Karlsruhe Institute of Technology

An Orographic Weakening Effect for Cold Pool Driven Convective Systems

Ulrich Blahak, Johannes Plieninger, Simon Lang, Klaus Dieter Beheng

Institut für Meteorologie und Klimaforschung,

Universität Karlsruhe / Forschungszentrum Karlsruhe

COSMO User Seminar, 10.3.2009

Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft

Universität Karlsruhe (TH) Research University • founded 1825

Motivation

- We are interested in effects of environmental conditions and orography on deep convective cells.

- Concerning the orographic effects, many studies focus on initiation of cells in mountaineous region (orographic enhancement), which is intimately linked to the development of the PBL, sometimes in connection with orographically induced flow patterns (e.g., valley winds).

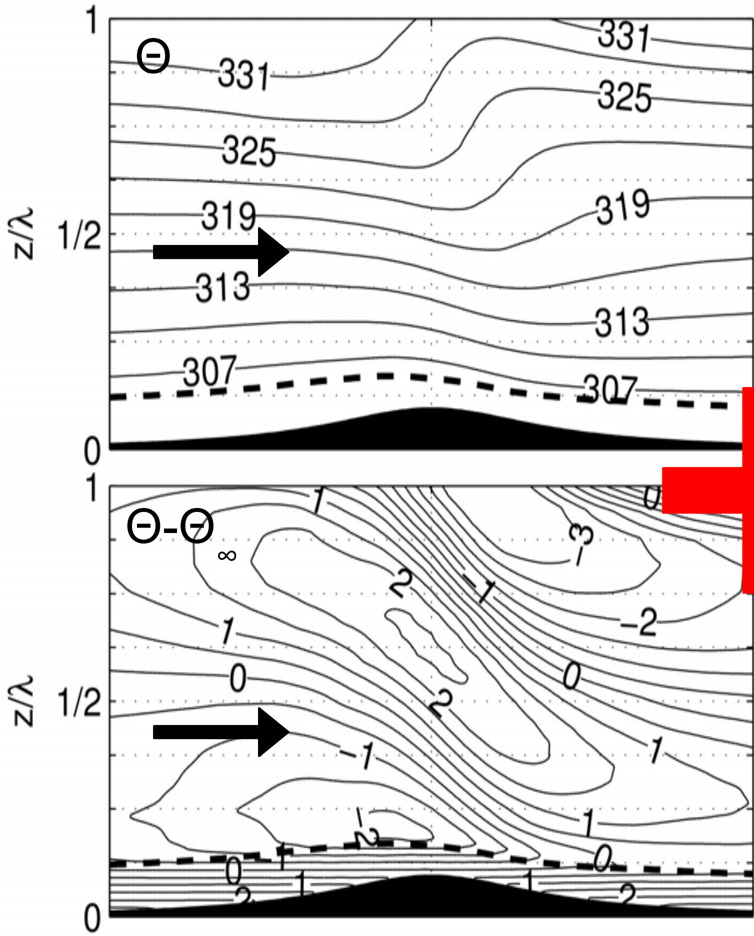
Another interesting question is:

- What may happen, if a pre-existing long-lived convective system passes over a mountain range and interacts with the orography and the wave flow?
- Which are the possible mechanisms of interaction and how do they depend on orography parameters and environmental conditions?

U. Blahak, Institut für Meteorologie und Klimaforschung

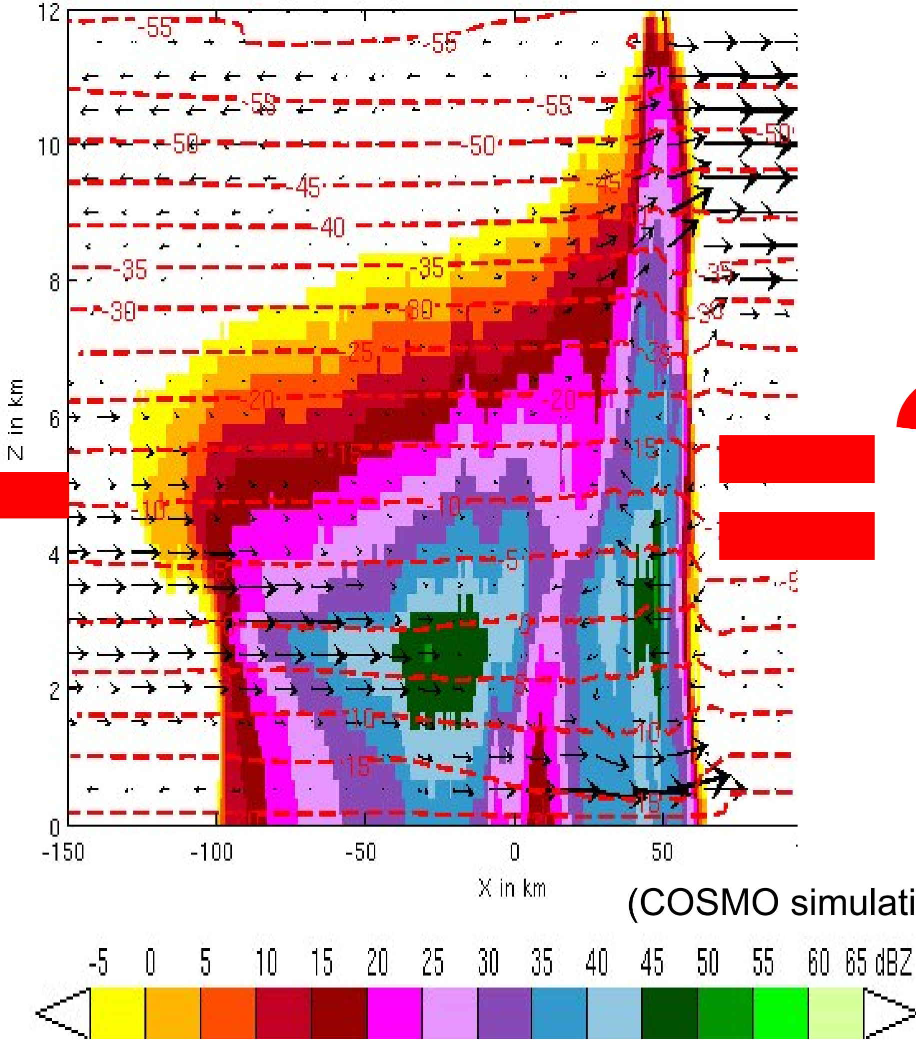
Research question

Mountain wave flow



(Courtesy of Straub, 2005)

Pre-existing conv. system (e.g., squall line)



(COSMO simulation)

U. Blahak, Institut für Meteorologie und Klimaforschung

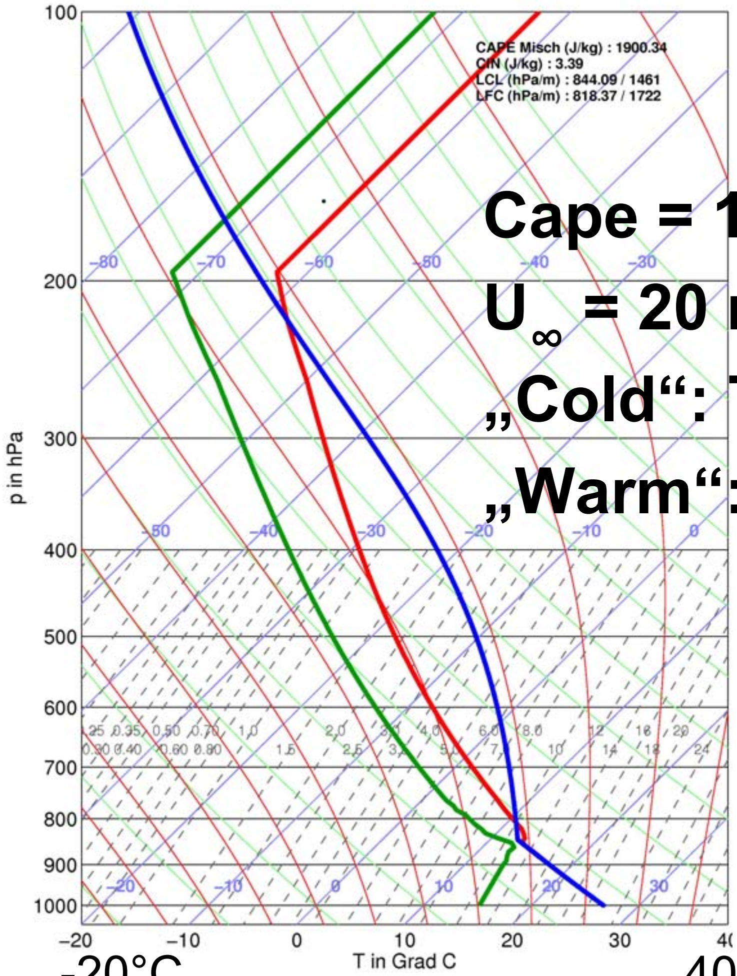
Simulation setup

- COSMO version 3.19
- 2-moment bulk microphysics (modified Seifert-Beheng)
- Idealized simulations:
  - Flat terrain with2D gaussian mountain ridge perp. to the flow (H=1 km, W=20km)
  - Initial flow from W to E (no directional shear)
  - Periodic BC at N and S boundaries
  - Relax. BC at W and E boundaries
  - Initial profiles of T, p, v and qv horizontally homogeneous
  - ΔX = 1 km, 64 vertical levels
  - No soil and vegetation model, no convection parameterization
  - Deep convective system triggered by warm bubble upstream of the mountain
- 4 simulations: with/without mountain; warm/cold environment (same CAPE, CIN, U, ...)

