



Supplement of

Measurement report: Temporal variability of vertical profiles of CO₂ and CH₄ over an urban environment

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S1. The description of meteorological sensors used in the study.

As the individual sensors varied in their sensitivities and response times, we have selected the best-performing for our analysis. Table S1 compares individual meteorological parameters measured by sensors deployed in balloon and UAV-based campaigns. Information on which sensors were used in each campaign is listed in Table S2.

5 **AirDust measurement system**

The ultra-light measurement AirDust system was dedicated to meteorological measurements within the urban boundary layer. The system was based on the Arduino MKR ZERO microcontroller, responsible for communication between the sensors and for storage of the measurements on the memory card. The system was powered by a drone battery via a step-down converter reducing the input voltage from 22 V to 5 V at 2 A. Air temperature, relative humidity and atmospheric pressure were measured using a digital sensor (BME280, Bosch Sensortec GmbH, Reutlingen, 10 Germany). To monitor temperature changes within the given vertical profile with a better spatial resolution, the system was also equipped with a thermocouple type T. Since the response time of the T-type thermocouple to temperature changes is shorter than for the BME280 sensor, by default, the measurement was taken from the thermocouple. For the corrections of thermocouple bias error and in the event of technical issues with the thermocouple, the BME280 sensor was used. The sampling frequency of the AirDust system was set to 1 Hz. Technical specification of the AirDust system is presented in Table S3.

15 **TriSonica™ anemometer**

The second measurement system used in the measurement campaigns was based on the acoustic anemometer TriSonica™. It was used to monitor horizontal wind components in the studied vertical profile. The system was equipped with an Arduino MKRZERO microcontroller for data storing and the NEO-7 GNSS module (u-blox AG, Thalwil, Switzerland) which allows monitoring of the horizontal and vertical position of the sensors. The TriSonica™ sensor is equipped with a 3D sonic anemometer, temperature, pressure and humidity sensors, as well as a magnetometer and 3D 20 accelerometer for correcting the wind speed and wind direction. The measurements of air temperature, pressure and humidity from the TriSonica sensor were not used in this study due to the fact their inertia was larger than those used in the AirDust system. To avoid measurement disturbances caused by turbulence generated by the drone's propellers during the UAV-based campaigns, the system was fixed on a small extension arm ca. 30 cm over the drone platform. The anemometer can measure wind speed and wind direction with different sampling frequencies, from 1 Hz to 10 Hz. It was found that measurements with a sampling frequency equal to 1 Hz were characterised by the smallest number of incorrect measurements 25 (glitches). Therefore, the frequency of the system was set to 1 Hz. Analysis of the wind direction observations in the vertical profile revealed that reliable measurements were difficult to achieve. The idea of wind direction correction using an onboard magnetometer during the flight was tested (balloon and UAV-based campaigns). In the case of UAV-based campaigns magnetic field disturbance generated by the currents supplying the drone's motors generated too much noise making it impossible to use a magnetometer for a correction procedure. Finally, wind direction measurements in vertical profiles were excluded from further analysis due to their unreliability. The specification of the TriSonica™ sensor was included in Table S3 30 (only wind speed measurements).

Mini Weather Station

The Mini Weather Station was used to monitor horizontal wind speed, air temperature, relative humidity and atmospheric pressure in a vertical profile. It is worth mentioning that the inertia of air temperature and relative humidity sensors in the Mini Weather Station is larger than for the sensors used in the AirDust system. Due to this fact, the Mini Weather Station was used as a backup system for AirDust sensors. The Mini 35 Weather Station provides also measurements of atmospheric precipitation and radiation components which were not used in this study. The sampling frequency of the HY-WDC6SE station was equal to 1 Hz. Technical specification of the Mini Weather Station for selected meteorological parameters is presented in Table S3.

S2. Additional figures.

Table S1. Sensors importance in balloon and UAV-based campaigns.

UAV-based campaign				
Sensor/Parameter	Air temperature	Relative humidity	Atmospheric pressure	Wind speed
Default	Thermocouple type T	BME280	BME280	TriSonica TM
Option 1	BME280	-	-	-
Balloon campaign				
Sensor/Parameter	Air temperature	Relative humidity	Atmospheric pressure	Wind speed
Default	Thermocouple type T	BME280	BME280	HY-WDC6SE
Option 1	BME280	HY-WDC6SE	HY-WDC6SE	TriSonica TM
Option 2	HY-WDC6SE	-	-	-

Table S2. Sensors used in UAV-based and balloon campaigns.

No.	Platform	Air temp.	Rel. Hum.	Atm. Pressure	Wind speed
1	BAL	HY-WDC6SE	HY-WDC6SE	HY-WDC6SE	HY-WDC6SE
2	BAL	Thermocouple	BME280	BME280	HY-WDC6SE
3	BAL	Thermocouple	BME280	BME280	HY-WDC6SE (TriSonica TM - 1 flight)
4	BAL	Thermocouple	BME280	BME280	HY-WDC6SE
5	BAL	Thermocouple	BME280	BME280	HY-WDC6SE
6	DRO	Thermocouple	BME280	BME280	TriSonica TM
7	BAL	Thermocouple	BME280	BME280	HY-WDC6SE and TriSonica TM (7 flights)
8	BAL	Thermocouple	BME280	BME280	HY-WDC6SE
9	BAL	Thermocouple	BME280	BME280	HY-WDC6SE
10	DRO	Thermocouple	BME280	BME280	TriSonica TM
11	DRO	Thermocouple	BME280	BME280	TriSonica TM

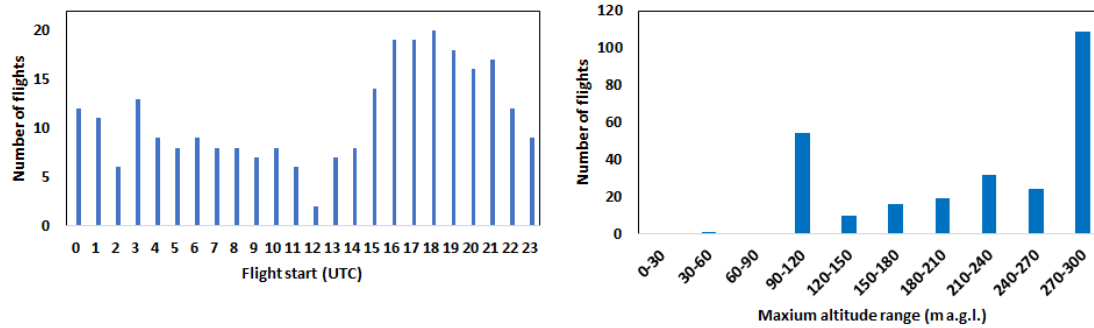


Figure S1. Flight characteristics: histogram of flight frequency at different times (left), and histogram of flight altitudes (right).

Table S3. Technical specifications of all three meteorological systems.

Bosh BME280 (AirDust system)			
Parameter	Operating range	Accuracy	Resolution
Relative Humidity	0 - 100 %	±3 %	0.008 %
Air Pressure	300 - 1100 hPa	±0.12 hPa	1.8×10^{-3} hPa
Temperature	-40 °C - 85°C	±1 °C	0.01 °C
Dimension/Weight	110 × 90 × 50 mm / 0.235 kg		
Thermocouple type T (AirDust system)			
Temperature	-50 °C - 150 °C	±0.1 °C	0.01 °C
TriSonica™ sonic anemometer			
Parameter	Operating range	Accuracy	Resolution
Wind Speed	0 - 50 m s ⁻¹	±0.1 m s ⁻¹ (0–10 m s ⁻¹)	0.1 m s ⁻¹
Dimension/Weight	91 mm × 91 mm × 52 mm / 0.05 kg		
Mini Weather Station (HY-WDC6SE)			
Parameter	Operating range	Accuracy	Resolution
Wind Speed	0 - 40 m s ⁻¹	±5 %	0.1 m s ⁻¹
Relative Humidity	0 - 100 %	±5 %	1 %
Air Pressure	150 - 1100 hPa	±1 hPa	0.1 hPa
Temperature	-40 °C - 80 °C	±0.5 °C	0.1 °C
Dimension/Weight	Φ84 mm × 210 mm / 0.33 kg		

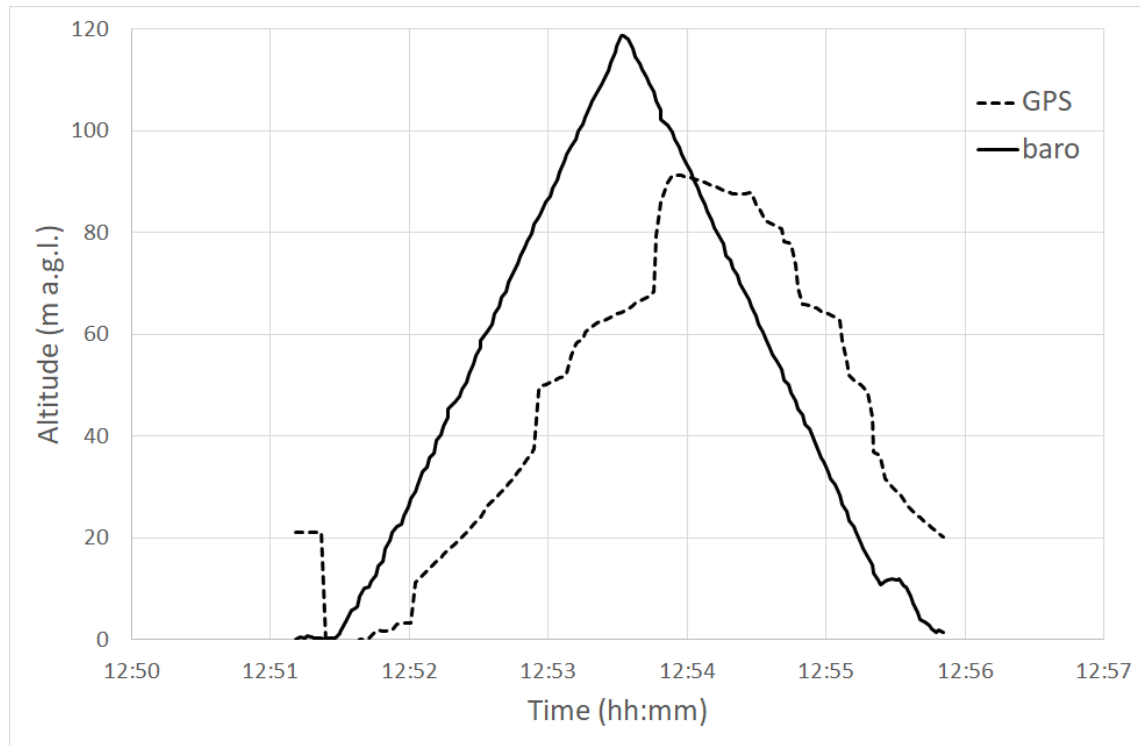


Figure S2. A comparison of the altitude determined based on GPS signal (dashed line) and atmospheric pressure (solid line).

