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The State of Diversity, Equity, and Inclusion in the Cloud Physics Community

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Abstract. The Geosciences are amongst the least diverse research fields, where women and other underrepresented groups face systemic biases. This paper presents the state of diversity, equity, and inclusion (DEI) in the cloud-physics community, by combining a metadata analysis of 6987 cloud-physics peer-reviewed journal articles published between 1970 and 2020 with responses from a survey of 198 participants from the cloud-physics community. Women first-author contributions are evident only after 1997 and presently only ~17% of studies in the cloud physics field are led by women. Authors from the Global North dominate first and corresponding-author positions, with only ~5% of studies led by tropical affiliation authors. The latter's participation was low even for study sites in the tropics, suggesting widespread practice of parachute science. Of the survey respondents, 23% identified as a minority group and feel that being a minority has had a negative impact on their scientific career, in terms of collaborations, promotions, publishing, funding, salary, and citations. Although the survey data shows the general experiences of cloud physicists globally, the perspectives from this work can aid the cloud-physics community to develop strategies to improve DEI in institutions beyond a business case for a diverse science community. Rather we should consider an equity-centered approach by understanding our ethical responsibilities to benefit research of the climate system.

1 Introduction

Diverse teams improve the quality of scientific research by fostering innovation, as well as offering unique and culturally sensitive perspectives in a variety of disciplines. Climate change research represents such an area that transcends academic research into a global equity issue. Its study demands diverse and inclusive perspectives in order to customize and optimize strategies that will inevitably influence developing countries that are already being disproportionately impacted (Dervis, 2007). Diversity, equity, and inclusion (DEI) refers to efforts and actions to

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create awareness and shift mindsets, practices, and policies to sustain an environment that is equitable and sensitive to people with diverse needs, with the goal of promoting inclusivity. A diverse, equitable, and inclusive workplace supports greater employee engagement, innovation, and attraction of talent, arising from the sharing of varied perspectives and experiences, thus enriching knowledge production and fostering innovation (Nielsen, 2016). In scientific research, diverse teams improve the quality of research and findings - a reality to which the research community has become increasingly aware in the past decades as the recognition of the importance of diversity in science has grown (Plaut, 2010). For example, ethnic diversity among authors increases the scientific impact of a publication (AlShebli et al., 2018). Although various programs, policies, and inclusive environments are being developed to address issues such as gender inequality in academia, many gaps in other minority representation still remain (e.g., Hispanic, black, and indigenous communities; Bernard and Cooperdock, 2018; NCSES, 2019; Gewin, 2020; Odekunle, 2020). Thus, we must recognize that developing a diverse, equitable, and inclusive workplace is a very challenging task (e.g., Apaaril, 2021; Reisch and Jani, 2025) and requires considerable reform of systemic deeply rooted institutionalized practices. The word "minority" denotes negatively stigmatized, ostracized, oppressed, and outcast individuals or groups (Blanz et al., 1995). In the context of DEI, it refers to a numerically smaller population of a group within a larger population based on characteristics such as gender, race, religion, ethnicity, disability, sexual orientation, or other attributes. In the present study, "minority" is used to describe an underrepresented or disadvantaged group, unless stated otherwise.

Many fields lack a diversity of gender, ethnicity, and language including health (Wenneras and Wold, 1997; Landman and Dandolu, 2009; McDermott et al., 2018), science, technology, engineering and mathematics (STEM)(Nadis, 1999; Watt, 2005; Haak, 2002; Barber et al., 2020; Ceci and Williams, 2011; Leslie et al., 2015), as well as humanities, in particular philosophy (Nielsen, 2016; Botts et al., 2014; Herfeld et al., 2022). The lack of diversity and inclusion across academic communities manifests itself in systematic bias of under-represented minorities (Gates et al., 2019) based on hiring and promotion processes (McDermott et al., 2018; Nielsen, 2016), scientific impact reflected on the number of citations (Aksnes et al., 2011; Lerback et al., 2020), scientific productivity (Abramo et al., 2018), publication acceptance rate (Lerback et al., 2020), funding and awards (Mehta et al., 2018), and recognition (Odekunle, 2020). Recently, Chen et al. (2022) found evidence of racial disparities when investigating data from the National Science Foundation, USA. The authors report that White principal investigators (PIs) were consistently funded at higher rates than most non-White PIs. Systemic bias, under-representation of minorities, and a lack of recognition of researchers in and from developing countries (the so-called "Global South") are reflected in the limited scientific collaborations between research groups from developed (the so-called "Global North") and developing countries (Gewin, 2023). For example, Wight (2021) highlights the lack of recognition of African collaborators and the difficulties they experience publishing in high-impact journals.

The geosciences are among the least diverse fields, in which women and underrepresented groups are exposed to systemic bias that prevents them from equal progress and recognition compared to the White men counterparts (Simarski, 1992; Stokes et al., 2015; Bernard and Cooperdock, 2018; Dutt, 2020). Ford et al. (2019) reported that women and minority groups are less often invited to give talks, which are essential to establish a network, funding, and academic collaborations. Pico et al. (2020) found that woman first-authorship on peer reviewed papers was

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underrepresented in several geoscience sub-fields and extended to establishing collaborations. For example, although there has been an increase in the number of international research networks in the last two decades of the 20th century (Adams et al., 2005; Wagner, 2005), the inclusion of researchers from new geographical locations was not significant from 1990 to 2000 (Wagner, 2005) but it was significant between 1990 and 2013 (Wagner et al., 2017). While scientific collaborations are also determined by the degree of the economic development of a country (Gazni et al., 2012), the authors found that existing scientific collaboration networks between USA, UK, Germany, France, Italy, and Canada are less likely to cooperate with low-income countries with typically low scientific development.

Recently, Gewin (2023) highlighted that parachute research, a practice where well-funded researchers often conduct short-term research in the Global South countries which are typically poorer without seeking equal partnerships and intellectual exchange, is very common in the geosciences, and needs to be curtailed in favor of equitable collaborations. The existing collaboration networks mentioned by Wagner (2005) and Gazni et al. (2012) highlight the limited connections between mid- and tropical-latitudes given that the tropical countries involved in international collaborations (i.e., Brazil, Mexico, Colombia, Venezuela, Cuba, Ecuador, Egypt, India, Papua New Guinea, and South Africa) represent a minority. The limited coordination and data sharing between Latin America and scientists from developed countries was also recently discussed in Wheeling (2021). Collaborations across a diverse set of individuals influence the degree of science quality (Katz and Martin, 1997; Gazni et al., 2012; Abramo et al., 2013) and the ability to effectively communicate science to different target audiences. Fostering collaborations between different geographic locations is therefore necessary. Given that the atmosphere and clouds containing air pollutants transcend continental and oceanic boundaries, studies from all over the globe are needed by scientists with a richly diverse set of perspectives.

This work explores the regional representation bias of collaborations in the cloud physics community, by assessing existing evidence on the association between the Global North and tropical countries. We achieved this by first combining objective insights from a metadata analysis of 6987 published papers in the cloud physics field. Second, we contextualized these results with personal insights from community members via a survey for the cloud physics community. This approach allowed us to gain firsthand knowledge of the experiences of the cloud physics community demographic, including those who identify as minorities. We discuss how diverse, equitable, and inclusive the cloud physics community is based on the survey responses. Using the metadata analysis, we address Global North collaborations with tropical countries by evaluating publication statistics and impact factors of journals.

