Mountain Volume Control on Deep-Convective Rain Amount

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Thunderstorms are the dominant mode of summer precipitation

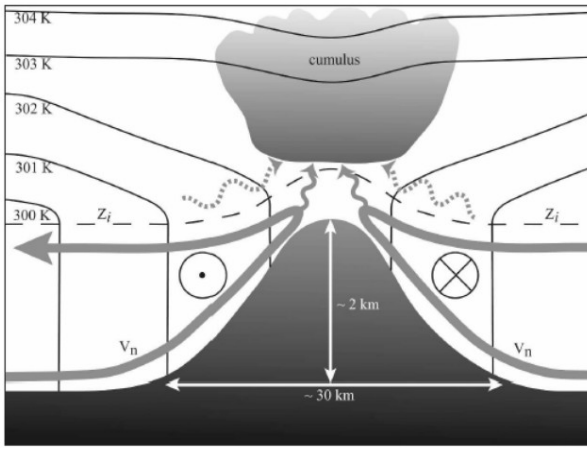


Zürich on the 6th June 2018 at 1640

Mountain are cumulus clouds and thunderstorm hot spots especially during episodes of weak synoptic forcing

Episode of weak synoptic forcing on the 6st August 2015

NASA's WorldView

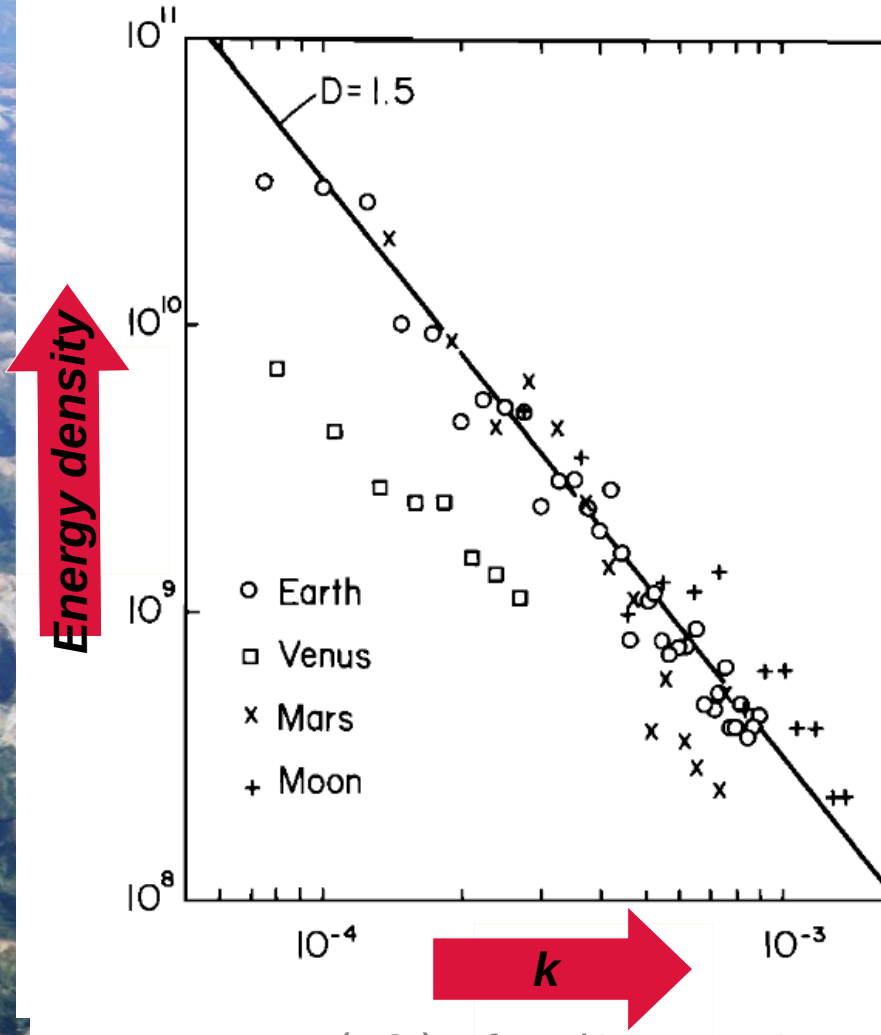


Demko and Geerts (2006)

Mountains are fractals, i.e. all horizontal length scales are contained



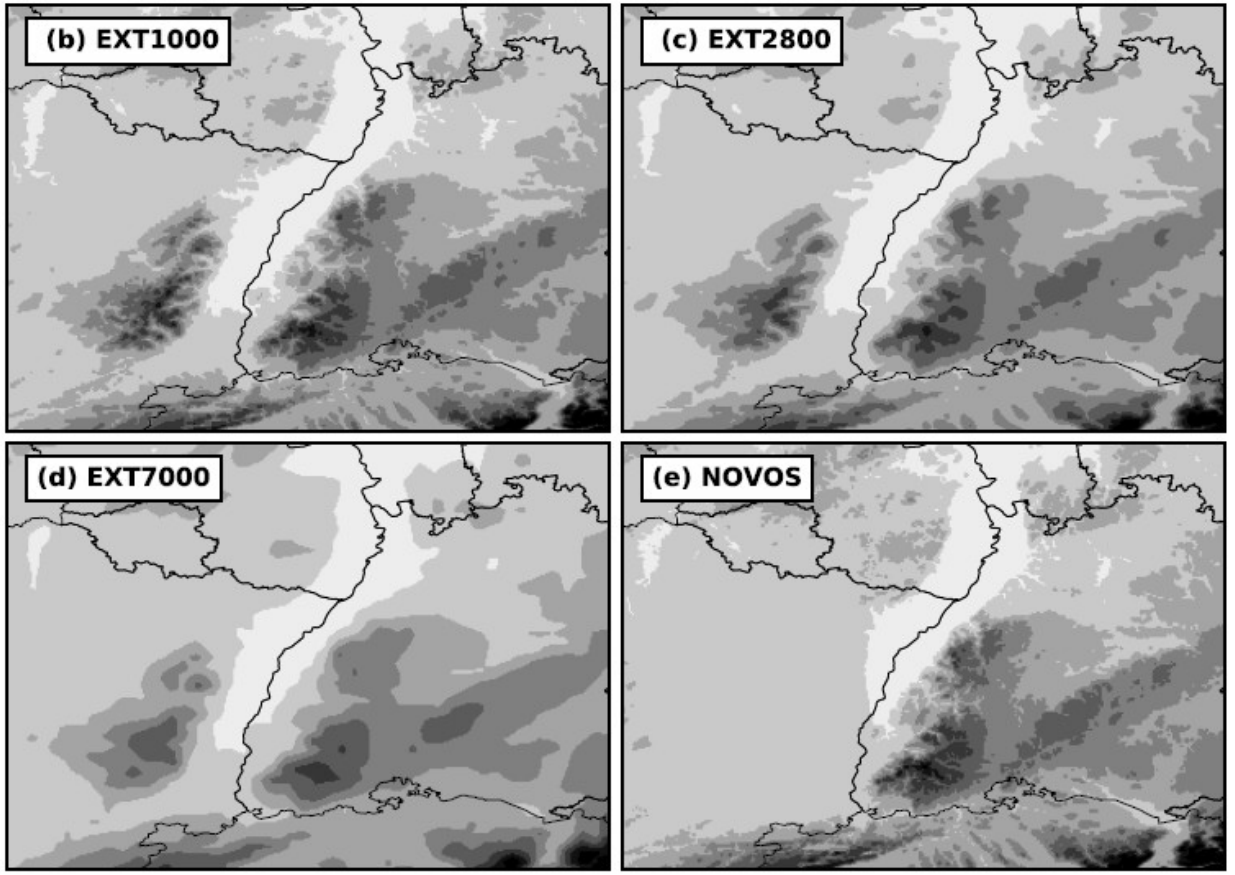
Google Earth, 2018



Turcotte (1987): A fractal interpretation of topography and geoid spectra on the Earth, Moon, Venus, and Mars, JGR-SE

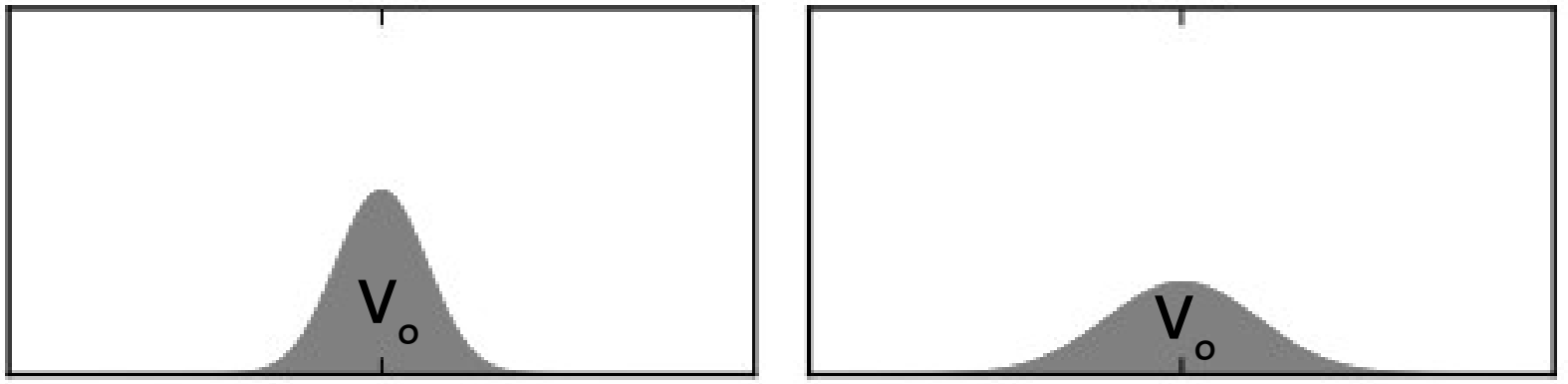
How to study the impact of orographic height and width scales on PBL and/or deep convection?

Low-pass filtering (e.g. Hohenegger et al., 2009; Ganter et al. 2017; Kang and Ryu; 2015; next talk by Davide Panosetti) or **shrinking or removal** of entire features**:**

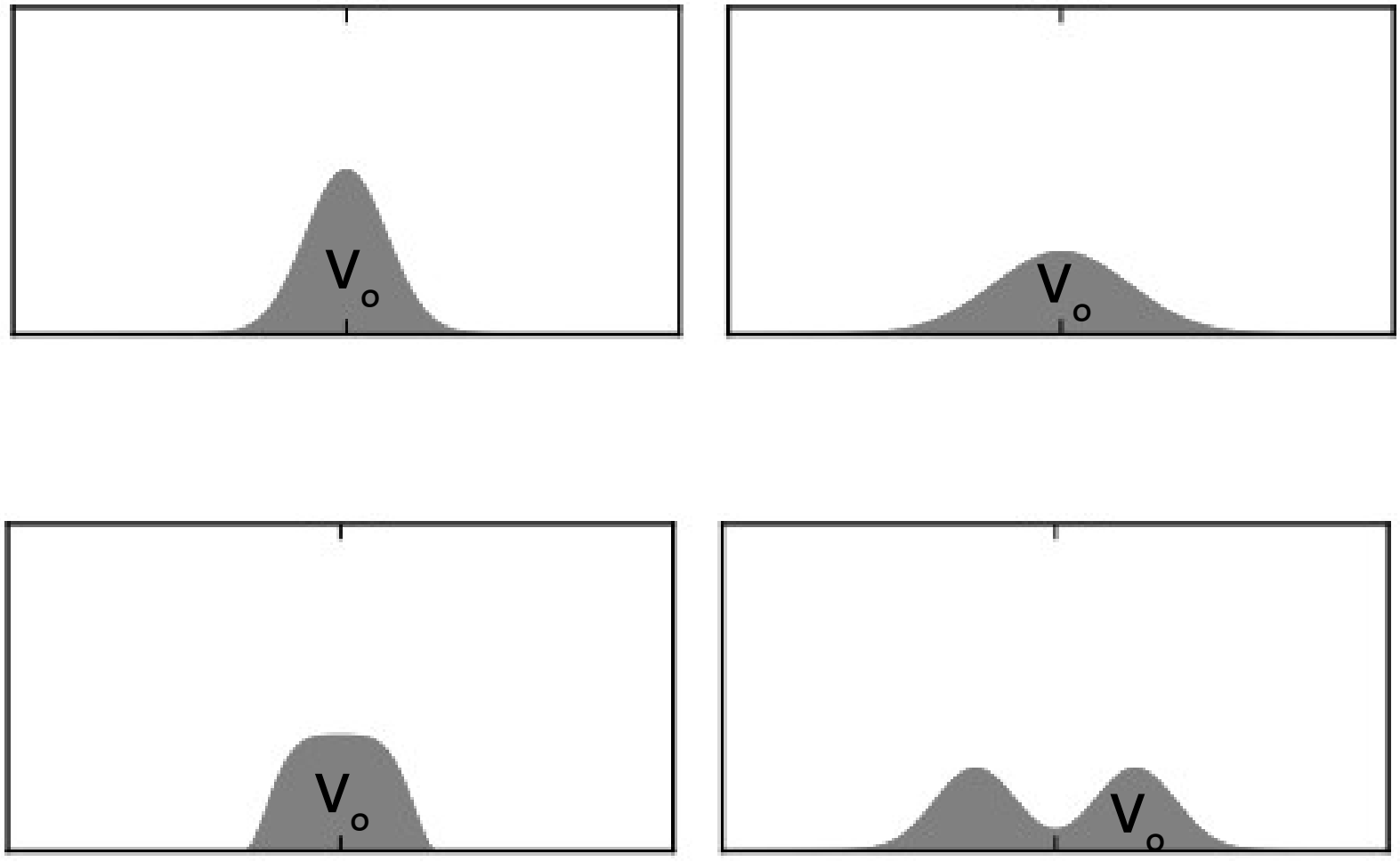


Schneider et al. (2018)

How to “design” a mountain to extract maximum moisture via deep convection?



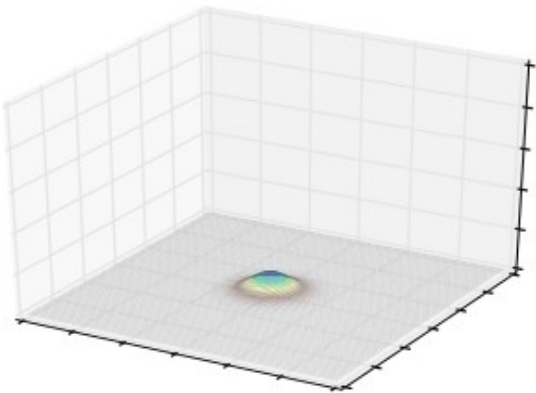
How to “design” a mountain to extract maximum moisture via deep convection?



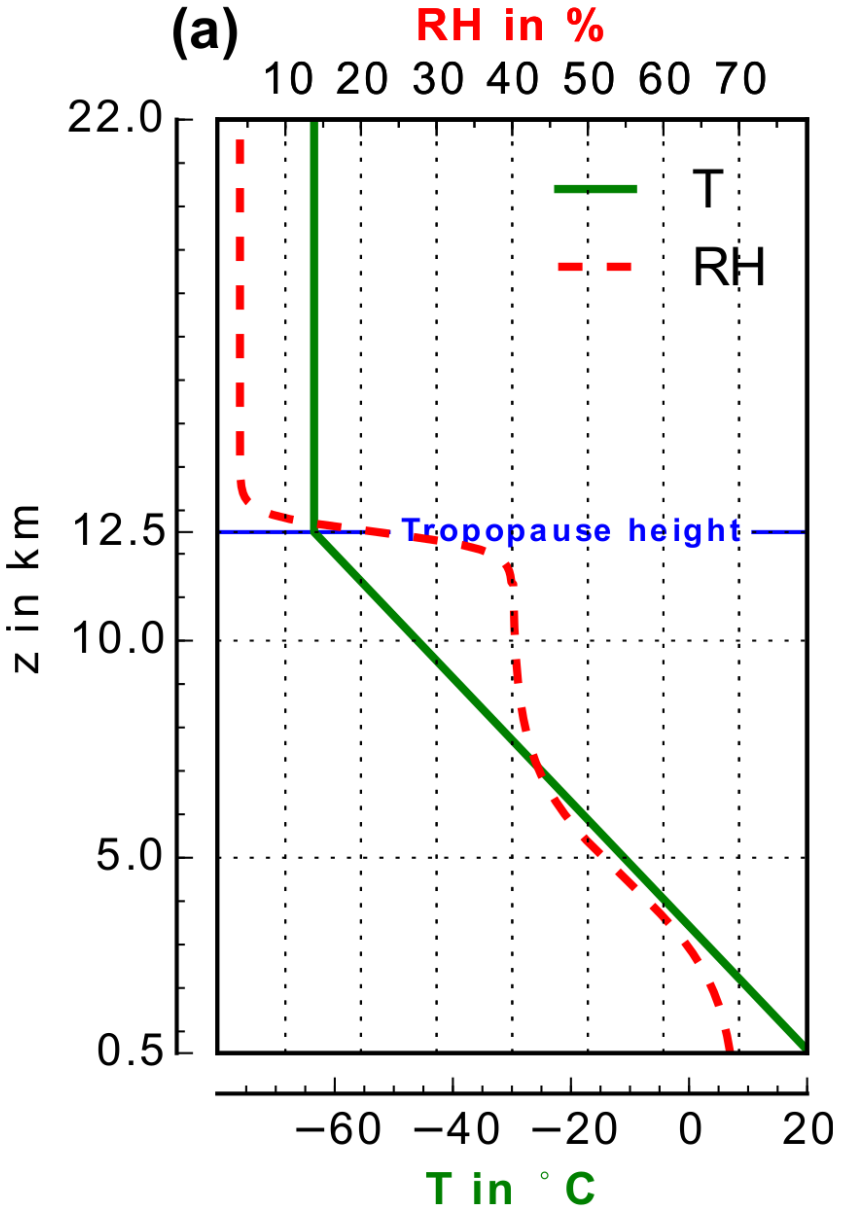
Simulation strategy

- COSMO **v.4.28** in CLM mode (coupled to TERRA_ML)
- **Full physics parameterization** (1 moment microphysics, delta-two stream approach for radiation, TKE-based closure for turbulence) **no shallow nor deep convection**

