

RESPONSE TO REVIEW OF THE MANUSCRIPT RETRIEVING CLEAR-AIR TURBULENCE INFORMATION  
FROM REGULAR COMMERCIAL AIRCRAFT USING MODE-S AND ADS-B BROADCAST BY ANONYMOUS  
REVIEWER #2

Dear Anonymous Reviewer #2,

thank you for your valuable and detailed comments. Thank you also and the time you have taken for evaluating our manuscript and for pointing out a number of formulations we have used can be interpreted in ways different than intended. Below are you will find responses to your comments.

On behalf of the authors,  
Jacek Kopeć

## Introduction

The response to the review is structured as follows: the reviewer comments are first reproduced in **bold font** followed by authors' responses and indication of appropriate changes in the manuscript.

## Review #2 response

This is an interesting paper to read. It describes how automatic and selected transmissions made by aircraft may be utilized to indicate the presence of atmospheric turbulence. The work describes three methods which utilize these transmissions to obtain an indication of turbulence. However, I felt that there was insufficient evidence to support the final conclusions this being due to the limited verification undertaken. The turbulence metric EDR cannot distinguish between clear air turbulence and other forms of turbulence. It essentially only indicates the presence of turbulence and its intensity. Further analysis of the aircraft trajectory is required to determine the class of turbulence. The methodology is reasonably clear but there are some points that further explanation or supplementary notes would help: the processing used for synthetic Mode-S (would need the algorithm if this is to be reproducible), the assumption that a linear track can be considered as an ensemble - an illustration. The work appears to have the main references (one or two more are suggested). The conclusions seem reasonable given the limitations of the available data. Most aircraft will report low level turbulence but would avoid areas of moderate and high - whether forecast or reported. It is not clear to me how these methods would be implemented routinely. Moreover, I doubt that these methods would be suitable for operational applications. But these are different questions. Nonetheless, I would recommend publication, if only to guide other researchers in this area on the best route to further development of the methods or to provide a means to improve upon the method of verification.

Before publication I recommend that the following comments noted below are addressed.

**PP11818 Title - no need for broadcast since this is the 'B' in ADS-B.**

Title changed accordingly.

**PP11818 L1 De Haan notation uses Mode-S EHS. Please check. Make this clear in the abstract**

Thank you for pointing this out. Mode-S EHS is a subclass of Mode-S. However, the territorial extent of Mode-S EHS availability is smaller than the territorial extent of availability of Mode-S ELS (which is another subclass and is useless for the present analysis). We have added EHS in suitable context throughout the article. We have also added an explanation in the introduction.

MANUSCRIPT CHANGE

Substituted Mode-S with Mode-S EHS in suitable context throughout the paper and made the following change:

*Previous:* (P11820 L7) Mode-S is a protocol of information exchange between the aircraft and the ATM system.

*Current:* (P11820 L7) Mode-S is a protocol of information exchange between the aircraft and the ATM system, whereas Mode-S EHS is a subclass of messages exchanged using this protocol that is of interest in the present study.

**PP11818 L2 Suggest rephrase "as new and valid source" to "a new source" There is insufficient verification to support 'valid'**

Removed the word 'valid'.

**PP11818 L The abstract should indicate that the Mode-S EHS data used was synthetic.**

Abstract changed.

MANUSCRIPT CHANGE

*Previous:* (Abstract) The comparison of the results of application of the processing against a reference eddy dissipation rate obtained using on-board accelerometer indicate a significant potential of those methods.

*Current:* (Abstract) The comparison of the results of application of the processing of a synthetic Mode-S EHS/ADS-B against a reference eddy dissipation rate obtained using on-board accelerometer indicate a significant potential of those methods. The synthetic dataset was carefully generated with help of the real overlapping Mode-S EHS/ADS-B transmissions from the research aircraft and technical documentation.

**PP11818 L5 "All the necessary parameters ..." needs to be rephrased since the characteristic constants need to be estimated or determined for each method.**

Rephrased.

MANUSCRIPT CHANGE

*Previous:* (Abstract) All the necessary parameters are conveyed in the Mode-S/ADS-B messages.

*Current:* (Abstract) Those parameters can be calculated using the standard content of Mode-S EHS/ADS-B.

**PP11818 L9 Suggest rephrasing "... accelerometer indicate a significant potential of those methods ..." to "... accelerometer indicate the potential of the methods described ..." [I would argue that further verification is needed to support the stronger claim.]**

Rephrased accordingly. Additional verification indeed is a must.

**PP11818 L17 "rely solely on forecasts or any slight visual characterizations" Pilots also listen into the "radio chatter" where they can be alerted by lead aircraft encounters with turbulence.**

We have added an appropriate remark.

MANUSCRIPT CHANGE

*Previous:* (P11818 L17) The lack of on-board detectors that could provide appropriate warning for the pilot forces airmen to rely solely on forecasts or any slight visual characterizations

*Current:* (P11818 L17) The lack of on-board detectors that could provide appropriate warning for the pilot forces airmen to rely on forecasts, information from other nearby aircraft or traffic control or any slight visual characterizations

**PP11819 L2 "due to the turbulent energy cascade" a suitable reference would be helpful**

Added suitable reference (Wyngaard, 2010)

**PP11819 L9 "buoyancy waves breaking" - e.g. Gravity waves**

"Gravity waves" is more popular term than "buoyancy waves". However, we think that the latter term is more precise and removes the connotation with gravitational waves (recently very popular).

**PP11819 L10 "All of those mechanisms ..." suggest "All of these mechanisms ..."**

The manuscript was changed accordingly.

