Interactive comment on "A multi-sensor satellite-based archive of the largest SO_2 volcanic eruptions since 2006" by Pierre-Yves Tournigand et al.

Anonymous Referee #1

Received and published: 27 August 2020

We would like to thank the anonymous reviewer for the insightful and constructive comments, which helped us to improve our manuscript. We appreciate the valuable comments and try to address the issues raised as best as possible.

Specific Comments
MANUSCRIPT
Reviewer: Line 17. I feel it would be beneficial to elaborate here on there being no other archive which compiles the results from multiple satellite instruments and eruptions to really emphasise the strength of this dataset.
See after
Reply: We now emphasized it in different sections of the paper.

Reviewer: Line 20. 'We've archived and collocated … the vertical backscatter from CALIOP …' – I think rather than 'vertical backscatter' this sentence should indicate that you have included the CALIOP height and aerosol type.
Reply: Corrected.

Reviewer: Line 25. Here you state that 'the cross-comparison of the datasets shows the high consistency of the parameters estimated with different sensors and algorithms'. This feels like quite a strong statement. In section 5 you compare the heights obtained with RO, CALIOP and IASI. You note that for a number of eruptions there is a good agreement between RO and CALIOP but that this is not the case for Calbuco. Table 4 shows that a number of the average differences between IASI/CALIOP and IASI/RO are greater than 3 km. Additionally, you have done no quantitative comparison of the partial column densities from AIRS, IASI and GOME-2. Some rewording would improve this statement.
Reply: The current paper introduces a new data archive that combines several satellite data-sets for recent eruptions and, for the first time, includes radio occultation data. Some limited inter-comparisons of the data are already published in the literature (Brenot et al., 2014; Carn et al., 2015; Theys et al., 2013), so here we concentrate on describing the archive. Future papers are planned to inter-compare different estimations of partial column densities and cloud top heights. We reworded the sentence to make it clearer and it now reads:

"*the cross-comparison of the datasets shows different consistency of the parameters estimated with different sensors and algorithms according to the sensitivity and resolution of the instruments*"

- Brenot, H., Theys, N., Clarisse, L., van Geffen, J., van Gent, J., Van Roozendael, M., et al.: Support to Aviation Control Service (SACS): an online service for near-real-time satellite monitoring of volcanic plumes, in: Natural Hazards and Earth System Sciences, 14(5), 1099–1123. https://doi.org/10.5194/nhess-14-1099-2014, 2014.
- Carn, S. A., K. Yang, A. J. Prata, and N. A. Krotkov (2015), Extending the long-term record of volcanic SO2 emissions with the Ozone Mapping and Profiler Suite nadir mapper, Geophys. Res. Lett., 42, doi:10.1002/2014GL062437.
- Theys, N., Campion, R., Clarisse, L., Brenot, H., van Gent, J., Dils, B., Corradini, S., Merucci, L., Coheur, P.-F., Van Roozendael, M., Hurtmans, D., Clerbaux, C., Tait, S., and Ferrucci, F.: Volcanic SO2 fluxes derived from satellite data: a survey using OMI, GOME-2, IASI and MODIS, Atmos. Chem. Phys., 13, 5945–5968, https://doi.org/10.5194/acp-13-5945-2013, 2013.

Reviewer: Line 91-102. This paragraph is a little confusing. You cite three papers/datasets: Ge et al. (2016); Carn et al. (2017); Carn et al. (2019) and it is a little difficult to tell if and how these papers/datasets are connected. Also, you suggest that Carn et al. (2017) included 'passive degassing' and 'main eruptive events' (line 94) but to the best of my knowledge this paper generates long term averaged fluxes that exclude large eruptive events. I would advise some rewording of this paragraph and perhaps some expansion on what is included in the Ge et al. (2016) and Carn et al. (2017) papers which might to help the reader better understand their content.
Reply: The paragraph has been reformulated as follows.

"*Considering SO_2 emissions, several datasets and inventories are available and updated over time, but generally include daily or yearly total emissions per volcano or per eruption. Ge et al. (2016) compiled an inventory for daily SO_2 emissions in the time frame 2005-2012 including global volcanic eruptions but also eight persistently degassing volcanoes retrieved by the Ozone Monitoring Instrument (OMI) on board the Aura satellite. Carn et al. (2017) implemented it including OMI retrievals from 2005 to 2015 of emissions related to passive degassing. The most updated … provided (Carn et al., 2016; Carn, 2019). The above-mentioned datasets provide important information for users mainly needing to assess the climatic impact of SO2 from volcanic sources, however, none of them allows for mapping the SO_2 emissions and related altitude estimations in space and time and thus the direct testing and comparison of new models and techniques, like GNSS RO, for example. We think it is important to provide a complementary multi-satellite archive covering the largest eruptive events and their development all around the world in order to facilitate the access to such data for future studies.*"

Details about Ge et al. (2016) inventory are available at http://wiki.seas.harvard.edu/geos-chem/index.php/Volcanic_SO2_emissions

Reviewer: Section 2. In this section it would be useful to have some more information about the performance of each technique. For example, conditions in which the technique performs well or badly. And information such as the detection limits and uncertainties. This has been done for AIRS (lines 135-138) and something similar for each instrument/technique would help the reader appreciate the strengths and limitations of each tool. It would also help a user to correctly interpret the archived data- especially if they are comparing the results from different instruments. Section 4.3 does point the reader to some of the relevant literature but it would be nice to have this in section 2 and with more detail.
Reply: For IASI limitation and uncertainties please see the next reply.
For GOME limitation and uncertainties we added the following text to the paragraph 2.3:

"*The volcanic emission measurement is facilitated by large SO_2 columns generally at high altitudes (free-troposphere to lower stratosphere). However, for large SO_2 columns (typically>50 DU) the absorption tends to saturate leading to a general underestimation and directly affecting the product accuracy. For most volcanoes, there is no ground-based equipment to measure SO_2 during the eruption and the validation approach is usually a cross-comparisons with other satellite products. The O3M SAF validation report (Theys and Koukouli, 2015) shows that GOME-2 SO_2 product reaches the target/optimal accuracy of 50%/30% respectively. It is important to notice that the SO_2 retrievals from GOME-2 are also affected by clouds and instrumental noise especially at high solar zenith angles. These limitations have been filtered in the data used in this work, according to the criteria shown by Brenot et al. (2014).*"

- Theys and Koukouli,
https://cdop.aeronomie.be/ProjectDir/documents/ValidationReports/Validation_Report_GOME-2_SO2_GDP4.8_Dec2015.pdf

- Brenot, H., Theys, N., Clarisse, L., van Geffen, J., van Gent, J., Van Roozendael, M., et al.: Support to Aviation Control Service (SACS): an online service for near-real-time satellite monitoring of volcanic plumes, in: Natural Hazards and Earth System Sciences, 14(5), 1099–1123. https://doi.org/10.5194/nhess-14-1099-2014, 2014.

