Evaluation of vertical mass flux in high-resolution simulations of convective clouds

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Outline

1) Motivation

2) Model set-up

3) Results from control simulation

4) Outlook (Simulation & Evaluation)

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Motivation

Craig and Cohen (2006) & Cohen and Craig (2006)

→ probability density function for the mass flux of a single cloud

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Assumptions:

- Region small enough that forcing does not vary significantly, but large enough to contain many clouds

- Forcing varies slowly
  → convection reaches an equilibrium state

- Convective clouds are sufficiently separated
  → interactions can be ignored

- Clouds are equally likely to occur in any location & with any mass flux

Motivation

Craig and Cohen (2006) & Cohen and Craig (2006)

→ probability density function for the mass flux of a single cloud

$$p(m)dm = \frac{1}{\langle m \rangle} e^{-m/\langle m \rangle} dm$$

$\langle m \rangle$: Ensemble average mass flux per cloud

Motivation

Craig and Cohen (2006) & Cohen and Craig (2006)

$\rightarrow$ mean cloud number density distribution

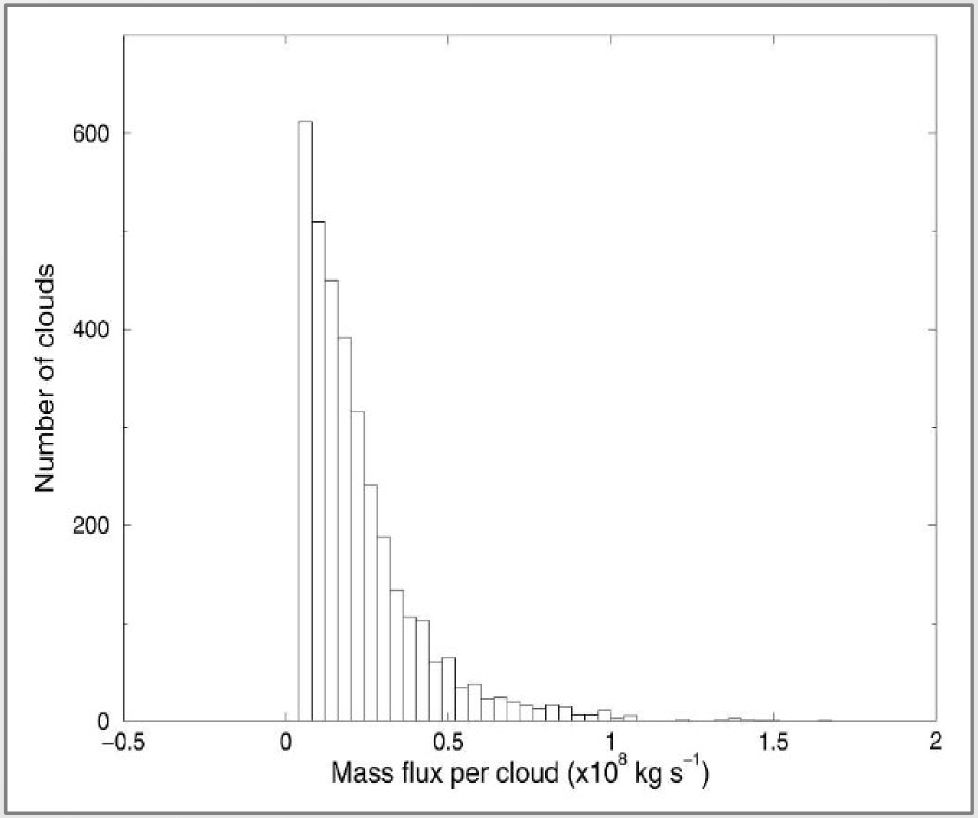
$$d\overline{n}(m) = \frac{\langle N \rangle}{\langle m \rangle} e^{-m/\langle m \rangle} dm$$

$\langle N \rangle$	:	Ensemble average number of clouds
$\langle m \rangle$	:	Ensemble average mass flux per cloud

Motivation

Histogramm: distribution of mass flux per cloud

$$d\overline{n}(m) = \frac{\langle N \rangle}{\langle m \rangle} e^{-m/\langle m \rangle} dm$$



Craig and Cohen (2006), Cohen and Craig (2006)

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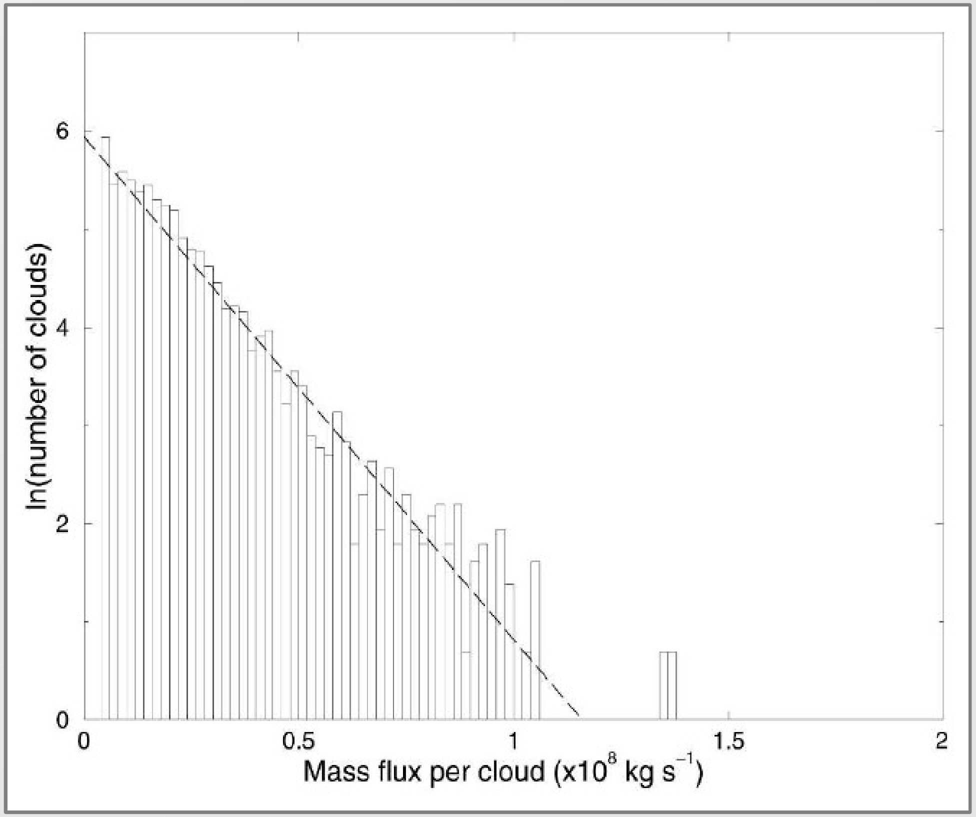

Craig and Cohen (2006), Cohen and Craig (2006)

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Craig and Cohen (2006) & Cohen and Craig (2006)

- Distribution exponential at 2 km for various forcings (e.g. -2 K/day, -16 K/day)

- increasing the forcing → increases the number of clouds in the domain

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Is this still true for higher resolutions (~100 m)?

