**We would like to express our gratitude for the valuable feedback from the Referee. We appreciate your tireless efforts in reviewing our manuscript so it allows us to improve the standard of our article.**

## RC1

This work is devoted to an interesting and insufficiently studied topic. Results of variations in mesospheric inversion layers are presented, but there are some comments:

1. Line 41: missing letter «e» in mesosphere

   Response: We have corrected the typographical error "mesospher" to "mesosphere" in line 40.

2. Line 74-77: The sentence is too long. And Figure 1 shows temperature, not causatives. Please rephrase.

   Response: We have modified to correct the long sentence in lines 84–88 in the new revision, as shown below. Additionally, we have corrected the expressions in Figure 1, which now display SABER observed MLT temperature instead of causative.

   "In the present, we have used the latest version of SABER temperature data over low-latitudes. The SABER vertical temperature profiles were taken in the range of 60-100 km altitude during the period January 2005-December 2020 over (3-15$^0$N) latitude and (33-48$^0$E) longitude regions. The monthly mean SABER temperature data of the mesosphere and lower thermosphere (MLT) region is presented as shown in Figure 1."

3. Figure 2 (as well as Figure 7.8) is not entirely clear. There are too many black isolines and the fill behind them is not visible. Try increasing the size of Figures and thinning out the isolines. Maybe leave one isoline that satisfies the inversion criterion.

   Response: Thank you for your comment. Based on your suggestions for visibility, we have enlarged and clarified Figures 3, 8, and 9.

4. Line 140-141: You claim that the base of the lower MILs lies in the range of 73-79, and the upper MILs is 86-89 km. Sorry, but I don't see this in Figure 2. Why did you indicated these heights?

   Response: We have corrected the sentences based on the output from Figure 3 in lines 195–199, and we can now observe the corresponding Figure 3.

"Our findings of the lower inversions in the range of (70-80 km) tend to approach the reports by Sivakumar et al. (2001), which show that the base of the lower mesospheric inversion layer (MILs) lies in the range of (73-79 km), as well as the Gan et al. (2012) seasonal variations of MIL in the planetary waves as a caustive over low-latitudes using the SABER observations."

5. I don't understand why histogram 4(c) shows a maximum MILs at 78 km, but histogram 4(f) does not have a maximum at this altitude.

   Response: Thank you for your comment. Figures 5(c) and 5(f) have been corrected in the revised manuscript. Figure 5(c) shows the upper inversion, while Figure 5(f) shows the lower inversion, in the specified intervals of base height (~70–80) and base height (~80–90) for the upper MLT region.

   In lines 238-240, "The base height of the upper MIL in Figure 5(c) ranges from ~80 to 90 km, with a peak value of a large number of upper mesospheric inversions occurring at a base height of around 83 km in a lower standard deviation (SD) 2.13."

   In lines 248-250, "The base height of the lower inversion of Figure 5(f) is in the range of 70 and 80 km, with a peak value of around 74 km, showing a lower standard deviation (SD) of 1.93."

6. In my opinion, the conclusions are overloaded with numbers. All parameters are listed in the text of the manuscript.

   Response: Thank you for your valuable suggestion. The conclusion has now been modified based on your suggestion in section 4, from lines 395-418, by reducing the number of crowded details as shown below.

## "3. Summary

In this article, 16 years of SABER mesosphere temperature profiles are utilized to investigate the MIL phenomenon and its causative mechanism through gravity wave potential energy ($P_E$) and instability criteria of Bruent-Vaisala frequency ($N^2$) over low latitude bands. The observational conclusions from this chapter are drawn as follows:

- ✓ The occurrence rate of the upper mesosphere inversion frequency is maximum relative to the mean occurrence rate of the lower mesosphere inversions.
- ✓ Based on the analysis of frequency of occurrence on mesospheric inversion layer (MIL) characteristic features, it is revealed that the most probable value for upper inversion amplitude is 38 k, inversion layer thickness is 5.5 km, and the base height is 78 km. Whereas the lower inversion amplitude is 25 K, the inversion layer thickness is 3.8 km, and a base height of 73 km.
- ✓ The gravity wave indicator potential energy depicts high energy at the upper mesosphere region compared to the lower mesosphere region.
- ✓ The result concludes that the observation of high potential energy in the upper mesosphere region is due to the deposition of high energy and momentum at the background temperature by gravity wave breaking, which could influence the dynamics of the inversion phenomenon
- ✓ The stability criteria at the mesosphere region are indicated by Brunt-Vaisala frequency ($N^2$), which shows low values at the upper mesosphere region relative to the lower mesosphere region, leading to the conclusion that the high potential energy at the upper mesosphere region is due to the instability over that region, which gives rise to large inversion phenomena.
- ✓ In general, we concluded that the processes in the atmosphere vary from region to region. As a result, the atmospheric state varies significantly with altitude as well as from place to place and time to time."

7. To what extent is it physically justified to explain the MILs by changes in the Brunt-Vaisala frequency? After all, in essence these are the same things; if there is an inversion, it means the atmosphere is not stable.

Response: Thank you for your suggestion and comment. In this investigation, the Brunt-Vaisala frequency is used to demonstrate the instabilities of the Mesospheric Inversion Layers (MILs). Our aim here is to assess by which extents of gravity waves impact atmospheric instability, based on the Brunt-Vaisala formulation, as explained in Figure 11 of the manuscript (lines 382-391), as described in lines 334-336.

"In this section, an attempt has been made to investigate the longitudinal variability of gravity waves' contribution to the mesospheric inversions (MILs) phenomenon by calculating potential energy and their instability based on Bruent-Vaisala frequency ($N^2$) using perturbed temperatures."

