Workshop on

EddyUH: a software for eddy covariance flux calculation

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Eddy Covariance technique: flux quality criteria and random uncertainty

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Outline

- Flux quality criteria
- Flux random uncertainty
- Methods to calculate random errors
- Flux uncertainty: some examples.

Flux quality criteria

Variable	Description	Apply to	Allowed values	References
Flux instationarity	Stationarity	Co-variances	FS < 0.30	Foken and Wichura, 1996
Flux intermittency	Intermittency	Co-variances	FI < 1	Mahrt et al., 1998
Friction velocity	turbulence well developed?	Co-variances	$U_* > 0.1$-0.3	Not discussed here
Kurtosis	Is the probability distribution narrow	Single variable time series	1 < KU < 8	Vickers and Mahrt, 1997
Skewness	Is the probability distribution skewed	Single variable time series	-2 < SK < 2	Vickers and Mahrt, 1997
σ_u/u_*, σ_T/T_*,…	Integral turbulence characteristics	Single variable time series	ITC<0.3	Foken and Wichura, 1996
Spectra		Power spectra Co-spectra	Visual inspection	

Flux (non)stationarity (Foken and Wichura, 1996)

- Measure the quality of co-variances
- Often about 40% of data omitted due to these, especially during night

The covariance calculated as a mean of the co-variances of 5min periods

$$FS = \left| \frac{\overline{w'x'}_{5\min} - \overline{w'x'}_{30\min}}{\overline{w'x'}_{30\min}} \right|$$

The covariance calculated for the whole period (e.g. 30min)

- x = u, T, CO_2, H_2O, etc.
- The flux is often considered non-stationary if FS>0.3 and the Reynolds' decomposition is not valid

- Flux intermittency (Mahrt et al. 1998)

  - The flux is considered intermittent if FI>1. Often in stable cases.

$$FI = \frac{\sigma_F}{|F|}$$

- Sigma_F is the standard deviation of the 5min averaged co-variances
- F is the 30min covariance

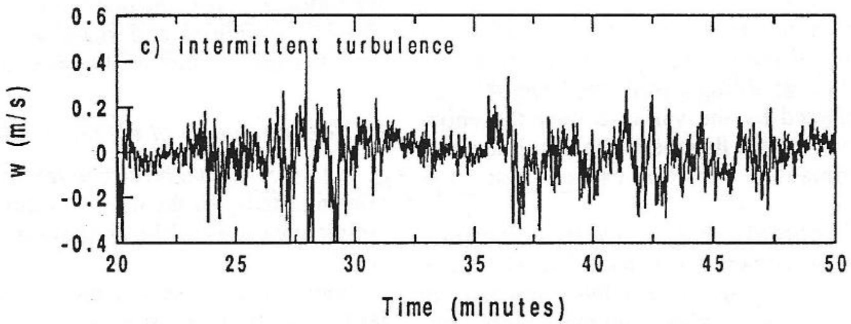


FIG. 4. Sections from three records hard flagged by the Haar criteria from the RASEX sonic anemometers but classified as physical after visual inspection. (a) Vertical velocity hard flagged for kurtosis and the Haar variance during a transition from near laminar flow to strong turbulence. (b) Virtual temperature hard flagged by the Haar mean and variance during a possible gravity wave train. (c) Vertical velocity hard flagged by the Haar variance criteria during intermittent turbulence.

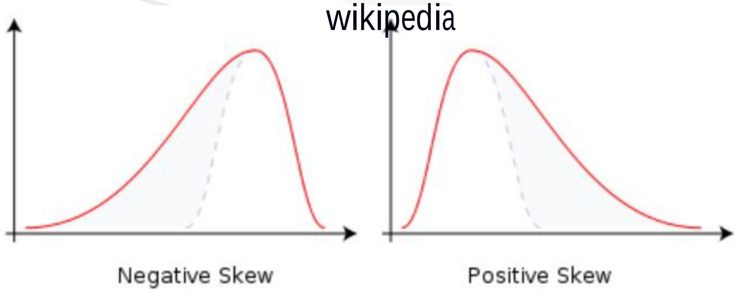
Kurtosis and skewness

- Measure the quality of the time series of a single variable (Vickers and Mahrt, 1997)
- Kurtosis
  - Measure of the peakness of the probability distribution
  - High kurtosis: variance is due to infrequent extreme deviations (peaks in data)
  - Hard flagged: 1< KU <8, soft flagged 2<KU<5

