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Initial assessment of the CAMS global reanalysis for reactive gases and aerosols, January-June 2020

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Initial assessment of the CAMS global reanalysis for reactive gases and aerosols, January-June 2020

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Executive Summary

This document contains an initial "quick-look" evaluation of the CAMS-global reanalysis of the reactive gases and aerosols (RG+AER) for the first half of 2020 (January-June).

Main conclusions

There are no specific major problems to report concerning the extension of the reanalysis to the first half of 2020. For most variables a comparable performance is reported for 2020 and earlier years. Point of concern is the tropospheric bias observed in the sonde observations (starting from 2013) and the increased ozone bias observed by IAGOS in Frankfurt in 2019, but both may be related to the in-situ measurements.

Global Aerosol

The performance until June 2020 for AOD, Ångstrøm against Aeronet V3 level 1.5 and PMs compared to surface observations in N-America and Europe show consistency with earlier years (Fig. 2.1.1 to 2.1.5).

Dust

The performance of the CAMS reanalysis is stable for the period 2003 to 30 June 2020 in comparison with AERONET. For the first six months of 2020, the DOD comparison with AERONET shows underestimations in comparison with AOD which tends to overestimate the observations (see Figure 2.1.6). Particularly in January and February 2020, strong DOD underestimations are observed which are associated with the winter transport in the Sahel. These underestimations were also identified in previous years. Overall for the year 2020 we find correlation coefficients of 0.80 and MNMB of -42%. Again, these results are comparable with those obtained in last years (see Tables 2.1.1 and 2.1.2).

Tropospheric ozone (O_3)

A quick evaluation of the reanalysis for 2020 against Airbase/EMEP observations for Europe revealed (compared to 2019) no major issues (Fig. 2.2.1). The CAMS reanalysis continues to overestimate seasonal cycles over 3 latitudinal zones in Europe as well as for the group of stations with altitude greater than 1000m, with an overestimation of summertime values for the latter. The CAMS control shows lower biases (better performance) during summertime compared to the CAMS reanalysis. The reanalysis overestimates surface ozone during June over Southern and Central Europe and during July over northern Europe.

CAMS reanalysis O_3 total column data have been compared with IASI satellite observations (Fig. 2.2.4). The reanalysis O_3 total columns are in good agreement with the satellite data, showing stable performance of model (biases within 5%).

Results for the validation with ozone sondes show that the time series of MNMbs continues without major jumps or differences compared to the previous years (Fig. 2.2.2). Over the Arctic free troposphere, a positive bias is observed since about 2017 and this bias is still present in the first half of 2020 for the CAMS reanalysis. From 2019 onwards a positive bias is also observed over the northern midlatitudes and continues in the first half of 2020. Note that this may be partly due to reported negative biases in more recent sonde observations (5-10%) in the stratosphere with possibly impacts for the troposphere as well.

Tropospheric ozone for January-August 2020 has been compared with IAGOS measurements at Frankfurt (Fig. 2.2.5). As mentioned in previous NRT evaluations, due to instrument issues with ozone measurements in 2019, an increase of the bias from the CAMS models is found during this year. For year 2020, ozone measurements (although Level 1) appear more reliable and for the aforementioned reasons are not only compared to 2019 for which Level 2 data is not available yet, but also to 2018 and 2017 which are Level 2 data. No notable difference is found in the behaviour of the reanalysis and control run with these other years.

Tropospheric ozone in the Arctic

The performance of the reanalysis run for Arctic ozone in the first half of 2020 is similar to the performance for previous years (Fig. 2.2.3). A good agreement is observed between the CAMS reanalysis and observations of surface ozone at three high Arctic sites except for ozone depletion events in March – May which are not captured due to lack of halogen chemistry in the simulations.

Tropospheric Carbon Monoxide (CO)

The CAMS reanalysis CO total column data have been compared with IASI (v20191122) and MOPITT version 8 satellite observations (Fig. 2.3.1). The reanalysis CO total columns are in good agreement with MOPITT data, showing the efficiency of the assimilation, and have a slight negative bias within 10% with some exceptions. In comparison with IASI observations, the relative biases are larger (note that CO from IASI is not assimilated in the model run). Starting from autumn 2019 the positive bias over the SH high latitudes changes sign to negative. In comparison to both instruments, an increase of positive bias by 10% over the northern low latitudes during autumn 2019/winter 2020 can be seen in the control run.

The reanalysis was compared with NDACC CO up to the first half of 2020 and no issues found so far, see Fig. 2.3.2 - 2.3.4. Mid 2019 there seems to be a discontinuity in the relative biases (Fig 2.3.4), which might be related to a change in the MOPITT version used in the CAMS reanalysis. The relative differences for the stations in the southern hemisphere show a significant positive trend in the relative biases: Maido +0.3%, Lauder +0.14% and Wollongong +1.1%. At the Antarctic station the trend is negative (see Fig. 2.3). The high latitude stations (both Arctic and Antarctic) show a seasonal dependence in the relative differences with a reduced bias during local spring/summer). A discontinuity is observed mid 2019 and might break the trend estimates.

No notable change is found in the bias for CO against IAGOS aircraft observations over Frankfurt when comparing 2020 results with those of the most recent years (Fig. 2.3.5).

Tropospheric Nitrogen dioxide (NO_2)

The CAMS reanalysis was compared with NO2 from SCIAMACHY and GOME-2. The quick evaluation of results for 2020 reveals no major issues. Time series comparisons (Figure 2.4.1) show no change in performance for 2020, except for East-Asia where the reanalysis now better matches the wintertime peak observed by GOME-2. The global maps (Figure 2.4.2 and 2.4.3) show similar features as for the CAMS operational forecast service, i.e. stronger shipping signals, overestimation of values over the Red Sea and a tendency to underestimate values over Central European pollution hotspots around the Benelux countries (especially during winter), while values over other distinct hotspots are overestimated (e.g. Moscow)

Formaldehyde (HCHO)

The quick evaluation of results for 2020 against GOME-2 reveals no major issues and a similar performance as for previous years is seen in the time periods (Figure 2.5.1) and global maps (Figure 2.5.2/3). Compared to GOME-2 satellite retrievals, the global maps show an overestimation of values for Central Africa as well as Australia.

Stratospheric ozone

The reanalysis was compared with NDACC ozone up to the first half of 2020 and no major changes in behaviour are observed with respect to previous years, see Fig. 2.6.1 – 2.6.2. The reanalysis seems to perform stable throughout the entire time series taking into account the measurement's uncertainties.

The stratospheric ozone profiles of the reanalysis were compared with MLS V4.2 offline and ACE-FTS v3.6 up to May 2020 (Fig. 2.6.3). There are no obvious changes or trends with respect to previous years.

Fig 2.6.4 shows the comparison with ozonesondes in the stratosphere for the period up to June 2020. The change of bias sign from negative to positive over the Arctic stratosphere likely relates to drop-offs in sonde ozone from 2014 onwards.

Table of Contents

1. Description of the reanalysis

For the reactive gases and aerosols, the experiment ID for the reanalysis for the year 2020 is:
exp = **hbsd**, class=rd.

The control run for 2020 is:
exp = **h7er**

2. Preliminary RG+AER reanalysis evaluation results 2018

2.1 Aerosol evaluation

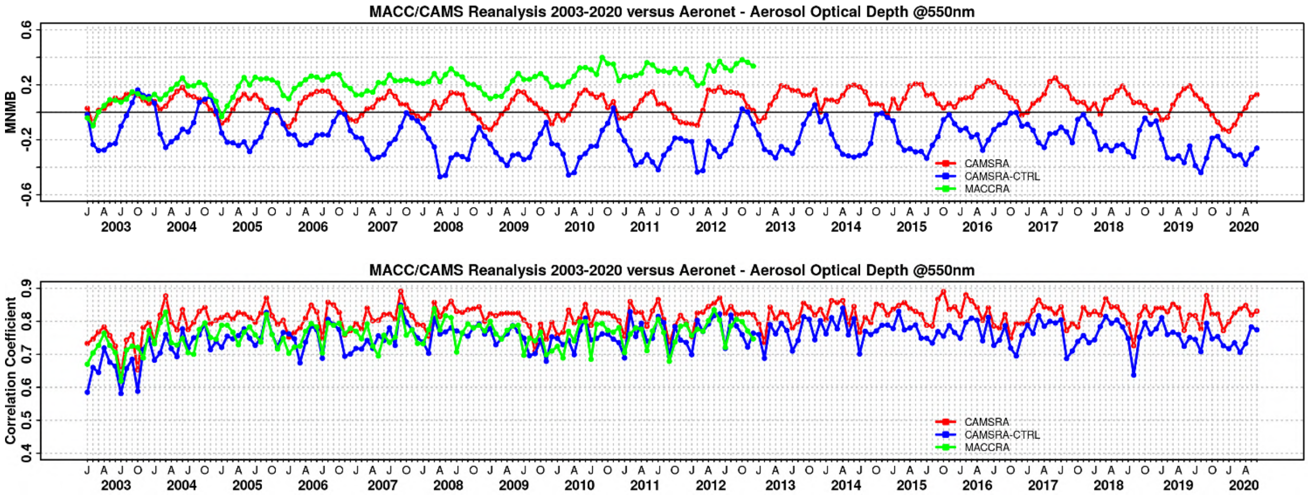


Figure 2.1.1: Aerosol optical depth at 550nm in IFS 00Z model simulations for 2003 – 2020 against daily matching Aeronet Version3 level 1.5; (top) Modified normalized mean bias (MNMB); CAMS reanalysis (red) and control run (blue); MACC reanalysis (green); (bottom) Corresponding correlation coefficient.

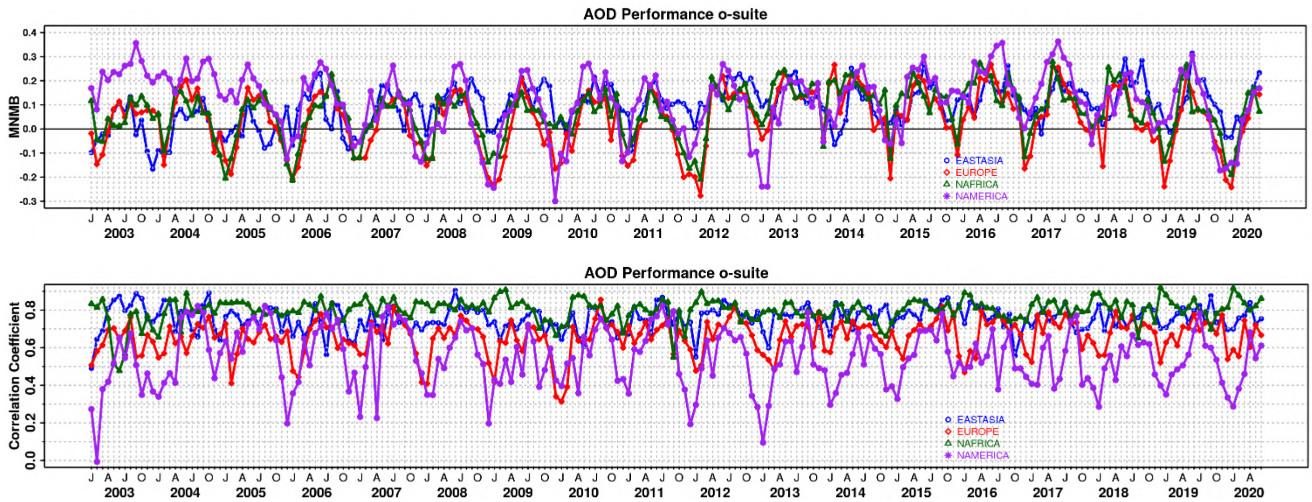


Figure 2.1.2: a) Modified normalized mean bias (MNMB) and b) correlation coefficient in AOD for 2003-2020 based on daily AOD comparison (Aeronet V3 level 1.5) in four world regions [East Asia (blue); Europe (red); North Africa (green); North America (purple)] for the CAMS reanalysis.

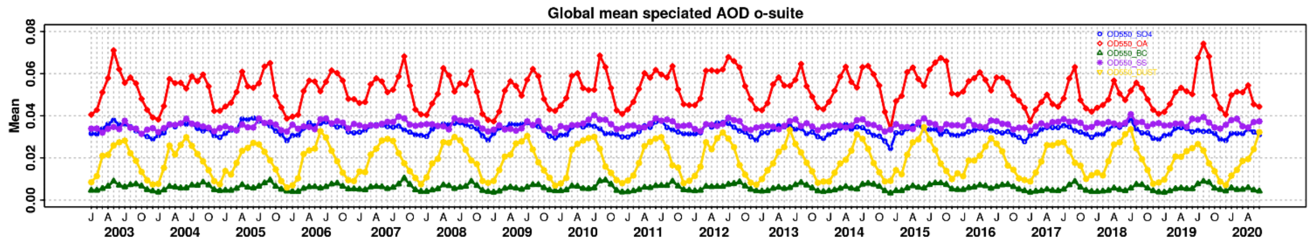


Figure 2.1.3: Evolution of the aerosol components of total AOD@550nm [OD550_SO4 = sulphate(blue); OD550_OA = organics(red); OD550_BC = black carbon(green); OD550_SS = sea salt(purple); OD550_DUST = dust(yellow)] for the CAMS reanalysis.

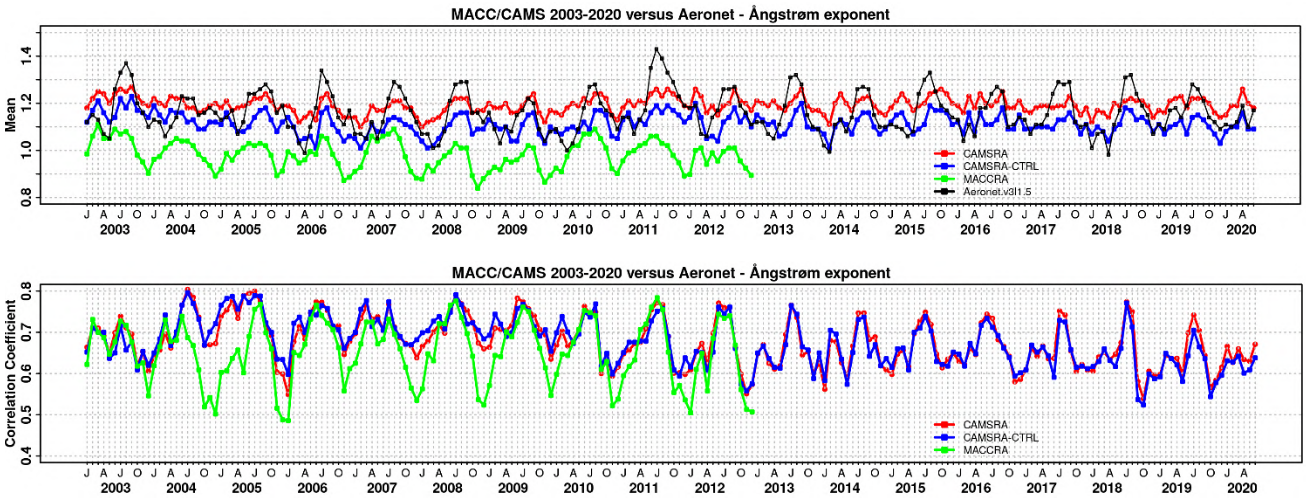


Figure 2.1.4: a) Evolution of mean Ångström exponent for 2003-2020 at Aeronet sites (Aeronet V3 level 1.5 based on matching monthly mean values [CAMS reanalysis (red) and control (blue); MACC reanalysis (green); observations (black)]. b) Correlation using daily matching Ångström exponent.

