACILITY
U.S. DEPARTMENT OF ENERGY
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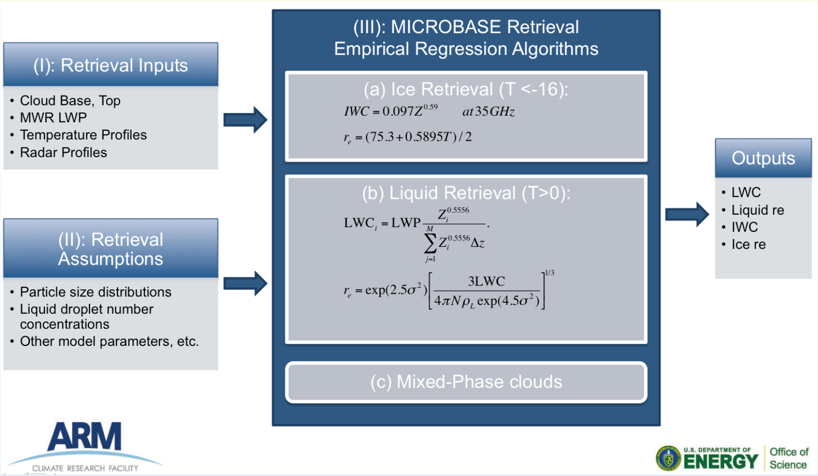
QUICR mission statement

"*to develop a methodology for ... quantifying uncertainties in ... ARM cloud retrievals ... in support of both retrieval algorithm improvement and cloud modeling study*"

Questions

- What are the vertically-resolved cloud retrieval uncertainties on model temporal resolution ($\sim$30 min)?
- How large are the uncertainties from individual sources (e.g., instrument noise, parameters, sampling, etc)?

MICROBASE algorithm



Perturb MICROBASE (w/ PSUADE). HOW?

Problem Solving environment for Uncertainty Analysis and Design Exploration

- "Curse of dimensionality" in the stochastic input space
  - 315(T)+512(Ze)+1(LWP)=828 input layers prohibit large random sampling. Correlated?
- Parameterization of inputs by random variables
- Sampling input random variables (i.e., PDF)
  - Assumption of probability distributions (e.g., uniform) disagrees with observations.
- Current MICROBASE frame work CANNOT do parallel runs. Large number runs are infeasible.
  - 50,000 times of perturbations per day require 50,000 min $\approx$ 35 days & 11 TB disk space

Karhunen-Loève (KL) + Central limit theorem (CLT)

- KLE reduces dimensions (828 to 14 modes) and extracts uncorrelated, independent input random variables.
- CLT shows that sample mean of random input variables approximately follows normal distribution (n$\rightarrow \infty$).

The central mean subtracted KLE w/ observation noise:

$$\overline{\mathscr{X}} = \sum_{i=1}^{r} U_i \frac{S_i}{\sqrt{m}} \sqrt{1 + \left(\frac{\sigma_0}{\frac{S_i}{\sqrt{m}}} \right)^2} \frac{z_i}{\sqrt{m}}$$

$z_i \sim N(0,1), noise_i \sim N(0, \sigma_0^2)$, where z_i and $noise_i$ are *i.i.d.*

Uniform distribution is used for parameter uncertainties.

