FLAIR – 2009 , Grainau (DE) 6-11 September, 2009

# An assessment of the performance of a commercial eddy covariance system for N2O flux measurements under-field conditions

Ivan Mammarella(1*), Peter Werle(2), Mari Pihlatie(1), Sami Haapanala(1), Ralf Kiese(2) and Timo Vesala(1)

(1)Department of Physics, University of Helsinki, Finland
(2)Karlsruhe Research Centre, Garmisch-Partenkirchen, Germany

*ivan.mammarella@helsinki.fi

# Outline

- In this case study we explore the limits of eddy covariance flux measurements of N2O using state-of-the art equipments.
- We used datasets from two distinct measurement campaigns, carried out within two different forest ecosystems.
- Allan variance and spectral analysis are used as a tools to investigate the effect of instrumental drift of N2O signal on the EC flux.
- Systematic and Random uncertainty of N2O flux observations.
- Chamber flux data are used as reference. Recommendations how to treat data for post-processing are derived from the assumption that below-canopy EC flux measurements should match the temporal pattern and magnitude of chamber flux measurements.

# Overview

- Nitrous oxide ($N_2O$) is a strong GHG having the greatest GWP over a long period (100 years), which is about 300 times larger than the GWP of $CO_2$ (IPCC, 2001).

- Microbial activity in soil ecosystems is the major source of $N_2O$ to the atmosphere (IPCC, 2001).

- Key factors of $N_2O$ emissions: soil moisture, temperature and nitrogen availability (Butterbach-Bahl et al., 2002, Papen and Butterbach-Bahl, 2004).

- Agricultural soils are the major sources of $N_2O$, however, due to their large areal coverage, forest soils have a substantial contribution to the total emissions of $N_2O$ (e.g. Skiba et al., 1994; Kesik et al., 2005).

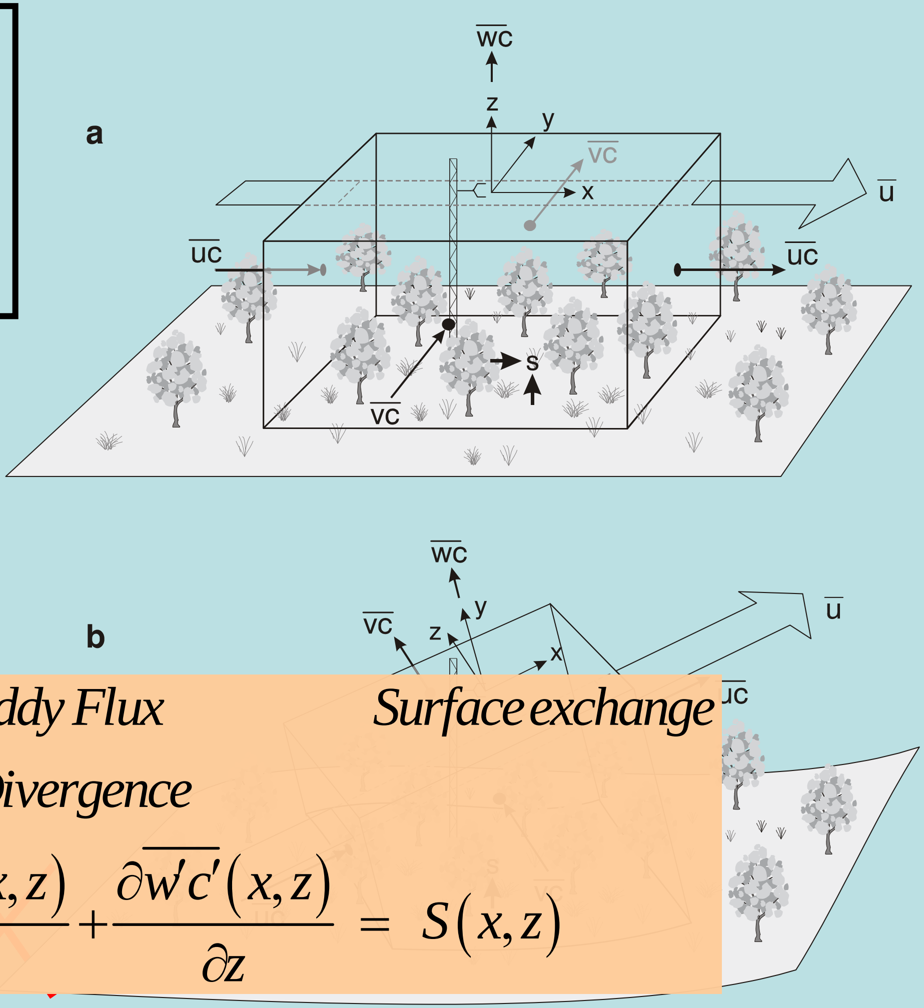
- How to estimate $N_2O$ emissions: closed chamber versus micrometeorological techniques.

