# Reviewer 2

## General comments

This study analysed Kelvin-Helmholtz billows in the planetary boundary layer over a station, New-Delhi using the SODAR measurements from March-November 2019. The subject is worth investigating as Kelvin–Helmholtz billows are a principal source of mixing by redistributing the momentum, mass, and thermophysical properties in the atmosphere. Nevertheless, this paper describes observations with little attempt to take any analysis further. The novelty of the work is missing. The evidence presented is not convincing for Kelvin-Helmholtz billows. The results presented are not supported by the analysis. Therefore, the manuscript needs substantial revisions before being suitable for publication.

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

## Specific comments

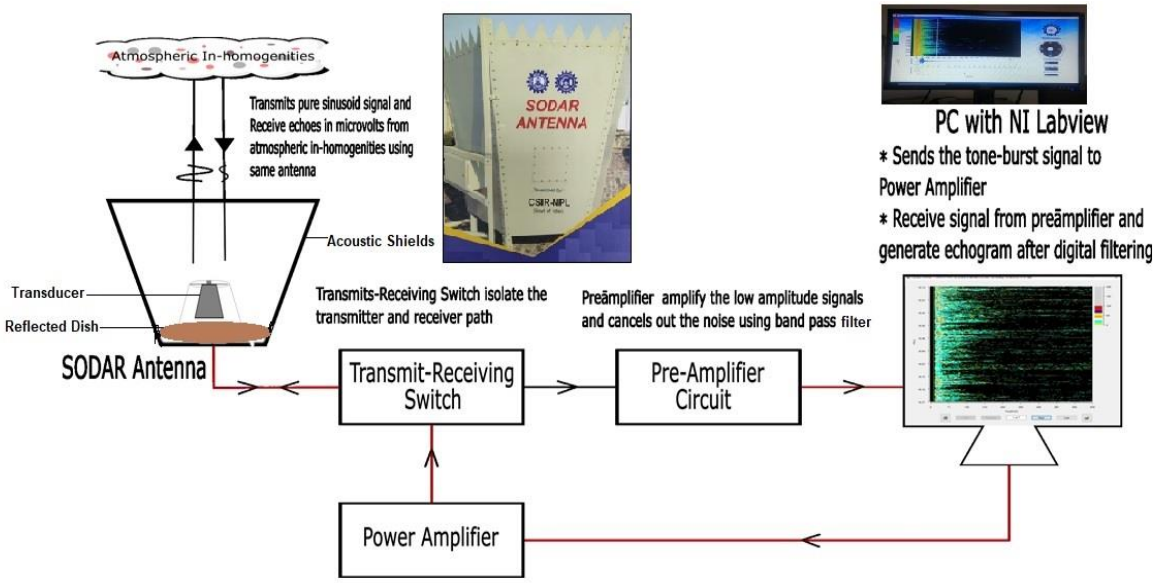
1. Abstract need to more focused on the findings. General statement about Kelvin-Helmholtz billows should be omitted in the abstract.
   **Reply:** The suggested in improvement has been done in respective section of revised manuscript. Page No.- 1, Line no.- 10-19.

2. In the Introduction, I miss the point of why this study has been carried out. I encourage rewriting the introduction section by clearly stating the importance of KH instability, the studies being carried out over India and worldwide, and the area of the gap they need to focus on. Also, state few scientific questions that will be addressed through your work.
   **Reply:** The introduction part has been modified as possible. Page No.- 2, Line no.- 80-86.

3. Ln 72: There is no description of the measurement site. Also, discuss the background meteorological conditions of the measurement site.
   **Reply:** The suggested in improvement has been done in respective section of revised manuscript. Page No.- 2, Line no.- 88-102.
   The SODAR system is developed by CSIR-NPL (National Measurement Institute of India), New Delhi and installed at the Capital Region of India i.e., Central Delhi (28.7041° N, 77.1025° E) in the homogeneous urban area (Kumar et al., 2015, 2017a). Delhi is placed near the bank of the river Yamuna. It occupies a special position in the form of a gateway between the Thar desert to its southwest, Aravalli range in North East- South West Direction and Himalayas which lie to its north. Fig. 1 shows the climate of Delhi is mainly influenced by its remote inland position and prevalence of air of continental character. Extreme dryness with intense summer and cold winter is the usual features of the climate of Delhi. This is modified by the air from the easterly or south-easterly direction and is responsible for the decrease in temperature, increase in humidity, cloudiness and precipitation for sometimes of the year. The wind is an important climate feature for Delhi. For most of the year, the wind is moderate. It is strongest in June and lightest in November. In the summer months hot and dust raising winds experienced which may result in thunderstorm and dust storm. Taking the year

as a whole, the prevailing wind direction is west to northwest from September to May while during monsoon easterly component predominates.

