

universität innsbruck

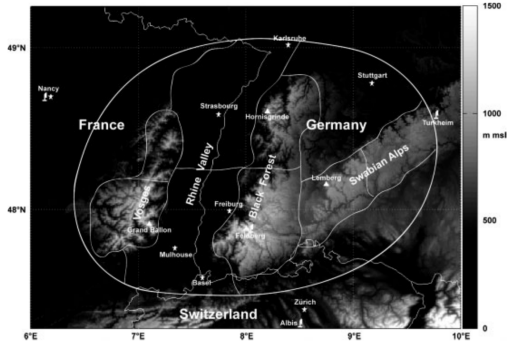
Idealized simulations of orographically-induced thermal circulations triggering deep moist convection

Matthias Göbel
Department of Atmospheric and Cryospheric Sciences
supervisors: Stefano Serafin, Mathias Rotach

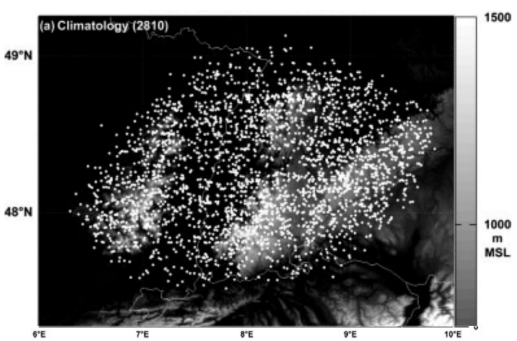
Photo | Marc Cooper

Importance of slope winds for CI

Demonstrated in many field experiments and related simulations (CuPIDO, DOMEX, COPS)
Radar climatology for COPS region (8 summers):



(a) domain



(b) convection initiation over mountain ranges

Figs. 1 and 6 in Weckwerth et al. (2011)

Importance of slope winds for CI

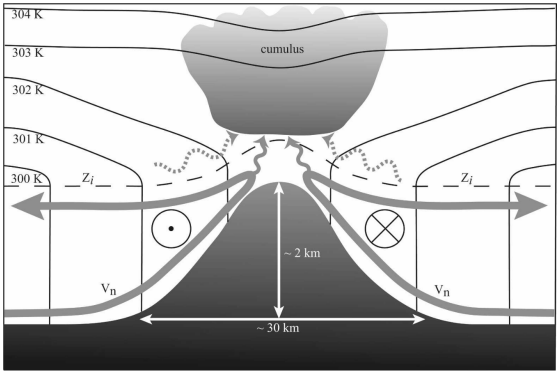
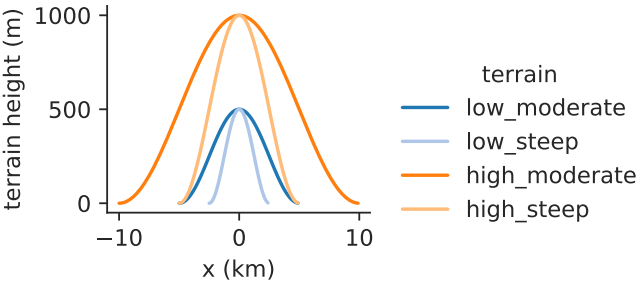


Fig. 1 in Demko et al. (2009)

Research question

In a strongly inhibited environment with considerable CAPE and without synoptic forcing, how does **mountain geometry** (height and width) affect the **time scale of convection initiation**?

