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Reply on RC2

Matthieu Plu et al.

Author comment on "Modelling the volcanic ash plume from Eyjafjallajökull eruption (May 2010) over Europe: evaluation of the benefit of source term improvements and of the assimilation of aerosol measurements" by Matthieu Plu et al., Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2021-97-AC2, 2021

RC2

The authors thank the reviewer for his.her positive evaluation of the manuscript and for his.her comments about the text. Here are the answers to the Reviewer Comments 2 (RC2) and how they have been addressed to improve the manuscript.

General comments

It is generally well written, although in places sentences are very long and should be revised for clarity. Maybe the manuscript would benefit from being read by a native English speaker?

Use of the English language has been improved after a careful proofreading and rewriting of sentences that are too long or unclear.

All figures should have panel labels as per the submission instructions. This makes referring to figures in the text and writing concise captions much easier.

In the new manuscript, labels have been added to the different figure panels and they have been used for reference in the text and in the captions.

Specific comments

Introduction:

L1-24 More information could be added about what is issued by the VAACs (e.g. flight levels). What is the impact of issuing concentrations on aviation operations? What was the motivation of moving to a concentration approach? Do other VAACs issue quantitative information (I wasn’t aware they did)?

This part of the paragraph has been rephrased as this: “They provide at least qualitative information (i.e., presence of ash in different vertical layers, at different forecast lead times), and some VAACs give also some more quantitative estimates. In Europe, the London and Toulouse VAACs issue messages when volcanoes erupt in their domain of duty, to warn of the presence of ash in different layers, defined as flight level (FL) bands: FL000-200, FL200-350, FL350-550. Since the Eyjafjallajokull eruption in 2010, it has been recognized that aircrafts may tolerate some ash ingestion and that procedures should be revised (Bolic et al, 2011) in the sense that decisions of flying should be taken according to the tolerance of aircraft engines to ash concentrations. As a consequence, the London and Toulouse VAACs provide concentration charts (ICAO, 2016) for different thresholds: >0.2~mg.m^{-3} and <2~mg.m^{-3} (low contamination), >2~mg.m^{-3} and <4~mg.m^{-3} (medium contamination), and >4~mg\,m^{-3} (high contamination). The concentrations are given in the same FL bands as stated above. Such forecast charts (up to 18 hours ahead) indicate different levels of hazardous zones and they should be used by authorities for flight safety."

L25 You mention short comings of the models used to produce the ash dispersion

forecasts, however you do not include the impact of driving meteorology (and potential

uncertainty) on the output. The driving meteorology also impacts on the plume model that

is used to determine the resolved source term and source inversion.

A sentence has been added in this paragraph: "The driving meteorological forecasts, for which error grows inevitably with time (Dacre et al, 2016), are also an important source of uncertainty for volcanic ash dispersion."

A sentence has been added in the following paragraph: "In all cases, the calculation of source term is sensitive to the driving meteorological data."

Case study:

Section 2.1 is rather brief and focusses mainly on listing the observations that are

available rather than features of the case study. The observations then seem to be

repeated in section 2.3.

Section 2.1 has been removed and replaced by a short introductory paragraph for the case study, for the MOCAGE simulations (referred now as Section 2.1) and for the observations (referrred now as Section 2.2).

L65 what ash properties are available from SEVIRI?

This sentence has been removed, and is now described in Section 2.2.1.

L86 What is the difference between 3D-VAR and 3D-FGAT? Which one is used in this study?

More details, based on the article by Sic et al (2016, Atmos. Meas. Techniques), have been added to the article to describe the MOCAGE 3D-VAR and 3D-FGAT.

In this study, MODIS AOD are assimilated using 3D-FGAT and EARLINET lidar profiles are assimilated using 3D-VAR. This information is stated in the relevant sections.

L96 I am unclear what an observation operator is. Can you define it?

The definition of the observation operator comes with the methodology of variational assimilation that has been added.

L109 'rather good' is a subjective statement. Can you support this statement with some

quantitative comparison?

