MAPP-CTB 2014 Project

Improving Cloud Microphysics and Their Interactions with Aerosols in the NCEP Global Models

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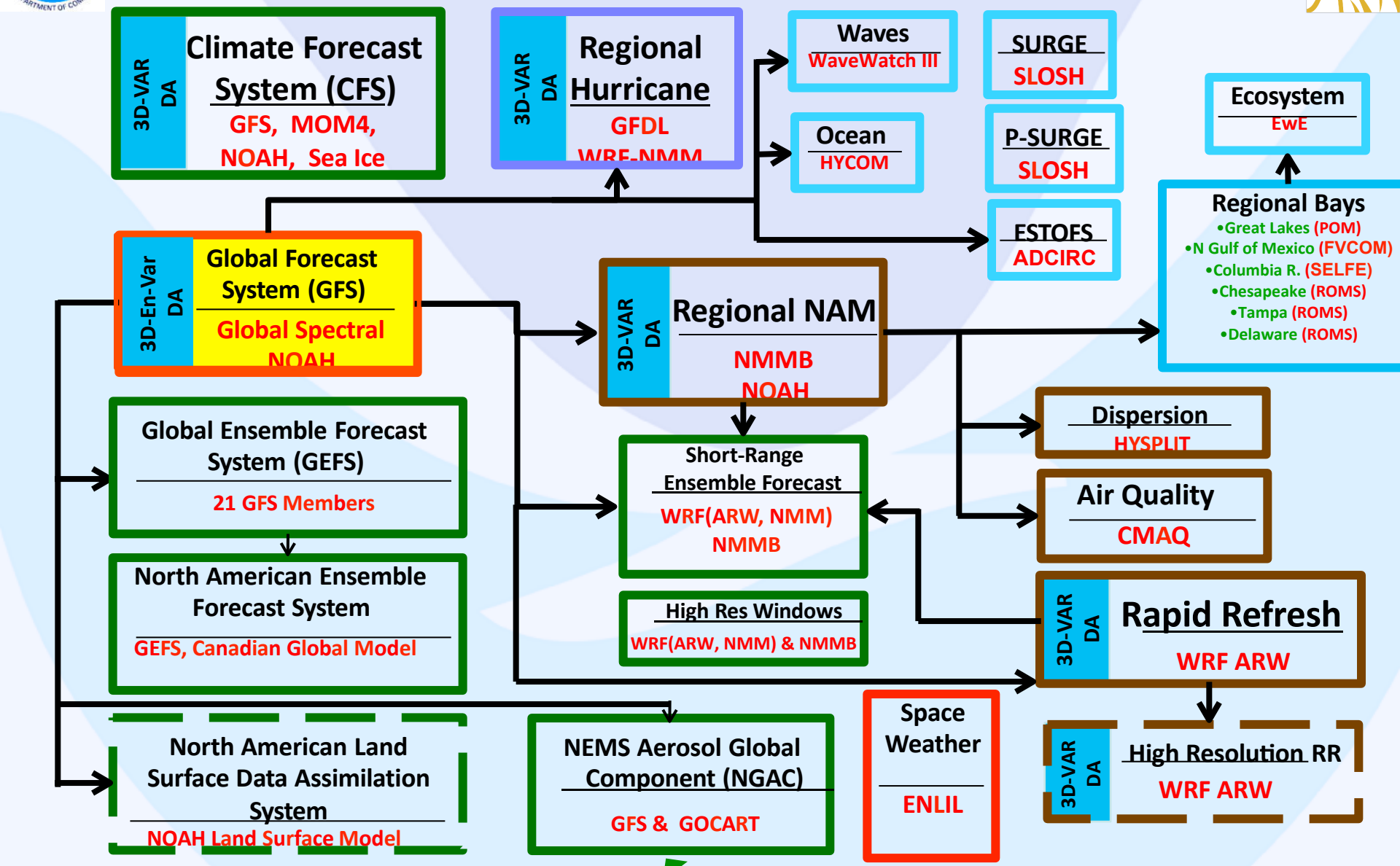
NOAA's Operational Numerical Guidance Suite



The first global in-line aerosol forecast system at NWS

Global aerosol prediction at NWP centers

- Aerosol modeling, traditionally serving regional air quality and climate communities, has seen rapid development at several operational NWP centers over the last few years
- Why include aerosols in the predictive systems ?
  - Improve weather forecasts and climate predictions by taking into account of aerosol effects on radiation and clouds
  - Improve assimilation of satellite observations by properly accounting for aerosol effects
  - Provide aerosol (lateral and upper) boundary conditions for regional air quality predictions
  - Produce quality aerosol information that address societal needs and stakeholder requirements

Global aerosol prediction at NWP centers – cont'd

- Aerosol prediction systems are built upon modeling/assimilation methodologies already in place for the meteorological systems.
  - NRL: NAAPS, driven by NOGAPS
  - ECMWF: MACC, IFS coupled with LMD
  - NCEP: NGAC, NEMS GSM coupled with GOCART
  - UKMO: MetUM with the Hadley Centre dust scheme
- NEMS GFS Aerosol Component (NGAC, NCEP's in-line aerosol forecast system)
  - Build upon NOAA Environmental Modeling System (NEMS) -- a common modeling framework using Earth System Modeling Framework (ESMF)
  - Provide 5-day dust forecast (at T126) since 2012
  - Multi-species forecast (DU, SS, SU, OC, BC) using satellite-based smoke emissions planned for Q4FY15

