Referee #1-(Report 1)

This paper uses multilayer observations (troposphere, mesosphere, and thermosphere) along with reanalysis data to characterize deep propagation of gravity waves generated above Super Typoon Chaba. The authors use wavelet analysis to examine the scales across the different layers and suggests that waves seen in the thermosphere could be secondary waves generated by wave dissipation in the mesosphere. This is determined by ray-tracing analysis and by examining the decay of wave amplitude in the OH layer. This paper is of interest to the community and can be published with just some relatively minor revisions. However, it could benefit significantly from some clarification and additions to the sections regarding ray-tracing, the link between the OH and 630 nm waves, and the explanations of wave dissipation and secondary wave generation processes. Comments are given below:

Thank you very much for your good comments concerning our manuscript entitled “How are the gravity waves triggered by typhoon propagate from the troposphere to upper atmosphere?”. Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We also thank you very much for your help in modifying the expression of English sentences. We have studied comments carefully and have made corrections which we hope meet with approval.

The detailed point-by-point responses are given below.

Line 23: Suggest removing ‘the’ from capture the concentric waves.

Response：
Thank you very much for your suggestion.
"the" is removed from "...... capture the concentric waves” in the revised manuscript.
(Please see line 23 in the manuscript with track)

Line 28: replace ray-tracing revealed that’ with ‘ray-tracing suggests that’

Response：
Thank you very much for your suggestion.
"revealed" is replaced by "suggests " in the revised manuscript.
(Please see line 29)

Line 30: What is meant by ‘resembling the relay in the context’??

Response：
Thank you very much for your comment.
We re-described this sentence as:"However, like the relay, the backward ray tracing

analysis suggests that CGWs in the thermosphere originated from the secondary waves generated by the dissipation of the CGW and/or nonlinear processes in the mesopause region." in the revised manuscript.
(Please see line 28-30)

Line 45: Are a unique type of GWs. Note: concentric waves have also been generated from primary wave breaking, volcanoes, explosions, rockets (e.g. see works by Vadas and Becker ; Lund et al. (2020), Kogure et al (2020)).

Response:
Thank you very much for your valuable suggestions.
The following description is added to the revised manuscript.

"CGWs can also be generated by primary wave breaking (Vadas and Becker, 2019;Lund et al., 2020; Kogure et al., 2020) volcanoes (Duncombe,2022), explosions (Pierceet al.,1971), and rockets (Liuet al., 2020)."
(Please see line 41-44)

Line 45: 'convective activity'

Response:
"activities" is replaced by "activity" in the revised manuscript.
(Please see line 41)

Line 65: Suggest re-writing as: This paper presents a case study examining GCWs excited by Super Typhoon Chaba (2016).

Response:
Thank you very much for your good suggestions.
"This study examined the CGWs excited by Super Typhoon Chaba (2016) as a study case" is replaced by "This paper presents a case study examining CGWs excited by Super Typhoon Chaba (2016)"in the revised manuscript.
(Please see line 65-66)

Line 81: Just "mainland China"

Response:
"...the mainland China" is changed to "...mainland China"in the revised manuscript.
(Please see line 82)

Line 89: "With a central wavelength"

Response:
"...with the centre wavelength... " is replaced by "...with a central wavelength..."in

the revised manuscript.
(Please see line 90)

Line 116: add a space between October and 2016

Response：
a space is added between "October" and "2016"in the revised manuscript.
(Please see line 117)

Lines 142-143: resolution is used twice in this sentence.

Response：
We appreciate your careful review.
"The horizontal resolution of the reanalysis temperature and wind data with a pre-interpolated resolution of 0.25° × 0.25° was used in this study." is changed to" The horizontal reanalysis temperature and wind data with a pre-interpolated resolution of 0.25° × 0.25° was used in this study." in the revised manuscript.
(Please see line 141-143)

Line 147: Suggest "We use a ray tracing method to estimate the source location of the thermospheric secondary CGWs.

Response：
Thank you very much for your help.
"We use a ray tracing method to track the excitation source of the thermosphere secondary CGWs." is changed to " We use a ray tracing method to estimate the source location of the thermospheric secondary CGWs." in the revised manuscript.
(Please see line 147-148)

Line 176: add space to ERA-5reanalysis data.

Response：
a space is added between "ERA-5" and "reanalysis data" in the revised manuscript.
(Please see line 177-178)

Line 177: Why different times?

Response：
Thank you very much for your comment.
We set the time of the three layer temperature perturbations to 23:00LT.
(Please see Figure 4)

Figure 4: Axis labels.

Response:
Thank you very much for your careful review.
Axis labels are added to Figure 4in the revised manuscript.

