Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

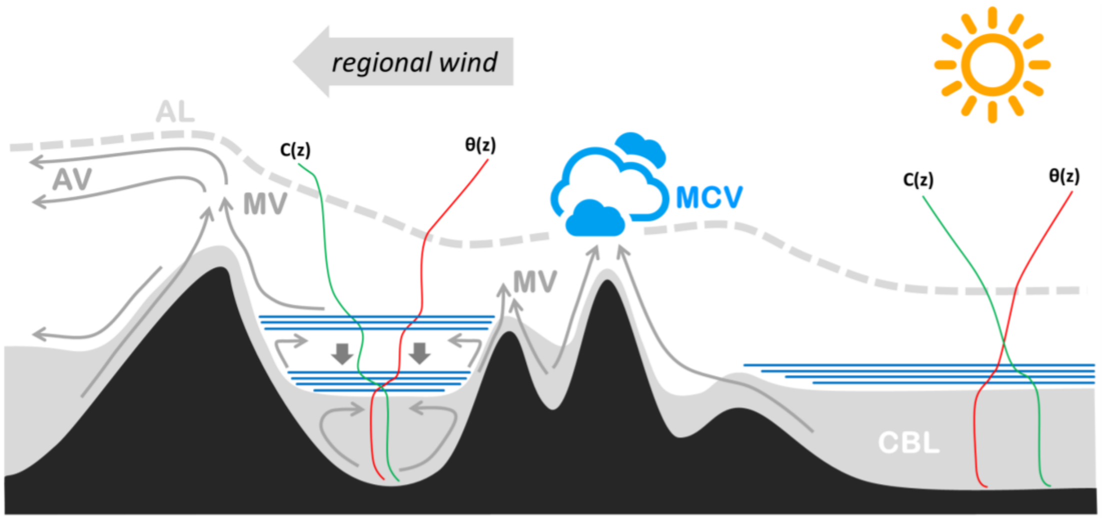
Thermally driven flows in the CBL over mountainous regions:

LES and budget analysis over idealized topography

Jan Weinkaemmerer, Ivan Bastak Duran, and Juerg Schmidli

Motivation

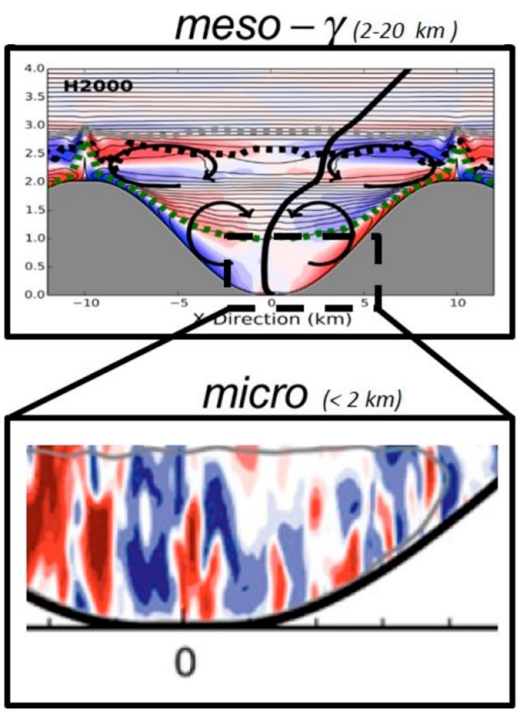
- Understanding the influence of thermal winds on the vertical **transport of heat, moisture, and pollutants** over mountainous terrain (locally and area mean)
- Influence of thermal winds on orographic convection (moisture convergence ↔ advective cooling)
- Lack of studies regarding the **impact of an upper-level wind**



