High resolution numerical modelling of moist convection in statistical equilibrium: buoyancy and velocity scales

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The radiative convective equilibrium problem: buoyancy and velocity scales (1)

One of the most important issues in the study of dry and moist convection in statistical equilibrium is the determination of buoyanc and velocity scales. These are relavant to such issues as:

- the phase transition of random convective states to organized tropical cyclone-dominated convection

- study of the interaction between moist convective plumes and boundary layer convection

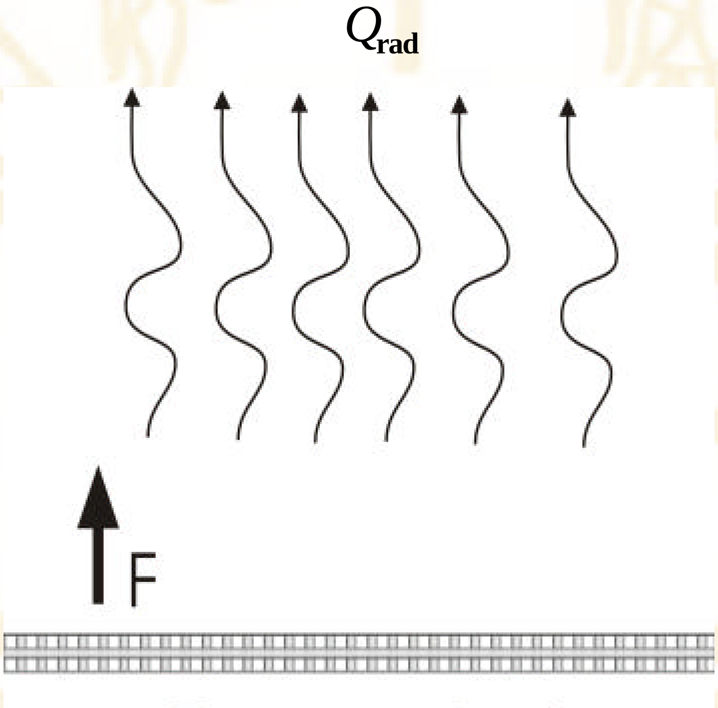
- the absence of a scaling theory for moist convection limits our understanding of the feedbacks of changes in large-scale forcing on convective ensembles and then the development of comprehensive representations of convection in large scale models

The radiative convective equilibrium problem: buoyancy and velocity scales (2)

In the absence of large-scale circulations, th
tropical atmosphere would assume a state c
radiative-moist convective equilibrium, in whic
the divergence of the net vertical radiative flu
(shortwave and longwave) would be compensate
by the convergence of the vertical flux of enthalp
in convective clouds, except for in a thin boundar
layer next to the surface, in which ordinary dr
turbulence would carry the flux.

The radiative convective equilibrium problem: buoyancy and velocity scales (3)

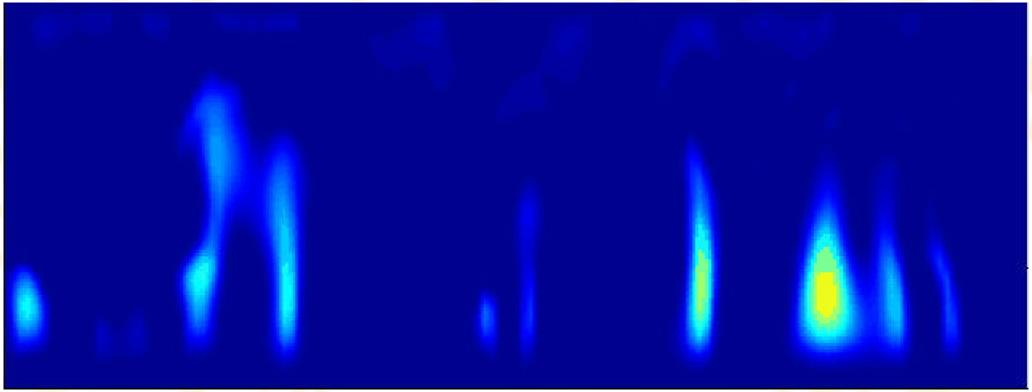
The canonical problem of radiative-dry convective equilibriu was first developed by Prandtl (1910, 1942). This problem *the simplest model that captures some of the essential aspec of atmospheric convection*.

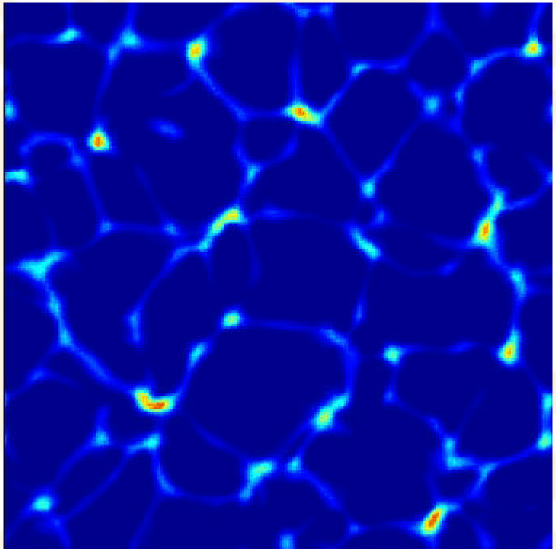


The radiative convective equilibrium problem: buoyancy and velocity scales (4)

Dry Prandtl Problem

W field





from Parodi, Emanuel and
Provenzale, New Journal o
Physics (2003)

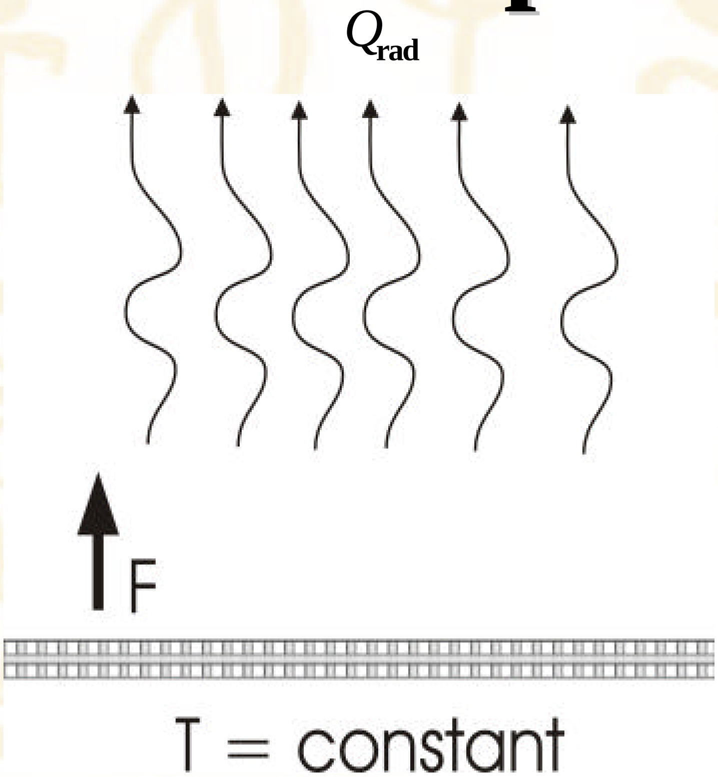
The radiative convective equilibrium problem: buoyancy and velocity scales

- Buoyancy and velocity scales for dry convection in statistical equilibrium were derived long ago by Prandtl (1910, 1925):

