# How inclusive is volcanology? Insights from global bibliometric analyses

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## Abstract

In this study, we use bibliometric methods to assess the way in which local researchers are included in volcanological publications by comparing the affiliation of authors with the country in which researched volcanoes are located. Globally, 40% of articles about a specific volcano do not include an author whose affiliation is based in the country where the volcano is located (a locally domiciled author). Over the past three decades, first authorship rates among local researchers have not increased. However, local researchers have become more frequently included as co-authors in research led by researchers domiciled elsewhere. We provide examples of how this

bibliometric analysis can be used to evaluate several specific inclusion-related topics. The results of these analyses suggest that there is room for improvement in inclusivity in volcanological research and cause for reflection on how we collaborate with international partners.

## 1 Introduction

Volcanology is defined as the study of volcanoes, their outputs, and the related geophysical, geological, and geochemical phenomena that control them, as well as their hazards and impacts on society. Thus, much of the practice of volcanology occurs in the field, particularly during moments of eruption. It is largely carried out by academic researchers, those in research institutes or national agencies, and volcanologists charged with monitoring those systems [Donovan and Oppenheimer, 2015]. While these diverse institutions and researchers can be found worldwide, active volcanic systems are concentrated within a limited number of regions. Approximately 70% of volcanoes active in the Holocene (603 out of 862) are located in just 18 of the world's 193 countries and approximately 50% of recorded Holocene eruptions (4,908 out of 9,826) took place from volcanoes in only 25 countries [Global Volcanism Program, 2013]. This concentration of volcanic activity means that research on active volcanic systems is frequently conducted by researchers based in institutions outside their territories. These foreign researchers often benefit from historically rooted networks and access to funding for travel and analyses [Asase et al., 2022]. Advances in remote sensing and technology have created further opportunities for remote participation in research on volcanic systems, more easily allowing volcanologists to conduct research on volcanoes far from their own country [Francis and Rothery, 2000; Pyle et al., 2013].

This international dimension to research is valuable and valued in this context because collaborators can often provide specialties and expertise that may not be available in the region in which the volcano is located. International collaboration can also allow scientists at external institutions to provide resources, support, analyses or equipment to further enhance research done locally. When this research is inclusive and collaborative, it can result in the co-creation of knowledge that has been shown to enhance research relevance [Ackerman, 2004; Katz and Hicks, 2006; Barton et al., 2020]. This is particularly important in volcanology, where there is a great need to build local capacity for volcano monitoring, risk communication, and disaster risk management [Bonadonna et al., 2018; Lowenstern et al., 2022]. International collaboration in volcanology is also vital for building collective knowledge about volcanic phenomena, some of which are high consequence but low recurrence, meaning opportunities for direct study are rare.

For international researchers, in addition to the intellectual benefits of writing together, collaboration with local scientists can provide vital knowledge of local and regional information (geological, cultural, bureaucratic, etc.), as well as access to field sites, and closer relationships with the beneficiaries of improved scientific knowledge. In many studies, collaboration with local scientists has been shown to bring benefits to research on volcanoes and other hazards through the greater use of local knowledge, experience, and support of local communities [e.g., Cronin et al., 2004; Cadag and Gaillard, 2012; Mothes et al., 2014; Donovan and Oppenheimer, 2015; Armijos et al., 2017; Cadag et al., 2018; Barclay et al., 2022]. Despite these clear benefits to all parties involved, research on volcanoes is often conducted without the inclusion of local scientists.

Recent research in other fields, such as coral reef science, has noted the lack of inclusion of local scientists in internationally conducted research, finding a trend of greater inclusion of local scientists when research is conducted in high-resource countries compared to when international researchers work in low-resource countries [Stefanoudis et al., 2021]. This lack of inclusion has resulted in an underrepresentation of authors from developing countries in research about their own country, which is harmful structurally and detrimental to the career advancement of individual scientists from those countries [North et al., 2020; Raja et al., 2022]. For example, amongst natural hazards studies, only 50% of publications about Indonesia involve Indonesian co-authors [Djalante, 2018].

In the past few years, there have also been analyses of the lack of diversity in geoscience, in particular, domestically in the United States and United Kingdom [e.g., Bernard and Cooperdock, 2018; Dowey et al., 2021]. As the published outcome of a research project, authorship can offer an insight into the process of research, and who is contributing (or is perceived to be contributing) to that work. A recent study of lead authorship location from 2017 to 2021 in two major volcanology journals, Bulletin of Volcanology and Journal of Volcanology and Geothermal Research, showed the greatest number of articles are published by authors in Europe, North America, New Zealand, and Japan [Kavanagh et al., 2022]. This study also found that regions with a high density of active volcanoes, such as South America, Central America, East Africa, and South-East Asia, face higher rejection rates and consequently are underrepresented in authorship [Kavanagh et al., 2022].

In this study we use a wider bibliometric analysis of papers across a range of journals that include volcanological research. We use authorship of published peer-reviewed research papers as a proxy for inclusion and involvement in the process of research: the bibliometric data include the domicile locations of those doing the research and the

85 locations of the volcanoes being researched, allowing us to assess the extent to which scientists domiciled in the study region are involved in doing research and how frequently they lead that research. Our bibliometric dataset includes material published between 1901 and 2021, which allows us to understand any long-term changes in inclusivity.

This type of analysis allows us to interrogate temporal and spatial patterns with comparatively large volumes of
90 data which can be used to identify geographical areas for improvement and changes in inclusion and leadership over time. Considering these data qualitatively within their broader context (authorship policies, the occurrence of iconic eruptive events) allows us to use these trends to suggest possible means to improve or accelerate positive change in scientific inclusion in volcanology.

## 2 Methods

95 In this study we use data downloaded from two large bibliometric databases: Web of Science and Scopus. A total of 149,275 entries with unique titles were downloaded from Web of Science on 6 April 2022. This constituted all articles returned from a search of the term 'volcan*' (included e.g., volcano, volcanoes, volcanic, anywhere within their metadata – title, authors, affiliations, keywords, abstract) across all Web of Science search categories, through to the end of 2021. Entries include multiple forms of written research outputs including but not limited to journal
100 articles, books, book chapters and conference proceedings (See Supplementary Material S1 for list of publications). For simplicity, we will refer to all individual entries as 'articles'. The Web of Science does not include articles from two relatively recent volcanology journals: *Volcanica* and the *Journal of Applied Volcanology*. Data on all articles from these two journals were downloaded from Scopus on 6 April 2022, contributing an additional 180 articles between 2012 and 2021 to give a total of 149,455 articles in our dataset from 2453 unique sources.

105 For our analysis, we first scanned article titles (and keywords where available) to extract volcano names from articles using code developed in R for this study, thereby identifying studies that are likely to have focused on a particular volcano or volcanoes; articles containing no volcano name in the title or keywords were discarded leaving 27,226 articles in our dataset. For all articles containing one or more named volcanoes we then assessed where the authors of each study were based using their affiliation addresses. By comparing the countries where studied
110 volcanoes are located with the countries where authors were based, we quantified how often volcanology research is led by or includes authors who are based in the country where the studied volcano is located. The workflow of our analytical procedure can be seen in Figure 1.

