Development of NMMB-AQ: Current status

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1. Introductions

Most current atmospheric models have already widely used grid interpolation to handle physical processes and data input/output, such as obtaining mesoscale models' lateral boundary conditions from global models. The Earth System Modeling Framework (ESMF) systematizes this grid interpolation as atmospheric/earth models run on their own grids with their own time steps and communicate with one another during their forecasts. This framework helps smooth the coupling issue arising from the use of different grids. A new NMM-B model using the ESMF framework is under development in NOAA/NCEP/EMC and other collaborating institutions. The NMM-B (Non-hydrostatic Mesoscale Model on Arakawa B grid) is one of the NCEP dynamic cores and is developed from WRF-NMM dynamics and physics. We are developing and testing an inline air quality (AQ) modeling system with this dynamical/physical core.

In this paper, we will illustrate the architecture of NMMB-AQ model, our development plan and current status of model development. Some special problems related to air quality model requirements, such as mass conservation and advection and diffusion are discussed.

Figure 1 shows two of the major modules of the forecast system: the atmospheric module that runs with a relatively fast time step, and the Sea/Ice/Land module which runs with a longer time step. The atmospheric module currently includes two major components: dynamics and physics. The AQ model resides in the atmospheric module and its main part is inline within the physical component which requires the dynamic component to provide advection for arbitrary passive tracers in certain time steps.

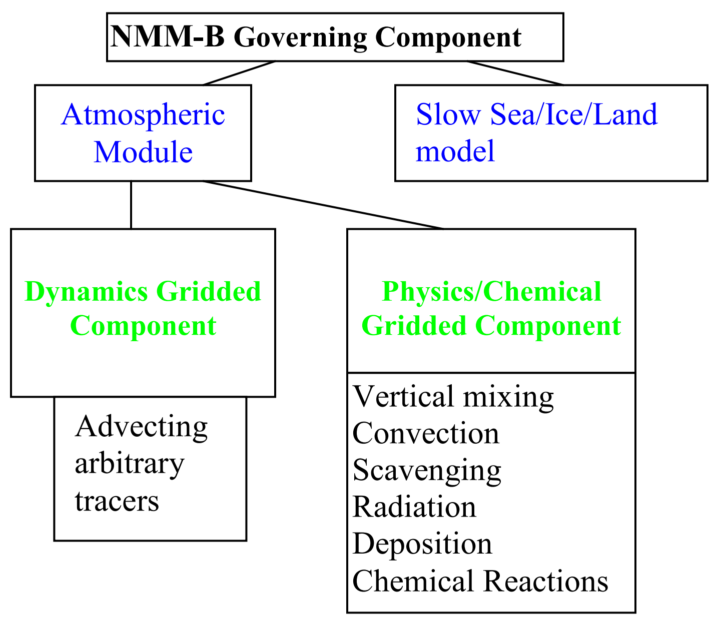

Figure 1. NMMB-AQ architecture

2. Model Configuration

In the physical/chemical component, the main operations are done vertically, such as the processes of vertical mixing, convection, and radiation. Most chemical-related processes (scavenging, deposition and reactions) can be suitably fitted into this architecture. The physical/chemical component is relatively portable, and can be attached to other dynamic cores. The dynamics component is the main gridded component whose grid uniquely depends on a particular dynamical core. The AQ model can be driven by any of these dynamics cores as long as they provide suitable advection for arbitrary tracers. In each of these dynamical cores, the AQ model is inline on the native grid. This architecture provides strong coupling flexibility for the AQ model to use various advection schemes without worrying too much about dynamics related issues. The AQ model can focus on its main task of describing chemical processes, which is relatively grid independent. Although currently we include physics and chemical processes in one component, they can be in separate components in the future. In that way, the chemical processes will become more independent from the given meteorological model. Instead, it can be easily attached to any of the meteorological models.

In the current stage, we focus on developing the AQ model based on the NMM-B dynamics/physical core, which is the main regional core developed in NOAA/NCEP but which can also run globally. The NMM-B will become the next-generation NCEP mesoscale model for operational national weather forecasting.

