Atmospheric Modeling II: Parameterizations

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NSF NCAR CGD. Atmospheric Modeling and Predictability (AMP)

CESM Tutorial: August 5, 2024

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Learning Outcomes

By the end of this talk, you should have:

- An understanding of what a model “parameterization” is and why it’s necessary
- Familiarity with some of the main parameterizations in the Community Atmospheric Model v6 (CAM6)
- The ability to find more information about any parameterization on your own

What is a parameterization?

The representation, in a dynamic model, of physical effects in terms of admittedly oversimplified parameters, rather than realistically requiring such effects to be consequences of the dynamics of the system.

-American Meteorological Society (AMS) Glossary

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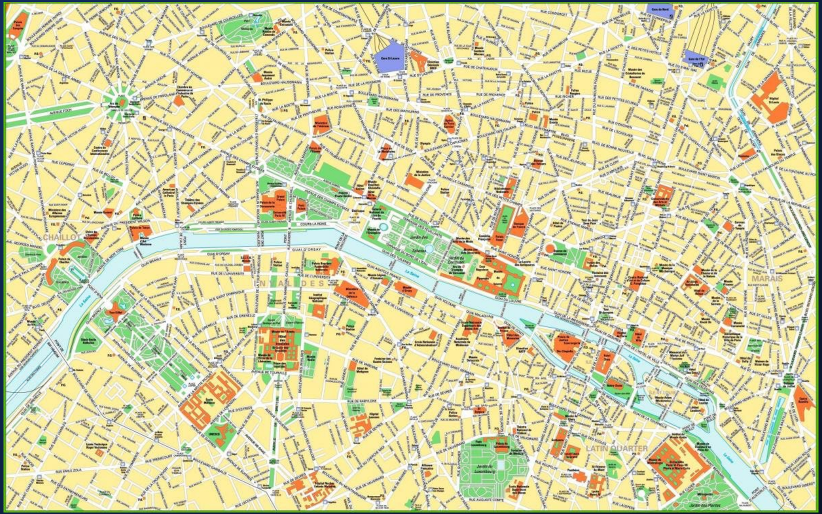
-American Meteorological So

A method of replacing processes that are **too small-scale or complex** to be physically represented in the model by a **simplified process.**

-Wikipedia

What is a parameterization?

- Imagine you're in Paris for the Olympics, but your phone broke and you can't zoom in on maps anymore! The map on the left has a *ton* of info, but the map on the right, with coarser resolution has enough info to get around!



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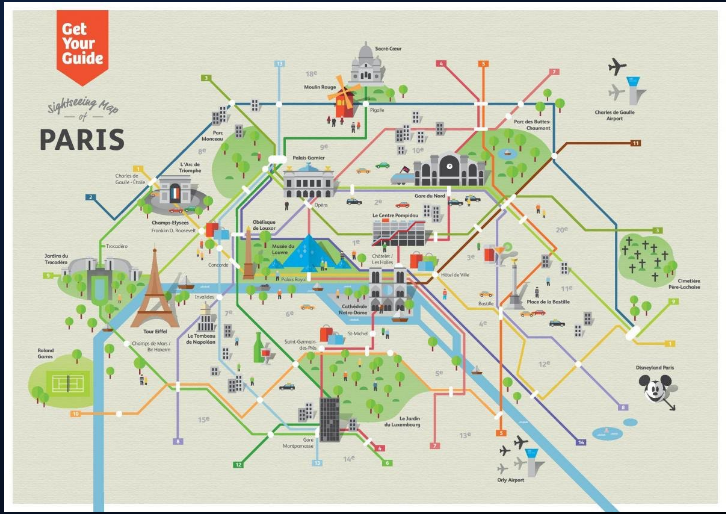

