The impact of microphysics and mixing on optical properties of shallow cumulus clouds

Joanna Slawinska[1], Wojciech W. Grabowski[2], Andrzej Wyszogrodzki[2],

pilvi@igf.fuw.edu.pl

Hanna Pawlowska[1], and Hugh Morrison[2]

[1] *Institute of Geophysics, University of Warsaw, Poland;* [2] *National Center for Atmospheric Research, Boulder, CO USA*

Motivation

• Recent modeling studies (e.g.Chosson et al. 2004, 2007; Grabowski 2006) demonstrate that assumptions concerning microphysical evolution of clouds (the homogeneity of cloud-environment mixing in particular) affect the albedo of a field of shallow convective clouds.

• We present results concerning the impact of subgrid-scale mixing on microphysical properties on trade-wind cumulus (BOMEX experiment; Holland and Rasmusson 1973).

• We use both one-moment and new double-moment warm-rain scheme of Morrison and Grabowski (2007, 2008).and contrast results applying the prescribed mixing scenarios: homogeneous (h) versus extremely inhomogeneous (ex)

Model and modeling setup

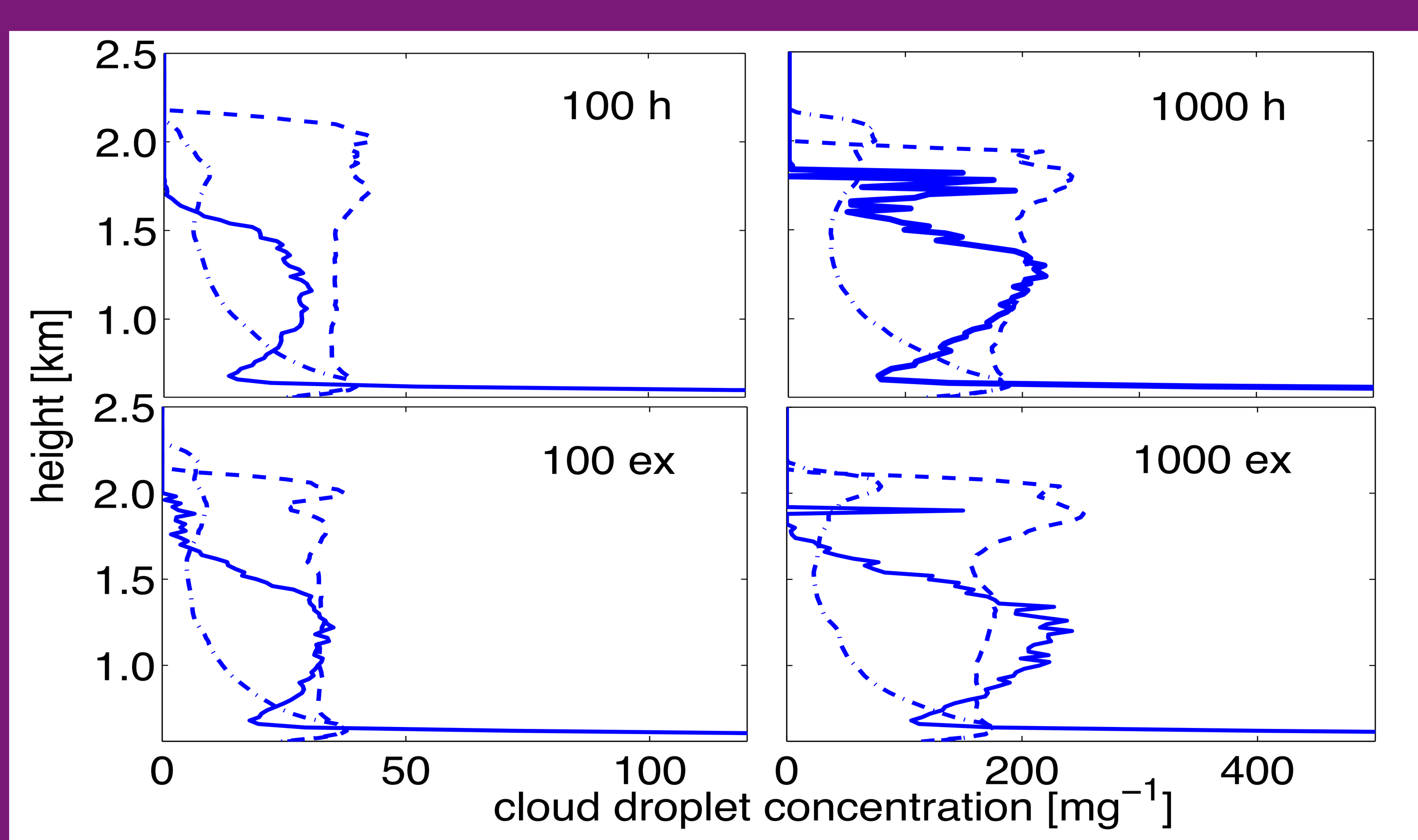
- Model: the Eulerian version of the three-dimensional anelastic model EULAG: http://www.mmm.ucar.edu/eulag/
- Cloud droplet/aerosol characteristics for one/double-moment scheme, respectively:
  - Maritime with concentration of 100 mg^{-1} – the PRISTINE case
  - Continental with concentration of 1000 mg^{-1} - the POLLUTED case
- For double-moment scheme, in-cloud activation is either turn on or turn off.
- Off line radiative transfer applying the independent column approximation
- Model setups: Siebesma et al. (2003)
- Computational domain sizes and gridlengths: 6.4 km × 6.4 km × 3 km; 50 m × 50 m × 20 m
- All simulations are run with time step of 1 s. Data are archived every 10 minutes.
- The simulations are run for 6 h and the last three hours are used in the analysis.

