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A discussion on the paper “Multi-scale sensible heat fluxes in the suburban environment from large-aperture scintillometry and eddy covariance”

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Date:02/10/2015

Framework

- Introduction
- Theory
- Methodology
- Results&Discussion
- Conclusions

Introduction

- Understanding the interactions between the land surface and the atmosphere is central to developing our predictive power in terms of weather forecasting, air quality events, thermal comfort, flood risk and tools for urban design.
- The surface energy balance has been closely linked to land use and land cover.This has been achieved largely through eddy-covariance (EC) measurements at multiple sites in a city.
- Scintillometry provides a means of estimating fluxes at a much larger scale than eddy covariance.Furthermore,unlike point measurements,direct access to the measurement area is not required.

- Measuring sufficiently high above the surface ensures the influences of surface heterogeneity are well-blended at the height of the measurement and reliable fluxes can be obtained.
- This study uses large-aperture scintillometry.The much larger sampling volume enables robust retrieval of turbulence statistics.Eddy-covariance measurements are analyzed together with results from large-aperture scintillometers installed on 2.8-km and 5.5-km paths in Swindon, UK.
- The goal of the work presented here is to investigate the influence of the surface on sensible heat fluxes across different spatial and temporal scales in the suburban environment.
- The contributions of different land-cover classes are related to the observations at each scale by applying a footprint model.

Theory

Scintillometers measure the intensity of an electromagnetic beam after propagation through the turbulent atmosphere. Changes in beam intensity are related to the strength of turbulence and can be converted to the structure parameter of the refractive index of air $C^2{}_n$ .This is the linear relation between path averaged $C^2{}_n$ and the variance of the logarithm of light intensity (I):

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$$\left\langle C^2{}_n \right\rangle = 4.48\sigma^2{}_{\ln I} \times D^{-7/3} \times L^{-3}$$

D is the diameter of beam,L is the length of path.

After obtaining $C^2{}_n$ from the instrument,these refractive index fluctuations must be related to temperature fluctuations:

$$C^2{}_T \approx \frac{T^2}{A_T{}^2} C^2{}_n$$

Where $C^2{}_T$ is the temperature structure parameter and $A^2{}_T$ is the structure parameter coefficient that depends on temperature (T), pressure (P) and weakly on humidity.

And the equation must be:

$$C^2{}_T = C^2{}_n \left(\frac{T^2}{-7.87 \times 10^{-7} P} \right)^2 \left(1 + \frac{0.03}{\beta} \right)$$

Where β is the Bowen ratio which is not implemented here for correction because it is not known a priori.

The conversion from structure parameters to fluxes entails iteration of similarity functions, $f_{MO}(\zeta)$,using Monin-Obukhov similarity theory (MOST) and the effective height of the scintillometer, z_{ef},the wind speed,U(which is measured at height z_U),displacement height, z_d ,and aerodynamic roughness length, z_0 .Commonly used forms of the similarity functions are:

$$f_{MO}(\zeta) = c_{T1}(1 - c_{T2}\zeta)^{-2/3}$$

for unstable conditions and

$$f_{MO}(\zeta) = c_{T1}\left(1 + c_{T3}\zeta^{2/3}\right)$$

for stable condition.

The stability variable ζ is given by $\left(z_m - z_d\right)/L_{Ob}$ or $\left(z_{ef}\right)/L_{Ob}$ where is the Obukhov length and z_m is the measurement height, z_{ef} has been calculated incorporating the displacement height. Different values of the empirically derived constants c_{T1-3} are used in the literature.

These similarity functions relate the temperature structure parameter to the temperature scaling variable $\left(T_*\right)$.

$$T_* = \left\{ \frac{C^2{}_T \left(z_m - z_d\right)^{2/3}}{f_{MO}\left(\zeta\right)} \right\}^{1/2}$$

The friction velocity, u_*, is estimated from the measured wind speed assuming a wind-profile adjusted for stability and a value of the roughness length. The wind-profile equation is solved iteratively with:

$$L_{Ob} = \frac{u_*{}^2 T}{g k_v T_*}$$

where g is the acceleration due to gravity and k_v is the von Kármán constant (0.4). Finally, the sensible heat flux is obtained using：

$$Q_H = -\rho c_p u_* T_*$$

where ρ is the density of air and c_p is the specific heat capacity at constant pressure.

Methodology

※ Site Description and Experimental Details

This study took place in Swindon (population 175,000),situated 120 km west of London.

Typical of the UK suburban landscape,Swindon consists mainly of residential areas with houses of varying ages extending outwards from the town centre, interspersed with green space, small parades of shops and institutional buildings. Larger industrial and commercial zones are mostly situated towards the edges of the development. The town centre comprises commercial areas, with some pedestrianized streets, offices, public buildings and transport hubs.

