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EGU

Supplement of

An improved TROPOMI tropospheric NO_2 research product over Europe

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S1. Validation of POLYPHEMUS/DLR NO_2 concentrations

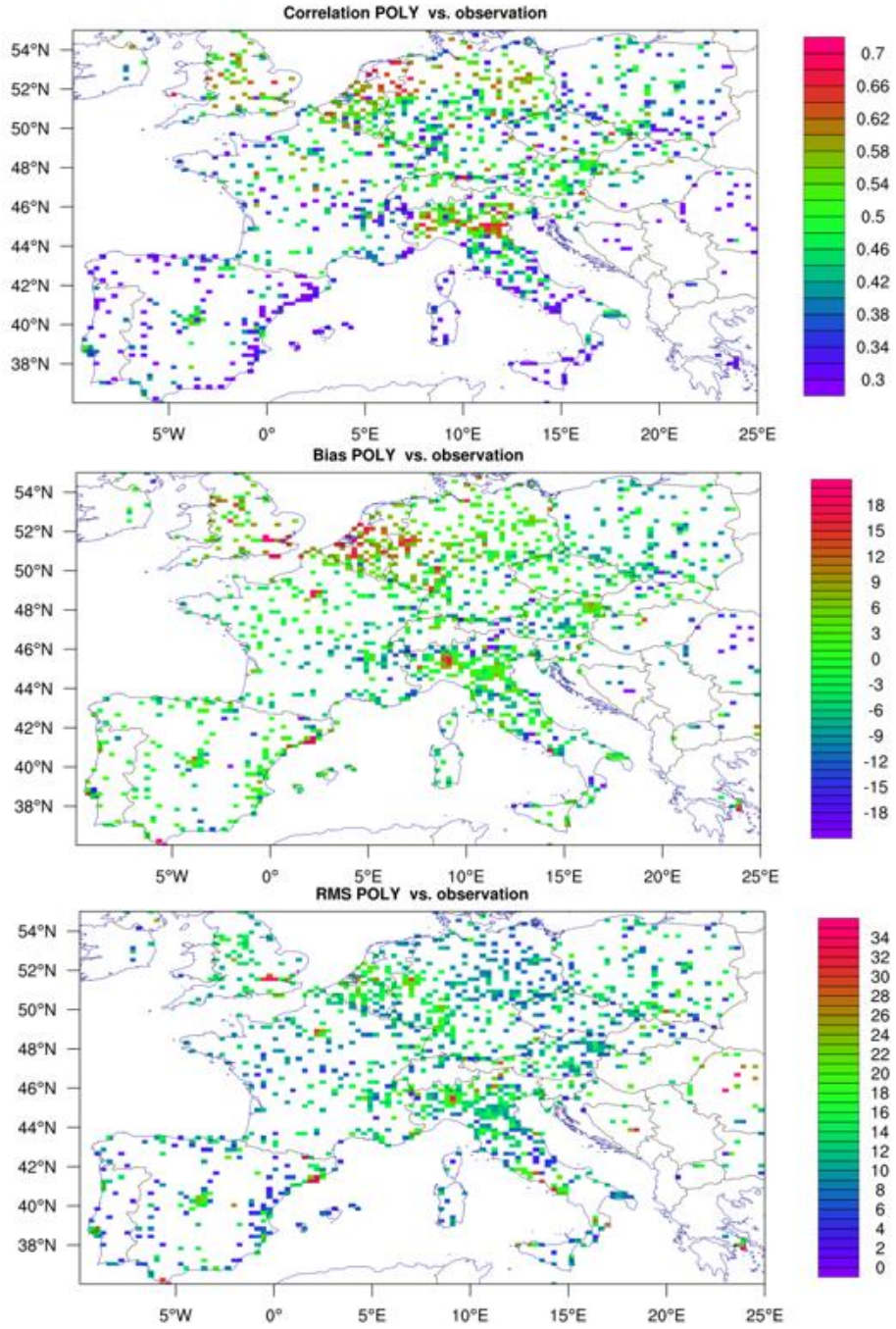


Figure S1. Comparisons of near-surface NO_2 concentrations [uq/m^3] from POLYPHEMUS/DLR simulations and ground-based air quality monitoring stations (POLYPHEMUS/DLR results – ground-based observations) for Europe in 2018.

Figure S1 compares the near-surface NO_2 concentrations from POLYPHEMUS/DLR and ground-based EEA air quality monitoring stations (https://discomap.eea.europa.eu/map/fme/AirQualityExport.htm). The correlation coefficients are generally higher than 0.6 for polluted hot spots, and the biases are generally lower than 20 uq/m^3 or 38%.

S2. Comparison of POLYPHEMUS/DLR data and the regional LOTOS-EUROS profiles

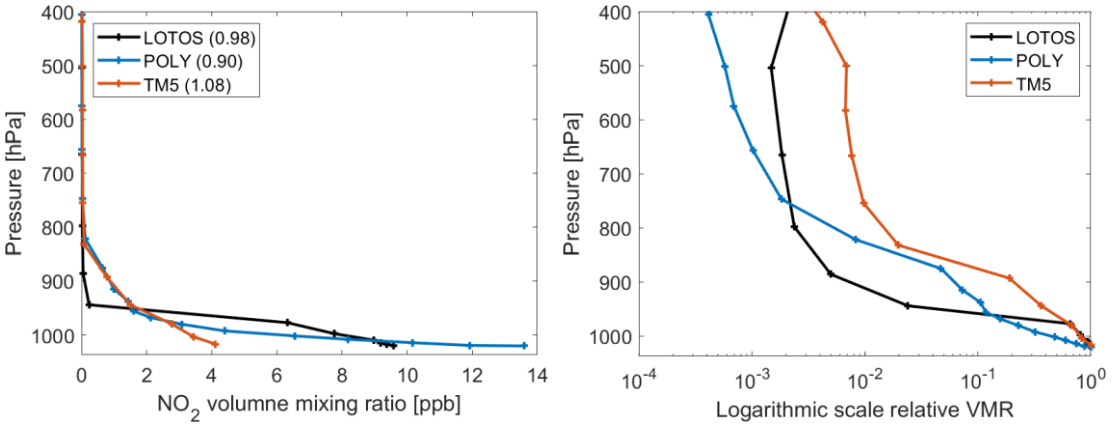


Figure S2. A priori NO_2 profiles from the chemistry transport models LOTOS-EUROS, POLYPHEMUS/DLR, and TM5-MP over Hamburg in Germany (53.55°N, 9.99°E) on 1 February 2019. The calculated clear-sky tropospheric AMF is given in the bracket next to each label in the legend. Normalized profiles (to the lowest values) are also shown on a logarithm scale.

Figure S2 compares the a priori NO_2 profiles from LOTOS-EUROS, POLYPHEMUS/DLR, and TM5-MP over Hamburg. POLYPHEMUS/DLR shows the largest surface layer NO_2 concentration (left panel) and the steepest profile shape (right panel), which yields the smallest tropospheric AMF. LOTOS-EUROS shows lower free tropospheric concentration and larger surface concentration than TM5-MP, and thus the tropospheric AMF is lower by 9%.

