MAPP-CTB Cld-Aer Project: Improving cloud microphysics and their interactions with aerosols in the NCEP global models

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Why include aerosols in the predictive system?

- Improve weather forecasts and climate predictions by taking into account of aerosol effects on radiation and clouds
- Improve the handling of satellite observations by properly accounting for aerosol effects during the assimilation procedure
- Provide aerosol (lateral and upper) boundary conditions for regional air quality predictions
- Provide global aerosol products to meet the stakeholder needs such as air quality, UV index, visibility, ocean productivity, solar energy production, and sea surface temperature retrievals

MAPP-CTB Cld-Aer Project Overview

- GFS physics current status: Aerosol attenuation is determined from the OPAC climatology; aerosol indirect effect is not considered.
- Objective: Improve the representation of aerosol processes, cloud microphysics, and aerosol-cloud-radiation interaction in NCEP global models
- SUNYA/ASRC-NCEP/EMC-GSFC/GMAO collaborative efforts to upgrade NEMS (NOAA Environmental Modeling System) physics suite by adapting GSFC's physically-based aerosol and cloud microphysics package (which in turn is based on NCAR CAM5)
- The development work is closely aligned with CPT's and NGGPS's efforts to advance physical parameterization suite in NEMS.

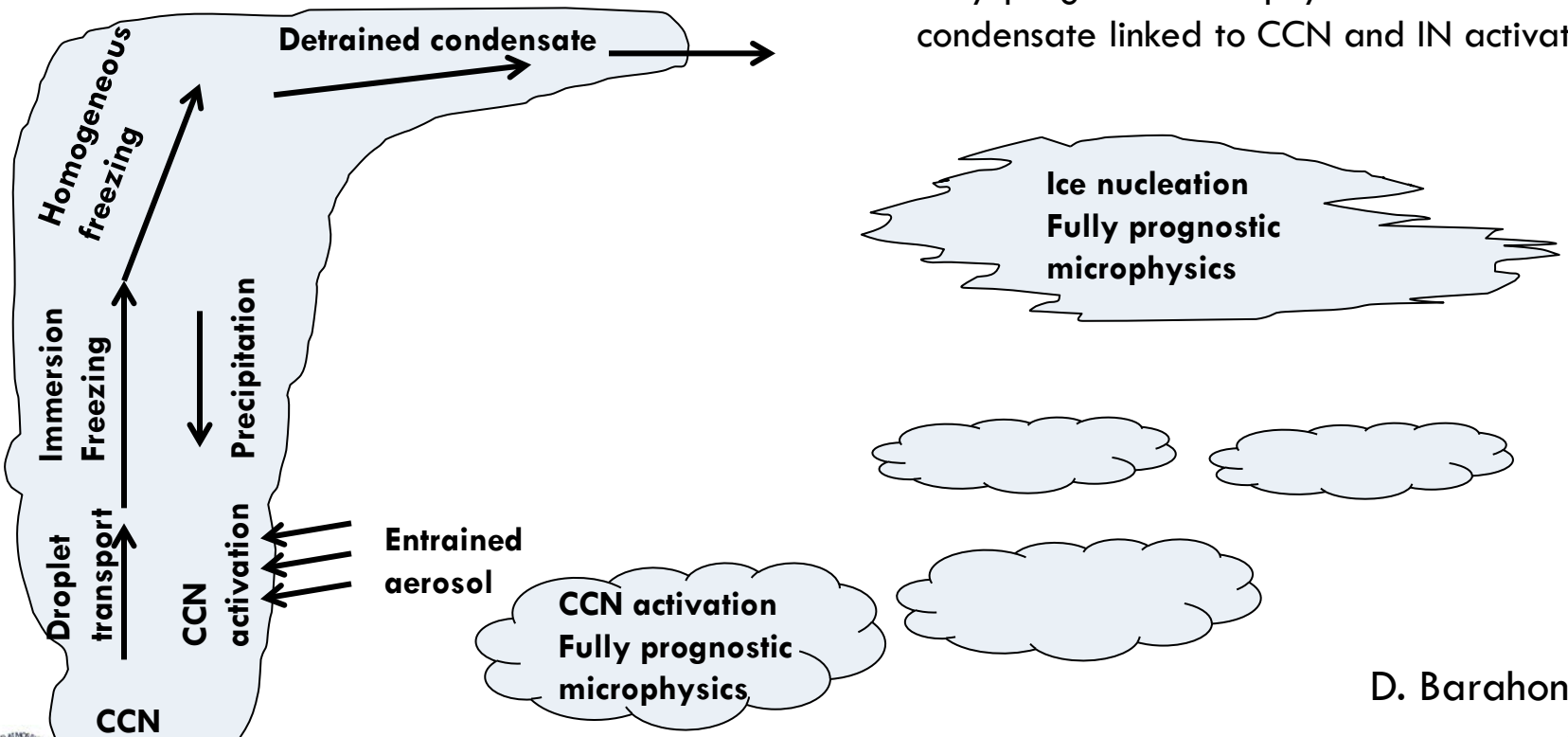
Two-moment cloud microphysics

Convection (Barahona et al., 2014)

Semi-prognostic microphysics: Aerosol affect Rain formation and phase partitioning but not cloud development (No invigoration effects)

Stratiform (Morrison and Gettleman, 2008)

Fully-prognostic microphysics: Generation of condensate linked to CCN and IN activation



