Investigation of cloud-aerosol interaction for extreme precipitation events using FV3GFS

Cheng-Hsuan (Sarah) Lu

University at Albany, State University of New York

This presentation reports a project co-funded by MAPP-CTB and NGGPS: Improving cloud microphysics and their interactions with aerosols in the NCEP global models

Collaborative efforts among multi-institutes:
UAlbany Sarah Lu, Sheng-Po Chen, Qilong Min
NCEP/EMC Yu-Tai Hou, Moorthi Shrinivas, Anning Cheng, Fanglin Yang
NASA/GMAO Arlindo da Silva, Donfian Barahona, Anton Darmenov

NOAA Testbeds & Proving Grounds program aims to facilitate transition of research capabilities to operational implementation

For the interest of TBPG, this presentation will focus on:

- Scientific background (***very brief***)
- Proposed tasks and deployment
- Testing and evaluation
- Project outcomes and Readiness Level (RL)

Aerosol Direct effect

Solar Radiation Scattered to Space

Mostly Scattering Aerosol

Less Solar Radiation Reaches Surface

Surface Radiative Cooling

Solar Radiation Scattered to Space

Mostly Absorbing Aerosol

Solar Radiation Absorbed by Aerosol Layer

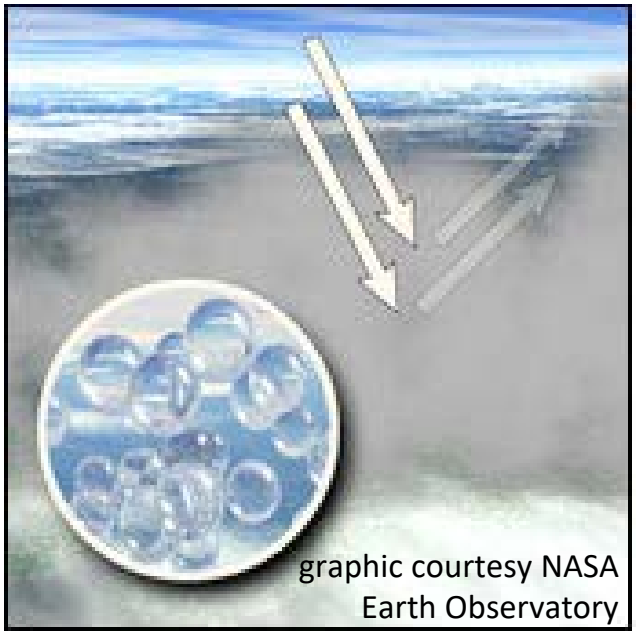
Atmospheric Radiative Warming

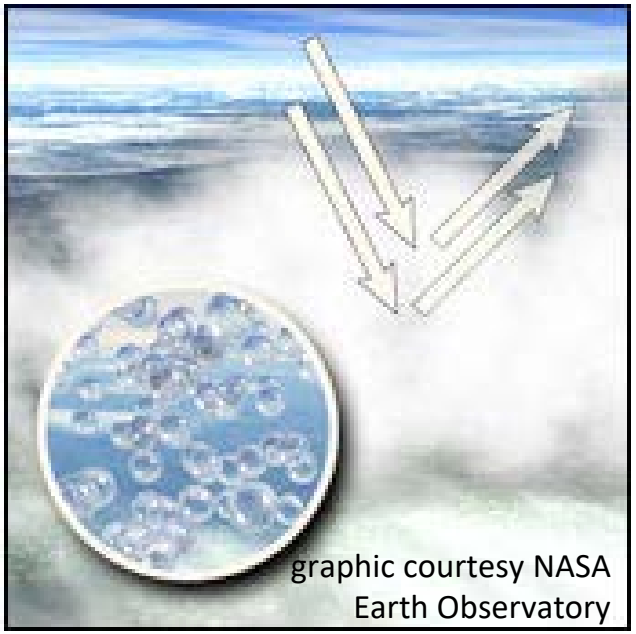
Less Solar Radiation Reaches Surface

Surface Radiative Cooling

Animation by C. A. Randles

Aerosol InDirect Effect





Larger cloud droplets, less reflective cloud.

Twomey Effect

Smaller cloud droplets, more reflective cloud.

Less Aerosols

Increased Cooling by Clouds

More Aerosols

Larger cloud droplets, droplets rain out easier, clouds dissipate quicker.

