JP3.4 **A REVIEW OF OUR UNDERSTANDING OF THE AEROSOL—CLOUD INTERACTION FROM THE PERSPECTIVE OF A BIN RESOLVED CLOUD SCALE MODELLING**

Andrea I. Flossmann and W. Wobrock
Clermont University, Aubière, France

ABSTRACT

The results of parcel model studies seem to indicate that increasing particulate pollution and decreasing solubility suppresses rain formation. In individual and short time cloud simulations this behaviour was confirmed in our 3D model studies. However, taking into account entire cloud fields over longer periods of time yields the strong spatial and temporal variability of the results with isolated regions of inverse correlation of the effects. Even though in general the expected behaviour was found, after several hours of simulation, the integrated precipitation of the more polluted cases caught up. This suggests that a changing pollution will affect the spatial and temporal pattern of precipitation, but will probably not reduce the overall long term precipitation amount which might be entirely governed by the moisture state of the atmosphere.

1. INTRODUCTION

Still in the 1970s, the community of the cloud physicists was well separated from the community of the aerosol physicists. It was commonly understood that clouds were determined by the sounding and water vapour supply and that saturation was mostly maintained. Aerosol particles were mainly related to health problems.

However, even at that time the role of particles in cloud nucleation was known already for about a hundred years from scientists like Aitken and Wilson (for a review see Pruppacher and Klett, 1997). But first attempts of planned weather modification to make use of this knowledge were only started in the middle of the 50s. In particular the role of silver iodide on the formation of the ice phase was used for hail prevention (see Cotton and Pielke, 1992 for a review of cloud seeding).

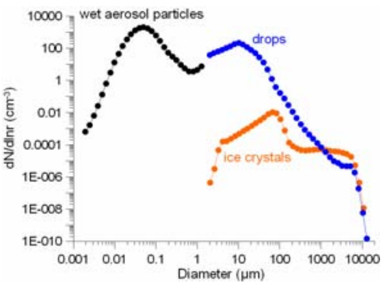
[a]Clermont Université, Université Blaise Pascal, Laboratoire de Météorologie Physique, F-63000 Clermont-Ferrand, France
[b]CNRS, INSU, UMR 6016, LaMP, F-63177 Aubière, France

In the 80s the first models were designed to put together the different pieces and obtain an overall picture of the importance of aerosol particle loading for the formation and evolution of the cloud. It became possible not only to study the role of the particles in the formation of a cloud, but also to study the cleaning capacity of the cloud in the overall pollution problem. A scientific review of the aerosol pollution impact on precipitation can be found in Levin and Cotton (2009). Also, the removal of accidental releases of particles by rain was an important issue (Cotton and Pielke, 1992).

In general, these studies seem to indicate that an increase of particulate pollution in the atmosphere suppresses precipitation formation. Often, these results were obtained by modelling exercises in an individual cloud using a simple dynamical framework. The following study aims to investigate the validity of the simple "air parcel" type assumption, in focussing on the particular role of supersaturation in a bin resolved microphysics model and a 3-D dynamics of an entire cloud.

2. THE MODEL

The 3D model with detailed (bin) microphysics used herein couples the 3D non-hydrostatic model of Clark and Hall (1991) with the Detailed Scavenging Model DESCAM (Leroy et al., 2009; Flossmann and Wobrock, 2010) for the microphysical package. It follows 5 density distribution function: the number distribution function for the aerosol particles $f_{AP}(m_{AP})$, for drops $f_d(m)$ and for the ice particles $f_i(m_i)$, as well as the mass density distribution function for aerosol particles in the drops $g_{AP,d}(m)$and in the ice crystals $g_{AP,i}(m_i)$.



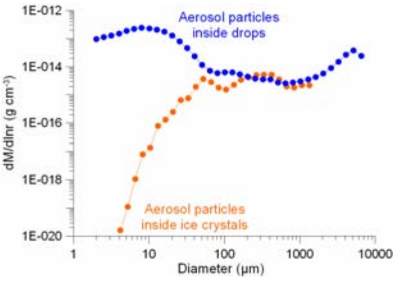


Fig.1: the grid resolution of the different distribution functions treated by DESCAM 3D.

