CEOS VC-20-01 Activity on Tropospheric Ozone

Geophysical Validation Goals and Plans

Jean-Christopher Lambert, Daan Hubert, Arno Keppens (BIRA-IASB),
Gordon Labow (NASA), and Diego Loyola (DLR)

CEOS AC-VC-16 teleconference

June 8-12, 2020

Atmospheric Composition Virtual Constellation
& Working Group on Calibration and Validation

Assessment of tropospheric ozone from satellites

Multi-satellite assessments

Typical findings

- 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.

Atmos. Meas. Tech., 11, 3769–3800, 2018
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], Réné Stübi[10], Sophie Godin-Beekmann[3], Michel Van Roozendael[1], and Claus Zehner[11]

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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

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Submitted to AMT for the TROPOMI Special Issue

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

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

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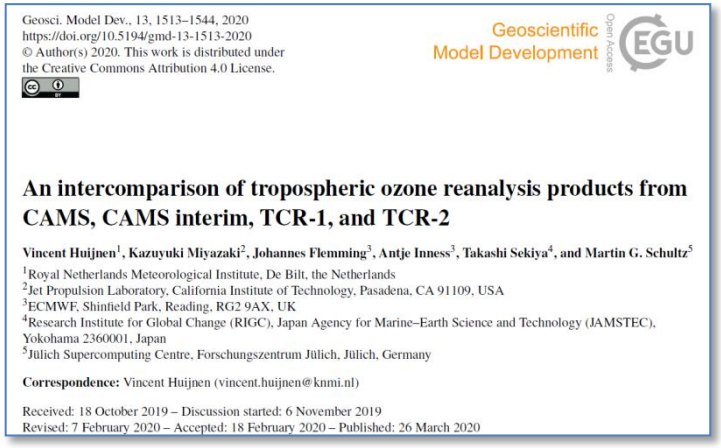
Assessment of tropospheric ozone from satellites

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)

Assessment of tropospheric ozone from satellites

IGAC Tropospheric Ozone Assessment Report (TOAR)

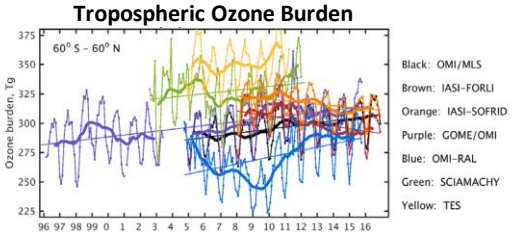
Lessons from TOAR-I (Gaudel *et al.*, 2018)

- 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 trajectories)

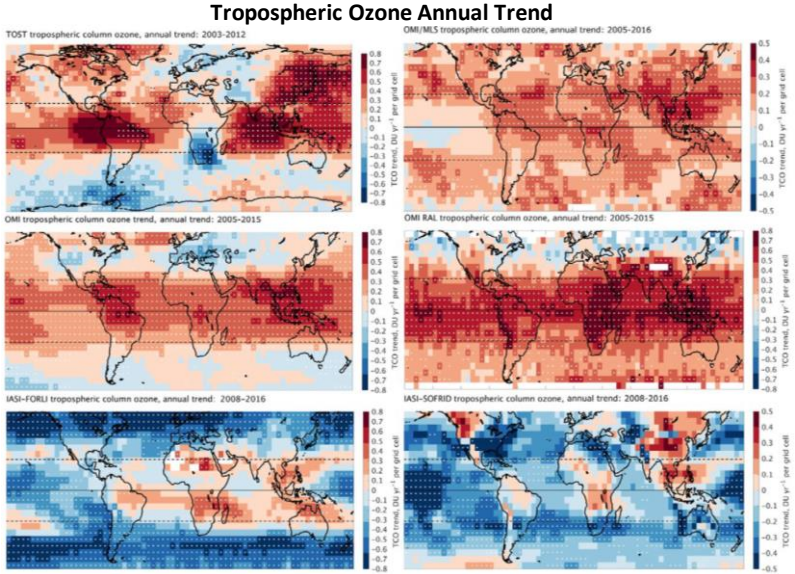
TOAR-II Satellite Ozone Working Group goals