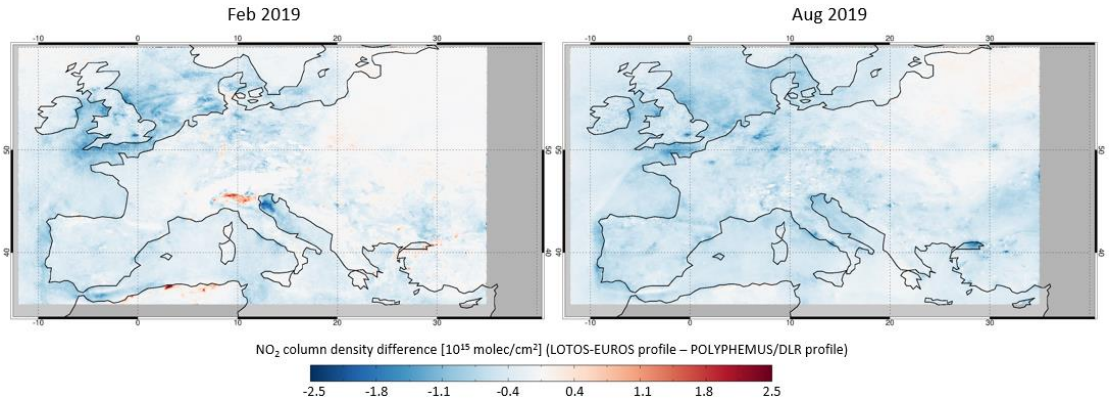
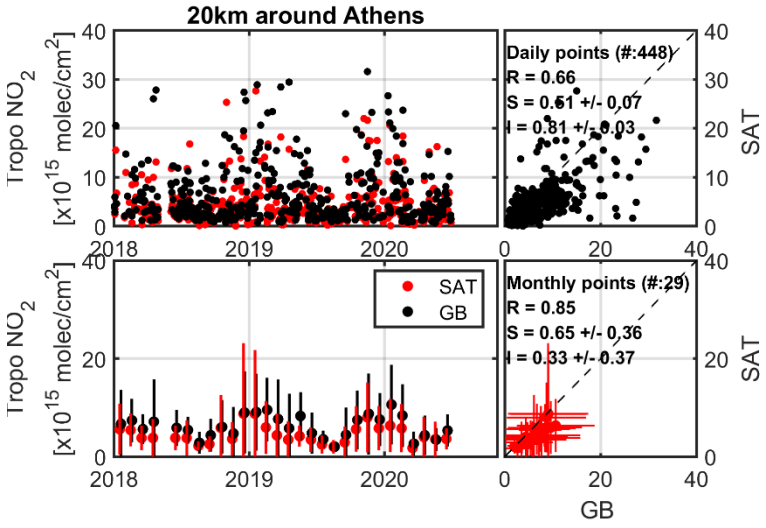
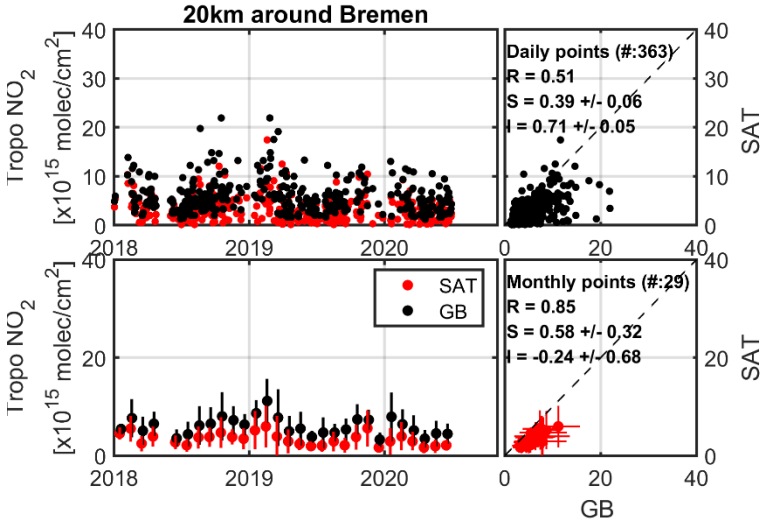


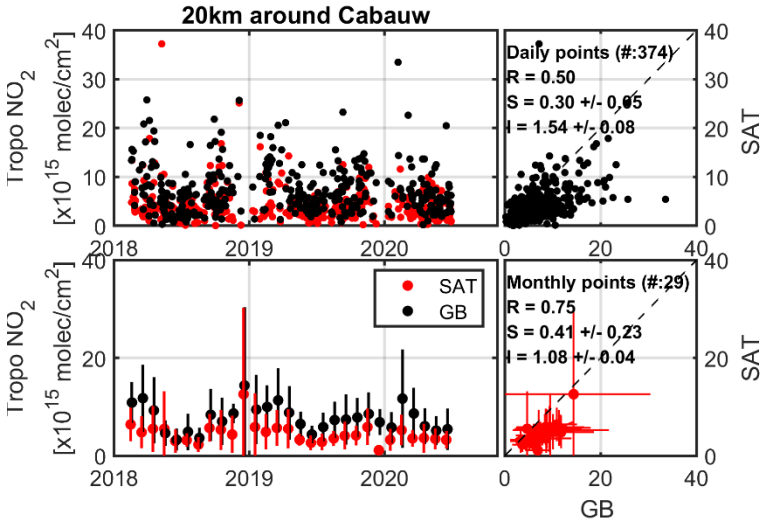
Figure S3. Differences in the tropospheric NO_2 columns retrieved using the POLYPHEMUS/DLR and LOTOS-EUROS a priori NO_2 profiles over Europe in February and August 2019.

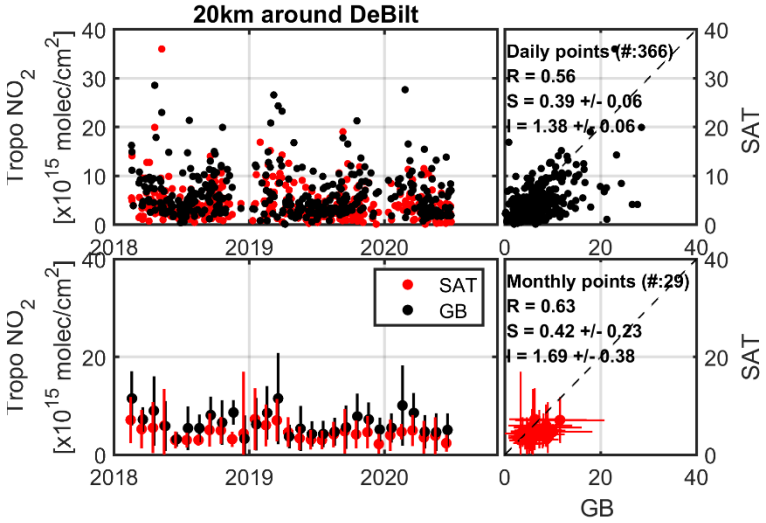
Figure S3 compares the tropospheric NO_2 columns retrieved using POLYPHEMUS/DLR and LOTOS-EUROS a priori NO_2 profiles, where the use of LOTOS-EUROS reduces the tropospheric NO_2 columns by up to ~1×10^{15} molec/cm^2, e.g. over the ocean partly due to difference in the shipping emissions.

