Committee on Earth Observation Satellites

Atmospheric Composition Highlights

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CEOS WGCV-47 Teleconference
July 14-17, 2020

Working Group on Calibration and Validation

Update to WGCV-46 ACSG report of May 15, 2020:

1. Status of the GHG related actions on WGCV / ACSG (CV-18)
    * Status of the 3 GHG measurement networks for L2 satellite validation
2. WGCV ACSG / AC-VC linkage
    * AC-VC-16 meeting, June 8-12, 2020
    * New tropospheric ozone activity (VC-20-01)
3. Cross-domain approach to Copernicus Cal/Val (CCVS)

GHG Actions

CEOS WP action CV-18:

"Greenhouse gas reference standards for interoperability" – "*Develop list of reference standards for CO_2 and CH_4 products that are suitable for use in intercomparison of multiple missions*" with reporting deadline ~~Q4/2019~~ → **Q4/2020**

WGClimate Roadmap, action Sens-3:

"Define best practices and facilitate exchange and harmonization of approaches for instrument cross-calibration in coordination with CEOS WGCV and GSICS" - *text from Rec#10: "The strategy for cross-calibrating the GOSAT and OCO-2 instruments has employed common standards, including observations of the sun, Moon, and surface vicarious calibration sites, such as Railroad Valley, Nevada, U.S.A. Additional effort by WGCV and GSICS is needed to maintain and improve the quality of these standards to better address the calibration needs of space-based CO_2 and CH_4 sensors."*

GHG Cal/Val Roadmap (draft) toward global stocktake 2023 and 2028

2003 2008 2013 2018 2023 2028

Moderate spectral resolution

High spectral resolution and wide coverage SWIR-TIR and pointing

Instruments

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

Status of NDACC, TCCON and COCCON data quality & readiness for GHG satellite validation

Material provided by M.K. Sha (mahesh.sha@aeronomie.be),
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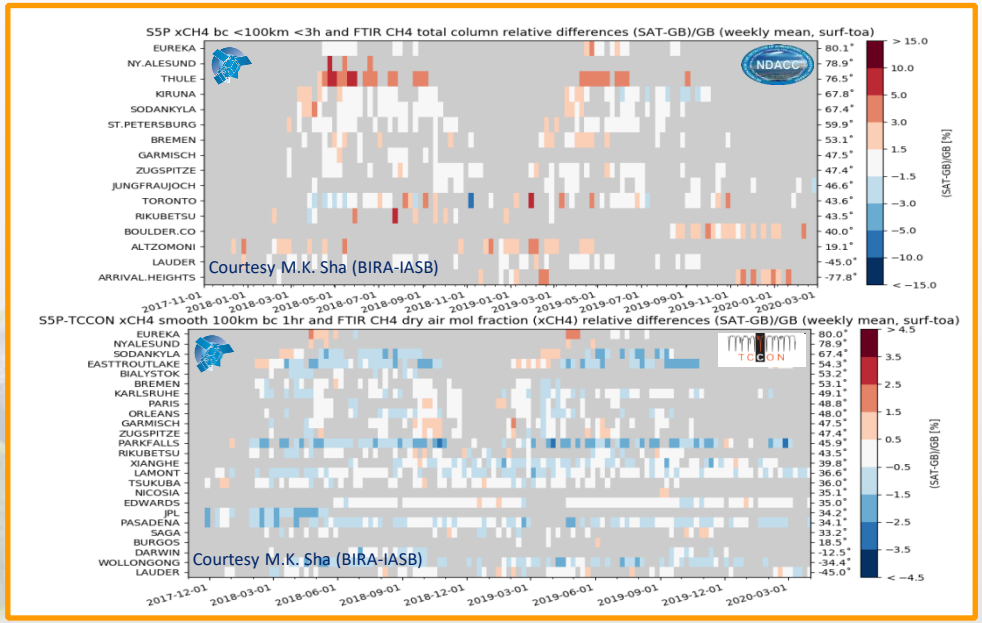
GHG Measurement Networks for Satellite Validation

Sentinel-5p MPC TROPOMI CH_4 validation relies on three GHG monitoring networks:

- NDACC FTIR : automated validation channel in MPC Automated Validation Server (https://mpc-vdaf-server.tropomi.eu)
- TCCON FTIR : manual validation channel
- COCCON EM27/SUN FTIR : validation channel in development



S5P TROPOMI CH4 validation updated every month.