Albrecht Effect

Smaller cloud droplets, droplets rain out less, longer-lived clouds.

Animation by C. A. Randles

Aerosol processes in climate models

- Bulk mass model. Mass-based aerosol models are used in 1st generation climate models.
- Modal aerosol model. Being added to new generation of climate models due to established recognition that model need to represent evolution of size distribution.
- Process-based sectional model. With high complexity (100+ tracers), it is not affordable in in-line mode. Future (3rd generation) GCMs.

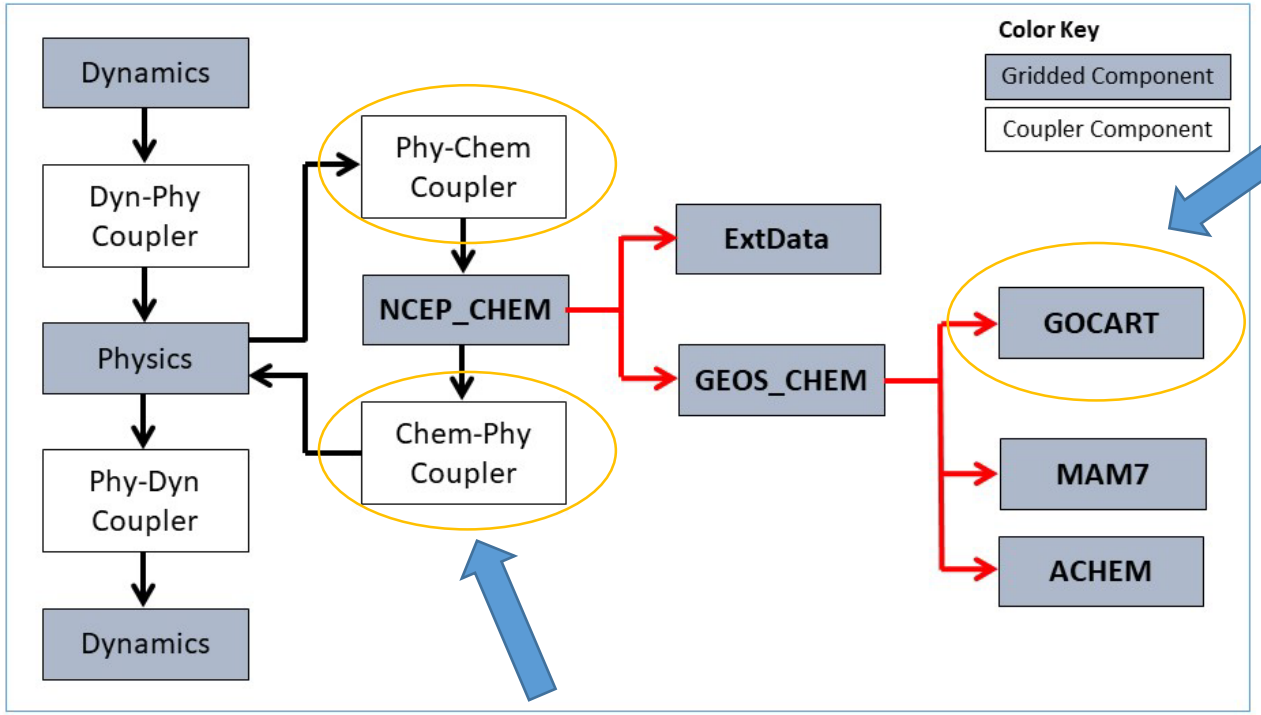
Cld-Aer Project Overview

- Background: In GFS physics, aerosol attenuation is determined from the OPAC climatology and aerosol indirect effect is not considered.
- Overarching goal: Improving the representation of aerosol processes, cloud microphysics, and aerosol-cloud-radiation interaction in NCEP global models
- Proposed approaches:
  - The NCEP model: NEMS GFS with GSM dynamic core (NEMS GSM)
  - Advance physical parameterization suite in NEMS GSM by adapting GSFC's physically-based aerosol and cloud microphysics package (multimodal and double-moment Modal Aerosol Module, MAM, and double-moment Morrison-Gettleman cloud microphysics, MG)
  - Tests of the two physics upgrades are conducted individually (uncoupled) initially and then interactively (coupled)