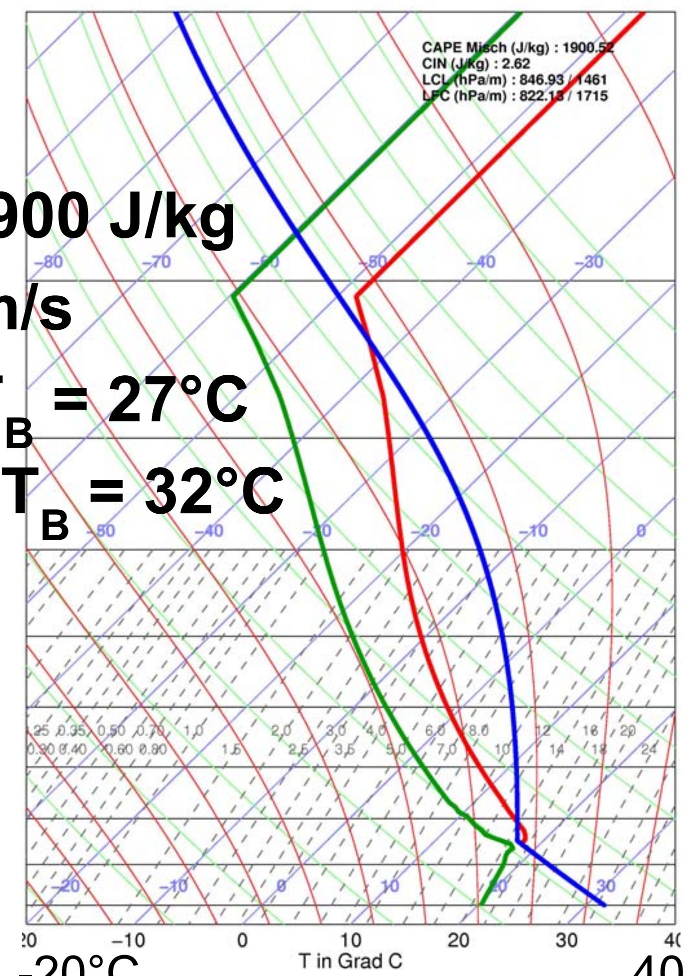
U. Blahak, Institut für Meteorologie und Klimaforschung

