

PRACTICE BRIDGE

A new generation of Early Career Researchers in atmospheric chemistry: Navigating a globalized scientific landscape

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As the International Global Atmospheric Chemistry (IGAC) project marks its 35th anniversary, this paper examines the multifaceted experiences of Early Career Researchers (ECRs) navigating the increasingly globalized landscape of atmospheric chemistry. Drawing upon collective insights from the ECR Scientific Steering Committee and quantitative data from a survey of 180 ECRs across 40 countries, we investigate their primary motivations, challenges, and opportunities. Key obstacles identified include systemic difficulties in securing funding and resources, achieving sustainable work-life balance, and uncertainty around long-term career prospects, often compounded by precarious employment conditions. While globalization offers significant avenues for international collaboration, data sharing, and knowledge exchange, it concurrently presents challenges such as heightened competition, visa restrictions, regional disparities, and the risk of inequitable research practices. Despite these hurdles, ECRs are driven by a strong interest in their field, a desire to make a tangible impact on societal concerns, and the appeal of a supportive community. This perspective paper offers actionable insights focused on 4 key pillars: (i) strengthening mentoring programs; (ii) reforming funding mechanisms for improved accessibility and equity; (iii) providing targeted skill development workshops; and (iv) promoting equitable collaborations and advancing the decolonization of research practices. To foster a supportive, inclusive, and sustainable environment for the next generation of atmospheric scientists, this work underscores the urgent need for systemic change and sustained collaborative action by networks such as IGAC, as well as by senior researchers, academic institutions, and funding agencies.

Keywords: Early Career Researchers, Challenges, Atmospheric chemistry, IGAC, Globalization, International community

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1. Context and purpose

For 35 years, the International Global Atmospheric Chemistry (IGAC, igacproject.org) project has facilitated international collaborations to advance understanding of the impact of atmospheric composition on air quality, climate change, and ecosystems at all scales. Originating in the 1950s as the Commission on Atmospheric Chemistry and Radiation (CACR), and later the International Commission on Atmospheric Chemistry and Global Pollution (iCACGP, imas.org/icacgp/), IGAC officially became a core project of the International Geosphere-Biosphere Programme (IGBP) and iCACGP in 1990, now a Global Research Network on Future Earth. Its focus has evolved from understanding the natural atmosphere to addressing human impacts and promoting a sustainable world.

Early Career Researchers (ECRs), defined in this paper as the transition from doctoral studies to an established career in atmospheric chemistry, have played a central role in this evolution, bringing fresh perspectives and advancing the use of emerging technologies within an increasingly interconnected scientific landscape. Recognizing this, IGAC has progressively increased its focus on engaging ECRs to foster future scientific leadership and expertise. Since 2004, IGAC has included dedicated ECR programs as part of its biennial conferences (Melamed et al., 2015), which are pivotal for building cooperation and disseminating scientific information. The 2006 conference in South Africa initiated ECR networking lunches with established scientists, promoting mentoring and exchange. This support expanded significantly, notably during the 2014 conference in Brazil, which featured a comprehensive ECR program including excursions, skills-development workshops, and introductory courses. The 2016 USA conference introduced the first official ECR short course (IGAC NEWS, issue 58, 2016). Furthering this commitment, the iCACGP awarded the first Paul Crutzen Early Career Award in 2018, granted for an outstanding research contribution in atmospheric sciences by an ECR.

In parallel, new regional and global ECR networks emerged, most notably the Latin America Early Career Earth System Scientist Network (LAECESS, established in 2016), which originated within the IGAC community, the Young Earth System Scientists (YESS, established in 2010), the Surface Ocean Lower Atmosphere Study ECR Committee (SOLAS ECR Committee, formed in January 2023), and the Integrated Land Ecosystem-Atmosphere Processes Study Early Career Scientists Network (iLEAPS ECSN). These networks also brought relevant ECR perspectives on region- or topic-specific issues (Rauser et al., 2017; Dike et al., 2018; Langendijk et al., 2019; Yáñez-Serrano et al., 2022). In 2022, the IGAC Scientific Steering Committee (SSC) and the iCACGP discussed establishing an ECR SSC to integrate more ECRs into the project's decision-making, bringing fresh perspectives to address rapid technological advancements and the evolving globalized scientific landscape. Initiated in January 2023, the IGAC-iCACGP ECR SSC (ecr-igac-icacgp.org) aims to connect ECRs, foster collaborations, and provide opportunities for networking and professional development by amplifying ECR voices. This aligns with IGAC's mission to build scientific capacity and

cooperation globally. Through this ECR network, IGAC and iCACGP have committed to improving inclusivity and representation for the next generation of atmospheric scientists, striving to drive innovation by acknowledging ECRs' unique challenges and opportunities, a crucial step toward developing targeted support mechanisms discussed later in this paper. We emphasize that the aim of this paper is to highlight systemic challenges and barriers as perceived by ECRs themselves. The survey and analysis were designed to capture lived experiences and structural patterns, rather than to conduct a comparative policy review.

