TERENO
TERRESTRIAL ENVIRONMENTAL OBSERVATORIA

HELMHOLTZ ASSOCIATION

Universität Trier

A scheme for assessment of quality and uncertainty for long-term eddy-covariance measurements

Clemens Drüe[3], M. Mauder[1], M. Cuntz[2], A. Graf[4], C. Rebmann[2], H. P. Schmid[1], M. Schmidt[4], and R. Steinbrecher[1]

[1] Institute for Meteorology and Climatology – Atmospheric Environmental Research (IMK-IFU), Karlsruhe Institute of Technology (KIT), Garmisch-Partenkirchen, Germany
[2] UFZ – Helmholtz Centre for Environmental Research, Leipzig, Germany
[3] Trier University, Environmental Meteorology, Trier, Germany
[4] Forschungszentrum Jülich, Institute for Bio- and Geosciences – Agrosphere, Jülich, Germany

HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

JÜLICH FORSCHUNGSZENTRUM

KIT Karlsruher Institut für Technologie

Introduction – Motivation

- **Goal: measure transports / fluxes between ecosystem and atmosphere**
- **TERENO Project produces extensive amount of data**
  - 10+ sites running for 10+ years
  - Data rate 20 Hz: 1.89216 x 10^{10} lines per year
- **Requirements:**
  - Automatically provide usable output
  - Yield comparable flux data
  - Provide simple quality flags & quantitative error estimates

Introduction – Choice of methods

- **Comprehensive quality assessment scheme**
  - detect instrumental failure
  - check validity of assumptions for EC method
  - quantify errors / uncertainty of flux values
  - Assess representativeness
- **Enable users to decide how to use data**
  - Simple flag system: good (0) / moderate (1) / bad (2)
    - Used by Vickers&Mahrt (1994) and CarboEurope-IP project
    - “moderate” data: not good for turbulence research, but ok for long-term observation

Quality control (1/2)

- **Tests on high-frequency data**
  - **Diagnostic values** from instruments
  - **Spike removal** using MAD
  - Plausibility screening vs. **instrumental / physical limits**
  - Rejected data replaced by **NaN**

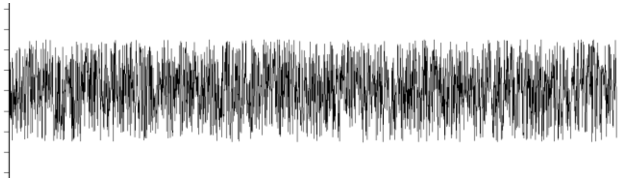
- **Calculation of fluxes etc.**
  - Using well established corrections
  - Schotanus, WPL, …

Quality control (2/2)

- **Tests on statistics (per averaging period)**
  - 90% high frequency data available (per avg. period)
  - Assumptions of the EC method (after Foken&Wichura,1996)
    - Stationarity of the means
    - Integral turbulence characteristic (well-developed turbulence)
    - Zero mean vertical wind
- **One flag per flux / averaging period**
  - Account for interdependence of conversions & corrections
    - by mutually increasing flag values