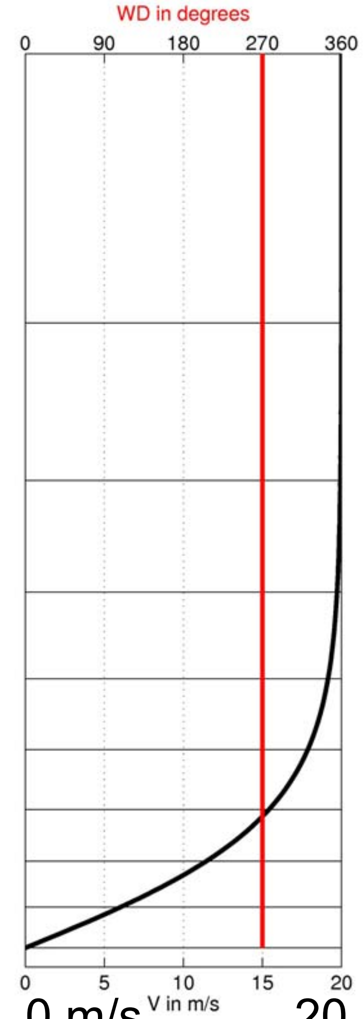
Initial profiles

„Cold“ case



„Warm“ case





Cape = 1900 J/kg

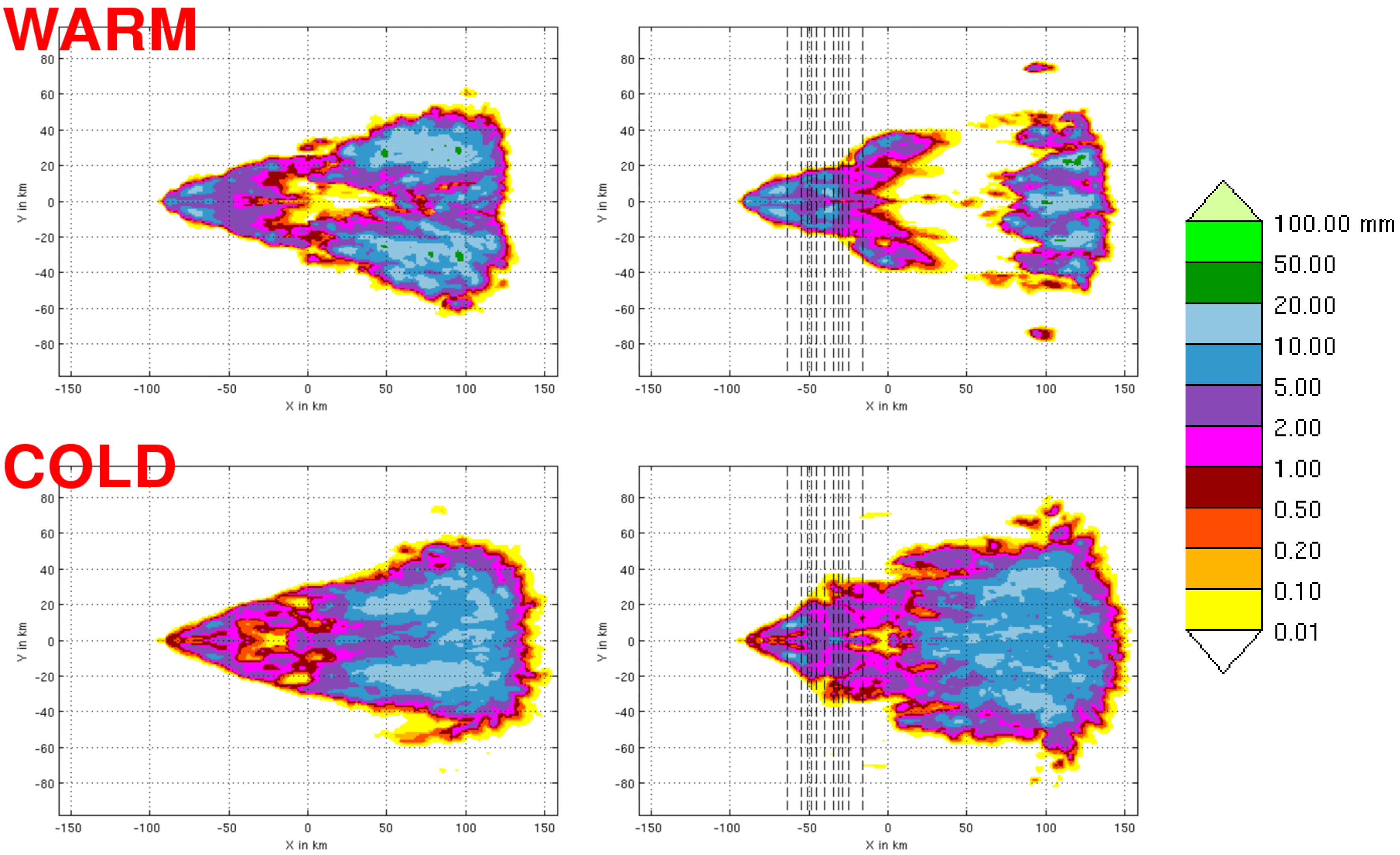
U_∞ = 20 m/s

„Cold“: T_B = 27°C

„Warm“: T_B = 32°C

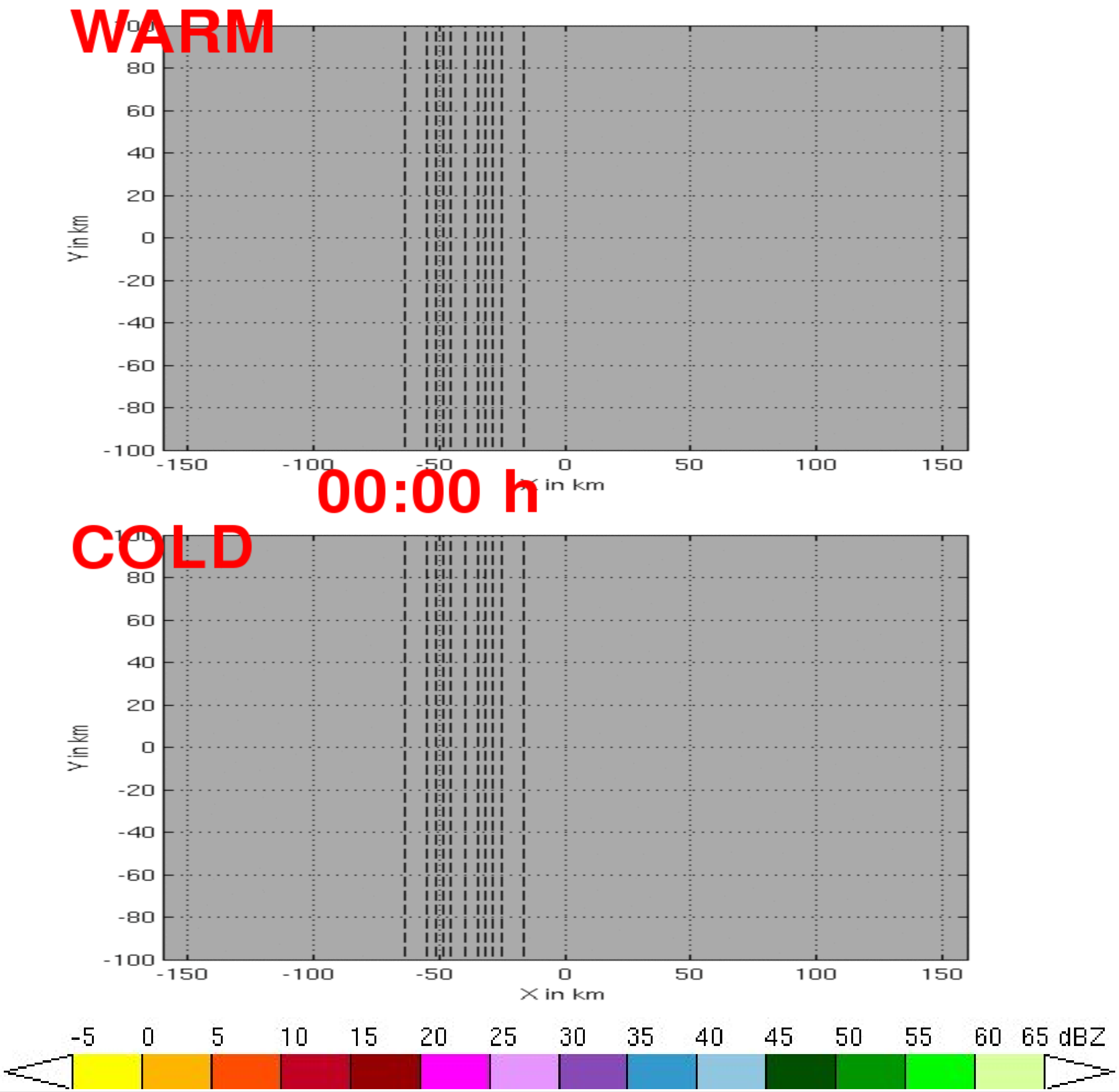
U. Blahak, Institut für Meteorologie und Klimaforschung

Results: Accum. Precip 4:00 h



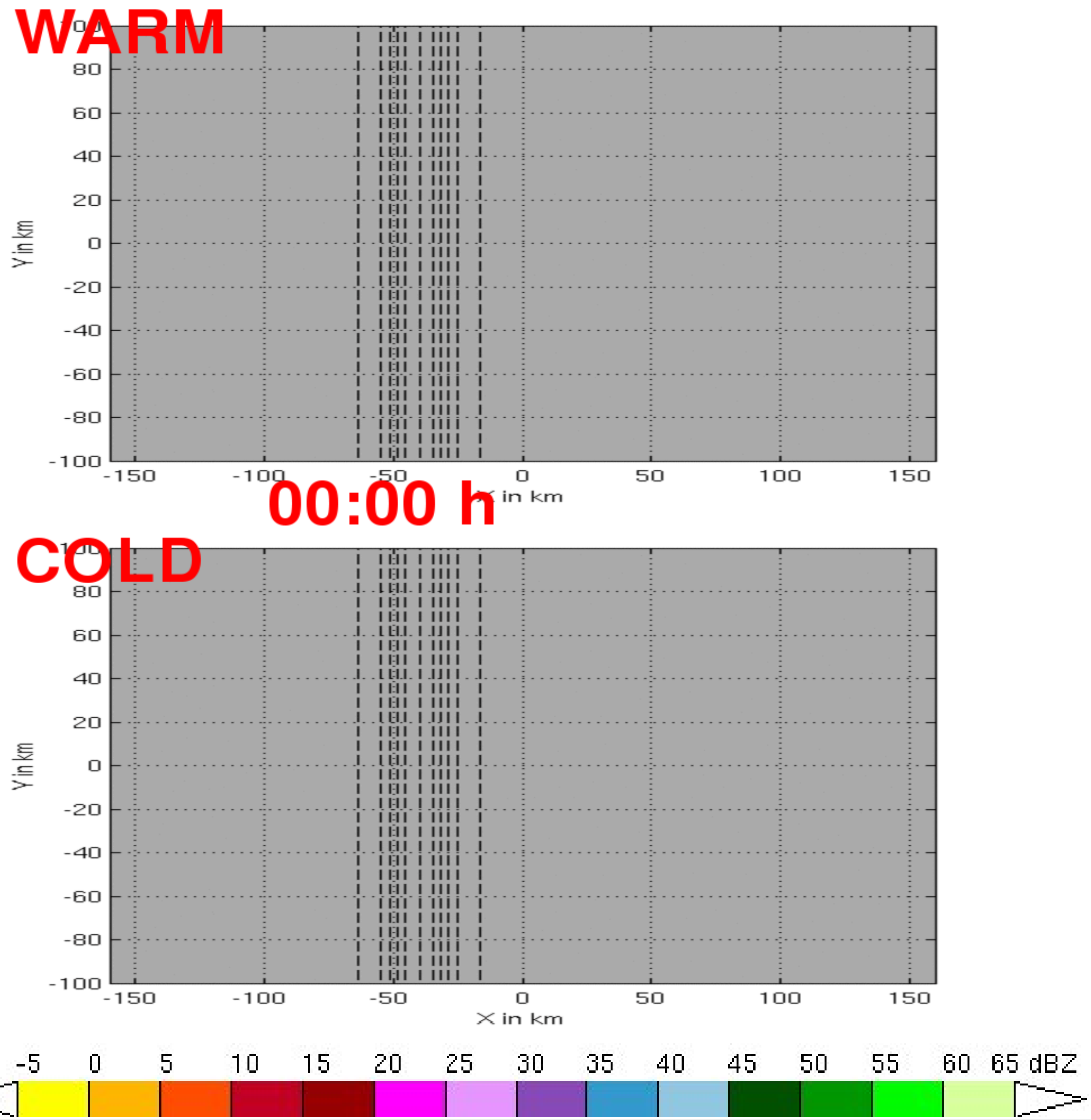
U. Blahak, Institut für Meteorologie und Klimaforschung

Results: Simul. Refl. 0:00 – 4:00 h



U. Blahak, Institut für Meteorologie und Klimaforschung

Results: Simul. Refl. 0:00 – 4:00 h



U. Blahak, Institut für Meteorologie und Klimaforschung

Why weakening in „warm“ case with hill?

Hypotheses:

1) Due to freezing in lower levels (additional latent heat release) cold cloud more vigorous and robust.

2) Coldpool dynamics different for warm and cold case: less intense coldpool for cold cloud due to less intense precipitation propagates somewhat slower than warm case and cannot be separated from its mother system by the acceleration over the mountain lee side (in favor: less intense precipitation in cold case, broader cloud system).

3) Modifikation 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.