The “globalized scientific landscape” of today is characterized by increased competition, diverse opportunities, and potential for cross-cultural collaborations (Yáñez-Serrano et al., 2022), with profound implications for ECRs. It is important to recognize that this landscape is not static; it is continually influenced by evolving geopolitical, economic, public health, technological, and policy shifts (e.g., changes in national research funding priorities or global pandemics) that can rapidly alter the specific pressures and opportunities ECRs face, pressures to which ECRs are often particularly vulnerable due to their career stage and limited institutional security. This dynamic is particularly relevant given that our survey was conducted prior to the recent change in the U.S. administration, a shift that is already having significant implications for U.S. federal science funding, international mobility policies, and the stability of global research collaborations on which many ECRs depend. This perspective paper draws on a recent survey (see Section 2) and the ongoing experiences of the IGAC-iCACGP ECR community. It aims to examine the complex obstacles and prospects that ECRs face within this contemporary, globalized scientific landscape. Using these inputs, we will examine critical areas including funding, work–life balance, and career prospects, explore the impacts of globalization and systemic inequalities, and ultimately provide actionable insights and recommendations that empower ECRs to navigate inclusive, sustainable, and fulfilling careers in atmospheric chemistry.

2. Our approach

To understand the challenges faced by ECRs in atmospheric chemistry, a survey was shared with the broader IGAC community in English and Chinese, using personal networks, email distribution lists, and newsletters. It garnered responses from 180 ECRs across 40 countries.

Table 1 provides a detailed overview of the geographical distribution and mobility patterns of these 180 respondents, based on their self-reported region of origin and current region of residence. The data reveal that a significant majority of respondents (71.1%, $n = 128$) originated from Asia, with a notable portion from China. Europe was the next most common region of origin (10%, $n = 18$), followed by South America (6.1%, $n = 11$), Africa (5.6%, $n = 10$), and North America (4.4%, $n = 8$). Oceania, the Middle East, and Central America each accounted for 2 or fewer respondents by origin. Regarding current residence, most ECRs (84.4%) remained within their broader region of origin.

Table 1. Geographical origin, current residence, and mobility of ECR survey respondents (*n* = 180)^a

Origin	Total	Currently	Count		Origin	Total	Currently	Count	
			Moved	Stayed				Moved	Stayed
Africa	10	Africa	0	7	C. America	1	C. America	0	0
		Asia	0	—			Africa	0	—
		Europe	3	—			Asia	0	—
		Middle East	0	—			Europe	0	—
		C. America	0	—			Middle East	0	—
		N. America	0	—			N. America	0	—
		S. America	0	—			S. America	1	—
		Oceania	0	—			Oceania	0	—
Asia	128	Asia	8	105	N. America	8	N. America	0	4
		Africa	0	—			Africa	0	—
		Europe	4	—			Asia	0	—
		Middle East	1	—			Europe	2	—
		C. America	0	—			Middle East	0	—
		N. America	5	—			C. America	0	—
		S. America	0	—			S. America	1	—
		Oceania	5	—			Oceania	1	—
Europe	18	Europe	2	13	S. America	11	S. America	0	9
		Africa	0	—			Africa	0	—
		Asia	0	—			Asia	0	—
		Middle East	0	—			Europe	1	—
		C. America	0	—			Middle East	0	—
		N. America	0	—			C. America	0	—
		S. America	0	—			N. America	1	—
		Oceania	3	—			Oceania	0	—
Middle East	2	Middle East	0	2	Oceania	2	Oceania	0	2
		Africa	0	—			Africa	0	—
		Asia	0	—			Asia	0	—
		Europe	0	—			Europe	0	—
		C. America	0	—			Middle East	0	—
		N. America	0	—			C. America	0	—
		S. America	0	—			N. America	0	—
		Oceania	0	—			S. America	0	—

^aSummary of all the answers to the questions: “Where are you originally from?” and “Where do you currently study or work?,” for each of the following regions: Africa, Asia, Europe, Middle East, Central America, North America, South America, and Oceania. Each subpanel presents the total number per region on the left, and the current number of people who moved from or stayed in the region on the right side. ECR = Early Career Researcher.

However, the survey highlights considerable international mobility; 21.1% (*n* = 38) of respondents had moved from their original country of residence. This includes 15.6% (*n* = 28) who moved to a different global region entirely, and an

additional 5.6% (*n* = 10) who moved to a different country while remaining within their broader Asian or European region of origin. For instance, 30% of ECRs from Africa (*n* = 3) had moved to Europe, and 50% of ECRs from North

