Does Sensor Positioning Impact Emission Estimation in Naturally Ventilated Dairy Barns?

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In naturally ventilated dairy barns (NVDB), accurately estimating gaseous emissions like CO_2, CH_4 and NH_3 is challenging. The NVDB has large side openings that interface with external wind conditions. Whereby, the inlet and outlet of NVDB depends upon meteorological wind flows approaching the barn. Direct method requires accurately recording the volume flow rate (Q) and target gas concentration (c_P) of the air exiting from the barn's outlet (Fig. 2). However, a sampling position for measuring c_P and Q at the barn outlet that is representative of the entire barn volume is unknown. Thereby, a precondition is to study the spatial distribution of target gases (c_{CO_2}, c_{CH_4}, c_{NH_3}) at the outlet considering the external wind flow effect.

Objective

- We investigated the effect of sampling height (H) and wind inflow speed (V) on average concentrations of each target gas (c_{CO_2}, c_{CH_4}, c_{NH_3}).
- Furthermore, we studied the relationship between sampling height and mixing ratio of $\frac{CH_4}{NH_3}$ which is a crucial indicator to find an optimal gas sampling height.

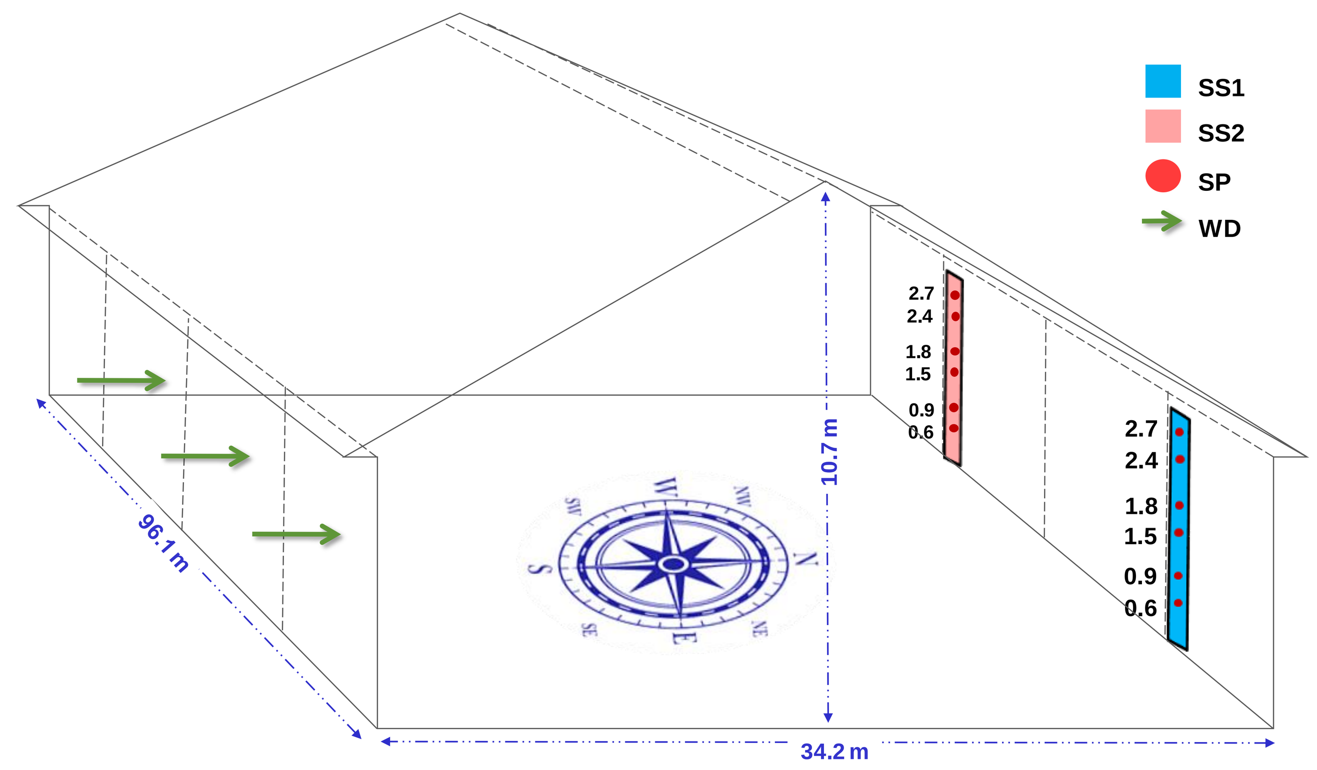


Figure 1. Sectional view of the investigated NVDB showing the two gas sampling setups (SS1 & SS2) and six sampling positions (SP) at the presumed outlet and arrows pointing out the southwest inflow wind direction (WD) entering from the presumed inlet of the barn (Location: Dummerstorf, Mecklenburg-Vorpommern, Germany)