https://igacproject.org/satellite-ozone-working-group

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

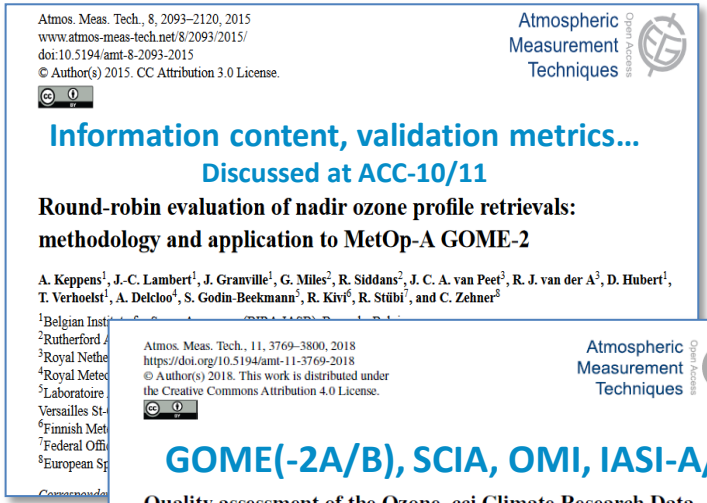


TOAR
tropospheric ozone assessment report



Assessment of tropospheric ozone from satellites

Validation practices for: sensitivity, bias, drift, precision, sampling errors, geophysical features



Atmos. Meas. Tech., 8, 2093–2120, 2015
www.atmos-meas-tech.net/8/2093/2015/
doi:10.5194/amt-8-2093-2015

Atmospheric Measurement Techniques

Information content, validation metrics…

Discussed at ACC-10/11

Round-robin evaluation of nadir ozone profile retrievals: methodology and application to MetOp-A GOME-2

A. Keppens[1], J.-C. Lambert[1], J. Granville[1], G. Miles[2], R. Siddans[2], J. C. A. van Peet[3], R. J. van der A[3], D. Hubert[1], T. Verhoelst[1], A. Delcloo[4], S. Godin-Beekmann[5], R. Kivi[6], R. Stübi[7], and C. Zehner[8]

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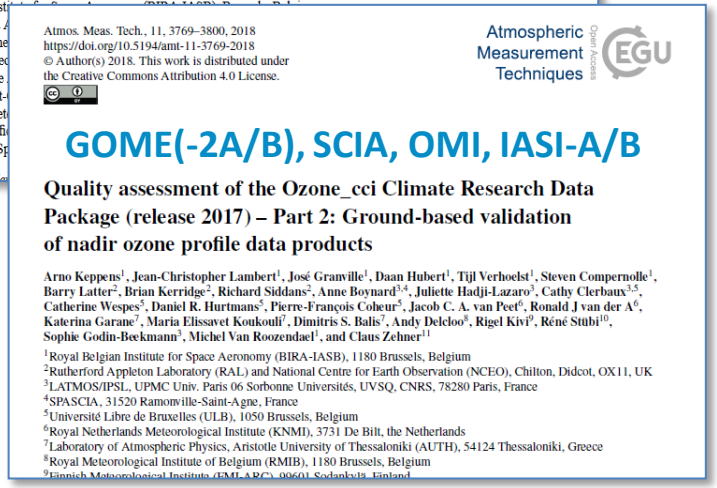

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https://doi.org/10.5194/amt-11-3769-2018

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], Réné Stübi[10], Sophie Godin-Beekmann[3], Michel Van Roozendael[1], and Claus Zehner[11]

