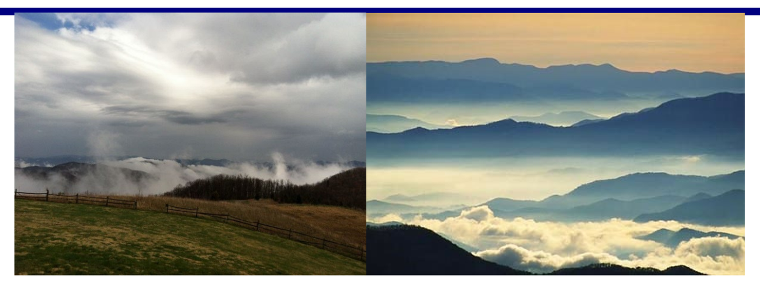
Micro2Macro Workshop 2024



Characterization of Aerosol-Cloud-Rainfall Interactions from µm-hm Scales in Complex Terrain: At Sunrise

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1. Introduction

Precipitation is a crucial component of the water cycle and energy budget, yet measurement of precipitation, understanding and modeling precipitation processes are challenging due to system complexity across scales from the hydrometeor scale range (µms-mms), the inertial subrange up to 100 m (hm scale), within organized cloud-scale circulations up to the small mesoscales that are not represented in large scale models atmospheric models, or accounted for in remote-sensing retrieval algorithms. The overarching goal of this research is to advance the quantitative understanding of the warm rain processes and land-atmosphere coupling at cloud-scale. The research aims to refine the parameterization of microphysical processes and their impact on radiative forcing toward facilitating the development of next-generation models by accurately capturing the 3D structure of clouds and precipitation.

2. coupled LES Land-Cloud model (CLCM)

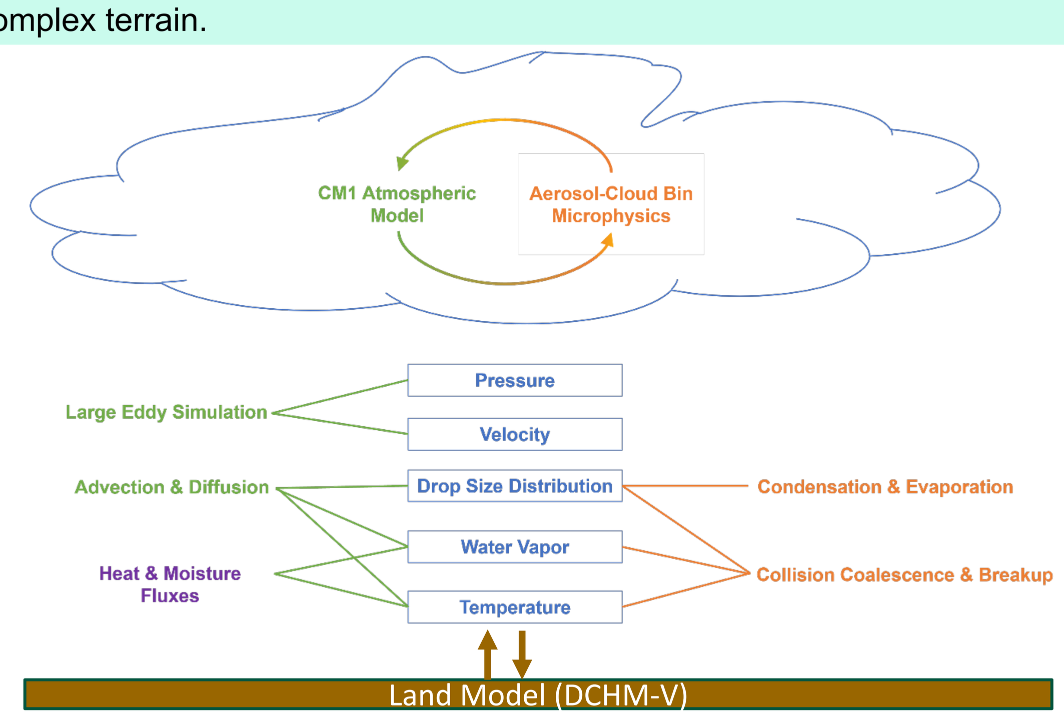
CLCM — To investigate characterize aerosol-cloud-rainfall interactions and land-atmospheric coupling from micron to hectometer scales in complex terrain.

