WGCV-55

Atmospheric Composition Sub Group Updates

Jean-Christopher Lambert, BIRA-IASB

Agenda Item 2.6

WGCV-55

8-11 July 2025

ISRO, Hyderabad, India

Committee on Earth Observation Satellites

Terms of Reference

Approved at the 15th CEOS Plenary in November 2001, the objectives of the Atmospheric Composition Sub Group (ACSG), beyond those of the Working Group on Calibration and Validation (WGCV), are to:

- Promote international collaboration and technical exchange to ensure the efficient use and maintenance of calibration/validation resources required for atmospheric composition and other missions
- Verify accurate scientific products by encouraging an end-to-end approach to the calibration and validation of Level 1 and Level 2 data products, and any subsequent re-calibration and reprocessing using established best practice procedures
- Ensure that validation sensors are calibrated to traceable national standards, with documented statements of accuracy and repeatability
- Encourage interaction between calibration scientists and data users to enable a better understanding of data uncertainties and user requirements
- Recommend a network of validation sites and to encourage continuous observation and quality control of data through the use of standard procedures and inter-comparison
- Develop comprehensive data validation methods that employ ground, aircraft, balloon, and satellite measurements and with models
- Specify a comprehensive, consistent and quality-controlled multi-mission validation database in an accepted format and employing user-friendly tools

Atmospheric Composition Updates

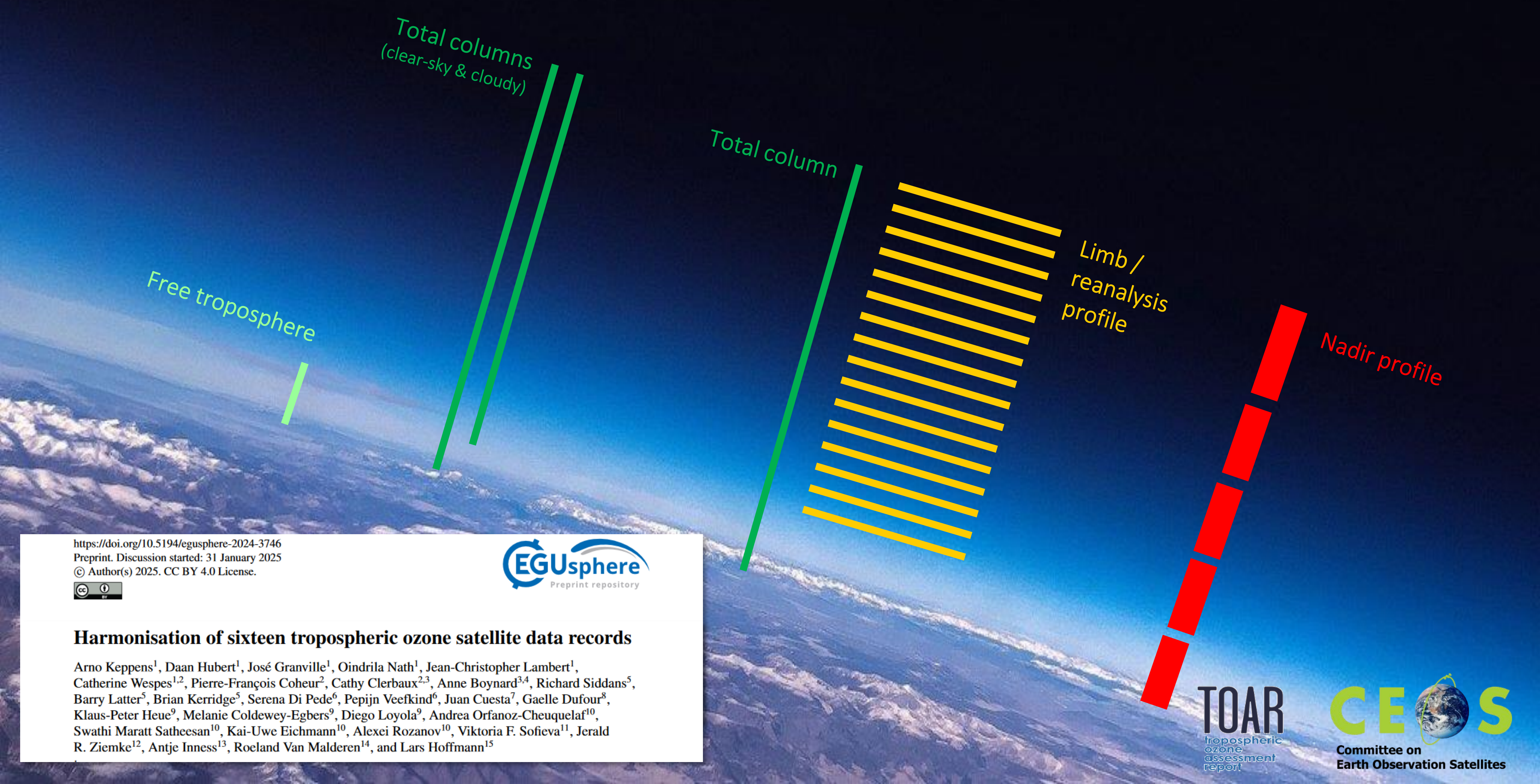
1. Tropospheric ozone datasets harmonization and validation — VC-20-01
2. Aerosol, Cloud & Precipitation Profile Protocol (ACPPV) — CV-22-01
3. GHG and AQ Constellations Cal/Val highlights — CV-20-02/03/04
4. CINDI-3 campaign — CV-24-01
5. CEOS-FRM – Atmospheric composition — CV-23-01
6. Validation networks design and evolution
7. AC-VC-21/ ACSG joint meeting 2025

Tropospheric Ozone Activity

VC-20-01

- CEOS activity on Tropospheric ozone (satellite) datasets validation and harmonization (Lead DLR, Co-Leads BIRA-IASB & NASA)
- Direct support to IGAC TOAR-II, responding to needs and questions highlighted by TOAR-I (2014-2019)
- TOAR-II community papers: Copernicus Special Issue closed
- TOAR-II assessment papers: to be published in *Phil. Trans. A*
- Formulating ideas for TOAR-III, e.g.:
  - Impact of wildfires and wildland-urban interface fires to O_3
  - Policy-relevant outcomes, e.g. "what reductions in precursor emissions would achieve a 0.1 K reduction from O_3 radiative forcing?"
  - Geostationary sounders for diurnal observations of ozone
  - Expanded use of AI for predicting surface O_3

Harmonization of TOAR-II satellite tropospheric ozone datasets



https://doi.org/10.5194/egusphere-2024-3746
Preprint. Discussion started: 31 January 2025

EGUsphere
Preprint repository

Harmonisation of sixteen tropospheric ozone satellite data records

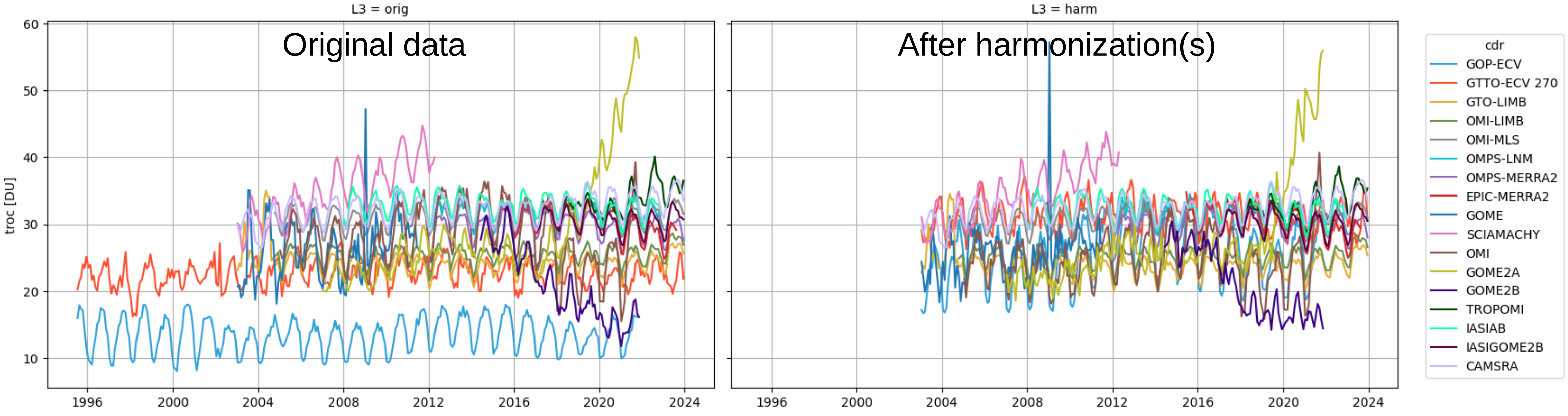
Arno Keppens[1], Daan Hubert[1], José Granville[1], Oindrila Nath[1], Jean-Christopher Lambert[1], Catherine Wespes[1,2], Pierre-François Coheur[2], Cathy Clerbaux[2,3], Anne Boynard[3,4], Richard Siddans[5], Barry Latter[5], Brian Kerridge[5], Serena Di Pede[6], Pepijn Veefkind[6], Juan Cuesta[7], Gaelle Dufour[8], Klaus-Peter Heue[9], Melanie Coldewey-Egbers[9], Diego Loyola[9], Andrea Orfanoz-Cheuquelaf[10], Swathi Maratt Satheesan[10], Kai-Uwe Eichmann[10], Alexei Rozanov[10], Viktoria F. Sofieva[11], Jerald R. Ziemke[12], Antje Inness[13], Roeland Van Malderen[14], and Lars Hoffmann[15]