Reviewer: Line 144. You mention the IASI retrieval technique is based on a BTD with the v3 absorption band – brightness temperature difference with what?
Line 144-149. Initially it is implied that the IASI VCD retrieval is run using fixed heights. But in the archived data there is only a single value for the IASI VCD. Could you clarify if this is obtained by interpolating the results with the height from the second retrieval?
Line 148. It would be useful if there was a line here explaining how the IASI height retrieval worked.
Reply: Thank you for these comments; we have now updated the relevant paragraph 2.2 clarifying these different aspects (including some general statement on sensitivity and uncertainties):

"*The Infrared Atmospheric Sounding Interferometer (IASI) is a Fourier transform instrument onboard the near-polar sun-synchronous orbiting satellites Metop-A and Metop-B, respectively, launched in October 2006 and September 2012 with ascending equator crossing local time at 9:30. IASI covers the full globe two times per day with a swath of 2200 km and a spatial resolution of 12 km at nadir (Clerbaux et al., 2009). The SO2 retrieval is based on a brightness temperature difference between channels in and outside the SO2 v3 band (Clarisse et al., 2012) which is converted to SO2 concentration integrated along the vertical axis the Vertical Column Density (VCD) using look-up tables and operational profiles of pressure, temperature and humidity. The retrieval of VCD assumes that all SO2 is located at particular atmospheric layers (5, 7, 10, 13, 16, 19, 25 or 30 km above sea level) providing different estimations at different altitudes. It has a detection limit of around 0.5 DU at the tropopause, which increases for decreasing altitude (depending on the amount of water vapour in the atmosphere). For plumes above 500hPa (about 5.5 km) the algorithm has a theoretical uncertainty between 3-6%. A second algorithm (Clarisse et al., 2014) is applied to compute the SO2 cloud altitude with an accuracy of about 2 km for plumes below 20 km. The algorithm exploits the fact that the SO2 v3 band interferes with strong water vapour absorptions, and that these interferences, by virtue of the vertical water vapour profile, have a strong dependency with height. Combining the two datasets, a single best-estimate VCD is obtained by interpolating the VCD columns of the first algorithm at the retrieved height.*"

Reviewer: Section 2.4. I think in this section it is important to highlight that with CALIOP you are not measuring SO2 but ash, sulphate, smoke and/or dust. It would be good to acknowledge here some of the limitations of assuming SO2/ash are collocated.
Reply: CALIOP instrument does not allow SO_2 measurements but dust, elevated smoke, volcanic ash and sulfate. However, the CALIOP classification algorithm do not include the volcanic ash type below the tropopause level (Kim et al. 2018) so it is difficult to distinguish the volcanic ash from other aerosol types in the lower troposphere. Both ash and SO_2 are not necessarily collocated during an eruption, this is the reason why all the CALIOP data have also been collocated with the SO_2 estimation from AIRS, IASI and GOME-2. We added a new sentence in the section 2.4 of the manuscript stating:

"*The CALIOP does not allow SO_2 measurements or estimation (it provides estimations of dust, elevated smoke, volcanic ash and sulfate) and the CALIOP classification algorithm do not include the volcanic ash type below the tropopause level (Kim et al. 2018) making difficult to distinguish the volcanic ash from other aerosol types in the lower troposphere., For these reasons, the selected CALIOP backscatter is collocated with the SO_2 estimation from AIRS, IASI and GOME-2 and this combination provides a complete information on the content and vertical structure of the cloud.*"

- Kim, M. H., Omar, A. H., Tackett, J. L., Vaughan, M. A., Winker, D. M., Trepte, C. R., ... & Kar, J. (2018). The CALIPSO version 4 automated aerosol classification and lidar ratio selection algorithm. Atmospheric measurement techniques, 11(11), 6107.

Reviewer: Section 3. This section details all the variables contained in the files. I think it would be really beneficial to a user to have these listed in a table (either in this paper or in the supplementary information).

I found I referred to the supplementary information (print out of all the variables) a lot while trying to load and plot the data. A table summarising the variable names, meaning, dimensions, type and units would be even more useful as a quick reference guide.

Reply: We added a table with all the info.

Variable name	Content	Dimension (rows, columns)	Type	Unit
AIRS_lat	Latitude data, each column corresponds to a granule and each row to one data point in a granule.	AIRS_lat, date_AIRS	double	degrees north
AIRS_lon	Longitude data, each column corresponds to a granule and each row to one data point in a granule.	AIRS_lat, date_AIRS	double	degrees east
AIRS_date	Date of granule contained in each column.	1, date_AIRS	int	seconds since 1970-01-01 00:00:0.0
AIRS_SO2	SO2 data, each column corresponds to a granule and each row to one data point in a granule.	AIRS_lat, date_AIRS	double	DU
IASI_lat	Latitude data, each column corresponds to a granule and each row to one data point in a granule.	IASI_lat, date_IASI	double	degrees north
IASI_lon	Longitude data, each column corresponds to a granule and each row to one data point in a granule.	IASI_lat, date_IASI	double	degrees east
IASI_date	Date of granule contained in each column.	1, date_IASI	int	seconds since 1970-01-01 00:00:0.0
IASI_SO2	SO2 data, each column corresponds to a granule and each row to one data point in a granule.	IASI_lat, date_IASI	double	DU
IASI_height	Cloud top height estimated with IASI	IASI_lat, date_IASI	double	m
GOME_lat	Latitude data, each column corresponds to a granule and each row to one data point in a granule.	GOME_lat, date_GOME	double	degrees north
GOME_lon	Longitude data, each column corresponds to a granule and each row to one data point in a granule.	GOME_lat, date_GOME	double	degrees east
GOME_date	Date of granule contained in each column.	1, date_GOME	int	seconds since 1970-01-01 00:00:0.0
GOME_SO2_1	SO2 data, each column corresponds to a granule and each row to one data point in a granule.	GOME_lat, date_GOME	double	DU
GOME_SO2_2	SO2 data, each column corresponds to a granule and each row to one data point in a granule.	GOME_lat, date_GOME	double	DU
GOME_SO2_3	SO2 data, each column corresponds to a granule and each row to one data point in a granule.	GOME_lat, date_GOME	double	DU
CALIOP_lat	Latitude data, each row corresponds to one point of a CALIOP track.	CALIOP_lat, 1	double	degrees north
CALIOP_lon	Longitude data, each row corresponds to one point of a CALIOP track.	CALIOP_lat, 1	double	degrees east
CALIOP_date	Date and time, each row corresponds to one point of a CALIOP track.	CALIOP_lat, 1	int	seconds since 1970-01-01 00:00:0.0
CALIOP_filename	Filename, each row provides the filename of the given data point.	CALIOP_lat, CALIOP_char	char	n.a.
CALIOP_height	Cloud top altitude data, each row corresponds to one point of a CALIOP track and each column to a collocated sensor.	CALIOP_lat, Sensors	double	m
CALIOP_type	Cloud type data, each row corresponds to one point of a CALIOP track, three columns corresponding to three levels of	CALIOP_lat, CALIOP_char2, CALIOP_type	double	n.a.

