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PARIS

Process Attribution of Regional Emissions

GA 101081430, RIA

Continuous APO observations established at Zweth (M22)

Preliminary report
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Milestone 22

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Milestone 22: Continuous APO observations established at Zweth

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1. Changes with respect to the DoA (Description of the Action)

This milestone is delayed due to a combination of mainly staffing issues and technical challenges. In January 2026, the staffing issues have been solved, and we expect the measurements to start later in 2026. This report gives a progress overview of the development of the measurement system.

2. Dissemination and uptake

This report is a preliminary version and will be updated after establishment of the station. The measurement data will be available through the ICOS Carbon Portal.

3. Short Summary of results

We are in the process of establishing a new measurement station for atmospheric O₂ and CO₂ measurements at the Zweth, near Rotterdam in the Netherlands. These measurements will be complementary to the measurement record started at the Cabauw station in the Netherlands. Together, these measurements will provide local, urban and regional O₂ and CO₂ signals.

The development of the instrument to be established at Zweth has been delayed due to staffing issues, and technical challenges. This preliminary milestone report describes the status of the development of the measurement setup and presents initial test results of the instrument.

In the next months, important parts of the setup will be replaced, and final tests will be made, before installing the system at Zweth in the course of 2026.

4. Evidence of accomplishment

4.1 Introduction | Background of the milestone

Atmospheric O₂ and CO₂ measurements allow to distinguish the natural and anthropogenic components in the atmospheric CO₂ mole fractions (e.g., Pickers et al., 2022; Stephens et al., 1998). Processes in the carbon cycle each have distinct O₂/CO₂ ratios, allowing to disentangle the signals. For example, fossil fuel combustion consumes atmospheric O₂, and releases CO₂. The O₂/CO₂ exchange ratio of these processes provides information on their origin (Steinbach et al., 2011, Faassen et al. 2023). Therefore, these measurements allow to disentangle the fossil fuel CO₂ (ffCO₂) component from the net atmospheric CO₂ signal (Pickers et al., 2022). Atmospheric O₂ and CO₂ can also be combined into the tracer Atmospheric Potential Oxygen (APO), which excludes the biosphere signal by assuming a fixed exchange ratio of 1.1, following the definition by Stephens et al. (1998). APO is primarily sensitive to ocean–atmosphere exchange on large spatial and temporal scales. However, on shorter timescales, the initial study by Pickers et al. (2022) shows that atmospheric O₂ has the potential to provide information on the fossil fuel CO₂ signal, through the deviation from the biospheric exchange ratio of 1.1. The exchange ratio of fossil fuels ranges between 1.2 and 1.9, with the global average fossil fuel mix corresponding to approximately 1.4 (Keeling and Manning, 2014).

In contrast to radiocarbon measurements, which are an established tracer for ffCO₂ (Levin et al. 2003), an advantage is that atmospheric O₂ can be continuously. So far, only few

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stations measure O₂, there are 2 stations in the UK, which are also part of the PARIS project, and since 2024, there is a new station in the Netherlands, at Cabauw. In this milestone, the goal is to add a fourth station, at the Zweth, near Rotterdam in the Netherlands. This preliminary report documents to progress towards that goal.

4.2 Scope of the milestone

This report documents the progress towards the establishment of the new measurement station for atmospheric O₂ and CO₂ measurements. A future update of this report will also include information about the data collected at the station.

4.3 Content of the milestone

4.3.1 The Zweth measurement station

The Zweth station has been established in 2014 for continuous measurements of CO₂, CO and CH₄ (Super et al. 2017). It is operated by TNO in the Netherlands. Fig. 1 shows the location of the site and a picture of the 10 m high tower and the container in which the instruments are placed. Fig. 2 shows the different characteristics of the area, including a large port, glasshouses and the urban area. The station is suitable to pick up urban signals. Together with the measurements at Cabauw, which give a more regional signal, this allows to see the urban contributions to the CO₂ signal.