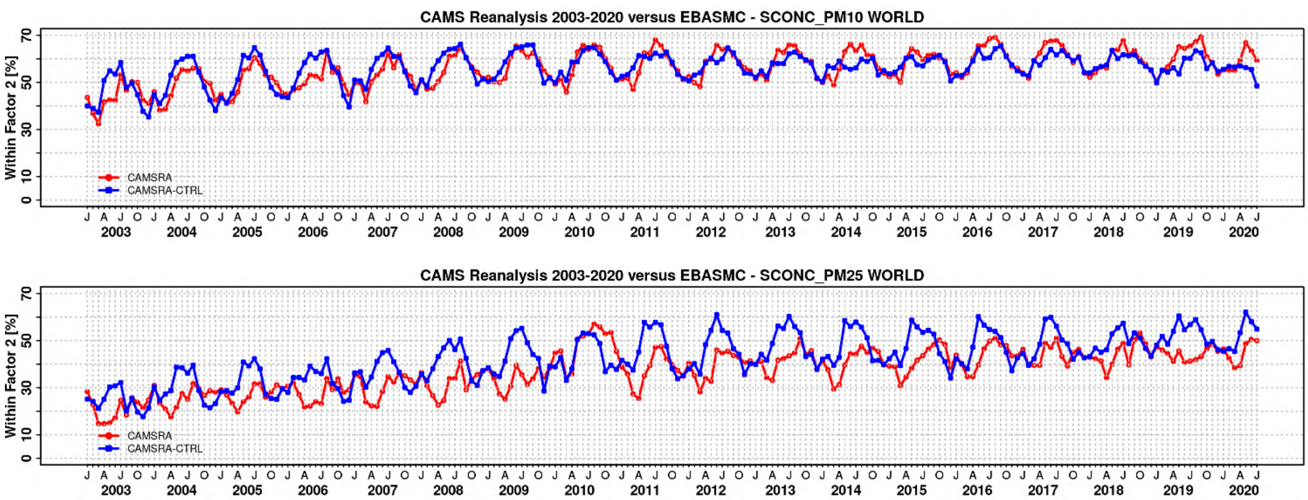


Figure 2.1.5: a) Timeseries (2003-2020) of PM10 concentrations within a factor 2 of observational climatology at 166 rural/remote sites in Europe and North America [CAMS reanalysis (red) and control (blue). b) As a) but for PM25 concentrations at 143 sites.

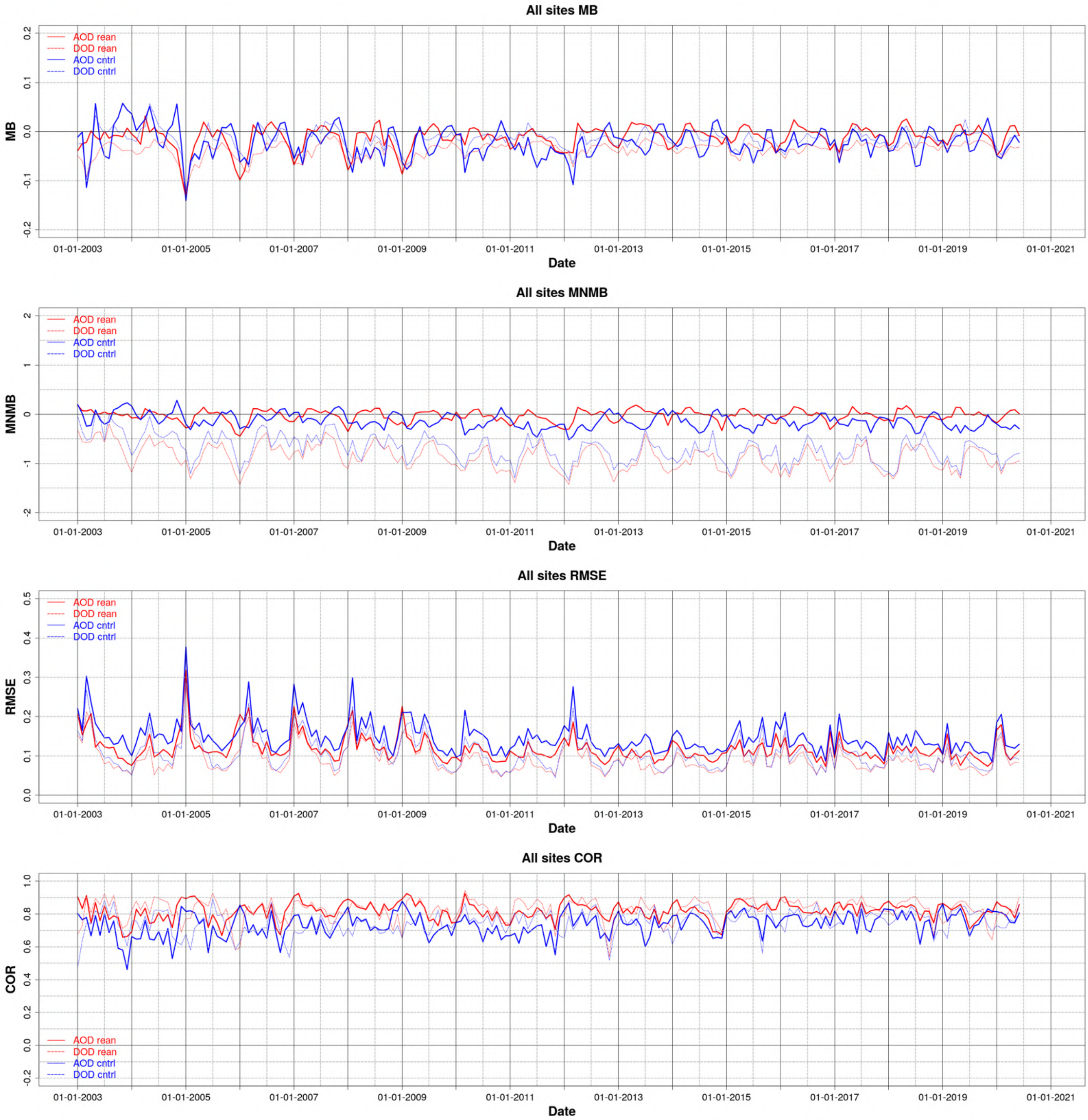


Figure 2.1.6: Monthly MB, MNMB, RMSE, and correlation coefficient results from 1 January 2003 to 30 June 2020 for all the available AERONET observations over Northern Africa, the Middle East and Southern Europe. AOD (solid lines) and DOD (dashed lines) from AERONET Version 3 cloud-screened is the reference and the colours identify the CAMS reanalysis (red colour) and control (blue colour) experiments.

Table 2.1.1: Annual skill scores (MEAN, SD, MB, MNMB, RMSE and r) of CAMS DOD reanalysis and control run from 1 January 2003 to 30 June 2020 for Northern Africa, the Middle East and Europe. 3-hourly dust-filtered AOD (i.e. DOD) from AERONET Version 3 SDA cloud-screened is the reference.

		DOD											
		Reanalysis						Control					
	NDATA	**MEAN**	**SD**	**MB**	**MNMB**	**RMSE**	**r**	**MEAN**	**SD**	**MB**	**MNMB**	**RMSE**	**r**
2003	16867	0.11	0.15	-0.08	-0.43	0.22	0.81	0.14	0.17	-0.06	-0.25	0.22	0.75
2004	18726	0.12	0.16	-0.09	-0.42	0.21	0.87	0.15	0.19	-0.06	-0.20	0.22	0.75
2005	23428	0.10	0.14	-0.09	-0.48	0.21	0.86	0.13	0.17	-0.06	-0.29	0.20	0.78
2006	22001	0.11	0.16	-0.09	-0.42	0.20	0.87	0.14	0.18	-0.06	-0.20	0.21	0.76
2007	25482	0.11	0.15	-0.08	-0.38	0.21	0.86	0.13	0.17	-0.06	-0.19	0.22	0.75
2008	25254	0.11	0.15	-0.08	-0.40	0.19	0.86	0.13	0.17	-0.06	-0.25	0.20	0.77
2009	24993	0.10	0.14	-0.07	-0.39	0.18	0.86	0.13	0.17	-0.04	-0.17	0.19	0.75
2010	27332	0.10	0.16	-0.08	-0.51	0.19	0.90	0.12	0.17	-0.06	-0.36	0.21	0.78
2011	34166	0.08	0.13	-0.05	-0.40	0.15	0.86	0.11	0.17	-0.03	-0.21	0.15	0.80
2012	34009	0.09	0.14	-0.07	-0.44	0.18	0.86	0.11	0.16	-0.05	-0.28	0.19	0.78
2013	37286	0.08	0.12	-0.05	-0.44	0.13	0.85	0.10	0.15	-0.03	-0.23	0.13	0.79
2014	34926	0.08	0.12	-0.05	-0.43	0.14	0.85	0.10	0.15	-0.03	-0.25	0.14	0.79
2015	38507	0.10	0.15	-0.07	-0.42	0.18	0.87	0.11	0.16	-0.05	-0.29	0.19	0.79
2016	40394	0.09	0.14	-0.06	-0.44	0.17	0.85	0.11	0.16	-0.04	-0.28	0.17	0.77
2017	38541	0.08	0.13	-0.06	-0.42	0.15	0.86	0.10	0.16	-0.04	-0.27	0.15	0.79
2018	34430	0.09	0.14	-0.06	-0.43	0.16	0.86	0.11	0.16	-0.04	-0.30	0.16	0.78
2019	35303	0.08	0.12	-0.05	-0.43	0.15	0.80	0.10	0.16	-0.02	-0.25	0.15	0.75
2020	16141	0.06	0.11	-0.04	-0.42	0.11	0.80	0.08	0.13	-0.02	-0.26	0.11	0.73

Table 2.1.2: Annual skill scores (MEAN, SD, MB, MNMB, RMSE and r) of CAMS AOD reanalysis and control run from 1 January 2003 to 30 June 2020 for Northern Africa, the Middle East and Europe. 3-hourly AOD from AERONET Version 3 direct-sun cloud-screened is the reference.

		AOD											
		Reanalysis						Control					
	NDATA	MEAN	SD	MB	MNMB	RMSE	r	MEAN	SD	MB	MNMB	RMSE	r
2003	20522	0.25	0.19	-0.01	0.23	0.17	0.76	0.25	0.19	-0.02	0.18	0.19	0.67
2004	23376	0.25	0.20	-0.01	0.19	0.14	0.84	0.25	0.20	-0.01	0.20	0.20	0.66
2005	28678	0.23	0.19	-0.02	0.19	0.14	0.83	0.23	0.19	-0.03	0.11	0.17	0.74
2006	27531	0.24	0.20	-0.01	0.29	0.14	0.84	0.24	0.20	-0.02	0.18	0.18	0.72
2007	32400	0.23	0.19	-0.01	0.26	0.14	0.84	0.22	0.19	-0.02	0.16	0.18	0.71
2008	32129	0.23	0.19	-0.01	0.22	0.13	0.85	0.21	0.18	-0.03	0.05	0.16	0.74
2009	33026	0.22	0.18	0.00	0.23	0.12	0.84	0.21	0.19	-0.01	0.10	0.16	0.72
2010	35883	0.22	0.20	-0.01	0.20	0.12	0.87	0.19	0.18	-0.03	0.04	0.18	0.72
2011	44176	0.21	0.16	0.00	0.19	0.12	0.80	0.18	0.18	-0.03	-0.01	0.14	0.72
2012	46319	0.21	0.19	0.00	0.25	0.12	0.86	0.18	0.18	-0.02	0.05	0.15	0.77
2013	50050	0.19	0.15	0.01	0.45	0.10	0.81	0.17	0.17	-0.01	0.19	0.12	0.74
2014	47046	0.19	0.15	0.01	0.45	0.11	0.81	0.17	0.17	-0.01	0.16	0.12	0.75
2015	51550	0.21	0.19	0.01	0.38	0.12	0.85	0.18	0.18	-0.02	0.10	0.15	0.77
2016	55283	0.20	0.17	0.01	0.39	0.12	0.82	0.18	0.18	-0.01	0.14	0.14	0.74
2017	53440	0.20	0.17	0.01	0.33	0.11	0.83	0.18	0.18	-0.01	0.13	0.13	0.76
2018	45742	0.21	0.18	0.01	0.34	0.12	0.83	0.19	0.18	-0.02	0.12	0.14	0.74
2019	49402	0.19	0.15	0.00	0.30	0.11	0.80	0.17	0.18	-0.01	0.04	0.13	0.75
2020	16141	0.18	0.16	-0.01	0.18	0.13	0.82	0.16	0.18	-0.03	-0.07	0.15	0.75

