

The manuscript by Qinzeng Li and colleagues report observations of Transient Luminous Events (TLEs) above a mesoscale convective system South of the Himalaya allied by observations of atmospheric gravity waves across China. It is convincingly shown that dynamic and electrical coupling were both caused by the mesoscale convective system, albeit perhaps by different parts of it. The manuscript is well written, and the figures are informative and support the text, but the structure of the manuscript has room for improvement. The vertical electrical coupling by the same storm was described in a previous publication which is only referenced on 1195. As a result, this manuscript should use the introduction to clearly describe the previous findings and how this manuscript expands on those. Similarly, the added value of the joint analyses of TLE's and gravity waves should be explained with a clear plan for the study at the end of the introduction. At present, it appears that both vertical coupling phenomena are coincidental, rather than physically related to each other. That would be fine, if it is clearly stated, but not stating it potentially results in rising expectations that are not satisfied by the manuscript. Section 2 describes instrumentation and models as part of the methodology used for the investigation rather than observations as its title implies. Section 3 starts with a summary of the results prior to describing the analyses that lead to the results. In fact, section 3 is relatively long and would be better separated into two sections, one on results and one section for discussion. The discussion section could describe uncertainties and articulate a critique of the interpretations in light of the scientific literature. Otherwise, the manuscript would benefit from more precise formulations and clarifications in places as described in more detail below.

Thank you for these constructive comments. We agree that the original manuscript did not sufficiently explain how the present study builds on the earlier work, clarify the relationship between the electrical and dynamical responses associated with the storm, or distinguish the datasets and methods from the results and their interpretation.

We have revised the Introduction to summarize Huang et al. (2025), who focused on the TLE outbreak, parent-lightning identification, and the associated vertical electrical coupling. We now distinguish their work from the focus of the present study, which investigates the gravity-wave response to the same convective system, including the long-distance propagation of CGWs and their dynamical coupling across atmospheric layers. We have also clarified the added value of considering the TLE and gravity-wave observations together: they provide complementary evidence of electrical and dynamical responses associated with the same convective system, potentially arising from different parts of the storm. We treat the TLEs and CGWs as distinct responses and do not infer a direct causal link between them.

At the end of the Introduction, we now identify the coordinated observations used in this study and state its main objectives: characterizing long-distance CGW propagation in the mesosphere and lower thermosphere, examining the generation mechanism of thermospheric CGWs, and assessing how thermospheric background winds affect their observability.

We have retitled Section 2 as “Data and Methods” to reflect its description of the observational instruments, data products, and models used in this study. We have also reorganized the former Section 3 into separate “3. Results” and “4. Discussion” sections. The Results section now presents the analyses and findings in a logical sequence, introducing the evidence before summarizing the corresponding results. The Discussion section interprets the observations in light of relevant previous studies and addresses uncertainties and alternative explanations. We believe these revisions make the manuscript’s structure and the scope of the study clearer.

l3,20,65,68,167,252,287,482: Better to use one single description of the investigated region, rather changing the wording multiple times throughout the manuscript.

Reply:

Thank you for this helpful suggestion. We have standardized the regional description throughout the manuscript. The title uses “south of the Himalayas” specifically to indicate the location of the convective system, whereas the broader study region is consistently referred to in the text as the “northern Bay of Bengal–Himalayan foothill region.” These terms therefore describe the source location and the broader study region, respectively.

•l24: According to l20 and Fig. 2, the thunderstorms occur over Bangladesh, north-east India, Bhutan and Myanmar, not China. Reword accordingly.

Reply:

Thank you for pointing this out. We have reworded the sentence about the sprite outbreak to make clear that it was detected from China, not that the storm occurred there: “This event represented the first large-scale detection from China of a massive red sprite outbreak.”

•l35: Clarify what is meant by ‘their asymmetric occurrence’. No asymmetry was mentioned before.

Reply:

Thank you for noting this ambiguity. We have clarified that “asymmetric occurrence” refers to the thermospheric CGWs being detected at Shuozhou but not at Korla. To make the abstract more concise, we have replaced the phrase with “the asymmetric detectability of thermospheric CGWs,” and describe the station-to-station difference in the main text. We also state that Doppler-induced dissipation by thermospheric background winds is a possible explanation for this difference.

•l38: State whether the two vertical coupling mechanisms are thought to be coincidental, or physically related to each other.

Reply:

Thank you for raising this point. We have clarified that the two coupling processes are related through their common convective source, rather than being regarded as entirely unrelated coincidences. However, TLEs and CGWs represent distinct electrical and dynamical responses, potentially associated with different parts of the MCS. The available observations do not establish a direct causal link between the two processes, and we have stated this explicitly in the revised manuscript.

•141: Is overshooting necessary to produce gravity waves? Perhaps better to say ‘... and vertical convective motion can generate...’

Reply:

Thank you for this suggestion. We agree that overshooting convection is not required for gravity-wave generation. We have revised the sentence to read: “Dynamically, latent heat release and vertical convective motions can generate atmospheric gravity waves (AGWs)...”

• 170: State the geographic coordinates of the optical TLE observations.

Reply:

Thank you for the suggestion. The red-sprite observation site was already indicated by the red square in Fig. 1. To make its location more explicit, we have now added its geographic coordinates (28.63°N, 90.44°E) to the revised manuscript.

• 188: Explain that these stations are remotely located from the source.

Reply:

Thank you for this suggestion. We have revised the description of Figure 1 to clarify that the airglow stations are located at substantial distances from the convective source region, with Xinglong approximately 3,000 km away.

• 1103: State the locations of the three cameras.