	altitude -0.5 to 8.2 km, 8.2 to 20.2km and 20.2 to 30.1km			
Only volcano files				
RO_lat	Latitude data, each row corresponds to one profile point and each column to a ro profile.	RO_lat, RO_profile	double	degrees north
RO_lon	Longitude data, each row corresponds to one profile point and each column to a ro profile.	RO_lat, RO_profile	double	degrees east
RO_date	Date and time data, each row corresponds to one profile point and each column to a ro profile.	RO_lat, RO_profile	int	seconds since 1970-01-01 00:00:0.0
RO_bending_angle	Bending angle data, each row corresponds to one profile point and each column to a ro profile.	RO_lat, RO_profile	double	rad
RO_anomaly_bending_angle	Bending angle anomaly data, each row corresponds to one profile point and each column to a ro profile.	RO_lat, RO_profile	double	percent
RO_temperature	Temperature data, each row corresponds to one profile point and each column to a ro profile.	RO_lat, RO_profile	double	K
RO_pressure	Pressure data, each row corresponds to one profile point and each column to a ro profile.	RO_lat, RO_profile	double	Pa
RO_refractivity	Refractivity data, each row corresponds to one profile point and each column to a ro profile.	RO_lat, RO_profile	double	1
RO_specific_humidity	Specific humidity data, each row corresponds to one profile point and each column to a ro profile.	RO_lat, RO_profile	double	kg.kg-1
RO_heightVC	Cloud top altitude data, each column corresponds to a ro profile.	1, RO_profile	double	m
Only daily files				
RO_AIRS_lat	Latitude data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	double	degrees north
RO_AIRS_lon	Longitude data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	double	degrees east
RO_AIRS_date	Date and time data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	int	seconds since 1970-01-01 00:00:0.0
RO_AIRS_bending_angle	Bending angle data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	double	rad
RO_AIRS_anomaly_bending_angle	Bending angle anomaly data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	double	percent
RO_AIRS_temperature	Temperature data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	double	K
RO_AIRS_pressure	Pressure data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	double	Pa
RO_AIRS_refractivity	Refractivity data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	double	1
RO_AIRS_specific_humidity	Specific humidity data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	double	kg.kg-1
RO_AIRS_heightVC	Cloud top altitude data, each column corresponds to a ro profile.	1, RO_AIRS_profile	double	m
RO_IASI_lat	Latitude data, each row corresponds to one profile point and each column to a ro profile.	RO_IASI_lat, RO_IASI_profile	double	degrees north

RO_IASI_lon	Longitude data, each row corresponds to one profile point and each column to a ro profile.	RO_IASI_lat, RO_IASI_profile	double	degrees east
RO_IASI_date	Date and time data, each row corresponds to one profile point and each column to a ro profile.	RO_IASI_lat, RO_IASI_profile	int	seconds since 1970-01-01 00:00:0.0
RO_IASI_bending_angle	Bending angle data, each row corresponds to one profile point and each column to a ro profile.	RO_IASI_lat, RO_IASI_profile	double	rad
RO_IASI_anomaly_bending_angle	Bending angle anomaly data, each row corresponds to one profile point and each column to a ro profile.	RO_IASI_lat, RO_IASI_profile	double	percent
RO_IASI_temperature	Temperature data, each row corresponds to one profile point and each column to a ro profile.	RO_IASI_lat, RO_IASI_profile	double	K
RO_IASI_pressure	Pressure data, each row corresponds to one profile point and each column to a ro profile.	RO_IASI_lat, RO_IASI_profile	double	Pa
RO_IASI_refractivity	Refractivity data, each row corresponds to one profile point and each column to a ro profile.	RO_IASI_lat, RO_IASI_profile	double	1
RO_IASI_specific_humidity	Specific humidity data, each row corresponds to one profile point and each column to a ro profile.	RO_IASI_lat, RO_IASI_profile	double	kg.kg-1
RO_IASI_heightVC	Cloud top altitude data, each column corresponds to a ro profile.	1, RO_IASI_profile	double	m
RO_GOME_lat	Latitude data, each row corresponds to one profile point and each column to a ro profile.	RO_GOME_lat, RO_GOME_profile	double	degrees north
RO_GOME_lon	Longitude data, each row corresponds to one profile point and each column to a ro profile.	RO_GOME_lat, RO_GOME_profile	double	degrees east
RO_GOME_date	Date and time data, each row corresponds to one profile point and each column to a ro profile.	RO_GOME_lat, RO_GOME_profile	int	seconds since 1970-01-01 00:00:0.0
RO_GOME_bending_angle	Bending angle data, each row corresponds to one profile point and each column to a ro profile.	RO_GOME_lat, RO_GOME_profile	double	rad
RO_GOME_anomaly_bending_angle	Bending angle anomaly data, each row corresponds to one profile point and each column to a ro profile.	RO_GOME_lat, RO_GOME_profile	double	percent
RO_GOME_temperature	Temperature data, each row corresponds to one profile point and each column to a ro profile.	RO_GOME_lat, RO_GOME_profile	double	K
RO_GOME_pressure	Pressure data, each row corresponds to one profile point and each column to a ro profile.	RO_GOME_lat, RO_GOME_profile	double	Pa
RO_GOME_refractivity	Refractivity data, each row corresponds to one profile point and each column to a ro profile.	RO_GOME_lat, RO_GOME_profile	double	1
RO_GOME_specific_humidity	Specific humidity data, each row corresponds to one profile point and each column to a ro profile.	RO_GOME_lat, RO_GOME_profile	double	kg.kg-1
RO_GOME_heightVC	Cloud top altitude data, each column corresponds to a ro profile.	1, RO_GOME_profile	double	m
RO_AIRS_lat	Latitude data, each row corresponds to one profile point and each column to a ro profile.	RO_AIRS_lat, RO_AIRS_profile	double	degrees north

Reviewer: Line 201. This is the first instance that 'granule' has been used. Please can this be clearly defined. The use of the word granule made it challenging to interpret the data structures described in sections 3.1-3.3 independently of reading in and looking at the data.

Reply: The term "granule" refers to the AIRS data, while, for IASI and GOME-2, we refer to scanning lines. AIRS collects data as it sweeps along the orbit, and the data is then sectioned into pieces called "granules". Each AIRS granule is roughly 2250 x 1650 kilometers and contains 6 minutes of data. There are nominally 240

Level 1B and 240 Level 2 granules of 6-minute duration generated each day. The orbital repeat cycle is 16 days, but orbital maintenance manoeuvres can shift granules along orbits by a small fraction of a granule. Maps showing the locations of granules are generated daily and available for download. AIRS data users use maps like these when making requests from AIRS data servers. We now explain the term granule in the manuscript with the following sentence:

"*A granule is a portion of AIRS orbit containing 6 minutes (2250 km x 1650 km) of data, which is officially defined by the National Aeronautics and Space Administration (NASA).*"

Section 3.4, Section 3.5. In these sections you mention collocation with between CALIOP, RO and the other instruments. I think it would be useful to know what conditions you use for the collocation here rather than in sections 4.1 and 4.2. This would help the reader immediately understand what is meant by collocation.
Reply: Done.

