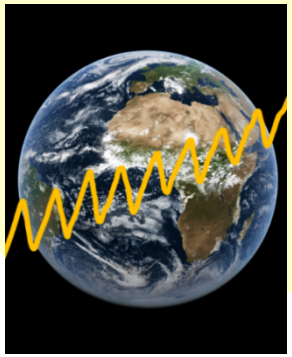
IWGGMS-15, 3-5 June 2019, Sapporo, Hokkaido, Japan

Generation of merged Level 2 and Level 3 XCO_2 data products from SCIAMACHY/ENVISAT, GOSAT and OCO-2 for the Copernicus Climate Change Service



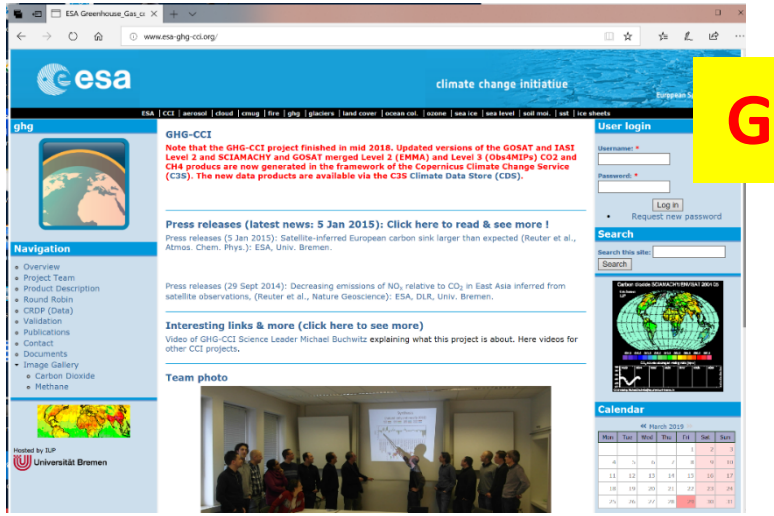
Michael Buchwitz, Maximilian Reuter, Oliver Schneising, Stefan Noël, Heinrich Bovensmann, John P. Burrows

Institute of Environmental Physics (IUP), University of Bremen FB1,
Otto Hahn Allee 1, 28334 Bremen, Germany

Satellite CO_2 and CH_4 CCI & Copernicus projects

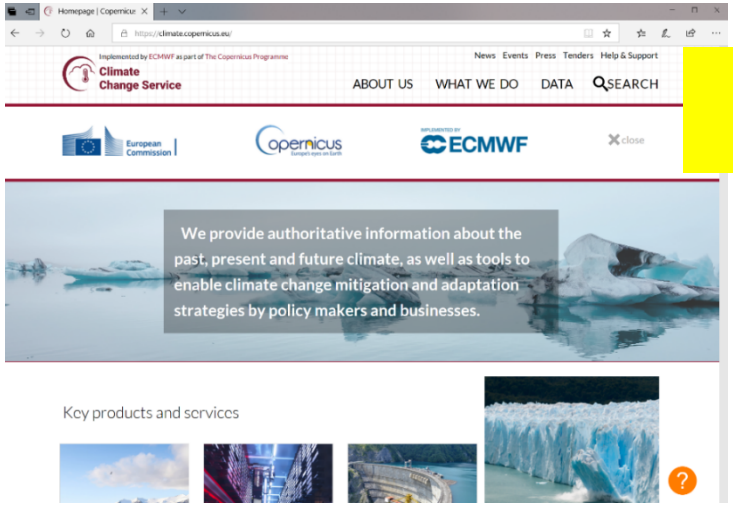
GHG Essential Climate Variable (ECV) products / Climate Data Records (CDR):

www.esa-ghg-cci.org/



GHG-CCI

https://climate.copernicus.eu/



C3S

Since 1-March-2019: **GHG-CCI+**

R&D to generate new / improved ECV XCO_2 and XCH_4 products (OCO-2, TanSat, GOSAT-2, Sentinel-5-Precursor)

Near-real-time:

CAMS

https://atmosphere.copernicus.eu/

www.iup.uni-bremen.de/~ghguser/

Merged Level 2 & Level 3 products (XCO_2 & XCH_4)

Atmos. Chem. Phys., 13, 1771–1780, 2013
www.atmos-chem-phys.net/13/1771/2013/
doi:10.5194/acp-13-1771-2013

Atmospheric Chemistry and Physics Open Access

Reuter et al., 2013

A joint effort to deliver satellite retrieved atmospheric CO_2 concentrations for surface flux inversions: the ensemble median algorithm EMMA

M. Reuter[1], H. Bösch[2], H. Bovensmann[1], A. Bril[3], M. Buchwitz[1], A. Butz[4], J. P. Burrows[1], C. W. O'Dell[5], S. Guerlet[6], O. Hasekamp[6], J. Heymann[1], N. Kikuchi[3], S. Oshchepkov[3], R. Parker[2], S. Pfeifer[7], O. Schneising[1], T. Yokota[3], and Y. Yoshida[3]

Why ?

- Some users want an **easy to use** product covering an as long as possible time period
- **Improved data quality** (potentially) – for certain applications such as regional-scale inverse modelling and climate model comparisons - by selecting „the best" products from an ensemble of products

obs4MIPs
Observations for Model Intercomparisons Project

https://esgf-node.llnl.gov/projects/obs4mips/

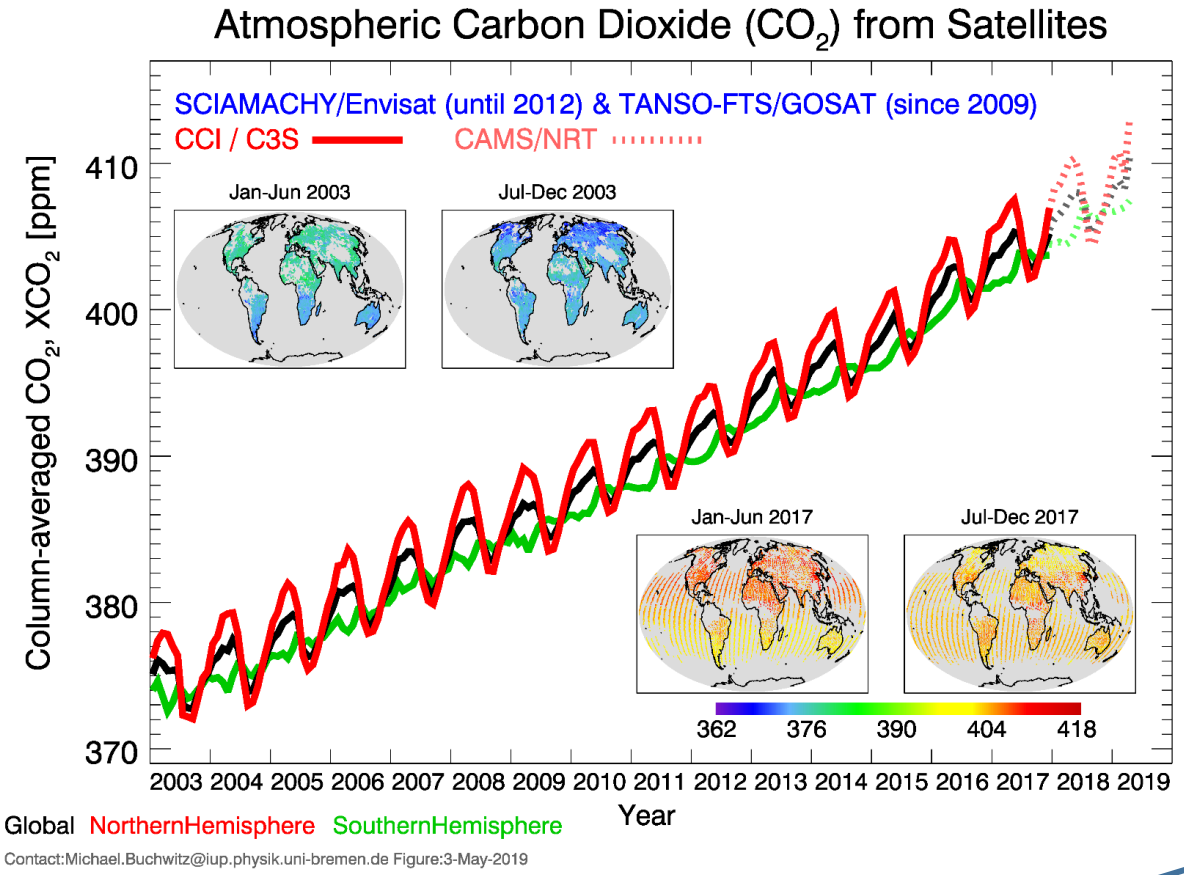
Merged Level 2 product:

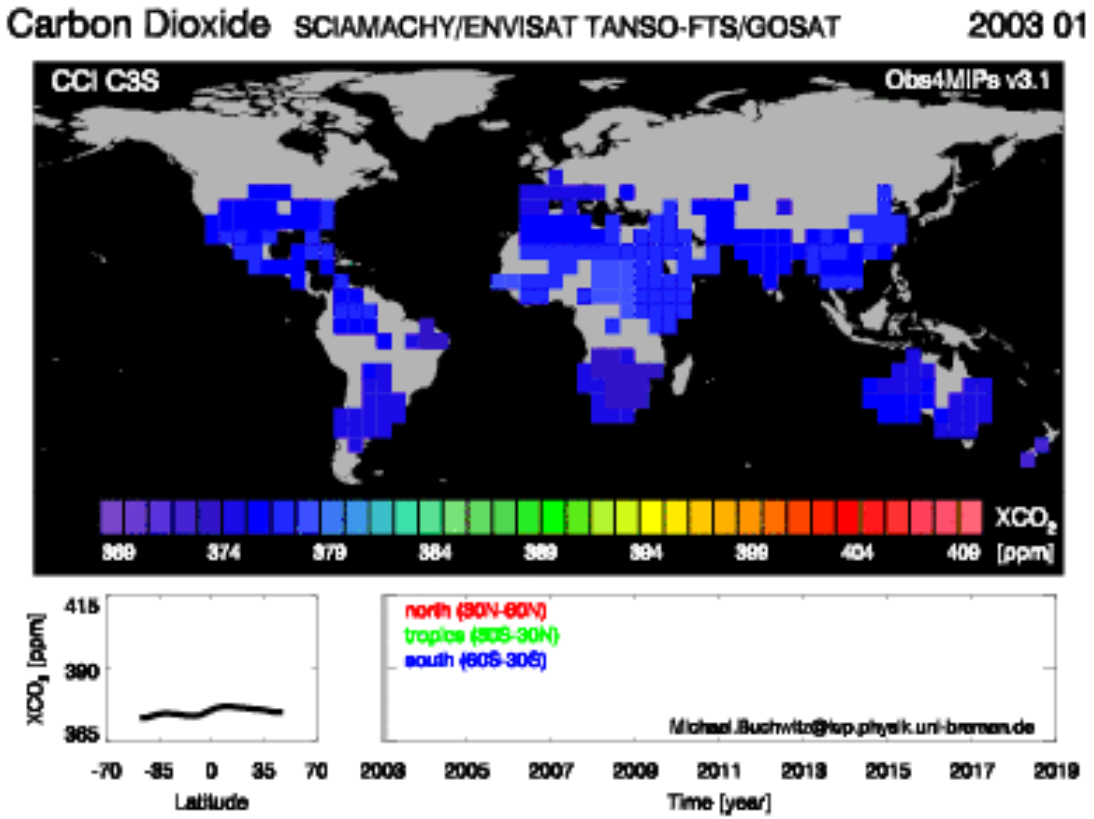
- Algorithm: **EMMA**
- Satellite input data: Individual sensor L2 products (European (CCI & C3S) and non-European (NIES, NASA))
- Format: NetCDF/GHG-CCI (nearly identical with NASA XCO_2 Lite)

Merged Level 3 product:

- Gridding of EMMA product: 5°x5°, monthly
- Format: **Obs4MIPs** (convenient for climate model comparisons)

XCO_2 merged products: L2/EMMA & L3/Obs4MIPs



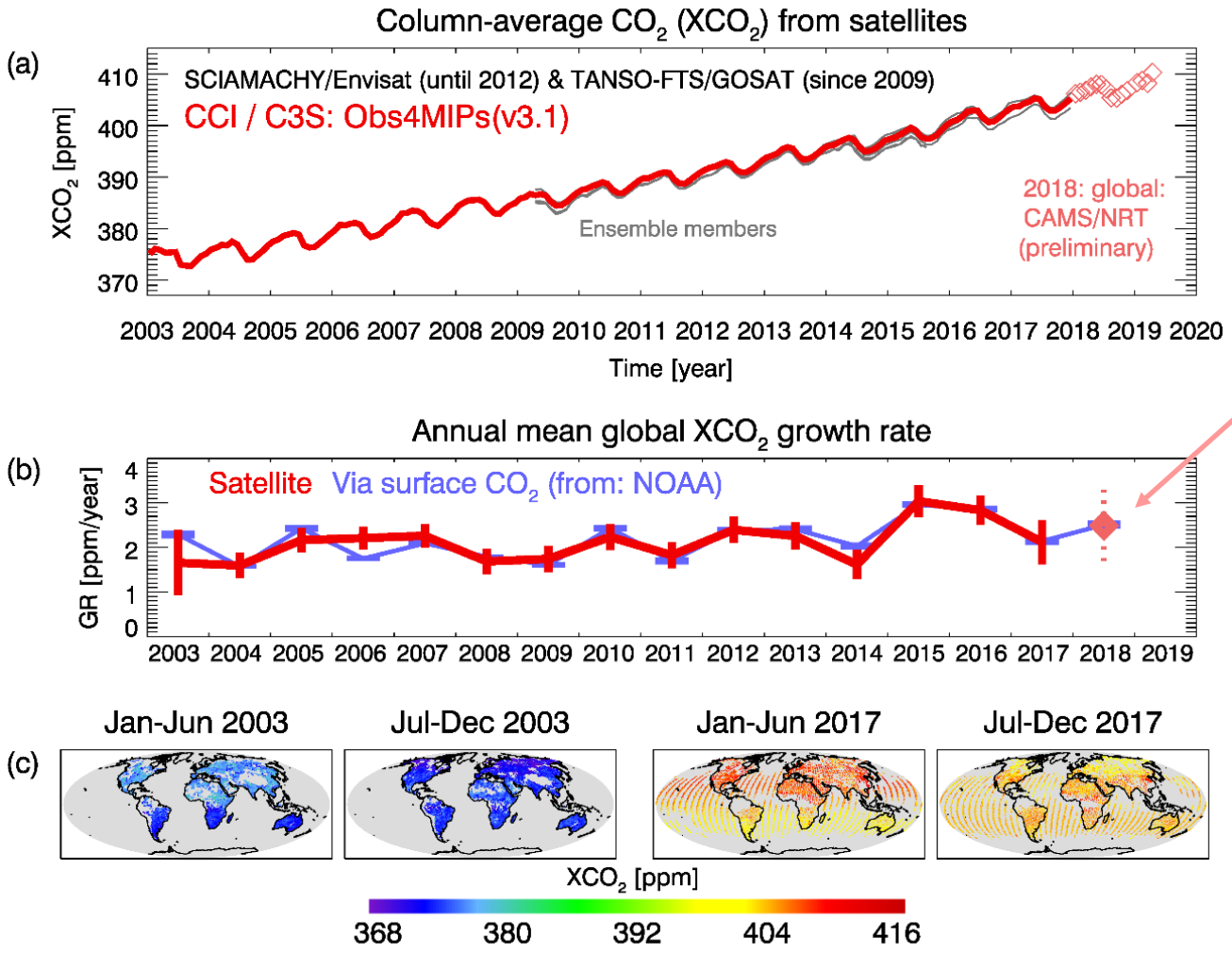


Latest version: v3.1 EMMA & Obs4MIPs, 2003-2017, from ensemble of SCIAMACHY & GOSAT-1 Level 2 products

In preparation: v4, 2003-2018, SCIAMACHY, GOSAT-1, OCO-2

-> Preliminary results („v4/beta“) are shown in this presentation (e.g., 2018 data not yet included)

XCO_2 annual growth rates



2018 CO_2 growth rate estimate (ppm / year):

Column CO_2 (XCO_2):

Satellite XCO_2 (preliminary): **2.5 +/- 0.8**
Algorithm: Buchwitz et al., ACP, 2018
See also:
European State of the Climate 2018
(https://climate.copernicus.eu/ESOTC)

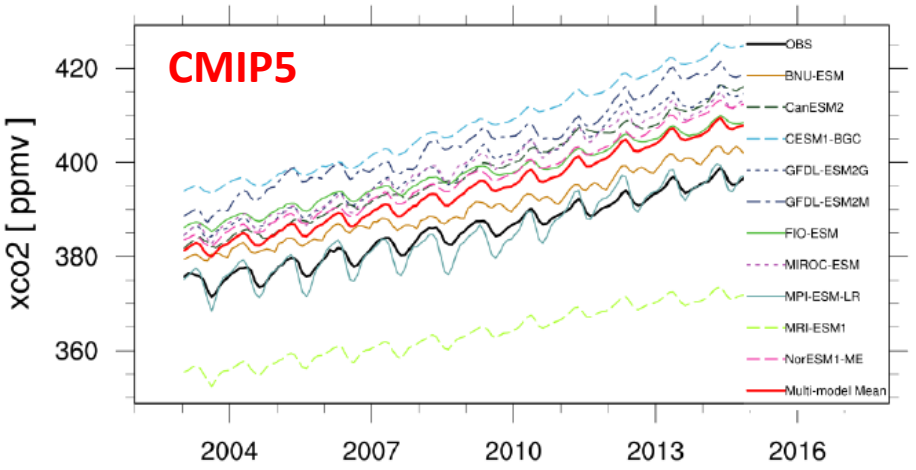
Surface CO_2:

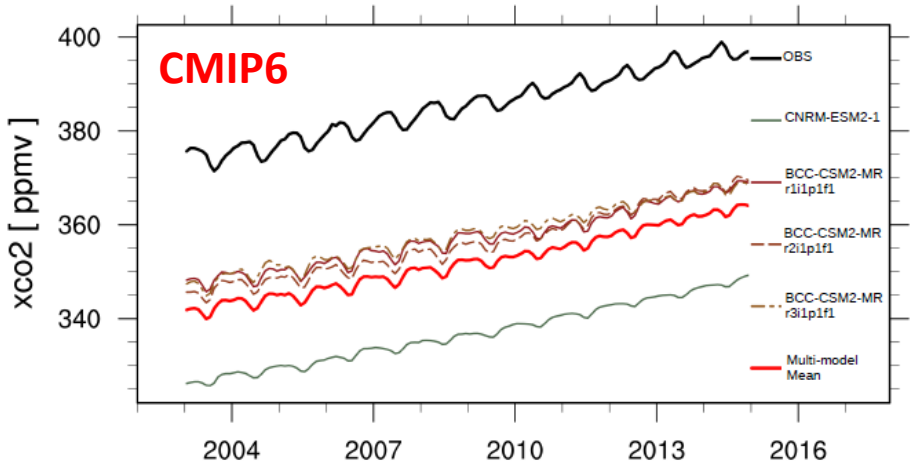
NOAA: Global marine: **2.51 +/- 0.09**

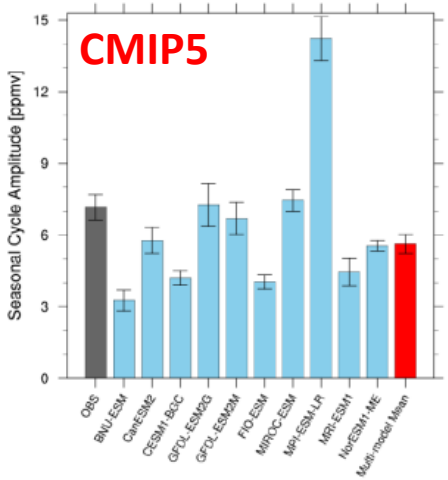
Satellite XCO_2: Comparisons with climate models

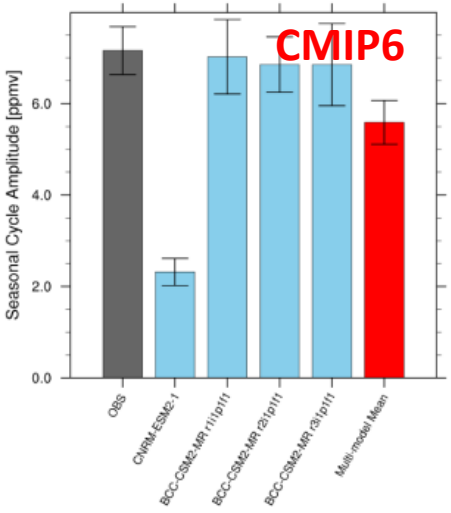
Satellite XCO_2 vs emission driven climate models

C3S/CCI XCO2_OBS4MIPS Multi-Model Mean









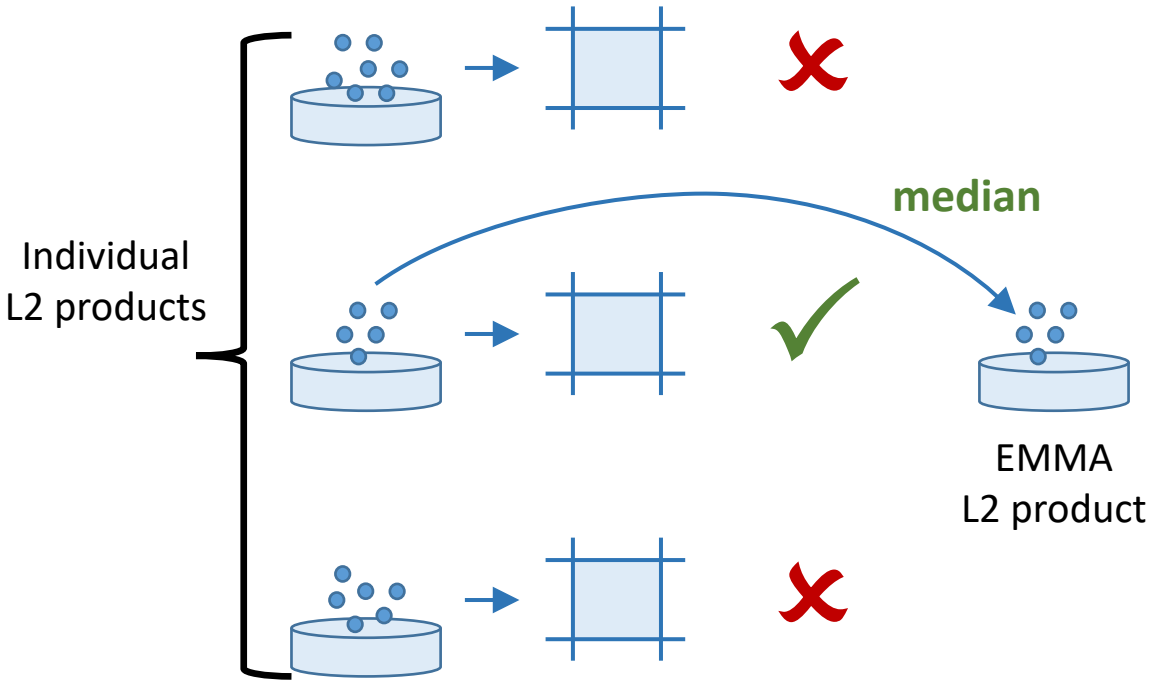
Changes of Growth Rate and Seasonal Cycle Amplitude of Column CO_2 in CMIP5&6 models and Satellite Data

Bettina K. Gier[1,2], Michael Buchwitz[1], Veronika Eyring[2,1], Maximilian Reuter[1], Peter M. Cox[3], and Pierre Friedlingstein[3]

1 University of Bremen, Institute of Environmental Physics (IUP), Bremen, Germany
2 Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
3 College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, UK.