**PP11819 L13 ".. at the same time it is impossible to detect it" ... Suggest "detection of CAT is difficult." If impossible then say why it is impossible. "using ordinary weather radar" suggest "using weather radar" if cannot detect using ordinary then this means require extra-ordinary radar.**

We have reformulated the sentence to make it clearer.

MANUSCRIPT CHANGE

*Previous:* At the same time it is impossible to detect it using ordinary weather radars.

*Current:* At the same time systematic detection of CAT using the conventional weather radars is impossible because these radars are able to detect turbulence either in the presence of appropriate tracers (e.g. water droplets, ice crystals), or in the clear air provided the sufficient variation in the refractive index occurs. The former method is not applicable to CAT while the latter has been found to be problematic in some cases (James, 1980).

**PP11819 L15 "by using active optical sensing" - need to give an example of what this means. I would say looking out the window would be a form of active optical sensing.**

Active optical sensing requires the sensor to measure a scattered, reflected or refracted signal transmitted by the sensor itself. As a result human sight belongs to the passive optical sensing category.

MANUSCRIPT CHANGE

*Previous:* (P11819 L15) The only feasible remote detection method is by using active optical sensing

*Current:* (P11819 L15) The only feasible remote detection method is by using active optical sensing (e.g. forward looking on board lidar)

**PP11819 L28 " only drawback of the EDR data is that it still is not an industry standard." suggest "only drawback of EDR reporting is that it is not in widespread use." I would argue that (a) a standard for reporting exists (ICAO/WMO) (b) in the US EDR is being used (c) FAA are developing a reference standard (d) EDR is specified as a parameter for ADS-B in**

**RTCA DO-339 Aircraft Derived Meteorological Data via Data Link for Wake Vortex, Air Traffic Management and Weather Applications - Operational Services and Environmental Definition (OSD) )**

This was a serious error in formulation. Thank you for suggesting suitable replacement.

MANUSCRIPT CHANGE

*Previous:* (P11819 L28) The only drawback of the EDR data is that it still is not an industry standard, hence its availability is an effect of negotiations with the individual airlines.

*Current:* (P11819 L28) The only drawback of the EDR data is that it still is not in widespread use, and its availability is by negotiation with individual airlines.

**PP11819 L24 "hence its availability is an effect of negotiations with the individual Airlines" suggest "; and its availability is by negotiation with individual airlines"**

Thank you. Rephrased, see previous remark.

**PP11820 L When referring to Mode-S please use de Haan notation Mode-S EHS.**

Added EHS where appropriate throughout the manuscript.

**PP11820 L9 "with a very high sampling rate ranging from" I find this statement troubling. It is not a sampling rate as such. The frequencies quoted are rotation rates.**

In our understanding, when one takes view of the receiver only, this is exactly the sampling rate (i.e. the rate at which one receives a time discretized signal). Whether this sampling rate is a result of SSR antennae rotation rate (lower bound) or transponder software (upper bound) is of secondary interest from the perspective of the signal processing abilities.

**PP11820 L10 "frequencies 1090 and 1030 MHz" - 1090 is the downlink while 1030 is the uplink. Could be confused with the preceding statement on sampling rate. Was the transmission of synthetic Mode-S emulated?**

Added uplink/downlink clarification. The previous sentence uses "sampling rate" to avoid ambiguity. Rephrased to make distinction clearer. The transmission was not emulated in case of the synthetic data. We have concentrated on the structure of the final received signal.

MANUSCRIPT CHANGE

*Previous:* The messages that are an integral part of the Mode-S are exchanged with a very high sampling rate ranging from 0.2 up to 2 Hz (references) on frequencies 1090 and 1030 MHz.

*Current:* The messages that are an integral part of the Mode-S are exchanged with a very high sampling rate ranging from 0.2 up to 2 Hz (references). The signal is transmitted using radio frequencies 1090 MHz (downlink) and 1030 MHz (uplink).

**PP11820 L24 " decoded by a relatively simple hardware" see also Stone and Pearce (<http://dx.doi.org/10.1175/JTECH-D-15-0184.1>) "and is relatively cheap" suggest "and is relatively inexpensive."**

Thank you for the reference. We have added the citation and rephrased according to suggestion.

**PP11820 L18 I do not think that ADS-B is a spontaneous transmission this suggests it**

is a random process suggest replacing the word spontaneous with automatic.

Replaced spontaneous with automatic in the manuscript.

**PP11820 L13 "Mode-S carries a very high frequency wind information." No, de Haan shows how to derive high frequency wind information."**

Rephrased.

MANUSCRIPT CHANGE

*Previous:* (P11820 L13) It has been shown (de Haan, 2011) that the Mode-S carries a very high frequency wind information.

*Current:* (P11820 L13) It has been shown (de Haan, 2011) that a very high frequency wind information can be derived from the Mode-S EHS.

**PP11820 L23 " ... available information since very significant part of civil aviation" suggest ".. available information since a very significant part of the commercial civil aviation ..."**

Added word 'commercial'.

**PP11821 L11 "Mode-S-like form" suggest synthetic Mode-S EHS messages were generated." This also should be indicated in the abstract.**

Rephrased.

MANUSCRIPT CHANGE

*Previous:* (P11821 L11) Due to this limitation there is no overlapping record of turbulence encounter but there are numerous overlapping flight fragments allowing for proper analysis based on the flight campaign dataset processed into Mode-S-like form.

*Current:* (P11821 L11) Due to this limitation there is no overlapping record of turbulence encounter but there are numerous overlapping flight fragments allowing for proper analysis based on the synthetic Mode-S EHS and ADS-B messages generated using flight campaign dataset.

**PP11821 L17 "track angle parameter" Please clarify what is this represents" Ground direction with respect to true north"**

Added clarification. We should have used "true track angle" according to Eurocontrol terminology.

MANUSCRIPT CHANGE

*Previous:* (P11821 L17) ... track angle parameter ...

