J5.2 Near-ground free convection conditions and energy balance closure over complex terrain – results from the surface turbulence network during COPS

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1. INTRODUCTION

A network of surface energy balance and turbulent flux measurement stations was set up during the comprehensive COPS (Convective and Orographically-induced Precipitation Study) field campaign (Wulfmeyer et al., 2008). 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 observed specific convective situations with a synergy of meteorological instruments (Wulfmeyer et al., 2010). The aim of the COPS energy balance and turbulence network was to provide information about the temporal and spatial heterogeneity of high-quality turbulent flux values of sensible and latent heat for individual IOPs. This is important since under weak synoptic forcing spatial inhomogeneities of surface characteristics result in inhomogeneities of turbulent fluxes of heat and moisture into the atmospheric boundary layer (ABL) and hence may determine if and where convection is initiated (e.g. Kottmeier et al., 2008).

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2. EXPERIMENTAL SET-UP

The surface energy balance and turbulence network consisted of sixteen stations set up within the heterogeneous landscape of the COPS area (see Figure 1 and Table 1). The eddy-covariance (EC) measuring technique was applied in order to provide high-quality and continuous surface turbulent flux data of the friction velocity (u_*) as well as the sensible (Q_H) and latent heat (Q_E) flux. Additionally, soil and radiation measurements and standard surface meteorological data were recorded at most of the sites. Heterogeneity in the COPS region exists due to orography and due to a patchy land use structure. Therefore, measuring sites were sorted by their target land use types and by their location according to Table 1. The measurement height of all stations was in the range of 1.8 to 10 m, and the sampling frequency of the EC raw data amounted to 10, 20 or 32 Hz.

Table 1: Turbulence measuring sites of the COPS field campaign. The column ‘Code’ abbreviates the responsible institute (UBT: University of Bayreuth, IMK: Karlsruhe Institute of Technology, MF: Météo France, UV: University of Vienna, UBN: University of Bonn) followed by a running number. Also given are the coordinates (latitude, longitude), the altitude (meter a.s.l.) and the EC set-up (Sonic anemometer, Hygrometer) with CSAT3: sonic anemometer by Campbell Scientific Inc., USA; USA-1: sonic anemometer by METEK GmbH, Germany; Solent R1012: sonic anemometer by Gill Instruments Ltd., UK; Young 81000: sonic anemometer by R. M. Young Company, USA; Solent HS: sonic anemometer by Gill Instruments Ltd., UK; KH20: krypton hygrometer by Campbell Scientific Inc., USA; LI-7500: open-path CO_2/H_2O gas analyzer by LI-COR Biosciences, USA. The station UV1 used the Optical Energy Balance Measurement System OEBMS1 with a Scintillometer SLS20 system by Scintec AG, Germany instead of the EC measuring technique. The column ‘Land use’ indicates the target land use type: grassland (G), maize (M), strawberry (S), fallow (F) and wheat (W). The column ‘Location’ sorts the stations by their location: valley (V) sites, mountain top (T) sites, Upper Rhine (R) valley sites and sites in the lee (L) of the Black Forest (see also Figure 1).

Code	Site	Coordinates (lat., long.)	Alt.	Land use	Sonic anemometer	Hygrometer	Location
UBT1	Fußbach I [a]	48° 22′ 7.82″, 8° 1′ 21.17″	178	M	CSAT3	LI-7500	V
UBT2	Fußbach II	48° 22′ 0.88″, 8° 1′ 16.68″	180	F	USA-1	-	V
UBT3	Fischerbach [a]	48° 16′ 57.40″, 8° 7′ 56.28″	226	G	CSAT3	KH20	V
UBT4	Hagenbuch [a]	48° 16′ 54.59″, 8° 12′ 16.81″	245	G	CSAT3	LI-7500	V
IMK1	Hornisgrinde [a]	48° 36′ 12.95″, 8° 12′ 4.88″	1158	G	Solent R1012	LI-7500	T
IMK2	Baden Airpark [a]	48° 46′ 40.51″, 8° 4′ 25.20″	120	G	Solent R1012	LI-7500	R
IMK3	Linkenheim [a]	49° 8′ 9.24″, 8° 23′ 32.21″	96	W	Young 81000	-	R
IMK4	Sasbach	48° 39′ 4.20″, 8° 5′ 19.53″	133	G	Solent R1012	-	R
IMK5	Oberkirch	48° 31′ 19.15″, 8° 5′ 54.00″	203	S	Solent R1012	-	V
IMK6	Bad Rotenfels	48° 49′ 29.35″, 8° 17′ 30.55″	127	G	Solent R1012	-	V
IMK7	Igelsberg	48° 31′ 40.85″, 8° 25′ 50.35″	770	G	Solent R1012	-	T
IMK8	Burnhaupt	47° 42′ 33.52″, 7° 9′ 16.07″	299	M	Solent R1012	-	R
MF1	Niederrott [a]	48° 26′ 34.40″, 7° 32′ 38.36″	155	M	Solent HS	LI-7500	R
MF2	Nordfeld [a]	48° 27′ 58.22″, 7° 32′ 22.35″	156	M	Solent HS	LI-7500	R
UV1	Deckenpfronn [a,b]	48° 38′ 21.12″, 8° 49′ 7.86″	574	G	-	-	L
UBN1	Deckenpfronn [a]	48° 38′ 21.12″, 8° 49′ 7.86″	574	G	CSAT3	LI-7500	L