3-montly updates available on http://mpc-vdaf.tropomi.eu

Courtesy M.K. Sha, April 2020

GHG Measurement Networks for Satellite Validation

NDACC IRWG

http://ndacc.org

- Bruker 120HR/125HR
- Resolution 0.0036 cm^{-1}
- Profile retrievals (limited vertical resolution, at least tropo/strato partial columns)

TCCON

http://tccon.org

- Bruker 125HR
- Resolution 0.02 cm^{-1}
- Profile scaling retrievals

COCCON

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

- Bruker EM27/SUN
- Resolution 0.5 cm^{-1}
- Profile scaling retrievals

GHG Measurement Networks for Satellite Validation

NDACC IRWG

http://ndacc.org

- Bruker 120HR/125HR
- Resolution 0.0036 cm^{-1}
- Spectral range: SWIR, MIR and TIR
- Measurements every ±10'
- 21 stations worldwide
- Targets: O_3, CH_4, N_2O, (CO_2, HCHO, SF_6, CFC, HCFC, H_2O, HDO not official), CO, HNO_3, HCl, HF, HCN, C_2H_6, $ClONO_2$, (C_2H_2, PAN, OCS, CH_3OH, NH_3, HCOOH, NO_2 not official)
- Profile retrievals (limited vertical resolution, typically tropo/strato partial columns)
- Retrieval software: SFIT or PROFFIT
- No central processing, QA/QC for selected targets in CAMS operational validation

TCCON

http://tccon.org

- Bruker 125HR
- Resolution 0.02 cm^{-1}
- Spectral range: SWIR
- Measurements every ~ 3'
- 28 stations worldwide
- Targets: CO_2, CH_4, N_2O, H_2O, 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^{-1}
- Spectral range: SWIR
- Measurements every ~ 1'
- > 60 instruments worldwide (some fixed sites but mostly for campaigns)
- Targets: CO_2, CH_4, CO
- Profile scaling retrievals
- Retrieval software PROFFAST
- Central calibration & processing facility at KIT

GHG Measurement Networks for Satellite Validation

NDACC IRWG

- 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

- Operational use in: OCO-2/3 & GOSAT/2 Cal/Val, CAMS validation, ESA TROPOMI validation (limited RD delivery)…
- GGG2020 will improve prior profiles (shape and possible bias), verify CO calibration factor, improve spectroscopy, reduce remaining airmass and H_2O dependences, reduce scatter in CO product, improve diagnostics for instrumental issues.
- Negotiations ongoing for 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

- 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

Further details

FTIR networks in operational validation facilities:

- Copernicus Atmosphere Monitoring Service (CAMS): https://global-evaluation.atmosphere.copernicus.eu
- ESA/Copernicus Sentinel-5p MPC: https://mpc-vdaf-server.tropomi.eu
- EUMETSAT AC SAF trace gases validation: http://cdop.aeronomie.be/validation/valid-results

Intercomparisons (recent papers):

- CO: https://doi.org/10.5194/amt-12-5979-2019
- N_2O: https://doi.org/10.5194/amt-12-1393-2019
- CH_4 Profile retrievals from TCCON spectra: https://doi.org/10.5194/amt-12-6125-2019
- FRM4GHG paper – low resolution FTIR comparison to TCCON: https://doi.org/10.5194/amt-2019-371