Proposed upgrades in physics suites

- Implement a multimodal and double-moment Modal Aerosol Module (MAM-7, Liu et al. 2012) as a potential upgrade to replace the operational GOCART scheme
- Implement a double-moment cloud microphysics scheme (Morrison and Gettleman 2008, Barahona et al. 2013) as an option that would replace the operational Zhao-Carr cloud microphysics scheme
- Build an interface to link cloud properties and aerosol physicochemical properties. The new cloud microphysics scheme can be driven by aerosol size and composition diagnosed from the operational bulk scheme, and provided by the new modal aerosol scheme.
- Consistent coupling of cloud micro and macro physics. Work will be done to ensure the linkage is consistent between new cloud microphysics and the PDF of cloud properties (i.e., cloud fraction and liquid water content for the existing scheme, and sub grid distribution of condensate amount for the experiment schemes developed by the CPT projects).
- Extend the unified and flexible model infrastructure used in RRTM radiation package to support the new cloud-aerosol package

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

1. Aitken
2. Accumulation
3. Primary carbon
4. Fine sea-salt
5. Fine dust
6. Coarse sea salt
7. Coarse dust

Aerosol microphysics

- Nucleation (H2SO4-NH3-H2O and BL nucleation)
- Coagulation (intra- and intermodal of AIT, ACC, PCM)
- Condensation(H2SO4, NH3 and SOA(g))
- Gas-aerosol exchange

A. Darmenov (GSFC)

Configuration of MAM7

Aitken

number
water
sulfate
ammonium
secondary OM
sea salt

coagulation and 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 H_2SO_4, NH_3 and SOA(gas)

Primary Carbon

number
water
hydrophobic OM
black carbon

Coarse Dust

number
water
dust
sulfate
ammonium

Coarse Sea Salt

number
water
sea salt
sulfate
ammonium

Two attachment states:

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

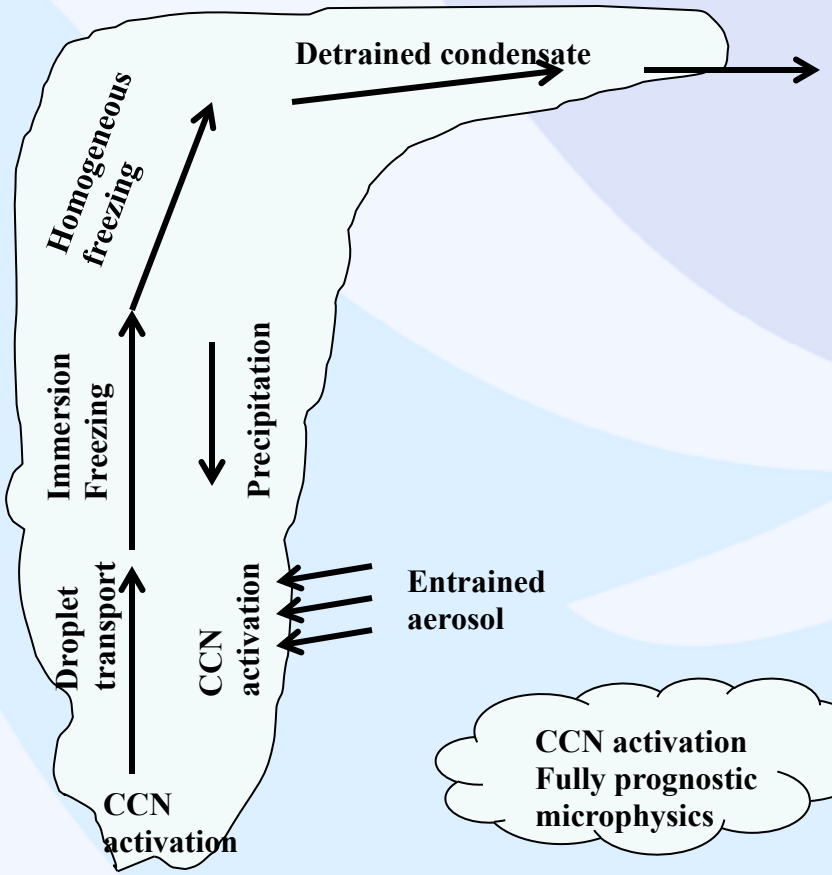
*b) **cloud-borne** - attached to / contained within stratiform cloud droplets (AP in convective cloud droplet are not treated explicitly)*

A. Darmenov (GSFC)

Two-Moment Cloud Microphysics

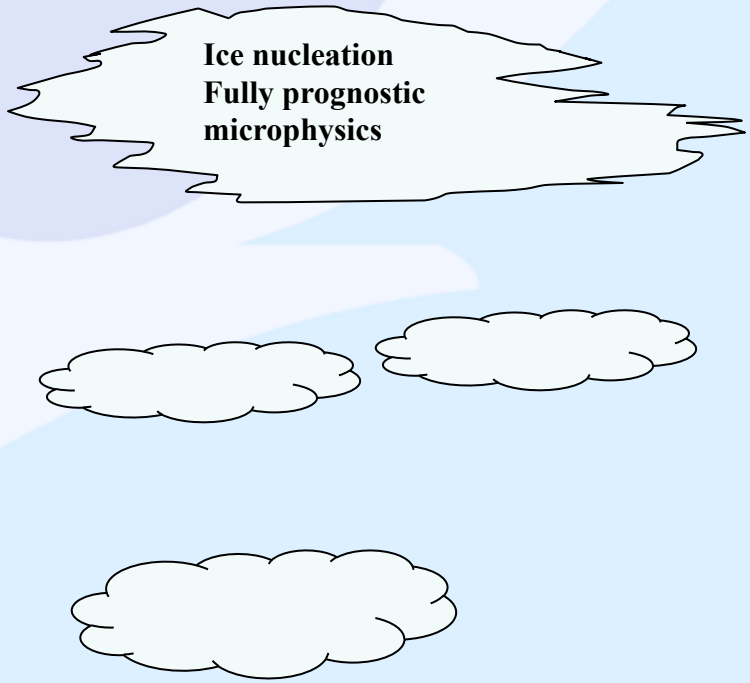
Convection (Barahona et al., 2014)

