



Energy research Centre of the Netherlands

# **Eddy covariance observations of CH<sub>4</sub> and N<sub>2</sub>O**

**Towards more accurate emission estimates**

**P. Kroon<sup>1,2</sup>**

**A. Hensen<sup>1</sup>**

**H. Jonker<sup>2</sup>**

**A. Schrier-Uijl<sup>3</sup>**

**M. Tummers<sup>2</sup>**

**F. Bosveld<sup>4</sup>**

<sup>1</sup>ECN, the Netherlands; <sup>2</sup>TU Delft, the Netherlands;

<sup>3</sup>WU, the Netherlands; <sup>4</sup>KNMI, the Netherlands

*Presented at the iLEAPS Science conference, 24 – 28 August, Melbourne, Australia*

# Eddy covariance observations of $\text{CH}_4$ and $\text{N}_2\text{O}$ Towards more accurate emission estimates

P. Kroon<sup>1,2</sup>, A. Hensen<sup>1</sup>, H. Jonker<sup>2</sup>, A. Schrier-Uijl<sup>3</sup>, M. Tummers and F. Bosveld<sup>4</sup>

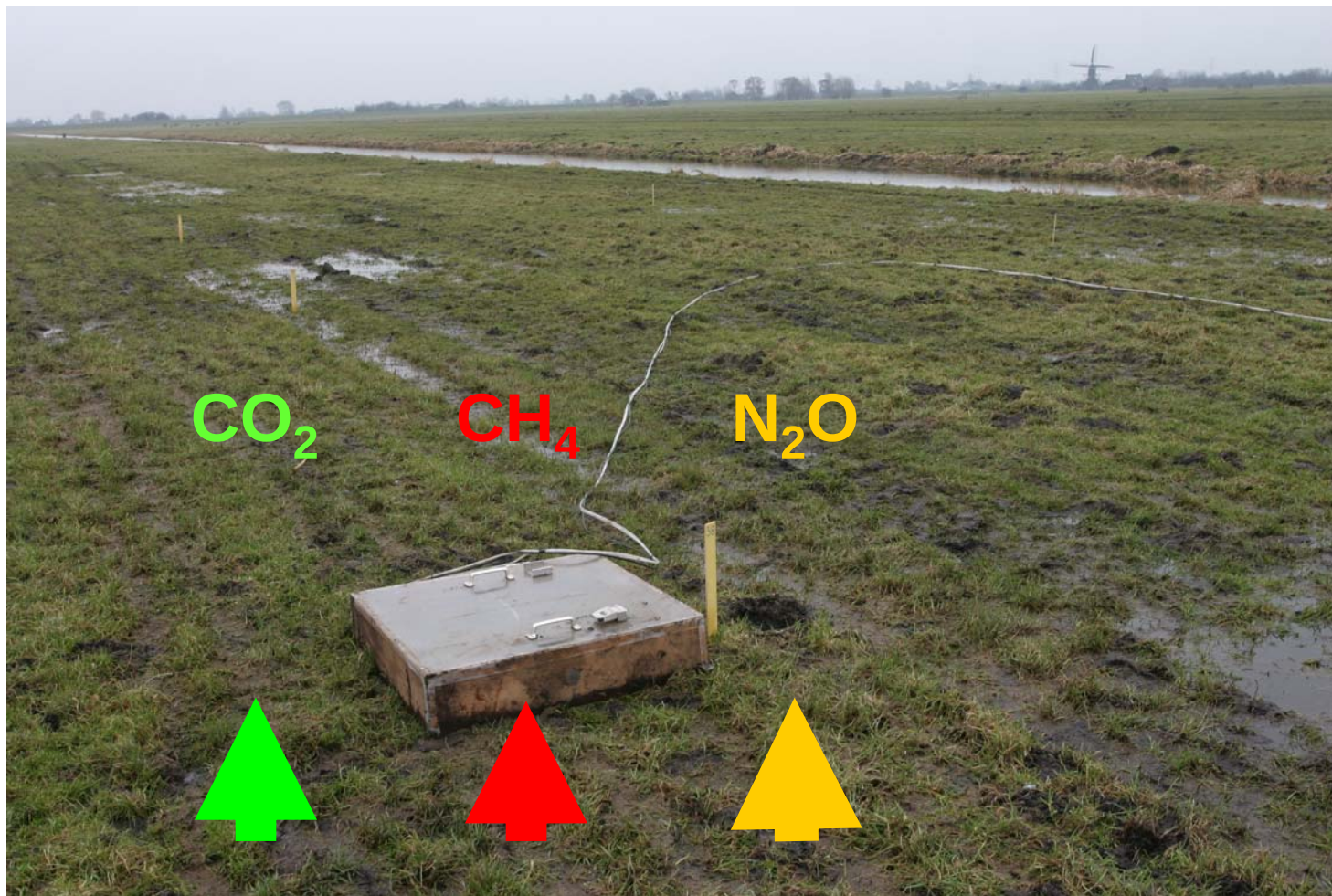
1. ECN, the Netherlands ; 2. TU Delft, the Netherlands; 3. WU, the Netherlands; 4. KNMI, the Netherlands