U. Blahak, Institut für Meteorologie und Klimaforschung

Hypotheses 1) and 2)

Can be put to the test by:

- **Additional model run with „cold“ environment, but increase T and qv within clouds in a way that the resulting convective system behaves similar to the „warm“ case („modified cold“ case).**

- **Goal: shift additional latent heat release by the ice phase processes (drop freezing, depositional growth) to higher altitudes, as in the „warm“ environment. Generate similar cloud dynamics, cold pool and precipitation amount.**

U. Blahak, Institut für Meteorologie und Klimaforschung

Hypotheses 1) and 2)

➔ Changes at cloudy gridpoints only:

- **To calculate source terms of solid ice particles due to nucleation, drop freezing and depositional growth, use:**

$$T^{(new)} = T^{(orig)} \min\left[\max\left[p_4(z),\ 1.0167\right],\ 1.0696\right]$$

$$\text{with:} \quad p_4(z) = \sum_{i=0}^{4} a_i z^i$$

$$\rho_v^{(new)} = \rho_v^{(orig)} \frac{T^{(orig)} E_{sat}(T^{(new)})}{T^{(new)} E_{sat}(T^{(orig)})} = \rho_v^{(orig)} \alpha$$

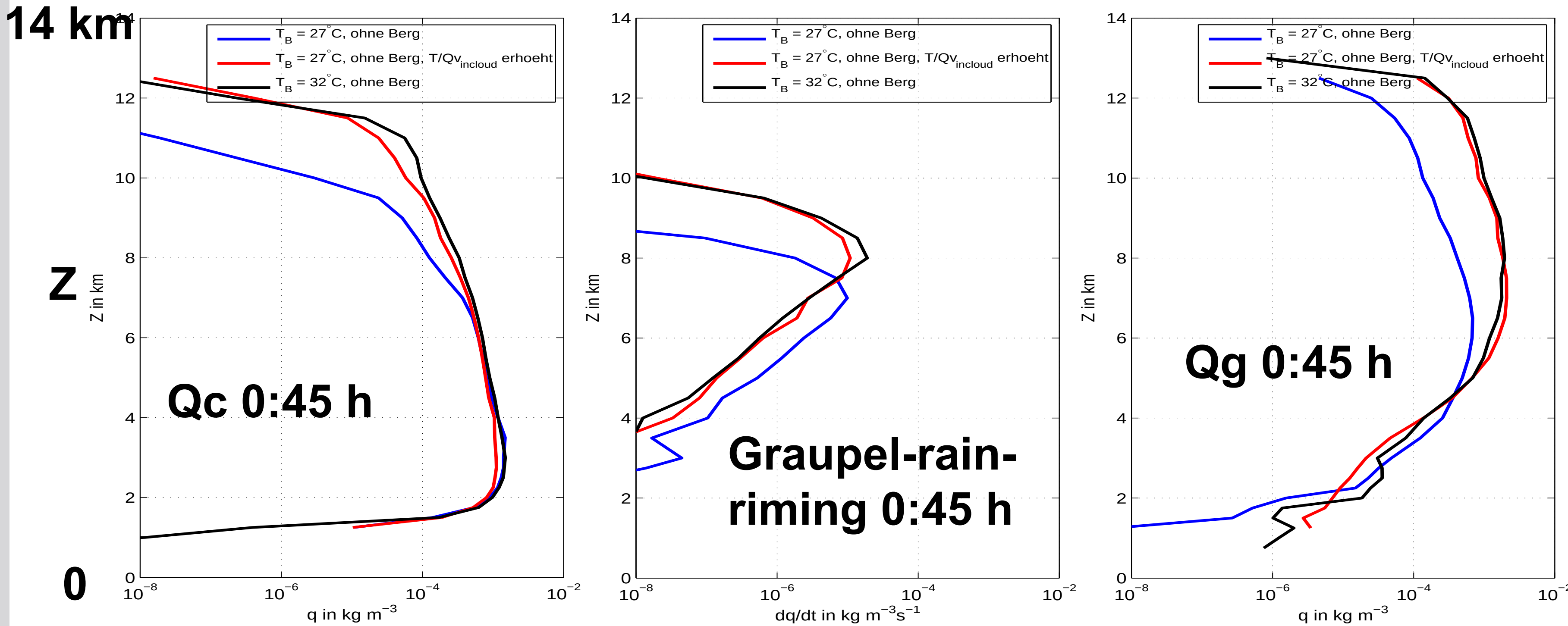
➔ Rescaling of the corresp. sink terms for water vapor by 1/α

- **Also: increase source term of cloud water due to condensational growth by a factor of 1.2 during the first 45 min after warm bubble release.**

U. Blahak, Institut für Meteorologie und Klimaforschung

Effect of modifications:

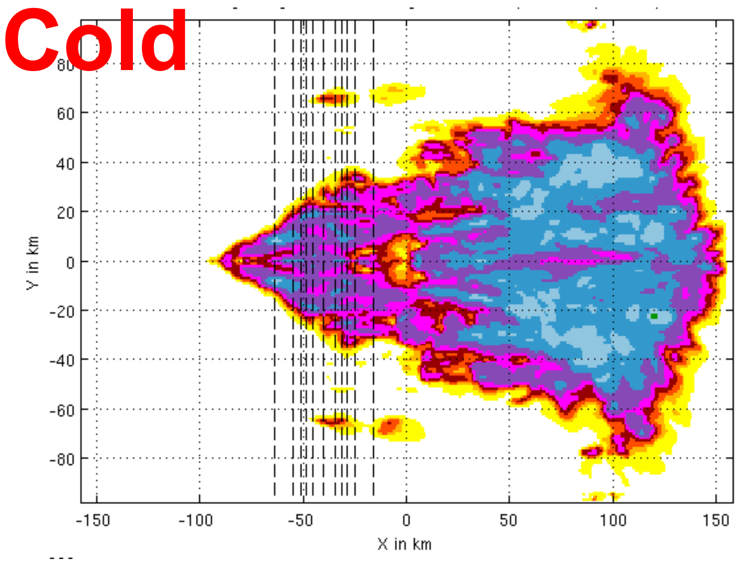
➔ **Because „warm" and „cold" case are constructed to have same CAPE and vertical buoyancy distribution, this manipulation leads to the desired „warm" cloud within „cold" environment.**

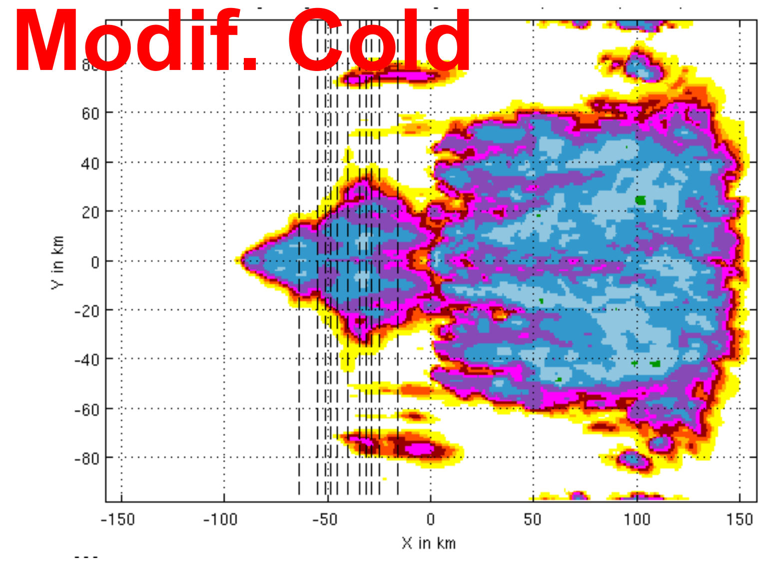


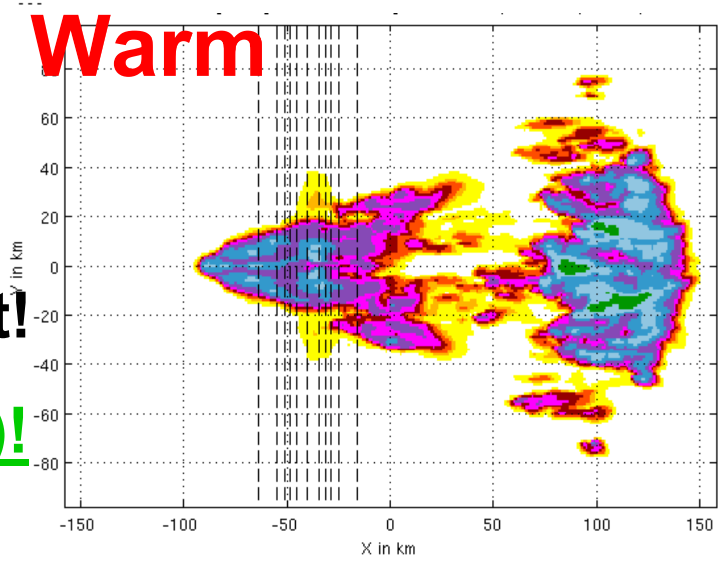
Also: get similar precip amount and similar cold pool during initial stage!

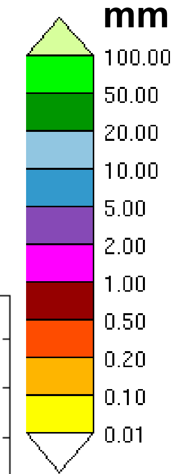
U. Blahak, Institut für Meteorologie und Klimaforschung

Effect of modifications on precip:









No effect on cloud weakening!

