Micrometeorological observations of CH_4 and N_2O at a managed fen meadow in the Netherlands

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ECN

Energy research Centre of the Netherlands

TU Delft

Delft University of Technology

climate changes spatial planning

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1. ECN, Netherlands ; 2. TU Delft, Netherlands

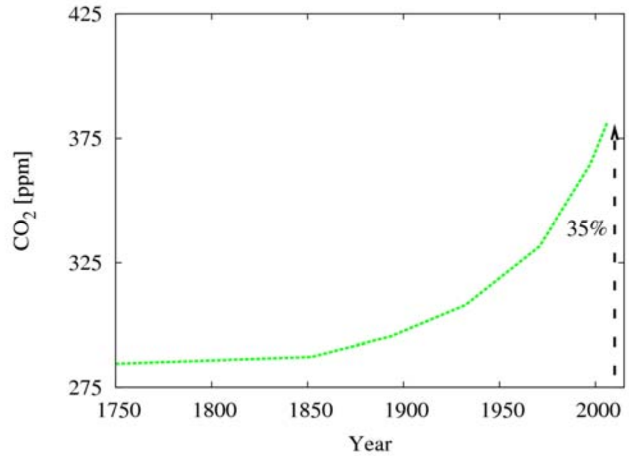


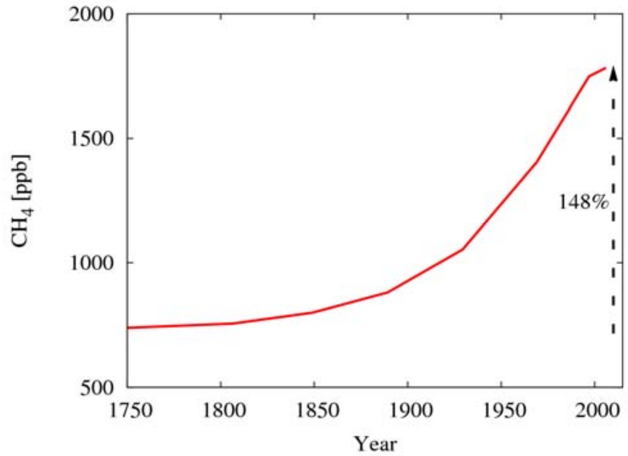


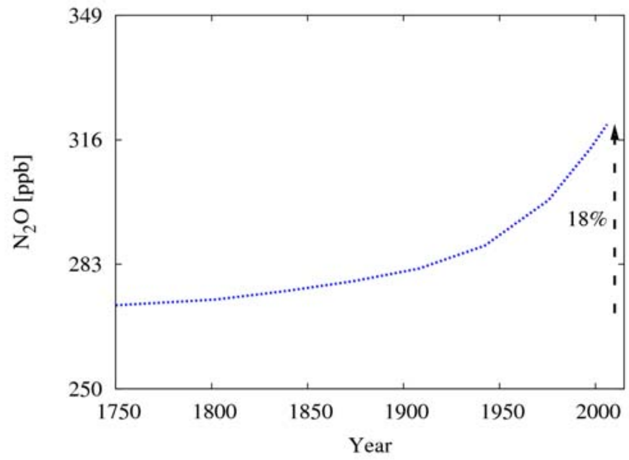

Outline

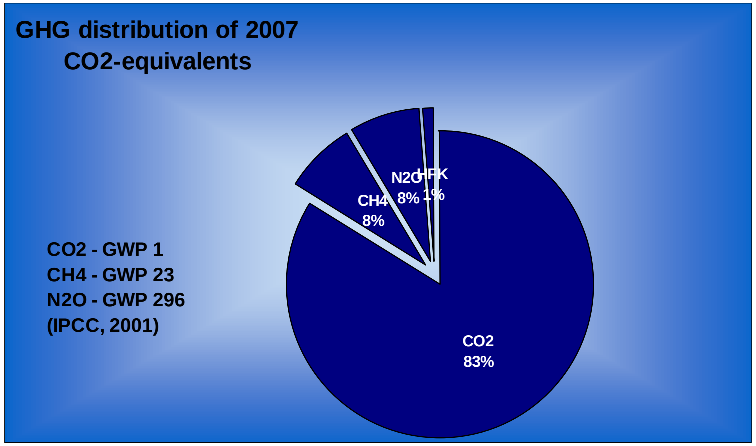
- Background
- EC flux measurements
- Summary
- Future plans

Background: Atmospheric concentrations









Background: Land-use change on peat land

Natural sink of CO_2

• 50% of atmospheric C content is accumulated in peat (Dolman et al., 2008)

Background: Land-use change on peat land

Natural sink of CO_2

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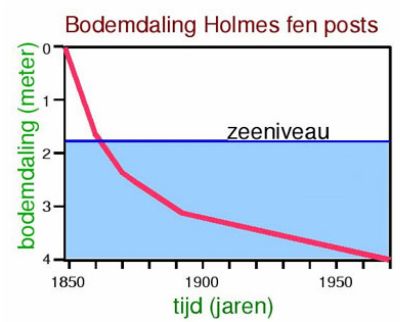
Drainage

• Sudden release of all peat would release in 50% increase of atmospheric CO_2 (Dolman et al., 2008)

