Supplement to Balloon-borne Stratospheric Vertical Profiling of Carbonyl Sulfide and Evaluation of Ozone Scrubbers

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S1 Tests on gas species removal due to O_3 scrubbers

The effects of different O_3 scrubbers on COS and O_3, tested on tropospheric compressed air, are shown in Fig. S1 and S2. The p-values of the ANOVA test for each species are reported in Table S1 and Table S2.

When O_3 was not generated, none of the two scrubbers showed significant differences with the bypass channel neither for COS, nor for O_3. Clearly, the O_3 scrubbing was performed quantitatively by the squalene-based scrubber, while the cotton-based one was likely saturated and could not remove the vast majority of the produced ozone. When O_3 was produced in the UV lamp, we measured higher COS molar fractions both with cotton and with squalene. We believe this is due to oxidation of other compounds (e.g., CS_2, DMS) in presence of UV radiation, and not due to the scrubbers themselves. The higher uncertainty for the tests with squalene is due to some spectroscopical effects that affected the instrument precision during part of the tests (not shown). Either way, no sign of negative biases on COS was measured for either of the two scrubbers.

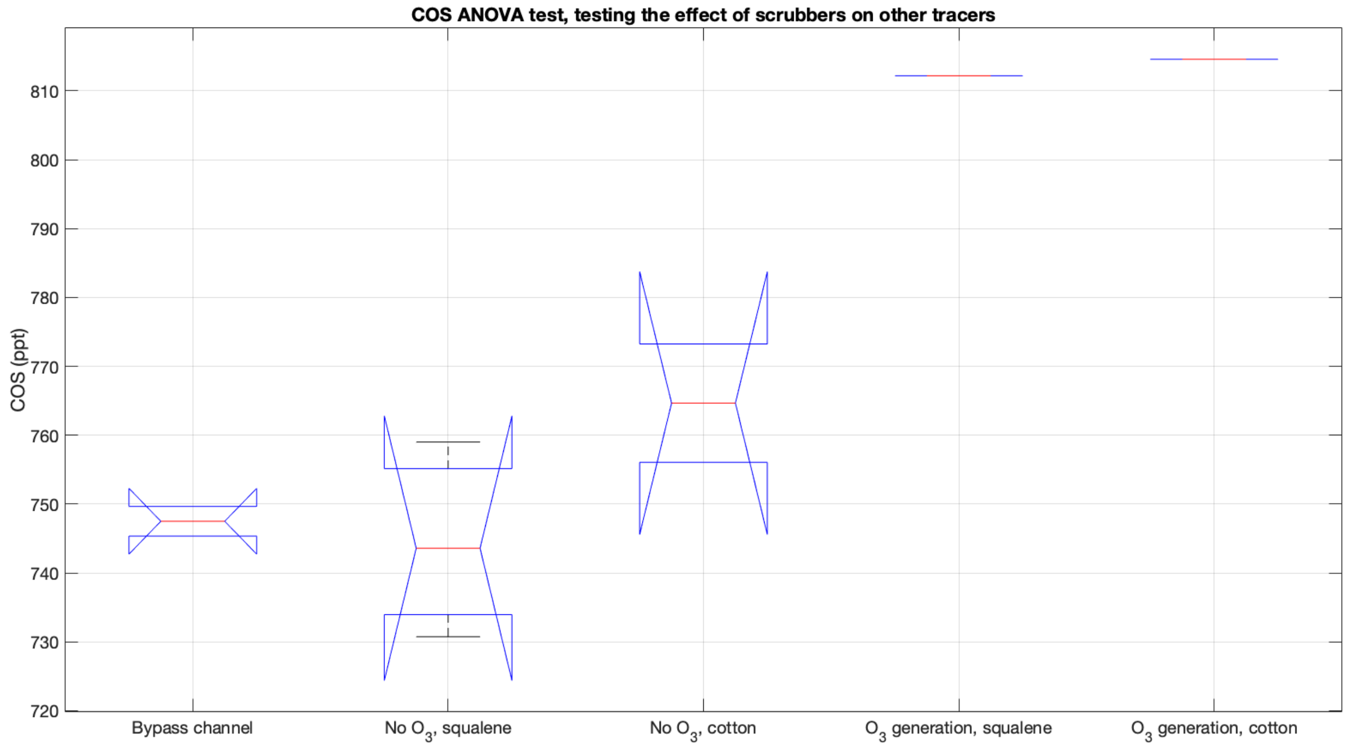


Figure S1: effects of different ozone scrubbers on COS.

Table S1: p-values resulting from the ANOVA test for COS molar fractions in the tracer removal tests. The p-values = 0 are due to a comparison between single measurements, therefore no standard deviation can be computed.

COS	**Bypass channel**	**No O_3, squalene**	**No O_3, cotton**	**O_3 generation, squalene**	**O_3 generation, cotton**
Bypass channel		0.792997793	0.192430962	0.036612983	0.0353083
No O_3, squalene	0.792997793		0.199969975	0.053576395	0.050245879
No O_3, cotton	0.192430962	0.199969975		0.193251053	0.184500858
O_3 generation, squalene	0.036612983	0.053576395	0.193251053		0
O_3 generation, cotton	0.0353083	0.050245879	0.184500858	0	

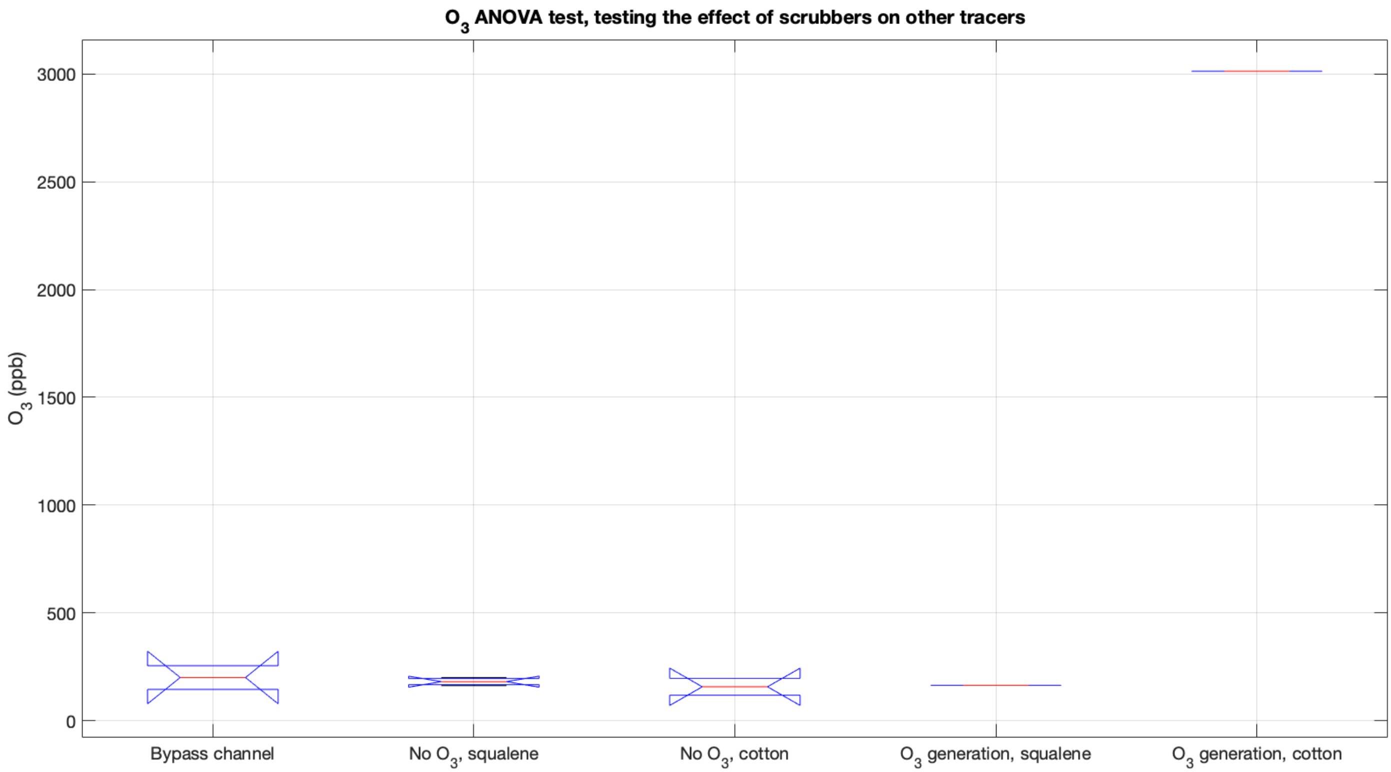


Figure S2: effects of different ozone scrubber on O_3.