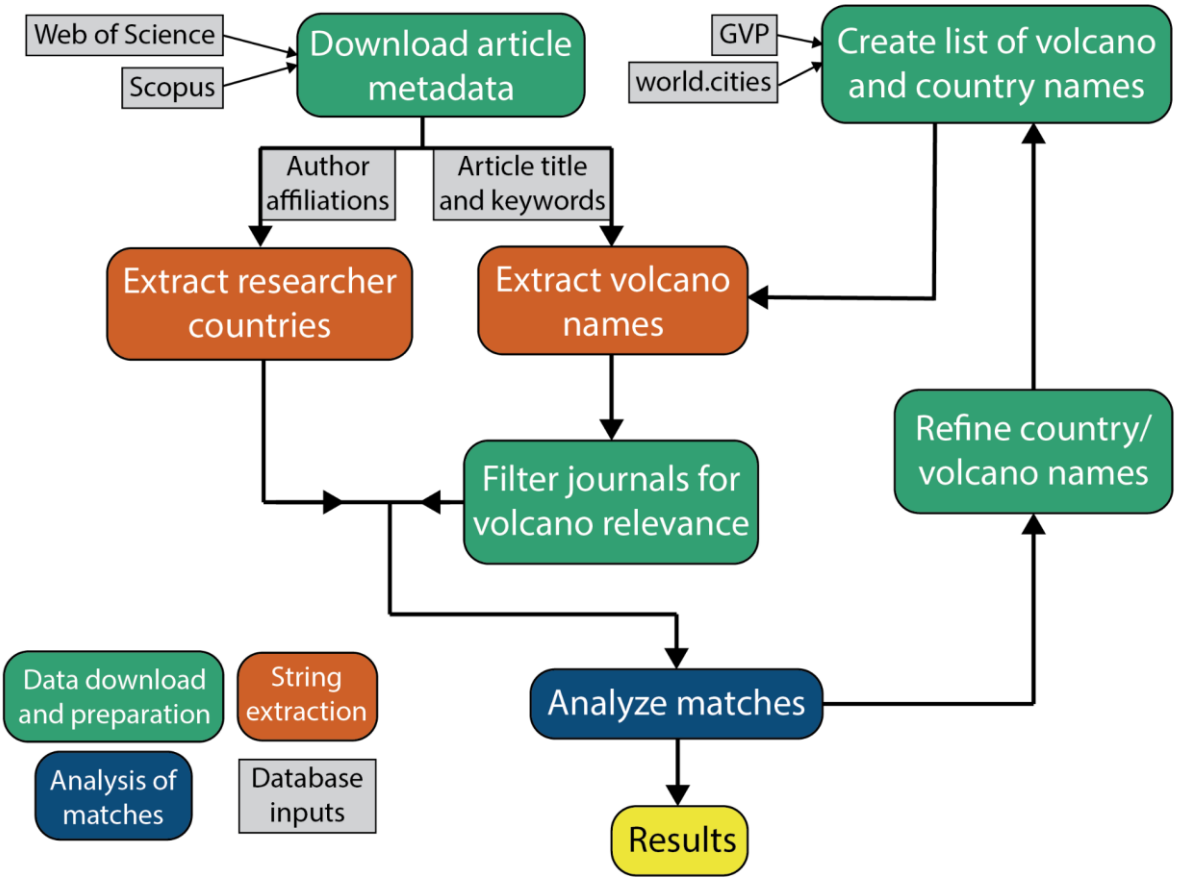


**Figure 1.** Procedure workflow for bibliographic analysis in this study. GVP = Smithsonian Global Volcanism Program Holocene volcano database [2013]. world.cities contains a database of city and country names from the "maps" R package obtained from www.world-gazetteer.com; copyright Stefan Holders).

Our analysis primarily focused on the affiliation address of the article authors and the location of the volcano being researched in the article. For the purposes of our analysis, we define the following terms:

- Author country – the country in which an author's affiliation is located,
- Volcano country – the country/countries in which the volcano or volcanoes identified in an article's title or keywords are located,
- Locally domiciled author (LDA) – an author whose author country matches the volcano country in a given article,

- LDA leadership – an article whose first author's author country matches the volcano country for that article.

The extraction of volcano names from article titles and keywords was conducted using the volcano names listed within the Global Volcanism Program's (GVP) list of Holocene volcanoes [Global Volcanism Program, 2013]. Specific volcanoes from the list were not analyzed, including 13 volcanoes that are unnamed, 24 volcanoes whose country is listed as 'Undersea Features,' and 18 volcanoes located in Antarctica. We manually identified and included six volcanoes within articles that were not named on the GVP's list: (Surtsey, Tarumae, Ngauruhoe, North Sister, Middle Sister, and South Sister). The full list of volcano names analyzed in this study is available in Supplementary Material S2. We identified 8 volcanoes in the GVP list that have non-unique names and are located in different countries (e.g., Flores, Guatemala and Flores, Portugal), in this case the specific volcano a study was referring to was determined by simultaneously scanning articles for the volcano's name and the name of the country that volcano is located within.

Bibliometric studies such as this one often limit their analysis to a relatively small number of journals [e.g., North et al., 2020; Kavanaugh et al., 2022]. Our downloaded article metadata comes from > 2,600 unique sources, meaning some articles that name volcanoes will inevitably not be concerned with volcanological aspects of the named volcanoes. To help filter out such articles from our analysis (and hence focus on volcanological research) we calculated the proportion of articles from each source that name a volcano and excluded all articles from any source where less than 1 in 20 of the downloaded articles included a volcano name. After this filtering process was completed, for every instance of a volcano name being extracted from an article, the country or countries that the volcano is located within was recorded and then compared to the countries where the authors' affiliation addresses are located. A collection of R scripts *Bibli_Volc* used for extracting and analyzing article metadata can be downloaded from the Earth Observatory of Singapore Volcano Hazard and Risk Group Github (https://github.com/vharg/Bibli_Volc).

We acknowledge some limitations of the analysis. Firstly, we cannot completely account for studies involving subjects such as remote sensing, far-reaching ash/aerosols, and interactions between volcanoes and aviation or climate, in which it is to be expected that authors may not have an affiliation in the country of the volcano they are studying, though we did carry out an analysis that attempts to filter remote sensing from more field-based studies (Section 4.5). Secondly, the Scopus and Web of Science databases are unlikely to adequately account for non-English language literature, which present a significant and frequently overlooked contribution to the literature and

often cover topics not covered in English-language journals [Amano et al., 2021; Peltier et al., 2022]. This bias will have affected our results, especially with regard to the research taking place in non-English-speaking countries. Finally, predictably, metadata is more frequently missing from older publications, limiting the extent to which our study could extend back in time. Despite the limitations, the dataset we have curated still allows for a series of useful analyses that provide informative insights for the volcanology community for understanding inclusivity in our publishing practices.

# 3 Results

## 3.1 Overview

Of the ~150,000 articles that were downloaded, ~27,000 articles included both the name of at least one volcano and author affiliation addresses. This excluded ~2,000 instances in which a volcano name had been extracted from an article, but the article contained no affiliation data. Such articles could not be used in subsequent analysis. Considering an article may contain multiple volcano names within their title and keywords fields, ~39,000 individual volcano names were extracted from within these ~27,000 articles. This final set of data included 740 volcanoes across 69 countries for articles between 1901 and 2021, inclusive.

## 3.2 Global results

Our analysis shows that between 57 and 63% of articles that contain a volcano can be considered inclusive, depending on the way in which inclusivity is measured. This range arises from articles that name multiple volcanoes from different countries. The 'generous' or highest rate of inclusion (63%) was derived by categorizing an article as inclusive if *any* of the authors have affiliations within *any* of the countries where the named volcanoes are located. For example, if an article mentions Pinatubo (Philippines), Kelud (Indonesia), and Calbuco (Chile) in its title and there is at least one author whose affiliation is located within any of these three countries then the article will be considered inclusive under the generous definition. The 'strict' or lowest rate of inclusion (57%) is derived by taking the opposite approach, where the same article from the previous example would not be considered inclusive unless it included authors from *all* three countries. A third option for calculating inclusivity is to categorize each instance where a volcano name has been extracted, rather than explicitly categorizing individual articles. Thus, for the above example, we would have three data entries: one for each of Pinatubo, Kelud, and

Calbuco. This third approach gives us an overall inclusion rate of 60% and an LDA leadership rate of 45%. We use this third, instance-based method for all statistics and figures from this point forward.

Global results showing the frequency of local author inclusion and leadership across all volcano countries for which at least fifty papers have been published can be seen in Figure 2 (full results for all countries can be found in Supplementary Material S3). Notably, the volcano countries with the highest rate of combined LDA leadership and inclusion are Taiwan, China, and Iran with a total of 98, 97, and 93% articles having at least one local author, as well as the highest rates of LDA leadership at 79, 88, and 72%. By contrast, the lowest rates of combined LDA leadership and inclusion can be seen in research done on volcanoes in Guatemala, Philippines, and Nicaragua at 9, 12, and 15%, with Guatemala, Vanuatu, and Nicaragua showing the lowest LDA-leadership rates at 0.7, 0.9, and 1.5%.