# Outline

- Background
- Eddy covariance flux technique
  - Description
  - Systematic errors
  - Uncertainties
- Annual field emission
- Conclusions

## Background: GHG emissions from a managed fen meadow

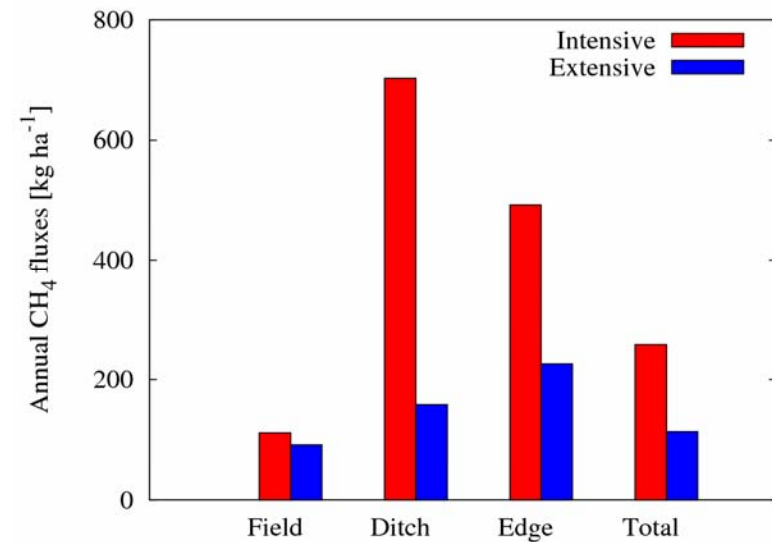


## Background: Lack of accurate annual sums

Due to spatial variation



Top view Reeuwijk site in the Netherlands



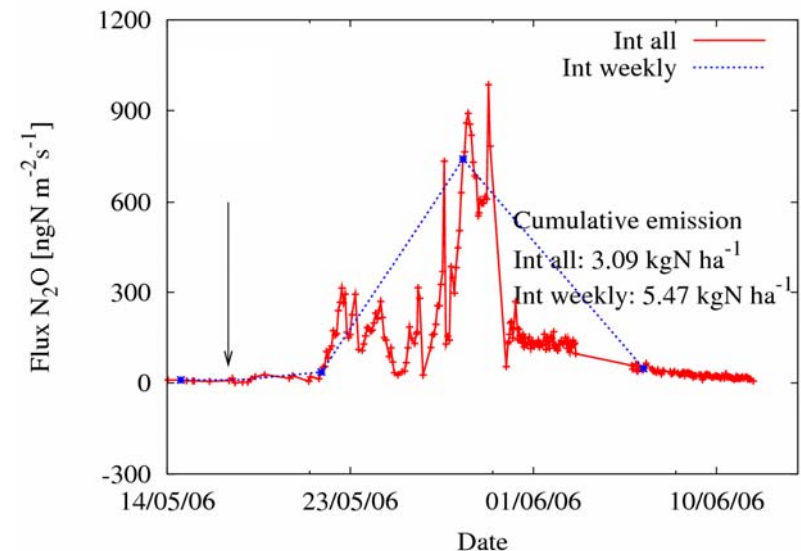
Based on Schrier-Uijl et al., BGD, 2008

## Background: Lack of accurate annual sums

Due to temporal variation



Managed site in Reeuwijk in the Netherlands



Kroon et al., Nutr. Cycl. AgroEcosyst., 2008

**Uncertainty in  $N_2O$  annual estimates derived by chamber may be as high as 50%.**  
(Flechar et al., Agric. Ecos. Environ., 2007)