https://maps-paris.com/maps-paris-tourist/paris-places-to-visit-map

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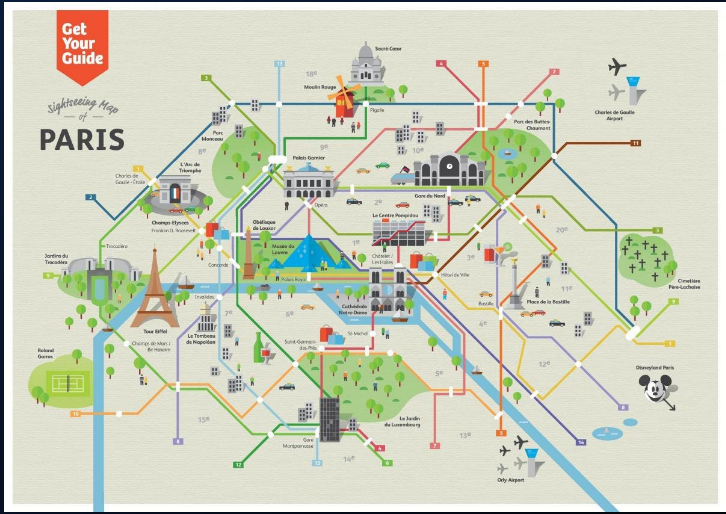
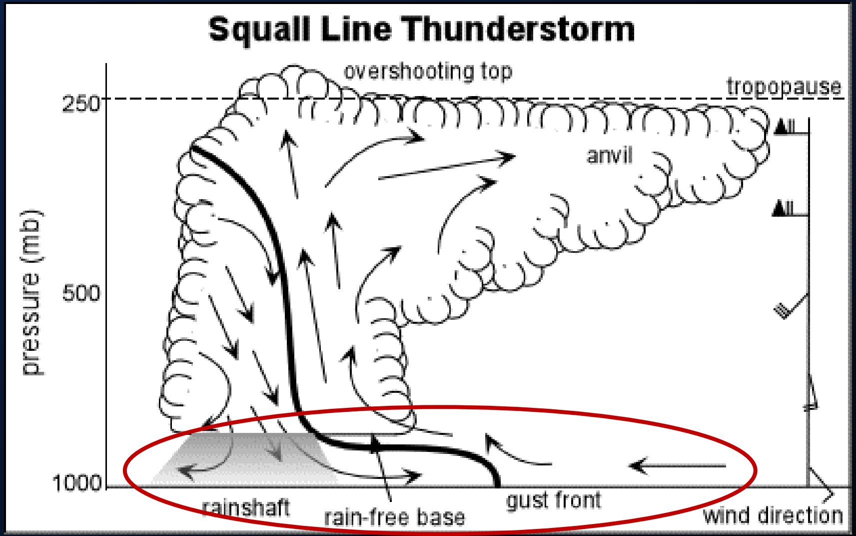
- This is *somewhat* the idea of model parameterizations; they take complex, detailed information and turn them into simplified representations at larger scales.
- The goal is to capture the impact of those smaller (sub-grid) phenomena on the larger (resolved) scale.



https://maps-paris.com/maps-paris-tourist/paris-places-to-visit-map

What kinds of things would an atmospheric model need to parameterize?



http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/svr/modl/line/squall.rxml

Factors that go into choosing parameterizations

- Impact on the Earth system
  - E.g., shape of a leaf vs. land use
- Computational expense
  - Should be cheaper than explicitly representing the process in question
- Process uncertainty
  - What can be represented with limitations in process -level knowledge?

Learning Outcomes

By the end of this talk, you will have:

- An understanding of what a model "parameterization" is and why it's necessary

A parameterization is a way to represent unresolved (and potentially uncertain) sub-grid processes for their impact on the resolved scale.

Often stems from physics (conservation principles, etc.) and/or from observationally-derived constraints

