MEMO$^2$: MEthane goes MObile – MEasurements and MOdelling

# Report on harmonized method for mobile $CH_4$ and $^{13}CH_4$

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| **Deliverable D1.5 - Report on harmonized method for mobile CH4 and 13CH4** | | | |
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# 1. Executive Summary

Within the MEMO$^2$ project 7 laboratories perform mobile $CH_4$ measurements installing a $CH_4$ analyser in a vehicle. The guideline describes how the mobile measurements of atmospheric $CH_4$ mole fraction in an emission plume should be performed within the MEMO$^2$ network. The individual setups of the different laboratories are described, and all are following principle guidelines of the World Meteorological Organisation (WMO) by using adequate tubing and valve for inlet lines. Differences like drying systems or the use of AirCore for isotope analysis are documented for each individual set-up. Special attention is paid for the three analysers used at LSCE, UHEI and AGU to measure $^{13}CH_4$. Here the cross sensitivity of water vapor and ethane can influence the measurements and need to be corrected for these effects.

The guideline describes the calibration strategy, as well as a recommendation on the inlet height, delay time and driving speed. As it is not possible to harmonise all parameter, it is important to document them in a good way. In the harmonized file format, we have several comment lines, which can be used for this purpose. The comments contain information like data provider and contact e-mail, calibration scale information, inlet height and delay time as well as a free text data description with a maximum of 500 characters. Here the ESR can give additional information of the campaigns, which they performed.

At the end of the document the link to the project data base and the storage of raw data and calibrated data format are defined.

The deliverable D1.5 is related to deliverable D5.3, the Data Management, Dissemination and Exploitation Plan (DMDE plan).

# 2. Introduction

Measurement networks of atmospheric methane and carbon dioxide at surface stations like NOAA/CMDL, AGAE or ICOS are well established and following WMO recommendations or even stronger network commitments for station setup and data treatment. Campaign based mobile measurements are not subject of such recommendations and these measurements are sometimes seen as individual data sets, which need not follow the specification of stronger network requirements. However, for a joint use of campaign data a harmonisation protocol is a helpful tool to ensure a minimum of standardisation and allows a better comparability of data and results.

Within the MEMO$^2$ project, 7 laboratories perform mobile $CH_4$ measurements using a Cavity Ring Down Analyser (CRDS). The $CH_4$ analysers were purchased already before the project and each group started to collect first experiences with analysers installed in a vehicle. At the first MEMO$^2$ training school we discussed, how we can harmonise our measurement set-up and inspected the way, each group performs its measurements.

We identified some critical points, which needs to be addressed and continued the discussion during the first annual meeting at EMPA (Dübendorf). In parallel, we worked out and discussed a data format, which contains sufficient meta data and can be handled by data provider and data user. The measurement harmonization and the data format were again improved during the Gaussian Plume workshop in Heidelberg.

# 3. Harmonization of mobile $CH_4$ measurements

Within the MEMO$^2$ project, no funding for instrumentation was distributed to the laboratories to purchase analysers or larger equipment. The $CH_4$ analysers were purchased and used already before the project started. In this guideline of good measurement practice, we summaries the different equipment and calibration strategy of each individual group and give advices how the measurements need to be performed to ensure producing FAIR data. Chapter 3.6 describes the harmonized data format and the submission of raw and calibrated data to the database.

## 3.1 Instrumentation and set-up of measurements in the car

For mobile $CH_4$ measurements, different CRDS analysers are used by the participating laboratories. Table 1 summarises the analyser models used in this project and the species which can be measured in addition to $CH_4$.

