We sincerely thank the Reviewer for the careful evaluation of our manuscript and for the many thoughtful comments and relevant literature suggestions. We appreciate the recognition that the topic is timely and important. Many of the concerns raised by the Reviewer overlap with those independently identified by Reviewer #1, particularly regarding the interpretation of the analogue framework, the characterization of the large-scale circulation, and the discussion of turbulence-generation mechanisms.

In the revised manuscript, we will carefully address all of these comments to strengthen the validation of the analogue-selection procedure, include additional upper-level dynamical diagnostics, expand the discussion of the physical interpretation of the results, and clarify the scope and limitations of TurboMeter. In particular, we emphasize throughout the revised manuscript that TurboMeter is a circulation-constrained attribution framework, rather than a process-specific turbulence attribution framework. Below we provide a detailed point-by-point reply to the three main comments. Reviewer's comments are in normal font, while our replies are in bold font.

1. Misuse of EDR ≥ 0.2 as "extreme turbulence"

The manuscript defines the event sample using automated in situ aircraft reports with **EDR ≥ 0.2 $m^{2/3}$ s^{-1}**, describing these as moderate-or-greater events and using them to frame "extreme aviation turbulence" in the title and throughout the paper. However, **EDR values higher than 0.2 from in situ AMDAR/ACARS aircraft data cannot automatically be linked to, or labeled as, "extreme" turbulence**. The authors should revise the title and terminology and should more carefully follow previous studies on EDR reporting and intensity classification. The current use of EDR ≥ 0.2 as the basis for "extreme turbulence" is misleading and needs substantial correction.

We thank the Reviewer for raising this important point. Our intention was not to redefine the operational classification of turbulence intensity, but rather to identify the upper tail of objectively observed turbulence events using automated EDR measurements. We agree, however, that the terminology adopted in the manuscript may unintentionally suggest that EDR ≥ 0.2 $m^{2/3}$ s^{-1} is equivalent to "extreme turbulence" in the operational aviation sense. To avoid ambiguity, we will revise the terminology throughout the manuscript. We will also include the suggested references.

2. Synoptic analogues cannot guarantee the same turbulence-generation processes

A second major concern is the assumption that **similar 500 hPa geopotential-height analogues can meaningfully represent the full downscaling pathway from synoptic flow to small-scale turbulence affecting cruising aircraft**. The method identifies historical analogues using Z500 patterns and compares turbulence diagnostics between past and present periods.

This approach may be useful for broad circulation context, but it does not guarantee the same mesoscale or microscale processes responsible for aircraft-scale turbulence. Numerous high-resolution modeling studies have shown that severe aviation turbulence depends on localized mechanisms such as gravity-wave breaking, jet-front interactions, near-cloud processes, and mesoscale convective influences. The authors should substantially weaken or reframe their attribution claims and more fully consider previous high-resolution modeling studies from both U.S. and Korean scientists.

We appreciate this important comment. We fully agree that similarity in large-scale circulation does not imply identical turbulence-generation mechanisms. However, this is not the objective of TurboMeter. The methodological philosophy underlying TurboMeter follows the same analogue-based attribution framework adopted in ClimaMeter and previous circulation-constrained attribution studies (Faranda et al., 2024; Faranda and Alberti, 2026). The purpose of the analogue selection is to constrain the large-scale atmospheric circulation, not to reproduce the complete atmospheric state associated with each individual turbulence encounter.

Accordingly, the reported attribution results, including the estimate that approximately 68% of the analysed events exhibit stronger turbulence-related diagnostics under present-day climate conditions, should not be interpreted as an attribution of the individual physical turbulence-generation mechanisms. Rather, they quantify the fraction of events for which statistically significant differences emerge after conditioning on comparable large-scale circulation states, consistent with the analogue-based attribution methodology established in the literature. We acknowledge that this distinction was not sufficiently emphasized in the original manuscript. Therefore, the revised version will clarify this point throughout the manuscript.

3. Convective systems are not sufficiently considered

Third, the manuscript treats many events primarily as clear-air/jet-related turbulence events, but **many extreme or severe turbulence encounters are directly or indirectly associated with convective systems**, and the separation between natural variability and anthropogenic forcing is not straightforward in such cases. The manuscript itself acknowledges that its framework could be extended in the future to convectively induced turbulence, mountain-wave turbulence, and other turbulence types, which underscores a key limitation of the current analysis. The authors should not present broad attribution conclusions without explicitly addressing convective contamination, near-cloud turbulence, convective outflow, and convectively induced gravity-wave processes.

We thank the Reviewer for highlighting the important role of convectively induced turbulence. We fully agree that aviation turbulence may originate from a variety of physical mechanisms, including clear-air turbulence, convectively induced turbulence, mountain-wave turbulence, and their interactions. However, TurboMeter was intentionally designed as an event-based circulation attribution framework, rather than as a turbulence-classification methodology. Accordingly, the event selection relies on objectively observed EDR measurements irrespective of the specific physical mechanism responsible for each encounter.

The revised manuscript will clarify this distinction more explicitly and will substantially expand the discussion regarding the possible coexistence of multiple turbulence-generation mechanisms, including convective processes. We will also explicitly identify process-specific attribution as an important direction for future developments of the TurboMeter framework.