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Parameterizations in CAM6

Convection

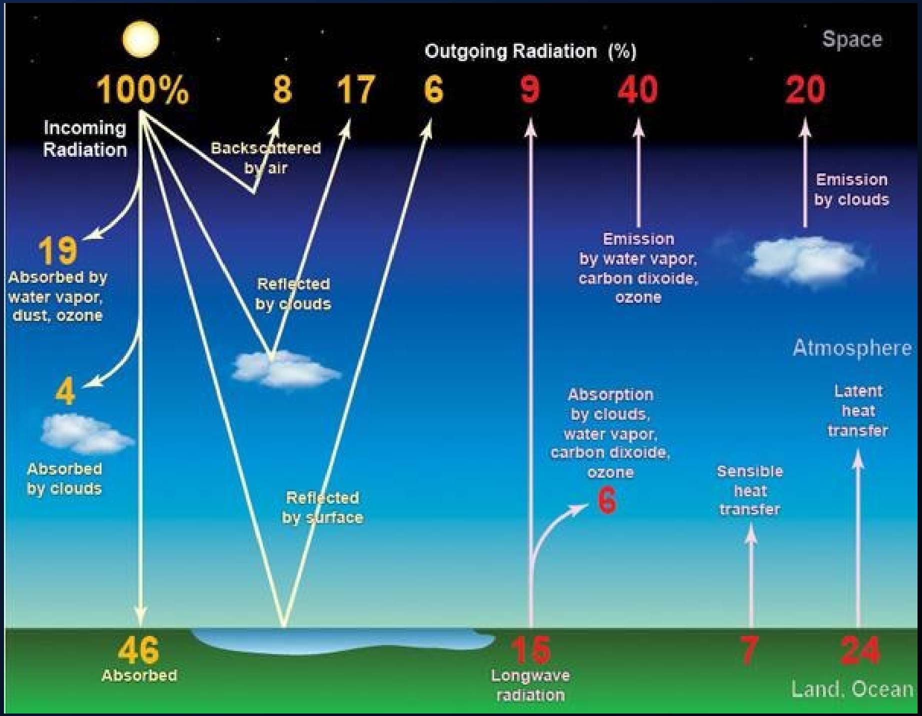
Radiation

Aerosols

Microphysics

Radiation in CAM6

- The radiative code must supply:
  - the total radiative flux at the surface to calculate the surface energy balance
  - the radiative heating and cooling rates at each level of the atmosphere
- The parameterization should include the combined effect of absorption and scattering by the radiatively active gases (H2O, CO2, O3…) together with cloud and aerosol.
- CAM6 uses the Rapid Radiative Transfer Model for GCMs (RRTMG), a correlated k-distribution band model.



https://ei.lehigh.edu/learners/cc/planetary/planetary1.html

Convection in CAM6

Shallow Convection

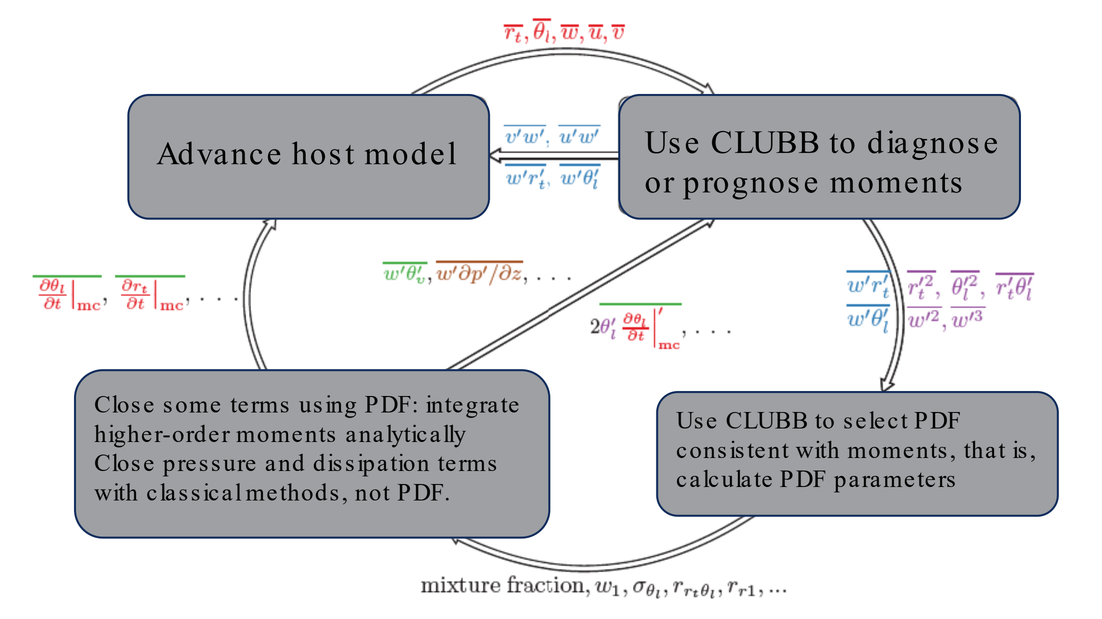
- Scale: tens to hundreds of meters
- Instability mainly within PBL, limiting vertical growth of plumes
- Represented in CAM6 by Cloud Layers Unified By Binormals (**CLUBB**)