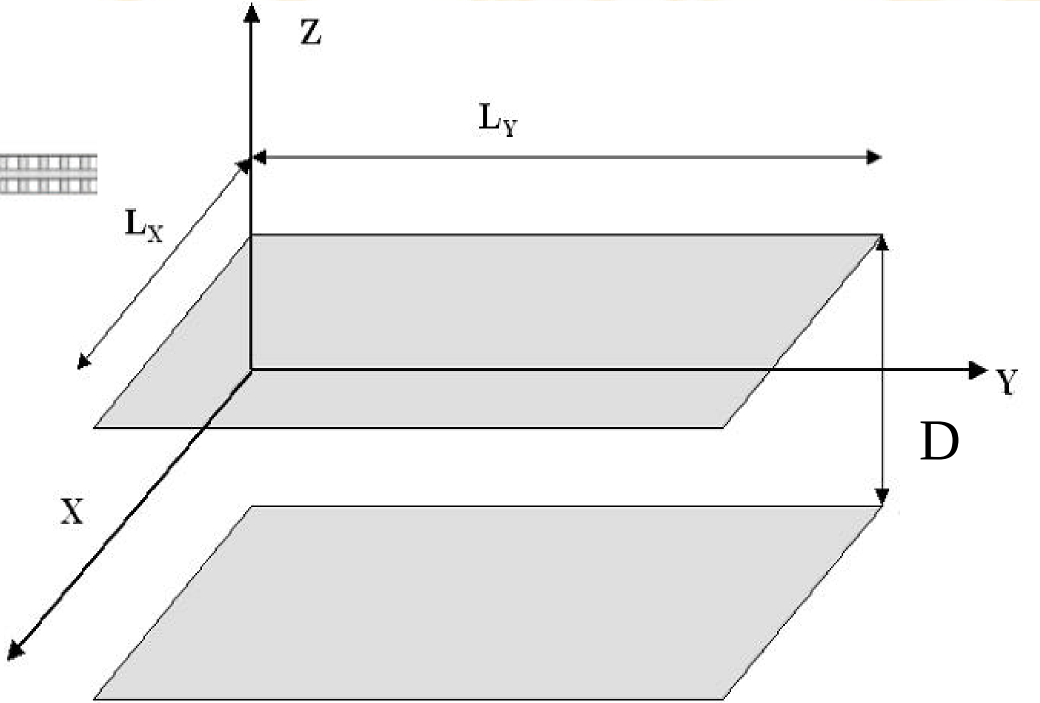
  for this problem the turbulence kinetic energy scales as $(Fz)^{2/3}$, where z is the altitude above the surface, while the unstable stratification decreases as $z^{-4/3}$

- But the question of convective velocity and buoyancy scales, as well as the topic of fractional area coverage of convective clouds, are unresolved in moist convection (in radiative convective equilibrium) (Emanuel and Bister, 1996; Grabowski, 2003; Robe and Emanuel, 1996, 2001; Xu and Randall, 1998; Wu, 2001)

Computational domain



- Doubly periodic domain
- Costant cooling rate Q_{rad} over the full height of the troposphere



The radiative convective equilibrium problem: buoyancy and velocity scales

- High resolution (meso-γ scale) simulations of a atmosphere in radiative convective equilibrium ar performed using the Lokal Model;

- Prescribing different constant cooling rates, Q_{rad}, we tr to characterize the velocity and buoyancy scales for moi convection in statistical equilibrium;

- The dependence of spatio-temporal properties of th convective flow field on numerical and physical detail such as domain size and microphysics, is investigated

The radiative convective equilibrium problem: buoyancy and velocity scales

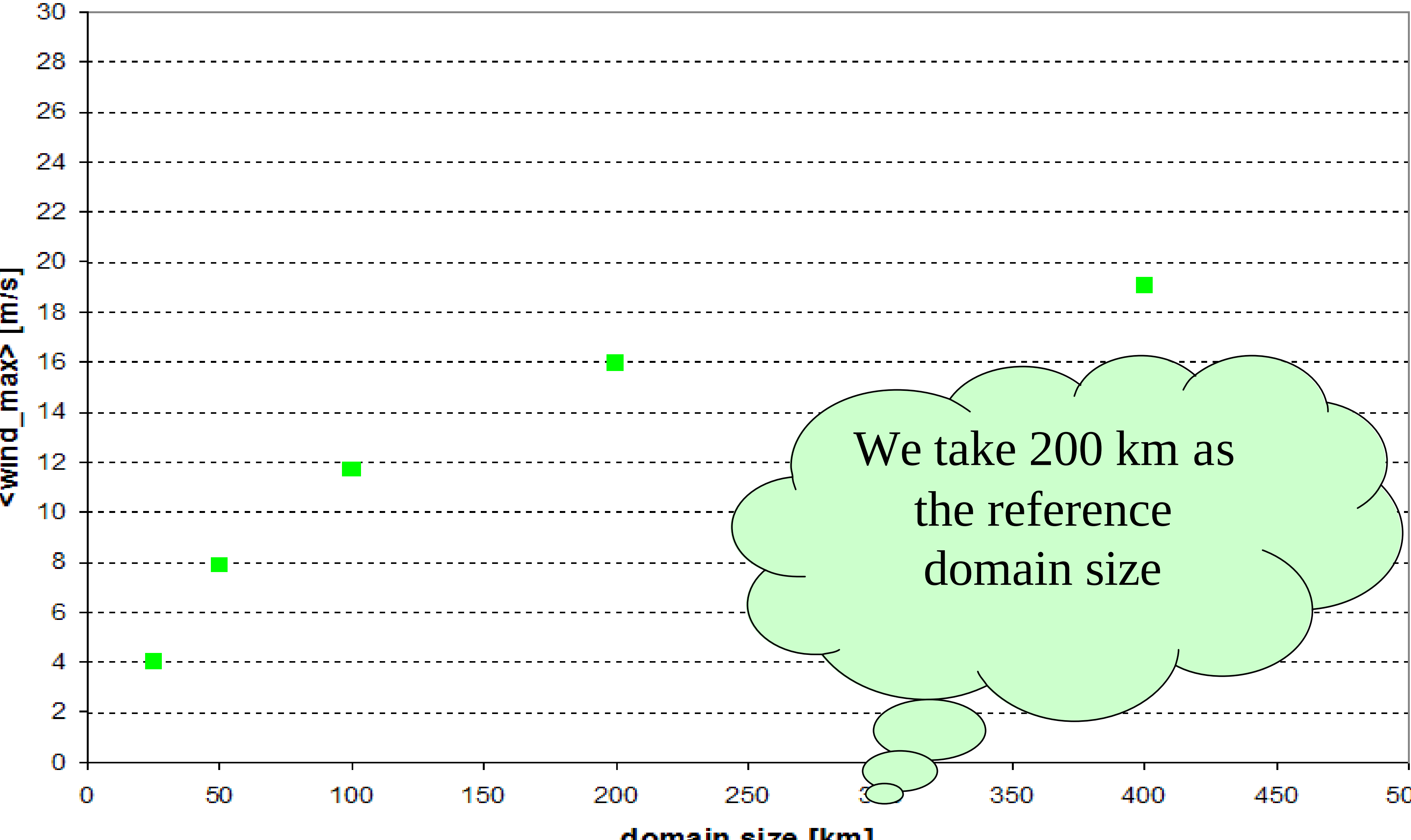
- The main hypothesis of the work is tha <u>convective updraft velocities and rainfall intensit scale with the terminal velocity of raindrops;</u>
- For prescribed cooling rate Q_{rad}, a set o simulations with different raindrop termina velocities (range: 2-50 m/s) is performed and th results are compared

Model settings

- Domain sizes: 25x25x20 km, 50x50x20 km, 100x100x20 km, 200x200x20 km and 400x400x20 km
- Horizontal resolution: 2 km (in the future 500 m is planned)
- No orography
- Doubly periodic boundary conditions
- Kessler microphysics
- Constant cooling rate Q_{rad}: -2 K/day, -4 K/day and -6 K/day
- Leapfrog HE-VI time integration scheme
- Rayleigh damping layer in upper layers ($15<z<20$ km)
- The lower boundary is a passive ocean with constant temperature $T_S=300$ K

