

FRM4GHG 2.0

Fiducial Reference Measurements for Greenhouse Gases



Technical Note on IRCube instrumental improvement

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1 DOCUMENT CHANGE RECORD

Issue	Date	Item	Comment
V1.0	2024-09-01	D1.1.2	Initial version
V2.0	2024-09-12	D1.1.2	Final version

2 ACCESS LIST

This document is a deliverable D1.1.2 Semesterly report Month T0+36 created for the project FRM4GHG 2.0 and will be submitted to ESA. The document can be downloaded from the project webpage <http://frm4ghg.aeronomie.be>.

3 PURPOSE

The document describes the progress of WP D.1.1.2, August 2023 to August 2024. In particular, a description of procedures for stable IRcube alignment and operation.

4 DOCUMENT STRUCTURE

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5 RESULTS

Technical Note on IRcube instrumental improvement (UoW)

Parallel measurements with the UoW Bruker IRcube and fibre-optic coupled solar tracker at Sodankyla, Broken Hill (see D2.1.2) and elsewhere have consistently shown step-wise biases relative to COCCON EM27/Sun and TCCON measurements. As described in D2.1.2, the same FO-tracker system on an EM27 FTS at the Broken Hill Aircore campaign and at the UoW campus do not show significant biases relative to COCCON or TCCON measurements. We therefore believe that these biases are rooted in the optical design and build of the IRcube, not the FO-solar beam coupling. To try to improve this, in 2023 we rebuilt the IRcube optics, to the extent permitted by the physical layout and construction, to emulate those of the EM27. This configuration has been operational at the UoW campus since late 2023. Here we briefly describe the optical rebuild and several months of data compared to the Wollongong TCCON standard measurements. Testing and further comparisons are ongoing.

Reconfiguration of the IRcube

The Bruker IRcube or “Matrix” FTS is a compact OEM design used in a wide range of applications with accessories for laboratory and industrial measurements. As such it is flexibly designed to accommodate different sampling requirements with adaptable input and output optics and detectors; in our case we configured it for solar measurements. The interferometer is of similar design to the EM27, but smaller, using Bruker’s Rocksolid® pendulum design but with 25mm diameter beam and 0.5 cm^{-1} resolution single-sided (1 cm^{-1} double sided). The detector is an extended range InGaAs.

Figure 1 shows (schematically) the standard configuration and the rebuilt configuration emulating the EM27 design. In the standard design, the incoming beam from the fibre optic is focussed through a side-window of the IRcube onto a 0.5 mm aperture (field stop, FS) and recollimated by a 69 mm focal length (FL) off axis paraboloidal mirror (OAP). The aperture wheel and OAP are mounted in a factory-aligned source module. The collimated beam passes through the interferometer and is refocussed by a short focal length ($\sim 25\text{mm}$) OAP onto the detector. The image of the field stop underfills the detector, and the field of view of the instrument is determined by the input aperture FS. This has two disadvantages that we suspect lead to the observed biases:

1. The aperture (FS) is mounted on a small motor-driven wheel and is repositioned whenever the instrument power cycles. It is unlikely that the FS is repositioned with better than 0.1 mm accuracy, 20% of the FS diameter. It also cannot be accurately adjusted to the optical axis of the interferometer, this alignment is preset at the factory and is known to be not perfectly on-axis. This setup would induce an imperfect and variable FOV and instrument lineshape (ILS), which we expect would lead to biases in retrievals from spectra.
2. The illumination of the FS varies with the mounting of the fibre optic, which does not have a perfectly uniform circular beam profile. We observe differences in trace gas retrievals as the mounting, focussing and rotation of the fibre are varied.

In addition, this IRcube is fitted with a single extended range InGaAs detector, which is known to show greater saturation and non-linearity than the narrow range InGaAs dual detector system employed in the EM27/SUN. Saturation and non-linearity induces potential for bias due to signal levels and zero offsets.