2.2 Verification of tropospheric ozone

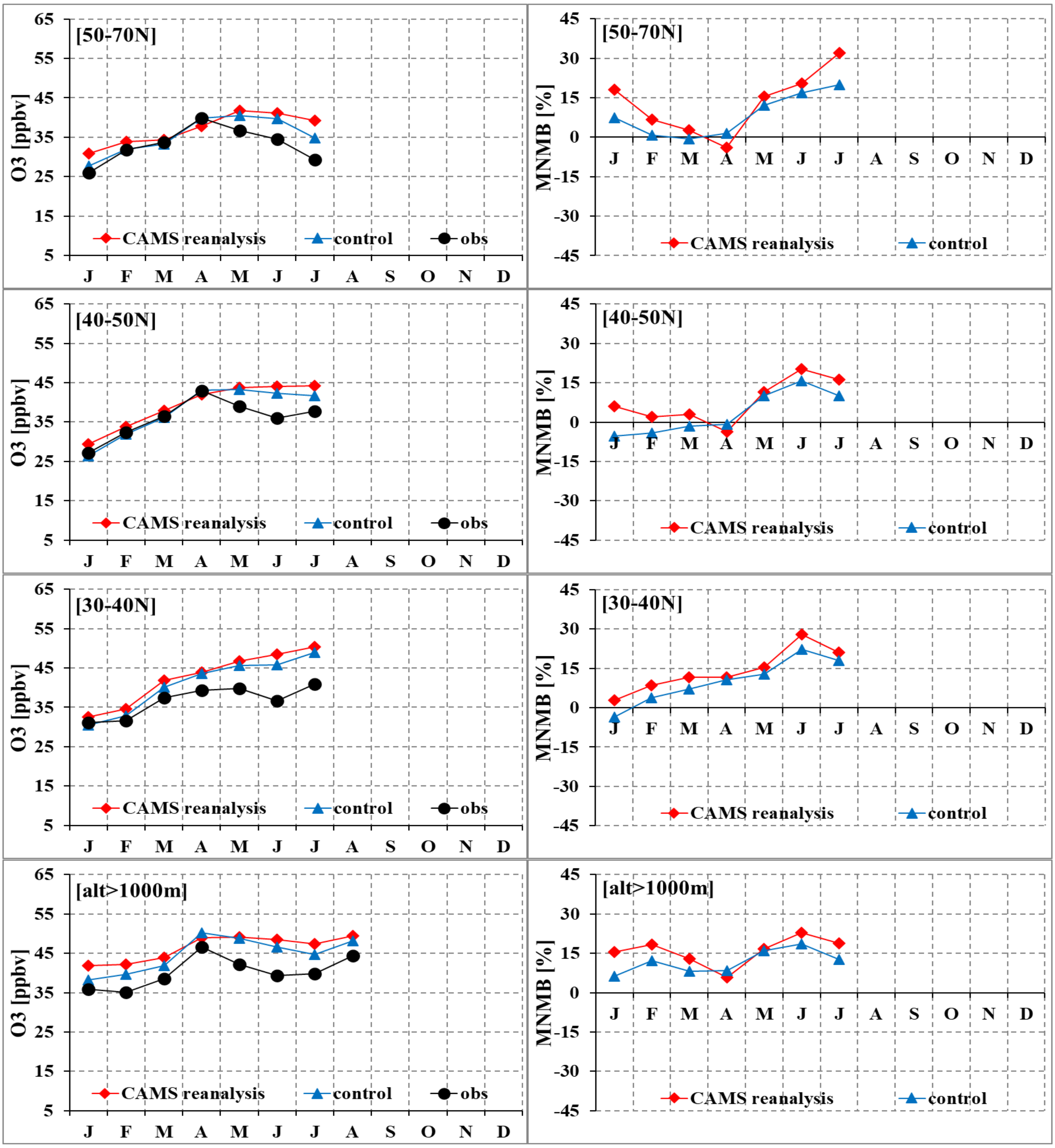


Fig. 2.2.1. Mean monthly ozone variability for the period January to July 2020 (left) and the MNMBs (right) of the CAMS Reanalysis (red robs) and the Airbase/EMEP observations (black circles) over Northern Europe (1st row, a and b), Central Europe (2nd row, c and d), Southern Europe (3rd row, e and f) as well as for stations with altitude greater than 1000m a.s.l. (4rd row, g and h).

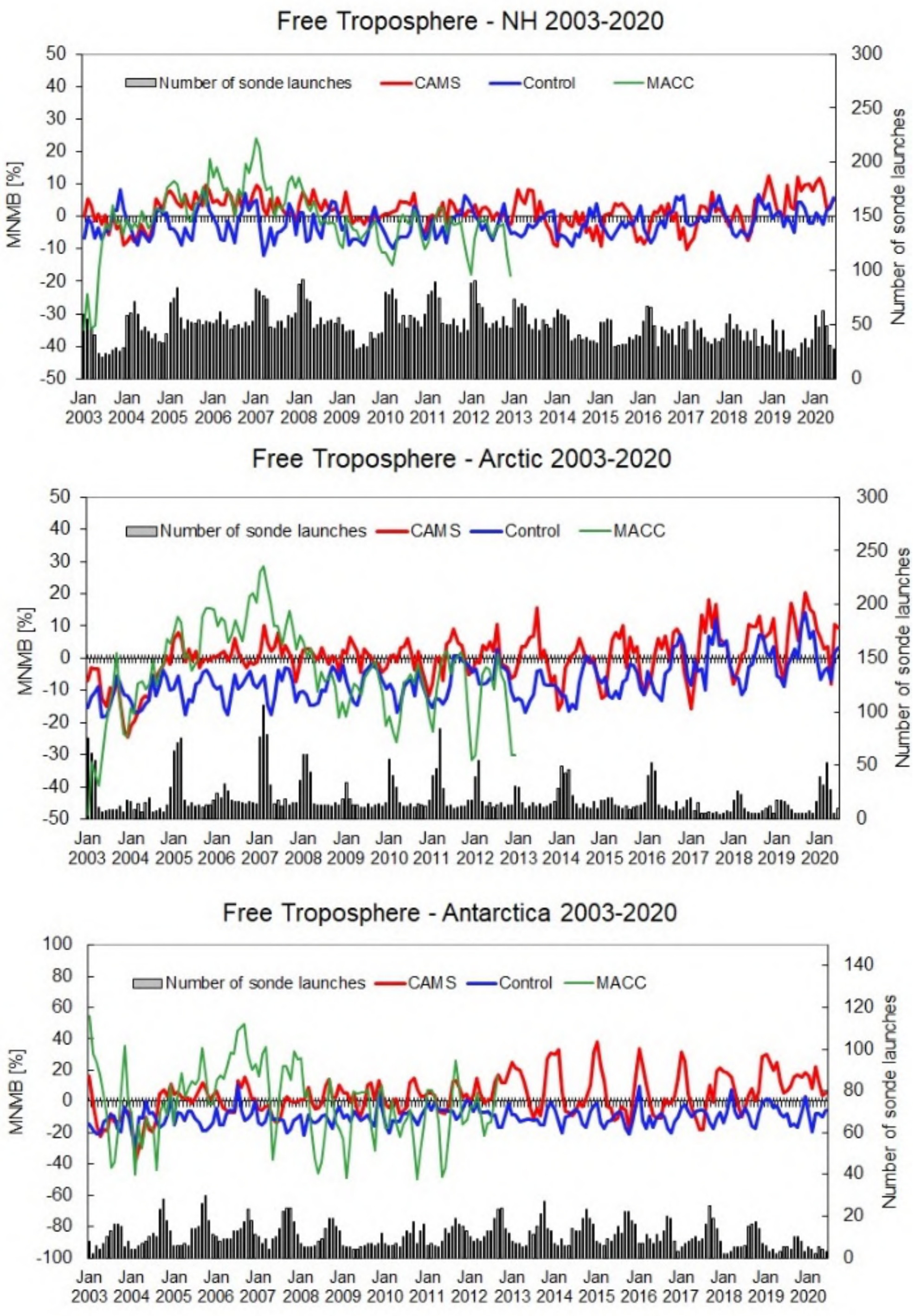


Fig. 2.2.2: MNMBs for the CAMS reanalysis (red), control run (blue) and MACC reanalysis (green) versus ozone sonde observations over the free troposphere of the Northern midlatitudes (top), Arctic (middle), Antarctica (bottom).

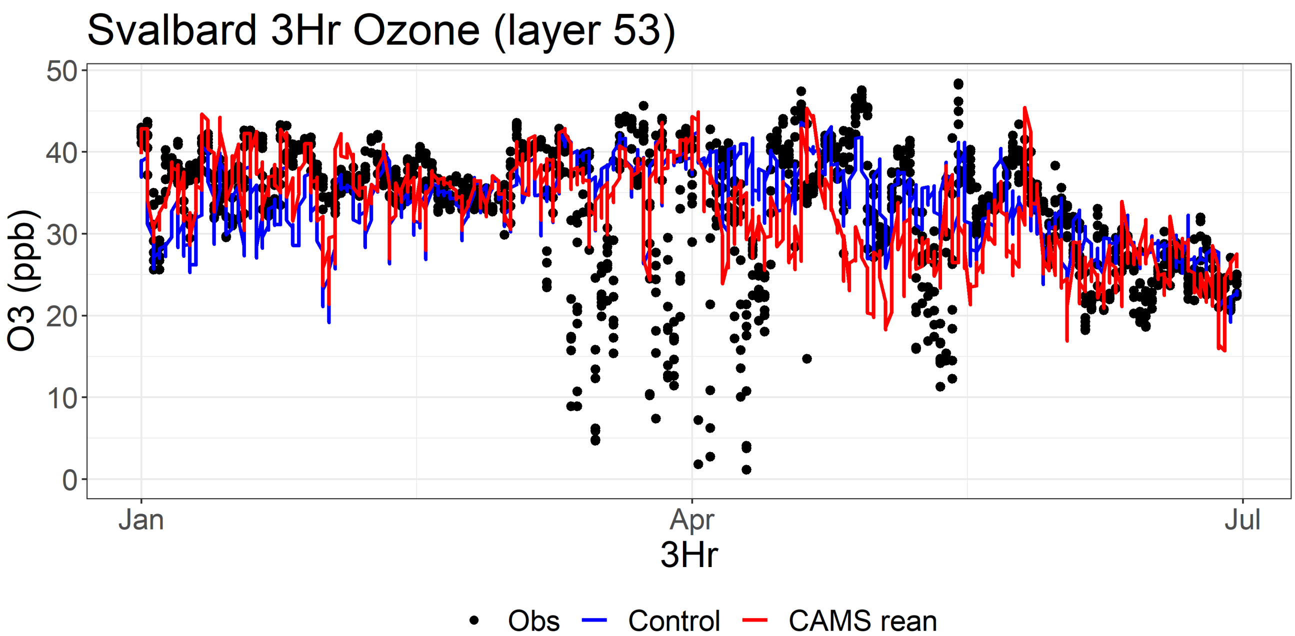


Figure 2.2.3: Three-hourly averaged surface O3 concentrations for 2020 for Zeppelin Mountain, Svalbard. Good agreement between CAMS reanalysis and observations except for ozone depletion events in March – May which are not captured due to lack of halogen chemistry in the simulations. Similar results are obtained for the other high Arctic sites.

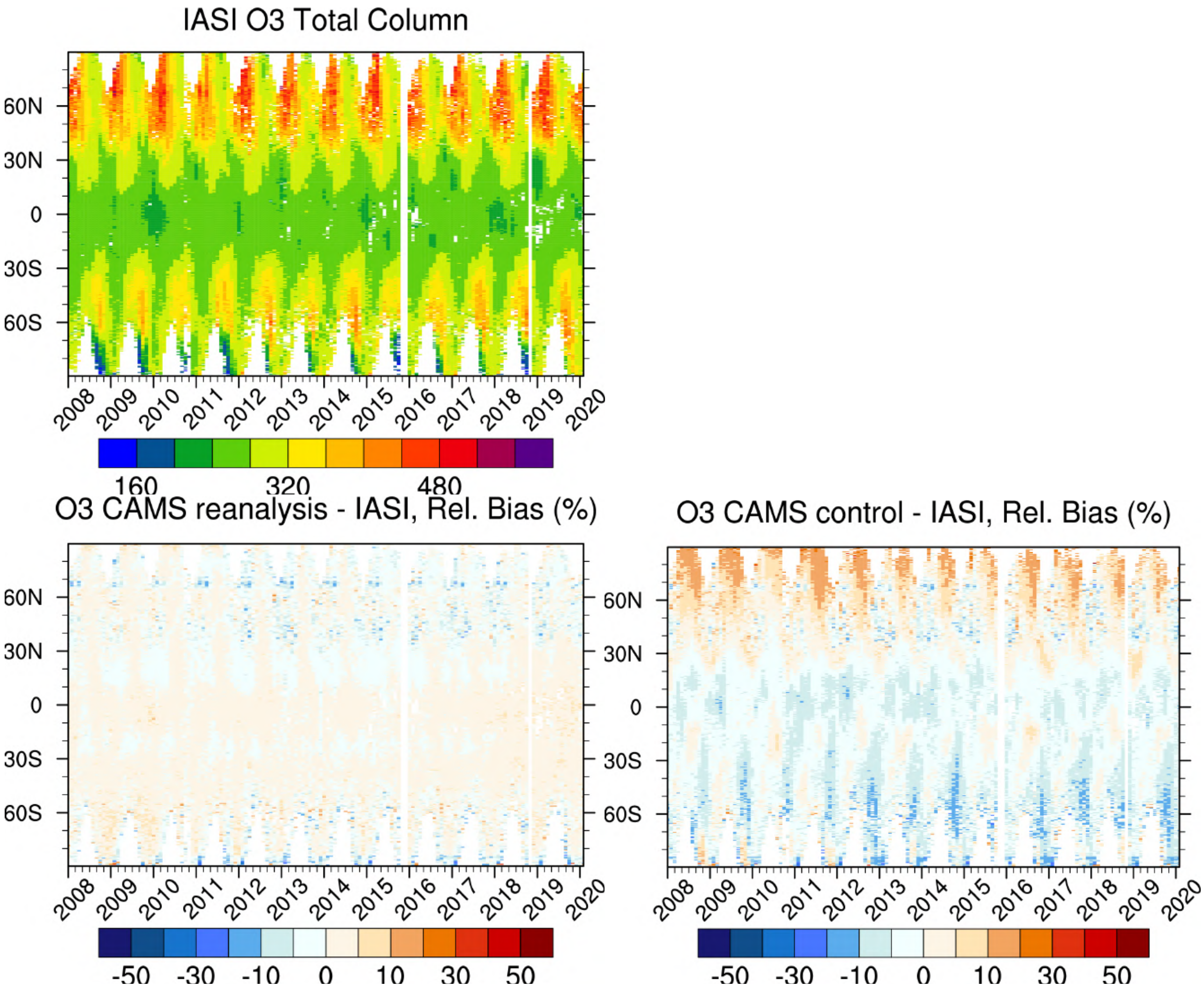


Figure 2.2.4: IASI MetopA O3 total column (top) as function of latitude and time from January 2008 to February 2020. Relative difference between CAMS reanalysis and IASI (bottom left) and control and IASI (bottom right). For the comparison with the IASI data, the vertically integrated model O3 data were transformed using IASI averaging kernels. The reanalysis captured well the high O3 values at middle and high northern latitudes during winter/spring seasons and low values over the Southern Hemisphere polar region during ozone hole seasons in autumns. The reanalysis bias is within 5%. The control run shows an overestimation of high O3 values over the mid- and high northern latitudes up to 20% and a slight overestimation the low values over the southern polar region in autumns within 10%. Underestimation within 10% can be seen over the southern mid-latitudes in autumn seasons.