➔ **Ambient T-level and initial cold pool strength unimportant!**

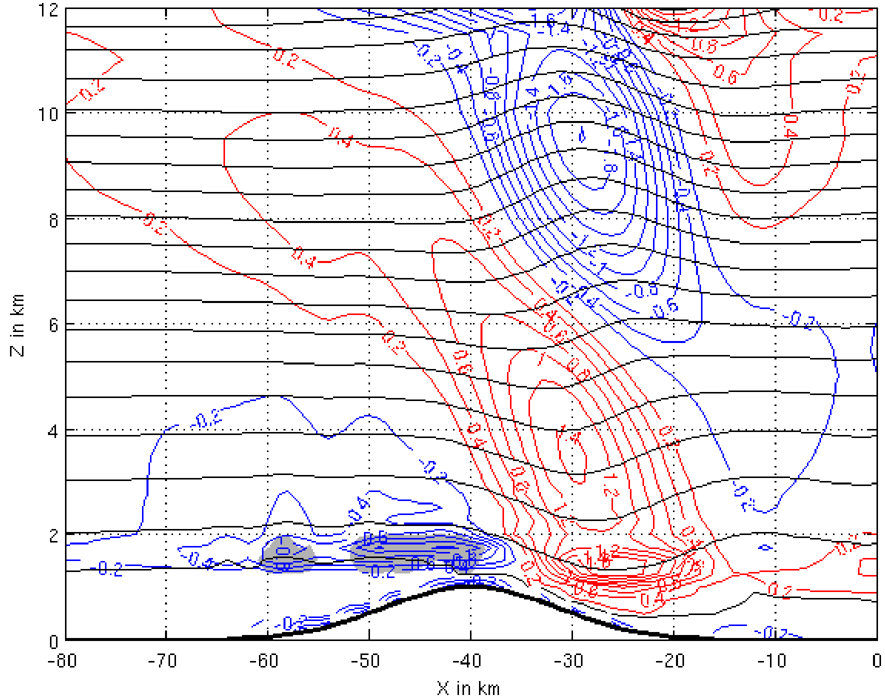
Rules out hypotheses 1) and 2)!

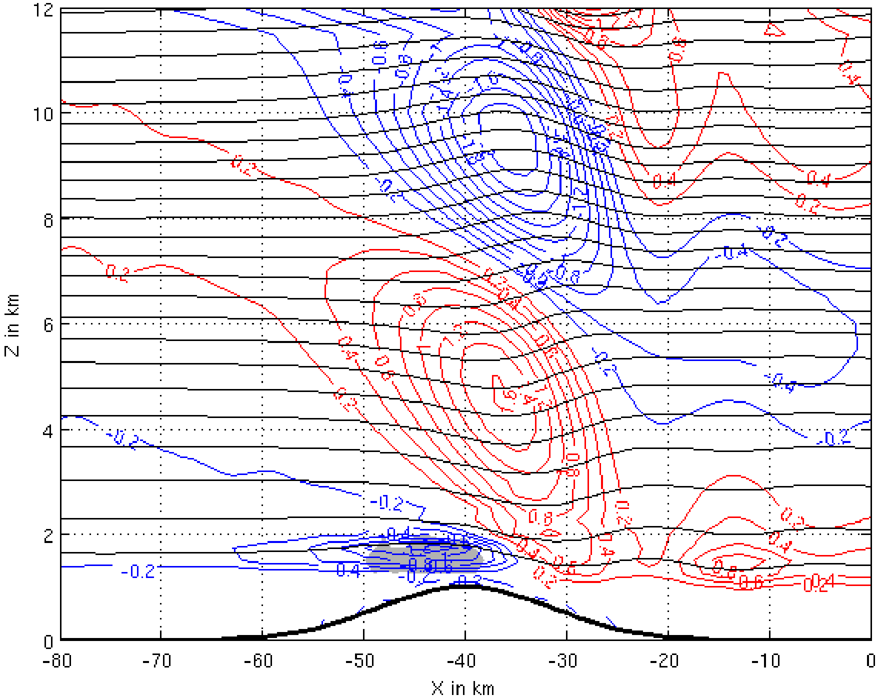
Hypothesis 3)

➔ **Wave flow patterns in „cold“ and „warm“ case at the time of warm bubble release (isentropes and Θ‘)**

„Cold“ case

„Warm“ case

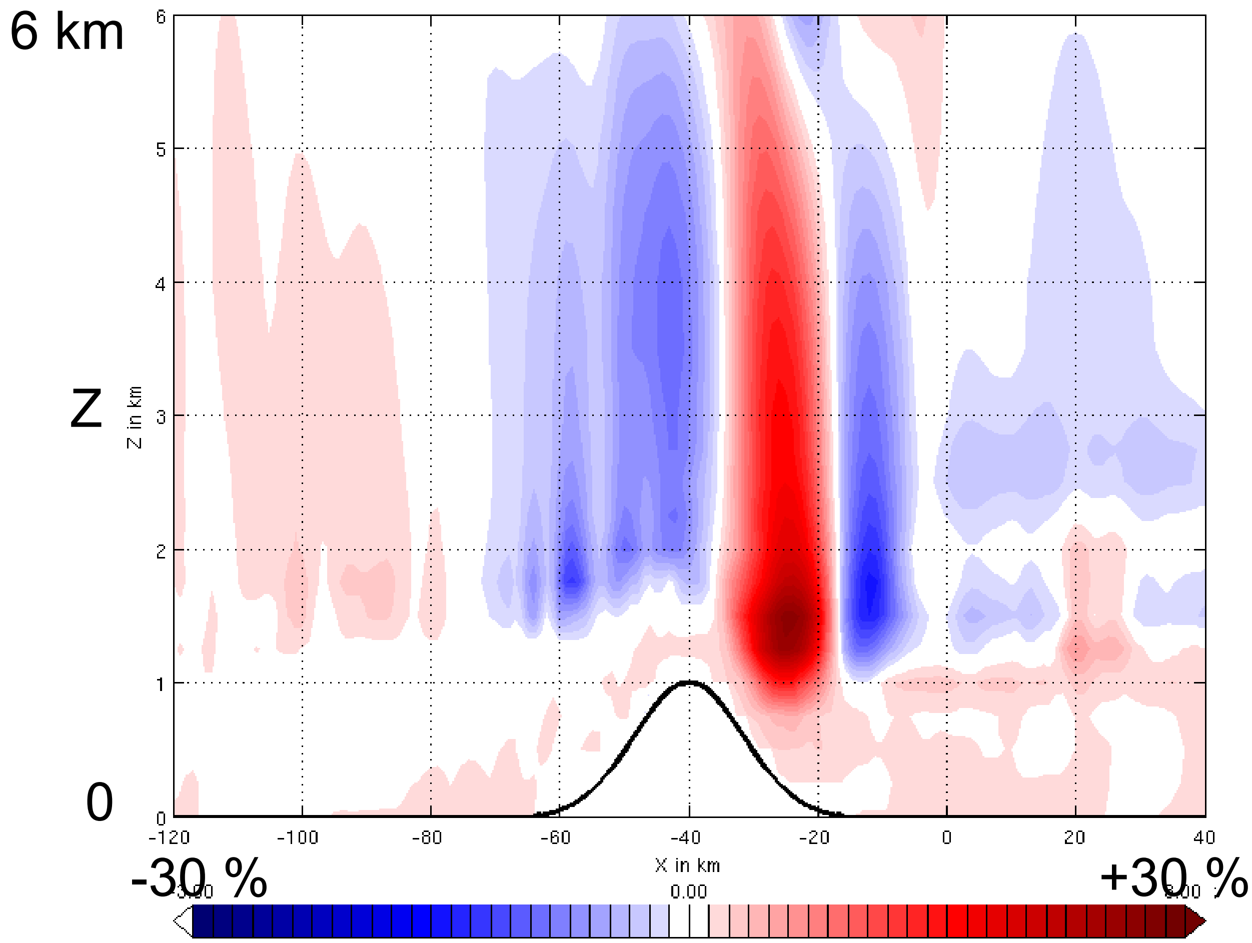




U. Blahak, Institut für Meteorologie und Klimaforschung

Hypothesis 3)

