Round 2: Review on
"Mesospheric gravity wave activity estimated via airglow imagery, multistatic meteor radar, and SABER data taken during the SIMONe–2018 campaign"
by Fabio Vargas et al.

Report #1
Submitted on 25 Jan 2021
Anonymous Referee #1

Thank you for addressing my suggestions to improve your paper.

We deeply appreciate your comments which have helped to improve our paper enormously.

I have a few more comments about your answers and the edited text, though.

- I will try to better explain my previous comment about the 20-min intrinsic period. If a wave has an observed period of 20 minutes (the limit due to the camera sequence), with an observed phase speed of for example 75 m/s (Lh would then be 90 km), but if it's traveling AGAINST the wind (25 m/s wind amplitude for example), the intrinsic period of the wave will be only 15 minutes. Since a lot of the waves you observed are propagating against the wind (Figures 5f and 5k), it is surprising that almost no waves have an intrinsic period < 20 min (Figure 5e).

I believe the answer for could be in the auto-detection method processing sequence. The Doppler shift caused by winds is corrected prior to obtain the wave parameters. Then we calculate the intrinsic wave parameters. I believe the scenario described by the reviewer would be true if the Doppler shift correction was done after the observed wave parameters were obtained. Ultimately, I believe it comes down to the sampling period of 10 minutes limiting the detection of periods longer than 20 minutes, which is a consequence of the Nyquist theorem.

- The time span of each set you analyzed is 20 min, not 30 (first image at time = 0, second at time = 10, third at time = 20).

- We agree with the reviewer and have corrected that in the paper.

- Furthermore, I don't agree that waves last only a short time and that they would have disappeared from the camera fov (512 km in your case) in 20 or 30 min (if the horizontal phase speed is 50 m/s, it would take the wave ~3 hrs to propagate 512 km!) Some GWs can be observed during the whole night as they depend on the source activity and the background atmosphere conditions. There are multiple publications about wave events lasting for hours, so you have to be careful when you consider that your wave detections are independent.

- The waves described by the reviewer resemble trapped oscillations, meaning these waves do not propagate vertically. The auto-detection method only outputs parameters of vertically propagating waves. Thus, the method samples waves that would move across the layer and disappear. For instance, taking our wave parameter distribution, the typical vertical wavelength is 20 km and typical period is 30 minutes, giving a vertical phase velocity of 0.7 km/minute. It would take about 15 minutes for the wave to cross the 10 km width of the layer. That justifies our claim that the waves have short duration. This short duration events hit at either a short lifetime excitation source, or intermittent transmission source, which the autodetection method does not tells apart since the gravity wave parameters change from set to set.

- a more "manual" method would have been interesting to identify the waves as the data set is not that big (only 4 nights with images every 10 min).
  - The benefit of the autodetection method is that the human bias is removed from the wave analysis, meaning that manual analysis would bias the statistics toward large amplitude waves because they are more appealing to the eye. Observe that this human bias exists indeed as parametrization of gravity waves rely on statistics of large amplitude wave events, which are the minority of waves observed. The impact of small amplitude gravity waves in the MLT dynamics should be also taken into account.

- difference imaging can create bias as it tends to filter out waves which don't propagate (like mountain waves),
  - That is correct. Terrain-trapped oscillations and any non-phase propagating perturbations (like ripples) are attenuated by the time difference filter.

or waves with an observed period which is proportional to the observation sequence (in your case 20, 30, 40... min).
  - That seems not the case since our results show multiple waves in the 40 minutes range.

Minor comments:
line 7: characterized: corrected.
line 8: percentage: corrected.
line 21: transports (maybe, not sure, does it apply to "class" or "waves"?): corrected.
line 24: When these waves... : corrected.
line 51: ... to study large-scale... : corrected.
line 58: provided: corrected.
line 92: discusses: corrected.
line 107: you explain where 725 km comes from later, but maybe you should do that here: removed.
line 114: to receive: corrected.
line 133: present: corrected.
line 135: window. : corrected.
line 145: word missing after "each": corrected.
line 161: simulated: corrected.
line 162: ...oxygen profiles... : corrected.
line 181: 20 minutes: corrected.
line 183: ...it is more... : corrected.
line 192: during the campaign: corrected.
line 194: returns: corrected.

