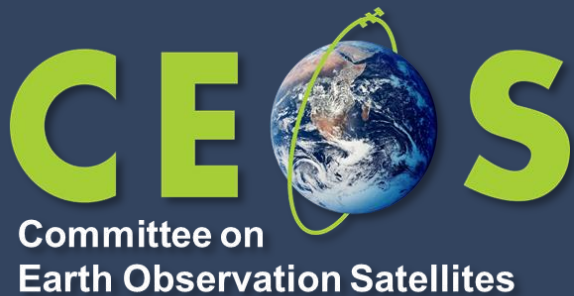


# *Greenhouse Gas Cal/Val Networks Sustainment*



J.-C. Lambert (BIRA-IASB, WGCV)  
M. De Mazière, B. Langerock, M.K. Sha (BIRA-IASB)  
J. Hannigan (NCAR), E. Mahieu (ULg)

2023 CEOS SIT TW  
GHG Task Team 3<sup>rd</sup> Workshop, Frascati, 17 October 2023

**WGCV-52**  
*Greenhouse Gases Cal/Val Network  
Updates and Future Requirements:  
NDACC, TCCON, COCCON*



M.K. Sha, B. Langerock, M. De Mazière,  
and J.-C. Lambert, BIRA-IASB  
Agenda Item 2.8  
WGCV-52, ESA/ESRIN, Italy, 5-9 June 2023



<https://ceos.org/meetings/wgcv-52/>



<b>WGCV-52-ACT-16</b>	WGCV Chair team to consider an approach to raise to CEOS leadership level the need for support to the GHG networks: NDACC/FTIR, TCCON, and COCCON networks.	<b>SIT Technical Workshop 2023</b>
<b>SEC-309-02</b>	WGCV Chair and WGClimate Chair to coordinate a side meeting during the SIT Technical Workshop on October 17-19, 2023, to discuss Greenhouse Gas cal/val network sustainment and potential coordination with WMO on this topic.	<b>SIT Technical   Workshop 2023</b>

## NDACC FTIR



<http://ndacc.org>

- Bruker 120HR/125HR
- Resolution 0.0036 cm<sup>-1</sup>
- Spectral range: SWIR, MIR and TIR
- Measurements every ±10'
- 21 stations worldwide
  
- Targets: O<sub>3</sub>, CH<sub>4</sub>, N<sub>2</sub>O, (CO<sub>2</sub>, HCHO, SF<sub>6</sub>, CFC, HCFC, H<sub>2</sub>O, HDO not official), CO, HNO<sub>3</sub>, HCl, HF, HCN, C<sub>2</sub>H<sub>6</sub>, ClONO<sub>2</sub>, (C<sub>2</sub>H<sub>2</sub>, PAN, OCS, CH<sub>3</sub>OH, NH<sub>3</sub>, HCOOH, NO<sub>2</sub> not official)
  
- Profile retrievals (low vertical resolution, typically tropo/strato separation)
- Retrieval software: SFIT or PROFFIT
- Measurement protocol (SOP), no central processing, QA/QC for selected targets in CAMS operational validation

## TCCON



<http://tcon.org>

- Bruker 125HR
- Resolution 0.02 cm<sup>-1</sup>
- Spectral range: SWIR
- Measurements every ~ 3'
- 28 stations worldwide
  
- Targets: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, H<sub>2</sub>O, HDO, CO, HF
  
- Profile scaling retrievals (profile retrievals in development)
- Retrieval software GGG
- Central QA/QC

## COCCON



<http://www.imk-asf.kit.edu/english/COCCON.php>

- Bruker EM27/SUN
- Resolution 0.5 cm<sup>-1</sup>
- Spectral range: SWIR
- Measurements every ~ 1'
- > 60 instruments worldwide (some fixed sites but mostly for campaigns)
  
- Targets: CO<sub>2</sub>, CH<sub>4</sub>, CO
  
- Profile scaling retrievals
  
- Retrieval software PROFFAST
- Central calibration & processing facility at KIT

# CV-6 Pathfinder: Sentinel-5P Operational Validation



CO<sub>2</sub>/CH<sub>4</sub> Roadmap CV-6: Operational reporting on the quality of space-borne GHG data

## ESA/Copernicus ATM-MPC Sentinel-5P TROPOMI CH<sub>4</sub> and CO operational validation based on three GHG column/profile monitoring networks