Reply:

Thank you for this suggestion. We have revised the manuscript to specify that the three Sony Alpha 7R III cameras were co-located at 28.63°N, 90.44°E.

• 1110: Explain the meaning of green, blue and black circles.

Reply:

Thank you for this comment. We have revised the caption of Figure 1 to clarify that the green, black, and blue circles indicate the effective observation ranges of the OH, OI 630.0 nm, and OI 557.7 nm imagers, respectively. The 557.7 nm imager was operated only at Lhasa. The observation ranges are shown for a 164° field of view.

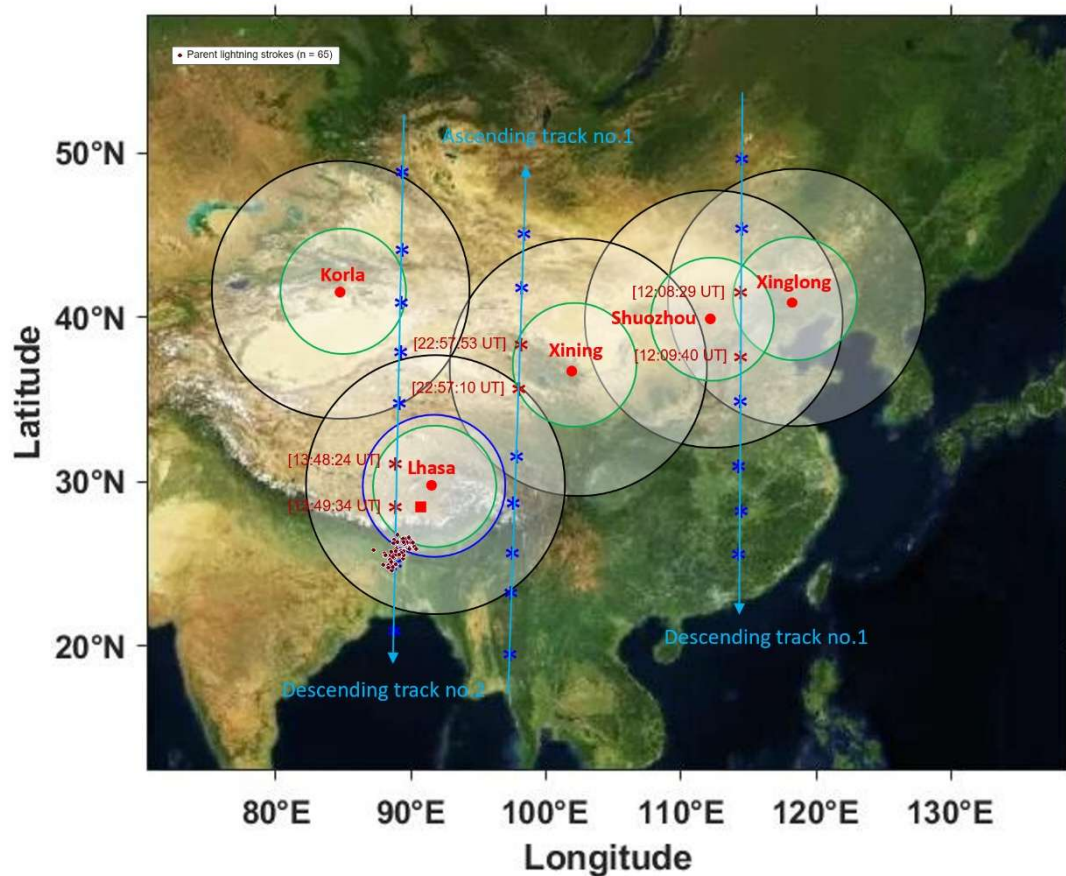


Figure 1 Map showing the geographic location of the airglow imagers station in Lhasa, Xining, Shuozhou, Xinglong, and Korla (red dots) and red-sprite observation site documented by amateur photographers (red square). Colored circles mark the effective observation ranges of the airglow imagers for a 164° field of view: OH (green), OI 630.0 nm (black), and OI 557.7 nm (blue; Lhasa only). The red asterisks denote the TIMED/SABER descending track footprints passing over Lhasa on 19 May 2022.

• 1110: It would be helpful to add the TLE locations to characterise the convective storm.

Reply:

Thank you for the suggestion. We have added the locations of the confirmed TLE-producing lightning strokes to the figure to better illustrate their spatial relationship with the convective storm.

• 1122: Briefly explain how the temperatures are derived from the measurements.

Reply:

Thank you for this suggestion. We have added a brief explanation that AIRS radiances in the 4.3 μm CO_2 band are converted to brightness temperatures using the inverse Planck function, and that the gravity-wave signatures are identified from perturbations relative to the background field.

- 1130: State the meaning of the acronym ‘LTE’.

Reply:

Thank you for pointing this out. We have defined LTE as “local thermodynamic equilibrium” at its first occurrence in the manuscript.

- 1141: Explain how the observations of the 12 spectral bands are related to the study.

Reply:

Thank you for this comment. We have replaced the MSG/SEVIRI imagery with FY-4A/AGRI observations, so the description of SEVIRI’s 12 spectral bands is no longer applicable. We have revised Section 2.4 to clarify that AGRI has 14 spectral bands, but this study uses only channel 12 (10.3–11.3 μm). Its brightness temperatures are used to track cold cloud tops and the evolution of deep convection; the other AGRI channels are not analyzed here.

- 1160: Reword this sentence, as lightning activity does not extend into the middle atmosphere.

