Karlsruhe Institute of Technology

Experimental Evaluation of Flux Footprint Models

KIT-Campus Alpi
IMK-IFU: Atmospheric Environmental Resear

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1. Motivation

In most footprint studies **computationally inexpensive models** are applied

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BUT:

Assumption of horizontally **homogeneous turbulence** can usually not be fulfilled in reality

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Increased uncertainties

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Evaluation at real-world flux sites

Up to now, there are no experiments that evaluate the **2D <u>flux</u> footprint <u>directly</u>**

2. TERENO-Research Site „Graswang", Bavaria

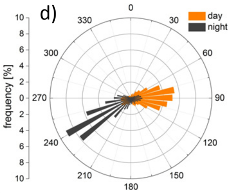

Fig. 1: a) Grassland site in Graswang, southern Germany (47.57° N, 11.03° E; 870 m a.s.l.) with b) the CH_4 flux measurement system and c) the tracer gas diffuser of ~1 m² size, c) frequency distribution of wind direction, July-Oct 2013.

- Located on a flat valley bottom (~1 km wide), flanked by steep sides
- Distinct mountain-valley breeze
- Natural flux of methane almost zero

3. Methods

- Eddy covariance measurements (CSAT3, LI7700, LI7500)
- Surface source of ~1 m² size (Fig. 1c)
- Tracer gas: CH_4
- Release rate: 6-8 l min^{-1} continuously over one averaging period (10 minutes)
- 3 different experiment configurations (Fig. 2)
- Evaluation of 3 footprint models: Kormann and Meixner (2001), Hsieh et al. (2000) and a parameterization of a backward Lagrangian footprint model (Kljun et al., 2004)
- Flux estimated by the model is determined with

$$\underset{\text{flux estimated by footprint model}}{\eta} = \underset{\text{tracer release rate}}{Q_\eta}\, \underset{\text{footprint weighting factor}}{f}$$

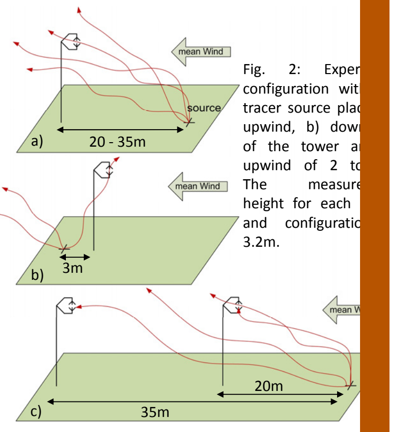

Fig. 2: Exper configuration wit tracer source plac upwind, b) dow of the tower a upwind of 2 to The measure height for each and configuratio 3.2m.

4. Results – Experiments with upwind source

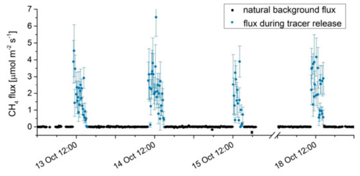

Fig. 3: Time series of measured (natural and artificial) 10-minute CH_4 fluxes

- Artificial flux in most cases ~100 times larger than the natural flux (Fig. 3)
  - → Surface source of just 1 m² is a good possibility to precisely validate the 2D footprint
- Daytime-experiments
  - → Mostly unstable conditions
- Hsieh et al. (2000) matches observations best (mode of frequency distribution closest to 1, Fig. 4 left)
- All models underestimate the maximum of the footprint (Fig. 4 right)

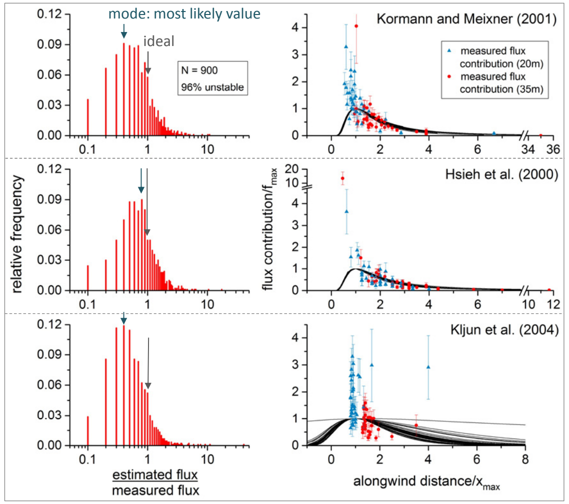

Fig. 4: Left: Frequency distribution of the ratio $\frac{\text{estimated flux}}{\text{measured flux}}$, data of experiment configurations a+c are included. Right: Measured and estimated flux contributions standardized with footprint maximum as a function of along-wind distance standardized with distance of footprint maximum for 3 different footprint models; only data of experiment configuration c are shown. Vertical bars denote the turbulence sampling error estimated following Finkelstein and Sims (2001).

5. Results – Experiments with downwind source

- Flux contribution from downwind source is measurable only occasionally (Fig. 5).
- Downwind contribution depends on streamwise turbulence intensity σ_u/u (Fig. 6+7a).
- Kormann and Meixner (2001) and Hsieh et al. (2000) do not consider downwind contribution.
- Kljun et al. (2004) estimates a downwind contribution for any time period, even when along-wind turbulence intensity is low (Fig. 7b+c).

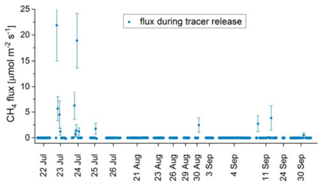

Fig. 5: Discontinuous time series of measured 10-minute CH_4 fluxes during periods of tracer release (**downwind source).**

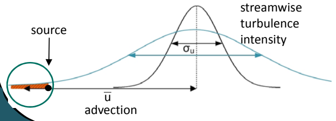

Fig. 6: The effect of streamwise turbulence intensity on downwind contribution with low (black) and high (blue) intensity.

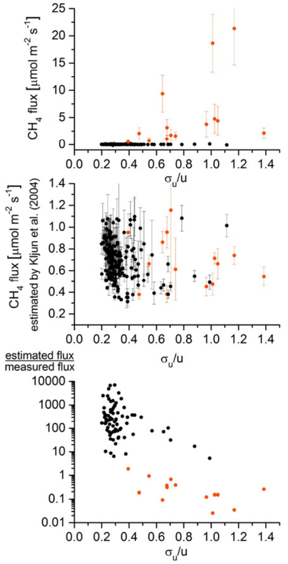

Fig. 7: a) measured 10-minute CH_4 fluxes, b) CH_4 fluxes estimated by Kljun et al. (2004) and c) model performance of Kljun et al. (2004) as a function of σ_u/u.

6. Summary

- Tracer experiments aimed assessing the applicability utility of commonly u footprint models at observation conditions.
- Overall, the three evalua models match observati roughly, but all und estimate the flux.
- We found a measura contribution to the flux fr the downwind sou depending on streamw turbulence intensity.
- Downwind contribution occ only intermittently and continuously.
- The downwind footp estimate of the Kljun et (2004) model needs to optimized.

TERENO
Terrestrial Environmental Observatories
HELMHOLTZ ASSOCIATION
MICMoR
REKLIM
Helmholtz-Verbund Regionale Klimaänderungen

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Acknowledgements

Funding for TERENO was provided by the Federal M Education and Research (BMBF). The support by the Ba Staatsforsten and our co-worker Elisabeth Eckart is app