CM1: *"a three-dimensional, non-hydrostatic, non-linear, time-dependent numerical model designed for idealized studies of atmospheric phenomena."*

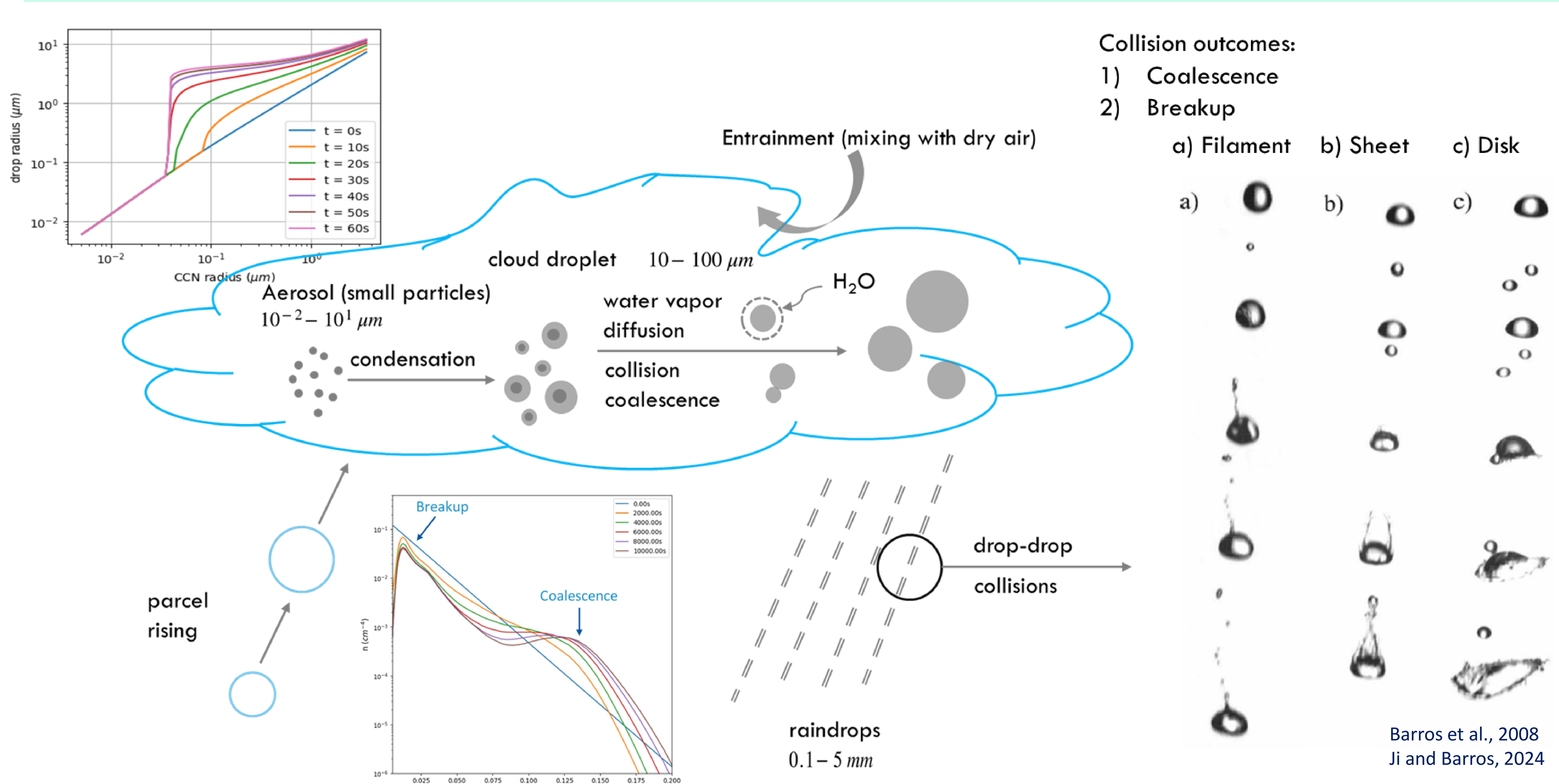
G. H. Bryan and J. M. Fritsch, 2002

DCPM (Duke Cloud Parcel Model): *a cloud model "to explicitly solve key cloud microphysical processes and predict the evolution of cloud droplet spectra originating from aerosol distributions of uniform chemical composition"*