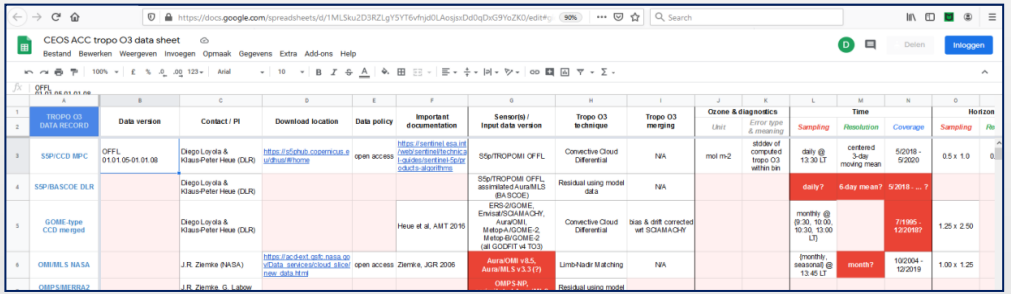
WGCV ACSG / AC-VC Linkage

Participation in CEOS AC-VC meetings

- AC-VC-16 and joint GEMS/Sentinel-4/TEMPO meeting originally planned to be hosted by BIRA-IASB in Brussels (turned into REMOTE MEETING, June 8-12, 2020)
- Validation perspective contributed to cross-agencies harmonization efforts in all AC-VC key topics:
  - Air Quality: Aerosols (Lead S. Kondragunta, NOAA)
  - Air quality: Trace gases (Leads J. Al-Saadi, NASA, B. Veheilmann, ESA)
  - Greenhouse gases (Lead D. Crisp, JPL)
  - Ozone (Lead D. Loyola, DLR)
  - AQ-GHG co-benefits, COVID-19, IGAC linkage (Chairs H. Tanimoto, NIES, J. Al-Saadi, NASA, B. Veheilmann, ESA)
- AC-VC-17 planned to be hosted (hopefully) by BIRA-IASB in Brussels in May/June 2021 (TBC)

CEOS VC-20-01 Tropospheric Ozone Activity

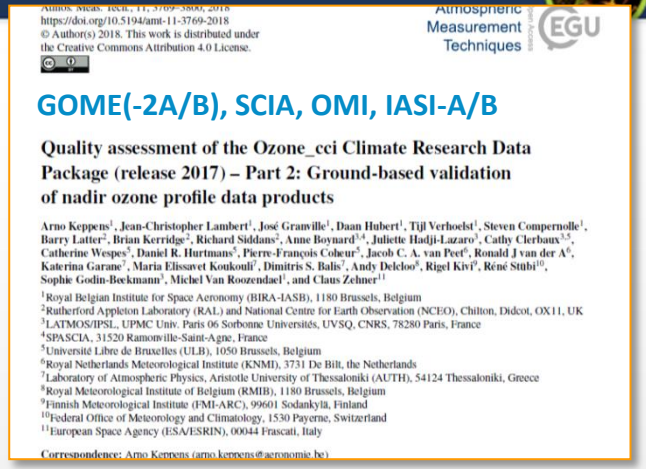
- VC-20-01: '*Tropospheric ozone dataset validation and harmonization*' due by end of 2022
- Lead: D. Loyola (DLR), support G. Labow (NASA/GSFC) and J.-C. Lambert (BIRA-IASB)
- CEOS activity, response to IGAC / TOAR-II needs
- Coordination with TOAR-II Satellite Ozone WG
- Tentative schedule:
  - TOAR-II Quickstart Event (webinar, September 16, 2020)
  - TOAR-II Workshop in Geneva (Spring 2021?, TBC)
  - Initial results at AC-VC-17 (June 2021, Brussels?)
  - TOAR-II Workshop (2022, TBD)
  - AC-VC-18 (May/June 2022, TBD)
  - AC-VC-18 (May/June 2022, TBD)
  - Contributions to TOAR-II publications (2022+)