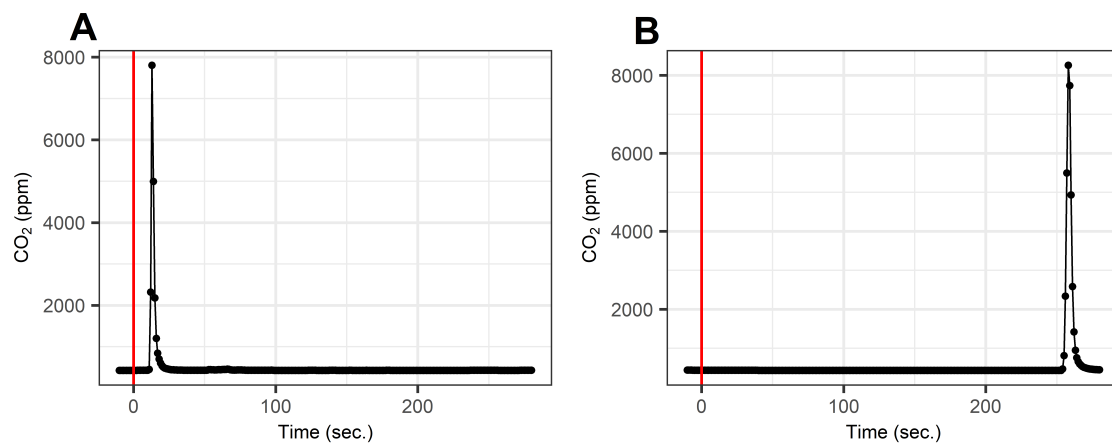


Figure S3. Evolution of 1s averaged CO₂ mole fraction during breath test as measured by the Picarro analyser with tube of (A) 10 m and (B) 200 m length. The vertical red line represents the moment of exhalation of air to the tube.

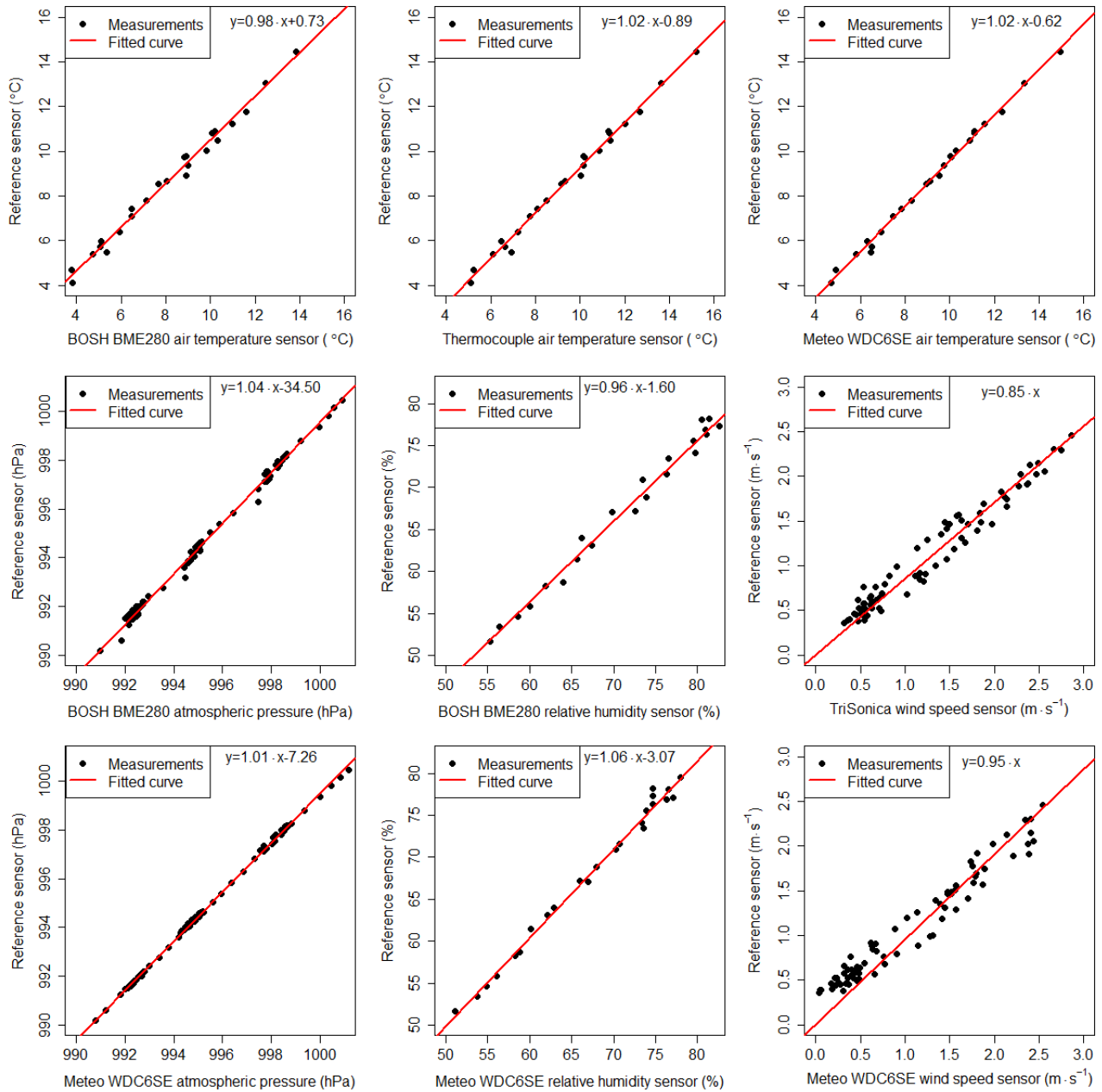


Figure S4. Calibration of meteorological sensors used in the measurements, the temporal resolution of all parameters is equal to 1 hour.

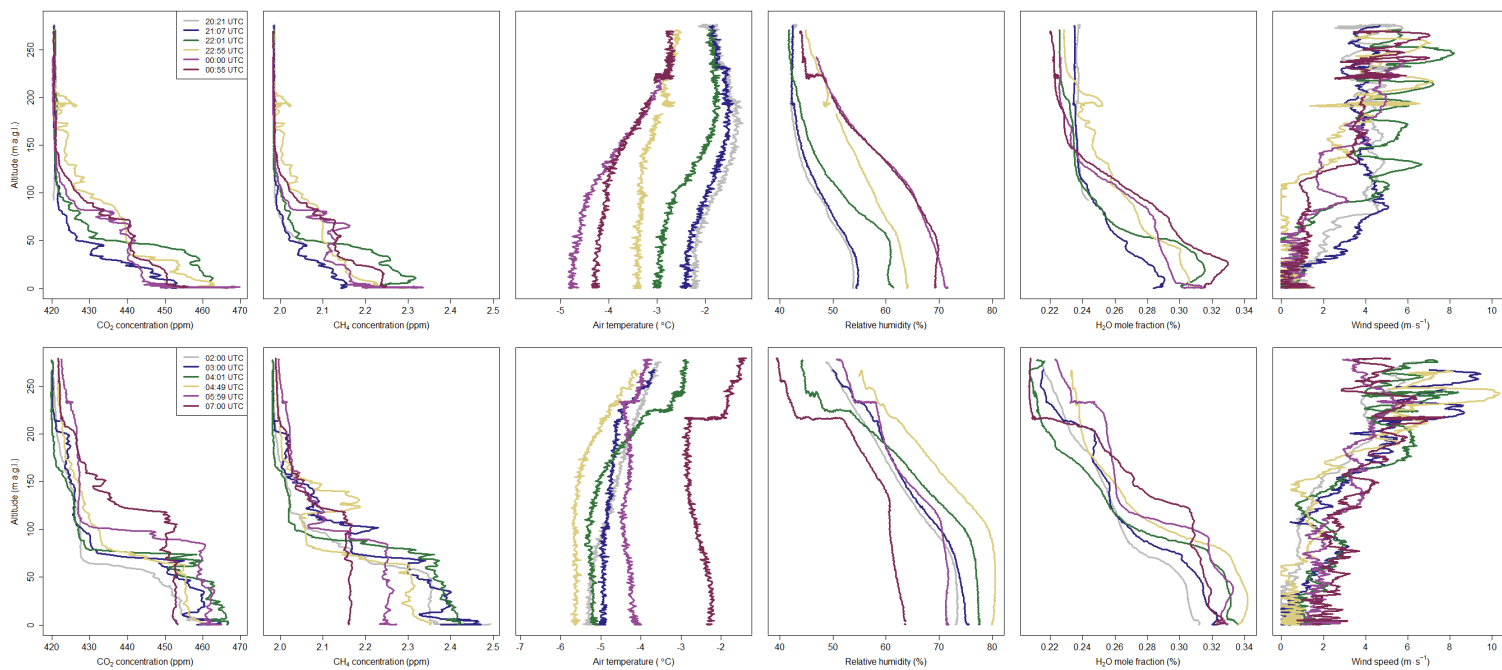


Figure S5. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 10-11.03.2021 - campaign 1.

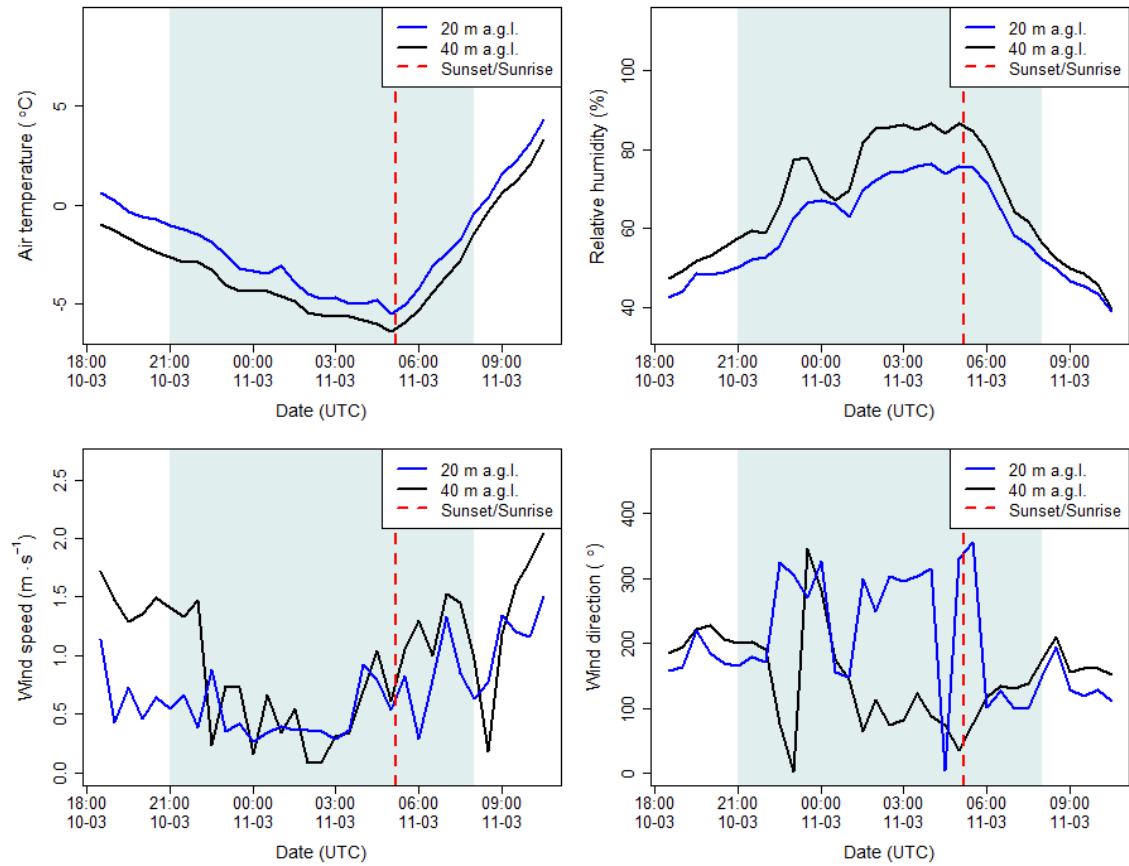


Figure S6. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 10-11.03.2021 - campaign 1. Azure background presents campaign duration.

