1. WGCV & ACSG
2. Highlights on recent activities
3. Cal/Val for the Constellations
WGCV activities with relevance to atmospheric composition missions

- Pre-flight/in-flight calibration, SI-Traceable Satellites  
  (talks Th-04, Th-07, Th-08)
- Cal/Val best practices and protocols  
  (e.g., talk Th-05 by R. Koopman)
- Support to Cal/Val networks: RadCalNet, HYPERNETS, TIRCALNET, FRM tailoring and infrastructures…  
  (e.g., talk Th-06 by A. Dehn)
- FRM Maturity Assessment Framework  
  (talk Th-02 by N. Fox)
- CEOS Cal/Val Portal  
  (talk Th-03 by P. Castracane)
- CEOS-ARD certification, VH-RODA, New Space…
- Interoperability framework: vocabulary, architecture, interfacing, quality, policy
- Collaboration with WMO, ISO/OGC, IMEO, CGMS-GSICS  
  (talk Th-09 by L. Flynn)
L1B Calibration and Validation

- Best practices: vicarious, DCC, PICS, SNO, Rayleigh Scattering, GEO/LEO, [...] and SITSat

- SWIR Cal/Val for GOSAT-1/2, OCO-2/3 & TROPOMI (see Tu-21 talk by S. Kei and Th-10 talk by A. Kuze)
  - Regular OCO-GOSAT-TROPOMI Calibration Meetings
  - RRV campaigns website at JAXA https://www.eorc.jaxa.jp/GOSAT/GHGs_Vical/index.html

- Collaboration with CGMS-GSICS (see Th-09 talk by L. Flynn)
  - UVN Spectrometer Break Out Session at GSICS annual meeting 2023/03
  - Pre-flight optical sensors calibration workshop, ESA/ESTEC, 2024/11

- SI-Traceable Satellites (SITSat) (see Th-04 talk by M. Thankappan)
Roadmap towards an Assessment Framework for Fiducial Reference Measurements (FRM)


Next step: pilot applications, ESA FRM4DOAS project for Atmospheric Composition

<table>
<thead>
<tr>
<th>self-assessment</th>
<th>independent assessor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>nature of FRM</strong></td>
<td><strong>FRM instrumentation</strong></td>
</tr>
<tr>
<td>descriptor</td>
<td>instrument documentation</td>
</tr>
<tr>
<td>location/availability of FRM</td>
<td>evidence of traceable calibration</td>
</tr>
<tr>
<td>range of sensors</td>
<td>maintenance plan</td>
</tr>
<tr>
<td>complementary observations</td>
<td>operator expertise</td>
</tr>
</tbody>
</table>

**FRM CLASSIFICATION**

A B C D (to be selected)
Ground-based networks design

There is a need for R&D on network design, in particular for emerging measurement networks, but also for FRM-tailoring and sustainability of the existing networks.

- Range of measurand
- Geographical coverage, types of atmospheric states (or regimes)
- Range and sampling of main influence quantities (SZA, T profile, surface albedo, aerosols, clouds…)
- Assessment of the spatio-temporal representativeness of measurements at a given location – requiring also assessment of spatio-temporal variability at that location => complementarity of airborne campaigns and modelling
- Co-location of instruments at ‘supersites’, e.g., SWIR with UVVIS, atmospheric composition and ancillary data (incl. surf. albedo) for in-depth validation of retrieval algorithms, validation of attribution proxies (simultaneous measurements of CO₂, NO₂, HCHO, SIF, smoke AOD)…
Maturity of Validation Method

Generic round-robin & validation protocol for atmospheric composition data

Keppens et al., AMT 2015

Presented at CEOS AC-(V)C 2014, College Park
# Maturity of Validation Method

## Maturity assessment process for AC Validation Methods based on

- **Round-robin generic protocol**  
  (Keppens et al., *AMT* 2015)

- **Validation across EO domains**  
  (Loew et al., *Rev. Geophys.* 2017)