Radiative convective equilibrium statistics: role of the domain size

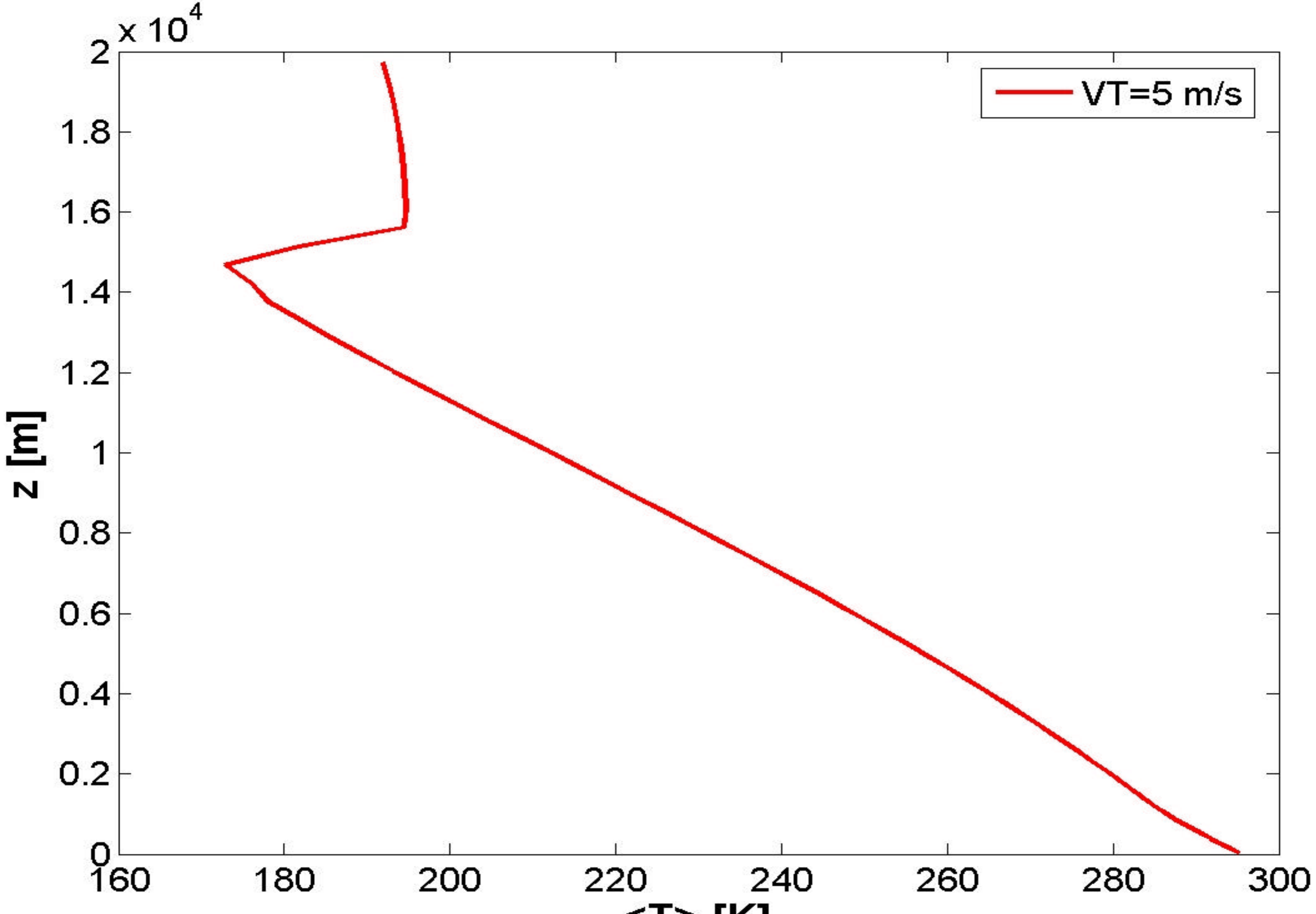
Q_{rad}=-4 K/day, raindrop terminal velocity VT=5 m/s



We take 200 km as the reference domain size

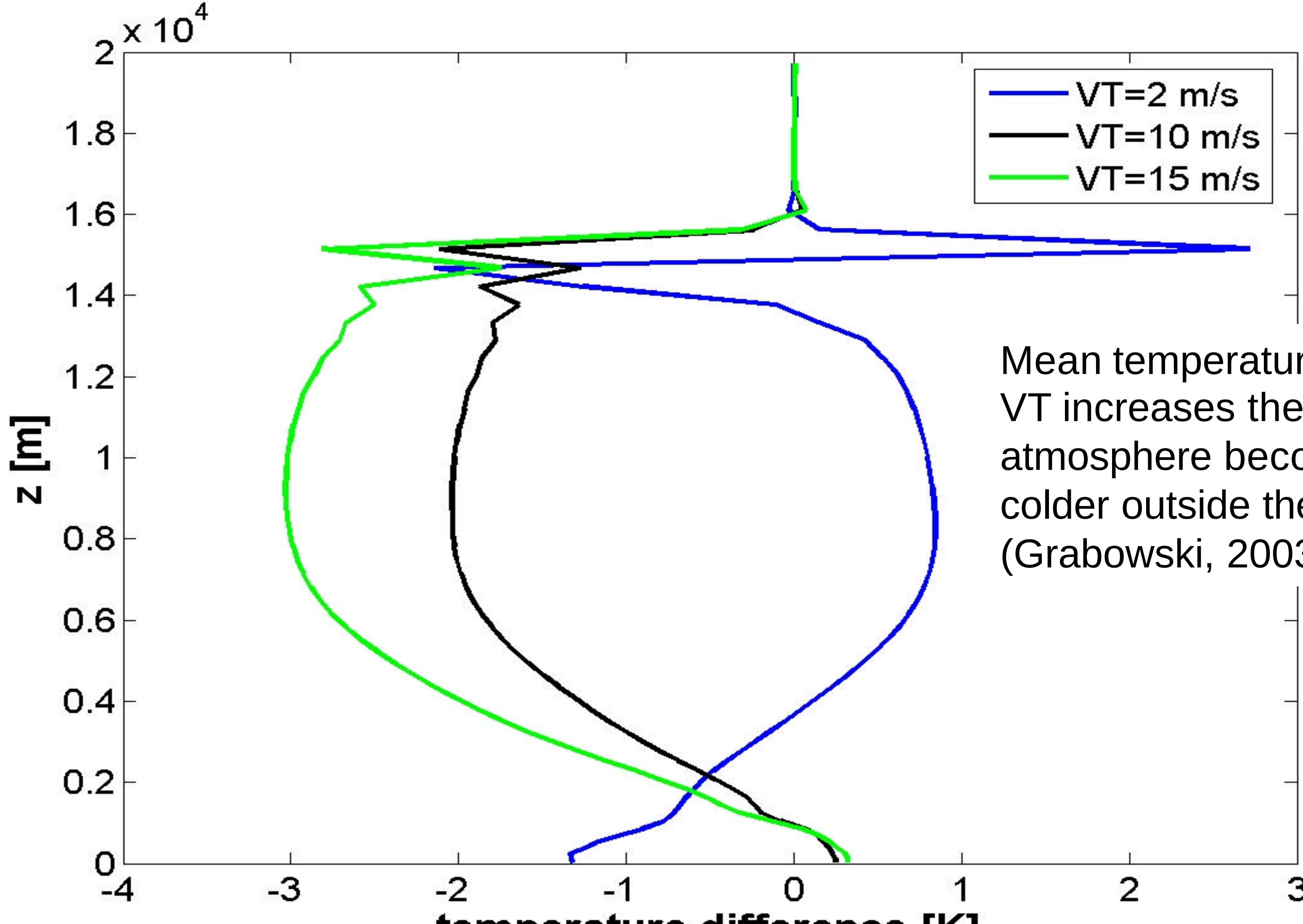
Radiative convective equilibrium statistics: Horizontally averaged thermodynamic profiles