Reply:

Thank you for pointing this out. We agree that the original wording incorrectly implied that lightning activity extended into the middle atmosphere. We have revised the sentence to distinguish the lightning activity in the parent storm from the TLEs, which indicate electrical coupling between the tropospheric storm and the middle atmosphere.

- 1166: Explain how the brightness temperatures are related to the evolution of the convection.

Reply:

Thank you for this comment. We have clarified that the 10.8 μm brightness temperature serves as a proxy for cloud-top temperature: lower values indicate colder, higher cloud tops associated with deep convection. We also explain that changes in the extent and temperature of the cold cloud shield are used to track the convective system’s evolution.

- 1170: State the time when the MCS was formed.

Reply:

Thank you for this comment. Based on the hourly FY-4A/AGRI 10.8 μm imagery, the convection appeared as separate cells at 10:00 UTC and intensified and began to merge between 11:00 and 12:00 UTC. The system had developed into a more organized MCS by approximately 13:00 UTC. We have clarified this formation time in the revised text.

- 1171: Explain the wording ‘eastward expansion’. Fig. 2 does not indicate preferential directions.

Reply:

Thank you for this comment. We agree that “eastward expansion” implies a preferential direction that is not clearly demonstrated in Fig. 2. We have removed this directional wording and revised the sentence to describe the general expansion of the cold cloud shield.

- 1173: It would be helpful to add the TLE locations to Fig. 2 to substantiate the connection.

Reply:

Thank you for the suggestion. In the revised manuscript, we have replaced the Meteosat/SEVIRI imagery with FY-4A/AGRI imagery, which provides more suitable coverage for monitoring the convective system investigated in this study and the surrounding region. The major intense convective system identified in the FY-4A/AGRI observations is consistent with that previously observed by Meteosat/SEVIRI, supporting the same identification of the primary convective source associated with the observed CGWs. The FY-4A/AGRI observations are further used to characterize the evolution of the parent convective system and to examine other potential convective sources over the broader region.

We have also added the locations of TLE-associated parent lightning strokes to the revised Fig. 2 to better illustrate the spatial relationship between the TLE activity and the convective system. Of the 95 TLE events listed in Supplementary Table S1 of Huang et al. (2025), 65 have reported coordinates for an associated parent lightning stroke, and all 65 have been plotted. The remaining 30 events have no reported coordinates for an associated parent stroke and therefore cannot be reliably mapped. The 65 geolocated parent strokes were assigned to the 14:00, 15:00, and 16:00 UT panels according to the UTC hour of their associated TLE occurrence, resulting in 26, 38, and 1 strokes, respectively. We emphasize that these markers represent the locations of TLE-associated parent lightning strokes rather than directly measured TLE positions, and that they represent events occurring within each one-hour interval rather than strokes simultaneous with the FY-4A/AGRI image at the labeled time. The corresponding descriptions and Fig. 2 have been updated accordingly.

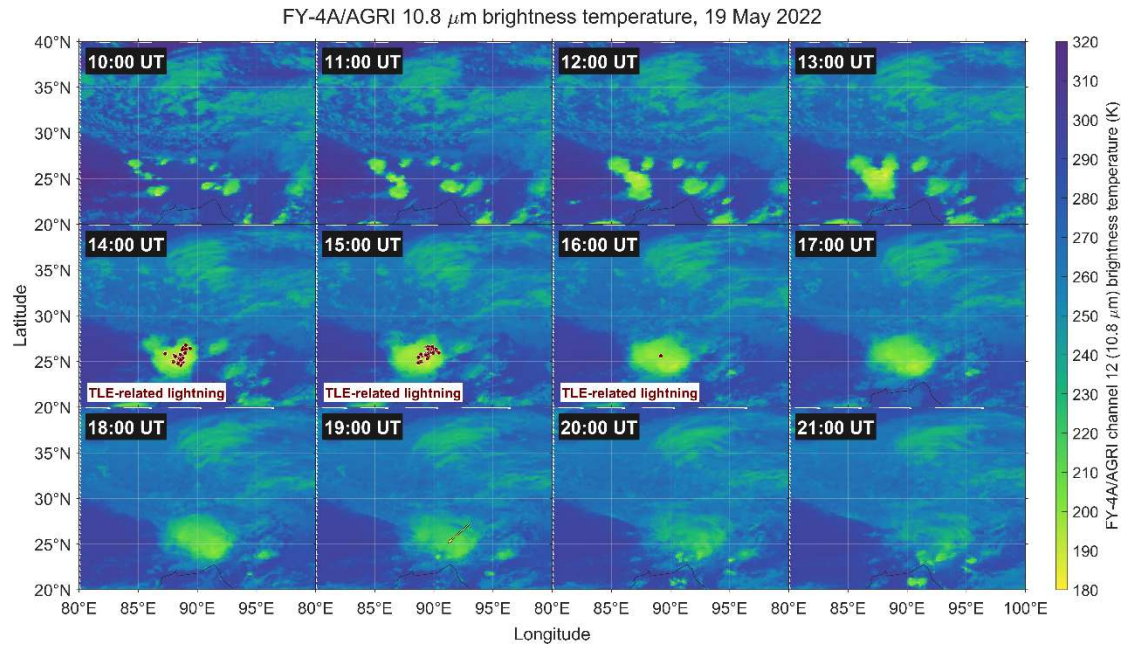


Figure 2 Hourly FY-4A/AGRI 10.8 μm brightness-temperature images from 10:00 to 21:00 UTC on 19 May 2022. Dark-red dots mark the locations of TLE-associated parent lightning strokes reported by Huang et al. (2025), grouped by the UTC hour of the associated TLE. The arrow in the 19:00 UTC panel indicates the center of the main cold-cloud cluster.

