EMI R&D PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2026
Project Title:	260 years of African climate: Transient projections with HCLIM
Computer Project Account:	spdktorr
Principal Investigator(s):	Dr Jose Abraham Torres Alavez
Affiliation:	Danish Meteorological Institute (DMI)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Shingirai S. Nangombe (Climate Scientist) Ruth Mottram, Senior Scientist Ole Bøssing Christensen, Senior scientist Fredrik Boberg, Senior scientist
Start date of the project:	2026
Expected end date:	2028

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)			45000000	537,318
Data storage capacity	(Gbytes)			250000	0

Summary of project objectives (10 lines max)

This project aims to investigate future climate change across Africa throughout the 21st century by dynamically downscaling CMIP6 GCM projections using the latest version of the HARMONIE-Climate (HCLIM) regional climate model, following the CORDEX framework. The project will first conduct evaluations and sensitivity experiments to optimize the model for pan-African, accounting for the continent's diverse climate regimes and complex large-scale climate drivers. Following model optimization, high-resolution climate simulations will be produced to provide detailed projections of temperature, precipitation, and climate extremes across Africa. The main objective of these simulations is to address a major gap in localised current climate information in Africa, as there are currently no high-resolution CMIP6-based CORDEX simulations available for the continent. The resulting datasets will support climate risk assessment, adaptation planning including through Danish Meteorological Institute's (DMI's) projects on climate services development, and detection and attribution studies in Africa, providing valuable climate information for decision-makers and stakeholders across Africa.

Summary of problems encountered (10 lines max)

The original plan was to dynamically downscale GCM simulations over Africa to a horizontal resolution of 12 km. However, the execution time for running long-term climate simulations over the entire African continent at this resolution is significantly greater than initially anticipated. To ensure the timely delivery of the simulations and enable their use in analyses contributing to the IPCC Seventh Assessment Report (AR7), the project scope was revised to produce simulations at a 25 km grid resolution instead of 12 km. This adjustment provides a practical balance between spatial detail, computational cost, and AR7 timelines while still delivering high-quality regional climate information for Africa.

Summary of plans for the continuation of the project (10 lines max)

The set-up and tuning of the model and hindcast downscaling are in the final stages of completion. The downscaling of CMIP6 model outputs is scheduled to begin on the 1st of July 2026 will be based on transient 130-year simulations (1970-2100) under the shared socio-economic pathway 3-7.0 (SSP3-7.0). These simulations will be driven by two GCMs i.e., NorESM2 and MPI-ESM1-2-HR. The plan is to run climate simulation of one member of each model in 2026, with additional simulations or models investigated in subsequent years. We plan that all outputs will be made open access and CORDEX (COordinated Regional-climate Downscaling Experiment) compliant. The outputs will support climate risk assessment, adaptation planning including through DMI's projects on climate services development, and detection and attribution studies in Africa, providing valuable climate information for decision-makers and stakeholders not only in project countries but across Africa.

List of publications/reports from the project with complete references

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Summary of results

The work so far has largely been on evaluating the model based on the ERA5 evaluation simulations. Fig 1 shows the pan-Africa domain we are using in this project spanning 45° S to 45° North, and 20° West to 60° East. It also shows a map with African regions marked used in the evaluation i.e., West Africa (WA), East Africa (EA), South Central Africa (SCA) and East Southern Africa (ESA) (Wu et al., 2020).