Harmonization of satellite tropospheric ozone data

Product	Provider(s)	Coverage	Native sampling resolution	Native top level
ERS2/GOME v3	RAL/ESA	global, 1995/06-2011/06	320×40 km^2 at 10:30 LST	-
Envisat/SCIAMACHY v3	RAL/ESA	global, 2002/08-2012/04	240×32 km^2 at 10:00 LST	-
Metop-A/GOME2 v3	RAL/ESA	global, 2007/01-2021/11	160×160 km^2 at 09:30 LST	-
Metop-B/GOME2 v3	RAL/ESA	global, 2014/06-2021/11	160×160 km^2 at 09:30 LST	-
Aura/OMI v2	RAL/ESA	global, 2004/10-2021/10	52×48 km^2 at 13:30 LST	-
S5P/TROPOMI v2	KNMI/ESA	global, 2018/05-2023/12	28×28 km^2 at 13:30 LST	-
Metop-AB/IASI v2015 CDR	ULB/LATMOS/EUMETSAT	global, 2008/01-2022/12	12 km diam. at 09:30 LST	-
Metop-B/IASI+GOME2 v2	LISA/AERIS	global, 2016/08-2023/12	12 km diam. at 09:30 LST	-
GOP-ECV* v3	DLR/RAL/ESA	global, 1995/07-2021/10	$5^\circ \times 5^\circ \times$ month	-
OMPS-LNM v2.0	IUP-UB	60°S-60°N, 2012/02-2022/12	$5^\circ \times 5^\circ \times$ month	LRT (ERA5) & PVU= 3.5
OMI-LIMB v1	FMI/DLR/ESA	global, 2004/10-2023/12	$1^\circ \times 1^\circ \times$ month	LRT (ERA5) & ozonopause
GTO-LIMB v1	FMI/DLR/ESA	global, 2003/01-2023/12	$1^\circ \times 1^\circ \times$ month	LRT (ERA5) & ozonopause
OMI-MLS	NASA	60°S-60°N, 2004/10-2023/12	$5^\circ \times 5^\circ \times$ month	LRT (NCEP)
OMPS-MERRA2	NASA	global, 2012/01-2023/12	$1^\circ \times 1^\circ \times$ month	$\theta = 380$ K & PVU= 2.5
EPIC-MERRA2	NASA	global, 2015/06-2023/08	$1^\circ \times 1^\circ \times$ month	$\theta = 380$ K & PVU= 2.5
GTTO-ECV v6lc	DLR/BIRA-IASB/ESA	20°S-20°N, 1995/07-2023/12	$1^\circ \times 1^\circ \times$ month	270 hPa
CAMSRA EAC4	ECMWF	global, 2003/01-2023/12	$0.75^\circ \times 0.75^\circ$ at 0, 6, 12, 18 UTC	-
Ozonesonde	TOAR-II HEGIFTOM	43 station locations	$1^\circ \times 1^\circ \times$ month	-

*Although GOP-ECV provides full ozone profiles, we consider its lowest (surface to 450 hPa) subcolumn in this work only.

Harmonization of satellite tropospheric ozone data



- Harmonization needs addressed: (i) Vertical representation & units, (ii) Tropospheric top levels, (iii) Surface pressure, (iv) Spatial sampling, (v) Temporal sampling, (vi) A-priori information sources, (vii) A-priori information (effective) contributions (vertical smoothing)
- Satellite data harmonization reduces dispersion between datasets by about ~10-40 %.
- Residual discrepancies between harmonized satellite data ⇨ other sources of uncertainty

Reported by Helen Worden (NCAR) at AC-VC-21 / ACSG 2025 (Takamatsu, June 2025)

TOAR-II Status and roadmap

2020
- Selection of new steering committee
- Planning of objectives and roadmap
- Development of enhanced data infrastructure

2021
- First TOAR-II workshops
- Formation of working groups (WGs)
- Beginning of new data collection

2022
- WGs: Develop manuscripts and initial data analysis
- Develop new ozone metrics and populate database

March 2023 to Nov. 2024
- Finalize database
- Complete data analyses
- Paper submissions to the Community Special Issue

Dec., 2025
- Publication of TOAR-II assessment papers

We are here

tropospheric ozone assessment report Phase II

https://igacproject.org/activities/TOAR/TOAR-II

TOAR-II / Satellites

VC-20-01

TOAR-II Community Special Issue in Copernicus journals (closed)

(30 papers published, 27 in review)

https://acp.copernicus.org/articles/special_issue1256.html

Satellite contributions: 21 in total

- Intercomparison & harmonization papers (2 published, 3 in review) ⇨ **VC-20-01**
- Satellite O_3 trend papers (4 published, 4 in review)
- Reanalysis papers (1 published, 2 in review)
- Satellite O_3 precursors trends (1 published)
- Other analyses: CoViD-19 period, O_3 production rates, O_3 Radiative Forcing, model evaluation (3 published, 1 in review)

Special issue

Articles / Special issue

Search

Tropospheric Ozone Assessment Report Phase II (TOAR-II) Community Special Issue (ACP/AMT/BG/GMD inter-journal SI)

Editor(s): ACP co-editors | Coordinators: Bryan N. Duncan and Andreas Hofzumahaus | Co-organizers: Owen R. Cooper and Martin G. Schultz

Special issue jointly organized between Atmospheric Chemistry and Physics, Atmospheric Measurement Techniques, Biogeosciences, and Geoscientific Model Development

The Tropospheric Ozone Assessment Report (TOAR-II) is an official activity of the International Global Atmospheric Chemistry Project (IGAC) (https://igacproject.org/activities/TOAR/TOAR-II). The goal of TOAR-II is to build on the success of TOAR-I (2014–2019) and produce an updated assessment of tropospheric ozone's global distribution and trends from the surface to the tropopause. This effort includes an analysis of the impacts of ozone on human health, crop and ecosystem productivity, and climate.

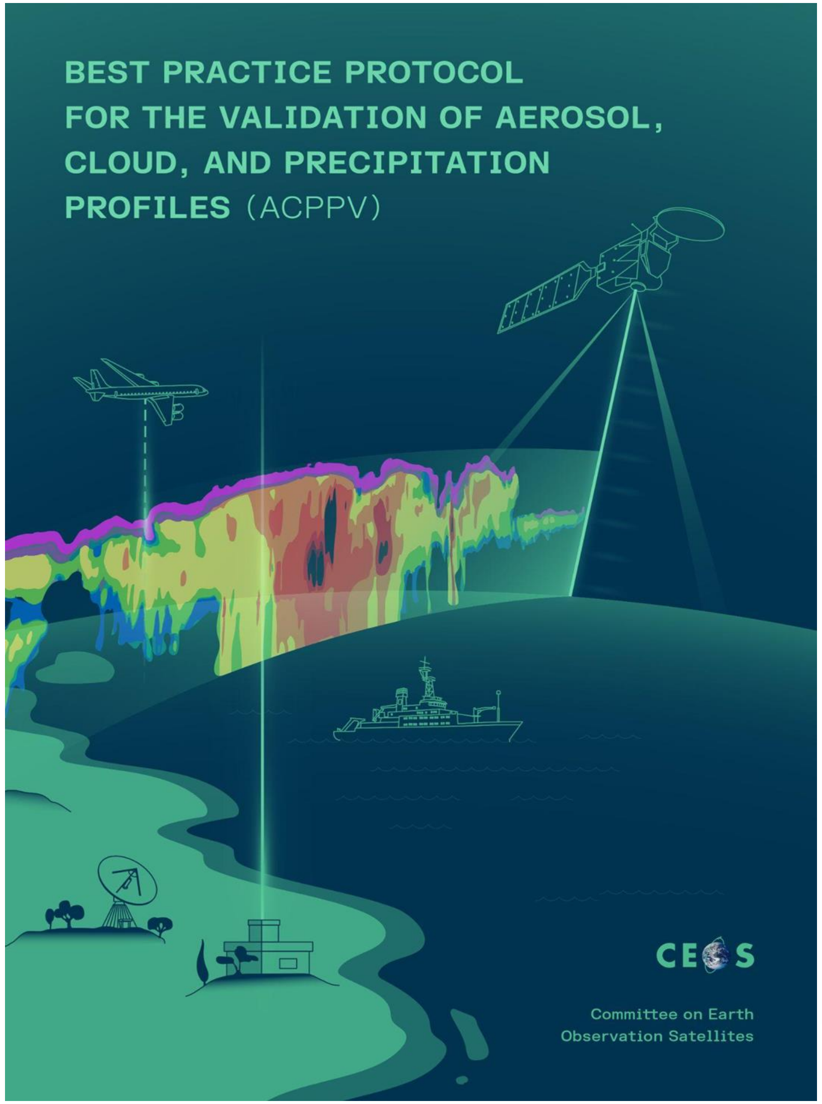
TOAR-II / Satellites

TOAR-II assessment papers (lead authors)

