Supplement of Atmos. Chem. Phys., 18, 16155–16172, 2018
https://doi.org/10.5194/acp-18-16155-2018-supplement

Atmospheric Chemistry and Physics
Open Access
EGU

Supplement of

Tropospheric ozone in CCMI models and Gaussian process emulation to understand biases in the SOCOLv3 chemistry–climate model

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1. Figures

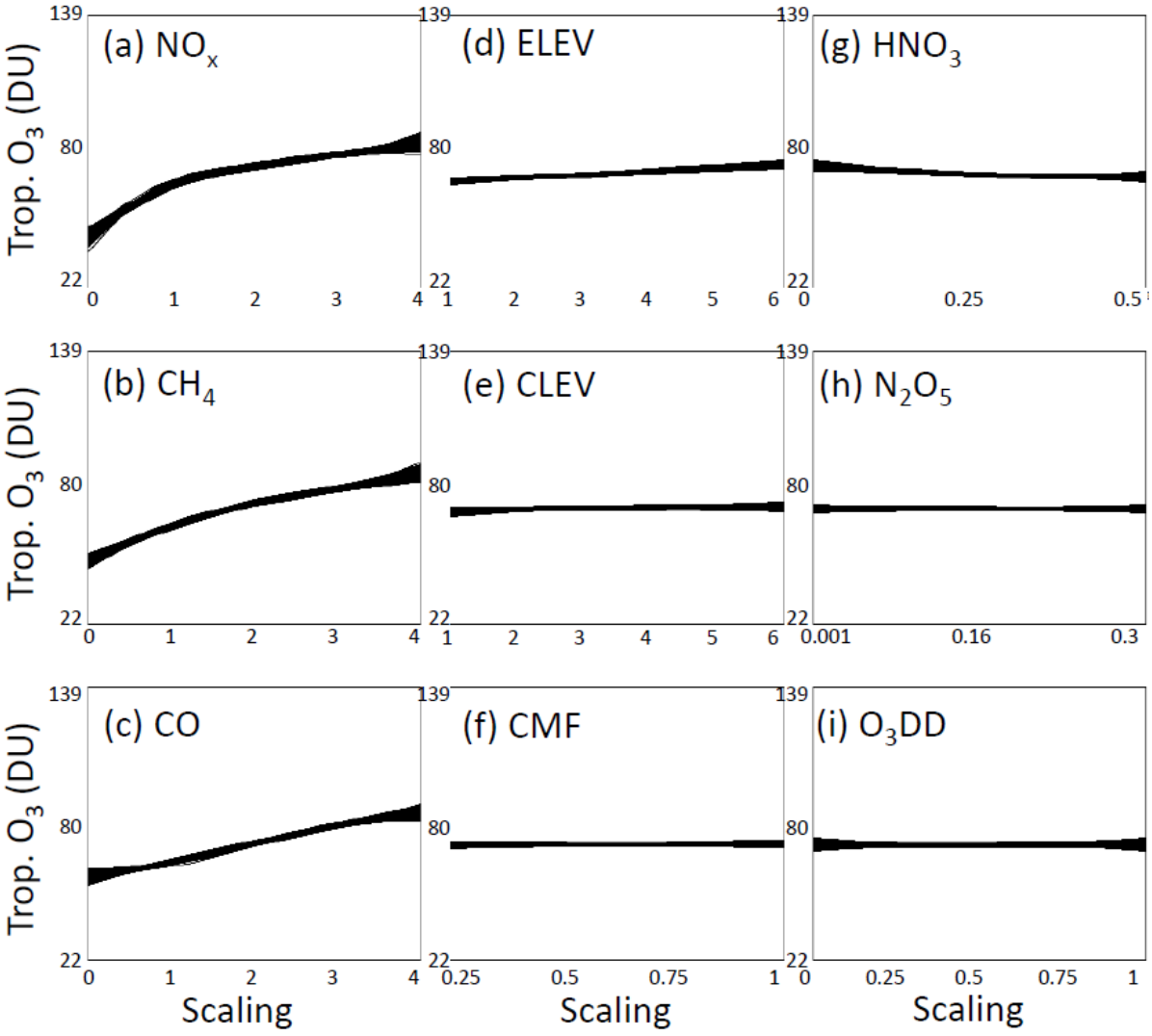

Figure 1. Sensitivity of annual-mean tropospheric column ozone over Europe in 2005 to each of the 9 sensitivity forcings/parametrizations listed in Table 1 of the manuscript, averaging over the other inputs. The horizontal axis shows the range of scaling factors applied to each variable.

