Validation of tropospheric NO_2 columns measurements from GOME-2, OMI and TROPOMI using MAX-DOAS and direct-sun network observations with focus on dilution effects

Gaia Pinardi, Michel Van Roozendael, François Hendrick, Nicolas Theys, Steven Compernolle, Jean-Christopher Lambert, Pieter Valks, Song Liu, Folkert Boersma, Henk Eskes and NIDFORVAL NO_2 team

GOME-2 and OMI study: paper in discussion on AMTD: https://www.atmos-meas-tech-discuss.net/amt-2020-76/

1. SATELLITE DATA

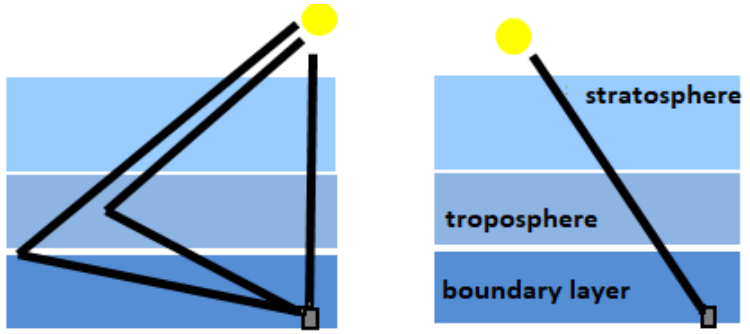
OMI and GOME-2 NO_2 data

$$VCDtropo = \frac{(SCD - AMFstrato * VCD\ strato)}{AMFtropo}$$

DOMINO v2.0: Boersma et al. 2011
QA4ECV v1.1: Boersma et al. 2018
GOME-2 GDP 4.8: Valks et al. 2011

Similar approach but different stratospheric correction, a-priori profile choices, cloud algorithms, …

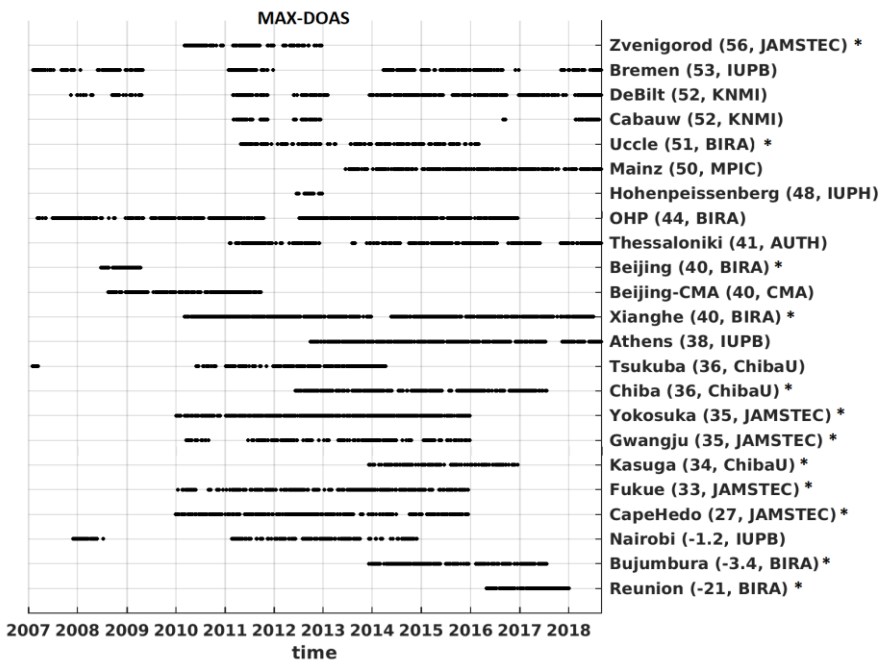
2. GROUND-BASED DATA

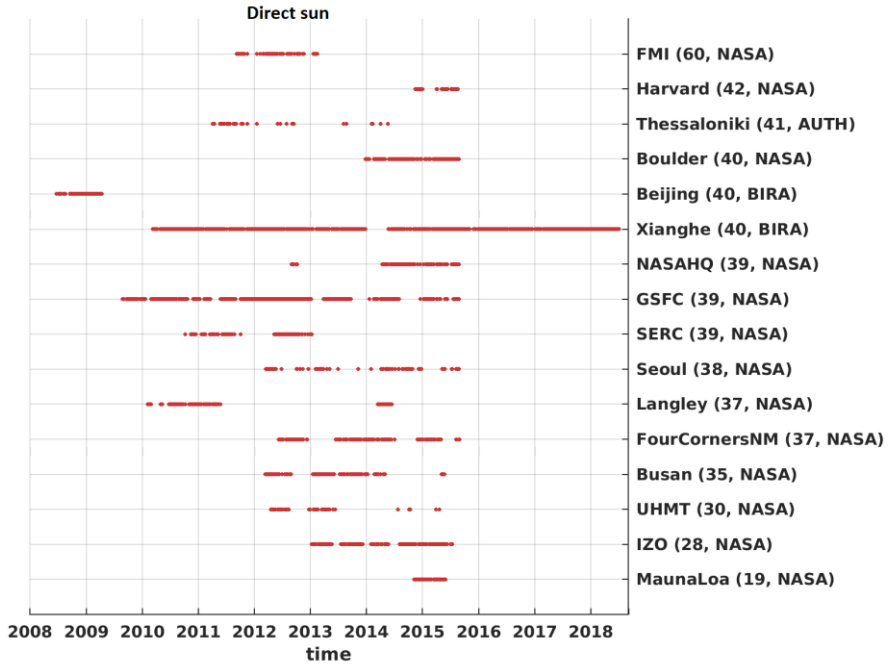


Estimate tropopsheric content from direct sun measurements:

$$VCDtropo(DS) = VCDtot(DS) - VCDstrato(SAT)$$

23 MAX-DOAS and 16 direct sun stations





Several retrieval methods exists: geometrical approximation, Optimal Estimation and parametrized profiling – focus on VCDtropo

Mostly Pandora instruments

Pinardi et al., 2020, AMTD

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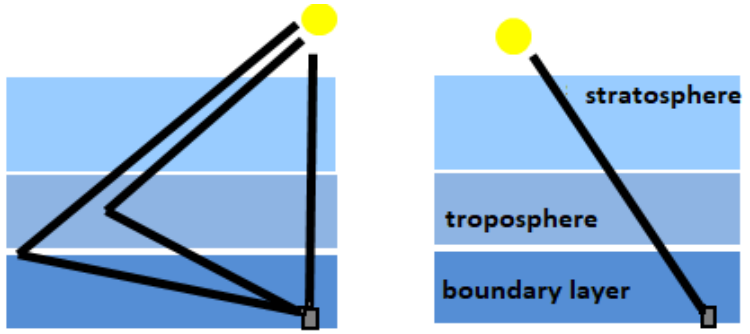

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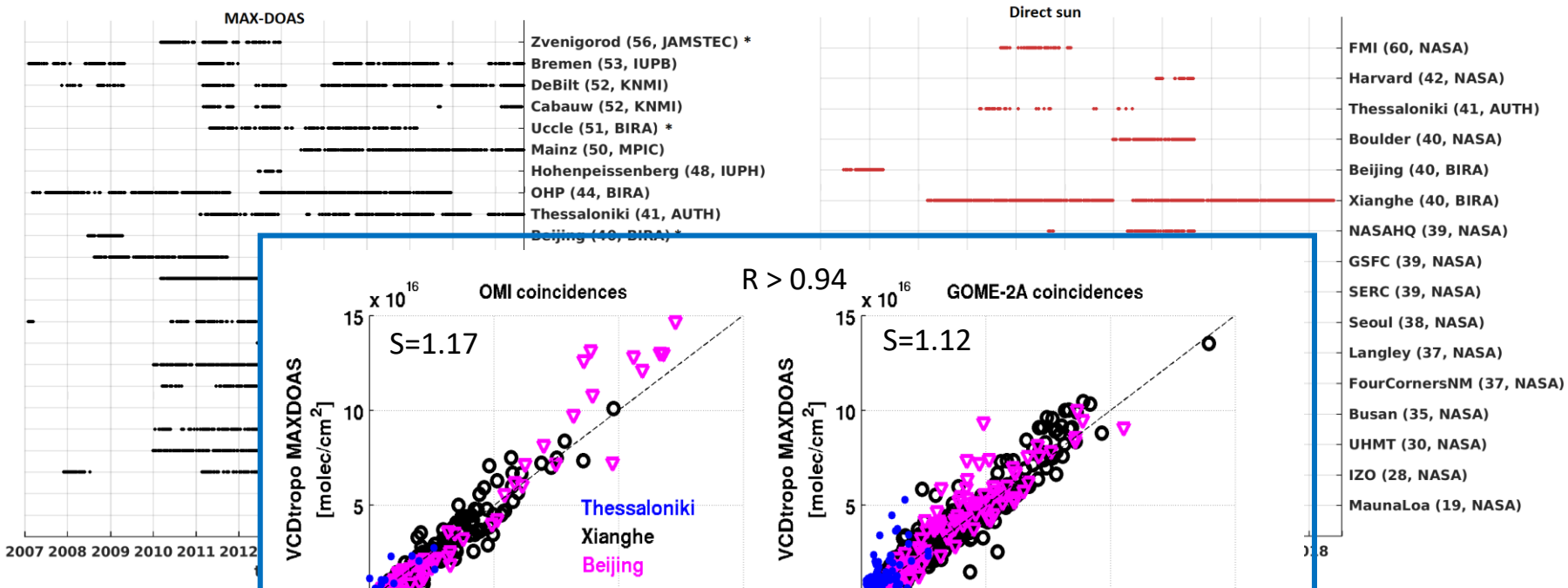