$$KU = \frac{mean(x'^4)}{\sigma^4}$$

- Skewness
  - Measure of the asymmetry of a probability

wikipedia



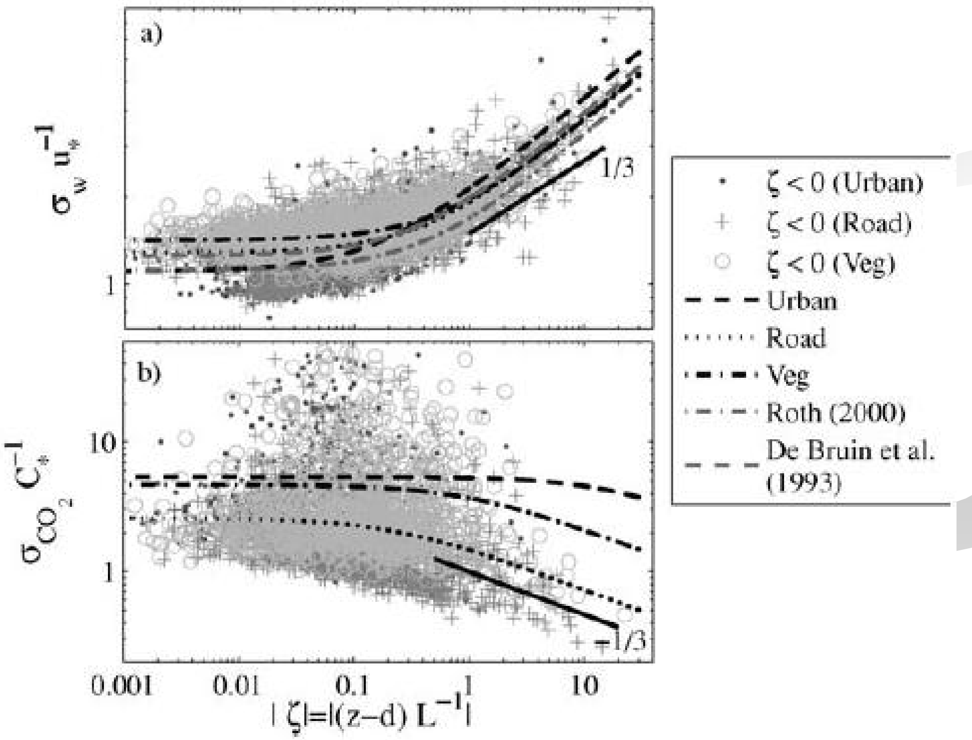
$$SK = \frac{mean(x'^3)}{\sigma^3}$$

  - Hard flagged: -2< SK <2, soft flagged -1<SK<1

Integral turbulence test

- Measure the quality of the time series of a single variable (Wichura and Foken, 1995)
- Is the turbulence well developed? Is the flux variance similarity followed?
- Normalized standard deviation for wind components and a scalar as a function of stability

$$\frac{\sigma_{u,v,w}}{u_*} = c_1\left(\frac{z-d}{L}\right)^{c_2} \qquad \frac{\sigma_x}{X_*} = c_1\left(\frac{z-d}{L}\right)^{c_2}$$