CEOS VC-20-01 Tropospheric Ozone Activity

State of the art of satellite tropospheric ozone:

- Satellites capture well major features and trends.
- Biases between satellites, change with time.
- Differences in sensitivity and sampling matter.
- Vertical sensitivity differences not straightforward to assess and handle
- Data harmonisation improves mutual consistency.



https://doi.org/10.5194/amt-11-3769-2018

Atmospheric Measurement Techniques

GOME(-2A/B), SCIA, OMI, IASI-A/B

Quality assessment of the Ozone_cci Climate Research Data Package (release 2017) – Part 2: Ground-based validation of nadir ozone profile data products

Arno Keppens[1], Jean-Christopher Lambert[1], José Granville[1], Daan Hubert[1], Tijl Verhoelst[1], Steven Compernolle[1], Barry Latter[2], Brian Kerridge[2], Richard Siddans[2], Anne Boynard[3,4], Juliette Hadji-Lazaro[3], Cathy Clerbaux[3,5], Catherine Wespes[5], Daniel R. Hurtmans[5], Pierre-François Coheur[5], Jacob C. A. van Peet[6], Ronald J van der A[6], Katerina Garane[7], Maria Elissavet Koukouli[7], Dimitris S. Balis[7], Andy Delcloo[8], Rigel Kivi[9], René Stübi[10], Sophie Godin-Beekmann[3], Michel Van Roozendael[1], and Claus Zehner[11]

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[2]Rutherford Appleton Laboratory (RAL) and National Centre for Earth Observation (NCEO), Chilton, Didcot, OX11, UK
[3]LATMOS/IPSL, UPMC Univ. Paris 06 Sorbonne Universités, UVSQ, CNRS, 78280 Paris, France
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[8]Royal Meteorological Institute of Belgium (RMIB), 1180 Brussels, Belgium
[9]Finnish Meteorological Institute (FMI-ARC), 99601 Sodankylä, Finland
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[11]European Space Agency (ESA/ESRIN), 00044 Frascati, Italy

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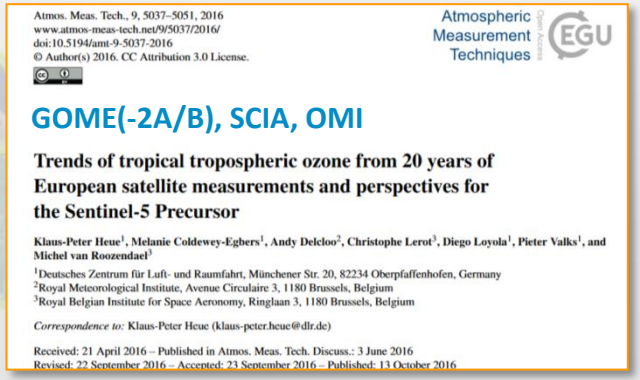

Atmos. Meas. Tech., 9, 5037–5051, 2016
www.atmos-meas-tech.net/9/5037/2016/
doi:10.5194/amt-9-5037-2016

Atmospheric Measurement Techniques

GOME(-2A/B), SCIA, OMI

Trends of tropical tropospheric ozone from 20 years of European satellite measurements and perspectives for the Sentinel-5 Precursor

Klaus-Peter Heue[1], Melanie Coldewey-Egbers[1], Andy Delcloo[2], Christophe Lerot[3], Diego Loyola[1], Pieter Valks[1], and Michel van Roozendael[3]

