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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Insights into the recurrent energetic eruptions on Awu, one of the deadliest volcano on earth" *by* Philipson Bani et al.

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We would like to thank Dr. Corentin Caudron (RC1) for the detailed review of this manuscript. Here we provide our response to the remarks, comments, and suggestions.

Specific comments (SC):

SC 1: The introduction just documents past eruptions. It would be interesting to briefly introduce your aim and which methods you're going to use in this study in a paragraph or two? It would be great to provide more information regarding this relatively poorly

known area of the world in terms of tectonic settings and volcanic activity. I would also perhaps even a create a separate section for the volcano history.

Response We agree that the introduction part of this manuscript is too long and the objective of the work doesn't stand out sufficiently. The new version of the introduction is divided into sub-sections which should allow readers to have general ideas about this Awu volcano. The objective of this manuscript is to highlight the intense eruptive character of this volcano and provide insights into the possible mechanisms that fueled the deadly energetic eruptions. The geodynamic context is summarized as suggested and figure 1 is modified to better illustrate the peculiar geodynamic context dominated by the unique present-day example of arc-to-arc collision.

Figure 1 full caption. Awu volcano is the northernmost active volcano of the Sangihe arc (A). It occupies the northern portion of Sangihe island (B). 3D map from https://maps-for-free.com. Sangihe and Halmahera arcs constitute the present-day example of arc-to-arc collision (C). The Molucca Sea Plate that existed between the two arcs is now sinking deeper beneath the Molucca Sea. Awu's crater is currently occupied by a lava dome (D). Note the person circled in red for scale.

SC 2: Going through the very interesting table 1, I noticed that eruptions are particularly short (a few days). You often refer to Kelud to interpret your results and understand the hazards at Awu which seem totally relevant to me. In our recent paper (Caudron et al., 2015, GRL), we noticed that Kelud had very short but intense eruption and hence reasonable VEI (4). Do you think this is the case at Awu? Any way to compute the intensity along with the VEI which may better reflect explosivity?

Response Awu is poorly studied and this manuscript is among the rarely available if any. Thus more work is needed to gain more information, particularly the mass discharges, the ash dispersal, plume heights, etc. Such information may help to compute the past eruptions intensities to better characterize the strength and the hazards behind each event. This is beyond the scope of this manuscript. However we agree on the short duration events and have added Caudron et al. (2015) for reference.

SC 3: As clearly stated in the paper, another manuscript is being considered for publication in GRL. It would be interesting to explain how they differ as 1 table and several figures are found in both manuscripts (https://www.essoar.org/doi/pdf/10.1002/essoar.10501997.1).

Response Yes there is another manuscript on Awu submitted to GRL in which the location figure, the crater figure, and the table of eruptive history are the same. However, in contrast to the manuscript considered in NHESS, the second manuscript focuses on the gas emission on Awu and more specifically on the abnormal CO2 emission. The manuscript highlighted this CO2 rich gas and provide some hypothesis on its source whilst this NHESS manuscript focuses on the volcano and its intense eruptive activity. We prefer to develop fully these two topics in separate manuscripts.

SC 4: L.167-169: I'm a bit lost here. You basically explain that 27 MW of radiant flux would be sufficient to evaporate all the incoming water (without infiltration) in maximum 8 hrs. This is convincing but why is this coherent with the drying out prior to the 1992 eruption? We don't know how fast it did evaporate since there is no date mentioned in Table 1, and the volume was more than 18 times larger than the one you mention on l.155. Similarly how does that support the drying out prior to the 2004 eruption? You may expect more heat to be transferred to the system prior to eruption but I'm a bit lost concerning the take-home message here. The section title Transition of heat to the surface controls the water accumulation is confusing to me at this stage. The fact that you did not observe any water in 2015 could simply be explained by the evaporation am I right? So the water accumulation is not simply controlled by heat coming from below.

