CoCO2

Prototype system for a Copernicus CO_2 service

Dataset of atmospheric observations from Krakow, Poland

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Co-ordinated by ECMWF

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D7.9 Dataset of atmospheric observations from Krakow, Poland

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Table of Contents

Figures

Tables

1 Dataset Summary

The summary provides an overview of the observations prepared in the framework of Task 7.5 ‘New measurement techniques and instruments to fill gaps’. This task was focused on investigation of potential of combining different in-situ observation systems with dynamic datasets and high-resolution modelling systems to capture the spatiotemporal variability in CO_2 concentrations and flux distributions in urban environment and thus better discriminate between anthropogenic and biogenic CO_2 fluxes. The observation systems include urban flux tower, meteorological observations, boundary layer profiling using airborne platforms based on Unmanned Aerial Vehicles (UAVs) or tethered balloon platform, as well as the application of a high-temporal-resolution radiocarbon tracer experiment on a campaign basis aimed at the characterization of the diurnal variability of anthropogenic emissions in cities. The dataset contains a description of the characteristics of Krakow, sampling point locations, and detailed information related to each specific data set. It consists of three types of observations (i) urban ecosystem flux time series obtained from eddy covariance flux tower, (ii) vertical profiles of the CO_2 and CH_4 mixing ratios from the Krakow urban area as a result of monthly based diurnal measurement campaigns and (iii) diurnal variability of the isotopic composition of atmospheric CO_2 ($\delta^{13}C$, $\delta^{18}O$ and $\Delta^{14}C$) performed during the monthly based measurement campaigns synchronised with boundary layer profiling campaigns. The dataset covers the period from February 2021 to February 2022.

2 Site Description

The city of Krakow is located in southern Poland, in the valley of the Vistula River. With 802 000 inhabitants [Statistical Bulletin of Krakow, Fourth Quarter 2022, Krakow 2023] and a municipal area of 327 km^2, it is one of the largest cities in Poland (Figure 2 – upper right panel). Characteristic features of the city landscape include densely built central districts, a historical city centre, an extensive industrial compound in the eastern part, and loosely built outskirts. The population density in the districts varies strongly from less than a thousand inhabitants per square km, to more than ten thousand.

Krakow is located in a temperate climate zone, in an area where maritime air masses coming with the westerly flow acquire more continental characteristics. Average annual air temperature based on the 30-year climatology of 1991-2020 at the World Meteorological Organisation (WMO) weather station Krakow-Balice (WMO no. 12566) is 8.9 °C with maximum temperatures occurring in July (climatological mean daily maximum temperature of July equal to 25.3°C) and minimum in January (climatological mean minimum daily temperature of January equal to -4.7°C). Annual precipitation reaches 673 mm with higher amounts during the summer and lower during the winter (Fig. 1).

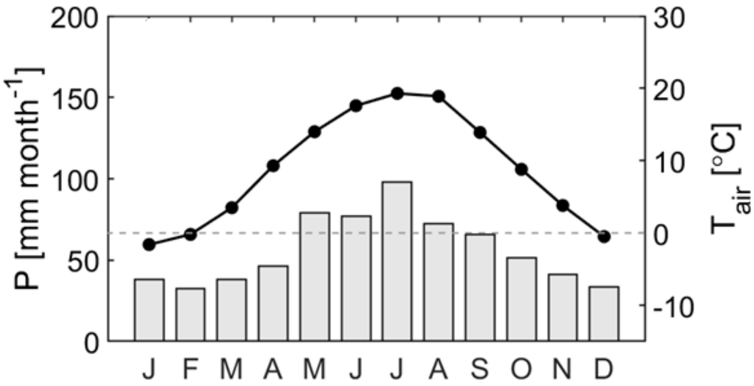

Figure 1 Climate of the Krakow-Balice WMO weather station located ca. 10 km west of the measurement sites: monthly mean air temperature (T_{air}, solid line) and monthly sum of precipitation (P, bars), averaged over 1991-2020.

