**Measurements of greenhouse gases from ground-based remote sensing and in-situ instruments and their application for satellite validation**

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The atmospheric concentration of greenhouse gases has been steadily increasing in recent years due to anthropogenic activities. Continuous monitoring of precise and accurate measurements of these gases is of utmost importance to determine their sources and sinks, and trends. In recent years, satellite based remote sensing measurements have been able to provide a global measurement coverage of these gases. The nadir looking satellites detecting scattered sunlight in the near-infrared spectral region provide the most powerful method for global mapping of these gases. These measurements cover the whole atmospheric column therewith providing the total column concentrations of the trace gases. However, satellite measurements require accurate validation. Such accurate reference measurements can be performed from surface based, air-borne or already validated satellites. To ensure equal dependency on the measurement parameters, the best validation method for the satellite data is to use the total column amounts of these gases calculated from the solar absorption measurements performed from the surface and satellites in the same spectral region.

The Total Carbon Column Observing Network (TCCON) has been the baseline ground-based network for measuring accurate and precise column-averaged dry air mole fractions of CO2, CH4 and CO amongst other gases. However, the number of stations (currently ~25) is limited and has a very uneven geographical coverage. To improve the satellite validation and better contribute to the carbon cycle science studies, a denser distribution of ground-based solar absorption measurements is needed to cover geographical gaps for various atmospheric conditions (humid, dry, polluted, presence of aerosol, varying surface albedo) and to create a large latitudinal distribution. For this reason, several groups are investigating portable low-cost instruments, which can complement the existing networks and thus enhance the validation of satellite measurements.

The “Fiducial Reference Measurements for Ground-Based Infrared Greenhouse Gas Observations (FRM4GHG; http://frm4ghg.aeronomie.be/)” campaign has been funded by the European Space Agency (ESA) to characterize the performance of several low-cost portable spectrometers for precise solar absorption measurements of CO2, CH4 and CO. These measurements were performed next to the TCCON instrument and ICOS station at Sodankylä for three years as of 2017 and with one of the instruments measurements were performed at the TCCON sites in Australia during 2019. In addition, regular AirCore launches were performed from the Sodankylä site to provide in-situ reference profiles of these gases; this is useful for the verification of the instrument calibration. The intercomparison results show that the tested low-resolution instruments provide high quality data comparable to that of TCCON. The data collected during the campaign were used for satellite validation.

The results of the campaign will be presented with an overview of the accuracy and precision achieved by each instrument and the results of the satellite validation. We show the benefits of the portable FTIR remote-sensing instruments by means of a few example cases.