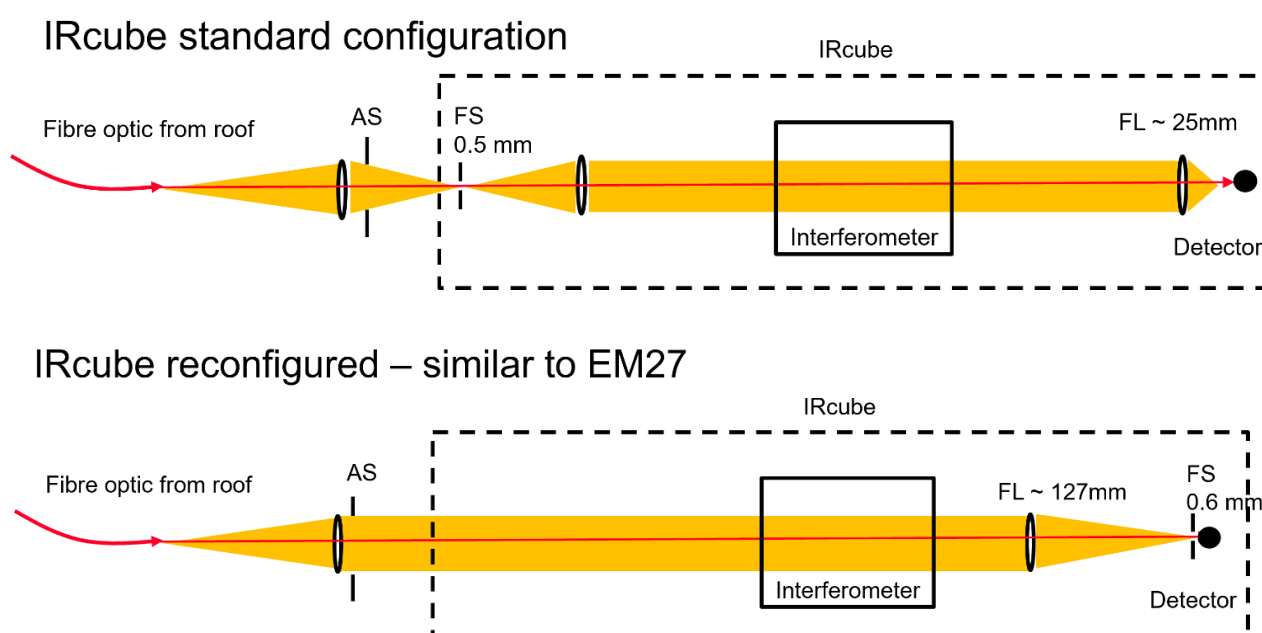


Figure 1: Schematic diagrams of the original (upper) and re-configured (lower) IRcube optics.

In the rebuilt configuration, the internal source module with aperture and OAP is completely removed from the IRCube and the output from the fibre optic is directly collimated into the FTS. An aperture stop (AS) of typically 6-8 mm in the collimated beam limits solar beam intensity to minimise non-linearity, similar to the AS in the EM27 (mounted after the interferometer). The collimated beam exiting the interferometer is now focussed by a 127 mm FL OAP onto a 6 mm field stop in front of the detector, as in the EM27. In this configuration the FOV is determined by the detector FS inside the IRCube and is robust and less susceptible to change or misalignment. The alignment of the OAP is adjustable to centre the FS on the optic axis and achieve close to ideal lineshape. The overall light throughput of both configurations is similar (and similar to the throughput of the EM27/SUN with Camtracker). The IRCube in the new configuration is pictured in Figure 2.