The location of Krakow in a river basin determines the prevailing direction of the wind along a west-east axis. The meridional component of the mean wind circulation is often restrained or blocked entirely by the terrain, lowering the wind speed in Krakow compared to outside the valley. In a two-year period from 2021 to 2023, wind speeds classified as weak by the national weather service (less than 4.0 m s^{-1}) occurred 85% of the time, including calm conditions (wind speed less than 0.5 m s^{-1}) 6.8% of the time. The mean wind speed of that period was 2.4 (1.6) m s^{-1}, and the 25th, 50th, and 75th percentiles were 1.1, 2.1, and 3.2 m s^{-1}, respectively.

The observations obtained in the framework of the CoCO2 project were collected in 3 locations marked in Fig. 2.

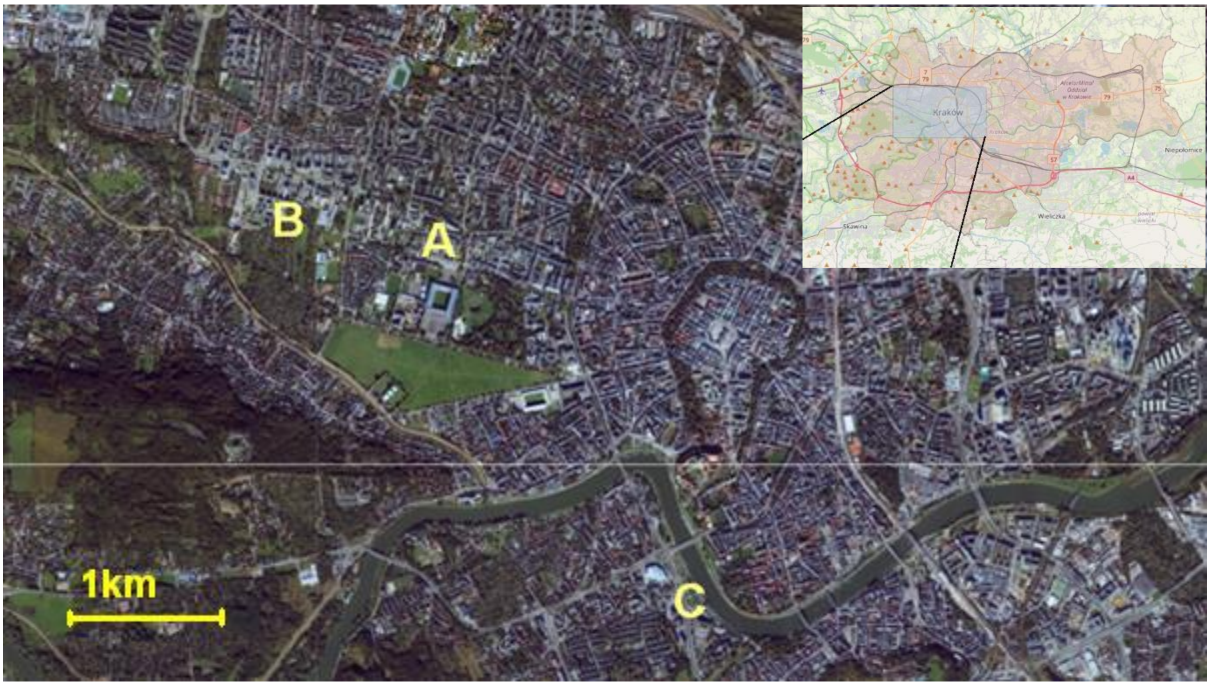

Figure 2: Aerial photo of Krakow's administrative boundaries (upper right panel) and city centre (main picture), with the location of the three sampling points: (A) AGH campus, Faculty of Physics building; (B) AGH campus, first drone campaign location; and (C) touristic tethered balloon location.

The aim of the task which was focused on investigation of potential of combining different in-situ observation systems with dynamic datasets and high-resolution modelling systems to capture the spatiotemporal variability in CO_2 concentrations and flux distributions in urban environment determined the selection of sampling points. The final locations used during the measurement campaigns were the result of a compromise between the optimal location of the observation point providing the representativeness of the urban environment and the technical and formal limitations of conducting measurements (accessibility, possibility of installing measuring equipment, power supply, 24/7 supervision).

