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 Cal/Val Roadmap (draft) 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

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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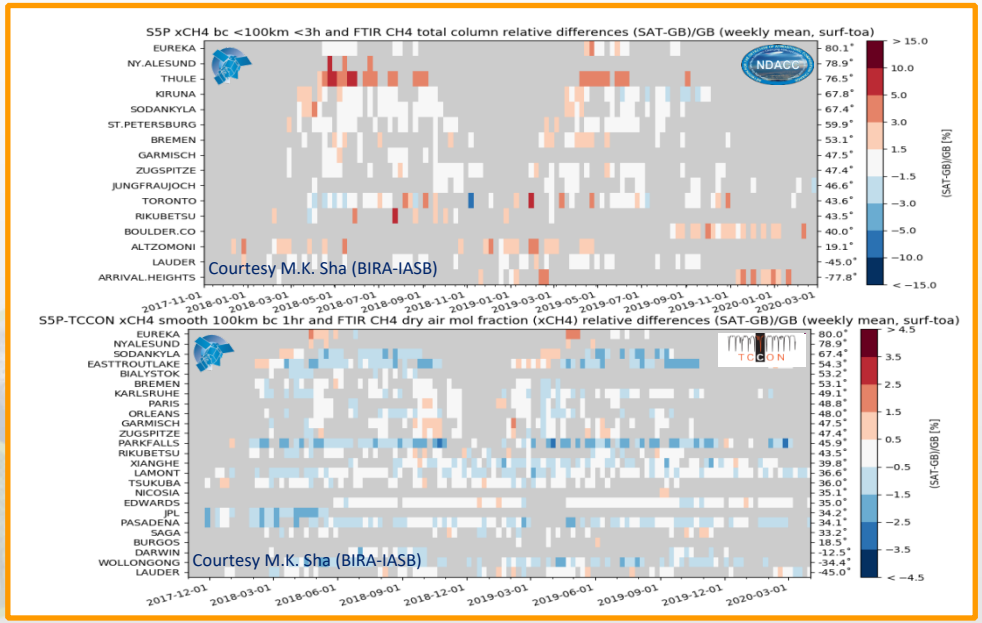
GHG Measurement Networks for Satellite Validation

Sentinel-5p / 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

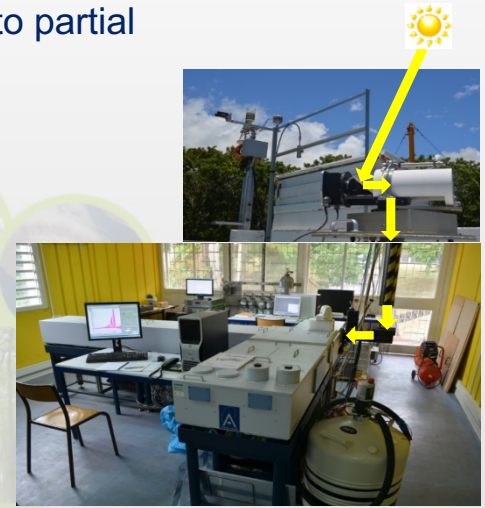
http://ndacc.org

- 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

Use 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

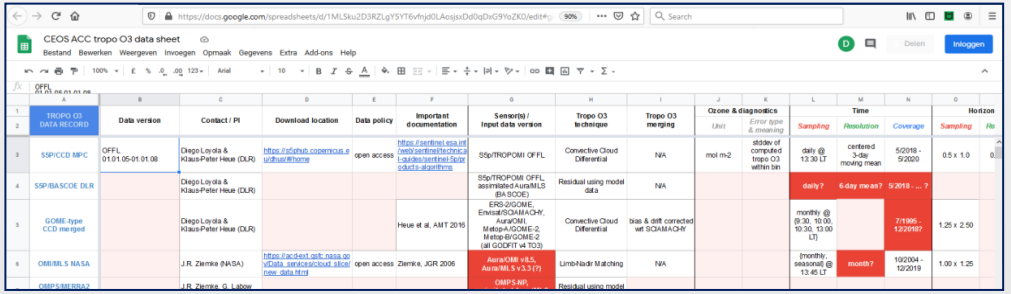
WGCV ACSG / AC-VC Linkage

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 VIRTUAL 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