Component Design

- NCEP: coarse-grained design in NEMS
  - Only large pieces of the models are modularized with ESMF components
  - No intrusion into parameterization and parallelization levels
- GMAO: fine-grained design in GEOS-5
  - ESMF components are used down to the parameterization level
- Fine vs coarse grinded component design determines how GMAO's package is implemented into NEMS GSM
  - MG is implemented into NEMS GSM physics suite after stripping away ESMF
  - MAM7 is implemented into NEMS GSM by extending ESMF-based chemistry infrastructure

Project outcome: NEMS infrastructure upgrade



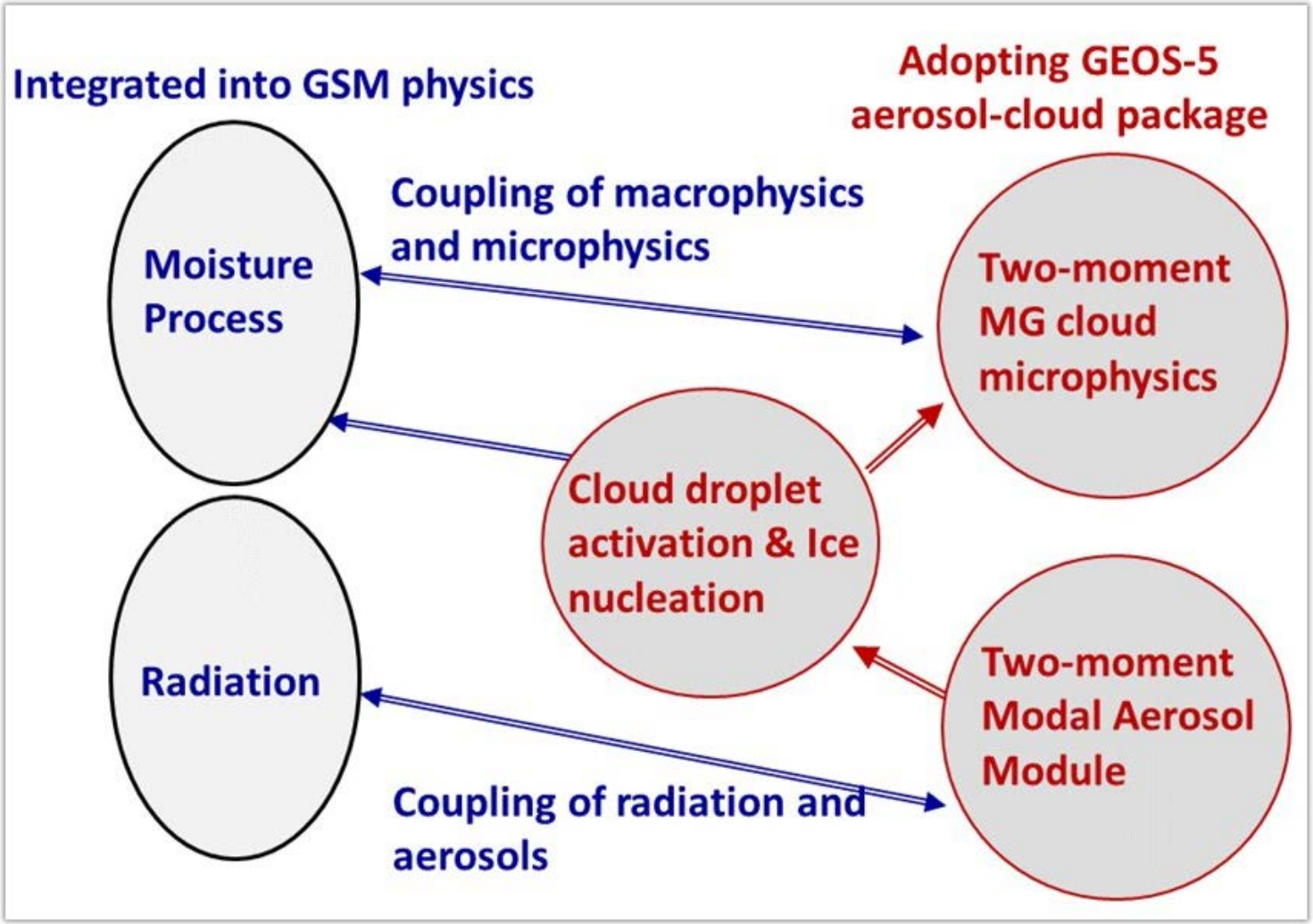
Same GOCART component as in NGACv2, except emissions are handled by ExtData

