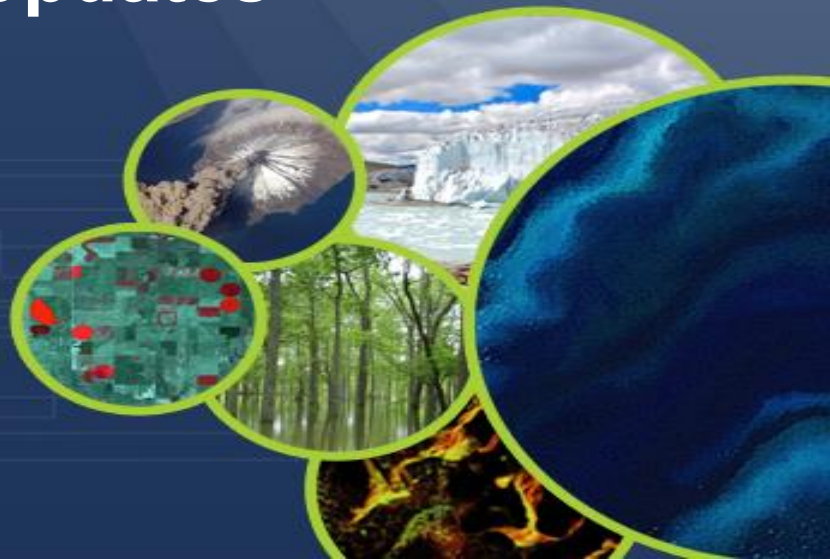
Committee on Earth Observation Satellites

Atmospheric Composition Updates

Jean-Christopher LAMBERT (BIRA-IASB)



CEOS WGCV-50 Teleconference

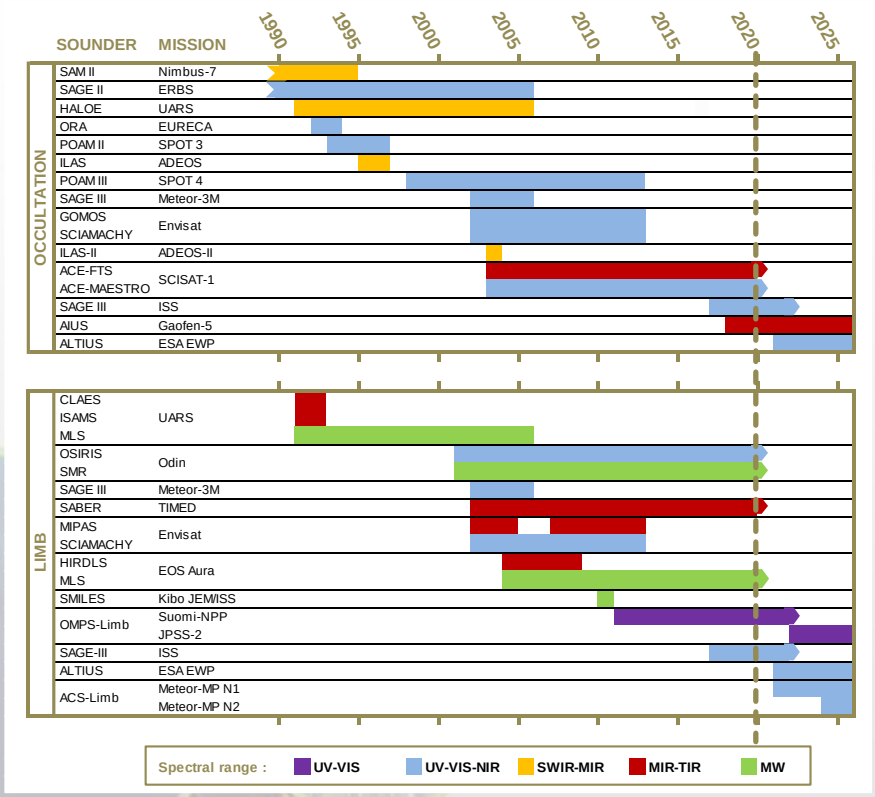
March 22-25, 2022

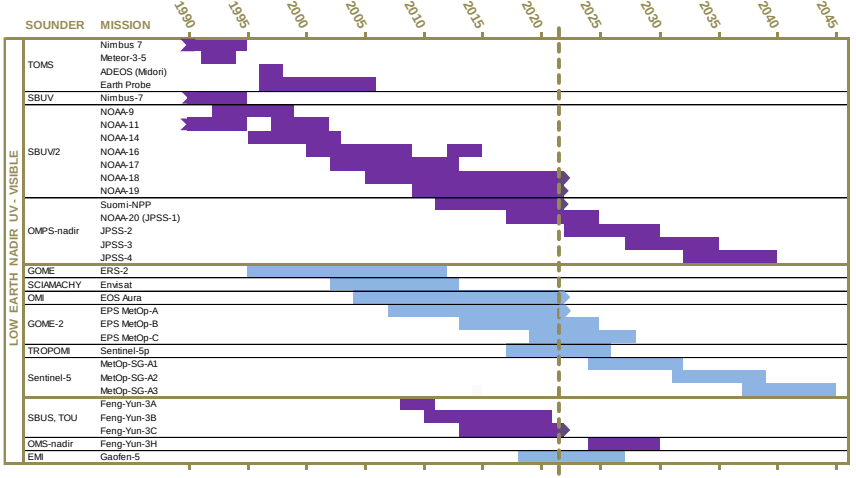
Working Group on Calibration and Validation

Atmospheric Composition Updates

1. ACSG update
2. AC-VC update
3. GHG validation
4. AQ Constellation [VC-20-02/03/04]
5. Tropospheric Ozone [VC-20-01]
6. Clouds, aerosols and radiation [CV-22-01]
7. Cal/Val Maturity Matrix

Atmospheric Composition Missions





Atmospheric Composition Sub Group

- **ACSG Chair Bojan Bojkov stepped down in 2021.**
  - Election of new Chair required (interim by former Vice-Chair J.-C. Lambert)
- **Evolution of ACSG over last years**
  - Topical activities: O3, limb/occ., AQ, GHG, FRM Gap Analysis, aerosols/clouds
  - Ad hoc support to AC-VC: joint VC/CV activities, white papers, plans, protocols…
  - Closer linkage of space agencies with ground-based monitoring networks
- **ACSG objectives and membership**
  - Need to get on with topical evolution and support to constellations
  - Possible structure: 3 Co-Leads + ad hoc expert/topic Leads
  - Membership: agencies + expert/topic lists

Atmospheric Composition VC 18th Meeting

- After AC-VC-15 (2019) in Nakano, AC-VC-16 and AC-VC-17 (and joint GEMS/Sentinel-4/TEMPO) meetings originally planned to be hosted by BELSPO and BIRA-IASB in Brussels => ONLINE MEETINGS (2020/06, 2021/06)
- AC-VC-18 meeting (2022/03, once again remotely):
  - Mo: Greenhouse gases (Lead J. Worden, JPL)
  - Tu: Air Quality: Aerosols (Lead S. Kondragunta, NOAA)
  - We: Air quality: Trace gases (Leads B. Lefer, NASA, B. Veheilmann, ESA)
  - Th: Tropospheric ozone (Lead D. Loyola, DLR)
  - Fr: Science serving society (Chairs B. Lefer, NASA, H. Tanimoto, NIES, B. Veheilmann, ESA)
- Sessions and discussions address Cal/Val activities, Cal/Val needs, coordination of constellation wide validation, interleaved AC-VC / WGCV activities, new validation needs beyond L2 (e.g., emissions, fluxes, services)