- 1178: State the height of the tropopause and its temperature for comparison with the observed brightness temperatures to provide evidence for the quoted penetration into the stratosphere.

Reply:

Thank you for this suggestion. We used ERA5 temperature profiles over the convective source region (23–27°N, 85–90°E) to determine the local WMO lapse-rate tropopause. The tropopause was located at approximately 16.8 km, with a temperature of about 195.4 K. We compared these values with the FY-4A/AGRI 10.8 μm brightness temperatures. At 14:00 UTC, when the convective cloud shield was well developed, the 1st and 5th percentiles of brightness temperature in the source region were 189.8 and 192.3 K, respectively, both below the ERA5 tropopause temperature (approximately 195 K). This comparison is consistent with deep convective overshooting to, and possibly locally above, the tropopause. We have added the ERA5 tropopause height and temperature, together with the brightness-temperature comparison, in Fig. R1 and clarified the relevant discussion. Because infrared brightness temperature does not directly provide cloud-top altitude, we describe the result as evidence consistent with localized penetration into the lower stratosphere rather than as a direct altitude measurement.

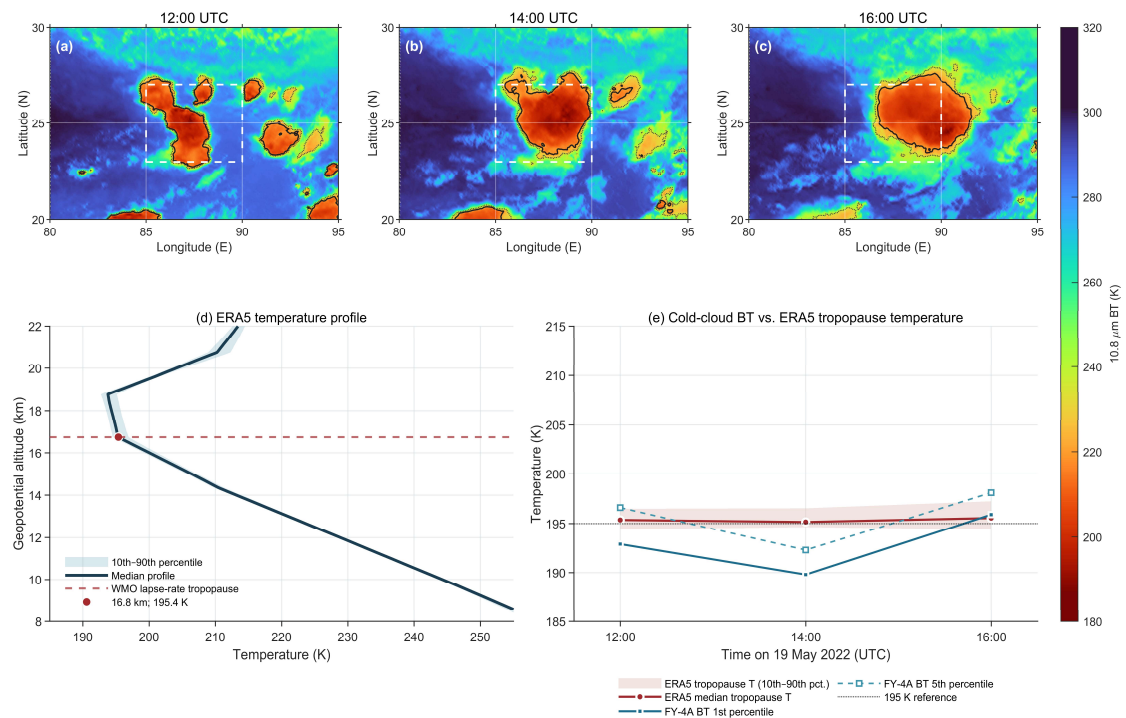


Figure R1 FY-4A/AGRI 10.8 μm brightness temperatures and ERA5 tropopause conditions on 19 May 2022. (a–c) Images at 12:00, 14:00, and 16:00 UTC; dashed boxes mark the source region, and solid/dotted contours mark 220/235 K. (d) ERA5 temperature profile and tropopause (16.8 km, 195.4 K). (e) Regional 1st and 5th percentile brightness temperatures compared with ERA5 tropopause temperatures.

• 1183: Does ‘subsequently’ mean TLEs started after 21UT? Please clarify.

Reply:

Thank you for pointing out this ambiguity. We agree that “subsequently” could be interpreted to mean that the TLE activity began after 21:00 UT, which was not our intention. The TLE outbreak occurred from approximately 13:00 to 16:00 UT, overlapping with the mature phase and early weakening of the MCS. We have revised the text to state this timing explicitly and removed “subsequently.”

• 1190: State the geographic coordinates of the camera.

Reply:

Thank you for this comment. The geographic coordinates of the co-located cameras (28.63°N, 90.44°E) are specified in Section 2.1. For clarity, we have also added the coordinates to the description of the photographs in the Results section.

• 1199: Explain what a ‘secondary gigantic jet’ is, and why its luminosity is not connected to the cloud top. State the integration time of the image with the sprite cluster and explain why this is not considered to be a dancing sprite.

Reply:

Thank you for pointing this out. We agree that our original description was ambiguous. Although secondary gigantic jets were documented during this TLE outbreak, the long-exposure image at 13:16 UT does not by itself provide sufficient temporal information to identify the structures shown in the image as secondary gigantic jets. In particular, no continuous luminous structure connecting the observed TLE structures to the thundercloud top is clearly visible in this photograph. We have therefore revised the text and now describe the features at 13:16 UT more conservatively as complex sprite structures, rather than secondary gigantic jets.

