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Application of in situ CO₂ and CH₄ concentrations measurements on-board UAV to monitor surface emissions on a grazed grassland, against ground-based Eddy Covariance

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MATERIAL & METHODS

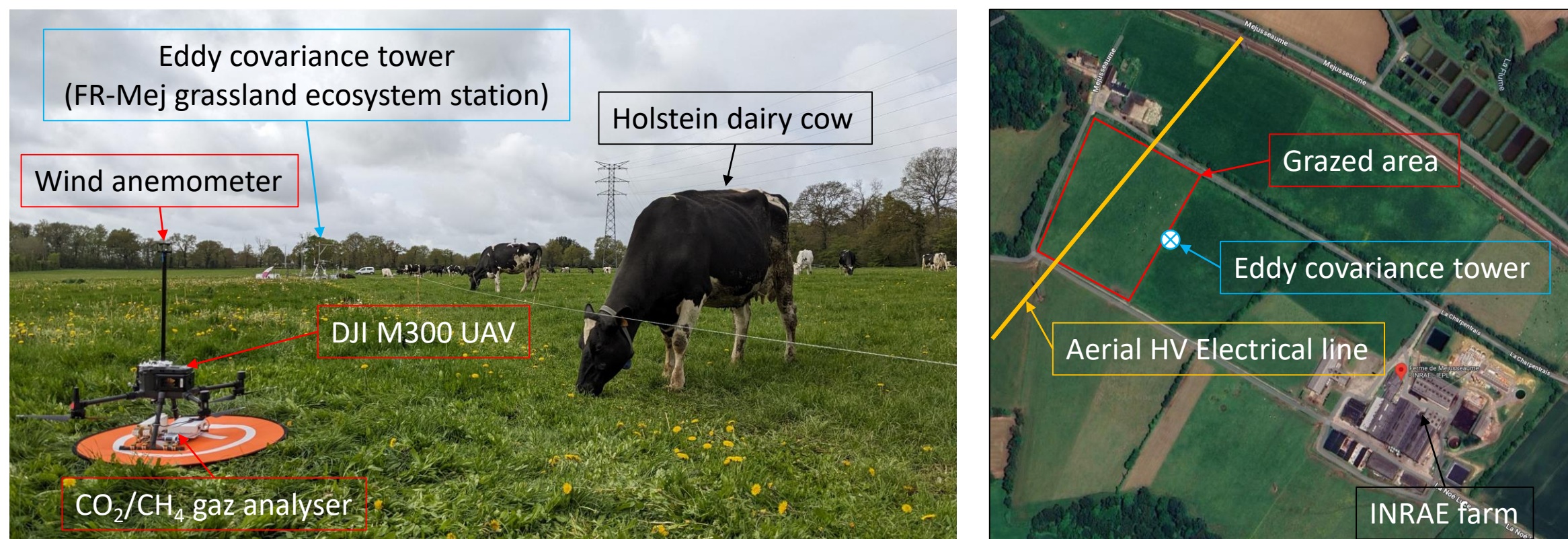
Field campaign

April 10th to 12th, 2024
 20 flights / 4 hours flight time / 18.5 km distance
 13 vertical profiles / 14 horizontal transects flights (3 upwind, 11 downwind)

Site
 INRAE-IEPL dairy experimental farm in Mejusseume NW, France
 ICOS / FR-Mej ecosystem station (associated), situated on an intensively managed grazed grassland by dairy cows : 90 livestock units (LU) during campaign

Instrumentation
Eddy covariance (EC)
 • Gill HS50 3-D ultrasonic anemometer at 1.5m: Wind and turbulence
 • LICOR-7200: CO₂ / H₂O mixing ratios at 20 Hz
 • MIRO MGA quantum cascade laser analyser : CH₄ mixing ratios at 10 Hz
 • Fluxes derived using the Eddypro software at 30 min and 10 min

UAV platform
 • Drone DJI M300, recording attitude and position (RTK GPS)
 • AUSEA open-path laser absorption spectrometer: in situ CO₂ and CH₄ at 200 Hz
 • Trisonica-mini 2D ultrasonic anemometer: wind speed and direction



UAV data processing

Mass balance model
 Developed and validated for point-source industrial emissions down to 0.01 g.s⁻¹ (Bonne et al., 2024)

Flight path for wind and concentration measurements:
 Within vertical plane downwind of the source, orthogonal to wind direction. Multiple horizontal transects at different elevations, covering an entire plume cross-section, up to the top of the plume.