## Background: Measurement techniques



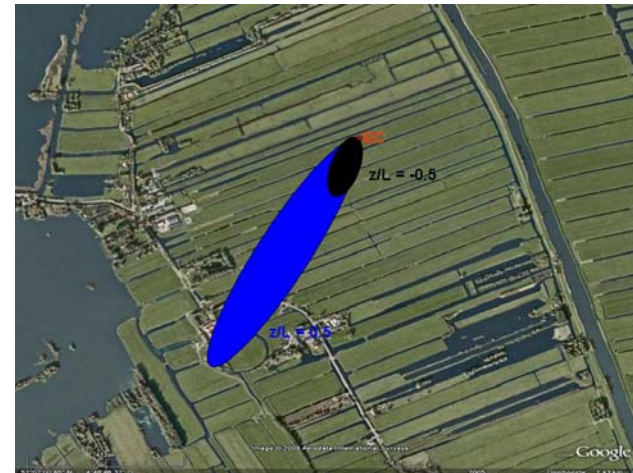
Chamber

$$F_{wc} = h \left. \frac{dC}{dt} \right|_{t=0}$$



Eddy  
Covariance

$$F_{wc} = \frac{1}{T_a} \int w'(t)C'(t)dt$$



## Background: Measurement techniques



Chamber



Eddy  
Covariance

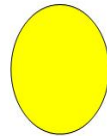
**Can EC flux measurements contribute to a decrease of the uncertainty in annual estimates of  $\text{CH}_4$  and  $\text{N}_2\text{O}$ ?**



# Eddy covariance flux technique: Description

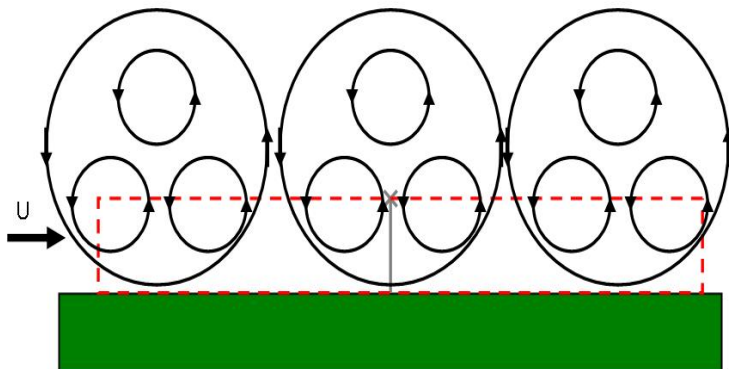
Tracer conservation equation

$$\underbrace{\frac{\partial \bar{c}}{\partial t}}_I + \underbrace{u \frac{\partial \bar{c}}{\partial x} + v \frac{\partial \bar{c}}{\partial y} + w \frac{\partial \bar{c}}{\partial z}}_{II, III, IV} + \underbrace{\frac{\partial \bar{u}'c'}{\partial x} + \frac{\partial \bar{v}'c'}{\partial y} + \frac{\partial \bar{w}'c'}{\partial z}}_V = \underbrace{S}_{VI}$$



After Reynolds decomposition, integrating over the height and assuming:

- Horizontal homogeneity
- Flat terrain
- Negligible mean vertical wind speed



$$F_{wc} = \underbrace{\int_0^h \frac{\partial \bar{c}}{\partial t} dz}_{St_{wc}} + \underbrace{\overline{w'c'}|_{z=h}}_{EC_{wc}}$$

