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Geoscientific Model Development Discussions

Interactive comment on "Implementation of a new aerosol HAM model within the Weather Research and Forecasting (WRF) modeling system" *by* R. Mashayekhi et al.

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General comments:

- *Why do the authors believe that their development is a significant scientific contribution? Which are the main benefits of using the HAM model instead of the ones already implemented within WRF-Chem? A more detailed discussion concerning the main scientific problem that the authors want to address in the manuscript is needed. There is no clear definition of objectives in the work.*

One of the main purposes of this study is implementing and testing the aerosol model HAM within a new regional weather prediction framework. The aerosol HAM model simulations were reasonable, when coupled with the ECHAM5 general circulation model. This study mostly aimed to investigate the performance of the HAM model within the Weather, Research and Forecasting WRF modeling system. WRF model provides a good test bed for testing new aerosol modules. There are currently two different aerosol schemes existing in the chemistry version of WRF model. Having in mind that models are simplifications of the very complex natural system and that different models simulate the real world differently, incorporation of different aerosol models in WRF can provide us with a better understanding of the uncertainties involved with the simulations. Furthermore, HAM is a simpler model compared to the two models already coupled with WRF. Many in the modeling community agree that 'complexity necessarily does not mean accuracy'. The new implementation paves the road for intercomparing WRF simulations based on three different view points regarding the parameterization of the aerosols, and finding out the similarities/differences among them. This will help us to gain an improved understanding of the physical/chemical processes.

- *Extending the description of the different processes implemented in the model.*

We agree with the reviewer that the description of some processes in the manuscript was not clear enough and needed more clarifications. We, therefore, have expanded descriptions of the wet deposition, sedimentation and the aerosol-radiation interactions in the revised manuscript by adding the following text:

Sedimentation and dry deposition (Sect. 2.3.1)
The gravitational settling (sedimentation) velocity, v_G is calculated us-

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ing the following formulation:

$$v_G = [\frac{g}{18\nu}(\frac{\rho_p}{\rho_{air}})D^2]C_c$$

where g is the gravitational acceleration, ν is the kinetic viscosity of air, ρ_p is the density of particles, ρ_{air} is the density of air, D is the particle diameter and C_c is the linearized slip correction which is given by:

$$C_c = 1.0 + 1.246(\frac{2\lambda}{D})$$

λ is the mean free path of air molecules.

Wet deposition (Sect. 2.3.2)
For the in-cloud scavenging within convective clouds, the local rate of change of aerosol mass concentration for each mode is calculated as:

$$\frac{\Delta C_i}{\Delta t} = \frac{R_i C_i}{LWC}(\frac{dp}{dt})$$

where C_i and R_i are the mixing ratio of the tracer and the scavenging parameter for mode i, respectively. LWC is the liquid water content and P is the precipitation rate.

Aerosol-radiation interactions (Sect. 2.4)
The aerosol optical properties are determined using the method outlined in Fast et al. (2006). In brief, the modal mass is first divided into 8 discrete size bins. The refractive index for each size bin is computed using the volume averaging which assumes internal-mixing of aerosol

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composition. The Mie theory is then used to calculate the extinction coefficient, single scattering albedo and the asymmetry factor for scattering as a function of wavelength. A Chebyshev economization (Fast et al., 2006; Ghan et al., 2001) is employed to save CPU so that full Mie computations are called only once and then expansion coefficients are used for subsequent times. The effect of aerosols on incoming solar radiation at the surface is determined by transferring the aerosol radiative parameters to the Goddard short wave radiation scheme (Chou et al., 1998). The aerosol optical properties in WRF-Chem are calculated only at four wavelengths, 0.3, 0.4, 0.6, and 1.0μm; however, the Goddard shortwave radiation scheme consists of a total 11 bands. Therefore, it is necessary to interpolate/extrapolate the aerosol properties from the four computed wavelengths to the wavelengths of the band centers. For aerosol extinction, this is done using the Angstrom relationship, while linear interpolation is used for single scattering albedo and asymmetry factor.

- *Which is the approximation used by the authors to treat the in-cloud and below-cloud scavenging?*

The below-cloud scavenging of aerosol particles has not been taken into account in the present study. We only consider the scavenging of aerosol species by the in-cloud precipitation for cumulus convective clouds. As presented above, this is done by using a simplified wet deposition scheme. The local rate of change of each tracer is calculated proportional to the precipitation formation rate. This method is a part of the simple wet scavenging approach that HAM is using in the ECHAM5 climate model. As mentioned in the manuscript, a size and composition-dependent scavenging parameter is prescribed for each of the seven different modes of aerosol particles. This parameter is defined as the fraction of the tracer in the cloudy part of a grid box that is embedded in the cloud liquid/ice water. A more detailed description of the in-cloud scavenging is now added to the wet deposition section of the revised paper.