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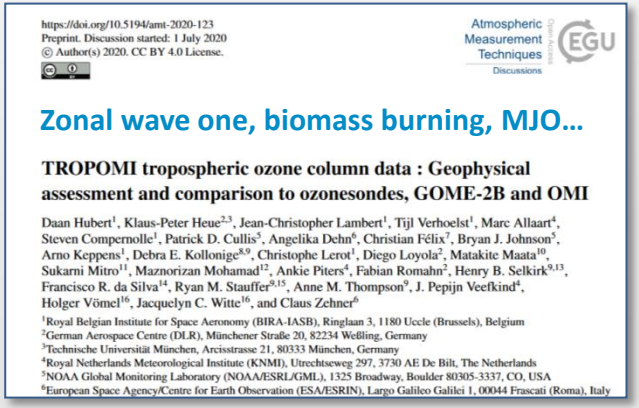
Received: 21 April 2016 – Published in Atmos. Meas. Tech. Discuss.: 3 June 2016
Revised: 22 September 2016 – Accepted: 23 September 2016 – Published: 13 October 2016



https://doi.org/10.5194/amt-2020-123
Preprint. Discussion started: 1 July 2020

Atmospheric Measurement Techniques Discussions

Zonal wave one, biomass burning, MJO…

TROPOMI tropospheric ozone column data : Geophysical assessment and comparison to ozonesondes, GOME-2B and OMI

Daan Hubert[1], Klaus-Peter Heue[2,3], Jean-Christopher Lambert[1], Tijl Verhoelst[1], Marc Allaart[4], Steven Compernolle[1], Patrick D. Cullis[5], Angelika Dehn[6], Christian Félix[7], Bryan J. Johnson[5], Arno Keppens[1], Debra E. Kollonige[8,9], Christophe Lerot[1], Diego Loyola[2], Matakite Maata[10], Sukarni Mitro[11], Maznorizan Mohamad[12], Ankie Piters[4], Fabian Romahn[2], Henry B. Selkirk[9,13], Francisco R. da Silva[14], Ryan M. Stauffer[9,15], Anne M. Thompson[9], J. Pepijn Veefkind[4], Holger Vömel[16], Jacquelyn C. Witte[16], and Claus Zehner[6]

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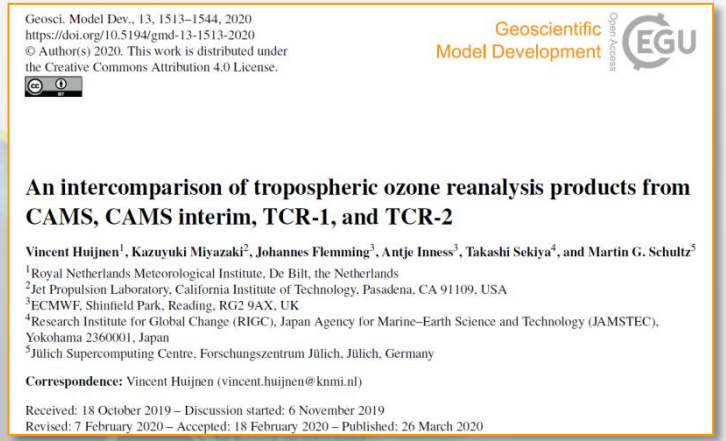
[6]European Space Agency/Centre for Earth Observation (ESA/ESRIN), Largo Galileo Galilei 1, 00044 Frascati (Roma), Italy

Data assimilation - Reanalyses

- Performance of reanalyses depends on assimilated satellite data.
- Temporal (in)consistency affects trends and interannual variability assessments.



Geosci. Model Dev., 13, 1513–1544, 2020
https://doi.org/10.5194/gmd-13-1513-2020

Geoscientific Model Development
Open Access
EGU

An intercomparison of tropospheric ozone reanalysis products from CAMS, CAMS interim, TCR-1, and TCR-2

Vincent Huijnen[1], Kazuyuki Miyazaki[2], Johannes Flemming[3], Antje Inness[3], Takashi Sekiya[4], and Martin G. Schultz[5]

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Table 2. Observations of ozone used in the CAMS-iRean assimilation system.