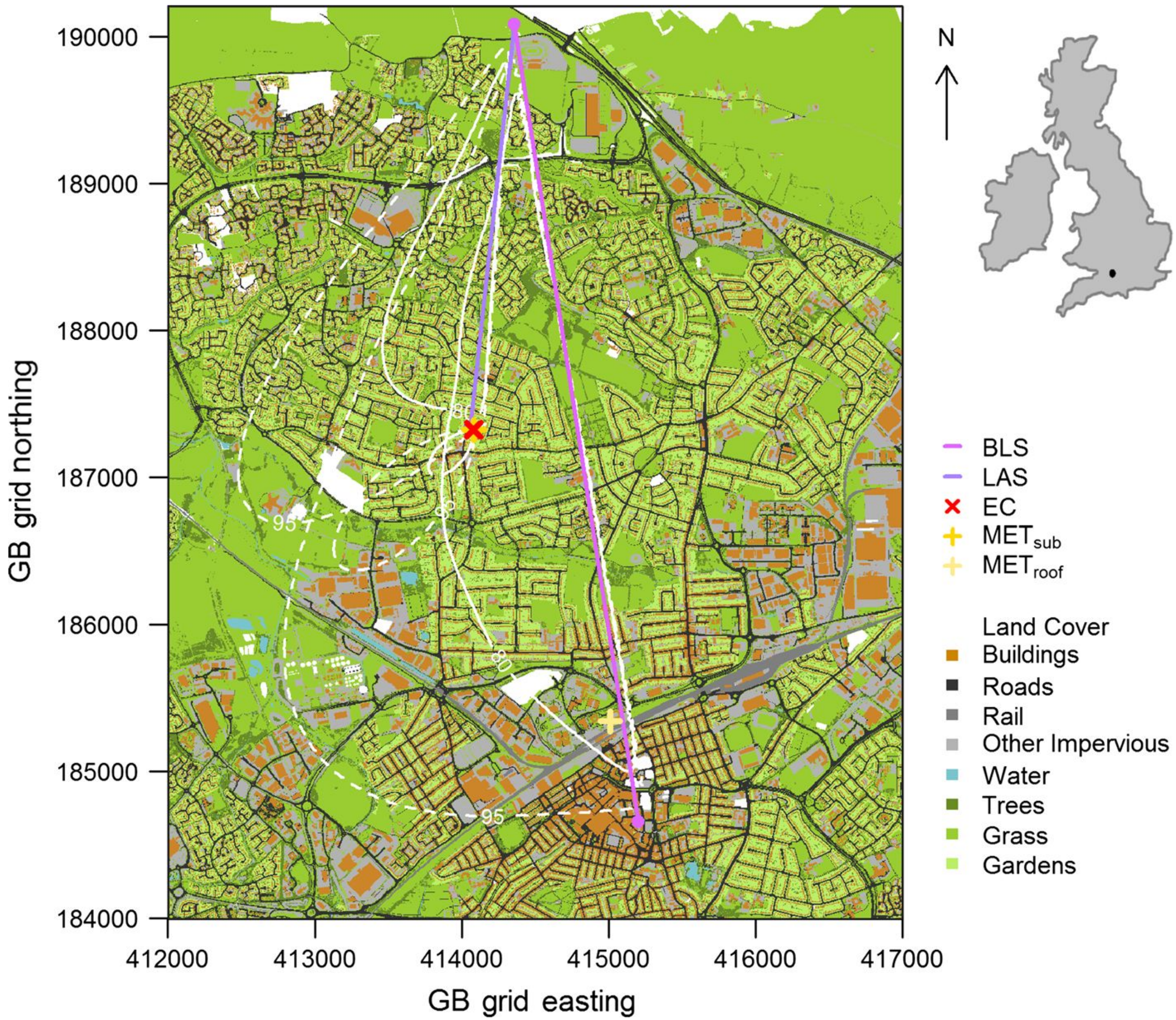

Fig. 1 Land cover surrounding the two scintillometer paths (BLS and LAS), eddy-covariance station (EC) and two meteorological stations (METsub and METroof). Example footprints for typical atmospheric conditions are indicated by the cumulative source area: the region within the solid (dashed) line contributes 80%(95 %) to the measured flux.

Instrument

Instrument	Path Location	Path length	Wavelength	Height
BLS900	between the town centre and the rural fringe at the northern edge of the settlement	5.5KM	880NM	27.9m/26.2m
LAS150	over relatively recently developed suburbs (in the last 20 years or so) 3–5 km north of the town centre	2.8KM	880NM	26.6m/1.7m
EC	approximately 3 km north of the town centre			12.5m
MET_{SUB}				10.1m
MET_{ROOF}				1.1m above roof

Table 1 Details of the instrumental set-up

Instrumentation	Dates	Location	z_m (m)	z_{ef} (m)	Path length (m)	Bearing (°)	z_0 (m)	z_d (m)
BLS	12 Jan 2011– 31 Dec 2012	51°36′33.9″N 1°47′38.6″W (Tx) 51°33′38.1″N 1°46′55.3″W (Rx)	44.3	45.0	5492	170	0.7	4.9
LAS	22 Jun 2011– 31 Dec 2012	51°36′33.9″N 1° 47′38.6″W (Tx) 51° 35′4.9″N 1° 47′53.0″W (Rx)	32.4	35.9	2761	184	0.6	4.5
EC	09 May 2011– 31 Dec 2012	51° 35′4.6″N 1° 47′53.2″W	12.5	–	–	–	0.5	3.5
MET_{sub}	09 May 2011– 31 Dec 2012	51° 35′4.6″N 1° 47′53.2″W	10.6 (WXT) 10.1 (NR01)	–	–	–	0.5	3.5
MET_{roof} [a]	01 Jan 2011– 31 Dec 2012	51° 34′0.3″N 1° 47′5.3″W	2.0 (WXT) 1.1 (NR01)	–	–	–	–	–

Tx denotes transmitter, Rx receiver. For the scintillometers the mean heights of the beams above the surface (z_m) and the effective measurement heights (z_{ef}) are given. The date range refers to the data used here.
[a] For MET_{roof} the heights above the roof surface are given; z_0 and z_d were not calculated for this site