Table S2: p-values resulting from the ANOVA test for O_3 molar fractions in the tracer removal tests. The p-values = 0 are due to a comparison between single measurements, therefore no standard deviation can be computed.

O_3	Bypass channel	No O_3, squalene	No O_3, cotton	O_3 generation, squalene	O_3 generation, cotton
Bypass channel		0.691559115	0.588818228	0.768190602	0.021501555
No O_3, squalene	0.691559115		0.510877137	0.510592973	5.93333E-05
No O_3, cotton	0.588818228	0.510877137		0.936761332	0.015074124
O_3 generation, squalene	0.768190602	0.510592973	0.936761332		0
O_3 generation, cotton	0.021501555	5.93333E-05	0.015074124	0	

S2 p-values from ANOVA test on stratospheric-mimicking gas mixture

Figures S3-S6 and their relative Table S3-S6 illustrate the results of the ANOVA tests on the other tracers measured by the QCLS. CO, similarly to COS, seem to be produced during the O_3 generation. The other tracers seem to be affected by O_3 and by squalene only marginally, with their ANOVA tests resulting in non-significant differences.

Table S7 and S8 report the p-values related to the ANOVA tests depicted in Fig. 3 and 4 in the main text, respectively.

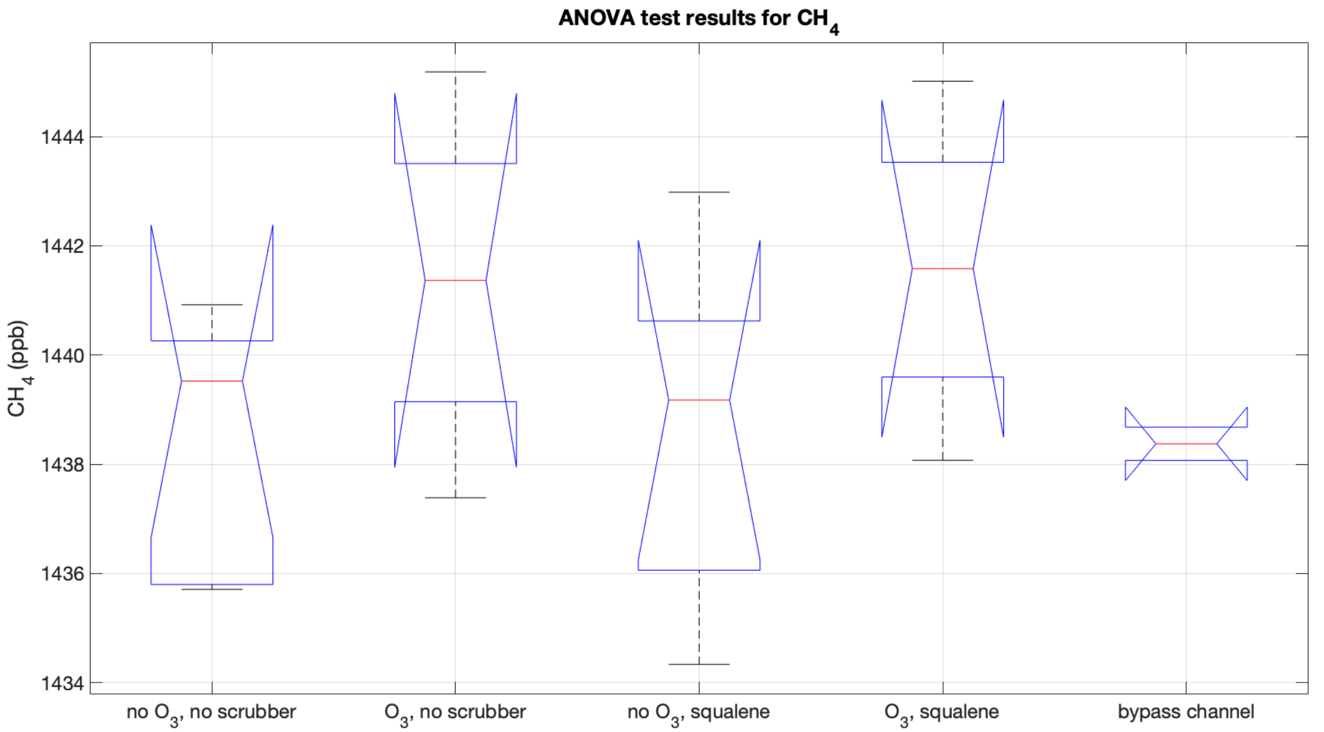


Figure S3: ANOVA test representation for CH_4.

Table S3: p-values resulting from the ANOVA test for CH_4 molar fractions.

CH_4	No O_3, no scrubber	O_3 generation, no scrubber	No O_3, squalene	O_3 generation, squalene	Bypass channel
No O_3, no scrubber		0.155378193	0.949217256	0.108066673	0.88969152
O_3 generation, no scrubber	0.155378193		0.236982215	0.915871475	0.288201694
No O_3, squalene	0.949217256	0.236982215		0.184145628	0.885169195
O_3 generation, squalene	0.108066673	0.915871475	0.184145628		0.212687552
Bypass channel	0.88969152	0.288201694	0.885169195	0.212687552	