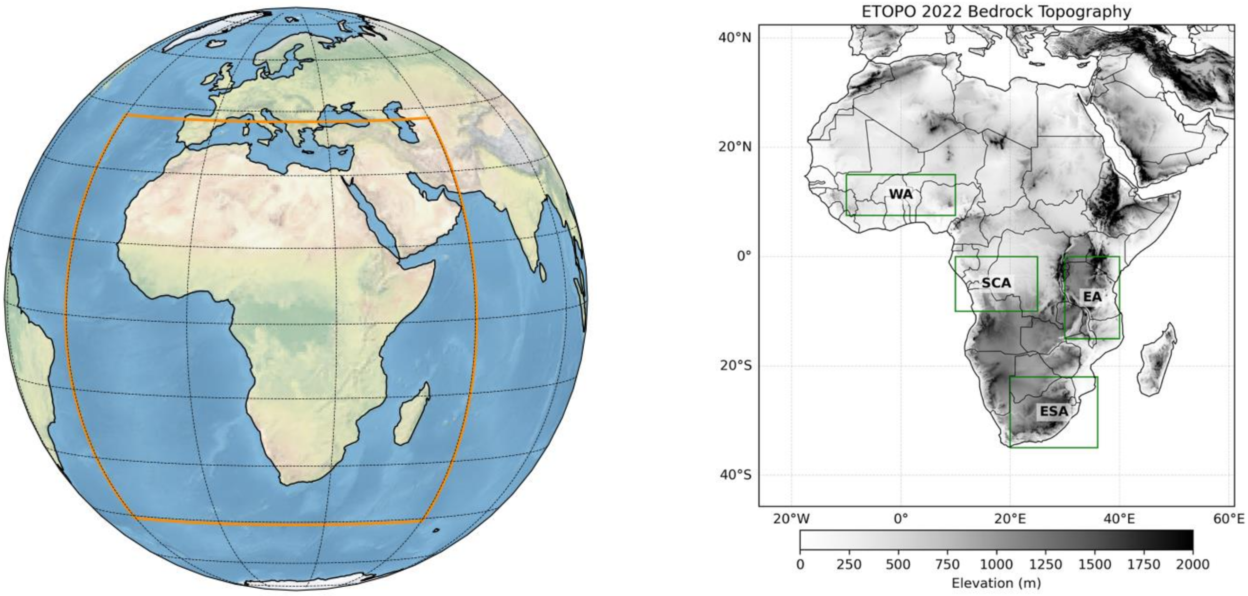

Figure 1. *Topography of the pan-Africa domain defined in the orange box (left plot), and map of Africa showing the subregions derived from (Wu et. al., 2020) focused in the evaluation process i.e., West Africa (WA), East Africa (EA), South Central Africa (SCA) and East Southern Africa (ESA).*

We had to first investigate which map projection works best for Africa when using the HCLIM model. After several trials, the rotated Mercator grid showed good results that did not cause model crushes as was the case for other projections. We then did simulations forced by ERA5 data for the period 1 January 2000 to 31 December 2025 at first. This also provided an opportunity to start investigating how the model can be optimised in terms of speed and computational resources required. Variables chosen for model evaluation were precipitation (pr), daily maximum temperature (tasmax) and daily minimum temperature (tasmin). We focus on these main climatic variables relevant to most sub-Saharan African countries' largest exporting and employment sector, agriculture. The model outputs were assessed against ERA5 and Climate Research Unit (CRU, Harris et al., 2014) datasets and at annual and seasonal timescale.