Simulation design: mountains of different height and width

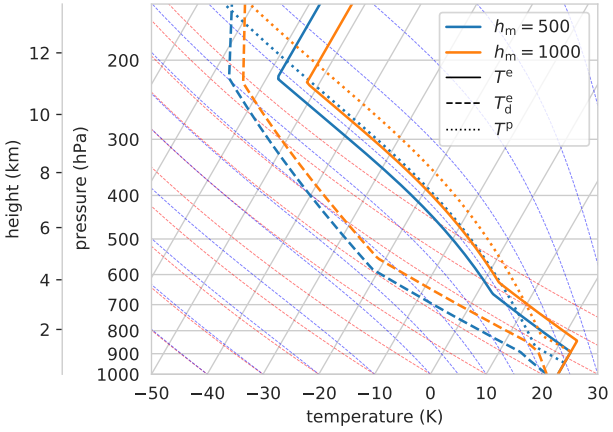


terrain homogeneous in y-direction

terrain	h_m (m)	w_m (km)	avg. slope (%)	CIN (J kg^{-1})	CAPE (J kg^{-1})	LCL (m a.g.l.)	LFC (m a.g.l.)
low_moderate	500	10	10	154	1547	727	1887
low_steep	500	5	20	154	1546	727	1887
high_moderate	1000	20	10	152	1542	746	1861
high_steep	1000	10	20	152	1542	746	1861

Initial soundings

Based on COPS sounding, 15th July 2007 (Wulfmeyer et al., 2011) close to Mulhouse, France

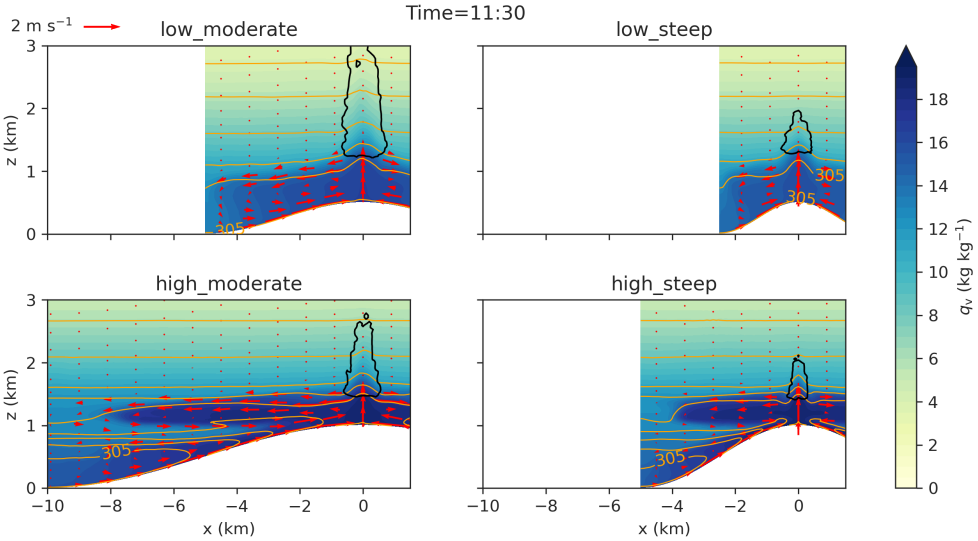


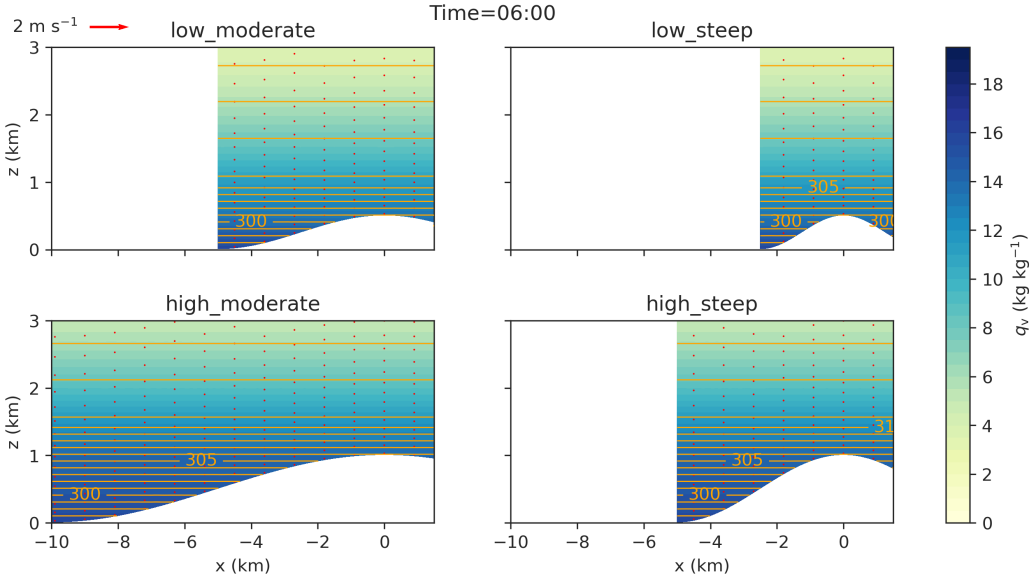
Dry simulations: lower dewpoint by 14 K at all levels to prevent cloud formation