- 512 km x 512 km domain; **Δx = 1 km,** cyclic boundary conditions
- Soil moisture is prescribed and homogeneous (60 %) but the surface heat fluxes and temperature fully interact with the atmosphere, summer insolation
- 5 days of simulations for every mountain configuration
- 10 ensemble members per configuration
  → **50 days of deep-convective weather** for every mountain
  → ~ **3500 days** of deep-convective weather simulated

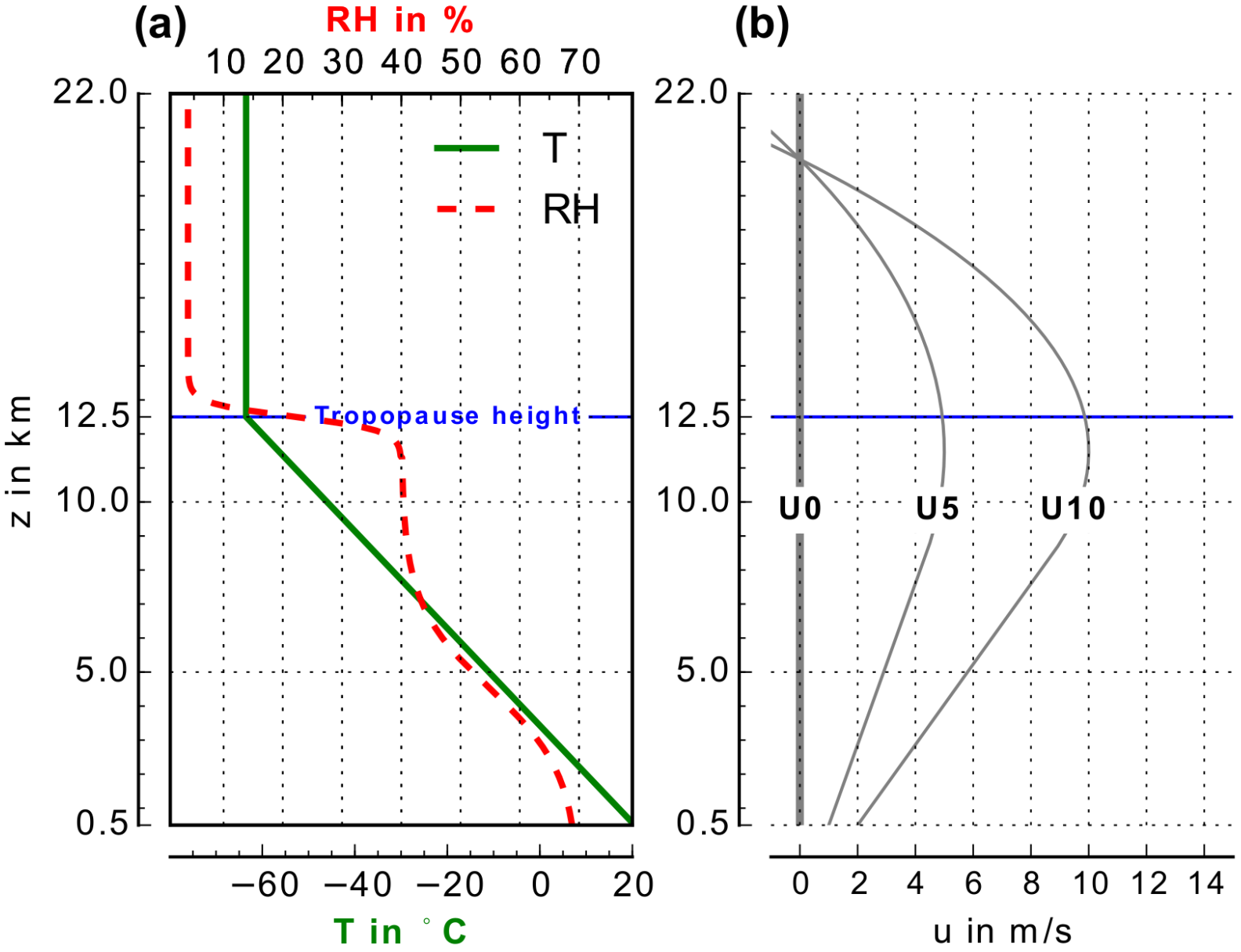


Idealized atmospheric profiles



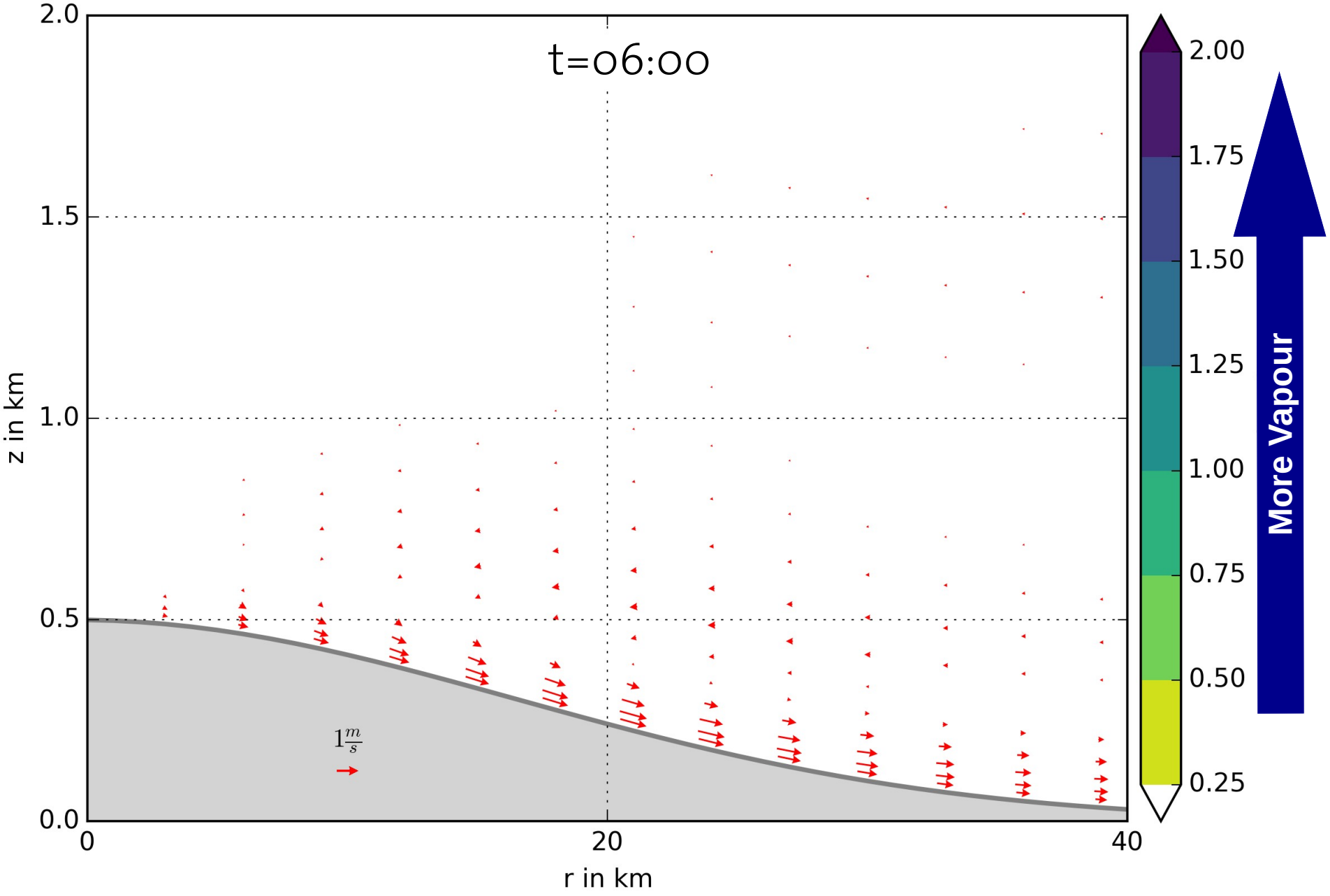
-7 K/km lapse rate, **CAPE ~ 1400 J/kg**, 70 %-40 % RH profile as motivated by Schlemmer et al. (2011)

Idealized atmospheric profiles

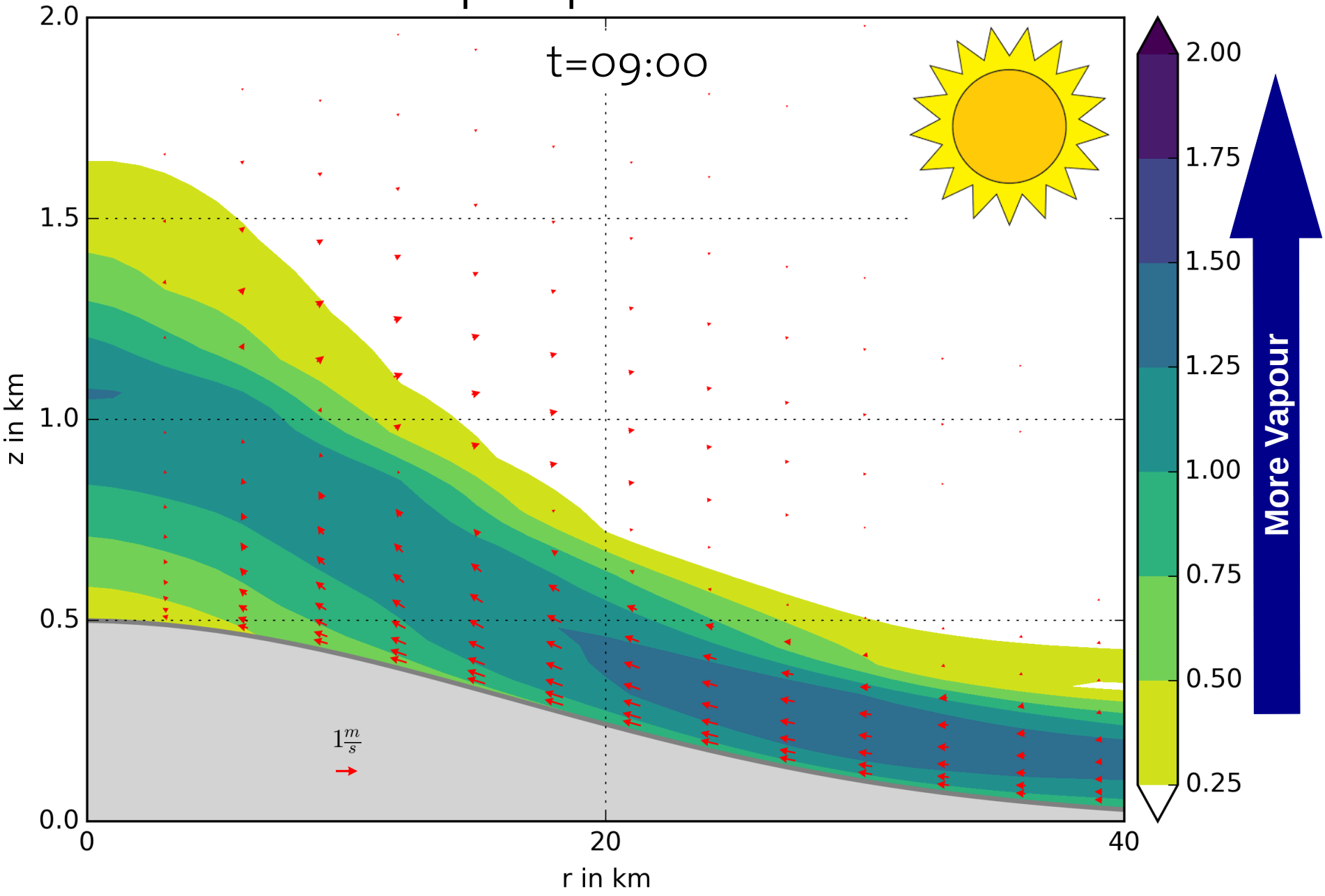


-7 K/km lapse rate, **CAPE ~ 1400 J/kg**, 70 %-40 % RH profile as motivated by Schlemmer et al. (2011)

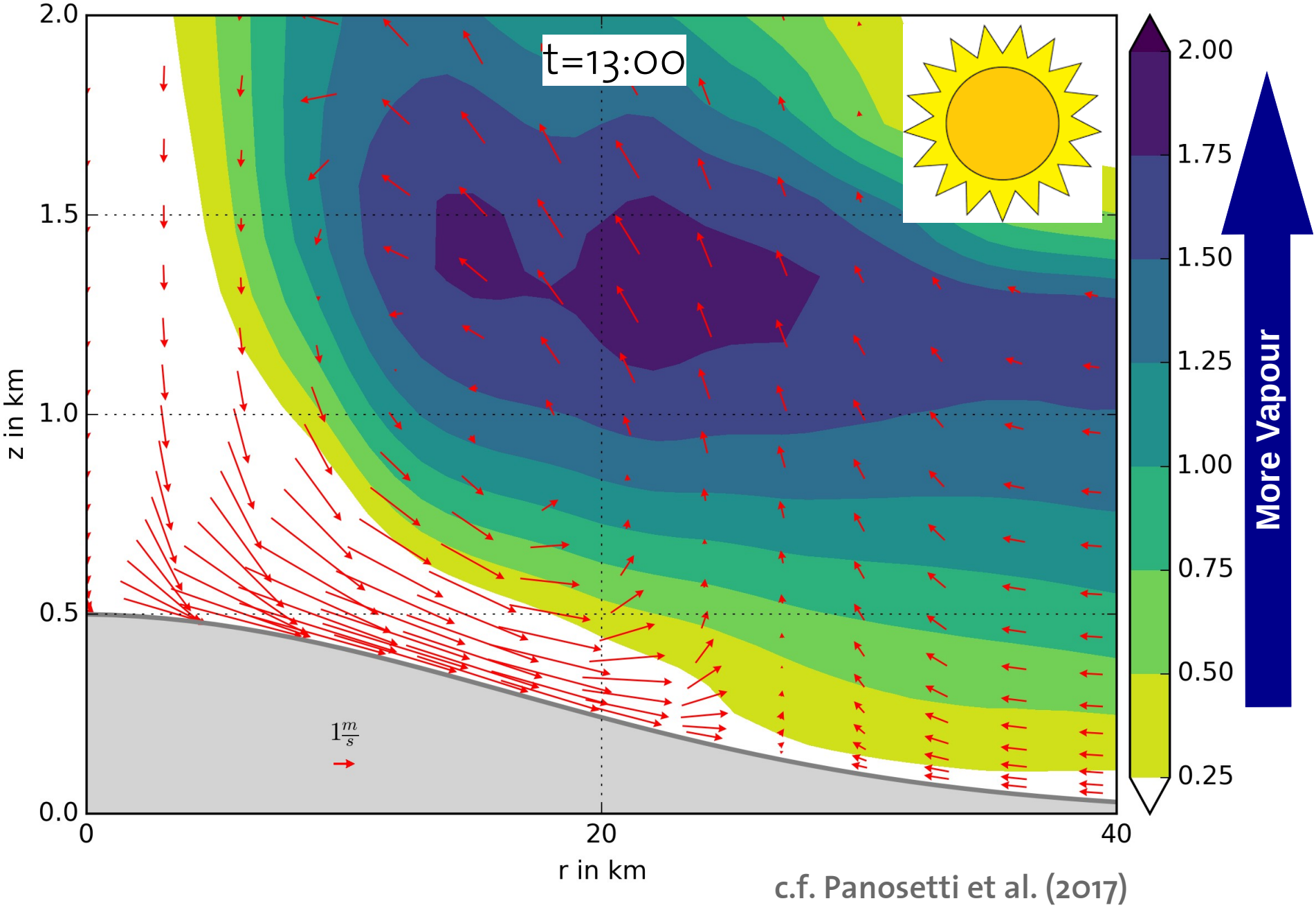
Numerical simulation of deep convection at an idealized mountain



