Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2016-292-AC2, 2016

Atmospheric Measurement Techniques Discussions
Open Access

AMTD

Interactive comment

Interactive comment on "High resolution observations of small scale gravity waves and turbulence features in the OH airglow layer" *by* René Sedlak et al.

René Sedlak et al.

rene.sedlak@dlr.de

Received and published: 4 November 2016

The authors thank anonymous Referee #2 for his detailed comment and the many suggestions for improvement of this paper.

The referee asked for "more discussion on what knowledge gap in these processes can be exploited or investigated with this new instrument development". He suggested elaborating the new aspects of this imager and how the observations could be used to quantitatively parameterize small scale wave instability and turbulence processes and how these could be used to improve or confirm simulations.

As the referee has stated correctly the high spatio-temporal resolution is the crucial

Printer-friendly version

Discussion paper

improvement of this airglow imager. We have elaborated the new possibilities our instrument provides more thoroughly in the following revised paragraphs:

“Compared to earlier airglow imagers (Hecht et al., 1997, Yamada et al., 2001) the resolution has been improved by at least one order of magnitude in both space and time. Achieving a spatial resolution of 30 m/pixel (zenith angle of 46 °) and 17 m/pixel (zenith angle of 0 °) the entire inertial subrange as well as the beginning viscous subrange of turbulence at airglow altitude is accessible to this instrument. Additionally, the temporal resolution of no longer than 2.8 s allows investigating the development of transient processes like breaking wave fronts.” (lines 79-84)

“FAIM 3 not only resolves the entire inertial subrange, it also provides insight into the beginning viscous subrange of turbulence. As concerns airglow imaging this opens a new scale range of dynamic processes that can be monitored, like it is shown in the first case study. Whereas structures like the larger one (periodicity $\sim$ 1.7 km) can now be studied in greater detail with FAIM 3, structures like the smaller one (550 m) are now observable for the first time at all.

Concerning the connection of our observations with previous work in terms of scientific aspects, the second event is more evident. It shows the formation and temporal evolution of an instability feature. Due to the high temporal resolution (2.8 s) one can determine the initial formation of this structure and its later orientation relative to the initial wave field. Thus, observations of this kind are valuable for determining the nature of instability concerning the question whether such features are primarily driven convectively or dynamically.

In this context several former studies (e.g., Yamada et al., 2001, Hecht et al., 2004, Fritts et al., 1996) question whether “ripples” were initially formed parallel or perpendicular to the gravity wave fronts and then rotated by the local wind fields or formed as a combination of both instabilities. These possibilities severely complicate scientific interpretation of ripple occurrence. With the new observation capabilities provided by the FAIM 3 we can now study this initial formation in greater detail. The two instability events presented in this paper appear to be driven dynamically but in both cases there are also indications for the presence of convective instability, which suggests that these two instability mechanisms could actually accompany each other.” (lines 290-305)

As concerns the improvement/confirmation of simulations we inserted the paragraph "The typical vortex structures and the decay into eddies also appear in the respective airglow modelling. Like outlined there and in the companion experimental paper (Hecht et al., 2014), the simulations have predicted such small features that could not have been resolved by airglow imagers at that time.“ (lines 308-310)

The referee remarked that "there is a considerable amount of ‘tentative’ statements [. . .] with the interpretation of both events, particularly in the discussion and conclusions. At the end the reader is left with a couple of possibly interesting image sequences of wave events but not really sure what to make of them and what new information they can reveal“.

As the referee has stated correctly it is the overall aim of this paper to demonstrate the ability of FAIM 3 to image small scale waves and instability features on scales below 1 km. When it comes to the interpretation of the observations we deliberately chose a tentative style of language because our discussion is based on bare 2D image data of airglow signals integrated from 0.9-1.7 μm. In this paper we focus on the performance of our instrument and interpret our observations just as far as it is possible in good conscience without supporting data like background wind or temperature. However we hope after revising the discussion and conclusion section as mentioned above the significance and the outcome of the presented case studies becomes more evident to the reader.