3. NMM-B Dynamics and Mass Conservation Issue

The NMM-B is developed from the WRF-NMM model with improved dynamics. The old Lagrangian WRF-NMM tracer advection scheme does not strictly conserve mass partly due to the specification of open inflow boundary conditions, which limits its usage in the air quality model. Most mesoscale meteorological predictions can use observation-analyzed fields or global model results as initial conditions, so they are not very sensitive to slowly accumulated mass inconsistencies as re-initialization can remove the accumulation. However, air quality models are usually very sensitive to mass inconsistencies since their prediction usually sets previously spun-up fields as initial conditions, and the errors due to mass inconsistencies can be accumulated. In order to satisfy the requirements of the AQ model, NMM-B improved the WRF-NMM's tracer advection. The improved scheme is Eulerian, positive definite, mass conservative and monotonic. The NMM-B is defined on the Arakawa B grid in contrast to the WRF-NMM's E-grid. Both of them use the same sigma-P hybrid vertical coordinate, and rotated latitude-longitude map projection for regional modeling. NMM-B can be also run globally using regular latitude-longitude projection. The NMM-B dynamics advects square roots of tracers using a modified Adams-Bashforth scheme for horizontal direction and the Crank-Nicholson scheme for vertical direction, and uses quadratic conservation to provide tracer mass conservation. Monotonization is applied *a posteriori* to eliminate new extrema.

Figure 2 shows the mass conservation testing results from WRF-NMM, WRF-ARW, and NMM-B. In this test, a cuboid-shaped air mass of a passive tracer is put into the center of the domain, while this tracer's values over all other grid points and boundaries are set to zero.

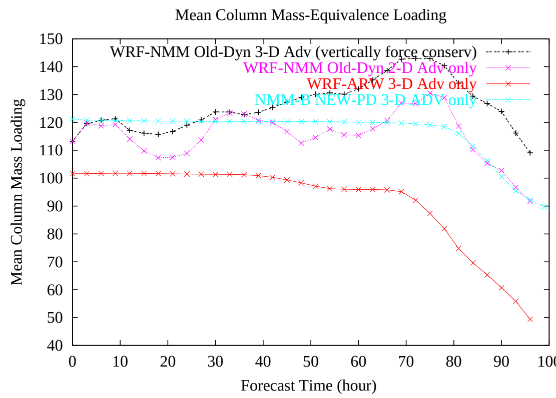

Figure 2, mass-conservation testing results over continental US domains

In this test, we turned off all processes other than the advection. If the advection scheme is strictly mass conservative, the column mass loading should be the same until the air mass reaches the boundary of the domain. The WRF-NMM and NMM-B have similar domains: 0.08°×0.076° horizontal resolution with 614×401 grid cells for the E grid and B grid in the rotated latitude-longitude projection. The WRF-ARW run uses a slightly smaller domain: 418×283 grid cells with 12km horizontal resolution over the continental USA, and the domain is a Lambert conformal projection. All the runs have 22 vertical layers up to 100hPa at the domain top, and all of them were initialized at 0000UTC, July 20, 2006. The results in Figure 2 show that the old WRF-NMM's advection can increase mass by up to 26% in 72 hours, while the WRF-ARW (red line) and NMM-B (blue line) schemes conserve mass very well. From a mass conservation perspective, the NMM-B satisfies the AQ model requirement.

4. A Tracer Test Case

To further test the quality of transport prediction in NMMB-AQ, we tried a tracer transport case driven by a damping volcanic eruption. In this test case, St. Helens volcano is assumed to erupt at 0000UTC, May 18,