Q$_{rad}$=-4 K/day, VT=5 m/s: control run



Radiative convective equilibrium statistics: Horizontally averaged thermodynamic profiles

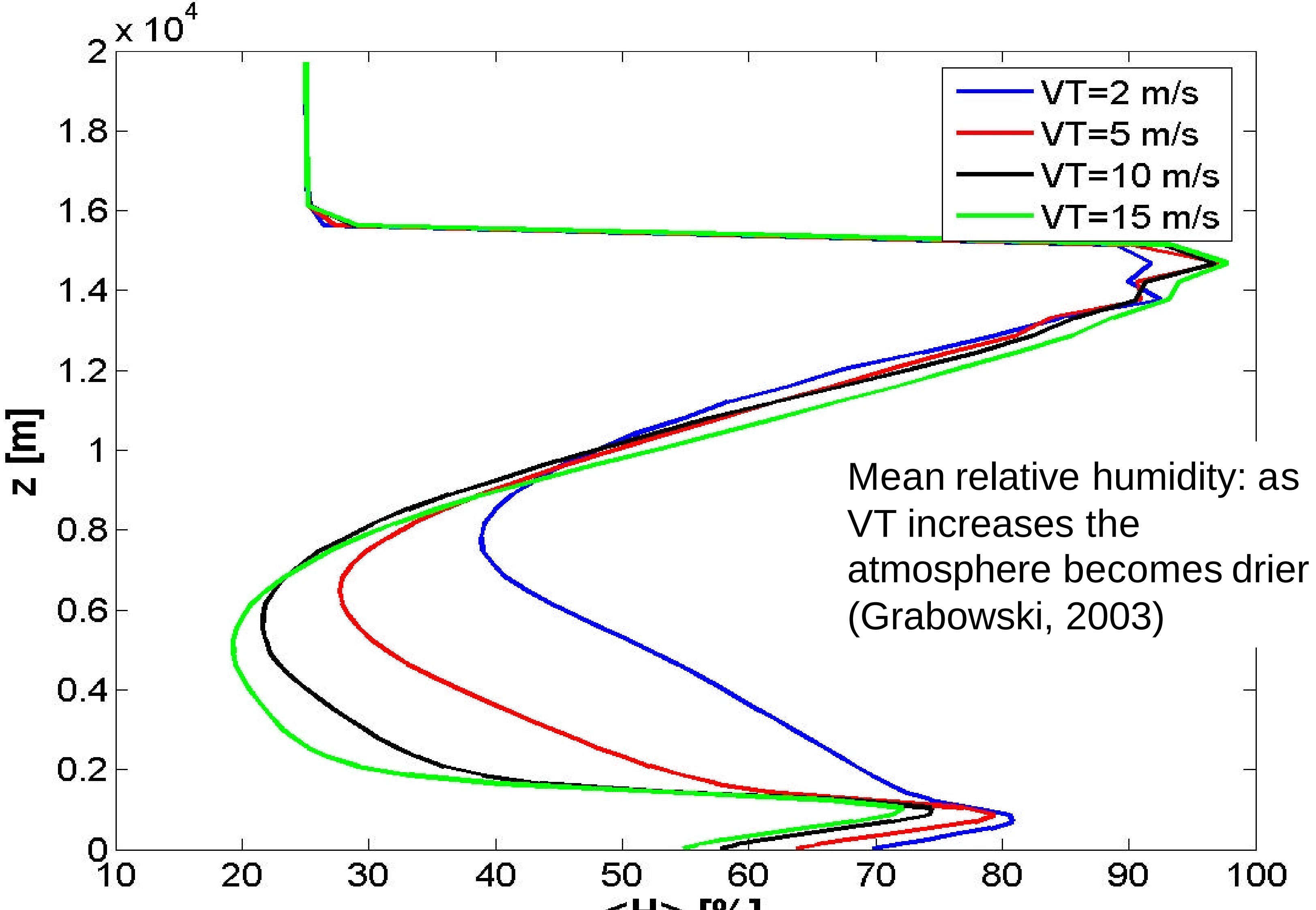
Q_{rad}=-4 K/day: $<T_{VT}>-<T_{VT=5\ m/s}>$



Mean temperature: as VT increases the atmosphere becomes colder outside the BL (Grabowski, 2003)

Radiative convective equilibrium statistics: Horizontally averaged thermodynamic profiles

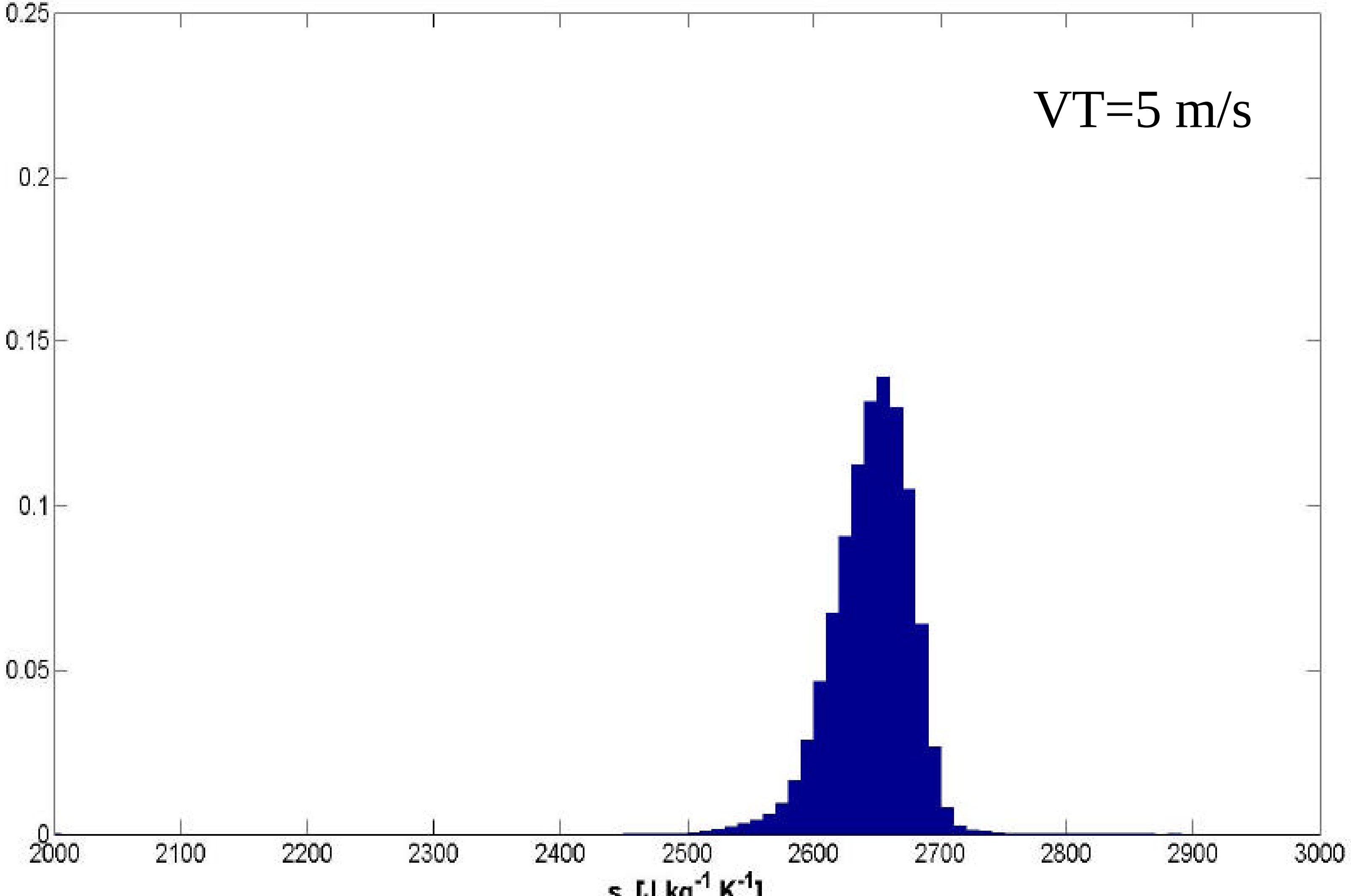
Q_{rad}=-4 K/day



Mean relative humidity: as VT increases the atmosphere becomes drier (Grabowski, 2003)

