

## **FY 2011 Second Quarter Department of Energy, Office of Biological and Environmental Research, Climate and Environmental Systems Division GPRA Metric**

**Title:** *Demonstration of new aerosol measurement verification testbed for present-day global aerosol simulations*

### **Product Definition/Description**

The regional-scale Weather Research and Forecasting (WRF) model is being used by a DOE Earth System Modeling (ESM) project titled “Improving the Characterization of Clouds, Aerosols and the Cryosphere in Climate Models” to evaluate the performance of atmospheric process modules that treat aerosols and aerosol radiative forcing in the Arctic. We are using a regional-scale modeling framework for three reasons: 1) It is easier to produce a useful comparison to observations with a high resolution model; 2) We can compare the behavior of the CAM parameterization suite with some of the more complex and computationally expensive parameterizations used in WRF; 3) we can explore the behavior of this parameterization suite at high resolution. Climate models like the Community Atmosphere Model version 5 (CAM5) being used within the Community Earth System Model (CESM) will not likely be run at mesoscale spatial resolutions (10 – 20 km) until 5 - 10 years from now. The performance of the current suite of physics modules in CAM5 at such resolutions is not known and current computing resources do not permit high-resolution global simulations to be performed routinely. We are taking advantage of two tools recently developed under PNNL Laboratory Directed Research and Development (LDRD) projects for this activity. The first is the *Aerosol Modeling Testbed* (Fast et al., 2011b), a new computational framework designed to streamline the process of testing and evaluating aerosol process modules over a range of spatial and temporal scales. The second is the *CAM5 suite of physics parameterizations that have been ported into WRF* so that their performance and scale dependency can be quantified at mesoscale spatial resolutions (Gustafson et al., 2010; with more publications in preparation).

### **Product Documentation/Deliverable**

As described in Fast et al., (2011b) and at <http://www.pnl.gov/atmospheric/research/aci/amt/index.stm>, the Aerosol Modeling Testbed (AMT) was designed specifically to target aerosol process modules since there are few tools available to take advantage of the wide range of state-of-the-science aerosol measurements available from field campaigns; however, it also has the capability of evaluating simulated meteorological (e.g. clouds) and chemical (i.e. precursors that affect aerosol formation and transformation) quantities. Porting the CAM5 physics modules into WRF (Gustafson et al. 2010) permits the AMT to quantify their performance when simulating meteorological, chemical, and aerosol quantities over multiple spatial resolutions.

A schematic diagram of how the CAM5 physics parameterizations are being evaluated for Arctic processes using the AMT is shown in Fig. 1. We have finished porting the following CAM5 physics parameterizations into WRF: the 1) Zhang & McFarlane deep convection scheme, 2) Park & Bretherton shallow convection scheme, 3) Bretherton & Park boundary layer scheme, and 4) Modal Aerosol Model (MAM). To ensure that CAM5 modules remain largely untouched, they have been linked to WRF using new interface subroutines that translate input and output arrays between the two models. In this way, future updates to the parameterizations in CAM5 can be ported to WRF with little additional work. Other research groups have ported the RRTMG radiation scheme and the CLM land-use scheme from CAM5 in WRF; therefore, no additional work was required for those two parameterizations. We have already released the deep convection, shallow convection, and boundary layer schemes to NCAR so that they can

be included in the next release of WRF version 3.3 expected in April 2011 and shared with the entire atmospheric modeling community. The MAM aerosol scheme will be released publically in a future release of WRF.

There are three remaining parameterizations that are currently being porting into WRF: 1) the Morrison & Gettleman microphysics scheme, 2) the simplified version of MOZART trace-gas chemical mechanism, and 3) aerosol-radiation-cloud interactions. Once this is completed, we will have the ability to perform global to regional downscaling simulations using consistent physics between CAM5 and WRF. We anticipate that the CAM5 physics suite in WRF will be a very useful tool because it provides a means to better evaluate the physics performance using field campaign data and examine scale-dependency issues in the parameterizations that have not been addressed before.