*Current:* (P11821 L17) ... true track angle parameter (ground track direction with respect to true north) ...

**PP11822 L27 "The original Mode-S data recorded by KNMI were then used as a reference for evaluating the successfulness of the processing on the overlapping flight fragment" suggest "The original Mode-S data recorded by KNMI was used as a reference for evaluating the success of generating synthetic Mode-S EHS on the overlapping flight fragments."**

Rephrased. Thank you. That was a terrible sentence.

**PP11823 L15 What is DADC" Digital Air Data Computer" As a general note please make sure that acronyms are expanded on first use.**

Acronym explained earlier in the manuscript, on first occurrence (P11822 L2).

**PP11824 L18 "In summary the reference data collected by the KNMI receiver proved to be insufficient for conducting tests of the post-processing methods." Are you saying here that the KNMI data could not be used for the CAT estimate algorithms" Hence the need to simulate Mode-S using the DELICAT data" Please clarify this statement.**

Yes, that is exactly what we are saying but only in the case of this particular aircraft in summer 2013. For other aircraft all the parameters were recorded properly. It is worth mentioning that S. de Haan has successfully used the data from the same receiver to estimate wind vectors and temperature previously. The statement "Hence the need to simulate Mode-S using the DELICAT data" does not occur anywhere in the manuscript. The mentioned line contains a similar statement: "To mitigate this we have established a method of processing the DELICAT data into Mode-S EHS/ADS-B form". It has been rephrased according to previous suggestions.

#### MANUSCRIPT CHANGE

*Previous:* (P11824 L18) In summary the reference data collected by the KNMI receiver proved to be insufficient for conducting tests of the post-processing methods. (...) To mitigate this we have established a method of processing the DELICAT data into Mode-S EHS/ADS-B form.

*Current:* (P11824 L18) In summary the reference data collected by the KNMI receiver proved to be insufficient to be the sole basis for estimating EDR and then compare it against the DELICAT measurements. (...) The overlap regions also contain mainly ascent/descent and none of the DELICAT turbulence encounters. To mitigate this we have established a method of generating synthetic Mode-S EHS and ADS-B data based on DELICAT measurements.

**P11825 L19 "as finite difference between the consecutive observations." What is the expected maximum elapsed time between consecutive observations." What happens in the event of signal drop-outs or a long elapsed time between messages?**

A very good remark. In the current analysis we have used uniform distribution with 2Hz sampling rate. Indeed this simplifies the preprocessing but allows us to focus more on defining the EDR estimation algorithms. We feel this approach is justified since in the case of reference KNMI data (originating from off shelf low cost receiver) less than 5.6% of the measurements were displaying lower sampling rate for any single flight. Moreover those interruptions were registered mainly far away from the receiver. That is why we have disregarded this problem for now. In fact the signal loss is much lower when using data originating from air navigation service provider (e.g. MUAC data in KNMI), see e.g. (de Haan et al., 2013). The maximum time between the consecutive observations encountered in the reference data was 307s and was registered near the maximum reception range of the KNMI receiver. For practical reasons observations separated by more than 1 - 2s would probably need to be disregarded. In case of long drop off periods the calculation of EDR would, of course, be impossible.

**P11826 L3 "Is the airspeed V the mean value, expected value, maximum value over the set time period T"**

Well spotted. Thank you. On the next page (P11826 L5-10) we have stated that already fixing B as constant is implying constant TAS. However, we have not stated explicitly that we chose to approximate TAS as constant (except for the discussion of the results) to emulate usage of purely ADS-B content. This is certainly confusing. In the discussion section we have also used variable TAS - there we have used mean value over time period T. Added necessary clarifications.

MANUSCRIPT CHANGE

*Previous:* (P11826 L23) Another factor lowering effectiveness...

*Current:* (P11826 L23) For further analysis we have assumed constant TAS to evaluate purely ADS-B based EDR estimation. However, we have also compared the results against the first approach - combined ADS-B and Mode-S EHS.

Another factor lowering effectiveness...

*Previous:* (P11826 L3) ... set period of time  $T$  and  $V$  is the true air speed (TAS) of the aircraft.

*Current:* (P11826 L3) ... set period of time  $T$  and  $V$  is the mean true air speed (TAS) of the aircraft in the time period  $T$ .

**P11826 L22 Reference for example "Mulally, D. and Anderson, A. Correction of Aircraft Flux Valve Based Heading for Two-Dimensional Winds Aloft Calculations Using Weather Model Comparison."**

Reference added.

**P11826 L26 Please provide a suitable reference that describes the Butterworth band pass filter in the context used for this paper.**

Reference describing the software used added (signal developers, 2013).

**P11827 L10 "Treating  $B$  as a constant" this is a significant limitation of the method.**

Yes, we agree. It has been emphasized in the manuscript.

**P11827 L23 "both of those publications authors mean ensemble average as an average over many realizations of the similar conditions." This does not make sense. Are you saying that the authors define the ensemble mean as the average value obtained from many realizations of the similar conditions.**

Yes, this is written explicitly in (Monin and Yaglom, 1975). We also consider an approach to aggregate two point differences in large areas (Frehlich and Sharman, 2010) to be somewhat similar. However, there is an inconsistency in the formulations used in the paragraph. We will rewrite the paragraph to make it clearer taking into account the next remark.

**P11827 L26 "processing of individual aircraft flight record we make an assumption that a series of consecutive observations of sufficient length forms such an ensemble" It is not clear how this assumption arises along a single trajectory. Perhaps a diagram would assist the explanation for this method.**

In fact this is one of the standard approaches to calculation of the structure functions using a time series of measurements. It has been used in for idealized experiments (e.g. Poggi and Katul, 2010) and it has been used to process aircraft measurements (e.g. Cho et al., 2003 or Meischner et al., 2001). We will reformulate and add appropriate references.