Ground-based validation measurements

Fiducial Reference Measurements and other validation data

- Asian/Pacific PGN and MAX-DOAS networks (GEMS, GOSAT-GW and S5P focus)
- ESA/NASA/USEPA/LuftBlick Pandonia Global Network (PGN) NO_2, O_3, SO_2, HCHO
- US EPA/NASA efforts to integrate remote sensing at existing AQ monitoring sites
- ESA FRM4DOAS, consistency between MAX-DOAS, direct-sun UV and FTIR (HCHO and NO_2)
- EUBREWNET recalibration and uncertainty budget
- EUMETSAT CO2M FRM study, ESA FRM4GHG, COCCON
- ACTRIS CLOUDNET, ESA FRM4RADAR, US ARM
- Copernicus Cal/Val Solution (CCVS) gap analysis

FRM/validation data distribution infrastructures

- 9 atmospheric Cal/Val data services assessed in CCVS T2.6
- ACTRIS, AERIS, ASDC, CEDA, EVDC, HALO, ICOS are FAIR
- Network data centers assessed previously in GAIA-CLIM: GRUAN, NDACC, TCCON, WOUDC…

GHG Measurement Networks for Satellite Validation

NDACC IRWG

https://ndacc.org

- Bruker 120HR/125HR, res. 0.0036 cm^{-1}
- Operational use in: EUMETSAT AC SAF IASI validation, ESA MPC TROPOMI validation, CAMS validation (RD delivery supported by CAMS27)
- Recent and ongoing harmonisation efforts in QA4ECV, GAIA-CLIM, CAMS27, C3S-311a-Lot3 (BARON)
  Upcoming SFIT/PROFFIT to improve harmonization of uncertainties evaluation, better spectroscopy
- Selected NDACC stations to join EU research infrastructure ACTRIS: with central processing facility, QA/QC, training…
- CO_2 retrieval strategy under development (IUP/UB & BIRA-IASB)

TCCON

https://tccon.org

- Bruker 125HR, resolution 0.02 cm^{-1}
- Operational use in: OCO-2/3 & GOSAT/2 Cal/Val, CAMS validation, ESA MPC TROPOMI validation (limited RD delivery)…
- GGG2020 improves prior profiles (shape and possible bias), CO calibration factor, spectroscopy, reduces remaining airmass and H_2O dependences, reduces scatter in CO product, improves diagnostics for instrumental issues.
- Selected TCCON stations to join EU research infrastructure ICOS, with central processing facility
- Profile retrievals under development. Tropospheric partial columns can be derived indirectly

COCCON

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

- Bruker EM27/SUN, resolution 0.5 cm^{-1}
- Operational usage in: OCO-2/3, GOSAT/2, S5P TROPOMI validation (started in 2020)…
- Planned update foreseen for PROFFAST, redefined spectroscopic descriptions + improved line lists
- EM27/SUN as travelling standard for TCCON, COCCON can complement TCCON, support by ESA for COCCON-PROCEEDS, follow-up crucial for current capabilities of COCCON
- Towards extension of COCCON with VERTEX70 and IRcube (2 other low resolution FTIR instruments – with higher spectral resolution and additional species) – ESA FRM4GHG project
  https://frm4ghg.aeronomie.be

Courtesy M.K. Sha, M. De Mazière and B. Langerock (BIRA-IASB)

GHG Cal/Val Roadmap toward global stocktake 2023 and 2028

2003 2008 2013 2018 2023 2028

Instruments

- Moderate spectral resolution
- High spectral resolution and wide coverage SWIR-TIR and pointing
- Imaging & high spectral resolution
- Imaging high spectral resolution & pointing
- Full spatial coverage
- GHG and NO_2
- Compact Geo

CAL

Challenge
(1) Mueller matrix

- Prelaunch Cross calibration: Intercomparison of radiometric standard
- Vicarious calibration, coincident observation of multiple sensors
- Cold site, uneven topography, thick aerosol

VAL
（GHG Density）

- International commercial flights, sampling, in-situ
- **Column density with ground-based high-resolution FTS**
- **Vertical profile** : radiosonde, airplane (spiral flight)
- **Portable moderate resolution FTS at CAL/VAL sites**

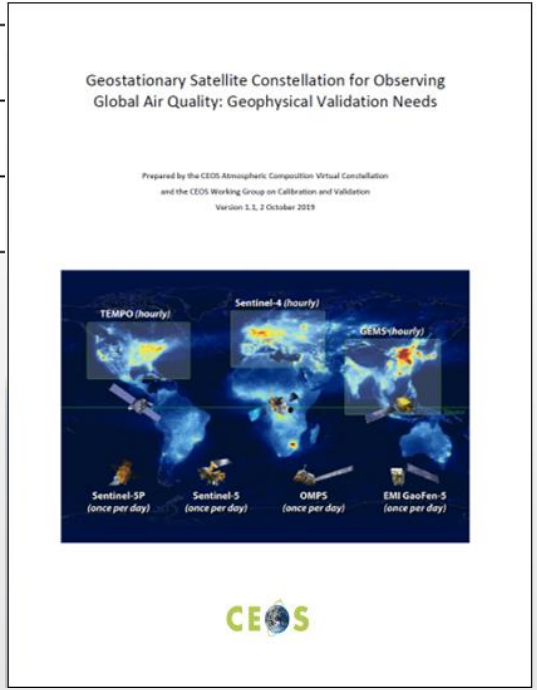
VAL
（Flux）

Challenge
(1) Global flux
(2) Windspeed and direction Accuracy

- Airplane: emission from different source sectors Mega cities
- Simultaneous NO_2 measurement

AQ Constellation Validation Coordination

VC-20-02	Air quality constellation validation coordination	2024 Q4	AC-VC WGCV
VC-20-03	Air quality constellation validation coordination: validation plans	2022 Q4	AC-VC WGCV
VC-20-04	Air quality constellation validation coordination: announcements of opportunity	2023 Q4	AC-VC WGCV



Contact: Ben Veihelmann (ESA)

Contributing agencies: ESA, EUMETSAT, IASB-BIRA, DLR, Luftblick, NASA, NIER, NOAA, SAO, U. Iowa, U. Seoul, U. Yonsei

Next steps: overall coordination, plans and AO

Active collaboration GEMS, Sentinel-5p, TEMPO and Sentinel-4/5

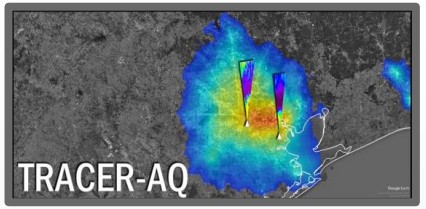
Ideas of multi-mission validation system evoked