"Hence, investigating MIL phenomena is important for the understanding of MLT atmosphere dynamics for two primary reasons: stability and energy transfer. As a result, an attempt has been made to examine the contributions of gravity waves to the MLT region's instability (MIL phenomenon) based on the Brunt-Vaisala frequency. The spatiotemporal variability of Vaisala frequency is displayed in the contour Figure 11(a and b) for the upper mesosphere region (90 and 85 km) and Figure 11(c and d) for the lower mesosphere region (75 and 70 km). Based on the Brunt-Vaisala frequency, N2, the upper MLT region is unstable (~0.027) at 90 km and (~0.029) at 85 km maximum relative to the lower inversion instability at 75 km (~0.033) and 70 km (~0.035). Hauchecorne et al., (1987) described a model in which a succession of breaking GWs would generate the MIL through the gradual accumulation of heat as a cause of instability."

8. The manuscript also lacks interpretation of physical processes. There is no attempt to speculate about the sources of gravity waves. Although Figure 1 clearly shows a quasiperiodic structure of temperature fluctuations. The periodicity is also visible in Figure 3. How does this relate to the QBO phase? Or with other processes in the low-latitude atmosphere. Perhaps winds and shears in the mesosphere generated gravity waves. Your figures show significant interannual variability. What features were there in 2012-2013 and 2019? Gravity wave potential energy is increased at longitudes 35-40E, maybe the source was the lower layers of the atmosphere, for example, The Low-Level Somali Jet? Discussions about the physical nature of the origin of gravity waves should be added to the manuscript.

Response: We thank you for your valuable comment and suggestion. Based on your comment we modified the interpretation of physical processes even the source of the gravity waves and their impacts are clearly stated in the manuscript as follows in lines 319-330.

"Atmospheric waves (gravity waves, planetary waves, and tidal waves) exist in different layers of the atmosphere and are generated by different mechanisms. Gravity waves are of local or regional dimensions, whereas the other two waves are of global extent. This dynamical gravity wave motion is a restoring force of gravity acting downward and buoyancy acting upward on vertically displaced air parcels from the troposphere/stratosphere through the upper thermosphere. These propagated gravity waves can be distributed from their source regions across the atmosphere and become saturated at the critical upper atmospheric level, particularly over the low latitudes. Thereby, the vertically propagated waves were breaking and dissipating to transfer their energy and momentum into the atmospheric background field, thus considerably affecting the structure and variability of the atmosphere, as shown in Figure 10, as well as the results of (Holton et al., 2003; Holton and Hakim, 2013) waves potential energy affecting the atmospheric temperature inversions."

## RC2

Comments on, **"The Role of Gravity Waves in the Mesosphere Inversion Layers (MILs) over low latitude (3-15° N) Using SABER Satellite Observations"** by Lingerew and Raju. Using sixteen years of SABER temperature data, the authors investigated the role of gravity waves (GWs) in the mesospheric inversion layers. To understand the role of GWs in the MILs, they estimate the potential energy, and based on the results they argue that the lower and upper MIL distinctions are due to the GWs. The strength of the manuscript is they used a long-term data set however, their methodology is not clear. Moreover, this manuscript also lacks the scientific discussion. The present form of the manuscript needs major changes before acceptance for publication. Therefore, I recommend to the editor for a major revision. The detailed major and minor comments are as follows:

**Major comments:**

1. **A)** In section 2, latitudinal information of the data used is given however there is **no information about the longitudes**! Which reading the whole manuscript, I could see the longitudinal limits of 32 to 48° in Figures 10 and 11 (in section 3.4).

   Response for 1A: Thank you for your comment. The Lat-Long information is referenced in various sections, including lines 66, 86–87, 264, and 368–371.

   "The SABER vertical temperature profiles were taken in the range of 60-100 km altitude during the period January 2005-December 2020 over (3-15$^{0}$N) latitude and (33-48$^{0}$E) longitude regions."

   **B) Are the temperature profiles averaged over 3-15°N and 32-48°E? If so mention it in section 2**.

   Response for 1B: No, we have taken the SABER temperature profiles across the full range of latitudes and longitudes but have not averaged them as we mentioned in the lines following 86-

87.: "The SABER vertical temperature profiles were taken in the range of 60-100 km altitude during the period January 2005-December 2020 over (3-15$^0$N) latitude and (33-48$^0$E) longitude regions."

**C)** More importantly, the information about **how do the MILs are identified is missing**. They have only **written as a diagnostic technique** is used. What kind of diagnostic technique, whether the authors validated the diagnostic method all this information should be provided in the methodology (e.g. Gan et al., 2012; Sivakandan et al. 2014, etc.).

Response for 1C: Thank you. It is not validated simply to use the authors' [(Leblanc and Hauchecorne (1997) and Fechine et al. (2008))] scientific diagnostic procedures based on the characteristics of temperature inversion amplitude and thickness. The MILs are identified using their techniques as follows in lines 96-112:

"The mean thermal structure of the Earth's middle atmosphere is characterized by a negative temperature gradient. However, there are several reports showing positive temperature gradients in the mesosphere which are in contrast to the ideal situation of negative gradients (Meriwether and Gardner, 2000; Gan et al., 2012). This kind of phenomenon is known as "mesospheric inversion layer (MIL)". MILs were identified based on following procedure outlined by Leblanc and Hauchecorne (1997) and Fechine et al. (2008) and which is briefly presented here. This procedure has been applied in many previous studies investigating the phenomenon of mesospheric inversion (Leblanc et al., 1998; Meriwether and Gardner, 2000; Duck et al., 2001; Duck and Greene, 2004; Cutler et al., 2001; Siva Kumar et al., 2001; Ratnam et al., 2003; Gan et al., 2012). Inversions of this MLT temperature are identified based on their characteristics thickness (the altitude difference between the point of warm & cool), while the temperature difference between the point of cooling and warming is termed as amplitude of the MIL (Meriwether and Gardner, 2000) as shown in figure 2, which have a positive value between the top and bottom levels"