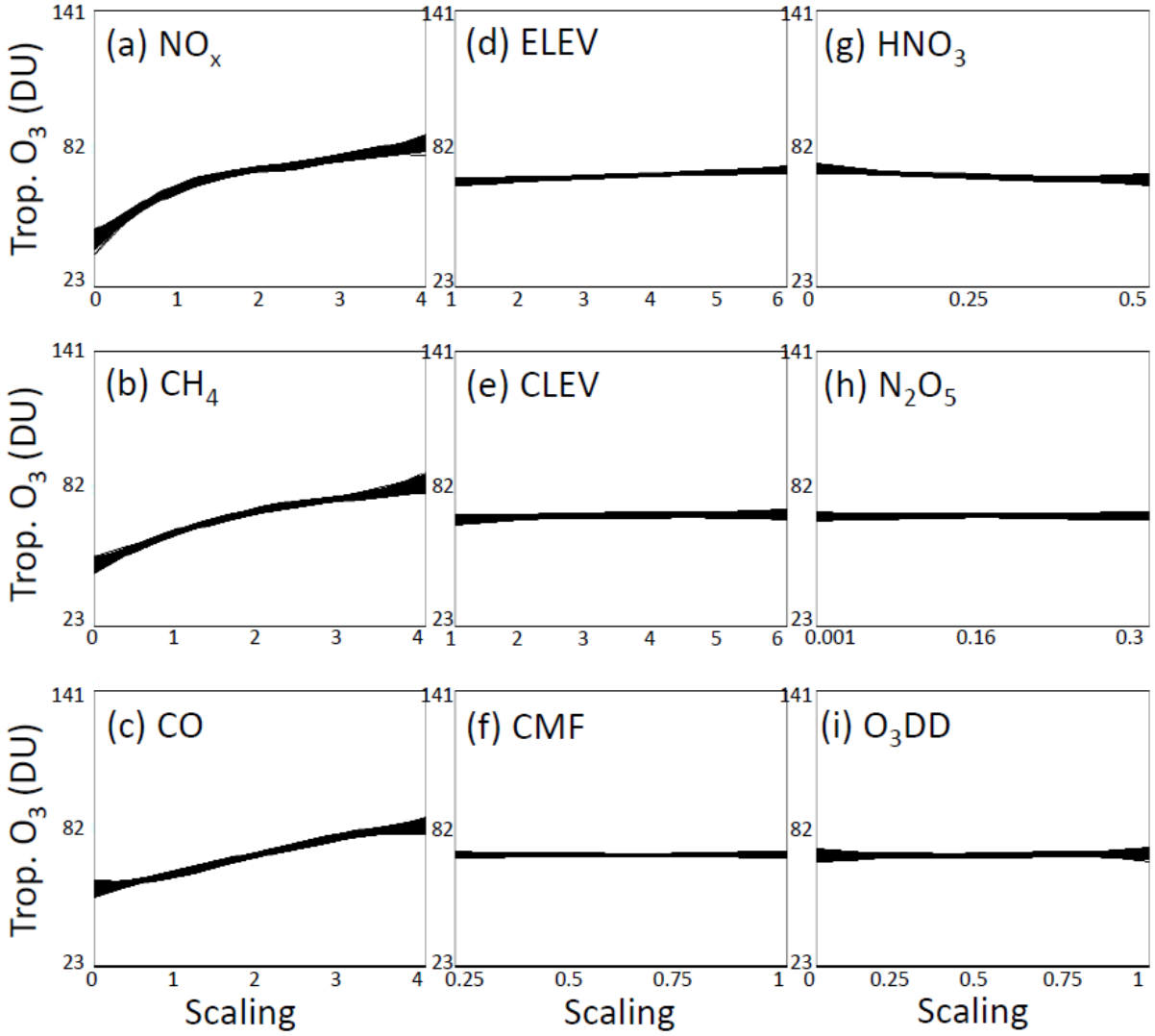

Figure 2. As for Figure 1, but for the United States.

