Authors' answer to Referee 1:

Reviewer comments in black, author's comments in blue.

Referee #1 Comments:

This paper addresses an important topic by attempting to provide statistical estimates of medium-scale gravity wave momentum fluxes (MF) over Antarctica. The scope is significant, and the dataset has potential value.

However, the analysis and interpretation of the presented results and distributions are not sufficiently developed. In several parts, critical methodological details and supporting evidence are missing, which raises concerns about the reliability of the findings. The comments I provide below are not limited to minor clarifications but rather point to substantial issues that require a re-examination of the overall results and interpretations. Therefore, in its current form, I believe this manuscript is not ready for publication, but it may become suitable if the authors carefully address the points raised.

Manuscript Recommendation: 1) Major Revision (70%) 2) Rejection (30%)

Minor concerns

1. The CF fitting method given by Vargas et al. (2021) for medium-scale gravity waves should be described in more detail to ensure reproducibility.

   Response:

We appreciate the reviewer's comment regarding the need for more methodological detail on the Cancellation Factor (CF) fitting method. To ensure reproducibility and clarity, we provide the following detailed explanation of the method's physical basis and mathematical implementation used in this study.

Physical Basis of the CF: The CF is a quantitative parameter used to relate the observed zenith-viewed airglow intensity perturbations (I') to the actual gravity wave temperature amplitudes (T'). Because airglow layers have a finite thickness (typically ~8–10 km), waves with vertical wavelengths (λ_z) on the order of, or smaller than, this thickness undergo "cancellation" when the emission is vertically integrated. The CF corrects for this effect:

$$C_f = I'/T'.$$

The Modeling and Fitting Procedure: The CF values were originally derived using a linear, one-dimensional model that simulates the response of volume emission rate (VER) profiles to upward-propagating gravity waves. The model:

1. Specifies a wave perturbation of known amplitude (T') at a reference altitude.

2. Calculates the resulting perturbations in species densities (O, O_2, N_2) and temperature-dependent reaction coefficients.

3. Integrates the perturbed VER profiles vertically to determine the resulting brightness amplitude (I').

4. Establishes the CF as the ratio of these perturbations (I'/T') over a range of vertical wavelengths.

For this manuscript, we adopted the analytical fitting function established by Vargas et al. (2021), which is particularly robust for vertical wavelengths where $\lambda_z > 10\ km$. The specific equation used is:

$C_f = 4.6 - 3.7e^{0.006\lambda_z - 6}$.

This function represents the asymptotic behavior of the cancellation effect, where the airglow emission becomes more sensitive to perturbations as the vertical wavelength increases relative to the layer thickness.

Please refer to the Lines 153-168 of the new version for the new description and modifications.

2. While frequent observations of airglow imagers are qualitatively described, quantitative information on the operational rate of the observation system is required.

Response:

Thanks for the suggestion. We have included a detailed but brief description of the airglow imagers, as reproduced here:

Airglow imagers installed at the stations of McMurdo (77.8° S, 166.6° E, hereafter MCM), Davis (68.5° S, 77.9° E, hereafter DAV), Rothera (67.5° S, 68.1° W, hereafter ROT), and Commandant Ferraz's Brazilian Antarctic station at the Antarctic Peninsula (62° S, 58° W, hereafter CF) {provided the primary data for this study. They measure the broadband hydroxyl (OH) emission originated from an $\sim$8 km-thick layer at $\sim$86 km altitude and is widely used as a tracer of the dynamical processes in the mesosphere and lower thermosphere (MLT) region. To ensure no direct light contamination or twilight, the cameras are controlled by a computer to work when the sun and moon are absent (with the Sun ~10 degrees below the horizon)}. The imagers installed at McMurdo and Davis are the Utah State University (USU) all-sky cameras, while multifilter all-sky imagers were used at Commandant Ferraz and Rothera stations. Furthermore, the imagers at McMurdo and Davis are owned and operated by USU.

The IR imagers located at McMurdo and Davis are fitted with a 320 × 256 pixel indium gallium arsenide (InGaAs) detector (from Xenics), sensitive to 900-1700 nm where contamination of auroral emissions (visible–800 nm) is smaller compared to CCD detectors. The camera is sensitive to the desired spectra and has good efficiency, thus does not require an interference filter. The imagers observe several OH emission bands, specifically the (3,1) and (4,2) bands (>100 kR), thus permit the use of a short exposure time, 3s with acquisition cadence of 10s per every image. A Fujinon E185C046H-1 C-mount fisheye lens is used to observe the whole night sky. Further details can be found in Matsuda et al. (2017).