**Table 1:** Analysers used in the MEMO² project for mobile $CH_4$ measurements in vehicles.

| Laboratory | Analyser Model | Serial number | Manufacture | Measured species |
|---|---|---|---|---|
| UHEI | CRDS G2201-i | 1317-CFIDS-2034 | Picarro | $CH_4$, $CO_2$, $^{13}CH_4$, $^{13}CO_2$, $C_2H_6$, $H_2O$ |
| LSCE | CRDS G2201-i | CFIDS-2072 / CFIFD-2069 | Picarro | $CH_4$, $CO_2$, $^{13}CH_4$, $^{13}CO_2$, $C_2H_6$, $H_2O$ |
| LSCE | CRDS G2203 | DFADS-2014 | Picarro | $CH_4$, $C_2H_2$ |
| LSCE | CRDS G2402 | Can vary | Picarro | $CO_2$, $CH_4$, CO |
| UU | CRDS G2301 | 2268-CFADS2394 | Picarro | $CO_2$, $CH_4$, $H_2O$ |
| TNO | CRDS G4302 | 4054-NOMADR4010 | Picarro | $CH_4$, $C_2H_6$, $H_2O$ |
| AGH | CRDS G2201-i | 1295-CFIDS-2012 | Picarro | $CH_4$, $CO_2$, $^{13}CH_4$, $^{13}CO_2$, $C_2H_6$, $H_2O$ |
| AGH | LGR Microportable GGA | 1598 | ABB | $CH_4$, $CO_2$, $H_2O$ |
| RHUL | CRDS G2301 | 1364-CFADS-2300 | Picarro | $CH_4$, $CO_2$, $H_2O$ |
| RHUL | OA-ICOS UMEA | US4300170100000250 | LGR | $CH_4$, $C_2H_6$, $H_2O$ |
| RUG | CRDS G2401-m | CFKBDS2102 | Picarro | $CH_4$, $CO_2$, CO, $H_2O$ |

The instrumental setups of all analysers follow typical rules recommended by WMO GGMT expert group (GAW Report 242) with inlet tubing made of stainless steel or Decabon, and stainless-steel valves and connectors. Below all instrument setups used by WP1 ESRs are shortly described.

### 3.1.1 UHEI instrument setup:

For mobile measurements in Heidelberg, the CRDS analyser is installed inside a vehicle and measures air while driving. The system consists of the CRDS analyser (G2201-I, Picarro), a nafion dryer and a storage tube (AirCore). The CRDS device and the vacuum pumps are powered by a portable power source (260 h deep cycle battery (Winnerbatterien Germany) and a 1000 W inverter, which offers 230 V output) and allows for over 12 hours of measurement time.

The ambient air enters the air intake line 20 cm above the vehicle roof. Due to the length of the intake line, the volume of the cavity, and a flow rate of 0.16 L/min the air needs approximately 20 to 25 sec to be measured in the CRDS analyser. This delay time is measured by a blow test (see 3.4) at the beginning and end of a measurement campaign.

With the AirCore it is possible to reanalyse the stored air from the last 2 minutes of continuous measurements in order to have more data points for $^{13}CH_4$ isotope measurements. The AirCore is a 25 m Decabon tubing with an inner diameter of 9.5 mm and a volume of 1.77l. The air is dried by using a nafion dryer (Perma Pure MD-070-96-S) and a vacuum pump to reach less than 0.1 % water vapour. More details are described in Hoheisel et al., 2019.

### 3.1.2 LSCE instrument setup:

At LSCE two G2201-i Picarro are used. One of them, CFIDS-2067, is dedicated to static measurements and since April 2018 located in Ispra, Italy. The second, a G2201-i Picarro is used during mobile measurements. The system to measure in situ concentrations and isotopic compositions consists of a CRDS analyser, chemical dryer (a stainless steel tube of 50 $cm^3$ volume, filled with magnesium perchlorate ($Mg(ClO_4)_2$)), a storage tube (AirCore), and two pumps. One pump is connected to the CRDS analyser, the other one to the AirCore. The AirCore consists of 53 m Decabon tubing with an inner diameter of 9.5 mm. Due to this, the AirCore storage volume is equal 3.75 L. This storage tube allows to obtain a better time resolution and accuracy for $^{13}CH_4$, and to measure the in-situ isotopic composition after the observation of a $CH_4$ peak. According to this, the air is measured in two modes: monitoring and replay mode. During the replay mode, the air stored in the AirCore is measured. The flow rate of the instrument is equal 0.150 L/min, and the delay time responding to the length of the inlet line is about 30 sec. This delay is measured at the beginning and the end of measurement campaign. The $Mg(ClO_4)_2$ dryer is installed after the AirCore tube to dry only the air from the storage tube to achieve less than 0.1 % of water vapor.

The G2203 Picarro can measure $CH_4$ and $C_2H_2$ and results can be used to estimate the source emissions. The delay time responding to the length of the inlet line is approximately 35 sec. This delay time is measured at the beginning and the end of the measurement campaign.