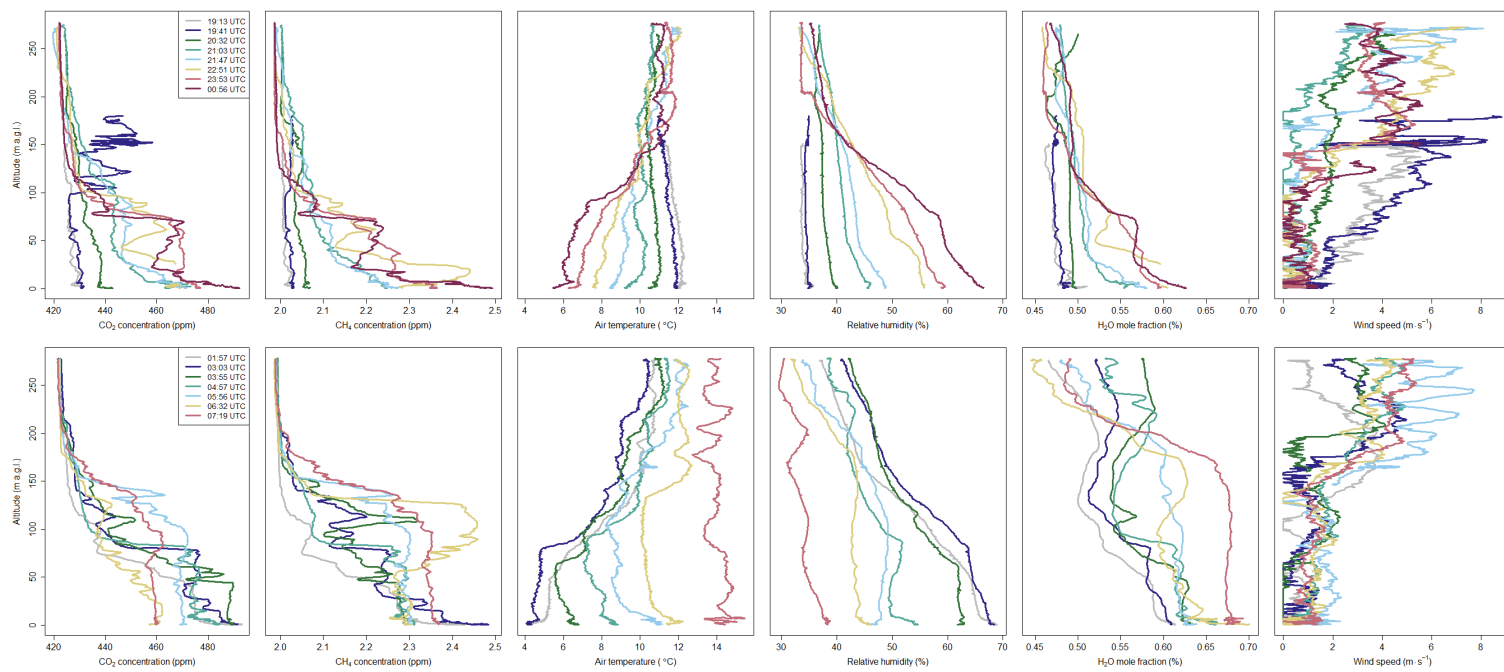


Figure S7. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 28-29.04.2021 - campaign 2.

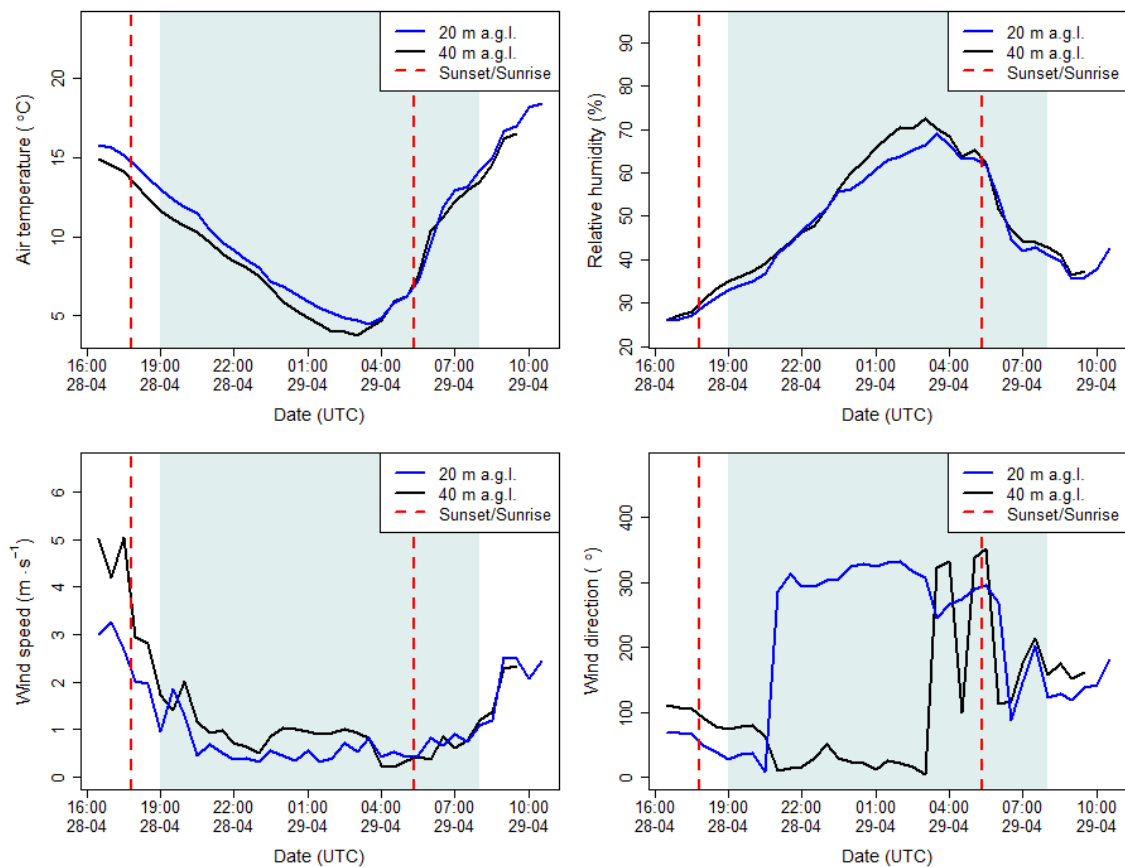


Figure S8. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 28-29.04.2021 - campaign 2. Azure background presents campaign duration.

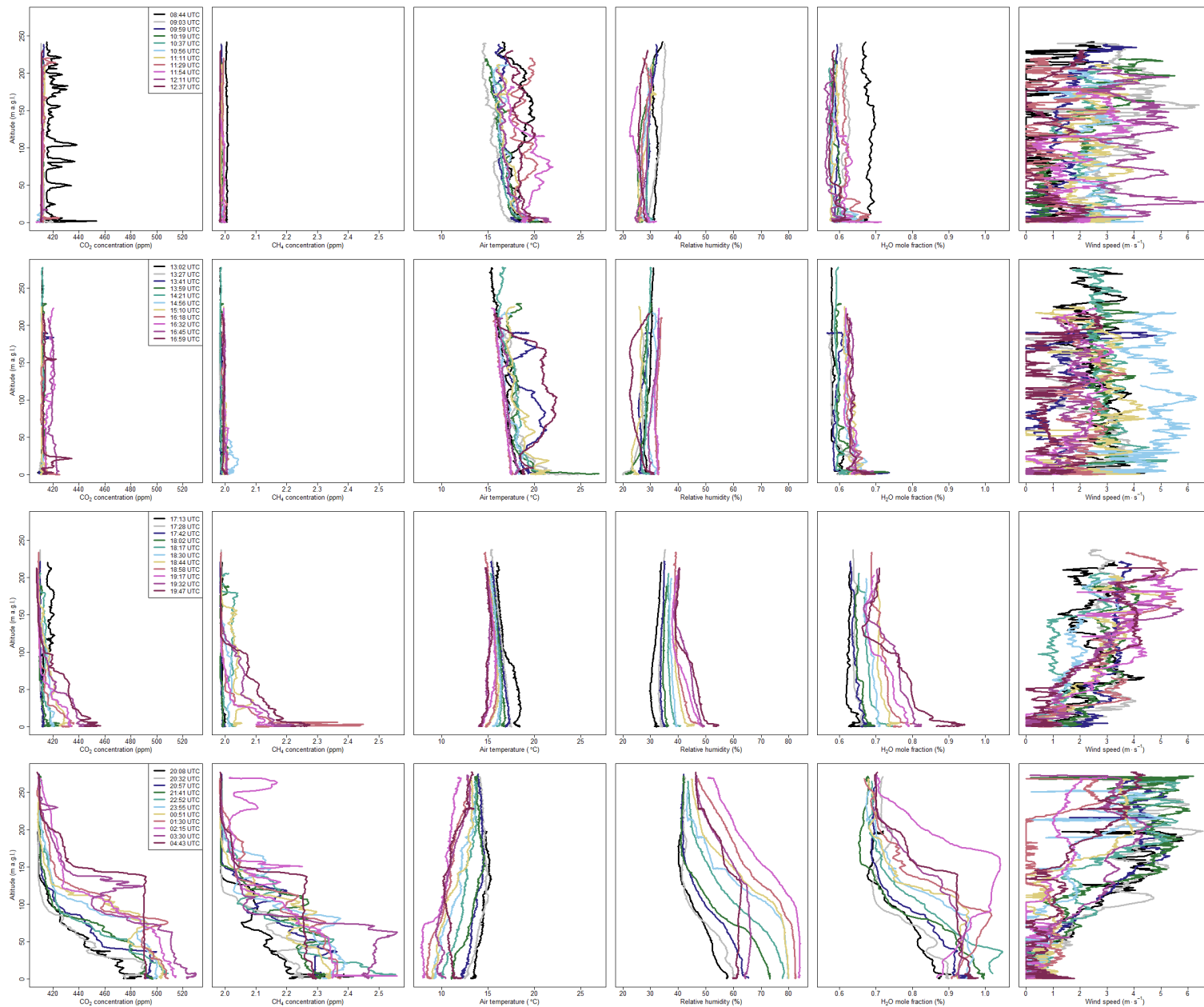


Figure S9. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 01-02.06.2021 - campaign 3.