The instruments at CF and Rothera are Keo Scientific Sentri cameras, made out of CCD intercooled with a telecentric image system and a fish-eye lens. The efficiency is near 90\% for all the near infrared emissions, corresponding to the used broad band filter of 700-900 nm; more information on the Keo cameras is available on their website (keoscientific.com/imagers). The effective field of view is about 145°. The resulting images were binned to a spatial resolution of 512x512 pixels for improving signal-to-noise ration. The exposure time of the images was 15s and temporal resolution is 2 min at CF and 4 min at ROT, due to different filter wheel operation sequence. A detailed description of the imager and the required image acquisition modes can be found in previous studies (Medeiros et al., 2005; Nyassor et al., 2018; Paulino et al., 2020).

The cameras operated automatically on winter nights and have operated simultaneously and almost uninterruptedly since 2015, providing a large amount of coincident all-sky observations. This study uses the airglow data from 2022, the most recent year of simultaneous observations from those four sites. It is important to note that the USU camera observes the OH layer in an infrared band (IR), while the multifilter cameras measure in the near-infrared spectrum (NIR), mainly emissions of OH (8-3) and OH (6-2), so they have different detection spectra, and the observed altitude layer may be slightly different. In Table 1, a summary of the four airglow imagers utilized for the current study is presented.

Table 1. Summar of airglow imager used.

Station	Geo. Location	Airglow	Exposure	Sampling Time	CCD Size
CF	62.1°S, 58.4°W	OH	15s	1 min	512 x 515
Davis	68.5°S, 77.9°E	OH	3s	10s	320 x 256
McMurdo	77.8°S, 166.6°E	OH	3s	10s	320 x 256
Rothera	67.5°S, 68.1°W	OH	3s	4 min	512 x 512

Minor concerns

1. Considering the spatial scale of the observation images, the claim of detecting gravity waves with wavelengths up to 1000 km is not convincing. With the presented method alone, it is difficult to justify such long-wave detection.

   The observation window of the MSGW observed by airglow is not rigorously determined, although we expect a considerable extension on the wavelengths able to be observed due to projection into the time domain, which removes the constraint of the observation window from the images size. As shown in the methodology paper, the wavelength is obtained by the slope of the wave front in the keogram, and how much inclination we can see will depends of the observation length on time. We always are sure to observe two wave fronts (and two troughs) on the keograms. Also, a detailed but brief description of the methodology is reproduced in the text lines: 103-129.

2. In the speed distribution, it is questionable how waves with minimum wavelengths of 50 km could exceed 200 m/s. This raises suspicion that raw calculated values were directly included in the distribution without sufficient physical justification.

   That is incorrect. We check by inspection wave by wave after the procedure is done to ensure that no wave have speeds larger than the sound speed, and no wave with as shorter wavelengths as 50 km have more than 200 m/s of speed. By inspecting the wavelength versus phase speed, we see that the phase speeds grow as a function of the wavelength, as expected. Please refer to the paper containing the methodology in more details, as it tested the spectral analysis against the previous version.

When using WACCM-X data, the authors must clearly describe how the model outputs were matched with image data, how regional sampling was performed, and provide example profiles of the parameters used in the dispersion relation.

Information added to the text. No regional sampling was used as the model output is very smooth along the space and already represents the atmospheric condition in an averaged way. More information on the WACCM-X was inserted. Please refer to the lines 130-140 of the new version.

3. The authors appear to have constructed a sufficiently large GW dataset at each station, and the attempt to present MF values not commonly documented is meaningful. However, a strong concern arises: why do MCM and DAV exhibit stronger MF and I′ distributions than the well-known GW hotspots at the tip of Antarctica/Antarctic Peninsula (CF, ROT)? Are the results truly reliable? To clarify this, the following requirements must be shown:

   4-1 (I′ part) → Specify the minimum image sequence time range and the minimum number of images used to calculate I′, and explain why these thresholds were chosen.

   We use the average brightness of the night, excluding the images with auroras (in DAV), twilight time and clouds. The brightness amplitude is determined from the output of the wavelet with the corrections described in the reference (Xu et al., 2024). Those corrections were carefully checked by the same methodology described in the previous paper. Also, relative amplitude was defined and explained how it was calculated, and how it is used for the momentum flux estimation. Please refer to Lines 125-129, and 153-168 for the new version.

   4-2 (MF part) → Similar to the above, present the distributions of the parameters included in Eq. (2) of the dispersion relation for each station, and interpret them. Since the paper relies heavily on distributional analysis, distributions of the source parameters must also be provided and discussed.

   Parameters included in the dispersion relation were presented along the results section: wavelengths, period, phase speed and amplitude.

Temperature and wind were taken from WACCM-X model, and buoyancy frequency is calculated from the temperature profile. The calculated parameters are thus, calculated from the observed ones, as well as momentum flux with the cancellation factor.

Otherwise, the hot spot region of the Antarctic peninsula was observed in the stratospheric heights, and we have evidence that the observed waves are secondary waves. So, we could infer that the secondary waves above the mountainous regions have less amplitudes hence momentum fluxes, although they are more frequent. Another aspect to take into account is the fact that waves with larger amplitudes are more intermittent, as were seen in the stratospheric observations.