Empowering the Next-Generation Climate Scientists: Insights from the 2023 Forecasters' WEB (ForWEB) Exchange Program/Hackathon at KNUST, Ghana

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Abstract

In response to the escalating climate change issues, the Forecasters' WEB (ForWEB), established by the Department of Meteorology and Climate Science, KNUST, collaborated with the Department of Atmospheric and Climate Science, UENR to host the first, exchange program/hackathon. The program aimed at equipping students with knowledge, practical skills, and a collaborative ethos for addressing the challenges posed by climate change. The program's curriculum included forecasting techniques, scientific programming, and interactive sessions with mentors from academia and industry. Participants engaged in practical case assessments, focusing on examining historical climate change across Africa. The analysis revealed discernible shifts in the climate patterns with increased temperatures across the continent, whereas no clearly defined pattern in precipitation was observed. The program yielded remarkable outcomes, substantiating the effectiveness of providing students with training that enhances their skills and fosters collaboration. The paper delves into the program's strengths, limitations, and outcomes, offering insights into fostering the next generation of climate scientists while bridging the academia-industry gap. Also, the program also provided a platform for the students to apply theoretical knowledge to real-world, climate issues. Such initiatives play pivotal roles in developing the skills and passion needed to address urgent climate-related issues, ensure sustainable climate futures.

Keywords: Climate Action; ForWEB; Forecasters' WEB; Climate Education; KNUST; UENR

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1. Introduction

In an era marked by unprecedented environmental challenges, the imperative to cultivate a new generation of climate scientists is not merely an academic endeavor but a global necessity **(Boyd, 2010, Porter et al., 2020; Antó et al., 2021)**. Climate change, with its far-reaching consequences, underscores the critical importance of advancing our understanding of Earth's complex systems and fostering innovative solutions to mitigate its impacts **(IPCC, 2021)**. Against this backdrop, the Forecasters' WEB (ForWEB) at the Department of Meteorology and Climate Science, Kwame Nkrumah University of Science and Technology (KNUST) and the Department of Atmospheric and Climate Science, University of Energy and Natural Resources (UENR) collaborated to organise a transformative 12-day exchange program/hackathon. This initiative sought to empower selected students with the multidisciplinary knowledge, practical skills, and collaborative spirit essential for addressing the intricate challenges posed by climate change, particularly through the utilisation of scientific computing tools and resources. The exchange program/hackathon aligns with the broader international efforts to enhance climate education and empower the next generation of scientists to contribute meaningfully to climate resilience **(Læssøe and Mochizuki, 2015; Mochizuki and Bryan, 2015; Arduino, 2017)**.

The ForWEB is a dynamic research and educational initiative originally started at KNUST, Kumasi, Ghana. Established in 2020 under the visionary leadership of the Vice Chancellor of KNUST and the Provost of the College of Science-KNUST, ForWEB emerged with a dedicated mission to cultivate expertise in climate science, environmental sustainability, environmental stewardship and related disciplines. It began with a humble but enthusiastic membership of five undergraduate students who shared a passion for understanding and addressing the pressing challenges of climate change.

The ForWEB's mission is twofold. Firstly, it seeks to improve daily, impact-based weather forecasting for enhanced early warnings, recognizing the critical role of accurate weather predictions in disaster preparedness and response. Secondly, it aims to engage weather and climate stakeholders through a series of outreach programs, fostering collaboration and knowledge exchange between academia, government agencies, stakeholder industries/groups, and local communities. Through intensive workshops, practical exercises, and mentorship, the program aims to enhance technical competencies, problem-solving abilities, and understanding of climate change challenges. Generally, the program strives to create a platform for students to exchange knowledge, ideas, and experiences, promoting a cross-pollination of insights and perspectives. By bringing together students from different academic backgrounds and institutions, the program encourages networking, collaboration, and the generation of innovative solutions to address the urgent climate-related issues faced globally. This initiative's commitment to fostering the next generation of climate scientists is exemplified through its partnerships with educational institutions like the UENR. By facilitating programs such as student exchange initiatives and hackathons, ForWEB plays a pivotal role in equipping students with the skills, knowledge, and passion needed to address the complex and urgent issues posed by climate change.

As we delve into the insights and outcomes of the KNUST-UENR joint exchange program/hackathon, it is essential to recognize the pivotal role that ForWEB has played since its inception towards providing daily, impact-based weather forecasting **(Figure 1a)** and engaging with stakeholders to promote climate resilience and early warnings **(Figure 1b)**.