- An ESMF component **NCEP-Chem** is created to wrap around GEOS-Chem and ExtData
- This architecture allows NEMS GSM to run the full suite of GMAO's chemistry.
- **Only GOCART and (MAM7, ACHEM)** are tested. Other chemistry modules are compiled as stub.
- ExtData is an ESMF component for reading/mapping emissions

ESMF infrastructure: Interoperability, portability, and reuse

ESMF coupler, developed to couple PHYS with GOCART in NGACv2, is used to couple PHYS with NCEP-Chem. Only minor code changes are made (e.g., adding extra fields needed by MAM7)

Project outcome: NEMS physics suite improvement

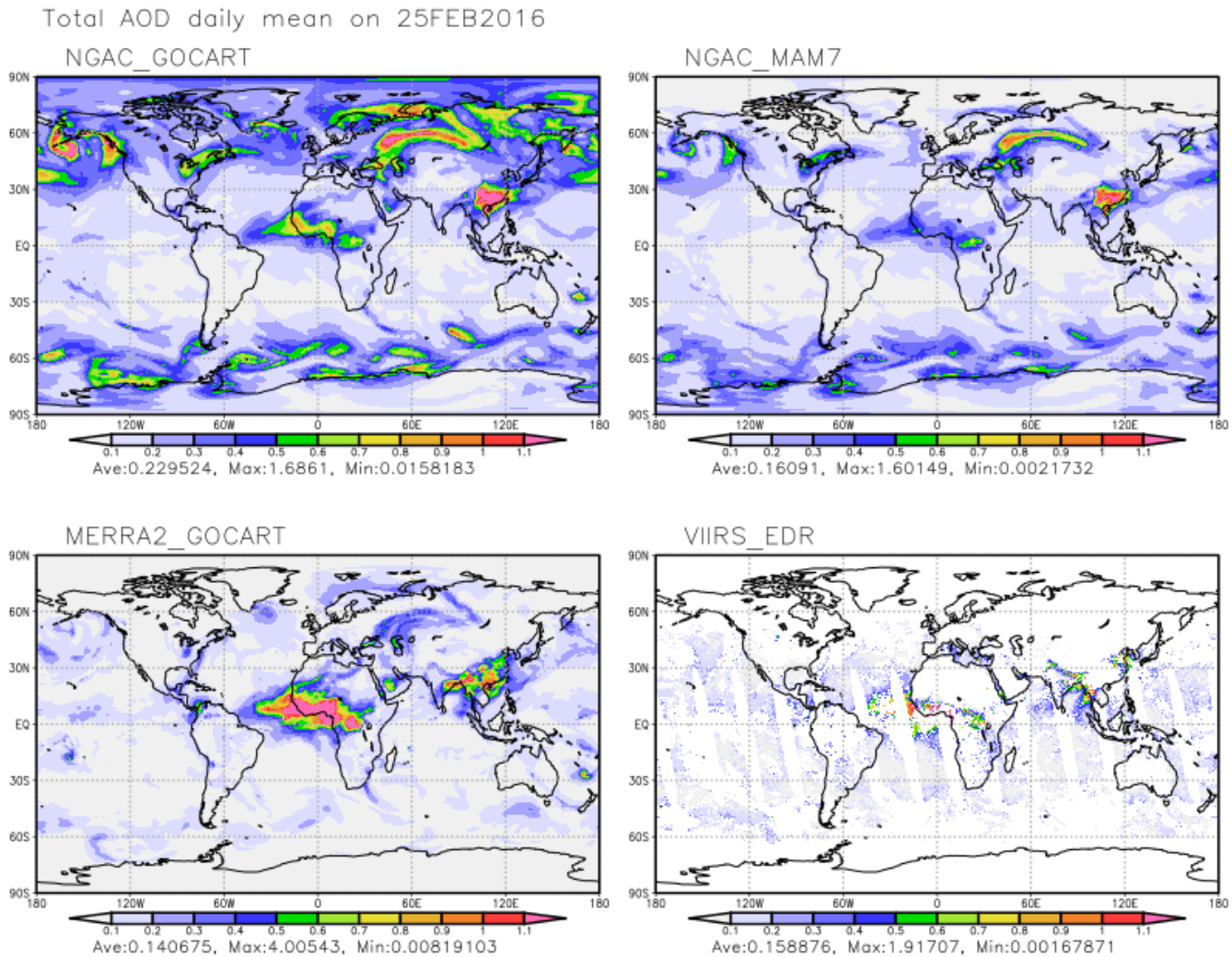


Extensive work on testing and fine tuning MG is done by Moorthi Shrinivas & Anning Cheng (NCEP/EMC)