Radiative convective equilibrium statistics: Moist static energy

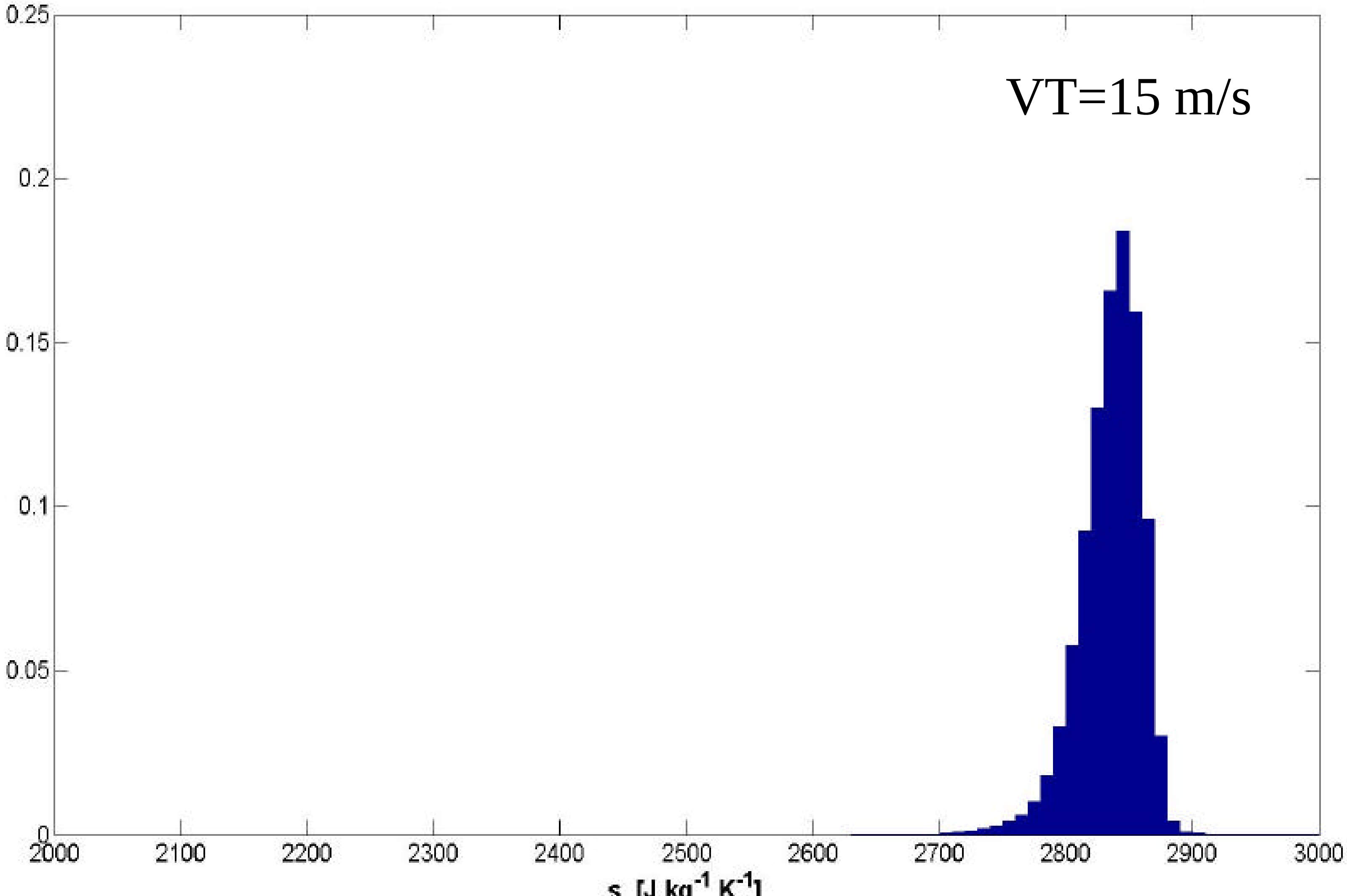
Q_{rad}=-4 K/day



VT=5 m/s

Radiative convective equilibrium statistics: Moist static energy

Q_{rad}=-4 K/day


VT=15 m/s

Radiative convective equilibrium statistics: Buoyancy and velocity scales

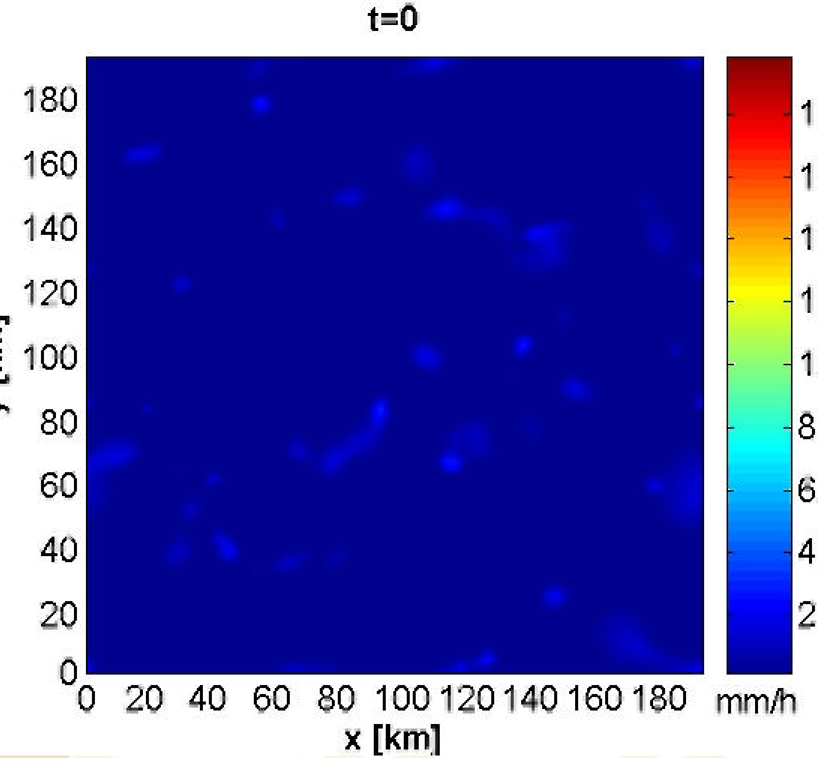
- Convective rain cell identification: first we detect loc maxima of the rainfall intensity field *R*. We retain onl those maxima in *R* that exceed the threshold of 30 mm/ The horizontal extent of each rain cell is then determined b identifying the connected region around the maximum th has R larger than 0.5 mm/h;

- For each cell we use this connected region (determined i the *R* field) as a mask to determine the mean and standar deviation of *w* field in the cell at z=5000 m;