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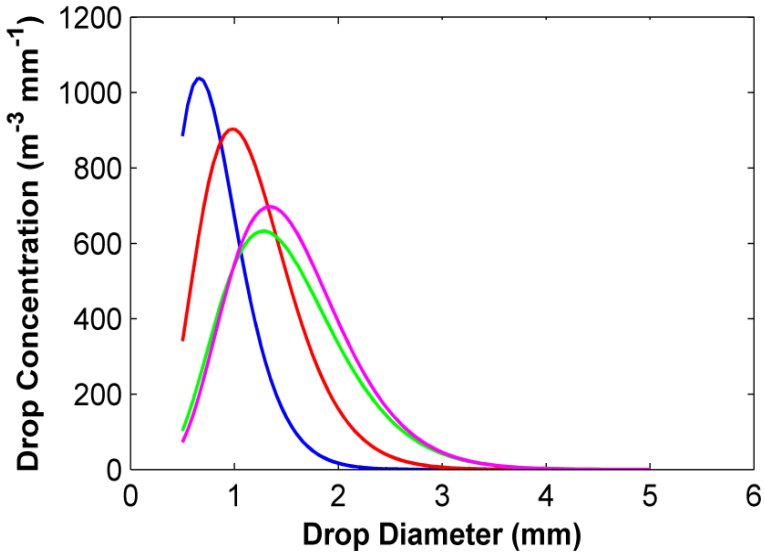
Two-moment cloud microphysics

Allows coupling of the aerosol physicochemical properties to cloud formation through CCN and IN activation.

Comprises a new set of balance equations, tracking droplet and ice crystal number concentration besides mass mixing ratios.



Since total mass and number can be known independently a better estimate of the droplet size distribution can be made.

All microphysical rates = f(cloud droplet and ice crystal size)

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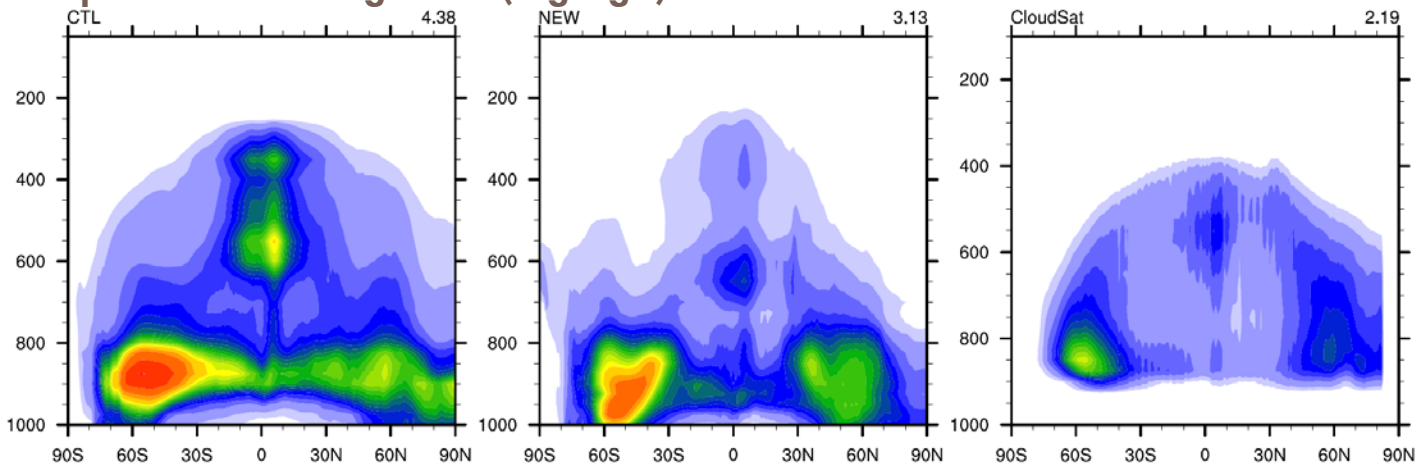
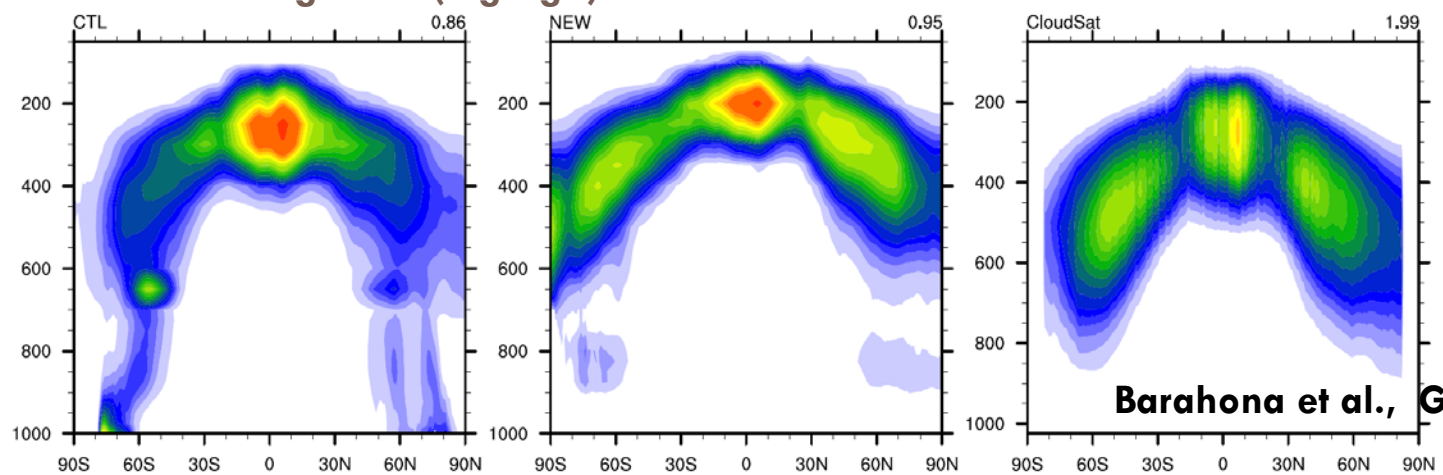
Cloud water content in GEOS-5

Annual Mean Liquid Mass Mixing Ratio (mg Kg^{-1})



Annual Mean Ice Mass Mixing Ratio (mg Kg^{-1})



Barahona et al., GMD. 2014

The Modal Aerosol Module (MAM)

A modal aerosol module (MAM, Liu et al., 2012) has been developed for the Community Atmosphere Model version 5 (CAM5), the atmospheric component of the Community Earth System Model version 1 (CESM1).