Deep Convection

- Scale: hundreds of meters to kilometers
- Instability through troposphere, allowing plumes to reach much higher
- Represented in CAM6 by Zhang McFarlane (**ZM**) scheme

CLUBB

- Represents boundary layer turbulence and shallow convection
- Predicts joint PDF of vertical velocity, temperature, and moisture
  - PDF used to predict grid means, (co)variances, and other higher-order moments of all three terms



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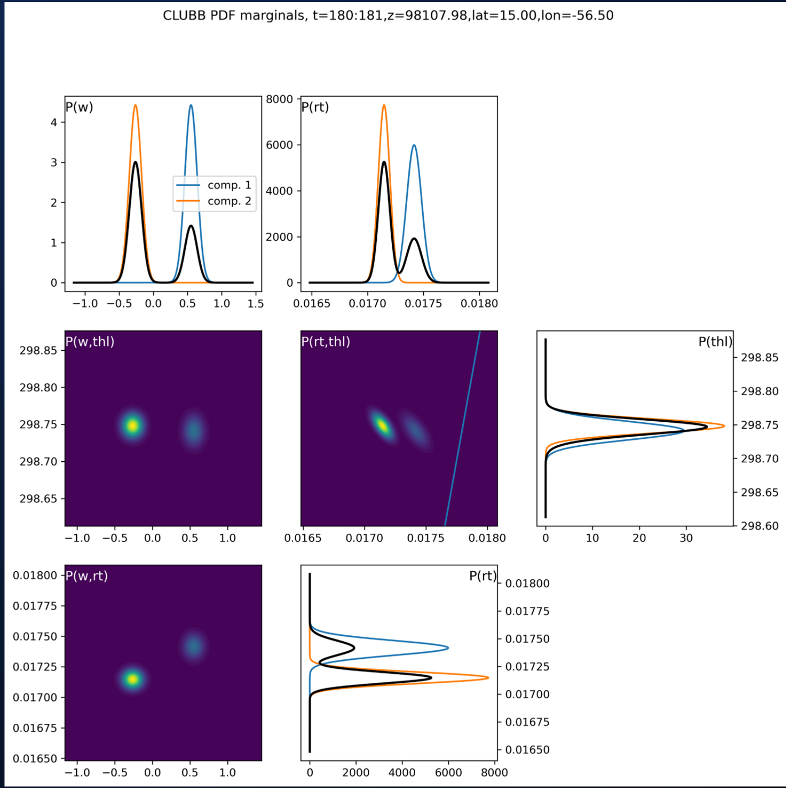
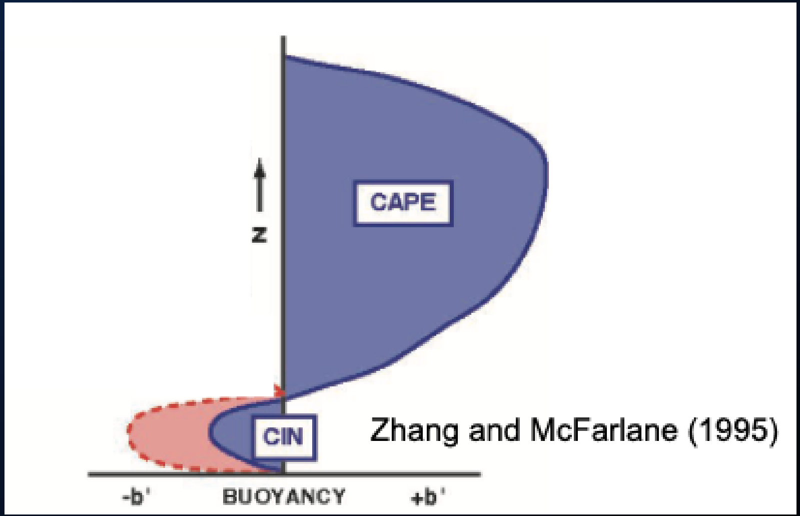


Deep Convection (ZM)