4. Mountain-wave turbulence is insufficiently addressed

Fourth, the treatment of **mountain-wave turbulence** is inadequate. Mountain-wave turbulence is an important source of upper-tropospheric and lower-stratospheric turbulence, especially over the western United States and other mountainous regions. Such processes cannot be fully captured by ERA5 fields and synoptic analogue matching alone. The CONUS case, for example, includes many reports over North America, but the manuscript does not sufficiently distinguish jet-related CAT from mountain-wave-related turbulence or other terrain-induced processes . The authors should explicitly discuss the limits of ERA5 and Z500-based analogue methods for diagnosing mountain-wave turbulence and should incorporate prior modeling and forecasting studies on this process.

We appreciate the Reviewer's observation. We agree that mountain-wave turbulence represents an important contributor to aviation turbulence in several regions, particularly over complex terrain. At the same time, as previously highlighted, we emphasize that TurboMeter is not intended to diagnose individual turbulence-generation mechanisms. Rather, it evaluates how turbulence-relevant atmospheric diagnostics differ between analogous large-scale circulation states belonging to different climate periods.

We acknowledge that the manuscript did not sufficiently discuss this limitation. The revised version will therefore explicitly recognize that ERA5-based circulation analogues cannot resolve the small-scale dynamics associated with mountain-wave breaking and will discuss the possible contribution of mountain-wave turbulence, particularly over North America.

5. East Asia and Pacific turbulence mechanisms are oversimplified

Fifth, the interpretation of East Asia and the Pacific is too simplified. The manuscript links East Asian turbulence mainly to jet-stream intensification and deformation/shear along the East Asian jet . However, in East Asia and the western Pacific, high turbulence-index values in ERA5 are not simply related to the jet stream alone. They often result from complicated combinations of typhoons, tropical cyclone outflow, upper-level frontogenesis, vertical shear, deformation, and convective or near-cloud processes. Therefore, the manuscript should avoid attributing high TI, VWS, and DEF values only to jet-stream changes and should consider previous regional studies on East Asian and western Pacific turbulence mechanisms.

We thank the Reviewer for this useful observation. We agree that aviation turbulence over East Asia and the western Pacific often results from a complex interaction among jet dynamics, tropical cyclones, frontal systems, convection, and near-cloud processes. Our intention was not to attribute the observed changes exclusively to jet-stream variability, but rather to interpret the analogue results in terms of the dominant large-scale dynamical differences identified by the framework. To avoid possible overinterpretation, we will revise the discussion accordingly, explicitly acknowledging the possible contributions of tropical-cyclone outflow, frontal dynamics, convective activity, and other regional processes.

6. Main methodological limitation: Z500 cannot represent the full turbulence pathway

The central methodological issue is that **500 hPa geopotential-height fields cannot represent the full synoptic-to-mesoscale story linking atmospheric circulation to turbulence reports**. The paper's framework may identify broad circulation analogues, but it cannot by itself establish the physical pathway to aircraft-scale turbulence. This limitation is especially important because the paper makes strong claims that approximately 68% of events were mainly strengthened by anthropogenic forcing . These claims require much stronger validation against observed EDR intensity, turbulence type, convective proximity, cloud environment, mountain-wave environments, and high-resolution model diagnostics.

We appreciate the Reviewer for summarizing what is indeed the central methodological limitation of the framework. We fully agree that the Z500 field alone cannot represent the complete multiscale dynamical pathway linking atmospheric circulation to aircraft-scale turbulence. However, this is not the scientific objective of TurboMeter.

TurboMeter follows the analogue-based attribution philosophy developed in ClimaMeter and related circulation-conditioned attribution studies. Within this framework, Z500 is used to constrain the large-scale atmospheric circulation, allowing differences in turbulence-related diagnostics to be evaluated under comparable synoptic conditions. The revised manuscript will further clarify this conceptual distinction, strengthen the validation of the analogue-selection procedure, include additional upper-level dynamical diagnostics (jet structure, upper-level winds, total-column water vapour), and explicitly discuss the limitations associated with interpreting circulation-constrained attribution in terms of individual turbulence-generation mechanisms.

Overall, the manuscript addresses an important topic, but the current analysis is not sufficient to support the strong wording in the title, abstract, and conclusions. I recommend **reject or major revision**, with substantial revision required in the event definition, terminology, physical interpretation, literature review, and attribution methodology.

We thank the Reviewer for the overall assessment of our work and for recognizing the importance and timeliness of the scientific problem addressed by this study.

We acknowledge that the original manuscript did not sufficiently clarify several important aspects of the framework, particularly regarding the interpretation of the analogue methodology, the scope of the attribution, and the physical interpretation of the results. We believe that this lack of clarity may have led to an interpretation of TurboMeter as a process-based turbulence attribution framework, whereas its actual objective is to provide circulation-constrained event attribution, following the analogue-based methodology already established in previous studies such as ClimaMeter (Faranda et al., 2024; Faranda and Alberti, 2026).

Accordingly, in the revised manuscript we will strengthen the presentation of the methodology and its validation by including additional diagnostics of the large-scale atmospheric environment (including upper-level winds, jet-stream structure, and moisture fields), expanded the discussion of the analogue-selection procedure, incorporated the relevant literature suggested by the Reviewer, and clarified the assumptions and limitations of the framework throughout the manuscript.

We have also carefully revised the wording to ensure that our interpretations remain fully consistent with the scope of the methodology and to avoid possible overstatement of the results. At the same time, we respectfully maintain that the analogue-based attribution methodology itself is scientifically well founded, as it follows an approach that has already been developed, validated, and applied in the recent attribution literature. The objective of TurboMeter is not to reproduce every physical mechanism responsible for individual turbulence encounters, but rather to quantify how turbulence-favourable atmospheric environments change under comparable large-scale circulation states. We believe that the revisions introduced in response to the Reviewer's comments substantially strengthen the manuscript while preserving this central methodological framework.