Unified Aerosol Microphysics for NWP

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LONG-TERM GOALS

The long-term goal of this research is to develop a practical predictive capability for visibility and weather effects of aerosol particles over any region of the world for timely use in planning and executing DOD operations and activities. Specifically, the goal is to develop a COAMPS that is capable of simulating the full range of interactions between aerosol particles, clouds, and radiative transfer while remaining flexible, extensible and operationally practical. The fundamental predicted

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variables are the concentrations of those aerosol species that are responsible for degradation of Electro-Optical (EO) propagation or that modify cloud behavior and lifetime.

OBJECTIVES

The primary objective for this project is to design and implement a flexible and extensible mechanism into COAMPS that allows new scalar variables to be added and accessed with less effort, thus enabling new development of more complex cloud-aerosol interactions. The work on this project has been divided into two phases, an investigation phase followed by an implementation phase. Because upgrading scalar variable handling is a major change to a model's infrastructure, we decided to focus significant effort in the investigation phase to refine the requirements and evaluate a number of software designs.

Another objective is the development of an aerosol microphysics library and emission inventories for use by COAMPS and other models. The final objective is a version of COAMPS configured to forecast the major aerosol species, yet suitable for operational use. The proposed capabilities will provide numerous opportunities to study and solve problems of interest to the Navy and DOD, as well as the climate community.

APPROACH

We are using a scaled-down version of our COAMPS model to quickly test different software approaches for the representation of scalar variables. Usually a scalar variable is processed from two perspectives; it may be treated as a generic variable such as when it processed by advection, or it may be used specifically like dust in ice nucleation. The primary difficulty in adding new scalar variables is the number of locations in the software that must be modified. Since much of this editing is for general processing, it was decided to implement a mechanism where this type of code generation could be automated. We knew that associating properties to variables would be useful to support generalized or property-driven processing so we implemented a simple registry to store meta-data about scalar variables. These properties are initialized at runtime and may be modified by a user through an ASCII file without rebuilding and/or recompiling the model's software. We wrap a looping mechanism around processing steps that automatically submits variables for processing based on properties set by the user. We tested three different approaches with an evaluation at the end of each approach before coming to a design decision for the implementation.

This new version of COAMPS will be the only operational model with data assimilation capable of studying the complex interactions between clouds, aerosol particles, radiative transfer and dynamics. A target application will be modeling the SE Asia region during the 7-SEAS Campaign of FY12. Persistent smoke AODs of 0.3, coupled with cirrus optical depths of similar magnitude are likely to have a complicated impact on visible and infrared radiative transfer and the meteorology of the region. The modifications to COAMPS will allow interactive studies of the impact of smoke from different types of fires.

For the library, we are investigating the availability of global high-resolution emissions inventories for use in COAMPS, NAVGEM, and other models. NRL hosts the world's only real-time smoke emission system (FLAMBE) as well as the only high-resolution dust source database. The development of similar high-resolution emissions inventories for anthropogenic species at global scales will be addressed.

WORK COMPLETED

This year we completed the reorganization of the new code by adding meta-data registry to centrally manage scalar variable properties and have added property driven processing, which automates some repetitive processing such as IO, dynamics, and grid-to-grid communications. It is user-modifiable at runtime via ASCII file, and accessed with simple, flexible, extensible API interface.

We completed the correction of two major drawbacks to the original implementation of the aerosol processing. The previous aerosol software was never designed to support more than one aerosol species in a single model run. Of more significance, the aerosol processing was a separate module running inside the COAMPS model. The aerosol scalars used a slightly different temporal scheme and could not be readily used with the model's microphysics processes. A significant redesign was required to overcome this barrier. The new aerosol module has been implemented from the top down that will now support any number of new aerosol variables being active in the same model run. These variables can have their existence and processing controlled by user modified settings, stored in the scalar registry. These software changes were first tested against the previous implementation and found to produce the exact same numerical results.

A major software module was added to consolidate the processing of scalar variables thus reducing the effort required to add new ones. To test this software one variable was converted to this new mode of processing aerosol dust, and it was evaluated over Southwest Asia. The results were compared against the previous implementation to verify the correctness of the coding. With this testing completed, new aerosol variables can now be added to interact with the COAMPS model microphysics.