To quantify the role of activation, the time needed for activation of all cloud droplets in the domain has been calculated:

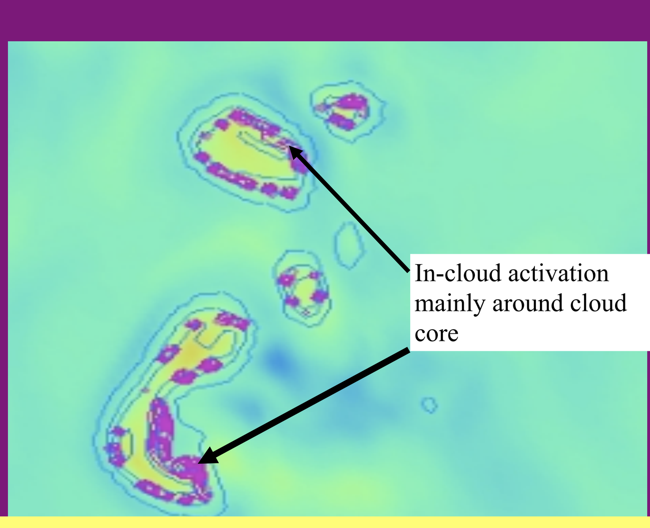
$$\tau = \frac{< \sum(N_c) >}{< \sum((\frac{\partial N}{\partial t})_{act}) >},$$

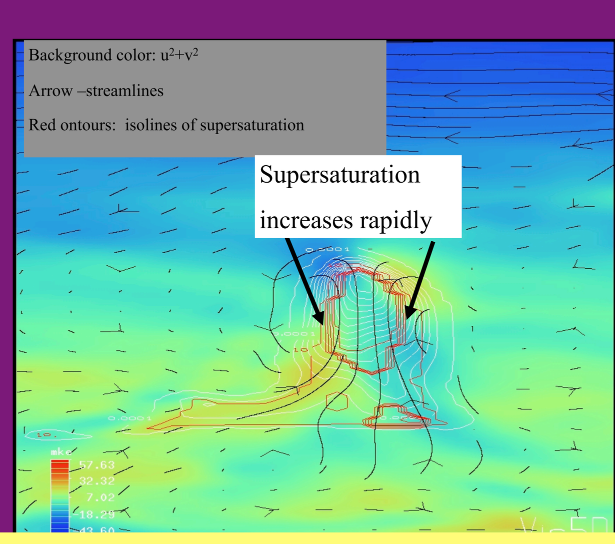
τ can be interpreted as the timescale of the cloud droplet lifetime, since it specifies how fast existing droplets are to be replaced by the one to be activated.

- The timescale (Table 1) is in the range of about **3-4 min**.
- Lower timescale (higher activation rate) values for extremely inhomogeneous mixing than for homogeneous mixing.
- Larger timescale values for cases where activation has been turned off above 700 m.
- Lower value for the POLLUTED than for the PRISTINE case (the effective radius is lower for the POLLUTED than for the PRISTINE case).