An example from SMEAR III
From Vesala et al. 2008a

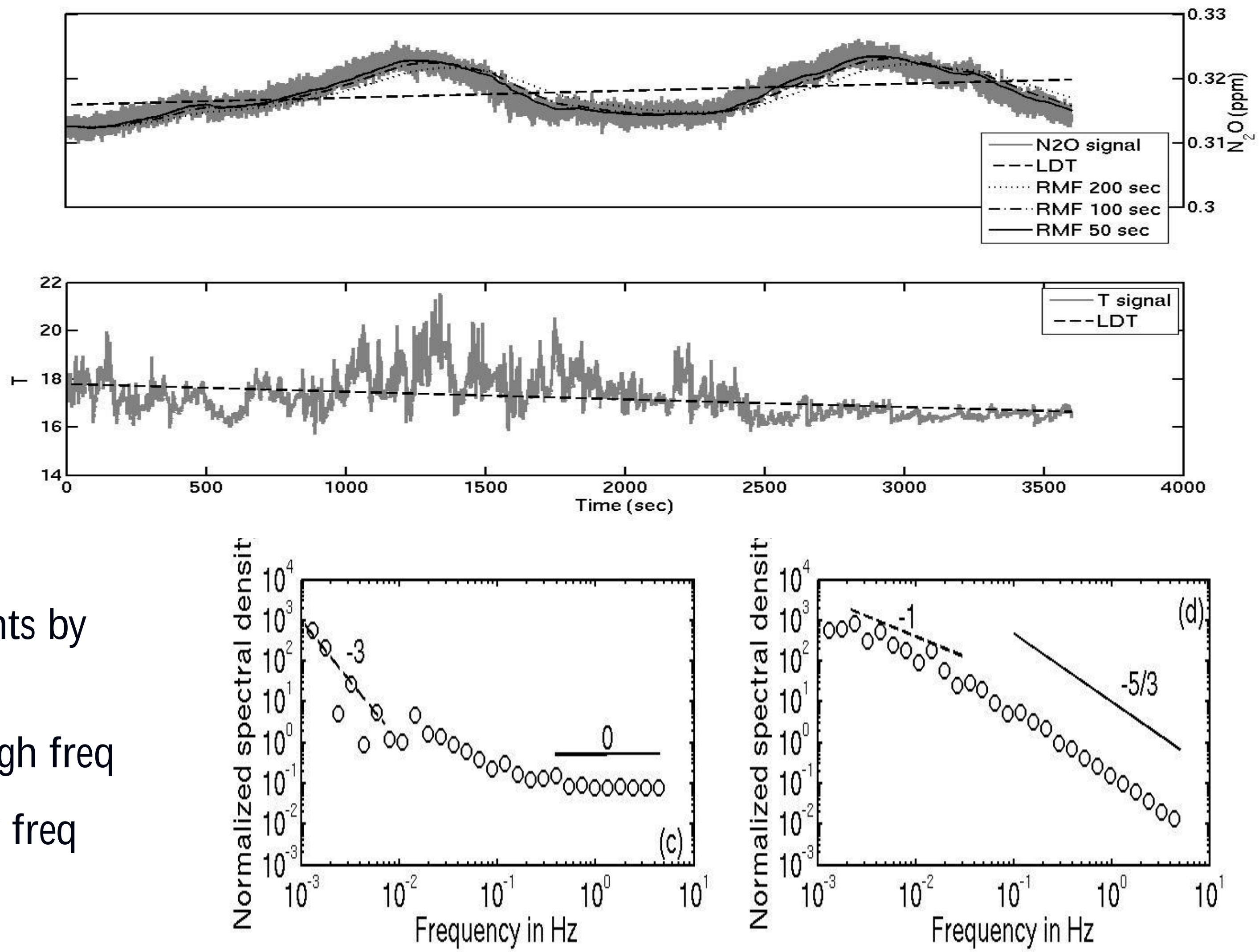
- If the measured normalized standard deviation deviates less than 30% from the model, the turbulence is considered well developed

$$ITC_{\sigma} = \left| \frac{(\sigma_x / X_*)_{\text{mod}} - (\sigma_x / X_*)_{mes}}{(\sigma_x / X_*)_{\text{mod}}} \right|$$

Parameter	z/L	c_1	C_2
σ_w/u_*	0>z/L>-0.0032	1.3	0
	-0.0032>z/L	2.0	1/8
σ_u/u_*	0>z/L>-0.0032	2.7	0
	-0.0032>z/L	4.15	1/8
σ_T/T_*	0.02<z/L<1	1.4	-1/4
	0.02>z/L>-0.062	0.5	-1/2
	-0.062>z/L>-1	1.0	-1/4
	-1>z/L	1.0	-1/3

From Lee et al. 2004, p.192
Originally from other papers.

Spectral analysis >>>to verify that your EC system is working properly.



N2O measurements by Campbell TDL

- White noise at high freq
- Laser drift at low freq

(from Mammarella et al., 2010, BG)

Quality Flag system in EddyUH (Foken et al., 2004)

Flag of the general data quality	Steady state test according to Equation (4.38)	Integral turbulence characteristics according to Equation (4.41)
1	1	1–2
2	2	1–2
3	1–2	3–4
4	3–4	1–2
5	1–4	3–5
6	5	≤ 5
7	≤ 6	≤ 6
8	≤ 8	≤ 8
	≤ 8	6–8
9		one flag equal to 9

Flux random uncertainty

Flux uncertainty as random error (δ), is the measure of one standard deviation of 30 min covariance (turbulent flux) observed over an averaging period *T.*

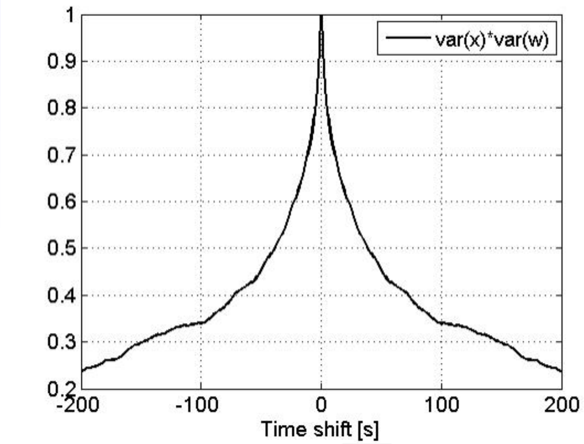
Random errors in flux measurements arise from a variety of sources. These include:

1) The stochastic nature of turbulence (Wesely and Hart, 1985), and associated sampling errors, including incomplete sampling of large eddies, and uncertainty in the calculated covariance between the vertical wind velocity (w) and the scalar of interest (χ_c);

2) Errors due to the instrument system, including random errors in measurements of both w and χ_c.

