CO_2 flux gap-filling with an aerodynamic-variance method over a tall forest

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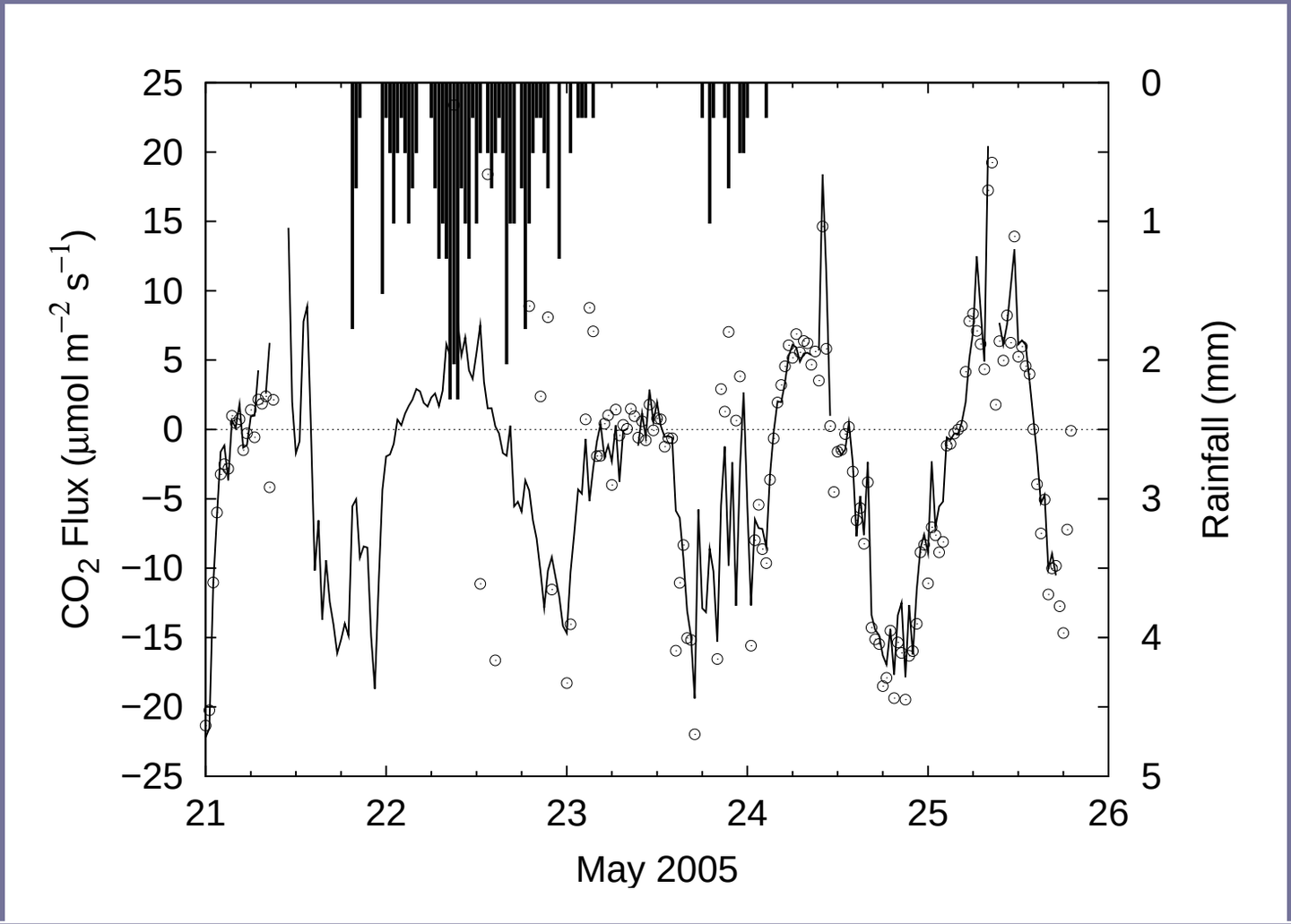
Persistent rainfall can be a problem for flux measurements in several regions of the world.

