

Referee #02 Comments

This study examines mesospheric wave front events observed using an all-sky camera in Brazil. A notable advantage of the dataset utilized in this research is its integration with height-resolved temperature and wind measurements obtained from a sodium LIDAR and a meteor radar, respectively. The duct structure has been assessed by estimating the square of the vertical wavenumber (m^2), and the occurrence of the bright/dark front has been discussed in relation to the relative location of the optical emission layer to the duct structure. However, it is important to note that the conclusions regarding the appearance of the bright/dark front are based on assumptions about the emission altitudes. While Section 4 presents some general topics related to the wave front, the article does not include a section dedicated to discussing causality in producing measurements. It would be beneficial to address these two aspects for publication. Additionally, there are several minor comments that could be considered.

Major comments

1. This study considers emission altitudes for the three optical wavelengths as 87, 94, and 97 km for OH, O₂, and 557.7 nm, respectively. Under this assumption, this study explains that the emission intensity at the wave front may decrease or increase depending on whether the emission altitude is above or below the duct structure. Based on this concept, the study seeks to understand the optical camera measurements from the four analysed events. While measurements such as sodium LIDAR temperature and MTR wind velocity are utilized to infer the duct structure, it is important to note that the emission altitude is hypothetical. In other words, one of the crucial pieces of information for drawing the conclusions of this study relies on the hypothesis. This could be considered a less robust foundation for the physical explanation. If there is a significant error in the hypothesis, it might fundamentally affect the results of this study. The authors should consider this point, and I would recommend revising the text in light of these comments.

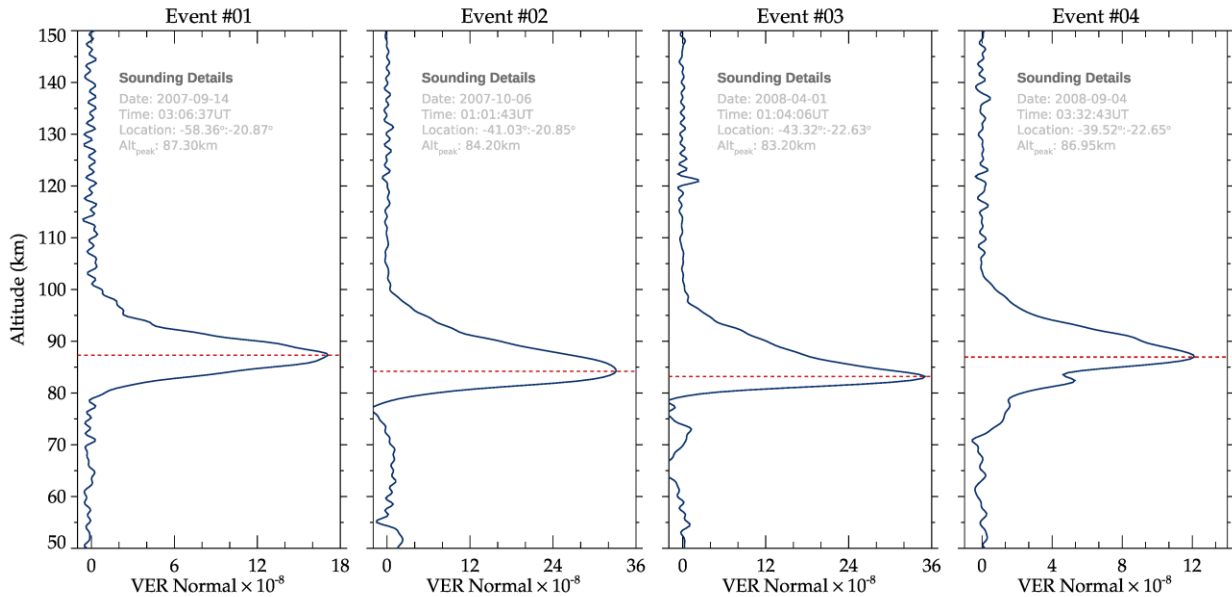
Response:

Thanks for the comment. At the beginning of the work, this aspect of the true peak altitude of the emission layer was considered. For this reason, the SABER observation was included to determine the height of the OH emission layer. Based on your comments and the referee #01, the entire manuscripts have been modified to include all this consideration and concerns.

- 1.1 Please address the following issues in a new "Discussion" section following Section 3.

Response:

Thank you very much, the above-mentioned concerns have been addressed in the discussion as mentioned. Based on your suggestion, a section is added at the beginning of the discussion to elaborate on the peak OH altitudes in relation to ducts and the respective dynamics.



1.2 In the section established in 1-1, it would be greatly appreciated if multiple references could be included to substantiate the assumption regarding the emission altitudes. To ensure a comprehensive perspective, it might be beneficial to reference as many sources as possible, thereby avoiding the impression of selectively citing literature that aligns conveniently with this study. It is important to consider that merely citing studies that assume the same emission altitude as this study does may not provide sufficient support for this study, as those studies only make similar assumptions. Valuable information can be derived from emission altitudes based on observations or simulations grounded in physical or chemical principles.

