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University of Oxford, United Kingdom

*CORRESPONDENCE
Leandro B. Díaz
✉ ldiaz@cima.fcen.uba.ar

†These authors share first authorship

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Connecting climate science and society: reflections from early and mid-career researchers at the World Climate Research Programme Open Science Conference 2023

Leandro B. Díaz[1,2,3*†], Carla Gulizia[1,2,3†], Shipra Jain[4,5†], Gaby S. Langendijk[6†], Hindumathi Palanisamy[7†], Valentina Rabanal[8,9†], Candice S. Charlton[10†], Alima Dajuma[11], Felix K. Donkor[12†], Temitope S. Egbebiyi[13,14†], Ghafi Kondi Akara[15,16†], Amna Jrrar[17†], Md Rezwan Siddiqui[18†], Yassine Ait Brahim[19,20], Bapentire D. Angnuureng[21], Anna-Adriana Anschütz[22], Founi M. Awo[23,24], Alejandro Builes-Jaramillo[25], Alison Cobb[26], Mohamadou A. Diallo[27,28], Houda Er-Retby[29,30,31], Thierry C. Fotso-Nguemo[32], Benjamin Gwinneth[33], Masilin Gudoshava[34], Franck E. Kemgang Ghomsi[23,35,36], Inés M. Leyba[1,37], Redouane Lguensat[38,39], Roché Mahon[40], Shailendra K. Mandal[41], Lucia Mumo[42], Meshel Muzuva[43,44], Rodric M. Nonki[45], Juan A. Rivera[3,46], Alcade C. Segnon[47,48], Laouali I. Tanimoune[49], Erlich-Honest E. I. Zauisomue[50] and Gilbert Siame[51]

[1]Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Ciencias de la Atmósfera y los Océanos (DCAO), Buenos Aires, Argentina, [2]Universidad de Buenos Aires. Centro de Investigaciones del Mar y la Atmósfera (CIMA), Buenos Aires, Argentina, [3]Instituto Franco-Argentino de Estudios sobre el Clima y sus Impactos (IFAECI)–IRL 3351–CNRS-CONICET-IRD-UBA, Buenos Aires, Argentina, [4]Department of Risk and Disaster Reduction, University College London, London, United Kingdom, [5]Centre for Climate Research Singapore, National Environment Agency, Singapore, Singapore, [6]Climate Adaptation and Disaster Risk Management Department, Deltares, Delft, Netherlands, [7]World Climate Research Programme, Science and Innovation Department, World Meteorological Organization, Geneva, Switzerland, [8]Servicio Meteorológico Nacional (SMN Argentina), Buenos Aires, Argentina, [9]Young Earth System Scientists (YESS) Community, Buenos Aires, Argentina, [10]Department of Physics, The University of the West Indies Mona, Kingston, Jamaica, [11]Université Peleforo Gon Coulibaly Département de Mathématiques-Physique-Chimie, Korhogo, Côte d'Ivoire, [12]University of Education-Winneba, Winneba, Ghana, [13]Climate System Analysis Group (CSAG), Department of Environmental and Geographical Science, University of Cape Town, Cape Town, South Africa, [14]African Climate and Development Initiative (ACDI), Department of Environmental and Geographical Science, University of Cape Town, Cape Town, South Africa, [15]African Institute for Mathematical Sciences Research and Innovation Centre (AIMS RIC), Kigali, Rwanda, [16]African Institute for Mathematical Sciences (AIMS), Kigali, Rwanda, [17]El Hassan Research Chair for Sustainability, Royal Scientific Society, Amman, Jordan, [18]Department of Social Relations, East West University, Dhaka, Bangladesh, [19]International Water Research Institute University Mohammed VI Polytechnic, Benguerir, Morocco, [20]Bishop's University, Sherbrooke, QC, Canada, [21]ACECoR, Centre for Coastal Management, University of Cape Coast, Cape Coast, Ghana, [22]Physical Oceanography and Instrumentation, Leibniz Institute for Baltic Sea Research, Warnemünde, Germany, [23]Nansen-Tutu Centre for Marine Environmental Research, Department of Oceanography, University of Cape Town, Cape Town, South Africa, [24]ICMPA-UNESCO Chair/UAC, Cotonou, Benin, [25]Facultad de Arquitectura e Ingeniería, Institución Universitaria Colegio Mayor de Antioquia, Medellín, Colombia, [26]ECMWF, Reading, United Kingdom, [27]Institute of Energy and Climate Research,

Stratosphere (IEK–7), Forschungszentrum Jülich, Jülich, Germany, [28]Center for Advanced Simulation and Analytics (CASA), Forschungszentrum Jülich, Jülich, Germany, [29]Geology and Sustainable Mining Institute (GSMI), Mohammed VI Polytechnic University (UM6P), Ben Guerir, Morocco, [30]Univ Lyon, ENTPE, Ecole Centrale de Lyon, CNRS, LTDS, UMR, Vaulx-en-Velin Cedex, France, [31]Green Energy Park (UM6P and IRESEN), Benguerir, Morocco, [32]Climate Change Research Laboratory (CCRL), National Institute of Cartography, Yaounde, Cameroon, [33]Département de Géographie, Université de Montréal, Montréal, Montreal, QC, Canada, [34]IGAD Climate Prediction and Applications Centre, Nairobi, Kenya, [35]National Institute of Cartography, Yaoundé, Cameroon, [36]Centre for Earth Observation Science, University of Manitoba, Winnipeg, MB, Canada, [37]College of Earth Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR, United States, [38]Institut Pierre-Simon Laplace, Paris, France, [39]Institut de Recherche pour le Développement, Marseille, France, [40]Caribbean Institute for Meteorology and Hydrology Husbands, St. James, Barbados, [41]Department of Architecture and Planning, National Institute of Technology Patna, Patna, India, [42]Research Center for Climate Sciences (RCCS), Pusan National University, Busan, Republic of Korea, [43]MANCOSA (Honoris Universities), Durban, South Africa, [44]Durban University of Technology, Durban, South Africa, [45]Laboratory for Environmental Modeling and Atmospheric Physics (LEMAP), University of Yaounde 1, Yaounde, Cameroon, [46]Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), Centro Científico Tecnológico CONICET Mendoza, Mendoza, Argentina, [47]International Center for Tropical Agriculture (CIAT), Dakar, Senegal, [48]Faculty of Agronomic Sciences, University of Abomey-Calavi, Cotonou, Benin, [49]WASCAL (West African Science Service Centre on Climate Change and Adapted Land Use), Accra, Ghana, [50]Environmental Science, University of Namibia, Windhoek, Namibia, [51]Department of Geography and Environmental Studies, School of Natural Sciences, The University of Zambia, Lusaka, Zambia

This paper reflects the discussions of early and mid-career researchers (EMCRs) during the World Climate Research Programme Open Science Conference 2023 EMCRs Symposium, to advance climate knowledge for greater transformative power in society and impact on policy-making. These discussions focused on three key priority challenges: how to produce robust, usable, and used climate information at the local scale; how to address key climate research and knowledge gaps in the Global South; and how EMCRs could support policy-making with climate information. We present here our perspective on these major challenges, possible ways to address them, and what could be the contribution of EMCRs. In addition, we provide recommendations for actions that could be taken at the international and national levels to increase the voice and leadership of Global South researchers and EMCRs in international scientific endeavors. These recommendations might facilitate the integration of new technological tools or innovative approaches, promote interdisciplinary collaboration, and foster connections with local communities. This coordinated approach to international, regional and local initiatives will catalyze the process for urgent action on the environmental crisis before us.

KEYWORDS

global south, kilometer-scale modeling, co-production of climate services, machine learning, diversity, equity, early and mid-career researchers, global sustainability

1 Introduction

In February 2024, more than 700 climate scientists issued the Kigali Declaration, a collective call for climate action (World Climate Research Programme (WCRP), 2024). This declaration was a result of the intensive discussions on how to advance climate science for a sustainable future for all during the 2023 World Climate Research Programme (WCRP) Open Science Conference (OSC; in Kigali, Rwanda) where early and mid-career researchers (EMCRs)[1] played a very active role. The Kigali Declaration, which was open to contributions from EMCRs, called on the climate science community to accelerate and amplify the relevance, impact, and benefit of climate research for society, enabling transformative actions (World Climate Research Programme (WCRP), 2024). One key commitment is to ensure equal visibility, voice, and access for EMCRs in WCRP's work, leadership, and global influence. Although the importance of ECRs' visibility, voice, and access to WCRP initiatives has been increasingly recognised in recent years, MCRs often find themselves in precarious career conditions. Thus, many MCRs still face a unique set of professional challenges, such as not fitting into either the junior or senior researcher categories, and often finding themselves between research opportunities or constantly working on grant proposals. Given these challenges, WCRP community members emphasized the need to involve MCRs in the early stages of OSC preparations.

Although there is still a long way to go, the voice of EMCRs has been gaining momentum in the last decade in the discourse on the future of climate science (Rauser et al., 2017; Dike et al.,

1 For WCRP OSC 2023, Early career researchers (ECRs) are master and PhD students, researchers, and practitioners within 7 years of highest obtained degree (excluding parental and care leave). Practitioners are those working at the interface of society, policy, practice, and research. Mid-career researchers (MCRs) are researchers and practitioners between 8 and 15 years of highest obtained degree (excluding parental and care leave).

