Comments on the manuscript 'Extraction of spatially confined small-scale waves from high resolution all-sky airglow images based on machine learning' by Sabine Wüst et al.

This paper reports the high resolution/wide area observations of OH airglow images using a scanning camera at DLR Oberpfaffenhofen, and a new method of analyzing ripple structures in the image using ML technique. The authors have also shown the statistical results of the ripples. The new analysis technique has extracted two order larger number of events than the past literatures, and the results are well compared with the past observations.

The reviewer would like to congratulate the authors' successful observation and analyses. Th e new method applied to a wide-horizontal range and high-resolution images is very capable of studying the statistics of ripple structures (small-scale wave-like structures) in the image, for which the relations with the instabilities and secondary gravity waves are of great interest.

However, there are some points that need to be improved before the manuscript is published. Thus, I would like to recommend 'minor revision'.

Thank you very much for the congratulation and also for the very valuable comments. We answered all of them (in orange, see below) and changed the manuscript accordingly.
One technical remark concerning the track changes mode: we use Citavi and somehow changes made with Citavi are not tracked in Word. We included one new reference (Jaen et al. 2023) and shifted another one (Jacobi et al., 2015). You will recognize it from the context, however, it is not marked as a change.

Main point:

The wording of propagation direction

There are many places where the authors mention 'propagation direction'. I understand there are three meeting what 'directions' mean.

(1) Direction of so called 'phase velocity', which is the apparent phase velocity of phase front lines.

(2) Direction of motion of the area that the wave-like structure 'packet' is moving to.

(3) Direction perpendicular to the phase front line (of a single image)

My understanding from the text is that (1) is the one we normally use in case of gravity waves and 2D-FFT is showing this by its peak (with 180 ambiguities in case of a single image.) (2) and (3) can be derived from ML technique shown here. I would like to suggest the authors to use clearly different words for (2) and others, to avoid confusion of the readers. My suggestion is to use the word like ‘direction of the wave structure movement’, ‘direction of wave packet motion’, ‘direction of wave migration’, ‘direction of wave drift’ etc. Or, Li et al. (2017) uses ‘advection’, instead. I would prefer not to use the word of ‘propagation’ for (2) because it is not related to wave parameters but observed area. I hope such wording separation would help readers to understand the paper correct.

Thank you for this very valuable hint. We went through the manuscript and replaced propagation direction with direction of advection, if we refer to case (2). We also tried to be more precise concerning the description of other publications, however, this is somehow challenging. Suzuki et al. (2011) separate their observed wave events according to the wavelength into ripples and gravity waves and provide in both case propagation directions. From their manuscript one gets the impression that this is the direction into which the structures move. So, we changed, for example, the sentence “They observe propagation direction towards …” into “These structures move mainly towards …”.

Related question.

L 410-412

‘If all the observed wave-like structures are (secondary) gravity waves, then there is no difference between the propagation directions derived from the two different approaches.’

I do not understand what this sentence means. Even in case of secondary gravity waves, wave packet motion direction may not be the same as the phase velocity of the wave. Please explain more.

I had a knot in my brain, thanks for bringing my attention to it.

Instability features are supposed to move with the background wind (see e.g. the argumentation in Li et al. (2017) in order to discriminate instability features from secondary gravity waves), gravity waves do not need to do this. In the intrinsic frame, they move perpendicular to their wave fronts; this can look different when we observe them while not moving with the background wind. For waves with smaller horizontal wave numbers (larger horizontal wave lengths), the difference between the intrinsic wave propagation direction and the observed wave propagation direction (direction of advection) is less pronounced than for waves with larger wave numbers (smaller wave lengths), as the intrinsic frequency differs less from the observed one. That is probably the reason why gravity waves observed in all-sky airglow imagers seem to move perpendicular to their wave fronts when observed from the ground; we focus on the large waves and not on the small ones.

Figure 15 shows the intrinsic wave propagation direction and the observed wave propagation direction (direction of advection) on a statistical basis. As the observed horizontal wave lengths should not vary to much with the seasons, the differences between both directions are driven by the background wind speed and direction relative to the intrinsic wave propagation direction. In summer, this effect is most pronounced (this is always limited by the 180° ambiguity). Summer is also the season when the highest wind horizontal velocities are observed.

