On the need for uncertainty assessment of long-term eddy-covariance measurements

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Introduction:

Eddy-covariance measurements are performed at several hundred sites all over the world on a long-term basis. The increasing demand on standardised and comprehensive quality flagging and uncertainty quantification of these fluxes has led to this review of established quality assessment procedures and the development of a strategy, focusing on automatically applicable tests on high-frequency data, expanding existing tests on statistics, fluxes and corrections, plus quantification of errors which will be used within the Helmholtz-project TERENO.

Overview of the test data sets

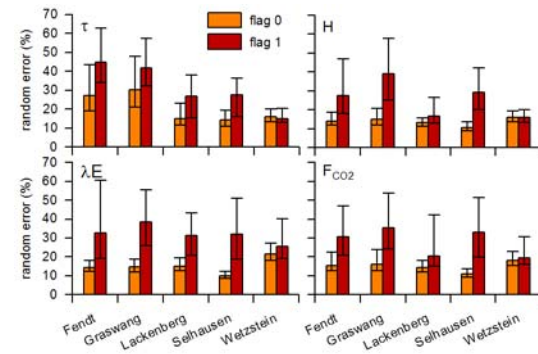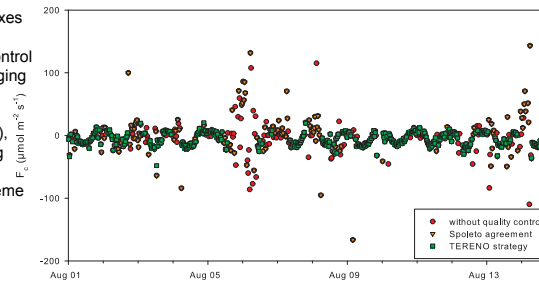| Site name	Operator	Ecosystem	Measurement height (a.g.l.*)	Sensor combination	Data period
Fendt	KIT	grassland in pre-alpine valley	3.5 m	CSAT3/ LI-7500	25/07/2010 – 23/08/2010
Graswang	KIT	grassland in pre-alpine valley	3.5 m	CSAT3/ LI-7500	25/07/2010 – 23/08/2010
Lackenberg	KIT	wind throw on low mountain range	9.0 m	CSAT3/ LI-7500	25/07/2010 – 23/08/2010
Selhausen	FZJ	agricultural land, sugar beet	2.5 m	CSAT3/ LI-7500	01/06/2011 – 30/06/2011
Wetzstein	MPI-BGC	Spruce forest on low mountain range	30.0 m	Solent-R3/ LI-6262	15/07/2006 – 13/08/2006

Table 1

Figure 1: Relative random flux error (%) for the investigated fluxes (median, lower and upper quartiles) as a function of their quality flags (orange: highest quality= flag 0, red: medium quality=flag1).

Tests on high-frequency data:
- **usage of internal quality tests** and diagnostic flags (e.g. Campbell CSAT3, Li-Cor LI-7500).
- **spike test** based on Median Absolute Deviation (MAD) for outlier or spike detection
- screening of the high-frequency data for **instrumental plausibility**

Tests on statistics:
assumptions of the EC method (simplified flagging after FW96):
- **stationarity** of the means
- **ITC**: well-developed turbulence
- zero mean **vertical wind velocity**
- **interdependence** of flux conversions and corrections on fluxes

Figure 2: CO₂-fluxes for Graswang: without quality control (red circles), flagging according to FW96/Spoleto (orange triangles), filtering according to quality assessment scheme proposed for TERENO (green squares)

	Fendt	Graswang	Lackenberg	Selhausen	Wetz-stein
τ	1/1277	5/1348	0/1044	1/1383	2/1395
H	1/916	7/1121	21/882	9/1262	19/1153
λE	2/820	5/850	7/762	13/1127	18/1059
Fc	3/757	9/888	8/765	7/1113	2/1064

Table 2: Results of the MAD-based outlier test (Papale et al. 2006) after application of the proposed flagging scheme: (number of detected values by the Papale et al. 2006 procedure / number of available data with flag 0 and 1. 1440 data records were tested for each site.

Results:
- discarding of momentum flux data due to the quality flagging is less than 10%
- **noise errors** typically ≤1%
- **random errors** 20-30%
- highest data quality associated with smallest random errors
- systematic errors: existence to be known, but difficult to account for

Conclusion:
Combination of diagnostic flags, robust spike detection, interdependence of fluxes, and footprint analysis improved the quality assessment strategy compared to established ones
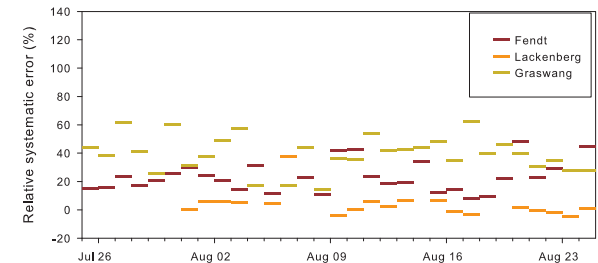
Errors and uncertainty:
- **instrumental noise:**
  only present in first term of auto-covariance function → error propagation
- **random error:**
  ~ 1 / √ # **independent** observations, Finkelstein & Sims (2001): the statistical variance of a covariance is expressed as function of its **auto-covariances and cross-covariance** → **detrending** through high-pass filter **before** calculation of random error
- **systematic error:**
  the total surface flux is not represented by the covariance in case of large eddies; indirect error definition via energy balance ratio:
  $$\sigma_F^{sys} = F \cdot \left(\frac{1}{EBR} - 1 \right) \qquad R_g > 20 \; \text{W m}^{-2}$$
- **source area – representativeness**
  application of footprint model (Kormann & Meixner, 2001) on each averaging interval

Figure 3: Relative systematic errors (%) for three test data sets determined from the energy balance ratio

References:

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