

Reviewer 1

The article is devoted to experimental studies of Kelvin-Helmholtz billows (KHB) in a stably stratified atmospheric boundary layer (SBL) by acoustic sounding. The measurements were carried out in the Delhi region (India) for 9 months using a research one-component (vertical) non-Doppler sodar developed at the National Physics Laboratory (NPL). The relevance of experimental studies of KHB in the ABL is not in doubt at present due to their relationship with the generation of turbulence under dynamic stability conditions. However, there are many remarks to the article.

Reply: Thanks for your valuable comments, Manuscript has been modified as suggested. The correction has been presented as red text.

General remarks:

1. In the Introduction, the research problem is very unclear. The synopsis is written inconsistently. Some parts of the review (for example, lines 49-53) are not related to the topic of the article. The publications cited in the review are randomly selected: many publications are not relevant to the subject of the article (for example, Beyrich, 1993; Choudhury, and Mitra, 2004; van Haren and Gostiaux, 2010). Some of the cited publications do not contain the statements cited by the authors of the article. Some publications are cited incorrectly (see, for example, lines 220 and 289).

In general, based on the review, it is impossible to get a clear idea of the problem, its current state and the specific task posed by the authors.

Reply: Thanks for the comments. In the revised manuscript, the suggestions are implemented and introduction part has been modified as possible. Some parts of review have been removed and inserted revised review related to KHB. Line no.- 47- 63, Page no.- 2-3.

2. The figures do not illustrate well the work done. KHB are visible more or less clearly only in Fig. 2 and Fig. 4c. But even on these echograms it is practically impossible to determine the wave parameters, and such estimates are also absent in the text. In addition, the figures are poorly represented (too small inscriptions and numbers along the axes).

Reply: In revised manuscript, the suggestions are implemented. Figures have been modified for clear display. Figure 2 and 3 have been merged with revised Figure 3 related to clear KHB.

3. The article does not analyze the conditions for the occurrence of KHB. Comparisons of sodar echograms with the time series of meteorological parameters according to the data of the weather station at 20 m a.g.l., shown in the two figures, do not give any idea of the relationship between the KHB and the average SBL parameters and are practically not commented on.

Reply: In the revised manuscript, the suggestions are implemented, and comparison of meteorological parameters with SODAR echograms have been inserted in the revised manuscript (figure 6 and 7).

4. The article does not contain statistics of frequency and parameters of KHB. The data shown in Table 2 are too few for analysis and conclusions, although they are given in the text.

Reply: In the revised manuscript, the suggestions by eminent reviewer are implemented, for the statistics analysis of KHB with meteorological parameter please see figure 6 and 7 with revised Table 2.

5. There are no comparisons of the results obtained with other experimental studies, or with models, although there are many such publications.

Reply: Thanks for your comments. Comparisons with other studies have been included in the revised manuscript.

6. The Conclusion consists of general phrases, and no specific conclusions from the study are provided.

Reply: Thanks for your comments. Conclusion section has been modified as possible.

7. The text of the article contains many stylistic, lexical and grammatical errors, which sometimes lead to a complete loss of the meaning of some phrases. Only a small subset of these errors are shown as examples in the next section.

Reply: As suggested by the reviewer the whole manuscript has been checked for errors as possible.

Some specific remarks:

8. **Line 12:** The abbreviation “KH” is explained on line 55.

Reply: The abbreviation has been modified as suggested, Page No.- 1, Line no.- 11.

9. **Line 12-13:** “KH billows are a primary cause of mixing in stably stratified conditions” – is an unwarranted strong statement. Mixing can be caused by individual bursts, buoyancy waves and non-periodic vortices. Which one is “primary” is unknown. Turbulence in LLJ without KHB is shown in [Kallistratova et al. 2013: Profiles of vertical wind speed variances within nocturnal low-level jets observed with a sodar]. In work [Zaitseva et al. 2017: The Effect of Internal Gravity Waves on Fluctuations in Meteorological Parameters of the Atmospheric Boundary Layer] it was shown that the effect of buoyancy waves on turbulent mixing can significantly exceed the effect of KHB.

Reply: The Sentence has been modified as suggested, Page No.-1, Line no.- 10-13.

10. **Line 16:** “K-H billows” is the third version of abbreviation for “Kelvin-Helmholtz billows” in 7 lines.