Referring to the specific comments:

Line 30: changed to ‘[the hydroxyl] is the brightest component of the airglow phenomenon’

Line 136-137: Unfortunately the wave packet is quite faintly visible in the individual images. It is best apparent in the video. It is still better visible in the difference images than in the originals. We have attached Figure 2 as it would look using the original images as a supplement to this comment. In our opinion difference images provide the best help for the reader to follow the propagation of the small wave packet. We dropped ‘obviously’ in line 141, as suggested.

Line 154: The level of significance is calculated by performing a simple Monte Carlo test. As the referee states correctly the 550 m wave is only evident in the first half of the data series in Figure 3. At a range of 1.5 km noise predominates the wave packet. The signature of the perfect 550 m wave (orange) has been added to guide the eye without being fitted to the data.

Line 155: We agree with the referee that the peaks below 200 m might be an artefact of the sampling rate and its harmonics coupled with detector noise. Since our focus in this paper lies on analyzing evident features in the images, we decided not to further discuss this here.

Line 168-183: First of all we thank Referee #2 (as well as Referee #1 who also noticed it) for indicating that the propagation direction of the wave front in FAIM 3 (figure 6) and FAIM 4 (figure 7, all sky) did not appear to match. This made us aware of the FAIM 3 FOV not being marked correctly in Figure 7 and Video 3. The upper side of the FAIM 3 images corresponds to 303 $^\circ$ azimuthal direction and the upper image side of FAIM 4 to 269 $^\circ$ azimuthal direction.

We corrected the orientation of the FAIM 3 FOV with respect to the FAIM 4 image and rotated Figure 7 and Video 3 northward for better orientation. The Referee suggested to zoom in or blow up the FAIM 3 FOV in the FAIM 4 image to aid the comparison between the two instruments. We appreciate this idea and recognized that not only marking the FAIM 3 FOV but embedding the respective FAIM 3 image directly into the FAIM 4 image would provide the best comparison between the two imagers (see revised Figure 7). Instead of featuring the respective difference image we present an enlarged view (fourfold magnification) which shows how the FAIM 3 image fits into the FAIM 4 FOV and to what extend this new instrument is able to resolve details that could not be recognized in all sky images. As Referee #2 suggested, we also added a red arrow to Figure 7, indicating the direction of propagation of the wave front.

We revised the paper at the following instances:

"To put the observations into a larger spatial context, the FAIM 3 data are compared to simultaneous all sky measurements taken by the FAIM 4 instrument. Since the two cameras are deployed next to each other, the FOV of FAIM 3 is embedded in the centre of the FOV of FAIM 4. The FAIM 4 measurements are presented in Video 3. Besides the normal image the difference image (time difference of 60 s) is displayed on the right side; both images are rotated northward. The approximate FOV of FAIM 3 is indicated by the white boxes in Video 3. The all sky images reveal a clear and starry sky with high gravity wave activity, which can be determined on the basis of the characteristic patchy structures. The remarkable structure observed by FAIM 3 can be found again in Video 3 as a bright feature within the white box, propagating to eastern direction, which agrees with the FAIM 3 observations. Figure 7 shows the FAIM 4 all sky image at 03:20:20 UTC with the respective FAIM 3 image embedded into it (image a) as well as the image centre magnified by a factor of four (image b)." (lines 193-203)

"The aforementioned wave front is also visible in the all sky images, but a close inspection of Video 3 hardly allows perceiving indications for the separation of parts from the bright crest. Zooming into the all sky image (Figure 7b) shows that only the high-resolution measurements of FAIM 3 can reveal closer details of this structure." (lines 259-263)

"FAIM 4 all sky image taken on 5th April 2016 at 03:20:20 UTC (image a) and the magnified (zoom factor 4) image centre (image b). The entire sequence is shown in Video 3. Due to their spatial structure and their wavelength, we interpret the patchy structures in the starry sky as gravity wave fronts in the airglow layer. Comparison with the respective FAIM 3 image, which has been placed at its correct position in the middle of the all sky image shows how the small scale details of the wave crest can be resolved with the new instrument. The direction of propagation is indicated by the red arrow and matches with the observations of FAIM 3." (caption Figure 7)

Please also note the new version of Video 3, which has been submitted.

