The impact of embedded valleys on daytime pollution transport over a mountain range

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MOTIVATION

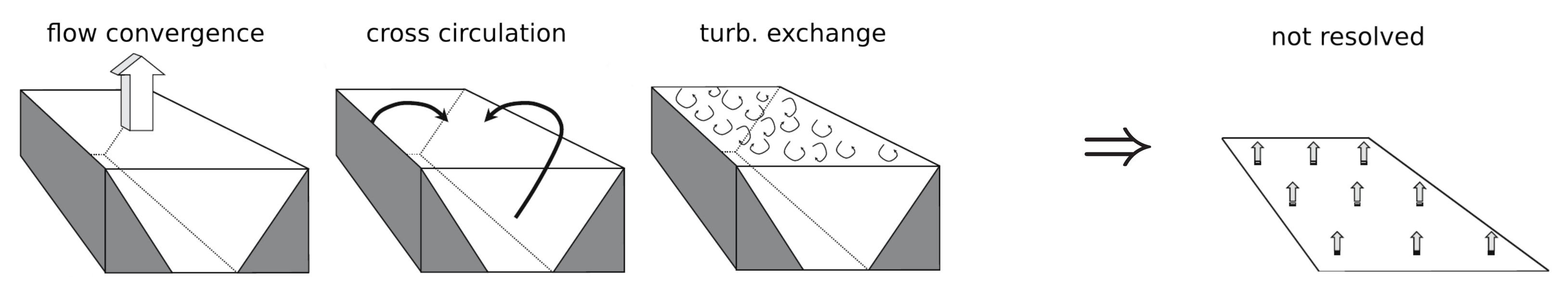

Figure 1 : Left: Schematic representation of the processes responsible for vertical moisture fluxes over a steep idealized and straight valley. Right: Moisture exchange as seen by a coarse numerical model not resolving the valley. Taken from Weigel et al. (2007).

- The **spatial resolution** of global NWP and regional climate models is too coarse to properly resolve topographically induced transport processes (cf. Fig. 1).
- Present-day **boundary layer parameterizations** are designed for the plain and are not capable of accounting for these missing subgrid-scale effects.

$\Rightarrow$ Perform large-eddy simulations (**LES**) and **tracer analyses**.

Goals

- Quantify the impact of terrain geometry on the convectice boundary layer (**CBL**) structure and the **pollution transport**.
- Investigate the interactions between **plain-to-mountain** and **slope wind** systems and analyze their influence on daytime pollution distribution over idealized terrain.

