Toward cloud-model assessment of the role of cloud turbulence in warm-rain development

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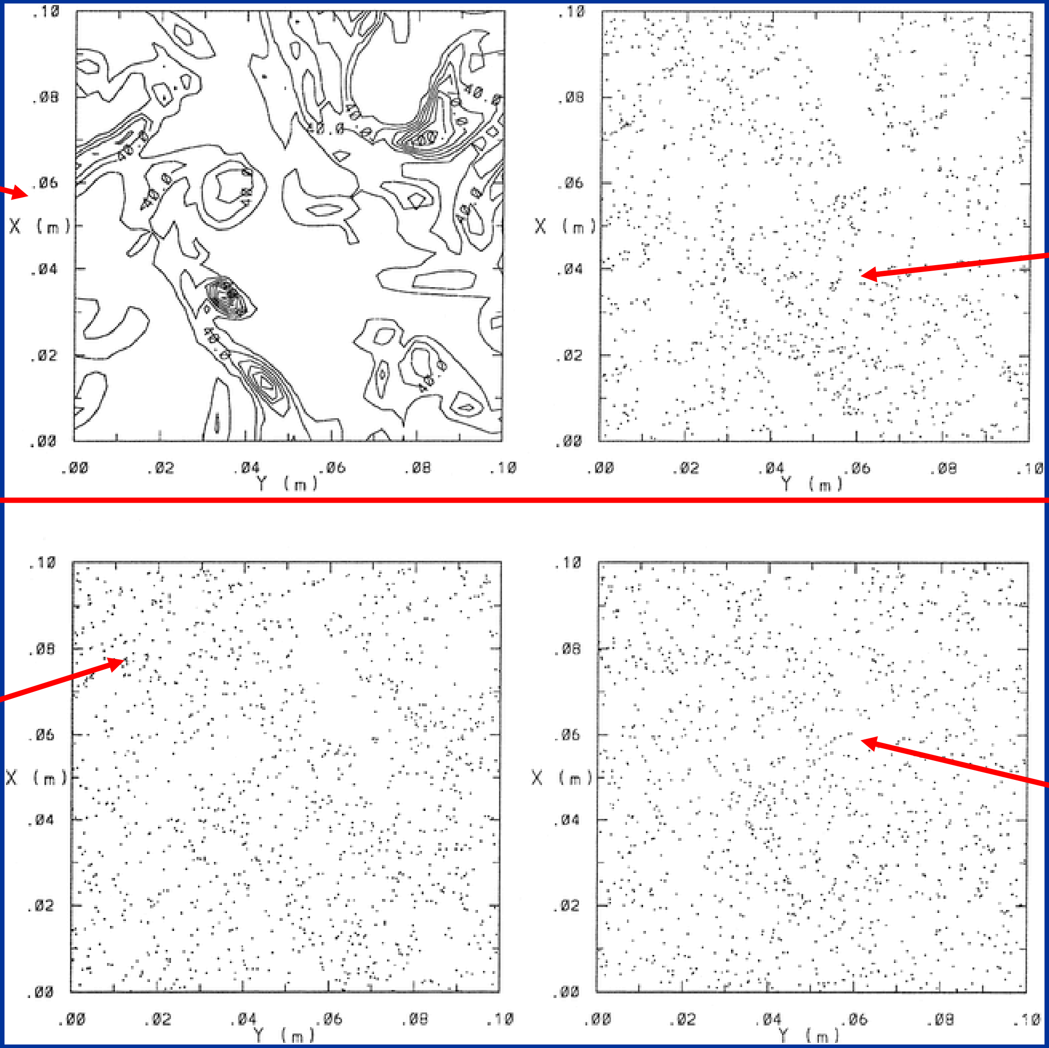
DNS simulations with sedimenting droplets for conditions relevant to cloud physics (ε=160 cm^2s^{-3})

Vorticity

(contour 15 s^{-1})

r=20 micron

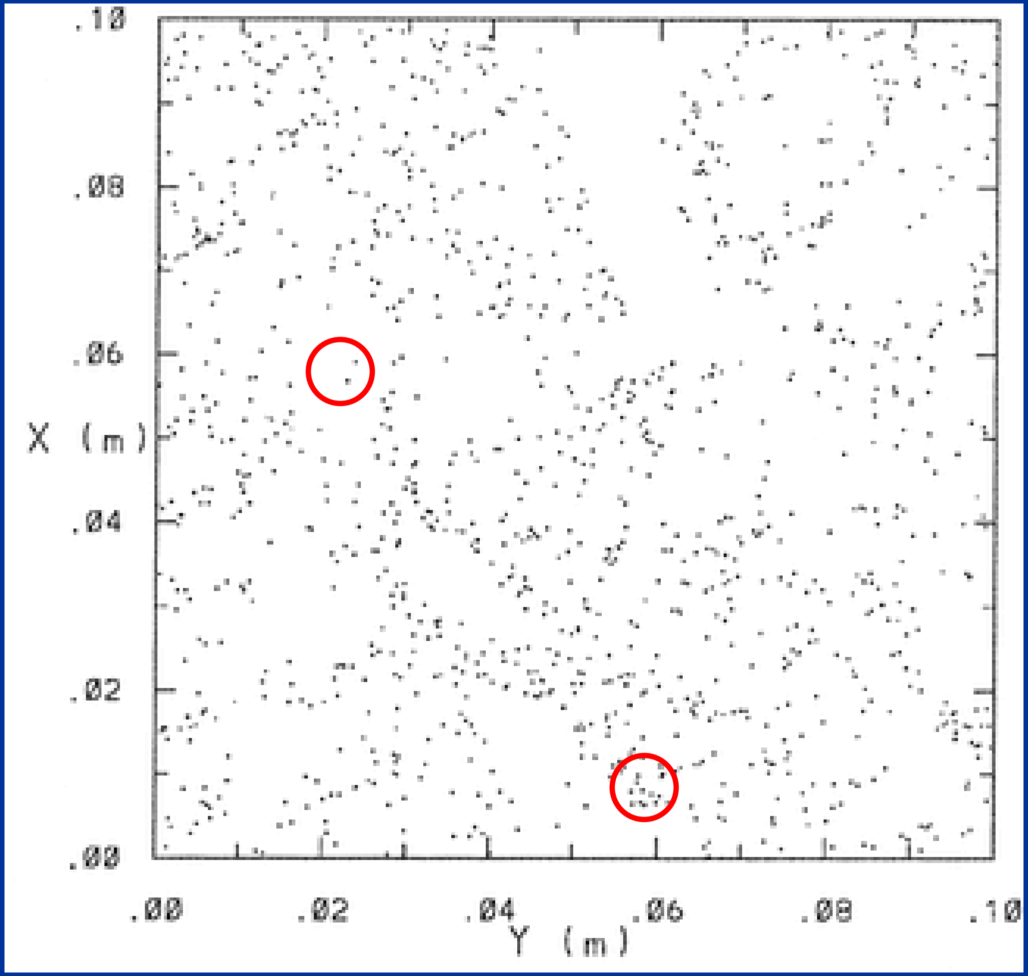


r=15 micron

r=10 micron

Vaillancourt et al. JAS 2002

Growth by collision/coalescence: nonuniform distribution of droplets in space affects droplet collisions…