Flux quantification calculation:

$$Q = \int_{plane} C \cdot U \cdot dydz$$

Q: source emissions flux (g.s⁻¹); C: concentration above background; U: wind speed (m.s⁻¹)

Vertical gradients method (application of Bolek et al. 2024)

Friction velocity u_{*}

Apply logarithmic fit to mean wind speed profile $\overline{U(z)} = a \ln(z) + b$ and derive friction velocity u_{*} (m.s⁻¹) from the fit slope, following theoretical profile:

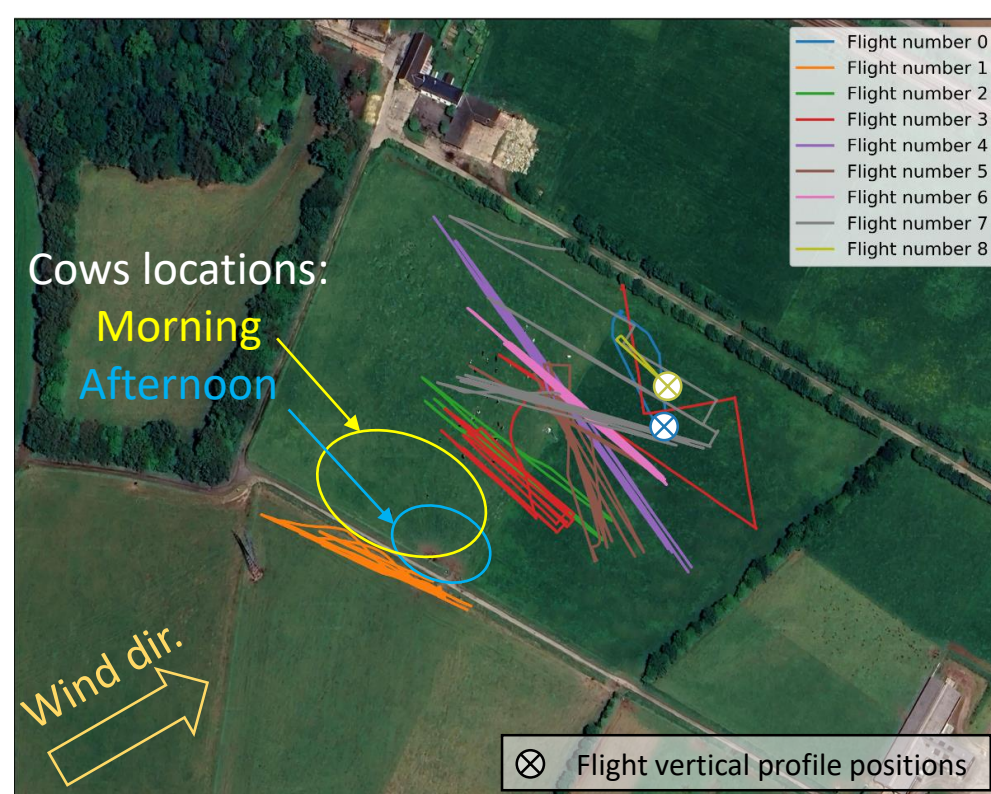
$$\overline{U(z)} = \frac{u_*}{\kappa} \ln \frac{z}{z_0}, \quad \kappa = 0.4 \text{ (von Karman constant)}$$

Vertical fluxes

Flux F (g.m⁻².s⁻¹) approximated as the product of the vertical gradient of GHG mole fractions (difference of mass concentrations X₁ and X₂ between elevations z₁ and z₂) and the eddy diffusivity K_{ed} (Baldocchi et al., 1988)

$$F = -K_{ed} \frac{X_1 - X_2}{z_1 - z_2}, \quad \chi = \frac{PM\overline{C}}{RT}, \quad K_{ed} = \kappa u_* z_g, \quad z_g = \sqrt{z_1 \cdot z_2}$$