Physics and dynamics options for WRF v4.3.1

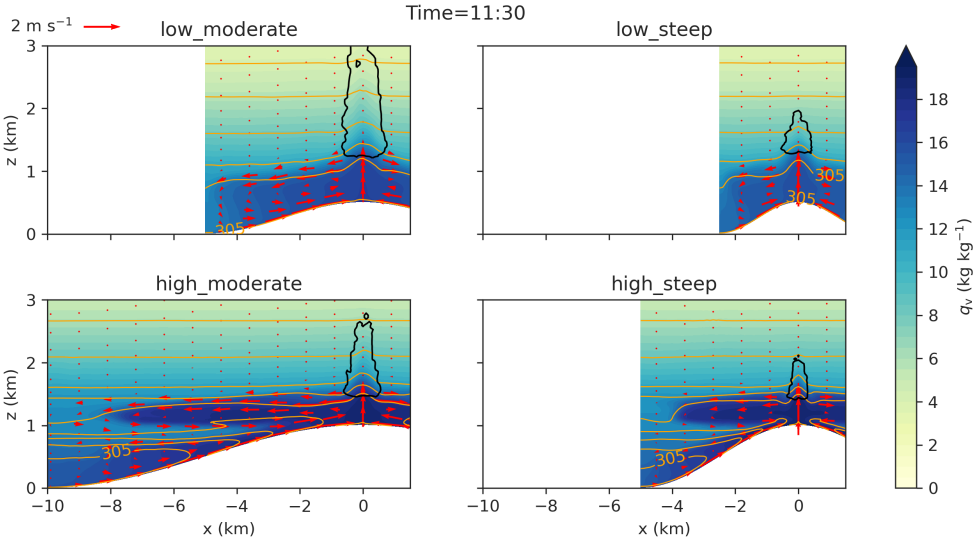
- Domain size w_m (x) x 40 km (y) x 17 km (z)
- $\Delta x = 100$ m, 20 m $\lesssim \Delta z \lesssim 100$ m
- Doubly-**periodic** boundary conditions
- **Radiation**: RRTMG-K
- **Land surface**: NOAH
- **Microphysics**: P3
- **SGS diffusion**: 1.5-order TKE scheme
- Neglect Coriolis and curvature

y-averaged cross-sections

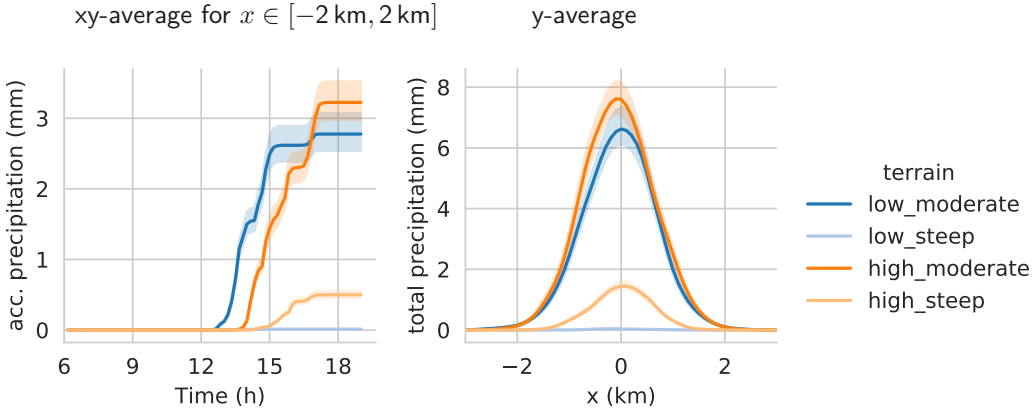



Time=06:00
2 m s^{-1}
low_moderate
low_steep
high_moderate
high_steep
z (km)
x (km)
300
305
310
q_v (kg kg^{-1})