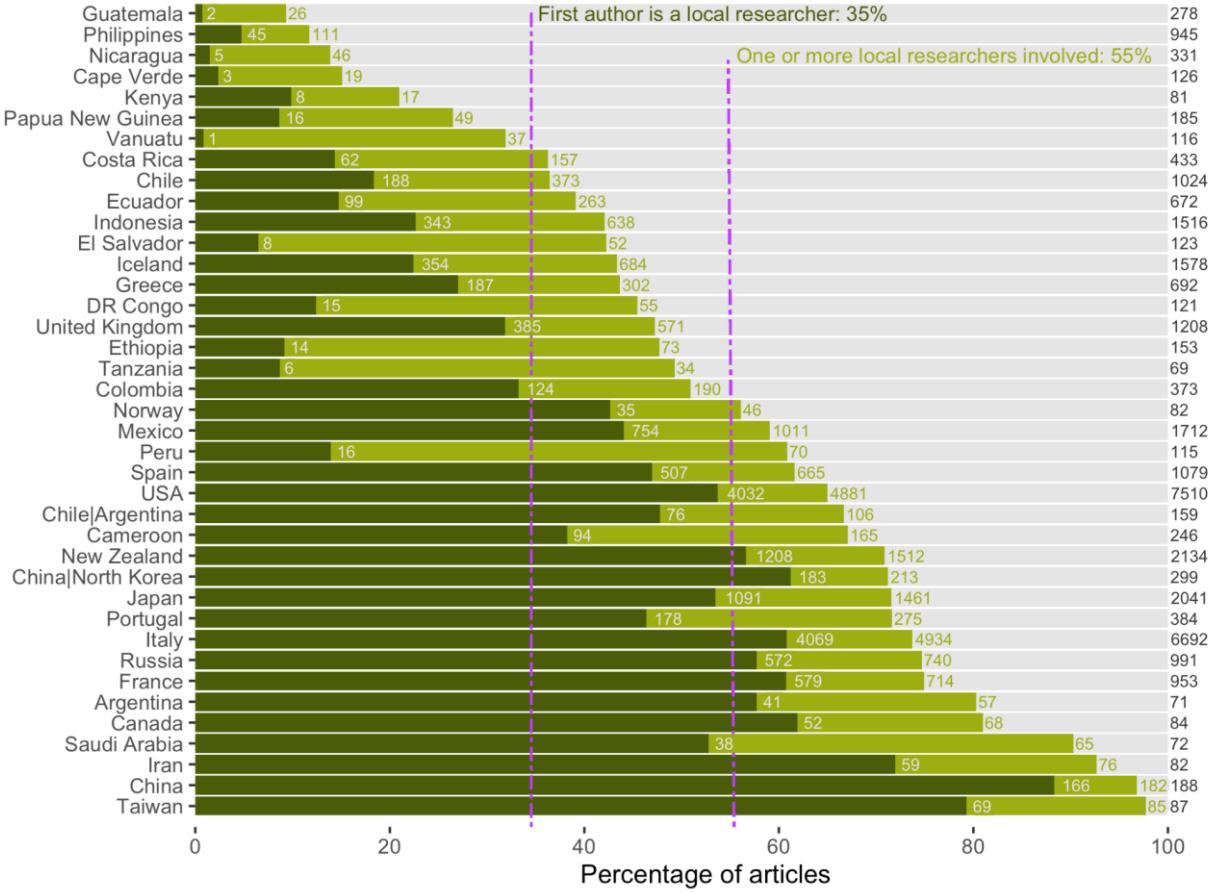

**Figure 2.** Plot showing the percentage and number of articles led by a locally domiciled author (dark green), including at least one local author (light green), and the total articles for each volcano country identified in the study (volcano countries with a minimum of 50 articles shown here). Labeled vertical dashed lines indicate unweighted mean inclusion percentages (i.e., where each country in the plot contributes equally to the average, regardless of its total number of articles). Volcano countries including a vertical bar refer to volcanoes situated at the border of the two named countries.

### 3.3 Temporal Analysis

An evaluation of authorship over time shows that there has been an approximately 20-fold increase in the number of volcanology articles published per year over the past three decades (Figure 3a). Over this period, article inclusion (not including leadership) has more than tripled from 6 to 19%, while rates of local author leadership have remained relatively stable and non-inclusive articles have become slightly less prevalent over this time (Figure 3b). Overall, these changes result in a net increase in the proportion of articles that are either led by or include at least one LDA from 48 - 64% when comparing percentages from the worst year (1991) to 2021.

Secondarily, attempts can be made to correlate the raw publication statistics (Figure 3a) with major events (volcanic or otherwise). Notable increases in total publications can be seen in 1997, 2008, and 2012, while notable decreases are seen in 2011 and 2021 (with the latter possibly connected to the COVID-19 pandemic).

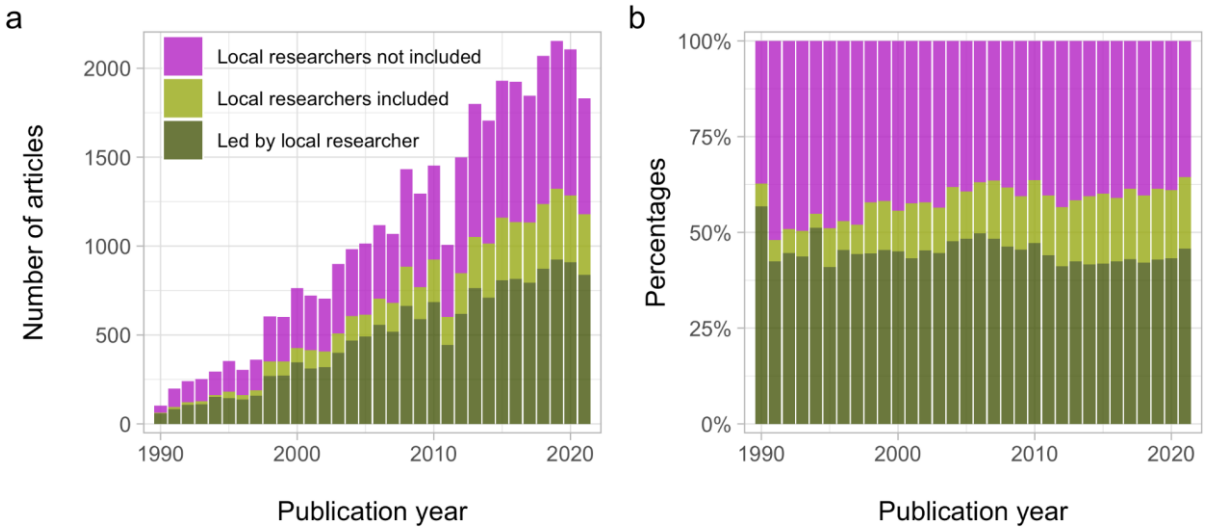

**Figure 3.** Total volcano naming articles published over time, split into three categories: led by local author, local co-author(s) included (but not leading) , and including no local co-authors. a) is the number of articles per year and b) is the percentage in each category.

## 4 Further analysis

The global dataset can be parsed and analyzed in a number of ways to evaluate a variety of topics related to authorship and inclusion. Here, we provide examples of valuable topics that can be addressed using these data.

### 4.1 Time series by country

The time series of local author inclusion and leadership over time can be evaluated for individual countries to identify nation-specific authorship inclusion trends. As previously noted, analysis of time series of non-English speaking countries may be significantly impacted by the possible omission of articles in non-English languages, which have not been catalogued by Web of Science. Nonetheless, these time series can be used to compare national inclusion trends, which can derive from a variety of influences, ranging from volcanic events to national publishing trends to international politics, to global trends.

In Figure 4, we see a variety of patterns in changing LDA inclusion and leadership over time for six countries chosen to highlight different trends (all countries with >50 articles are shown in supplementary material S4). Trends include countries with generally high inclusion that have seen a minor decrease over time (e.g., USA, New Zealand). The decline in leadership and LDA-only articles has been somewhat offset by an increase in non-leading authorship, which may indicate an increase in collaboration with foreign researchers, resulting in LDAs leading fewer articles themselves (but often still being involved as co-authors). A contrasting trend is countries that had generally low inclusion 30 years ago that have seen either a moderate or marked increase over time, though this increase is not always driven by the same factors. In Ethiopia, the rise from 0 to ~50% inclusion has been driven almost entirely by non-leading inclusion in articles, with Ethiopian-led articles almost exclusively restricted to LDA-only articles. By contrast, Indonesia's increase in inclusion from ~25 to ~50% in the past 15 years was caused by an increase in LDA-led articles (especially LDA-only), with LDA-led articles actually overtaking inclusive articles during the past 10 years.

China and Colombia represent countries in which LDA inclusion has risen from relatively moderate (50-75%) to high (>75%) in the past 20 years. In Colombia, this was caused by a general increase in authorship of all types, while China's inclusion is due to the near-total LDA leadership of all articles about Chinese volcanoes.

It is also possible to attempt to correlate increase or decrease in inclusion with major eruptive events. For example, New Zealand shows a marked increase in all types of local authorship in the years following the 1995-6 Ruapehu eruption. The beginning of Indonesia's steady upward trend in inclusion and LDA-led publications began immediately following the 2010 Merapi eruption. We discuss eruption-related effects on articles and their inclusivity in Section 4.2.

