We would like to thank the reviewers for their well-considered and constructive comments. We have considered the feedback at length and have revised the paper extensively based on the reviews. Original reviewer comments are in plain text and our responses are in bold italics below.

Reviewer 1

Mukesh Rai et al. extend the atmospheric river (AR) concept to the long-range transport of trace gases, specifically O_3, CO, and PAN. Using a TGAR detection algorithm applied to 14 years of TCR-2 reanalysis data (2005–2019), the authors identify and quantify the frequency and structural characteristics of TGARs, as well as their contribution to global-scale trace gas transport. The manuscript claims to make meaningful conceptual and methodological contribution by adapting established AR detection approaches to the domain of chemical transport. While the theoretical framework is compelling and has clear potential to improve our understanding of episodic pollution events, the manuscript currently falls short in several key areas outlined below. In particular, the discussion and interpretation lack sufficient depth. Although some limitations are acknowledged, the manuscript would benefit from a more robust effort to address these issues and to strengthen the scientific narrative.

My specific comments and recommendations are provided below and should be addressed prior to publication, which I believe this work has the potential to merit.

Throughout the abstract, introduction, and conclusion, the authors emphasize that understanding the long-range transport of pollution is critical for assessing regional and local air quality and for informing effective air quality management strategies. While this is a broadly valid and important motivation, the manuscript does not present specific results or case studies that demonstrate how the TGARs identified in this study could be interpreted or applied by air quality management practitioners. To strengthen the practical relevance of the work, the authors are encouraged to include at least a couple illustrative case studies that highlight the regional and/or local implications of TGARs for air quality, particularly in relation to exceedance events or pollution episodes. Since long range transport of particularly O_3 and CO is extensively studied, the authors should clarify how the datasets and results presented in this work offer new insights or can be used to advance current scientific understanding in this area.

On reflection, we can see that the submitted version of the paper made some sweeping statements about long range transport, TGAR and air quality without providing specifics on how the TGAR approach can be used to advance understanding. The TGAR approach provides systematic estimates of horizontal transport on global and decadal scales that cannot be easily achieved using conventional approaches such as trajectory analysis. We have revised the abstract, introduction and conclusions to try to articulate the value of an objective and globally applicable approach to quantify long-term variations in the frequency, intensity, and spatial characteristics of extreme pollution transport events. An objective and globally applicable approach can provide insight into how long range pollution transport is changing with a changing climate. In the revised version, we have tried to better emphasize where we see the TGAR approach adding value to existing techniques for evaluating impacts of long range

transport on air quality events, as well as acknowledging the limitations of the approach that the reviewers have alluded to.

In particular, we now include the following text in the Conclusions section: "The approach presented here could, in principle, be applied in support of air quality management studies to quickly identify whether or not long-range transport was a contributing factor in specific air pollution events. The vertically integrated TGAR approach captures horizontal transport at large scales occurring at all levels in the troposphere. Long-range transport can influence surface air quality when downward transport occurs. However, actual surface-level impacts relevant to human exposure would still need to be evaluated by carefully analyzing local near-surface circulation alongside the TGAR long-range transport. Trajectory or tagged simulations would still be required to provide direct insights into air quality management."

We have also now explicitly included a "Case study" section, and have included an additional figure that illustrates a particular transpacific transport event identified by the TGAR algorithm, where polluted air descended over Los Angeles and the Western US. We focus here on an event that had been studied in detail in previous work by Lin et al. (2012).

The abstract and introduction need rework:

Abstract: The abstract should clearly articulate the scientific gap this study aims to address, outline the methodology used, and highlight the key findings that substantiate the central concept of TGARs. It should also emphasize how the results advance the current understanding of long-range transport and conclude with a concrete statement on their broader implications. As written, the conclusion of the abstract is vague and does not adequately convey the scientific significance or practical relevance of the work.

We have rewritten the abstract to address these points.

Introduction: The introduction currently focuses only on the general concept of long-range pollutant transport and does not adequately introduce the atmospheric river (AR) framework, which is central to this study. Since TGARs are proposed as an extension of ARs and aerosol ARs, the introduction should provide a concise but informative background on the physical characteristics of ARs, detection methodologies, validation efforts, associated uncertainties, and established climatologies. It should also discuss the role of ARs in transport processes and contextualize how this study builds on and extends that framework. A more targeted introduction is required to better prepare readers for the contributions of this work and clarify the scientific motivation behind the TGAR concept.

Thank you for this feedback. We have rewritten the introduction and have endeavored to address the points raised here by the reviewer. We believe that the revised introduction now should better prepare readers for the contributions described in the rest of the paper.

The results section closely follows the organization as Chakraborty et al. (2022). While this provides a logical framework, the authors should consider including one or two illustrative case studies that highlight source-specific and/or source-region-specific TGAR events. These examples would help ground the broader statistical findings and demonstrate the relevance of TGARs to specific emission sources or regions.

As stated above, we have now explicitly included a "Case study" section, and have included an additional figure that illustrates a particular transpacific transport event identified by the TGAR algorithm, where polluted air, transported from East Asia, descended over Los Angeles and the Western US. This event had been studied in detail in previous work by Lin et al. (2012), helping to ground the TGAR example.

The discussion section requires substantial revision. As it stands, the content is general and reiterates well-established knowledge without sufficiently tying it to the specific findings of this study. To enhance its impact, the authors should restructure the discussion to directly engage with their own results, offering clear reasoning and interpretation of their significance. The section should highlight how the findings advance the understanding of TGARs and their implications for long-range transport and air quality. Specific connections between the results and their broader scientific relevance are needed to highlight the manuscript's contribution. The "Remaining Uncertainty and Limitation" section, in its current form, adds little value. To improve its relevance, the authors should either integrate these points into the relevant parts of the results and discussion sections, where the limitations directly impact interpretation or expand this section to explain why these limitations could not be addressed, their significance in the context of the study's findings, and how future work might overcome them. A more thoughtful treatment of these limitations would strengthen the manuscript's credibility and transparency.

Thank you for the feedback. After consideration of the comments from both reviewers, we decided to restructure into a "Results and Discussion" and a "Conclusions" section. We have removed the "Uncertainty and Limitations" subsection and have integrated these points into other parts of the manuscript, as suggested.

In the "Conclusions" section, we highlight the following specific contributions of this work:

- ***We have established a global climatology of TGAR events, which allows us to evaluate long-term variations in the frequency of these events and to quantify their relative contribution to total global transport.***
- ***This work points to changes in large scale circulation patterns over time, including poleward shifts of the mid-latitude jets, that are affecting long-range pollution transport.***
- ***Our analysis using the TCR-2 dataset reveals significant regional variations in PAN trends over the 2005-2019 time period. The most pronounced increases are observed in East Asia. Substantial decreases in PAN are observed in North and South America as well as Europe.***

We also include some discussion of limitations raised by the reviewers.