Response to interactive comments from Referee #1

We are a little surprised by the comments by the referee and realise that we have somehow failed to communicate what the manuscript aims to present. To this end we have revised the title, abstract, introduction and conclusions to clarify the manuscript. Besides adressing the comments, we have also made the following changes to the manuscript:

- In the previous version of the manuscript all results were reported in the units of camera pixels. We now report in physical units (meters) where appropriate.
- To obtain statistics for locations further downwind from the release point, we have included results for three more camera positions. One, camera B, at the same location as the original camera A, but with a smaller horizontal field of view, and similar cameras at about 300 m (camera B), and 500 m (camera C) downwind from the release point. For cameras B, C and D the release point of the plume is at a higher altitude to allow the cameras to see the full vertical extent of the plume. Furthermore, these cameras have more pixels in the vertical direction than camera A.
- To be able to compare the LES with the simulated images for these new camera viewing directions (viewing the plume at an elevation angle of 30.7° compared to 5.7°) new software had to be developed to calculate column densities along the camera line of sight through the LES 3D concentration.

The referee give several comments in a non-listed format. Below we have extracted the comments from the referee response and answered them one by one. The referee's comments are in italic font. The responses to the comments are shown in roman font.

Comments

- *There are no comparison with real measurements data of any kind.*

  This is modelling study with the aim to investigate whether it is feasible to derive statistics from UV camera images or not. To make this clear, we have changed the title to: 'Can statistics of turbulent tracer dispersion be inferred from camera observations of SO_2 in the ultraviolet? A modelling study'.

- *Generally speaking, the LES with the setup that the authors have chosen is not adequate to simulate plume dispersion. The grid resolution is around 1 m in all three directions and it is well known that only eddies of the size of almost ten grid cells are well resolved.*

  We investigated effects of grid resolution on plume dispersion in great detail in a recent work (Ardeshiri et al., 2020) where we used also higher resolutions. Indeed, the somewhat inadequate resolution near the source generates a larger effective source size by numerical diffusion. Unfortunately, these high-resolution simulations cannot be used because of the memory requirements of the radiative transfer model. Radiative transfer is non-local in nature and the full domain must be in memory for calculations to be efficient. Increasing the spatial resolution by a factor of 10, in 3D increase the memory demand by a factor of 1000, which is not available to us. However, the purpose of this paper is not to provide the most realistic LES results, but to demonstrate that integrated characteristic of the plume can be reconstructed accurately from camera data. And for showing this, the LES that we use is sufficient.

- *The authors use the plume from it is released until 200 meters down-stream for their investigation. Even 125 m downstream from the source the plume is not larger than ten times the grid resolution which means that the plume is not dispersing due to turbulence but rather because of the sub-grid-scale parametrisation of the LES, which I assume it more like molecular diffusion (The authors do not describe that process in detail). This means that most of the plume does not look like real*

Table 1: The mean±the standard deviation for the difference between the simulated images and the LES densities for seven (camera A) and nine (cameras B, C and D) randomly chosen time steps.

Camera	Timestep(s)	Centerline (m)	Absolute dispersion (m)	Relative dispersion (m)	Skewness
A	5, 13, 22, 31, 41, 60, 97	0.060±0.203	0.955±0.655	1.243±0.602	-0.029±0.094
B	7, 23, 32, 48, 60, 61, 65, 75 91	-0.503±1.164	-1.088±1.612	-0.240±0.565	-0.187±0.252
C	7, 23, 32, 48, 60, 61, 65, 75 91	-1.069±2.582	4.989±2.141	4.429±2.030	-0.159±0.794
D	7, 23, 32, 48, 60, 61, 65, 75 91	-0.353±2.851	7.658±1.839	7.036±1.681	0.505±1.375

dispersion but appears much smoother. It is therefore dubious to replace experimental measurements with LES in this case.

We are well aware of the effects of numerical and sub-grid-scale diffusivity, see also answer to previous question. Furthermore we have revised our results to use world coordinates instead of pixel coordinates. Revised results for the camera in the original manuscript are shown in Fig. 1. We note that at the horizontal angle of 90°, corresponding to about 110 m downstream from the release point, the plume is already about 4-5$\times\sigma_r \approx 16-20$ m. Thus, already at 110 m downstream the actual plume size is much larger than the LES voxel size.

