Re-construction of CH_4 emissions from a biogas plant – meteorological aspects

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Outline

- Background: CH_4 emissions from biogas plants
- Methodology for multi-source identification
- Field experiment to quantify methane losses from biogas facilities
- On-site meteorology
- Results: Source identification for six experiment days with a broad range of meteorological conditions
- Conclusions

Background

Biogas plants can contribute to the reduction of greenhouse gases (GHG)

Net GHG reduction will heavily depend on the process efficiency

Numbers of biogas plants has considerably increased

GHG emissions and methane losses can arise from diverse parts of biogas facilities along the entire process chain of biogas generation and utilization

Certain plant components (e.g. open digestate storage tanks, membranes, safety valves) are suspected as potential emitters

Up to now, no reliable data records available to evaluate relevance of these losses and emissions

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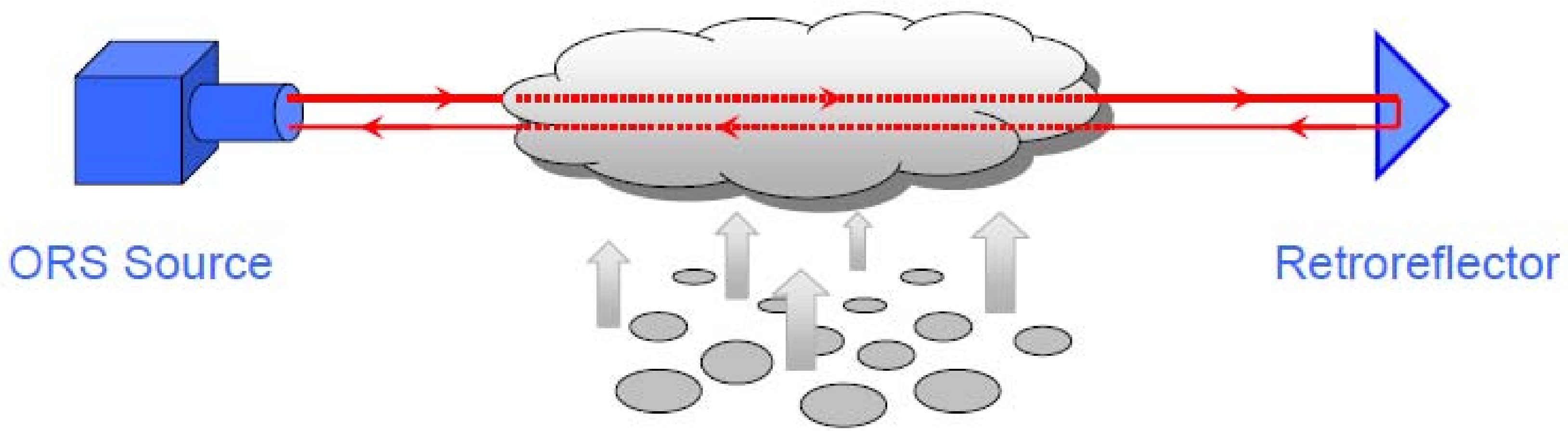
Optical remote sensing (ORS) technology



Diffuse emission sources

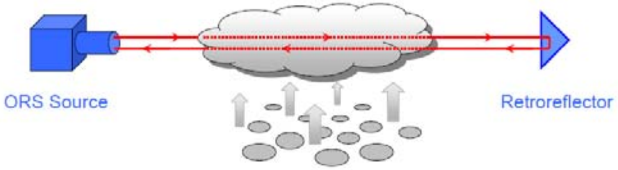
Gas concentrations obtained by Lambert-Beer law:

$$A = \varepsilon c_m l$$

A … absorption intensity
ε … absorption coefficient
c_m … gas concentration
l … length of measurement path

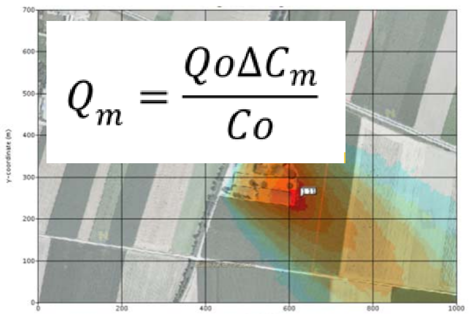
Determination of emission rates – two ways