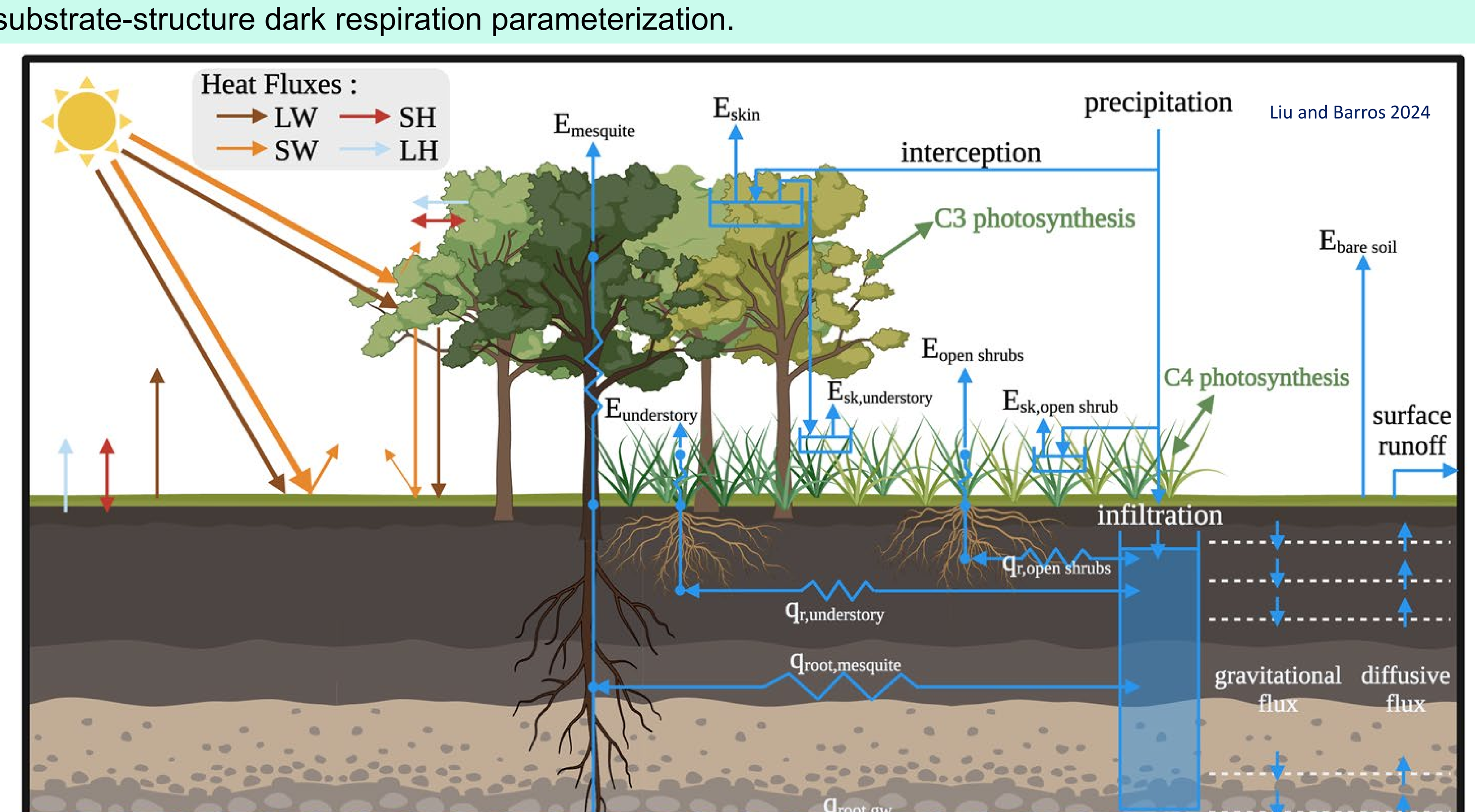
Duan, Petters and Barros, 2019



Microphysics Formulation — A virtual microphysics laboratory (VML) to investigate rainfall dynamics at process scales. Drop activation, condensation, and collision are solved via spectral bin microphysics (SBM, Duan et al. 2019) model.

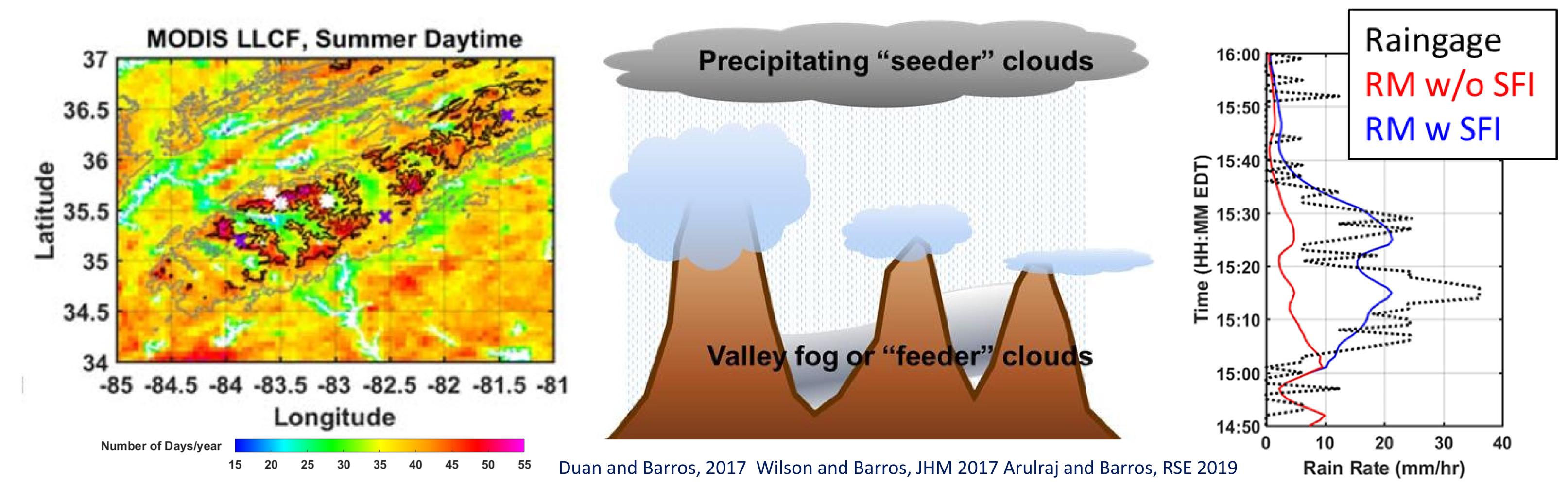


Land Model — Duke Coupled Hydrology Model with Vegetation (DCHM-V), a land surface column model that solves for water mass balance and energy balance, coupled with a biochemical representation and a substrate-structure dark respiration parameterization.

