Modular, unified, robust and validated:
chasing the dreams of a climate model parameterization developer

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Caltech

CliMA CLIMATE MODELING ALLIANCE

DA/ML techniques offer a way of calibrating parameterizations and reducing model uncertainty. They can't reduce structural errors stemming from individual parameterizations or the coupling, and rely on access to high quality data.

Process-level understanding can inform model design. But if unconstrained by observations, it can lead to unnecessary complexities.

Parameterization stack

$$\frac{\partial\langle\phi\rangle}{\partial t}+\nabla_h\big(\langle\phi\rangle\langle \boldsymbol{u}\rangle\big)=-\frac{\partial}{\partial z}\big(\langle w\rangle\langle\phi\rangle\big)-\frac{\partial}{\partial z}\langle w^*\phi^*\rangle+\langle S_\phi\rangle$$

$$\frac{\partial(\rho a_i\overline{\phi}_i)}{\partial t}+\frac{\partial(\rho a_i\overline{w}_i\overline{\phi}_i)}{\partial z}+\nabla_h\cdot\big(\rho a_i\langle \mathbf{u}_h\rangle\overline{\phi}_i\big)=\underbrace{-\frac{\partial(\rho a_i\overline{w_i'\phi_i'})}{\partial z}}_{\text{Turbulent transport}}+\underbrace{\rho a_i\overline{w}_i\Big(\sum_j\epsilon_{ij}\overline{\phi}_j-\delta_i\overline{\phi}_i\Big)}_{\text{Entrainment/detrainment}}+\underbrace{\rho a_i\overline{S}_{\phi,i}}_{\text{Sources/sinks}}$$

Dynamical core numerics
- ClimaTimesteppers.jl
- ClimaCore.jl

Sub-grid scale dynamics (turbulence, convection)
- ClimaAtmos.jl

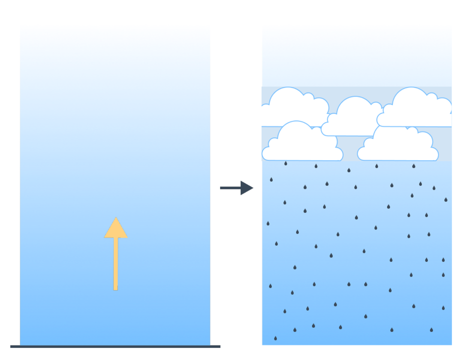
Sources (microphysics, radiation, …)
- CloudMicrophysics.jl
- Cloudy.jl
- KinematicDriver.jl

Machine learning
- EnsembleKalmanProcesses.jl
- ClimaParameters.jl

Example parameter calibration

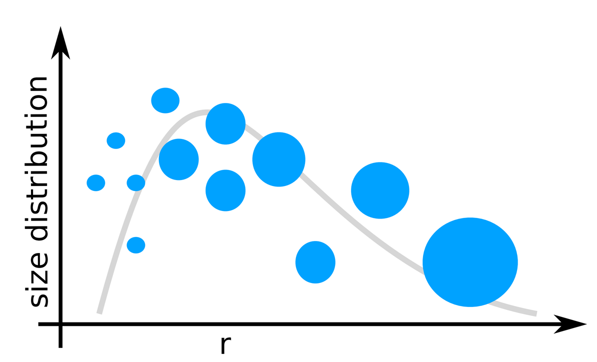
Model

Prescribed flow 1D (KinematicDriver.jl) coupled to 1-moment and 2-moment bulk microphysics schemes (CloudMicrophysics.jl)



