Dear Editor –

Thank you for the opportunity to revise this paper again. We are pleased that reviewer 2 recommended accepting the manuscript as is and reviewers 3 and 4 recommended acceptance after minor revisions. (There was no reviewer 1.)

We have addressed comments from reviewers 3 and 4 point-by-point below. Reviewer comments are in normal text and our responses are in bold font.

Two changes in response to the reviewers deserve mention here. In response to a request for more information about the fires that were sampled, we added Table A1, which summarizes the sampling dates, fires, and smoke ages. One reviewer asked for more explanation of why smoke ages were calculated for some, but not all, eastern US fires. Ages of some fires were omitted because no one on the FIREX-AQ science team had requested them. To make the dataset more complete, we computed the additional smoke ages for eastern US fires where feasible. This slightly increased the dataset size and resulted in small changes to some statistics in several sections of the paper. For example, the difference between the mean-wind age and trajectory-based age decreased from 14% in the previous manuscript version to 12% in this version. There is no meaningful impact on any result or conclusion of the paper, so we do not think the additional data requires another round of review.

REVIEWER 3

Thank you for the suggestions and corrections. We address them individually in the bold text below and explain changes that we will make to the manuscript.

This revised manuscript describes calculations of the age of smoke from wild and prescribed fires across the USA that were measured using two aircraft. Two different methods are used to establish the age of smoke: one which used in-situ measurements of wind and another which used a trajectory model informed by several reanalysis products.

This dataset is unique and comprehensive, with measurements made at an impressive scale, and the data has evidently clear use. The manuscript is excellent, with the methodology and results very clear. Careful and substantial consideration has been given to the quantification of uncertainty, and this is elaborated well in the text. Although I was not an original reviewer, I believe the responses to previous reviewers adequately address their concerns. Other than a few minor changes to improve the clarity of figures, I have little to suggest that would improve the scientific content of the manuscript. However, the dataset is not particularly user-friendly at the moment, and further additions to the manuscript could provide useful information to remedy this.

I recommend that the article be accepted subject to minor revisions. I have outlined suggestions for these below.

Comments about the data usability:

1. File structure: When going to the ASDC folders for smoke age indicated by the URLs, there are often several files which are not directly relevant (although potentially useful). For instance, in the DC-8 data, there are files pertaining to water vapour measurements from an instrument. To aid the reader, it would be useful to add to Section 4 the prefixes used for the files containing the age of smoke data: fireaq-fire-Flags and FIREXAQ-FSU-SMOKEAGE so that it is easy to retrieve data. Similarly, please indicate the filename prefixes and contents of files in these folders containing auxiliary data which the authors believe are useful to contextualise the age of smoke data. Perhaps this would be best as a table.

We added text in Section 4 (Data Availability) that specifies all the file prefixes for data used in the paper. This is a few sentences, so we don't think a table is necessary.

2. Metadata: In the fireaq-fire-Flags data files, there is a comment which contains information about the metadata tabulated data file. This is liable to be missed by users (particularly as it is named wrong in the metadata files), which is a shame as it is a detailed and apparently very useful file. Please add to Section 4 a link to the file: FIREXAQ-FIREFLAG-TABULARDATA_Analysis_20190724_R12_thru_20190905.xlsx found at https://www-air.larc.nasa.gov/cgi-bin/ArcView/firexaq?ANALYSIS=1

We added a bullet point in Section 4 to explain this file and provide a DOI link to it.

3. File format: The data is presented in ICARTT format. Though this is used by many NOAA-operated instruments, they are not trivial to open or navigate by naïve users due to their varied header sizes and changing number of columns. Perhaps the authors could suggest specific Python (or equivalent) packages that can be used to easily open these for quick looks, or software that does, especially since code which generated the figures is unfortunately not provided. If no such software exists, a brief description of the file format and any quirks (such as the use of -9999 for NaNs) would suffice.

In Section 4, we added a reference to the ICARTT format specification document, which contains information about the motivation and purpose of the format, and several software packages that can read these files. This reads (line 453), "Many of these data files use the ICARTT file format (Northup et al., 2017). Software tools are available to read ICARTT files in Python (e.g. Knote, 2022) and other languages (https://www-air.larc.nasa.gov/tools.htm)."