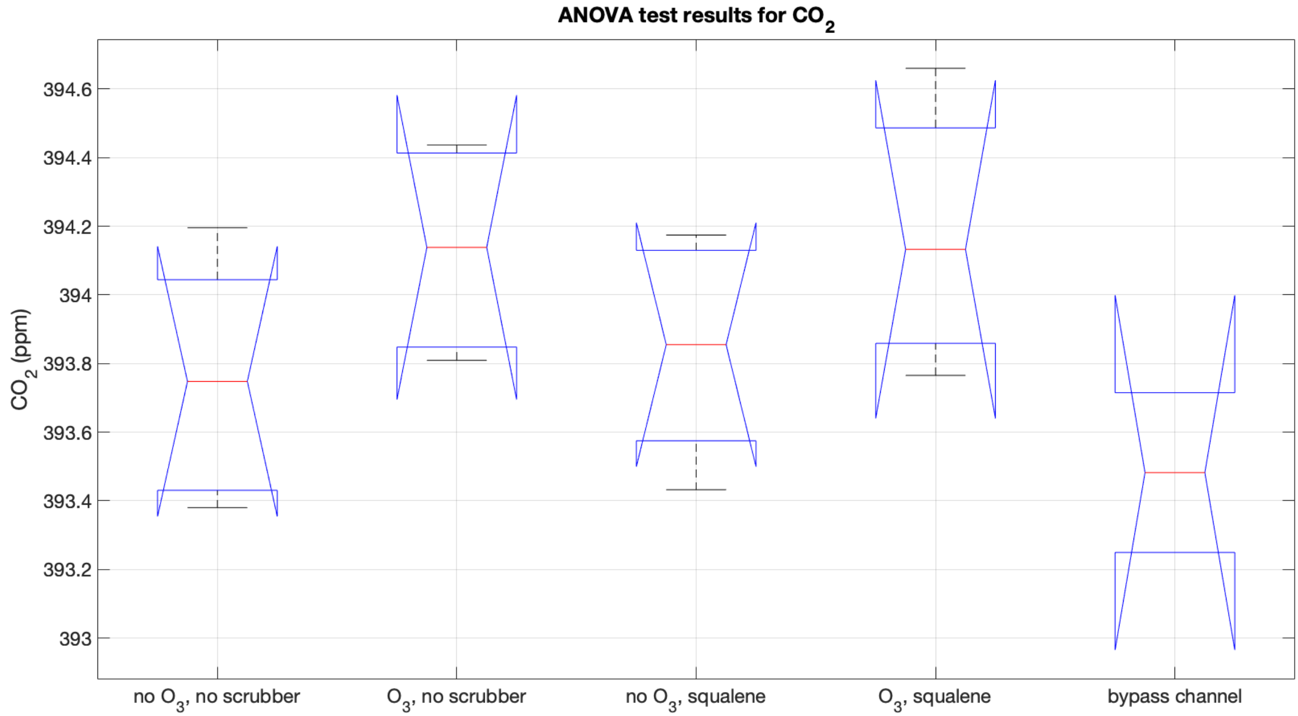


Figure S4: ANOVA test representation for CO_2.

Table S4: p-values resulting from the ANOVA test for CO_2 molar fractions.

CO_2	No O_3, no scrubber	O_3 generation, no scrubber	No O_3, squalene	O_3 generation, squalene	Bypass channel
No O_3, no scrubber		0.120593543	0.674240248	0.111410702	0.351443899
O_3 generation, no scrubber	0.120593543		0.178580774	0.875554317	0.084883879
No O_3, squalene	0.674240248	0.178580774		0.161549618	0.200493163
O_3 generation, squalene	0.111410702	0.875554317	0.161549618		0.104353378
Bypass channel	0.351443899	0.084883879	0.200493163	0.104353378	

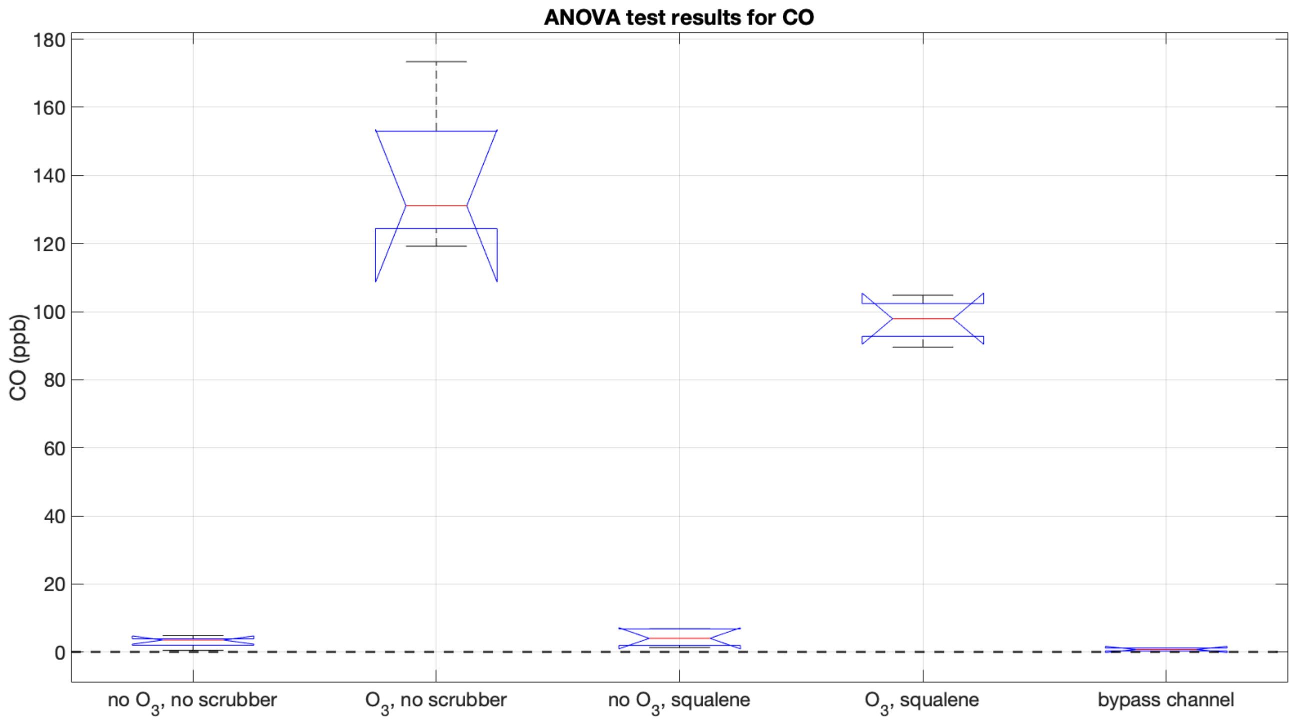


Figure S5: ANOVA test representation for CO.

Table S5: p-values resulting from the ANOVA test for CO molar fractions.

CO	No O_3, no scrubber	O_3 generation, no scrubber	No O_3, squalene	O_3 generation, squalene	Bypass channel
No O_3, no scrubber		5.44265E-07	0.382133147	4.43905E-10	0.100030491
O_3 generation, no scrubber	5.44265E-07		6.06495E-07	0.015757839	0.001519548
No O_3, squalene	0.382133147	6.06495E-07		8.38815E-10	0.123950163
O_3 generation, squalene	4.43905E-10	0.015757839	8.38815E-10		3.69703E-05
Bypass channel	0.100030491	0.001519548	0.123950163	3.69703E-05	

Figure S6: ANOVA test representation for N_2O.

Table S6: p-values resulting from the ANOVA test for N_2O molar fractions.

N_2O	No O_3, no scrubber	O_3 generation, no scrubber	No O_3, squalene	O_3 generation, squalene	Bypass channel
No O_3, no scrubber		0.359325384	0.217409312	0.277689103	0.377699683
O_3 generation, no scrubber	0.359325384		0.112412874	0.137165062	0.289831556
No O_3, squalene	0.217409312	0.112412874		0.761757143	0.972574391
O_3 generation, squalene	0.277689103	0.137165062	0.761757143		0.843816095
Bypass channel	0.377699683	0.289831556	0.972574391	0.843816095	

Table S7: p-values resulting from the ANOVA test for COS molar fractions (see Fig. A2 in the main text).

COS	No O_3, no scrubber	O_3 generation, no scrubber	No O_3, squalene	O_3 generation, squalene	Bypass channel
No O_3, no scrubber		0.00096097	0.38152	0.0048316	0.16598
O_3 generation,	0.00096097		0.0090425	0.028935	0.028613

no scrubber					
No O_3, squalene	0.38152	0.0090425		0.11413	0.92189
O_3 generation, squalene	0.0048316	0.028935	0.11413		0.0080331
Bypass channel	0.16598	0.028613	0.92189	0.0080331	

Table S8: p-values resulting from the ANOVA tests for O_3 molar fractions (see Fig. A2 in the main text).

O_3	**No O_3, no scrubber**	**O_3 generation, no scrubber**	**No O_3, squalene**	**O_3 generation, squalene**	**Bypass channel**
No ozone, no scrubber		1.0201E-09	0.55868	0.56586	0.89317
O_3 generation, no scrubber	1.0201E-09		3.0293E-10	8.3646E-08	3.3303E-05
No O_3, squalene	0.55868	3.0293E-10		0.89497	0.72736
O_3 generation, squalene	0.56586	8.3646E-08	0.89497		0.68112
Bypass channel	0.89317	3.3303E-05	0.72736	0.68112	

S3 Tropopause heights of the presented flights

Figures S7 – S15 show lapse rate and relative humidity for all flights. The tropopause height was identified following the thermal tropopause height definition by WMO (1957). For TRN1, no temperature or relative humidity data was available, therefore the tropopause height could not be identified. SOD5 (Fig. S11) shows a particularly weak tropopause, with H_2O injections up to almost 15 km of altitude.