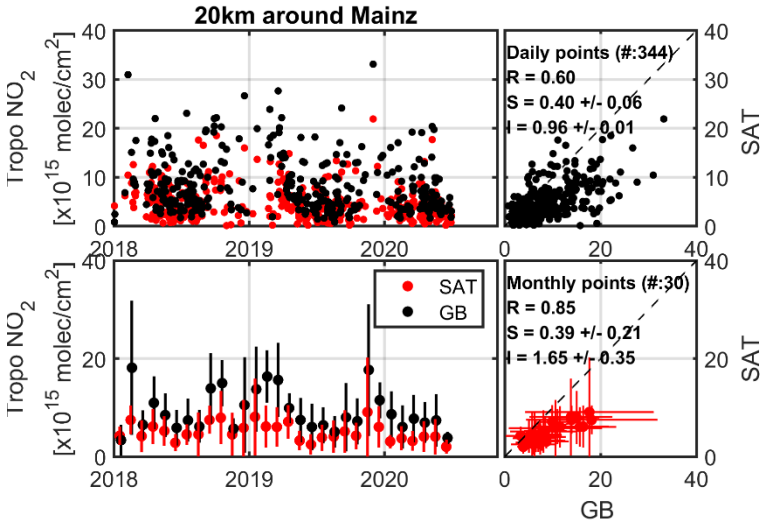
S3. Validation for different MAX-DOAS stations

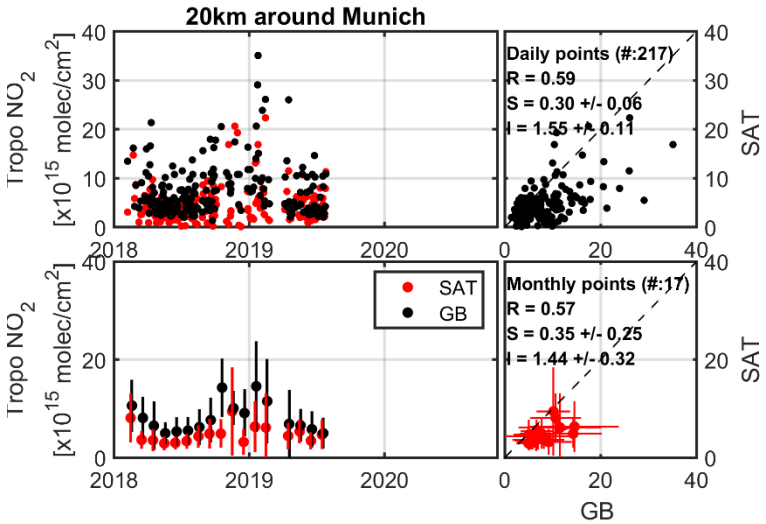







20km around DeBilt
Tropo NO2 [x10^15 molec/cm^2]
Daily points (#:366)
R = 0.56
S = 0.39 +/- 0.06
I = 1.38 +/- 0.06
SAT
Monthly points (#:29)
R = 0.63
S = 0.42 +/- 0.23
I = 1.69 +/- 0.38
GB


20km around Mainz
Tropo NO2 [x10^15 molec/cm^2]
Daily points (#:344)
R = 0.60
S = 0.40 +/- 0.06
I = 0.96 +/- 0.01
SAT
Monthly points (#:30)
R = 0.85
S = 0.39 +/- 0.21
I = 1.65 +/- 0.35
GB


20km around Munich
Tropo NO2 [x10^15 molec/cm^2]
Daily points (#:217)
R = 0.59
S = 0.30 +/- 0.06
I = 1.55 +/- 0.11
SAT
Monthly points (#:17)
R = 0.57
S = 0.35 +/- 0.25
I = 1.44 +/- 0.32
GB

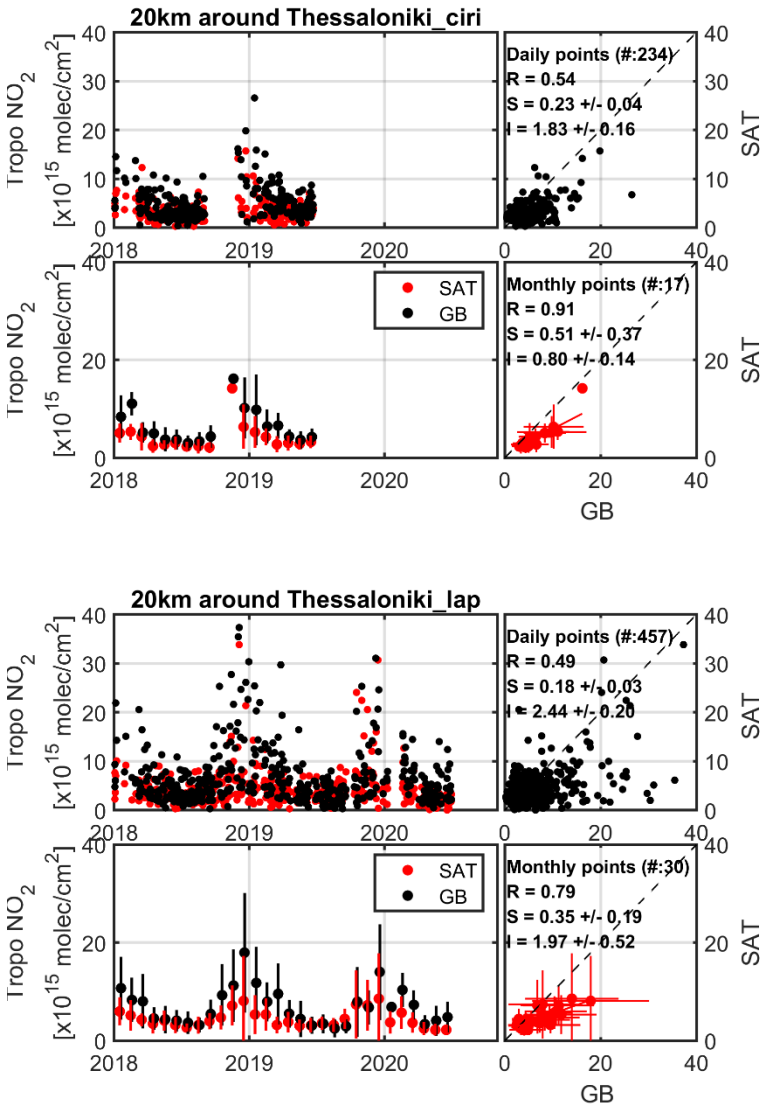
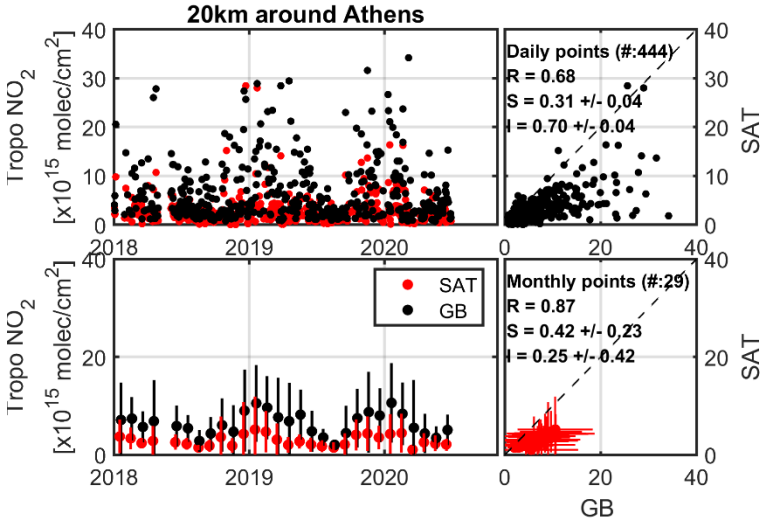
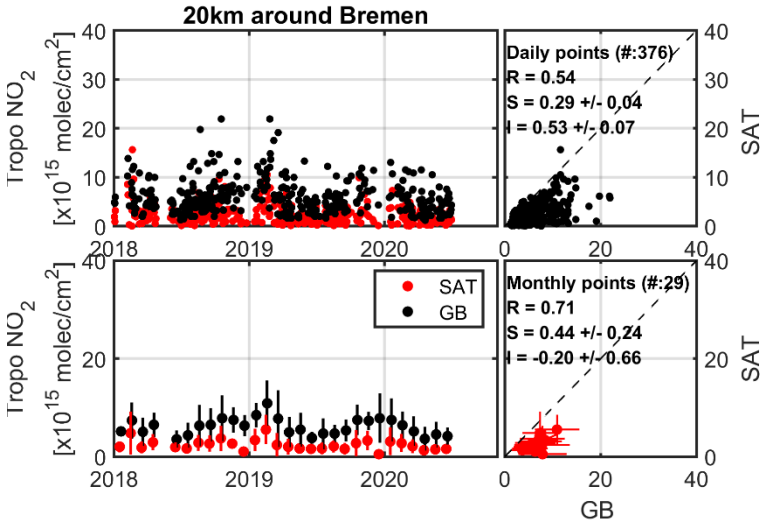
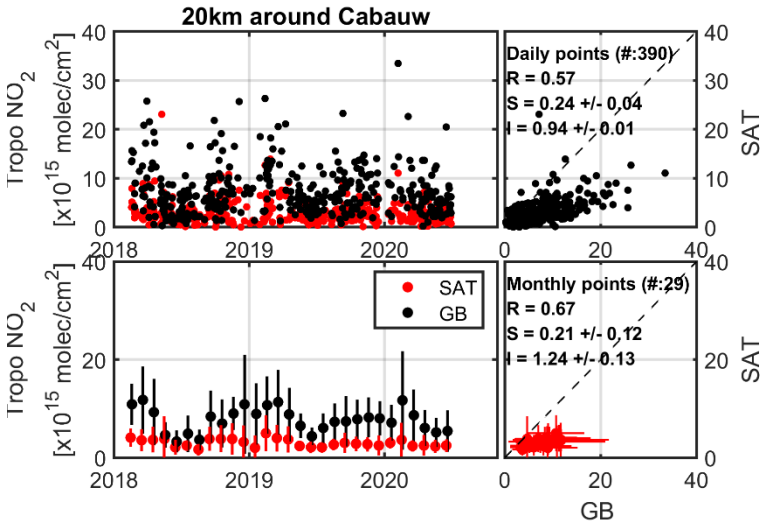
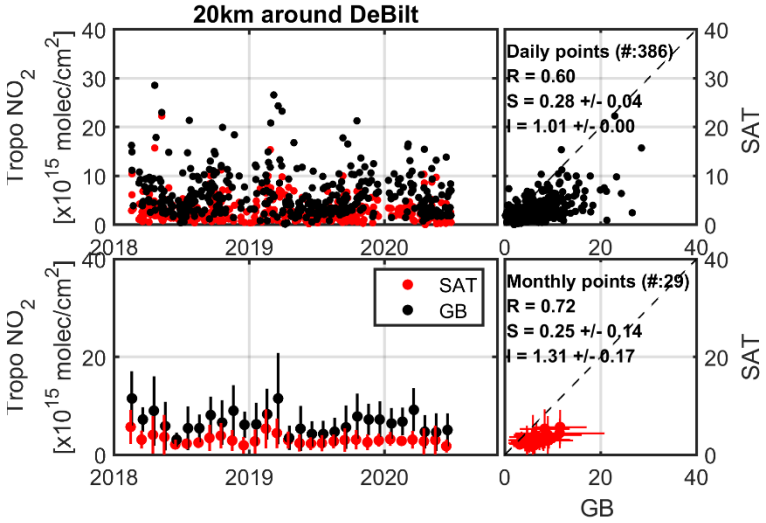