Reviewer: Lines 340-344. Here you discuss the average differences between the cloud heights for different eruptions. Are there any reasons why the average difference is greater at Calbuco than for Eyja, Kasatochi and Grimsvotn? Also, is there a reason why the differences are greater between IASI and RO/CALIOP? I think it would be useful for a user of the dataset to understand why differences might arise between the different datasets (e.g. the time difference between the overpasses and the method used to obtain the height information).
Reply: The reasons are due to different eruption types and the different sensitivity and resolution of the measurement techniques. As reported in section 2.2 (IASI), some assumptions have been made to retrieve the cloud height allowing an estimation with an accuracy of about 2 km. Moreover, the IASI height estimations are sampled every 0.5 km. The RO cloud height estimation is based on the density variation of the atmosphere, so denser clouds (e.g. Kasatochi 2008) can be detected more likely than less dense clouds (e.g. Calbuco 2015) and with better accuracy. Most importantly, the RO and CALIOP are limb profiling techniques with high vertical resolution, while IASI is a nadir sounding technique. This does not allow IASI to provide the same vertical resolution and accuracy that we can get from RO/CALIOP.
In addition, the number of colocations between RO and CALIOP is much smaller than for RO-IASI and IASI-CALIOP, respectively. We revised the text at the end of section 5 (Data cross-comparisons) and added further explanations:

"*The difference in cloud top estimations can be partly explained by the different sensitivities and vertical resolution of the different instruments. In addition, the number of colocations between RO and CALIOP is much smaller than for RO-IASI and IASI-CALIOP, respectively. The cloud top height estimation for eruptions with a large number of colocations (Calbuco, Kasatochi, Nabro and Sarychev Peak) is in general consistent within the techniques.*"

Reviewer: Additionally, have you considered a quantitative comparison of the VCDs retrieved with AIRS, IASI and GOME-2? What differences would you expect to see between these?
Reply: As we reported above, the current paper introduces a new data archive that combines several satellite data-sets for recent eruptions and, for the first time, includes radio occultation data. Some limited inter-comparisons of the data are already published in the literature (Brenot et al., 2014; Carn et al., 2015; Theys et al., 2013), so here we concentrate on describing the archive. In Table 3 we report the SO_2 mass loading for each eruption with different instruments reported in literature. We prefer to refer to published studies, instead of re-computing the mass loadings in these specific cases, to avoid confusion to the readers.

Reviewer: Table 1. You could add the eruption VEI and the eruption end date or duration to this table. Additionally, it could be helpful to add the geographic region considered for each eruption and the start/end date for the data in the archive – both of these would be valuable to the data user.
Reply: We added to the table the VEI and the archive start/end dates for each eruption. Please note that the VEI is not always appropriate for SO_2-rich eruptions since it corresponds to ash-rich eruptions. Instead of

adding the geographic region in the table, we prefer to provide an intuitive plot of SO_2 detection for each volcano in the supplementary material.

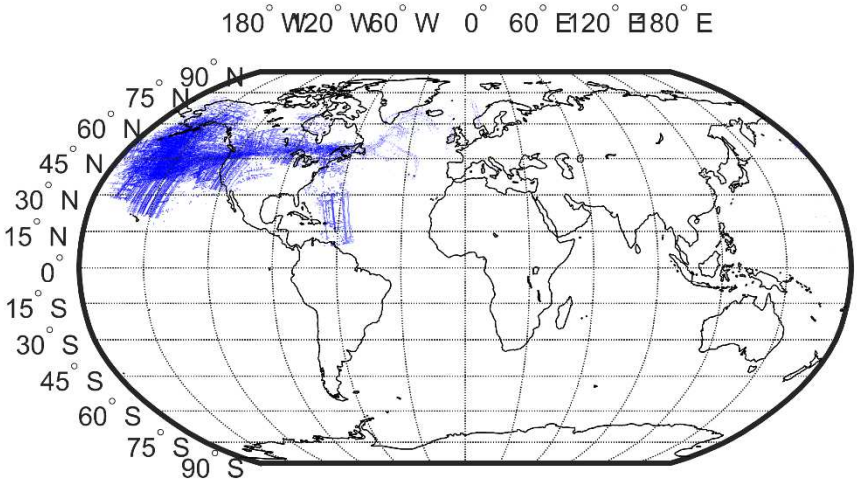

Figure S1. Okmok cloud map.

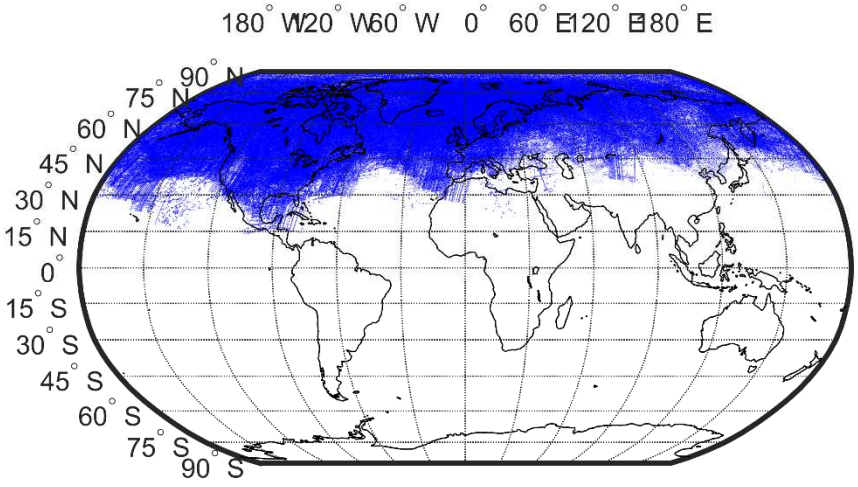

Figure S2. Kasatochi cloud map.

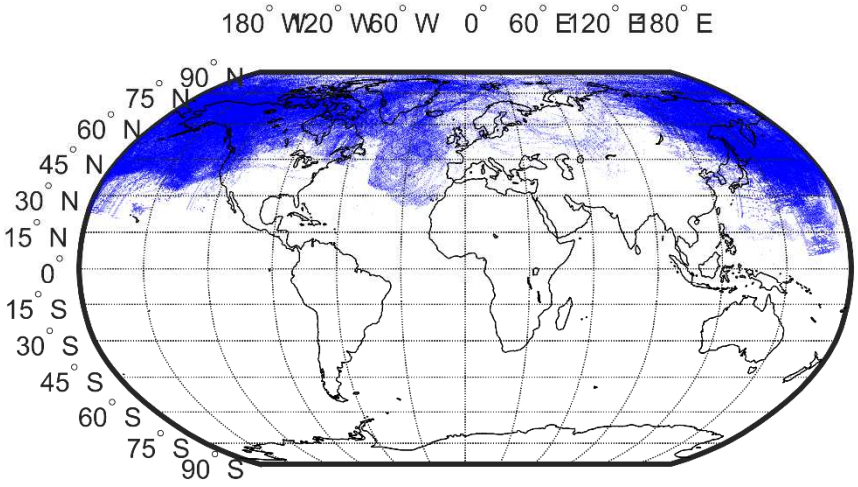

Figure S3. Sarychev cloud map.