For discriminating between secondary waves and instability features, the direction of advection and the direction of the background wind are compared. According to Jacobi et al. (2015), who measured approximately 400 km away from Oberpfaffenhofen, the averaged wind is for SW (NE-ward) for spring, NW (SE-ward) for summer, and N/NE (S/SW-ward) for autumn and winter. The dominating directions of advection in our measurements (see Figure 12) is SW in spring, S in summer, NE in autumn and E in winter. So, only in summer the observed small-scale wave-like features are overall advected with the wind. Therefore, the probability that an observed small-scale wave-like structure is an instability feature (secondary gravity wave) is highest (lowest) during summer.

We added this info in the manuscript and deleted the sentence 'If all the observed wave-like structures are (secondary) gravity waves, then there is no difference between the propagation directions derived from the two different approaches.'. Furthermore, we changed the conclusion drawn from figure 15 into "Qualitatively, however, the difference between the intrinsic propagation directions and the directions of advection (observed propagation direction) is most pronounced in summer."

Other points

1. 40-49

The authors describe airglow imaging observation of breaking gravity waves with citation of a few papers. To my knowledge the first clear observation of showing gravity wave breaking by airglow and its analysis was published by Yamada+ (GRL, 2001, DOI: 10.1029/2000GL011945) and Fritts+(GRL DOI: 10.1029/2001gl013753) . I would suggest to cite these papers which are earlier publication by about 20 years.

Done

L 94-100

The description of the FAIM 4.

It would be useful if the authors can also provide chip (or pixel) size of the InGaAs camera, and F number of the lens (or the effective aperture of the lenz) for the reader to understand the sensitivity of the optics (e.g. for knowing 'A x omega' value (throughput) of the camera).

The pixel size was already given in the former line 95 (320x256 pixel), we added the F-number.

L 173-179

It would be helpful, if the authors briefly introduce how the FOVs of FAIM 4 and FAIM 3 (13 km x 13 km?) are different.

Info added.

L 214 – 215

'Firstly, performing a 2D-FFT, especially on high-resolution images, is time-consuming and computationally expensive, leading to longer processing times and significantly affecting efficiency in analysing large data sets.'

（similar expression is at L 325.）

My feeling is that 2D-FFT is not so time consuming nowadays, as long as the number of points (most efficient one is 2^N) is selected properly. I would like to know how difficult it is to use 2-D FFT for the images introduced here. I believe zero-padding to make a square image of (2^N) * (2^N) size would make the computation time short enogh.

That is true and we added here some info: Firstly, performing a 2D-FFT, especially on high-resolution images, is time-consuming and computationally expensive as not only one 2D-FFT needs to be calculated but several ones using differently sized sub-samples of each image. This is necessary since the FFT assumes that the waves are present in the whole image. If this is not the case – which is very likely when sensing the whole sky – their amplitude is underestimated. This leads to long processing times and significantly affects efficiency in analysing large data sets.

L 517 – 522

The authors refer to Jacobi et al. (2015) and speculated that the meridional wind is strong in April/May, and the zonal wind is in August, which can explain the probability of dynamical instability is large. I do not understand this logic. Why the largest wind at around OH altitude shows probability of dynamical instability, without a measurement of wind shear.

You are right, the argumentation is not very thorough. It would be better to refer to the vertical shear of the horizontal wind. We replaced this passus of the manuscript referring to Jacobi et al. (2015) by a text referring to Jaen et al. (2023), who showed that the wind shear has its maximum during summer.

L 576

'we observe in our data changes from south in spring to east in winter'. I cannot read the direction is south in spring from Figure 15. Please check it.

Thanks for bringing our attention to this part. One cannot see this from in figure 15 (which is the natural choice when reading the manuscript) but must refer to figure 12. We added this info and tried to make the info a little bit more precise.

Figure 15.

Please indicate the location of center of the plot, as well as WE and NE line. Is 'zero' value shifted from the center, which is my guess from the scale axis? If so, what is the reason?

You are right, the "zero" value is shifted from the centre and there is no specific reason for it. We made some modifications and hope that the figure is now clearer for you.