Validation of satellite-based GHG with TCCON (Total Carbon Column Observing Network)

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Outline

• TCCON (Total Carbon Column Observing Network)
  – Remote sensing of total column CO₂, CH₄, N₂O, CO ...
  – TCCON data usages
  – TCCON spectra
  – Expansion of TCCON
  – TCCON data record

• TCCON sites operated by Japanese organizations
  – Rikubetsu, Tsukuba and Saga
  – Burgos

• Publications with TCCON

• Recent paper list related satellite validation with TCCON

• Summary

• TCCON challenges for satellite validation

• COCCON (COllaborative Carbon Column Observing Network)
TCCON (Total Carbon Column Observing Network): Remote sensing of total column CO$_2$, CH$_4$, N$_2$O, CO ...

- Direct-sun solar absorption spectroscopy in the near IR using FTS
- Retrieve total column amounts
- Derive column average dry air mole fractions (e.g. $X_{CO2}$)
  - Using column O$_2$ as internal standard
  - $X_{CO2} = CO_2/O_2 \times 0.2095$
- Precisions (2σ)
  - $XCO_2$: ~1 ppm (0.3%)
  - $XCH_4$: ~5 ppb (0.5%)
  - $XCO$: < 4%
- Accuracies by comparison with integrated aircraft in situ profiles using WMO-calibrated instruments
TCCON data usages

TCCON has formed a crucial part of the validation efforts of all past and current satellites!

- Verification datasets and assimilation datasets in modelling study and improving our understanding of the carbon cycle

- Providing the primary validation (ground-truth) dataset for satellite remote sensing instruments
  - SCIAMACHY (ESA, stop operation in 2012)
  - GOSAT (JAXA-NIES-MOE, launched in 2009)
  - OCO-2 (NASA, launched in 2014)
  - GHGSat (Claire, launched in 2016)
  - TanSat (CAS-MOST-CMA, launched in 2016)
  - TROPOMI(ESA, 2017)
  - GOSAT-2 (JAXA-MOE-NIES, launched in Oct 2018)
  - OCO-3 (NASA, deployed in May 2019)
  - MicroCarb (CNES, to be launched in 2021)
  - GeoCARB (NASA, to be launched in 2022)
  - Merlin (DLR-CNES, to be launched in 2024)
  - GOSAT-3 (JAXA-MOE-NIES, considered, to be launched in 2023)

- Providing a transfer standard between the satellite measurements and the ground-based in situ network
NIR absorption spectrum used in TCCON

H$_2$O: 4000～6500 cm$^{-1}$ region

Intensity [arbitrary unit]

Wavenumber [cm$^{-1}$]

InGaAs det. Aug. 10, 2011, Tsukuba 125 HR
Spectra analyzed by GFIT profile scaling retrieval

Nov 16, 2013/11/16

CO

CH₄

CO₂

O₂
Expansion of TCCON for validating space-based GHG data and reducing uncertainties in carbon cycle studies

- Established in 2004 and the measurements at Park Falls, Lauder, and Ny Alesund have started. More than 25 sites! Operating by individual sites.
- The lack (red ellipses) of reliable validation data for the satellite-based greenhouse gas observing missions is a common limitation in global carbon-cycle studies that. **Contribution by the GOSAT series project**

https://tccondata.org
The TCCON data record

Providing time-resolved, high quality, consistent retrievals around the globe.

A network of highly skilled FTS experts.

A network of scientists who are integrated into the communities we serve who can advise on the appropriate use and interpretation of our dataset.
Burgos Philippines as a new TCCON site in South-East Asia

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EDC Burgos Wind Farm Project site* photo from a drone-borne camera (Nov. 8, 2016)

*Located in Ilocos Norte, Philippines, a “coal-free” province
A new TCCON site within the EDC Burgos Wind Farm Project

The TCCON container was placed within the EDC (Energy Development Corporation) Burgos Wind Farm Project, specifically at the substation site where technical support is available in close proximity.
HALO into sunset over Burgos on March 12, 2018

TCCON container where Bruker FTS 125 HR FTS and Mie LiDAR are installed on right and left sides, respectively

An EM27/SUN portable FTS to compare the TCCON FTS and contribute to the EMeRGe campaign in March 2018
Retrieved column-averaged dry air mole fractions of CO$_2$, CH$_4$, H$_2$O and CO.