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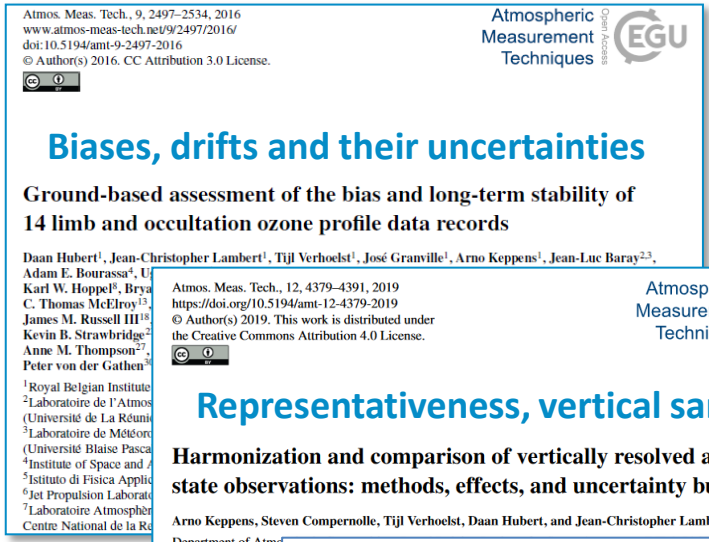

Atmos. Meas. Tech., 9, 2497–2534, 2016
www.atmos-meas-tech.net/9/2497/2016/
doi:10.5194/amt-9-2497-2016

Atmospheric Measurement Techniques

Biases, drifts and their uncertainties

Ground-based assessment of the bias and long-term stability of 14 limb and occultation ozone profile data records

Daan Hubert[1], Jean-Christopher Lambert[1], Tijl Verhoelst[1], José Granville[1], Arno Keppens[1], Jean-Luc Baray[2,3], Adam E. Bourassa[4], U…
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Atmos. Meas. Tech., 12, 4379–4391, 2019
https://doi.org/10.5194/amt-12-4379-2019

Atmospheric Measurement Techniques

Representativeness, vertical sampling

Harmonization and comparison of vertically resolved atmospheric state observations: methods, effects, and uncertainty budget

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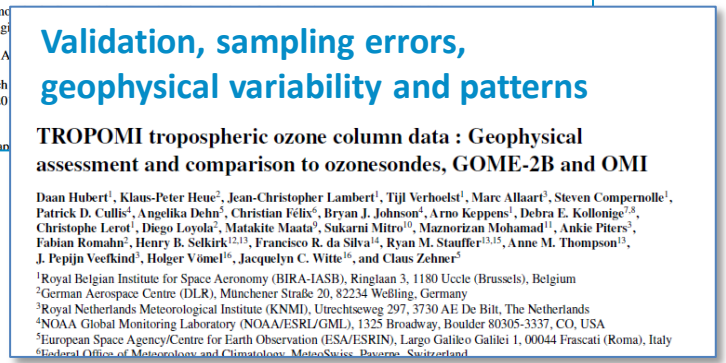
Received: 21 March…
Revised: 18 June 20…

Abstract. Many ap…



Validation, sampling errors, geophysical variability and patterns

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

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

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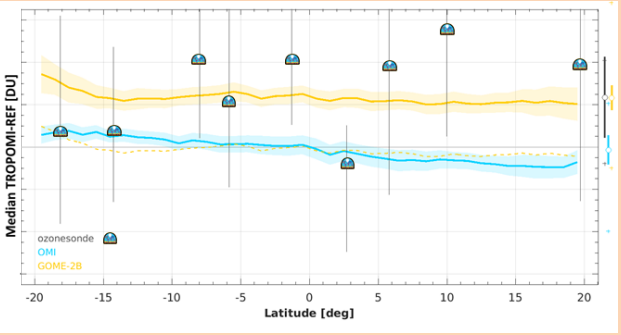
Quality Indicators for tropospheric ozone column

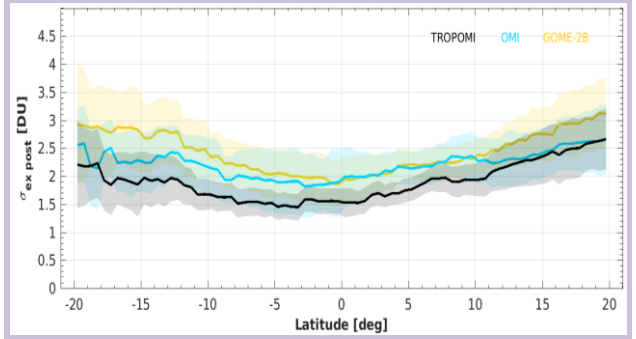
Bias

- Vs. ozonesondes :
- Dependences SAT-to-SAT :
  - meridian :
  - zonal :
  - seasonal :
- Consistent with ex-ante systematic error?
- Consistent with tropopause definition/sensitivity effects ?



