Atmospheric Modeling II: Parameterizations

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NSF NCAR CGD

CESM Tutorial: July 7, 2025

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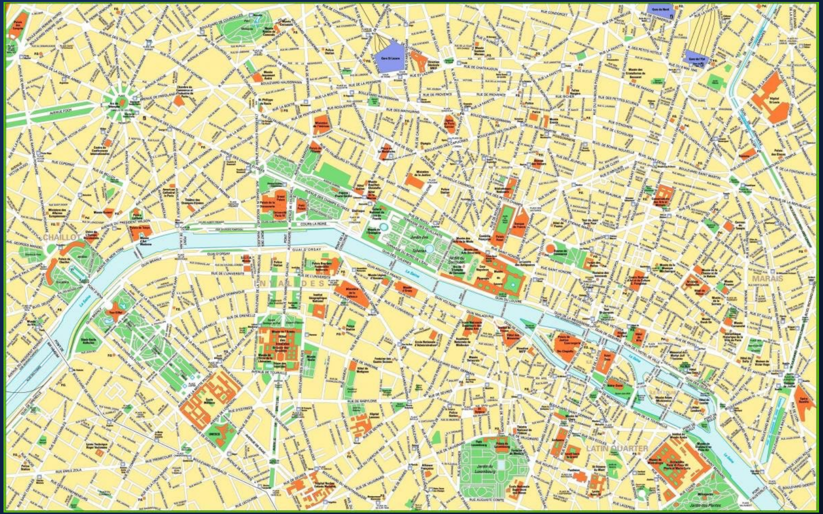
A method of replacing processes that are **too small-scale or complex** to be physically represented in the model by a **simplified process.**

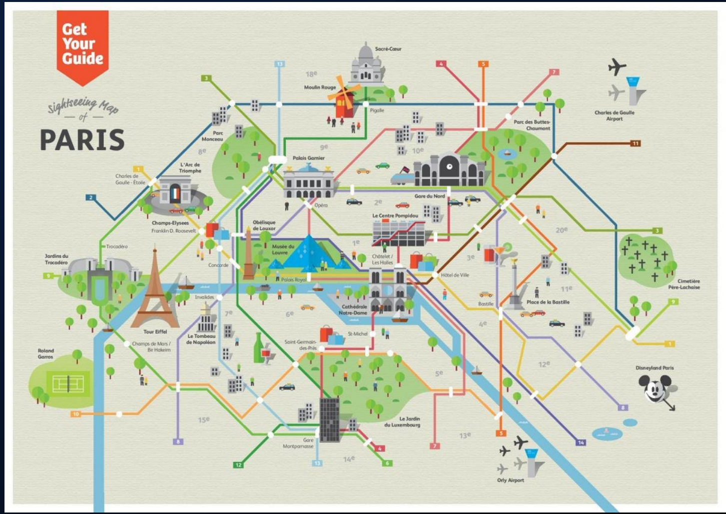
-Wikipedia

What is a parameterization?

- Imagine you’re in Paris, 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!