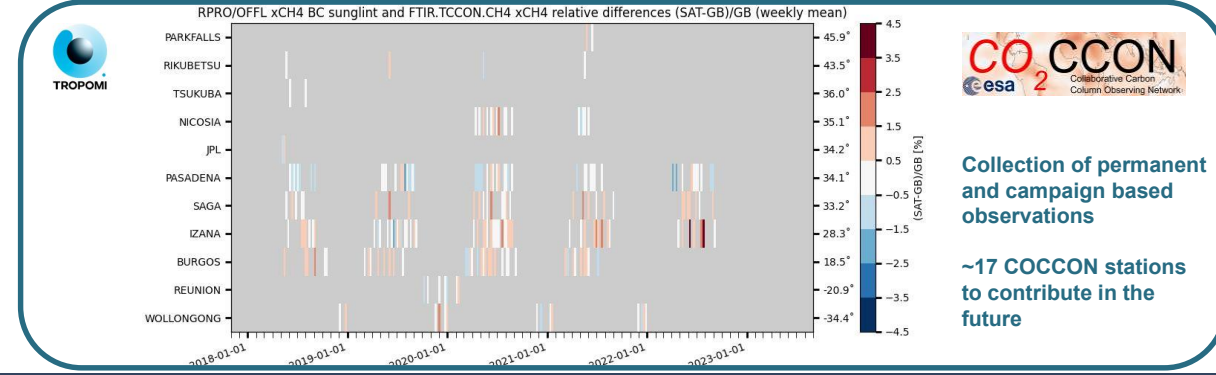
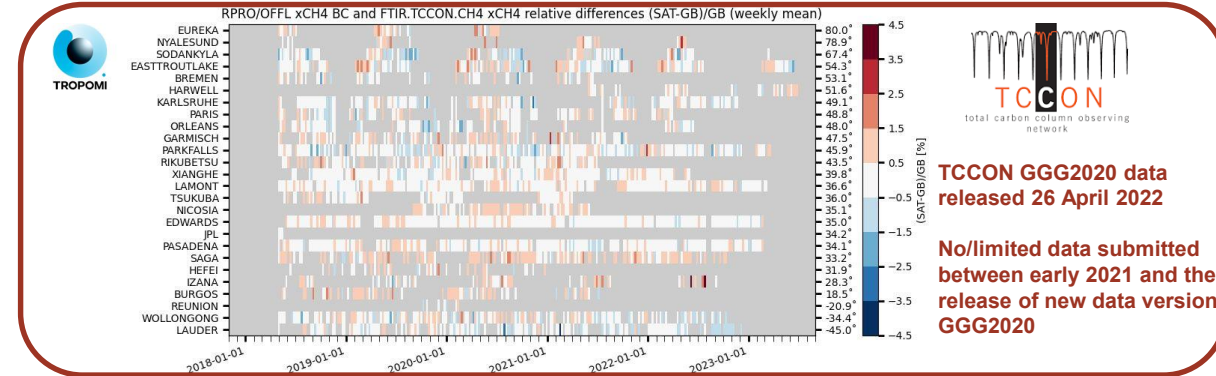
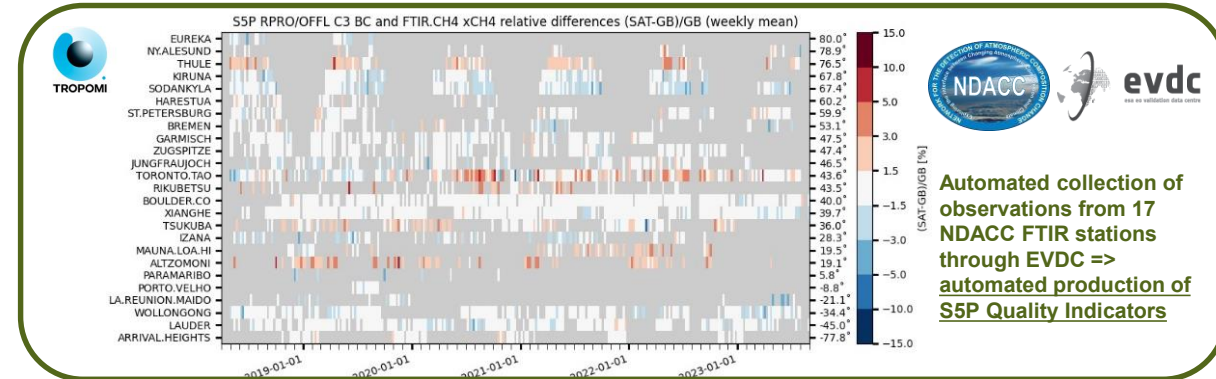
- **NDACC FTIR** : automated validation channel in ATM-MPC Automated Validation Server (<https://mpc-vdaf-server.tropomi.eu>).