- Thanks to recent development of fast response N2O analyzers based on spectroscopic techniques (TDL and QCL spectrometers), the eddy covariance method has become an approach, which is potentially suitable for measuring long-term and spatially integrated N2O fluxes.

- Recent studies (Pihlatie et al., 2005; Eugster et al., 2007, Kroon et al., 2007) reported large uncertainty and temporal variability of EC N2O fluxes, reported by these studies, is related either to biogeochemical soil processes and/or several systematic and random error sources of the EC measurements.

# Our main task is to estimate NEE

$$\int_0^{z_m} \frac{\partial \bar{c}}{\partial t} dz + \overline{w'c'}(z_m) = \bar{S}$$




*Storage* | *Advective Flux Divergence* | *Eddy Flux Divergence* | *Surface exchange*

$$\frac{\partial \bar{c}}{\partial t} + \bar{u}\frac{\partial \bar{c}(x,z)}{\partial x} + \bar{w}\frac{\partial \bar{c}(x,z)}{\partial z} + \frac{\partial \overline{u'c'}(x,z)}{\partial x} + \frac{\partial \overline{w'c'}(x,z)}{\partial z} = S(x,z)$$

How to measure the turbulent motion and transport (fluxes) in the ABL. **Eddy Covariance Technique**

**(nice overview on Tuesday by Dayle McDermitt)**

# Soroe campaign / May-June 2003

**Location:** Denmark

Beech forest

Canopy height: 25 m

# Kalevansuo campaign / 25 April – 27 June 2007

**Location:** Southern Finland

Pine forest

Canopy height: 15 m

| Site | Kalevansuo | Sorø |
|---|---|---|
| Sonic anemometer | CSAT3 -Campbell | Solent 1012 - Gill |
| $N_2O$ analyser | TGA 100 A - Campbell | TGA 100 - Campbell |
| $CO_2$ and $H_2O$ analyser | LiCor 7500 | - |
| Inlet height | 4 m | 3 m |
| $N_2O$ sampling tube | PE aluminium composite | PTFE Teflon |
| Length | 4m | 10 m |
| Outer/inner diameter | 9.75 mm / 4.25 mm | 6 mm / 4 mm |
| Dryer | 142 cm Nafion dryer (PD1000, Perma pure Inc.) | 142 cm Nafion dryer (PD1000, Perma pure Inc.) |
| Sample cell (length) | 1.5 m | 1.5 m |
| -volume | 480 ml | 480 ml |
| -flow | 15 slpm | 14 slpm |
| -pressure | 50 mbar | 70 mbar |
| -sampling cell response time (effective bandwidth) | 0.095 sec (1.67 Hz) | 0.14 sec (1.12 Hz) |

- The TDL was calibrated once during the measurement period using zero and span (290.3 ppb N2O) calibration gases.

- The 10Hz noise level (std) of TDL was estimated to be around 1.0 ppbv in the lab.

- The measured N2O lag time was about 1 sec for Kalevansuo and 2 sec for Sorø.

- The correction for density fluctuations (Webb et al., 1980) was not necessary for N2O flux.