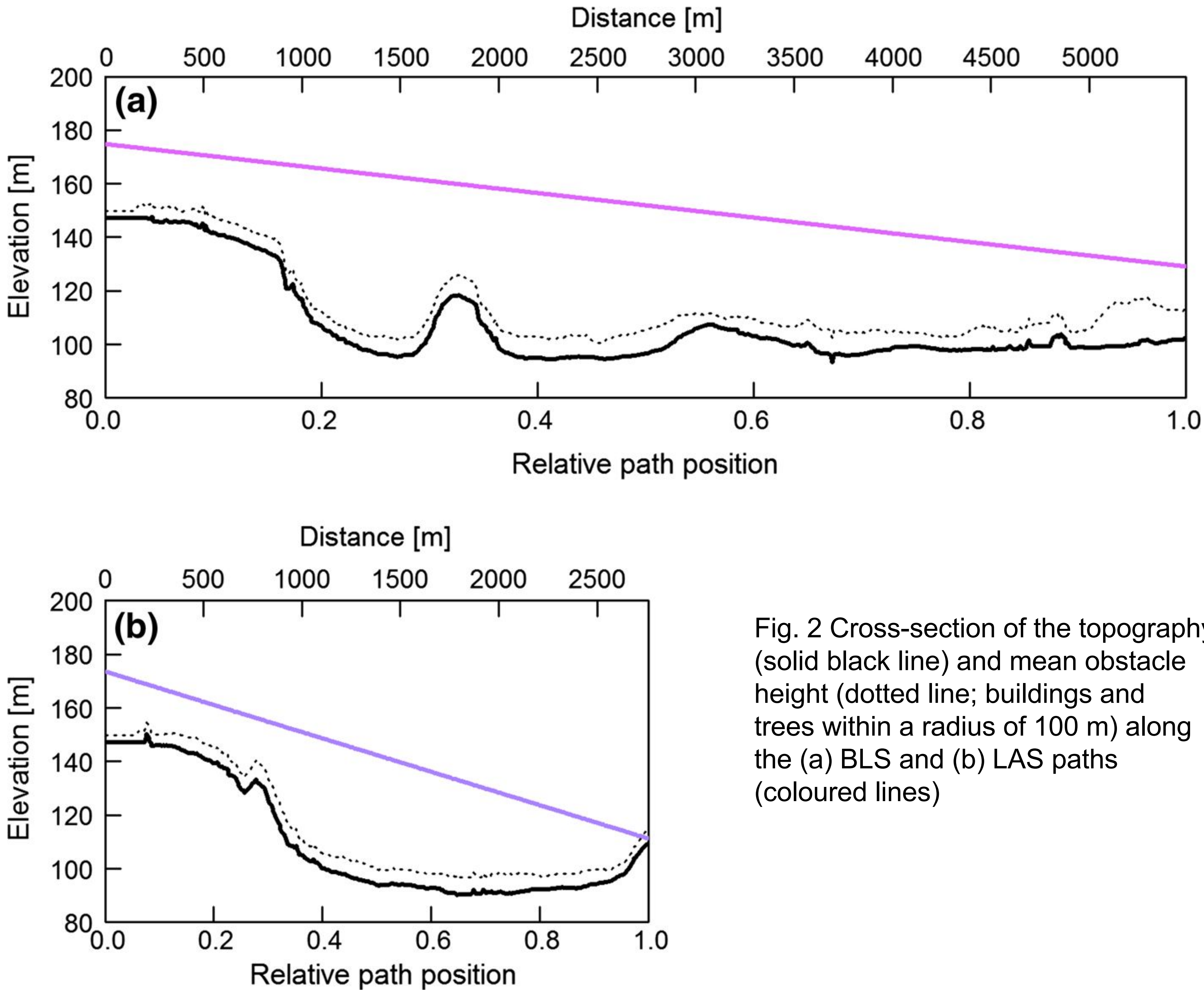

Fig. 2 Cross-section of the topography (solid black line) and mean obstacle height (dotted line; buildings and trees within a radius of 100 m) along the (a) BLS and (b) LAS paths (coloured lines)

※ The reason why the Bowen ratio isn't implemented here

① An initial estimate of the Bowen ratio is recommended to account for the contribution of humidity and combined temperature-humidity fluctuations to optical $C^2{}_n$.

② However, estimating the available energy is challenging in urban areas as the net storage heat flux (ΔQ_S) plays a more significant role in the energy balance than for most rural areas,yet it is very difficult to measure directly.

③ Given the uncertainty in estimating the available energy and the lack of representative EC data across the whole study area, the Bowen ratio correction has not been applied for the results presented here.

④ For the BLS, the $C^2{}_T$ values here were found to be within around 6 % of the values calculated incorporating data from the millimetre-wave scintillometer which do not require a Bowen ratio correction.