April 11th flights



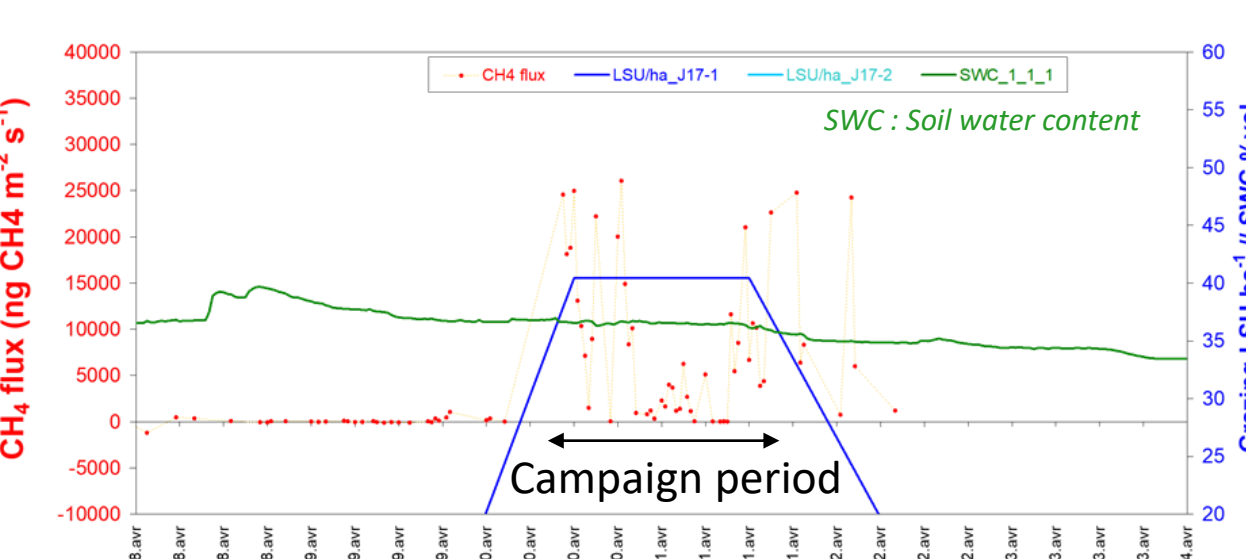
Flight #	Take-off (UTC)	Distance to source center (m)	Flight type
0	08:02	120	5 vertical profiles (1-120 m)
1	08:34	-	Background round trips transects
2	09:06	25	Round trips transects in plume*
3	09:27	25	Round trips transects in plume*
4	10:19	25	Round trips transects in plume*
5	12:27	80	Round trips transects in plume*
6	12:58	80	Round trips transects in plume*
7	13:22	80	Round trips transects in plume*
8	15:16	150	3 vertical profiles (1-120 m)

* Plumes upper limits not monitored due to high voltage electric line over the field

EXPECTED FLUXES

Eddy covariance results

CH₄ flux close to zero before grazing and fluctuating around 20 μgCH₄.m⁻².s⁻¹ during campaign



Emissions factors in the literature

Average western European dairy cow:
 → 117 kg_{CH₄} LU⁻¹.yr⁻¹ (Gavrilova et al. 2019), combining all breeds, all phases (heifer & lactating) and all stages of lactation (peak to dry-off)
 ⇒ 0.28 g.s⁻¹ for 90 LU
 Lactating Holstein cows:
 → 350 to 400 g_{CH₄} LU⁻¹.day⁻¹ (Nadège Edouard, personal communication)
 ⇒ 0.36 to 0.42 g.s⁻¹ for 90 LU

