THE ROLE OF AEROSOL PARTICLES ON PRECIPITATION AND ICE PHASE PROCESSES: NUMERICAL STUDIES WITH A HIGH RESOLVED 3D CLOUD MODEL USING DETAILED (BIN) MICROPHYSICS

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Abstract: A three-dimensional (3D) cloud model with detailed microphysics is used to study the role of aerosol particles (AP) on the ice phase processes and precipitation formation in mixed phase clouds. The model couples the dynamics of the NCAR *Clark-Hall cloud scale model* (Clark and Hall, 1991) with the detailed scavenging model (*DESCAM*) of Flossmann and Pruppacher (1988) and the ice phase module of Leroy et al. (2007). The microphysics follows the evolution of AP, drop, and ice crystal spectra each with 39 bins. Aerosol mass in drops and ice crystals is also predicted. The first simulated case is a deep convective cloud with a large anvil, sampled during the CRYSTAL-FACE campaign on July 2002 18th (Heymsfield et al., 2005). Our model (*DESCAM-3D*) is able to simulate the cloud in good agreement with the measurements in 10 km. Concerning the role of AP, the simulations clearly show that changes in AP concentration in the boundary layer affects significantly the dynamical evolution of the cloud and thus have an impact on the microphysical characteristics of the cloud even at high altitudes. The second case is a medium convective case over the Cévennes' foothills in fall 2004 (Chapon et al., 2007). Once again, *DESCAM-3D* simulates a realistic cloud field with radar reflectivities, rain accumulation and spectra in agreement with the radar and disdrometer observations. As precipitation formation proceeds via mixed phase processes, the impact of pollution in terms of AP number on both the warm and on the cold processes is studied.

Keywords: *3D cloud model, detailed microphysics, ice processes, aerosol particles impact, Cévennes Region*

1. INTRODUCTION

The microphysical properties are key parameters to understand the overall impact of anvils and cirrus clouds on radiative transfer. Ice crystals in natural cirrus clouds or contrails are formed on ice nuclei that are present at high altitudes. The origin of ice and cloud condensation nuclei in anvil, however, is less evident as deep convective clouds can extend from a few hundred meters above the ground up to the tropopause. Further investigations are thus needed to answer this specific question but they require both highly resolved microphysical models to treat precisely the aerosol particles and a three dimensional (3D) dynamical framework to simulate realistically deep convective clouds. Here, we investigate the impact of aerosol particle concentration in the boundary layer on the microphysics properties at high levels with a 3D cloud model with detailed microphysics called DESCAM 3D (Detailed Scavenging Model). As case study, we choose the 18 July 2002 CRYSTAL-FACE case which provides a large set of microphysical measurements inside a cumulonimbus cloud and its anvil (Heymsfield et al., 2005).

The impact of aerosol particle loading on precipitation formation is only partly understood. Several modelling studies (Reisin et al., 1996; Leroy et al., 2006) have highlighted the reduction of precipitation at the ground in convective clouds developing in polluted environments. Here, we focused on intense precipitation events that occur regularly in fall over the Cévennes-Vivarais region. Pinty et al. (2001) have shown that both the amount and the location of precipitation are sensitive to changes in the number of cloud condensation nuclei. Their study, however, is restricted to a warm precipitation events over the Cévennes' foothills. Here, we simulate with DESCAM-3D a mixed case for which ice processes are involved in precipitation formation and we thus study the impact of AP on both warm and cold rain processes.

Hereafter, this paper is divided into 5 parts. The model DESCAM 3D is briefly described in Section 2. The impact of mid-tropospheric aerosol particles (AP) versus boundary layers AP on the microphysical properties of the cloud at high levels is then presented in Section 3. The results with DESCAM 3D concerning the role of aerosol particles in precipitating events over the Cévennes' foothills are discussed in Section 4. And finally the conclusions will be presented in Section 5.

2. MODEL DESCRIPTION

The 3D model with detailed (bin) microphysics couples the 3D non-hydrostatic model of Clark and Hall (1991) with the Detailed Scavenging Model (DESCAM, Flossmann and Pruppacher., 1988, Leroy et al., 2007) for the microphysical package. To summarize briefly, the microphysical model employs five distribution functions: f_{AP}, f_d, f_i are number distributions functions respectively for the wet aerosol particles (AP), the drops and the ice crystals and $g_{AP,d}$ and $g_{AP,i}$ account for the mass distribution of aerosol particles inside drops and ice particles. The five functions cover 39 bins grids from 1 nm to 6 µm radius for the wet AP and from 1 µm to 6 mm radius for the liquid or solid hydrometeors. The detailed microphysics introduces 195 supplementary variables in addition to the initial code.