Serafin et al., 2018

Overview

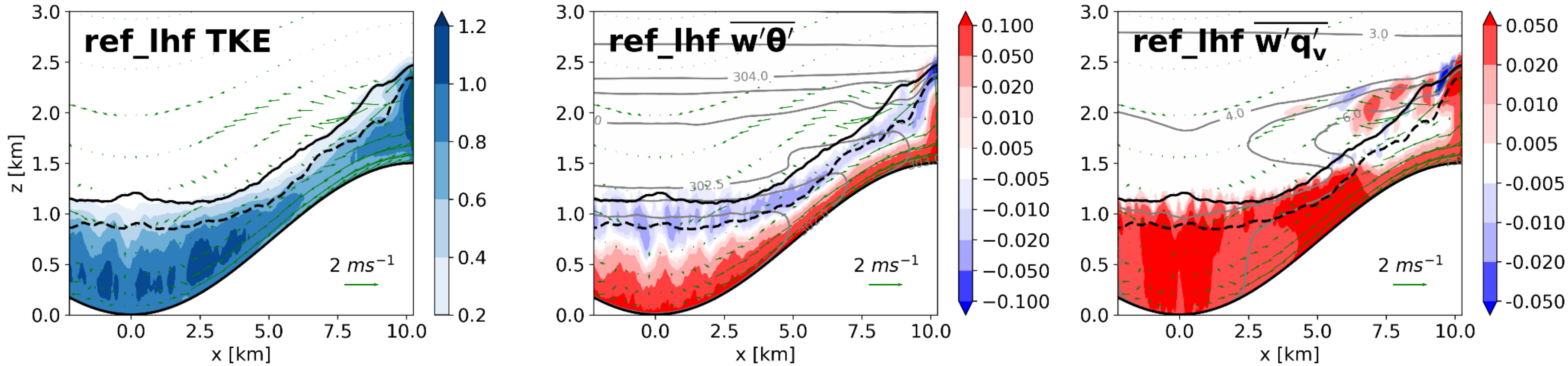
- Stacked **cross-valley circulation cells** formed by upslope flow and partial recirculation to valley center (Vergeiner and Dreiseitl, 1986)
- Relatively homogeneous heating rate inside the valley with a **net heat export out of the valley** (→ valley volume effect) (Steinacker, 1984; Schmidli, 2013)
- **Three-layer thermal structure** and **secondary heat-flux maximum** at crest height
- **Interactions over a range of scales:**
  - Upper-level geostrophic flow
  - Thermal mean circulation (cross-valley)
  - Local turbulent exchange



Lehner and Rotach, 2018

Setup

- Using **CM1** (Bryan, 2017) in **LES** mode**,** resolution 40 m x 40 m x 8…40 m
- **Periodic**-valley test case (Schmidli, 2013)
- Prescribed surface turbulent fluxes
- Turbulence statistics calculated by averaging along the y-axis (along-valley direction) and in time over a period of 40 min
- Reference case *(ref)* **without background flow**
- Cases **with upper-level wind** *(wind)* increasing above crest height (U = 0 below)



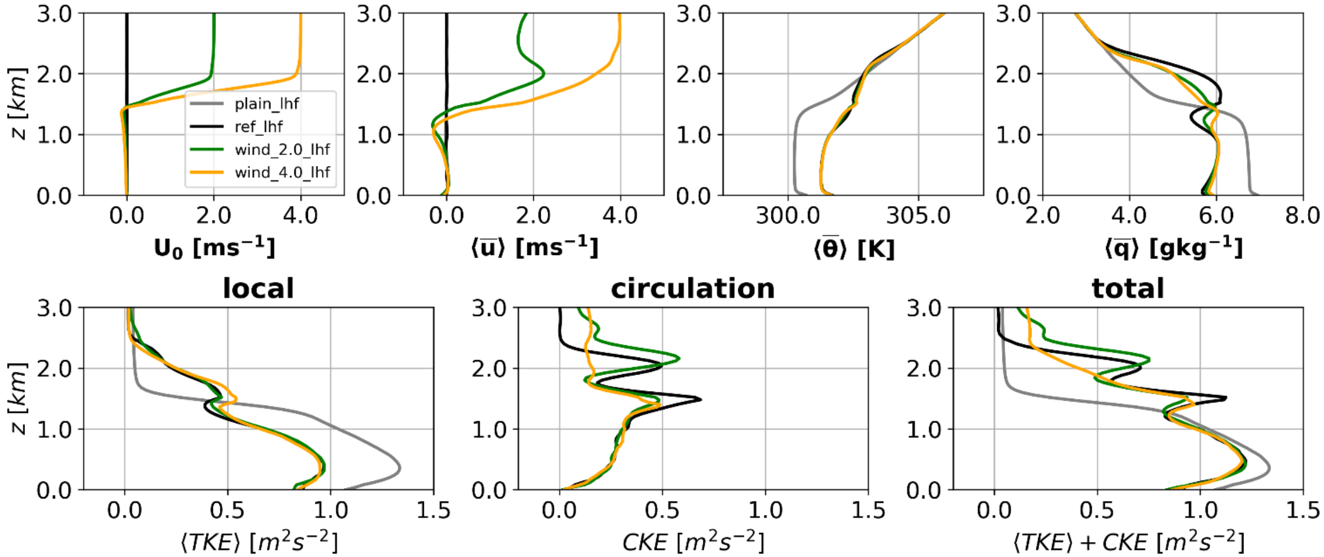
TKE in m²/s², sensible heat flux in K m/s, and latent heat flux in g/kg m/s, after 4 h. Also showing the BL height (solid line), the ML height (dashed line), the contour lines of the potential temperature in K (middle), and of the specific moisture in g/kg (right).