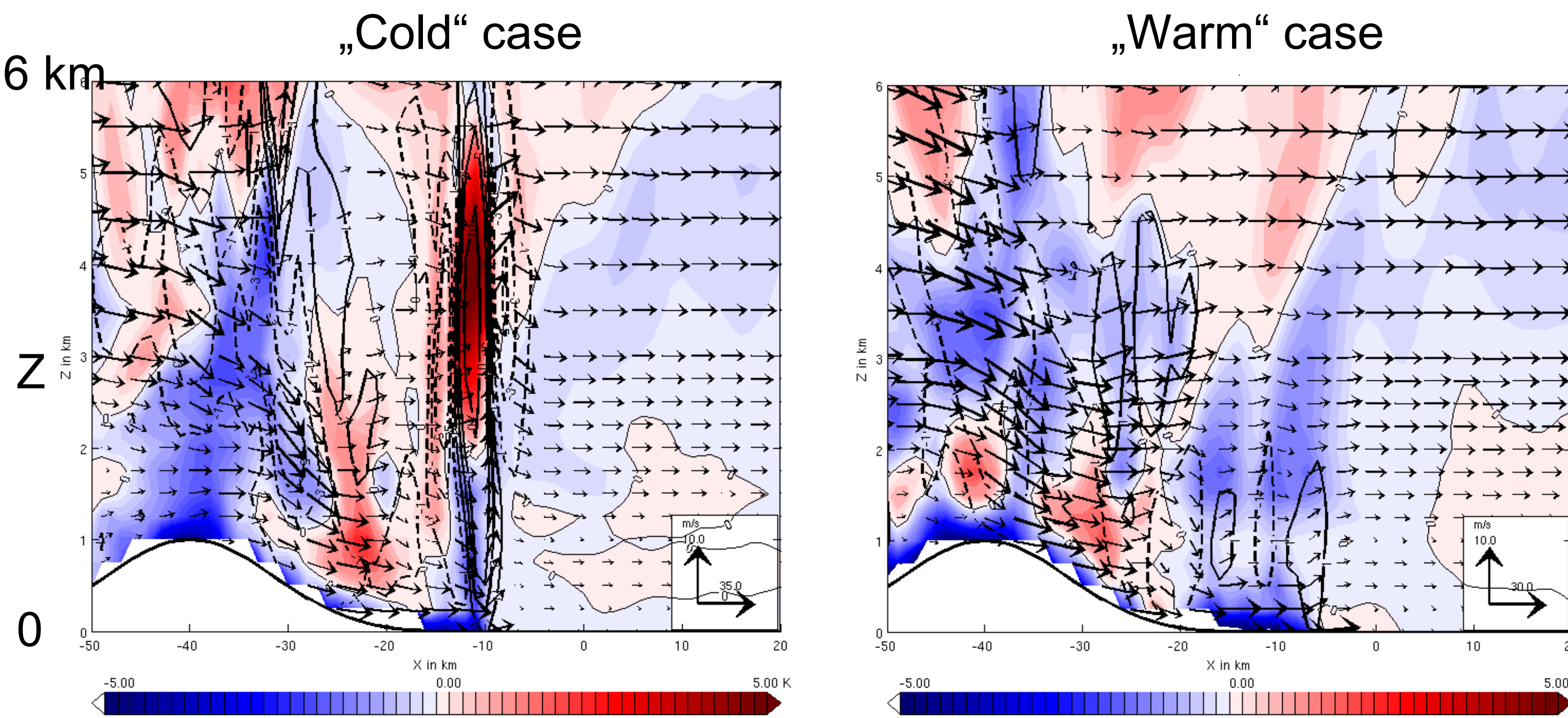
→ RH_warm – RH_cold, at the time of release of warm bubble (X-Z-cut at Y = 0 km):



U. Blahak, Institut für Meteorologie und Klimaforschung

Hypothesis 3)

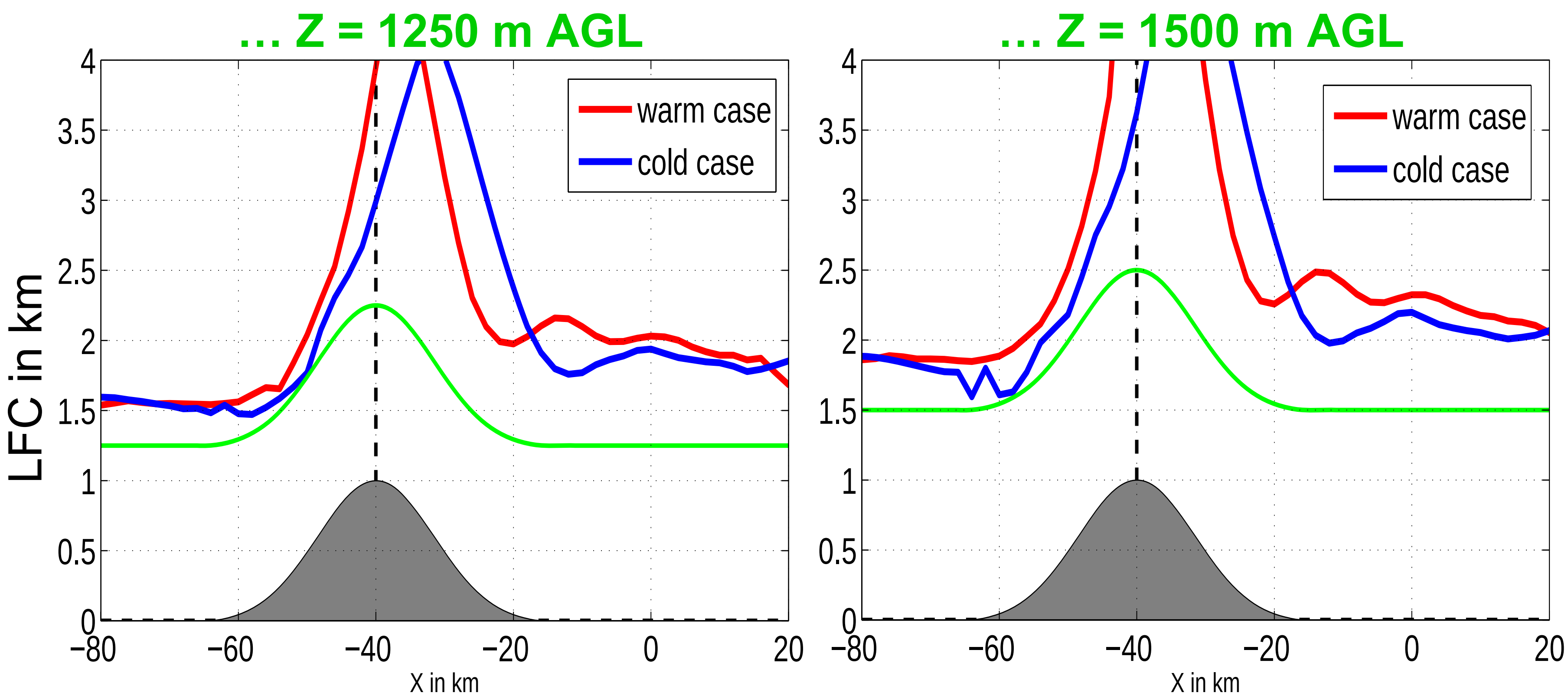
➔ U, W and T‘, 1:30 h after release of warm bubble (X-Z-cuts at Y = 5 km):



U. Blahak, Institut für Meteorologie und Klimaforschung

Hypothesis 3)

➔ **Level of free convection for air parcels rising from…**
(at the time of warm bubble reselase)