Closed-path and open-path IRGAs in wet conditions

DF49 (British Columbia)



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The aerodynamic-variance method

Standard Eddy-Covariance (EC) instrumentation for CO_2 fluxes includes the measurement of U, V, W, Θ_v and C.

Reynolds decomposition: $A = \overline{A} + a$

Coordinate rotation: $\overline{V} = \overline{W} = 0$.

Assume that we have an alternative set of measurements:

Propeller anemometer	$U_\beta \rightarrow$	$\overline{U}_\beta$
Closed-Path IRGA	$C_\beta \rightarrow$	σ_c
Fast-response thermometer	$\Theta \rightarrow$	σ_θ

Algorithm: iterate until convergence

$$u_* = \frac{\kappa \overline{U}_\beta}{\ln\left(\frac{z-d}{z_{0\tau}}\right) - \Psi_\tau(\zeta, \zeta_0)},$$

$$\frac{\sigma_a}{a_*} = \phi_a(\zeta),$$

$$\zeta = -\frac{\kappa g (z-d)\theta_*}{\overline{\Theta} u_*^2}$$

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- Essentially simple ideas that work well in the *Surface Layer*
- Problem: measurements are being made well within the *Roughness Sublayer*.

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Site and data description

- DF49: a mature stand of Douglas Fir in the British Columbia
- $z = 43\,\mathrm{m}$, $h = 33\,\mathrm{m}$; $d = 22\,\mathrm{m}$ (assumed based on $d = 2h/3$)
- EC: *Gill* Solent R2 and *Licor* LI-6262
- β: Young propeller anemometer
- Site is very homogeneous, no significant directional effects found by Humphreys et al. (2006).

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Similarity functions in the roughness sublayer

$$\Psi_\tau = (C \ln((0.28 + (-\zeta)^{3/4})/(0.28 + (-\zeta_0)^{3/4})) - D((-\zeta)^{1/3} - (-\zeta_0)^{1/3})),$$

