Near-ground free convection conditions and energy balance closure over complex terrain

Results from the surface turbulence network during COPS

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Experimental set-up

Sixteen surface energy balance and turbulence measurement stations were set up during the COPS (Convective and Orographically-induced Precipitation Study) field campaign[1] (Fig. 1). The campaign took place in south-western Germany and eastern France from 1 June to 31 August, 2007. It was organized into Intensive Observation Periods (IOPs), which aimed at observing specific convective situations with a synergy of meteorological instruments. The eddy-covariance (EC) technique was applied to measure fluxes of sensible (Q_H) and latent heat (Q_E).

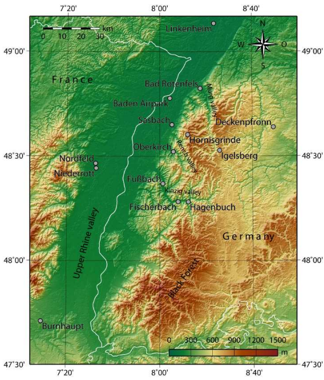

Fig. 1: Topographic map of the turbulence measuring sites during the COPS field campaign.

Energy balance closure

At the surface, the net radiation (Q_S^*) is transformed into Q_H and Q_E and into the ground heat flux (Q_G):

$$-Q_S^* = Q_H + Q_E + Q_G + res$$

The residuum (*res*) of the surface energy balance ranges between 17% and 36% at the COPS sites (Tab. 1). The main reason for the residuum of the surface energy balance is assumed to be the landscape heterogeneity causing advective and low-frequency flux components and stationary circulations, which transport the surplus of energy, but are not caught by single tower observations[2,3]. Large Aperture Scintillometer (LAS) measurements (Kipp & Zonen; path length: 2.8 km; height: 8 m) show in average up to 40 Wm^{-2} higher values of Q_H than the EC measurements (Fig. 2). This finding suggests that flux contributions of stationary circulations caused by surface heterogeneities are captured by the area-averaging measurement technique (LAS), but not by the fixed-point EC measurements.

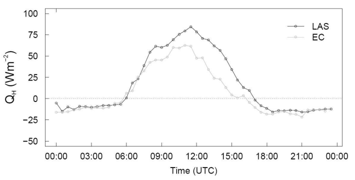

Fig. 2: Mean diurnal courses of Q_H from Large Aperture Scintillometer (LAS) and from eddy-covariance (EC) measurements at Nordfeld.

Station	residual	intercept	R^2	number of cases
Fußbach	21	5.2	0.86	3322
Fischerbach	30	-3.6	0.82	1705
Hagenbuch	17	11.6	0.89	3206
Hornisgrinde	24	30.3	0.86	1290
Baden Airpark	26	12.0	0.88	1929
Niederrott	36	11.0	0.87	106
Nordfeld	24	17.4	0.89	1073
Deckenpfronn	26	13.1	0.93	622

Tab. 1: Average residual, 1-b (%), intercept, a (Wm^{-2}), R^2, and the number of cases of the linear regression analysis $Q_H+Q_E = a+b \cdot (-Q_s^*-Q_G)$ at each station.

Moreover, *res* is found to increase from 56 Wm^{-2} to 101 Wm^{-2} with the onset of the oasis effect over maize during IOP 8b (Fig. 3). The strong latent cooling of the surface leads to more advective flux components directed towards the maize field which are not caught by the EC system. As a consequence, the residuum increases.

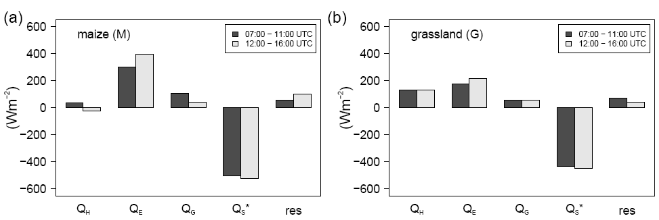

Fig. 3: Energy balance components at (a) Fußbach and (b) Hagenbuch for IOP 8b.