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



Stratiform (Morrison and Gettleman, 2008)

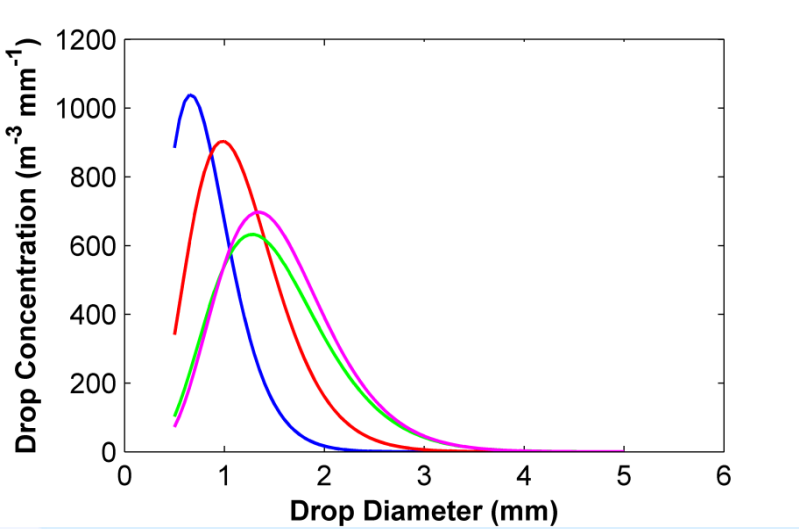
Fully-prognostic microphysics: Generation of condesate linked to CCN and IN activation



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)

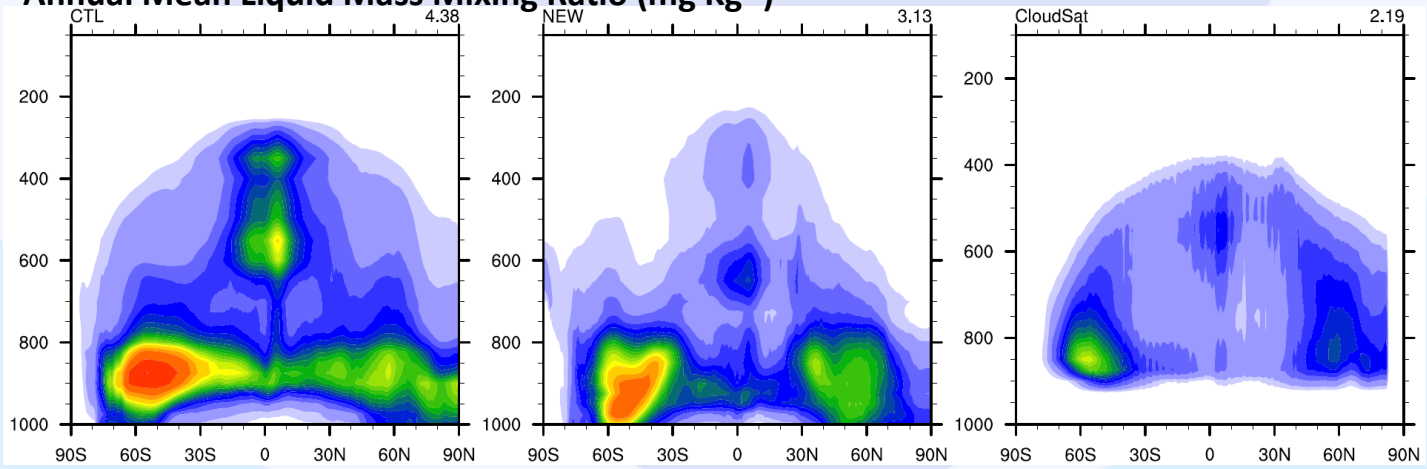
New Cloud Microphysics

	Current microphysics	New microphysics
Cloud Type	Large scale (stratus, anvils and cirrus)	Convective and Large Scale
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

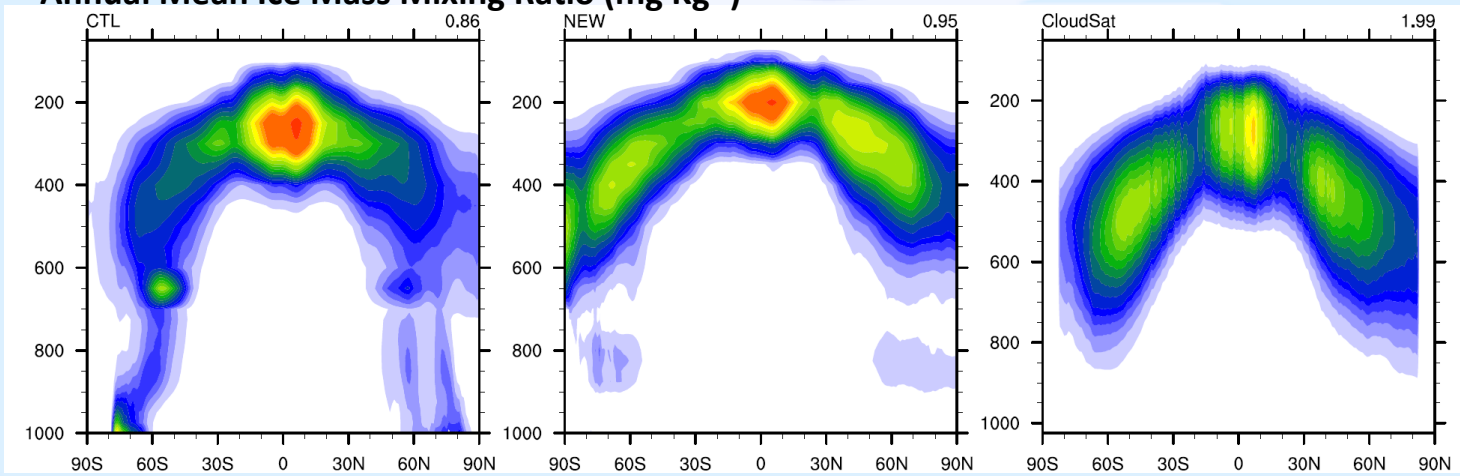
Barahona, D., Molod, A., Bacmeister, J., Nenes, A., Gettelman, A., Morrison, H., Phillips, V., and Eichmann, A.: Development of two-moment cloud microphysics for liquid and ice within the NASA Goddard Earth Observing System Model (GEOS-5), Geosci. Model Dev., 7, 1733-1766, doi:10.5194/gmd-7-1733-2014, 2014.

