Atmos. Chem. Phys. Discuss., 10, C5524–C5529, 2010
www.atmos-chem-phys-discuss.net/10/C5524/2010/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Intercomparison of aerosol-cloud-precipitation interactions in stratiform orographic mixed-phase clouds" *by* A. Muhlbauer et al.

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Received and published: 20 July 2010

On behalf of all contributing authors I would like to express my gratitude to the reviewer for the very useful and constructive comments that clearly helped to improve our manuscript.
The purpose of our sensitivity studies with varying thermodynamic states is to investigate the effect of cloud base temperature on the aerosol-cloud-precipitation interaction problem as suggested by the reviewer. Our simulated clouds show a dominant warm-phase in one case and a dominant ice-phase in the other. These sensitivity studies are performed in two experiments (low mountain vs. high mountain experiments) to

investigate also the effect of the flow dynamics. However, for the sake of brevity, we restricted our presentation to two temperature sensitivities per experiment. It is important to stress that a dominance of the warm-phase does not necessarily imply that collision/coalescence as a microphysical process is dominant too as suggested in the simulations.
Below is our item-by-item response to the comments and suggestions made by the reviewer with a detailed description of how we addressed them. For convenience, the original comments of the reviewer are repeated in italic.

1. *Why is the resolution so course given that it is a simple 2D study.*

   The choice for 2 km grid spacing are manifold. First, some of the participating models have computationally expensive microphysical parameterizations (e.g., WRF with bin microphysics, UWNMS with ice habit prediction), which lead to substantial computational burdens even in 2D studies. Especially for the second case with flow blocking, the time step in the model needs to be small to ensure the numerical stability of the simulations. Second, the prescribed environmental conditions do not allow for embedded cellular convection, which would require higher grid resolutions. Third, the prescribed idealized topography is sufficiently smooth to be well resolved at 2 km. Forth, the choice of the 2 km grid spacing facilitates comparison with previous studies such as Muhlbauer and Lohmann (2008).
   However, to test the impact of the horizontal grid spacing, we also repeated some of the COSMO simulations with finer grid spacing, which slightly affected the precipitation distributions but did not affect our main conclusions.

2. *In COSMO is a binned approach used or is it a simple single-valued riming efficiency? Saleeby and Cotton(2007) showed that use of a single-valued bulk approach results in over-depletion of supercooled water amounts and thus loss in sensitivity of riming to CCN concentrations.*

The riming efficiencies in COSMO are parameterized according to Lew et al. (1986) and vary over a range of values depending on the size of the particles and the relative fall speeds. The exact equations for the riming efficiencies can be found in Muhlbauer and Lohmann (2009) and are referenced in our table 1.

3. *It is important to provide documentation of the differing fall speed equations or fall speed curves for each model as it might explain differences in snow and graupel accumulations rather than be speculated.*

   References for the different fall speed equations are cited in table 1. We agree with the reviewer that differences in the terminal fall velocities may explain discrepancies in the accumulated precipitation from snow and graupel but directly comparing the terminal fall velocities among the models can be misleading. The reason being that some models parameterize the fall speeds dependent on the microphysical process whereas others do not. E.g., some models calculate the fall velocity for ice crystals depending on the degree of riming whereas others strictly follow fall speed relations according to hydrometer category (as long as the hydrometer does not change category). Consequently, a direct comparison of the terminal fall speeds between the models would only be valid if the microphysical processes affecting the hydrometeors would be the same, which is not the case in our simulations.

4. *Some documentation of the size or number concentrations for each model when CCN is increased is needed to help understand the reversal in the riming process with different cloud regimes.*

   We fully agree with the reviewer. For the first case with small mountain, the cloud droplet number concentrations are shown in figure 4 (clean case) and 7 (polluted case) for each model. We added two more figures that illustrate the change in cloud droplet number concentration also for the second experiment with high mountain (figures 14 and 16).

5. *In the case of COSMO why do both riming and aggregation increase with increasing CCN in the warm case while both decrease in the cold case?*

   Since riming and aggregation can operate independently from each other it is not necessarily expected that effects on riming or aggregation compensate or show opposite tendencies. Similar behavior can also be seen in the UWNMS simulations (e.g., SIM_2) or the WRF simulations (e.g., SIM_3).