The microphysical processes that have been implemented are: AP growth and activation/deactivation, condensation and evaporation of droplets, coalescence, homogeneous and heterogeneous nucleation, vapour deposition on ice crystals and riming. Droplet nucleation relies on the calculation of the activation radius derived from Koehler equation, but is also dependent on temperature as described in Leroy et al. (2007). Growth rate of drops and ice crystals are given by Pruppacher and Klett (1997). Homogeneous and heterogeneous nucleation follows respectively Koop et al. (2000) and Meyers et al. (1992). Ice crystals are assumed to be spherical and the density of ice is set to 0.9 g m^{-3}.

3. CRYSTAL-FACE CUMULONIMBUS

3.1 Model Setup

The model domain covers 32 x 32 km in the horizontal and 15 km high in the vertical. The resolution is 250 m for both the horizontal and the vertical coordinates. The dynamical time step is 1 second. The thermodynamical conditions are given by the sounding from Miami airport, 15 UTC. To initialise convection, a thermal bubble is placed in the north east part of the model domain and is kept during the first ten minutes of integration.

To initialise the microphysics, vertical profiles of aerosol particle spectra are needed. In our simulations, aerosol particles spectra are almost identical to those used by Fridlind et al. (2004) in their cases called “clean” and “polluted”. Aerosol particles spectra follow log-normal distributions and the total number of aerosol particles in the boundary layer is 400 cm^{-3} in the clean case and 6500 cm^{-3} in the polluted one.

3.2 Results

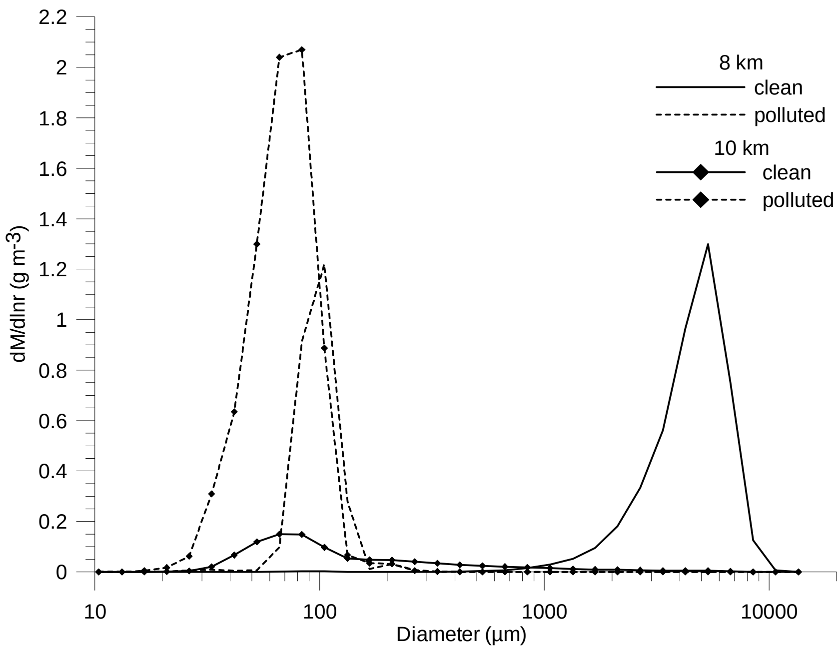

Figure 1 : Mean ice particle mass spectra at 8 and 10 km height after 38 min of integration for both the clean and the polluted case.

Ice crystals spectra at 8 and 10 km are shown in Fig. 1. In the polluted case, the size of the ice crystals never exceeds 300 µm in diameter at 8 as well as at 10 km height. In the clean case, there are very few ice crystals with diameters above 300 µm at 10km whereas at 8 km, the ice spectrum covers now diameters from 1 mm to 1 cm. The size and number of ice crystals are thus very different between the two cases. Therefore, we can conclude that changes in the aerosol particles concentration in the boundary layers influences significantly the ice crystal spectra at high altitudes.

Detailed investigation on the impact of AP in the boundary layer shows in fact that the dynamic of the cloud is largely changed when the cloud develops in a polluted instead of a clean airmass. In the clean cloud, raindrops form early in cloud evolution and fall down through cloud updraft. In a polluted environment, a large number of cloud droplets form and delay rain formation. The main updraft core contains mainly small cloud drops. Thus, the polluted cloud develops faster and reaches higher levels than the clean one. Those results are in agreements with the findings of Khain et al. (2005). As AP in the boundary layer influence the dynamics, the clean and polluted clouds evolve differently and finally the AP loading of the boundary layer can significantly influence the microphysics at high levels (see Fig. 1).

4. INTENSE PRECIPITATION OVER THE CEVENNES-VIVARAIS REGION

4.1 Model Setup

In the second case study, the model domain is 128 x 128 km^2 horizontally with a resolution of 1 km. The vertical grid is the same as for CRYSTAL-FACE simulations. The time step is 4 s. The dynamical model is initialised with the sounding from Nîmes, 23 UTC, October 2004 27th. Aerosol spectra follow Jaenicke (1988) for a continental airmass. Aerosol number starts from roughly 700 cm^{-3} near the ground, then decreases exponentially until 3 km height and remains afterwards constant. In order to simulate a more polluted environment, the number of aerosol particles is increased by a factor of 3.