Background: Land-use change on peat land

Land surface in 1848



CO_2 to atmosphere

↑

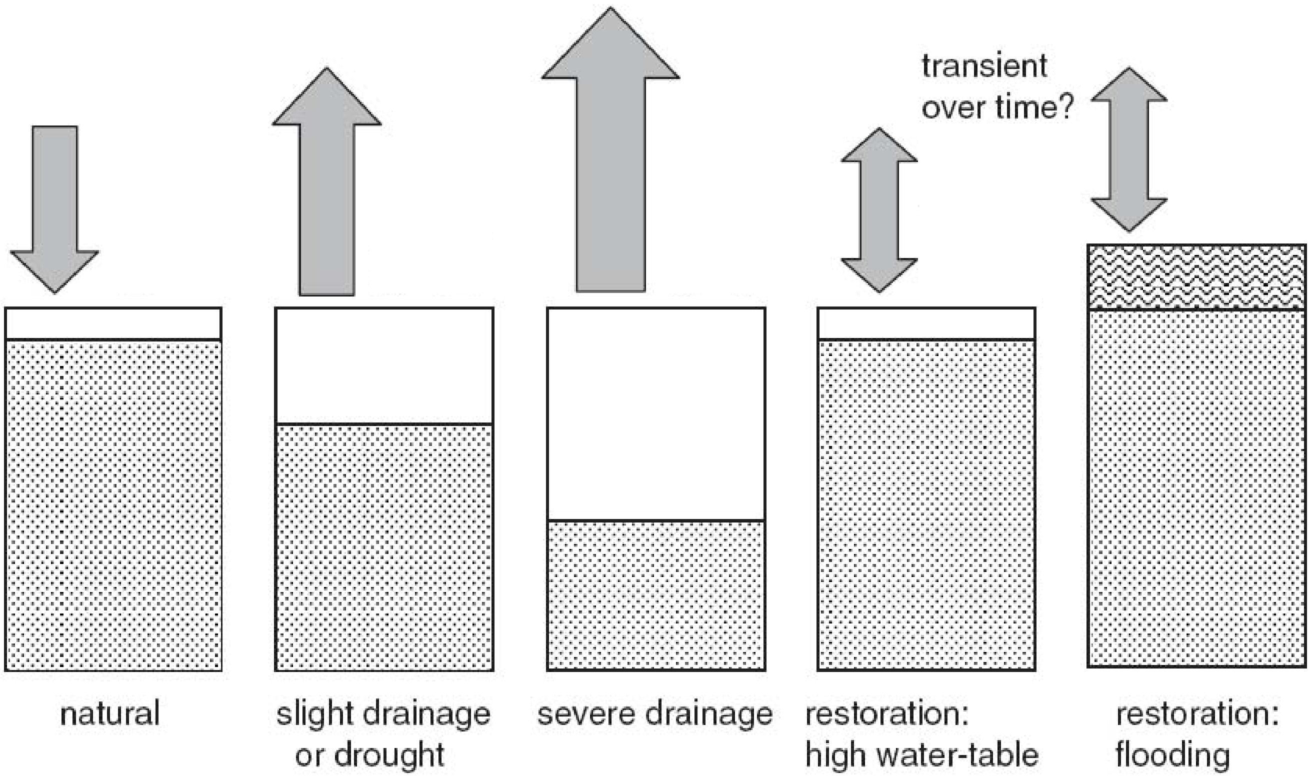
Oxidation of peat

Drainage caused oxidation and thus dramatic land subsidence in East England

Land surface in 2000

http://www.geo.vu.nl/~huik/moeras.html

Background: Land-use change on peat land

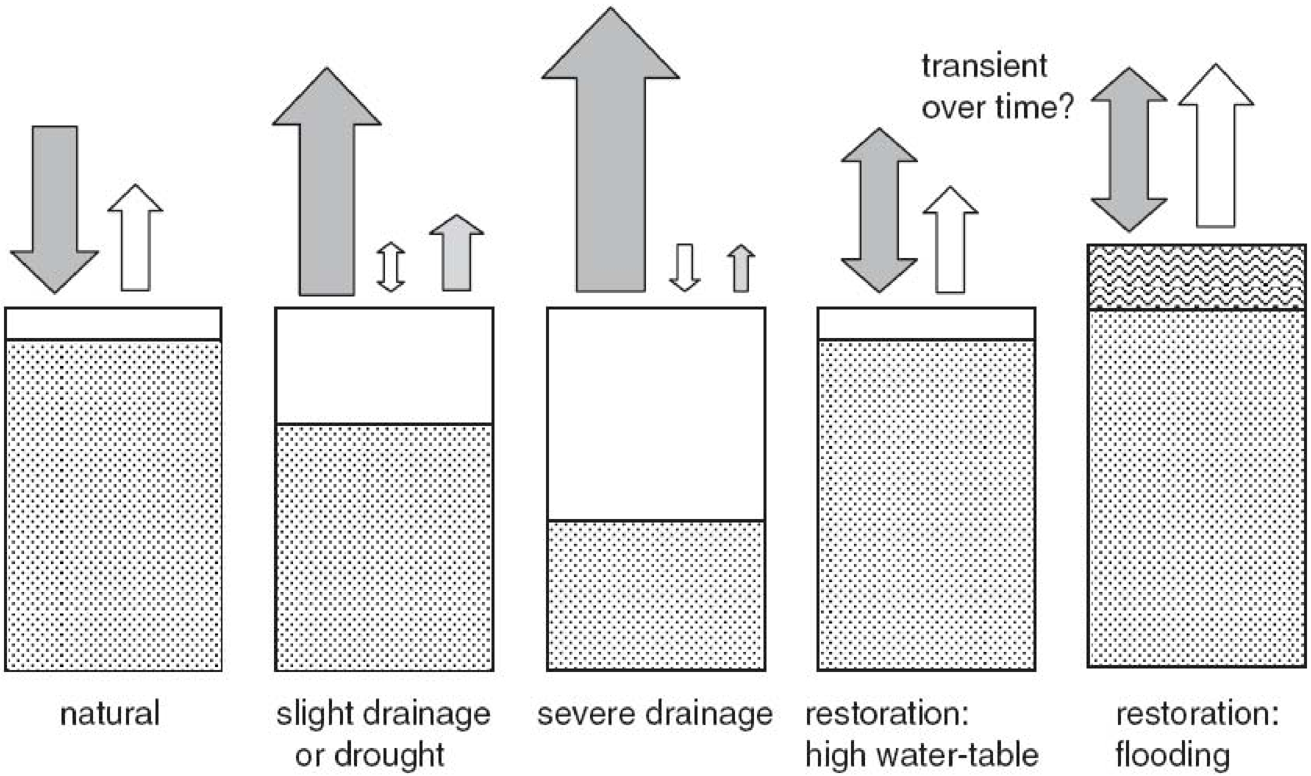


- CO_2GWP 1

(IPCC, 2001)

Drösler et al., 2008

Background: Land-use change on peat land

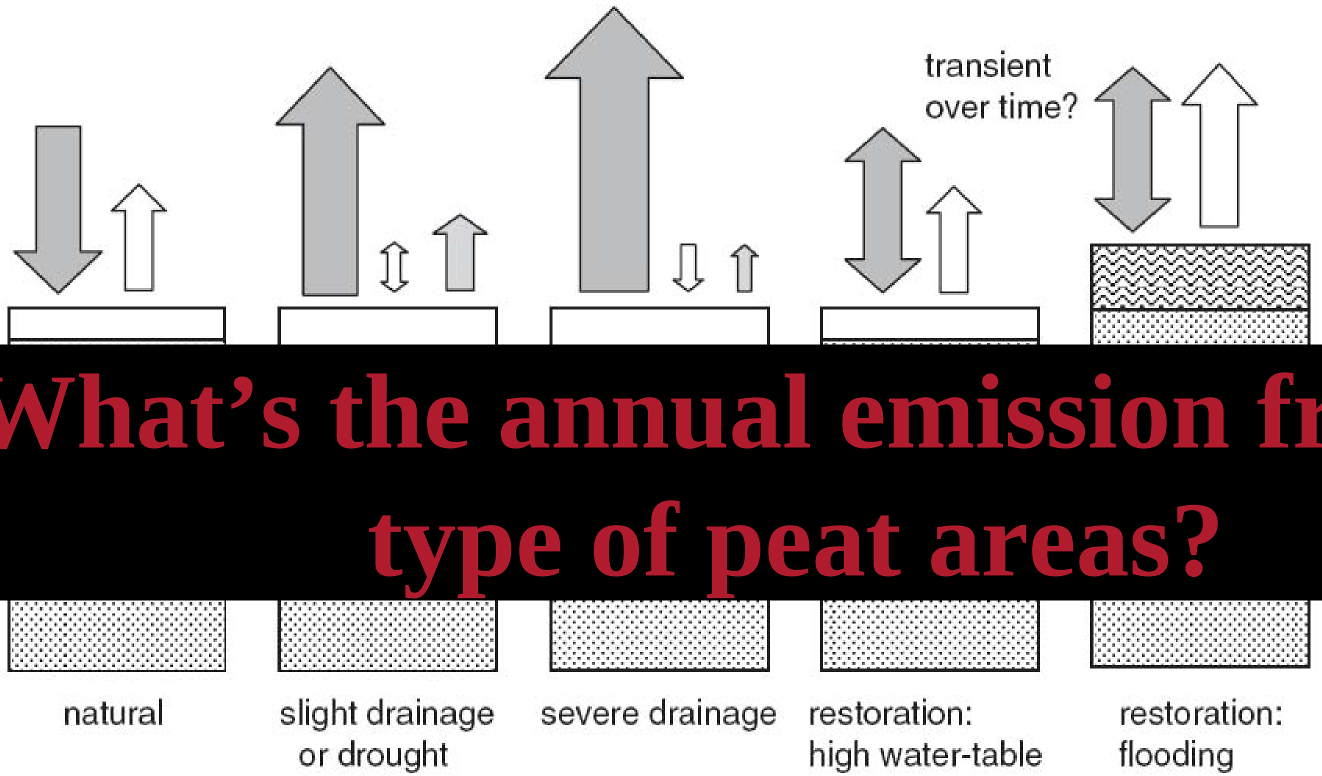


- CO_2 GWP 1
- CH_4 GWP 23
- N_2O GWP 296

(IPCC, 2001)

Drösler et al., 2008

Background: Land-use change on peat land



- CO_2 GWP 1
- CH_4 GWP 23
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(IPCC, 2001)

What's the annual emission from all type of peat areas?

Drösler et al., 2008

Background: Lack of accurate annual sums

Table 1.2 Uncertainty of total annual emissions

CO_2	±5%	HFCs	±50%
CH_4	±25%	PFCs	±25%
N_2O	±50%	SF_6	±50%
Total greenhouse gases			±5%

Table 1.3 Top ten sources contributing most to total annual uncertainty in 2006

IPCC category	Category	Gas	Combined uncertainty as a percentage of total national emissions in 2006
4D3	Indirect N_2O emissions from nitrogen used in agriculture	N_2O	3.1%*)
4D1	Direct N_2O emissions from agricultural soils	N_2O	1.4%
1A4a	Stationary combustion : Other Sectors: Commercial/Institutional, gases	CO_2	1.0%
6A1	CH_4 emissions from solid waste disposal sites	CH_4	0.9%
4B1	Emissions from manure management : cattle	CH_4	0.7%
1A1b	Stationary combustion : Petroleum Refining: liquids	CO_2	0.6%
2B2	Nitric acid production	N_2O	0.6%
1A3b	Mobile combustion: road vehicles: diesel oil	CO_2	0.5%
4B8	Emissions from manure management : swine	CH_4	0.4%
4A1	CH_4 emissions from enteric fermentation in domestic livestock: cattle	CH_4	0.4%

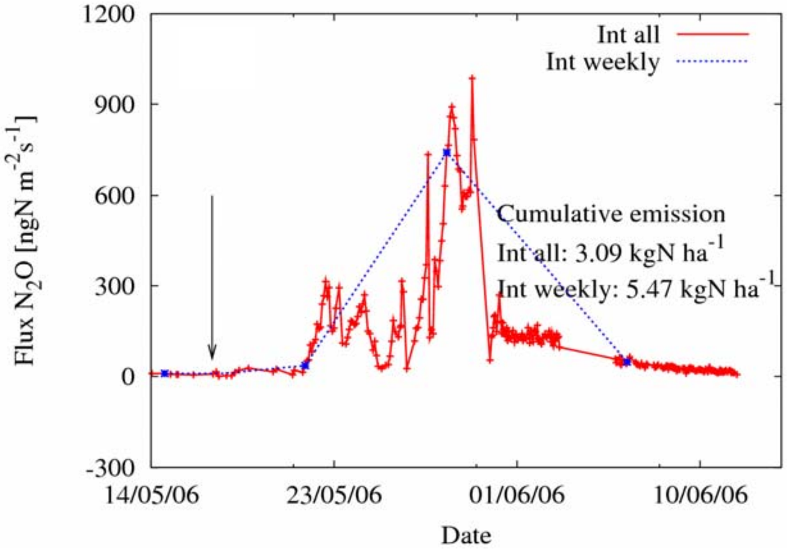
*) calculated uncertainties, for ranking purposes not rounded off

Maas et al., MNP, 2008

Background: Lack of accurate annual sums

Due to temporal variation

Managed site in Reeuwijk in the Netherlands



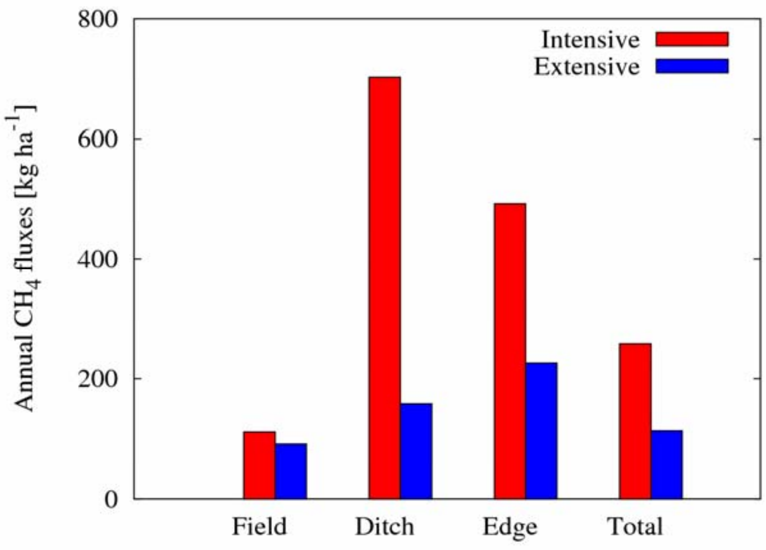
(Kroon et al., 2008)