Testing and Evaluation: aerosol processes

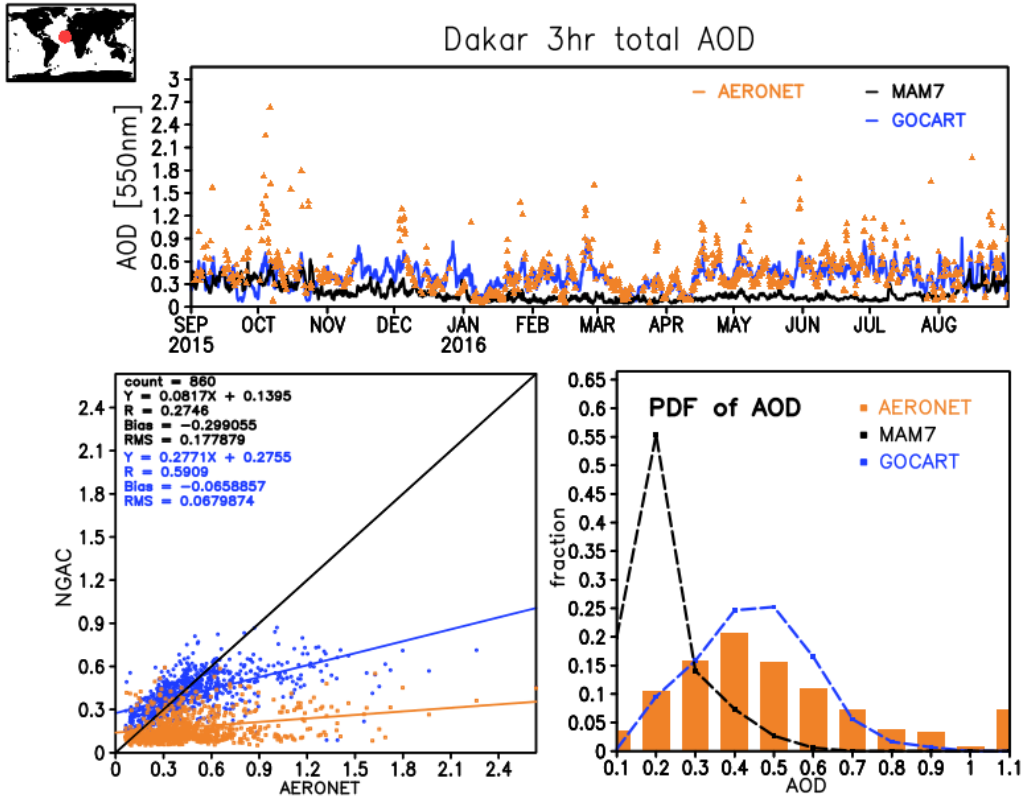
GOCART versus MAM7

Verified against aerosol reanalysis (MERRA2) and satellite observations (VIIRS)



Testing and Evaluation: aerosol processes

GOCART versus MAM7
Verified against in-situ observations (AERONET)