Three basic mechanisms of turbulent enhancement of gravitational collision/coalescence:

-Turbulence modifies local droplet concentration (preferential concentration effect)

-Turbulence modifies relative velocity between colliding droplets (e.g., small-scale shears, fluid accelerations)

- Turbulence modifies hydrodynamic interactions when two droplets approach each other

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geometric collisions

(no hydrodynamic interactions)

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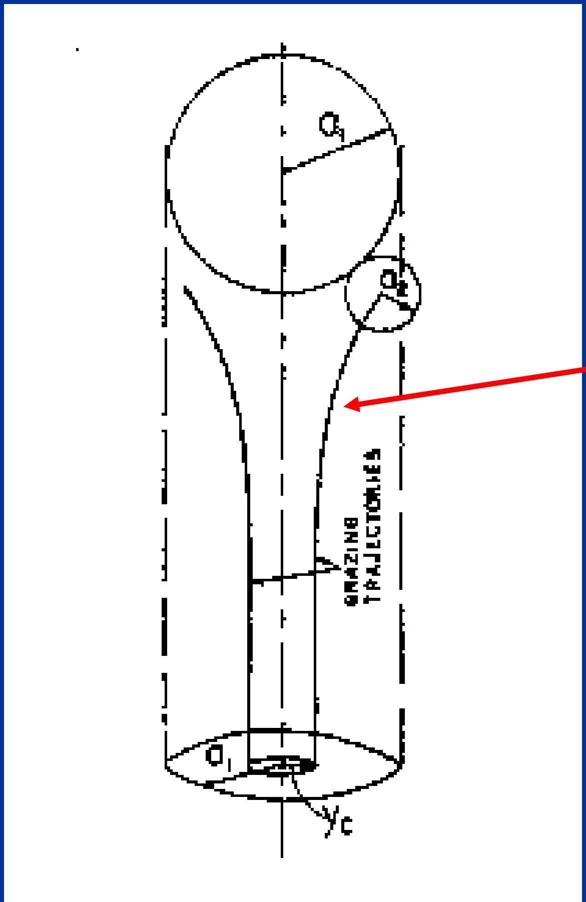
collision efficiency

- Turbulence modifies hydrodynamic interactions when two droplets approach each other

Collision efficiency E_c for the gravitational case:



Grazing trajectory

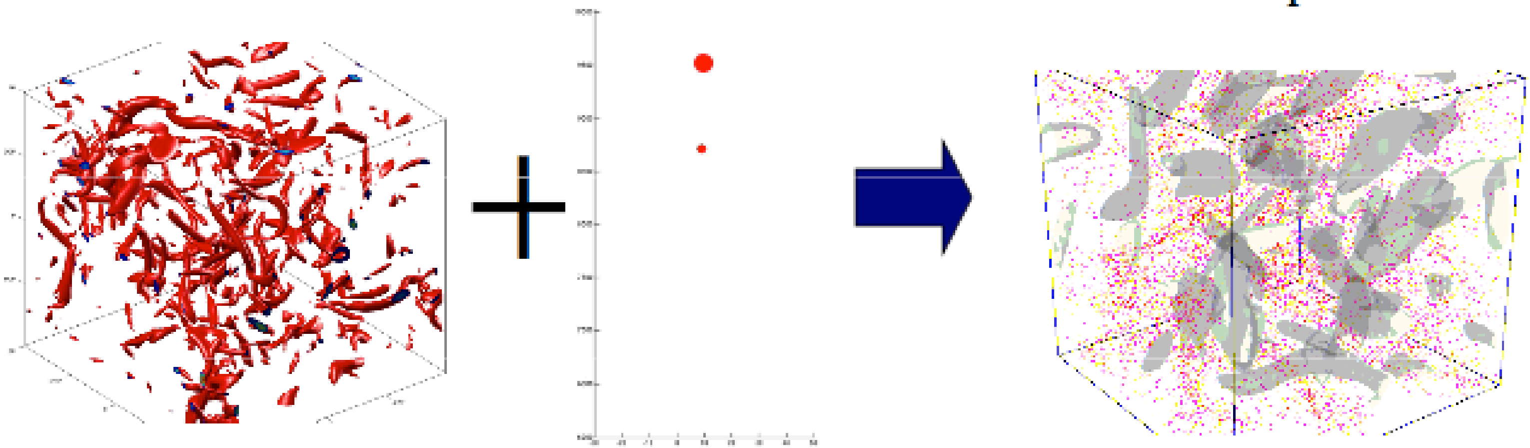
$$E_c = \frac{y_c^2}{(a_1 + a_2)^2}$$

The hybrid DNS approach: including disturbance flows due to droplets

$$\vec{U}(\vec{x},t)+\sum_{k=1}^{N_p}\vec{u}_s(\vec{r}_k;a_k,\vec{V}_k-\vec{U}(\vec{Y}_k,t)-\vec{u}_k)$$