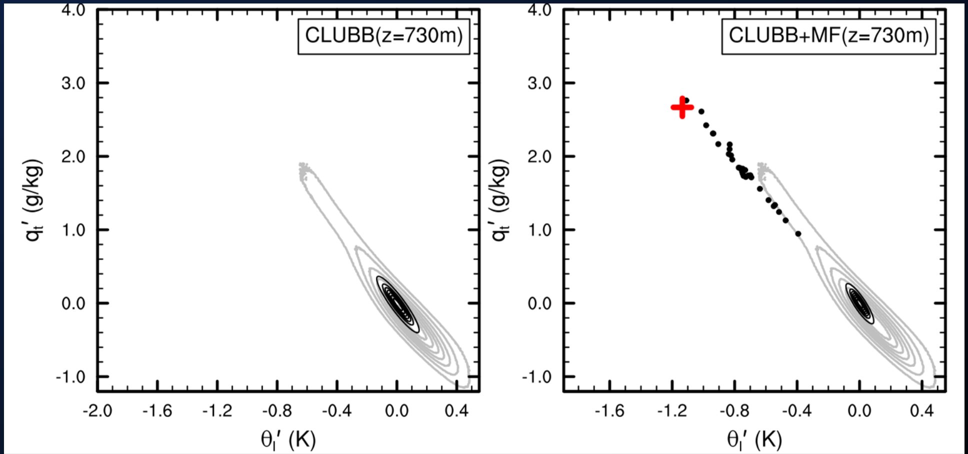
- Originally based on Zhang & McFarlane 1995
  - Modifications made over time, see more detail in the CAM6 documentation
- Triggers based on hourly Convective Available Potential Energy (CAPE)
- Convective intensity proportional to amount of CAPE
- Mass flux approach to calculate air motion within plumes
- Parameterized entrainment and detrainment
- Calculates convective heating and moistening at each level



Convection in the future: unification?

CLUBB+MF

- New parameterization avoids hand off between shallow/deep convection schemes by combining
  - CLUBB continues to serve as boundary layer and shallow convection parameterization.
  - Mass Flux (MF) scheme introduces explicit updraft plumes for deep convection

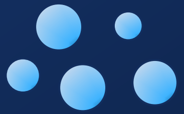


Adapted from Fig. 3 of Witte et al. (2022): LES (gray contours), CLUBB (black contours), and MF plumes (dots).

Cloud Microphysics in CAM6

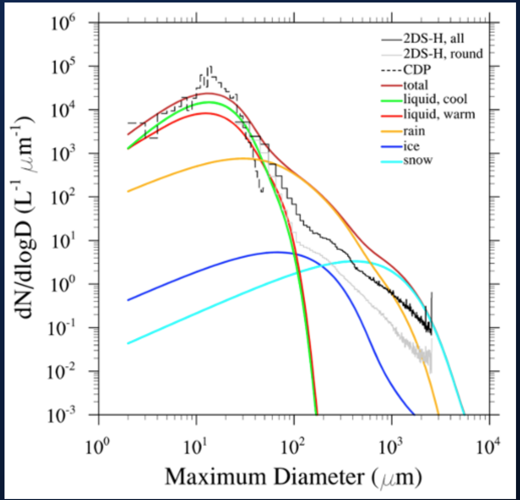
Parameterization of Unified Microphysics Across Scales (PUMAS)