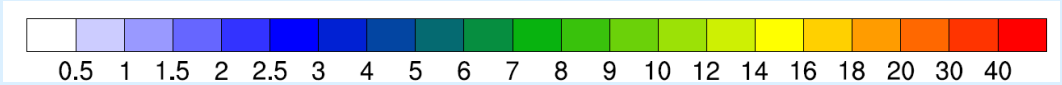
NASA GEOS-5 Cloud Water Content

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



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

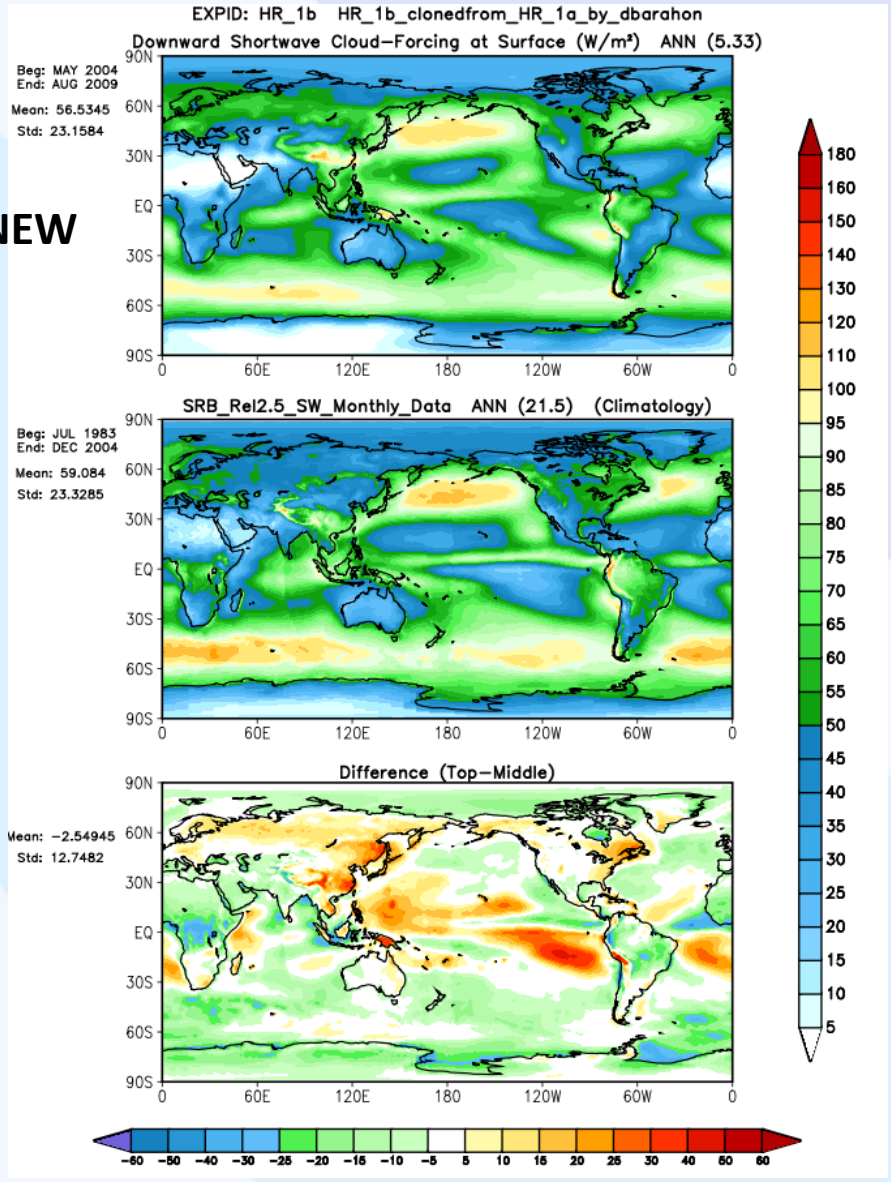




