Structures in the Horizontal Wind Field over Urban Mountainous Terrain detected with Coplanar Doppler Lidar Scans

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Motivation

- Over complex terrain, convection and thermally and dynamically driven flows interact in the atmospheric boundary layer (ABL) → relevant for ventilation and air quality → ABL is highly variable in space and time → in situ measurements on towers may have limited representativeness → simultaneous measurements at many locations are necessary to capture flow variability → coplanar Doppler lidar scans can be the answer to that
- Coplanar horizontal Doppler lidar scans were conducted over the city of Stuttgart located in mountainous terrain in south-western Germany in summer 2018 within the Urban Climate Under Change [UC][2] program

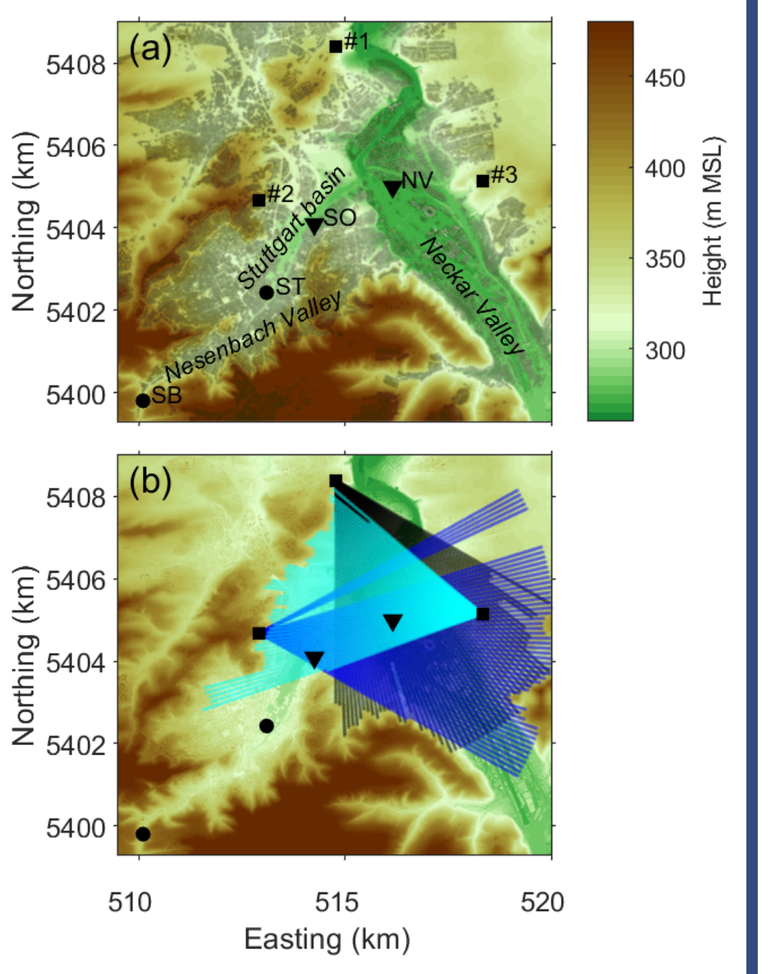
Research questions

- What mesoscale flow pattern occur in the Neckar Valley and opening of the Stuttgart basin? How regularly are they and how do they depend on stratification and wind above mean ridge height?
- Can convective cells in the daytime ABL be traced over complex terrain and can the convection velocity, i.e. the velocity with which the cells move downstream, be estimated? How does it relate to the horizontal wind speed?

Approach

- Orography around Stuttgart is characterized by a basin-shaped valley (Stuttgart basin) which opens into Neckar Valley (mean ridge height 520 m MSL, mean valley depth 170-270 m)
- Three 'Windcube 200s' Doppler lidars (#1, #2, #3) installed on opposing slopes (a) at 365 m MSL (about 62 m above the valley floor) and performed synchronized coplanar horizontal scans (duration 60 s) (b)

  → Every 60 s, horizontal wind field is retrieved in overlapping area on Cartesian horizontal grid with lattice length of 100 m (NV and SO are grid points used for further investigation)