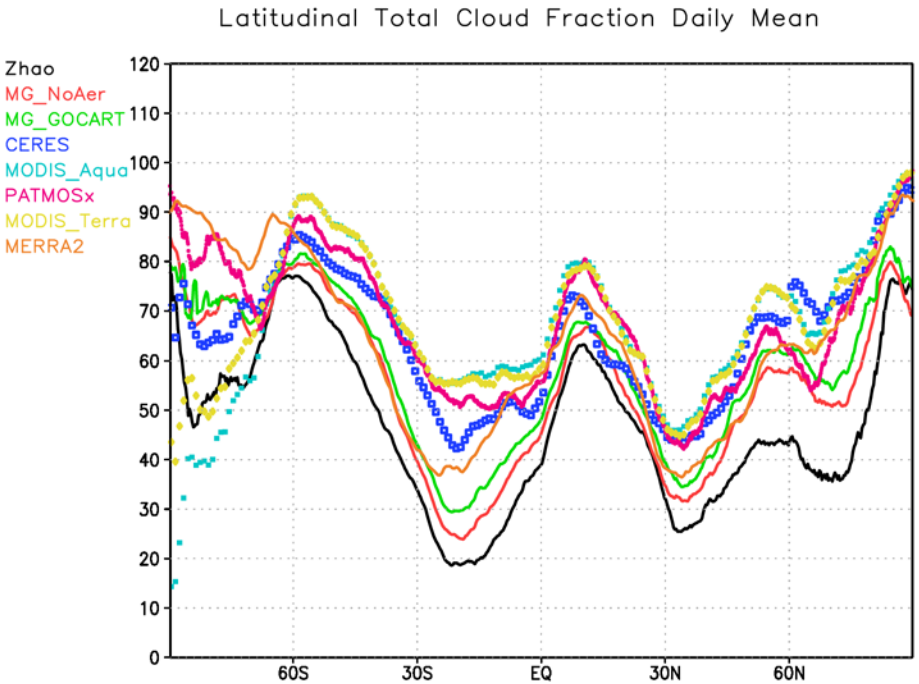


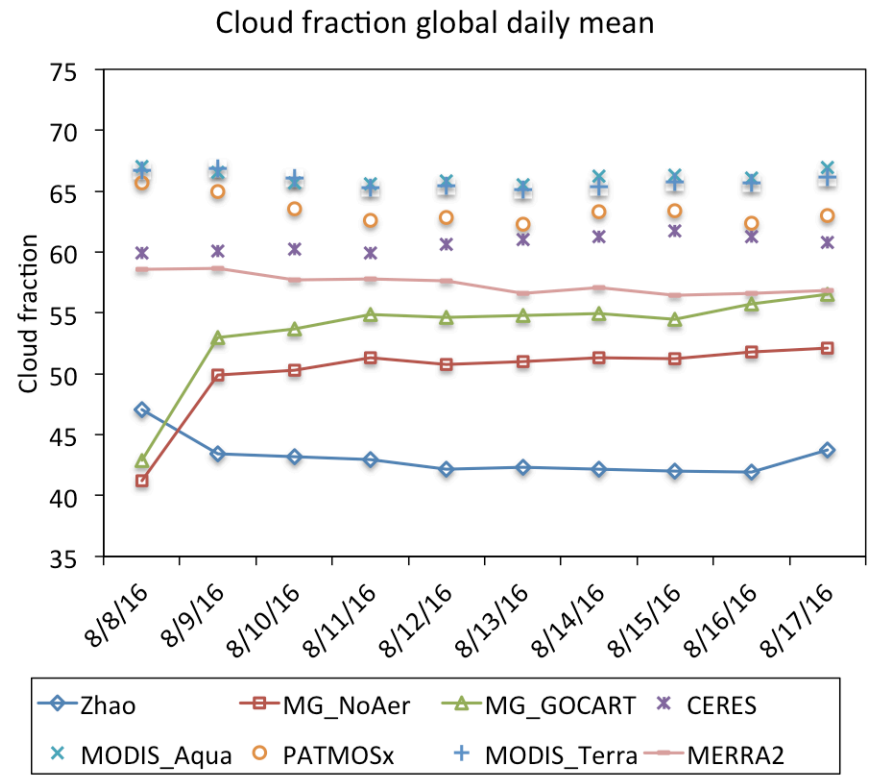
Wish-list: Observation-based data set for vertical distribution, chemical composition, emissions and removal fluxes, and surface mass concentrations

Testing and Evaluation: NEMS Forecasts

Zhao vs MG without aerosol feedback vs MG with aerosol feedback
Verified against reanalysis (MERRA2) and satellite products (MODIS, CERES, PATMOSx)

