Authors' reply to referee #2

We thank the referee for reviewing our paper and for the critical remarks. This helped us to realize the shortcomings in the structure of our work and to reveal missing data and useful illustrative materials. We have partially reorganized the paper and supplied it with additional tables, graphs, and maps. We believe that all these changes and additions will make our study clearer for understanding and will successfully address all the issues raised by the reviewer.

Below, the actual comments of the referee are given in **bold courier font and blue colour**.
The text added to the revised version of the manuscript is marked by red colour.

***Although the amount of data used is quite limited (11 days using 2 instruments in 2019, 6 days with one instrument in 2020), the authors hope to build on previous studies that have shown the utility of groups of EM27/SUN sensors to detect small enhancements in trace gas column concentrations associated with urban emissions. Their ultimate goal is to use the little data they have to determine the emission rate of the entire city. Anyone who has attempted to infer urban emissions from scarce atmospheric observations of this kind will recognize the difficulty of this task, as there are numerous sources of noise and uncertainty that are hard to account for.**

We agree with the referee and recognize the difficulty of our task. However, in our research, we rely on measurements performed by high-precision and well-calibrated spectral equipment – EM27/SUN FTIR spectrometers, which have been successfully used in several similar field campaigns. Our team of researchers has extensive experience in estimating anthropogenic emissions from experiments, including those based on various remote measurements in the area of St. Petersburg. Thus, EMME campaigns of 2019 and 2020, the results of which we use in this work, are definitely not our first experiments of this kind. Below we present several references to our previous studies:

Ionov, D.V. and Poberovskii, A.V.: Quantification of NO_x emission from St. Petersburg (Russia) using mobile DOAS measurements around entire city, Int. J. Remote Sensing, 36, 2486-2502, https://doi.org/10.1080/01431161.2015.1042123, 2015.

Ionov, D.V. and Poberovskii A.V.: Integral emission of nitrogen oxides from the territory of St. Petersburg based on the data of mobile measurements and numerical simulation results, Izv. Atmos. Ocean. Phys., 53, 204-212, https://doi.org/10.1134/S0001433817020049, 2017.

Makarova, M.V., Arabadzhyan, D.K., Foka, S.C., Paramonova, N.N., Poberovskii, A.V., Timofeev, Yu.M., Pankratova, N.V., and Rakitin, V.S.,: Estimation of nocturnal area fluxes of carbon cycle gases in Saint Petersburg suburbs, Russ. Meteorol. Hydrol., 43, 449-455, https://doi.org/10.3103/S106837391807004X., 2018.

We would like to emphasize that although the field measurements of our study are limited in time, they form a set of a series of data that is not scarce but quite typical for an intensive measurement campaign and cover a period from March to May for two adjacent years, 2019 and 2020. It is indeed common that atmospheric observations of this type are few in number, as they are very resource-intensive and time-consuming, and highly depend on favorable weather conditions.

We agree with the referee that installation of a permanent city observation network based on several EM27/SUN units would be a desirable ultimate goal. We hope that this paper describing the successful pilot study will help to raise the required funding for extending the collaboration between Russian and EU researchers fostering the quantification of greenhouse gas emissions in Russia.

***This paper falls short, however, on presenting a convincing method for retrieving an urban emission rate using this data. Most strikingly, the entire manuscript lacks detailed equations describing exactly how the FTIR data, transport model, and ODIAC data, and combined.**

We agree with this comment. As we noted above, the paper has been significantly revised and provided with additional material (equations, tables, plots), making our results more convincing. In particular, the equation mentioned by the reviewer was added to the text (subsection 3.1 "The results of the EMME-2019 campaign"):

In order to obtain a quantitative agreement between simulated and observed ΔCO_2, the inventory data (the ODIAC emissions), which are used as input information for the HYSPLIT dispersion model, should be scaled (Flesch et al., 2004). The scaling factor (*SF*) is derived as follows. The data from all days of measurements are compared to the corresponding model simulations, see Fig.6 as an example of a scatter plot. The scaling factor is determined as a slope value of the following regression line (e.g. the slope is 2.88 ± 0.21 , as shown in Fig.6):

$$\Delta CO_2[\mathrm{FTIR}]_i = SF \times \Delta CO_2[\mathrm{HYSPLIT}_{\mathrm{ODIAC}}]_i \qquad (1)$$

where $\Delta CO_2[\mathrm{FTIR}]_i$ is is the difference between the downwind and upwind FTIR measurements averaged over the duration of experiment *i* (see Table 1 and Table 2, Appendix A and Appendix B for the details of every field experiment) and $\Delta CO_2[\mathrm{HYSPLIT}_{\mathrm{ODIAC}}]_i$ is the averaged difference between the downwind and upwind CO_2 column calculated using the HYSPLIT dispersion model for the location and time of FTIR observations, and initialized with ODIAC CO_2 emissions.

***I would expect a paper that presents a data-model fusion product like this to not only have extensive equations and tables, but also a supplement with additional tables and figures, but there appears to not be any supplemental information provided.**

We agree with this comment. Apparently, it was our mistake to refer too much to our previous study (Makarova et al., 2021), so as not to reproduce the same material in both papers. Following the reviewer's suggestion, we fix this and supply a set of additional figures available in the Appendix A and B of revised manuscript. Please, see Appendix A below:

Appendix A: Location of ground-based measurement points with respect to the urban pollution plume.

The location of FTS field measurements is shown on the maps of vertically integrated CO_2 (total column: TC) produced by HYSPLIT for selected campaign days in 2019 and 2020 (10:00 UTC), see Fig. A1 and A2. The locations of the FTS instruments on the upwind and downwind sides are indicated by blue and red circles, respectively. Note that in 2020 there were days when the downwind measurements were performed twice, at different locations – on March 23 and May 1 (see Fig. A2).

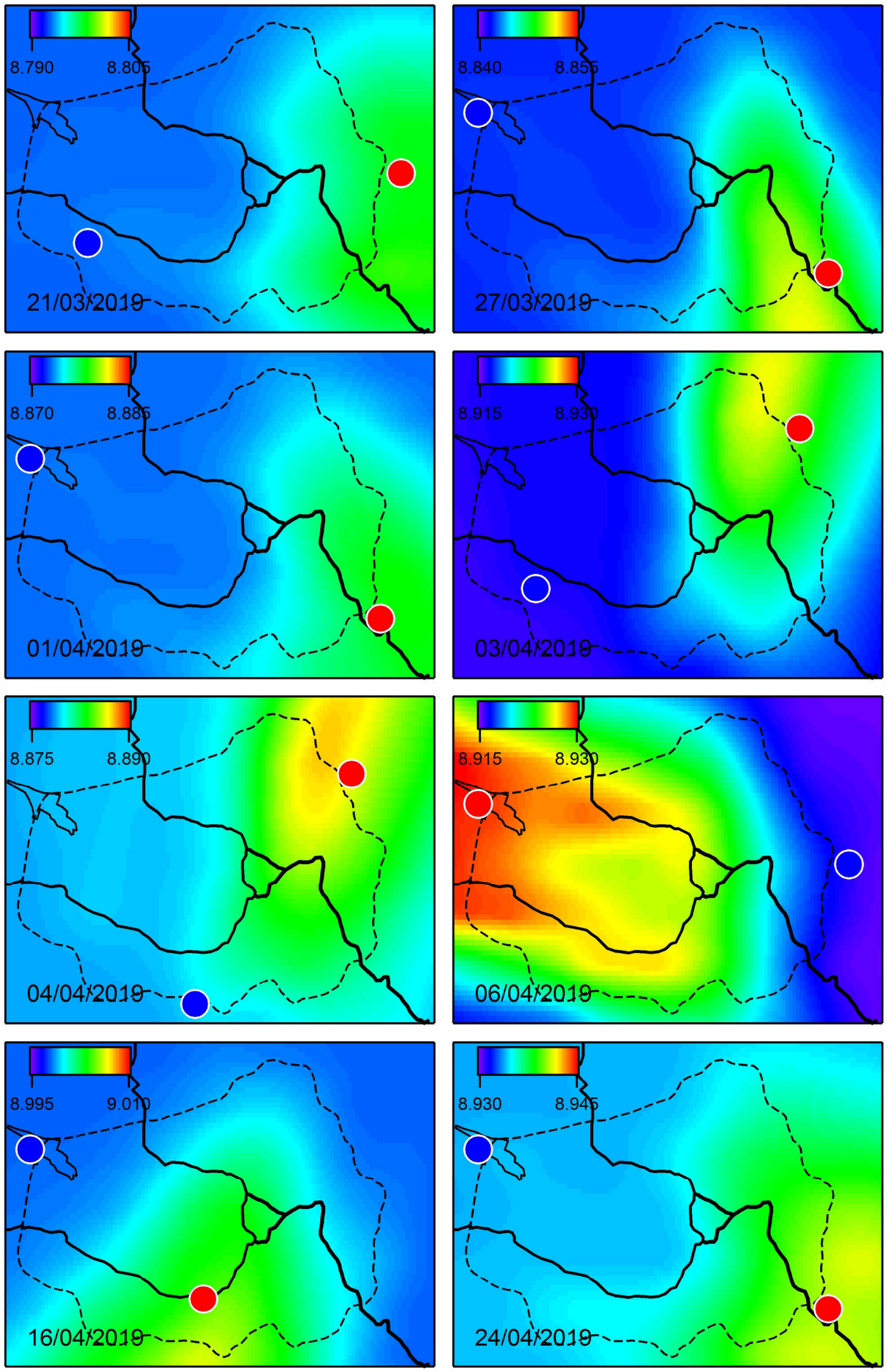

Figure A1: Urban pollution CO_2 plume over St. Petersburg calculated with HYSPLIT model for the days of field campaign in 2019 (10:00 UTC). The colour bar units for TC_{CO2} are 10^{21} cm^{-2}. The blue and red circles indicate the locations of upwind and downwind FTS observations, accordingly.

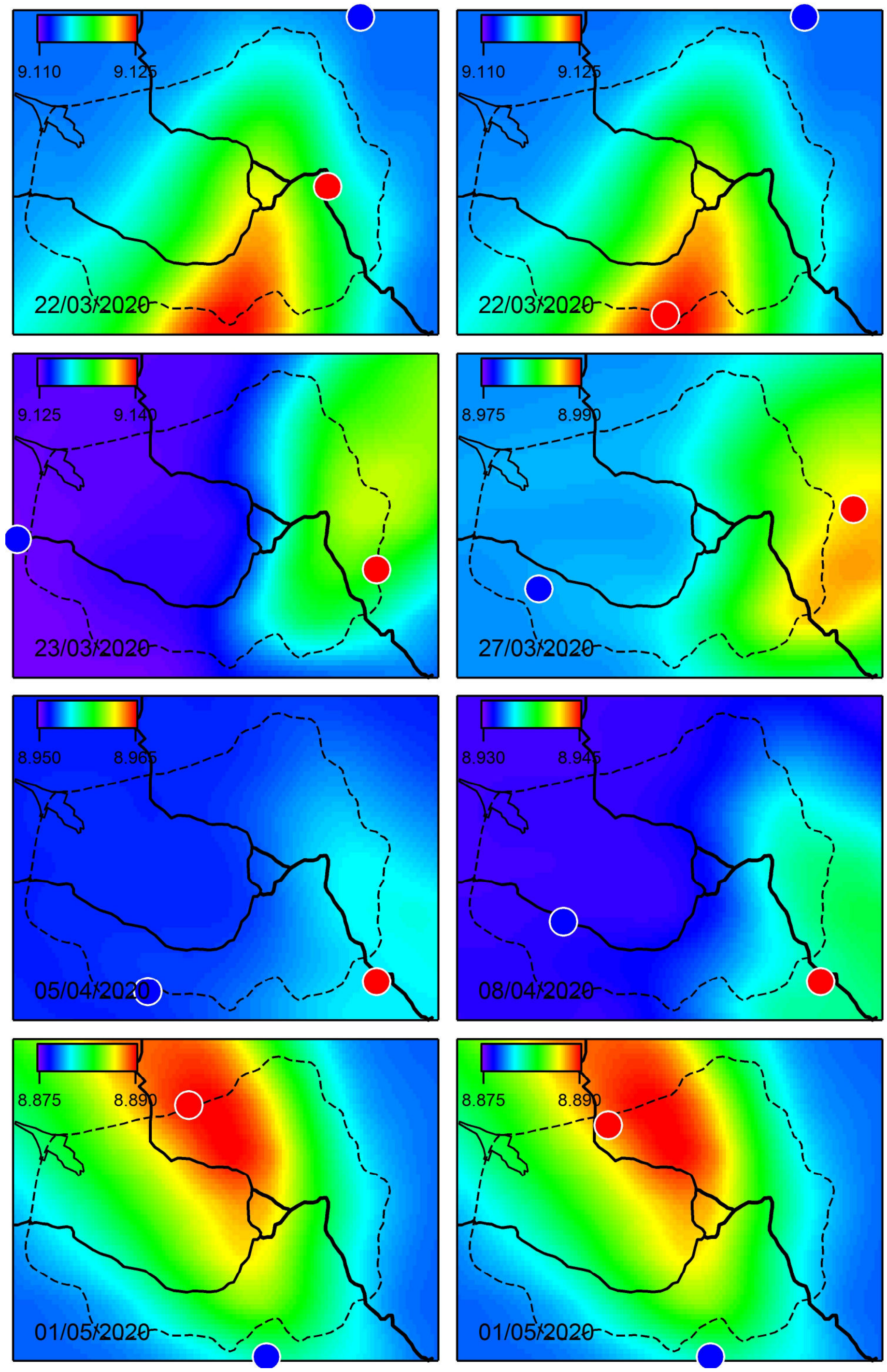

Figure A2: Urban pollution CO_2 plume over St. Petersburg calculated with HYSPLIT model for the days of field campaign in 2020 (10:00 UTC). The colour bar units for TC_{CO2} are 10^{21} cm^{-2}. The blue and red circles indicate the locations of upwind and downwind FTS observations, accordingly.

We also made the description of the two EMME campaigns more detailed by including the tables with information about each mobile experiment in 2019 and 2020 (see below):

> Details of both field campaigns are given in Tables 1 and 2 for 2019 and 2020, respectively. The tables contain the Fourier transform spectrometer (FTS) instrument IDs (#80 and #84 in 2019, #84 in 2020), the position on the upwind and downwind sides of the city (latitude and longitude), and the duration of observations. Note that each experiment presented in the tables consists of a pair of series of measurements – from the upwind and downwind sides. In 2019, observations of two FTS instruments (#80 and #84) simultaneously were used for this purpose (see Table 1). In 2020 the single FTS instrument (#84) was moved between the upwind and downwind positions (see Table 2). The average duration of measurements in 2019 was 3 hours within the period of ~12:00-15:00. In 2020, the duration of the measurements was limited to about 1 hour (sometimes less), and the observation time varied from 11:00 to 19:00. Since a single instrument was used in 2020, the time difference between upwind and downwind measurements in 2020 ranged from 3 to 5 hours.

Table 1. EMME-2019 field campaign details: the dates of experiments in 2019 and the locations of FTS instruments during the upwind and downwind observations. The data on the direction and speed of the surface wind correspond to observations at one of the meteorological stations in the center of St. Petersburg at local noon (http://rp5.ru/Weather_archive_in_Saint_Petersburg, last access: 11 March 2021).

No.	Date	Wind speed, ms^{-1}	Wind direction	FTS identifier (instrument #) location (latitude, longitude) observation time (local)	
				upwind	downwind
1.	21 March 2019	3	WSW	#80 59.88°N, 29.83°E 14:07-15:07	#84 59.95°N, 30.59°E 13:08-15:36
2.	27 March 2019	2	WSW	#84 60.01°N, 29.69°E 11:49-15:08	#80 59.85°N, 30.54°E 11:42-14:57
3.	01 April 2019	3	WSW	#84 60.01°N, 29.69°E 11:01-13:24	#80 59.85°N, 30.54°E 11:15-14:31
4.	03 April 2019	3	S	#84 59.88°N, 29.83°E 14:47-16:02	#80 60.04°N, 30.47°E 11:57-14:21
5.	04 April 2019	3	SW	#84 59.81°N, 30.09°E 11:59-14:16	#80 60.04°N, 30.47°E 11:59-14:16
6.	06 April 2019	2	SE	no.84 59.95°N, 30.59°E 12:14-15:23	no.80 60.01°N, 29.69°E 12:15-15:29
7.	16 April 2019	2	NE	#84 60.01°N, 29.69°E 11:13-15:08	#80 59.86°N, 30.11°E 11:21-14:59
8.	18 April 2019	2	NE	#80	#84

No.	Date	Wind speed, ms^{-1}	Wind direction	upwind	downwind
				60.04°N, 30.47°E 12:07-14:56	59.81°N, 30.09°E 11:38-15:24
9.	24 April 2019	1	WSW	#84 60.01°N, 29.69°E 11:38-14:55	#80 59.85°N, 30.54°E 11:52-15:22
10.	25 April 2019	1	WSW	#80 60.04°N, 30.47°E 12:07-14:49	#84 59.81°N, 30.09°E 11:19-15:08
11.	30 April 2019	2	SSE	#80 59.85°N, 30.54°E 12:35-13:31	#84 60.01°N, 29.69°E 12:22-13:46

Table 2. EMME-2020 field campaign details: the dates of experiments in 2020 and the locations of FTS instrument during the upwind and downwind observations. The data on the direction and speed of the surface wind correspond to observations at one of the meteorological stations in the center of St. Petersburg at local noon (http://rp5.ru/Weather_archive_in_Saint_Petersburg, last access: 11 March 2021).

No.	Date	Wind speed, ms^{-1}	Wind direction	FTS identifier (instrument no.) location (latitude, longitude) observation time (local)	
				upwind	downwind
1.	22 March 2020	1	N	#84 60.11°N, 30.48°E 10:38-11:55	#84 59.94°N, 30.40°E 13:17-14:38
2.	22 March 2020	1	N	#84 60.11°N, 30.48°E 10:38-11:55	#84 59.81°N, 30.14°E 15:55-17:16
3.	23 March 2020	2	W	#84 59.93°N, 29.64°E 12:55-14:33	#84 59.90°N, 30.52°E 16:24-18:02
4.	27 March 2020	2	WSW	#84 59.88°N, 29.83°E 10:35-11:51	#84 59.94°N, 30.60°E 13:24-14:12
5.	27 March 2020	2	WSW	#84 59.88°N, 29.83°E 10:35-11:51	#84 59.96°N, 30.60°E 14:34-15:15
6.	05 April 2020	4	WSW	#84 59.82°N, 29.96°E 12:44-13:43	#84 59.83°N, 30.52°E 10:53-11:48
7.	08 April 2020	3	WSW	#84 59.89°N, 29.89°E 14:58-16:46	#84 59.83°N, 30.52°E 11:09-13:43
8.	01 May 2020	1	ESE	#84 59.73°N, 30.25°E 18:01-19:03	#84 60.05°N, 30.06°E 13:22-14:27
9.	01 May 2020	1	ESE	#84 59.73°N, 30.25°E 18:01-19:03	#84 60.03°N, 30.00°E 15:10-16:11

***Even the EM27 data itself is not presented clearly in this manuscript. It would be useful to see a couple of daily time series plots of the XCO_2 data from both sensors so the reader can see not only the difference between them, but the (likely) large hourly variations typically seen by urban EM27 instruments.**

Addressing this issue, we have provided the revised version of the manuscript with an appendix showing the data series of measured and calculated CO_2 content for the selected campaign days in 2019 and 2020. The graphs in the figures clearly demonstrate that the "downwind-upwind" CO_2 enhancements are reliably detected with FTIR measurements during each mobile experiment and are not masked by the hourly CO_2 variations. Please, see Appendix B below:

Appendix B: The data series of measured and calculated CO_2 content

The upwind and downwind CO_2 total column values acquired from FTIR measurements and HYSPLIT calculations are shown for selected campaign days in 2019 and 2020 in Fig. B1 and B2. The HYSPLIT data are in fact the values of an integrated vertical column in the range of 0-1500 meters (10 altitude layers) calculated with the 15-minute time step. The background level of the CO_2 column is set equal to an average of the FTIR upwind measurements during a day. Note that in 2020, there were days when the downwind measurements were performed twice, at different locations – on March 22 and May 1 (see Fig. B2).

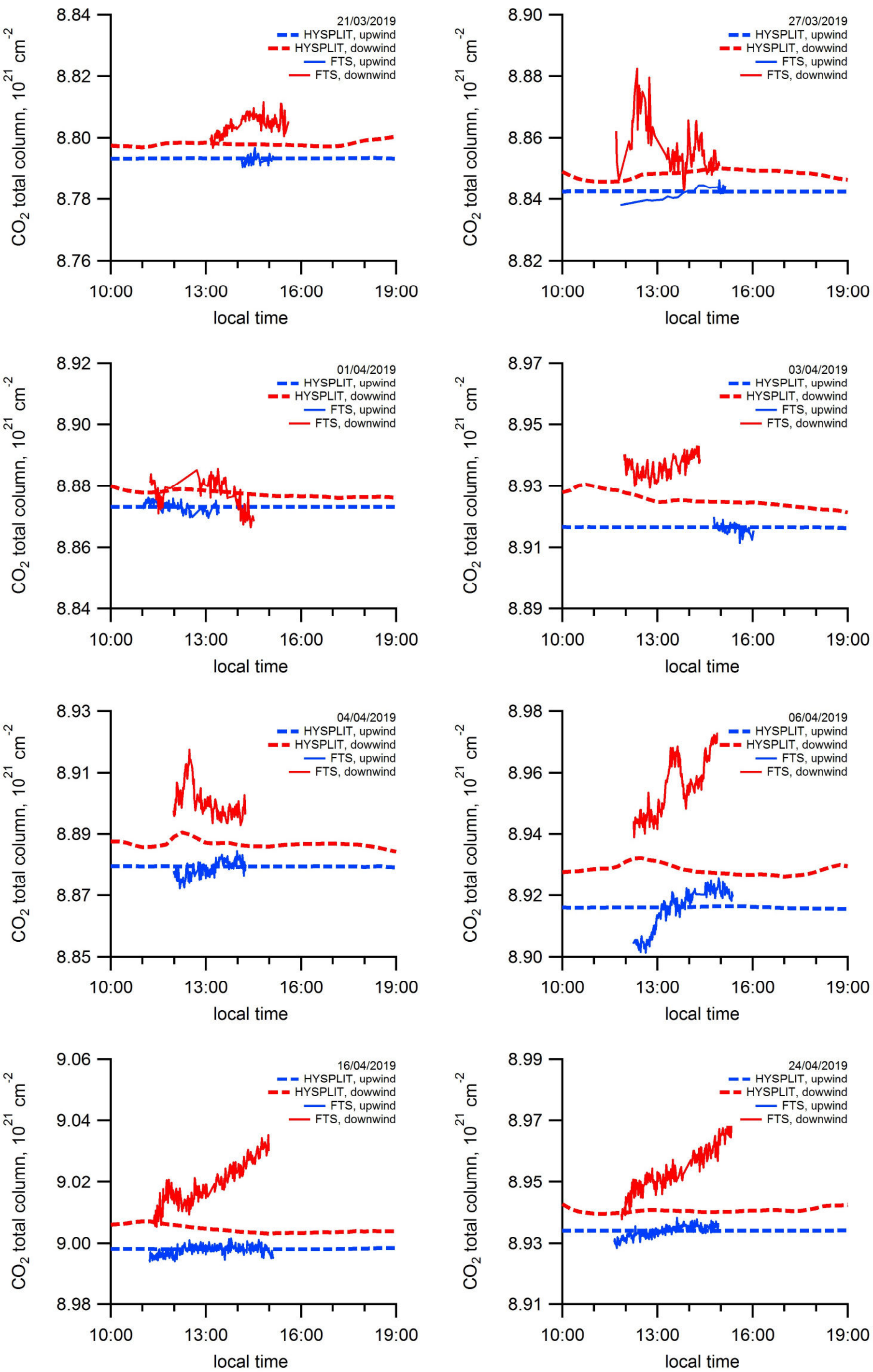

Figure B1: Time series of measured (FTS) and simulated (HYSPLIT, without scaling of the ODIAC emissions data) CO_2 total column at the upwind (blue lines) and downwind (red lines) locations for selected campaign days in 2019.

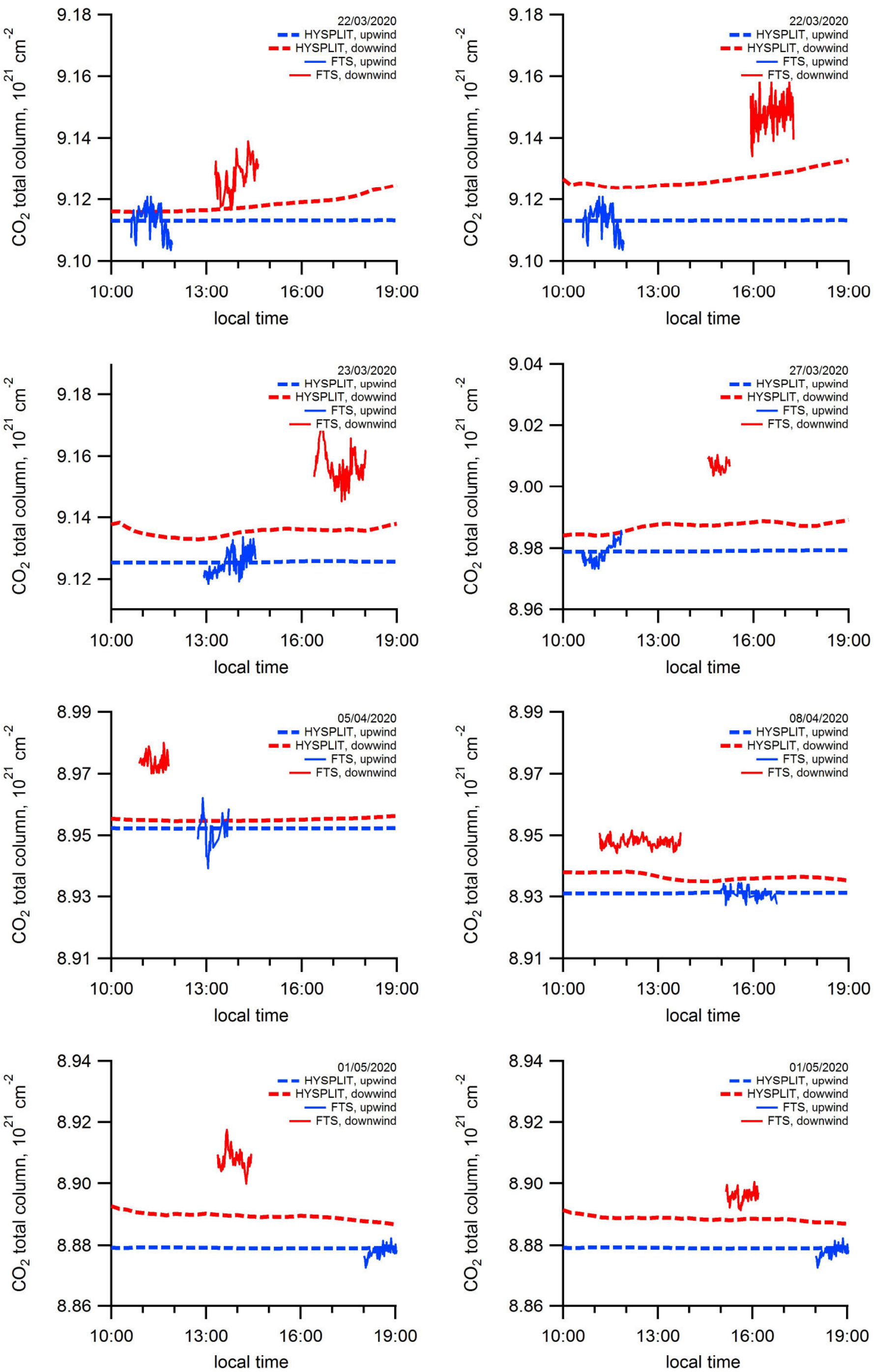

Figure B2: Time series of measured (FTS) and simulated (HYSPLIT, without scaling of the ODIAC emissions data) CO_2 total column at the upwind (blue lines) and downwind (red lines) locations for selected campaign days in 2020.

In addition, two examples of HYSPLIT-simulated CO_2 plumes and corresponding time series of CO_2 total column measurements for the typical days of experiments in 2019 and 2020 are presented in Figs. 5 and 9:

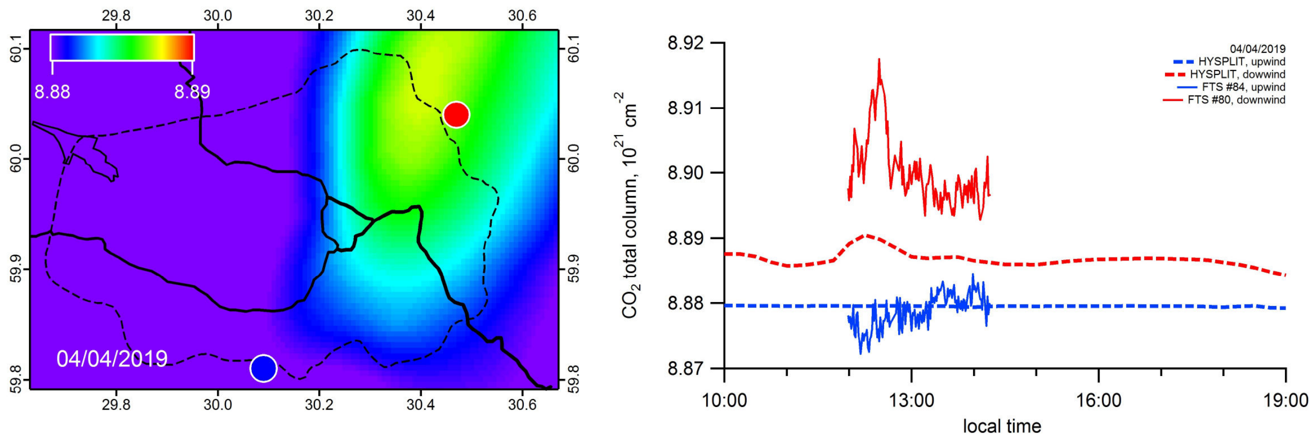

Figure 5: Left panel: Urban pollution CO_2 plume over St. Petersburg calculated by HYSPLIT model for April 4, 2019 (10:00 UTC). The colour bar designates the CO_2 total column in units 10^{21} cm^{-2}. The blue and red circles indicate the locations of upwind and downwind FTS observations, accordingly. Right panel: Time series of measured (FTS) and simulated (HYSPLIT, without scaling of the ODIAC emissions data) CO_2 total column at the upwind (blue lines) and downwind (red lines) locations for the same day.

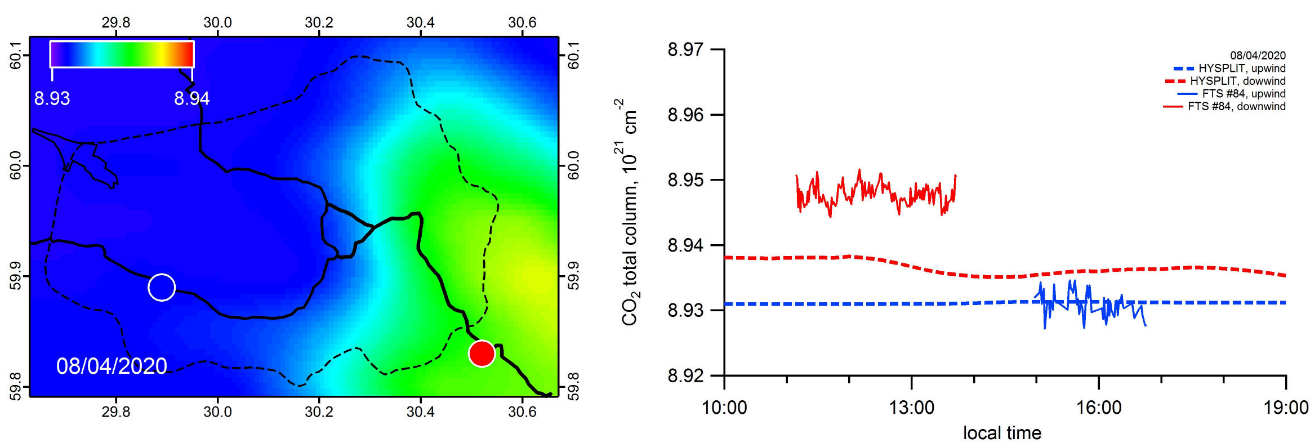

Figure 9: Left panel: Urban pollution CO_2 plume over St. Petersburg calculated by HYSPLIT model for April 8, 2020 (10:00 UTC). The colour bar designates the CO_2 total column in units 10^{21} cm^{-2}. The blue and red circles indicate the locations of upwind and downwind FTS observations, accordingly. Right panel: Time series of measured (FTS) and simulated (HYSPLIT, without scaling of the ODIAC emissions data) CO_2 total column at the upwind (blue lines) and downwind (red lines) locations for the same day.

***It is not entirely clear how background XCO_2 concentrations are determined. For the 2019 campaign, when 2 FTIRs were used, it appears that the sensors were placed such that one was inside the "urban plume" and that one was placed outside of this plume. The sensor outside the plume is then assumed to be the background, but there is nothing presented in this manuscript that builds confidence that this a reasonable assumption. Is the background site even upwind of the city? What is the uncertainty associated with this decision? Are there emission sources upwind of this background site? For the 2020 data, the background determination is even worse, as only one instrument was available, so the sensor was moved during the course of the day in an attempt to capture a useful background value. Unfortunately, total-column CO_2 concentrations can vary greatly over the course of a day, and it is not uncommon for background variations to be on the order of a urban emissions signal, making this assumption unadvisable.**

In part, the answer to the reviewer's questions is contained in the figures mentioned above - Figure 5 and 9, Figure A1 and A2 (Appendix A) and Figure B1 and B2 (Appendix B). The HYSPLIT simulation maps, based on the ODIAC CO_2 emission inventory, clearly show that the "upwind" FTS instruments are placed indeed on the upwind side of the city, in the background area, with no sources of emission upwind of the background site. Besides, the data series of FTS measurements at the background site show mainly stable CO_2 behavior. We would like to emphasize that in any case variations of the background CO_2 are considerably lower than an urban emissions signal.

***The implementation of the transport model is also questionable. The authors state that they are using the HYSPLIT dispersion model, but nowhere in the figures or texts does it appear that any dispersion is actually being simulated. It is unclear, but it looks like HYSPLIT was configured to run backwards in time to compute single particle trajectories, with no stochastic (dispersion) component. It is then stated that "The width of the air paths was assumed to be 10km" [Line 262], which I assume means that plume of influence on each observation is simply modelled as a straight line 10km wide. This type of modelling would suggest that the column observed is equally sensitive to emissions 500 meters upwind as it is to emissions 15 km upwind, which is incorrect. It is then unclear how surface emissions are "integrated" into the column based on these trajectories. Also, how is vertical transport dealt with? Are particles that rise to the top of the boundary layer treated the same as those that travel closer to the surface?**

Unfortunately, the reviewer got the wrong idea about this part of our work. Perhaps this is due to the insufficient amount of illustrative material in the original version of our manuscript. In the revised version we tried to do our best in order to present the method and the details of modeling as clear as possible. However, we would like to note that in fact, the scheme of using the HYSPLIT model was outlined by us already in the original version (see subsection 3.2 "HYSPLIT model general setup"):

> *The <u>spatial and temporal evolution of the urban pollution plume</u> was simulated using the HYSPLIT model (Draxler and Hess, 1998; Stein et al., 2015). Calculations were performed for the territory of the St. Petersburg agglomeration using the offline version of the HYSPLIT model with the setup similar to the one that was successfully used previously for the NO_x plume modelling (Ionov and Poberovskii, 2019; Makarova et al., 2021). A <u>3-dimensional field</u> of anthropogenic air pollution was calculated for a spatial domain with coordinates 54.8°-61.6° N, 23.7°-37.8° E; the domain grid size is 0.05°×0.05° latitude and longitude (see Fig. 3, top). The vertical grid of the model is set to <u>10 layers with the altitude of the upper level at 1, 25, 50, 100, 150, 250, 350, 500, 1000 and 1500 meters a.s.l., respectively</u>. As a source of meteorological information (vertical profiles of the horizontal and vertical wind components, temperature and pressure profiles, etc.), the NCEP GDAS (National Centers for Environmental Prediction Global*

Forecast System) data were used, presented on a global spatial grid of 0.5° × 0.5° latitude and longitude with time interval of 3 hours (NCEP GDAS, 2020).

We now add some more details of the HYSPLIT configuration in the revised version of our manuscript:

> To run HYSPLIT we used the software package: HYSPLIT 4, June 2015 release, subversion 761.
> The advanced setup of the HYSPLIT model was configured as follows (basic parameters):
> - default method of vertical turbulence computation,
> - horizontal mixing computed proportional to vertical mixing,
> - boundary layer stability computed from turbulent fluxes (heat and momentum),
> - vertical mixing profile set variable with height in the planetary boundary layer (PBL),
> - boundary layer depth set from the meteorological model (input meteorology data),
> - puff mode dispersion computation with a "tophat" concentration distribution on a horizontal and vertical scale.

We believe that taking into account new illustrative materials added to the revised manuscript, the reader will get a complete view of the intensive model calculations which we carried out. We have also to mention, that quite similar HYSPLIT simulations helped us to plan each of the field experiment in 2019 and 2020. For this purpose, the forecasts of urban plume evolution have been calculated. To get an idea of the degree of spatio-temporal detail of these calculations, the reviewer can look at animations, available from the following direct links:

21 March 2019:	https://youtu.be/0GD8_YsNt2Q
27 March 2019:	https://youtu.be/40mGPgkCAmw
01 April 2019:	https://youtu.be/Gc3LUV4jmVI
03 April 2019:	https://youtu.be/cPZ-71ZvKHw
04 April 2019:	https://youtu.be/ekc2ip9OplY
06 April 2019:	https://youtu.be/rgtq6JLPhig
16 April 2019:	https://youtu.be/1POH1GghvXA
18 April 2019:	https://youtu.be/PByNmoR800E
24 April 2019:	https://youtu.be/jBydWV84XQY
25 April 2019:	https://youtu.be/fFwb-AuitxU
30 April 2019:	https://youtu.be/9y7SC29iEgI
22 March 2020:	https://youtu.be/5-fyy69DdV4
23 March 2020:	https://youtu.be/KZD6c23BDDY
27 March 2020:	https://youtu.be/p2vx3RyAq0U
05 April 2020:	https://youtu.be/kf7YAI1PFyg
08 April 2020:	https://youtu.be/xcQyDO8IjbA
01 May 2020:	https://youtu.be/GlicSVAZIyU

One should keep in mind that the animations presented above are not directly related to the calculations relevant to the present study, since they model the evolution of the tropospheric NO_x plume in time increments of one hour, using the forecast meteorology data (for full details see Makarova et al., 2021). Our HYSPLIT simulations of CO_2 are even more detailed, as they utilize the ODIAC emissions inventory and reanalysis meteorology data to calculate CO_2 concentrations with 15-minute time step.

***The current version of HYSPLIT is able to run in a mode that actually simulates dispersion and surface influence on observations, using the Stochastic Time-Inverted Lagrangian Transport (STILT) model. The HYPSLIT-STILT model produces a**

influence function (footprint) with the correct units (ppm / umol/m2s) to relate surface emissions to atmospheric observations, and have been used many times in studies with similar goals as this one. I would strongly suggest using this, or a similar model, to reprocess these results.

We hope that all our answers to the referee's comments and the new plots shown in the revised version will definitely convince the reviewer that in this paper we have used the capabilities of dispersion modeling with HYSPLIT tools in their entirety. To our opinion, the functions of the HYSPLIT model are quite sufficient for the tasks we solve, which is confirmed, in particular, by our own long-term experience in HYSPLIT atmospheric modeling. One can mention, for example:

Ionov, D.V. and Poberovskii, A.V.: Nitrogen dioxide in the air basin of St. Petersburg: Remote measurements and numerical simulation, Izv. Atmos. Ocean. Phys., 48, 373–383, https://doi.org/10.1134/S0001433812040093, 2012.
Ionov, D.V. and Poberovskii, A.V.: Quantification of NO_x emission from St. Petersburg (Russia) using mobile DOAS measurements around entire city, Int. J. Remote Sensing, 36, 2486-2502, https://doi.org/10.1080/01431161.2015.1042123, 2015.
Ionov, D.V. and Poberovskii A.V.: Integral emission of nitrogen oxides from the territory of St. Petersburg based on the data of mobile measurements and numerical simulation results, Izv. Atmos. Ocean. Phys., 53, 204-212, https://doi.org/10.1134/S0001433817020049, 2017.
Ionov, D. V. and Poberovskii A. V.: Observations of urban NO_x plume dispersion using the mobile and satellite DOAS measurements around the megacity of St. Petersburg (Russia), Int. J. Remote Sens., 40, 719-733, https://doi.org/10.1080/01431161.2018.1519274, 2019.

We do not see any need to involve the HYPSLIT-STILT model to this study, since our HYSPLIT calculations already take into account all the effects mentioned by the reviewer. It is also worth noting that all the calculated fields of the CO_2 content are already presented in the correct units – [molecules cm^{-2}] for total column and [ppmv] for concentration (one can make sure of this by looking at Figure 4 and Figure X1 and X2 of the manuscript).

***It is unclear (due to the lack of math presented) how the observations, transport model, and prior inventory are combined to produce the resulting emissions scaling factors and uncertainties. Did the fitting process take into consideration different uncertainties in the model and observations? It is mentioned that "The error assessment for the scaling factor should be discussed is some detail" [Line 231], however this is followed by only a few sentences which present an error analysis that does not account for any large sources of error, such as errors in the transport do to wind speed and direction uncertainty, or errors due to uncertainties in the background estimate or spatial distribution of emissions.**

It seems to us that taking into account a number of additions made to the text and new illustrative material, the revised manuscript already contains answers to the questions raised here by the reviewer. In particular, the full use of the HYSPLIT dispersion modeling tools minimizes errors associated with wind direction and speed uncertainty. Meteorological data that is used as input to the HYSPLIT simulation pass a rigorous preprocessing to ensure its self-consistency. Getting information on spatial distribution of emission sources is a complicated task itself, especially if emissions are considered for the megacity at high resolution grid. Therefore we use in our study the recognized and open access ODIAC database. Any varying of the position/intensity/type of emission sources should have well-reasoned basis.

We also slightly edited the part of the text ("*The error assessment for the scaling factor* ..") that the reviewer pointed out in his comment:

> The error of the scaling factor was estimated under the assumption that the measurement errors are the same for all days as well as the model simulation errors. The error bars indicated in Fig. 6 as boxes are in fact the variations of ΔCO_2 obtained as standard deviation of observations and simulations within one observational series (see Appendix B, Fig. B1). Obviously, these quantities comprise both measurement errors and simulation errors (including those associated with wind direction and speed uncertainty), and temporal variability of the CO_2 TC. One can see that these quantities differ from day to day.

***It is my opinion that the work as is does not present a robust, reproducible, or innovative analysis that adds scientific value to the dataset.**

We completely disagree with the reviewer's last comment. In contrast to his/her opinion, we would like to note the following:

1. Robustness.

Our study is based on the measurements made by state-of-the-art spectroscopic instruments, namely EM27/SUN FTIR spectrometers, during two consecutive field campaigns. An EM27/SUN spectrometer has already proven itself in the scientific community as an appropriate tool for studies of the horizontal inhomogeneities of atmospheric composition on a regional scale. For simulations of the 3D CO_2 field, we used the HYSPLIT model in the dispersion calculation mode. HYSPLIT is a well known and widely used tool for the simulation of this kind. The approach based on emission scaling is also well known and has proven its efficiency. The a priori emissions database ODIAC is also widely used. So, we do not see any reasons to consider our analysis as not robust.

2. Reproducibility.

If necessary, every number and plot presented in our paper can be easily reproduced by any researcher. As indicated in the "Data availability" section of the manuscript: "The datasets containing the EM27/SUN measurements during EMME-2019 and EMME 2020 can be provided upon request". Then, the HYSPLIT model package is available for free download from the NOAA Air Resources Laboratory at https://www.ready.noaa.gov/HYSPLIT.php. For example, to produce a 3-day 3D simulation of 15-minutes step CO_2 concentration over the spatial domain of our interest it takes only one hour of processing time by standard Microsoft Windows XP personal computer (Intel Core i3-4150 CPU @ 3.50Ghz, 4GB RAM). Anyone who has attempted to run such atmospheric simulations will recognize that it is really cost-effective processing setup.

3. Innovative character.

The results of our research provide an independent and new top-down estimate of CO_2 emission by one of the main industrial cities of European Russia. This estimate is approximately twice the value indicated in modern global emission inventories (such as, for example, the well known ODIAC database).

We guess that the referee's opinion expressed in the last comment is based mainly on the lack of detailed information on FTIR measurements and HYSPLIT simulations in the original manuscript. We do hope that our extensive revision of the article will make the presentation of our study more clear. And we thank the referee once again for the insightful and helpful comments.