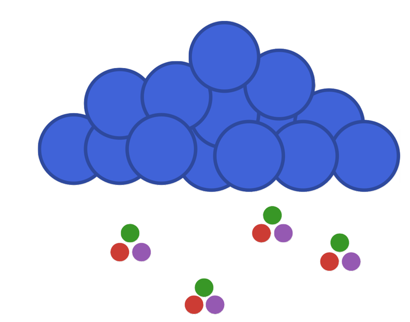
Data

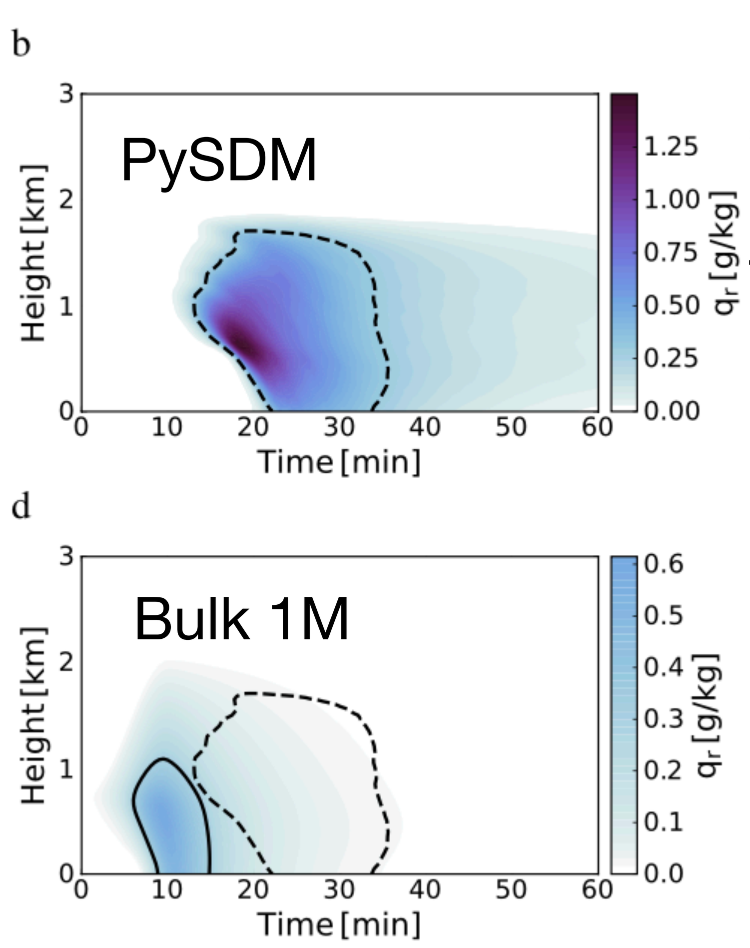
PySDM (particle based Lagrangian microphysics) coupled to the same modeling setup. Generated size distributions of aerosol cloud and precipitation particles.