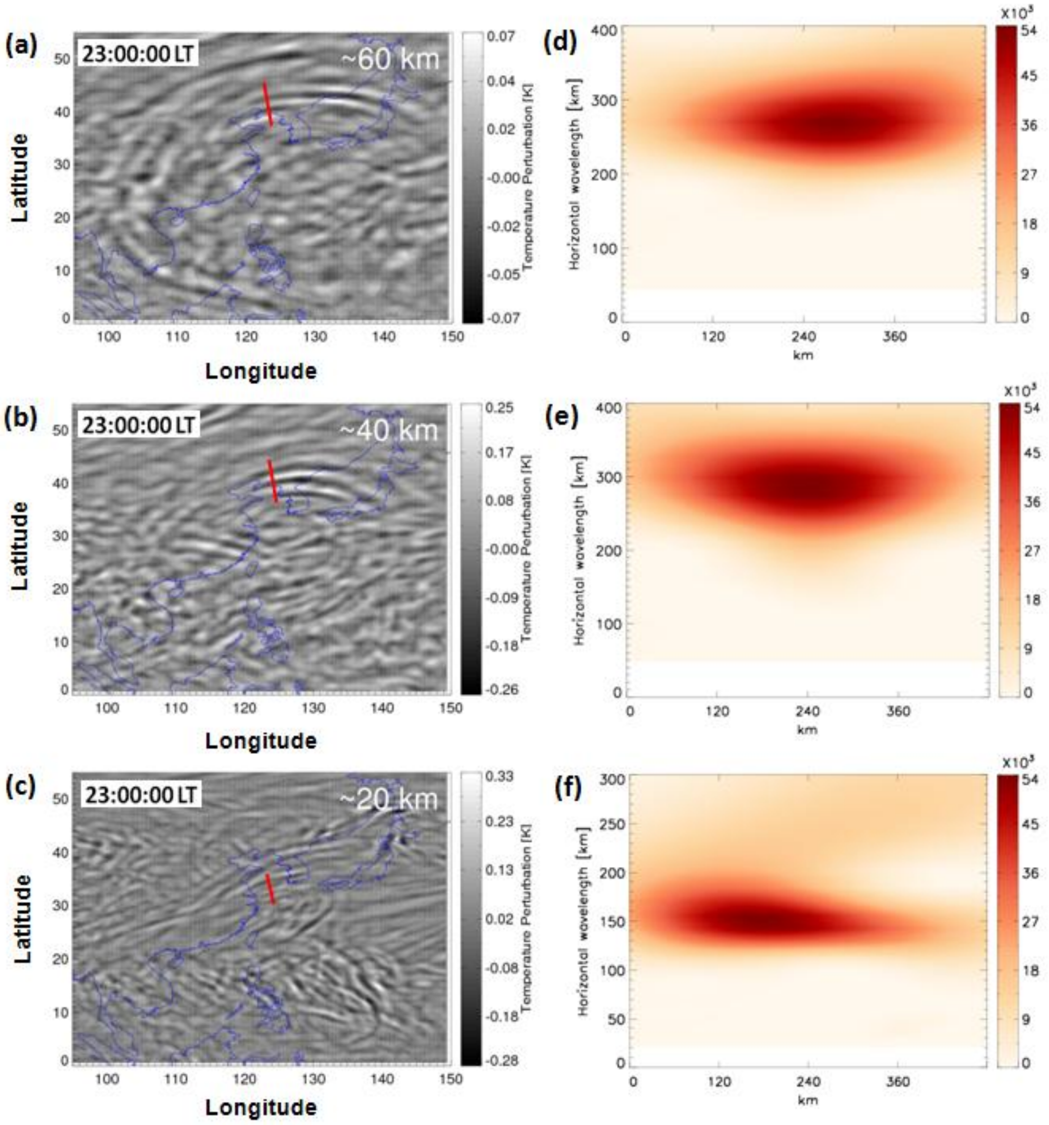


Figure 4. Temperature perturbations at **(a)** ~60 km, **(b)** ~40 km, and **(c)** ~20 km at 23:00LT on 4 October 2016 derived from ERA-5 reanalysis.**(d)** The wavelet power spectrum along the red line in **(a)**, **(e)** the wavelet power spectrum along the red line in **(b)**, and **(f)** the wavelet power spectrum along the red line in **(c)**.

Line 184: replaced “embraced” with “were present over a large area”

Response:
"embraced " is replaced by " were present over "in the revised manuscript.
(Please see line 186)

Line 208: How similar are the reanalysis datasets and the OH data? This seems a strange scientific decision. How do you justify this?

Response：

Thank you very much for your criticism.

What we want to express is the propagation of phase plane of CGWs from ERA-5 reanalysis datasets to the OH airglow layer. As long as the CGW does not encounter the critical layer or break, it can propagate to the OH airglow layer. Through the propagation group velocity, we can determine the propagation time to the OH layer.

(Please see line 211-214)

Line 208: also, I'm not sure single wavelength is correct, more a single wave packet, or a single dominant wavelength.

Response：

Thank you very much for your valuable suggestions. It should be more appropriate to describe wave with wave packet. "dominant" is added between "single" and "horizontal" in the revised manuscript.

(Please see line 214-215)

Line 211: Due to resolution of the reanalysis?

Response：

Thank you very much for your comment.

We have re-expressed this sentence as:"A single dominant horizontal wavelength is seen at the altitudes of 20 km, 40 km, and 60 km in the ERA-5 reanalysis due to the limited resolution. In contrast, the horizontal scales of the CGW obtained by OH airglow network are diverse, ranging from approximately 30 km to 300 km as the imager has much higher spatial resolution." in the revised manuscript.

(Please see line 214-218)

Line 213: You are talking about in the reanalysis dataset here?

Response：

Sorry, we didn't make it clear. We re-described it as:

"In order to verify whether the phase plane of the same wave is propagated from the reanalysis data layer to the OH layer," in the revised manuscript.

(Please see line 223-224)

Line 214: When the CGWs from ERA-5 at the altitudes….