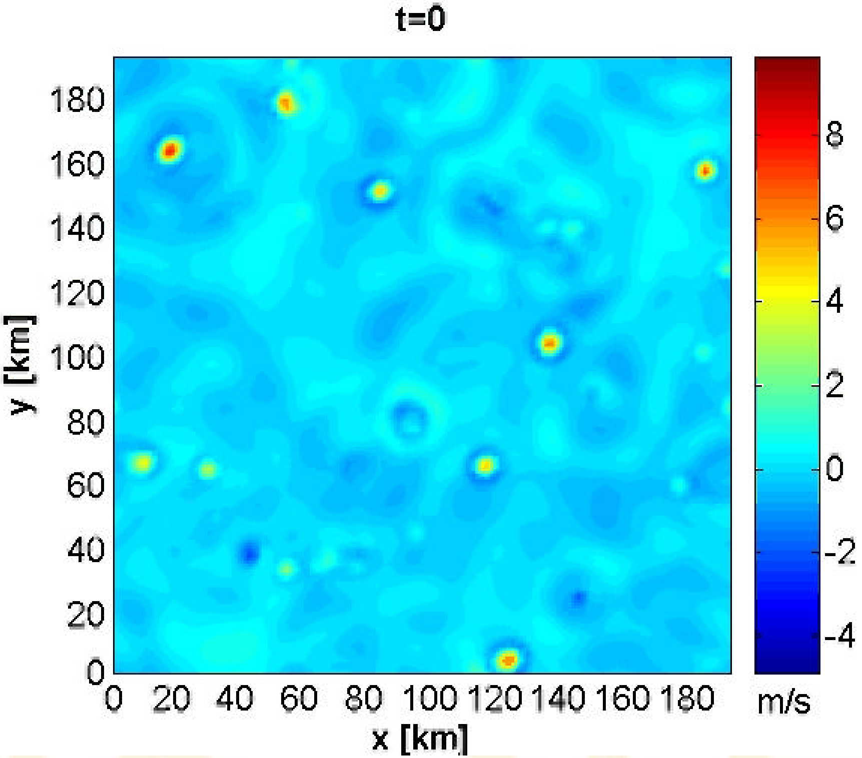
- We evaluate the dependence of some statistical ce properties (mean vertical velocity, mean rainfall intensit and number of cells) on the raindrop terminal velocity