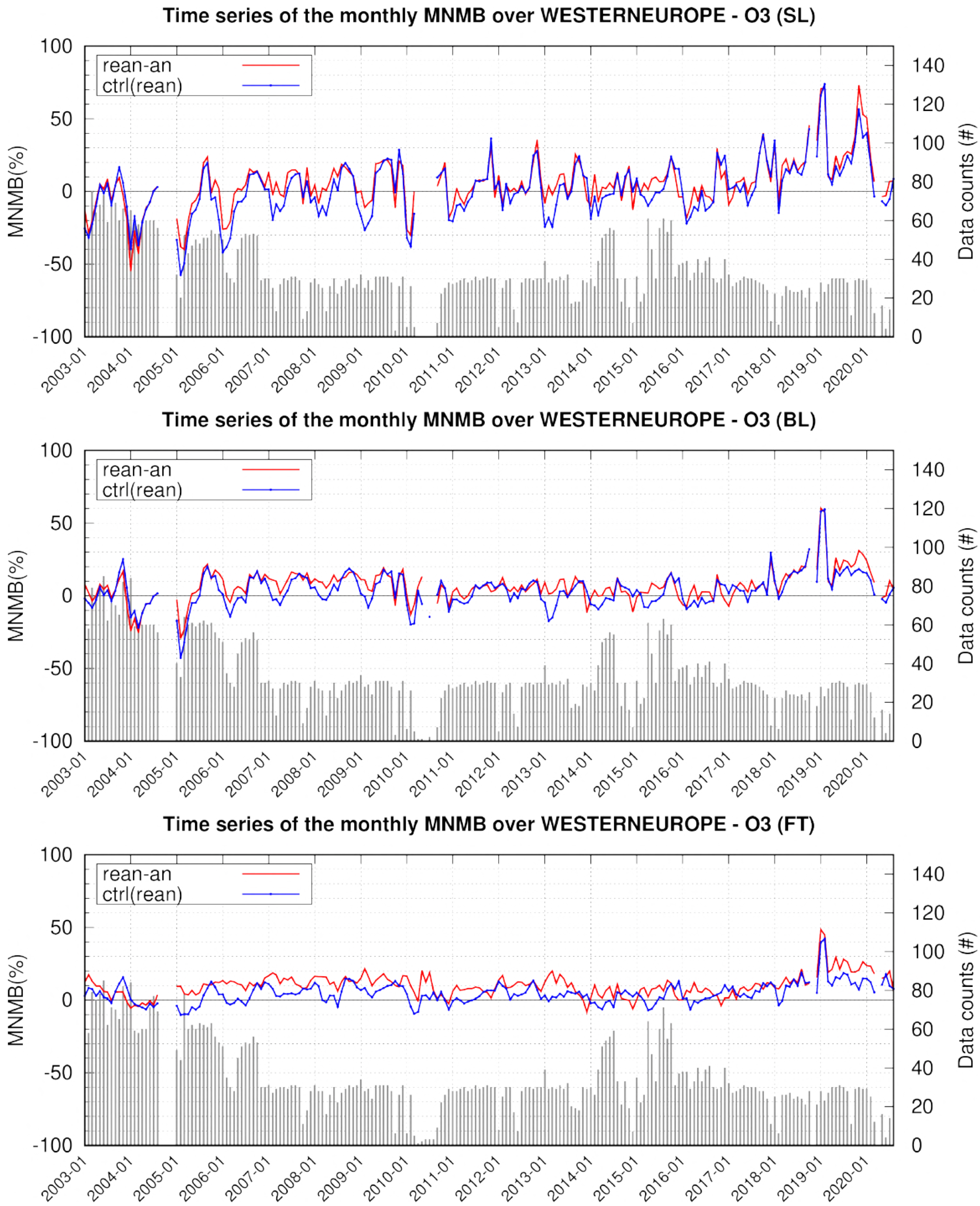
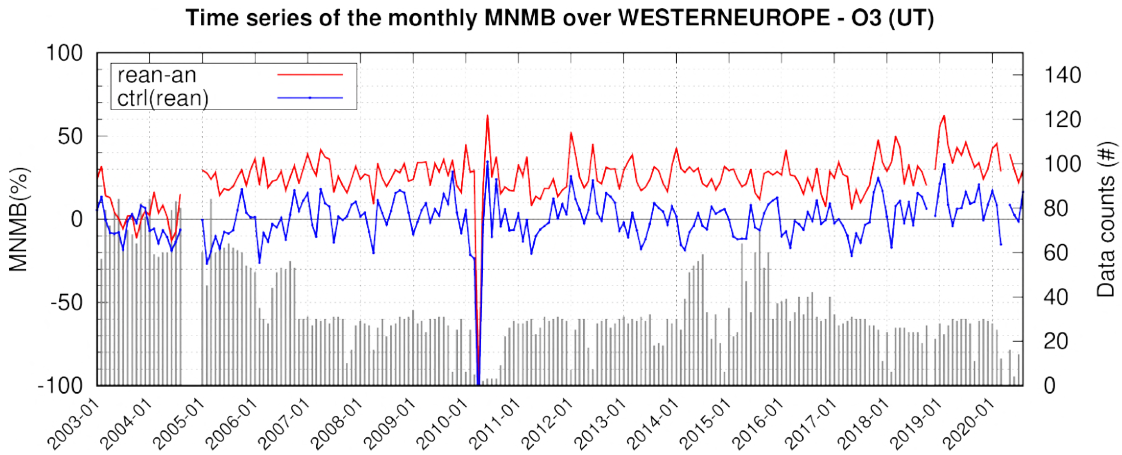


Figure 2.2.5: Monthly time series for ozone in different atmospheric layers at Frankfurt during the period 2003-2020 compared to IAGOS aircraft data. From top to bottom for SL: Surface Layer, BL: Boundary Layer, FT: Free troposphere, UT: Upper troposphere, LS: Lower Stratosphere. Units:ppbv. The large MNMB values obtained in 2019 due to the issue of IAGOS Level 1 data are not present anymore in 2020 Level 1 data. The values of MNMB for 2020 are similar to those of the years before 2019 such as 2018 or 2017 (see also Fig. 2.2.4 and 2.2.5).



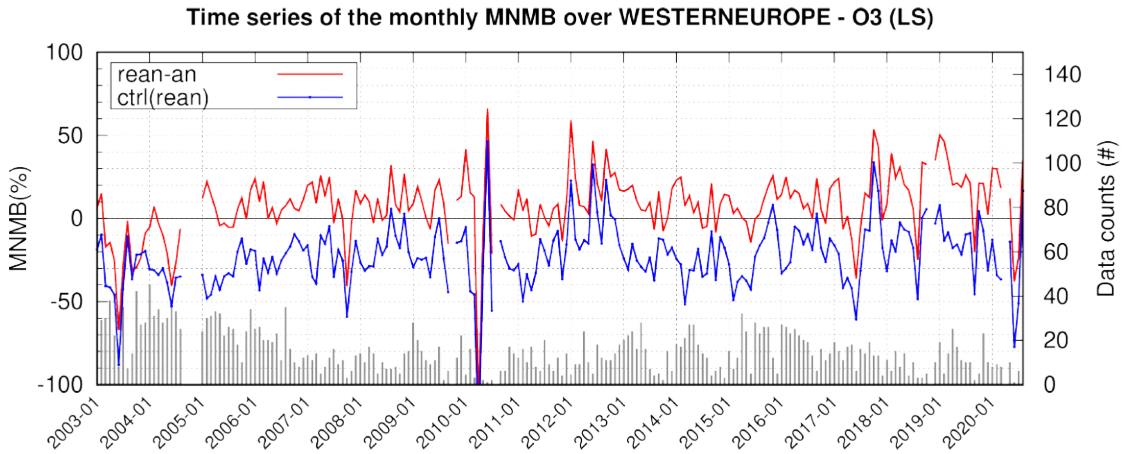


Figure 2.2.5: Continued

2.3 Carbon monoxide

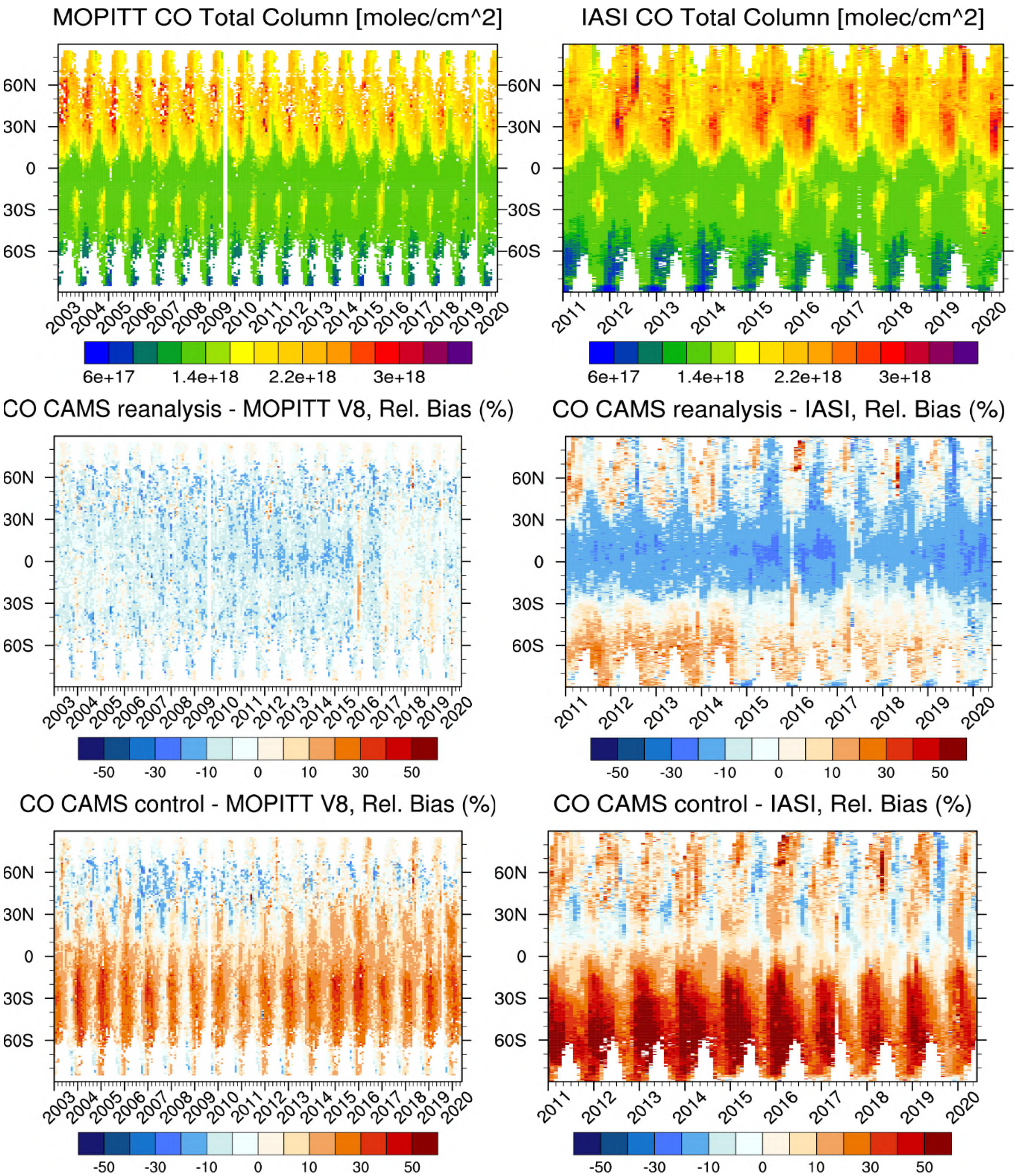
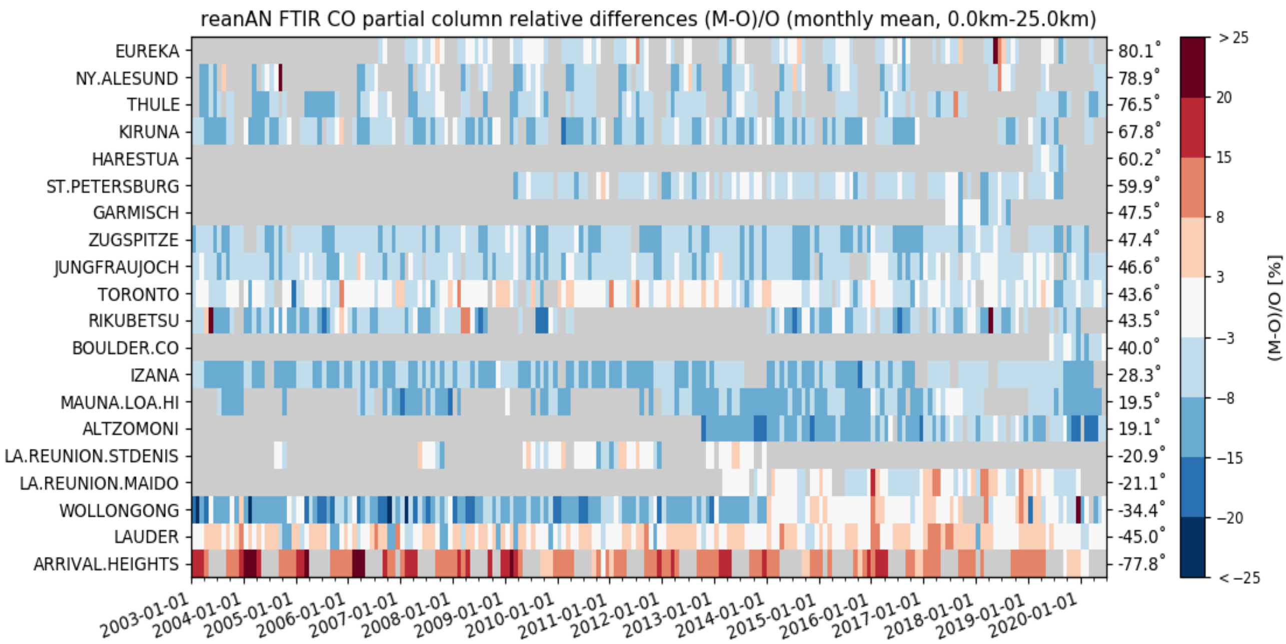


Fig. 2.3.1. (see previous page) MOPITT V8 (top left) and IASI CO total column (top right) as function of latitude and time. Relative difference between CAMS reanalysis (middle left) and CAMS control run (bottom left) and MOPITT V8 and relative difference between CAMS reanalysis (middle right) and CAMS control run (bottom right) and IASI. Please, note the different time axis, from January 2003 to June 2020 for MOPITT and from January 2011 to June 2020 for IASI. For the comparison with the satellite data, the modelled CO concentrations were transformed using averaging kernels from IASI and MOPITT respectively. The CAMS reanalysis CO total column is in good agreement with the MOPITT observations and have a slight negative bias within 10 % with some exceptions where the underestimation reach 20 %. The positive bias in the control run in the northern lowlatitudes is within 20% and during autumn 2019/winter 2020 it reached 30%. In comparison with IASI observations, starting from autumn 2019 the positive bias in reanalysis data over the SH high latitudes change the sign to negative. In comparison to both instruments, an increase of positive bias by 10% over the northern low latitudes during autumn 2019/winter 2020 can be seen in the control run. Note that IASI data versions were changed on 20141001, on 20190515 and on 20191211, which can be reflected in the comparison. Metop-B data were used for the comparison instead of Metop-A from March 2020.