Uncertainty in N_2O annual estimates derived by chamber may be as high as 50%
(Flechard et al., 2007)

Background: Lack of accurate annual sums

Due to spatial variation

Top view Reeuwijk site in the Netherlands



(Based on Schrier et al., 2008)

Background: Measurement techniques

Chamber

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

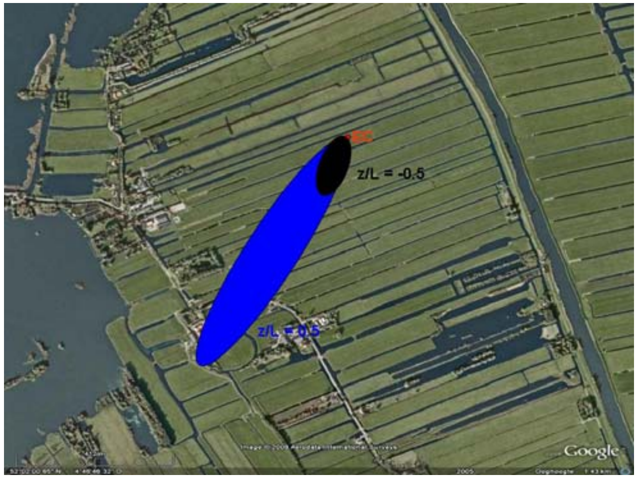
Background: Measurement techniques

Chamber

$$F_c = h\frac{dC}{dt}\bigg|_{t=0}$$

Eddy Covariance

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

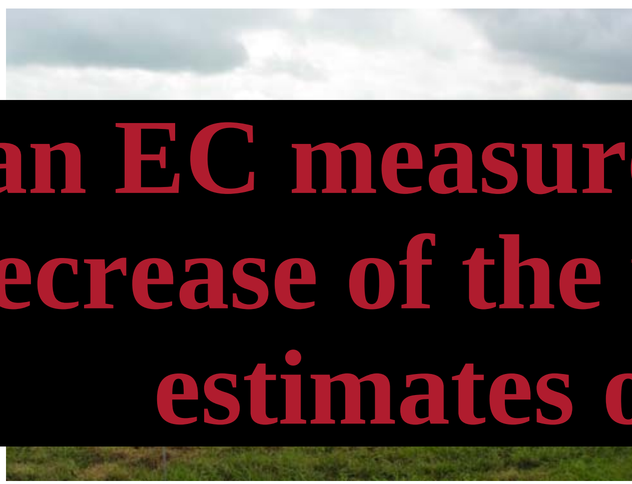


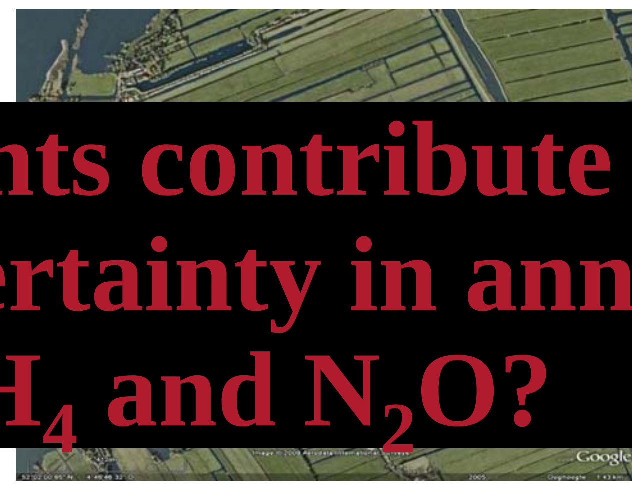
Background: Measurement techniques

Chamber

Eddy Covariance

Is it possible to perform EC measurements of CH_4 and N_2O?





Can EC measurements contribute to a decrease of the uncertainty in annual estimates of CH_4 and N_2O?

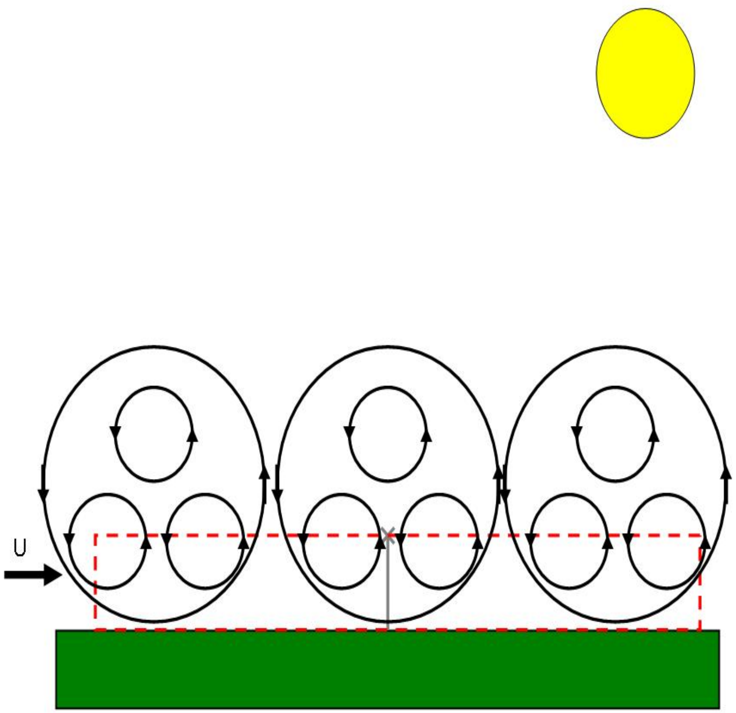
Detailed outline

- Background
- EC flux measurements
  - Is it possible to perform EC measurements of CH_4 and N_2O?
  - What's the uncertainty in EC measurements of CH_4 and N_2O?
  - How comparable are fluxes measured by EC and chamber for CH_4?
- Summary
- Future plans

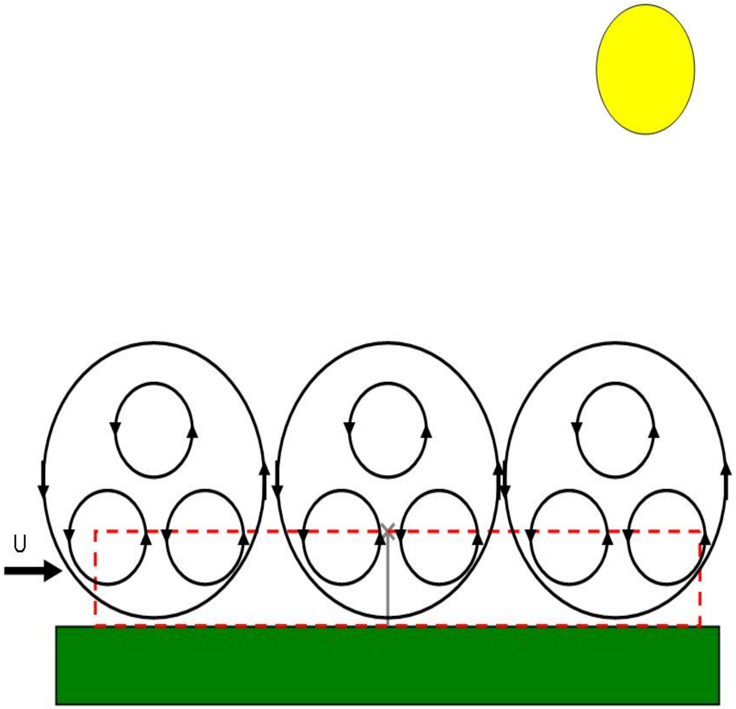
Eddy covariance flux theory

Tracer conservation equation

$$\underbrace{\frac{\partial \bar{c}}{\partial t}}_{\mathrm{I}} + \underbrace{\bar{u}\frac{\partial \bar{c}}{\partial x} + \bar{v}\frac{\partial \bar{c}}{\partial y}}_{\mathrm{II}} + \underbrace{\bar{w}\frac{\partial \bar{c}}{\partial z}}_{\mathrm{III}} + \underbrace{\frac{\partial \overline{u'c'}}{\partial x} + \frac{\partial \overline{v'c'}}{\partial y}}_{\mathrm{IV}} + \underbrace{\frac{\partial \overline{w'c'}}{\partial z}}_{\mathrm{V}} = \underbrace{S}_{\mathrm{VI}}$$



Eddy covariance flux theory



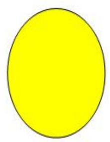
Tracer conservation equation

$$\underbrace{\frac{\partial \bar{c}}{\partial t}}_{\mathrm{I}}+\underbrace{\cancel{\bar{u}\frac{\partial \bar{c}}{\partial x}+\bar{v}\frac{\partial \bar{c}}{\partial y}}}_{\mathrm{II}}+\underbrace{\bar{w}\frac{\partial \bar{c}}{\partial z}}_{\mathrm{III}}+\underbrace{\cancel{\frac{\partial \overline{u'c'}}{\partial x}+\frac{\partial \overline{v'c'}}{\partial y}}}_{\mathrm{IV}}+\underbrace{\frac{\partial \overline{w'c'}}{\partial z}}_{\mathrm{V}}=\underbrace{S}_{\mathrm{VI}}$$

After Reynolds decomposition, integrating over the height and assuming:

- Horizontal homogeneity
- Flat terrain

Eddy covariance flux theory



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- Horizontal homogeneity
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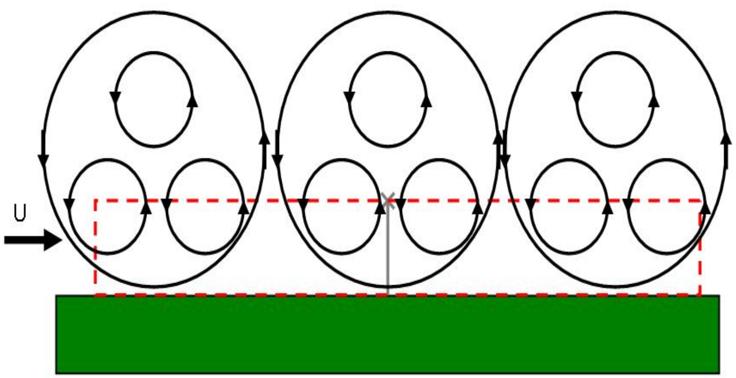
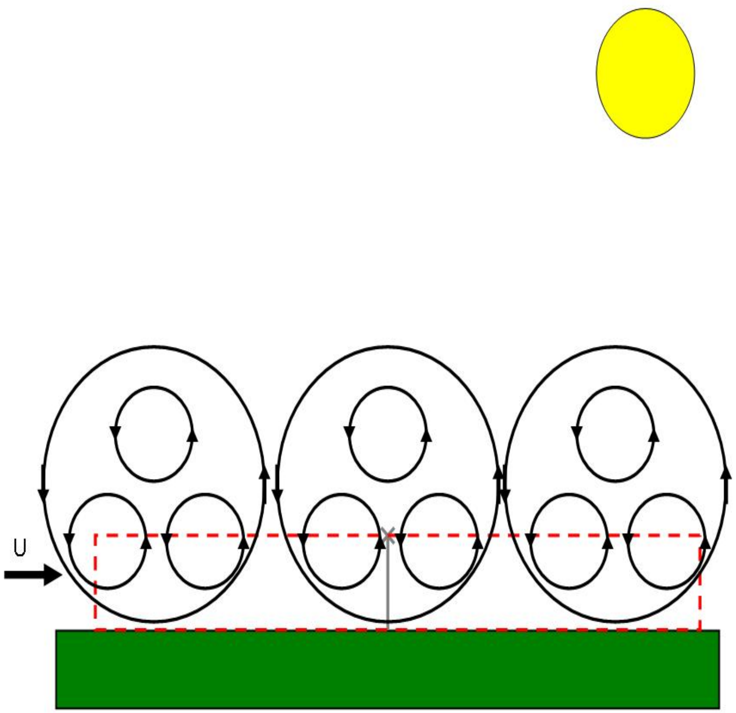
- Negligible mean vertical wind speed



$$\underbrace{\int_0^h S_c dz}_{NEE} = \underbrace{\int_0^h \frac{\partial \bar{c}}{\partial t} dz}_{Storage} + \underbrace{\overline{w'c'}|_{z=h}}_{\tilde{\tilde{F}}_c}$$

Eddy covariance flux theory



Tracer conservation equation

$$\underbrace{\frac{\partial \bar{c}}{\partial t}}_{\mathrm{I}} + \cancel{\underbrace{\bar{u}\frac{\partial \bar{c}}{\partial x} + \bar{v}\frac{\partial \bar{c}}{\partial y}}_{\mathrm{II}}} + \cancel{\underbrace{\bar{w}\frac{\partial \bar{c}}{\partial z}}_{\mathrm{III}}} + \cancel{\underbrace{\frac{\partial \overline{u'c'}}{\partial x} + \frac{\partial \overline{v'c'}}{\partial y}}_{\mathrm{IV}}} + \underbrace{\frac{\partial \overline{w'c'}}{\partial z}}_{\mathrm{V}} = \underbrace{S}_{\mathrm{VI}}$$

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- Horizontal homogeneity
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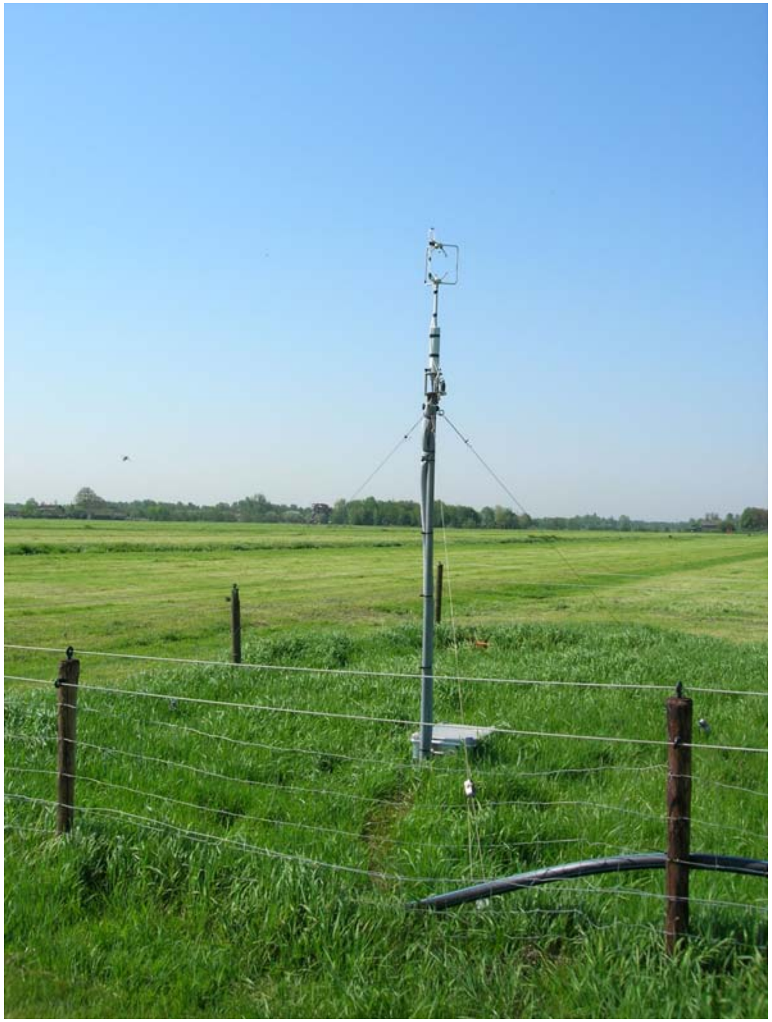
$$\underbrace{\int_0^h S_c dz}_{NEE} = \underbrace{\int_0^h \frac{\partial \bar{c}}{\partial t} dz}_{Storage} + \boxed{\underbrace{\overline{w'c'}|_{z=h}}_{\tilde{\tilde{F}}_c}}$$

Can we measure EC fluxes of CH_4 and N_2O?



Sonic anemometer

Wind measurements

Tube connected to QCL

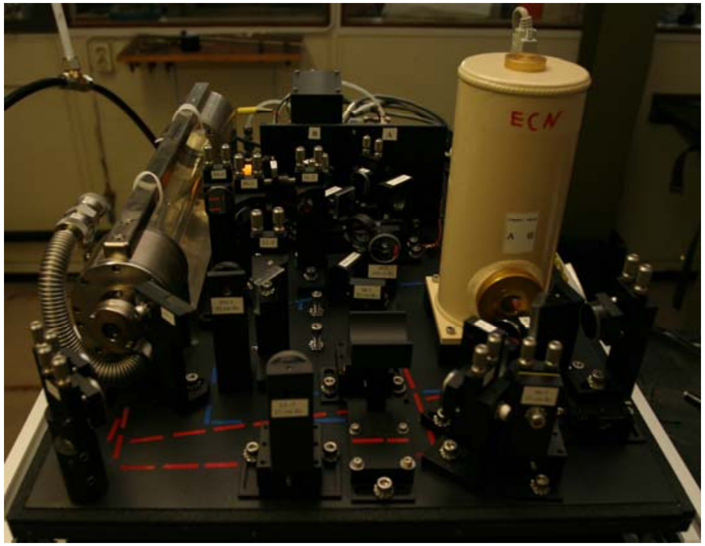
CH_4 measurements

N_2O measurements

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

Can we measure EC fluxes of CH_4 and N_2O?

Quantum cascade laser



Requirements EC flux measurements:

- Stationair at least over 30 min
- Continuously running
- Sensitivity of 0.3 ppb and 1 ppb for N_2O (average 310 ppb) and CH_4 (average 1800 ppb)

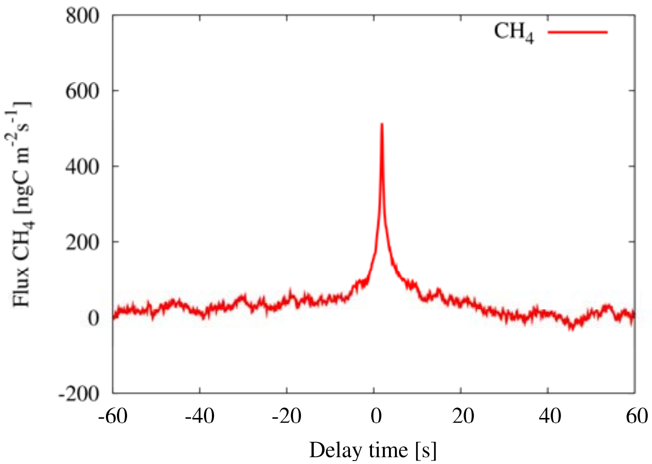
Kroon et al., BG, 2007

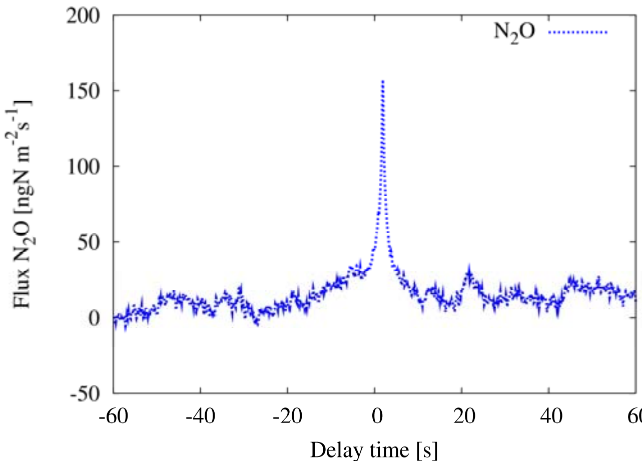
Can we measure EC fluxes of CH_4 and N_2O?