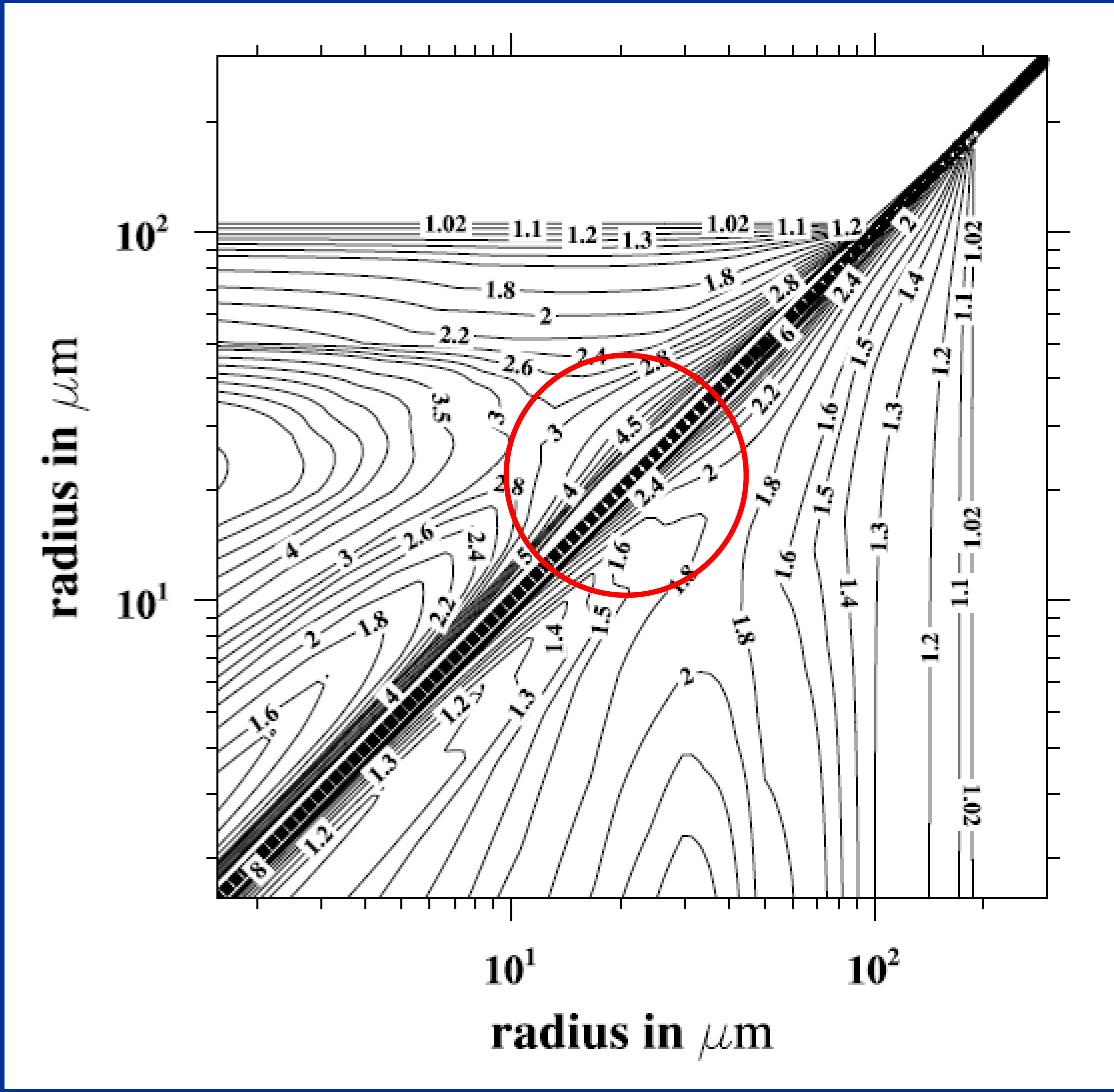
Background turbulent flow

Disturbance flows due to droplets



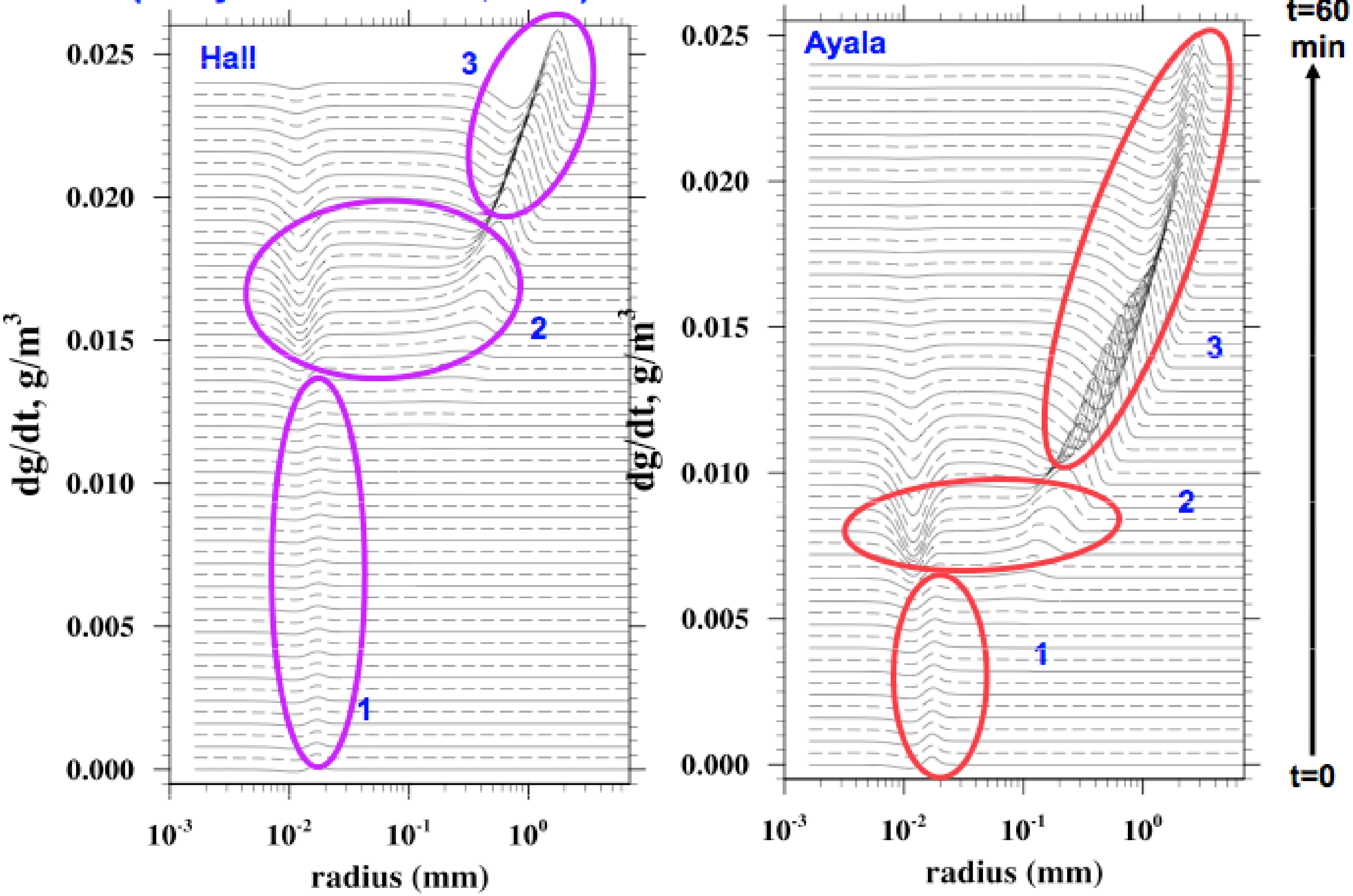
Features: Background turbulent flow can affect the disturbance flows;
No-slip condition on the surface of each droplet is satisfied on average;
Both near-field and far-field interactions are considered.