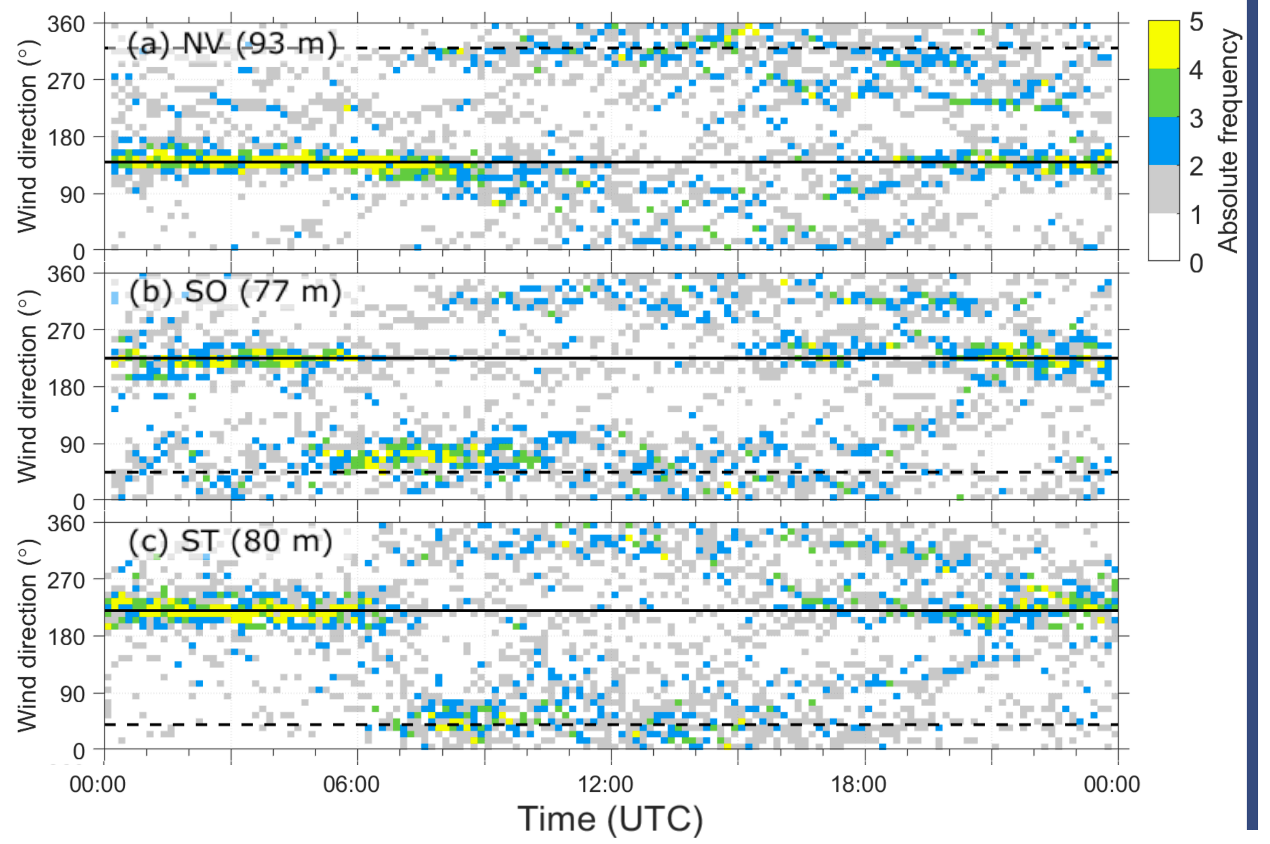


- Profiling Doppler lidar and microwave radiometer at ST for horizontal wind and temperature profiles
- In total 22 days available for analysis

