[Responses to the Comment by the Anonymous Referee #2]

>> We deeply appreciate the referee #2 for providing constructive comments. We carefully addressed all comments and tried our best to improve the manuscript based on the referee's suggestions and comments.

EDR estimation in aircraft continues to be an issue for commercial aircraft and the relationship between good observation data and applicable use for safety and integration into planning such as meteorological impacts such as numerical modeling. As the author notes, EDR is the ICAO official observing unit for turbulence in aircraft. This is an important point in all of this work, as it increases the relevancy of this work. One of the biggest hurdles is finding an efficient way to calculate this data for safety applications. Many commercial airlines use various observing methods, not EDR, to communicate turbulence impacts internally. One of these is the DEVG unit of measurement that the author uses as a basis for some of their EDR estimations.

Suggestions:

1-1) The first suggestion is clarifying what and where the QAR data is retrieved. Previous papers have used QAR data, but are quick to point out that this data is retrieved post-flight and do not have a real time application.

➔ Thank you for your good suggestion. As the reviewer mentioned, the quick access recorder (QAR) data used in this study is not the real-time data but the retrieved post-flight data. This is clarified in the manuscript. [Page 3, Line 26; Page 14, Lines 28-29]

1-2) Also, the author should explain up front what the advantage to 1-Hz data estimations have over current operational EDR observations done at 10-Hz.

➔ Thank you for pointing out this. The high-frequency EDR data is considered as a truth of atmospheric turbulence measured by aircraft in terms of intensity and location, because it can capture highly transient and intermittent small-scale turbulence hazardous to cruising aircraft. However, when the high-frequency in-situ aircraft measurement is not available, 1-Hz data can be used as an additional source for measuring the EDR. This can contribute to expand more EDR information at the cruising altitudes in the upper troposphere and lower stratosphere (UTLS) in the world. A similar attempt can be made for other lower-frequency QAR and/or other navigational information of commercial aircraft such as Mode-S Enhanced Surveillance

(EHS) and Automatic Dependent Surveillance-Broadcast (ADS-B) in the future. This statement is included in the manuscript. [Page 3, Lines 16-18, 20-24; Page 15, Lines 17-19; Page 16, Lines 23-27]

1-3) Is the cost/loss of higher frequency data to support commercial safety enough to continue to advance this?

➔ Thank you for pointing out this. The high-frequency (e.g., 8 Hz or 10 Hz) aircraft data has been used to estimate EDR, which can capture highly transient and intermittent of small-scale turbulence hazardous to cruising aircraft. For instance, the high frequency National Center for Atmospheric Research (NCAR) EDR algorithm has been developed and implemented in some US-based commercial aircraft, and will be extended to more airliners worldwide in the future (e.g., Sharman et al. 2014; Cornman 2016). In this paper, we focused more on the additional EDR estimations from the currently available source of aircraft data. This statement is included in the manuscript. [Page 3, Lines 16-20, 24-25]

1-4) The results presented would indicate it is, but would need to be tested in a real-time experiment.

➔ We totally agree that a real-time experiment is needed. Currently, the main purpose of this study is trying to find out an additional source of EDR estimations by applying all possible EDR methods to different wind component (U, V, W) of 1-Hz (coarser frequency) post-flight data including some of different cases [Clear air turbulence (CAT), mountain wave turbulence (MWT), and convectively induced turbulence (CIT)] of atmospheric turbulence in cruising altitudes. This test can be extended by applying these EDR estimation methods to the 1-Hz real-time data in future, which can be eventually useful for a better awareness of atmospheric condition for cruising aircraft. Possible candidates for the 1-Hz real-time data are the navigational information of commercial aircraft such as the Mode-S EHS and ADS-B. This statement is included in the manuscript. [Page 3, Lines 21-25; Page 15, Lines 17-19; Page 16, Lines 23-27]

2) In section 2.2, since data sampling is limited, is this an optimal percentage of data used to calibrate? Why were those percentage of data chosen?

