Treatment of microphysics in the MPI-Hamburg LES model

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Outline

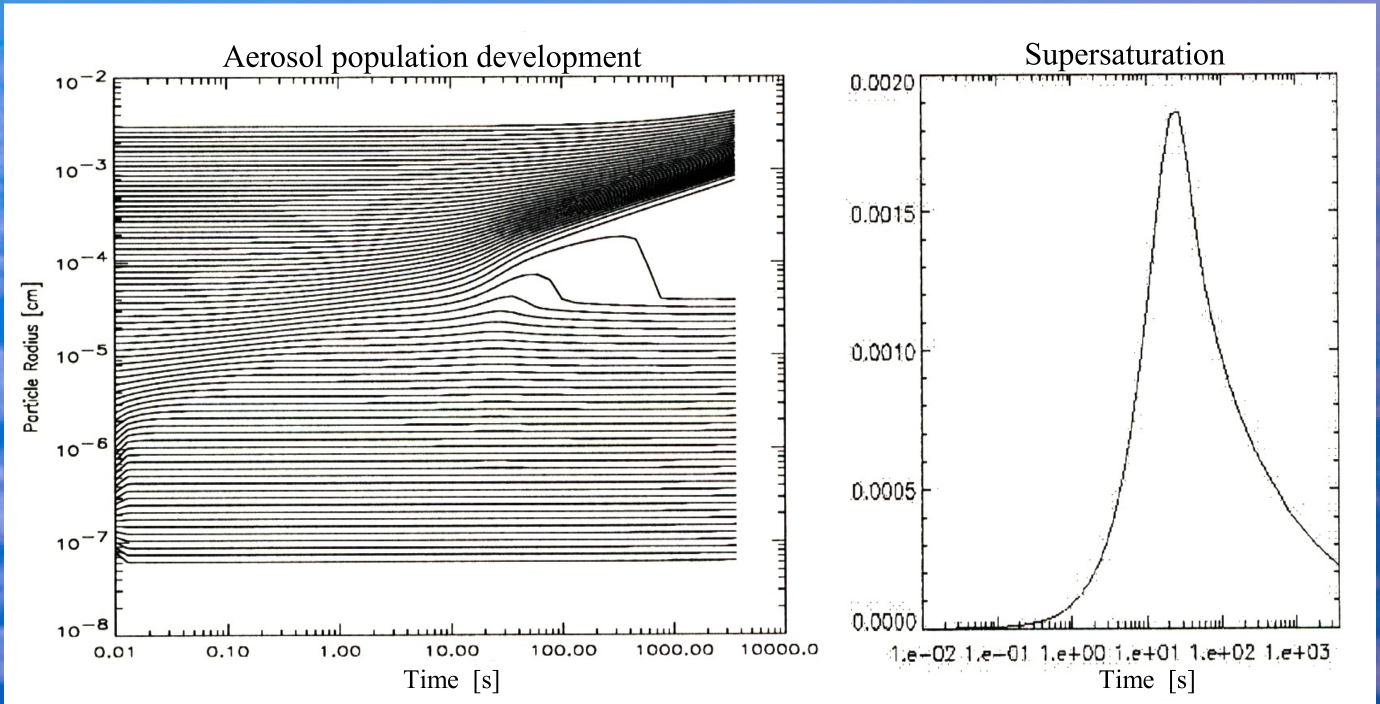
- The microphysical modules in the MPI-LES model
- Cloud droplet formation – activation of aerosols
- Comments on submitted results
- Outlook

The microphysical modules in the MPI-LES model

- 3 (+ 1) microphysical schemes are implemented in the current LES version:

1. no-rain microphysics: sat. adjustment to form cloud water (including sub-scale condensation), no droplets (Sommeria and Deardorff, 1977)
2. classical 'Kessler' scheme: q_c, q_r, sat. adjustment, auto-conversion, accretion, sedimentation and evaporation of q_r (Kessler, 1969)
3. 'Lüpkes' scheme: q_c, q_r, N_r, 2.+ rain drop self-collection, sedimentation of N_r (Lüpkes, 1989; Lüpkes, 1991)
4. two-moment scheme for cloud and rain water, resp.: q_c, q_r, N_c, N_r, 3.+ self-collection of N_c, sedimentation of q_c and N_c, activation (Seifert and Beheng, 2000; Seifert, 2002)

Cloud droplet formation – activation of aerosols



- A detailed treatment of aerosol population development is very computer resource demanding.
- Since non-activated aerosols are in thermodyn. equilibrium aerosol activation is in general a good approximation to describe the corresponding cloud droplet sources

Cloud droplet formation – activation of aerosols (cont.)