Wang, Ayala, and Grabowski, J. Atmos. Sci. **62**: 1255-1266 (2005).
Ayala, Wang, and Grabowski, J. Comp. Phys. **225**: 51-73 (2007).



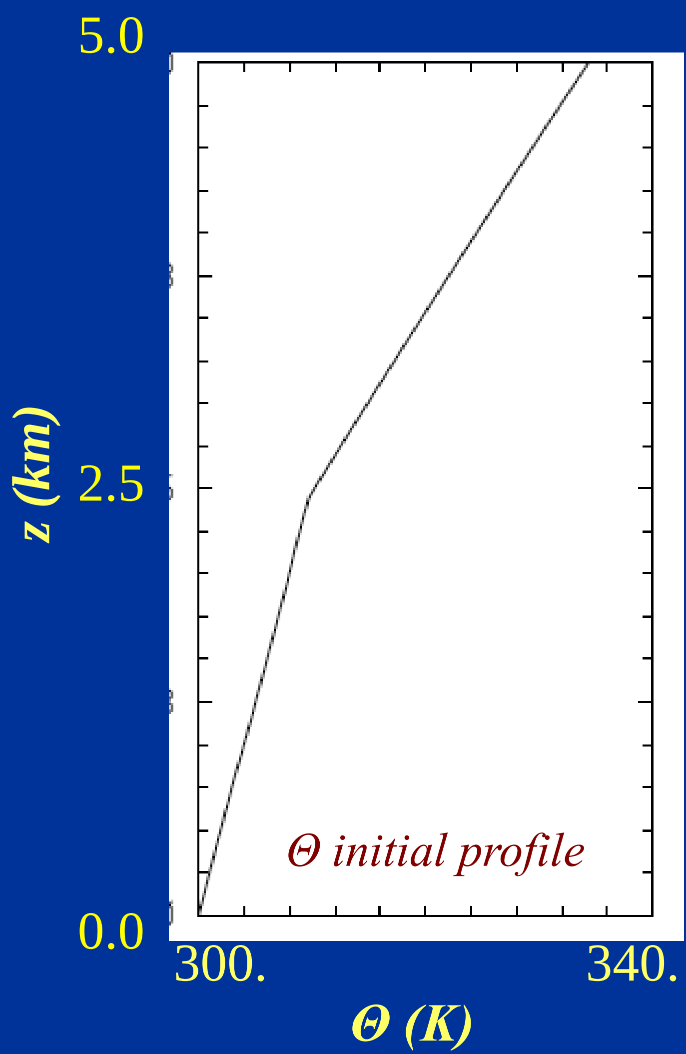
Enhancement factor for the collision kernel (the ratio between turbulent and gravitation collision kernel in still air) including turbulent collision efficiency; ε = 100 and 400 $cm^2\ s^{-3}$.

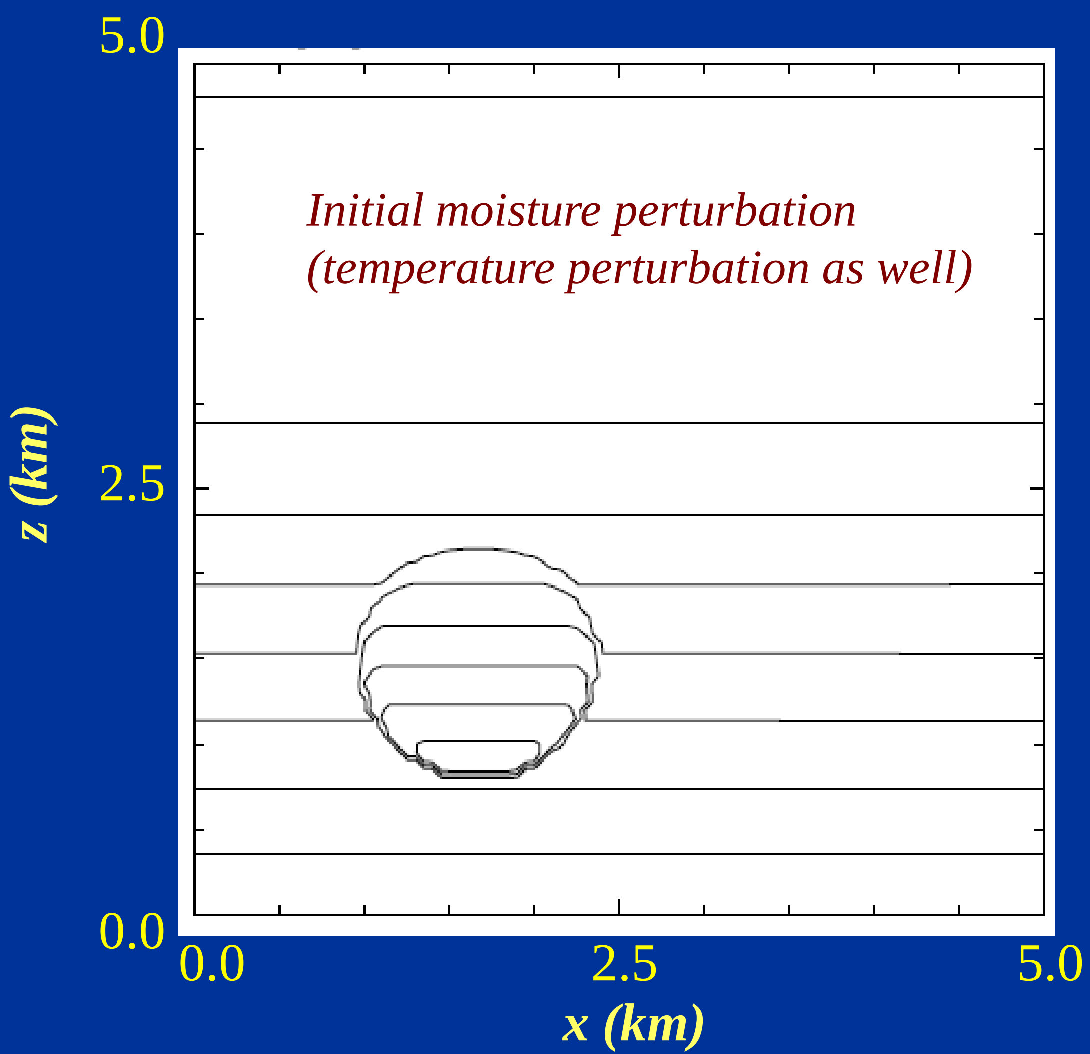
1. Autoconversion; 2. Accretion; 3. Hydrometeor self-collection
(Berry and Reinhardt, 1974)