▪ Overview paper	Helen Worden and Martin Schultz
▪ Health	Gaige Kerr
▪ Vegetation	Lisa Emberson
▪ Climate	Sophie Szopa
▪ S. America Regional	Rodrigo Seguel
▪ Africa Regional	Raeesa Moola
▪ STE	James Keeble and Paul Griffiths
▪ **Satellite Data**	**Daan Hubert and Kazuyuki Miyazaki**
▪ Oceans+Polar	Roberto Sommariva
▪ Tropics (TBD)	Audrey Gaudel and Bastien Sauvage

Submission deadline 31 December 2025

ACPPV: Finalization and Publication



Published on CEOS portal

https://ceos.org/publications-key-documents/

DOI assignment in Zenodo

https://zenodo.org/records/15025627

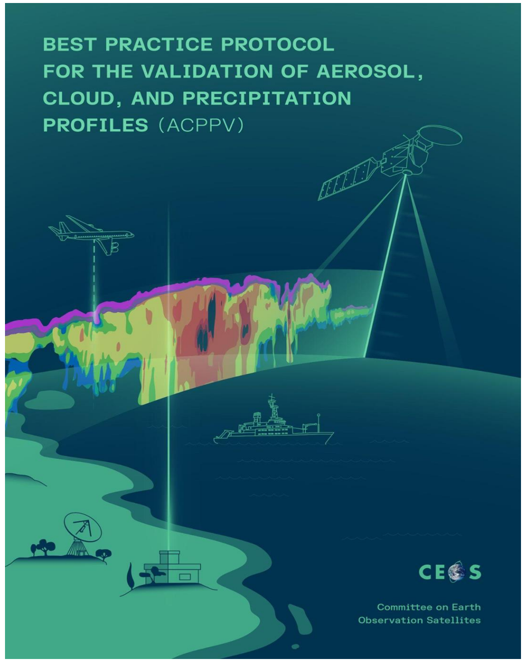
97 authors from 58 institutions

Amiridis, Vassilis; Marinou, Eleni; Hostetler, Chris; Koopman, Rob; Cecil, Daniel; Moisseev, Dmitri; Tackett, Jason; Groß, Silke; Baars, Holger; Redemann, Jens; Marenco, Franco; Baldini, Luca; Tanelli, Simone; Fielding, Mark; Janiskova, Marta; Tanaka, Toshiyuki; O'Connor, Ewan; Fjaeraa, Ann Mari; Paschou, Peristera; Voudouri, Kalliopi Artemis; Ferrare, Richard; Burton, Sharon; Schuster, Gregory; Kato, Seiji; Winker, David; Shook, Michael; Bley, Sebastian; Haarig, Moritz; Floutsi, Athena Augusta; Wandinger, Ulla; Trapon, Dimitri; Pfitzenmaier, Lukas; Papagiannopoulos, Nikolaos; Mona, Lucia; Posselt, Derek; Mason, Shannon; Rennie, Michael; Benedetti, Angela; Hogan, Robin; Sogacheva, Larisa; Balis, Dimitris; Michailidis, Konstantinos; van Zadelhoff, Gerd-Jan; Nowottnick, Edward; Yorks, John; Mroz, Kamil; Donovan, David; L'Ecuyer, Tristan; Okamoto, Hajime; Sato, Kaori; Henderson, David; Nishikawa, Tomoaki; Barker, Howard; Cole, Jason; Qu, Zhipeng; Clerbaux, Nicolas; Nakajima, Takashi; Chase, Randy; Wolff, David; Landulfo, Eduardo; Kirstetter, Pierre-Emmanuel; Mather, Jim; Ohigashi, Tadayasu; Ryder, Claire; Tzallas, Vasileios; Tsikoudi, Ioanna; Tsekeri, Alexandra; Tsichla, Maria; Koutsoupi, Iliana; Kubota, Takuji; Siomos, Nikolaos; Takahashi, Nobuhiro; Horie, Hiroaki; Suzuki, Kentaroh; Mace, Jay; McLean, William; Borderies, Maria; Mangla, Rohit; Escribano, Jerónimo; Moradi, Isaac; Zhang, Jianglong; Juli, Rubin; Ikuta, Yasutaka; Marbach, Thierry; Bojkov, Bojan; Accadia, Christophe; Fougnie, Bertrand; Spezzi, Loredana; Bozzo, Alessio; Chimot, Julien; Jafariserajehlou, Soheila; Flament, Thomas; Mattioli, Vinia; Strandgren, Johan; Barlakas, Vasileios; Kollias, Pavlos.

ACPPV: Conclusion and Outlook

Reported by Robert Koopman (ESA) at AC-VC-21 / ACSG 2025 (Takamatsu, June 2025)
Look at CEOS.org/meetings/AC-VC-21 for details

VC-20-01



Conclusion

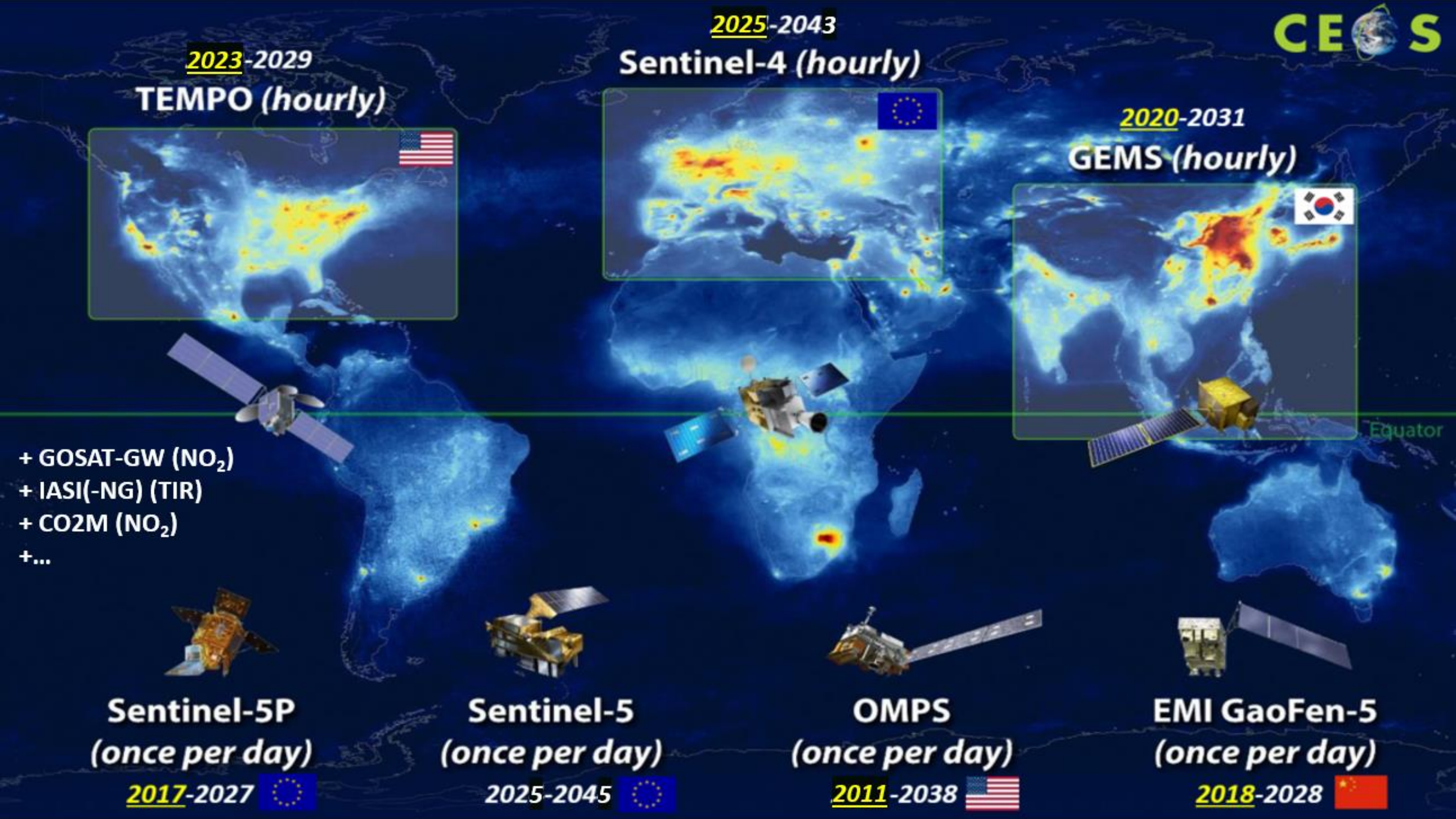
- Comprehensive study on best practice for space profiler validation
  - Large community working together
  - Gaps identified and recommendations made
- New tools provided
- Some knowledge/measurement gaps already identified and filled