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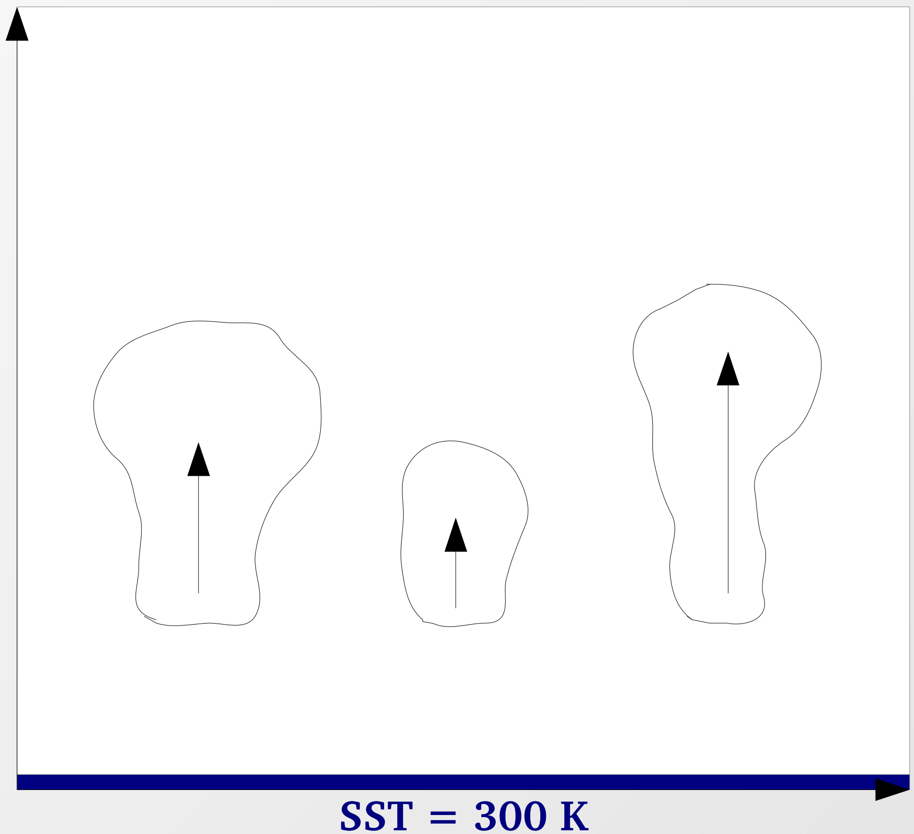
EULAG: set-up of the control simulation



- domain: 128 km * 128 km * 20 km

- 2 km   horizontal resolution
- 200 m vertical resolution
- time step: 1 s
- run time: ~3*10^6 time steps

- periodic boundaries in the horizontal
- damping layer in the vertical

- neglecting coriolis force

- SGS model: Smagorinsky-type turbulence model (Margolin et al., 1999)

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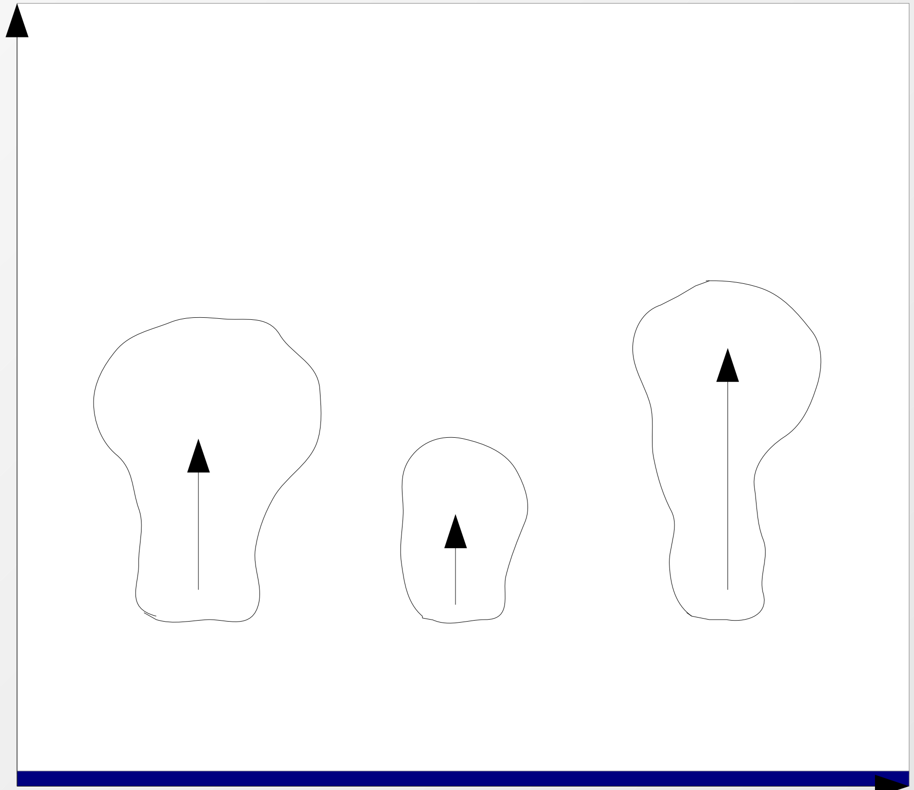
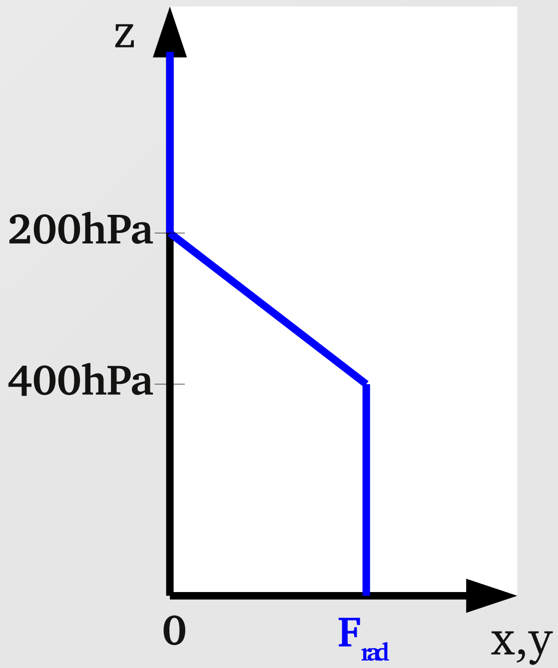


- horizontally homogeneous cooling $\mathbf{F}_{rad}$



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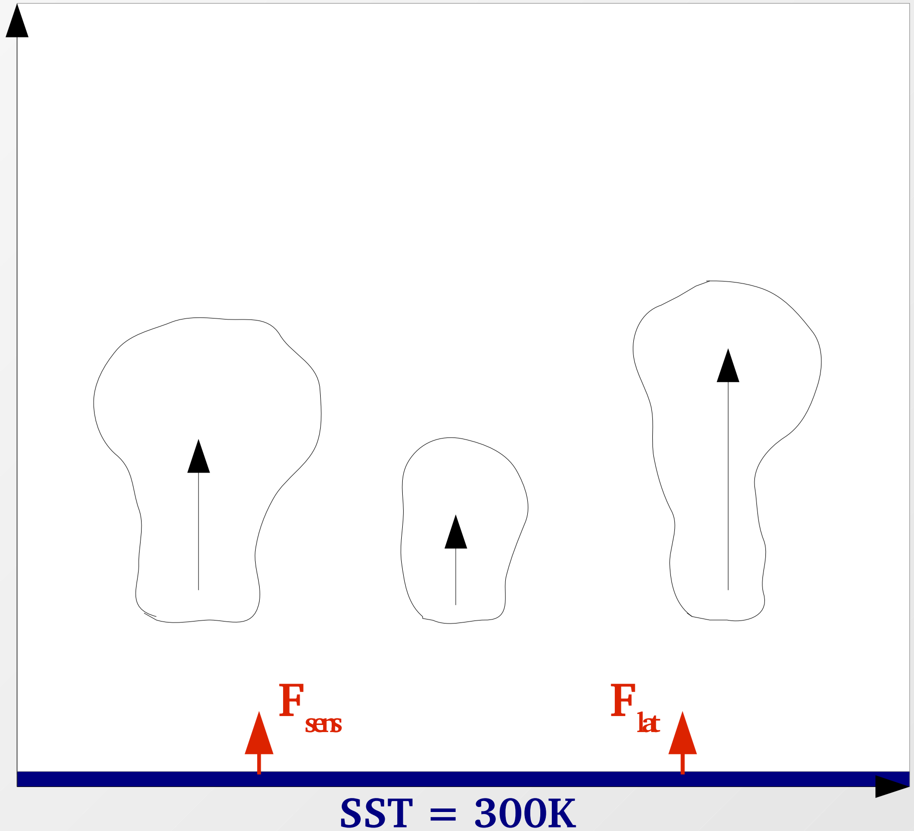