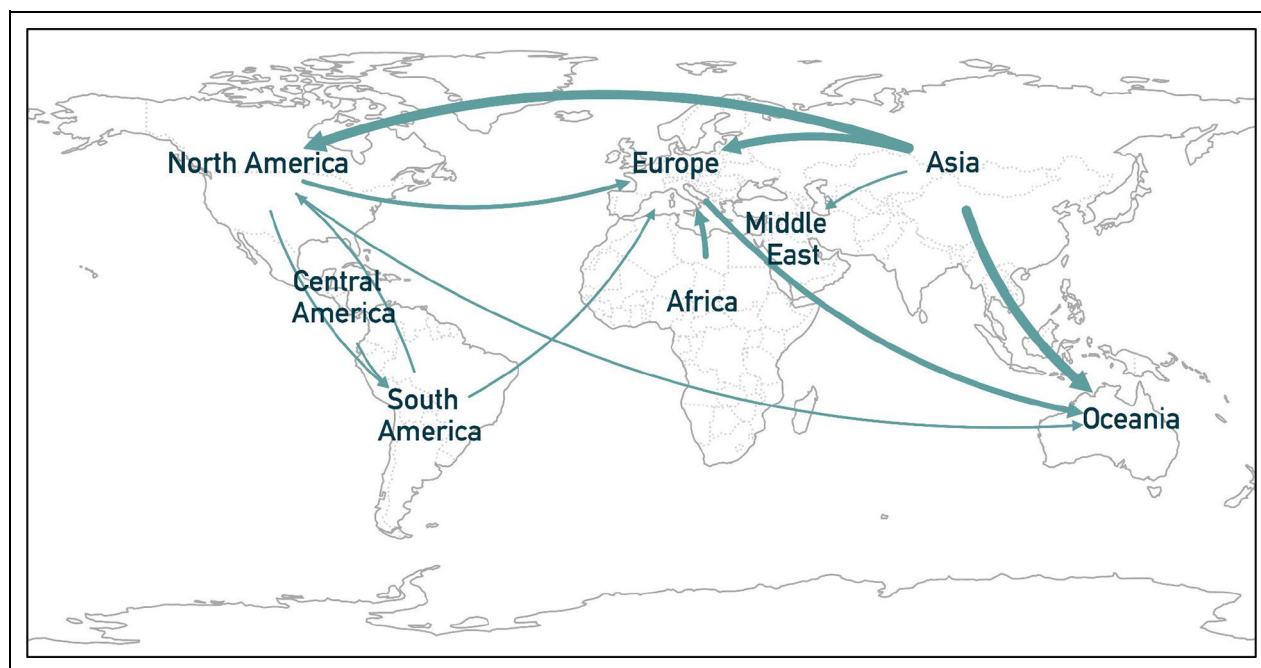


Figure 1. Global flow map of Early Career Researcher (ECR) interregional mobility ($n = 28$ respondents who moved from their region of origin). Summary of all the answers to the questions: “Where are you originally from?” and “Where do you currently study or work?,” where there is a difference in regions. Arrow thickness corresponds to the number of ECRs moving between specific regions.

America ($n = 4$) had moved to other regions. ECRs from Asia also showed movement to Europe, North America, Oceania, and the Middle East (11.7% of Asian-origin ECRs, $n = 15$).

To further visualize this international mobility, **Figure 1** presents a flow map illustrating the primary pathways of these interregional movements for the 28 ECRs who relocated from their region of origin to a different global region. Arrow thickness is proportional to the number of respondents. The map highlights key trends, such as notable movement from Asia to North America, Oceania, and Europe, and Europe as a significant destination for ECRs from Africa, Asia, and North America. This complements **Table 1** by geographically representing ECR mobility streams. This demographic overview, including the comparatively lower response rates from Africa, the Americas, the Middle East, and Oceania (relative to Asia and Europe) noted in **Table 1**, provides essential context for interpreting the perspectives shared and is an important consideration for the thematic analysis discussed in Section 3.

Participants also identified their biggest career obstacles (up to 3 entries) and their reasons for being in atmospheric science. These qualitative responses were unified for analysis and are visually represented through word clouds. All word clouds in this manuscript derive from these survey responses.

To generate the word clouds, all survey responses were first translated into English where necessary. Text preprocessing included conversion to lowercase, removal of punctuation, correction of common spelling errors, and filtering of standard English stopwords. To reduce redundancy and improve clarity, conceptually similar responses (e.g., “skills workshops” and “skill seminars”; “stressful work environment” and “stress at work”) were grouped

under shared terms. This grouping was performed manually using the four-eye principle, meaning that at least 2 authors independently reviewed and validated each grouping decision. The resulting cleaned and grouped datasets were used to generate word clouds using a Python script, with word or phrase frequency determining the relative font size. These word clouds serve as visual summaries that highlight key themes and recurring ideas across the ECR responses.

3. The ECR experience: An overview of motivations and common challenges

Atmospheric science draws people from around the world driven by a deep sense of curiosity, purpose, and concern for the planet. As reflected in our survey responses (**Figure 2**), ECRs enter the field motivated by interests in climate change, air quality, health impacts, and the broader societal relevance of atmospheric processes. Words like “passion,” “impact,” “community,” and “curiosity” dominate the responses, alongside themes of sustainability, public engagement, and the desire to contribute to meaningful change. For many, atmospheric science offers the chance to explore complex environmental systems, address urgent global challenges, and apply interdisciplinary thinking to real-world problems. It is a field where scientific inquiry intersects with societal need, an intersection that makes the work not only intellectually rewarding but also personally fulfilling. Still, navigating a career in atmospheric science, particularly in its early stages, comes with a unique set of challenges that warrants attention.

Early stages in academic careers, typically encompassing postdoctoral positions and early to mid faculty or