The Referee remarked that the interpretation and description of this second event was speculative and not entirely convincing to that reader and that in particular the assertion of a 'vortex' structure was very difficult to determine from the 2D image sequence.

We agree that the six images in Figure 6 are hardly sufficient to entirely display the transient event of 5th April 2016. In the revised Figure 6 we now present fifteen images of this period so that the reader can better follow the temporal evolution of the structures. We have carefully revised the description by analyzing the behaviour of six prominent features, which are also highlighted in the revised Figure 6. This should help the reader to track the filament-like structures and to follow the formation of the vortex also in the image series. From the former version of Figure 6 we have retained the red arrow indicating the direction of propagation of the overall structure, which can now also be found in the all sky image (revised Figure 7).

We have revised the following paragraph, describing the observations of the second event more detailed:

"A wave front, indicated by the dashed black line in the images of Figure 6, enters the FOV in the upper right corner. While it continues propagating to the lower left, a filament separates from it on the left side (Figure 6a – b, orange). This filament moves much slower than the wave front. At around 03:18:30 UTC (Figure 6c) a second filament structure becomes visible below the first filament. In the further course of the image series (Figure 6e – f) it turns out to separate into two structures, a filament moving downward (yellow) and a stationary filament (green). At about 03:19:26 UTC

(Figure 6g) the orange and the green structure begin to dissolve. The yellow structure continues propagating for a few more seconds and finally also starts decomposing at 03:19:54 UTC (Figure 6i). At 03:18:44 UTC (Figure 6d) two more filaments form at the upper right of the FOV right behind the initial wave front and are, in contrast to the other filaments, aligned perpendicular to it. They decompose at 03:19:26 UTC (Figure 6g). While the dynamics of the filaments take their course and form a vortex, rotating around a horizontally oriented axis, the initial wave front (black) overtakes the other structures, retaining its original direction (indicated by the red arrow in Figure 6h). At about 03:19:54 UTC (Figure 6i) another filament (blue) separates from it. This new filament remains stationary and starts decaying at 03:20:50 UTC (Figure 6m). The wave front (black) keeps on propagating and leaves the FOV toward the lower left." (lines 173-185) and the caption of Figure 6 similarly.

Referring to the suggested corrections: Line 31: omitted 'full' as suggested.

Line 34: The sentence has been expanded to "Once the waves reach the airglow layer, they influence the intensity of the airglow emission due to temperature and density variations."

Line 36: brackets omitted as suggested Line 46: We added Browning, 1971 as a reference for KHIs. Line 56: We dropped the paragraph. Line 71: Corrected to "with wavelengths down to..." Line 71: 'discovered' replaced by 'observed' as suggested. Line 71: The instruments mentioned here (FAIM 1 @ Sonnblick Observatory, Austria and FAIM 4 @ Oberpfaffenhofen, Germany) are the FAIM version described in (Hannawald et al., 2016). So the word 'similar' does not fit in this context, because they really are 'the same'.

Line 74: as suggested. 'air-craft based' changed to 'aircraft based' (now line 75) Line 80: omitted 'already mentioned' as suggested. Line 84: 'drawing' replaced by 'diagram' as suggested. Line 89: Changed to "The geometry of this arrangement implies a trapezium-shaped FOV at the airglow layer with a height of 18.6 km and a width of 15.2

km to 16.9 km.