MANUSCRIPT CHANGE

*Previous:* Here  $u_{LL}$  denotes the component of the horizontal wind velocity vector along the track of the aircraft,  $x$  is a position of measurement,  $\mathbf{r}$  is the displacement vector,  $r = |\mathbf{r}|$  is the displacement distance and  $\langle \cdot \rangle_x$  stands for position averaging. The position averaging in our setting will be understood as the mean of  $N$  observations performed by the same aircraft separated by a constant distance  $r$ . This

is somewhat different from the averaging used in Frehlich and Sharman (2010) and Monin and Yaglom (1975). In both of those publications authors mean ensemble average as an average over many realizations of the similar conditions. However when using this methodology in post processing of individual aircraft flight record we make an assumption that a series of consecutive observations of sufficient length forms such an ensemble. This assumption is based on the fact that commercial aircraft have velocity much greater than velocity perturbations associated with atmospheric turbulence at a kilometre spatial scale.

*Current:* Here  $u_{LL}$  denotes the component of the horizontal wind velocity vector along the track of the aircraft,  $\mathbf{x}$  is a position of measurement,  $\mathbf{r}$  is the displacement vector,  $r = |\mathbf{r}|$  is the displacement distance and  $\langle \cdot \rangle_{\mathbf{x}}$  stands for position and ensemble averaging. In order to estimate  $D_{LL}$  we have used a standard approach to aircraft originating time series described in (Cho et al., 2003; Meischner et al., 2001). However, in our analysis we deal only with the horizontal component of wind. That denies us the possibility to calculate  $D_{LL}$  accurately during aircraft turns. In addition, this method has been previously applied to time series with sampling rate  $O(10)$  Hz whilst in our case the sampling rate is 0.25 Hz. Frehlich and Sharman (2010) have used similar methodology for estimating  $D_{LL}$  based on AMDAR measurements with even greater spatial distances than in our case (up to 1000 km). However their treatment of ensemble and spatial averaging is closer to the original Monin and Yaglom (1975) where ensemble average as an average over many realizations of the similar conditions.

**P11828 L17 "... we have chosen a band better covering the expected CAT scales" suggest "... we have chosen a frequency range covering the expected CAT scales."**

Substitution made.

**P11829 L17 This section seems to suggest that the chosen method will depend on the available transmission medium for the data source. The referring to "methods" seem to be mixed with the transmission "method". Suggest that this paragraph is redrafted to make it clear the advantages and disadvantages of each EDR method for each mode of transmission.**

Indeed the choice of methods is dependent on the available transmission medium. One can not determine the horizontal wind from ADS-B only. Also, the Mode-S EHS sampling rate is too low to reasonably use it as the basis for the method based on vertical acceleration. However, the paragraph clearly needs some improvement.

MANUSCRIPT CHANGE

*Previous:* The first method uses only the vertical position (or vertical velocity) information. This information is available in ADS-B frames. This makes it possible to receive this kind of data globally since ADS-B broadcast is not limited to any areas. This is in contrast to the territorial extent of Mode-S EHS data being determined by the presence of the ground based interrogators. The main disadvantage of this method is its obvious dependence on the aircraft type. Second and third methods (structure functions and threshold-crossing) need high resolution wind measurements thus their range of application is limited to the areas where Mode-S EHS is available. These are the main disadvantages of those methods. However both of those methods are based on quite robust understanding of turbulence physics. Moreover using the background wind as a source of information should make the measurements inherently aircraft independent.

*Current:* The first method uses only the vertical position (or vertical velocity) information available in ADS-B. This makes it possible to receive this kind of data globally since ADS-B is not limited to any areas. The main disadvantage of this method is its obvious dependence on the aircraft type. The second and the third methods (structure functions and threshold-crossing) need high resolution horizontal wind measurements. Therefore their use is limited by territorial extent of Mode-S EHS data availability. This in turn is determined by the presence of the ground based interrogators (implying e.g. lack of satisfactory ocean and sea coverage). However, they do not explicitly incorporate aircraft dependent variables into calculations which reduces the potential aircraft type dependence. These are the main expected advantages and disadvantages of the proposed methods.

**P11831 L9 Delete "As well as the threshold crossing method" suggest rephrase "the structure function based approach results in an underestimation" as "the structure function based approach also results in an underestimation when using ...."**

Thank you. Rephrased.

**P11831 L14 "...small business jet thresholds in (Sharman et al., 2014) one must .." suggest rephrasing as "... small business jet thresholds as reported in Sharman et al. (2014) one must ..."**

Thank you. Rephrased.

**P11831 L23 " ... the roll off the aircraft was exceeding 7 ..." suggest rephrase " if the roll angle exceeded 7 ...". How does this roll angle compare with that used for AMDAR reporting and de Haan Mode-S EHS**

This quantity was determined individually for this aircraft by comparing trajectories and corresponding roll angle. Since this was a small research aircraft we assumed that its maneuvering pattern could differ from that of the standard commercial airliners.

**P11832 L17 "the length of period of moving variance calculation" suggest rephrasing "the time-window for the moving variance calculation ..."**

Thank you. Rephrased.

**P11832 L26 " As for indicator function too small window ..." suggest rephrasing "An indicator function window that is too small (less than 10s) causes stray peak signals to arise whereas for longer periods the indicator function do not damp the signal."**

Thank you. Rephrased.

**P11833 L When discussing this point please make clear references to which parts of figure 9 apply.**

Divided Fig. 9 into clearer parts. Also changed discussion.