- horizontally homogeneous cooling $\mathbf{F}_{rad}$

- surface fluxes of sensible and latent heat computed according to a simple bulk formula: $\mathbf{F}_{sens}$, $\mathbf{F}_{lat}$

(Grabowski, 1998)

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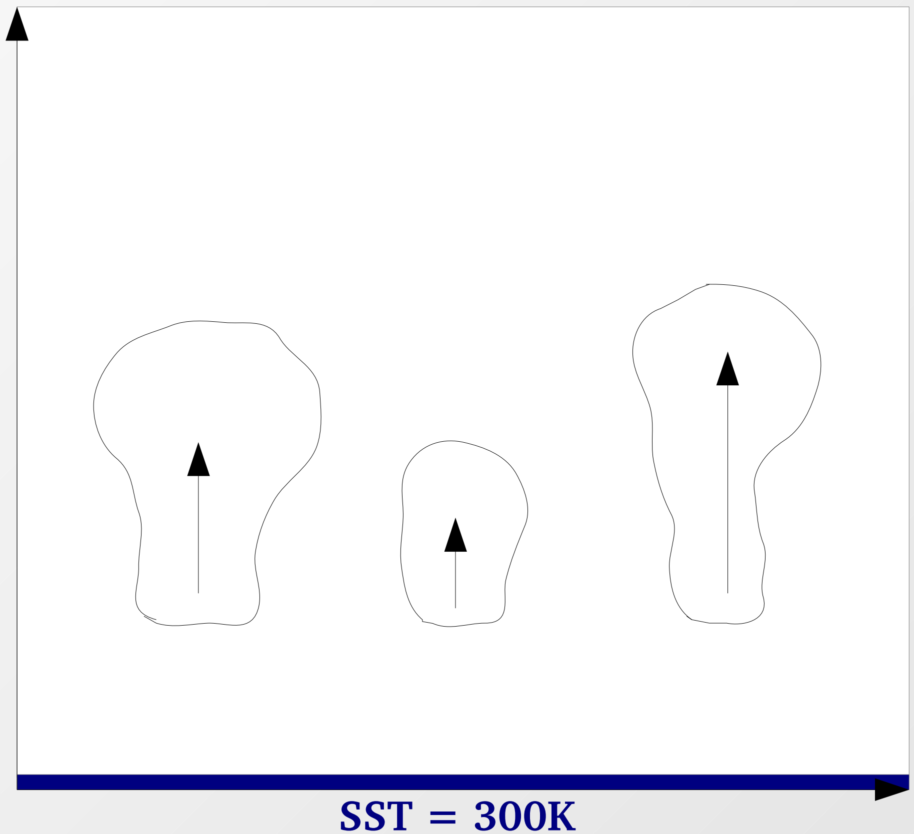

- Mean soundings from the west indies (Jordan, 1958) as background profiles

- initially at rest
- small perturbation of w-field

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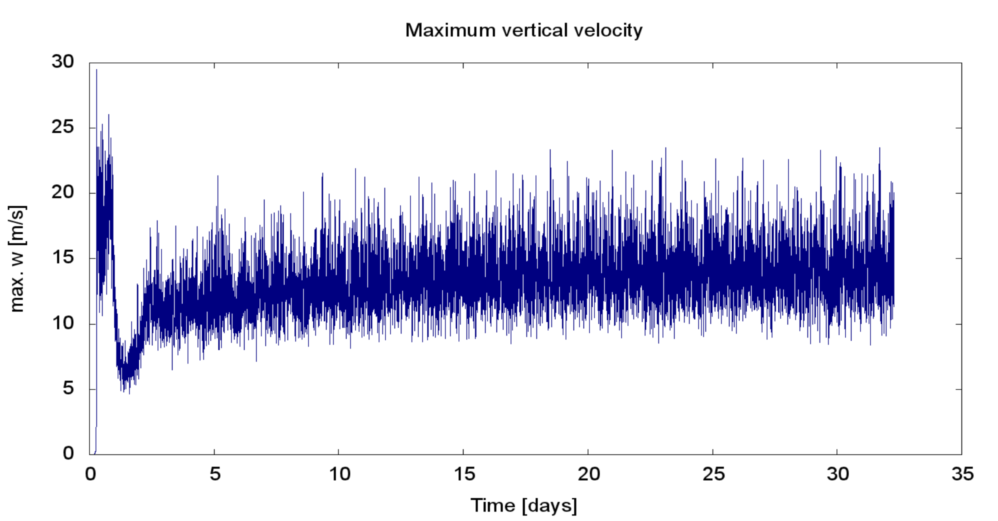
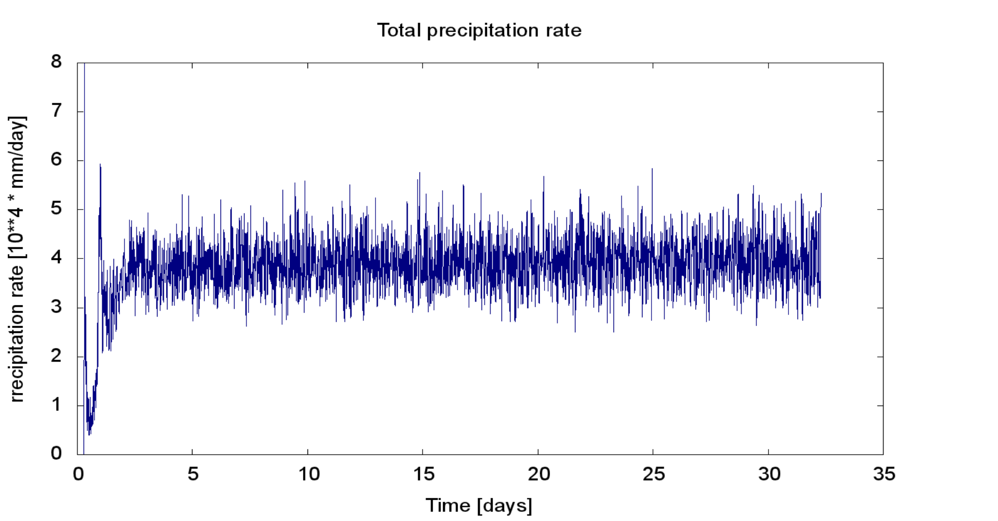
RESULTS of the control simulation