line 201: ... layers as the layer peaks are within... : corrected.
line 204: larger scales: corrected.
line 224 and Figure 8: can you change the time in the figure from am/pm to zulu (21, 22...)? : corrected.Same thing for Figures 1 and 10. : corrected.
line 247: reveals: corrected.
line 252: remove the extra "the": corrected.
line 254: on Nov. 6-7... : corrected.
line 262: Within the 86-98 km range... : corrected.
line 284: during a week: corrected.
line 289: which only allows: corrected.
line 291: ... minutes, near... : corrected.
line 299: for the results of... : corrected.
line 314: not sure they are so short. Do you have any references to back that up? No, this is based on our own experience.
line 315: As I wrote before, I think they are unlikely to be always independent. Please see reply above.
line 338: "presented" instead of "demonstrate": corrected.
line 341: "calculated" instead of "demonstrated": corrected.
line 349: revealed: corrected.
line 381: have also... : corrected.
line 415: second Lz should be Lh: corrected.
line 415: ...will be smaller because... : corrected.
line 416: unlikely: corrected.
Maybe Appendix A could be included in the text. We have decided to keep it in the appendix and closer to the other technical s appendix sections.

As another reviewer pointed out concerning SABER data, it is surprising that nobody from Boston University is included as a co-author or at least acknowledged since they provided the image data.
Boston University does not own the imager and did not provided the image data, but only host the images generated by the system. We have added to the Acknowledgements: “We thank the support of Boston University colleagues and in particular J. Baumgardner to operate the airglow imager.”

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Report #2
Submitted on 25 Jan 2021
Anonymous Referee #3

I appreciate the efforts of the authors to answer my comments. From my point of view the quality of the manuscript improved a lot.

We thank you and appreciate the time taken to read and point out issues in our manuscript.

However, I am still a bit unsure about the analysis the authors applied for the derivation of the short-scale waves in the following sense:

• Thanks for providing a figure in the comments which shows the ratio of the amplitude measured in TD pictures and the original one versus wave period. From my point of view, it is important to know to which waves the analysis is sensitive, so which waves come out of the analysis with which amplitude. It would be great if the authors could include a similar figure (but for delta t = 10 min instead of 2 min since the difference between the images is 10 min) or at least the corresponding information (e.g., waves with periods between 20 min and 60 min are enhanced by a factor between 1 and 2, the shorter the period the stronger the enhancement) also in the manuscript. This makes it easier to find out which waves are addressed in this study and facilitates comparisons with future studies.

- We have provided a plot in the appendix A for the time resolution of our imager (lines 475-480 in the revised paper draft).

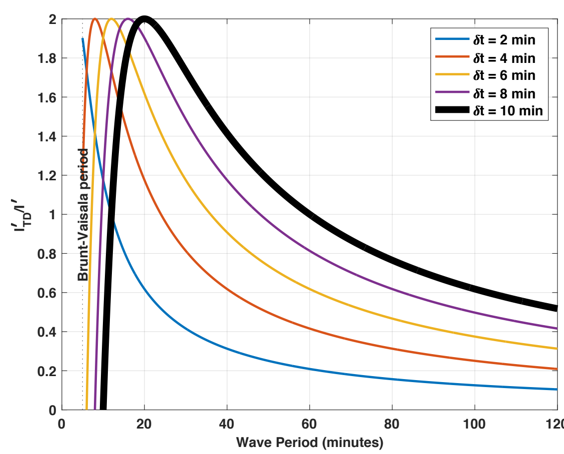

Figure 1 - Effect of time difference image filter on gravity wave amplitudes of various periods and acquisition times (δt) . The black thick line corresponds to the acquisition time of our imager during SIMONe--2018.

- The plot is derived by applying the following equation

$$I'_{TD}/I' = 2 \sin(\text{omega} \cdot dt / 2) \quad (1)$$

where I'_{TD} is the TD wave amplitude, I' is the real wave amplitude (prior TD filtering), omega is the wave frequency, and dt is the time resolution (10 minutes for our imager; dark continuous line in the Fig. 1 above).

• The calculation of TD images leads to a change in the amplitude of the waves (in the TD images compared to the original ones). The amplitude influences the FFT and therefore also the result of the cross-correlation analysis. The authors use the values of the cross-correlation analysis, e.g. for the derivation of the momentum flux. That means the calculation of TD images influences the momentum flux as far as I understand the algorithm. Has this been taken into account, for example, in the calculation of the error bars or is the effect negligible?

- The reviewer is correct. The TD filter affects the amplitude obtained from the cross-spectra. This issue is taken care of prior any wave parameter is computed. We estimate the correct wave amplitude I' by using equation (1) above.

