FRM4GHG
Fiducial Reference Measurements for Greenhouse Gases

Deliverable D1 Phase 2
Campaign site and instrument definition

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1 DOCUMENT CHANGE RECORD

Issue	Date	Item	Comment
V0.0	2018-03-28	–	Initial version
V0.1	2018-15-10	–	Added updates from all project partners
V1.0	2018-12-12	-	Additional information was included in response to the reviewers

2 ACCESS LIST

This document is a deliverable "D1: Campaign site and instrument definition" created for the project FRM4GHG phase 2 and will be submitted to ESA. The document can be downloaded from the project webpage http://frm4ghg.aeronomie.be.

3 PURPOSE

This document provides an overview of the campaign site and instrument definition. The same set of instruments as in the initial phase of the project is used during the continuation phase.

4 DOCUMENT STRUCTURE

Section 5. Description of the campaign site
Section 6. Changes and modifications to the measurement site and to all instruments compared to the initial phase
Section 7. Reference documents

5 CAMPAIGN SITE

The second phase of the campaign is continuing in Sodankylä at the TCCON facility of the FMI. The TCCON instrument serves as reference for all other spectroscopic observations.

The same set of instruments as in the initial phase of the project is used during the continuation phase.

The visiting spectrometers of FRM4GHG are installed in a separate 30 feet container. The container is located in the vicinity of the TCCON building: about 30 m South. The TCCON facility is equipped with Bruker IFS 125HR spectrometer and a large solar tracker A547N, manufactured by Bruker Optics. The TCCON instrument has been operational since early 2009 (Kivi and Heikkinen, 2016).

AirCore balloon observations are performed from the FMI balloon facility. The AirCore and other sondes are launched within 70-80 meters west from the FRM4GHG container. Alternatively a mobile launch system is also available at the site. This includes a trailer with balloon filling equipment and a radiosonde receiver system. The AirCore analysis after each flight is performed at FMI using a Cavity Ring-Down Spectrometer (Picarro Inc., CA, model G2401). The AirCore laboratory is located on the ground floor of the TCCON building. In addition continuous in-situ measurements of CH4, CO, CO2 are performed at a mast located within less than a kilometer from the TCCON building, at 3 vertical levels: 50 m, 22 m and 2 m of altitude above ground.

Figure 1: Location of site, scale level of the close up-map (right) is 1:8000.

FMI Sodankylä facility is located in northern Finland, about 6 km south of Sodankylä. The coordinates of the TCCON instrument are 67.3668º N, 26.6310 º E, 188 m.a.s.l. The observatory around the TCCON facility has long term history. The continuous weather observations at the present location started in year 1908. In 1949 FMI established an aerological observatory at Sodankylä. Since then balloon soundings have been performed at Sodankylä on regular basis. The site is relatively consolidated, since most of the relevant instruments are located in Tähtelä area

(Figure 1). Distances between the instruments are generally less than 200 m. The site participates also in some other relevant networks, such as GRUAN and GAW. List of atmospheric measurements at the FMI Sodankylä facility and the starting year of each measurement program is presented in Table 1. Regular sonde launches at the FMI include CFH (Cryogenic Frostpoint Hygrometer), ozonesondes and RS41 radiosondes. The facility has an automated launcher for the radiosondes Vaisala RS41. The AirCore system was established in September 2013 in collaboration with the University of Groningen. Since then several improvements have been introduced to the AirCore system, including data analysis methods and recovery system. As a new activity also UAV-based AirCore is under development.

Figure 2: Campaign site at FMI Sodankylä.

6 CHANGES AND MODIFICATIONS TO THE MEASUREMENT SITE AND TO ALL INSTRUMENTS COMPARED TO THE INITIAL PHASE

The following changes and modifications to the instruments have been made since Phase 1 of the project.

The TCCON instrument:

TCCON instrument alignment was performed prior to the start of the 2nd phase of the FRM4GHG campaign using an in –vacuum alignment method (Kivi et al., 2018). InGaAs detector non-linearity effect was investigated and the effect was minimized by reducing signal to the detector. This was achieved after testing with several alternative approaches and finally by installing an aperture stop in the instrument entrance from 32 to 16 mm.