Two circulations cells for high, one for low mountains

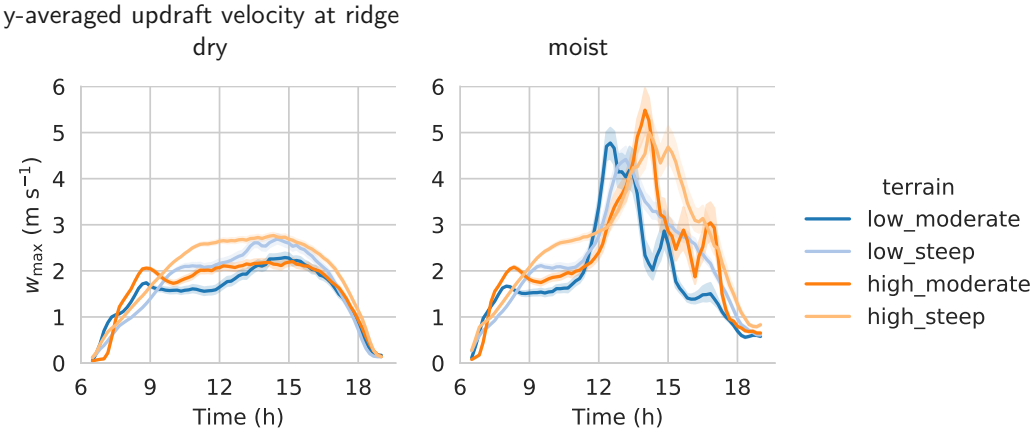


Earlier onset of precipitation for moderate mountains



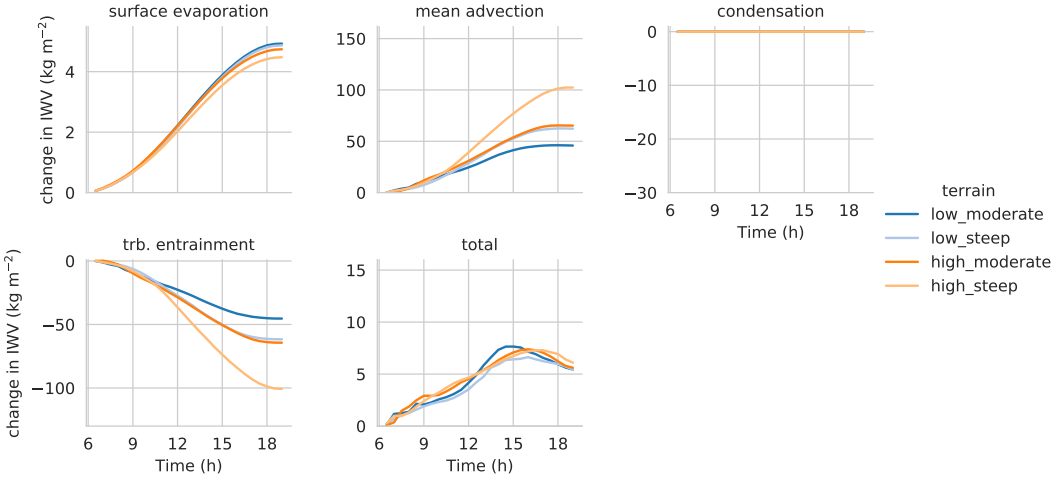
error bands: 95 % confidence intervals from bootstrapping in y-direction

