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Valley wind-controlled transport of near-ground air into the upper boundary layer – Observations and simulations

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Outline

- Observations in complex terrain during the COPS[1] experiment indicate that often orographically-induced wind fields control the onset of vertical transport of near-ground air
- Numerical simulations were set up to investigate the transport of this air through the turbulent flow of the convective boundary layer (CBL)

Observations

- Free convection conditions (FCCs) were detected by eddy-covariance (EC) measurements at the valley bottom of the Kinzig valley in the Black Forest, Southwest Germany (Fig. 1)
- FCCs were connected to low wind speed periods during the reversal of a thermally driven valley wind system in the morning hours (Fig. 1)

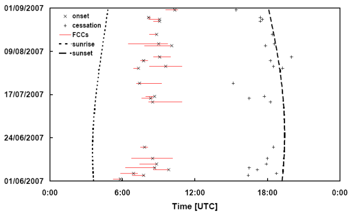

Fig. 1: Periods of near-ground FCCs (—) detected by the stability parameter ζ (ratio of the measurement height to the Obukhov length) calculated from EC fluxes. Also depicted are the onset (x) and cessation (+) times of the up-valley wind direction and the times of sunset and sunrise (from [2]).

- Spectral analysis of the turbulence during these situations indicated the presence of large-scale eddy motions close to the ground (Fig. 2)

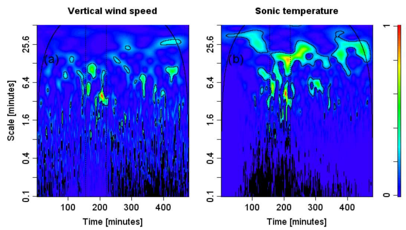

Fig. 2: Normalized wavelet power spectra of the EC vertical wind speed (a) and sonic temperature (b) from 5:00–13:00 UTC (480 min) for COPS IOP 8b (15 July 2007). The period of FCCs (7:35–8:40 UTC) is indicated by the black dotted vertical lines (from [2]).

- Often these near-ground observed turbulence characteristics could be related to enhanced vertical wind speeds measured by boundary layer profiling techniques (Fig. 3)

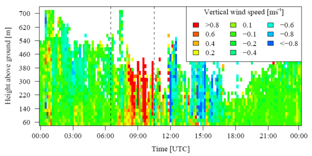

Fig. 3: Sodargramm of the vertical wind speed for COPS IOP 15b (13 August 2007) as measured by a Sodar/RASS system close to the EC station. The black dashed vertical lines indicate the period (06:30–10:35 UTC) of FCCs (from [2]).

Simulations

Two series of simulations with zero and non-zero along valley wind.

Setup:

- Large-eddy simulation (LES) of the CBL (EULAG-Model[3])
- Homogeneous thermal forcing of 60 Wm^{-2} (morning situation)
- Realistic topography
- Passive tracer released at the bottom of the valley

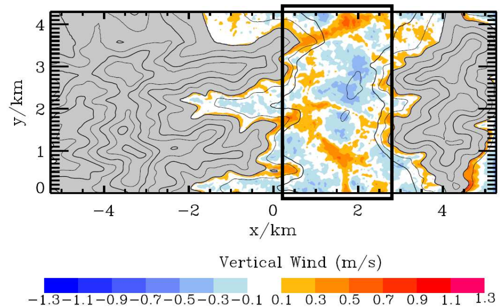

Fig. 4: Horizontal cross section through the ensemble and time mean vertical wind component (color) at 300 m a.s.l. Averaging was made with eight ensemble members and a time period of one hour. The contour lines show the orography in steps of 50 m. Shaded areas indicate intersection with the orography. The black frame outlines the area shown in Fig. 5.

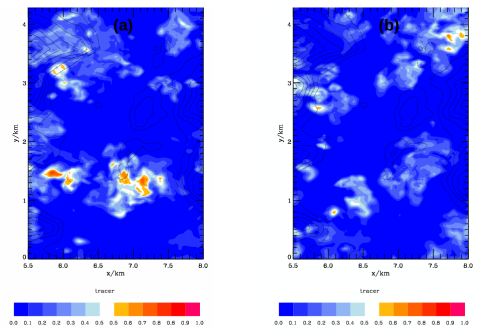

Fig. 5: Horizontal cross section at boundary layer height z_i = 800 m a.s.l. Normalized tracer mixing ratio for the case with 0 ms^{-1} (a) and 0.5 ms^{-1} (b) along valley wind.

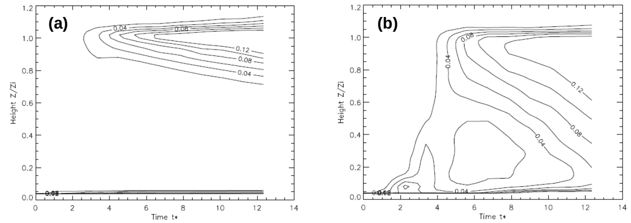

Fig. 6: Time-height diagrams of the horizontal-averaged tracer concentration for two idealized simulations with no topography. (a) u = 0 ms^{-1} and (b) 10 ms^{-1}. Normalization of height with z_i = 500m. Normalization of time with $t_* = w_*/z_i \cdot t$ (Deardorff velocity w_*). The tracer is normalized with the predefined value of the tracer in the lowest two layers at the beginning of the simulation.

Discussion

- Topography induces spatially localized turbulence structures in the case when the mean wind is zero (Fig. 4)
- These structures allow the formation of local maxima of near ground air at the height of the inversion of the CBL (Fig. 5a)
- With onset of the valley wind the structures move and smear the tracer. The formation of strong local maxima is inhibited (Fig. 5b + 6)
- Observations report a frequent occurrence of free convection close to the ground (Fig. 1)

Outlook

- Effect of realistic thermal forcing combined with the real topography on the formation of the organized structures (Fig. 7)
- Simulations of the moist atmosphere with cloud microphysics

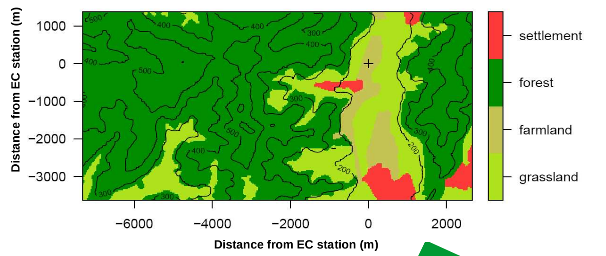

Fig. 7: ASTER GDEM topographical data by NASA and land use data based on CORINE Land Cover (CLC2006); Umweltbundesamt, DLR-DFD 2009.

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[2] Eigenmann et al., 2009. Generation of free convection due to changes of the local circulation system. Atmos. Chem. Phys., 9: 8587–8600.

[3] Prusa et al., 2008. EULAG, a computational model for multiscale flows. Comput. Fluids, 37: 1193–1207.