MAM is capable of simulating the aerosol size distribution and both internal and external mixing between aerosol components, treating numerous complicated aerosol processes and aerosol physical, chemical and optical properties in a physically-based manner.

Aerosol components

- Sulfate
- Ammonium
- Black carbon
- Dust
- Sea salt
- Primary organic
- Secondary organic

Aerosol modes

- Aitken
- Accumulation
- Primary carbon
- Fine sea-salt
- Fine dust
- Coarse sea salt
- Coarse dust

Aerosol microphysics

- Nucleation (H_2SO_4-NH_3-H_2O and BL nucleation)
- Coagulation (intra- and intermodal of AIT, ACC, PCM)
- Condensation(H_2SO_4, NH_3 and SOA(g))
- Gas-aerosol exchange

Configuration of MAM7

Aitken

number
water
sulfate
ammonium
secondary OM
sea salt

coagulation & condensation

Accumulation

number
water
sulfate
ammonium
secondary OM
hydrophobic OM
black carbon
sea salt

Fine Dust

number
water
dust
sulfate
ammonium

Fine Sea Salt

number
water
sea salt
sulfate
ammonium

aged to the accumulation mode due to condensation of H2SO4, NH3 and SOA(gas)

Two attachment states:

*a) **interstitial** - suspended in (clear or cloudy) air*

*b) **cloud-borne** - attached to /contained within stratiform cloud droplets (AP in convective cloud droplet are not treated explicitly)*