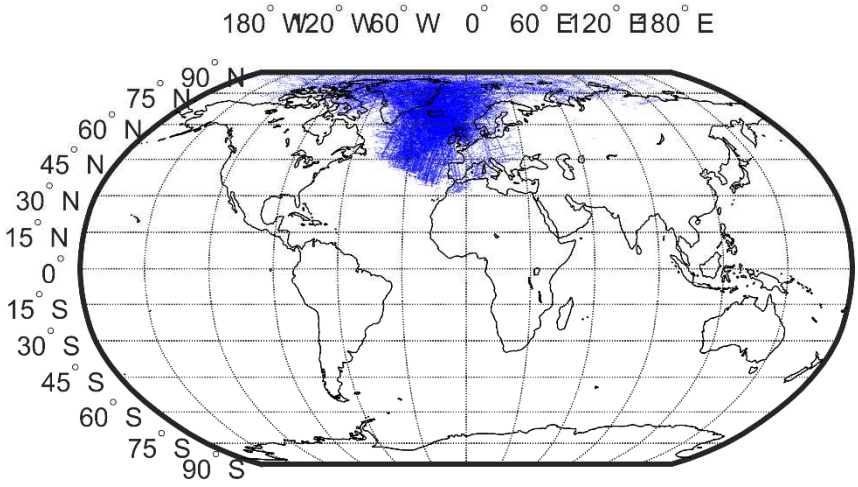

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Figure S4. Eyjafjallajokull cloud map.

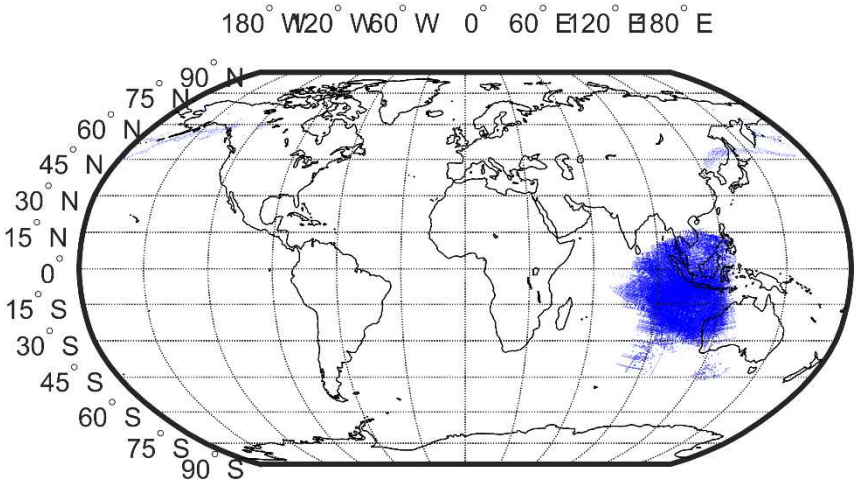

Figure S5. Merapi cloud map.

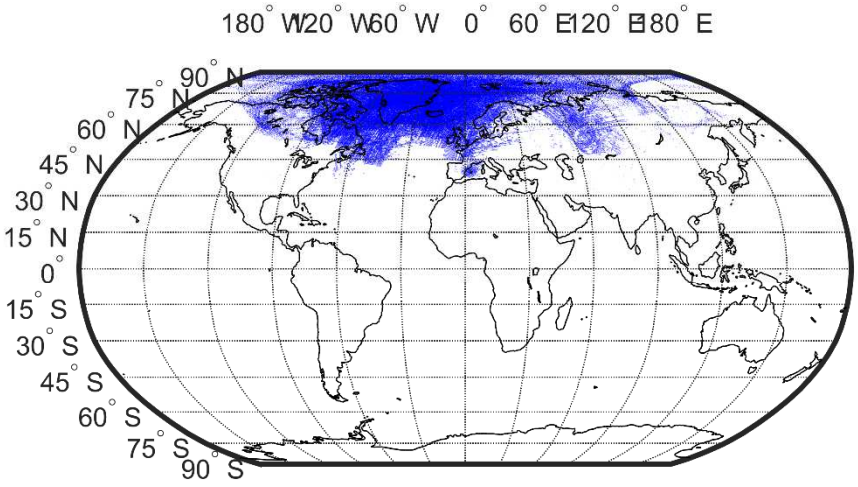

Figure S6. Grimsvotn cloud map.

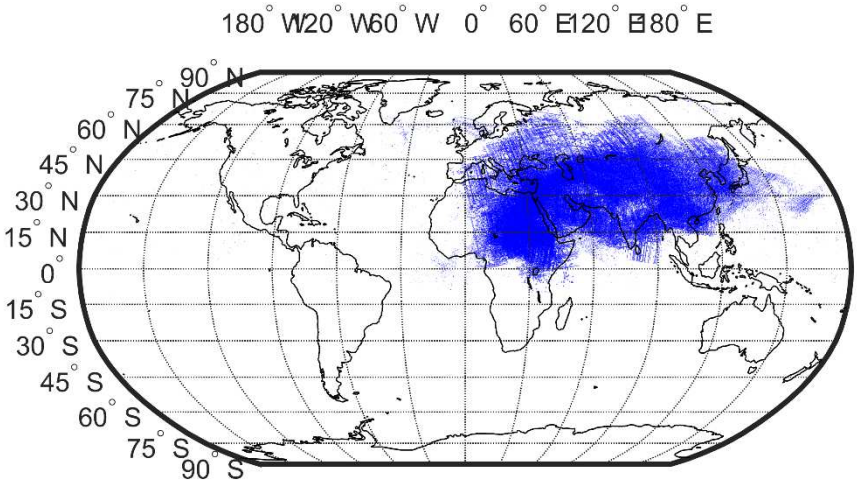

Figure S7. Nabro cloud map.