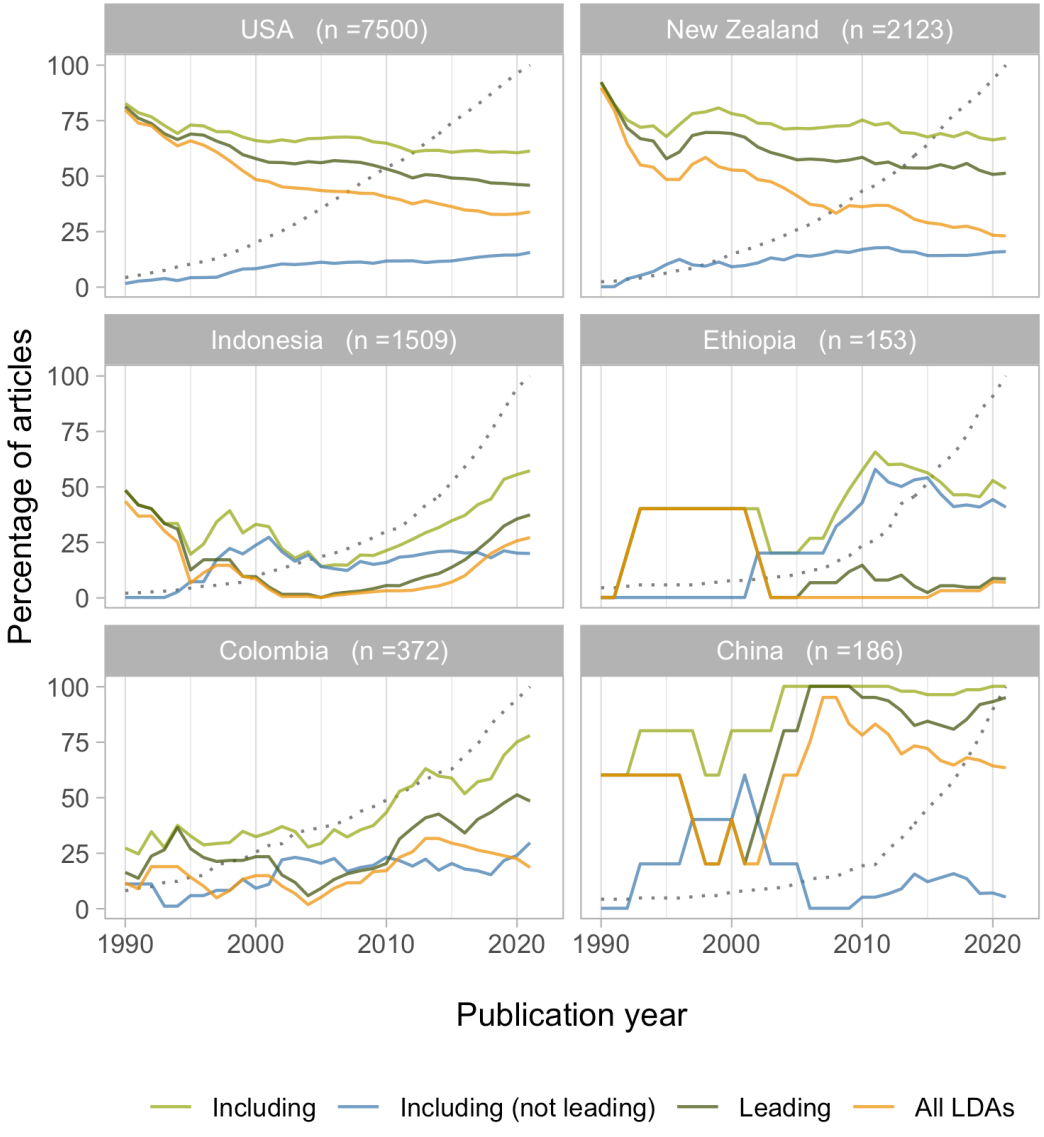

**Figure 4.** Time series of local author inclusion in selected countries, showing percentage of articles led by LDAs (Leading), with LDAs as co-authors only (Including (not leading)), as well as overall inclusion (Including). An additional line shows articles including only LDAs (All LDAs). The remaining percentage, from the uppermost line to 100%, represents articles with no LDAs. The dotted line shows the cumulative percentage of all articles published since 1901. Note that the n values provided here are slightly lower than those in Figure 2 reflecting the omission of a small number of papers with no publication year metadata.

### 4.2 Inclusion in the study of specific volcanoes

Individual volcanoes can be evaluated for authorship inclusion in the same way as countries to see if global and country trends apply. The most researched volcanoes on each continent tend to show a lower level of inclusion than the overall level of their volcano country, indicating that there is a higher level of non-inclusive foreign research on highly studied volcanoes and/or those with important eruptions (Figure 5). Among the 3 most named volcanoes on each continent, 13 of 18 have lower total LDA inclusion rates (leading plus included) than that of their volcano country (the four more inclusive volcanoes relative to their country are Fogo (+1%), Nyirigongo (+11%), Taranaki (+14%), and Yellowstone (+7%); Soufrière Hills is roughly equal). The overall inclusion rate across these 18 volcanoes (n=13,317) is 56% compared to an overall inclusion of 61% (n=25,196) for the 13 associated volcano countries.

As with volcano countries, trends over time can also be analyzed for individual volcanoes (Figure 5; all volcanoes with >50 articles are shown in supplementary material S5). One clear pattern visible is the steep increase in overall publication that frequently follows a significant eruption. This can be seen clearly at Soufrière Hills (Montserrat) after its 1997 eruption, and Merapi (Indonesia) and Eyjafjallajökull (Iceland), which both had major eruptions in 2010 (Figure 5), as well as several other volcanoes (e.g., Redoubt 2009, Puyehue-Cordon Caulle 2011, Chaitén 2008; supplementary material S5). However, the effect of these large eruptions on inclusion is less consistent. At Pinatubo, a very minor initial increase in locally led articles (to <25%) following the 1991 eruption quickly gave way to almost exclusively non-inclusive publishing that persists to the present day (Figure 5). At Soufrière Hills, locally led articles initially increased at a rate nearly equal to non-inclusive ones, after which overall inclusion stabilized at around 50%. By contrast, at Eyjafjallajökull, the 2010 eruption coincided with a steep decrease in inclusion. Before the eruption, the vast majority of articles about the volcano were led by LDAs, but within two years following the 2010 eruption, publications had become (and remain) primarily non-inclusive. At Merapi, the relationship between major eruptions and inclusion is less clear, however, the trend of gradual increase in LDA-led articles following the 2010 eruption mirrors the trend seen for Indonesia overall (Figure 4).

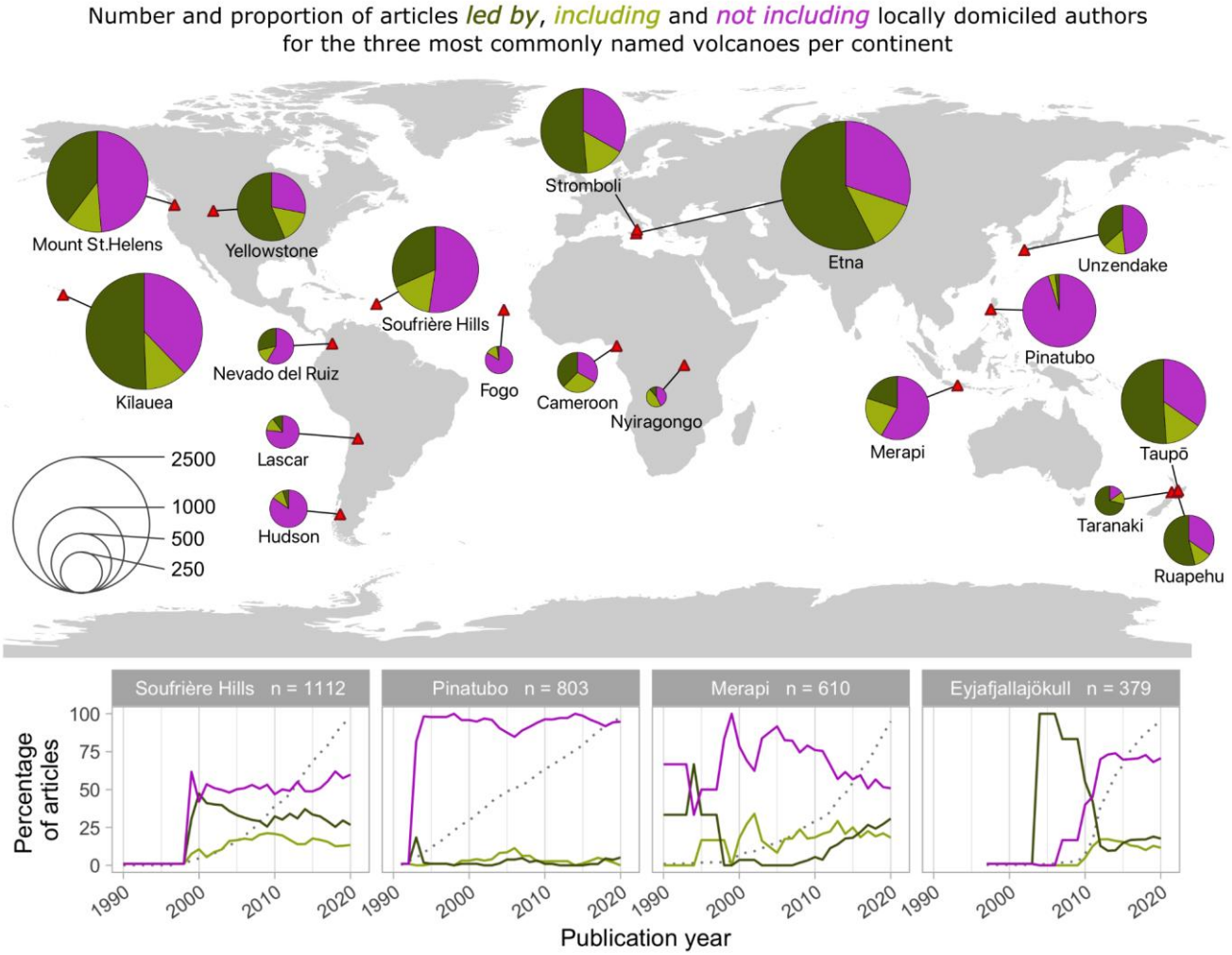


**Figure 5.** Map (above) shows LDA leadership (dark green), inclusion (light green), and non-inclusion (purple) for the 3 volcanoes from each continent with the most publications. Montserrat (Soufrière Hills) is an overseas territory of the United Kingdom (Europe). Hawaii (Kīlauea) is a state of the United States (North America). Time series (below) highlight yearly rates of articles led by, including, and not including LDAs for four highly-published volcanoes (using the same color scheme) chosen to illustrate differing publishing trends. Dotted line on time series represents cumulative percentage of all articles analyzed.