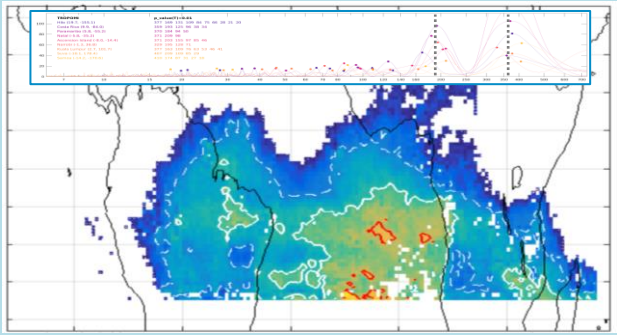
Dispersion

- From pairwise :
- From triplets :
- Dependences SAT-to-SAT :
  - meridian :
  - seasonal :
- Sampling errors :
- Consistent with ex-ante uncertainty estimate?



Geophysical patterns & signals

- Annual + semi-annual cycles ?
- ENSO, MJO, QBO ?
- Zonal wave one ?
- Biomass burning season ?
- Other known features ?



Sensitivity and Tropospheric Burden

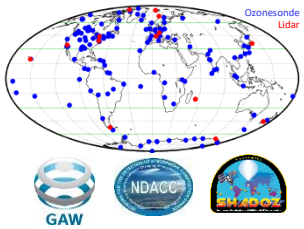
Lack of harmonisation between the different satellite records, e.g., regarding terms and definitions of the tropopause and the tropospheric content

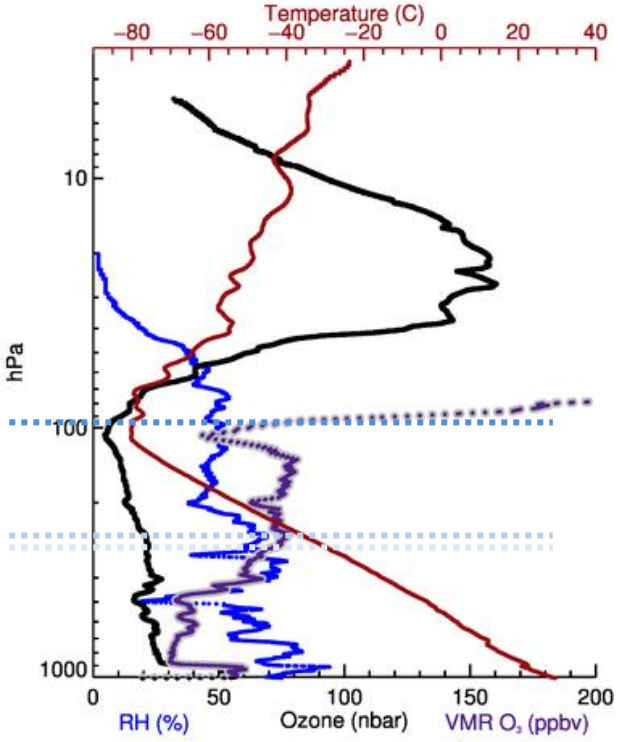
Use high-resolution T and O_3 profiles and averaging kernels (or weighting functions) to explore effects of

- difference in top level tropospheric column,
- difference in tropopause definition,
- difference in auxiliary data to define tropopause.