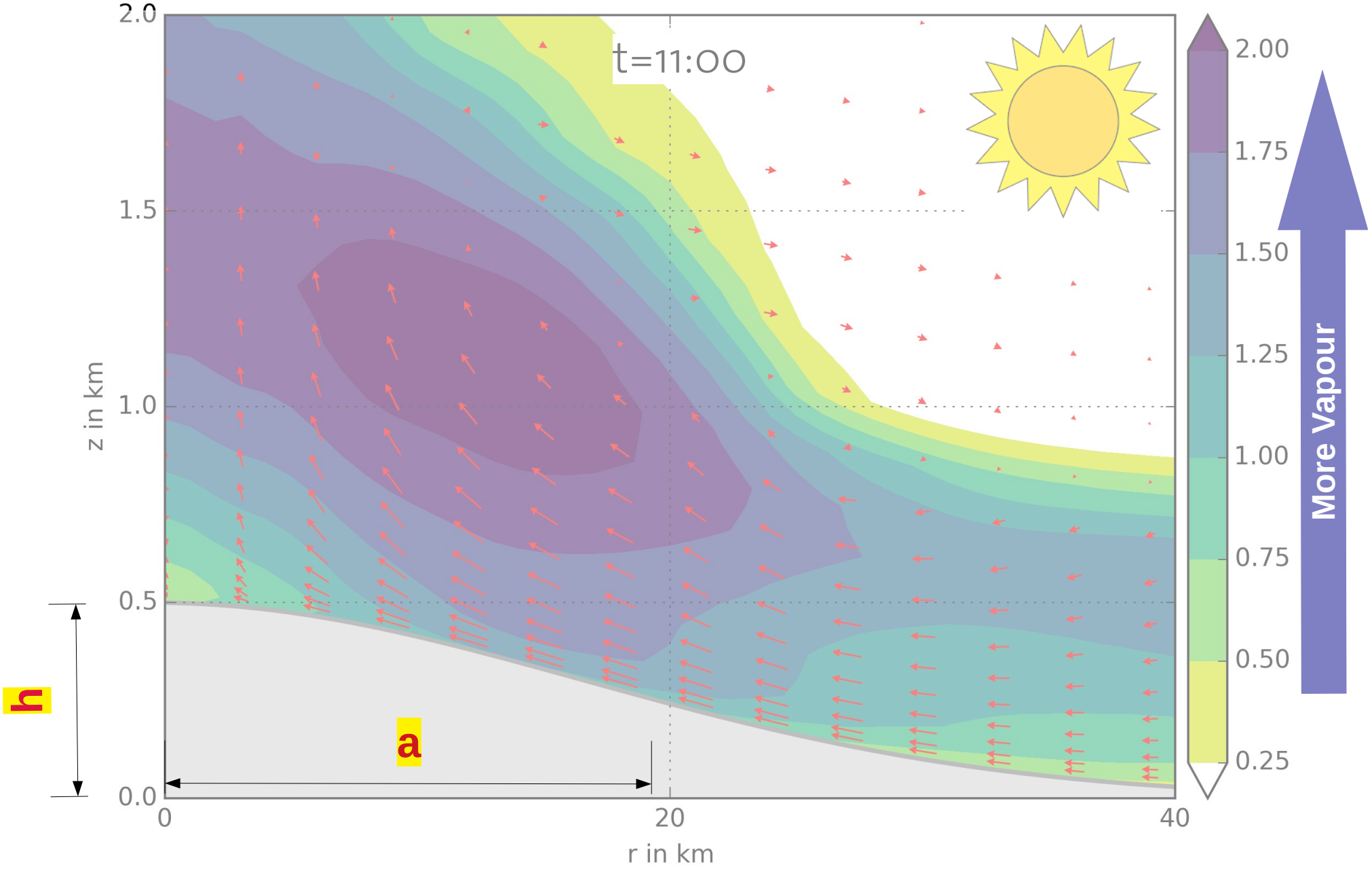
Insolation drives PBL destabilization and upslope flow



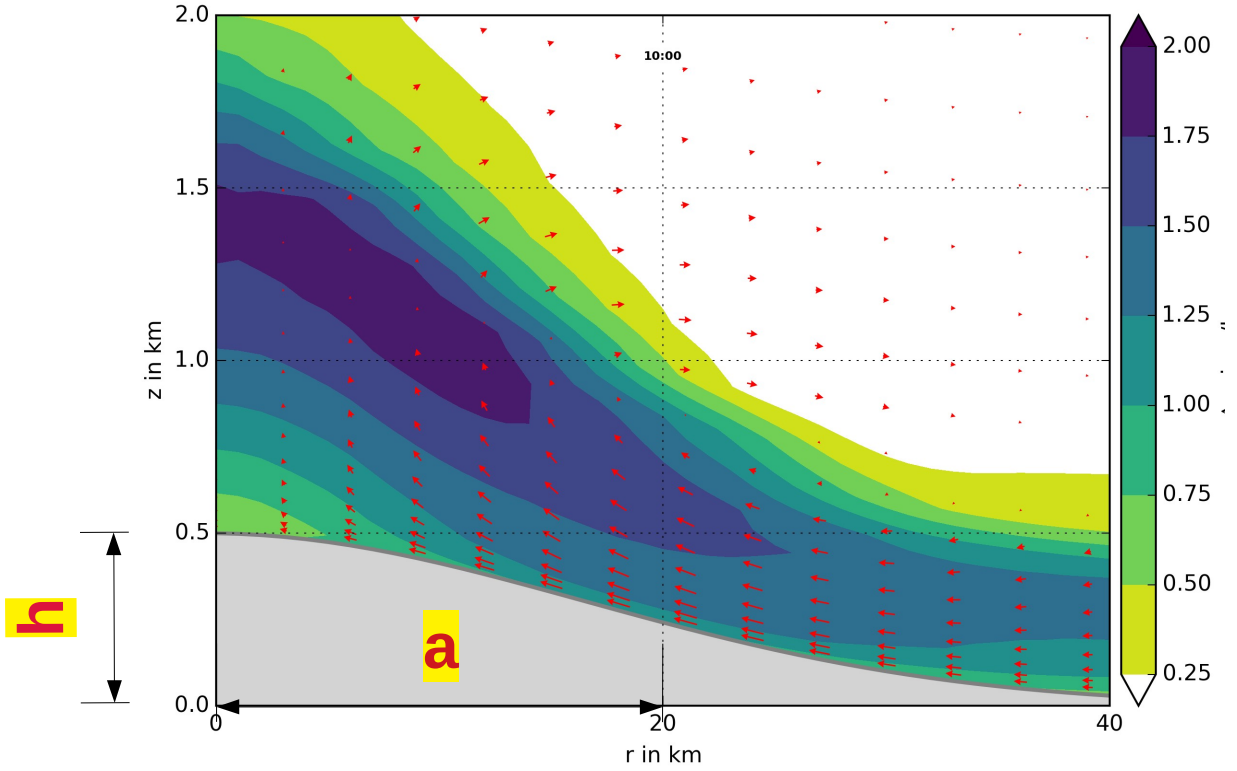
Rain → cold pool → secondary convection initiation



c.f. Panosetti et al. (2017)

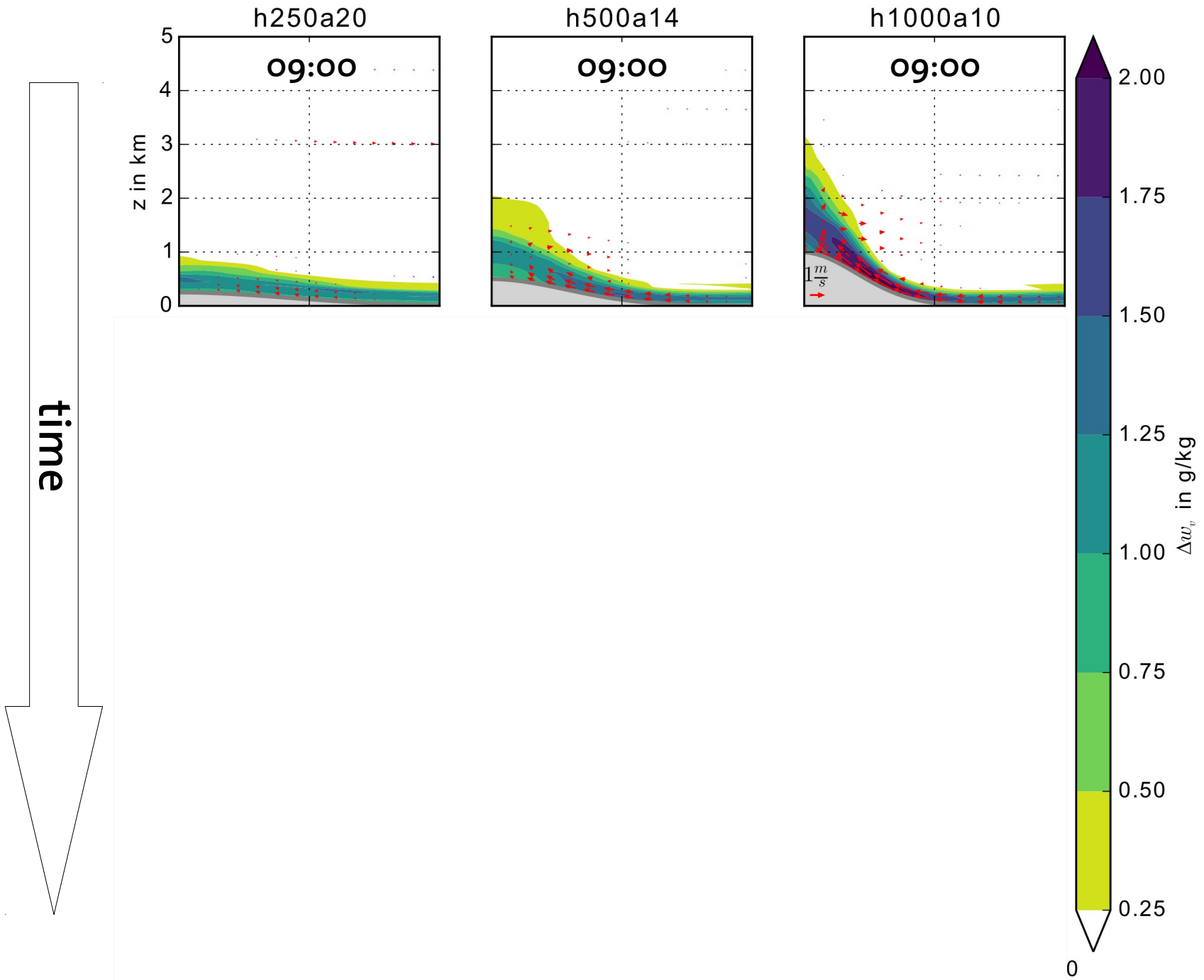

t=11:00
2.0
1.5
1.0
0.5
0.0
z in km
0
20
40
r in km
h
a
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
More Vapour

(h,a) space explored



- **h** in H = {250, 500, 750, 1000, and 1500 m}
  a in A = {5, 7, 10, 14, 20, 25, 30 km}, 3D Gaussian mountain
- Initial temperature at mountain matches temperature of lowest atmospheric level
- Tests with cos²-shaped, and multiple peak mountains performed for a reduced set of (h,a) configurations

Three mountains with the **same volume, but different slopes**
→ Large differences in deep-convective timing and intensities



Three mountains with the **same volume, but different slopes**
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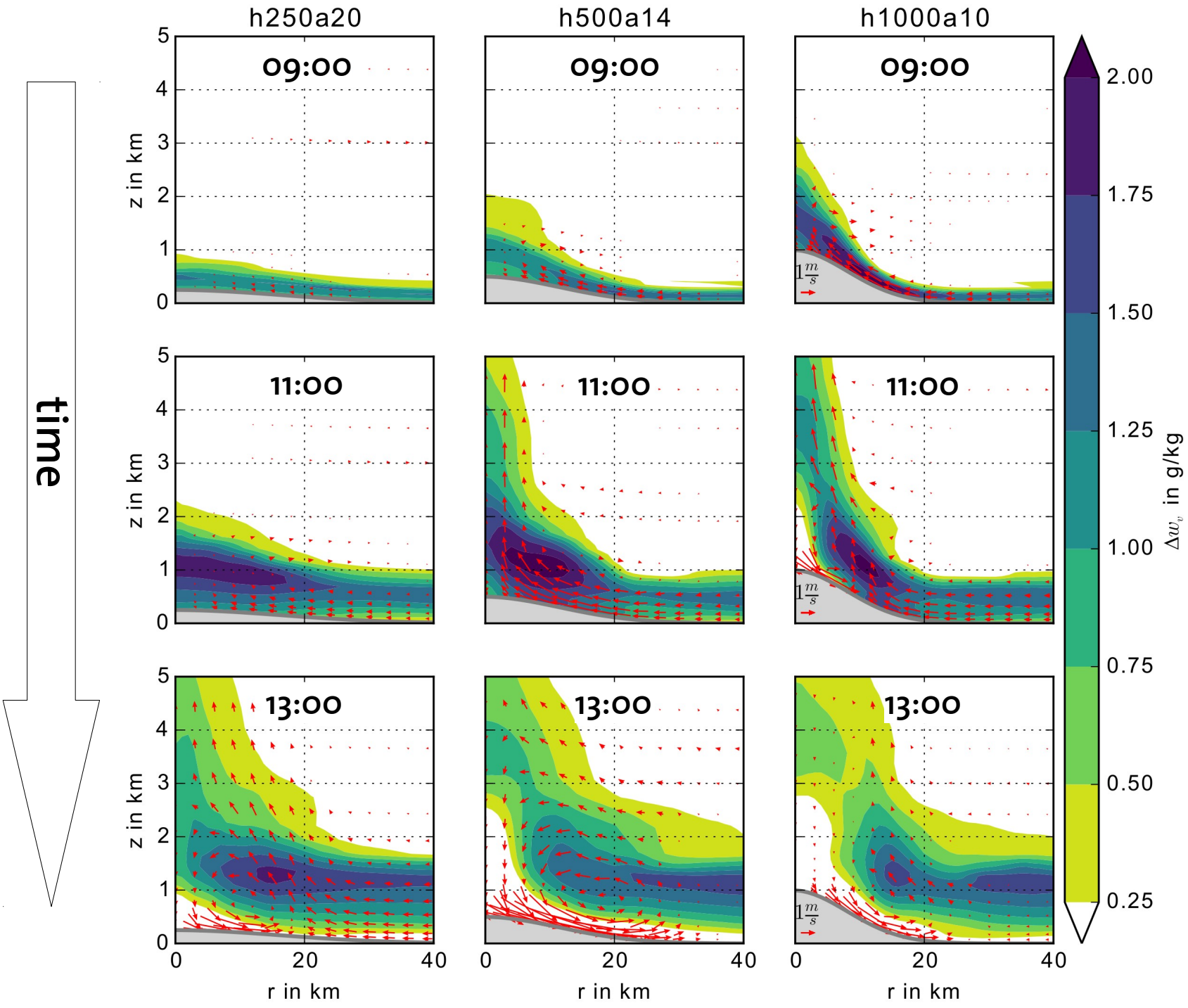
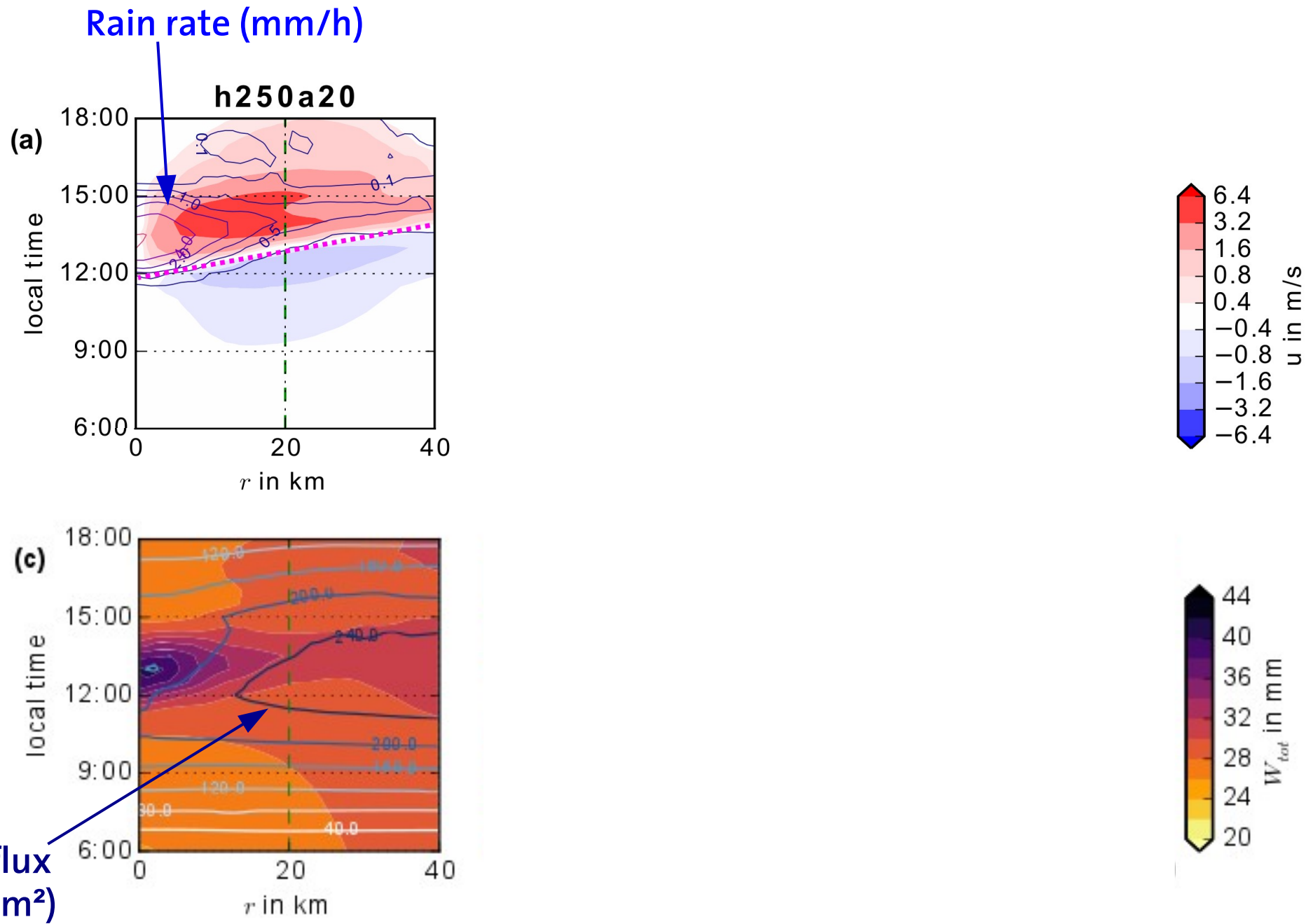
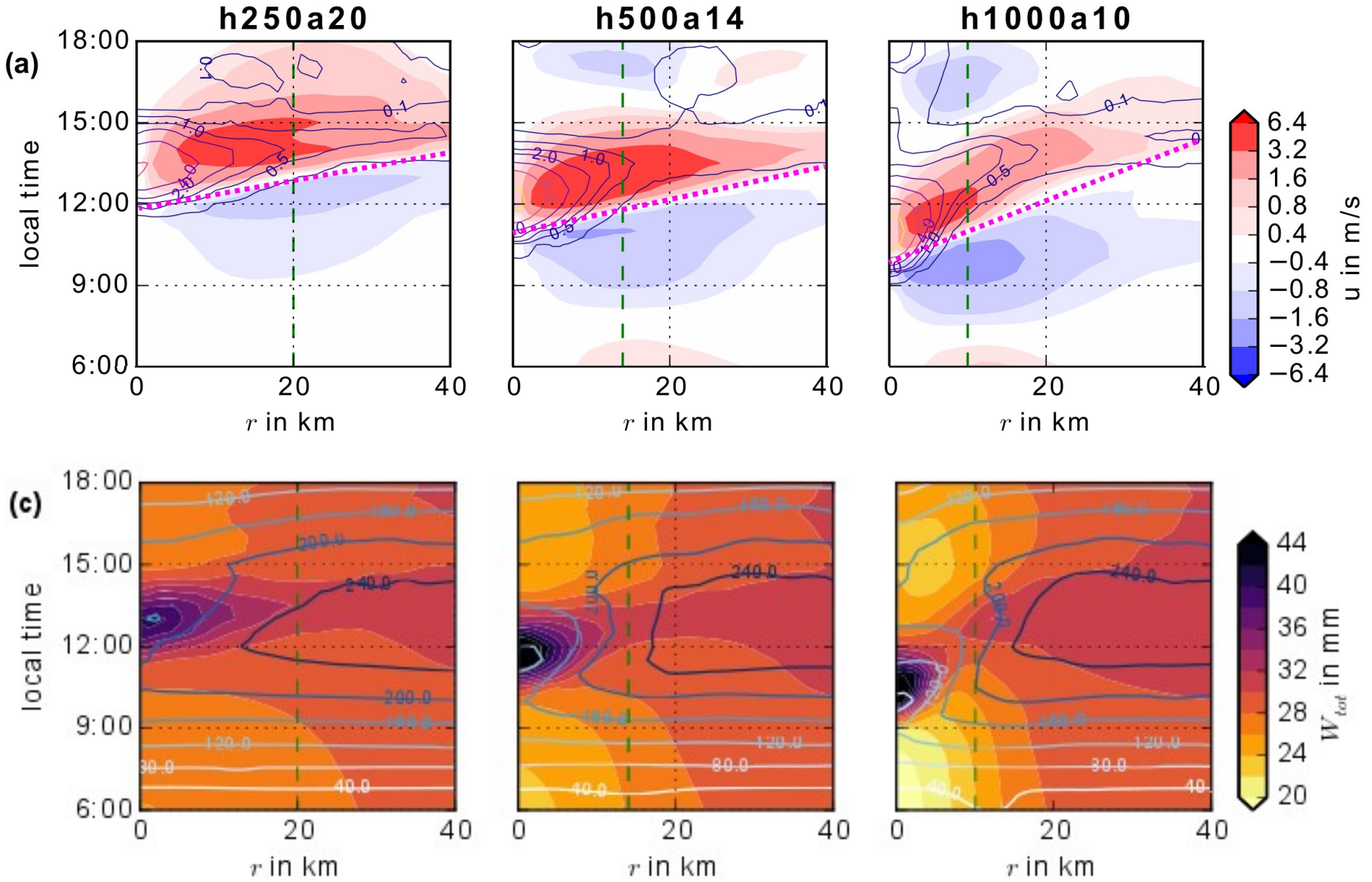