Radiative convective equilibrium statistics: Buoyancy and velocity scales

Qrad=-4 K/day, raindrop terminal velocity VT=2 m/s, domain size=200 km



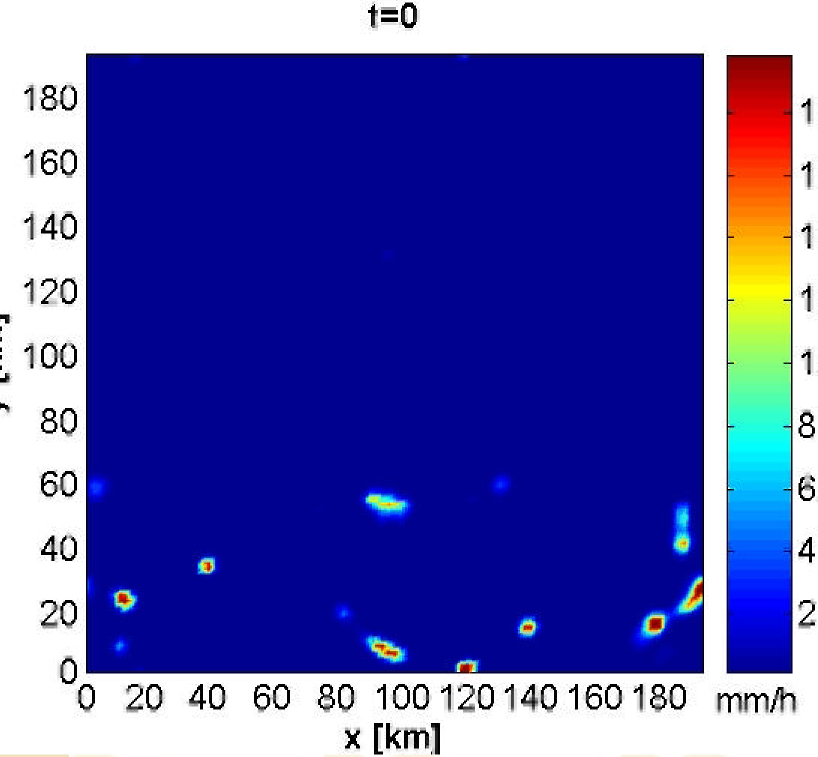
Rainfall intensity field

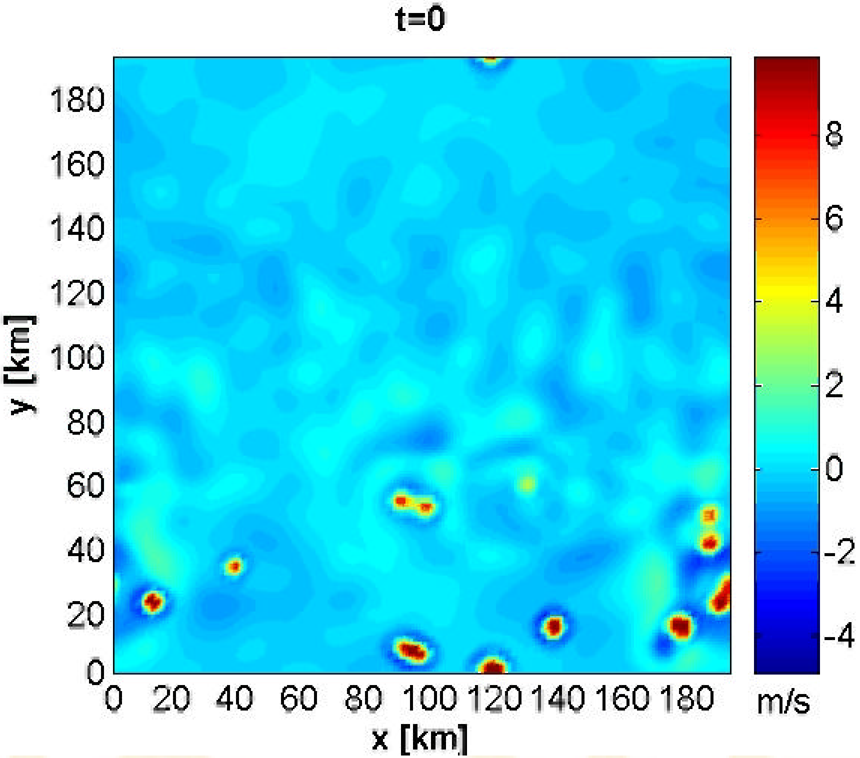


Vertical velocity field: z=5000 m

Radiative convective equilibrium statistics: Buoyancy and velocity scales

Qrad=-4 K/day, raindrop terminal velocity VT=15 m/s, domain size=200 km



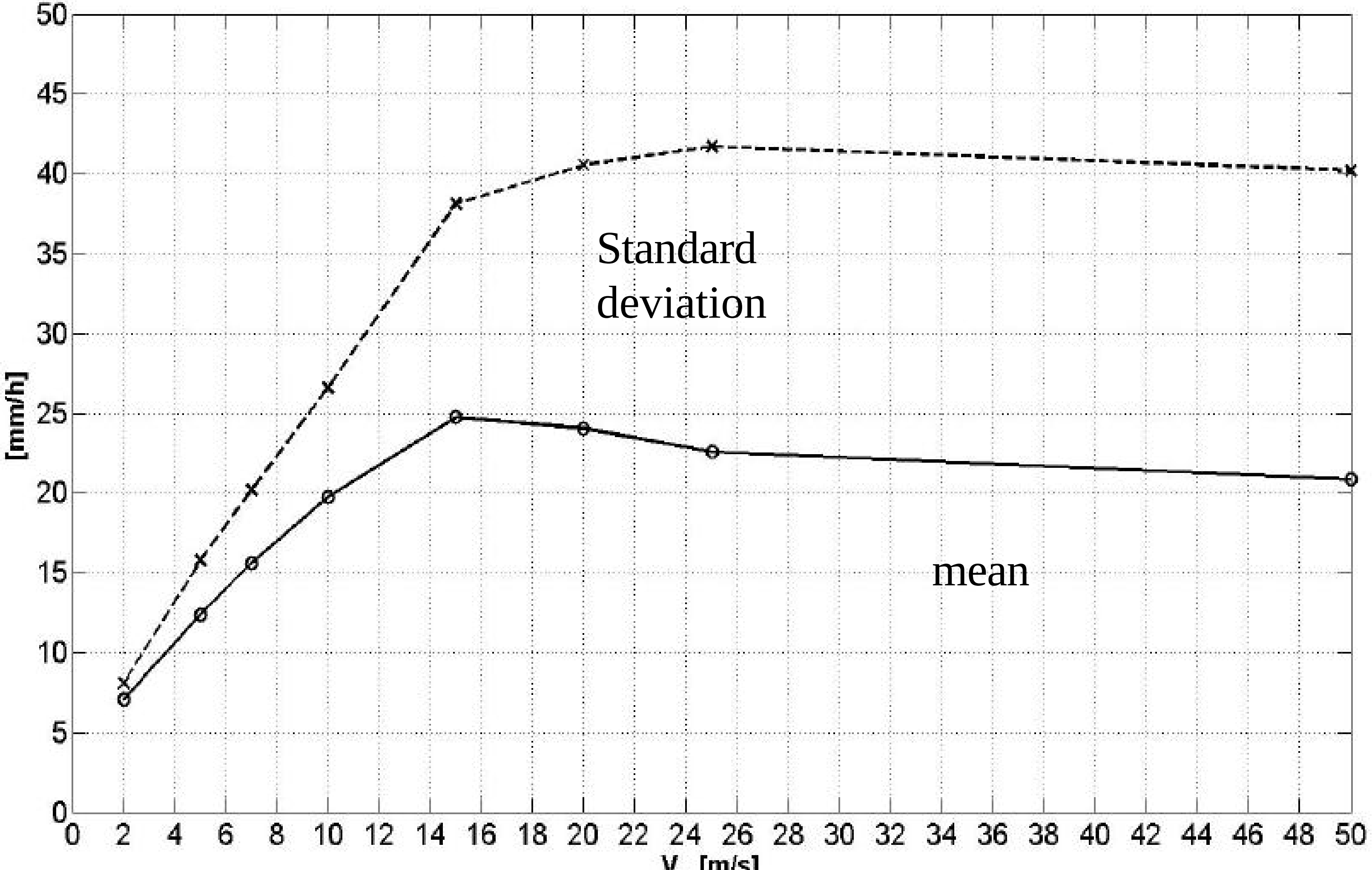


Rainfall intensity field

Vertical velocity field: z=5000 m

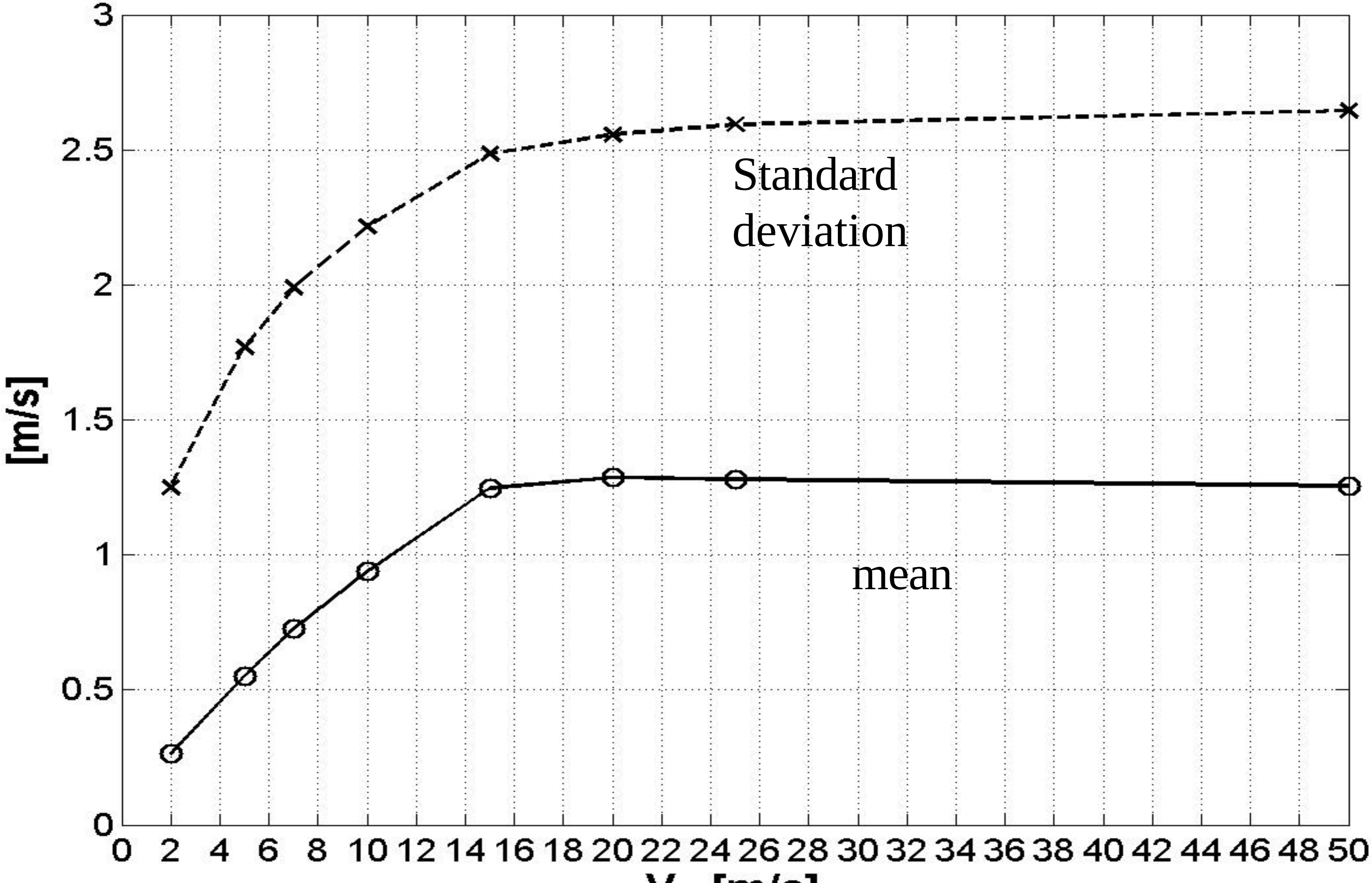
Radiative convective equilibrium statistics: Buoyancy and velocity scales

ainfall intensity scaling (over a period of 4 days in radiative convective equilibrium: 30 frames, time resolution =12 min)



