Avoiding Conversion Rates with Flexible Moment-Based Microphysics

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The Warm Rain Problem

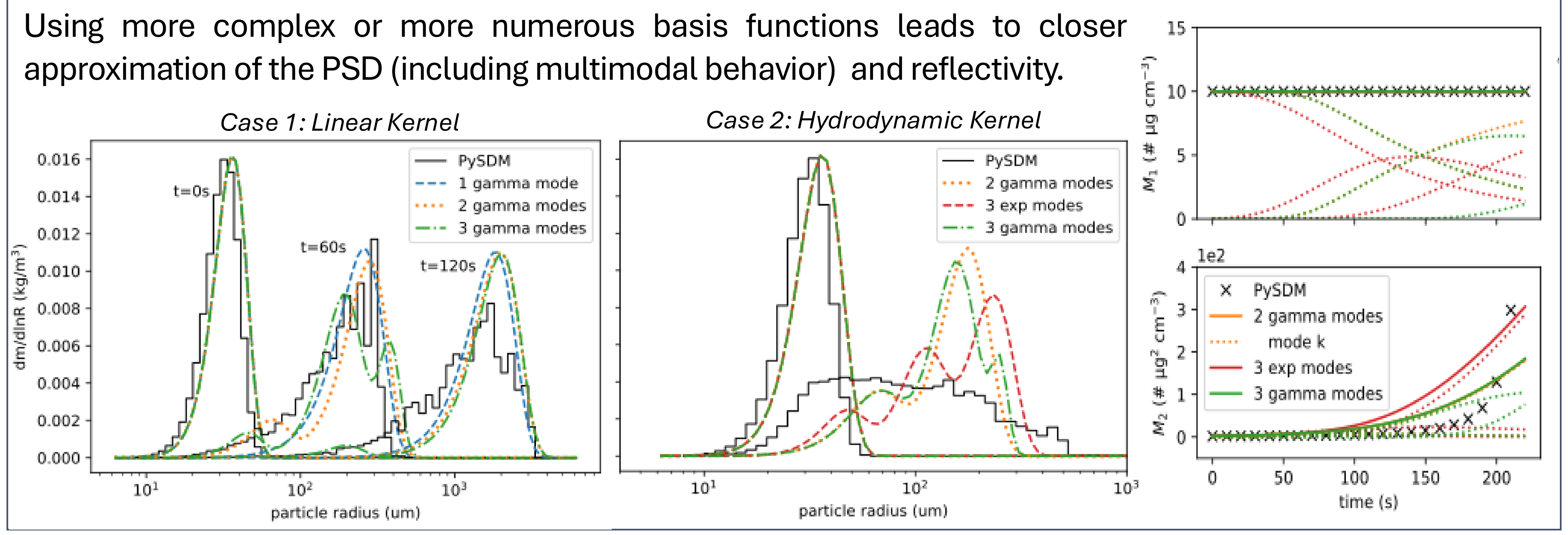
Microphysics parameterizations are becoming a critical limitation in climate and weather models, necessitating smarter methods of tracking hydrometeor populations and their properties. Typical moment-based representations separate liquid droplets into "cloud" and "rain" categories, tracking moments (number or mass density) of each category. This categorization necessitates **artificial conversion rates** between cloud and rain and contributes a massive source of uncertainty in simulating precipitating clouds. Single-category moment-based approaches are promising, but inverting a multi-modal distribution to its parameters can be unstable and ill-defined.