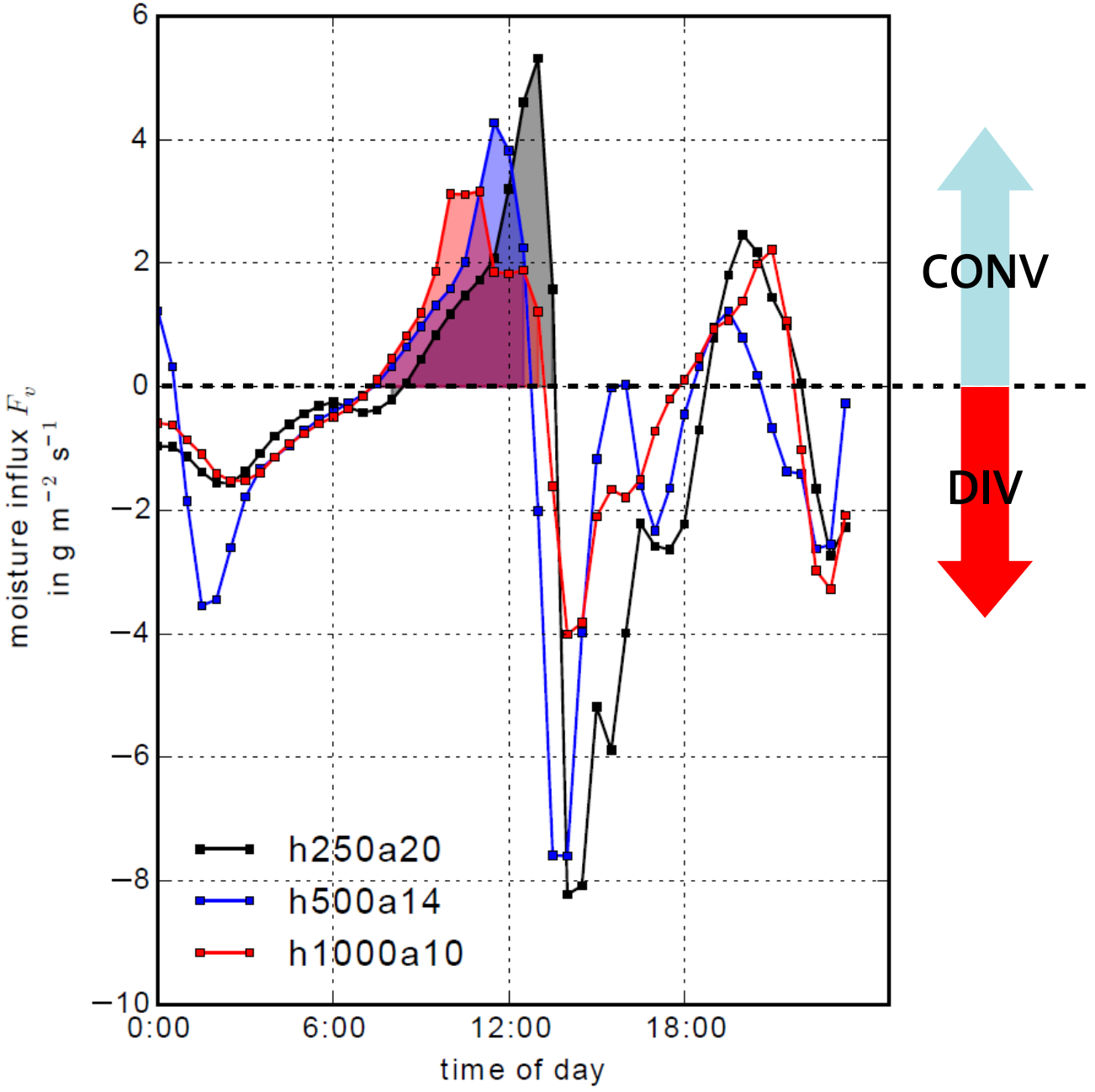
Hovmöller diagrams of **surface wind** and **water mass:**



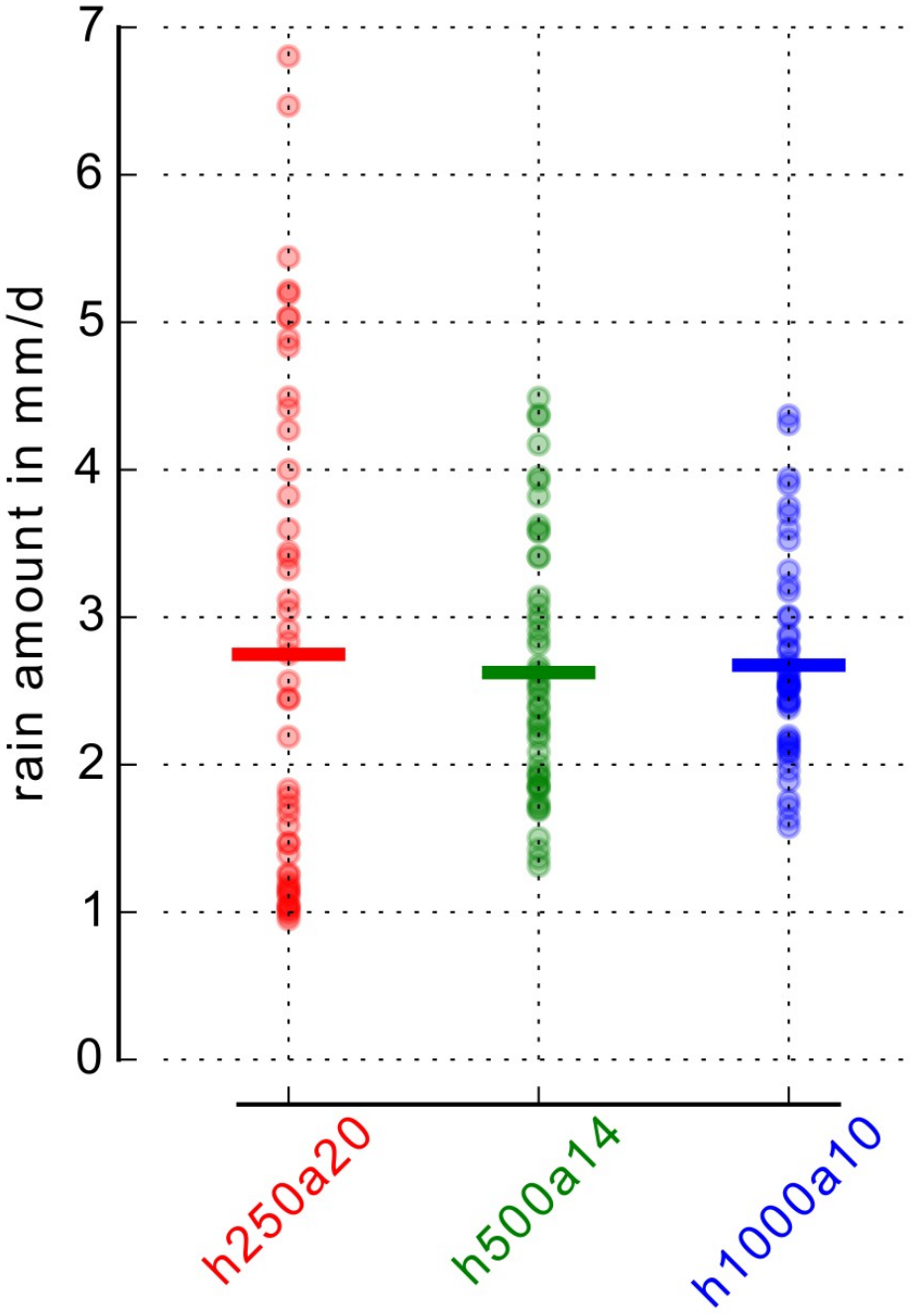
Deep-convective dynamics at mountains with the same volume strongly differ as the Hovmöller diagrams of **surface wind** and **water mass** show:



Moisture influx at r=30 km distance from mountain top

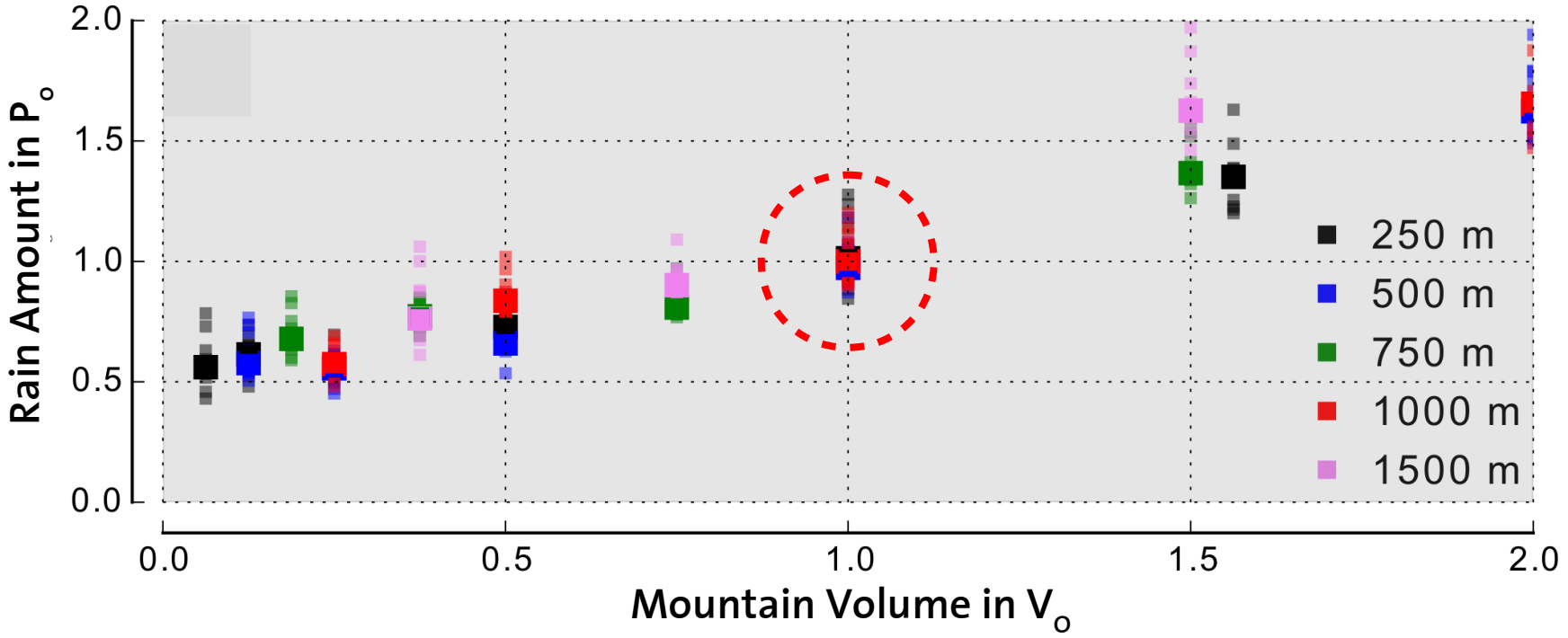


Large day-to-day variability (1 point → 1 day), but **in the statistical mean** the mountains receive the same rain amount



