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

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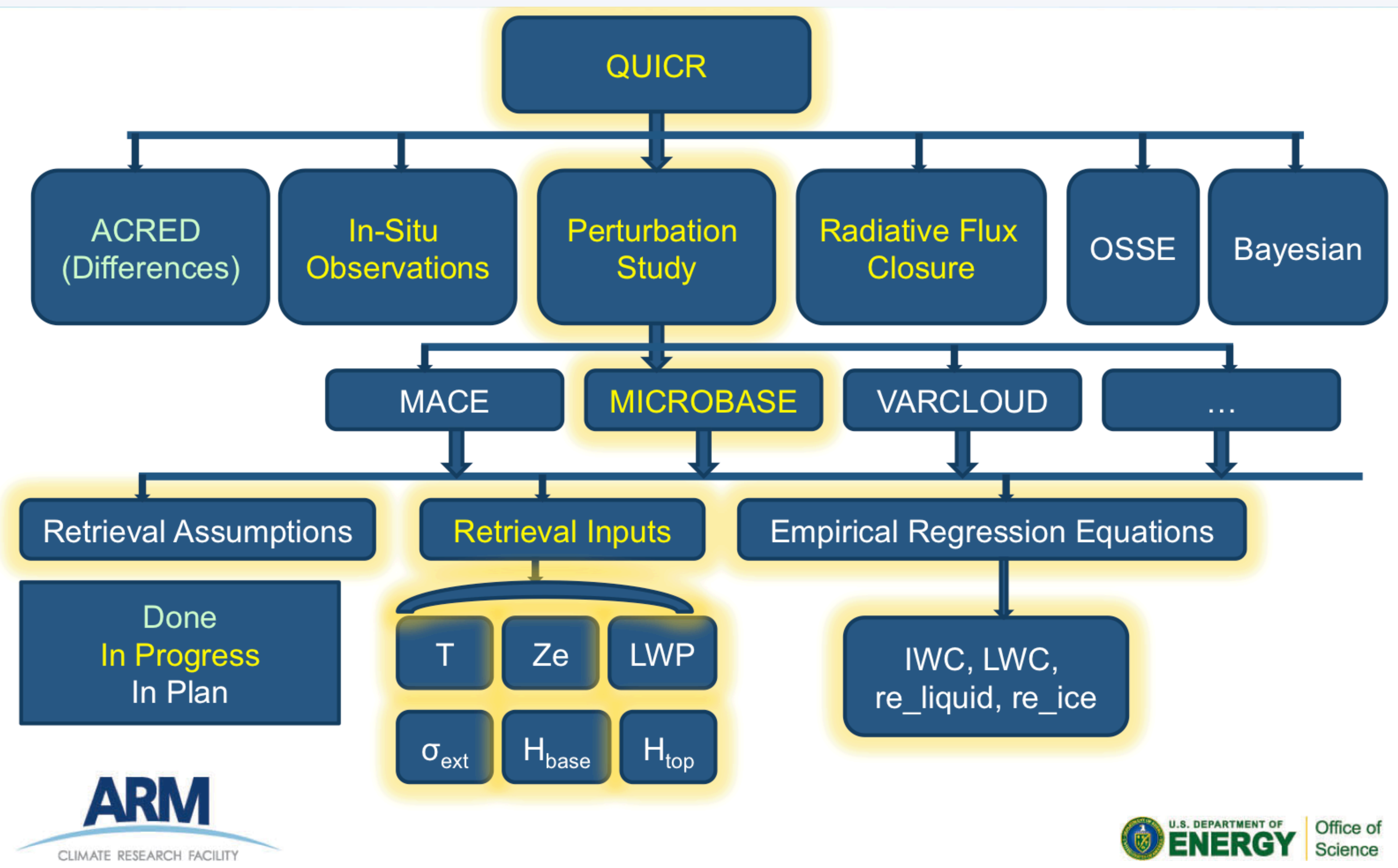
Overview