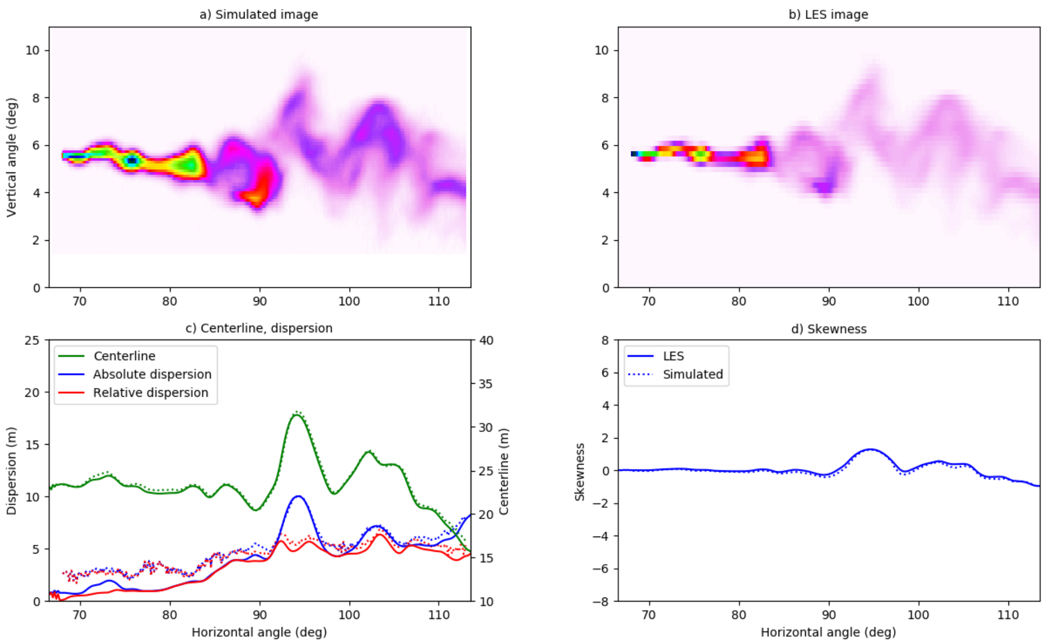

Figure 1: a) The plume apparent absorbance. b) The LES column density integrated along the line of sight. Colorscales in a) and b) are relative and thus no colorbars are provided. c) The centerline, absolute and relative dispersions. d) The skewness. The solid lines are LES results and dotted lines are values calculated from the simulated images.

We have made simulations for cameras seeing the plume further downstream, Fig. 2.

One example for camera D is shown in Fig. 3. We have updated the table describing the reference comparison to include the results for the new cameras, see Table 1. The manuscript have been updated with these new results and corresponding discussions.

Finally, the sub-grid-scale treatment of the LES is described by the following senence in section 2.1 of the manuscript:

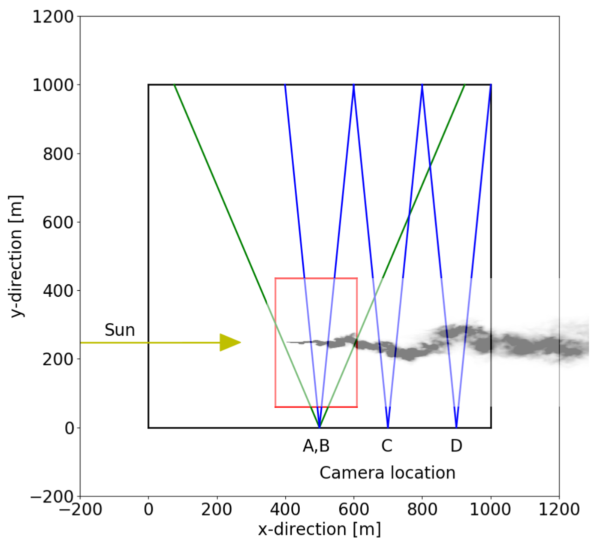

Figure 2: Bird's eyes view of the 3D domain (black square) and the SO_2 plume location within the domain (red square, for camera A simulation, shifted along x-axis for the other cameras). The UV cameras are located where the two green or blue lines intersect. The lines indicate the horizontal field-of-view of the cameras. The column density of the plume is included for illustrative purpose. The direction of the incoming Sun ray is shown by the yellow line.