Idealized baby-EULAG simulations with bin microphysics:

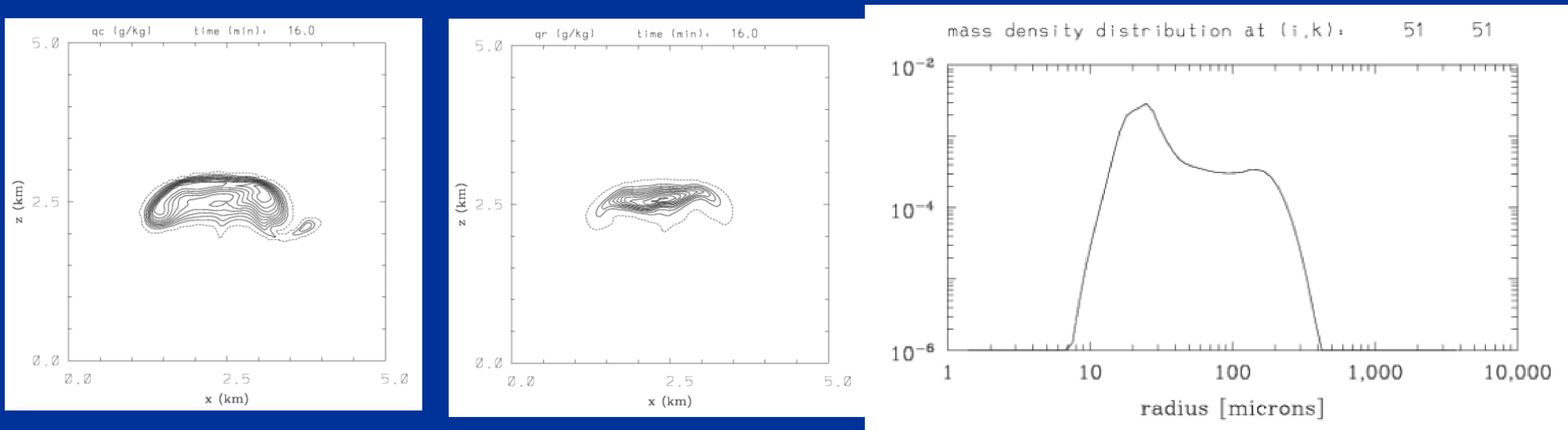
Setup as in Grabowski et al (JAS 2009): 2D domain, 50 m gridlength, 72 bins, maritime aerosol.