We present findings that reveal biases in the representation of minorities and their experiences, as well as publication biases, and discuss the implications that these observations might have for research and performance. We propose recommendations for strategies on how to encourage and motivate collaborations between scientists, and thus increase diversity within the cloud physics field. To arrive at these recommendations, we discuss how to tackle the lack of infrastructure, resources, and trained personnel in tropical countries to perform high-quality research in cloud physics. Finally, the grander question of systemic barriers in cloud physics is discussed.

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2 Materials and Methods

To evaluate the state of DEI in the cloud physics community, two approaches were used to gather the data. First, we assessed the current state of DEI and the systemic experience of the cloud physics community members, via a survey of the community conducted prior to the International Commission on Clouds and Precipitation (ICCP) meeting in 2021 hosted virtually in Pune, India. Second, we conducted a metadata analysis of peer-reviewed published studies between 1970 and 2020 as a publicly accessible metric to trace the temporal evolution of authorship in the field.

2.1 Survey data

The survey was created by the authors of the present study using Google Forms and distributed by email. The questions were designed and discussed amongst the authors and after being finalized it received the Texas Tech University Institutional Review Boards (IRB) approval (IRB2021-472; Title: Diversity, Equity, and Inclusion in the Cloud Physics Community). The survey was conducted anonymously and did not contain any direct identification (i.e., name or place of employment of the participants). It contained a total of 42 questions (67 questions including sub-questions, see supplementary information). We distributed the survey via the ICCP mailing list and a list used to advertise a virtual colloquium related to the topics of ice nucleation and/or aerosol-cloud interactions. The latter targets research scientists who may identify with ice nucleation research but not necessarily with the wider cloud physics community. The survey was also distributed through the list of registrants of the 2021 ICCP conference held virtually and hosted in Pune, India from August 2-6, 2021. It was distributed and open for responses from July 1 to August 4, 2021. The closing date was deliberate because part of the survey results was presented at the ICCP conference in 2021 as a plenary talk on August 5, 2021. After the talk, we did not collect any responses to avoid biases after presenting the preliminary results at the conference.

The survey was completed by 231 respondents, but the sample size used in the analysis here decreased to 198 after data quality assurance in which participants who did not identify with either the ice nucleation field and/or cloud physics field were removed. We estimate that the sample of this survey is representative of the membership and distribution list of the ICCP based on a comparison to the attendance of three previous ICCP meetings carried out in Leipzig 2012 (665 attendees, 3% Indian, 22% German), Manchester 2016 (429 attendees, 1% Indian, 19% UK), and Pune 2021 (570 attendees, 28% Indian). For the survey, the number of local respondents (Indian) was proportionally higher (14% of survey respondents) compared to previous Indian affiliation registrants likely due to the ICCP 2021 conference being hosted in India. This was also the case for increased registrants from local scientists when the host country in previous meetings were Germany and UK. The survey covered 30-47% of the cloud physics membership based on the past attendee statistics. Although the ICCP membership is representative of the international cloud physics community, there could be some unintended biases in the survey data coming from the overrepresentation of respondents born in India, Germany, and US (above 15% each) as well the overrepresentation of respondents younger than 40 years old (64%). Specific questions (see supplementary information) were asked to allow an assessment of the biographic data, career stage, experience regarding career progress, promotions, hostile environments, bullying, and diversity of working with students and supervisors from the Global South. The results were stratified by gender, age, and ethnicity with all analysis and plotting performed in Microsoft Excel and Origin Pro. We used Chi-square tests in R (version 4.3.1) to assess group differences, reporting Cramér's V as effect size (0.1 = small, 0.3 = moderate, 0.5 = strong; Cohen, 1988).

The assignment of which ethnicities and cultures are considered minorities can differ depending on the geographical location. This may arise from the prevailing ethnicity in the location of the survey respondents. Therefore, in further analysis, we classify the Caucasian, White or European categories as "White", while the other ethnicities are classified as "non-white" with the exception of participants who preferred not to identify their ethnicity.

2.1 Metadata analysis

2.2.1 Study search and criteria

For the metadata analysis, the Scopus database was used. The search algorithm for the papers that were analyzed in the present study is described in Fig. S1 (supplementary information). The following criteria were applied for papers written in English and published in indexed journals: In the "Search within Article title, Abstract, Keywords" option, "cloud physics" was added with an additional search field with the word "cloud microphysics" linked with the option "OR". Subsequently, the following filters were applied. a) year range: 1970 to 2020, b) subject area: Earth and Planetary Sciences, c) document type: Article, Review, and Letter, d) publication stage: final, and e) source type: Journal. Although 8199 papers were pre-selected (from the documents available in Scopus on December 2021), those papers published in Astronomical and Astrophysical journals and other papers not related to cloud physics or written in a language different than English were removed leaving us with a total of 6987 papers as shown in Fig. S1. We note that the number of papers (i.e., 97) removed because of language could slightly impact the outcome of the present analysis; however, this was necessary because the authors of the present study were unable to translate them to get the needed information. Also, it is important to highlight that the conclusions raised from the metadata analysis could be biased as Scopus, and most databases, does not cover all areas of interest leaving out important information from e.g., non-English-speaking countries or Global South countries (Martín-Martín et al., 2018; Tennant, 2020; Pranckuté, 2021).

2.2.2 Coding procedure

The author's name, year of publication, title of the paper, journal name, DOI, affiliations, first author country, and funding agencies were directly extracted from Scopus. The journal's impact factor was obtained from the Journal Citation Report 2021 which was updated in November 2022 (https://impactfactorforjournal.com/ wp-content/uploads/2022/11/JCR-2021-Impact-Factor-PDF-list.pdf). On the other hand, the first authors' gender, the number of woman/man co-authors, and if any of the co-authors was affiliated with a tropical country were assigned by a self-written automated script in Python (an open-source code used for this analysis is available at https://doi.org/10.3929/ethz-b-000654489). Each co-author's gender was evaluated employing the genderize.io web server (Demografix ApS, 2022) and included in the analysis if the certainty estimate provided by the tool was larger than 75%. The genderize.io tool relies on web-collected data and has previously been used for similar demographic science research (e.g., Holman et al., 2018; Shen et al., 2018). It is important to note that genderize.io assigns the gender based on the person's first name. Although this could be a good approximation, names cannot always be used to infer the gender (e.g., Sebo, 2021; Lockhart et al., 2023; Marty et al., 2023). Therefore, the results presented below must be taken with caution and considering the aforementioned bias. Each paper was checked for co-authors with tropical affiliations by comparing their affiliations with a list of tropical countries. For a country to be considered tropical in this study, at least 50% of its inhabitants need to live in the tropics, i.e., between 23.5° N and 23.5° S. From our analysis, the total number of countries (where the first authors were located at the publication time) represented in the publications were 72, of which 23 countries were coded as tropical. However, it is important to note that 11 additional countries were coded as tropical when considering the coauthors.

3 Results and discussion

3.1 Biographic description of sample from survey data

The biographic information of the survey respondents is summarized in Fig. 1. Sixty seven percent of the participants were < 40 years old and 57.1% of the participants identified themselves as men, 41.4% as women, with 1.5% preferring not to respond (Fig. 1a). Seventy three percent of women and 58% of men were < 40 years old, while 13% of women and 25% of men were > 50 years old (Fig. 1a). The majority of participants identified themselves as heterosexual with 8% as LGBTQIA+ (Homosexual, Queer, Bisexual or Pansexual-listed by the respondents), and 5.6% preferred not to provide information on sexual identity (Fig. 1b). Figure 1b also shows the distribution of the highest academic degree obtained. The majority of the participants were students (from undergraduate to PhD) with 37% of women and 32% of men reporting this category. Also, most women (57%) were early career researchers (undergraduate to Post-doctoral level inclusive) compared to 53% of men being mid-senior career (above Post-doctoral level), as shown in Fig. 1b.