CO₂ and CH₄ fluxes from UAV and Eddy Covariance

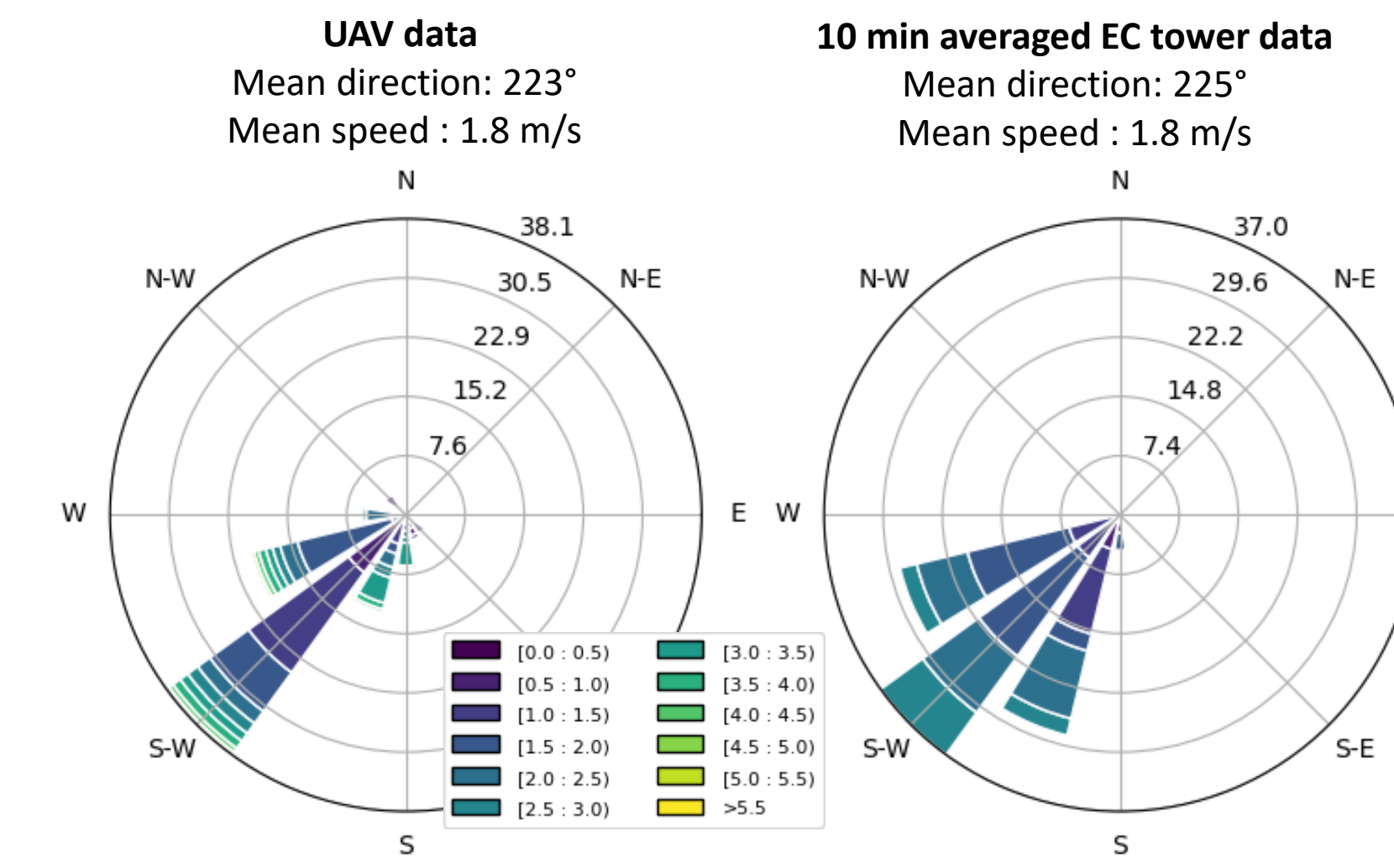


A methodological campaign to develop new applications of UAV-based flux monitoring methods on a grazed grassland with CO₂ & CH₄ emissions, validated against Eddy Covariance