These two instruments can be used together during a measurement campaign or separately. When they are used at the same time, two inlet lines are used. The measurement systems are powered by two 150 Ah lead batteries, and are connected to an inverter which gives 230V output. This allow for more than 12 hours of measurements with either one instrument or for about 8 hours of measurements with two instruments.

In addition, a CRDS G2402 to measure $CO_2$ and CO is available.

### 3.1.3 UU instrument setup:

The mobile measurement setup of the UU during the campaigns consists of two Picarro CRDS instruments; G2301 and G4302. The mobile measurements are carried out with a diesel Volkswagen (VW) transporter van. The G4302 has a built-in battery. Normally both instruments run by a battery which is connected to the vehicle dynamo and allows to carry out measurements for a very long time. Each of the instruments can be connected to an inlet from the vehicle bumper (~30 cm height) or from the top of the car (~2 m height); depending on the measurement purpose. All the inlets are ¼" outer diameter nylon tubing. A Gill GMX200 2-D anemometer and a temperature sensor are mounted on top of the vehicle. Geographical coordinates are recorded by the anemometer, a built-in GPS of G4302 and a GPS recorder run on a mobile phone. Meteorological information is either retrieved from a local meteorological mast or from a stationary meteorological station which provides data about vertical and horizontal wind speed, temperature, sunshine radiation, and wind direction (see also chapter 3.5).

### 3.1.4 RHUL instrument setup:

The set-up of the Picarro system is fully described in Zazzeri et al. (2015). The Picarro mobile module (A0941) consists of a pump, control systems for a Climatronics sonic anemometer and a Hemisphere GPS receiver. Two air inlets, plus the GPS and sonic anemometer are attached to a mast above the roof of the vehicle at 2 m above the ground. Three fully charged 12 V, 110 Ah lead-acid batteries allow the instrument to run for up to 9 hours. The airline is ¼" outer diameter and 2 m length Nylon tube with the inlet end blocked and a series of 2 mm diameter holes drilled into the first 30 cm to allow ingress of air. This is pumped to the mobile module through a 2 µm Swagelok filter, where the flow splits allowing approximately 300 cc/min to flow through the Picarro and the rest of the air to vent. This greatly reduces the lag time between air entering the inlet and the measurement to 7 seconds, allowing successful surveying of small plumes at a vehicle speed of up to 50 km/hr, and large plumes at up to 80 km/hr on first pass.

An LGR UMEA instrument within a yellow Pelicase is connected to the second air inlet line that is parallel to the first. This is operated by a single Li-Ammonia battery that gives 6.5 hours of survey time, with a smaller back-up unit allowing a further 2.5 hours of analysis. Air passes through a 2 µm Swagelok filter with a delay time similar to that of the Picarro, so that peaks from both instruments can be viewed simultaneously.

Both instruments and battery packs are contained within the boot space of the vehicle.

### 3.1.5 AGH instrument setup:

A Picarro 2201-i is installed in the trunk of the AGH passenger 4x4 car. It can be installed and de-installed within approx. 3 min with quick connectors (Swagelock) allowing to deliver the air using $^1/_8$" tube with water droplet separator installed on the roof of the car. The delay time between the methane concentration peak and the recorded signal oscillates around 35 sec and is mostly affected by the internal volume and flow of the analyser. The 15" diameter monitor is installed on the back seat to observe the status of instrument and current reading from Picarro analyser. The Wifi router (Asus 4G AC68U) is connected to a local GSM available network sending the data from the logger and Picarro analyser to the database. Data can be downloaded on any mobile device with active data transfer and displayed on the map with predefined colour scale including the delay time. It allows users to return exactly to the place where higher methane concentrations were observed. The data are available from any place via data transfer or WiFi, so the path of the car can be monitored online and in real time.

The power up system is instantaneous whenever batteries (Four Nerbo batteries NBC 100 – 12i 12 V 100 Ah) are loaded. For start-up the CRDS analyser should be switched to the MeanWell TN-1500 true sine wave inverter, which can deliver up to 1.5 kW and can be supplied from 2 or 4 batteries allowing for 24 h operation without loading (2 loading units, each one loads 2 batteries, MeanWell PB-600-12 8 stage loading units allowing for conditioning of batteries). It should not be stored inside the car during low temperature periods below 10 °C as well as during high temperature days above 25 °C to avoid damage of the analyser.