CLOUD DROPLETS
q, N



ICE CRYSTALS
q, N

Gamma hydrometeor size distributions



Gettelman et al., 2020

RAIN
q, N

SNOW
q, N

Note: all cloud hydrometeors are assumed to be spherical

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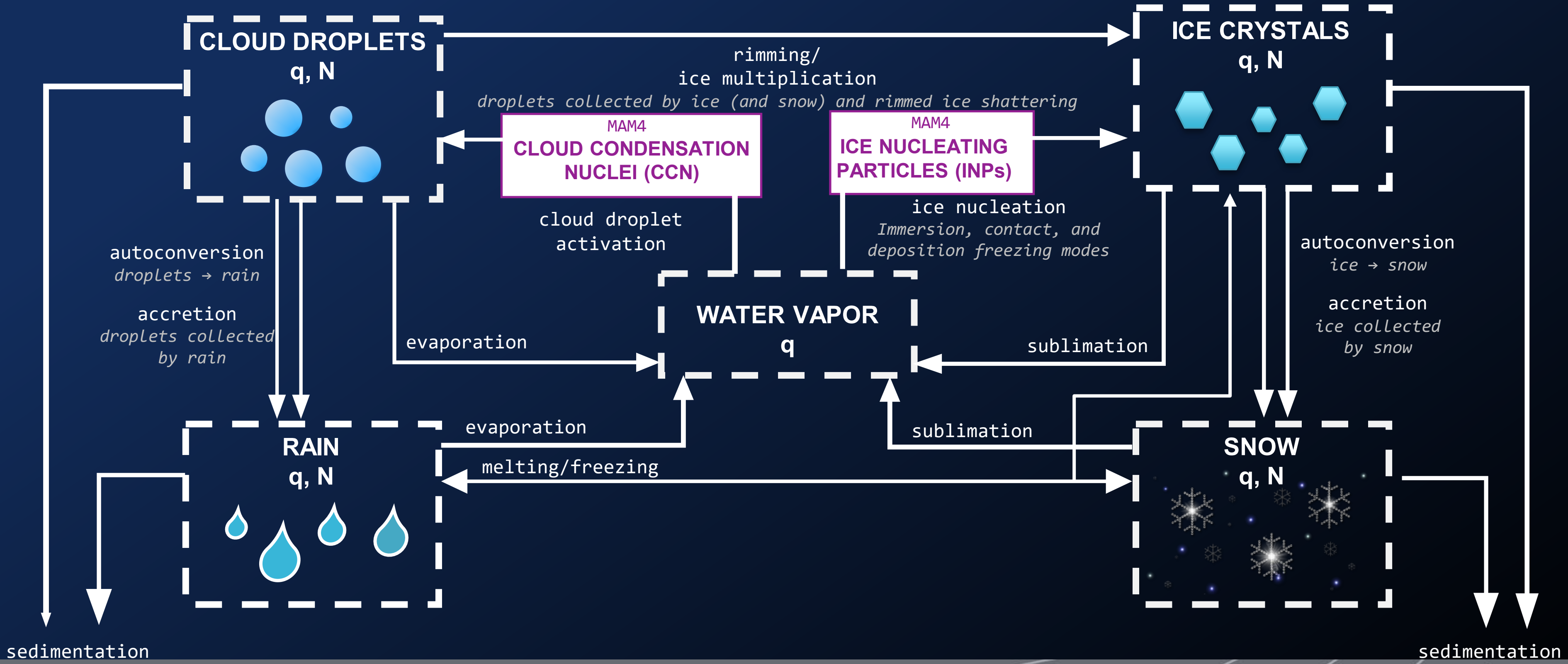

