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Solid Earth Discussions

Interactive comment on "Satellite-derived SO_2 flux time-series and magmatic processes during the 2015 Calbuco eruptions" *by* Federica Pardini et al.

Anonymous Referee #2

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This paper presents a method to simultaneously retrieve the flux and the altitude of SO2 emitted from a volcano, using two consecutive satellite images of a volcanic plume and HYSPLIT trajectory simulations. Based on this method, the authors estimate the SO2 mass load emitted during two distinct phases of the Calbuco eruption in 2015. The comparison of this result with the SO2 mass load deduced from microprobe analysis following the standard petrological method allows the authors to propose an interpretation of the dynamics of degassing during the eruption. The authors argue the presence of excess SO2 during the first phase of Calbuco eruption whereas the second phase does not exhibit such excess degassing.

The objective of this paper is of significant interest for the communities of volcanologists and atmospheric scientists as the knowledge of volcanic emissions is critical to better

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understand sub-surface magma processes. It is also crucial to make progress in our appraisal of the broad impact of volcanoes on the atmosphere.

This being said, the method developed in this study suffers from several issues and inconsistencies that are developed in the following. The validity of the method is consequently highly questionable. In this context, a robust validation, which is relatively weak in the present version of the paper, would be necessary before the method may be published and considered worth of interest beyond the special case presented here.

The authors also do not make proper reference to various pieces of research that have been already published on the topic.

For these various reasons, which are developed below, I would recommend ‘major corrections’, if not a rejection.

Issues/inconsistencies of the method

The method consists first in evaluating, from the known location of the volcanic plume at the time of satellite acquisition and by using HYSPLIT backtrajectory simulations, three variables associated to each pixel of the satellite image : 1- the SO2 altitude at a given pixel (h), 2- the altitude of SO2 injection above the vent (h_{vent}), 3- the associated time of SO2 injection above the vent (t_{vent}). To do so, the authors test a broad range of SO2 altitudes (between 2 and 30 km) at a given pixel and select the pixel altitudes which correspond to backward trajectories that pass over the Calbuco vent (or within a certain radius around the volcano). The set of solutions found for these 3 parameters (h, h_{vent}, t_{vent}) may be refined in a second step. This refinement consists in subsetting the range of pixel altitudes selected in the first step, to keep only those which initialise HYSPLIT forward trajectories that point toward pixels where the SO2 plume is detected in a second satellite image acquired 24 h later.

However, such a problem has multiple solutions, especially because a strong interdependency often exists between the time and altitude of injection when trying to explain the location of a gas parcel detected in a satellite image. Here, the authors present a unique solution for the set of variables (h, h_{vent}, t_{vent}) which they compute from the mean value (h , h_{vent},t_{vent})) considering all the possible solutions found for the altitude of the pixel of interest (Fig. 3 and Fig.4) – by the way, the formula is provided in caption of Fig 3, but should be in the text. The validity of this presented solution is highly questionable.

The strong interdependency between time and altitude of injection is clearly shown by the results of the authors. For example, the comparison between results in Fig. 3 and Fig. 4 indicates that for the exact same pixels in the zone indicated by black arrows in the figure 1 of this review (figure 1 of this review includes subplots taken from Fig. 3 and Fig. 4), an altitude of 14-16 km (associated eruption time retrieved : 23/04/15 at 04 :00 AM) is retrieved on Fig. 4, whereas an altitude of 7-10 km (associated eruption time retrieved : 22/04/15 at 22 :30 AM) is retrieved on Fig. 3.

This example shows the extreme instability of the results which are presented: given the range of time intervals which is assumed for the time period of injection of SO2, very different results are obtained for the exact same pixels. Another case illustrates these unstable results : neighbour pixels in the subplot taken from Fig. 3 above show a drastic difference in altitude: turquoise blue pixels (5 km altitude) are direct neighbours of red pixels (23 km altitude) emitted at different times of injection.

According to this instability of the results, one can hardly envisage an uncertainty on the SO2 height (at distance or above the vent) of less than 1 km, as presented in Fig.3-d/Fig.3-e. The authors report a mean uncertainty of 0.5 km (Line 30 page 7). In the present state of the paper, this uncertainty appears to be greatly underestimated. Indeed, the authors only illustrate a single solution for the set of variables (h, h_{vent}, t_{vent}). Unfortunately, they do not provide any additional figures that could show intermediate results on the panel of solutions which has been selected so as to allow the reader to apprehend the range of variability of these solutions before the procedure of averaging.