Reply: The abbreviation has been modified as suggested. Page No.- 1, Line no.- 16

11. **Line 16:** “various minutes” - wrong word choice

Reply: The abbreviation has been modified as suggested, Page No.- 1, Line no.- 16-17

12. **Line 17:** “lower portion of the troposphere» - wrong word choice

Reply: The Sentence has been rephrased, Page No.- 1, Line no.- 17.

13. **Line 18:** Most recognised billows are round the resolution limit of SODAR» grammatical errors lead to ambiguous meaning of the phrase

Reply: The Sentence has been removed and abstract has modified.

14. **Line 18-19:** “several of the cases” – grammatical error

Reply: The Sentence has been rephrased as suggested, Page No.- 1, Line no.- 17-19

15. **Line 20:** “October months”, “related with”

Reply: The Sentence has been rephrased as suggested, Page No.- 1, Line no.- 17-19.

16. **Lines 25-42** are not related to KHB, many references are incorrect (eg Asimakopoulos et al., 1976 - not about ABL width, but about Ct^2).

Reply: The reference has been corrected, Page No.- 2, Line no.- 30.

As we are using SODAR that’s why we have used this reference. Asimakopoulos et al. 1976 also discussed regarding SODAR in paper Page no.- 140, second paragraph. Screen shot of the paper is given below:

The acoustic radar operates at a frequency of 1730 Hz transmitting pulses of duration 74 ms at a pulse repetition frequency of 0.44 Hz and up to 25 W of peak acoustic power. The aerial which is used for both transmission and reception is a six-by-six array of 16.5-cm diameter re-entrant horn loudspeakers. These figures correspond to a height range of 380 m with a range resolution of $12\frac{1}{4}$ m. The pulse length and hence the resolution and the transmitted power can be varied. The receiver gain can be varied up to 155 dB which includes a ramp gain to compensate for the spherical divergence of the acoustic echoes as they are received from the longer ranges (Simmons *et al.*, 1971). The receiver bandwidth is 50 Hz to allow for any Doppler shift of the received echo due to vertical winds. Facilities are available to measure any Doppler shift in the received echo. The acoustic echo is recorded graphically by means of a facsimile recorder and also directly on magnetic tape for subsequent digitization and computer analysis. The digitization rate was chosen after inspection of the analogue voltage output of the sounder. Six hundred and fifty samples for each pulse were found to be necessary.

17. **Lines 40-45:** Descriptions of two independent processes are mixed, descriptions are inaccurate and do not correspond to the given references.

Reply: The Sentence has been corrected and rephrased as suggested, Page No.- 2, Line no.- 40-46.

18. **Line 45:** “the turbulence here is thought to be associated with Clear Air Turbulence” – is a tautology here. The term CAT is used in the aviation safety literature to refer to turbulence in the troposphere.

Reply: The Sentence has been modified as suggested, Page No.- 2-3, Line no.- 47-64.

19. **Line 48:** “The static stability also modifies the forms of turbulent eddies” - this is an incorrect statement, possibly due to incorrect formulation.

Reply: The Sentence has been modified as suggested by eminent reviewer, Page No.- 3, Line no.- 64.

20. **Line 51-53:** “The continuous exhaust of smoke from industries and vehicles spreads throughout the atmosphere; however, the direction of movement of smoke is horizontal rather than vertical.” - Neither before nor after this phrase is the physics of smoke propagation mentioned, it is not clear why this phrase is here.

Reply: The paragraph has been modified. Page No.-3, Line no.- 66-70.

21. **Lines 53-56:** “When the shear in laminar flow between the masses (e.g., between the cold air below and the warm air above) rises to the point where the flow again becomes unstable, the onset of turbulence increases as Kelvin-Helmholtz (KH) instability on the interface.” - it is not clear which physical process is described here, and where this description comes from

Reply: This part of the paragraph has been removed. Page No.- 3, Line no.- 60-70.

22. **Line 57:** there is “First”, but no “second” in text

Reply: The paragraph has been modified. Page No.- 3, Line no.- 39-49.

23. **Line 61:** “by using SODAR and RADAR (Singh et al., 1999; Van and Gostiaux, 2010)” – first author should be cited as “van Haren”. There is neither SODAR nor RADAR studies in this article, as this work is about waves in the ocean

Reply: The sentence has been modified as suggested by eminent reviewer. Page No.- 3, Line no.- 68-70.