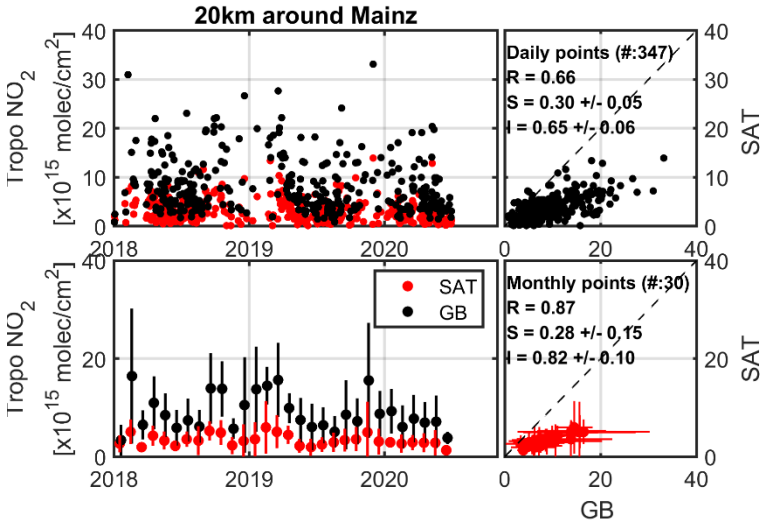
Figure S4. Daily and monthly mean time series and scatter plot of TROPOMI and MAX-DOAS tropospheric NO_2 columns (closest valid pixel within 20 km) over Athens, Bremen, Cabauw, De Bilt, Mainz, Munich, Thessaloniki_ciri, and Thessaloniki_lap. Results are shown for the improved satellite retrieval algorithm.

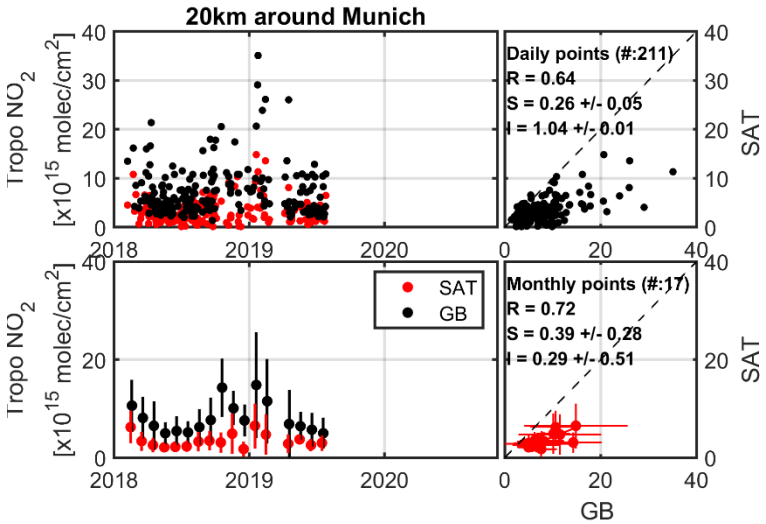

20km around Athens
Tropo NO2 [x10^15 molec/cm^2]
Daily points (#:444)
R = 0.68
S = 0.31 +/- 0.04
I = 0.70 +/- 0.04
SAT
GB
Monthly points (#:29)
R = 0.87
S = 0.42 +/- 0.23
I = 0.25 +/- 0.42
2018
2019
2020


20km around Bremen
Tropo NO2 [x10^15 molec/cm^2]
Daily points (#:376)
R = 0.54
S = 0.29 +/- 0.04
I = 0.53 +/- 0.07
SAT
GB
Monthly points (#:29)
R = 0.71
S = 0.44 +/- 0.24
I = -0.20 +/- 0.66
2018
2019
2020


20km around Cabauw
Tropo NO2 [x10^15 molec/cm^2]
Daily points (#:390)
R = 0.57
S = 0.24 +/- 0.04
I = 0.94 +/- 0.01
SAT
GB
Monthly points (#:29)
R = 0.67
S = 0.21 +/- 0.12
I = 1.24 +/- 0.13
2018
2019
2020