Results&Discussion

※ Assessment of Seasonal Cycles and Annual Variations

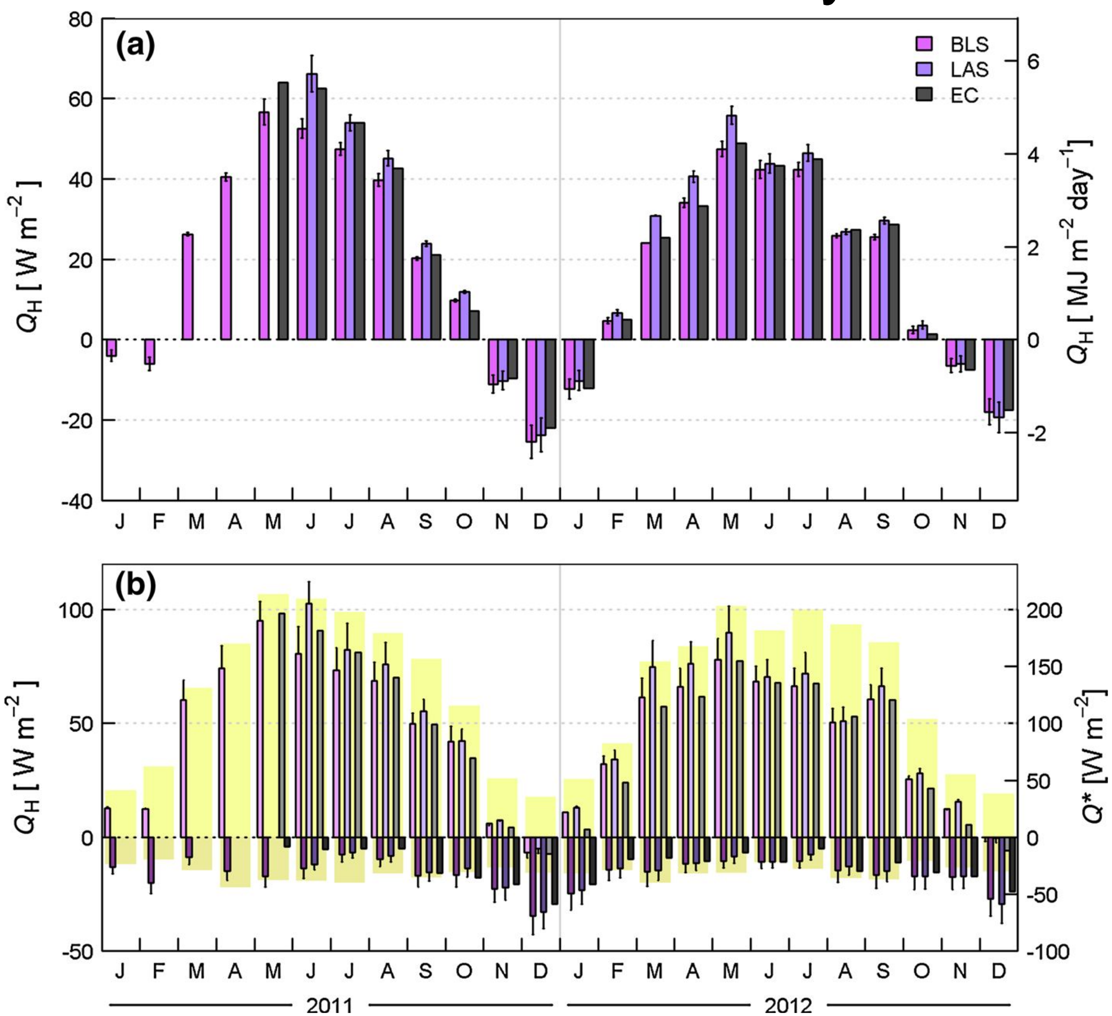

Fig. 3 Monthly mean sensible heat-flux observations from scintillometry (BLS and LAS) and eddy covariance (EC) for all available data (a) over 24 h and (b) separated into day (K↓ > 5W m− 2) and night. Partial months in relation to the installation dates (Table 1) are January 2011 (BLS), May 2011 (EC) and June 2011 (LAS, note only 4 days of data due to an instrument fault). Error bars indicate the impact on the scintillometer fluxes of altering the input roughness length by ± 0.2 m (a) or using the similarity functions of De Bruin et al. (1993)(b). The net radiation is indicated by shading (b, right-hand axis)

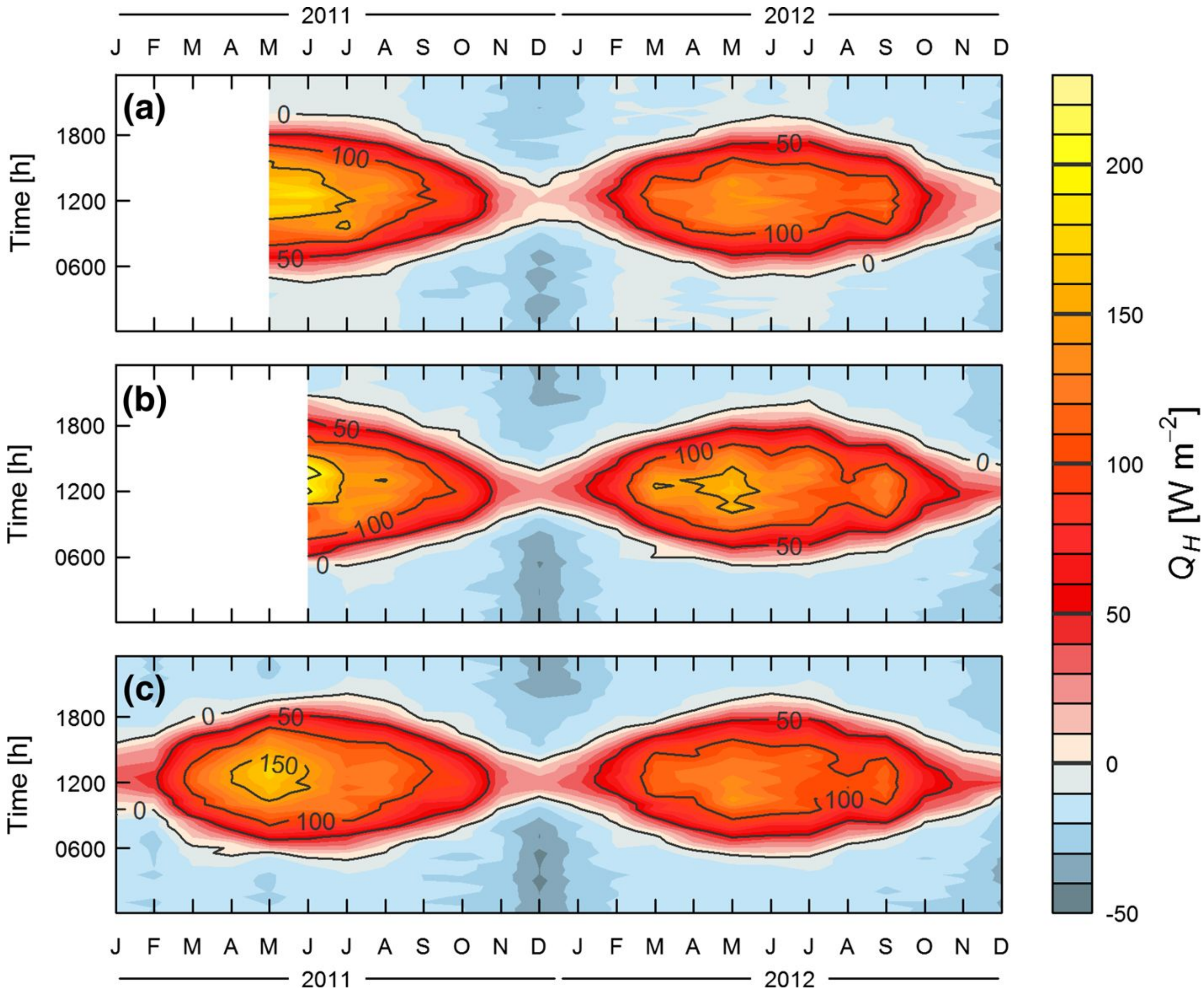

Fig. 4 Temporal variation of monthly mean diurnal cycles of sensible heat fluxes from (a) eddy covariance, (b) the LAS and (c) the BLS