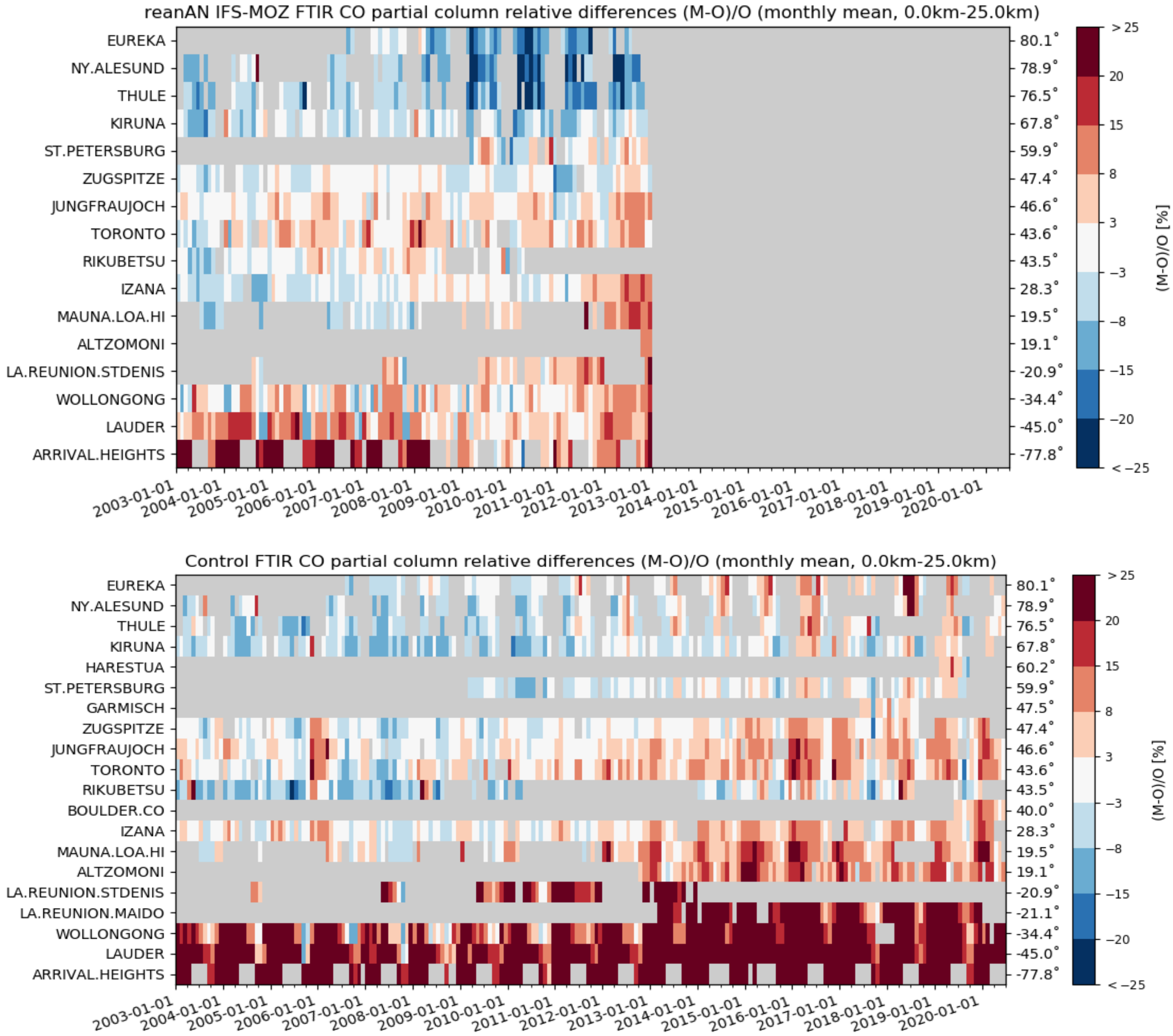


Figure 2.3.2. Mosaic plot of seasonal relative biases at all sites. The CAMS reanalysis (top) performs more stable compared to the CAMS control run (bottom) and MACC reanalysis (middle). Negative bias is found in the NH for the CAMS reanalysis. At the tropical sites in the northern hemisphere the negative bias reaches values up to 10% (Izana, Mauna Loa, Altzomoni). Between 2017 and mid 2019 the bias at these tropical sites and in the SH seem to have decreased, which may coincide with the assimilation of MOPPIT v7.

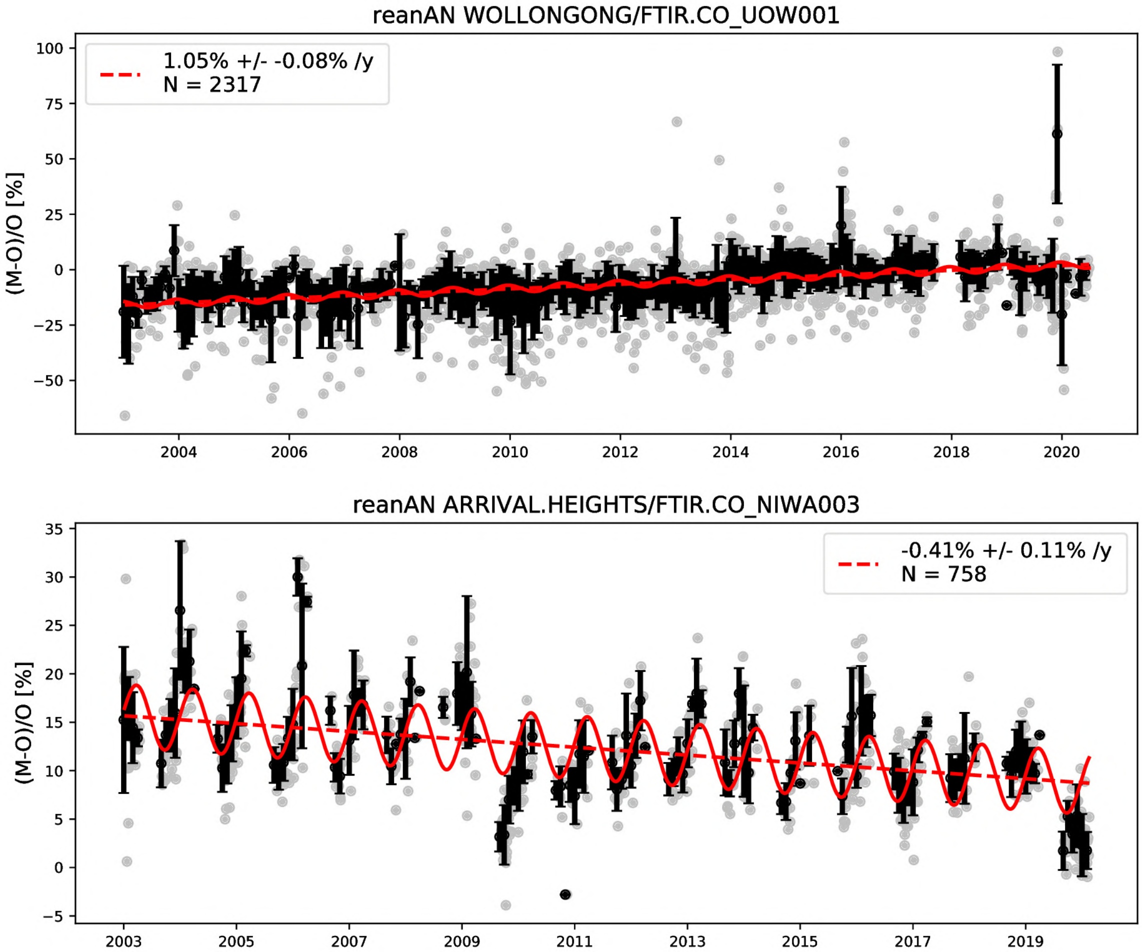


Figure 2.3.3. Trend estimates for the CAMS reanalysis for southern hemispheric NDACC stations. At Maido, Lauder and Wollongong a positive trend is observed, while at the Antarctic site Arrival Heights a negative trend is seen with a significant seasonal change in the relative differences.

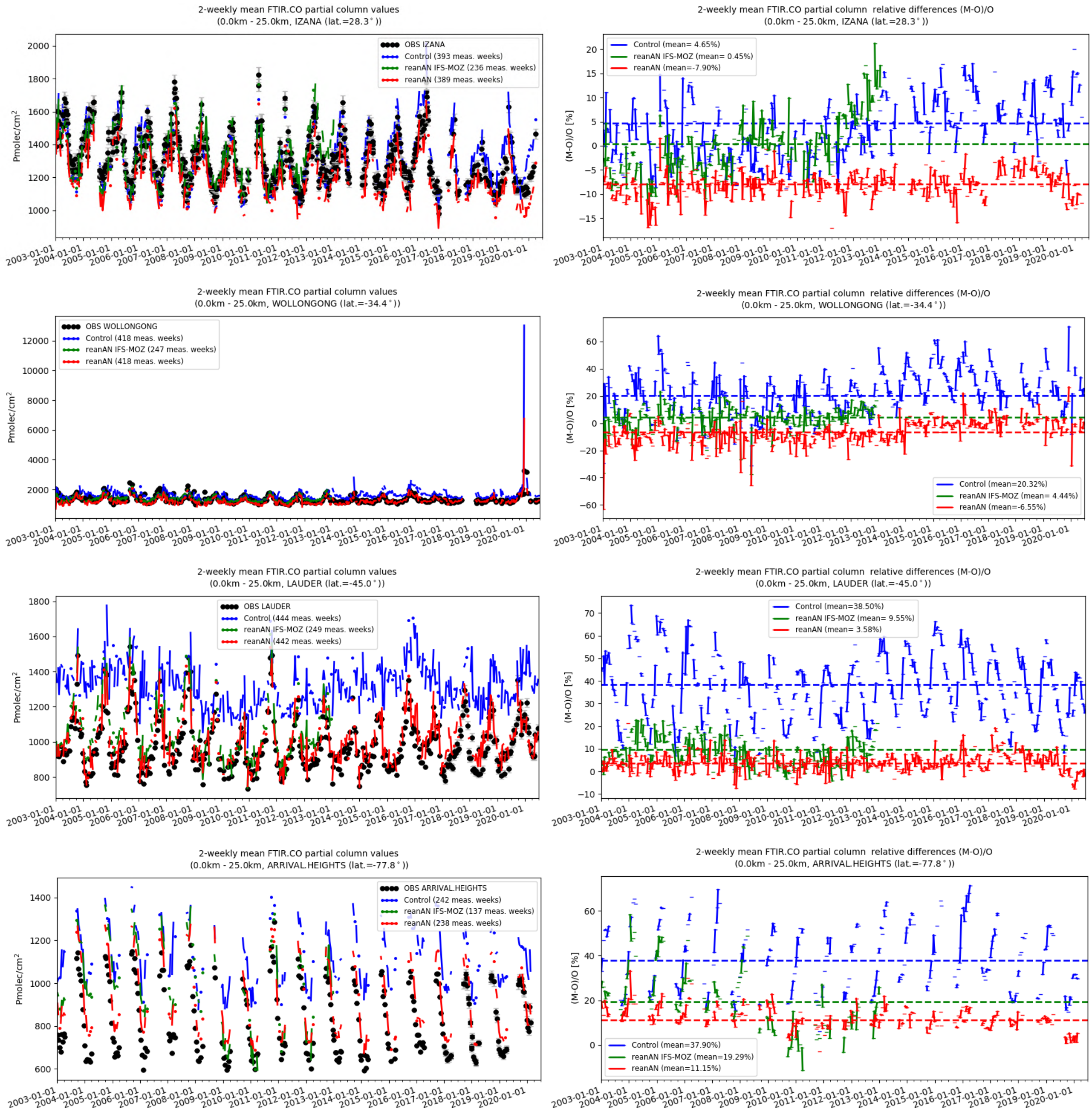
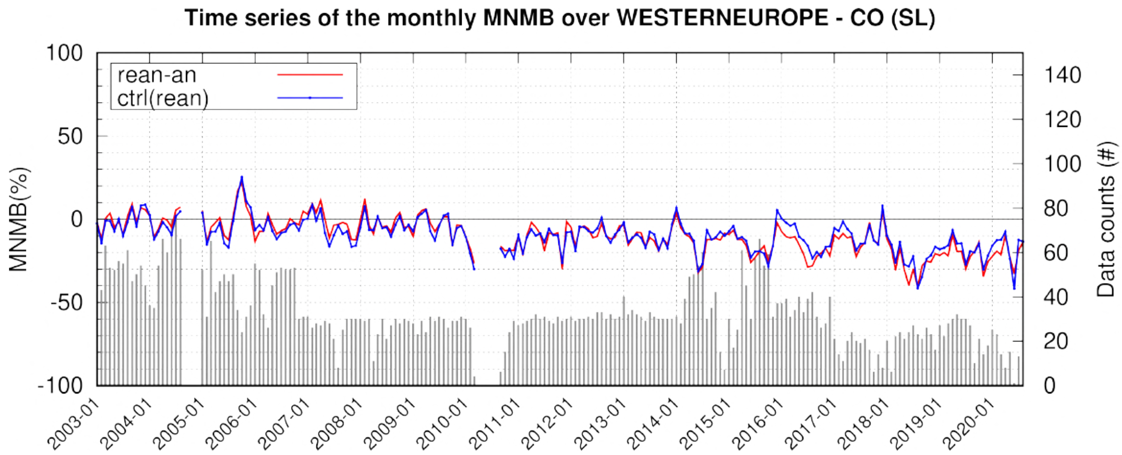


Figure 2.3.4. Time series plots at three NDACC stations (sorted by decreasing latitude, Izana, Wollongong, Lauder and Arrival Heights (Antarctic station)). The right column shows the biweekly mean differences. For reanAN the time series do not show strong differences within the entire time period (2003-mid 2020), which was the case for the previous reanAN IFS-MOZ (e.g. the increased bias in 2011-2012 at Izana). The Australian fires during Dec 2019 Jan 2020 seem to have been overestimated by both the reanalysis and the control run (differences above 150% have been removed from the difference plot in the right panel). At all three sites, the biweekly bias decreases mid 2019. It takes a longer time series to exclude seasonal effects.