RESULTS

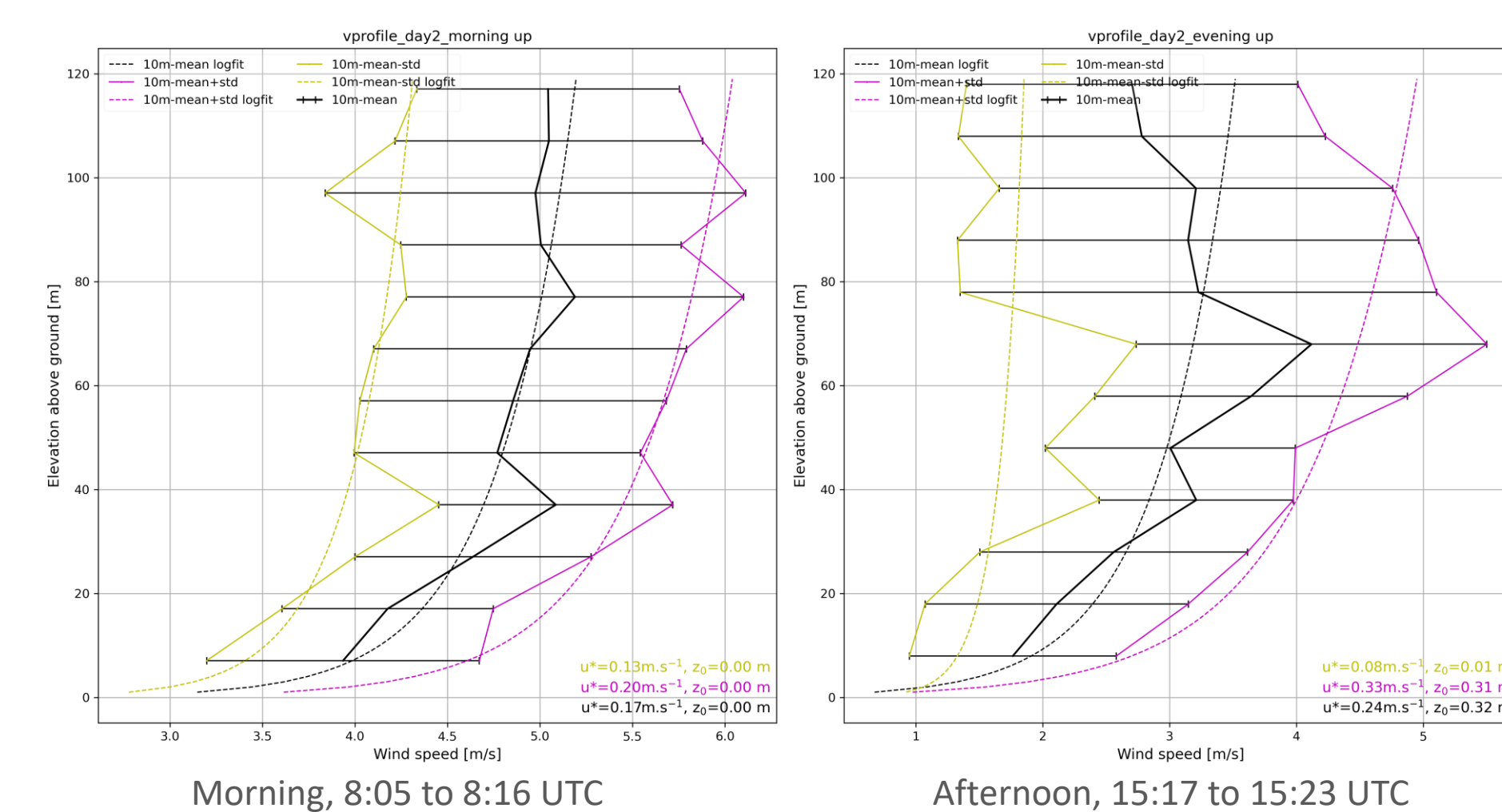
Wind measurements

UAV and EC tower wind measurements comparison, Period: 2024-04-11, 08:00 to 15:30