General comments about the manuscript

4. I think it's clear that this is a large and useful dataset from context, but it may be nice to include a short paragraph explicitly about how this dataset differs from/advances upon previous datasets in scale, location or otherwise. However, I appreciate that the manuscript is already quite long for ESSD as is.

We added sentences at several places in the paper to address this suggestion.

In the Introduction (line 76), "Innovative aspects of this work are the inclusion of plume rise and thorough accounting of age uncertainty in the trajectory-based method.

At the start of Section 3.2 (line 304), we added a paragraph that describes the scale of the dataset: "This dataset provides age estimates every second for 24.3 hours (87,370 s in 549 transects) of in situ smoke sampling by the DC-8 during FIREX-AQ and 18.9 hours (68,157 s in 266 transects) of in situ smoke sampling by the Twin Otter. For the DC-8, this includes 20.1 hours (302 transects) sampling smoke from 15 wildfires in the western US and 4.1 hours (247 transects) sampling smoke from 89 prescribed, slash, and agricultural fires in the eastern US. These comprise nearly 97.5% of in situ smoke samples by the DC-8. The remaining in situ smoke measurements did not have a clear source fire, so no age could be determined. Trajectory-based ages are provided for all of these smoke samples; mean-wind ages are provided for 323 crosswind and along-wind transects by the DC-8, where assumptions in the method are met. Smoke age estimates for the 10 fires sampled by the Twin Otter are solely from the trajectory-based method (see Section 2.3 for reasons). Table A1 summarizes the sampling dates and fires with smoke age estimates."

In the Conclusions (line 475), we added, "In total, the dataset includes smoke age estimates for 24.3 hours (549 transects) observing smoke in situ from 104 fires by the DC-8 and nearly 19 hours (266 transects) observing smoke from 10 fires by the Twin Otter. The large scope, treatment of plume rise, and thorough uncertainty quantification are novel aspects of this smoke age dataset."

In the Abstract (line 41), we added, "Across the two aircraft, the dataset provides ages for over 43 hours (815 transects) of in situ measurements in smoke plumes from 115 different fires, with smoke ages ranging from 1 minute to 40 hours."

Specific comments about the manuscript

5. Abstract: While commendably clear, this abstract is rather long at over 400 words. Perhaps the authors could consider cutting it down a little? I believe ESSD has no word limit on abstract, so there's no need to if the authors think this can't be done while maintaining clarity, but its length may unnecessarily discourage future readers.

We confirmed with the editorial staff that the abstract length is acceptable, so we would like to keep the abstract as it is.

6. Figure 1: I think the two different subplots are used to make it easier to view fires in different regions of the US rather than for a particular scientific reason (if so, it was unclear in the text). However, it would be good to make this clear in the caption and label the subplots. Additionally, for readers unfamiliar with US geography, it may be useful to show these sub-figures relative to the contiguous US.

Yes, the panels make it easier to see individual fires. We added an inset map to orient the panels within the US and added explanatory text to the caption.

7. Figures 4, 5 and 6: I think the diagonal line is a 1:1 line rather than a line of best fit, but it would be good to make this clear and keep the format consistent between figures.

The captions now clearly state that the diagonal line is 1:1 and this is consistent in all three figures.

8. Figure 7b: I found this figure difficult to interpret. Maybe it's just me, but I think this shows the spread in the rise time uncertainty relative to the rise time, but from the text I think the intent is to show the magnitude of the uncertainty relative to the rise time. The uncertainty PDFs look like they're squashed versions of the time, so presumably this distribution is pretty centered on 50% uncertainty for most time values? But it's hard to see whether there's a systematic trend of uncertainty magnitude with time which I think is what's implied. If the authors particularly want to include this, then rather than the dashed lines, perhaps new axes might be useful, plotting time on x-axis against percentage uncertainty magnitude on the y-axis?

The reviewer correctly interpreted the figure's meaning, but we appreciate that this could be confusing. Our goal was to show that the uncertainty was about 50% of the age, not trying to make a point about any systematic trend. To improve clarity of the figure, we removed the uncertainty PDF, which also enables displaying the figure in a more compact layout.