One might wonder if the very small uncertainty on altitude could be due to the rather narrow range of injection time prescribed in input by the authors (the reason for choosing such a narrow range is not explicited in the paper). In other words, the posterior uncertainty reported by the authors seems artificially underestimated by severely restricting the size of the manifold of a priori parameters. If emissions were allowed to occur beyond the start/stop times prescribed by the authors, then a much broader range of h, h_{vent} and t_{vent} would almost certainly be obtained.

2- Results on altitude presented in Fig. 3 and 4 are also suspicious. The authors find approximately the same altitude for both the SO2 injection at the vent and the pixel of the satellite image at distance from the volcano. This result means that a parcel of SO2 emitted at a specific altitude is detected by the satellite at the exact same altitude, even after a travel of several hundreds (up to a thousand) kilometers. In other words, the plume travels at constant altitude at continental scale. This implicitly indicates an extremely stratified and stable atmospheric environment all over the region of study, which includes the Andes Mountains. This is really surprising and doubtful.

3- Authors report a 10 min time resolution for their retrieved time series of flux and altitude, while they also mention ' an uncertainty on injection time in 0 – 110 min with a mean value of 45 min ' (caption of Fig. 4). Isn't it contradictory?

(by the way, more information on the calculation of the uncertainty on injection time should be provided)

4- For all the issues mentioned above, the validity of the evaluation of the variables (altitude of satellite image pixels, associated altitude of injection, associated time of injection) is questionable. As the time series of flux and injection altitude are deduced from (1), their validity is also questionable.

Unfortunately, a weak validation of the results is presented with only comparison with mean values of altitudes roughly evaluated from tephra deposit studies and remote sensing methods. However, the authors could compare their results on pixel altitude

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with for example the altitude of the SO2 plume retrieved from IASI satellite images. See the paper of Begue et al. 2017 in discussion in ACPD, which provide IASI SO2 altitudes on 24/04 in Fig 3:

https://www.atmos-chem-phys-discuss.net/acp-2017-544/

One might wonder if the problem posed here is not underdetermined. At least to check the validity of the results, I recommend using a longer time series of GOME-2 satellite images (which exists for this eruption, as mentioned by the authors). It would at least allow for checking that the trajectory is correctly modeled by comparison with GOME-2 images which are acquired later.

No reference of studies published on the same topic.

Another major concern is that the authors do not properly acknowledge in the introduction section papers that have already been published on the exact same subject, such as: 1- papers that develop algorithms that allow for retrieving both the volcanic SO2 column amount and plume height at a given pixel of a satellite image collected from various UV and thermal IR sensors (OMI : Yang et al., 2010; Nowlan et al., 2011; Rix et al., 2012; IASI : Carboni et al., 2012; Clarisse et al., 2014; Carboni et al., 2015). 2- papers which presented robust methods for retrieving both the flux and injection altitude of volcanic SO2 emissions from satellite imagery (e.g. Moxnes et al. 2014, Boichu et al. 2015, Heng et al. 2016).

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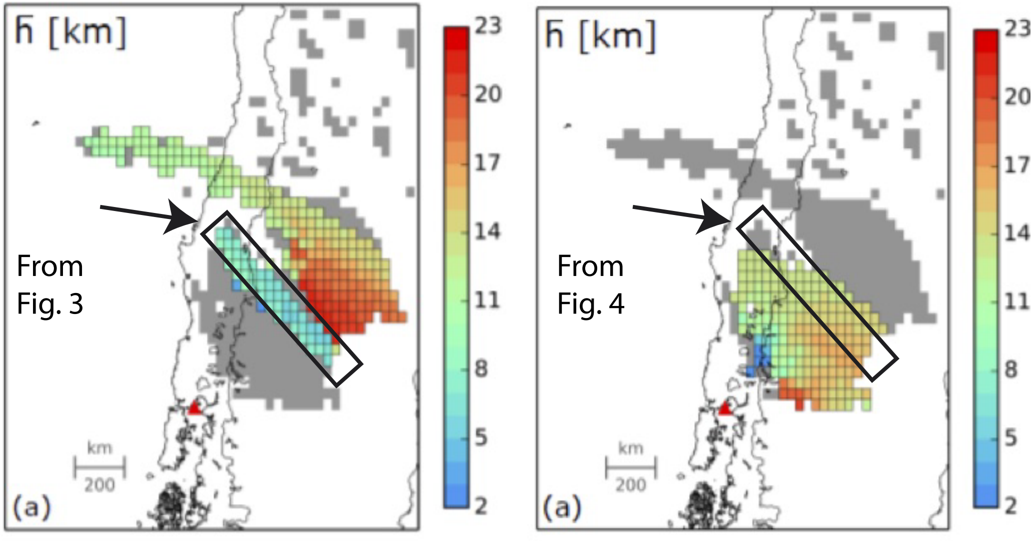

Fig. 1.

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