Time series of the monthly MNMB over WESTERNEUROPE - CO (SL)
rean-an
ctrl(rean)
MNMB(%)
Data counts (#)
100
50
0
-50
-100
140
120
100
80
60
40
20
0
2003-01
2004-01
2005-01
2006-01
2007-01
2008-01
2009-01
2010-01
2011-01
2012-01
2013-01
2014-01
2015-01
2016-01
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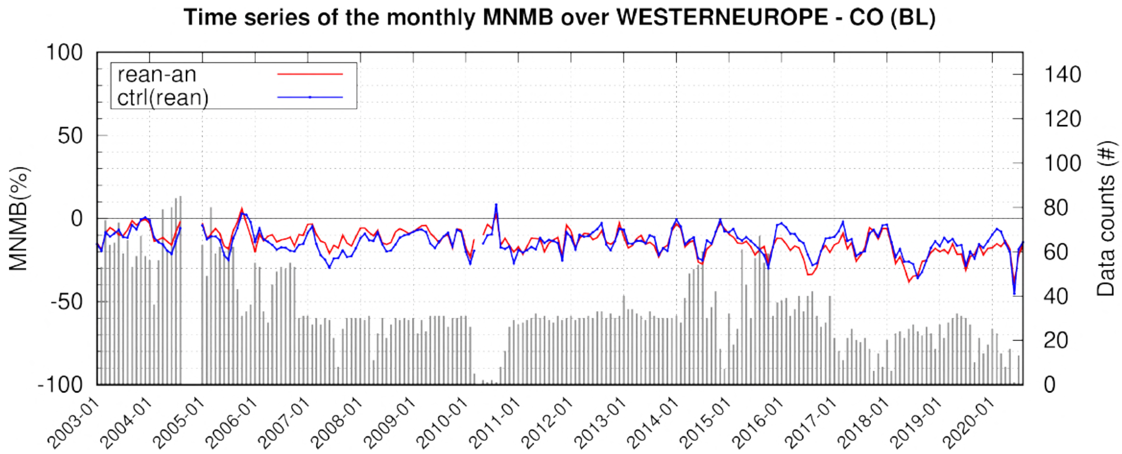
2018-01
2019-01
2020-01


Time series of the monthly MNMB over WESTERNEUROPE - CO (BL)
rean-an
ctrl(rean)
MNMB(%)
Data counts (#)
100
50
0
-50
-100
140
120
100
80
60
40
20
0
2003-01
2004-01
2005-01
2006-01
2007-01
2008-01
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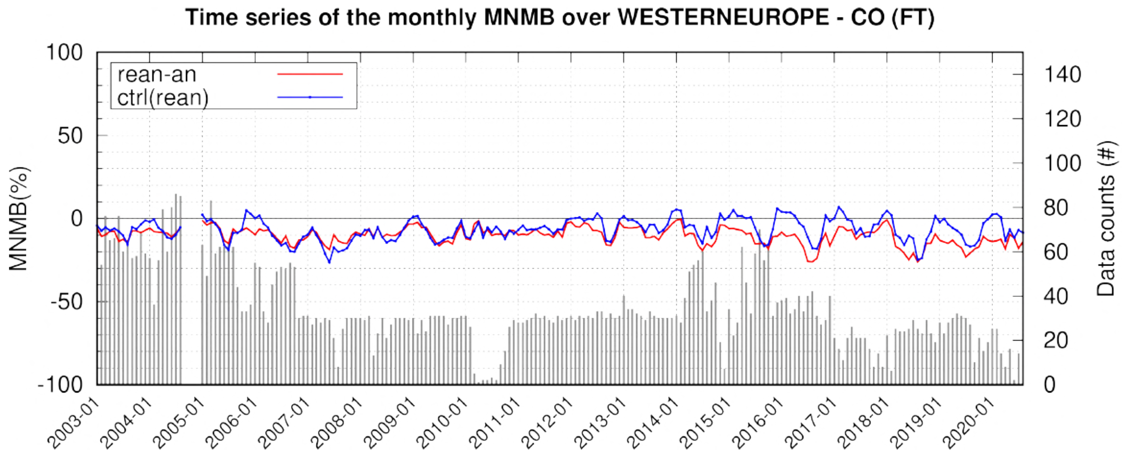
2018-01
2019-01
2020-01


Time series of the monthly MNMB over WESTERNEUROPE - CO (FT)
rean-an
ctrl(rean)
MNMB(%)
Data counts (#)
100
50
0
-50
-100
140
120
100
80
60
40
20
0
2003-01
2004-01
2005-01
2006-01
2007-01
2008-01
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2018-01
2019-01
2020-01

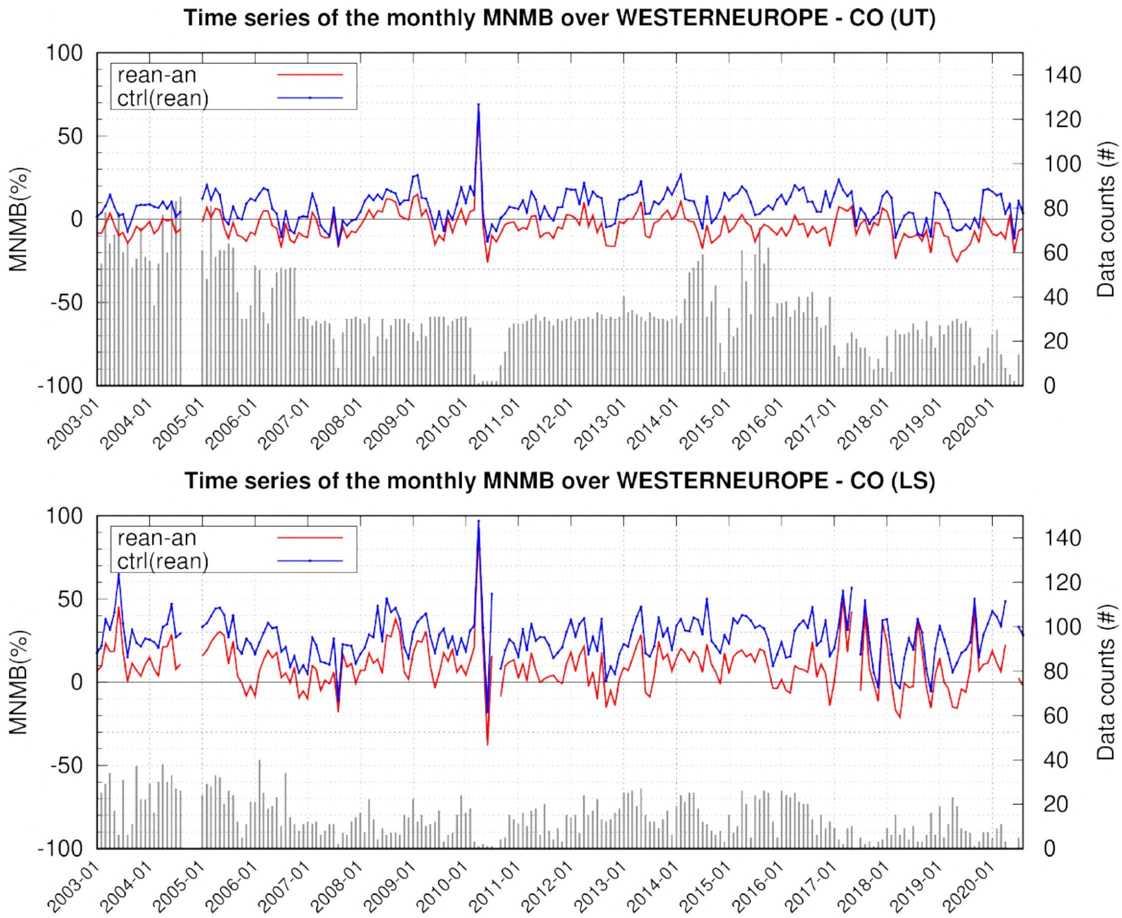


Figure 2.3.5: Time series of the monthly MNMB for CO in different atmospheric layers at Frankfurt during the period 2003-2020 compared with IAGOS aircraft data. From top to bottom for SL: Surface Layer, BL: Boundary Layer, FT: Free troposphere, UT: Upper troposphere, LS: Lower Stratosphere. Units: ppbv. In the surface and boundary layer MNMB results from the reanalysis and control run are similar. In the free troposphere, the control run is showing a smaller bias than the reanalysis in winter in the most recent years. MNMB values from the reanalysis appear larger in 2019 and 2020 than in 2018 or 2017, when the reanalysis shows results closer to those of control run. It is in the upper troposphere and lower stratosphere that the two runs differ the most. In the upper troposphere, for the most recent years MNMB presents a strong seasonality pattern for control run, with large positive values in winter and a good agreement in summer, while for the reanalysis the MNMB remains negative with a slightly better performance than control run. In the lower stratosphere, MNMB is positive for both runs with smaller values from the reanalysis. As compared to most recent years, no notable change is found for year 2020 so far.

2.4 Nitrogen dioxide

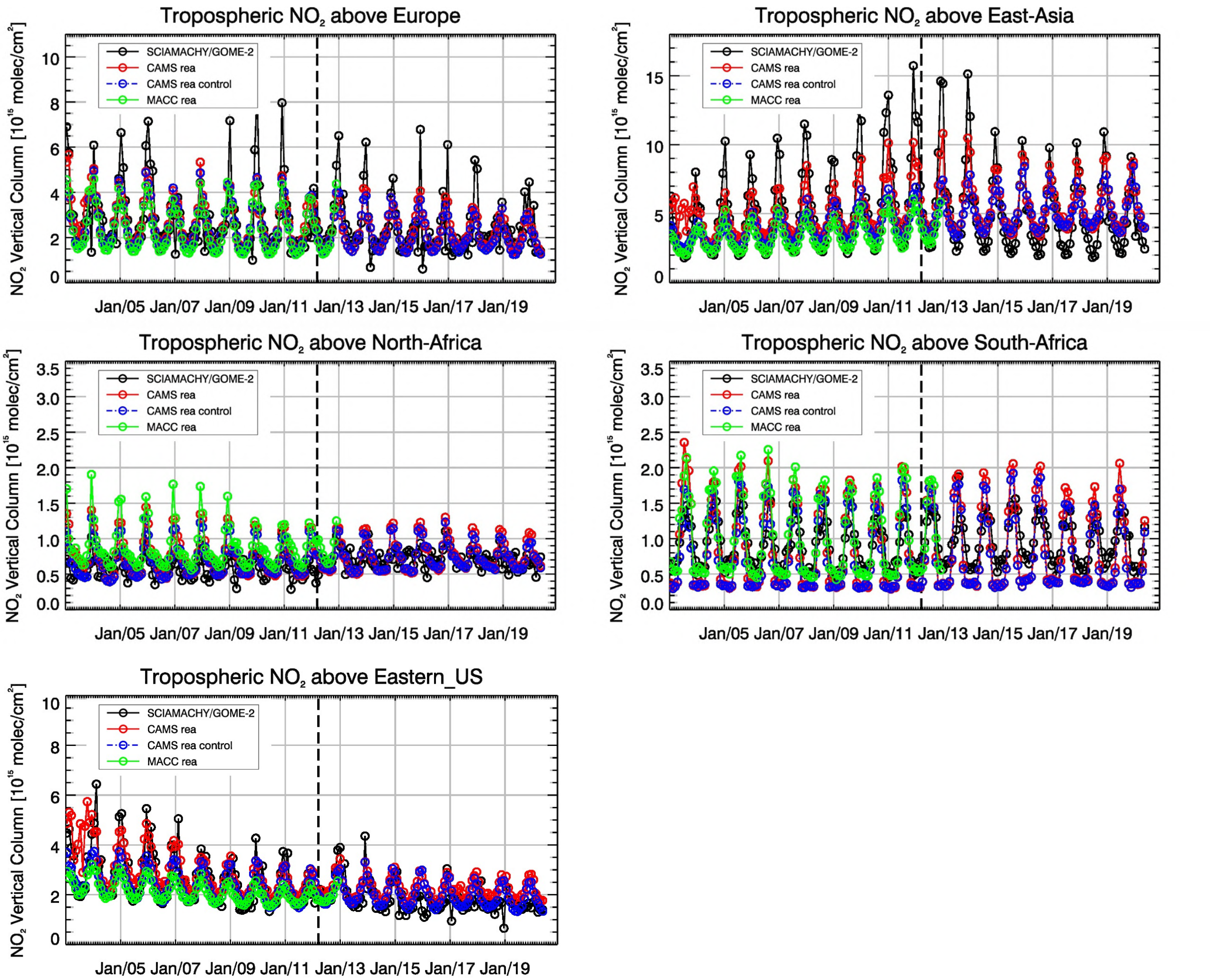


Figure 2.4.1: Comparison of time series of tropospheric NO2 columns up to June 2020 from SCIAMACHY (up to April 2012) and GOME-2 (from April 2012 onwards) to model results over selected regions. The switch from SCIAMACHY to GOME-2 is indicated by the vertical black dashed lines. Panels in the first and third row represent regions dominated by anthropogenic emissions; panels in the second row represent those dominated by biomass burning.

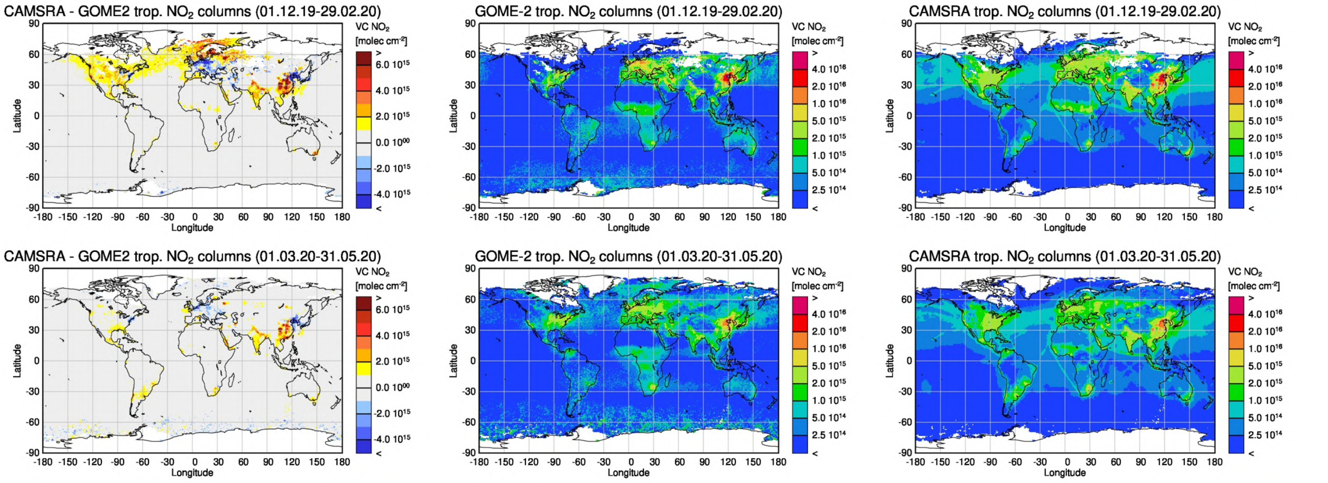


Figure 2.4.2: Global map comparisons of satellite retrieved and model simulated seasonally averaged tropospheric NO_2 columns [molec. cm^{-2}] for (top) DJF 19/20, (bottom) MAM 20. Shown are (from left to right): the difference between CAMS reanalysis and GOME-2, GOME-2 and CAMS reanalysis. GOME-2 data were gridded to model resolution (i.e. 0.75° x 0.75°). Model data were treated with the same reference sector subtraction approach as the satellite data.