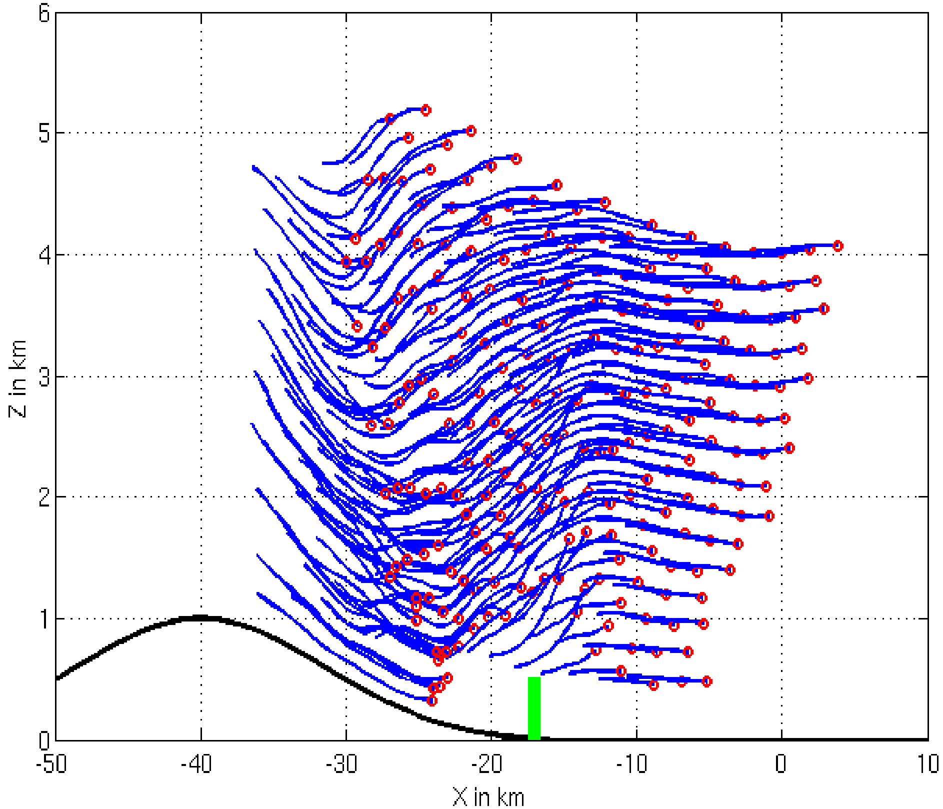


U. Blahak, Institut für Meteorologie und Klimaforschung

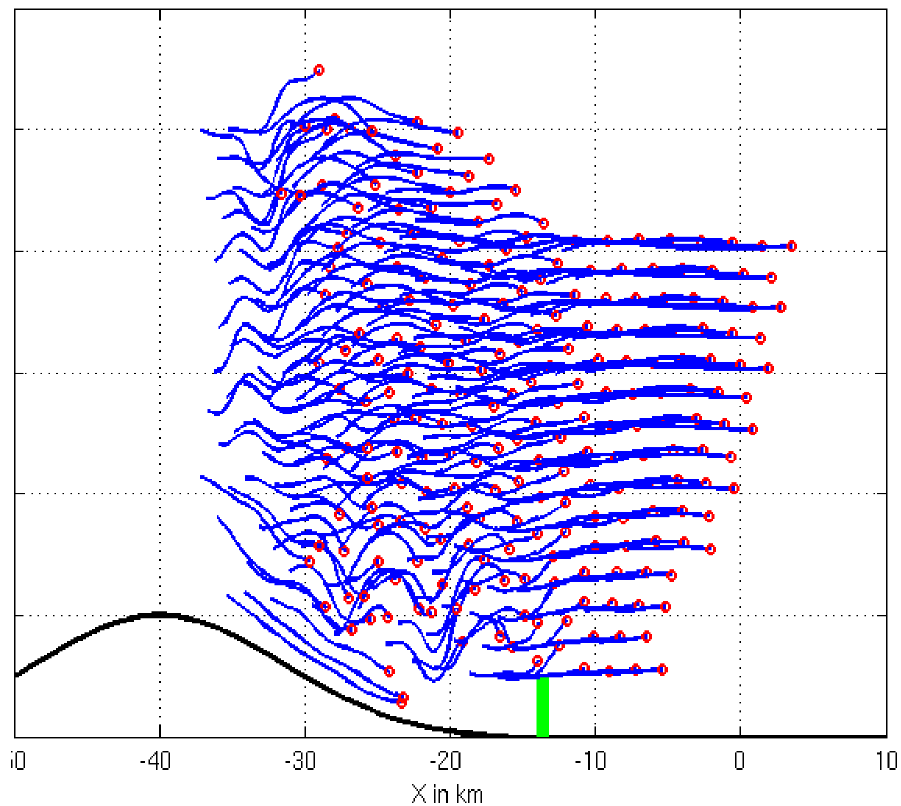
Hypothesis 3)

➔ Trajectories in the flow around the cold pool, at 1:24 h after release of warm bubble:

„Cold“ case



„Warm“ case

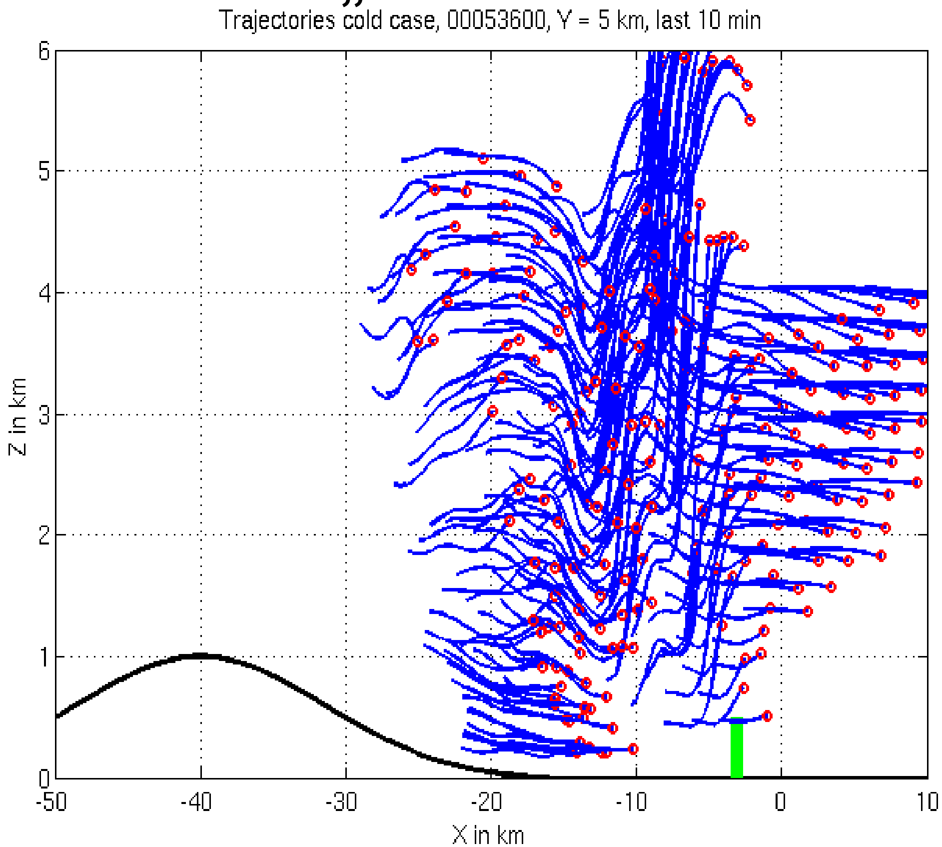


U. Blahak, Institut für Meteorologie und Klimaforschung

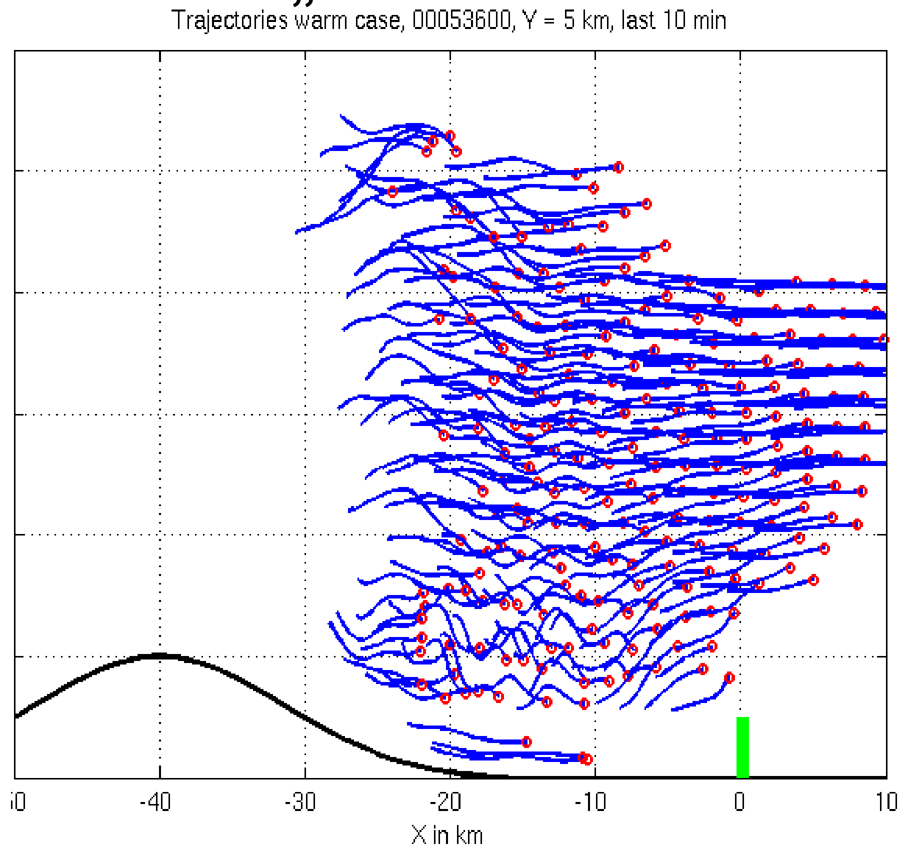
Hypothesis 3)

➔ **Trajectories in the flow around the cold pool, at 1:36 h after release of warm bubble:**