P_o = 2.7 mm/day

Rain amount P scales linearly with the mountain volume V



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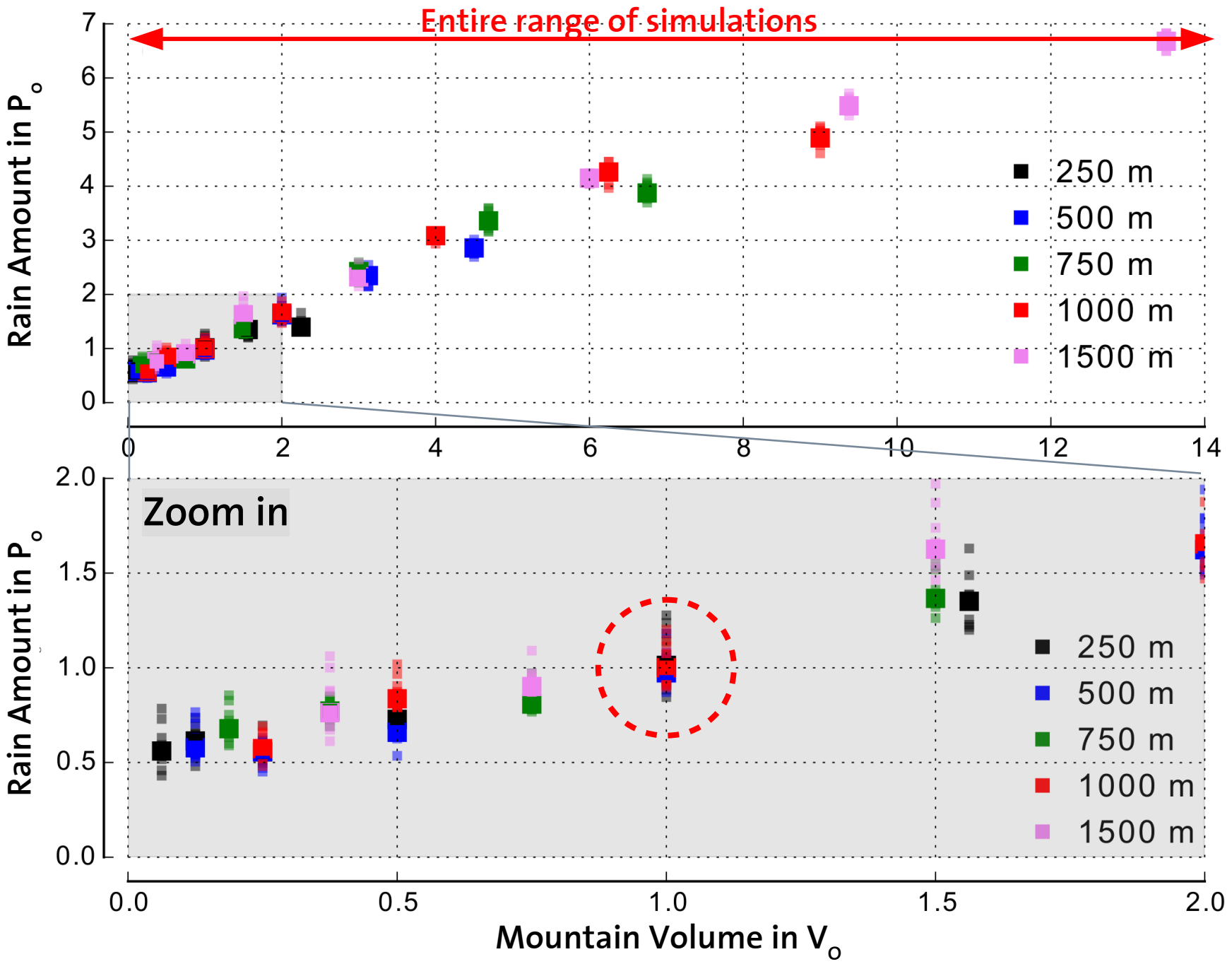
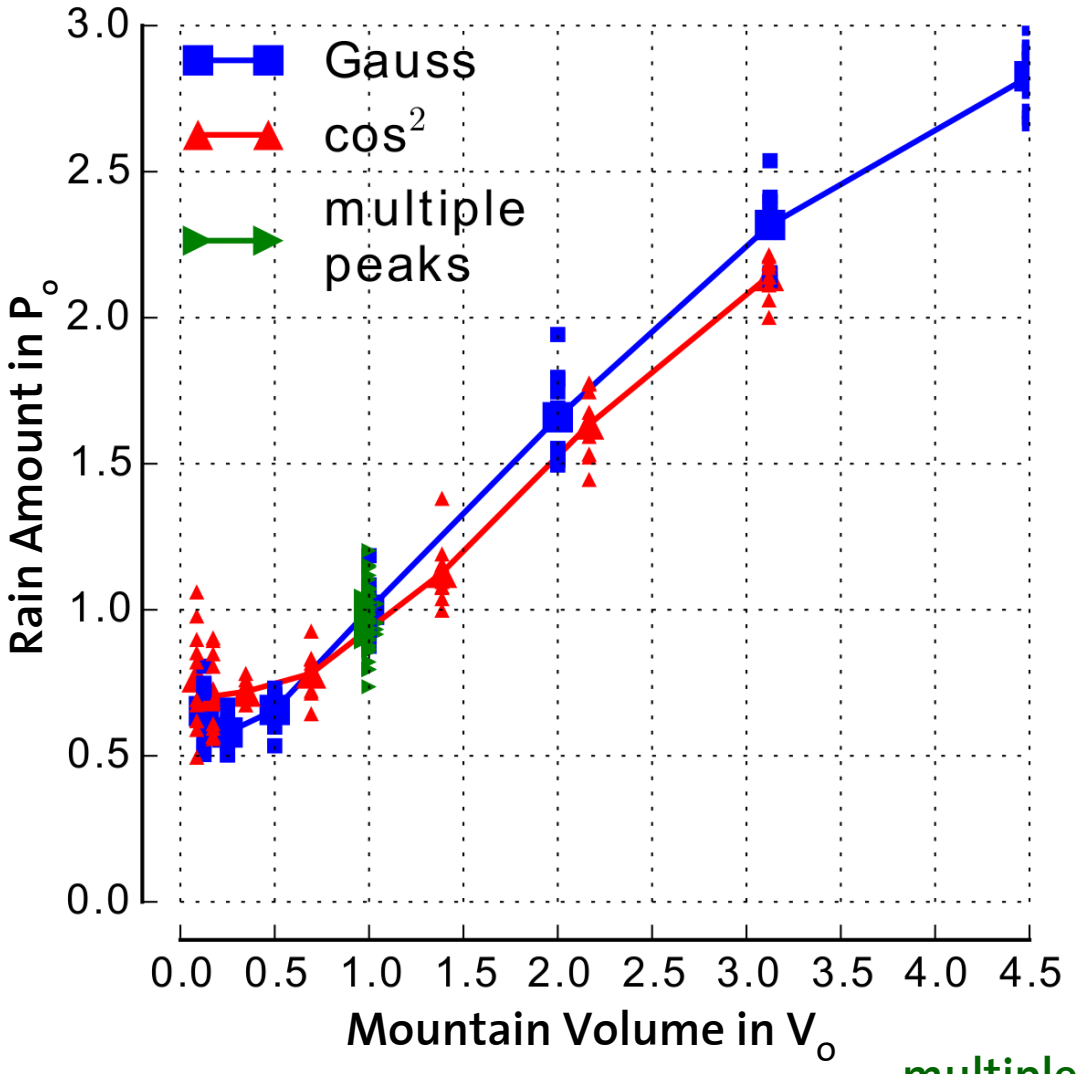
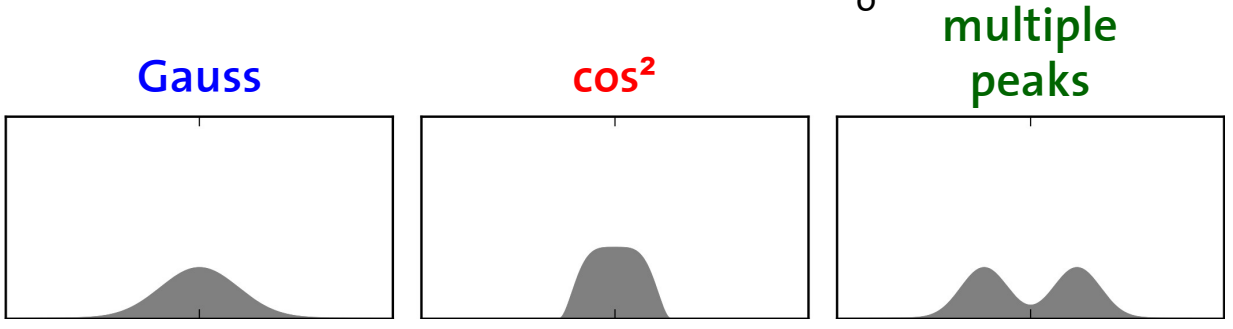
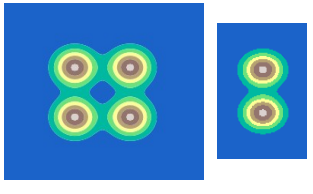


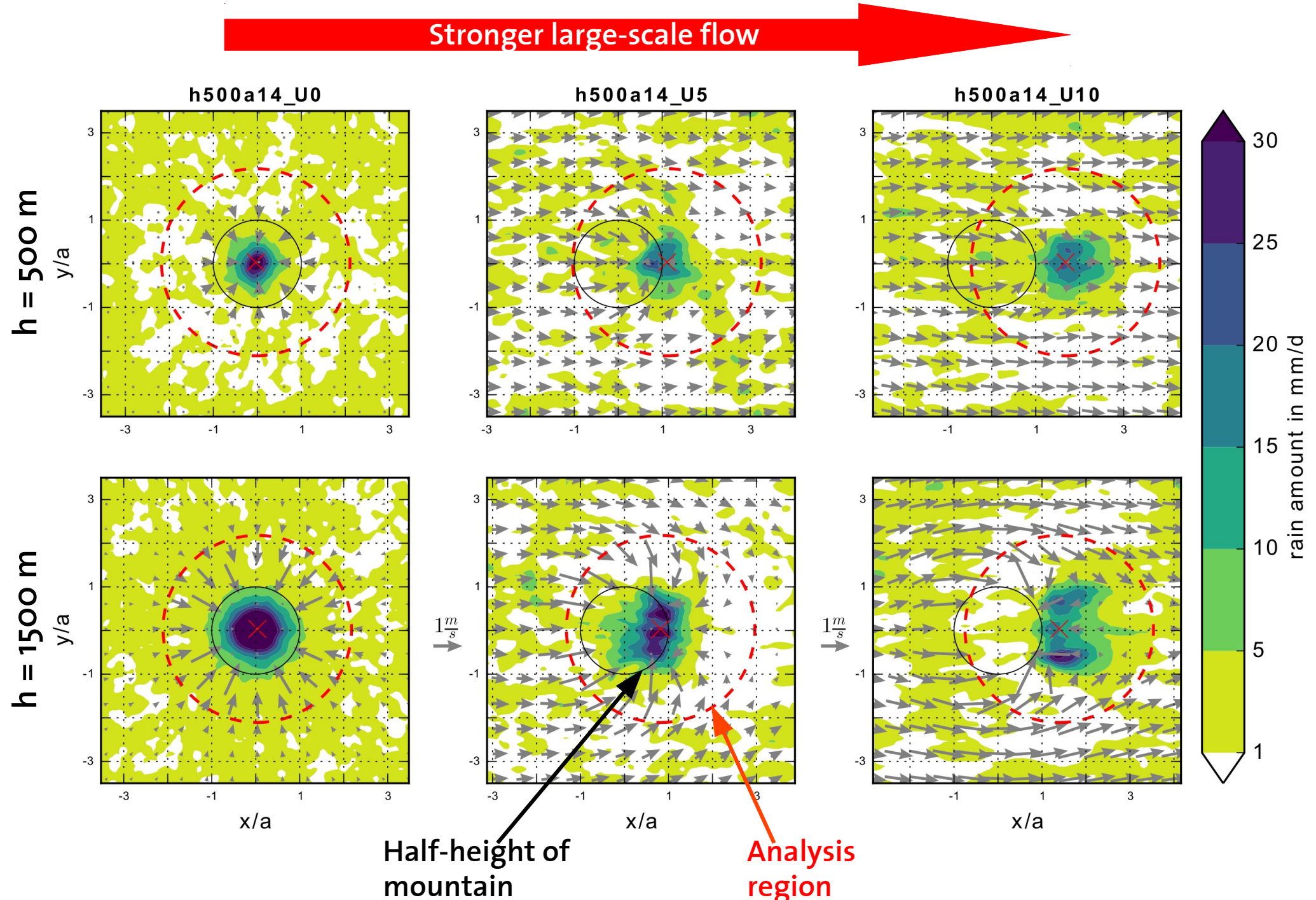
P ~ V scaling prevails for alternative mountain geometries