MODEL SETUP

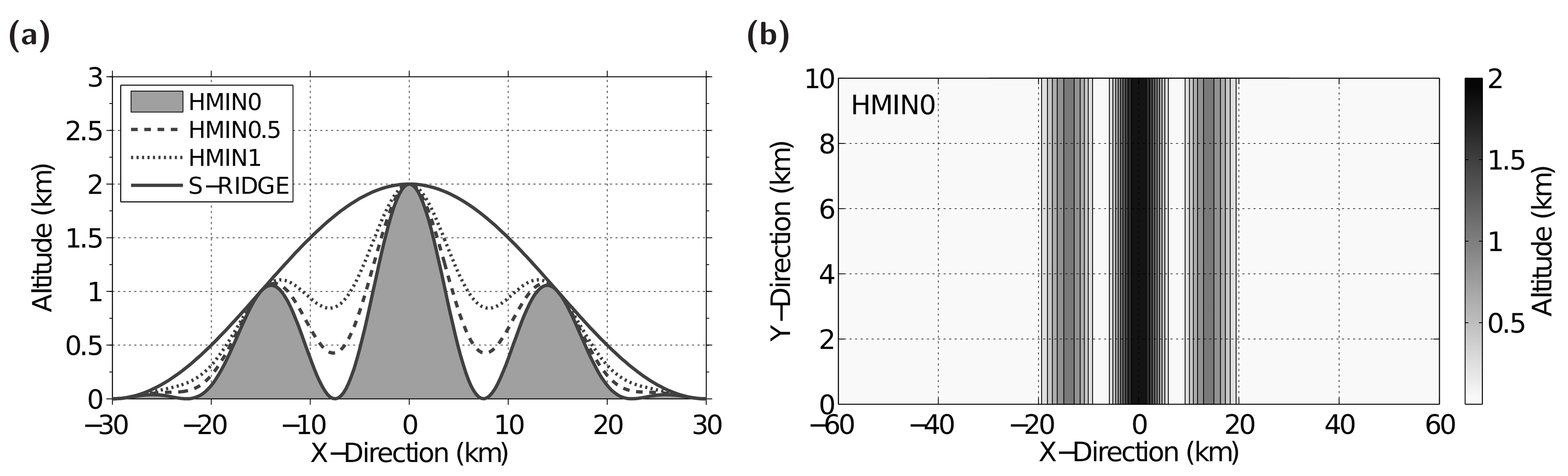

Figure 2 : Idealized model topography of the reference run HMIN0 as **(a)** vertical cross section (gray shading) and **(b)** plan view (showing the full domain). Additional topography setups with three ridges and different elevated valley floor heights, and with a single ridge are used in sensitivity simulations and are shown in **(a)** as dashed, dotted and solid lines.

Model topography

- Quasi-two-dimensional mountain range (cf. Fig. 2)
- Flat foreland in cross-mountain direction
- Embedded valleys with different valley heights
- Ridges of different crest heights
- In addition: Single-ridge and plain simulations

Numerical setup

- WRF-ARW (3.4) in LES mode
- $\Delta x = \Delta y = 100$ m
- $\Delta z = 10$ m to 100 m with 74 levels
- Initialization: atmosphere at rest, $\frac{\partial \theta}{\partial z} = 3$ K m^{-1}
- Forcing: Constant surface sensible heat flux (HFX $= 150$ W m^{-2})
- 6 hours simulation
- Time averaging: 40 min
- Space averaging: whole y-domain