Validation protocols based on published experience with HALOE, MOPITT, SCIAMACHY, MIPAS, ACE-FTS, IASI, GOSAT...

- **TCCON FTIR** : manual validation channel in ATM-MPC, ESA contract for operations support to be placed

- **COCCON FTIR** : manual validation channel in ATM-MPC, EVDC data collection and automation in progress (ESA contract 2023-2027)

S5P TROPOMI CH<sub>4</sub> & CO validation updated permanently vs. **NDACC FTIRs** and monthly – when and where data available – vs. **TCCON & COCCON FTIRs**. Quarterly validation reports available on <http://mpc-vdaf.tropomi.eu>



CH<sub>4</sub> images courtesy M.K. Sha ATM-MPC review October 2023

# State of the art of the GHG Networks



CO<sub>2</sub>/CH<sub>4</sub> Roadmap CV-5: Gaps and improvements in ground-based and airborne validation infrastructure

**CV-5** Identify gaps and suggest improvements in ground-based and airborne validation infrastructure (i.e. geographical / geophysical gaps for FRM) and other long-term validation needs (at horizon 2025-on)

**NDACC-IRWG-TCCON-COCCON Annual Meeting 2023**

Jun 12 – 16, 2023  
Radisson Blu Balmoral Hotel, Spa  
Europe/Brussels timezone

Enter your search term

**Overview**

The annual meeting of the NDACC-IRWG / TCCON / COCCON will be hosted by the [Royal Belgian Institute for Space Aeronomy \(BIRA-IASB\)](#) supported by the [Belgian Science Policy Office \(BELSPO\)](#).

This event will take place from 12 to 16 June 2023 at the [Radisson Blu Balmoral Hotel, Spa, Belgium](#). The address is [Avenue Léopold II, 40, 4900 Spa, Belgium](#).

The meeting brings together the ground-based Fourier transform infrared spectroscopy experts from around the world who are associated with the [Infrared Working Group of the Network for the Detection of Atmospheric Composition Change \(NDACC-IRWG\)](#), the [Total Carbon Column Observing Network \(TCCON\)](#) and the [Collaborative Carbon Column Observing Network \(COCCON\)](#) and the users of the data.

<https://events.spacepole.be/event/160/>

# I. Availability of FTIR data for Cal/Val: AS IS

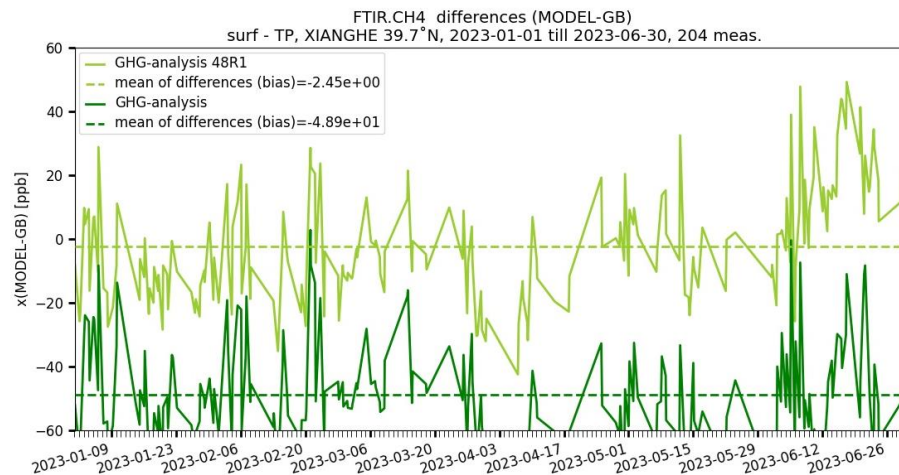


- Growing awareness for importance and successful use of NDACC-IRWG, TCCON and COCCON data for satellite and model validation in various programmes: ESA ATM-MPC, EUM AC-SAF, CO2M validation, OCO-2/3, GOSAT series, TANSAT, Copernicus services (CAMS, C3S), ESA CCI (ozone, GHG, ozone & aerosol precursors)...