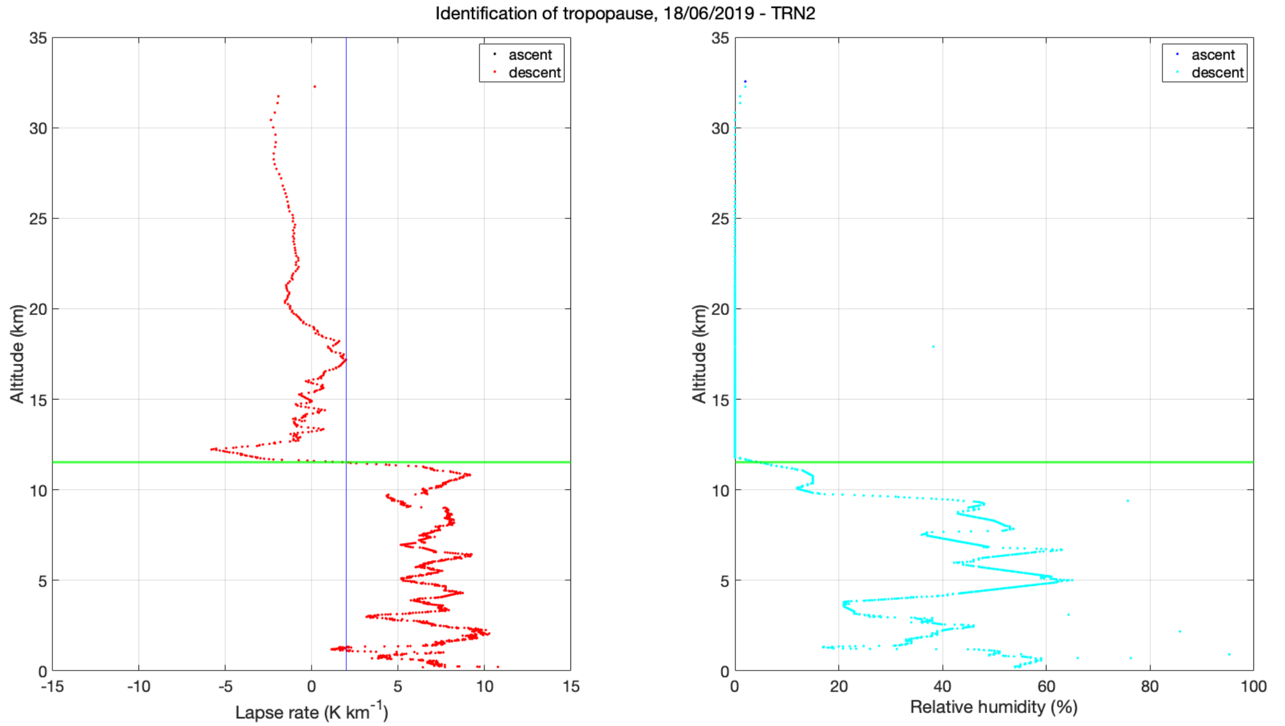


Figure S7: identification of the tropopause height for TRN2 (11.54 km).

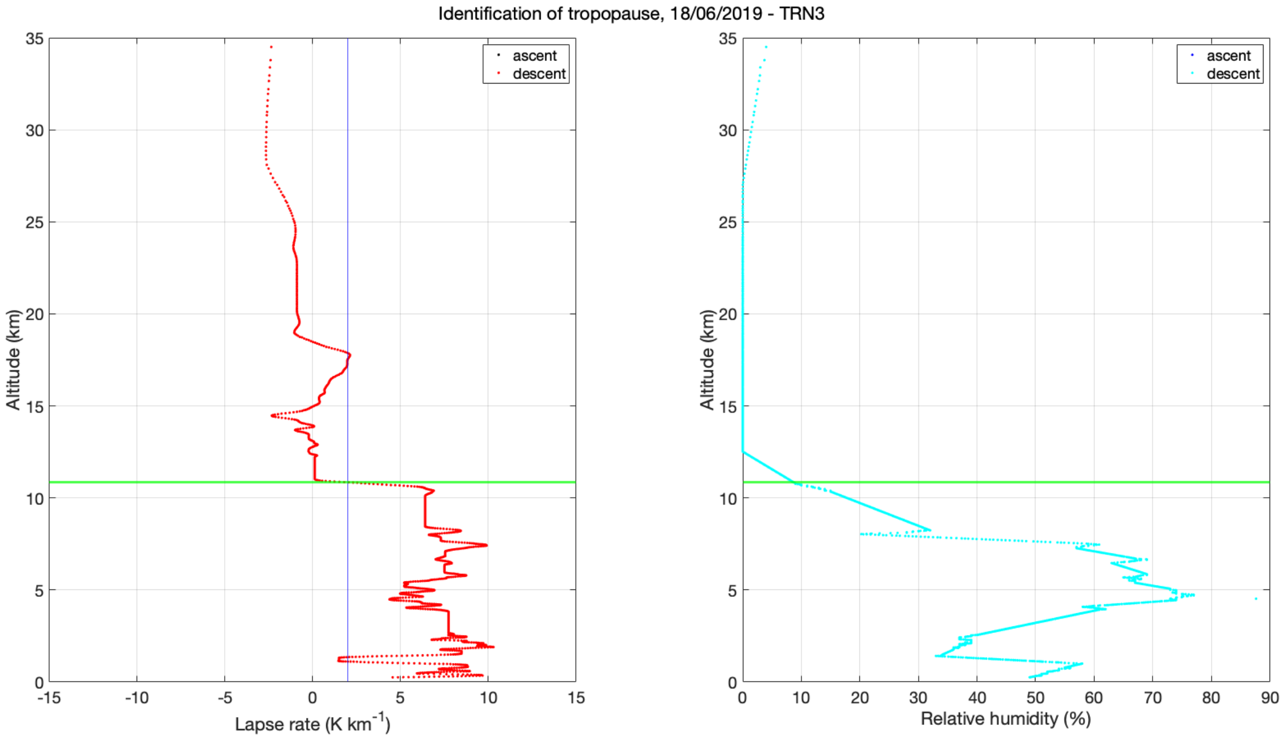


Figure S8: identification of the tropopause height for TRN3 (10.79 km).