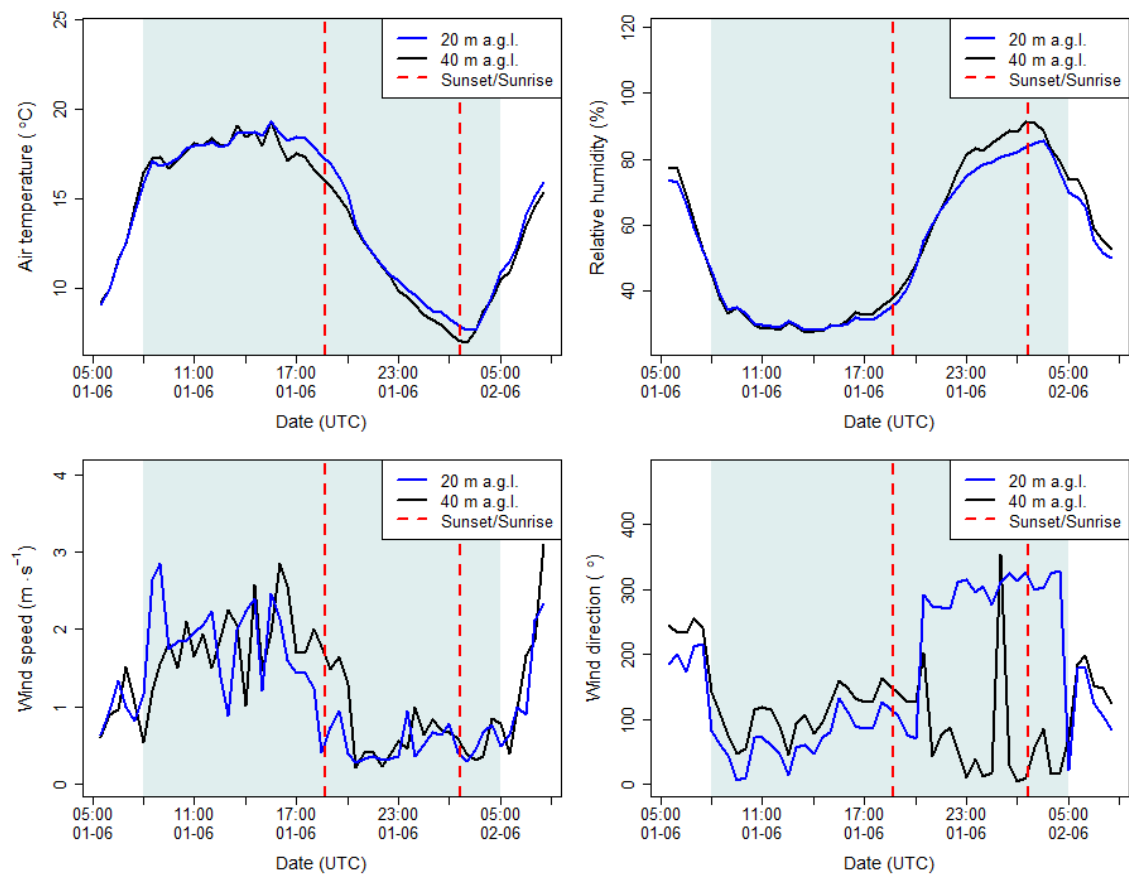


Figure S10. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 01-02.06.2021 - campaign 3. Azure background presents campaign duration.

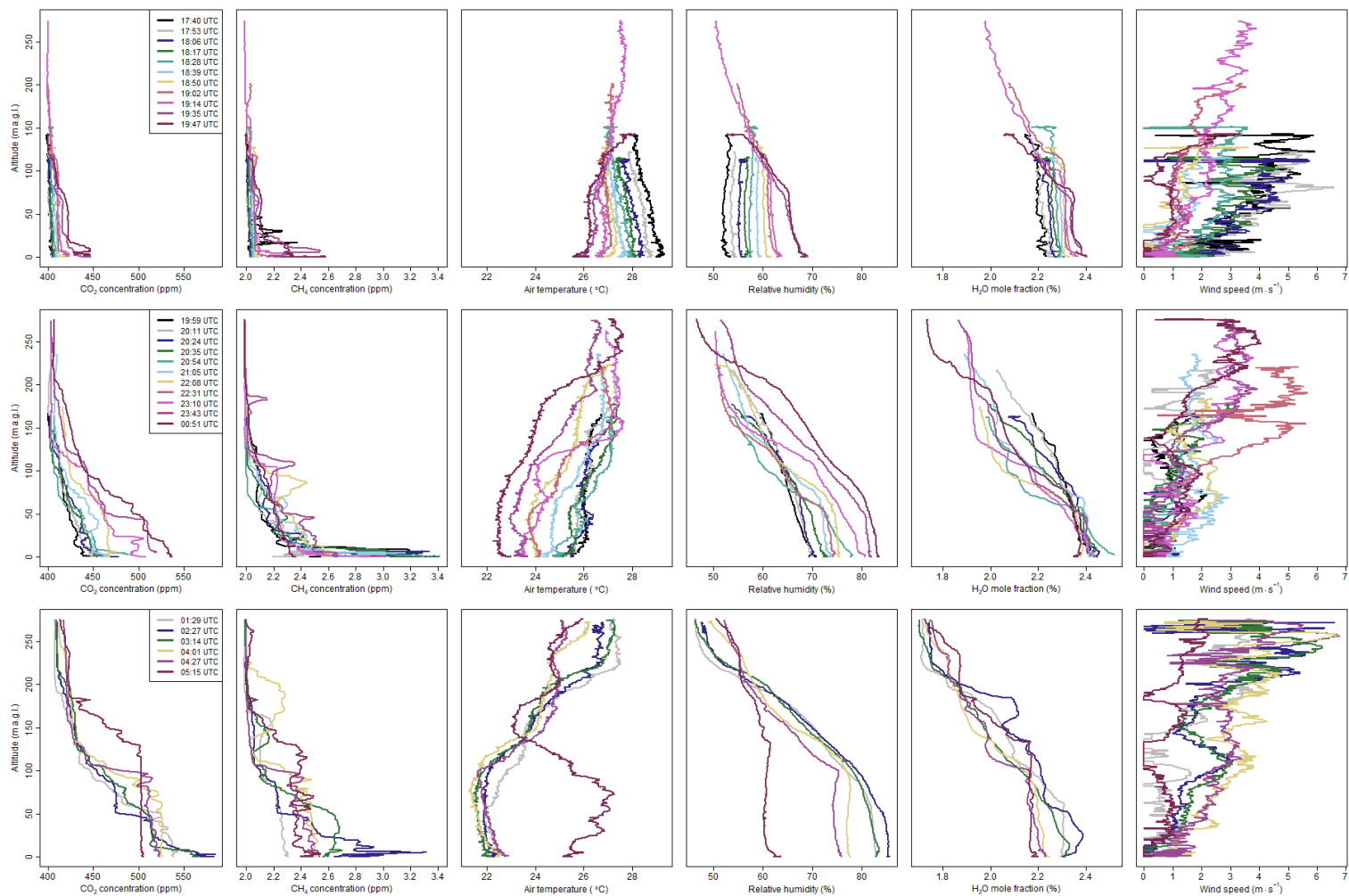


Figure S11. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 13-14.07.2021 - campaign 4.

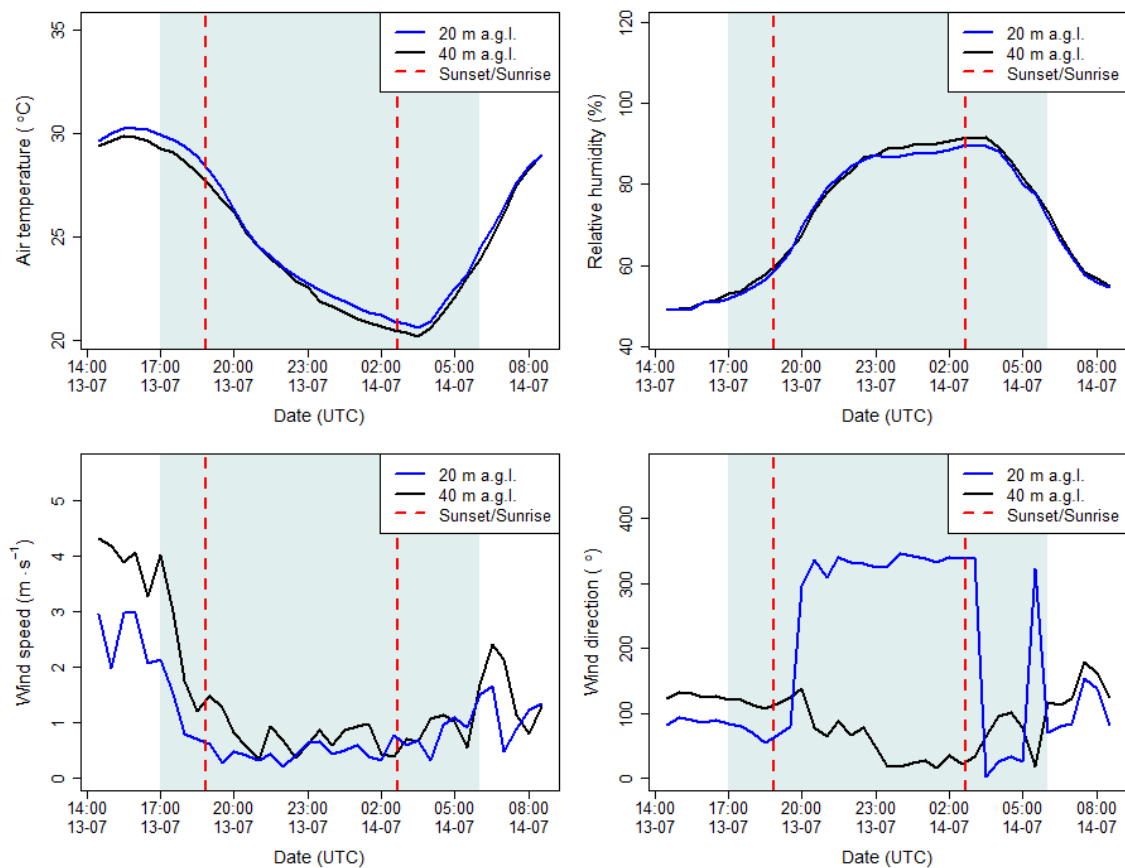


Figure S12. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 13-14.07.2021 - campaign 4. Azure background presents campaign duration.

