PROGRAMME OF THE EUROPEAN UNION

co-funded with esa

Five years of TROPOMI Formaldehyde measurements

Isabelle De Smedt, G. Pinardi, C. Vigouroux, S. Compernolle, K.U Eichman, P. Hedelt, K.P. Heue, B. Langerock, C. Lerot, F. Romahn, N. Theys, J. Vlietinck, H. Yu, J.C. Lambert, D. Loyola, M. Van Roozendael and NIDFORVAL HCHO team

S5P HCHO L2 Product: DOAS

Slant columns: SCD

- Fit: 328.5-359 nm
- Daily averaged radiance as I_0 reference
- Reference sector: the Pacific
- Spike removal.

Air Mass Factors: AMF

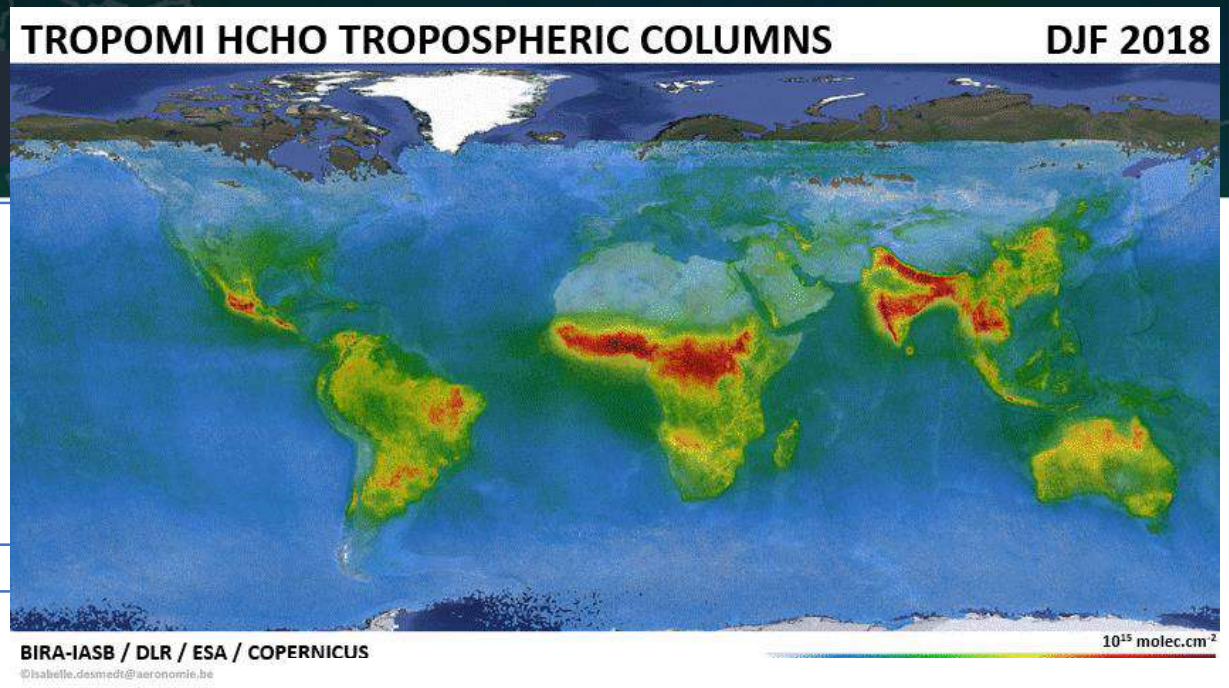
- Altitude resolved AMF LUT
- TM5-MP profiles: daily forecast, 1°
- S5P cloud product (OCRA ROCINN CRB)
- Albedo: OMI min LER climatology, 0.5°

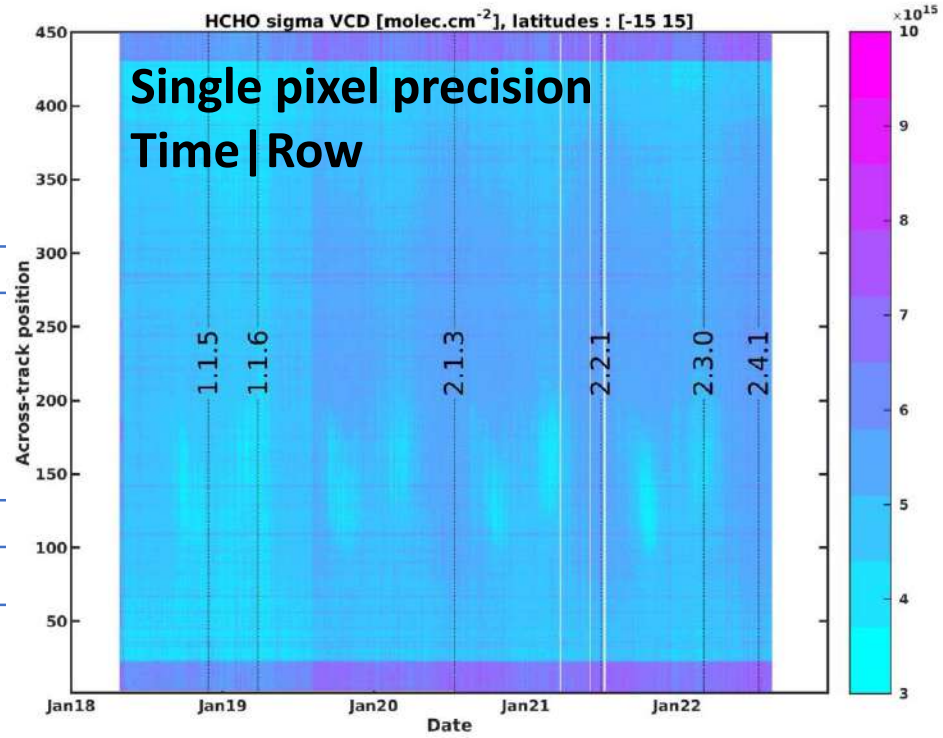
Destriping + Background correction

- Based on the 4 previous days in the Pacific region
- Global source of CH_4 oxidation from TM5-MP CTM

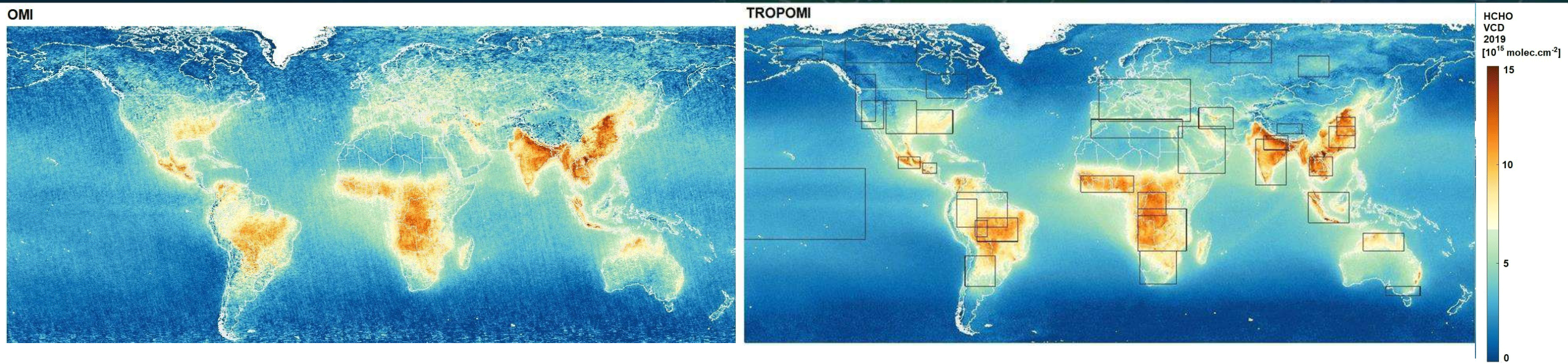
Error estimates, AK, quality assurance values

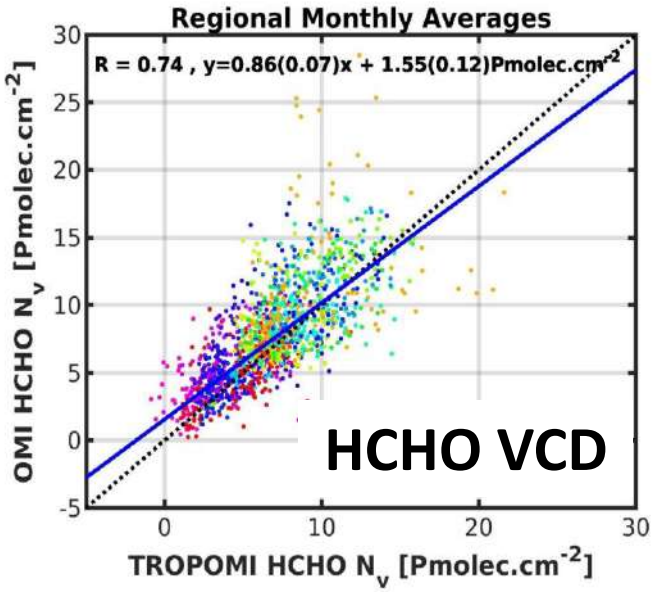
ATBD + PRF + PUM

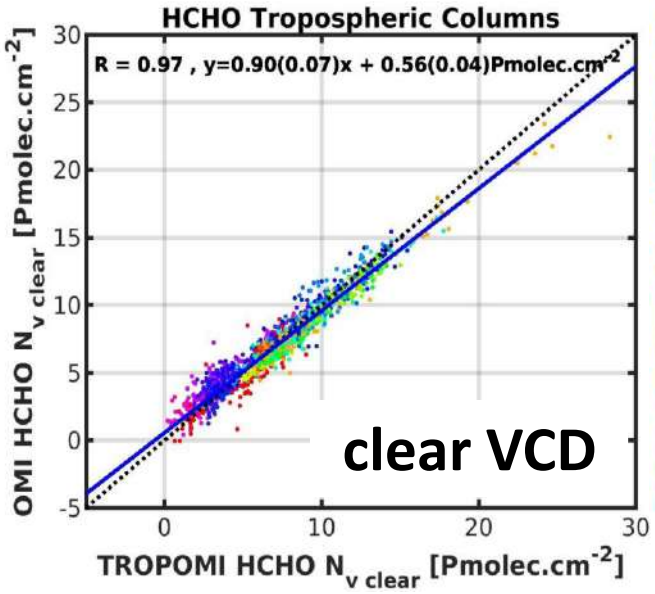




From OMI To TROPOMI







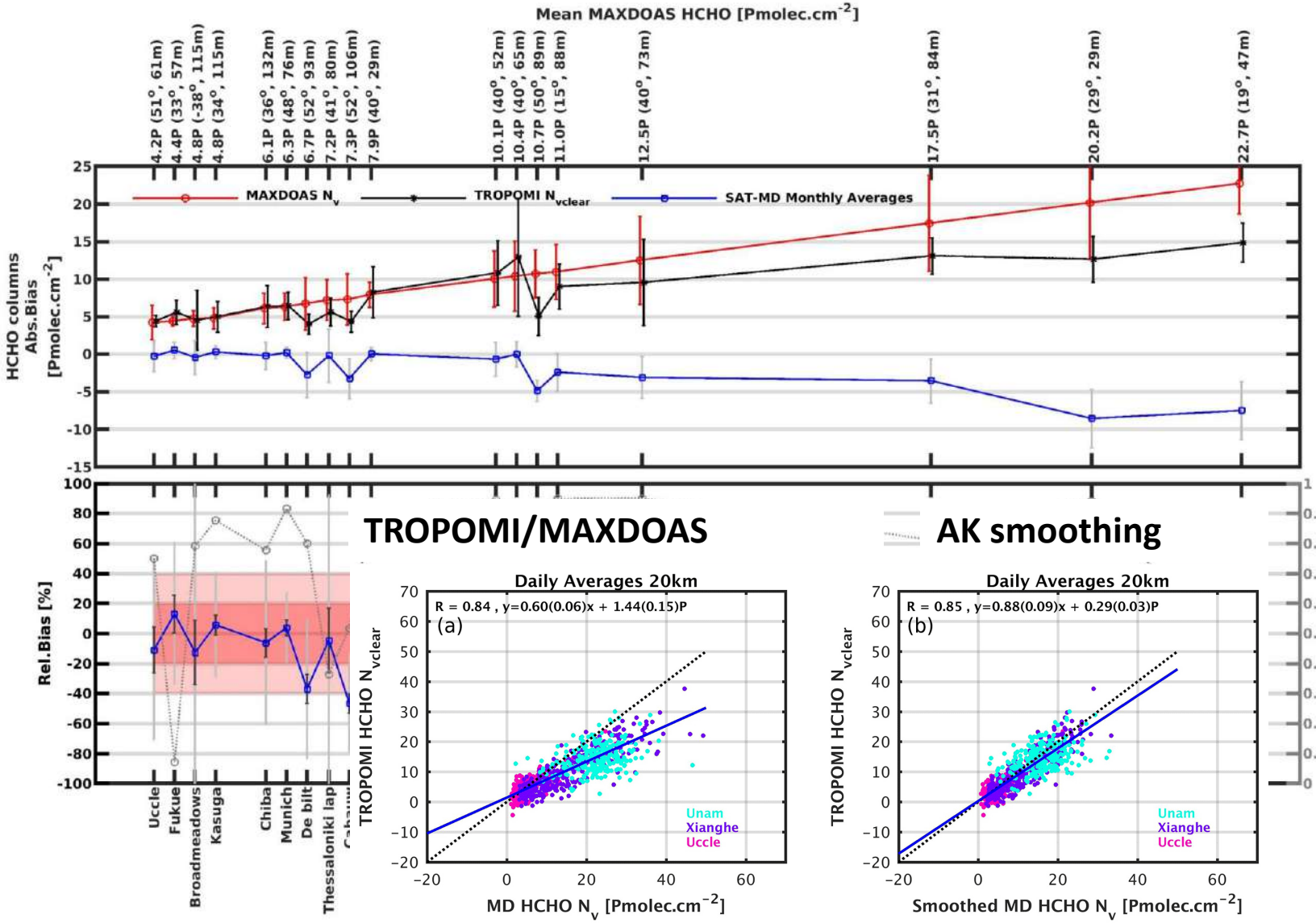
Equatorial Africa
Northern India
Northern Africa
Northern China
Southern Africa
Southern China
South Asia
Amazonia BB
India
Mexico
Amazonia Bolivia
Northern Australia
Guatemala
Western Amazonia
Amazonia
Southeastern US
Argentina
Indonesia
South Africa
Middle East
Iran
Central US
Europe
Maghreb
Western US
Northwestern US Canada
Tibet
Southeastern Canada
SouthEast Siberia
Central Siberia
Southern Australia
Equatorial Pacific
Alaska
Northwestern Canada

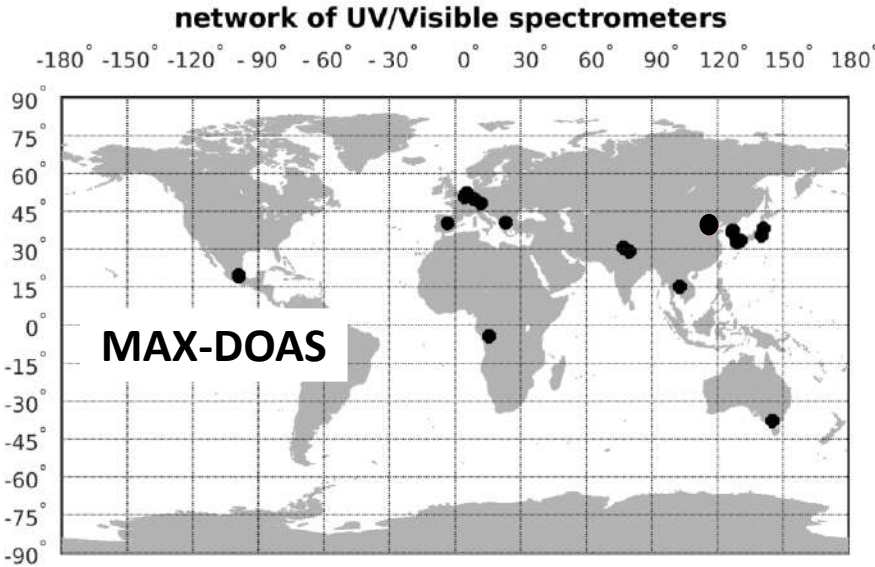
- **Correlation between OMI and TROPOMI regional monthly averages.**
- **Best agreement is found for clear VCD.**

Updated from De Smedt et al. 2021.