Barahona et al., GMD. 2014

NASA GEOS-5 Cloud Radiative Forcing

NEW



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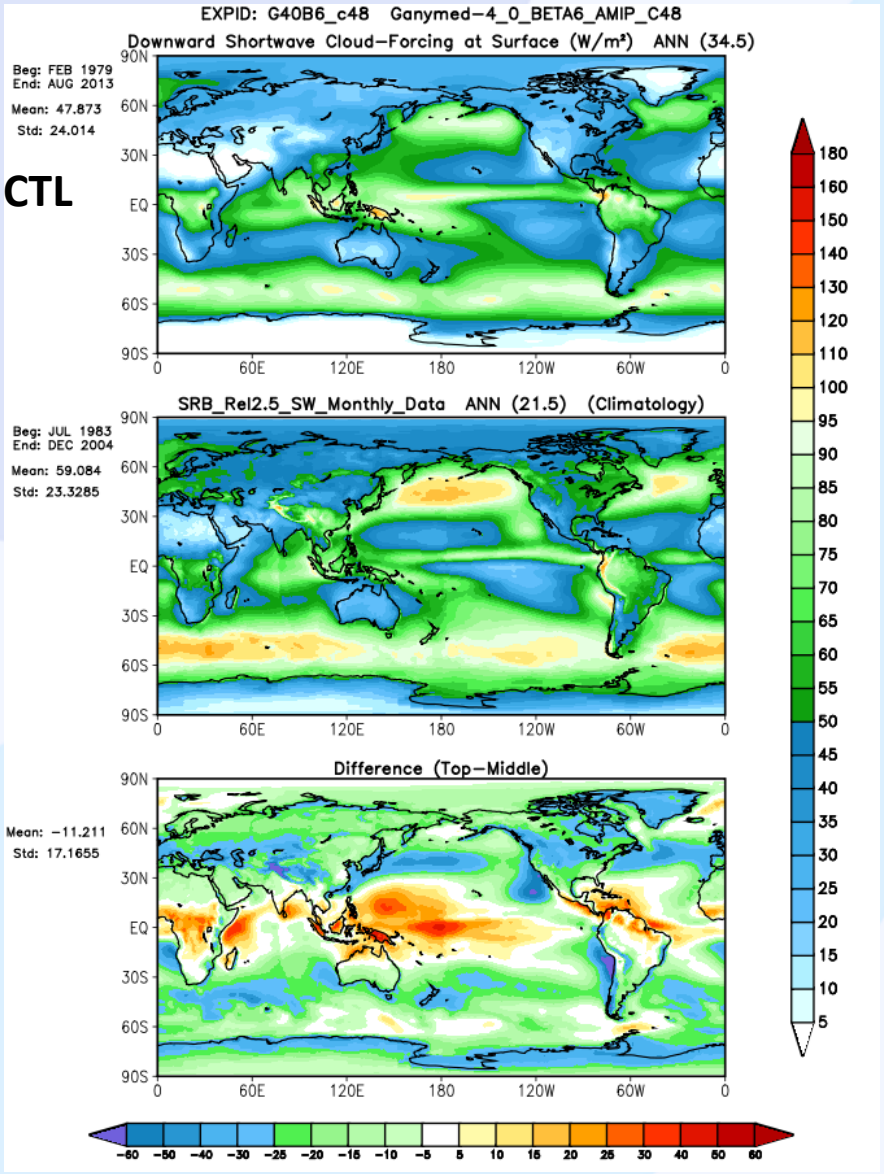
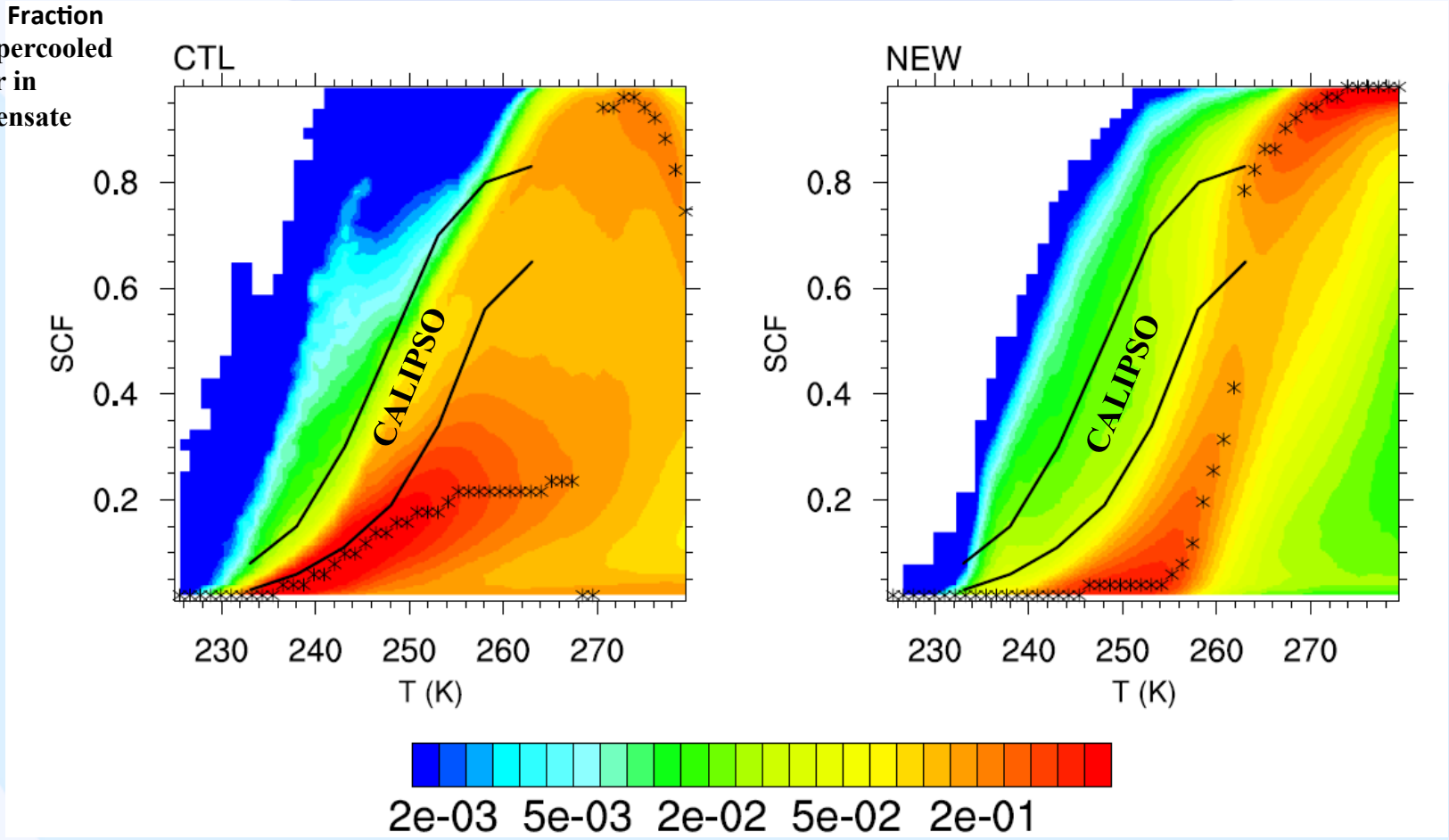