FLOW STRUCTURE

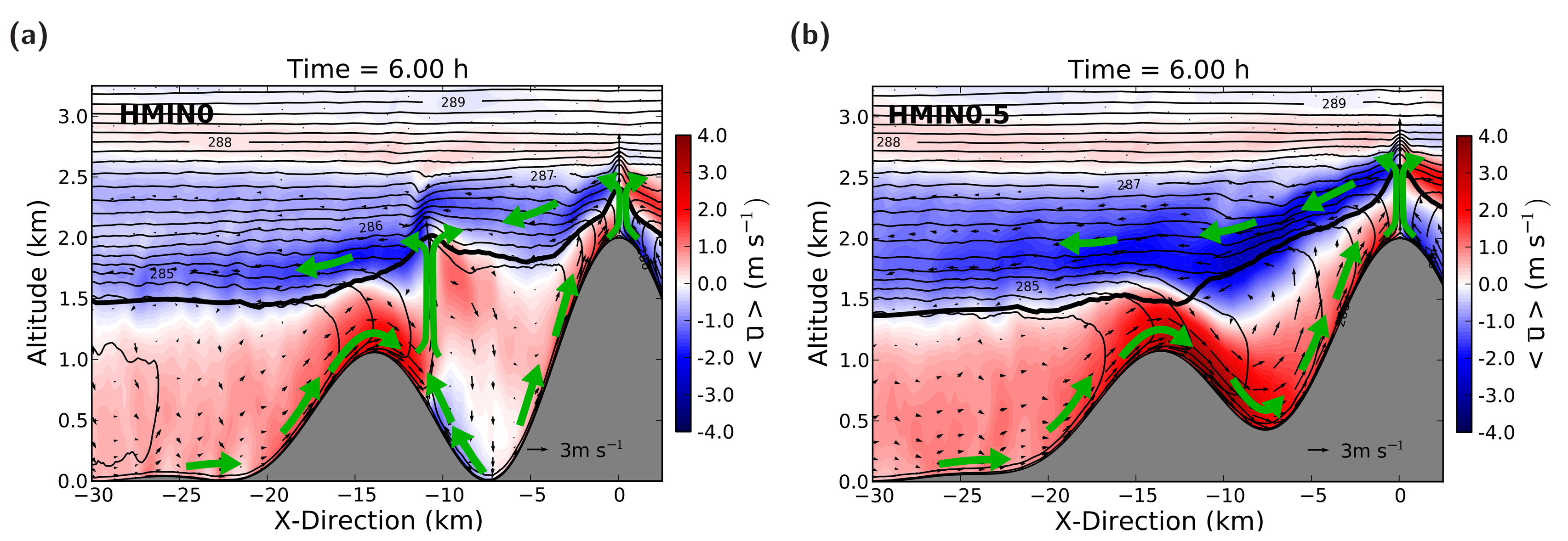

Figure 3 : Cross sections of averaged cross-mountain wind speed as color contours after 6 h of simulation for **(a)** a deep valley (HMIN0) and **(b)** an elevated valley (HMIN0.5). Potential temperature as black contour lines (0.25 K increment) and wind vectors for components parallel to the cross section. Variables are averaged in space and time. The black solid line shows the CBL height.

Deep valley (HMIN0)

- Development of a plain-to-mountain wind over the foreland and establishment of a slope wind regime within large parts of the valley (Fig. 3a).
- Formation of strong updrafts over both mountain peaks and of a return flow towards the foreland above the CBL (Fig. 3a).

Elevated valley (HMIN0.5)

- Replacement of the slope flow on the upwind side of the valley by the opposing plain-to-mountain wind (Fig. 3b).
- Formation of a single updraft over the main ridge and of a return flow towards the foreland above the CBL (Fig. 3b).