[a] additional measurement of radiation and soil components
[b] not included in the data analyses of Section 4 due to comparability reasons

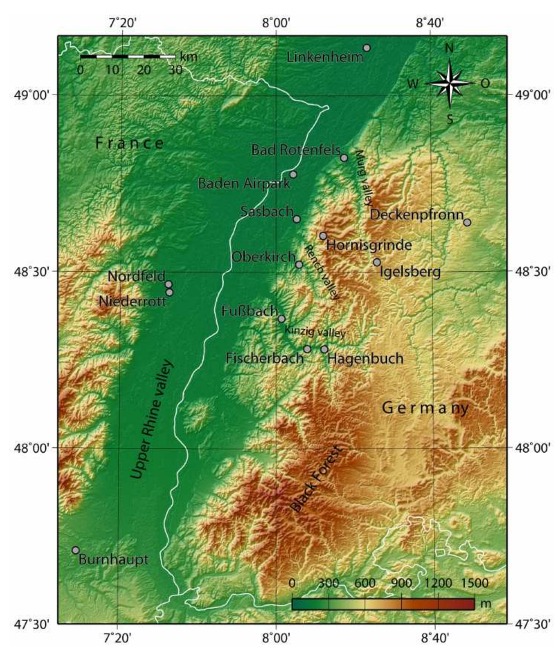

Figure 1: Topographic map of the turbulence measuring sites of the COPS field campaign (see also Table 1).

3. QUALITY CONTROL

All EC flux data were processed and quality-controlled with the software package TK2 developed by the Department of Micrometeorology, University of Bayreuth (Mauder and Foken, 2004), which includes flux corrections (Mauder et al., 2008) and quality tests. The tests consist of a stationarity test and a test on the fulfillment of integral turbulence characteristics and result in final quality flags ranging from 1 to 9 (Foken and Wichura, 1996; Foken et al., 2004).

Additionally, a footprint model was applied to all EC flux sites following the approach of Göckede et al. (2004, 2006) which allows the calculation of the flux contribution of the target land use type to the total flux measured.

Furthermore, a simple equation for the fetch-height relation according to Raabe (1983) and Jegede and Foken (1999) was applied to estimate the influence of internal boundary layers (IBL) on the EC flux measurements and flags were defined (0: below IBL, 1: transition range, 2: above IBL).

Table 2: Numbers of cases, in %, for each EC station which fulfill the applied data selection criteria: flux contribution from the target land use type (AOI = area of interest) to the total flux measured > 70%, flags of the internal boundary layer (IBL) evaluation procedure ≤ 1, quality flags of u_*, Q_H and Q_E ≤ 6. Also given is the data availability (DA), in %, after the data rejection according to the previously mentioned criteria for u_*, Q_H and Q_E.

Station code	AOI $> 70\%$	IBL flag ≤ 1	flag $u_* \leq 6$	flag $Q_H \leq 6$	flag $Q_E \leq 6$	DA u_*	DA Q_H	DA Q_E
UBT1	96	100	90	94	92	89	90	89
UBT2	74	93	91	87	-	65	61	-
UBT3	73	99	74	83	82	63	62	62
UBT4	100	100	80	90	88	80	90	88
IMK1	81	64	98	94	89	59	57	50
IMK2	86	95	96	88	86	82	74	72
IMK3	54	0	90	89	-	0	0	-
IMK4	71	29	92	84	-	26	24	-
IMK5	54	44	96	90	-	27	26	-
IMK6	59	13	96	85	-	12	12	-
IMK7	89	100	95	87	-	87	78	-
IMK8	67	81	98	87	-	66	60	-
MF1	10	22	93	90	88	10	9	9
MF2	100	100	84	90	88	84	90	87
UBN1	53	29	91	88	87	23	22	22

The resulting data availability at all EC stations after the application of the above-mentioned quality control steps is shown in Table 2.