Primary Carbon

number
water
hydrophobic OM
black carbon

Coarse Dust

number
water
dust
sulfate
ammonium

Coarse Sea Salt

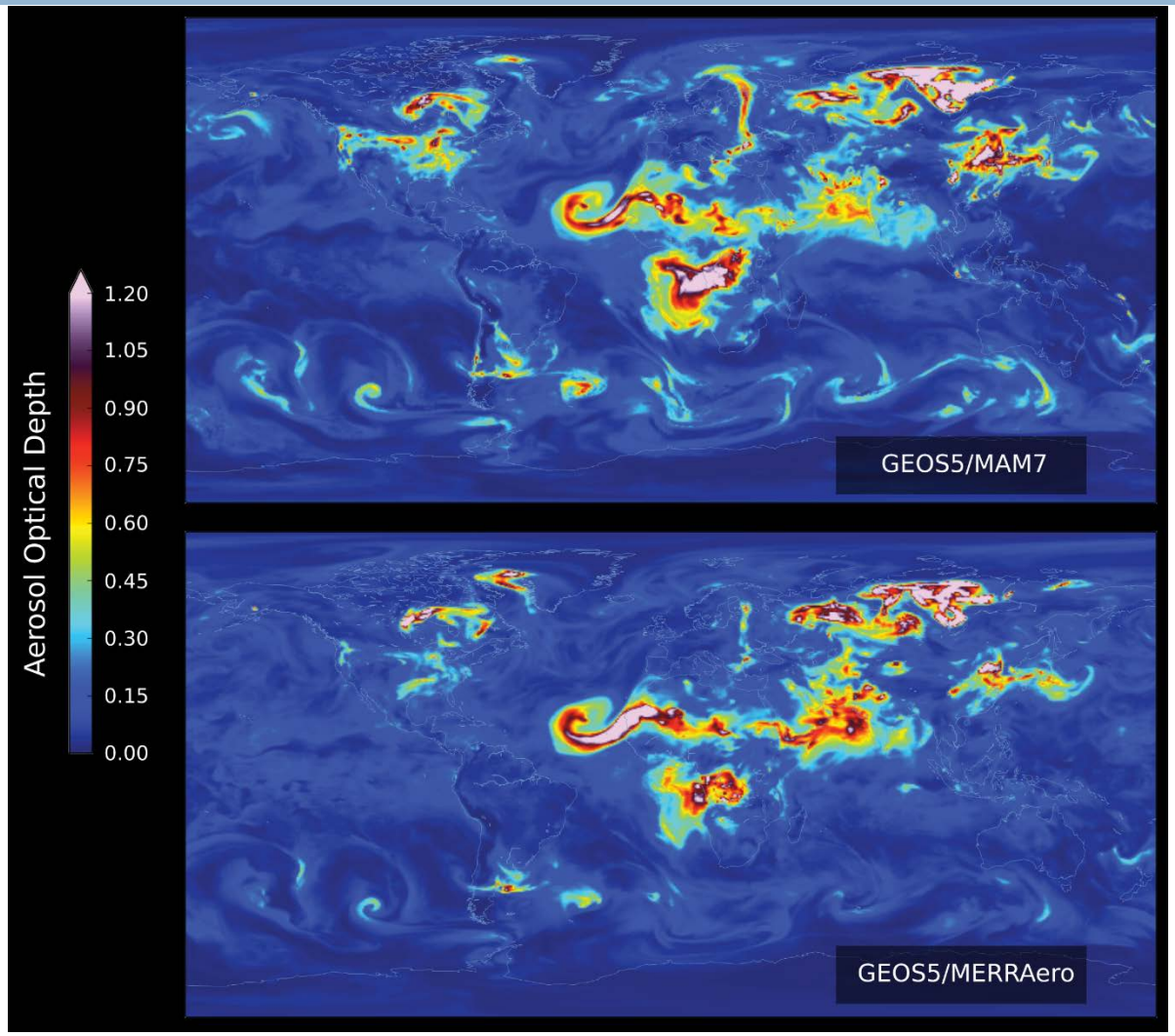
number
water
sea salt
sulfate
ammonium

Aerosol optical thickness in GEOS-5

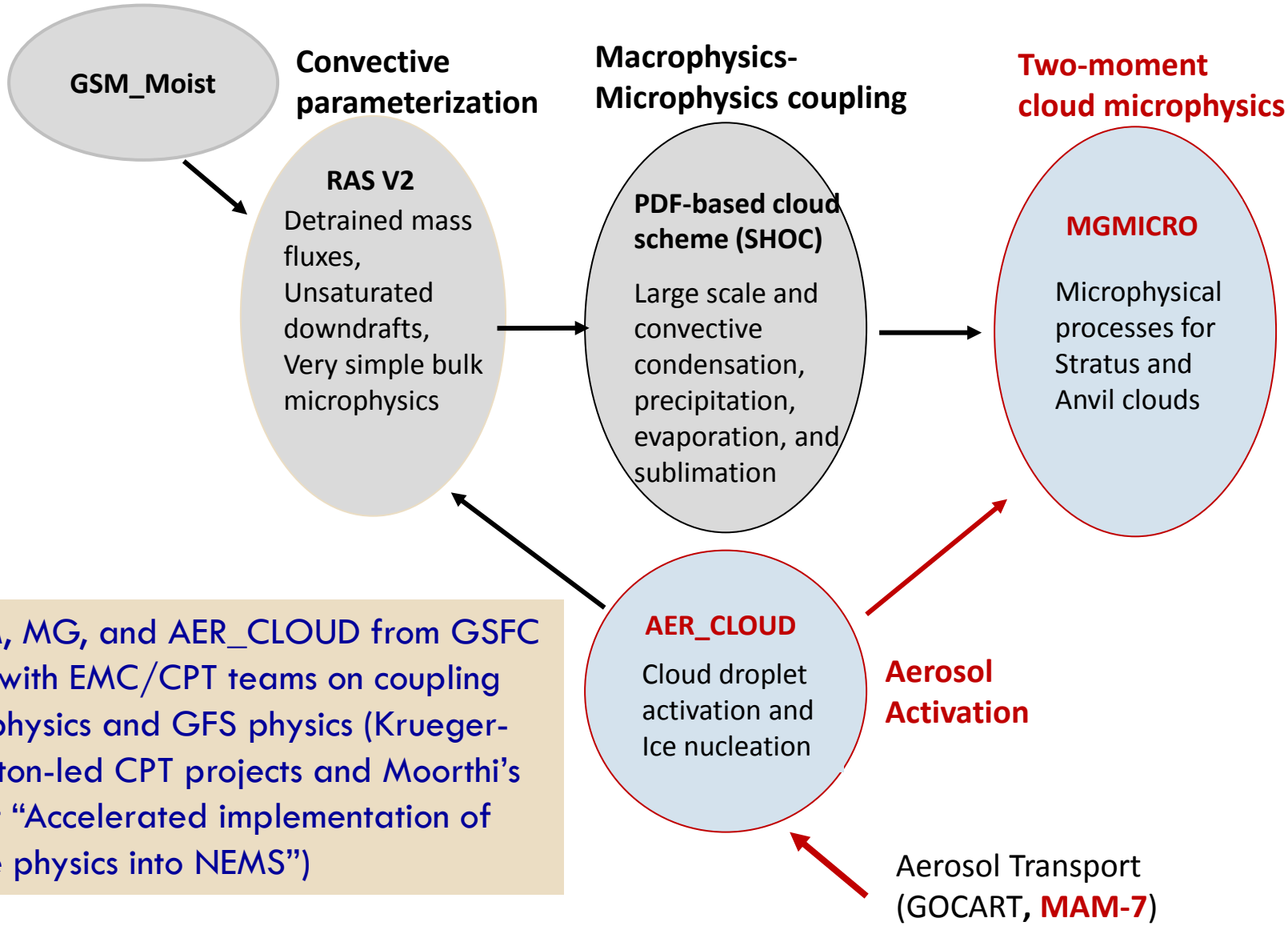
2013-07-31 12Z

MAM7, with no aerosol data assimilation

GOCART with MODIS AOD data assimilation



Adopting GEOS-5 aerosol-cloud package in NEMS

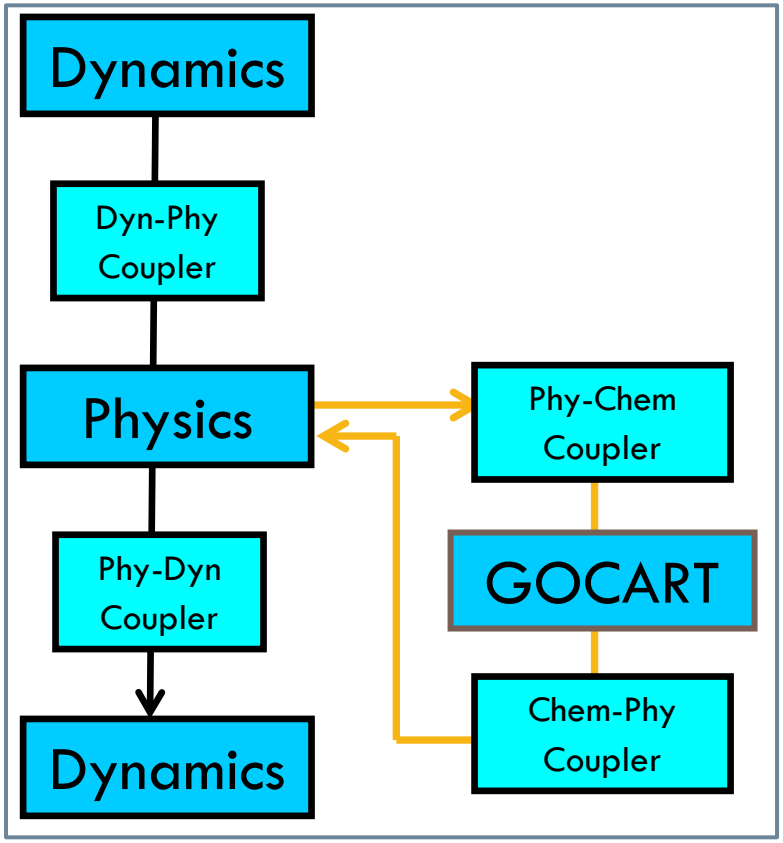


- Adopt MAM, MG, and AER_CLOUD from GSFC
- Coordinate with EMC/CPT teams on coupling cloud microphysics and GFS physics (Krueger- and Bretherton-led CPT projects and Moorthi's R2O project "Accelerated implementation of scale-aware physics into NEMS")