20km around DeBilt
Tropo NO2 [x10^15 molec/cm^2]
Daily points (#:386)
R = 0.60
S = 0.28 +/- 0.04
I = 1.01 +/- 0.00
SAT
GB
Monthly points (#:29)
R = 0.72
S = 0.25 +/- 0.14
I = 1.31 +/- 0.17


20km around Mainz
Tropo NO2 [x10^15 molec/cm^2]
Daily points (#:347)
R = 0.66
S = 0.30 +/- 0.05
I = 0.65 +/- 0.06
SAT
GB
Monthly points (#:30)
R = 0.87
S = 0.28 +/- 0.15
I = 0.82 +/- 0.10


20km around Munich
Tropo NO2 [x10^15 molec/cm^2]
Daily points (#:211)
R = 0.64
S = 0.26 +/- 0.05
I = 1.04 +/- 0.01
SAT
GB
Monthly points (#:17)
R = 0.72
S = 0.39 +/- 0.28
I = 0.29 +/- 0.51

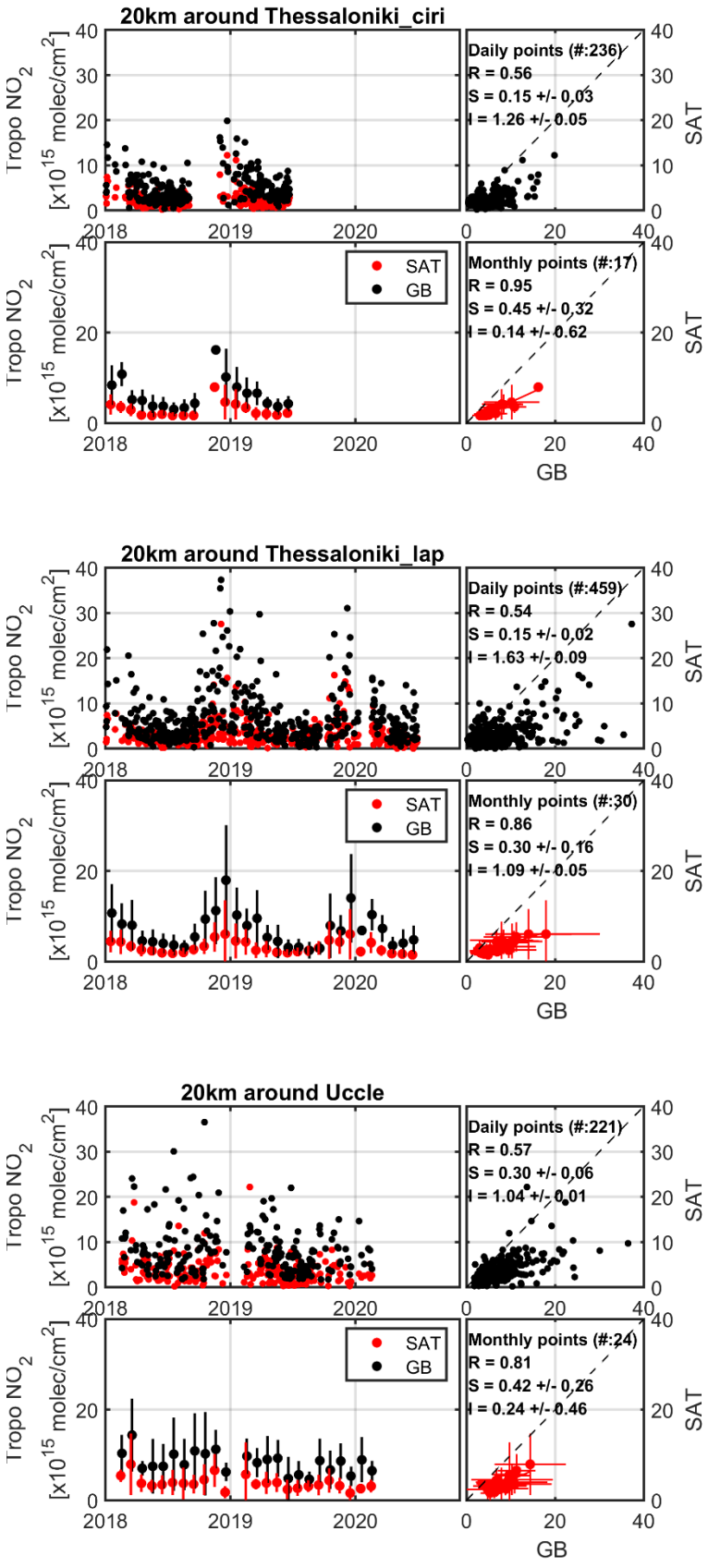
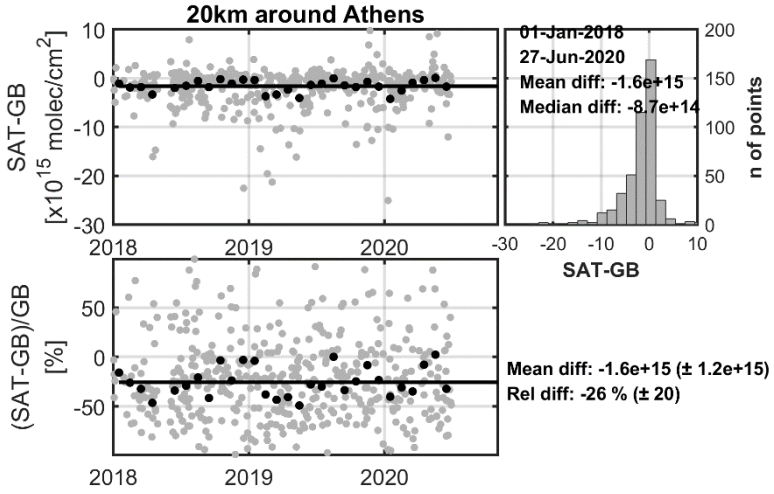
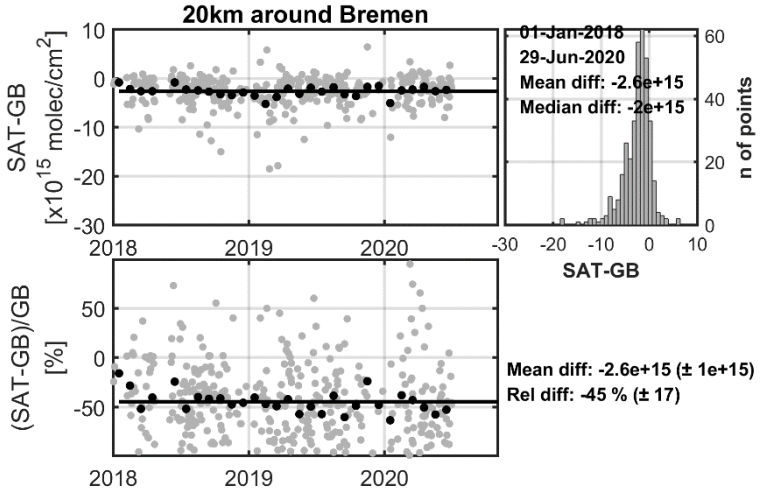
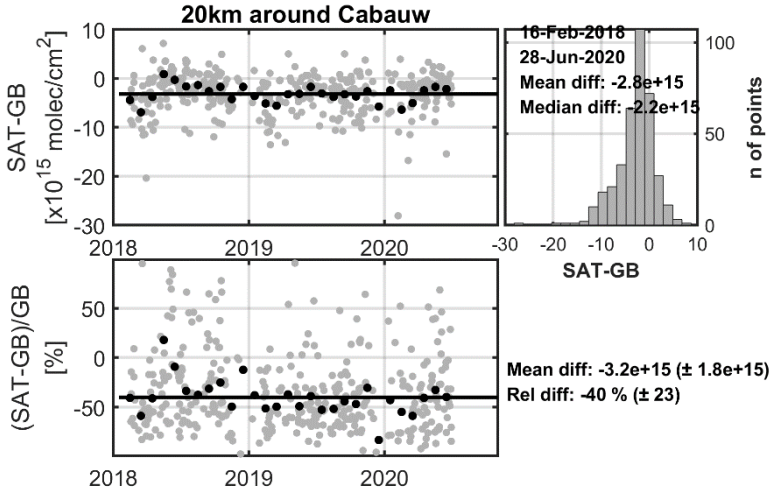
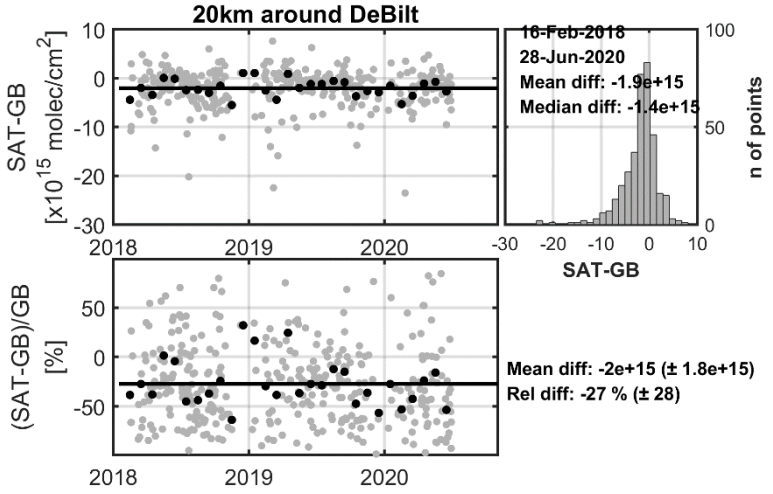