Outlook

- Keep large community working together
- Continue to develop best practices
- Continue to identify and fill knowledge/measurement gaps
- Continue to improve tools

GHG Constellation Cal/Val Highlights

- Details: see Thursday report 3.12 on GHG Cal/Val and Networks
- L1 calibration
  - RRV Intercalibration campaigns
  - VICAL GHG Cal/Val website
  - Match-up database for SWIR and TIR sounders
- L2 GHG networks
  - Several actions in progress, e.g., FTIRs and Pandora's deployment in India
  - Joint NDACC-IRWG/TCCON/COCCON meeting 2025 in Nainital, June 16-20
  - EUMETSAT study/service for CO2M product validation methods, reference data provision and processing, incl. TCCON, COCCON and NDACC
  - EUMETSAT project for Pandora NIR development
- Facility scale emissions/fluxes validation guidelines


CEOS
2023-2029
TEMPO (hourly)
2025-2043
Sentinel-4 (hourly)
2020-2031
GEMS (hourly)
Equator
+ GOSAT-GW (NO_2)
+ IASI(-NG) (TIR)
+ CO2M (NO_2)
+...
Sentinel-5P
(once per day)
2017-2027
Sentinel-5
(once per day)
2025-2045
OMPS
(once per day)
2011-2038
EMI GaoFen-5
(once per day)
2018-2028

Cal/Val coordination, plans and joint activities

VC-20-02/02/03

- GEMS AO, TEMPO MVP, ESA/EUMETSAT joint AO for S-4/-5
- L2 algorithm testing and intercomparisons (S-4 L2 prototype testing on GEMS etc.)
- International collaboration on FRMs and other validation data: collaborative airborne campaigns, Pandora network expansion, CINDI-3 MAX-DOAS campaign with participation of other networks
- International collaboration on validation
  - Sentinel-5P MPC operational validation service (2017-2027)
  - ESA PEGASOS validation service for GEMS and TEMPO (2025-2026)
  - U. Yonsei Geo-Ring validation and research for GEMS and TEMPO (2025-2028)
  - Joint meetings/conversations of GEMS, TEMPO and Sentinel-5P validation teams

The Third Cabauw INtercomparison of DOAS-like Instruments (CINDI-3)

Semi-blind intercalibration and intercomparison campaign with external referee

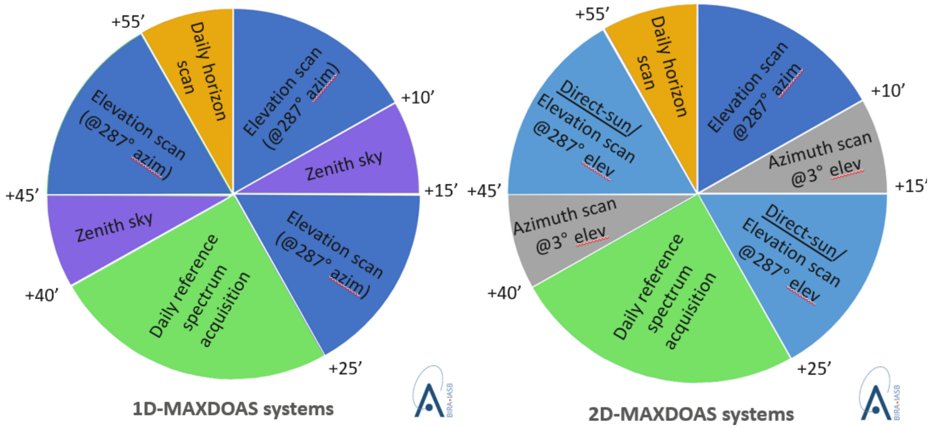
- to intercalibrate instruments and assess mutual consistency of measurements
- to get NDACC and ACTRIS-CREGARS certification for new instruments
- to assess and improve FRM maturity for validation of CEOS Air Quality and Ozone satellite constellations

Data product	Fitting range
NO_2 (VIS range)	425 – 490 nm
NO_2 (alternative VIS range)	411 – 445 nm
NO_2 (UV range)	338 – 370 nm
O_4 (VIS range)	425 – 490 nm
O_4 (UV range)	338 – 370 nm
HCHO	324.5 – 359 nm
HONO	335 – 373 nm
CHOCHO	436 – 468 nm
O_3 (Chappuis bands)	450 – 540 nm
O_3 (Huggins bands)	320 – 340 nm

Additional species: CHOCHO and HONO

Observation protocol

Every day between 11:10:00 and 12:10. Local noon is at ~11:40



CINDI-3: ~30 research institutes, companies and international organisations

Third Cabauw INtercomparison of DOAS-type Instruments

NASA
University of Toronto
LOA Laboratoire d'Optique Atmosphérique
CNR ISAC
BIRA-IASB
Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment
iup
Max-Planck-Institut für Chemie
esa
BK Scientific
Airyx – Different thinking. Better measuring.
SciGlob
LATMOS
The University of Suwon
PGN
RAL Space
Virginia Tech
The University of Melbourne
Universidade de Évora
Universidad de la República Uruguay
Australian Government – Bureau of Meteorology
NDACC – Network for the Detection of Atmospheric Composition Change
UNAM
INTA
LuftBlick – Earth Observation Technologies
Pukyong National University
NILU
ACTRIS

CINDI-3 (May 21 – June 21, 2024)

CV-24-01

Cabauw, The Netherlands

UV-Vis intercalibration campaign organized as part of NDACC and ACTRIS CREGARS topical center, with additional ESA support.

Overview

- 35+ UV-VIS MAX-DOAS instruments intercompared, from 16 countries
- 60+ instruments deployed
- 100+ participants
- FRM4DOAS central processing applied to 50% of participating instruments
- Airborne deployment for NO_2 mapping and profiling
- Data analysis in progress

CINDI-3 in-field calibration (LuftBlick & NASA)

Goal

For each instrument, to measure:

- ***Gain and S/N ratio***
- ***Detector linearity***
- ***PRNU (Pixel Response Non-Uniformity)***
- ***Effective exposure time***
- ***Stray light***

Semi-blind intercomparison of slant columns

Pandora

#	Institute	Instrument PI	Instrument type
34	KNMI	Ankie Piters	Pandora-1S
35	LBLICK	Alexander Cede	Pandora-1S
36	LBLICK	Alexander Cede	Pandora-1S

(3)

Airyx SkySpec

#	Institute	Instrument PI	Instrument type
01	UOM	Rob Ryan	Airyx SkySpec-1D
02	ABOM	Rob Ryan	Airyx SkySpec-1D
03	KNMI	Ankie Piters	Airyx SkySpec-1D
06	UOT	Ramina Alwarda	Airyx SkySpec-1D
07	SUWON	Hyeong-Ahn Kwon	Airyx SkySpec-1D
14	LMU	Mark Wenig	Airyx SkySpec-1D
21	BIRA	Alexis Merlaud	Airyx SkySpec-2D
24	ISAC	Elisa Castelli	Airyx SkySpec-2D
28	IUPH	Udo Frieß	Airyx SkySpec-2D
32	AIRYX	Johannes Lampel	Airyx SkySpec-2D
33	RAL	Ka Lok Chan	Airyx SkySpec-2D
39	USTC	Cheng Liu	Airyx SkySpec-2D

(12)