Several retrieval methods e
Optimal Estimation and par

MAX-DOAS and direct sun coherence at 3 common stations: small bias 10-15%

Pinardi et al., 2020, AMTD

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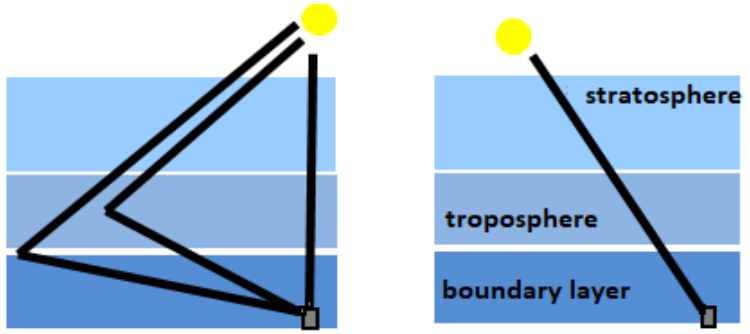

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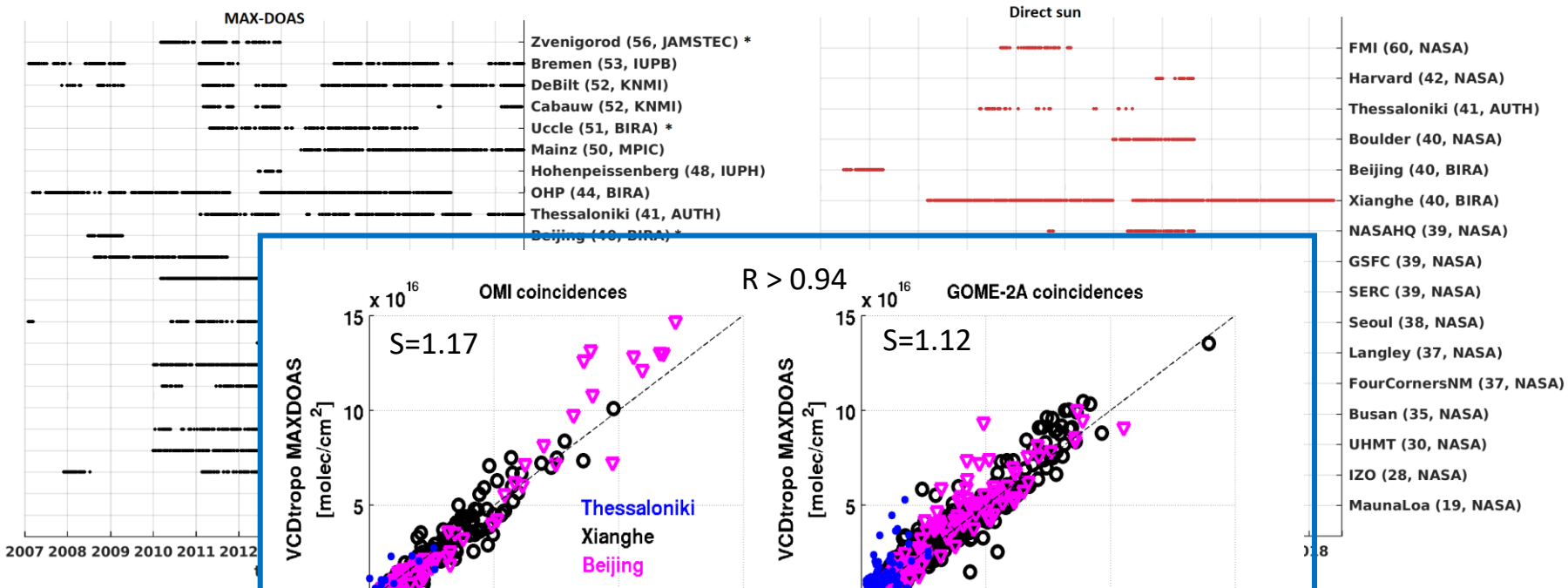

3. COMPARISON METHOD

- Extraction of satellite data 50 km around the 36 stations for CRF<50%, smaller pixels and AMFtropo/AMFgeom > 0.2
- Closest and mean of pixels per day
- Test with pixels over station

- Interpolate GB at SAT overpass time or average around 1h

Several retrieval methods e
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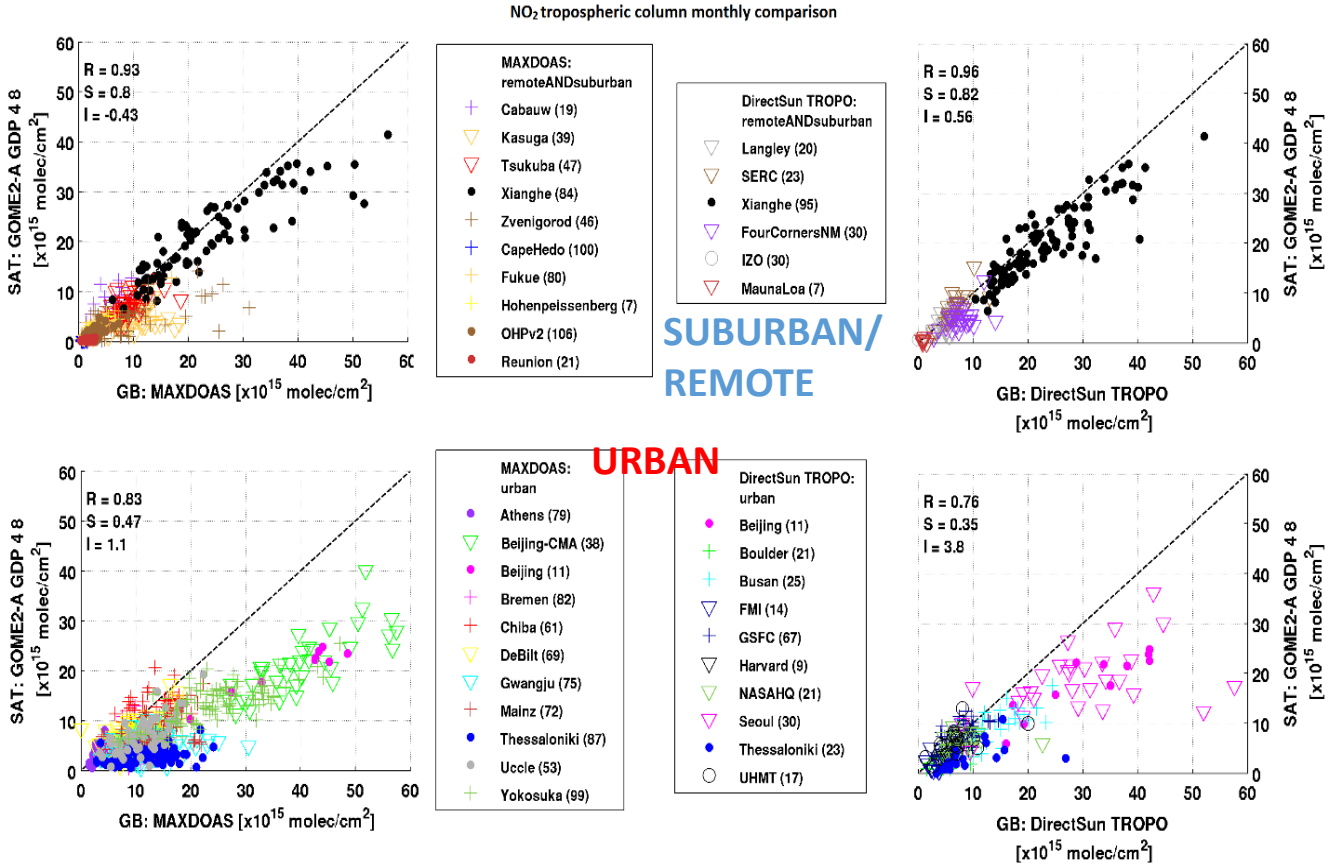
Pinardi et al., 2020, AMTD