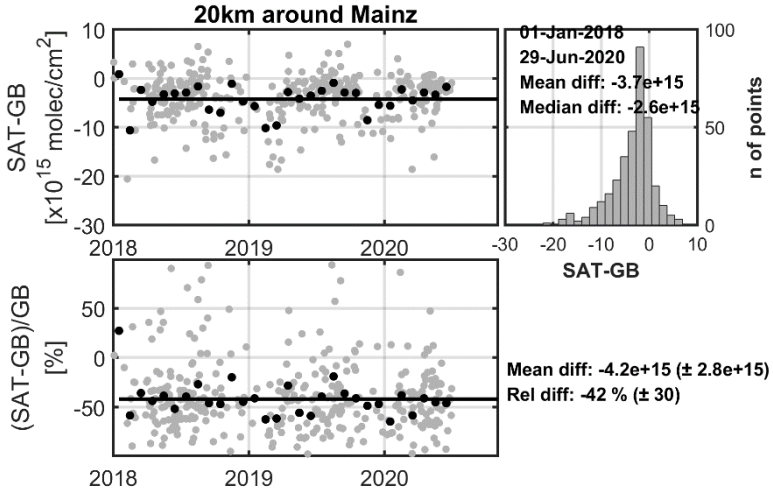
Figure S5. Similar as Fig. S4 but for the reference satellite retrieval algorithm over Athens, Bremen, Cabauw, De Bilt, Mainz, Munich, Thessaloniki_ciri, Thessaloniki_lap, and Uccle.

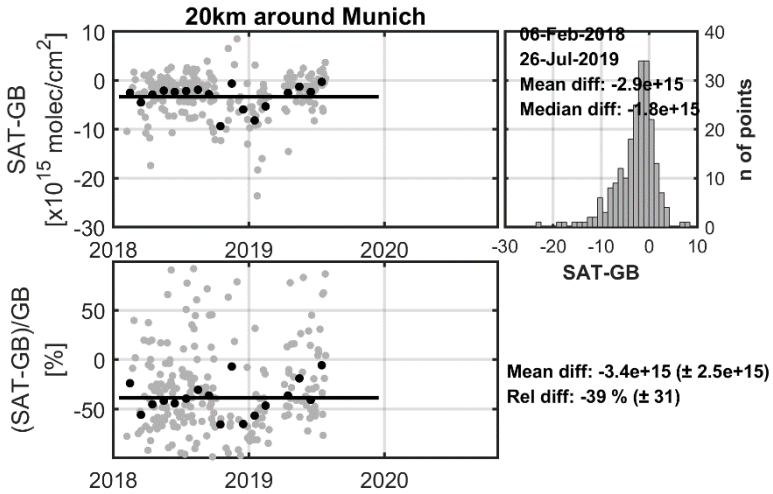

20km around Athens
SAT-GB [x10^15 molec/cm^2]
01-Jan-2018
27-Jun-2020
Mean diff: -1.6e+15
Median diff: -8.7e+14
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -1.6e+15 (± 1.2e+15)
Rel diff: -26 % (± 20)


20km around Bremen
SAT-GB [x10^15 molec/cm^2]
01-Jan-2018
29-Jun-2020
Mean diff: -2.6e+15
Median diff: -2e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -2.6e+15 (± 1e+15)
Rel diff: -45 % (± 17)


20km around Cabauw
SAT-GB [x10^15 molec/cm^2]
16-Feb-2018
28-Jun-2020
Mean diff: -2.8e+15
Median diff: -2.2e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -3.2e+15 (± 1.8e+15)
Rel diff: -40 % (± 23)


20km around DeBilt
SAT-GB [x10^15 molec/cm^2]
16-Feb-2018
28-Jun-2020
Mean diff: -1.9e+15
Median diff: -1.4e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -2e+15 (± 1.8e+15)
Rel diff: -27 % (± 28)


20km around Mainz
SAT-GB [x10^15 molec/cm^2]
01-Jan-2018
29-Jun-2020
Mean diff: -3.7e+15
Median diff: -2.6e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -4.2e+15 (± 2.8e+15)
Rel diff: -42 % (± 30)


20km around Munich
SAT-GB [x10^15 molec/cm^2]
06-Feb-2018
26-Jul-2019
Mean diff: -2.9e+15
Median diff: -1.8e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -3.4e+15 (± 2.5e+15)
Rel diff: -39 % (± 31)