Validation data: MAX-DOAS (NIDFORVAL)

co-funded with esa



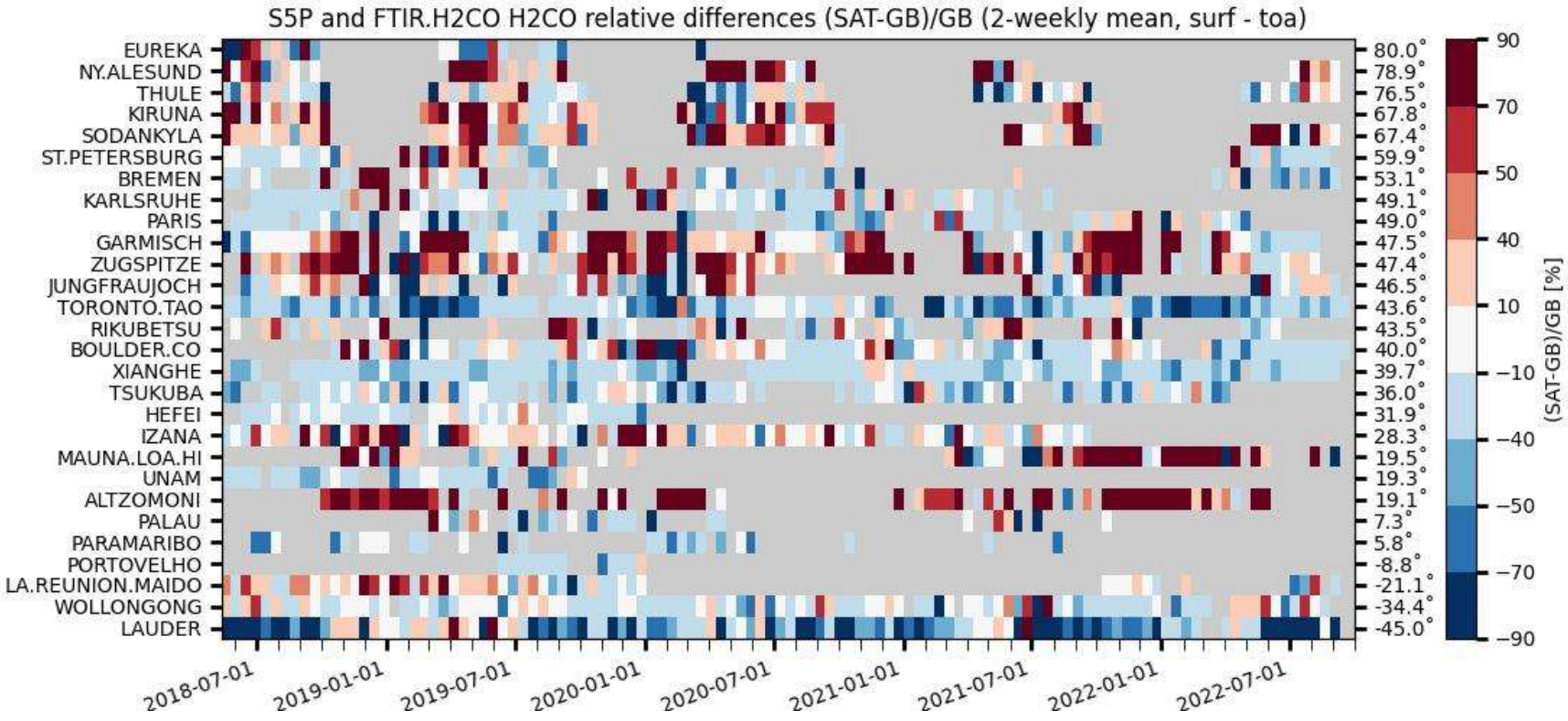


- NIDFORVAL dataset: more than 18 MAX-DOAS instruments
- Validation results are stable in time.
- Relative bias depends on the column:
  - Within 20% for moderate columns
  - Up to 40% for larger columns
  - Exception: De Bilt, Cabauw , Mainz
- Bias can be reduced using local profiles.

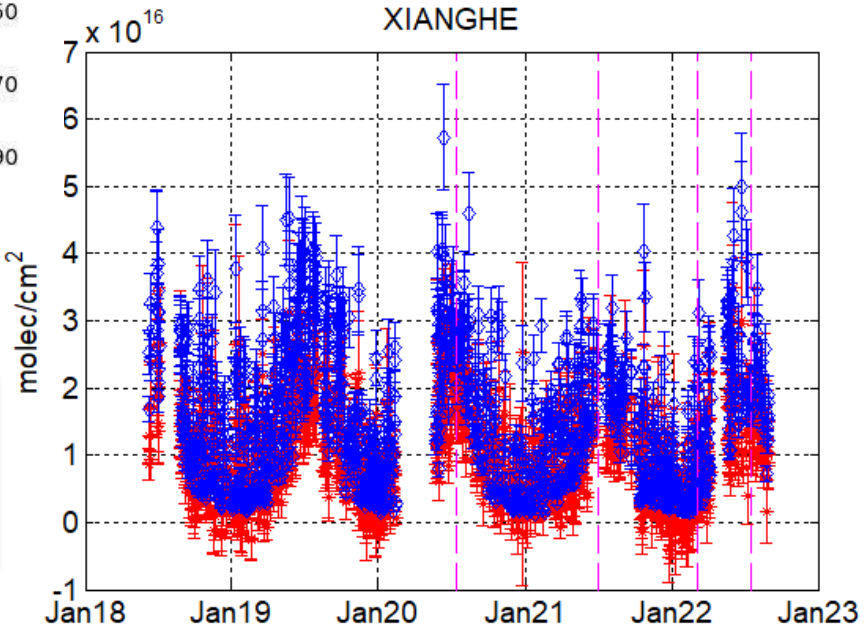
Updated from De Smedt et al. 2021.

Validation data: FTIR (NIDFORVAL)

co-funded with esa



- **NIDFORVAL dataset: more than 28 FTIR instruments**
- **Bias for all sites: -13.5%**
- **Negative bias over high-HCHO-level sites: -27% for HCHO>8 Pmolec.cm^{-2}**
- **Positive bias at clean sites: +25% for HCHO <2.5Pmolec.cm^{-2}**

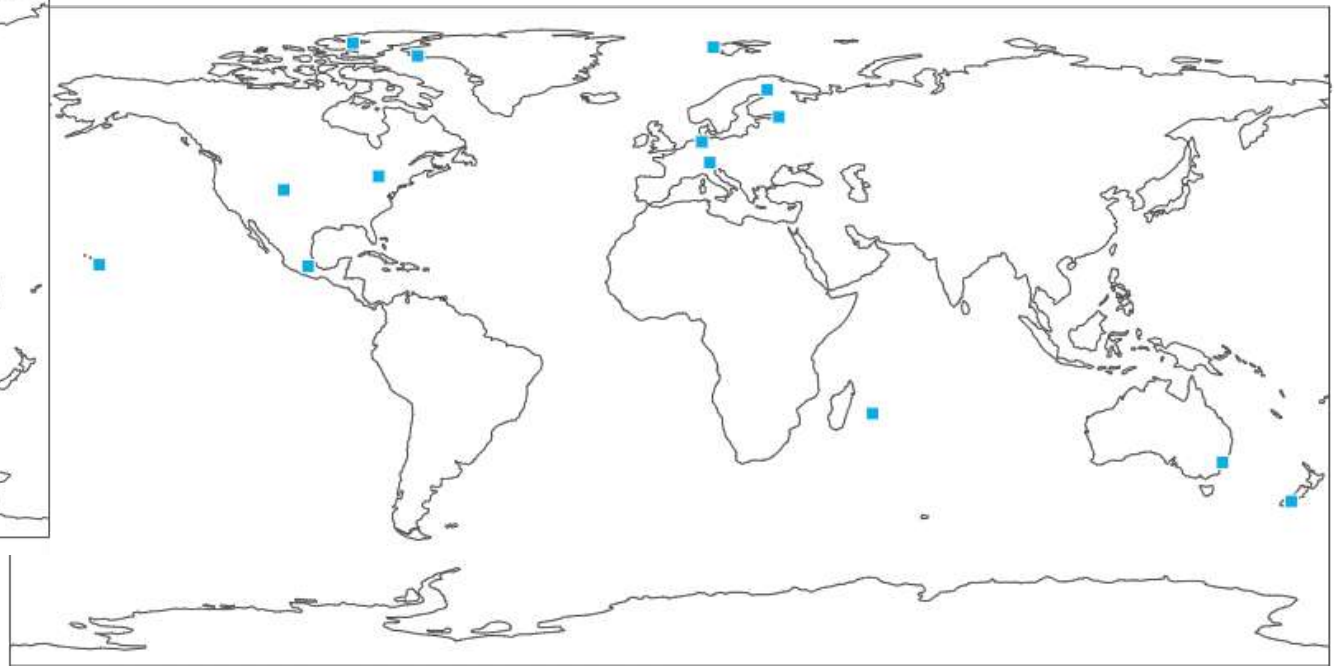


Poster 19: Corinne Vigouroux
A win-win success story: the HCHO and stratospheric NO2 TROPOMI/S5P validation using the FTIR ground-based network.

Updated from Vigouroux et al. 2020.

MPC Validation Server

- **MAX-DOAS Stations**
  - **GEOMS format (only 3 are still measuring)**
  - **CHIBA stations will be soon online**
- **FTIR Stations: soon online**
- **Pandora network: newly online**



Royal Netherlands Meteorological Institute
Ministry of Infrastructure and Water Management

Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

s[&]t

University of Bremen

Science & Technology Facilities Council

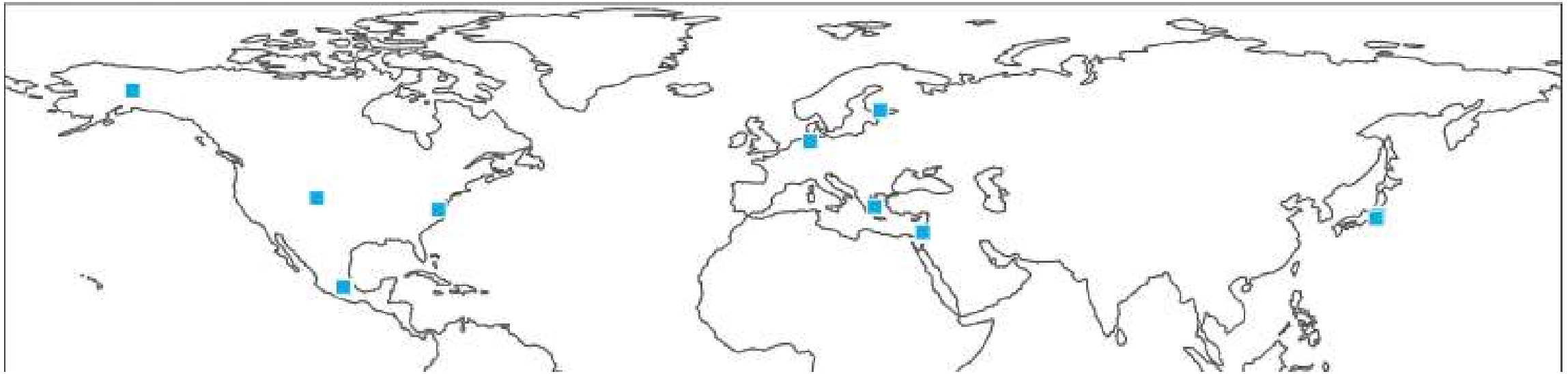
SRON
Netherlands Institute for Space Research