Response：

"from ERA-5" is added between" CGWs" and "at the altitudes" in the revised manuscript.

(Please see line 229)

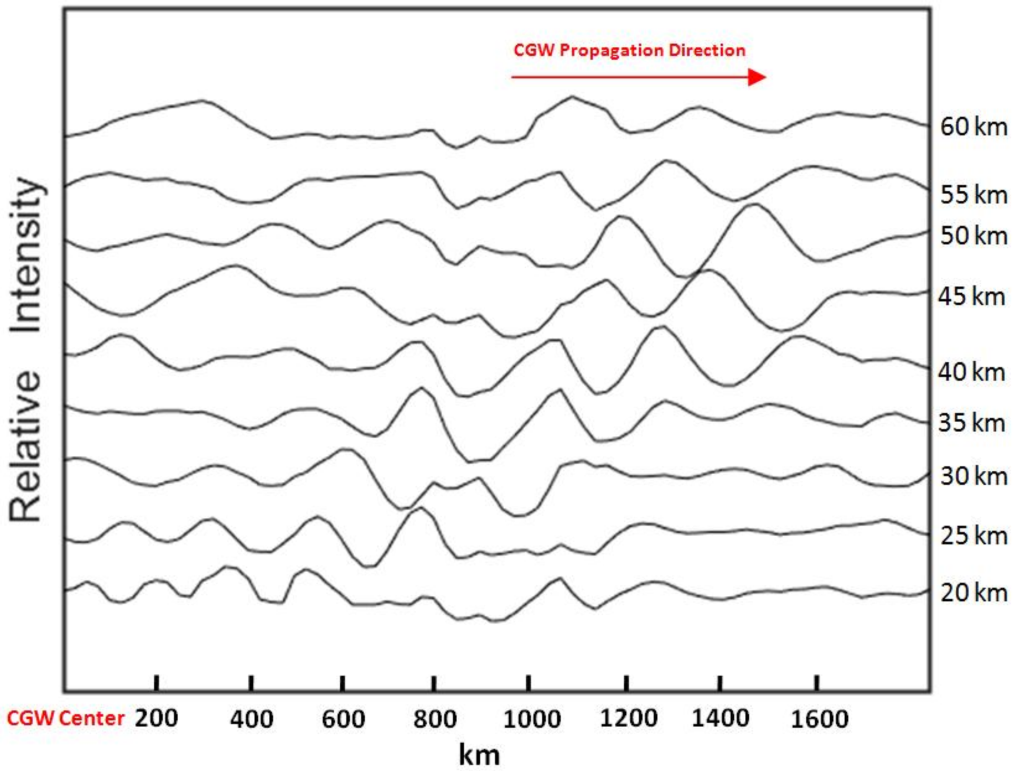
Line 214: Can you confirm that the waves in the ERA-5 at 20, 40, and 60km are the same wave? Perhaps using a meridional-vertical slice through the ERA-5 dataset to show continuity of wave phases with altitude.

Response：

Thank you for your suggestion. We want to express that the CGW scale on the specific reanalysis layer is consistent with that on the OH airglow layer due to the phase plane of the same wave propagating from the reanalysis data layer to the OH layer.

As your suggestion, a slice along wave propagation from the ERA-5 showing continuity of wave phases with altitude from 20 km to 60 km is given below:

Since the scale of CGW at the height of 20km is half that at the height of 40 km, it is not the same CGW spectrum.



Line 217: Usually waves generated from convective sources are part of a continuous spectrum of waves rather than discrete.

Response：
Yes, you are right.
Gravity waves generated by convective sources are often broad-spectrum. The

gravity wave observed at a certain height is only part of a continuous spectrum. We have re-described it as：

"Therefore, the time when the phase plane of CGWs from ERA-5 at the height of 60 km, 40 km, and 20 km reaches the OH airglow layer is approximately 23:28 LT, 23:39 LT, and 23:53 LT as shown in Fig. 5a, 5b, and 5c, respectively." in the revised manuscript.

(Please see line 228-231)

Lines 221, 224, and 225: Change 'observation period' to 'observed period'.

Response：

"observation " is changed to " observed "in the revised manuscript.

(Please see line 233)

Line 222, Line 226: change "horizontal wavelength of the atmosphere" to 'dominant horizontal wavelength of the CGWs in the ERA-5 reanalysis'

Response：

"horizontal wavelength of the atmosphere" is changed to "dominant horizontal wavelength of the CGWs in the ERA-5 reanalysis "in the revised manuscript.

(Please see line 234;239)

Line 224: I think a better sentence structure would be "The wave packet observed in the OI 630 nm airglow was quasi-monochromatic"

Response：

Thank you very much for your help.

"The wave scale observed at the OI 630.0 nm airglow was monochromatic." is replaced by "The wave packet observed in the OI 630 nm airglow was quasi-monochromatic ."in the revised manuscript.

(Please see line 257)

Figure 6: I am curious why you do not perform a wavelet analysis on the 630 nm data as you did with the OH and ERA-5 data? This may be beneficial for comparison

Response：

Thank you very much for your good suggestions.

We applied a wavelet analysis to the630 nm airglow data.