Line 92: changed to "horizontally an overall area of about 299 km^2...". We decided nevertheless to keep the word 'horizontally' in order to stress that Line 95: Omitted 'shown' and 'corresponding to 12 measured nights' as suggested. Line 98: as suggested. Line 105: In our case there is no difference between 'horizontal' and 'spatial' resolution. We decided to use 'spatial resolution'. Like the referee remarked, 'm/pixel' is of course the correct unit to describe the spatial resolution. We corrected it in lines 9, 67, 71, 97, 102, 109, 138, 168, 247 (twice), 248 (twice) and 281.

Line 107: omitted 'for example' as suggested. Line 114: Omitted the sentence as suggested and changed the beginning of the following sentence to "The periodic brightness variation related to a wavelike structure appears in the series of pixel intensities...".

Line 115: In this first analysis the direction perpendicular to the wave front has been determined by hand. Further investigation methods based on pattern recognition are currently being developed and will be applied on FAIM data in future papers.

Line 135: 'relevant period' replaced with 'interval', as suggested. Line 164: changed to "acquired at the zenith position with a spatial resolution of..." as suggested.

Line 190: dropped "if our speculation holds." Line 209-211: sentence omitted. Line 218: 'in' omitted as suggested. Line 221: see the specific comment to lines 168-183. Line 255: corrected.

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/amt-2016-292/amt-2016-292-AC2-supplement.zip

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2016-292, 2016.