1. **Concentration measurement (ppm*m)**



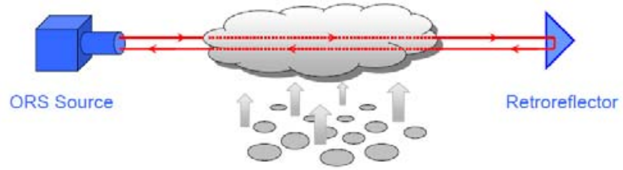
2. **Wind and turbulence**

3. **Dispersion model**
   => Emission rate (kg/h)



$$Q_m = \frac{Qo \Delta C_m}{Co}$$

1. **Concentration measurement (ppm*m)**



2. **Tracer gas release (ppm*m), (kg/h)**

3. **Proportionality calc.**
   => Emission rate (kg/h)

$$Q_m = \frac{Q_t \Delta C_m}{\Delta C_t}$$

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$\kappa = \|(C/Q)_{sim}\| * \|(C/Q)_{sim}^{-1}\|$

Multi-source emission determination

Regularized least-squares (Flesch et al., 2009)
(n measurement paths, m sources
=> Matrix n x m)

$$\begin{bmatrix} (C_{A,1}/Q_1)_{sim} & (C_{A,2}/Q_2)_{sim} \\ (C_{B,1}/Q_1)_{sim} & (C_{B,2}/Q_2)_{sim} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} = \begin{bmatrix} C_A \\ C_B \end{bmatrix}$$

The **condition number** *κ* is a measure of “ill-conditioning”, i.e. if the solution is extremely sensitive to changes in the input data (measurements or model estimates)

$$\kappa = \|(C/Q)_{sim}\| \; \|(C/Q)_{sim}^{-1}\|$$

Decomposition of a single source: k ~ < 10 – 20
Total emission: k ~ < 50

Accuracy of emission calculation measured by **single source or total recovery ratio** $R = Q_{mod}/Q_{fix}$; perfect calculation: $R = 1$

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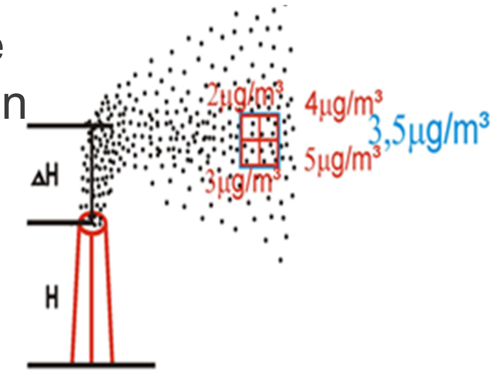
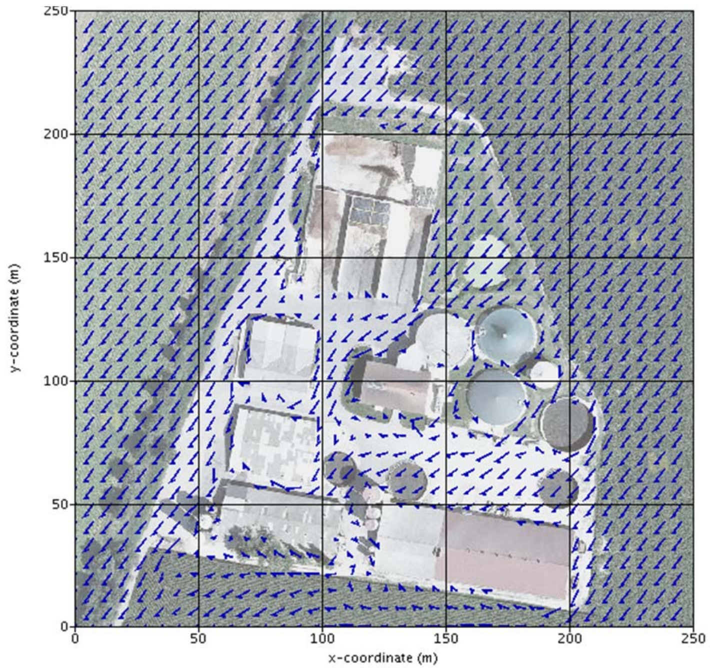
Dispersion Model LASAT



- Lagrange dispersion model LASAT is used to back-calculate emissions from measured concentrations (Inverse Dispersion Technique)
- Allows for point, area and line sources
- Inclusion of a 3D diagonstic wind field (flow around buildings or in moderately complex terrain)
- Wind speed ≥ 0,5 m/s



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Experimental set-up

Source: Biogas plant NW of Vienna, complex building structure, multiple point and volume sources with unknown releases