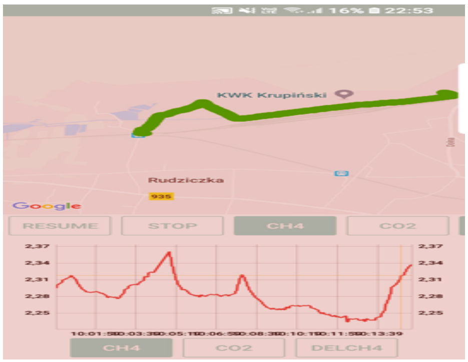


**Fig. 1:** Screenshot from mobile device during $CH_4$ measurement at a mining area

A car or smaller platform (bike) can be equipped with a Los Gatos Microportable GGA analyser produced by ABB company. This instrument requires 30 W power supply (might be plugged to cigarette lighter socket in a car) and can be operated with installed LiPo battery up to 4 h. Additionally 2 LiPo battery packs were manufactured by AGH to allow for 12 h operation in condition when no external power supply is available. It can be combined with 3D anemometer (Young ultrasonic) and $CH_4$ concentration together with 3D wind coordinates are logged with 10 Hz resolution allowing for eddy covariance measurements.

### 3.1.6 RUG drone measurements:

The active AirCore system was developed based on the concept of balloon AirCore. As opposed to the conventional concept of passively sampling air using the atmospheric pressure gradient during descent, the active AirCore collects atmospheric air samples using a pump to pull air through the tube during a flight. The RUG drone measurement system consists of a trace gas analyser (CRDS, Picarro, Inc., CA, USA, model G2401-m), a small quadcopter or unmanned aerial vehicle (UAV, model DJI Inspire 1), an active AirCore system, and an analysis box that simplifies the analysis of the air samples from the active AirCore and reduces the potential contamination of the sample from non-sampled air.

The active AirCore system consists of a ~ 50 m long stainless-steel tube, a dryer (small stain-less-steel tube filled with $Mg(ClO_4)_2$, a datalogger, a KNF micropump, and a 45 µm orifice working together to form a critical flow of dried atmospheric air through the active AirCore. It is placed in a carbon fiber box and attached to the UAV using two carbon fiber rods. Before every flight, the active AirCore needs to be flushed with a calibrated fill gas that is enhanced with ~ 10 ppm CO, which helps to identify the starting point of the sample later during the data analysis. The active AirCore starts to collect air samples after the micropump is turned on using a switch located outside the box (shortly before a UAV flight), and later the pump is turned off aft the UAV lands. Air samples are collected during the flight and retained within the active AirCore. Collected air samples are then immediately analysed with a trace gas analyser on site, and afterwards are stored in gas sampling bags (Supel™-Inert Multi-Layer 0.6 L, Push/Pull Lock Valve (PLV)). Total weight of the active Air-Core system, including the AirCore box is ~ 1.1 kg.

The UAV (including battery and propellers) weighs ~ 2.9 kg, has a maximum flight time of ~ 15 min, and is capable of flying at wind speed up to 10 m/s. When carrying the active Air-Core as payload, the UAV system weights ~ 4 kg, and is able to make a ~12 min flight. The payload is attached to the bottom of the UAV, so that the inlet is facing downwards towards of the UAV, using two 10 mm carbon fiber rods that are fixed to the UAV using zip ties and duct tape.

### 3.1.7 Lund airborne system:

The mobile flux platform (MFP) for measuring methane concentrations and fluxes on board the Sky Arrow ERA consists of two major parts: the wind measurements and gas concentration measurements. A GPS/INS system is used to determine the aircraft's position. Atmospheric turbulence measurements are made with the "Best-Aircraft-Turbulence Probe" (BAT-probe), developed by NOAA's Atmospheric Turbulence and Diffusion Division (NOAA-ATDD) and Airborne Research Australia (ARA). The BAT-probe measures the velocity of air with respect to the aircraft using a hemispheric 9-hole pressure sphere that records static and dynamic pressures by means of four differential pressure transducers. The actual 3-dimensional wind components relative to the surface can be derived from a blend of the

GPS/INS data, BAT-probe data, and corrections for the aircraft's movements (heading, roll and pitch). A fast temperature sensor is placed at the nose of the measurement probe. $CH_4$ measurements are done using a close path gas analyser (G2301-m, Picarro Inc., Santa Clara, CA, USA). The analyser's 1 Hz measurements are oversampled with 10 Hz. The T shaped tubing's inlet (length 3.1 m) is placed below the measurement probe at the nose of the aircraft. $CH_4$ analyser and pump are battery driven, while the other components of the MFP are powered by the aircraft's power supply.