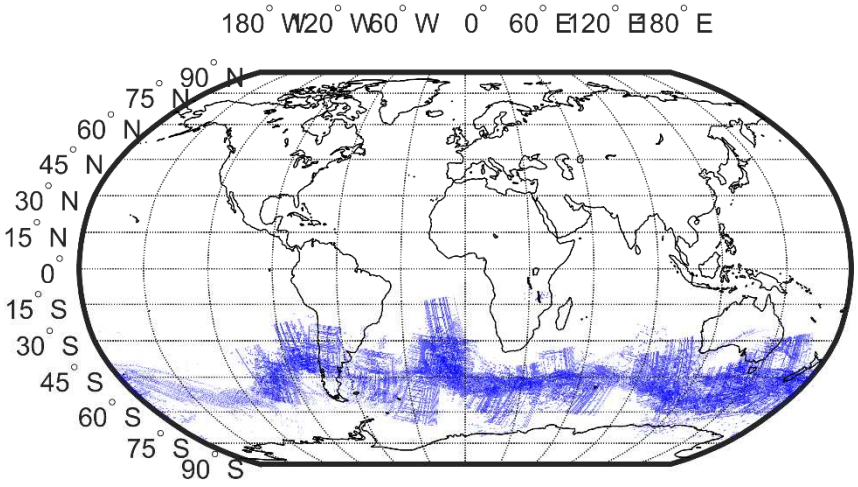

Figure S8. Puyehue Cordon Caulle cloud map.

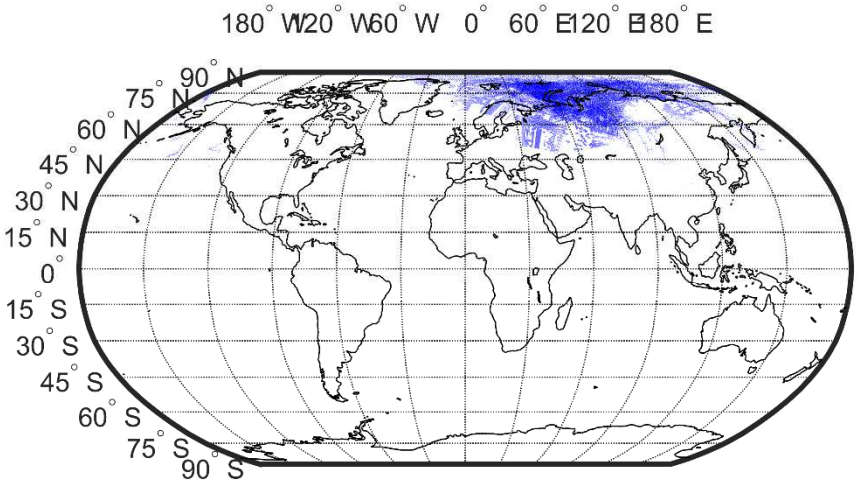

Figure S9. Tolbachik cloud map.

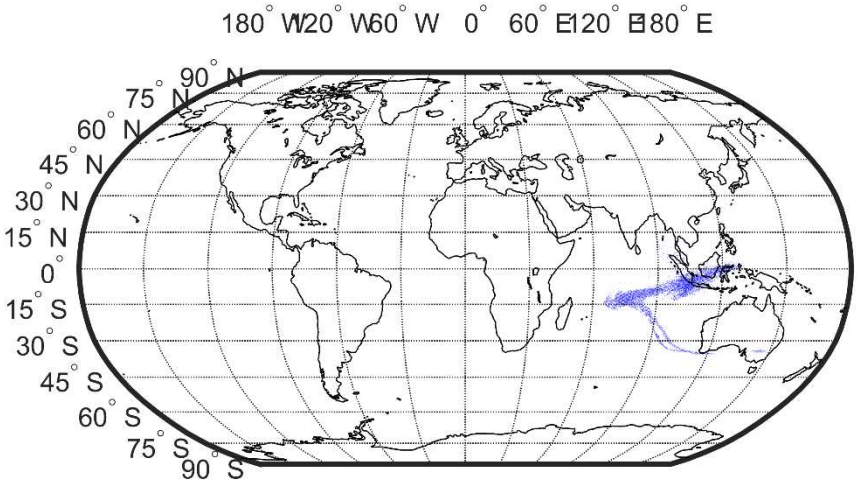

Figure S10. Kelut cloud map.

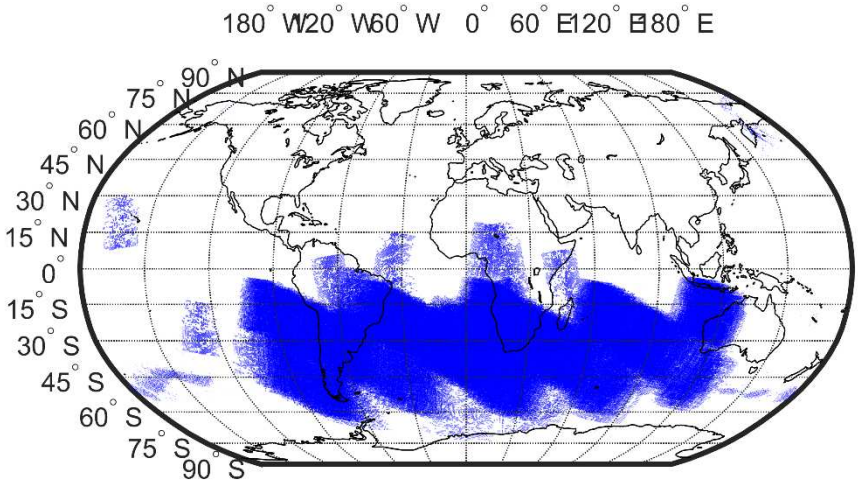

Figure S11. Calbuco cloud map

Reviewer: Table 2. In addition to the information given you could also mention the spectral range/resolution of the instruments.
Reply: Table 2 was modified accordingly.

Reviewer: Figure 2. It would be interesting to see the cloud top heights obtained with CALIOP and RO in this plot rather than just the tracks/points.
Reply: Corrected. We added the average values of cloud top heights in each panel. We believe that reporting the values (with numbers or with different colors) on these maps, could make the figure difficult to read. We also added a short discussion in the new section "Results" explaining how the archive can be used to compare the cloud top heights computed with different instruments (Tournigand et al., 2020).

- Tournigand, P.-Y., Cigala, V., Prata, F., Steiner, A. K., Kirchengast, G., Brenot, H., Clarisse, L., Biondi, R.: The 2015 Calbuco volcanic cloud detection using GNSS radio occultation and satellite lidar, IGARSS 2020 Proceedings, accepted.

SUPPLEMENT AND DATA
Reviewer: NULL values – Throughout much of the dataset the null values are reported as -9999. However, for the RO profiles they are recorded as NaN. For the RO cloud top heights it goes back to -9999. For the CALIOP heights there are no -9999 or NaN instead there are 0's- are these null values too? This should probably be consistent and whichever is chosen should be clearly noted somewhere.
Reply: the archive has been modified, we decided to use -9999 as common filling value.

Reviewer: Different number of variables - The files do not contain consistent numbers of variables. For example, in the file 'Calbuco_2015_05_24.nc' there is data available for IASI and RO but not GOME-2, AIRS or CALIOP. Presumably this is related to the availability of the data. It would be good to clarify this in the manuscript (perhaps at the start of section 3). Even better would be to summarise how many days or which

days are covered by each instrument for each eruption – this could be an addition to table 3 and would be slightly easier to interpret than the number of granules.
Reply: Yes, just the available instruments are reported in this archive. We have updated the text at Line 199:

"…the variables available from one day to another may differ according to SO_2 detection results and instruments availability".