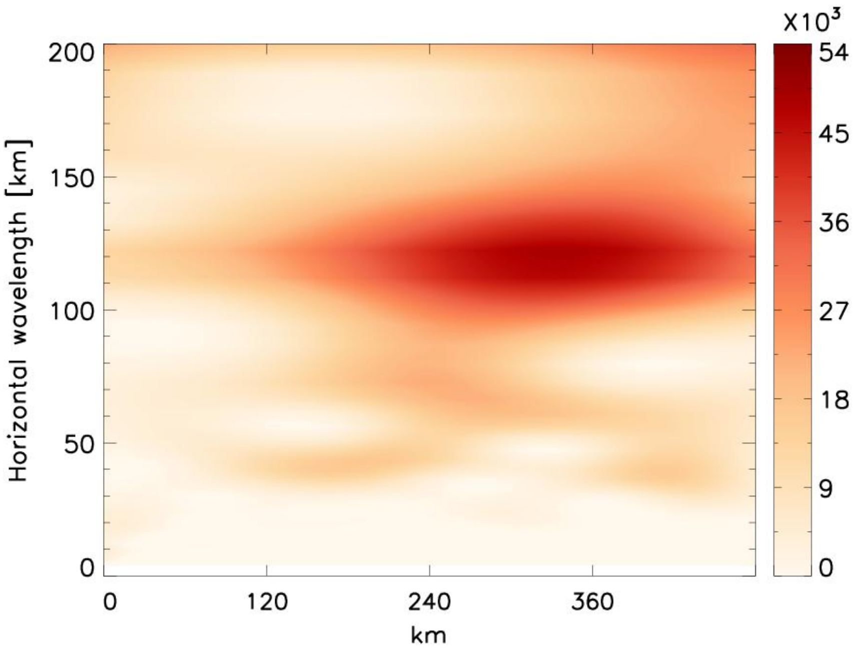


Figure 7. The wavelet power spectrum along the red line at 01:00:18 LT in Fig. 6.

Line 254: Maybe I am confused here? But the wavelet analysis in 5d, e, and f all show spectral power between 100-150km horizontal wavelength. The blue lines in Figure 7c also appear to match up with dark phases in the intensity of the OH image? The waves seen in the 630 nm will have relatively smaller amplitudes at OH heights and you wouldn't necessarily expect them to dominate there. The waves in the 630 nm data also have much faster phases speeds, shorter periods and thus a more vertical trajectory. This means that they will not travel as far horizontally as the waves noted as dominant in the OH layer so the radius of the concentric pattern would be expected to be smaller.

Response：

We appreciate your careful review, which is very beneficial for improving our paper. Yes, you are right. There exist spectral powers between 100-150km horizontal wavelength. But compared with the main spectral powers, they are very weak. The blue lines in Figure 9in the revised manuscript also appear to match up with dark phases in the intensity of the OH image. However, the difference can be seen because the blue lines do not completely overlap with the fitted red circles.

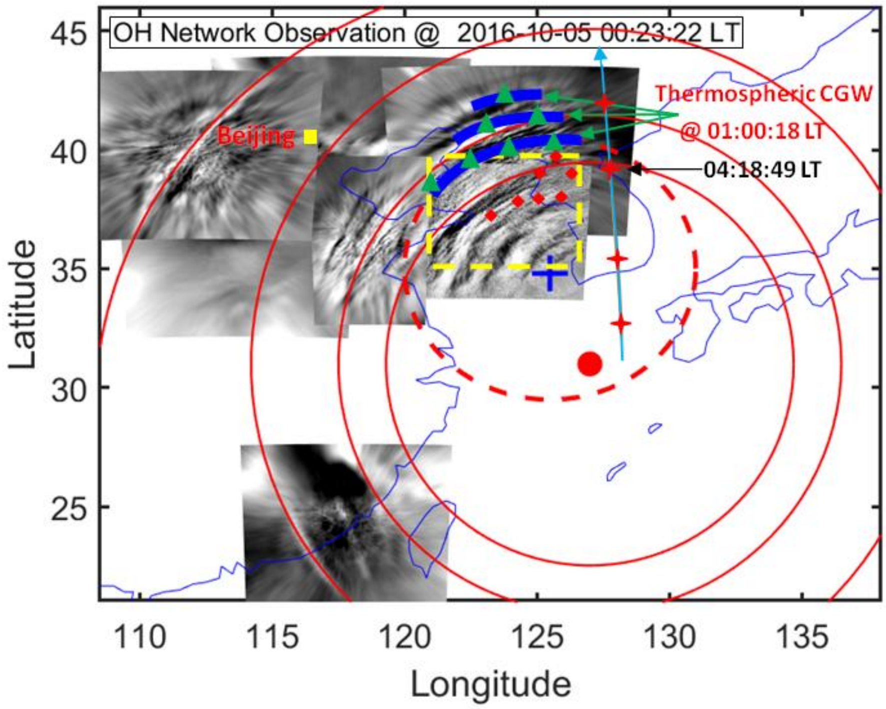


Figure 9. Two layer superimposed graph: The blue arcs represent the thermospheric CGW observed at 01:00:18 LT. The dotted circle represents the approximate fitting blue arcs. The center of the circle is marked by a blue cross. The solid circles represent the approximate fitting CGWs observed by the OH airglow network. The center of the circles is marked by a red dot. The green triangles and diamonds represent the trace start and termination points, respectively. The red crosses represent the sounding footprints of the TIMED/SABER measurements. The yellow box marks the location of meteor radar station.