# Eddy covariance flux technique: Systematic errors



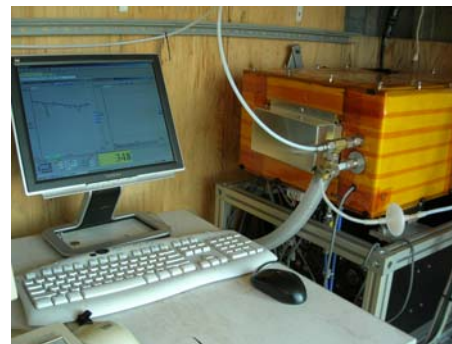
**Sonic anemometer**

Wind measurements

**Tube connected to QCL**

CH<sub>4</sub> measurements

N<sub>2</sub>O measurements

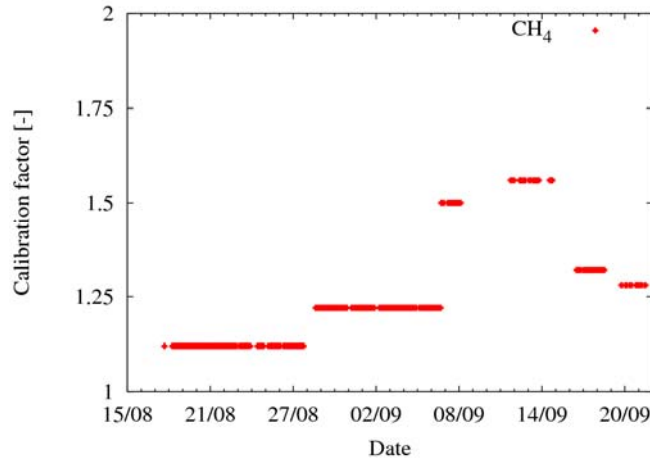


$$EC_{wc}^{meas} = \overline{w'c'} \Big|_{z=h}$$

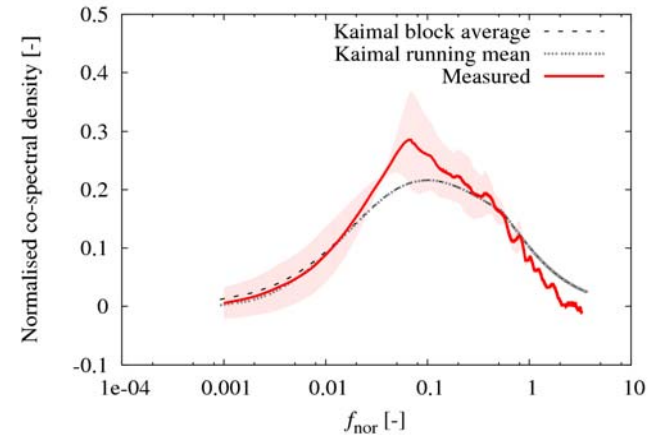
= ?

$$EC_{wc} = \overline{w'c'} \Big|_{z=h}$$

# Eddy covariance flux technique: Systematic errors



Kroon et al., BG, 2007



Kroon et al., AFM, accepted

- Calibrations
- Alignment sonic anemometer
- Low frequency response losses
- High frequency response losses
- Density fluctuations

Rotation algorithm on  $u$ ,  $v$  and  $w$

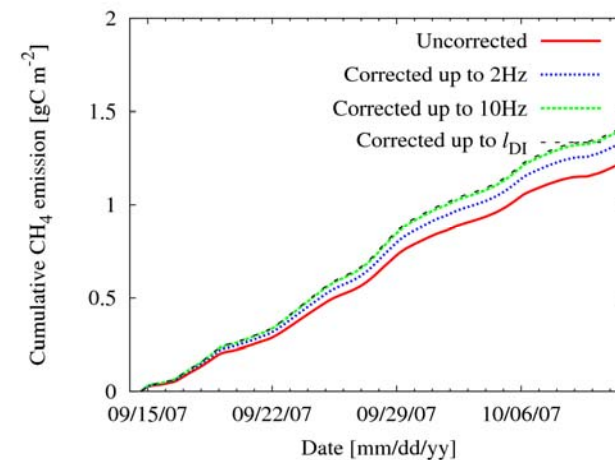
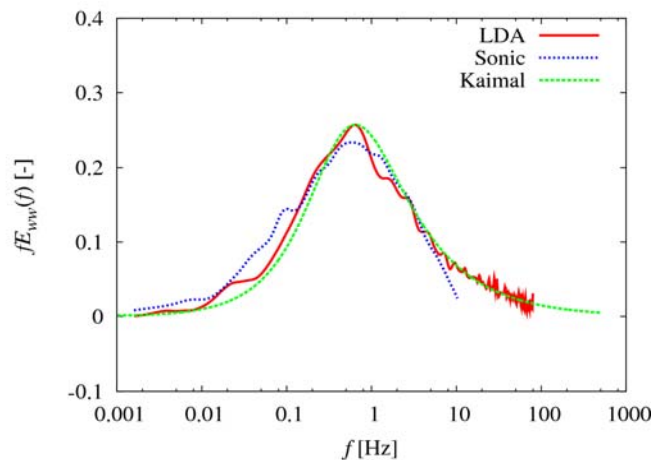
$$EC_{wc} = \chi_{cal} \chi_{low} \chi_{high} EC_{wc}^{meas} + \chi_{cal} \chi_{Webb}$$