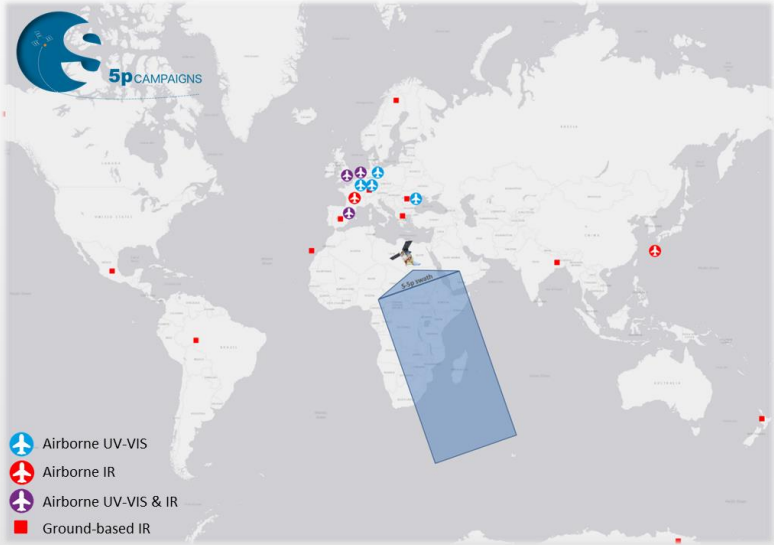
Coordination wished with CO_2 missions measuring CO & NO_2

AQ Constellation Validation Coordination

AC-VC-18, Air Quality Trace Gases Session (2022/03)

	Calibration/Validation of AQ Observations	
3.09	S5P/TROPOMI AQ Products Cal/Val Status	Jean-Christopher Lambert (BIRA)
3.10	Pandora Asia Network for Air Quality Diagnosis and GEMS Validation	Limseok Chang (NIER)
3.11	GMAP2021 Campaign, MAX-DOAS and Pandora Consistency, GOSAT-GW Validation Plan	Yugo Kanaya (JAMSTEC)
3.12	ASIA-AQ Campaign Plans	Jim Crawford (NASA)
3.13	AEROMMA Campaign: Objectives for TEMPO Validation	Brian McDonald (NOAA)
3.14	EPA Efforts on Preparing for TEMPO Validation	Luke Valin (US EPA), Jim Szykman (US EPA)
	Discussion	
3.15	what to do to make the satellite products more useful? issues related to assimilating AQ trace gas products into AQ forecasts multi-sensors synergy for AQ trace gas observation? exploring the relationship between AQ trace gases and GHGs and value to the Global Stocktake WGCV-atmospheric sub-group	All





IGAC Tropospheric Ozone Assessment Report

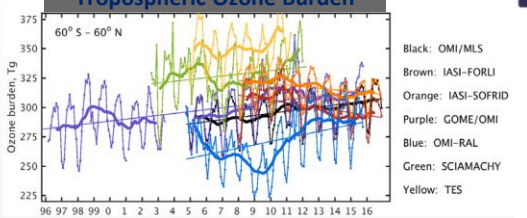
Questions from TOAR-I (Gaudel *et al.*, 2018)

- Why do measured distributions and trends differ (i) among satellites, and (ii) w.r.t. monitoring networks ?

TOAR-II Satellite Ozone Working Group goals

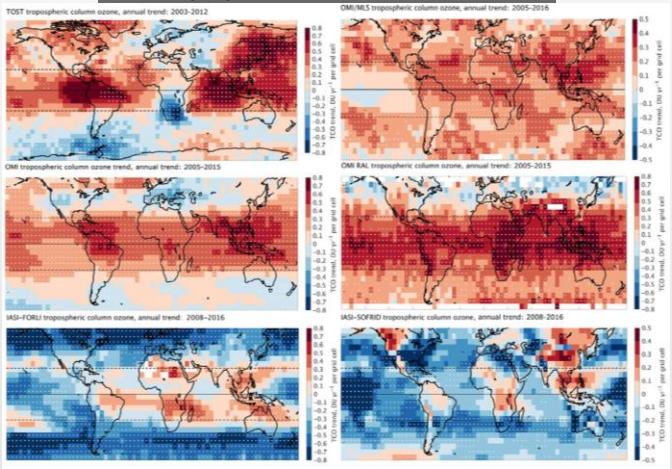
- Reconcile satellite-, ground- and aircraft-based data
- Global chemistry transport models as transfer standard
- Provide common methodology for validation of trends

Tropospheric Ozone Burden



TOAR tropospheric ozone assessment report

Tropospheric Ozone Annual Trend

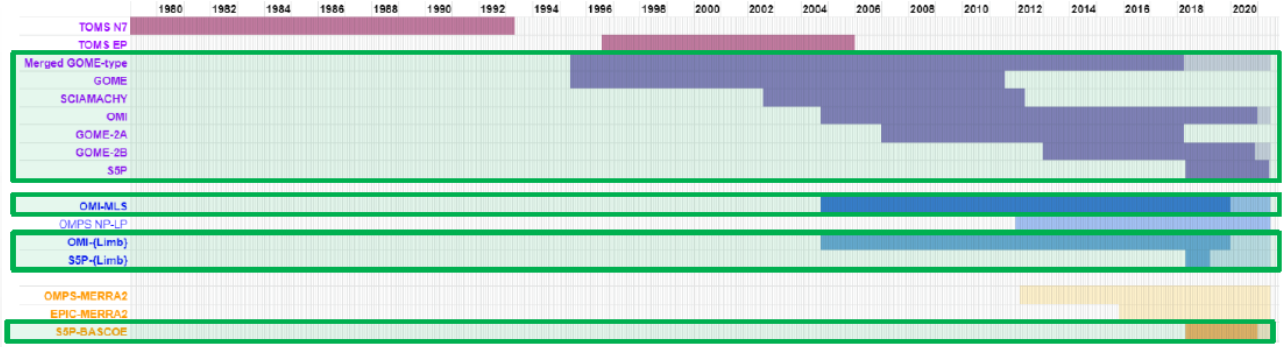


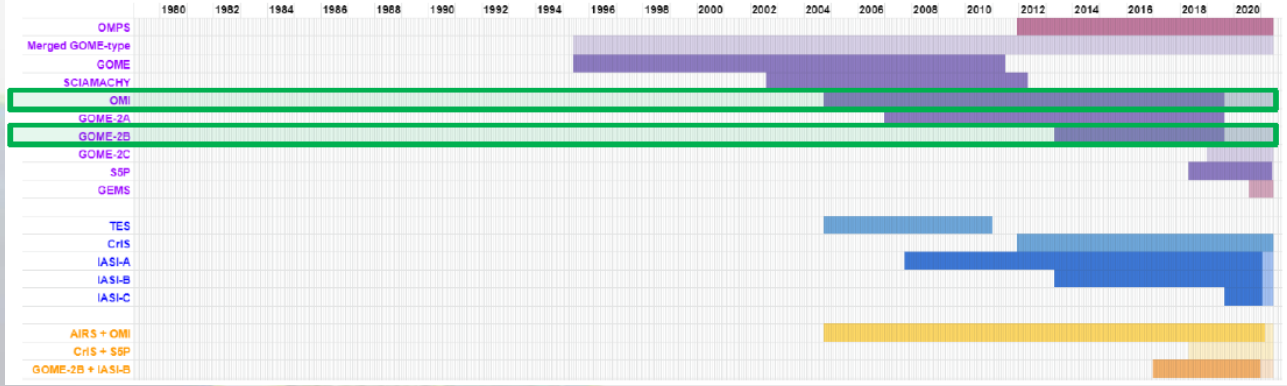
CEOS VC-20-01 Tropospheric Ozone Activity