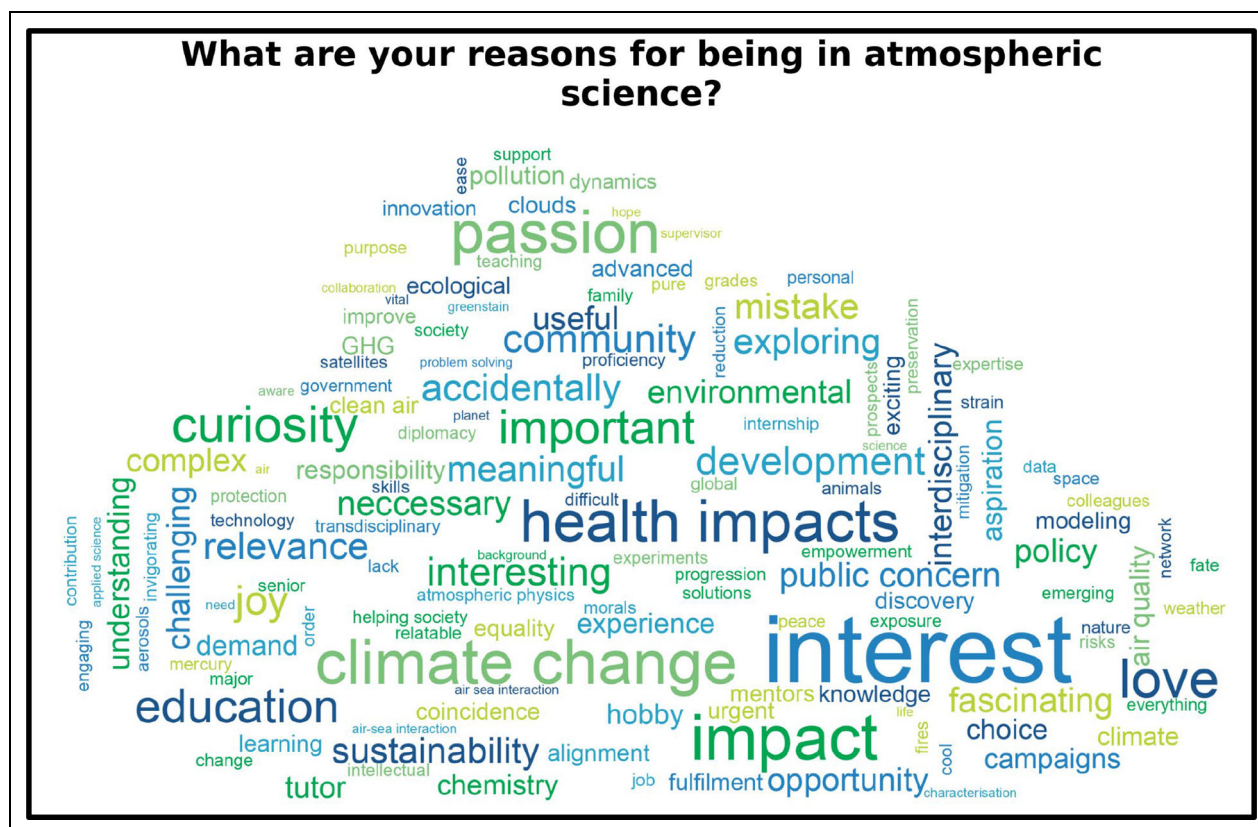


Figure 2. Word cloud of answers from all participants ($n = 180$) to the survey question: “What are your reasons for being in atmospheric science?” Font sizes displayed for words or phrases according to the relative frequency of responses for each one.

research scientist roles before achieving long-term stability, are characterized by intensive professional development, burgeoning independence, and the drive to establish a distinct scientific identity. However, it is also a phase marked by significant vulnerabilities and a common suite of challenges that transcend geographical and institutional boundaries, even as their specific manifestations and intensities vary.

Our survey data (**Figure 3**) highlight several overarching difficulties. The most prominent is structural and financial insecurity, stemming from difficulties securing funding, accessing essential resources, and the prevalence of short-term, precarious employment contracts. Secondly, ECRs consistently report struggles with well-being and maintaining a healthy work environment, due to intense workloads, pressures to achieve work–life balance, and associated mental health strains. Thirdly, significant uncertainty clouds career development and recognition, with unclear pathways to long-term positions and intense competition. These core themes, visually summarized by ECR responses to “What are the biggest challenges you faced as an ECR?” (**Figure 3**), form the backdrop against which this paper explores the ECR experience. It is important to note that the prominence of certain themes in our survey, or the lesser emphasis on others like specific mental health issues or instrumentation access (a known barrier in many regions), may be influenced by the respondent demographics (Section 2: **Table 1**, **Figure 1**), particularly the

overrepresentation from Asia and lower response rates from other regions. However, as a qualitative check, the diverse author group, representing a wide range of geographical regions and career stages, found that the overarching themes from the survey aligned closely with their own collective experiences, which provides some confidence that the core challenges identified are broadly representative. The following sections delve into these key challenge areas, examine globalization's impacts, and propose recommendations to improve the ECR experience.

4. Key challenge areas for ECRs

The following subsections explore the 3 core themes of challenges identified in Section 3 in greater detail, drawing on further survey insights, relevant literature, and regional examples.

4.1. Structural and financial insecurity

ECRs face significant challenges in securing adequate funding and resources (**Figure 3**). Perceptions of funding in science are dominated by terms like “competitive,” “difficult,” “scarce,” and “uncertain” (**Figure 4**). This insecurity, acute for ECRs (Dike et al., 2018; Valenzuela-Toro and Viglino, 2021; North et al., 2022; Yáñez-Serrano et al., 2022), is marked by complex, bureaucratic, and often perceived as “political” processes, with significant regional disparities.



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For ECRs in some regions, such as parts of Southeast Asia, securing funding is a major hurdle without a strong publication record or network. Many opportunities prioritize senior researchers, creating a frustrating cycle: no funding means fewer resources (e.g., purchased data, lab equipment), hindering outputs needed for future funding, a cycle requiring intervention. This reliance on external collaborations restricts independence and can lead to methodological shifts, for example, toward primarily computational modeling due to a lack of access to field and laboratory resources, even if advanced modeling also requires significant computational resources and a combined approach would be scientifically optimal.