The cruise speed of the Sky Arrow ERA is about 85 knts, the maximum total flight path length during research flights is about 200 km. The operating altitudes range from 50 m to 2000 m a.s.l. Flight plans include straight level flights and profile flights. Straight level flights, are performed straight and at constant pressure level and at rather low levels (< 100 m a.g.l.), and are most favourable to determine ecosystem energy and greenhouse-gas fluxes. Measurements from flights at low levels are influenced mostly by relatively small areas, which are more likely to be homogeneous than larger areas. Spiral profile flights provide vertical profiles of concentrations and meteorological parameters up to 2000 m a.g.l., which give information vertically across the atmospheric boundary layer.

## 3.2 Calibration of mobile measurements

In order to compare measurements carried out by different laboratories it is important to relate them to international scales. This is especially important when several groups participate to the same campaign and when datasets are merged together. For $CH_4$ mole fraction the international calibration scale is WMO X2004A, updated July 7, 2015. Methods used to prepare the original and new primary standards are described in Dlugokencky et al. (2005). Calibration gases can be purchased by NOAA/GMD (https://www.esrl.noaa.gov/gmd/ccl/services.html).

Each MEMO² laboratory is related to the WMOX2004A scale, via "primary laboratory standards". These standards cover typically an atmospheric range up to 2300 ppb. We identified during the first annual MEMO² meeting the need of calibration gases spanning a $CH_4$ mole fraction range of 5 ppm or even 10 ppm. The MEMO² community will work on this issue during the project duration.

Mole fraction of working standards should be determined by comparison with the laboratory "primaries" standards. The working standards should be regularly (every few months or at least 2 times during life time) calibrated against the laboratory "primary" standards.

Each analyser should be calibrated with one or several working standards on a regular base to link the mobile measurements to international scale. The frequency should be a function of the drift behaviour of the analyser for different species. When analysing $^{13}CH_4$ isotopes with CRDS analyser a regular calibration and drift correction is required. Each laboratory carrying out mobile measurements needs to perform its own tests and come with a dedicated calibration strategy. For safety reasons, it is not allowed to transport or measure a high-pressure cylinder with a connected pressure regulator during driving. A good practice is to calibrate the analyser in the laboratory before or after short campaigns, or working with a small calibration cylinder for longer campaigns. Table 2 summarizes the calibration strategy of the MEMO partners.

**Table 2:** Link to international $CH_4$ scale and calibration strategy during campaign.

| Institute | $CH_4$ scale | Link to scale | Calibration routine |
|---|---|---|---|
| UHEI | WMO-2004A | Gases purchased from NOAA | During diurnal campaigns we calibrate the CRDS analyser in the lab, during longer campaigns we perform 1-2 calibration runs a day with one working standard |
| LSCE | WMO-2004A | Gases calibrated against NOAA scale | During campaigns, we calibrate the CRDS with one working standard, using it as well to turn the instrument off properly. We plane to calibrate the instruments in the lab about once a month close to the campaign dates. |
| UUtrecht | WMO-2004A | Gases calibrated by MPI-Jena | We calibrate the CRDS occasionally with one working standard. We plan to calibrate the instruments in the lab about once a month close to the campaign dates. |
| RHUL | WMO-2004A | Gases purchased from NOAA, plus cylinders filled by UEA and calibrated by MPI-Jena | Both instruments are calibrated in the laboratory using a 3-point calibration before and after each campaign. |

## 3.3 Cross-sensitivity

This section is less important when analysing only $CH_4$ mole fraction with CRDS instruments, but depending on the manufacturer also water vapor or other gases might play a role especially when using the smaller backpack or ultraportable instruments. Comparison of several analyser can help to highlight problems, which then can be tested. The studies of Rella et al. (2015), Assan et al. (2017) and Hoheisel et al., (2019) demonstrated the importance of a careful determination of cross-sensitivities and a good calibration strategy for precise $\delta^{13}CH_4$ measurements with a CRDS analyser. The cross-sensitivities of $H_2O$, $CH_4$, $CO_2$ and $C_2H_6$ concentrations on $\delta^{13}CH_4$ need to be investigated to determine correction factors.