Friction velocity

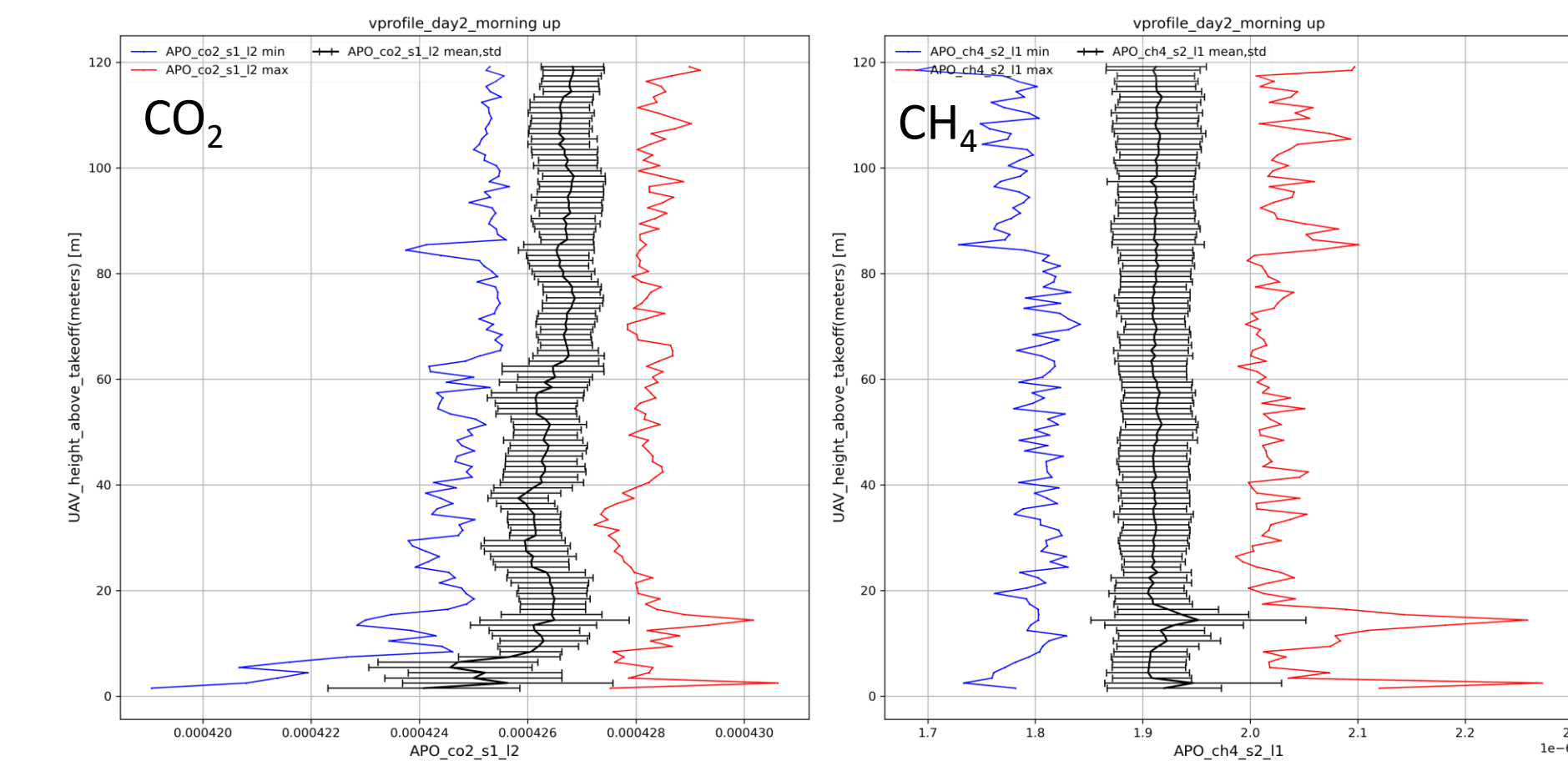
Merged ascending profiles, averaged at 10m resolution



	Friction velocity u _* (m.s ⁻¹)	
	UAV	EC
Morning 8:05 to 8:16 UTC	0.17 ± 0.04	0.18
Afternoon 15:17 to 15:23 UTC	0.24 ± 0.13	0.23