Response Thank you for this remark. The subtitle is changed to avoid confusion and reflect the content better. The new sub-title is "The heat transfer to the surface controls the water accumulation". With the high annual rainfall of 3500 mm and the 3.5 million

cubic meter of water in the crater, the solar heating, combined with the heat provided by the atmospheric radiation may not be sufficient to evaporate out the 95 % the lake water, if the heat input from a shallow magma is negligible. The main message here is the role of heat provided to the surface. If the increase of heat flux can lead to water lake evaporation, the cooling of the crater surface can in contrast allow water to accumulate. Hence with the current cooling trend in the crater, one would expect that ultimately the heat supply to the surface and the solar heating will no longer be sufficient to dry out the incoming water from the rainfall. Water may then accumulate to form a new crater lake, as already seen in the past.

SC 5: L.179: I don't understand what supports the statement regarding lava domes emplacement without explosive magma-water interactions?

Response By the time the viscous lava reaches the surface, its temperature could be as hot as 600°C. Thus if the water comes into contact with such hot magmatic body one can expect intense magma-water interaction and eventual phreatic eruption. However, alternatively, during ascent, the crystallizing magma body may release much of its gas and the carapace surface temperature can rapidly drop below 100°C once it reached the surface (Sherrod et al., 2008). In such a scenario the dome may passively emerge through a crater lake without explosive magma-water interactions.

SC 6: L.186-187: this is wrong. The 2014 Kelud eruption occurred after 7 years following the dome emplacement. Question: my understanding was the dome quickly grew at Kelud, within a few months or so, then completely stop growing? Is it the case for Awu?

Response Thanks for this remark. We reformulate the text to better express the delay between dome emplacement and violent eruption. Similar to Kelud, the lava dome on Awu has rapidly reached its current size then completely stopped from growing. This is now mentioned in the text.

SC 7: L.196: other mechanisms exist. Just to keep the parallel with Kelud, Cassidy et al. 2019 (G3) suggest internal triggering: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GC008161. Another may relate to permeability reduction due to alteration at dome-forming volcanoes (Heap et al., 2019). I feel you should discuss these options in detail taking into account their knowledge of the Awu system.

Response We agree with this remark and many thanks for the references. Other mechanisms that are likely to trigger an explosion are now included in the manuscript as suggested, including the second crystal nucleation and rapid crystallization of a degassed magma, as well as the reduction of lava dome permeability with the hydrothermal processes.

SC 8: L.215-220: this message is an important one but need to be supported better. You seem to imply that the explosivity of the past vigorous eruptions is related to magma water interactions. Am I right? The example of Kelud 2007 vs 2014 shows that the water had only a negligible effect on the explosivity. Could you comment/elaborate on this?

Response The similarity that we highlight between Awu and Kelud focuses on the passive emplacement of the lave dome through crater lake and the time delay between the dome emplacement and the VEI 4 eruptions. In contrast we consider that there was a coexistence of crater lake and lava dome when the VEI 4 eruption occurred on Awu which is not the case on Kelud. The triggering mechanism of kelut 2014 eruption was the second crystal nucleation event and the subsequent rapid crystallization at shallow depth that led to over-saturation of the source with intense diffusion of volatiles and growth of bubbles. Investigate the triggering mechanism is beyond the scope of our work. We simply quote the common process – the injection of a new magma – as the triggering event. Thanks for the remark, we now include in the manuscript other mechanisms that can trigger the eruptive activity on Awu, including the second crystal nucleation and the acidic-sulphate alteration processes.

Minor questions (MC)

MC 1: L.24: what is a little know volcano? It should be little known – now corrected

MC 2: L.28: what are global impacts? L.40: It would be interesting for the reader to explain why/how some injections in the stratosphere lead to a cooling while other produce a warming. Just in 1-2 sentences. In general massive sulfate aerosol injections into the stratosphere, increase the stratospheric aerosol's optical depth leading to a reduce of surface temperature. However, major tropical eruptions can produce asymmetric stratospheric heating that can ultimately enhance warming on some regions and cooling on others. We add reference to Robock (2015) for further detail on asymmetric stratospheric heating.

MC 3: L.75: was the Multi-GAS deployed on the dome? The arrow on figure 2. You mention different locations in the text but there is only 1 arrow in the figure. Thanks for this remark – indeed we deployed the multi-GAS on 3 points but only one of them is less diluted and considered as representative of the system. It is now clearly mentioned.