2018; Langendijk et al., 2019; Gulizia et al., 2020). It has been argued that EMCRs can play a pivotal role in bridging generational differences and developing novel solutions to complex problems concerning sustainability issues (Lim et al., 2017). On the other hand, the collaboration of EMCRs in global sustainability initiatives can help to address what has been called a double intergenerational conundrum: despite inheritance of the current and potential future consequences as professionals as well as human-beings, the EMCRs have relatively little influence on current strategic decisions (Jørgensen et al., 2019). In that way, the growth in global EMCR networks in the last 15 years has played an important role in articulating the voice of EMCRs and having a greater interaction and presence in international climate and environmental research programmes such as WCRP or Future Earth (Jørgensen et al., 2019). There has been a strengthening engagement of EMCRs in the WCRP community since 2015. For instance, the Young Earth System Scientists (YESS) community was officially endorsed in 2017 by WCRP. Other EMCR communities involved in WCRP are the Young Hydrologic Society (YHS), the Association of Polar Early Career Scientists (APECS), and the PAGES Early-Career Network (ECN). In recent years, WCRP Core Projects (CPs) and Lighthouse Activities (LHAs) have actively appointed ECRs in their panels and working groups. WCRP CPs such as Climate and Ocean Variability, Predictability and Change (CLIVAR), Atmospheric Processes and their Role in Climate (APARC) or Earth System Modelling and Observations (ESMO), as well as WCRP LHA My Climate Risk and WCRP Coupled Model Intercomparison Project (CMIP) now have dedicated working groups to ensure and promote EMCR engagement within their communities.

To ensure that EMCRs have greater visibility, voice and access to the work, leadership and global influence of the WCRP, the WCRP organized a 2-day symposium in conjunction with the OSC. The symposium, hosted by the African Institute for Mathematical Sciences (AIMS), was organized with the support of EMCRs and included the participation of around 80 EMCRs from over 50 countries, balancing geography, gender, expertise, and career-stages (Figure 1). One of the goals of this symposium was to enable EMCRs to identify priorities for advancing climate science for a sustainable future. The WCRP OSC 2023 EMCRs symposium discussions focused on three key topics:

- What are the key challenges for creating robust, usable, and used climate information at local scales from a climate science perspective?
- What are key climate research and knowledge gaps in the Global South, and how can we advance climate science in and for the Global South?
- How can we (EMCRs) contribute to supporting policy-making with climate science and knowledge, during the upcoming decade, also called the "decade of decisions"?

FIGURE 1
Group photo from the World Climate Research Programme Open Science Conference 2023 early and mid-career researcher symposium held in Kigali, Rwanda in October 2023.

These three topics were chosen because of their relevance to the advancement of climate science and to the creation of more effective climate information for decision making. In addition, EMCRs could play a relevant role in addressing them by proposing innovative ideas with a better connection to other disciplines and societal sectors.

The perspective presented here is a result of the reflections carried out during the Symposium. Participants of the event were divided into 3 groups that worked separately to answer each of the three key topics previously presented, first from their own experience, and then feeding on the presentations and experiences throughout the entire week of the OSC. The following is a summary of the main outcomes that emerged from the discussions held during the EMCRs Symposium and subsequently by its participants. Although the discussion topics have been addressed separately before, in this work we address them together, reviewing recent advances and proposing ways forward in which EMCRs can play a protagonist role.

The manuscript is organized as follows. Section 2 describes the whole process that led to the EMCRs reflections presented here and the composition of the co-authors. Section 3 presents the three priority challenges discussed by the symposium participants which are summarized in Figure 2. On the other hand, Section 4 provides recommendations on how EMCRs and researchers from the Global South could be better involved in international efforts related to climate science. Finally, Section 5 summarizes the main conclusions.

2 Methodology

The reflections presented in this article were developed through a series of discussions and activities, which can be grouped into three phases: (i) pre-OSC activities, (ii) OSC activities, and (iii) post-OSC activities.

2.1 Pre-OSC activities

The WCRP OSC Scientific Committee agreed that a strong EMCR component would be desirable during the WCRP OSC, particularly to reflect on the future of WCRP activities and climate science. With this aim, an EMCRs Symposium Scientific Organising Committee (SOC) was appointed almost 1 year before the conference. The SOC was primarily composed of EMCRs who had experience of organising other similar EMCRs events and are also familiar with the WCRP vision and mission. The EMCRs who were part of the SOC, in conjunction with representatives from the WCRP Secretariat and members of the OSC Scientific Committee, outlined the three key topics intersecting the three OSC themes (i.e., Advances in Climate Research, Human Climate Interactions, Co-Produced Climate Services and Solutions), that were presented above.

Simultaneously an initiative was taken to bring a large cohort of EMCRs, about ~80 from 50 countries, to the EMCRs symposium. The

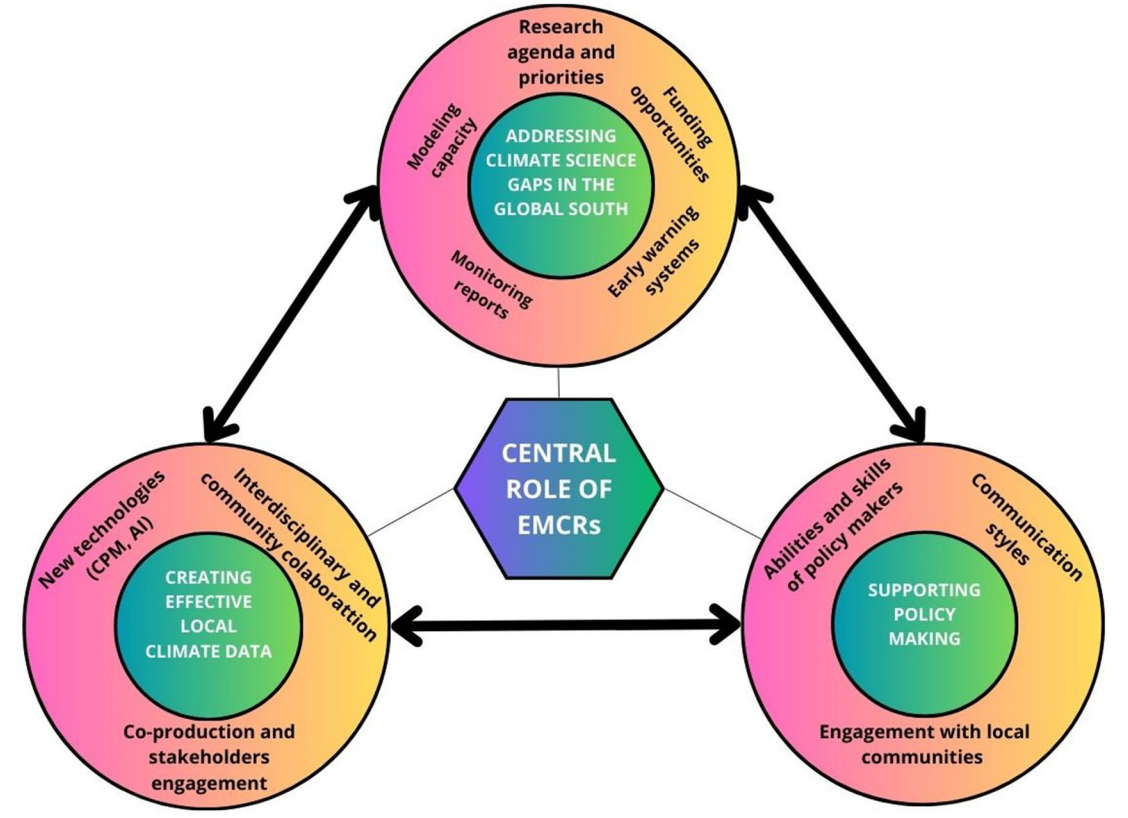

FIGURE 2
Overview of the three key priorities where EMCRs would like to be more involved and recognized as a key actor.

participants for the symposium were selected through an open call by the WCRP, balancing geography, gender, expertise and career stages. Based on their interests, the symposium participants were organized in three groups, each group tackling one of the three topics presented above. The questions of these topics were shared with the participating EMCRs before the conference. Guided by designated moderators from the EMCR Symposium SOC, participants were asked to write and share their thoughts on the topic before the in-person Symposium.

2.2 OSC activities

The 2-day EMCRs symposium took place 1 day before and after the OSC. In the pre-OSC day, symposium participants participated in breakout sessions to discuss the question in-depth of their interest. After these sessions, some designated members of each group shared the main outcomes of their discussion. The activities of the EMCRs Symposium continued during the OSC week, when Symposium participants were invited to share their perspectives each day, nurtured by the OSC sessions. Discussions centred on several key issues shaping the future of the WCRP. First, they explored the key scientific challenges and knowledge gaps that the WCRP must address in the coming decade to enhance its societal impact, with a focus on identifying areas where new research could lead to actionable solutions. Priority areas requiring significant scientific advances were also explored. In addition, key scientific controversies were analysed to promote dialogue on contentious issues that could benefit from greater consensus or innovative approaches. Finally, the role of EMCRs was discussed, highlighting their potential contributions in advancing these challenges and priority areas through fresh perspectives, interdisciplinary collaboration and technological innovation. The outcome of these discussions was shared on the final day of the OSC plenary session and also contributed to the Kigali Declaration. Finally, the post-OSC symposium day included small group discussions on the outcomes of the WCRP OSC and the role of EMCRs in the WCRP. These discursive sessions laid the foundation for this paper, as the key messages were agreed upon through a thorough process of summarizing debates, discussions and written documentation.