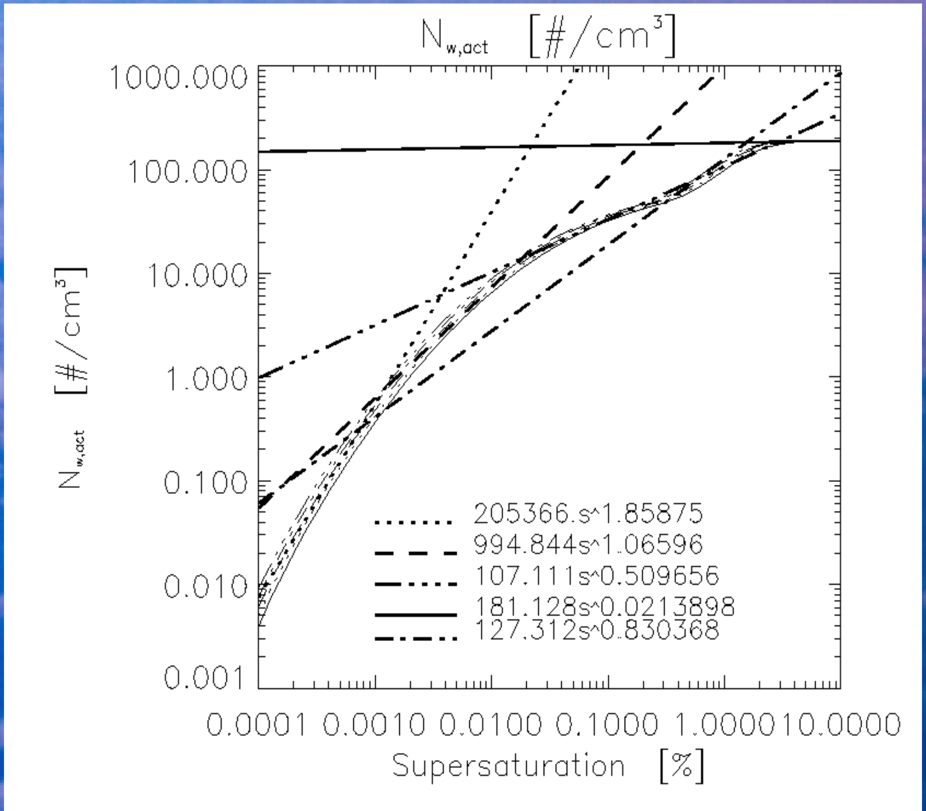
- Activation is based on N_{CCN} spectra (Twomey, 1959; Twomey and Wojciechowski, 1969; Hudson, 1980)

$$N_{CCN}(s) = C\,s^{k}$$

- The power law parameters C and k, given in the legend, were fitted to the activation spectrum based on the given aerosol size distribution.

- The activation spectrum is gained from:

$$N_{CCN}(s) = -\int_{r_{ap}(s_c=0)}^{r_{ap}(s_c=s)} f_{ap}(r_{ap})\,dr_{ap} = \int_{r_c}^{\infty} f_{ap}(r_{ap})\,dr_{ap}$$



Cloud droplet formation – activation of aerosols (cont.)