6. *It would be nice to include how each model predicts supersaturation with respect to ice and water as well as vapor deposition growth to help us understand the great disparities in the relative amounts of hydrometer mixing ratios.*

   Supersaturation with respect to ice and water is diagnosed in all models depending on temperature according to commonly used relations for the saturation water vapor pressure. For the temperature range under consideration, differences in the formulation and accuracy of the saturation water vapor pressure over supercooled liquid water and ice are negligible (Murphy and Koop , 2005). All models explicitly solve the diffusional growth equation. We added the following sentence to the model setup section 3.1 for clarification:

   "The diffusional growth on existing hydrometeors is calculated explicitly by solving the diffusional growth equation (Pruppacher and Klett , 1997)."

   Following the good suggestion of the reviewer, we expanded our microphysical comparisons and included the budgets for diffusional growth in figures 10, 12, 19 and 20. The diffusional growth terms include the contribution from vapor deposition, condensation, evaporation and sublimation. We also changed the caption of figure 10 accordingly. Further changes have been applied to section 4.1.3, 4.2 and 4.3.3 to discuss and intercompare the contributions from diffusional growth. For example, the changes in section 4.1.3 related to diffusional growth read:

"In UWNMS and WRF diffusional growth is by far the dominant microphysical process and all processes involving collections are smaller. Contrary, in COSMO the contributions from diffusional growth and riming are of comparable magnitude.“ ... ”In simulation Sim_1 all models agree on the result that the net diffusional growth decreases with increasing aerosol number concentrations due to enhanced evaporation of the smaller cloud droplets and rain drops.“

In section 4.2:

”Similar to the previous case diffusional growth is dominant in all models.“

In section 4.3.3:

”Similar to the case with small mountain and warmer temperature (SIM_1) all models concur that diffusional growth is the dominant microphysical process.“ ... ”In the simulations with increased aerosol number concentrations the net diffusional growth is decreased consistently in all models.“

7. *In the discussion of the CLASE field campaign it would be informative to tell us the typical values of kappa inferred from the measurements.*

   We do not have this particular information for the CLACE 3 field campaign. However, earlier studies by Weingartner et al. (2002) measured growth factors between roughly 1.4 and 1.5 at the Jungfraujoch site and suggested that most of the particles are internally mixed. In a recent paper, Kammermann et al. (2010) infer mean kappa values of approximately 0.24 for the Aitken and the accumulation mode with little inter-annual variability. This kappa value falls within the broad range of values typically found in continental air masses (Andreae and Rosenfeld , 2008).

References

Andreae, M. O., and Rosenfeld D.: Aerosol-cloud-precipitation interactions. Part 1. The nature and sources of cloud-active aerosols, Earth-Sci. Rev., 89, 13–41, 2008.

Kammermann, L., Gysel, M., Weingartner, E., and Baltensperger, U.: 13-month climatology of the aerosol hygroscopicity at the free tropospheric site Jungfraujoch (3580 m a.s.l.), Atmos. Chem. Phys. Discuss., 10, 13573–13608, 2010.

Lew, J. K., and Montague, D. C., and Pruppacher, H. R.: A wind tunnel investigation on the riming of snowflakes. Part I: Porous disks and large stellars, J. Atmos. Sci., 43, 2392–2409, 1986.

Muhlbauer, A., and Lohmann, U.: Sensitivity studies of the role of aerosols in warm-phase orographic precipitation in different dynamical flow regimes, J. Atmos. Sci., 65, 2522–2542, 2008.

Muhlbauer, A., and Lohmann, U.: Sensitivity studies of aerosol-cloud interactions in mixed-phase orographic precipitation, J. Atmos. Sci., 66, 2517–2538, 2009.

Murphy, D. M., and Koop, T.: Review of the vapour pressure of ice and supercooled water for atmospheric applications, Q. J. R. Meteorol. Soc., 131, 1539–1565, 2005.

Pruppacher, H. R., Klett, J. D.: Microphysics of Clouds and Precipitation, 2nd ed., Kluwer Academic Publishers, 954pp, 1997.

Weingartner, E. and Gysel, M. and Baltensperger, U.: Hygroscopicity of Aerosol Particles at Low Temperatures. 1. New Low-Temperature H-TDMA Instrument: Setup and First Applications, Environ. Sci. Technol., 36(1), 55-62, 2002.