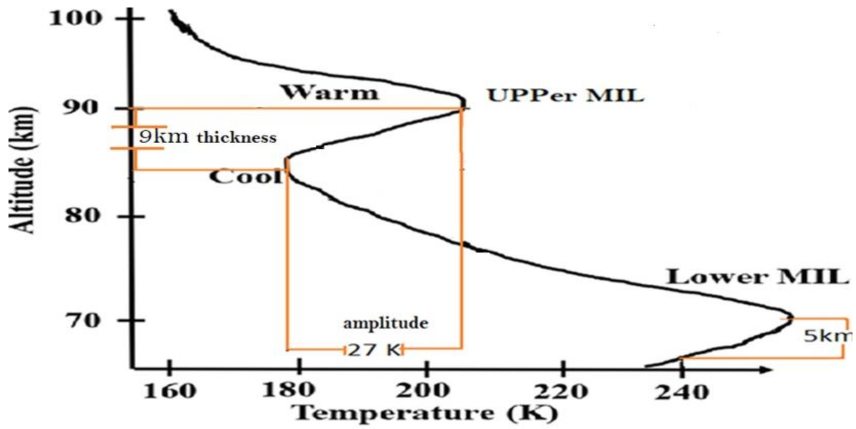


Figure 2. Schematic of upper and lower mesospheric inversion layers shown in the temperature profile for the MLT regions (Adapted from Meriwether and Gerrard, 2004).

2. **A)** One of the major issues in the manuscript lack of a literature survey, though they have cited some of the important papers (Meriwether and Gardner 2000; Gan et al., 2012) but the essential points from those papers are not reflected in their approach.

Response for 2A: Thank you for your comment and suggestion. Based on your comment, we have corrected and appropriately referenced the materials in a different section of the manuscript (e.g., Gan et al., 2012, mentioned in lines 51-53, 77-79, 82-84, 96-99, 102-105, 213-215, 286-287), while the reference (Meriwether and Gardner, 2000) is utilized in lines 96-99, 102-108, as follows:

"The mean thermal structure of the Earth's middle atmosphere is characterized by a negative temperature gradient. However, there are several reports showing positive temperature gradients in the mesosphere which are in contrast to the ideal situation of negative gradients (Meriwether and Gardner, 2000; Gan et al., 2012)."

"Further, the gravity wave-breaking influence on mesosphere dynamics is an attempt to demonstrate their impacts on the inversion phenomenon over mid and high latitudes (Gan et al., 2012; Walterscheid and Hickey, 2009; Collins et al., 2011; Szewczyk et al., 2013)."

"SABER temperature data has been widely used to investigate the typical thermal structure and dominant dynamical processes in the mesospheric region (Garcia et al., 208, Gan et al., 2012, 2014; Bizuneh et al., 2022; Lingerew et al., 2023)."

"The valuable nature of SABER observations for the study of the middle atmosphere is well documented in previous research (Meriwether and Gerrard, 2004; Fechine et al., 2008; Dou et al., 2009; Gan et al., 2012; France et al., 2015)."

"This procedure has been applied in many previous studies investigating the phenomenon of mesospheric inversion (Leblanc et al., 1998; Meriwether and Gardner, 2000; Duck et al., 2001; Duck and Greene, 2004; Cutler et al., 2001; Siva Kumar et al., 2001; Ratnam et al., 2003; Gan et al., 2012)."

"Not only this, Gan et al. (2012) also found the seasonal variation of MILs over the low latitudes under the causative planetary waves."

**B)** There are various sources proposed as the causative mechanism of the lower and upper MILs. For example, the planetary waves are believed to be the causative mechanism of lower MILs similarly, gravity waves, tidal interactions, and chemical heating are proposed as a cause of upper MILs. These points are not considered and there is no reason why the authors only focus on the GWs. It is well understood that in most cases the GWs breaking in the mesosphere can cause only very few Kelvin temperature changes (>10K). If this is the scenario it cannot explain the higher amplitude MILs. Comment on it.

Response for 2B: Thank you for your comments on atmospheric waves. Scientists have long hypothesized that these inverted temperature profiles, known as mesospheric temperature inversions (MTIs), are caused by atmospheric gravity waves. A gravity wave is a vertical wave characterized by high vertical and low horizontal scales. Therefore, these waves play a significant role compared to other waves in vertically transferring energy from the lower atmosphere to the upper layers. We can refer to the following citations as examples in lines 372-381.

"Many possible mechanisms have been suggested for the cause of lower MIL formations, nonlinear interactions between GWs and tides (Liu and Hagan, 1998), and chemical heating (Meriwether and Mlynczak, 1995) including GW breaking (Hauchecorne et al., 1987). The role of gravity wave propagation and dissipation has been accepted as the dominant wave forcing in the MLT region (Lindzen, 1981; Holton, 1983), which affects the middle and upper atmospheric inversion. It is also understood that tides, planetary waves, and chemical processes affect the middle atmospheric variability as well as gravity waves (Sivakandan et al., 2014). However, gravity waves are multi-scale in nature; small-scale waves may contribute predominantly to instability, and turbulence in the MLT dynamic region (Liu and Meriwether, 2004; Szewczyk et al., 2013)."

3. As mentioned in comment 1, the authors should provide longitudinal information, because this has an important role if they try to understand the role of GWs which are highly localized in nature. **It is not clear how the 1hr cutoff frequency applies to the data**, if the authors used a particular region then in a day maximum of two to three satellite passes can be observed based on the area, with this limited data set how effective or logical is the 1hr band pass filter?

Response: Thank you. It does not pertain to a specific region for a short period; instead, we utilized 16 years of SABER satellite observation data over the latitude (3-15$^0$) and longitude (32-

$48^0$) regions. While a TIMED/SABER satellite rotates 16 times in 24 hours on its orbit in 1.5-hour intervals to access approximately 1440 data points, in a minute interval, SABER may pass over our study regions more than once. A one-hour interval cut-off frequency of a low-pass band filter is applied to the perturbed temperatures (Tp) to calculate the gravity wave potential energy (PE) by removing tidal and planetary waves, as mentioned in lines 167-173.