Beyond project work, limited funding also constrains professional development opportunities such as conference attendance, especially for researchers in low-resource settings. Participation in major international meetings (e.g., American Geophysical Union—AGU, European Geosciences Union—EGU) is critical for building networks and visibility, yet travel and registration costs often place these events out of reach. Regionally focused conferences such as the Asia Oceania Geosciences Society (AOGS) or the Japan Geoscience Union (JpGU) may offer more accessible options for ECRs in specific regions and could be further encouraged to strengthen dedicated ECR support initiatives. These barriers not only affect individual career progression but also limit the diversity of voices shaping global atmospheric science.

International mobility, often considered essential for career progression, presents significant financial and structural barriers for ECRs. Costs associated with visas, health surcharges, and relocation are frequently unreimbursed, while variations in fees and funding schemes across countries can disadvantage researchers moving to high-cost-of-living regions. These financial obstacles can limit access to diverse research environments, international collaborations, and global networks.

The impacts of limited funding and constrained mobility are evident across regional contexts. For instance, in Latin America, funding challenges persist alongside other structural issues such as precarious professional roles, visa limitations, language barriers, gender bias, heavy teaching loads, limited access to scientific literature, scarce grant funding, high processing fees, leading to a disproportionate underrepresentation of Latin America research in international events and open-access indexed journals (Valenzuela-Toro and Viglino, 2021; Moutinho, 2024). In Japan, declining PhD student numbers are linked to stagnant income and resource constraints, reducing research capacity and shifting graduates to industry (Shimmi, 2021). South Africa saw significant ECR grant reductions (e.g., a reported 28% drop in postgraduate/researcher grants for 2023–2025), exacerbated by socioeconomic movements like *#FeesMustFall*, highlighting education access/affordability issues (Nordling, 2024). These findings underscore the urgent need for systemic reform to simplify funding processes, expand access for ECRs, address financial inequalities, improve infrastructure and data availability, and ensure that opportunities for mobility and advancement are equitably distributed.

4.2. Well-being and work environment

The demands of globalized science have reshaped ECRs' professional lives. Expectations for high-impact research, funding acquisition, international collaboration, teaching, and outreach, overlap with unstable employment and a challenging work–life balance (Levecque et al., 2017). The Coronavirus Disease 2019 (COVID-19) pandemic further amplified these issues (Lopez-Verges et al., 2021). The demands of atmospheric chemistry, such as intensive fieldwork, laboratory experiments, and continuous monitoring, often lead to long working hours and limited flexibility. Consistently, ECRs report elevated stress and work overload (**Figure 3**). Surveys indicate over 50% of ECRs work more than 50 h per week, many regularly on weekends (Woolston, 2020), and nearly 70% struggle with work–life balance, with over 25% working 10–12 h daily (Arslan and Bartlett, 2020). These demands often conflict with personal responsibilities.

Job insecurity from short-term contracts often necessitates relocation. This transient lifestyle, while offering international experience, can hinder stable support systems, impacting mental health and productivity (Cilli et al., 2023), exacerbate stress, and lead to “mobility fatigue” (Schaer, 2022). Consequently, ECRs face elevated risks of anxiety, depression, and burnout (Levecque et al., 2017; Bartels et al., 2022; Cilli et al., 2023), highlighting an urgent need for supportive frameworks. Empirical evidence underscores this: 49.7% of young Chinese researchers reported anxiety symptoms (Wang et al., 2021), and over half of young Belgian researchers reported multiple mental health problems (Levecque et al., 2017). In Latin America, unwritten standards in international science and the language barrier lead to feelings of exclusion (both cultural and academic), as mental health issues, learning gaps, brain drain, and the rise of anti-science movements were exacerbated by the pandemic (Valenzuela-Toro and Viglino, 2021; Sigahi et al., 2023).

While support mechanisms exist, their availability and effectiveness are uneven. For instance, initiatives in Japan aim to reduce language/cultural barriers for foreign ECRs, fostering collegiality (Ali et al., 2020; Sakurai and Mason, 2023). However, even where formal support like mentoring exists, often concentrated in the Global North, access can be inconsistent. In the United Kingdom, ethnic minority academics may lack effective mentoring (Harris and Ogbonna, 2023), and self-stigma can deter help-seeking (Cage et al., 2020). Similar constraints hinder programs in Africa (Mabokela and Mlambo, 2017) and India, where institutional inefficiencies can undermine ECR well-being (Parveen et al., 2025). Many ECRs thus rely on informal networks and individual strategies, often insufficient for systemic issues (Woolston, 2020).

Generational comparisons show a widening gap: today's Millennial/Generation Z (Gen Z) ECRs face a hyper-competitive environment with fewer permanent positions and greater instability than previous generations (Ng et al., 2018; Fuchs et al., 2024), increasing uncertainty. Academia's digitalization has blurred work–life boundaries, fostering constant availability and burnout risks (Guthrie et al., 2018). This necessitates institutional

5. Impact of globalization on ECRs

Globalization has profoundly reshaped science, fostering collaboration, knowledge exchange, and innovation by breaking down geographical/institutional barriers. However, while offering immense opportunities, it presents downsides: resource concentration in the Global North, unequal access to networks/journals/scholarships, and potential reproduction of colonial science hierarchies. Despite this, globalization underscores environmental/climate research's unifying potential. Examples include UN-promoted regional collaborations in Asia (Gupta et al., 2004), the National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS), the European Union's (EU) Copernicus program, and the global AErosol RObotic NETwork (AERONET), which democratize data and support collaborative study of climate impacts across divides (Yáñez-Serrano et al., 2022). For ECRs, this globalized framework brings transformative opportunities and complex challenges. Access to shared datasets, networks, and international mentorship empowers ECRs but demands adaptability to cultural differences, logistical hurdles, and heightened competition. Understanding globalization's impact on ECRs is critical for equitable scientific progress and advancing IGAC's mission. While promising for equitable opportunities, systemic inequities persist; some ECRs leverage global networks while others face barriers from geography, resource disparities, or institutional hierarchies. The following sections explore this duality.