$$\phi_a(\zeta) = A(1 + B|\zeta|)^{-1/3}$$

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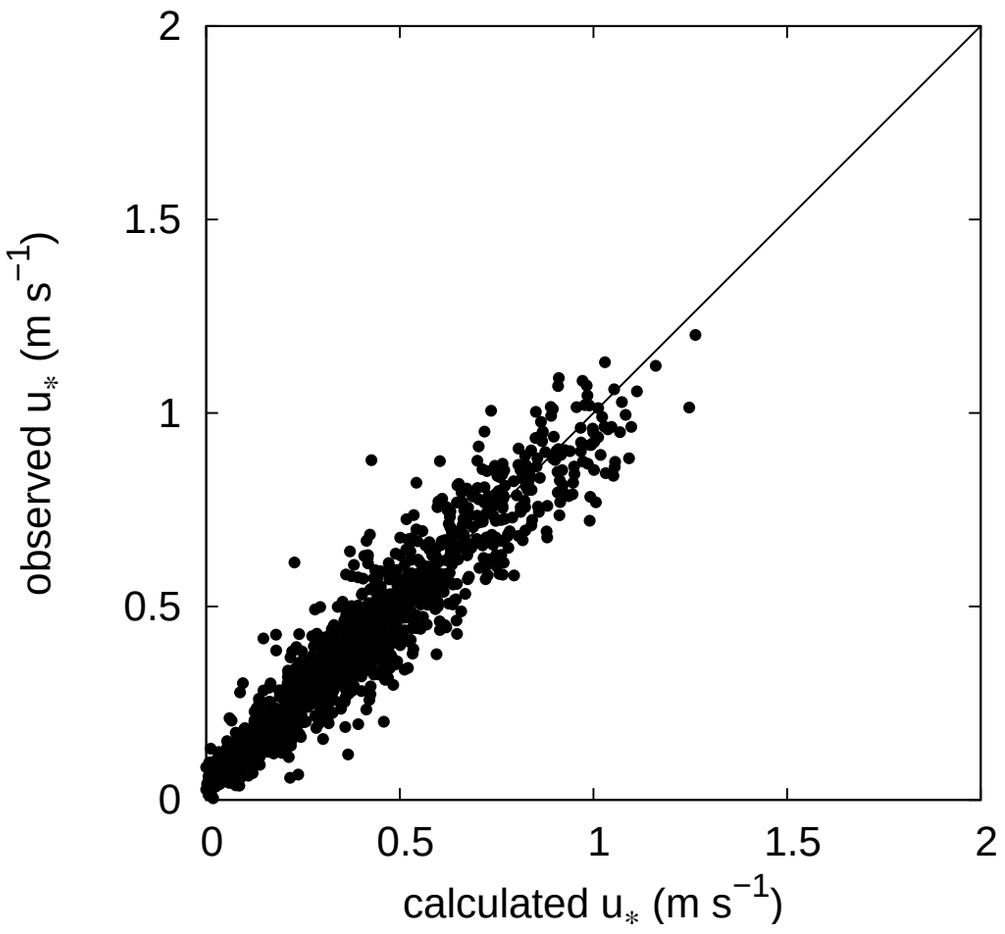
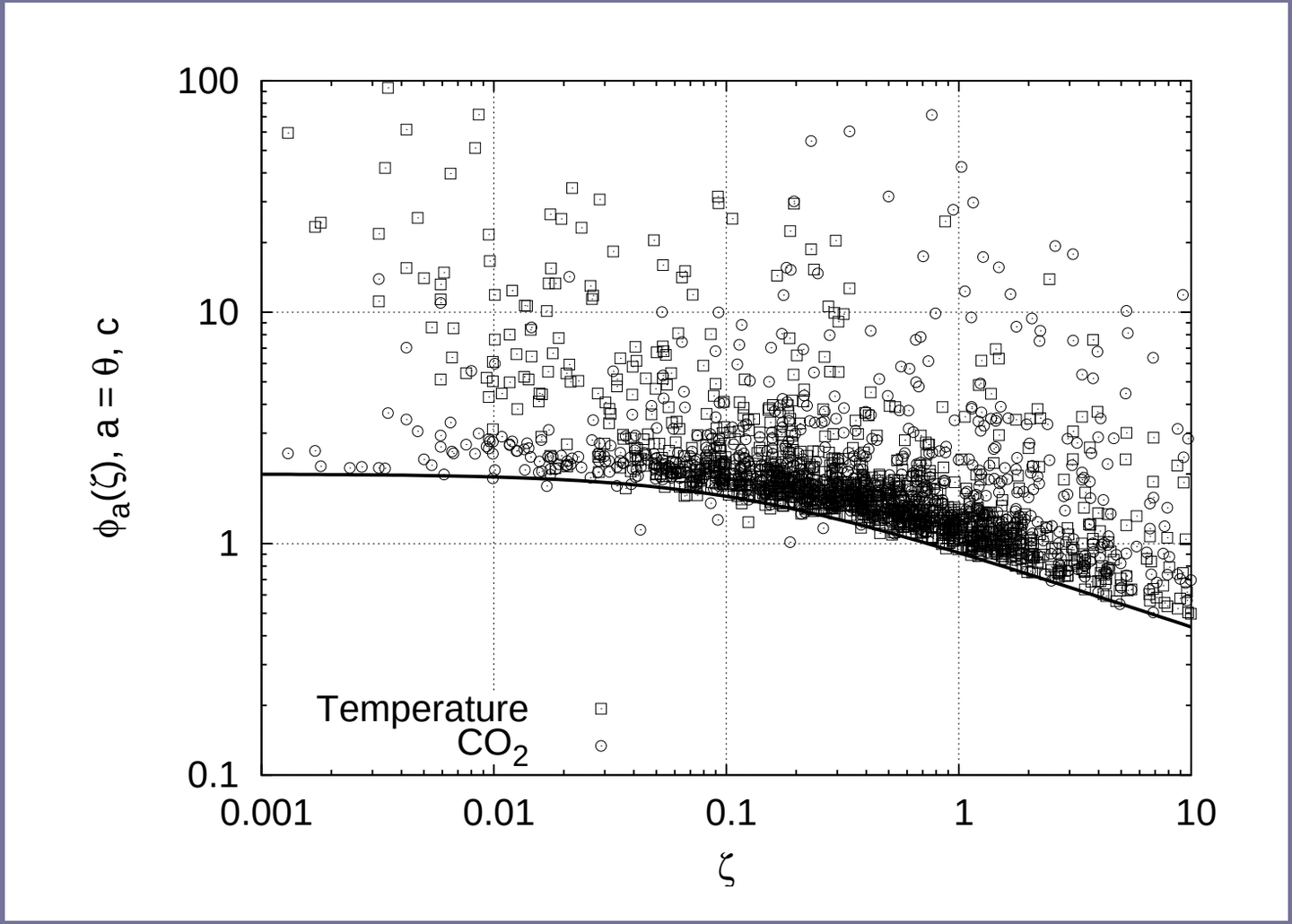
- Ψ_τ "works" at the cost of locally calibrating C and D.
- ϕ_a doesn't work

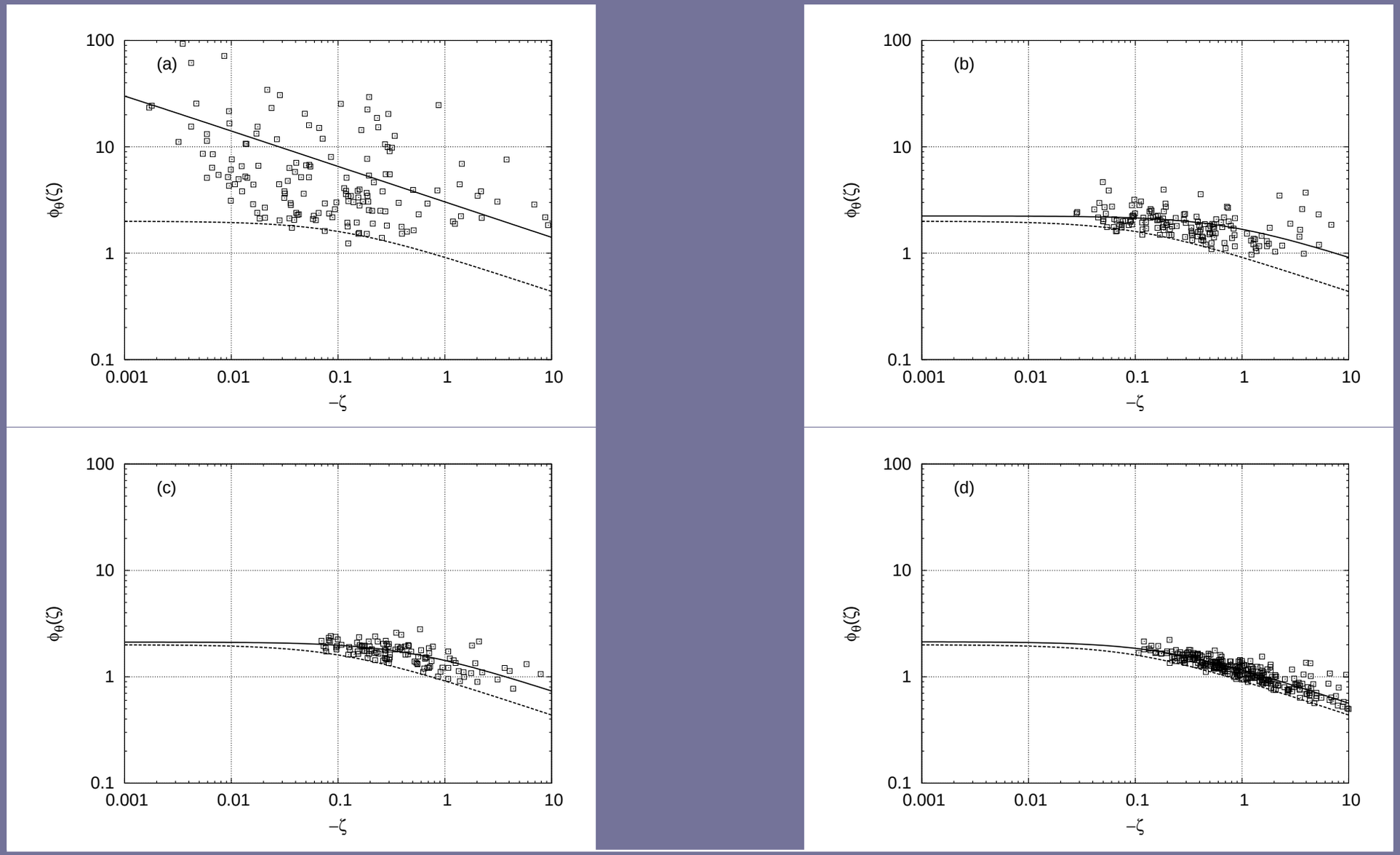
Performance of similarity functions: Ψ_τ



Performance of similarity functions: ϕ_a



Classify ϕ_θ according to θ_*: 0.0–0.1, 0.1–0.2, 0.2–0.3 and $> 0.3\ \mathrm{m\,s^{-1}}$



ϕ_a parameter estimation per class of a_*

(Using *Gnuplot*'s Levenberg-Marquardt non-linear least squares)

Table 1: A and B for each θ_* and c_* class

$\lvert\theta_*\rvert$ K	A	B	$\lvert c_*\rvert$ $\mu\mathrm{mol\,mol}^{-1}$	A	B
0.0 – 0.1	87.82	24121	0.00 – 0.30	5.50	0.00
0.1 – 0.2	2.24	1.37	0.30 – 0.60	2.16	9.50
0.3 – 0.3	2.12	2.31	0.60 – 0.90	1.81	0.65
0.3 –	2.13	5.31	0.90 –	1.79	1.67

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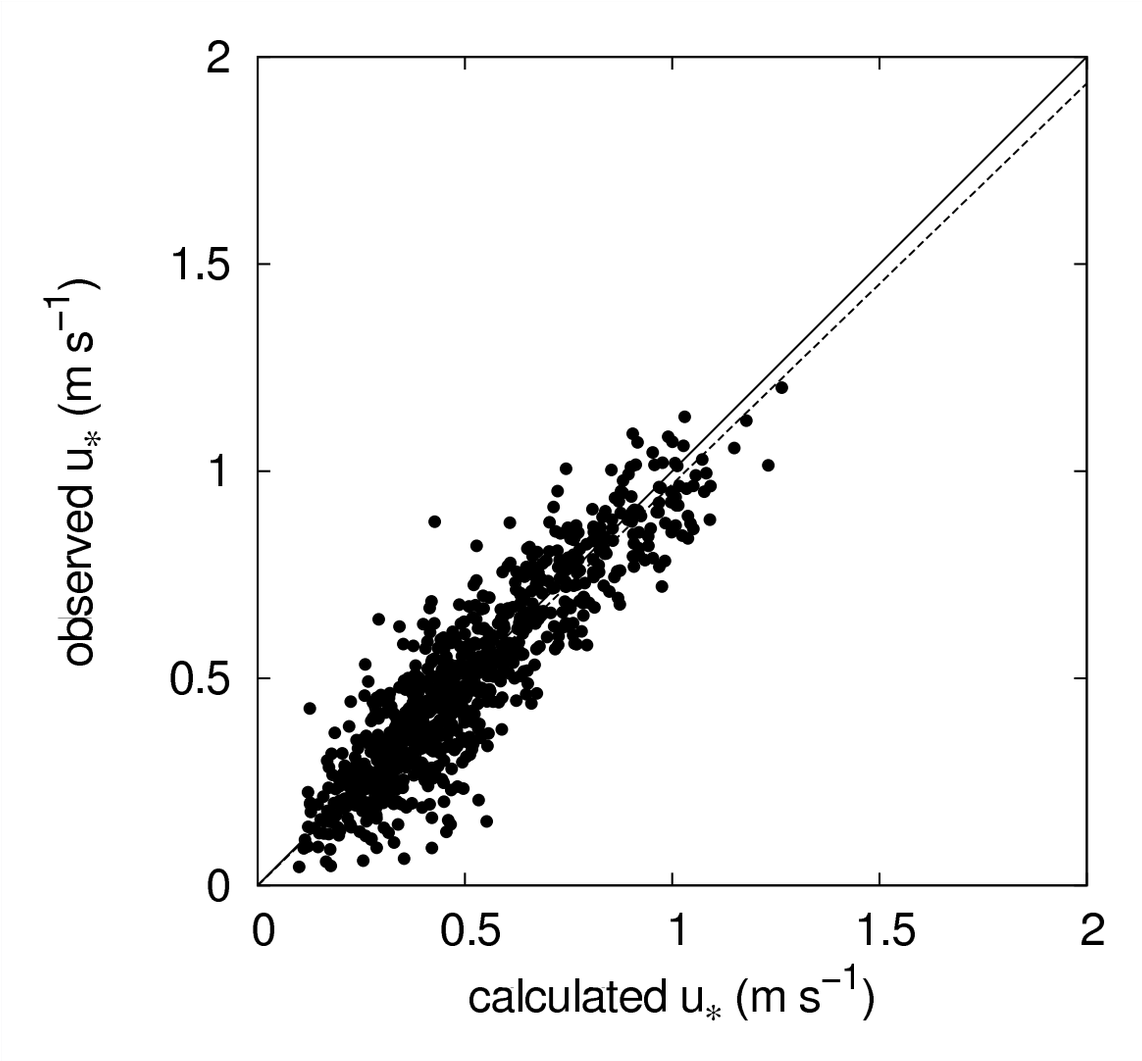
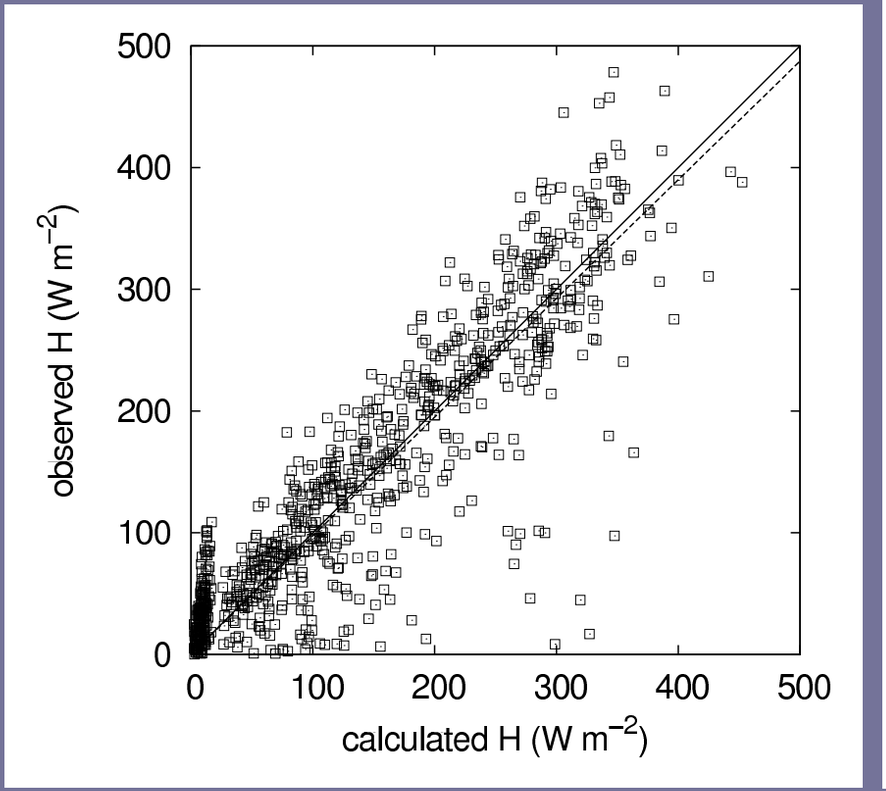
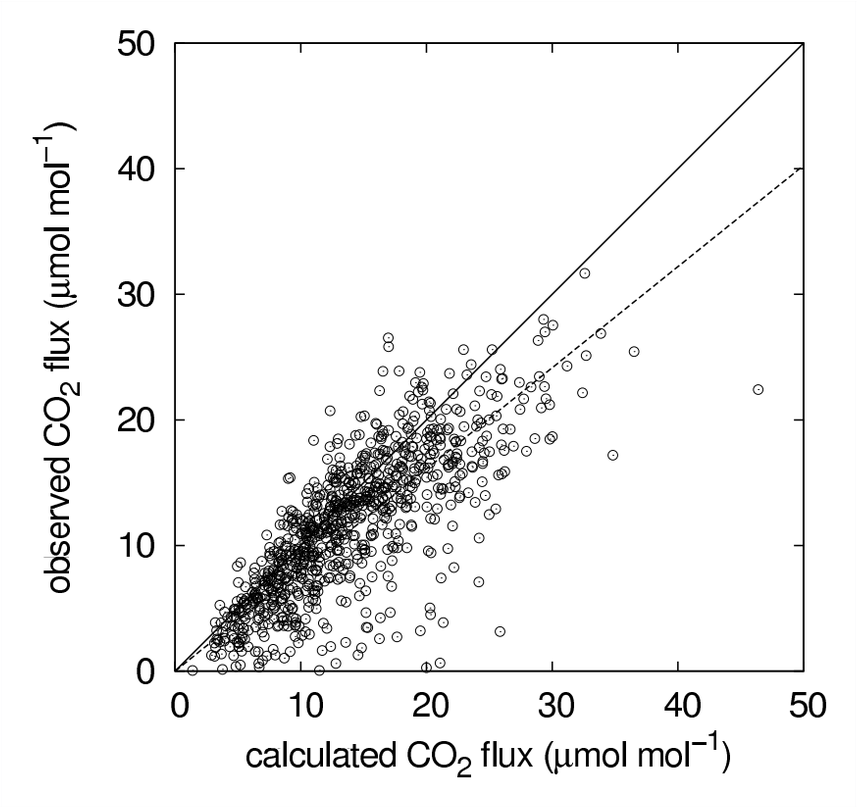
u_* estimates