Delay time between

w and *c* measurement!!

$$F_c(\mathrm{n}\Delta t) = \frac{1}{\mathrm{n_s}} \sum_{\mathrm{k}=1}^{\mathrm{n_s}} w'_{\mathrm{k}} c'_{\mathrm{k}+\mathrm{n}\Delta t}$$





Kroon et al., BG, 2007

Can we measure EC fluxes of CH_4 and N_2O?

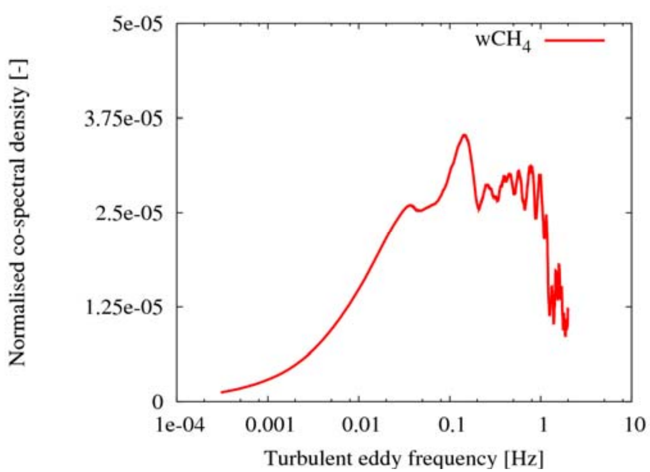
Do we detect all contributing eddies?

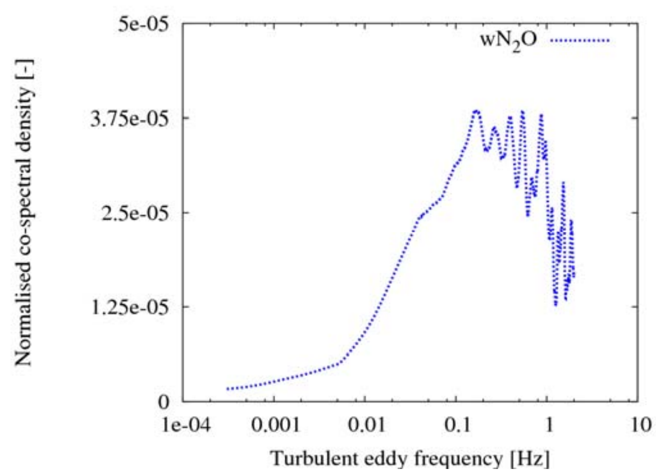
Time Domain

$$F_c = \int w'(t)c'(t)dt$$

Frequency Domain

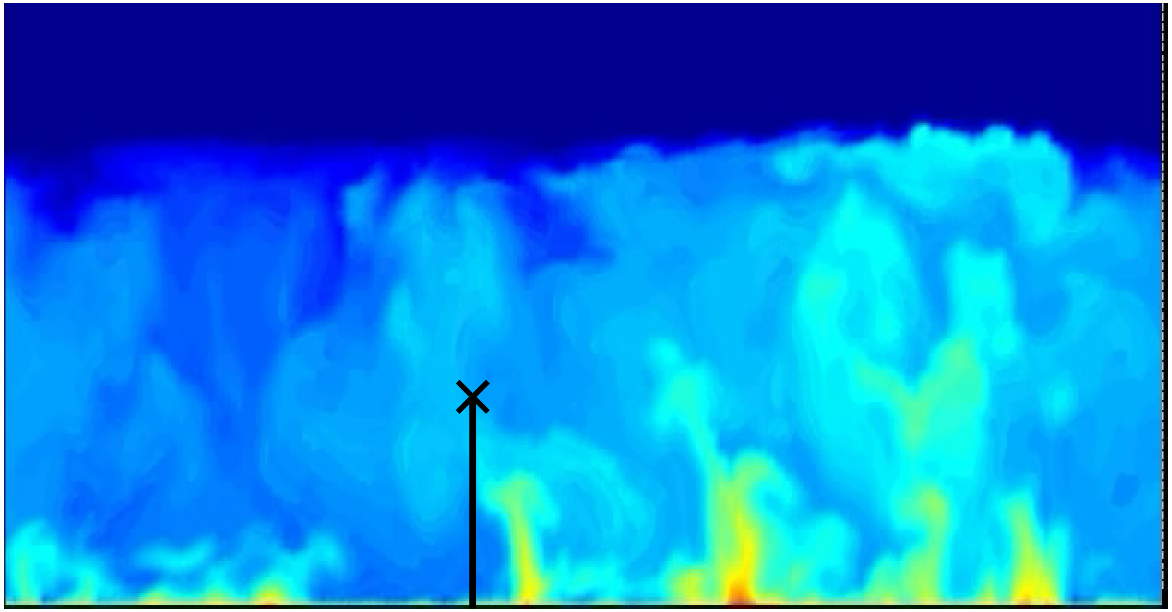
$$F_c = \int C_{wc}(f)df$$





Kroon et al., BG, 2007

Uncertainty in EC flux measurements of CH_4 and N_2O



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

$$= ?$$

$$\tilde{\tilde{F}}_c = \overline{w'c'}\Big|_{z=h}$$

Courtesy: J. Schalwijk

Uncertainty in EC flux measurements of CH_4 and N_2O

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

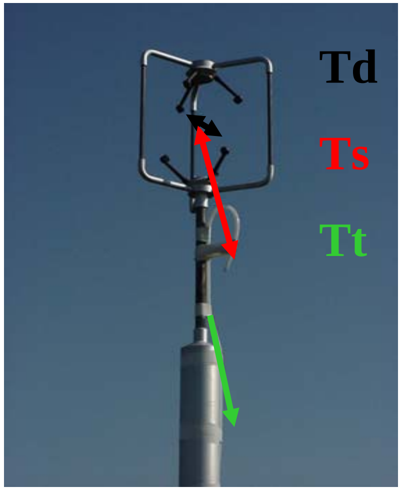
Uncertainties

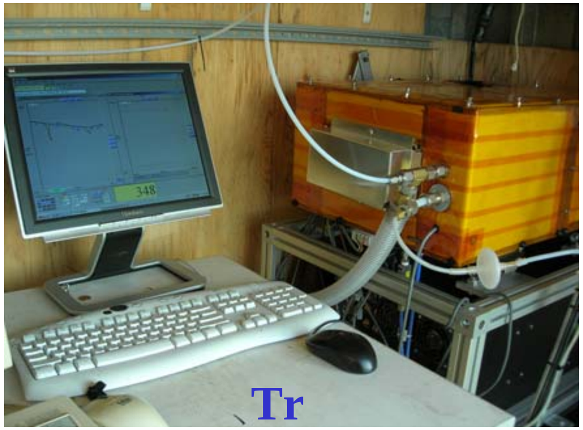
- Drift in instruments (R)
- Precision of instruments (R)
- One point sampling (R)
- Alignment sonic anemometer (S)
- Calibrations (S)
- Low frequency response losses (S)
- High frequency response losses (S)
- Delay time determination (S/R)

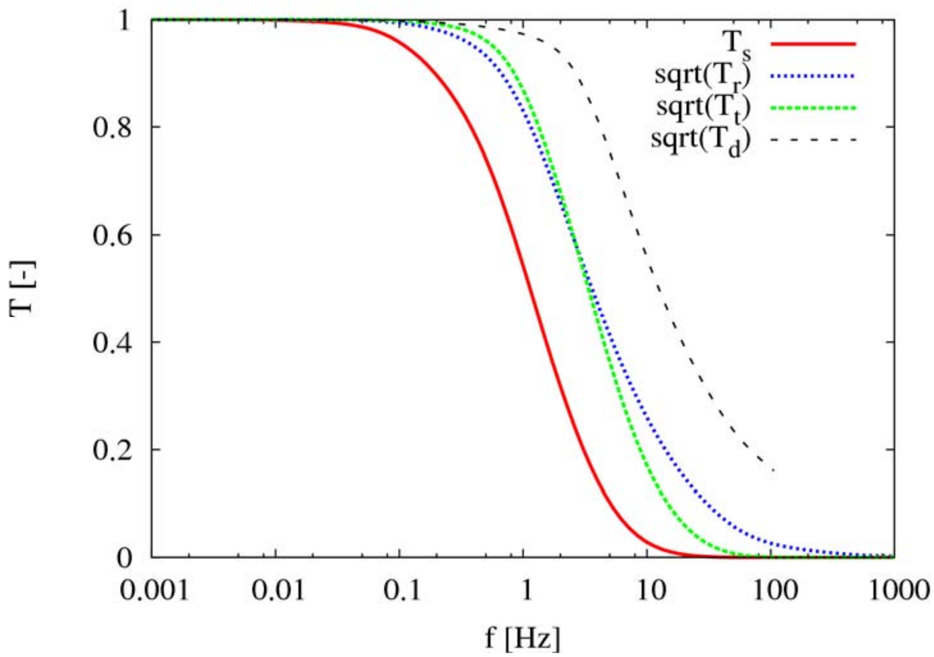
$$\tilde{\tilde{F}}_c = \chi_{cal}\chi_{low}\chi_{high}F_c + \chi_{Webb}$$

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

High frequency correction







$$T_{high}(f) = T_s(f)\sqrt{T_r(f)T_t(f)}\sqrt{T_d(f)}$$

Kroon et al., submitted

High frequency correction

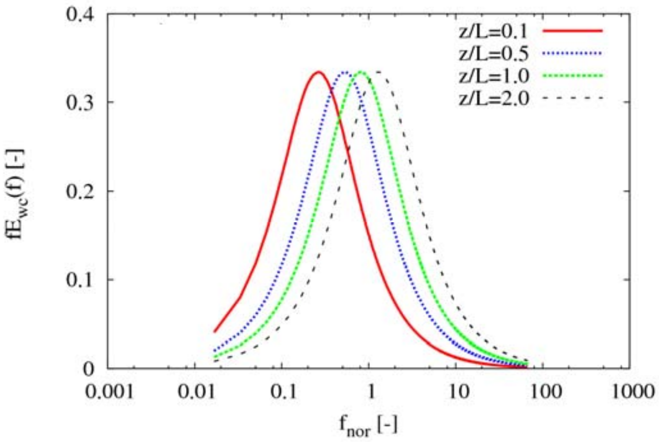
$$\chi_{high} = \frac{\int_0^\infty C_{wc}(f)df}{\int_0^\infty T_{high}(f)C_{wc}(f)df}$$