„Cold“ case



„Warm“ case

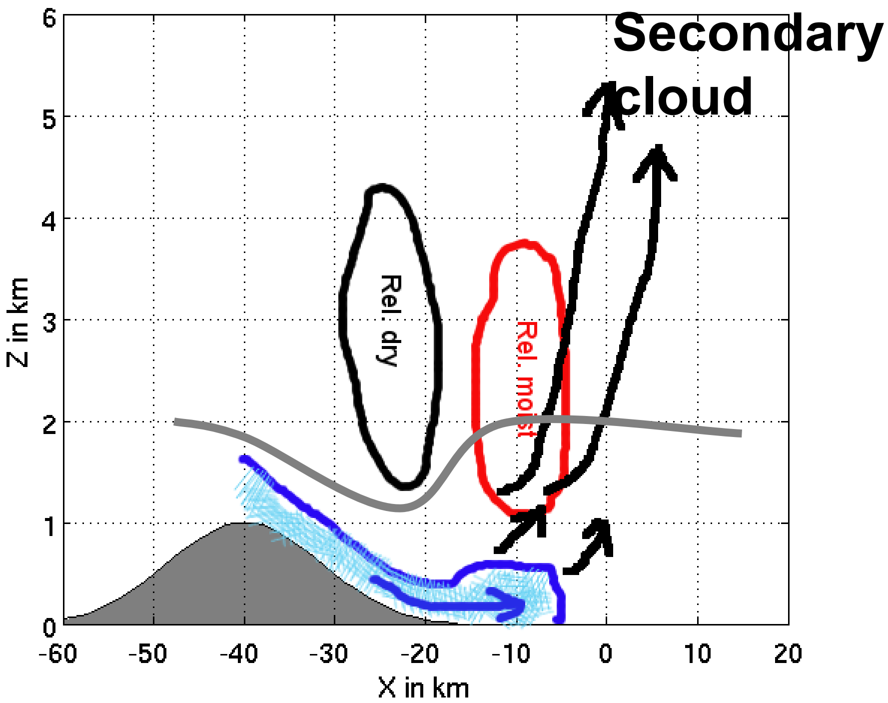


U. Blahak, Institut für Meteorologie und Klimaforschung

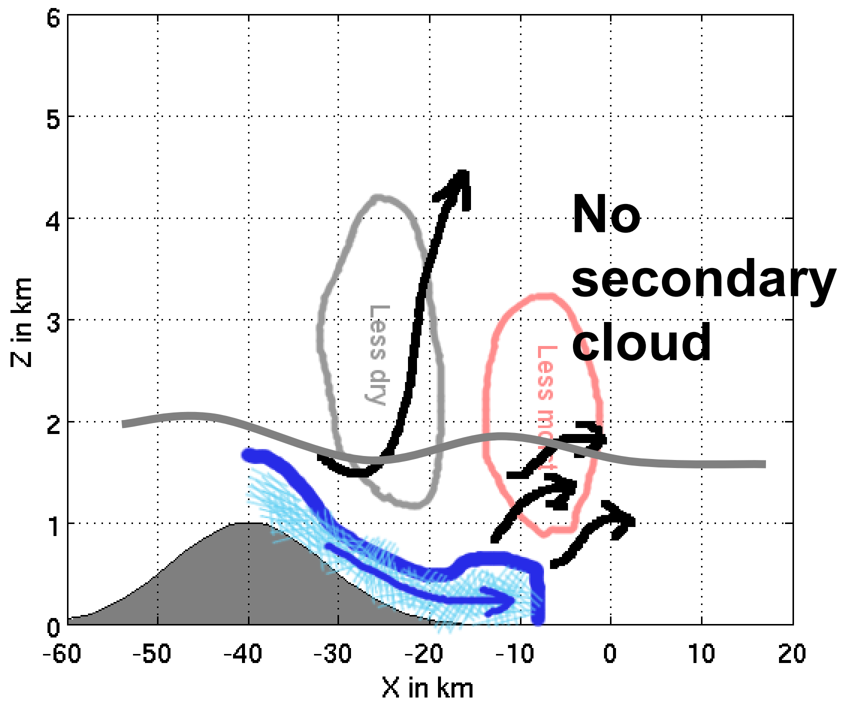
Conceptual sketch

After having crossed the ridge, ability of cold pool to trigger secondary system is determined by wave flow amplitude and RH modification just above the PBL height.

„Cold“ case



„Warm“ case



Conclusions and outlook

Karlsruhe Institute of Technology

- Lee-side weakening in „warm“ case is due to modification of RH and different amplitudes of the orographic wave flow, which causes triggering of leeside secondary system only in the „cold“ environment. Differences in microphysical feedback mechanisms only play a minor role, if any.

- Having learned this, the weakening effect depends on parameters, which affect the mountain wave flow (such as mountain height, width, asymmetry) and the RH just above the well-mixed layer.

  Mountain position relative to the development stage of the convective system may play a role.

  ➔ Effect may also act the other way round!

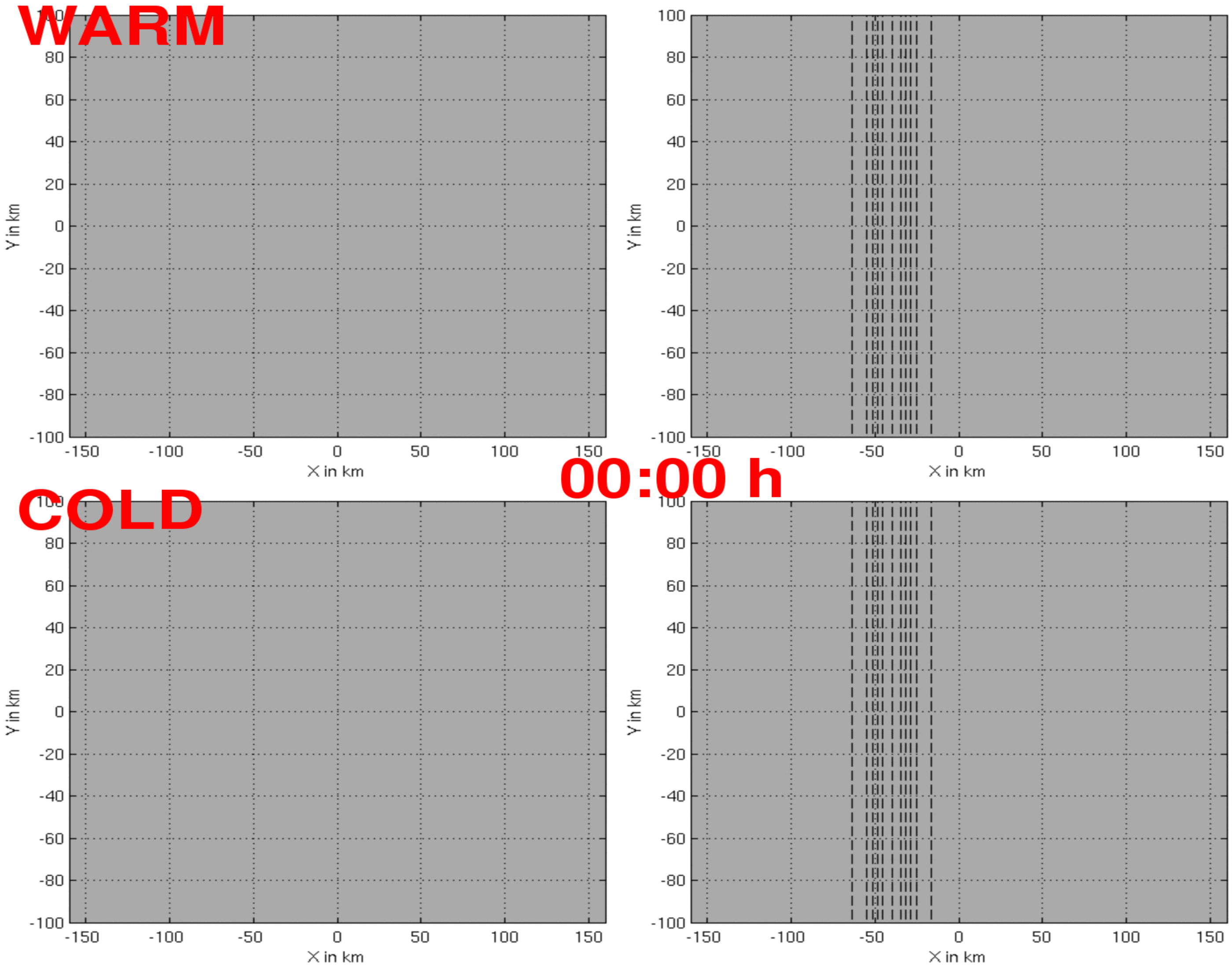
  Have already investigated:

  - Mountain position ➔ no significant effect seen so far
  - RH just above well-mixed layer ➔ increase of RH leads to less weakening, as expected.
  - Others will follow …

U. Blahak, Institut für Meteorologie und Klimaforschung

Thank you for your attention!

Results: Simul. Refl. 0:00 – 4:00 h



U. Blahak, Institut für Meteorologie und Klimaforschung

$$T^{(new)} = T^{(orig)} \min[\max[p_4(z);\ 1.0167];\ 1.0696]$$

$$\text{with:}\quad p_4(z) = \sum_{i=0}^{4} a_i z^i$$

$$\rho_v^{(new)} = \rho_v^{(orig)} \frac{T^{(orig)} E_{sat}(T^{(new)})}{T^{(new)} E_{sat}(T^{(orig)})} = \rho_v^{(orig)} \alpha$$