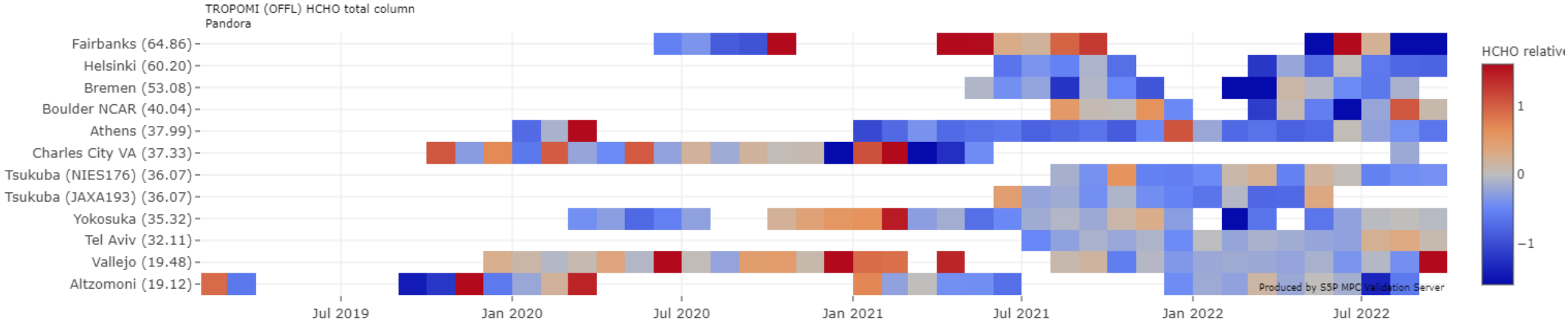
NILU

aeronomie.be

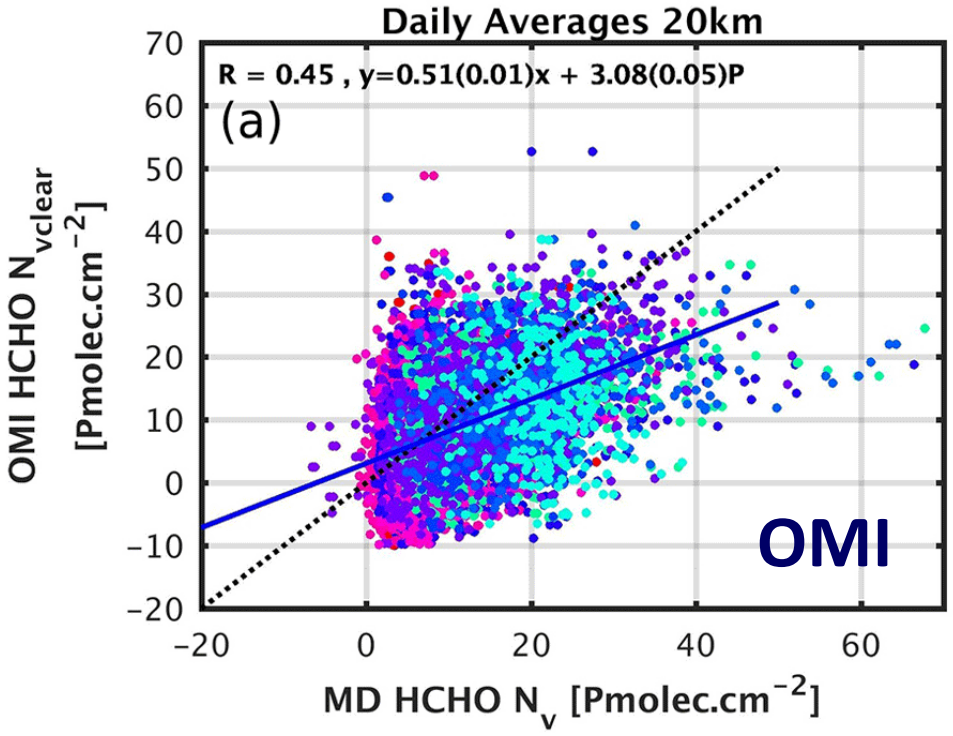
ARISTOTLE UNIVERSITY OF THESSALONIKI

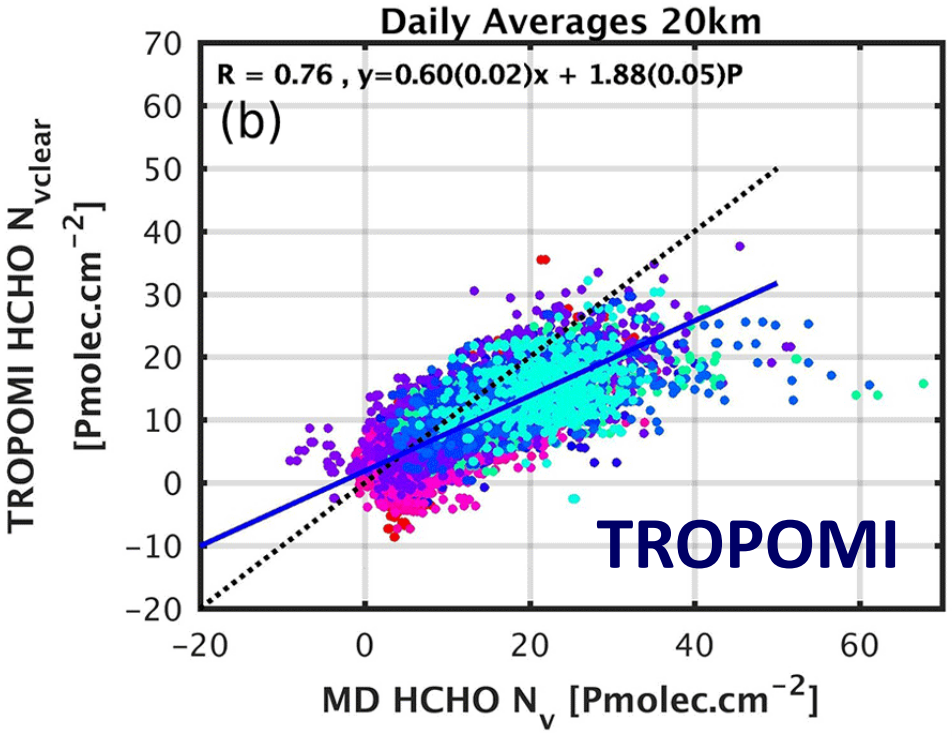
MPC Validation Server: PANDORA network





TROPOMI precision





Validation results using daily averages of OMI and TROPOMI HCHO columns within 20km around the stations.

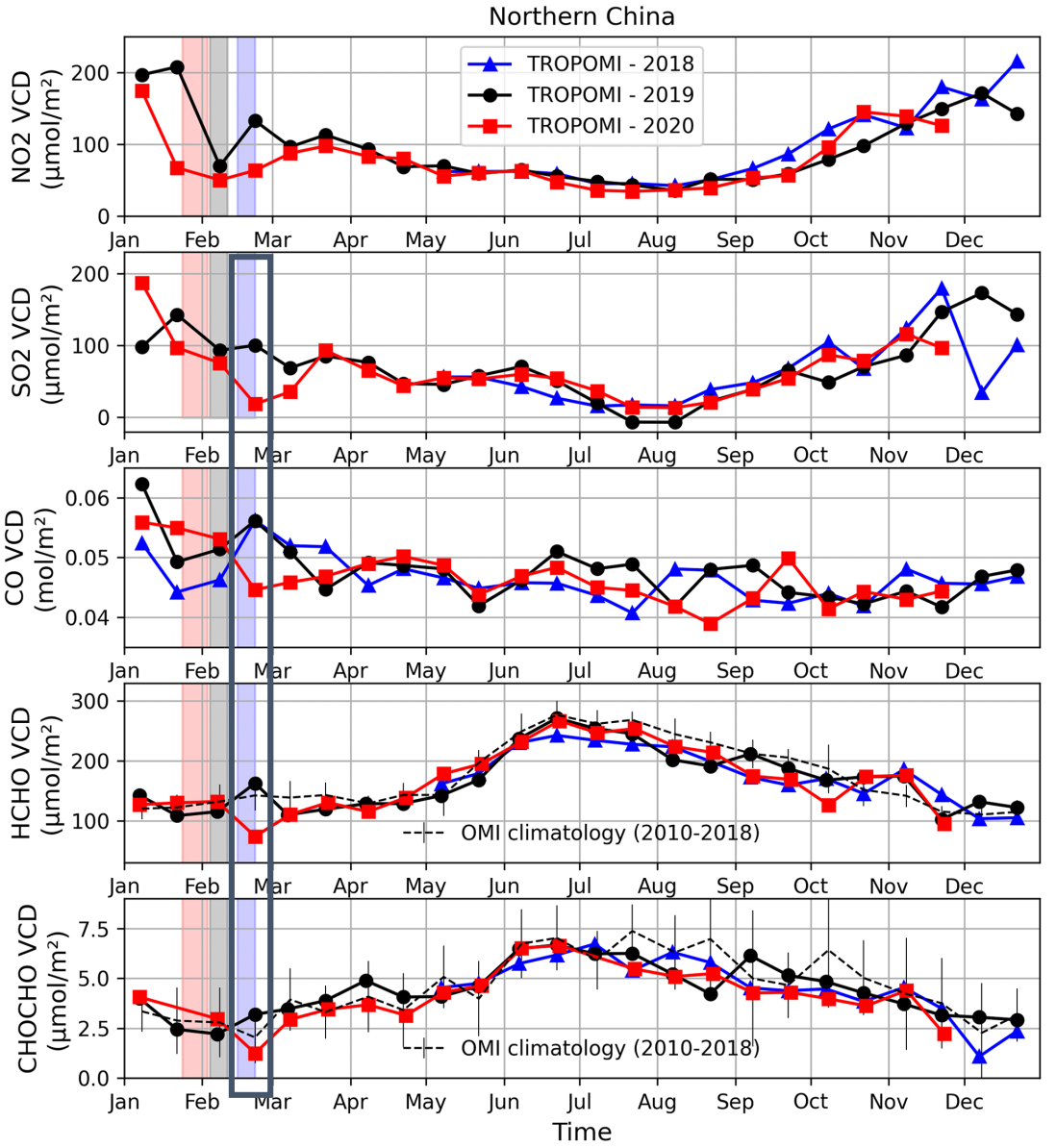
- **Bias is similar for OMI and TROPOMI. Can be reduced using local profiles.**
- **TROPOMI offers a significant improvement of HCHO observations for the detection of small signals, on a shorter time scale.**
- **Precision of TROPOMI daily averages at 20 km ranges from 1 to 4 Pmolec.cm^{-2}, depending on the site. This is a factor 3 improvement compared to OMI.**

TROPOMI precision: shorter time scale

Lockdown effect in Northern China

- **Bi-weekly averages of HCHO columns showed a short decrease during the second half of Feb.2020 in HCHO, CHOCHO, SO2 and CO.**

- **Levelt et al. 2022: *Air quality impacts of COVID-19 lockdown measures detected from space using high spatial resolution observations of multiple trace gases from Sentinel-5P/TROPOMI*.**

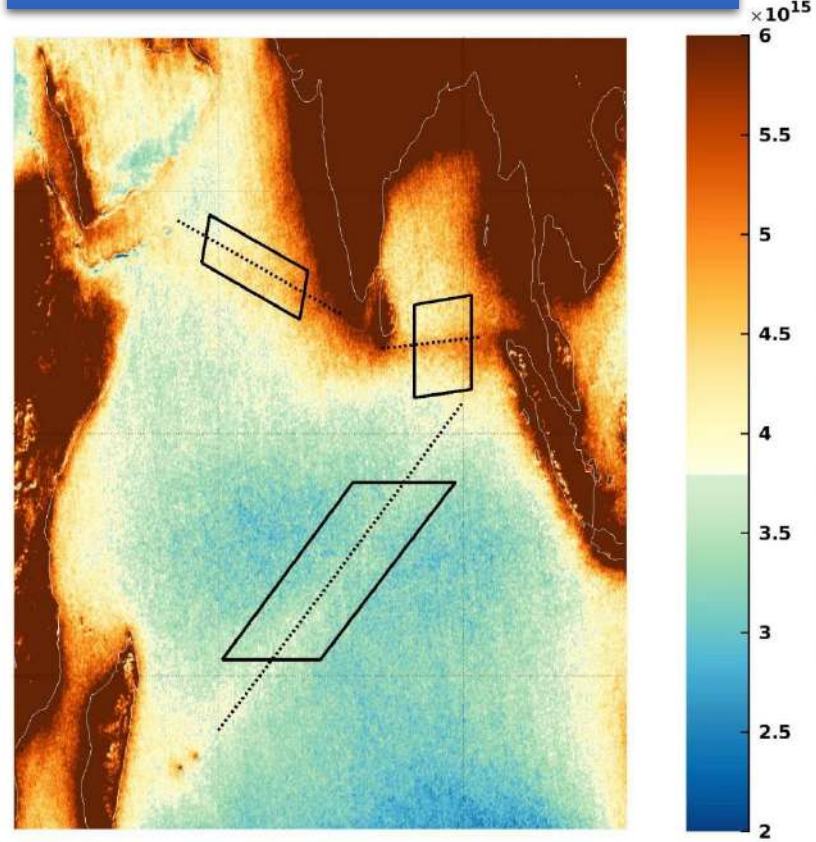


Poster 40: Glenn-Michael Oomen
Using Weekly TROPOMI HCHO Observations to Quantify Biogenic VOC Fluxes over Europe in 2018-2021

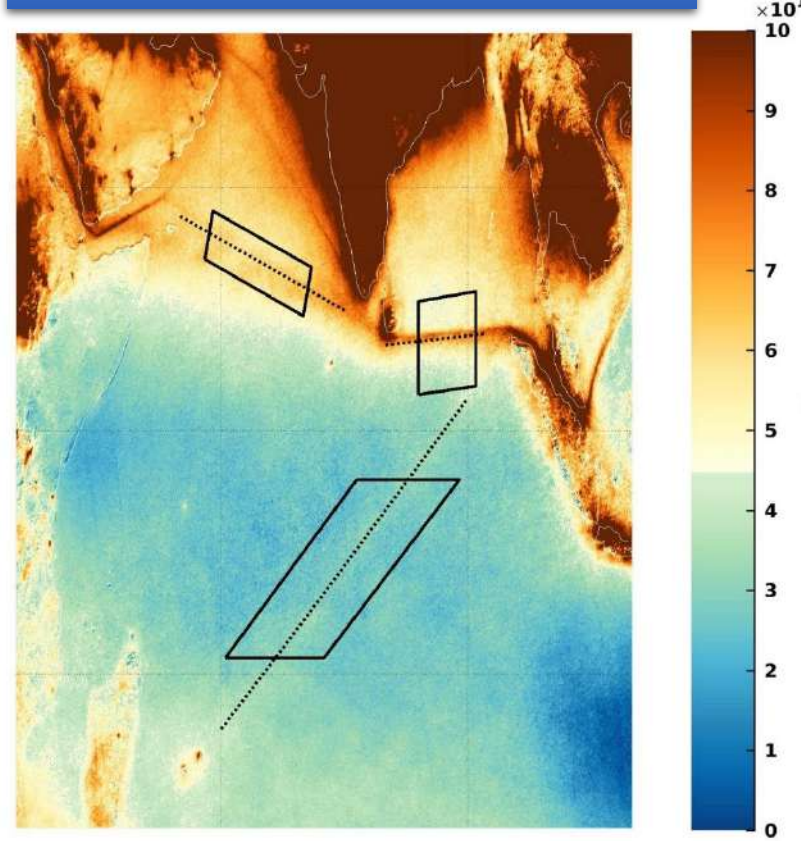
TROPOMI precision: small signals

Shipping lane detection

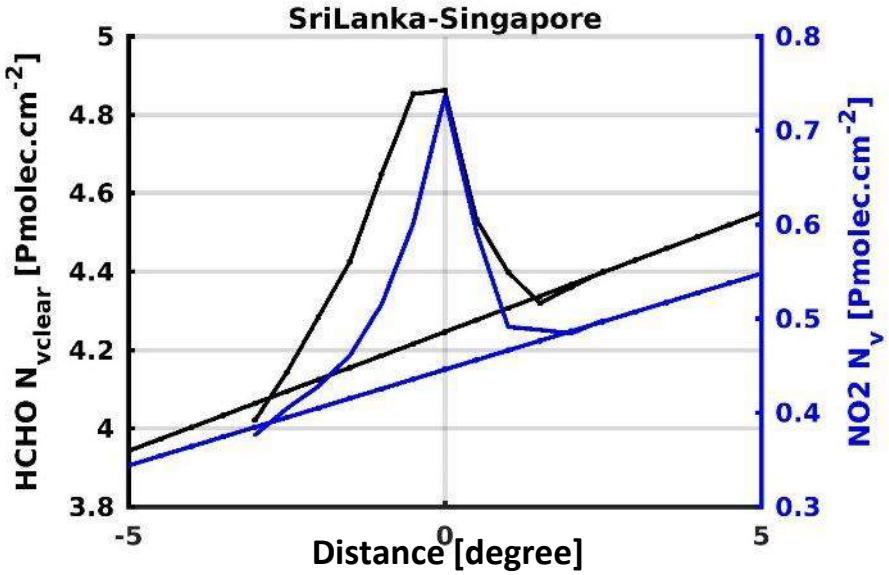
S5P HCHO VCD - DJF 2019-2021



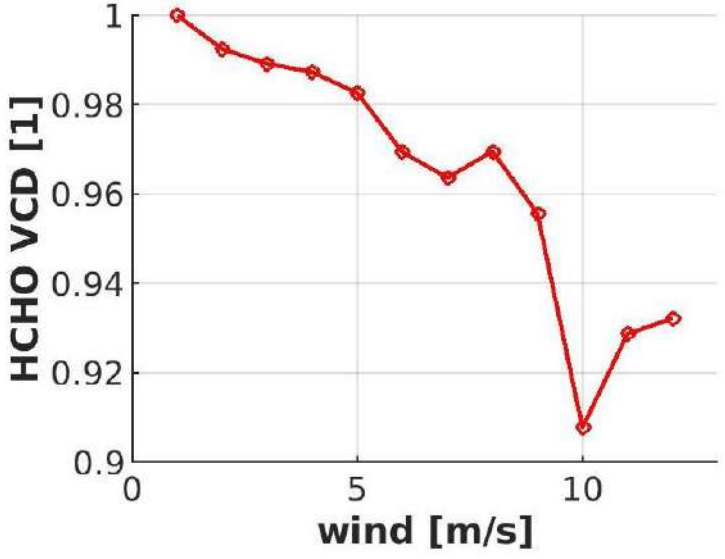
S5P NO_2 VCD - DJF 2019-2021

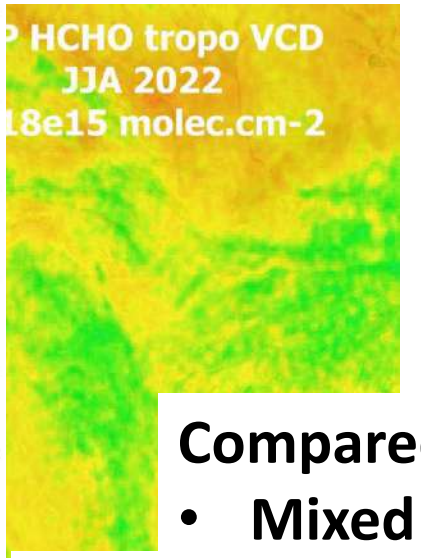


- TROPOMI data 2019-2021.
- DJF averages of HCHO and NO_2.
- Different scales (almost 10x more HCHO than NO_2).
- Several shipping lanes are visible in the NO_2 maps.
- Enhanced HCHO can be observed over some of the NO_2 lanes.
- HCHO: +10%, NO2: +80%