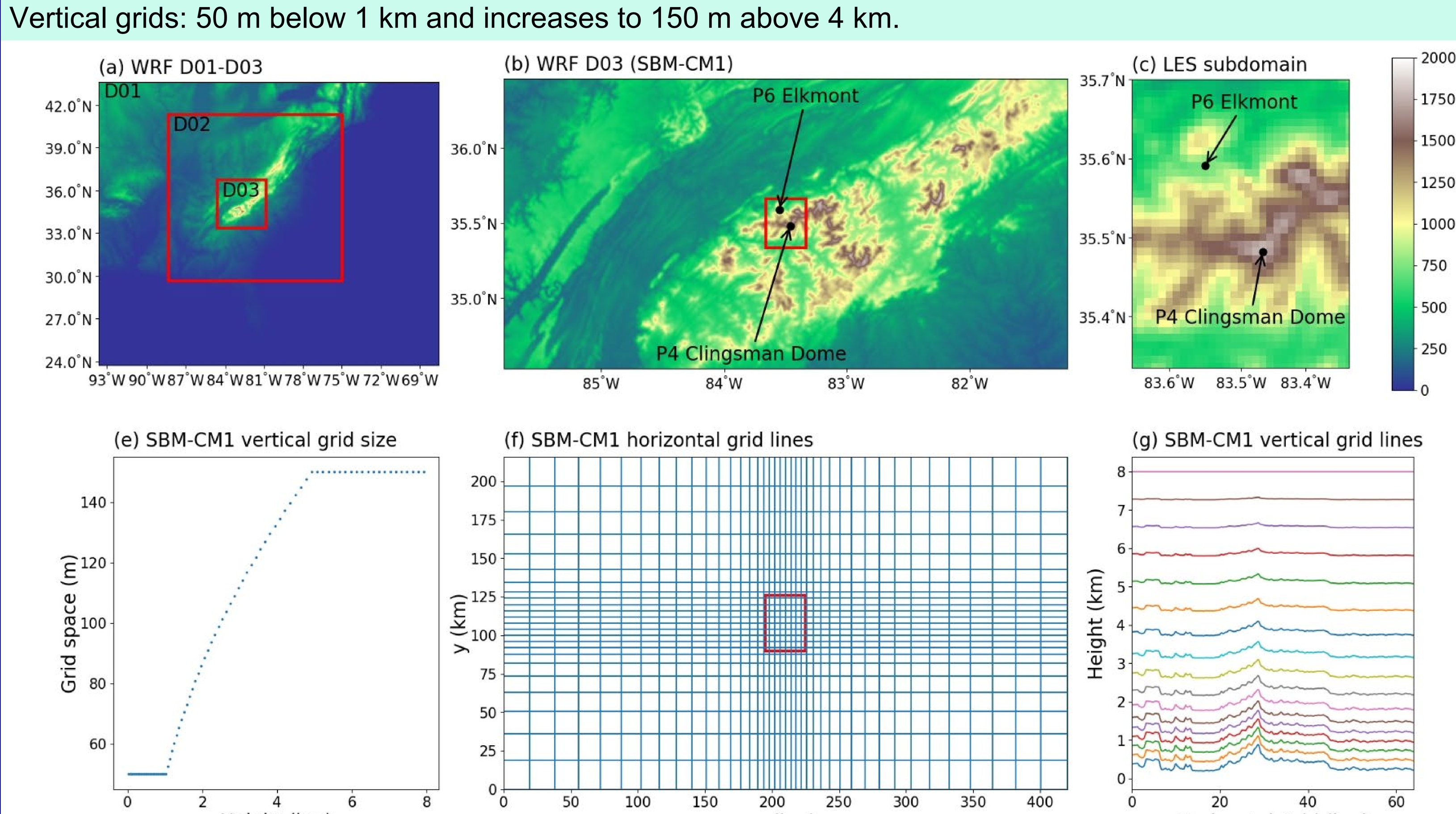


3. Case Study – Low Level Orographic Clouds and Fog Mountains

Context — Low level clouds and fog (LLCF) is dominant in the inner southern Appalachian Mountains (SAM), and significantly enhance the rainfall rate at lower elevations through the seeder-feeder interactions.