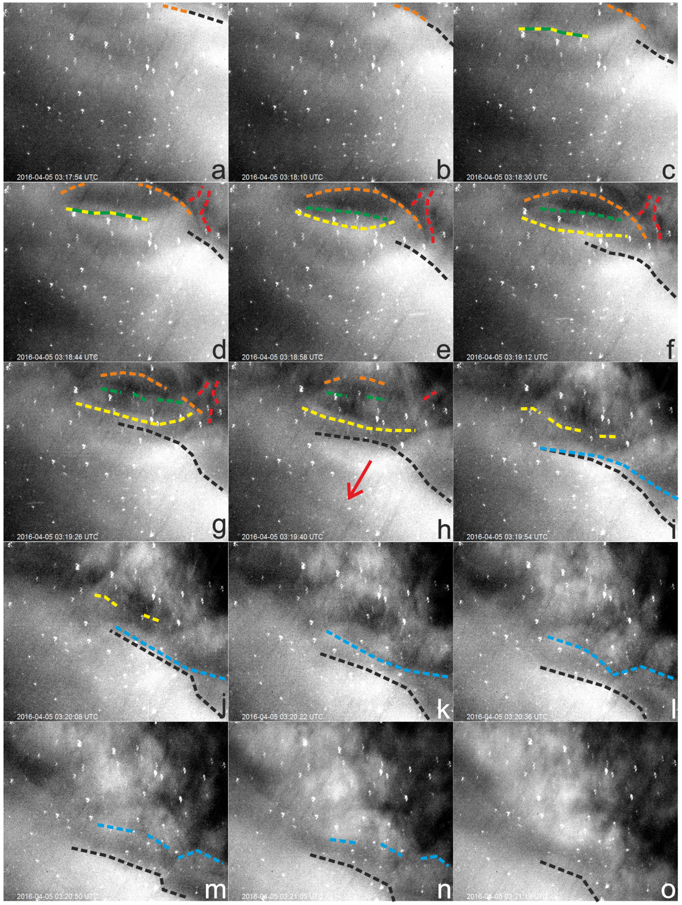

Fig. 1. Figure 6 revised

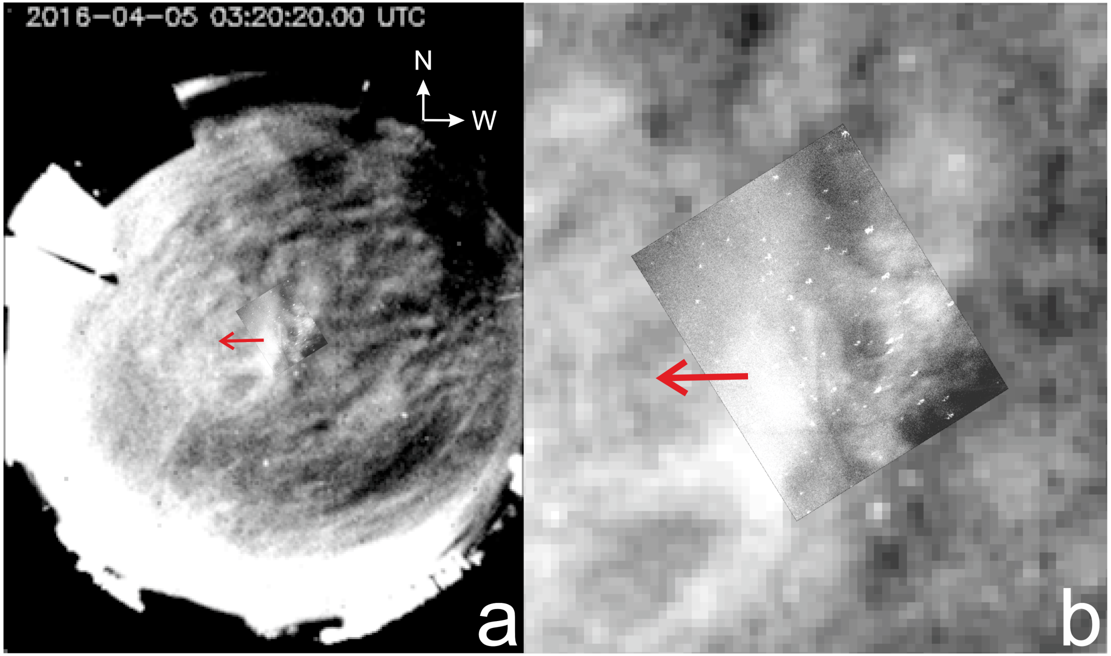

Fig. 2. Figure 7 revised

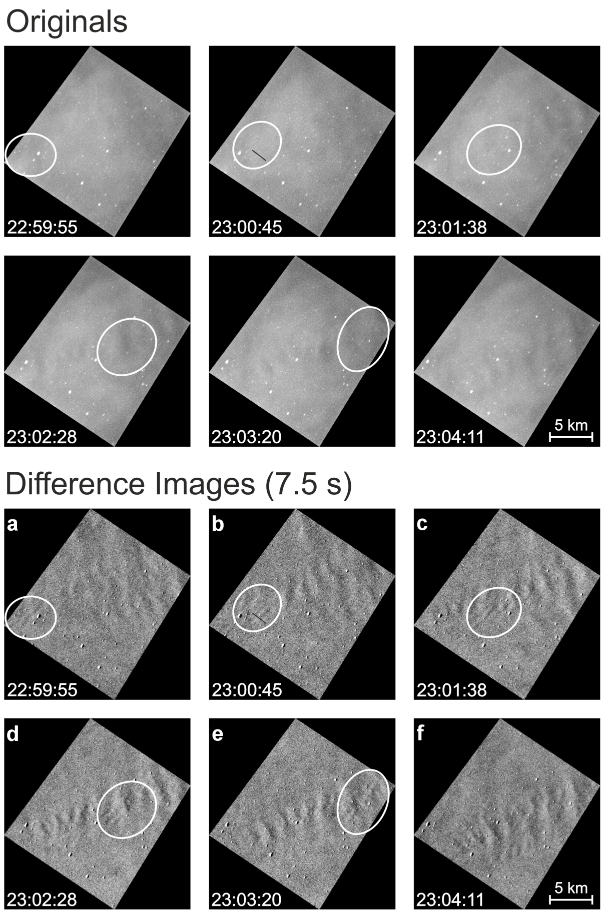

Fig. 3. Figure 2 - comparison of original images to difference images

Printer-friendly version

Discussion paper