The following description is deleted from the manuscript.

"Nevertheless, the waves with a scale similar to that of the thermosphere GWs were not identified by the OH airglow network."

The following description is added to the new manuscript.

"The CGW observed in the OI 630.0 nm airglow having much faster phases speed and shorter period, which indicate that its propagation trajectory relatively vertical. This means that they will not propagate as far horizontally as the CGWs noted as dominant in the OH layer."
(Please see line 270-274)

Line 257: remove the word “moreover”

Response：
The word “moreover” is removed in the revised manuscript.
(Please see line 276)

Line 270: How sensitive is the result to the starting altitude and the phase of the 630 nm wave where the starting point for the reverse ray-trace is chosen?

Response：
Yes, you are right.
Uncertainty analysis is necessary for scientific research.
We added three more starting points(see Figure 6 at 01:00 18 LT) in different phases. The ray tracing results of three different heights of 240 km, 250 km and 260 km are analyzed.

We find that the termination points of ray tracing almost fall in the dissipative and/or nonlinear processes region or at the edge of the region. The maximum uncertainty of horizontal change of ray tracing termination point caused by different starting heights is approximately ±0.36° in latitudinal and ±0.17° in longitudinal (see Figure 8c).

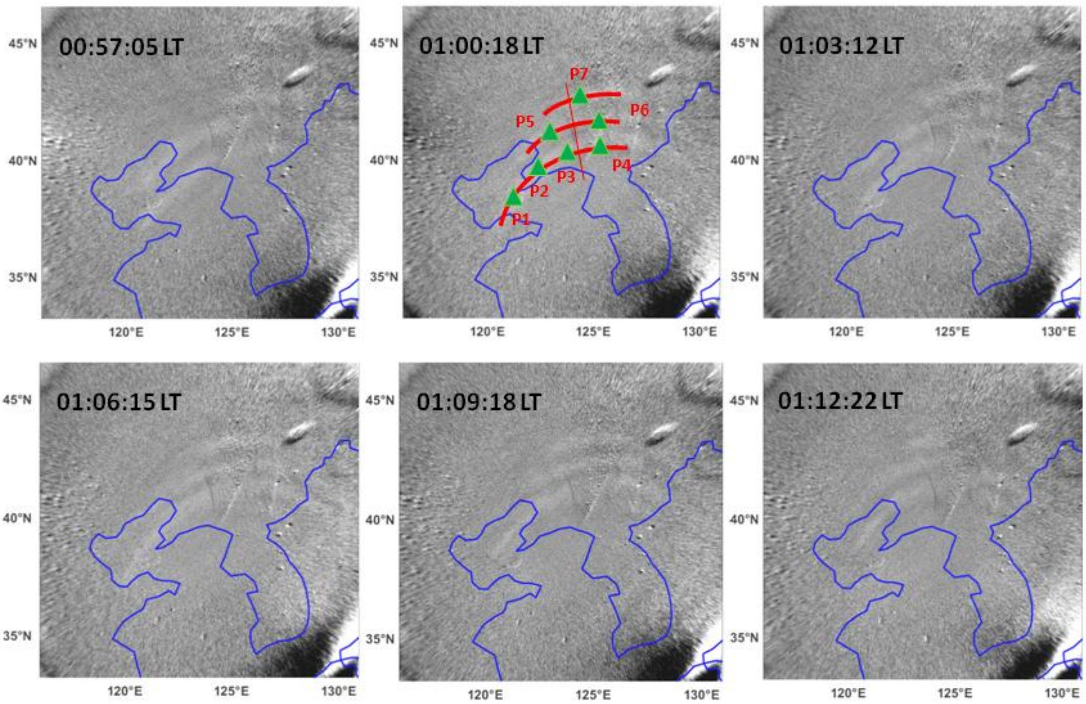


Figure 6. A time sequence of OI 630.0 nm airglow images observed by Donggng station during 00:57:05-01:12:22 LT on the night of 4 October2016. Green triangles (P1-P7) in the red arcs are used as ray tracing sampling points. The blue line in each panel represents the coastline.

