A review of our understanding of the aerosol – cloud interaction from the perspective of a bin resolved cloud scale modelling

[(Flossmann and Wobrock, 2010) is part of the special issue of Atmos. Res. honoring H.R. Pruppacher]

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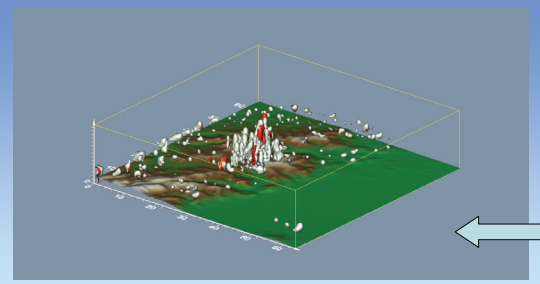
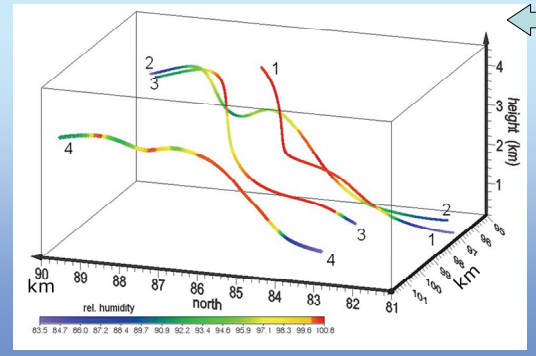
One aspect of the (Flossmann and Wobrock, 2010) was:

What is the role of aerosol particle composition and number concentration for: **- microphysics and rain development** **in short time individual clouds** **in longer lasting cloud fields** **how is the spatial and temporal evolution?**



Simulation of a cloud field over complex terrain during the COPS campaign (Planche et al, 2010):

white: cloud water, red: rain water



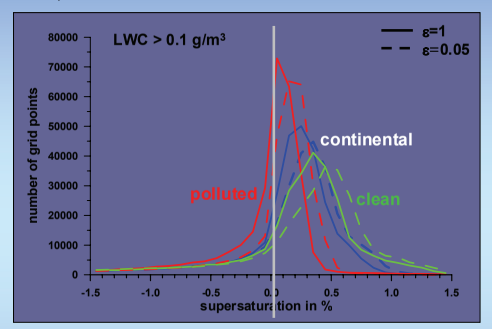
Study of 4 trajectories:
red: supersaturated
blue: outside cloud
green: still in cloud

Overall results:

85% of the parcels:
one, two, three, or more periods of subsaturation (ex: 3;4)

15% of the parcels:
always supersaturated after passing cloud base (ex:1)

Role of aerosol concentration and composition for supersaturation:
$S_{mean,min}$=0.05% for polluted all soluble (ε=1)
$S_{mean,max}$=0.5% for clean mostly insoluble (ε=0.05)

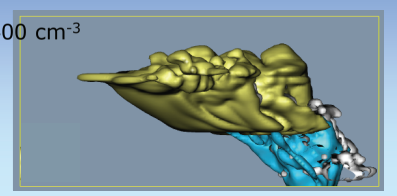


- **Inside cloud (LWC > 0.1 gm^{-3}) about 20% of the area is subsaturated**
- **The most probable supersaturation in clouds increases with decreasing total number and decreasing solubility**

Simulation of an individual cloud (Crystal-Face; Leroy et al, 2009):

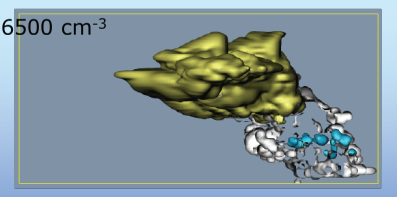
Clean boundary layer: N_{AP} ≈ 400 cm^{-3}

Cloud drops : 0.01 g m^{-3}
Raindrops : 1 g m^{-3}
Ice crystals : 0.01 g m^{-3}



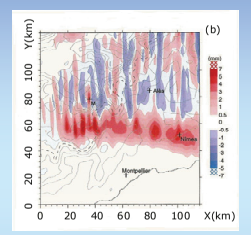
Polluted boundary layer: N_{AP} ≈ 6500 cm^{-3}

Cloud drops : 0.01 g m^{-3}
Raindrops : 0.03 g m^{-3}
Ice crystals : 0.01 g m^{-3}



- **Varying particle number concentration can suppress precipitation for individual clouds**

Over longer periods of simulation the influence decreases (Cevennes mountains in France):



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

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

- **For cloud fields and longer simulations times, we note a strong temporal and spatial variability**
- **The differences seems to decrease in the course of time**

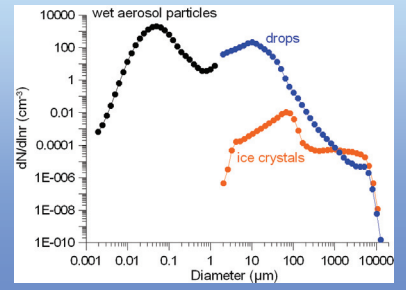
The model DESCAM (DEtailed SCAvenging Model)

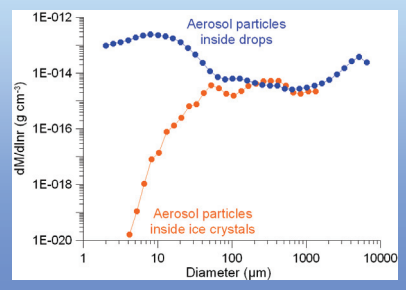
Flossmann and Wobrock (2010); Leroy et al (2009)

***3 + 2 density distribution functions*:**

f_d : drop number
f_i : ice crystal number
f_{AP} : wet aerosol particle number
$g_{AP,d}$: aerosol mass inside drops
$g_{AP,i}$: aerosol mass inside ice crystals

- ***Warm microphysical processes*** **: aerosol particle growth and activation, droplet de-activation, growth of drops by condensation and collision-coalescence**
- ***Cold microphysical processes*** **: homogeneous and heterogeneous nucleation, growth by vapor deposition, riming and melting.**



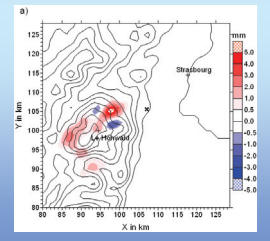


Coupled to 3-D meso-scale dynamic model (Clark and Hall, 1991)

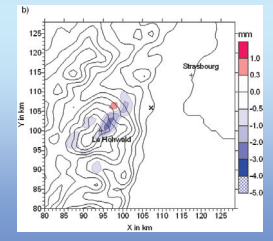
Simulation of the COPS clouds with different particle spectra (strong spatial variability):

	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

Difference continental - polluted



Difference continental - clean



Decreasing pollution and decreasing solubility (not shown here) increases the total amount of precipitation and the total watered surface

- **Some locations show an inverse behavior from the overall trend**

Conclusions

- **Pollution can suppress precipitation, but locally and temporarily inverse behavior can be found; influence of pollution seems to decrease with time**
- **Hypothesis: precipitation is mainly determined by water vapor availability; pollution will just influence the spatial and temporal variation over a longer period and a larger area?**
- **To be confirmed by further studies!**

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.
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*
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