The integration time of each time-lapse photograph was 6 s, and this information has now been added to the manuscript. Because transient events occurring within the 6-s exposure are superimposed in a single image, their temporal evolution cannot be resolved. Therefore, the sprite cluster shown in the photograph cannot be reliably classified as a dancing sprite based on this image alone.

•I202: ‘Electrical activity’ could also refer to numerous lightning discharges or their intensity; what is meant here is ‘significant charge removal from the thunderclouds’. Consider to reword to be more specific.

Reply:

Thank you for the clarification. We agree that “electrical activity” is too broad in this context. We have revised the text to explicitly refer to significant charge removal from the thunderclouds, which more accurately describes the physical process associated with the observed TLEs.

•I204: Explain how the images are obtained or processed to produce such high level of detail when compared to the images shown by Huang et al., 2025, and in Fig. 5.

Reply:

Thank you for this comment. We have clarified the image acquisition and processing procedures in the revised manuscript. The photographs were acquired using Sony Alpha 7RIII cameras equipped with 14, 35, and 135 mm lenses, with 6 s exposures at f/1.4. The differing focal lengths provided different fields of view and apparent levels of detail. For image presentation, we adjusted the tonal curves to enhance the contrast of features in the sky, typically using an S-shaped curve to brighten highlights and suppress darker tones. To avoid unnecessarily darkening the landscape, the curve adjustment was applied selectively to the sky where needed. These adjustments improve the visibility of features in the original photographs but do not add or reconstruct image details.

•I216: Use an arrow to pinpoint the localised convection in Fig. 2 at 19:00 UT, and show its centre location in Fig. 4 for comparison.

Reply:

Thank you for the suggestion. We have added an arrow in Fig. 2 to pinpoint the

localized convection at 19:00 UT and marked the center of this convective region in Fig. 4 for direct comparison with the observed CGWs.

•l223: State whether the gravity waves in Fig. 4 and Fig. 5 are thought be the same. When photographed from north to south, the gravity waves seem most pronounced to the west of the storm in Fig. 5, whereas Fig. 4 indicates more pronounced gravity wave signatures to the east of the storm.

Reply:

Thank you for pointing this out. The gravity waves shown in Figs. 4 and 5 are not considered to be the same wave event. They exhibit different horizontal wavelengths and represent distinct CGW events associated with the same convective system. Therefore, the apparent difference in the locations of the most pronounced wave signatures relative to the storm between Figs. 4 and 5 does not indicate an inconsistency between the two observations. We have clarified this point in the revised manuscript.

•l237: The gravity waves appear to be coloured in red and green. Comment on whether the reddish colour is an optical illusion corresponding to a grey/green contrast in the original image and state whether the images were post-processed/enhanced in any way.

Reply:

Thank you for this comment. Inspection of the original images confirms that the gravity-wave structures do not have a distinct reddish color. Their reddish appearance in the displayed image is a perceptual color contrast against the surrounding gray/green tones, rather than an actual red emission. The images were post-processed using tonal-curve adjustments to improve the visibility of features in the sky. An S-shaped curve was generally used to brighten highlights and suppress darker tones; where needed, the adjustment was applied selectively to the sky to avoid unnecessarily darkening the landscape. No artificial red or green coloration was added. We have clarified both the apparent color contrast and the image-processing procedure in the revised manuscript.

•l257: State the integration times for the images.

Reply:

Thank you for this comment. We have added the image integration times to the Figure 6 caption: 3 min for the OI 630.0 nm and OI 557.7 nm images, and 1 min for the OH-band image.

•l271: The determination of the wavelengths contradicts the statement on l232 that this is not possible.

Reply:

Thank you for pointing out this inconsistency. We agree that the statement that the photographs do not permit quantitative estimation of wave parameters was incorrect.

The star-calibrated photographs do allow us to quantitatively estimate the horizontal wavelength. We have corrected the text accordingly.

•1280-282: Use arrows to indicate gravity wave detections, similar to Fig. 6, and show the direction of propagation.

Reply:

Thank you for the suggestion. We have revised the corresponding figure by adding arrows to indicate the detected gravity waves and their propagation directions, similar to those shown in Fig. 6.