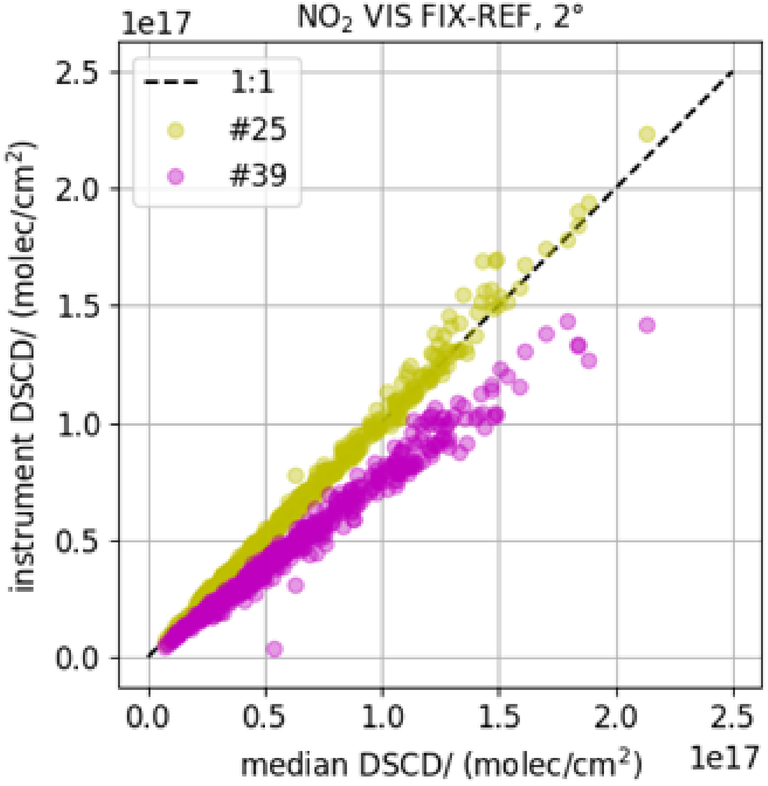
Research grade instruments

#	Institute	Instrument PI	Instrument type
04	KNMI	Ankie Piters	Mini-DOAS Hoffmann
05	MPIC	Thomas Wagner	Tube-DOAS
08	LATMOS	Andrea Pazmino	SAOZ
09	LATMOS	Andrea Pazmino	Mini-SAOZ #1
10	LATMOS	Andrea Pazmino	Mini-SAOZ #2
11	EVORA	Daniele Bortoli	SPATRAM-1
15	AIOFM	Ang Li	2D-MAXDOAS
16	AIOFM	Pinhua Xie	2D-MAXDOAS
17	AIOFM	Yuhan Luo	2D-MAXDOAS
18	AUTH	Dimitris Karagkiozidis	PHAETHON
19	AUTH	Dimitris Karagkiozidis	DELTA
20	BIRA	Alexis Merlaud	2D-MAXDOAS
25	IUPB	Kai Krause	2D-MAXDOAS
27	IUPB	Kai Krause	IMPACT
29	IUPH	Udo Frieß	PMAX-DOAS
30	INTA	Monica Navarro	RASAS-III
40	PKNU-NIER	G. Park/ H. Hong	AQ-Profiler

(17)

18 days (June 2 -> 19)

- 8 data products
- 3 reference spectra types
- 9 elevation angles

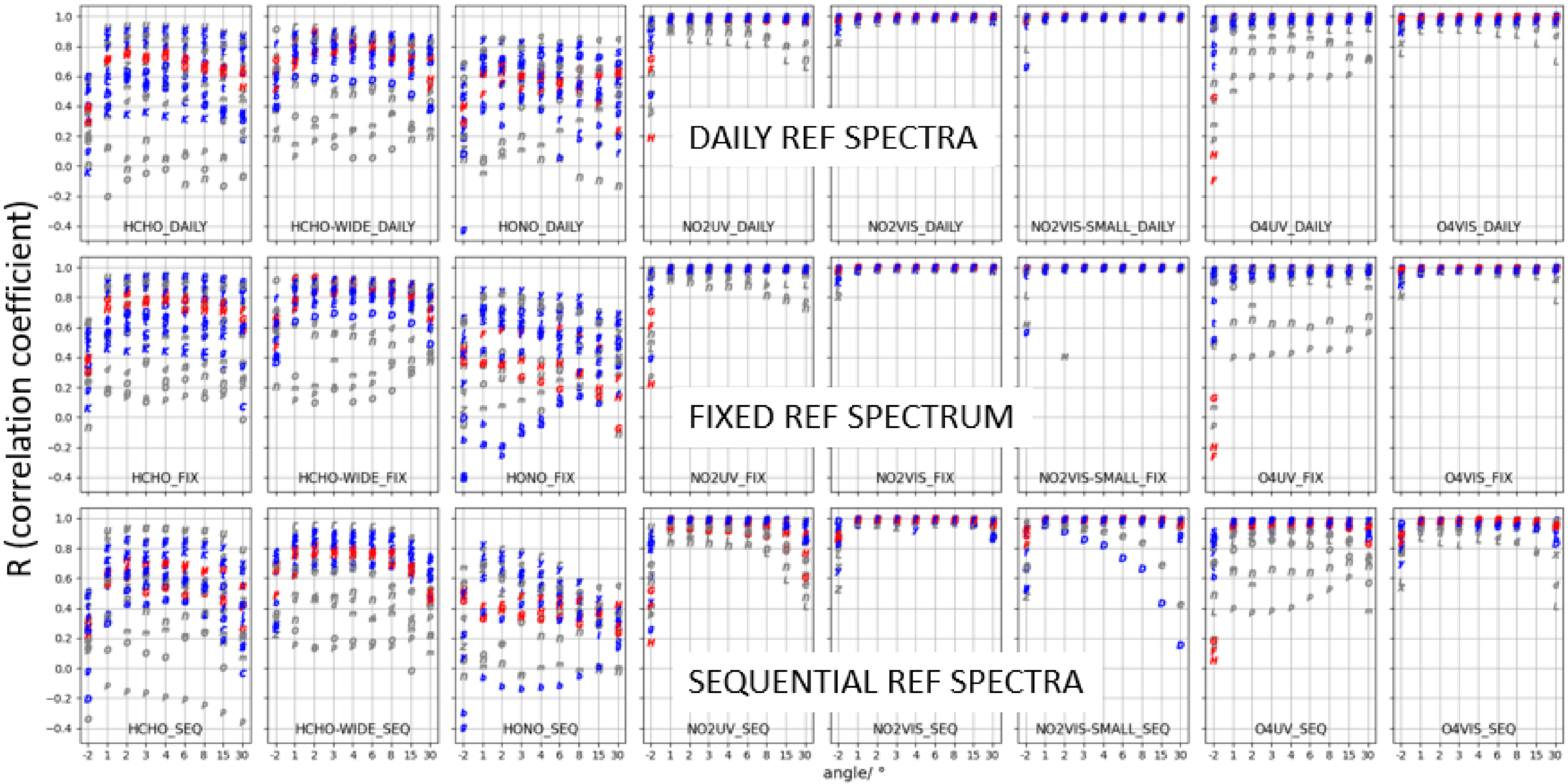


Overview of regression results

Pandora

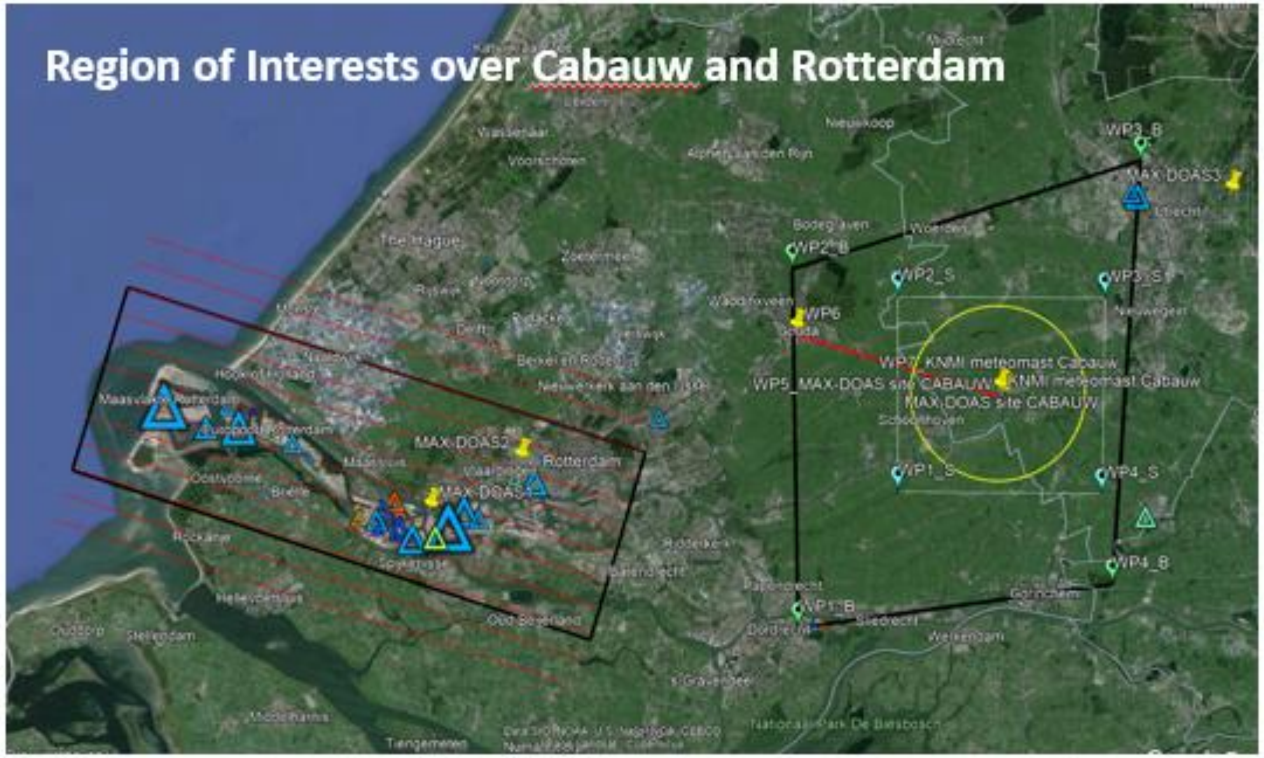
Airyx SkySpec

Research grade instruments



Airborne NO_2 mapping and profiling

- 10 flights performed (4 over Rotterdam, 6 Antwerp)
- NO_2 mapping over predefined ROIs for S5p validation
- Spirals for vertical distribution profiling using in-situ sensors