5.1. Challenges of globalization

While globalization expands scientific opportunities, it presents significant challenges, especially for ECRs from less-developed regions or marginalized institutions. International collaborations can be difficult for developing countries due to complex rules and data transfer issues. Hybrid conferences, despite accessibility benefits, pose technical/engagement challenges. Visa restrictions are a major issue, with ECRs struggling to secure visas for events in nations like the United Kingdom/United States (Lubošny et al., 2025), missing crucial networking and knowledge exchange. Professional mobility is key, but not accessible to all due to personal/financial constraints (e.g., U.K. work visas may not permit spousal work). In a system that often prefers a diverse international resume, those unable to relocate may find themselves at a disadvantage.

For ECRs moving abroad, especially from low- to middle-income countries, challenges persist post-arrival. Scholarship living allowances may be below minimum wage, often insufficient for living costs, forcing students to seek extra work. This is harder for those with families due to childcare/health-care costs. Securing additional scholarships is difficult, as many are restricted to citizens/permanent residents. Finding jobs is also hard, with many positions prioritizing citizens or excluding international applicants from government roles. The COVID-19 pandemic highlighted these vulnerabilities.

Globalization has intensified academic competition. ECRs from less-resourced regions face disadvantages from limited access to training, resources, and networks. This

power imbalance can lead to inequitable collaborations, with wealthier institutions dominating. Exploitation or “colonial science,” where Global South ECRs contribute significantly to Western-led campaigns without due recognition, is a concern (Haelewaters et al., 2021; Lambert et al., 2024), with anecdotal evidence suggesting it's prevalent, demanding shifts toward equitable paradigms (explored in Section 6.4). Publishing is another hurdle; researchers from lesser-known institutions/regions struggle for recognition in high-impact journals. Limited funding for Article Processing Charges (APCs), lack of mentorship in peer-review navigation, and global science biases restrict research visibility. Systemic inequalities persist even within the Global North (e.g., Western vs. Eastern Europe, prestige vs. underfunded universities).

Language barriers exacerbate these issues. Non-native English speakers spend significantly more time on reading/writing papers, face higher rejection rates, and receive more revision requests due to language (Amano et al., 2023). This linguistic disadvantage affects confidence, deterring conference presentations vital for career growth. It can also subtly hinder leadership development, as perceived competence can be influenced by fluency, irrespective of qualifications, particularly in virtual interactions. Securing positions abroad is effortful for ECRs from less-developed countries. Upon return, many face difficult career trajectories due to gaps in the home-country research infrastructure/support, hindering translation of international experience into local progression. Limited funding, facilities, and under-prioritization of fields like air pollution/climate science prevent local advancement, often forcing repeated searches for international roles. This stifles growth and contributes to brain drain, where trained researchers cannot fully contribute to their home countries, perpetuating a cycle that requires concerted international effort and strategic investment to counteract.

5.2. Opportunities of globalization

ECRs today encounter unprecedented opportunities to advance their careers and drive scientific progress, potentially aligning with many core career aspirations (Figure 5, Section 4.3). Globalization empowers ECRs to connect with international networks, fostering cross-border collaborations essential for global atmospheric challenges and contributing to goals like “positive impact” and a “better world.” Accessing diverse funding and global platforms enhances research capacity and builds reputations as “scientists” and “experts.” This interconnected landscape allows engagement with cutting-edge ideas and technologies, accelerating personal development toward “self-fulfillment” and scientific advancement. However, these opportunities are not equally accessible, and translation into stable careers remains a hurdle.

Mobility is key (Table 1, Figure 1), with international funding grants (e.g., Marie Curie, Chevening, Fulbright) facilitating travel for new networks, skills (“innovator”), and “influential publications,” strengthening profiles for roles like “professor” or “teacher.” Persistent ECR-supervisor networks aid professional circle expansion and

future “leadership” (Potts, 2015). Virtual tools and remote work offer alternatives for those unable to travel, enabling international collaboration and continued engagement. International training and mentorship programs offer guidance from experienced researchers worldwide. Effective mentorship aids “scientific success” and talent retention, though often at the institution level (Section 6.1) (Muschallik and Pull, 2016; Wang and Shibayama, 2022).

Open science resources and Artificial Intelligence (AI) tools facilitate collaboration, knowledge sharing, and bridge language barriers. Global conferences, workshops (including IGAC’s biennial science conference and dedicated ECR online events), and digital platforms enhance research dissemination and networking, vital for “reputation.” Many offer financial aid to increase diversity. Preprint servers and increasing open-access journals (though APCs can be high; Nobes and Harris, 2023) improve research transmission, with some journals offering fee waivers for low-income countries, supporting “influential publications.” Global datasets (e.g., Group on Earth Observations—GEO, Coupled Model Intercomparison Project—CMIP), repositories, and open-source software reduce research costs and empower “innovators.” These ECR opportunities also benefit the broader scientific community. International collaborations enhance research quality through diverse perspectives and local expertise (Kendal et al., 2022) and are more likely to be published in open-access (e.g., Iyandemye and Thomas, 2019). The Amazon Tall Tower Observatory (ATTO) research station (German-Brazilian project) exemplifies such success. Funding bodies benefit from supporting international research via global expertise and high-quality outputs. Despite these advances, challenges in accessibility, sustainability, flexible work policies, open-access costs, and effective data sharing persist. These challenges are particularly vulnerable to the influence of shifting geopolitical priorities and rising scientific nationalism, where the principles of open collaboration and data sharing can be undermined by national interests, unpredictable funding shifts, and increasing pressure from commercial data providers.