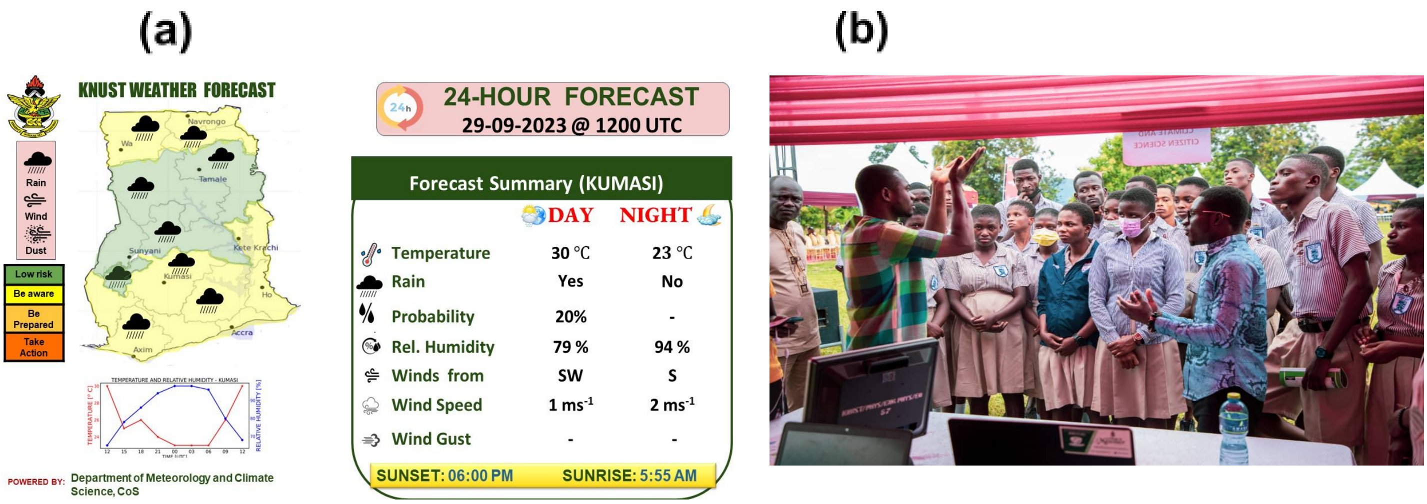

Figure 1: ***(a)*** *Sample 24-hour forecast issued on the 29th September 2023 and* ***(b)*** *section of some past ForWEB members educating students from the School for the Deaf on “Climate, Weather and Citizen Science” at a Science Fair and Outreach program in the Atiwa East District, Ghana on June 30, 2022.*

The urgency of climate action **(Hansen, 2013; Phillis et al., 2014; Fesenfeld & Rinscheid, 2021; Gills and Morgan, 2022)** compels us to critically assess the effectiveness of such educational initiatives aimed at nurturing the next generation of climate scientists. This paper focuses on the insights gleaned from the 2023 KNUST-UENR exchange program/hackathon, offering a comprehensive analysis of its strengths, weaknesses, sample outputs from the program and potential avenues for leveraging its impact. By exploring the experiences of participants and evaluating the program's outcomes, we aim to provide a roadmap for institutions and organizations seeking to develop similar initiatives. As we navigate the complex terrain of climate science education, this collaborative effort exemplifies the convergence of science, innovation, and collective action required to effectively confront and mitigate the pressing challenges posed by contemporary climate-related issues.

2. The Exchange Program and Hackathon

A. Overview of the program

Over the course of 12 days, a total of 6 student participants from the Department of Atmospheric and Climate Science (DACS), School of Geosciences, UENR and 3 peer-learners from ForWEB-KNUST, Department of Meteorology and Climate Science, Faculty of Physical and Computational Sciences, College of Science, KNUST participated in a rigorous and intensive program which gave them the opportunity to peer-learn and advance their knowledge in Scientific Computing and Atmospheric Sciences; highlighting the importance of Scientific Computational Resources for educating future climate scientists **(Pollock et al., 2019; Molthan-Hill et al., 2022)** and showcasing both institutions' commitment to achieving this. Participants for the exchange program/hackathon were selected based on various factors, including but not limited to **(i)** gender, **(ii)** diverse educational levels and research interests, **(iii)** academic performance and **(iv)** their interests in advancing atmospheric sciences beyond the frontiers of research into the realms of co-production for improved solutions that meet the needs of vulnerable communities. Particularly for the students from DACS-UENR, they were selected through their stellar performance and demonstration of the above-highlighted criteria at an earlier three-day Python programming workshop held at UENR as part of the Atmospheric and Climate Science Students Association (ACSSA) Week celebration. Although numerous students attended the workshop (rigorous crash course in Python) at UENR, only these top six students were selected for the exchange program. The knowledge and experience gained during the earlier workshop proved invaluable for the exchange program/hackathon.

The exchange program/hackathon solidified the existing partnership between both institutions (2 of the only 4 institutions that pursue a mainstream undergraduate programme in Atmospheric Sciences). Not only did this collaboration advance students' skills, it also enhanced academic growth, joint research and innovation which has significant benefits for the wider community. This collaboration is a testament to the strength of collaborative work that impacts society and the nation as a whole. Thus, fulfilling the larger goal of the hackathon to encourage a sense of community and co-development among young climate scientists with similar interests in using technology to study, understand, and potentially mitigate the challenges posed by climate change and other atmospheric phenomena.

B. Curriculum and activities during the exchange program/hackathon

The exchange program/hackathon, among other things, introduced participants to basic forecasting techniques and Scientific Programming with Python for atmospheric science applications. The skills and knowledge acquired in the highlighted areas will prove beneficial to instituting a formidable ForWEB at UENR, with a goal of training other students. The Organizers recognized the varying levels of knowledge and diversity among the participants. As such, peer-facilitation modes were employed which allowed the participants to co-learn in a conducive environment. They began with the basics of Python programming language, and then moved on to analysing climate data using the various Python libraries such as pandas, and matplotlib among others. The peer-facilitation style encouraged effective participation by all participants.

As part of the training, the participants interacted with mentors from both industry and academia who educated them on how climate change affects us, and the need for collaborative strategies in dealing with climate change **(Figure 2)**. The mentors also shared various academic and industry-related advice on major application areas of Climate Science. As part of the engagement, the participants interacted with (i) an expert in Air Quality and Clean Air Advocacy, (ii) Provost of the College of Science, KNUST, and (iii) an experienced Grants Manager with the Office of Grants and Research, KNUST.

Figure 2: *Some resource persons engaging a section of the participants during the exchange program/hackathon.*

Also, participants had an educational tour of the KNUST Agro-meteorological field site **(Figure 3)** where they were introduced to some meteorological instruments, their working principles and their data collection processes.

