

## **Answers to Review2** of paper “First results of the Piton de la Fournaise STRAP 2015 experiment: multidisciplinary tracking of a volcanic gas and aerosol plume”

### **Main comments**

#### **Comments from Referee**

My main comment about this study is that I found it hard to follow - the introduction to the paper is verbose and discusses the motivation for the whole STRAP project rather than that specifically relevant to the results presented here. The results are separated out into separate sections that also describe methodological considerations for each method. Synthesis and comparison of the different results is not introduced until the conclusions, and is then very brief.

On page 17, line 16 (conclusions) the authors write that “The purpose of this article was twofold: (i) to present the methodological approach developed to track plume evolution from source to the distal area, and (ii) to summarize the preliminary observations of gaseous emissions, plume location, height and dispersion and gas-particle conversion”

This would be a much clearer structure than the outline followed from page 3 lines 19-32 and currently followed. My suggestion is that the article is restructured on the following basis:

- 1) The introduction could be shortened and made more relevant to the results presented here, e.g., on page 3 lines 9 -19 are dominated by affiliations of the co-authors and some other information that could be in the acknowledgements; section 3.1 is long and could be condensed into an introduction to the more relevant material in section
- 2) The methods of the STRAP experiment, for which results are presented in this article, should be outlined in a methods sections. This should include a clear account of the temporal coverage of the observations that are being presented here (e.g., in a table or figure) It would help the article’s readability if methods were clearly linked to the stated goal of tracking plume evolution from source to distal area.
- 3) The results should be described in a separate section and could be subdivided into (1) a presentation of preliminary observations of plume properties with clear reference to figures and (2) a synthesis of measurements relevant to understanding plume evolution. At present some of the results are well represented by figures, while others are described but not shown.
- 4) Discussion and conclusions should place the new observations made from measurements presented in this paper into context of past studies at Piton de la Fournaise and other volcanoes.

#### **Author's response and general changes in manuscript**

We agree that the paper will benefit with a re-organisation by separating the methods, results and discussions. It has been done taking into account the recommendations of both reviewers 2 and 3. Now the paper is constructed as follow:

1 - Introduction

The introduction has been shortened.

## 2 - Description of the 2015 STRAP campaign on Piton de la Fournaise:

We thought that it is important to give in this section information about Reunion Island (meteorology conditions and topography), the geological context of Piton de la Fournaise, and to summarize the 4 eruptions of the STRAP campaign. The section 3.1 of the previous version has been condensed.

## 3 – Methods, models and measurements

We have introduced a subsection named “Campaign management” to summarize the section 2.2 and to point out the location of the main sites of observations.

We agree that most of the affiliations of 2.2 are not necessary in the text; they have been deleted and put in the acknowledgements.

A subsection “Flexpart modelling” corresponding to section 4.1.

A subsection named “Measurements near the plume source”: this part integrates the description of the methods and instrumentation, previously introduced in section 5.

A subsection “Measurements of the physical and chemical properties of the plume” which contains the technical elements and measurement methods introduced in the previous sections 6, 7 and 8.

## 4 - Preliminary results

The results have been separated into three subsections of results and figures descriptions.

“Simulation of the regional distribution in 2015”: this part corresponds to section 4.2

“Plume geometry and gas emissions at the volcanic vent”: this part corresponds to section 5 excluding the technical elements introduced in the new section 3.

“Examples of volcanic plume distribution and chemical properties”: this part groups the results of distal plume measurements at (sections 6, 7 and 8 of the previous version).

## 5- Discussion

This new section has been proposed by both reviewer 2 and 3. This section contains the discussion of results previously introduced in the conclusion.

## 6 – Conclusion

The conclusion has been modified and place the new observations made from measurements presented in this paper into the context of past studies at Piton de la Fournaise and other volcanoes.

## **Line by line comments:**

### **Comments from Referee**

Abstract:

line 5 – do measurements span 85 days in total? Does this include gaps in activity?

### **Author's response**

The STRAP campaign was conducted during all of the year 2015. 85 days represents the number of days of eruptive activity of the volcano and thus corresponds to the number of days of plume observations. We added « in the whole

2015 » in line 2 to be clearer and emphasize that the STRAP campaign occurred during the entire year of 2015.