Point A (50.0671N 19.9132E) indicates the AGH Faculty of Physics and Applied Computer Science building within the AGH university campus, where the eddy covariance tower is installed and most of the drone campaigns were performed (campaigns 7, 11 and 12). Point B (50.0679N 19.8991E) is also located within the AGH campus, ca. 1km west of the Faculty building. This location was used for the first drone campaign. Selection of this point was determined by the change in drone regulations introduced at the beginning of 2021. At that time, flights were limited to areas at least 150 m away from buildings[1]. In a densely populated urban area of Krakow the closest possible place that met the criteria and relatively easy access from the laboratory was located at point B (see Figure 2). Due to logistical problems at this location (no power supply), a new flight procedure was developed and future drone campaigns were shifted to point A. The flights were performed in accordance with the National Standard Scenario 2 (NSTS-02)[2]. Point C (50.0459N 19.9359E) represents the location of a tethered touristic balloon where most of the vertical profiling campaigns were performed. This location was selected because of the higher maximum altitude available for this platform and its location closer to the city centre, better representing the dynamics of the urban boundary layer.

3 Datasets

The delivered dataset contains three types of observations carried out within the CoCO2 project.

3.1 Urban ecosystem flux time series

The location and design of the urban ecosystem flux tower is following the general recommendations of such stations[3]. The system is installed on the roof of the Faculty of Physics and Applied Computer Science building. The elevation of instruments installed on the top of the tower is approximately 40 m a.g.l. The measurement system consists of a Gill Windmaster sonic anemometer, LICOR LI7500DS open path CO_2/H_2O analyser, a Huxeflux NR01 net radiometer, and a SmartFlux 3 datalogger. It is supplemented by a VAISALA WXT520 combined weather station delivering Biomet data for the system.

The elevation of flux tower allows one to obtain a station footprint covering the surrounding areas located within a distance of few hundred metres (Fig.3).

[1] Corresponding to UAS.OPEN.040 UAS operation in subcategory A3 of EU Regulation 2019/947: It is forbidden to fly over persons and gatherings of people. The minimum horizontal distance from residential, commercial, industrial or recreational areas is 150 m.

[2] NSTS-02 allows for operations within the line of sight (VLOS) with a multi-rotor un-manned aerial vehicle (MR) with a take-off mass of less than 25 kg (Budkowski, 2022, http://dx.doi.org/10.15576/GLL/2022.2.27).

[3] E.G. Stagakis et al. (2019) Eddy Covariance measurements and source partitioning of CO_2 emissions in an urban environment: Application for Heraklion, Greece, Atmospheric Environment 201 , pp.278-292 DOI10.1016/j.atmosenv.2019.01.009