Information on the ethnicity of the participants can be found in Fig. 1c, with the majority identifying as white (115 respondents), followed by non-white (77 respondents), and 6 respondents preferred not to identify their ethnicity. This trend agrees with the overall geoscientist population in the US (Dutt, 2020). For a given race, there were more men than women or hardly any difference between the two genders, except for Hispanic or Latin X where women represented 79% of this race. In the participants' own perception, only 23% identified themselves as minorities. We note that these numbers do not match up with the ethnicity stratified by gender in Fig. 1c because three respondents either preferred not to respond to the gender question, identified as non-binary or as scientists. Participants came from a wide variety of countries (by birth and country of residence) as seen in Fig. 1d, with the majority from USA, Germany, and India. The difference between these two bars (residence vs. birth country) indicates the number of foreign researchers in each country. For example, if the country of birth bar is lower than the country of residence, this implies that more foreigners occupy research positions (at all levels) in that country. However, if these two bars are similar it does not necessitate the absence of foreigners. On the other

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hand, if the country of birth bar is higher than the country of residence, it shows that more local scientists are working in the country at the time of the survey.

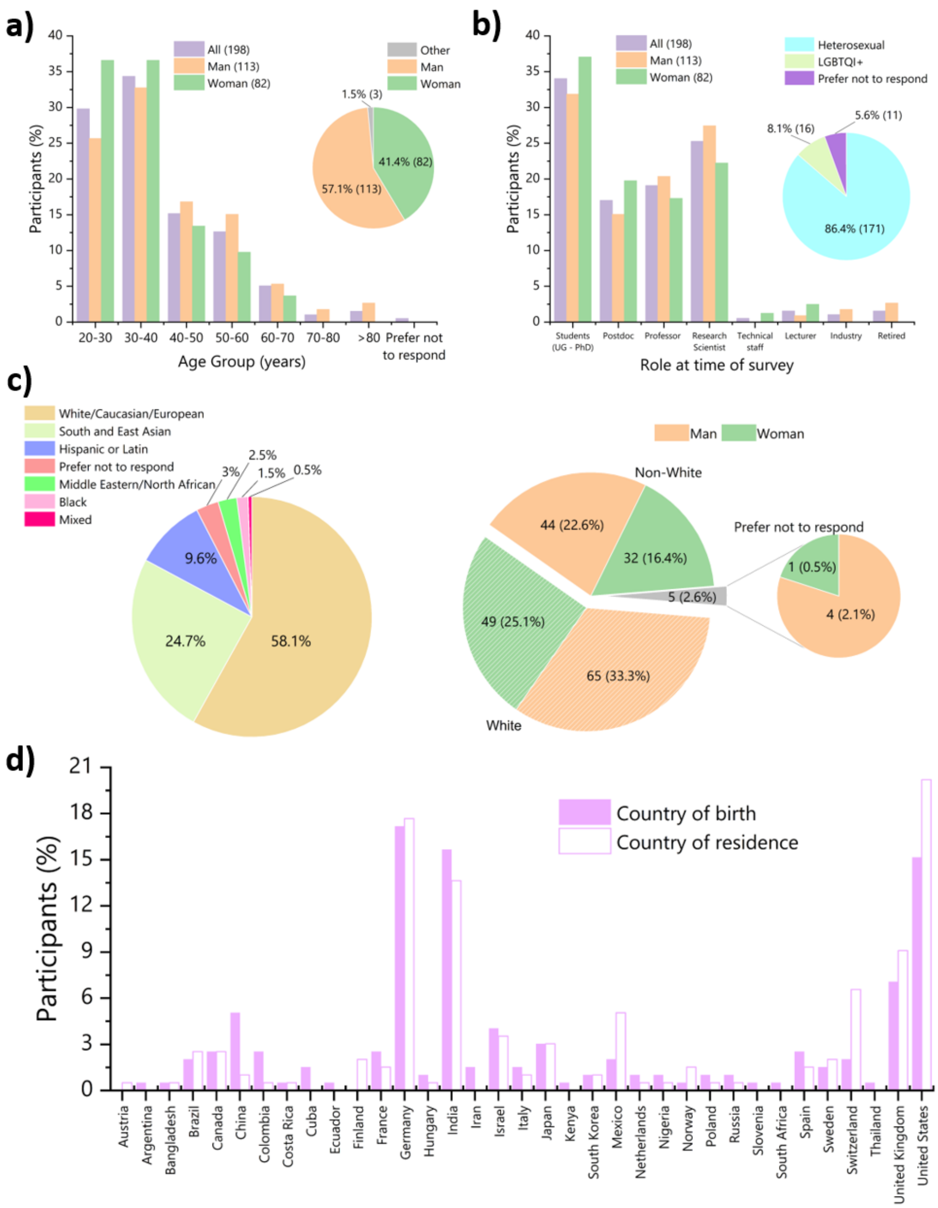

Figure 1: Cloud physics survey biographic data obtained from a total of 198 respondents showing their age, gender, ethnicity, and role distributions.

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3.2 DEI general perceptions from the survey

To evaluate the general experiences of the cloud physicists about inclusivity in their working environments, we first describe our findings and then present the outcomes on questions regarding hostility, bullying, and supervision across those who identify as white and minorities. We use the terminology of women and men in preference to male and female to represent gender and not biological sex, consistent with the question asked in the survey (see supplementary information for questionnaire).

It was encouraging that most respondents (70%) felt included in the cloud physics community, but a closer look at the 30% who did not feel included reveals that the majority were < 40 years old; 35% of this age group did not feel included in the community (Fig. 2a). Out of the total respondents, the percentage of men and women who do not feel included is similar. When considering the feeling of exclusion amongst participants who identified as part of the LGBTQIA+ community the fraction increases from 30% to 44% (not shown). This is not exclusive to the cloud physics community as this is also the case for LGBTQIA+ geoscientist (Le Bras, 2021). We also found that a third (33%) of those who identified as non-white (i.e., South- or East-Asian, Hispanic, LatinX, Black or Mixed-race) indicated not feeling completely included in the cloud physics community (not shown).

The majority of respondents (60%) perceived their workplace to be sensitive to gender issues, of which women and men comprised 58% and 61%, respectively. The small difference is consistent with random variation. Statistically and practically, there is no meaningful differences between genders, suggesting a concerted effort for workplace sensitivity (see Fig. 2b). This perception changes when considering the LGBTQIA+ community as 56% of them (N = 15) did not perceive their workplace to be sensitive to gender issues. A large portion of participants (75%) reported that their gender does not impact their scientific career, but for the remainder 25%, who do feel an impact, 69% were woman (Fig. 2c). This difference is statistically significant ($\chi^2(1) = 18.60$, $p < 0.001$, Cramér's $V = 0.31$), indicating a moderate association between gender and perceived career disadvantage, as reported in other fields (e.g., Cambois et al., 2017; Gibney, 2017). Participants indicated different ways in which they felt gender sensitivity was lacking. For example, one participant indicated that during her interview process for professorship, several instances of topics that are illegal in the respective country were raised surrounding marital status and family planning. In their role, the respondents thought that "women in the program were disproportionately asked for service work and to serve on more committees than the men faculty". On the other hand, a small number of respondents indicated that they were at a disadvantage due to positive discrimination because they belonged to the most represented gender group (men). The majority of comments from women referred mostly to childbirth and childcare as a disadvantage and included a claim that not enough institutional support is available for normalizing these rights of passage for women. Finally, when the participants were asked if their perception of the number of women at the Post-doctoral level and above has increased over the course of their career, 65% of men agreed vs. only 50% of women (the difference is not statistically significant ($\chi^2(1) = 2.14$, $p = 0.144$, Cramér's $V = 0.13$). Despite the disparity, these opinions resonate with the numbers of the survey which showed early career researchers were mostly women.