Response:

We appreciate your suggestion. Due to your suggestion, more references have been included to support the subject.

(Added to the Methodology section) The nominal peak heights of airglow emissions are approximate altitudes of vertically extended layers rather than fixed emission surfaces. In this study, representative peak altitudes of about 87 km for OH, 94 km for O₂, and 97 km for OI 557.7 nm are adopted, consistent with previous observational, modelling, and airglow-imaging studies. The OH Meinel emission layer is commonly reported to peak near 87 km with a finite vertical thickness of about 8 km (Baker & Stair, 1988; Zhu et al., 2020). The O₂ atmospheric band is generally located above the OH layer, near about 94 km, while the OI 557.7 nm green-line emission is commonly placed near 95–97 km in the upper mesosphere/lower thermosphere region (Saunkin et al., 2021; Takahashi et al.,

2013). These representative heights are also consistent with mesospheric bore and ducting studies, where the relative position of the OH, O₂, and OI 557.7 nm layers with respect to ducting regions is used to interpret bright and dark airglow responses through the complementary-effect framework (Fechine et al., 2009; Snively et al., 2010).

- 1.3 The emission altitudes proposed in various references may differ. It would be helpful to discuss in the newly created section (1-1) how this variability might affect the conclusions of this study.

Response: We thank the reviewer for this important observation. We agree that the emission altitudes reported in the literature may differ because airglow layers are vertically extended and their peak heights can vary with local time, season, latitude, atmospheric chemistry, temperature structure, tides, gravity waves, and bore-related perturbations. To reduce the uncertainty associated with the OH altitude assumption, we examined TIMED/SABER OH volume emission rate profiles close to the event times. The retrieved OH peak altitudes were approximately 87.30 km, 84.20 km, 83.20 km, and 86.95 km for Events 1 to 4, respectively. These results show that the OH layer remained within the expected mesopause region but varied by several kilometres between events.

- 1.4 In the newly created section (1.1), it would be beneficial to examine whether the emission altitude could fluctuate due to the special events or wave fronts, and if so, to what extent, and what impact this might have on the conclusions of this study.

Response: Well noted. The retrieved OH peak altitudes varied from approximately 83.20 km to 87.30 km across the four events, indicating an event-to-event variation of about 4 km. This confirms that the OH emission layer remained within the expected mesopause region but was not fixed at a single altitude. The possible fluctuation in emission altitude may affect the detailed interpretation of the complementary effect, especially when the emission layer is close to the duct boundary or when the duct is narrow. In such cases, a vertical displacement of a few kilometres could change whether the layer is interpreted as being below, within, or above the duct.

2. Could the authors explain the mechanism by which the emission intensity at the wave front varies with the relative height of the duct and the altitude of the airglow emission? Specifically, it would be helpful to understand why the same wave structure is observed in

camera images of the emission layer measured outside the duct, considering the concept that atmospheric waves propagate through the duct, meaning they propagate horizontally while reflecting off the upper and lower planes of the duct.

Response: Thanks for the suggestion.

The variation of the intensity at the relative to the depths of the duct is primarily due to the uniformity of the emission layer. The airglow emission varies based on the O and H constituents, temperature, energy, wind, time etc. Thus, if there exist no uniformity in the intensity within the emission due to this factor, the emission intensity at the wave front will be affected.

3. It is important to note that the sodium LIDAR and MTR used to estimate duct altitude differ significantly in temporal resolution and field of view. The former is considered to capture smaller scale phenomena both temporally and spatially compared to the latter. Additionally, the temporal and spatial measurement scales of each instrument are likely to differ relative to those of the atmospheric waves under study. When comparing the altitude profiles of temperature and wind velocity (e.g., Figures 2a and 2c), finer fluctuations are more distinctly visible in the temperature profile or the LIDAR measurement. This may be attributed to differences in measurement methods. Such differences may also impact the m^2 altitude profile (e.g., Figures 2e and 2f), potentially leading to an underestimation of the m^2 wind term. I would be grateful if you could discuss these points comprehensively in the new section established in 1-1.

Response: We appreciate your suggestion

It is true that the temporal resolution of the Lidar and the meteor radar are different from the observed phenomena (which is of smaller). This was well noted and considered. However, since the focus is to understand the background state of the atmosphere support the formation of ducts or not. From the hourly analysis requested by Referee 1, we could ascertain that the background condition indeed supported the possible formation of the ducts observed in the four events considered. Also, in the computation process of the m^2 the Lidar data was hourly binned to attain similar temporal resolution. Furthermore, an interpolation in altitude was also applied. All these were done in other to achieve the same resolution data in space and time.

Minor comments

1. **Line 76:** Include the optical wavelength for O2.

Response: Well noted. Correction has been made.

2. **Line 78:** What is the sequence for measuring the three optical wavelengths?