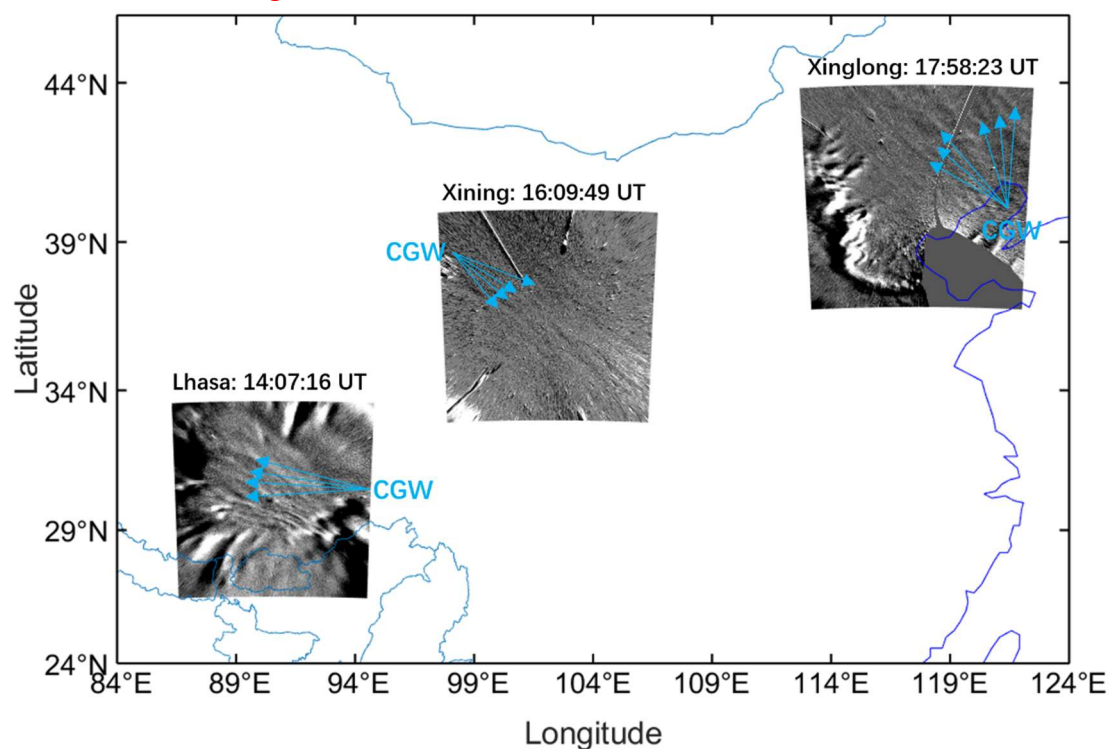


Figure 7 CGWs observed by OH airglow imagers: Lhasa station at 14:07:16 UT, Xining station at 16:09:49 UT, and Xinglong station at 17:58:23 UT.

• 1286: State whether the other two stations shown in Fig. 1 show the same signatures.

Reply:

Thank you for this helpful comment. We have clarified this point in the revised manuscript. The signatures observed at the stations are interpreted as the same CGW event because they are consistent in both propagation direction and temporal sequence. Specifically, the wavefronts appear first at the station closer to the convective source region and subsequently at stations farther downstream, following the expected northeastward propagation path. Their orientations and apparent propagation directions are also mutually consistent, supporting their association with a common source rather than independent local disturbances.

• 1289: State which station is 3,000 km away and how it was determined that no other

thunderstorms, or other sources, contributed to the waves observed at such a remote distance.

Reply:

Thank you for pointing this out. The station approximately 3,000 km from the convective source region is Xinglong; we estimated this distance along the great circle between the source-region center and the station. To assess alternative convective sources, we examined FY-4A/AGRI 10.8 μm images from 12:00 to 22:00 UTC (Fig. R2). The identified MCS was the dominant, evolving deep-convective system. Although patchy, nearly stationary cold features appeared over the Tibetan Plateau, they did not develop into a comparably organized cold-cloud system along the inferred propagation corridor, including after 16:00 UTC. The CGW detections at Lhasa, Xining, and Xinglong also occurred in the expected northeastward sequence, with mutually consistent wavefront orientations and propagation directions. Together, these observations favor the identified MCS as their common source. We have qualified this attribution in the revised manuscript: infrared imagery does not rule out weaker convection or non-convective wave sources, but provides no evidence for another comparable deep-convective source along the corridor.

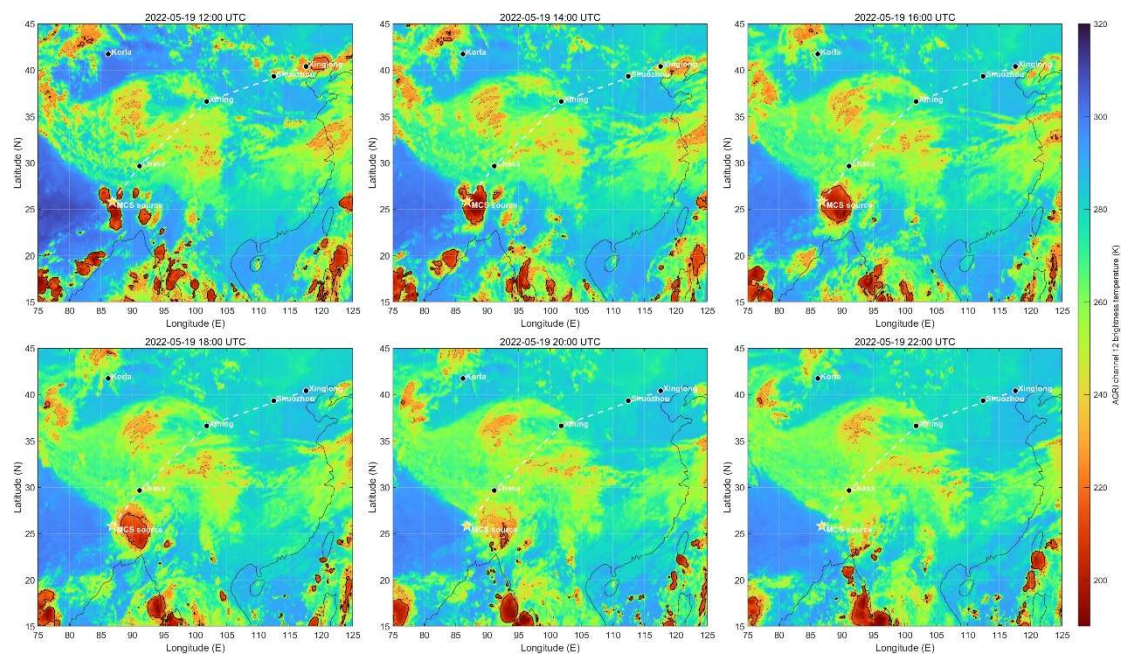


Figure R2 FY-4A/AGRI 10.8 μm brightness temperature images from 12:00 to 22:00 UTC on 19 May 2022. The yellow star marks the convective source region, and the white dashed line indicates the inferred propagation path toward the airglow stations. Dark red contours denote cold cloud tops associated with deep convection.