### 4.3 Local author inclusion by lead author country

When inclusiveness is evaluated in terms of the publishing country of an article's lead author (i.e., does an article led by an author working outside the country of their affiliation include any local authors?) results show consistently

low rates of inclusion. Of the 41 countries whose affiliated lead authors have published at least 25 articles that name volcanoes in other countries, none surpass a rate of 50% of inclusion of LDAs as co-authors (range between ~5-45% with a mean of 25%) (Figure 6).

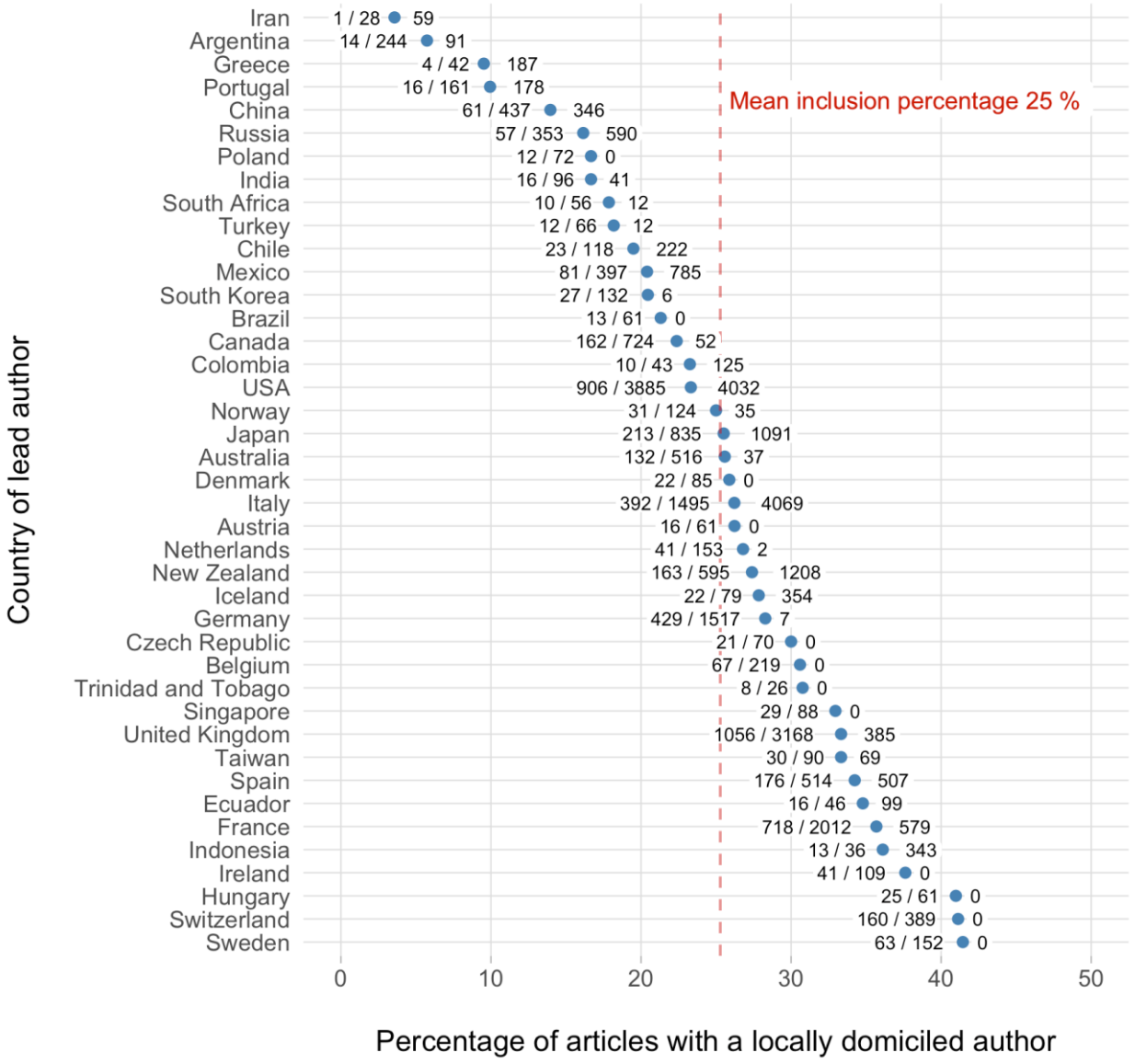


**Figure 6.** Rate of inclusion of LDAs as co-author(s) filtering for articles led by an author working outside the country of their affiliation (minimum articles = 25). Dashed line represents the (unweighted) average inclusion rate of all the countries in the plot (25%). Number right of the point is the number of articles led by the country on volcanoes from

their own country. Example: out of the 249 articles led by Argentinian authors on non-Argentinian volcanoes, 14 include LDAs whilst there are 91 Argentinian-led articles on Argentinian volcanoes.

### 4.4 Authorship trends in territories and dependencies

It is possible to look at specific relationships within the global dataset to infer trends in publication involving research in territories and dependencies as these are geographically located away from the mainland of their country, which creates complications with the concept of an LDA. We have selected populated volcanic islands that have their volcano listed in the GVP Holocene volcano database [2013] as not located on the mainland, we have excluded island nations such as Indonesia and the Philippines (a list of volcanoes, territories, and mainland countries can be seen in supplementary material S6). This investigation can look at the relationship between scientists from the mainland and the territory/dependency by assessing what proportion of LDAs are from the territory itself, and what proportion of LDAs are actually from the mainland. This information can be used to assess whether research being done on territorial volcanoes is truly or only apparently inclusive.

On a global scale, this analysis shows that across all articles written about volcanoes in this category (149 volcanoes across 31 island territories associated with 15 mainland countries), 70% include LDAs (where an LDA is an author from either the island or its associated mainland) (Figure 7). However, when LDA is restricted only to authors with an affiliation on the volcano island, only 23% of all articles about these volcanoes include LDAs affiliated with the territory.

This can also be applied to specific examples which can illustrate the nuance within the larger dataset for instances like this. For example, when applied to research taking place on Kīlauea volcano (Hawaiian Islands, USA), while 72% of articles (n=1,875) include an author from the USA, only 25% of articles (n=471) include an author from Hawaii (primarily from the Hawaiian Volcano Observatory). As another example, for the Soufrière Hills volcano (Montserrat, a British Overseas Territory), when the United Kingdom (including Montserrat) is used as the volcano country, 53% of articles (n=549) include at least one local author. However, if only Montserrat-based affiliations are considered, only 9% articles (n=92) are inclusive (primarily from the Montserrat Volcano Observatory; MVO). Case-specific information does go some way to explain this; in this instance it must be noted that the MVO was developed during the 1995-1997 Soufrière Hills activity and eruption [Aspinall et al., 2002], and many of the non-LDA authors of a significant portion of the relevant articles were previously affiliated with MVO but were no

longer LDAs by the time of publication. Nonetheless this represents a very low proportion of direct inclusion of working observatory scientists in the research following this eruption.