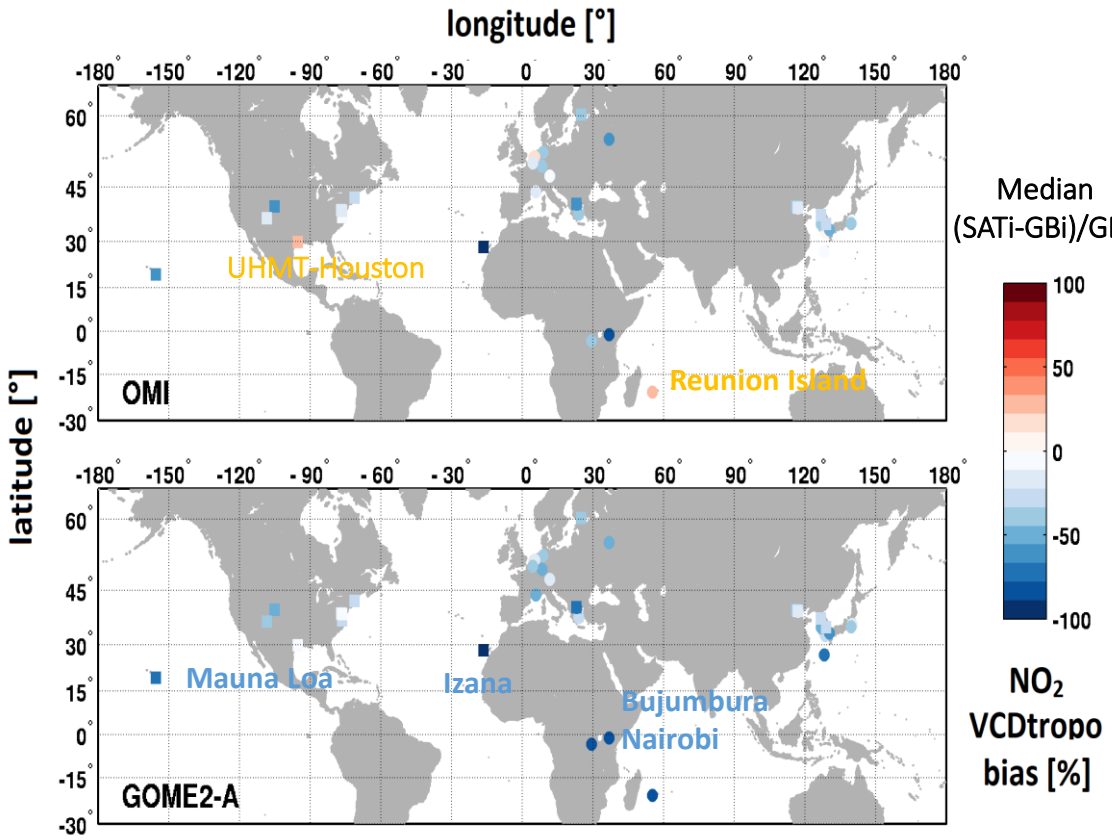
RESULTS

GOME-2A GDP 4.8



smaller slopes and larger biases are found at urban locations compared to background/sub-urban ones

Similar nagative results for OMI DOMINO and GOME-2A GDP, only few exceptions:



Similar picture for OMI and GOME2 (10 out of 16 direct sun and 10 out of 23 MAX-DOAS sites have differences in validation bias < 15%)

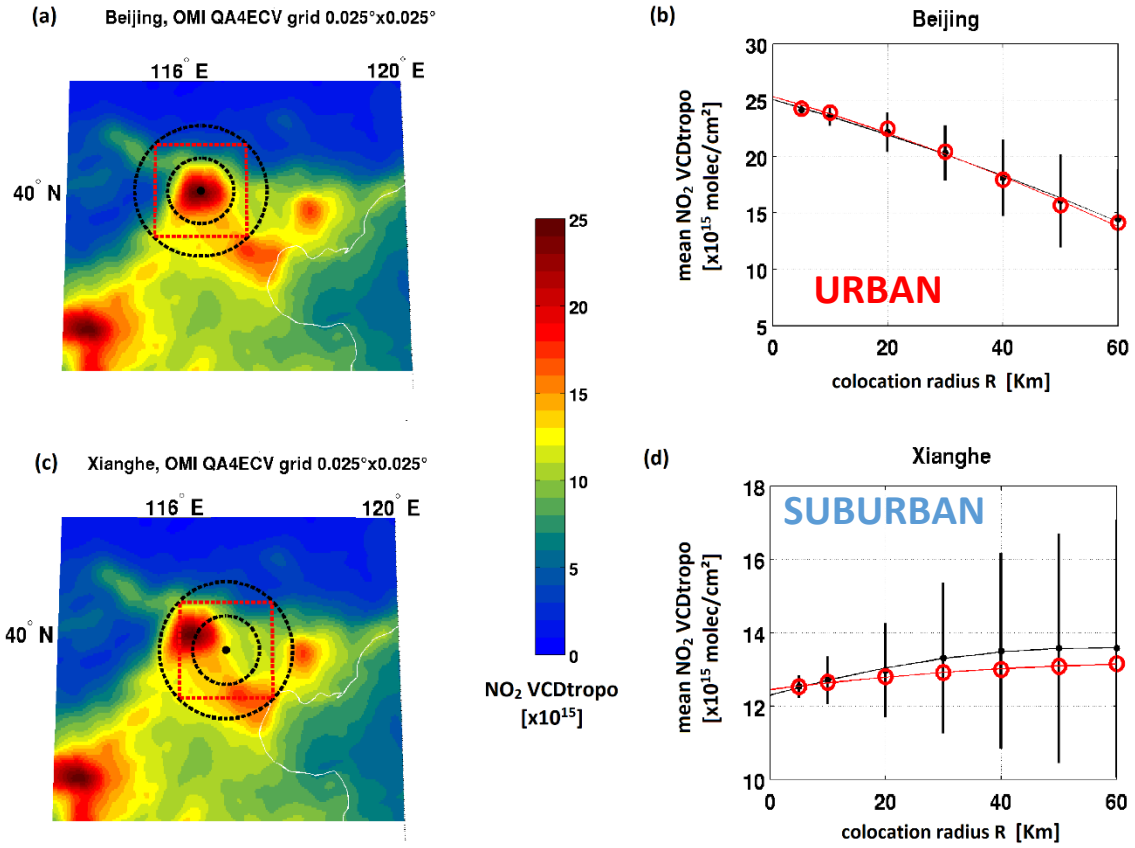
Pinardi et al., 2020, AMTD

UNDERSTANDING THE RESULTS

exploration of the horizontal smoothing effect due to the pixels selection: dilution effect

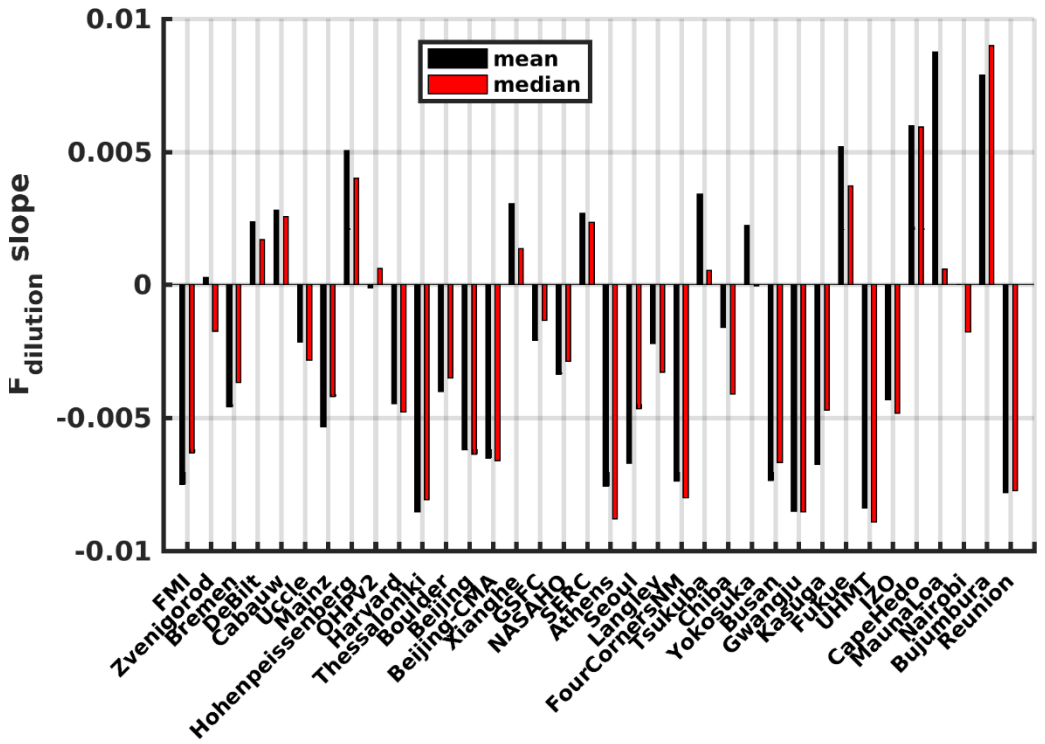
investigate the horizontal variability of the NO_2 field at the 36 different stations: using one full year (2005) of OMI NO_2 QA4ECV dataset v1.1 (Boersma et al., 2018), to map the average NO_2 column distribution at a grid of 0.025°x0.025° (only using the smallest OMI pixels, rows 11 to 49)

variation of the tropospheric NO_2 VCD sampled in concentric circles of different radii around each of the stations:



Estimate the dilution factor:

$$F_{dil}(\mathrm{R}) = NO2\_VCD(R)/NO2\_VCD(0)$$



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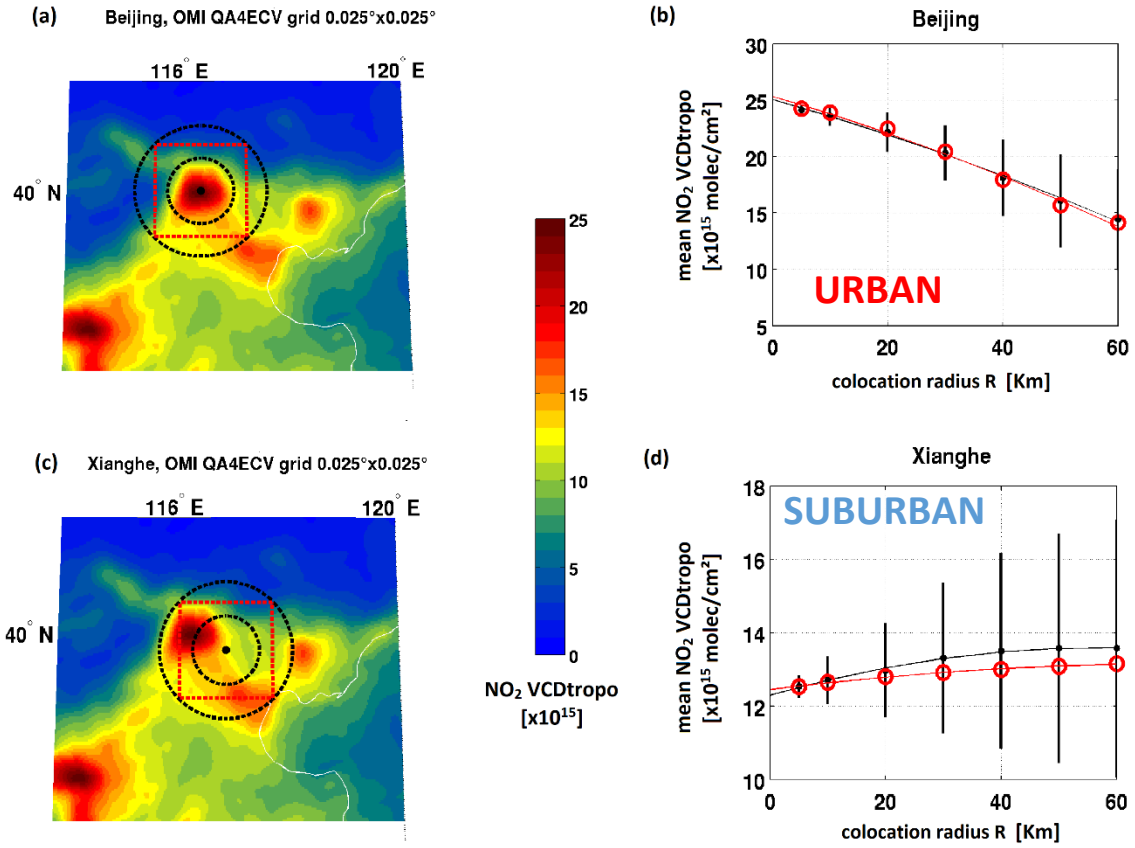


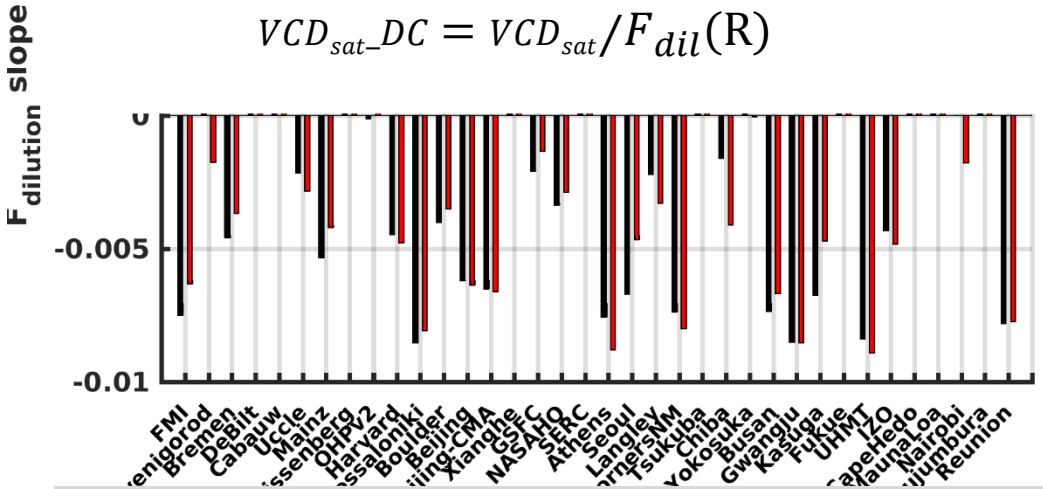
Pinardi et al., 2020, AMTD

Estimate the dilution factor:

$$F_{dil}(\mathrm{R}) = NO2\_VCD(R)/NO2\_VCD(0)$$

Use it to correct the satellite data, for site where this factor is negative:

$$VCD_{sat}\_DC = VCD_{sat}/F_{dil}(\mathrm{R})$$

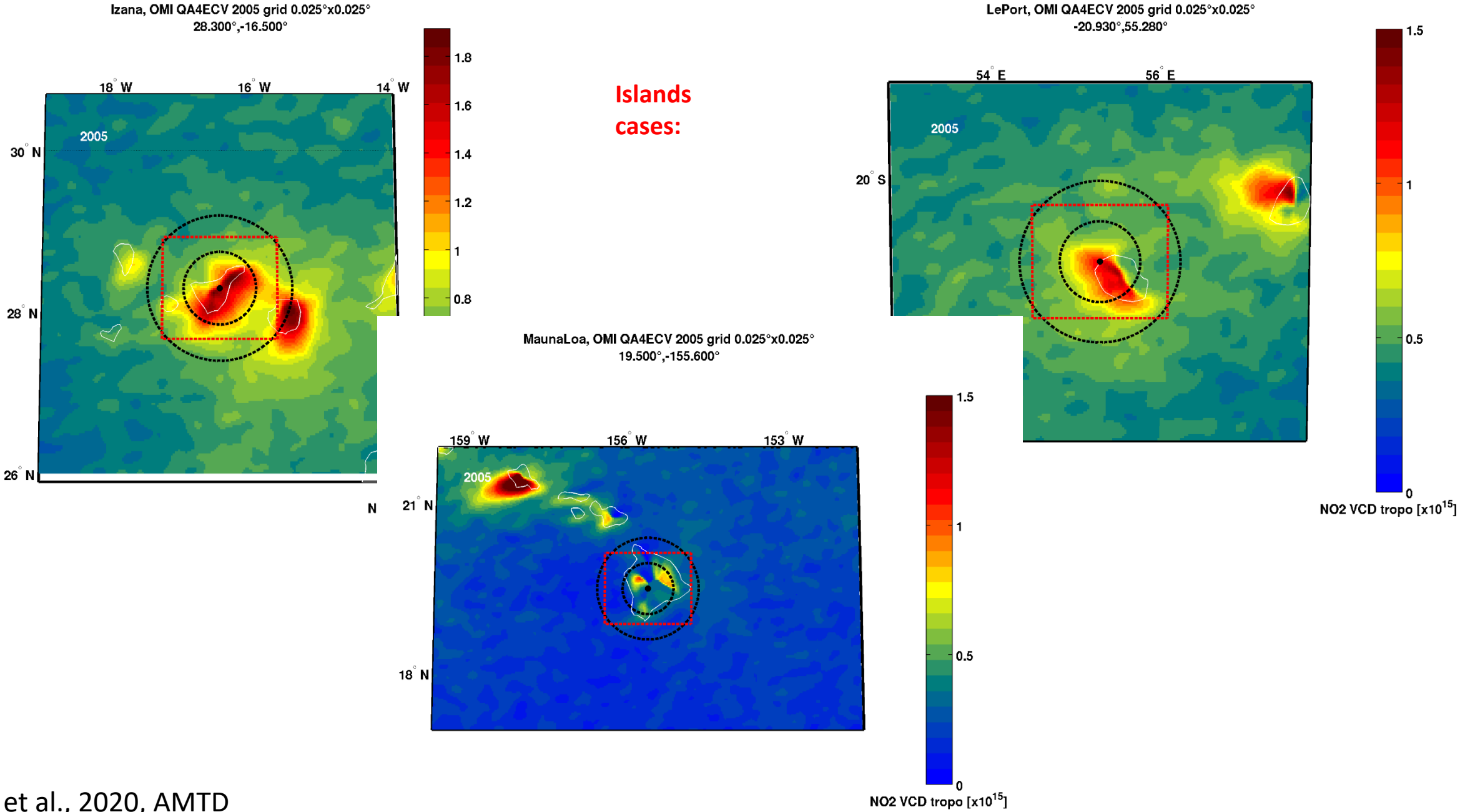


Typically, applied to large urban sites, stations isolated on small islands or stations close to a large power plant (→ UIPP) - sites characterized by a NO_2 hotspot surrounded by a clean area

UNDERSTANDING THE RESULTS

exploration of the horizontal smoothing effect due to the pixels selection: dilution effect

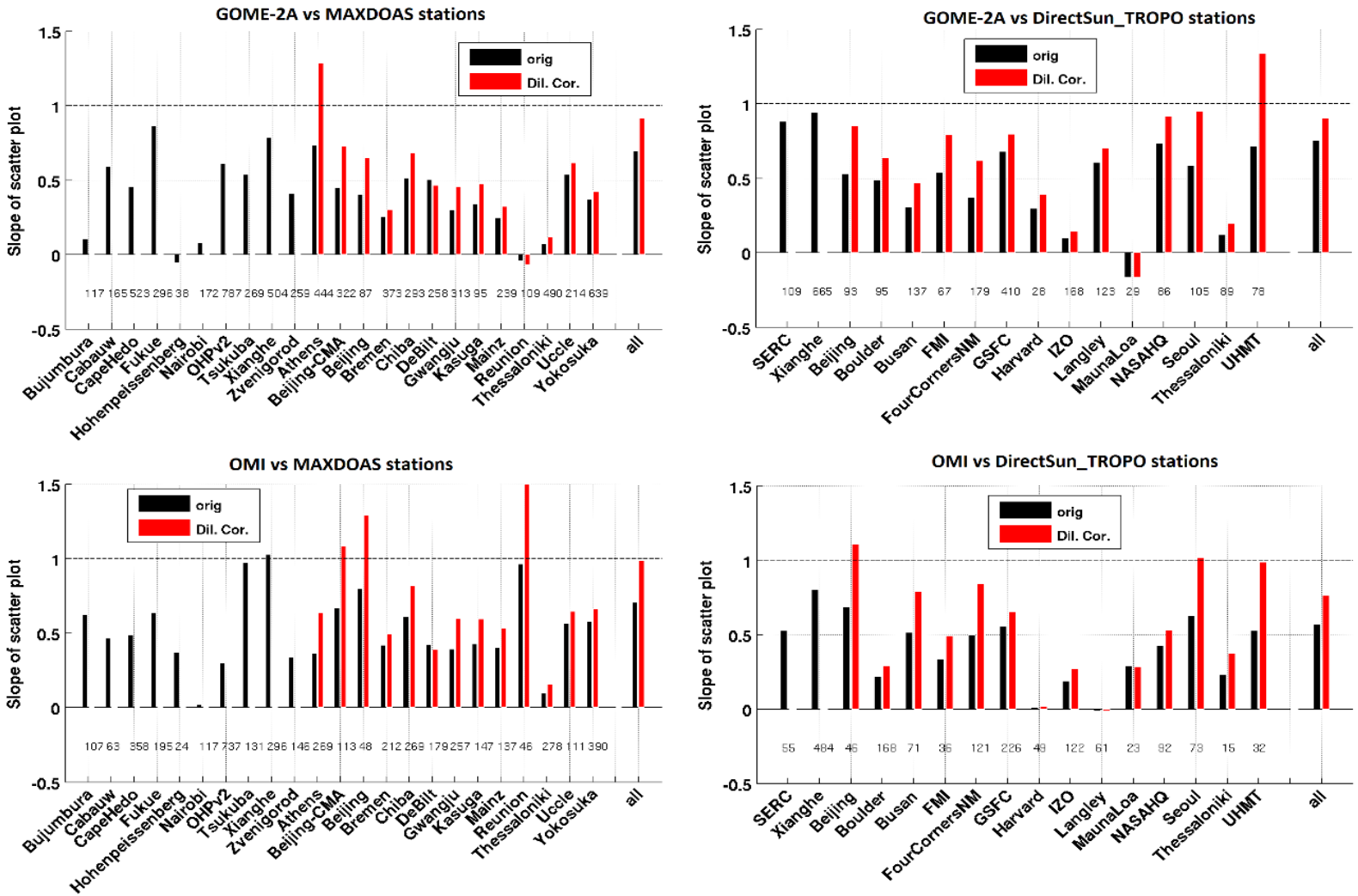
Islands cases:



Pinardi et al., 2020, AMTD

RESULTS USING THE DILUTION CORRECTION

Impact on daily per-station scatter plots: slopes of the linear regressions:



Generally slopes closer to 1 with Dilution Correction, but some negatives (stratospheric correction for DS?), and over-estimation for a few sites (for some sattellite data).
Some sites: very small slopes (very local GB signal: Nairobi, Thessaloniki, Harvard)

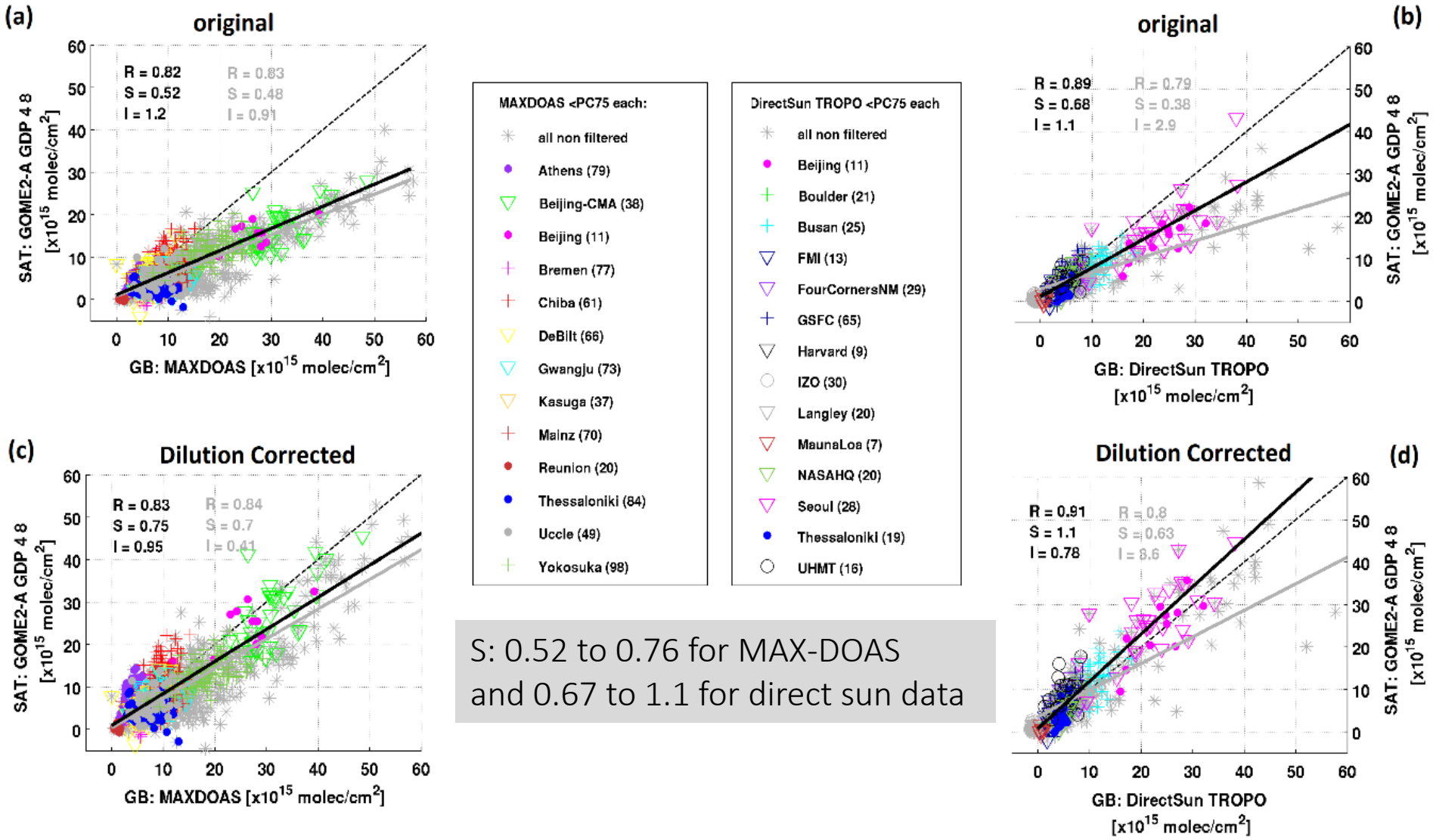
Filter of daily comparison points (removing values larger than the 75th percentile of GB values of each station) to excludes large local values that cannot be captured by satellite measurements → allows for a more robust statistical regression analysis

