The CARMA 3.0 microphysics package in CESM

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CARMA 3.0

Community Aerosol and Radiation Model for Atmospheres

- *Turco et al.* [1979] – 1D, 195 citations
- *Toon et al.* [1988] – 3D, 149
- *Jacobson et al.* [1994] – Coagulation, 91
- Sectional (Bin) Microphysics
- Flexible & Extensible
  - Sedimentation
  - Coagulation
  - Nucleation
  - Growth & Evaporation
  - Brownian Diffusion
  - Dry Deposition
  - Particle Swelling
  - Optical Properties (Mie)

*blue means new or modified in CARMA 3.0

CARMA 3.0 Design Goals

- Embed as cloud and/or aerosol component in other 3D models (GCMs)
  - F77 -> F90
  - Common Blocks -> Modules, Defined Types, Dynamic Allocation
  - Thread Safe
  - Implicit None
  - 3-D -> 1-D (Remove horizontal advection, fewer dimensions in arrays)
  - Consistent across restarts and decomposition
  - Constants from parent model
  - Conserve mass and energy
  - Radiative Transfer -> Optical Properties
  - Use from many models (e.g. CAM, WACCM, GEOS5, WRF)
  - Generalized interface to configure the model definition (no direct CARMA field access from parent model)
- Keep code familiar to CARMA 2.3 users
  - Use #define to map common block names to field names
  - Keep files names for core routines the same
- Additions
  - Bug Fixes
  - New/Updated Physics Parameterizations
  - Standalone Test Cases