2.3 Post-OSC activities

After the OSC, Symposium participants were invited to express their interest in contributing as co-authors to this concept paper. Following this, a group of 37 participants committed to collaboration and began holding regular virtual meetings to advance with the manuscript. Some participants volunteered to co-lead different sections of the text, which included reflections on the three prioritized questions as well as strategies to enhance engagement from the Global South and EMCRs in international research endeavors. This collaborative process began with initial discussions to outline the content of each section, consolidating the main ideas that emerged during the symposium. These ideas were juxtaposed with state-of-the-art literature and supplemented with new insights. The writing process involved multiple rounds of revisions, allowing all co-authors to provide suggestions. The main structure and writing guidelines were discussed in plenary meetings. Authors with shared first authorship took primary responsibility for integrating inputs from the group, ensuring consistency in style and avoiding redundancies throughout the manuscript.

The 37 participants who co-authored this manuscript represent a diverse group in terms of geographical distribution, age, gender, career stage, and research expertise, ranging from biogeochemistry to climate modeling (Figure 3, Supplementary Information A2). A notable proportion of co-authors are from the Global South, with a strong representation from Africa, spanning the entire continent, and South America, where Argentina contributes the majority. However, there is comparatively lower representation from Asia and Europe, and no representation from Oceania or North America. When considering institutional affiliations rather than nationalities, the Global North is better represented, and the number of African countries decreases. African representation becomes more concentrated in countries with more developed scientific systems, such as South Africa. This distribution reflects, in part, the migration of many EMCRs from countries with limited resources for science to those with greater scientific infrastructure.

The group spans an age range of 23 to 52, with most participants between 30 and 40 years old and a median age of approximately 35 (Figure 3). Gender distribution is nearly balanced, with a slight male predominance (54% male, 46% female). ECRs make up the majority 73%, while 27% are mid-career researchers MCRs, with most co-authors already holding a PhD. The research focus of the group centers on climate change and variability, climate services, and climate modeling. Their expertise spans a wide range of disciplines, including hydroclimatology, biogeochemistry, geomorphology, oceanography, and meteorology.

3 Priority challenges for advancing climate science for a sustainable future

3.1 Creating robust, usable, and used climate information at the local scale

It is now widely recognized that local scale information is needed for sustainable development and therefore should be prioritized. Climate information could be defined as the data and knowledge obtained from investigation, which is used to describe past climates, monitor current climate conditions, and predict future states of different climate system components. The most common sources of climate information are observations, reanalyses, and model simulations. Climate information enlightens decisions worldwide about adaptation action, climate policy, climate mitigation action, and societal development. Nevertheless, a pivotal challenge remains to develop robust climate information at local scales that is useful and used by decision-makers for action on the ground. We present here three key research and practice priorities that could be addressed by the climate science community to advance this challenge: (1) the use of kilometer-scale modeling, (2) the incorporation of artificial intelligence approaches, and (3) the co-production of climate information, through participatory approaches.

3.1.1 Use of kilometer-scale modeling

As a first step, the generation of robust and usable climate information at local scales could be enhanced through the

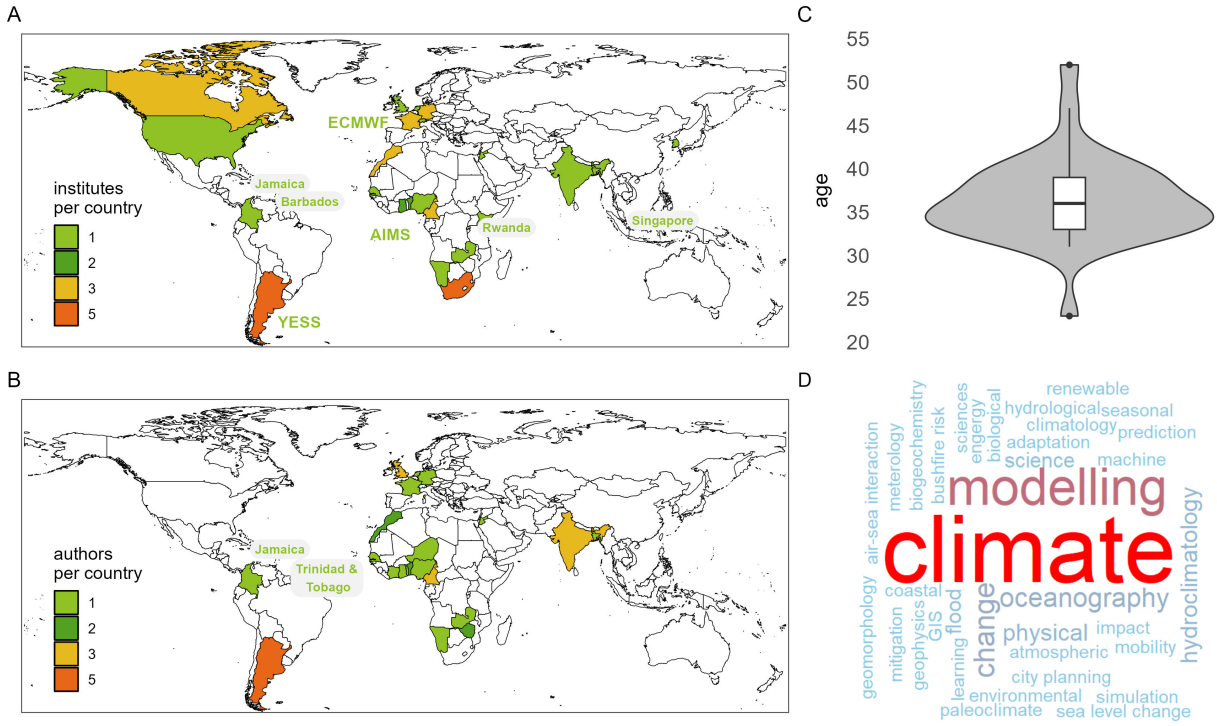

FIGURE 3
(A) Geographical distribution of co-authors' affiliated institutions. The names of international organisations (AIMS, ECMWF, YESS) are shown separately from the countries on the map. **(B)** Geographical distribution of co-authors' nationalities. **(C)** Violin plot illustrating the distribution of co-authors' age. **(D)** Word cloud representing co-authors' research fields, with word size corresponding to relative frequency.

advancement and wider application of convective permitting modeling (CPM), or so-called kilometer-scale modeling. The CPM simulations, generated through downscaling from Global Climate Models (GCMs) to Regional Climate Models (RCMs), could capture the short-timescale extreme events, especially for temporal plausibility and accuracy and the influence of high mountain ranges in a region and/or urban areas (Prein et al., 2015). As highlighted in recent scientific articles (Dominguez et al., 2024; Duan et al., 2024), developing ultra-high-resolution climate models with horizontal scales of less than 10 km presents a potential new paradigm for climate prediction, which is expected to enable the simulation of extreme weather events and their driving factors with greater accuracy. These models offer the potential to address local and regional climate extremes, such as multi-year droughts and floods, which are crucial for adaptation to climate change, disaster risk management, and land use planning, among others. By employing such models, we can gain deeper insights into climate variability at the local level and develop more effective tools for predicting and projecting future changes. The challenges associated with CPMs development and improvement, such as those related to the processes needed to represent them at increasingly higher resolution, will be best addressed by EMCRs who can contribute their expertise as both model developers and users of their simulations. Additionally, the larger volume of data involved in these simulations necessitates the implementation of new data analysis techniques that facilitate a more straightforward examination of the underlying physical processes. The continued development and application of increasingly sophisticated techniques by EMCRs, who need to be able to devote significant amounts of time, is vital for the accelerated advancement of this technology. For example, emphasizing the evaluation of processes rather than standard performance metrics to improve the representation of small-scale processes in climate models to reduce uncertainties in climate information. Process-based diagnostics include storm structure or atmospheric vertical profiles, though data availability could be still a caveat to implement this diagnostics (Kendon et al., 2021).

Although kilometer-scale modeling is promising to advance in the generation of climate information at local level, it requires a higher understanding of the processes that explain regional climate variability, of the interactions across temporal and spatial scales and of the interactions between local climate and their environments. For instance, there are challenges to represent land-surface processes or the sub-kilometre scale processes that still need to be parametrized (Kendon et al., 2021). On the other hand, large-domain CPM climate simulations have the potential to improve the representation of local processes but also of remote teleconnections. However, due to its computational cost, there are more limitations to produce them to the same extent as current model intercomparison projects, such as CMIP. This presents a significant challenge in the realization of large ensembles, which have been demonstrated to more accurately represent climate signals and their associated uncertainty (Maher et al., 2021). This raises new questions about their potential use and added value in the context of generating climate predictions on different time scales (subseasonal to multi-annual), as well as for generating climate projections. To the extent that we as EMCRs are at the frontier of climate service production, these activities will inevitably present a challenge to the EMCRs in managing

data-intensive activities with underpinning science (Jain et al., 2022). It is therefore critical to ensure that we promote activities that allow us to better understand the potential of this type of modeling, and that we contribute to the improvement of the models, both as model developers and as users. In addition, it is desirable to promote mentorships where senior researchers actively support EMCRs by providing guidance, sharing expertise and collaborating on capacity building initiatives. This could strengthen the collective ability of the climate scientist to effectively address complex climate challenges, and contribute positively to the progress of the EMCR's career progress and continued work in research and academia (e.g., Bercht and Kamm, 2024).

