Entrainment influences on surface layer measurements:

detection and impact on Monin-Obukhov similarity theory

(submitted to BLM)

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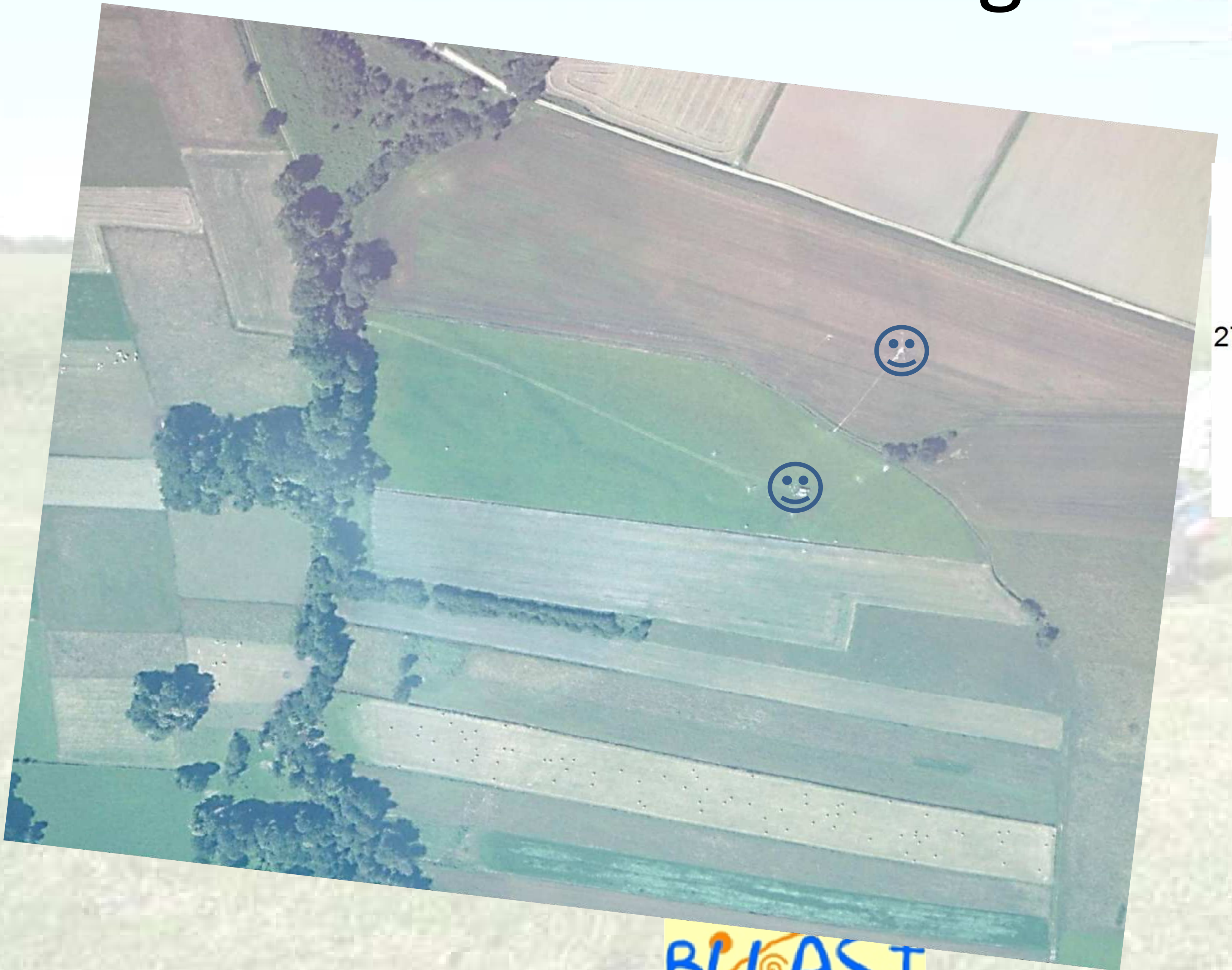
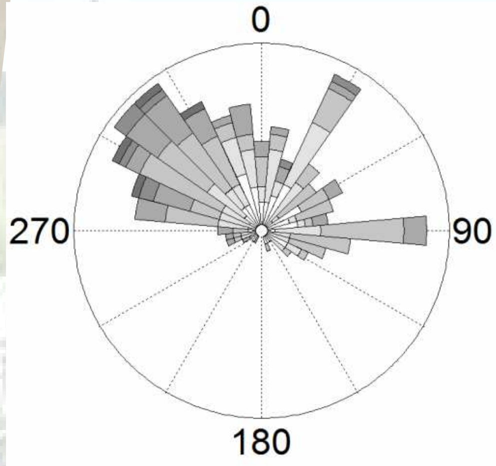
EC-data from edge-site





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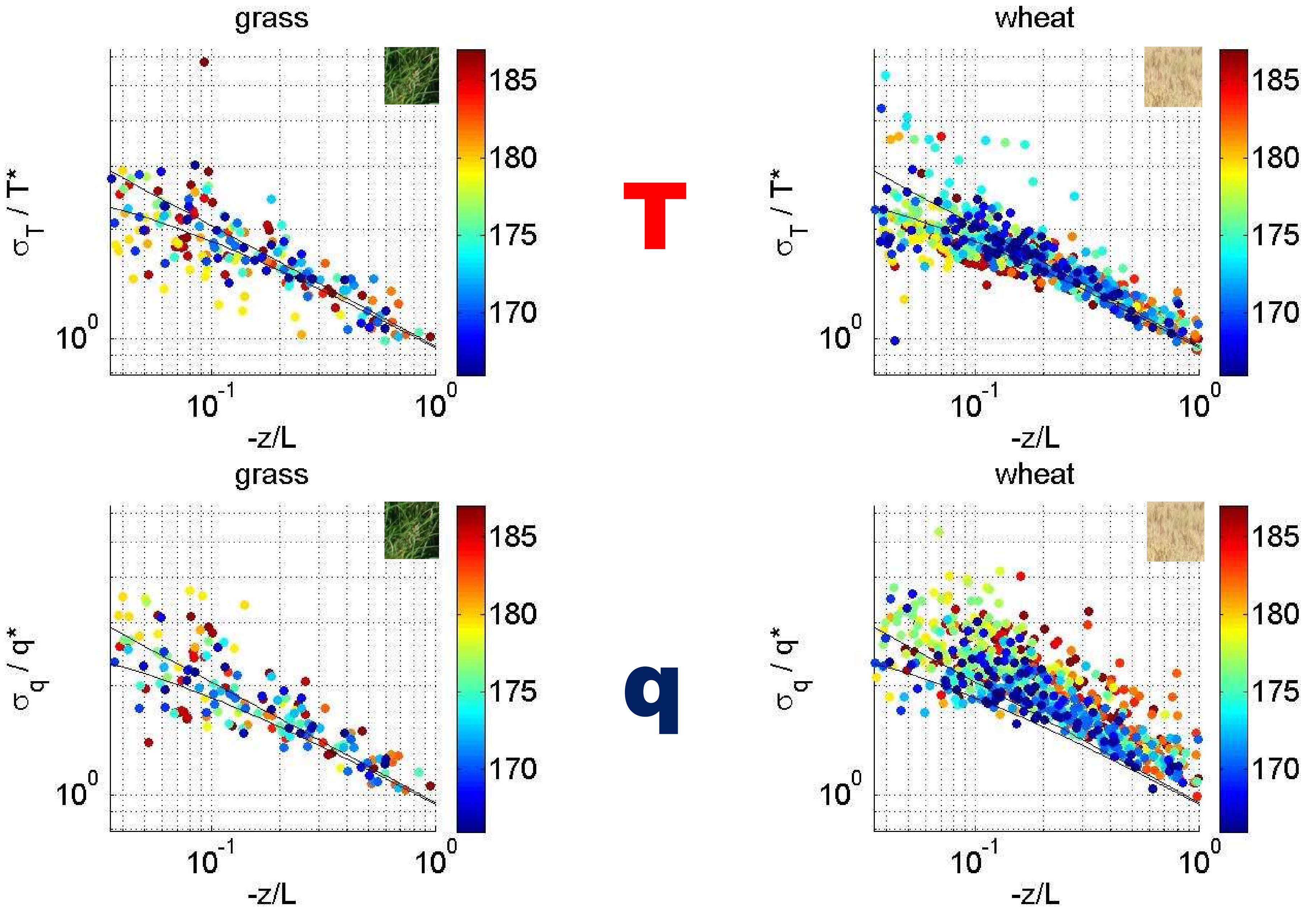
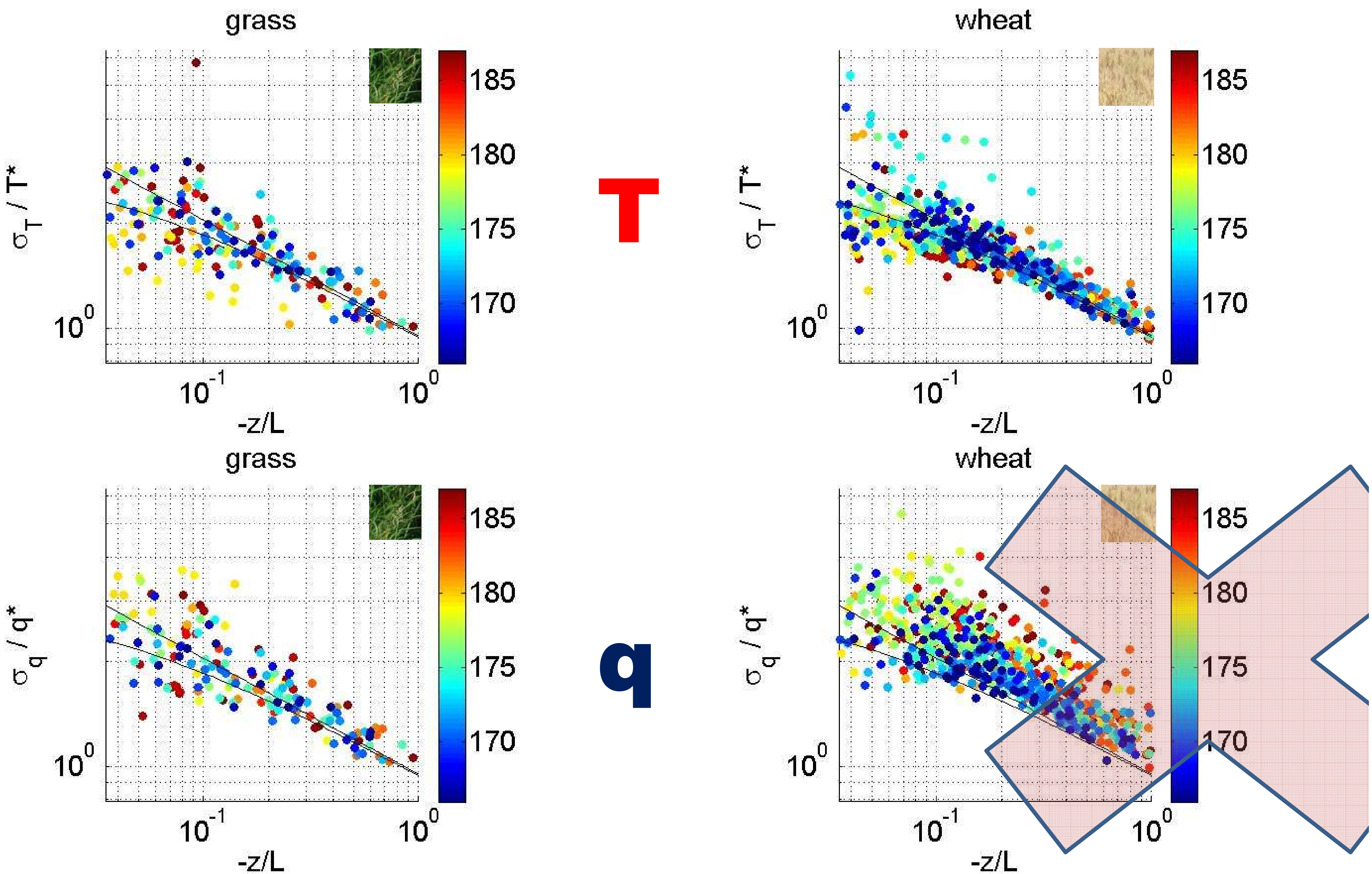
Monin-Obukhov: agreement