Elevated XCO, XCH$_4$, and XCO$_2$, probably due to biomass burning were clearly detected!

210 measurement days from Mar. 2017 to Mar 2018!!
GOSAT & OCO-2 Satellite Data Comparisons

Target mode XCO₂ retrievals from the OCO-2 satellite vs. XCO₂ from TCCON stations. Only stations in Tsukuba, Wollongong, Darwin and Burgos are shown for clarity. The calibration line (solid black line) is derived from all TCCON sites. The most recent GOSAT sounding (red circle) is also added on this plot, but not included in the calculation of the calibration curve. It falls within 0.13 ppm of the OCO-2 calibration line. The two outliers in the OCO-2 measurements over Wollongong (downward triangles) are probably due to bias induced by stratospheric aerosols caused by the eruption of the Calbuco volcano on Apr. 22 2015. [http://www.mdpi.com/2072-4292/9/12/1228]
255 Publications with TCCON as of Apr 27, 2019

Total papers per year

Sum of citations per year
Recent paper list related satellite validation with TCCON

SCIAMACHY CO:
• P. Hochstaffl, F. Schreier, G. Lichtenberg and S. G. García, Validation of Carbon Monoxide Total Column Retrievals from SCIAMACHY Observations with NDACC/TCCON Ground-Based Measurements, Remote Sens. 2018, 10(2), 223; https://doi.org/10.3390/rs10020223
  • plus Addendum to add TCCON references!

OCO-2 CO₂:
• Kulawik et al., in prep
Recent paper list related satellite validation with TCCON

Copernicus CO₂ and CH₄:

GOSAT CO₂, CH₄ and H₂O:
Recent paper list related satellite validation with TCCON

GOSAT CO₂, CH₄ and H₂O (continued):

TROPOMI CO and CH₄:
• Sha et al., in prep.
• Schneising et al., in prep.

MOPITT CO
Summary of TCCON

- **TCCON data:** compared to the WMO scale.
  - Uncertainties: $XCO_2<0.25\%$, $XCH_4<0.5\%$, $XCO<4\%$, $XN_2O<1\%$, and $XH_2O<1.3\%$.
- Widely used in studies on atmospheric chemistry and carbon cycle
- Firmly established as an important validation resource for satellite-based products
- TCCON data is publicly available in the web [https://tccondata.org](https://tccondata.org)
  
  We would like ask you to read the TCCON Data License when using!
TCCON challenges for satellite validation

• Satellites are now achieving sub-ppm precision in XCO₂
  – TCCON claims ~0.4 ppm precision (1σ): ILS, instrumentation, surface pressure, improved spectroscopy and a priori profiles etc.

• Site-to-site consistency is our biggest challenge
  – Airmass dependence is seen as a major problem in the satellite and modeling community

• Active missions (e.g. MERLIN) have vastly different averaging kernels to TCCON

• With TROPOMI, GOSAT-2, and near future missions, we will be relied upon for XCO and other products (XN₂O, XH₂O, XHDO) in addition to XCO₂ and XCH₄
  – These retrievals have not been under the same scrutiny as XCO₂
  – We have no tie to a trace-gas standard scale for HDO
  – Our 7% CO scaling remains an outstanding issue,

• Network continues to expand:
  – Missing areas: Africa, India, Siberia, South America
  – Expensive for setting up a new site (about 1 M US$) and operation (about 0.1 M US$)
  – Portable FTS network → COCCON
COCCON  
(COLlaborative Carbon Column Observing Network)

EM27/SUN (pendulum FTS-Spectrometer, 0.2 M US$)
Resolution: 0.5 cm⁻¹, two InGaAs detectors
Dimension: 35 x 40 x 27 cm, weight: ~25 kg
data processing: PROFFAST* (PROFFIT, GFIT)
*designed for low resolution spectra
Checking of ILS and stability
Calibration
More than 30 devise operated worldwide
Measurement campaigns
- Paris, Berlin, Boulder, Tokyo etc.
- City emissions, dairy farm, coal mining etc.
Now networking started!

https://www.imk-asf.kit.edu/english/COCCCON.php