Figure 3: *A section of the participants embarking on a fieldwork at the KNUST Agrometeorological Field Site on September 29, 2023.*

3. Sample Analysis: Historical Assessment of Precipitation and Temperature Changes in Africa

Despite the relatively brief duration of the program, participants were engaged in practical applications, leveraging acquired skills for real-life analysis. Specifically, participants investigated climate change over Africa using near-surface air temperature and precipitation data. The data used for this sample analysis was retrieved from the Climatic Research Unit **(CRU)** produced by the University of East Anglia **(UEA)**. The data is a time series version 4.05 **(CRU TS4.05)** data and can be assessed via https://crudata.uea.ac.uk/cru/data/hrg/, together with accompanying metadata. The analyses involved employing statistics to scrutinise four (4) historical climatological regimes (namely, the baseline climatic regime **[BC; 1901-1930]**, climatic regime 2 **[CR2; 1931-1960]**, climatic regime 3 **[CR3; 1961-1990]**, and climatic regime 4 **[CR4; 1991-2020]** respectively) and assessing the spatiotemporal changes across the African continent.

Figure 4 captures the baseline climatic regime (1901-1930; hereafter termed **BC**) mean annual total precipitation and the respective anomalies of the successive climatic regimes (1931-1960, 1961-1990, and 1991-2020, hereafter termed **CR2, CR3 and CR4 respectively**), which represents the magnitude of precipitation change between each individual climatic regime and the baseline. Spatial absolute climatologies and standard deviations are detailed in **Appendix A2**.

Generally, the precipitation changes show more spatial heterogeneity. In tandem with existing literature **(Hulme, 1992; Nicholson, 2000; Hoerling et al., 2006)**, the regions of West Africa and Central Africa experience heavier annual rainfall. The interplay of topography, vegetation, and climate dynamics in these areas contributes significantly to deep convection, cloud formation and rainfall activities **(Aryee et al., 2018, 2019, 2021; Baidu et al., 2017)**. Across West Africa, a greater part was characterized by wetter climates (exceeding 50 mm) within CR2 and followed by vast drier regions (below 75mm) in CR3 which marginally reduced in its spatial extent in CR4. The Sahel has recorded similar features as West Africa, however with the central parts of the Sahel recording a weak, wet signal in the final climatic regime. In East Africa, drier climates prevail during CR2, with subsequent regimes (CR3, CR4) witnessing a reversal characterized by reduced intensities in the final climatic regime. Southern Africa exhibits systematically drier conditions on its eastern parts compared to the baseline, while the western ends record relatively wetter conditions, albeit with reduced spatial coverage. These findings contribute valuable insights into the temporal evolution and spatial dynamics of precipitation patterns in the demarcated zones of Africa.

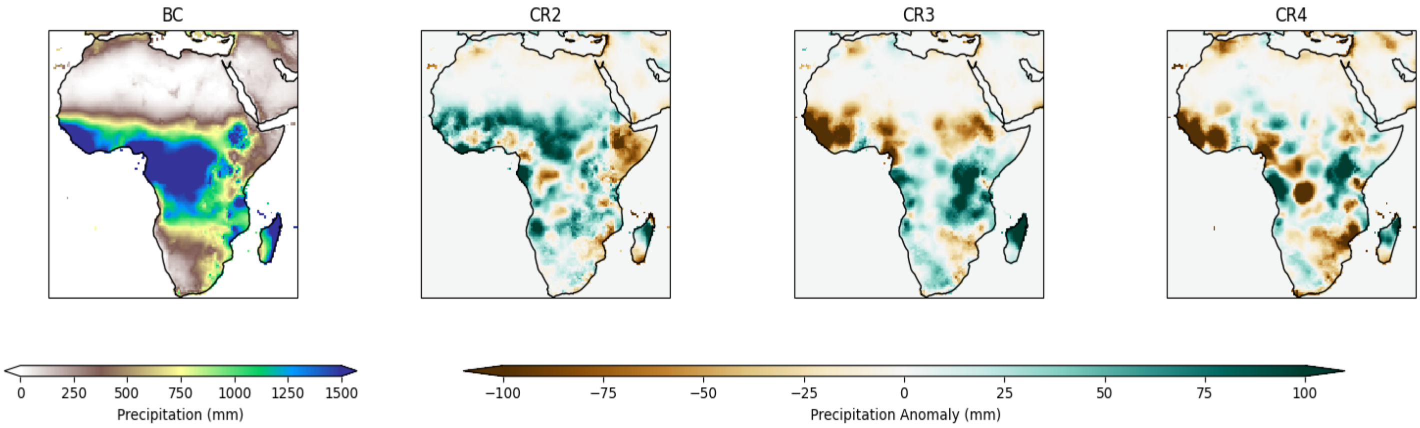

Figure 4: *Mean annual rainfall total for the **BC** regime and respective anomalies for the **CR2, CR3** and **CR4** regimes. The green color range of the precipitation difference/anomaly indicates wetter climates and the brown color indicates dry climates compared to **BC**.*

Figure 5 captures the **BC** mean annual temperature and the respective anomalies of the successive climatic regimes (**CR2, CR3 and CR4**), which represents the magnitude of temperature change between each individual climatic regime and the baseline. Spatial absolute climatologies and standard deviations are detailed in **Appendix A1**. A general and sequential increase is observed in the historical temperature profile, with hotspots of significant increase experienced in the western Sahel, across the Greater Horn of Africa (in East Africa) and Southern Africa. On the other hand, Madagascar, which was relatively cooler within the CR2 and CR3 regimes has gradually been warmed within CR4, especially in the southern part of the country.