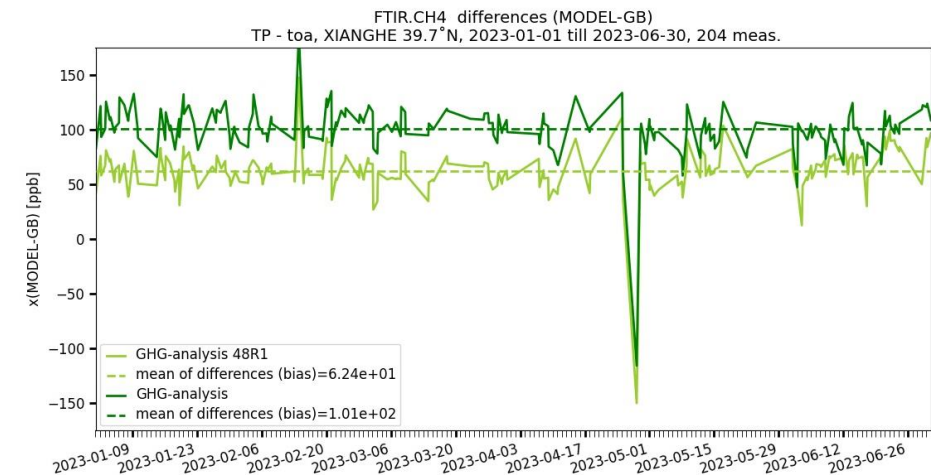
*E.g., FTIR data used for model validation (reanalysis, o-suite forecasts, GHG o-suite analysis and high-resolution forecasts, e-suite analyses at ECMWF, ...)*

Example of a CH<sub>4</sub> comparison at Xianghe (China): bias between FTIR data and 2 different models

CH<sub>4</sub> tropo- column comparison



CH<sub>4</sub> strato- column comparison



# I. Availability of FTIR data for Cal/Val: ISSUES



- NDACC PIs get (limited) financial support through Copernicus (ECMWF) and ESA (*to complement funding*) via CAMS-27 project for rapid data (RD) delivery (<1 month instead of yearly) of target species: CH<sub>4</sub>, CO, O<sub>3</sub> and H<sub>2</sub>CO. *Funding for RD secured until 2026/Q1.*
- NDACC – Europe embedded in research infrastructure ACTRIS for more sustainable support by Member States, *but for now limited to a few target species (no long-lived GHG) and very few stations.*  
A central data processing and data delivery system (CDPS) will benefit NDACC-FTIR partners in ACTRIS.

Rapid & continuous data delivery remains a problem, especially for TCCON data

cf. governance of research network type, with various funding mechanisms

cf. maintenance of data acquisition infrastructure is costly, a burden for operators, hampered by delays when ordering spare parts...

