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Geoscientific Model Development Discussions

Interactive comment on "Inclusion of Ash and SO_2 emissions from volcanic eruptions in WRF-CHEM: development and some applications" *by* M. Stuefer et al.

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A comparison between online and offline models was requested. Our main intention is to show a possible implementation of volcanic eruptions within the WRF-Chem model. Model inter-comparison studies will follow based on this work. We refer to the work from Grell and Baklanov (2011) for a discussion of the various differences between online and offline models. However we included some description and arguments in favor of the online modeling approach within the introduction paragraph: 'Grell and Baklanov, (2011) emphasize the differences between offline and online approaches for both air quality and numerical weather prediction. In general operational prediction centers use

de-coupled offline models due to the low computational cost. However, with the fast increase in computing power, integrated modeling systems become more and more popular. Online models account for inclusion of two-way interactions of physical and chemical atmospheric processes. The weather is the main factor for air quality, and on the other hand, chemical species may influence weather due to radiative effects or changes in cloud microphysics. These effects are most pronounced for high aerosol concentrations during the extreme events of volcanic eruptions or large wildfire emissions into the atmosphere. Grell et al (2011) demonstrated that aerosol feedback processes calculated within the online modeling approach induced considerable improved meteorological fields during the extreme 2004-wildfire season in Alaska. During such intense aerosol events it is easy to show that online models represent the atmosphere more realistically. Errors in air quality prediction introduced by the offline approach can be quite substantial especially as the model resolution is increased (Grell and Baklanov 2011). The online approach using models such as the Weather Research and Forecasting (WRF) with Chemistry (WRF-Chem, Grell et al. 2005) accounts for a numerical consistent air quality forecast; no interpolation in time or space is required.'

The reviewer indicates the possibility to use volcanic plume dynamics coupled to the surrounding atmosphere (the Pinatubo example). While a focus of our ongoing work deals with different options to include different volcanic eruption models in WRF-Chem, this initial development uses a fairly simplified geometric volcanic plume model, -the umbrella cloud with volcanic ash mass assumptions based on the work of Mastin et al (2009). We show that our model can be used to predict ash and SO2 emissions for past eruptions and as well for near real-time eruptions when there is little known about individual eruption dynamics. Therefore we used the simplified umbrella shaped plume, which does not account for rapidly expanding umbrella clouds pushing a very long way upwind from the volcano.

WRF's governing equations are Newton's laws, conservation of mass, and the first law of thermodynamics. WRF and WRF-Chem conserve momentum, mass and energy.

The total sources of volcanic ash equal in amount the total sinks of ash. We represent the volcanic ash with WRF-Chem as masses (concentrations), and do not associate thermodynamic characteristics. Thus buoyant thermals due to settling ash are not parameterized within the model; these thermals would also most likely need to be considered at a fairly small scale (meters to a few hundreds of meters). Depending on the studied phenomena (ash deposition versus long range ash dispersion), our typically used WRF-Chem horizontal resolution is a few to several tens of kilometers (1 – 50 km).

The reviewer asks for the purpose of this effort. We added within the introduction the following sentences: 'We use WRF-Chem for studies of past volcanic eruptions to better understand volcanic emissions and their transport within the atmosphere. The modeled feedback between volcanic emissions is suitable for climate impact studies and for detailed studies of the dispersion and the weather following an eruption event. In the following, we describe the implementation of generalized volcanic source parameters within WRF-Chem indicating an opportunity to use the modeling system for near-real time eruptions at times when the user might know a location and maybe the height of a volcanic plume, but otherwise there is little information available about the characteristics of a certain eruption.'

Specific comments: We are aware of the effects of particle aggregation, but aggregation of ash has not been parameterized in WRF-Chem so far. We state in the conclusions: 'Studies with different volcanic ash source models are in progress to test the sensitivity of the various eruption source parameters. Obviously the initial ash particle size distribution and the associated mass are critical for the downwind ash concentrations. So far there are no aggregation effects of volcanic ash particles included in WRF-Chem, although Sparks et al (1997) state that most of the fine ash typically aggregates. We currently most likely overestimate concentrations of fine ash afar from the erupting volcano without considering the effects of aggregation. Future work is needed and online models such as WRF-Chem will facilitate the implementation of pa-

rameterization schemes for aggregation of ash particles as described by Costa et al (2010).' Section 3 has been changed to explain in more detail the (3) different options used to include ash particles either as invariant tracer or within the PM variables to account for detailed feedback processes (also in response to reviewer 1). GOCART and MOSAIC are modules, which parameterize aerosols and allow the prediction of a number of different feedback processes between the aerosol and the environment (atmosphere). There are fairly complex parameterization schemes implemented within those modules, and a detailed description would increase the size of the manuscript substantially. We therefore think that a reference to the dedicated publications is preferable, especially since those modules are listed as options, which will be mainly used for climate impact studies of volcanic emissions.?