Wind information





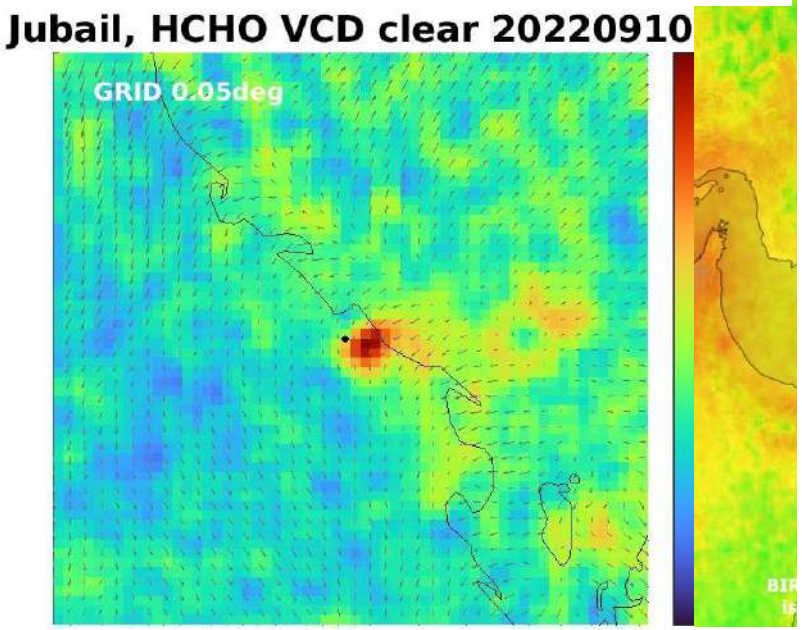
- In some locations, it is possible to observe the change of the HCHO spatial distribution with the winds.
- Case study: Jubail in the Persian Gulf coast of Saudi Arabia

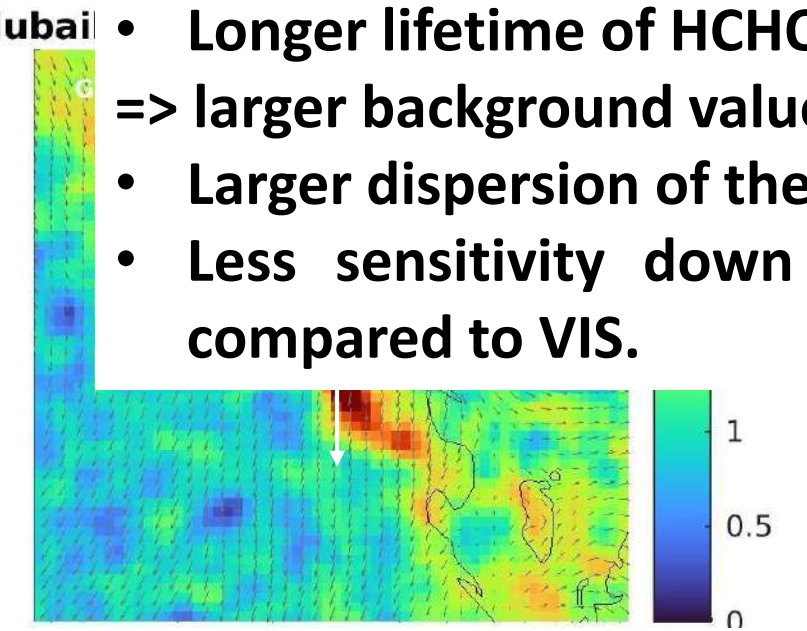
Compared to NO_2, more difficult to observe because:

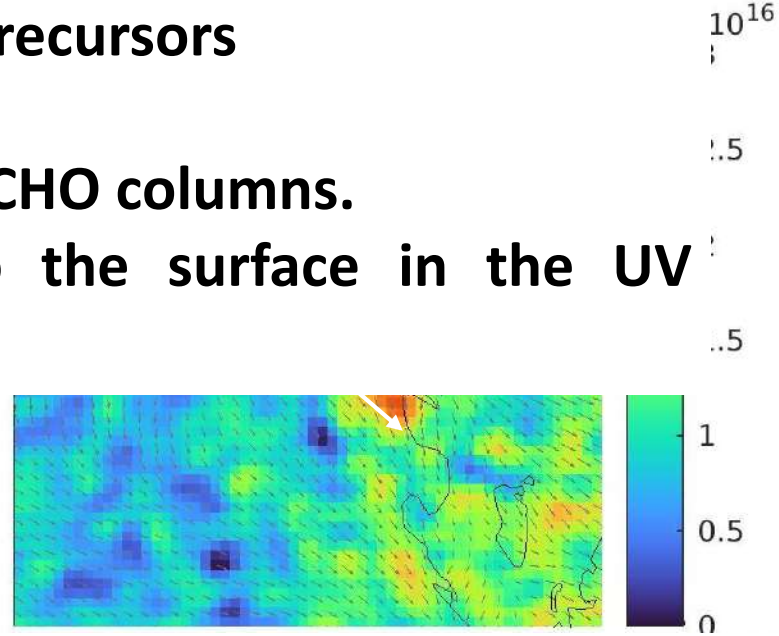
- Mixed sources
- Longer lifetime of HCHO precursors

=> larger background values.

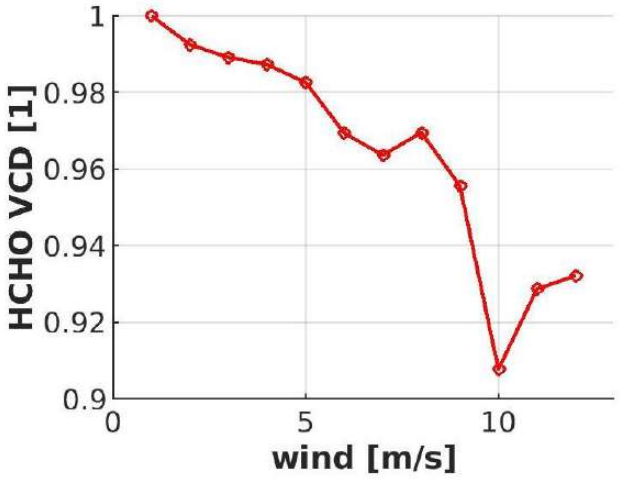
- Larger dispersion of the HCHO columns.
- Less sensitivity down to the surface in the UV compared to VIS.



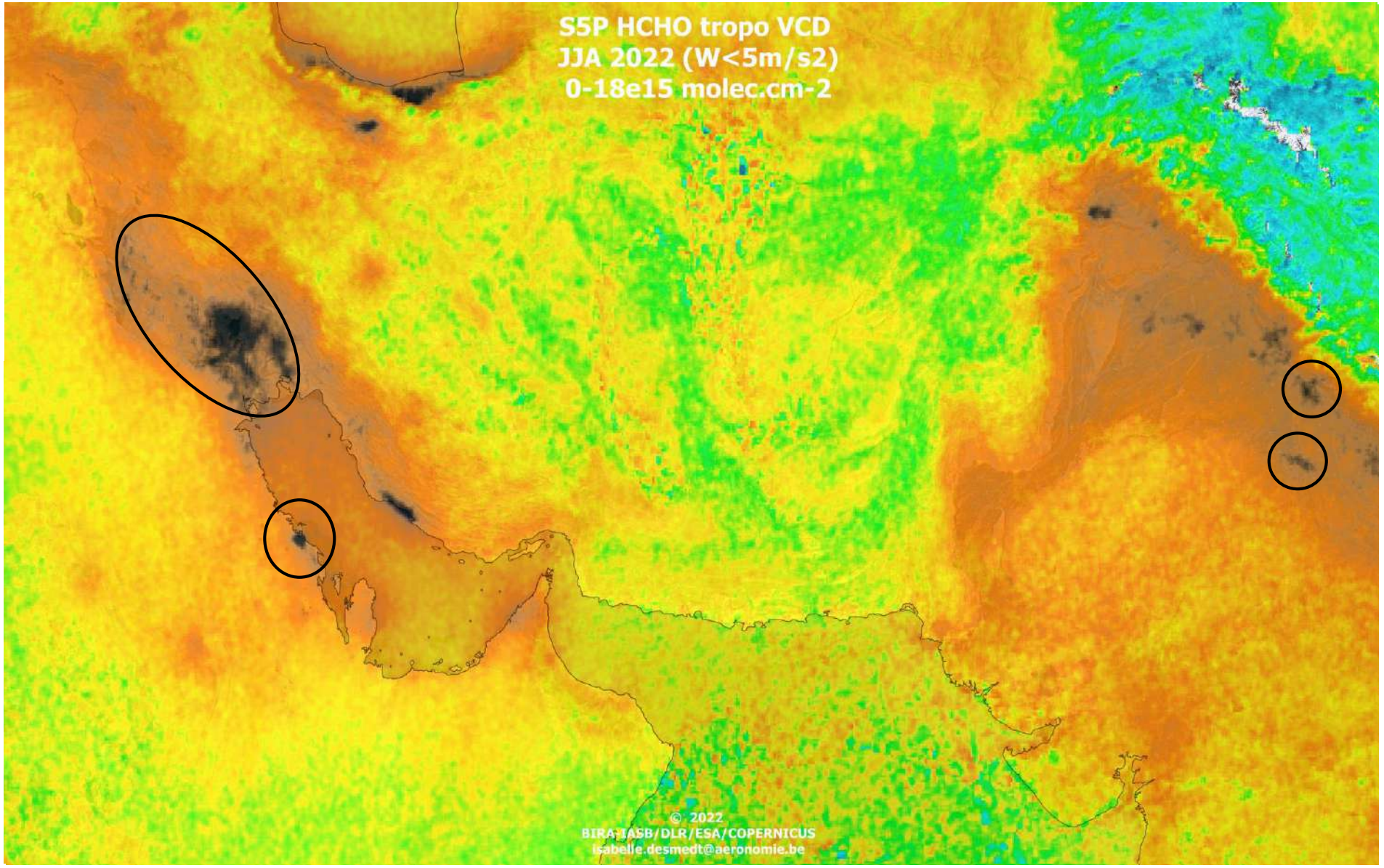




Wind information



- **Add a filter for wind velocity larger than 5m/s.**
- **HCHO columns detection can be improved by this selection.**

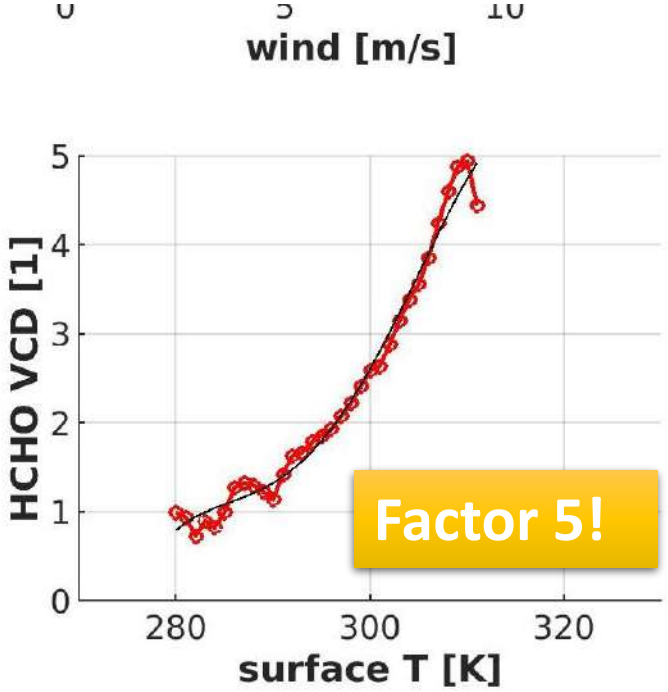


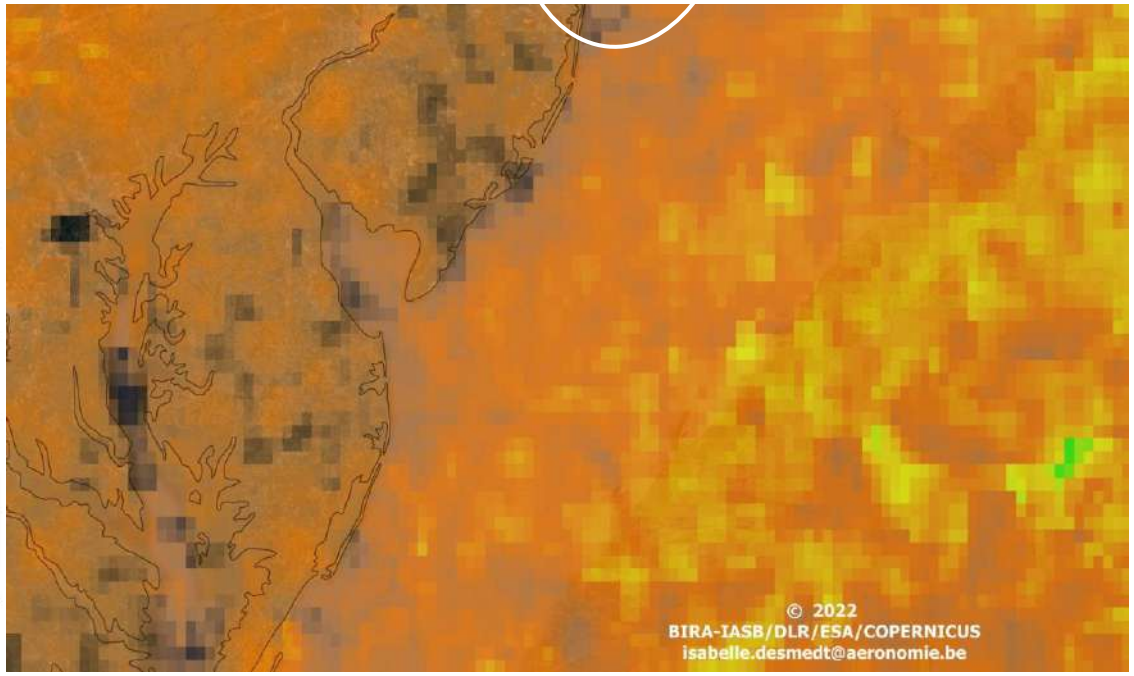
Wind information

HCHO Temperature correction:

- **Air quality impacts of COVID-19 lockdown** measures detected from space using high spatial resolution observations of multiple trace gases from Sentinel-5P/TROPOMI, Levelt et al. 2022.
- Spaceborne evidence for significant **anthropogenic VOC trends** in Asian cities over 2005–2019, Bauwens et al. 2022.
- **T-dependency can explain up to 40 % of the HCHO variability from day to day.**

- **Often the situation is more complex:**
  - **Transport from further away**
  - **Strong day to day variability related to T dependency.**