The model considers as warm microphysical processes aerosol particle growth and activation, droplet de-activation, growth of drops by condensation and collision-coalescence. As cold microphysical processes homogeneous and heterogeneous nucleation, growth by vapor deposition, riming and melting are taken into account. A discussion of the different processes considered in the microphysics code can be found in Flossmann and Wobrock (2010), and the coupling with the 3-D code is discussed in Leroy et al (2009).

3. RESULTS

3.1 In-cloud dynamics of a single cloud

As was already shown in Leroy et al (2009), even the evolution of an individual cloud is far from being adiabatic.
The figures below show the Crystal-Face cloud simulated by them and indicate the complex dynamics, giving rise to rather different life histories of the individual "air parcels" making up the cloud

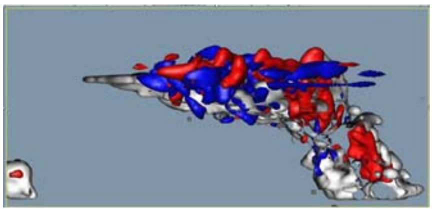


Fig. 2a. Simulation of a Crystal-Face convective cloud (situation after precipitation formation): Red: updrafts > 8 m s^{-1}; Blue: downdrafts > 8 m s^{-1}; Grey: cloud water > 0.03 g m^{-3}

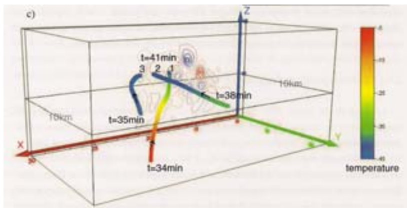


Fig.2b: Life history of 3 neighbouring points ending in the anvil at 11 km altitude

3.2 In-cloud dynamics of a cloud field

We note from Fig.2 the complex structure of an individual cloud. In an entire cloud field, as modelled by Planche et al (2010) for the COPS field campaign, the situation is equally complex, as shows the figure 3.
We note that in the complex cloud field about 85% of the parcels experience one, two, three, or more periods of subsaturation, while only 15% of the parcels stay always supersaturated after passing cloud base, as is suggesting the rising air parcel concept. 4 examples of parcels are displayed in Fig.3b.

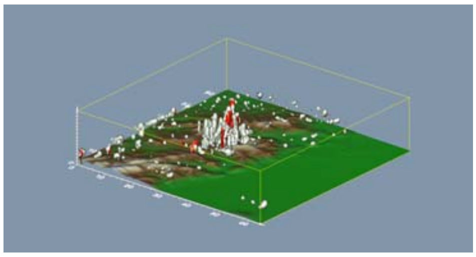


Fig. 3a. Cloud field over complex terrain white: cloud water, red: rain water

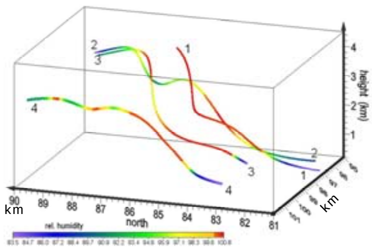


Fig. 3b. Red: supersaturated; blue: outside cloud; green: still in cloud

In figure 4, we have analyzed the distribution of the supersaturation in the grid points with liquid water contents exceeding 0.1 g m^{-3} in the white box of fig.4b.

