



APARC
Atmospheric Processes
And their Role in Climate

Sensitivity of Monsoon Cloud Microphysics to Aerosol Activation and Modal Characteristics in CRM Simulations

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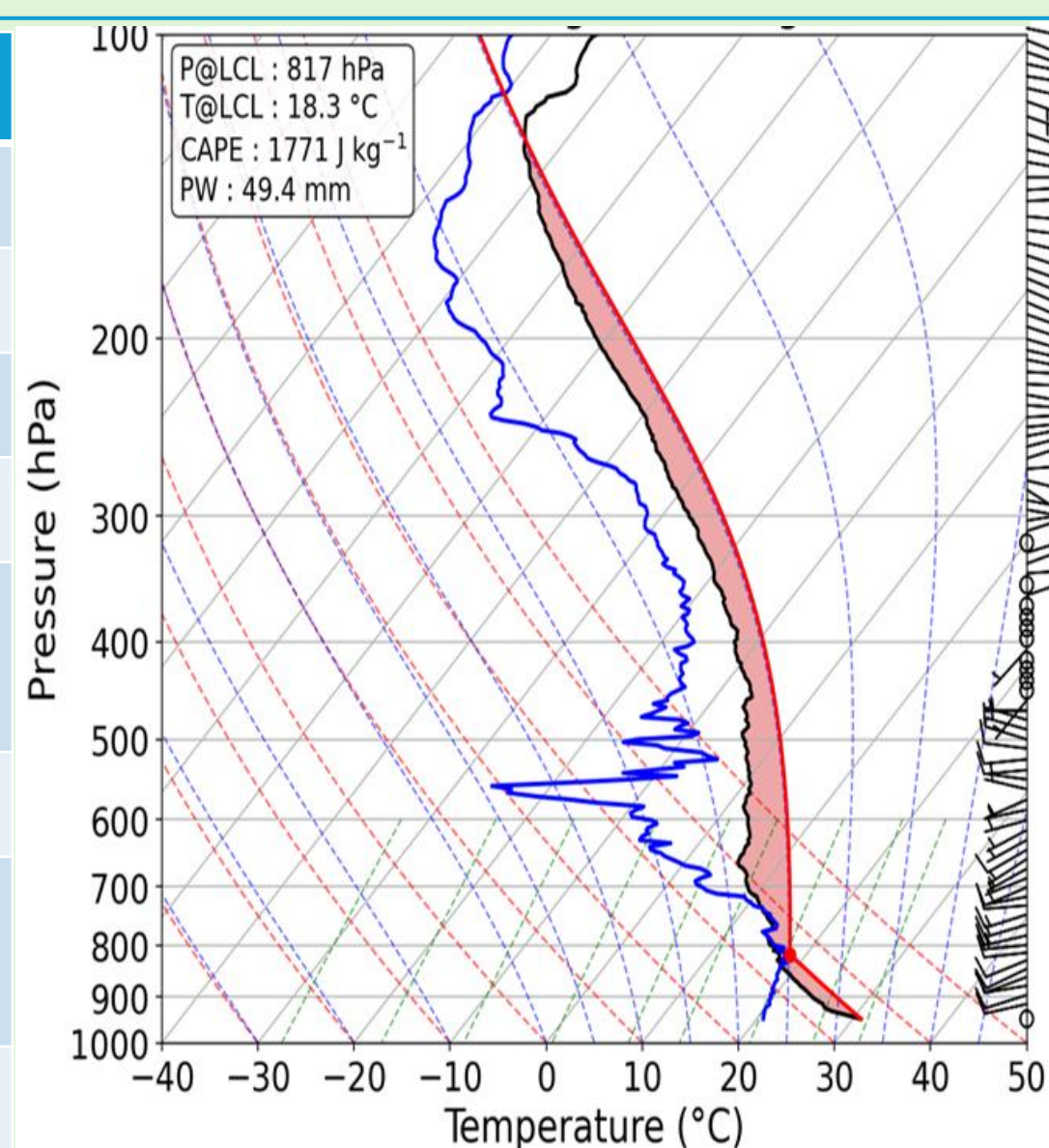


INTRODUCTION & MOTIVATION

- Aerosol Cloud Interaction (ACI)** remains one of the biggest uncertainties in our models. **Ambient aerosol is highly heterogeneous spatially and temporally.**
- AEROSOL ACTIVATION** to form cloud droplets near the cloud base is the first in the chain of processes determining ACI.
- Bulk microphysics schemes employ a broad classification of aerosols as marine or continental with emphasis on the accumulation mode. Some schemes, such as the Morrison double moment, use a constant droplet concentration (CDNC) at cloud base.**