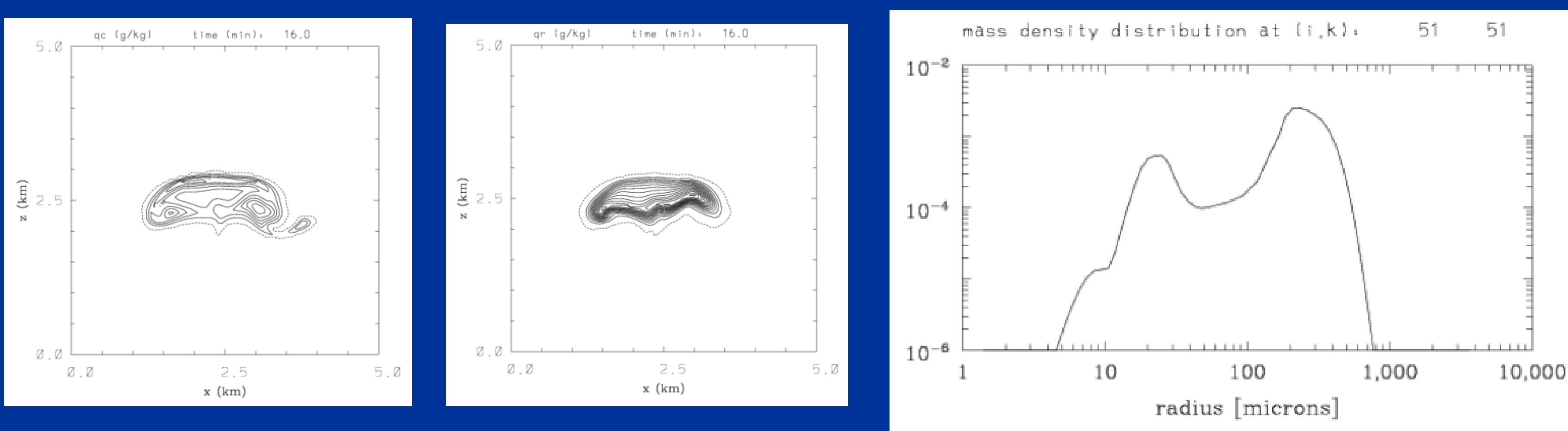




2D simulation of a small precipitating cloud: t=16 min

no turbulence

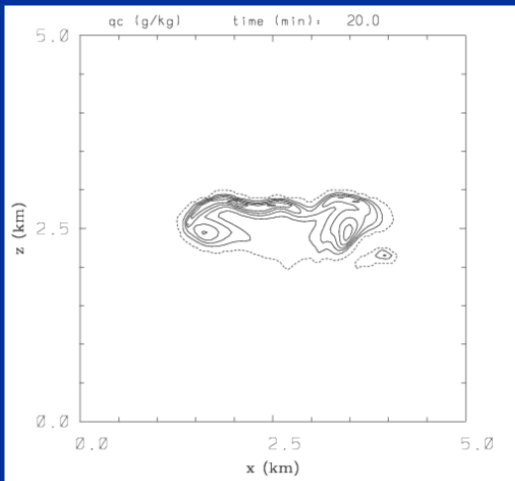


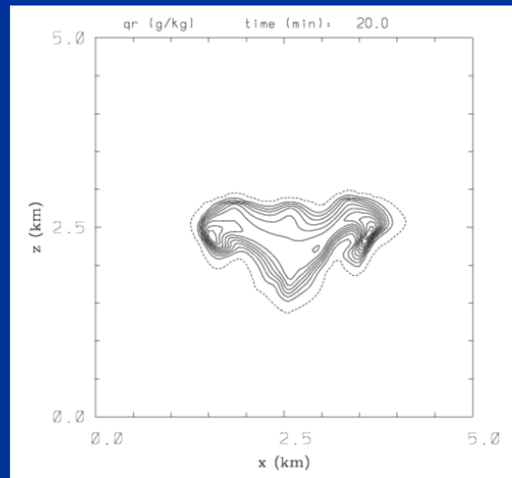


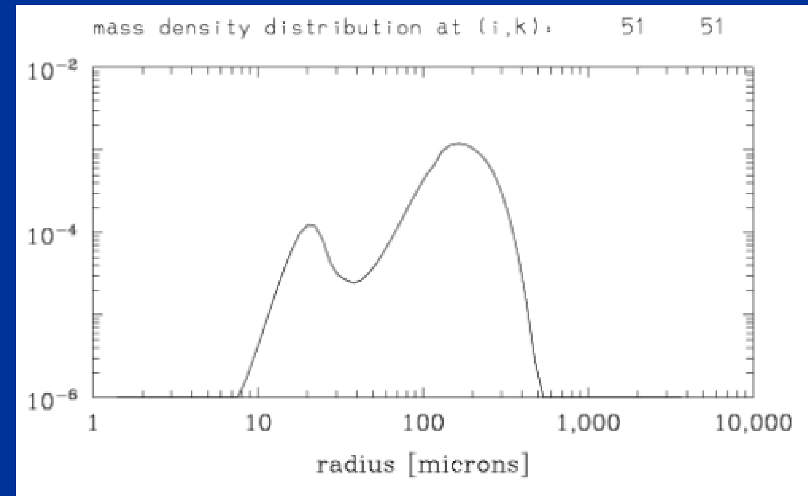
with turbulence – Ayala kernel with 100 cm^{2}s^{-3}

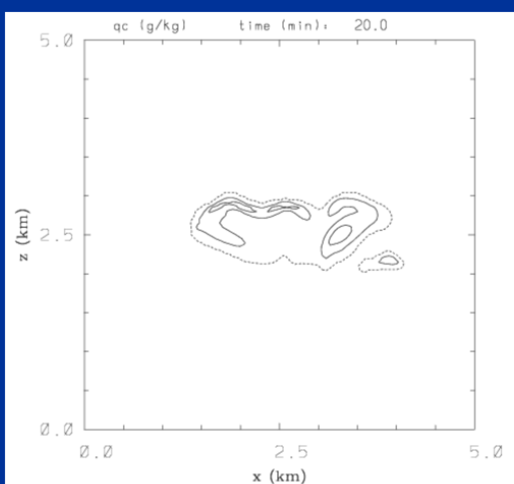
2D simulation of a small precipitating cloud: t=20 min