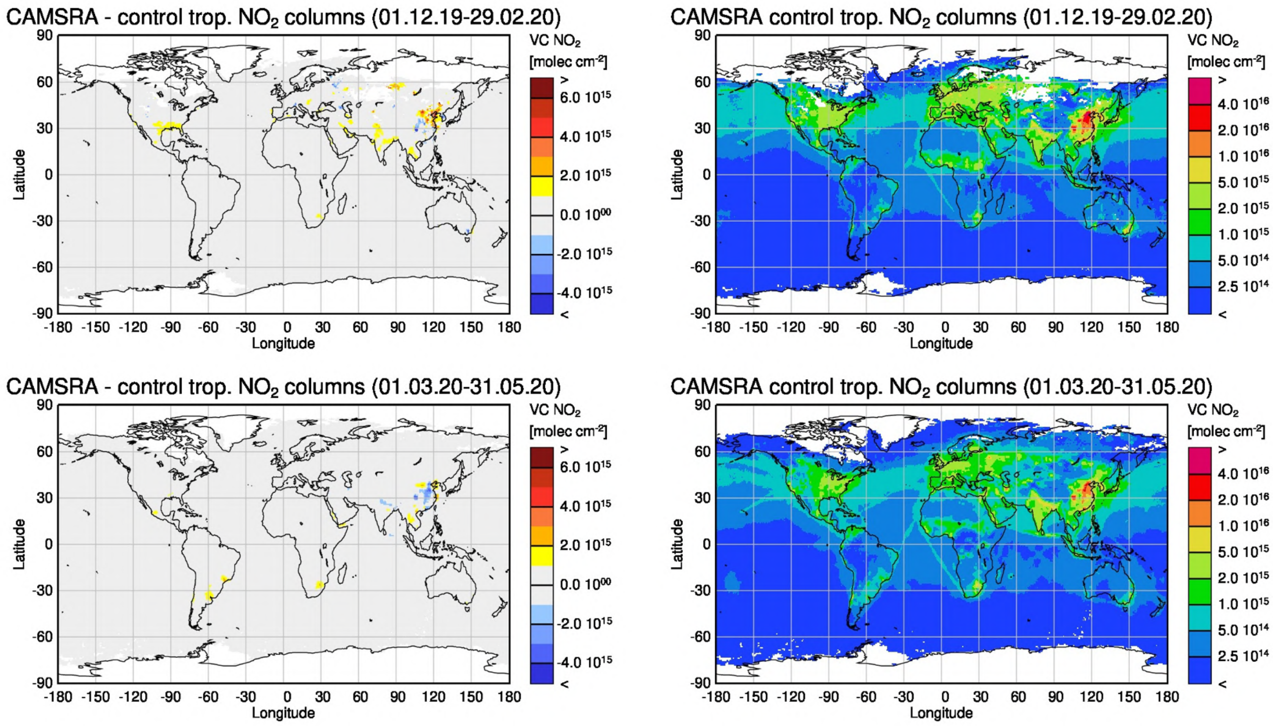


Figure 2.4.3: Same as Figure 2.4.2 but for (left) the difference between CAMS reanalysis and control and (right) the control run

2.5 Formaldehyde (HCHO)

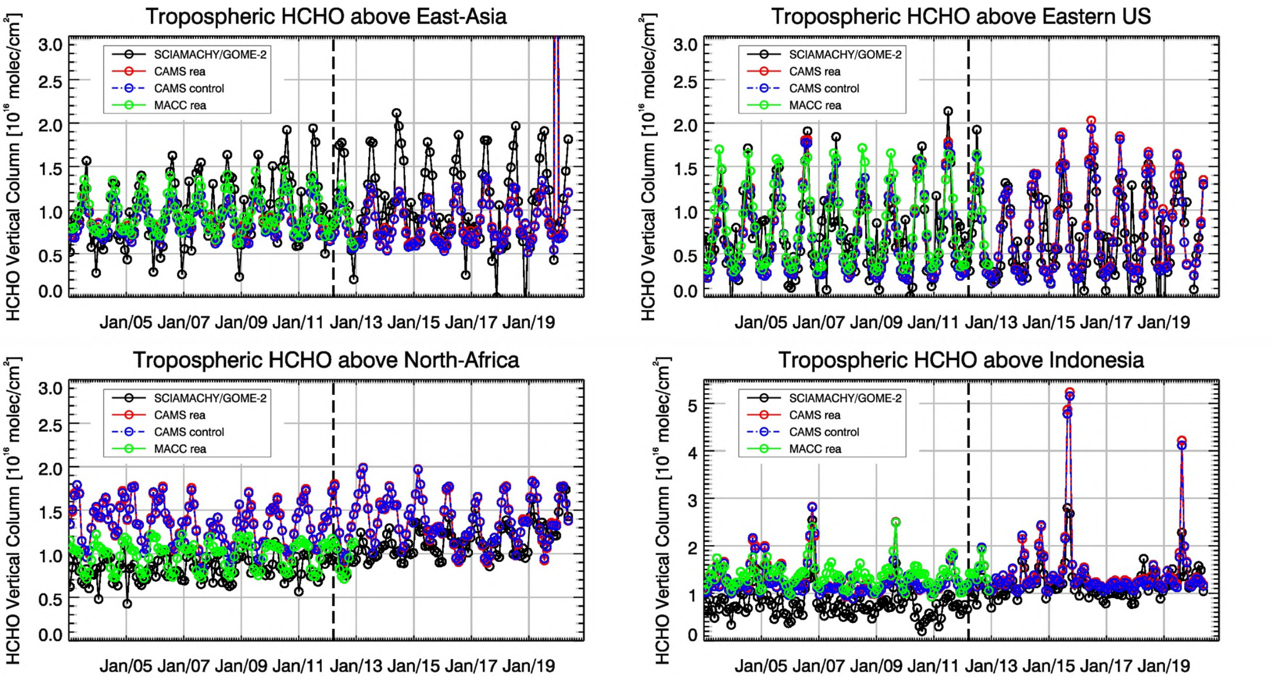


Figure 2.5.1. Comparison of time series of tropospheric HCHO columns from SCIAMACHY (up to April 2012) and GOME-2 (from April 2012 onwards) to model results over selected regions. Satellite data were gridded to model resolution (i.e. 0.75° x 0.75°). The switch from SCIAMACHY to GOME-2 is indicated by the vertical black dashed lines. The regions differ from those used for NO2 to better focus on HCHO hotspots: East Asia (25-40°N, 110-125°E), Eastern US (30-40°N, 75-90°W), Northern Africa (0-15°N, 15°W-25°E) and Indonesia (5°S-5°N, 100-120°E). Negative satellite retrieved values over Eastern US and East-Asia are due to a lack of data during Northern Hemisphere winter months for this region. The strong peak over East-Asia for Jan 2020 is as it seems a bug in the comparison results and should be ignored (will be checked before the full reanalysis report 2003-2020 is compiled).

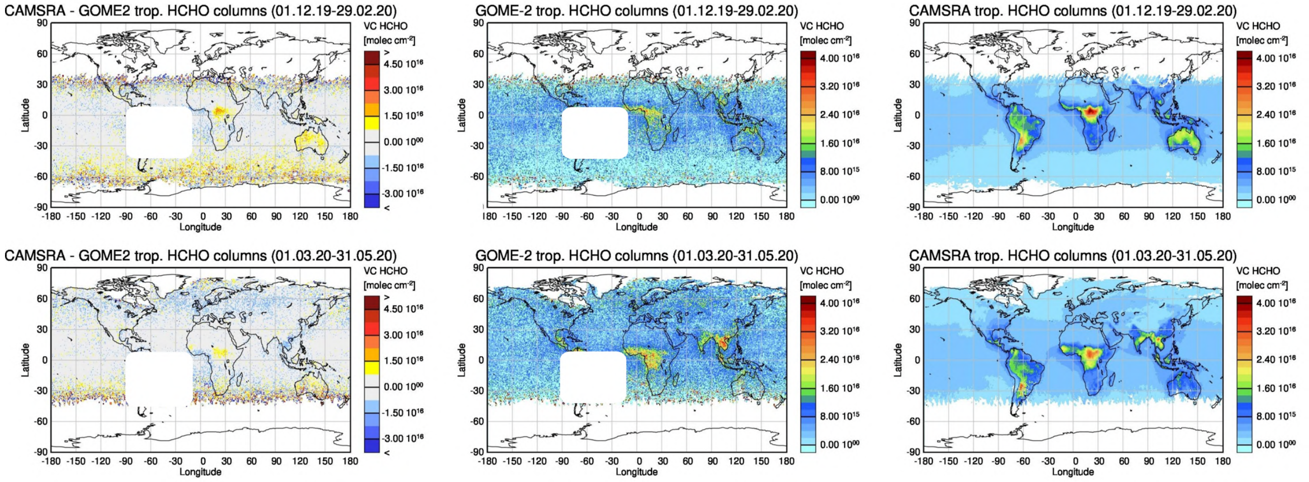


Figure 2.5.2: Global map comparisons of satellite retrieved and model simulated tropospheric HCHO columns [molec cm-2] for (top) DJF 19/20, (bottom) MAM 20. Shown are (from left to right): the difference between CAMS reanalysis and GOME-2, GOME-2 and CAMS reanalysis. GOME-2 data were gridded to model resolution (i.e. 0.75° x 0.75°). Satellite retrieved values in the region of the South Atlantic anomaly are not valid and therefore masked out (white boxes in all images except those that base on model results only). Noise at higher latitudes is an artefact of the satellite retrievals.

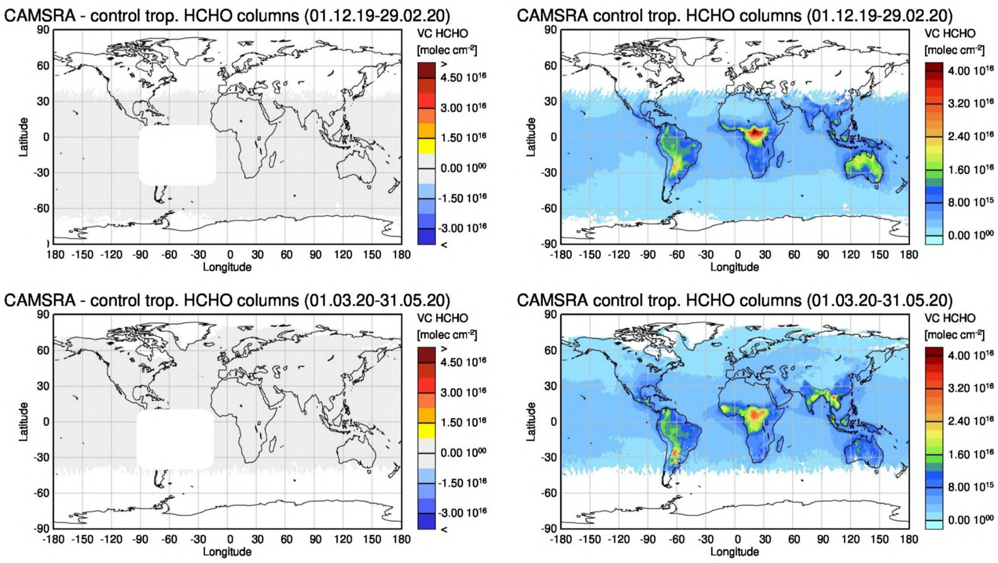


Figure 2.5.3: Same as Figure 2.5.2 but for (left) the difference between CAMS reanalysis and control and (right) the control run.