Pinardi et al., 2020, AMTD

RESULTS USING THE DILUTION CORRECTION

Impact on monthly-mean overview scatter plots at UIPP sites with/without correction:

+ impact of percentile 75 filtering (grey to black regression lines)



S: 0.52 to 0.76 for MAX-DOAS and 0.67 to 1.1 for direct sun data

direct sun data are more affected by the filtering (S from 0.38 to 0.67) than MAX-DOAS ones (S: 0.49 to 0.52). → likely related to sampling of sites. Pandoras tend to be located closer to strong NO_2 emission sources than MAX-DOAS instruments

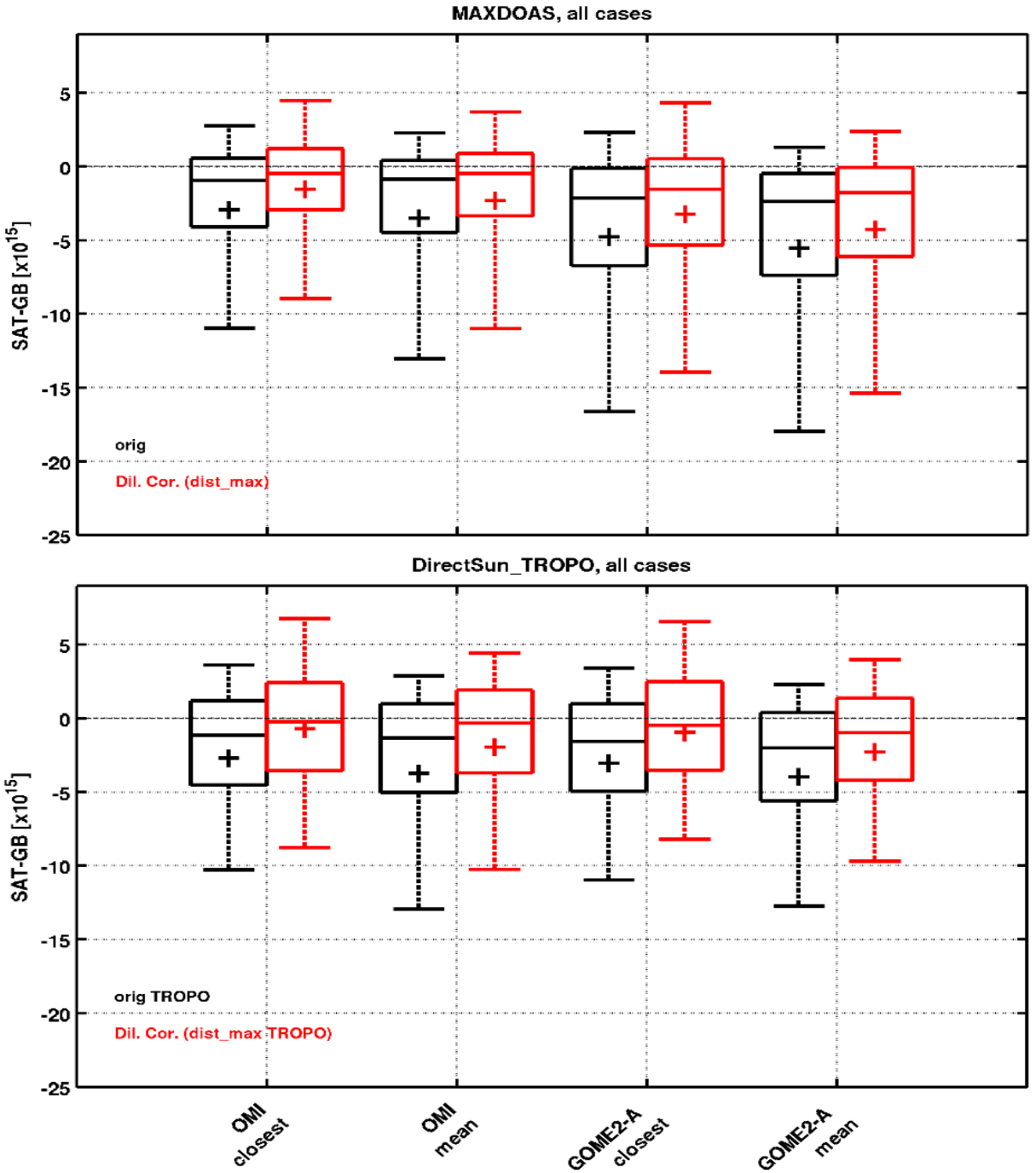
Pinardi et al., 2020, AMTD

RESULTS USING THE DILUTION CORRECTION

Impact on biases at all sites with/without correction:

For different selections of satellite pixels: closest cloud free pixel per day, or daily average within 50km

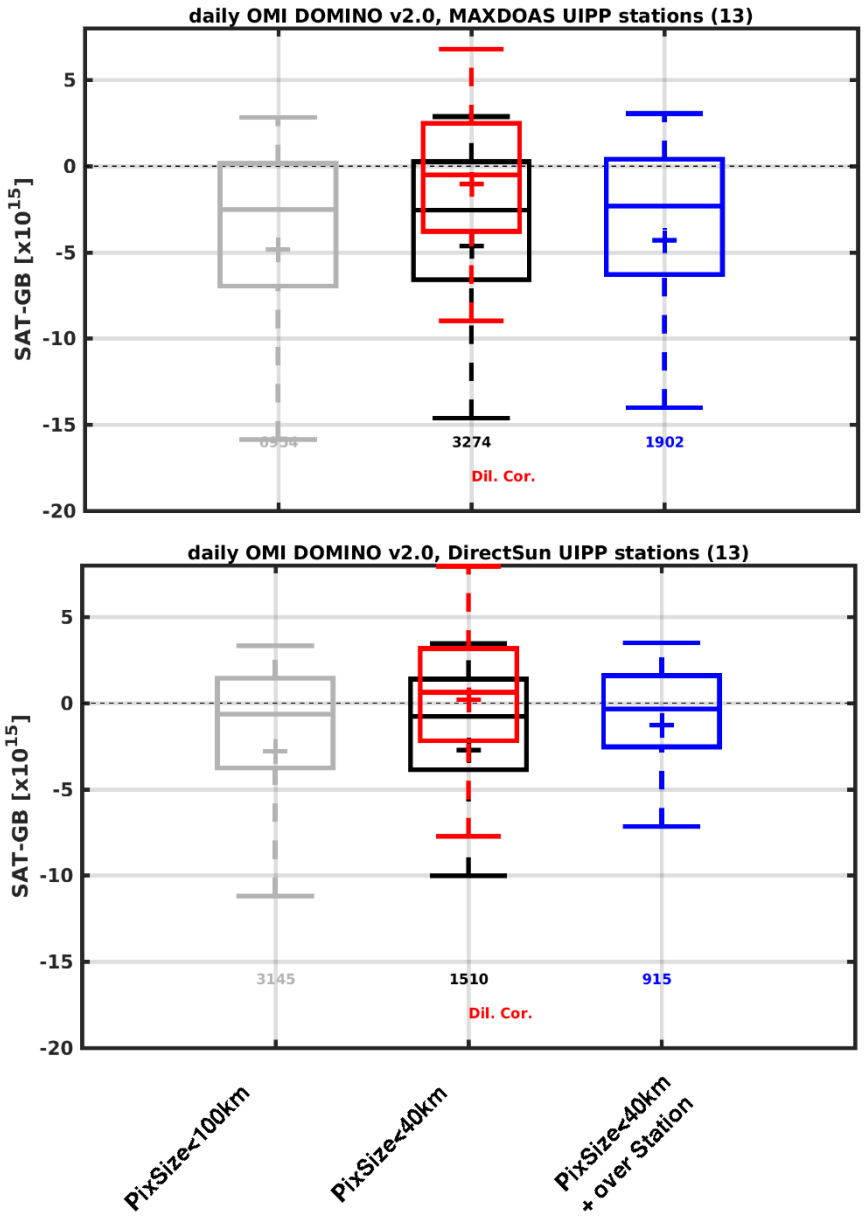
- overall agreement better for OMI comparisons
- after dilution correction, slightly better for direct sun than for MAX-DOAS sites (cf site sampling)
- Larger spread in MAX-DOAS comparisons (measurements made under more variables conditions, e.g. cloudy conditions)
- Best agreement: daily closest OMI vs direct sun (median bias -1.16 x10^{15} to -0.23 x10^{15} molec/cm² with DC). For the MAX-DOAS comparisons: -0.95 to -0.47 x10^{15} molec/cm²