Monin-Obukhov: agreement



Monin-Obukhov: when dissimilarity?

- non-stationarity (use only midday data)
- surface heterogeneity (which scale?, footprints)
- advection
- entrainment processes

Detection of entrainment influences on surface layer measurements

1. Are there larger scales in the EC-signal?

   Wavelet analysis: time scales processes

2. Are larger scales caused by entrainment?

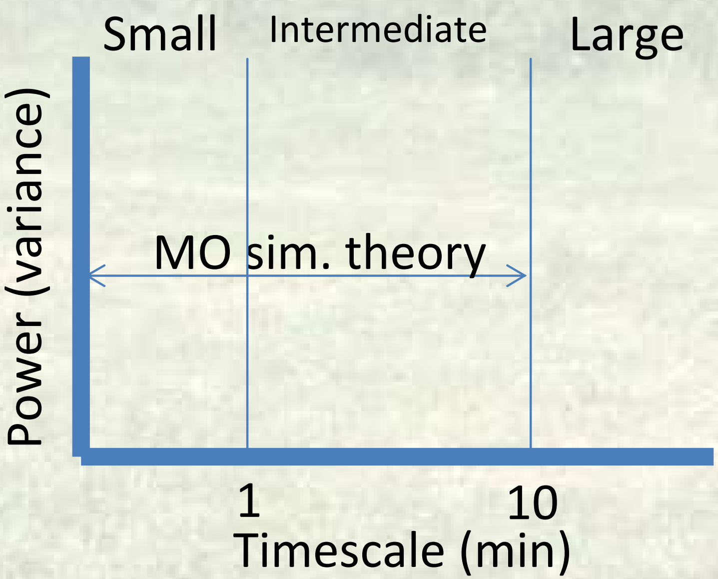
   Radio soundings: entrainment ratio’s

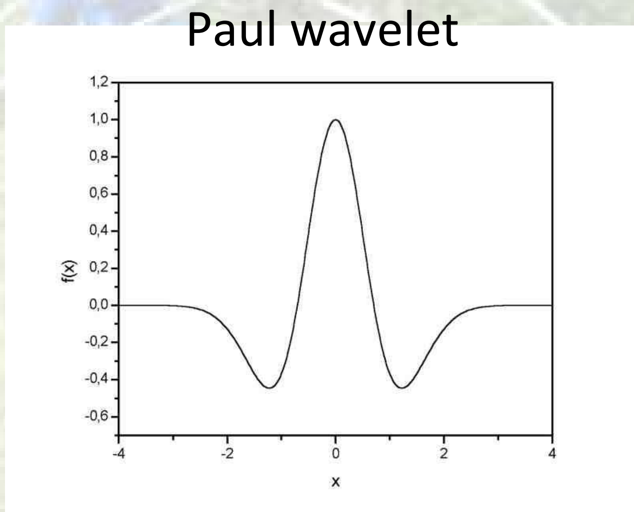
3. Are larger scales caused by advection?