• I309: Explain u and v wind directions used in Fig. 8.

Reply:

Thank you for this comment. We have clarified in the revised Fig. 9 (Fig. 8 in the original manuscript) that U denotes the zonal wind component (positive eastward) and

V the meridional wind component (positive northward).

- I321: Explain how the presence of ducting layers is inferred from the profiles in Fig. 9.

Reply:

Thank you for this comment. We have clarified how the ducting layers are identified from revised Fig. 10 (Fig. 9 in the original manuscript). The squared vertical wavenumber m^2 is calculated from the gravity-wave dispersion relation using the observed wave parameters, SABER temperature profiles, and SD-WACCM-X background winds. Positive m^2 indicates vertically propagating conditions, whereas negative m^2 indicates evanescence. We therefore identify potential ducting layers as positive m^2 regions bounded above and below by evanescent regions.

- I332: State how the volume emission rate is related to gravity wave properties in the context of the ducting.

Reply:

Thank you for this comment. We have clarified that the OH volume emission rate (VER) is not a direct measure of gravity-wave amplitude or duct strength. Rather, it describes the altitude distribution and intensity of the OH emission layer. The overlap between this layer and the wave-permitting duct, together with the wave's vertical wavelength relative to the emission-layer thickness, can affect the visibility of the wave signatures in airglow observations. We have revised the discussion accordingly.

- I351: Use arrows to indicate gravity wave detections, similar to Fig. 6, and show the direction of propagation. State how it was determined that no other thunderstorms, or other sources, contributed to the waves observed at these remote distances.

Reply:

Thank you for this helpful suggestion. We have revised Fig. 8 (Fig. 10 in the original manuscript) by adding arrows to indicate the detected CGWs and their propagation directions, similar to those shown in Fig. 6.

Examination of the contemporaneous FY-4A infrared observations over the broader region showed no other significant deep convective systems along the propagation path or in the vicinity of the remote observation sites that could reasonably account for the observed CGWs. Together with the consistent propagation directions and the spatial and temporal evolution of the observed wave patterns, this supports their association with the convective system south of the Himalayas.

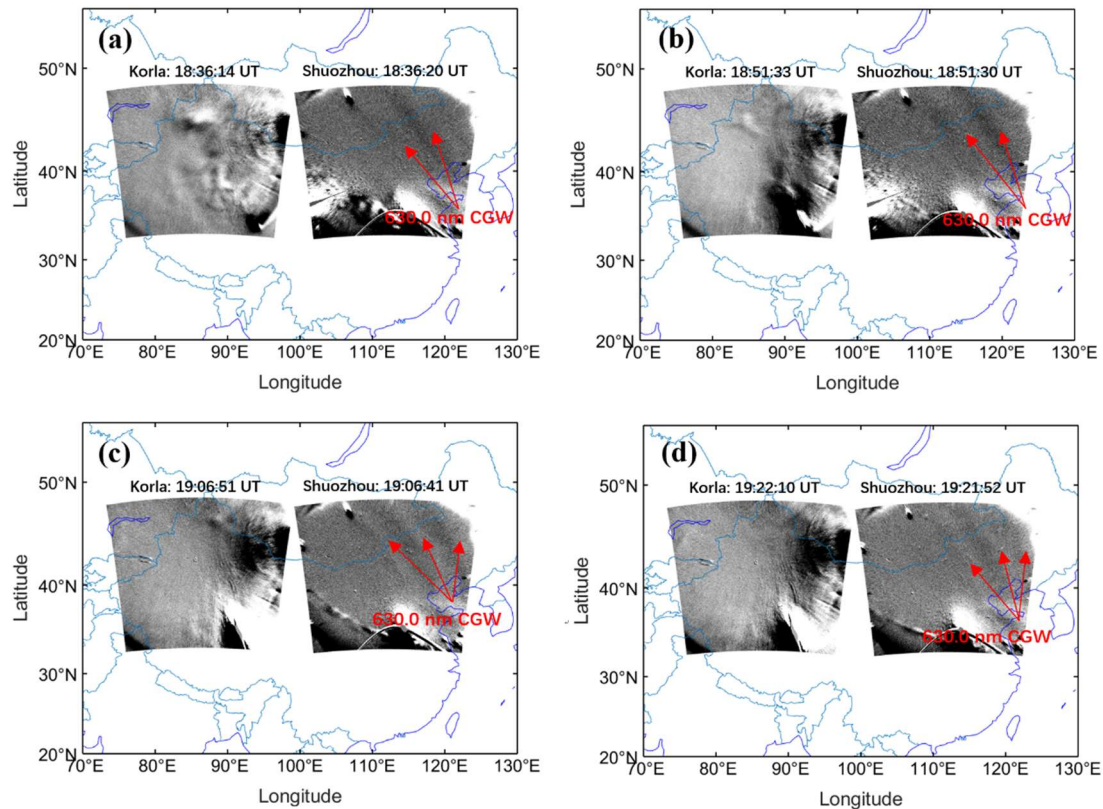


Figure 8 Red-line (630 nm) airglow observations from the Shuozhou and Korla stations. Thermospheric CGWs are clearly observed over Shuozhou, whereas no obvious CGW signatures are detected over Korla. Panels (a)–(d) correspond to 18:36, 18:51, 19:06, and 19:22 UT, respectively.