2.6 Stratospheric ozone

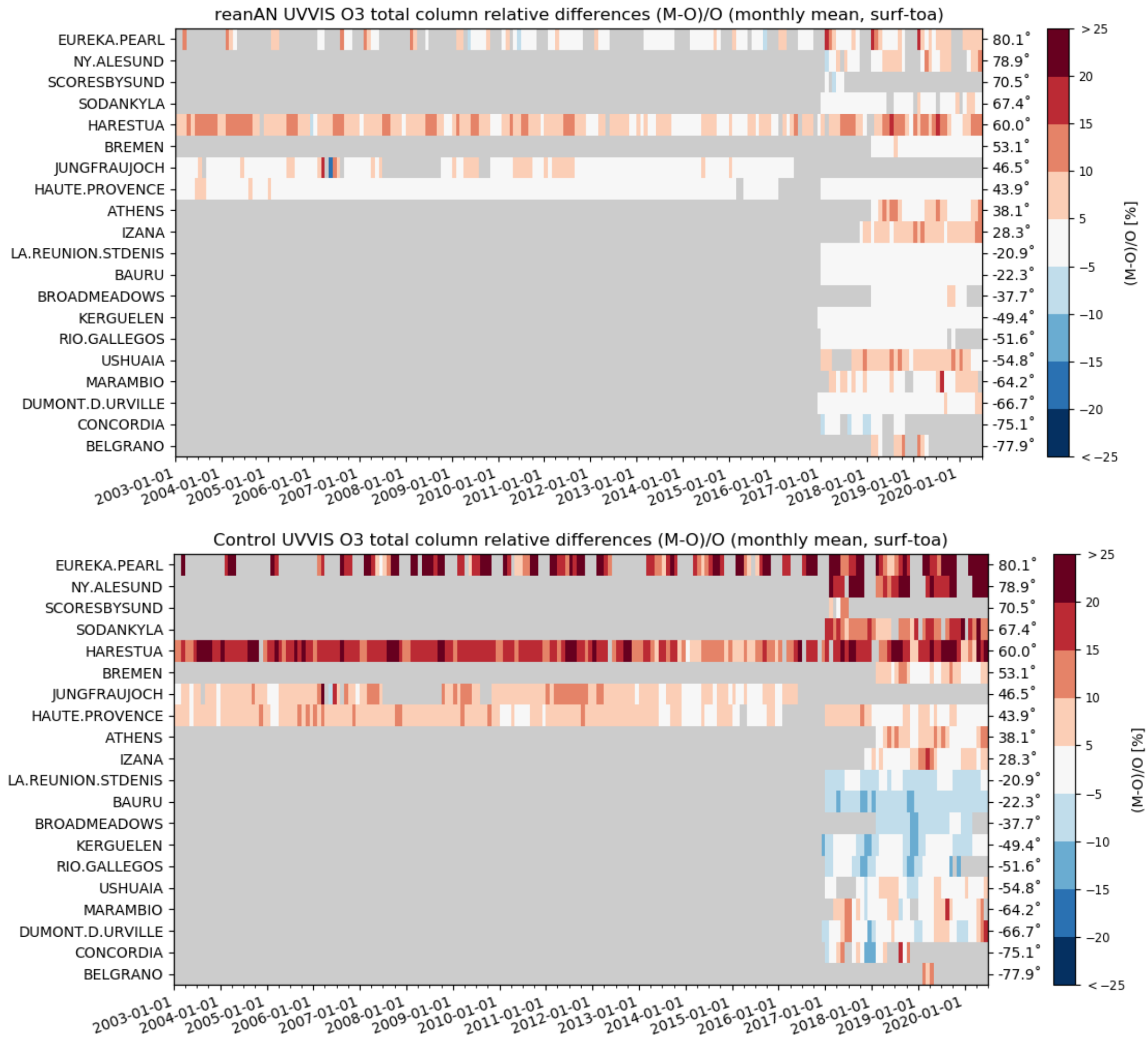
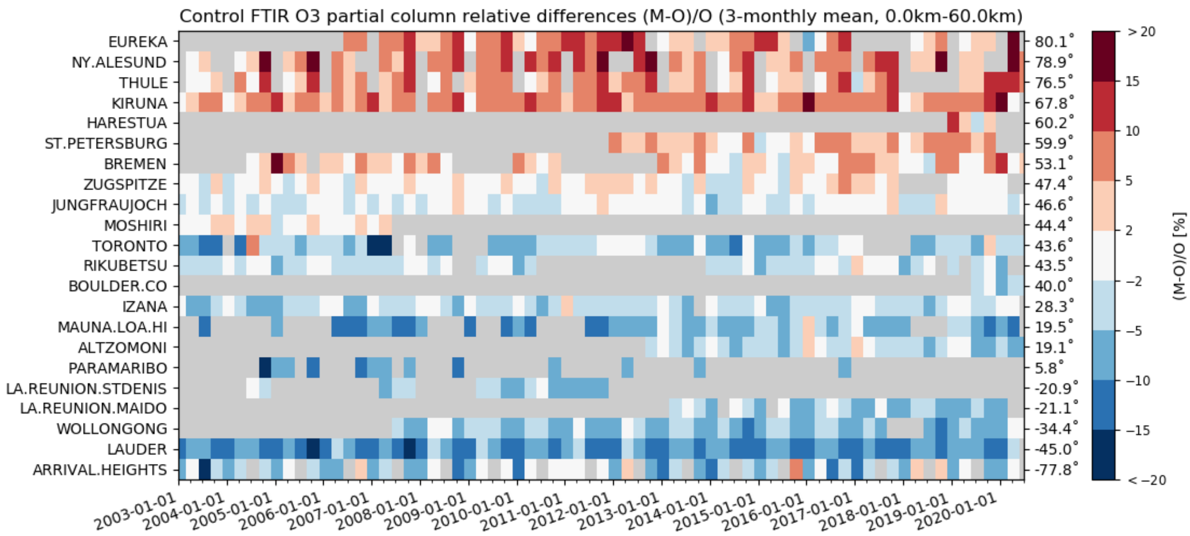


Figure 2.6.1. Time series of seasonal column differences for stratospheric ozone measurements from the NDACC UVVIS instruments. At some sites a trend can be observed in the seasonal biases for the models.



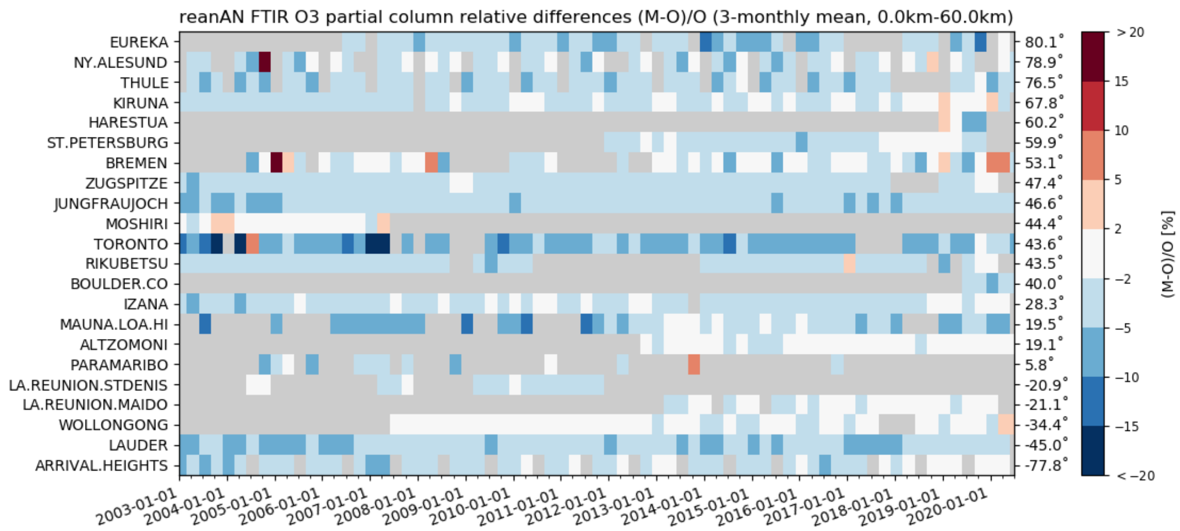


Figure 2.6.2. Time series of seasonal relative total column differences from the NDACC FTIR instruments for control (top) and the reanalysis (bottom).

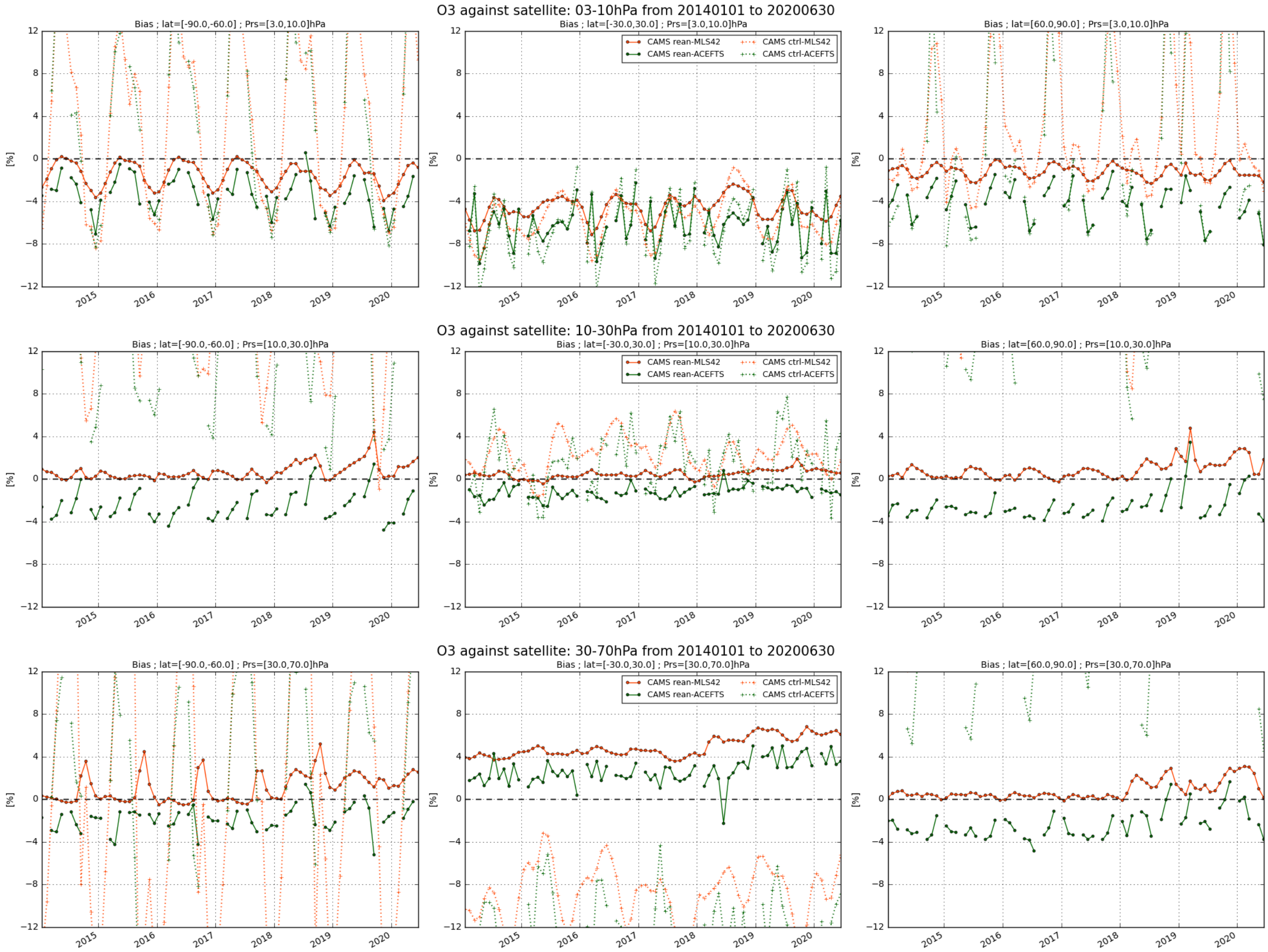


Fig 2.6.3. Time series since 2014 of NMB of CAMS reanalysis (solid) and its control run (dotted) against ACE-FTS (green) and AURA MLS (orange) for 3 layers (row 1: 3-10 hPa, row 2: 10-30 hPa and row 3: 30-70 hPa) and for 3 latitude bands (left: south Polar, middle: tropics, and right: north Polar). Seasonality and amplitudes remain the same over the period, except for a slight increase (~+2%) of the NMB since 2018 in the 30-70 hPa layer 2018 (attributed to the switch of the assimilated MLS data from v4.2 offline to V4.2 NRT). The patterns are similar for the profiles (not shown) of the mean seasonal biases against MLS and ACE-FTS for the 5 usual latitude bands in 2020 compared to the full period (since 2004)

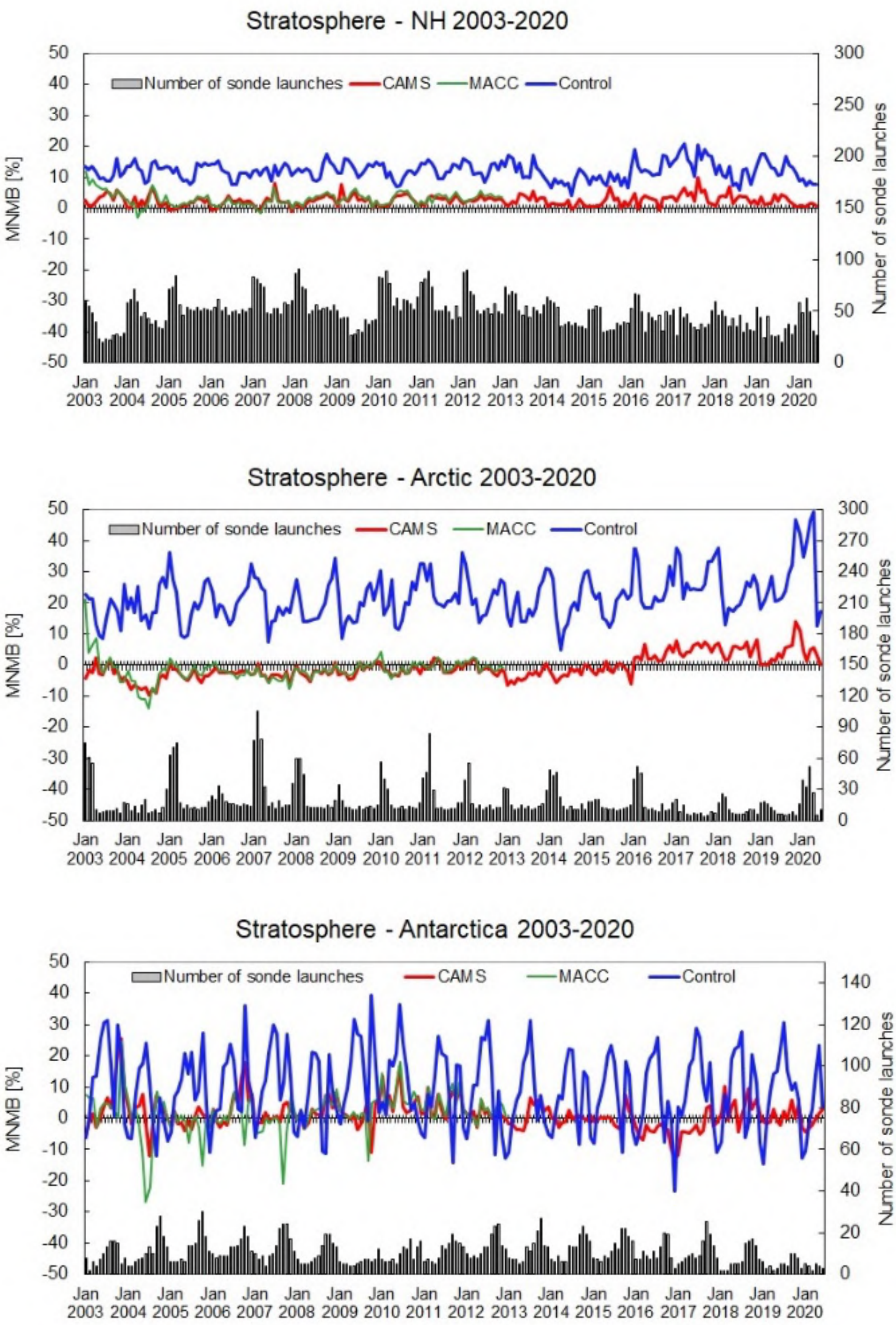


Fig. 2.6.4: Comparison with ozone sondes: MNMBs for the CAMS reanalysis (red), CAMS control run (blue) and MACC reanalysis (green) over the stratosphere of the Northern midlatitudes (top), Arctic (middle), Antarctica (bottom).

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