MANUSCRIPT CHANGE

*Previous:* For positive  $T_C$  the signal appears at 0.25 and quickly vanishes at 0.45 also the FL9 MOD event is quite weak. For negative thresholds the signal was appearing at  $-0.2$  and disappears at  $-0.6$  and the MOD event is more pronounced. Example of  $T_C$  sign comparison is in Fig. 9.

*Current:* For positive  $T_C$  the signal appears at 0.25 and quickly vanishes at 0.45 also the FL9 MOD event is quite weak also the period of calm air between Light CAT-2 and Light CAT-3 is not so well indicated (Fig. 9b) . For negative thresholds the signal was appearing at  $-0.2$  and disappears at  $-0.6$  and the MOD event is more pronounced (Fig. 9a).

**P11833 L17 " for the correct differentiation of its intensity .." suggest "... for the correct discrimination of its intensity ..." (differentiation could be interpreted as the rate of change) The methods described can only provide a qualitative indicator for turbulence.**

Rephrased. The supplied evidence indicates some of the proposed methods can correctly discriminate turbulence intensity. Whether this discrimination is only qualitative remains to be seen. Please note that the peak recorded turbulence intensity has been classified as borderline moderate by the aircraft crew.

**P11833 L27** "...Butterworth filters with limiting frequencies that are as much based on physics as possible .." suggest rephrasing as "... Butterworth filters with expected frequencies that are based on turbulence physics ..."

Thank you. Rephrased.

**P11834 L3** "...however we had to few cases at our disposal to try to find such filter as ...." suggest rewriting as "however, we had too few cases at our disposal to refine the filtering as ..."

Thank you. Rephrased.

**P11834 L5** "... areas of use for those methods." suggest "... areas of use for these methods."

Thank you. Rephrased.

**P11834 L6** "allow a potential observer to use quite cheap and simple set-up for observing" suggest "allow a potential observer to use inexpensive equipment for observing ...."

Thank you. Rephrased.

**P11834 L10** "In most of the highly developed regions the implementation of this technology is well under way. Most newly produced aircraft are properly equipped. However, older aircraft in less developed regions of the world can be quite useless." I would suggest removing or rephrasing - this seems to express a value judgment, which I am sure the authors do not intend. Suggestion is "For the highly developed routes the implementation of this technology is well under way. Most newly produced aircraft are properly equipped. However, older aircraft require to be retrofitted before they can provide the necessary data."

Indeed this is not a good formulation.

MANUSCRIPT CHANGE

*Previous:* In most of the highly developed regions the implementation of this technology is well under way. Most newly produced aircraft are properly equipped. However, older aircraft in less developed regions of the world can be quite useless.

*Current:* Most newly produced aircraft are properly equipped. However, some of the older aircraft require to be retrofitted before they can provide the necessary data.

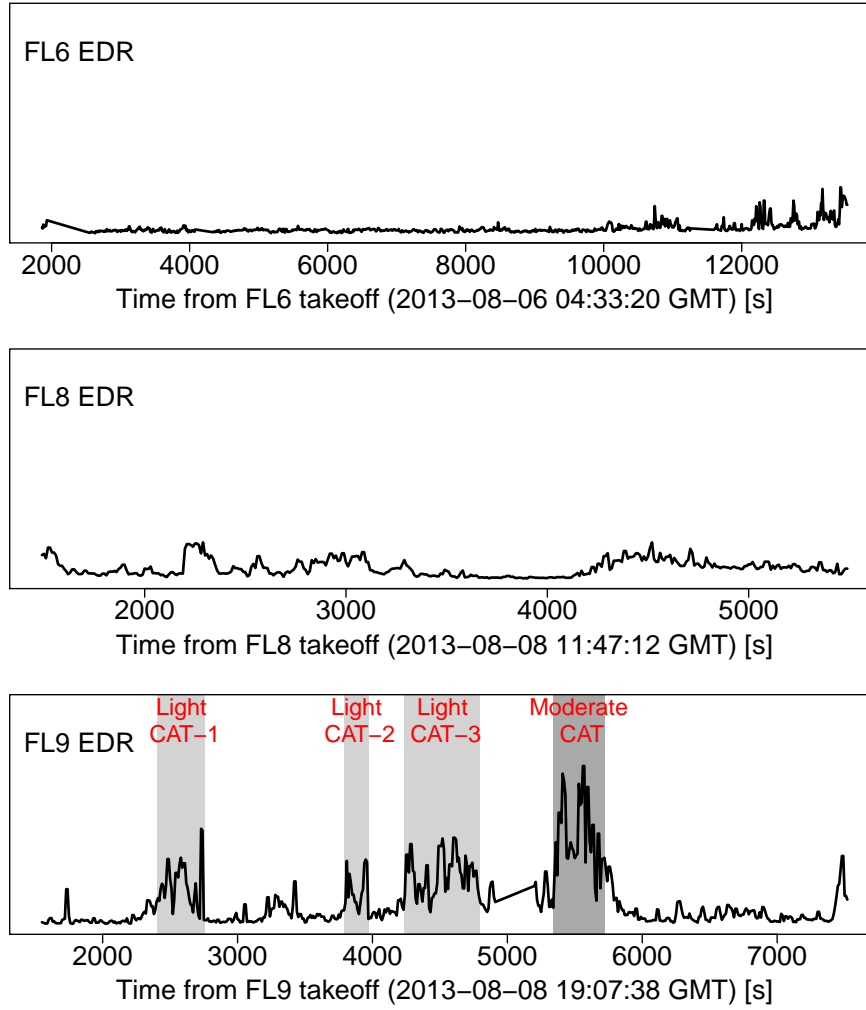
**P11841 Table 2** "Define IRS and DADC, indicate the precision of the recorded data."

Both DADC and IRS are defined in the manuscript text prior to the table reference. Added resolution column to the table.

