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African contributions are missing from cryosphere research in Africa and worldwide

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Introduction

The cryosphere—Earth's collection of frozen water—is integral to global climate processes and is in precipitous, accelerating decline due to anthropogenic warming (Hugonnet et al., 2021). The most obvious evidence of cryosphere decline is visible on every continent: ice sheets and mountain glaciers are receding, and in some instances, disappearing entirely. Given strong links between the cryosphere and earth system processes, particularly feedback to climate and ocean circulation, robust cryosphere science is necessary for accurate predictions of how anthropogenic change will propagate worldwide. Yet, despite the global repercussions of cryosphere decline, cryosphere science is not evenly distributed worldwide with entire continents (e.g., Africa) dramatically underrepresented. Limited cryosphere-focused infrastructure (i.e., research and education) raises two practical issues: (1) limited capacity for collection of important, time-sensitive monitoring information for tracking change and associated impacts, and (2) a lack of in-country (or in-region) expertise to inform decisions and represent interests on broader scales (e.g., international meetings), ensuring those countries affected by cryosphere changes are heard.

Perhaps nowhere is the lack of cryosphere science (cryoscience) more apparent than Africa, Earth's second largest continent. Africa is home to ~1.4 billion people (World Bank, 2023) and heavily burdened by climate change (Overland et al., 2021). Like the geosciences writ large (North et al., 2020), as well as plant genomics (Marks et al., 2021), scientists based at African institutions are underrepresented in cryoscience (Overland et al., 2021). Due to limited cryosphere areas in Africa and distance to polar regions, this may not be surprising. However, the interconnectedness of global systems requires African participation. Furthermore, Africa hosts some of the world's smallest, highest glaciers, some of which have been intensely studied (Mölg et al., 2003; Thompson et al., 2002; Prinz et al., 2011). These already small glaciers are at great risk of completely disappearing. Since the beginning of the 21st century, African glaciers have lost more than 50% of their area (Hinzmann et al., 2024). Thus, a pressing need exists to understand how glacier loss within and beyond Africa will impact African infrastructure, tourism, ecosystems, and biodiversity (Uetake et al., 2014; Zawierucha and Shain, 2019). However, loss of African glaciers will not stop the local need for cryosphere science in the region. For

instance, subterranean ice features—e.g., rock glaciers and permafrost—are globally common, buffered against atmospheric conditions by debris cover, contain significant water stores (Jones et al., 2018), and have received little to no attention on the African continent.

Here, we quantify African academic representation in cryoscience in two ways: membership in early career researcher (ECR) networks and the proportion of authors at African institutions on studies relating to the African cryosphere. ECRs are defined differently by institutions and associations, however, they are generally defined as researchers within 8 years of their PhD (Moreno-Ibáñez et al., 2024). Two organizations—the Association of Polar Early Career Scientists (APECS) and the Permafrost Young Researchers Network (PYRN)—serve as capacity-building organizations, connecting ECRs involved in cryosphere research in polar and alpine regions worldwide. In this way, these organizations represent the cryosphere scientists of the future. Aside from limited representation in APECS among South African and Nigerian scientists, there is virtually no representation in either organization among populous African nations (Figure 1a). In the context of global membership, African representation is exceptionally low—just 1% for APECS and 0.6% for PYRN (Figure 1a). Notably, of the African countries with high mountains and existing glaciers (Knight, 2023) (e.g., Uganda, Kenya), there is only one member in either organization (Figure 1a). African representation in other cryosphere-related organizations not focused on early career researchers is also lacking. There are currently no African national correspondents to the Global Terrestrial Network on Permafrost, and the International Glaciological Society has no members from Africa. Finally, only 0.7% of members of the International Association of Cryospheric Sciences are from Africa.