Objectives

QUICR mission statement

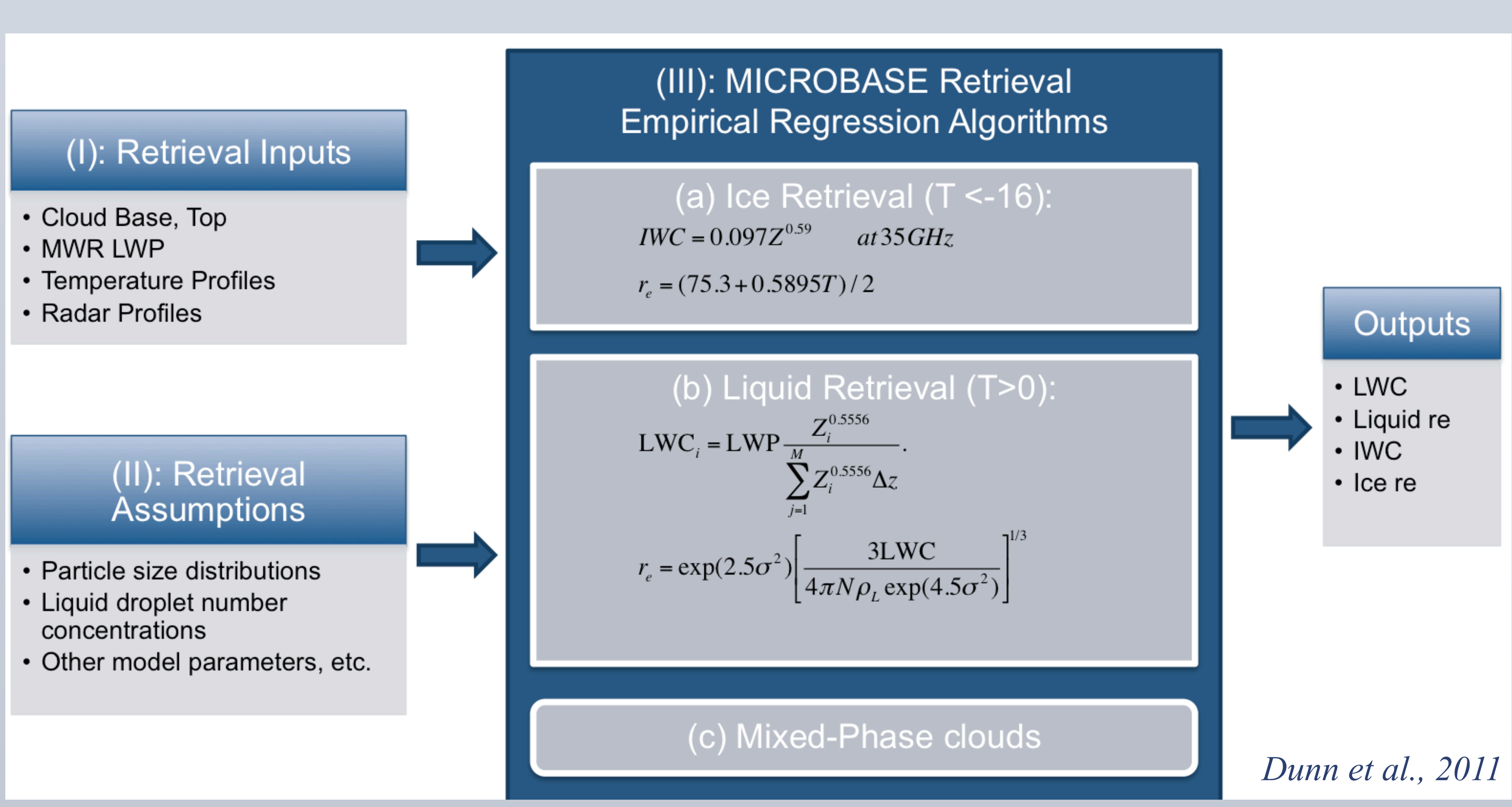
"to develop a methodology for characterizing and quantifying uncertainties in current and future ARM cloud retrievals, separately for different cloud regimes, in support of both retrieval algorithm improvement and cloud modeling study"