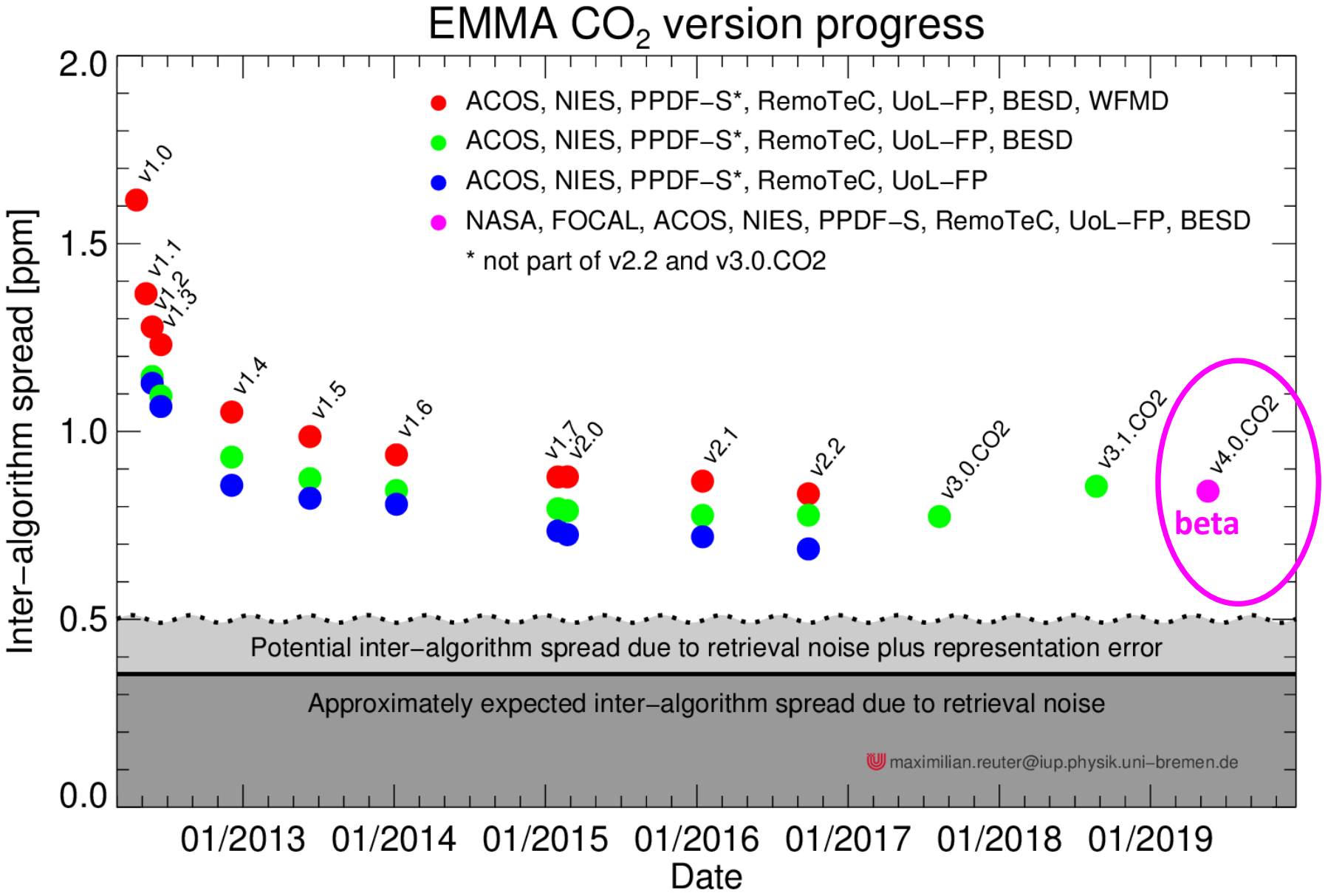
EMMA: Purpose & basic idea

- **Purpose:** To generate an easy to use high-quality Level 2 product covering an as long as possible time period (currently (v3.1): 2003-2017; soon (v4): 2003-2018; each year extended by 1 year)
- **Input data:** Ensemble of Level 2 XCO_2 (and XCH_4) products
- **Algorithm:** Determines **monthly** averages in **10°x10°** grid cells, selects the **median**, and stores the corresponding individual soundings in a data base:



- Harmonization w.r.t. *a priori*, offset correction, …
- Thresholds depending on potential information content to prevent from over-weighting individual algorithms.
- Requires a consistent validation of all contributing XCO_2 (or XCH_4) data sets and their reported uncertainties; EMMA is therefore also a data quality assessment tool.

EMMA XCO_2: version progress



To be done for v4:

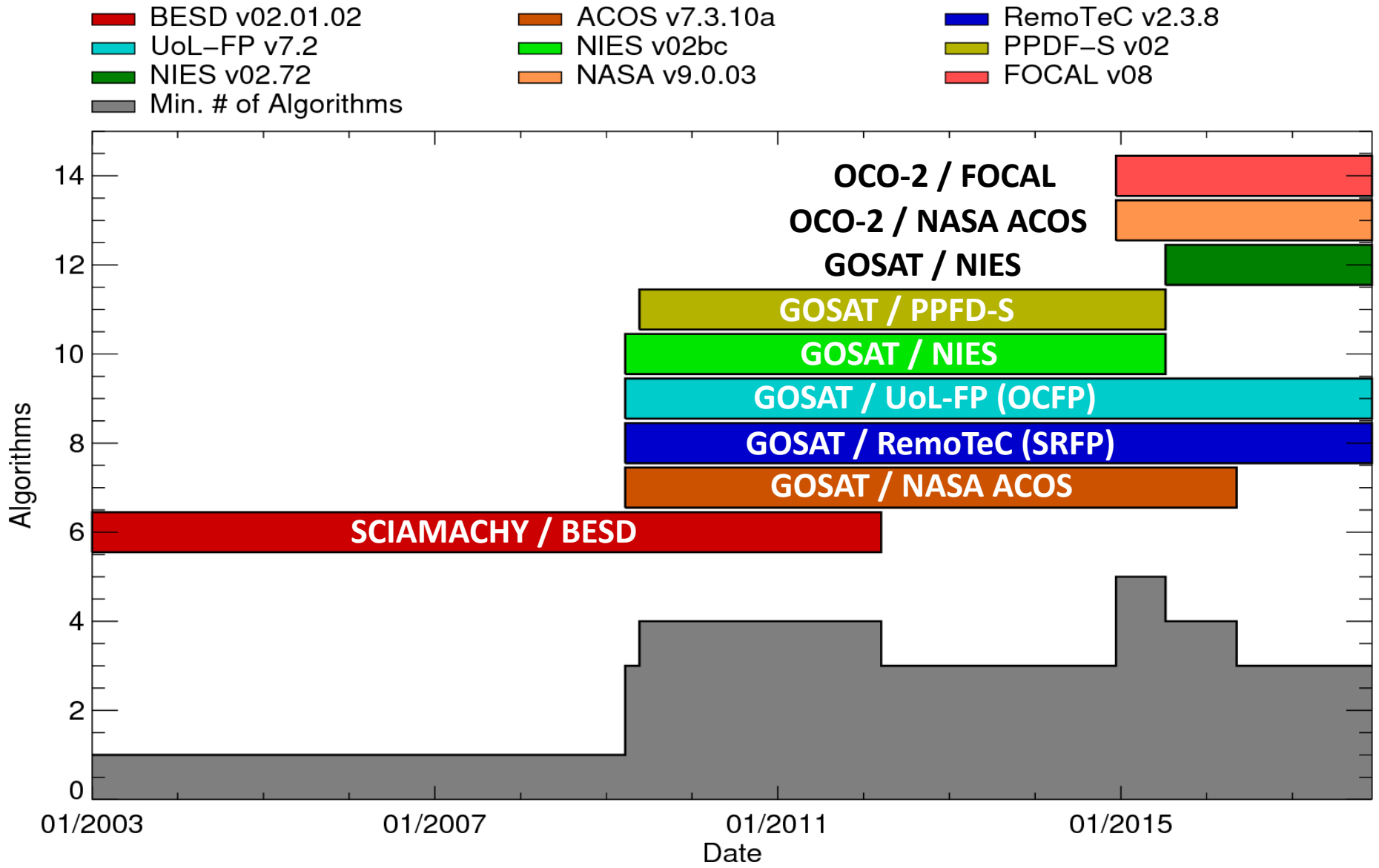
- Update for latest versions
- Adding year 2018

EMMA XCO_2 v4/beta: Contributing Level 2 products

Here: EMMA XCO_2 v4/beta

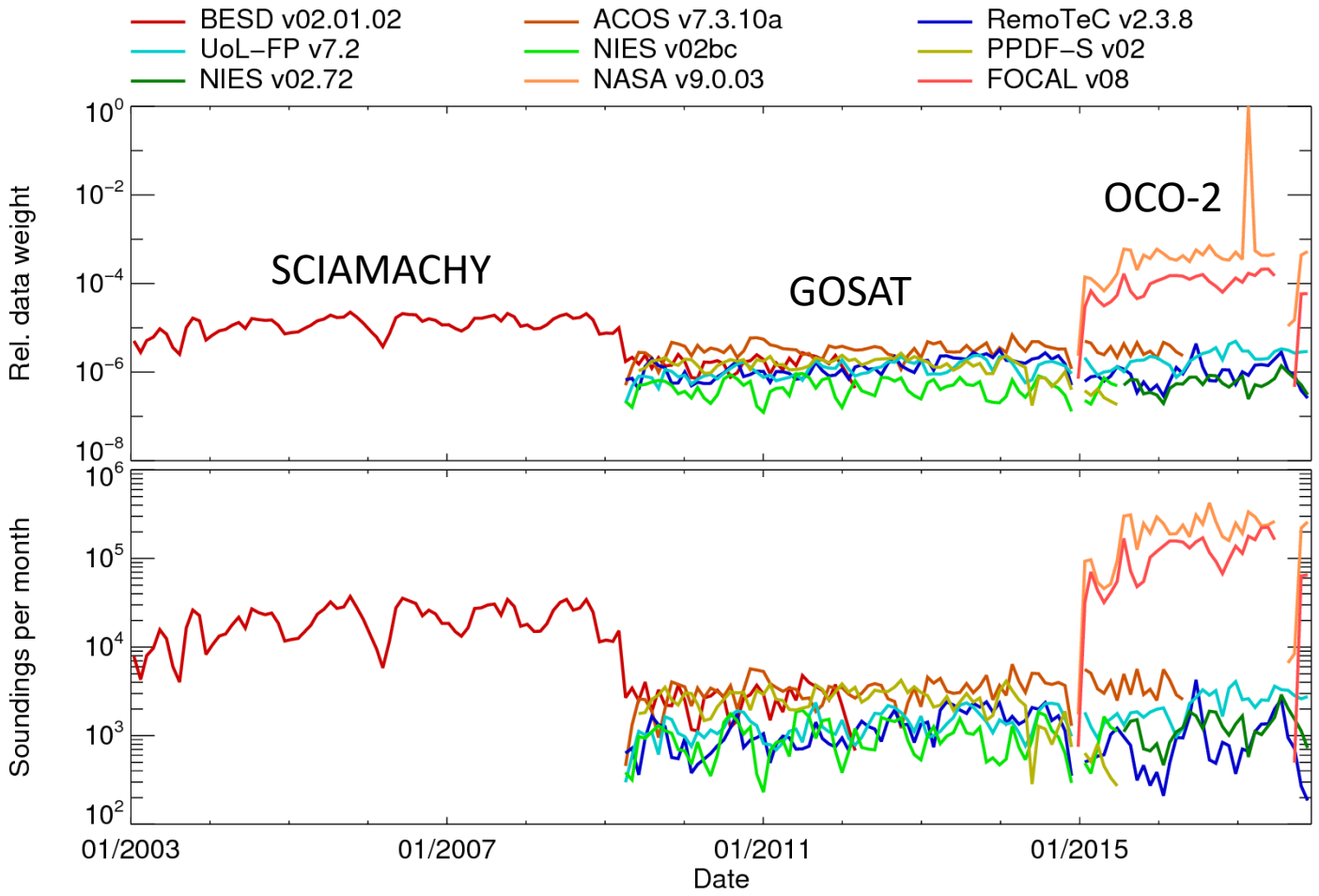
To be done for v4:

- Update for latest versions
- Adding year 2018



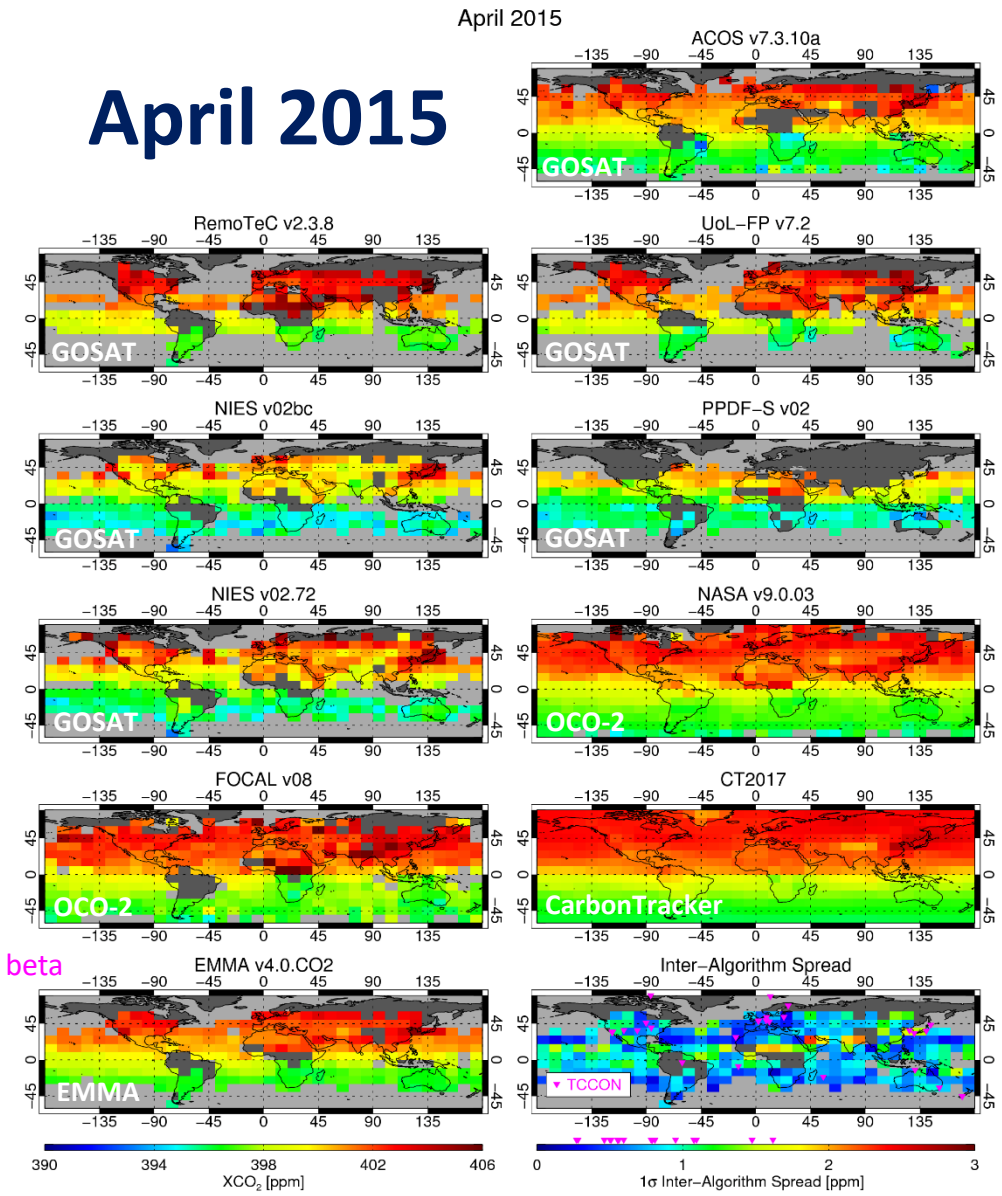
EMMA XCO_2 v4/beta: Algorithm/product contributions

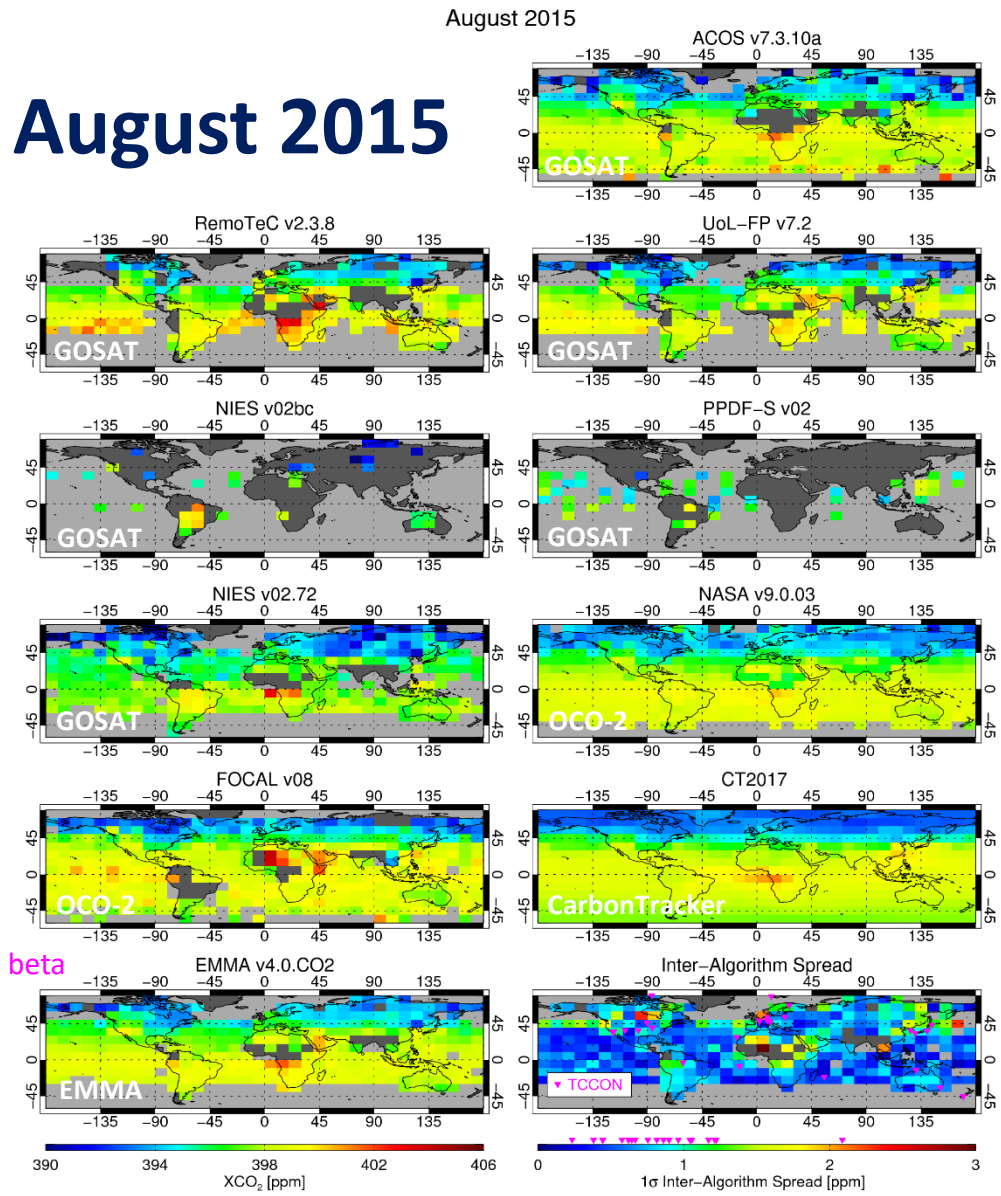
Contributions to EMMA: Rel. data weight & Nobs/month