Sources, laser paths, picture and location (red dot) of the ultrasonic anemometer at the biogas plant (north orientated)
Q2, Q3, Q5: open digestate storage tanks
Q1, Q4: closed tanks of liquid manor

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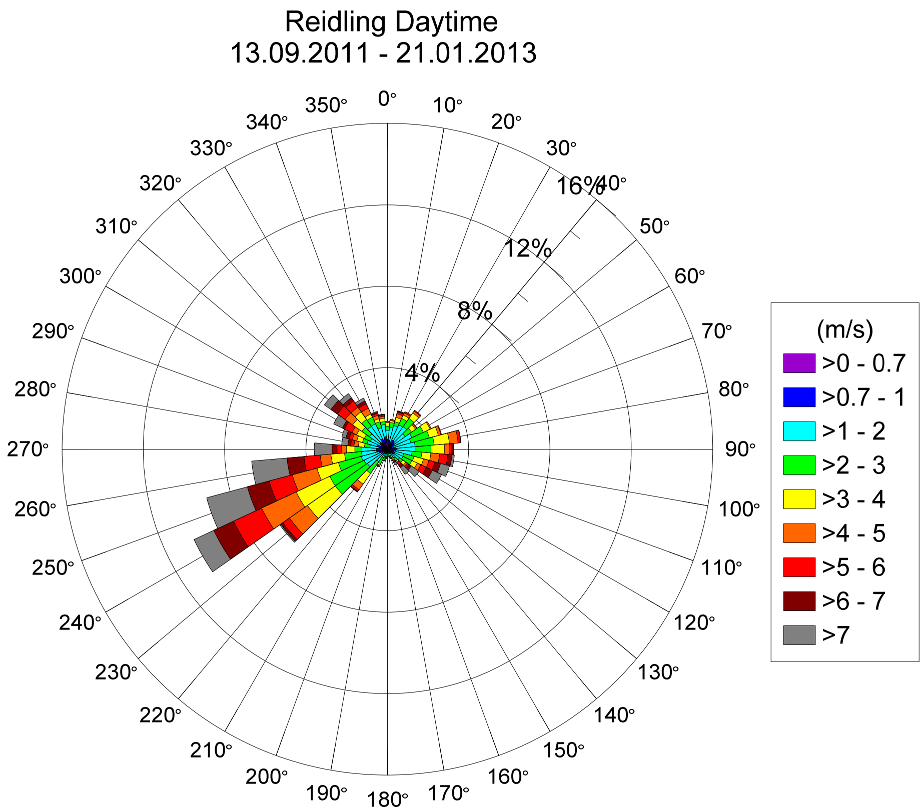
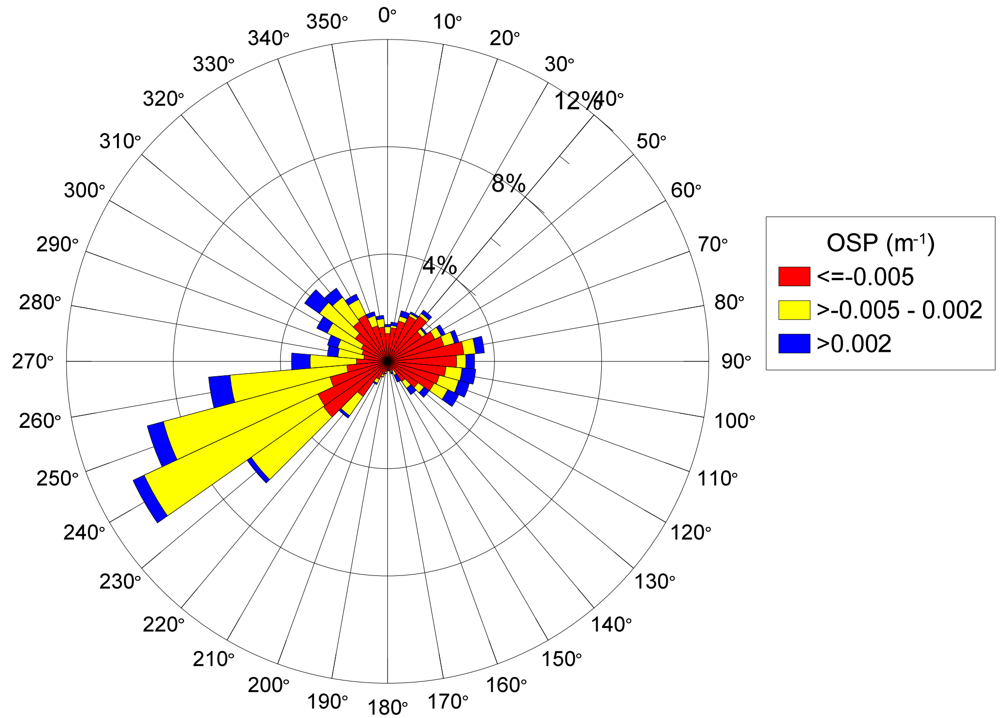
Meteorology