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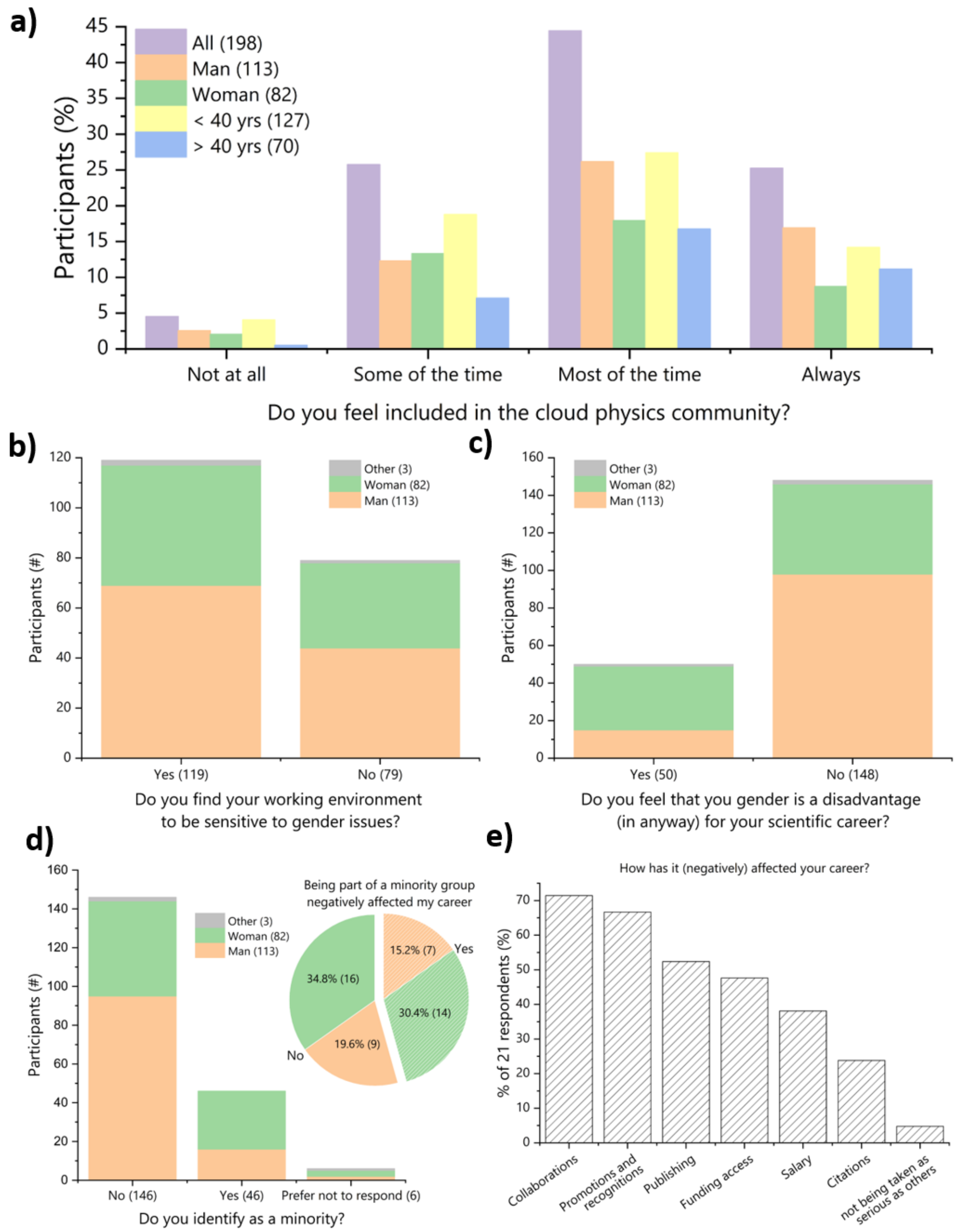

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260 **Figure 2: Cloud physics survey (total 198 respondents) on inclusivity and negative impact of gender issues and minority identity on scientific careers. For all panels, in parenthesis the number of absolute respondents for the respective category is given. Panels with questions below indicate the main question and those with questions above the plot are sub-questions.**

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When asked if students or colleagues from a minority (specified as overall minority such as ethnic, or disability) group are equitably treated in their working environment, 81% agreed. Although 46 respondents (24%) identified themselves as part of a minority group (Fig. 2d), only 21 (46%) reported that their career was negatively affected (Fig. 2d) by being a minority in different ways, spanning from collaborations to publishing and having access to funding, among others (Fig. 2e). Seventy-eight percent of the minority respondents indicated working with research group members that belong to a minority category. This percentage is lower (48%) for those who did not identify as minorities, suggesting a lower diversity in the non-minority cases. Ten participants indicated they have disabilities including physical, mental and neurological, potentially placing them in a minority group. Six of the 10 participants felt excluded in their academic career or working environment because of their disability, and four of them felt that being part of a disability group negatively affected their scientific career.

Although the terms bullying and harassment are not strictly synonyms (Einarsen, 2000), the way the question was formulated in the survey led participants to understand that these concepts were the same. One third (33%) of the respondents experienced a form of bullying or harassment from someone in the cloud physics community (Fig. 3a). A higher fraction of women, 44% compared to 27% of men reported having experienced harassment, a difference that was statistically significant ($\chi^2(1) = 5.70$, $p = 0.017$, Cramér's V = 0.18), although the size of the gender difference is modest. The proportion of respondents who experienced harassment increased with age (see Fig. 3a) with 41% of participants > 40 years old having experienced harassment. This trend could be explained by the increased probability of experiencing harassment with time spent in the field, or a more recent evolution in an awareness of harassment behavior related to work activities resulting in less harassment experience in the lower age category; however, more research is needed to fully understand this. When stratified by ethnicity (Fig. 3a), 39% of the white vs. 26% of the non-white respondents reported harassment. The difference is not statistically significant ($\chi^2(1) = 2.63$, $p = 0.105$, Cramér's V = 0.12). A higher fraction of non-White women reported experiencing bullying and harassment, which aligns with the concept of intersectionality, where overlapping social identities and positions can increase the likelihood of discrimination (Crenshaw, 1991). However, the sample size prevents statistical verification of this pattern.

The term hostility used below is related to a hostile working environment, as stated in the survey. Most respondents did not experience hostile working environments because of their gender, ethnicity, sexual orientation or disability (Fig. 3b). However, from the 21% who did experience hostility (see Fig. 3b), women were the majority, with 37% compared to 10% of men reporting having experienced hostile working environments. This difference is statistically significant ($\chi^2(1) = 18.46$, $p < 0.001$, Cramér's V = 0.33), indicating a moderate association between gender and reported hostility. By age, the trends were similar for the harassment, where 25% of respondents > 40 years old reported having experienced hostile working environments versus 18% of respondents under the age of 40. Both the time spent in the field and the recent evolution of sensitivities in the workplace could account for the lower percentage in the younger group. Lastly, 25% of the white and 18% of the non-white participants reported experiencing hostile environments. This difference was not statistically significant ($\chi^2(1) = 1.04$, $p = 0.307$, Cramér's V = 0.08), indicating a very small association.