The warming of the African continent has repercussions on climate extreme events and socio-economic activities. These repercussions likely include more frequent and intense heatwaves, erratic rainfall, and prolonged droughts **(Nkomo et al., 2006; Ayugi et al., 2022; Clarke et al., 2022)**. Also, potential sea level rise may threaten coastal regions, causing saltwater intrusion and displacement **(Gornitz, 1991; Urama and Ozor, 2010; Nicholls, 2011)**. Again, the potential for intensified tropical cyclones could lead to destructive storms, impacting infrastructure and lives **(Nkomo et al., 2006; Hope Sr, 2009; Clarke et al., 2022)**. Other socio-economic indicators that could potentially be affected include changes in agriculture, driven by altered temperature and precipitation patterns, thus posing risks to food security **(Gregory et al., 2005; Fonts et al., 2011; Kotir, 2011; Myers et al., 2017)**. Moreover, the prevalence and distribution of vector-borne diseases, like malaria and dengue, could be altered, with plausible expansions in their spread associated with climate change, thereby affecting public health **(Githeko et al., 2000; Sutherst, 2004; Vora, 2008; Bouzid et al., 2014; Campbell-Lendrum et al., 2015; Ogden, 2017; Chala and Hamde, 2021; Tozan et al., 2021)**. Urgent adaptation strategies, sustainable development, and international cooperation are imperative in light of these observations. Addressing these challenges demands immediate action and collaborative efforts on a global scale.

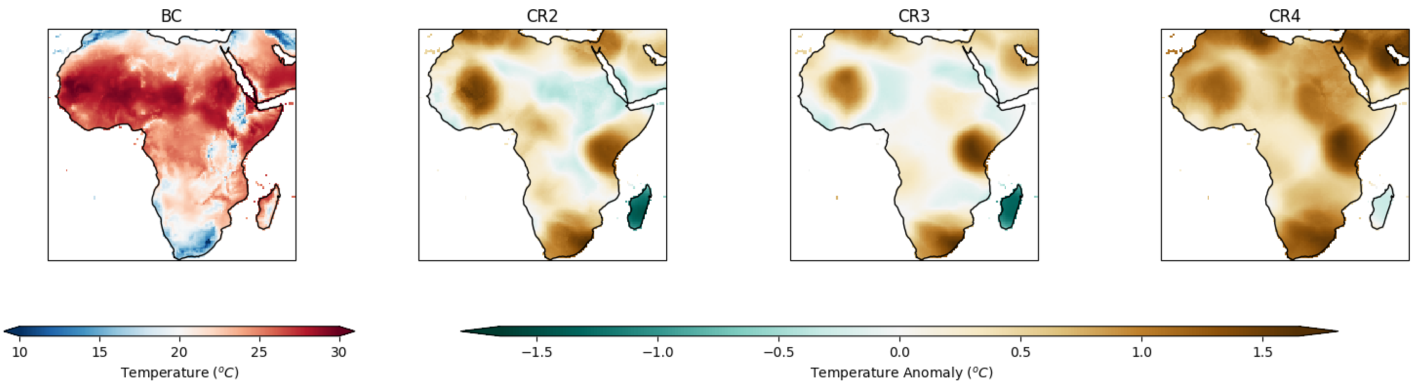

Figure 5: *Mean annual temperature for the* ***BC*** *regime and the respective anomalies for the* ***CR2, CR3*** *and* ***CR4*** *regimes. The green color range of the temperature difference/anomaly indicates cooler climates and the brown colors indicate warmer climates compared to the baseline climate.*

Thereafter, the continent was demarcated into 7 distinct bounding boxes **(Figure 6a)** and further temporal assessments were performed for each demarcation. Unstandardized timeseries are captured in **Appendix A3** and **A4**. From **Figure 6b**, all the demarcated regions experienced peak temperature anomalies within CR4, which were warmer than normal (exceeding +1 standardized anomaly). The North, by far, experienced the warmest temperature with anomaly peaks extending as high as +3 (~ 2 standard deviations above normal). The general temperature anomaly profiles detects a steady increase towards the end of BC, which thereafter declines towards the early 1970s. During the BC, temperatures were relatively cooler with, North-eastern, East and West Africa indicating temperature anomalies below the -1 standardized anomaly. Although South-Eastern Africa remained relatively cooler, a significant rise in temperature anomaly was observed, peaking in the mid-BC periods. North Africa showed an increasing trend in temperature anomaly. Temperature anomaly in West Africa dropped significantly reaching a record low of about -2 standardized anomaly. The start of CR2 was marked by an increase in temperature anomalies across West Africa, the Sahel and Central Africa. While industrialization and human activities were not as prominent in the 1930s as most recent decades, the observations of climate warming are likely attributable to a combination of natural factors (such as increased solar radiation, natural climate variability, possible Atlantic Multidecadal Oscillation, amid other climate cycles) and anthropogenic factors (such as extensive aerosol concentrations linked to numerous volcanic eruptions and the World War II, land use modifications) as highlighted in **(Hegerl et al., 2018)**. Thereafter, the mid of CR2 to the end of CR3 witnessed a significant climatic cooling, with record-low temperature anomalies within the Sahelian region. Generally, the post-CR2 periods which mark the global industrialization periods, and more so, heightened industrial activities across Africa **(McNeill & Engelke, 2016)** recorded exponential rise in the temperature anomalies.This compelling evidence strongly supports the assertion that the climate is indeed warming and doing so at a fast pace.

Regarding precipitation **(Figure 6c)**, no clear or defined pattern is established in any of the demarcated zones. Precipitation amounts seem rather sporadic and the most obvious observation is a huge dip in precipitation amounts (maximum aridity) for almost all zones except the southern zones in the early 1980s **(Spinage, 2012)**. Prior to this period, the lowest peak recorded was in 1915 over Central Africa. Also, there are significant increases in annual rainfall totals in East Africa within CR4. Additionally, the greatest rainfall anomalies were observed within the late CR2 and early CR3 periods, with almost all the zones recording wetter than normal conditions (standardized anomalies exceeding +1 and extending even to +3 in some instances). From these observations, it is imperative to know that unlike temperature, the storylines for precipitation are highly uncertain, and thus raises more concern for instituting climate-resilient measures.