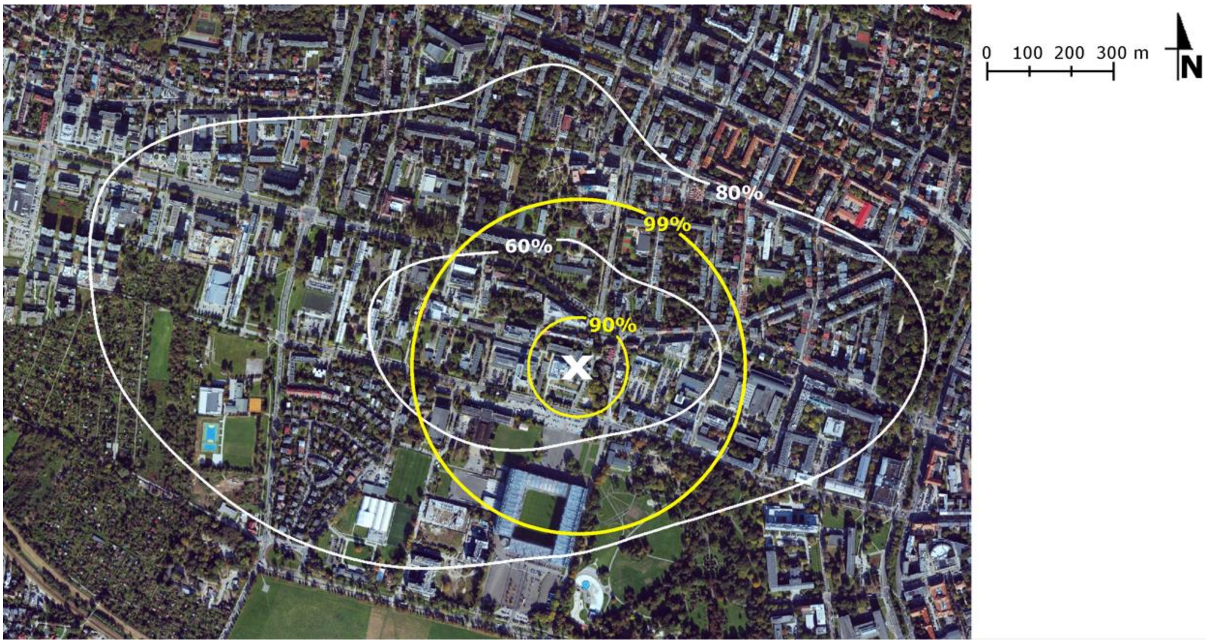

Figure 3 EC station footprint (white lines) and net radiometer footprint (yellow lines) averaged over the whole 2022 year.

The ecosystem station was established in February 2021 and since that time it has been running continuously. The dataset contains measurements for the period from 21 February 2021 up to 31 of August 2023. Flux data coverage varied throughout the year. Monthly coverage was usually above 90% with a few exceptions (Fig. 4).

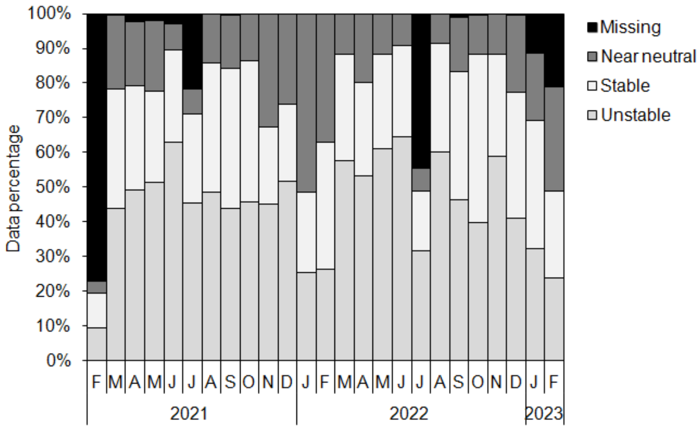

Figure 4 Monthly statistics of data coverage and atmospheric stability based on Obukhov length.

The summary of the diurnal variability of CO_2 fluxes and the corresponding wind roses observed at different seasons obtained during tower operation is presented in Fig. 5.

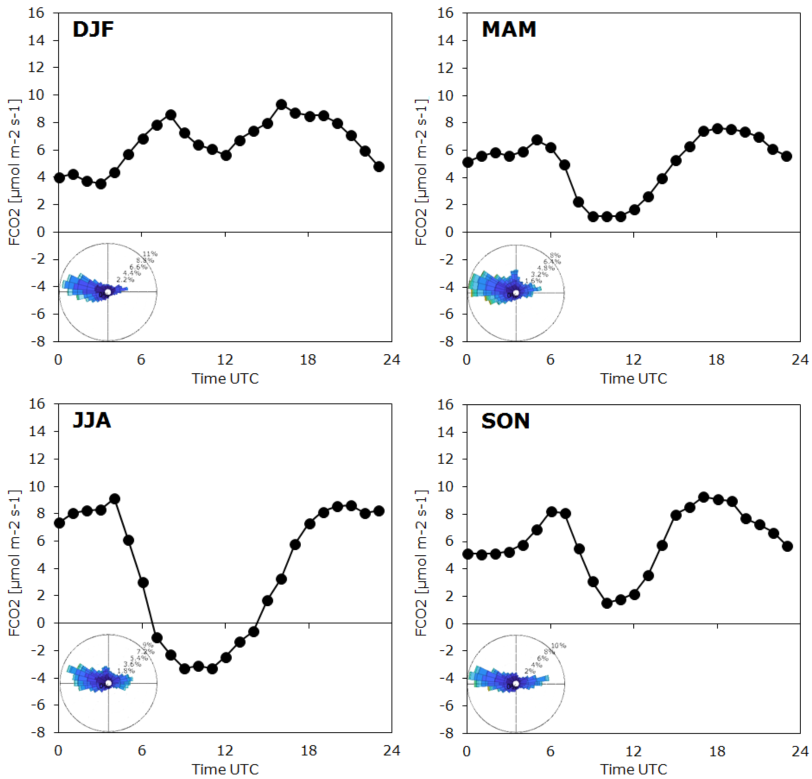

Figure 5 Summary of diurnal CO_2 flux variability observed at different seasons in Krakow. The corresponding wind roses are included in the inset.