*The Uncertainty:

a.introduced by the choice of similarity function is a major limitation of the scintillometry technique across all environments.

b.the uncertainty in z_0 is large as z_0 can vary spatially, with time of day and stability,and with shape,density and arrangement of surface structure.(±0.2 m is ±7 % in Fig 3a)But not significant.

c.Allowing a±5% uncertainty in z_{ef} (±2.25m) affects the fluxes by±3%.

※ Short-Term Variability

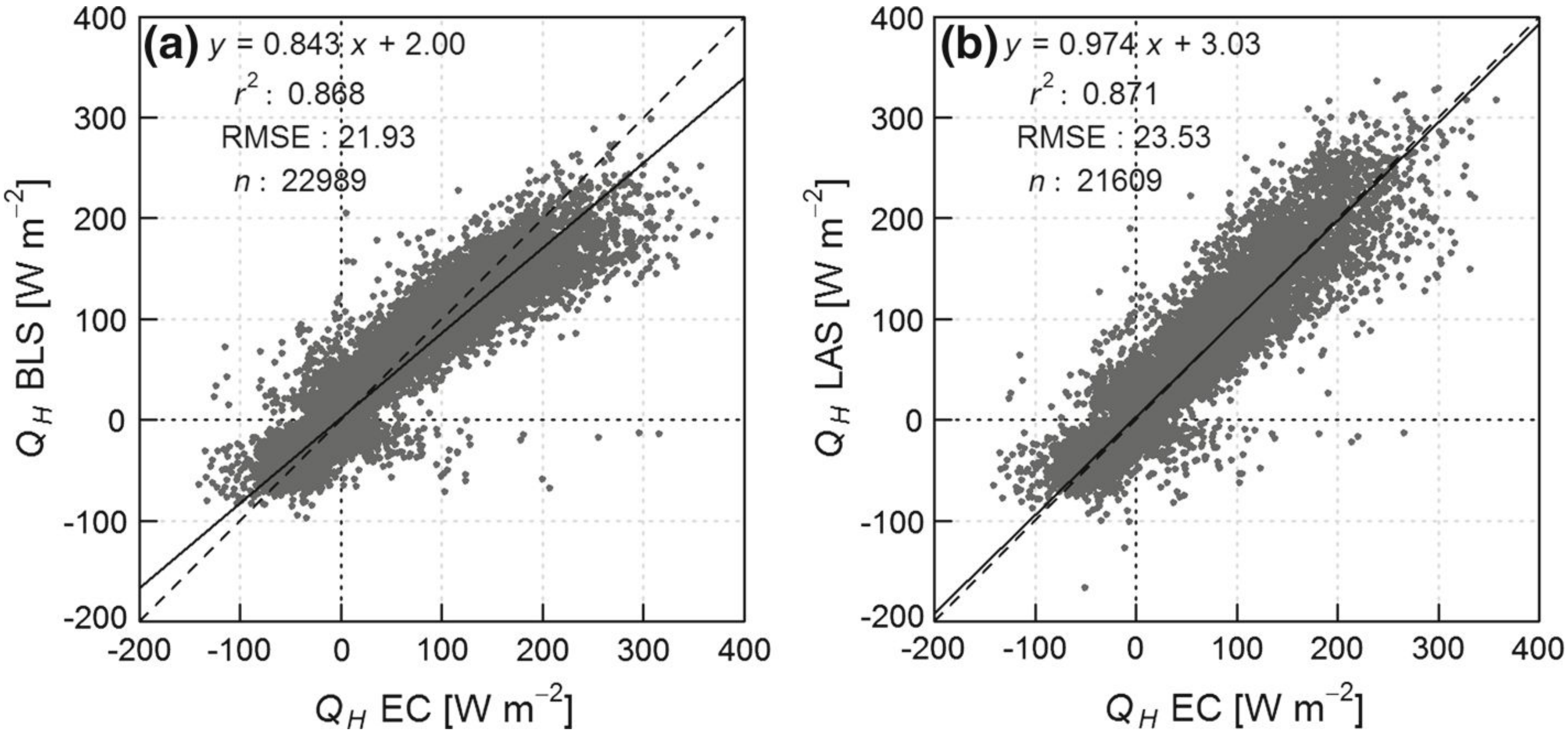

Fig. 5 Comparison of 30-min sensible heat fluxes derived from the scintillometers (BLS, LAS) and eddy covariance (EC) for all available data

① reasonably good agreement between the measurement techniques and across the scales with strong correlation ($r^2 \approx 0.87$).

② the BLS tends to give lower Q_H than EC particularly towards large values of Q_H.The BLS data distribution appears more curved at high Q_{H_EC} which may partly be explained by the difference between EC mast and BLS.