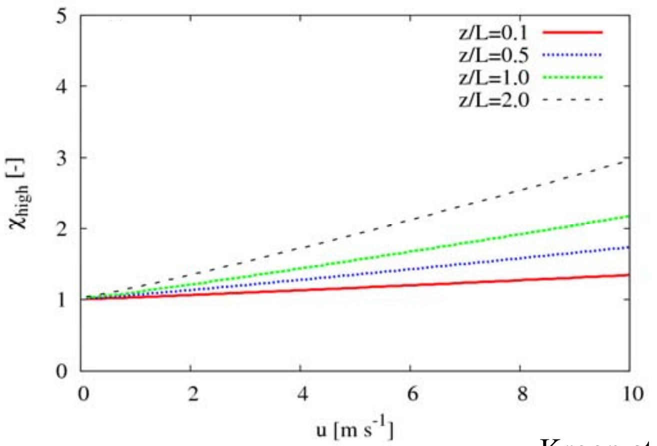
Empirical Kaimal spectrum for z/L>0

$$fE_{wc}(f) = f\frac{C_{wc}(f)}{\overline{w'c'}} = \frac{f_{nor}}{A_{wc} + B_{wc}f_{nor}^{2.1}}$$

$$A_{wc} = 0.284\left(1+6.4\frac{z}{L}\right)^{0.75}$$

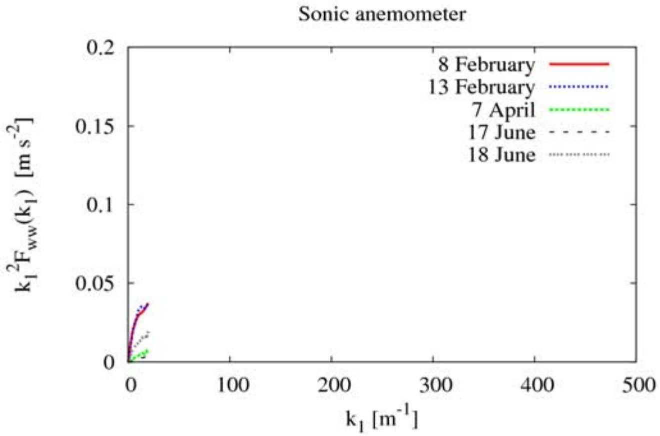
$$B_{wc} = 2.34A_{wc}^{-1.1}$$

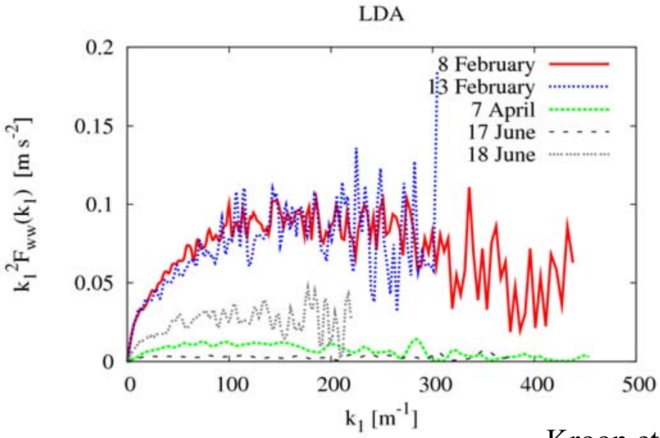




Kroon et al., submitted

High frequency correction





Kroon et al., submitted

High frequency correction

Model Pope (2000)

$$E(k) = C\varepsilon^{2/3}k^{-5/3}f_L(kL)f_\eta(k\eta)$$

$$F_{ww}(k_1) = \frac{1}{4}\left(F_{uu}(k_1) - k_1\frac{dF_{uu}(k_1)}{dk_1}\right)$$

$$F_{uu}(k_1) = \frac{1}{2}\int_{k_1}^{\infty}\frac{E(k)}{k}\left(1-\frac{k_1^2}{k^2}\right)dk$$

e.g. Nieuwstadt (1998)

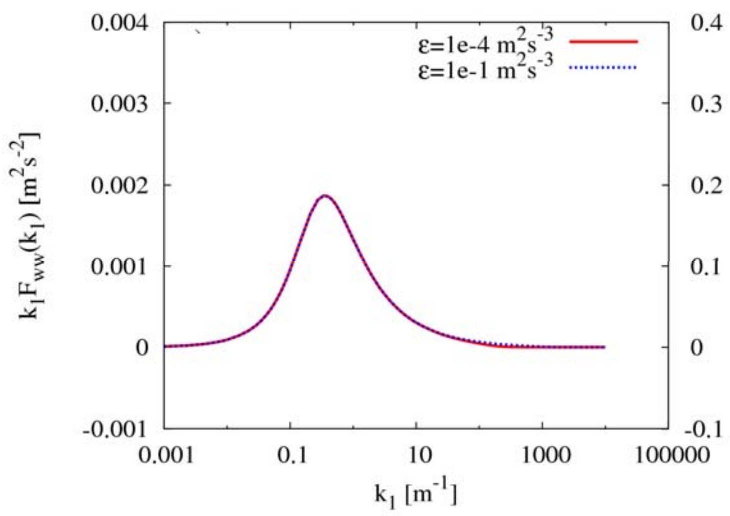
$$\varepsilon \approx \int k_1^{\ 2}F_{ww}(k_1)dk_1$$

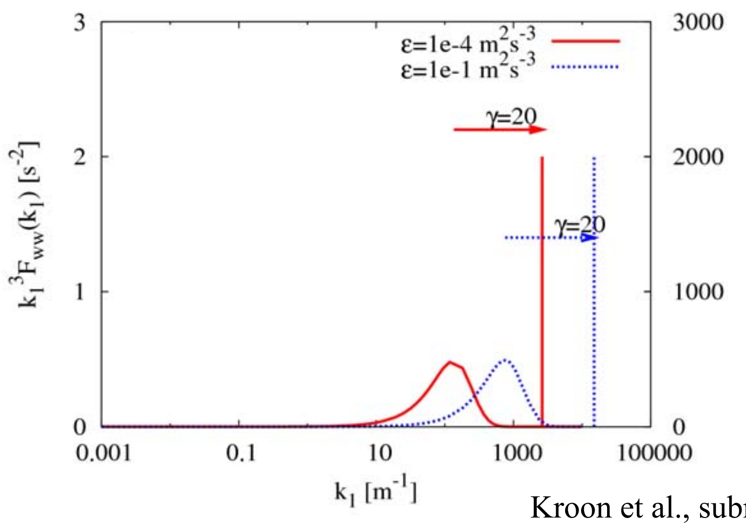
$$\eta = \left(\upsilon^3/\varepsilon\right)^{1/4}$$

Kroon et al., AFM, submitted

$$\lambda_\varepsilon = \gamma\eta$$

	γ
$E(k)$	15
$F_{uu}(k_1)$	25
$F_{ww}(k_1)$	20





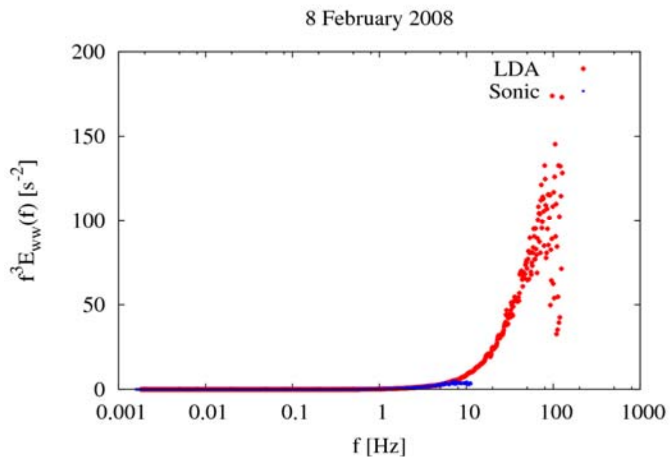
Kroon et al., submitted

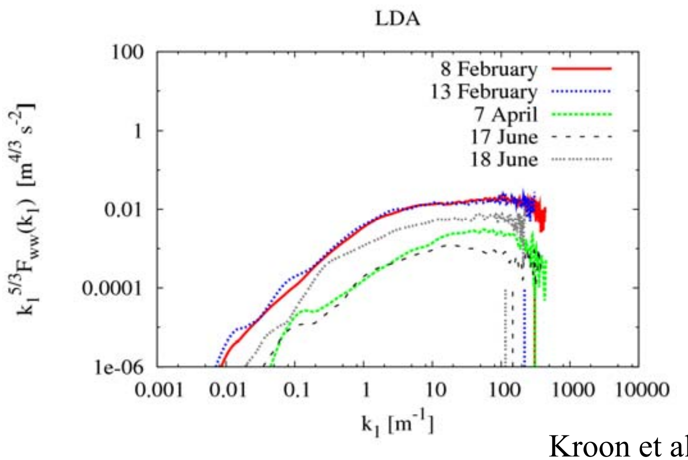
High frequency correction

	8 February	13 February	7 April	17 June	18 June
η [m]	1×10^{-3}	1×10^{-3}	2×10^{-3}	3×10^{-3}	2×10^{-3}
λ_ε [m]	20×10^{-3}	20×10^{-3}	43×10^{-3}	54×10^{-3}	29×10^{-3}
$Min(\lambda_{son})$ [m]	157×10^{-3}	157×10^{-3}	157×10^{-3}	157×10^{-3}	157×10^{-3}
$Min(\lambda_{LDA})$[m]	14×10^{-3}	20×10^{-3}	13×10^{-3}	16×10^{-3}	28×10^{-3}

Dissipation scale is detected!!