This part of the dataset consists of 2 files. The metadata file contains information on dataset name, data affiliation, acknowledgements, data file characteristics station location, timeframe, contributors, and list of variables included in the dataset. The second file is a comma-separated text file containing half-hourly flux data. The list of variables is specified in Table 1 below:

Table 1 List of variables in the ecosystem flux time series

Variable name	Description	Unit	Physical quantity
TIMESTAMP	time instant, UTC	YYYY-MM-DD hh:mm:ss	
date	measurement date	YYYY-MM-DD	
time	measurement time	Hh:mm:ss	
H	sensible heat flux	W m^{-2}	energy flux
LE	latent heat flux	W m^{-2}	energy flux
Fc	carbon dioxide (CO_2) flux	µmol m^{-2} s^{-1}	particle flux
Ustar	friction velocity	m s^{-1}	velocity
WS	wind speed	m s^{-1}	velocity
WD	wind direction	°	angle
NEE	net ecosystem exchange	µmol m^{-2} s^{-1}	particle flux

Variable name	Description	Unit	Physical quantity
LE_f	gap-filled latent heat flux	W m^{-2}	energy flux
H_f	gap-filled sensible heat flux	W m^{-2}	energy flux

The dataset will be downloadable from the ICOS Carbon Portal (https://doi.org/10.18160/8DSK-R4JS).

3.2 Vertical profiles of the CO_2 and CH_4 mixing ratios from the Krakow urban area

Vertical profiles of CO_2 and CH_4 within the urban boundary layer of Krakow city were acquired using two different platforms. The first platform was a tethered touristic balloon operated by the Balon Widokowy Sp. z o.o. company in the city centre (location C in Fig. 1). An overview of the platform is presented in Fig.6.

Figure 6 An overview of the tethered balloon platform (left) and the location of the measurement equipment in the balloon gondola (on the right).

This platform allows for a full set of equipment (meteorological sensors, GHG analyser, independent power supply system) to be installed in the balloon gondola. The air inlet was placed ca. 2 m above the gondola to minimise the possible influence of tourists flying on the balloon during operating hours (daytime). The balloon flights were performed with hourly resolution during the night. The daytime frequency was dependent on the number of tourists, but at least one flight per hour was performed.

The second platform was the drone system presented in Fig. 7. It was used in cases when the balloon platform was not operating. The drone was equipped with a multi-sensor suite allowing one to measure meteorological conditions at different altitudes (temperature, relative humidity, wind speed). It was also connected to a Picarro analyser using a 200-m-long tube, enabling the measurement of the vertical distribution of CO_2 and CH_4. In the case of drone missions, the maximum altitude allowed by the airspace regulations was limited to 100 m a.g.l. Drone flights were performed with hourly resolution.

Figure 7 An overview of vertical profiling using the drone system.

The initial analysis showed that during the day, when well-mixed conditions occur, the vertical profiles of CO_2 and CH_4 are very constant (see Fig.8, left panel), representing mixing ratios close to the background levels (CO_2 between 409ppm in late summer and 422ppm in early spring seasons) observed at the remote background station at Kasprowy Wierch, located ca. 100 km south of Krakow in in Tatra mountains. The observed daily profiles and logistical constraints meant that campaigns were planned in most cases to cover the period of nocturnal boundary layer formation, the night, and the morning disappearance of the inversion layer. The period of measurement was sometimes shorter due to limitations related to meteorological conditions (e.g. strong wind or foggy weather and subzero temperatures leading to icing on the balloon).

A tabular and graphical summary of the profiles obtained are presented in Table 2 and in Fig. 8.