TRACER ANALYSES

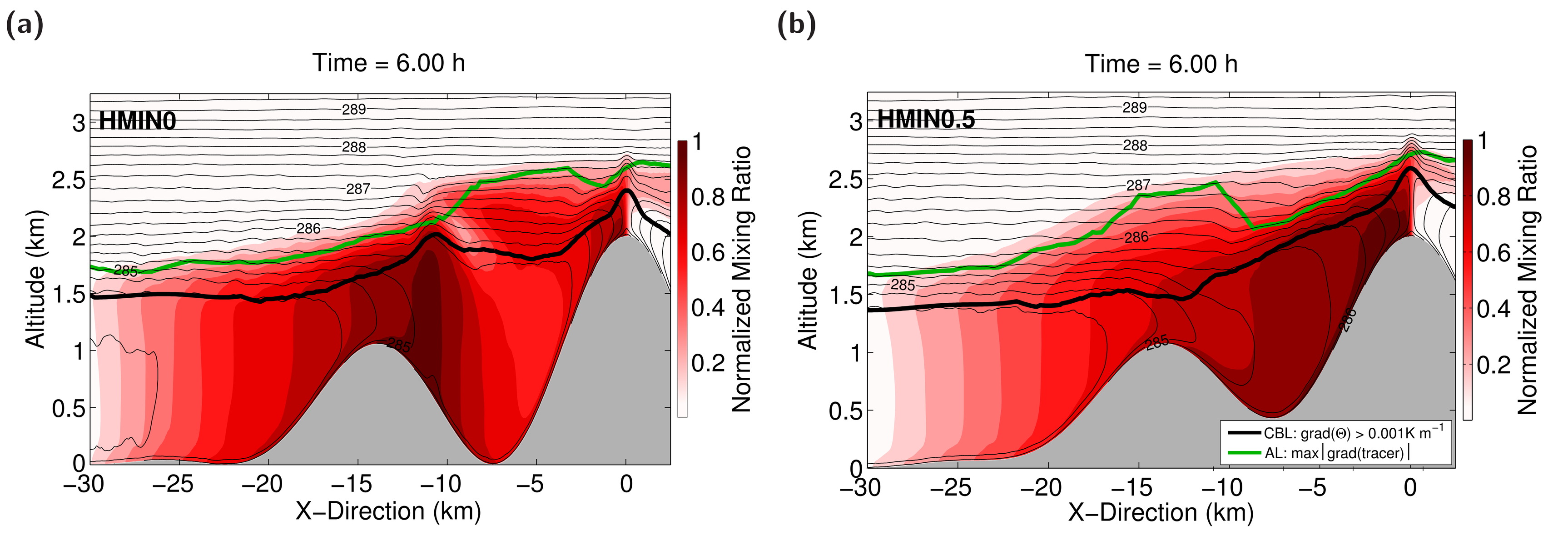

Figure 4 : Cross sections of tracer concentrations (color contours) after 6 h of simulation for **(a)** a deep valley (HMIN0) and **(b)** an elevated valley (HMIN0.5). A passive tracer has been constantly emitted over the whole along-mountain domain within the region of -30 km $\leq x \leq 0$ km on the lowermost 8 model levels (within a depth of approximately 110 m). Mixing ratios are averaged in space and time, and normalized by their corresponding maximum value. The black and green solid lines mark the CBL and AL heights, respectively.

- Pollution distribution depends on the valley floor height (Fig. 4).
- In HMIN0.5 increased pollution transport towards the main ridge by additional 20%.
- CBL height lower and rather terrain-following than the aerosol layer (AL) height (i.e., the height up to which aerosols are mixed, cf. Fig. 4).

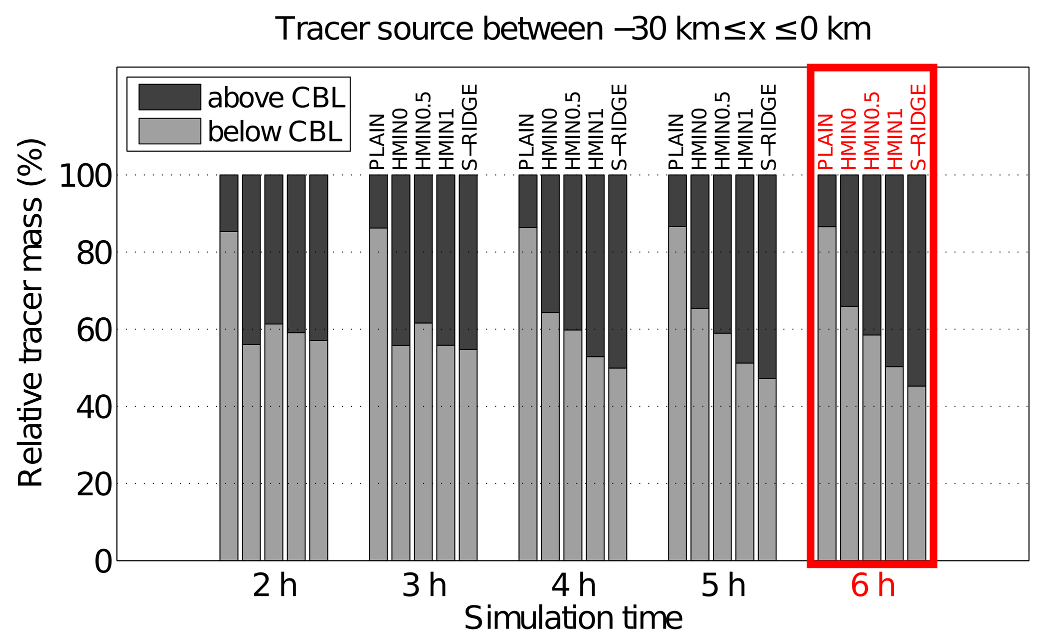

Figure 5 : Relative tracer mass located above (dark gray) and below (light gray) the CBL as a function of time. A tracer has been constantly emitted near the surface over the half space of the mountain range within the region of -30 km$\leq x \leq 0$ km. Shown are all simulations (from left to right) between 2 and 6 h: PLAIN, HMIN0, HMIN0.5, HMIN1, and S-RIDGE (see Fig. 2a for explanation of simulation name).

- More than threefold increase in vertical exchange for all mountain shapes compared to the reference plain simulation (Fig. 5).