CESM/CARMA Projects

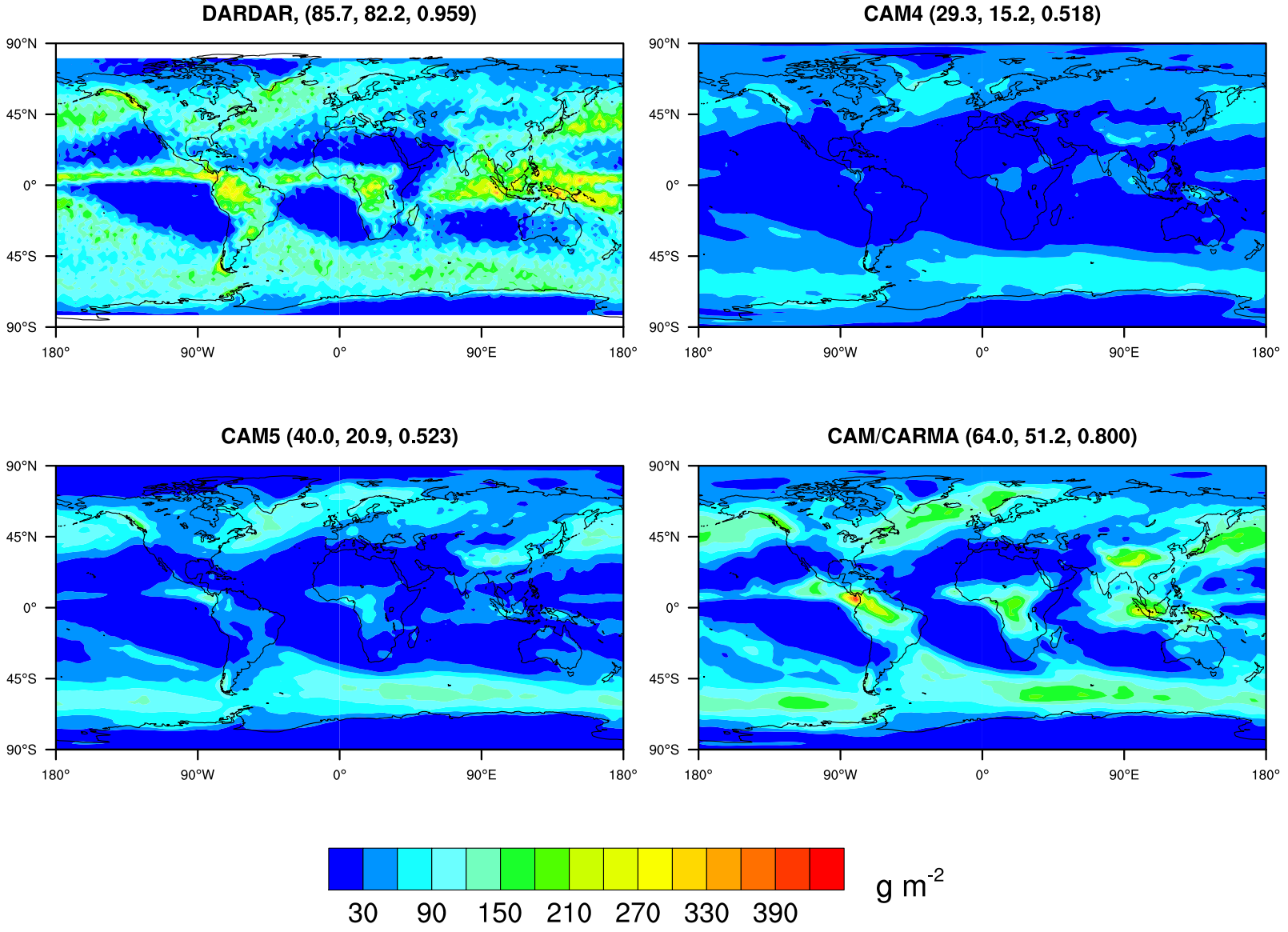
CAM/CARMA

- Sea Salt (Fan)
- Dust (Su)
- Cirrus (Bardeen)