➔ Thank you for pointing out this. There is a misunderstanding in this part. To objectively retrieve the intensity of atmospheric turbulence using the aircraft data (especially using vertical velocity; W), we should find the best relationship between the measured angle of attack ($\bar{\alpha}$) and aircraft pitch angle (θ) for estimating the derived W by the Eq. (4) of the manuscript. Because two parameters (pitch angle and angle of attack) are highly sensitive to the navigation (maneuvering) of aircraft, we tried to extract any data that are not related to the altitude changes by the lower limits of altitude and altitude rate as 15 kft and 10 ft/s, respectively. Using this criterion, we found that most of the flight data [81% of Boeing (B)737 and 94% of B777] were in the cruising mode of the steady flights, which are eventually used to construct the best linear regression between the measured angle of attack ($\bar{\alpha}$) and aircraft pitch angle (θ) for estimating the derived W by the Eq. (4). After this, we eventually use all of the 1-Hz of zonal (U), meridional (V), and derived W data above 15 kft for estimating various EDRs. To avoid any confusion, the statements are modified in the manuscript. [Page 5, Lines 20-26]

3) Section 3.3, the author uses the climatological values from Sharman and Pearson (2017). This dataset has become too outdated as the number of EDR equipped aircraft that could be used for those calculations and perhaps those numbers should be updated.

➔ Thank you for the comment. Considering that the 1-year (2012) period of the QAR data used in this study overlaps the research period (from 2009 to 2014) of the dataset used in Sharman and Pearson (2017), we think that the use of climatological values of Sharman and Pearson (2017) is acceptable. Although in recent days there are some efforts to update C_1 and C_2 for the low-level turbulence using high-frequency sonic anemometer mounted in the tall towers (e.g., Muñoz-Esparza et al. 2018; Kim et al. 2021a), to the knowledge of the authors at the present, there is no recent update on C_1 and C_2 for the upper level because it requires a large amount of high-frequency aircraft data for the EDR estimation. This study can be one of these efforts to provide more EDR data that are required to update C_1 and C_2 based on all available flight information including relatively low-frequency flight data such as 1-Hz post-flight data. The statements related to this are also included in the manuscript. [Page 9, Lines 26-30; Page 10, Lines 1-3]

4) Also, the degree of work down to the python library used, might be a little too much information for this paper.

➔ Thank you for the comment. This sentence is deleted in the manuscript.

5) Onward in 3.4, up to this point, it appears this paper is more focused on comparing estimation

methods than what the benefits of the 1-Hz data represents. Perhaps a title change or additional information on the 1-Hz calculations would suffice.

➔ Thank you for the comment. We include the statements related to the benefits of the 1-Hz data in the manuscript as responded above [Page 3, Lines 20-24; Page 15, Lines 17-19; Page 16, Lines 23-27]. Because we have the comparison of the EDR methods and characteristics of EDR for possible sources, the title and subtitle of section 3.4 were slightly changed in the revised manuscript.

6) Section 4, for the convective case, is there any lightning data that would make this more likely due to convection? This would allow you to change verbiage from likely to certainty.

➔ Thank you for the comment. We tried to get the lightning data from Central Weather Bureau of Taiwan. However, they only archive lightning data for recent 12 hours. Therefore, we calculate the minimum brightness temperature near the location of turbulence encounter using 3-hourly GridSat-B1 dataset that has a spatial resolution of 0.07° (Knapp et al. 2011). It is found that the minimum brightness temperature is the lowest at 1800 UTC which is the closest time with the turbulence encounter (Fig. A1). This implies a rapid increase of cloud top height and corresponds well to the COMS satellite images of Fig. 8 of manuscript that show a single-cell-type convection. Therefore, this study considers this turbulence case as the CIT. This statement is included and relevant statements are modified in the manuscript. [Page 12, Lines 3-6]