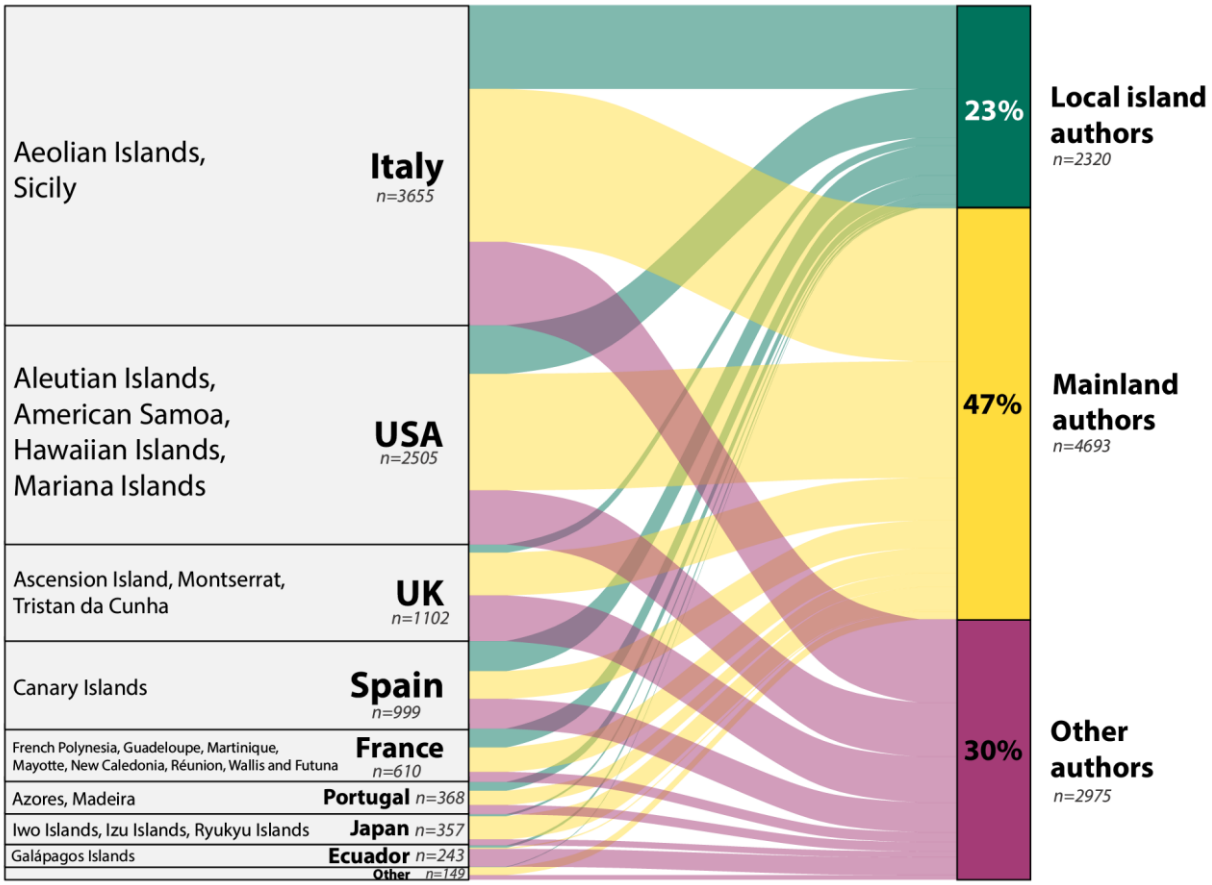


**Figure 7.** Alluvial plot showing the breakdown of authorship of articles on volcanoes on volcanic islands. The country label "Other" includes Chile, Equatorial Guinea, India, Japan/Russia, Russia, and the Netherlands. Local island authors = LDA only with affiliation from the volcanic island, Mainland authors = LDA only with affiliation from mainland associated with volcano island, Other authors = no authors from the island or the mainland.

### 4.5 Effect of the use of remote sensing techniques on authorship trends

We assessed whether our analysis was limited by failing to identify studies that have been conducted using remote sensing methods and that may be concerned with the broad, widespread effects of a given eruption. Take for example, all the remote sensing studies assessing the climatic forcing associated with the 1991 Pinatubo eruption. Many of these do not include any researchers based in the Philippines within their co-author lists, and our approach

would classify these studies as non-inclusive, when perhaps it should not. To gain some insight on inclusivity of remote sensing-based articles compared to articles from the entire dataset, we labeled remote sensing-based articles by scanning each article's title, abstract and keywords for a set of 10 words (or word pairs) that are commonly associated with remote sensing methods (the list is provided in Supplementary Material S7). After identifying articles that were led by a non-local author and likely employed remote sensing methods, we grouped them by the country of the lead author to compare inclusivity of remote sensing articles with that of non-remote sensing articles from the same country (Figure 8).

Around 2,600 articles included one or more of the 10 words we associated with remote sensing methods. From this group of 'Remote Sensing articles' we filtered out any countries that had led ≤ 25 articles on volcanoes from other countries, leaving 15 countries (Figure 8). For 11 of the 15 countries in Figure 8, the difference in inclusivity between the 'Remote Sensing articles' and 'All articles' groups was < 5% (with a maximum difference in the remaining countries of 15%). The 'Remote Sensing articles' group had a slightly higher inclusivity percentage (30.6%) compared to the 'All articles' group (29.4%), showing. on average, negligible difference in authorship trends between remote and non-remote methods in publication. Some countries show greater discrepancy (e.g., New Zealand, Belgium, Canada), but the differences are not consistent with each other (e.g., New Zealand and Belgium remote sensing articles include more LDA than all articles, while Canada shows the opposite trend).

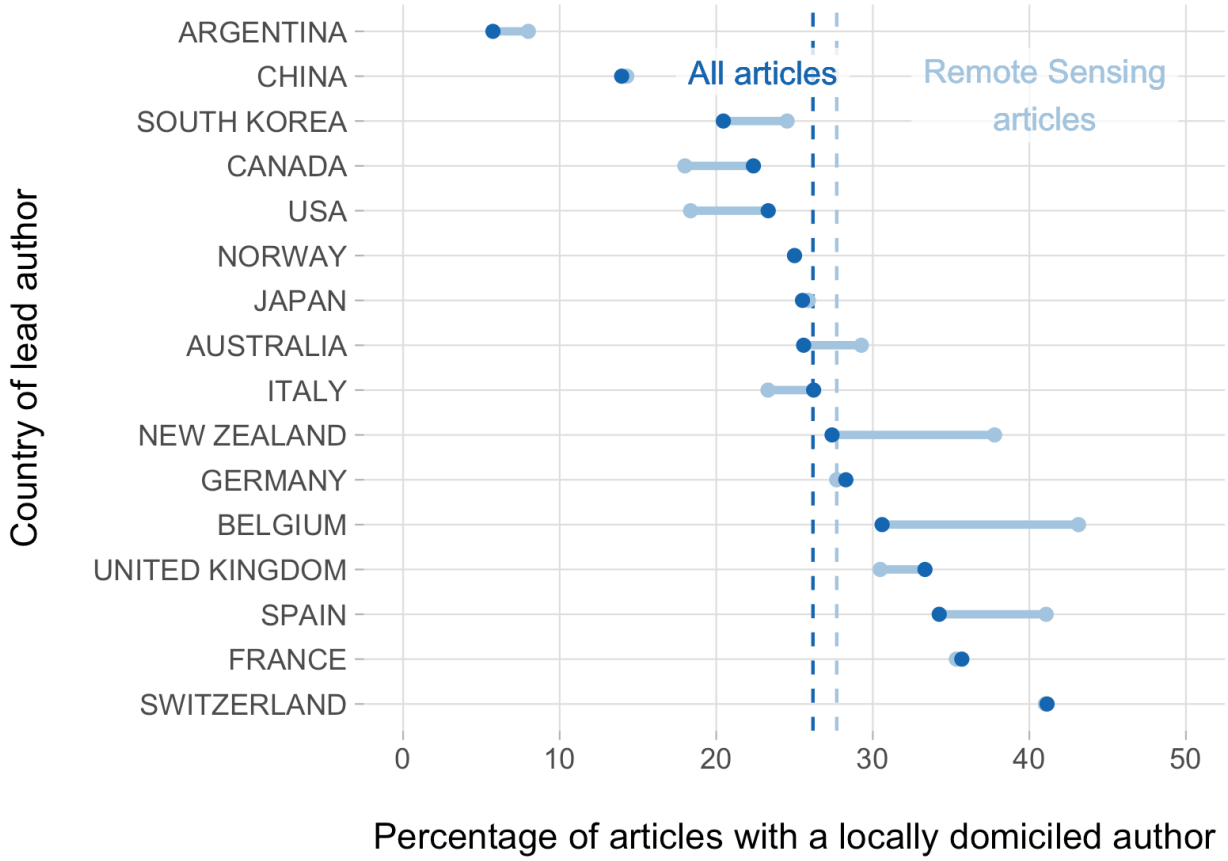


**Figure 8.** Differences in rate of inclusion of local co-authors between all articles from a given country and articles that are likely to have employed remote sensing methods (amongst articles that have a non-local lead author). Articles were labeled as remote sensing-related by scanning the title, abstract and keywords of each article for a set of 10 keywords specified in Supplementary Material S7. Minimum number of remote sensing articles required for inclusion = 25. Vertical dashed lines show average inclusivity for all countries on the plot.

### 4.6 Inclusivity by journal and effect of deliberate policies on inclusion

We assessed the rate of inclusivity by journal amongst the 15 journals with the highest number of volcano names extracted from their articles and an additional 5 subject-relevant journals with ranks ranging from 34-129 with relatively high impact factors, or those that were launched relatively recently (Figure 9). Volcano name extractions from these 20 journals account for 51% of our data (n = 18,180), and this analysis found both the LDA leadership and inclusion rates among these 20 journals are marginally lower than the overall rates (see Figure 2). They have an average inclusion rate of 59% compared to 60% across all articles and an average leadership rate of 41%

compared to 45% for all articles. When restricted to publications from the past four years (the age of the youngest journal analyzed, *Volcanica*), these publications show a consistently lower leadership rate coupled with a slight rise in inclusion (Figure 9).