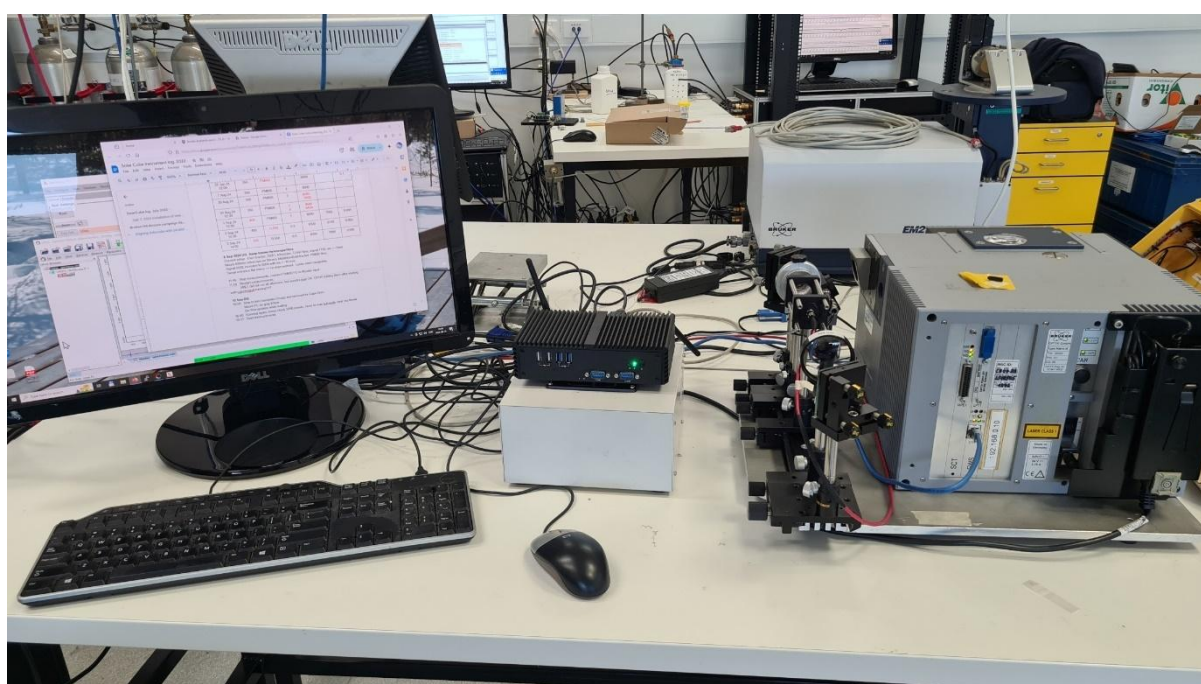


Figure 2. Lab layout: The IRCube is on the right, with the FO mount, collimating lens, aperture stop and steering mirror into the interferometer mounted on an optical rail to the left on the same baseplate.

Initial results

The reconfigured IRCube has been operating at the UoW campus since Feb 2024 beside the Wollongong TCCON station. Figure 3 shows IRCube (red) and TCCON (black) data for X_{LUFT} , X_{CO_2} and X_{CH_4} for this period. All spectra have been analysed using GGG2020 – comparisons between GGG and PROFFAST are described elsewhere in this document and are in generally good agreement. TCCON analyses follow the standard TCCON protocol including network-wide airmass dependent (ADCF) and airmass independent (AICF) correction factors. For comparability with other data, IRCube analyses use the EGI-network ADCF values from Pak et al. ADCF values derived from this dataset are similar. The full data series has been used to derive the mean AICF value for each X_{GAS} quantity as the mean ratio between time-coincident IRCube and TCCON data points. The AICF values are shown in Figure 3 and are all in the range 0.99-1.00. The AICF values have been applied to the IRCube data plotted in Figure 3, bringing them to the same mean as the TCCON data. The data presented in Figure 3 include several re-alignments of the external fibre optics, a range of signal levels, two different fibres (550 and 800 mm diameter), and two different telescope focal

lengths (350, 400 mm). X_{LUFT} shows some sensitivity to such changes over the Feb – Sep period (up to 2%); this is largely cancelled in X_{CO_2} (~0.25%) but not entirely in X_{CH_4} (1%). The causes of these drifts are as yet unidentified, changing ILS and the effects of non-linearity are the most likely causes and currently under scrutiny.

A similar side-by-side comparison is currently underway at KIT, Karlsruhe, using the same fibre optic and Ekotracker system as described here but a KIT-operated EM27 FTS (without Camtracker) in place of the IRcube. This dataset (not shown) is still undergoing analysis, but initial results show less variability in X_{LUFT} and the X_{GAS} differences between EM27 and TCCON.