MC 4: L.101: this low frequency is interesting. What would create a 0.3 Hz pulsation? Are there other peaks at other frequencies? This figure is provided to highlight the dynamic of the degassing. The mechanism in the hydrothermal system that lead to this dynamic is not developed here as longer time series may be required in order to investigate the process.

MC 5: L.159: what is the ambient temperature considered? There was no available meteorological data for Awu summit, thus 16°C obtained with the IR is used as ambient value. It is now indicated in the text.

MC 6: L.187-188 : which volcano are you referring to? The sentence is modified and refers to Awu 1992 eruption.

MC 7:Technical Corrections L.26: reference for the extension to the sea bed is missing thanks – a link is added for reference (www.opendem.info). MC 8: Table 1: 1892: Why do you capitalize Tsunami and Pyroclastic here? And you don't use bold style for the number of victims. Make sure to be consistent throughout the table – characters are now homogenized.

MC 9: Figure 1: Great figure. There is a A, but no B or C. A color scale is missing for the3D map on the right side. The bold labels on the map are a bit hard to read. Now corrected in new Figure 1.

MC 10: Figure 6: can't find the GVP, 2013. I'd would also use consistent label sizes and perhaps change the white color to black for the 28/07/2015 photo. - the GVP 2013 reference is now added and the figure labels are homogenized.

Typo: L.44: casualties – corrected L.97: it should be Figure 4 - corrected L.129: Cashmana? - corrected L.133: order of references? - corrected L.136: It is also - corrected L.168: will no longer be sufficient - corrected L.176: the Kelud crater lake was not huge (2 million m3). - corrected L.176-177: But it is - corrected l.193: destabilize - corrected L.195: megapascals - corrected L.206: suggestion: rephrase this sentence. 'arc. 18 eruptions occurred over the last 3.5 centuries, including: : :' - the sentence is modified L. 208: Earth - corrected Figure 7: typo: circulations - corrected

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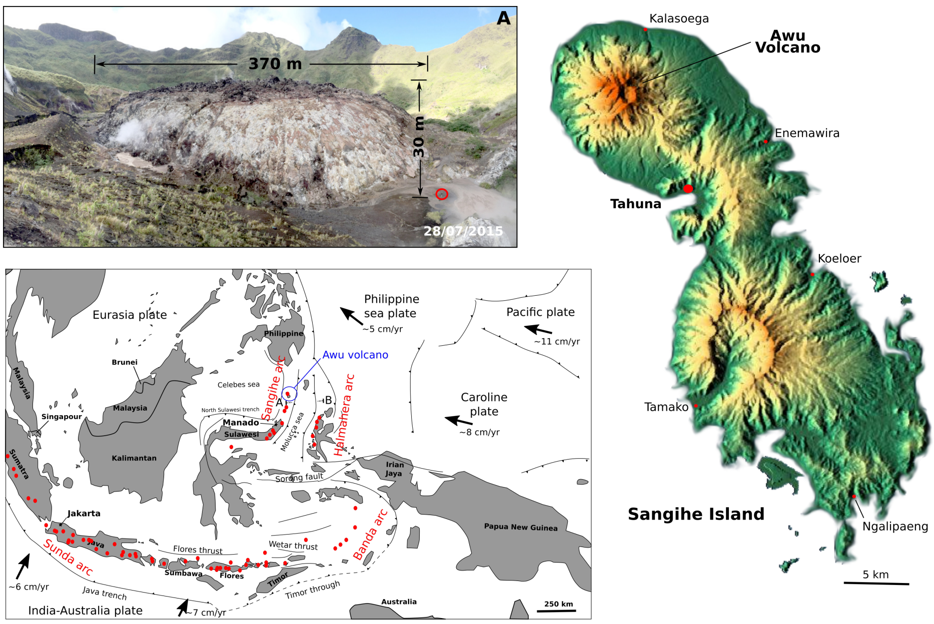

Fig. 1. Awu volcano is the northernmost active volcano of the Sangihe arc