# Eddy covariance flux technique: Systematic errors

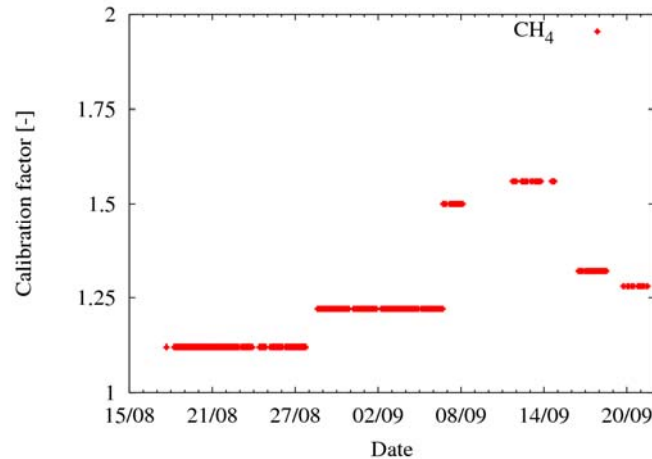
High frequency response correction:

$$\chi_{\text{high}} = \frac{\int_0^{\infty} E_{\text{wc}}(f) df}{\int_0^{\infty} T_{\text{high}}(f) E_{\text{wc}}(f) df}$$

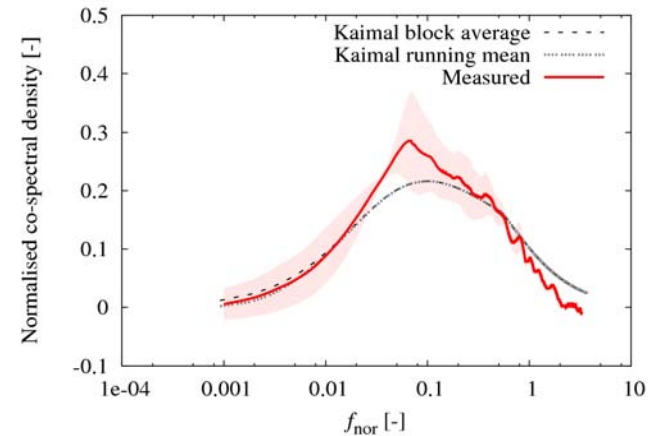
Kroon et al., AFM, accepted



# Eddy covariance flux technique: Systematic errors



Kroon et al., BG, 2007



Kroon et al., AFM, accepted

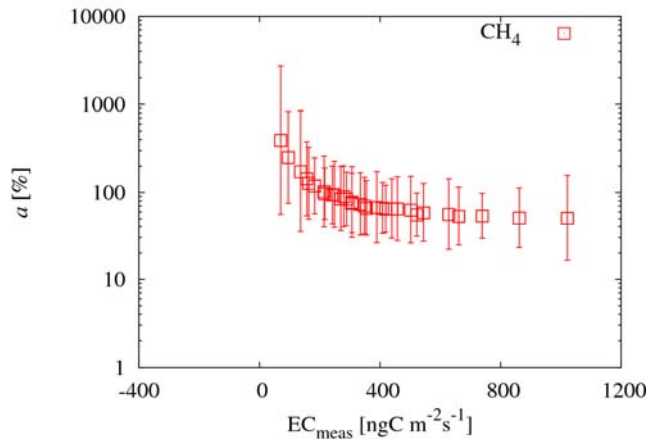
- Calibrations
- Alignment sonic anemometer
- Low frequency response losses
- High frequency response losses
- Density fluctuations