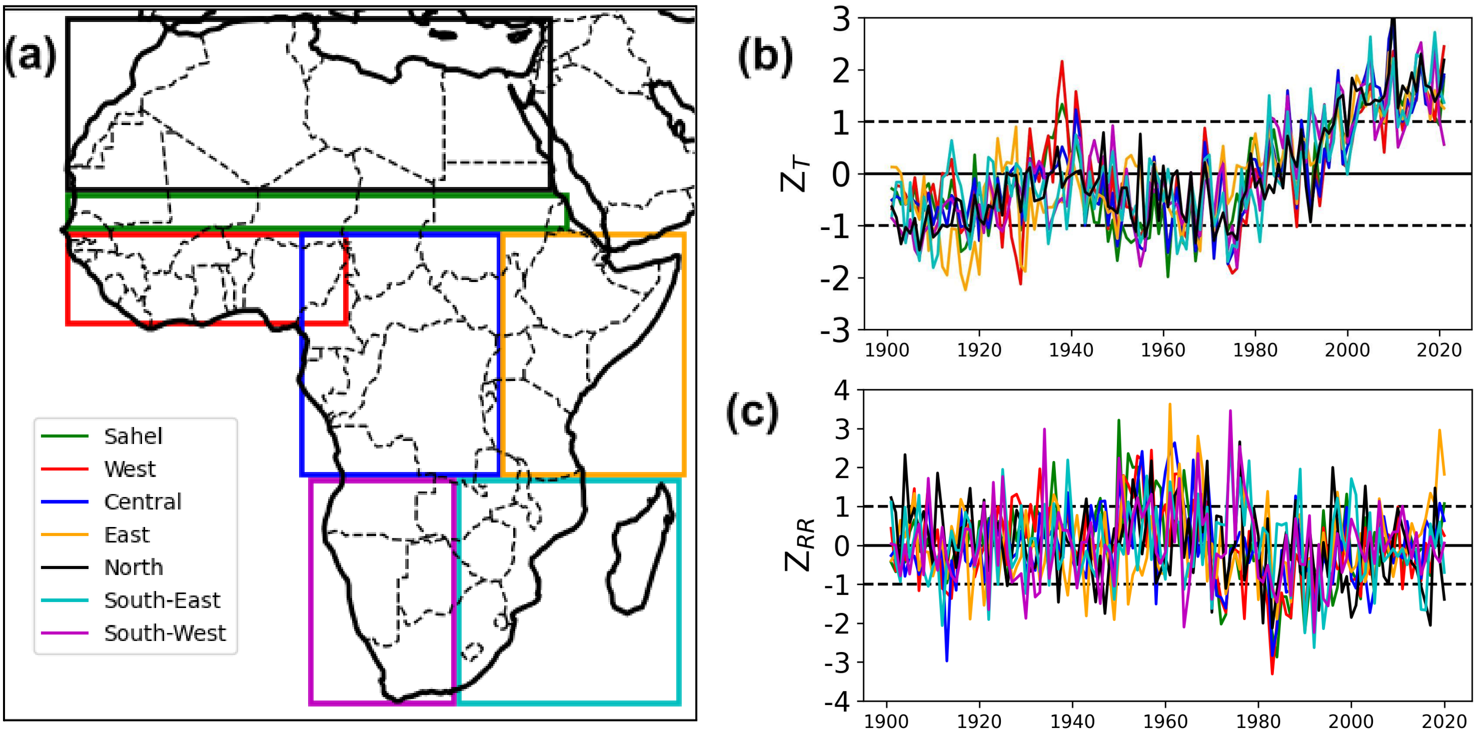

Figure 6: *Evolution of temperature and precipitation changes across seven demarcated zones of Africa, namely West Africa (West), Sahel, East Africa (East), Central Africa (Central), South-western Africa (South-West), South-eastern Africa (South-East) and Northern Africa (North) as highlighted in the figure legend. The demarcations are detailed in* ***(a)****. Standardized temperature anomalies (b) and standardized precipitation anomalies (c) indicate normal events (-1⩽ z ⩽ 1), warmer/moister (z>1) or cooler/drier (z<-1) periods per each zone.*

4. Insights and Discoveries from the Exchange Program/Hackathon

The partnership between the two institutions yielded remarkable outcomes, further substantiating the efficacy of providing students with training that enhances their skills. The joint effort by both institutions in this year’s training is clear testament of their dedication to providing quality and real-world-impacting education. Both universities combined resources and expertise, and created an environment where students can access top-quality training that fosters a spirit of collaboration and facilitates the sharing of knowledge that extends beyond the confines of their respective campuses. Among the many benefits derived from this training, include but not limited to:

A. Fostering the next generation of climate scientists

The responsibility for addressing the critical challenges presented by climate change majorly rests in the hands of the emerging generation of climate scientists, indicating that the future is reliant on their contributions and efforts. By providing educational opportunities, mentorship programs and research initiatives, ForWEB aims at cultivating a team of passionate individuals dedicated to unravelling the complexities of climate science. Also, FworWEB fosters a culture that values critical thinking, creativity and interdisciplinary cooperation through teamwork and sharing of resources. As such, the exchange program/hackathon made strides towards this target by training and grooming the UENR cohorts who upon return to their campus will spearhead the formation of ForWEB-UENR chapter as part of the FORWEB approach to ensuring a sustainable and resilient climate future.

B. Bridging the gap between academia and practical climate solutions

Academic research plays a turning point role in deepening our understanding of the climate dynamics, assessing the consequences of human activities and innovative technology exploration. However, the communication and translation of this knowledge must be done effectively into tangible strategies that address the pressing issues of climate change faced by many communities, industries, and the governments in general. One of the gaps between academia and practical climate solutions is the accessibility of academic findings. One of the benefits of this exchange/hackathon was the engagement with some industry players who encouraged the participants to make their research works industry-oriented and as much as possible, need to involve the industries along the research rather than only communicating end-of-research recommendations to them. This will ensure an effective co-production and joint stewardship of the findings/research outputs and policy actions that the study will produce. Also, the participants received training on how to ensure that their research communications to industry players are in both **(i)** technical, and **(ii)** easy-to-assimilate, non-technical formats for broader engagement.