   Pdf humidity-signal: origin signal

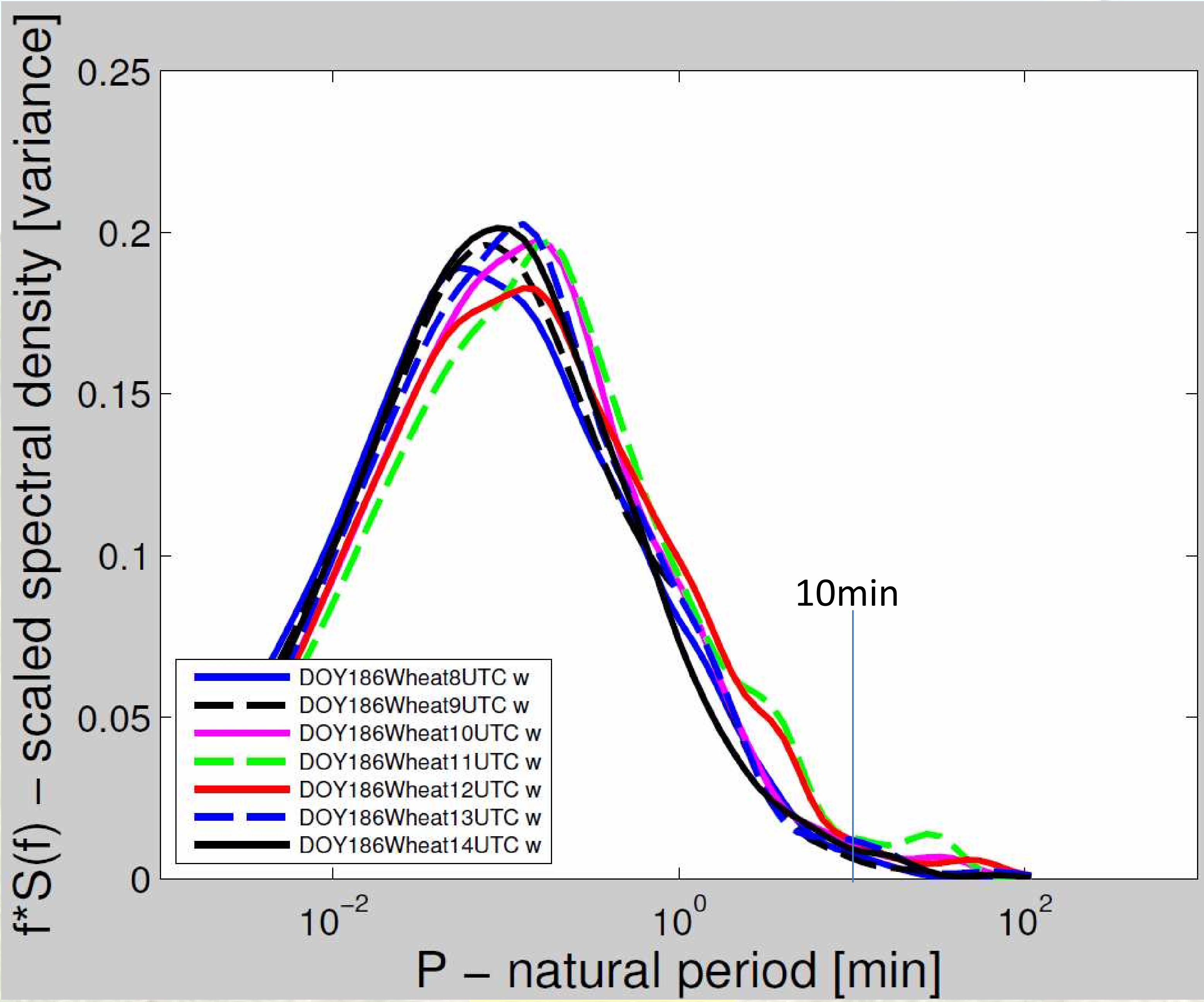
1. Are there larger scales in the EC-signal?

Wavelet instead of Fourier: wave doesn't have to be periodic





Timescales transport (1h data): w



Timescales transport (1h data): T en q

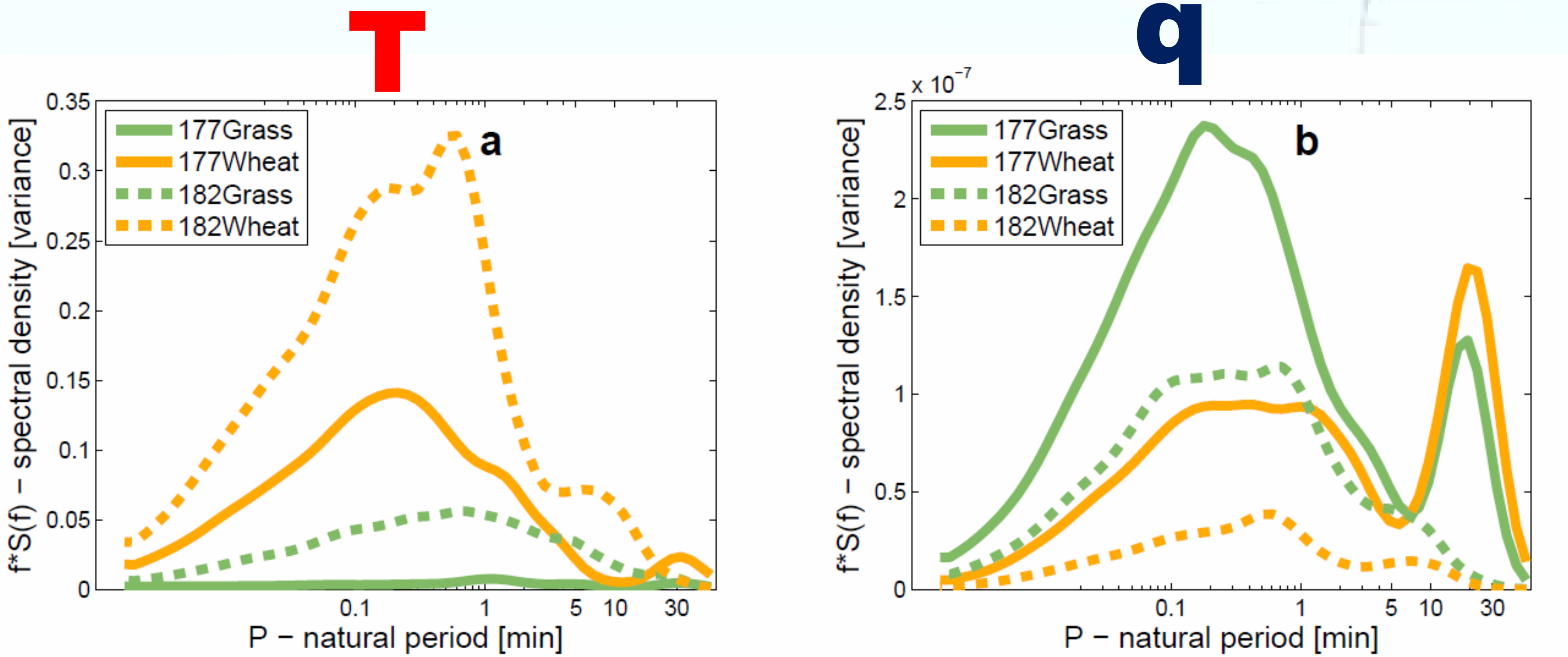


Fig. 8 Wavelet spectra of a) temperature and b) humidity. The data was measured above grass (green) and wheat (yellow) at 13-14 UTC. Dashed lines refer to data from DOY 177, a day with significant large-scale fluctuations in humidity. Solid lines refer to data from DOY 182, a day without such large-scale fluctuations.