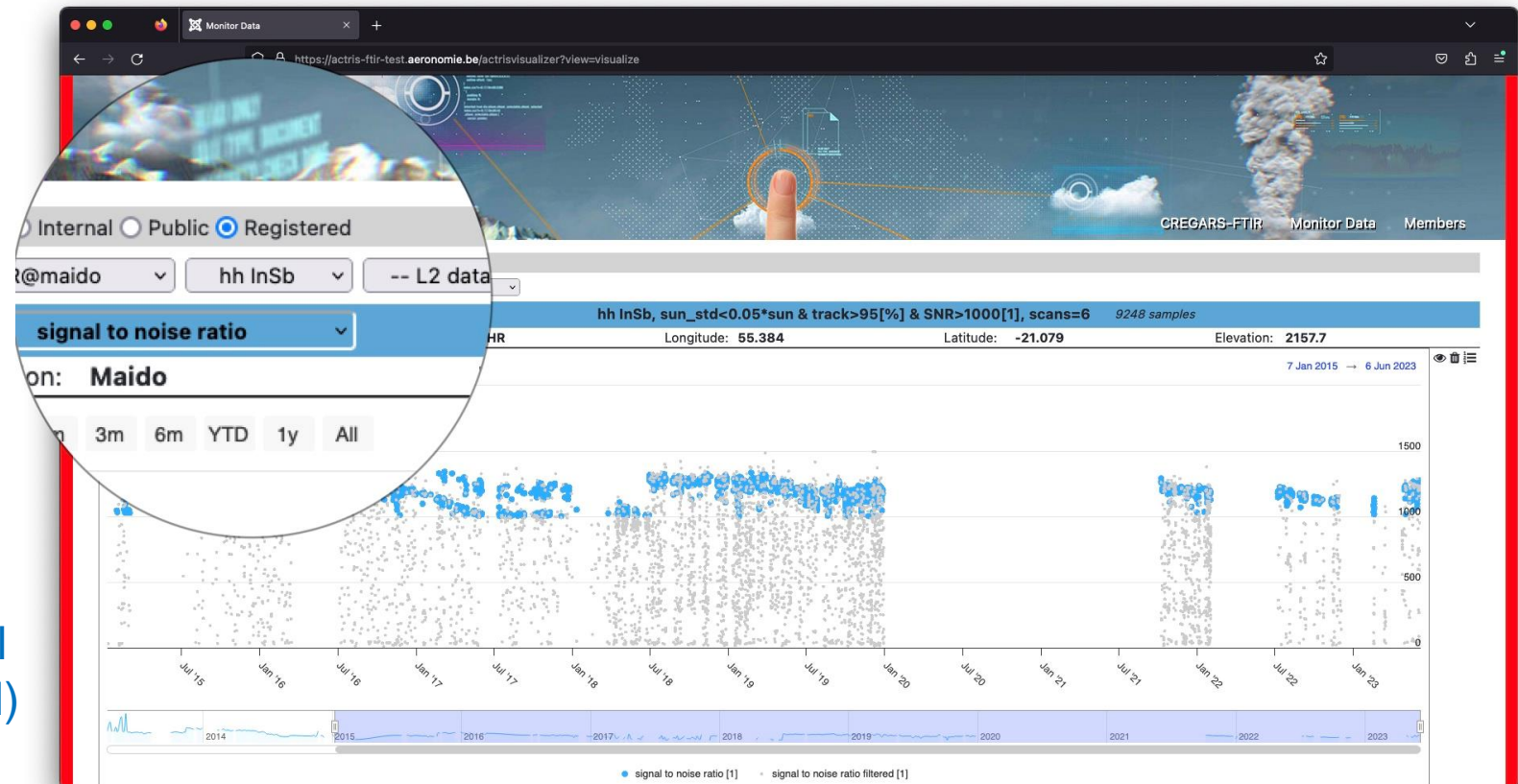
cf. each individual TCCON PI is responsible for the whole data production chain using the standard TCCON data processing code; data QA/QC is done by a group of people where an editor and two reviewers are assigned to each site.

cf. embedding of TCCON-Europe is still pending, not supported by all

## II. Access to FTIR data for Cal/Val: AS IS



- Consolidated (fully QA/QC-ed) FTIR GHG data are available from dedicated datacentres ([NDACC DHF](#), [TCCON data archive](#), [EVDC for COCCON](#)) in standard formats, at latest one year after data acquisition (official protocol)
- ACTRIS CDPS includes QA/QC and L1 & L2 data visualization tools; currently in prototype status at <https://actris-ftir-test.aeronomie.be>

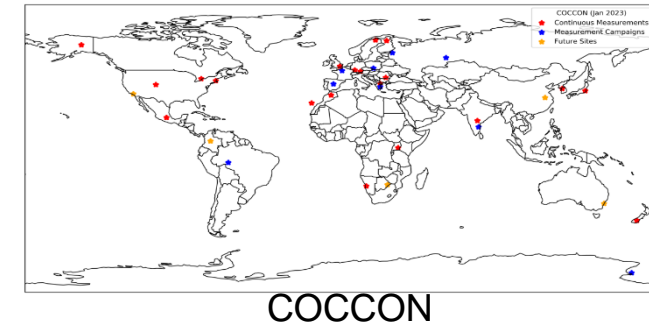
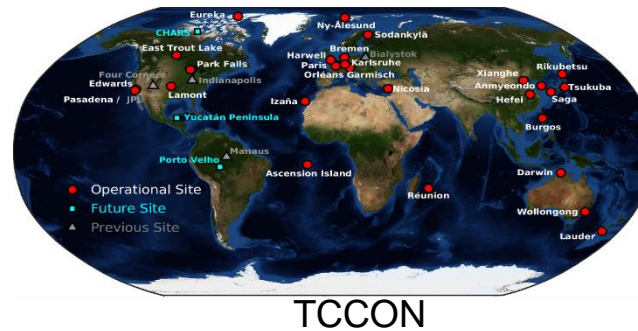
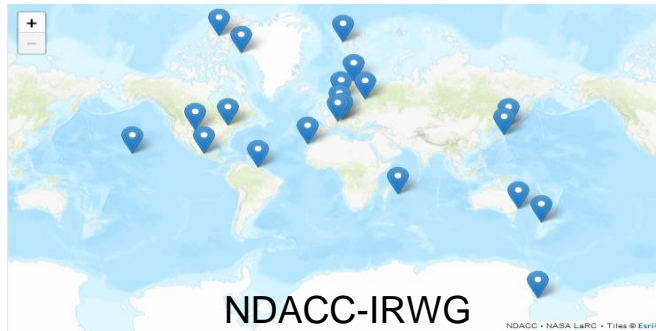