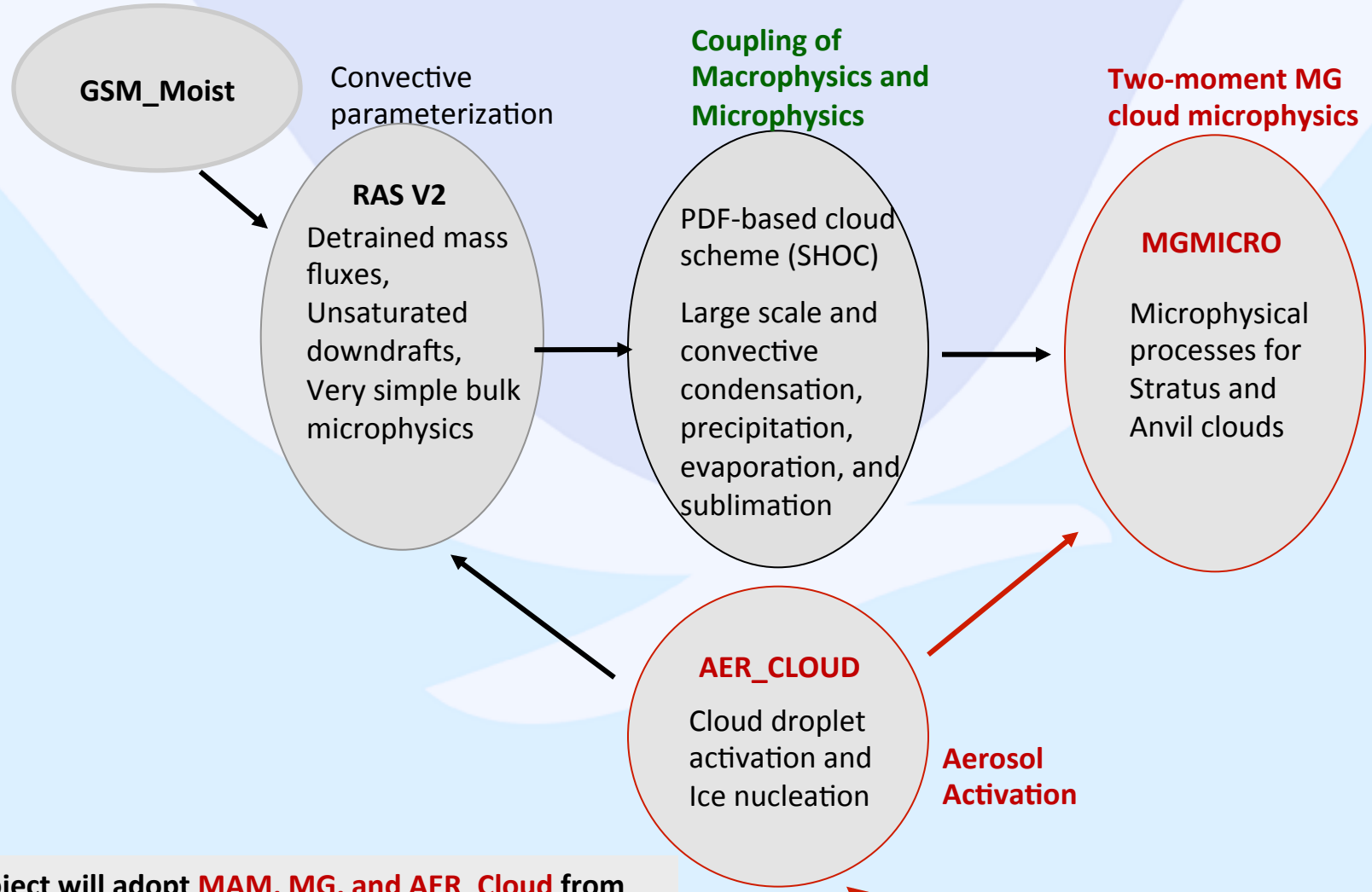
NASA GEOS-5 Phase Partitioning

SCF: Fraction of supercooled water in condensate



Barahona et al., GMD. 2014

Adopting GEOS-5 aerosol-cloud package



This project will adopt MAM, MG, and AER_Cloud from GSFC and coordinate with EMC/CPT teams on coupling cloud micro and macro physics

Challenges from the aspect of this CPT project:

- Emission estimates
  - Near-real-time forecasts versus reanalysis
  - Scale-aware emission algorithms
- The use of NWP model to transport chemical species
  - Need mass conserving, positive definite advection scheme
- Resources versus complexity
  - What is the optimal strategy to best use the available computer resources?
  - How much complexity is needed to accurately represent the aerosol processes and effectively account for aerosol effects?
- Observation-based diagnosis package to examine whether the model with improved aerosol-cloud package better capture the aerosol/cloud properties and the processes relevant to aerosol-cloud-radiation interactions.
- Performance metrics to demonstrate objective performance, as “traditional verification no longer assesses all uses of GFS (Glenn White)”