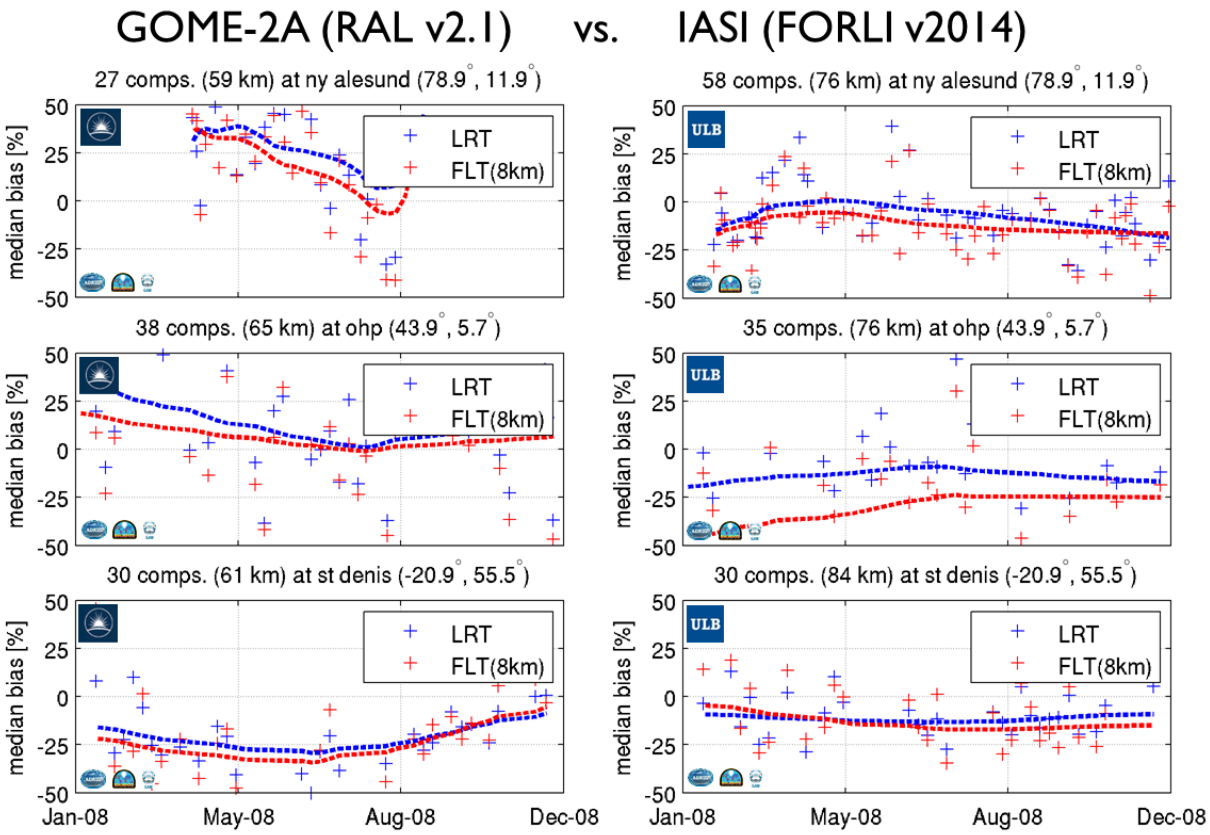
Correlative T and O_3 profile data

- ozonesonde network (GAW, NDACC, SHADOZ)
- (IAGOS aircrafts)
- (NDACC and TOLNet tropospheric lidars)
- (NDACC FTIR)