- *Does the radiative interaction only occur in the shortwave radiation or it considers also the interactions with longwave lengths?*

Since the aerosol radiative effects are primarily over shortwave length spectrum (solar radiation) and for simplicity, we have only considered the interactions of aerosols with shortwave radiation at this stage. The direct aerosol radiative forcing at the surface is calculated by transferring the aerosol radiative properties to the Goddard short wave radiation scheme in WRF. More description of the aerosol-radiation interaction is presented in the revised paper.

- *Why is the microphysics scheme turned off while the convective parameterization is activated? A clear discussion about the configuration is required.*

The microphysics option was actually on in our simulations since we needed the precipitation formation rate for calculating the wet scavenging of particle. The Lin et al. (1983) scheme is used for the parameterization of cloud microphysics. The phrase "turned off" for microphysics in the configuration list (Table 3) was written just by

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our mistake and is corrected to "Lin et al. scheme" in the revised paper.

- *The top of the model should be specified.*

The top of the model is explicitly specified in the manuscript. As mentioned in the present manuscript, the model domain extends 31 levels in vertical, from surface to 50hPa (16km above the mean sea level), with finer resolution near the surface.

- *A clear explanation of the initial conditions of the aerosols should be included.*

In the manuscript, all aerosol species considered in our study were initialized to the horizontally and vertically homogeneous value equal to zero. It seemed not to be a reasonable assumption to initialize the model with such a clean atmosphere. Thus, we have improved the chemical initial conditions in the model by using the final results of our previous model simulation for initialization of chemical species and aerosol particles in the revised paper. Therefore, we first performed two different 6-day simulations with initially clean atmosphere (one initialized at 00 UTC 16 February 2006 and the second at 00 UTC 1 May 2006). The simulation results for the last day in both previous simulations are then used to initialize the chemistry. The simulations with these new chemistry initial conditions have been included in the revised paper.

- *What are the main implications of using emissions of 2000 for a 2006 simulation?*

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We are well aware of the fact that using the aerosol emission inventory in year 2000 for simulations in 2006 is not accurate. Moreover, there is additional uncertainty introduced by the use of a constant rate for emission of all aerosol species in this present manuscript. The uncertainty introduced by using the constant monthly mean value for emission rates can be even greater than that introduced by using the monthly mean values of year 2000 for 2006 simulations. Unfortunately, the domain of interest in our simulations consists of regions with very limited aerosol information. No data set is available for the emission rate of aerosol particles over the whole domain of our simulations, except for the prescribed AEROCOM emission inventory in year 2000. Although, we agree that using the more accurate emission rate for the aerosol particles can improve the model results, we believe that simulations using this constant emission rate in the coupled system are reasonably in good agreement with the measurements.

- *Mineral dust emissions are very sensitive to the meteorological conditions in the source regions; does it have sense to model a dust event with prescribed emissions of 2000 at a constant rate?*

No online calculations have been currently made for the mineral dust particles in this study. In the absence of any reliable observational data and for simplicity, the emission of all aerosol species including wind-induced mineral dust particles has been considered as a constant flux, although, we are well aware of the fact that the mineral dust emission rates are very sensitive to meteorological conditions,

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land use conditions and surface moisture. Calculating an online mineral dust emission rate is among the aims of the authors for the future and we are currently planning to add a dynamic dust emission model to the WRF-HAM modeling system. Although, we agree that the online calculation of the emission of wind-induced mineral dust should be considered in our simulations, the model results using these constant emission rates are in reasonably good agreement with the measurements. It was shown by simulations in both periods that the model could well capture the diurnal cycle and magnitude of the observed PM10 mass concentrations (Figure 4) except for some fine characteristic features resulted from using a prescribed emission rate for dust aerosols. The authors of manuscript believe that in spite of the simplifications in emission fluxes, the model performance is reasonably good at least for some polluted city such as Tehran with a few studies in aerosol modelling.