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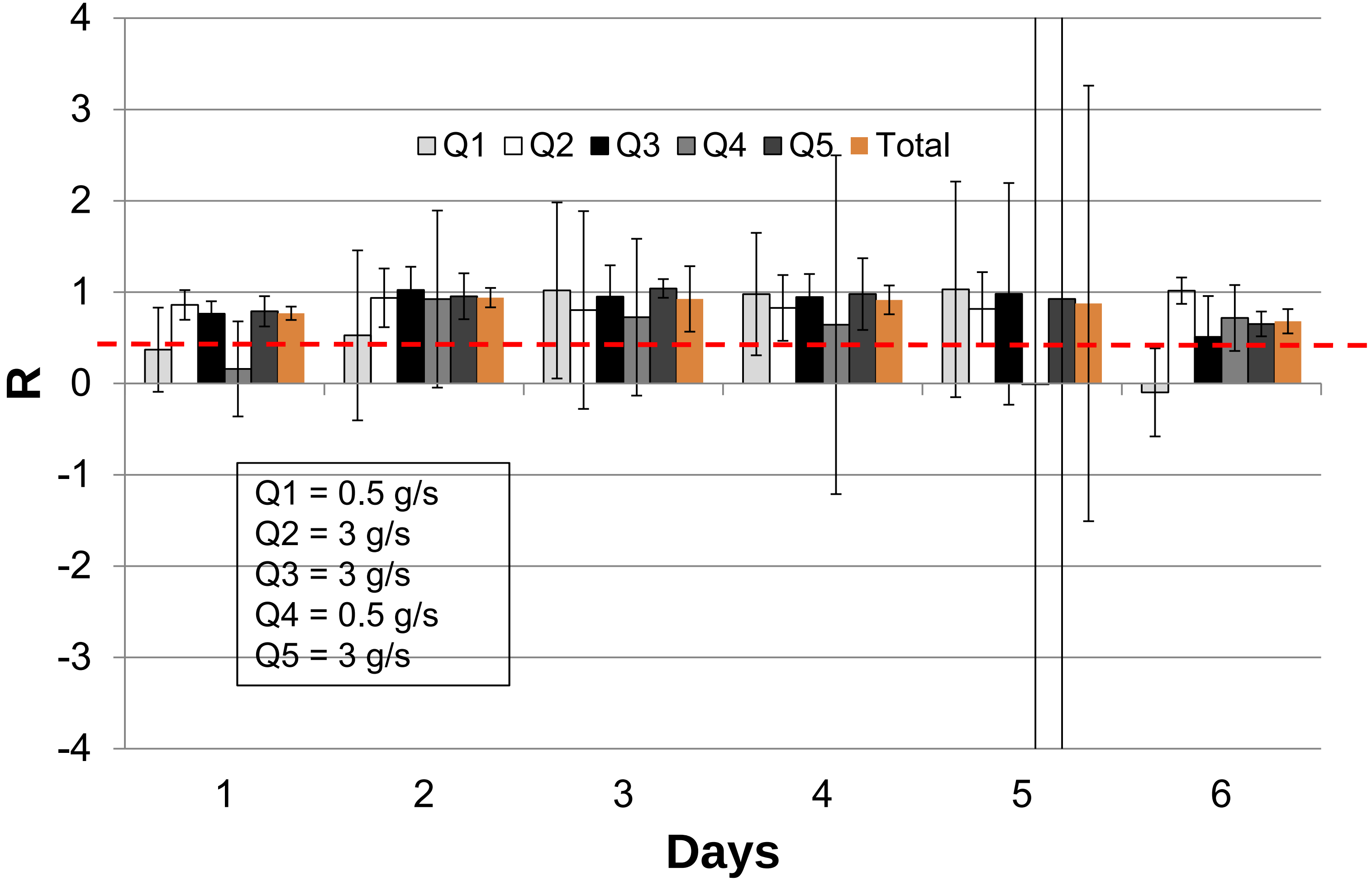