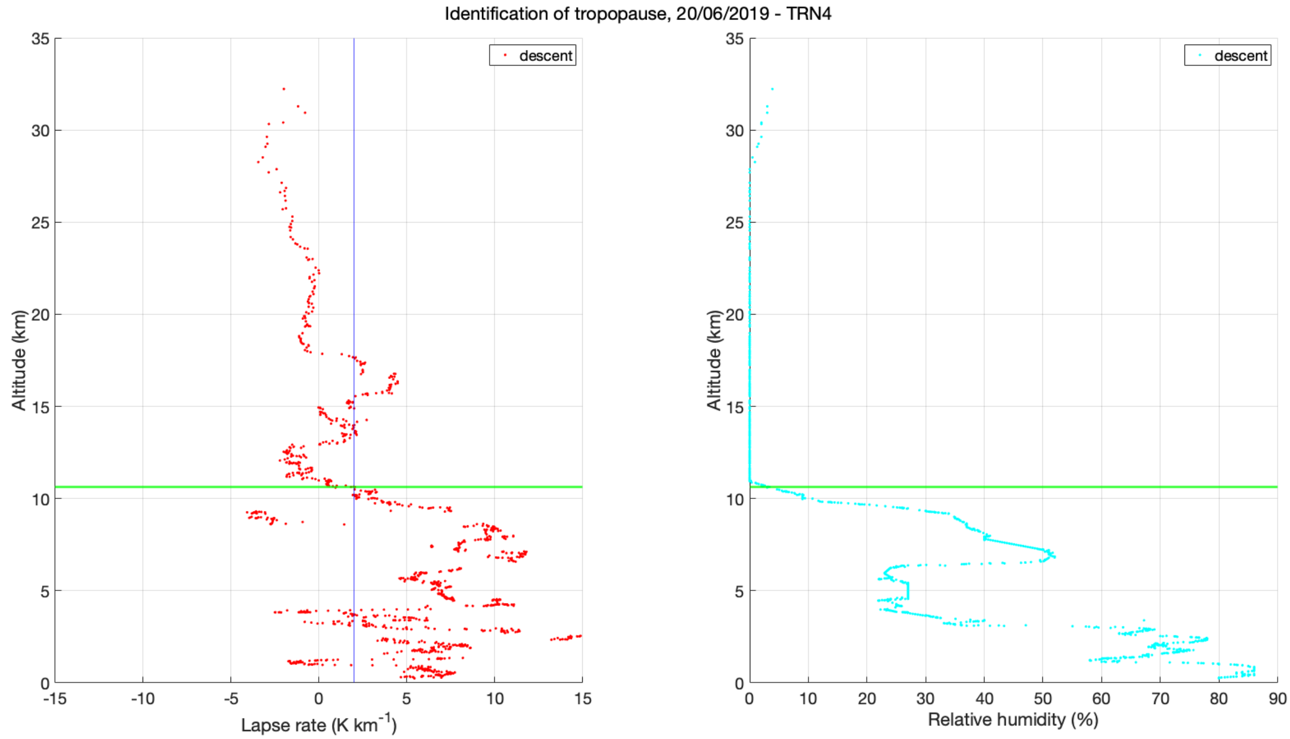
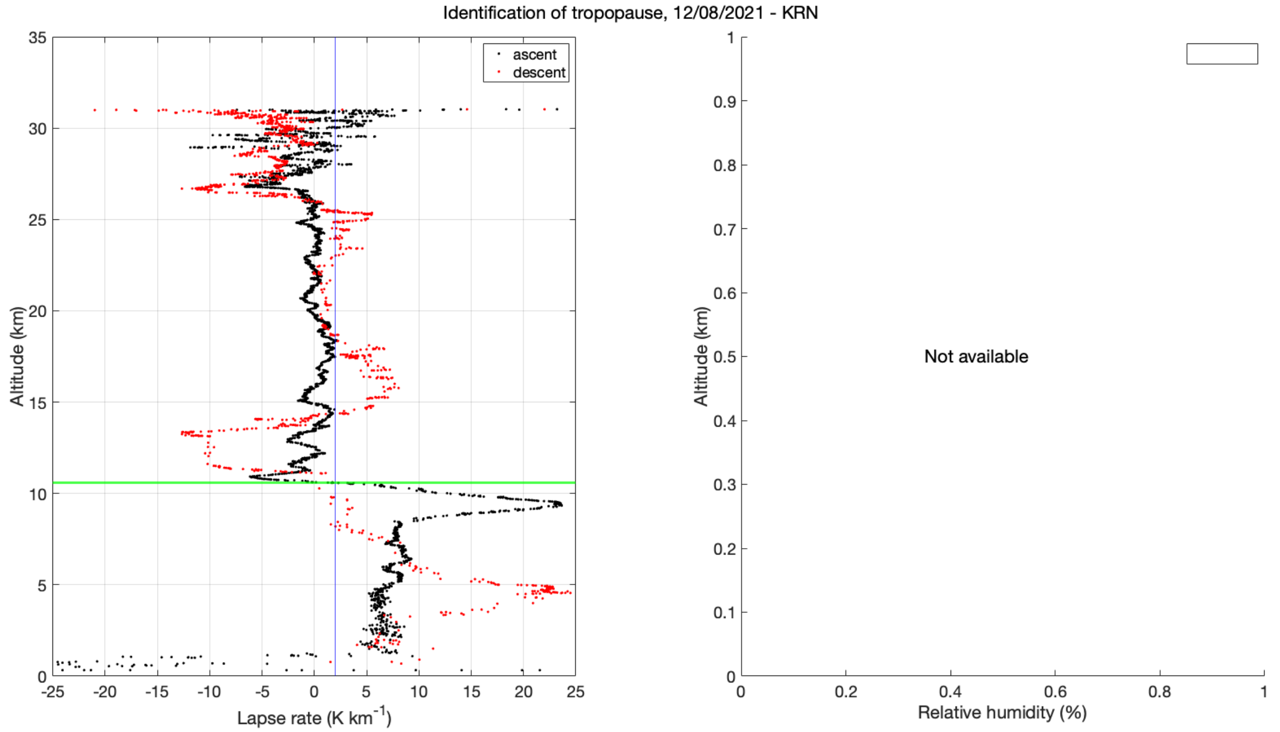


Figure S9: identification of the tropopause height for TRN4 (10.69 km).



65 **Figure S10: identification of the tropopause height for KRN (10.93 km).**

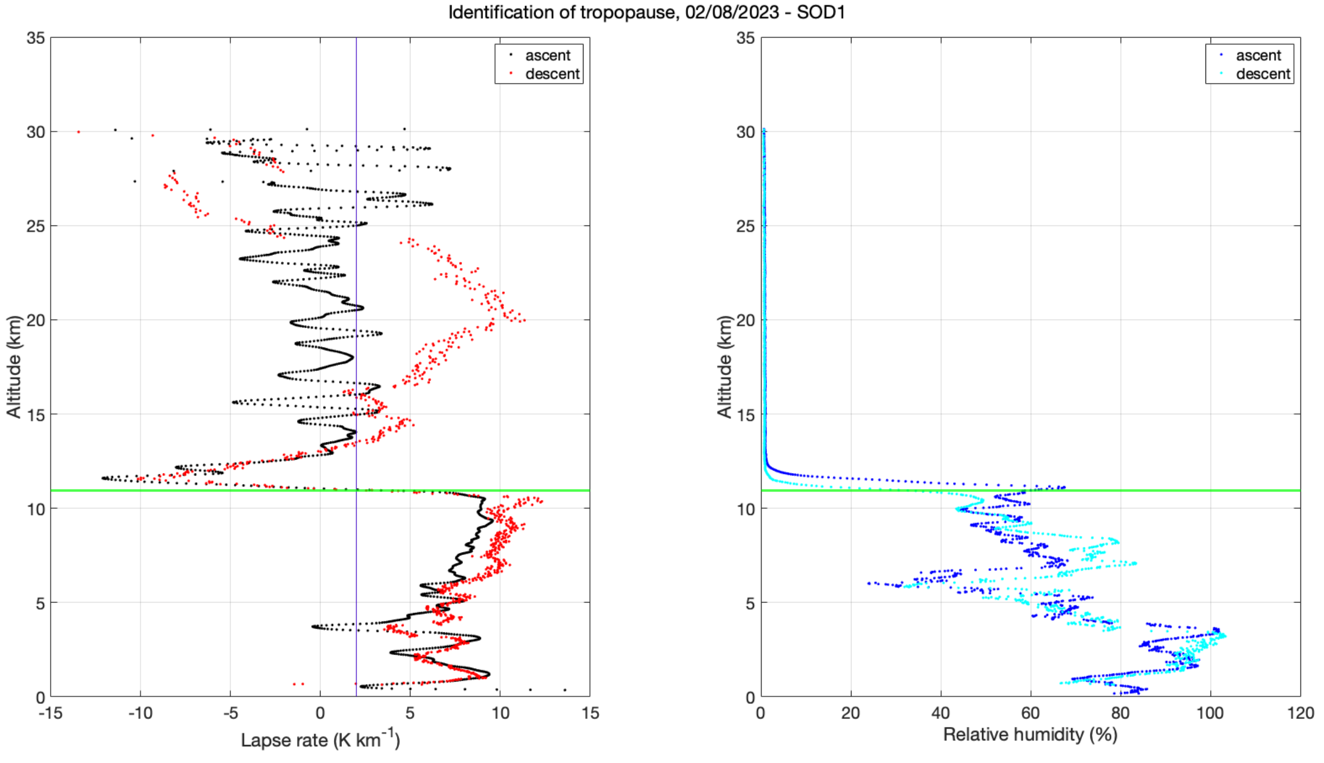


Figure S11: identification of the tropopause height for SOD1 (10.94 km).