4. EFFECT OF LAND USE AND LOCATION ON FLUX VALUES

The effect of land use and location of the sites (see Table 1) on surface turbulent fluxes is investigated in this chapter.

Flux differences between different land use types mainly occur due to altering surface characteristics such as albedo, emissivity, leaf are index (LAI), canopy height, structure and type (e.g. Munn, 1966; Oke, 1987). Different stages of vegetation development and mowing of grassland sites also lead to temporal variations of surface characteristics at a single location.

The turbulent fluxes at individual locations are also influenced by differences in altitude. Wenzel et al. (1997) gives theoretical considerations for the dependence of the Bowen ratio (*Bo*) on altitude. They showed that an increase or decrease of *Bo* with altitude depends on the air temperature and the relation of the temperature and humidity gradient. Observations of both an increase or decrease of *Bo* with altitude were made (e.g. Kessler, 1985).

Figure 2 shows the daily courses of Q_E and Q_H during IOP 8b (15 July 2007, weak synoptic forcing) averaged according to the different locations (V, T, R, L) and to the different target land use types (G, M) distinguished in Table 1. Only target land use types where both turbulent fluxes were measured are taken into account. In order to guarantee that the effect of land use and location is clearly separated, the daily courses averaged according to their location only consider grassland (G) sites. This type of land use is available at all locations (see Table 1). Conversely, for the daily courses averaged according to their target land use type only valley (V) sites are considered. However, it has to be mentioned that even the fluxes over the same type of land use are not comparable on a specific day due to different surface characteristics (e.g. the grassland sites in Fischerbach and Hagenbuch were mown on 14 July). Therefore, we will also show the daily courses of Q_E and Q_H in the same way as Figure 2 but averaged over the entire COPS period (Figure 3). Daily flux differences due to changing surface characteristics within the class of grassland sites (mainly due to mowing events) are minimized by averaging over the entire COPS period allowing the effect of orography to become visible.

Regarding Figure 2c and d the occurrence of the oasis effect (e.g. Stull, 1988) is obvious at the maize field during IOP 8b. The strong evapo-transpiration results in latent cooling near the ground, while the air above the surface is still warmer. This leads to negative values of Q_H already at around 12:00 UTC (see M in Figure 2d). The flux differences during IOP 8b between different locations (Figure 2a and b) are smaller than those which can be found on different land use types (Figure 2c and d). However, as mentioned above, the effect of orography on flux values is barely visible on any specific day as varying surface characteristics within the same class of land use type also have to be considered.

Therefore, Figure 3 also presents the daily courses of Q_E and Q_H averaged over the entire COPS period. Figure 3c and d show that in a long-term view, fluxes of Q_E and Q_H hardly differ between grassland and maize. As well, for the three month COPS period values of the Bowen ratio (Bo=Q_H /Q_E) can be determined, which would not make much sense for a single day like IOP 8b with the occurrence of the oasis effect.