Calibrated parameters

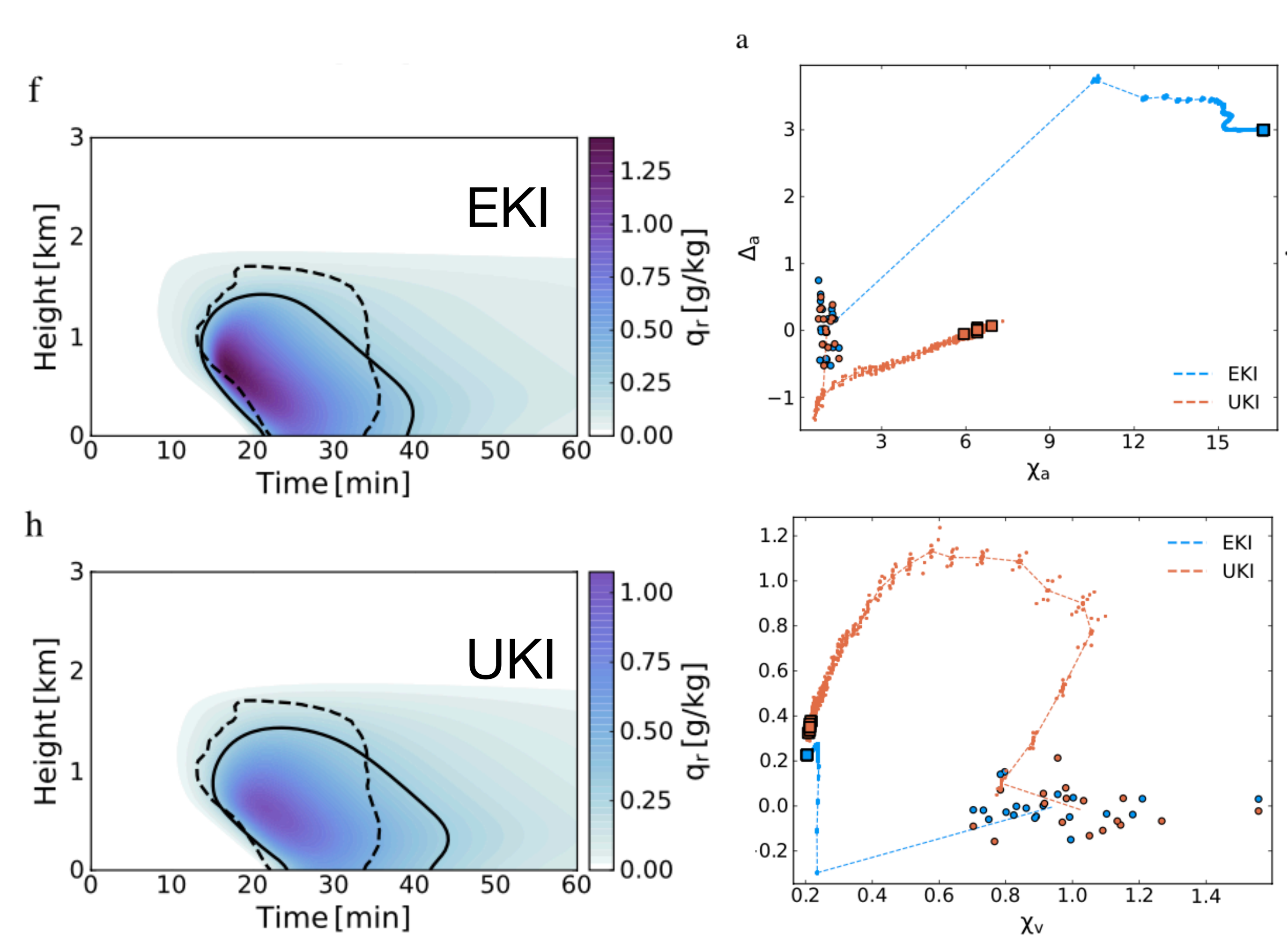
Bulk microphysics scheme parameters from Abdul Razzak and Ghan (ARG) aerosol activation and 1-moment rain formation parameters.





Left panels show the time evolution of precipitation in PySDM and in the uncalibrated 1-moment bulk scheme from the 1D kinematic model.

Right panels show the time evolution of precipitation in the bulk 1-moment scheme after calibration using two optimization algorithms EKI and UKI. We also show the evolution calibrated parameter values for EKI and UKI.



- Documentation online for each of the packages
- A hierarchy of tests (unit tests, performance tests, CPU/GPU, integration, reproducibility)
- Tutorials and use examples

github.com/CliMA

Microphysics calibrations: Azimi et al. 2024: Training warm-rain bulk microphysics schemes using super-droplet simulations
Ensemble Kalman methods: Huang et al. 2022: Iterated Kalman methodology for inverse problems.
EDMF: Tan et al. 2018: An extended eddy-diffusivity mass-flux scheme for unified representation of subgrid-scale turbulence and convection.
Kinematic driver: Shipway and Hill 2012: Diagnosis of systematic differences between multiple parametrizations of warm rain microphysics using a kinematic framework.
Cloud microphysics: clima.github.io/CloudMicrophysics.jl/dev/