VC-20-01	Tropospheric ozone dataset validation and harmonization	2022 Q4	AC-VC

- **VC-20-01: *'Tropospheric ozone dataset validation and harmonization'***
- **Contact: D. Loyola (DLR)**
- **Contributors: BIRA-IASB, DLR, ESA, JPL, KNMI, LISA, NASA, NOAA, UPusan, ULB…**
- **CEOS response to IGAC TOAR-II needs**
- **Active cooperation with TOAR-II Satellite Ozone WG and HEGIFTOM WG**
- **VC-20-01 schedule and status:**
  - ✓ **Kick-off at AC-VC-16 (June 2020)**
  - ✓ **Harmonization and validation protocol discussed at AC-VC-17 (June 2021), test results**
  - ✓ **TOAR-II SOWG and HEGIFTOM meetings (2021, 2022)**
  - ✓ **VC-20-01 report at AC-VC-18 (March 2022): harmonization results, validation results**
  - **Ongoing: more datasets, further work, contributions to TOAR-II publications (2022+)**

CEOS VC-20-01 Tropospheric Ozone Activity: Contributing Satellite Data Records





Residual technique (UV-VIS sensors)

- Convective Cloud Differential
- Nadir minus Limb
- Nadir minus Reanalysis

Profile retrieval

- UV-VIS
- IR
- VIS+IR synergy

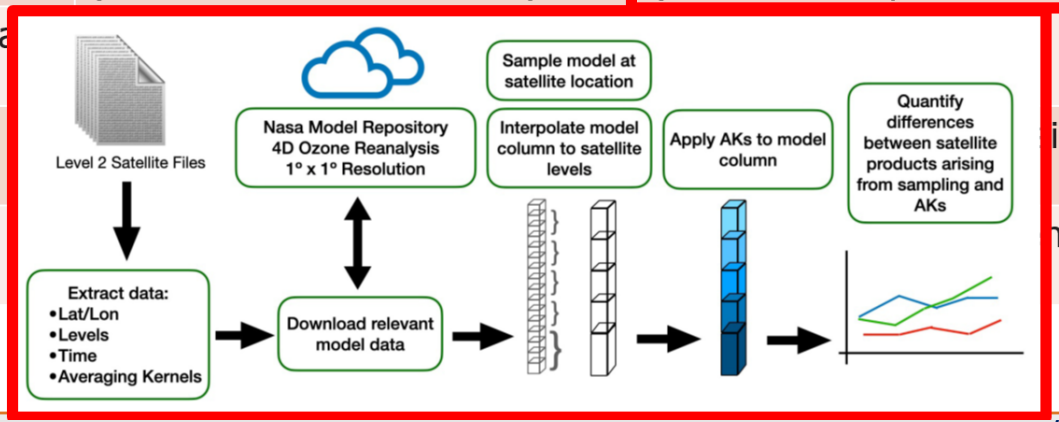
Courtesy: daan.Hubert@aeronomie.be

CEOS VC-20-01 Tropospheric Ozone Activity: AC-VC-18 Tropospheric Ozone Session

Thursday, March 17	
Tropospheric Ozone Session	**Chair: Diego Loyola (DLR)**
Introduction / goals	
TOAR-II	
TOAR-II: General progress report and an update on satellite intercomparisons	Owen R. Cooper (NOAA) and Helen Worden (UCAR)
TOAR-II data portal for global measurements of ozone and its precursors	Sabine Schröder (FZ Jülich)
Validation	
Vertical harmonization of satellite tropospheric ozone data	Arno Keppens (BIRA)
Intercomparison of satellite tropospheric ozone CDRs	Daan Hubert (BIRA)
EPIC tropospheric ozone validation	Jerry Ziemke (NASA)
OMI tropospheric ozone validation	Juseon Bak (Pusan National University)
IASI/GOME-2 tropospheric ozone validation	Juan Cuesta (LISA)
AIRS/OMI tropospheric ozone validation	Greg Osterman (JPL)
CrIS/TROPOMI tropospheric ozone validation	Ed Malina (JPL)

Vertical harmonization approaches
(cf. 2021 QOS21, IGAC, LPS22 talks)

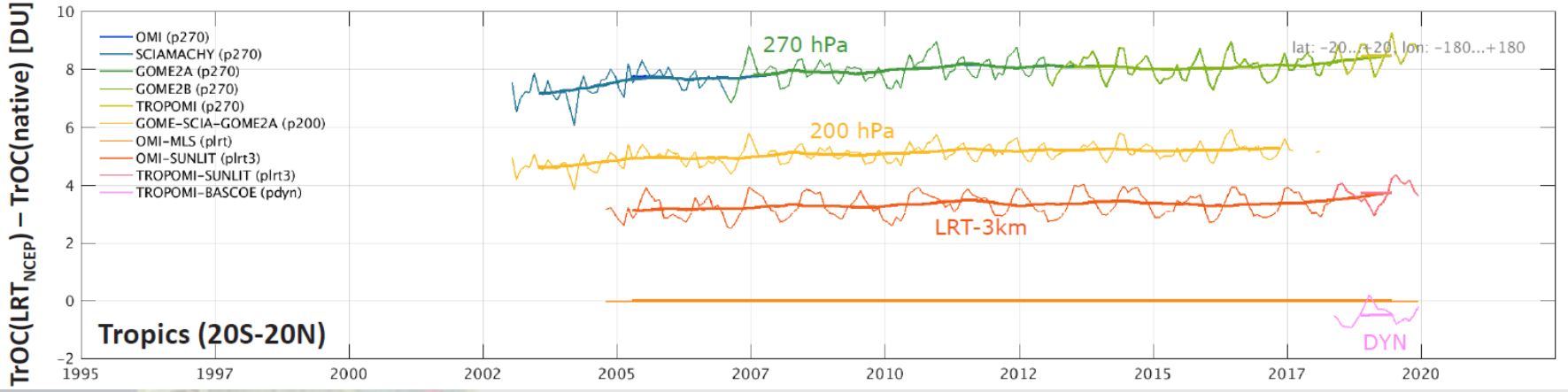
	CEOS VC-20-01	TOAR-II SOWG (see A4.02)
Phase 1: L2 profile data	Prior replacement by transfer standard and vertical integration within predefined spatiotemporal grid (BIRA-IASB Multi-TASTE)	Quantifying trend differences arising from sampling and vertical sensitivity differences (tool to data providers)
Phase 1: L3-like column da		
Phase 2		ing
Phase 3		nds on



Courtesy: arno.keppens@aeronomie.be

CEOS VC-20-01 Tropospheric Ozone Activity: Satellite Data Harmonization

- Different data records have different Top of Troposphere definition *l*
  - CCD DLR : fixed pressure 270 hPa
  - CCD IUP : fixed pressure 200 hPa
  - SUNLIT : altitude WMO lapse-rate tropopause – 3 km (ERA5)
  - S5P-BASCOE : pressure dynamical tropopause (ERA5)
  - OMI-MLS : pressure WMO lapse-rate tropopause (NCEP)

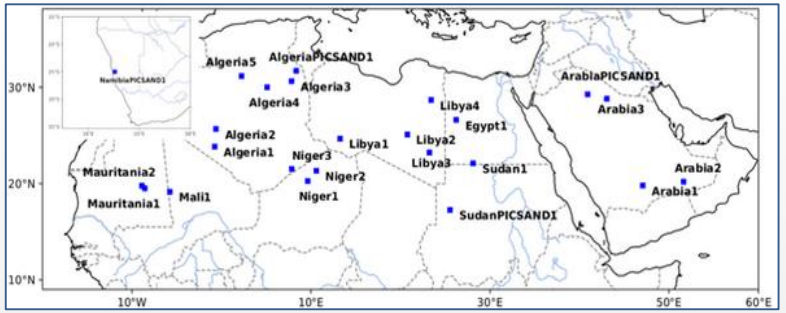


Courtesy: arno.keppens@aeronomie.be

Surface related validation activities for atmospheric missions

WGCV-49: Emerging interest in validation of Level-1 FCDRs (calibration validation), in validation of LER/DLER/GLER/GELER retrievals and climatologies, in use of PICS, in directional properties of surface, in validation of pixel geolocation… from UV-Vis to SWIR and TIR