In the various paper, they have discussed that the structures of the KHB have been observed in the raised inversion layers above the convection layer after the 1960s by using SODAR, RADAR and LIDAR (Singh et al., 1999; van Haren and Gostiaux, 2010; Lyulyukin et al., 2019).

24. **Line 52-63:** “LIDAR (Lyulyukin et al., 2019)” – this work is devoted to SODAR studies

Reply: The sentence has been modified as suggested by eminent reviewer. Page No.- 3, Line no.- 70.

25. **Line 68:** “SODAR (SONic Detection And Ranging)” - abbreviations SODAR already used above

Reply: The abbreviation has been removed as suggested. Page No.- 3, Line no.- 68.

26. **Lines 109-110:** “Sound backscattering is found at small-scale turbulent temperature inhomogeneity's (Gilman et al., 1946)” - the link is incorrect because Gilman et al were unaware of scattering by small-scale turbulence

Reply: The sentence has been corrected as suggested by eminent reviewer.

27. **Lines 111-113:** the references here are not well chosen, reference should be made to the original works of Tatarsky, Monin and Kallistratova
Reply: The reference has been modified as suggested by eminent reviewer. Page No.- 6, Line no.- 154.
28. **Line 106:** “The example of KHB is presented in Fig. 2” – there is only one example in Fig 1
Reply: The sentence and figure have been modified as suggested by eminent reviewer. In old manuscript Figure 1 represent the diurnal variation of ABL in normal day, whereas Figure 2 represent the KHB example in ABL. But now Figure and their captions are modified. In revised manuscript, Figure 1 is replaced with Figure 2, which represent the diurnal variation of ABL height and Figure 2 is merged with Figure 3 and show the example of KHB. Page No.- 5, Line no.- 135, figure- 2 and 3
29. **Line 119:** “about the resolution” – wrong word error
Reply: The sentence has been modified as suggested by eminent reviewer. Page No.- 6, Line no.-148-149.
30. **Line 128:** “temporal analysis”, “height of the time series” – lexical or logical errors
Reply: The sentence has been modified as suggested by eminent reviewer. Page No.- 7, Line no.-172.
The ABL height of the time series using the SODAR echogram is used to evaluate and compare the periods of the KHB structure during the rising layer.
31. **Lines 133-135:** “the assumption of a prominent role of convection in the formation of waves” - the conclusion looks logically unfounded. The small number of KHB episodes in comparison with the episodes of rising inversions rather indicates the opposite, which is confirmed by the data for March. In general, it is not entirely correct to draw conclusions about the relationship between the two parameters on such a small statistical sample.
Reply: We have added three months data in manuscript and the paragraph has been modified as suggested by eminent reviewer. Page No.- 7, Line no.-17-181.
32. **Line 137:** Incorrect reference. An article (Browning, 1971) is devoted to the study of waves in the upper troposphere, at altitudes of 6-11 km, and does not say anything about the “rising inversion layer” in the ABL
Reply: The reference has been removed. Page No.- 7, Line no.-173.
33. **Lines 140-141:** “an example ... are shown” – grammatical error
Reply: The sentence has been modified as suggested by eminent reviewer. Page No.- 7, Line no.-185-187.
SODAR echograms visualising the shape of the detected waves and averaged ABL height are presented in Fig. 3, the pre-monsoon (19th May 2019) and winter season (1st December 2019 and 11th January 2020).

34. **Lines 146-147:** The references here are not correct, in the cited works propagation and evolution of the waves are considered. The phrase also contains grammatical errors, probably several prepositions are missing.

Reply: The sentence has been corrected as suggested by eminent reviewer. Page No.- 7, Line no.-189-192.

The significant change in the structure of wind velocity, temperature gradient within KHB is strongly associated (Klaasen and Peltier, 1985a, 1985b; DeSilva et al., 1996; Lyulyukin et al., 2013) and provided a braid shape of the turbulence structure.

35. **Lines 148-150:** Link to Figure 4 is provided without any analysis. It is not clear what should be paid attention to in the figure, and what conclusion should be drawn.

Reply: The sentence has been modified. Fig. 4 and 5 represent the comparison of SODAR ABL echogram with meteorological parameters i.e., wind direction, wind speed, relative humidity and temperature observed on 18-20th May 2019 and also demonstrates the composite forms of KHB and meteorological parameters. Fig. 4a shows the temporal variation of the ABL height and meteorological parameter for the 24-hours of 19th May 2019. Fig. 4b also shows the temporal variation of ABL height and meteorological parameters during the KHBs period.. Page No.- 7-8, Line no.-193-215.