https://maps-paris.com/maps-paris-city/map-of-central-paris



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

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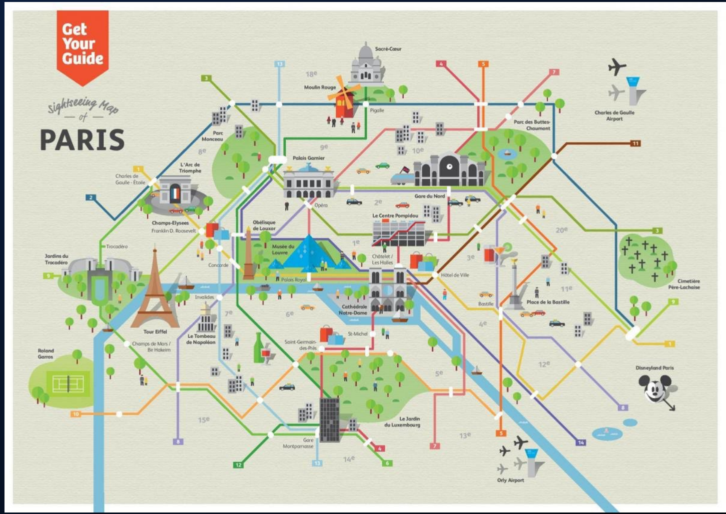
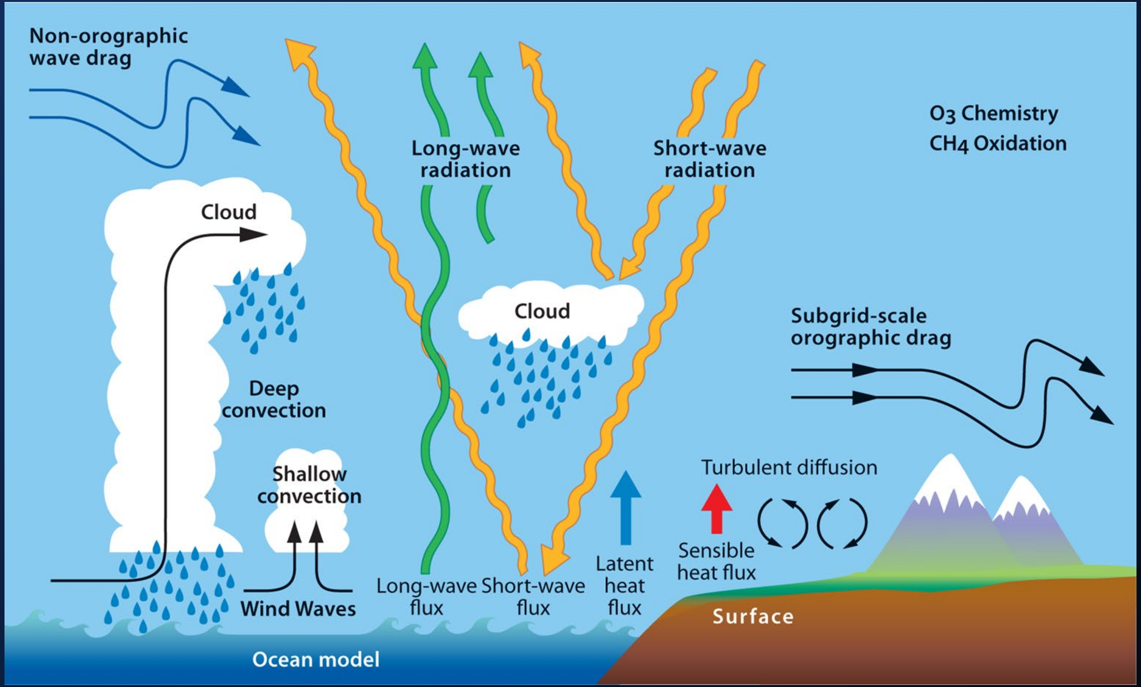
- This is *somewhat* the idea of model parameterizations; they take complex, detailed information and turn them into simplified representations at larger scales.
- The goal is to capture the impact of those smaller (sub-grid) phenomena on the larger (resolved) scale.



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

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



Source: https://www.ecmwf.int/en/research/modelling -and-prediction/atmospheric -physics

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?

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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