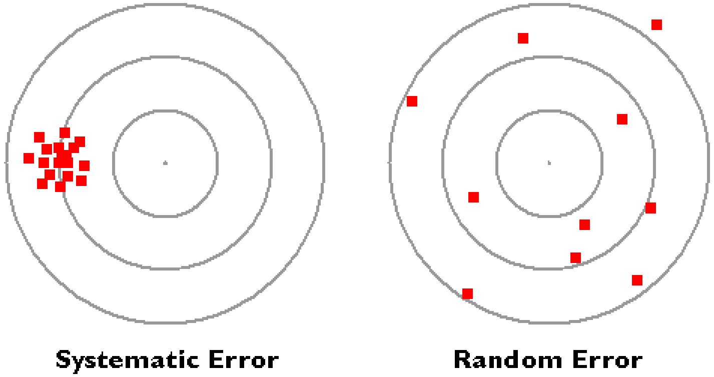
Errors and uncertainty – Overview

1) Instrumental noise

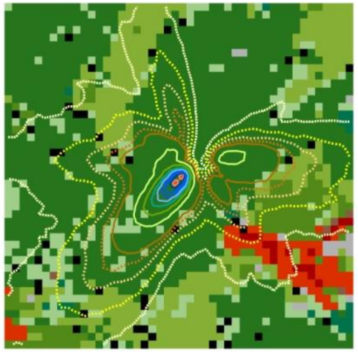


2) Random error

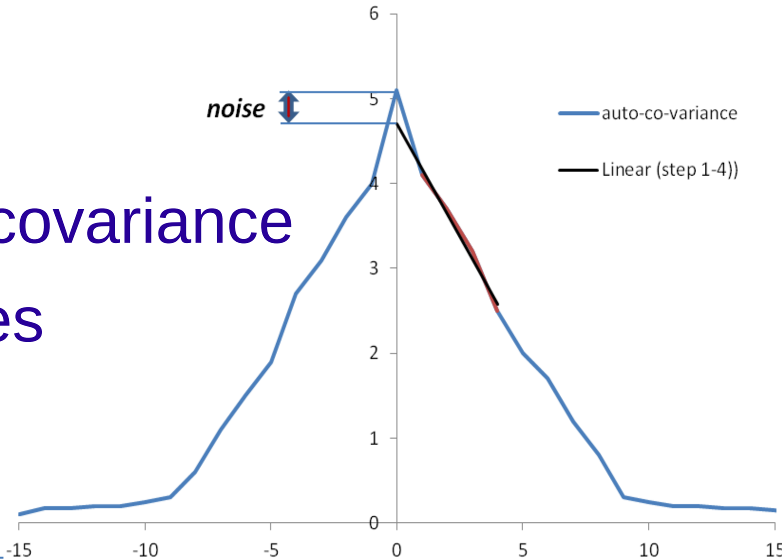
3) Systematic error



4) Representativity – Source area



Errors and uncertainty (1/2)



- **Instrumental noise**
  - Only present in 1st term of auto-covariance
  - Non-correlated across time series
    ⇒ error propagation
- **Random error**
  - generally ~ $1/\sqrt{\#}$ independent obs
  - What is independent ? Integral length scale ?
  - Scheme after Finkelstein&Sims (2001)
    - variance of a covariance as function of its auto-covariances and cross-covariance
    - calculated from detrended (copy of) dataset

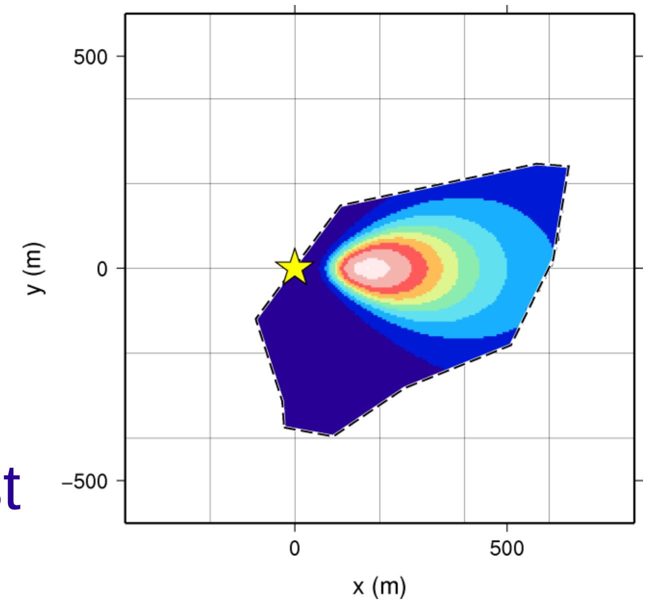
Errors and uncertainty (1/2)

- **Covariance does not represent total surface flux**
  - in presence of large eddies (e.g. "attached" to surface)
  - Indirect estimation by energy balance ratio **EBR**

$$EBR = \sum_{i=1}^{K}(H_i + \lambda E_i) \Big/ \sum_{i=1}^{K}(R_{n,i} - G_i - J_i)$$

$$\sigma_F^{sys} = F \cdot \left(\frac{1}{EBR} - 1\right) \qquad R_g > 20\ \mathrm{W\ m^{-2}}$$

- **Representativity – Source area**
  - Footprint-Model by Kormann&Meixner (2001)
    - Analytical, robust and fast
  - Output fraction from area of interest