- To calculate the no. of newly activated cloud drops the maximum supersaturation has to be determined:

$$\frac{ds_{vw}}{dt} = A_1 \mathbf{w} + A_2 \frac{\mathbf{dq_c}}{\mathbf{dt}} = f(s_{vw}) = 0$$

$$A_1 = \frac{\epsilon\, l_{21}\, g}{R_a T^2 c_{pa}} - \frac{g}{R_a T} \qquad A_2 = \frac{p}{\epsilon\, e_{sat,w}} + \frac{\epsilon\, l_{21}^{\,2}}{R_a T^2 c_{pa}}$$

- The determination of the cloud water mixing ratio tendency is crucial!

$$\frac{dq_c}{dt} = 2\pi \frac{\rho_w}{\rho_a} (2 A_3)^{2/3} s(t) \int_0^s n(s') \left[\int_{t_o}^{t} s(t')\, dt' \right]^{\frac{1}{2}} ds'$$

- Using the droplet growth equation yields:

$$r \frac{dr}{dt} \approx A_3\, s \qquad \mathit{with} \qquad A_3 = \left[\frac{\rho_w R_v T}{e_{sat,w} D_v} + \frac{l_{21} \rho_w}{k_a T} \left(\frac{l_{21}}{R_v T} - 1 \right) \right]^{-1}$$

$$r(t) = \left[r(t_o)^2 + 2 A_3 \int_{t_o}^{t} s(t')\, dt' \right]^{\frac{1}{2}}$$

Cloud droplet formation – activation of aerosols (cont.)

- According to the original work of Twomey (1959) the activation spectrum is written as:

$$n(s) = k\,C\,s^{k-1}$$

- ***Taking into account only the loss of water vapor due to condensation of newly activated droplets*** results in a change of cloud water mixing ratio as follows:

$$\frac{dq_c}{dt} = 2\pi \frac{\rho_w}{\rho_a} A_3\, k\, C \left[\frac{A_3}{A_1 w}\right]^{\frac{1}{2}} s^{k+2}\; B\left(\frac{k}{2}, \frac{3}{2}\right)$$

- Maximum supersaturation s_{max} and N_{CCN} are given by:

$$s_{max} = C^{-\frac{1}{k+2}} \left[\frac{\left(A_1 w\right)^{\frac{3}{2}}}{2\pi \frac{\rho_w}{\rho_a} A_2 A_3^{\frac{3}{2}}\, k\, B}\right]^{\frac{1}{k+2}} \qquad N_{CCN,max} = C^{\frac{2}{k+2}} \left[\frac{\left(A_1 w\right)^{\frac{3}{2}}}{2\pi \frac{\rho_w}{\rho_a} A_2 A_3^{\frac{3}{2}}\, k\, B}\right]^{\frac{k}{k+2}}$$

Cloud droplet formation – activation of aerosols (cont.)

- Extending the previous derivation by considering also ***condensation on already existing cloud droplets*** yields:

$$\frac{dq_l}{dt} = \left.\frac{dq_l}{dt}\right|_{act} + \left.\boldsymbol{\frac{dq_l}{dt}}\right|_{cond}$$