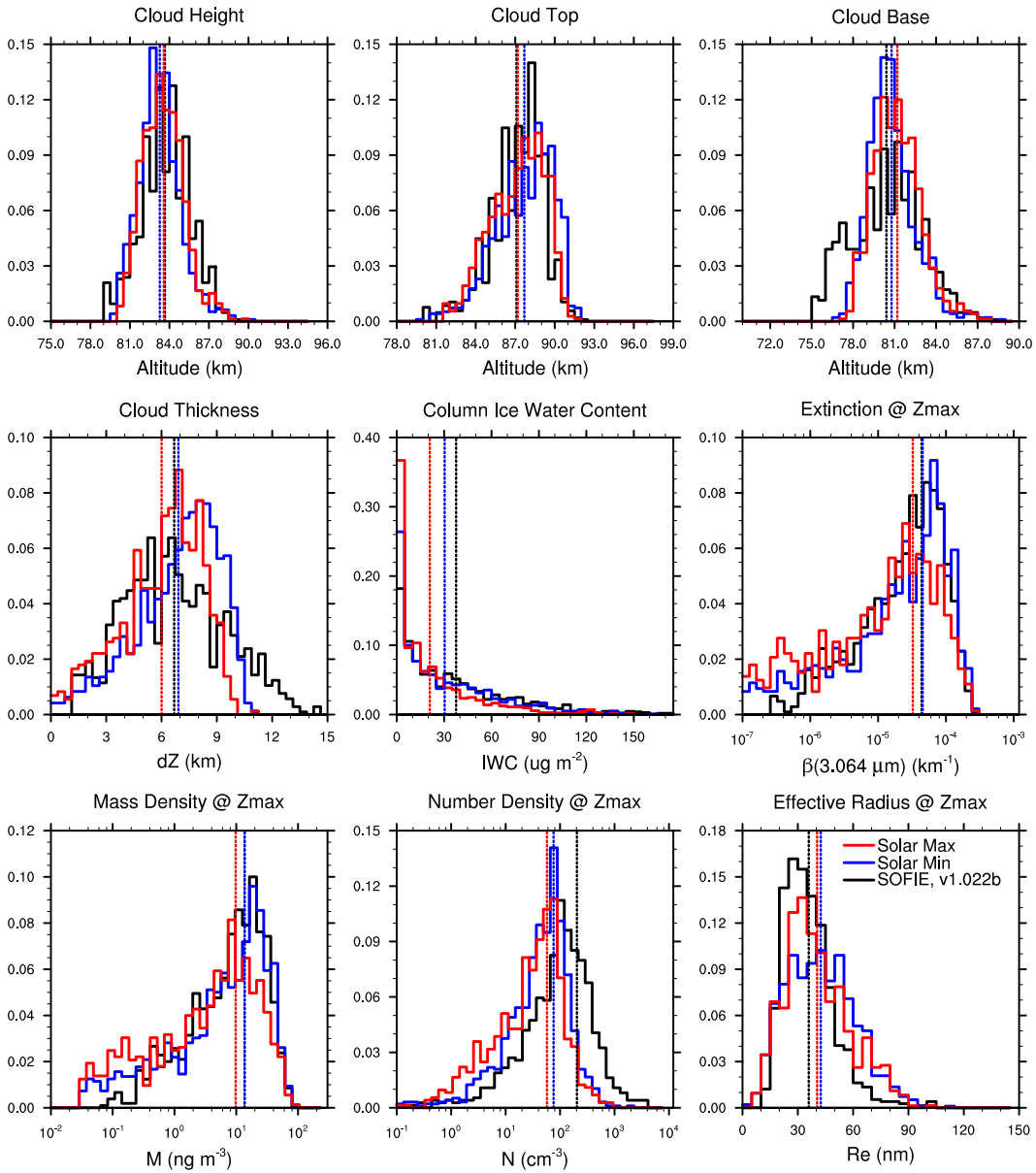
WACCM/CARMA

- Sulfates (Mills, English, Fan, Neely)
- Soot (Mills, Smith)
- PSC (Zhu)
- Early Earth Haze (Wolf)
- Meteor Smoke (Bardeen)
- PMC (Bardeen)
- Meteor Impact (Bardeen, Mills, Garcia)