Only 29% of respondents (9 % women and 20 % men) had supervised students (BSc., MSc. or PhD.) or employees from tropical latitudes. This translates to 35 % of the men and 21% of the women respondents supervising personnel from tropical countries (Fig. 3c). When stratified for ethnicity, men were still the majority to have supervised employees from tropical latitudes. These percentages were unsurprisingly dominated by older respondents (56% of those above 40 years), who were majority men in the White category (Fig. 3c). White respondents who supervised personnel from tropical latitudes increased with age, whereas in the non-White category the proportion decreased with age. This reflects the decreasing proportion of senior to mid-career respondents in the non-White category as seen in Fig. 3c or the recent increase in awareness of DEI and thus only reflected in the younger (< 40 years population) population of the non-White respondents. The percentage of White respondents (31 %) who supervised personnel from tropical latitudes is significantly different from the non-White category (27 %), with a small-to-moderate association between ethnicity and supervision ($\chi^2(1) = 5.26$, $p = 0.022$, Cramér's V = 0.187). There was no difference in the proportion of men supervisors by ethnicity, 21% of both White and non-White men respondents had supervised personnel from tropical latitudes (Fig. 3c), while these numbers were 10% and 6% for women respectively. The proportion of women who supervised personnel from tropical latitudes was lower than men.

Only 24% of total respondents (10% women and 14% men) were supervised by someone from the tropical latitudes. The gender difference for this question mostly arose from the lower proportion of women in the non-White category (see Fig. 3d) as the ratio between men and women in the White category was equal. Majority of the 24% was made up of younger participants (< 40 years old, 78% vs. above 40, 22%) regardless of ethnicity. Most respondents who had a supervisor from developing or tropical countries were non-White (Fig. 3d), i.e., 48% of the non-White respondents had a supervisor from developing countries compared to only 10% of the White respondents. This implies that non-White respondents were more likely to get an offer from or accept a position in a group led by someone from tropical countries.

Overall, from the survey it is evident that women researchers are disproportionately affected by harassment, bullying, and hostile working environments regardless of ethnicity (see Fig. 3). This aspect may result in a negative gender feedback, discouraging women from remaining in academia and research in the cloud physics community, i.e., these factors could also contribute to the leaky pipeline, the concept of the diminishing number of woman scientists as they move up the career ladder (see Section 3.5 below, Wolfinger et al. (2008)). Although there is a consensus (67% of total respondents) that collaborating with colleagues and institutions from developing countries (no latitudinal definition was given for this question) is key for the development of the cloud physics field, a large fraction of the survey participants (60%) are not planning to do so. In fact, 33% of the respondents did not have an opinion or did not agree that it was important to collaborate with colleagues from developing countries. The 33% who did not agree or have an opinion were made up of 34% of the women vs. 30% men. There is also a bias for non-White respondents being supervised by non-White people (Fig. 3d), but for the majority of non-White students or employees, their supervisors are White (Fig. 3c). Only 35% of men and 21% of women supervised students or staff from tropical latitudes.

It is important to note that some of the aforementioned conclusions are not exclusive to the cloud physics community and they may apply to other fields. Also, some of the survey results are related to individual workplaces without direct

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influence from people from the cloud physics. Therefore, these conclusions reflect the general experiences of cloud physicists globally.

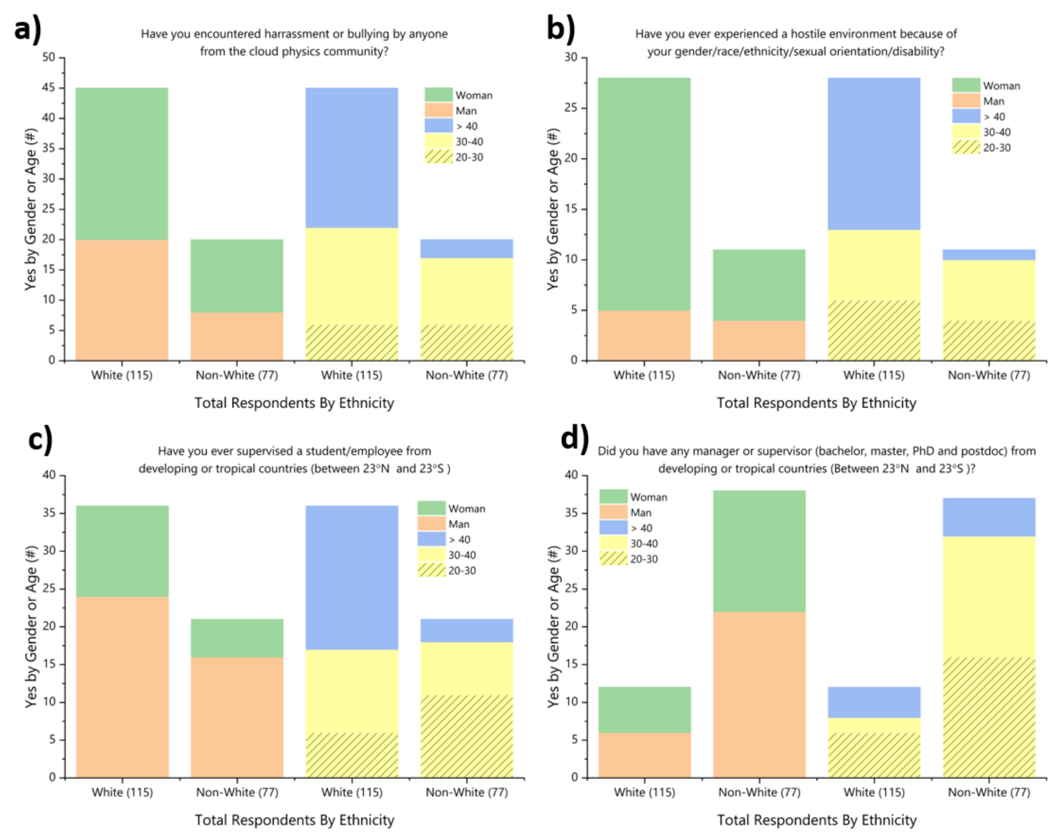

Figure 3: Stratification by age, gender and ethnicity for respondents who a) experienced bullying and harassment by someone from the cloud physics community; b) experienced a hostile working environment due to their gender, ethnicity, sexual orientation or disability; c) supervised personnel from developing or tropical countries defined as between 23°N and 23°S; d) were supervised by someone from developing or tropical countries defined as between 23°N and 23°S. Note that 6 respondents opted not to disclose their ethnicity.

3.3 DEI as evidenced from the metadata analysis

For several decades the participation of women was relegated to secondary roles in scientific articles in many fields (e.g., Pico et al., 2020). As shown in Fig. 4, only after ca. 1997, the role of women as leading authors is evident. Since then, the number of studies led by women has increased with time. As of 2020, only ca. 17% of the studies published by our community were led by women. Although the number of women working in the cloud physics community has an increasing trend; the number of women as leading authors is far from being equitable (Fig. 4). Figure 5 shows how

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gender inclusive published articles led by women and men are. The metadata analysis clearly shows that the papers led by women are better balanced yet still not balanced in the gender of co-authors (Fig. 5a,b). It is important to note that this trend is stronger for articles with a low number of co-authors. Women first authors thus are more likely than men first authors to choose women co-authors. This was also found in a recent study in ice-core science where women-led studies had 20% more-women co-authors than men-led studies (Koffman et al., 2023). This may not be the result of them being more equitable but could rather mirror a preference for working with people similar to oneself. Nevertheless, it implies that one route to increase women co-authorships is to have women authors in the lead. Similarly, first authors with a tropical affiliation are likely to bring in other co-authors with a tropical affiliation (see Fig. 5c). It is important to note that typically most of the senior authors get listed at the end in the cloud physics community.