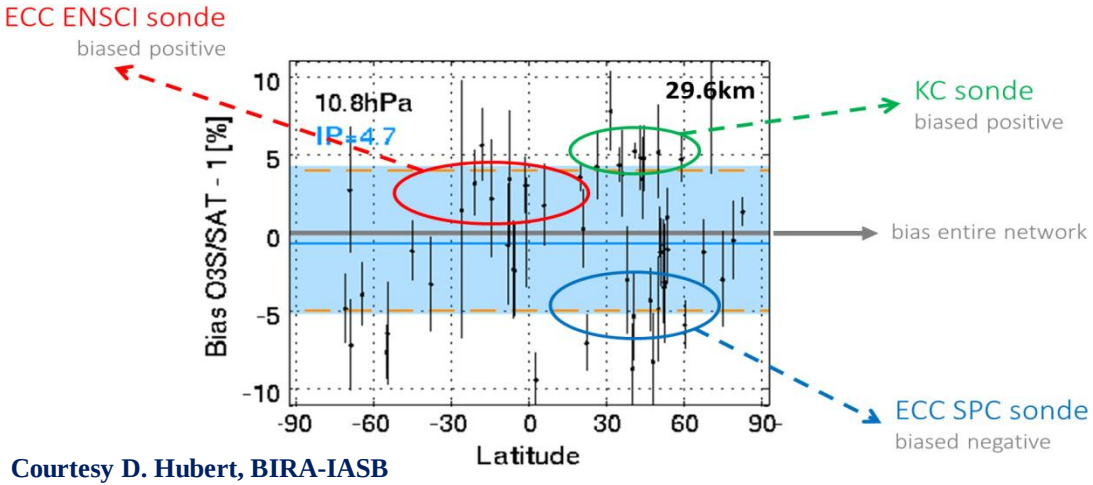
Sensitivity and Tropospheric Burden



Adapted from Keppens *et al.*, 2018

O3S-DQA Improving Ozonesonde Network Homogeneity

WMO/GAW O3S-DQA evaluation/improvement of ozonesonde network(s) homogeneity



Courtesy D. Hubert, BIRA-IASB

- Satellite ensemble based evaluation approach
- 2000-2013; 60 WOUDC sites, 28 NDACC sites, SHADOZ
- Network inhomogeneities caused by ozonesonde type, manufacturer, solution strength
- By-product: mutual consistency of data archives (WOUDC, NDACC, SHADOZ, ESRL…)

Assessment of tropospheric ozone from satellites

Ongoing activities

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 RMIB (A. Delcloo)

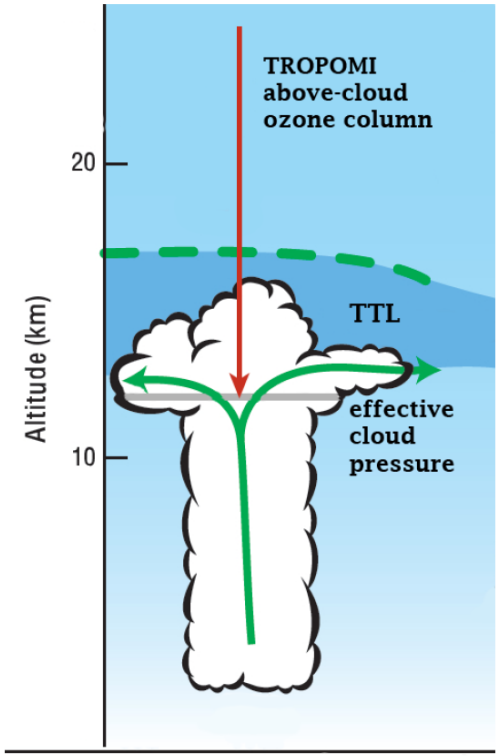
BIRA-IASB (D. Hubert, A. Keppens, J.-C. Lambert, C. Vigouroux)

- National project CASTOAR 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)
  - Tropospheric content
  - Vertical sensitivity & smoothing
  - Long-term stability
  - Trends
- Assessment of known geophysical signatures

Other activities/groups welcome

- IAGOS aircraft data ?
- … ?

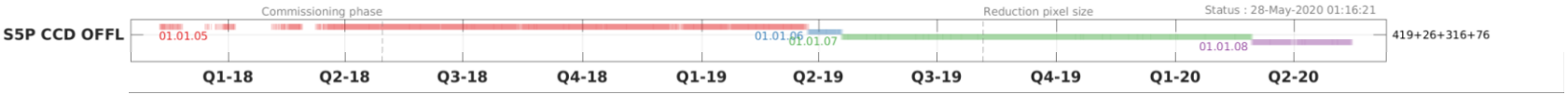
Requirement: Identification of tropospheric ozone column datasets