"After estimating the perturbed temperature ($T_P$), $T_p = T - T_0$, a one-hour cut-off frequency of the low-pass band filter is applied on the perturbed temperature to calculate the atmospheric gravity wave potential energy ($E_P$) by removing the planetary and tidal wave impacts or contribution in the perturbed temperature (John and Kumar, 2012).

$$E_p(z) = \frac{1}{2}\left(\frac{g(z)}{N(z)}\right)^2 \left(\frac{T_p(z)}{T_0(z)}\right)^2 \qquad (13)$$

The potential energy of the waves is a function of altitude, z, which is utilized to determine the impact of atmospheric gravity waves on atmospheric dynamics."

4. Why 3rd order polynomial fit? Ramesh and Sridharan (2012) do not elaborate on any method, instead they have cited Leblanc and Hauchecorne (1997). Therefore the article cited here is not relevant. Provide more information about the methodology and its validity (how good it is? if the authors did any test to validate the method etc.)
Response: Thank you for your comment. Based on your comment, it has now been corrected. We did not use any validation to prefer the 3rd-order polynomial fit here; instead, we relied solely on previous scientific techniques (Leblanc and Hauchecorne, 1997) as references, as stated in lines 161–163.

"In the meantime of estimating the Brunt-Vaisala frequency ($N^2$), the third-order polynomial fit of the least square has been applied to the SABER observed temperature (T) profile to estimate the background temperature ($T_0$) following the procedure Leblanc and Hauchecorne (1997)."

5. Lines 138-140; in this context, Gan et al., (2012) could be a more suitable paper to cite here than Sivakumar et al. (2001), because they also used SABER data, on the other hand, Sivakumar et al. (2001) only used Rayleigh lidar data over a single location (the data quality above 80 km is questionable). Gan et al. (2012) also found the seasonal variation of MILs in the low latitudes and planetary waves as the cause of lower MILs, whether these authors could find such a relationship? If yes or no provide reasons!
Response: Thank you. We have now made the correction based on your comments by substituting the reference Gan et al. (2012) instead of Sivakumar et al. (2001), as mentioned in lines 212-215 as well as in lines 195-199.

"In this regard, Hauchecorne et al. (1987) and France et al. (2015) show the impacts of Gws on the upper and lower mesosphere inversion variability. Not only this, Gan et al. (2012) also found the seasonal variation of MILs over the low latitudes under the causative planetary waves."

"Our findings of the lower inversions in the range of (70-80 km) tend to approach the reports by Sivakumar et al. (2001), which show that the base of the lower mesospheric inversion layer (MILs) lies in the range of (73-79 km), as well as the Gan et al. (2012) seasonal variations of MIL in the planetary waves as a causative over low-latitudes using the SABER observations."

6. There is no clear information about how the occurrence frequency is estimated. Provide it?

   Response: Thank you. The occurrence rate of the frequency (percentage) for lower and upper inversions is presented in Figures 4a and 4b, as shown in line 200 and described in lines 121-125.

   "As well as identifying inversions, the frequency occurrence rate (%) of mesospheric inversion layers (MILs) is derived during the period 2005–2020 in the upper and lower MLT regions. The occurrence rate of the frequency (percentage) is estimated based on dividing the monthly inversion days for each month (dates of a month) of 16-year (2005–2020) observation data."

7. **A**. How the mesopause altitudes are taken care of or eliminated from the statistics? Which could be a false indication of inversion.

   Response for 7A: Thank you. The reason we disregard Mesopaous' misleading signal of an inversion is that, in our analysis, the Mesopous region is considered to be more than 90 km away.

   **B.** And could the authors note any solar activity dependency of MILs occurrence (for example, Sivakandan et al. (2014))?

   Response for 7B: Thank you. The causal atmospheric waves (gravity waves) for an inversion are the only ones in our study that have not been further explained about solar radio flux activities in the upper and lower inversions, as studied by Sivakandan et al. (2014).

8. Lines 151-155, In the literature there are different causative mechanisms are proposed for the multiple MILs, (I suggest the authors go through Meriwether and Gardner (2004); Gan et al. (2012)).

   Response: Thank you for recommending the scientific results of Meriwether and Gardner (2004) and Gan et al. (2012), which we are using as references. We have included these references in various sections, including lines 211-212.

9. Section 3.2, is a good point to investigate but before doing that the data need to be binned properly with local time. I am a bit concerned about how good to investigate the latitudinal and longitudinal variations in a small region using satellite data, each temperature profile could be nearly 500 km spatial averaged.

Response: Thank you for your comment. However, our investigation does not focus solely on local time; instead, we analyze data spanning from 2005 to 2020 across latitudinal (3–15$^0$) and longitudinal (32–48$^0$) spatial regions. The TIMED-SABER satellite provides observations at a temporal resolution of approximately 58 seconds (or ~1 minute) and vertical spatial resolutions with intervals of 2 km. With the SABER observation orbiting 16 times per day, we can access approximately 1440 temperature data profiles. Therefore, we do not bin the data.

10. The scientific discussion is very spare and weak. They should compare the present results with earlier studies based on the similarities and differences the scientific reasoning also should be included in the manuscript.

Response: Thank you for your comment on improving our manuscript. Based on your suggestion, we have modified the output results by comparing them with previous scientific works in the results section of the revised version. As examples, comparisons can be found in lines 195–201, 326–330, and 349–353.

"Our findings of the lower inversions in the range of (70-80 km) tend to approach the reports by Sivakumar et al. (2001), which show that the base of the lower mesospheric inversion layer (MILs) lies in the range of (73-79 km), as well as the Gan et al. (2012) seasonal variations of MIL in the planetary waves as a causative over low-latitudes using the SABER observations. Whereas Sivakandan et al., (2014) also investigated the lower and upper mesospheric inversions in the altitudinal regions from 60-105 km over low latitudinal regions, which nearly coincides with our work results."