**P11843 Figure 2** It would be useful to add labels on the time axis to indicate the time of day or at least the date and time at take-off. This may indicate the type of turbulence encountered during the flight.

We have tried using date and time labels in first drafts and they were not a good solution. We have indicated date and time of the take-off for each flight in the horizontal axis labels.

New Figure 2:



**P11845 Figure 3 KNMI data - indicate if this is the Mode-S EHS data. DELICAT data - indicate if this is the synthetic Mode-S EHS. Rephrase (note that for clarity 97% of the ...)**

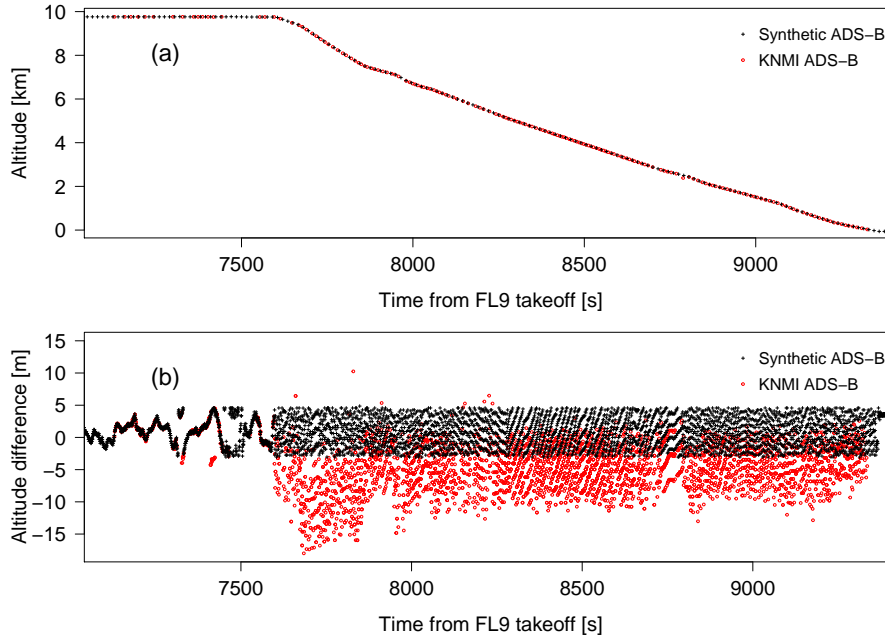
Rephrased caption and changed the labels on the plots.

MANUSCRIPT CHANGE

*Previous:* (Fig. 3 caption) A comparison between the processed DELICAT data (black crosses) and KNMI data (red circles) of (a) the altitude profile (note that for the sake of clearness 97% of the observations are not plotted here) and (b) the difference of the altitude with respect to the DELICAT reference altitude.

*Current:* (Fig. 3 caption) A comparison between the synthetic ADS-B data (black crosses) and reference KNMI ADS-B data (red circles) of (a) the altitude profile (note that for clarity 97% of the observations are not plotted here) and (b) the difference of the altitude with respect to the DELICAT reference altitude.

New Figure 3:



**P11846 Figure 4 Please indicate the type of IRS. Gyro-magnetic systems are more prone to drift. Inertial Navigation Systems are far more precise (see Mulally). If IRS then the 2km drift does not make sense.**

We are unable to fulfil this request. The only specification of the device we have is 'IRS'. In addition in communication with DELICAT personnel we were told 2km drift is normal for this kind of IRS. Based on your comment we could deduce it was a gyro-magnetic system yet we will retain formulation used in the documentation we have.

**P11848 Figure 6 Suggest " ....For reference the indicative turbulence levels ...." Add a scale on the y-axis. Put a small horizontal gap between each plot otherwise it is quite confusing and difficult to interpret.**

**P11849-50 Figures 7 and 8 See comments for figure 6 - small gap required.**

Adding a vertical scale on graphs depicting results based on the vertical acceleration method (as well as reference DELICAT EDR) is somewhat questionable since they are known up to a constant which we have no way to determine robustly. The only known values are the results of Mode-S EHS based methods. However, to fulfil the request we have assumed certain values of  $B$  so that the resulting EDR is roughly of the same magnitude as the results of Mode-S EHS methods. Appropriate remarks have been made in the manuscript. Plots have been modified accordingly.