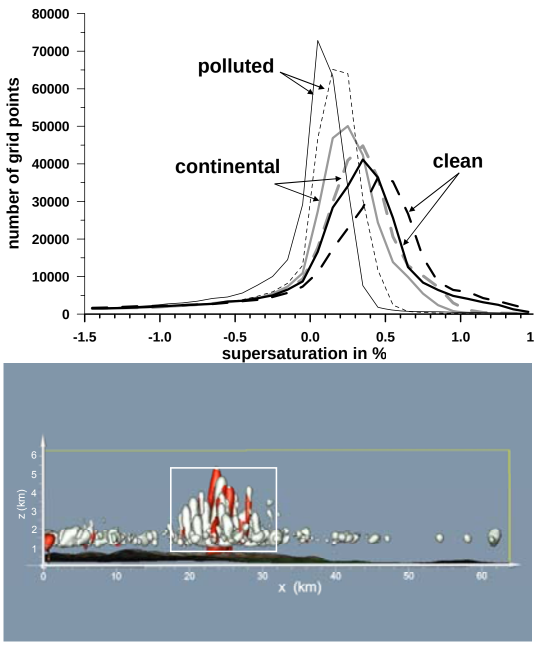


Fig. 4. Role of aerosol concentration and composition for supersaturation in the white box of the cloud field (solid line pertains to complete soluble particles; dashed curve to particles with 0.01% solubility (Planche et al, 2010).

We note from Fig.4a that the most probable supersaturation is a function of the total number of particles available and their composition: $S_{mean,min}$= 0.05% for polluted all soluble particles and $S_{mean,max}$=0.5% for clean mostly insoluble particles. The influence of the initial aerosol particle spectrum propagates to the precipitation on the ground.

3.3 Precipitation for a single cloud

Fig.5 indicates the sensitivity of a single cloud with respect to the initial pollution of the boundary layer.

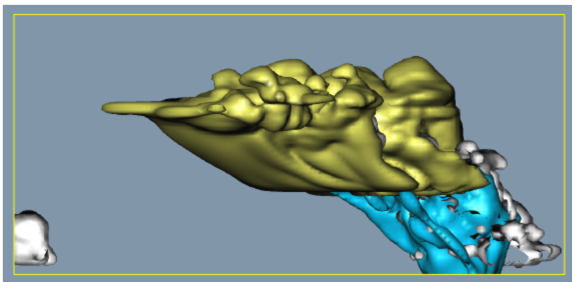


Fig. 5a. Clean boundary layer: N_{AP} ≈ 400 cm^{-3}; Cloud drops (grey): 0.01 g m^{-3}; Raindrops (blue): 1 g m^{-3}; Ice crystals (yellow) : 0.01 g m^{-3}

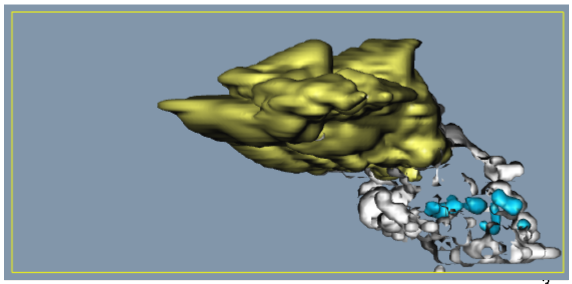


Fig. 5b. Polluted boundary layer: N_{AP} ≈ 6500 cm^{-3}; Cloud drops (grey): 0.01 g m^{-3}; Raindrops (blue): 0.03 g m^{-3}; Ice crystals (yellow) : 0.01 g m^{-3}

We note that a highly polluted boundary layer is able to suppress precipitation entirely in the model. However, this result applies to an individual cloud and for the lifetime of an individual cloud (Leroy et al, 2009).

3.4 Precipitation of a cloud field as a function of time

Fig.6 shows the result of a cloud field that remained stagnant over the Cevennes Mountains in the south of France. It depicts the difference of rain for a simulation initialized with a rather clean spectrum and one with a polluted one.
We note that not at all locations the cleaner case gives more precipitation (red colour), but that at some location the more polluted one rains more (blue colour).

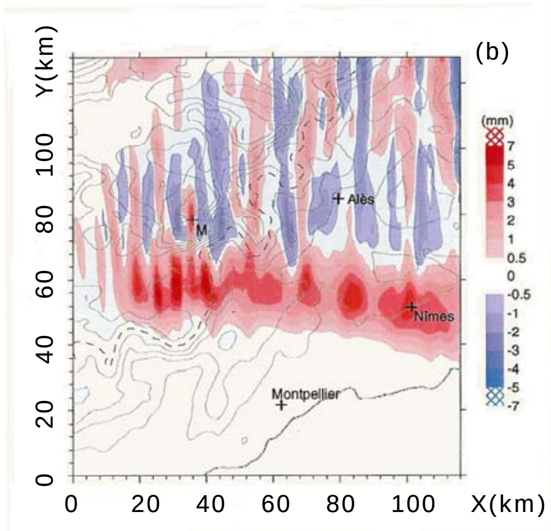


Fig. 6. Difference of precipitation between the continental particle spectrum and a polluted particle spectrum: Red: more rain for continental case; Blue: more rain for polluted case