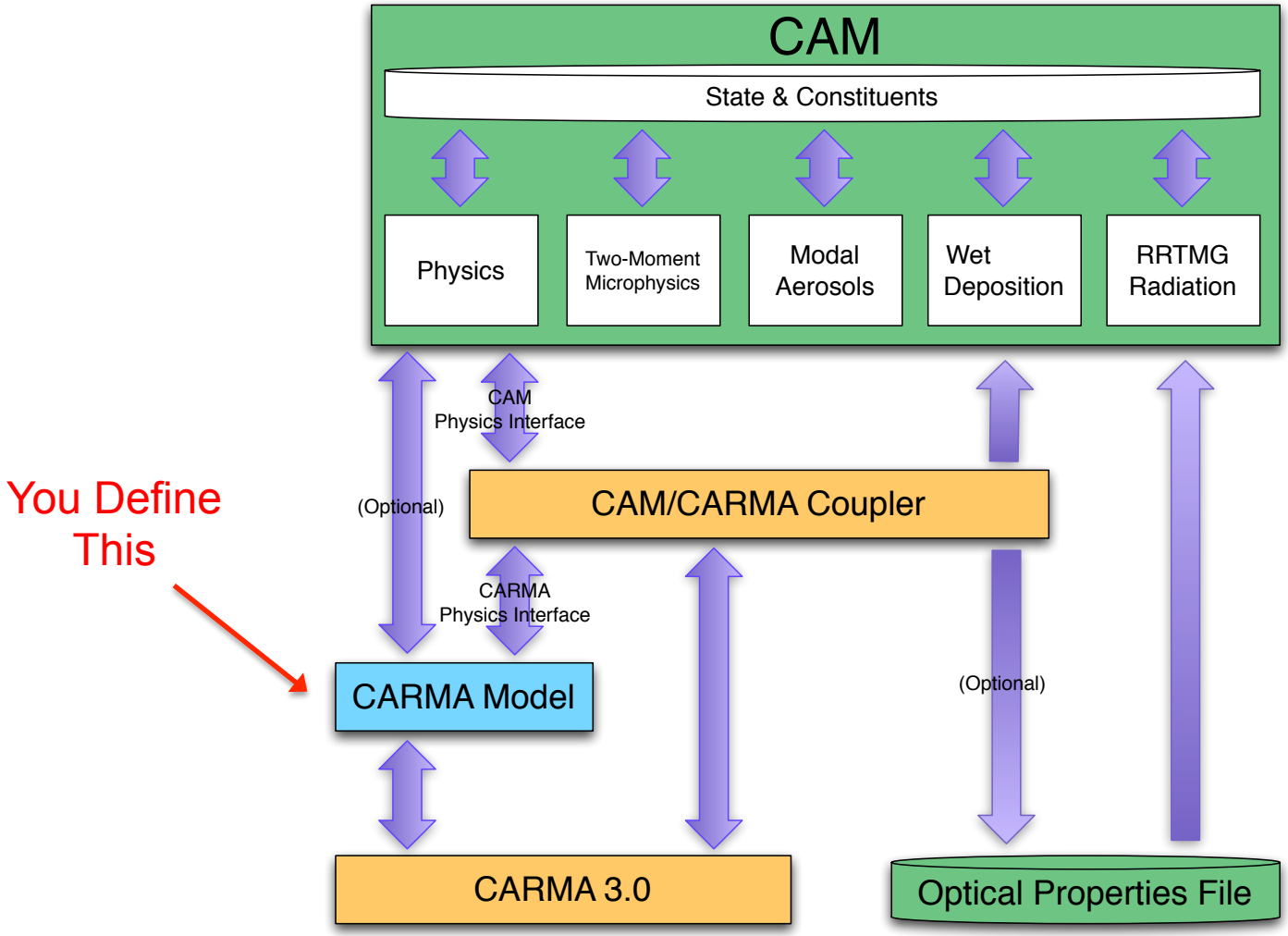
Cirrus, Ice Water Path



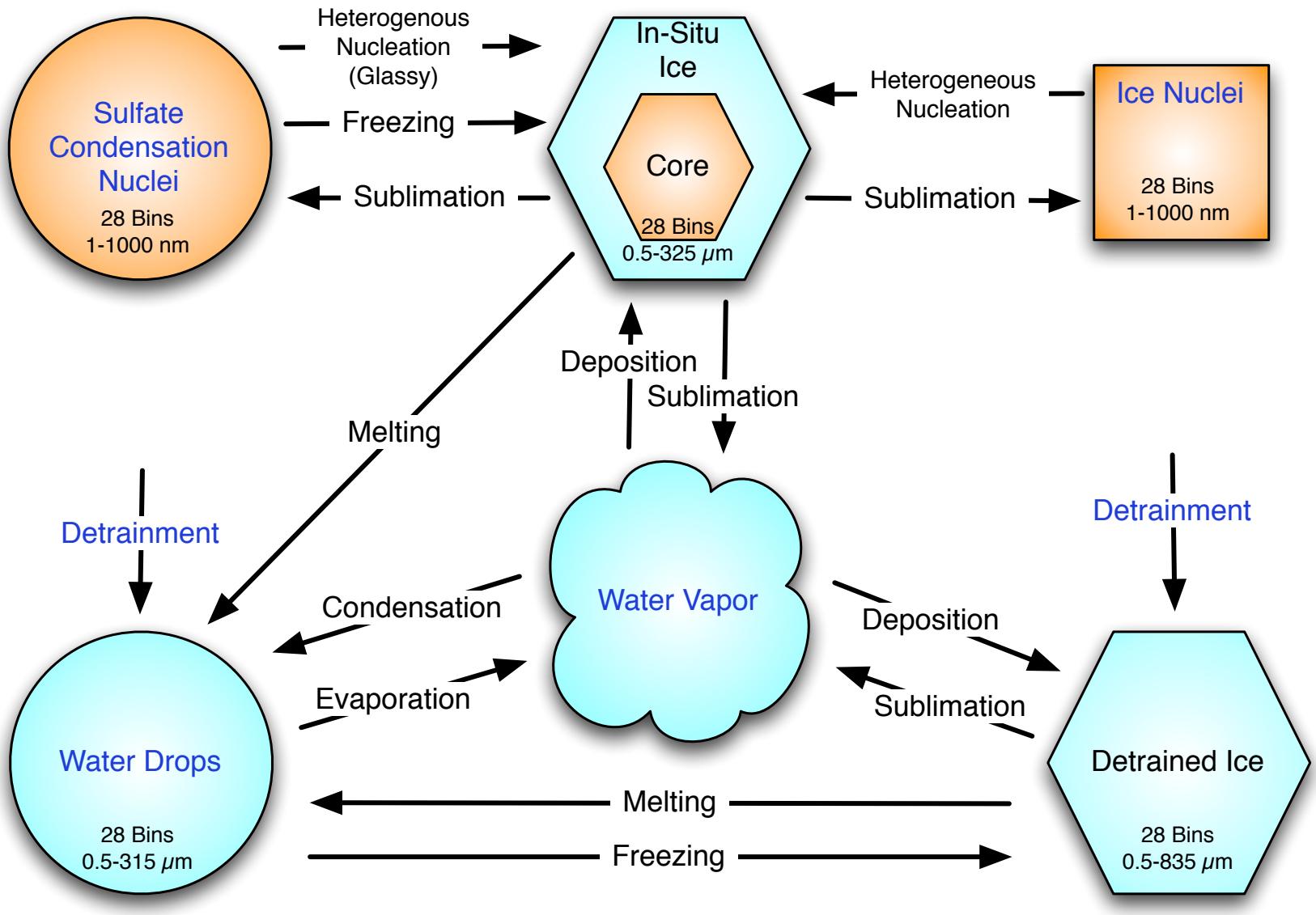
Polar Mesospheric Clouds



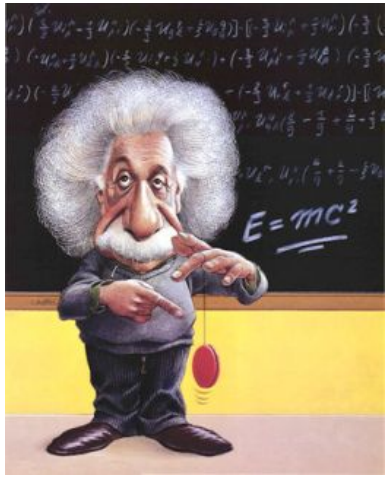
CAM5/CARMA


CAM
State & Constituents
Physics
Two-Moment Microphysics
Modal Aerosols
Wet Deposition
RRTMG Radiation
CAM Physics Interface
(Optional)
CAM/CARMA Coupler
CARMA Physics Interface
You Define This
CARMA Model
(Optional)
CARMA 3.0
Optical Properties File

Cirrus Microphysics



CAM Physics Interface