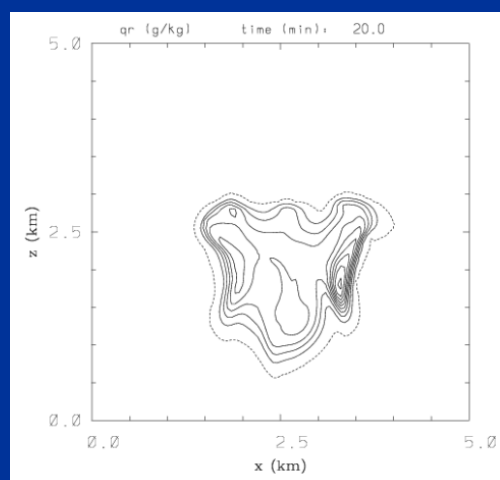
no turbulence

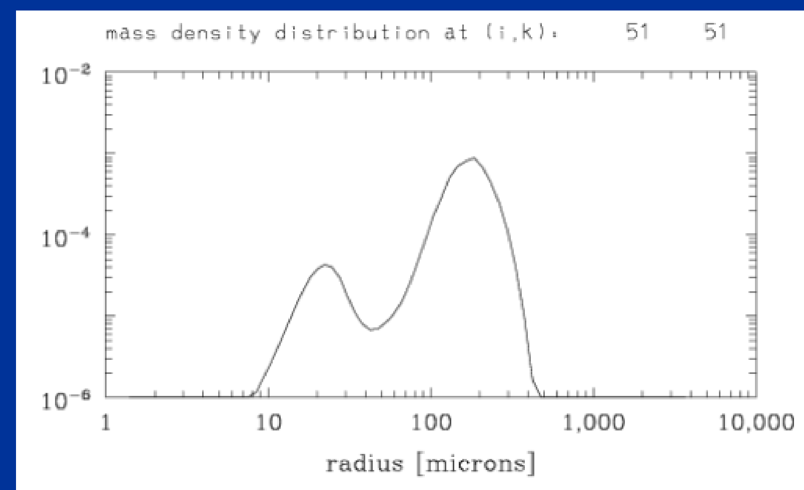








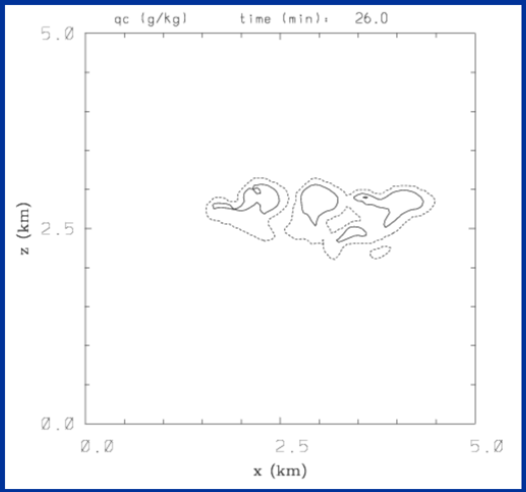


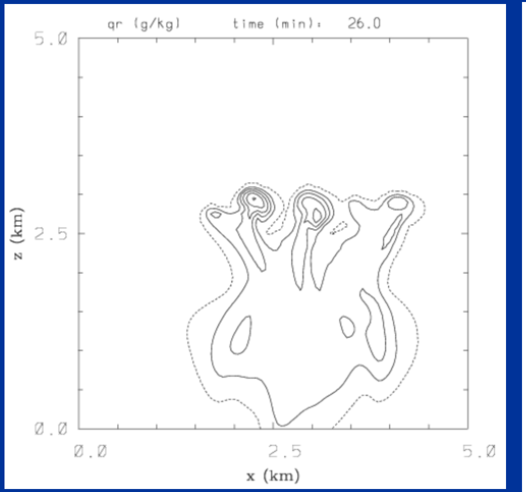


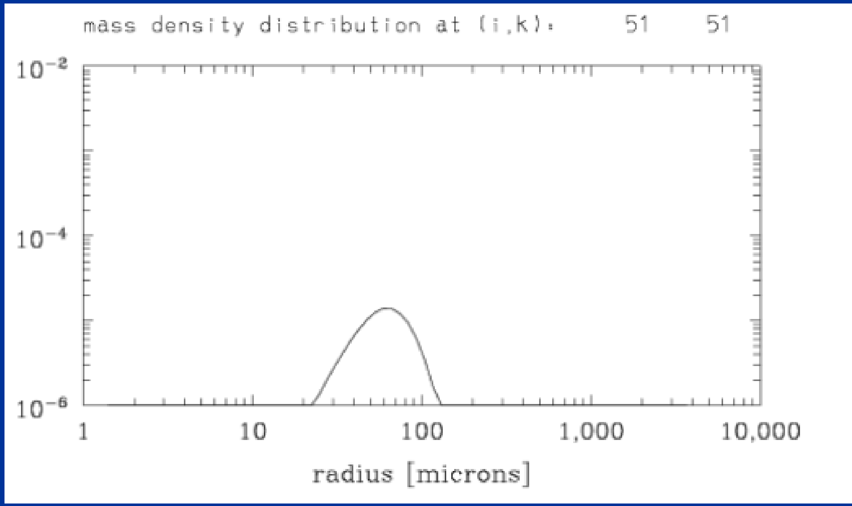
with turbulence – Ayala kernel with 100 cm^2s^{-3}

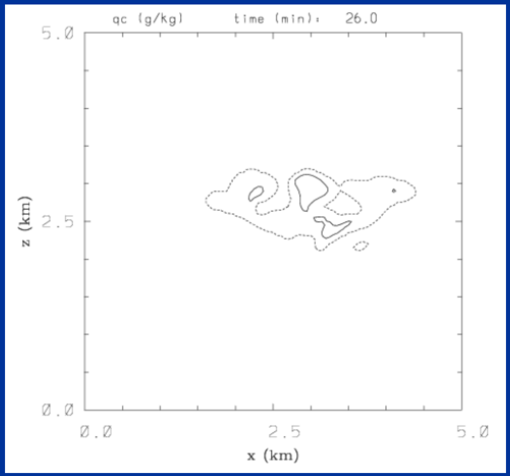
2D simulation of a small precipitating cloud: t=26 min