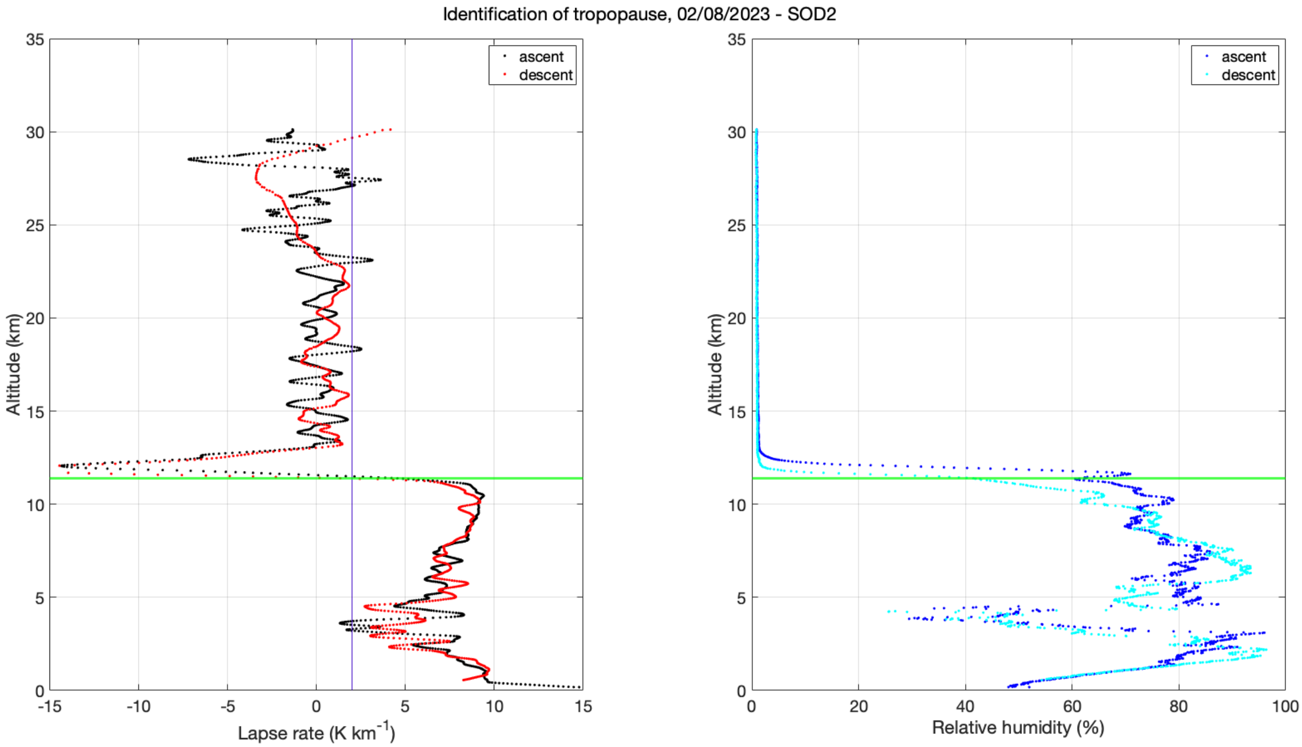


Figure S12: identification of the tropopause height for SOD2 (11.37 km).

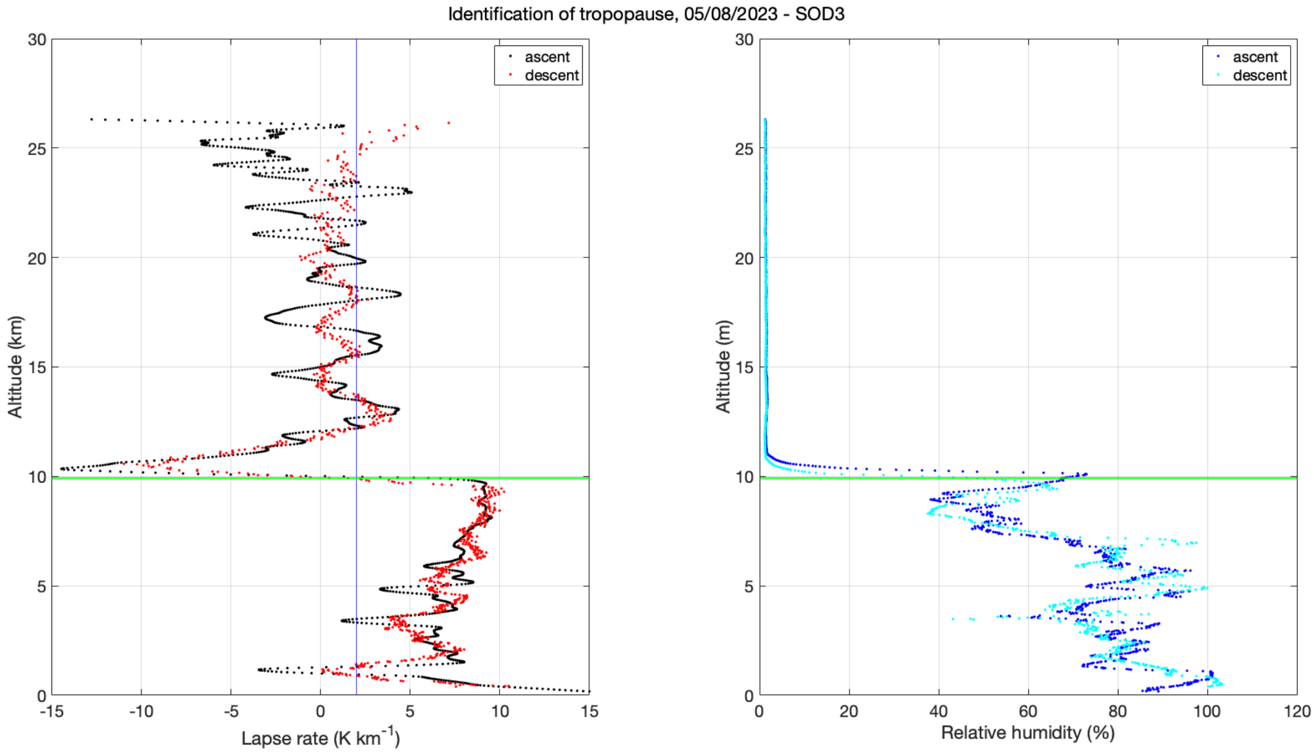


Figure S13: identification of the tropopause height for SOD3 (9.92 km).