36. **Lines 159-160:** “And advection velocity that is close to the wind speed averaged over their bottom” - the meaning of this phrase is not clear.

Reply: The sentence has been modified Page No.- 3, Line no.-77-79.

37. **Lines 152-160** and the literature on convection cited in them are not related to the topic of the article and fall out of context.

Reply: The paragraph has been modified Page No.-3, Line no.-72-74.

38. **Lines 161-163:** «Petenko et al. (2016) observed and suggested that the eddies responsible for plume-like structures are on the order of the Kolmogorov scale for smooth walls and roughness height for rough walls» - such statements are absent in the work of Petenko

Reply: The paragraph has been modified as: Page No.- 8, Line no.-217-220.

Petenko et al. (2016) have performed the experiment at the French–Italian station of Concordia at Dome C in Antarctica during the summer months of 2014 to explore processes that exist in the polar ABL and the duration of the observed wavy structures are often between 40 and 50 seconds, with wavelengths of 250–350 metres based on Taylor's hypothesis.

39. **Lines 165-170:** also several statements that do not completely coincide with those presented in the work of Petenko (2020)

Reply: The paragraph has been modified.

Zaitseva et al. (2018) used Doppler minisodar at the Obukhov Institute of Atmospheric Physics' Tsimlyansk Scientific Station to find that Kelvin–Helmholtz waves have a minor effect on turbulence speed, while buoyancy waves cause the temperature structure parameter and vertical fluxes to increase by more than an order of magnitude. They also

look at what happens before, during, and after waves to see how wave motions affect meteorological parameters. Page No.- 8, Line no.-223-228

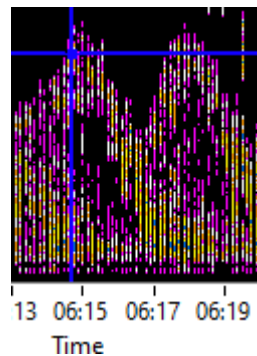
40. **Lines 176-177** fall out of context. Paragraph construction looks inconsistent and confusing
Reply: The sentence has been removed and new paragraph has been added. Page No.-9, Line no.-234-243.

41. **Line 178:** Fig. 4 has already been discussed above, prior to Table 3, it confuses more
Reply: The paragraph and figure have been modified as suggested by the reviewer. The table 3 (in old manuscript) is replaced with Figure 6 (revised manuscript) Page No.- 9, Line no.-244-254.

42. **Line 181 (Table 4):** What Table 3 shows is not clear. There are no heights there, no units are specified. What periods are indicated and how they were determined is not clear. The numerical values themselves and the methods of their determination also raise questions: what is the meaning of the value 625 ± 620 ? Is there a 99.2% error? It is not clear what days are in question if only one date is given.
Reply: The paragraph has been modified as suggested by eminent reviewer. The table 3 (in old manuscript) is replaced with Figure 6 (revised manuscript) Page No.- 9, Line no.-244-254.

43. **Lines 192-193:** “The periodicity of the braids is average $(150 \pm 10\%)$ s in the layer depending on the meteorological conditions in Delhi region” - it is not clear how this parameter was calculated; this estimate does not occur in the text above. In the example shown in Fig. 4b, the period of the waves seems to vary from 150 to 300 s. On line 107, the authors give an estimate of 90-110 s. Dependence on meteorological conditions is also not specified.

Reply: The paragraph has been modified. From the below figure, it is clear that braid is more 150 s. In the manuscript braid time is modified



44. **Line 220:** should be written as “DeSilva, I. P. D.”
Reply: The reference has been modified as suggested by eminent reviewer. Page No.-10, Line no.-282.
DeSilva, I. P. D., Fernando, H. J. S., Eaton, F., and Hebert, D.: Evolution of Kelvin-Helmholtz billows in nature and laboratory, *Earth and Planetary Science Letters*, **143(1-4)**, 217-231, 1996.

45. **Line 289:** should be “van Haren, H.”

Reply: The paragraph has been modified as suggested by eminent reviewer. Page No.- 13, Line no.-353.

van Haren, H., and Gostiaux, L.: A deep-ocean Kelvin-Helmholtz billow train, *Geophysical Research Letters*, **37(3)**, L03605(1-5), 2010.