Under the assumption of ergodicity and stationarity, the turbulent flux is simply estimated as

$$F = \overline{w'c'}$$

In covariance calculation, the fluctuations x' (where x is either w or c) are obtained by

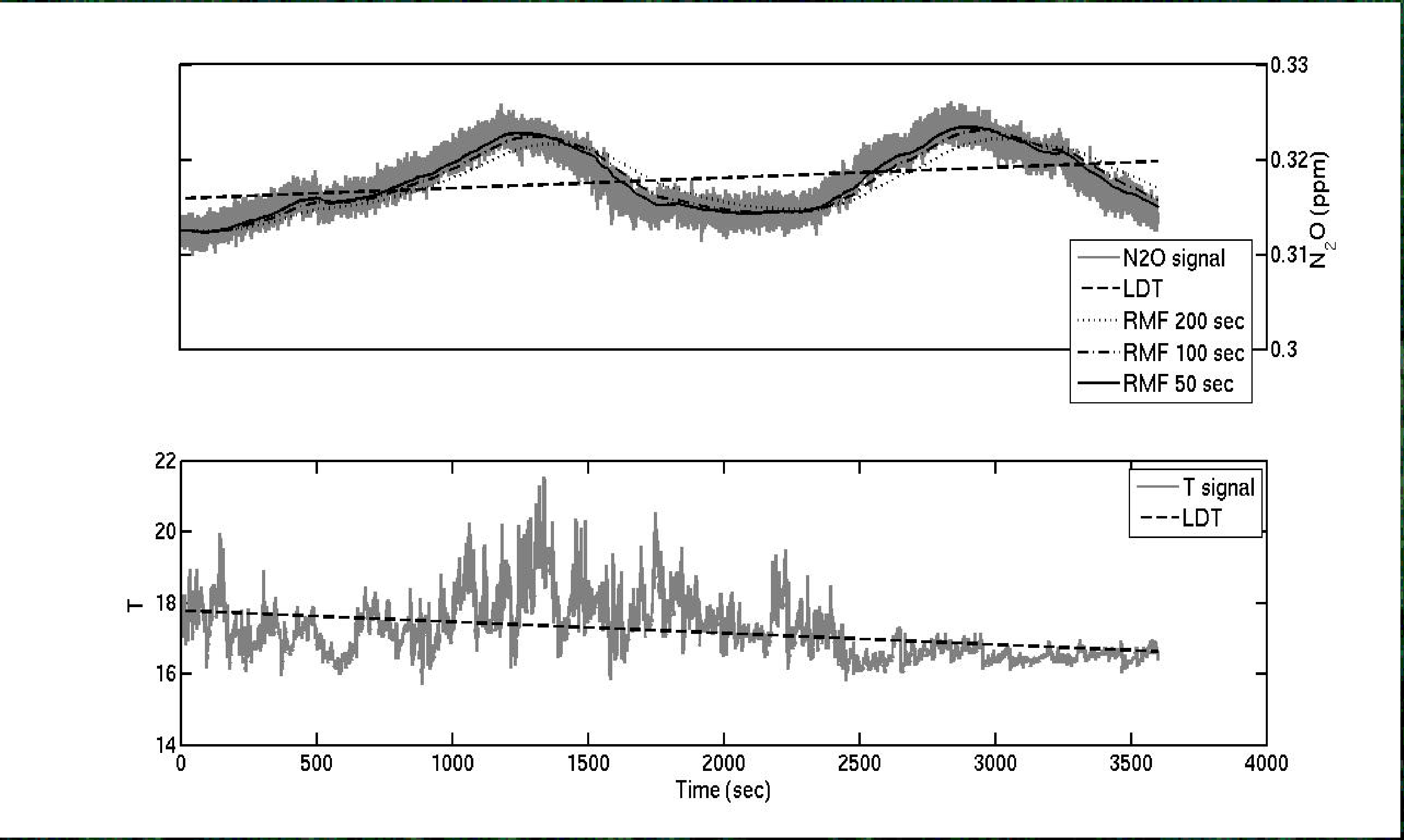
- $x'_t = x_t - \overline{x}$ (BA)
- $x'_t = x_t - X_t$

$$X_t = Sx_t + I$$ (LDT)