#### **Author's changes in manuscript**

“The STRAP (Synergie Transdisciplinaire pour Répondre aux Aléas liés aux Panaches volcaniques) campaign was conducted in 2015...”

by

“The STRAP (Synergie Transdisciplinaire pour Répondre aux Aléas liés aux Panaches volcaniques) campaign was conducted during the entire year of 2015...”

#### **Comments from Referee**

Abstract Line 11 – ‘a particular emphasis is placed on...’ this is an ambiguous phrase. Do you mean that this is a particularly interesting result?

#### **Author's response**

Yes, we wanted to emphasize this result. The sentence has been simplified to be less ambiguous.

#### **Author's changes in manuscript**

“A particular emphasis is placed on the gas-particle conversion with several cases of strong nucleation of sulphuric acid observed within the plume and at the distal site of the Maïdo observatory.”

by

“Several cases of strong nucleation of sulphuric acid have been observed within the plume and at the distal site of the Maïdo observatory.”

#### **Comments from Referee**

Abstract: How do the SO<sub>2</sub>, CO<sub>2</sub> & H<sub>2</sub>O levels compare to past measurements/periods of activity. What are the implications for plume interaction with the atmosphere? Are there implications for understanding the development of the eruption (e.g., from increase in SO<sub>2</sub> at end of phase referred to later?)

#### **Author's response**

The PdF emission are negligible outside eruptive period (see review of Di Muro et al., 2016). So the concentration level of volcanic pollutant (gas and aerosols) are several times lower than during the eruptions.

#### **Author's changes in manuscript**

We added “During the last decades, the degassing of Piton de la Fournaise was negligible outside the eruption periods.” in section “Geological context of Piton de la Fournaise”.

#### **Comments from Referee**

I understand from Section 3.2 that observations from 20th June 2014 to October 2015 are presented in the paper, but from the Figures (Especially 12 and 13) it looks like data were only acquired in 2015 ( the abstract refers to 85 days of measurements and from page 3 line 28 (and figures) it sounds like only the climatology for two eruptions is described). Overall I found it difficult to get my head around the differences in temporal coverage of all the different measurement types –

I suggest that the authors include a table, or perhaps a figure, to compare the duration and temporal coverage of each type of observation.

#### **Author's response**

You are right, the section 3.2 is confusing by including a part of 2014 in the STRAP period. It has been corrected in the new version. As explain above, the STRAP campaign only occurred during the year 2015. However, the OVPF managed continuously all eruptions of the Piton de la Fournaise.

We did not find the way to summarize all the observations on one figure due to the disparity of measurements types and their duration.

We have chosen to introduce four tables (two in the main text table 1 and table 2 and two in the appendix table A1 and table A2), and one figure for the Maito observatory (permanent observation).

#### **Comments from Referee**

Page 2 line 7-8. Use of 'on one side', 'on the other side' is confusing – these are not opposing ideas?

#### **Author's response**

Thanks, it has been corrected.

#### **Author's changes in manuscript**

The new sentences are:

“ Improving our ability to quantify and model the genesis, dispersion and impact of a volcanic plume is thus a key challenge for scientists and societal stakeholders. Furthermore, mitigation of volcanic crisis relies on efficient, and effective, communication and interaction between multidisciplinary scientific actors in geology, physics, chemistry, and remote sensing.”

#### **Comments from Referee**

Page 2 line 18. Please add reference for impossibility of obtaining source parameters at Eyja?

#### **Author's response**

It has been done: the reference of Ripepe et al., 2013 is added.

#### **Comments from Referee**

Page 2 line 31: 'an objective' - is this the particular aim of this work? The following sentence refers to real-time measurement, which I think is not necessary for these goals.

#### **Author's response**

This is true, “Real-Time” has been deleted.

### **Comments from Referee**

page 3, line 5: I don't think this is true. The Boulon 2011 paper does not include measurements made within a volcanic plume. And there are certainly other earlier studies that present measurements of aerosol within volcanic plumes (e.g., Mather et al., 2004; Rose et al., 2006; Martin et al., 2008). Although it provides no information about nucleation mechanism Ebmeier et al., 2014 also shows that there is elevated aerosol and depressed cloud droplet size downwind of PdIF in satellite retrievals averaged over a decade (and a greater effect for periods of eruption). It would be interesting to know how these course observations compare to your much more detailed multi-sensor measurements.