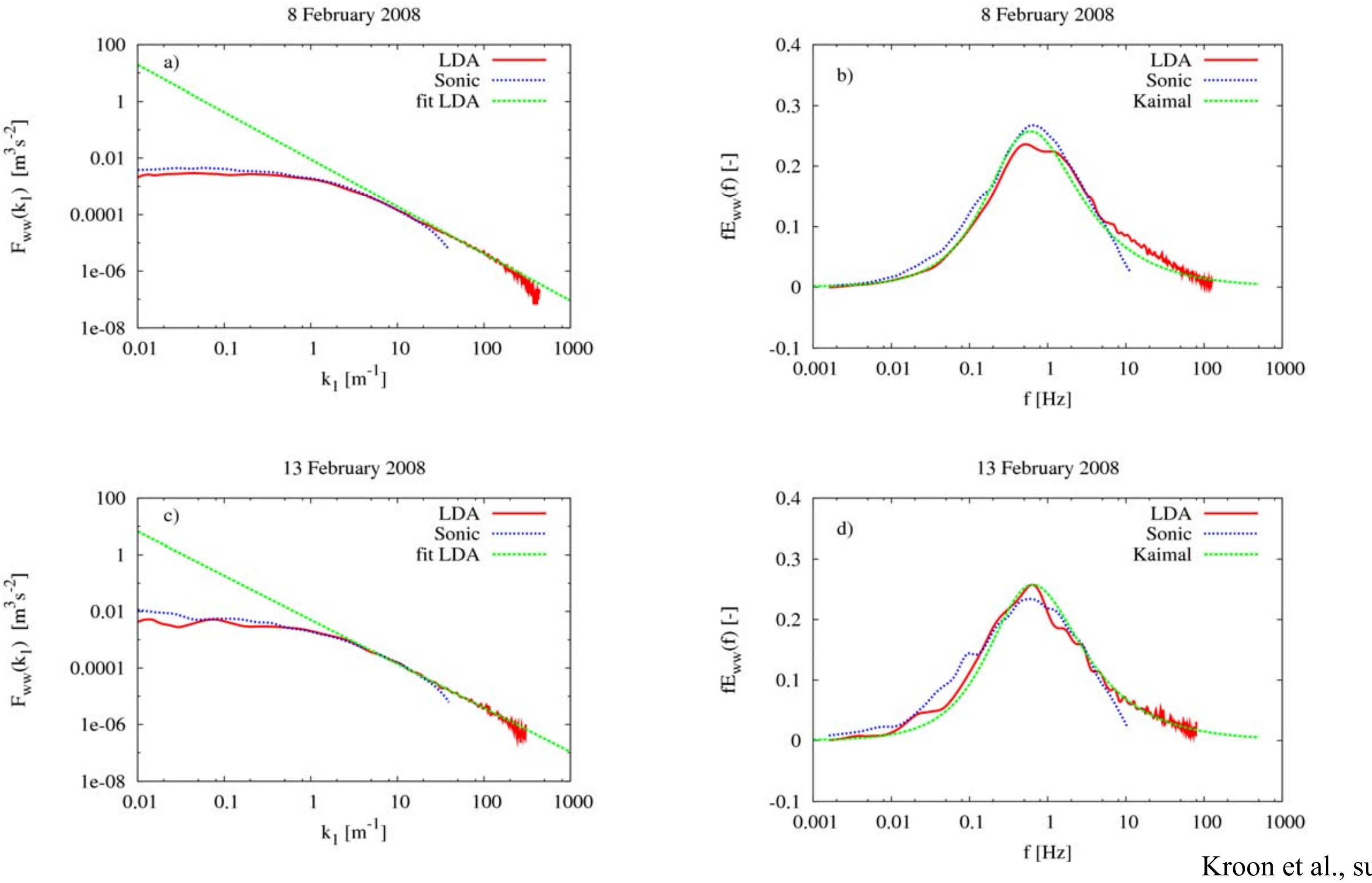
Empirical Kaimal spectrum can be validated!!





Kroon et al., submitted

High frequency correction



Kroon et al., submitted

Reminder: High frequency correction

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Empirical Kaimal spectrum for z/L>0

$$fE_{wc}(f) = f\frac{C_{wc}(f)}{\overline{w'c'}} = \frac{f_{nor}}{A_{wc} + B_{wc} f_{nor}^{2.1}}$$

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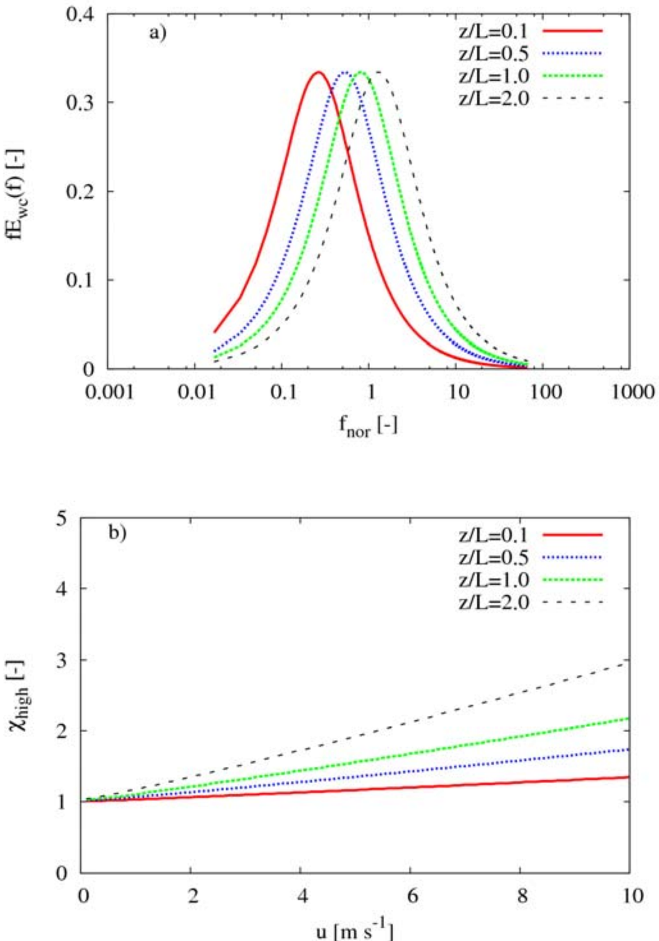
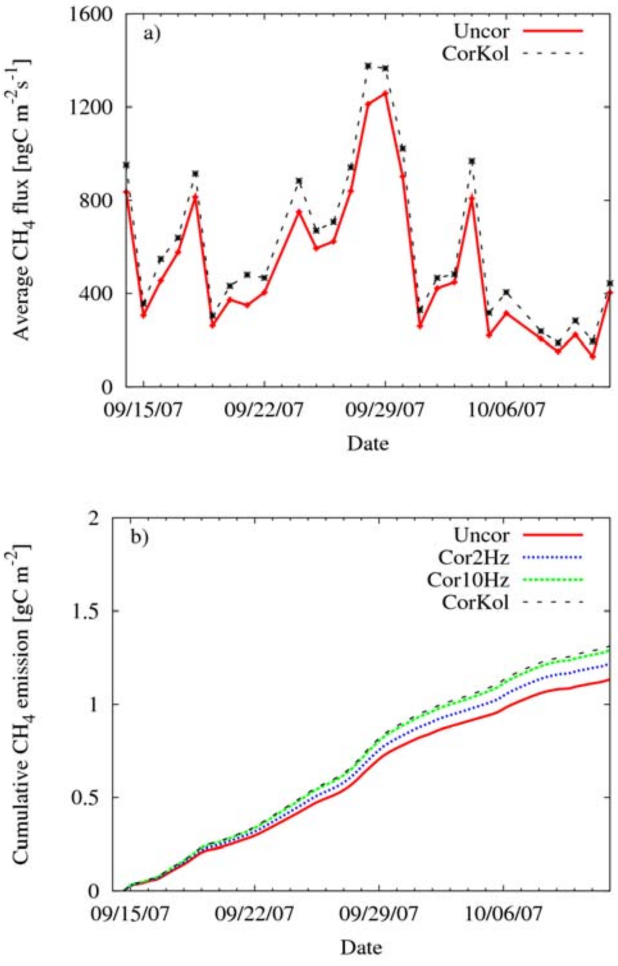


Kroon et al., submitted

High frequency correction



Cumulative emissions after high frequency correction about 14% higher

Kroon et al., submitted

Uncertainty in EC flux measurements of CH_4 and N_2O

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

Uncertainties

- Drift in instruments (R)
- Precision of instruments (R)
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$$\underbrace{\qquad\qquad\qquad\qquad}$$

$$\tilde{\tilde{F}}_c = \chi_{cal}\chi_{low}\chi_{high}F_c + \chi_{Webb}$$

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

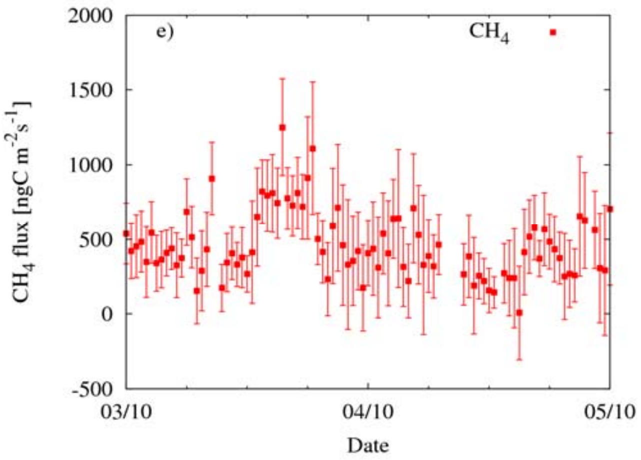
Uncertainty in 30 min EC flux measurement