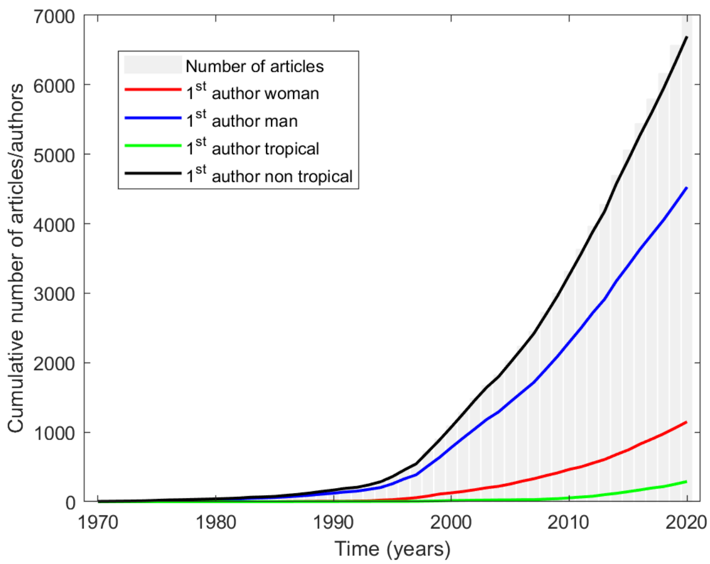

Figure 4: Cumulative number of articles published in the cloud physics community during the last 50 years. The red, blue, green, and black lines indicate if the first author is woman, man, from a tropical, and non-tropical affiliation, respectively.

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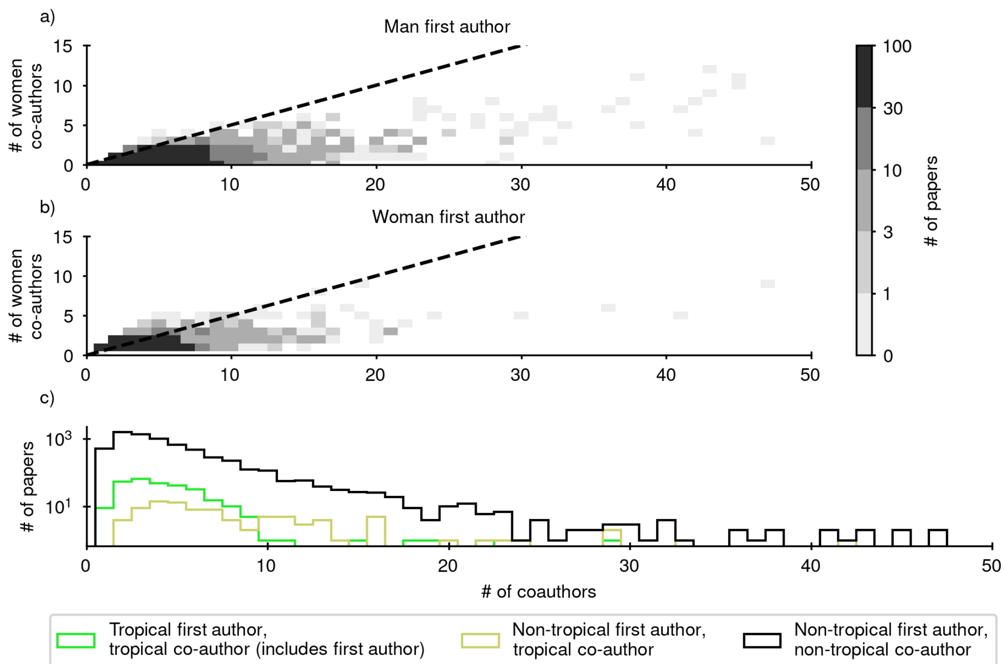

Figure 5: Distribution of women co-authorship versus the number of total coauthors, split by a) man and b) woman first author, and c) The number of papers versus the number of coauthors for three different categories of tropical/non-tropical affiliation. For a) and b), the black dashed line shows where the number of men and women co-authors would be equal, i.e., the same amount of men and women contributing to each paper.

Authors from tropical countries have contributed only 5% of the total number of cloud physics publications, with most of them coming from India, Brazil, Taiwan, Mexico, Indonesia, and Thailand. Table 1 shows that 77% of all analyzed studies were led by authors from only seven countries from the Global North (i.e., Canada, China, France, Germany, Japan, the UK, and the US). On the other hand, Fig. 4 also shows that the role of tropical PIs is increasing with time, especially in the last decade. However, the number of studies coming from this part of the world is very low. Figure 5c shows that it is extremely rare that a tropical author is included as co-author in articles led by non-tropical authors. It was also found that the number of tropical coauthors does not change if the lead author is a woman or man (not shown). The lack of leadership and participation from tropical authors is an example of the biased international collaboration network existing in the cloud physics community. The factors associated with this gap can be the limited funding, scientific facilities and infrastructure, lack of security for tenure, and underrepresented groups' equality (Gazni et al., 2012; Yáñez-Serrano et al., 2022).

The present data shows that in addition to the low number of studies published by tropical coauthors, on average, their indexed studies get published in lower-impact journals (impact factor IF=3.91, 95% confidence interval (CI): 3.72, 4.10 (n=287)) compared to their non-tropical peers (IF=4.58, 95% CI: 4.28, 4.88 (n=6638)). However, it is important

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to note that the lower rates of English proficiency and the apparent "narrow impact" of some tropical studies (based on e.g., desk rejections by Editors), could pressure authors to publish some of their studies in local (mostly non-indexed) journals with low visibility or accessibility to the community contributing to their overall lower IF (e.g., Solarino, 2012; Chavarro et al., 2017). The publications led by women are accepted and published by journals having a similar IF (average IF 4.37, 95% CI: 4.26, 4.47 (n=1140)) as those led by men (average IF=4.62, 95% CI: 4.29, 4.96 (n=4491)). This is a positive finding indicating that papers usually get published in equally ranked journals from our community regardless of gender.

It was found that the inclusion of authors from tropical affiliations in the analyzed cloud physics studies is limited. Just 383 studies out of the 6987 analyzed papers have coauthors with a tropical affiliation. Additionally, a qualitative analysis shows that out of the 6987 analyzed papers, 44 studies were performed in tropical Africa or used data from this geographical region (as stated in the paper title); however, only seven of them (i.e., 16%) included a coauthor with a tropical affiliation. Our results suggest that the so-called helicopter or parachute science (i.e., research practices in which scientists from wealthier countries conduct studies in lower-income countries, often without meaningful collaboration or involvement with local researchers or communities, and then publish the results without authorship acknowledgment or benefit to the locals) is unfortunately common in the cloud physics community; however, a deeper analysis is required to confirm this. It is important to note that our conclusion on parachute science needs to be caveated as the non-English papers were excluded from the present analysis. Therefore, it is possible that a different scenario emerges if the excluded papers are considered. In support of this conclusions, a recent article reported that across 82 natural science journals tracked by The Nature Index, between 2015 and 2022, only 2.7% of the articles published featured collaborations between scientists in higher-income and lower-income countries (Baker et al., 2023). In these articles, for every three authors in the richer countries one author from the lower-income country was featured (Baker et al., 2023). It is desirable that field studies performed in the tropics by research groups from the Global North guarantee the active inclusion and involvement of local research groups (or local scientists/students) to pursue more equitable collaborations. In doing so, local trainees acquire new knowledge and develop new local capacities to strengthen their scientific independence. It is important to note that this gap will be reduced more effectively if these collaborations involve technology transfer, equipment loan/donation, teaching courses to locals, and if the proposals are submitted by both parties.