Timeseries: evolution of the simulation towards radiative-convective equilibrium





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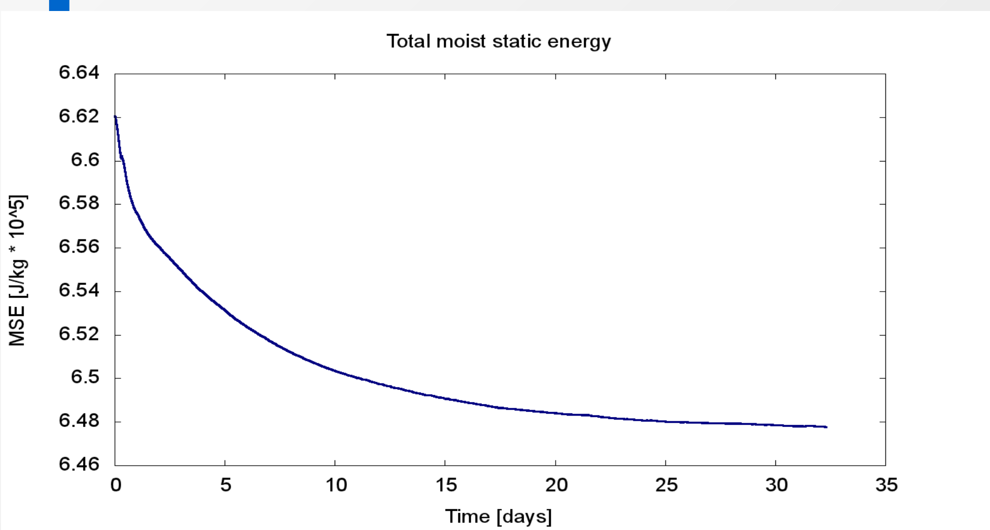
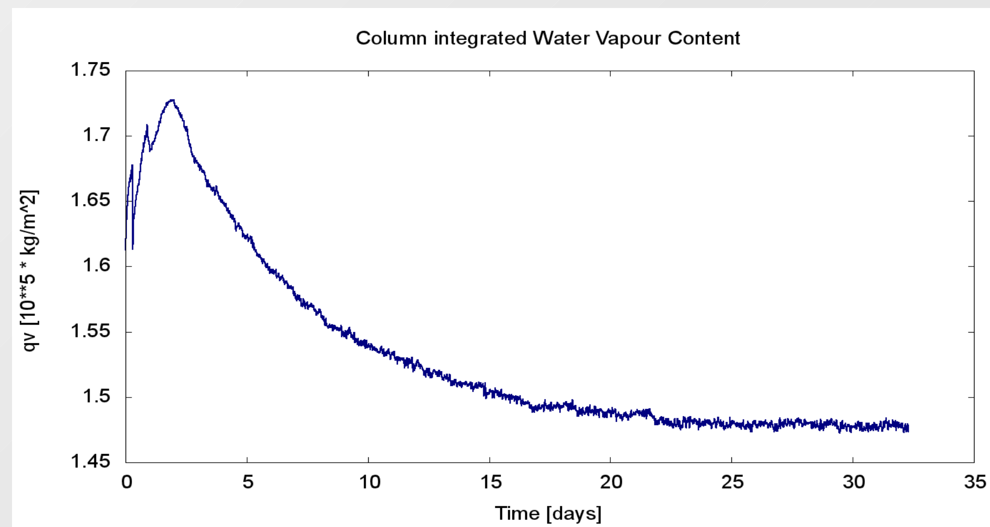


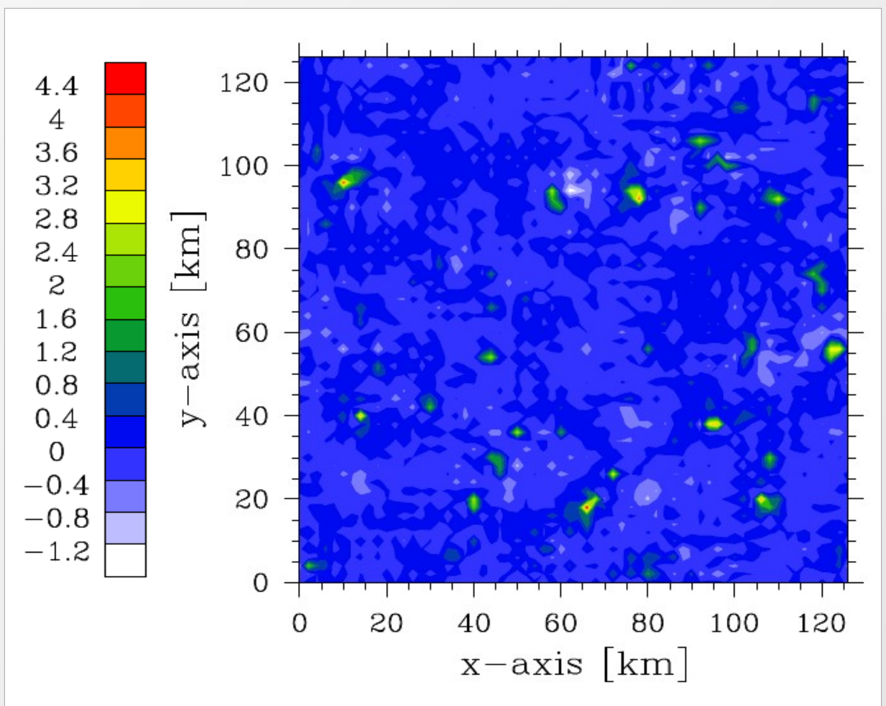


$$MSE = c_P*T + g*z + L_v*q$$

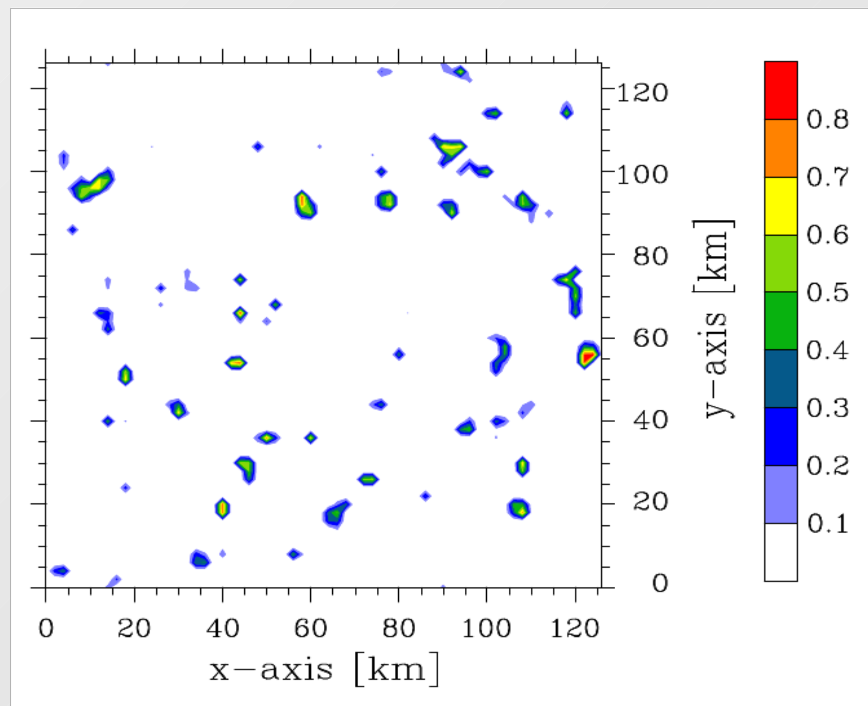
RESULTS of the control simulation

the equilibrium state: horizontal slices through the domain (z=1.8km)

Vertical velocity [m/s]



Cloud water/ice [g/kg]



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Computation of mass flux per cloud:

- x-y slice of vertical wind field at 1.8 km

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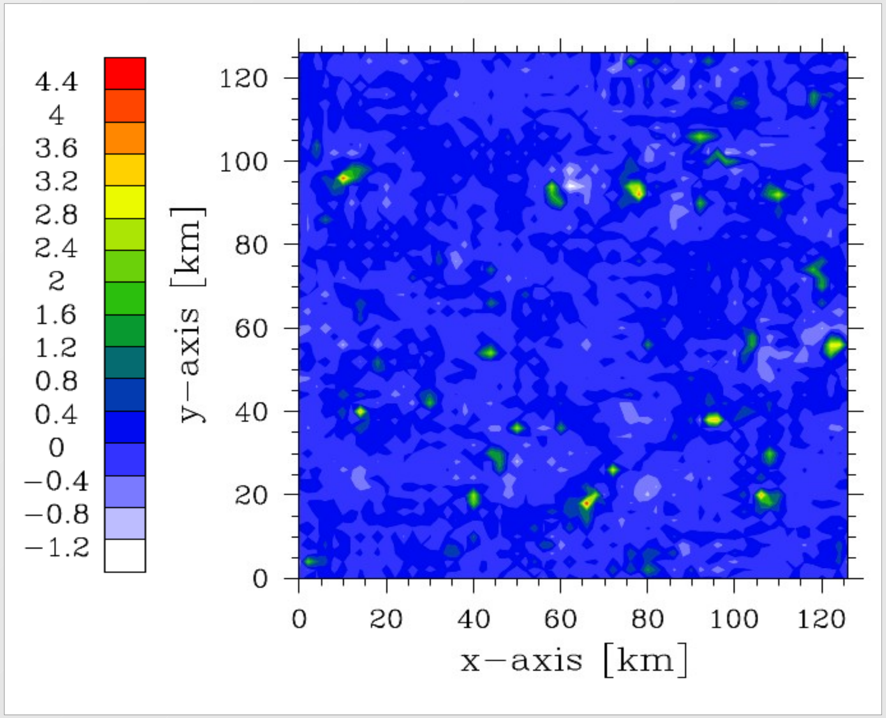