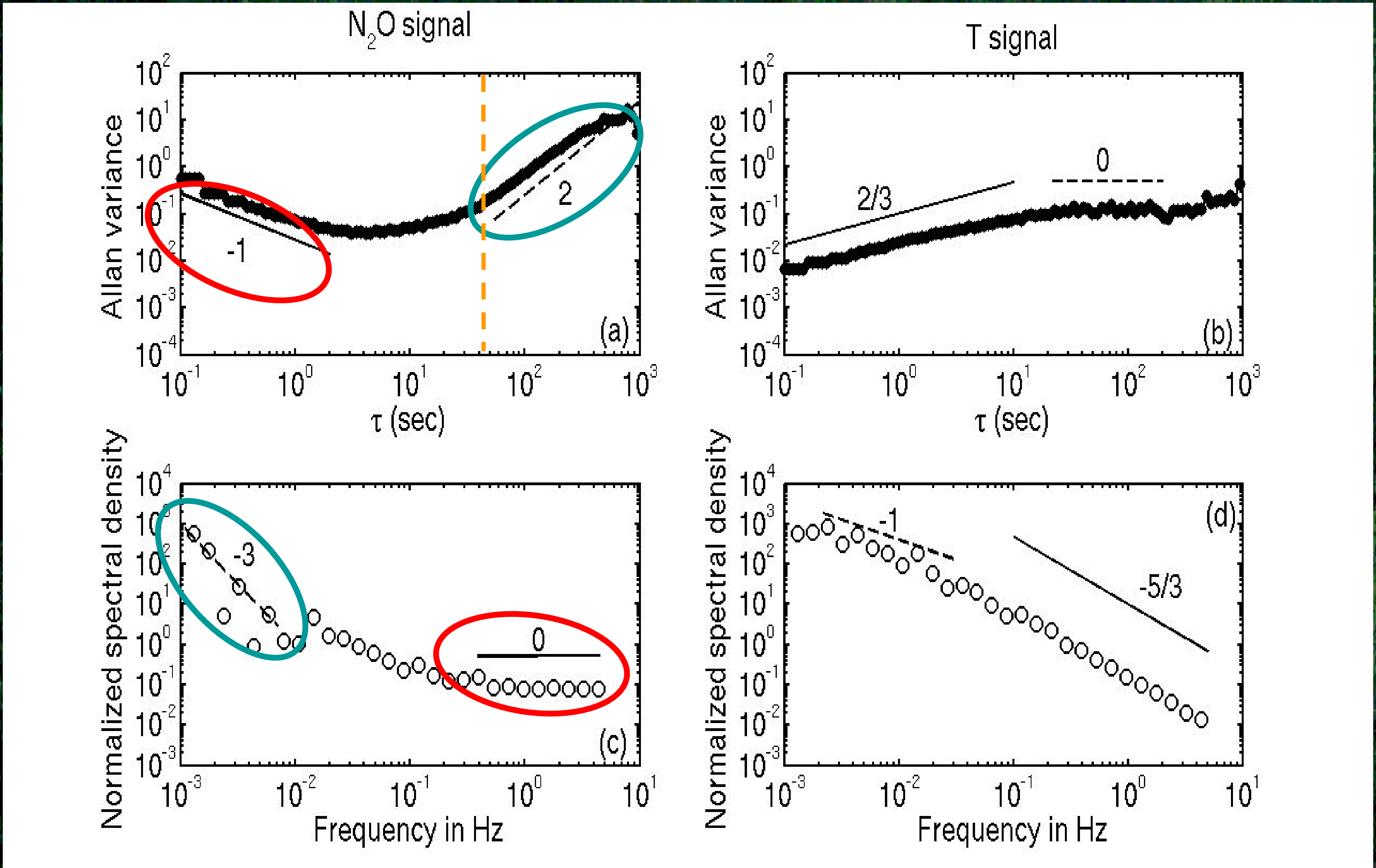
$$X_t = aX_{t-\Delta t} + (1-a)x_t$$

$$a = \exp(-\Delta t/\tau)$$ (RMF)