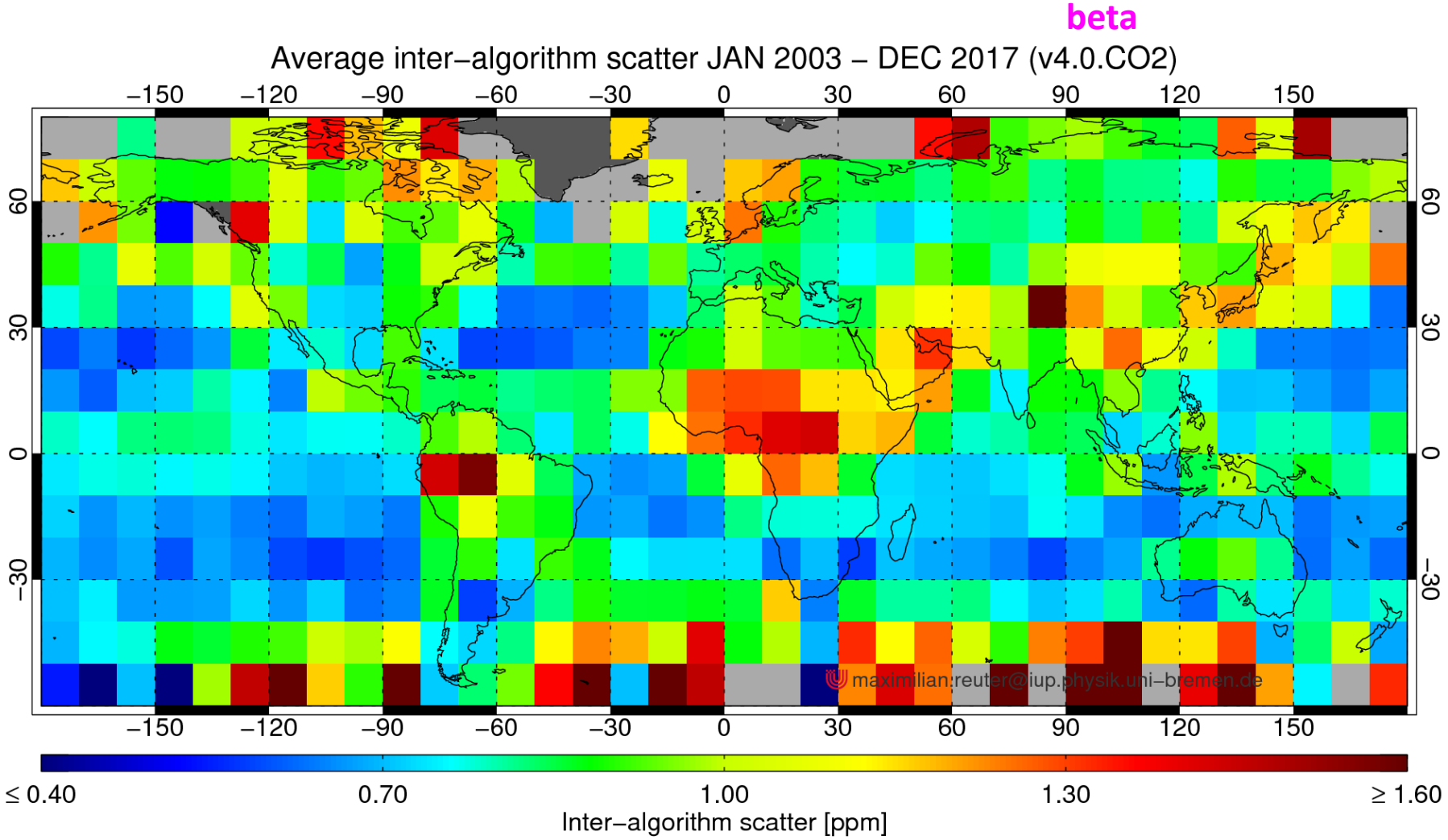
- OCO-2 algorithms (esp. NASA ACOS) with most soundings per month and largest "relative data weight" (= approx. variance weighted number of observations)
- Contains not the latest version of the GOSAT NIES data and we did a mistake by not using the bias corrected data -> EMMA will be updated to improve on this

EMMA XCO_2 v4/beta: Comparison of monthly XCO_2 maps





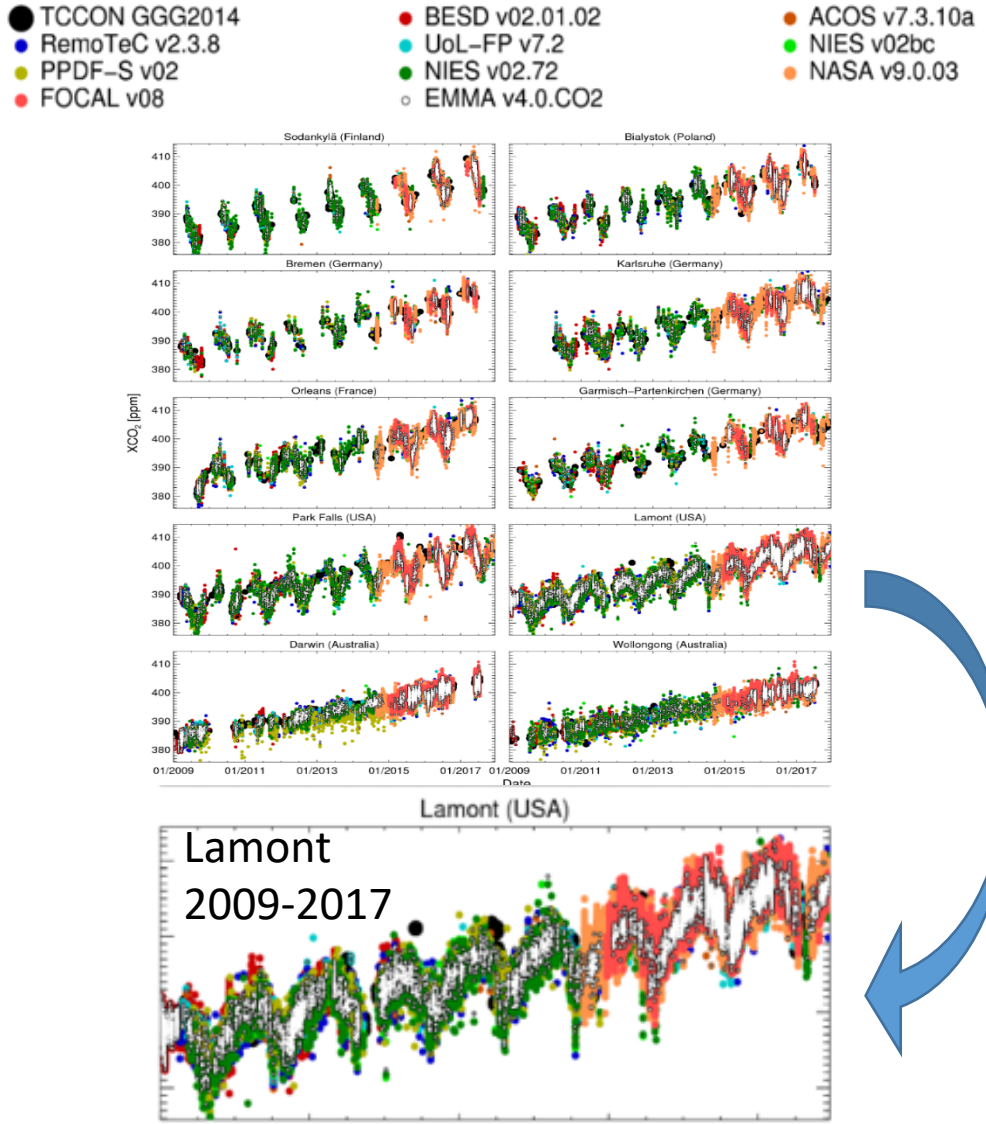
EMMA XCO_2 v4/beta: „Inter-algorithm scatter“