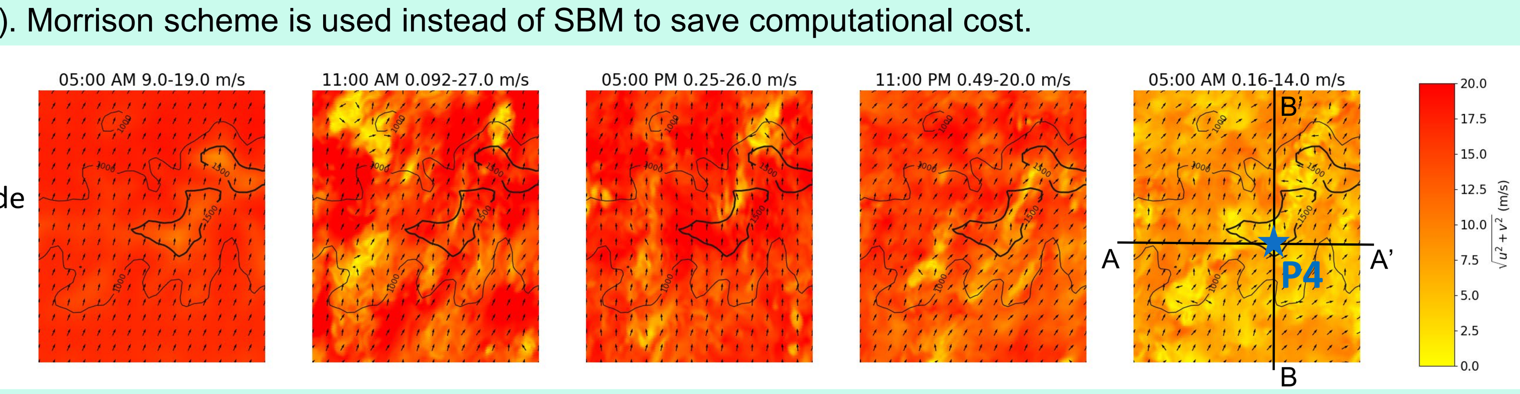


Initial and boundary conditions: one-way nested simulation of three domains (D01, D02, and D03). Horizontal grids: 1 km in the outer domain and increases to constant 200 m in the inner domain (30 km × 36 km). Vertical grids: 50 m below 1 km and increases to 150 m above 4 km.

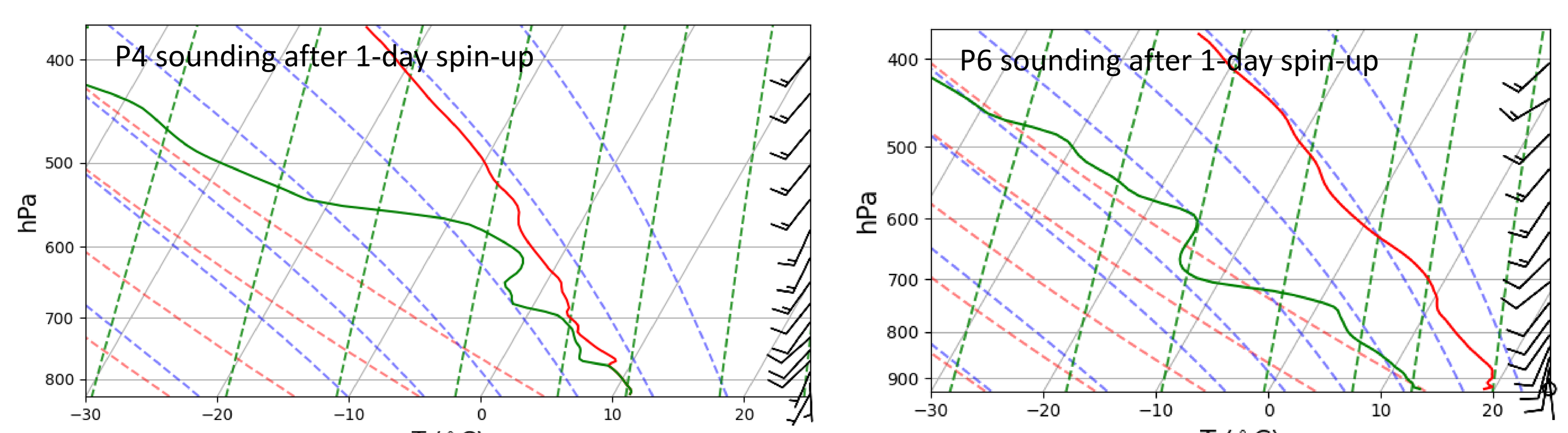


The CLCM is run one day prior 06/12 2014 from 5am to spin up turbulence and soil properties (one diurnal cycle). Morrison scheme is used instead of SBM to save computational cost.