4. SODAR: How often the SODAR is being calibrated? Discuss more on SODAR technical parts. What kind of experimental set-up has been done?
**Reply:** The corresponding section has been modified by incorporating the suggestions. Page No.- 3, Line no.- 103-128.




5. Ln 96: Fig1. Diurnal variation of which day/month. What does the colour bar indicate? The figure is too noisy; how authors eliminate those noises? How you defined ABL.

**Reply:** The corresponding section and Figure 1 have been modified by incorporating the suggestions. Now Figure 1 (old manuscript) is replaced with Figure 2. The colour bar is indicating the intensity of sound signal, which is reflected back by the inhomogeneities of the atmosphere. The figure is seen noisy when the complete 24 hours data is presented but when the figure is seen in small frame (like 6-8 hours in single frame) then noise are less. A SODAR emits sound pulses and receives backscattered pulses from the temperature inhomogeneities at various heights of the atmosphere. These return signal has been processed and filter, the signal is plotted in intensity graph, where x-axis and y-axis show the time and ABL height respectively. Page No.- 3, Line no.- 110-128.

6. Fig 1: How the authors have eliminated the presence of aerosol loading?
**Reply:** All pollutants emitted from industrial emission, vehicular emission, household etc. are accumulated in the atmospheric boundary layer (ABL). ABL provides the overall loading of pollutants when multiplied with the average wind speed i.e., ventilation coefficient.

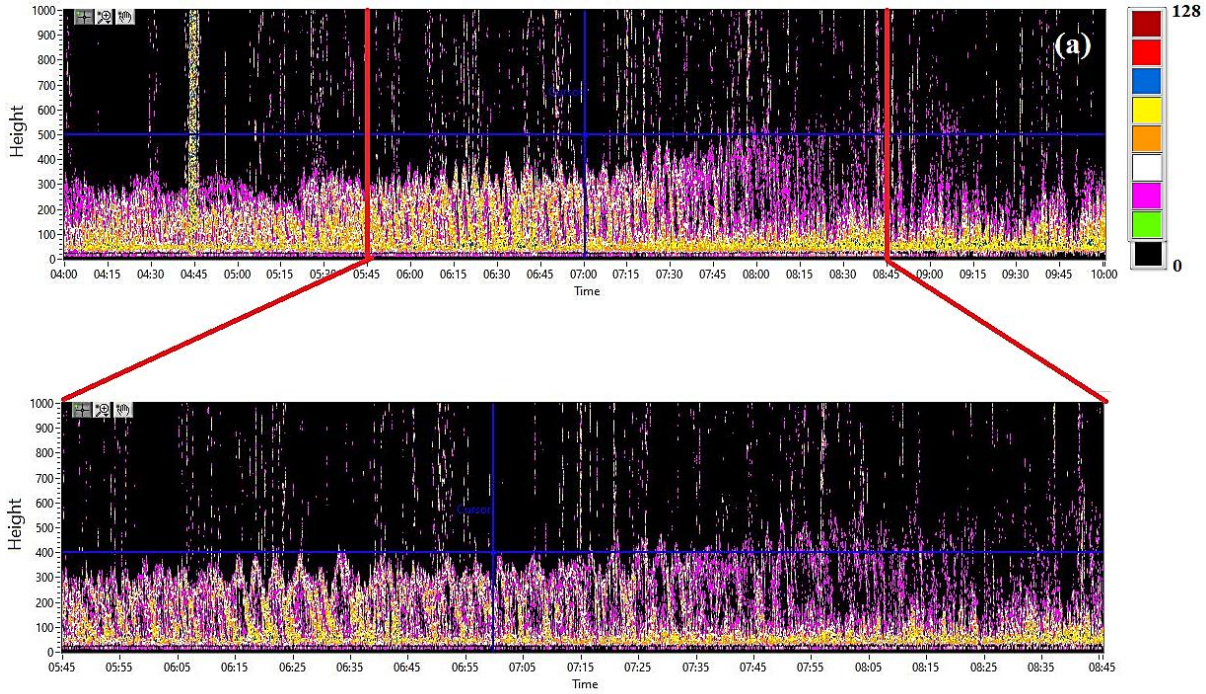
**References:**


I. **Lu, C., Deng, Qh., Liu, Ww. *et al.* Characteristics of ventilation coefficient and its impact on urban air pollution. *J. Cent. South Univ. Technol.* 19, 615–622 (2012). https://doi.org/10.1007/s11771-012-1047-9**