As suggested by the reviewer, we have also added to the table 3 the number of days covered by each instrument for each eruption.

Reviewer: Dimensions - a list of dimensions is given on page 1 and page 8 of the supplement. It would be very helpful if these were expanded on. In particular the definitions for 'CALIOP_char' and 'CALIOP_char2' are not very informative.
Reply: Dimensions descriptions have been expanded.

Reviewer: P1, P2 supplementary info – there is a slight discrepancy between the long names between IASI and GOME-2. For GOME-2 the long name states that the data is a composite of GOME-A and B – is it also the case for IASI that the data is a composite of IASI-A and B?
Reply: the archive and supplementary information have been modified accordingly.

IASI_SO2 – I suggest expanding the long name of this variable to make it clear that this is a vertical column density and to explain what interpolated is referring to P3, P4. It is not clear what the dimensions should be here.
Reply: the archive and supplementary information have been modified accordingly.

Reviewer: CALIOP_CHAR, CALIOP_char2 and CALIOP_type should be more clearly defined in the supplementary data. CALIOP_type (the dimension) is not defined in the dimensions list.
Reply: Corrected.

Reviewer: CALIOP_type – This variable was very challenging for me to read in (in both IDL and python). The supplementary information (page 4) suggested that these were doubles but they had to be read in as strings. I think the choice of saving these as a string is so that multiple flags can be indicated. Initially on reading in this variable I obtained an array with 3 dimensions. These then had to be converted to strings and joined together to extract the CALIOP type (a similar thing had to be done for CALIOP_filename- also not immediately obvious how to read in IDL). Following that the newly joined strings had to be searched to determine which aerosols were present. Could there be a better way of saving this variable? Perhaps simply an integer array for each variable type with 1 indicating the presence of this aerosol and 0 indicating its absence. Alternatively, more information on how to read in and interpret these results would be very useful.
Reply: Indeed, this variable was indicated as double while it is a string. This was corrected (see section 3.4). It is also correct that the choice of saving these data as string is to allow multiple flags. We didn't elect to use an integer array of 0 and 1 because we think that the possibility to distinguish one aerosol type from another is crucial for the user of the archive. For example, the user will be able to know if ash is likely to be present in the area of interest together with the SO_2 detected by AIRS, IASI and GOME-2. Finally, the description of the variable's dimensions has been modified in order to allow the user to better understand how to use it.

Reviewer: P5-P7. For the RO variables expanding the long names for 'air_temperature', 'air_pressure', 'refractivity', 'specific_humidity' would provide more information- these could for example mention that these are profiles.
Reply: the archive and supplementary information have been modified accordingly.

Reviewer: RO – cloud top heights. The units do not seem to be consistent for these (in the daily files). For colocations with AIRS and IASI the heights appear to be in meters (which are the standard units and consistent with heights reported by CALOP and IASI). Whereas for GOME-2 they seem to be in km.

Reply: the archive has been modified accordingly.

Reviewer: P4-7. The dimensions for the RO profiles are listed as RO_AIRS_lat by RO_AIRS_PROFILE (or IASI/GOME). Could these be defined more clearly in the dimensions list.
Reply: Corrected.

Reviewer: Dates covered by each eruption. Some of the daily files start before the start date of the eruption. For example, for Nabro (eruption starting on the 13th June 2011) the first file in the dataset is 31st May 2011. In the first few files it seems to include the outputs for other eruptions. For example, the file Nabro_2011_05_31 includes SO2 measurements from the Grímsvötn eruption, while the file Nabro_2011_06_05 includes measurements from both Grímsvötn and Puyehue. Including this twice in the dataset is a little unnecessary and means the user has to download more data than is needed for this eruption. It is possible to see plumes from different eruptions in many of the datafiles.
Reply: the archive has been modified accordingly.

Technical Comments/Suggestions
MANUSCRIPT
Reviewer: Throughout – Some of the volcano names have accents (e.g. Grímsvötn, Eyjafjallajökull, Puyehue-Cordón Caulle)
Reply: Corrected.

Reviewer: Line 16. 'Forecast' should be forecasting or forecasts
Reply: Corrected.

Reviewer: Line 17. 'Single events' would be more precise as 'single eruptive events'
Reply: Corrected.

Reviewer: Line 17. '… but not any archive is available' need rewording. Perhaps: '… no such archive is available'.
Reply: Corrected.

Reviewer: Line 18. 'from three different instruments' would be clearer as 'from three different satellite instruments'
Reply: Corrected.

Reviewer: Line 19. 'the atmospheric parameters vertical profiles from …' This line is a little confusing.
Reviewer: Perhaps rephrasing as something like: 'vertical atmospheric profiles obtained from …'
Reply: Corrected.

Reviewer: Line 21. 'We additionally' would read better as 'Additionally we'
Reply: Corrected.

Reviewer: Line 22. 'The dataset consists of 223 days monitored with SO2 clouds' This line does not read very well – consider rephrasing it.
Reply: Corrected.

Reviewer: Line 38-39. What is meant by 'consequent cloud'? – are you referring to the volcanic cloud or ice/water clouds (e.g. indirect climate effects)
Reply: Corrected.

Reviewer: Line 40. 'SO2 injections in the stratosphere' may read better as 'SO2 injections into the stratosphere'
Reply: Corrected.

Reviewer: Line 42. ‘hence transported’ may read better as ‘hence be transported’
Reply: Corrected.

Reviewer: Line 46. ‘has occurred per year since 1994 worldwide’ might read better as ‘have occurred worldwide each year since 1994’
Reply: Corrected.

Reviewer: Line 47-48. ‘… the energy of the eruption, amount, type and size of the ejected material’ would read better as ‘… the energy of the eruption, and the amount, type and size of the ejected material’
Reply: Corrected.

Reviewer: Line 49-51. To improve sentence clarity move the Newhall and Self reference to the start of the sentence: ‘The VEI was introduced in 1982 by Newhall and Self (1982) …’
Reply: Corrected.

Reviewer: Line 50. I think it is Richter scale rather than Richter’s scale.
Reply: Corrected.

Reviewer: Line 50. I think it should be earthquake rather than earthquakes’
Reply: Corrected.

Reviewer: Line 54. ‘VEI index’ can just be VEI
Reply: Corrected.

Reviewer: Line 60. Putting ‘e.g. VEI 4 events’ within brackets would help the readability of the Sentence
Reply: Corrected.

Reviewer: Line 71. ‘and’ should be used instead of ‘or’
Reply: Corrected.

Reviewer: Line 72. ‘although’ would make more sense than ‘even though’
Reply: Corrected.

Reviewer: Line 74. ‘focusing on single or a few eruptions’ would read better as ‘focusing on a single or a few eruptions’
Reply: Corrected.