Globally, if averaged over the entire domain, the text book results come out again, however, the difference between the two cases decreases with time (Table1):

Simulation time	Mixed phase continental case (700 cm^{-3})	Mixed phase polluted case (2400 cm^{-3})	Difference (mixed cont.-mixed poll.) in %
2h	7.1	5.7	-20
3h	30.9	26.4	-15
4h	62.3	54.3	-13

Table 1 evolution with time of the total integrated amount of rain for the different cases considered.

3.5 Precipitation of a cloud field as a function of particle number

For the COPS field campaign we have varied the number of particles in the boundary layer as already discussed in Fig. 4. The resulting pattern for the integrated amount of rain on the ground can be found in Fig.7. For these simulations the solubility was kept the same and ε=1.
We note that, globally, decreasing pollution increases the total amount of precipitation and the total watered surface. But locally, the tendency can be opposite. Table 2 summarizes the properties for the three cases:

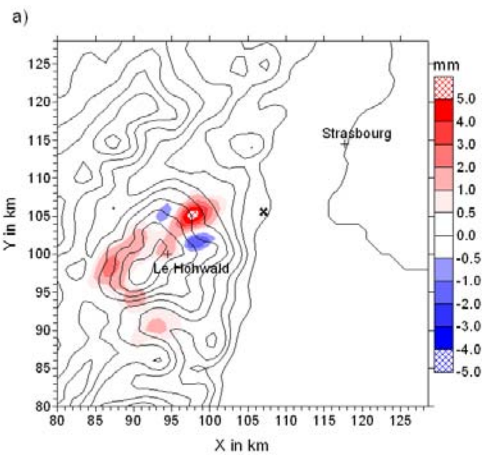


Fig. 7a. Difference continental - polluted

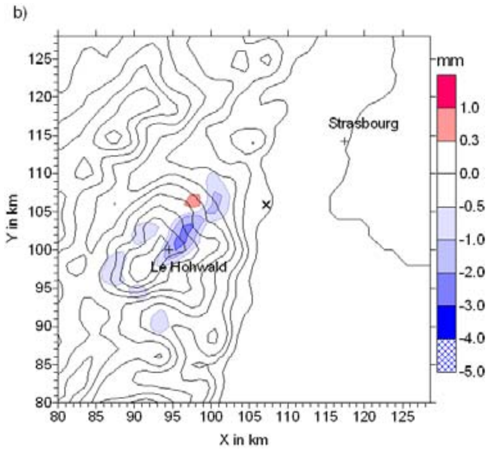


Fig.7b Difference continental - clean

	Continental ε =1	Clean ε =1	Polluted ε =1
rain max. (mm)	7.42	8.02	6.39
mean rain (mm)	1.74	2.00	1.31
rain area (km2)	337	344	307
total rain (Mt)	0.59	0.69	0.40

Table 2: varables for the cumulative rain on the ground as a function of initial aerosol particle number.

If the number concentration is kept constant, but only the solubility is varied, we obtain the results of fig. 8:

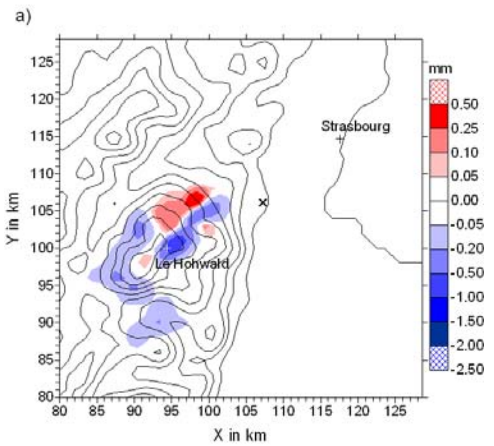


Fig.8a : Difference continental (ε=1 – ε=0.5)