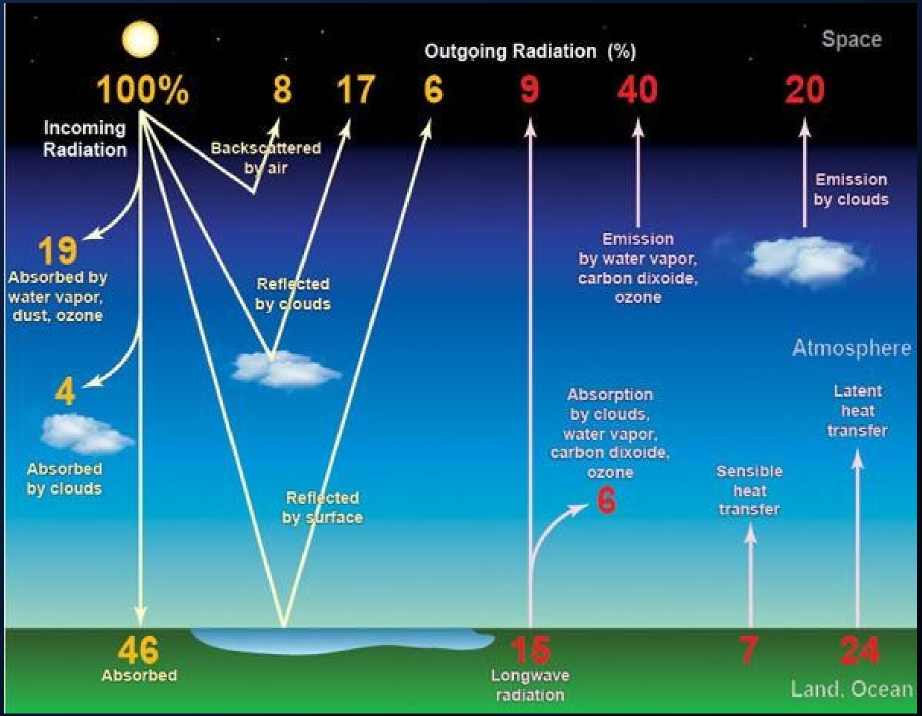
Radiation

Aerosols

Microphysics

Radiation in CAM6

- CAM6 uses the Rapid Radiative Transfer Model for GCMs (RRTMG), a correlated k-distribution band model.
- 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.

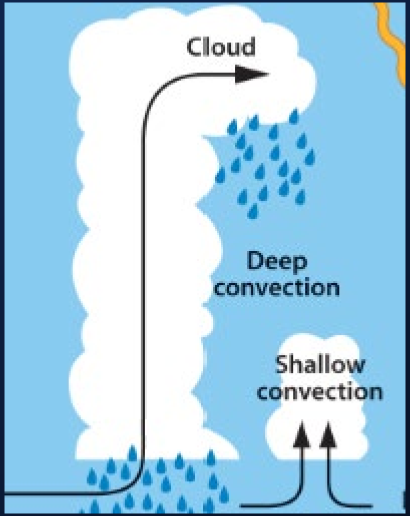


https://ei.lehigh.edu/learners/cc/planetary/planetary1.html

Convection in CAM6

Deep Convection

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

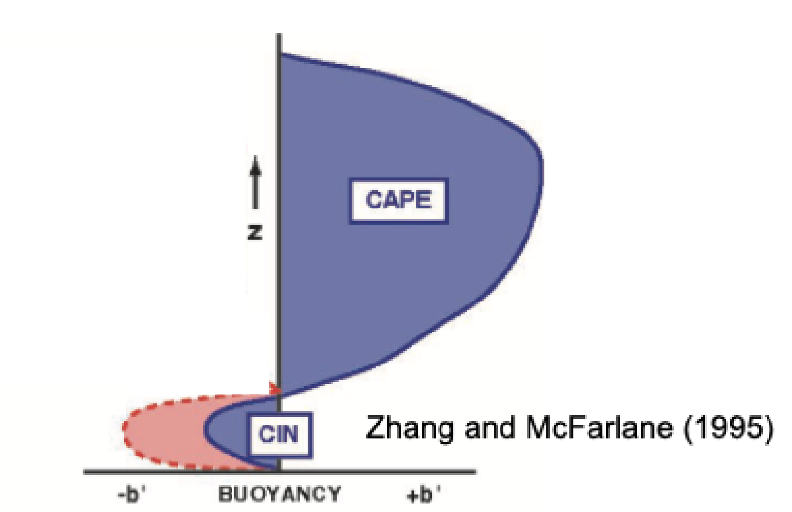


Shallow Convection

- Scale of convective plumes: 100s of meters to ~km
- Instability mainly within PBL, limiting vertical growth of plumes
- Represented in CAM6 by Cloud Layers Unified By Binormals (**CLUBB**)

Deep Convection (ZM)

- Originally based on Zhang & McFarlane 1995
  - Modifications made over time, see more detail in the CAM6 documentation
- Triggers based on 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



CLUBB

- Represents boundary layer turbulence and shallow convection
- Advances a system of equations to model heat, moisture, winds

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CLUBB prognoses 11 moments:

- Fluxes:
  - (2) Heat and moisture fluxes
  - (2) Momentum fluxes
- Variances:
  - (2) Heat and moisture variances
  - (1) Covariance of heat and moisture
  - (3) Momentum variances
- One third-order moment
  - (1) Third moment of vertical velocity

CLUBB

- Represents boundary layer turbulence and shallow convection
- Advances a system of equations to model heat, moisture, winds
- Some terms in eqs are unclosed
- To close some, CLUBB…
  - Predicts a joint PDF of vertical velocity (w), temperature (T), and moisture (q)
  - PDF is used to predict grid means, (co)variances, and other higher-order moments of all three variables (w, T, q)
- Others are closed with standard methods

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Cloud Microphysics in CAM6

Parameterization of Unified Microphysics Across Scales (PUMAS)