Cloud fraction





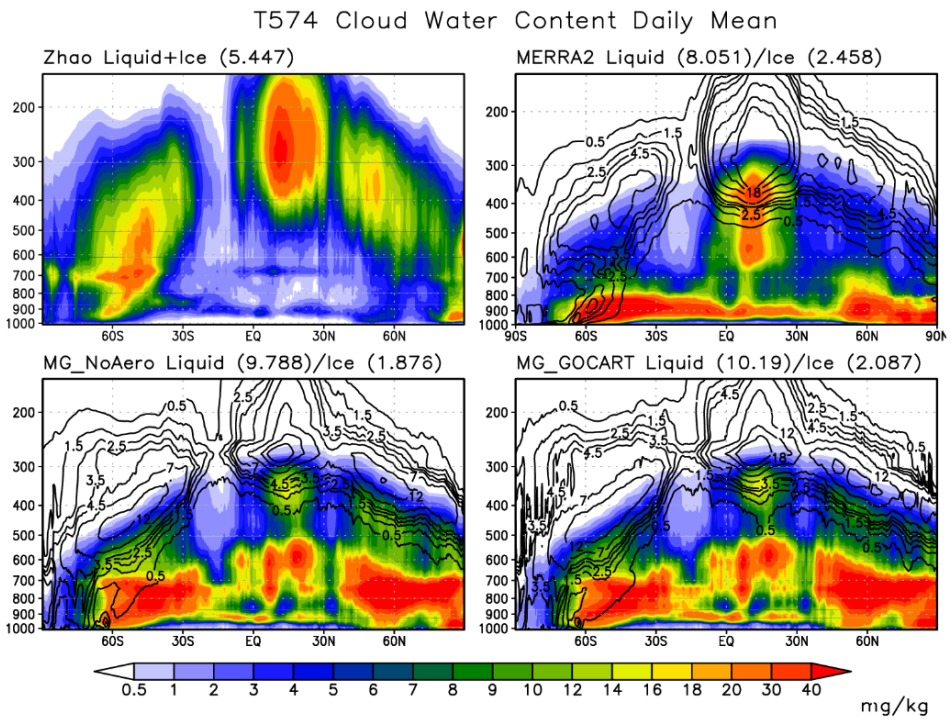
Data sources

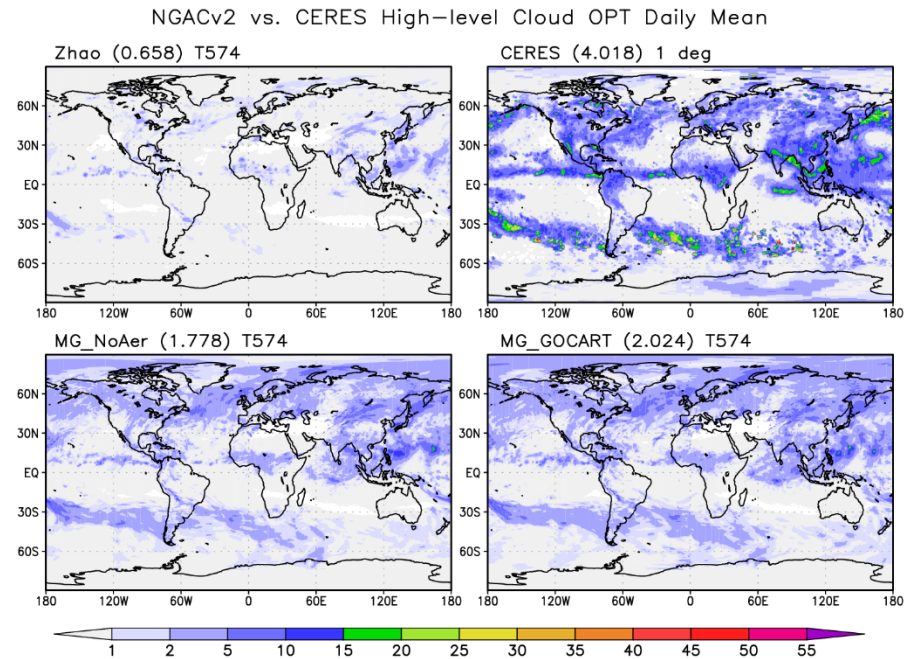
- MODIS: Aqua and Terra Dark Target Deep Blue combin
- CERES: SYN1deg MODIS-derived and 3-hourly geostationary satellite cloud properties
- PATMOSx: AVHRR-derived daily cloud fraction (CALVR-x algorithm)

Testing and Evaluation: NEMS Forecasts

Zhao vs MG without aerosol feedback vs MG with aerosol feedback
Verified against reanalysis (MERRA2) and satellite products (CERES)

Cloud water content and cloud optical depth





Wish-list: A diagnosis tool (satellite simulator) that mimics the observational process by converting model variables into pseudo-satellite observations