Pinardi et al., 2020, AMTD

IMPACT OF SATELLITE PIXEL SELECTION

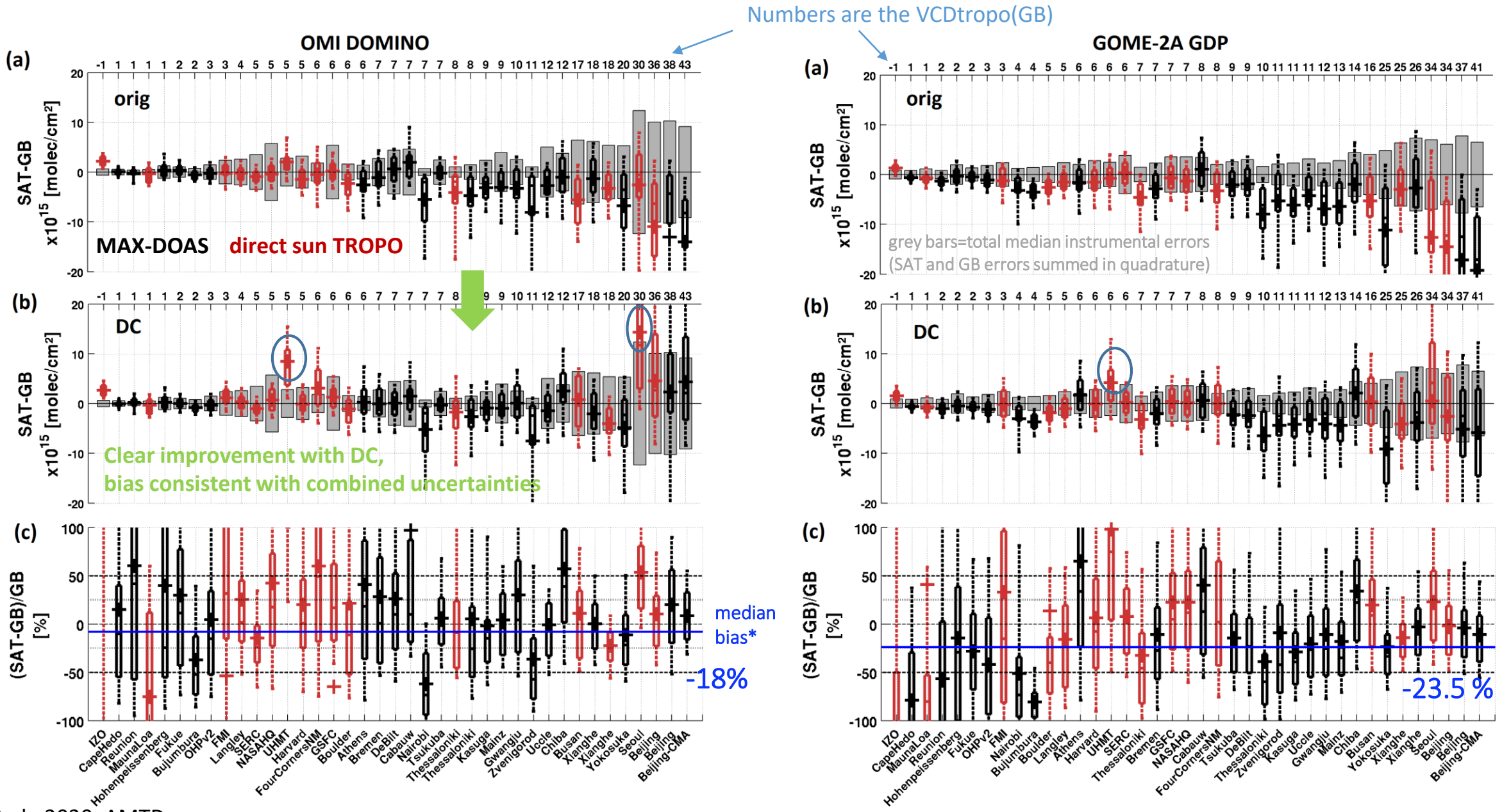
Alternative approach of selection restricted to OMI pixels covering the stations:



- restricting the comparison to small pixel sizes (from 100 to 40 km) slightly improves median bias, but reduces the comparison spread
- pixels in strict overpass with the stations: bias is reduced, but for the MAX-DOAS ensemble, not as much as when a horizontal dilution correction is applied.