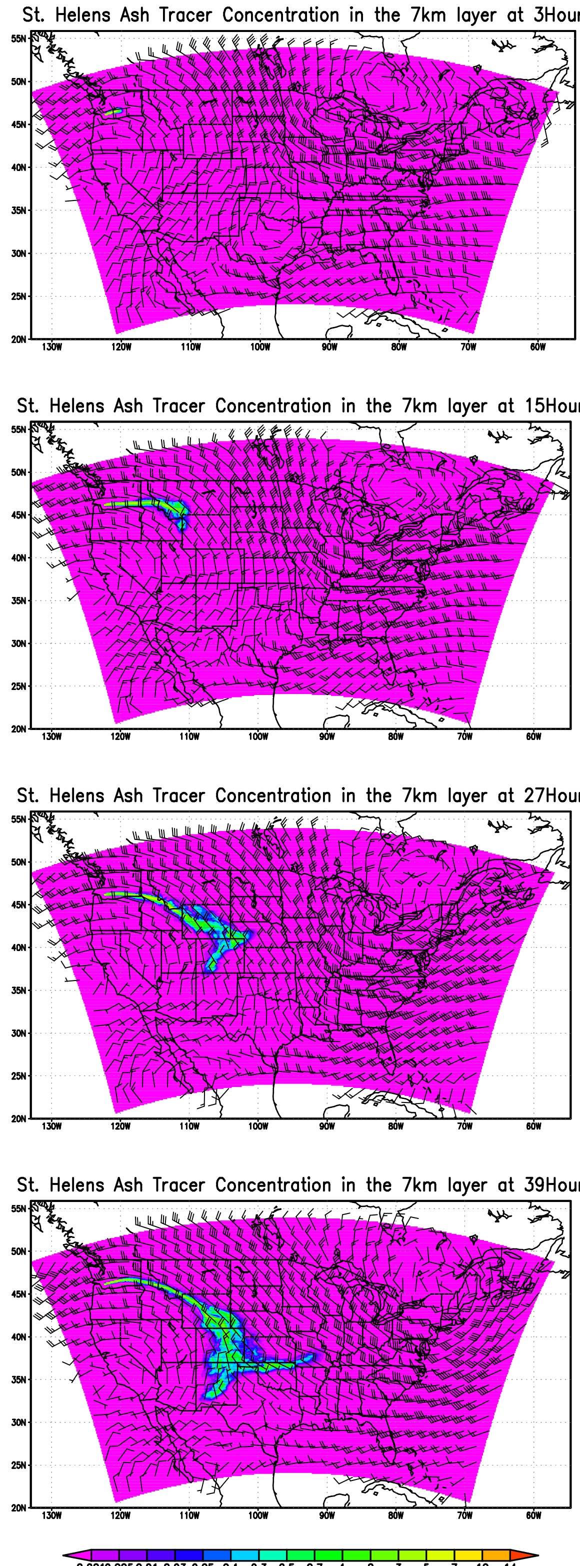

Figure 3, St. Helens volcano ash transport simulated by NMM-B

2008 and volcanic ash is injected into 5 to 8km layers. During the forecast period the volcanic emission is assumed to remain constant. Only emission, advection and PBL vertical diffusion (MYJ scheme) are considered. The tracer case is driven by GFS initial and boundary conditions, pre-processed by modified WPS for NMM-B.

Figure 3 shows the transport pattern of St. Helens volcanic ash starting from its initial eruption. In this event, there is a low-pressure system north of the Great Lakes region. The volcanic ash transport is mainly driven by northwest wind extending from Washington, Idaho, Montana, Wyoming to Colorado. After reaching Colorado, the airflow splits into southwestward and eastward branches. The ash plume simulated by NMMB-AQ agrees well with the observed airflow. The last plot of Figure 3 shows that the NMM-B advection scheme has very little horizontal diffusion before reaching Colorado. The NMM-B advection scheme shows high-order precision and good shape reservation.

5. Summary and development plan

In this study, we report the progress on developing and testing the NMMB-AQ model. The NMM-B dynamic core has been tested for the application on air quality modeling, and shows significant improvement over WRF-NMM's dynamics. Right now we are still working on the infrastructure testing, such as ESMF communication and coupling between chemical and physical processes. Our preliminary result shows that NMMB-AQ can yield a reasonable transport pattern. The model coding, testing and debugging are underway.

We plan to adopt an existing mature chemical mechanism for NMMB-AQ, such as CMAQ's CB05 mechanism and thus the EPA standard emission inventory for CB05 can be used directly in our prediction with minor changes (mainly map projection). It should be noted that other than NMMB-AQ, other inline chemical modules, such as GFS-GOCART dust module, are also being developed using ESMF. In the future, all these modules should be able to communicate with one another using an ESMF framework. The inline coupling among the AQ model, the meteorological model, and the sea/ice/land model should yield a comprehensive earth environmental model.

Acknowledgement

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