Model Configuration : WRF 4.6-CRM

Model top	20 km
Grids	201x 201
Resolution	1000 x 1000 m
Run time	10 hours
Cloud microphysics	Aerosol aware Morrison double moment (Gloftetty et al. 2019)
Aerosol Activation	Abdul Razzak & Ghan (2000)
Radiation SW and LW physics	RRTGM
PBL physics	YSU

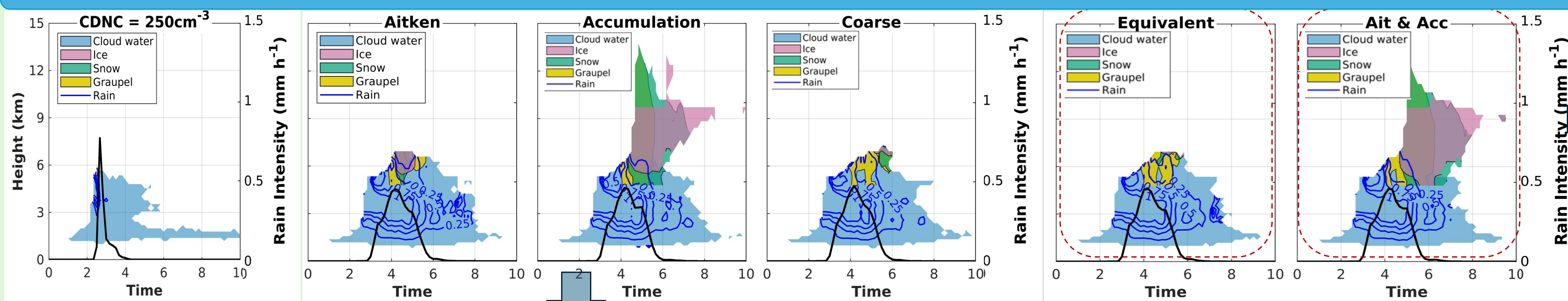


OBJECTIVE & METHODOLOGY

- Study the effect of aerosol activation on the cloud microphysics.
- Idealized cloud-resolving simulations initialized with the **sounding profile from SOLAPUR (17.68°N, 75.92°E, 457m)**, a rain shadow region at 05:45 UTC.
- Examine the individual effect of different aerosol mode - **Aitken, accumulation, and coarse aerosol** (Varghese & Prabhakaran, 2025) on cloud formation.
- Examine the sensitivity of cloud microphysics to the different aerosol parameters like number concentration, mode diameter, hygroscopicity,