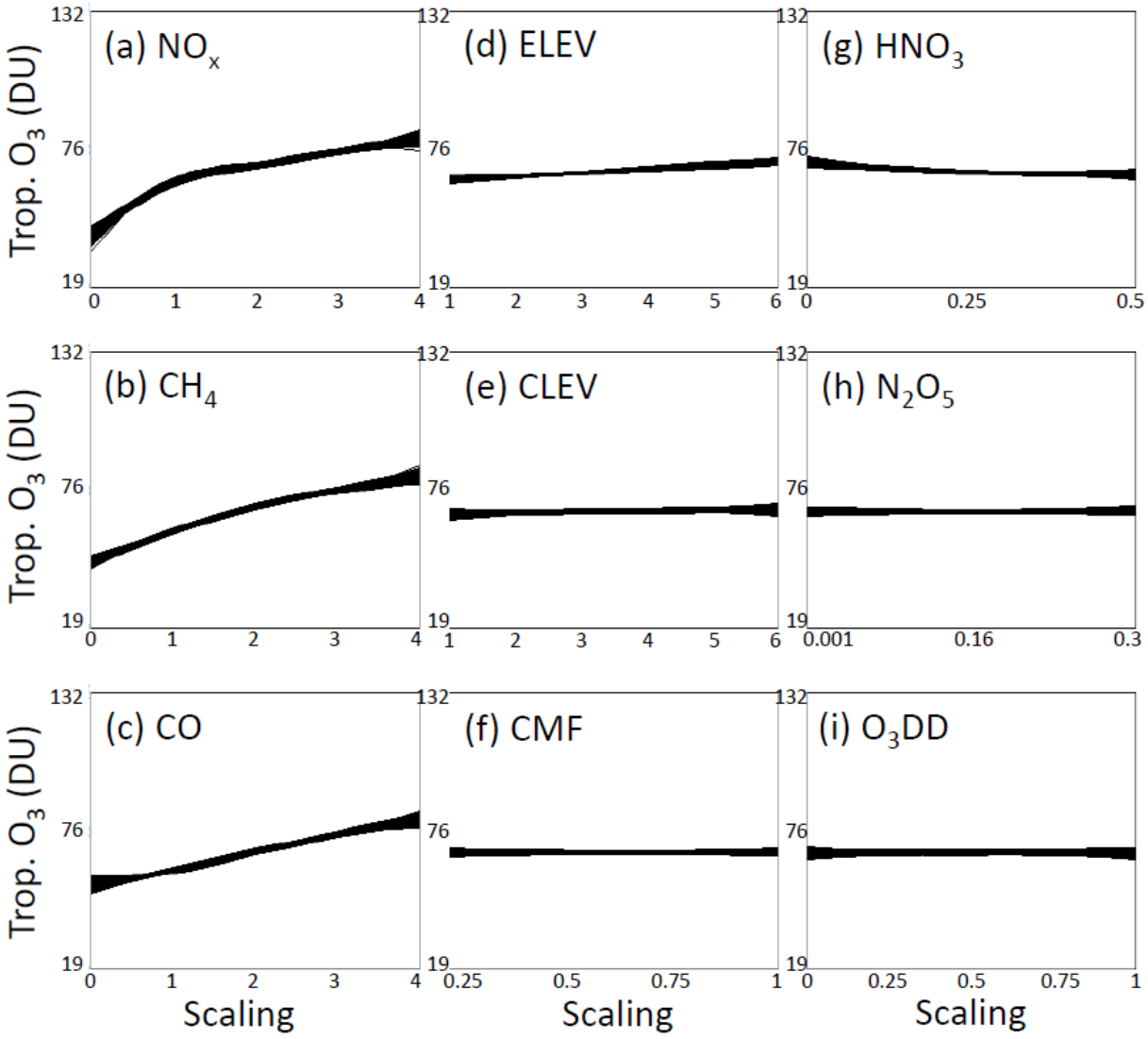

Figure 3. As for Figure 1, but for Asia.