The quantitative comparison has been published by Piontek et al (2021) and by Plu et al (2021a). The new paragraph states: "VACOS has a fairly good volcanic ash detection probability \citep{Piontek2021b} for ash layers with column loads between 0.2 and 1~g\,m^{-2} (between 1 and 10~g\,m^{-2}) of approximately 93\,\% (99\,\%) and also allows for the quantification of the ash load of the plume with a mean absolute percentage error of ca. 40\,\% (26\,\%). The capacity of VACOS data to detect ash and to estimate ash load during this eruption phase has also been assessed by \citet{Plu2021}. The overall conclusion is that VACOS can be reliably applied to detect volcanic ash concentrations larger than 0.2~g.m^{-2}, and that the ash load estimates are in good agreement with estimates in the literature. The comparison with other satellite products shows similar peak values of ash load \citep[3~g\,m^{-2} against 2~g\,m^{-2},][]{Prata2012}. Comparable ash loads have also been found at locations where lidar-based measurements have been done, e.g., around 1~g\,m^{-2} east of England on 17 May \citep{Francis2012}. So VACOS data may be used as a reasonable reference data set for assessing and comparing the performance of different model outputs.".

I am not an expert in aerosol optical depth retrievals or data assimilation methods – When you assimilate AOD is this done at a specific height or does it somehow effect the whole column?

Some explanations have been added: "… the assimilation of AOD constrains the aerosol load but it does not constrain directly neither the vertical profiles nor the distributions of aerosol size and species, which proportions are kept as the ones in the background. The indirect effects (and improvements) of the AOD assimilation on aerosol vertical profiles are described by \citet{Sic2016}.".

Figure 1 – it is not clear what is shown by the shading in the plot on the left. Is it the fraction of time in your simulations that ash is present in that location?

The caption has been corrected: "Map of the number of instants (at hourly step from 13 to 20 May 2010) that are contaminated by volcanic ash (ash load above 0.2~g.m^{-2}) according to the observations (grey shadings)."

Representation of the emission and of the plume

L142 There are many more studies that are related to this issue e.g. Kristiansen et al.

2012, Harvey et al. 2020, Prata et al. 2021

Kristiansen et al. 2012 has been added, but we cannot be sure about the two other references that have been suggested by the reviewer.

L147 I am unsure what is meant here by 'regular'

"regular" replaced by "usual".

L174 Is this value of 30% analogous to the distal fine ash fraction used by the London

VAAC? This value seems quite high if this is the case.

We do not know the values used by the London VAAC. This 30% ratio comes from the recommendation of Mastin et (2009) for a medium-size silicic eruptions. This has been added in the text.

L182 Is the uniform distribution of ash in the parameterised case by design?

To address this question, an argument has been added in the manuscript: "Some tests have also been done using an umbrella-shape vertical distribution of ash mass, but the resulting atmospheric dispersion of ash was not better than a uniform vertical distribution.".

Figure 2 What is meant by the yellow shading in the bottom panel below the green line? Is it ash at the vent?

Yes, the yellow shadings reflects that the FPLUME source term emits some ash just above the vent; though lower than above the neutral buoyancy level. A sentence has been added in the text where the FPLUME source term results is discussed.

L187 The authors state that the 'plume has a realistic shape which goes in the right direction' but they don't say what evidence they use to come to this conclusion. Is it compared to the VACOS information?

Yes, this has been added in the manuscript.

Figure 3

Qualitatively, the ash distributions in both simulations are quite similar and are both a reasonable match to the VACOS retrieved information. What is the additional cost of running with FPLUME?

Running FPLUME on a 24-hours period of time costs 200s approximately on a single AMD EPYC 7742 64-Core (2250 Mhz) processor. Parallelization and optimizations (reducing the number of FPLUME vertical levels for instance) are possible to reduce the delay to deliver FPLUME source terms for MOCAGE.

Along the plume axis, the high ash column loadings that are simulated are not reflected in the VACOS retrievals. Is there an upper limit on the value that can be retrieved?

Close to the vent the typical volcanic ash spectral signature in the thermal infrared (i.e., the brightness temperature difference between channels located at 11um and 12um, Prata, GRL, 1989) might vanish if the ash plume becomes opaque (Watkin, Met. Appl., 2003), which might also lead to underestimations in the retrieved mass load. For simplicity, VACOS also neglects the impact of SO2 and ice-coated ash (Piontek et al., Remote Sens., 2021, "1. Development"), both of which might be present close to the eruption source. These arguments have been added to the manuscript.

