We would like to thank the Anonymous Referee #2 for the detailed comments about our work, as they have been very helpful to improve our study. Our response is organised as follows. After each one of the referee's comments (in black) can be found the authors' response (in blue) followed, if needed, by changes made in the manuscript (in dark blue). In the revised version of the manuscript, only the significant changes have been coloured in blue to help identifying any new content. Please note that the structure of the manuscript has been slightly modified to clarify each sections purpose in the paper (see our answer to Anonymous Referee #2 for more details).

This study presents analyses of carbon monoxide (CO) distributions in the upper troposphere and lower stratosphere in connection with its sources over different regions using the global chemistry transport model, MOCAGE and also SOFT-IO, which calculates Lagrangian backward trajectory of the air parcels. The surface emissions inventory used in this study is GFAS and the model results are compared with the comprehensive airborne measurements obtained from IAGOS. My main comment is about the motivation and background of this study. Why is CO important in the upper troposphere? Has there been an issue with the injection height in global chemistry transport models in general? I believe improving the goals and motivations of this study will improve the quality of the manuscript significantly.

General Comments:

1. Motivation and expectation - It would be nice to see the plume injection height has been an issue in representation of CO in the global chemistry transport model, which can provide strong motivation for this work.

Indeed, the justification to the choice of the injection height implementation was not developed enough to justify our motivations for this work. In addition to our response to one of the following comments (P3, L22), we added the following explanations in the introduction of the revised manuscript:

"Moreover, Fromm et al. (2019) recently carried out a reinterpretation of existing literature on the pathway of wildfires emissions to the UTLS, stating that on multiple occasion studies have wrongly attributed plumes observed in the upper troposphere to transport from traditional cumulonimbus (Cb) instead of pyrocumulonimbus (pyCb). They concluded that the phenomenon of pyroconvection has probably been overlooked and its impact underestimated in past studies, encouraging the use of reliable information on its occurrence to accurately quantify vertical transport of emissions."

2. It is important to discuss the importance of UTLS CO. Why do you want to look at UTLS? Importance of UTLS CO distribution? CO in the UTLS must depend not only the emissions but also the convection in the model.

We decided to add more comments about the importance of UTLS CO, its distribution and impacts on the overall chemical composition off the atmosphere. We also provided explanations on the role of biomass burning in these processes. Additions are made in the manuscript at two places:

- P2, L15-16 of the revised manuscript:

"Moreover, because ozone radiative impact relies mostly on its distribution in the UTLS (Riese et al., 2012), it makes CO indirectly influencing the global radiative budget of the Earth."

- P2, L31 – P3, L2 of the revised manuscript:

"As biomass burning emissions can reach rapidly the upper troposphere in the form of plume transported though convection or pyroconvection, they have been studied for their potential to contribute to ozone production at this altitude. Enhancements of ozone amounts have been observed and modelled in biomass burning plumes (Thomas et al., 2013), with production increasing while the plume ages. It can lead to export of ozone as the plume are transported by the general circulation on a hemispheric scale (Brocchi et al., 2017)."

3. Results - GFAS plume rise parameters do not improve the simulation significantly. Does this mean the plume injection height is not important in general? Focus on the case where injection height makes difference instead of presenting all the cases.

The use of GFAS injection parameters instead of 3 fixed heights depending on latitudes in MOCAGE improves significantly the forecast of fire plumes in the UT in boreal regions with respect to IAGOS cruise data. This is mainly because, there, plumes are more driven by pyroconvection than at other latitudes. Therefore, this is where we expected and we do get most improvement from the GFAS injection parameters that provide an estimate of the actual height reached by pyroconvection for each fire. Taking the variability of heights of pyroconvection into account in the model is an important outcome of this study even though there is no significant improvement on average in the UT at other latitudes with respect to IAGOS data. Another important point, from Figs. 10, 11 and 12 from the original manuscript, one can see that the new parameterization induces changes in the distribution of CO in the mid-latitudes, in the whole troposphere and lower stratosphere. This is partly related to transport processes from boreal regions to other regions (e.g. Brocchi et al. 2018). Also, the original injection parameterization leads to a sharp discontinuity at 60° latitude while in reality, the change of the height of fire injection occurs smoothly from the boreal regions to the mid-latitudes. This is another argument for the use of GFAS parameters.

All these arguments have been made clearer in the revised manuscript and the part devoted to the other regions than boreal has been reduced (fig. 9 removed).

4. Writing can be improved. Some of the detailed comments are provided below.

Following comments from both Anonymous Referees, the manuscript was improved, as some sentences were unclear, typos remained, and acronyms were not always defined in the manuscript.

Specific Comments:

P1, L13 - This was done by comparing simulations 'were' -> Could this be 'with' instead? Revised

P2, L12 - hydroxyl (OH) radicals -> hydroxyl radical (OH) revised

P2, L15 - CO can also be a way to discriminate air from the troposphere and the stratosphere, since it is only found in very low amount above the tropopause. -> This is somewhat misleading. CO decreases rapidly right above the tropopause and increases due to chemical production (For example, see Fig. 9 of Schoeberl et al., 2008JGR).

Indeed, for clarity it has been rephrased to:

"CO can also be a way to discriminate ~~air from the troposphere and the stratosphere~~ upper tropospheric from lower stratospheric air masses, since it is only found in very low amount directly above the tropopause."

P2, L17 - transported up to the -> transported in to the revised

P2, L19 - thanks to deep convection -> due to deep convection revised

P3, L3-4 - . . .the sensibility to the injection of CO from biomass burning. . . -> This sentence is not complete. Please consider revising.

Sentence was revised as follows:

'In this study ~~the sensitivity to the injection of CO from biomass burning in the troposphere is investigated~~, we investigate biomass burning emissions and their impacts on CO distribution in the upper troposphere, through global modelling and in-situ measurements.'

P3, L5-7 – The reference (Deeter et al., 2013) is more appropriate for the MOPITT data. Either use MOPITT instead of IASI as an example or revise the sentence here.

Replaced ‘IASI’ by ‘MOPPIT’ in the sentence.

P3, L10 – air planes –> airplanes revised

P3, L14-16 – I recommend revising this sentence for clarity. For instance, what does ‘source appointment’ mean? The actual word is apportionment and the sentence has been revised accordingly.

P3, L17 – discriminate sources of CO anomalies encountered by the aircraft -> identify. . .the aircraft measurements?
Sentence was revised as follows:
“Lagrangian backward transport calculation. SOFT-IO (Sauvage et al., 2017) is a recently developed tool coupling backward transport calculation and emission inventories to ~~discriminate sources of CO anomalies encountered by the aircraft~~ to estimate the contribution of recent emissions to CO anomalies identified in the aircraft measurements.”

P3, L22 – It would be helpful to include why considering plume injection height matters here in addition to the citation.
The following sentence was added:
“It was found that not only the vertical distribution of emitted trace gases was impacted, but also their long range transport as injection can occur directly in the upper troposphere.”

P4, L18 - Carbon monoxide measurements begun -> were begun revised

P5, Figure 1 – A description of Figure 1 should be included in the text.
Figure 1 has been simplified and now only displays trajectory regardless of the IAGOS package as we focus in this study on CO which is always measured by IAGOS packages. A description of its main features is now discussed in the text:
“It is noticeable that the northern mid-latitudes are the most sampled, with two main axes for IAGOS flights: from Europe to North America going over the Atlantic Ocean, and from Europe to Eastern Asia going over Boreal Asia. The tropics flights tracks mainly cover the African continent and the maritime continent.”

P5, L3-4 – The complete method. . .features. -> The complete description of the method can be found in Sauvage et al. (2017). Here is the summary of its main features. Revised

P5, L5-L9 – References for FLEXPART, ECMWF and MACCcity should be included here. Reference added.

P5, L13 – attribute to revised

P6, Figure 3 – It should be mentioned how the CO_anomaly is calculated and what it represents here. Does it represent one plume? Why is it called anomaly?
Figure and caption have been redone to be consistent with CO anomaly calculation from Eq. 1.
The single plume is also visually highlighted.

P7, L1 – Does ‘superior’ mean anything larger than the anthropogenic sources even if the difference is very small?
Yes, it means larger. A plume is considered originating from biomass burning, even if it leads to selecting plume with mixed (anthropogenic/biomass burning) origins, we know that most of it is due to biomass burning. A sentence is added in the manuscript for clarification:

"For each CO anomaly detected during a flight, if the biomass burning contribution from SOFT-IO is on average higher than 5 ppb and is greater than the anthropogenic contribution from SOFT-IO, the anomaly is selected as a biomass burning plume. This ensures that biomass burning provides a significant anomaly with respect to CO background and that this is the main contributor."