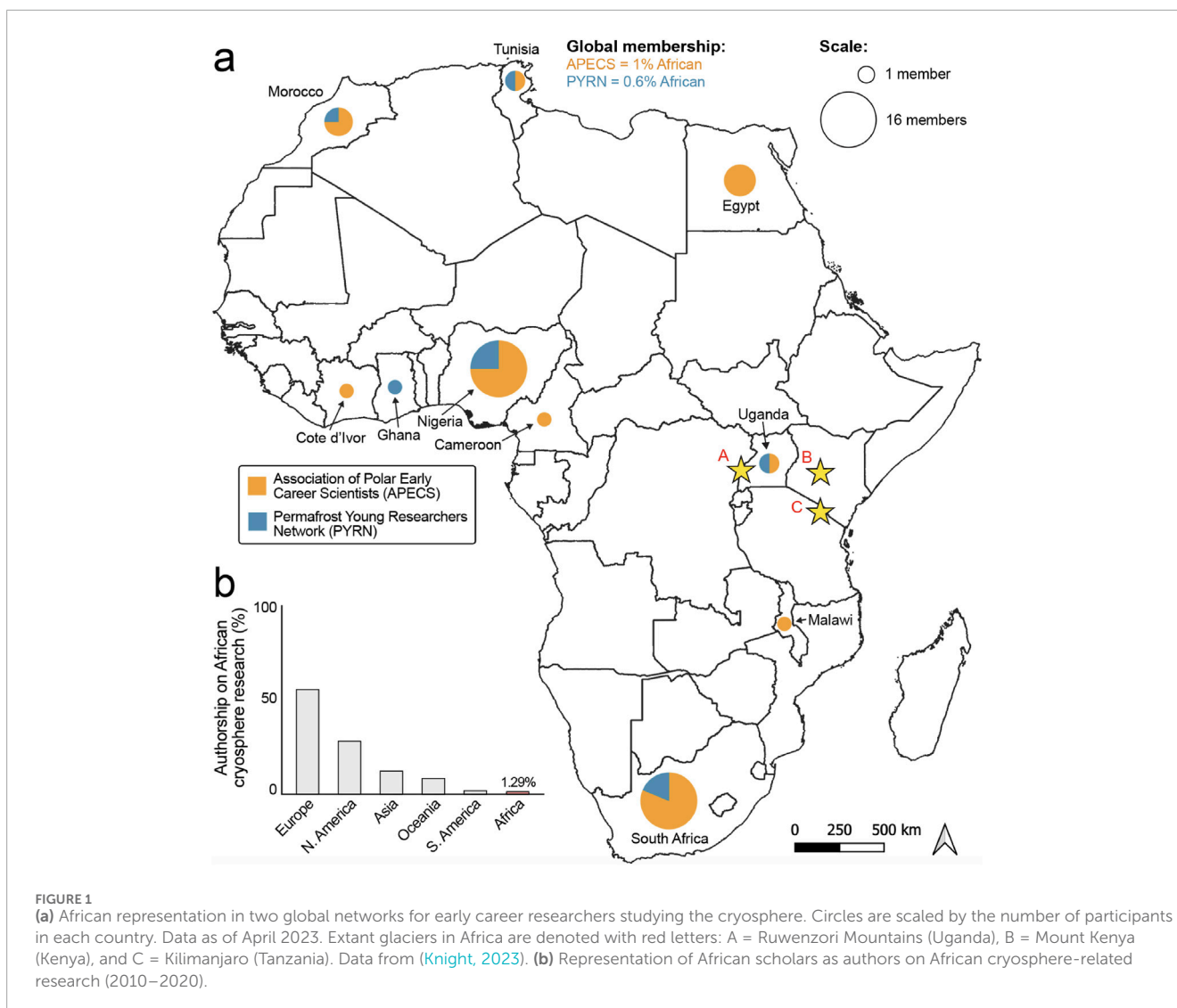
To assess contemporary African representation in African-focused cryoscience, we performed a Web of Science search for articles published from 2010 to 2020 containing relevant search terms in the titles (e.g., cryosphere, glacier, snowfield). We restricted the output to only those articles related to Africa (or including Africa within a broader focus, e.g., tropical glaciers), identifying 28 articles. Next, we binned authors on each study into the continent they represented based on their institutional affiliation (if an author had two affiliations, e.g., one in North America and one in Africa, we scored them as 0.5 for each continent). Of 116 authors, only 1.5 (1.3%) had an African affiliation (Figure 1b) and the majority of scientists studying the African cryosphere are based at either a European or North American institution (52.2% and 25.9%, respectively; Figure 1b). In terms of individuals, the attribution of credit for publications does not account for authors' continents of origin. For example, the lead author of this Comment—a native of Ghana—is presently affiliated with a North American institution and thus would not count as an African author in our analysis. So, while there may be more African authors than our results indicate, our findings still reveal a stark paucity of contributions from African institutions, reflecting a 'brain drain' of African skills and knowledge (Moreno-Ibáñez et al., 2024).

We also considered the cryoscience infrastructure within African countries. Here, it is truly a tale of two Africas: South Africa and the rest of the African continent. South Africa is an original signatory of the 1959 Antarctic Treaty System (ATS, 1959). South

Africa is also the only African member of the Scientific Committee on Antarctic Research (SCAR) and the only African country with an Antarctic program (SANAP), polar research vessels (SA Agulhas I and II), and dedicated polar research funding. To some degree, development of South Africa's polar research infrastructure is due to a geographic advantage, given its southern location and the potential for ships to depart from its harbors for Antarctic waters. However, to that end, Kenya and other African nations with glaciers and seasonal snow have an even greater geographic advantage, yet these resources are receiving little study from African scientists. While anecdotal, our author group's interactions with local scientists suggest that this lack of study is likely not due to a lack of interest. South Africa also has more robust infrastructure and thus many advantages for cryosphere research. But South Africa, like other African countries, still lags non-African nations in multiple respects. Notably among these is education, particularly at the undergraduate level where students often gain their first exposure to cryosphere-related topics (e.g., glaciology). Cryospheric topics are included in some South African courses, these are part of broader physical geography or geomorphology offerings. And, while a larger focus on climate change and climate change adaptation is growing on the continent (e.g., African Climate and Development Initiative), to our knowledge, no university course dedicated to glaciers or ice caps is presently offered at any African institution.