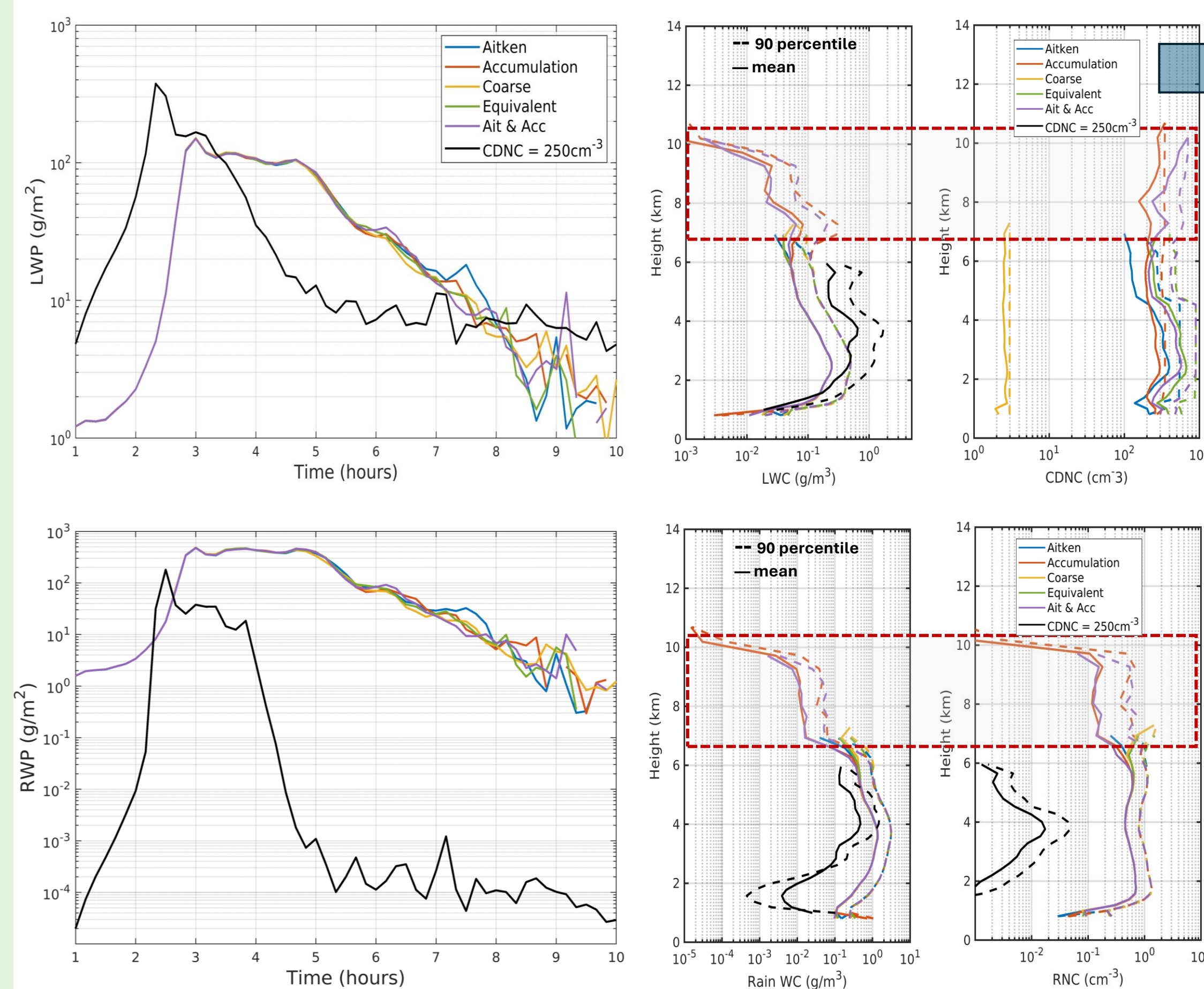
Run	Aerosol Detail
Control	CDNC = 250 cm ⁻³
Aitken	N = 550 cm ⁻³ , D _m = 0.0725 μm, σ = 1.6, κ = 0.25
Accumulation	N = 350 cm ⁻³ , D _m = 0.16 μm, σ = 1.8, κ = 0.5
Coarse	N = 3 cm ⁻³ , D _m = 1.0 μm, σ = 2.0, κ = 0.1
Equivalent	N = 902 cm ⁻³ , D _m = 0.083 μm, σ = 1.9, κ = 0.25
Ait & Acc Bimodal distribution	parameters of Aitken and Accumulation, κ = 0.25