$$\frac{d}{dt} M^k_{cloud,rain} = f(\{M^k_{cloud,rain}\})$$

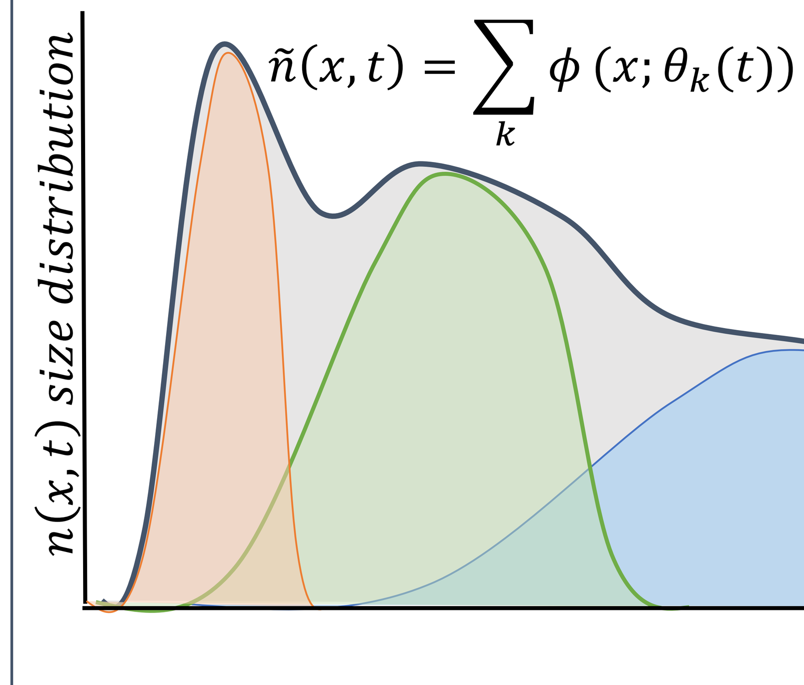
Autoconversion, accretion, self-collection

Convergence in Box Model

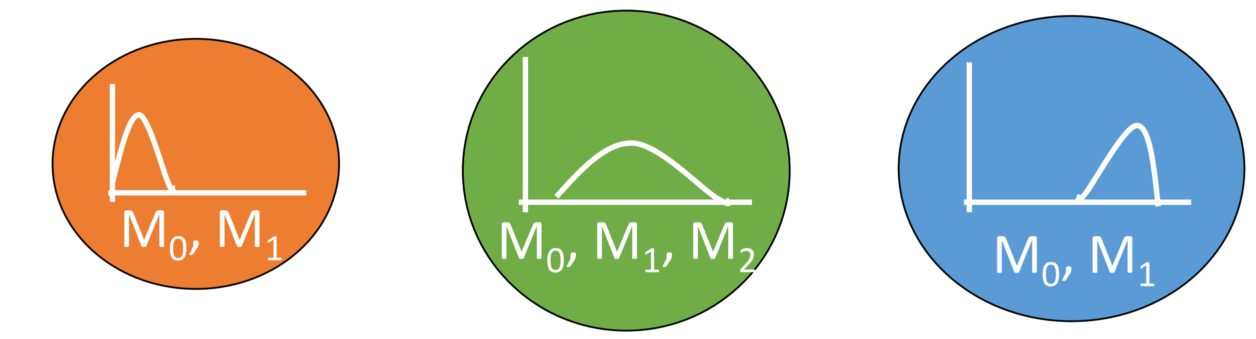
Using more complex or more numerous basis functions leads to closer approximation of the PSD (including multimodal behavior) and reflectivity.



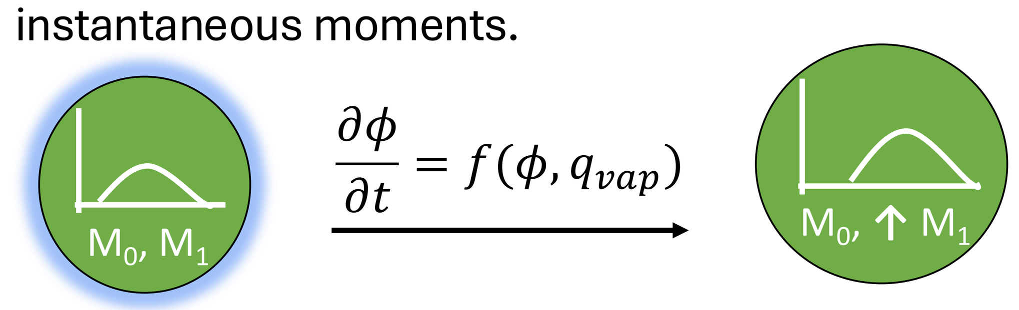
Flexible Moments or Moving Basis Functions