Separating the cross-valley circulation

- Decomposition of the flow into a **large-scale**, **cross-valley,** and **turbulent** component:

$$a(x,z) = \overline{a}(x,z) + a'(x,z) = \overline{a}_l(z) + \overline{a}_c(x,z) + a'(x,z)$$

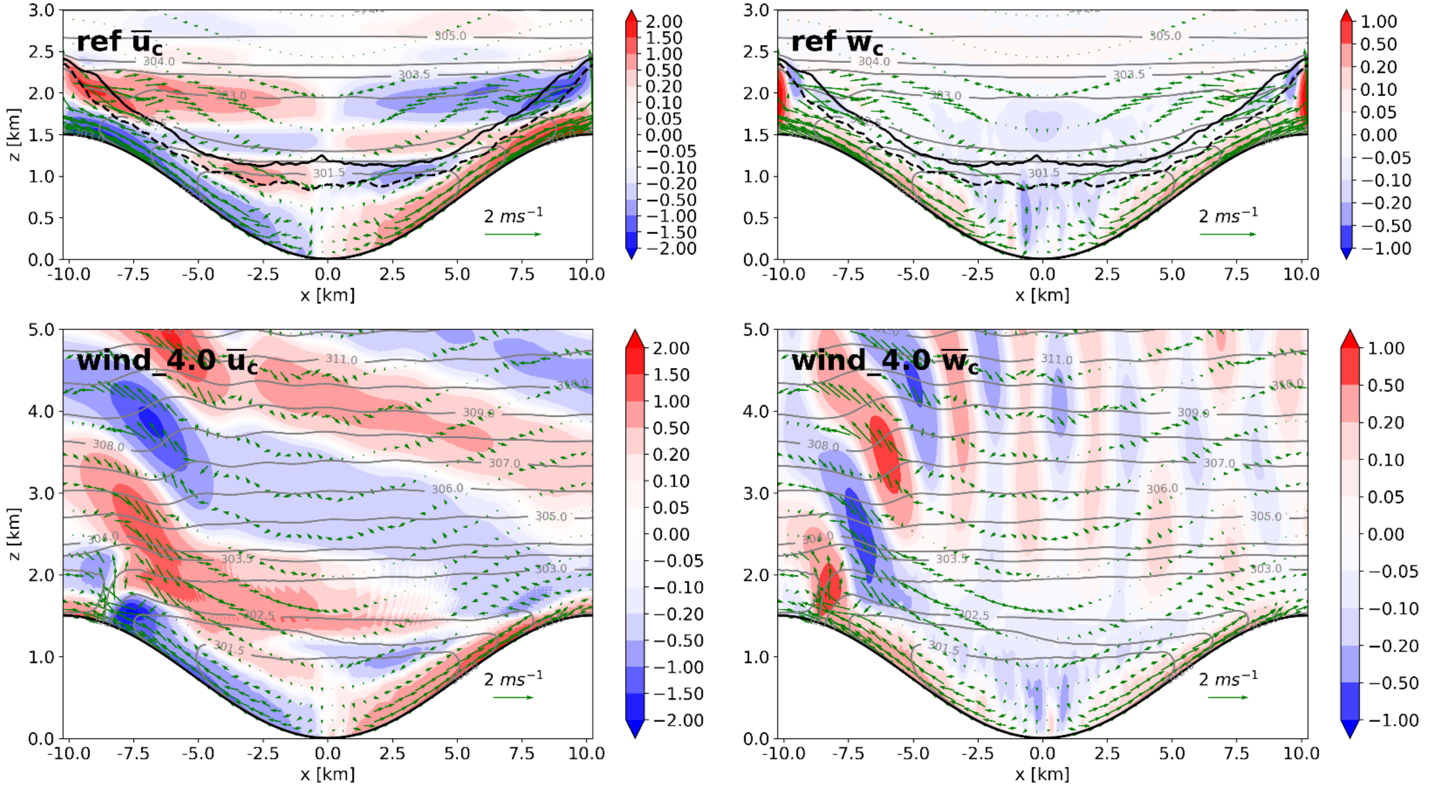
Horizontally averaged profiles:



- Stronger heating **compared to plain**, below crest height reduced TKE (mainly because of reduced $\overline{w'^2}$) but total KE and turbulent sensible heat flux similar to plain case
- Gain in KE above crest height almost entirely due to horizontal branch of cross-valley circulation $\bar{u}_c$

Generation of gravity waves

- Disturbance of large-scale flow by upslope winds
- **Stationary waves,** similar to mountain waves
- Amplitude scales with surface heat flux (~ thickness of slope wind layer)



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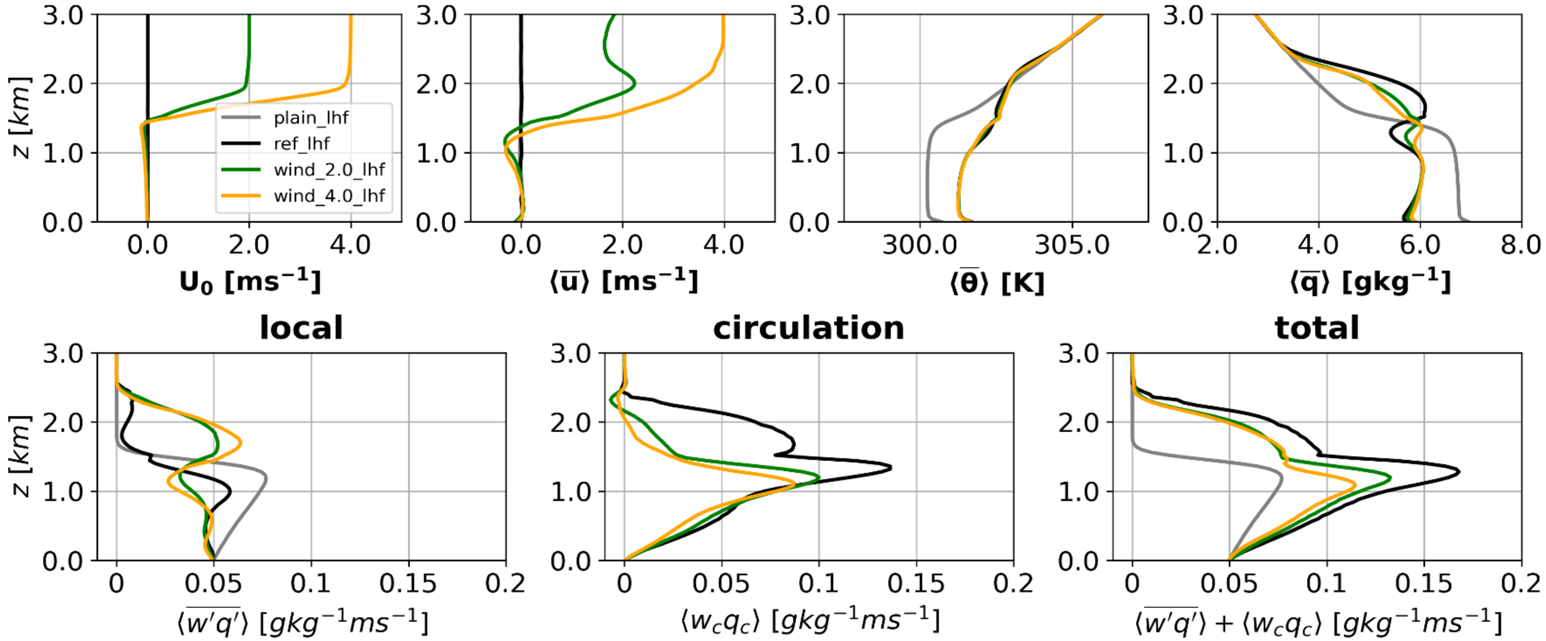
Sensitivity to upper-level wind