"Thereby, the vertically propagated waves were breaking and dissipating to transfer their energy and momentum into the atmospheric background field, thus considerably affecting the structure and variability of the atmosphere, as shown in Figure 11, as well as the results of (Holton et al., 2003; Holton and Hakim, 2013) waves potential energy affecting the atmospheric temperature inversions."

"By using the time series of filtered perturbed temperature data at selected heights of 90, 85, 75, and 70 km, the potential energy ($E_p$) is constructed based on the formula mentioned in the methodology section, since the gravity wave activity is projected by the potential energy calculation as described from numerous authors (Tsuda et al., 2000; Wang and Geller, 2003; Liu et al., 2014; Thurairajah et al., 2014)."

11 How the GWs potential energy is connected to the MILs? First, establish the connection by showing a single case in which a physical connection should be clear and then go for the statistics.
Response: Thank you. We have outlined their connections in Section 3.4, particularly in lines 330–333, as follows:

"The gravity wave propagation at the saturation stage is broken in the upper region to dissipate their energy, which impacts the normal mesospheric temperature by increasing its temperature with elevation, known as an inversion. This is the reason the gravity wave potential energy is connected with an inversion."

## Minor comments:

1. Lines 8-9, The mesosphere…This is a transitional region not only in the low latitudes! So modify the statement.
   Response: Thank you for your comment. The sentence is modified in lines 8–9 as follows:
   "The Mesosphere and lower thermosphere (MLT) transitional region is a distinct and highly turbulent zone of the atmosphere."

2. Lines 40-41, define the MILs.
   Response: Thank you for your recommendation. The sentence has been modified in lines 38–40 as follows:

   "The mesospheric inversion layers (MILs) are a common feature that appeared to increase the mesosphere temperature variability."

3. Line 41, a typo, 'mesosphere'
   Response: Thank you, the typo error has been corrected.

4. Line 73, these references are irrelevant here. Provides references about the data validation and limitation as well as instrumental specifications.
   Response: Thank you. We have included references to illustrate the validation and limitations of SABER observations in the MLT region, as stated in lines 75-79.

5. Line 75, longitudinal information is missing!
   Response: Thank you for the comment you previously raised in the main question (1). It has been addressed in the revised manuscript, starting from line 85-87, as follows:
   "The SABER vertical temperature profiles were taken in the range of 60-100 km altitude during the period January 2005-December 2020 over **(3-15$^0$N) latitude** and **(33-48$^0$E) longitude** regions."

6. Figure 4: Sivakandan et al. (2014) also did such a statistical analysis using the SABER data over Indian low latitudes, could you compare the present results with their results and provide some scientific reasoning for the observed differences or similarities.
   Response: Thank you for your recommendation. We have compared his scientific work with our results based on their statistical analysis of mesospheric inversion amplitudes and thickness, as presented in lines (250-256), as follows:
   "In the earlier investigation, from the Indian sector, Sivakandan et al. (2014) reported amplitudes in the range of (14–39 K) during 2002 and (15–42 K) in 2008, whereas their thickness was in the range of (2.7–7.5) during 2002 and (2.8–7.3) in 2008 to characterize the mesospheric inversion variability under the influence of solar flux, which agrees well with the present investigation. This comparison reveals that there is no significant variation in characterizing the mesosphere inversion based on amplitude and thickness over the low-latitude region in the altitude range of 60 to 90 km."

7. Line 218 …that the inversion temperature is in the range of…It is not an inversion temperature range only a temperature range.
   Response: Thank you for your comment. I accepted and the sentence from lines 295-296 has been modified as follows:
   "It is noted that the observed temperature is in the range of ~170-220 K with less detectable variability."

8. Line 242 onwards, the longitudinal information is suddenly introduced here, it should be introduced in section 2.
   Response: Thank you for your comment. It has now been corrected by incorporating the longitudinal information into line 82: "(33-480E) longitude regions'."

9. Lines 245-247, these lines are not clear. Please see the major comment 3.
   Response: Thank you for your comment and recommendation. The sentence in lines 337-340 has been rewritten for clarity, as follows:
   "Before deriving the waves' potential energy from the perturbed temperature ($T_P$), a one-hour interval cut-off-frequency of low-pass band filter is applied on a perturbed temperature ($T_P$) during the period 2005-2020 at selected heights of 90, 85, 75, and 70 km, as depicted in Figure 9 (a, b, c, and d)."

10. Figure 5b, a typo 'thickness' References suggested to read and compare with the present results and include in the discussion part (some of the articles are cited here but those results are not utilized to improve the discussion part):
    Response: Thank you for your comment and recommendation. We have corrected the typo error and included some of the references you mentioned below, based on their relevance

1. Gan, Q., S. D. Zhang, and F. Yi (2012), TIMED/SABER observations of lower mesospheric inversion layers at low and middle latitudes, *J. Geophys. Res.*, 117, D07109, doi:10.1029/2012JD017455.
2. Meriwether, J. W., and C. S. Gardner (2000), A review of the mesosphere inversion layer phenomenon, *J. Geophys. Res.*, 105(D10), 12405–12416, doi:10.1029/2000JD900163.
3. Sivakandan, M., Kapasi, D., and Taori, A.: The occurrence altitudes of middle atmospheric temperature inversions and mesopause over low-latitude Indian sector, Ann. Geophys., 32, 967–974,https://doi.org/10.5194/angeo-32-967-2014,2014.
4. Ramesh, K., S. Sridharan, and S. Vijaya Bhaskara Rao (2014), Causative mechanisms for the occurrence of a triple-layered mesospheric inversion event over low latitudes, *J. Geophys. Res. Space Physics*, 119, 3930–3943, doi:10.1002/2013JA019750.

## RC3

The manuscript presents an investigation of the likely effects of atmospheric gravity waves on Mesospheric Inversion Layers (MILs) in equatorial latitudes. Indeed, the topic is interesting and not explored very well by the communities. Additionally, it is within the scope of Annales Geophysicae because it is an experimental investigation of the mesosphere using satellite measurements. Before I consider the paper suitable for publication, some concerns could be explored and revised by the authors to improve the quality of the manuscript. In general, the observations present in all figures were not explained or explored very well. Consequently, I missed consistent interpretations of the present results.