No common approach for now for all  
(NDACC-IRWG, TCCON, COCCON)  
FTIR data



# III. FTIR data coverage for Cal/Val: AS IS

## Permanent stations



- New planned sites: Porto Velho, Brazil; Yucatán Peninsula, Canadian High Arctic Research Station (CHARS)
- Number of (LR) spectrometers growing every year
- Permanent installations of LR spectrometers in array (by groups from: TUM - Germany, UoT + EC – Canada, French groups, AEMET - Spain)
- New cal/val planning and ground-based network design website <https://co2m.aeronomie.be/> : cal/val support for CO2M Product Validation and Monitoring and extendable to related missions, website also enables joint visualization of satellite L3 files and global or regional emission inventories

## Campaigns

- Several campaign activities performed by various groups (targeting cities, coal mining areas...); some supported by ESA SVANTE project (Kolkata (India); Yangambi (DRC))
- New activities planned with shipborne measurements, AOD retrievals, open path measurements, ...

# III. FTIR data coverage for Cal/Val: ISSUES



- Lacking validation data over high albedo regions – current TCCON sites cover albedo of  $\sim 0.4$ , spectrally less smooth locations are required, lacking validation data over oceans
- Wish list for stations at SMO, Bouvet Island, Alice Springs, Riyadh – regions with large biases in OCO-2 data compared to models
- Better coverage needed in S-E Asia because of important contributions to global CO<sub>2</sub> budget
- Access to campaign data not optimal (application of FAIR principles recommended)
- Continuation of measurements at successful and highly relevant campaign sites ?
- Mid- to long-term and /or mobile deployment of LR spectrometers requires automation and an appropriate enclosure for hosting the FTIR system and its accessories: several individual groups are developing one but currently without a common approach and without ‘commercialization’ in view.
- Required coverage may be different depending on focus on anthropogenic/biogenic emissions, large point sources, or else...

# IV. FTIR data quality (accuracy, precision, homogeneity) for Cal/Val: AS IS



- TCCON GGG2020 released (few sites still missing, datasets are being extended) with many improvements over GGG2014
  - new approach to generate a priori trace gas profiles for CO<sub>2</sub>, CH<sub>4</sub>, CO, N<sub>2</sub>O and HF,
  - prior improvement, but some remaining issues with prior profiles (CO in high polluted regions – e.g., California, Xianghe, CH<sub>4</sub> in stratosphere)
  - Update in telluric and solar spectroscopy, added non-Voigt line shapes for some species,
  - update from noontime NCEP meteorology to 3-hourly GEOS FP-IT meteorology,
  - new retrieval vertical grid to better resolve surface gradients,
  - per window airmass dependent correction rather than per-gas,
  - two new CO<sub>2</sub> windows reported separately which have quite different vertical sensitivity compared to standard CO<sub>2</sub>,
  - additional in-situ profiles used to tie to the WMO scale, CO is not tied to WMO scale,
  - non-linearity correction applied to data from many sites which improved the overall quality of TCCON data significantly,
  - additional diagnostics to flag out-of-family data in the QC process
- NDACC provides profile retrievals (limited DOF); TCCON profile retrievals have been demonstrated for CH<sub>4</sub> but not yet implemented as standard in TCCON
- Current TCCON error budget (precision): XCO<sub>2</sub> = 0.5 ppm (<0.15%), XCH<sub>4</sub> = 5 ppb (<0.3%), XCO = 2 ppb (<2%)
- COCCON data processing improved from PROFFAST to PROFFAST2
- Concept of travelling standard to improve intra-network and inter-network (COCCON tied to TCCON) consistency