Stronger circulation for steep mountains



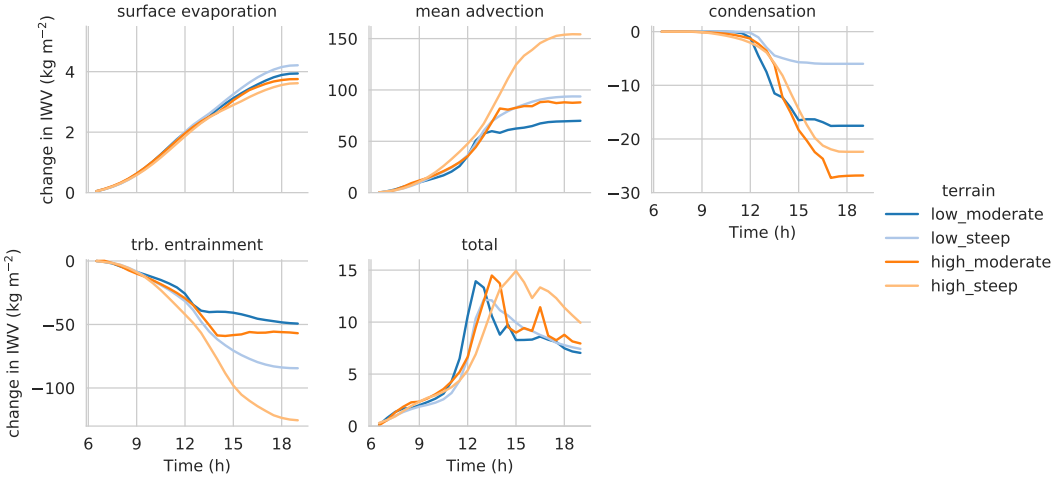
Moisture budget at ridge: dry runs

Budget from WRFlux (Göbel et al., 2022), integrated vertically and in time

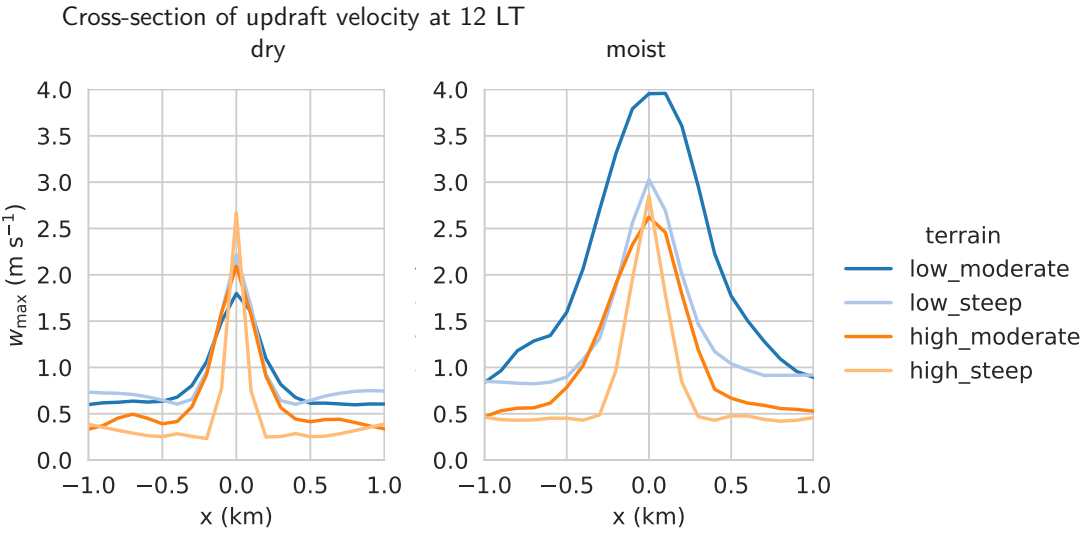


Moisture budget at ridge: moist runs

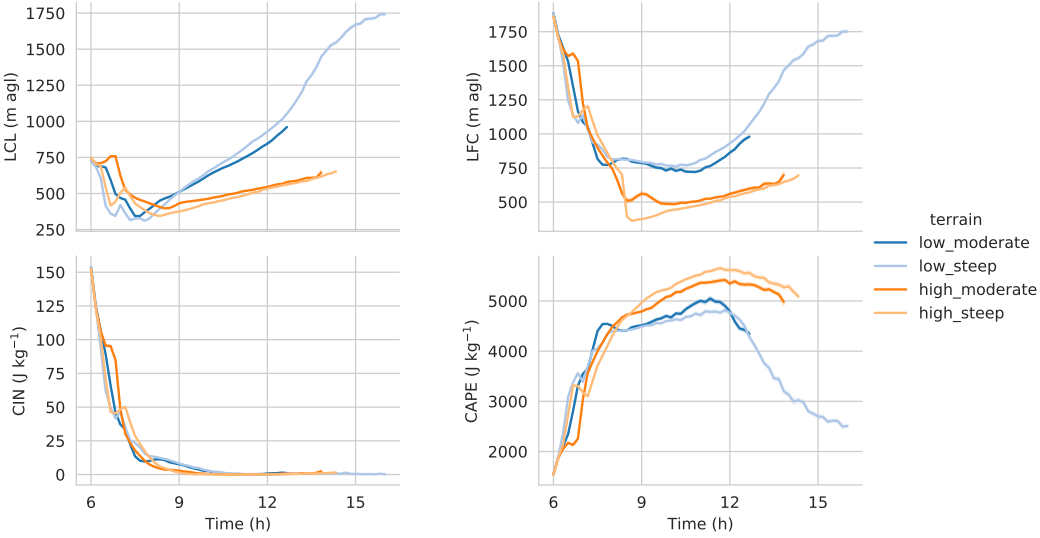
Budget from WRFlux (Göbel et al., 2022), integrated vertically and in time



Narrower updraft for steep mountains



Convective indices for surface parcel at the ridge



Conclusions and references

- **Mountain geometry** has a significant impact on convection initiation time and strength under synoptically undisturbed, inhibited conditions.
- Classical convective indices like **LCL, LFC, CIN, and CAPE not very informative** in this case
- Moistening at mountain top is not only driven by the strength of the mean circulation: the **balance with turbulent entrainment** is crucial.
- **Steep mountains lead to later and weaker DMC**: updrafts are stronger but narrower and lose more moisture due to entrainment.

Computational results achieved using the Vienna Scientific Cluster and the LEO cluster of the university of Innsbruck; Funded by FWF project P30808-N32

Demko, J. C., B. Geerts, Q. Miao, and J. A. Zehnder, 2009: Boundary Layer Energy Transport and Cumulus Development over a Heated Mountain: An Observational Study. *Monthly Weather Review*, **137 (1)**, 447–468, doi:10.1175/2008MWR2467.1.