Vertical gradients

Mean gradients of concentrations, 8h05 to 8h16 UTC

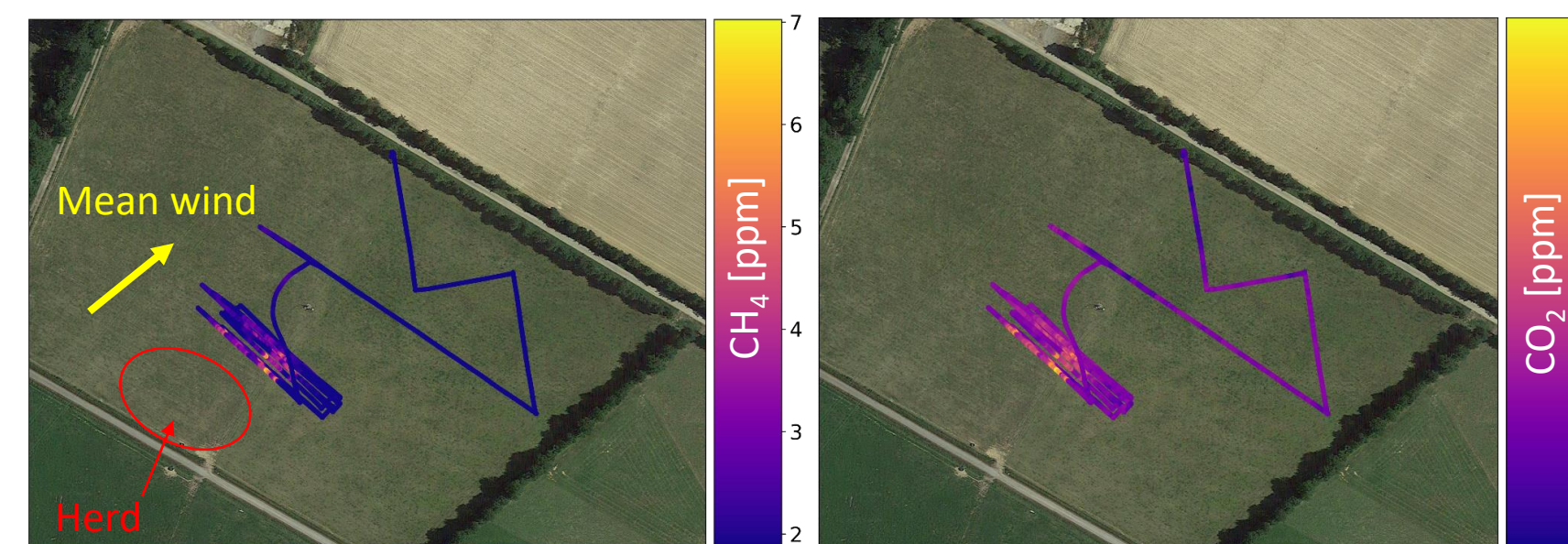


→ Multiple plumes at 5 and 15 m elevations
 → Strong temporal variations of concentrations between profiles

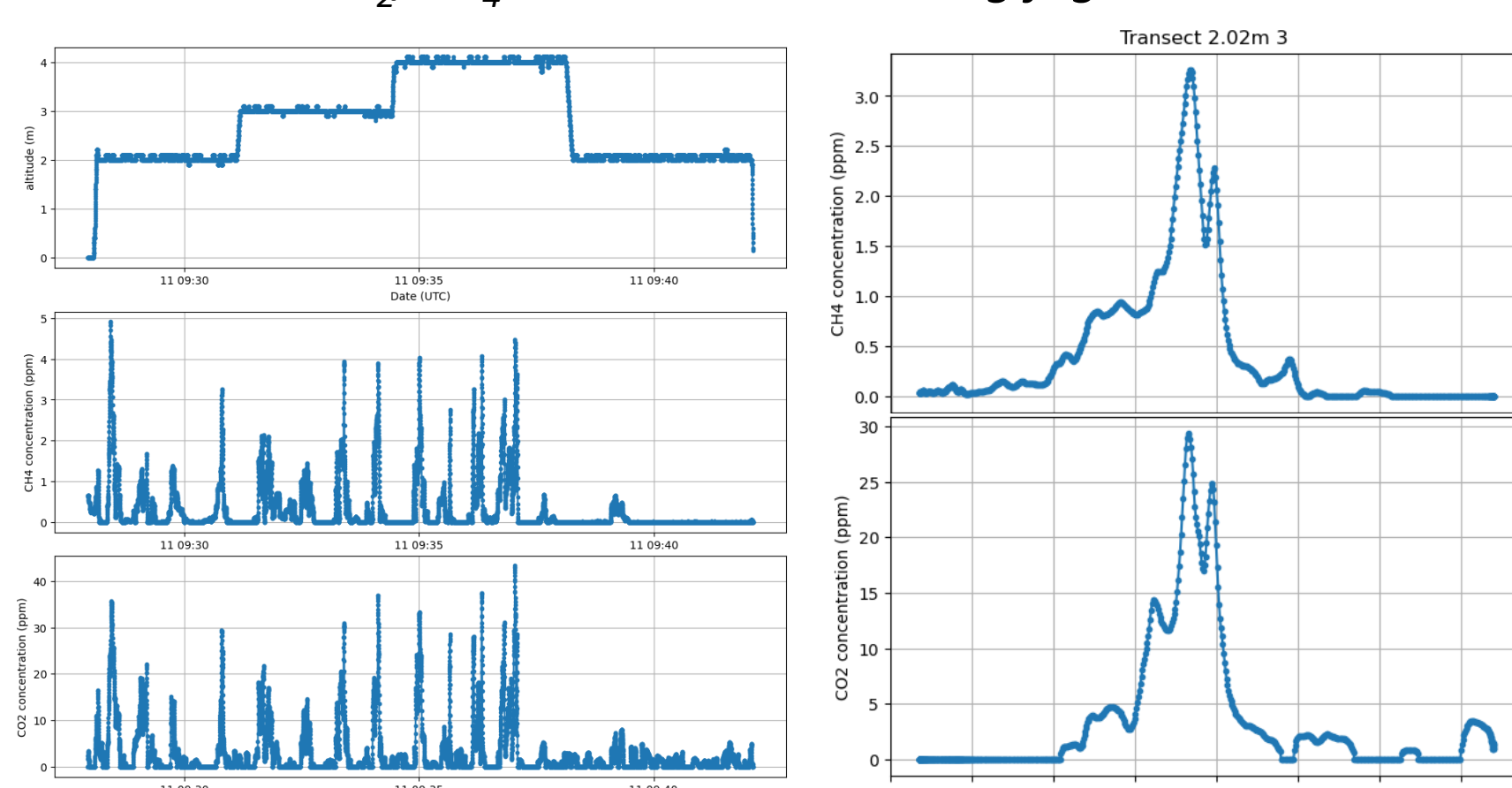
- Fluxes from CO₂/CH₄ gradients between 2 and 4 m (z_g = 2.8 m)
- The dominant source of uncertainties for fluxes is the temporal variability of concentrations