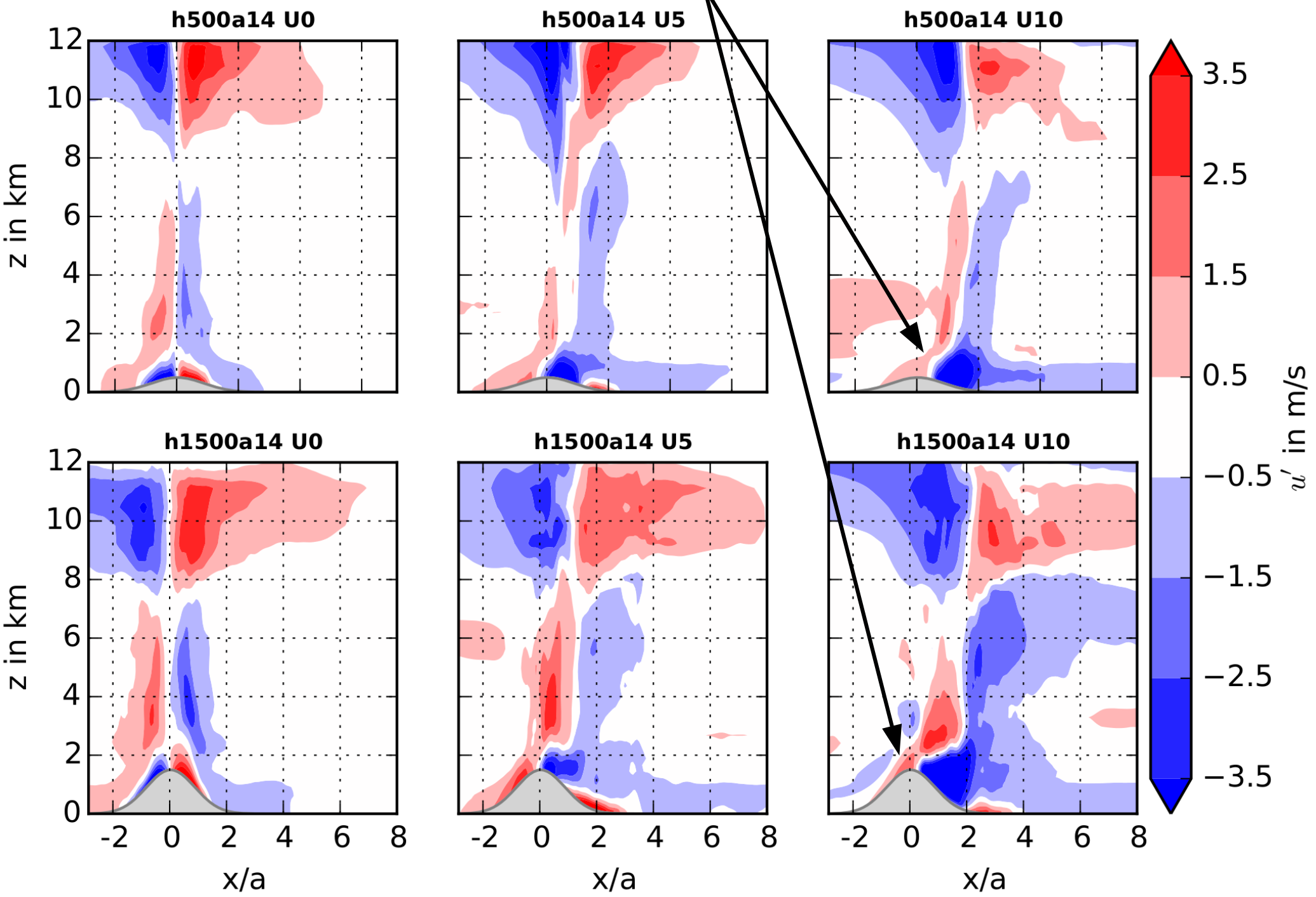




Large-scale flow affects the position and shape of the rain maximum

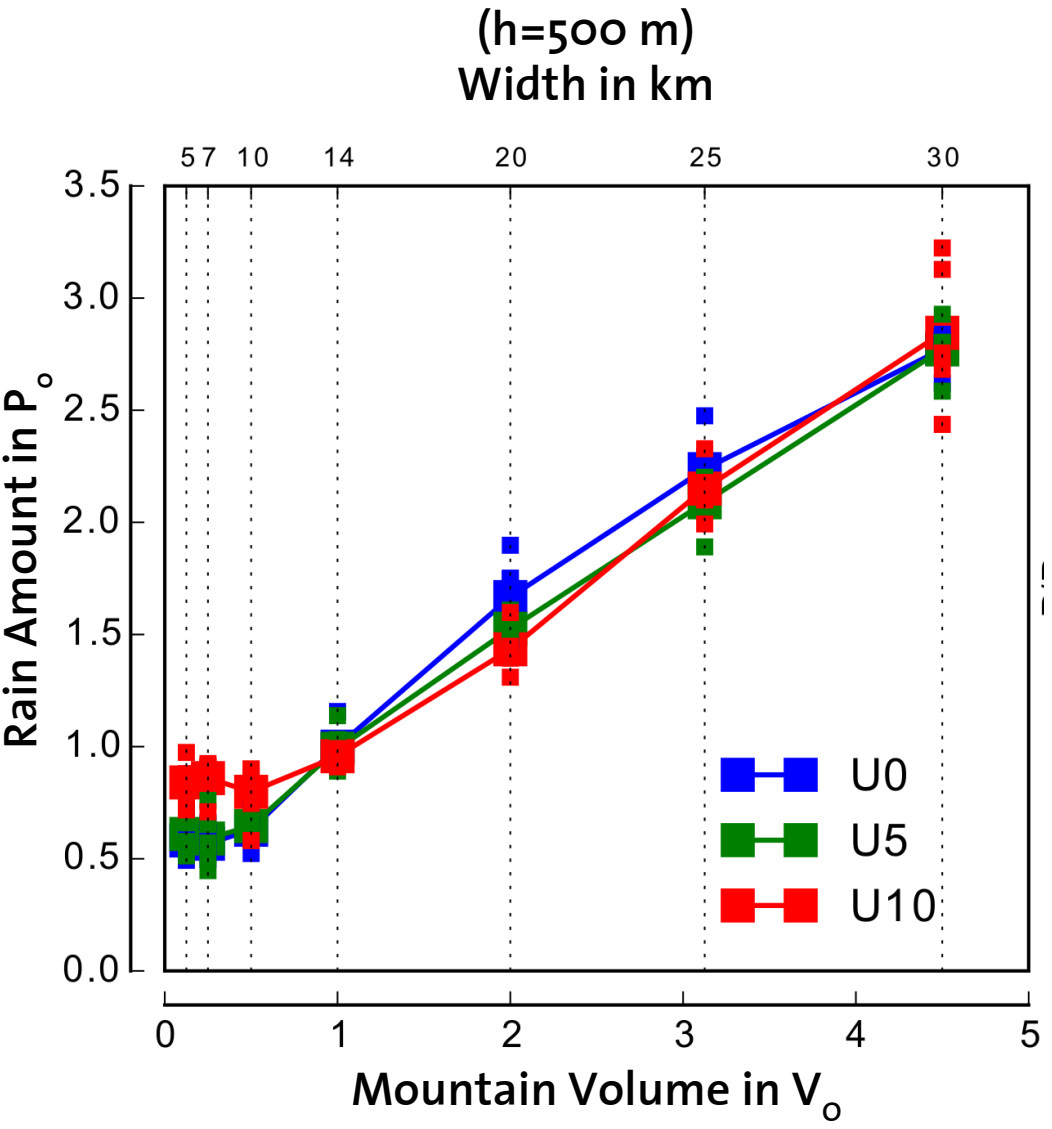


Downwind shift of convergence zone → Ventilation of mountain top heat

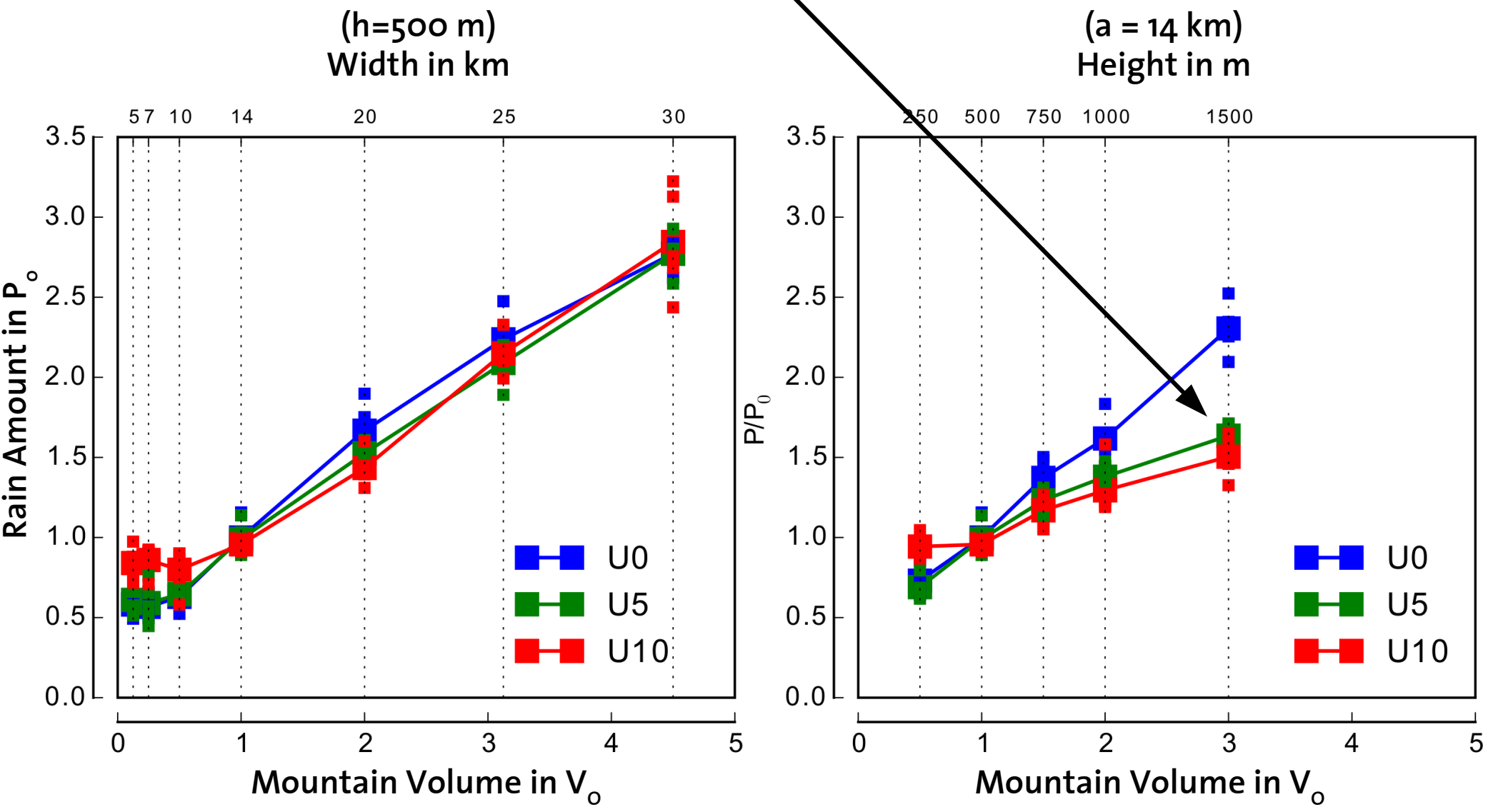


Snapshot at 10:00 in the morning

The P~V scaling prevails for mountains < 750 m in height

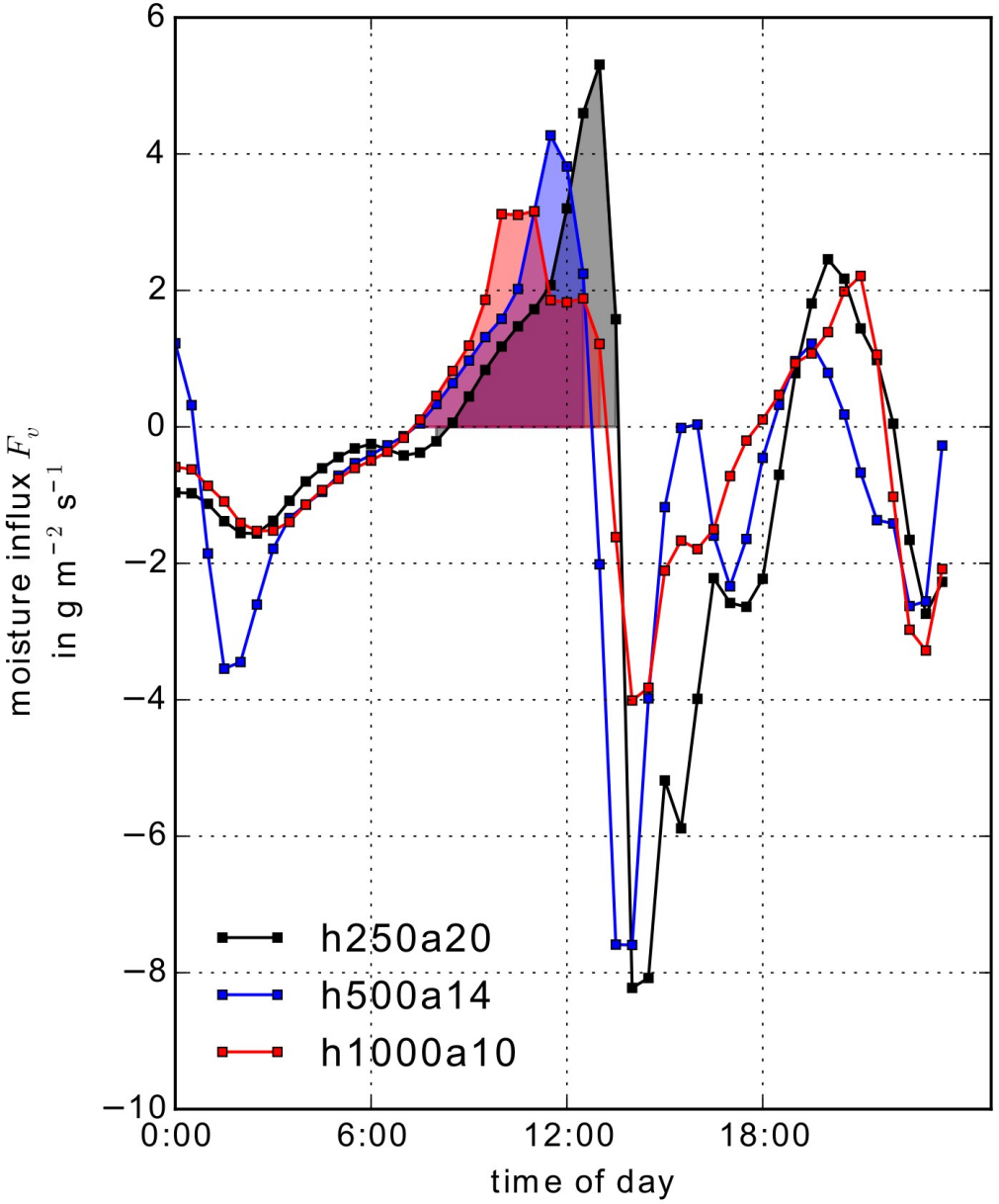


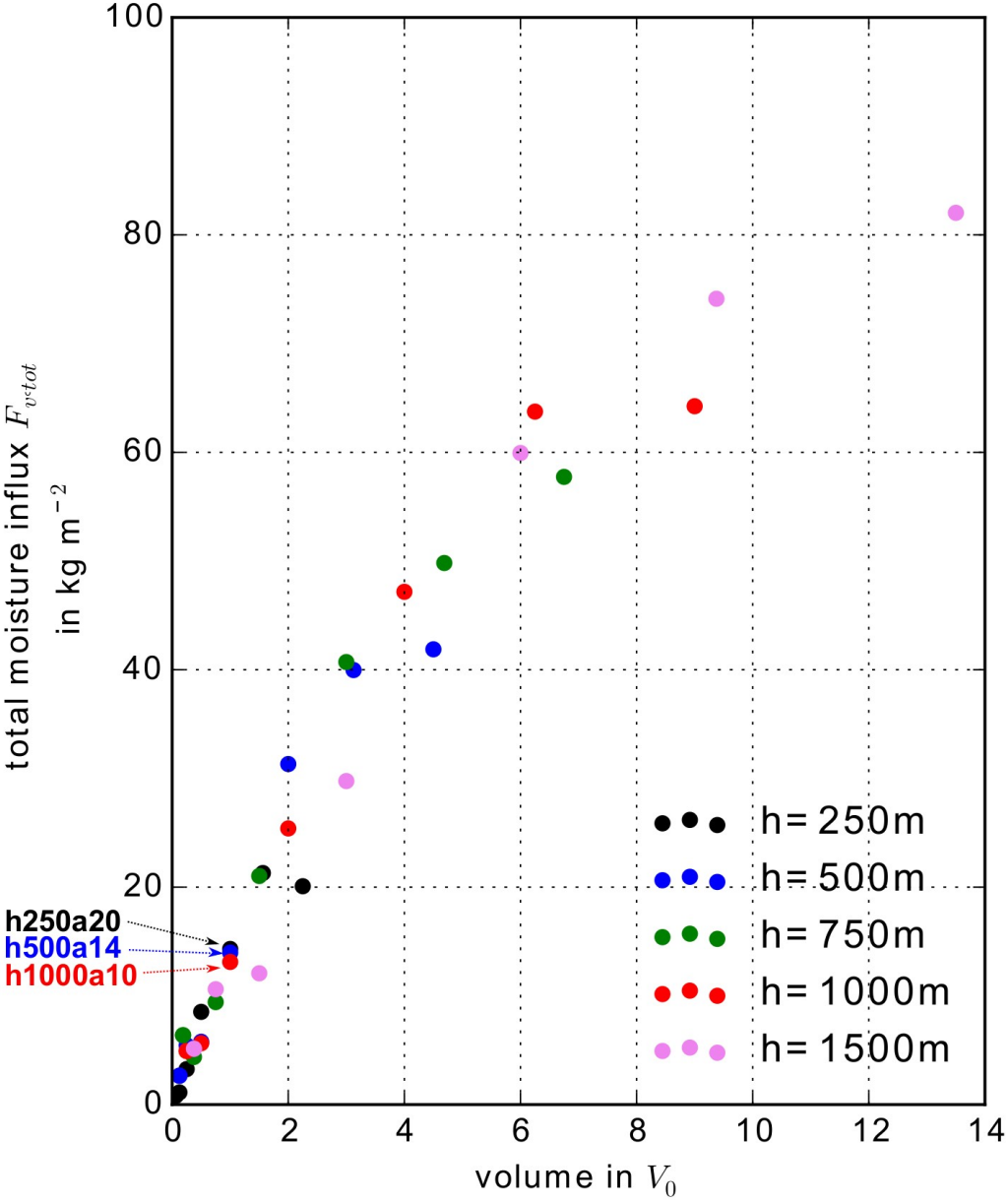
The P~V scaling breaks down in the limit of tall mountains and strong large-scale flow