Fig. 1: the Zweth measurement station (left), and the location (right).

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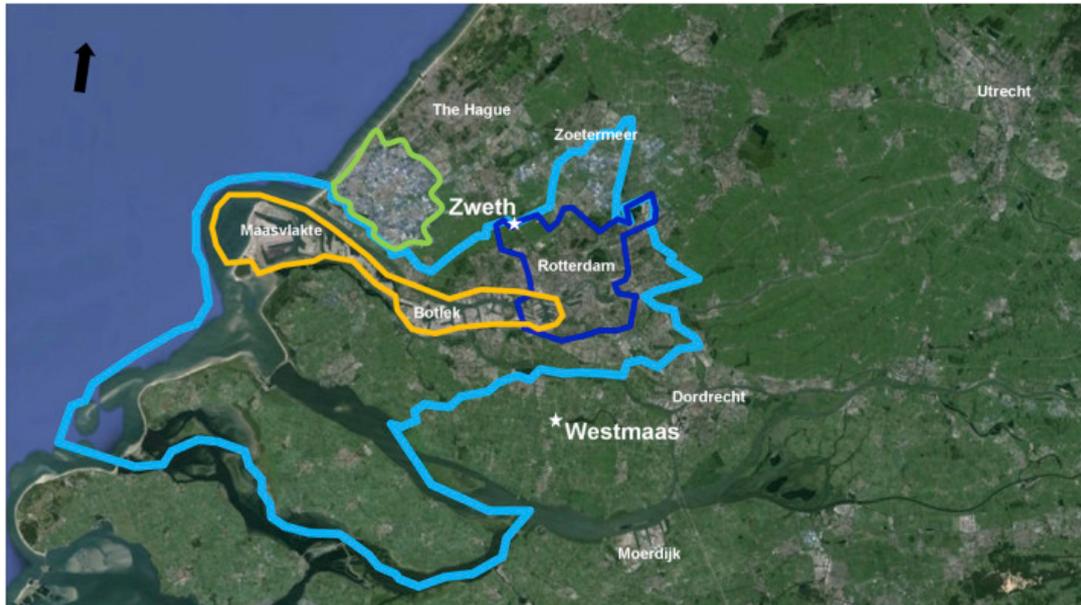


Fig. 2: Map of the Rijnmond area (light blue outline), including the city of Rotterdam (dark blue outline), the port (yellow outline) and the glasshouse agriculture source sector (green outline); the observation sites are indicated with white stars; the prevailing wind direction during the observations is given by the black arrow (from: Super et al. 2017).

4.3.2 The O₂/CO₂ instrument

Continuous O₂ and CO₂ measurements require a custom-build measurement setup. In our case, we use an Oxzilla O₂ analyzer and an URAS CO₂ analyzer. The elaborate gas handling system includes air drying, pressure and flow stabilization and switching between reference and sample lines. The measurement system has been developed at the University of Groningen (RUG) and is described by van der Laan-Luijkx et al. (2010) and Faassen et al. (2023).

In summary, the instrument includes an Oxzilla O₂ analyzer that measures a double differential O₂ signal and is therefore continuously compared to a reference gas. This signal



Fig. 3: the O₂/CO₂ measurement setup

is calibrated with 3 calibration tanks every 23 hours. A target tank is measured twice per day, to check the accuracy and precision of the measurements. CO₂ is measured with an URAS CO₂ analyzer in one of the lines. The lines are switched every minute to eliminate differences between the fuel cells in the Oxzilla analyzer. The pressure difference between both lines is kept stable close to 0 mbar using MKS pressure controllers. The flows in both lines are also equalized using a mass flow controller in one of the lines and needle valves in the other. The sample air is dried using a two-stage cooler, one at 2 degrees and the other at -80 degrees. Fig. 3 shows a picture of the instrument while being tested in the laboratory at University of Groningen. For elaborate details, see van der Laan-Luijkx et al. (2010) and Faassen et al. (2023).