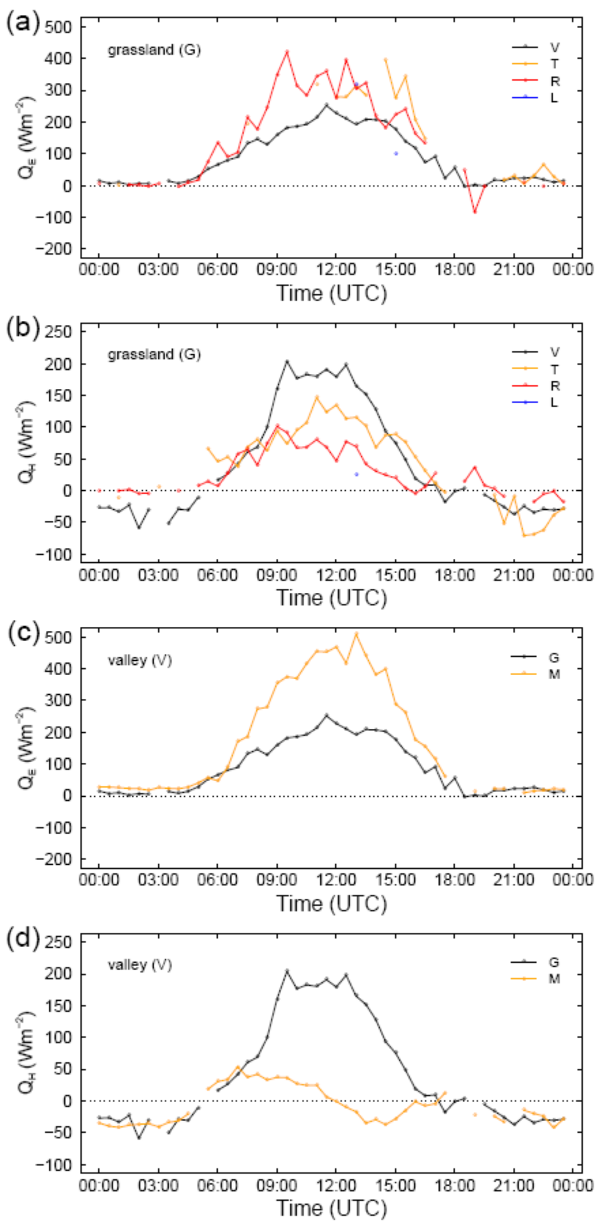

Figure 2: Surface turbulent fluxes of (a and c) latent, Q_E, and (b and d) sensible heat, Q_H, during IOP 8b. For the daily courses (a and b) averaged according to their location (V, T, R, L) only grassland (G) sites are considered. For the daily courses (c and d) averaged according to their target land use type (G, M) only valley (V) sites are taken into account.

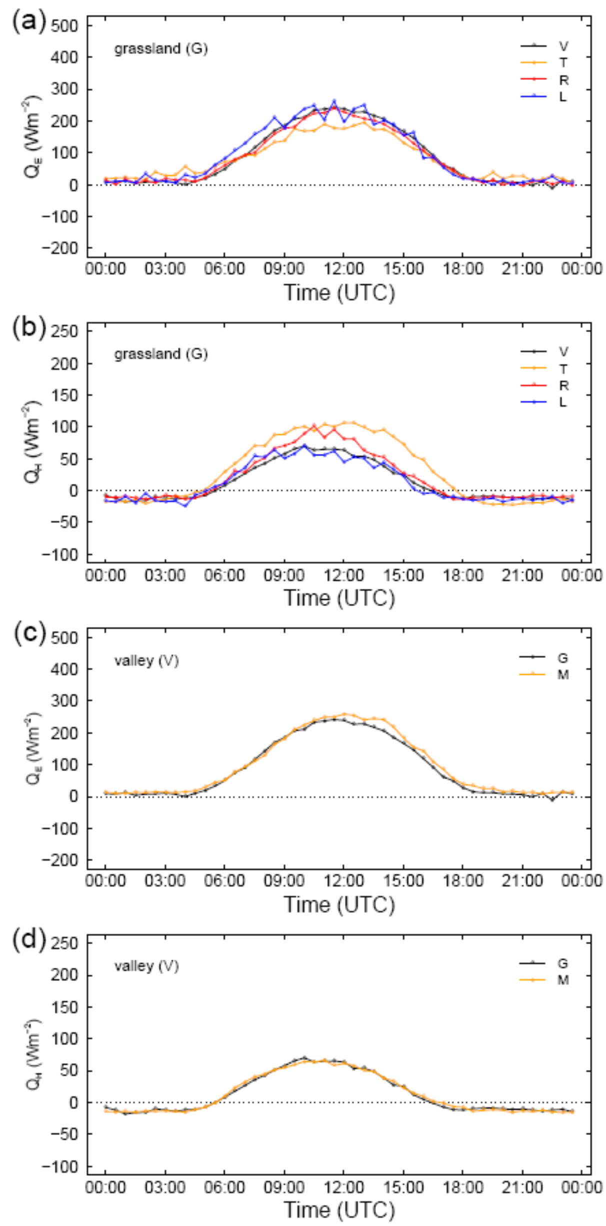

Figure 3: Same as Figure 2 but for the entire COPS measurement period.