Further comments:

p.15, l. 443 The authors write here that they restrict the data to 174 x 174 km², then, they calculate the TD pictures and apply a 2D FFT with a Hanning window on them (which makes the FoV smaller).

- The Hanning window does not make the FOV smaller, meaning the output frame size is the same as the input frame size. The window treats the edge effects due to the limited FOV size. We apply a symmetric 2D Hanning window (same size of the image) to the image frame prior calculating the FFT. The Hanning window tapers down from 1 at the center of the image to ~0 at the edges following the equation

$$w(n)=0.5(1-\cos(2\pi n/N)); \quad 0\leq n\leq N; \quad \text{window length} = N+1$$

In section 3.1, they define short-scale waves as waves with wavelengths shorter than 725 km since this is the diagonal of their original FoV (512 x 512 km²). I am aware of the fact that the FFT can also deliver wavelengths which are larger the side length or the diagonal of the reduced FoV (so 174 x 174 km²)

- See our comment above please.
- We agree the FFT can deliver wavelengths that are larger than the diagonal length. Please read our reasoning below (reply to your second question).

, however, if the waves do not fit completely into the FoV, the amplitude one gets from the FFT is reduced (the larger the wavelength, the worse the effect). The application of a Hanning window does not improve the situation since it makes the FoV smaller.

- The Hanning window helps in avoiding fake spectral peaks and aliasing. But the reviewer is correct, if the wave does not cover entirely the FOV, it is not possible to recover the full wave amplitude, although we have chosen the analysis window FOV to minimize that issue.

First question: Did I get the authors right that they used the FFT applied on the 174 x 174 km² FoV to derive wavelengths of up to 725 km? In figure 5 they show a maximum horizontal wavelength of 150 km but in the manuscript they state that the short wavelengths reach 725 km at maximum.

- The nominal FOV is determined by the dewarping operation to remove the fisheye lens distortions and mapping the image into an uniform geographical coordinate system. By default, we map the image into 512x512 km^2 FOV into a 512x512 pixel^2 frame, giving a pixel resolution of 1km/pixel. In this frame, the diagonal measures sqrt(512) ~725 km and defines the limit of the largest horizontal wavelength (lh) seen. In that case, the wave would cover the entire FOV. In general, waves seen have much smaller horizontal scales, and the analysis window of 174x174 km^2 was chosen by taking into consideration this fact, meaning the analysis window is well calibrated to capture most of the waves. If one do the analysis manually using the entire FOV, the wave scales observed will be in the output range the auto-detection method that is, lh<sqrt(174) km.

Second question: does a reduction of amplitude depending on the horizontal wavelength influence the results and if yes and this effect is not negligible, have the authors taken that into account?

- As stated above, we have taken care of the TD filter effect on the amplitude. It is different of what the reviewer wants to know, which is the FFT effect on the amplitude for waves with lh larger than the FOV diagonal length. The answer for that is: partially. That means, the analysis window is small enough to permit waves covering the entire area, since the horizontal extension of the wave packet is ~174x174 km^2 or smaller. By horizontal extension we mean the area covered by the wave oscillatory structure.
- If the horizontal extension of the wave package is larger than that, but lh<sqrt(174) km than we can obtain the wave amplitude fairly well, but we do not track departures of that case as we hypothesize that does not occur frequently based on observations.

Minor points:

p. 1, l., 14 relative amplitudes: relative to what? : corrected.

p. 5, l., 135 It's probably meant a rectangular window not a Gaussian one or something like that. It would be great if this info could be added. : corrected.

p. 5, l., 145 there needs to be "day" after "each" : corrected.

p. 5, l. 127 in the first version of the manuscript: I asked the authors to concretize the lapse rate they mean and they asked me whether I would like them to explicitly give the value of the lapse rate. No, it would just be good if the authors could insert "atmosphere" before "lapse rate" (in the line before the authors mentioned the atmosphere lapse rate and the adiabatic lapse rate) to make it clearer for the reader. : understood. Thanks for the clarification.

Table 3 I appreciate the error bars, but could the authors please also them to all components? : corrected.

Some typos:

p.5, l., 137 the instead of The: corrected.

p. 6, l. 161 simulated instead of simulate: corrected.

p. 9, l. 262 Probably 88–98 km instead of 86–98 km: corrected.

p. 14, l. 416 second lambda_z must be a lambda_h: corrected.

p.15, l. 439 Replace "." with ",": corrected.
p.16, l. 477 c_v instead of cv: corrected.