Table 2 Summary of airborne campaigns

No.	Date	Sunset [UTC]	Sunrise [UTC]	First flight [UTC]	Last flight [UTC]	Number of flights	Location of flight [°N]	Location of flight [°E]	PLATFORM
1	09-10.02.2021	15:45	06:00	12:30	11:10	26	50.067941	19.899127	DRONE
2	10-11.03.2021	16:30	05:00	21:20	08:00	12	50.045982	19.935972	BALLOON
3	28-29.04.2021	18:50	04:20	19:00	08:00	15	50.045982	19.935972	BALLOON
4	01-02.06.2021	19:40	03:30	08:20	05:00	48	50.045982	19.935972	BALLOON

No.	Date	Sunset [UTC]	Sunrise [UTC]	First flight [UTC]	Last flight [UTC]	Number of flights	Location of flight [°N]	Location of flight [°E]	PLATFORM
5	13-14.07.2021	19:50	03:40	17:30	06:20	29	50.045982	19.935972	BALLOON
6	07-08.09.2021	18:00	05:00	16:50	08:00	32	50.045982	19.935972	BALLOON
7	11-12.10.2021	17:00	06:00	17:00	08:00	13	50.067119	19.913281	DRONE
8	25-26.10.2021	16:30	06:20	15:50	10:00	29	50.045938	19.936062	BALLOON
9	24-25.11.2021	15:00	06:00	13:20	12:00	34	50.045938	19.936062	BALLOON
10	22-23.12.2021	14:40	06:30	14:00	12:20	21	50.045938	19.936062	BALLOON
11	11-12.01.2022	15:00	06:30	14:00	05:00	16	50.067123	19.912997	DRONE
12	31.01-1.02.2022	15:30	0:20	14:00	10:00	20	50.067239	19.913218	DRONE

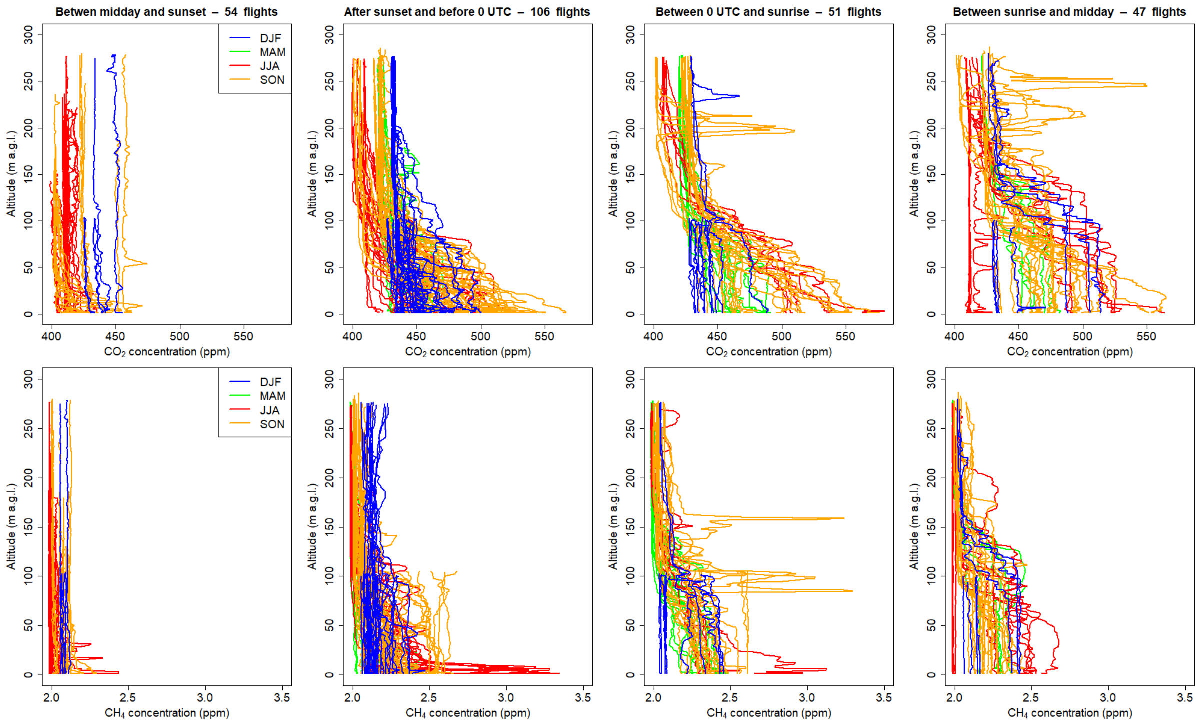

Figure 8 Summary of vertical profiles recorded at different periods for CO_2 (upper row) and CH_4 (lower row).

The Picarro analyser was calibrated before and after each campaign in the laboratory using a set of internal standards. The meteorological sensors were calibrated on the roof of the faculty building by comparing them with the VAISALA WXT520 meteorological station.

This part of the dataset is in the form of a zip archive that contains a metadata file and a separate file for each measurement campaign. The metadata file contains the information on the dataset name, data affiliation, acknowledgements, data file characteristics, sampling points location, general timeframe, contributors, and a list of variables included in the dataset. The data files are comma-separated text files containing 1-s temporal resolution measurement data. Each data file has a header with information about the number of flights and a table containing timestamps for the beginning, maximum altitude and end of each flight, as well as the maximum altitude, which varied across the campaigns. The list of variables is specified in Table 3 below:

Table 3 List of variables in the atmospheric time series

Variable name	Description	Unit/valid options
date_UTC	date time UTC synchronised with GPS	YYYY-MM-DD hh:mm:ss
CH4_dry	Methane mixing ratio	[ppm]
CO2_dry	Carbon dioxide dry air mixing ratio	[ppm]
H2O	Water vapour mixing ratio	[%]
GPS_lat	WGS84 Datum/Latitude	[deg]
GPS_lon	WGS84 Datum/Longitude	[deg]
GPS_alt	Altitude	[m]
CO2_qc_flag	Quality flag for CO_2 data	0: data OK; 1: data uncertain; 2: bad data or lack of data
CH4_qc_flag	Quality flag for CH_4 data	0: data OK; 1: data uncertain; 2: bad data or lack of data
H2O_qc_flag	Quality flag for H_2O data	0: data OK; 1: data uncertain; 2: bad data or lack of data
air_temperature	Air Temperature	[degC]
air_temperature_qc_flag	Quality flag for air temperature data	0: data OK; 1: data uncertain; 2: bad data or lack of data
relative_humidity	Relative Humidity [%]	
relative_humidity_qc_flag	Quality flag for relative humidity data	0: data OK; 1: data uncertain; 2: bad data or lack of data
air_pressure	atmospheric pressure	[hPa]
air_pressure_qc_flag	Quality flag for air pressure data	0: data OK; 1: data uncertain; 2: bad data or lack of data
wind_speed,	wind speed	[m/s]
wind_speed_qc_flag	Quality flag for wind speed data	0: data OK; 1: data uncertain; 2: bad data or lack of data
altitude	Altitude calculated from atmospheric pressure	[m a.g.l.]
altitude_qc_flag	Quality flag for altitude data	0: data OK; 1: data uncertain; 2: bad data or lack of data
flight_code	Flag indicating the type of flight	TRANSFER - Transfer of the system between laboratory and measurement site GROUND - system at the ground level UP_#- ascending flight DOWN_# - descending flight where # is flight number

The data set will be available for download from the ICOS Carbon Portal (https://doi.org/10.18160/8DSK-R4JS).

3.3 Diurnal variability of the isotopic composition of atmospheric CO_2

The last part of the data set contains the isotopic analysis of flask samples collected every 4 hours during flight campaigns. The sampling location (Figure 2 point A) was the same as eddy covariance tower. Air inlet was located on the tower installed on the roof of Faculty of Physics and Applied Computer Science building at a fixed elevation of ca. 25m a.g.l. The isotope sampling campaigns were in most cases temporary synchronised with boundary layer profiling campaigns. There was one exception on 10-11.03.2021 when due to technical problems the flasks were not collected and the isotopic campaign was shifted to 25-26.03.2021. Each sample was collected using an automatic flask sampler (shown in Fig. 9) in a pair of glass flasks (1 l and 3 l capacity) by flushing with dry air. The water vapour was removed from the air stream in a cryogenic trap cooled down to -30°C.