Near-ground free convection conditions: FCCs

FCCs occur during situations of high buoyancy fluxes which coincide with very low wind speeds. These situations can be detected with the EC measurements by calculating the stability parameter, ζ:

$$\zeta = \frac{z}{L} = -\frac{z \cdot \kappa \cdot g \cdot \left(\overline{w'\theta_v'}\right)_0}{\overline{\theta_v} \cdot u_*^3}$$

Buoyancy-driven turbulence then dominates over shear-driven turbulence near the ground, which results in an effective vertical transport mechanism of heat and moisture, enhanced in near-ground regions, into upper parts of the atmospheric boundary layer.

FCCs are found to occur in the morning hours during the reversal of the valley wind circulation system[4] in the valleys of the Black Forest (Fig. 4). During the period of wind direction change from down to up-valley winds the friction velocity (and also shear) is significantly reduced, while the buoyancy flux is already large enough (not shown).

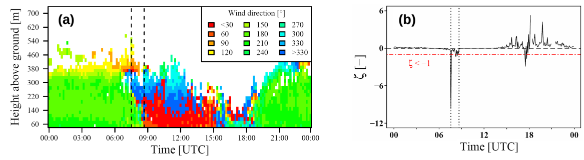

Fig. 4: (a) Sodargramm of the wind direction and (b) the stability parameter, ζ, at Fußbach during IOP 8b. The black dashed vertical lines indicate the period of FCCs.

Regarding the entire COPS measurement period FCCs are detected on about 25% of the days in the valleys of the Black Forest (Fig. 5). In the Upper Rhine valley FCCs are also detected during periods of low wind speeds. FCCs are rarely observed due to enhanced wind speeds at the mountain tops (Hornisgrinde, Igelsberg). Moreover, the land use is found to influence the occurrences of FCCs. During the oasis effect over maize after midday FCCs cannot be observed over this type of land use, while FCCs still occur over grassland (Fig. 6).

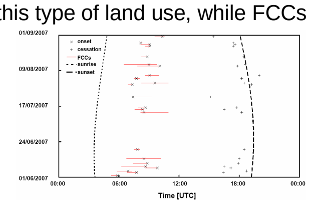

Fig. 5: Onset (x) and cessation (+) times of the up-valley wind direction and the periods of FCCs (—) at Fußbach.

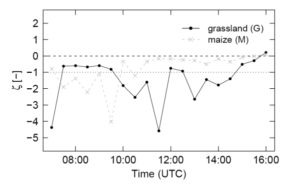

Fig. 6: Averaged stability parameter, ζ, over grassland and maize at the Upper Rhine valley sites during IOP 8b.

An analysis of the scales of turbulent motions using wavelet transform suggests that large-scale turbulence structures exist during FCCs (Fig. 7a). Moreover, the periods of FCCs can be related to periods of enhanced vertical wind speeds in the boundary layer (Fig 7b).

Conclusions

- ✓ Residuum due to advective flux components and stationary circulations
- ✓ FCCs occur during the reversal of the valley wind direction and depend on land use
- ✓ During FCCs: larger turbulence structures and enhanced vertical wind speeds

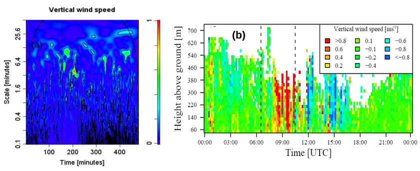

Fig. 7: (a) Normalized wavelet power spectrum of the vertical wind speed from 5:00-13:00 UTC (480 min) at Fußbach during IOP 8b. (b) Sodargramm of the vertical wind speed at Fußbach during IOP 15b. The period of FCCs is indicated by the black dashed vertical lines in both images.

References:
[1] Wulfmeyer et al.: The convective and orographically induced precipitation study. B. Am. Meteorol. Soc., 89, 1477–1486, 2008.
[2] Foken T. : The energy balance closure problem: An overview. Ecol. Appl., 18, 1351–1367, 2008.
[3] Foken et al.: Energy balance closure for the LITFASS-2003 experiment. Theor. Appl. Climatol., 101, 149–160, 2010.
[4] Eigenmann et al.: Generation of free convection due to changes of the local circulation system. Atmos. Chem. Phys., 9, 8587–8600, 2009.

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