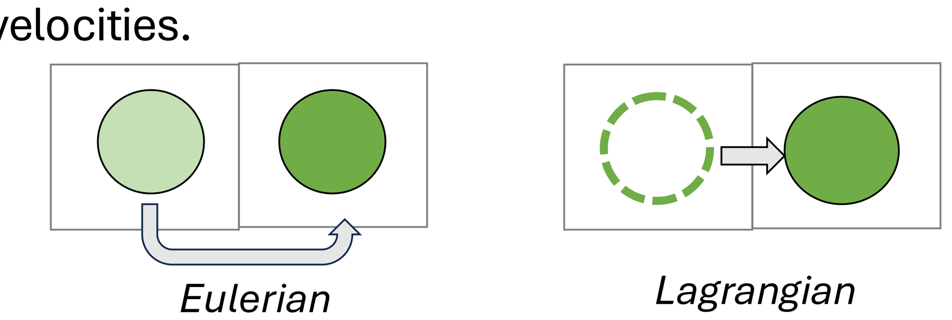
Our approach assumes the distribution is composed of several "modes", or sub-distributions ϕ with time-varying parameters $\theta(t)$ that commute with their moments. Think of them as moving basis functions, or as Lagrangian particles that represent a subpopulation.



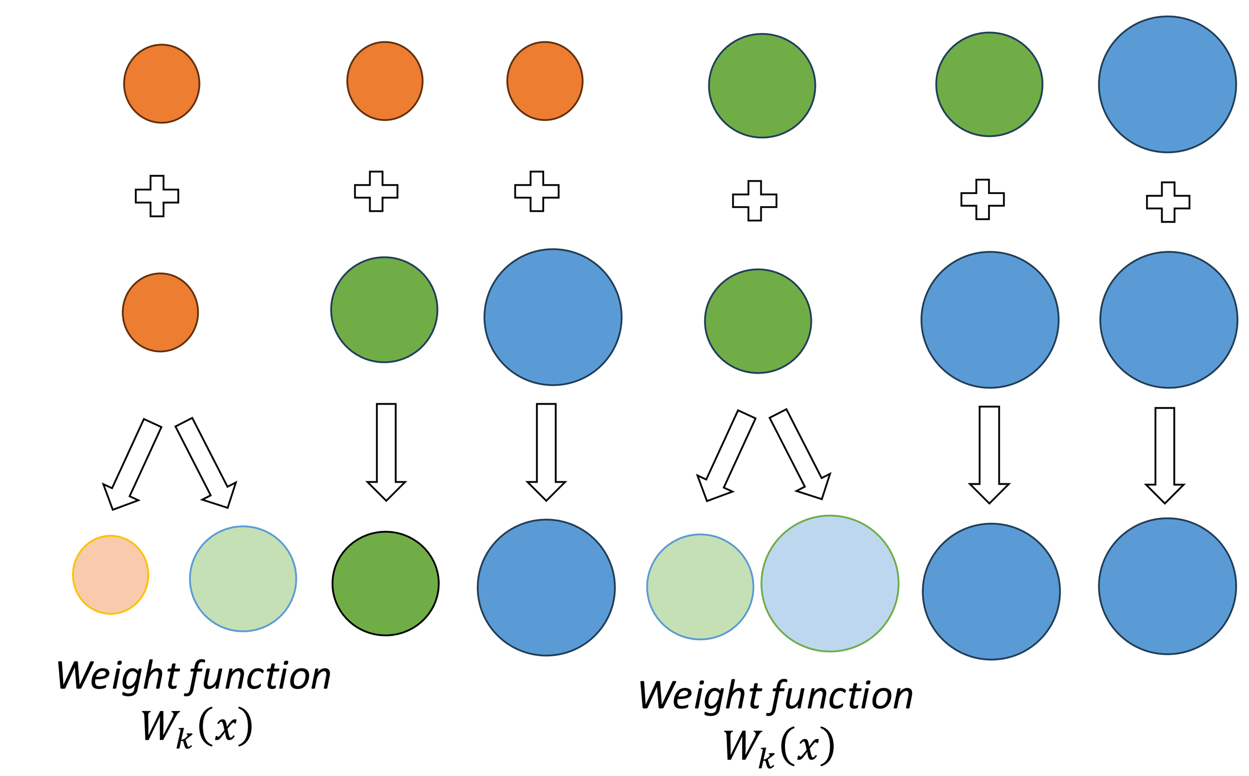
Condensation/evaporation rates are computed by explicitly solving the condensation equation using the subdistribution implied by instantaneous moments.