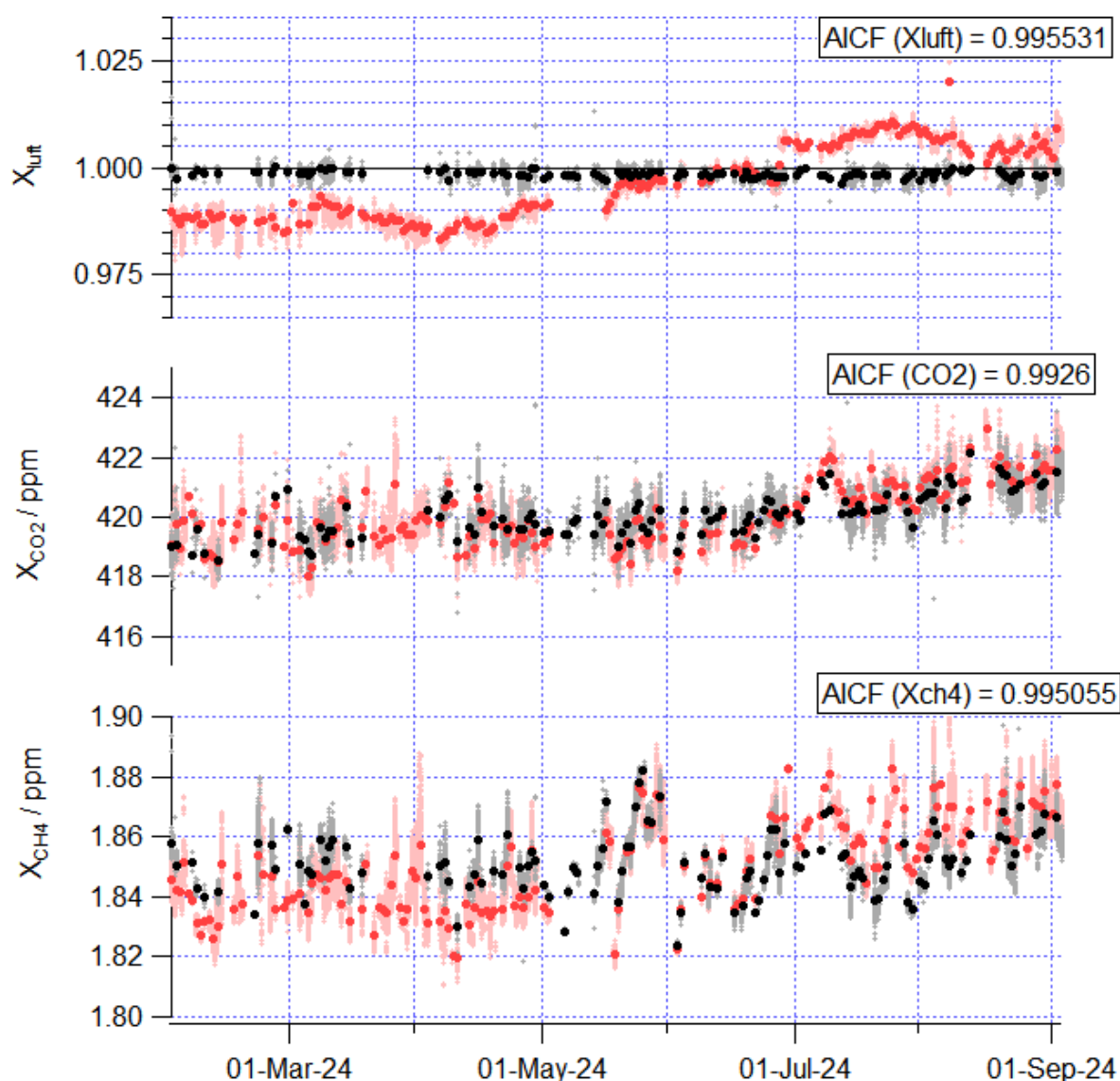


Figure 3a. X_{LUFT} , X_{CO_2} and X_{CH_4} data for the IRcube and TCCON at Wollongong, Feb – Sep 2024. Solid circles are daily averages, pastel colours are all data. Red = IRcube, black = TCCON. See text for further details and discussion.

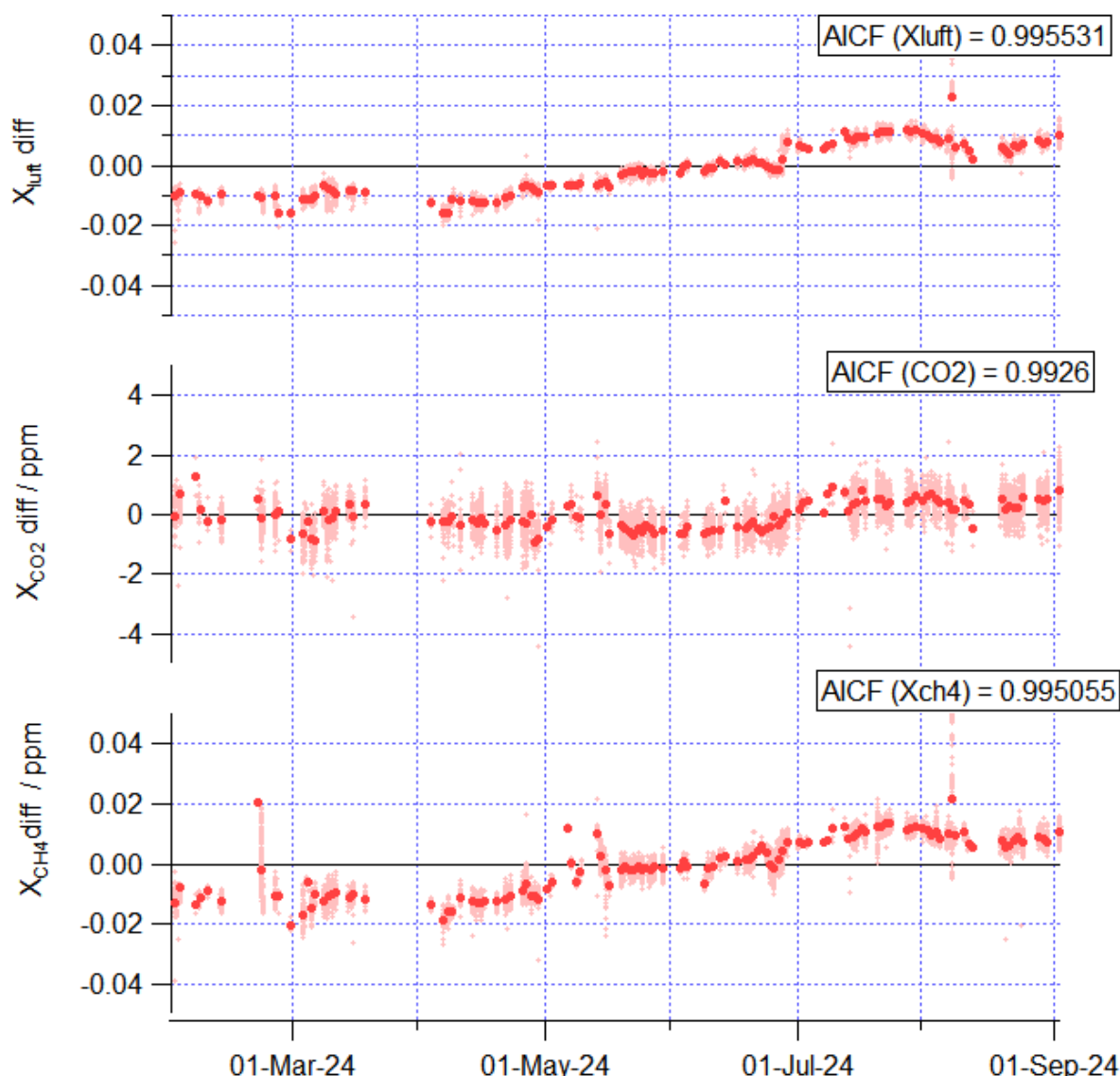


Figure 3b. As 3a, but showing differences IRCube - TCCON.

6 OUTLOOK

The IRCube system as described here will be deployed at the Cape Grim Baseline Air Pollution GAW station in NW Tasmania, Australia, in Oct 2024 alongside a full suite of GAW-compliant in situ measurements. Environmental, weather and staffing requirements do not allow TCCON or COCCON EM27/SUN measurements at this remote site, but the autonomous nature of the Ekotracker and FO system will allow total column GHG measurements at Cape Grim for the first time. This pilot project (~ 1 year) will be used to assess the practicability of establishing long-term remote sensing at such remote clean air sites, to provide a comparison with co-located GAW-quality in situ measurements, and to provide an additional clean-air site for satellite

validation. A successful pilot program will potentially open the way for satellite validation at other global clean air GAW stations not currently practical for remote sensing measurements. The second Ekotracker/FO system currently operating at KIT will be used to further characterise and validate this approach to solar FTS remote sensing at Karlsruhe and Wollongong.

7 APPLICABLE DOCUMENTS

Statement of Work: Fiducial Reference Measurements for Ground-Based IR Greenhouse Gas Observations (FRM4GHG 2.0)

Prepared by: EOP-GMQ, Reference: ESA-EOPG-EOPGMQ-SOW-21

8 REFERENCE DOCUMENTS