Technical corrections:

9. Line 145 (and elsewhere): Table 2 is referred to before Table 1. This might be picked up in typesetting, but the tables should be re-ordered and relabelled accordingly.

This is fixed.

10. Sec 2.4 (and throughout): Subscripts which are words or abbreviations of them should be in Roman (upright) font, rather than italics. Variables/indices in subscripts such as m should remain italic.

This is fixed.

REVIEWER 4

Thank you for your comments and suggestions. We address them individually in the bold text below and explain changes that we will make to the manuscript. We believe that the revisions will clarify and strengthen the manuscript.

This is my second-round review of the manuscript "Age of smoke sampled by aircraft during FIREX-AQ: methods and critical evaluation." The authors estimate smoke age during FIREX-

AQ using two complementary approaches and discuss the associated uncertainties. Based on the revised manuscript, I think the authors have adequately addressed the comments from the two independent reviewers in the first round. The dataset should be useful for studies of biomass-burning chemistry, smoke evolution, and model evaluation. I recommend publication after the following comments are addressed.

Major comments

1. The manuscript would be more useful to future users and field campaign planners if the authors included a table summarizing fires or plume encounters for which smoke age was not reported, or for which only one age method was applicable. The text notes several cases where the methods were limited, including eastern US fires sampled close to the source with little downwind sampling, plumes with transport distances greater than about 200 km, plumes affected by wind shifts, and trajectory ensemble members excluded based on satellite imagery. A supplementary table listing the fire name, date, aircraft, sampling geometry, available age products, and reason for exclusion or limited applicability would make these limitations clearer and help future users interpret the dataset. If providing additional table is too much work, should consider providing at least opinion or insight to those tracks, somewhere in the manuscript.

We added Table A1 to summarize the plume transects for which smoke ages are reported. The table contains sampling dates, fire names, fire ID numbers (for cross-referencing to other FIREX-AQ datasets), state locations, basic fuel categories, transect counts and orientations (e.g. crosswind, along-wind, other), and the mean and range of ages estimated with the two methods.

As already mentioned, we added smoke ages for eastern US fires, so that trajectory-based ages are now provided for all smoke transects in which the source fire can be identified. The criteria for inclusion are now explained clearly in Section 2.

Section 2.1 (line 91) now defines the three types of smoke transects more clearly: "Most plume transects were crosswind (i.e. transverse), meaning the aircraft flew nearly perpendicular to the local wind, or along-wind (i.e. longitudinal), meaning nearly parallel to the wind, while some had other or unclear wind orientation, such as when winds were light or variable or when the transect was almost directly above the fire."

Section 2.3 (line 144) now says: "The mean-wind age is computed for all smoke plume transects with crosswind or along-wind orientations."

And in Section 2.4 (line 155): The trajectory-based method "is applied to all smoke transects with a known source fire (regardless of wind orientation), so trajectory-based ages are available in many cases where the mean-wind age is not."

2. The trajectory-based framework can be applied to pyroCb outflow in a formal sense because ages are calculated from each aircraft location. However, the physical assumptions are weaker for fresh active-anvil samples than for ordinary downwind smoke transects. The Williams Flats pyroCb sampling geometry differs "substantially" from the non-pyroCb plume transects. In pyroCb cases, the sampled air may still be affected by active convective transport and

detrainment (D. Peterson's paper cited in the original manuscript, see Fig.4), so the estimated age depends on uncertain updraft residence time, detrainment height, and timing. These uncertainties may not be fully represented by using a representative plume-rise vertical velocity of approximately 12 m/s, right? The method appears more defensible for detached aged-anvil samples than for fresh active-anvil or cloud-top samples. Additional guidance on how users should interpret pyroCb age estimates would be helpful, and should be discussed.