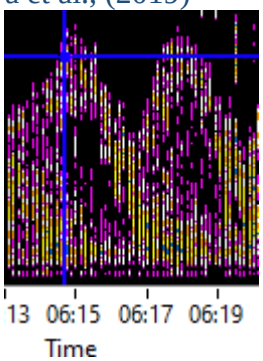
II. **GOYAL S K, CHALAPATI R C V. Assessment of atmospheric assimilation potential for industrial development in an urban environment: Kochi (India) [J]. Science of the Total Environment, 2007, 376(1/2/3): 27–39.**

7. Fig 1: Authors need to discuss the possible reason for the observed Kelvin-Helmholtz billows.
   **Reply:** In Fig. 1, there is no KHB. This figure represent the simple 24 hours variation of ABL height with time scale.

8. Fig 2. I cannot see the KH billow structure. At what height it is observed? Please mark in Figure
   **Reply:** From 0545-0800 IST the KHB is observed at less than 400 m height.




9. Ln 107: How periodicity (90-110 s) is determined?
   **Reply:** Fine structure and periodicity of KHB determined according to Lyulyukin et al., (2013, 2019) and Kallistratova et al., (2019)



10. Ln 110: return signal intensity is directly related. Please demonstrate how SODAR backscattered is related to temperature.
**Reply:** SODAR is a high-power, highly sensitive acoustical remote sensing system. It transmits a sound signal into the atmosphere and receives backscattered pulses from the temperature inhomogeneities at various heights of the atmosphere. SODAR provides a continuous vertical profile of the temperature structure parameter $C_T^2$ and also a clear ABL structure. These return signal has been processed and filter, the signal is plotted in intensity graph, where x-axis and y-axis show the time and ABL height respectively, whereas different colour code represent the strength of the signal.

11. Ln 117: … visual inspection of echograms… What factors are considered during visual inspection of the SODAR signal?
**Reply:** This SODAR is a new generation, high-power, highly sensitive monostatic SODAR system. It transmits a sound signal into the atmosphere with periods of 100 ms at 2250 Hz and average acoustic power of 20 W in the vertical direction at a pulse recurrence rate of 4 s, restraining the maximum potential range to 1000 m, with the lowermost observation height of about 50 m and perpendicular resolution of about 17 m. SODAR provides a continuous vertical profile of the temperature structure parameter $C_T^2$ and also a clear ABL structure. A SODAR emits sound pulses and receives backscattered pulses from the temperature inhomogeneities at various heights of the atmosphere. These return signal has been processed and filter, the signal is plotted in intensity graph, where x-axis and y-axis show the time and ABL height respectively, whereas different colour code represent the strength of the signal. This graph has known as the SODAR echogram. The atmospheric conditions can be broadly categorized as convective period and non-convective(stable) period based on the vertical profile of acoustic refractive index which can be seen in the echogram. Methods and algorithm to derive the ABL height from SODAR data are compiled in Singal et al., (1994), Beyrich, (1997) and Emeis et al., (2008). The observer needs to broadly classify the data into two categories namely: inversion-time and convection-time. The other classifications of ABL structure are fog-layer, rising-layer, and multi-layer and each classified structure demand a different approach for the ABL height estimation. The ABL height can be directly picked up from the echogram by using visualization, apart from the convection period.

12. Are there always clear sky conditions for 90 cases? How about during the monsoon?
**Reply:** KHB observed during the clear sky conditions. During monsoon we didn't observe any KHB.

Table 2: Number of KHB episodes in March 2019 to February 2020

| Season | Month | Rising layer | KHB |
|---|---|---|---|
| Pre-Monsoon | March | 13 | 1 |
| | April | 10 | 4 |
| | May | 14 | 4 |
| | June | 8 | 3 |
| Monsoon | July | 5 | 0 |
| | August | 8 | 0 |