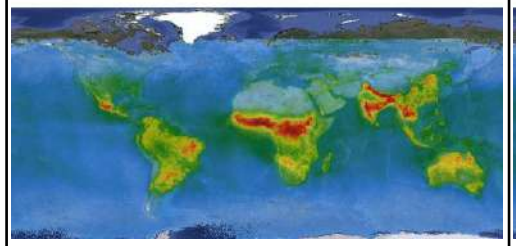
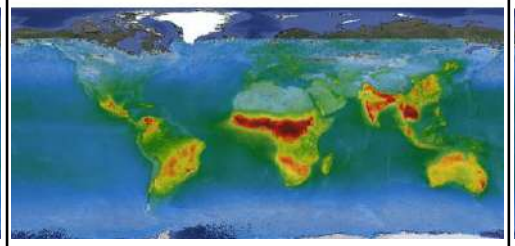
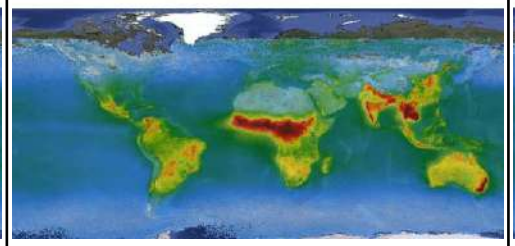
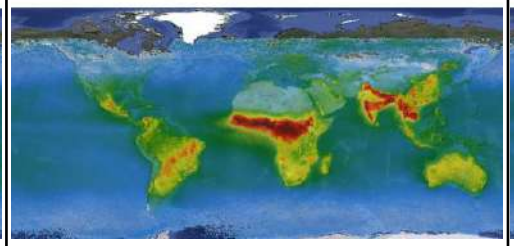
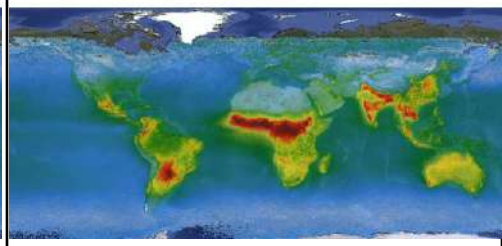
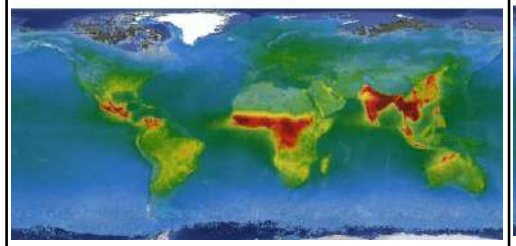
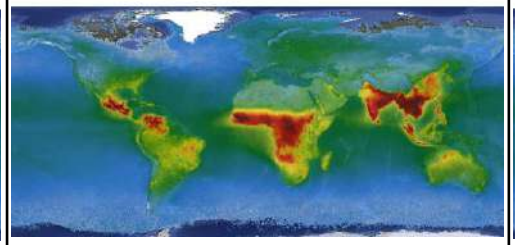
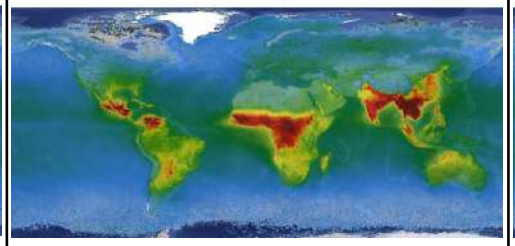
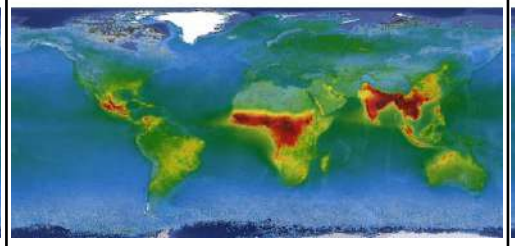
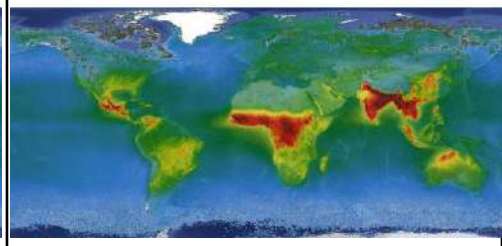
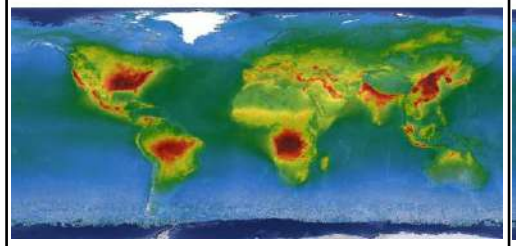
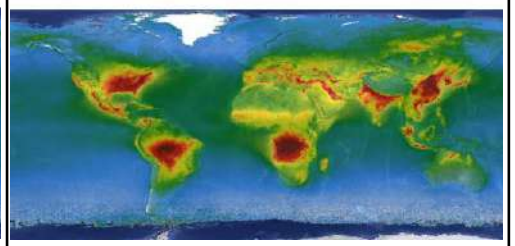
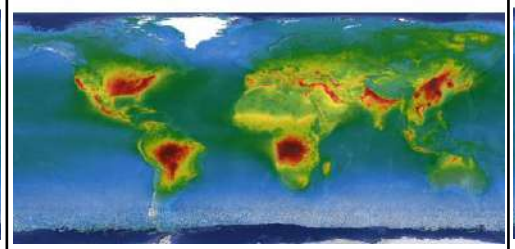
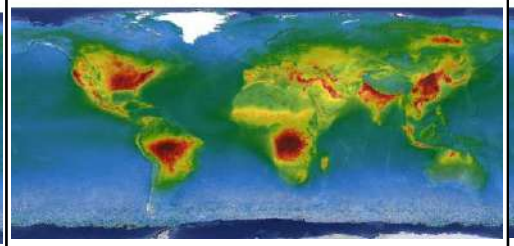
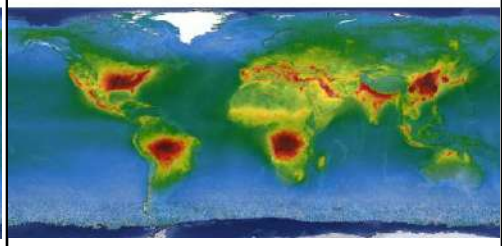
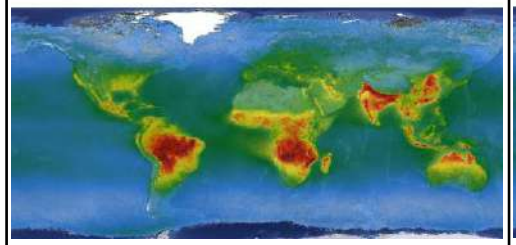
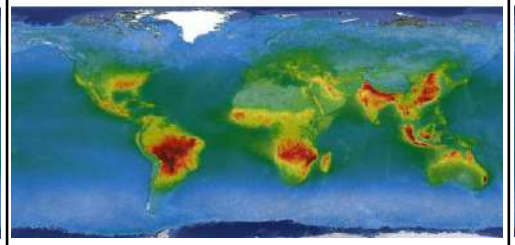
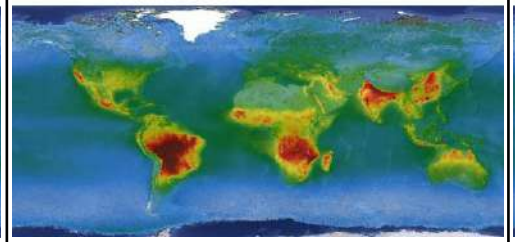
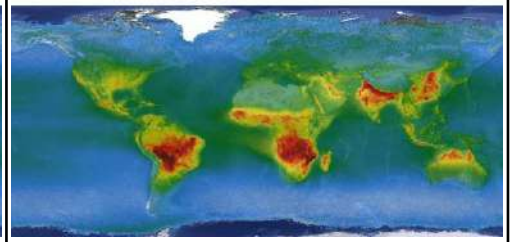
Future product updates

- **Reprocessing**
  - **New improved L1b version 2.1**
  - **Updated clouds**
  - **More robust background correction**
  - **Wind and surface temperature included in the HCHO L2 files.**

- **Surface albedo database:**
  - **Not updated yet, because the L1b v2.1 is needed in the UV (340nm).**
  - **First priority when the new albedo database will be ready, based on the reprocessed data.**

5 Years of HCHO measurements with TROPOMI

esa

	2018	2019	2020	2021	2022
DJF					
MAM					
JJA					
SON					

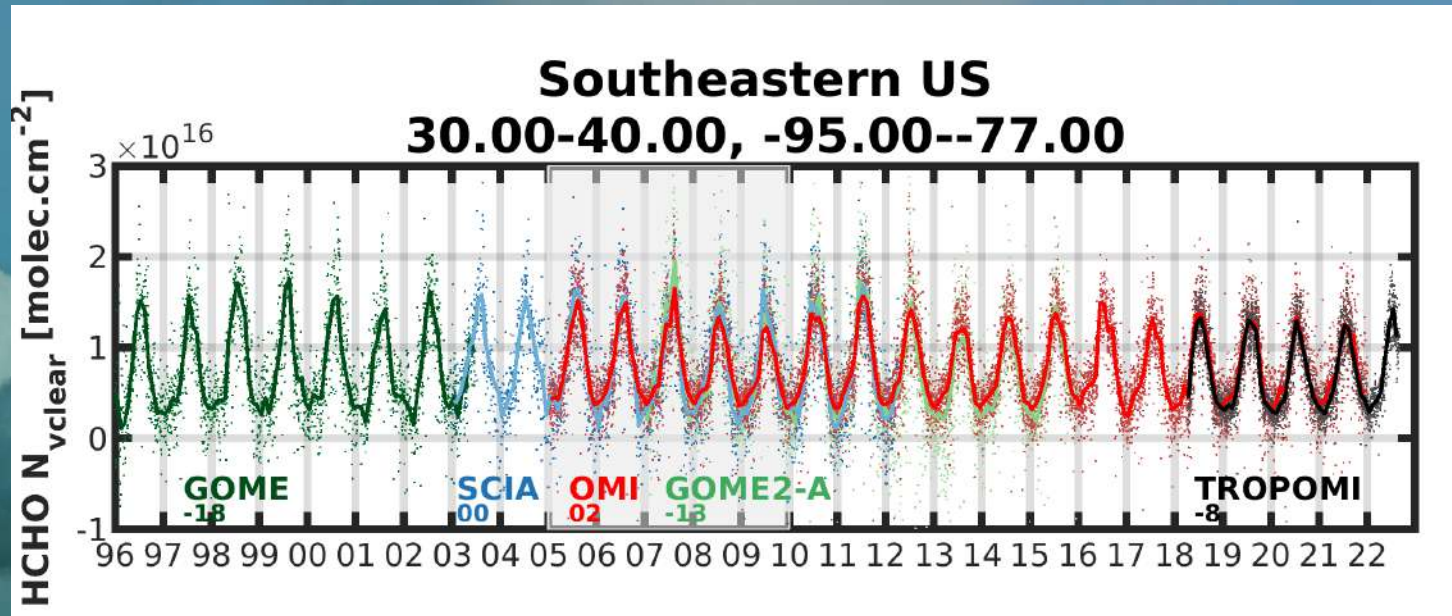
More slides

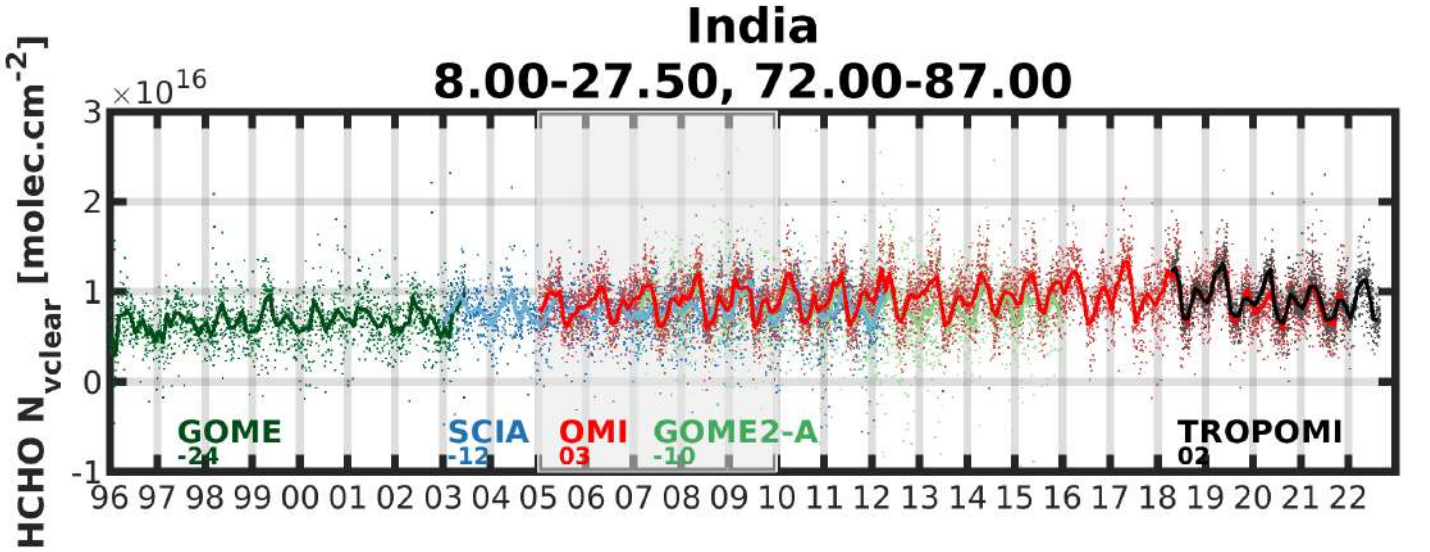
PROGRAMME OF THE EUROPEAN UNION
co-funded with esa

Climate Data Record

Ozone precursors CCI+ and ACSAF:

- from GOME to TROPOMI
  - Handling of bias
  - Different auxiliary data
  - Different spatial and temporal resolution.
  - Provide consolidated L3 data.





precursors cci

Processor version changes

Processor Version	In operation from	In operation until	Relevant improvements
02.04.01	OFFL: orbit 24655, 2022-07-17 NRTI: orbit 24697, 2022-07-20	Current version	- No changes in the HCHO retrievals - CLOUD input product: the OCRA L1 soft correction is switched off when the latest L1b version 2.1.0 (with both radiance and irradiance degradation corrected) is processed - The variable `surface temperature` is now written correctly (it was set to fill-value in the previous version) **Note:** Starting from this processor version, new improved Level 1b version 2.1.0 data products are used as input [RD04]
02.03.00	OFFL: orbit 22768, 2022-03-06 NRTI: orbit 22813, 2022-03-09	Orbit 24654, 2022-07-17 Orbit 24697, 2022-07-20	- Improve robustness of Background calculation - The variables `satellite_altitude`, `satellite_latitude`, `satellite_longitude`, `satellite_orbit_phase` are now written correctly (were set to fill-value in the previous versions)
02.02.01	OFFL: orbit 19258, 2021-07-01 NRTI: orbit 19308, 2021-07-05	Orbit 22767, 2022-03-06 Orbit 22811, 2022-03-09	- From this version, the variable `surface altitude precision` is correctly written (previous versions reported fill-value) - Added surface temperature and DOAS polynomial coefficients (see section 6.1) - Background calculation: improved robustness of earthshine reference calculation to avoid failures due to the presence of fill values in the input L1b product **Note:** Starting from this processor version, new improved Level 1b version 2.0.0 data products are used as input [RD04]
02.01.04	OFFL: orbit 16213, 2020-11-29 NRTI: orbit 16259, 2020-12-02	Orbit 19257, 2021-07-01 Orbit 19306, 2021-07-05	No changes with respect to previous version
02.01.03	OFFL: orbit14239, 2020-07-13 NRTI: orbit 14285, 2020-07-16	Orbit 16256, 2020-12-02 Orbit 16212, 2020-11-29	- New surface albedo retrieval algorithm (GE_LER) from TROPOMI for the CLOUD product replaces the climatologies - New OCRA cloud-free maps based on TROPOMI instead of OMI (affects CLOUD input product) - New cloud flags have been introduced (e.g. ice-clouds) - The required interpolation of cloud properties co-registration between band 3-4 and band 6 due to the instrument co-registration issues has been improved in the CLOUD product - Improved background correction for HCHO product - Updated metadata generation to reflect the improved spatial resolution after 6th Aug 2019 - Improved handling of the ECMWF information, reading and deriving snow-ice information and propagating wind-information in the level 2 products - Improved the parameter `qa_value` determination - Invalid values of `geolocation flags` set to correct values - New variables added (see section 6.1)
01.01.08	OFFL: orbit 12432, 2020-03-07 NRTI: orbit 12482, 2020-03-11	Orbit14238, 2020-07-12 Orbit 14285, 2020-07-16	No changes with respect to previous version
01.01.07	OFFL: orbit 7907, 2019-04-23 NRTI: orbit 8000, 2019-04-30	Orbit 12431, 2020-03-07 Orbit 12482, 2020-03-11	No changes with respect to previous version
01.01.06	OFFL: orbit 7542, 2019-03-28 NRTI: orbit 7632, 2019-04-04	Orbit 7906, 2019-04-23 Orbit 7999, 2019-04-30	- Surface classification climatology updated - Fixed a bug in the interpolation of the surface albedo climatology - Fixed a problem regarding the retrieved CLOUD product parameters being too close to the *a-priori* values. This might have affected the calculation of the HCHO in cloudy cases (see section 4.2)
01.01.05	RPRO: orbit 3017, 2018-05-14 OFFL: orbit 5833, 2018-11-28 NRTI: orbit 5932, 2018-12-05	Orbit 5832, 2018-11-28 Orbit 7541, 2019-03-28 Orbit 7631, 2019-04-04	Alignment of the configuration for NRTI, OFFL and RPRO chains regarding the Chemistry Transport Model input, leading to the same product quality (see section 4.2)
01.01.02	NRTI: orbit 5003, 2018-10-01	Orbit 5929, 2018-12-05	Initial operational version