Currently, climate model developments primarily address the physical understanding of the Earth system. However, the increasing resolution of CPMs necessitates further efforts to better represent the biogeochemical components of these models and the coupling between different systems, which requires knowledge from different disciplines. In this regard, the higher skill and motivation of EMCRs in inter-or multidisciplinary approaches can provide more rapid progress in model development.

To ensure the climate model output is more fit-for purpose at local scales, physical and human-driven processes that require model developments should be informed by societal needs while continuing to understand the processes that lead to large model uncertainties (e.g., deep convective clouds, soil-atmosphere interactions, and connection of extreme precipitation over land) to reduce those uncertainties (Prein et al., 2015). Examples of society-driven model developments would be improved simulations for cities, coasts, mountainous regions, and heavy precipitation events under climate change. This is one of the research and development areas where EMCRs can make a significant contribution in the future, given the scientific challenges of this type of modeling and its social importance.

Despite the potential benefits of km-scale modeling, its extensive use could be a challenge for EMCRs due to the large amounts of data that will be generated. A potential problem is that EMCRs will spend a lot of time on data-intensive activities instead of promoting novel scientific ideas and pushing the frontiers of climate science (Jain et al., 2022). Thus, as a caveat to this type of methodology, we emphasize the need for a better balance between data-intensive and basic climate science activities, as well as more open-ended research opportunities that strengthen the scientific freedom of EMCRs.

3.1.2 Incorporation of artificial intelligence approaches

The kilometer-scale climate model resolution, which is pivotal for livelihoods and risk projections, is extremely computationally expensive to obtain, especially within the context of the Global South. Therefore, finding ways to reduce the resources needed for running climate models is essential. Machine Learning (ML) and particularly deep learning techniques based on neural networks are some of the current tools being used to further downscale RCMs to higher resolutions that reduce computational cost with minimal loss in performance (Hobeichi et al., 2023). The use of CPMs and ML techniques shows promise in correcting biases in driving large-scale processes in GCMs (Prein et al., 2015). This presents the ability to capture more Earth processes through further advances in physical parameterization and produce climate information fit for hazard or sectoral analysis with reduced error/uncertainties.

Other new techniques, structures, and methods are still needed to bridge the gap between available observation data sets and current unexplained processes. An example of an underrepresented process at this scale is capturing the onset of drivers such as the vertically integrated moisture flux convergence in the Americas to the Asian Monsoon in Eastern Asia for water resources in the respective regions (e.g., Liu et al., 2021). These gaps have remained due to the lack of observations for the region and it is this same issue that adds to GCM and RCM uncertainties.

Considering that these new computational techniques present new challenges and opportunities for the climate science community, it is necessary to incorporate the discussion of their use in future research guidelines. The incorporation of the EMCRs in this discussion is essential considering that they are at the frontier of adoption of these technologies, knowing through their use, their pros and cons.

3.1.3 Co-production of climate information

The creation of useful and used information is not solely driven by modeling efforts but through engagement of the climate information user in order to tailor the information. Taking usable climate information coupled with local knowledge and transforming it into used information is commonly hindered by the lack of clarity in communicating uncertainties and limitations of models and how these dictate the use of the results in varying sectors. The lack of contextual understanding coupled with the difficulties in interpreting the information presented is one of the reasons for the lack of use (Dookie et al., 2023).

Communities are best positioned to understand climate-related impacts at the local scale. Thus, conveying climate information at a local scale, going from usable to used, requires a partnership approach that combines the method of assessing the traditional and indigenous knowledge of the users (Cappelletti et al., 2023). To that end, it is necessary to identify a medium that can capture and understand the temporal and spatial scales at which local scale players such as cattle herders, farmers, and fishermen, among others, commonly operate to adapt to protect livelihoods. These local adaptive capacities should be integrated into climate model scenarios to address the current limitations in predicting human adaptation, whether through changes in land use, migration, population, or others. This will provide a baseline or threshold of change that will inform the usefulness of the scenarios. EMCRs role is to provide the scientific foundation for ensuring the quality and usability of this information, enabling it to best address local needs. For instance, EMCRs are called upon to act as bridges between traditional practices and new approaches, such as Gamification (e.g., Douglas and Brauer, 2021) or Mapathons (e.g., Rivera-Flórez et al., 2024), which incorporate community-generated data obtained through participatory (research data collection) approaches.

A major barrier in conveying climate information at the local scale has been the need for more ease in formulating impacts-based, policy-driven assessments out of climate model information as climate models generally lack direct impact-based metrics in realms such as agriculture, fisheries, or water resources. In addition, the lack of contextual understanding and the difficulties in translating this information into useful services (Dookie et al., 2023), such as hazard mitigation, is a barrier to moving climate information from usable to "used." Thus, the adoption of

co-production approaches by the climate science community is central to creating climate information that meets local needs (Bremer et al., 2019; Bojovic et al., 2021; Hernández et al., 2022). Co-production should not be only at the stage of stakeholder feedback but from inception. Co-developing climate information products with multidisciplinary stakeholders and local players allows the creation and evaluation of impacts-based metrics with the usual climate variables at the model output. In this context, we need to define what we mean by "local." Would this entail communities, scientists, climatology, sectors, or an area? The co-creation of useful and used climate information would involve local stakeholders, scientists, or other relevant actors. Equally important to the inclusion of local users, is the collaboration with policy and decision-makers to ensure reaching practical solutions and proper implementation. In addition, what happens at local scales is driven by trans-local processes (e.g., floods in informal settlements, driven by hydro-processes at regional and global scales). As co-production approaches become more widely used, EMCRs will have the opportunity to develop their scientific careers in an environment that encourages cross-disciplinary dialogue and engagement with other sectors of society. These new practices offer a unique opportunity to consider future problems from a fresh perspective, diverging from the approaches typically employed by researchers trained in more traditional methodologies.

Investing the effort and time needed to understand local challenges and develop research questions that are timely and locally relevant is crucial. This can be achieved by not relying solely on the (academic) literature and creating a platform for local researchers to contribute their expertise and perspectives. Community-driven involvement in studies, for example, allows scientists to communicate directly with local communities to pinpoint urgent problems and share answers, therefore fostering cooperation. Setting up centers of excellence and regional research hubs may also help improve capacity and information exchange. Programs such as the WCRP can encourage and promote regional EMCRs to engage in citizen science activities. As EMCRs, we can work towards this approach to ensure an effective solution to the identified problems. With regard to addressing the issue of connecting science with societal needs, the newly established WCRP CP Regional Information for Society (RIfS) or the MCR LHA main aim is to establish effective links between climate research and the information needs of society. Active participation of EMCRs through dedicated symposiums for EMCRs, especially those from Global South, within these programmes will support this aim.

As a possible pathway, to generate scientific information that could lead to a positive change in society, the direct availability of sector-based variables from model output such as the Universal Thermal Climate Index (UTCI) used for the health field (Di Napoli et al., 2023) or climate velocity metrics used for marine life migration (Carroll et al., 2015) might provide impacts based advisors and policymakers with usable climate information. This would improve both access and timely use of the information to inform the planning of local scale players aiding in the protection of livelihoods and ecosystems. However, it is important to be aware that metrics that are defined in a broad manner may not be the most suitable for all types of situations. By involving the communities that will benefit from the availability of the generated climate information in the co-production of these metrics, it is possible to address more specific questions and to gain a better understanding of the decision-making process. As EMCRs, we have a crucial role to play in the development of climate information that is more context-specific.

As EMCRs, we are called to play a relevant role in pursuing the transformation of climate science, firstly to produce more robust information, incorporating new technologies such as kilometer-scale modeling or ML techniques. Secondly, to incorporate into our training and practice new approaches from the social sciences to co-produce climate information, working hand in hand with scientists from different disciplines as well as local communities (understood as a group of individuals interacting within their immediate surroundings in a region or even a smaller place such as an urban or rural area) who need better climate information to make climate-smart decisions.

3.2 Addressing key climate research and knowledge gaps in the global south

Due to economic, political, social instabilities, and historical inequalities and exploitation, climate priorities and the ability to respond to them have developed relatively slowly in the Global South than in the Global North (e.g., Demeter, 2020; Mercer and Simpson, 2023). This is one of the major barriers to address threats posed by the current climate crisis. For this reason, it is urgent to make the necessary efforts to reduce this knowledge gap. Below are seven high priority issues we have identified for the advancement of climate science in the Global South that may be addressed to reduce the existing knowledge gaps:

3.2.1 Lack of research agenda and priorities

There is a shortage of data science hubs and strong independent research entities in the Global South that could prioritize the research needs of the Global South in international climate endeavors and modeling efforts. This further exacerbates the existing disparities. It is essential the creation of hubs like these for harnessing the power of evidence and data-driven research and innovation in climate science and adaptation. In addition, they could raise the profile of Global South institutions in international efforts to ensure that their key priorities are recognized and that efforts are made to address them. These hubs could create a better environment for EMCRs in the Global South to strengthen their research in collaboration with other Global South centers, as well as to prioritize research topics of interest to their regions.