Identification via GoogleDoc registration sheet

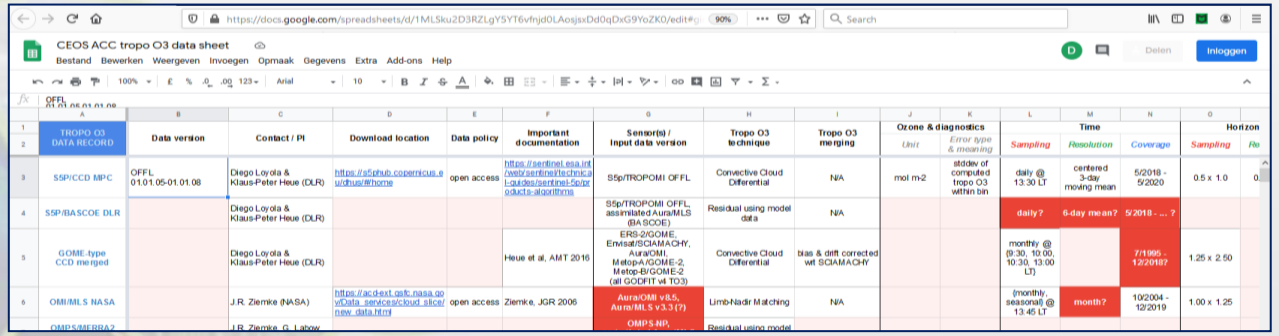
Example: S5P TROPOMI tropical tropospheric ozone

- Convective Cloud Differential (CCD) technique using
  - TROPOMI Level-2 total ozone column data (GODFIT v4)
  - TROPOMI Level-2 cloud data (OCRA + ROCINN_CRB)
- Represents
  - O_3 column between surface and 270 hPa
  - daily Level-3 product, 0.5° lat. x1° long., latitude range 20°S-20°N
  - 3-day moving average of cloud-free data
  - Associated vertical sensitivity/smoothing estimate: …
  - Associated uncertainty estimates: …
- Processed at DLR with L2_O3_TCL OFFL processor v01.01.05-08
- Available operationally since 30 Apr 2018 on the Copernicus data hub: https://scihub.copernicus.eu



Geophysical Validation Goals and Plans

- VC-20-01: '*Tropospheric O3 dataset validation and harmonization*' due by end of 2022
- Initial results to be presented next year in AC-VC-17
- Agreed two reference years for global and regional distributions: 2017-2018
- Agree on ground-based stations & regions for trend & drift studies
- Register and give access to satellite data with requested identification and guidelines (QA filters etc.) ⇨ Request *GoogleDocs* link to Arno.Keppens and Daan.Hubert both at @aeronomie.be
- Coordination with TOAR-II plans and needs



TROPO O3 DATA RECORD	Data version	Contact / PI	Download location	Data policy	Important documentation	Sensor(s) / input data version	Tropo O3 technique	Tropo O3 merging	Ozone & diagnostics: Unit	Ozone & diagnostics: Error type & meaning	Time: Sampling	Time: Resolution	Time: Coverage	Horizon: Sampling	Horizon: Re
S5P/CCD MPC	OFFL 01.01.05-01.01.08	Diego Loyola & Klaus-Peter Heue (DLR)	https://s5phub.copernicus.eu/dhus/#/home	open access	https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms	S5p/TROPOMI OFFL	Convective Cloud Differential	N/A	mol m-2	stddev of computed tropo O3 within bin	daily @ 13:30 LT	centered 3-day moving mean	5/2018 - 5/2020	0.5 x 1.0	0.
S5P/BASCOE DLR		Diego Loyola & Klaus-Peter Heue (DLR)				S5p/TROPOMI OFFL, assimilated Aura/MLS (BA SCOE)	Residual using model data	N/A			daily?	6-day mean?	5/2018 - ... ?		
GOME-type CCD merged		Diego Loyola & Klaus-Peter Heue (DLR)			Heue et al, AMT 2016	ERS-2/GOME, Envisat/SCIAMACHY, Aura/OMI, Metop-A/GOME-2, Metop-B/GOME-2 (all GODFIT v4 TO3)	Convective Cloud Differential	bias & drift corrected wrt SCIAMACHY			monthly @ (9:30, 10:00, 10:30, 13:00 LT)		7/1995 - 12/2018?	1.25 x 2.50	
OMI/MLS NASA		J.R. Ziemke (NASA)	https://acd-ext.gsfc.nasa.gov/Data_services/cloud_slice/new_data.html	open access	Ziemke, JGR 2006	Aura/OMI v8.5, Aura/MLS v3.3 (?)	Limb-Nadir Matching	N/A			(monthly, seasonal) @ 13:45 LT	month?	10/2004 - 12/2019	1.00 x 1.25	
OMPS/MERRA2		J.R. Ziemke, G. Labow				OMPS-NP,	Residual using model								