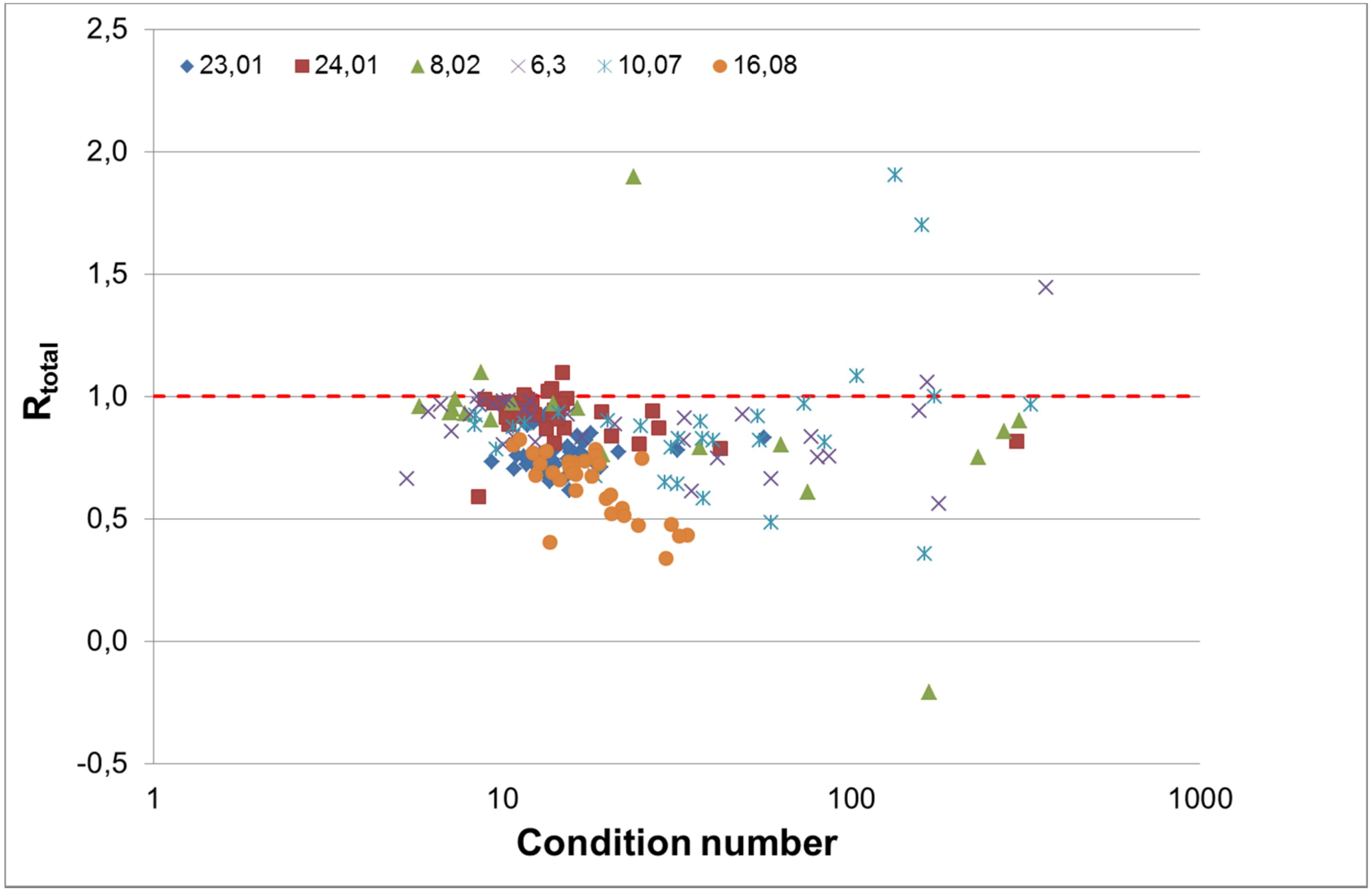
Short characterization of the days of the experiment