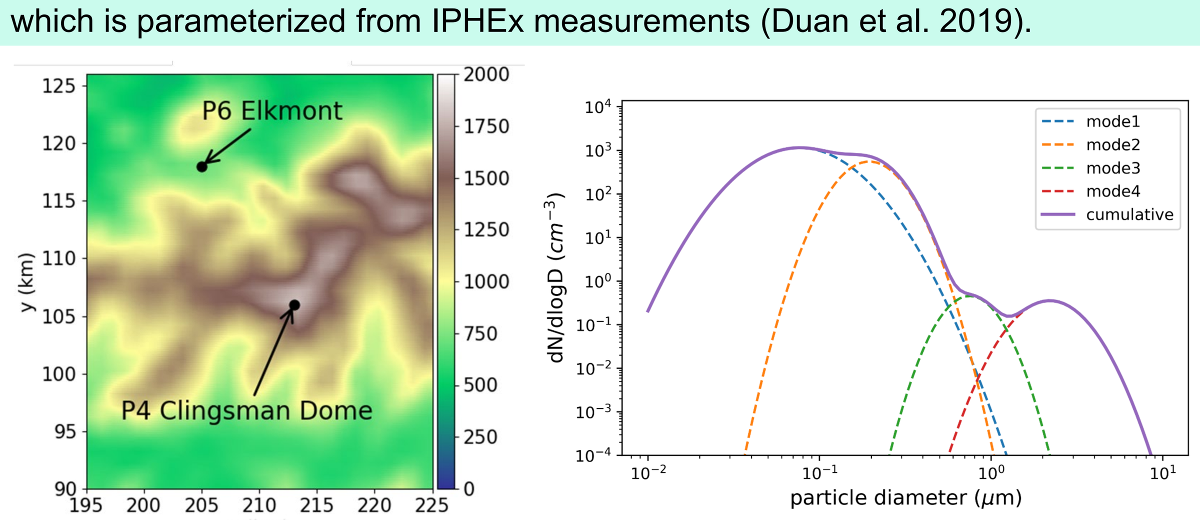
2 km altitude wind map



Atmosphere is saturated at P4, favoring LLCF, while P6 is dry due to terrain blockage.



The aerosol size distributions are initialized with a cumulative sum of four modes of log normal distributions, which is parameterized from IPHEx measurements (Duan et al. 2019).

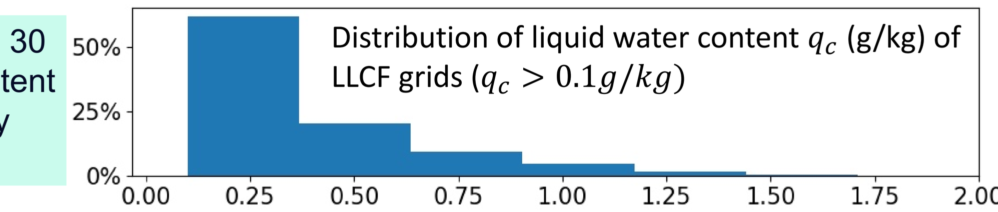


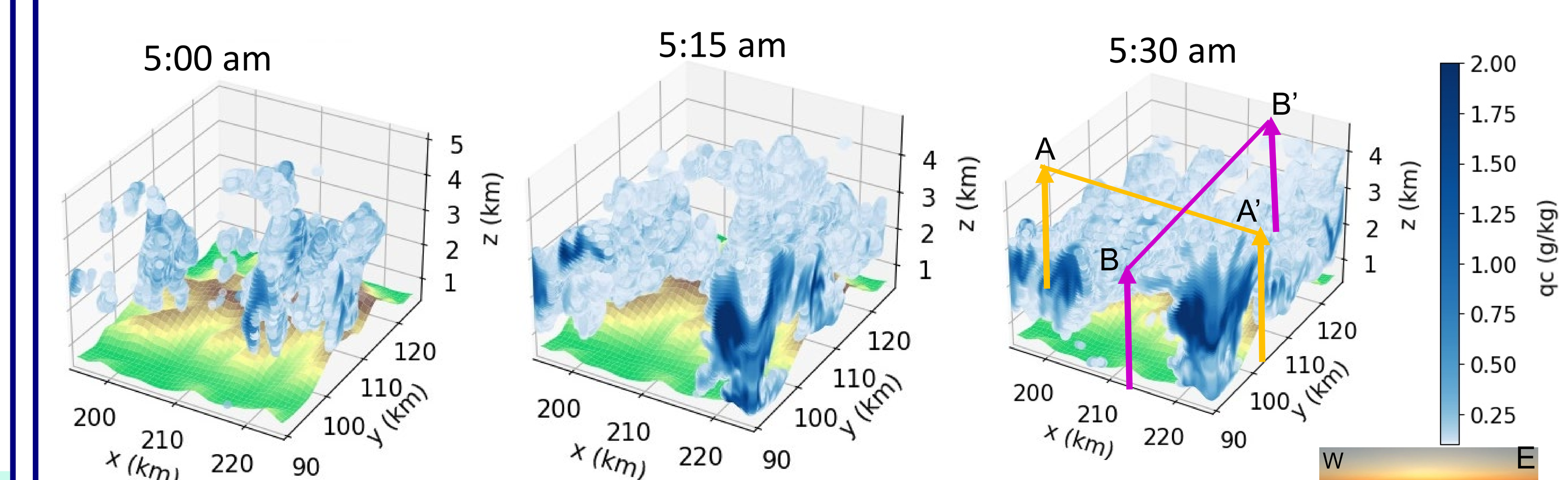
Mode n°	N_{surf} (cm^{-3})	D_g (µm)	σ_g
1	1401.9	0.076	1.63
2	415.7	0.195	1.35
3	0.3	0.750	1.30
4	0.3	2.200	1.40

