Response to the Referee's Comments

The authors appreciate reviewers' valuable suggestions and insightful guidance. We carefully considered reviewers comments and tried our best to improve the manuscript based on their comments below.

Referee 1.

Major comments:

1.) Description of the methods: In order to separate between total and GW related horizontal divergence some kind of frequency identification / filtering is required. This process is not described in the paper. Even if the details should be provided elsewhere (please provide the reference), a short description of the applied method must be given here. There are certain details (cf. specific comments) in the relation between GW related and total horizontal divergence, which cannot be understood without knowing the methods.

The process to isolate IGWs from the wind field was described in the original manuscript (ACPD: Line 14-19, Page 28956). Following the reviewer's suggestion, a detailed explanation in calculation of the horizontal divergence of TGWs is provided in the revised manuscript (line 56-68, page 5).

2.) Figure 1 is used to give evidence that mesoscale GWs have a major influence on the development of the typhoon. There are several problems with this part, however. First, the argumentation is based on similar patterns in various time series. Such correspondence (called correlation in the paper, but I miss the analysis) is evident in some cases, but some described patterns need to be made more evident. Either these points need to be better described or the authors could actually perform correlation analysis. In this case they will need to decide on the relevant time scales. A few more questions with this regard are formulated in the specific comments.

We have calculated lag correlation coefficients between the two variables shown in Fig. 1 originally, which can examine cause and effect from the two time series. However, since we agree with the Editor's suggestion that calculating lag correlation coefficients using any subset of total time series is not so meaningful, we discuss the correlations between each variable without lag correlation coefficients in the final manuscript of ACPD. In the revised manuscript, we only have added the correlation coefficient between total divergence and HDTGW during 36 hours before a decaying period (line 88, page 6). Elsewhere, we do not include coefficients. The correlation coefficients between the two variables shown in Fig. 1 during a rapidly developing 12 hours period (00 UTC to 12 UTC 9) are below.

Correlation coefficients at lag=0 (00 UTC to 12 UTC 9)

Variables	Coefficients (Confidence level)
HDTGW / Total Div	0.99 (99%)
HDTGW/ SLP	-0.93 (99%)
Total Div / SLP	-0.89 (99%)
HDTGW / W	-0.81 (99%)
HDTGW / Precipitation	-0.75 (99%)

Second, accepting the similarity/correlation in the curves this only shows that there is some connection but a correlation cannot tell apart cause and effect. Is the GW divergence field cause of changes in the typhoon? Or does the typhoon cause more GWs? Or is there a larger scale GW influencing the typhoon which in turn causes small scale GWs? Unless some clear idea of a mechanism is presented this point remains unsolved. Some ideas for a mechanism are presented in Koch and Siedlarz (1999). The authors indicate further work. In all this they assume that mesoscale GWs most dominant in their simulation are the main driver.

Although a correlation analysis is useful to examine connections between two variables, the method has a limitation to explain causalities, as the reviewer pointed out. In this study, we not only employed correlation analysis but also tried to explain the mechanisms. The reason to consider horizontal divergence in the present study is based on the fact that surface pressure tendency is determined by vertically integrated divergence/convergence (Holton 1992) in air column. Competition between the low-level convergence and upper-level divergence determines surface pressure tendency, and upper-level divergence is known to be one of the major factors affecting typhoon intensity change, as revealed in many previous studies. The low-level divergence is found not to be significant in the present case, compared with upper-level divergence during the typhoon evolution, as shown in the response to the Editor's comments previously. Considering that GWs generated by convection influences the wind fields above convection, TGWs can influence on the horizontal divergence in UTLS. We indeed have found that TGWs contribute significantly to the total divergence in UTLS. In the present study, we would like to understand feedback process between TGWs and their sources (convection associated with typhoon). That is, TGWs are generated by convective clouds associated with typhoon, and then TGWs influence typhoon evolution through changes in horizontal divergence in UTLS, especially in domain-averaged HDTGW. There is a strong correlation between domain-averaged HDTGW and MSLP during rapidly developing period, and this feedback process could be one of mechanisms to explain typhoon evolution. This is a new concept and further research with more typhoon cases may require for robust conclusion.