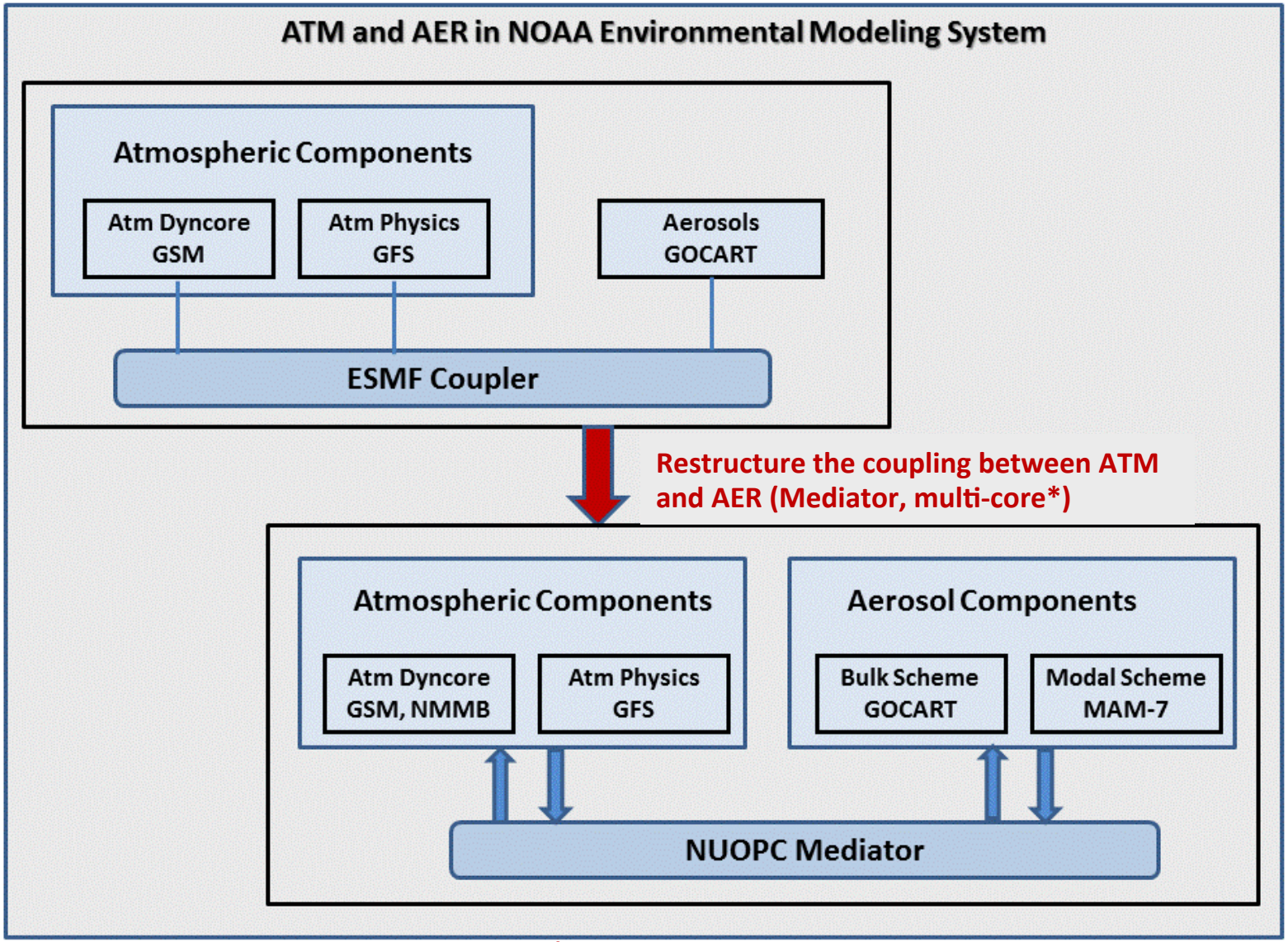
Tracer friendly dynamic code in NGGPS

Thanks.

Questions and Comments?