Statistics of mesoscale flow structures

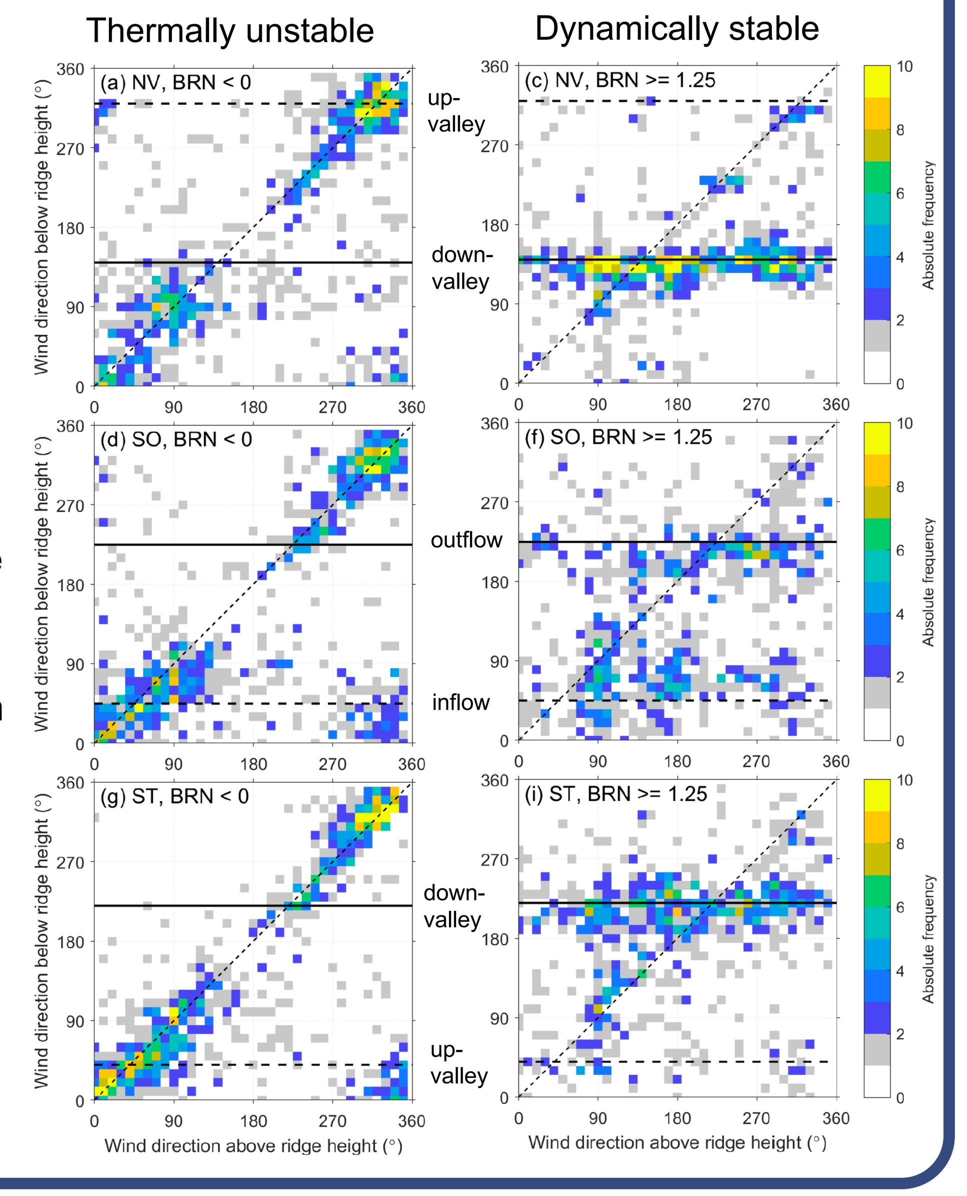
Diurnal cycle of wind direction

- In the Neckar Valley (NV, a) and Stuttgart basin (ST, c), wind direction is downvalley (solid line) during nighttime and variable with slight preference for northerly (upvalley, dashed line) during daytime
- At the opening of the Stuttgart basin (SO, b), outflow from late evening until early morning (solid line) and inflow in the morning



Dependency on Bulk-Richardson number (BRN) and wind direction above ridge height (705 m MSL)

- BRN calculated for lower 250 m, critical BRN = 1.25
- During thermally unstable conditions, wind direction below and above ridge height match at all three locations in the Neckar Valley (NV, a), at the opening (SO, d) and in the Stuttgart basin (ST, g)
- During dynamically stable conditions, downvalley wind in the Neckar Valley (NV, c) and Stuttgart basin (ST,i) and both inflow and outflow at the opening (SO, f) → decoupling of the flow below and above ridge height
- In- and outflow regimes at SO may be relevant for ventilation of Stuttgart basin