---

<table>
<thead>
<tr>
<th>Operation</th>
<th>Input</th>
<th>Task</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Design of the validation study</strong></td>
<td>Data quality requirements</td>
<td>Design validation objectives, quality indicators to produce, domains and ranges to evaluate</td>
<td>Design of following steps, including list of targeted quality indicators</td>
</tr>
<tr>
<td>2. <strong>Data selection and pre-processing</strong></td>
<td>Original datasets, quality flags, usage recommendations</td>
<td>Quality control of satellite sensor data, data set</td>
<td>Original datasets + cleaned datasets</td>
</tr>
<tr>
<td>3. <strong>Data content analyses</strong></td>
<td>Analytical approaches</td>
<td>Quality screening of calibration data</td>
<td>Validation of quality flags, identification of geospatial/seasonal coverage and horizontal resolution</td>
</tr>
<tr>
<td>4. <strong>Information content analysis</strong></td>
<td>Iterative approaches</td>
<td>Algorithmic analysis of vertical averaging kernels matrices, eigenvectors, covariance, SP, Rayleigh-Green spread</td>
<td>Information content metrics, vertical sensitivity and resolution, height representation</td>
</tr>
<tr>
<td>5. <strong>Spatio-temporal co-location</strong></td>
<td>Co-located data points and metadata</td>
<td>Analysis of co-located points and associated parameters (coherence, accuracy data)</td>
<td>Co-located satellite and validation data sets and metadata</td>
</tr>
<tr>
<td>6. <strong>Data harmonization</strong></td>
<td>Co-located data points, associated averaging kernels, a priori and covariances</td>
<td>Change in co-regionalization, vertical and horizontal smoothing</td>
<td>Co-located satellite validation data sets with comparable vertical and horizontal resolution and improved intercomparability for consistency</td>
</tr>
<tr>
<td>7. <strong>Data comparison and analysis</strong></td>
<td>Co-located data points, associated averaging kernels</td>
<td>Visual comparison of time series and product differences</td>
<td>Time series, maps, histograms, distributions, average values (bias, spread, drift)</td>
</tr>
<tr>
<td>8. <strong>Quality estimation</strong></td>
<td>Outcomes of previous steps</td>
<td>Statistical testing of the assumptions, quality indicators and conclusions</td>
<td>Confidence and quantified quality indicators, recommendations and conclusions</td>
</tr>
<tr>
<td>9. <strong>Acceptance</strong></td>
<td>Acceptance criteria</td>
<td>Comparison of satellite data quality performance against mission and/or user requirements</td>
<td>Validation of satellite data quality, mission and/or user requirements</td>
</tr>
</tbody>
</table>

## Maturity assessment of validation methods for Sentinel-4/5p/5 & CO2M data products

(Verhoelst et al., *CCVS* D3.2, 2022)
CEOS CV-22-01: Validation protocols for atmospheric aerosol and cloud profiles

See Th-05 presentation by R. Koopman

Coordinator: R. Koopman (ESA/ESTEC). Agencies: ESA, NASA, JAXA and EUMETSAT, group expanding with 83 contributors at present

ESA-JAXA EarthCARE workshop, ESA/ESRIN, 13-17 Nov. 2023
Recent launches
❖ MATS (L 2022/11)
❖ NOAA-21 OMPS-LP (L 2022/11)

Upcoming missions
❖ ARGOS (L 2024/Q2)
❖ ALTIUS (L 2026/03)

Developments
❖ C-MLS, SMILES-2
❖ CAIRT (candidate EE-11)
❖ SAGE IV, CubeMAP
❖ HAWC ALI, TICFIRE and SHOW

Validation challenges: mesosphere, H₂O, aerosols and clouds, dynamics/waves, 3D/tomography, operational validation for DA & services, constellations
Questions from TOAR-I  
(Gaudel et al., 2018)

- Why do measured distributions and trends differ (i) among satellites, and (ii) w.r.t. monitoring networks?
- Differences in vertical sensitivity and sampling?
- Differences in tropopause column definition?
- (In)consistencies with TOST (ozonesonde based trajectories)?