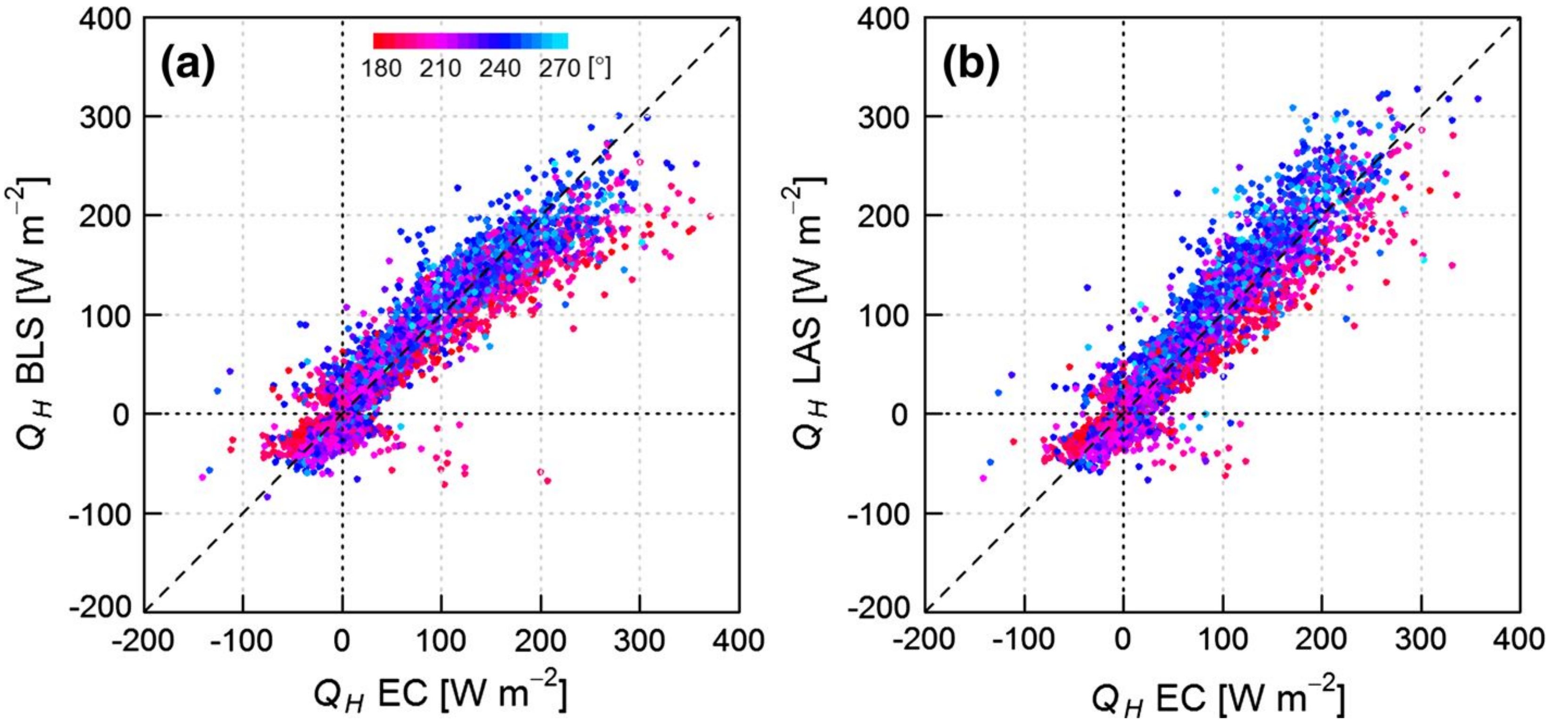

Fig. 6 As for Fig. 5 but for summertime (May–September 2011–2012) data only and for wind directions180–270◦ (colours)

※ The reason why the agreement between the datasets is poorer at night and during transition time.

① the limitations in instrument performance are reached when fluxes are small.

② the time of stability transition may vary with location, even along the scintillometer paths.(different signs)

③ The stability may also change more than twice per day,which would mean the scintillometer data are processed assuming the wrong stability regime.

④ The corrections for the influence of humidity fluctuations on $C^2{}_T$ and L_{Ob} are generally larger at these times. (when β is small)

⑤ Near-neutral to stable atmospheric conditions do not always satisfy the assumptions required for the measurement theory.