Rotation algorithm on  $u$ ,  $v$  and  $w$

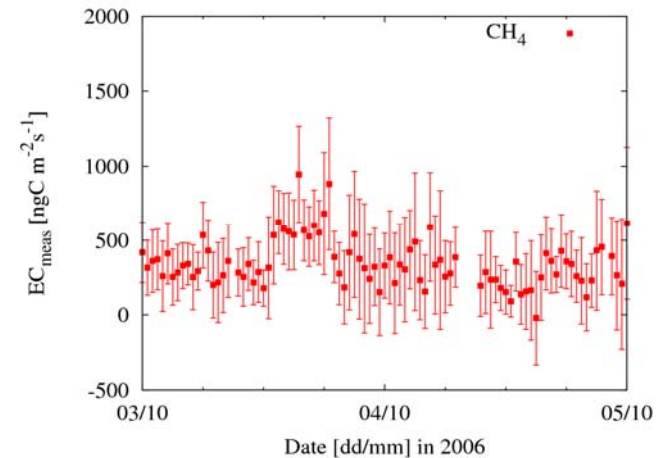
$$EC_{wc} = \chi_{cal} \chi_{low} \chi_{high} EC_{wc}^{meas} + \chi_{cal} \chi_{Webb}$$

**After applying corrections 30 min fluxes can increase by even more than 100%!**

# Eddy covariance flux technique: Uncertainties



Kroon et al., AFM, accepted



Kroon et al., AFM, accepted

Random uncertainty in correction algorithms

Other random uncertainties:

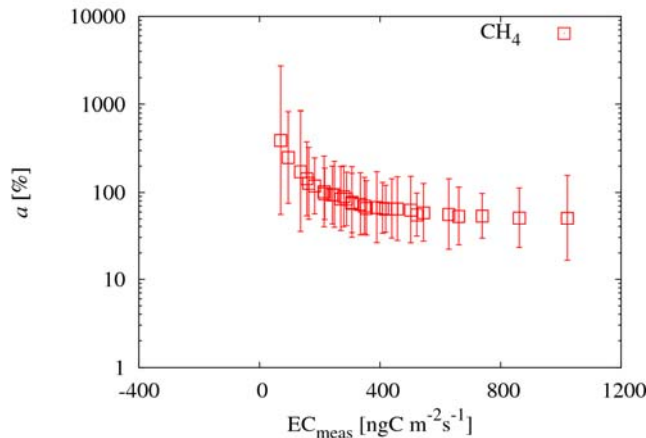
- Drift and precision in instruments
- One-point sampling

90% of 30 min EC flux uncertainty is caused by one-point uncertainty!

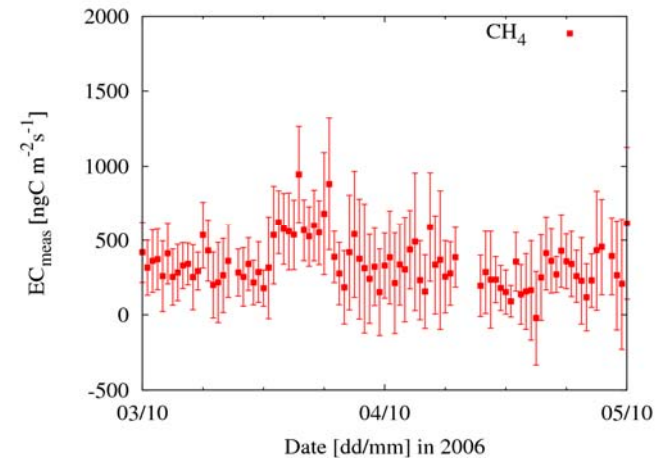
$$u_{op} = \sqrt{\frac{2}{M}} \sigma_{w'c'} = \sqrt{\frac{20z}{TU}} \sqrt{(\overline{w'c'})^2 - (\overline{w'})^2 \overline{c'}^2}$$

$$= aEC_{wc}^{meas}$$

# Eddy covariance flux technique: Uncertainties



Kroon et al., AFM, accepted



Kroon et al., AFM, accepted

Random uncertainty in correction algorithms

Other random uncertainties:

- Drift and precision in instruments
- One-point sampling

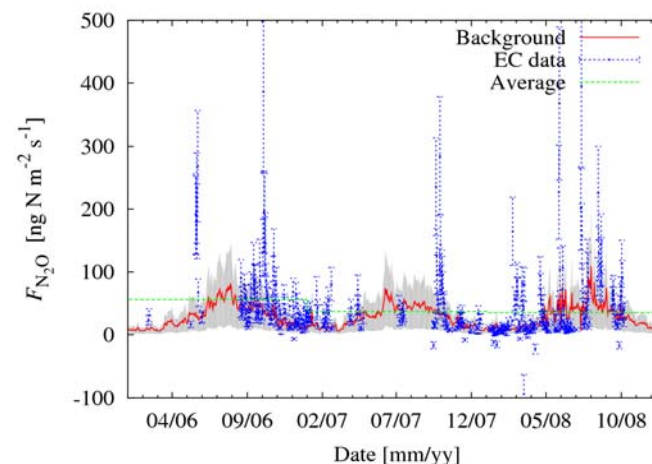
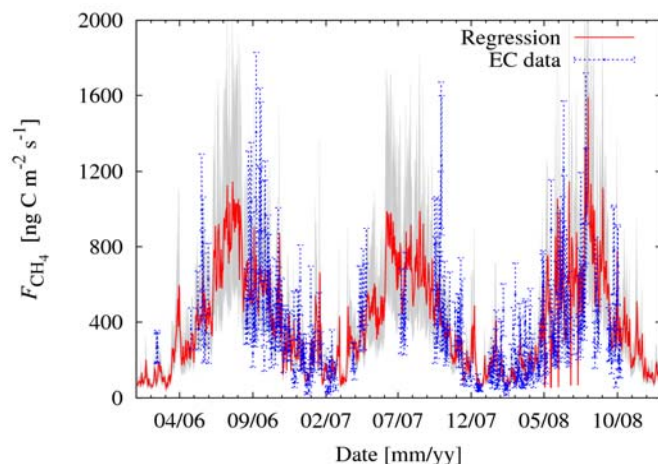
90% of 30 min EC flux uncertainty is caused by one-point uncertainty!

$$u_{op} = \sqrt{\frac{2}{M}} \sigma_{w'c'} = \sqrt{\frac{20z}{TU}} \sqrt{(\overline{w'c'})^2 - (\overline{w'})^2 \overline{c'}^2}$$

$$= a EC_{wc}^{meas}$$

**Uncertainty in a 30 min flux can be much larger than 100%; however it decreases with  $1/\sqrt{N}$ .**

## Annual field emission: $\text{CH}_4$ and $\text{N}_2\text{O}$ emissions



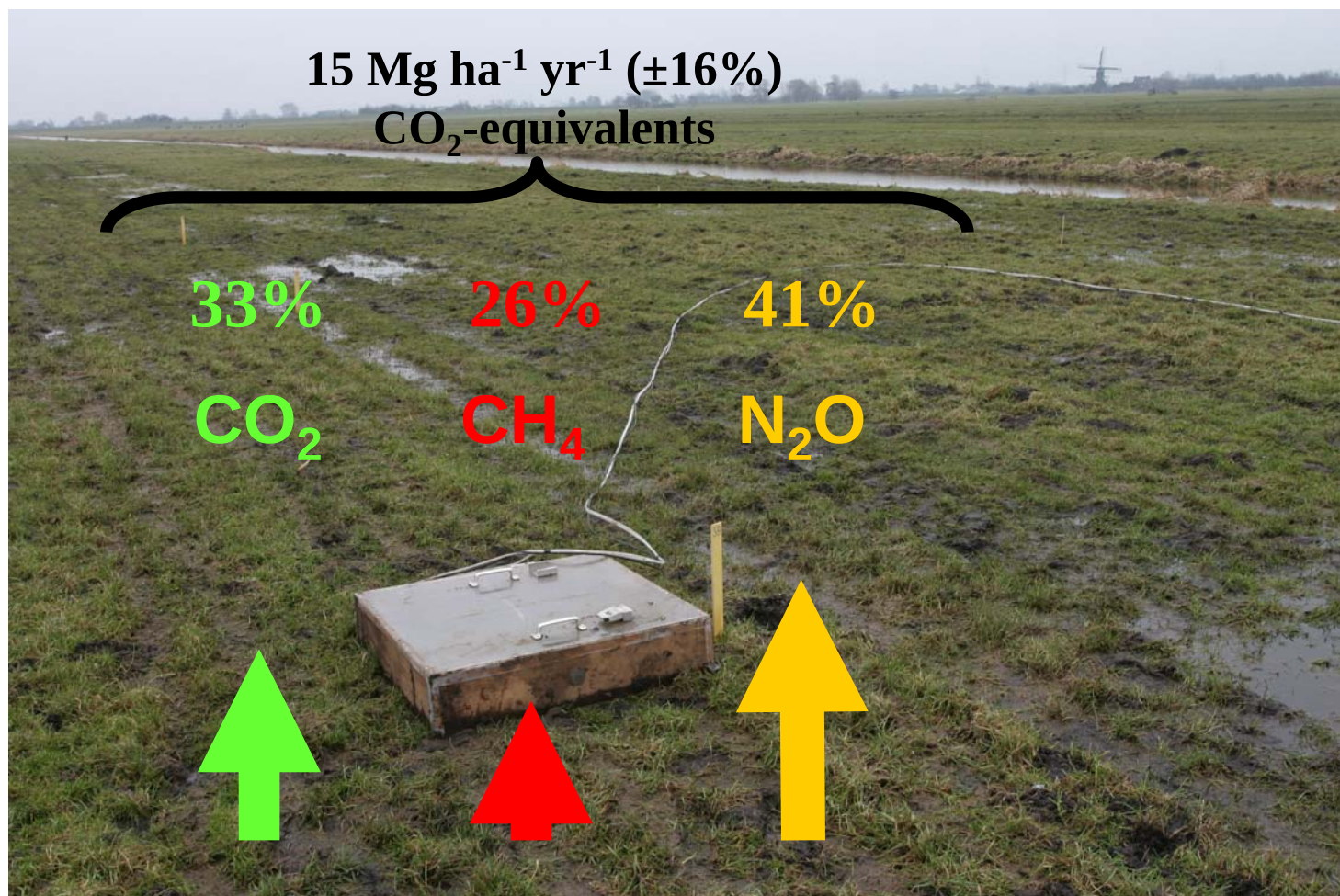
Average annual emissions over 2006 – 2008