Table 1. Percentage of cloud physics publications led by different countries in the last 50 years. Each country represents the location of the first author affiliation. Bold text highlights the tropical countries.

First author country	Fraction of publications	First author country	Fraction of publications
USA	43.90	New Zealand	0.10
Germany	8.09	Croatia	0.10
China	7.54	**Indonesia**	**0.07**
UK	6.43	**Thailand**	**0.07**
France	4.59	**Bangladesh**	**0.06**
Canada	3.48	Chile	0.06

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Japan	3.45	Romania	0.06
India	**2.86**	**Hong Kong**	**0.06**
Israel	1.85	**Cuba**	**0.06**
Russia	1.79	**Singapore**	**0.04**
Switzerland	1.60	Egypt	0.04
South Korea	1.43	Turkey	0.04
Australia	1.30	**Vietnam**	**0.04**
Italy	1.20	**Philippines**	**0.04**
Netherlands	1.19	United Arab Emirates	0.03
Sweden	1.13	Saudi Arabia	0.03
Finland	0.77	**Rwanda**	**0.03**
Spain	0.64	**Zimbabwe**	**0.03**
Taiwan	**0.64**	North Macedonia	0.03
Poland	0.57	Estonia	0.03
Brazil	**0.46**	Slovakia	0.03
Greece	0.39	**Puerto Rico**	**0.03**
Norway	0.34	**Malaysia**	**0.03**
Argentina	0.24	**Nigeria**	**0.01**
Hungary	0.23	**Peru**	**0.01**
Austria	0.21	**Cote D'ivoire**	**0.01**
Belgium	0.20	**Niger**	**0.01**
Serbia	0.17	Nepal	0.01
Denmark	0.17	Armenia	0.01
Mexico	**0.17**	Afghanistan	0.01
Iran	0.16	**Cameroon**	**0.01**
Czech Republic	0.14	Algeria	0.01
South Africa	0.13	**Kenya**	**0.01**
Bulgaria	0.11	Cyprus	0.01
Belarus	0.11	**Botswana**	**0.01**
Ireland	0.10	Unknown	0.82
Portugal	0.10		

3.4 Improving future climate projections by increasing data coverage in the Tropics

To better describe the climate and develop future projections, its fundamental to improve field observation coverage globally. Although the social, economic, environmental, pollution, biodiversity, and geographical characteristics of the tropics significantly differ from those in mid- and high-latitudes, the majority of the cloud physics field studies (both continental and maritime), have been performed in the Global North countries (e.g., DeMott et al., 2010; Beswick et al., 2015; Paramonov et al., 2015; Welti et al., 2020; Choudhury and Tesche, 2022). This excludes important information related to aerosols and clouds needed to accurately simulate the climate of our planet. The tropics represent a rich source of biodiversity (Raven et al., 2020) that produce aerosol particles with a range of physicochemical properties (Adams et al., 1983; Raemdonck et al., 1986; Li et al., 2003; Després et al., 2012; Mayol et al., 2017; Ladino et al., 2019), such as biomass and waste burning, incomplete combustion of low-quality fuels, agricultural and industrial emissions, mineral dust emissions (Wentzel et al., 1999; Eck et al., 2003; Beirle et al., 2004; Le Canut et al., 1996; Tian et al., 2015) with implications to impact the climate system on a regional and global scale (Andreae et al., 2009; Yakobi-Hancock et al., 2013). The tropics are also characterized by vast amounts of precipitation and cloud cover, especially at the Intertropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ) (Lohmann et al., 2016; Mülmenstädt et al., 2015). Mesoscale convective systems (MCSs) resulting in vast amounts of precipitation are prevalent in the tropics between December and February (Wang et al., 2019). The aforementioned characteristics place the tropical latitudes as important data spots for field measurements to determine the role that tropical emissions play in the climate system at different scales, aiding improved future climate projections (Baumgardner et al., 2012; Cesana and Storelvmo, 2017; Schneider et al., 2017; Heymsfield et al., 2017; Finney et al., 2018; Burrows et al., 2022). Cloud physics field studies are also very important to obtain in-situ information to validate satellite observations, validate reanalysis calculations, and to develop parameterizations for their inclusion in climate models (e.g., DeMott et al., 2010; Baumgardner et al., 2012; Reutter et al., 2020; Burrows et al., 2022).

The role of tropical scientists as PIs or collaborators is limited as shown in the analysis of the work presented here (see Figure 4). Even though the survey respondents agree that establishing collaborations with Global South scientists is important for the development of the cloud physics field, as stated above 60% of them are not planning for this. We need to incorporate changes and strategies in our community to increase the global coverage of field measurements that would provide the needed information for model validation to improve future climate projections for the whole globe, including the tropics. Achieving this with avoiding parachute science and promoting studies led by tropical scientist is crucial, as is reflected by the low number of tropical co-authorships in Figure 4.

3.5 Tracing Scopus author ID to identify the rate of gender retainment

The Scopus author ID allows counting the scientific contributions of each (co-)author in the metadata database. To investigate how long each author stayed in the cloud physics field, we classified the year they first (co-)authored a publication and the years until their last indexed cloud-physics-focused contribution. The frequency analysis of this data is shown in Fig. 6. It was found that the number of entries into the field has increased in each five-year interval. However, rates of decline (the slopes in Fig. 6), i.e. scientists leaving the field, have increased at the same time. This is in line with the common perception that while scientific fields are growing, secure positions and long-term prospects for staying in academia are not increasing (Afonso, 2014).

Again, it is obvious that women scientists started appearing in the community only after 1985. Initially, they left the field faster than men (1990-1995). However, in recent years, after 1995, we see no difference in years between the genders in how long they remain in the cloud physics field judging by publication activity. Since this analysis did not take academic positions into account, we cannot make a definitive statement on the leaky pipeline (Wolfinger et al.,

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2008). Judging from the publication output alone, we do not find evidence for women leaving the field faster than men. With increasing proportions of women starting in the field, this can act to increase their proportions in the field overall (Jacob and Teichler, 2011; Hirschauer, 2016). However, while the relative number of scientists staying in the field seems to have become equal, the total numbers of scientists entering the field are far from being equal (see Figure 6). The share of women has increased for each age class, but even in the most recent age class, between 2015 and 2020, only about a third of new-coming scientists were women.