The UHEI data evaluation for $\delta^{13}CH_4$ measurements follows the calibration and correction procedure described by Hoheisel et al., 2019. Air is dried before analysis and an ethane correction is implemented. It is planned to repeat the cross-sensitivity test in 2019 to see if the correction factors change over time.

The LSCE data evaluation for $\delta^{13}CH_4$ measurements follows the calibration and correction procedure described by Hoheisel et al., 2019. Air is dried before analysis and an ethane correction is implemented. For the acetylene instrument, as it is mostly used to evaluate concentration differences, cross-sensitivities are less important and no special protocol is applied though the cross-sensitivities have been determined in the laboratory. It is planned to repeat the cross-sensitivity test mid-2019.

## 3.4 Inlet height, delay time and driving speed

The harmonization of the inlet height is due to the different vehicles models difficult to realize. The inlet height of each instrument should be noted carefully and is part of the metadata for the data reporting.

Similar to the inlet line also the driving speed along an emission source is difficult to harmonies. Several factors such as e.g. infrastructure, traffic volume or regulations are beyond control and are influencing the speed and distance to the source. For security reason a minimum speed at highways or similar roads should be navigated. For private roads, we recommend to drive as slowly as possible.

Each instrument setup has a typical delay time, until the air arriving at the inlet is measured in the cavity. This is a function of the length (volume) of the intake line, the volume of the cavity, and the flow rate of the set-up. Due to aging of pumps, blocking of aerosol filters or bottlenecks in the tubing, the delay time can change over time. It is recommended to keep the delay time as short as possible, working with higher flow rate and/or shorter tubing with less resistance.

The delay time is a very important parameter and needs to be determined at the beginning and end of each measurement day with a breath test (breathing close to the inlet line and record the time until $CO_2$ increases). For a better statistic this breath test should be repeated several times.

## 3.5 Additional parameter measured

In addition to the $CH_4$ and $\delta^{13}CH_4$ analysers, most vehicles are equipped with 2-D wind sensors on the roof and a GPS device. Some groups have supplementary meteorological sensors, which they install close to the emission source. Table 3 summarizes the additional sensors used for the mobile equipment.

**Table 3:** Additional parameters measured

| Beneficiary | Additional parameter |
|---|---|
| UHEI | Meteo sensor on the roof of the vehicle (Gill Maximet GMX500-5),<br>vehicle position is recorded by a GPS mouse (Navilock 602u) with an accuracy of 2 m CEP (circullar error probable).<br>Weather station (Vantage Pro2, Davis Instruments) is set up near the measurement site to record the wind speed and direction, the temperature and the incident solar radiation.<br>A 3D sonic anemometer will be used for campaigns after spring 2019 |
| UVSQ | A Meteo and GPS sensor has been ordered and will be used in future campaigns (AIRMAR, model 44-833)<br>Up to now, vehicle position is recorded by a GPS mouse (Navilock 602u) with an accuracy of 2 m CEP (circullar error probable).<br>A 3D sonic anemometer (Gill, Windmaster GI-WM-1000) has been purchased and will be used in the future campaigns.<br>Up to now a simple Campbell Scientific weather station was set up near the measurement site to record the wind speed and direction and the temperature when access to the site was possible. |