Göbel, M., S. Serafin, and M. W. Rotach, 2022: Numerically consistent budgets of potential temperature, momentum, and moisture in Cartesian coordinates: Application to the WRF model. *Geoscientific Model Development*, **15 (2)**, 669–681, doi:10.5194/gmd-15-669-2022.

Weckwerth, T. M., J. W. Wilson, M. Hagen, T. J. Emerson, J. O. Pinto, D. L. Rife, and L. Grebe, 2011: Radar climatology of the COPS region. *Quarterly Journal of the Royal Meteorological Society*, **137 (S1)**, 31–41, doi:10/dxz7gf.

Wulfmeyer, V., et al., 2011: The Convective and Orographically-induced Precipitation Study (COPS): The scientific strategy, the field phase, and research highlights. *Quarterly Journal of the Royal Meteorological Society*, **137 (S1)**, 3–30, doi:10/c9kc6j.

Model initialization

- Random initial perturbations of θ drawn from uniform distribution with maximum amplitude of $\Delta\theta = 0.1\,\mathrm{K}$ applied equally to the lowest 12 model levels ($\sim 250\,\mathrm{m}$) based on Kealy et al. (2019)
- Soil moisture from Schlemmer et al. (2011): 60 % at the surface increasing to 75 % at 1.5 m depth
- Soil temperature: $T_s(z < -0.5\,\mathrm{m}) = 297\,\mathrm{K} - z_t \cdot 5\,\mathrm{K\,km^{-1}}$; linear interpolation to surface temperature