Good agreement

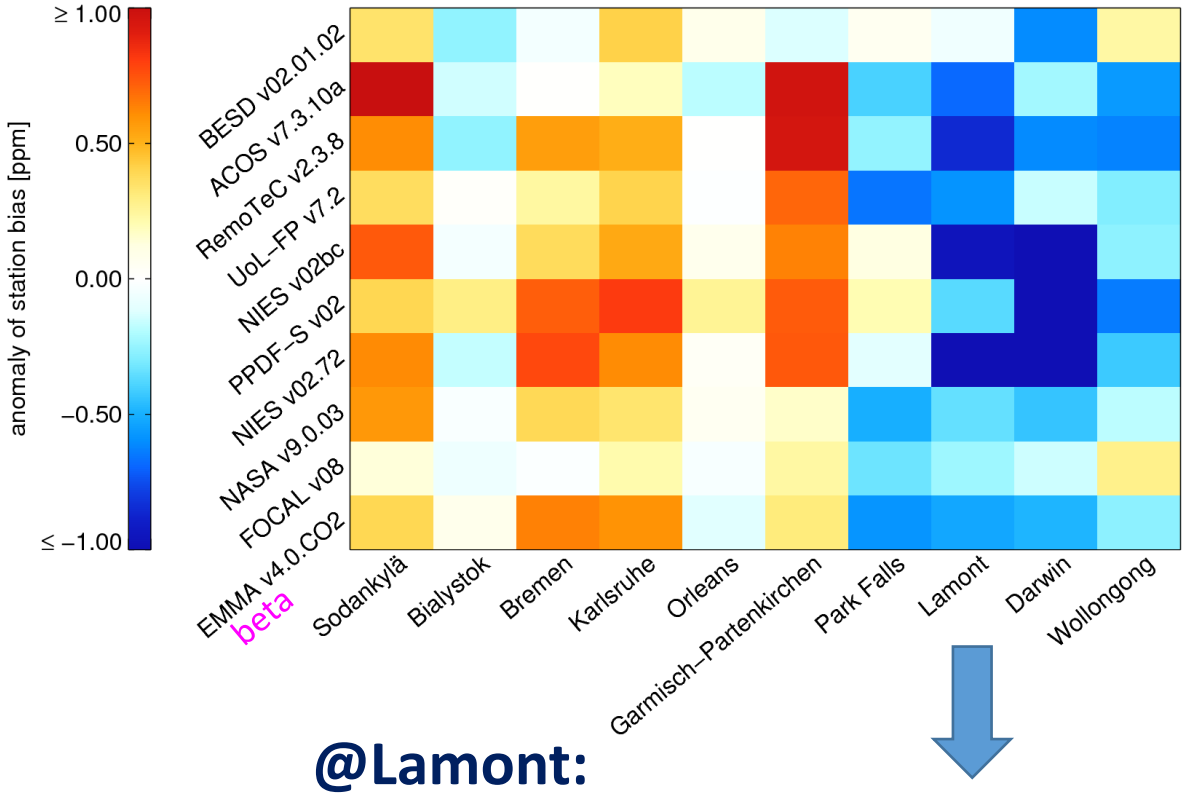
Poorer agreement

EMMA XCO_2 v4/beta: Comparison with TCCON



Anomaly of station bias:

(sum of each row = 0)



@Lamont:

- (All) Satellite products have low bias?
- OR: TCCON/GGG2014 has high bias?
- OR: Mixture?

- EMMA (white circles): „In the middle“ as expected

Note: TCCON GGG2014 site-to-site accuracy/bias: 0.8 ppm (2σ) (e.g., Hedelius et al., AMT, 2017)

XCO_2@TCCON: mean differences

Product Quality Assessment Report (PQAR) – Main document for data set CDR 2 (2003-2017)

Satellite – TCCON:

Two satellites, several XCO_2 products & different assessment methods

(C3S CDR#2 2003-2017; EMMAv3.1 (SCIA & GOSAT), …)

TCCON site	Satellite product													TCCON site
	Method	XCO2 difference Satellite minus TCCON in ppm:												
	Reference													
	CO2_SCI_BESD	CO2_SCI_WFMD	CO2_GOS_OCFP	CO2_GOS_SRFP	XCO2_EMMA	CO2_GOS_OCFP	CO2_GOS_SRFP	CO2 GOS ACOS	CO2_GOS_SRFP	CO2_GOS_OCFP	XCO2_EMMA	Mean diff.	StdDev	Satellite
	QAQC	QAQC	QAQC	QAQC	QAQC	DP	DP	EMMA	EMMA	EMMA	EMMA	Sat-TCCON	[ppm]	bias ?
	Main_Fig_10	Main_Fig_12	Main_Fig_14	Main_Fig_16	Main_Fig_18	A_Tab_3	B_Fig_3	D txt file	D txt file	D txt file	D txt file	[ppm]		
Ascension I.			-0,25		0,05									Ascension I.
Bialystok	-0,07	0,69	0,07	0,03	0,24	0,12	-0,15	-0,15	-0,26	0,01	-0,18	0,03	0,25	Bialystok
Bremen	0,06	1,00	0,32	0,85	0,87	0,29	0,65	-0,01	0,53	0,22	0,51	0,48	0,32	High bias ? Bremen
Darwin	-0,11	-0,49	0,28	0,22	0,19	0,19	-0,02	-0,20	-0,55	-0,12	-0,74	-0,12	0,33	Darwin
Garmisch	-0,23	0,63	0,59	1,09	0,69	0,71	0,45	0,95	0,94	0,68	0,50	0,64	0,33	High bias ? Garmisch
Izana				-0,62	-0,75									Izana
Karlsruhe			0,50	1,19	0,94	0,45	0,36	0,16	0,47	0,38	0,40	0,54	0,30	High bias ? Karlsruhe
Lamont	-0,11	-0,13	-0,45	-0,44	-0,10	-0,49	-0,40	-0,68	-0,84	-0,57	-0,56	-0,43	0,23	Low bias ? Lamont
Paris			-1,13	-0,45	-0,97							-0,85	0,29	Low bias ? Paris
Park Falls	-0,15	0,76	-0,61	0,31	0,43	-0,40	0,28	-0,40	-0,27	-0,67	-0,08	-0,07	0,44	Park Falls
Reunion I.			0,23		0,23									Reunion I.
Saga			-0,10	0,68	0,59	0,05	0,58					0,36	0,32	High bias ? Saga
Sodankyla	0,25	0,54	0,44	0,58	1,00	0,54	0,80	1,05	0,58	0,36	0,70	0,62	0,24	High bias ? Sodankyla
Wollongong	0,52	-0,37	0,09	0,53	0,61	0,03	-0,02	-0,53	-0,59	-0,26	-0,45	-0,04	0,42	Wollongong

E.g., **Lamont:** Mean difference SAT-TCCON +/- StdDev: **-0.43 +/- 0.23 ppm**

This suggest one of the following:

- Low bias satellites?: -0.43 +/- 0.23 ppm
- High bias TCCON GGG2014 Lamont?: +0.43 +/- 0.23 ppm
- Mixture?

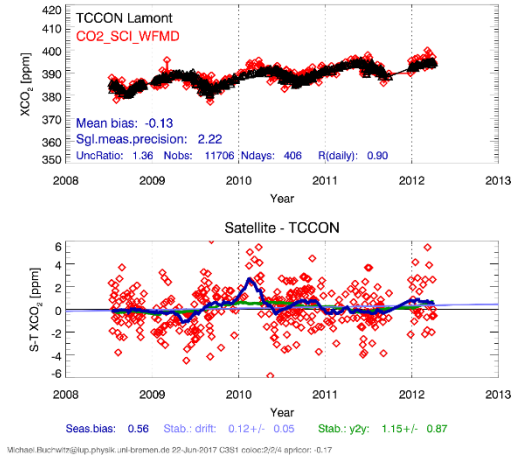
Note: TCCON GGG2014 site-to-site accuracy/bias: 0.8 ppm (2σ) (e.g., Hedelius et al., AMT, 2017)

XCO_2@Lamont: trend of differences

Product Quality Assessment Report (PQAR) – Main document for data set CDR 2 (2003-2017)

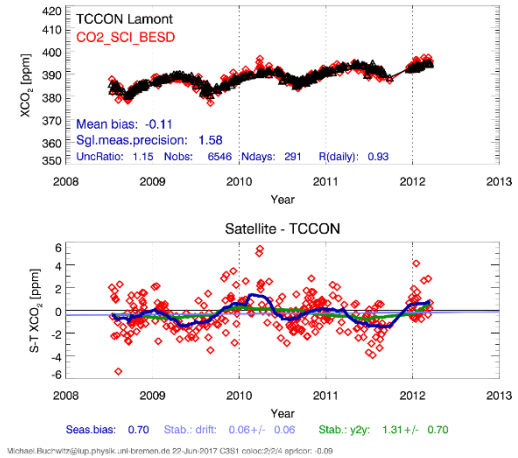
CO2_SCI_WFMD v02.01.02

Trend: +0.12 +/- 0.05 ppm/year



CO2_SCI_BESD v02.01.02

Trend: +0.06 +/- 0.06 ppm/year

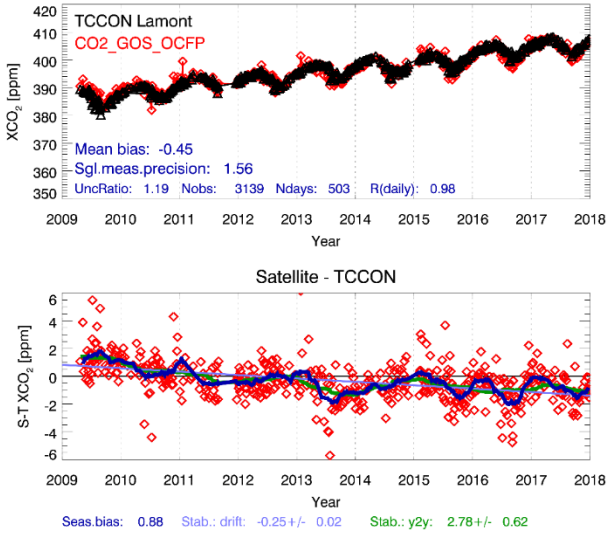


SCIAMACHY: No clear trend

Satellite vs TCCON:

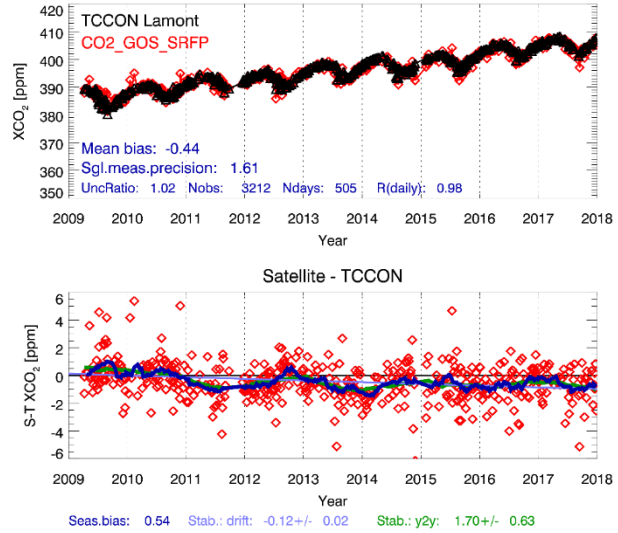
CO2_GOS_OCFP (UoL-FP) v7.2

Trend: -0.25 +/- 0.02 ppm/year



CO2_GOS_SRFP (RemoTeC) v2.3.8

Trend: -0.12 +/- 0.02 ppm/year



Low bias trend GOSAT XCO_2 (approx. -0.18 ppm/year) ?

OR

High bias trend TCCON GGG2014 Lamont (+0.18 ppm/year)?

OR

Mixture ?

Note: TCCON GGG2014 site-to-site accuracy/bias: 0.8 ppm (2σ) (e.g., Hedelius et al., AMT, 2017)

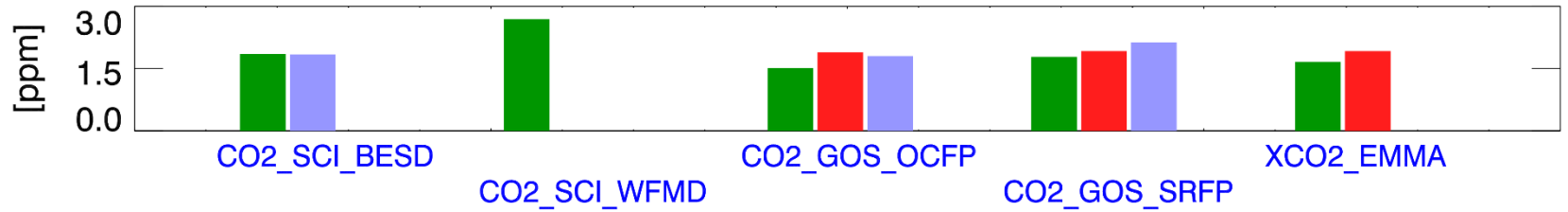
Satellite XCO_2 quality overview

Product Quality Assessment Report (PQAR) – Main document for data set CDR 2 (2003-2017)

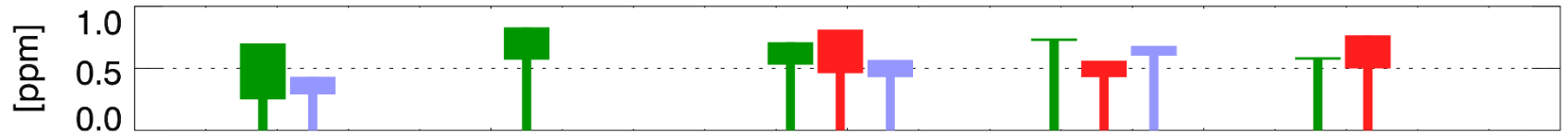
C3S Level 2 products: XCO_2

QA/QC method (applied to all products)
DP methods (applied by data provider) EMMA method

Single measurement random error (precision, 1-sigma)

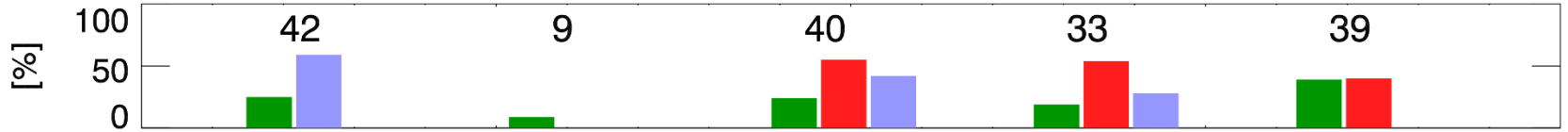


Accuracy (spatial/spatio-temporal bias range)

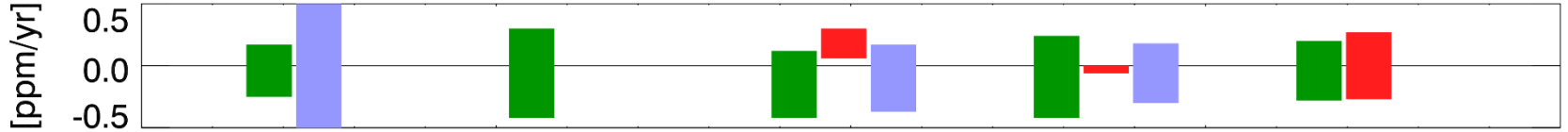


Accuracy: Probability that TR is met

Unc.reference (1-sig.): 0.4



Stability (drift, +/- 3-sigma)



Stability: Probability that TR is met

Unc.reference (1-sig.): 0.2

Overall: High stability of the satellite retrievals

(no significant linear trend as scatter around zero due to slightly positive, zero or slightly negative trends depending on TCCON site)

Michael.Buchwitz@iup.physik.uni-bremen.de, 4-Oct-2018

Summary & conclusions

- Greenhouse gas (GHG) Essential Climate Variable (**ECV**) satellite-derived data product (CO_2 & CH_4) have been generated initially via the **GHG-CCI** project of ESA's Climate Change Initiative (CCI); since end of 2016 these products are generated operationally via the Copernicus Climate Change Service (**C3S**) and are made available via the Copernicus Climate Data Store (**CDS**)
- Near-real time products are generated via the Copernicus Atmosphere Monitoring Service (**CAMS**)
- The C3S XCO_2 & XCH_4 products are:
  - Individual sensor L2 products as generated with European retrieval algorithms
  - Merged L2 product via **EMMA** algorithm (includes also non-European (NIES, NASA) products)
  - Merged L3 product in **Obs4MIPs** format (monthly, 5°x5°)
  - Latest version: **v3.1** (2003-2017; **SCIAMACHY & GOSAT**)
- Ongoing:
  - R&D to add new sensors via **GHG-CCI+** project: OCO-2, TanSat, Sentinel-5-Precursor, GOSAT-2
  - Generation of v4 EMMA & Obs4MIPs products: 2003-**2018**, with **OCO-2**, …
  - **Preliminary XCO_2 v4/beta results have been presented**; v4 will be available in Q4/2019
  - Publication planned (input data providers will be offered co-authorship)

Acknowledgements

Data sets:

- Satellite Level 1 input data:
  - **JAXA** (GOSAT)
  - **ESA** (GOSAT via Third Party Mission archive)
  - **ESA & DLR** (SCIAMACHY)
  - **NASA** (OCO-2)
- Satellite Level 2:
  - **NIES** (GOSAT)
  - **NASA** (GOSAT, OCO-2)
- Ground-based:
  - **TCCON** network
  - **NOAA** (CO_2 growth rates)
- Meteorology:
  - **ECMWF**
- Model / assimilation system:
  - **NOAA** (CarbonTracker)

Funding:

- **European Commission**:
  - **Copernicus** projects **C3S** (C3S_312b_Lot2 led by DLR) & **CAMS** (CAMS41 led by LSCE)
  - **H2020** projects **CHE & VERIFY** for supporting the development of the FOCAL OCO-2 XCO_2 retrieval algorithm
- **ESA** Climate Change Initiative (CCI) via projects **GHG-CCI** (2010-2017) & **GHG-CCI+** (since March 2018)

Research conducted under the framework of the GOSAT RA (PI project CONSCIGO)