An orographic weakening effect for coldpool driven convective systems

U. Blahak[1], J. Plieninger[1], S. Lang[1] and K. D. Beheng[1]
[1]*Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology (KIT), Hermann-von-Helmhotz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany, ulrich.blahak@imk.fzk.de*
(Dated: September 16, 2009)

I. INTRODUCTION

Mountains might affect deep convection not only by providing favorable conditions for triggering convective cells by, e.g., (differential) surface heating on differently oriented slopes, but also through a modification of the ambient environmental conditions caused by mountain wave flow. In our research, the interaction of a pre-existing convective system with the flow over an idealized quasi-2D mountain ridge oriented perpendicular to the flow is investigated by means of idealized simulations. The flow over such a mountain ridge exhibits modified temperature- and velocity fields which imply modified profiles of stability, windshear and moisture and which in turn might feed back to the convective system. It is supposed that the effect should be most prominent in situations of high windspeed which are usually also connected with long-lived windshear-driven convective systems.

These studies led to the interesting result, which is reported in this paper, that mountain ridges might, under certain circumstances, be responsible for dissolving a coldpool driven convective system.

II. SIMULATIONS OF A PREEXISTING CONVECTIVE SYSTEM IMPINGING ON A MOUNTAIN RIDGE

Idealized simulations are performed with the COSMO-model of the German Weather Service (DWD) using different idealized thermodynamic initial- and boundary conditions, in which a convective system is artificially triggered by a "warm bubble" upstream the crest of a 2D mountain ridge. To investigate the effect of the orographic flow on the convective system, these simulations are compared to control runs with flat orography but otherwise same conditions. Important settings and parameters for our simulations are given in Table I.

To adapt the physical description the relatively small horizontal grid spacing of $\Delta x = 1$ km, instead of the standard one-moment five-class one-moment bulk microphysical parameterization scheme, the extended two-moment scheme of Seifert and Beheng (Blahak [1], Noppel et al. [2], Seifert and Beheng [3]) is used. This scheme distinguishes six hydrometeor categories (cloud drops, cloud ice, rain, snow, graupel and hail) and represents each particle type by its respective number- and mass density, enabling better parameterizations of, e.g., particle collisions and rain evaporation below cloud base (responsible for the formation of the so-called "coldpool" or gust front).

As mentioned in the introduction, an interesting result has been found when considering results obtained with the two sets of initial profiles of temperature T and dew point T_d shown in Figure 1 **at same values of $CAPE$, CIN, wind shear and vertical buoyancy distribution.** These conditions comprise a warmer (designated as "warm") and colder ("cold") environment with same "convective potential". Each is applied with and without a 2D mountain ridge (height = 1000 m, halfwidth = 20 km) located 60 km downstream of the initial warm bubble. The wind profile resembles that of Weisman and Klemp [4] with a free-troposphere speed U_∞ of 20 m s^{-1} and no directional shear. For the simulations with mountain ridge, convection was initiated only after a spin-up time of 4 h to allow the (dry) mountain wave flow to develop.

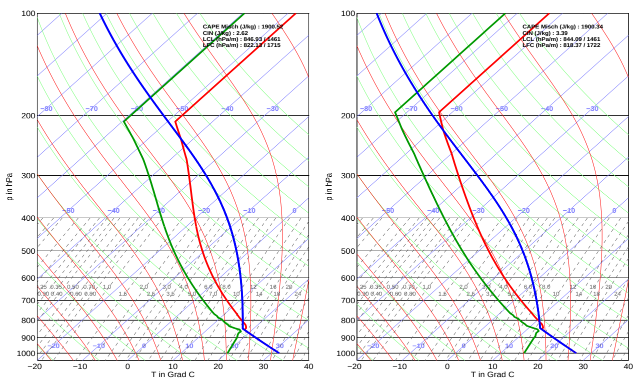

FIG. 1: Initial profiles (skew-T/log-p) of T (red) and T_d (green) for the "warm" cases 1 and 2 (left figure) and the "cold" cases 3 and 4 (right figure). Blue: pseudoadiabatic ascent of an air parcel, in this case both representing a surface air parcel and an "average" parcel over the lowest 100 hPa. Not shown here: wind profile after Weisman and Klemp [4] for $U_\infty = 20$ m s^{-1} (cf. Table II).

TABLE I: Settings and parameters used for the COSMO-runs.

Horiz. resolution	1 km
Vert. resolution	40 m – 600 m (64 layers)
Large timestep	6 s
Time discretisation	3rd order Runge-Kutta
Initial conditions	Idealized, horiz. homogeneous
Lat. Boundary conditions	X fixed, Y periodic
Turbulence param.	TKE-based, 3-D, including "moist" effects
Other physics packages	none

TABLE II: Characteristic parameters of the 4 idealized simulations (cases). T_0 = temperature at ground, Z_{fr} = freezing level, LCL = lifting condensation level, RH_{LCL} = rel. humid. at LCL, N_{3000} = Brunt-Vaisala frequency at 3000 m height, U_{3000} = windspeed at 3000 m height, $\lambda_{char} = 2\pi U_{3000}/N_{3000}$ is the characteristic buoyancy-oscillation wavelength (≈ horizontal wavelength of mountain waves).