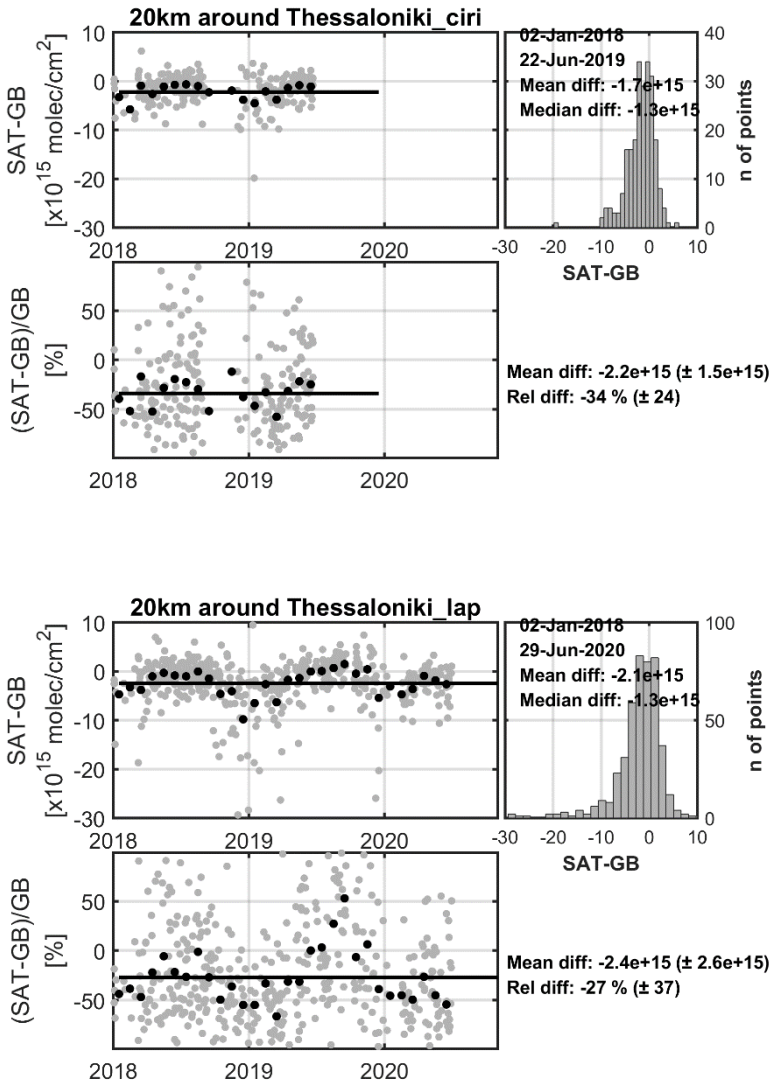
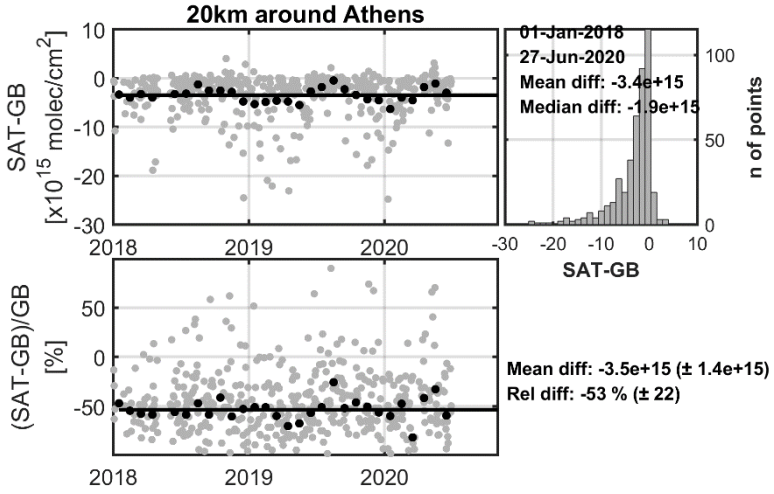
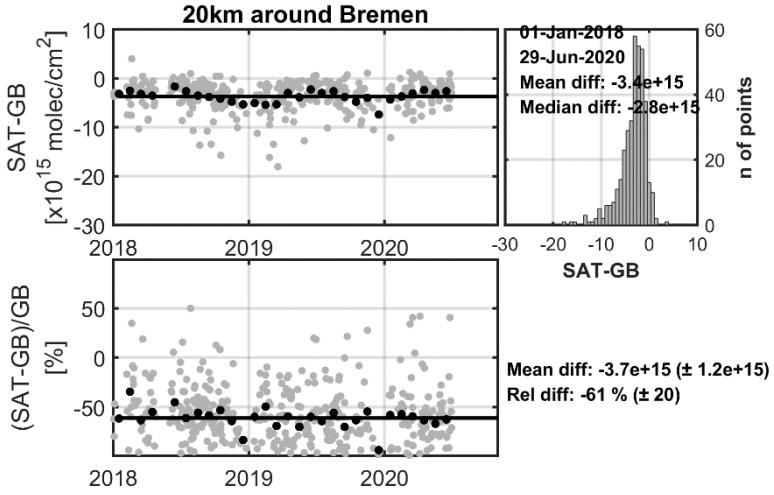
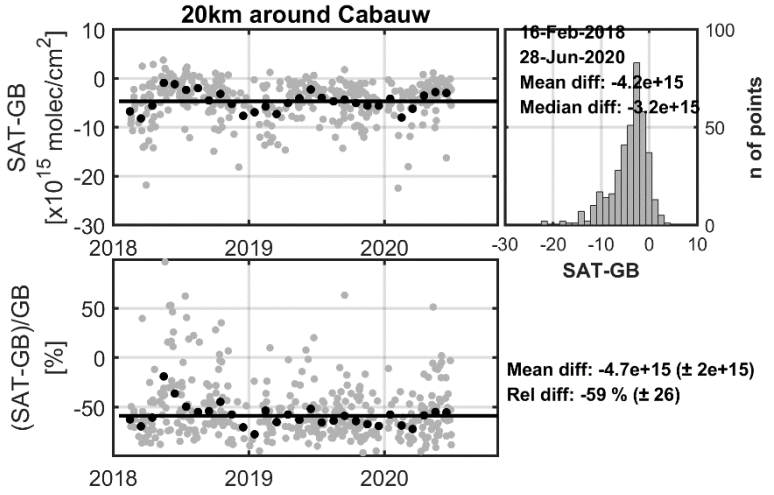
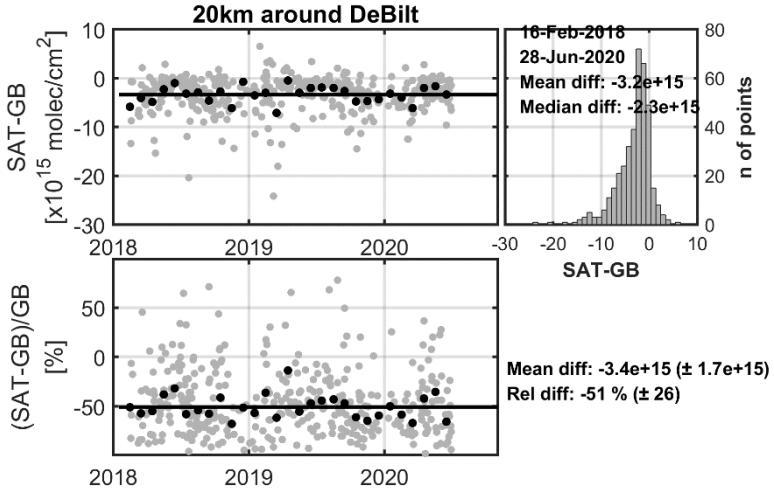


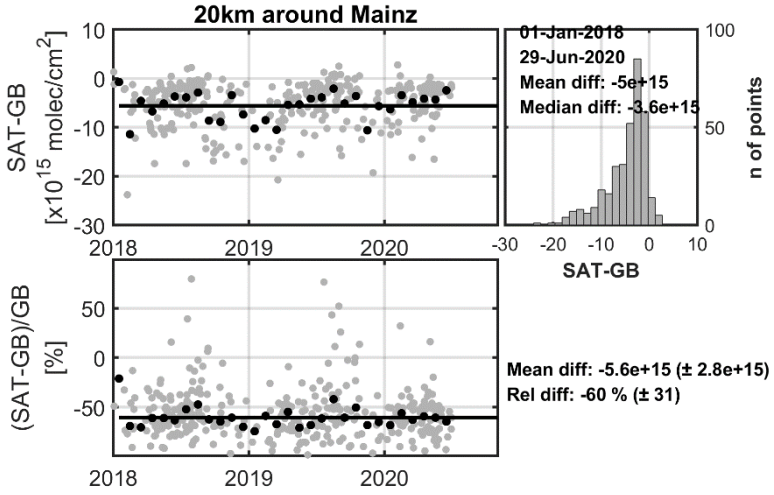
Figure S6. Daily (grey dots) and monthly mean (black dots) absolute and relative TROPOMI (SAT) and MAX-DOAS (GB) time series differences over Athens, Bremen, Cabauw, De Bilt, Mainz, Munich, Thessaloniki_ciri, and Thessaloniki_lap. Results are shown for the improved satellite retrieval algorithm. The histogram of the daily differences is also given, showing the mean and median difference. The total mean values of absolute and relative monthly differences are given in the bottom-right panel.