> In this methodology, the large scales of the turbulent flow are explicitly simulated while a low-pass filter is applied to the governing equations to remove the small scales information from the numerical solution. The effects of the small scales are then parameterized by means of a sub-grid scale (SGS) model (e.g. Deardorff, 1973; Moeng, 1984; Pope, 2000; Celik et al., 2009).

- *Then the authors go to radiative transfer calculations with the sun as the light source. It is rather surprising that the calculations use circular boundary conditions such that when one photon leaves the domain on one side it appears again on the opposite side. The refer to energy conservation for this, but I simply dont understand the reasoning behind. It appears unphysical and gives rise to various artefacts such as ghost plumes that have to be removed.*

  The radiative transfer model used is based on the Monte Carlo technique and trace photons through the model-domain (the atmosphere). The model-domain is a rectangular cuboid. With a solar source the photons enter the domain through the top surface. Photons are traced until they leave the domain or are absorbed. If a photon leaves the domain through one of the four sides it is lost and will remain unaccounted for, and hence energy conservation is broken which might lead to non-physical results. Thus, to quote Mayer (2009):

  > If a photon leaves the model domain through the side, we apply periodic boundary conditions: the photon re-enters at the opposite side; this ensures energy conservation and is appropriate for most applications, given that the model domain is large enough so that the process under consideration are not affected by edge effects.

- *They analyse only one (!) out of the 100 snapshots which I think is a very little number for getting good statistics.*

  This statement is not correct. In Table 1 of the manuscript statistics based on 7 snapshots are presented. In addition we have now also performed simulations for more cameras, see Table 1. For the sensitivity analysis, however, only one snapshot is used. Though, there is no physical reason