C. Enhancing interdisciplinary learning

An effective interdisciplinary learning catalyst is the incorporation of climate and weather forecasts into educational courses. This interdisciplinary approach provides students with a comprehensive perspective on the Earth's complex systems. By studying weather patterns, students can grasp the scientific principles governing atmospheric phenomena, fostering a solid foundation in physics and meteorology. This understanding also helps young scientists to know the intricate processes shaping the Earth’s atmosphere and find solutions to the challenges posed by the changes in these processes. However, the ability to achieve the deepest, comprehensive knowledge about the Earth’s climate system through rigorous study has been imparted to the upcoming scientists through the exchange program/hackathon, making them develop an idealistic way of solving climate problems and other issues.

D. Strengthening university partnerships

Another integral benefit of the exchange program/hackathon is the strengthening of existing collaboration between both institutions. A key item both institutions look forward to is to have ForWEB institutionalized and sustained in UENR as has been done in KNUST. The greater focus is to have ForWEB impact a greater Ghanaian community and this can be done if every partner institution is strengthened sufficiently enough. Generally, by harnessing the uniqueness of each institution in the training of students, ForWEB will produce high-calibre ambassadors, well equipped to tackle the numerous climate challenges confronting today's societies.

E. Encouraging innovation and research

The exposure of students to learn and interact with diverse groups of peers can catalyse innovation, facilitate cross pollination of ideas, promote creativity and the potential for groundbreaking research outcomes. Through the exchange program/hackathon, a research environment was created where students could leverage on the atmospheric science knowledge and programming skills they acquired to enhance their research skills and address real-world climate challenges. Additionally, the exchange program/hackathon provided the students access to computing resources, software, programming tools and research database, to encourage their undertaking of ambitious research initiatives.

5. Student Perspectives on the Exchange Program/Hackathon and Recommendations for Future Events

While documenting the challenges of this experience, we also highlight general challenges that have faced the ForWEB team since its inception. Some of these include logistical issues and resource constraints arising from the limited availability of accurate meteorological data in Ghana and challenges related to internet connectivity. Moreover, balancing academic commitments with the demanding forecasting program is another challenge for the ForWEB ambassadors, who are concurrently students. Simply put, ForWEB is not an operational meteorological centre, as some activities such as provision of forecasts are issued only once daily at 1100 UTC. In response, the initiative is promoting time management strategies and support mechanisms to help ambassadors maintain a balance between academic responsibilities and their forecasting roles.

Also, an evaluation survey was taken at the end of the exchange program/hackathon and below are some responses from the participants as recommendations for future exchange programs/hackathons:

- In subsequent sessions, it will be helpful to increase the number of participants admitted into the initiative in order to help realize the dream of empowering more climate scientists to be at the forefront of the current climate crisis.
- It will be beneficial if the duration of the program is extended to at least a month to help the beneficiaries learn and grasp more concepts and also get ample time to work on more real-life projects.

- Of course, increasing the number of beneficiaries and the duration of the program calls for an increase in logistics.

- Inclusion of a stakeholder engagement/outreaches will also add to the participants' co-production skill.

6. Conclusion

The relevance of initiatives like the exchange program/hackathon for nurturing climate scientists are critical in developing the next generation of climate scientists and promoting innovation and problem-solving in the field of climate change. It provides a hands-on, experiential learning platform for students and aspiring climate scientists to apply their theoretical knowledge to real-world climate concerns. The KNUST-UENR joint exchange program/hackathon organized by the Forecasters' WEB (ForWEB) stands as a pivotal initiative in the realm of climate science education. The collaboration exemplifies the essential role of education and interdisciplinary learning in preparing students for impactful contributions to climate resilience in the face of escalating environmental challenges. Summarizingly,

I. The program successfully advanced the mission of cultivating a new generation of climate scientists, emphasizing critical thinking, creativity, and interdisciplinary cooperation. By empowering participants with both theoretical knowledge and practical skills, ForWEB is effectively contributing to the development of a team of passionate individuals dedicated to unraveling the complexities of climate science.

II. Through engagement with industry players, the program addressed the gap between academic research and practical climate solutions. Encouraging participants to orient their research towards industry needs ensures effective co-production and joint stewardship of findings, facilitating impactful policy actions based on the study's outcomes.

III. Incorporating climate and weather forecasts into educational courses showcased the effectiveness of an interdisciplinary approach. By studying weather patterns, participants gained a comprehensive perspective on Earth's complex systems, fostering a solid foundation in physics and meteorology. This understanding equips emerging scientists to find solutions to challenges posed by changes in these processes.

IV. The exchange program/hackathon strengthened collaboration between KNUST and UENR, furthering the institutionalization of ForWEB. This collaboration not only benefits the participating students but also contributes to the greater Ghanaian community. By leveraging the unique strengths of each institution, ForWEB is poised to produce high-caliber ambassadors equipped to tackle the numerous climate challenges confronting today’s societies.

V. The exposure of students to diverse peers and mentors during the exchange program/hackathon catalyzed innovation and facilitated cross-pollination of ideas. By creating a research environment focused on real-world climate challenges, the program stimulated the potential for groundbreaking research outcomes and enhanced the participants' research skills.

VI. Despite its success, challenges such as logistical issues and resource constraints were acknowledged. The participants' recommendations, including increasing the program's duration and the number of beneficiaries, provide valuable insights for enhancing future exchange programs/hackathons. Addressing these recommendations could further amplify the positive impact of ForWEB initiatives in empowering climate scientists for the ongoing climate crisis.

In essence, the collaborative efforts serve as a model for institutions globally seeking to prepare students for the multifaceted challenges posed by contemporary climate issues.