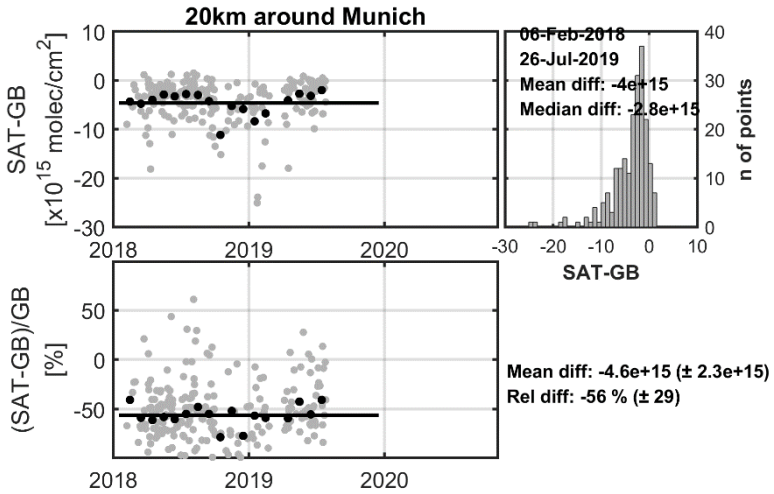

20km around Athens
SAT-GB [x10^15 molec/cm^2]
01-Jan-2018
27-Jun-2020
Mean diff: -3.4e+15
Median diff: -1.9e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -3.5e+15 (± 1.4e+15)
Rel diff: -53 % (± 22)


20km around Bremen
SAT-GB [x10^15 molec/cm^2]
01-Jan-2018
29-Jun-2020
Mean diff: -3.4e+15
Median diff: -2.8e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -3.7e+15 (± 1.2e+15)
Rel diff: -61 % (± 20)


20km around Cabauw
SAT-GB [x10^15 molec/cm^2]
16-Feb-2018
28-Jun-2020
Mean diff: -4.2e+15
Median diff: -3.2e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -4.7e+15 (± 2e+15)
Rel diff: -59 % (± 26)


20km around DeBilt
SAT-GB [x10^15 molec/cm^2]
16-Feb-2018
28-Jun-2020
Mean diff: -3.2e+15
Median diff: -2.3e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -3.4e+15 (± 1.7e+15)
Rel diff: -51 % (± 26)


20km around Mainz
SAT-GB [x10^15 molec/cm^2]
01-Jan-2018
29-Jun-2020
Mean diff: -5e+15
Median diff: -3.6e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -5.6e+15 (± 2.8e+15)
Rel diff: -60 % (± 31)


20km around Munich
SAT-GB [x10^15 molec/cm^2]
06-Feb-2018
26-Jul-2019
Mean diff: -4e+15
Median diff: -2.8e+15
n of points
SAT-GB
(SAT-GB)/GB [%]
Mean diff: -4.6e+15 (± 2.3e+15)
Rel diff: -56 % (± 29)

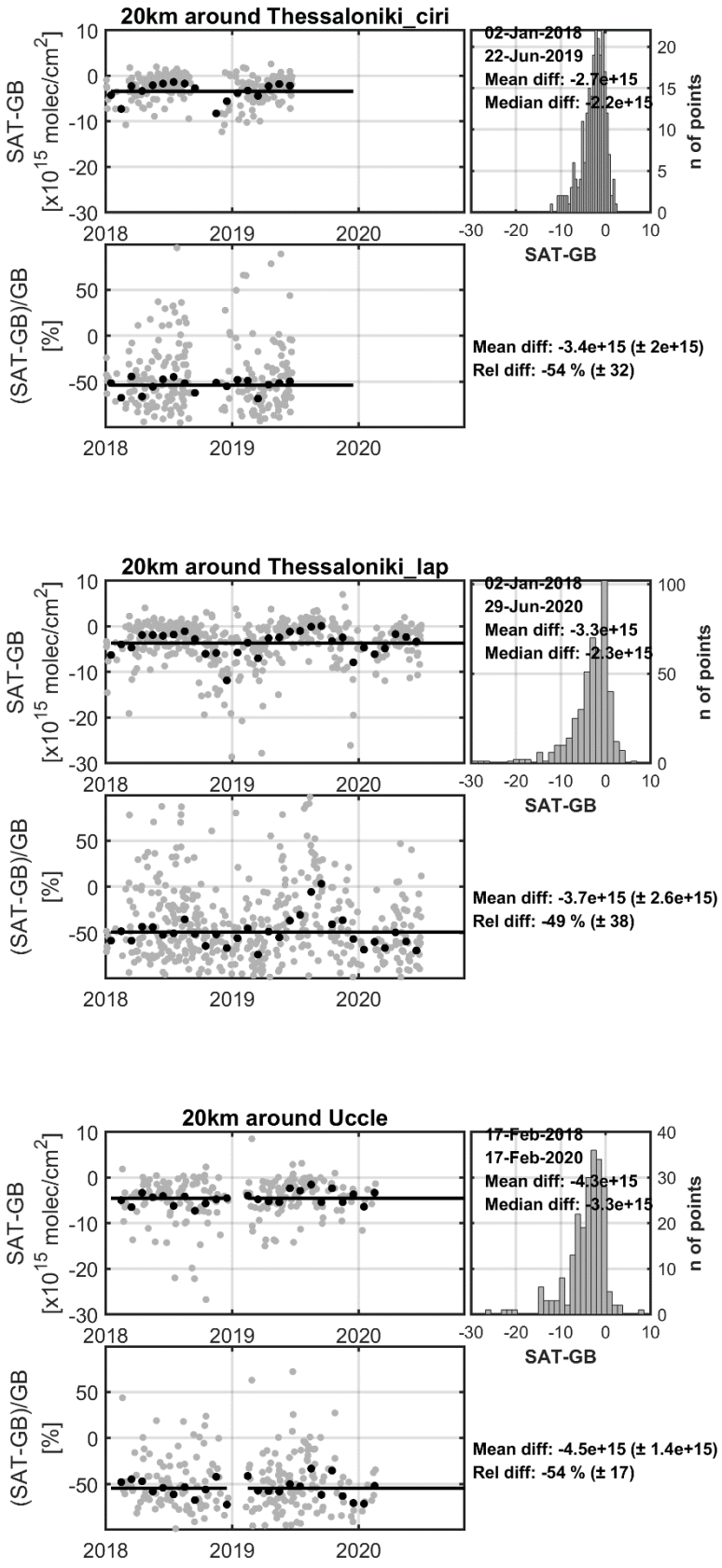


Figure S7. Similar as Fig. S6 but for the reference satellite retrieval algorithm over Athens, Bremen, Cabauw, De Bilt, Mainz, Munich, Thessaloniki_ciri, Thessaloniki_lap, and Uccle.