At 0900 on 16th May in the parameterised simulation there is a lot of ash to west of Ireland that isn't present in the FPLUME simulation. Is this ash at low levels?

The ash pattern that is west of Ireland in the parameterised simulation is mostly confined between the surface and 5~km altitude, which is below the denser plume (around 8km altitude). The most probable explanation is the injection of mass at every vertical level in the parameterised simulation and not in FPLUME, combined with some vertical wind shear. This argument has been added to the manuscript.

At 2000 on 17 th May there are large parts of the simulated ash plume that are not evident in the VACOS retrievals. Do you have a hypothesis for why this is? Over the Netherlands there is no ash simulated in either simulation. Could this be due to errors in the meteorology?

Considering Fig. 3 for 17 May 20 UTC, VACOS shows ash retrievals at the latitude of Iceland and a separated cloud above the North Sea, whereas these patches are connected in the model. We find this separation also in the brightness temperature difference 11um-12um (e.g., Fig. 15 in Schumann et al., ACP, 2011) and in the retrievals of VADUGS (e.g., Fig. 2 in https://www-cdn.eumetsat.int/files/2020-04/pdf_conf_p_s11_06_kox_v.pdf). As the MODIS visible images show rather clear conditions at North Sea (see https://worldview.earthdata.nasa.gov/?v=-17.587440569968944,46.621509795561295,27.292399149472,68.29005741010387&l=MODIS_Terra_Aerosol(hidden),MODIS_Aqua_Aerosol(hidden),Reference_Labels_15m(hidden),Reference_Features_15m(hidden),Coastlines_15m,VIIRS_NOAA20_CorrectedReflectance_TrueColor(hidden),VIIRS_SNPP_CorrectedReflectance_TrueColor(hidden),MODIS_Aqua_CorrectedReflectance_TrueColor,MODIS_Terra_CorrectedReflectance_TrueColor(hidden)&lg=true&t=2010-05-17-T09%3A32%3A41Z), the retrievals can be considered reliable.

Possible causes for differences between the model simulations and VACOS are errors in meteorology or eruption source term. These have been discussed by Plu et al (2021, doi:10.5194/nhess-21-2973-2021).

L195 Remove this sentence

Done

L200 This 12% error seems quite small? Is it from literature?

This value has been used by Sic et al (2016), who designed the AOD assimilation in MOCAGE.

Figure 4 It is quite difficult to compare Fig 3 and Fig 4 as the differences seem to be very small. One way to make this easier would be to combine Fig 3 and Fig 4 to have all the simulations in one plot.

If all panels are in a single plot, fitting it in a page would make the panels too small to be readable. That is why we preferred to make 2 figures.

Do the authors think that this small impact is a surprise? Is it just valid for this case study or a more general feature of assimilating this variable?

Indeed the impact of assimilation of MODIS AOD is rather small. We are not aware of other articles that evaluate the MODIS AOD on a volcanic ash plume. On a desert dust plume (Sic et al, 2016), assimilating AOD has a larger impact on the representation of the plume. But the context is different: a desert plume is larger, sky is less contaminated by clouds or rain, which leads to a larger number of assimilated pixels than for an Icelandic volcanic eruption. The impact of the MODIS observations is a function of the number of observations covering the plume and the relative weight given to the observations compared to the model by the B and R matrices. These arguments have been added in the manuscript. Besides, daily maps of the assimilated MODIS AOD have been added to the manuscript (following a recommendation by RC1), in order to facilitate the discussion.

Figure 5

What is meant by hits for VACOS? It is just the number of grid cells with ash in the retrievals?

Yes. The legend of Figure 5 has been clarified.

Are all the hits along the plume axis and misses around the edges?

We do not have diagnostics to address this question. It may depend on the simulations and on times.

It seems all the simulations perform similarly in the hit metric, although there are obvious phases in the period considered.

Yes, this comment has been added to the manuscript.

The caption mentions grey shading but there is none in the figure.

It has been removed from the legend.

L224 Unsure what is meant by 'data spots' here

Changed to "...the VACOS retrievals reveal...".