# IV. FTIR data quality (accuracy, precision, homogeneity) for Cal/Val: ISSUES



- Higher precision still needed: goal is to achieve precision  $X_{CO_2} = 0.2$  ppm,  $X_{CH_4} = 4$  ppb and  $X_{CO} = 1$  ppb
- Mutual consistency within and between networks not good enough yet
- Formal GGG/PROFFAST intercomparisons needed
- Deployment of travelling standard currently (too) limited because of limited resources (ESA FRM4GHG-2)
- No travelling standard yet for connecting TCCON data to NDACC-IRWG data
- Additional in-situ profiles are used to tie TCCON to the WMO scale, but CO is not yet tied to WMO scale,
- AirCore data are the best source for verification/improving a priori vertical profiles: currently there is no central archive of all available AirCore data (mainly NOAA and French/AERIS AirCore data archives)
- Deployment of AirCore not yet fully 'operational' and not feasible at all sites (cf. problem of recovery). A remotely controlled/automatic glider-borne AirCore does exist at NOAA but is not widely available.
- NDACC-IRWG not yet tied to WMO scale; travelling standard for NDACC could support this 'calibration'
- Do we know requirements for validating GHG emissions (in addition to concentrations) ? Need for a new cal/val methodology ?

- 1. NETWORKS DESIGN AND EVOLUTION:** to support gap analysis studies with a view to tailoring CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O networks deployments to Cal/Val needs of the GHG satellite constellation: background/hot spots, land/ocean, low/high albedo, full range of atmospheric temperature...
- 2. INSTRUMENT DEPLOYMENT:** (i) to further develop (low-cost, light-weight, mobile) low-resolution infrared instruments; (ii) to support standardized production of enclosures for their deployment in the field; (iii) to maintain a supply of spare parts.
- 3. CALIBRATION:** to support the development of and maintain mutually consistent calibration and QA/QC of the GHG Cal/Val networks – within and across networks. Key actions: (i) traceability towards internationally agreed standards; (ii) more regular and network-wide deployment of traveling standard; (iii) more regular intercomparisons within and across networks, and between in situ (AirCore...) and remote sensing (networks); (iv) facilitate AirCore deployment; (v) establish a central AirCore data archive.
- 4. DATA PROCESSING:** to support GHG Cal/Val network data processing improvements needed to maintain FTIR data precision/accuracy and meet future goals: formal intercomparison exercise of the GGG and PROFFAST retrieval algorithms, development and standardization of profile retrievals, spectroscopy studies.

5. **DATA ACCESS:** to establish interoperable GHG Constellation Cal/Val Data archives and tools for tailored network data (traceable, open, metadata, co-located...) and 'hidden' data (e.g. campaigns), ideally coupled to New Space related matchup database(s).
6. **TIMELINESS:** to organize concertation between stakeholders and with networks data providers to support rapid and continuous availability and improved access to networks-wide GHG data.
7. **CENTRAL PROCESSING FACILITIES (CPF):** to establish central processing facilities for every network product, which will directly support harmonized calibration **(3)**, data processing, QA/QC and tailoring **(4-5)** and timeliness **(6)**.
8. **GHG EMISSIONS AND ATTRIBUTION:** to support the development of new Cal/Val protocols for satellite derived GHG emissions and fluxes, in collaboration with relevant bodies and initiatives (global stocktakes, WMO GGGW, UNEP IMEO, New Space...) Consider co-located measurements of GHG and tracers of anthropogenic/biogenic contributions for better attribution of emissions.