46. **Figure 1:** The capture is too laconic, it is not indicated what is shown on specific panels. Black background makes it difficult to read. No date, too small and frequent numbers on the axes, and especially on the color bar. The time zone, the moments of sunrise and sunset are not specified.

Reply: The figure and figure caption have been modified for clear display. Figure no.-2.

47. **Figure 2:** Two images of the same fragment, with a time scale difference of less than 30%
Reply: Two images of the same fragment are shown to see the clear periodicity in high resolution. The first figure shows the five hours (0400-1000 IST) data whereas second figure shows the three hours (0545-0845 IST) data of first figure.

48. **Figure 3:** Chosen examples extremely poorly illustrate “clear KHB structures”, as indicated in the text

Reply: The figure has been modified with more clarity. Figure no.-3.

General conclusion.

Despite the fact that the language and presentation of the data can be corrected, the content of the article remains unsatisfactory. The article does not present new and original ideas, the data are scarce and poorly presented. There is no acceptable quantitative (or at least qualitative) data analysis. Rather, the article is based on a presentation of the raw data and its general description. Despite the importance of the subject matter, there is no way to improve the content of the article and it should be rejected.

Reply: There are several studies (some are given below) are reported of KHB occurrence over other countries except India. In this paper, we have reported for the first time, the detection of KHB structures using SODAR over Delhi region of India. And also analysed seasonal, monthly KHB with the meteorological parameters, as surface meteorological parameters are also responsible for turbulence. From this study we found that the time span is higher in Delhi in comparison to the study at other places.

Reference:

1. Blumen, W., Banta, R., Burns, S. P., Fritts, D. C., Newsom, R., Poulos, G. S., and Sun, J.: Turbulence statistics of a Kelvin–Helmholtz billow event observed in the night-time boundary layer during the Cooperative Atmosphere–Surface Exchange Study field program, *Dynamics of Atmospheres and Oceans*, **34(2-4)**, 189-204, 2001

2. Browning, K. A.: Structure of the atmosphere in the vicinity of large-amplitude Kelvin-Helmholtz billows, *Quarterly Journal of the Royal Meteorological Society*, **97(413)**, 283-299, 1971
3. DeSilva, I. P. D., Fernando, H. J. S., Eaton, F., and Hebert, D.: Evolution of Kelvin-Helmholtz billows in nature and laboratory, *Earth and Planetary Science Letters*, **143(1-4)**, 217-231, 1996.
4. Lyulyukin, V., Kouznetsov, R., and Kallistratova, M.: The composite shape and structure of braid patterns in Kelvin–Helmholtz billows observed with a sodar, *Journal of Atmospheric and Oceanic Technology*, **30(12)**, 2704-2711, 2013.
5. Sekioka, M.: Application of Kelvin-Helmholtz instability to clear air turbulence, *Journal of Applied Meteorology*, **9(6)**, 896-899, 1970.
6. van Haren, H., and Gostiaux, L.: A deep-ocean Kelvin-Helmholtz billow train, *Geophysical Research Letters*, **37(3)**, L03605(1-5), 2010.
7. Kallistratova, M., Petenko I., Kouznetsov R., Kuznetsov D., Lyulyukin V., and Perepelkin V.: Kelvin-Helmholtz billows in rising morning inversions, In *IOP Conference Series: Earth and Environmental Science*, **231(1)**, 012025 (1-9), 2019.
8. Klaassen, G. P., and Peltier, W. R.: Evolution of finite amplitude Kelvin–Helmholtz billows in two spatial dimensions, *Journal of the atmospheric sciences*, **42(12)**, 1321-1339, 1985a.
9. Chang, M.-H., S.-Y. Jheng, and R.-C. Lien (2016), Trains of large Kelvin-Helmholtz billows observed in the Kuroshio above a seamount, *Geophys. Res. Lett.*, 43, 8654–8661, doi:10.1002/2016GL069462
10. Plant, R. S. and Keith, G.J. (2007) Occurrence of KelvinHelmholtz Billows in Sea-breeze Circulations. *Boundary-Layer Meteorology*, 122 (1). pp. 1-15. ISSN 0006-8314 doi: <https://doi.org/10.1007/s10546-006-9089-x> Available at <http://centaur.reading.ac.uk/787/>