Key questions

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

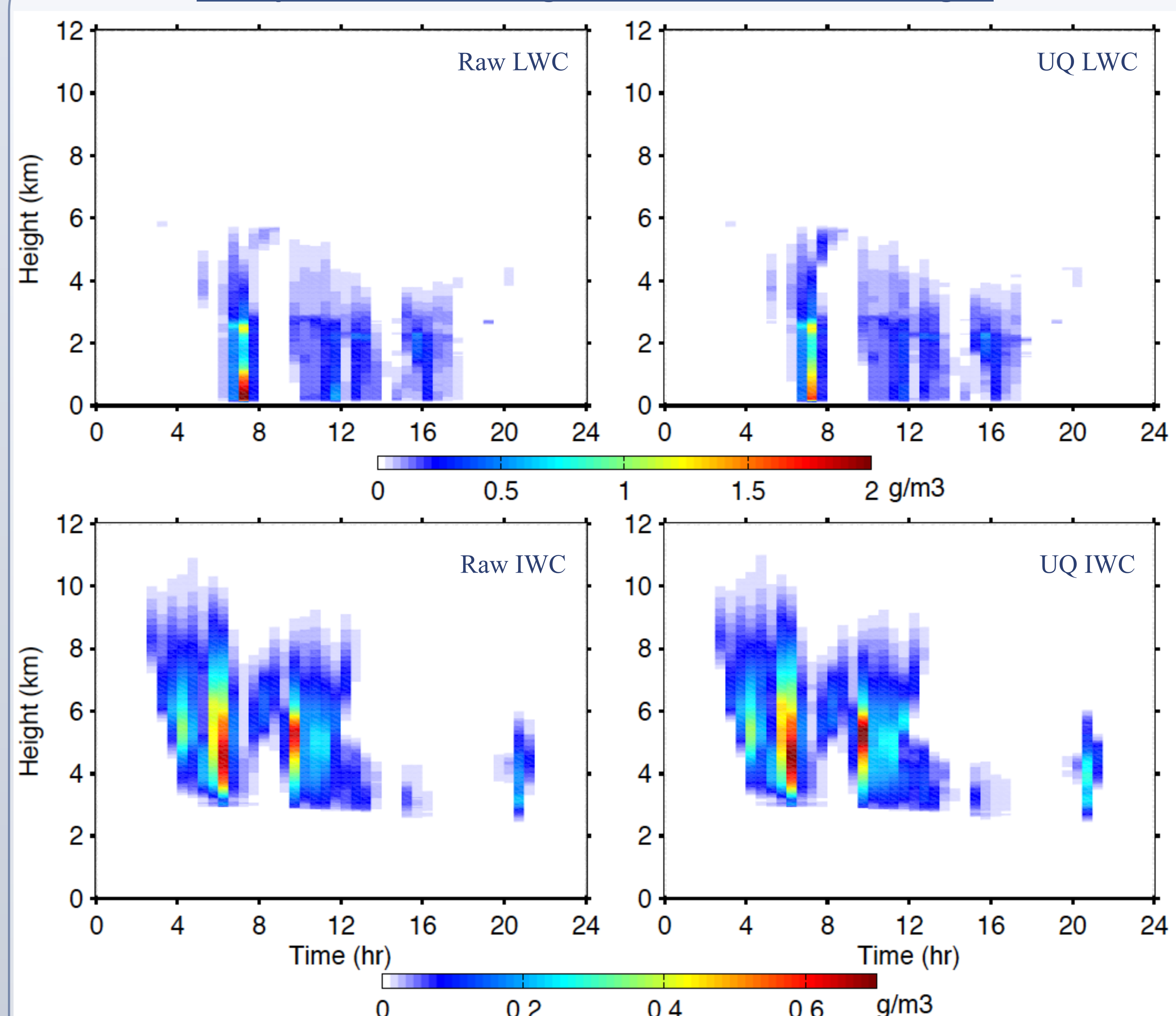
Problems

- "Curse of dimensionality" in the stochastic input space
  - 828 input layers prohibit large random sampling.
- Parameterization of inputs by random variables
- Sampling input ransom variables (i.e., PDF)
  - Assumption of probability distributions (e.g., uniform) disagrees with observations.
- Current MICROBASE frame work CANNOT do parallel runs.
  - 50,000 times of perturbations/day require 50,000 min (35 days) and 11 TB disk space.