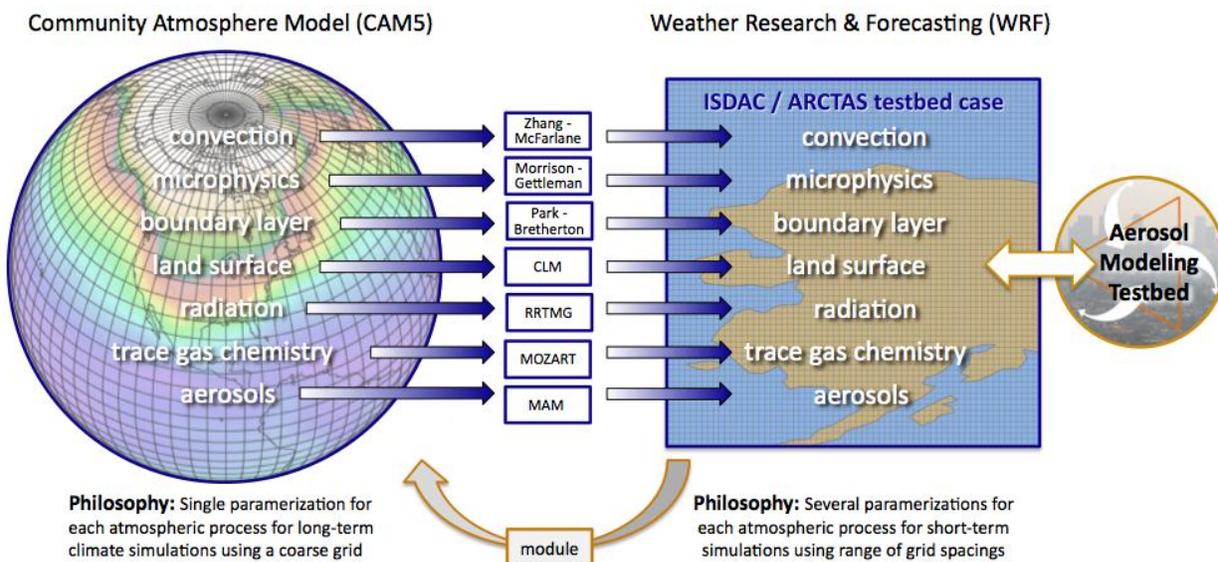


Figure 1. Schematic diagram depicting relationship CAM5 and WRF and how CAM5 physics modules are evaluated at higher spatial resolution using field campaign data in the Arctic via the Aerosol Modeling Testbed.

We are using this new tool to examine how well CAM5 physics parameterizations perform in the Arctic as shown in Figure 1. WRF is being run using a domain encompassing Alaska with a horizontal grid spacing of ~5 km, so that ~1900 cells fall inside a typical 1.9 x 2.5 degree grid cell of CAM. This will enable simulated clouds and aerosols to be directly compared to aircraft and surface based measurements that were collected over Alaska and the surrounding ocean during April 2008 as part of Indirect and Semi-Direct Aerosol Campaign (ISDAC) field campaign supported by DOE's ARM Aerial Facility (AAF, <http://campaign.arm.gov/isdac/>). In addition, the long-term measurements from DOE's Atmospheric Climate Research Facility (ACRF) at Barrow, Alaska are available to supplement those collected aloft.

Under the auspices of the Third International Polar Year, there were several other measurement campaigns conducted in the Arctic including:

**ARCTAS:** Arctic Research of the Composition of Troposphere from Aircraft and Satellites supported by NASA, <http://www.espo.nasa.gov/arctas>

**ARCPAC:** Aerosol, Radiation, and Cloud Processes affecting Arctic Climate supported by NOAA, <http://www.esrl.noaa.gov/csd/arpac/>

ICEALOT: International Chemistry Experiment in the Arctic L<sup>O</sup>wer Troposphere supported by NOAA, <http://saga.pmel.noaa.gov/Field/icealot/>, and

POLARCAT: POLAR study using Aircraft, Remote sensing, surface measurements and models of Climate chemistry, Aerosols and Transport (POLARCAT) supported by the French National Center for Scientific Research, <http://www.latosm.ipsl.fr/index.php/en/tact/themes-de-recherche/polarcat>

The combined campaigns consisted of six research aircraft and several surface sampling sites that collected extensive meteorological, chemical, and aerosol property measurements. While aircraft flight paths were conducted over a large region of the Arctic, most of the sampling time occurred in the vicinity of Alaska during April 2008.

Many of the measurements from ISDAC and ARTCAS have been assembled into a ‘testbed case’ within the framework of the Aerosol Modeling Testbed (Fast et al., 2011a; 2010). An example comparing the simulated black carbon, organic matter, and sulfate from one of the NASA’s DC-8 flights on April 16, 2008 is shown in Figure 2. Lateral boundary conditions for the high resolution WRF simulation are obtained from a global-scale aerosol simulation.