⇒ **AI: to maintain a watch on surface related validation activities emerging in the atmospheric composition world (PICS, (D)(G(E))LER, etc.) over the coming months, collect material and contact points, and investigate opportunities for a concrete action or activity.**



Van Kempen et al., AMT 2021
PICS-based TROPOMI SWIR stability monitoring

Recent advances in TROPOMI L1b UV-Vis and SWIR evaluation

- **TROPOMI comparison to SNPP OMPS-NP demonstrates improvement from L1b v1 to L1b v2; comparisons to VIIRS, OCO-2 and TANSO envisaged**
- **Use of pseudo-invariant sites (PICS) to monitor long-term stability of reflectance (ISO 19159 calibration validation):**
  - spatial uniformity and homogeneity and temporal stability of spectral characteristics,
  - high reflectance for better SNR,
  - low aerosol loading, little rainfall, quasi no vegetation or human impact

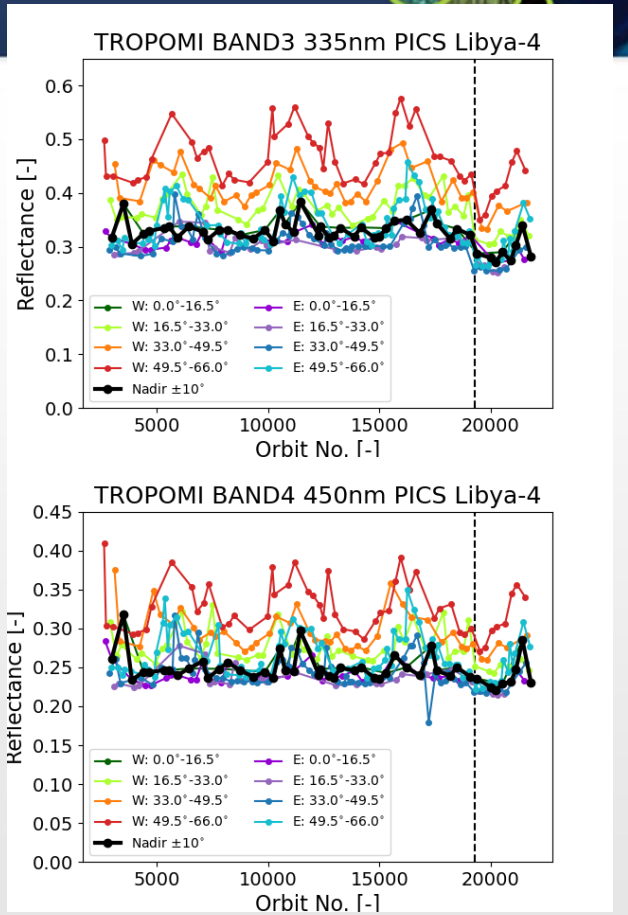


Illustration courtesy: M. Coldewey-Ebgers, D. Loyola (DLR)

Surface related validation activities for atmospheric missions

Status:

- Specific contact points and AC-VC plenary contacted and probed
- Relevant information conveyed: GHG_VICAL, PICSCAR, RadCalNet
- UV-Vis: R&D ongoing, use of desert PICS (RRV, Sahara) investigated, surface BRDF effects, results (being) published
- SWIR: GOSAT-OCO-TROPOMI activity, sunglint validation; broader range of influence quantities and co-located vertical profiling (aircraft, AirCore) required
- TIR: see CNES CEOS Chair priority (P. Henry, talk 4.2)
- Expertise and role of GSICS underlined, duplication to be avoided
- Interest in specific resource section on CEOS Cal/Val Portal

(Radiometric) Clouds as Influence Quantities for L2 Trace Gas Retrievals

- Clouds modify the radiance measured by atmospheric composition sounders and influence the L2 retrieval of trace gases by masking and by modified sensitivity.
- Radiometric (not geometric) cloud fraction, cloud top height and/or cloud optical thickness for GOME-2, MODIS, TROPOMI, VIIRS, … are retrieved in the NIR (O_2-A), VIS (O_2-O_2) and with imagers, with several key assumptions: reflecting boundaries, multi-layered…
- Changes in L1 calibration do impact radiometric cloud retrievals.
- Several intercomparison studies ongoing
- Interest of agencies probed at AC-VC-18: several AQ agencies interested in discussing a cloud intercomparison exercise dedicated to effects on AQ data retrievals.

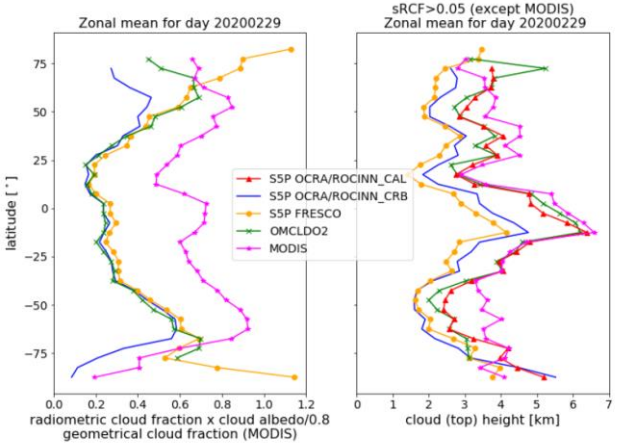
Atmos. Meas. Tech., 14, 2451–2476, 2021
https://doi.org/10.5194/amt-14-2451-2021

Atmospheric Measurement Techniques
Open Access
EGU

Validation of the Sentinel-5 Precursor TROPOMI cloud data with Cloudnet, Aura OMI O_2–O_2, MODIS, and Suomi-NPP VIIRS

Steven Compernolle[1], Athina Argyrouli[2,3], Ronny Lutz[3], Maarten Sneep[4], Jean-Christopher Lambert[1], Ann Mari Fjæraa[3], Daan Hubert[1], Arno Keppens[1], Diego Loyola[3], Ewan O'Connor[6,7], Fabian Romahn[3], Piet Stammes[4], Tijl Verhoelst[1], and Ping Wang[4]

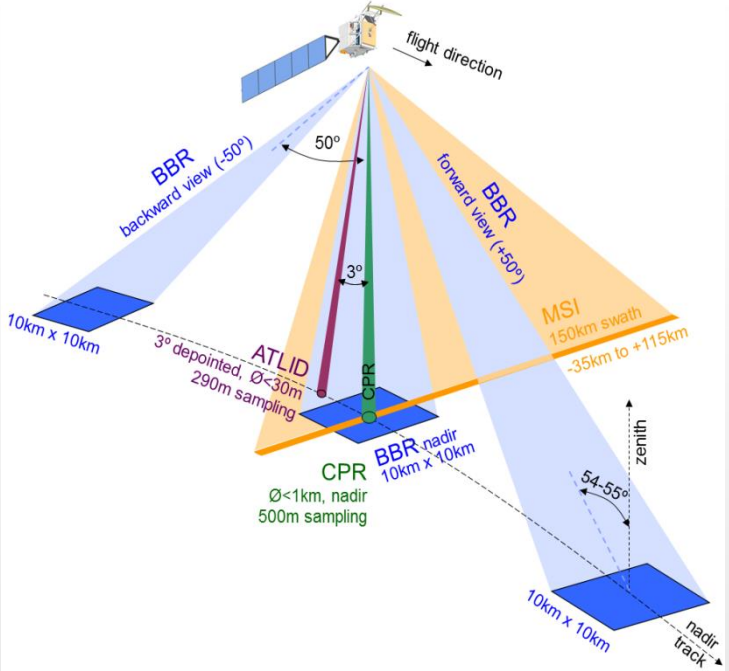
[1]Atmospheric Data Synergies, Atmospheric Reactive Gases, Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Ringlaan 3, 1180 Uccle (Brussels), Belgium
[2]TUM Department of Civil, Geo and Environmental Engineering, Chair of Remote Sensing Technology, Technical University of Munich, Munich, Germany
[3]Atmospheric Processors, Remote Sensing Technology Institute, German Aerospace Center (DLR), Münchener Straße 20, 82234 Weßling, Germany