Response: OH, O₂ and OI557.7nm

3. **Line 79:** It would be preferable to write “670 x 650” to maintain consistency with the order of 1340 x 1300 in L74.

Response: The adjustment was explained in the write up

4. **Line 103:** Does “the wind” refer to “the wind effect”?

Response: Yes, Correction has been made.

5. **Line 107-109:** Please explain the rationale behind classifying the information obtained from these three optical wavelengths.

Response: The use of OH, O₂, and OI 557.7 nm emissions enables altitude-resolved observations of mesospheric dynamics, as each emission originates from a distinct layer (~87 km, ~94 km, and ~97 km, respectively). This multi-wavelength approach provides a quasi-vertical profile of wave-induced perturbations, allowing identification of ducting conditions, vertical phase relationships, and the complementary effect. Consequently, it enhances the reliability of mesospheric front classification and improves interpretation of airglow intensity variations.

6. **Line 124:** Besides “signal-to-noise ratio,” what constitutes “image quality”? Please specify in the text.

Response: Due to limitations in image quality including cloud contamination, background light interference (e.g., moonlight), instrumental artifacts, and reduced contrast in some frames in addition to signal-to-noise ratio only the OH emission band was used for quantitative spectral analysis.

7. **Line 138:** Event 4 > Event 3

Response: Well noted. Correction has been made.

8. **Line 138:** Event 3 is the longest observed event, lasting over an hour, while the other events are brief (20, 43, and 14 minutes). Could this discrepancy introduce bias in period identification?

Response: Although Event 3 spans a longer observation interval of approximately 71 min, the shorter durations of the other events (20, 43, and 14 min) do not introduce a

systematic bias in period identification. Period estimation in this study is based on tracking coherent wave crests in OH airglow images.

As shown in Table 1, the ratio of observation duration to wave period indicates that all events include at least one full wave cycle: Event 1 (~1.35 cycles), Event 2 (~4 cycles), Event 3 (~1.9 cycles), and Event 4 (~1.5 cycles). This satisfies the minimum requirement for reliable period estimation from image sequences. While longer-duration observations (e.g., Event 3) provide more robust estimates due to multiple sampled cycles, the shorter events still contain sufficiently resolved and coherent wave structures to allow confident determination of their periods. Therefore, the variation in event duration does not introduce significant bias.

9. Table 1: Are the dates based on the evening when the optical measurement began, or when the event was detected? Special attention is needed for the presentation of Event 1.

Response: The dates were based on when the event were observed

10. **Line 150:** The time zone listed as Local Time in Table 1 is inconsistent. Please verify. Similar comments apply to other events.

Response: For the table, the time used corresponds to when the spectral airglow imaging analysis was performed. This differs from the total observation time across the field of view of the ASI.

11. **Line 151:** from northwest to southeast (NW-SE) > southeastward

Response: Well noted. Correction has been made.

12. **Figure 3:** Since it mentions "Mid-plane," the horizontal axis of the graph likely represents horizontal distance rather than time. Is this interpretation correct? In any case, please specify what the horizontal axis represents on the graph.

Response: Well noted. Correction has been made.

13. **Figure 3:** Does the emission altitude not oscillate vertically due to the ducted wave?

Response: Yes, the airglow emission layers (OH, O₂, and OI) undergo vertical oscillations in response to the ducted wave. These oscillations arise from vertical parcel displacements associated with the bore, leading to compression and rarefaction of the emitting layers. However, Figure 3 is intended as a schematic representation of the duct structure and the resulting complementary emission effect, rather than a literal depiction of the time-dependent vertical motion of the emission layers. For clarity, the emission altitudes are shown as fixed reference levels, while the bright and dark regions indicate the net intensity response to these oscillations.

14. **Line 200:** from northwest to southeast > southeastward

Response: Well noted. Correction has been made.

15. **Line 222-223:** “Moreover, the narrow width ... gravity wave propagation.” Could you explain the reasoning behind this statement in the text?

Response: The narrow width of this duct (~2.0 km) is likely insufficient to support efficient gravity wave trapping, this is because ducted propagation requires that the duct thickness be comparable to the vertical wavelength of the wave to allow constructive reflection between its duct boundaries. When the duct is too thin, wave energy is not effectively confined and instead leaks vertically, inhibiting the formation and maintenance of mesospheric bores.

16. **Line 242:** from northwest to southeast > southeastward

Response: Well noted. Correction has been made.

17. **Line 280:** From southwest to northeast > northeastward

Response: Well noted. Correction has been made.

18. **Figure 8:** Event 5 > Event 4

Response: Well noted. Correction has been made.

19. **Line 329-331:** Can you identify any corresponding wave patterns in the O₂ and OI images?

Response: Yes, there are corresponding patterns, but the differences in altitude and duct position cause minor variations in wave appearance between O₂ and O I images.

20. **Line 383-385:** The image data analyzed in this study is not available on this webpage.

Response: The data can be requested from embrace.