FLUX RANDOM ERROR ESTIMATION IN EDDYUH (FINKELSTEIN AND SIMS, 2001)

$$\sigma_F^2 = \frac{1}{n}\left[\sum_{p=-m}^{m} \overline{w'w'}(p)\overline{c'c'}(p) + \sum_{p=-m}^{m} \overline{w'c'}(p)\overline{c'w'}(p)\right]$$

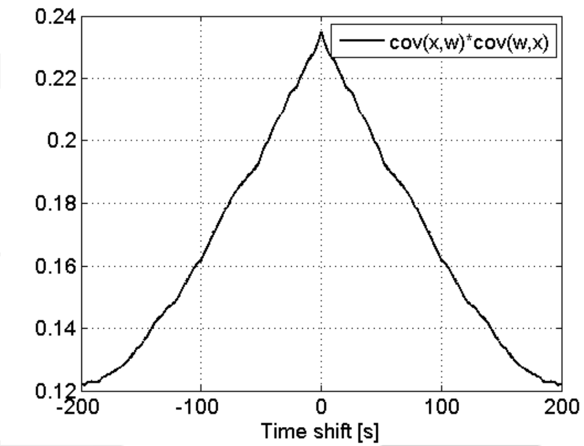


where

$$\overline{w'w'}(p) = \frac{1}{n}\sum_{i=1}^{n-p}\left(w(t_i) - \overline{w}\right)\left(w(t_{i+p}) - \overline{w}\right)$$

and

$$m = 200 \qquad n = 18000$$



This gives error variance of the covariance. In the calculation square root of this was used.

Other Methods for estimating Flux uncertainty

$$\delta_{IF} = \sqrt{\frac{2\tau_\varphi}{T}\left[\overline{(w'c')^2} - \overline{w'c'}^2\right]}$$

"instantaneous flux" (Wyngaard, 1973)

$$\delta_{SE} = \sigma_\Phi N^{-1/2}$$

"standard error" (Vickers and Mahrt, 1997)

$$\delta_{FM} = \sqrt{T^{-1}\int_{-\infty}^{\infty} S_w(f)S_c(f) + \left|S_{wc}(f)\right|^2 df}$$

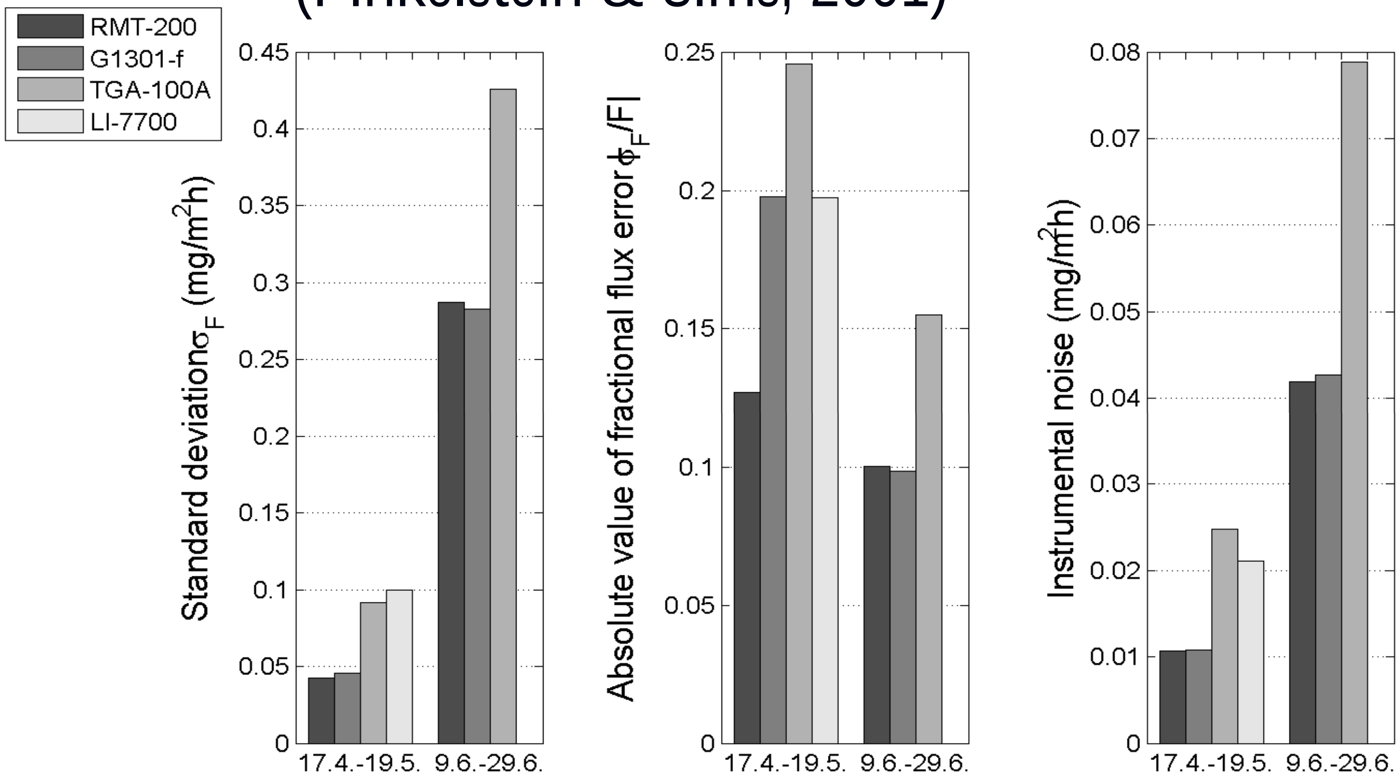
"Fourier method"(Rannik and Vesala, 1999)