Also data from year 2017 were corrected for non-linearity (Kivi et al, 2018; Sha et al., 2018). As a result we have provided two data sets: original and non-linearity corrected, which are both available via the project web server.

Prior to the start of 2nd phase of the project we have also replaced the mirrors of the solar tracker by new mirrors. Cell measurements have been performed to monitor instrument behavior, no data quality deviations were detected by the measurements.

Vertex 70:

Within the Vertex 70 system two detectors have been in use: an InGaAs detector and a liquid nitrogen (LN) cooled InSb detector. Several updates have been made for the Vertex system during year 2018. The automatic LN detector filling system, helpful for the automatic InSb measurements was installed successfully in mid-July 2018. The InSb detector was originally equipped with an internal cold filter, blocking the intensity below 3500 cm-1, to reduce the noise when measuring CO. For measurements of other trace gases of interest within phase 2 of the project, the cold filter had to be dismounted, and the detector evacuated afterwards. The InSb detector was shipped to Bremen on August 16. The detector without cold filter was reinstalled on September 10. More improvements to the InSb system are foreseen in the future. Regarding the InGaAs measurements of CO, there is a data gap from May 16 until August 13, after which the original extended InGaAs was reinstalled.

EM27/SUN:

As the extension phase is mainly intended to extend the observational period covered by phase 1 and for characterisation of the long-term stability of the device, instrumental changes should only be made if shortcomings or technical problems significantly hampering performance or reliability of measurements have been identified. As no issues with the EM27/SUN spectrometer were detected during phase 1, no instrumental modifications were done.

For demonstrating remotely controlled observations with the EM27/SUN, the operation in an enclosure provided by Technical University Munich (Heinle and Chen, 2018) was foreseen for phase 2. Due to fabrication delay at TUM and time required for pretesting in Karlsruhe, the shelter was put into service by September 25, 2018. Remote observations have been successful since installation of the shelter.

LHR:

Methane channel was included. CO2/H2O and CH4/N2O channels are operating sequentially switching on a common detector.

The LHR instrument was returned to RAL after phase 1 (October 2017) and a full characterization of the long-term stability was performed in order to understand and mitigate the instrumental variations observed during the phase 1 deployment. At the same time ILS measurements were also done. This inter-phase laboratory re-characterization identified a number of issues to be addressed for the phase 2. These include:

- Instabilities in the frequency of the optical amplitude modulation of the signal. This was remediated by implementing voltage control of the modulation frequency of the mechanical chopper used for phase sensitive detection to allow remote control.
- Phase variation across a laser scan was observed to skew the spectral measurements. The original lock in amplifier was replaced by a dual-phase lock-in amplifier to simultaneously provide both in-phase and quadrature outputs from the phase-sensitive detection.
- A random background offset variation was also observed in the CO_2 channel during phase 1, which led to a varying bias within the XCO_2 data. A mechanical shutter in the solar radiation arm was introduced to allow near real time backgrounds to be collected, if compensated for if needed.

In order to expand the capabilities of the instrument and make it relevant to Sentinel 5P, the system has been upgraded to cover CH4 and possible N2O. For this the following changes were made:

- Incorporation of a second laser channel operating at ~7.8 µm and the associated control systems as well as optical switch for channel selection.
- Upgrade of the control software to include new features required for dual laser operations and new level 0 data output.

Following the upgrade, a brief characterization was carried out in our laboratory. The upgraded LHR was installed at Sodankylä at the end of April 2018. Figure RAL1 shows a picture of the instrument installed within the FRM4GHG container and coupled to a small portion of the solar radiation captured by the BIRA solar tracker.
As for the phase 2 RAL implemented a remote switch for the instrument controllable from their premises to enable full remote operation.