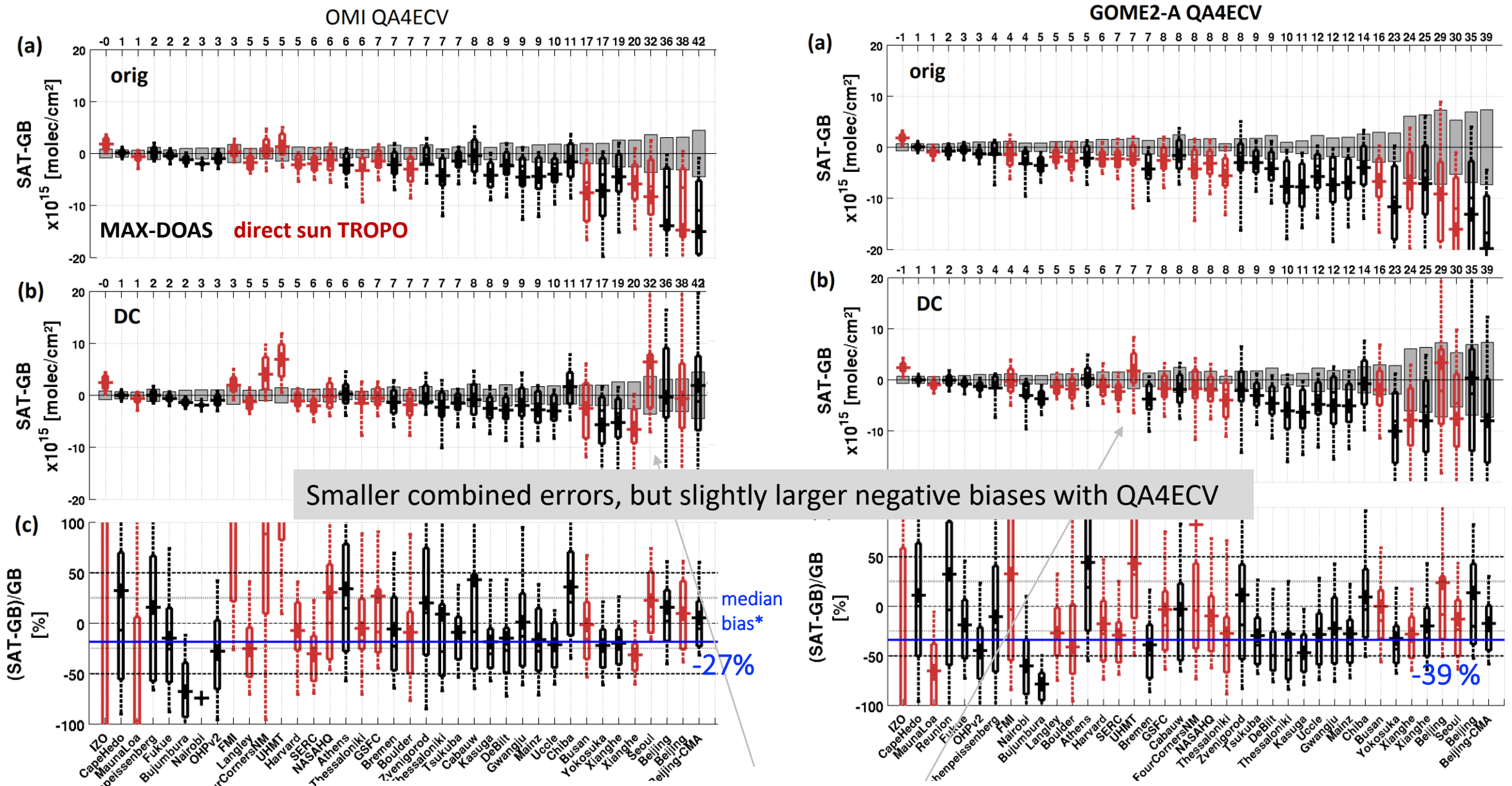
Pinardi et al., 2020, AMTD

OVERALL RESULTS: Merge MAX-DOAS and direct-sun results



Pinardi et al., 2020, AMTD * for GB VCDtropo >2e15 molec/cm²

OVERALL RESULTS: Merge MAX-DOAS and direct-sun results and compare to QA4ECV NO2 products



Pinardi et al., 2020, AMTD

grey bars=total median comparison errors (SAT and GB errors summed in quadrature)

OVERALL RESULTS: Merge MAX-DOAS and direct-sun results

- The **dilution correction** improves the validation results for both sensors, by **about 10 to 13% in total** over the station ensemble
- Only **pixels over the stations** is to reduce the bias by **2 to 6% for OMI**, but negligible effect on GOME-2A, probably due to the large size of the GOME-2A pixels (40x80 km²)

	Original baseline	Original over stations	DC baseline	DC over stations	
OMI DOMINO	-2 x10^{15} [-30 %]	-1.7 x10^{15} [-24 %]	-1.2 x10^{15} [-18 %]	-0.8 x10^{15} [-10.6 %]	-11% to -22%
OMI QA4ECV	-2.5 x10^{15} [-38 %]	-2.2x10^{15} [-34.4%]	-1.8 x10^{15} [-27 %]	-1.4 x10^{15} [-21.5%]	
GOME-2A GDP	-2.9 x10^{15} [-36 %]	-2.8 x10^{15} [-34.2 %]	-2 x10^{15} [-23.5 %]	-1.9 x10^{15} [-21.6 %]	-22% to -36%
GOME-2A QA4ECV	-3.7 x10^{15} [-48 %]	-3.7 x10^{15} [-45.6%]	-2.9 x10^{15} [-39 %]	-2.9 x10^{15} [-36.5%]	

Pinardi et al., 2020, AMTD

CONCLUSIONS:

Pinardi et al., 2020, AMTD: Tropospheric NO2 from 39 stations (MAX-DOAS + direct sun) used to validate OMI and GOME-2A data from several products:

- Despite the lack of network harmonization settings, there is a clear capacity of the instruments to perform as a network (sampling of different NO_2 levels and scenarios)
  → Harmonization ongoin within NDACC/FRM4DOAS/PGN
- Challenging situations in urban environment : smoothing difference errors due to the horizontal dilution of the measured NO_2 field → proposal of quantitative characterization and dilution correction
  →Simplified method but reduction of the horizontal comparison smoothing error
- Dilution correction generally reduces the comparison bias (10 to 13% impact in total) and spread (with a few exceptions)
- Pixels over the station: better agreement for OMI (2 to 6%), negligible for GOME-2
- Final validation results: remaining significant bias for the 4 products.
  → OMI DOMINO v1.2 (-11%), OMI QA4ECV (-22%), GOME-2 GDP 4.8 (-22%), GOME-2 QA4ECV (-36%)

PANDONIA GLOBAL NETWORK
Reference Measurements of Atmospheric Composition

Fiducial Reference Measurements for Ground-Based DOAS Air-Quality Observations
FRM4DOAS

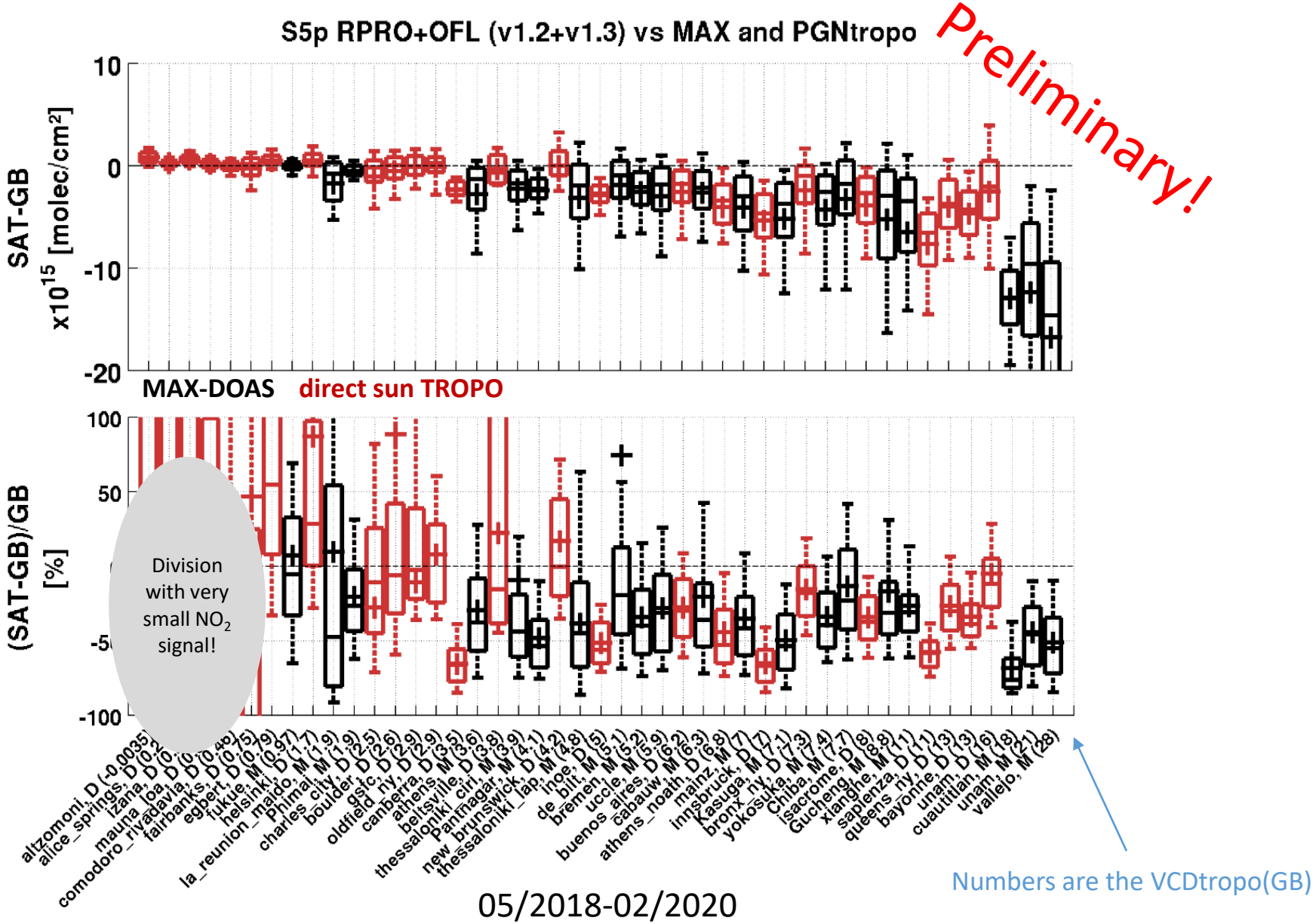
EXTENSION OF THE STUDY TO TROPOMI:

Extention of the comparison study (without the dilution correction) to TROPOMI tropopsheric NO_2 validation with MAX-DOAS data from the NIDFORVAL project and Pandora data from PGN (https://www.pandonia-global-network.org/):

Extension of the study of Verhoelst et al., submitted to AMTD.

Ongoing study…

Rk: only a few stations are the same than Pinardi et al AMTD analysis, and comparison time periods are different !!



More on TROPOMI NO_2 validation results:

- http://mpc-vdaf-server.tropomi.eu/no2/
- https://nikal.eventsair.com/QuickEventWebsitePortal/sentinel-5-precursor-workshop-2019/sentinel-5p/ExtraContent/ContentPage?page=5