5.3. Role of networks

Global networks are essential to solving global problems, particularly in atmospheric chemistry, where the drivers and impacts of atmospheric change transcend national borders and demand collaborative, cross-disciplinary action. Organizations like IGAC and other networks (from large international to smaller national scale) play a crucial role in enabling such collaboration by connecting researchers across regions, facilitating knowledge exchange, and building capacity. In doing so, they also help create more equitable environments for ECRs, promoting regional committee representation, empowering ECRs, and strengthening global science. These networks expand access to resources that are often unevenly distributed, including advanced training, opportunities for authorship, and entry into international research collaborations that would otherwise remain inaccessible to many.

However, networks have limitations and can reproduce power dynamics, requiring conscious facilitation. Virtual informal interactions are harder, potentially favoring previously established connections at in-person events. ECRs from less-visible institutions/regions may struggle with access due to a lack of connections or support; language barriers and cultural hierarchy norms can also hinder participation. While IGAC aims for regional diversity, balanced participation is challenging; our ECR committee grapples with this, potentially impacting this publication’s global perspective. Volunteer fatigue is pressing, with network tasks often unrecognized institutionally, burdening underrepresented groups expected to lead representation efforts.

Despite challenges, network value is clear. Respondents describe the IGAC community as “collaborative,” “supportive,” “international,” and “diverse” (**Figure 6**). Some members refer fondly to the “IGAC family,” reflecting a sense of community for those engaged, often via conferences. At their best, these networks provide not just opportunities but a community that supports researchers through the multifaceted challenges of academic life. In a competitive and complex system, these relationships can often be the most meaningful and enduring part of the job.

6. Recommendations and way forward

The preceding sections analyzed ECR challenges in atmospheric chemistry within a globalized landscape. While significant, these are not insurmountable. This section explores potential recommendations, drawing on literature and IGAC community insights, aiming to foster a more supportive, equitable, and sustainable ECR environment. These proposed actions broadly encompass strengthening mentoring, improving funding accessibility/equity, targeted skills development, and promoting equitable/decolonized research practices. The recommendations detailed below are designed to address the core challenges identified by ECRs. **Table 2** provides a summary mapping of these key challenges to the corresponding pillars of action, which are discussed in the following subsections. By examining these areas, we aim to provide actionable recommendations for institutions, funding bodies, senior researchers, and ECR networks, including examples of initiatives already undertaken by the IGAC-iCACGP ECR SSC.

6.1. Mentoring programs

Effective mentoring is a cornerstone of ECR support, offering guidance beyond formal training for career and psychosocial well-being. Amid pressures to publish, secure funding, and collaborate, robust mentoring helps ECRs shape trajectories and foster ethical practices. Today’s approaches focus more on shared learning, mutual support, and building networks among peers, rather than relying on one-way, top-down mentorship. Thoughtful design and critical evaluation are key for effectiveness, as success often depends on mentor–mentee compatibility, the preparedness and training of mentors themselves (though mentoring skills are also often honed through

6.2. Improved access to funding

Securing adequate, timely funding is a major ECR challenge (Section 4.1). Addressing this requires a multipronged approach for systemic change. Funding agencies, research institutions, and universities must implement strategies for better ECR access: more numerous, targeted ECR grants recognizing potential over extensive track records, and enhanced support for international collaborations via dedicated funding. Funding mechanisms must also be designed to accommodate the realities of short-term contracts. Equitable funding distribution across regions/institutions is critical. Though researcher distribution is uneven, current mechanisms can exacerbate disparities. Efforts should identify/support talent globally, via targeted initiatives or weighting applications for regional resource limitations. Agencies could learn from the European Research Council's streamlined ECR grant proposals. Promoting international mobility necessitates funding reform, including the reduction or full coverage of ancillary relocation costs such as visa fees and health surcharges. Institutional initiatives for open data, research infrastructure, and collaborative network access are essential, as they are linked to funding success. Shared open-access repositories and facilities can help bridge resource gaps faced by ECRs. Finally, greater emphasis on capturing and showcasing ECR project successes and impacts, beyond traditional publications, can highlight achievements such as skills development, network expansion, and societal contributions. Structured impact statements can be a valuable tool to demonstrate this value, advocate for sustained investment, and reinforce the case for more equitable ECR funding.

De Winde et al. (2021) provide outlines for improving the grant review process and recommendations to both funders and reviewers, aimed at equalizing research funding for ECRs. They categorize their recommendations into 4 key topics: funding priorities (such that funding is also given to fundamental research and considering how we assess applications and whether the need for funding can be included), improving the application and review process (targeting bias and wasted time on applications among other suggestions), improving grant conditions (such that they better account for factors such as parental leave, career breaks, nontraditional career routes, and international candidates or those wanting more academic mobility), and finally funding schemes (considering alternative funding schemes such as lottery funding to eliminate bias in the review process).