We appreciate for noting Koch and Siedlarz (1999). As we understand, this study showed and analyzed mesoscale GWs that influenced the convective system by initiating convection. However, the GWs considered in their study were not generated or related to convective sources. In that sense, this study is not directly related to the present study that would like to show the feedback between GWs and their sources.

I would like to suggest an alternative: the presence of a large scale GW may explain some features rather nicely. It should not be filtered in calculating HDTGW, if this is properly set-up. A large-scale GW would have a close to 24 hour period and a propagating feature and it is less noticeable in horizontal divergence than the smaller scale, short-period waves. While the shorter horizontal scales average out, as nicely described in the paper, the long horizontal-wavelength GW would not.

Such a wave has been detected in CRISTA data (cf. Figure 52 of Preusse, 2001 showing the temperature structure of a large scale GW with approx. 3000km horizontal wave- length and 24h period (note that panels a and b are approx. 12h appart). Figures 56 and 57 then indicate that the oscillation is also present in cloud-top height. The thesis can be found at http://elpub.bib.uni-wuppertal.de/servlets/DerivateServlet/Derivate- 412/d080111.pdf).

The long horizontal-wavelength GWs contribute mostly in domain-averaged HDTGW, which oscillate about 24 hours period. It is very nice to know that similar result has been found from CRISTA data by Preusse (2001). Thank you very much for providing website information to download pdf form of Preusse (2001). Some of results by Preusse (2001) are included in the revised manuscript (line 159, page 9).

Also global scale modeling suggests the presence of such large scale GWs (e.g. Evan et al., 2012). Whether it is able to propagate into the stratosphere of course would depend on the actual phase speed of the wave in the model and the background wind conditions. It would be interesting to look into smoothed horizontal divergence fields and maybe also in variables such as temperature. Also it would be interesting to investigate whether other convective events in the vicinity show a similar oscillation.

I should add that this point does not need to be completely resolved before publication of the paper. Even the suggestion is worthwhile. But the discussion can and needs to be strengthened.

We agree with you that similar large-scale GWs generated by convection can appear near other convective events as well. Please note that the main object of this study is to understand a feedback between TGWs and their sources (typhoon evolution). With the same reason for the present study focusing on Typhoon Saomai, understanding a feedback process between GWs and other convective systems during their evolution will advance our knowledge on both the GWs and convective systems. However, it may be more difficult to figure out the feedback process between the GWs and their convective sources, compared with that between TGWs and typhoon evolution of which source structure is relatively well defined including their intensity changes and tracks. Further studies are required to deduce other feasible ways with variables more than horizontal divergence in UTLS representing feedback process between GWs and convective sources. A statement related to this issue is included in the last section of the revised manuscript (line 346, page 18).

3.) A general comment on all Figures: The numbers at the axes and color bars are tiny. This should be improved.

Following the reviewer's comments, we have improved figures in the revised manuscript.

Specific comments:

Obviously the current paper is strongly based on the previous publications KC10 and KC11. The introduction should clarify the relation of these three publications.

Both KC10 and KC11 investigated typhoon-generated gravity waves (TGW) using the simulations of Typhoon Saomai (2006). Earlier study (KC10) was focused on characteristics of TGW but KC11 expanded KC10 and focused on possible influence of TGW by modifying environmental flow such as wind sear and horizontal divergence in upper level. Previous study (KC11) shows possibility of TGW influence on TC intensity change. This study, motivated by KC11, conducted comprehensive analysis of HDTGW to find the possible mechanism of feedback process between HDTGW and TC intensity change. This was included in the original manuscript.

You use both the domain-integrated total divergence and the divergence by TGWs. It remains unclear in this paper how these are defined. A short definition/description needs to be given! The current paper must be readible without reading KC11.