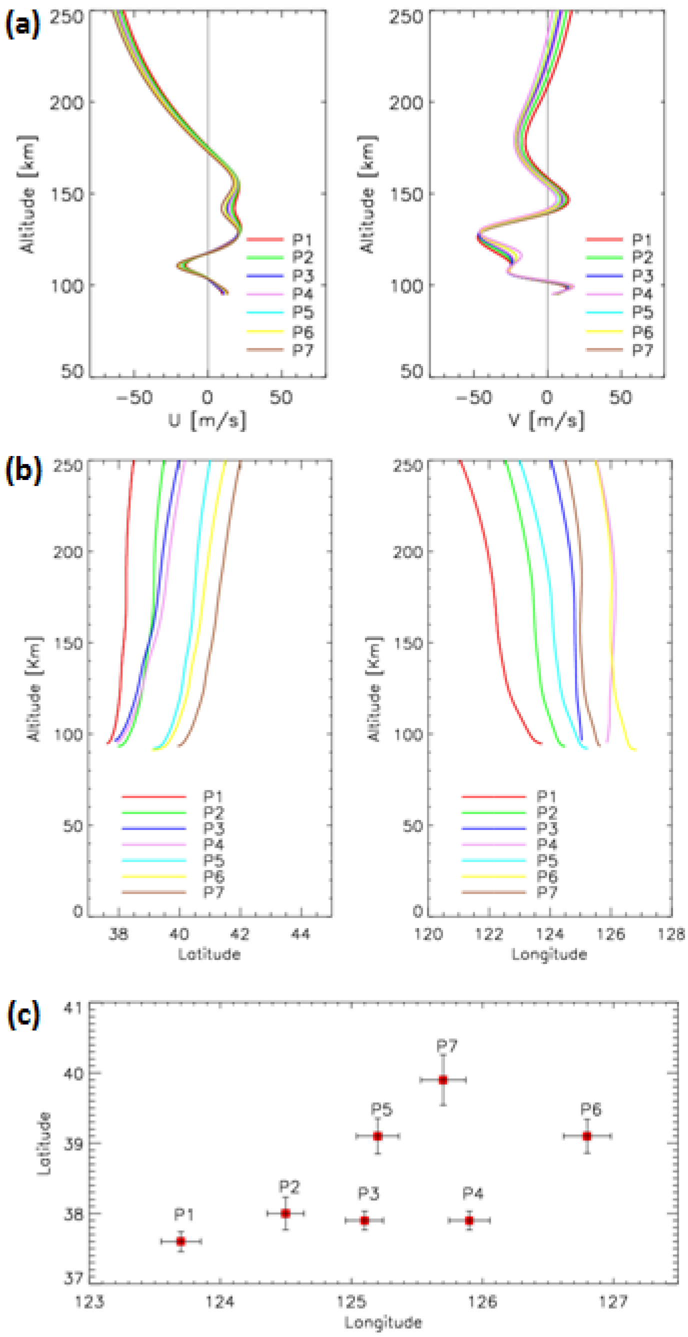


Figure 8. (a) The wind profiles along the four ray-tracing paths. **(b)** The ray paths of the wave starting from the seven sampling points in Fig.6. **(c)** Horizontal area distribution of the terminal positions of the seven backward traced trajectories. Error bars give standard deviation for each point from the starting altitude of 240km, 250km, and 260km.

Line 275: Just because the wave would have been reflected at 95 km there doesn't necessary mean it was generated there. It just suggests that the wave could not have comes from below this altitude according to linear theory. However, the wave could have been generated at any altitude between 95 km and the altitude of observation.

Response：

Thank you very much for your criticism.

We have re-described this issue in the new manuscript

"Subsequently, four backward traced trajectories took 37 minutes and terminated at the altitude of approximately 95 km thereby indicating that it met the reflection layer, which suggests that the thermospheric CGW could not have comes from below95 km according to linear theory. the thermospheric CGW could have been generated at any altitude between 95 km and the altitude of the OI 630.0 nm airglow. In other words, the CGW observed in the thermosphere was excited after approximately 00:23 LT."

(Please see line 298-304)

Line 315: I think the images in Figure 8 show clear signs of nonlinearity, instability, and smaller scale wave generation via wave-wave interaction and/or wave breaking.

Response：

Thank you for your constructive suggestions.

The following description is added to the revised manuscript.

"Interestingly, the wavefronts 2 and 3 collided and connected in the northeast, indicating that wave-wave nonlinear interactions may have occurred."

"At the same time, we also identified the generation of approximately 110 km and 20-50km small-scale waves from the larger scales, which may be caused by wave-wave nonlinear interactions and/or wave breaking."

(Please see line 343-344;356-358)

Line 316: I'd suggest rewriting as: "However, it is noted that wavepacket amplitude fluctuations can also result from the transient nature of the wavepacket."

Response：

"However, the observed CGW dissipation may be caused by the upward CGW passing through the airglow." is changed to "However, it is noted that wavepacket amplitude fluctuations can also result from the transient nature of the wavepacket." in the revised manuscript.

(Please see line 376-377)

Line 317: I'm not sure I understand the statement: "the observed CGW dissipation is real, unless it propagates horizontally"

Response：

We found the following description redundant, so the following description is deleted from the manuscript.

"Notably, the observed CGW dissipation is real, unless it propagates horizontally."

Line 328: Why does this imply that the CGW may be dissipated? I think the Figure 8 with its evidence of small-scale structure and nonlinearity is evidence enough. What wave parameters were used for the m2 analysis in Figure 10?

Response：

Because the observed amplitude change is not only caused by dissipation, but also by a wave packet passing through the layer as it propagates upwards. Of course, this is only a possibility. According to your suggestion, we also discussed the nonlinear interaction processes such as wave-wave interaction and/or wave breaking.

The wave parameters used for the m2 analysis in Figure 13 are from the wavefronts (w1-w5) in Figure 10. The average horizontal wavelength is approximately 96 km and the average observed phase velocity is approximately 90 m/s.

(Please see line 388-390)

Lines 330-332: While this statement is true, this is a huge simplification of the problem. Secondary waves can be generation via many mechanisms that are both non-dissipative and dissipative. Momentum does not need to be deposited in the mean flow to generate secondary waves but can be transferred nonlinearly from the primary wave mode to harmonics or subharmonics, the wave can also induce local mean flow accelerations just because of the transience of the wave packet which can lead to wave breaking. Local momentum flux divergence associated with wave breaking, vortex generation, and wave interactions can also generate secondary acoustic and gravity waves. For some references see: Franke and Robinson (1999), Fritts et al (2006), Zhou et al (2002), Chun and Kim (2008), Lund and Fritts (2012), Fritts et al (2015), Dong et al. (2020), Fritts et al (2020), Heale et al (2020; 2021), Bolini et al (2016), Vadas et al (2003), Vadas and Becker (2019), Scinocca and Ford 2000, Snively 2017. I'd recommend sections 2.2 and 4 from Fritts et al. (2006): Mean and variable forcing of the middle atmosphere by gravity waves.

