D4.4 Ground-based FTIR data

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Document change record

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V0	26/08/2026	First version circulated to the consortium
V1	05/09/2026	Comments from consortium integrated, version uploaded to portal.

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List of abbreviations

Abbreviation	Definition
FTIR	Fourier-Transform Infrared
ILS	Instrument Line Shape
COCCON	COllaborative Carbon Column Observing Network
Xgas	Column-averaged dry-air mole fraction of a gas
ICOS	Integrated Carbon Observing System
GNSS	Global Navigation Satellite System

List of reference/applicable documents

Document title	Document author	Date of issuance

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1 Executive Summary

1.1 SCARBOn Overview

SCARBOn (Space CARbon Observatory Next step) is an innovation action project funded under the Horizon Europe Programme. It is the continuation of the Horizon 2020 SCARBO project. SCARBOn is a multidisciplinary project carried out by a gender-diverse team, through a consortium including the space industry, SMEs and scientific institutes. It is led from Toulouse, France by Airbus Defence and Space. SCARBOn project started in January 2024, with a total 40 months of implementation.

The main objective for the of the SCARBOn collaborative project is to mature the SCARBOn overall system based on a constellation of small satellites - with miniaturised static spectrometer concept (NanoCarb) coupled with aerosol sensors (SPEXone) - that will be able to monitor greenhouse gases (GHG) – notably the CO_2,, and CH_4 as well – from space. The instruments together will deliver daily accurate global measurements to monitor the diurnal variations of fossil CO_2 emission. This CO_2 and CH_4 anthropogenic emissions monitoring data aims to be a valuable contributor to the European Commission's endeavour to fight climate change. As an upside, the monitoring data will foster the development of added-value services and will represent a state-of-the-art European alternative to the burgeoning non-European commercial initiatives.

The SCARBOn project maturation is articulated over the detailed technical definition of the NanoCarb instrument, the industrial definition of both instruments and the constellation concept confirmation, targeting an operational system availability before the end of the decade. The design of the NanoCarb instrument will be upgraded and refined following the outcomes of the previous SCARBO study, and its performances will be carefully modelled. An instrument breadboard will provide valuable data during an airborne campaign, which will be used together with modelled data to verify the instrument design. This will allow raising the instrument TRL to at least 5 by the end of the project. Furthermore, data processing at levels L1 to L4 will validate the concept capability to monitor GHG plumes from space.

1.2 Document summary

This document gives supporting information about the instruments and methodology used to acquire the ground-based FTIR measurements and meteorological data during the NanoCarb flight campaign over the Niederaussem power plant in Germany in April 2026. It describes the processing software used to analyse the data and presents plots of the final level 2 data: the column-averaged dry air mole fractions of CO_2, CH_4, CO and H_2O.

2 Ground-based FTIR measurements during the flight campaign

2.1 Data link

Campaign FTIR data is publicly available from the following repositories:

- https://evdc.esa.int/doi/10.48477/COCCON.PF241.BEDBURG.SN113.R01 (Level 2 data)
- https://doi.org/10.18758/kprvo4ef (supporting data)

2.2 Instruments

FTIR spectra were recorded using a Bruker EM27/SUN spectrometer, on loan from the Ruisdael observatory in the Netherlands (https://ruisdael-observatory.nl/). This instrument has serial number 113 and is part of the COCCON network (https://www.coccon.kit.edu/). The EM27/SUN is equipped with a compact solar tracker and measures direct solar absorption FTIR spectra in the range from 4000 to 15000 cm^{-1} at a resolution of 0.5 cm^{-1} using two InGaAs detectors.

Auxiliary meteorological data was collected using a Gill MetConnect One weather station mounted on a portable mast. This station was installed next to the FTIR spectrometer.

Figure 1 Bruker EM27/SUN spectrometer with compact solar tracker and Gill MetConnect One weather station at location Wed.3. A portable battery and solar panel provide power for the measurements in the field.