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- “cloudy grid point” where w > 1 m/s

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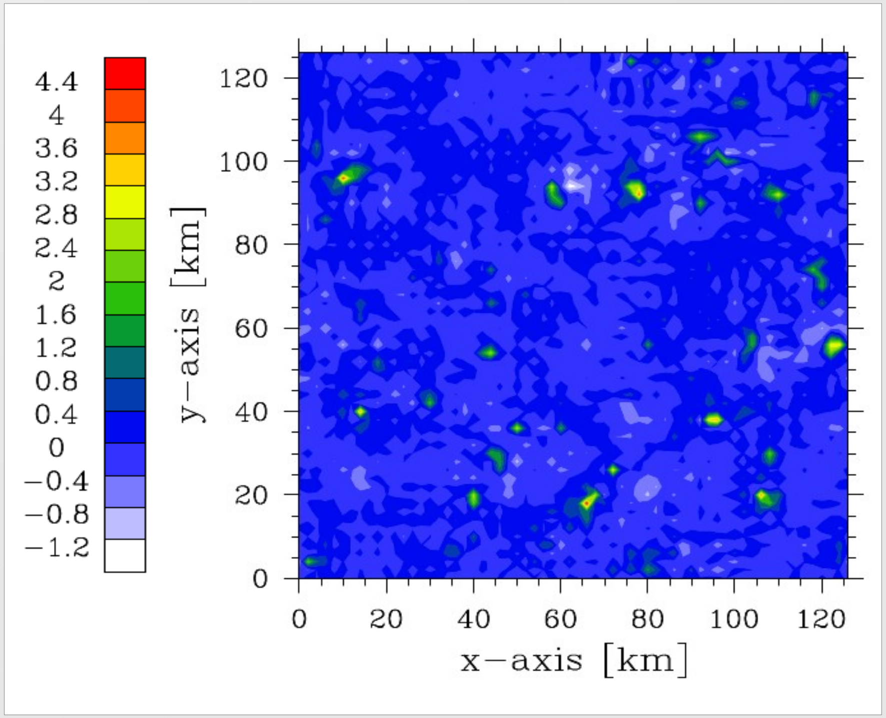

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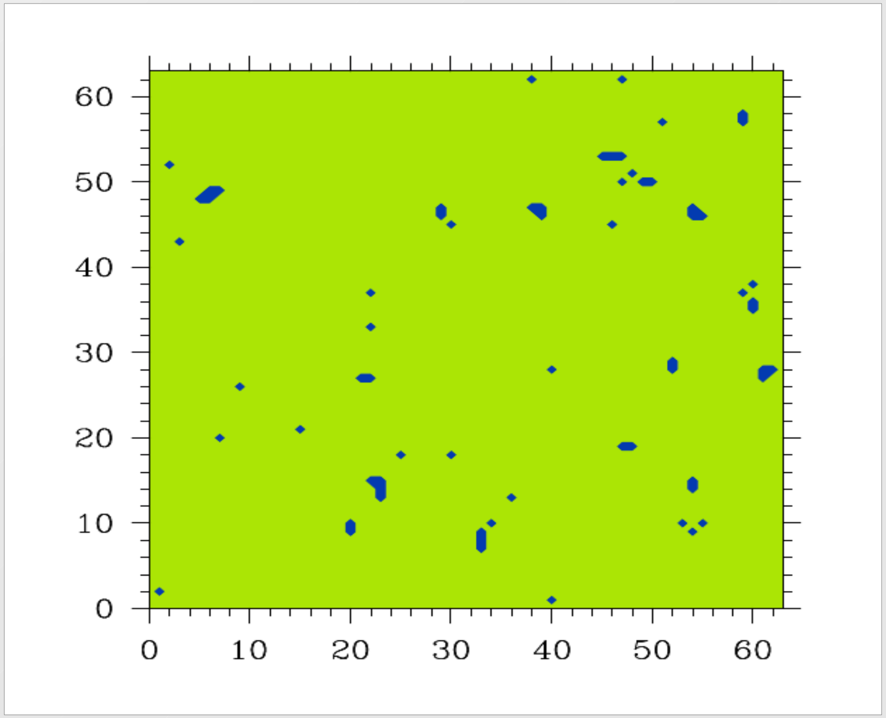

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→ domain is searched for adjacent cloudy grid points

(Hoshen and Kopelman (1976), Dahl et al. (2011))

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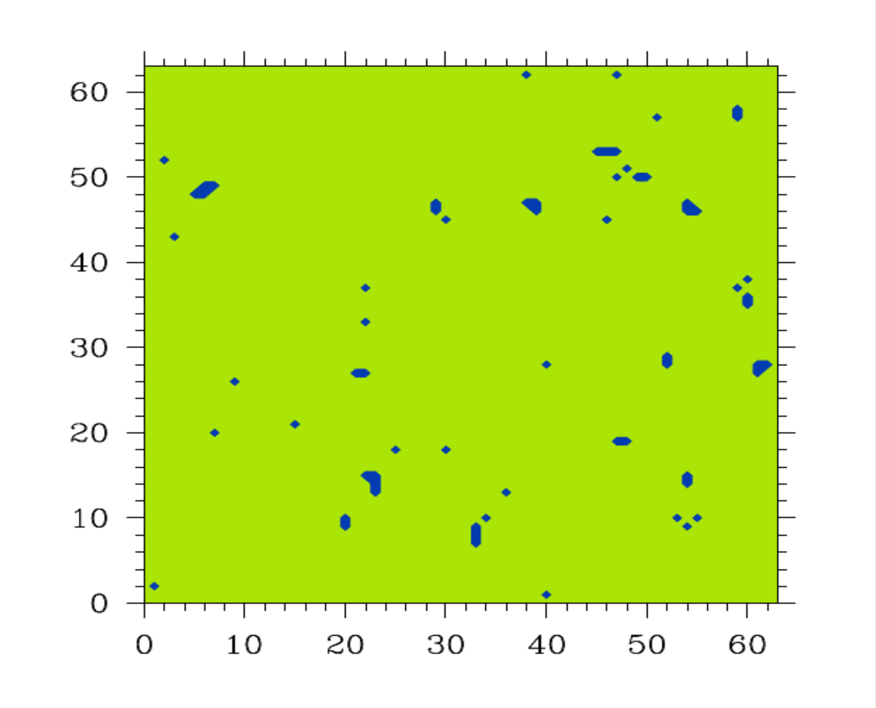

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(Hoshen and Kopelman (1976), Dahl et al. (2011))

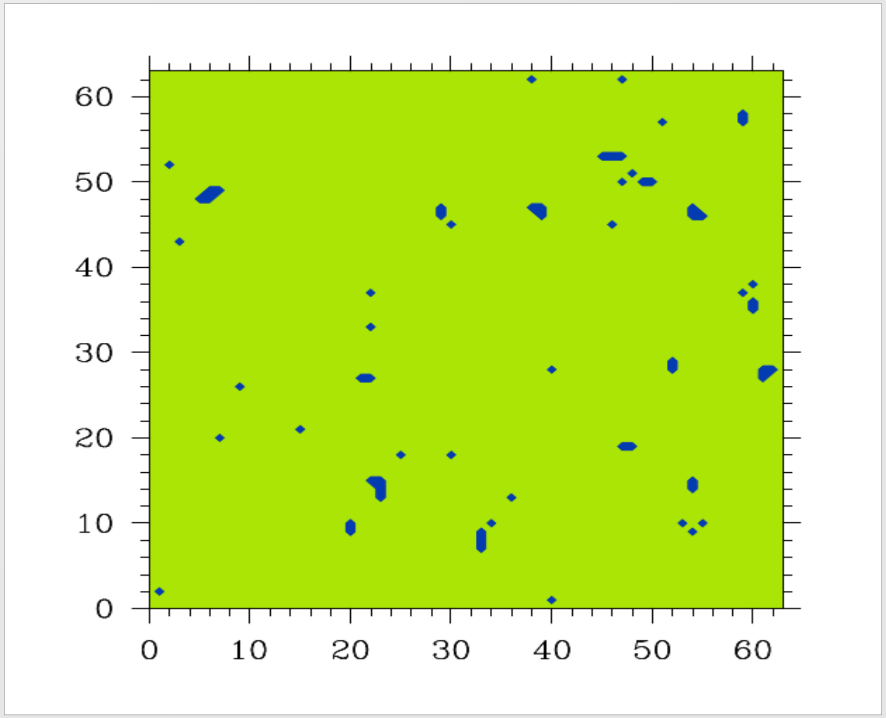
$$\boxed{m_i = \rho * \sigma_i * \langle w_i \rangle}$$