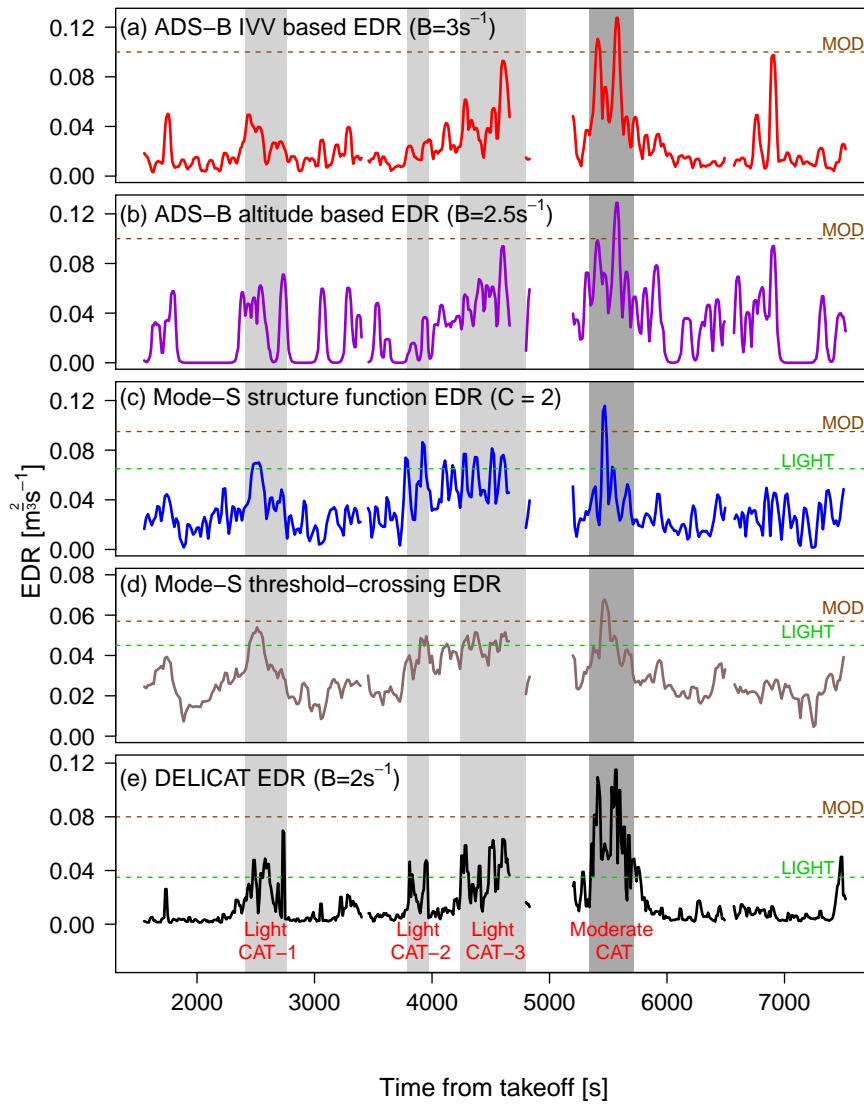
#### MANUSCRIPT CHANGE

*Previous:* (P11830 L18-20) Results of ADS-B EDR based methods along with the reference EDR were arbitrarily normalized for appropriate presentation in Figs. 6– 8. This scaling is possible since they are determined up to a constant. On the contrary, the threshold crossing EDR (according to Eq. 8) as well as the structure function based EDR is known exactly (when assuming the theoretical value of  $C = 2$  in Eq. 3).

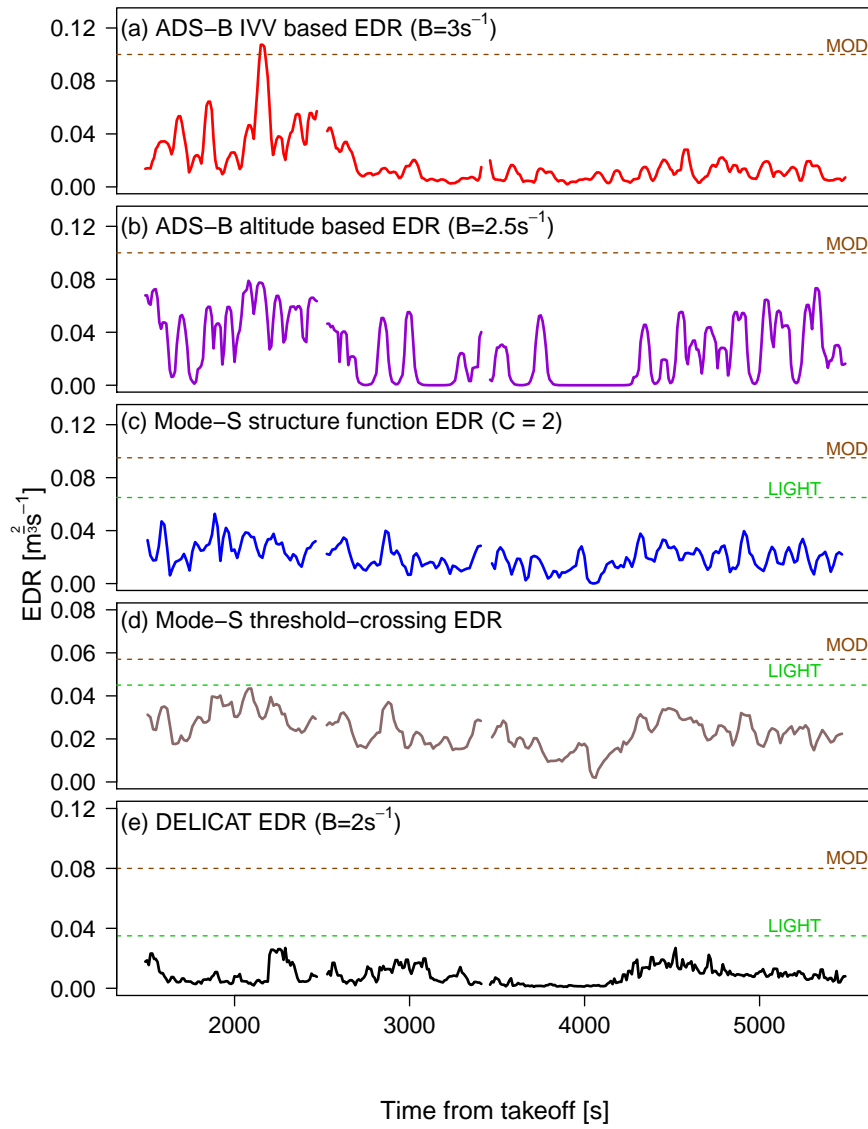
*Current:* (P11830 L18) The threshold crossing EDR (according to Eq. 3) as well as the structure function based EDR is known exactly (when assuming the theoretical value of  $C = 2$  in Eq. 3). However, results of ADS-B based methods along with the reference DELICAT EDR are determined up to a constant  $B$  (see Eq. 3). For the sake of presentation we have chosen values of  $B$  for each method so that their results ranges correspond to those obtained from Mode-S EHS based methods. These values of  $B$  are

indicated in Figs. 6–8.