CH4 flux random uncertainty

(Peltola, MSc thesis)

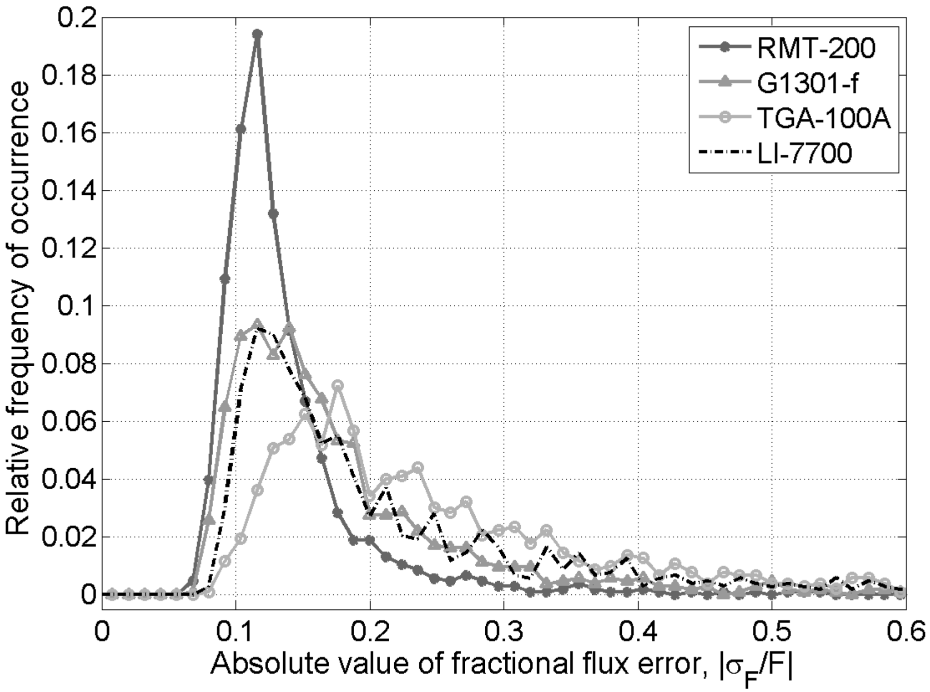
Instrumental noise according to (Billesbach, 2011)

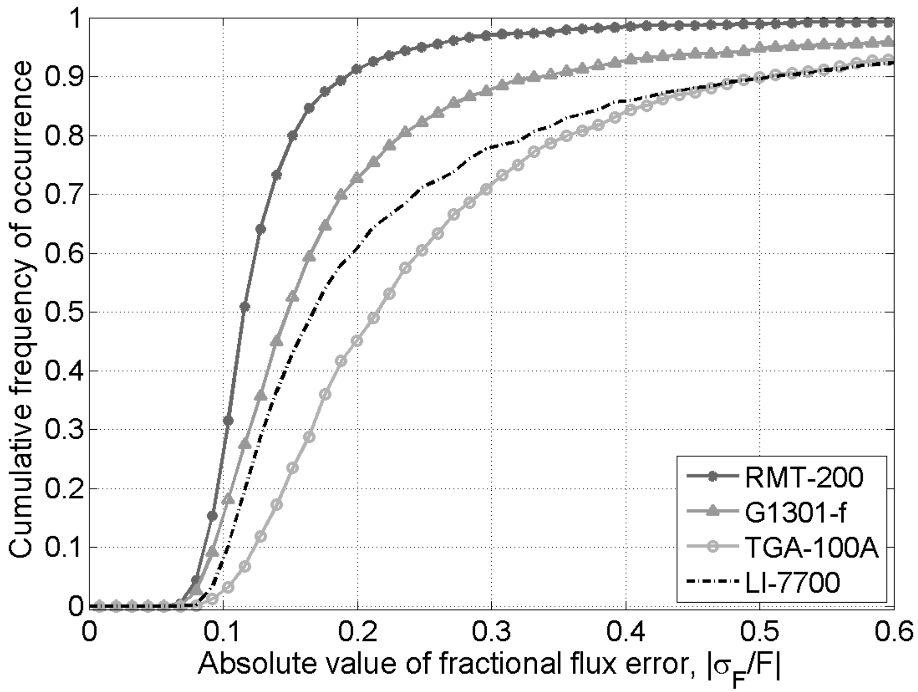
Standard deviation of covariance according to (Finkelstein & Sims, 2001)



CH4 flux uncertainty

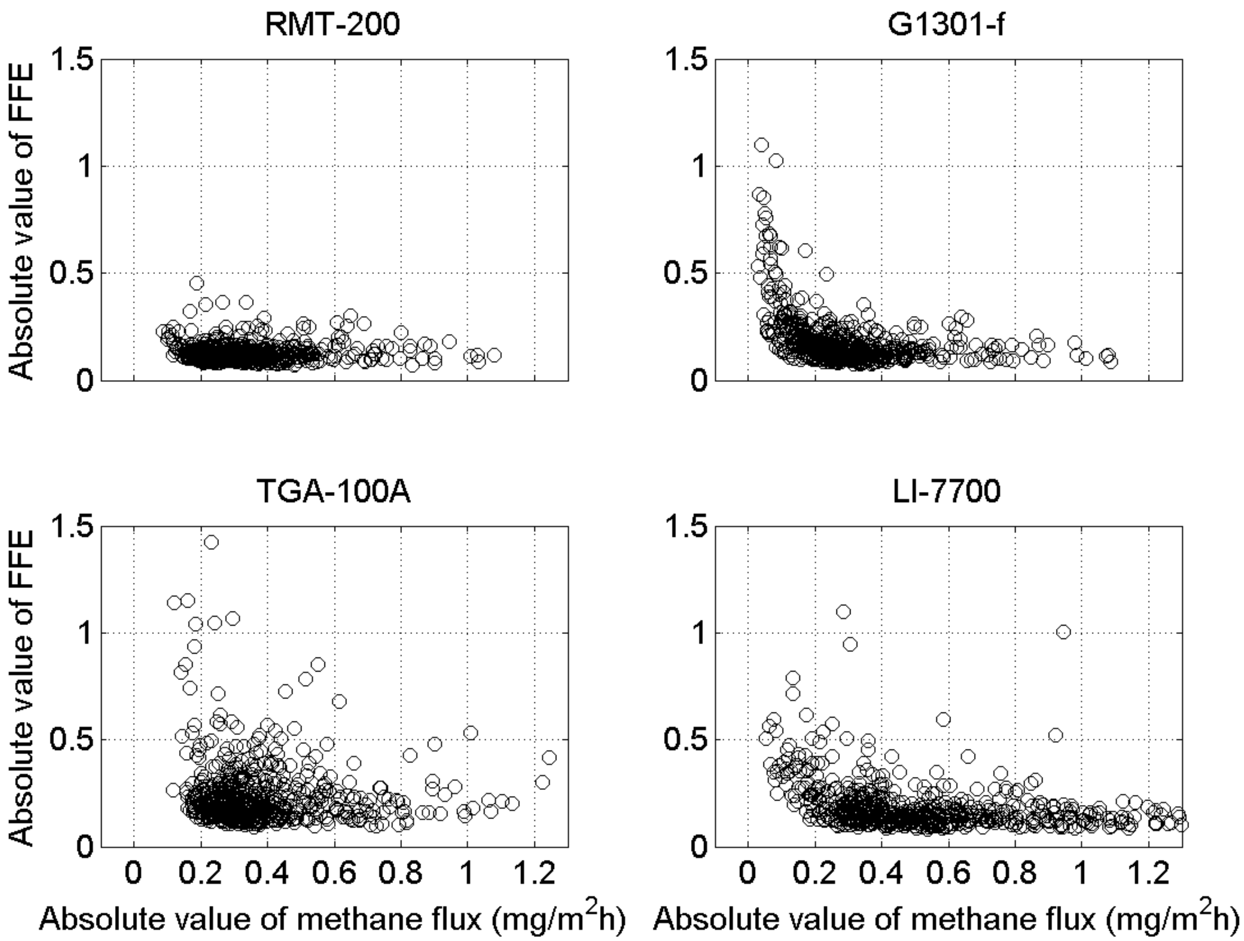
RMT-200 has the narrowest distribution



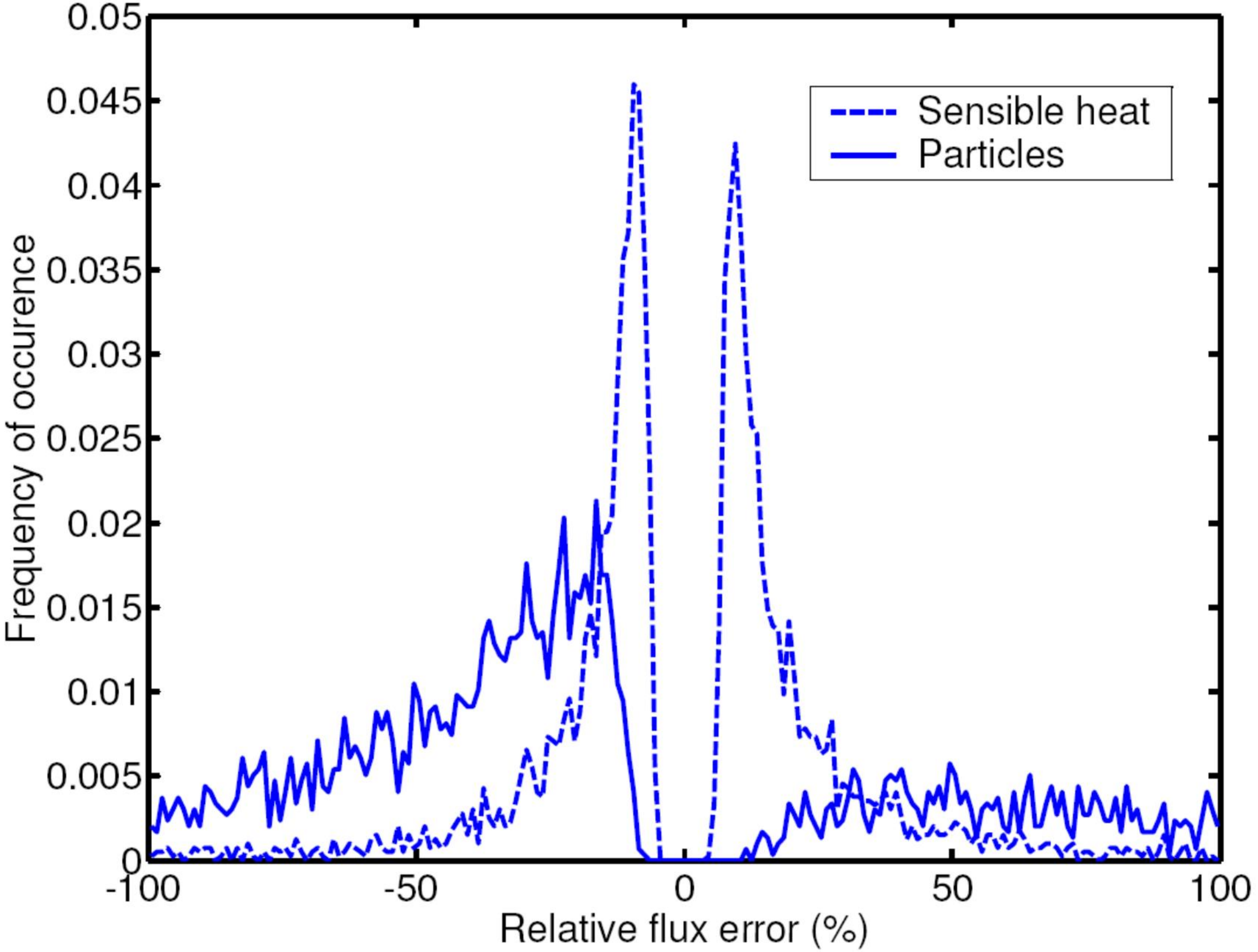


CH4 Flux uncertainty

RMT-200 measures also small fluxes accurately



Flux uncertainty estimations

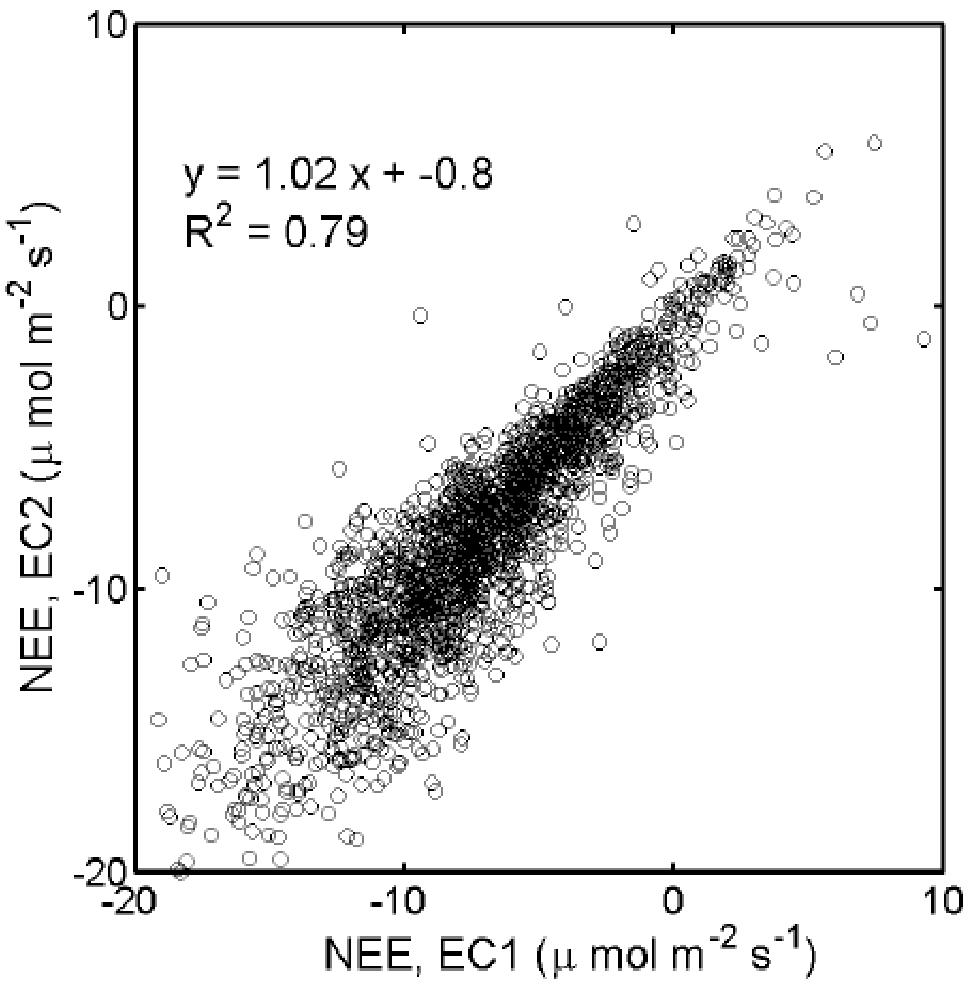


Particle flux data selection according to random flux error estimates and thresholds

L < 0 Unstable	ΔF_{IF} with estimated τ_φ			ΔF_{IF} with $\tau_\varphi = z_e / U$			ΔF_{SP}		
	% passing	% F< 0	100* v_d/u_*	% passing	% F< 0	100* v_d/u_*	% passing	% F< 0	100* v_d/u_*
RFE < 1	32.3	72.0	0.274	28.1	73.4	0.305	33.9	71.4	0.263
RFE< 0.5	17.6	82.0	0.596	13.3	85.5	0.821	20.1	80.6	0.494
RFE< 0.3	7.4	93.2	1.08	4.55	96.6	1.50	10.0	89.8	0.839
L > 0 Stable	% passing	% F < 0	100* v_d/u_*	% passing	% F < 0	100* v_d/u_*	% passing	% F < 0	100* v_d/u_*
RFE < 1	38.1	76.0	0.247	30.1	78.9	0.300	40.3	74.8	0.240
RFE < 0.5	26.0	81.6	0.409	15.0	86.6	0.568	29.3	80.1	0.319
RE F< 0.3	15.6	87.5	0.556	4.8	92.6	0.937	19.2	85.6	0.444

An example of the “same flux“ measured by two different EC systems (Rannik et al., 2006)

- Measured at SMEAR II
- Two EC systems located approx. at 30 m distance
- Measuring almost the same flux footprint
- But not exactly the same realisations of turbulence
- Turbulence not (fully) independent



The uncertainty of annual C balance is 80 g(C) m-2, e.g. 30% of annual net exchange.

To take home....

- Random errors tend to be quite large at the half-hourly time scale and cannot be ignored even in the context of annual flux integrals, especially as they propagate through to gap-filled and partitioned net ecosystem exchange (NEE) time series.

- Typical random flux error for EC fluxes in the order of 20%.

- Can be much larger depending on the instrumental noise (signal to noise ratio).

- Random flux error should not be used as quality criteria (for filtering out the data).