New two moment cloud microphysics

	Current microphysics	New microphysics
Moments	One	Two
Species	Mass of ice and liquid	Mass and number of ice and liquid
Ice-liquid Partitioning	Prescribed as a function of Temperature	Determined by the microphysics
Droplet activation	Not available	Explicit, linked to the aerosol
Ice nucleation	Not available	Explicit, Linked to the aerosol
Subgrid scale variability	Only total water	Total water, liquid, and vertical velocity

Primary integration runstream



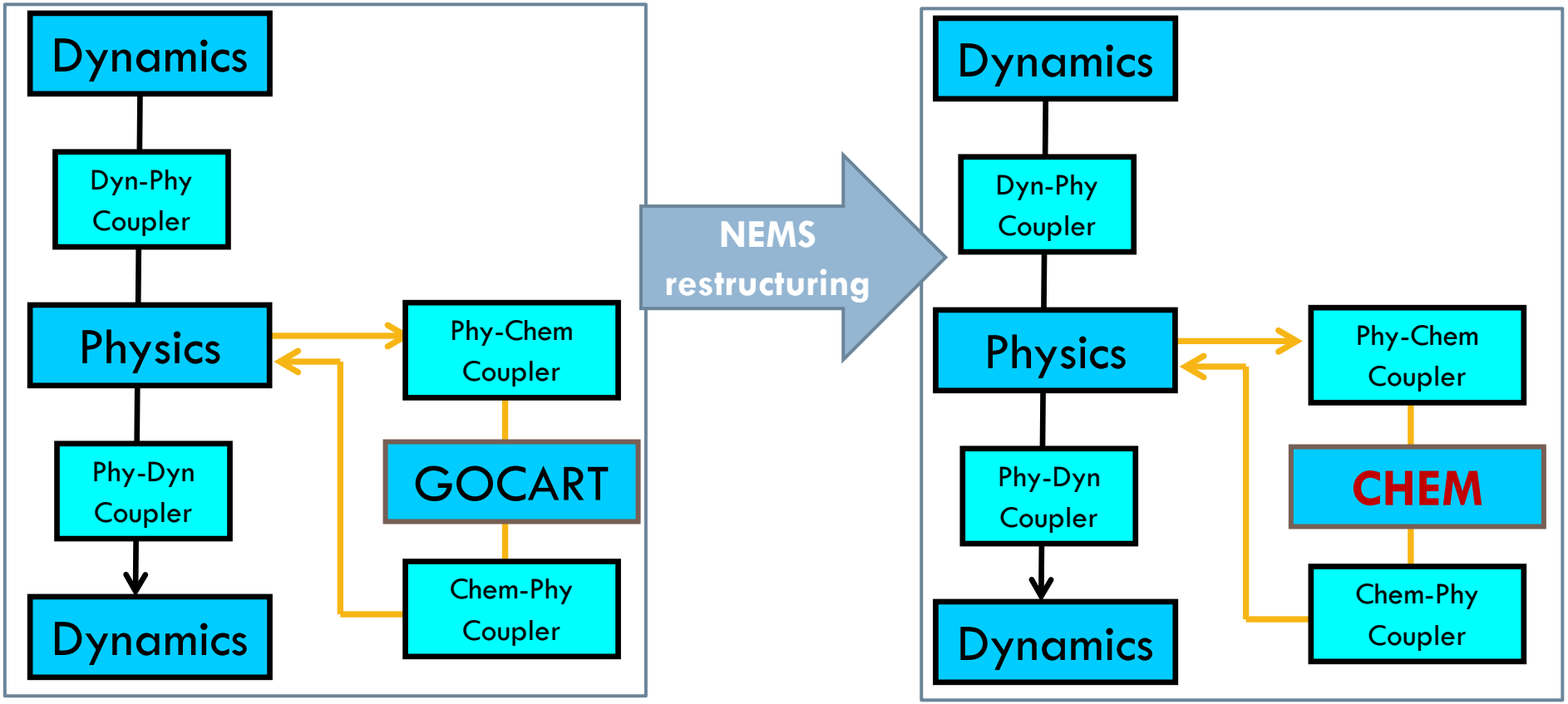
In-line coupling:

- Consistency: no spatial-temporal interpolation with same physics parameterization
- Efficiency: lower overall CPU costs and easier data management
- Interaction: allow aerosol feedback to meteorology

NEMS GFS coupled with GOCART:

- ESMF coupler components are developed to transfer and transform data between GFS physics and GOCART
- Provide dust-only forecast since Sept 2012 and will be upgraded to produce multi-species forecast (dust, sea salt, sulfate, and carbonaceous aerosols) in Dec 2015

Primary integration runstream



CHEM: multiple child components, including GOCART and MAM7

Proposed deployment

- Physics upgrade: adapting GSFC's aerosol and cloud microphysics package
- NCEP center: EMC
- Targeted schedule: FY17
- HPC requirements: The plan is to conduct all development and tests at NOAA R&D cluster (GAEA)
- Cost to NCEP for deployment:
  - The transition-to-operation require minimal cost to NCEP
    - Code development will be committed to NCEP code repository
    - All tests will be based on NCEP parallel infrastructure
  - Aerosol and moist processes development have been supported by EMC base fund and external funds (e.g., CPT, NGGPS, JCSDA)