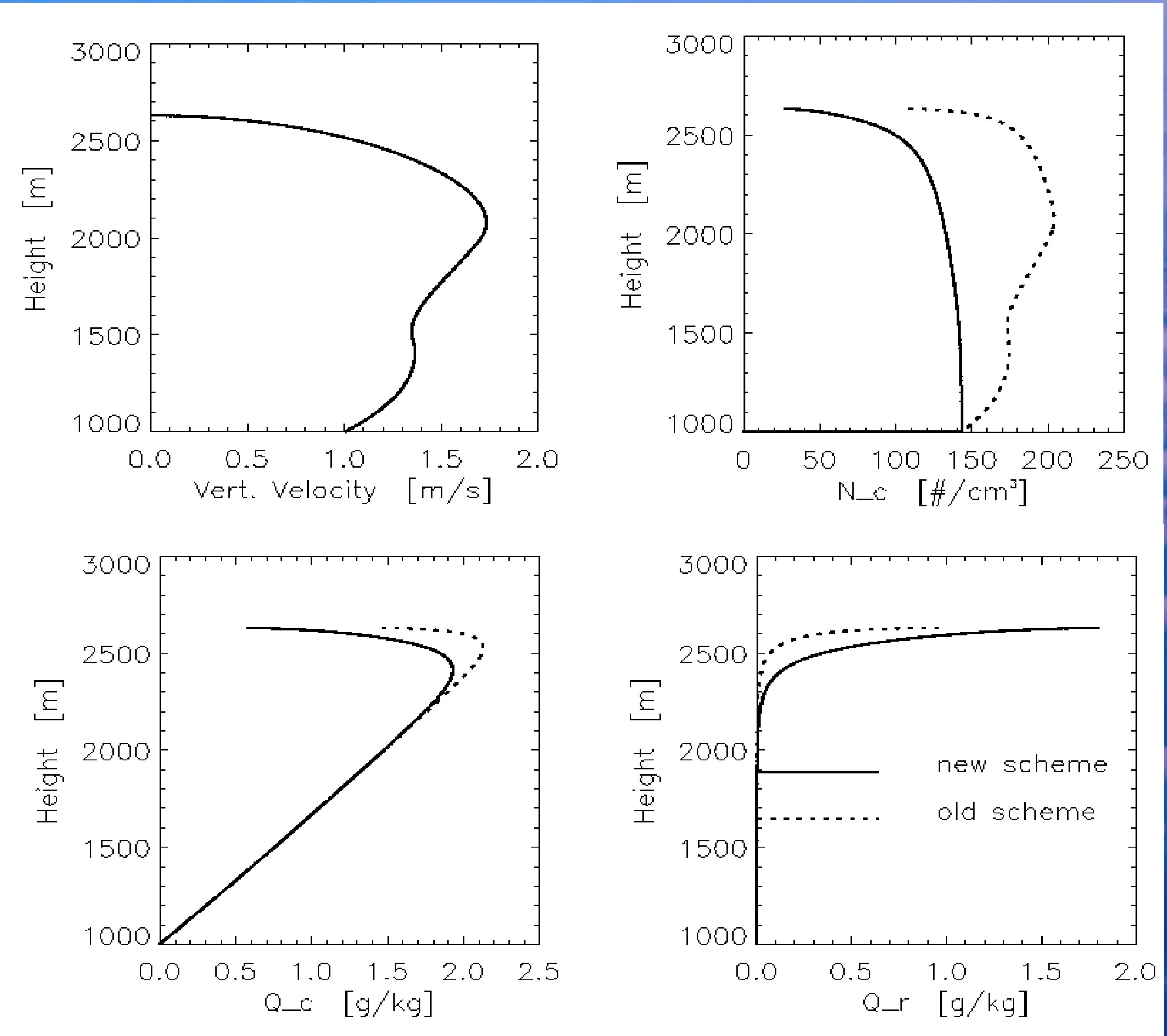
$$= 2\pi\frac{\rho_w}{\rho_a}A_3\,k\,c\,B\left(\frac{k}{2},\frac{3}{2}\right)\left[\frac{A_3}{A_1 w}\right]^{1/2} + \boldsymbol{4\pi\frac{\rho_w}{\rho_a}A_3\bar{N}_c\left[\bar{r}_c^{\,2}+\frac{A_3}{A_1 w}s^2\right]^{1/2}}$$

- The maximum supersaturation s_{max} is given by:

$$s_{max}^{\,n+1} = s_{max}^{\,n} - \frac{f(s)}{f'(s)}$$

$$f'(s_{vw}) = 2\pi\frac{\rho_w}{\rho_a}A_2\,A_3\left[\begin{array}{l} k(k+2)\left[\dfrac{A_3}{A_1\,w}\right]^{1/2}s_{vw}^{\,k+2} + \boldsymbol{2\bar{N}_c\left[\bar{r}_c^{\,2}+\dfrac{A_3}{A_1\,w}\right]^{1/2}} + \\ \boldsymbol{+\,2\bar{N}_c\,s_{vw}\dfrac{A_3}{A_1\,w}\left[\bar{r}_c^{\,2}+\dfrac{A_3}{A_1\,w}s_{vw}^{\,2}\right]^{-1/2}} \end{array}\right]$$

Cloud droplet formation – activation of aerosols (cont.)



Simulation results from an entraining air parcel model using the two-moment scheme.