L225 Can the author's say something more quantitative here than 'rather good'?

Replaced by "The most contaminated areas in the model outputs and in VACOS match generally well."

L235 What is meant for by a 'meaningful' metric?

"meaningful" has been removed.

L244 Is a radius used or is it a square of a specified number of grid boxes as per the original FSS methodology?

It is distance (in km) on the sphere. It has been clarified in the manuscript.

Figure 6

Why did you choose these neighbourhood sizes? 500km is a very large area.

The differences between each of the simulations is quite small especially one you get to

the larger neighbourhood sizes. Do the authors need to show 200km and 500km? Highlight the FSS=0.5 level on the plots

The FSS gives an estimation of how the ash patterns simulated by the models match the observed ones, using a tolerance. It is common (Harvey and Dacre, 2016; Plu et al, 2021) to have different radius for FSS, in order to see how the models perform depending on the scales. FSS=0.5 is shown on the plots.

What happens on 19 May? Skill drops off very quickly at all scales.

It is related to the decrease of ash gridpoints due to loss of volcanic emissions from 18

May. Remaining ash is leaving the field of regard quickly due to south-westerly winds.

Is it possible to show how much information is being assimilated at each time? This might be interesting to know.

The impact of assimilation depends on the location (relative to the ash plume) of the assimilated gridpoints. This impact can last in time. So we do not believe useful to show how much data are assimilated in relation to the scores.

The metrics that are used in this study consider the presence of ash above a column loading threshold. This analysis could be extended to determine the performance of the simulations regarding the magnitude of ash column loadings.

A discussion of ash load performance has been added in relation to Figure 3 and 4 (references of the submitted manuscript).

Assimilation of ground-based lidar profiles

L262 I don't think that the signature is 'obvious' if you are not used to looking at this type of data. Also, the maximum at Hamburg really isn't that clear.

Indeed the signature on Hamburg profile is not so clear. "Obvious" has been replaced by "can be seen". The following of the sentences helps to point out the altitudes to look at on the profiles.

Figure 7 The x,y labels and legend are very small in all panels.

Done

L288 A 10% error seems quite small? Is it from literature?

Considering the experience and litterature with aerosol lidar assimilation and particularly for cases where volcanic ash is present, we do not have precise estimates of lidar observation error variance. El Amaroui et al (2020, Atmos. Meas. Tech.) propose an error between 10% and 25%. What is important is the ration between the variances of model error and of observation error. Further studies should help to tune these variances.

L305 -308 I don't really follow the argument here. If there is a negative bias of non-ash aerosols in MOCAGE then how can the ash concentrations decrease after assimilation on 18 May?

The last sentence of this paragraph has been removed, since there was no logical link with the previous sentence.

Figures 8 and 9

Add units to color bar

Is it possible to indicate the values of the insitu measurements on this Figure?

Following RC1 (see supplement to answers to RC1), an additional figure has been done to compare model simulations to in-situ measurements directly. The discussion has been completed accordingly.

You only use a few snapshots of the insitu measurements. Is there more that can be used? (E.g. to create a plot that shows the impact of the assimilation more generally – maybe a scatter plot).

There is no other measurement available for this study. The additional figure following RC1 mentioned above brings comparison of model simulations with in-situ measurements.

Conclusions

L336 change 'look more realistic' to 'compare more favourably to insitu measurements'

Done

L342 How general do you think that your findings are given that you have only run a small number of simulations for one case study? Do you intend to apply the approaches presented here to eruptions in different geographical locations or to create "synthetic" eruptions to study? Another approach to address some of issues used as motivation in this study is to use ensembles of simulations. Is this something your group has considered?

We studied a long duration eruption that covers a multitude of different conditions (meteorology, cloudiness, observation density, etc), so it is not just "one case study". Desert dust plumes are covered in other papers (Sic et al) and other studies address forest fires for instance. Volcanic eruptions are rare, so considering other pollutants, more case studies or synthetic eruptions can also be considered.

Technical corrections

All technical corrections requested by the reviewer have been implemented in the new manuscript.

We hope that we have addressed RC2 satisfactorily and that, after implementation of theses changes in the manuscript, it can be accepted for publication.