RESULTS

To date the scientific results of this effort are limited, but we are able to reproduce previous dust simulations using the new software. Software that was originally produced to support a few experiments has been replaced by more capable and robust software designed to support a much richer array of investigations. The dust prediction is now integrated, for example, with the COAMPS two-moment cloud microphysics scheme where it serves as a source of cloud droplet nuclei. The dust and cloud microphysical processes are fully interactive in that the cloud droplet nucleation acts as a sink on the dust concentration in regions of supersaturation and as a source of dust in regions where droplet evaporation is occurring. Auto-conversion from cloud water to rain water in the two-moment cloud scheme also acts a sink on the dust concentration through the precipitation process. An effective measure of the impact on the dust on the cloud properties is through the changes in the cloud effective radius and its impact on the cloud precipitation efficiency and associated changes in the radiative properties of the cloudy atmosphere. We believe this two-way coupling will also provide considerable realism to the forecasted cloud properties when compared against standard two-moment prediction schemes initialized with idealized aerosol distributions that run without viable sources. Experience has shown such simulations quickly loose realism due to the lack of viable replenishment processes needed to recoup the initial aerosol losses which arise through the precipitation process.

The new software strategy of collecting scalar fields within "process families" at run-time (such as advection, turbulent mixing, or boundary updates) greatly simplifies the treatment of the scalar fields used in COAMPS. A simple loop index for a given process is used to determine whether a given scalar belongs (or not) to a given process family. This eliminates the need for multiple if-checks at run-time and readily allows the user to include additional scalars with minimal additional effort. All that is required is that all scalar fields operated on by a given physical or dynamic process be specified at run-time. No additional changes are required within the code as updates to the loop index controlling this process are computed automatically to accommodate all added scalar fields. Structuring the code in this manner allows COAMPS developers to add complex physics parameterizations developed either in-house or within the broader community without the need to make extensive changes to the body of the code itself. In fact, such modifications will be confined to a single look-up table set-up by the user at run-time in any fashion desired. This means the user will have considerable control over the ability to conduct numerous sensitivity studies where dynamical or physical processes are systematically included or excluded in an effort to gain further insight into the model and atmospheric behavior.

To evaluate the new handling of aerosol dust and its interaction with COAMPS microphysics, an operational test case has been developed covering Southwest Asia. This case was used to validate handling of feedback between nests. Once the aerosol dust was confirmed to be working, it was connected into the COAMPS microphysics and evaluated. A typical result is shown in Figure 1. It was determined that this test area did not contain enough cloud water in useful situations to evaluate the interaction with dust particles. A case off of West Africa during HS3 is now being used to evaluate these dust/cloud interactions. During the second week of September 2012, an interesting event occurred that showed some interactions between the Sahara Air Layer (SAL) and Hurricane Nadine off of West Africa. Dust is seen wrapping around the north side of the storm on Sep 11 in Figure 2. We are using this event to evaluate the interactions between dust aerosol particles and cloud moisture in the new version of COAMPS. A preliminary result is shown in Figure 3.

IMPACT/APPLICATIONS

Climate studies have suggested the importance of interactions between aerosol particles, clouds, and radiative transfer via the processes known as the direct effect (changes in radiative transfer), semi-direct effect (changes in boundary layer dynamics), and indirect effect (changes in the cloud life cycle). Since climate is made up of many weather events, these same processes should be important to NWP. However, the case for fully interactive aerosol particles in operational NWP models has not been made. The climate metric of radiative forcing is not meaningful to NWP since extensive spatial and temporal averaging is invoked and the local impact is hidden. Regional impacts have been largely demonstrated with model sensitivity studies and anecdotal evidence. The interactive COAMPS model will allow a quantitative assessment of the significance of aerosol particles to NWP.

An alternate impact on NWP lies in the aerosol direct effects on remote sensing, data assimilation and validation. Aerosol particles can cause biases in satellite-sensed radiances at the top-of-the-atmosphere, errors in sea surface and other ocean and surface retrievals, and errors in forward modeling of observed quantities. An interactive COAMPS model will allow the study of these effects and the development of mitigation strategies.

RELATED PROJECTS

ONR 6.2 “Application of Earth Sciences Products” supports improvements in aerosol microphysics and model initialization. The implementation of COAMPS at FNMOC is supported by 6.4 funding from PMW-120 for “Small-scale Atmospheric Models”. This funding also supports development and generation of products for use by the fleet. The NRL 6.1 Accelerated Research Initiative “Physics of Cloud Variability” helps understand atmospheric aerosol interactions. The NRL 6.2 base project “Atmospheric Correction for Oceanography” investigates the impact of aerosol particles on retrievals.