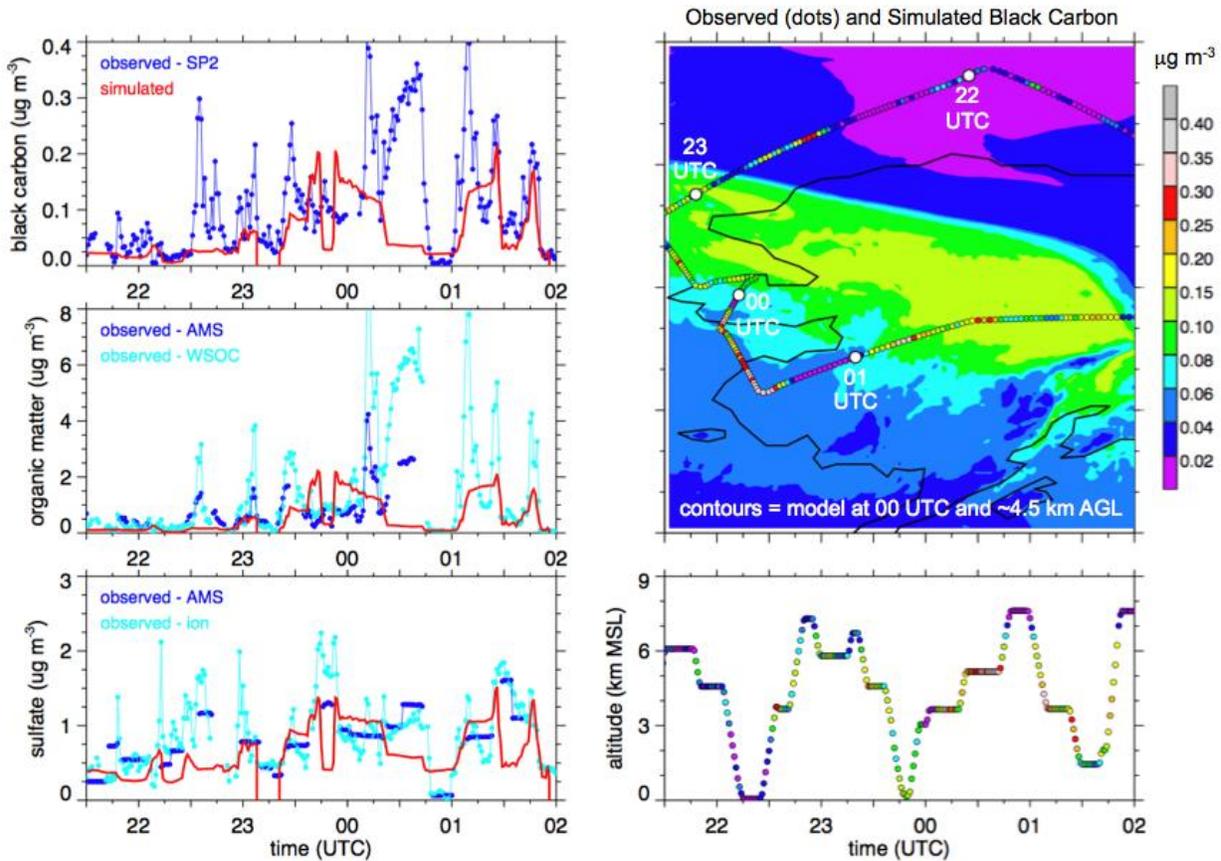


Figure 2. Example evaluation of simulated aerosol composition in the ISDAC/ARCTAS field campaign domain using the Aerosol Modeling Testbed tools.

As seen in this Figure 2, only a qualitative agreement between observed and simulated aerosol composition is currently produced. Simulated carbonaceous aerosols (the sum of black carbon and organic matter) are about a factor of two too low. Simulated sulfate is also too low, but it is closer to the measurements than simulated carbonaceous aerosols. The spatial pattern in black carbon (upper right panel in Figure 2) shows that while the model produces a large region of aerosols being transported

towards the Arctic by southwesterly ambient winds, the model does not place the peak values at the correct locations. This large region of black carbon (as well as other aerosol species) is the result of long-range transport from emission sources in Asia as simulated by the global model that provides the boundary conditions to WRF. These errors in simulated aerosol mass and hygroscopicity associated with composition could impact cloud-condensation nuclei (CCN) and consequently cloud-aerosol interactions in the mixed phase clouds observed in the region. Simulated droplet number that depends upon activation of simulated CCN is surprisingly similar to observations within mixed-phase clouds (not shown), suggesting that cloud-aerosol interactions are being simulated correctly but for the wrong reasons.