We insert more information concerning the 'more complex chemistry options' mentioned on page 2579, lines 7-9 (also see technical comments below). We added necessary information concerning the model specifics and eruption source parameters used for the applications. The annotation of figure 4 has been changed to explain the contour lines and dots in more detail. A more detailed explanation was added for the Redoubt 1989 eruption example. '

Section 4.2: We added a table and text to explain the used eruption source parameters in more detail. A comparison of the S1 and the S2 particle size distribution was added, and the figure 5 was changed accordingly. We use the 10-ash bin option for the demonstrated applications. The text was changed to show the different WRF-Chem options more clearly. We also added references in the text, and give a brief explanation of the vertically confined distal ash plume. We believe that the online WRF-Chem approach represents the vertical dynamics within the atmosphere better than offline models (i.e. the NAME model), which might be a reason for the better vertical structure of the plume. Corresponding text was added in the applications and the summary paragraphs.

Figure 4 was annotated in more detail to explain what is shown by the different lines

and dots. Our main intention is to give an explanation of the modeling development. More detailed model comparison studies will follow. Also the comparison between the model and observations (in-situ airborne observations and LIDAR observations) will be subject to further work. We did not update the figure 6 to compare the exact period shown by Ansmann et al. (2010) at this point.

Technical Comments: 1.Page 2573, l.3: we removed the sentence. We removed the word 'parameters' in line 16, which was changed to: 'Section 2 of this paper describes the source parameters that we use to determine volcanic emissions, as well as sulfur dioxide (SO2) from volcanic degassing processes.' Line 21: deleted 'Volcanic emissions as a major natural source of volcanic ash'. Line 23: the wording was changed to 'composed'.

2.Page 2574, l.10-11: The data generator package is the same as the volcanic emissions preprocessor as described in the following paragraph. For clarity we changed the wording to 'preprocessor'. Line 18 (ash emission fields) was changed to eruption source parameters.

3.Page 2575, l.11 changed to' Twenty-five percent of the erupted mass is linearly detrained from the umbrella base to the vent height.'

4.Page 2577, Line 25, what does the term "first and second indirect effects" mean?: Sentence and reference included: 'The WRF-Chem aerosol modules allow for quantification of the interaction between aerosol and precipitation, such as the first aerosol indirect effect (Twomey, 1977) referring to the modification of the cloud droplet number concentration by aerosols, or the second indirect effect, which was first proposed by Albrecht (1989), who showed that the suppression of precipitation by aerosols could increase cloud water content (or cloud liquid water path, LWP) and fractional cloud cover.'

5.Page 2578, l.6-7. We assume a spherical shape. 'For each bin, the aerodynamic radius, needed by the settling velocity calculation, is defined as half of the arithmetic

mean between the limits of the diameters of each bin size.' Line 14 was changed to: 'Many of the heavy ash particles fall out within less than 200km distance of the eruption'.

6.Page 2579, l.8-9, the more complex chemistry setups refer to the gas phase chemistry within WRF-Chem. We added a sentence:' Additionally, SO2 emissions are added to the gas-phase SO2 variable, if SO2 is available for the chosen chemistry option. The lifetime of SO2 is a few days depending on the atmospheric humidity and the amount of hydroxyl (OH) radicals. Typically most of the SO2 oxidizes in clouds, some SO2 reacts with OH radicals and is converted to sulfuric acid, H2SO4. The calculation of SO2 requires choosing a WRF-Chem gas-phase chemistry option (Grell et al, 2005). These much more complex chemistry setups come with a heavy computational burden'. Lines 13-14: There was a space missing between the WRF-Chem and the namelist. WRF and WRF-Chem runs are defined by specific namelists, thus we would prefer to leave the WRF-Chem namelist statement in this context: 'While the emissions preprocessor provides not only volcano location, but also total mass and injection height, the latter will most often be overwritten by the user in the WRF-Chem namelist'. Line 17: space has been added between 'Mastin' and 'et'.

7.Page 2580, l.7, 'simulation' entered, l.8 'that' changed to 'which', l.15 'interactions' changed to 'reactions', l.16 species was changed to 'grain-size bins'.

8.Page 2581, l.11-12, spaces were added.

9.Page 2584, l.9-10: the phrase concerning aggregation has been deleted, and we are very thankful for the references. We added a statement. The parameterization of aggregative effects within WRF-Chem is subject to future development work and to be implemented in future versions of the WRF-Chem model.

Please also note the supplement to this comment:
http://www.geosci-model-dev-discuss.net/5/C1018/2012/gmdd-5-C1018-2012-

supplement.pdf

Interactive comment on Geosci. Model Dev. Discuss., 5, 2571, 2012.