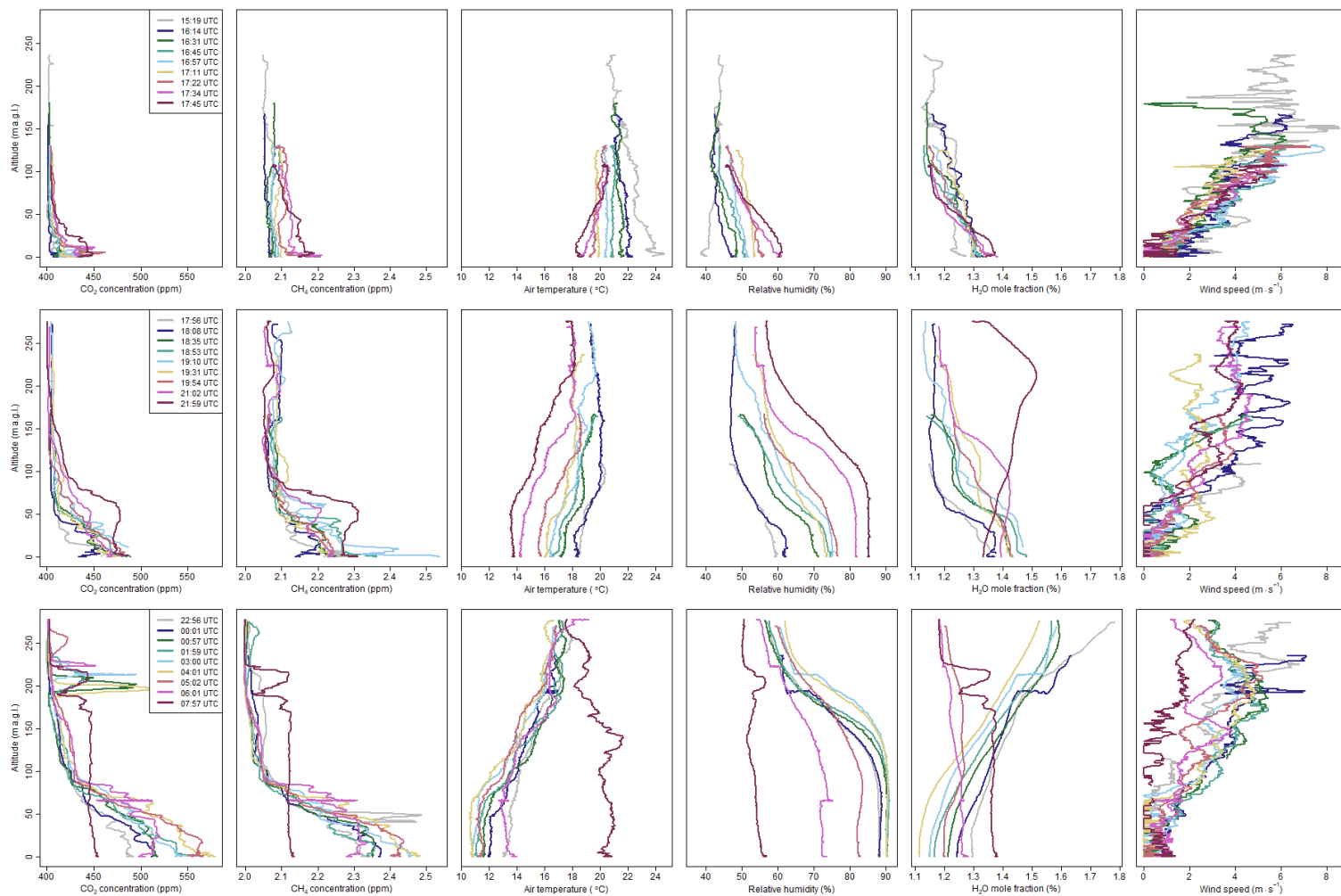


Figure S13. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 07-08.09.2021 - campaign 5.

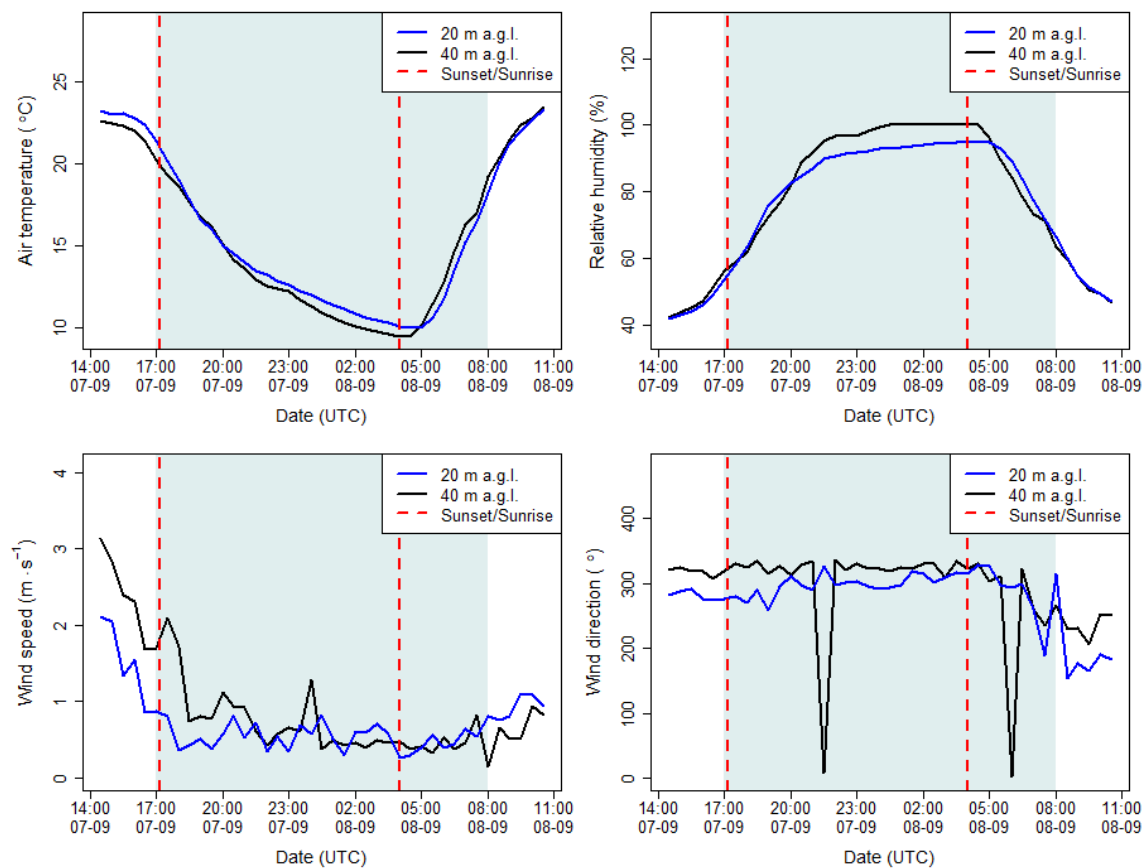


Figure S14. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 07-08.09.2021 - campaign 5. Azure background presents campaign duration.

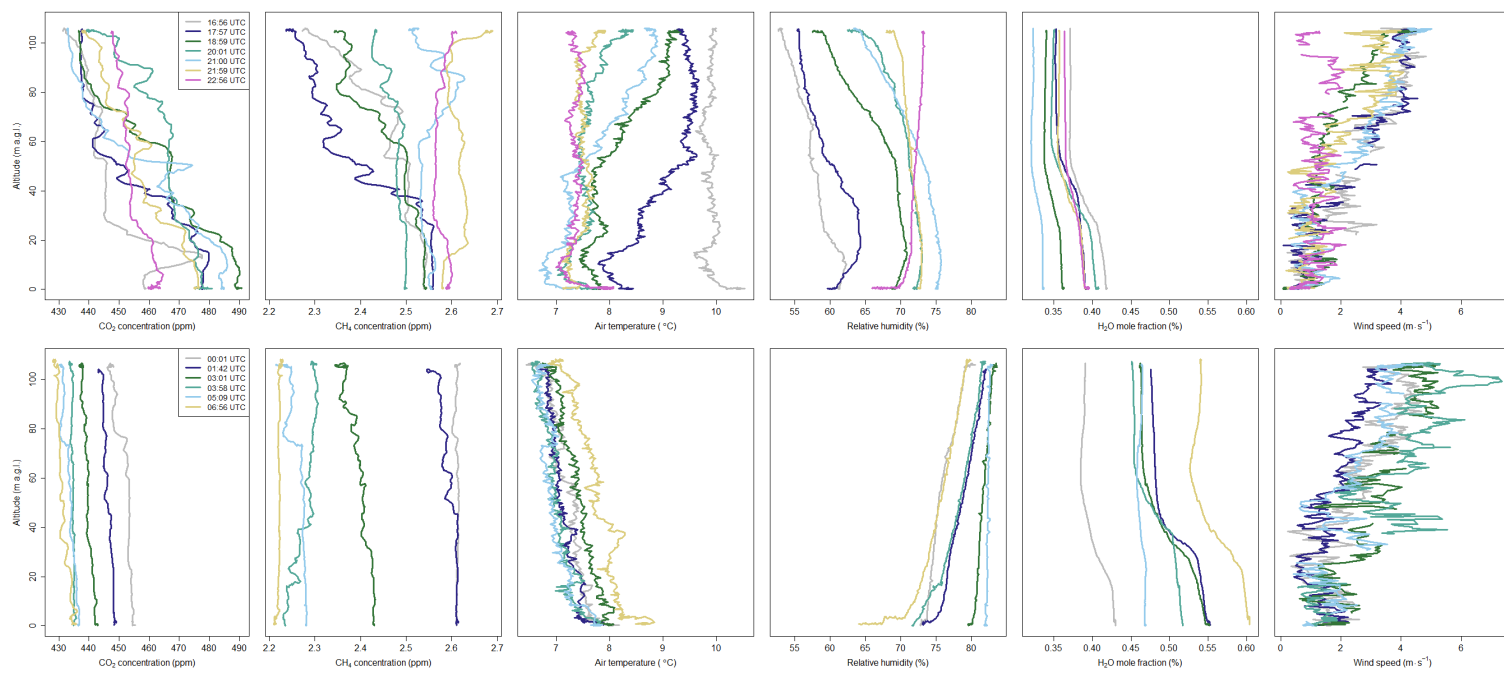


Figure S15. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 11-12.10.2021 - campaign 6.

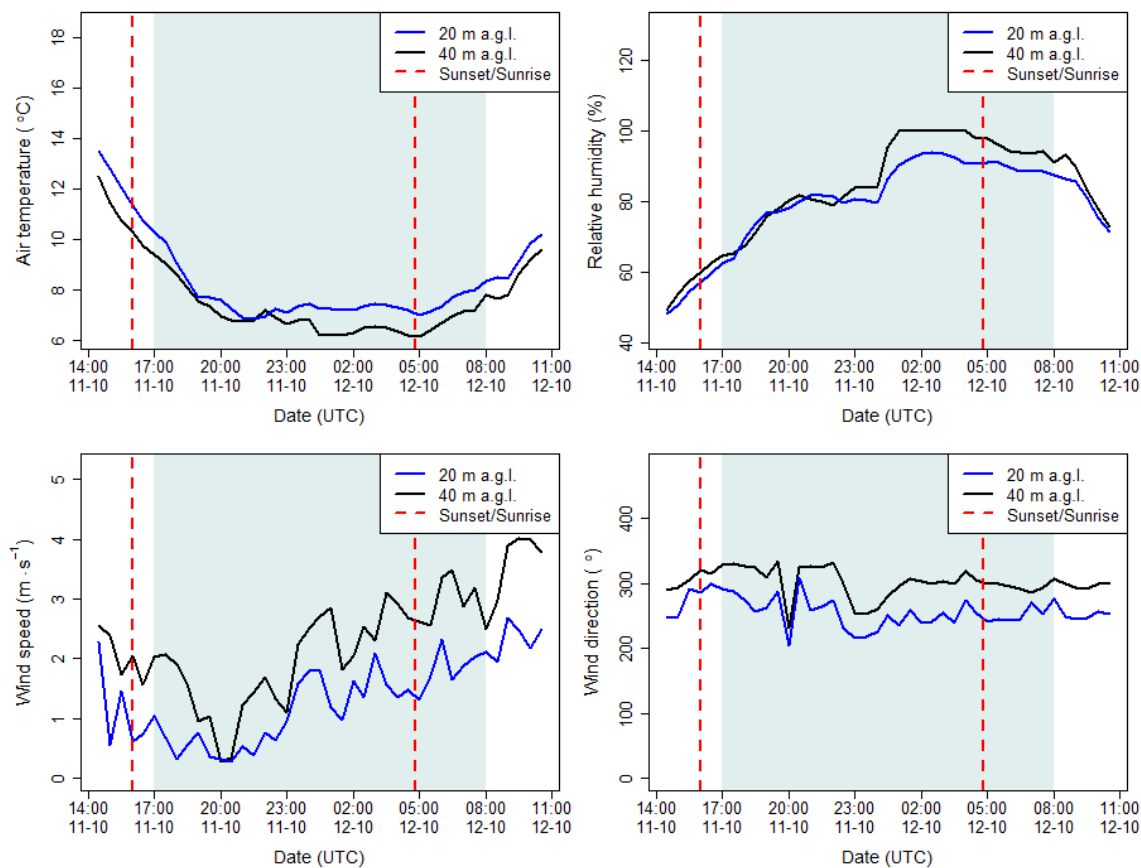


Figure S16. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 11-12.10.2021 - campaign 6. Azure background presents campaign duration.