2.3 Measurement locations

Table 1 Overview of the different measurement locations

Code	Date [UTC]	Start time [UTC]	End time [UTC]	Latitude [deg. N]	Longitude [deg. E]	Altitude [m]
Mon.1	Mon Apr 6, 2026	09:55:32	14:40:12	51.0252	6.5292	94
Tue.1	Tue Apr 7, 2026	08:47:24	15:09:57	51.0960	6.5173	81
Wed.1	Wed Apr 8, 2026	07:36:52	08:51:04	50.9634	6.6429	86
Wed.2	Wed Apr 8, 2026	09:47:51	12:46:10	51.0160	6.5701	61
Wed.3	Wed Apr 8, 2026	13:27:07	14:56:42	50.9917	6.5869	61

Because GNSS data has a large uncertainty for the altitude, the altitudes were determined using https://www.randymajors.org/elevation-on-google-maps and were verified to correspond roughly with recorded GNSS data.

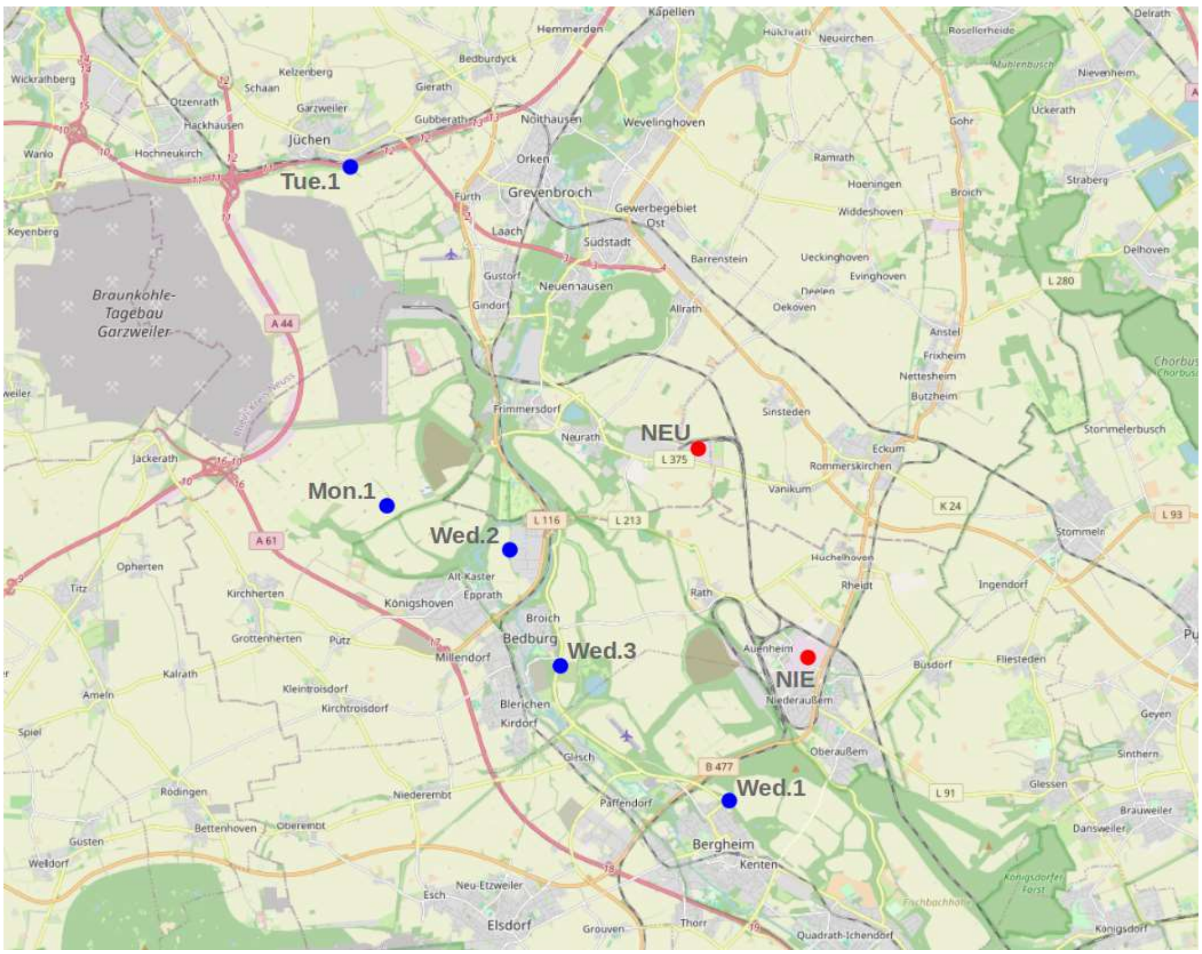

Figure 2 Measurement locations are indicated by blue dots. Red dots are the positions of the Neurath (NEU) and Niederaussem (NIE) power plants.

2.4 Background measurement days

The BIRA-IASB team was in the Bedburg area from Friday April 3 until Friday April 9. On Saturday and Sunday, the team did reconnaissance of the area, finding suitable measurement locations for a range of likely wind directions based on the weather forecast for the campaign week.

On Monday April 6 and Tuesday April 7, the weather was sunny and solar observing FTIR measurements were carried out in background locations, *i.e.* locations that were not downwind from the Niederaussem or Neurath power plants. These Monday and Tuesday measurement locations are designated Mon.1 and Mon.2 respectively.

Post-flight, on Thursday April 8, there were intermittent clouds, and conditions were deemed not suitable for FTIR measurements.

2.5 Flight campaign day

The flight campaign took place on Wednesday April 8, 2026. In the days preceding the flight, DLR had been monitoring the output of both power plants, and on the flight day, the Niederaussem plant was predicted to have the higher output and was selected as the target. On the morning of the flight, several wind-trajectory models were