The Bowen ratio at the grassland sites (Bo=0.26) is slightly higher than that for maize (Bo=0.23). This can be attributed to the enhanced evapotranspiration of maize during the growing period in June and July. For other land use types, however, totally different values of *Bo* can be expected. The effect of altitude on the daily courses of Q_E and Q_H can be seen in Figure 3a and b. The highest values of *Bo* can be found at the mountain top (T) sites (*Bo*=0.56) followed by the Upper Rhine (R) valley sites (*Bo*=0.36), the valley (V) sites (*Bo*=0.26) and the site in the lee (L) of the Black Forest (*Bo*=0.23). An increase of *Bo* from the Rhine valley to the top of the Black Forest was also found by Wenzel et al. (1997) within a one year dataset. In general, the observed values of *Bo* in our study are in good agreement with those found in previous studies within this area (see also Kalthoff et al., 1999).

To sum up, on a specific day the flux values of Q_E and Q_H are strongly determined by different types of land use and surface characteristics while the effect of altitude plays a minor role. The spatial inhomogeneity of the transformation of radiative energy at the surface into Q_E and Q_H can be strongly influenced by the heterogeneity of surface characteristics. Therefore, on convective days with weak synoptic forcing, land use characteristics may be decisive if and where convection is initiated. Hot spots of increased transport of heat or moisture into the ABL may form. However, it should be mentioned that slope and valley winds which frequently occur in the Black Forest (Kossmann and Fiedler, 2000; Kalthoff et al., 2000) as well as secondary circulations (Barthlott et al., 2006) may redistribute the surface-initiated heat and moisture distribution in the ABL and thus may modulate the local forcing of convection initiation by surface fluxes.

5. ENERGY BALANCE CLOSURE

A possible residuum, *res*, of the surface energy balance can be evaluated at all measuring sites of the turbulence network where additional radiation and soil measurements were carried out and both turbulent fluxes, Q_H and Q_E, were measured (see Table 1). At the surface, the net radiation, Q_S*, is transformed into Q_H and Q_E and into the ground heat flux, Q_G:

$$-Q_S^* = Q_H + Q_E + Q_G + res \qquad (1)$$

The storage of heat in the upper soil layer is included in this study within the value of Q_G and was calculated according to the “simple measurement” method after Liebethal and Foken (2007). Other storage terms (plants, air, etc.) and photosynthesis can be neglected as they are usually very small (Foken, 2008).

Regarding the entire COPS measurement period, the residuum of the surface energy balance ranges between 17% and 36% at the sites within the COPS region (see Table 3). This is comparable with the range reported by e.g. Mauder et al. (2006) for different agricultural sites (residuum: 20-30%) during the LITFASS-2003 experiment. The residuum of 36% at the station Niederrott (MF1) should be considered with care as only 106 half-hourly measurements were available for the determination of the residuum (see Table 3). A residuum of 10-30% is often found in micrometeorological field experiments (e.g. Foken et al., 2010; Oncley et al., 2007) and at FLUXNET sites (Wilson et al., 2002). An overview of the energy balance problem is given in e.g. Culf et al. (2004) and Foken (2008). The main reason for the residuum is assumed to be the landscape heterogeneity causing advective and low-frequency flux components (Foken et al., 2006) and secondary circulations (Inagaki et al., 2006), which are not caught by the standard eddy-covariance measurements and which transport the surplus of energy. The imbalance has important consequences for the use of surface turbulent flux data for ground truth and model validation. As the energy balance is, by definition, closed in most of the applied models, the residuum has to be considered when comparing modelled and measured flux values (e.g. Kracher et al., 2009). As a first guess it is a common procedure to distribute the residuum according to the Bowen ratio (Twine et al., 2000).

Some indications can also be found for the COPS measurements that the landscape heterogeneity is responsible for the non-closure of the surface energy balance.

First, at the station Nordfeld (see Figure 1), additional 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 (see Figure 4).

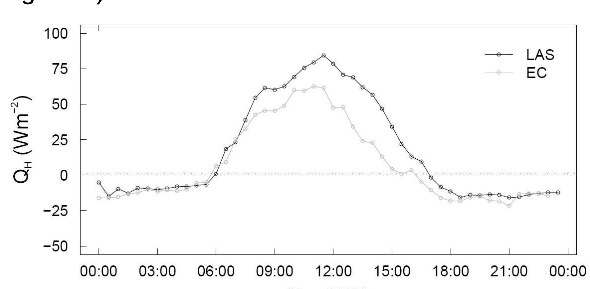

Figure 4: Mean diurnal courses of sensible heat, Q_H, from Large Aperture Scintillometer (LAS) and eddy-covariance (EC) measurements.