Sedimentation/advection can proceed in either a Eulerian or a Lagrangian sense by computing moment-weighted fallspeeds and mean flow velocities.

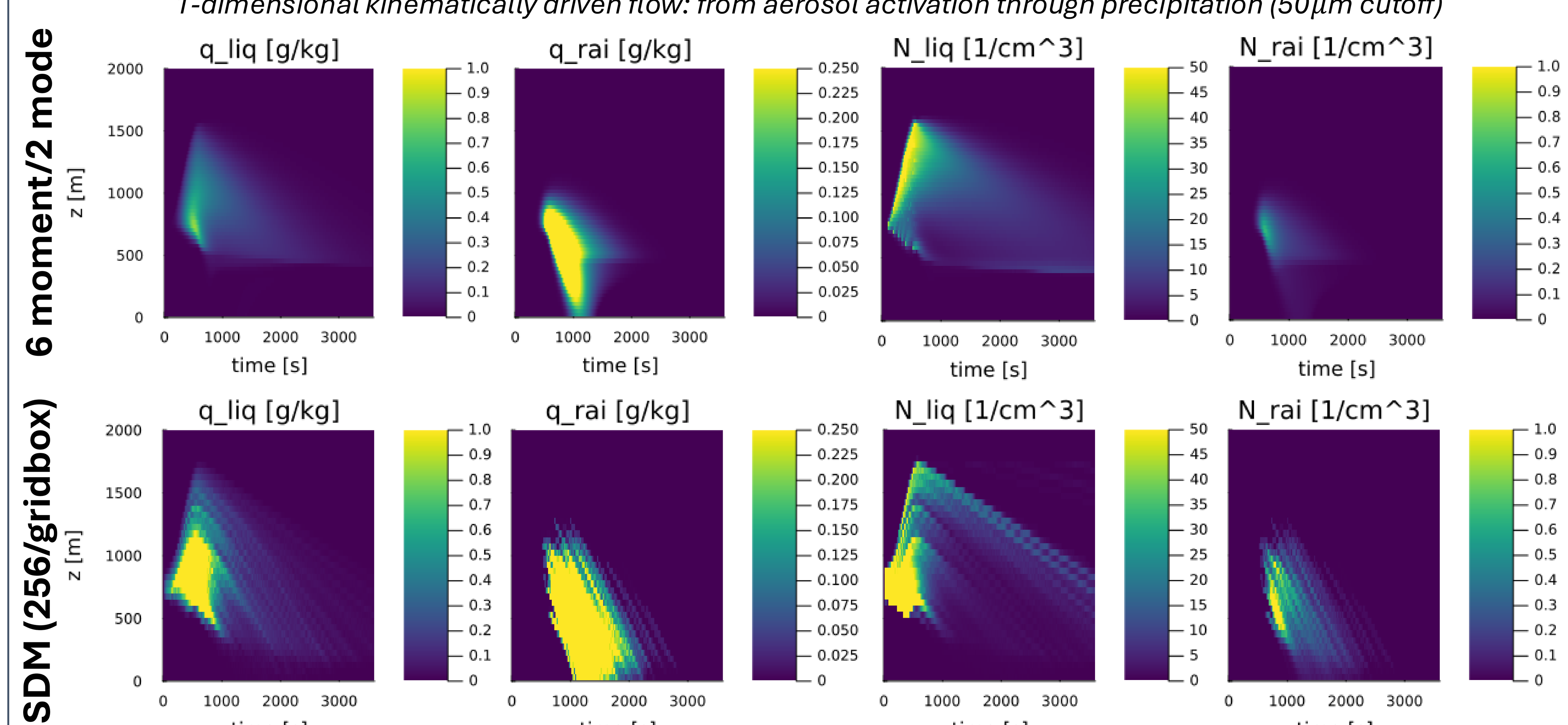


Collisional coalescence re-parameterizes the rate of collisions based on particle size as a polynomial compute pairwise interactions between modes analytically. Intra-mode collisions partition moments using a weight function and numerical integration.



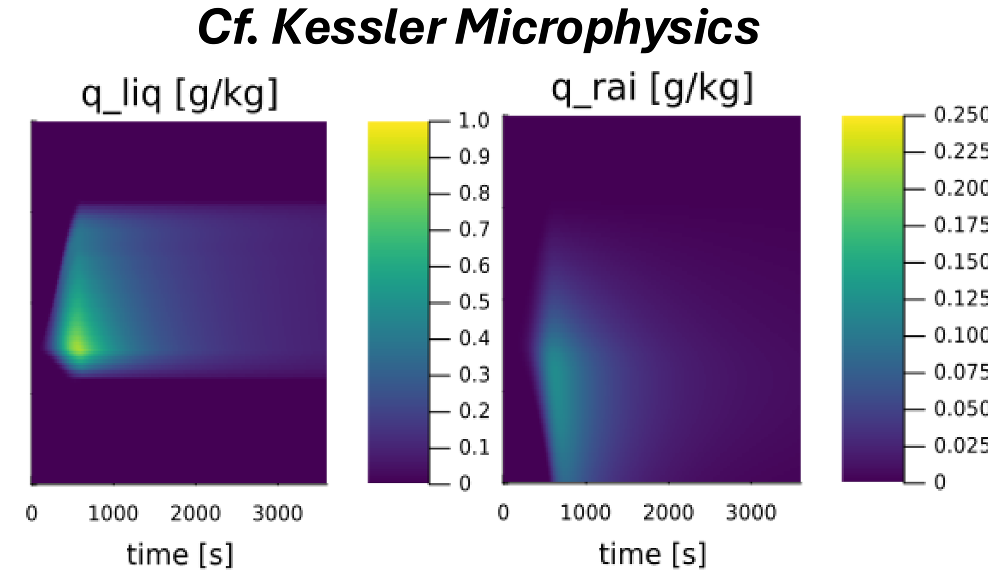
Validation in Idealized Rainshaft

1-dimensional kinematically driven flow: from aerosol activation through precipitation (50µm cutoff)



We capture all stages of cloud development from aerosol activation through precipitation consistently with the SDM. Rather than relying on regime-specific parameterizations of rain formation, we utilize the same core *rate of collisions* regardless of the number of moments or modes used.

Cf. Kessler Microphysics



Development Status & Next Steps

- Implementation of the flexible method exists in a standalone module **Cloudy.jl** as part of the CliMA project, and is fully integrated into our idealized model playground **KinematicDriver.jl**.
- Ongoing work to integrate with the **ClimaAtmos.jl** framework will allow for higher complexity LES and climate simulations, including simulation of the **RICO test case** for validation.
- Exciting opportunities exist to extend the flexible moment approach to:
  - Aerosol physics: hygroscopicity or chemical component attributes
  - Ice microphysics: density and/or geometry distribution axis
- New work in *data-driven unstructured models* for cloud microphysics will build on this hybrid Lagrangian-Eulerian approach.

Ask me about my PostDoc research!

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