Instrument (satellite)	Product	Data provider, version	Period	Reference
SCIAMACHY (Envisat)	TC	ESA, CCI (TC_SCIAMACHY), fv0300	1 Jan 2003 to 8 Apr 2012	Lerot et al. (2009)
MIPAS (Envisat)	Prof	– ESA CCI (HARMOZ_MIPAS), fv0004	27 Jan 2005 to 31 Mar 2012	Von Clarmann et al. (2003, 2009)
MLS (Aura)	Prof	NASA, V2 NASA, V3.4	3 Aug 2004 to 31 Dec 2012 1 Jan 2013 to 31 Dec 2016	Schwartz et al. (2015)
OMI (Aura)	TC	KNMI, V3 KNMI, NRT	3 Aug 2004 to 31 May 2015 1 Jun 2015 to present	Liu et al. (2010)
GOME (ERS-2)	Prof	RAL	1 Jan 2003 to 31 May 2003	Munro et al. (1998)
GOME-2 (Metop-A)	TC	ESA, CCI, fv0100 ESA, CCI, fv0300 NRT	23 Jan 2007 to 31 Dec 2012 1 Jan 2013 to 31 Dec 2016 1 Jan 2017 to present	Hao et al. (2014)
GOME-2 (Metop-B)	TC	ESA, CCI, fv0300 NRT	1 Jan 2013 to 31 Dec 2016 1 Jan 2017 to present	Hao et al. (2014)
SBUV/2 (NOAA-14–NOAA-19)	PC	NASA, v8.6 13L NRT 21L	1 Jan 2003 to 31 Dec 2012 1 Jan 2013 to present	Bhartia et al. (1996), McPeters et al. (2013)

Table 3. Observations of ozone used in the CAMS-Rean assimilation system.

Instrument (satellite)	Product	Data provider, version	Period	Reference
SCIAMACHY (Envisat)	TC	ESA, CCI (TC_SCIAMACHY), fv0300	1 Jan 2003 to 8 Apr 2012	Lerot et al. (2009)
MIPAS (Envisat)	Prof	ESA, NRT ESA, CCI (HARMOZ_MIPAS), fv0004	27 Jan 2003 to 26 Mar 2004 and 27 Jan 2005 to 31 Mar 2012	Von Clarmann et al. (2003, 2009)
MLS (Aura)	Prof	NASA, V4	3 Aug 2004 to 31 Dec 2016	Schwartz et al. (2015)
OMI (Aura)	TC	KNMI, V3 KNMI, NRT	3 Aug 2004 to 31 May 2015 1 Jun 2015 to present	Liu et al. (2010)
GOME-2 (Metop-A)	TC	ESA, CCI, fv0100 ESA, CCI, fv0300 NRT	23 Jan 2007 to 31 Dec 2012 1 Jan 2013 to 31 Dec 2016 1 Jan 2017 to present	Hao et al. (2014)
GOME-2 (Metop-B)	TC	ESA, CCI, fv0300 NRT	1 Jan 2013 to 31 Dec 2016 1 Jan 2017 to present	Hao et al. (2014)
SBUV/2 (NOAA-14–NOAA-19)	PC	NASA, v8.6 13L NRT 21L	1 Jan 2003 to 7 Jul 2013 8 Jul 2013 to present	Bhartia et al. (1996), McPeters et al. (2013)

IGAC Tropospheric Ozone Assessment Report

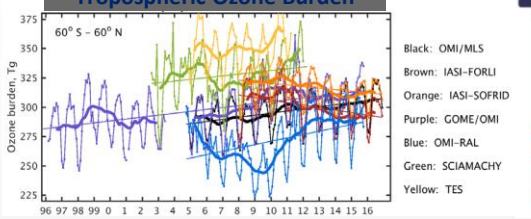
Lessons from TOAR-I (Gaudel *et al.*, 2018)

- Satellites report a wide variety of trends (2008-2016) and variations in tropospheric ozone.
- Differences in vertical sensitivity and sampling
- Differences in tropopause column definition
- Biases change over time.
- (In)consistencies with TOST (ozonesonde based trajectories)