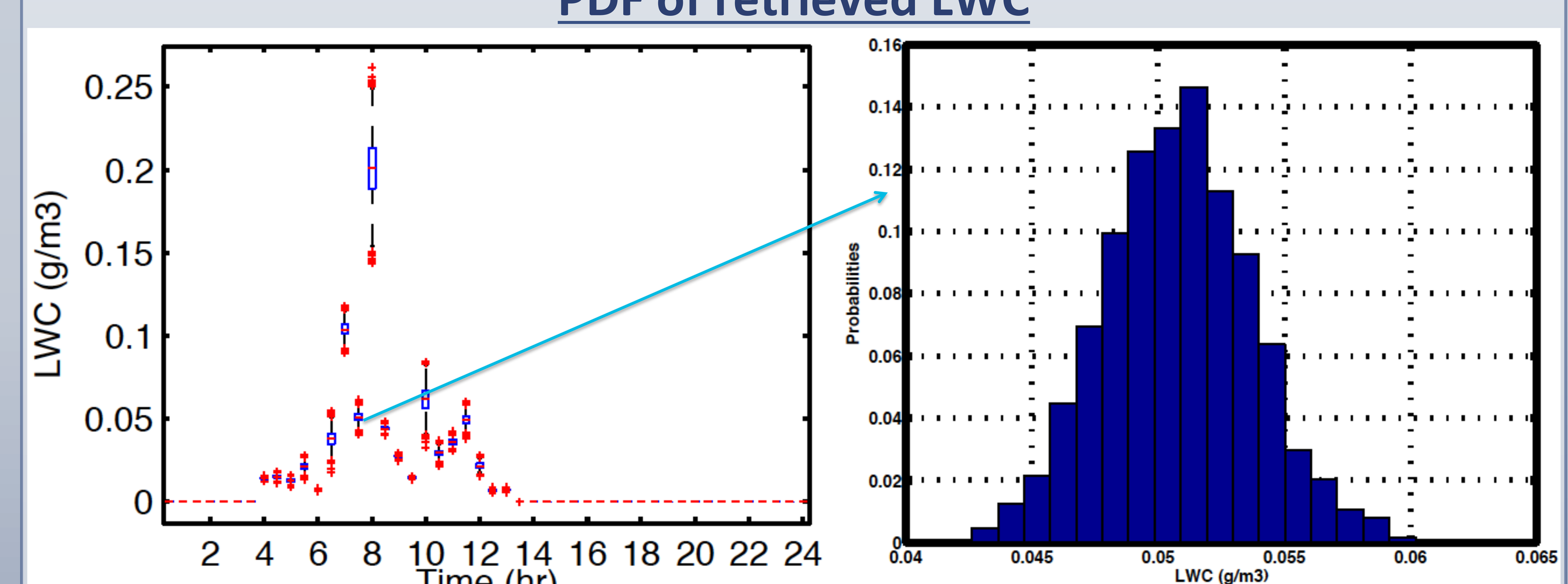
Dunn et al., 2011

Comparison with original MICROBASE averages



- 0.5-hr averages of LWC (top) and IWC (bottom) at SGP on 2006/05/10

PDF of retrieved LWC



- Retrieved LWC possibility distribution functions (PDFs) at 5 km by adding instrument noise and parameter uncertainties
- These observation-based PDFs provide better a priori for other uncertainty quantification (UQ) studies (e.g., MCMC).

Methods

Karhunen-Loève expansion (KLE) + Central limit theorem (CLT)