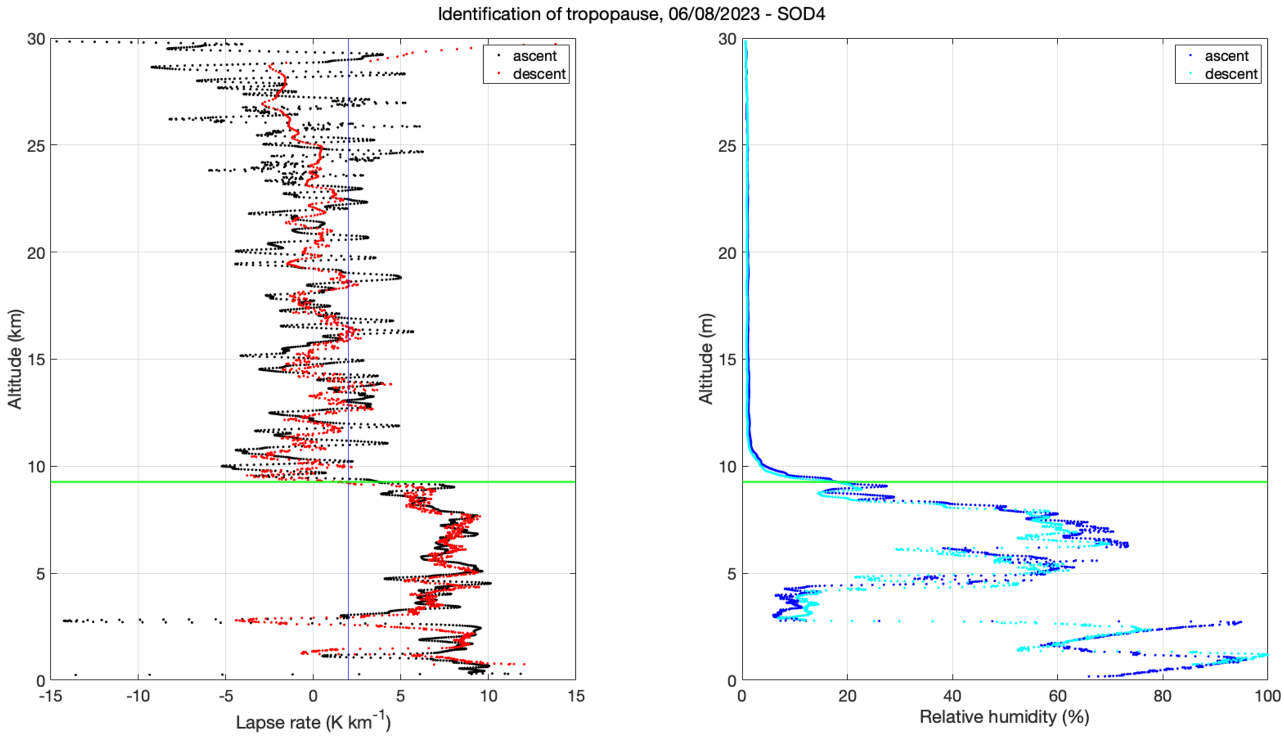


Figure S14: identification of the tropopause height for SOD4 (9.25 km).

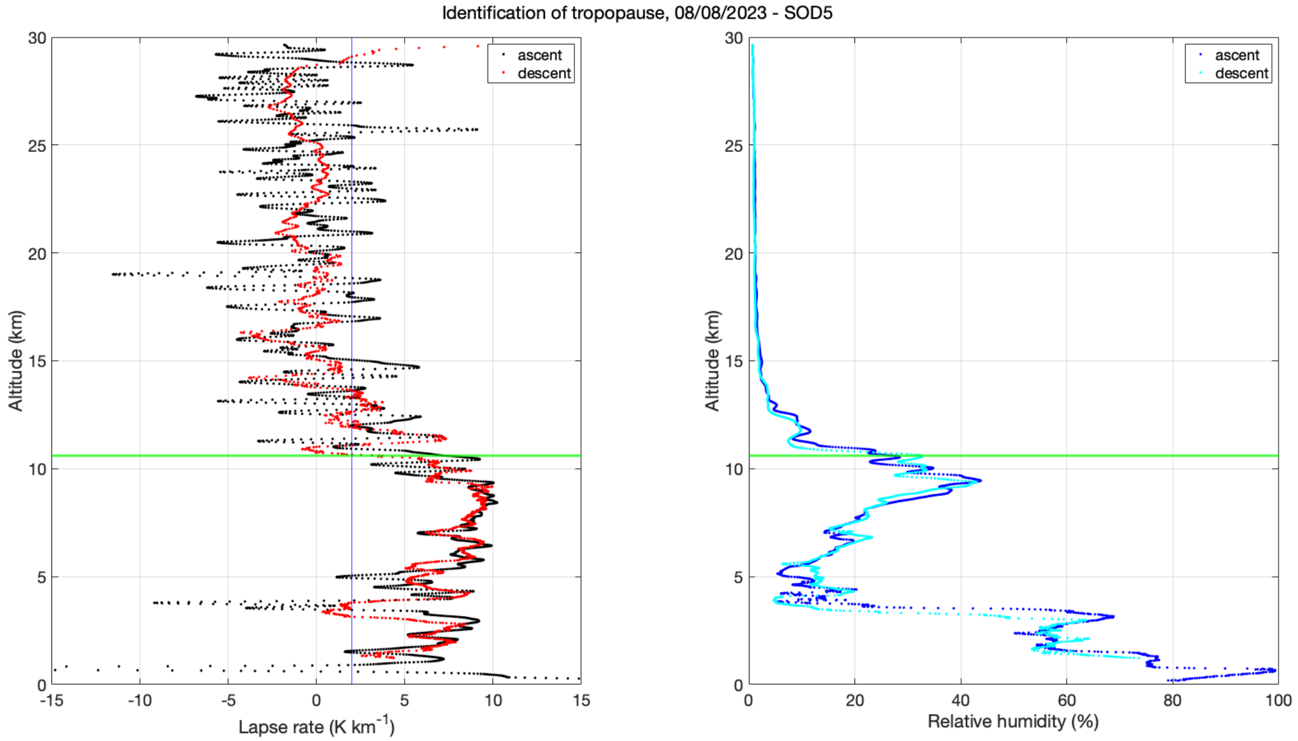
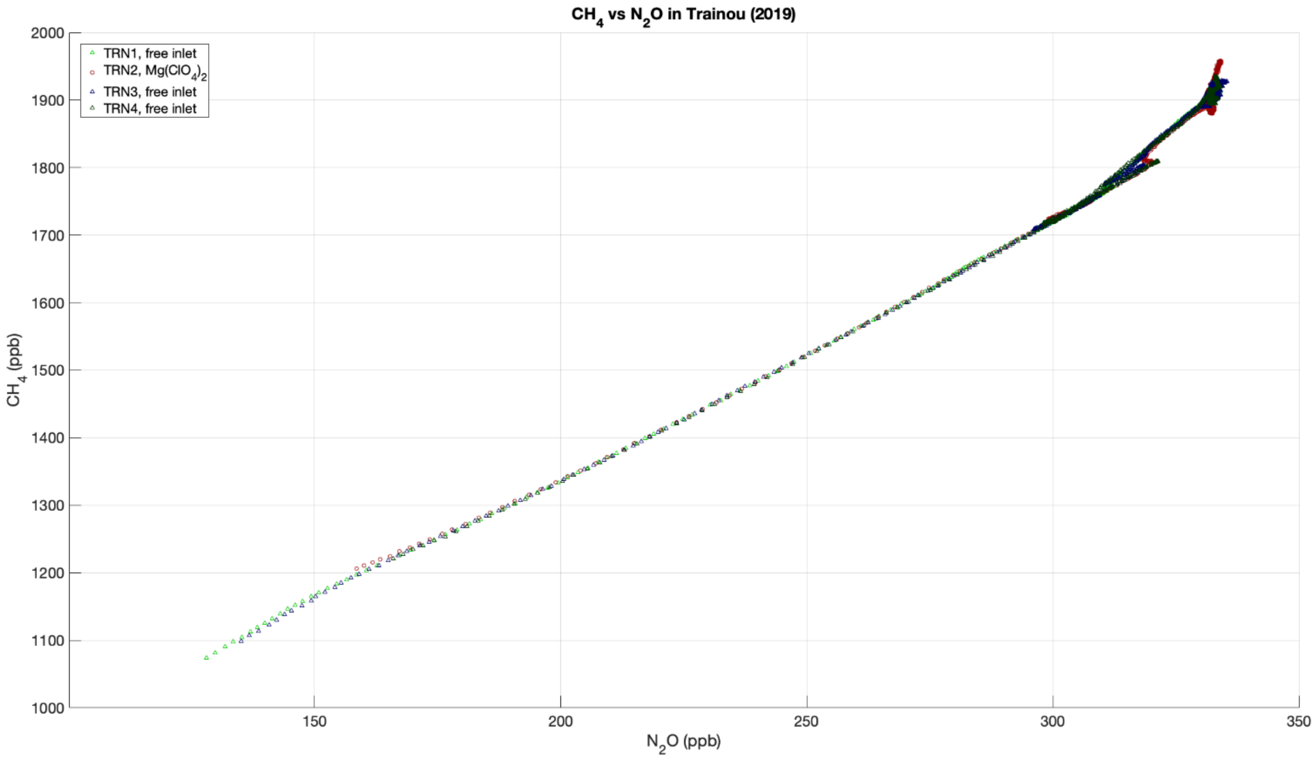