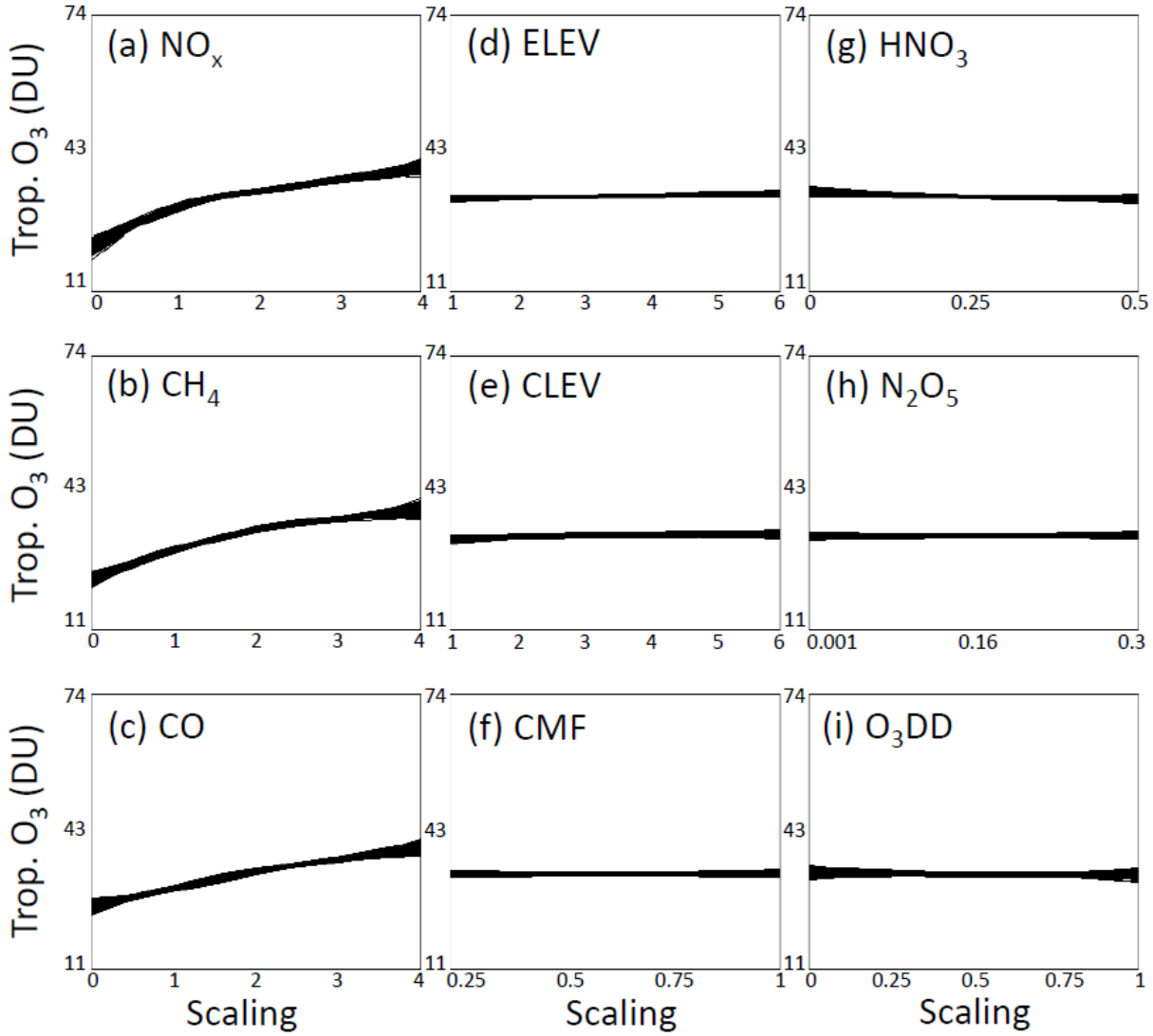

Figure 4. As for Figure 1, but for the Southern Ocean.