P7, Table 1 – Are those 6 regions chosen as they have the largest numbers of plumes out of 14? It has to be mentioned in the text.
No plume has been detected from a region other than the 6 detailed in Table 1, but 29 of them come from multiple areas. The text and table description have been clarified:

"A summary of the number of plumes by origin can be found in Table 1. The choice was made to merge together plumes origination from NHAF and SHAF, as well as plumes from BONA and BOAS, as their characteristics are expected to be similar."

"**Table 1.** Number of biomass burning plumes sampled by IAGOS aircrafts in 2013, following SOFT-IO contribution calculations per geographical origin. Regions from which no plume were sampled are not shown. The MULTIPLE origin corresponds to plume having more than one possible region of origin (other than AFR and BOREAL)."

P8, L11 – What does 'impact of climate' refer to? Is this a current climate or change for the future? Changed to 'impact of present and future climate'

P8, L20 – important fires -> fires revised

P8, L21 – Here a different study. . .exploring -> Our study explores revised

P8, L24 – taken here from – taken from revised

P9, L3-4 – References for GFAS and MODIS should be included. References included.

P9, L13 – I think the injection height not only depends on the latitudes but the kinds of fires, e.g., forest fires, bush fires and etc.
Yes, the injection height depends heavily on the nature of the fuel as well as on the kind of fire (from crop, peat, …) and the meteorological environment where the fire develops, but since that information was unavailable, latitude dependent profiles were chosen. The manuscript was modified accordingly:
"~~The choice was made that the injection height depends~~ In this approach the injection height was set depending on the latitude of the fire, even though it relies on other parameters like the type of fire."

P15, L5 – carbon monoxyde –> carbon monoxide revised

P16, Figures 10 & 11 – I don't think the differences between the Figs. 10 & 11 are significant. Either including one of them or emphasize the differences.
Since comments on the vertical distribution of CO can be made using Fig. 12, Fig. 11 has been removed from the manuscript as it does not provide additional information. Associated comments in the manuscript are modified and moved in the paragraph about the original Fig 12.

P20, Figure 13 – Here, results from the MOCAGE INJH runs are compared with IAGOS data. I am curious how MOCAGE BASE would look like.
MOCAGE BASE are almost identical to MOCAGE INJH results when plotted as vertical mean profiles and compared to IAGOS data, and thus have not been shown in this figure. The lack of difference comes from the fact that this figure makes use of all IAGOS data (not only biomass burning plumes)

and that there is no airport in the boreal region, only region where significant changes are expected from figure 8.

P21, L6 – Around the equator -> Near the equator revised

P21, L18-19 – and transport. . .troposphere. -> Needs a reference for this statement.
Reference added to Huang et al. (2012,2014) and Liu et al. (2013) :

Huang, L., Fu, R., Jiang, J. H., Wright, J. S., and Luo, M.: Geographic and seasonal distributions of CO transport pathways and their roles in determining CO centers in the upper troposphere, Atmospheric Chemistry and Physics, 12, 4683–4698, https://doi.org/10.5194/acp-12-4683-2012, 2012.

Huang, L., Fu, R., and Jiang, J. H.: Impacts of fire emissions and transport pathways on the interannual variation of CO in the tropical upper5 troposphere, Atmospheric Chemistry and Physics, 14, 4087–4099, https://doi.org/10.5194/acp-14-4087-2014, 2014.

Liu, J., Logan, J. A., Murray, L. T., Pumphrey, H. C., Schwartz, M. J., and Megretskaia, I. A.: Transport analysis and source attribution of seasonal and interannual variability of CO in the tropical upper troposphere and lower stratosphere, Atmospheric Chemistry and Physics, 13, 129–146, https://doi.org/10.5194/acp-13-129-2013, 2013.

P23, L10-12 – Needs citation here.
According to comments from Anonymous Referee #1, this sentence is actually inaccurate since cases of pyroconvection have been reported in Australia, and the point was more about particular strength of convective transport over the maritime continent. Manuscript was modified accordingly.

P24, L8-10 – I would like to see the examples of contribution from the biomass burning is poorly represented in the UTLS to make this as a strong case.
We are not understanding this comment. Is this comment for P25, L8-10, instead of page 24 ? if so, here is our answer :

These two lines may have gone further than what can be concluded from our work. We decided to rewrite them to be in line with the content of the manuscript:
"Based on the results of this study and previous ones that have shown that transport through pyroconvection has been underestimated (Fromm et al.,2019), it appears that the use of products such as GFAS injection height can offer improvement in the representation of biomass burning plumes in atmospheric models, especially for mid to high latitudes."

Full names for all the acronyms should be provided in the manuscript. So, please double check. revised