Response：

Thank you for your serious criticism. We have made a more complete discussion.
The following description is added to the section 4 of the revised manuscript.

"In addition, the secondary wave can be generated by momentum transferred nonlinearly from the primary wave mode to harmonics or subharmonics (Snively, 2017). Local momentum flux divergence associated with wave breaking, vortex generation, and wave interactions can also generate secondary GWs (Fritts et al., 2006)."

(Please see line 396-400)

Relevant contents have also been modified in the Abstract:

"However, like the relay, the backward ray tracing analysis suggests that CGWs in the thermosphere originated from the secondary waves generated by the dissipation of the CGW and/or nonlinear processes in the mesopause region".

and in the Summary:

"Our analysis demonstrated that the CGWs in the mesopause region were excited directly by the typhoon, but the CGW observed in the thermosphere may be secondary wave excited by the primary CGW dissipation, breaking and/or nonlinear processes in the mesosphere, rather than being directly excited by the typhoon from backward ray tracing analysis and the CGWs evolution process observed by OH network."

Referee #1-(Report 2)

Thank you for the responses. I appreciate you taking the time to improve the manuscript based upon my comments. I still have a few comments on your corrections that I think may improve the manuscript further. I have shown your responses in red and commented in blue.

Thank you very much for your further comments concerning our manuscript. Those comments are all valuable and very helpful for revising and improving our manuscript, as well as the important guiding significance to our researches. We have studied comments carefully and have made corrections which we hope meet with approval.

The detailed point-by-point responses are given below.

1. Firstly, I believe the English in the title is not quite correct. If you can, I'd suggest changing it to: How do gravity waves triggered by a typhoon propagate from the troposphere to the upper atmosphere?

Response：
Thank you very much for your good suggestion.
"How are the gravity waves triggered by typhoon propagate from the troposphere to upper atmosphere?" is changed to "How do gravity waves triggered by a typhoon propagate from the troposphere to the upper atmosphere?" in the revised manuscript.

2. "A single dominant horizontal wavelength of CGW at the altitude of 20 km, 40 km, and 60 km obtained by the ERA-5 reanalysis due to the limitation of resolution. In contrast the horizontal scales of CGW obtained by OH airglow network are diverse, ranging from approximately 30 km to 300 km."

I'd suggest re-wording as: A single dominant horizontal wavelength is seen at the altitudes of 20 km, 40 km, and 60 km in the ERA-5 reanalysis due to the limited resolution. In contrast, the horizontal scales of the CGW obtained by OH airglow network are diverse, ranging from approximately 30 km to 300 km as the imager has much higher spatial resolution."

Response：
"A single dominant horizontal wavelength of CGW at the altitude of 20 km, 40 km, and 60 km obtained by the ERA-5 reanalysis due to the limitation of resolution. In contrast the horizontal scales of CGW obtained by OH airglow network are diverse, ranging from approximately 30 km to 300 km." is changed to "A single dominant horizontal wavelength is seen at the altitudes of 20 km, 40 km, and 60 km in the

ERA-5 reanalysis due to the limited resolution. In contrast, the horizontal scales of the CGW obtained by OH airglow network are diverse, ranging from approximately 30 km to 300 km as the imager has much higher spatial resolution.".
(Please see line 214-218)

3. We appreciate your careful review, which is very beneficial for improving our paper. Yes, you are right. There exist spectral powers between 100-150 km horizontal wavelength. But compared with the main spectral powers, they are very weak. The blue lines in Figure 9 in the revised manuscript also appear to match up with dark phases in the intensity of the OH image. However, the difference can be seen because the blue lines do not completely overlap with the fitted red circles.

I am still a little confused here. Both Figures 5d and f show strong power at ~150 km which to me suggests either possible harmonic generation of the 300 km mode by nonlinear processes or these modes are simply part of the spectra. These waves could be the same waves seen in the Thermosphere, which also seem to have power around ~150 km from the wavelet analysis you sent in the review response. In addition, figure 9 (assuming the x-axis is distance in km) also suggests a dominant wavelength of around ~150 km (with smaller scales of ~25 km present which are likely wave breaking structures (e.g. in Heale et al. (2020) figures 5,7,8, 10) Can you overlay the OI 630 nm data on these plots to compare scales? My thinking is that primary gravity waves are breaking or nonlinearly generating these smaller scale secondary waves which are those seen in the thermosphere.

Response：

We are extremely grateful to you for pointing out this issue.
Yes, you are right. Figures 5d and f do show strong power at ~150 km. As your suggestion, we compared the wave scales in OH and OI 630 nm by overlay the OI 630 nm data on OH plot.

The following description is added to the revised manuscript.