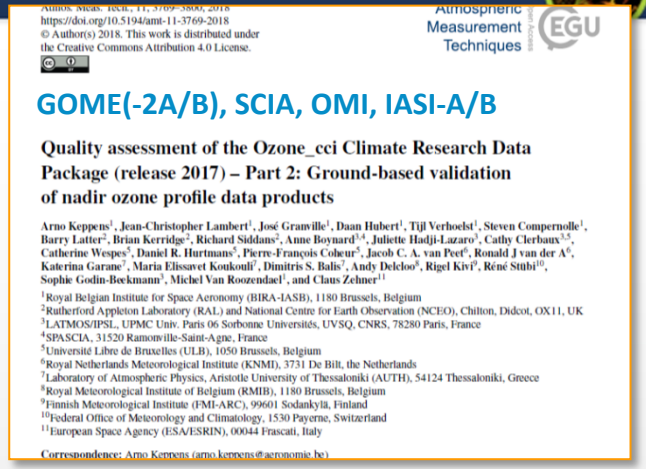
- VC-20-01: '*Tropospheric ozone dataset validation and harmonization*' due by end of 2022
- Lead: D. Loyola (DLR), support G. Labow (NASA/GSFC) and J.-C. Lambert (BIRA-IASB)
- CEOS activity, response to IGAC / TOAR-II needs
- Coordination with TOAR-II Satellite Ozone WG
- Tentative schedule:
  - TOAR-II 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)
  - 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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[8]Royal Meteorological Institute of Belgium (RMIB), 1180 Brussels, Belgium
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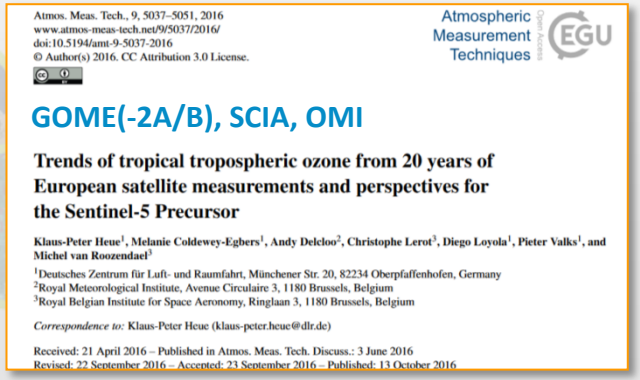

Atmos. Meas. Tech., 9, 5037–5051, 2016
www.atmos-meas-tech.net/9/5037/2016/
doi:10.5194/amt-9-5037-2016

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
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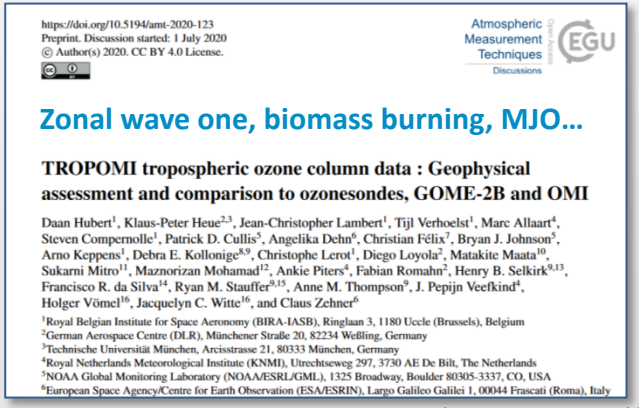

https://doi.org/10.5194/amt-2020-123
Preprint. Discussion started: 1 July 2020

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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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

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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)

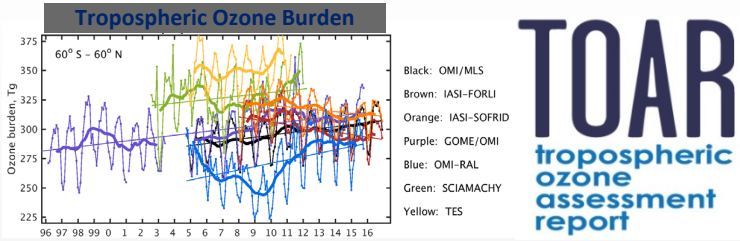
IGAC Tropospheric Ozone Assessment Report

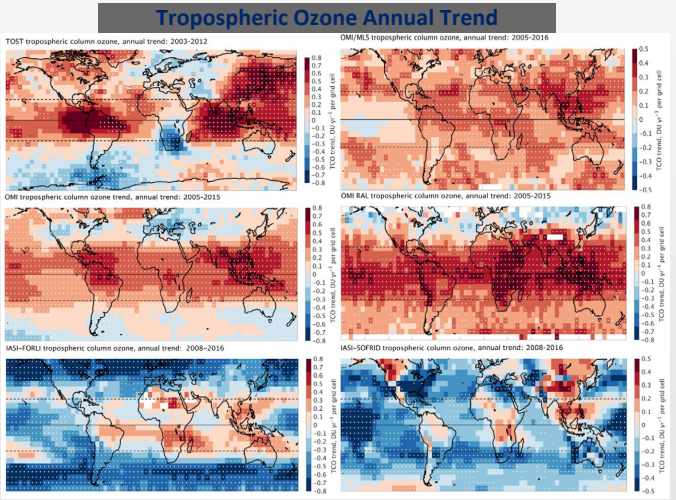
Lessons from TOAR-I (Gaudel *et al.*, 2018)

- 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





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 project BERTOLDT with ULB (P.F. Coheur, C. Wespes) and RMIB (R. Van Malderen)
- Characterise & understand differences between satellite tropospheric O_3 using ground-based comparisons (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…
- IAGOS aircraft data ?
- Coordination with TOAR-II Satellite Ozone WG

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!