3.2.2 Deficiency of funding opportunities

The lack of funding, funding discontinuity, and unequal power dynamics in scientific collaborations, are key barriers faced by researchers and mostly affect EMCRs in developing countries (Molosi-France and Makoni, 2020). Many countries in the Global South face budget constraints that limit their capacity to invest in climate research (Valenzuela-Toro and Viglino, 2021). Government budgets are often stretched to address immediate development and infrastructure needs, leaving limited funding for long-term research projects. Funding dedicated to Global South does not necessarily go to Global South but stays in Global North. For instance, research on Africa received only 3.8% of global climate change research funding since 1990, and of this funding, 78% went to European and North American institutions (Trisos et al., 2022). Funding needs to be directed to initiatives in the Global South that can inform adaptation, identify maladaptation, and

guide governance and innovation. Even if there is funding available in some cases, the allocation of the budget and partnership may not be equitable.

We call that all Global South researchers as well as funding agencies should also be aware of the disparity, maybe imposing a better share of funding between Global North and Global South institutions. Moreover, providing equitable opportunities for Global South researchers to access direct and flexible research funding is crucial, specially in the first stages of our careers and could be determinant of the kind of research topics that we could address. Long-term partnerships based on mutual learning should be prioritized to build capacity and infrastructure within Global South institutions, reducing their reliance on Global North funders. Humanitarian research in the Global South should be a priority for donors, with a focus on Global South-led research and South-to-South research collaborations (Cordua, 2023).

3.2.3 Shortage of direct monitoring reports

Limited historical and regional coverage of records, data gaps, insufficient high-quality data, and inadequate monitoring systems, particularly in sub-Saharan Africa (Edwards et al., 2023) and South America (Condom et al., 2020; Arias et al., 2021), are some of the main issues for climate research in the Global South. In some cases, the data is not accessible because it has not been digitized such as in Africa (Lamptey et al., 2024). The lack of scientific analysis in regions like Africa and South Asia due to insufficient data collection, or the absence of data-sharing mechanisms or policy priorities hinders the assessment of climate impacts and societal costs of extreme weather events (Edwards et al., 2023). The lack of measurements makes it difficult to constrain climate and weather models, therefore narrowing model uncertainties. The countries in the Global South are also highly reliant on various external authorities for observational data. Therefore, even when data is available, insecurity and piracy attacks remain a challenge. Furthermore, a significant challenge arises in many countries from the lack of collaboration between data providers, such as national weather services, and the climate research community. This hinders the effective utilization of data in climate research. It is therefore essential to intensify efforts to expand and reinforce observation networks in the Global South, with a particular focus on areas where coverage is inadequate or where there is greater complexity and social interest. It is crucial that a portion of international funding is allocated to this objective. This will also facilitate the enhancement of modeling in the region and the advancement of the generation of more effective climate services.

3.2.4 Inadequate modeling computing capacity

Despite the great potential of kilometer-scale climate modeling described in section 3.1.1, the climate modeling capacity is deficient in the Global South. For example, most countries are reliant on global modeling initiatives [e.g., WCRP CMIP or Coordinated Regional Downscaling Experiment (CORDEX)] for their climate assessments. This limitation presents itself in the lack of training opportunities, mentorship, and the unavailability of sufficient computing resources. This gap normally translates into scientists from the Global South having sparse involvement in model development and process improvement (Engelbrecht et al., 2017). Most of the models are developed in the Global North and for the mid-latitudes resulting in low accuracy over Africa and other Global South regions. Consequently, climate models may not adequately represent the unique regional characteristics and climate dynamics of these regions, leading to potential biases and inaccuracies in projections and assessments. Another major obstacle to the development of research in the Global South concerns equitable access to stable and good network connections for data downloading, pre-processing, and storage (Jain et al., 2022).

Therefore, there is a need to develop strategies to implement a model design for the Global South regions. One way to tackle this will be to facilitate a major involvement of Global South researchers on coordinated activities between modeling groups all over the world, such as WCRP LHA Digital Earths to address common challenges, and uncertainties, and to assess the added value of kilometer-scale models for these regions (Schär et al., 2020). In addition, it is needed to ensure equitable access to computational resources and data volumes required for using the kilometer-scale model outputs. As EMCRs, we are called upon to take the lead in our regions (Shaaban et al., 2024), advocating for enhanced computing capacity and model development to improve the quality of climate information and facilitate more effective climate services.

3.2.5 Capacity development

There is a shortage of educational opportunities in the Global South, which forces EMCRs to move abroad looking for opportunities and generating more South–North inequalities. One way to tackle this issue is to establish climate training hubs in Global South regions that could be endorsed by WCRP Academy activities.[2] They could help to deliver climate-specific training, enabling researchers to receive comprehensive education locally, reducing the need for overseas training, and fostering more impactful climate research. Efforts to support researchers in the Global South to engage with and leverage kilometer-scale models are essential for enhancing regional climate modeling capabilities. There is a need to encourage university programs in Global South regions [e.g., West African Science Service Centre for Climate Change and Adapted Land Use (WASCAL), Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL); or the Regional Master 2 in Physical Oceanography and Applications (RMPOA) at the International Chair (UNESCO) in Mathematical Physics and Applications (ICMPA)], although they exist but are still limited. Also, strengthening institutions such as the Abdus Salam International Centre for Theoretical Physics (ICTP), whose mission is to promote sustainable science throughout the Global South and which has a long tradition of scientific capacity building. In addition, one of the most important promising research paths in the backbone of kilometer-scale modeling is the use of ML algorithms. However, there is a serious North–South disparity in high performance computing and ML methods. Therefore, there is a clear and urgent need for training for Global South EMCRs in order to not miss the important technological tipping point.

3.2.6 Barriers to the use of climate information

Various aspects of climate information have been identified as being problematic for end users, especially on the Global South,

2 https://wcrp-academy.org/

including inadequate coverage of important geolocalized variables (Tall et al., 2012; Ouedraogo et al., 2022); inappropriate spatial and temporal resolution for decision-making (Tall et al., 2012, 2014); the technical content and format of climate information (Ochieng et al., 2017) and lack of forecast reliability (Nkiaka et al., 2019). Moreover, on the end user side, end user competency to interpret and use climate information (Dookie et al., 2023), in some cases due to low education and literacy levels (Ochieng et al., 2017); low end user confidence in climate information (Tall et al., 2012) often due to the lack of clarity in communicating uncertainties and limitations of models; as well as the low capacity to act on forecasts (Tall et al., 2012) have all been reported as barriers to the adoption and use of climate information. Thus, building capacity for the coproduction of user-oriented climate information among climate information providers and end users has been highlighted as a priority need in the Global South (Mahon et al., 2019) with a call for greater investments that support the co-production process. EMCRs in the Global South could act as a bridge between the communities and the climate science community production, launching educational and research projects or campaigns to work with the community on climate science issues.

3.2.7 Establishment of functioning early warning systems

In 2022, the United Nations tasked the World Meteorological Organization (WMO) to lead an initiative to ensure that by the end of 2027, everyone on Earth is protected from hazardous weather, water, or climate events through early warning systems (World Meteorological Organization, 2022). Many countries in the Global South still lack sufficient early warning systems hence increasing their vulnerability to climate hazards. Promptly, early warning systems help local people feel more empowered and less vulnerable by protecting essential facilities, making communities more resilient, and quickly responding to health and environmental risks more easily. By safeguarding the most defenseless from the unequal impact of disasters, they promote global solidarity and collaboration, which aids in sustainable development and reduces inequality. Within the framework of this initiative, efforts should be made to ensure the development of early warning systems all over the world, especially in the Global South, where there are less resources and communities are more vulnerable to climate hazards. As EMCRs, we have an important role to play in this field, contributing to scientific development and generating increasingly robust climate information for monitoring and prediction. We also have the opportunity to enhance the methodologies that facilitate the effective use of this information by the relevant stakeholders.

If the benefits of advancing climate knowledge and its application to society are to be shared globally, it is necessary to reduce the North–South gap in the above-mentioned aspects. Efforts must be made by the EMCRs of the Global South, and especially those of the Global North, to establish equitable collaborations that contribute to reducing these gaps. This entails that the scientific community in the Global North must acknowledge the significance and value of the contributions that its counterparts in the Global South can offer. It also presents a challenge for both communities to facilitate the advancement of research in the Global South by the Global South community and to foster local, regional, and global networking.

3.3 Supporting decision-and policy-making with climate information

There is a persistent disparity between the generation of knowledge and its utilization to inform decision and policy-making processes at various levels, from the local to the global, in the context of environmental issues (Kirchhoff et al., 2013; Lacey et al., 2018). This issue affects the entire scientific community, and as EMCRs, we must consider it when seeking to produce scientific knowledge with a greater social impact. It is, therefore, crucial for us to reflect on how our work as researchers and professionals can address this problem in the climate science field. The main challenges for EMCRs in supporting decision and policy-making with climate science and knowledge can be divided into three categories: (1) challenges associated with opportunities for EMCRs to develop necessary abilities and skills, (2) challenges in understanding the diverse requirements and communication styles of policy makers, and (3) challenges associated with the particular environment of each country.

3.3.1 Challenges associated with opportunities for EMCRs to develop necessary abilities and skills

Depending on both career levels and available opportunities, there is a general perception that EMCRs could either be underqualified to give advice on policy matters or overqualified to be trained as an intern to get into policy-making. Furthermore, the day-to-day activities of climate science researchers are largely disconnected from the contexts of decision-making and policy formulation. This separation is particularly pronounced in the case of EMCRs. As a result, they could lack knowledge about how they can contribute to these processes (Rougier and Crucifix, 2018). To reverse this situation, climate science training programs must provide greater opportunities for both theoretical and practical training at the science-policy interface, as well as in decision-making environments. This may also have a transformative effect on the way in which EMCRs conduct their research, considering how it can then be incorporated into these contexts.