RESULTS & DISCUSSION



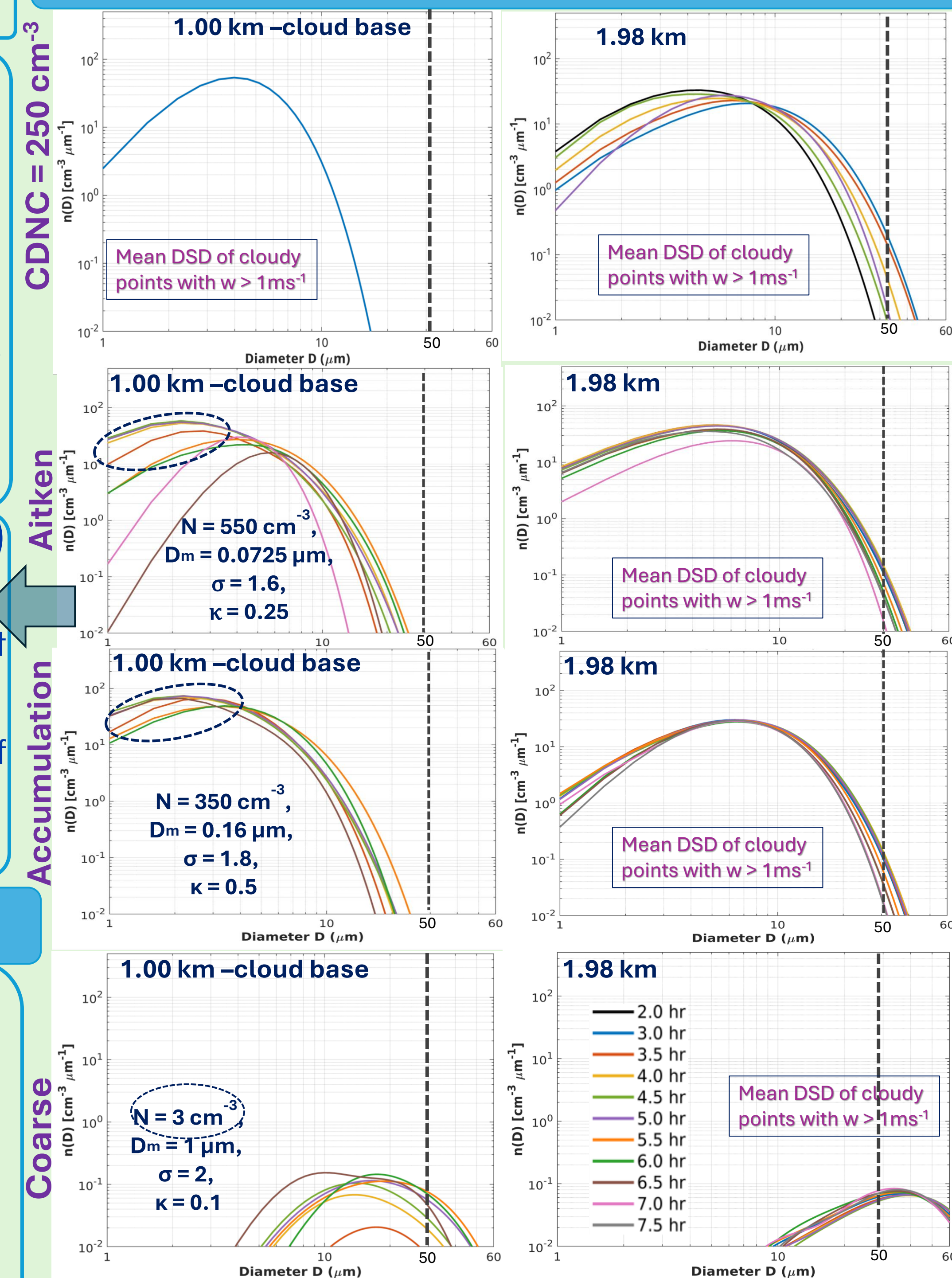
- No noticeable change in the rain intensity between different aerosol inputs
- Cloud development is different in a Bimodal distribution (Ait& Acc) and an Equivalent unimodal.
- Pronounced vertical growth with accumulation-mode input

- Control run** - rainout is quick, suggesting accelerated droplet growth, hence the short lifetime.
- Aerosol activation runs** - delayed rain, more ice phase hydrometeors, longer lifetime