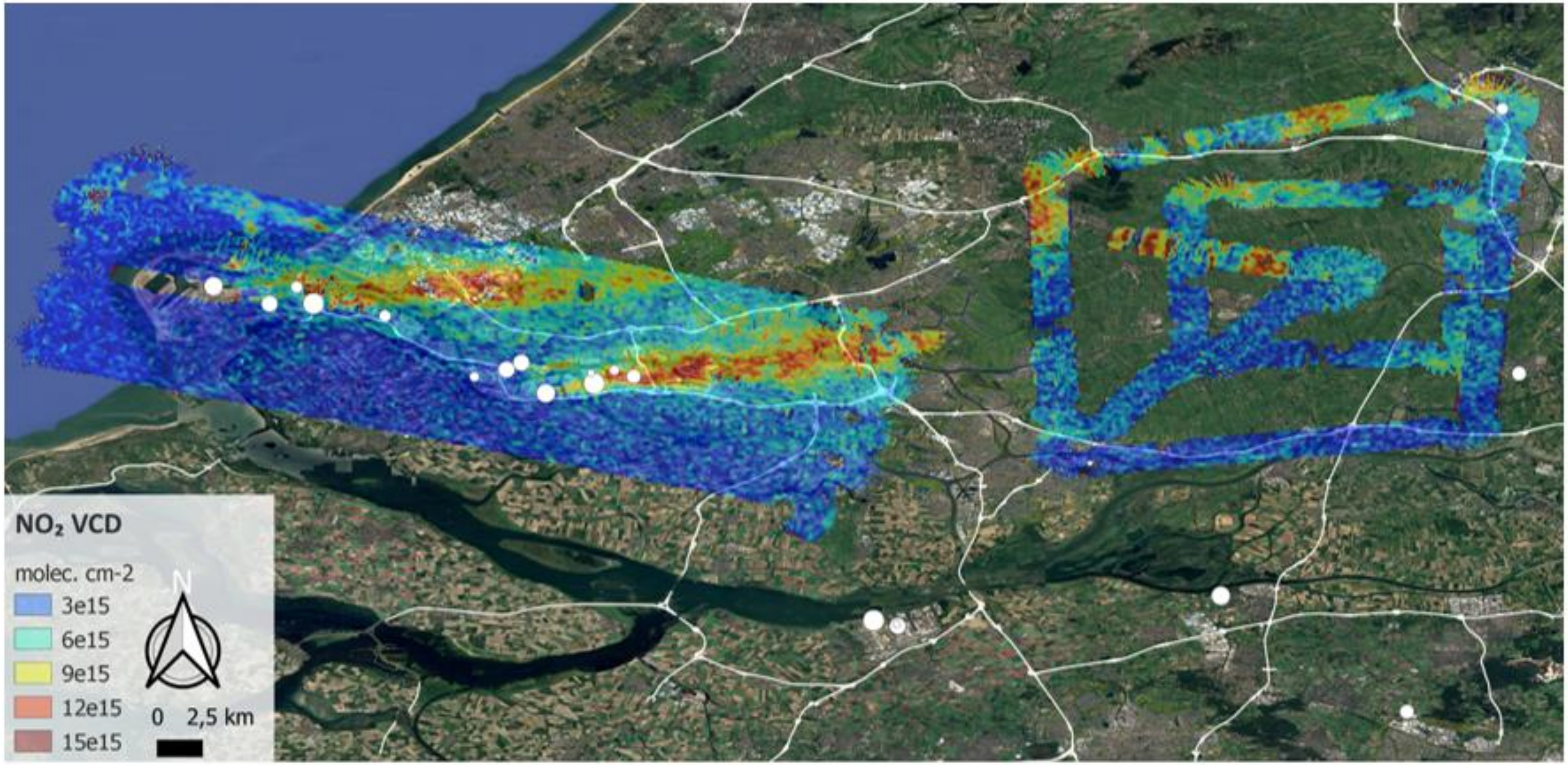
SWING (NO_2 mapping)

ICAD (NO_2)

POM (O_3)

Preliminary results: SWING+ NO_2 VCD maps

Rotterdam 20240607



CINDI-3 – Summary

- 32 UV-Vis DOAS instruments were intercompared in Cabauw during one month in May-June 2024
- Preliminary evaluations show good agreement for NO_2 and O_4 measurements, more challenging for other gases
- In-depth analysis of data in progress in several task groups
- CINDI-3 workshop hosted by Kirchhoff-Institute for Physics (KIP), Heidelberg, 17-19 March 2025
  - Hybrid, ~100 participants (50 in person)
  - 25 talks covering all data and aspects of the campaign
  - Extensive discussions of results in 4 sessions
  - Visit of new Airyx facility in Heidelberg

CINDI-3 – Outlook

- Publication plan: AMT/ACP Special Issue
- CEOS-FRM maturity level (for Sentinel-4/-5 and CO2M classes)
  - Initial CEOS-FRM maturity assessment of FRM4DOAS data published by Van Roozendael *et al.* in *Remote Sens.* 2024, https://doi.org/10.3390/rs16234523
  - Post-campaign improvement of MAX-DOAS measurements + update to version 2 of CEOS-FRM guidelines
  - ➢ Updated CEOS-FRM maturity assessment anticipated
- Next meeting: DOAS Workshop, Thessaloniki, 9-11 July 2025

CEOS-FRM Maturity Assessment Framework v1

https://calvalportal.ceos.org/web/guest/frms-assessment-framework

remote sensing

MDPI | Order Arti

Open Access | Communication

Fiducial Reference Measurements (FRMs): What Are They?

by Philippe Goryl [1,*], Nigel Fox [2], Craig Donlon [3] and Paolo Castracane [4]

CEOS-FRM Maturity Assessment Framework version 1 (2023)

Self-assessment					Independent assessor
Nature of FRM	**FRM Instrumentation**	**Operations/ sampling**	**Data**	**Metrology**	**Verification**
Descriptor	Instrument Documentation	Automation level	Data completeness	Uncertainty Characterisation	Guidelines adherence
Location/ availability of FRM	Evidence of traceable calibration	Measurand sampling	Availability and Usability	Traceability Documentation	Utilisation/Feedback
Range of sensors	Maintenance plan	ATBDs on processing/software	Data Format	Comparison/calibration of FRM	Metrology verification
Complementary observations	Operator expertise	Guidelines on transformation to satellite Pixel	Ancillary Data	Adequacy for intended class of sensors	Independent Verificaton
				FRM CLASSIFICATION	**A B C D** (to be selected)

CEOS Working Group on Calibration and Validation

Self-assessment pilots

FRM4DOAS | PGN

Self-assessments published in *Remote Sensing* Special Issue

FRM4DOAS | TCCON | CO_2 CCON

FRM4DOAS and FRM4GHG CEOS-FRM v1 self-assessments published

Special Issue

Copernicus Sentinels Missions Calibration, Validation, FRM and Innovation Approaches in Satellite-Data Quality Assessment

Remote Sensing

remote sensing MDPI

Article

Fiducial Reference Measurements for Air Quality Monitoring Using Ground-Based MAX-DOAS Instruments (FRM4DOAS)

Michel Van Roozendael [1,*], Francois Hendrick [1], Martina M. Friedrich [1], Caroline Fayt [1], Alkis Bais [2], Steffen Beirle [3], Tim Bösch [4], Monica Navarro Comas [5], Udo Friess [6], Dimitris Karagkiozidis [2], Karin Kreher [7], Alexis Merlaud [1], Gaia Pinardi [1], Ankie Piters [8], Cristina Prados-Roman [5], Olga Puentedura [5], Lucas Reischmann [3], Andreas Richter [4], Jan-Lukas Tirpitz [6,†], Thomas Wagner [3], Margarita Yela [5] and Steffen Ziegler [3]