Dominant timescales q, IOP days

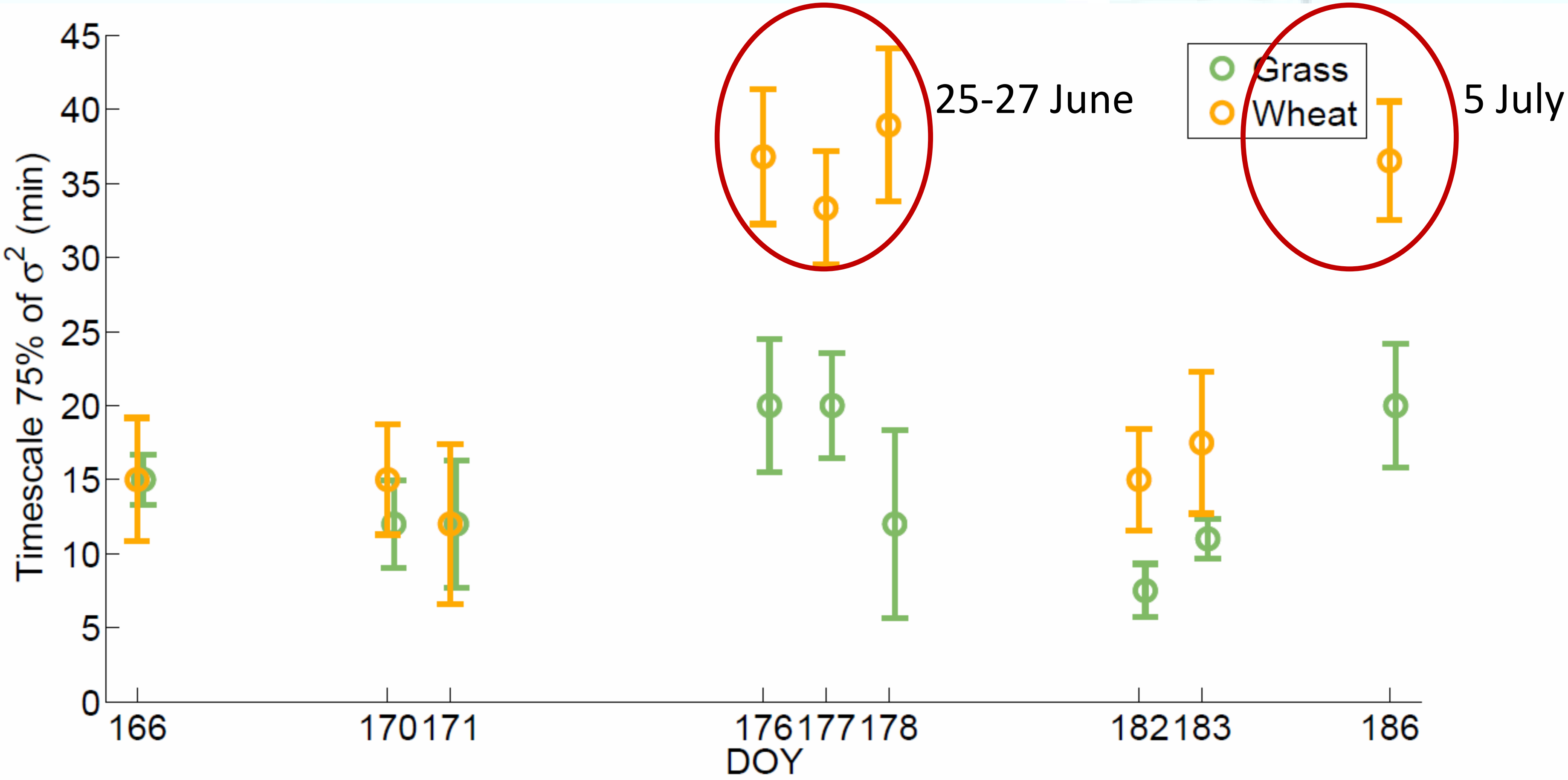


Fig. 9 The daily median and standard deviation of time scales at which 75% of the humidity variance was reached above grass (green) and wheat (yellow) per hour between 8 and 16 UTC of IOP days.

2. Are larger scales caused by entrainment?

$$\beta_{es\theta_v} = \frac{H_{ve}}{H_{vs}} = -0.2$$ (assumption)

$$B = \frac{H_{ve}}{L_v E_e} = \frac{C_p \Delta\theta_v}{L_v \Delta q}$$ (Betts 1992)

$$\beta_{esq} = \frac{L_v E_e}{L_v E_s}$$

Radio soundings site 1

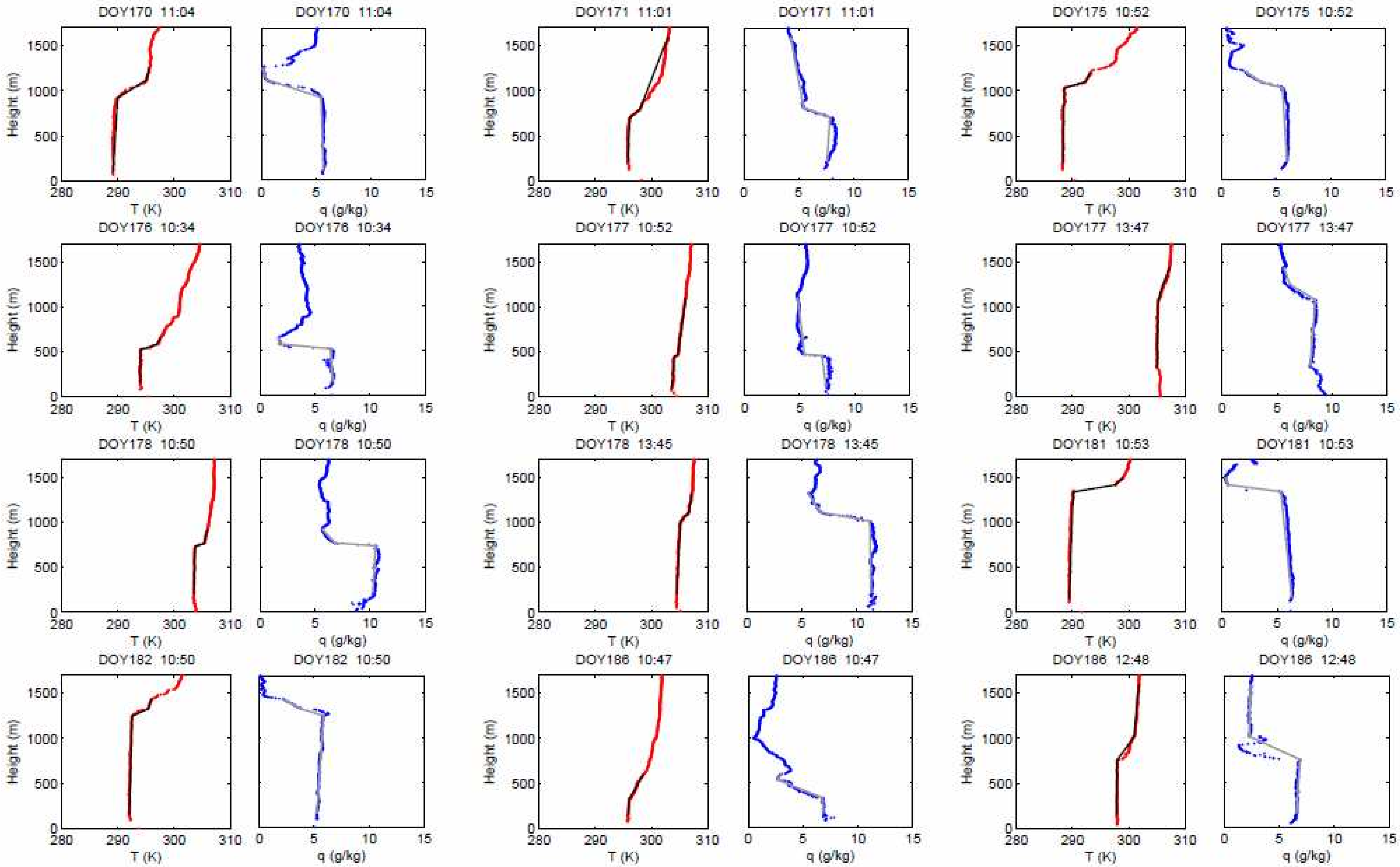


Fig. 15 Vertical profiles of temperature (red) and humidity (blue) measured at a distance of 1 km from our EC stations, using radio soundings (MODEM-LA). From left to right, then from top to bottom, the sets of θ and q are placed in chronological order. Black lines indicate the first order jump model. Corresponding DOY and time are given above every vertical profile.

Radio soundings site 1

Table 1 Entrainment fluxes ($H_{v_e}, L_v E_e$) and ratio for humidity over the wheat field (β_q), calculated from surface fluxes ($H_{v-area}, L_v E_{wheat}$) and the temperature and humidity jumps ($\Delta\theta_v$ and Δq) in the vertical profiles in Figure 15 (1 km from EC stations).

DOY	**Time** UTC	z_i m agl	$\Delta\theta_v$ K	Δq gkg^{-1}	H_{v-area} Wm^{-2}	H_{v_e} Wm^{-2}	$L_v E_e$ Wm^{-2}	$L_v E_{wheat}$ Wm^{-2}	β_q -
170	11:04	983	5.4	-5.0	191	-38	88	267	0.33
171	11:01	713	1.8	-2.6	104	-21	75	266	0.28
175	10:52	1110	3.5	-2.0	146	-29	42	202	0.21
176	10:34	531	2.6	-4.7	173	-34	156	221	0.70
177	10:52	349	0.8	-2.2	127	-25	174	208	0.84
177	13:47	1052	0.6	-2.0	127	-25	211	208	1.01
178	10:50	481	1.7	-3.7	83	-16	90	289	0.31
178	13:45	1062	1.7	-4.6	83	-16	112	289	0.39
181	10:53	1363	6.8	-5.3	87	-17	34	146	0.23
182	10:50	1368	2.9	-1.1	116	-23	22	199	0.11
186	10:47	480	0.7	-4.9	104	-21	362	210	1.72
186	12:48	797	2.8	-4.6	104	-21	85	210	0.40

Large scales + entrainment ratios q

IOP: DOY	'Large' βq	'Large' scales present
166	-	-
170	-	-
171	-	-
176	Y	Y
177	Y	Y
178	Y	Y
182	-	-
183	-	-
186	Y	Y