"We also overlay the OI 630 nm airglow relative intensity variation on OH airglow variation. Figure 12 shows OH and OI 630 nm airglow relative intensity variations. The OH plot is obtained at 00:29:27 LT and the OI 630 nm plot is obtained at 01:06:15 LT. The time interval of 37 min is calculated by the above ray tracing analysis. We found that similar scale fluctuations were obtained in the two airglow layers. The horizontal wavelength of the wave obtained by OI 630 nm airglow layer is approximately 118 km. The OH airglow layer has also obtained near scale fluctuations with a wavelength of approximately 109 km. Therefore, the CGW seen in the thermosphere may suggest come from breaking or nonlinear processes of that primary gravity wave."
(Please see line 358-366)

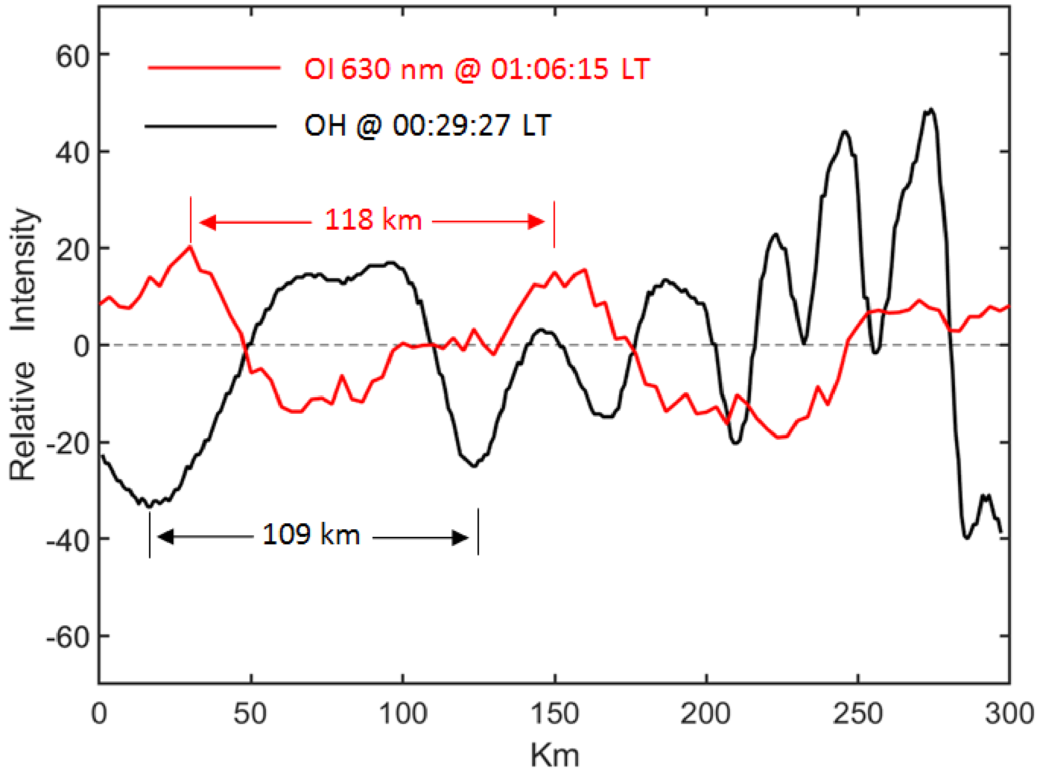


Figure 12. OH (black) and OI 630 nm (red) airglow relative intensity variations. The OH relative intensity variation is obtained as Fig. 11. The OI 630 nm relative intensity variation is from red dotted line in Fig.10 at 01:06:15 LT.

4. "In addition, the second waves can be generated by momentum transferred nonlinearly from the primary wave mode to harmonics or sub harmonics (Snively, 2017). Local momentum flux divergence associated with wave breaking, vortex generation, and wave interactions can also generate secondary GWs (Fritts et al., 2006)."

Change second waves to secondary wave.

Response：
" second waves " is changed to "secondary wave".
(Please see line 396)

5. "Our analysis demonstrated that the CGWs in the mesopause region were directly by the typhoon, but the CGW observed in the thermosphere may be excited by the CGW dissipation and/or nonlinear processes in the mesosphere, rather than being directly excited by the typhoon and propagated to the thermosphere. Overall, the complete propagation process of the CGWs was studied and demonstrated. Specifically, it was shown how CGWs were generated by typhoon in the troposphere, passed through the stratosphere, reached the mesosphere. The obvious nonlinear

wave-wave interaction and the dissipation process of CGWs are observed in the mesopause region. Therefore, momentum deposition due to wave dissipation and/or local momentum flux divergence associated with wave interactions generated secondary GWs, and then propagated to the thermosphere. "

I’d suggest re-writing as: Our analysis demonstrated that the CGWs in the mesopause region were excited directly by the typhoon, but the CGW observed in the thermosphere may be secondary wave excited by the primary CGW dissipation, breaking and/or nonlinear processes in the mesosphere, rather than being directly excited by the typhoon.

Response：

This description has been re-described according to your suggestion.

(Please see line 415-419)

Referee #2

The subject of the manuscript is rather interesting and there is a lot of new information about gravity waves generation, propagation and dissipation. The powerful meteorogical source should generate the concentric gravity waves and the all-sky camera network together with reanalysis data very convincing demonstrate it. It will be very interesting to all in the Earth atmospheric research community to read the article.

Response：
Thank you very much for taking your time to review our manuscript. Thank you very much for your very positive and constructive comments.