# Is instrumental drift a big issue for EC?



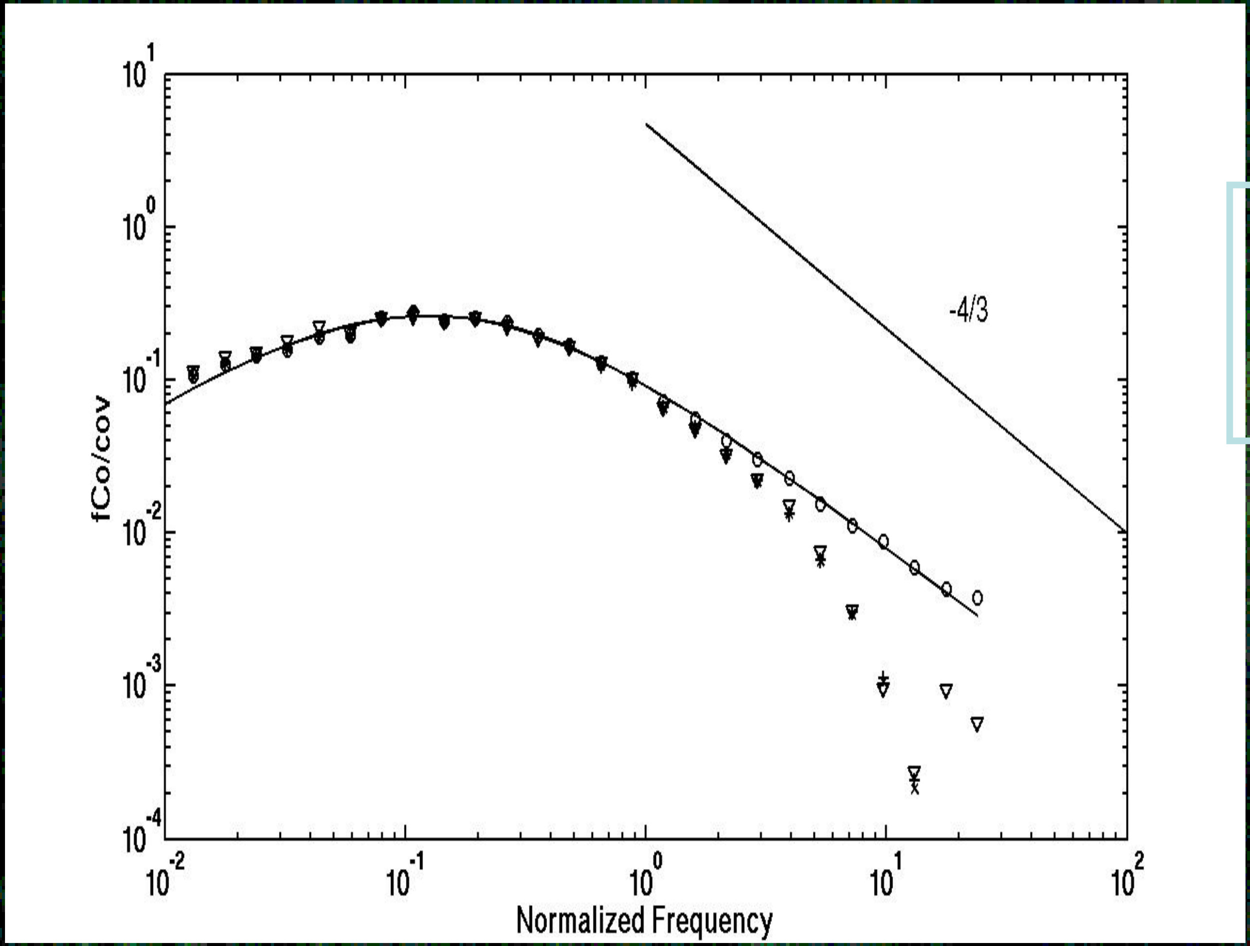
# Allan variance and spectral analysis




NOTE the correspondence between the slope α of the FFT spectrum and the slope β of the Allan variance, e.g. **$\alpha = (-\beta - 1)$.**