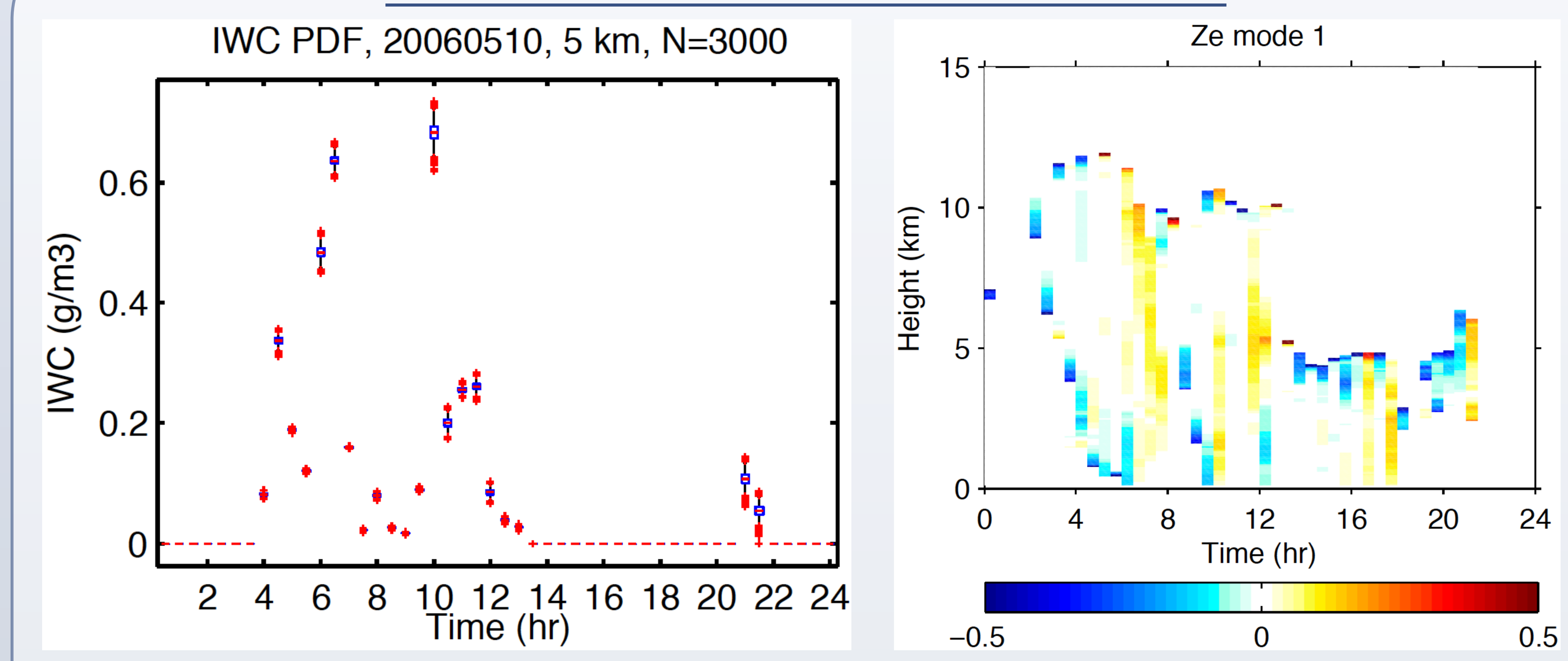
- KLE reduces dimensions (828 to 14 at 90% variance truncation) and extracts uncorrelated, independent random variables for T, Ze, and LWP.
- CLT shows that the sample mean of random input variables approximately follows normal distribution when sample size is large.
- Problem Solving environment for Uncertainty Analysis and Design Exploration (PSUADE) is applied for sampling random variables and sensitivity analysis (Tong 2009).

The central mean subtracted KLE w/ observation noise (z_i and noise$_i$ are *i.i.d.*):