Remote Sens. **2024**, *16*(23), 4523; https://doi.org/10.3390/rs16234523

remote sensing MDPI

Article

Fiducial Reference Measurement for Greenhouse Gases (FRM4GHG)

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Remote Sens. **2024**, *16*(18), 3525; https://doi.org/10.3390/rs16183525

remote sensing MDPI

Article

Fiducial Reference Measurements for Greenhouse Gases (FRM4GHG): Validation of Satellite (Sentinel-5 Precursor, OCO-2, and GOSAT) Missions Using the COllaborative Carbon Column Observing Network (COCCON)

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Remote Sens. **2025**, *17*(5), 734; https://doi.org/10.3390/rs17050734

CEOS-FRM Maturity Assessment Framework v2

CEOS-FRM Maturity Assessment Framework version 2 (2025)

- V1 applicable to a measurement ⇨ classification
- V2: additional column characterizing ‘completeness of validation capacity’ achieved e.g. by network deployment of the same instrumentation, centralized processing, and timeliness; not classification criteria
- Applicable to a network deployment of similar instruments measuring the same measurand, not meant for multi-constituents/multi-instruments/GHG-AQ-synergy “*supersites*”
- Test cases for v2: FRM4DOAS, PGN, NDACC, ACTRIS-CREGARS (Centre for Reactive Trace Gases Remote Sensing)

Completeness, coverage and distribution
Validation capacity
Geographical coverage
Temporal sampling
Centralized data, processing, quality assessment and adherence to community standards
Timeliness

CEOS-FRM – Validation Capacity

Capacity of assessing the properties of the measuring system in terms of completeness and capability to properly get characteristics of the

- measurand over full range of possible values
- appropriate sampling of its variations (e.g.: diurnal cycle to long-term trends, oscillations, Brewer-Dobson Circulation, polar vortex, emissions…)
- most relevant atmospheric states (urban/rural/facility, meridian, land/ocean…)

but also capability to get range and sampling of the

- most influencing quantities (e.g., constituent profile shape, surface albedo, cloud properties, temperature contrast, aerosol load, etc.),
- most influencing measurement parameters (e.g.: Solar Zenith Angle, View Zenith Angle, South Atlantic Anomaly etc.)

Ground-based Cal/Val Network Design and Evolution

Staggered approach to satellite validation

1. ‘Traceability validation’: end-to-end validation of L1b-to-L2 retrieval diagram elements and associated uncertainties
2. L2 product validation: global, long-term production of L2 quality indicators
3. ‘Product-to-service validation’ connecting space, surface, modelling and applications; multi-constituent/multi-theme; may have operational needs

Tiered approach to Cal/Val sites and measurements

Tier 1: High CEOS-FRM classes; end-to-end, full suite of retrieval & influencing quantities; may include L1b related data and user-oriented data

Tier 2: High-to-mid CEOS-FRM classes; classical L2 product validation, CDRs

Tier 3: Low CEOS-FRM classes; global, specific, first-order quality assessment

Ground-based Cal/Val Network Design and Evolution

Needs, status and issues regarding FRM networks discussed at

- ESA/Copernicus Atmospheric Missions Performance Cluster (Service Reviews)
- EUMETSAT CO2M Cal/Val Support Study for GHG and NO_2
- Quadrennial Ozone Symposium (Boulder, CO, 2024/07) for O_3
- NDACC Steering Committee annual meeting (Santiago, Chile, 2024/11)
- AGU Fall Meeting 2024 (Washington DC, 2024/12) for Air Quality Constellation
- AC-VC-21 / ACSG joint meeting 2025 (Takamatsu, Japan) for AQ, GHG & O_3
- NDACC-IRWG / TCCON / COCCON joint meeting 2025 (Nainital, India, 2025/06)
- WMO GAW Global O_3 and ODS Monitoring Strategy Meeting (WMO, 2025/07)

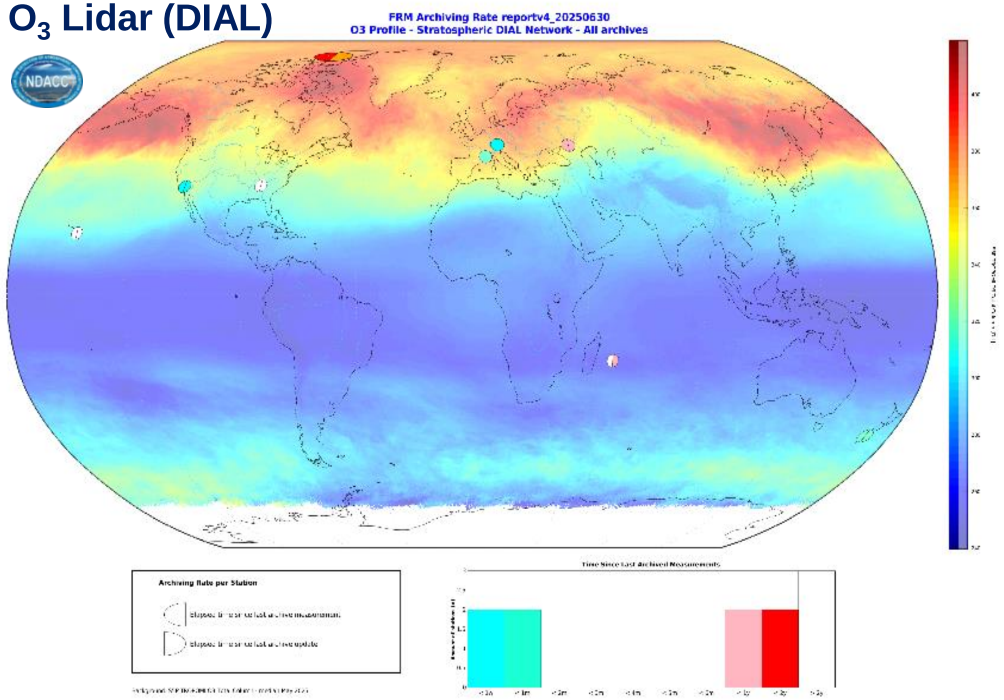
Ground-based Cal/Val Network Design and Evolution

Time dependent operation of ozone lidars and ozonesondes (funding, staff, supplies, station access…)

⇨ **Incomplete ozone validation coverage !**

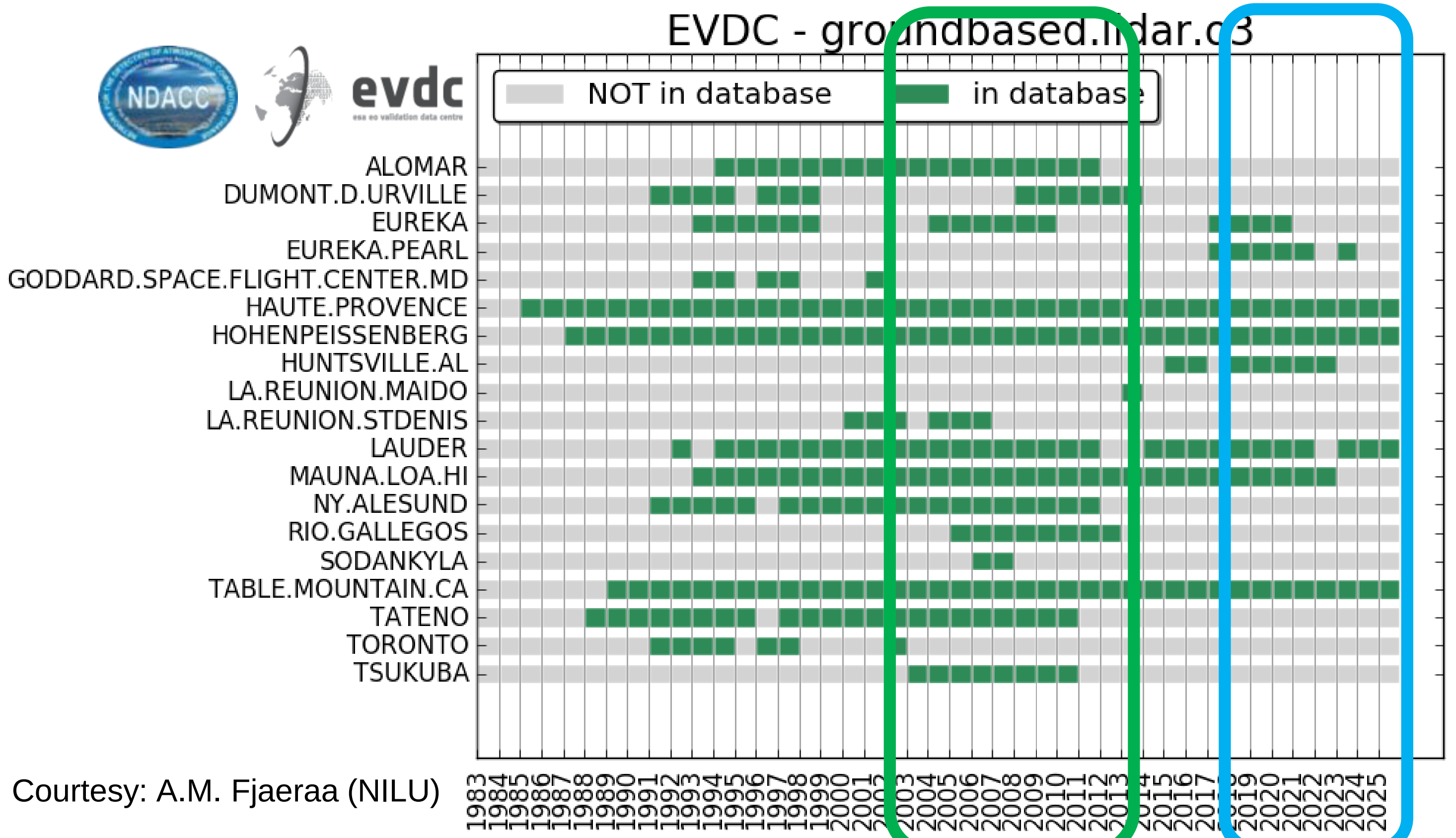
E.g., no recent lidar measurements in Arctic/Antarctica and in the tropics !