Proposed tasks and timeline for deployment

Year-1

- Implement a multimodal and double-moment Modal Aerosol Module
- Implement a double-moment cloud microphysics scheme

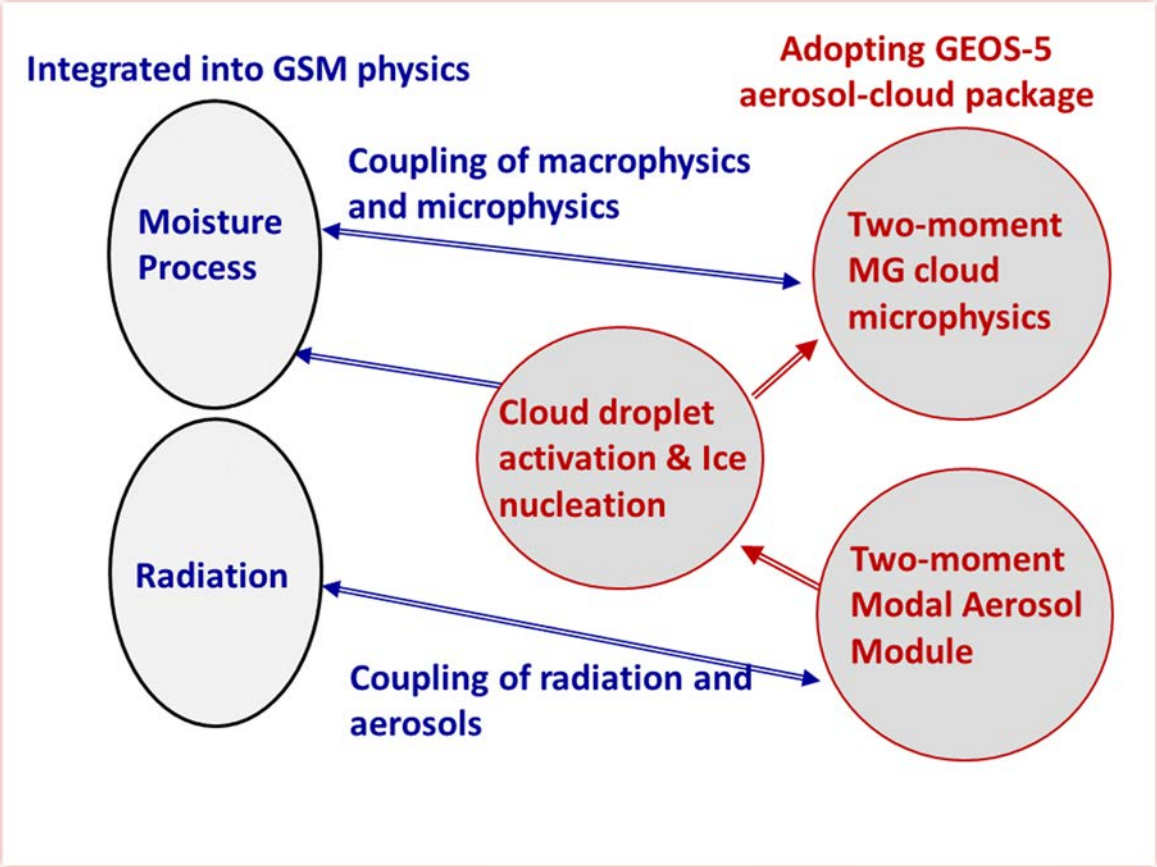
Year-2

- Build an interface to link cloud properties and aerosol physicochemical properties
- Consistent coupling of cloud micro and macro physics.
- Modify RRTM radiation package to support the new cloud-aerosol package

Strategy during the demonstration phase: The two physics upgrades can be run either individually (uncoupled) or interactively (coupled)

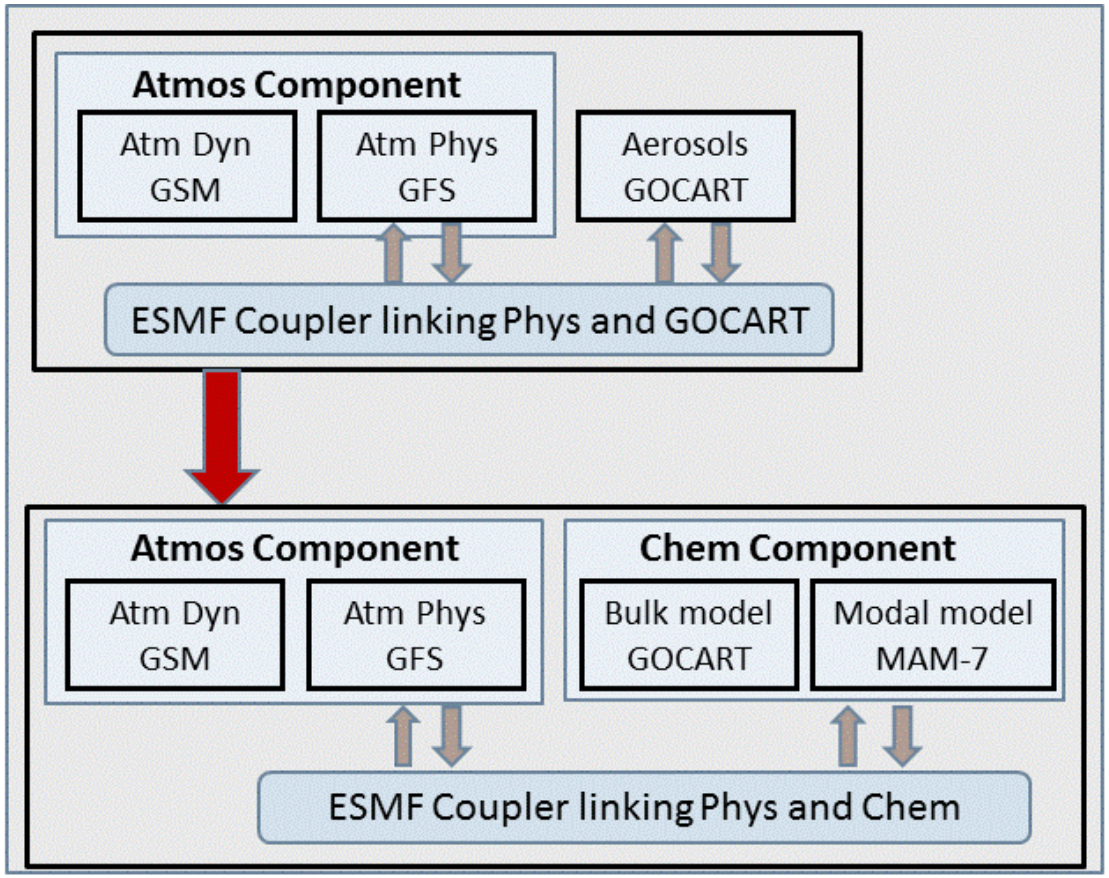
Cld-Aer project outcome: NEMS physics suite improvement