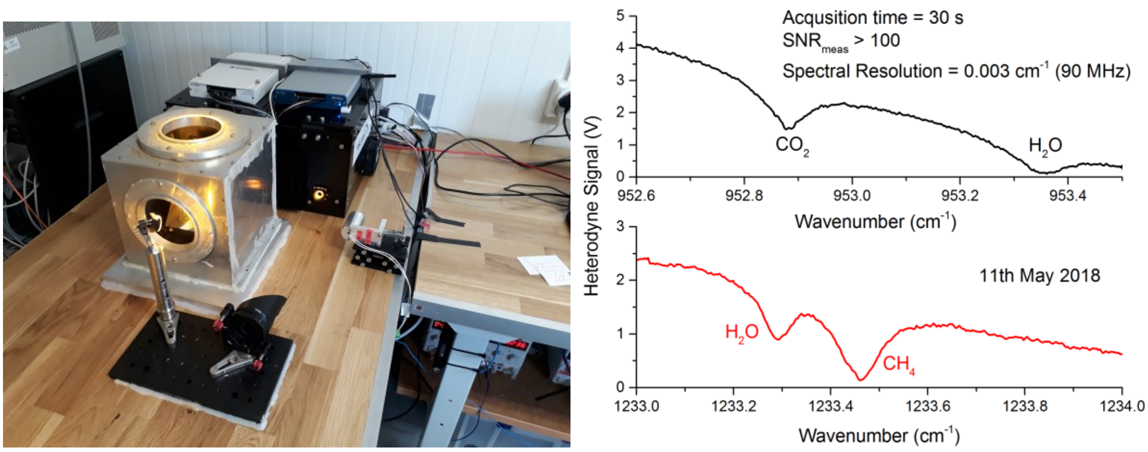

Figure 3: Left, picture of the upgraded LHR installed in the FRM4GHG container for the 2018 campaign. Right, atmospheric traces from the LHR recorded in both CO_2 and CH_4 channels.

The performance of both channels was optimized and spectral traces from 11th May 2018 are shown in the right hand panel of Figure 3.

IR Cube:

The instrument was returned to the University of Wollongong where upgrades were made to the external optics and electronic control systems before phase 2 of the project. After the upgrades the instrument was transported back to Sodankylä in spring 2018 and the measurements restarted on April 4, 2018. The upgrades included more robust mounting of the external optics (external aperture and solar pickoff), and a new control box for digitizing the solar pickoff and pressure sensor data.

Some non-linear effects (solar intensity dependence) were noted in xCO2 with the 0.5 mm internal aperture that was used throughout the 2017 campaign. The external aperture on the optics rail was adjusted from 13 mm to 10 mm which introduced a step in the xCO2 of 2 ppm. Testing with a larger 1mm aperture indicated that these effects, particular with respect to xCO2, were significantly reduced. The intensity-dependent bias was not fully resolved at the start of the measurements.

AirCore:

Based on extensive laboratory tests, we have established the AirCore pre-flight criteria, i.e. these must be reached before being part of the comparison flights. The criteria were established for CO_2, CH_4, and CO, respectively (see Table 1).

Table 1. the AirCore pre-flight criteria based on the results of slug tests, the thresholds for the difference between the slug and direction measurements are presented for the certain flushing volume of air (in mL).

	CO2	CH4	CO
± Compared to direct measurement	0.1 ppm	1ppb	5ppb
Stable after switch	120 ml	110ml	100ml

For the two AirCores that failed the pre-flight criteria, we re-coated the inner surface of the AirCore tubing. It was a success since the laboratory tests afterwards clearly met the pre-flight criteria.

7 REFERENCES

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Kivi, R., et al. TCCON site updates, presented at the FRM4GHG Meeting in 26-27 September 2018, ESRIN, Frascati, available at the project web site; http://frm4ghg.aeronomie.be/index.php/documents/meetings/esrin-20180926-27

Sha, M. K., et al., Inter-comparison results of phase 1, presented at the FRM4GHG Meeting in 26-27 September 2018, ESRIN, Frascati, available at the project web site; http://frm4ghg.aeronomie.be/index.php/documents/meetings/esrin-20180926-27

FRM4GHG deliverable D2.1: Description of the measurement site, made available via the project website; http://frm4ghg.aeronomie.be/index.php/outreach/deliverables.

FRM4GHG deliverable D2.2: Instrumental overview, made available via the project website; http://frm4ghg.aeronomie.be/index.php/outreach/deliverables; and the reference therein.