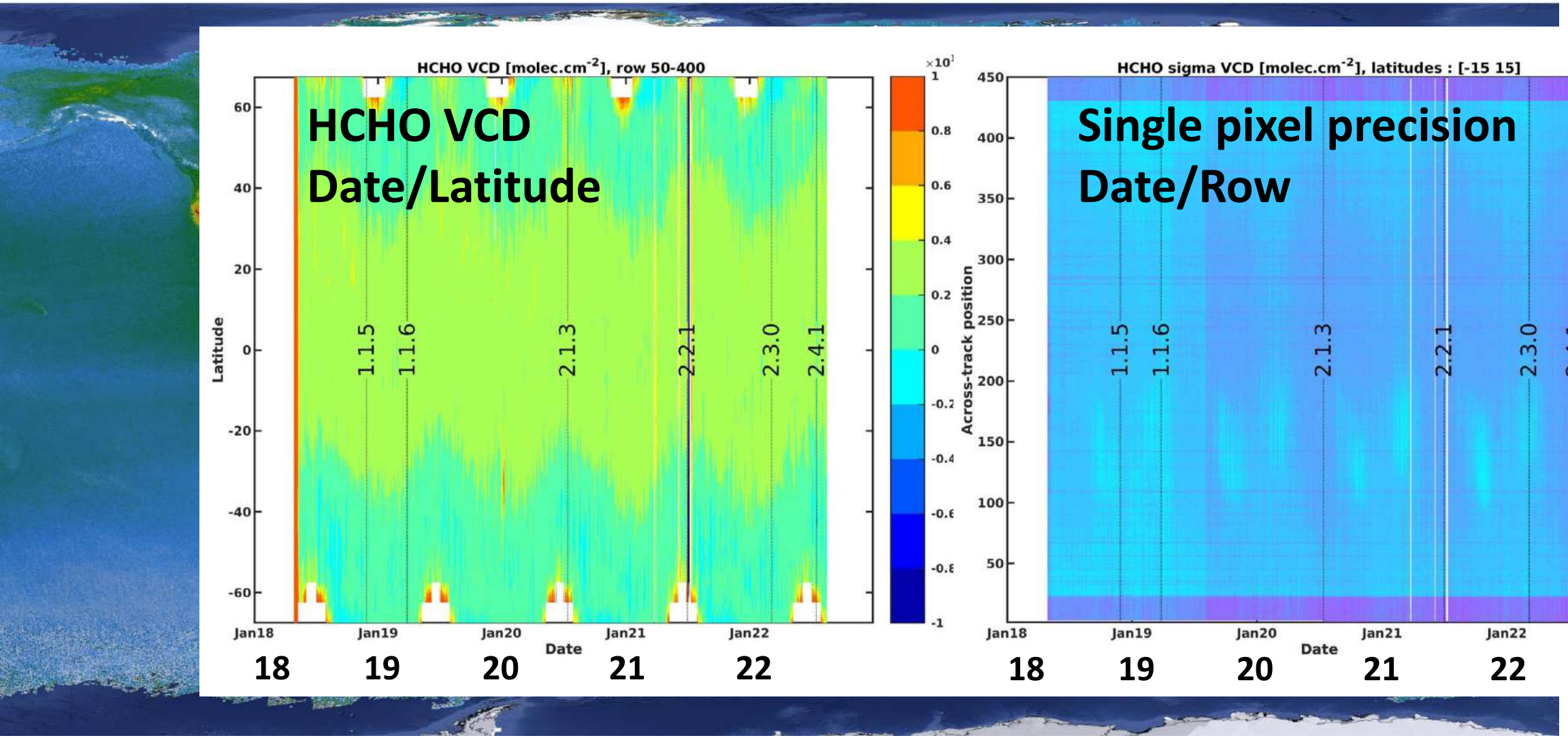
Table 2: History of HCHO processor versions

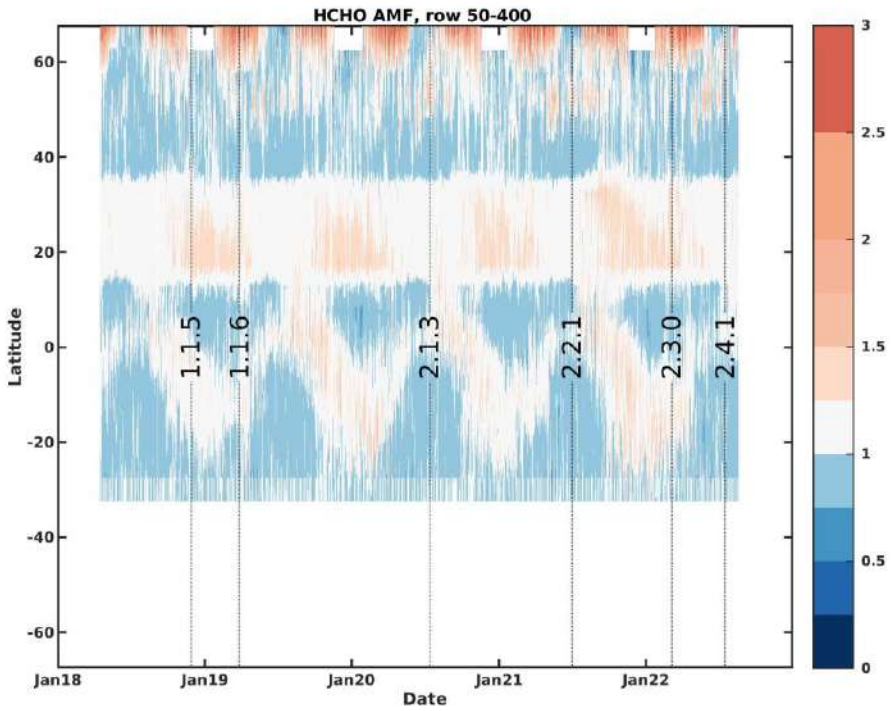
- Updated version of the ATBD, PRF and PUM for UPAS v2.3.0 to be activated in March.

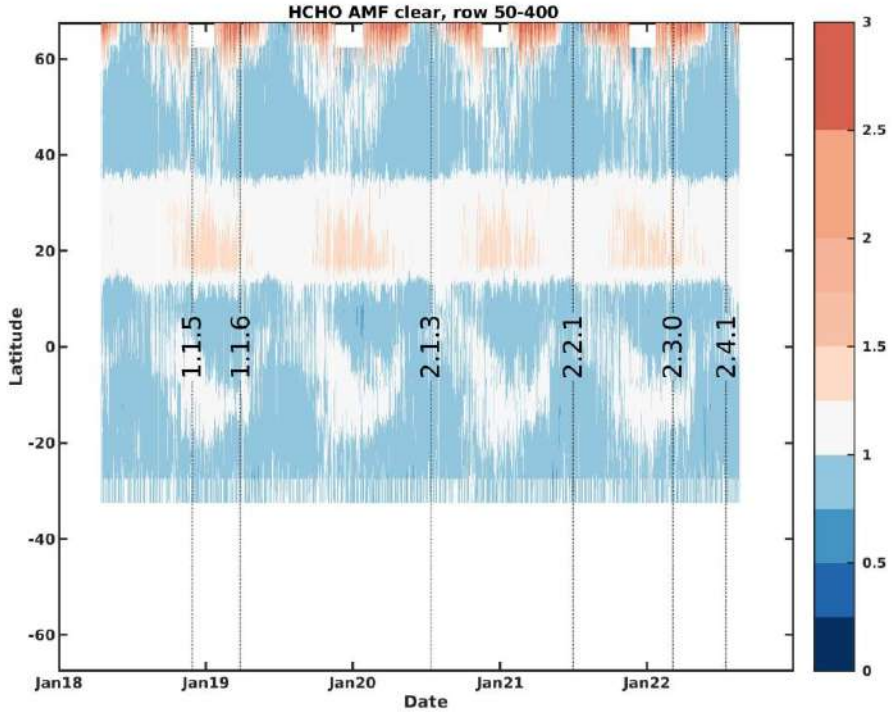
Product Roadmap, mid-term (HCHO/SO2)

- Background correction improvements: new fallback file to be implemented.
- Use of the thermal instability flag (#34201) to filter the SCDs used in the background correction.
- Tests and updates of new surface albedo databases based on TROPOMI measurements.(1) tests of DLR and KNMI products, (2) implementation for SO2 and HCHO products.
  - Conclusion so far is that the updated L1b are needed to improve the TROPOMI LER.
- Effect of scene heterogeneity in TROPOMI spectra: (1) filtering with qa, (2) correction
  - Copy the heterogeneity factors provided in the L1b files into the L2 files.
- Retrievals over snow/ice scenes, improved AMFs.
- Improved treatment of non-linear effects in the SO2 spectral fitting (optimized fitting windows and transitions).
- Refinement of QA values for degraded quality events and user needs.
- Updated analysis of TROPOMI slit functions with new L1 version. If needed, update of the cross-section datasets.

Stability in the reference sector

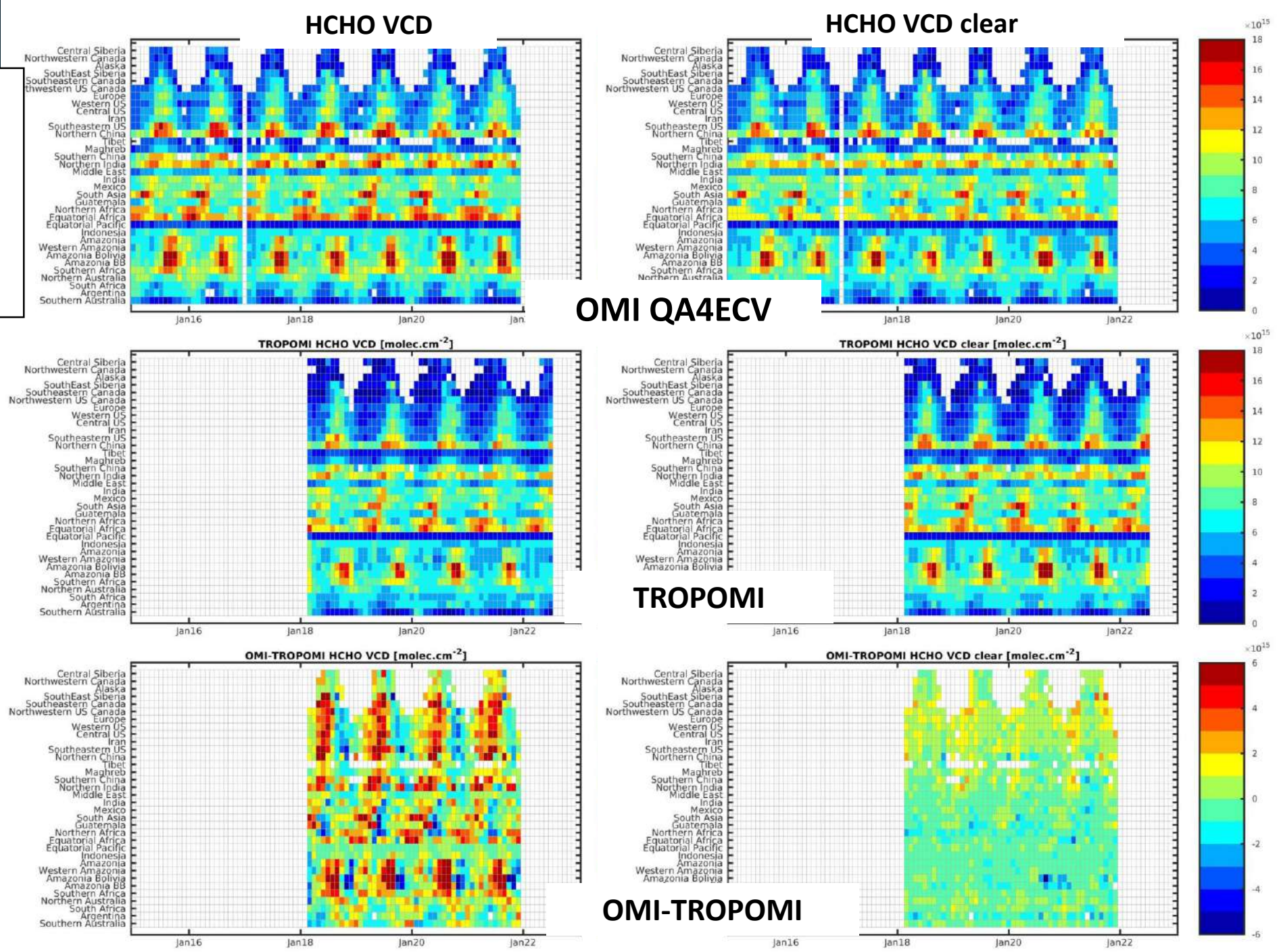



HCHO AMF, row 50-400
Latitude
Date
Jan18
Jan19
Jan20
Jan21
Jan22
1.1.5
1.1.6
2.1.3
2.2.1
2.3.0
2.4.1


HCHO AMF clear, row 50-400
Latitude
Date
Jan18
Jan19
Jan20
Jan21
Jan22
1.1.5
1.1.6
2.1.3
2.2.1
2.3.0
2.4.1

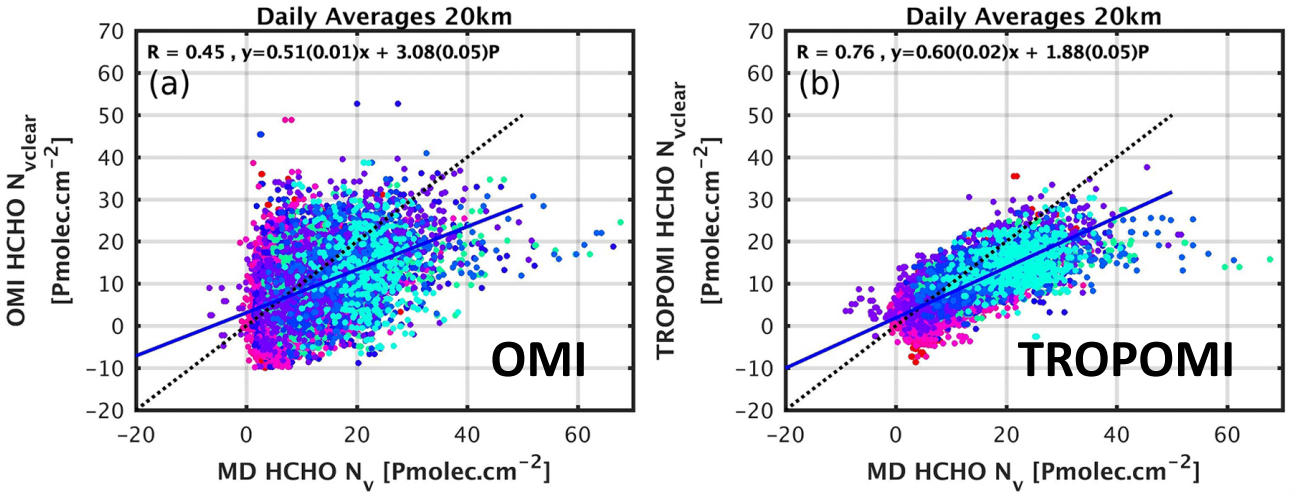
Time variation of the monthly averaged OMI and TROPOMI HCHO columns (Nv and Nv_clear), and the mean absolute bias between OMI and TROPOMI.