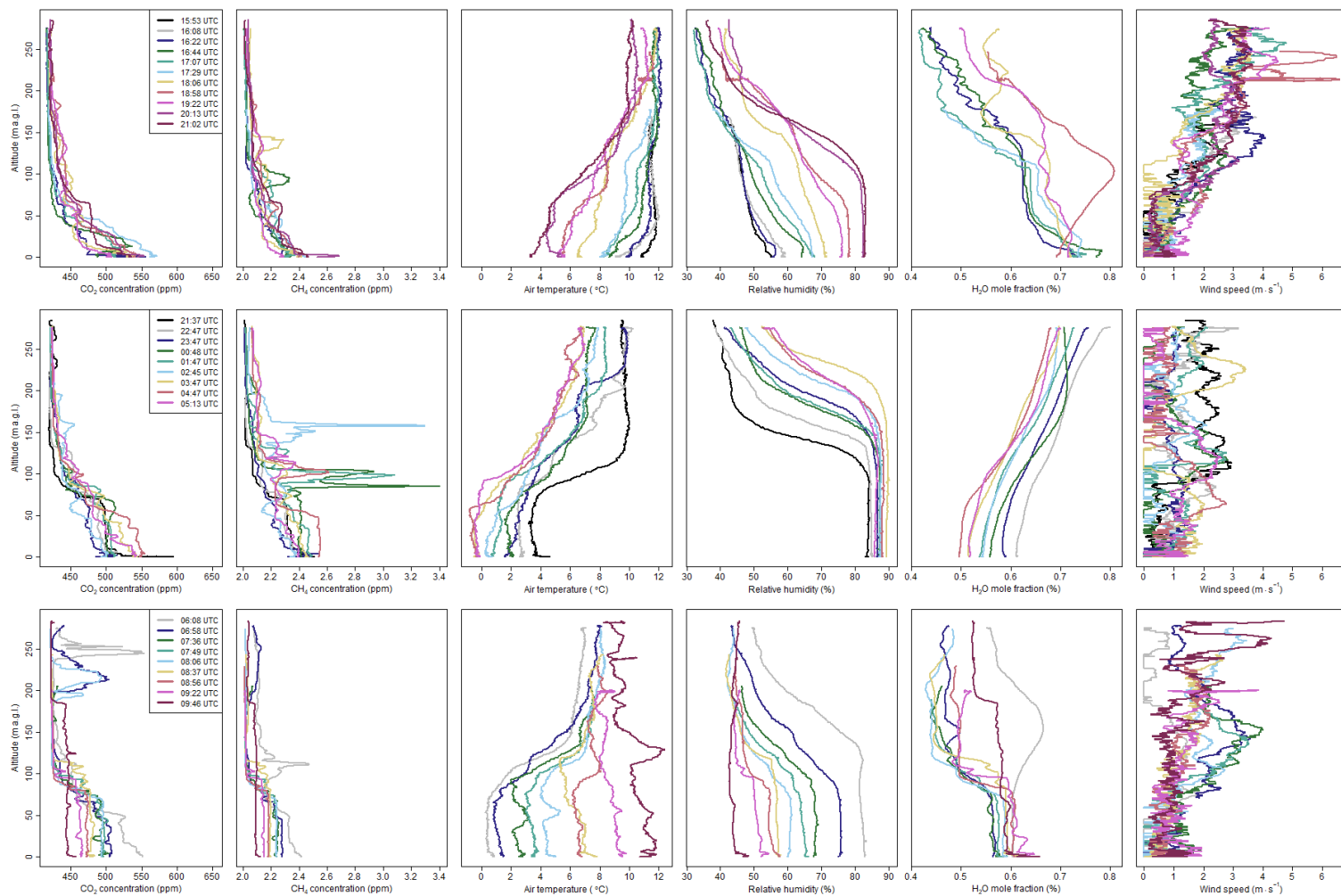


Figure S17. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 25-26.10.2021 - campaign 7.

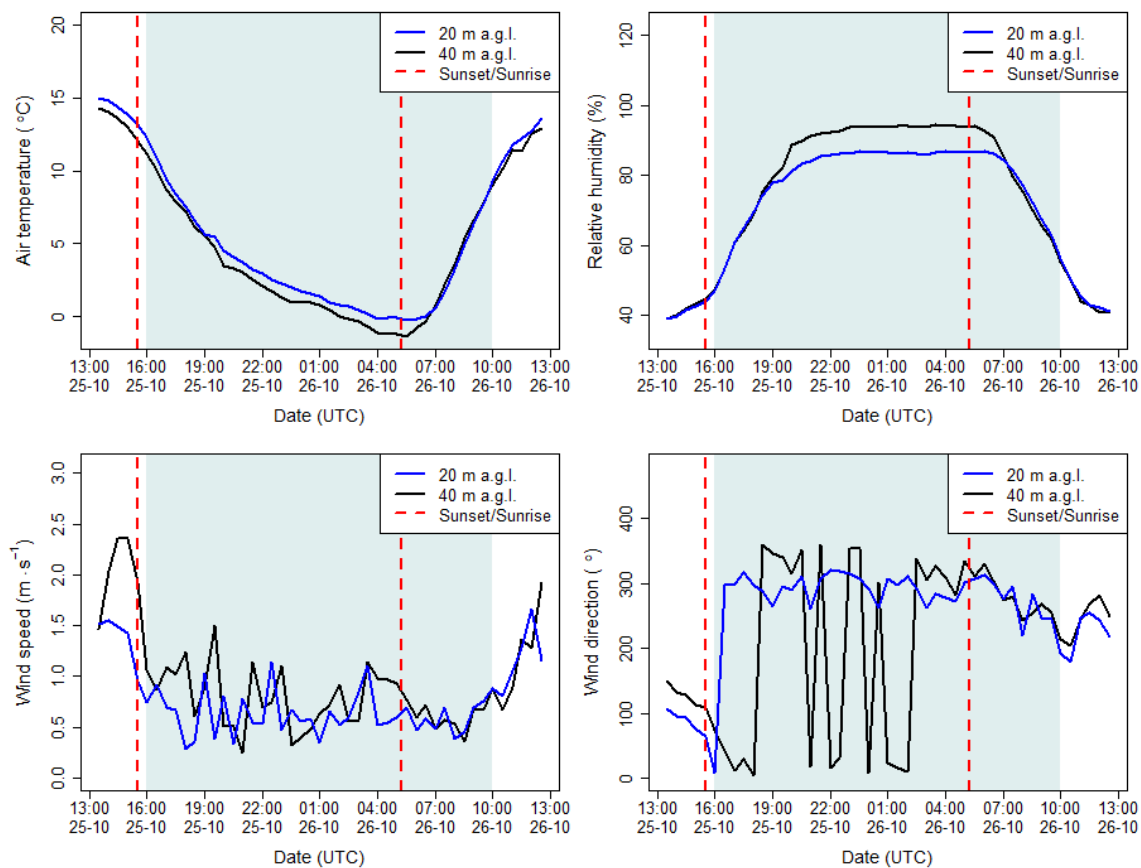


Figure S18. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 25-26.10.2021 - campaign 7. Azure background presents campaign duration.

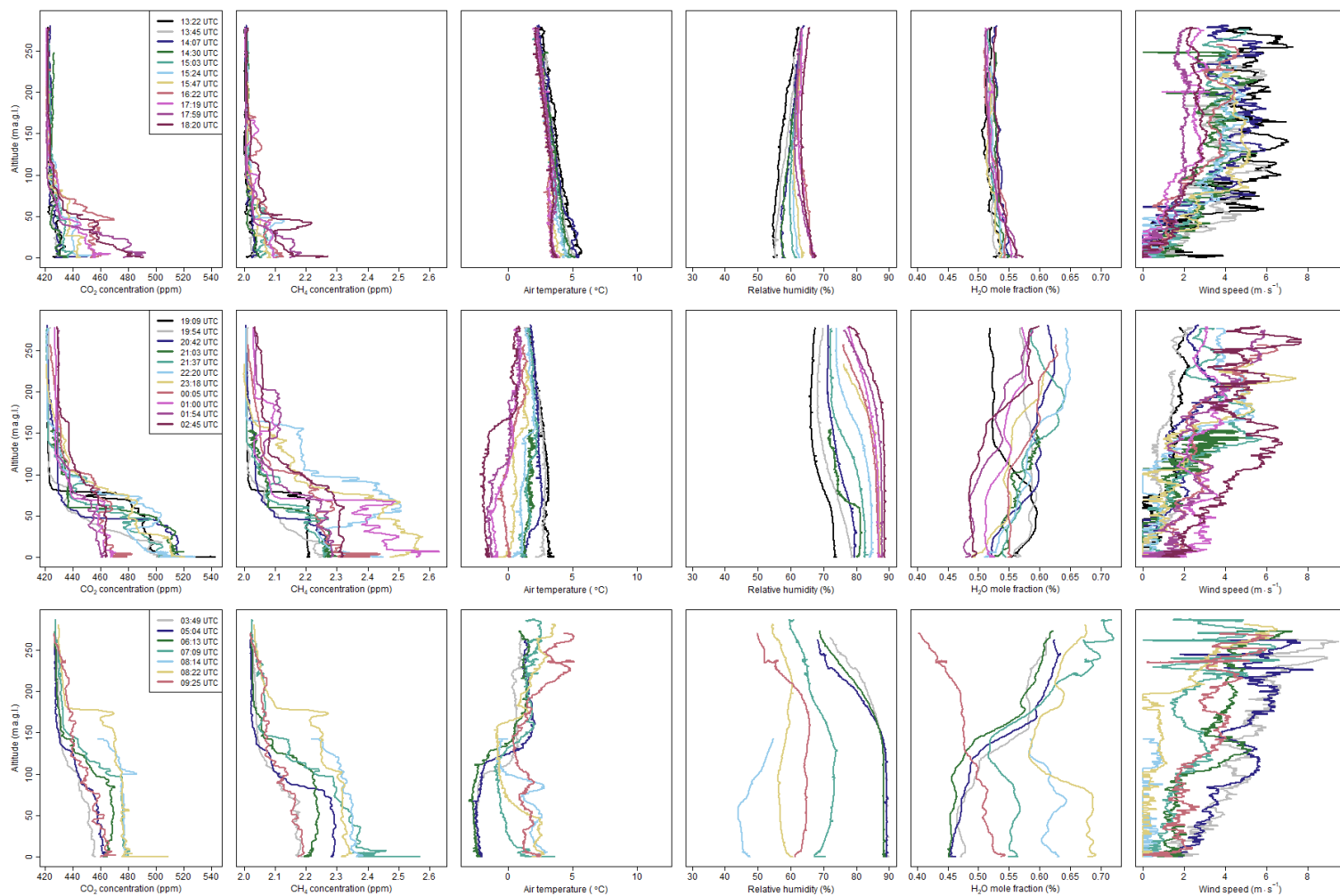


Figure S19. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 24-25.11.2021 - campaign 8.