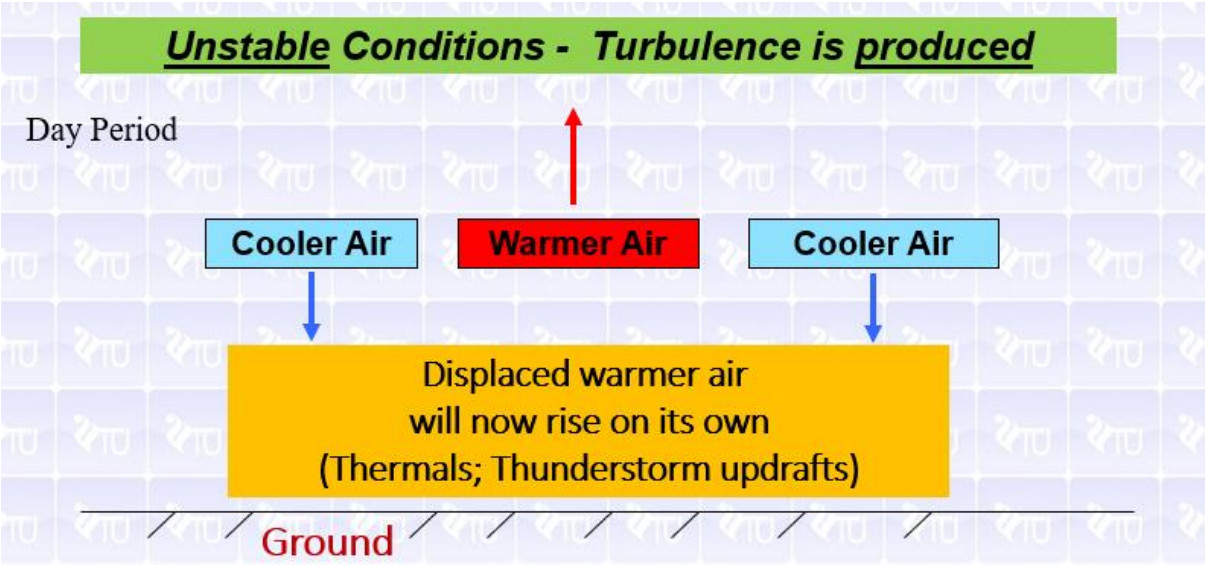
| | | | |
|---|---|---|---|
| | September | 6 | 0 |
| Post-Monsoon | October | 10 | 5 |
| | November | 14 | 4 |
| Winter | December | 10 | 1 |
| | January | 18 | 3 |
| | February | 16 | 2 |

13. Kelvin-Helmholtz billows presence should be associated with larger variability of the physical observables such as wind and wind shear. Authors need to consider this aspect also.
    Reply: Thanks for your suggestion in the revised manuscript we have added the analysis with meteorological parameters like wind speed/direction, temperature, relative humidity etc.

14. Table 2: Why monsoon months (June-September) have fewer Kelvin-Helmholtz billows?
    **Reply:** Taking the year as a whole, the prevailing wind direction is west to northwest from September to May while during monsoon easterly component predominates and clouds are presented in fully or partially.

15. Ln 148: Fig. 4: The metrological variables should be discussed in terms of anomaly (difference between without and with Kelvin-Helmholtz billows).
    **Reply:** In **t**he revised manuscript difference between without and with Kelvin-Helmholtz billows has been included. Page-9, Lines -241-251.

16. Table 3: What is convection period? How have authors defined convection?
    **Reply:** When the atmospheric boundary layer is completely transfer from stable to unstable condition i.e., the warm air is going up and cool air is coming down. Then the thermal plume's structure is formed in SODAR echogram. Thermal plume structure is a day time structure and is associated with the solar heating of the ground with the day break. The plumes start forming early in the morning when the surface inversion dissipates. With more and more heat input to the ground, the intensity of this phenomena increases and reflected on the SODAR echograms in the form of taller plumes




17. Findings of the work need to discussed in context to other studies.
    **Reply:** Revised manuscript has been modified as suggested.

18. Authors should discuss what the implication of their work and future work area.
    **Reply:** Thanks for your comments. Revised manuscript has been modified as suggested.

Technical corrections

19. Ln 12: Change KH billows to KHB
    **Reply:** Revised manuscript has been modified as suggested.

20. Ln 16: Change K-H billows to KHB. Please make it consistent throughout the manuscript.
    **Reply:** Revised manuscript has been modified as suggested.

21. Ln 39: According to Stull (2012) in the structure of ABL…. The structure of the sentence is not correct.

    **Reply**: Revised manuscript has been modified as suggested. Page no- 2, Line no.-37-38.
    When the stratocumulus topped, a mixed layer moved over the colder ground surface in the ABL structure (Stull, 2012).

22. Ln 25-43. This paragraph is too wordy and can be concise in 3-4 sentences.
    **Reply:** Revised manuscript has been modified as suggested.

23. Ln 89-91. Considering the vastness….This is a redundant statement.
    **Reply:** Revised manuscript has been modified as suggested.