We now discuss this issue in Section 3.4 (line 416) by adding, "An additional uncertainty for pyrocumulonimbus smoke is that, after detrainment from the deep convective column, unresolved vertical winds within and around the active anvil cloud could transport smoke vertically, which is not included in the trajectories. For the specific pyrocumulonimbus over the Williams Flats fire, the effect magnitude is bounded by the measured horizontal wind speed in the active anvil (~12 m s^{-1}), range in wind speed from the anvil top to bottom altitudes (~30%), and horizontal extent of the active anvil (~50 km), which gives an upper bound age uncertainty of ~20 minutes (~20% of mean smoke age in these transects) due to unresolved vertical transport within the anvil."

3. Line ~482: smoke age products provide a basis for interpreting chemical and physical aging in FIREX-AQ smoke observations. This is an important conclusion and deserves a little more discussion. The treatment of plume-rise time is one of the key contributions of the study, and it has implications for both measurement interpretation and model evaluation. Many chemical transport models output hourly fields, which is much coarser than the age resolution discussed here. In fresh smoke, dilution and chemical transformation can occur on time scales of minutes to tens of minutes, depending on plume conditions. A short discussion of how physical plume age affects chemical age interpretation, inferred aging rates, and comparison with model output would make this point clearer.

The issues involved in comparing high-resolution observations to coarser-resolution models with unresolved (e.g. sub-grid scale) processes is complex and dependent on the type of model and analysis goals. Nevertheless, we added a sentence about the plume rise issue to this paragraph: "Plume rise time is a significant fraction of the smoke age for measurements near the fire source, so it should be considered when interpreting measurements or comparing to models."

Minor comments

4. Line 53. The Introduction describes the FIREX-AQ campaign broadly before narrowing to the smoke-age dataset developed in this study. Should mention the ER-2, which also sampled multiple fires and provided important remote-sensing observations. Alternatively, the authors could revise the sentence to clarify that they are referring specifically to aircraft with in situ smoke measurements used in this age analysis, namely the DC-8 and Chem Twin Otter.

We followed the second suggested approach, revising the sentence to, "Two participating aircraft focused on in situ measurements of smoke composition: the NASA DC-8 and NOAA Chemistry Twin Otter."

The ER-2 is mentioned on line 83: "The NASA ER-2 and a second NOAA Twin Otter (NOAA46) that collected remote sensing measurements will not be discussed here."

5. Line 59. Please specify the approximate time scale meant by "short periods of time when winds are steady."

We added a parenthetical clarification "(often 1-3 hours or less)".

6. Line 85. Please define carbon monoxide as carbon monoxide (CO) at first use. Several instrument acronyms, including DACOM and SP2, are also introduced quickly in this section. Please provide the full names at first use. And please double check same issue for other places.

We added full acronyms and chemical names where they were missing.

7. Lines 120-122: The text states that the Williams Flats and Sheep Fires were the two largest fire complexes and had multiple centers of fire activity separated by more than 10 km. Please provide a more quantitative description of "very large fires," such as approximate burned area, fire extent, or distance among active fire centers.

We added burn areas for the Williams Flats fire (44,000 ac) and Sheep fire (112,000 ac) to this sentence. All other fires sampled during FIREX-AQ were < 19,000 ac.

8. Figure 1 is central to the manuscript, but the current layout makes it difficult to compare age distributions across individual fires. The authors could consider splitting the figure into multiple panels (as they already did it for top/bottom), for example by region or fire group. A discrete color scale may also make the age ranges easier to distinguish.

While we experimented with other layouts and color scales, we were unable to find an alternative figure layout that significantly improved the ability to compare smoke ages between fires. However, we think this need is satisfied by the added Table A1, which provides means and ranges of ages for smoke from all fires.

9. Table 2 is difficult to read in its current format. Italic font in the Table content..? Additional horizontal lines or clearer grouping of variables would improve readability. The formatting of Tables 1 and 2 should also be made more consistent.

We rearranged the table (renumbered as Table 1) so that it should be more clear.

10. In Section 2.5, the authors use HRRR meteorological fields to drive HYSPLIT. Please cite the HRRR system description paper, such as Dowell et al. (2022), "The High-Resolution Rapid Refresh (HRRR): An Hourly Updating Convection-Allowing Forecast Model. Part I: Motivation and System Description," or otherwise explicitly acknowledge NOAA's HRRR product. And if possible, GFS and NAM as well.

We added citations papers and documents describing all three models.