	Source	Period	
		Morning 8:05 to 8:16 UTC	Afternoon 15:17 to 15:23 UTC
F _{CO₂} (μgCO ₂ .m ⁻² .s ⁻¹)	UAV	-71 ± 535	-16 ± 160
	EC (30 min)	167	-547
F _{CH₄} (μgCH ₄ .m ⁻² .s ⁻¹)	UAV	1 ± 5	0.1 ± 3
	EC (30 min)	0.04	4.4
	EC (10 min)	0.04	-

Mass balance



CO₂/CH₄ concentrations during flight #3



CO₂/CH₄ enhancement during flight #3 (left) / along a transect (right)

Flight #	2	3	4	5	6	7
Time	09:06	09:27	10:19	12:27	12:57	13:22
Transects heights (m)	2, 3	2, 3, 4	3, 4	2	2, 3, 4, 5	2, 3, 4
z _{max} (m)	5	5	5	15	15	15
Q _{CH₄,UAV} (g.s ⁻¹)	0.34	0.26	0.17	0.10	0.16	0.38
Q _{CO₂,UAV} (g.s ⁻¹)	10.6	8.75	3.5	3.9	5.9	14.2

Plumes upper limits z_{max} manually defined from Gaussian hypotheses and distances to the source

Eddy Covariance: At 12:30, F_{CH₄,EC} = 10.7 μgCH₄ m⁻².s⁻¹
 For a density of 90 LU/23500 m² → 2.8 e3 μgCH₄ LU⁻¹.s⁻¹
 → Total herd emission Q_{CH₄,EC} = 0.25 g.s⁻¹

CONCLUSIONS & PERSPECTIVES

UAV measurements

- CO₂/CH₄ measurements suitable for this type of source
- Wind measurements validated against ground anemometer

Friction velocity

- Good estimate compared to EC, giving confidence in method

Mass balance

- Standard protocol not applied due to technical issues
 → hypotheses on plumes upper limits, influencing fluxes results
- Quantifications for 6 flights, coherent between flights, with expected theoretical emissions and with Eddy Covariance

Vertical gradients fluxes

- Not comparable with Eddy Covariance : method not appropriate to this type of source (unmixed plumes)

Perspectives

- Footprint analysis to compare Eddy Covariance surface fluxes to mass balance emissions
- Apply vertical gradient method to large homogeneous surface sources such as peatlands (on-going analysis of campaigns)
- Alternative quantification methods where mass balance protocol not applicable: inversion with Gaussian, Lagrangian or CFD models

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