This analysis also allowed for the comparison with two relatively new volcanology-focused journals, *Journal of Applied Volcanology (JAV)* and *Volcanica* that maintain policies designed to foster increased inclusion in publishing (*JAV* grants frequent open access waivers, while *Volcanica* is a diamond open access journal and has a number of inclusive policies such as non-English abstracts and some fully bilingual publications). The inclusion rates of *JAV* and *Volcanica* are much higher than average, with inclusivity scores of 75 and 79% respectively, compared to the overall inclusion rate of 56% for all articles. However, the ~30% gap between rates of LDA inclusion (75-79%) and LDA leadership (43-47%) are relatively high for these two journals compared to the others where the gap is more typically 10-20%, with the notable exception of Nature communications where it is similarly around 30% but with much lower inclusivity overall. Looking at the past four years, *JAV* has by far the highest inclusion rate at 87%, but as with most of the other journals, its leadership rate is lower over this time frame (39%).

The *Journal of Geophysical Research-Atmospheres* stands out at the low end of inclusion and may be significantly impacted by our previously anticipated factor of a high proportion of remotely conducted research that did not involve any physical presence in the volcano country, and thus an underrepresentation of LDAs. This conflicts with the overall results of our remote sensing research analysis in Section 4.5 and may indicate that remotely conducted climate-related research is less inclusive of LDA than the articles captured by our “remote sensing” keywords.

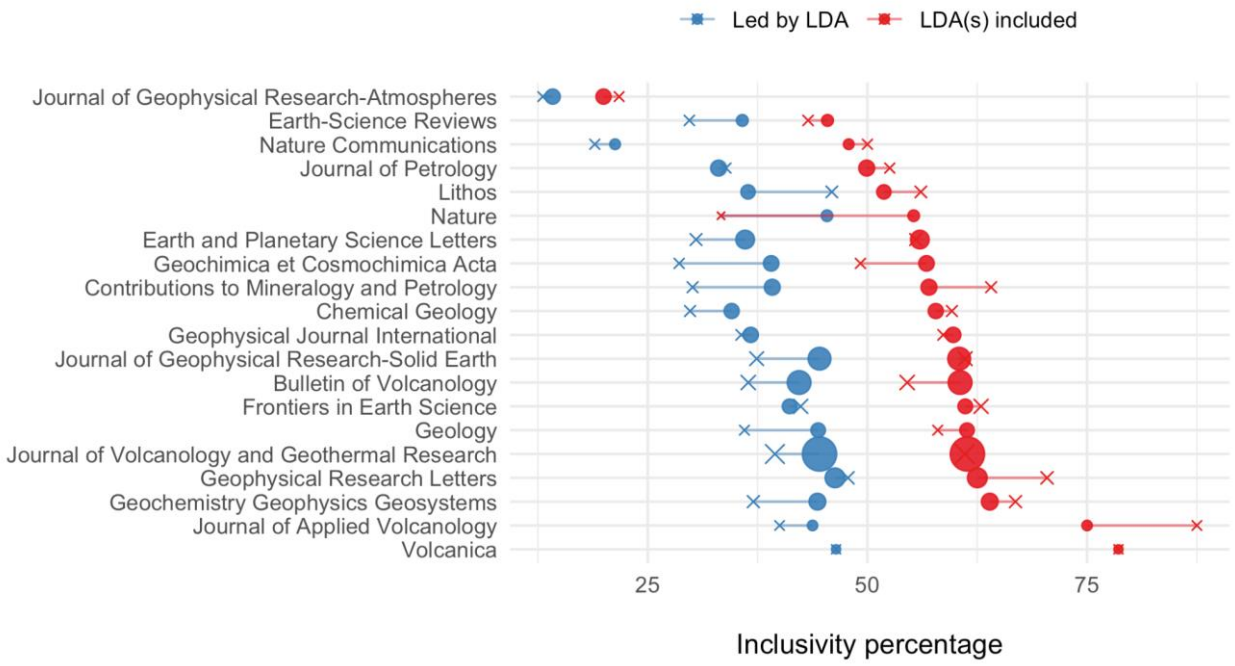


**Figure 9.** Differences in rate of inclusion and leadership of LDAs based on journal of publication for their entire history (circles) and the past four years (X's), the age of the youngest journal included (Volcanica). The 20 journals include the top 15 as ranked by number of articles that name a volcano in their title or keywords, and an additional 5 journals with ranks ranging from 34-129 (Earth Science Reviews, Nature Communications, Nature, Journal of Applied Volcanology, and Volcanica) were selected to capture journals with relatively high impact factors or those that were launched relatively recently. Point sizes represent the relative number of articles included in analysis. Minimum number = 28 articles for Volcanica. Maximum number = 5210 articles for Journal of Volcanology and Geothermal Research.

## 5 Discussion

The results of this bibliometric study demonstrate practices and patterns of inclusion and collaboration in the production of peer-reviewed journal articles. These reflect inclusion and collaboration in terms of the paper-writing process, and the broader research processes that feed into paper writing. Evidence-based analyses such as these prompt questions about what constitutes authorship and when involvement of LDAs should be considered necessary.

The journals evaluated in our study cover a wide range of volcanological practices (Section 4.5 and 4.6), with the work involved ranging from sample collection to viewing of deposits to studies that are conducted entirely via

remote sensing. Our analysis of publications associated with remote-sensing indicates that inclusion is not significantly lower in articles that don't involve in-country fieldwork by foreign researchers (Figure 8), but our analysis by journal indicates that this may be the case to some extent across the differing fields of volcanology (Figure 9). The variations seen between journal subjects in comparison to inclusion rates raise questions about differences in the ethics of inclusion in different subjects, geographic unevenness in knowledge production, and ultimately whether critical mass of knowledge about specific volcanic systems reside outside of the region where potential hazards may need to be managed. In other geological fields such as paleontology, discussions have begun about the extractive nature of knowledge accumulation via the removal and storage of samples, and not only its implications for inclusion in research, but whether concentration of focus and intensity stymies faster progress across the field [Monarrez et al., 2022; Raja et al., 2022]. This type of discussion can be extended to volcanology to consider whether some types of research lend themselves to lower inclusion rates and whether widening the geographic foci of researchers and study sites could accelerate progress in our discipline, as well as improve ethical practices in research.

In the first instance our compound results in Figures 8 and 9 do reveal that practice varies across volcanological sub-disciplines, prompting questions as to why that might be. Our results might suggest that inclusive journal policies affect the publishing practices of submitting authors. Journals typically have explicit policies about what constitutes authorship–these policies may impact whether local researchers and people who are involved in a project are included in articles as LDAs, mentioned in acknowledgements, or not credited at all. Two more recently established journals (*Journal of Applied Volcanology* and *Volcanica*) have journal policies that may have contributed to their higher rate of inclusion of LDAs as co-authors. Our analysis in Section 4.6 suggests that inclusive journal policies can encourage inclusion of LDAs as co-authors, though these policies have not yet led to a similar increase in paper LDA leadership. In other fields, a recent innovative journal policy requires (for all relevant submissions) an explanation if LDAs have not been included. This policy was adopted in late 2021 by all *PLOS* journals and requests an open-ended answer on an "Inclusivity in Global Research" questionnaire that is included as a publicly available supplement to all published articles [Archer and Males, 2022]. A similar policy in volcanology journals could encourage inclusivity and careful reflection by visiting researchers on the need to include and properly recognize the contribution of local colleagues and to engage with them from the outset of research.

Ultimately, however, broader research practices which feed into article writing probably have a greater impact on inclusion than specific writing and publication processes. Articles are an outcome of collaboration, meaning that the many factors involved in creating and maintaining collaborations will have the greatest impact on the level of inclusion seen in the end result. There has been a positive improvement in total inclusion globally in the past 30 years (Figure 3). However, the fact that LDA lead authorship has not increased despite the overall increase in inclusion points to how and where further improvements can be made. Disaggregating the data by country demonstrates important insights (Figure 4). Some high inclusion countries, like the USA, are consistent with the global trends (Figure 3), showing any decrease in LDA leadership being offset by increases in LDA inclusion. Some countries, like Ethiopia, show an exaggerated version of the global trends, with an overall increase in inclusion almost entirely represented by non-leadership inclusion.

By contrast, some countries, like Indonesia, have patterns of authorship that are not consistent with the global trend, with recent increases in inclusion represented primarily by LDA leadership. The trends demonstrated by this analysis point to the need for more detailed case studies to understand the drivers behind them. These explanations may extend beyond immediate practice in volcanology but reflect wider practices in knowledge creation. For example, in the case of Indonesia, recent university policies requiring first authorship for career advancement may have partially, but not completely, influenced the increase in LDA leadership (as this policy was implemented in 2017, after the start of this trend) [Sandy and Shen, 2019].