| | |
|---|---|
| UU | Wind speed and direction (Gill GMX200 2-D anemometer)<br>GPS by mobile phone<br>Temperature (Vaisala PT100)<br>At interesting locations we can deploy an automated weather station to record the wind speed and direction, temperature and radiation (Young Wind Sensor, Kipp and Zonnen CNR1 Radiation Sensor, Sensirion SHT25 Humdity Sensor) |
| RHUL | The mast on top of the vehicle contains a Climatronics sonic anemometer and a Hemisphere GPS receiver, controlled by the Picarro A0941 mobile module. A back-up GPS system is provided by a GPS mouse (Navilock 602u) with an accuracy of 2 m CEP, normally used only when the LGR UMEA is removed from the vehicle for localized walkover surveys for pinpointing sources. So far it has proved difficult to calculate sensible wind speed and direction from the moving vehicle. |
| AGH | 2D Gill WindSonic anemometer with GPS and logger installed on the roof of the car. The logger calculates the wind direction and speed subtracting car velocity (obtained from GPS) from measured values. Data are stored every 1 second. |
| RUG | A data logger (an Arduino MEGA 2650) is implemented in the active AirCore system, and records meteoro-logical data such as ambient pressure, relative humidity, and ambient tem-perature. Besides these, a GPS (Global Positioning System) receiver is installed to record the location and a low-cost sensor is implemented to measure in situ methane concentrations.<br>The ambient pressure is monitotred by a silicon pressure sensor (model Honeywell TruStabil-ity HSC) that is positioned at the bottom of the box. The sensor has an accuracy of 0.25% in the range of 67–1034 hPa (1–15 psi).<br>The ambient relative humidity (model DHT22) measures in the range of 0–100% with an uncertainty of 2.5 %. The temperature sensor embedded in the relative humidity sensor, and measures in a range of -40 to 125 °C with an uncertainty of 0.5 °C.<br>The GPS coordinates and time are measured using a GPS model ATM2.5 NEO-6M module with EEPROM built-in activity.<br>A low-cost methane sensor (model TGS2600 sensor, Figaro USA, Inc.) is a low-power consumption gas sensor for the detection of air contaminants, which is sensitive to CH4 and other hydrocarbons. |

## 3.6 Synchronisation of clocks

When using several analysers, or devices it is important to synchronise all clocks. This can be done in the lab by using special Apps to synchronize the PC clocks of analyser and devices on a regular basis. During campaigns, the clocks of CRDS analyser PCs as well as Meteo sensors and GPS needs to be checked and synchronized if needed.

## 3.7 Data format and data reporting

During the annual MEMO$^2$ meeting at EMPA it was decided to use a data format based on former research projects like InGOS (https://www.ingos-infrastructure.eu) in order to exchange the data be-tween different partners. Below we described the file format and naming convention that needs to be used by all MEMO partners. This convention should be followed for all calibrated and quality-controlled data. Raw data can be stored as original output file of the analyser.

### 3.7.1 Database

The data are stored and shared for the project members in the ICOS database (https://fileshare.icos-cp.eu/login). For WP1 we prepared separated directories to store raw data as well as calibrated and quality-controlled data files. The file structure allows to separate individual campaigns for each ESR as well as joint campaigns. In addition, it allows to store meta data, documents, reports within the project. All members of MEMO$^2$ have access to all documents wherever and anytime they want.

### 3.7.2 Data Format

Raw data can be stored as original output of the analyser and need no special format. We expect, that the raw data will only be used by the ESR performing the measurements. For data sharing all ESR need to carry out a quality control of the data and relating the data to an international scale (calibration). We developed a common file format which consists of a file naming convention with an informative name, and the file content with comments, header and data.

## File format and naming convention

### A – File name

The file name should be standardized to contain:

- Institute identifier (3-letter code, or similar to be distributed)
- Instrument unique identifier (Serial number or distributed by ICOS)
- Sampling date (one data file per day)
- Species ($CH_4$, $CO_2$, $^{13}CH_4$, $C_2H_6$, Meteo)
- location/campaign name

**Examples:**

IUP_120_20180323_CoMet.CH4

This file corresponds to $CH_4$ data from IUP measured with instrument 120 on 23 March 2018 during the CoMet campaign.

### B- File content

The file should contain three sections: comments, header and data.

**1 – Comments**

The file should contain comments with the following information:

- Used data separator (fixed to semicolon)
- Used value for invalid data (fixed to -999.99)
- Data unit for each field (knowing that it will be fixed)
- Data provider (PI first name and last name, if there are more than one provider separate the names by a semicolon)
- Data contact (e-mail of PIs)
- Scale (scale name to be chosen among a list available names)
- Submission date (YYYY-MM-DD, 2000-11-12)
- Data description (for final data, free text with a maximum of 500 characters)

The key of each comment is fixed and given in the following examples for validated data

```
# Data separator = ;
# Invalid data =-999.99
# Unit =ppb
# Data provider = Piotr Korben; Martina Schmidt
# Contact details = Piotr.Korben@iup.uni-heidelberg.de;
# Martina.Schmidt@iup.uni-heidelberg.de
# Scale =NOAA-2004A
# Submission date = 2018-09-25
# Data version=version_20180925
# Delay inlet = 24sec
# Data description= mobile measurements in the region of Heidelberg.
# 14:30-16:20 downwind of a landfill in Sinsheim, 16:40-17.30 downwind of a farm in
# Ladenburg, 18:40-22:15 Screening of streets in Heidelberg. All Aircore
# measurements are excluded
```