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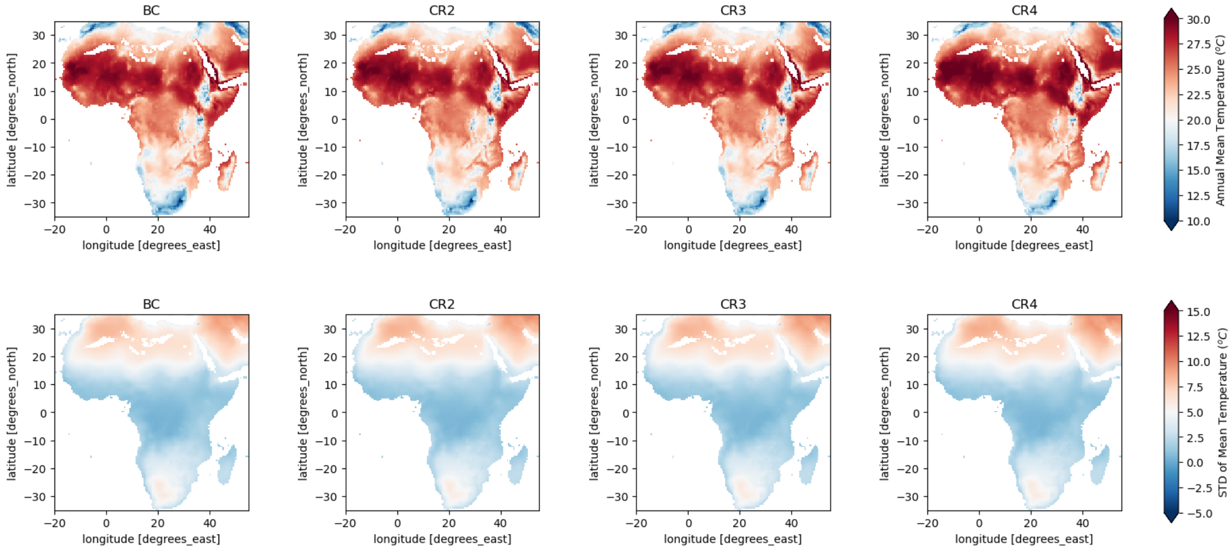
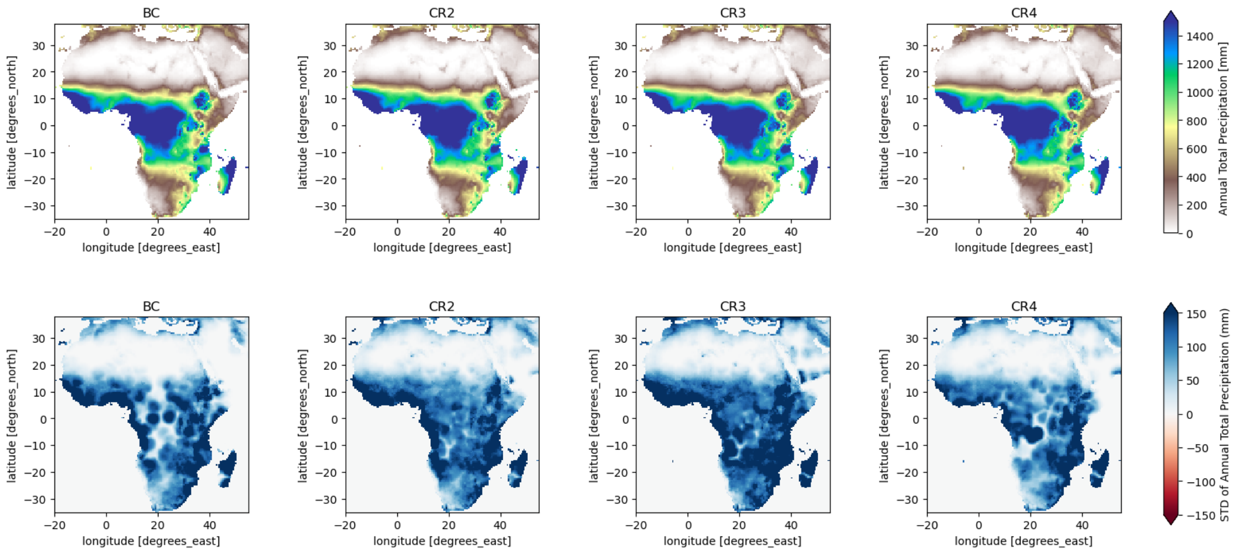
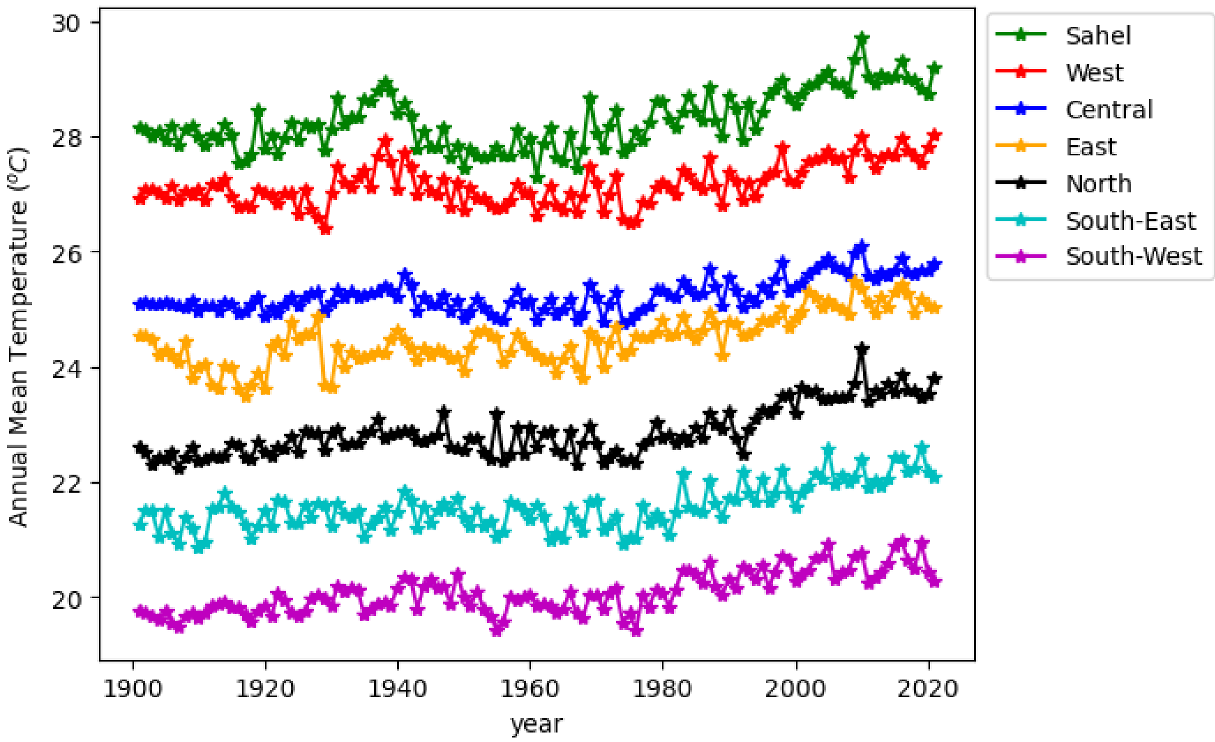
Appendix