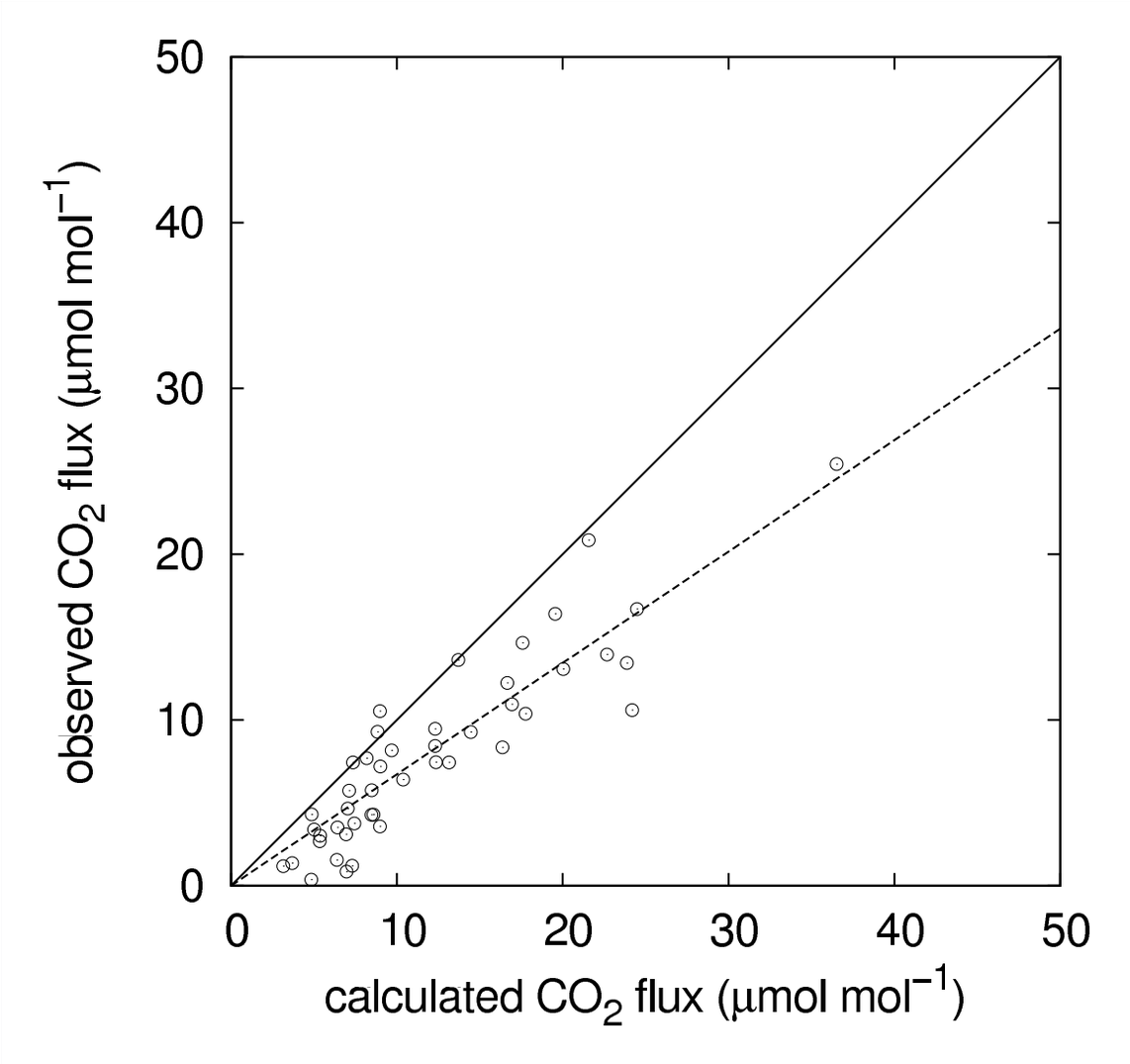


Scalar fluxes





CO_2 flux in rainy conditions



Error statistics

Table 2: Aerodynamic-variance model evaluation of the form $y = ax$, for u_*, H, F and F in rainy periods. s_a is the standard deviation of the a-estimate; r^2 is the coefficient of determination, and s_y is the standard error of estimate of y; n is sample size.

Flux	a	s_a	r^2	s_y	n
u_*	0.968	0.014	0.806	$0.10\,\mathrm{m\,s^{-1}}$	836
H	0.975	0.021	0.776	$53\,\mathrm{W\,m^{-2}}$	836
F	0.782	0.013	0.450	$4.31\,\mathrm{\mu mol\,mol^{-1}}$	836
F (rain)	0.672	0.058	0.816	$2.34\,\mathrm{\mu mol\,mol^{-1}}$	45

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- Good u_* estimates, in spite of surface-layer parameterization.
- Reasonably good and unbiased H estimates (need to improve both over- and underestimates).
- Well correlated, but biased, F estimates.
- Need to investigate if, and how, rain increases the bias in the estimated F.

Thank you.