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The instrument was built, and the custom build software was finalized in the first year of the Paris project. Staffing issues were leading to delays in the testing of the instrument. In 2025, MSc thesis student Nicolò De Santis, together with PhD candidate Lois de Beijl took on the task of testing the Zweth system in the laboratory. We describe the first test results below.

4.3.3 Test results

The MSc thesis of De Santis (2025), shows the first tests with the instrument. Fig. 4 shows the results of 3 different test measurement series of the target tank for CO₂ and O₂. As shown in the figure, the first and third test had some jumps in the values, but test 2 shows a more stable result. Extensive details of these tests are described in the MSc thesis report, but the main take away is that the system is able to measure with acceptable precision. Test 2 results in a standard deviation for the target tank measurements over 15 periods of 7 per meg (see also table 1).

De Santis (2025) also includes first results of measurements of outside air from the rooftop of the laboratory at the University of Groningen for a period of 3 days. These results are shown in Fig. 5. It shows the anticorrelated behavior of O₂ and CO₂. In general, these first tests were promising, although some issues appeared due to instable pressure/flows in the system which required further testing after the MSc project.

4.3.4 Issues in the Oxzilla analyser

During the subsequent testing by PhD candidate Lois de Beijl, issues already found by De Santis (2025) in test 3 (see

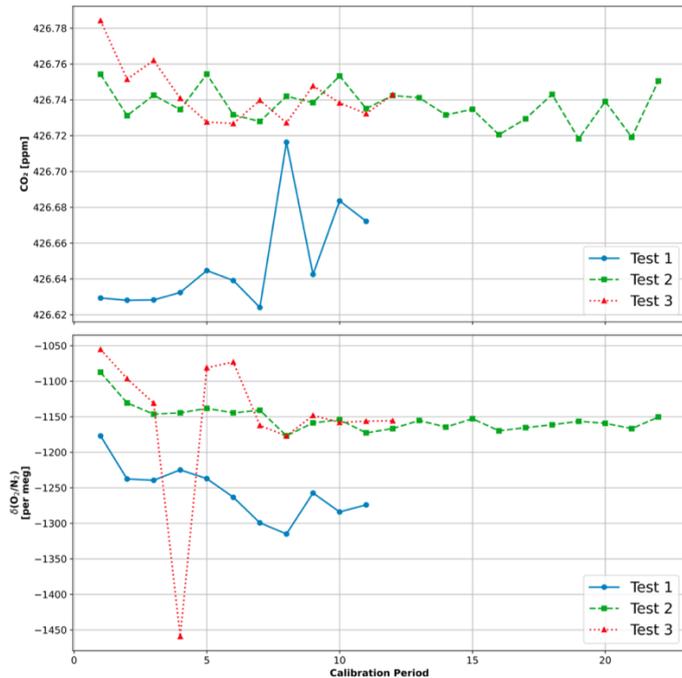


Fig. 4: First test measurements of target tanks

Table 1: Standard deviations and 95% confidence intervals for O₂ in target tank measurements for Test 2 and Test 3, excluding the first 7 periods.