Reviewer: Line 77. Stating that ‘all’ platforms and algorithms were studied in this volume seems quite strong. Perhaps: ‘a large number’ would be better
Reply: Corrected.

Reviewer: Lines 77 and 81. Starting the sentence with ‘Sarychev Peak 2009’ and ‘Grimsvotn 2011’ does not read very well. It might sound better as ‘The Sarychev Peak eruption in 2009 …’ etc.
Reply: Corrected.

Reviewer: Line 91. ‘… and updated in the course of the years.’ This line does not read very well – consider rephrasing.
Reply: Corrected.

Reviewer: Line 110. It should read ‘... and humidity from GNSS RO profiles’

Reply: Corrected.

Reviewer: Line 111-112. This sentence would benefit from being rewritten to improve the clarity. Maybe something like: 'This information is provided for eruptions, after 2006, classified by the GVP as VEI 4 or larger and with an SO2 mass loading of greater than 0.05 Tg. At the time of archive preparation, no eruptions after 2016 had yet been classified as VEI 4 or greater.'
Reply: Corrected.

Reviewer: Line 113. Rather than include '(table 1)' in this sentence, perhaps add a sentence at the end of the paragraph saying 'Further information on these eruptions can be found in table 1.'
Reply: Corrected.

Reviewer: Line 117-118. 'there is no current unique database'. This does not read very well – I would suggest rewriting the sentence
Reply: Corrected.

Reviewer: Line 119-121. It should read 'accurate knowledge of volcanic SO2 cloud concentration and altitude as well as their spatial and temporal evolution: : : of an eruption's climatic impact'
Reply: Corrected.

Reviewer: Line 122. 'retrievals' should be 'retrieval'
Reply: Corrected.

Reviewer: Section 2 – title. Maybe this should be titled 'Instrument and Retrieval Description'
Reply: Corrected.

Reviewer: Line 126. 'due to their own limitations.' It is not clear what is meant by this.
Reply: Corrected.

Reviewer: Line 130. It should read 'an ascending orbit'
Reply: Corrected.

Reviewer: Line 133. It would be good for a reference to be included for this sentence so the reader is immediately aware of which paper describes this technique.
Line 135. Again it would be good to have a reference for this statement.
Reply: We now added a sentence to text stating

"*The AIRS SO_2 retrieval used is described in detail by Prata and Bernardo (2007); here we provide a very brief overview.*"

Reviewer: Line 142. It should read 'an ascending orbit'
Reply: Corrected.

Reviewer: Line 144. V3 has not been defined. SO2 is also not formatted correctly.
Reply: Corrected.

Reviewer: Line 151. Slight inconsistency - On board has a space here but elsewhere it is written onboard.
Reply: Corrected.

Reviewer: Line 153. Slight inconsistency - Here the pixel size is listed as 40x80 km. For AIRS it was written as 13.5 x 13.5 km (with spaces).
Reply: Corrected.

Reviewer: Line 165. 1,67 should be 1.67
Reply: Corrected.

Reviewer: Line 175-176. It may read better as 'In this archive we use the RO bending …'
Reply: Corrected.

Reviewer: Line 192. It should read 'the number of days' rather than 'amount of days'
Reply: Corrected.

Reviewer: Line 232-233: 'Four of those types are of interest for this archive: type 2, 6, 9 and 10 respectively corresponding to dust, elevated smoke, volcanic ash and sulfate/other.' Include a colon between archive and type.
Reply: Corrected.

Reviewer: Line 234-235. There should be a space between 20.2/30.1 and km
Reply: Corrected.

Reviewer: Line 240. I think a colon would be better than a comma between provided and latitude
Reply: Corrected.

Reviewer: Line 264. Should read 'Where _ is the bending angle anomaly …'
Reply: Corrected.

Reviewer: Line 277. Should read 'consists of' rather than 'consists in'
Reply: Corrected.

Reviewer: Line 285. I think this should be 'Thus we' rather than 'We thus'
Reply: Corrected.

Reviewer: Line 308. Having a list (in brackets) of parameters that affect the uncertainty, followed by a line about altitude affecting the uncertainty does not read so well. Maybe combine all the factors that affect the uncertainty into one line.
Reply: Corrected.

Reviewer: Line 315. Should read 'volcanic cloud' detection rather than 'volcanic clouds'
Reply: Corrected.

Reviewer: Line 317. It should read 'in charge of processing them'
Reply: Corrected.

Reviewer: Line 317. Is it not 10 VEI 4 and 1 VEI 5 eruptions? The Puyehue eruption in 2011 is listed on the GVP as VEI 5 (https://volcano.si.edu/volcano.cfm?vn=357150 ; under eruptive history). Also here you state the period you a looking at is 2008 to 2016 when previously you've said you were looking at eruptions from 2006-2016.
Reply: Corrected.

Reviewer: Line 318. 'With a total of' rather than 'for a total of'
Reply: Corrected.

Reviewer: Line 320-321. 'Several parameters are measured using different instruments, such as SO2 VCD and cloud top altitude, to allow cross correlation between the different retrieval algorithms.' Do you mean to say

‘Several parameters are included within the dataset: : : to allow cross correlation between the different algorithms’ ?
Reply: Corrected.

Reviewer: Line 335. It should read ‘compared the date, time …’
Reply: Corrected.

Reviewer: Line 336. ‘We have additionally’ would read better as ‘Additionally we have’
Reply: Corrected.

Reviewer: Line 360. Not just detection but also the retrieval of VCDs
Reply: Corrected.

Reviewer: Line 365. ‘Up to date’ would read better as ‘At present’
Reply: Corrected.

Reviewer: Line 370. ‘and test new algorithms contributing to improving the accuracy on the estimation of fundamental volcanic clouds parameters’. This may read better as ‘and test new algorithms on, thereby contributing to improving the accuracy on the estimation of fundamental volcanic clouds parameters’
Reply: Corrected.

Reviewer: Line 373. ‘allowing to reconstruct …’ may sound better as ‘allowing the reconstruction of …’
Reply: Corrected.

Reviewer: Table 2. Maybe differentiate between AIRS and IASI spatial resolutions (13.5 by 13.5 km vs. 12 km diameter circular pixels)
Reply: Corrected

Reviewer: Figure 2. In the caption ‘upright’ should be ‘top right’. Also, this caption reads a little strangely. I would suggest: ‘Example of data use and data collocation. (a) Kasatochi cloud on 9th August 2008; (b) Sarychev peak cloud …’ At present there is no (b). Additionally, no full stop is required in line 610.
Reply: Corrected.

SUPPLEMENT AND DATA
Reviewer: P1. VC – is undefined in the supplementary material.
Reply: Corrected.

Reviewer: P1. DATE_IASI – The use of the word ‘because’ in this description doesn’t make sense.
Reply: Corrected.

Reviewer: P2, P9. In the GOME_lon variable- dimensions include GOME_late rather than GOME_lat
Reply: Corrected.