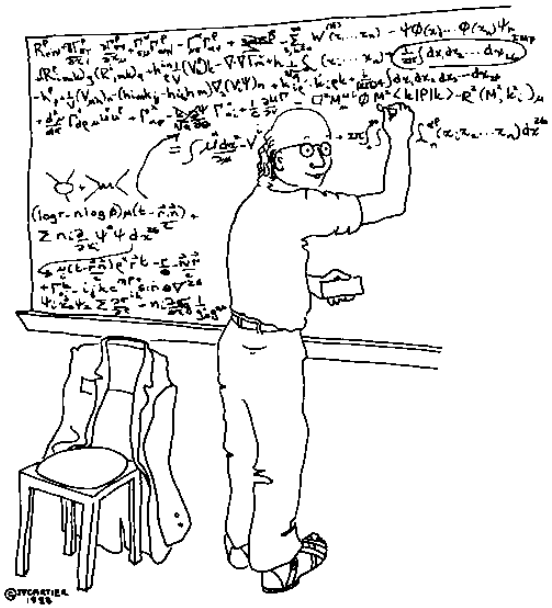


- Implementation is in physics/carma/cam/carma_intr.F90.
- You should not change the files in physics/carma/cam. Instead you should customize the routines in carma_model_mod.F90.
- Routines
  - carma_register
  - carma_is_active
  - carma_implements_cnst
  - carma_init_cnst
  - carma_init
  - carma_timestep_init
  - carma_timestep_tend
  - carma_final
  - carma_accumulate_stats
  - carma_emission_tend
  - carma_wetdep_tend