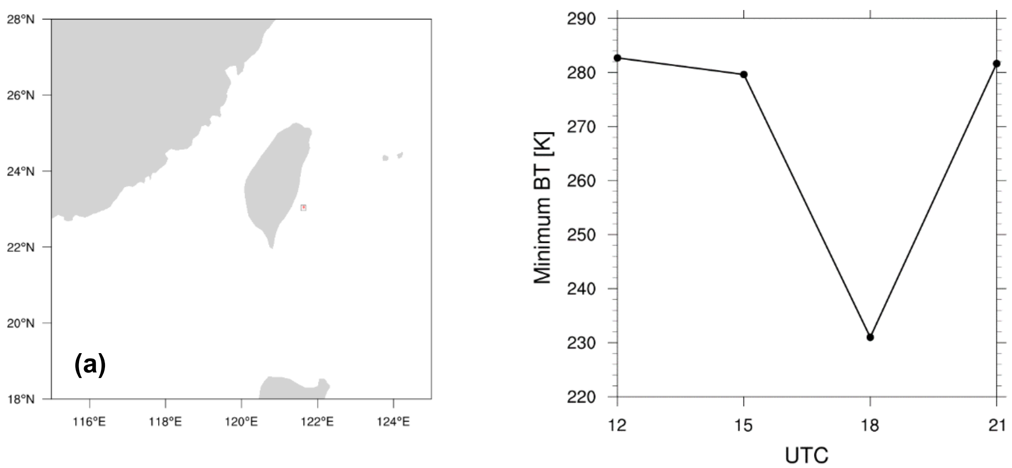

Figure A1. (a) Location of turbulence encounter (asterisk) and 3-point by 3-point domain centered on the observed location (box), and (b) the minimum brightness temperature calculated in domain of (a) using 3-hourly GridSat-B1 data from 1200 to 2100 UTC 20 September 2012.

7-1) Overall message from the case studies is that the EDR estimations are impacted more or less based on the synoptic or mesoscale regimes that form the base.

➔ Thank you very much for your clarification. Yes, the results in this paper strongly suggest that the observed EDR estimates derived from different wind components such as U, V, and W can show different characteristics depending on the potential sources of atmospheric turbulence in the cruising altitudes (UTLS). This is of interest because it can provide a basic information for the classification of the recent in situ EDR from the aircraft-based observation (ABO) data that are useful for producing a better climatology of upper-level turbulence and turbulence forecast systems (e.g., Sharman et al. 2006; Kim et al. 2011, 2018, 2019a, 2021b; Kim and Chun 2016; Sharman and Pearson 2017). Statements with more discussions related to this are included in the manuscript. [Page 14, Line 23; Page 15, Lines 19-24]

7-2) Is there any work done to validate which ones are more accurate?

➔ As far as we know, there is no work done to compare the accuracy of EDR among the EDR estimation methods in the different synoptic and mesoscale regimes, which needs for further investigation in the future. This statement is included in the revised manuscript [Page 14, Lines 23-25].

7-3) Is the author inferring that different EDR methods should be used for different situations, similar to radar changing scanning modes for different weather? This is a fascinating conclusion and I think worth a lot more discussion.

➔ No, this study does not tell that the different EDR methods show different characteristics of the observed EDR. When we used all available methods to estimate EDR using 1-Hz data, it is found that there is no significant difference depending on the different EDR methods. However, this study emphasized that the different EDR values from various wind components such as U, V, and W show significantly different characteristics in the same EDR method. As shown in the case analyses in this study, the characteristics of the EDR observations from different wind components are highly depending on the sources (CIT, CAT, and MWT) of turbulence in the UTLS. This can be eventually useful for situational awareness of cruising aircraft and tactical avoidance for turbulence, and for a better climatology of turbulence classification. The related statements and discussions are included in the manuscript. [Page 15, Lines 25-34; Page 16, Lines 1-22]

8) Also, the author might suggest more how 1-Hz data could be used for in-situ observing and data transmission.

➔ Thank you for your good suggestion. As already mentioned in the response to the reviewer's question 1-4, the current EDR estimations applied to post-flight QAR data should be tested on the real-time wind retrievals. Possible candidates for the real-time data are the navigational information of commercial aircraft such as the Mode-S EHS and the ADS-B. The statements are included in the manuscript. [Page 3, Lines 21-24; Page 16, Lines 23-27]

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