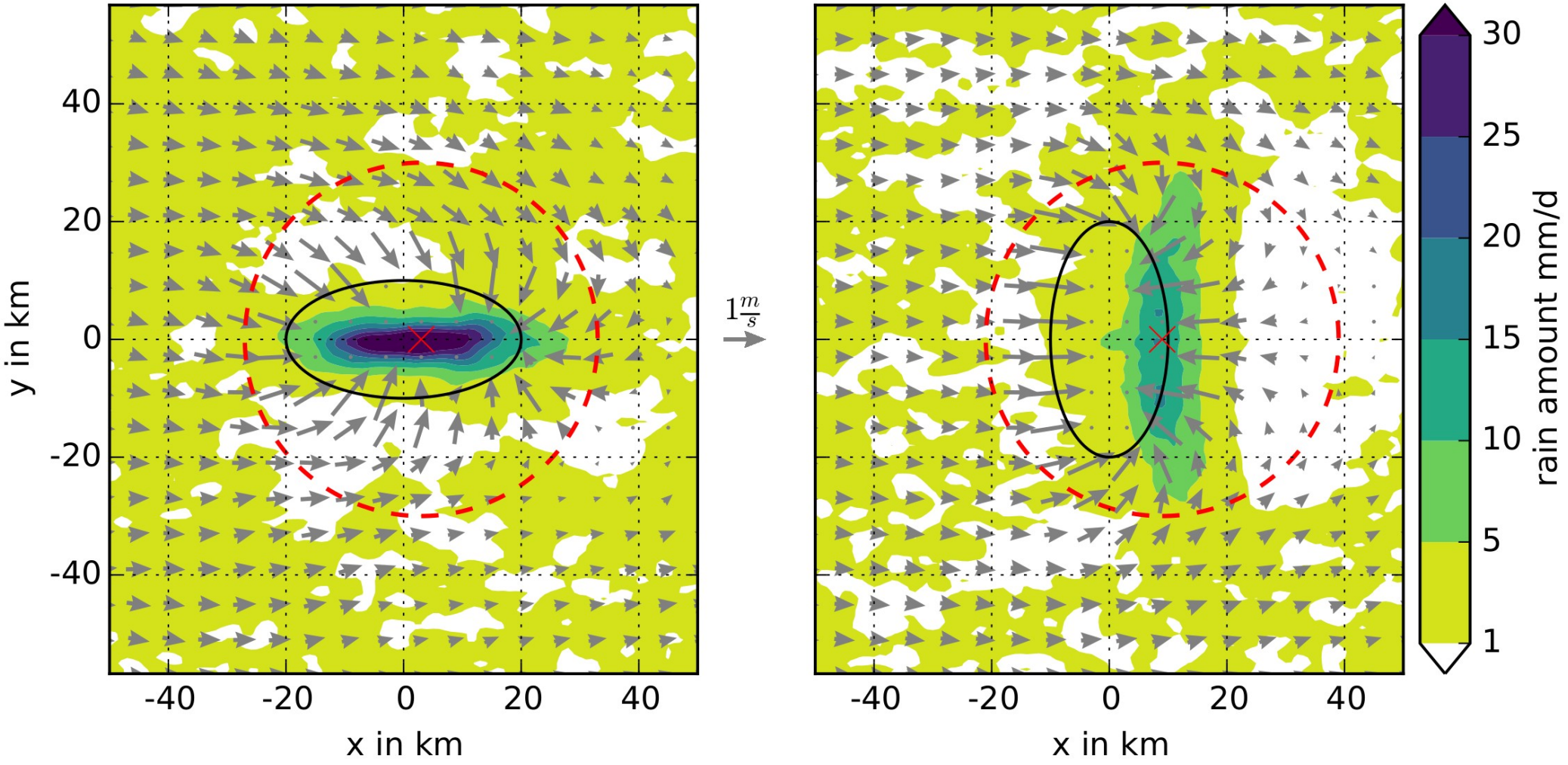


Summary

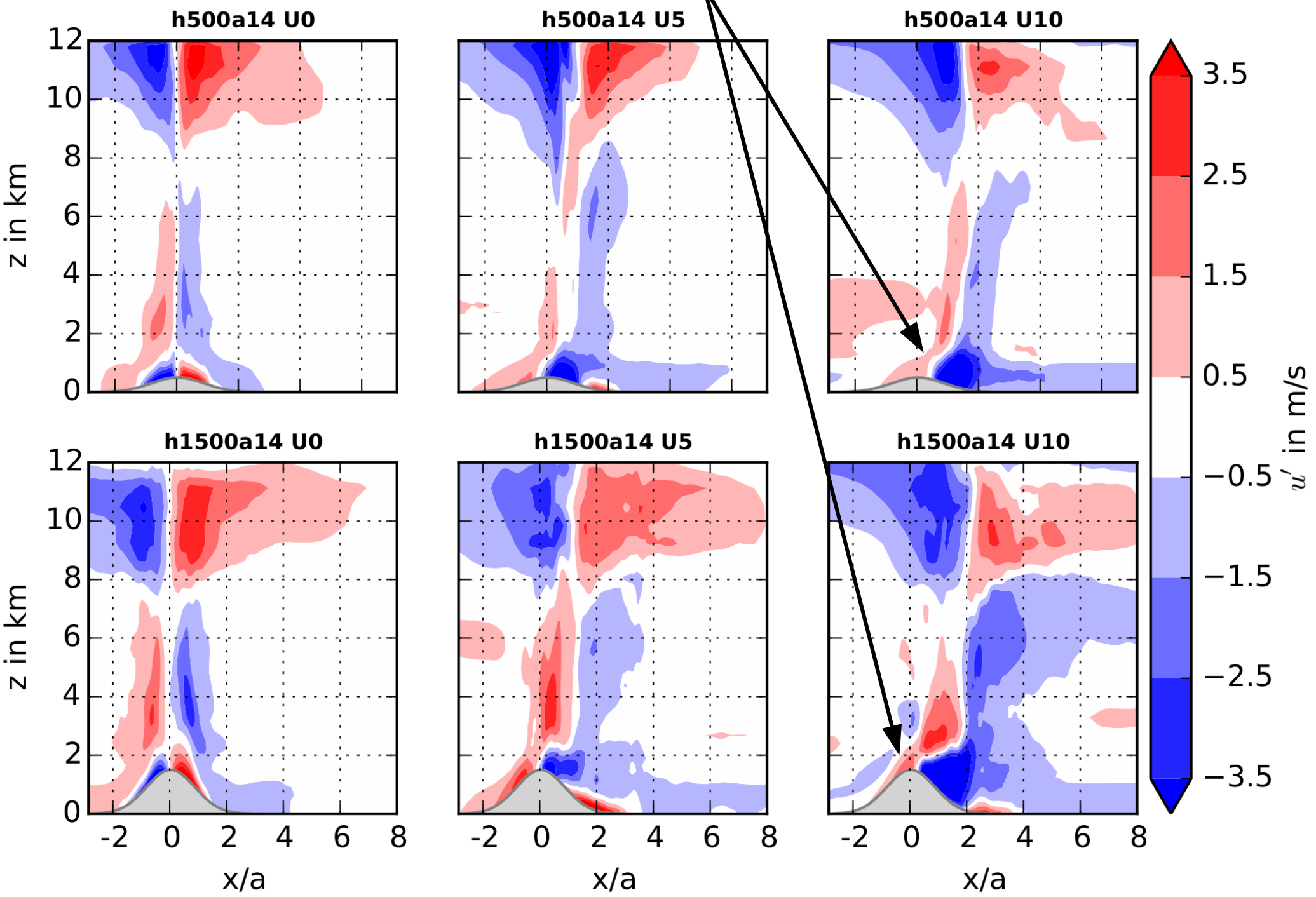
- We found a regime of orographic deep convection in which rain amount scales linearly with the **mountain volume**.
- The scaling is **robust** over a wide portion of parameter space however it starts to **breaks down** for tall mountains and strong large-scale flow.
- Given that the large horizontal scales disproportionally contribute to the volume of mountains, the P~V scaling suggests that the **largest width scales** control the rain amount **in the statistical mean.**


moisture influx F_v
in g m^{-2} s^{-1}
6
4
2
0
−2
−4
−6
−8
−10
0:00
6:00
12:00
18:00
time of day
h250a20
h500a14
h1000a10


total moisture influx F_{vtot}
in kg m^{-2}
100
80
60
40
20
0
0
2
4
6
8
10
12
14
volume in V_0
h250a20
h500a14
h1000a10
h= 250m
h= 500m
h= 750m
h= 1000m
h= 1500m


40
20
0
-20
-40
y in km
-40
-20
0
20
40
x in km
$1\frac{m}{s}$
-40
-20
0
20
40
x in km
30
25
20
15
10
5
1
rain amount mm/d

Downwind shift of convergence zone → Ventilation of mountain top heat



Snapshot at 10:00 in the morning

How Robust is the Linear Scaling?

- **Mountain geometry test**

  $\cos^2$ surface profile

  multiple Gaussian peaks

- **Sheared background wind test**

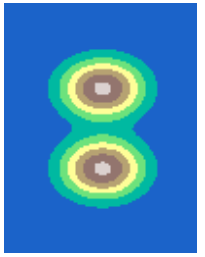
  U0, U1, U2, U4, U8

- Fix mountain height to h=500 m,
  a in A = {5, 7, 10, 14, 20, 25, 30} km

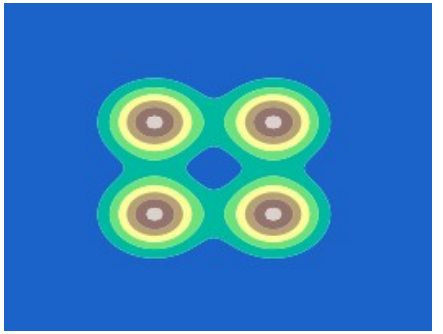
Multiple Gaussian peaks

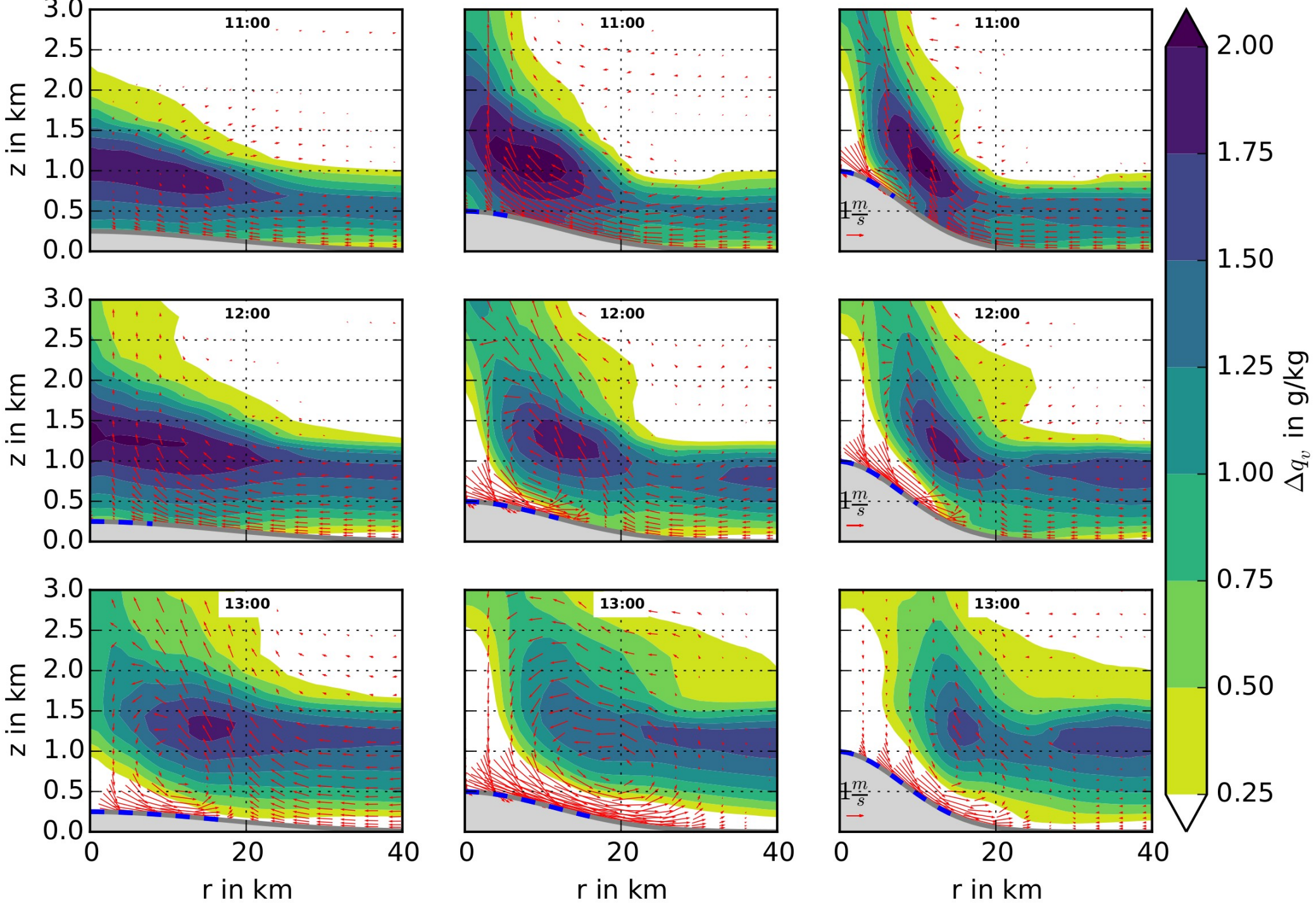
Split the volume of the h10000a10 mountain into:

- 2 x h500a10 (10 km apart)
- 2 x h10000a7 (10 km apart)

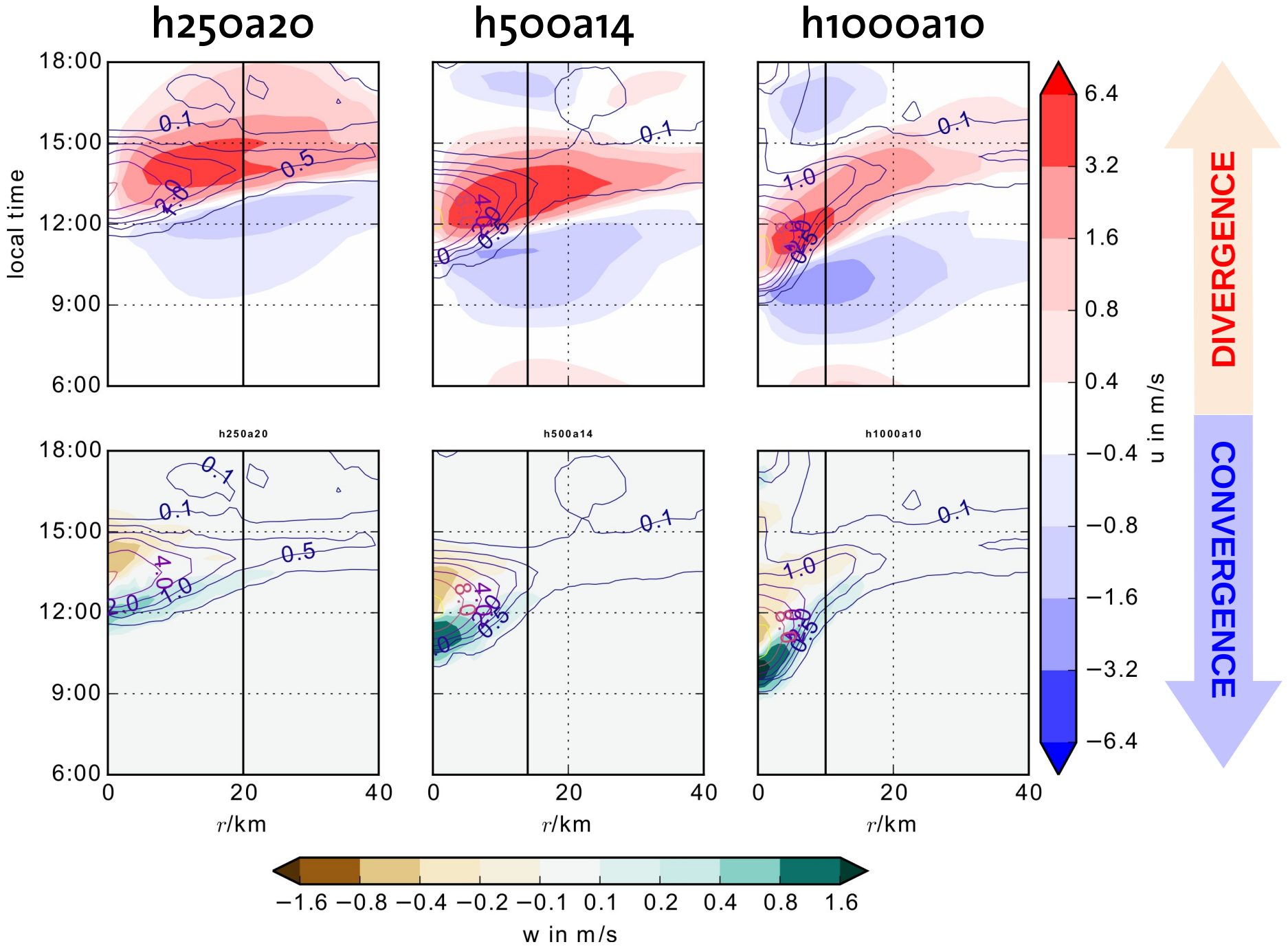


- 4 x h500a7 (on a 10 km grid)
- 4 x h250a10 (on a 10 km grid)



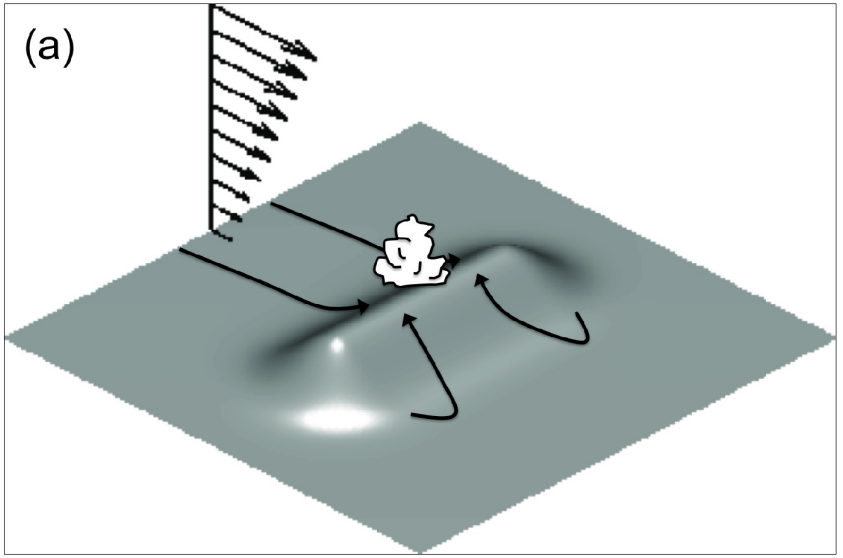

h250a20
h500a14
h1000a10
11:00
12:00
13:00
z in km
r in km
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
20
40
$1\frac{m}{s}$
Δq_v in g/kg
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

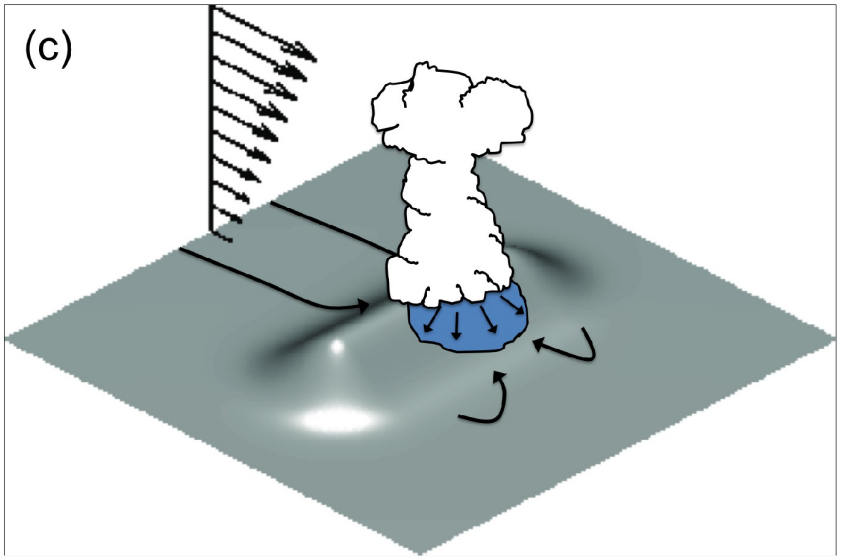
Hovmöller Diagrams of Upslope Winds



Breakdown of Volume Scaling if Mechanical Forcing Becomes Dominant?