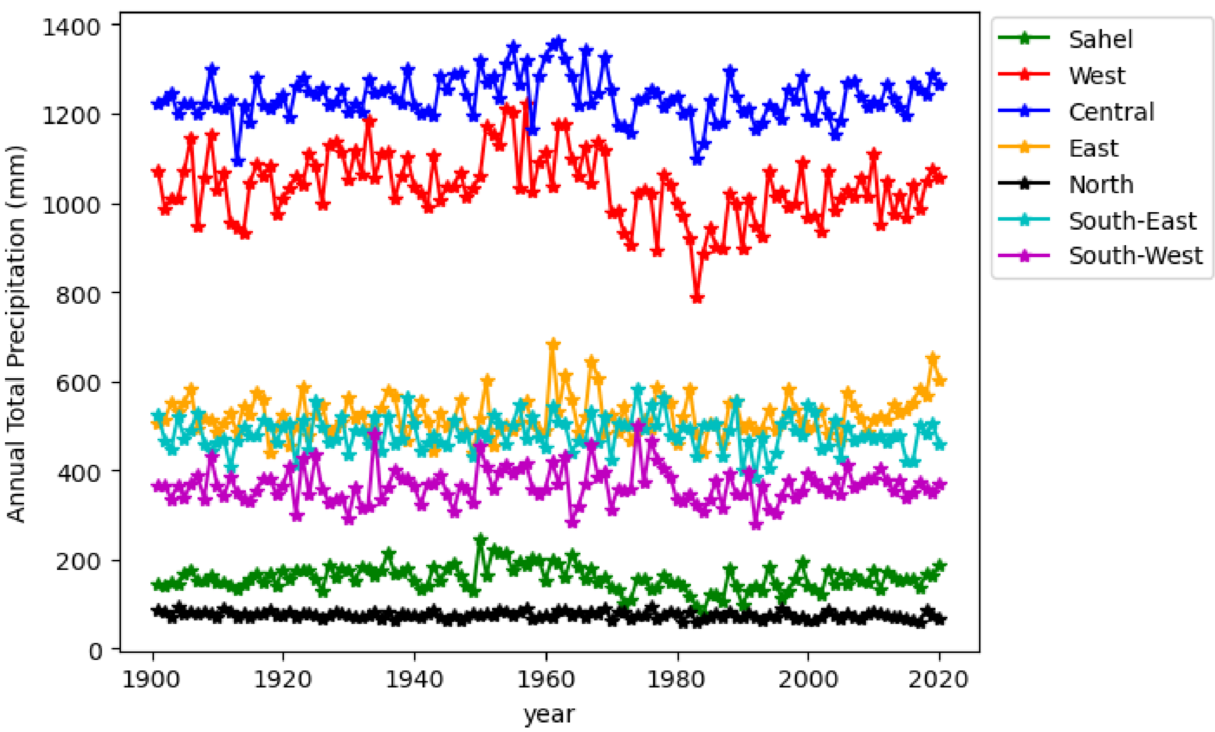
A1: *Climatological means (top) and standard deviations (bottom) of temperature over Africa for the BC, CR2, CR3 and CR4 climatic periods (from left to right). Red regions in the top highlight warmer areas while the blues capture colder regions. Positive standard deviations suggest that the temperature data points are spread out above (generally higher than) the average, whereas negative deviations suggest that the temperature data points are spread out below (generally lower than) the average. The larger the positive (negative) standard deviation, the more spread out the higher (lower) temperatures are from the mean.*



A2: *Climatological mean annual totals (top) and standard deviations (bottom) of rainfall over Africa for the BC, CR2, CR3 and CR4 climatic periods (from left to right). Positive standard deviations suggest that the rainfall data points are spread out above the average (generally wetter), whereas negative deviations suggest that the rainfall data points are spread out below the average (generally drier). The larger the positive (negative) standard deviation, the more spread out the higher (lower) rainfalls are from the mean.*



***A3:** Annual Mean Temperature time series for the seven demarcated regions.*



***A4:** Annual Total Precipitation time series for the seven demarcated regions.*

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Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

All authors contributed equally to the manuscript. The exchange program/hackathon was conceptualized by JNAA, CM and NAP.