Test	O ₂ Std Dev (per meg)	Number of periods
2	7 (6, 12)	15
3	11 (7, 31)	5

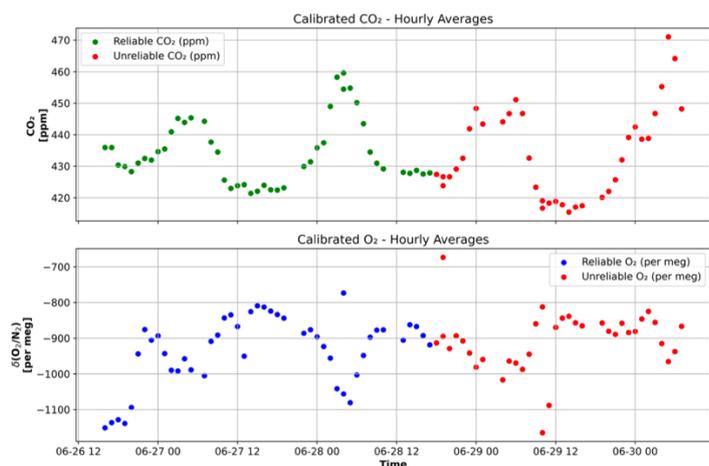


Fig. 5: First test measurements of outside air at the laboratory at University of Groningen. Reliable observations are shown in green and blue; periods marked in red indicate unstable pressure/flow conditions.

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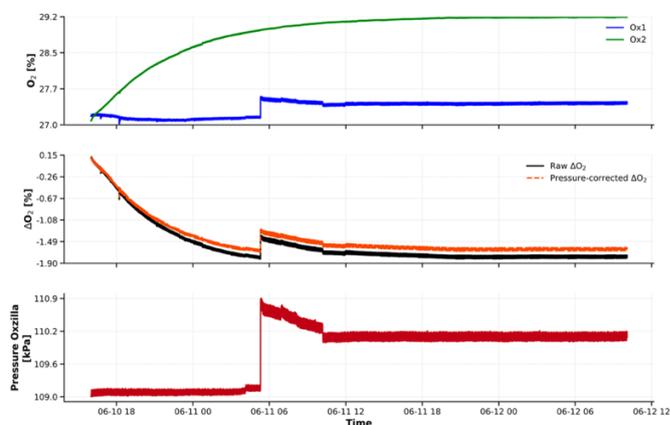


Fig. 6: Raw analyzer output from the Oxzilla and pressure sensor during test 3

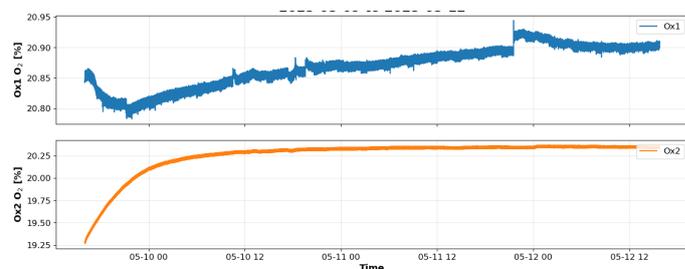


Fig. 7: Raw measurement signal from the Oxzilla analyzer, showing jumps in the signal indicating malfunctioning of (likely) the electronics

Fig. 4) were confirmed in follow up experiments (see Fig. 6, 7).

The Oxzilla analyzer shows unexpected jumps in the raw signal, including that of the pressure sensor. However, correcting for this pressure difference does not resolve the issue (middle panel Fig. 6). Further tests led us to think that there is a malfunctioning in the electronics of the Oxzilla analyzer, given also that the analyzer itself is relatively old (bought in 2005). A new analyzer has been ordered and once it arrives, the testing will be continued. The results of the target tanks above indicate that the (newly build) gas handling system itself is likely ready for measurements, and we hope that once the new analyzer arrives, we can quickly start to do tests of outside air and once these are successful, install the instrument at Zweth.

4.4 Conclusion and possible impact

The work in this milestone will be continued in 2026. The instrument will be further improved and tested and will be installed at Zweth in 2026. The data will be provided at the ICOS Carbon Portal. The new observations will be an important addition to the existing O₂ measurements in the UK and the Netherlands. Together, these measurements will facilitate the interpretation of the CO₂ signals in these countries.

All measurements will be made available publicly through the ICOS Carbon Portal, ensuring that the data can be used by scientists in the PARIS project, as well as other projects focusing on estimating CO₂ emissions over Europe.

4.5 References

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5. History of the document

Version	Author(s)	Date	Changes
V0	Ingrid Lujikx	23 February 2026	Preliminary version