On the Moisture Extraction of Mountains via Deep Convection

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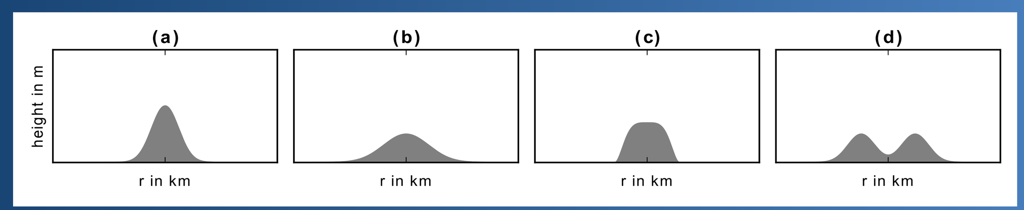
Motivation and Research Q

Deep convection is the dominant mode of summer precipitation in many extratropical regions. Especially during episodes of weak synoptic forcing, mountains are deep convection hot spots, in particular due to the elevated moistening by upslope flows. What is the relative contribution of different orographic scales on deep convective precipitation? Or alternatively: which of the following mountains extracts most rain via deep convection?



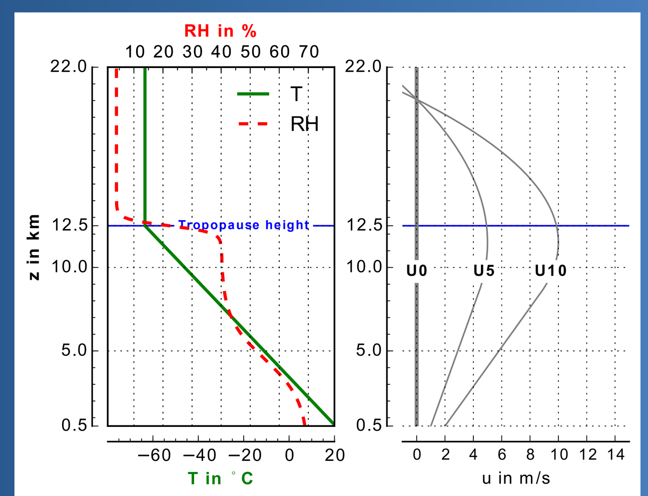
Numerical Experiments

We use the Consortium for Small-Scale Modeling (COSMO, Baldauf et al., 2011) in climate mode (CCLM) at a Δx=1 km horizontal grid spacing. Full physics parameterizations are employed. No shallow/deep convection parameterization.

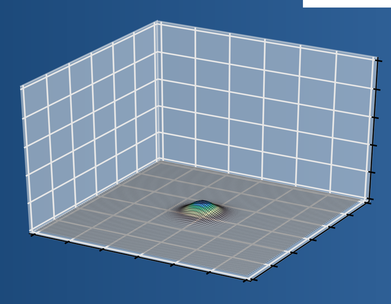
512x512 km² domain, 22 km deep, double periodic boundaries, no Coriolis force, extratropical summer insolation, COSMO is interactively coupled to the 2nd generation, multi-layer soil model TERRA_ML. (c.f. Imamovic et al., 2017).

Idealized atmospheric profiles:

Constant lapse rate -7 K/km, RH decreases from 70 % in PBL to 40 % at tropopause. Experiments with initially resting atmosphere (U0) and with sheared background wind (U5 and U10) are performed.
CAPE < 1400 J/kg



Isolated Mountain



Height scales
H={250,500,750,1000, 1500 m}
Width scales
A={5,7,10,14,20,25,30 km}