Entr ratio VS contr larger scales

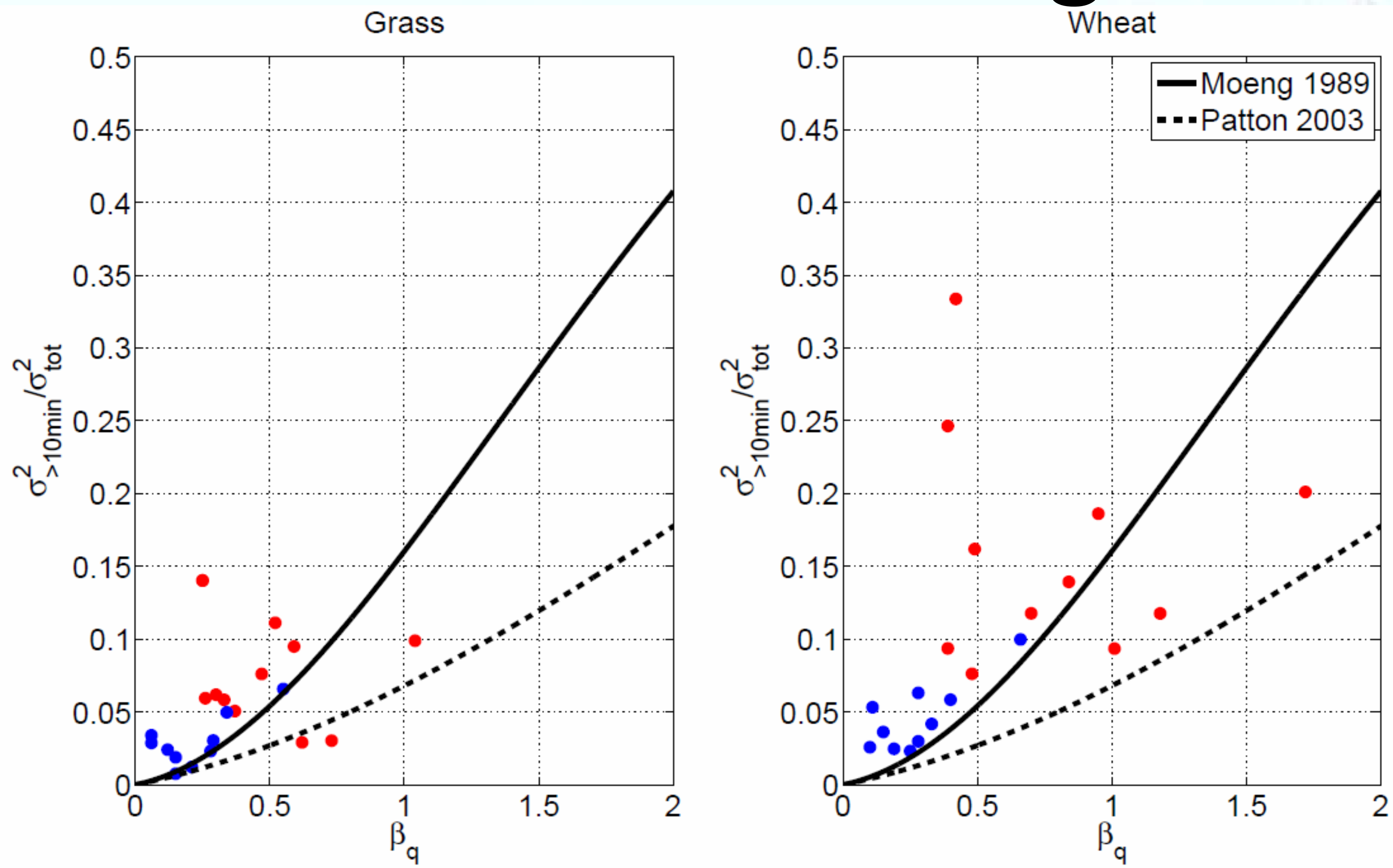


Fig. 12 The contribution to the total variance of variance of a scale larger than 10 minutes increases with the entrainment ratio (each point is 1 hr data). Black lines: contribution of entrainment-related variance to the variance following Moeng and Wyngaard (1989) and our fit in Patton et al. (2003). Red dots indicate signs (small humidity skewness, larger scales) of entrainment.

Theory: contr top-down (entrainment)

LES Moeng and Wyngaard, and Patton et al.

$$\frac{\sigma_x^2}{X_*^2} = \beta_x^2 f_e(\frac{z}{z_i}) + f_s(\frac{z}{z_i}) + \beta_x f_{es}(\frac{z}{z_i}),$$

$$f_s(\frac{z}{z_i}) = 1.8(\frac{z}{z_i})^{-2/3} \qquad | \quad \frac{z}{z_i} < 0.1,$$

$$f_e(\frac{z}{z_i}) = 2.1(1 - \frac{z}{z_i})^{-2/3} \qquad | \quad \frac{z}{z_i} < 0.1.$$

Theory: contr top-down

Variance budget

budget equation after equation B3 in Moene et al. (2006):

$$\frac{\sigma_{q_e}^2}{q_*^2} = \frac{\tau_D}{q_*^2}(-2\overline{w'q_e'}\frac{\partial \overline{q_e}}{\partial z} - \frac{\partial \overline{w'q_e'^2}}{\partial z}), \tag{10}$$

which is only a fair approximation near the surface and the top of the boundary layer. The total scaled variance in the surface layer due to local production (surface related) and production in the upper part of the boundary layer (entrainment related) can then be written as:

$$\frac{\sigma_q^2}{q_*^2} = f_s(\frac{z}{L}) + \frac{\tau_D}{q_*^2}(-2\overline{w'q_e'}\frac{\partial \overline{q_e}}{\partial z} - \frac{\partial \overline{w'q_e'^2}}{\partial z}). \tag{11}$$

We rewrite the boundary layer production terms using the entrainment ratio (Equation 5), the turbulent scale q_*, and three derivations from figure 22, 11 and 14b respectively in Moeng and Wyngaard (1989):

$$\tau_D \approx \frac{z_i}{w_*}, \tag{12}$$

$$\frac{\partial q_e}{\partial z} \approx -\frac{\overline{w'q_e'}}{w_* z_i}, \tag{13}$$

and

$$\frac{\partial \overline{w'q_e'^2}}{\partial z} \approx -4\frac{\overline{w'q_e'}^2}{w_* z_i}. \tag{14}$$

Furthermore we derived from Equation 1 and 4 that

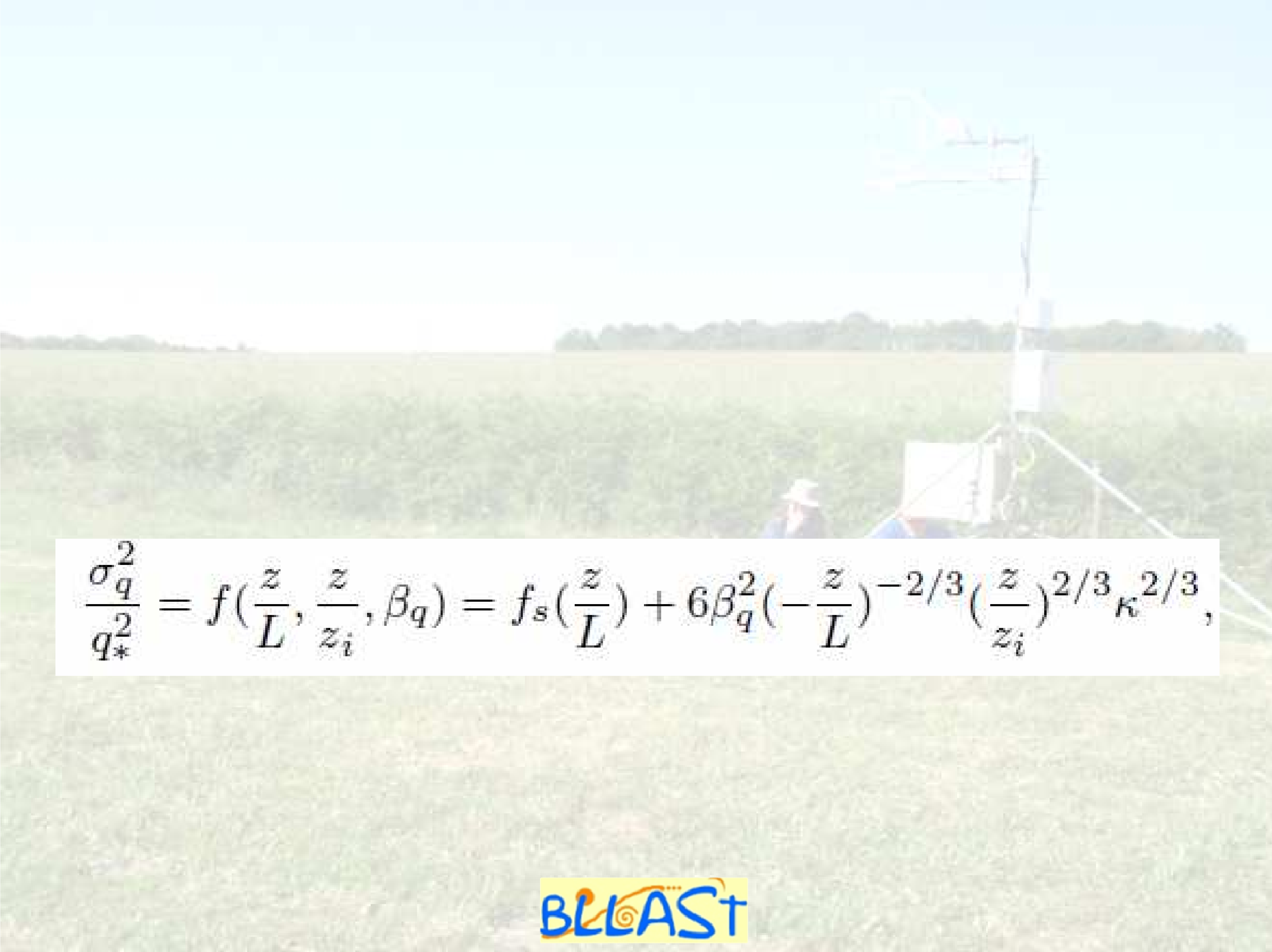
$$\frac{u_*}{w_*} = (-\frac{z_i}{L})^{-1/3}\kappa^{1/3}, \tag{15}$$

and use this to obtain a quantification of the contribution of entrainment processes to the total variance:

$$\frac{\sigma_{q_e}^2}{q_*^2} = (2+4)\beta_q^2(-\frac{z_i}{L})^{-2/3}\kappa^{2/3}. \tag{16}$$