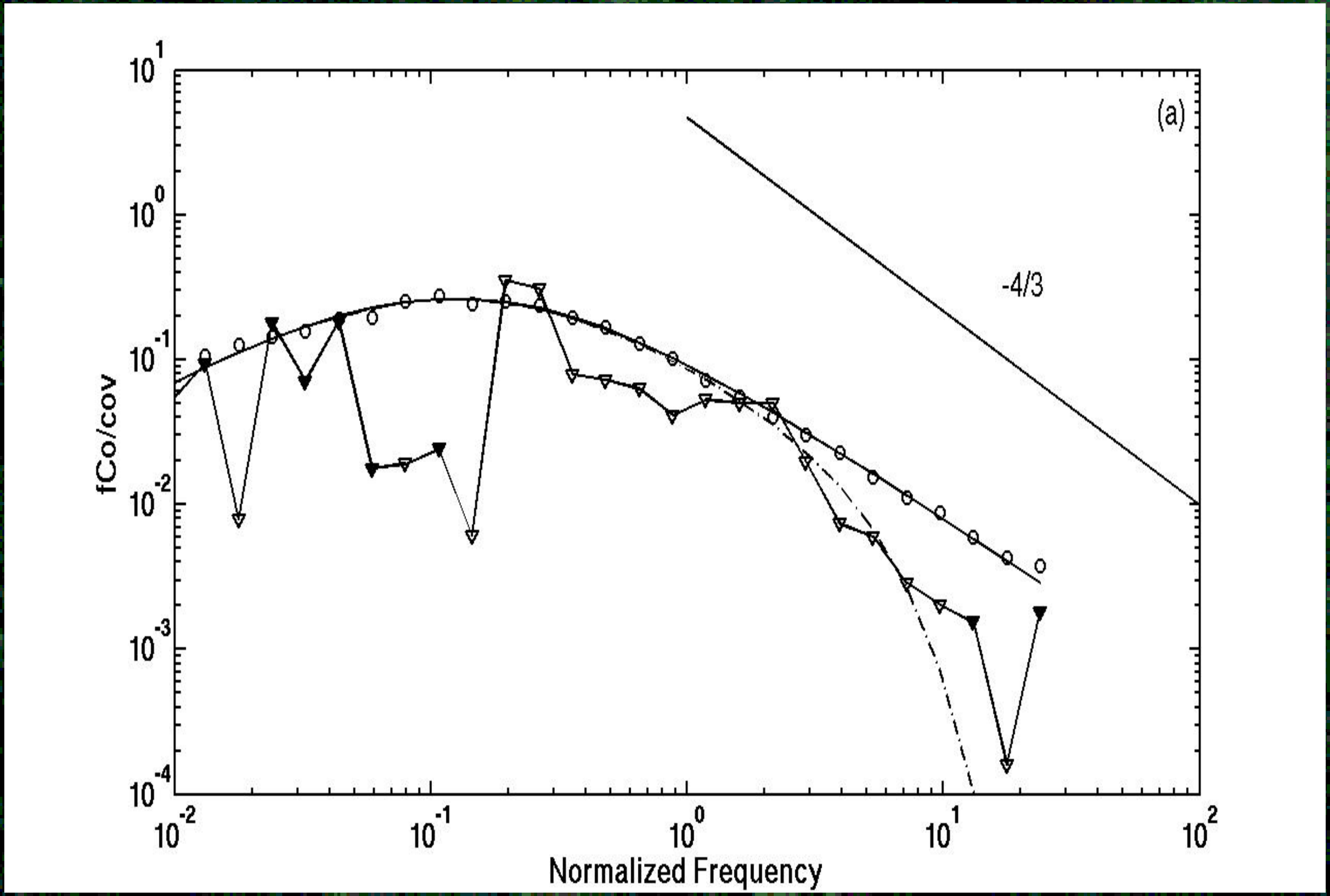
Systematic error of flux estimates →

Corrected by using co-spectral transfer function method.




For $CO_2$ the high frequency flux loss was about 5%.