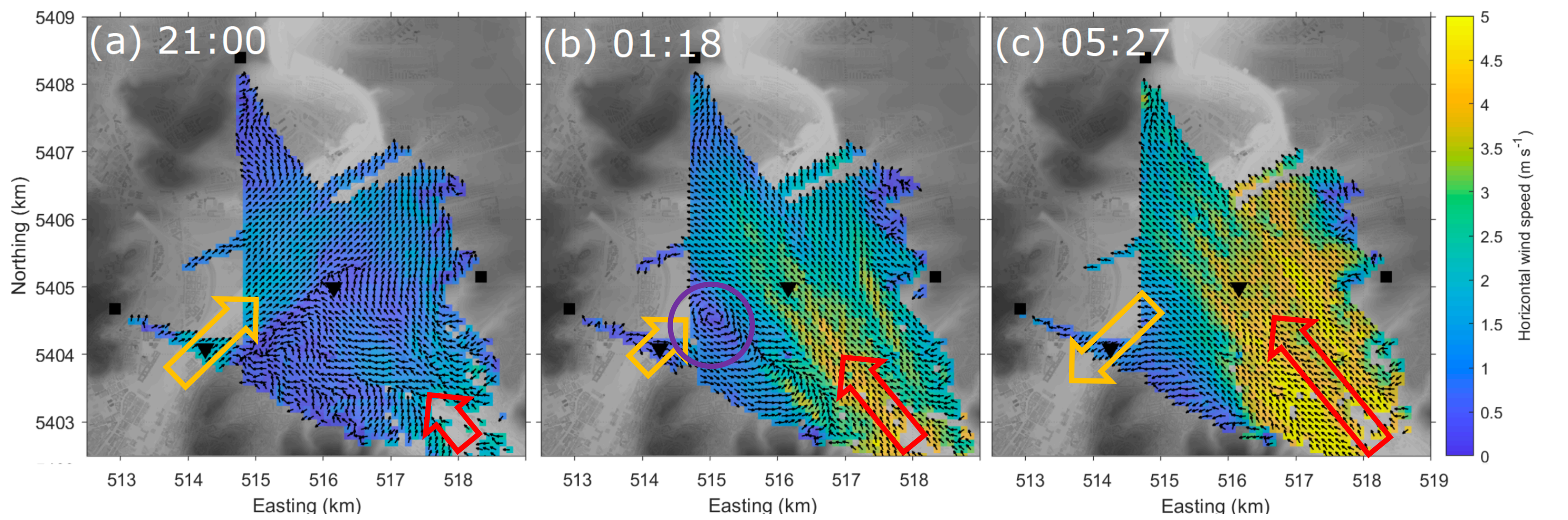
Flow examples

Nocturnal conditions

a) Weak south-easterly downvalley wind and outflow of Stuttgart basin

b) Stronger downvalley wind, weak outflow of Stuttgart basin and vortex over slope