Large eruptions also have a clear impact on the absolute number of publications produced about a volcano country (Section 4.2) but the effect of these important sites of new understanding on inclusion is less clear or consistent. Evidence from different events shows a large eruption can spur an increase in local research (as apparently seen in the years following the 2010 Merapi and 1996-7 Ruapehu eruptions), an increase in both inclusive and non-inclusive research (1997 Soufrière Hills), or a surge of non-inclusive research by foreign scientists (1991 Pinatubo, 2010 Eyjafjallajökull) (Figure 5).

Research funding policies can strongly influence the adoption (or avoidance) of inclusive research practices. Nationally-based funding agencies often fund their scientists' time and costs but only pay for logistical support in the country of interest, which discourages equity of collaboration in research. More recently some agencies have more deliberately sought to include LDAs more inclusively in funding, for example, some of the programs

associated with the EU funding agencies and the now canceled 'Global Challenges Research Fund' of United Kingdom Research and Innovation (UKRI). A relevant example in volcanology is the 'Volcanic Disaster Assistance Program' (VDAP) that is a collaboration of the United States Geological Survey and US Aid [Lowenstern et al., 2020]. Although explicitly set up to respond to eruptive crises, the practices and outcomes of this funding, rooted in inclusive practices in volcano monitoring have undoubtedly contributed to deeper and more inclusive practices in volcanological research too.

Some aspirational goals for volcanological research that could lead to improved inclusion include funded, longer term research projects and collaborations. These create better opportunities for mutually beneficial relationships, involving a commitment to ongoing research, potential exchanges for students and faculty, and the chance for more active involvement on both sides. Inclusion requirements from funding bodies could also be used to encourage more inclusive collaboration. Further study that explicitly looks at levels of inclusion as a function of funding policy would provide further evidence for the role that this plays in diversity and inclusion in research practice in volcanology.

With or without more funding, research cultures should create and nurture opportunities for local colleagues to contribute significantly and substantively. Local colleagues should be treated as partners and asked to contribute in a non-onerous, mutually beneficial way (particularly when the resource for funded 'time' on research projects can often lie with external partners). This will not only capitalize on local knowledge, but properly recognize local contribution and create spaces for mutual creation of knowledge that will be more robust and insightful than otherwise might be the case [c.f., Trisos et al., 2021; Raja et al., 2022]. If non-local institutes have a well-established connection to the volcanic area, they are in a strong position to be more inclusive of LDAs in their research, and ultimately this can strengthen and deepen the global spread of knowledge about volcanic centers and volcanism. The room for improvement can be seen in our analysis of volcanic islands (Section 4.4), which have a higher-than-global-average inclusion rate when including mainland authors (70%), but a significantly lower than average inclusion rate (23%) of LDAs who are local to the island (Figure 7).

While writing and publishing is a typical waypoint in research, this step is often planned along with collaborations and research projects, meaning that the combination of inclusive collaborative and writing process from the inception of research has the potential to improve inclusion. Creation of a policy for inclusivity in fieldwork would

provide general guidelines for any authors conducting fieldwork outside their country of domicile that would carry through the research process from the fieldwork through to the publication of articles. The International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI), one of the most prominent global volcanology societies, has released guidelines on roles and responsibilities of scientists involved in volcanic hazard evaluation, risk mitigation, and crisis response, which broadly supported collaboration with local scientists [IAVCEI Task Group on Crisis Protocols, 2016]. The International Network for VOLcanology Collaboration (INVOLC) has recently developed a "Guidelines for Best-Engagement Protocols" document [IAVCEI-INVOLC, 2022] pending approval by the IAVCEI. These new guidelines provide much more concrete and specific direction for inclusivity in publishing, and their adoption by the volcanological community would be a step forward in collectively recognizing the importance of fair collaboration and inclusivity in our research.

During this study, some limitations became apparent, either with the method or the dataset. One is the imperfections of author affiliation as a proxy for whether an author is "local." This overlooks and undercounts the possibility of "local authors" who published while based at an institute outside their home country. These authors may have important cultural and geological knowledge and local connections but are not considered an LDA within our analysis. It also cannot account for authors who may have been LDAs at the time the research took place but are no longer affiliated with the volcano country by the time of publication. A more significant, unavoidable limitation of our study, as previously mentioned, is the incompleteness of article databases. This incompleteness is particularly apparent when looking further back in time at individual time series for countries (Section 4.1), as the number of articles and sometimes inclusion rates could be unreasonably low. Gaps in the databases are especially notable with regard to non-English-language journals and articles. This creates the risk of overlooking and undercounting a potentially significant number of articles written in the authors' native language, thereby underestimating the number of LDA-led and also LDA-only articles. It also demonstrates a broader problem in the recognition of the work of scientists from non-English-speaking countries that has been noted previously [Ramírez-Castañeda et al., 2020; Amano et al., 2021], which is a problem both for the use of vital local knowledge in research and practically for individual authors given that publications (and recognition of them) are often related to career advancement in academia. Additionally, bibliometric data represent *an* outcome of a research process, however, peer-reviewed literature does not reflect the only source of information for improving volcanological knowledge [Peltier et al., 2022]. This study does not account for a variety of other types of outputs that may reflect positive outcomes of inclusive research. We encourage further research that explores this.

## 6 Conclusions and suggestions for further analysis

Our bibliometric study provides an analysis of trends in research inclusivity and leadership in volcanology through the lens of article authorship. By comparing the locations of volcanological research with the affiliations of authors, we were able to quantify inclusion of LDAs in the research done in volcanic countries around the world, and measure change in inclusion over time. Overall, net LDA inclusion in volcanological research articles has been increasing at a gradual rate (despite no increase in LDA leadership), but the results clearly show there is much room for improvement in inclusivity in our field. This is most apparent in the fact that for the 38 countries that do the most volcanology research outside their own borders, inclusion of LDAs is uniformly below 45% (Section 4.3).

It was possible to extend this analysis to look at a range of specific inclusion-related topics. We have presented brief examples of these topics, but many, including country-specific trends, inclusion by journal, and more, could be explored in greater detail to obtain more targeted insights. Integration with more literature databases, particularly those that better account for non-English literature, could provide a clearer picture of global or regional inclusion. Our results suggest that there are a variety of related topics that merit more detailed exploration, both within our dataset and beyond, including:

- A deeper exploration of the relationship between funding and publishing policies and inclusion. Attempts to improve inclusion in volcanological publishing would benefit from an understanding of how the origin and availability of funding impacts inclusion, as well as how publishing policies related to funding and to journals impacts inclusion (something our results indicate may be the case).
- Extension of the study of the publishing relationships between non-self-governing territories and their mainlands. This could include the expansion of case studies such as the example of Montserrat used in this study, as well as this application to further case studies. This could even be expanded to include the post-colonial relationships between currently independent countries and their formerly controlling colonizing countries.
- Qualitative analysis of the value of local inclusion. Social science studies involving interviews or discussions with local monitoring agencies could evaluate which type of volcanic studies are most useful to those agencies and how frequently the most useful studies involve LDAs. These studies could also explore whether certain characteristics associated with long term collaborations produce better inclusion

and more useful results and the effect of inclusion and accessibility of published research on its circulation into practice.

- The effect of major eruptions (or other important events) on publishing trends and research investment. Our results hint at possible relationships between specific volcanic events and LDA inclusion (and an overall increase in publications). It would be valuable to investigate the extent of these trends and whether a significant event that leads to increased inclusion in publishing also results in improved local capacity for monitoring and/or studying the local volcanoes.

We hope that our data create an opportunity for volcanologists who work outside their own country to reflect on their research practices and for those who work within their own borders to consider how and why more inclusive research practices can be encouraged.

## Supplementary material

**S1. List of publications analyzed**

**S2. List of volcano names analyzed**

**S3. Global inclusion results**

**S4. Time series for all countries (n > 50 articles)**

**S5. Time series for all volcanoes (n > 50 articles)**

**S6. List of territorial volcanic islands and associated mainlands**

**S7. List of keywords used to identify "Remote Sensing" articles**

**S8. Instructions to download datasets from Web of Science**

## Data Availability

Raw data downloaded from Scopus (for *Journal of Applied Volcanology and Volcanica*) are located in the DR-NTU (Data) repository at https://doi.org/10.21979/N9/CMOA4Z. Sharing of raw data used for bibliometric

analysis was not permitted by Web of Science. Instead, step-by-step instructions to download the same dataset we used from Web of Science are described in supplementary file S8.

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## Author Contributions

GTW conceived the project. GAL wrote the first draft. GTW and ESM wrote the *Bibli_volc* code and performed the bibliometric analysis. GAL, GTW, ESM, SFJ, and JB all contributed to discussion on the direction of the project and editing of the manuscript.

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