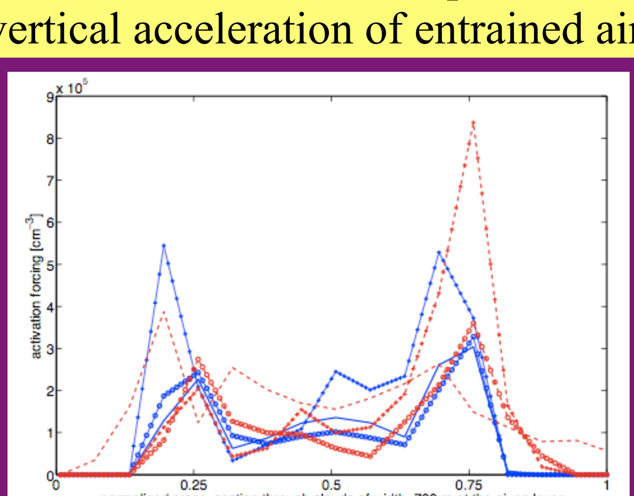


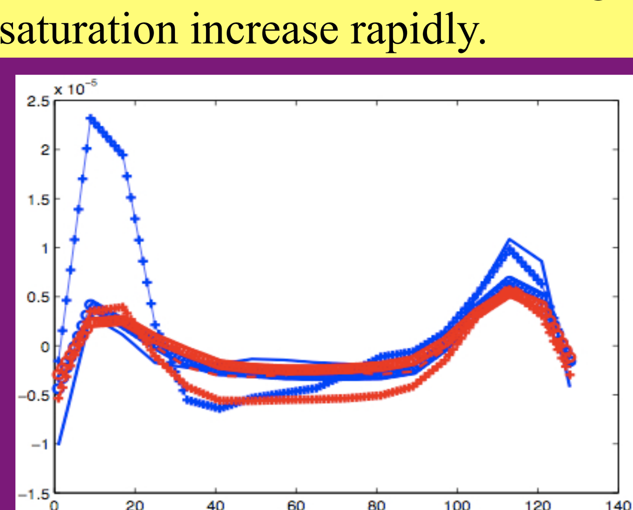
- Cloud droplet concentration (dashed line) is either constant or slightly increasing with height.
- Besides a peak at the cloud base, there is an **additional peak in the profile of activation** (solid line) **around 1.2 km** (correlated with peak of vertical velocity).
- For simulations with in-cloud activation turn off (dashed dotted line), cloud droplet concentration decreases with height drastically.