The production term caused by transport of scalar variance (in our case humidity) is twice as large as the production term caused by the vertical scalar gradient. The total variance can be written as

$$\frac{\sigma_q^2}{q_*^2} = f(\frac{z}{L}, \frac{z}{z_i}, \beta_q) = f_s(\frac{z}{L}) + 6\beta_q^2(-\frac{z}{L})^{-2/3}(\frac{z}{z_i})^{2/3}\kappa^{2/3}, \tag{17}$$



$$\frac{\sigma_q^2}{q_*^2} = f(\frac{z}{L}, \frac{z}{z_i}, \beta_q) = f_s(\frac{z}{L}) + 6\beta_q^2(-\frac{z}{L})^{-2/3}(\frac{z}{z_i})^{2/3}\kappa^{2/3},$$

Monin-Obukhov agreement

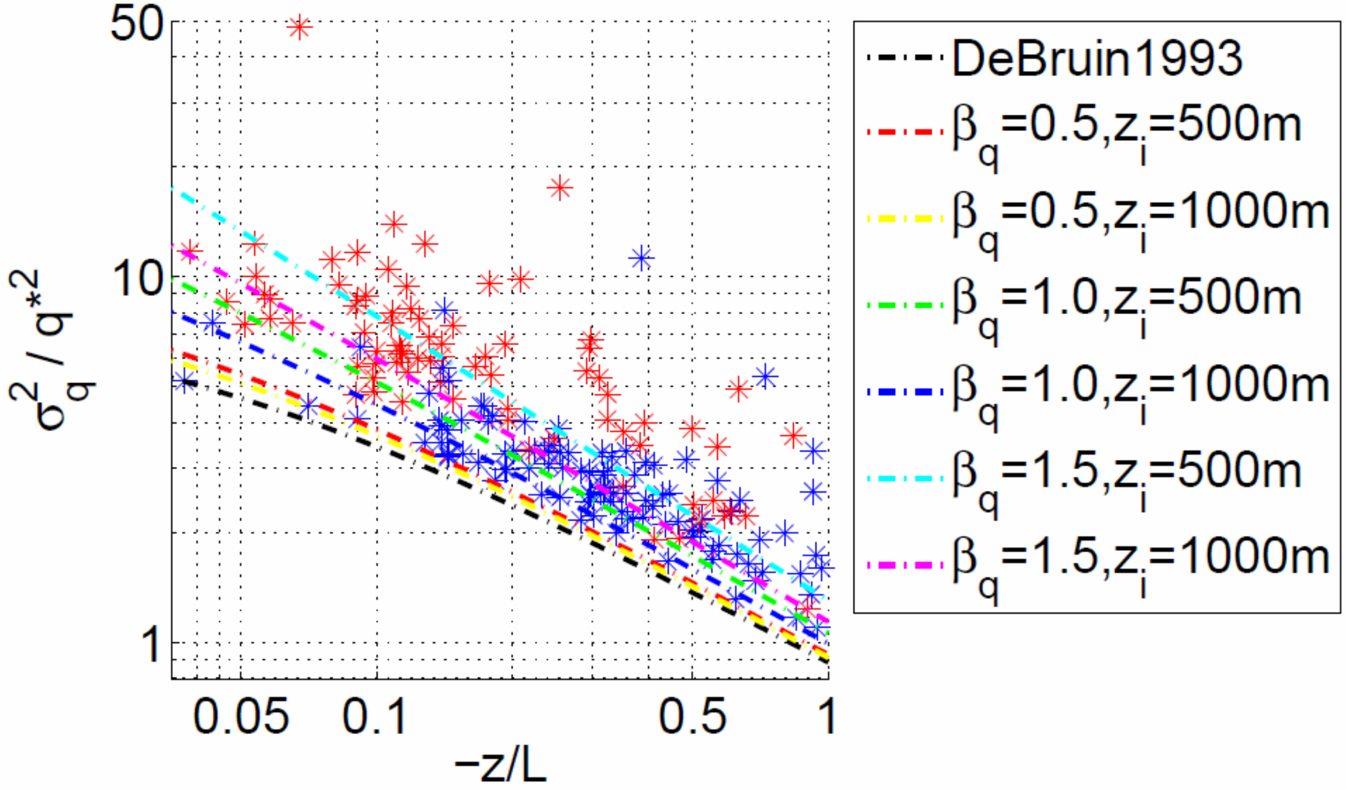


Fig. 14 Normalized variances of humidity above the wheat depending on atmospheric stability for 30-minutes intervals, including the Monin Obukhov similarity function proposed by De Bruin et al. (1993). Other lines show Equation 17 for a range of boundary-layer depths and entrainment ratios. Red markers indicate days with entrainment signals (only data of IOP days are shown here).

3. Are larger scales caused by advection?

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Skewness pdf humidity

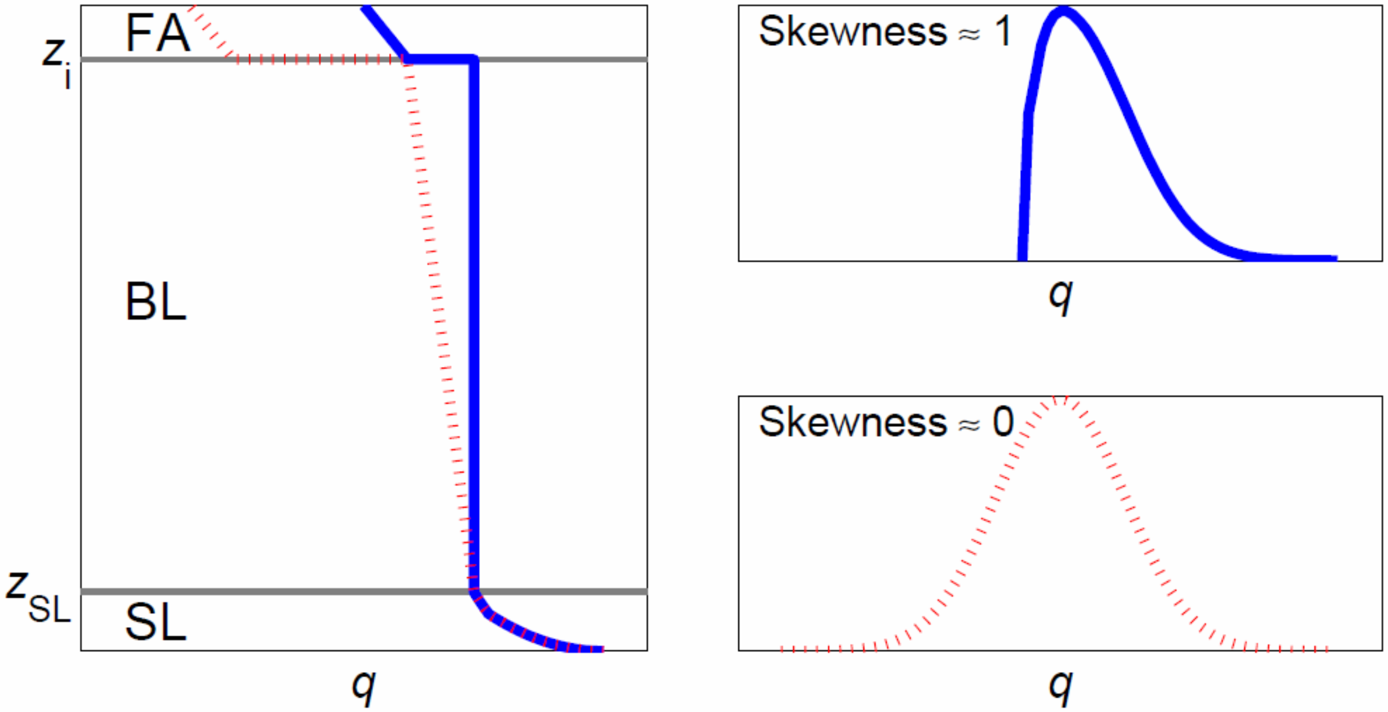

Fig. 1 Sketch of the vertical profile and distribution of the humidity signal observed in the surface layer in case of weak entrainment (solid blue, high skewness) and in case of strong entrainment (dashed red, zero skewness).