For responding the first comment of the Major Comments, we have added detailed description and procedure to calculate total divergence and HDTGW. (line 56-68, page 5)

HDTGWs refers to the horizontal divergence. That is singular. Therefore I would find an abbreviation indicating singular easier to read: HDTGW. And please, use it consistently throughout the text.

We have changed.

P955L19 Only trivial processes can be understood "precisely", a complex system like a typhoon will always have to rely on some approximations.

Thank you for your comment. We have removed the word in the manuscript.

Fig1: Axis notations and color bar legends are very small, in some cases much too small. Panel c) at normal size the solid and dotted line are hard to distinguish. Please use colors and bolder lines.

Thank you for the suggestion. Following the reviewer's comment, we improve the quality of Fig. 1 in the revised manuscript.

P957L9 over -> above

It is changed.

P957L14 significant correlation -> close correspondence I see a certain correspondence, but it looks to me whether on shorter timescales and in general trends the two quantities correspond, but that there is also a development on the scale of a day in total divergence which is not contained in HDTGW. I definitely do not recognize any particularly highlighted or exceptional periods. For instance, from 15UTC8 to 3UTC9 every small scale structure is contained in both quantities but the larger trend is somewhat different.

As reviewer pointed out, small timescale perturbation shows distinctively similar pattern between total divergence and HDTGW in a specific period (e.g. 15UTC8 to 3UTC9). Our calculation of correlation coefficient between HDTGW and total divergence during 36 hour period (from 12 UTC 08 to 00 UTC 10) also revealed a strong correlation, which is added in revised manuscript (line 88, page 6). Spectral analysis of HDTGW shows distinct peaks at between 16 to 24 hours (Figure 1(e)).

P957L17 "During this period, IGWs contribute to the total divergence about 30% in UTLS." How do you reach this conclusion? If you claim a "correlation" you should calculate correlation coefficients. If you want this time dependent you could do it in sliding windows.

The magnitudes of total divergence and HDTGW are calculated at each time step, and then we can estimate how much portion of total divergence is from TGWs at each time step.

P957L27 "Strong correlations between the total divergence and minimum SLP, HDTGW and minimum SLP, and total divergence and HDTGW in UTLS during the rapidly developing period demonstrate the contribution of IGWs to typhoon evolution." How do you know what is cause and what is effect? Please expand the argument.

The main objective of the present study is to understand a feedback process between TGWs and typhoon evolution through HDTGW. At the first step, TGWs are generated by convective clouds associated with typhoon, and then TGWs influence on total divergence that influence on MSLP. After the first step, continuous feedback process may take place, which may difficult to separate causalities at each time. A statement related to this issue is included in the revised manuscript. (line 104, page 7)

P958L5 "The domain-averaged vertical velocity averaged over 3–15 km a.g.l. and domain averaged 30 min accumulated precipitation amount (Fig. 1c) is generally well matched throughout the whole 48 h, except in a decaying period after 00:00UTC 10." At this point I really would like to ask you to calculate a correlation. My impression is that the two curves are not particularly similar except the fact that they seem to have similar auto-correlation time scales. If you think that at this position an intensification of the typhoon is most likely caused by the divergence fields then argue along these lines.

We appreciate your insightful comments. The correlation coefficient between vertical velocity and precipitation during entire 48 hours is -0.61 at 11 hours lag with 99% confidence level, while that during the rapidly developing 12 hours period (00UTC9-12UTC9) is 0.86 at 0 lag with 99% confidence level. Based on this result, the statement is modified in the revised manuscript (line 109, page 7).

P958L5 peaks -> peak

It is changed.

P959L2 If you say primary / secondary peak I would expect two distinct spectral features. For me this looks like a single broad peak.