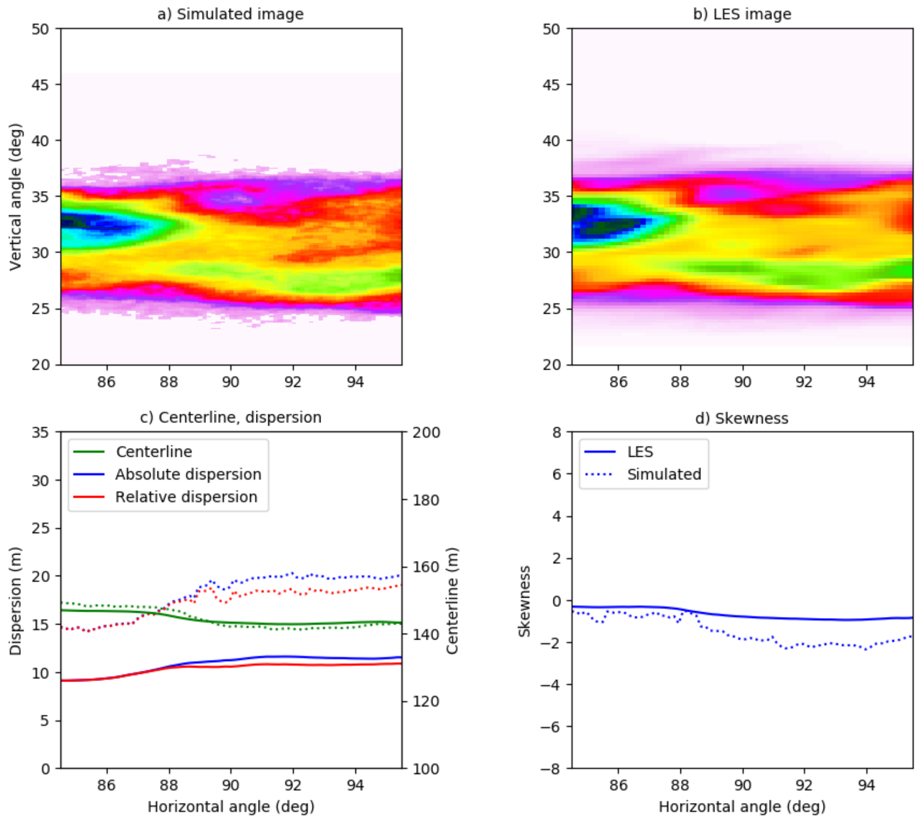

Figure 3: Results for Camera D and time step 91. a) The plume apparent absorbance. b) The LES column density integrated along the line of sight. Colorscales in a) and b) are relative and thus no colorbars are provided. c) The centerline, absolute and relative dispersions. d) The skewness.

for the results from the sensitivity analysis to be different if other or more snapshots are used. Also, note that if the instantaneous spatial statistics are correct, the ensemble statistics will also be correct. This is not necessarily true the other way around. We have revised the abstract and the introduction part of the manuscript to make this clearer.

- *The plume statistics analysis is a bit messy. There is an equivalence between the x and z position in space and the two pixel coordinates in the camera. This might be a good approximation but it is confusing that the same symbols are used for the different physical quantities. The mean plume height is a mean of plume heights at all downstream positions. Usually, in a boundary layer the mean plume height is a function of downstream position x since the plume may rise if it is released close to the surface. As a consequence of choosing the average plume height over all x values is that the absolute dispersion sigma$_z$ is a mix of ordinary absolut dispersion (which is relative to the mean height at a specific downstream position x) and the general plume rise. The definition of meandering dispersion suffers some of the same inconveniences. The poor reason for those somewhat awkward definitions is that the authors have an ensemble of one which prevents making ensemble means as is usually done.*

  In the revised manuscript we do not use pixel coordinates, but world coordinates x and z throughout. Furthermore, as pointed out by the referee: The absolute dispersion can be properly defined only using an ensemble or time average. This is not possible here as we do not have an esemble available. We thus adopt the center of the source ($\overline{z} = z_0$) as the reference vertical position and define the absolute dispersion accordingly. It is noted, that with this definition of the absolute position, relative and absolute dispersion are correctly the same at the source location, since meandering here is zero. The revised statistics are shown in Fig. 1.

- *Jumping to fractal dimensions, the authors fail to describe exactly what they do, and one could ask how relevant fractal dimensions are given the poor resolution of the LES. Often fractal dimensions are used to describe the interface between the plume and the surrounding air, but here it is unclear what N(epsilon) really is. There is no supporting figure to let the reader know.*

  In response to the comment we have decided to leave this section out.

- *The lack of realism of the LES of the plume is also displayed in figure 4 where the relative dispersion is shown. The slope of the red curves in this double logarithmic plot around 1/2 indicating pure molecular-like dispersion (if it is* $sigma_{zr}$ *which is plotted). It is confusing that the authors talk about slope between 0.01 and 0.0217 while I get something from the plot around 1/2. Theoretically, the slope in this range should be close to 3/2 as also mentioned in the Dinger et al paper which they refer to.*

  In response to the comment we have decided to leave this section out.

- *To summarize, it looks like the work does not spend enough computational resources on doing a realistic dispersion simulation and, secondly, doing analysis of all their snap-shots to get proper statistics.*

  As discussed briefly above, and fully discussed in Ardeshiri et al. (2020), the LES simulations are not perfect, despite this the grid resolution preserve qualitative characteristic similar to more resolved simulations. Indeed in Ardeshiri et al. (2020) it is demonstrated that concentration PDF of the coarser resolution simulations has the same shape but with less fluctuations. As mentioned in the manuscript, and further explained above, it is not computationally feasible to perform radiative transfer simulations for all snap-shots. Nor is it required to reach the aims of this manuscript. Both these points have been emphasized in the revised manuscript.

- *Turbulence is one of the unresolved problems of physics it is written at several occasions. It is not very clear that this work brings us much further.*

  This sentence has been removed throughout the manuscript.

Bibliography

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