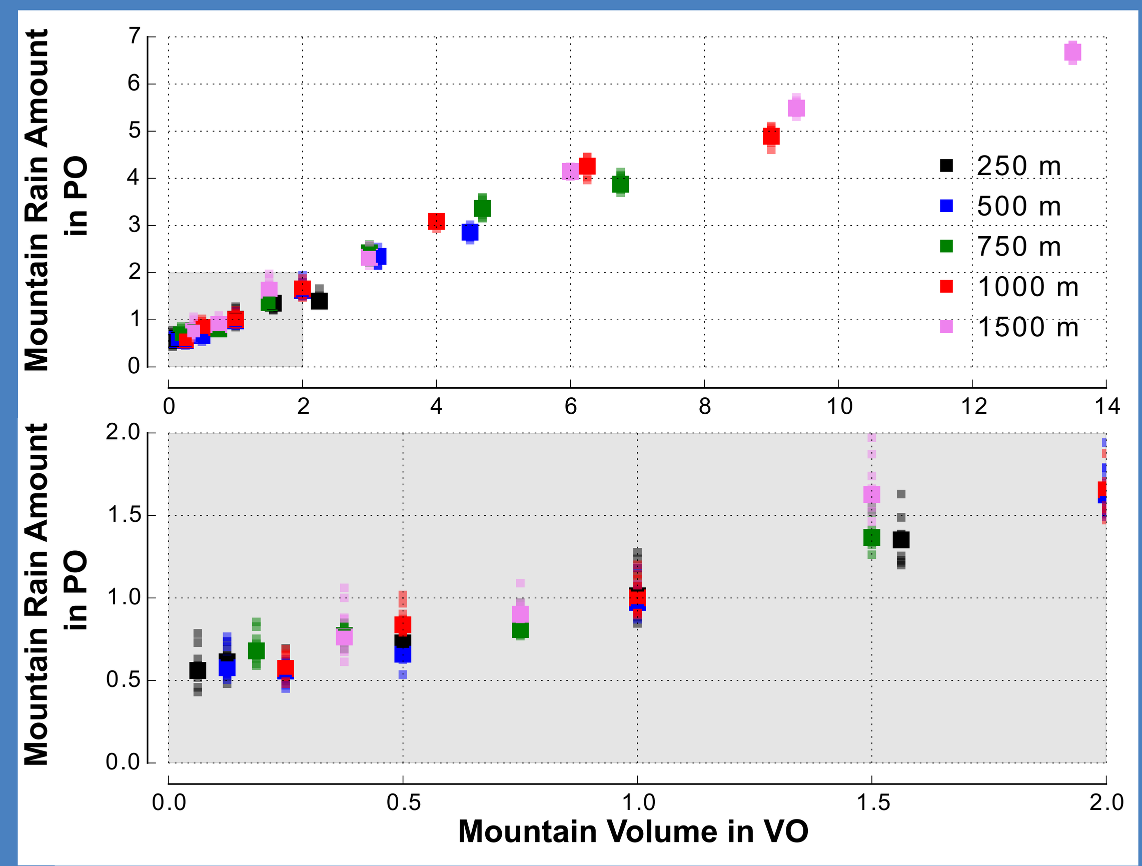
Full range of simulations

Mountain Geometry / Wind Profile	U0	U5	U10	# of Simulations
Gaussian	$\mathscr{H} \times \mathscr{A}$	VARh & VARa	VARh & VARa	590
$\cos^2$	VARa	-	-	70
multipeaks	4	-	-	40
# of Simulations	460	120	120	**= 700 ~ 3500 days**

10 ensemble members per configuration (differ only in initial noise in lowest T level)
5 days free run per configuration
VARh: keep a=14 km fixed and vary full range of heights h.
VARa: keep h=500 m fixed and vary full range of widths a.

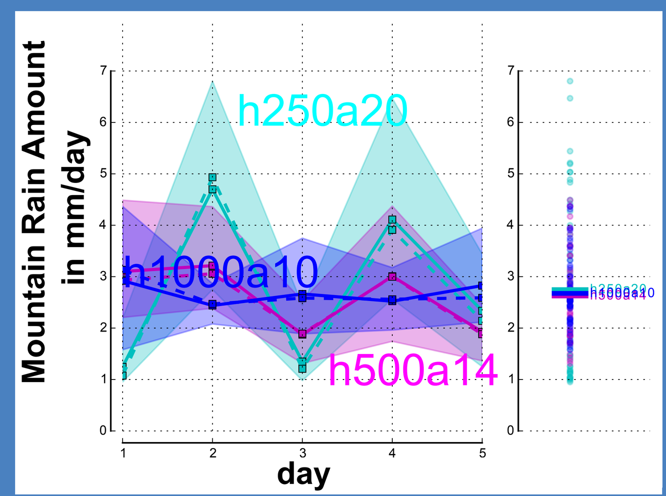
Mountain Volume V Controls Rain Amount P: the P~V Scaling

In the statistical mean (ensemble and day average) the rain amount ***P*** (at r<30 km) is fully determined by the mountain volume ***V*** across the whole range of simulations:



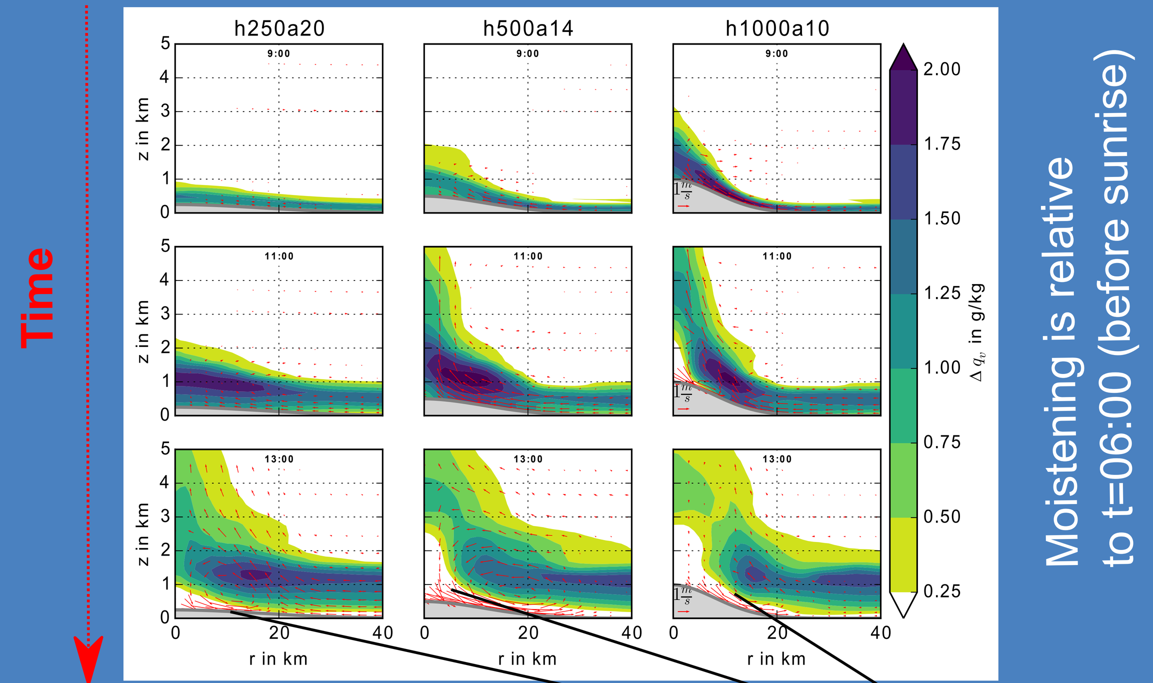
P0=2.9 mm/ day, V0 =458 km³
(rain amount and volume for h1000a10 mountain)

The P~V scaling emerges only statistically: The daily rain amount P at r<30 km for three mountains with the same volume (h250a20, h500a14 and h1000a10) undergoes considerable daily and ensemble spread:

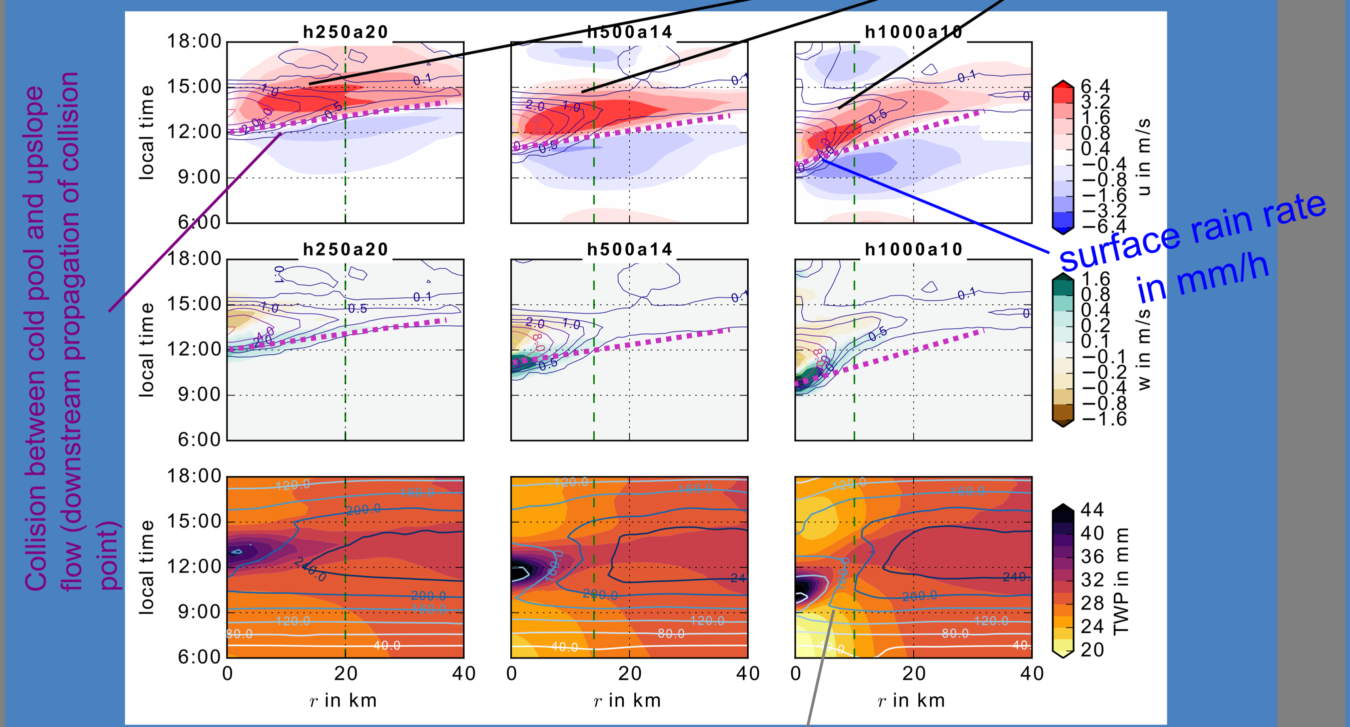


Deep Convective Life Cycle at Mountains with the Same Volume

The P~V scaling is surprising given that the deep convective life cycle over mountains with the same volume V strongly differs in terms of timing and amplitude. E.g. the moistening of the atmosphere by the upslope flows is determined by the slope of the mountain and not the volume:



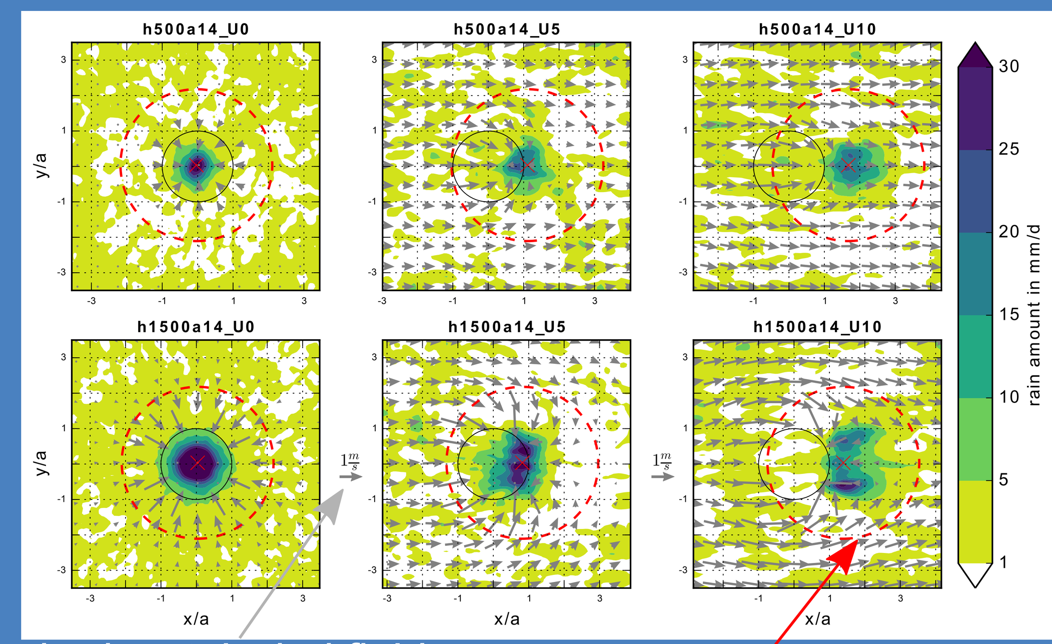
Hovmöller diagrams of radial wind u, vertical wind at 2 km AGL, and total water path (TWP) further highlight these differences:



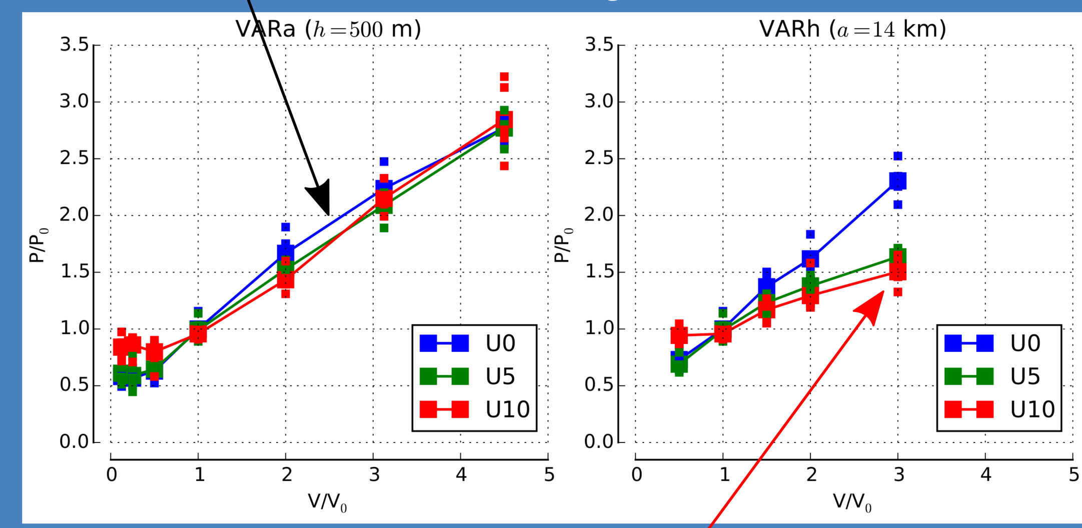
Surface latent heat fluxes (contours in W/m²) hardly contribute to moisture excess over the mountain

Impact of Large-Scale Flow on the P ~ V scaling

Accumulated rain amount for the h500a14 and h1500a14 as a function of background wind (U0,U5, and U10):



P~V scaling prevails with large-scale flow for mountains < 750 m in height and all widths....



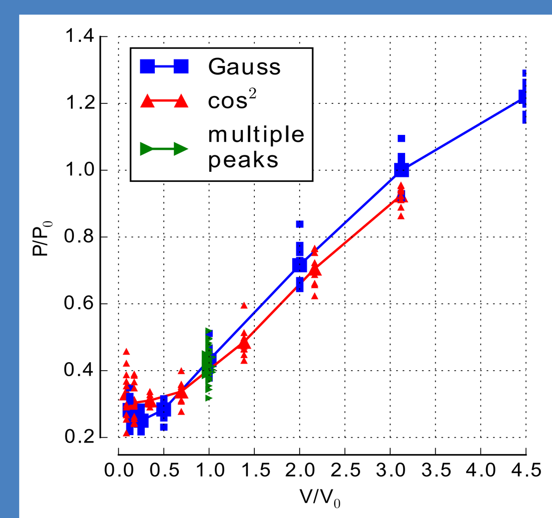
... but we find a breakdown of the scaling for large-scale flow past the tallest mountains (>1000 m)

Conclusions

- We found a linear scaling between rain amount P and mountain volume V
- The P~V scaling regime is valid for a surprisingly large portion of parameter space. The scaling does not seem to depend on the details of mountain profiles / number of peaks.
- The scaling prevails if background wind is present for mountains lower than 750 m. For strong background wind flowing past tall mountains the scaling breaks down, likely due to the ventilation of the mountaintop heat anomaly by the background flow.

Origin and Breakdown of P~V Scaling

The P~V scaling is also valid for cos² mountain profile and experiments with multiple Gaussian peaks



The breakdown of the scaling is likely related to the venting of the mountaintop heat anomaly by the large-scale flow (c.f. Nugent et al. 2014). Linear theory (Smith and Lin, 1982) implies that the relative contribution of the thermal component to the updraft speed W decreases with background wind speed scale U as:

W~1/U²

Acknowledgments

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