Skewness pdf humidity

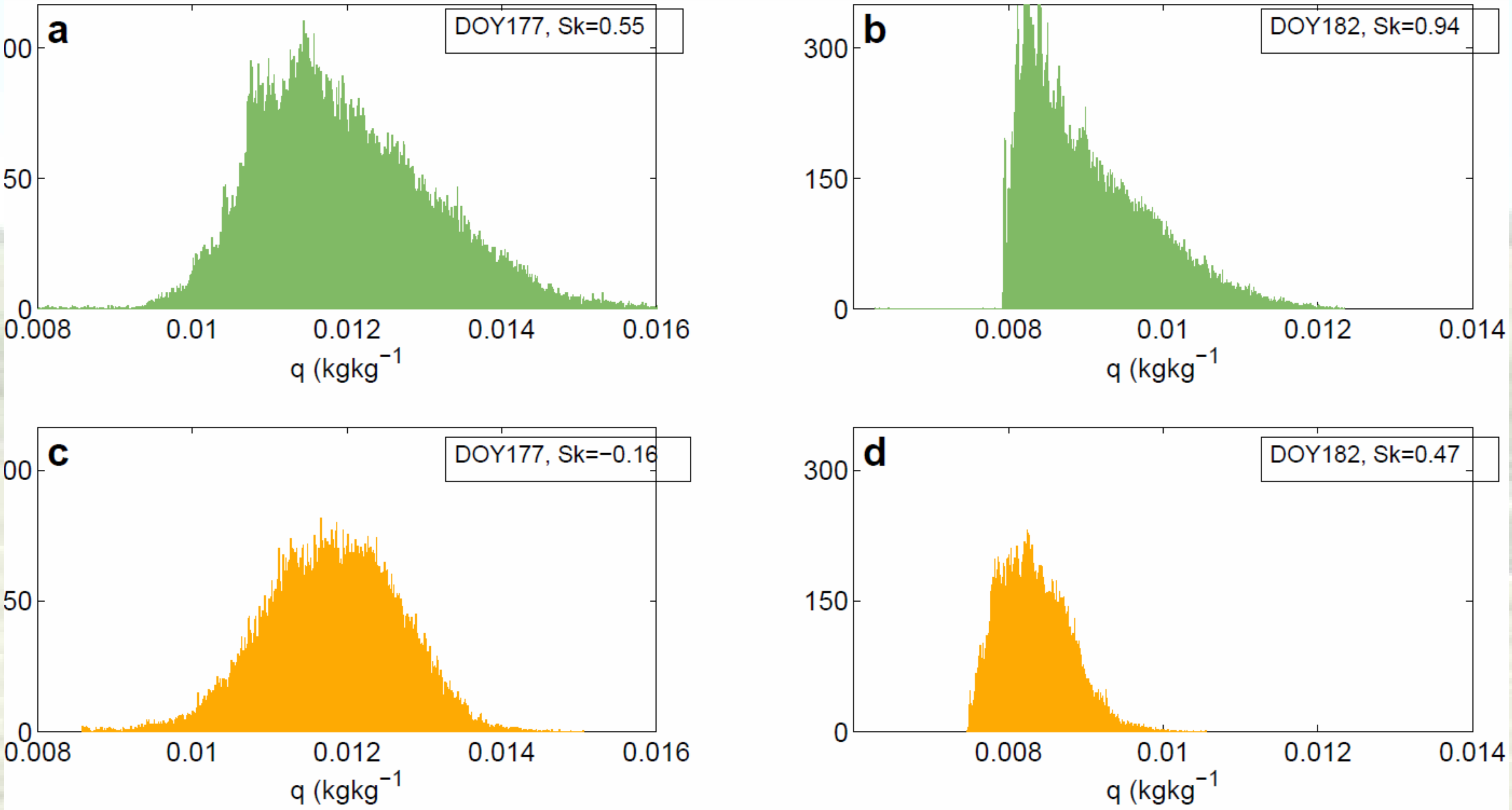

Fig. 11 Probability density of humidity at DOY 177 (left, a day with large-scale influences) and DOY 182 (right, a day without large-scale influences) measured above the grass (top, green) and the wheat (bottom, yellow) at 13-14 UTC.

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Skewness IOP days

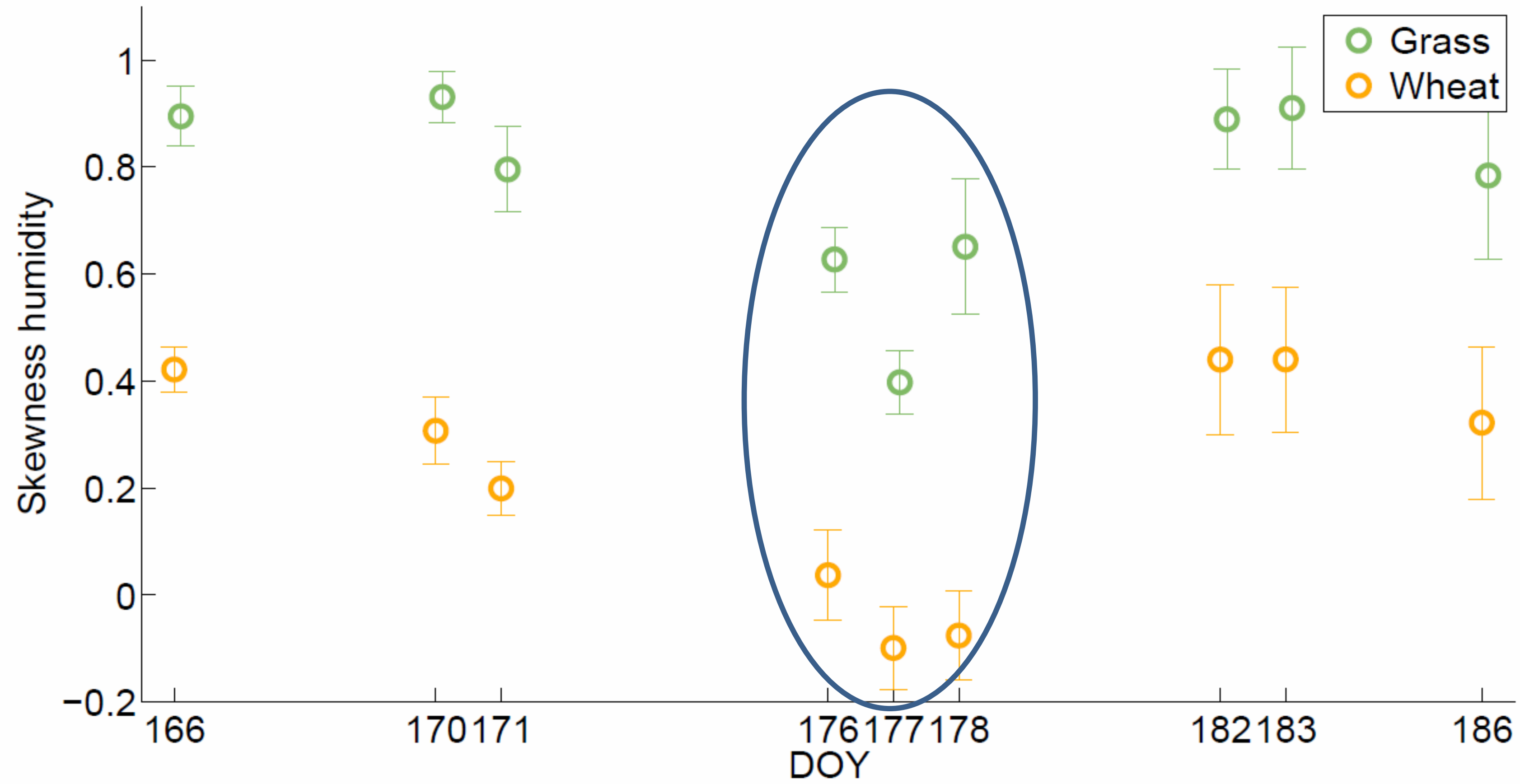

Fig. 10 The daily median and standard deviation of Sk_q of one hour data above grass (green) and wheat (yellow) between 8 and 16 UTC.