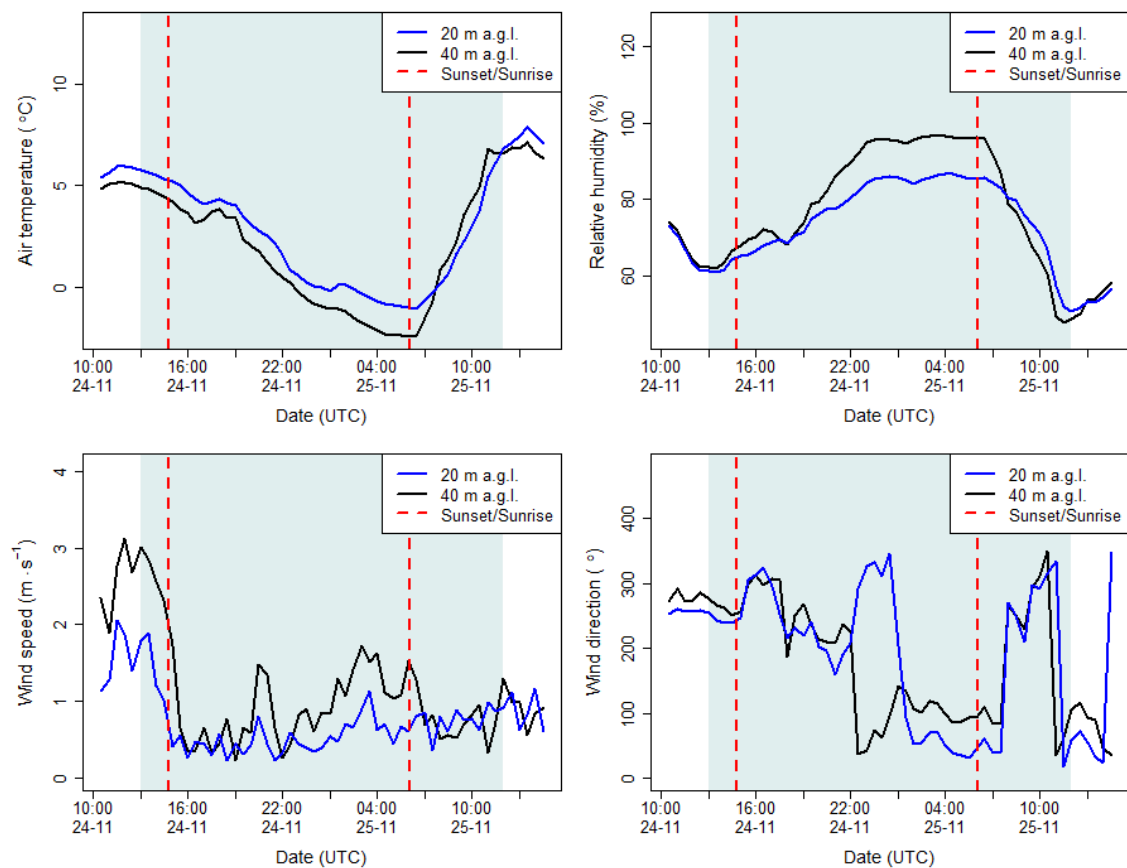


Figure S20. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 24-25.11.2021 - campaign 8. Azure background presents campaign duration.

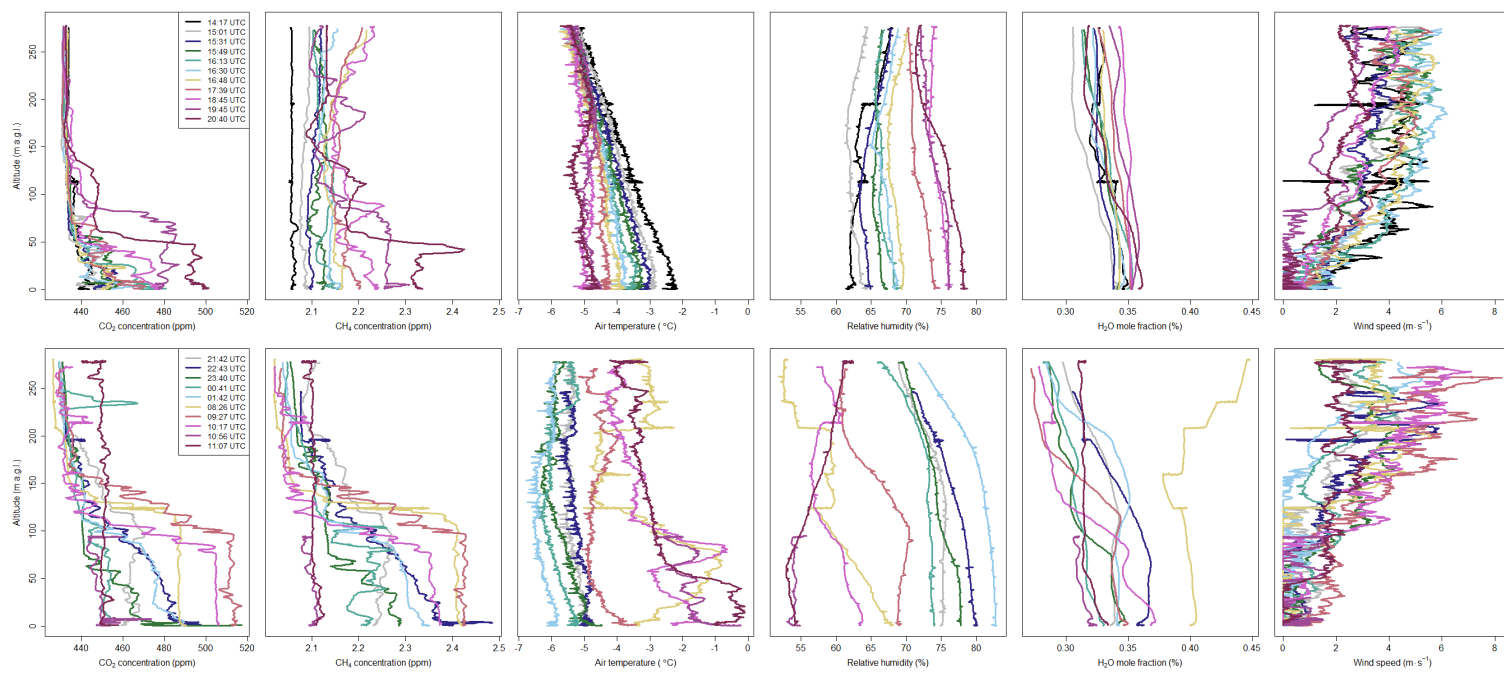


Figure S21. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 22-23.12.2021 - campaign 9.

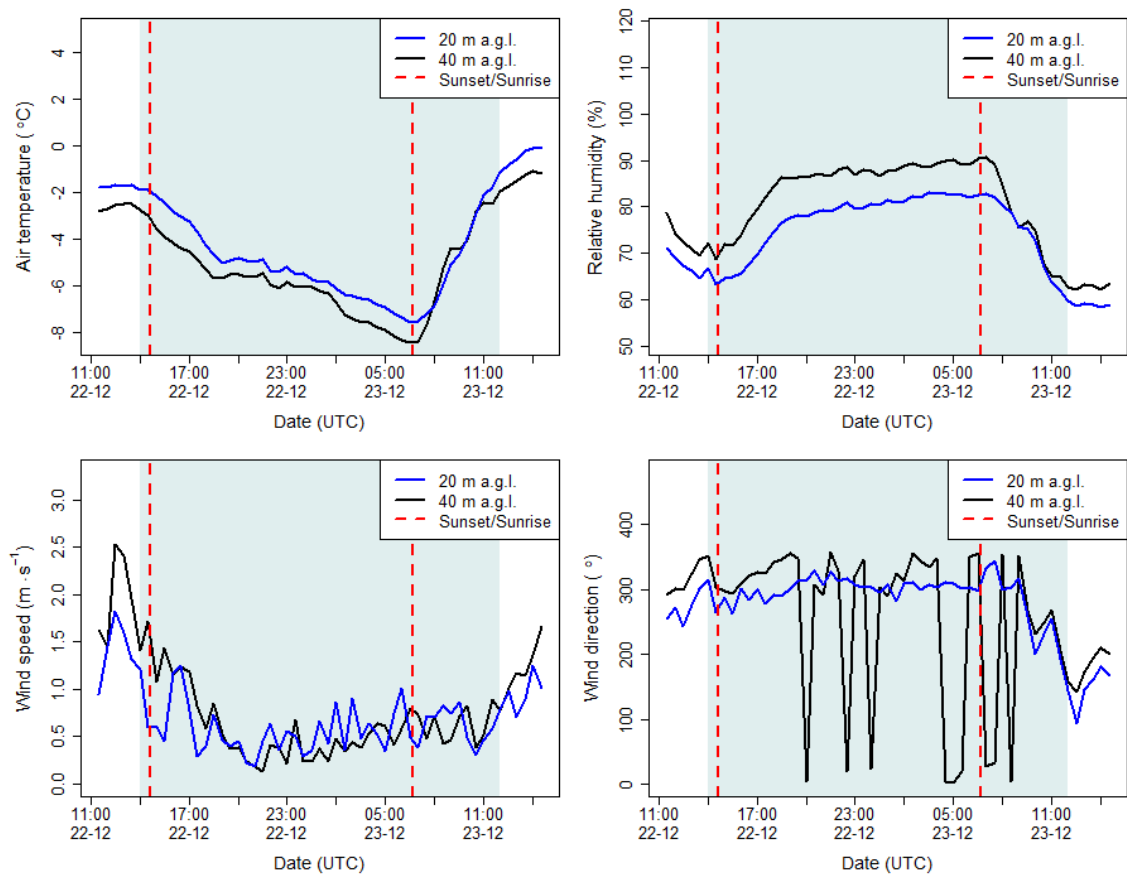


Figure S22. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 22-23.12.2021 - campaign 9. Azure background presents campaign duration.

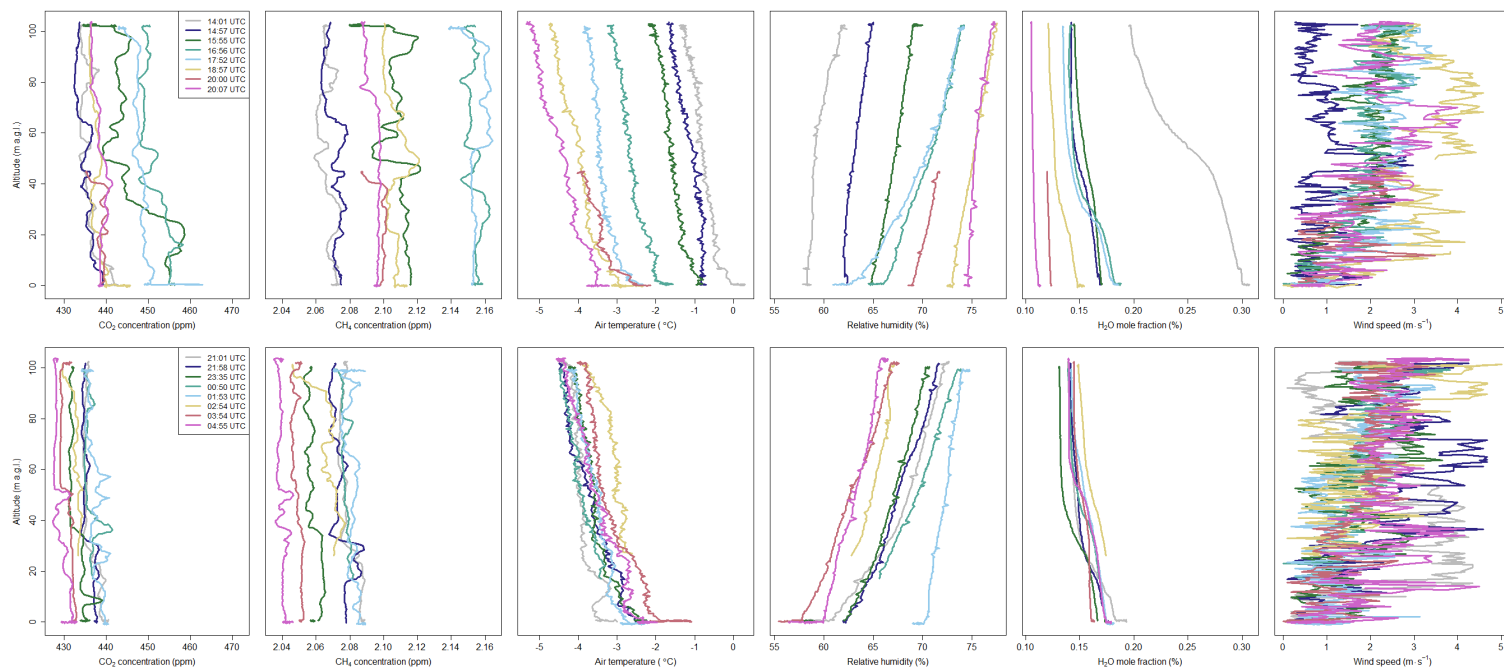


Figure S23. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 11-12.01.2022 - campaign 10.