1. 23.01.2012: WSW-Wind 7 ms^{-1}, stability: neutral
   (all storage tanks filled); digestate sample of Q3
2. 24.01.2012: WNW-Wind 5,5 ms^{-1}, stability: neutral
   (all storage tanks filled)
3. 08.02.2012: NE-SE-Wind 2,5 ms^{-1}, stability: variable
   (all storage tanks filled)
4. 06.03.2012: NE-E-Wind 2,5 ms^{-1}, stability: unstable
   (storage tanks partly filled since 15.02); digestate sample of Q3
5. 10.07.2012: SE-Wind 2 ms^{-1}, stability: unstable
   (only Q3 filled); digestate sample of Q3
6. 16.08.2012: SW-Wind 3 ms^{-1}, stability: neutral
   (only Q3 filled); digestate sample of Q3

Individual recovery ratios, specific source strengths



Total recovery ratio vs. condition number



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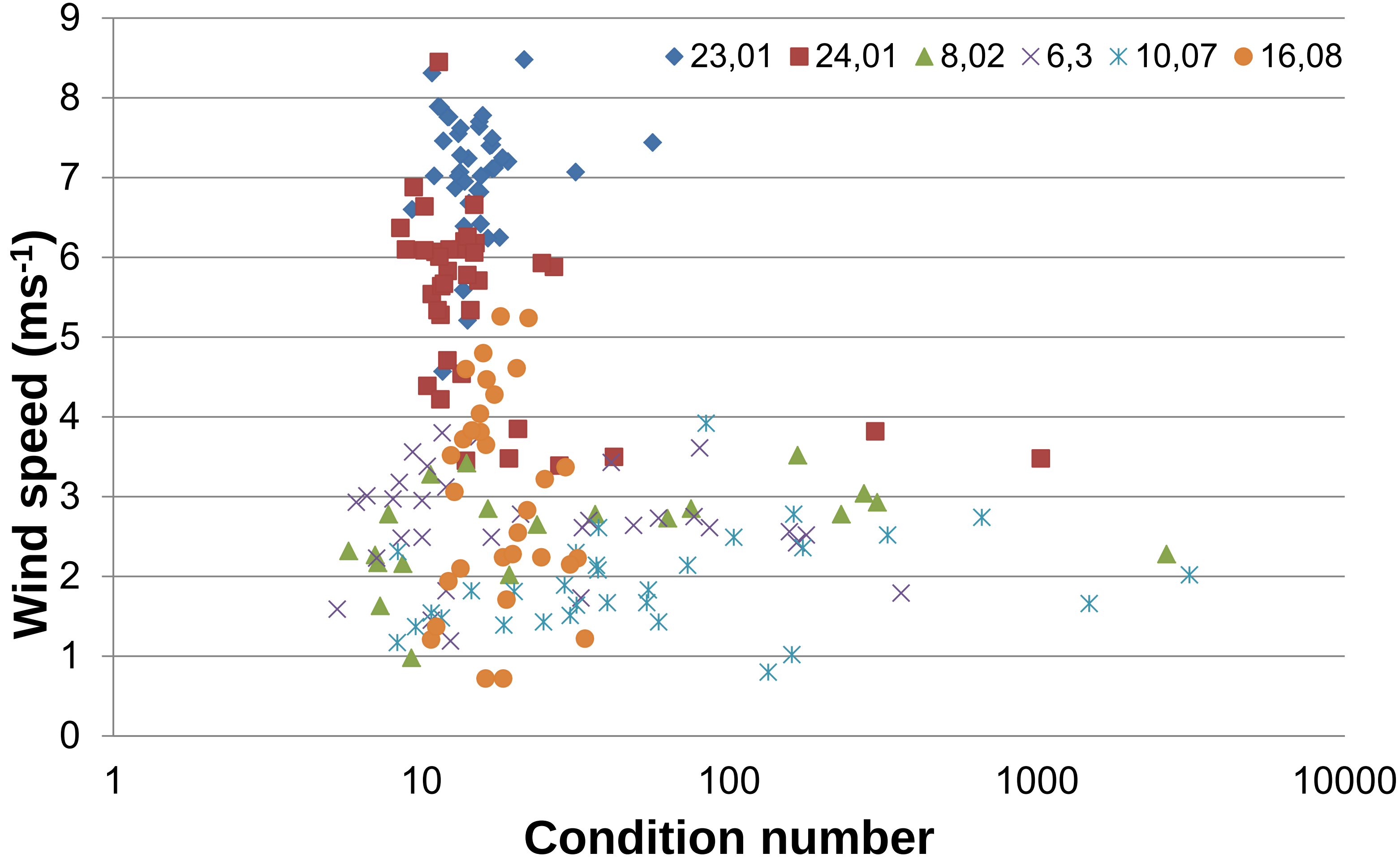
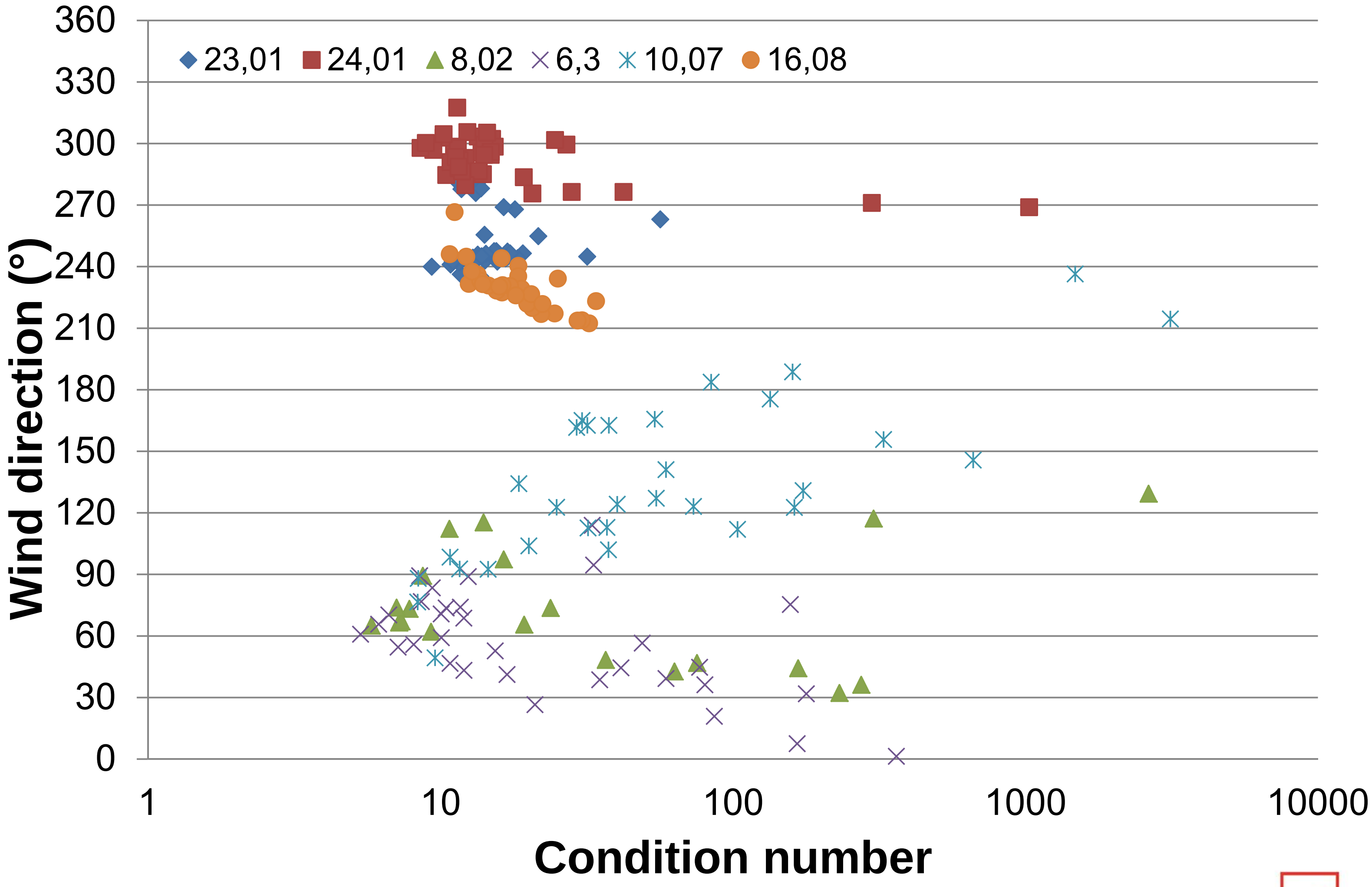
Condition number depending on wind speed