2. Latin hypercube for training GEM-SA

Rows correspond to the 90 SOCOLv3.1 experiments performed to train the emulator. Columns correspond to the 9 sensitivity forcings/parametrizations listed in Table 1.

1.528090	2.426966	1.393258	4	4	0.384831	0.606742	0.058112	0.865169
0.449438	0.988764	1.797753	6	3	0.553371	4.449438	0.014438	0.404494
3.640449	0.314607	2.606742	3	4	0.528090	7.887640	0.121944	0.561798
3.820225	2.157303	0.000000	4	3	0.747191	3.438202	0.269764	0.280899
1.258427	3.280899	2.561798	6	2	0.275281	1.213483	0.037955	0.797753
2.606742	1.887640	0.359551	2	5	0.460674	15.168539	0.263045	0.764045
1.033708	3.325843	0.539326	4	2	0.342697	5.460674	0.286562	0.741573
2.157303	1.438202	2.786517	2	5	0.359551	13.348315	0.091708	0.359551
0.988764	2.516854	2.516854	5	3	0.443820	17.191011	0.074910	0.067416
1.932584	3.820225	0.853933	3	3	0.258427	8.696629	0.071551	0.640449
0.359551	0.853933	0.134831	2	1	0.865169	11.730337	0.001000	0.112360
3.280899	0.764045	2.471910	2	1	0.932584	9.101124	0.128663	0.842697
3.460674	1.348315	3.011236	6	3	0.266854	9.910112	0.041315	0.202247
0.089888	2.202247	3.910112	2	3	0.890449	8.898876	0.152180	0.393258
2.561798	3.595506	1.752809	5	4	0.250000	10.516854	0.226090	0.247191
3.415730	1.258427	1.617978	2	5	0.966292	4.247191	0.172337	0.943820
1.303371	3.415730	2.022472	4	5	0.410112	17.797753	0.283202	0.460674
3.056180	1.168539	2.292135	5	5	0.907303	2.629213	0.125303	0.471910
2.786517	3.370787	3.280899	2	5	0.780899	12.539326	0.300000	0.101124
3.910112	1.752809	3.955056	2	6	0.823034	0.000000	0.145461	0.292135
1.617978	3.910112	1.438202	6	3	0.637640	1.617978	0.155539	0.707865
3.595506	3.955056	1.213483	3	5	0.856742	13.955056	0.185775	0.348315
3.775281	2.921348	3.370787	2	5	0.949438	18.000000	0.115225	0.269663
3.191011	2.247191	2.426966	1	3	0.831461	7.078652	0.004360	0.505618
3.370787	2.831461	3.325843	2	2	0.292135	11.932584	0.239528	0.898876
4.000000	2.337079	3.415730	4	2	0.797753	7.280899	0.081629	0.539326
1.168539	3.505618	0.269663	6	2	0.671348	14.359551	0.051393	0.606742
2.966292	2.022472	0.629213	5	1	0.334270	5.056180	0.189135	0.382022
3.685393	1.977528	0.314607	4	3	0.519663	10.921348	0.192494	0.820225
0.719101	2.561798	1.842697	5	3	1.000000	11.528090	0.289921	0.449438
1.977528	0.898876	0.179775	1	4	0.924157	12.134831	0.236169	0.213483
0.629213	2.696629	3.775281	2	3	0.435393	8.494382	0.088348	0.000000
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1.123596	0.719101	0.494382	3	6	0.300562	3.235955	0.031236	0.314607
2.247191	1.078652	1.168539	3	4	0.317416	16.179775	0.095067	0.876404
1.438202	3.146067	1.078652	5	3	0.620787	5.258427	0.024517	0.022472
0.134831	0.269663	3.685393	4	5	0.730337	8.089888	0.048034	0.629213
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0.674157	1.617978	1.033708	6	4	0.544944	2.224719	0.266404	0.516854
1.213483	0.404494	2.112360	1	3	0.755618	1.820225	0.252966	0.370787
1.078652	2.786517	0.674157	2	5	0.696629	14.561798	0.276483	0.089888
0.179775	2.741573	1.707865	2	2	0.283708	14.157303	0.259685	0.966292
1.662921	1.662921	3.820225	5	1	0.494382	5.865169	0.158899	0.191011
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0.224719	0.584270	2.966292	4	4	0.477528	1.011236	0.179056	0.674157
0.808989	4.000000	1.932584	2	6	0.426966	6.876404	0.101787	0.932584
3.235955	2.651685	3.595506	5	3	0.806180	9.303371	0.296640	0.752809

```
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1.393258 2.112360 1.977528 1 5 0.991573 3.033708 0.162258 0.224719
0.584270 0.494382 0.224719 4 1 0.688202 7.685393 0.068191 0.831461
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0.764045 0.674157 3.235955 5 2 0.848315 16.584270 0.205933 0.584270
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2.292135 3.011236 3.865169 3 6 0.603933 3.640449 0.084989 0.853933
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2.741573 1.797753 2.831461 4 5 0.325843 15.370787 0.242888 0.786517
3.955056 2.292135 1.573034 5 5 0.772472 16.786517 0.256326 0.325843
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1.573034 2.471910 2.741573 4 1 0.662921 9.505618 0.007719 0.651685
```