Test data sets

Site	Ecosystem	Sensor height	Sensors	Data period (approx)
Fendt	grassland, pre-alpine	3.5 m	CSAT3 & LI-7500	Aug 2010
Graswang	grassland, pre-alpine	3.5 m	CSAT3 & LI-7500	Aug 2010
Lackenberg	Wind throw, low mountain range	9.0 m	CSAT3 & LI-7500	Aug 2010
Wetzstein	spruce forest, low mountain range	30.0 m	Solent-R3 & LI-6262	Jul 2006
Selhausen	Farmland, Lowlands	2.5 m	CSAT3 & LI-7500	Jun 2011

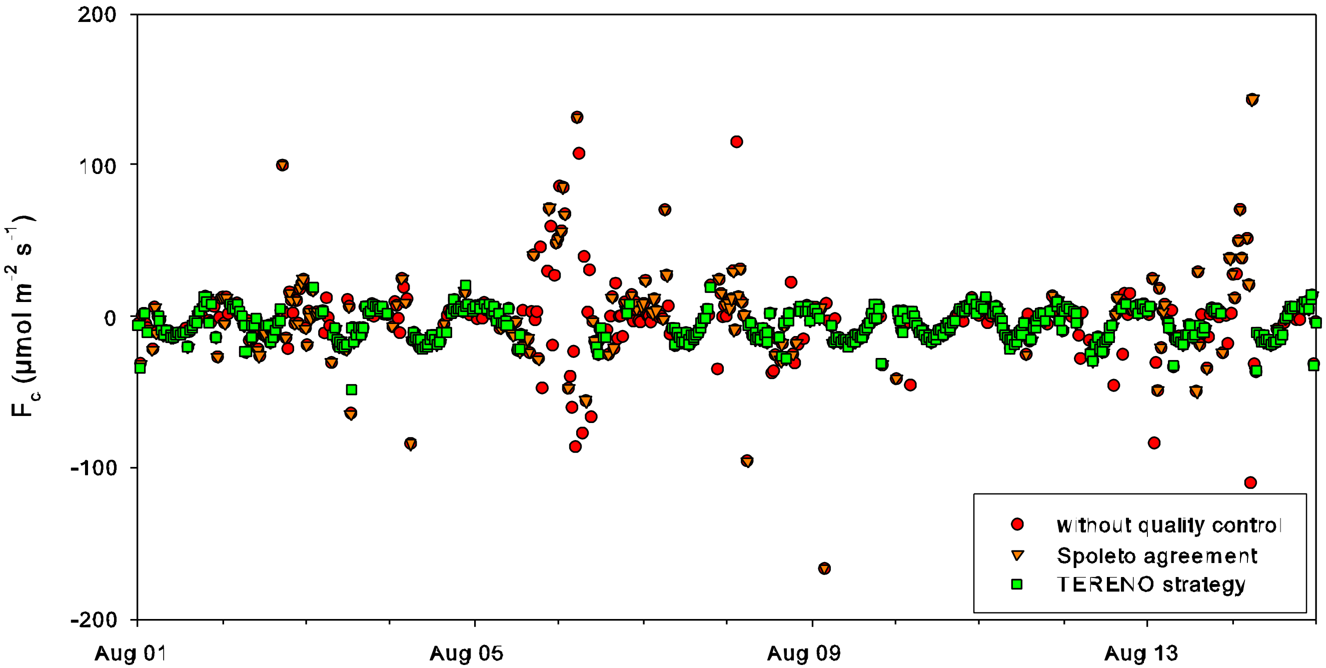




* Photo: Richard Webb
www.geograph.org.uk

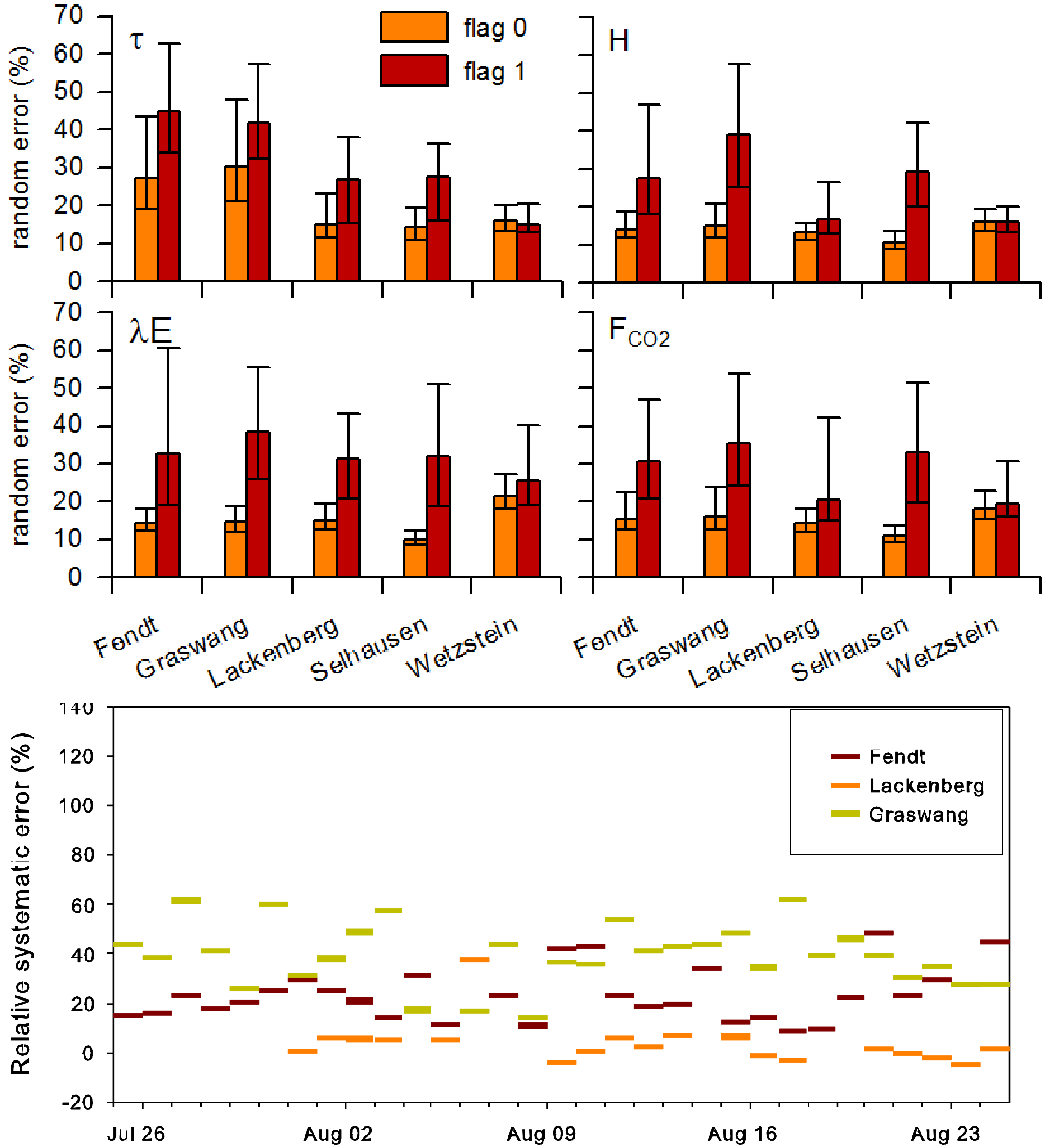
Results – Flagging

- **Example: F_{CO2} at Graswang**
  - Flagging accords with visual inspection
- **Typical flagging:**
  - τ
    - 65% flag 0
    - 25% flag 1
  - F_{CO2}
    - 45% flag 0
    - 15% flag 1



Results – Errors

- **Noise errors on average << 1%**
  - maximum relative noise error 9% (!)
- **Relative random error**
  - associated to quality flag
- **Systematic errors**
  - Lackenberg small ↔ most homogeneous



Results – Effectiveness of the scheme

- **Comparison to MAD-based outlier test (Papale et al. 2006)**
  - number of detected values/available data after QC
  - total 1440 data were available per data set

	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
F_{co2}	3/757	9/888	8/765	7/1113	2/1064

Conclusions

- **The quality assessment scheme presented is**
  - effective automatic for long-term EC measurements
  - combination of methods is improved compared to established ones
  - will become standard in then TERENO project
  - further development possible if science advances

- **Regular visual inspection of data still required**
  - Expert knowledge may help to retain more usable data

Thank you !

PS: Where can I get it ?

- ✓ Publication in review at Agricultural and Forest Meteorology.
- ✓ is available in software **TK3.1** (Bayreuth University, KIT: *matthias.mauder(§)kit.edu*),
- ✓ Extension **ECFrame** (Trier University) for **ECPACK** (Wageningen University) is in beta state,
- ✓ will be available as part of **EddySoft** (Max Planck Institute for Biogeochemistry, Jena)