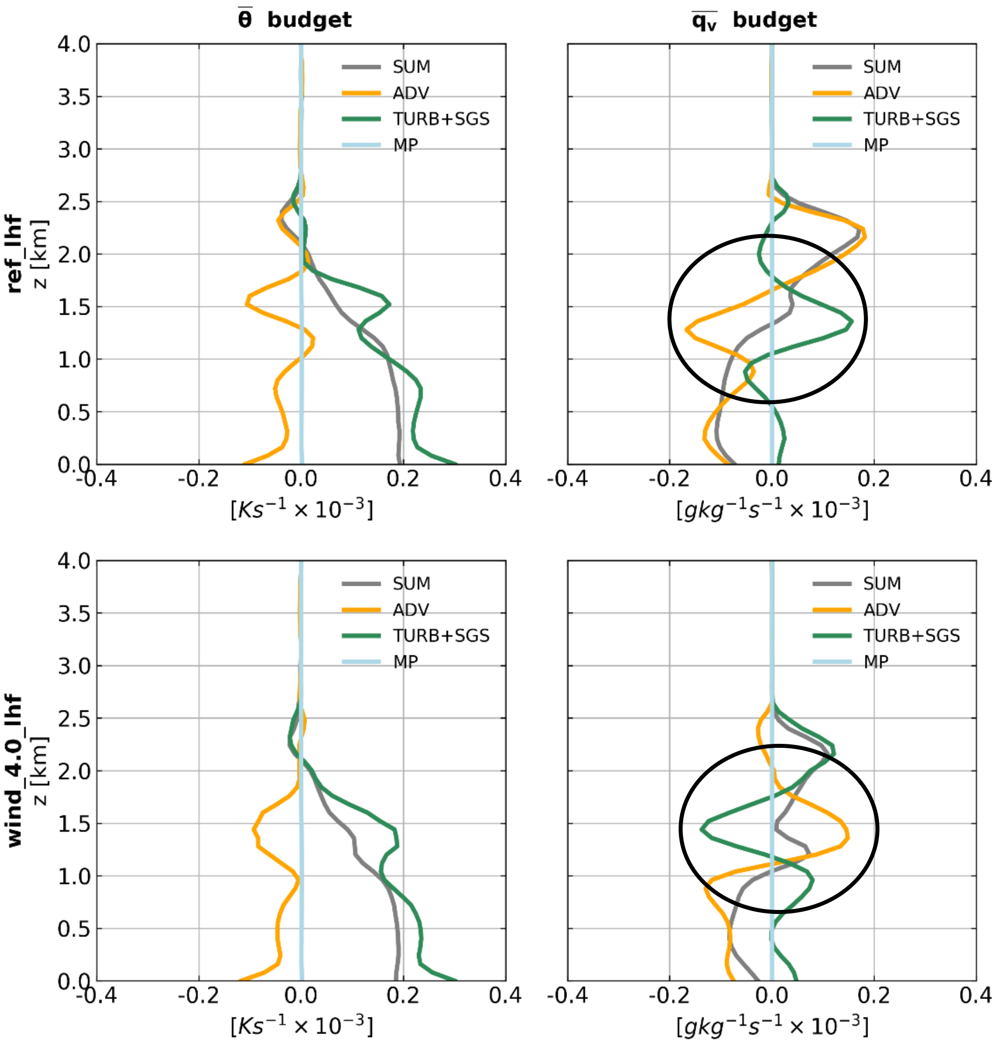
- Almost no impact of upper-level wind on **temperature profile** and area-mean **turbulent sensible heat flux**
- ↔ Strong impact on mean **moisture profile and transport:**



- Hypothesis: the temperature can not be treated as a passive tracer in presence of a thermal circulation. Large-scale flow along the nearly horizontal isentropes does not affect the temperature distribution but it redistributes moisture

Budget analysis

- Advection and turbulent transport of similar importance
- **Temperature:** generally, thermal winds (ADV) have a slight net cooling effect, heating of the valley mainly by turbulent transport (TURB)
- **Moisture:** export out of the valley by thermal winds, around crest height **very sensitive to large-scale flow**
- Interscale transfer: thermal winds lead to additional gradient terms in the turbulent budgets (mainly in the TKE budget by the slope winds, not shown)



Conclusion

- **Decomposition of the flow** into large-scale wind, thermal mean circulation and turbulence is helpful to study exchange processes in the CBL over mountains
- In comparison to the CBL over a plain:
  - ❖ Stronger heating but reduced moistening inside the valley
  - ❖ Reduced TKE, thermal circulation contains the remaining kinetic energy
- Thermal winds may affect the generation of orographic gravity waves
- Budget analysis: **Export of moisture** out of the valley **by thermal winds**
- **Impact of an upper-level wind:**
  - ❖ Sensible heat fluxes and **temperature profile fairly insensitive**
  - ❖ **But strong impact on latent heat fluxes and moisture profile**
  - ❖ Export of moisture out of the valley can be supressed by an upper-level wind

→ **Temperature can not be treated as a passive tracer in presence of a thermal circulation**

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