3.3.2 Challenges in understanding the diverse requirements and communication styles of policy-makers

Another important challenge facing EMCRs is how they can emphasize the value of their research and how they communicate it to different kinds of stakeholders. These challenges stem from its inherent diversity and complex nature, which creates difficulties in understanding the exact needs in terms of policy and its relevance. There is also a significant difference in the communication style used for policy briefs compared with research articles, which further extends the gap between these two disciplines. Decision makers often rely on general articles from newspapers and social media for information (e.g., Roby et al., 2018; Sultana et al., 2024). Research papers are often too technical for the common understanding that decision-makers seek, leading to frustration when scientific data is inaccessible, difficult to interpret, and challenging to apply in practical decision-making frameworks, which can result in criticism of scientists (e.g., Pierce, 2020; Bisbal, 2024). In this regard, the most significant challenge is that for research to exert a greater influence on decision-making and policy-making processes, researchers must

dedicate time and effort to other forms of written or visual outputs that are not typically included in evaluation systems to the same extent as scientific articles. Consequently, there is a need for greater encouragement of this type of output, enabling EMCRs to engage with it at an early stage without compromising their advancement in their scientific careers.

3.3.3 Challenges associated with the particular environment of each country

When we talk about policy relevance, it is crucial to take into account the particular environment of each country. Transferring solutions from one environment to another without a proper understanding of particular needs and risks of each local environment/community carries a great deal of risk. Moreover, as we seek to co-produce knowledge in a specific community and also learn from the experience of the members of that community, we will be facing the challenge of how to gain their trust.

To address the challenges presented here and earlier, EMCRs should focus on engaging with policy makers and stakeholders from local communities to better understand their needs in order to address their practical needs in climate policy assessment (Rougier and Crucifix, 2018). It is essential that EMCRs actively participate in discussions regarding climate action and policy with policy and decision makers, with a focus on communicating uncertainties that influence the assessment of risks and the design of interventions (Smith and Stern, 2011). EMCRs need to increase their participation in science diplomacy, where it has been shown that they could play a relevant role (Cuellar-Ramirez, 2021). The integration of components of policy knowledge into EMCRs initiatives, such as specific training programs, might bridge the gap between science and policy. It is also important to provide training to EMCRs on how to effectively communicate their research to policymakers. Alternatively, the increasing use by the new generations of Integrated Assessment Models (IAMs), which combine world economic activity and the environment, could provide useful information on policy choices (Halkos, 2014). Furthermore, the EMCRs role in new global governance will be strengthened by their engagement in international programs as well as through EMCRs networks.

It is paramount that greater efforts are made to guarantee that research topics and projects, especially from EMCRs, match and support the decision-and policy-making. The identification of these topics will be fostered through the engagement of EMCRs in advisory boards or group discussions with decision and policy makers. Such initiatives could also be used to demonstrate the value that EMCRs can bring to policy. It is also crucial to bridge the gap between information creation and accessibility by preparing summaries of research findings and making them accessible to policymakers. In addition, it is essential to consider the time constraints typically faced by decision-makers and politicians when generating climate information. To advance knowledge with greater impact, we must also stimulate it through a scientific evaluation, recognition system and long-term contracts that support this kind of applied research. Besides, policymakers should be encouraged to communicate their requirements, and EMCRs can help deliver relevant information accordingly. It is worth noting that even if the most rigorous scientific research is conducted and questions of social or political relevance are addressed, this does not guarantee that the findings will be utilized by decision-and policy-makers. Therefore, it is essential for researchers to advocate for evidence-based decision-making at all levels, from local to international.

Finally, local communities (local population, local leaders of various kinds who are based in climate sensitive locations) are key stakeholders that should be encouraged and involved in climate policy development. To this end, as described in section 3.1.3, EMCRs could play an important role in changing the standard approaches to climate information production. This implies first understanding the unique realities of each community and localizing any solution in collaboration with them. This could help advance simple adaptation solutions that can be implemented with measurable impact.

4 Moving forward: involvement of researchers from the global south and of EMCRs in international research endeavors

There is an increasing recognition in the science community of the importance of diversity, equity, and inclusion (DEI). International cooperation is crucial for both ethical and practical reasons, particularly in light of the rise of global challenges. For instance, the WCRP is leading efforts to promote diversity in climate science, leveraging collaboration and nurturing diversity within its own structure to maximize knowledge foundations to confront global environmental challenges. For example, in recent years the WCRP's main activities have actively appointed a larger number of EMCRs to its panels and working groups. It has also encouraged the organization of special events for ECRs or EMCRs in the context of WCRP conferences, workshops, or other events where they have played a leading role in the organization, such as the WCRP OSC 2023 symposium. In addition, the WCRP has a guideline to ensure gender balance and representation from countries of the Global South in the WCRP High-Level Steering Committees. Based on this guideline it is expected that a single gender should not dominate the membership by more than 60%, and at least one third of all members should be resident in countries not designated as high-income economies according to the World Bank. However, the forced migration of scientists from the Global South to the Global North is another relevant issue that needs to be considered in order to ensure diversity and representation from all regions, including those with low scientific funding.

Through the promotion of diversity in climate science, the WCRP is revealing new pathways for overcoming cultural and societal barriers that prevent the effective use of climate knowledge. The WCRP could be able to ensure that climate science looks at the climate system from diverse perspectives, recognizing that issues of equity in relation to the distribution and effects of climate change are important components of climate research. The ultimate goal is to collectively steer the Earth's climate system onto a sustainable path and help vulnerable societies cope with and adapt to the impacts of these changes.

The establishment of an Advisory Council on Diversity and Inclusion (ACDI) is one of the actions that international initiatives such as the WCRP could take to strengthen their promotion of diversity in climate science at all levels and in all fields. The ACDI could identify barriers to climate research and propose positive

actions targeting specific groups and themes, as well as reinforcing data and modeling structures. This might foster diversity in climate science, ensuring inclusion regardless of gender, nationality, career stage, sexual orientation, or disability. The ACDI will benefit greatly from the inclusion of a large proportion of EMCRs as well as members from the Global South.

In the next subsections, we will describe actions that could be taken to strengthen the engagement and leadership of Global South researchers and better promote the EMCRs engagement in international initiatives.

4.1 Global south engagement

The Global South is a broad and heterogeneous group of countries, with different levels of economic development, political regimes, and political orientations (UNCTAD, 2018). Therefore, a one-size-fits-all approach to representation is unlikely to be effective. To ensure that the Global South is appropriately represented in multi-national endeavors, it is crucial to understand the complexities and limitations of the term, as well as the diverse interests and needs of the countries it encompasses. The United Nations Conference on Trade and Development (UNCTAD) report 'Forging a Path Beyond Borders: The Global South' (UNCTAD, 2018) outlined justifications behind this and pathways for recognising the Global South. Firstly, it is important to recognize that the Global South is not a monolithic entity, but rather a category that includes a wide range of actors, discourses, institutions, and movements (Ballestrin, 2020). As such, representation should be tailored to the specific context and interests of each country or group of countries. This may involve engaging with regional organizations, such as the African Union or the Association of Southeast Asian Nations, as well as with individual countries. Secondly, representation should be based on inclusive and participatory processes that take into account the perspectives and priorities of the Global South. This may involve strengthening South–South cooperation, as well as North–South dialogue and collaboration. The UNCTAD report highlights the importance of regional and interregional integration, as well as the removal of trade and non-trade barriers, in supporting the 2030 Agenda for Sustainable Development and promoting sustainable and inclusive development in the Global South. Thirdly, representation should be guided by a commitment to addressing the structural economic barriers that continue to hold back the least developed countries in the Global South. This may involve supporting efforts to diversify economies, build trade and productive capacities, and promote economic integration. The New Development Bank, established by the BRICS countries, is an example of Southern-led development finance that can support infrastructure development and economic growth in the Global South. Finally, representation should be based on a shared understanding of the value of multilateral cooperation and a commitment to building a more just, prosperous, and peaceful world for all (Galant and Darnal, 2024). This may involve recognizing the legitimacy of the demands of the Global South for a more equitable international economic system and working together to address global challenges such as climate change, food security, water accessibility, poverty, and inequality.

To enhance the integration of the Global South into international research endeavors, fostering more diverse, inclusive, and locally relevant research outcomes, it is imperative to address the current low participation of the EMCRs especially from the Global South in international climate research endeavors. Strategies gleaned from WCRP OSC 2023, multiple and parallel discussion sessions between EMCRs, and empirical sources are listed in Table 1 and summarized below.

4.1.1 Reduce epistemic arrogance

The North–South knowledge gradient or even the invisibilization of several regions of the world has been leaving behind the Global South in the development of climate science and it was one of the key points that was raised in the WCRP OSC 2023. We will need to build healthier international collaborations based on the recognition of our own and each other's privileges and disadvantages, which could create ways to reduce them (Blicharska et al., 2017).

4.1.2 Promoting strong South–South and South–North collaborations

Encouraging strong collaborations between researchers from the Global South, and between the Global South and North can help address the imbalance in research participation and output. This can be achieved by incorporating researchers and co-investigators from the Global South in research projects conducted within their geographical locations, leading to increased patents, published articles, and other research outputs from the Global South (Ade and Ciuffa, 2022) or promoting transnational institutions. International programs could further encourage and ensure science without borders: scientists in the Global North need to engage much more with their colleagues in the Global South (migration from North to South and vice versa, not just often in one direction, from South to North) in order to address the realities of the Global South, particularly concerning the challenges of climate change. International initiatives could foster a better environment for Global South scientists, promoting better practices when engaging in South–North collaborations, as recommended by Haelewaters et al. (2021), and supporting the creation of Climate Sciences institutions in the region with global financing. This could help to create competing positions for scientists worldwide (thus compensating for South–North migration), enhance participation from local universities, encourage public engagement, and facilitate regional assessments.

TABLE 1 List of actions to increase Global South researchers' engagement in international endeavors.

Actions to increase Global South researchers engagement in international endeavors
Reduce epistemic arrogance
Promoting strong South–South and South–North collaborations
Supporting dedicated campaigns or programs
Enhancing Global South researchers in the co-design of projects for Global South regions
Promoting justice and equity in the scientific community
Valuing local knowledge and context
Creating time and resource reserves

4.1.3 Supporting dedicated campaigns or programs

The financing and promotion of long-term or continuous programs in the Global South by international or regional initiatives should be encouraged. These may contribute to enhancing local capabilities and the production of high quality information to develop high quality science. Several initiatives have already begun such as the ANDEX Regional Hydroclimate Project, from the Global Energy and Water Exchanges (GEWEX) WCRP CP or WCRP's My Climate Risk (MCR) LHA with different regional hubs. They are examples of one step in providing information to better address climate questions and solutions at the local level for a particular South Global region.

4.1.4 Enhancing Global South researchers in the co-design of projects for Global South regions

International initiatives could help Global South researchers, especially EMCRs, to take a lead and get involved at the beginning of the project or program writing to tackle issues related to Global South regions in collaboration between other regions of the Global South or the Global North in order to translate the societal needs and problems to be addressed. In fact, currently, most of the projects are drafted by countries in the Global North, wherein scientists from the Global South join to carry out the work. Instead, researchers from the Global South need to be involved right from the start of the project design and ensure that they will integrate into the project challenges to be addressed and achieve the desired results in order to improve people's living standards.

A fast emerging new branch of climate research is the study of carbon dioxide removal (CDR) methods to meet net zero emission goals. Currently, most of the related research is driven by the Global North (Satterfield et al., 2023) including projects on mangrove afforestation which grow primarily in the Global South. It should be avoided that these methods are employed at the cost of local livelihoods and/or ecosystem health by, for example aforesting critical agricultural land. Global models on CDR methods may furthermore overestimate their potential by not considering regional nuances that researchers from the Global South have expertise on. It is therefore crucial that significant research on such climate intervention methodologies are conducted considering region-wise impacts and ensuring that researchers and policy makers have agency in climate action that affects their regions.

4.1.5 Promoting justice and equity in the scientific community

Unrealistic standards imposed by scientific rewards in many countries, the productivity of researchers in well-funded institutions, and the business of academic publications promote not only unethical and pernicious practices like publication mills (Abalkina, 2023) but also high inequality in production and scientific advancement in climate science in the Global North (Nobes, 2023; Tandon, 2021). Being devoted to a scientific career is a privilege in developing countries. When a Global South researcher has to struggle for income or other basic needs, or even if there is civil unrest or political repression, the temptation to migrate and advance their career in the Global North is strong. This leads to a situation where researchers may respond to the day-to-day 'publish or perish' routine, maybe influenced by the practice of 'helicopter science' (Reidpath and Allotey, 2019) without having the opportunity to delve into deep scientific questions relevant to the Global South that could advance the region (Haelewaters et al., 2021).

Researchers from the Global South are faced with hurdles such as the high cost of open-access publications. It is noteworthy that often when waivers are offered, the price tends to be prohibitive, thus further marginalizing Global South researchers (Nakamura et al., 2023). Moreover, the citing of literature from the Global South researchers will provide further exposure to contextual environmental and socioeconomic factors, whilst promoting their careers and opportunities for collaboration with Global North. EMCRs from the Global South can play a crucial role in advancing research in the Global South, promoting equity and justice in the scientific community, and addressing the unique challenges and needs of the region.

4.1.6 Valuing local knowledge and context

Knowledge co-creation to inform policy and forging of robust partnerships between researchers is critical to overcoming the pressing and sometimes "wicked" problems of contemporary society, as also indicated in section 3.1.3. Climate research must understand and value local researchers' different embeddedness in their communities. EMCRs in the Global South can play a pivotal role in connecting the local context to scientific research, and the broader international arena. Adopting an intersectional perspective that considers the various layers of disparities within countries is also critical for ensuring local legitimacy and representation in research (OECD, 2023). Therefore, in addressing the dearth of integration of Global South research in global issues, it is vital to first recognize that the knowledge emanating from these underrepresented areas is credible and valuable (Nakamura et al., 2023). This is more so as responses to our global climate challenges necessitate tailored and contextual knowledge (Donkor et al., 2019). One of the ways it can be achieved through integrating flexibility into grant agreements can help researchers adapt research goals and designs based on local needs. This can facilitate adaptation and ensure that research remains relevant to local contexts and challenges (von Richthofen and Gümüsay, 2023).

In particular, international initiatives such as the WCRP could help to promote EMCRs from the Global South to take a lead in expressing the challenges and problems that Global South countries are facing. For instance, in the context of climate change, the damage caused by it is not a major issue in some Global South countries compared to everyday problems such as poverty, and underdevelopment in certain vital sectors, among others. These challenges need to be considered to improve Global South's participation and engagement in international research endeavors.

4.1.7 Creating time and resource reserves

Conducting research in the Global South may consume substantially more time and effort due to bureaucracy, inaccessibility of various forms, lack of access to readily available information, among others. Creating a time and resource buffer can help Global South researchers engage with the local ecosystem and make the local context central to the research.

In recent decades, there have been several successful examples of South–South scientific cooperation, demonstrating the potential of regional partnerships to advance common goals. One prominent initiative is the Pan-African University (PAU), a network of

postgraduate education and research centres supported by the African Union and the Association of African Universities. The PAU focuses on improving the quality of science and technology education across Africa, fostering innovation and addressing continental challenges through collaborative research and capacity building. Similarly, the Latin American Biotechnology Centre (CABBIO) is an example of a regional integration programme that strengthens cooperation among Latin American countries by expanding knowledge and expertise in biotechnology, and the International Center for Tropical Agriculture (CIAT) located in Colombia have the mandate of reducing hunger and poverty and improve human health in the tropics through research that increases the eco-efficiency of agriculture. These initiatives demonstrate the power of South–South cooperation in building local capacity, addressing regional priorities and promoting sustainable development. These types of initiatives could be replicated to advance climate science in the Global South, involving close partnerships between these countries that could be supported by international initiatives.

4.2 EMCRs engagement: reflections on how EMCRs could become more involved in international initiatives

Over the last decade, EMCRs have demonstrated the importance of having an autonomous voice that can influence the agendas of major international climate science programs and bring fresh perspectives to the climate science community. First, by highlighting some of the challenges from an EMCR perspective and secondly, by proposing solutions and new ways to address them, with strong EMCR involvement. This takes into account that there is a generational shift in the scientific landscape of climate science. For example, the current generation is more motivated to pursue interdisciplinary studies and demands greater skills in this field (Hein et al., 2018). For example, the YESS community calls for the need for seamless prediction systems for environmental processes that are robust and informative for local users at all scales, with the aim of providing optimal information to society (Rauser et al., 2017). These prediction systems will require an improved understanding of physical processes, more high-resolution global observations, advanced modeling capabilities, as well as high-performance computing at unprecedented scales. Swart et al. (2018) as part of their reflections on the 2016 CLIVAR ECRs Symposium, identified the research priorities for the future evolution of CLIVAR as improved understanding and predictability of regional climate variability and change, improved process-based understanding, seamless climate prediction, and improved and expanded global observations. With a more regional focus, Dike et al. (2018) discussed the main barriers faced by young African climate scientists, such as inadequate facilities or limited collaborations, and some possible ways to address them. In addition, to address the study and understanding of climate, weather, or hydrological extreme events and the provision of regional information, ECRs proposed three main ways in which they could make a major contribution: greater interaction between users and scientists, a collaborative modeling approach between the different modeling communities, and the assessment and possible inclusion of unconventional data sources in scientific studies (Langendijk et al., 2019). Another critical area for EMCR involvement is in global science policy bodies such as the Intergovernmental Panel on Climate Change (IPCC). To overcome the barriers for ECRs to actively participate in the IPCC assessment process, Gulizia et al. (2020) outline a number of recommendations for both the IPCC and ECRs, such as facilitating group reviews for ECRs. A successful group review led by ECRs communities was conducted for the IPCC 6th Assessment Report (Moreno-Ibáñez et al., 2024). Recently, Jain et al. (2022) emphasized the urgent need for a better balance between data-intensive and basic climate science activities, more open research opportunities that enhance the scientific freedom of ECRs, and strong coordinated action to provide infrastructure and resources to ECRs working in under-resourced environments. All of the above examples show that it can be mutually beneficial for EMCRs to have a voice in the organizations that formulate climate research programs, and for those organizations to benefit from the fresh perspectives of the new generations who will be the future of those organizations.