ρ : density of air

σ_i : size of the cloud

$\langle w_i \rangle$: average vertical velocity

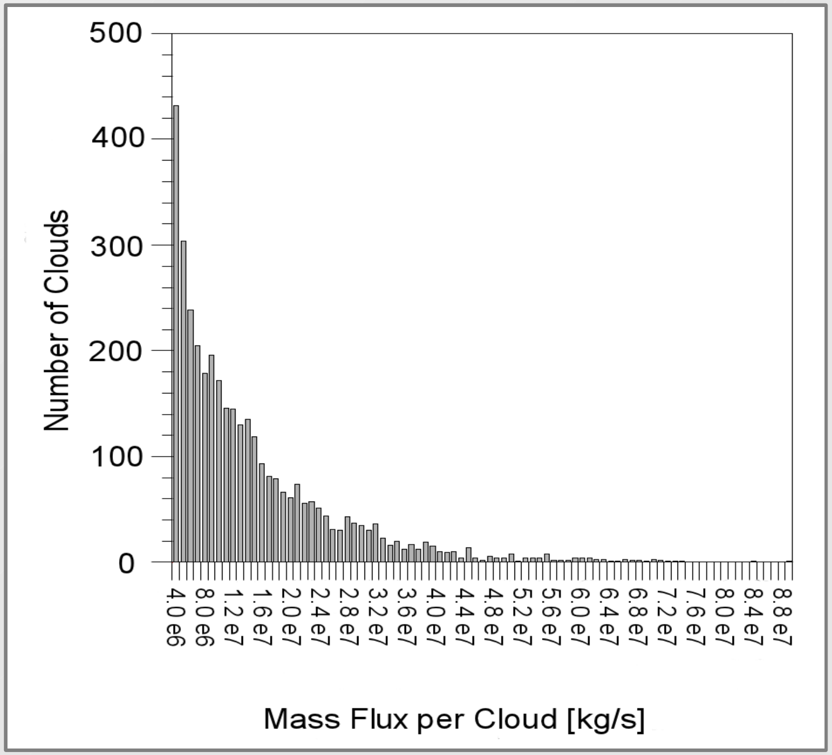
Vertical velocity [m/s]



RESULTS of the control simulation

Histogram: distribution of mass flux per cloud

Is this distribution exponential?



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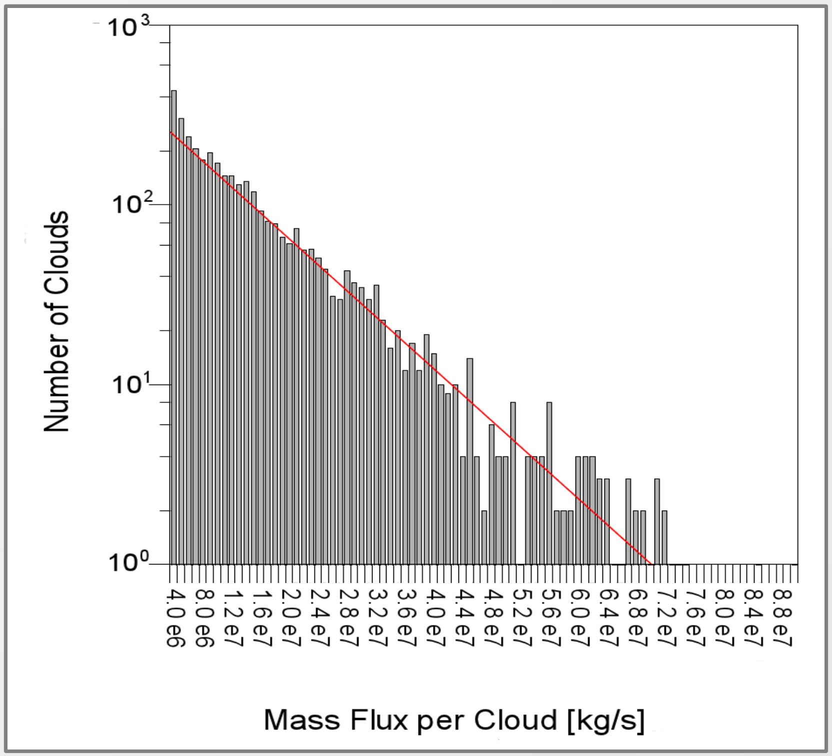
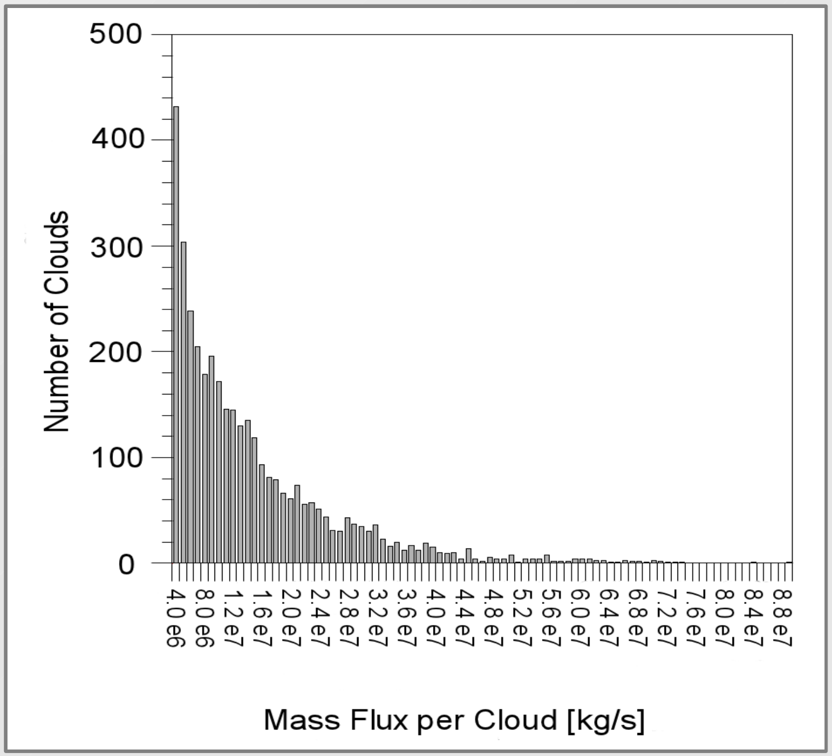
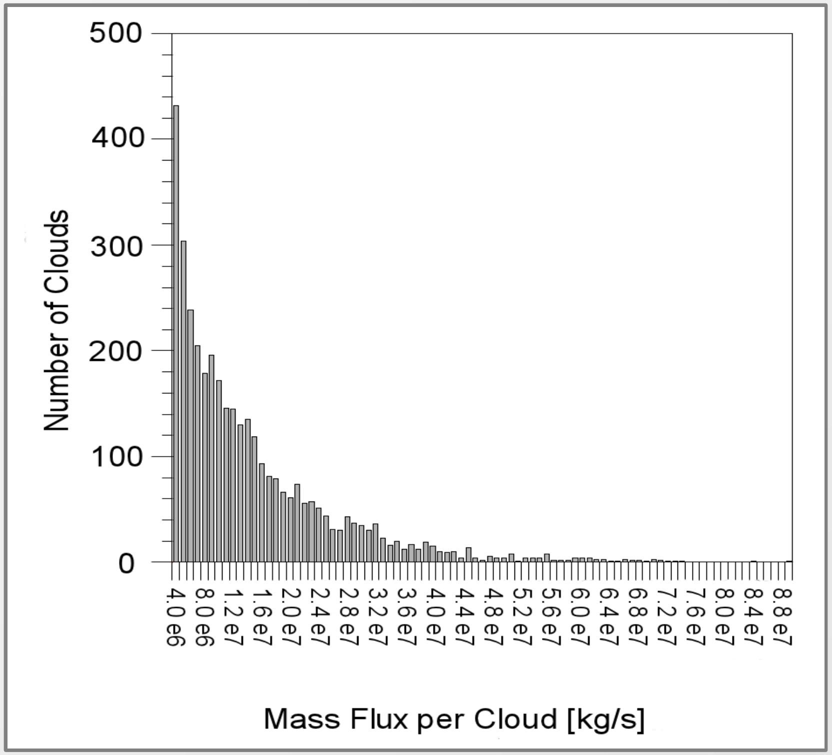