•1422: Show in the figure the height of thermospheric airglow observations for comparison.

Reply:

Thank you for the suggestion. We have added a horizontal dashed line at ~250 km to indicate the approximate altitude of the thermospheric 630.0 nm airglow observations. This provides a direct reference for identifying the range of horizontal phase speeds for which gravity waves can propagate to the observed thermospheric airglow layer.

•1441: Add the convergence zone in Fig. 14 b&c and explain why horizontal convergence is favoured when compared to vertical conversion. Comment on the uncertainty of the convergence zone.

Reply:

Thank you for this suggestion. We have added shaded boxes to Fig. 14b, c to indicate the broad region where the reverse-ray trajectories approach one another (approximately 30–36°N, 88–98°E, and 115–155 km). The trajectories do not share a sharply defined intersection in either horizontal position or altitude. We therefore no

longer claim that horizontal convergence is favored over vertical convergence, and instead describe an approximate region of trajectory clustering. This region is consistent with a possible lower-thermospheric excitation region for the secondary CGWs, but does not establish a unique three-dimensional source location. The inferred region is uncertain because the trajectories depend on the linear ray-tracing approximation and model-derived background winds and temperatures. The gray dashed boxes delineate an approximate region of closest approach.

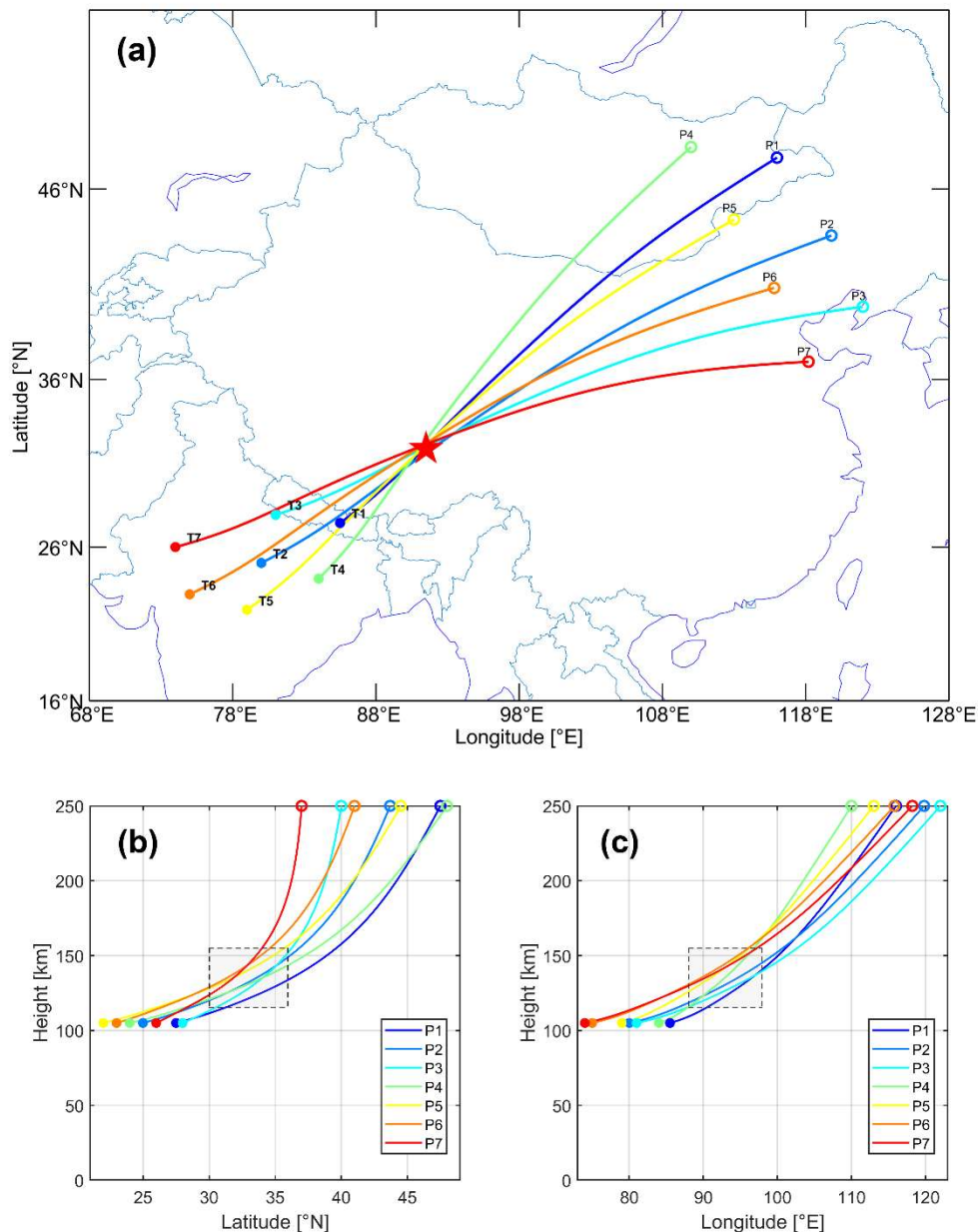


Figure 14 Reverse ray-tracing results for the thermospheric gravity wave observed at 250 km altitude. (a) Horizontal propagation paths projected onto the geographic map. (b) Altitude–latitude distributions of the ray trajectories. (c) Altitude–longitude distributions of the ray trajectories. Gray dashed boxes in (b) and (c) mark the approximate clustering region estimated visually from the plotted ray paths.

Overall, a very interesting publication on dynamic and electrical vertical coupling of atmospheric layers.