The wider and more active participation of EMCRs in international initiatives will contribute to faster progress of the whole climate science community. EMCRs bring to the table the use of new approaches such as co-production methodologies, as their most recent education and training is more open to trans−/interdisciplinary research. In addition, EMCRs may be able to adopt new technologies such as AI or CPM, described in section 3.1, earlier and more quickly.

Efforts should be made by institutions at national, regional, and international levels to promote participation and leadership of EMCRs in international endeavors such as the WCRP and to build a strong foundation and develop a diverse skill set for EMCRs (Hawcroft et al., 2023; Irfanullah, 2023; John et al., 2023). In Table 2, we list some of the priorities that need to be considered to make this possible which are described below in more detail:

4.2.1 Strengthening participation in international scientific committees and initiatives

There should be greater involvement of EMCRs in international initiatives, such as WCRP activities, so that their collective voice is well represented. Such initiatives must ensure that EMCRs' representation on committees is diverse, notably providing opportunities and avenues for Global South EMCRs to contribute and provide a first hand leading voice in the discussion related to climate change impacts and its associated effects in their region (e.g., Hughes et al., 2022). Greater leadership by EMCRs in such programs can

TABLE 2 List of actions to increase EMCRs' engagement in international endeavors.

Actions to increase EMCRS engagement in international endeavors
Strengthening participation in scientific committees of international initiatives
Encouraging international engagement
Increasing advocacy
Fostering participation in EMCRs networks
Increasing exposure to diverse perspectives
Presenting research
Leveraging social media and online platforms
Establishment of Advisory Council on Diversity and Inclusion (ACDI) in scientific international programmes

facilitate the adoption of new ways of working and methodologies that are more compatible with the current needs of climate science. Regional committees composed of EMCRs could be created in different international initiatives to enhance their engagement.

4.2.2 Encouraging international engagement

EMCRs international engagement with established researchers is crucial for their careers. Researchers in developing countries need access to technology and knowledge to address regional problems. EMCR attending international events can lead to successful partnerships. Scientific meetings and industry conferences are also great opportunities to find potential collaborators. This collaboration should not be limited to conferences alone but should consider international businesses and organizations with regional offices to expand networking opportunities beyond the academic sphere, fostering a stronger socio-economic connection.

4.2.3 Increasing advocacy

Advocacy for the inclusion of EMCRs in delegations to major climate meetings, such as United Nations Framework Convention on Climate Change's Conference of the Parties (COP) events, and participation in organizing youth forums and side events ensure that young researchers' voices are heard. Developing soft skills for communication, negotiation, and diplomacy, along with gaining interdisciplinary knowledge, equips EMCRs to contribute more effectively to international climate discussions and initiatives. By taking these steps, EMCRs can significantly enhance their involvement and impact in global efforts to address climate change.

4.2.4 Fostering participation in EMCRs networks

The establishment of EMCRs networks in recent years, such as YESS, YHS, APECS, or PAGES ECN (non-exhaustive list), has allowed EMCRs to establish international connections and to have an autonomous voice in the field of Earth science. In addition, the participation of EMCRs in these networks provides them with new skills and contributes to their formation (Hill et al., 2024; Spence et al., 2024). As a first step to enable EMCRs to participate in international initiatives, the EMCRs network should receive stronger institutional support and funding.

4.2.5 Increasing exposure to diverse perspectives

The collaboration of academics in close proximity can yield fruitful outcomes. Allocating designated areas for EMCRs at global conferences proves to be quite beneficial. As research capabilities differ among individuals, conference organizers need to take diversity into account when convening stakeholders. Moreover, participating in international exchange programs such as the National Oceanic and Atmospheric Administration (NOAA) International Desk or European Centre for Medium-Range Weather Forecasts (ECMWF) facilitates knowledge sharing and networking.

4.2.6 Presenting research

Presenting research at international climate conferences and symposia, as well as publishing articles, opinion pieces, and policy briefs in prominent climate science journals, allows EMCRs to significantly contribute to policy and research discussions. Seeking mentorship and collaboration through mentorship programs and collaborative research projects with an international scope can further enhance their professional development. This could be accomplished by applying for funding and fellowships, such as those offered by the IPCC or the WMO, that support their participation in international climate initiatives.

4.2.7 Leveraging social media and online platform

Leveraging social media and online platforms like LinkedIn, ResearchGate, or X is essential for EMCRs to share research findings with a wide range of audiences, engage in global discussions, and stay connected with the climate community. Active participation in webinars and virtual conferences also keeps EMCRs informed and involved.

The inclusion of EMCRs in governing councils and organising committees of international initiatives has gained significant momentum in recent years. For example, the Future Earth Governing Council reserves three dedicated seats for ECRs out of a total of 17, ensuring that their voices are heard and that their perspectives shape key decision-making processes and activities. We encourage other international initiatives to take more decisive steps in this direction, building on the progress made in recent years and incorporating lessons learned to further advance inclusive representation.

5 Conclusion

This paper reflects the discussions of the EMCRs in the context of the WCRP OSC 2023 to advance climate knowledge for greater transformative power in society and impact on decision-and policy-making. Firstly, the production of robust, usable, and actionable climate information at local level requires further advances, which could be achieved through kilometer-scale modeling and the use of advances in tools such as machine learning. While these tools have the potential to enhance regional climate prediction and climate projections for better climate services, they also pose a threat to the community, especially EMCRs, due to the large amounts of funding and research time that is required in these initiatives. It must be reinforced that it is not enough to simply incorporate these technological advances; it is also necessary to work with local actors and disciplines through methods such as co-production. Secondly, some of the key gaps in climate knowledge in the Global South have been identified, including lack of data, modeling capacity and funding, and need to set the research priorities. We call for greater involvement of EMCRs and marginalized Global South researchers in global initiatives, particularly in leadership and decisive positions, to drive the development of climate science and tackle the main challenges previously identified. This is particularly important given that countries in the Global South are bearing the worst impacts associated with climate change and that the younger generations are the ones who will have to face the major challenges associated with an increasingly extreme world as a result of climate change in their lifetimes. Thirdly, the challenges associated with how EMCRs can generate climate information for policy-making range from the capacity of EMCRs to engage, the difficulties associated with the different languages or communication styles of science and policy, and understanding the particular country context. Co-creating knowledge to inform policy and establishing partnerships to drive sustainability are core themes in addressing global sustainability challenges including climate-induced ones.

We believe that international endeavors such as the WCRP can play a fundamental and influential role in increasing the participation and leadership of EMCRs, and especially Global South researchers, in global initiatives related to the advancement of climate knowledge for societal needs. Firstly, it is essential to broaden the participation of EMCRs in all its activities. Secondly, it is necessary to recognise the gap between the Global South and the Global North, to give Global South researchers a central voice in their initiatives, and to promote new evaluation and recognition criteria that take into account historical inequalities between regions. This means that a large part of the funding should be allocated to support the development of the EMCRs of the Global South. Finally, we strongly recommend the creation of an Advisory Council on Diversity and Inclusion (ACDI), with a majority participation of EMCRs representing the different regions of the Global South, so that they can develop cross-cutting policies for all activities to ensure greater diversity and inclusion in the community.

The WCRP has a historic role to play in promoting the advancement of climate science, raising the voice of the climate change problem, and providing climate services for the benefit of society. As the future of the organization, we, the EMCRs, need to be able to play an increasing leadership role. It is also time to put the priorities of the Global South at the top of the WCRP agenda. These are essential actions if we are to achieve a more diverse science that seeks to ensure climate justice.

Author contributions

LBD: Conceptualization, Writing – original draft, Writing – review & editing, Visualization. CG: Conceptualization, Writing – original draft, Writing – review & editing. SJ: Conceptualization, Writing – original draft, Writing – review & editing. GSL: Conceptualization, Writing – original draft, Writing – review & editing. HP: Conceptualization, Writing – original draft, Writing – review & editing. VR: Conceptualization, Writing – original draft, Writing – review & editing. CSC: Writing – original draft, Writing – review & editing. AD: Writing – original draft, Writing – review & editing. FKD: Writing – original draft, Writing – review & editing. TSE: Writing – original draft, Writing – review & editing. GKA: Writing – original draft, Writing – review & editing. AJ: Writing – original draft, Writing – review & editing. MRS: Writing – original draft, Writing – review & editing. YAB: Writing – original draft, Writing – review & editing. BDA: Writing – original draft, Writing – review & editing. A-AA: Writing – original draft, Writing – review & editing, Visualization. FMA: Writing – original draft, Writing – review & editing. AB-J: Writing – original draft, Writing – review & editing. AC: Writing – original draft, Writing – review & editing. MAD: Writing – original draft, Writing – review & editing. HE-R: Writing – original draft, Writing – review & editing. TCF-N: Writing – original draft, Writing – review & editing. BG: Writing – original draft, Writing – review & editing. MG: Writing – original draft, Writing – review & editing. FEKG: Writing – original draft, Writing – review & editing. IML: Writing – original draft, Writing – review & editing. RL: Writing – original draft, Writing – review & editing. RM: Writing – original draft, Writing – review & editing. SKM: Writing – original draft, Writing – review & editing. LM: Writing – original draft, Writing – review & editing. MM: Writing – original draft, Writing – review & editing. RMN: Writing – original draft, Writing – review & editing. JAR: Writing – original draft, Writing – review & editing. ACS: Writing – original draft, Writing – review & editing. LIT: Writing – original draft, Writing – review & editing. E-HEIZ: Writing – original draft, Writing – review & editing. GS: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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