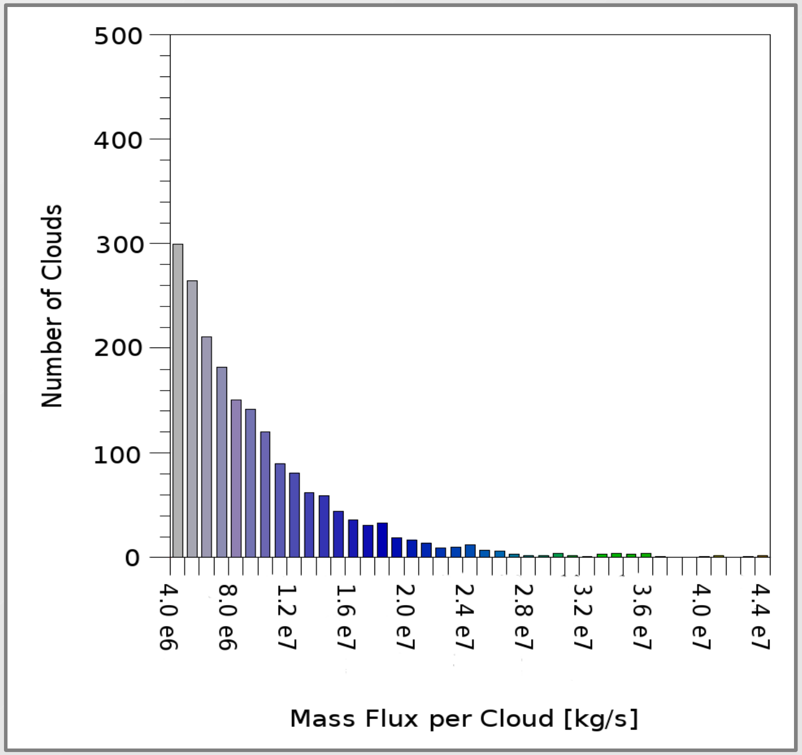


RESULTS of the control simulation

-8 K/day



-4 K/day



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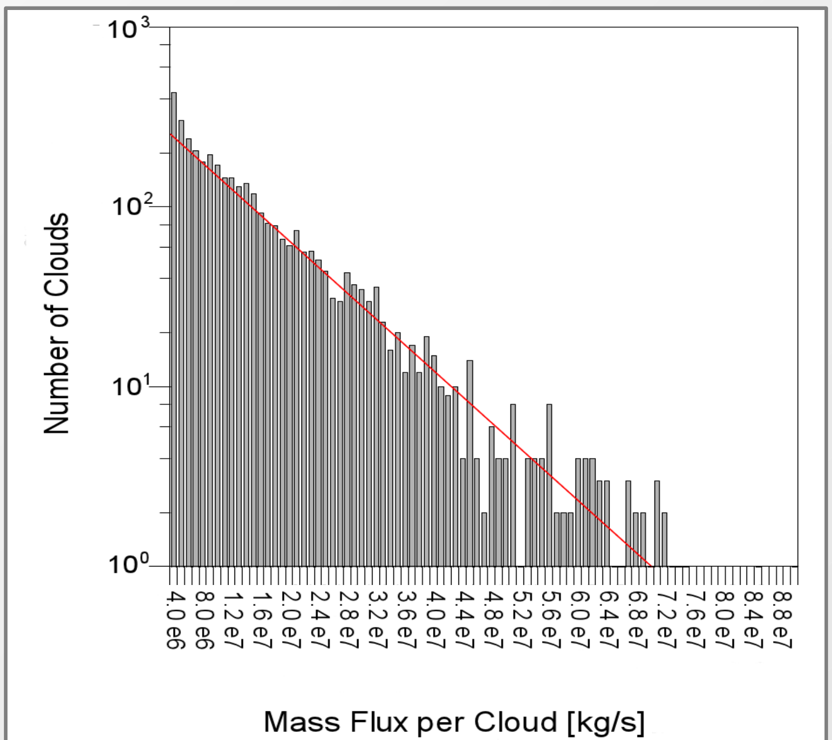

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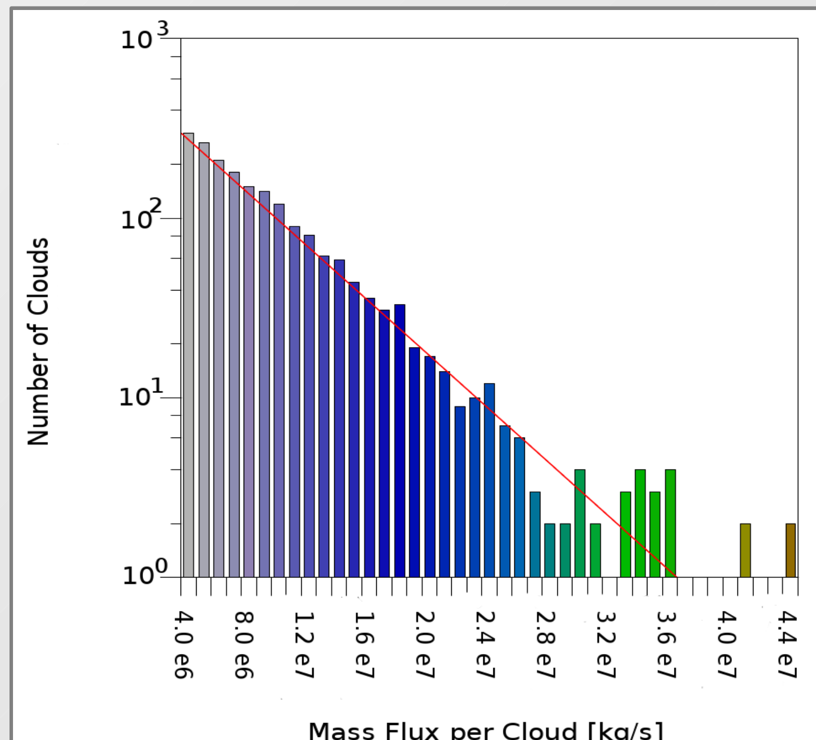
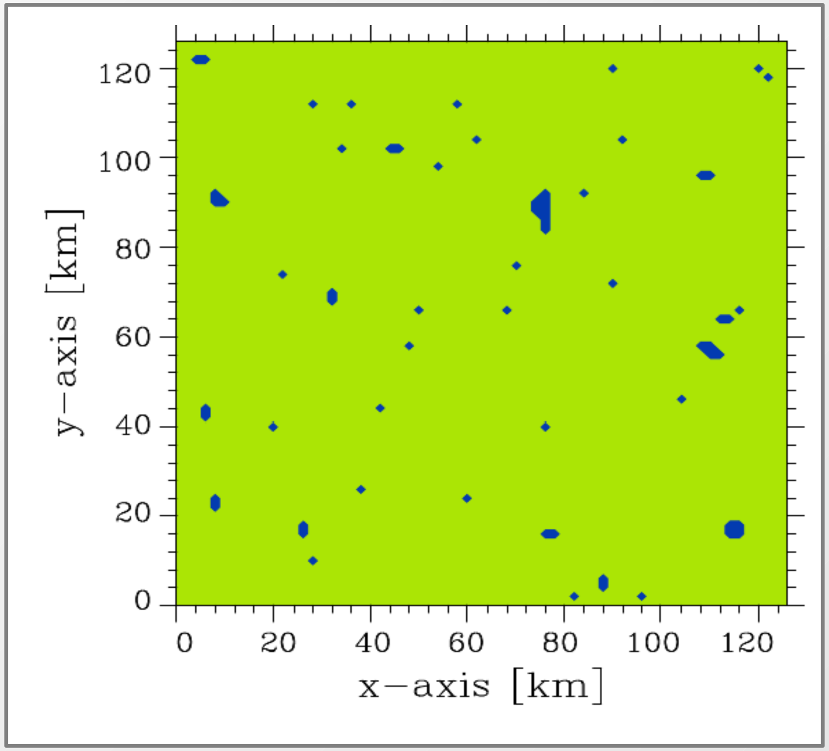