3. Latin hypercube for testing GEM-SA

Rows correspond to the 27 SOCOLv3.1 experiments performed to train the emulator. Columns correspond to the 9 sensitivity forcings/parametrizations listed in Table 1.

```
1.846154 1.846154 3.538462 6 5 0.307692 13.153846 0.058500 0.269231
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0.615385 2.461538 1.230769 2 5 0.942308 4.153846 0.208000 0.807692
```

4. Annual-mean tropospheric column ozone for training GEM-SA

a) Global-mean

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c) United States

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73.7833306826414
66.5386509135047
70.7268321297041
83.0047085959973
82.4496852484327
48.0900420178651
75.1552909214263
79.6544803457206

d) Asia

71.1189768252949
46.1984142544024
61.3073062739345
63.6535030717030
75.9879552258782
56.5222985670954
57.5430877055836
69.6349028739410
65.7475140194824
69.7135863048525
30.0962715187457
65.0865308404878
82.5448938537341
39.2166569038697
82.5889908963265
65.9165694601650
68.9495931342433
72.1868127496880
88.3381310348807
131.803416252491
77.9824543572276
84.5361462434283
91.3717987982971
77.8526568843629
88.0623182253695
91.7582717020157
60.6642570523697
64.7791285195757
61.8885355536836
57.5515701421050
39.8166110520640
60.2300481520126
90.4218709124610
44.9263082407904
43.5842983436838
18.9802663659043
80.8047933426246
31.9024656784285
73.3661997287915
47.2075745636098
38.3163452492353
50.7952231753323
39.5811053929194
53.9410479989090
66.9142450580376
71.9779566012792
39.8552163777888
67.8691461132313
53.9014171776893
49.1442131746711
52.0646277389947
41.1711265322832
62.6214926345280
52.0098989074459
50.1102011958535
49.5438424876854
55.2401245802080
42.5585670445074
75.7889148575881
52.3625585909376
74.9353963791082
73.3901217509718
84.9604850259962
42.8821913962796
64.0238982948246
92.4694331979996
31.9231985443371
77.6725975587399
63.4097796228508
28.7570723492937
71.7975503351959
87.6983899582155
56.5940983492367
46.9779927912161
87.2790263875118
47.7221297490315
71.3723997212485
70.2726569405883
77.2862066504119
79.7562426576933
87.0784495025989
65.8276937920593
74.7755361923550
68.5775025084649
60.5478512693232
64.5460065203203
75.6016862431438
76.0998238882012
45.3029412084740
65.9033617001924

e) Southern Ocean

35.4442934099174	20.9220923286040
24.6642630280487	33.2551472813228
28.5396560513084	28.0216371563466
30.7617451514325	26.5679303816482
38.7952550301757	26.7345674298650
28.6620451002733	22.2075493023921
29.4818975806757	31.8237543152294
35.3048822458157	27.0064186035049
34.5386802265149	26.1735741277334
35.2026710990223	24.2044576241861
16.5727035540977	28.9003251607638
31.5817734800531	23.8635034102648
40.4967149236137	37.6190602464838
22.1628380798472	26.0613366308730
41.8862033786950	39.2803733145246
32.0368658497386	36.3902713808934
36.5326159776999	42.4821483176575
35.4805926178325	22.0087839199444
44.7122529401323	33.2105540199244
73.7922380180535	46.4139389327705
39.2427945221364	17.8681233341553
41.4605895566142	38.5424165618360
45.8218994328396	32.4804701366125
40.0532510535314	15.7199318942089
44.6830169000786	35.8327945104799
45.2744113714635	41.9386772717501
30.0354703482622	28.3289213361804
32.0659072407578	22.7187029626352
31.0145723065249	44.3504990727673
30.7135466773455	26.0560513582564
21.3306038347072	37.2436054078251
32.3088179279301	35.6973547063742
45.0434787507881	39.1446472148575
23.3894532699434	39.4709909072132
23.8872528824644	42.8036575847542
10.2419780383730	32.9858209009018
39.0517212068710	36.2967421750196
20.4654526434439	34.3316084289945
38.3283857164841	27.0006854797322
23.4990655117832	33.2694318473688
19.6038245675493	38.1598345609232
24.3756496645922	35.9607342008613
20.4622491097795	21.7554788361890
27.5638517195855	34.2421070814071
33.9247273611012	36.8396173167922

5. Annual-mean tropospheric column ozone for testing GEM-SA

a) Global-mean

64.1094260139236
39.8592878759897
25.9762660560213
68.3437733742903
50.8466442608444
63.0679790599457
78.1981097297149
25.8936348537035
49.4863643961266
54.0855283201165
38.3228021916278
66.0254192120765
124.904022167976
35.1455177115560
57.2593712257349
35.1532240023364
55.5934820608264
41.9104365689689
55.9601089189313
69.2523856919063
34.8668071442939
60.4911858496477
70.1647059367720
45.9705883166739
59.3812191696582
49.5223807929822
42.9760105764364

b) Europe

90.0173555495990
55.7256662725488
33.1056928817908
89.5521403686594
69.7881386146251
86.0307575452015
109.021892107235
34.8025008267001
71.8263025815471
73.4777318292815
54.9855794939209
92.3511883299382
153.857023952015
48.7605384989760
73.9477464499798
50.3857062153926
75.2782389483391
54.1035214949172
75.7491128228839
91.8009266525501
47.1257153159602
81.0591831422651
94.3482806405009
61.9015688657900
81.0236231000321
70.2635009532136
58.9854258940294

c) United States

87.5815733291822
54.3553534251862
33.7432916814090
89.8988967733506
68.9285630514810
84.8682910766119
106.575164512325
34.7982609694395
69.8444982287127
73.0708158621856
53.3307421198716
89.5877147739196
153.286578071294
48.1249793394503
74.8734613627370
48.4856044422142
74.3961789108807
55.1396171453112
74.7116328555402
91.5470757180299
46.4423243911773
80.6466110969580
94.3819230172457
61.4820154528789
80.3619922614012
68.1421017370951
57.7819515150578

d) Asia

78.5903616906933
47.1195200547662
30.9036284741404
85.0484072264480
62.7050608006358
78.0979801961360
97.1948058442665
28.5064128413996
60.9783835991939
66.9712989795977
46.8046307407175
83.1504887575895
141.958605895552
41.0235594462740
71.0848018721525
42.7281042503446
67.4771827402513
52.2745100852010
67.8232629664757
85.3905742292168
42.1093639051140
75.3404232532580
87.4203431808494
57.0020504484040
73.5135623315723
59.9414583677055
51.5555296890324

e) Southern Ocean

40.1245027677369
25.5416463720283
17.1272126772397
42.3480411243712
31.7318924214952
38.5566182860552
48.2242189629273
17.0128641527830
30.6176417602181
32.7734268612336
22.6413549066323
37.5384863374725
81.9253762530247
22.9015439646450
34.2870309902752
21.8189979928048
34.9580529370217
25.0866744285978
35.1658954088420
43.6583315482298
21.8896230120542
37.1037949287741
44.1556902787817
28.2118229471738
36.4729457951587
31.1854478099042
27.1324156514906