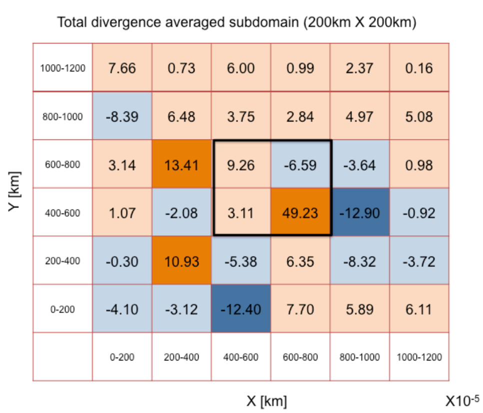
We agree with the reviewer's point. We change the primary and secondary peaks to distinct peaks throughout the revised manuscript.

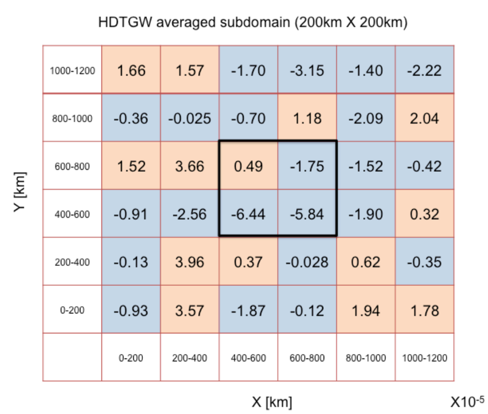
P960L25 How did you calculate the phase differences? Please describe.

We calculated in and out of phase between the total and TGW divergence fields. The phase is decided by comparing signs of total divergence and HDTGW at each grid point. When both total divergence and HDTGW has the same (different) sign, the grid point is marked by "+1" ("-1").

P961L2 "especially in the inner-core region" To me it appears at least as obvious in the SW. I think a method to analyze this would be to use averages over suited subdomains (e.g. 200km x 200km). If there are general biases these should become visible. This could be also helpful to detect phase changes of a larger scale GW (cf. major comments).

We appreciated your valuable suggestion. We setup subdomain (200 km by 200 km) and calculated subdomain-averaged horizontal divergence at each subdomain at the same time as in Fig 2. (03UTC9). Results are shown below. There are more numbers of positive subdomains in total divergence (left) and negative subdomains in HDTGW (right). Black box shows the location of inner core and evidently divergence (convergence) is dominant in this region for total divergence (HDTGW), as mentioned in the manuscript. Last figure shows phase differences between total divergence and HDTGW based on top figures. The results show in phase in western subdomains and out of phase in the southern subdomains of inner core and south of the inner core, although with less evidence. Considering that subdomain-averaged total divergence and HDTGW are due relatively longer-wavelength GWs, the phase is somewhat difference from that shown in Fig. 2d, especially near inner core and SE in which relatively short horizontal wavelength waves have strong powers, as shown in Fig. 3a. A paragraph related to this subdomain calculation is included in the revised manuscript (line 212, page 12).





Phase difference (in phase:1 and out of phase: -1)

Y [km] \ X [km]	0-200	200-400	400-600	600-800	800-1000	1000-1200
1000-1200	1	1	-1	-1	-1	-1
800-1000	1	-1	-1	1	-1	1
600-800	1	1	1	1	1	-1
400-600	-1	1	-1	-1	1	-1
200-400	1	1	-1	-1	-1	1
0-200	1	-1	1	-1	1	1

Top left (right) shows total divergence (HDTGW) averaged over subdomain (200 km by 200 km). Note that units are s^{-1} and red (blue) color represents divergence (convergence) dominant subdomain. Darker color shows the subdomain having larger value (over $\pm 10 \times 10^{-5}$). Bottom figure shows same as top figure but phase differences. Gray color shows subdomain having in phase.

P961L5 Why refer to KC11, was that not shown in Fig1b?

The statement is modified using Fig. 1b instead of referring KC11 (line 202, page 11).