We also encourage regionally focused conferences to continue expanding ECR participation opportunities through travel support and accessible formats.

In addition to individual-level funding, sustaining the infrastructure of international scientific networks is critical. Organizations like IGAC may also need to explore diversified and resilient funding sources, including philanthropic and non-U.S. governmental support, to safeguard long-term coordination and ECR programming.

6.3. Skill development workshops

Skill workshops are crucial, offering competencies complementing formal training and addressing curricular gaps.

They enhance ECR independence, confidence, and career longevity. Given the IGAC-iCACGP ECR community's disciplinary and geographical diversity, workshops must be inclusive, flexible, and responsive. This includes ensuring accessibility across different time zones, language background, and levels of available research infrastructure, so that ECRs from resource-limited regions or non-English-speaking contexts can participate on equal footing. Our survey highlighted communication, programming, writing, data analysis, and networking as vital (**Figure 7**). Technical skills (programming, data analysis) are fundamental for large datasets/computational methods; “soft skills” (collaboration, resilience, critical thinking) are equally valued. This aligns with studies that found that ECRs prioritize training in how to secure funding (Bhakta and Boeren, 2016) and identify commonly required skills via job vacancy analysis (Maer-Matei et al., 2019).

Workshop themes include communication/writing (science communication, thesis, publication, and grant writing); data science/programming (coding, visualization, AI applications); and professional development (networking, career planning, leadership, cross-cultural collaboration, research ethics including “helicopter science”). Recognizing these needs, the IGAC-iCACGP ECR SSC has organized workshops on topics such as science communication and proposal writing. Emphasizing interdisciplinary and transferable skills not only supports immediate research goals but also enhances long-term career versatility. Effective workshop design requires balancing synchronous and asynchronous formats, optimizing duration and interactivity, and committing to regular evaluation. Equity in implementation can also be advanced by offering free registration, travel support for in-person sessions, and recorded content for those with limited Internet connectivity or schedule conflicts, thereby broadening access for underrepresented or marginalized ECR groups. In parallel, providing ECRs with leadership opportunities within scientific societies offers invaluable experience and professional growth.

6.4. Equitable collaborations and decolonizing research

While globalization offers opportunities, actively fostering equitable collaborations and decolonizing research is imperative for fair benefit distribution (Heleta and Jithoo, 2023). This means dismantling historical power imbalances that disadvantage ECRs from less-developed and marginalized settings. Equitable collaboration ensures genuine partnership: equal voice in research design, execution, data ownership, interpretation, and dissemination, irrespective of location and affiliation. Decolonizing atmospheric science research means challenging norms perpetuating “colonial science” (e.g., Global South ECRs contributing significantly to Western-led campaigns without proportionate recognition and benefit; Garland et al., 2024). Counterstrategies to address inequities in atmospheric science include codesigning projects with local stakeholders and scientists, establishing fair data sharing and intellectual property agreements, prioritizing the development of local research capacity and infrastructure,

- Third, the widespread provision of skill development workshops addressing important technical and professional competencies, from data science and communication to leadership and ethical research practices.
- Finally, a commitment to fostering equitable collaborations and sound research practices to address power imbalances and ensure fair recognition and benefits for all contributors, particularly those from less-resourced regions. An overarching goal of these measures is to support the well-being of ECRs.

Yet we must also acknowledge that many of these recommendations depend on adequate resources. As global research systems face increasing financial constraints, some challenges, particularly around funding security and long-term career prospects, may intensify. In this context, it is vital that we also support ECRs in exploring and transitioning into diverse, meaningful careers beyond academia. These pathways should still honor the motivations that drew them to atmospheric science: curiosity, a commitment to public good, and a desire to address urgent environmental challenges. Supporting diverse, meaningful career outcomes must be part of a broader vision for a healthy and inclusive scientific ecosystem.

Looking ahead, this perspective piece could serve as a foundation for more formal, wide-scoping analyses. Future efforts would be greatly enhanced through collaboration with social scientists specializing in survey methodology, working alongside other ECR networks within Future Earth and the broader community, to quantitatively assess these challenges and the efficacy of support mechanisms across the environmental sciences.

Organizations like IGAC, along with other international and national scientific bodies, institutions, and funding agencies, have a significant part to play in promoting and facilitating these adjustments. By fostering inclusive networks, advocating for policy improvements, encouraging best practices, and providing direct support to ECRs, these entities can contribute to a more equitable and supportive global scientific community. This is a collective responsibility, requiring coordinated efforts from senior researchers who mentor, institutions that cultivate supportive work environments, funders who adapt their strategies, and ECRs themselves who continue to articulate their needs and contribute their perspectives. Achieving a fully supportive global environment for the next generation of atmospheric scientists is an ongoing process, but by addressing these challenges proactively and collaboratively, we can better enable ECRs to navigate their careers and contribute effectively to the innovative research required to understand and address significant atmospheric challenges.

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Competing interests

The authors have declared that no competing interests exist.

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During the preparation of this manuscript, generative AI tools (Google Gemini 2.5 Pro) were utilized to assist with organizing initial author contributions, ensuring stylistic consistency across sections, and refining language for clarity and conciseness. All authors reviewed and edited the AI-assisted outputs, taking full responsibility for the final content and conclusions presented.

Author contributions

Contributed to conception and design: MD, MOPR, STA, CB, SD, HB, TH, SS, KV, YL, EM.

Contributed to analysis and interpretation of data: MD, MOPR, FB, SM, PT.

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