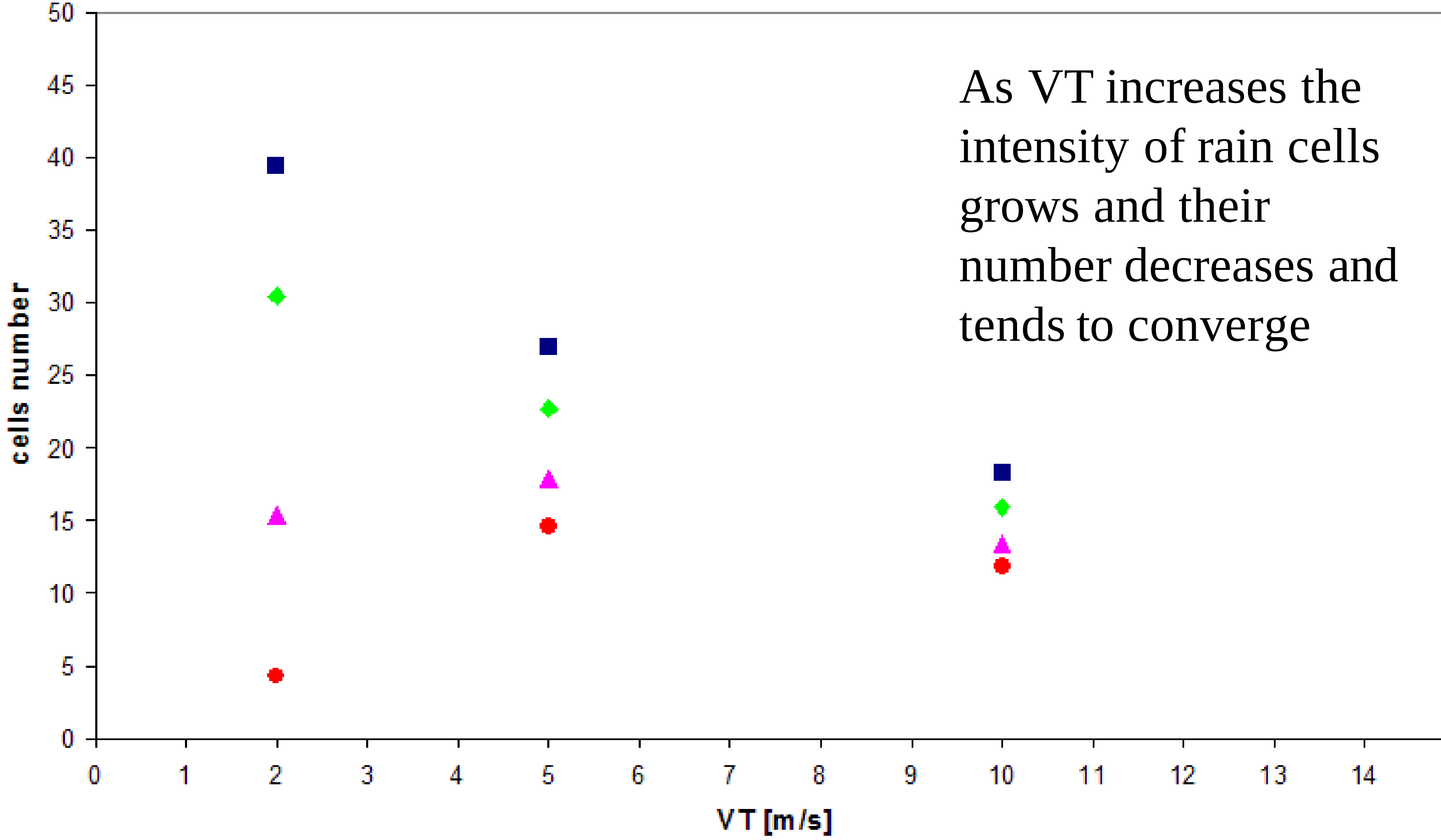
Radiative convective equilibrium statistics: Buoyancy and velocity scales

ertical velocity scaling (over a period of 4 days in radiative convective equilibrium 30 frames, time resolution= 12 min)



Radiative convective equilibrium statistics: Buoyancy and velocity scales

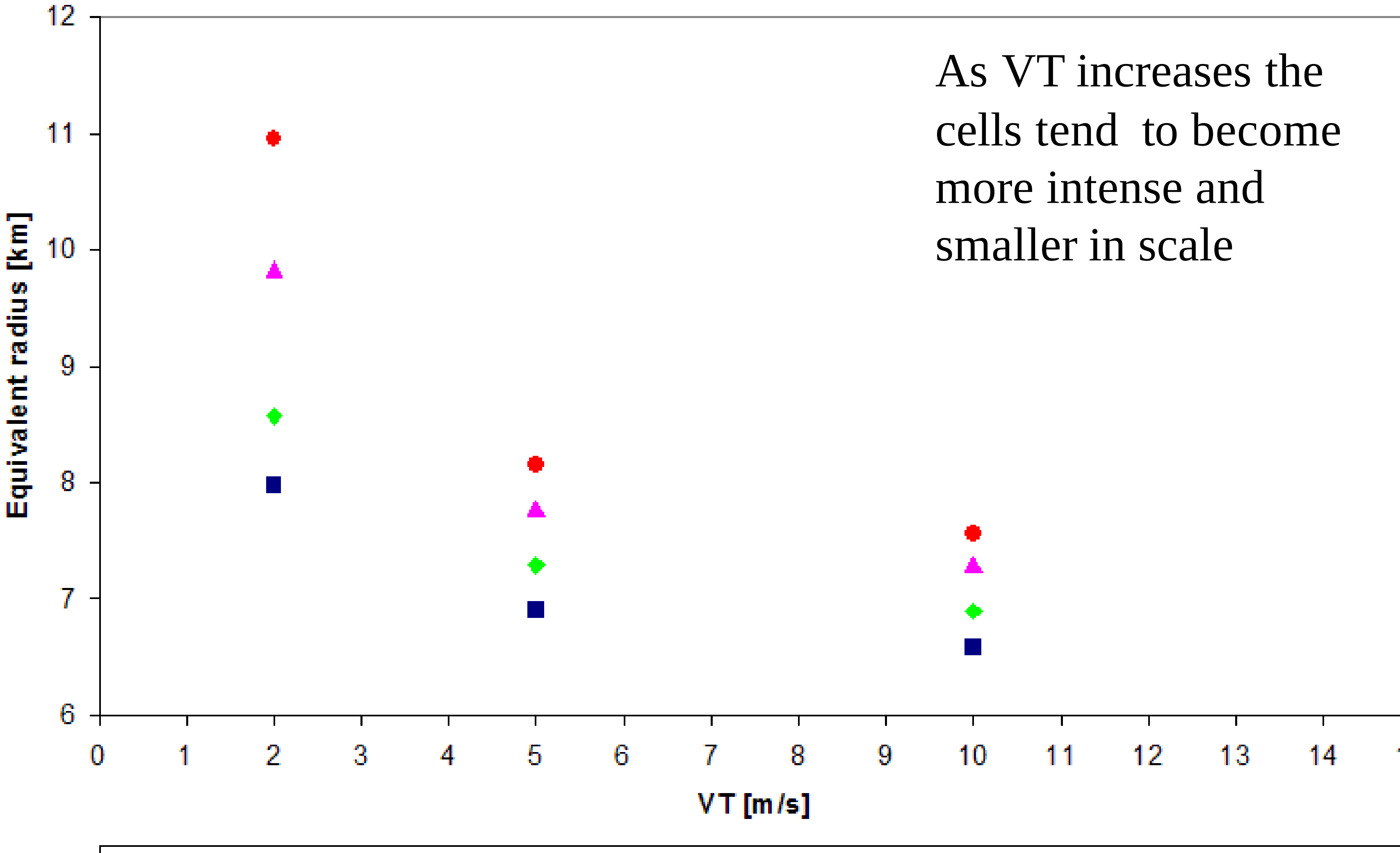
Number of detected cells depends on the adopted threshold



As VT increases the intensity of rain cells grows and their number decreases and tends to converge

Radiative convective equilibrium statistics: Buoyancy and velocity scales

Rain cell equivalent radius depends on the adopted threshold



As VT increases the cells tend to become more intense and smaller in scale

Conclusions

- Buoyancy and velocity scales for moist convection i statistical equilibrium are studied;

- We find that convective updraft velocity and rainfa intensity scale with the raindrop terminal velocity;

- A minimum domain size (around 200x200 km^2) t achieve a significant convergence in the statistica properties of the moist convection is identified;

- In agreement with Grabowski (2003) and others, we fin that as VT increases the atmosphere becomes more convective and drier

Future work

This work is in progress and the results deserve further investigation:

- It is planned to repeat the same analysis with the WRF model in order to further assess the reliability of the results and of the proposed scalings

- Evaluation of the role of other parameters: especially highe cooling rates (e.g Q_{rad}= -6 K/day and -8 K/day) and lower horizontal resolution (1 km and 500 m);

- Developing and testing a theory for this scaling.

- Use of the moist radiative convective problem to compare behaviour of different (1D and 3D) turbulence parameterizations in LM

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