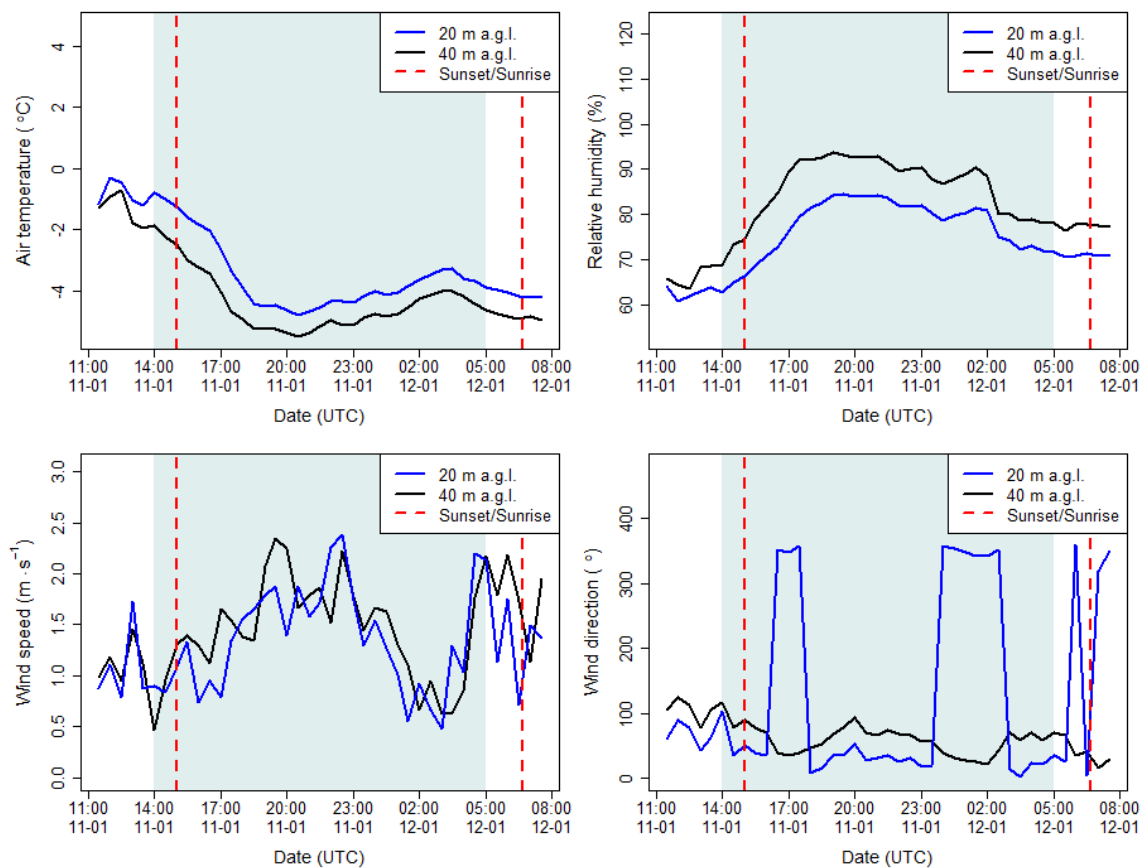


Figure S24. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 11-12.01.2022 - campaign 10. Azure background presents campaign duration.

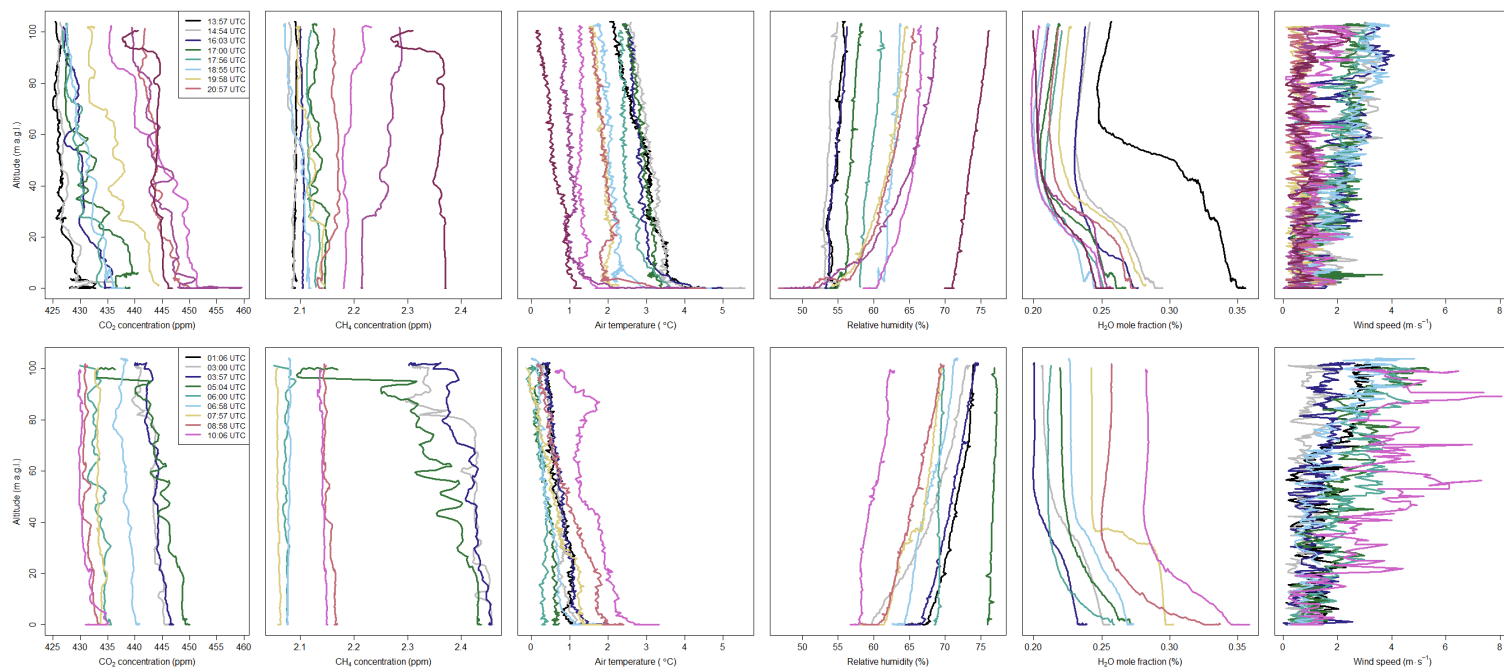


Figure S25. Vertical profiles of CO₂, CH₄, air temperature, relative humidity, H₂O and wind speed on 31.01-1.02.2022 - campaign 11.

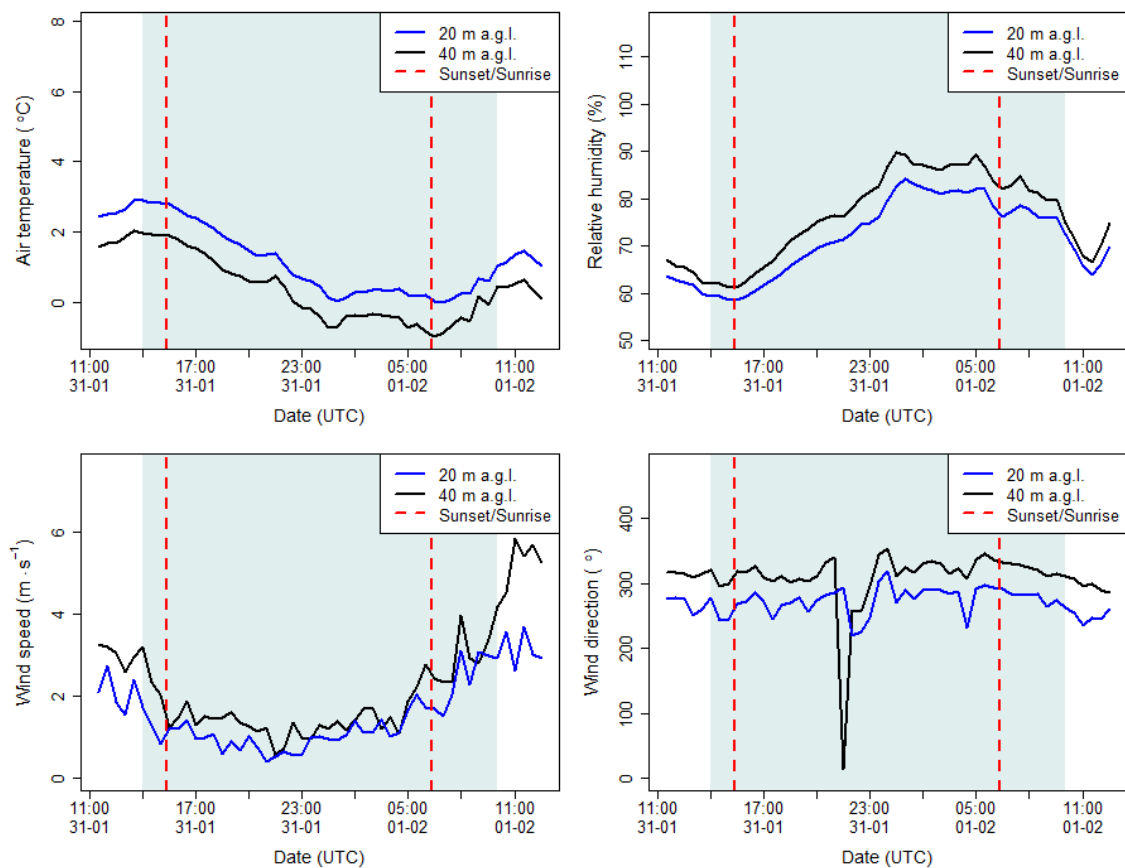


Figure S26. Time courses of air temperature, relative humidity, wind speed and wind direction at two altitudes (20 and 40 m a.g.l.) from measurement point at Reymonta St. on 31.01-1.02.2022 - campaign 11. Azure background presents campaign duration.