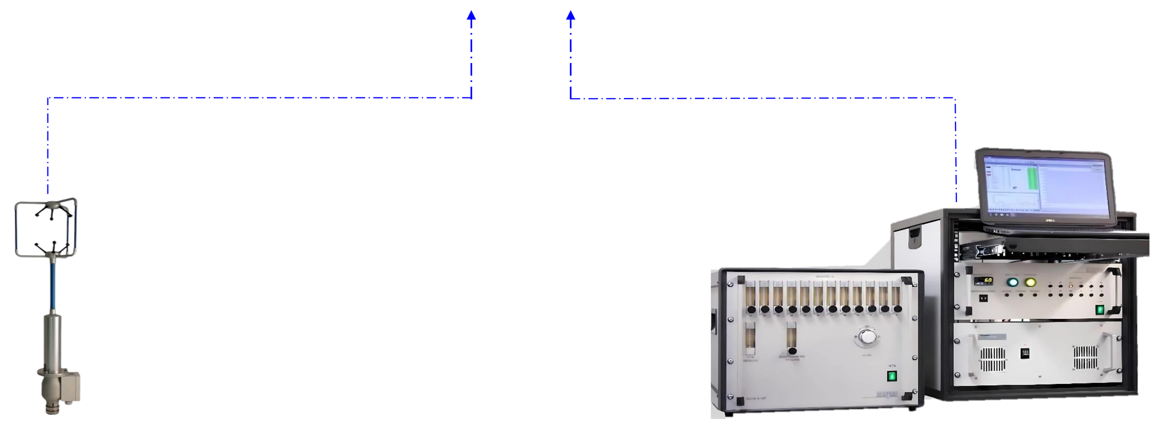
Experimental Setup and Data Collection

Two vertical gas sampling setups (SS1 and SS2), were fixed at the barn's north side opening of the barn. The southern side opening was presumed as the inlet, whereas the northern was presumed as the outlet of the barn (Fig. 1).

Gas concentration data: We used a Fourier-transform infrared (FTIR) spectrometer to measure the CO_2, CH_4, NH_3 concentrations coupled with a multiplexer that collected air samples for 3 minutes at each height cyclically in a numerical sequence from top to bottom.

Wind flow data: We recorded the wind direction and speed information at a frequency of 1Hz by an ultrasonic anemometer. Using wind information, we filtered all the observations by dominant wind direction, (i.e., southern), to establish a uniform inlet.

$$\mathbf{E} = \mathbf{Q} \cdot \Delta \mathbf{c_P} \quad \text{... (Equation 1)}$$



(a) (b)

Figure 2. Equation for measuring gas emission by direct method. (a) Ultrasonic anemometer for measuring wind speed and direction, (b) Fourier-transform infrared (FTIR) spectrometer to measure gas concentrations

Results

- Sampling height significantly influenced the mean concentrations of each target gas (p < 0.001, KW, GLM).
- Adding wind speed as a covariable revealed that all three gases (c_{CO_2}, c_{CH_4}, c_{NH_3}) trended positively during low wind speed & negatively during low wind speed.
- During low wind speed events, the mean CH4 concentrations at H = 2.7 were increased by +24.18% in SS1 and +81.04% in SS2.
- Mean NH3 concentrations at H = 2.7 were also greater for low wind speeds, exhibiting an increase of +55.47% and +105.10% in SS1 and SS2, respectively.
- In addition, the mixing ratios of $\frac{CH4}{NH3}$ were almost stable at H ≥ 1.5 and highly deviated from the mean particularly at H = 0.6 and 0.9 in both SS1 and SS2.

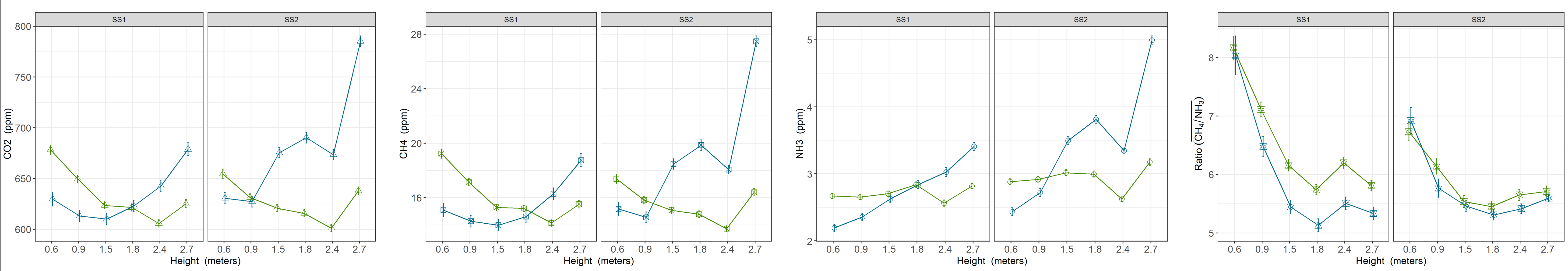


Figure 3. Line plots showing mean values of c_{CO_2}, c_{CH_4}, c_{NH_3} and $\frac{CH4}{NH3}$ at different heights and sampling setups, including the two levels of wind speed i.e., high (V > 3 m/s) and low (V < 3 m/s) in green and blue color, respectively

The study's conclusion highlights vertical dispersion in average CO2, CH4, and NH3 concentrations at the barn's outlet, suggesting a potential influence of sensor positioning on measurement accuracy. These findings have practical implications for selecting an appropriate gas sampling position when only one constant height can be used, such as with open-path lasers or cost-effective monitoring devices. Understanding the spatial variability of gas concentrations within the barn is crucial for reducing systematic errors and improving the reliability of emission measurements. This research contributes valuable insights for optimizing gas sampling strategies, ultimately enhancing the accuracy of data collection and analysis.

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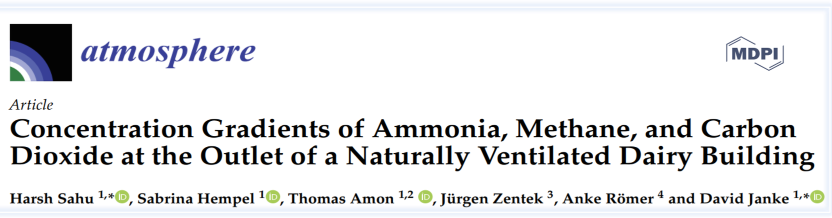
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Article

Concentration Gradients of Ammonia, Methane, and Carbon Dioxide at the Outlet of a Naturally Ventilated Dairy Building

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