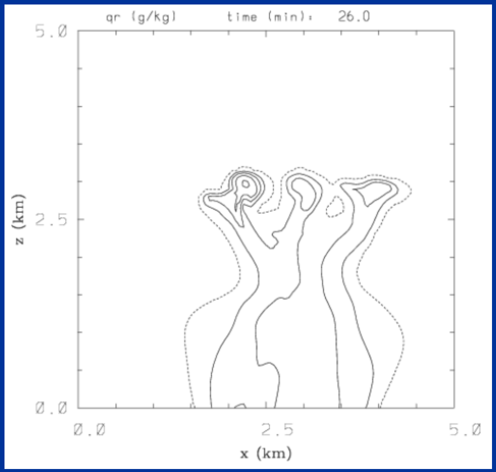
no turbulence

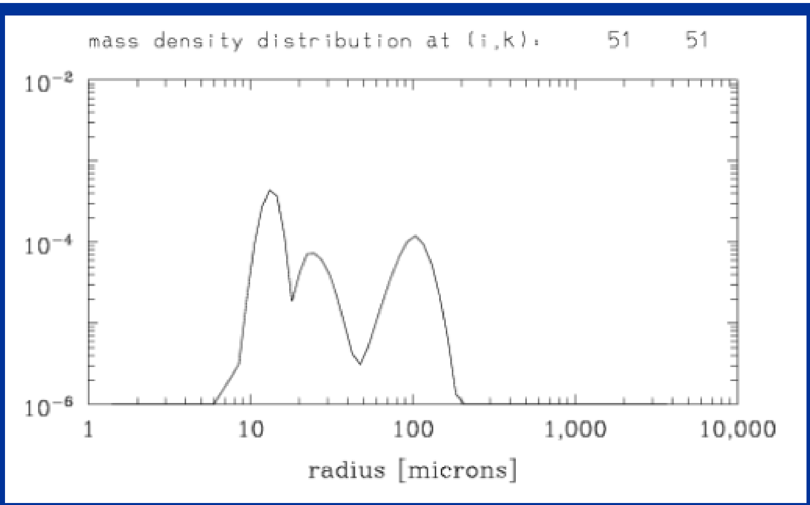






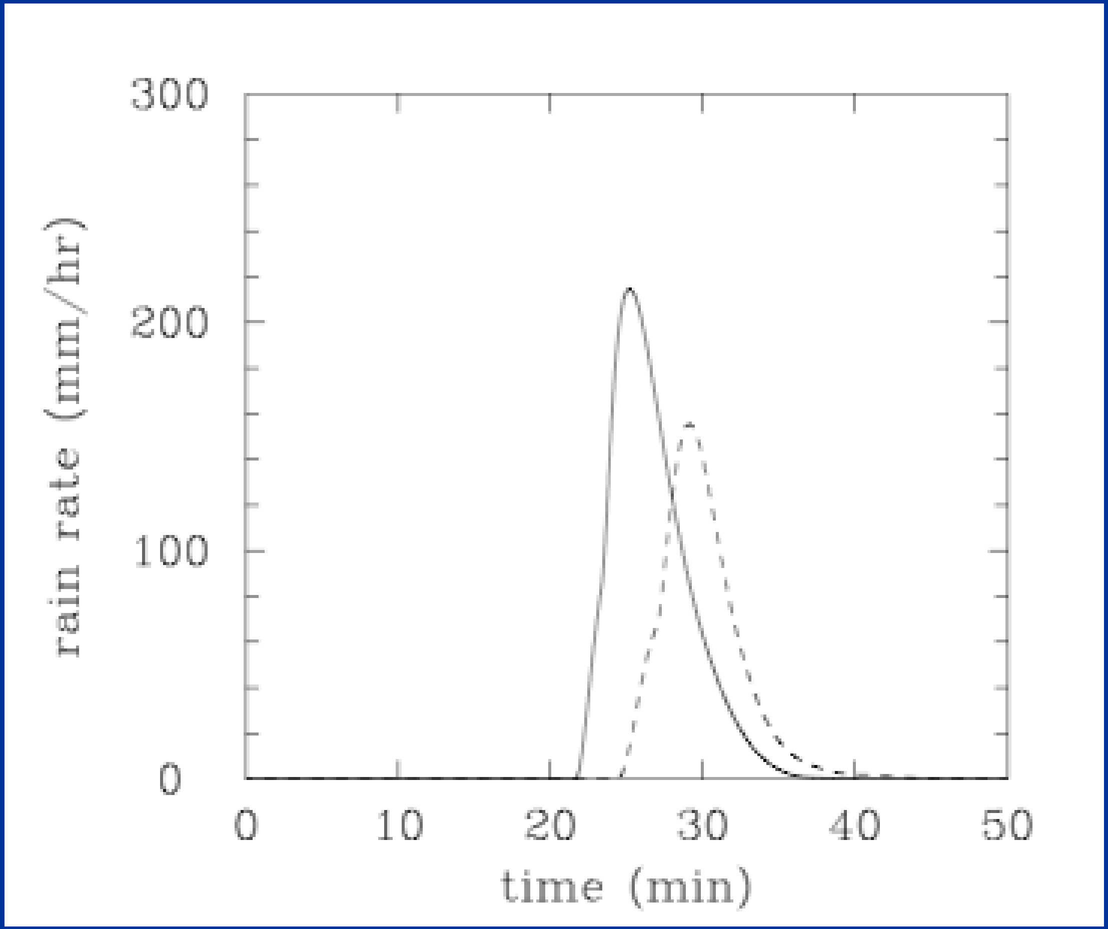




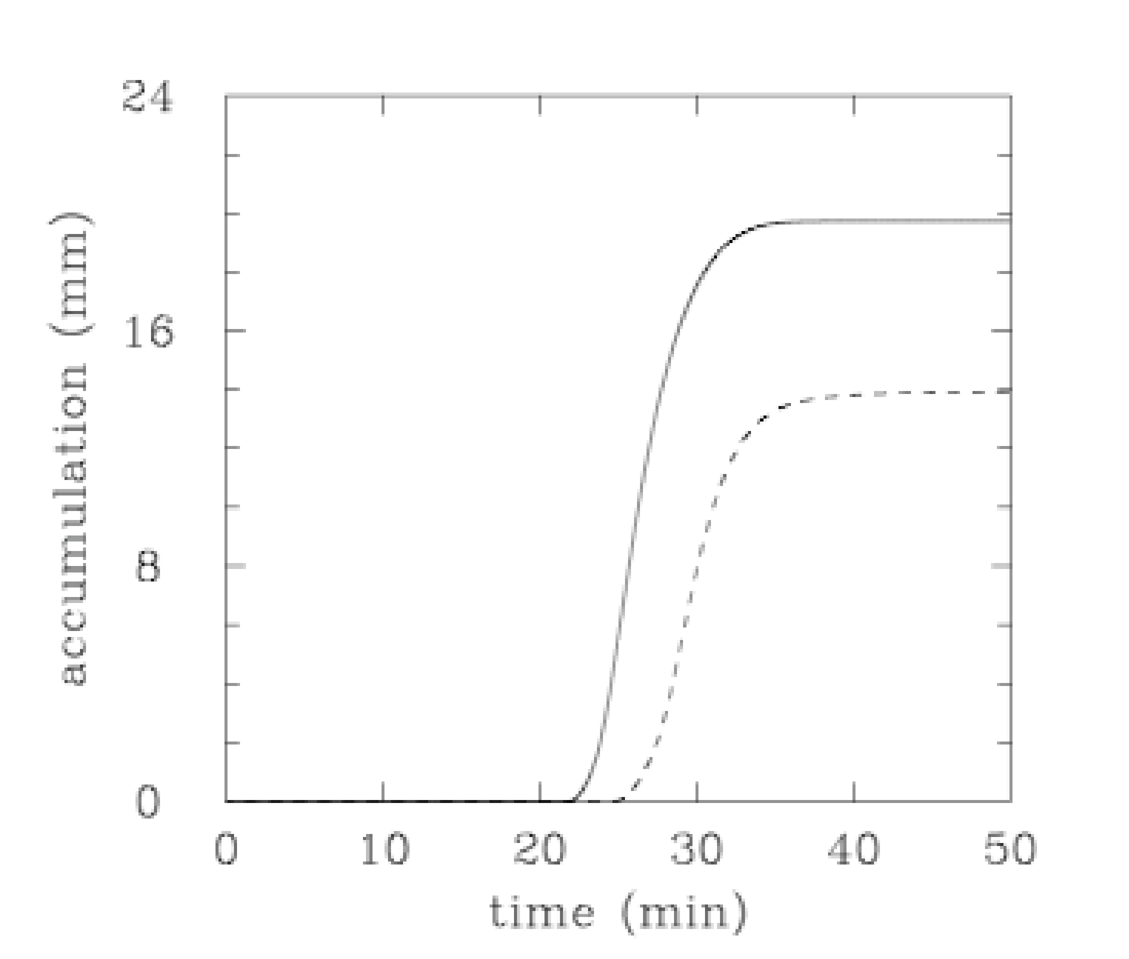


with turbulence – Ayala kernel with 100 cm^2s^{-3}

Time evolution of the surface rain rate



Time evolution of the surface rain accumulation



SUMMARY:

-Guided by DNS, turbulent enhancement of the gravitational collision kernel has been developed (Ayala et al. papers).

-Simple tests show that turbulence can significantly enhance growth of cloud droplets by collision/coalescence, resulting in earlier rain formation, but also in more rain falling from a given cloud.

-More realistic large-eddy simulations with *local* enhancement of the kernel are needed to fully assess the impact of turbulence on rain development.