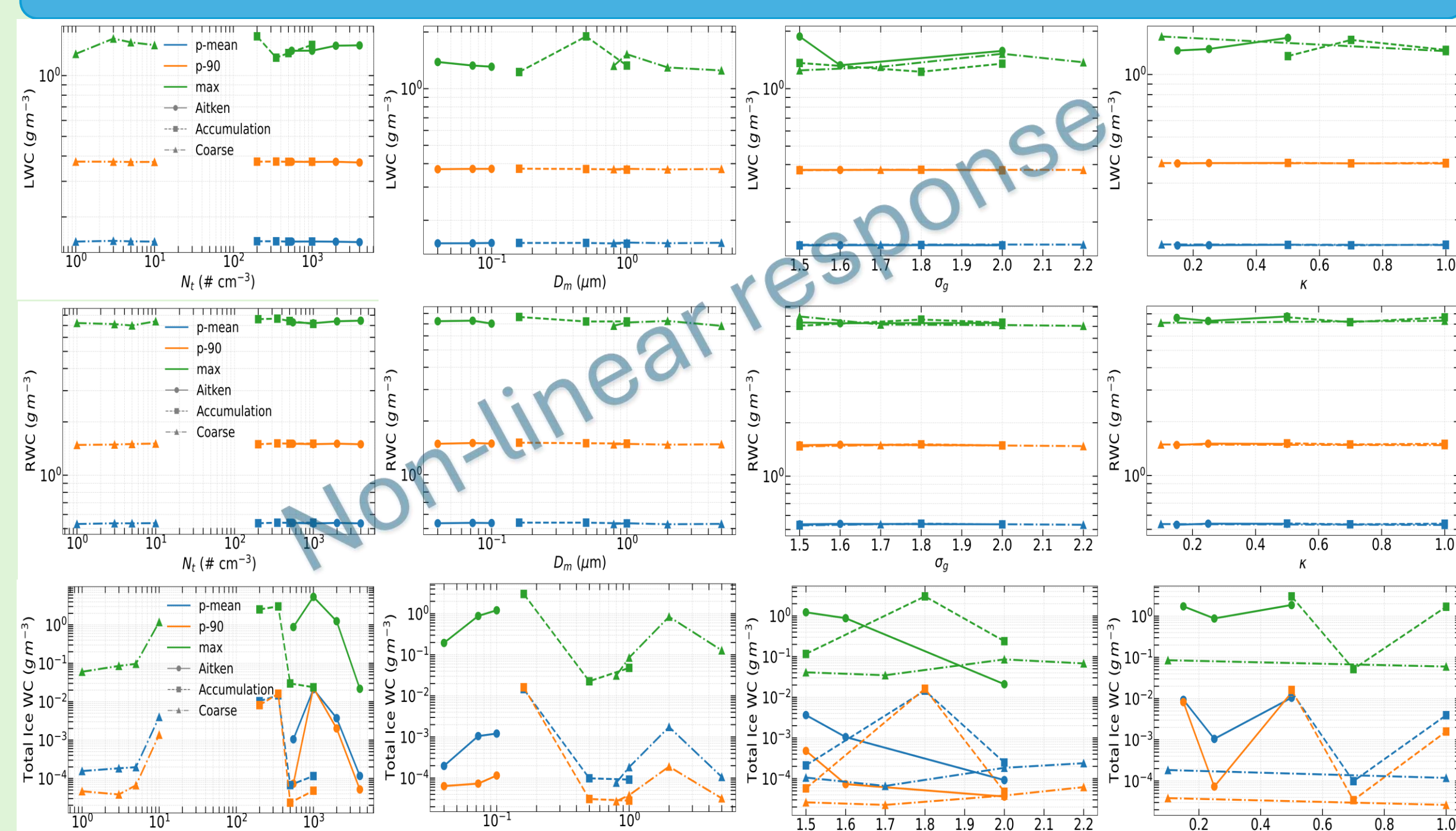


- Mean LWC profile decreases with altitude when the activation is on; vice versa with RWC in cloud
- Supercooled droplets found above 7 km in cases with deeper clouds
- SATURATION ADJUSTMENT** leads to overly uniform cloud water despite varying aerosol conditions (Lebock et al. 2011; Lebo et al. 2012; Seifert et al. 2012)
- DSD at cloud cores (updraft > 1ms⁻¹) reconstructed using Γ distribution
- Control** - $w > 1\text{ms}^{-1}$ near cloud base absent due to quick rainout
- Aitken & Accumulation** - Large number of small droplets formed, competition effect.
- Coarse** - Inefficient Collision Coalescence

Evolution: Drop Size Distribution



Sensitivity Analysis



REFERENCES

- Lebo, Z. J., H. Morrison, and J. H. Seinfeld, 2012: Are simulated aerosol-induced effects on deep convective clouds strongly dependent on saturation adjustment?, Atmos. Chem. Phys., 12, 9941–9964, <https://doi.org/10.5194/acp-12-9941-2012>.
- Gloftetty, T., K. Alapaty, J. He, P. Hawbecker, X. Song, and G. Zhang, 2019: The Weather Research and Forecasting Model with Aerosol–Cloud Interactions (WRF-ACI): Development, Evaluation, and Initial Application. Mon. Wea. Rev., 147, 1491–1511, <https://doi.org/10.1175/MWR-D-18-0267.1>.
- Varghese, M., and T. Prabhakara, 2025: Reconciling observed and predicted droplet concentration at the Indian summer monsoon cloud base, Sci. Total Environ., 973, 79077, <https://doi.org/10.1016/j.scitotenv.2025.179077>

CONCLUSIONS

- Aerosol activation affects the ACI, specifically the cloud lifetime and vertical growth. However, unlike bin microphysics, **bulk microphysics with saturation adjustment makes the liquid phase of clouds insensitive to aerosols**
- Accumulation mode has the advantages of size, number concentration, and hygroscopicity, enabling vertical growth by pushing small supercooled droplets above the freezing level, which appears to be essential for the ice phase hydrometeors to form.
- An **equivalent unimodal aerosol representation cannot replace the multimodal aerosol representation in numerical models**
- The mechanism leading to the invigoration is not well understood, as the process rates were not analyzed

