Response to the referee comments

We thank the referees for their valuable and helpful comments. We have addressed all of them one-by-one in details as listed below. The comments are in bold and our replies are in regular font. The page/line numbers indicated in our replies are given with respect to the old manuscript, and may differ from the revised manuscript.

Referee #2

General comments:

The manuscript investigates requirements for satellite limb optical measurements using O_2 A-band emissions to retrieve characteristics of gravity waves (GWs) and GW momentum flux that strongly influences global circulation in the middle and upper atmosphere. The manuscript is mainly based on modelling results. The present study is very useful and worth publication. However, the text is rather demanding to read, partly due to the complexity of the problem. Nevertheless, I believe that some formulations could be simplified, some points better explained and specified or located in more convenient places in the text. I provide several examples in the specific comments below, but I encourage the authors not to limit themselves to them only. I recommend a moderate revision.

The referee's comments helped us to improve our manuscript. We revised the manuscript thoroughly, reduced/simplified the side-topics and rephrased some parts of the text to make them more clear. Specifically, we excluded Appendix A since the discussed scale-separation method was actually not used in our study. The explanation about the Key Quantity – zonal mean GW momentum flux was updated in the Introduction and Sect. 2.2. The description of the interferogram split method in Sect. 3.5 was reformulated. In the Discussion section, we included the discussions about the existing satellite observations and their limitations, as well as the global wind data availability in the MLT region.

Specific comments

1. **Introduction (for example in Key Quantities), the authors only speak about zonal GW momentum flux and direction distribution of the flux. Does the direction only mean the sign of zonal flux, or also the meridional component. Please explain and reformulate. Why is the meridional component not mentioned in the Introduction section when it is shown in some Figures of the following Sections?**

For the Key Quantities we considered the zonal mean GW momentum flux, i.e., the zonally averaged vertical flux of horizontal momentum of GWs, since it can be directly inferred from the wind data and can thus serve as an absolute reference for global GW characterization, described in more detail in Section 2.2. The direction refers to the sign of the zonal mean GW momentum flux, which itself consists of two components: zonal component F_{px} and meridional component F_{py}. The two, i.e., zonal and meridional, components of zonal mean GW momentum flux are illustrated in left and right panels respectively in Fig.9 and Fig.13-16.

Regarding to the referee's comment, we added the detailed explanation in former l.94-96 in the Introduction:

"In order to close the momentum budget, in particular the zonal mean of the zonal GW momentum flux is required, but zonal mean meridional momentum flux may contribute as well (Ern et al., 2013). ...

For our study the zonal mean of zonal GW momentum flux is of particular importance as the values directly inferred from the winds provide a true reference value. This is, to a somewhat lesser degree, also true for the meridional momentum flux, as will be discussed below."

2. **It is difficult to understand, namely in the Introduction, why "by separately inverting left-hand and right-hand part of the interferogram", independent observation tracks are obtained. Please reformulate or explain better here.**

For a better understanding, we reformulated this sentence as "by splitting one interferogram into two left-hand and right-hand parts and separately mirroring each parts (cf. Sect. 3.5), " in former l.137 in the Introduction and referred to the corresponding Section 3.5 for a detailed method description.

3. **line 190, u', v', w', define the coordinate system.**

As recommended, we added the definition of the coordinate system after former l.190.

4. **Section 2.2. Last sentence. It is partly explained in the Discussion, but here, the meaning of this sentence is quite unclear. Please reformulate/explain or remove.**

Following the referee's suggestion, we removed the last sentence from Sect. 2.2.

5. **line 210, S3D, it should be defined here at the first usage.**

As recommended, we added the definition of S3D after former l.210.

6. **Section 3.1, around line 241, "... moist convection..." The moist convection at such high altitudes deserves some explanation.**

Though of course there is no moist convection at the observation altitude it is one of the important sources of the waves which govern this height region: GWs, tides and equatorial wave modes. This explanation was included in the revised text after former l.241.

7. **Section 3.3. A comparison of usable height ranges for day- and night-time observation should be discussed in more detail.**

We considered for the daytime an observation altitude region of 60-120 km, which was reduced to the range of 80 km to 100 km during nighttime as only the photochemical production channel exists.

We added the corresponding description about the altitude range at the end of Section 3.3.

In addition, HAMMONIA model should be briefly introduced and/or referenced.

We added the reference to the HAMMONIA model data in former l.283.

8. **Section 3.5. It should be better explained how two independent temperatures are obtained along the horizontal axis using O_2 A-band emissions only.**

For clarification, we reformulated most of the description about the interferogram split method in Section 3.5.

9. **last line on page 15, "... retrieved temperatures, which are about 17 km apart...". That doesn't make sense to me. Please reformulate.**

This comment is related to the previous one. We have reformulated most of Sect. 3.5, which should make this point much clearer.