Note: all cloud hydrometeors are assumed to be spherical

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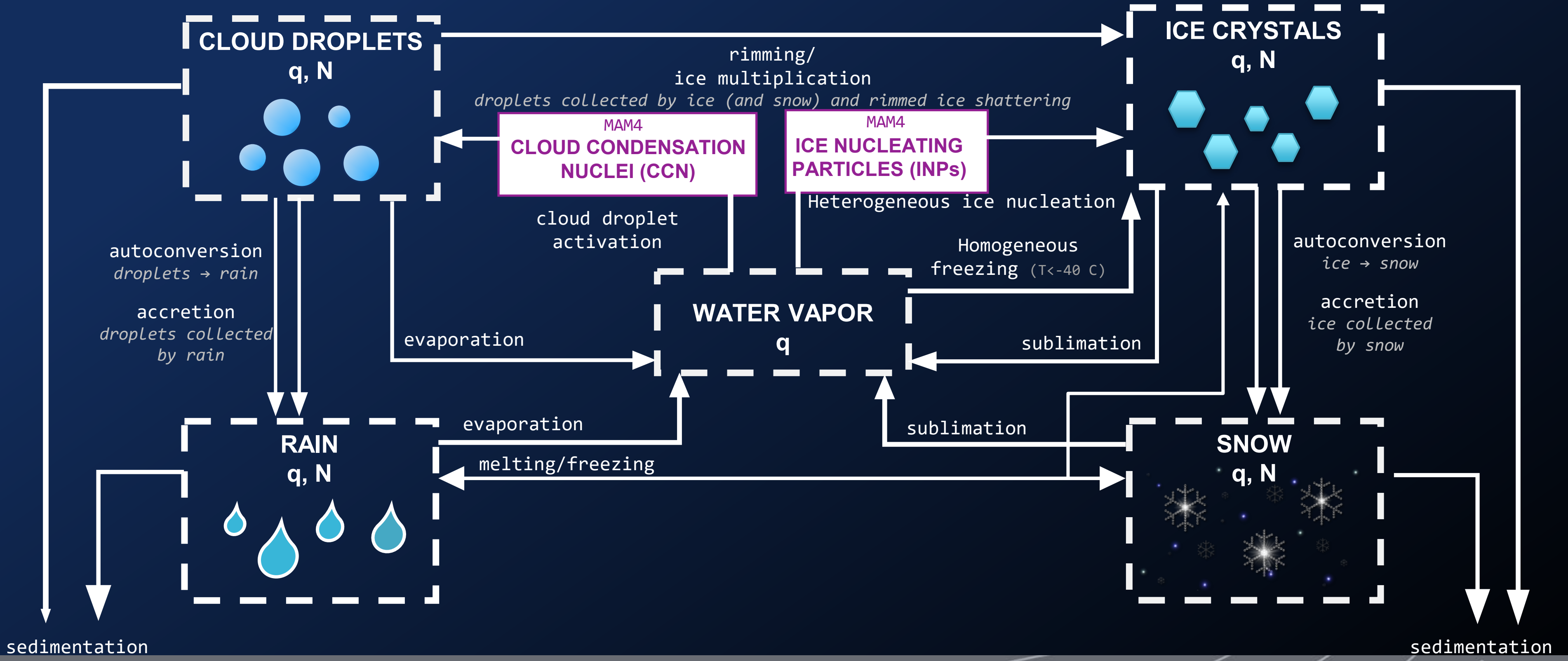