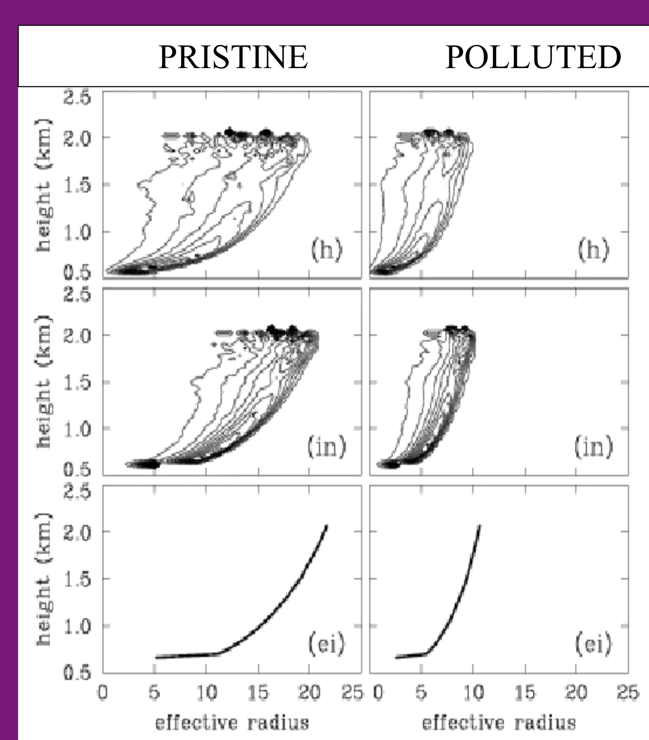


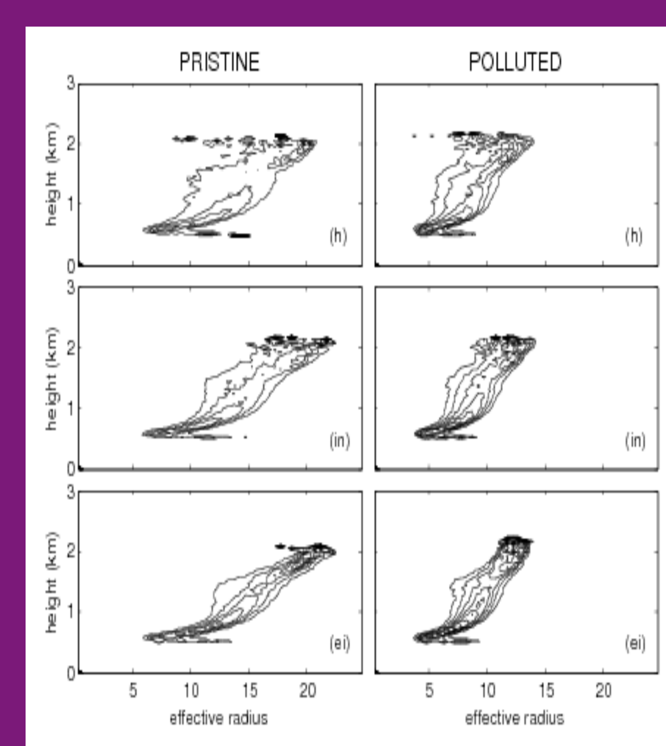
In-cloud activation takes place around the cloud core, where, due to strong vertical acceleration of entrained air, supersaturation increase rapidly.



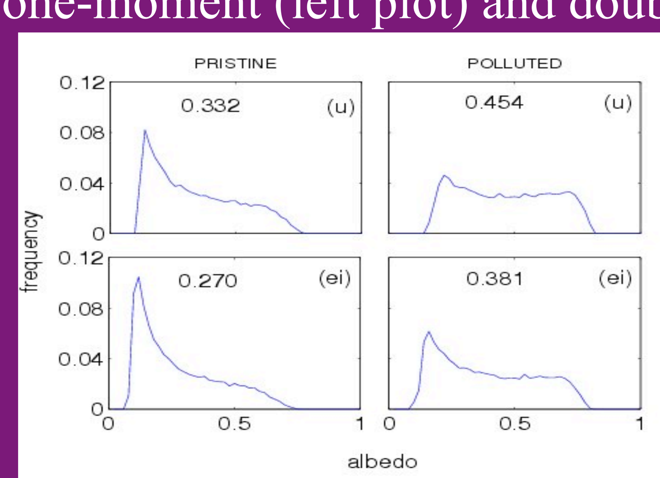


CFADs of the effective radius of cloud droplets for simulation with either one-moment (left panel) or double-moment (right panel) warm-rain scheme





Histograms of cloud TOA (top of the atmosphere) albedo for model columns with LWP (liquid water path) larger than 0.005 kg m^{-2}.
for one-moment (left plot) and double-moment (right plot) warm-rain scheme.



	PRISTINE				POLLUTED			
mixing scenario	(u)	(h)	(in)	(ei)	(u)	(h)	(in)	(ei)
τ (1)	11.5	10.4	9.0	7.7	23.5	21.2	18.3	15.8
$\overline{r}_e$ (μm)	8.1	9.1	11.1	13.6	4.0	4.4	5.4	6.7
A_{cloudy} (1)	0.332	0.320	0.292	0.270	0.454	0.441	0.409	0.381
SF_{cloudy} (W m^{-2})	229	234	245	255	177	182	196	208