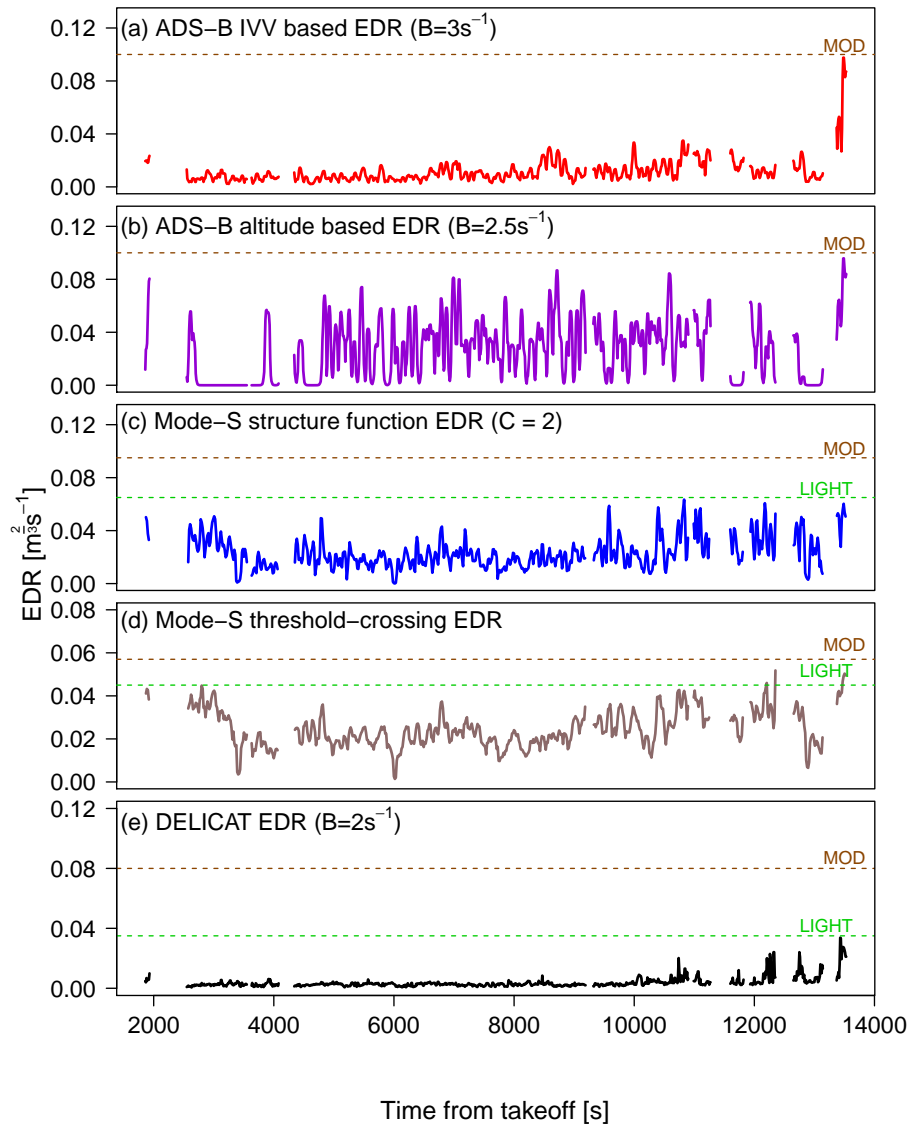
New Figure 6:



New Figure 7:



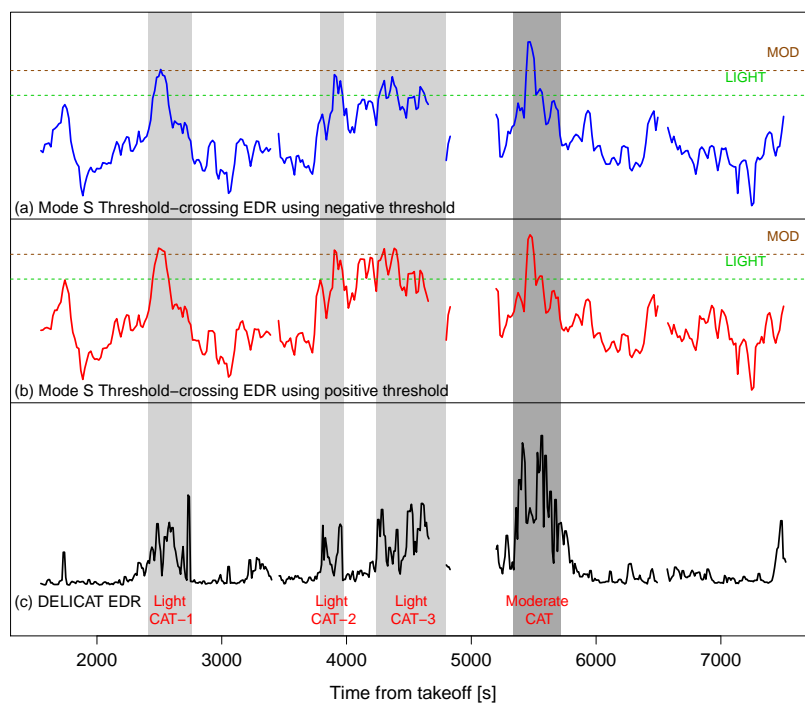
New Figure 8:



**P11851 Figure 9 "Label events light CAT-1, light CAT-2, etc so that these can be referenced in the corresponding text in the main article."**

Light event labels have been modified throughout the manuscript. This implicated changes in other figures (1, 2, 6-9).

New figure 9:



New figure 1:

