

Towards Fiducial Reference Measurements of Greenhouse Gas Abundances in the Atmosphere

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Fiducial Reference Measurements for Ground-Based Infrared Greenhouse Gas Observations (**FRM4GHG**) is a European Space Agency (ESA) funded project focusing on the **intercomparison** of instruments and **harmonization** of retrievals and products from colocated new and established GHG observing **ground based Infrared remote sensing (RS) instrumentation** for achieving Fiducial Reference Measurements (FRMs) of Greenhouse Gases (GHGs), specifically CO₂ and CH₄.

Key project activities:

- Develop new and improved RS instrumentation
- Field demonstration and characterization of these novel devices
- Enhance data processing algorithms for RS measurements
- Validate and assess the collected RS data sets using standard TCCON (Wunch et al., 2011) observations
- Improve the calibration of RS data by in-situ profile measurements (AirCore, upgrade to match WMO CO₂ X2019 scale in progress)

The Collaborative Carbon Column Observing Network (**COCCON**) has been launched by ESA for building a ground-based RS sensing network to deliver FRMs of GHGs, complementary to TCCON and NDACC. It uses the portable commercial EM27/SUN FTIR spectrometer. The required level of performance of this device and of additional portable commercial FTIR spectrometers has been demonstrated in the framework of FRM4GHG (Sha et al., 2020). COCCON is the first RS network for measuring GHGs that incorporates an extensive centralized verification of instrumental performance: each unit is tested and characterized (by laboratory and side-by-side solar observations at the TCCON site Karlsruhe) prior to its commission and repeatedly if service measures change the instrumental state or if indications for instrumental drifts are found (Frey et al., 2019; Alberti et al., 2022). Moreover, a standard travelling EM27/SUN spectrometer has been developed for ensuring TCCON site-by-site consistency.

FRM4GHG and COCCON impressions:



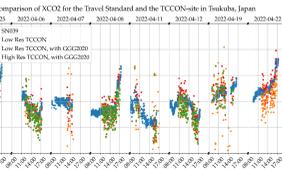
A Vertex 70 FTIR (left) and a Laser Heterodyne radiometer (right) operated in a mobile container system (right photo: outside view)



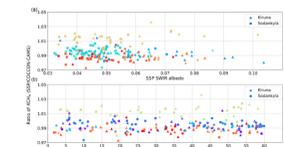
Testing of a fiber-coupled IR-Cube FTIR spectrometer.



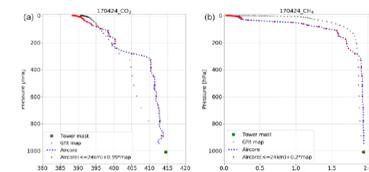
Side-by-side intercomparison of COCCON spectrometers, open path measurements



The COCCON travel standard (for checking the level of site-to-site consistency of TCCON)



Validation of space-borne S5P observations (from Tu et al., 2020)



AirCore in-situ profiles (from Sha et al., 2020)

Interface to metrology: the verification of many important RS performance indicators can be achieved solely by relative comparisons, without need for an explicit metrological reference.

The traceability of a spectroscopic remote sensing measurement to proper WMO units, however, cannot be achieved by network-internal measures. It requires either (1) adjustment of scale to a set of available colocated well-calibrated in-situ measurements, or (2) the use of well-calibrated spectroscopic line lists for the spectral analysis. A successful closure experiment comparing both pathways on the required level of accuracy would assure the desired fiducial character of the RS network beyond any reasonable doubt. The quality of metrological calibration of available line lists does not meet the requirements of today's GHG remote sensing, so the networks' calibration needs to rely on approach (1). From the viewpoint of achieving fiducial GHG RS measurements, the improvement and proper characterization of the relevant spectroscopic data appears to be the prominent metrological key task. Proper characterisation of the remaining spectroscopic uncertainties will enable characterization of the GHG data uncertainties by the RS experts.

Outline of a RS / metrology cooperation project:

- Specify line list requirements (WP lead: RS experts)
- Construct reliably calibrated line lists, build on existing lists, produce and analyse additional traceable lab spectra of relevant gases (H₂O, CO₂, CH₄) (WP lead: metrologists)
- Provision of line lists and reference algorithm for generating x-sections over relevant range for atmospheric observations (pressure, temperature, H₂O mixing ratio) (WP lead: metrologists)
- Perform described closure experiment using atmospheric RS observations and in-situ reference measurements. (WP lead: RS and AirCore experts)

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