4.2 Results

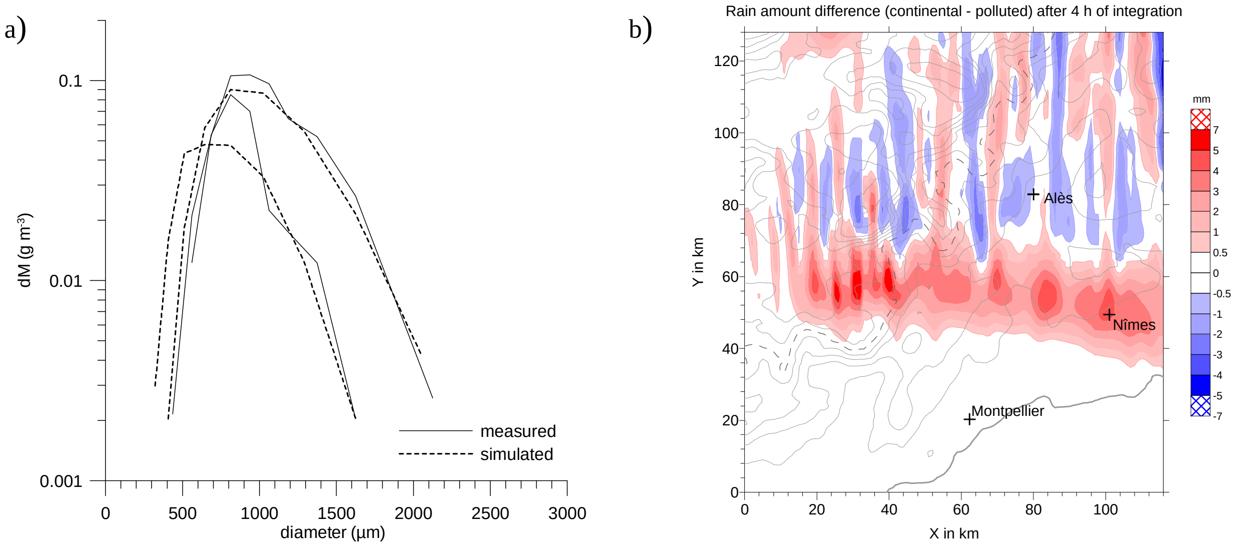

Figure 2 : a) Observed and simulated raindrop spectra. b) Difference in rain amount at the ground between the continental and the polluted cases after 4 h of integration.

During fall 2004, disdrometer measurements were performed in Alès (Chapon et al, 2007). Fig 2a compares observed and simulated raindrop spectra and clearly shows that the model results are in good agreement with the disdrometer measurements.

Fig. 2b represents the difference in the rain amount at the ground between the continental and the polluted cases. Over the Cévennes' foothills, the rain amount is sometimes larger in the continental case (red regions) and sometimes lower (blue regions) than in the polluted run. This is the result of small differences in the precise location of the maxima values in the rain accumulation between the two cases, as already pointed out by Pinty et al. (2001). The impact of the number of aerosol particles is more obvious upwind of the mountainous area. Along the line Y=60 km, the rain accumulation at the ground is always larger in the continental than in the polluted case. The maximum rain accumulation of the entire domain is also reduced from 20 mm to 17 mm when the polluted aerosol spectrum is considered.

5. CONCLUSIONS

Using our 3D cloud model with detailed cloud microphysics DESCAM-3D, we studied the impact of the aerosol particle concentration on the evolution of deep convective clouds sampled during CRYSTAL-FACE and on an intense precipitation event over the Cévennes' foothills during fall 2004. The analysis of the results shows that in the case of the cumulonimbus, the polluted cloud develops more rapidly and extends to higher levels than the clean one. Aerosol particles concentration in the boundary layer directly influences the microphysical properties next to the cloud base. Then, those differences in the microphysical characteristics can propagate to higher levels and finally, the ice crystal spectra at high levels are quite different. The largest ice crystals are found in the clean case. Thus our results support the idea that aerosol particles from the boundary layers have an impact on the microphysical properties of convective clouds even at high level and thus, on the radiative balance of such clouds and their anvils. Concerning the case of medium convection over the Cévennes region, a polluted aerosol spectrum is found to reduce the precipitation amount at the ground especially upwind of the mountains. Over the foothills, the maxima in the rain accumulation are not located at the same place in both cases. In general, aerosol particles concentration in the boundary layer is thus an important parameter in cloud simulations as it influences deep convective as well as mean convective cloud developments by modifiying both the dynamics and the microphysics even at higher altitudes.

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