**CEOS response:** VC-20-01 - Tropospheric ozone dataset validation and harmonization

- Coordinator: D. Loyola (DLR); support G. Labow (NASA) & J.-C. Lambert (BIRA-IASB)
- 15+ participating agencies
- Participation in TOAR-II Satellite Ozone WG
- Participation in SPARC TUNER (Towards Unified Error Reporting)
- Status: reports in the Tropospheric Ozone session this afternoon (talks Th-12 to Th-18)
**GHG Satellite Constellation**

**GHG constellation roadmap – Annex C: Implementations actions – Calibration & Validation**

<table>
<thead>
<tr>
<th>AREA</th>
<th>ACTION ID</th>
<th>ACTION DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration &amp; Validation</td>
<td>CV-1</td>
<td>Address existing CEOS Action by Q1 2020 on “Greenhouse gas reference standards for interoperability”: Develop a list of reference standards for CO₂ and CH₄ products that are suitable for use in inter-comparison of multiple missions.</td>
</tr>
<tr>
<td></td>
<td>CV-2</td>
<td>Identify the current shortcomings/gaps/sustainability in GHG calibration and validation capabilities, and formulate recommendations on the medium- to long-term way forward, that is with a specific focus on GHG Fiducial Reference Measurement (FRM).</td>
</tr>
<tr>
<td></td>
<td>CV-3</td>
<td>Identify gaps and suggest improvements in the inter-calibration of a future LEO/GEO constellation of GHG sensors</td>
</tr>
<tr>
<td></td>
<td>CV-4</td>
<td>Define protocols for comparing and validating GHG retrieval algorithms</td>
</tr>
<tr>
<td></td>
<td>CV-5</td>
<td>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).</td>
</tr>
<tr>
<td></td>
<td>CV-6</td>
<td>Work towards an operational reporting on the quality of space-borne GHG measurements and the underlying calibration and validation infrastructure.</td>
</tr>
<tr>
<td></td>
<td>CV-7</td>
<td>Identify a repository for hosting quality-controlled CO₂ and CH₄ products - see Rec#13: CEOS and CGMS agencies should consider a [centralized or possibly geographically distributed] repository for hosting quality-controlled CO₂ and CH₄ products, with internal capability for product inter-comparison.</td>
</tr>
</tbody>
</table>

**ROADMAP FOR IMPLEMENTATION OF A CONSTELLATION ARCHITECTURE FOR MONITORING CARBON DIOXIDE AND METHANE FROM SPACE**

In cooperation with the Coordination Group for Meteorological Satellites (CGMS) & WMO Global Space-based Inter-Calibration System (GSICS)

v2.3, March 2020
Update in progress
CV-2 Identify the current shortcomings/gaps/sustainability in GHG calibration and validation capabilities, and formulate recommendations on the medium- to long-term way forward, that is with a specific focus on GHG Fiducial Reference Measurement (FRM).

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)
GHG Satellite Constellation

GHG constellation roadmap – Annex C: Calibration & Validation

**CV-6 Pathfinder:** ESA/Copernicus ATM-MPC Sentinel-5P TROPOMI CH₄ and CO operational validation based on three GHG column/profile monitoring networks

- **NDACC FTIR:** automated validation channel in ATM-MPC
  - 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 CH₄ & 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

CH₄ images courtesy M.K. Sha

S5P TROPOMI CH₄ and FTIR CH₄ relative difference (sat–gob) (weekly mean)

S5P TROPOMI CH₄ and FTIR CH₄ relative difference (sat–gob) (weekly mean)

TCCON GGG2020 data released 26 April 2022

NDACC FTIRs

Collection of permanent and campaign based observations

~17 COCCON stations to contribute in the future

AC-VC #19 / ACG Joint Meeting, 24-27 October 2023

Th-01 - Cal/Val for Atmospheric Composition - Slide 14
1. **NETWORKS DESIGN AND EVOLUTION**: to support gap analysis studies with a view to tailoring CO₂, CH₄ and N₂O 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.
### Air Quality Constellation

<table>
<thead>
<tr>
<th>VC-20-02</th>
<th>Air quality constellation validation coordination</th>
<th>2024 Q4</th>
<th>AC-VC WGCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC-20-03</td>
<td>Air quality constellation validation coordination: validation plans</td>
<td>2022 Q4</td>
<td>AC-VC WGCV</td>
</tr>
<tr>
<td>VC-20-04</td>
<td>Air quality constellation validation coordination: announcements of opportunity</td>
<td>2023 Q4</td>
<td>AC-VC WGCV</td>
</tr>
</tbody>
</table>