	Case 1	Case 2	Case 3	Case 4
Profiles	"warm"	"warm"	"cold"	"cold"
Hill	no	yes	no	yes
$CAPE$ [J kg^{-1}]	1900	1900	1900	1900
T_0 [°C]	32	32	27	27
Z_{fr} [m]	4200	4200	3200	3200
LCL [m]	1500	1500	1500	1500
RH_{LCL} [%]	91	91	91	91
N_{3000} [s^{-1}]	0.0095	0.0095	0.0084	0.0084
U_∞ [m s^{-1}]	20	20	20	20
U_{3000} [m s^{-1}]	15	15	15	15
λ_{char} [km]	9.9	11.5	9.9	11.5

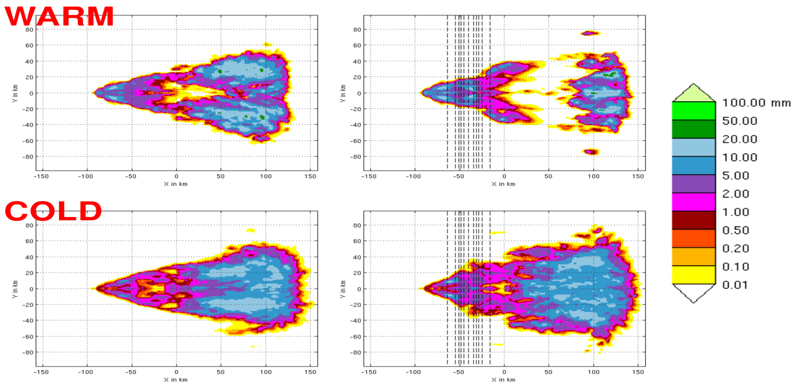

FIG. 2: Accumulated surface precipitation in mm for the 4 simulated cases, 4 h after warm bubble release. Upper left: case 1, upper right: case 2, lower left: case 3, lower right: case 4.

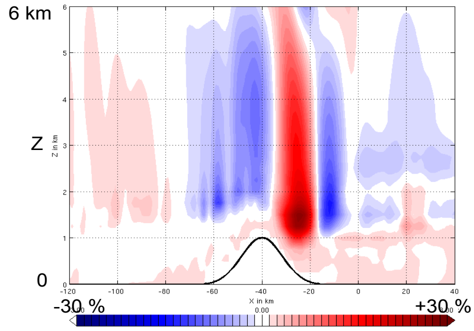

FIG. 3: X-Z-cut through the center of the model domain showing the difference of relative humidity in % between case 2 ("warm", mountain) and 4 ("cold", mountain) at the time of warm bubble release.

Important parameters of the resulting 4 cases are listed in Table II.

III. RESULTS AND DISCUSSION

The accumulated surface precipitation at the end of the simulations for all 4 cases is presented in Figure 2. It can be seen that in the control runs with flat orography (case 1 and 3), an initially split-cell type convective system further develops into an intense squall-line, moving with the ambient flow from left to right.

In contrast, in the presence of the mountain, the convective system drastically weakens in the warm case 2 and somewhat recovers only very far behind the ridge, whereas in the cold case 4, it remains relatively unaffected or even slightly enhanced. This difference between case 2 and case 4 is very interesting, since it shows that even longlived convective systems might be considerably influenced by the underlying topography and that, as is the case here, a slight change in the environmental temperature level at otherwise same (thermo-) dynamic conditions can have a drastic influence.

Three reasons for the different behaviour of case 2 and 4 have been hpothesized and scrutinized:

a) Freezing of droplets in lower levels (add. latent heat release) leads to more vigorous and robust dynamics in case 4.

b) Coldpool dynamics is different: for the "cold" cloud, there is a less intense coldpool in the early stage due to less intense precipitation, which propagates somewhat slower than in the "warm" case and in contrast cannot be decoupled from its "mother" system when accelerating down the lee side mountain slope; with the coldpool too far ahead, the "warm" cloud dies out at first, before the travelling cold pool is able to trigger a new convective line far downstream.

c) Modification of stability, shear and moisture is different for warm and cold case and leads to different interactions with the convective cloud and its cold pool.

Hypotheses **a)** and **b)** could be ruled out by conducting a further "cold" simulation but where the temperature and moisture inside the cloud was artificially modified to resemble the cloud microphysical behaviour of the "warm" case. Whereas all cloud properties, the precipitation and even the early-stage coldpool were very similar to the "warm" case, the cloud still "survived" the mountain crossing as in case 4.

In contrast, it turns out, that hypothesis **c)** comes closest: in both cases, the coldpool accelerates down the mountain lee slope, gets ahead of the system and thins vertically by horizontal divergence. Only when it reaches the leeside plain, it gets decelerated and, by horizontal convergence, lifting of air just above the coldpool is enhanced. It is now decisive for the following development, if these lifted air parcels reach their level of free convection and trigger a secondary convective system. From Figure 3 (X-Z-cut of the difference between the relative humidity for "warm" and "cold" case at the time of warm bubble release) it can be anticipated that this is only happens in the "cold" environment. The characteristic horizontal wavelength of the mountain flow pattern (see Table II) is shorter in the "warm" environment, bringing the moisture disturbance at heights of 1000 - 3000 m AGL over the leeside mountain foot out of phase with the coldpool induced lifting, so that no new system is triggered here. In contrast, in the "cold" environment, positive moisture disturbance and coldpool induced lifting are in phase.

Having unravelled the mechanism, it is immediately clear that the phenomenon is very subtle and depends on the details of the (dry) flow (vertical profile of the Scorer parameter, typical horizontal wavelength) in conjunction with mountain parameters (width, height, slope) and the humidity just above the boundary layer, whereas cloud microphysical aspects at different temperature levels seem to be relatively unimportant. This will be systematically explored in future.

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