- We do not observe a change in time in the bias between OMI and TROPOMI.
- The main source of bias lies in the cloud correction impact.
- When looking at the Nv_clear bias, the main remaining dependency lies in the latitude.



Validation data: MAX-DOAS (NIDFORVAL)

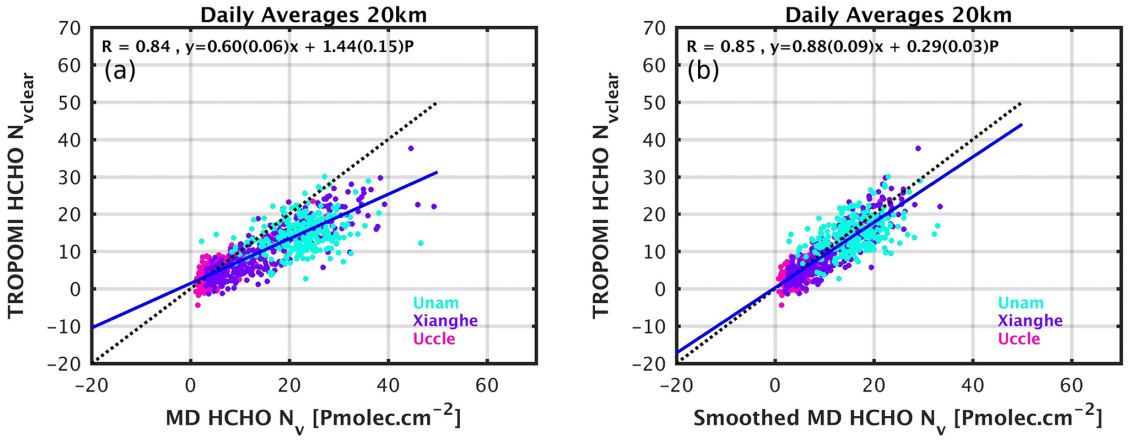
co-funded with esa



- OMI / TROPOMI versus MAX-DOAS
- Daily medians of collocated data.
  - Equivalent slopes for OMI and TROPOMI
  - Offset for small columns and precision is significantly improved with TROPOMI

TROPOMI/MAXDOAS

AK smoothing

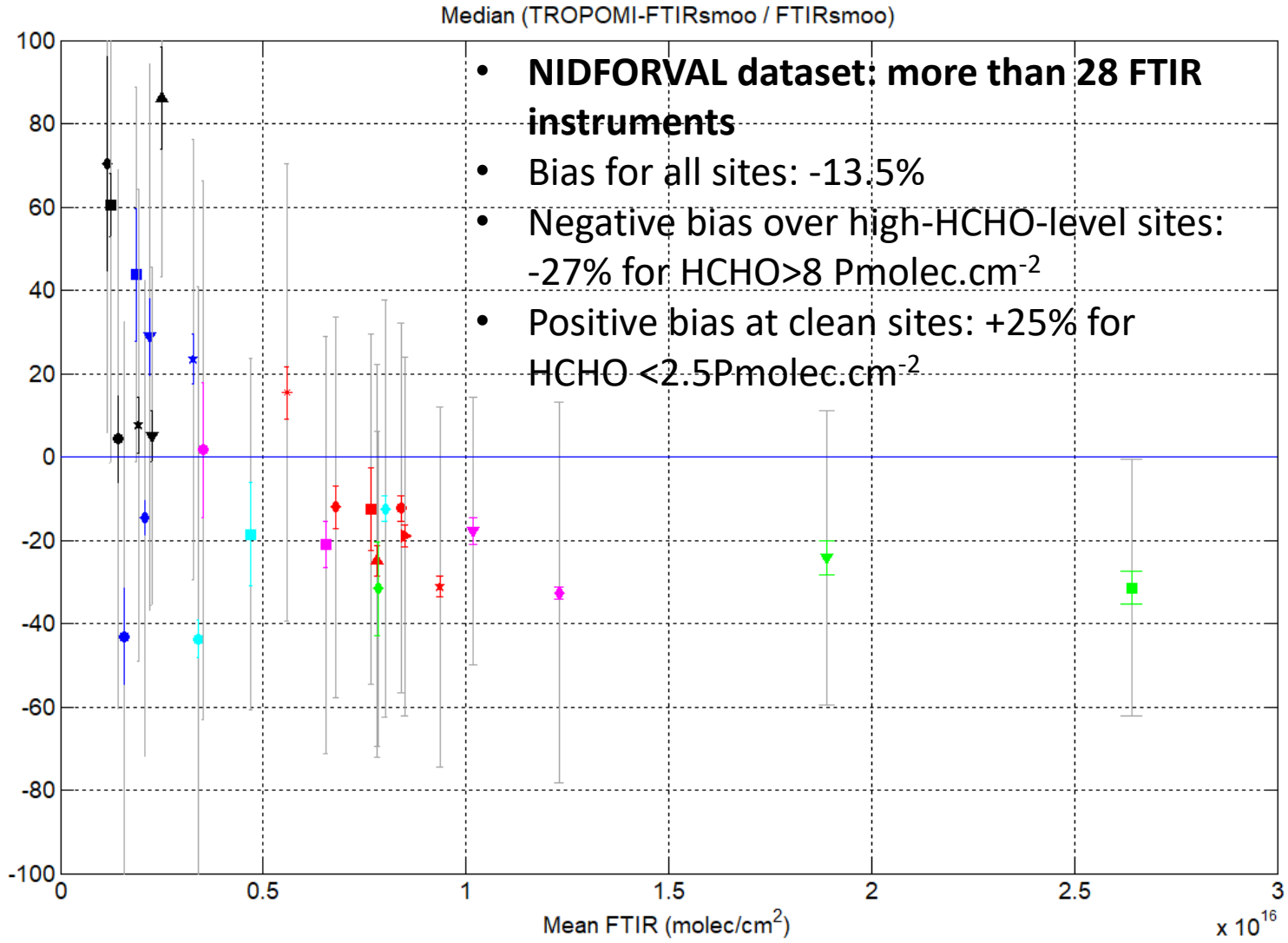


- TROPOMI versus MAX-DOAS
- Daily means of collocated data.
- Before / After vertical smoothing of the MAX-DOAS profile.

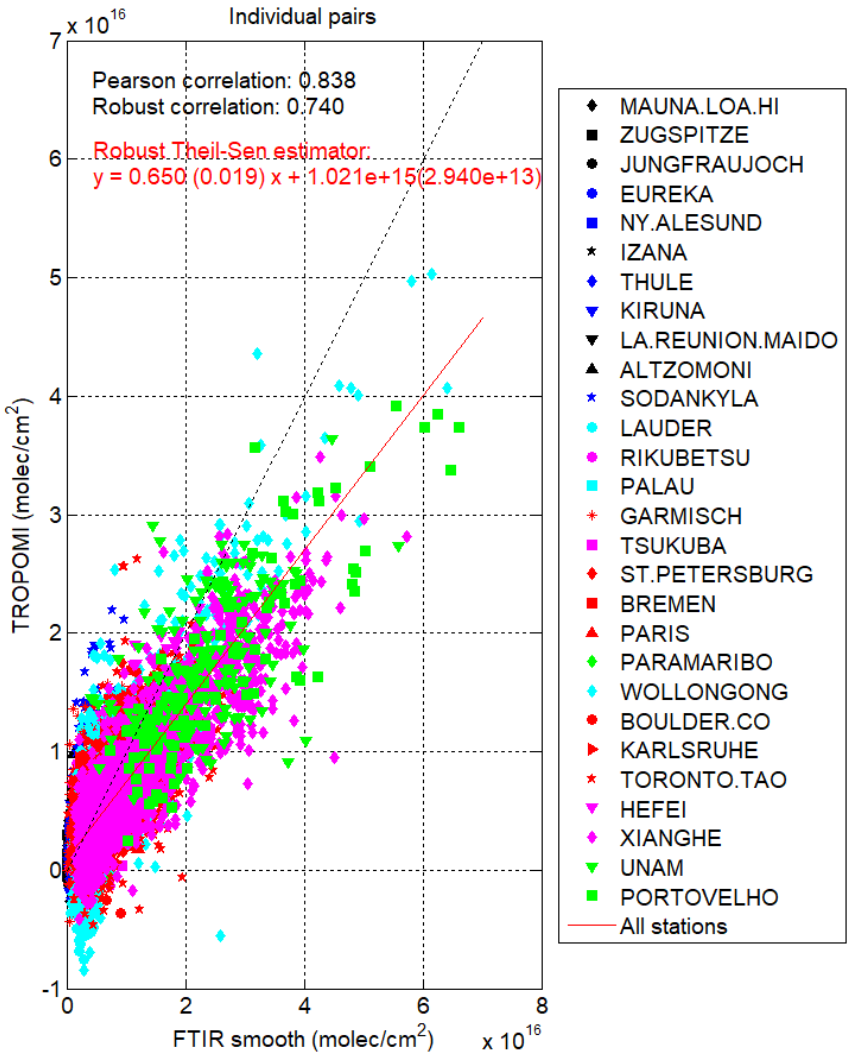
Updated from De Smedt et al. 2021.

Validation data: FTIR (NIDFORVAL)

co-funded with esa

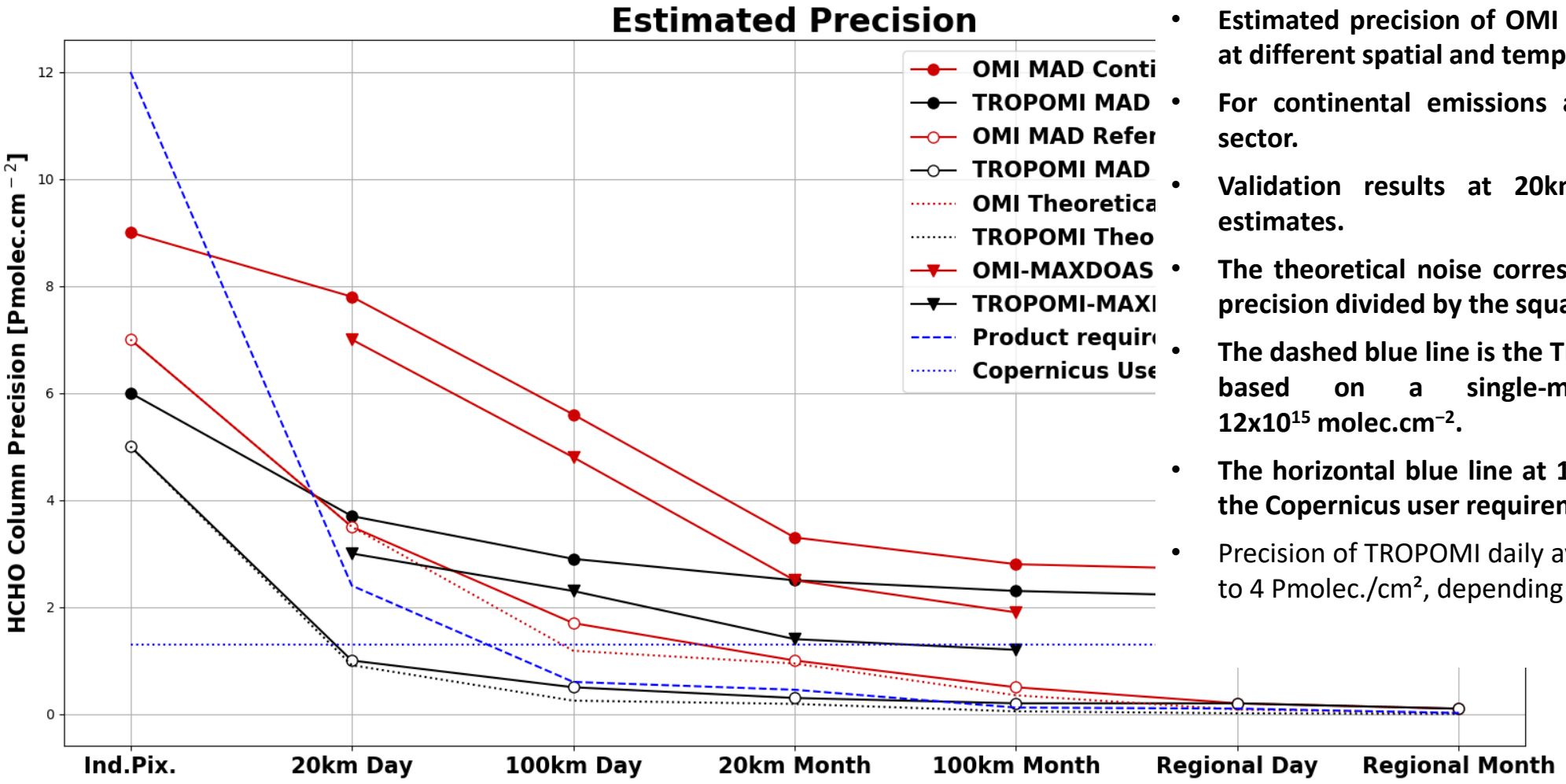


- **NIDFORVAL dataset: more than 28 FTIR instruments**
- Bias for all sites: -13.5%
- Negative bias over high-HCHO-level sites: -27% for HCHO>8 Pmolec.cm^{-2}
- Positive bias at clean sites: +25% for HCHO <2.5Pmolec.cm^{-2}



Updated from Vigouroux et al. 2020.

TROPOMI precision



- **Estimated precision of OMI and TROPOMI HCHO columns at different spatial and temporal scales.**
- **For continental emissions and in the remote reference sector.**
- **Validation results at 20km and 100 km confirm the estimates.**
- **The theoretical noise corresponds to single-measurement precision divided by the square root of observations.**
- **The dashed blue line is the TROPOMI product requirement, based on a single-measurement precision of $12x10^{15}$ molec.cm^{-2}.**
- **The horizontal blue line at $1.3x10^{15}$ molec.cm^{-2} represents the Copernicus user requirement.**
- Precision of TROPOMI daily averages at 20 km ranges from 1 to 4 Pmolec./cm², depending on site (natural variability).