consulted via Windy (https://www.windy.com/) to select the optimal flight path for the airplane to fly cross sections across the plume, and to determine the best locations for in-plume and out-of-plume ground-based FTIR measurements and co-located in-plume measurements of with the airplane instruments.

Based on this analysis, the following FTIR measurement locations were selected:

- Before the flight: FTIR measurements outside of the Niederaussem plume (Wed.1)
- During the flight: co-located FTIR measurements underneath the Niederaussem plume (Wed.2)
- After the flight: FTIR measurements in the flanks of the plume (Wed.3)

Table 2 Distances from the measurement locations to the Niederaussem power plant

Location [Code]	Distance to NIE [m]	Heading to NIE [deg. N]
Wed.1	3800	29
Wed.2	7390	110
Wed.3	5770	88

Distances and headings are based on a Cartesian projection, which given the short distances should be valid. Distances were verified in Google maps.

2.6 Data analysis

The interferograms recorded by the EM27/SUN during the measurement campaign were processed using Proffastpyplot version 2.4.1-0 [https://doi.org/10.21105/joss.06481], a python wrapper for the PROFFAST version 2.4 retrieval code. The EM27/SUN with serial number 113 is part of the COCCON network and its ILS and calibration factors have been determined by the COCCON team at KIT [https://doi.org/10.5194/amt-15-2433-2022].

2.7 Trace gas retrieval results

The results of the PROFFAST retrieval are column-averaged dry-air mole fractions (Xgas) for the target gases CO_2, CH_4, CO and H_2O. Xair is a diagnostic parameter of the retrieval, which relates the vertical column of O_2 to the observed ambient air pressure measurements from the weather station.

The Xgas calibration factors for EM27/SUN with serial number 113 determined by the COCCON have been applied to the results in the figure. The mean of the two sets of calibration factors given in [https://doi.org/10.5194/amt-15-2433-2022] has been used.