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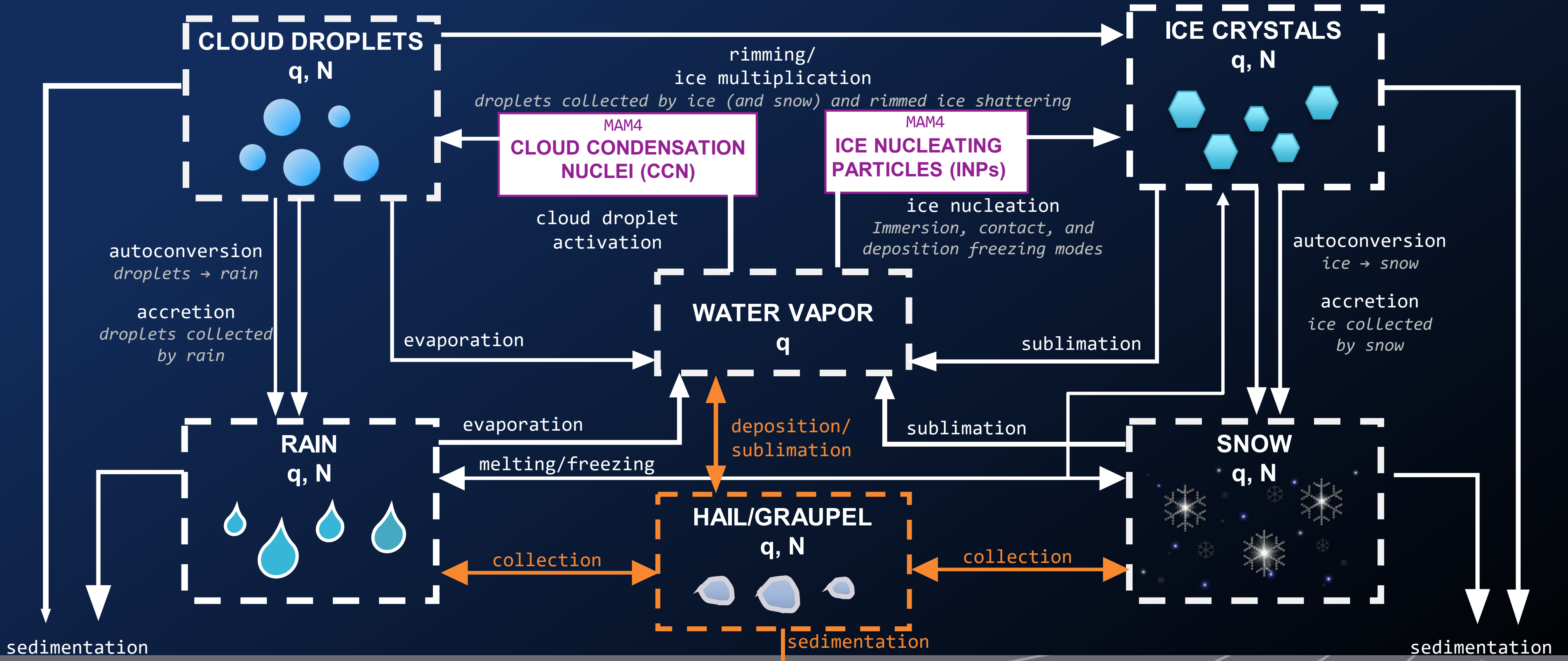


CAM6 Aerosol

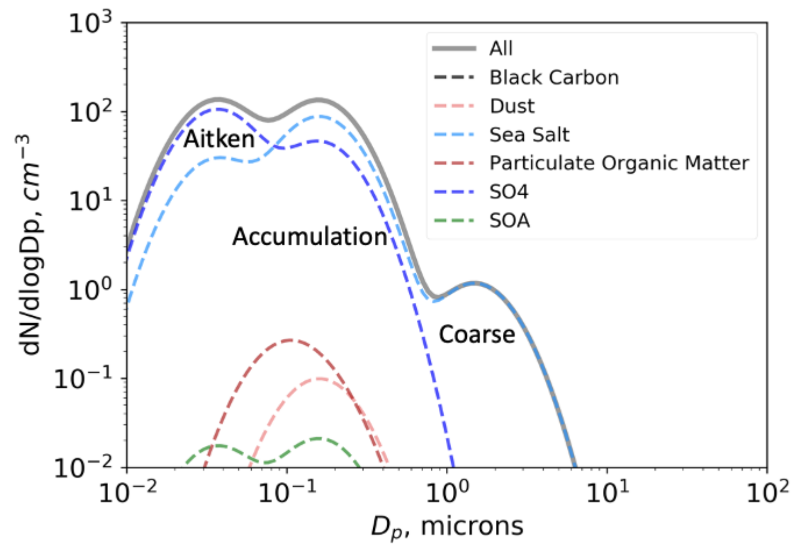
Modal Aerosol Model (MAM4)

- Aerosol are emitted, advected, scavenged
- Modal scheme (lognormal):
  - Number and modal diameter (D_g) prognostic
  - Constant modal width (sigma)

	Aerosol Type	Aitken	Accum., soluble	Accum., insoluble	Coarse
	Black Carbon		x	x	
*	Dust		x		x
*	Sea Salt	x	x		x
	Particulate Organic Matter		x	x	
	SO_4	x	x		x
	Secondary organic aerosol	x	x		