**2 – Header and data**

The file should contain a header and the data. The data information needs to be repeated on each line:

- Date (YYYY-MM-DD) UTC
- Time (HH:mm:ss) UTC
- Date (YYYY-MM-DD) local time
- Time (HH:mm:ss) local time
- latitude
- longitude
- altitude
- calibrated data and corrected for delay time
- raw data
- Quality control flag (o : good data, k .bad data, q : questionable)
- Comment /Location

The header columns and data are separated by a semicolon.

Examples:

```
Date_UTC;Time-UTC; Date_loc; Time-loc; latitude; longitude; altitude; Value_cal_cor; Value_raw; Flag; Comment
2017-11-11; 10:00:00; 2017-11-11; 08:00:00; 49.40768; 8.69079; -99, -.999; 1970.25; 1987.4; o; landfill Heidelberg
2017-11-11; 10:00:02; 2017-11-11; 08:00:02; 49.40768; 8.69079; -99, -.999; 1970.25; 1988; o; landfill Heidelberg
```

# 4. Conclusion and possible impact

This guideline describes how the mobile measurements of atmospheric $CH_4$ mole fraction in an emission plume should be performed within the MEMO² network.

Most groups purchased the $CH_4$ analysers and designed the setup already before the project started. Therefore, we discussed during MEMO² meetings and training school, how we can harmonise our measurement set-up and inspected the way each group performs its measurements. We identified some critical points, which needs to be addressed in a general guideline for good measurement practice. In parallel, we worked out and discussed a data format, which contains sufficient meta data and can be handled by data provider and data user.

The individual setups of the different laboratories are described, and all are following principle guidelines of WMO by using adequate tubing and valve for inlet lines. Differences like drying systems or the use of AirCore for isotope analysis are documented for each individual set-up. Special attention is paid for the three analysers used at LSCE, UHEI and AGU to measure $^{13}CH_4$. Here the cross sensitivity of water vapor and ethane can influence the measurements and need to be corrected for these effects.

The guideline describes the calibration strategy, as well as a recommendation on the inlet height, delay time and driving speed. As it is not possible to harmonise all parameter, it is important to document them in a good way.

In the harmonized file format, we have several comment lines, which can be used for this purpose. The comments contain information like data provider and contact e-mail, calibration scale information, inlet height and delay time as well as a free text data description with a maximum of 500 characters. Here the ESR can give additional information of the campaigns, which they performed.

# 5. Dissemination & Exploitation

All data from raw data to calibrated quality-controlled campaign data are stored in a traceable way on the ICOS file server. To share the data with the MEMO² group and other users we designed a common file format. The deliverable D1.5 is related to deliverable D5.3, the Data Management, Dissemination and Exploitation Plan (DMDE plan).

# 6. References

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**Hoheisel, A.,** et al. (2018). "Characterisation of δ13CH4 source signatures from methane sources in Germany using mobile measurements." Atmos. Meas. Tech. Discuss. 2018: 1-29.

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**Zazzeri, G.,** D. Lowry, R. E. Fisher, J. L. France, M. Lanoisellé, and E. G. Nisbet. "Plume mapping and isotopic characterisation of anthropogenic methane sources." *Atmospheric Environment* 110 (2015): 151-162.

**GAW Report**, 242. 19th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2017) Crotwell Andrew; Steinbacher M.; World Meteorological Organization (WMO) - WMO, 2018

# 7. History of the document

## 7.1 Document history

| Version | Author(s) | Date | Changes |
|---|---|---|---|
| V0 | Schmidt, Martina | 25 October 2018 | First draft sent to WP1 |
| V0.1 | Schmidt, Martina | 29 March 2019 | Second draft sent to PM |
| V0.2 | Schmidt, Martina | 17 May 2019 | Final version sent to PM |
| V0.2 | Walter, Sylvia | 3 June 2019 | Final version sent to PO |
| | | | |

## 7.2 Internal review history

| Internal Reviewer | Date | Comments |
|---|---|---|
| S. Walter | 18 April 2019 | First draft review, parts from partners missing |
| S. Walter | 24 May 2019 | Second draft review, finalized regarding texts and format, sent for last check to lead author |
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