- *Discuss the author's results with the previous results.*

We have included the discussion of model results with some previous studies in the revised paper. The previous works have been reviewed in the introduction section of the revised paper and compared with our model results in discussion section. We have significantly expanded the results and discussion section, in particular including the following text:
Sokolik and Toon (1996) used a simple box model to estimate the shortwave radiative forcing. They pointed out that on the regional scale, the forcing due to mineral dust aerosols can greatly exceed that due to other type of aerosols. The simulated shortwave radiative

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forcing using the coupled WRF-HAM model in our study shows also the dominant contribution of mineral dust over most parts of the simulation domain. In agreement with the findings of Sokolik and Toon (1996), Woodward (2002) and Myhre et al. (2003) we found a negative radiative forcing averaged over both two 6-day periods in our study. The sign of our simulated shortwave radiative forcing seems not to be in agreement with the results of Tegen and Lacis (1996) in which the calculated global radiative forcing is positive using a chemical transport model.

Specific comments:

We will include more specific values and specific phrases in the revised manuscript according to many of the comments by the referee. Here we reply to the referee's comments that need more explanation.

Title: As mentioned in the main scientific subject of the manuscript, this paper is testing the implementation of the aerosol HAM model within a new regional WRF framework. Although, a great part of this manuscript is about the radiation impacts of aerosol, this study is mostly aiming at the performance of aerosol HAM model within WRF. Therefore, we do not agree with the reviewer on changing the title. We believe that the title of the manuscript is well reflecting the main scientific subject of this study.

Abstract: However, according to the reviewer's concern it seemed that the present results do not represent a significant advance in the field study; this manuscript presents the preliminary results of implementation of a new aerosol HAM model within WRF model. This is exactly the main scientific subject of this

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study. We believe that HAM model simulations are reasonable when it is coupled with the weather prediction WRF model.

Introduction: The introduction in the revised paper now includes a more detailed discussion concerning the main objective of this study.

Model description:

- *Why do the authors only treat five primary global aerosols?*

  We only considered the treatment of five primary aerosols, since this study aimed to implement the aerosol HAM model within a new test-bed and HAM treats currently only these five primary aerosols. These aerosols are the most important particles in both global and regional scales. On the other hand, as discussed in the results section, for this simulation domain the mineral dust plays the most important role in radiative forcing. Although, extending the aerosols to other organic and inorganic species may improve the results, simulations using these five primary aerosols agreed reasonably with the measurements.

- *Is there any coupling between RADM2 chemistry mechanism and the HAM module?*

  The RADM2 chemical mechanism has been coupled with the HAM model through the gaseous sulfate variable. The gas-phase sulfate produced in RADM2 model is passed to the aerosol microphysics

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module M7 and allows to nucleate or condense on pre-existing particles.

- *Are the aerosols treated as inertial substances?*

  Grid scale transport of all aerosol species is done by the advection scheme in WRF model. The horizontal velocity of aerosol particles is taken the same as the wind velocity in WRF model. It means that they are all treated as non-inertial substances and assume to transport horizontally by the wind velocity components.

- *Is there any heterogeneous chemistry of sulfate and sulfur dioxide?*

  The heterogeneous (cloud-phase) chemistry for aerosol species is not considered in the current version of this coupled system.

- *Provide a clear description about the aerosol-radiation interactions; does the model only consider the shortwave interactions? How are the cloud and aerosol layers treated in the radiative model?*

  These all discussed in more details in the general comments section.

Model configuration:*why is the microphysics of the model turned off? Provide the top of the model. The approach used to initialize the aerosols is not clear.*

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These all are answered in the general comments above.

Emissions: *The emission section should be extended in order to describe in more detail the emission schemes applied in the simulations and their implications in the final results.*

As discussed in more detail in general comments section, we used a constant emission flux, equal to the monthly mean emission values, for each aerosol species. No emission schemes have been currently applied for the emission rates of particle in our study and it would be one of our main aims for the future works.

Results and Discussion: *compare the results with the scientific literature.*

It has already discussed in general comments.

Conclusion: *there are no concluding remarks and discussions of the work and its implications at a scientific level.*

According to the main scientific subject of this study, the simulations with HAM aerosol module coupled with WRF model agreed reasonably with the available measurements in the domain of study. The results showed that in spite of the simplicity of the HAM model comparing with two other aerosol schemes in WRF, its performance is reasonable. The results can also improved by using an online dynamic emission calculation for mineral dust particles. We have extended the conclusion section in the revised paper regarding to the concluding remark of the study.

Figures 1 and 2: The horizontal and vertical discontinuities in temperature and short wave radiation difference plots (Figures 1c,1d and 2c,2d in the manuscript) was due a bug in our coupled system. We checked the model runs again and solved the problem. The correct figures are replotted in the revised paper. We also use a bigger font for the labels of our figures.

Figure 1 caption: It is done in the revised paper.

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