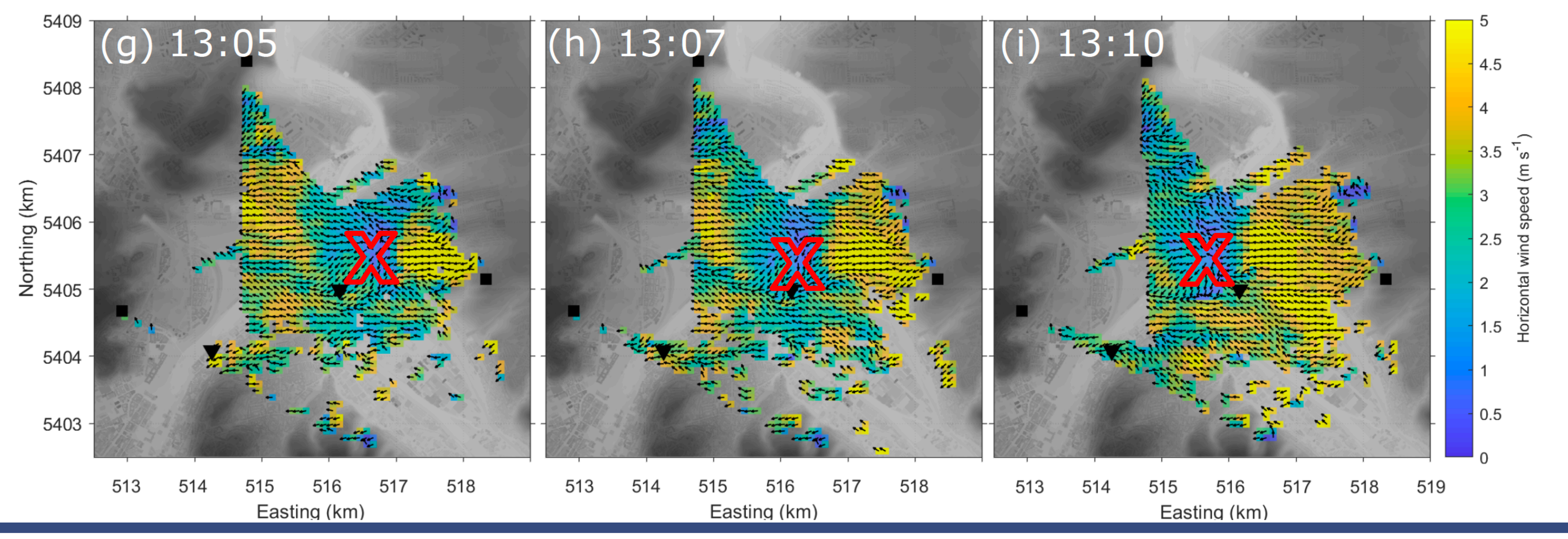
c) Strong downvalley wind and inflow into Stuttgart basin



Daytime conditions

- Areas with enhanced or reduced horizontal wind speed move (related to convective cells) move downstream with the mean wind
- Cell ✗ moves around 1.5 km in 5 min from east to west (g-i)