De Smedt et al. 2021

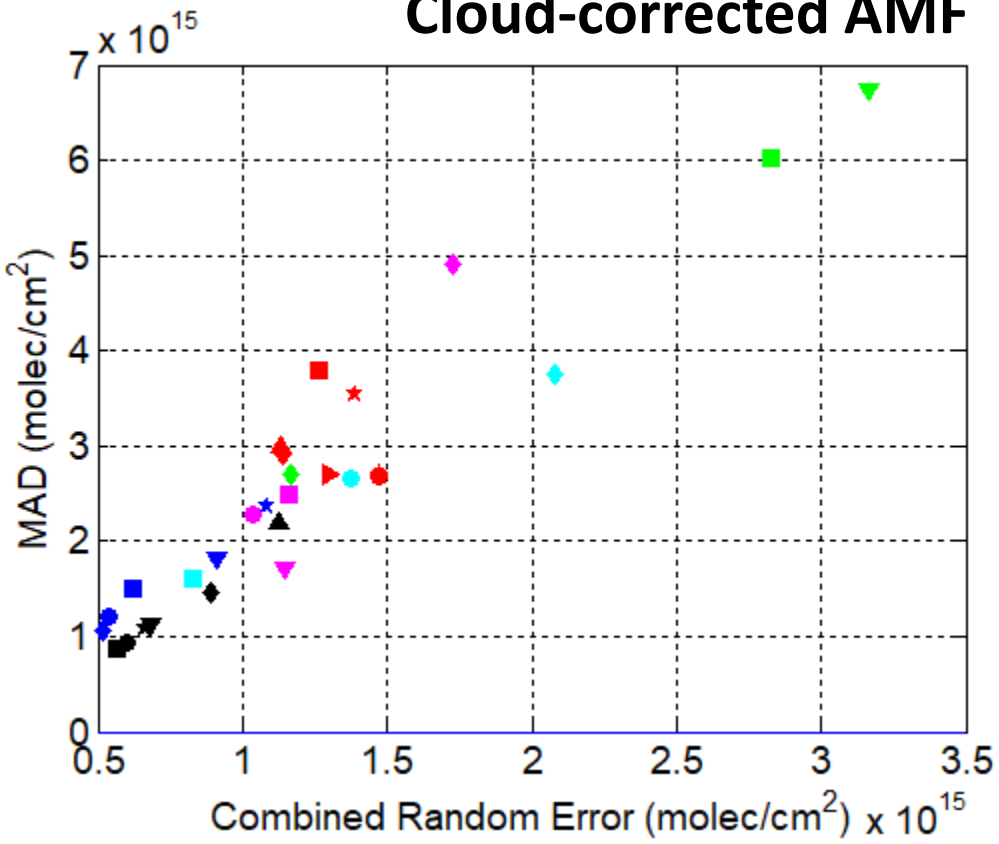
Validation data: precision estimate with FTIR

co-funded with esa

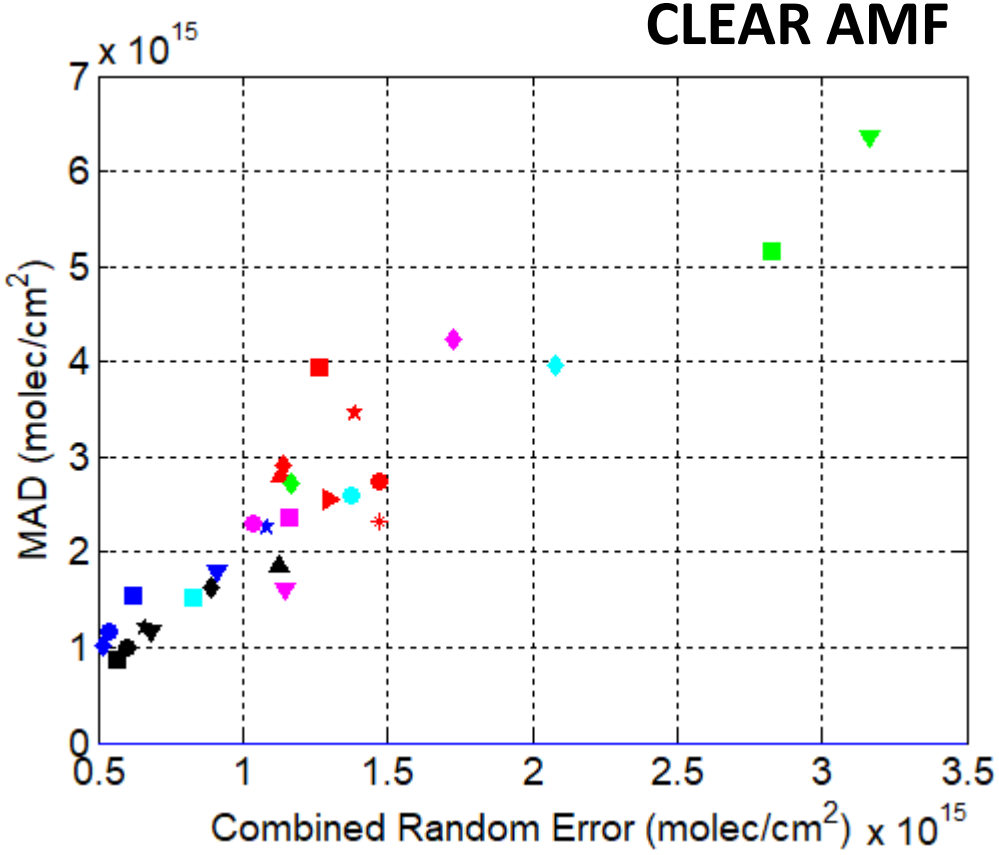
Daily means

- Precision of TROPOMI daily averages at 20 km ranges from 1 to 7 Pmolec./cm², depending on site (natural variability).
- **Twice larger than the provided combined random errors.**

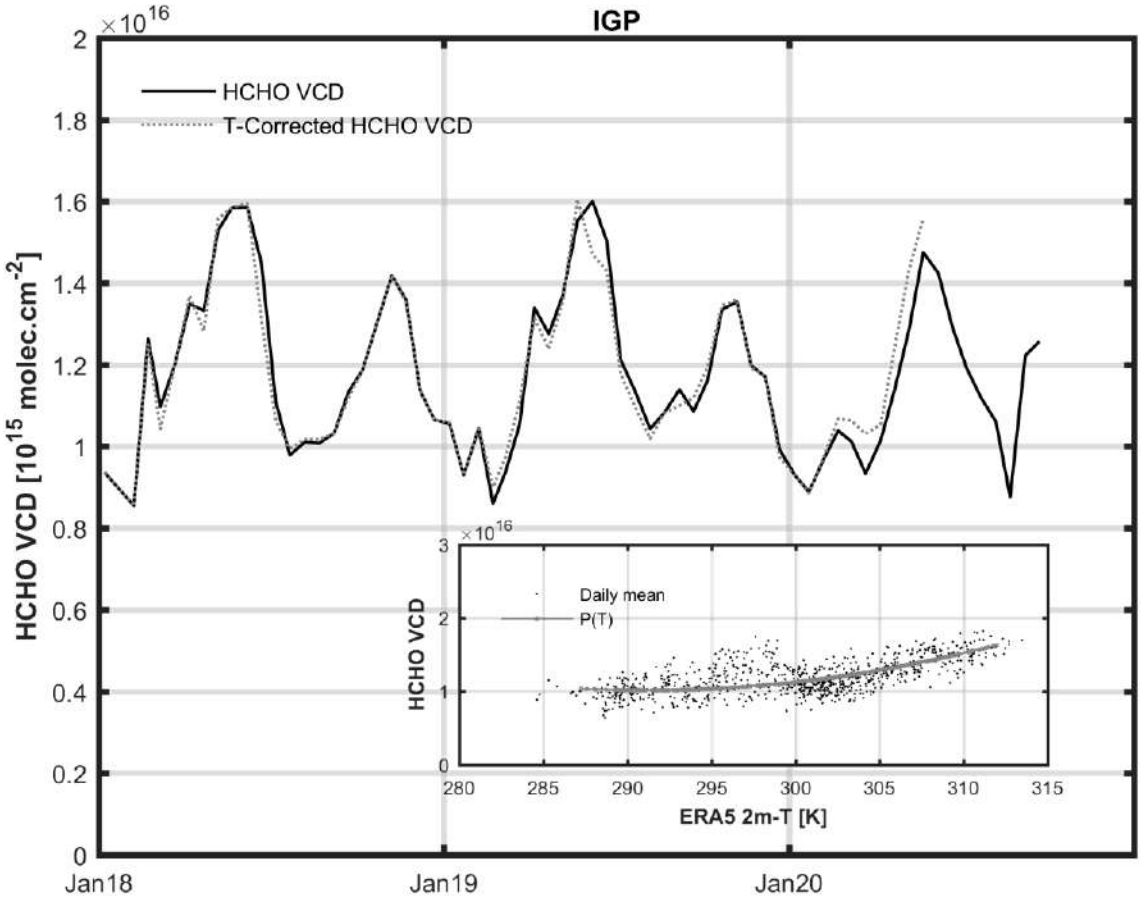
Cloud-corrected AMF

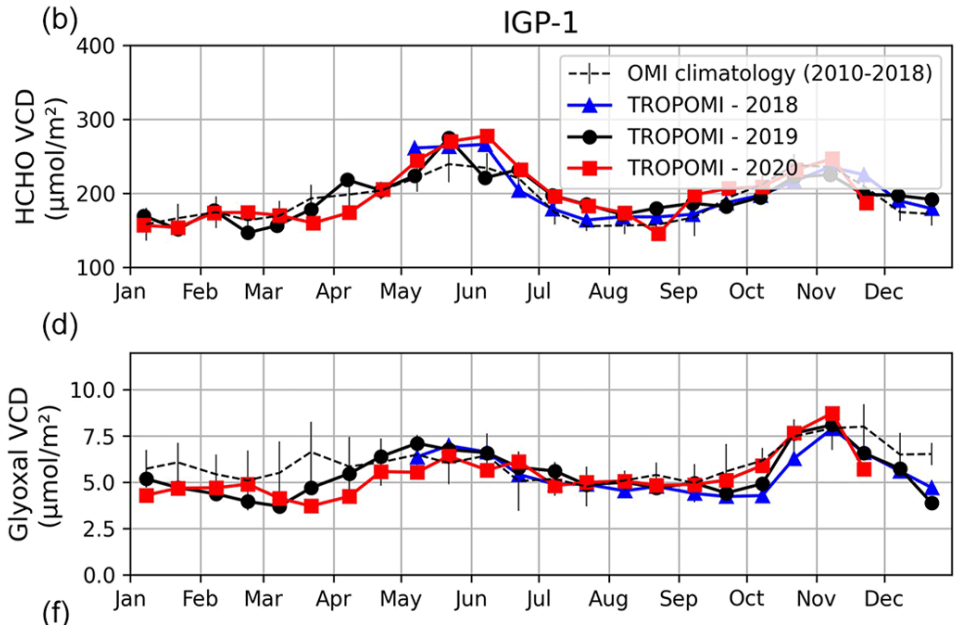


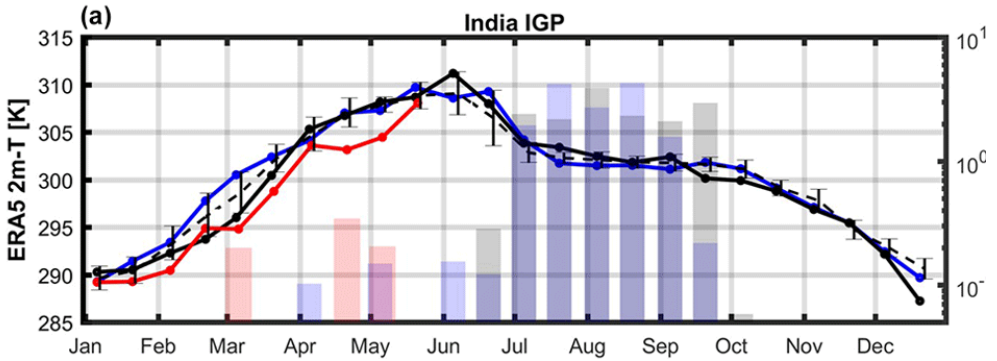
CLEAR AMF



Surface temperature information (since July 22)





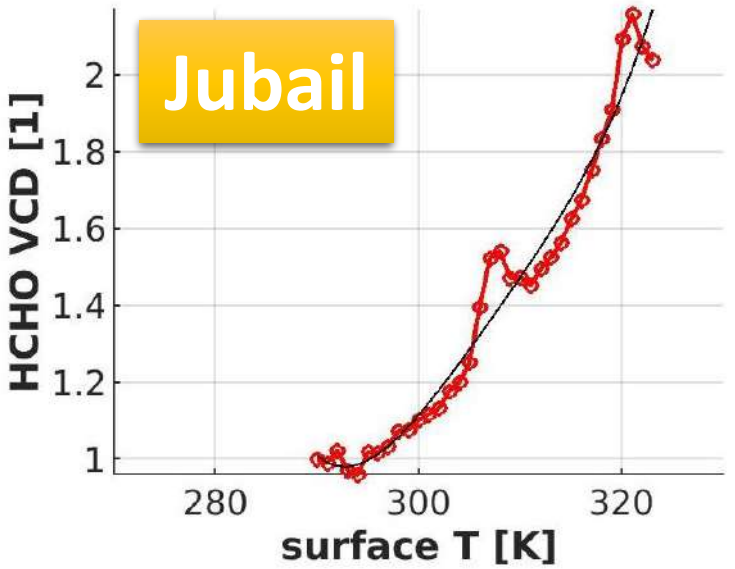


Spaceborne evidence for significant anthropogenicVOC trends in Asian cities over 2005–2019, M Bauwens et al 2022 Environ. Res. Lett. 17 015008

Natural variability: temperature effects

HCHO Temperature correction:

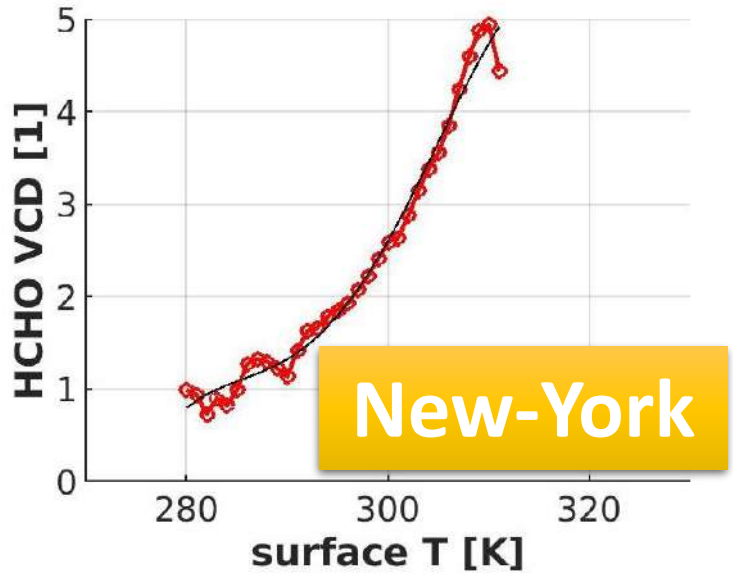
- **Air quality impacts of COVID-19 lockdown** measures detected from space using high spatial resolution observations of multiple trace gases from Sentinel-5P/TROPOMI, Levelt et al. 2022.
- Spaceborne evidence for significant **anthropogenic VOC trends** in Asian cities over 2005–2019, Bauwens et al. 2022.



Validation: precision of TROPOMI daily averages ranges from 1 to 4 Pmolec.cm^{-2}.

=> T-dependency can explain 30 to 40 % of the HCHO variability from day to day.

Dispersion of daily averaged columns (08-09 2022)	HCHO VCD	T-corrected HCHO VCD
Jubail	1.3e15	1e15
New York	2.9e15	2e15



- Winds info in L2 since July 2020 (v2.1.3)
- Surface temperature in L2 since July 2022 (v2.4.1)

Wind information