<u>Author's Response to Referee 2 Commentary</u>

The authors acknowledge that many EOF tutorials already exist in the literature and as such agree to reduce the amount of technical detail in the methods portion of our manuscript, moving these aspects to the appendix instead. The authors add in a table to our introduction section on source variability with an accompanying discussion to help us summarize our current understanding of the variability from specific sources of CO. We add additional discussion in our introduction to make a better case up front for why we had expected EOF analysis to have better success in being able to separate sources into independent signals. We also add in our Results section 3.2 a clearer recommendation for why in our specific case, it was better to use our unrotated modes rather than to use our varimax modes. We agree to incorporate all changes which have been requested in the specific and technical comments. The authors would like to thank Referee 2 for asking many general questions regarding our manuscript including its structure, motivation, and our approach to data analysis. We especially appreciate Referee 2's questions about area weighting in our data and our time scales, as we believe answering these questions will address a vital gap in our methods. We also appreciate that Referee 2 was kind enough to give us 2 specific citations to help us address gaps in our literature.

<u>General Changes Throughout Manuscript</u>

1. We add a table with discussion to Section 2.2 of our introduction to aid in summarizing current understanding CO variability from specific sources and to understand what scales of time are most relevant.

2. We add additional discussion in our introduction to make a better case up front for why we had expected EOF analysis to have success in being able to separate sources into independent signals.

3. We reorganize our Methods section, putting the more technical details in our appendix to reduce the emphasis of our paper being a tutorial on EOF analysis.

<u>Changes Addressing "Specific Comments" with References to Line/Page Numbers</u>

The following changes are implemented to address the "specific comments" from Referee 2, with line/page references. For each change we indicate in parenthesis which referee is being addressed in our proposed changes. Please note that the line numbers refer to the **original version** of the manuscript.

Line 87 Pg. 3

We clarify that in our specific context the global background refers to a mathematical, non-physical quantity and simply refers to an average value.

Lines 90-100 Pg 3-4

We add discussion regarding the application of EOFs to air quality monitoring in the US. We use citations including Eder, B. et. al. (1993), who used EOFs to study spatiotemporal variability of non-urban ozone.

Line 136 Pg. 5

We add discussion that daily data would not be better suited because MOPITT does not have daily global coverage. We must ensure global coverage in the analysis because EOF analysis fails to produce patterns if there are gaps in the data.

Line 141 Pg. 5

Discussion is added regarding the fact that our data was detrended by taking the globally averaged time series and then applying a Fourier fit to it. Because the trends in the total column data are a non-linear combination of the trends from individual sources, it is not immediately clear what sources may have had their long-term trends removed.

Lines 185-188 Pg 7

We edit our discussion with appropriate citations including Fiore et al. (2024) to incorporate up-to-date information on the sinks and sources of OH.

Lines 250-251 Pg 9-10

We add discussion regarding the fact that for our specific application, it makes very little difference in whether we choose to normalize our covariance since we are only using one observation field. If we were to compare EOFs of different datasets, then we should normalize the covariance.

Results 3.1 Pg 15-16

We respond to a comment that initially refers to Figure 2, however because it refers to multiple patterns, we assume Referee 2 had intended to ask about how the EOF patterns may change over time in Figure 3. We clarify that the EOF patterns did not show significant changes when we segmented the data into yearly sets to compare them from year to year. It's possible this could be because the data had long-term trends removed.

Lines 403-405 Pg 15-16

We clarify that our data is area weighted, and we include a new equation to indicate the weighting in Methods 2.1. We discuss, using citations, that this choice is to ensure that the EOFs are invariant to the choice of grid and each pixel contributes equally to the total variance.

Results 3.2 Pg 16-19

We add discussion to clarify that for our study, varimax rotation did not improve the representation of modes and that for further analysis with our seasonal decomposition we used our unrotated EOF modes. We note that decision should not be done in general for climate data. Our decision is because our unrotated modes were reproducible across multiple domains and had better representation with respect to variance.

Lines 441-442 Pg 17

We add discussion to indicate that we have no reason to believe the patterns fit the behavior of source variability *or* that of weather patterns either large scale or local scale.

Line 459 Pg 18-19

We add discussion in the introduction as well as to results Section 3.2 to describe sources of oceanic CO including photoproduction from colored dissolved organic matter (CDOM), direct production from phytoplankton, and dark production from CDOM in the absence of sunlight.

Line 476 Pg 20-21

We clarify, using citations, that the use of time scales for CO makes sense even when the scales are longer than its lifetime. Some variability of CO is driven by large scale weather patterns, for example mixing time is about 6 months and hemispheric exchanges can happen across 1-2 years. It also makes sense from a perspective of studying the impact of climate drivers

Line 534 Pg 25

We add discussion as to what physical processes drive the sharp gradients in skewness related to Figure 9. The annual cycle should be driven by seasonal changes in its sources and sinks and will differ depending on hemisphere and region. For example, in the northern hemisphere it's primarily driven by changes in fossil fuel burning usage i.e. it's largest in winter and smallest in summer because of changes in heating demands. In the southern hemisphere biomass plumes drive variability in central Africa and over part of Australia while biogenic and VOC emission mostly drives changes in South America. The large banding effect over latitude in the SH variability is probably because of a combination of regional transport as well as long term variability due to the North/South movement of the ITCZ which affects the strength of hemispheric exchanges through the Hadley circulation.

Appendix A1. Line 589. Pg 27

Here we clarify the reason for our normalization and mention other potential normalizations which could be used.