O_3 Lidar (DIAL)



Envisat

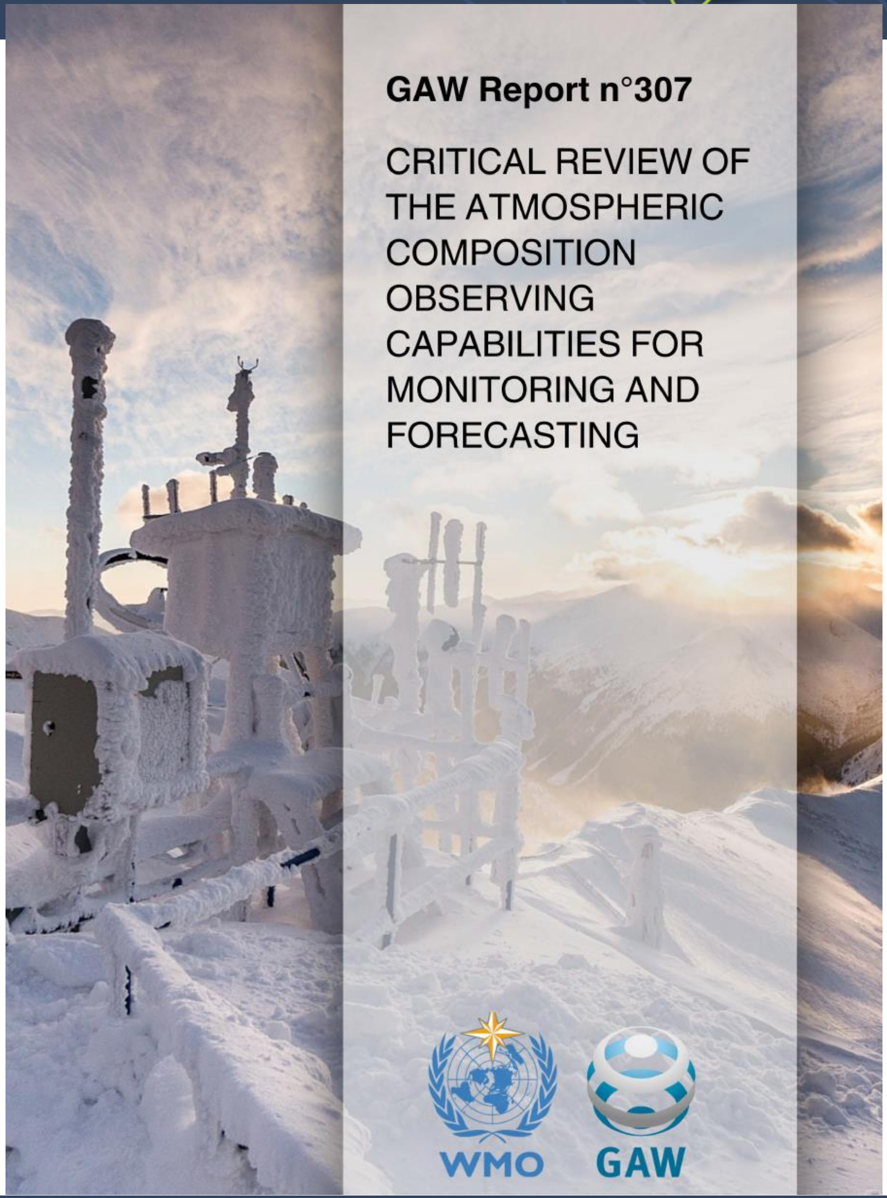
TROPOMI, OMPS, EMI…



Courtesy: A.M. Fjaeraa (NILU)

Ground-based Cal/Val Network Design and Evolution

- ❖ WMO GAW Expert Team on Network Design and Evolution (ET-ACNDE)
- ❖ Chairs R. Eckman, H. Tanimoto and S. Moreno
- ❖ GAW Report No 307 just published



Ground-based Cal/Val Network Design and Evolution

- WMO GAW Global Ozone Monitoring Strategy
  - Dedicated GAW report in preparation, to be published before the next GAW Symposium (April 2026)
  - Will include a Satellite Validation Needs section with ACSG contributions
- NDACC network strategy
  - Peer-reviewed Strategy paper in finalization, including satellite validation strategies and viewpoint of stakeholders (incl. ACSG and space agencies)
  - Satellite session at "*NDACC Symposium 2025 Celebrating 35th Anniversary of the Network*", Virginia Beach, VA, USA (2025/10)
- GHG Roadmap v2 Annex C – Tracking needs, gaps and issues (agenda item 3.12 on Thursday)

AC-VC-21 / ACSG Joint Meeting 2025

AC-VC-21 / ACSG Joint Meeting 2025 hosted by NIES in Takamatsu, June 9-13

Co-hosted with IWGGMS-21

AC-VC-21 / ACSG Joint Meeting 2025

- Coordinated agenda with interleaved parts
- WGCV-ACSG session with general Cal/Val relevant to the constellations
- WGCV-ACSG session on operational validation capacity
- AC-VC-21/GHG agenda coordinated with IWGGMS-21

<table>
<tr><th>Date</th><th>Room</th><th>IWGGMS</th><th>AC-VC</th><th>WGCV-ACSG</th></tr>
<tr><td>Mon 09 June</td><td>Kagawa International Conference Hall</td><td colspan="2">1 GHG Missions Overview</td><td></td></tr>
<tr><td rowspan="3">Tue 10 June</td><td rowspan="3">Small Hall 1/ Sunport Hall Takamatsu</td><td rowspan="3"></td><td colspan="2">2 Tropospheric Ozone</td></tr>
<tr><td></td><td>2 General Cal/Val</td></tr>
<tr><td colspan="2">2 Limb and GEO Ozone</td></tr>
<tr><td>Wed 11 June</td><td>Small Hall 1/ Sunport Hall Takamatsu</td><td></td><td colspan="2">3 AQ Trace Gases</td></tr>
<tr><td>Thu 12 June</td><td>Small Hall 1/ Sunport Hall Takamatsu</td><td></td><td colspan="2">4 AQ aerosol</td></tr>
<tr><td>Thu 12 June</td><td>Small Hall 1/ Sunport Hall Takamatsu</td><td></td><td colspan="2">5 General Discussion</td></tr>
<tr><td>Fri 13 June</td><td>Shoko-Shorei-Kan Hall, Ritsurin Garden</td><td></td><td colspan="2">6 GHG</td></tr>
<tr><td>Fri 13 June</td><td>Shoko-Shorei-Kan Hall, Ritsurin Garden</td><td></td><td>7 AC-VC Wrap Up</td><td></td></tr>
</table>

Discussion topics

- ❖ WGCV-ACSG and AC-VC collaboration
- ❖ CEOS-FRM V2, Cal/Val Portal updates, Cal/Val Resources document
- ❖ Tracking gaps and issues for validation systems and networks, incl. completeness of validation and operational validation capacity
- ❖ New research and applications, connecting validation, research and users/services
  - ▪ Develop multi-constituents/multi-domains Cal/Val sites integrating satellite-derived L1B and L2(+) column validation with AQ/GHG/O_3 synergies, near-surface concentration measurements, emissions/fluxes
  - ➢ Co-located MAX-DOAS/Pandora/FTIR, sondes… + **(national) in-situ data + flux towers (e.g., ICOS)…**

Thank you for your attention !