Relevance of the Total Carbon Column Observing Network (TCCON) for satellite calibration and validation

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Atmospheric greenhouse gas measurements

- **Stratosphere**
  - Free Troposphere
  - Boundary layer
  - Surface air sampling
  - Tower (~500m) since 1959

- **Troposphere**
  - AirCore (0-35km) since 2011
  - Aircraft (0-20km) since 1993

- **Satellite (column)**
  - Since 2002

- **TCCON (column)**
  - Since 2004

Altitude (km)
Solar absorption measurements using FTIR spectrometry
Solar absorption measurements using FTIR spectrometry
Calibration and validation

Solar absorption FTIR-spectrometry

- is the only ground-based remote sensing technique that has demonstrated the required precision
- measure the same quantity as the satellites but do so at a fixed point making it amenable to direct comparison with aircraft
  → Indirectly calibrate satellite retrievals against the in situ standards
- shows a very good instrumental comparability
  → Global network of FTIR spectrometers (TCCON) is able to detect a spatial bias and/or temporal drift in the satellite data
Solar absorption FTIR-spectrometry

- is the only ground-based remote sensing technique that has demonstrated the required precision
- measure the same quantity as the satellites but do so at a fixed point making it amenable to direct comparison with aircraft

→ Calibrate satellite retrievals against the existing in situ measurements

- shows a very good instrumental Comparability

→ Global network of FTIR spectrometers (TCCON) is able to detect a spatial bias and/or temporal drift in the satellite data
In Europe (IMECC campaign)

- **Purpose:** validation of European TCCON measurements
- **Aircraft measurements:** in-situ GHG profiles near stations from 300-12000 m (spiral) + dips during transfer flights
- **Schedule:** September 30 to October 9, 2009
- **Platform:** Learjet 35A operated by Enviscope/GfD

Results:

- Systematic differences between FTIR and in situ measurements is well within spectroscopic errors, e.g. FTIR-CO$_2$-column is ~1% lower than the „in situ“ column
- Very good agreement with similar measurements outside Europe
- Accuracy limited by uncertainties in GHG profiles above aircraft ceiling.

(Fig. courtesy of D. Feist)
The AirCore with magnesium perchlorate driers and shut-off valves attached on each end, 152 m long, 7 kg [Karion et al. 2010]

Calibration: Link to the WMO standards by AirCore measurements (courtesy of H. Chen)
TCCON calibration by \textit{in situ} measurements

\begin{figure}
\centering
\begin{tabular}{c c}
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\multicolumn{2}{c}{\textbf{CO}_2} \\
\hspace{-0.5cm} & \hspace{-0.5cm} \\
\multicolumn{2}{c}{\textbf{CH}_4} \\
\hspace{-0.5cm} & \hspace{-0.5cm} \\
\end{tabular}
\end{figure}

\textit{Wunch et al.}, 2015
• The stratospheric CH$_4$, calculated from the retrieved HF column and a linear correlation of HF and CH$_4$ in the stratosphere, is subtracted to get the tropospheric XCH$_4$

• Instead of HF one can use N$_2$O, which is advantageous in the tropics because the precision of the HF retrievals is limited by the atmospheric H$_2$O.
Tropospheric XCH$_4$ - aircraft comparison

(Wang et al., 2014, updated)
Use of TCCON data

Satellite validation (reference network for GHG validation)

Flux inversions

Model Evaluations

(Chevallier et al., 2011)
Problem: TCCON data availability (1 yr after measurement) limits the usefulness of TCCON for validation of CAMS forecast models
Total Carbon Column Observing Network (TCCON) 2016
TCCON coverage of regions with different albedo

High and low land surface albedo regions currently not covered by TCCON

Problem for satellite validation, because high and low albedo conditions are most difficult for satellite retrievals
Extension using mobile/portable FTIR instruments

IUP Bremen

BRUKER IFS-66

Petri et al., AMT 2012

KIT Karlsruhe in cooperation with Bruker

EM27/Sun

Gisi et al., AMT 2012
Applications of mobile spectrometers

1) Complementing TCCON
   - tropics
   - low / high surface albedo
   - short term campaigns
   - moving platforms

2) Quantifying emissions by column budgeting
Comparison of mobile spectrometers for greenhouse gas measurements (ESA-project FRM4GHG)

<table>
<thead>
<tr>
<th>Institute</th>
<th>Instrument</th>
<th>Spectral range</th>
<th>Resolution</th>
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</thead>
<tbody>
<tr>
<td>FMI</td>
<td>Bruker IFS 125HR</td>
<td>1800 - 15000 cm⁻¹</td>
<td>0.02 cm⁻¹</td>
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<td>2500 - 15000 cm⁻¹</td>
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<td>Bruker EM27/SUN</td>
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<td>RAL</td>
<td>QCLHR</td>
<td>950 / 1280 cm⁻¹</td>
<td>0.002 and 0.02 cm⁻¹</td>
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<tr>
<td>Uni Groningen</td>
<td>AirCore</td>
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</table>

Characterisation of the precision, accuracy and comparability of the participating mobile spectrometers

Poster: Fiducial Reference Measurements for Ground-Based Infrared Greenhouse Gas Observations (FRM4GHG) at the Sodankylä TCCON site by Mahesh Kumar Sha et al.
COCCON offers a framework for consistent and reliable operation of the EM27/SUN spectrometer as well as for the retrieval of XCO₂, XCH₄ and XCO from the spectra (CO only for upgraded instrument).

Current status:

- KIT has 10+ EM27/SUN spectrometers and operates them with international partners (Namibia, India, Mexico,…) and during campaigns.
- All COCCON spectrometers are checked and calibrated at KIT before delivery and after return (drift within campaign duration of one month < 0.003%)
- KIT published recipe and software for instrumental line shape characterisation
- KIT supports the community by introducing further instrumental extension
- KIT provides tools for spectra preprocessing and atmospheric retrievals
Summary

- TCCON is the reference network for the validation of GHG satellite retrievals and enables to link satellite retrievals to the WMO reference scale. TCCON has grown significantly over the last 10 years.
- TCCON lacks sites in the inner tropics and in regions with high and low albedo.
- TCCON data is available only one year after the measurement, which is a limitation for several applications.
- Mobile spectrometers have the potential to complement the TCCON. A systematic test of currently used mobile spectrometers will be performed within the ESA-funded project FRM4GHG (Poster by M. Kumar Sha et al.)
- The Karlsruhe Institute of Technology (F. Hase) founded the Collaborative Carbon Column Observing Network (COCCON) providing a framework for consistent and reliable operation of the EM27/SUN portable spectrometer as well as the retrieval.