**Cal/Val coordination (VC-20-02), plans (-03), Announcements of Opportunities (-04)**

*See presentations in Wednesday morning AQ Session*

- GEMS AO (issued 2018) → Cal/Val activities with international participation, ESA PEGASOS routine validation service, comparisons with Sentinel-5P, testing of Sentinel-4 L2 algorithms
- TEMPO (L 2023/04), Mission Validation Plan, joint NASA/NOAA summer 2023 field campaigns
- Sentinel-4/5 Cal/Val AO Call to be issued end 2023
- New Pandora products (SO₂, HCHO, O₃), growing Pandora Asian Network complementing Pandora Global Network for operational acquisition of reference data
- CINDI-3 field campaign (2024/05-06): MAX-DOAS inter-calibration, aerosols, tomography…
- NDACC FTIR network expanding to/operationalizing for new species: HCHO, NH₃…
Recommendations

1. Consistently perform intensive campaigns dedicated to the validation of the capability of the Geo-AQ missions to observe the diurnal cycle of the target species. Such campaigns are conducted at several supersites within each Geo-AQ mission domain where a comprehensive suite of correlative reference measurements is made and a comprehensive set of auxiliary data from a variety of sources is exploited.

2. Conduct joint validation campaigns with exchange of reference airborne and ground-based instruments.

3. Further develop and eventually apply approaches to the radiometric inter-calibration of the Geo-AQ missions, based on comparisons of Earth radiance data acquired over known targets, traceable test sites where available, precise and approximate ray matching between GEO and LEO pairs of missions, and by taking the LEO missions as a travelling standard. These activities should be pursued within the frame of the WMO GSICS initiative.

4. Further develop and eventually apply approaches to the inter-calibration of the Level-2 products of the Geo-AQ missions. These approaches include the comparison of products with inter-calibrated ground-based network data, cross-validation of Level-2 algorithms by exchanging Level-1b data, comparing zonal mean values of the stratospheric sub-column in the Level-2 ozone products, and taking validated LEO missions as a travelling standard.

5. Systematically process the Level-2 Constellation Products of the Geo-AQ missions, using one selected common algorithm per Constellation Product.

6. Further pursue the harmonization of the reference data used for validation and inter-mission consistency verification of Level-2 products, aiming at common measurement protocols, common QA protocols, common data formats, harmonized data policy and open access.

7. Implement a data centre for storage and exchange of all validation data collected for the Geo-AQ missions. Make these data accessible to the entire community involved in the validation of the Geo-AQ mission products and their inter-mission consistency, very soon after acquisition.

8. Implement a coordinating unit for ensuring the consistency of the approach and the metrics used for validating the Geo-AQ mission products and their inter-mission consistency.

Next steps: roadmap, gap analysis

Air Quality Constellation
Whitepaper “Monitoring Surface PM2.5” (VC-20-05) endorsed at plenary 2022

Cal/Val related recommendations:

6. Continue efforts to establish, monitor, and enhance the radiometric calibration consistency of space-borne multispectral imagers. Continue and strengthen related efforts made by the Global Space-based Inter-Calibration System (GSICS).

14. Collect and analyze comprehensive reference data sets including measurements from ground-based in-situ PM sensors and co-located radiometers and ceilometers, in order to enhance the understanding of the link between satellite observables and near-surface PM concentrations.

15. Validate satellite-informed PM products, using ground-based in-situ PM data from operational networks. Pursue extending the source of PM reference data by calibrating low-cost PM$_{2.5}$ sensors and developing correction methodologies.

16. Create a data center for providing access to validation data.

Next steps: Cal/Val needs → roadmap
### 12:00 - 13:00

**Th-11 - Panel review of Cal/Val needs for the AER, GEO-AQ and GHG constellations.** Discussion on the way forward (suggestions): need for framework documents, Cal/Val protocols, Task Teams, match-up databases, field activities…?

General Q&A, wrap-up