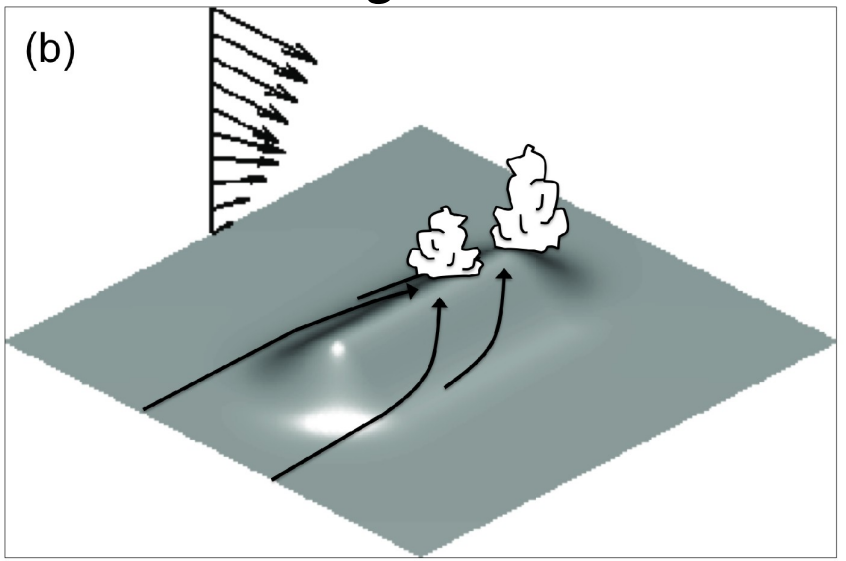
Across-Barrier Flow

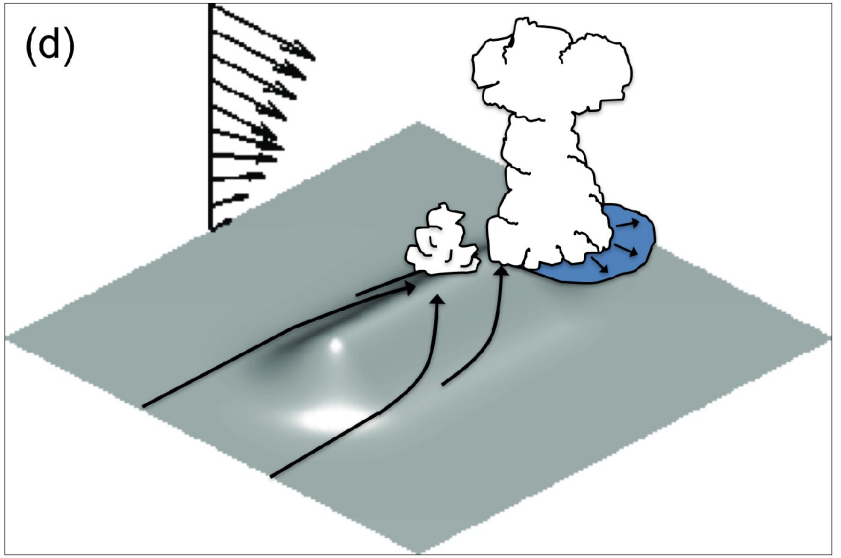




VS.

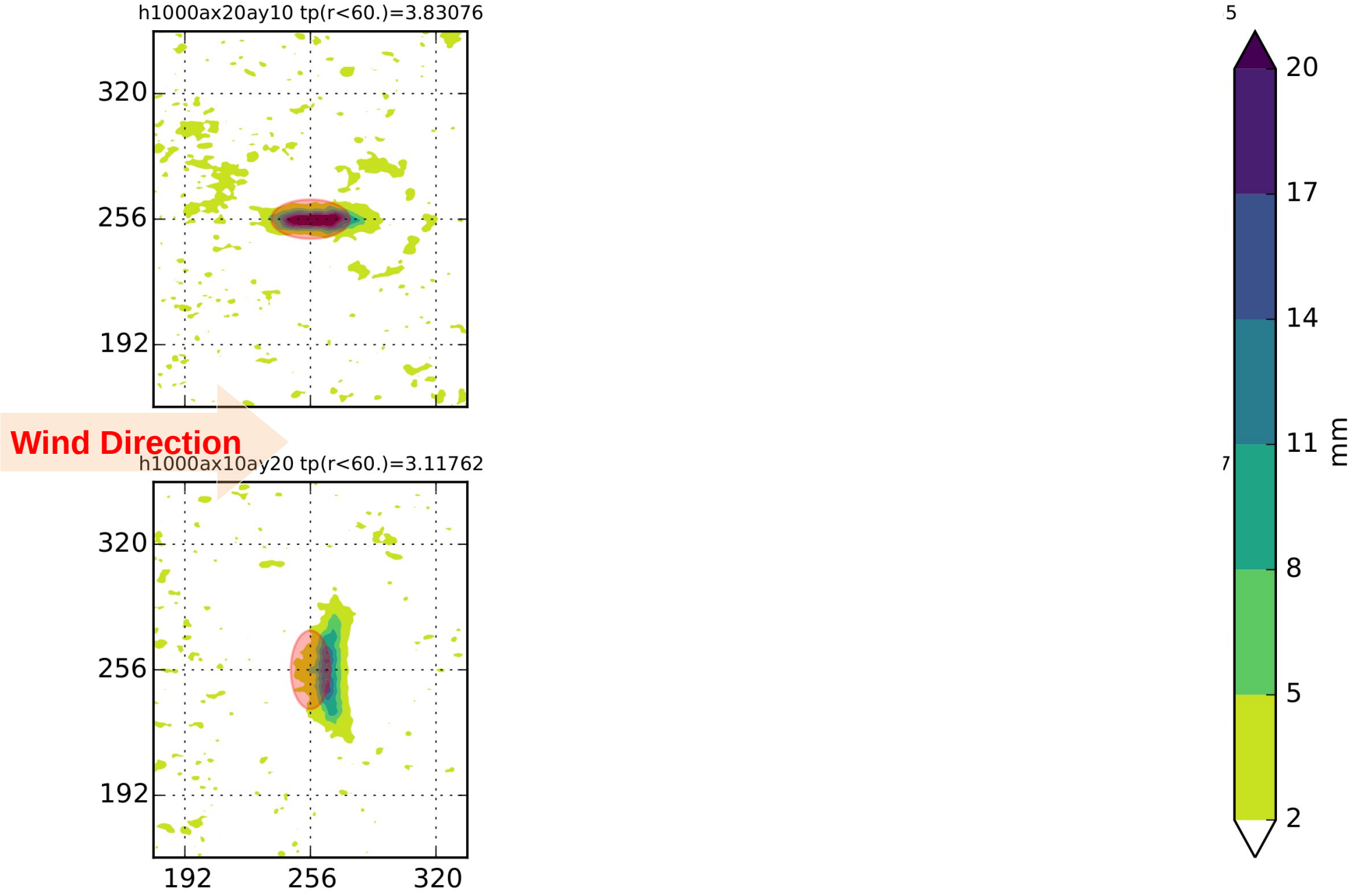
Along-Barrier Flow



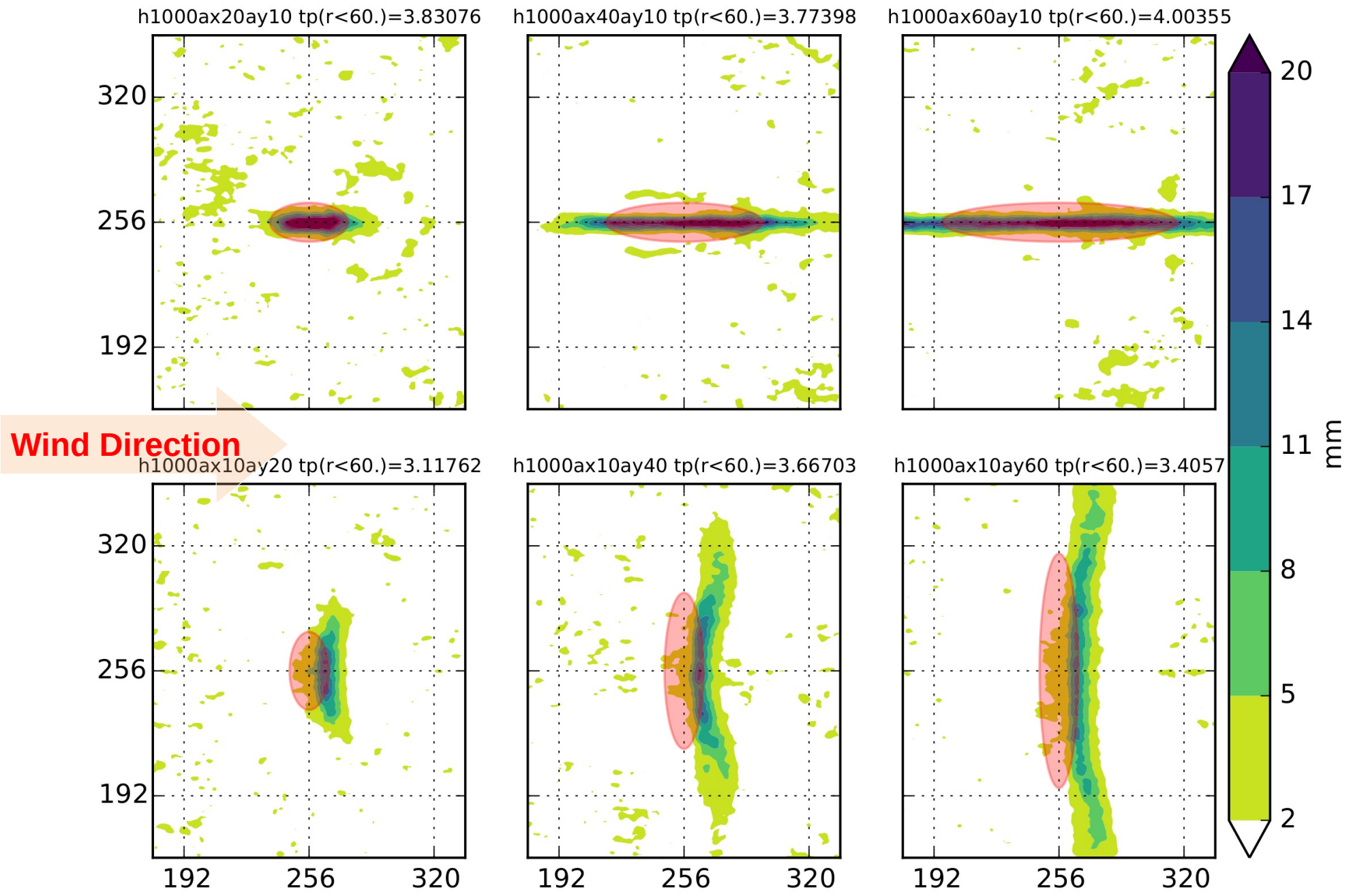


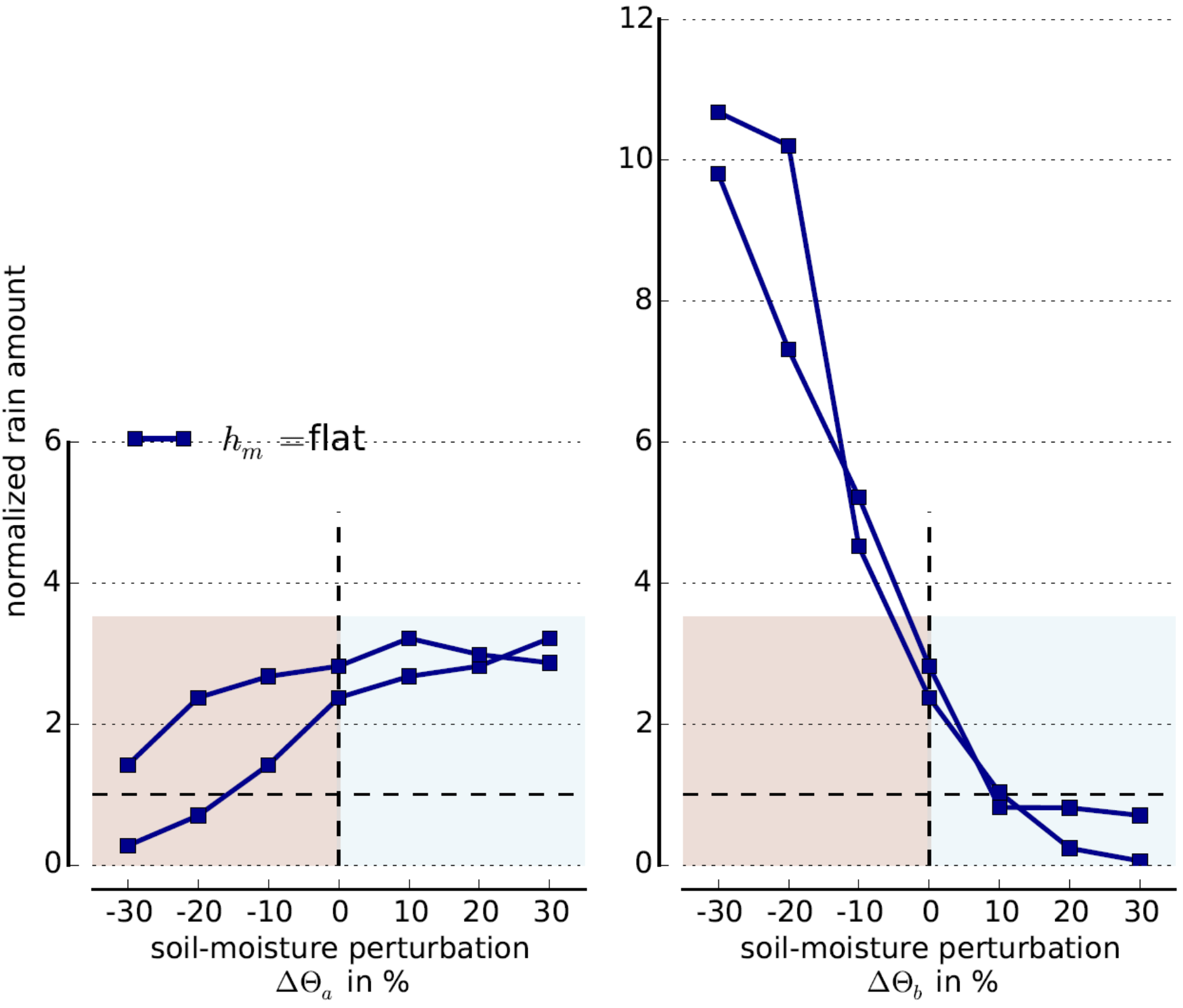
Kirshbaum et al.,2018

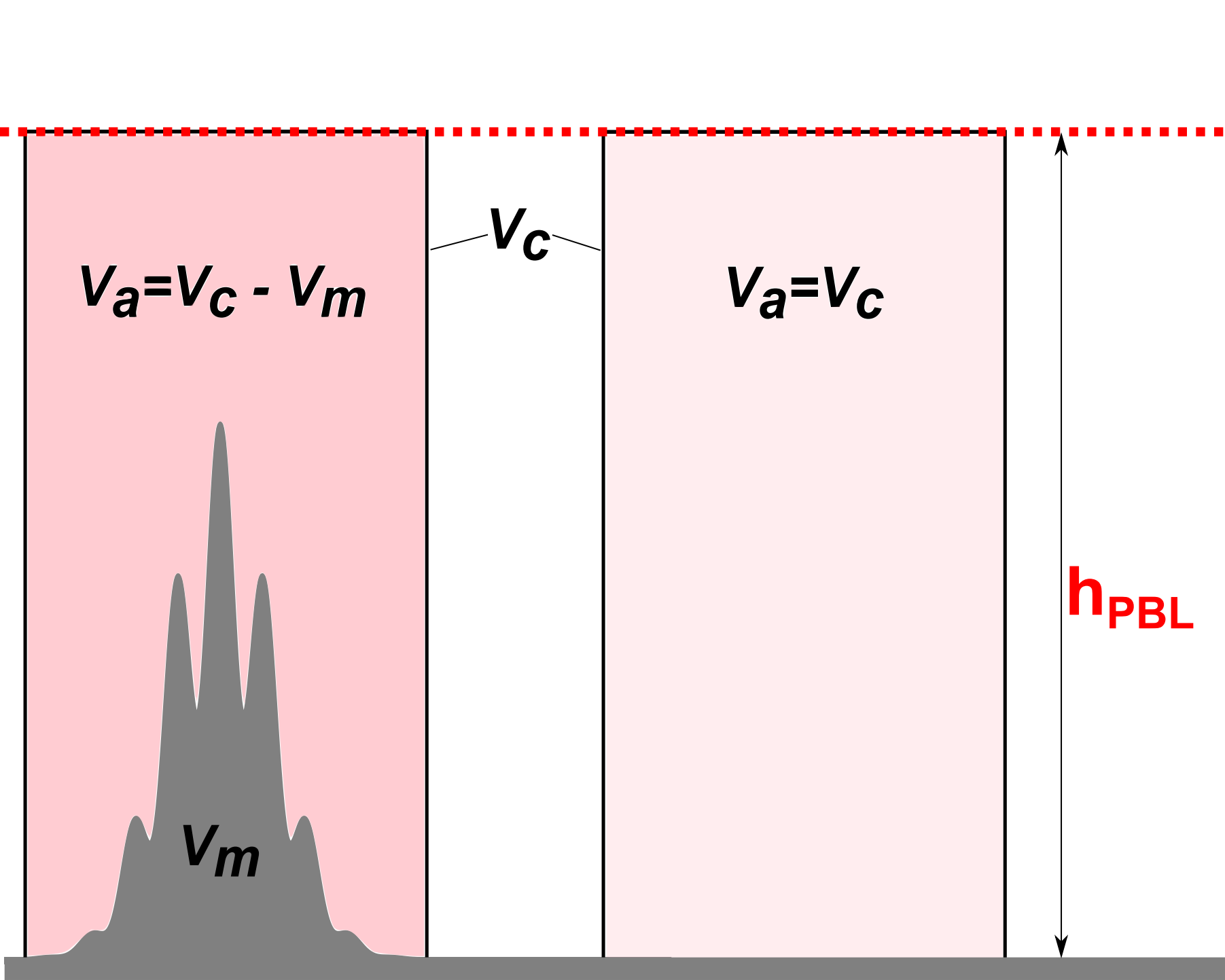
Departure from the Volume Scaling



Departure from the Volume Scaling




normalized rain amount
h_m =flat
0
2
4
6
8
10
12
-30 -20 -10 0 10 20 30
soil-moisture perturbation
$\Delta\Theta_a$ in %
soil-moisture perturbation
$\Delta\Theta_b$ in %


$V_a=V_c - V_m$
V_c
$V_a=V_c$
h_{PBL}
V_m