CV-22-01 - Development of validation protocols for atmospheric aerosol and cloud profiles

- EarthCARE = Earth Clouds, Aerosols and Radiation Explorer
- Joint ESA-JAXA mission.
- For scientific background, see B.A.M.S. special issue on the EarthCARE Mission
- Launch in June 2022. 6-Months Commissioning Phase
- ESA and JAXA each organize the validation of their own data products.
- Validation Research Announcements for the JAXA products in 2013 and 2019
- Validation Announcement of Opportunity for the ESA products in 2017: 33 proposals accepted and reviewed at the 1st ESA EarthCARE Validation Workshop: programme considered adequate but areas of improvement remain (see workshop conclusions in the workshop report at same URL): better coverage in tropics and Oceania, better coverage of cloud-profiling radars.

Futher validation contributions are welcome (contact ecvt-esa@earthcare.esa.int). Please spread the word



EarthCARE Validation Portal at

https://earthcare-val.esa.int

CV-22-01 - Development of validation protocols for atmospheric aerosol and cloud profiles

2nd EarthCARE validation workshop May 25-28, 2021, recommended to proceed with the development of validation protocols for aerosols, clouds and radiation

→ New WGCV / ACSG activity CV-22-01 to develop these validation protocols

- **Contact: Rob Koopman (ESA)**
- **Time frame: 2022-2024**
- **Work plan currently in development for the EarthCARE subgroups, including development of validation protocols**
- **Good participation from ACCP, clearly a broader perspective (at least ESA and NASA)**
- **WGCV / ACSG to advise on QA4EO, generic protocols, best practices…**

Development of validation protocols for atmospheric aerosol and cloud profiles

- Consultations with domain experts have taken place to identify key persons to drive the protocol formulation process and foster the community convergence processes in their domain.
- A first joint meeting of candidate key persons took place on March 15. The next steps are to confirm participation/contribution, identify further key persons to complete domain coverage, agree on a structure for the protocol document.
- Ongoing and planned projects related to fiducial reference measurements, algorithm develoment, and data assimilation will also contribute to this protocol.
- A special case is the topic of simulation of orbital (nadir) radiance parameters (e.g. attenuated backscatter) from sub-orbital observations, where the contributions to the protocol will include also development of scientific code to peform such transformation. The modules will be made available publicly as open source code.

Copernicus Cal/Val Solution (CCVS) – Atmosphere

CCVS – Atmosphere: requirements and status (December 2020 – May 2021)

- **D1.4 – Cal/Val Requirements for Atmospheric Composition Missions**
- **D2.1 – On-board calibration**
- **D2.2 – Vicarious methods**
- **D2.3 – Inter-satellite comparisons**
- **D2.4 – Systematic ground-based measurements**
- **D2.5 – Field and aerial campaigns**
- **D2.6 – Cal/Val data distribution services**

Reviewed by ACRI-ST, Copernicus, EC/JRC, EEA, ESA, EUMETSAT, U. Tartu, revised, delivered on June 1, 2021, available on https://ccvs.eu/

Copernicus Cal/Val Solution (CCVS) – Atmosphere

Current CCVS – Atmosphere activities (June 2021 – June 2022): gap analysis and solution

- **T3.1 – Needs for new/enhanced instrumentation**
- **T3.2 – Audit of Cal/Val methods per product, compliance with Cal/Val requirements, need for further developments**
- **T3.3 – Evaluation and optimization of ground-based networks configuration**
- **T3.3 – Concept of supersite**
  - **End-to-end validation of Level-1-to-2 data production**
  - **Synergies with other EO Cal/Val domains: PICS, RadCalNet, surface BRDF…**
- **T3.4 – Cal/Val data distribution**
- **T3.5 – Impact of Level-1/2 Cal/Val on Level-3 data quality**
- **T3.6 – CCVS Solution**

Next (by end 2022): Reference scenarios for implementation

Copernicus Cal/Val Solution (CCVS) – Atmosphere

- Standards and traceability
- Cardinal validation targets
- Mission and user requirements
- Data product content
- Documentation
- Validation approaches
- Data analysis
- Domain specifics
- Planning, organization and inte rnational collaboration
- Tools and services

5 Summary: Matrix of Cal/Val requirements

This section summarises in the form of a matrix the key Cal/Val requirements identified in the previous sections. Quantitative requirements specific to the Sentinel missions are not reproduced. The matrix describes shortly the requirement and indicates the section(s) describing or referring to this requirement.

Table 12 : Overview of Cal/Val requirements for the atmospheric composition Copernicus Sentinels.