Adapting physically-based aerosol and cloud microphysics package to improve aerosol-cloud-radiation interaction in NEMS physics



Cld-Aer project outcome: NEMS infrastructure upgrade

Introducing a chemistry component (containing GOCART and MAM) which can be extended to include GEOS-5 tropospheric and stratospheric chemistry



R2O or O2R issues: HPC resources and code management

- S-P Chen joined the Cld-Aer project around late Jan 2015
  - The paper work for his GAEA account was submitted in mid Feb 2015
  - Status as of Nov 9, 2015: **Pending (no firm answer on when it will be approved)**
- We obtained accounts at JCSDA S4 cluster (NESDIS-funded Supercomputer for Satellite Simulations and Data Assimilation Studies) in July 2015.
  - Operation-like environment with access to NCEP SVN code repository
  - The NEMS has been ported to S4 for aerosol-related development work
- A. Chen's cloud microphysics work (leveraging NGGPS-R2O support) has been conducted at WCOSS and THEIA
- JCSDA JIBB (Joint Center in a Big Box) is used to check out GEOS5 code from GMAO code repository and for code exchange between GSFC and NCEP/SUNYA
- Version control (SVN for NCEP) is used to sync the code among multiple developers from multiple institutes on multiple platforms

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Is it feasible to have a secure and accessible HPC? YES. Lu obtained an account at ECMWF dev cluster (WCOSS-equivalent) on her first day at ECMWF during her 2-month visit in 2011

Proposed tasks and timeline for deployment: Project status update

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- Implement a double-moment cloud microphysics scheme

Year-2

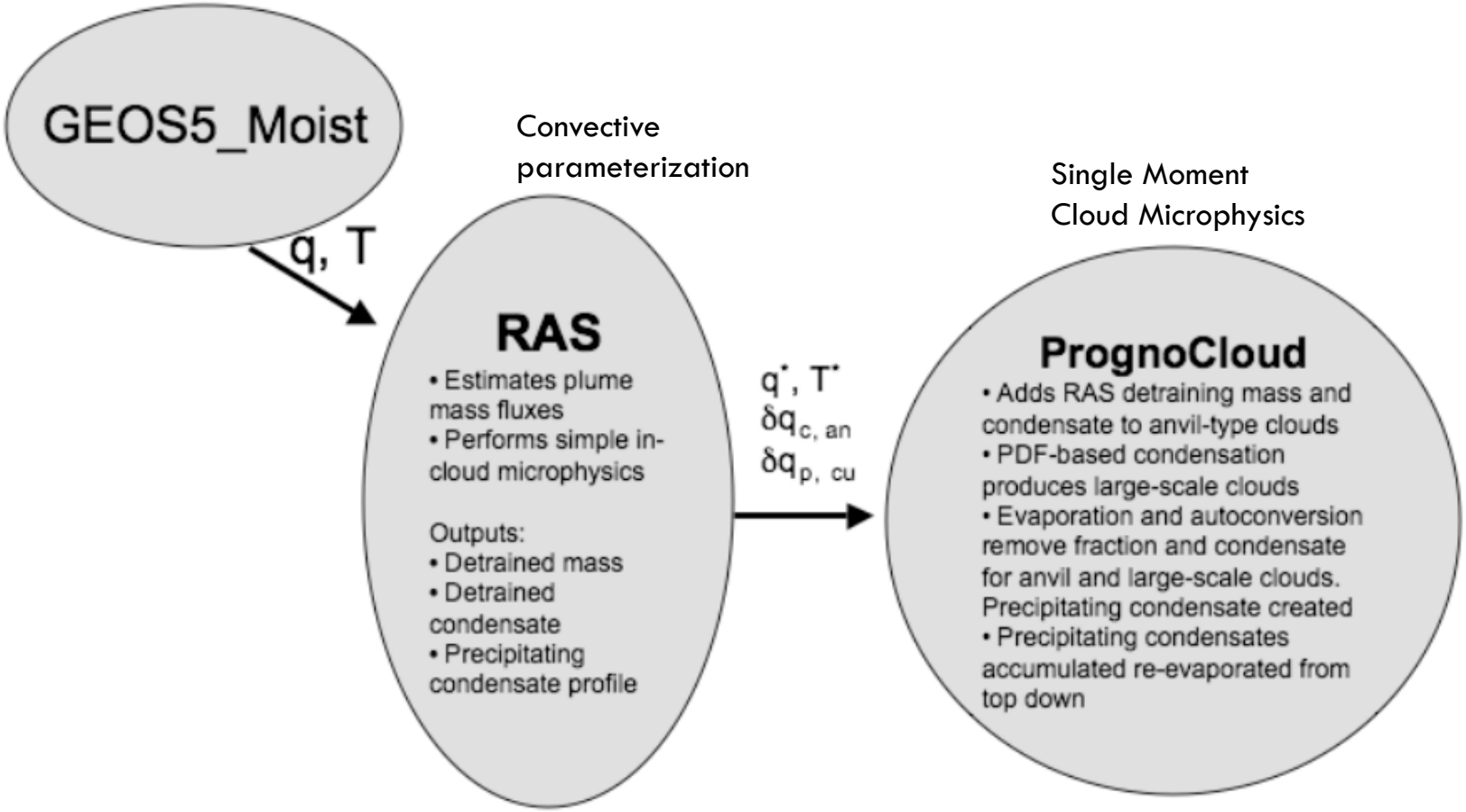
- Build an interface to link cloud properties and aerosol physicochemical properties
- Consistent coupling of cloud micro and macro physics.
- Modify RRTM radiation package to support the new cloud-aerosol package