SUMMARY

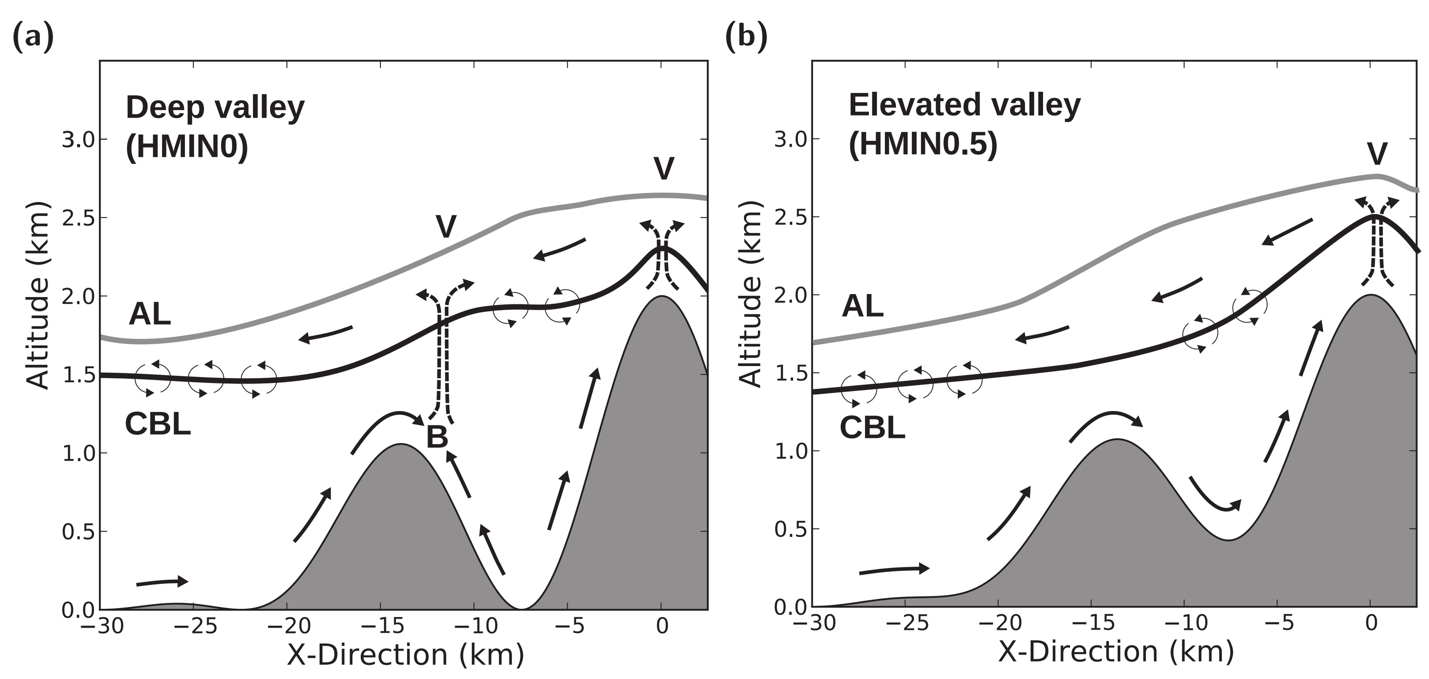

Figure 6 : Conceptual diagram of the flow pattern for **(a)** a deep valley (HMIN0) and **(b)** an elevated valley (e.g., HMIN0.5) after 6 h of simulation. The black and gray solid lines mark the temperature based CBL and the AL height, respectively. Thick, solid arrows represent the cross-mountain flow and thin, solid arrows mark the turbulent exchange in the entrainment layer over the foreland and the valley region. Dashed, double-lined arrows indicate the vertical transport from the boundary layer beyond the CBL height as a result of horizontal flow convergence. V denotes mountain and advective venting and B indicates flow blocking.

- The flow regime depends on the valley floor height:
  - **Deep valley:** Blocking of the plain-to-mountain flow and ongoing slope wind circulation within the valley (Fig. 6a).
  - **Elevated valley:** Replacement of the slope wind regime by the potentially cooler plain-to-mountain flow (Fig. 6b).
- Increased pollution transport towards main ridge by 20% for the elevated valley.
- Threefold increased vertical exchange over complex terrain compared to the flat plain.
- CBL height lower and rather terrain-following than AL height.
- More details can be found in Lang et. al (2015).

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References

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