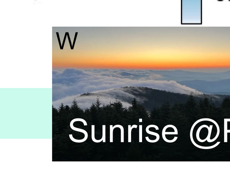
$$N(z) = N(0)\exp(-z/H_s)$$

$$H_s = 1000\ m$$

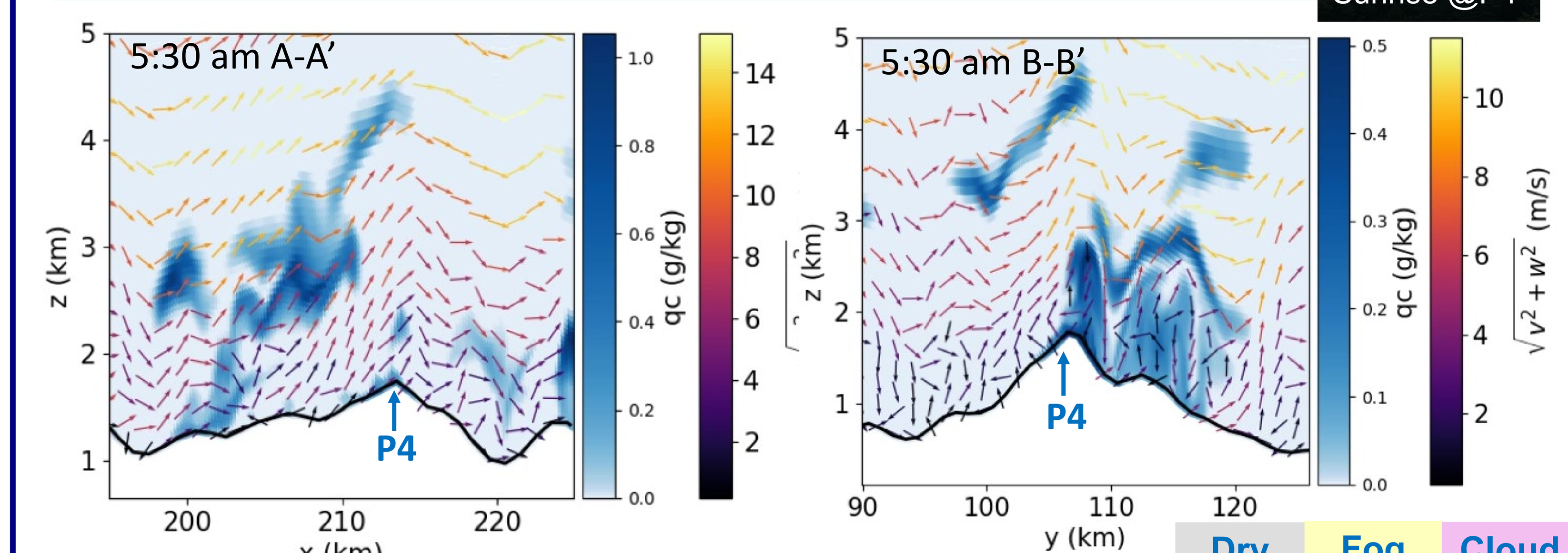
Results — Sunrise LLCF evolves within 30 minutes. Most grids have low water content due to the competition of water vapor by large amount of CCNs in SAM.