Condition number depending on wind direction



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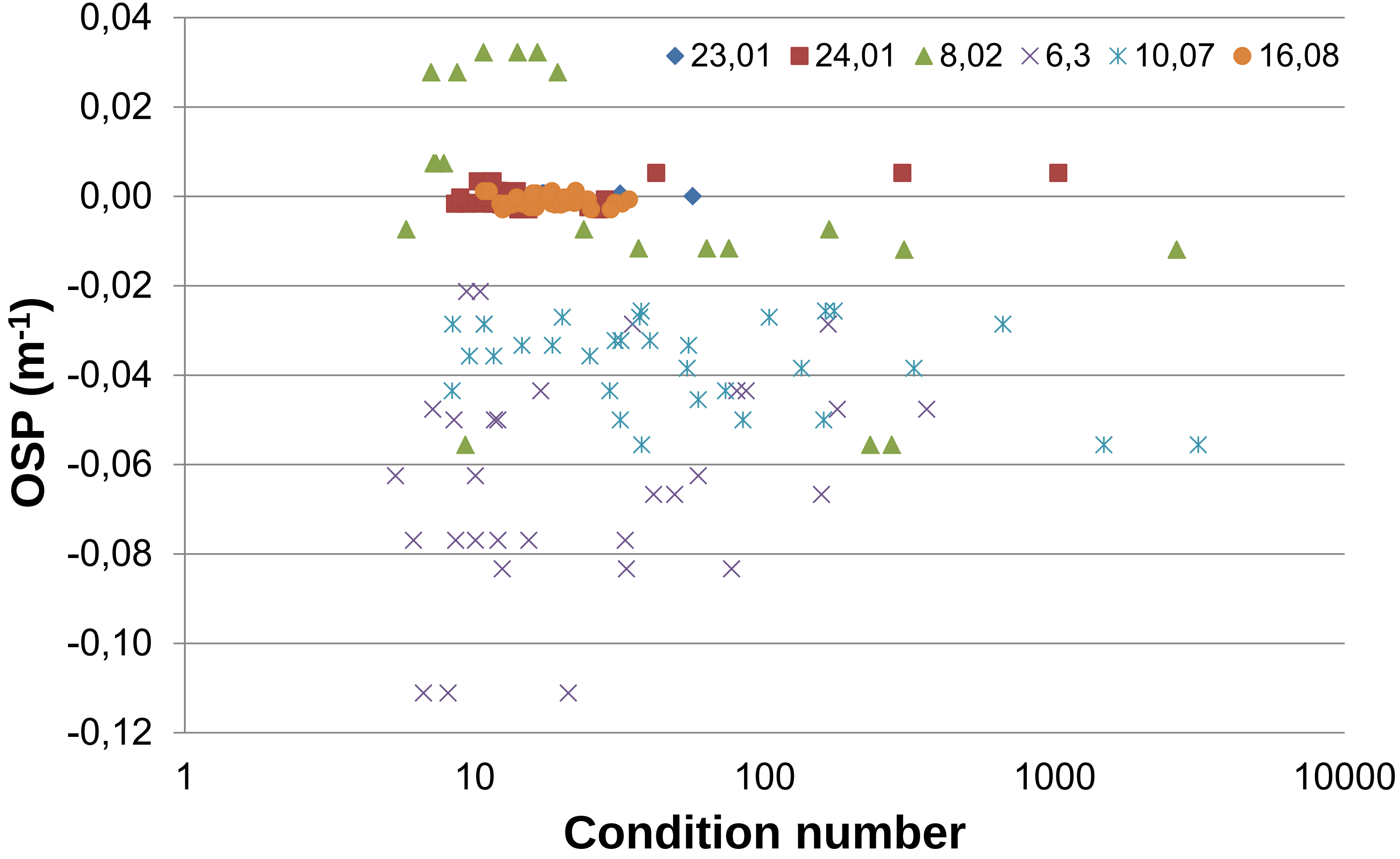
Condition number depending on the OSP



Summary

- For a biogas plant NW of Vienna, Austria, CH_4 source identification was undertaken by a combination of Optical Remote Sensing Technique and a Lagrangian dispersion model
- For six experimental days with different meteorological conditions, the individual and total recovery ratios were calculated and interpreted with respect to the condition number and meteorology
- R_{total} mostly varies between two times over-estimation and 70 % under-estimation, with a lot more cases of slight under-estimation on all experiment days
- A few outliers are found for condition numbers well above 20, mainly on days 4 and 5 with unstable conditions and weak winds
- The dependence of the condition number on wind speed is strongest: large condition numbers indicating uncertainty in recovering the sources are found for wind speeds below 4 ms^{-1} only. The latter are mainly associated with experimental days 3 to 5 on which wind speeds were lowest on average.
- More scatter for easterly airflow and in unstable conditions

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Thank you very much for

your kind attention!