- Work in progress is in brown, and tasks to be completed are in grey
- NEMS is restructured to couple with GEOS-CHEM. Under the new structure, the option to call GOCART child component is working, and the option to invoke the MAM7 child component needs additional code development.
- GSFC's cloud microphysics scheme has been implemented in NEMS GFS (supported by Moorthi's R2O project), and will be coupled with cloud macrophysics, convection, and aerosols
- Radiation module is being modified to calculated aerosol optical properties from GOCART using GSFC's LUTs, and will be modified to include the MAM7 option

Thanks.

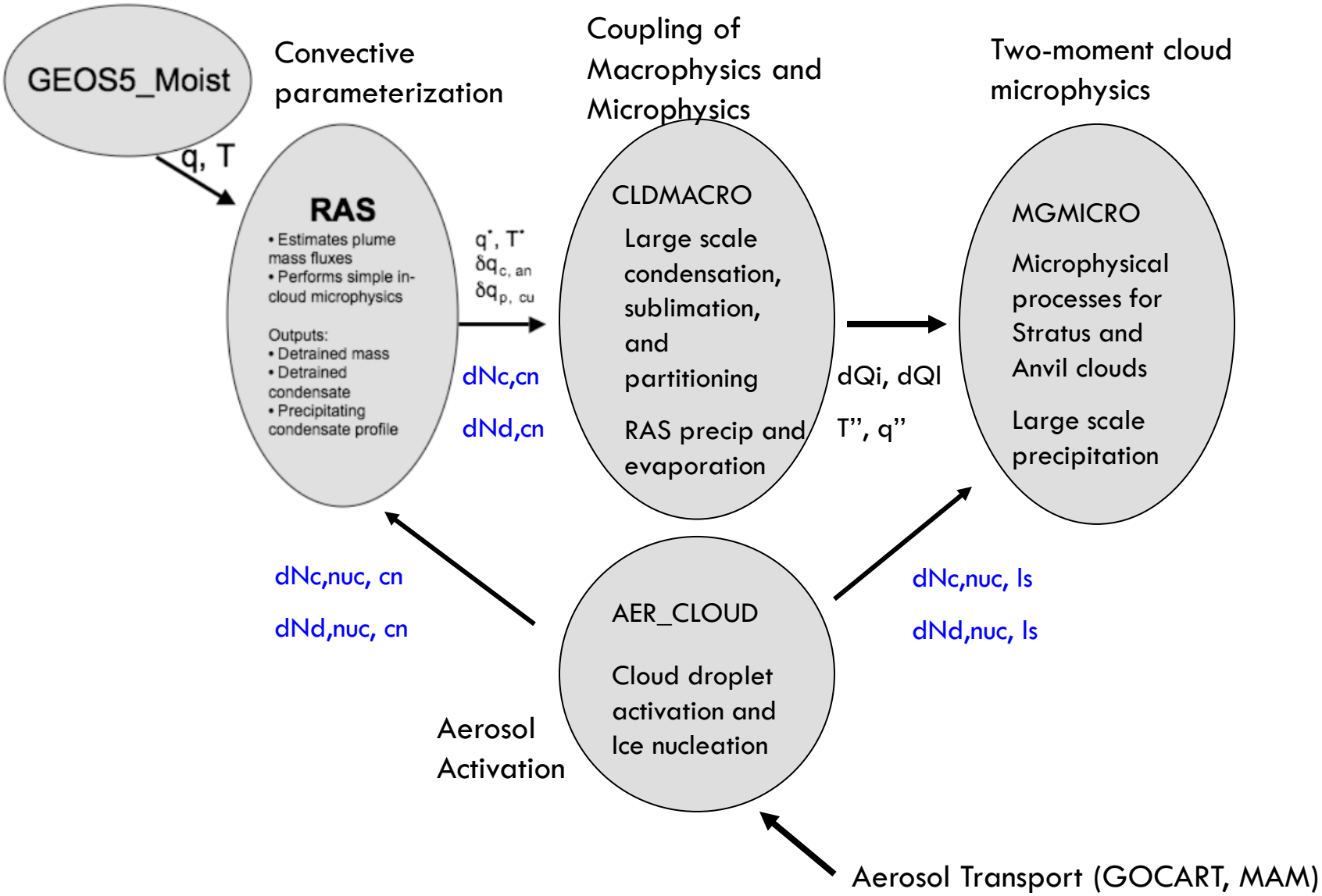
Comments or Suggestions

Current Microphysics in GEOS-5: Single Moment



Rienecker et al., 2008

New Two Moment Microphysics in GEOS-5



Experiences learn in GEOS-5

- A new double-moment microphysics was implemented in GEOS-5. The new microphysics links to aerosols and cloud properties for large-scale and convective clouds.
- The new implementation resulted in a general model improvement in cloud fields, i.e., effective radii, cloud and ice water content. Cloud droplet and ice crystal number concentration are now available as prognostic fields.
- Better clouds do not necessarily mean better climate. Some tuning and adjustments are still necessary.

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