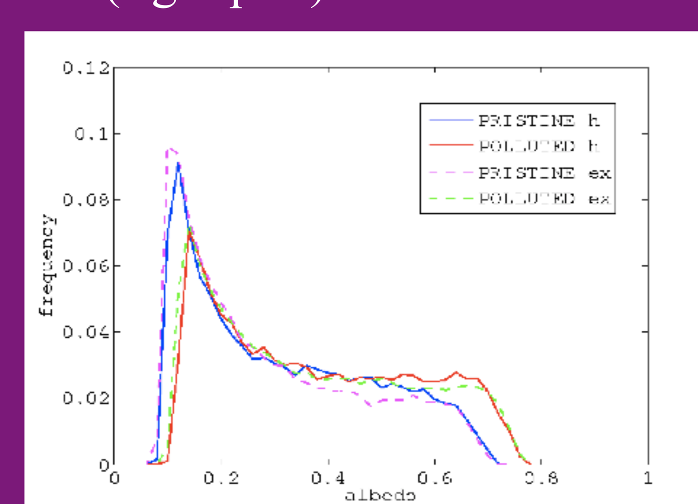


Table 1: Cloud droplet lifetime (τ) mean effective radius (r_{eff}) and mean TOA albedo (A_{cloudy}) for PRISTINE (100) or POLLUTED (1000) cases with homogeneous (h) or extremely inhomogeneous (ex) mixing scenario, with in-cloud activation turn on (ACT ON) or off (ACT OFF)

	τ [min]	r_{eff} [μm]	A_{cloudy} [1]
100 h; ACT ON	4.00	11.20	0.270
100 ex; ACT ON	3.20	11.97	0.265
1000 h; ACT ON	3.48	6.97	0.347
1000 ex; ACT ON	2.91	7.33	0.338
100 h; ACT OFF	4.20	15.51	0.238
100 ex; ACT OFF	3.48	17.74	0.233
1000 h; ACT OFF	4.53	9.80	0.308
1000 ex; ACT OFF	3.71	11.23	0.289

Summary and conclusions

- In-cloud activation is a significant process for shallow cumulus convection.
- In-cloud activation occurs at the edge of the cloud core, in the region of strong increase of vertical velocity as well as supersaturation gradient.
- Mean cloud droplet lifetime is about 3-4 min, with lower value for extremely inhomogeneous mixing scenario than for the homogeneous mixing scenario (keep in mind that cloud droplets are depleted faster for the extremely inhomogeneous mixing scenario).
- Wider distribution of the effective radius and slightly smaller mean effective radius for the homogeneous mixing case than for the extremely inhomogeneous.
- PDFs of cloud albedo have pattern similar to those in Grabowski (2006), with differences between different mixing scenarios significantly smaller for double-moment warm-rain scheme.
- Mean albedo is lower for PRISTINE case than POLLUTED case by about 0.05-0.09 for double-moment warm-rain scheme (differences larger for one-moment scheme).

A few words about applications of model EULAG:

International Journal for Numerical Methods in Fluids:, Volume 50 Issue 10 , Pages 1121 - 1293, 10 April 2006

Computers & Fluids, Volume 37, Issue 9, October 2008, Pages 1193-1207 'EULAG, a computational model for multiscale flows', Joseph M. Prusa , Piotr K. Smolarkiewicz and Andrzej A. Wyszogrodzki

EULAG has been applied in the areas of turbulence, orographic flows, urban flows, gravity wave dynamics, flows past complex/moving boundaries, micrometeorology, cloud microphysics and dynamics, global atmospheric, and basic fluid dynamics of incompressible fluids. Derivatives of EULAG also have been applied to simulations of visco-elastic waves in the human brain, oceanic flows, and stellar convection. Present developments include extensions to gas dynamics and solar MHD.

References

Chosson et al., 2004: *Proceedings of the International Conference on Clouds and Precipitation*, Bologna, Italy, 371-374.
Chosson et al., 2007: *J. Atmos. Sci.*, **54**, 2670-2682.
Grabowski, 2006: *J. Climate*, **19**, 4664-4682.
Holland and Rasmusson, 1973: *Mon. Wea. Rev.* **101**, 44-55.
Morrison and Grabowski, 2007: *J. Atmos. Sci.*, **64**, 2839-2861.
Morrison and Grabowski, 2008: *J. Atmos. Sci.*, **65**, 792-812.
Siebesma et al., 2003: *J. Atmos. Sci.*, **60**, 1201-1219.
Slawinska et al., 2008: *J. Climate*, **21**, 1639-1647.

Acknowledgments:

Computer time was provided by NSF MRI Grant #CNS-0420873, NSR MRI Grant #CNS-0420985, NSF sponsorship of the National Center for Atmospheric Research, the University of Colorado, and a grant from the IBM Shared University Research (SUR) program.

Tuesday, September 7, 2010