# GHG Cal/Val Networks in CEOS Pubs

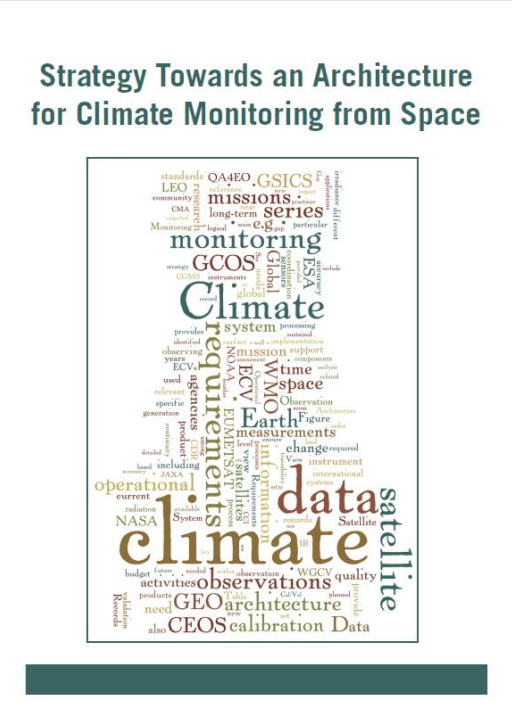


**NDACC implicitly,  
as a contributor to WMO GAW**

**TCCON only**

**TCCON primarily,  
EM27/SUN as extension**

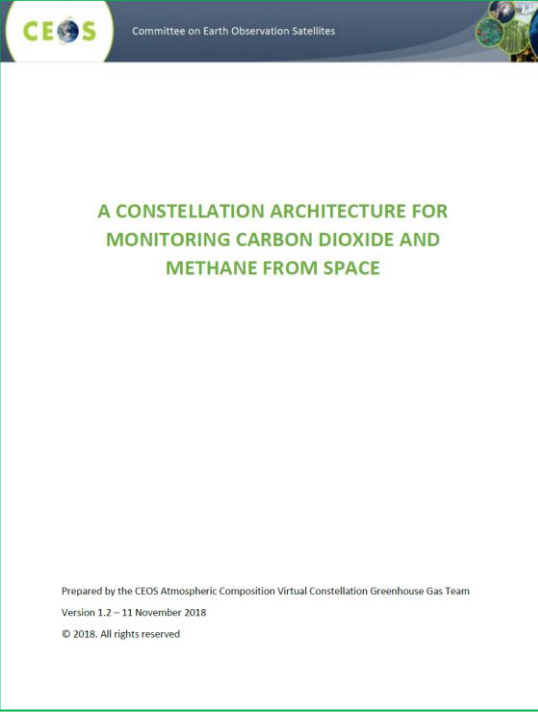
**TCCON primarily,  
EM27/SUN as extension**



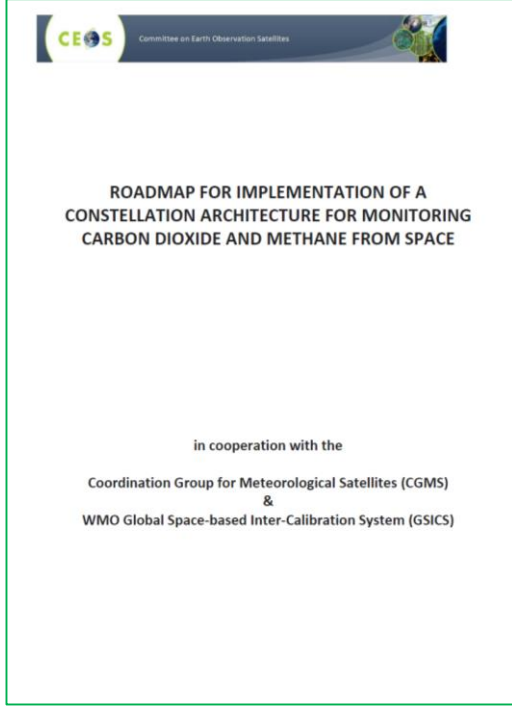
2013



2014



2018



2020

## AC-VC-19 / ACSG joint meeting 2023 next week in Brussels

<https://ceos.org/meetings/ac-vc-19-acsg-joint-meeting-2023/>

In **Greenhouse Gases** session (Chairs J. Worden and Y. Meijer, Tuesday 24/10)

- Talks of GHG Cal/Val networks, campaigns, other initiatives
- 5 talks and general discussion on *Cal/Val Status/Needs/Synergies* (10:45-11:45 CEST)

In **Cal/Val for the Constellations** session (Chair J.-C. Lambert, Thursday 26/10, 09:00-13:00 CEST)

- General talk on Cal/Val needs for the constellations (incl. GHG constellation)
- GHG Cal/Val talk with outlook to Copernicus Contributing Missions
- Panel review of the GHG constellation Cal/Val needs, general discussion on way forward