|                                                                          | Static chamber     | Eddy covariance    |
|--------------------------------------------------------------------------|--------------------|--------------------|
| $\text{CH}_4$ [ $\text{kg CH}_4 \text{ ha}^{-1} \text{ yr}^{-1}$ ]       | 170 ( $\pm 32\%$ ) | 165 ( $\pm 13\%$ ) |
| $\text{N}_2\text{O}$ [ $\text{kg N}_2\text{O ha}^{-1} \text{ yr}^{-1}$ ] | NA                 | 20 ( $\pm 34\%$ )  |

Kroon et al., Eur. J. Soil Sci., submitted; Schrier-Uijl et al., Plant and Soil, accepted

**Thus, EC flux measurements can contribute to more accurate annual estimates of  $\text{CH}_4$  and  $\text{N}_2\text{O}$ !**

## Annual field emission: Total GHG field balance



Kroon et al., Eur. J. Soil Sci, submitted; Veenendaal et al., BG, 2007

## Conclusions

- The annual field emission estimates of  $\text{CH}_4$  and  $\text{N}_2\text{O}$  are very uncertain.
- Corrections should be applied for the systematic errors in EC flux measurements.
- There are many uncertainties in EC flux measurements.
- The uncertainty in a 30 min EC flux measurement can be even larger than 100%.
- Assuming 100% data coverage, the uncertainty of a monthly EC flux average can be smaller than 10%.
- The total field emission is estimated at  $15 \text{ Mg ha}^{-1} \text{ yr}^{-1} \text{ CO}_2$ -equivalents (41% due to  $\text{N}_2\text{O}$ ); however the emission will increase by more than 250% when biomass removal and farm based emissions are included.

## Thanks to ...

Reeuwijk-team



BSIK-team



Cabauw-team



LDA-team



- Arjan Hensen (ECN)
- Hans van 't Veen (ECN)
- Alex Vermeulen (ECN)
- Pim van den Bulk (ECN)
- Piet Jongejan (ECN)
- Rob Rodink (ECN/TU)
- Harm Jonker (TU)
- Erwin de Beus (TU)
- Adriaan Schuitmaker (TU)
- Huug Ouwersloot (TU)
- Mark Tummers (TU)
- Fred Bosveld (KNMI)
- Arina Schrier (WUR)
- Elmar Veenendaal (WUR)
- Dimmie Hendriks (VU)
- Mark Zahniser (Aerodyne)
- ....

# Eddy covariance observations of $\text{CH}_4$ and $\text{N}_2\text{O}$ Towards more accurate emission estimates

P. Kroon<sup>1,2</sup>, A. Hensen<sup>1</sup>, H. Jonker<sup>2</sup>, A. Schrier-Uijl<sup>3</sup>, M. Tummers and F. Bosveld<sup>4</sup>

1. ECN, the Netherlands ; 2. TU Delft, the Netherlands; 3. WU, the Netherlands; 4. KNMI, the Netherlands