Table 3: Average residual, 1 – b (%), intercept, a (Wm^{-2}), R^2, and the number of available half-hourly measurements of the linear regression analyses Q_H+Q_E = a+b • ($-Q_s^*$ $-Q_G$) at each EC station with additional radiation and soil measurements (see Table 1). Also given are the sensor types for the radiation and soil heat flux measurements with CM24, CM14: pyranometer/albedometer by Kipp&Zonen, The Netherlands; DD-PIR: double direction precision infrared radiometer by Eppley Laboratory, Inc., USA; CNR1: net radiometer by Kipp&Zonen, The Netherlands; CG3: pyrgeometer by Kipp&Zonen, The Netherlands; HFP01SC, HFP01: heat flux plates by Hukseflux Thermal Sensors, The Netherlands; RIMCO HP3: heat flux plate by McVan Instruments, Australia; CN3: heat flux plate by Carter-Scott Design, Victoria, Australia.

Station code	Class	residual	intercept	R^2	number of cases	radiation sensor(s)	soil heat flux plate
UBT1	M,V	21	5.2	0.86	3322	CM24/DD-PIR	HFP01SC
UBT3	G,V	30	-3.6	0.82	1705	CNR1	RIMCO HP3
UBT4	G,V	17	11.6	0.89	3206	CNR1	HFP01SC
IMK1	G,T	24	30.3	0.86	1290	CM14/CG3	CN3
IMK2	G,R	26	12.0	0.88	1929	CM14/CG3	CN3
MF1	M,R	36	11.0	0.87	106	CNR1	HFP01
MF2	M,R	24	17.4	0.89	1073	CNR1	HFP01
UBN1	G,L	26	13.1	0.93	622	CNR1	HFP01

This finding suggests that flux contributions of secondary circulations caused by surface heterogeneities are captured by the area-averaging measurement technique (LAS), but not by the fixed-point EC measurements. A detailed comparison of EC and area-averaging measurement techniques (scintillometers, aircraft) was e.g. done by Foken et al. (2010).

Secondly, the residuum, *res*, is found to increase with the onset of the oasis effect (see also Section 4 and Figure 2c and d for the description of the oasis effect). Exemplarily, the increase of *res* during the oasis effect on a maize field (Fußbach I) compared to a grassland site (Hagenbuch) is shown in Figure 5 for IOP 8b. For two time periods of equal length before (07:00 - 11:00 UTC) and after (12:00 - 16:00 UTC) midday (maximum net radiation at 11:30 UTC) average values of Q_H, Q_E, Q_G, Q_s* and *res* are calculated. The two time periods appear to be comparable, as the average value of Q_s*, available for the transformation into Q_H, Q_E and Q_G, only differs by about 3% between the two time periods at both sites. The oasis effect is clearly visible at the maize field, as it shows positive values of Q_H before midday and negative values after midday. At the grassland site, however, the same positive value of Q_H during both time periods is found and no oasis effect occurs. The difference between the values of Q_E before and after midday is 2.5 times higher at the maize field (93 Wm^{-2}) than at the grassland site (37 Wm^{-2}), indicating enhanced evapotranspiration. The residuum, *res*, can be seen to increase from 56 Wm^{-2} before midday to 101 Wm^{-2} after midday at the maize field. This contrasts with the grassland site, which shows 38% lower values of *res* after midday (44 Wm^{-2}) when compared to the period before midday (71 Wm^{-2}).