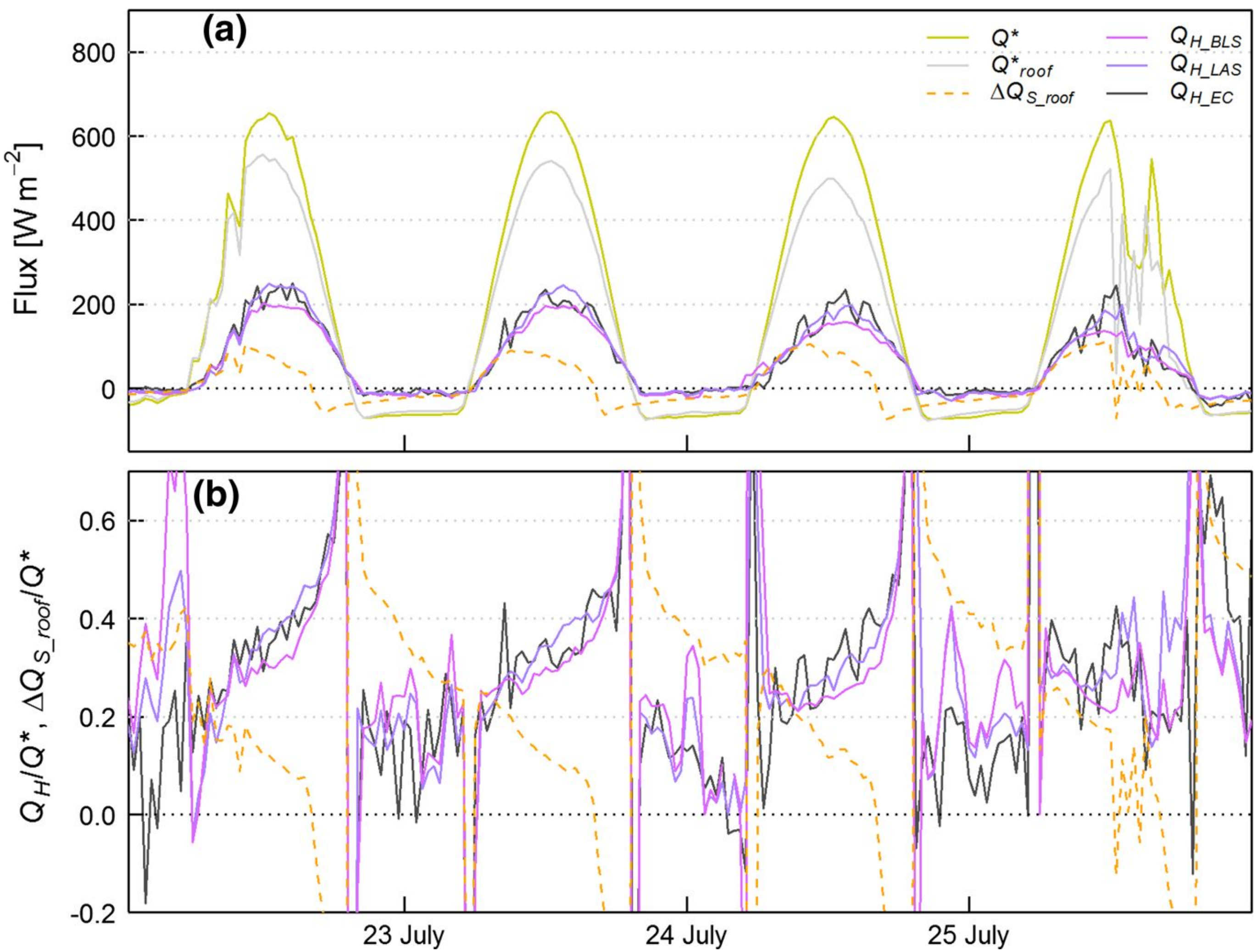

Fig. 7 Diurnal variation in sensible heat fluxes (Q_H) and net all-wave radiation (Q^*) for four days in July 2012. Data from a heat-flux plate installed on a rooftop, representing one component of the storage heat flux (ΔQ_{S_roof}) and a second radiometer located on the rooftop (Q^*_{roof}) are also shown. In (b) the fluxes have been normalized by the net all-wave radiation measured at the EC site (Q^*)

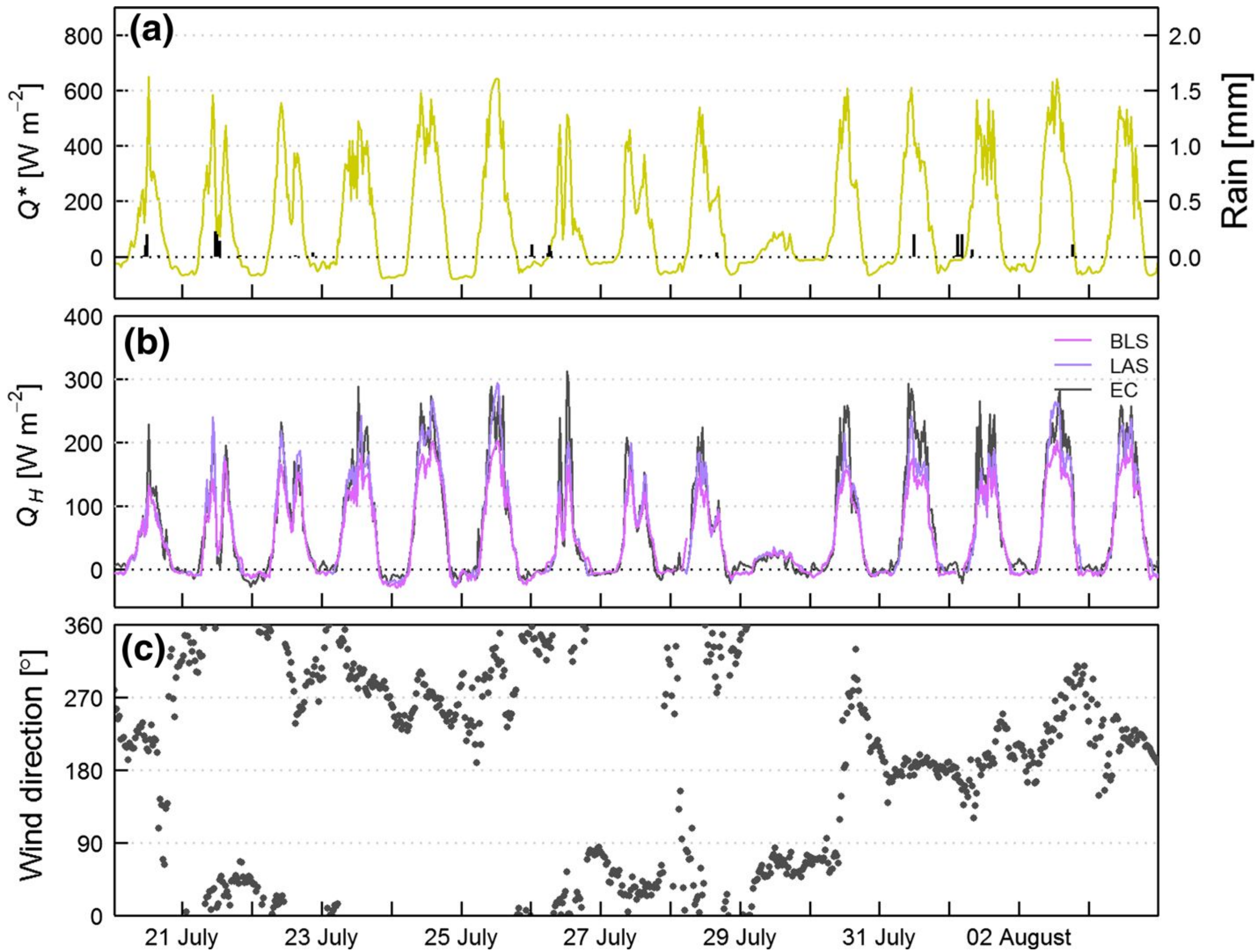

Fig. 8 Sensible heat fluxes from EC and the scintillometers alongside net all-wave radiation from the EC site(Q^*), rainfall and wind direction (also measured at the EC site) for two weeks in July–August 2011.