### **Author's response**

The observation of the reviewer is valid. There is an error in the reference of Boulon et al., 2011.

Boulon Julien, Karine Sellegri, Maxime Hervo and Paolo Laj, Observations of nucleation of new particles in a volcanic plume », PNAS, July 11, doi: 10.1073/pnas.1104923108, 2011

To our knowledge, the paper is the first where measurement of ultra-fine particles (sub 5 nm, which characterize the gas-particles nucleation process) have been made within a volcanic plume. However these measurements have been made far from the volcanic vent (in France on a plume from Island). Here we probably present the first observation of ultra-fine particles observed at few km of the vent (AIS instrument). The concentration are thus much higher in our study thus adding a new perspective to the work of Boulon et al., 2011.

The reference has been corrected in the new version of the article.

We also added the reference of Ebmeier et al., 2014 in the introduction (thanks for this interesting paper). There were no cloud droplet measurement during the STRAP campaign. So it is not possible to compare our results with the study of Ebmeier et al. at this stage. However, cloud resolving models (MesoNH, see Durand et al., 2014, jgr) will be applied in some of the case studies of the STRAP period. One focus will be on evaluating the aerosol activation (small cloud droplet formation) downwind of the Piton de la Fournaise vent. We hope to simulate the same process of cloud formation associated with a volcanic plume composed by high number of CCN. This new study could then be compared to satellites observations of Ebmeier et al., 2014.

The references to the papers of Mather et al., 2005; Rose et al., 2006, and Martin et al., 2008 have been added to Robock, 2000.

### **Comments from Referee**

Page 4, line 2: 'unique and craggy' is uninformative, 'benefits from a tropical climate softened by the breezes of the Indian Ocean' is also rather informal in style.

### **Author's response**

You are right about the rather vague meaning of the terms "unique" and "softened". The term craggy was used to emphasize that the topography of the Island is steep and the local circulation is complex in the valley. The sentences have been modified.

### **Comments from Referee**

Section 2.2 title: 'means'=methods?

#### **Author's response**

We wanted to refer to capabilities in instrumentation. Nevertheless, the word “means” and the title have been removed with the reorganisation of the paper, described above.

### **Comments from Referee**

Page 4 line 19: what kind of imagery? Photographs? Figure 1: Resolution appears to be quite low for the size of Figure.

#### **Author's response**

Visible and IR imagery are routinely acquired. The text has been modified accordingly.

Figure 1 has been modified: the colours of characters were changed, the resolution was increased.

### **Comments from Referee**

Caption: Page 5 line 20 range of dates is surprisingly precise

#### **Author's response**

We don't understand this comment. There is no range of dates specified in page 5 line 20.

### **Comments from Referee**

page 10 line 10: I'm not sure that this is an acceleration?

#### **Author's response**

The word acceleration is probably not appropriate. In the new version, the word “accelerate” has been changed into “increase”.

### **Comments from Referee**

Page 17 line 21 – where are these geometries shown?

#### **Author's response**

Fig. 4 summarizes the results of plume height and direction measurements by the NOVAC instruments and ground Meteo-France stations.

### **Comments from Referee**

Page 18 line 10 → rugged?

#### **Author's response**

Thanks, it has been corrected.

### **Comments from Referee**

Conclusions: Comparison to the previous level of knowledge about the PdIF plume would be useful here – both to place your results in context and help the reader

appreciate the level of advance in knowledge offered by such an integrated multi-methodological approach.

#### **Author's response**

Piton de la Fournaise is one of the most active volcanoes in the World. In spite of that, very little is known about its gas emissions in terms of fluxes, composition and evolution in time and space (see the recent review of Di Muro et al., 2016). The 2015 experiment provides the first complete complete characterisation of gas emissions of Piton de la Fournaise. Interestingly, the experiment captured two distinct end-members of the typical PdF activity: i) a fast and exponentially declining eruptive activity (May 2015) and ii) a complex, long lasting and large volume eruption (August-October eruption). These elements have been added in the new section "Discussion".

#### **Comments from Referee**

Through the article there are English phrases that are ambiguous and some rather awkward constructions. I suggest that English language proof reading would help the final version of this article.

#### **Author's response**

We have done our best to improve the English. The new version of the paper has been read by a native English speaker. Your review and help was strongly appreciated.