Author's Response

The authors would like to appreciate the reviewers for their comments and suggestions.

We have addressed and responded to the comments and suggestions of the reviewers accordingly. The text highlighted in blue are the responses. These responses are implemented in the manuscript and also highlighted in blue as well.

General review:

This paper investigates the characteristics of vertical propagating gravity waves (GWs) using observational data from co-located photometers, all-sky imagers, and meteor radars at São João do Cariri. The focus is on quantifying the momentum flux and potential energy associated with GWs as they propagate vertically through various atmospheric layers. The study leverages airglow emissions and rotational temperature data to analyse phase progression and vertical wavelength across different altitudes. The results emphasize the dynamics of momentum and energy transfer under varying propagation conditions, including ducted and near-vertical propagation scenarios.

Areas for improvement:

The paper includes a vast amount of technical detail but lacks an initial high-level summary that could provide readers with an overview of the key findings and their significance. Add a summary at the beginning that outlines the study's objectives, methodology, key findings, and implications in a concise format.

Response:

Momentum flux and propagation dynamics of two vertical propagating atmospheric gravity waves (GW) are studied using observation at São João do Cariri, Brazil (36.31°W; 07.40°S) by co-located photometer, all-sky imager, and meteor radar. Time series of atomic oxygen green line (OI 557.7 nm), molecular oxygen (O_2), sodium D-line (NaD), and hydroxyl (OH) airglow intensity variations measured by the photometer were used to investigate the vertical characteristics and phase progression of the GWs with similar/same period across these emission layers. The horizontal parameters of the same GWs were determined from the OH airglow images, whereas the intrinsic parameters of the horizontal and vertical components of the GWs were estimated with the aid of the observed winds. Using the phase of the GWs at each emission layer, the characteristics of the phase progression exhibited near vertical propagations under a duct background propagation condition. This indicates that the duct contributes significantly to the observed near vertical phase propagation. The GW momentum flux and potential energy were estimated using the rotational temperatures of OH and O2, revealing that the time series of momentum fluxes and potential energies are higher in the O_2 emission than OH, a transfer of momentum and energy across OH to the O_2 altitude. These results reveal the effect of a duct on vertical propagating GW and associated momentum flux and potential energy transfer from the lower to the upper altitudes in the mesosphere.

The study does not explore how the findings can be applied to broader atmospheric modeling or real-world scenarios like weather prediction or satellite operation. Please Add a summary at the beginning that outlines the study's objectives, methodology, key findings, and implications in a concise format.

Response:

Numerous studies (e.g., Fritts et al., 2006; Suzuki et al., 2013; Love and Murphy, 2016 Kaifler et al., 2020) employed some of these observational techniques to explore the subject of dynamics of GWs and their momentum fluxes and potential energies. Fritts et al. (2006) investigated the momentum fluxes due to GW activities in the MLT region using wind measurement from incoherent scatter radar (ISR) at Arecibo observatory. Using a time resolution of ~50 minutes, between 71 and 95 km, they quantified GW momentum fluxes profiles. VHF mesosphere-stratosphere-troposphere (MST) radar measurements situated near Davis station (68.5°S, 78.0°E) were used by Love and Murphy, 2016 to study the hourly averaged profiles of GW momentum fluxes between 79 and 90 km along the day. Love and Murphy, (2016g) investigated hourly averages of momentum fluxes of days considered within the period of 14 December 2014 to 6 January 2015 as well as GW intermittency with altitude. Using a co-located observation, Suzuki et al. (2013) investigated the vertical propagation of GW from the lower to the upper atmosphere at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) station (69.31°N, 16.01°E). Using the sodium (Na) airglow imager, the horizontal structure of GWs is observed, whereas the ALOMAR Rayleigh/Mie/Raman (RMR) lidar and sodium lidar reveals the two-dimensional vertical structure of GWs between the stratosphere and the lower thermosphere. This coincident observation permitted the study of horizontal and vertical characteristics of GWs and the momentum flux at the Na airglow altitude. Kaifler et al. (2020), on the other hand, used high temporal and vertical resolution Lidar to study the derived time series absolute momentum fluxes of mountain waves at 40 km and profile of mean and peak of the absolute momentum fluxes between 10 and 80 km.

The above-mentioned works have by far contributed to quantifying the characteristics of the momentum fluxes of GWs and mountain waves (MWs) through statistical and case studies. However, none of these studies explored the aspect of how the momentum fluxes and possibly potential energies would behave under different vertical and horizontal propagation of GWs. Therefore, the standing question this work addresses is, the behaviour of the momentum flux and potential energy of GW under different phase/energy propagations, thus, upward, downward or ducted. Using the vertical phase propagations of GWs, the energy propagation can be determined.

For this, investigation was made on the vertical characteristics of GWs with similar or the same period propagating vertically across four (4) airglow emission layers: atomic oxygen green line (OI 557.7nm), molecular oxygen (O_2 - 864.5nm), sodium D-line (NaD-589.0nm), and hydroxyl (OH) (6-2) band. Next is the determination of the phases of the wave at each layer and, consequently, the phase propagation. The horizontal characteristics of the same GWs are estimated from OH all-sky images. Using observed wind, the intrinsic parameters were also estimated. Having determined and classified these GWs as vertically propagating, the background propagation conditions are studied as well as the potential energy and momentum flux at the OH and O_2. The temperature measurements employed to determine the potential energy and momentum flux were obtained using the rotational temperature at the OH and O_2 emission layers. The dynamics of the GWs potential energy and momentum flux under the determined propagation condition were then studied. It was discovered that the vertical propagation of the cases selected were controlled by the background conditions imposed by the wind and temperature.

The selection of the two gravity wave events could benefit from a more explicit justification regarding their uniqueness or representativeness. Please Provide a stronger rationale for selecting the specific GW events analysed and discuss how they compare to other observed events.

Response:

To select the cases, they must satisfy the following criteria:

1. GWs with similar or nearly the same periods must be observed in all the four (4) emission layers;
2. similar or nearly the same periods observed in the four airglow intensity variations must be present in the OH and O2 rotational temperature;
3. similar or the same periods observed in item #01 must be present in the OH and possibly O_2 all-sky images;
4. the periods of the GWs at each emission layer must be present in the time series for 3 hours or more.

Besides selecting these two GW events due to the presence of nearly the same periods in the four emission layers, these events permit the exploration of the dynamics of GWs using (1) observed variables in the MLT region at high temporal resolution and (2) derived momentum flux.

To achieve this, all three (3) criteria must be satisfied. Most of the observed cases that met criteria #3 either lack criteria #1 or #2. This is to say that most of the cases have nearly the same period in three emission layers and one rotational temperature, like the work of Nyassor et al., 2018. On the other hand, majority of the events have similar or the same period in just two (2) emission layers.

Minor suggestions:

Line 567, thee -> the (now Line 627)

Response: the word “thee” has been changed to “the”.