※ Influence of the Surface

① Towards the end of the case study in Fig. 8 (30 July–1 August 2011), Q_{H_EC} peaks at larger values than either of the scintillometers, whilst Q_{H_LAS} is generally largest near the beginning of the period (21–25 July).

② The wind direction (Fig. 8c) provides a partial explanation due to the variation in source areas.

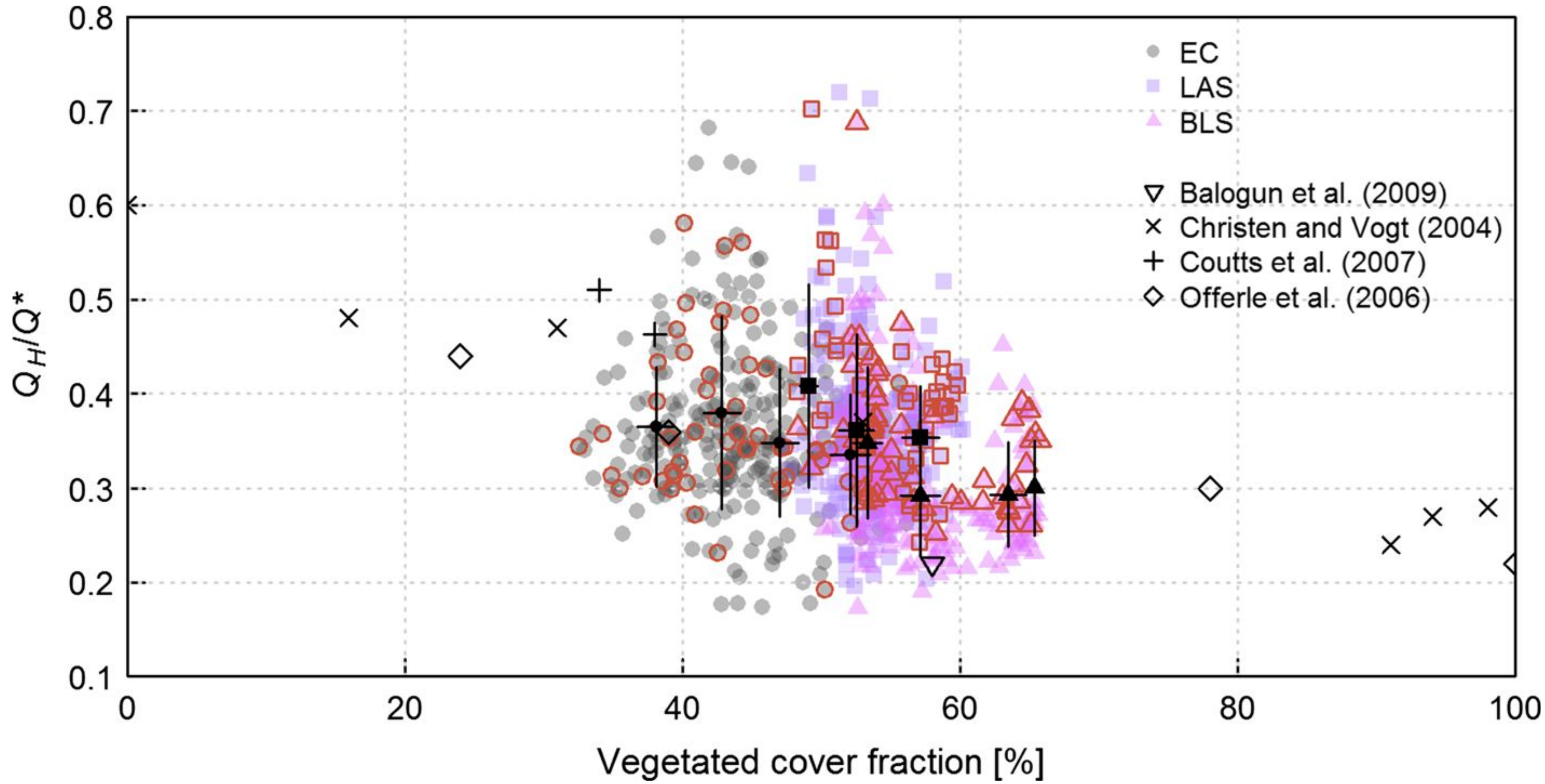

Fig. 9 Ratio of the observed sensible heat flux to net all-wave radiation versus the proportion of vegetation within the flux footprint of the EC station, LAS and BLS in Swindon. Points are 30-min values around midday (1100–1500 UTC) for the period 21 May–31 July 2012. Data are excluded for times during and $\leqslant$ 2 h after rainfall and when $K\downarrow \leqslant 200 \mathrm{W m^{-2}}$. Black symbols with error bars represent the mean ± standard deviation of the respective observed values binned in 5 % intervals of the vegetated cover fraction (bins with >10 data points are plotted). Those data collected more than 2 days since rainfall are outlined in red. Average summertime values from various sites in the literature are shown for comparison (see references for details)

Conclusions

- For many purposes we are interested in fluxes at large scales, whether the application is input data for, or evaluation of, land-surface models or numerical weather prediction,assessment of satellite remote sensing products, or representative observational datasets to characterize a particular environment.
- Differences in magnitudes of the fluxes between sites are attributed primarily to the role of vegetation and reveal the influence of anthropogenic materials on surface-atmosphere interactions.
- The scintillometer fluxes tend to be smoother as a result of the greater spatial averaging.The large-scale flux measurements are also much less sensitive to source area variability, for example due to changing wind direction over heterogeneous surfaces.

- Scintillometry offers a promising way forward, but there are still limitations. A major source of uncertainty arises from the MOST functions.
- Future work will likely focus on the development of the scintillometry technique and the application for routine monitoring at large scales.Such observational networks would offer valuable data for assimilation into models that assess air quality or heat stress, both highly relevant to human health and well-being.

Thank You!