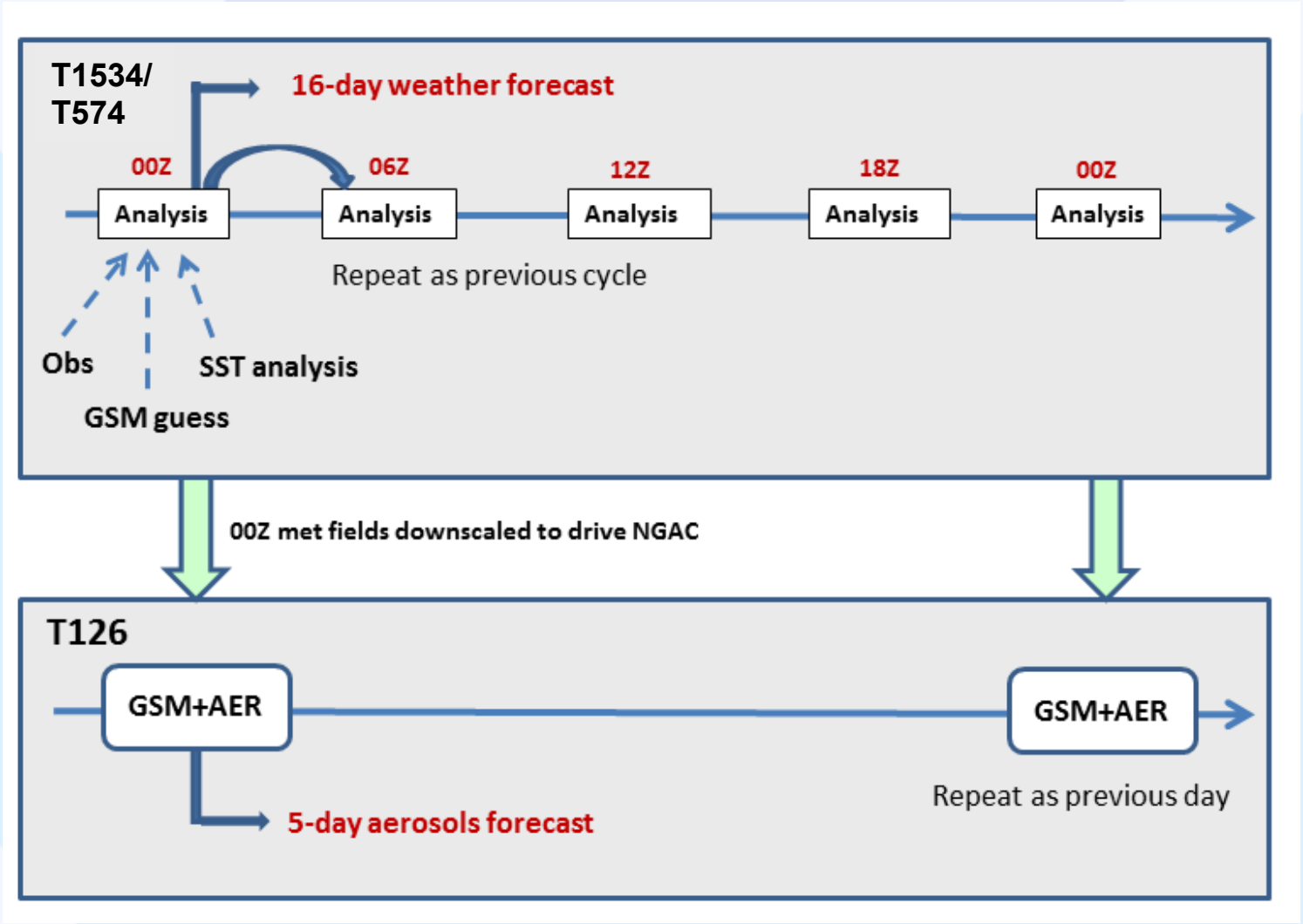
Backup Slides

Proposed NEMS infrastructure changes

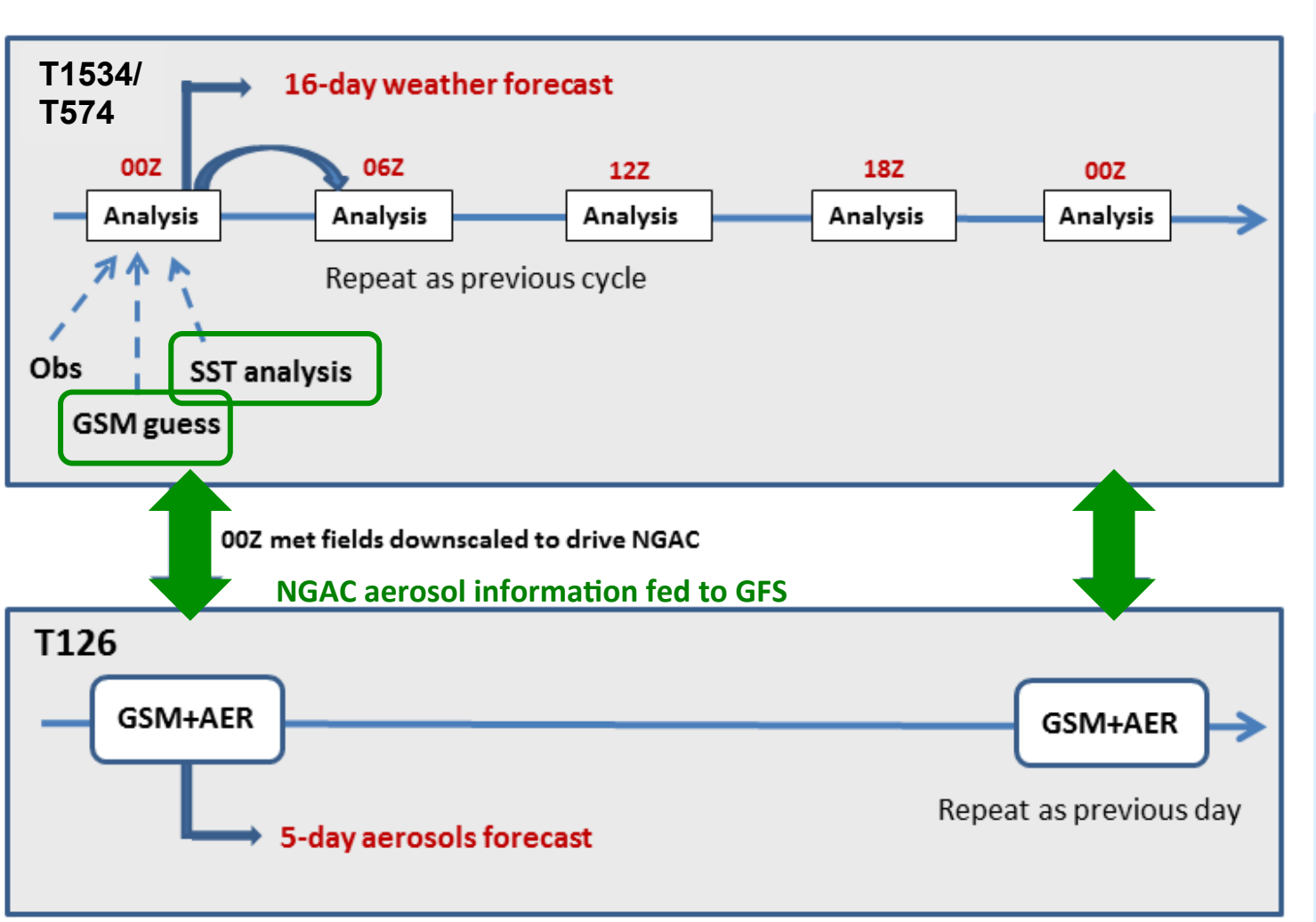


* Pending R2O support for multi-core code development

Dual-resolution weather-aerosol system at NCEP



Dual-resolution weather-aerosol system at NCEP
Proposed 2-way loose coupling*



* Pending R2O support for investigating aerosol effects on weather forecasts