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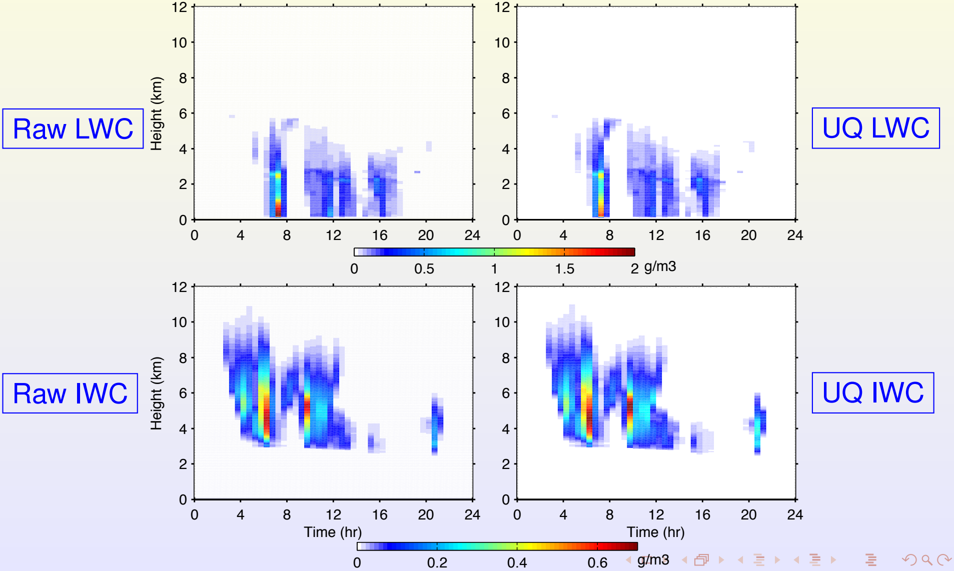
The perturbation range follows Zhao et al. 2013, submitted to JGR.

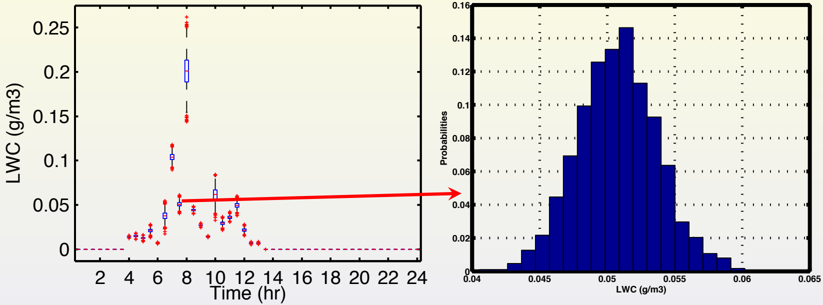
Input	T (K)	Ze (dbZ)	LWP (%)
Range	0.5	0.5	15

Pars	a (g/m^3)	d (μm $^\circ$C)	g	σ	N (cm^{-3})
Range	0.03–0.22	0.2311–0.8211	0.5–0.6	0.2–0.6	10–350

0.5-hr averages of LWC & IWC at SGP on 2006/05/10



PDF of LWC at 5 km on 2006/05/10

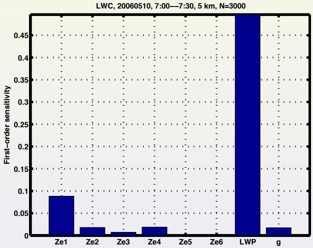


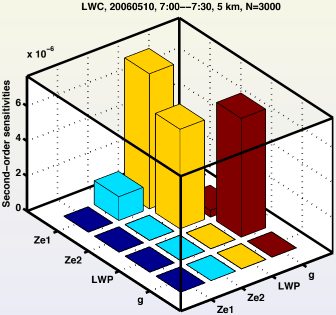
- Perturbing MICROBASE inputs by adding instrument noise and parameter uncertainties yields height-time probability distribution functions (PDFs) for retrieval products.
- These observation-based PDFs are better a priori for other UQ studies (e.g., MCMC).

Sensitivities of LWC to input random variables

$$LWC = LWP \frac{Z_e^g}{\sum_{j=1}^{M} Z_e^g \Delta z}$$

PSUADE





- Allows attributing uncertainties to individual input variables.
- Provides directions to improve instruments & obs strategies.

Dunn et al., 2011; Sobol 2001

Summary of MICROBASE UQ

Source	Type	Approach implemented by PSUADE	Mathematical Theorem
Retrieval Inputs	Inputs Data Variability and Noise	Perturb principal modes	Principal Component Analysis or Karhunen-Loeve expansion
		Sampling distribution of sample mean	Central Limit Theorem
Parameters in Retrieval Assumptions and Algorithms	Parametric Uncertainties	Alertory variability	Uniform/Triangular Distribution Assumption
		Epistemic uncertainty quantification	Evidence Theory
Equations of Retrieval Algorithms	Model-Form Uncertainties	Model error/ discrepancy analysis	Validation, Verification and Uncertainty Quantification

Done
In Plan

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Thank you!