1. For example, Figure 1 shows the variability of the temperature in the mesosphere and lower thermosphere (MLT), what is the objective of it? Is it possible to see MILs, where? If not, why is it not possible to see? In summary, how can Figure 1 help the authors?

   Response: Thank you. Figure 1 represents the SABER observed temperature variability of the MLT region before separating the inversion (MIL). It is intended to illustrate the patterns of the MLT inversion temperature in the altitude range of 75–90 km as well as show the SABER observed temperature variability. However, the inversions are not visibly shown.

2. Figure 2 shows upper (left) and lower (right) MILs, to be sincere, I did not understand the bottom panels. May the authors explain them better? I also suggest enlarging captions and the size of the panels.

   Response: Thank you. The upper horizontal panels of Figures 3(a) and (c) represent the (upper and lower) SABER observed MLT temperatures before segregating the inversions, while the lower horizontal panels of Figures 3(b) and (d) represent the (upper and lower) inversions of the MLT temperature variability respectively. The figure has now been enlarged.

3. Figure 3: what is the bin size and which criteria were used to determine the percentage of occurrence of MILs?

Response: Thank you. We don't binned the observed data. The occurrence rates (percentages) for lower and upper inversions are estimated by counting the number of inversion days for each month from 2005 to 2020, as described in lines (121-125).

"The frequency occurrence rate (%) of mesospheric inversion layers (MILs) is derived during the period 2005–2020 in the upper and lower MLT regions. The occurrence rate of the frequency (percentage) is estimated based on dividing the monthly inversion days for each month (dates of a month) of 16-year (2005–2020) observation data."

4. Figure 4: Are the red curves indicating a Gaussian fit? If yes, please, explain it in the text. Please, note that the statistic used for panel (c) does not represent the data, in this case, the authors could use another statistic or explain what is causing the discrepancies.

Response: Thank you. The red curve fitting is the Gaussian fit distribution, which is a probability distribution that is symmetric about the mean, showing that data near the mean are more frequent in occurrence than data far from the mean, as mentioned in lines 220-224.

"The frequency occurrence of amplitude, thickness, and base height of inversion variability in the form of the histogram along with the best-fit red lines of the Gaussian distribution are presented in Figure 5. The observed distributions coincide with Gaussian curves (best fits), indicating that the number of MILs is distributed over their attributes according to normal laws, implying that the representations are real-valued random variables."

Their statistical values are corrected in Figures 5(c) and 5(f) in the revised manuscripts from lines 238-245 and 248-256 in lines respectively.

"The base height of the upper MIL in Figure 5(c) ranges from ~80 to 90 km, with a peak value of a large number of upper mesospheric inversions occurring at a base height of around 83 km in a lower standard deviation (SD) 2.13. The number of upper inversions all over the period 2005–2020 at a height of 82 km is the highest relative to the rest in the range between 80 and 90 km. Such maximum mean to fit of Gaussian distribution may be the reason for the gravity wave breaking is that it dissipates energy as a causative factor for an inversion, while the wave generated from the lower to the upper atmospheric region as well as the impacts of the solar flux generated from the upper solar system."

"The base height of the lower inversion of Figure 5(f) is in the range of 70 and 80 km, with a peak value of around 74 km, showing a lower standard deviation (SD) of 1.93. In the earlier investigation, from the Indian sector, Sivakandan et al. (2014) reported amplitudes in the range (14–39 K) during 2002 and (15–42 K) in 2008, whereas their thickness was in the range of (2.7–7.5) during 2002 and (2.8–7.3) in 2008 to characterize the mesospheric inversion variability under the influence of solar flux, which agrees well with the present investigation. This comparison reveals that there is no significant variation in characterizing the mesosphere inversion based on amplitude and thickness over the low-latitude region in the altitude range of 60 to 90 km."

5. Figure 5: What is the relevance of these results and how could they be related to gravity waves? I guess the quality of the presentation of this figure could be improved by enlarging the caption and size. Figure 6: Same comments as Figure 5.2.

   Response: Thank you. Before investigating the impacts of gravity waves on the MLT inversions, the spatiotemporal (time vs. latitude) variabilities of an inversion are presented in Figures 6 and 7 to characterize both the upper and lower inversions, which is the reason we described. The figure has now been enlarged for clarity.

6. I recommend the authors use a more complete expression of the potential temperature (Vadas and Fritts, 2005; Vdas, 2007) instead of what was presented in Equation (1). In addition, the discussion of atmospheric stability is very superficial and it does not include a real aspect of the atmosphere that is certainly present in the SABER data. I suggest including an example of the methodology used to calculate the MILs in the real data (section 2). In my opinion, it could help the readers to promptly understand the process.

   Response: Thank you for your valuable suggestion. Based on your recommendation, we have used the references [(Liu, 2011; Vadas and Fritts, 2005); (e.g. Gan et al., 2012 and Sivakandan et al. 2014)] along with equations 1–13 to elaborate on the expressions of the gravity wave potential energy through the potential temperature ($\theta$) instead of using a single equation, as well as calculating the Brunt-Vaisala frequency, $N^2$, to characterize atmospheric stability/instability in lines (126-154).