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Horizontal advection?

From Lannemezan (south-east of site)?

NO:

–Skewness-entrainment theory agrees with selected days

–south-easterly wind doesn’t always give low skewness or large time scales

–Lannemezan is a small town (Tapper, 1990)

Ideas

- Area-averaged flux from Oscar for entrainment ratio calculations
- Check entrainment velocity; dzi/dt (UHF)
- Same story for CO2 (aircraft data)

- Continue heterogeneity study after improvement footprint model

THANKS FOR LISTENING

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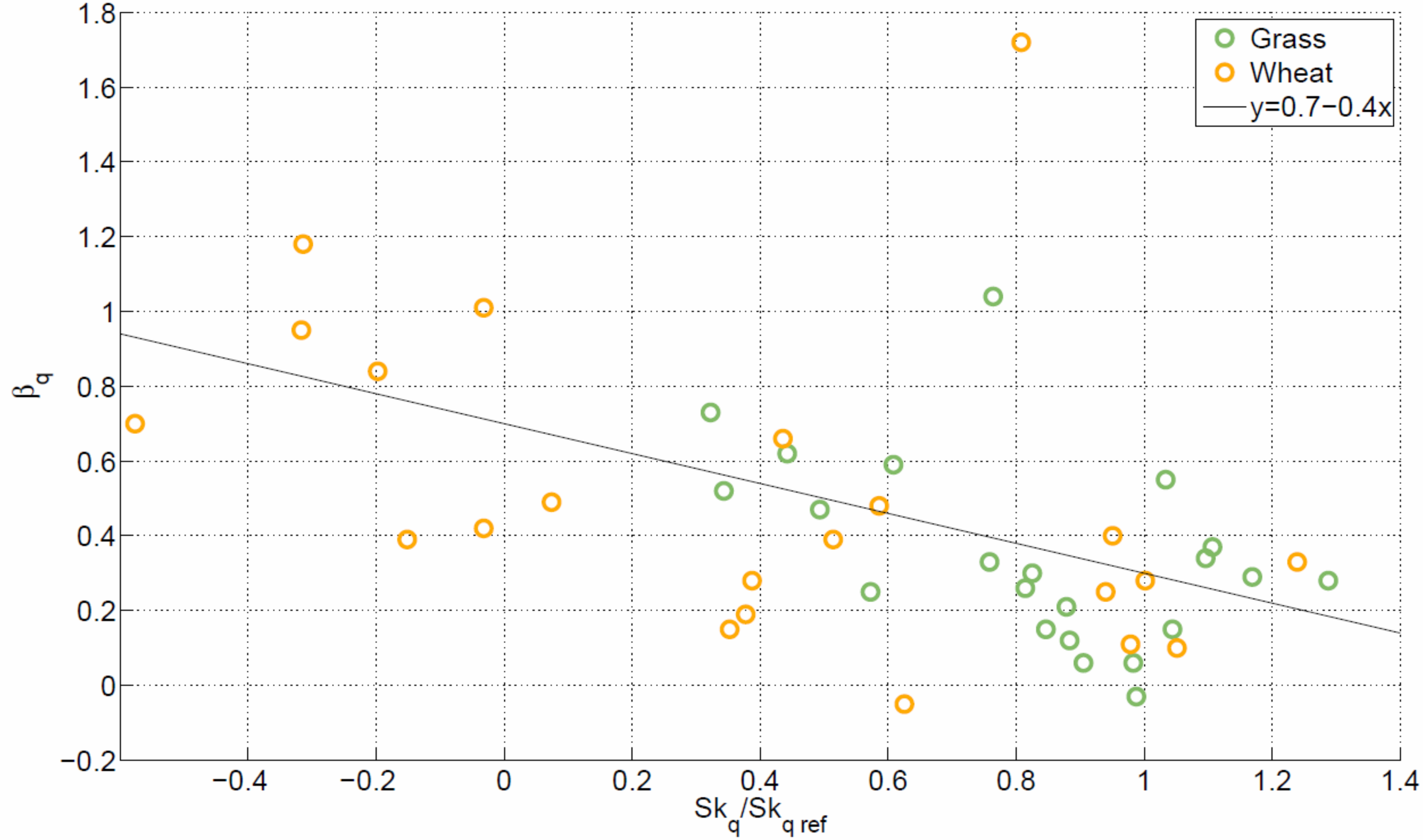
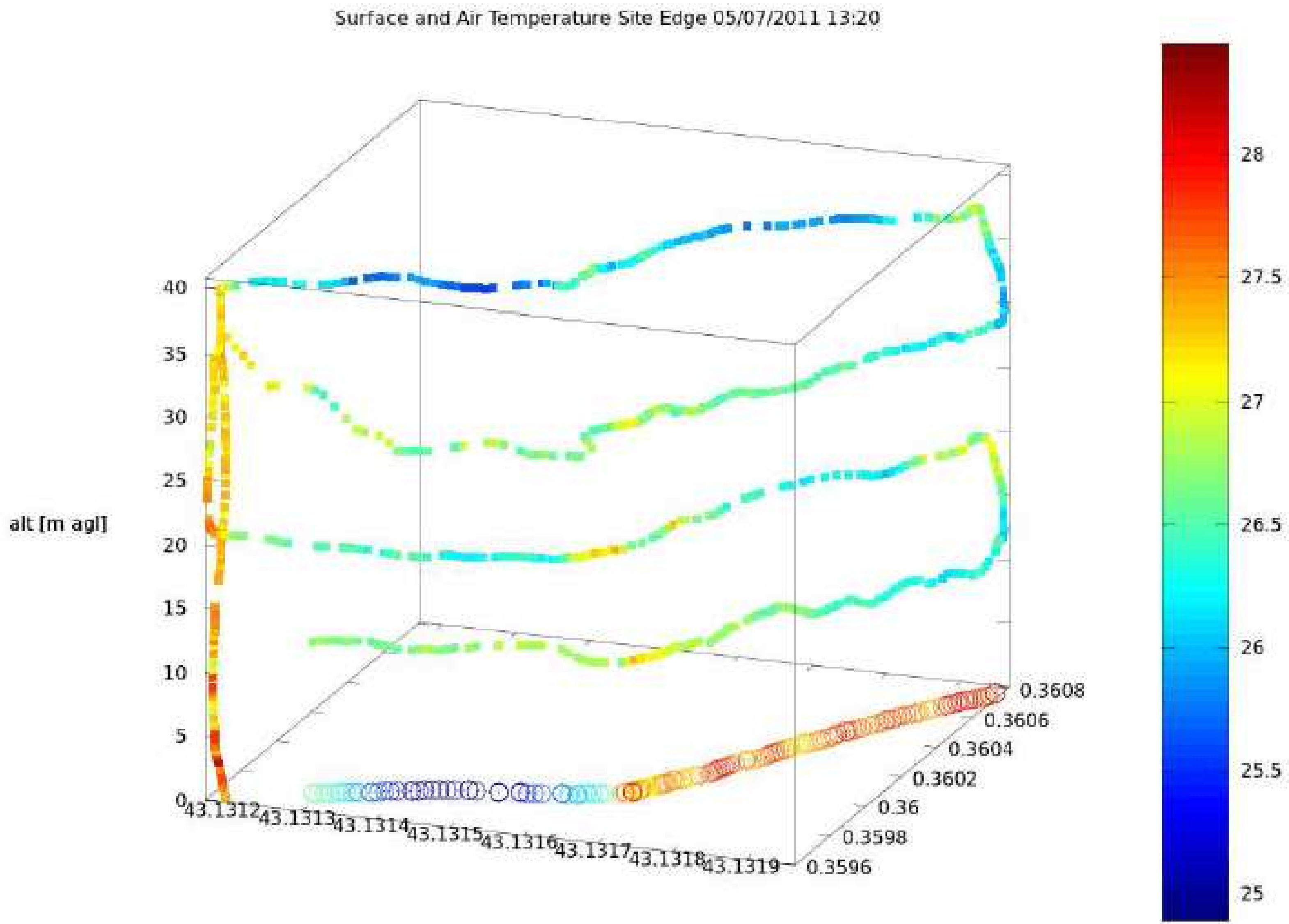


Fig. 13 The normalized Sk_q decreases with the entrainment ratio for both land use types (each point is 1 hr data). $R^2 = 0.25$, $Sk_{q\ ref}$ =0.9 for grass and 0.5 for wheat.

Quadcopter – Ostwestfalen-Lippe: site edge

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