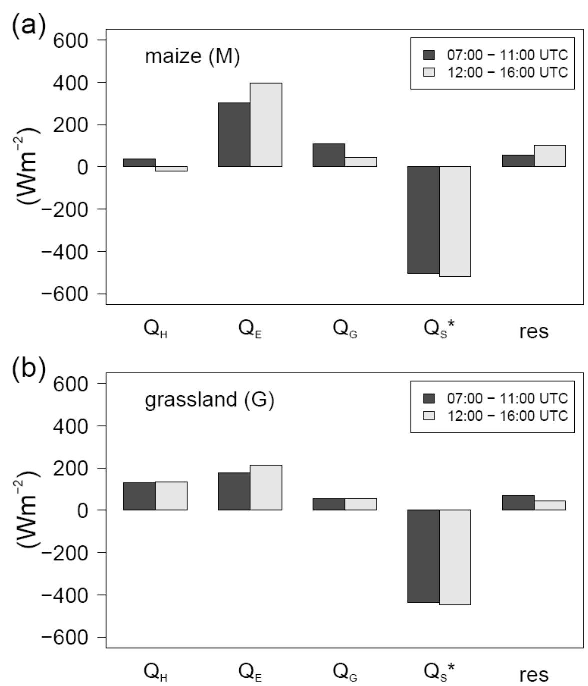

Figure 5: Sensible, Q_H, and latent heat flux, Q_E, ground heat flux, Q_G, net radiation, Q_s*, and the residuum, *res*, of the surface energy balance at the stations (a) Fußbach I and (b) Hagenbuch (see Table 1) for IOP 8b. Average values for the time periods from 07:00 to 11:00 UTC (black) and from 12:00 to 16:00 UTC (grey) are given. The target land use types at Fußbach I and Hagenbuch are maize (M) and grassland (G), respectively.

The enhanced residuum after midday at the maize field may be explained by an intensification of advection during the oasis effect. The strong latent cooling of the surface leads to more advective flux components directed towards the target land use type. As these advective flux components are not caught by the EC system, the residuum increases. Following the idea of Foken (2008) and Foken et al. (2010), energy transported by advection over a heterogeneous landscape can also be transferred to energy within larger eddies, not seen by the EC system, at significant heterogeneities and roughness changes of the land surface. The higher residuum before midday at the grassland site may be explained by enhanced advective flux components due to stronger temperature gradients between adjacent land use types and the grassland in the morning hours which are reduced in the time period after midday.

In the future, further investigations on flux contributions from secondary circulations and advection will be made with the help of a large-eddy simulation (LES) model.

6. NEAR-GROUND FREE CONVECTION CONDITIONS

The present study also aims at extending the investigation of the occurrences of near-ground free convection conditions (FCCs) of Eigenmann et al. (2009) in the Kinzig valley of the Black Forest to all sites in the COPS region. FCCs occur during situations of high buoyancy fluxes which coincide with very low wind speeds. 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 ABL. As the dimensions of the target land use types of most of the COPS sites are large enough (> 250 m) so that the surface fluxes are able to influence the structure of the ABL (Shen and Leclerc, 1995), the detected FCCs may have a strong impact on ABL characteristics, and hence on the pre-convective environment in the COPS region. An impact of FCCs on vertical wind speeds (Eigenmann et al., 2009) and on ozone concentrations (Mayer et al., 2008) in the ABL was recently demonstrated.

FCCs can be detected with the EC measurements by calculating the stability parameter, ζ, which is the quotient of the measurement height, z, and the Obukhov length, L:

$$\zeta = \frac{z}{L} = -\frac{z \cdot \kappa \cdot g \cdot (\overline{w'\theta_v'})_0}{\overline{\theta_v} \cdot u_*^3} \qquad (2)$$

Here, u_* is the friction velocity, g the acceleration due to gravity, $\overline{\theta_v}$ the mean virtual potential temperature and $(\overline{w'\theta_v'})_0$ the buoyancy flux at the surface. The von-Kármán constant amounts to κ = 0.4. FCCs occur for $\zeta < -1$, as buoyancy-driven turbulence then dominates over shear-driven turbulence near the ground (e.g. Stull, 1988; see also Eigenmann et al., 2009).

In the study of Eigenmann et al. (2009), FCCs were found in the Kinzig valley (Black Forest) in the morning hours during the reversal of the valley wind circulation system (see Figure 6). 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). According to Equation 2 these are the situations where FCCs can be detected.

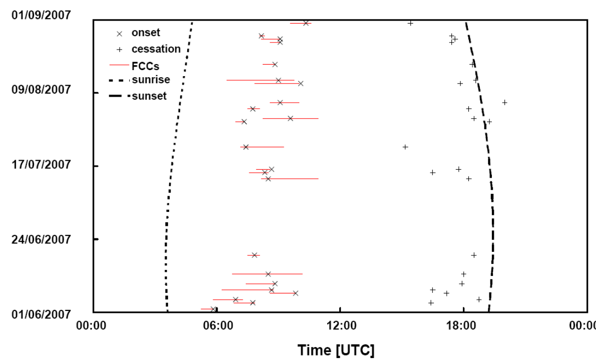

Figure 6: Onset (x) and cessation (+) times of the up-valley wind direction and the corresponding periods of FCCs (—) in the morning hours at Fußbach I in the Kinzig valley (see Figure 1) during the entire COPS measurement period. Also depicted are the times of sunrise and sunset (Eigenmann et al., 2009).