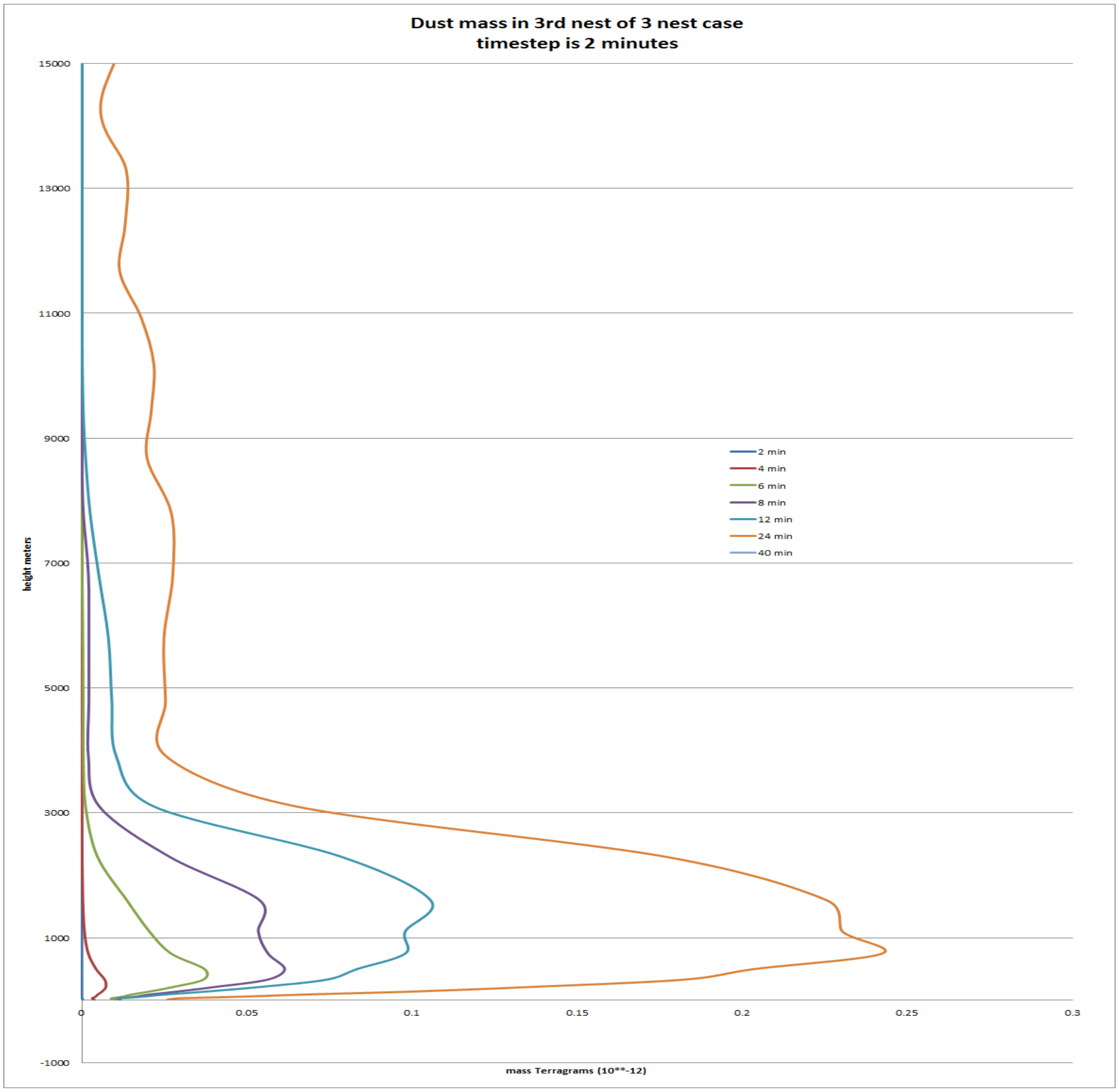

Figure 1: This chart shows evolution of the dust profile during mobilization at a grid point on the fine mesh of the SW Asia test case. Starting from the left, the curves are valid at 2, 4, 6, 8, 12, 24, and 60 minutes. The bimodal shape at 8, 12, and 24 minutes implies that another source is present upwind.