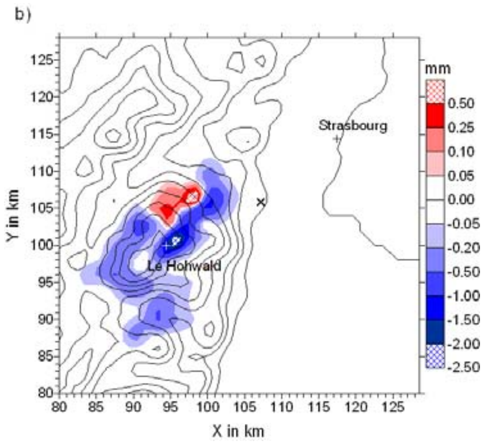


Fig.8b : Difference continental (ε=1 – ε=0.05)

Table 3 shows the overall results if only solubility is varied:

	Continental ε=1	Continental ε =0.5	Continental ε =0.05
rain max. (mm)	7.42	7.52	7.68
mean rain (mm)	1.74	1.80	1.93
rain area (km2)	337	335	339
total rain (Mt)	0.59	0.60	0.65

Table 3: variables for the cumulative rain on the ground as a function of initial aerosol particle solubility.

We note that globally decreasing solubility increases the total amount of precipitation and the total watered surface. However, the effect is much weaker than the influence of the number concentration. However, locally (Fig.8), we have also an inverse behaviour (Planche et al, 2010).

4. CONCLUSION

From the simulations we noted that inside cloud (LWC > 0.1 gm^{-3}) about 20% of the area is subsaturated. The most probable supersaturation in clouds increases with decreasing total number concentration and decreasing solubility. Varying particle number concentration can suppress precipitation for individual clouds. For cloud fields and longer simulations times, we note a strong temporal and spatial variability. Some locations show an inverse behaviour from the overall trend at some time. The differences seem to decrease in the course of time.

We can conclude that the air parcel concept generally overpredicts the reaction of the cloud to the initial parameters. The complex dynamics and microphysics installs a non-linear feedback. Great caution is, thus, advised before making climate relevant conclusions.

For the time being, we can state, that pollution can suppress precipitation, but more research is needed to confirm the behavior for longer periods and larger scales.

One hypothesis seems to impose itself: precipitation is mainly determined by water vapor availability; pollution might only influence the spatial and temporal variation. This hypothesis needs to be validated in the future.

5. REFERENCES

Clark, T.L. and W.D. Hall, 1991: Multi-domain simulations of the time dependent Navier-Stokes equation: benchmark error analysis of some nesting procedures. J. Comput. Phys., 92, 456-481.

Cotton W.R. and R. A. Pielke, 1992: Human impacts on weather and climate. Cambridge University Press, 288pp.

Flossmann, A. I. and W. Wobrock, 2010: A review of our understanding of the aerosol – cloud interaction from the perspective of a bin resolved cloud scale modelling, accepted Atmos. Res. doi:10.1016/j.atmosres.2010.05.008

Leroy, D., W. Wobrock and A. I. Flossmann, 2009: The role of boundary layer aerosol particles for the development of deep convective clouds: a high-resolution 3D model with detailed (bin) microphysics applied to CRYSTAL-FACE , Atmos. Res.; *DOI: 10.1016/j.atmosres.2008.06.001*

Levin, Z., and W.R. Cotton (Eds.), 2009: Aerosol pollution impact on precipitation, a scientific review. Springer, 386pp.

Planche, C., Wolfram Wobrock, Andrea I. Flossmann, Frédéric Tridon, Joël Van Baelen, Yves Pointin et Martin Hagen, 2010: The influence of aerosol particle number and hygroscopicity on the evolution of convective cloud systems and their precipitation: A numerical study based on the COPS observations on 12 August 2007; accepted Atmos. Res. doi.:10.1016/j.atmosres.2010.05.003

Pruppacher H. R. and J.D. Klett, 1997 : *Microphysics of clouds and precipitation*. 2nd ed. Kluwer Academic, 954p.