CARMA Physics Interface

- Implementation is in model specific versions of physics/carma/models/<model name>/carma_model_mod.F90 & carma_model_flags_mod.F90.
- You should not change the files in physics/carma/base or physics/carma/cam. Instead you should customize the routines in your carma_model_mod.F90. If needed, you can copy a file from physics/carma/base to your model directory and modify the copy.
- Global Variables
  - NGROUP, NELEM, NBIN, NSOLUTE, NGAS (NSOLUTE and NGAS can be 0)
  - NMIE_RH, mie_rh
- Routines
  - CARMA_DefineModel (carma_register)
  - CARMA_InitializeParticle (carma_init_cnst)
  - CARMA_InitializeModel (carma_init)
  - CARMA_EmitParticle (carma_emission_tend)
  - CARMA_DiagnoseBins (carma_timestep_tend)
  - CARMA_Detrain (carma_timestep_tend)
  - CARMA_DiagnoseBulk (carma_timestep_tend)
  - carma_model_readnl

blue = must specify for each model, others optional



"At this point we notice that this equation is beautifully simplified if we assume that space–time has 92 dimensions."

New Features

- CAM/CARMA
  - Radiatively active particles via RRTMG
  - Diagnostic & prognostic particles
  - Updated CAM wet deposition code
  - OPEN/MP and hybrid modes
  - Same result independent of decomposition and restarts
  - Cloud (before coupling) & aerosol (after coupling) CARMA models
  - Detrainment of cloud condensate to CARMA (optional)
  - Initialize CARMA every timestep or once against a reference temperature profile
  - Multiple CARMA models in the same source tree

- CARMA
  - 1-Dimensional
  - Thread safe
  - Bug fixes
  - Substep retry mechanism for more efficient nucleation & growth
  - Brownian diffusion
  - Particle swelling (Fitzgerald 1975, Gerber 1985)
  - Ice sedimentation (Heymsfield & Westbrook 2010, Heymsfield et al. 2010)
  - Vapor pressure of water (Murphy & Koop 2005)
  - Aerosol freezing (Koop et al. 2000, Mohler et al. 2010)
  - Heterogeneous nucleation of glassy aerosols (Murray et al. 2010)
  - Dry deposition

Source Directory Structure

- physics
  - cam : CAM physics code, CAM/CARMA Coupler stub
  - carma
    - base : CARMA 3.0 code
    - cam : CAM/CARMA Coupler
    - models : individual CARMA models
      - <model_name>

CARMA 3.0 Models

- Example Models
  - test_detrain : convective detrainment test
  - test_growth : simple ice cloud particles
  - test_passive : passive dust
  - test_radiative : radiatively active dust
  - test_swelling : simple sea salt particles
- Science Models (please contact author)
  - bc_strat (Mills)
  - cirrus (Bardeen)
  - meteor_smoke (Bardeen)
  - pmc (Bardeen)
  - sea_salt (Fan)
  - sulfate (Fan, in progress)

Building CAM/CARMA

- Using CAM scripts:
  - configure –carma <model>
  - build and run as usual

- Using CESM scripts:
  - create_newcase …
  - edit env_conf.xml
  - add ” –carma <model>” to the CAM_CONFIG_OPTS tag:
    <entry id="CAM_CONFIG_OPTS" value=”-carma test_passive" />
  - build and run as usual

Summary

- CARMA sectional microphysics has been used successfully in CAM and WACCM for cloud and aerosol models.
- CARMA 3.0 provides enhancements over CARMA 2.3 and was designed to be embedded in GCMs.
- CARMA will soon become available as an optional component in CAM.
- Please contact me (bardeenc@ucar.edu) if you are interested in using CARMA 3.0 or CAM/CARMA.