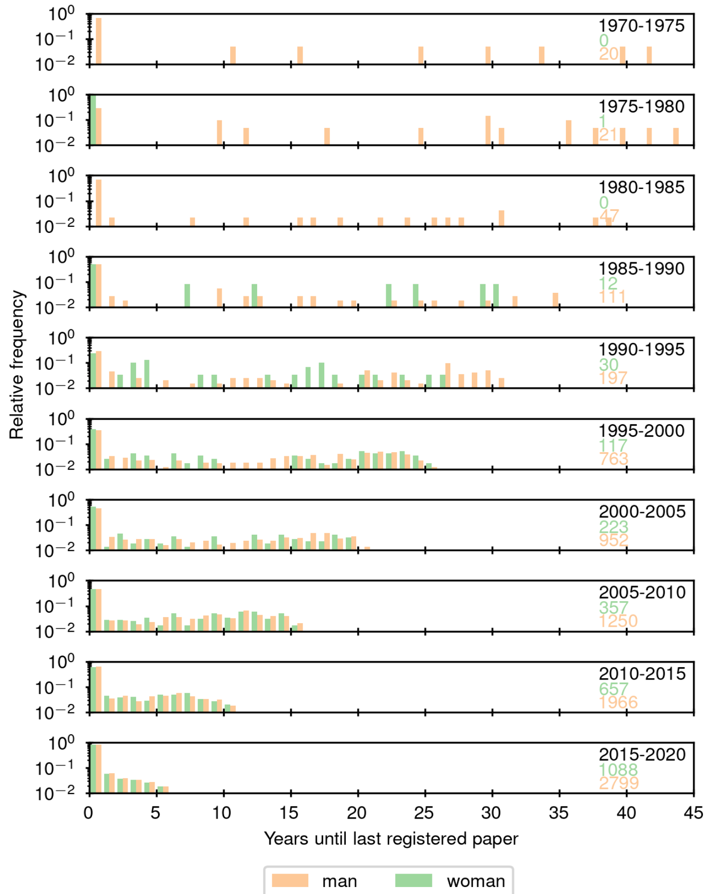

Figure 6: Frequency distribution of the years that specific scientists were co-authoring publications in the metadata analysis database, separated by gender. The rows represent the time period in which any given scientist's first co-authored paper was published. The last paper the scientist co-authored determines the position on the x-axis and is taken to be an indication of when the scientist left the field or academia. The time periods as well as the total numbers of woman (man) authors are given in green (orange) on the right of each plot.

4 Conclusions

To evaluate how diverse, equitable, and inclusive the cloud physics community is, two different approaches were used: a survey, which was distributed in summer 2021 within the community and an extensive metadata analysis of 6987 cloud physics peer-reviewed articles from Scopus, which were published between 1970 and 2020. The survey focused on topics of diversity and inclusion.
The overall conclusion from this study is that the cloud physics community follows other geosciences fields and needs continued efforts on DEI. Although the representation of women in the cloud physics community has increased after ca. 1997, the community is still far from reaching a gender parity. It is remarkable that most of the publications in this field (77%) come from just seven countries, all in the Global North. Additionally, the lead authors on papers are mostly White men with a clear lack of gender diversity and Global South collaborators. The observed gender inequality highlights the fact that although programs, policies, and inclusive environments are developed to promote gender equity, there are still gaps that require attention.

While the majority of the cloud physics community feel included, a considerable number, particularly those who are young (< 40 years old), women, or LGBTQIA+, do not feel fully included in the community. The survey data also indicates that there are concerns with harassment and hostility of scientists within the cloud physics community, with a larger proportion of older women scientists reporting such issues. Tropical co-author participation is also limited compared to those from the Global North. The absence of leadership and engagement from tropical academics is an illustration of the cloud physics community's geographically biased worldwide collaboration network.

Despite the observed lack of diversity and equity in the cloud physics community, it was found that men and women authors publish their indexed articles in journals with comparable IF. However, the articles from tropical authors typically get published in indexed journals with lower IF, and in some cases, their articles inevitably end up being published in local non-indexed and non-English journals due to language barriers which we believe is compounded by lack of funding for research (including the additional services for language editorial services).

Is the lack of diversity a problem of gate keeping, or minorities being unable to sustain career paths in the field? The present results suggest that on the one hand, women report more frequent concerns with harassment and hostility which supports the notion of minorities are unable to sustain career paths in the field. Nevertheless, the metadata paints a different picture: the difference between the academically active years of men and women has decreased in the past 50 years, meaning that women are increasingly retained in the cloud physics community. At least this can be concluded by the absence of a notable difference between the frequency of first and last year of publication between the genders. However, the prevalence of women entering the publishing process in the cloud physics field remains far from equitable.

Increasing inclusion and diversity is essential to promote fairness and equal chances for all authors. Furthermore, expanding data coverage in the tropics is critical for a better understanding of the Earth's climate. As a result, the scientific community must collaborate to address these gaps and encourage fair collaboration and opportunities for all scientists in order to increase the quality of scientific research. Finally, fostering a more inclusive and welcoming environment within the cloud physics community will benefit not only individuals who are currently underrepresented

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or marginalized, but it will also help to foster a more productive and collaborative research culture that can better address the complex challenges facing the field. Lastly, the following recommendations could provide a guideline on how to achieve a more diverse, equitable, and inclusive community:

- Provide institutional resources for diversity and inclusion training that align with the ethical responsibilities to be adhered to at all levels, from undergraduate students to senior professors. This should extend beyond just recruiting but be available to facilitate the careers after recruiting.
- Promote, facilitate, and secure the participation of graduate students and early careers scientists from the Global South in the most important cloud physics academic events that take place annually, especially those organized by the ICCP (i.e., workshops, conferences, etc.)
- Persons in reviewer roles for conferences, funding applications, and peer-reviewed articles should receive training on how to avoid unconscious bias in treating submissions from women, minorities or scientists from the Global South fairly, solely focusing on the science.
- Seek a gender balance and pursue individuals from minority and underrepresented groups for faculty positions, editorial boards, scientific committees, awards, and review panels.
- Foster a culture of inclusivity in which scientists of all backgrounds experience a sense of belonging (instead of bullying or harassment). This can be achieved by promoting respect for diverse opinions and increasing the visibility and retention rate of diverse opinions and ideas.
- Journals should implement policies to avoid the practice of parachute or helicopter science and promote fair collaborations where support for colleagues from the Global South prevails.
- Increase the number of submitting proposals led by Global South scientists in collaboration with Global North research groups. Building partnerships and collaborations across institutions and regions can help break down silos in science and promote diversity of thought.
- Funding agencies should prioritize projects conceived and led by researchers in the Global South and must provide partnership, mentorship and supervision programs that encourage underrepresented groups in science, which aim to build resources in economically disadvantaged countries.
- Foster a sense of community which can be a powerful motivator for collaboration and engagement, which can be achieved through events and activities that bring different scientists together, such as workshops, seminars or social events.
- Support and promote DEI initiatives such as the Latin America Early Career Earth System Scientist Network (LAECESS, Yáñez-Serrano et al 2022).

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Ethical Statement

This research has been approved by the Texas Tech University Institutional Review Boards (IRB) named IRB2021-472: Diversity, Equity, and Inclusion in the Cloud Physics Community. The survey was conducted anonymously and did not contain any direct identification (i.e., name or place of employment of the participants).

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Data Availability Statement

The survey questionnaire and the algorithm used to collect data and analyze the articles can be found in the supplementary information file. The code for analysis of the metadata can be found at https://doi.org/10.3929/ethz-b-000654489. The data used to produce the figures in this paper has been uploaded at https://polybox.ethz.ch/index.php/s/tAPD5mkAKZeRDDP (private link for review) and upon acceptance of the paper will be uploaded to the ETH repository with a persistent DOI in the form: https://doi.org/10.3929/ethz-b-XXXXXXXXX.

Author Contributions

All authors contributed to writing and reviewing the manuscript. The figures were prepared by ZAK, KAD, LAL, DLP and UP. The survey was prepared by all authors and survey data was analyzed by KAD, ZAK and AV. The metadata search and analysis was conducted by LAL, UP, ZRD, and DLP. All authors discussed and interpreted the results in the manuscript.

Conflict of Interest

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The authors declare that they do not have any conflict of interest. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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