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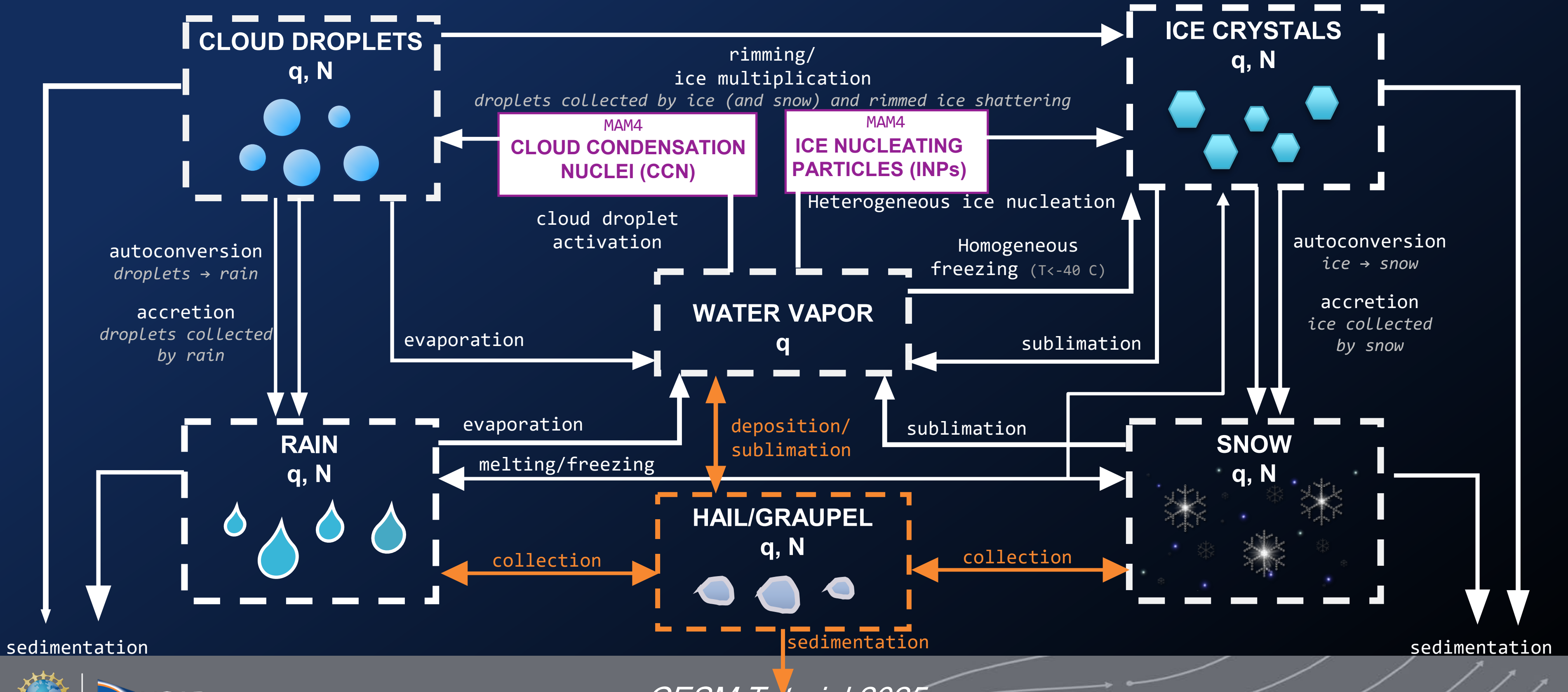
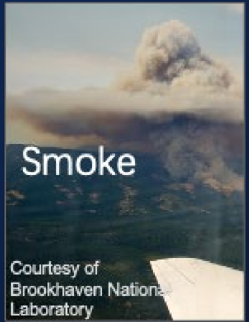
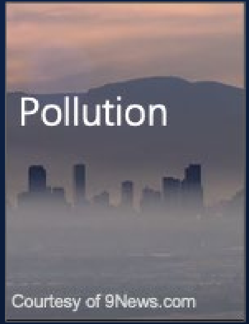


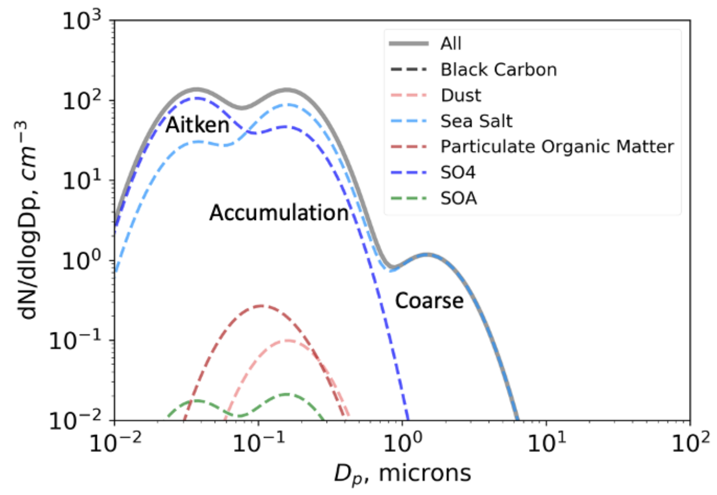
CAM6 Aerosol





Modal Aerosol Model (MAM4)

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



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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’)
- CLUBB tutorial (ask Ben Stephens for access to online materials, stepheba@ucar.edu)

Questions?

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