  → convection velocity $v_c \approx 5$ m s^{-1}

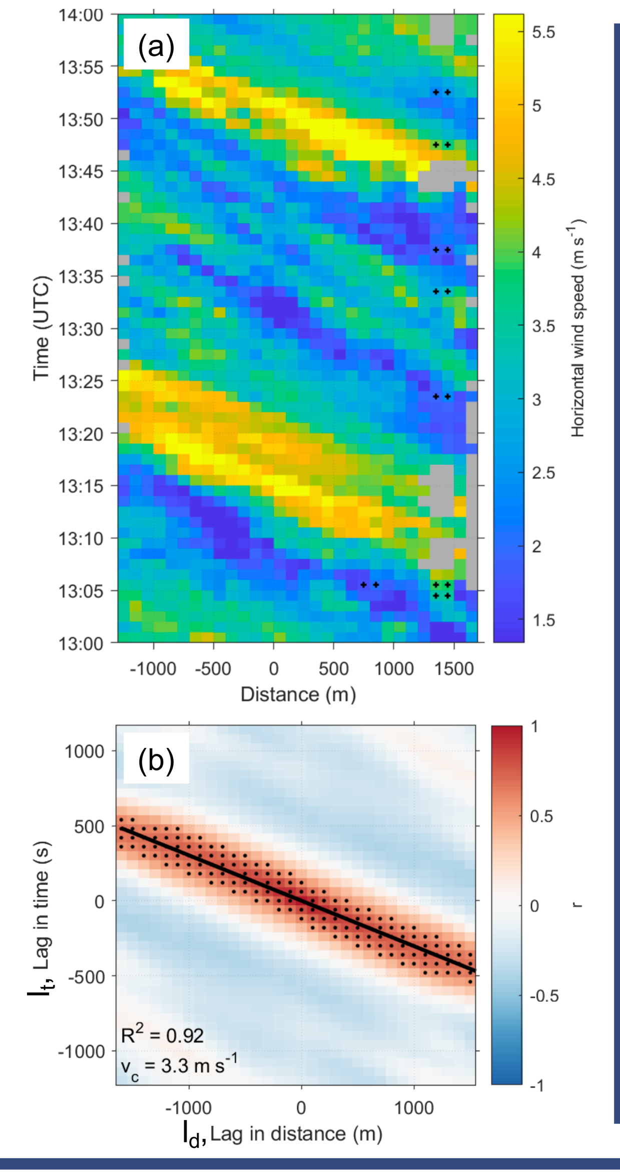


Convection velocity vs horizontal wind speed

Estimation of convection velocity

1. Determine 60-min mean wind direction from horizontal wind field
2. Extract horizontal wind speed along the line of the mean wind direction going through NV in the Neckar Valley (a)
3. Slopes of elongated streaks with low and high wind speed in (a) represent displaced cells
4. Calculate two-dimensional auto-correlation function for 60-min time distance plot (b)
5. From fit to positive auto-correlation pixels, convection velocity results:

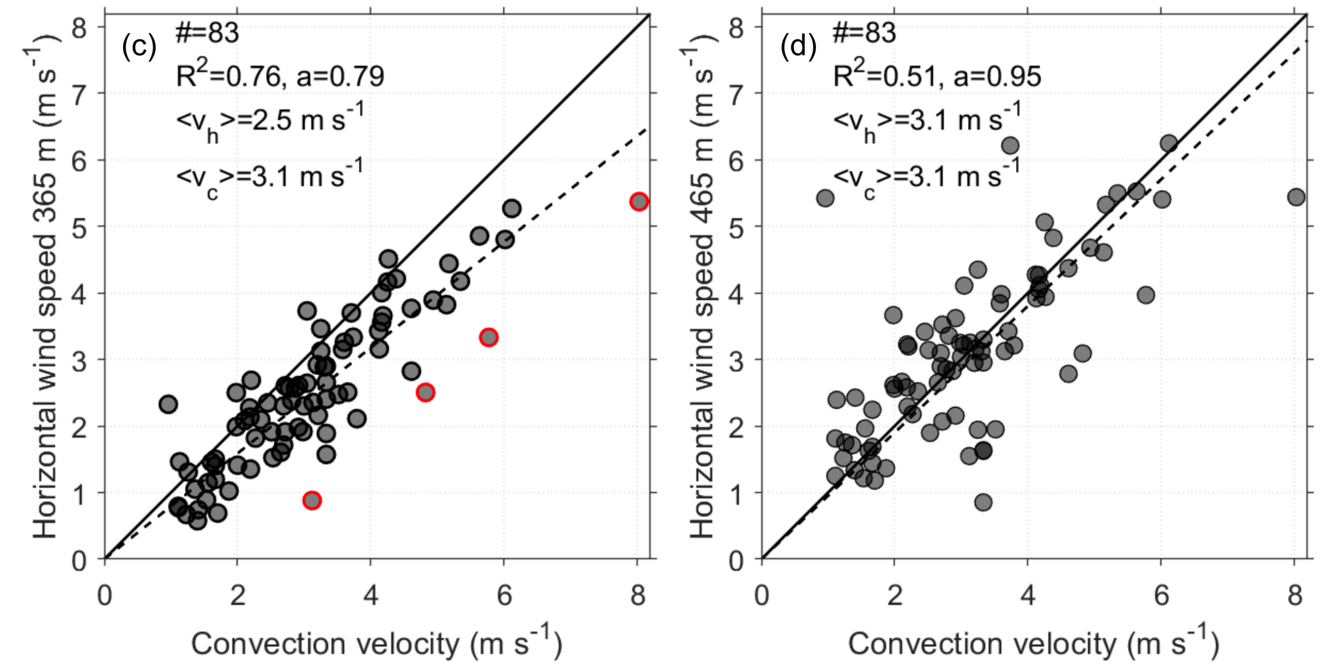
$$v_c = |l_d/l_t|$$



Comparison with horizontal wind speed

- Convection velocity is on the average 0.6 m s^{-1} (24 %) higher than mean horizontal wind speed at the same height (365 m MSL) (c)
- Convection velocity is closer to horizontal wind speed 100 m higher up (from profiling Doppler lidar at ST) (d)

→ Convective cells in lidar scanning plane are steered by flow at higher level



Further reading:
Adler, B., Kalthoff, N, Kiseleva, O., 2020: Detection of structures in the horizontal wind field over complex terrain using coplanar Doppler lidar scans. Meteorol. Z. accepted.