Project Management Challenges

- O2R support: the lengthy process to obtain an account at NOAA R&D cluster for foreign national scientists.
  Solution: *Code development is done using JCSDA S4 cluster (NESDIS-funded Supercomputer for Satellite Simulations and Data Assimilation Studies).*

- Code management: concurrent code development among multiple developers from different institutes.
  Solution: *SVN (SubVersion) version control is used to sync and manage code development between UAlbany and NCEP.*

- Shift in program priority: proposed transition plan is to commit code development into NEMS GSM (development has been frozen).
  Solution: *The transition plan has been re-scoped in order to align with the transition toward FV3GFS*

Transition NEMS GSM code development to FV3GFS

- Fine vs coarse grinded component design determines how GMAO's package is implemented into NEMS GSM as well as how our NEMS GSM code development is integrated into FV3GFS.
- In NEMS GSM
  - MG is implemented into physics suite as Fortran routines
  - MAM7 is implemented by extending ESMF-based chemistry infrastructure
- FV3GFS adopts NEMS GSM physics suite and strips away ESMF-based chemistry couplers
  - MG, implemented in NEMS GSM physics suite, is already in FV3GFS
  - GOCART is being re-implemented into FV3GFS (by ESRL)
  - A new option for prescribed GOCART aerosol fields is being added to FV3GFS. Aerosol properties can be determined either by prognostic aerosols (inactive option for now) or prescribed aerosols (from external files based on MERRA2 climo). This enables FV3GFS to be aerosol aware.

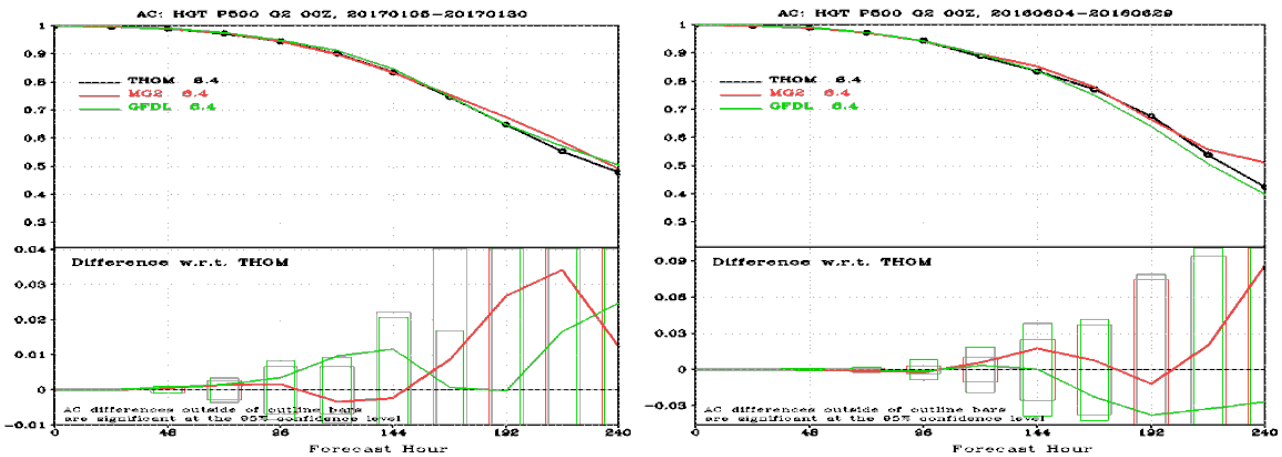
Project Readiness Level

Based on EMC review:

- For cloud microphysics, the transition of the advanced MG element has reached the RL 8 level and should be considered for advanced physics option.
- For aerosol processes, the transition is limited by the switchover from GSM to FV3 dynamic core in GFS. This element can be considered at the RL 6 level.

Summary --

- The new cloud microphysics scheme (MG) is implemented and tested in FV3GFS. See Anning Cheng's C768 L65 FV3GFS results below.
- FV3GFS is aerosol aware, allowing the aerosol attenuation in radiation and CCN/IN activation in cloud microphysics to be determined from <u>prescribed</u> GOCART aerosols.



ACC from Thompson (THOM), MG2, and GFDL microphysics for January 2017 (left), June 2016 (right)

We greatly appreciate MAPP-CTB and NGGPS funding support.

Questions or Comments?