EMPIR Call 2019 – Energy, Environment, Normative and Research Potential

Selected Research Topic number: **SRT-v14**
Version: 1.0

Title: Metrology for improved greenhouse gas retrievals in atmospheric remote sensing

Abstract

The Total Carbon Column Observing Network (TCCON) is a key member of the World Meteorological Organization's Global Atmosphere Watch (WMO-GAW) program, performing measurements of atmospheric greenhouse gases (GHG) for calibrating satellite observations and carbon cycle modelling. Due to insufficient accuracy in the underpinning spectroscopy, TCCON currently requires costly aircraft calibrations that do not cover the full atmospheric column and have limited geographical coverage. Proposals addressing this SRT should contribute to improving the accuracy of spectroscopic methods for GHG column retrievals, reducing the calibration system costs and generating equivalence between measurement sites by providing more accurate spectral line data and performing robust Monte Carlo uncertainty analysis.

Keywords

greenhouse gases (GHG), The Total Carbon Column Observing Network (TCCON), WMO-GAW (World Meteorological Organization - Global Atmosphere Watch), NDACC (Network for the Detection of Atmospheric Composition Change), Frequency comb stabilised cavity mode dispersion spectroscopy (FS-CMDS), Fourier-transform spectrometry (FTS), Hartmann-Tran (HT), International Union of Pure and Applied Chemistry (IUPAC)

Background to the Metrological Challenges

TCCON is a key member of WMO-GAW and NDACC programs. It consists of 26 ground-based global stations (9 in the EU) measuring atmospheric gases, including CO_2, CH_4, N_2O, H_2O and others. TCCON data are essential for validating and calibrating satellite GHGs observations and for carbon cycle modelling. Both applications have stringent accuracy requirement of 0.3 % (k=2) on TCCON retrievals. The high accuracy is needed to identify emission sources and sinks from space with high background signal (e.g. for CO_2, resolution of 1-2 ppm upon 411 ppm background). However, the accuracy of TCCON direct retrievals is currently limited to 1-2 % and has biases between sites, mainly due to insufficient accuracy of the underpinning spectroscopy. Although it is possible to calibrate TCCON to the WMO in situ measurement scale using aircraft flying above TCCON sites, it has several disadvantages: the calibration campaigns cost 100 k€, only covering 80 % of the total column, and having only been performed at a quarter of all stations (breaking the traceability chain).

TCCON spectroscopic measurements contain vibration-rotation signatures of absorbing atmospheric gases which can only be interpreted through reliable line data (a collection of parameters, such as line centre, line width, line intensity, etc.) derived from laboratory measurements of these gases. Therefore, the goal of 0.3 % on TCCON GHGs column retrievals can be only achieved with stringent inputs based on accurate laboratory spectroscopy and gas metrology. There has been only a handful of traceable measurements of spectral line data from NIST and PTB, despite the enormous efforts by the community of participating labs. In order to meet the stringent accuracy requirement (0.3 % or better) of recent satellite missions (attempting to establish traceability in the measurements), a close cooperation between NMIs and the community of participating labs to measure traceable line data and to validate existing line data of GHGs is required. Furthermore, advanced spectroscopic measurement techniques, such as FS-CMDS which links to the time standard, have the potential to be used as primary methods for gas composition analysis.

The current official release of the TCCON retrieval software GGG/GFIT does not yet employ higher-order line shape functions. This leads to systematic errors in the retrieval of O_2, CO_2, CH_4, etc. especially at high solar zenith angles (high air masses) and makes observations unusable. Precise modelling of the measured spectra with very high signal to noise ratio (SNR) needs sophisticated line shape models beyond the currently used profile (Voigt). IUPAC recently reviewed different line shape theories developed during the last 30 years and recommended the Hartmann-Tran (HT) profile developed at LISA institute in Paris for its great accuracy, speed and transferability. Spectral fitting codes utilising a HT profile has also been developed for fitting single line, giving the opportunity to be further extended to multi-line multi-spectrum fitting code with the capability of including line-mixing parameters. In order to improve the accuracy of satellite observations and carbon cycling modelling, a homogenous calibration standard, as well as traceable spectroscopic data with associated uncertainties, should be provided.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the development of metrological capacity in observations of atmospheric greenhouse gases.

The specific objectives are

1. To measure and significantly improve the accuracy of spectral line data or cross-sections for CO_2, CH_4, and N_2O in selected TCCON bands and to inter-compare the measured data with *ab initio* calculations. In addition, to investigate the spectral line data of O_2 and H_2O and to measure the most critical molecular lines and spectral parameters.
2. To significantly improve the accuracy, reliability and comparability of measured spectral line data using metrologically sound interlaboratory comparisons by applying techniques like Frequency comb stabilised cavity mode dispersion spectroscopy (FS-CMDS) and Fourier-transform spectrometry (FTS).
3. To integrate the IUPAC-recommended line-shape (the Hartmann-Tran (HT)) profile and line-mixing model into TCCON spectral modelling software. In addition, to include a novel uncertainty budget, of use to the user community, by performing robust Monte Carlo error analyses. This should include an error analysis of the TCCON retrieval algorithm with respect to the solar zenith angles, O_2 spectral line data and line shape functions.
4. To re-analyse existing TCCON observations (since 2004) using the improved spectroscopy and to verify these at TCCON stations with high latitude (e.g. Sodankylä, Finland). In addition, to carry out AirCore flights for comparison with simultaneous TCCON observations.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by: the measurement supply chain (NMIs, calibration laboratories), European Metrology Network on climate and ocean observation, standards developing organisations (ISO, CEN, GCOS), European and international satellite remote sensing community (Sentinal-5, MERLIN, MircoCarb, CarbonSat and OCO-2) environmental monitoring and regulatory agencies (e.g. NDACC, WMO, IPCC) and other end-users.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research, the involvement of the appropriate user community such as industry, standardisation and regulatory bodies is strongly recommended, both prior to and during methodology development.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.0 M€, and has defined an upper limit of 2.3 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the GHG observation sector.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)".

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.