We are also collaborating with Dr. Kathy Law and her team from the Laboratoire Atmospheres Milieux, Observations Spatiales (LATMOS) of the Institut Pierre Simon Laplace in Paris, France. Her group has started to use the same modeling system to examine meteorological conditions and atmospheric chemistry over the Arctic during the POLARCAT campaign. They are using the Aerosol Modeling Testbed to evaluate model performance against their measurements collected over Canada and Greenland. This collaboration will benefit our project by expanding the ISDAC/ARCTAS testbed case over a wider region in the Arctic and developing consistent emission data sets.

Our ultimate objective is to evaluate the performance of the entire CAM5 physics suite for the ISDAC/ARCTAS testbed case, and use the knowledge gleaned from that evaluation in helping to understand the processes that are influencing the Arctic climate, and the changing sea ice in polar regions. Before evaluating the physics suite in the Arctic, we are testing such a coupling for the MILAGRO campaign (Molina et al, 2010; Fast et al., 2011b) over Mexico. An example of downscaling CAM5 to a 12 km grid in WRF is shown in Fig. 3. On March 19 (about 13 days into the simulation period), CAM5 predicts a broad region of aerosols at the 700-hPa level transported by ambient southwesterly winds from Mexico, over the Gulf of Mexico, and towards Louisiana as shown in the left panel of Fig. 3. The CAM5 simulation is used to provide boundary conditions and WRF is run with the identical deep convection, shallow convection, boundary layer, aerosol parameterizations, and emissions from CAM5. The WRF simulation, shown in the center panel of Fig. 3, is qualitatively similar to CAM5 but exhibits much more spatial variability associated with the plume downwind of Mexico due to resolving local meteorological processes that affect aerosol transport, mixing, and transformation. A second simulation was performed that was identical to the previous one, except that the CAM5 emissions were replaced by anthropogenic and biomass burning sources specific to this period and on-line dust and sea-salt calculations that depended upon the high-resolution meteorology. As seen in the right panel of Figure 3, the local emissions lead to higher aerosol concentrations. Over northwestern Mexico, most of the increase is associated with on-line emissions of dust. Over the Gulf of Mexico, the increase results from both dust and higher anthropogenic and biomass burning emissions of carbonaceous aerosols. These results also demonstrate that the default emissions used in CAM5 simulations could lead to an underestimation of aerosols over regional scales.

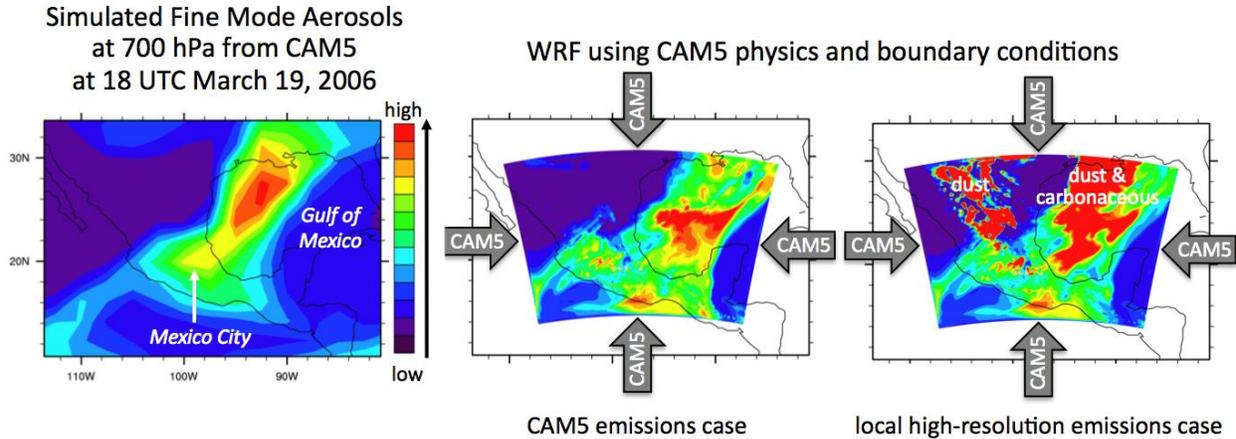


Figure 3. Example downscaling simulation using CAM5 physics in WRF. CAM5 and WRF are qualitatively similar, except that smaller grid spacing ( $\Delta x = 12$  km) captures more local variability in meteorology that affects aerosol transport and mixing. When high-resolution emissions are employed, even greater variability is produced, mostly due to on-line dust emissions.

## References

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