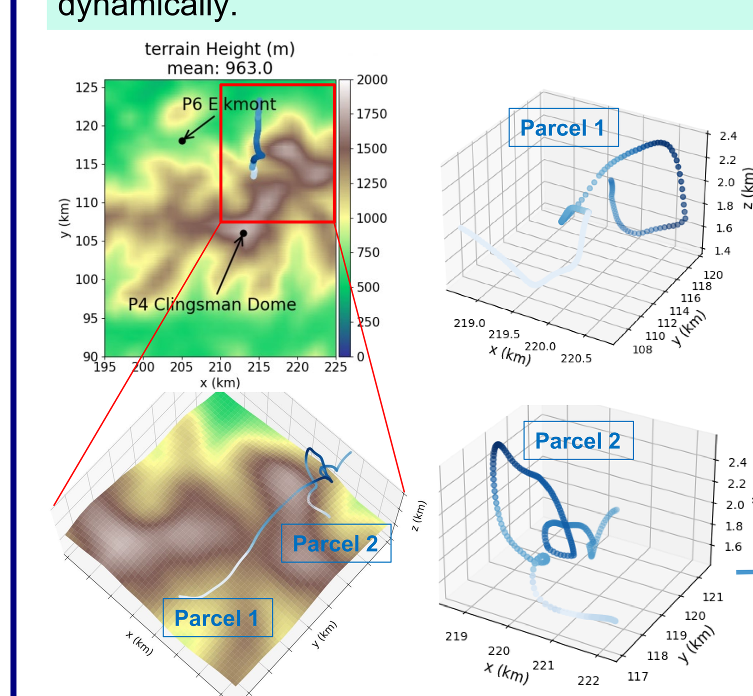


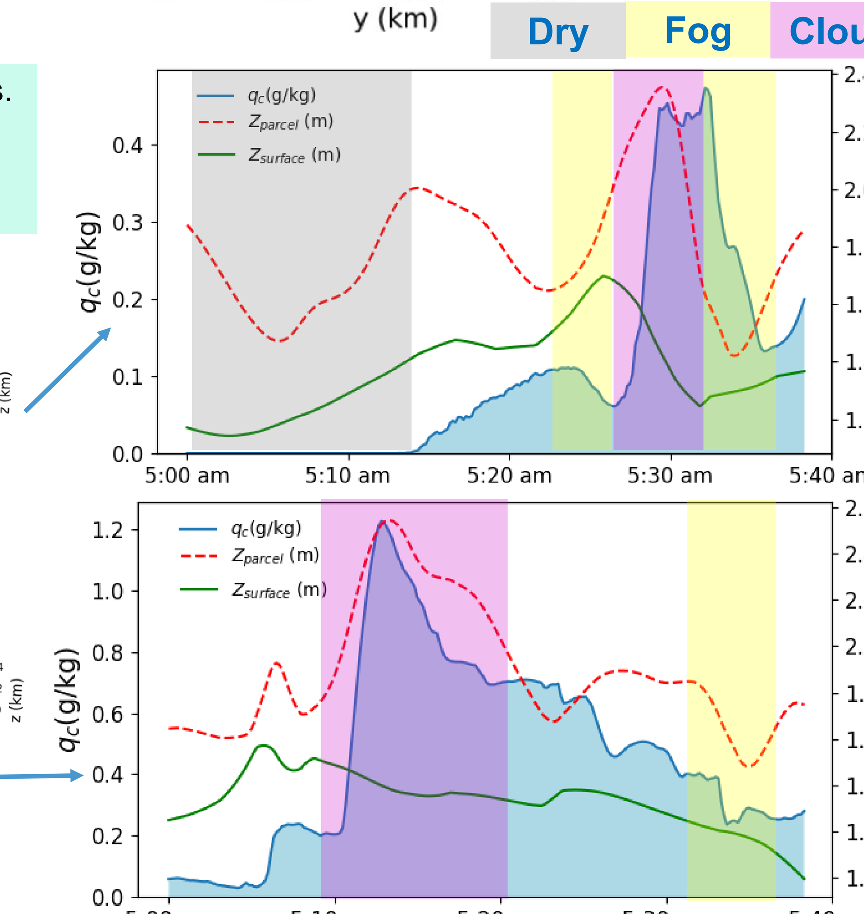


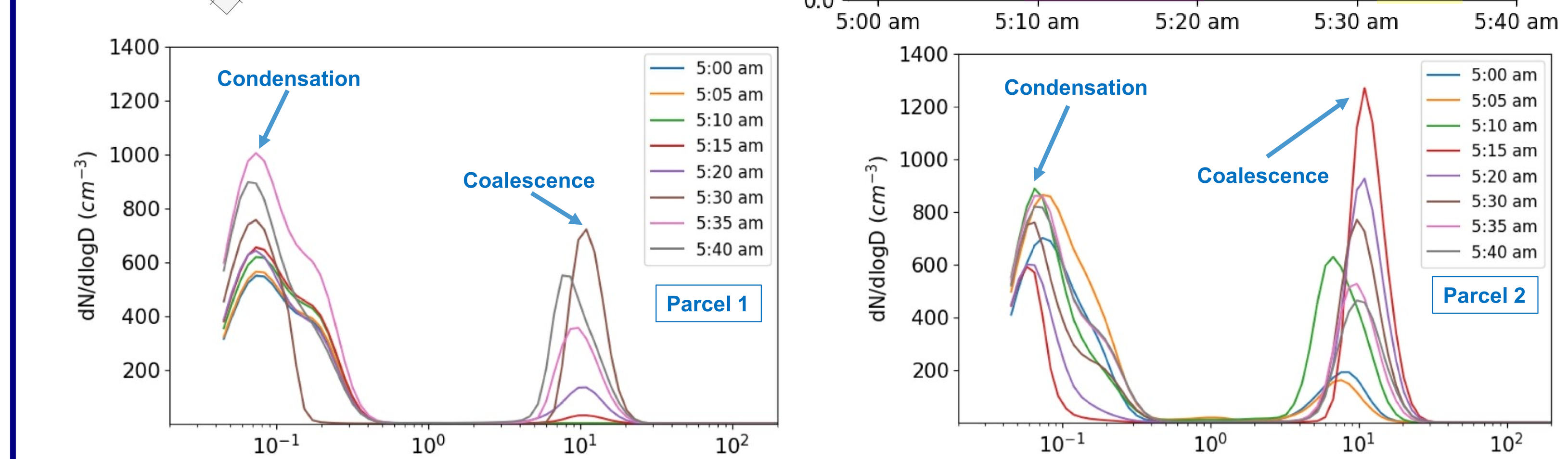
Spatial Organization of warm orographic clouds with shallow convection



Air parcels travel in turbulence, rolling in eddies. Liquid water mixing ratio (q_c) oscillates during ascent and descent, contribute to cloud or fog dynamically.







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