# For N2O, the flux loss was about 10% .

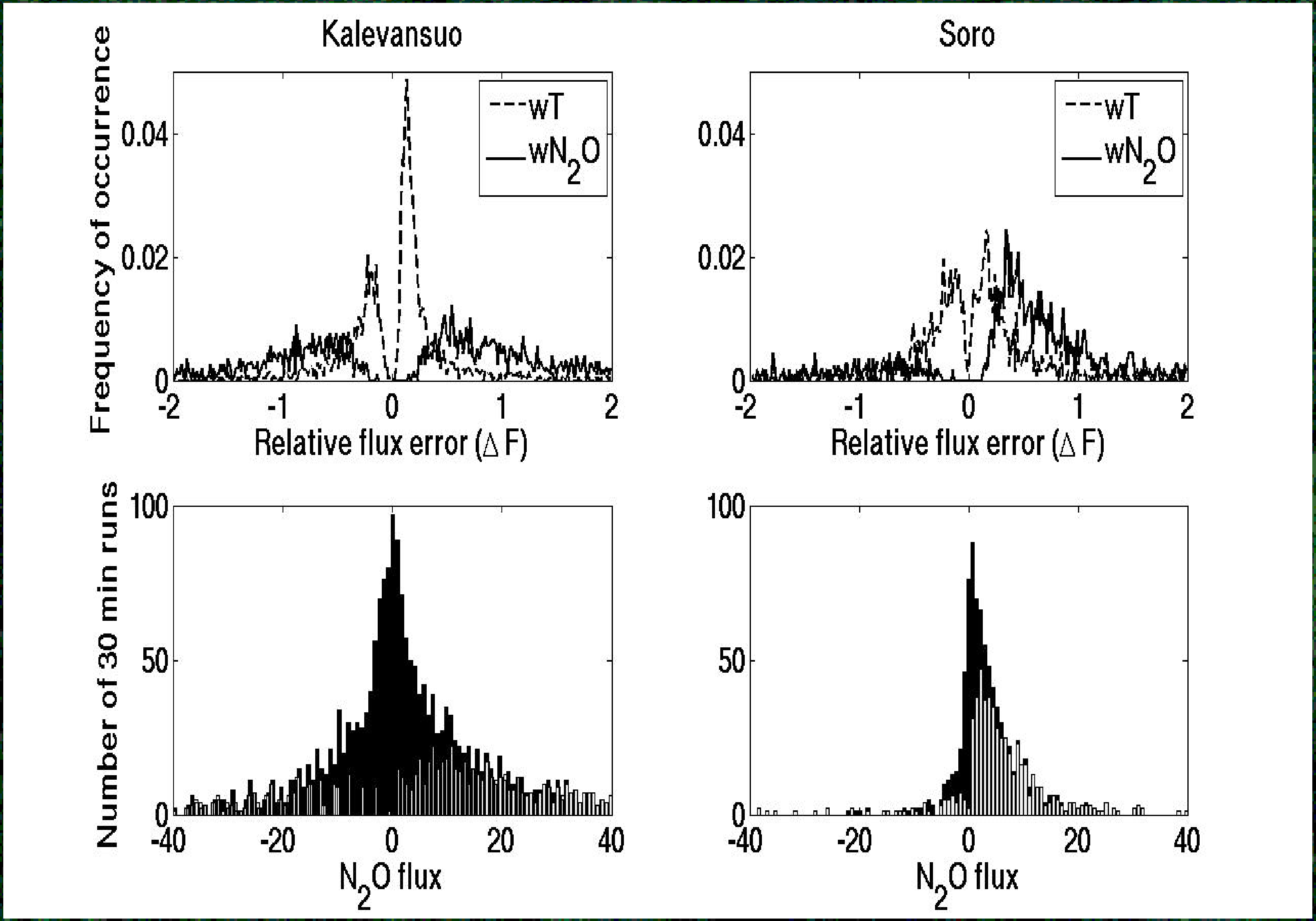


# Flux Random error

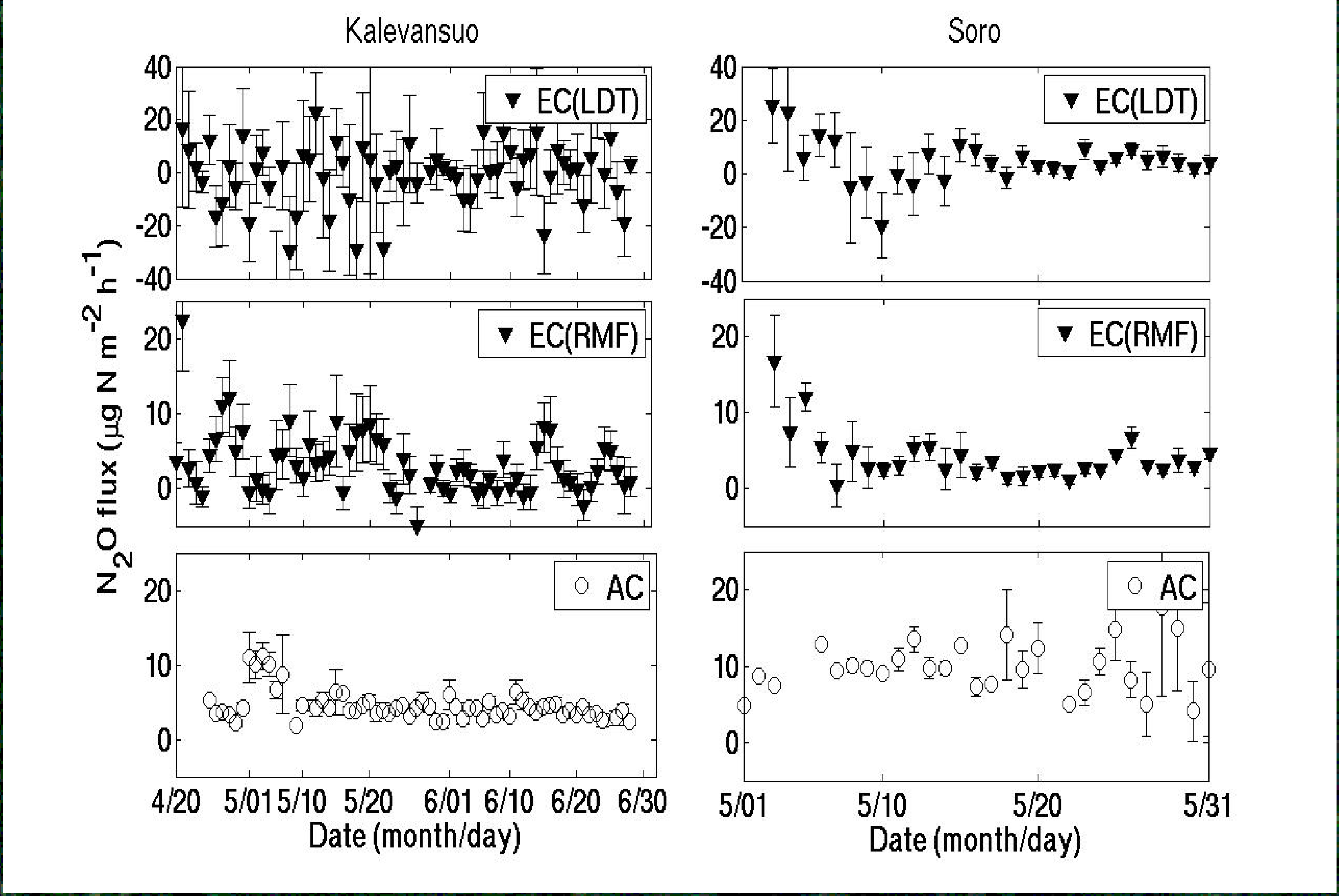
Flux uncertainty as random error (δ), being the measure of one standard deviation of the random uncertainty of turbulent flux observed over an averaging period *T*, was evaluated by three different approaches:

- $$\delta_{IF} = \sqrt{\frac{2\tau_{\varphi}}{T}\left[\overline{(w'c')^2} - \overline{w'c'}^2\right]}$$ (Wyngaard, 1973)
- $$\delta_{SE} = \sigma_{\Phi} N^{-1/2}$$ (Vickers and Mahrt, 1997)
- $$\delta_{FM} = \sqrt{T^{-1}\int_{-\infty}^{\infty} S_w(f)S_c(f) + \left|S_{wc}(f)\right|^2 df}$$ (Rannik and Vesala, 1999)

# Flux Random error



# Comparison of N2O flux estimates



# Summary

• N2O signal was often characterized by fringe effects.

• We demonstrated that signal processing strategies still are a key issue.

• Allan variance analysis was applied to real time measurements in order to choose a time constant of RMF.

• We demonstrated the applicability of cospectral transfer function method in sub-canopy layer.

• EC N2O flux measurements showed larger random uncertainty than the other EC fluxes (downward N2O fluxes have larger random error).

• The estimated RMF fluxes show less scatter and random variability, and they are in good agreement with soil chambers.