10. **Section 3.6. Specify the time interval over which the snapshots used for the tomography are taken. Discuss this time interval with respect to the GW period/wavelength and propagation velocity. Discuss also the assumed angle difference between different positions marked by different colors in Figure 8.**

Looking at the individual "rays" of measurements from the simulations, one can analyse, where an overlap occurs. For the given geometry, overlaps occur for measurements up to 160s apart. This largest time difference for this backwards-looking instrument occurs between measurements at high angles, i.e. tangent point altitude at 120km, and later measurements at low angles, i.e. tangent point altitudes at 70km.

As most information is gained from the emissions around the tangent point, the practical time delta is more in the order of 80s.

This is at least one order of magnitude smaller than the periods of GWs that our proposed instrument is sensitive to: We aim at GWs of $\lambda_h > 100$ km and $\lambda_z \approx 10$ km which corresponds to an intrinsic period of roughly one hour. By Doppler shift shorter ground based periods may occur, but it is expected that the bulk of the observed GWs has ground-based periods of a few hours.

The angular differences are rather small for a tomographic method and form an extreme case of limited-angle-tomography. For the proposed retrieval scheme, the different overlaps of line-of-sights as well as the exponential increase of number densities to lower altitudes are more important for localisation of information.

We added the following sentence to the main text in former l.385:

"The satellite speed allows to gather all relevant measurements for on spatial sample in the order of minutes, which is short compared to typical periods of gravity waves observable by our instrument."

11. **Section 3.6 or 3.7 (Table 2). Note that the definition of spectral wavenumbers (in cm^{-1})is $1/\lambda$ here, where λ is the wavelength, and not $2\pi/\lambda$ which is often used.**

We added a footnote in Table 2 for to remind of the definition of spectral wavenumber.

12. **line 393, define FWHM**

We added the definition of FWHM in former l.393.

13. **Section 3.7, last but one paragraph. The text is difficult to read. Please reformulate/simplify.**

Following the referee's suggestion, we rephrased this paragraph as below:

"The synthetic observation data have a fixed sampling in x, y and z direction, on which the analysis cube size is defined via the number of sampling points. For the model data, a fixed model sampling in terms of degrees longitude in zonal direction means a coarser (in distance) sampling close to the equator and a finer sampling at high latitudes due to the shorter distance between two respective longitudes at higher latitudes. Therefore, the size of a fixed cube is specified in kilometers instead of degrees and the number of fitting points is adapted accordingly. This ensures that the same part of the spectrum is targeted independent of latitude along the longitude direction."

14. **Section 4.2.1, second paragraph " From the model set-up we expect shortest horizontal wavelengths of O(200km) . . . " It should be discussed here that a number of radio and optical observations show shorter wavelengths than 200 km (Nishioka et al., 2013; Chum et al., 2021; Shiokawa et al., 2009; among others).**

For various reasons we would have preferred, of course, a model with higher resolution encompassing the entire MLT. At the end we have to take what is feasible nowadays. The fact that short waves must not be neglected, has been now included in Sect. 4.2.1 after former l.477 and also in the discussion after former l.643.

The authors partly discuss this wavelength limit in the Discussion section and in Appendix E, but this information should be briefly given already here. Moreover, the Discussion section mainly relies on modelling. The already available observations should also be mentioned.

Chum, J., Podolská, K., Rusz, J., Baše, J., Tedoradze, N. (2021), Statistical investigation of gravity wave characteristics in the ionosphere. Earth Planets Space 73, 60, https://doi.org/10.1186/s40623-021-01379-3

Nishioka M, Tsugawa T, Kubota M, Ishii M (2013) Concentric waves and short-period oscillations observed in the ionosphere after the 2013 Moore EF5 tornado. Geophys Res Lett. https://doi.org/10.1002/2013GL0579 63

Shiokawa K, Otsuka Y, Ogawa T (2009) Propagation characteristics of nighttime mesospheric and thermospheric waves observed by optical mesosphere thermosphere imagers at middle and low latitudes. Earth Planets Space 61:479–491. https://doi.org/10.1186/BF033 53165

True. we have included also a reference to both short and mesoscale wavelength observations in the discussion. This hopefully clarifies that we need to have new observations in order to identify the relative contribution of different scales.

15. **Figure 13. Specify the time interval (season) for which the Figure was constructed.**

We added in the caption "01-Jan-2016 06 UT" and in the text in former l.541: "for 01-Jan-2016 06 UT (i.e., winter in the northern hemisphere and summer in the southern hemisphere)" to specify the season in Fig. 13.

16. **line 622, " tides cause changes of the large scale winds at similar time scales as the periods of the GWs propagating through these winds ". Specify the periods of tides and GWs considered here.**

We added "e.g., diurnal and semi-diurnal tides," in former l.622 to specify the periods.

References

Ern, M., Arras, C., Faber, A., Fröhlich, K., Jacobi, C., Kalisch, S., Krebsbach, M., Preusse, P., Schmidt, T. and Wickert, J. (2013), Vertical coupling by gravity waves in atmospheric dynamics: Observations, ray tracing, and implications for global modeling, *in* Franz-Josef Lübken, ed., 'Climate and Waether of the Sun-Earth System (CAWSES)', Springer Atmospheric Sciences, Dordrecht, Netherlands, pp. 383–408.