*Dynamic emissions scheme

Liu et al., 2016



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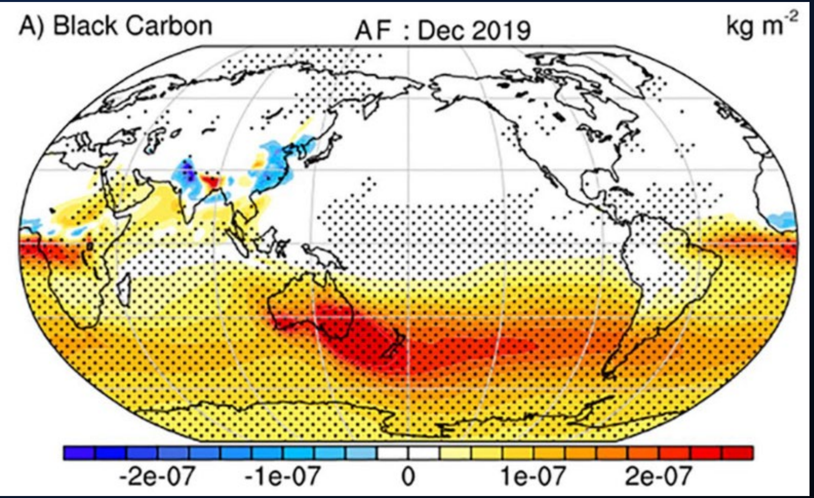

Fasullo et al., 2021

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Finding more detailed information on parameterizations in CAM

- GitHub CAM6 documentation
- Technical documents (e.g., CLUBB-SILHS arXiv document)
- Main parameterization papers
  - RRTMGP: Pincus et al., 2023
  - CLUBB: Golaz et al., 2002
  - ZM: Zhang & McFarlane 1995
  - PUMAS: Gettelman et al., 2023 (doi:10.5194/gmd-16-1735-2023)
  - MAM4: Liu et al., 2012 doi:10.5194/gmd-5-709-2012)
- Terminal (command line) scavenger hunt (grep -rni 'CLDLIQ')

Questions?

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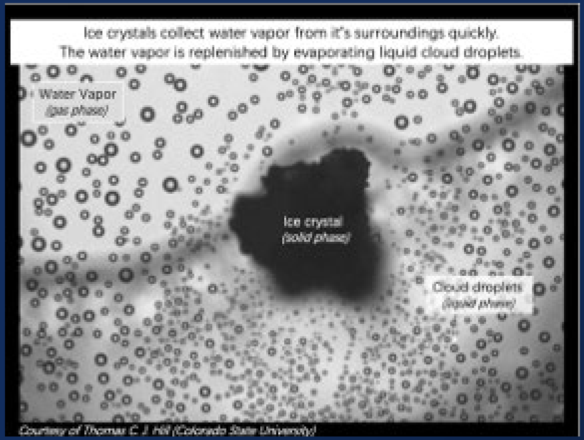

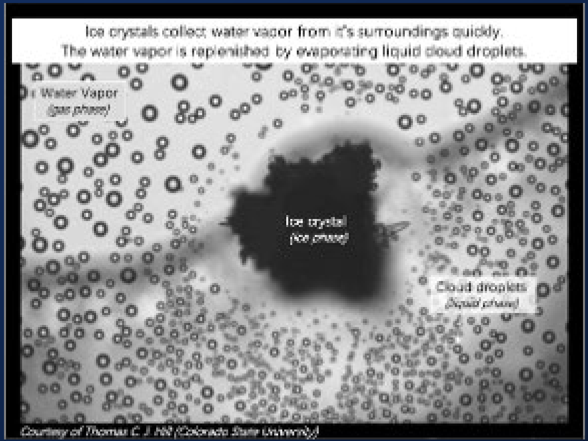

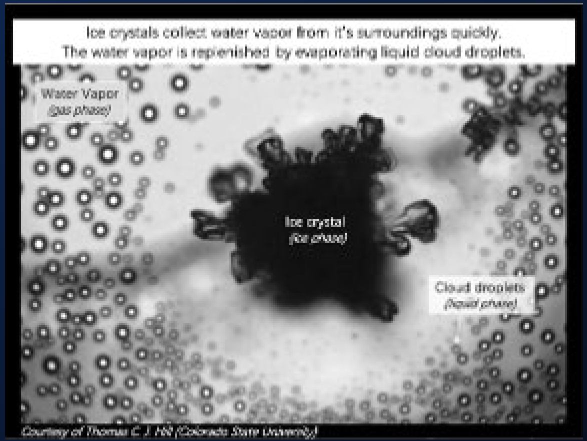

Possible images for WBF process as an example of sub-grid scale processes