Cal/Val requirement by category	Sections	Identifier
Standards and traceability		
EO Cal/Val activities shall adhere to the general EO data quality strategy established in the QA4EO framework.	3.1.1	CCVS-REQ-AC-001
Traceable Quality Indicators shall be produced to enable users to evaluate readily the fitness-for-purpose of the EO data.	3.1.1	CCVS-REQ-AC-002
EO Cal/Val activities shall adopt standards and best practices for terminology. The expression of terms ambiguously used across teams and communities (e.g. accuracy) shall be clarified.	1.3.1	CCVS-REQ-AC-003
EO Cal/Val activities based on data comparisons shall adopt community endorsed processes of generic operations and specific operations.	3.3	CCVS-REQ-AC-004
Maturity of the EO Cal/Val shall be assessed against the CEOS WGISS Data Management and Stewardship Maturity Matrix for satellite data validation.	3.4	CCVS-REQ-AC-005
Traceability of the validation process, methods, tools and data shall be documented.	3.1.1	CCVS-REQ-AC-006
Validation reporting shall include traceability information on the Sentinel data product, the validation processing, and the validation teams having performed the work and issued the report.	3.1.1	CCVS-REQ-AC-007
Cardinal validation targets		
Quality indicators shall be established for Level-1b data (radiance, reflectance and irradiance) and for their radiometric calibration, spectral assignment and geolocation.	3.1.2	CCVS-REQ-AC-008
Quality indicators shall be established for Level-2 geophysical quantities (column and profile of atmospheric constituents).	3.1.1, 3.1.2	CCVS-REQ-AC-009
Validity of the ancillary and auxiliary parameters used by the Level-1-to-2 data processors shall be verified.	3.1.2	CCVS-REQ-AC-010
Theoretical ex-ante uncertainties associated with the Level-1b and Level-2 data products shall be given quantitative evidence of their validity.	3.1.1, 3.1.2	CCVS-REQ-AC-011
Quality flags and of data usage recommendations associated with the data products shall be given evidence of their validity and efficiency.	3.1.1, 3.1.2	CCVS-REQ-AC-012
Compliance of actual quality of the data product shall be evaluated with respect to mission requirements and core user requirements.	3.1.2	CCVS-REQ-AC-013
Compliance of actual quality of the data product shall be evaluated with respect to product specifications.	3.1.2	CCVS-REQ-AC-014
Mission and user requirements		
Cal/Val activities shall establish quality indicators enabling to judge the fitness-for-purpose of the Sentinel data quality comply with product specifications and mission requirements.	3.1.1	CCVS-REQ-AC-015
Cal/Val activities shall establish quality indicators enabling the Copernicus services to readily evaluate the fitness of the Sentinel data for their purposes.	3.1.1, 4.2.1	CCVS-REQ-AC-016
Cal/Val activities shall establish quality indicators enabling to readily evaluate whether the Sentinel data comply with interoperability requirements within the Copernicus constellations and within the CEOS and CGMS constellations.	4.2.2 , 4.7	CCVS-REQ-AC-017
Cal/Val requirements for the atmospheric composition Sentinels shall be adapted during mission lifetime and beyond to reflect the evolution of core user data quality requirements.	1.1.3, 4.2, 4.2.1.2	CCVS-REQ-AC-018
Requirements on Sentinel data content and documentation		
Each Sentinel data product shall be provided with full identification of the data processing chain: data processor versions, but also identification of the ancillary and auxiliary data used in the processing.	3.1.1	CCVS-REQ-AC-019
Each Sentinel data product shall have associated with it a full uncertainty budget described in detail in an Algorithm Theoretical Basis Document (ATBD), with identification of the intermediate parameters, influence quantities and ancillary parameters influencing data quality.	2.4, 3.1.2	CCVS-REQ-AC-020
Each Sentinel data product shall include intermediate retrieved quantities, diagnostic data (averaging kernels…) and other quality information required to perform data content and information content analysis.	2.4, 3.3, 3.1.2	CCVS-REQ-AC-021
Validation approaches		
Sentinel Level-1b radiance and reflectance data shall be compared to natural targets for validation of geolocation, of calibration, of long-term stability, and of mutual consistency with other missions.	3.1.2	CCVS-REQ-AC-022
Sentinel Level-1b radiance and reflectance data shall be inter-compared with other satellite measurements.	3.1.2, 3.2.4	CCVS-REQ-AC-023
Sentinel Level-1b data shall be compared to (ground-based) Fiducial Reference Measurements.	3.2.2	CCVS-REQ-AC-024
Sentinel-1b extra-terrestrial spectral irradiance data shall be compared to other satellite measurements.	3.1.2	CCVS-REQ-AC-025
Sentinel Level-2 data shall be compared to (ground-based) Fiducial Reference Measurements tailored to Cal/Val needs of traceability, documentation, uncertainty assignment, timeliness of delivery, and long-term continuity.	3.2.2	CCVS-REQ-AC-026

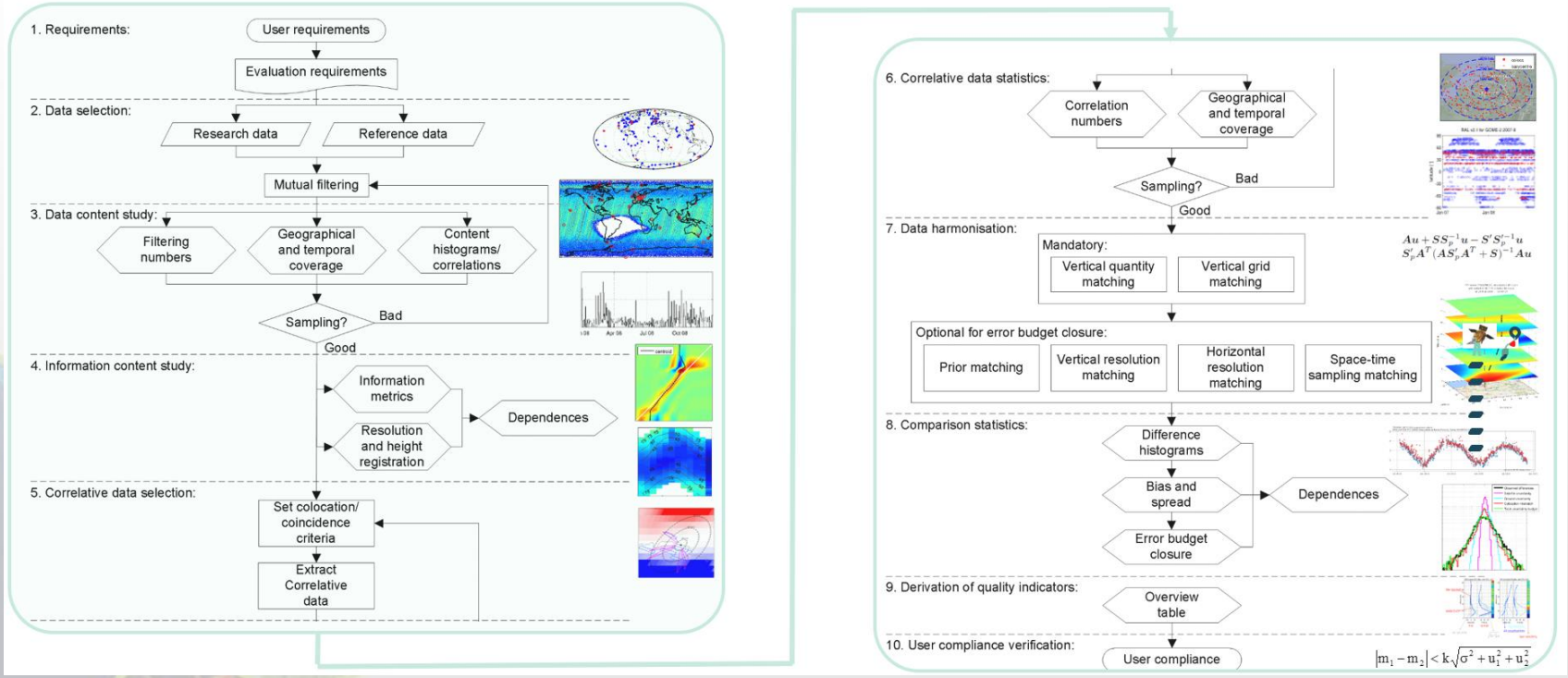
aeronomie.be

BIRA-IASB | J.-C. Lambert | CCVS PM4 | 4-5 March 2021 | Slide 15

Maturity of L2 validation process and tools

Generic nadir satellite validation protocol (including round-robin functions)

(Keppens et al., AMT, 2015; AC-VC-10, College Park, 2014)



Towards a generic validation protocol for atmospheric (L2) data products ?

- Objectives of Cal/Val
- Terminology
- Mathematical formulation
- Validation metrics
- Advanced methods and strategies
- Referred to in ISO 19124-1

AGU PUBLICATIONS

Reviews of Geophysics

REVIEW ARTICLE
10.1002/2017RG000562

Key Points:
- First review of EO validation approaches across different Geoscience communities
- Validation approaches depend on the intermittency and inhomogeneity of the geophysical variables
- Enhanced traceability in EO validation approaches required

Correspondence to:
T. Verhoelst,
tijl.verhoelst@aeronomie.be

Citation:
Loew, A., et al. (2017), Validation practices for satellite-based Earth observation data across communities, *Rev. Geophys.*, *55*, doi:10.1002/2017RG000562.