TOAR-II Satellite Ozone Working Group goals

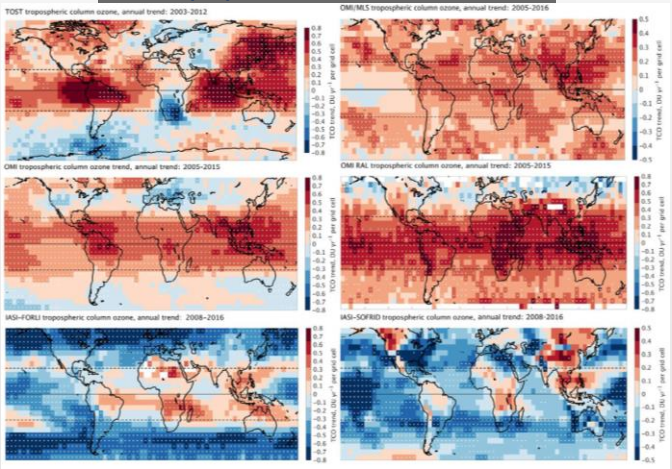
- Address above issues
- Global chemistry transport models as transfer standard
- Reconcile satellite-, ground- and aircraft-based data
- Provide common methodology for validation of trends

Tropospheric Ozone Burden



TOAR tropospheric ozone assessment report

Tropospheric Ozone Annual Trend



CEOS VC-20-01 Tropospheric Ozone Activity

NASA (G. Labow *et al.*)

- The Great Tropospheric Ozone Cook-Off @CEOS AC-VC-15
- Intercomparison of monthly/daily gridded satellite data records
  - Spatial structure of the bias

DLR (K.-P. Heue, M. Coldewey-Egbers, D. Loyola *et al.*)

- Harmonisation, multi-satellite trends
- Intercomparison CCD S5P, GOME-2, OMI and S5P/BASCOE
  - Spatial & temporal structure of the bias
  - Trends
  - Validation with ozonesondes and lidars at RMIB (A. Delcloo)

BIRA-IASB (D. Hubert, A. Keppens, J.-C. Lambert, C. Vigouroux)

- National proposal BERTOLDT with RMIB (D. Poiraz, R. Van Malderen) and ULB (P.F. Coheur, C. Wespes)
- Characterise & understand differences between satellite tropospheric O_3 using ground-based networks (ozonesondes, NDACC FTIR)
  - Global distribution and trends
  - Tropospheric content and profile
  - Vertical sensitivity & smoothing
  - Geophysical features: zonal wave one, NAO, QBO, MJO…

Other activities/groups welcome

- Cooperation with ongoing activities at ESA, NASA, NOAA…
- Coordination with TOAR-II Satellite Ozone WG
- Other data: IAGOS aircraft?

Cross-domain Cal/Val Approach for Copernicus

- EC H2020 call LC-SPACE-19-EO-2020 for a Coordinated Support Action to elaborate a holistic Cal/Val solution for the Copernicus Sentinel missions, overcoming current limitations:
  - Lack of cross-Sentinel synergies: methodologies, data collection, distribution, processing and inter-validation,
  - Insufficient handling of inter-operability requirements within the Copernicus programme,
  - Excessive dependency on data obtained from external entities without any long-term operational commitments to the Copernicus programme,
  - Global lack of reference data compliant with internationally endorsed good practice methods for operational Cal/Val, both from permanently maintained sites and campaign-based acquisitions.
- Proposal Copernicus Cal/Val Solution (**CCVS**) selected, coordinator ACRI-ST + 13 partners
- Partners/stakeholders: Copernicus, space agencies, Cal/Val experts & infrastructures, measurement networks & infrastructures
- WGCV and GSICS are key stakeholders and will be contacted for cooperation in 2021.
- CCVS addresses GHG Roadmap CV-2 and CV-5, and is also relevant to CV-6.

Thank you for your attention!