P961L14 And no reader (or reviewer) can follow (or help with) it, since the methods are not described! Actually, this finding worries me. General biases are one thing, but almost the same structures at just larger amplitudes and a shifted phase could point to a problem with the method you use to isolate the horizontal divergence of the GWs.

Following the reviewer's suggestion, the method to calculate total divergence and HDTGW is described precisely in the revised manuscript (line 56-68, page 5). Please note that there is no ambiguity in extracting IGW components from the "total" perturbation wind fields, and that the total divergence contains HDTGW, because divergence is the linear term. That is, perturbation winds contain TGW and other components, and total divergence is just a sum of the HDTGW and remaining divergence by longer and shorter period perturbation components than IGW frequency range. The phase analysis (Fig 2(d)) is employed to find reason for the disappearing of short period wave components when the HDTGW was domain-averaged.

P961L15 While Typhoon Saomai was rapidly developing, a strong outflow layer developed near the tropopause.

It is changed as suggested.

Fig2e) In panels a,c white at the typhoon center presumably marked values out of the color scale. I presume that happens in panel e, too. It would be better to use a "saturated" color scale, i.e. to use the largest (largest negative) value for all values exceeding the color scale. In any case you need to mention this point in the text.

We have changed the figure following reviewer's suggestion.

Referee 2.

Specific Comments:

In the last paragraph, more clarity or a statement is expected about the relative contribution or comparison of short period gravity waves (with 20-30 km horizontal wavelength) with that of ~24 h wave (with large horizontal wavelength) to the horizontal divergence or the interaction between them. As mentioned in the paper that domain averaged HDTGW (indicating short period gravity waves role is minimized) the feedback seems active between large period gravity wave and the horizontal divergence. It is apparent the interaction is two way process and may be difficult to speak about the cause and effect, however a tentative statement may be given at this stage about the time-evolution of the typhoon once the inertia gravity wave is produced.

The domain-averaged HDTGW is due mostly to long-wavelength and low-frequency components of GWs of IGWs that are likely generated by low-frequency convective sources in outer rainbands. It is not straightforward to clearly separate the role of short-period GWs and ~24 h GWs on the feedback between TGWs and typhoon evolution. However, as long as typhoon evolution has a period near 24 hours, in terms of MSLP, we can guess the contribution by short-period GWs is limited. Following the reviewer's suggestion, relative importance in contribution by long and low-frequency GWs to the feedback process is included in the last section of revised manuscript (line 340, page 17).

Technical Comments:

I think use of HDTGW is more precise than HDTGWs in the text.

We agree with you. Along with the other reviewer's suggestion, we have changed HDTGWs to HDTGW in the revised manuscript.

Page 4, L 6, Year of the typhoon after the date may be mentioned.

Thank you for your suggestion. It is changed.

Page 4, Correction L10, 12:00UTC 8 -> 12:00UTC 8 August (or Aug), without mentioning month seems incomplete. Make it uniform at all places in the text.

Thank you for your suggestion. We have added month throughout the manuscript.

Figure 1: Font size of Fig (s) is too small and be increased proportionately.

We improved Fig. 1 following the reviewer's suggestion.

Page 9, L 12-14 - the reason is not known?

The difference between HDTGW and total divergence is that the total divergence includes additional divergence by perturbations with intrinsic frequencies longer than and shorter than IGW frequency range shown in Eq. (2). At this moment, it is not clear which parts of wave spectrum (low- or high-frequency or both) makes phase difference between HDTGW and total divergence. Following the other reviewer's suggestion, we calculated the total and HDTGW averaged over subdomains (200 km by 200 km) within a total domain shown in Fig. 2a. The result is included in the revised manuscript without figures (line 212, page 12). Please refer figures of subdomain results in the response to the first reviewer's comments.

Page 13. L6, Already, acronym HDTGW is defined, no need to define again.

It is changed as the reviewer suggested.

Page 14. L9, azimuthal angle -> varying azimuthal angle

It is changed.