Received 17 MAR 2017
Accepted 4 JUN 2017
Accepted article online 6 JUN 2017

Validation practices for satellite-based Earth observation data across communities

Alexander Loew[1,2], William Bell[3], Luca Brocca[4], Claire E. Bulgin[5], Jörg Burdanowitz[6], Xavier Calbet[7], Reik V. Donner[8], Darren Ghent[9], Alexander Gruber[10], Thomas Kaminski[11], Julian Kinzel[12], Christian Klepp[13], Jean-Christopher Lambert[14], Gabriela Schaepman-Strub[15], Marc Schröder[12], and Tijl Verhoelst[14]

[1]Department of Geography, Ludwig-Maximilians-Universität München (LMU), Munich, Germany, [2]Deceased 2 July 2017,, [3]MetOffice, Reading, UK, [4]Research Institute for Geo-Hydrological Protection-National Research Council, Perugia, Italy, [5]Department of Meteorology, University of Reading, Reading, UK, [6]Max Planck Institute for Meteorology, Hamburg, Germany, [7]Spanish Meteorological Agency, AEMET, Madrid, Spain, [8]Potsdam Institute for Climate Impact Research, Potsdam, Germany, [9]Department of Physics and Astronomy, University of Leicester, Leicester, UK, [10]Department of Geodesy and Geoinformation, TU Wien, Vienna, Austria, [11]Inversion Lab, Hamburg, Germany, [12]Deutscher Wetterdienst, Offenbach, Germany, [13]Initiative Pro Klima, University of Hamburg, CliSAP/CEN, Hamburg, Germany, [14]Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium, [15]Department of Evolutionary Biology and Environmental Studies, University of Zurich, Zurich, Switzerland

Abstract Assessing the inherent uncertainties in satellite data products is a challenging task. Different technical approaches have been developed in the Earth Observation (EO) communities to address the validation problem which results in a large variety of methods as well as terminology. This paper reviews state-of-the-art methods of satellite validation and documents their similarities and differences. First, the overall validation objectives and terminologies are specified, followed by a generic mathematical formulation of the validation problem. Metrics currently used as well as more advanced EO validation approaches are introduced thereafter. An outlook on the applicability and requirements of current EO validation approaches and targets is given.

Cal/Val Maturity Matrix

Several maturity matrices with

- Product quality/user focus: CEOS WGISS DMSMM, CORE-CLIMAX, EDAP, EPA…
- Cal/Val maturity focus:
  - atmosphere: Keppens et al. (2015), Gaia-CLIM Gap Analysis and Impacts (2018),
  - cross-domains: Loew et al. (2017), CCVS Gap Analysis (in progress), ISO 19124-1

Need to have a MM enabling end-to-end <u>evaluation of the cal/val process</u>:

- Validation of data product quality, but also evaluation of Cal/Val management, infrastructures etc.
- Generic process, metrics and output, prognostic/diagnostic uncertainties, reporting…
- Specificities by product, practical criteria (ISO 19124 discussions): number of comparison points, range of influence quantities, vertical sensitivity and smoothing …
- Validation data: documentation, 4D representativeness (& co-location), range, QC…
- Implementation and operation: validation data procurement, automation, sustainability

→ **CCVS discussions to possibly converge to a management oriented Cal/Val maturity matrix (cross-domain, applicable to all Sentinels)**

Linkage with ground-based monitoring networks

NDACC SC expressed interest in info and easier access to:

- General satellite validation resources
- Satellite overpass predictors
- Overpass (satellite L2) data files
- Cal/Val databases: what, where, how
- Validation protocols and toolkits
- Satellite validation services

→ NDACC Satellite WG AI

Potential input to/synergies with CEOS Cal/Val Portal

NDACC SATELLITE RELATED RESOURCES

https://ndacc.org

Satellite Validation Resources

Atmospheric Toolbox: CODA, HARP, VISAN and QDOAS toolsets
CEOS (Committee on Earth Observation Satellites): international coordination, publications, data stewardship, tools, information systems
CEOS Cal/Val Portal: best practices, Cal/Val data access, Cal/Val sites, FRM projects, terms & definitions
ESA Atmospheric Validation Data Centre (EVDC): Cal/Val data, GEOMS format, FLEXTRA trajectories, ECMWF maps, overpass tool
ESA Envisat CAL/VAL database at NILU
HDF-EOS Tools and Information Center / HDF Explorer software
NASA/GSFC Aura Validation Data Center (AVDC)
Quality Assurance framework for Earth Observation (QA4EO): guidelines, documentation, resources, case studies
QA4ECV Terms and Definitions applicable to the quality assurance of Essential Climate Variable data records

Satellite Validation Services

ESA/Copernicus Sentinel-5p Automated Validation Server
ESA/Copernicus Sentinel-5p Validation Data Analysis Facility
EUMETSAT AC SAF validation services: ozone, trace gases, surface UV
NOAA Products Validation System (NPROVS)
SCIAMACHY Validation and Interpretation Group (SCIAVALIG)

Validation Reference Measurements

Aerosol Robotic Network (AERONET): columnar aerosol optical depth (AOD)
CEOS Pseudo Invariant Calibration Sites (PICS): sites charaterized for surface BRDF, spectral and atmospheric properties, and temporal stability
COllaborative Carbon Column Observing Network (COCCON)
Fiducial Reference Measurements for Ground-Based DOAS Air-Quality Observations (FRM4DOAS): column O3 and tropospheric NO2 profile data
GCOS Reference Upper Air Network (GRUAN): radiosonde data
Halocarbons & other Atmospheric Trace Species (HATS): O3 depleting substances and greenhouse gases
Micro-Pulse Lidar Network (MPLNET): aerosol and cloud vertical structure, boundary layer height
Network for the Detection of Atmospheric Composition Change (NDACC): air quality, greenhouse gases, H2O, O3 and O3 depleting substances, spectral UV, temperature...
Pandonia Global Network (PGN): column measurements of HCHO, NO2, O3, and SO2
Radiometric Calibration Network (RadCalNet): Top-of-Atmosphere spectrally-resolved reflectances (380 to 2500 nm) at 10 nm sampling
Southern Hemisphere ADditional OZonesondes (SHADOZ): ozonesonde profile data in the tropics
Solar Radiation Network (SolRad-Net): high-frequency total solar flux (305-2800 nm), PAR (400-700 nm), UV-visible irradiance (305-695 nm)
Total Carbon Column Observing Network (TCCON): column-averaged abundance of CO2, CH4, N2O, HF, CO, H2O, and HDO

Satellite Overpass Predictors and Data Access

ESA Atmospheric Validation Data Centre (EVDC) Orbit Prediction Tool Orbit Prediction Tool for AEOLUS, Copernicus Sentinels, Envisat, EOS, GOSAT, MetOp, OCO...
EU Copernicus Space Component Data Access (CSCDA)
EUMETSAT Satellite Application Facility on Atmospheric Composition Monitoring (AC SAF)
GOSAT Data Archive Service (GDAS)
ICARE Overpass Predictor for Aqua, Calipso, Cloudsat, Parasol and Envisat
IPSL IXION Orbit Predictor for EOS, FengYun, HIMAWARI, JPSS, Meteor, MetOp, MSG...
NASA/GSFC EarthData Atmospheric Composition (GES DISC)
NASA/LARC EarthData Atmospheric Science Data Center (ASDC)
NOAA NPROVS Orbital Display System (ODS)

Thank you for your attention!