..... std. Activation (Twomey, 1959)

___ modified activation scheme

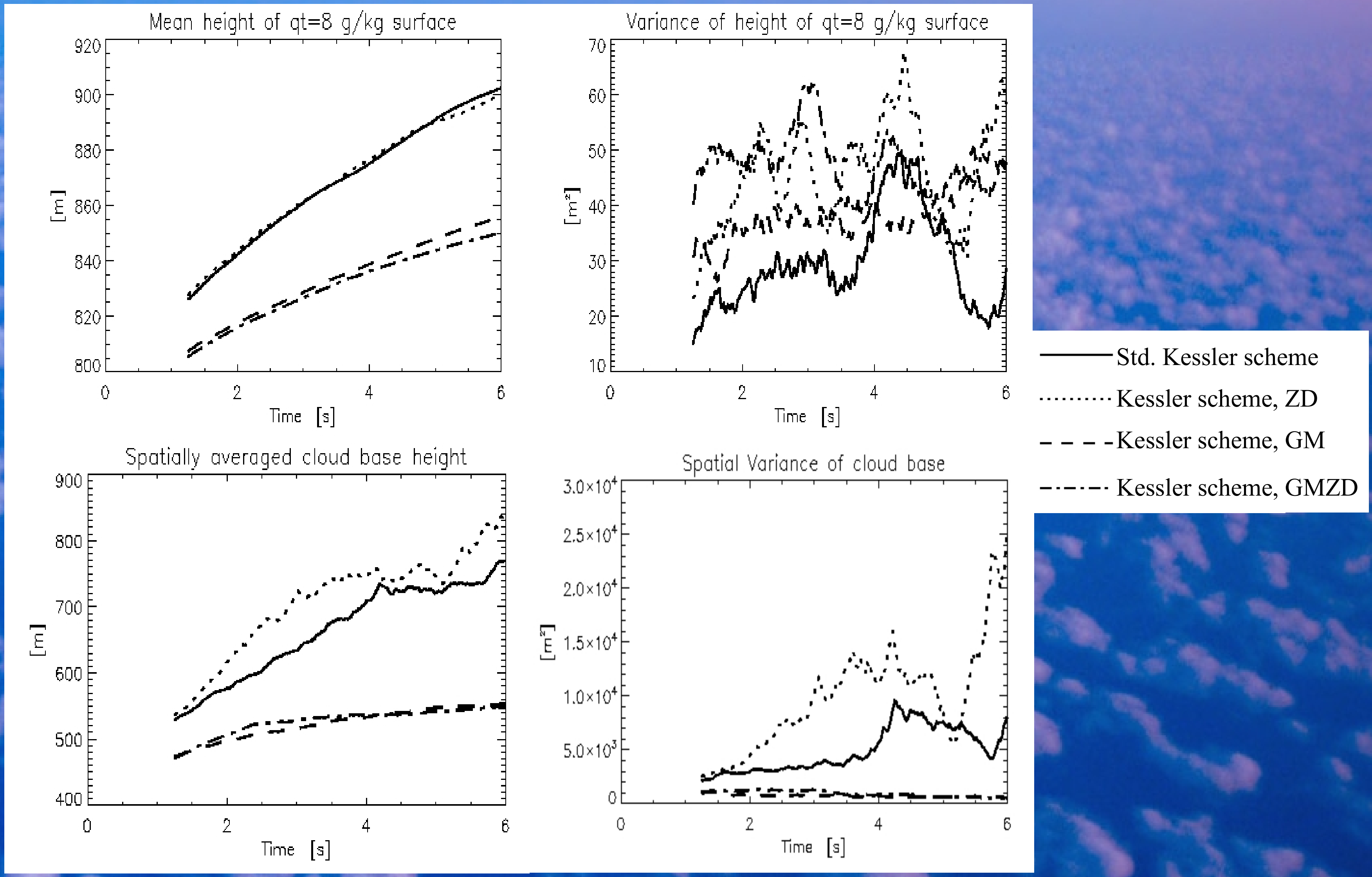
Comments on submitted results

Our submitted results had the following features:

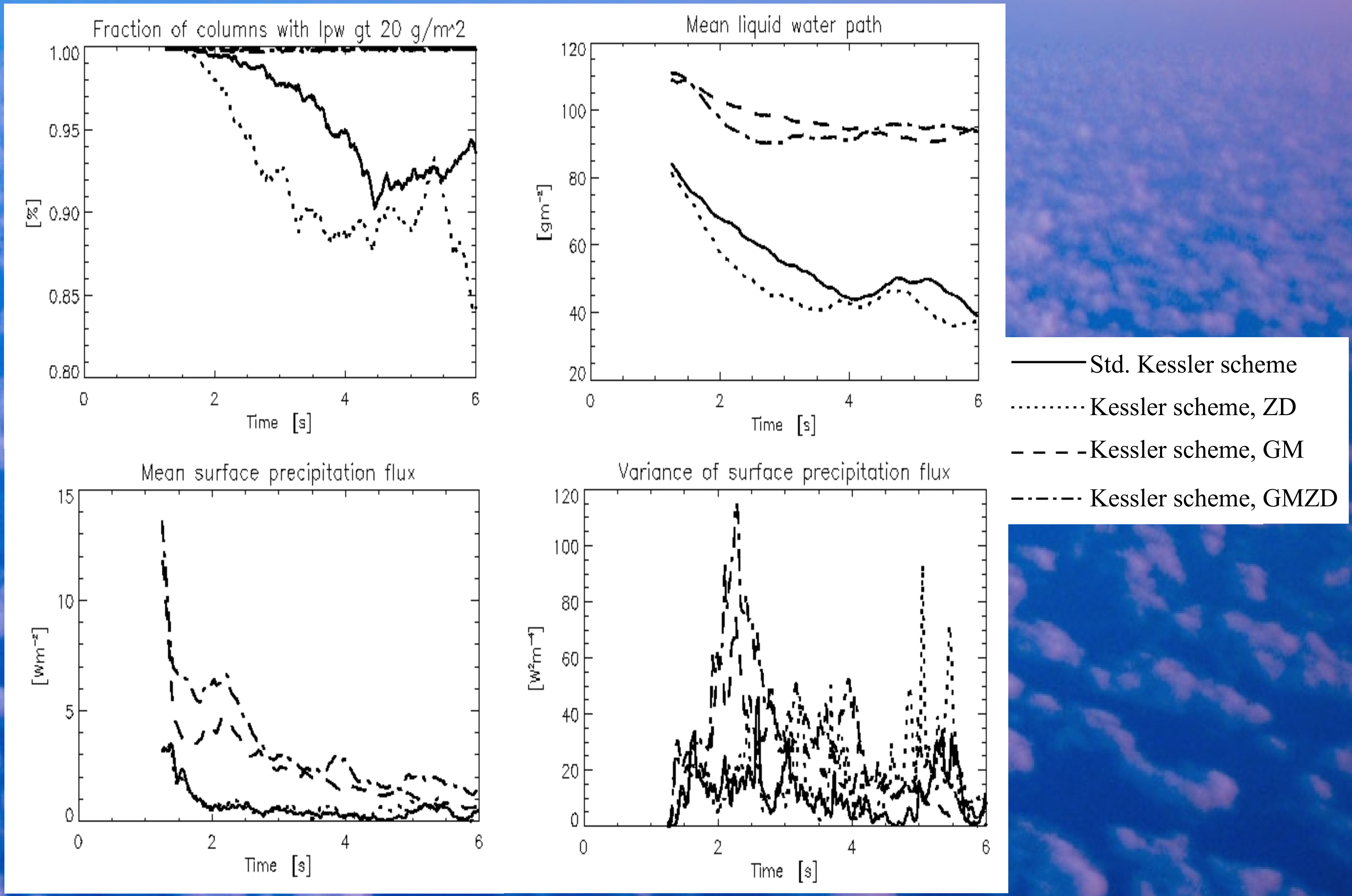
- Too fast increasing cloud top and cloud base
- Cloud breakup (Lüpkes scheme) with $1<cc<0.4$
- Gradually diminishing LWP: t=6h: $70d/m^2<LWP<20g/m^2$
- Precipitation only with Kessler scheme

What is the reason for this behaviour? Wrong physics? Bad numerics?

Comments on submitted results (cont.)



Comments on submitted results (cont.)



Outlook

- Perform simulations with the new two-moment scheme
- Implementation of a detailed (size resolved) cloud microphysical scheme
- Look at aerosol-cloud interactions