"The inversion of the mesosphere temperatures is related to the instabilities. Hence, we are going to derive the hourly atmospheric gravity waves via the Brunt-Vaisala frequency ($N^2$). Whereas another important concept to estimate the Brunt-Vaisala frequency is the potential temperature ($\theta$), which stands for the air parcel's temperature when it is displaced adiabatically to a standard pressure level, $p_0$, from the current pressure level, p, the first law of thermodynamics:

$$\frac{dT}{T} = \frac{R}{c_p}\frac{dp}{p} \Rightarrow \quad \int_T^0 \frac{dT}{T} = \int_p^{p_0} \frac{R}{c_p}\frac{dp}{p} \qquad (1) \text{ it yields}$$

$$\theta = T\left(\frac{p_0}{p}\right)^{R/c_p} \qquad (2)$$

Therefore, the motion of the vertical atmospheric air parcel can be described by (Liu, 2011; Vadas and Fritts, 2005) as follows in equation (2.3) to calculate the Brunt-Vaisala frequency of the parcel due to the Buoyant and gravitational forces acting on the parcel:

$$\frac{d^2s}{dt^2} = -g\,\frac{\rho-\rho_0}{\rho}\ sina \qquad (3)$$

Based on the hydrostatic equation, $\rho = \rho_0$, and $p = p_0 \Rightarrow \frac{\partial p}{\partial z} = \frac{\partial p_0}{\partial z} = -g\rho_0$ (4) and the ideal gas law, $\rho = p/RT = p_0/RT$ gives the parcels motion of an equation:

$$\frac{d^2s}{dt^2} = -\frac{g}{\rho}\left(\frac{d\rho}{dp}\frac{\partial p_0}{\partial z} - \frac{\partial \rho_0}{\partial z}\right)z \qquad (5)$$

Following the same approach using the hydrostatic equation (4) and adiabatic equation (6)

$$dln\rho = \frac{dlnp}{\gamma}, \gamma = c_p/c_v \qquad (6) \text{ yields}$$

$$\frac{d^2s}{dt^2} = -\frac{g}{\rho}\left(\frac{\rho}{\gamma p_0}\frac{\partial p_0}{\partial z} - \frac{\partial \rho_0}{\partial z}\right)z = g\left(\frac{\partial ln\rho_0}{\partial z} - \frac{1}{\gamma}\frac{\partial lnp_0}{\partial z}\right)z \qquad (7)$$

For the ideal gas law of p = ρ$RT$, the natural logarithm is taken for altitude, z on both sides, yielding

$$\frac{\partial ln\rho}{\partial z} = \frac{\partial lnp}{\partial z} - \frac{\partial lnT}{\partial z} \qquad (8)$$

Then after, the potential temperature ($\theta$) of the parcel is calculated as follows based on the equation (2):

$$\frac{\partial ln\theta}{\partial z} = \frac{\partial lnT}{\partial z} - \frac{R}{c_p}\frac{\partial lnp}{\partial z} = \frac{1}{T}\left(\frac{\partial T}{\partial z} + \frac{g}{c_p}\right) = \left(1 - \frac{R}{c_p}\right)\frac{\partial lnp}{\partial z} - \frac{\partial ln\rho}{\partial z} \qquad (9) \text{ to derive the}$$

Parcels acceleration based on equations (7) to become:

$$\frac{d^2s}{dt^2} = -\,g\,\frac{\partial ln\theta_0}{\partial z}z\ sina = -\,g\,\frac{\partial ln\theta_0}{\partial z}ds.sin^2a \qquad (10)$$

Whereas by introducing the frequency, N, with $N^2 = g \frac{\partial ln\theta_0}{\partial z}$

The Brunt-Vaisala frequency, $N^2$ is calculated based on the following mathematical formulation used to characterize atmospheric stability.

$$N^2(z) = \frac{g(z)}{T_0(z)}\left(\frac{\partial T_0(z)}{\partial z} + \Gamma_d\right) \quad (11)$$

Further, the methodology (technique) for segregating (separating) the MIL is presented in Section 2.2 with Figure 2 for more clarification for readers as follows in lines 110-121.

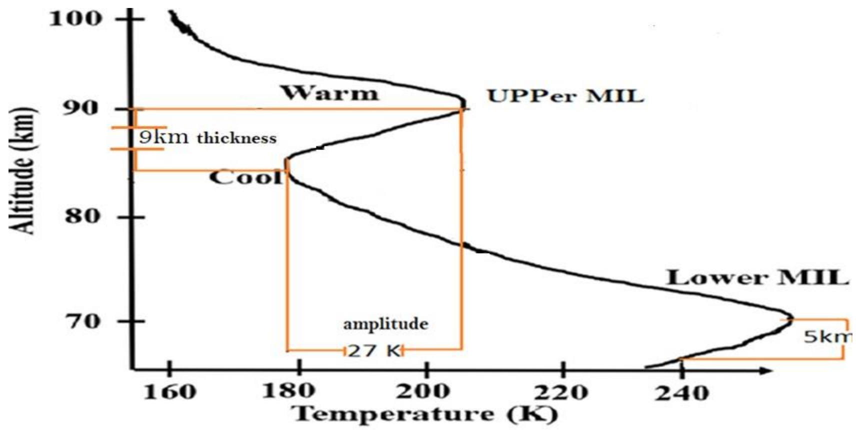


Figure 2. Schematic of upper and lower mesospheric inversion layers shown in the temperature profile for the MLT regions (Adapted from Meriwether and Gerrard, 2004).

7. Section 3.4: The authors wrote that they used a low pass filter to exclude the effects of tidal and planetary waves in the residual signal. If I understood the process, I guess they could use high-frequency filters to maintain low periods. Indeed, the blue lines in Figure 9 show a smoothed signal that excludes short-time variations.

   Response: Thank you. We utilized a 1-hour interval cut-off frequency for a low-pass band filter. Figure 9 demonstrates how this filter smooths data signals by eliminating peaks while also employing 1-hour interval perturbed temperature data profiles to exclude variations exceeding 1 hour in duration. The discussion section about the results shown in Figures 11 and 12 has undergone substantial revision.

If I am correct, Figures 10 and 11 could be revised and the interpretations as well.

Response: Thank you I am rewriting all the discussion parts of the figures (11 &12) to improve the way of presentation as follows in lines 359-391.