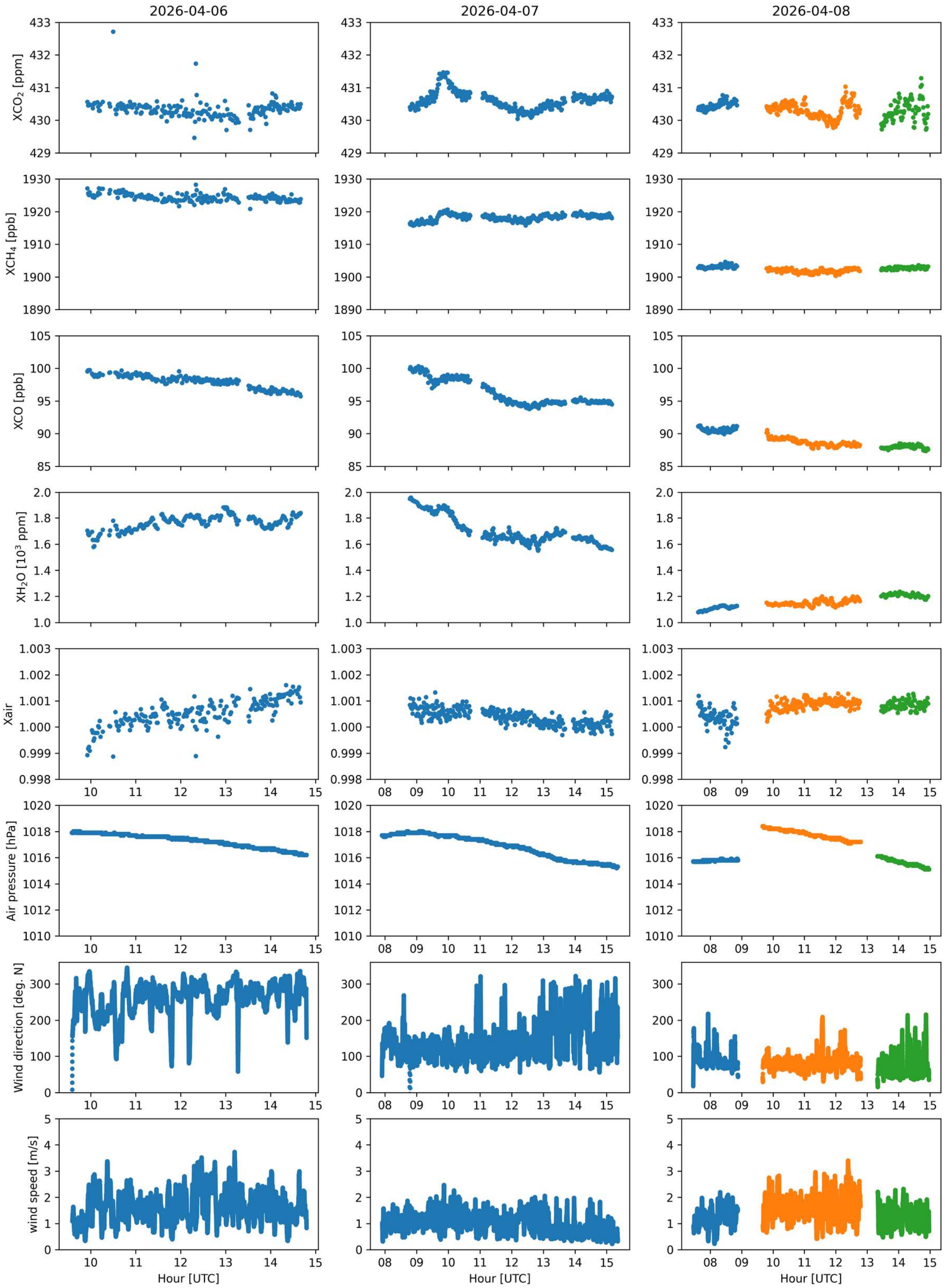

Figure 3 Xgas retrieval results and air pressure, wind speed and wind direction from the Gill MetConnect One weather station. A running average of 60 s has been applied to smooth data in the plot of wind speed and direction. The different colors in the plots for April 8 represent the time series obtained at each of the three different measurement locations on the flight campaign day.