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

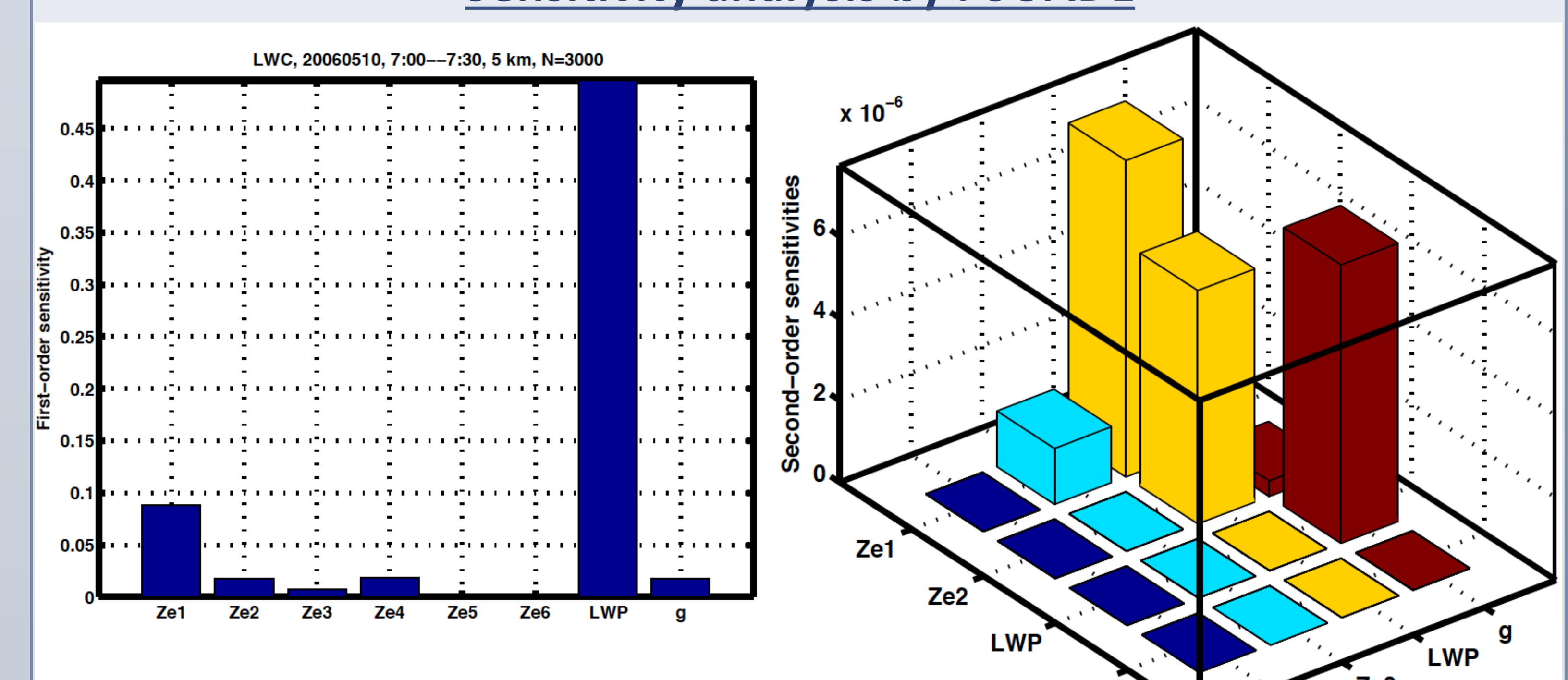
$$z_i \sim N(0,1), \quad \text{noise}_i \sim N(0, \sigma_0^2)$$

PDF of retrieved IWC & Ze first mode



- Results are NOT sensitive to the variance truncating point used for dimension reduction.

Sensitivity analysis by PSUADE



Sobol, 2001

- Allows attribution of uncertainties to individual input variables.
- Provides directions to improve instruments and observation strategies.

Perturbation range of MICROBASE input & parameters

Input/ Pars	T (°C)	Ze (dBZ)	LWP (%)	a (g/m³)	d (µm °C)	g	σ	N (cm⁻³)
Range*	0.5	0.5	15	0.03 -0.22	0.2311 -0.8211	0.5-0.6	0.2-0.6	10-350

*Perturbation ranges are based on Zhao et al., 2013

- Uniform distribution is used for perturbing retrieval parameters.

References

Dunn, M., K. Johnson, M. Jensen (2011), The Microbase Value-Added product: A baseline retrieval of cloud microphysical properties, DOE/SC-ARM/TR-095.

Sobol, I. M. (2001), Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates, *Math. Comput. Simulat.*, 55, 271-280.

Tong, C. (2009), PSUADE User's manual (version 1.2.0), LNL-SM-407882.

Zhao, C., S. Xie, X. Chen, M. P. Jensen, and M. Dunn (2013), Quantifying uncertainties of cloud microphysical property retrievals with a perturbation method, *J. Geophys. Res.*, submitted.

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