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Atmospheric Measurement Techniques
Discussions
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Interactive comment on "Optical flow gas velocity analysis in plumes using UV cameras – Implications for SO_2-emission-rate retrievals investigated at Mt. Etna, Italy, and Guallatiri, Chile" *by* Jonas Gliß et al.

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General Remarks

This manuscript describes an innovative method for improving optical flow velocity analysis in SO2 camera imagery of volcanic gas plumes. Optical flow algorithms cannot estimate velocity in regions of an image with little or no contrast. Such regions are often found in volcanic plume images, mostly in the center of the plume where detected gas column densities can be relatively homogeneous. Some existing optical flow methods

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by default assign a very low velocity to low-contrast areas. The authors show that this issue can lead to underestimation of volcanic SO2 emission rates, as areas with high gas column density are assigned incorrect velocities.

Next, a method for improving velocity estimates in these low-contrast regions is described. A number of criteria are introduced to determine which pixels in a given image are associated with reliable velocity information. A histogram of velocities is derived from these reliable values, and areas in which a reliable velocity determination is not possible are filled in with the mean velocity obtained from this histogram.

Finally, the new method is tested on SO2 camera data from Mt. Etna (Italy) and Guallatiri (Chile). The authors make a compelling case for the improved quality of results obtained by their new technique when compared to other, previously employed methods. The manuscript is extremely well-written and presents relevant results. It will be particularly useful to the volcanic gas remote sensing community. I recommend that the manuscript be published in Atmospheric Measurement Techniques and below list only a few minor comments and corrections that might help improve it slightly.

Specific issues

Aside from some minor corrections, I really only have one issue with this study. The authors state that optical flow algorithms tend to fail for low-contrast image areas. It is true that all optical flow images rely on contrast in the image to derive velocity fields and cannot derive accurate velocities in low-contrast regions. However, this issue has been known for a long time. It's often referred to as the 'aperture problem' because, in general, contrast will depend on the size of the region that is being analyzed. Two adjacent pixels may have the same intensity, but by increasing the area of interest, one will eventually find an intensity gradient (unless the image is completely homogeneous in which case all is lost).

The method developed in this manuscript appears to work well. However, I wonder if there aren't other existing optical flow algorithms that essentially do the same thing. For example, the original Horn-Schunck method introduces a global smoothness constraint to solve the aperture problem. The velocity field is determined in regions with sufficient contrast. Velocities in areas with low-contrast are determined by forcing the vector field to be smooth. If properly initialized, I would imagine that the Horn-Schunck method could give very good results even in plume areas with low contrast, and even when the Farnebaeck method fails.

I don't doubt that the method presented by the authors here works well, but I do think it could be worth reviewing existing optical flow methods in a bit more detail to see if there aren't already some that essentially solve the problem in the same or a similar way. In particular, a discussion of the differences between the author's method and the original Horn-Schunck method could be warranted.

Minor corrections

Title: You might consider changing the title slightly to reflect the fact that the main focus of this manuscript is the improvement of the velocity analysis techniques. Also, since the techniques presented here apply equally well to UV and IR SO2 cameras, I would suggest replacing 'UV cameras' with 'SO2 cameras' in the title. Perhaps: Improved optical flow velocity analysis in SO2 camera images of volcanic plumes – Implications for SO2 emission rate retrievals investigated at Mt Etna, Italy and Guallatiri, Chile

Introduction: The phrases 'for example', 'for instance', and 'e.g.' are used overwhelmingly often in the introduction. Consider rephrasing some of these sentences such that these phrases are not needed as often.

P2, L13 – Please clarify: CDs are not simply multiplied by the gas velocities. Instead, the product needs to be integrated across a cross-section of the plume.

P2, L19 – Please add a reference to the original work by McElhoe and Conner who, as it turns out, already built an SO2 camera in the 1980s but seldom receive credit for it: McElhoe, H. B., and W. D. Conner (1986), Remote Measurement of Sulfur Dioxide

Emissions Using an Ultraviolet Light Sensitive Video System, J. Air Pollut. Control Assoc., 36(1), 42–47, doi:10.1080/00022470.1986.10466043.

P2, L22 – Consider changing ‘volcanic craters’ to ‘individual volcanic vents’

P2, L24 – Consider removing ‘hence’ before ‘often’

P2, L34 – Consider removing ‘often’ before ‘tend’

P2, L34 – Some OF algorithms have ways of dealing with low-contrast areas in images (see discussion above). Perhaps it’s better to simply state that OF algorithms cannot track movement in the absence of intensity gradients, so information on velocities in these areas must be obtained from elsewhere.

P4, L9 – ‘. . . angle between plume DIRECTION and image plane’

Figure 1 caption - ‘the town OF Milo’

Figure 1 - In my copy, the colors are not very clearly identifiable. The line that is supposedly yellow appears more green, and there are two blue lines. Perhaps choose a different color scheme, or use solid and dashed lines?

P5, L6- ‘town OF Milo’.

P5, L13- ‘downwind OF the source’

Figure 2 – Some of the structures in the Guallatiri plume look similar to structures that I have obtained when not recording images in both channels coincidently. That is, if the plume moves between the time that the on-band image is taken and when the off-band image is taken, this can lead to artefacts. Is this something you have observed before? How fast are the images taken in succession? Is this why you prefer to perform the optical flow analysis on the on-band image rather than on the optical depth (AA) image?

Figure 2 – Can you please clarify why the Guallatiri image appears to have only 300

horizontal pixels while the Etna image has 600 despite the fact that the same detector was used?

P7, L30 – Figure 13 shows the DOAS calibration curves. However, the caption says that the calibration was retrieved from AA images that were not corrected for the dilution effect. Why? The text on page 7 says that the AA images were corrected first. Please clarify.

P8, L11 – Please remove last sentence in this paragraph as it is repeated twice.

P8, L31 and P9, L13 and P11, L2 – Please replace 'constraint' with 'constrained'.

P9, L10 – '. . . vectors manifest as A constant offset and as A peak. . .'

P11, L27 – Can you please explain how you arrive at 15% uncertainty? Is this a guess?

P12, L17 - Suggest rewording this sentence for clarity: '. . . all pixels on l while Xpixok corresponds to the SO2 ICA considering only pixels showing reliable flow vectors.

P12, L21 – Is there a specific reason for performing the velocity analysis on the on-band images rather than on the AA images?

Figures 4 and 8– It's very difficult to see the vectors. Can the color scheme be improved, or the vectors made longer/bolder?

P17, L12 – I assume that the 'flow_histo' method should be the 'flow_hybrid' method.

P18, L3 – '. . . gradual decrease in the effective gas velocities after 14:54 at the main crater, which could. . . I wonder whether the velo: glob method should even be discussed here if it failed to retrieve velocities for the main crater. Perhaps omit it in Figure 10 (left) and only discuss it for the fumaroles?

Figure 11 – Similarly, it might be best to only plot the glob method for the fumaroles, not for the main crater.

P19, L15 – '. . . during the observation PERIOD.'

P20, L3 – Etna's (please add apostrophe)

P20, L6 – 'In the case of Guallatiri, these are the first SO_2 emission rates reported in the literature.'

Figures 1, 2, and 13 – The unit for column density is molecules/cm2. Adding the 'molecules' in plot labels would improve clarity.

Figures 14 and 15 – Is there a reason why the AA is plotted in figure 14, but only the on-band optical depth is plotted in figure 15? Perhaps it's best to be consistent?

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