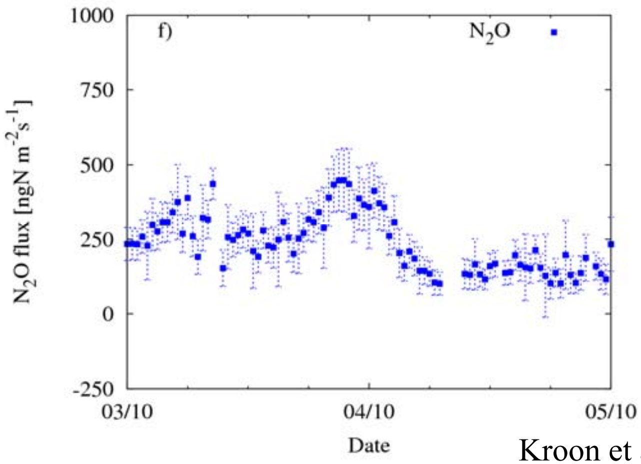
Estimated relative uncertainty $u\left(\tilde{\tilde{F}}_c\right)$

Averaging period	**CH_4**		**N_2O**	
	***U*=1 ms^{-1}**	***U*=10 ms^{-1}**	***U*=1 ms^{-1}**	***U*=10 ms^{-1}**
30 min	142%	48%	269%	87%
Day	22%	11%	40%	15%
Month	10%	9%	12%	8%
3 months	9%	9%	9%	8%

Dominated by random uncertainty due to one point sampling

$$u_{op} = aF_c = \sqrt{\frac{20z}{TU}\left|\frac{\left(\overline{w'c'}\right)^2}{\left(\overline{w'c'}\right)^2} - 1\right|}F_c \quad \text{(Businger, 1986)}$$





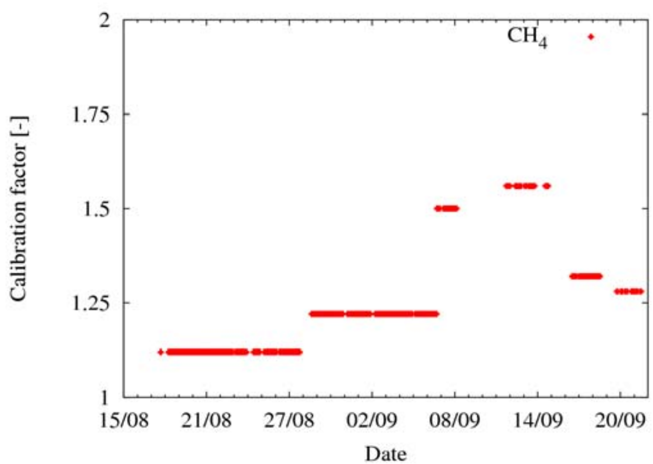
Kroon et al., submitted

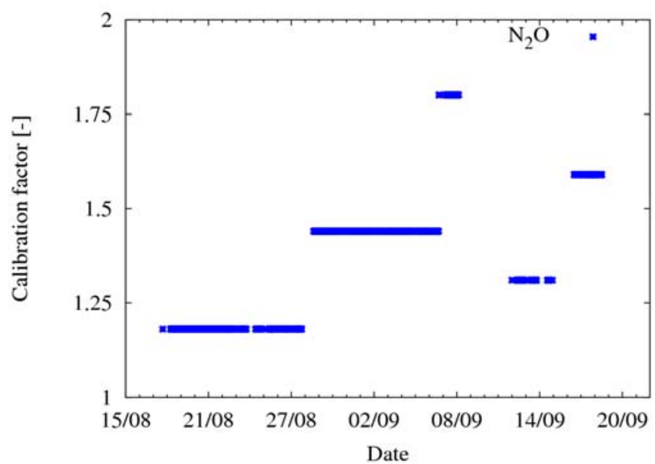
Uncertainty in 30 min EC flux measurement

Estimated relative uncertainty $u\left(\tilde{\tilde{F}}_c\right)$

Averaging period	**CH_4**		**N_2O**	
	U=1 ms^{-1}	**U=10 ms^{-1}**	**U=1 ms^{-1}**	**U=10 ms^{-1}**
30 min	142%	48%	269%	87%
Day	22%	11%	40%	15%
Month	10%	9%	12%	8%
3 months	9%	9%	9%	8%

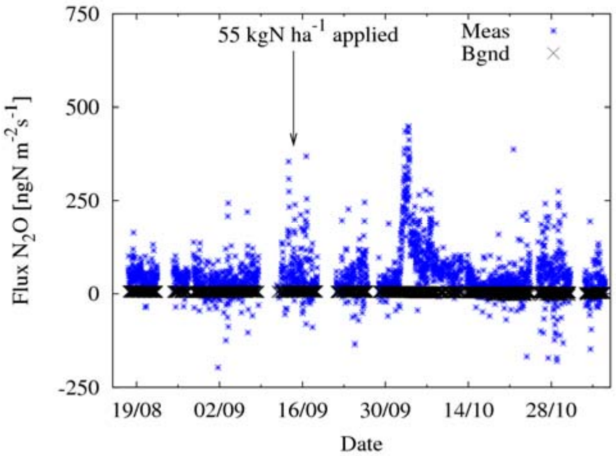
Dominated by systematic uncertainty due to calibration

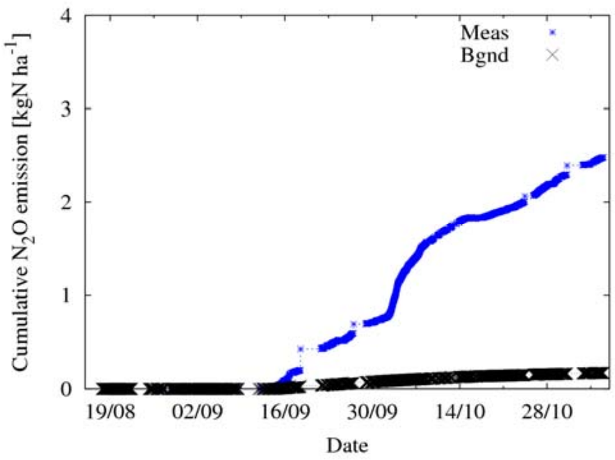




Kroon et al., 2007

Uncertainty in emission coefficient





$5.2\% \pm 0.8\%$

Uncertainty due to e.g. storage and advection are not included!!

Kroon et al., in prep.

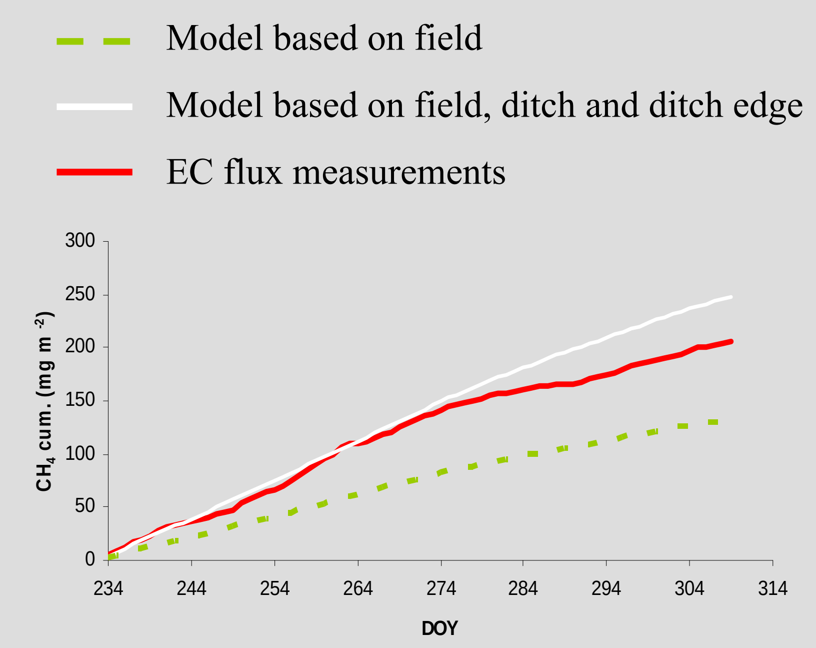
Comparability of EC and chamber for CH_4

Simple model based on manual chamber:

$$F_{CH4} = e^{a+bT}$$

	Coverage	*a*	*b*
Ditch	16%	-0.75	0.19
Ditch edge	5%	0.37	0.12
Field	79%	-1.03	0.07

Schrier and Kroon et al., submitted



Summary technical

- The annual emission estimates of peat areas are very uncertain
- Micrometeorological technique is required to include the spatial and temporal variation
- It is possible to perform EC flux measurements of CH_4 and N_2O using a QCL
- Corrections should be applied for the systematic errors in EC flux measurements
- LDA measurements can resolve the *w* spectra down to the scale on which most dissipation takes place.
- The Kaimal co-spectrum is valid as well in the high frequency range

Summary technical

- The cumulative emissions increased by about 14% after high frequency correction
- There are many uncertainties in EC flux measurements
- The uncertainty over one day EC flux measurement is between 11-40% for CH_4 and N_2O
- EC flux measurements can contribute to more accurate estimations of CH_4 and N_2O
- Models based on chambers must include the different land elements
- Chamber based model and EC flux measurements agreed within 20%

Summary policy related

- CH_4 emissions from ditches are much higher than from field
- CH_4 emissions are influenced by management
- N_2O emission coefficient can be much higher than default value of 1% of IPCC

Future plans

- Determination of the reliability of an one-point measurement (with TU Delft & KNMI)
- Developing and employing REA system for CH_4 and N_2O
- Determination of emission coefficient of N_2O of Oukoop (with WUR & TU Delft)
- Determination of the total GHG balance of Oukoop (with WUR)
- Comparison of three different peat areas in the Netherlands (with WUR, VU & TNO)

Thanks to …

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- ….

ECN

Energy research Centre of the Netherlands

TU Delft

Delft University of Technology

climate changes spatial planning

Micrometeorological observations of CH_4 and N_2O at a managed fen meadow in the Netherlands

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