In the Rench and Murg valley (see Figure 1), FCCs are also observed during the thermally-induced reversal of the valley wind system in the morning hours. In the Upper Rhine valley FCCs are detected during periods of low wind speeds which presumably can be attributed to local circulations which break down and re-establish in the course of the day. FCCs are seldom observed at the mountain top sites (Hornisgrinde, Igelsberg; see Table 1) due to enhanced wind speeds.

Moreover, the land use is found to influence the occurrence of FCCs in the Upper Rhine valley. During the oasis effect over maize (see Section 4 and 5), which leads to negative values of Q_H after midday, no FCCs can be observed over this type of land use. This can be seen in Figure 7, which shows the daily course of ζ from 07:00 to 16:00 UTC during IOP 8b averaged over the maize fields and over the grassland sites in the Upper Rhine valley. It is obvious that ζ is occasionally lower than –1 for both land use types in the morning hours until 10:30 UTC. However, from 11:00 to 16:00 UTC ζ only reaches –1 over the grassland sites where the oasis effect does not occur. Consequently, a strong influence of the target land use type on the occurrence of FCCs is evident.

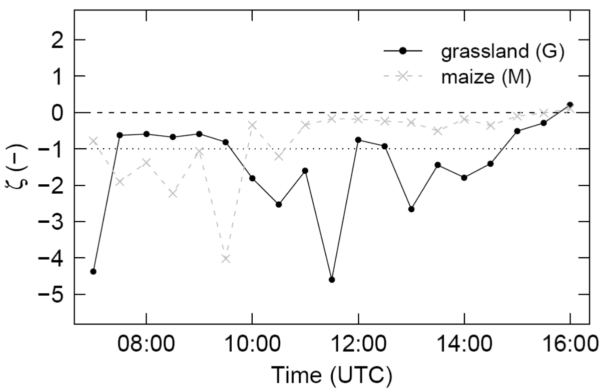

Figure 7: Stability parameter, ζ, from 07:00 to 16:00 UTC during IOP 8b averaged over the maize (M) fields and over the grassland (G) sites in the Upper Rhine (R) valley (see Table 1).

7. CONCLUSIONS

A comprehensive data set of surface turbulent fluxes was collected during the COPS experiment in summer 2007. Much effort was put on a uniform data processing and quality control.

An investigation of the effect of land use and orography on fluxes of Q_H and Q_E shows that on a specific day with weak synoptic forcing (IOP 8b), flux differences of Q_H and Q_E between different land use types but also between sites of the same type of land use are found. For the latter, different surface characteristics, e.g. due to mowing of the grassland sites or different stages of vegetation development, are relevant. Flux differences of Q_H and Q_E between individual sites due to different surface characteristics are often larger than the flux differences with changing altitude. Therefore, the spatial distribution of land use characteristics and thus the spatial inhomogeneity of turbulent fluxes of heat and moisture into the ABL may be strongly decisive if and where convection is initiated on a specific day with weak synoptic forcing. A modulation of the atmospheric temperature and moisture fields by thermally-driven wind systems in the complex terrain of the Black Forest has to be considered. Averaging the fluxes over the entire COPS period minimizes temporal flux differences due to mowing and vegetation development within the class of grassland sites allowing the effect of altitude to become visible. Higher Bowen ratios are found at the top of the mountains and lower values in the valleys.

The oasis effect which frequently occurs on the highly evapotranspirating maize fields is found to influence the non-closure of the surface energy balance. With the onset of the oasis effect shortly after midday the residuum on a certain maize field increases from 56 Wm^{-2} to 101 Wm^{-2} during IOP 8b. Enhanced advective flux components during the oasis effect not caught by the EC measuring system are assumed to be the main reason for the increase of the residuum. Another indication that the landscape heterogeneity is mainly responsible for the non-closure of the energy balance is found by comparing EC fluxes of Q_H with area-averaged scintillometer values. The latter are up to 40 Wm^{-2} higher presumably due to additional measured flux contributions of secondary circulations not seen by the fixed-point EC measurements. Further investigations with a large-eddy simulation (LES) model will be made in the future.

Near-ground free convection conditions (FCCs) are found at all sites of the Rench, Murg and Kinzig valley in the Black Forest due to low wind speeds during the reversal of the valley wind system from down to up-valley winds in the morning hours. FCCs seldom occur on the mountain top sites of the Black Forest. During the oasis effect at the maize fields in the Upper Rhine valley no FCCs can be observed.

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