“In this investigation, the maximum gravity wave potential energies were observed in the range of around ~70–90 J/kg over the longitudinal regions of 45-47$^0$ E, 43$^0$ E, and 44$^0$ E during 2011, 2017, and 2019 (Figure 11(a)) for upper mesosphere inversions at 90 km, whereas the potential energy of gravity waves around ~10–60 J/kg is presented all over the longitudinal region from 33-48$^0$ E. While the maximum potential energy ~(70-100 J/kg) is observed as shown in Figure 11(b) over the longitudinal (340, 440, and 460) regions during 2014, 2016, and 2018 at 85 km. The minimum potential energy of gravity wave between 20 and 70 J/kg appears over the longitude (33-48) regions. However, Figures 11 (c and d) show the lower MLT regions of gravity wave potential energy at 75 and 70 km, respectively. At a height of 75 km allocated in Figure 11(c) is a relative maximum potential energy appeared in the range of 40-50 J/kg over the longitudinal (46$^0$, 42$^0$, 40$^0$, 37$^0$, 36$^0$, and 38$^0$) region during 2011, 2012, 2017, 2013–2015, 2018, and 2020. Similarly, Figure 11(d) depicts the gravity wave potential energy in the range of 2–30 J/kg for the lower MLT region at 70 km over the longitudinal region (33-48$^0$). Out of which, the maximum potential energy of 25-30 J/kg is found in a certain longitude region over a while. Many of possible mechanisms have been suggested for the cause of lower inversions; nonlinear interactions between GWs and tides (Liu and Hagan, 1998), and chemical heating (Meriwether and Mlynczak, 1995) including GW breaking (Hauchecorne et al., 1987). The role of gravity wave propagation and dissipation has been accepted as the dominant wave forcing in the MLT region (Lindzen, 1981; Holton, 1983), which affects the middle and upper atmospheric inversion. It is also understood that tides, planetary waves, and chemical processes are affects the middle atmospheric variability as well as gravity waves (Sivakandan et al., 2014). However, gravity waves are multi-scale in nature; small-scale waves may contribute predominantly to instability, and turbulence in the MLT dynamic region (Liu and Meriwether, 2004; Szewczyk et al., 2013).

Hence, investigating MIL phenomena is important for the understanding of MLT atmosphere dynamics for two primary reasons: stability and energy transfer. As a result, an attempt has been made to examine the contributions of gravity waves to the MLT region's instability (MIL phenomenon) based on the Brunt-Vaisala frequency. The spatiotemporal variability of Vaisala frequency is displayed in the contour Figure 12(a and b) for the upper mesosphere region (90 and 85 km) and Figure 12(c and d) for the lower mesosphere region (75 and 70 km). Based on the Brunt-Vaisala frequency, N2, the upper MLT region is unstable (~0.027) at 90 km and (~0.029) at 85 km maximum relative to the lower inversion instability at 75 km (~0.033) and 70 km (~0.035).

Hauchecorne et al., (1987) described a model in which a succession of breaking GWs would generate the MIL through the gradual accumulation of heat as a cause of instability. ”

7. Lines 279-282: "The result concludes that the observation of high potential energy in the upper mesosphere region is due to the deposition of high energy and momentum at the background temperature by gravity wave breaking, which could influence the dynamics of the inversion phenomenon". Lines 291-293: "This result leads us to the conclusion that a high amount of gravity wave potential energy is a consequence of the high instability of the upper inversion relative to the lower." I guess, it is possible to reach these conclusions from the present work. Conclusions: I think it will be better to change the name of the section to Summary and exclude the last two ones that are very general.

Response: Thank you. The sentences have been removed from the sections that you mentioned in lines 279-282 and 291-293, and they are now included in the summary section. The subtitle for Section 4, Conclusion, has been modified to Summary.

“4. **Summary**

In this article, 16 years of SABER mesosphere temperature profiles are utilized to investigate the MIL phenomenon and its causative mechanism through gravity wave potential energy ($P_E$) and instability criteria of Bruent-Vaisala frequency ($N^2$) over low latitude bands. The observational conclusions from this chapter are drawn as follows:

- ✓ The occurrence rate of the upper mesosphere inversion frequency is maximum relative to the mean occurrence rate of the lower mesosphere inversions.
- ✓ Based on the analysis of frequency of occurrence on mesospheric inversion layer (MIL) characteristic features, it is revealed that the most probable value for upper inversion amplitude is 38 k, inversion layer thickness is 5.5 km, and the base height is 78 km. Whereas the lower inversion amplitude is 25 K, the inversion layer thickness is 3.8 km, and a base height of 73 km.
- ✓ The gravity wave indicator potential energy depicts high energy at the upper mesosphere region compared to the lower mesosphere region.
- ✓ The result concludes that the observation of high potential energy in the upper mesosphere region is due to the deposition of high energy and momentum at the background temperature by gravity wave breaking, which could influence the dynamics of the inversion phenomenon

- ✓ The stability criteria at the mesosphere region are indicated by Brunt-Vaisala frequency ($N^2$), which shows low values at the upper mesosphere region relative to the lower mesosphere region, leading to the conclusion that the high potential energy at the upper mesosphere region is due to the instability over that region, which gives rise to large inversion phenomena.

In general, we concluded that the processes in the atmosphere vary from region to region. As a result, the atmospheric state varies significantly with altitude as well as from place to place and time to time."

Whereas the following references you mentioned have been included in the updated manuscript.

**Reference**


1. Garcia-Comas, M., Lopez-Puertas, M., Marshall, B. T., Wintersteiner, P. P., Funke, B., Bermejo-Pantaleon, D., Mertens, C. J., Remsberg, E. E., Gordley, L. L., Mlynczak, M. G., and Russell III, J. M.: Errors in Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) kinetic temperature caused by non-local-thermodynamic-equilibrium model parameters, J. Geophys. Res., 113, D24106, doi:10.1029/2008JD010105, 2008.
2. Meriwether, J. W., and Gerrard, A. J.: Mesosphere inversion layers and stratosphere temperature enhancements, Rev. Geophys., 42, RG3003, http//doi:10.1029/2003RG000133, 2004.