Figure S15: identification of the tropopause height for SOD5 (10.59 km).

S4 Correlation between CH_4 and N_2O in the observed profiles



80 **Figure S16: correlation between CH_4 and N_2O in the Trainou campaign (2019).**

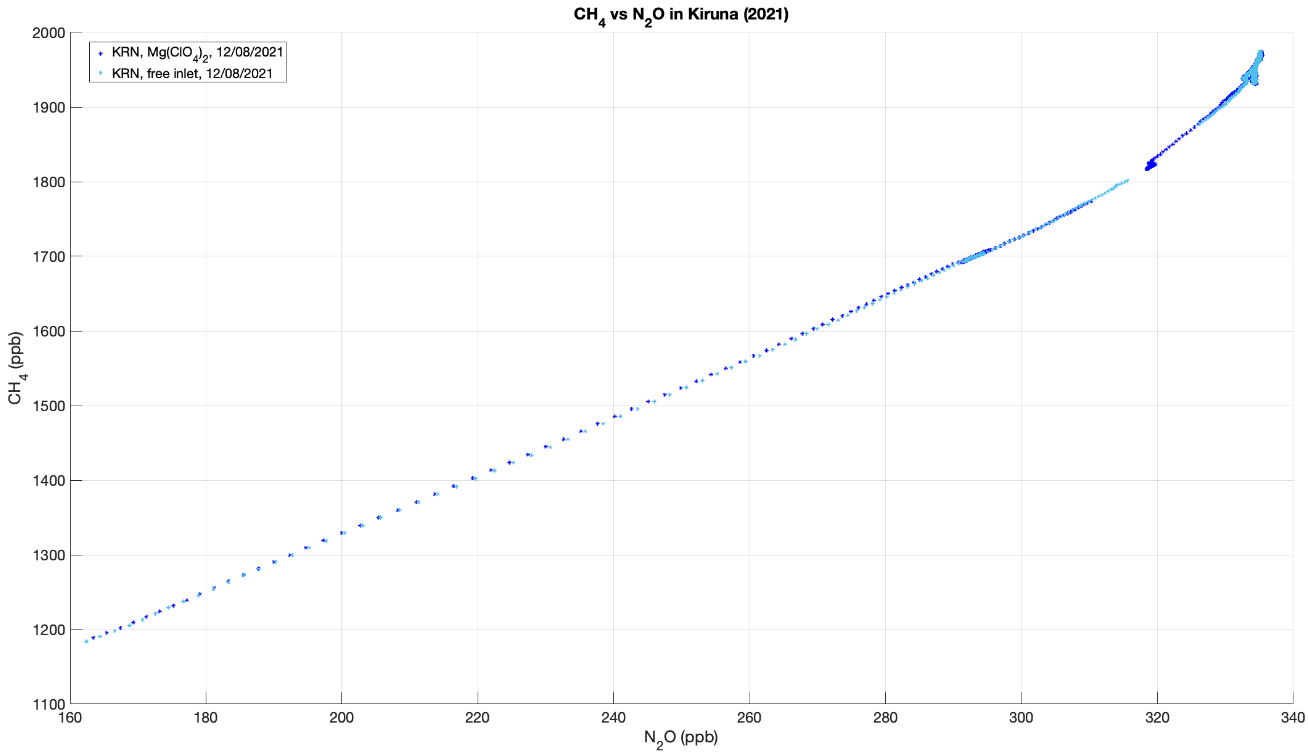


Figure S17: correlation between CH4 and N2O in the Kiruna campaign (2021).

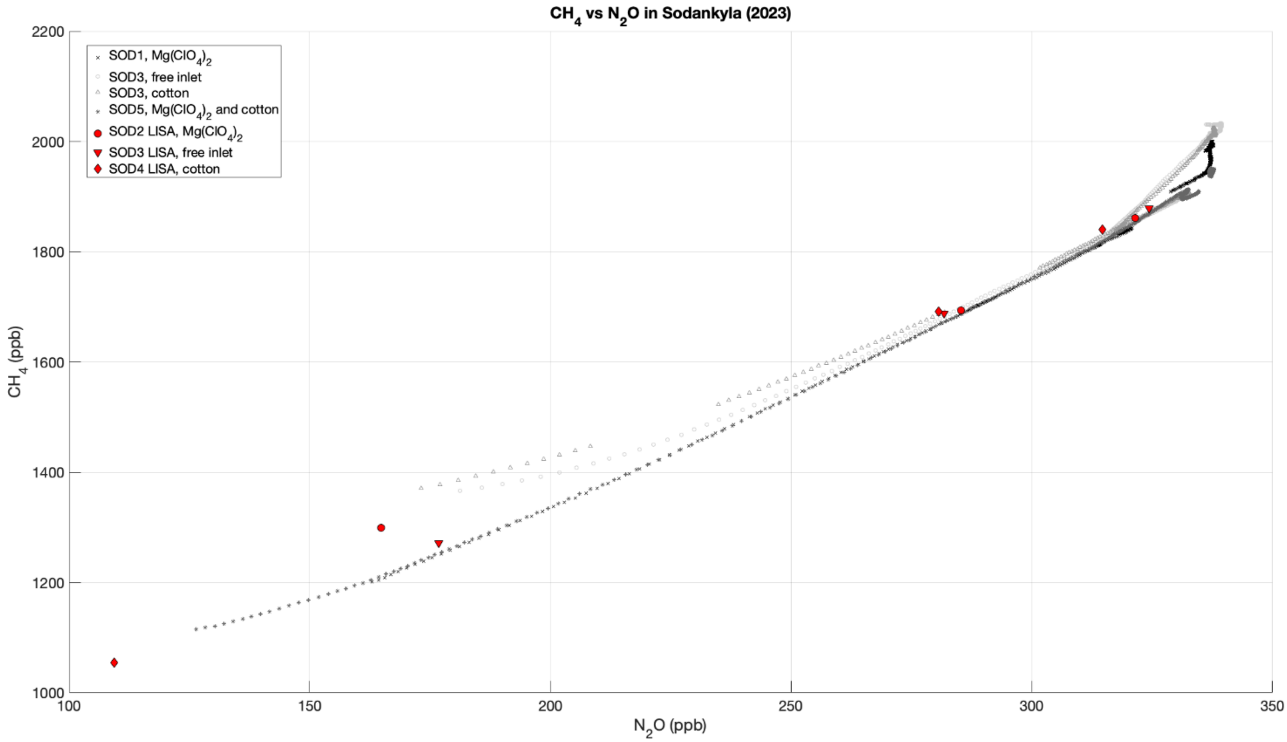


Figure S18: correlation between CH4 and N2O in the Sodankylä campaign (2023).