2.8 Additional data sources

The atmospheric ICOS station Juelich (https://meta.icos-cp.eu/resources/stations/AS_JUE) is situated approximately 20 km to the southwest of the Neurath and Niederaussem power plants. The ICOS tower measures wind speeds at 50, 80 and 120 m above ground level. This tower data might be more representative of the wind speed and direction encountered by the power plant plumes, than those of the Gill MetConnect One station, which measures these parameters at ground level and may be impacted by topography and vegetation in the immediate environment.

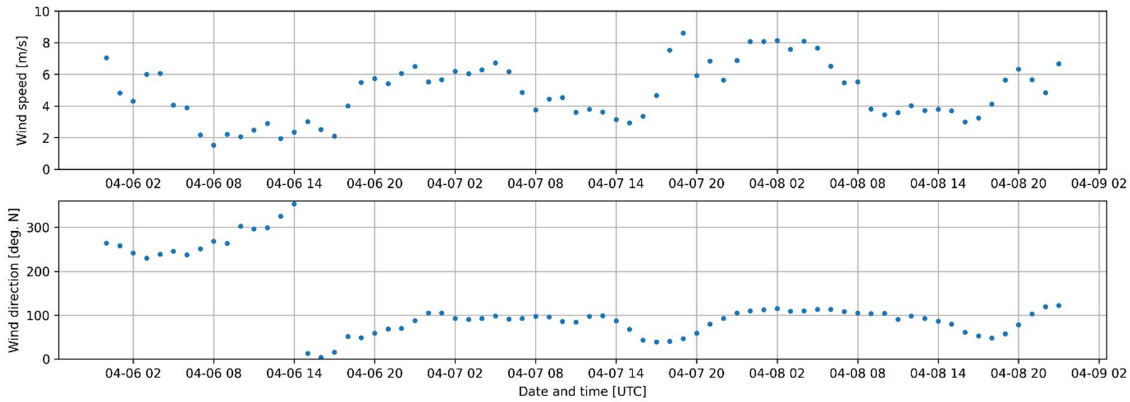

Figure 4 Juelich ICOS station wind speed and direction at the 120 m tower level from April 6 to 8, 2026. [Kubistin, D., Plaß-Dülmer, C., Kneuer, T., Lindauer, M., Müller-Williams, J., Zwerschke, E. (2026). ICOS ATC Meteo Release from Jülich (120.0 m), 2021-07-2]

2.9 Conclusion

Direct solar absorption spectra were successfully measured during the NanoCarb-P flight campaign and the two days preceding the flight. From these spectra the column-averaged dry-air mole fractions of CO_2, CH_4, and CO were retrieved using the PROFFAST retrieval software.

The results of the flight day, April 8, show increases in XCO_2 at location Wed.2 between 12:00 and 13:00 UTC, around the time when the anemometer data shows the wind direction matching the direction towards the Niederaussem power plant. No increase in XCO was observed at the same time, potentially indicating complete combustion in the power plant. Co-located measurements with the NanoCarb-P and FENIX instruments on board of the aircraft was achieved at this location (see D4.3 Flight Campaign Report), allowing the FTIR data to serve as a reference for the analysis and interpretation of the results from NanoCarb.

The measurements at location Wed.3 also see increases in XCO_2, this again corresponds with a wind direction matching the direction towards the power plant, and again no increase in XCO was observed.

We refer to the meteorological data from the nearby Juelich ICOS station to aid in the interpretation of the results. The wind speed and direction measured at 50, 80 and 120 m above ground level at Juelich may be more representative of the wind field experienced by the power station plume than the anemometer data from the FTIR weather station at ground level.

The FTIR measurements on April 6 and 7 were intended to capture a background reference atmosphere, measured outside of the plume of both power stations. However, there is a change in wind direction from west to east between April 6 and 7. This change is also visible in the Juelich ICOS station data (where the change occurs earlier than at the FTIR measurement location). This change in wind direction means that the observed airmasses will have followed quite different trajectories between the April 6 and 7 measurement days, that will most likely (although this needs to be confirmed by wind trajectory modelling) not be representative for the April 8 flight campaign day.