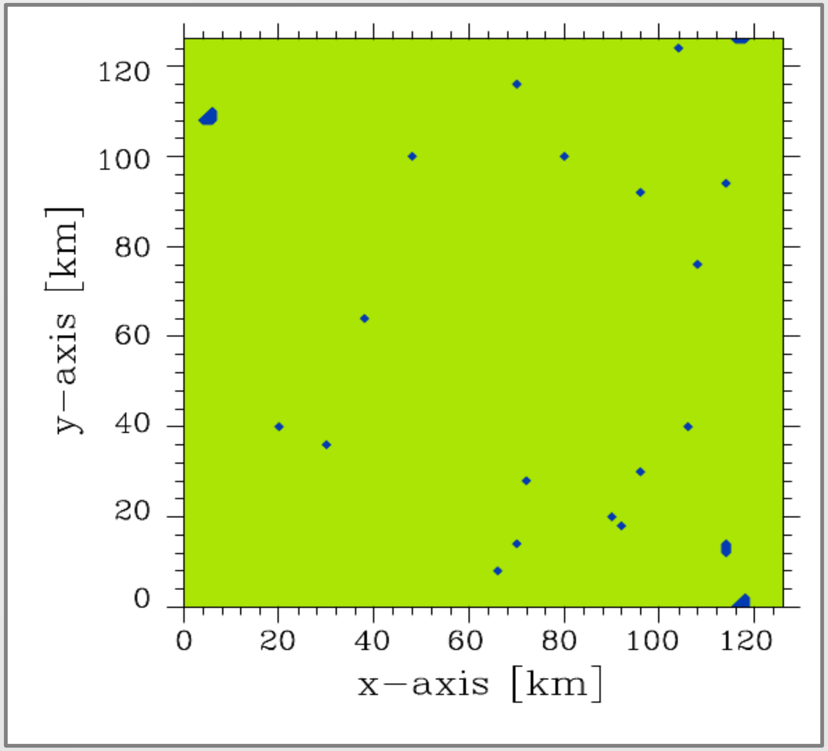
RESULTS of the control simulation

Number of clouds in the domain

-8 K/day

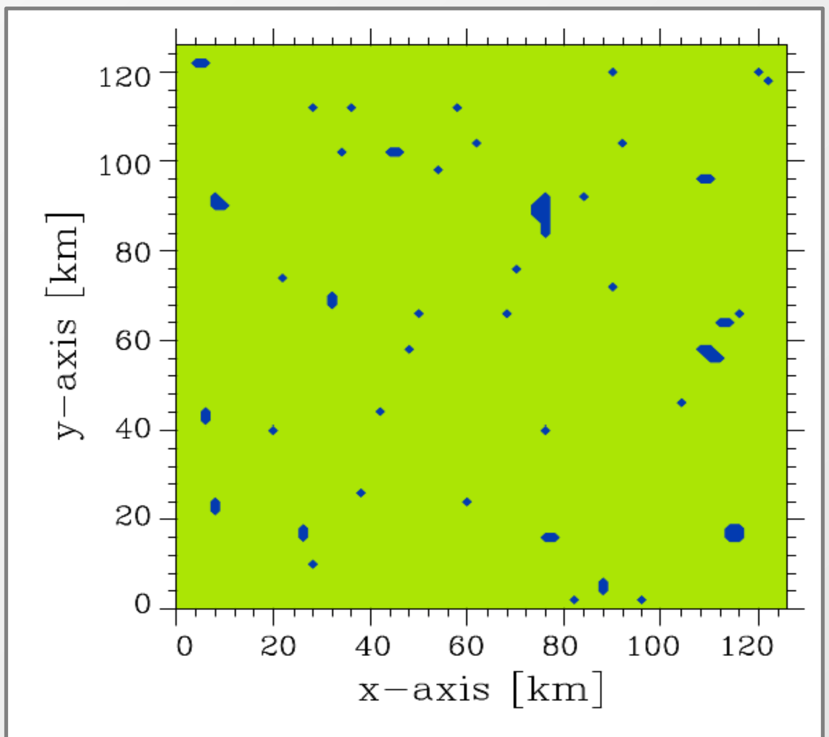


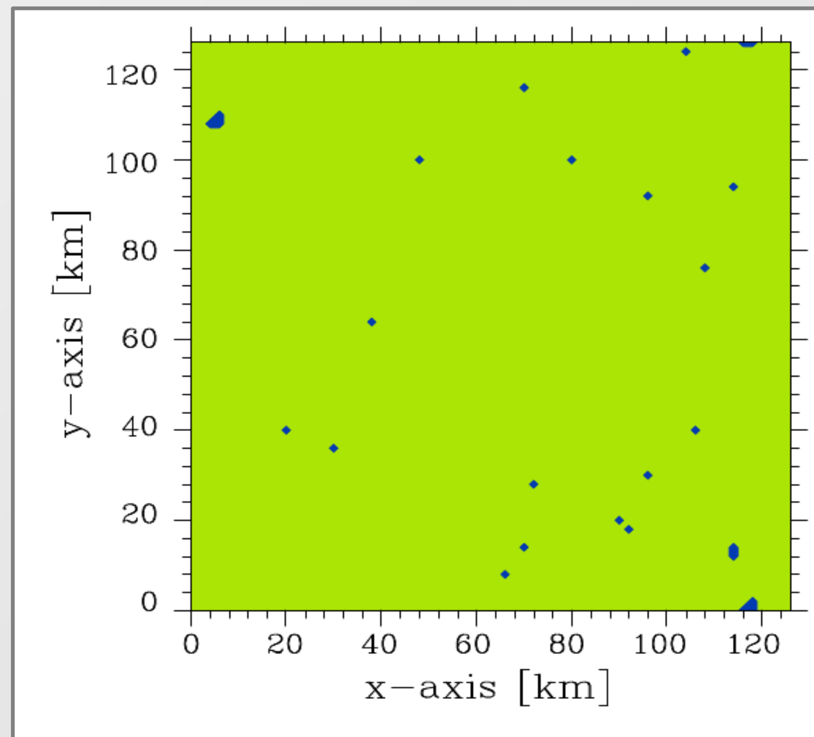
-4 K/day



RESULTS of the control simulation

~ 36 clouds per time step	~ 18 clouds per time step
-8 K/day	**-4 K/day**





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Outlook (1):

Simulations to test the distribution of mass flux per cloud:

- horizontal resolutions: 1 km, 500 m, 200 m, 100 m

- different cooling rates

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→ does the distribution change when significantly increasing the resolution ?

→ do changes in the forcing continue to primarily effect the cloud number ?

Outlook (2):

Evaluation of entrainment/detrainment:

- entrainment per cloud

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Evaluation of entrainment/detrainment:

- entrainment per cloud
- e.g. using direct measurement technique by David Romps (2010)
- e.g. interpolation of LES cloud surfaces by Dawe and Austin (2011)

Thank you very much

for your attention!