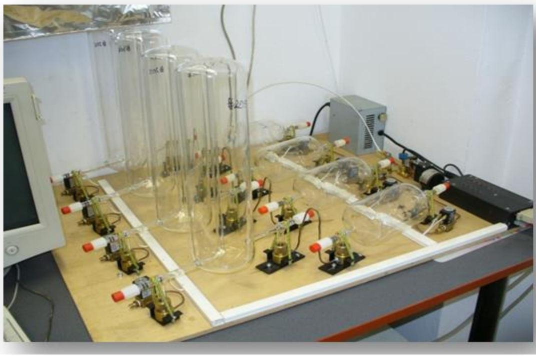

Figure 9 Automatic flask sampler used for measurement campaigns.

In the next steps, the mixing ratio was measured using a PICARRO G-2311-f analyser and CO_2 was cryogenically extracted from the air samples. The smaller 1-l flask sample was then used for stable isotopic analysis ($\delta^{13}C$ and $\delta^{18}O$) using the Finnigan Delta-S isotope ratio mass spectrometer in the Environmental Physics Group laboratory, while CO_2 extracted from the 3-l flasks was sent to Poznan Radiocarbon laboratory for AMS analysis of ^{14}C. In total, 72 isotopic samples (12 campaigns, 6 samples each) were collected and measured. The results obtained are submitted as a part of this deliverable and can be used for the calculation of the fossil fuel contribution to the total CO_2 load in Krakow during the measurement campaigns at 4-hour resolution.

The dataset is in the form of a zip archive containing metadata files and a separate data file for each measurement campaign. The metadata file contains the information on the dataset name, data affiliation, acknowledgements, data file characteristics, sampling point location, general timeframe, contributors, and list of variables included in the dataset. The data files are comma-separated text files containing CO_2 and CH_4 mixing ratios and the isotopic composition of carbon and oxygen in each sample. The list of variables is specified in Table 4 below:

Table 4 List of variables in the isotopic timeseries

Variable name	description	unit
Timestamp_UTC	date time UTC	DD.MM.YYYY hh:mm
delta_13_C	carbon-13 isotopic composition in the flask	[‰]

	sample expressed in V-PDB scale	
delta_18_O	oxygen-18 isotopic composition in the flask sample expressed in V-PDB scale	[‰]
Delta_14_C	radiocarbon capital delta value in the flask sample (relative deviation from the concentration in the standard of modern biosphere)	[‰]
CH4	Methane mixing ratio in the flask sample	[ppm]
CO2	Carbon dioxide mixing ratio in the flask sample	[ppm]
Delta_14_C_bg	radiocarbon capital delta value in the nighttime monthly -averaged sample collected at the Kasprowy Wierch background station (relative deviation from the concentration in the standard of modern biosphere)	[‰]
delta_13_C_bg	carbon-13 isotopic composition in the nighttime monthly -averaged sample collected at the Kasprowy Wierch background station expressed in V-PDB scale	[‰]
CH4_bg	Nighttime monthly -averaged methane mixing ratio measured at the Kasprowy Wierch background station	[ppm]
CO2_bg	Nighttime monthly -averaged carbon dioxide mixing ratio measured at the Kasprowy Wierch background station	[ppm]

The data set will be available for download from the ICOS Carbon Portal (https://doi.org/10.18160/8DSK-R4JS).

4 Conclusion

The document contains the summary of the datasets prepared as delivery D7.9 within Task 7.5 of CoCO2 project. There is a short description of the city, detailed descriptions of the measurement locations, a description of the equipment used for the measurements, and information about the data files and their contents.

Document History

Version	Author(s)	Date	Changes
0.1	M. Zimnoch(AGH)	28/09/2023	
0.2	M. Zimnoch(AGH)	09/10/2023	Corrections according to 1-st reviewer comments (DLR)
1.0 (final)	M. Zimnoch(AGH)	14.10.2023	Corrections according to 2-nd and 3-rd reviewers comments (CEA, ECMWF)

Internal Review History

Internal Reviewers	Date	Comments
Julia Marshall (DLR)	06/10/2023	Some minor grammatical and typographical corrections, harmonization of units in all tables, clarification of drone regulations. There is a reference to a Figure 2 in the text that is missing (showing wind speeds). The current Figure 2 could use a spatial scale.
Gregoire Broquet	09/10/2023	Comments and recommendations
Aura Lupascu (ECMWF)	13/10/2023	Small comments and corrections.

Estimated Effort Contribution per Partner

Partner	Effort
AGH	1
Total	**1**