Little progress has been made to improve African scientists' participation in climate research and earth systems science (Anson et al., 2017; Dike et al., 2018). From 1990 to 2020, 78% of African climate change studies research funds were granted to non-African institutions (Overland et al., 2021). While the studies did not directly focus on cryoscience, changes to the cryosphere are impacted by climate change. To realize a future that includes African scientists and policymakers in broader efforts to curb climate change and mitigate impacts, specifically those related to cryosphere change, the time is now. At present, four African nations still have mountain glaciers—Kenya, Tanzania, Uganda, and the Democratic Republic of the Congo—but these ice features are in rapid decline (Zawierucha and Shain, 2019). Establishing infrastructure and expertise for monitoring the African cryosphere by Africans and incorporating the data and scientists performing the research into international collaborations, including funding, is crucial. This bridge also represents a great opportunity for improving cryoscience on the continent. To do this, training and mentoring at multiple levels (e.g., elementary through graduate school) will be required, and the international cryosphere science community should rise to this occasion. Encouraging African ECR memberships for APECS and PYRN will provide cryoscience-related networking and learning opportunities for African young scientists, providing a platform for these young scientists to become the next potential policymakers and African representatives in cryoscience on the global scale (Dike et al., 2018). Ultimately, the best mechanism for inspiring cryoscience participation in Africa is likely through first-hand experiences on the continent's fascinating glaciers while such an opportunity is still possible.

As the country with the only cryosphere research program, South Africa represents a vital conduit for supporting this effort. Indeed, a different approach to polar research (Lavery, 2019) and



a broadening of South Africa's cryoscience to include mountain glaciers and permafrost, and researchers adjacent to them, would be valuable as it would provide in-continent opportunities for education and training for other African cryoscientists. Thus, value likely exists in concentrating cryoscience resources (e.g., new faculty), at least initially, in South Africa to broaden cryoscience representation for the continent. A potential vehicle for this is the Polar Lab of the South African Polar Research Infrastructure (SAPRI), which will democratize African access to polar science by enabling African scientists access to polar research without the logistical and financial barriers of Polar expeditions. Collectively, the intentional development of African cryoscience would be integrated with similar calls to bolster climate change literacy continent-wide (Simpson et al., 2021).

However, training and infrastructure development can only go so far without support from African governments, particularly those in countries with mountain glaciers and snowpack. Our author group is aware, in some cases with first-hand knowledge, of situations where projects that would have been boons for African cryosphere research were impeded or derailed by poor

communication and/or overly burdensome and expensive permits. Ideally, a brighter future for African cryoscience will include training and education of government officials about the need for and minimal risk of cryosphere research (e.g., the negligible mass balance impact of ice core extraction).

Beyond infrastructure and logistics, the broader cryosphere community can bolster African cryoscience through meaningful, equitable collaboration. With only 1.3% of research papers that included the African cryosphere also containing an author from an African institution and less than 1% African membership in the various cryosphere-focused ECR organizations (Figure 1), there is considerable room for improvement. However, this "solution" should not end with representation on scientific papers. We need more African cryoscientists to ensure more active participation at all levels, from research to policy, to improve the resilience of Africa to climate-change-induced impacts that are cryosphere-related, like sea level change and snowpack decline. Non-African scientists should thus actively seek opportunities for training and developing the expertise of African cryoscientists with the long-term vision of in-continent researchers leading cryosphere research on

the continent, and greater representation of African cryoscientists as policymakers on the international stage. In terms of timing for these efforts, there may be no time like the present given the international focus on the cryosphere that is stemming from the UNESCO's ongoing initiative for the Decade of Action for Cryospheric Sciences (2025–2034).

Author contributions

CA: Resources, Conceptualization, Investigation, Writing – review and editing. CH: Formal Analysis, Writing – review and editing, Investigation, Resources, Visualization, Data curation. DH: Writing – review and editing, Investigation, Resources, Conceptualization. SH: Data curation, Conceptualization, Methodology, Writing – review and editing, Investigation, Formal Analysis, Writing – original draft, Project administration.

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