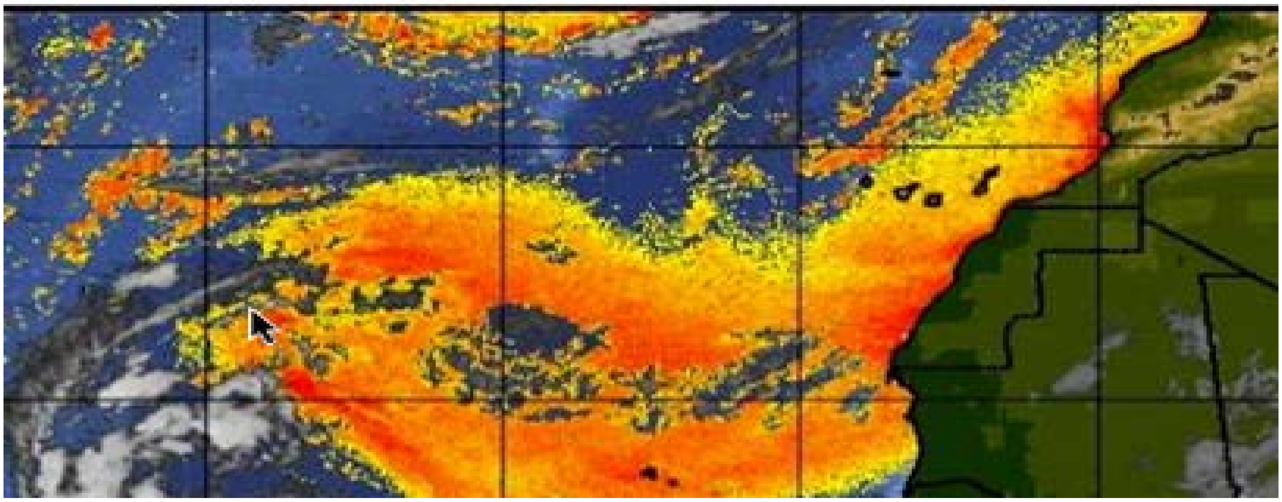

Figure 2: METEOSAT-9 satellite image for 06Z September 11, 2012 showing convective clouds (grey shades) and the Saharan Air Layer (SAL) airmass (orange and red shades.) The SAL is being wrapped counterclockwise around TC Nadine, located at about 20N, 40W. Interactions between dust particles and clouds are likely.

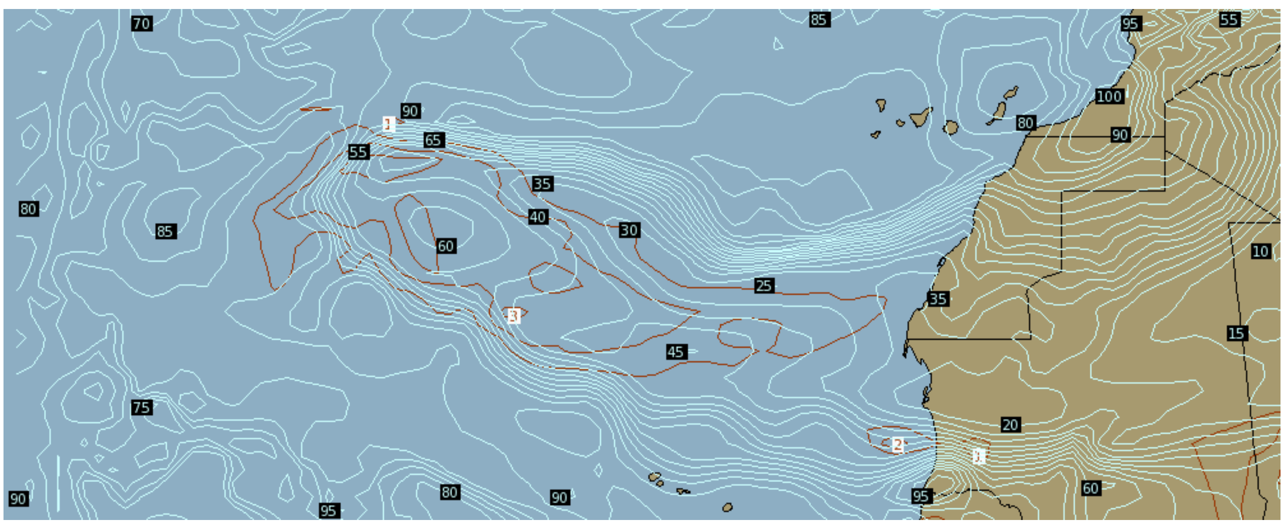

Figure 3: COAMPS 6 hour forecast of relative humidity (light blue contours with dark labels) and dust concentration (mg/m$^{3;\ r}$; red contours with light labels) valid at 06Z September 7, 2012. The area of heavy dust concentrations and low humidity corresponds with the 'SAL Airmass' seen in Figure 2.