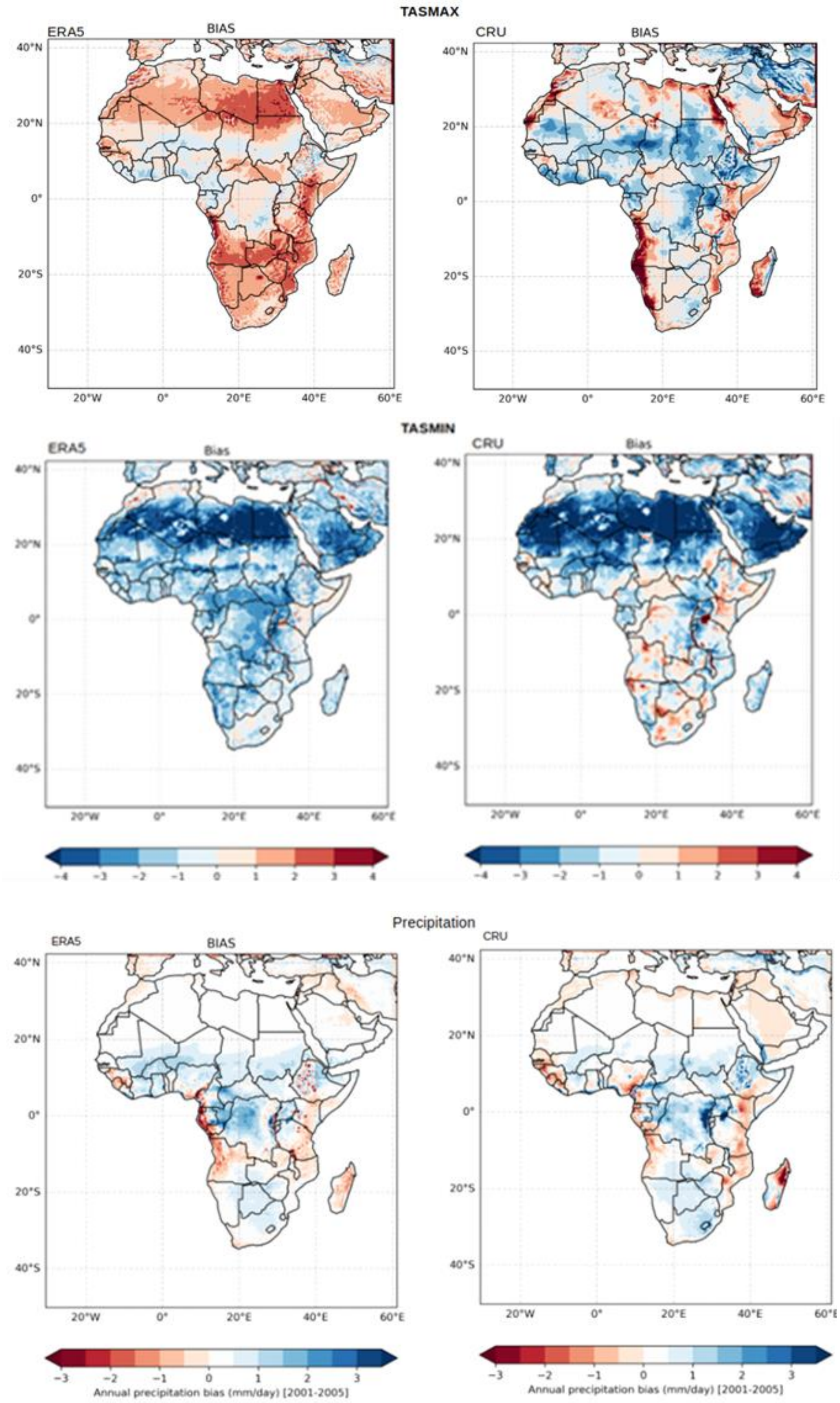

Figure 2. *HCLIM model output bias for annual averaged (top panel) daily maximum temperature, (middle panel) daily minimum temperature, and (bottom panel) precipitation with respect to (left panel) ERA5 outputs and (right panel) CRU outputs based on the period 2001-2005. Temperature and precipitation bias values are in ℃ and mm/day, respectfully.*

Fig. 2 shows that the HCLIM simulations compared to ERA5, overestimated annual average maximum temperature in most parts of Africa with the highest estimation in the subtropical regions where the overestimation is as high as 2℃. However, the model simulations compared to CRU shows a different spatial coverage with most parts showing underestimation of annual maximum temperature. Examining annual minimum temperature, the model bias with respect to ERA5 and CRU both show widespread underestimation with the highest underestimation in North Africa. The temperature biases in the subtropics are probably linked to how the model is handling albedo and aerosols hence the need to further tune the model to try to minimise these. There are slight wet biases consistent in ERA5- and CRU-based evaluations across the continent when it comes to annual average precipitation with the highest overestimation in the range of 1.5 to 2.5mm/day found in the tropical region (Fig 2). However, the coastal areas especially north of latitude 20° S and Madagascar show that the model underestimated annul precipitation.

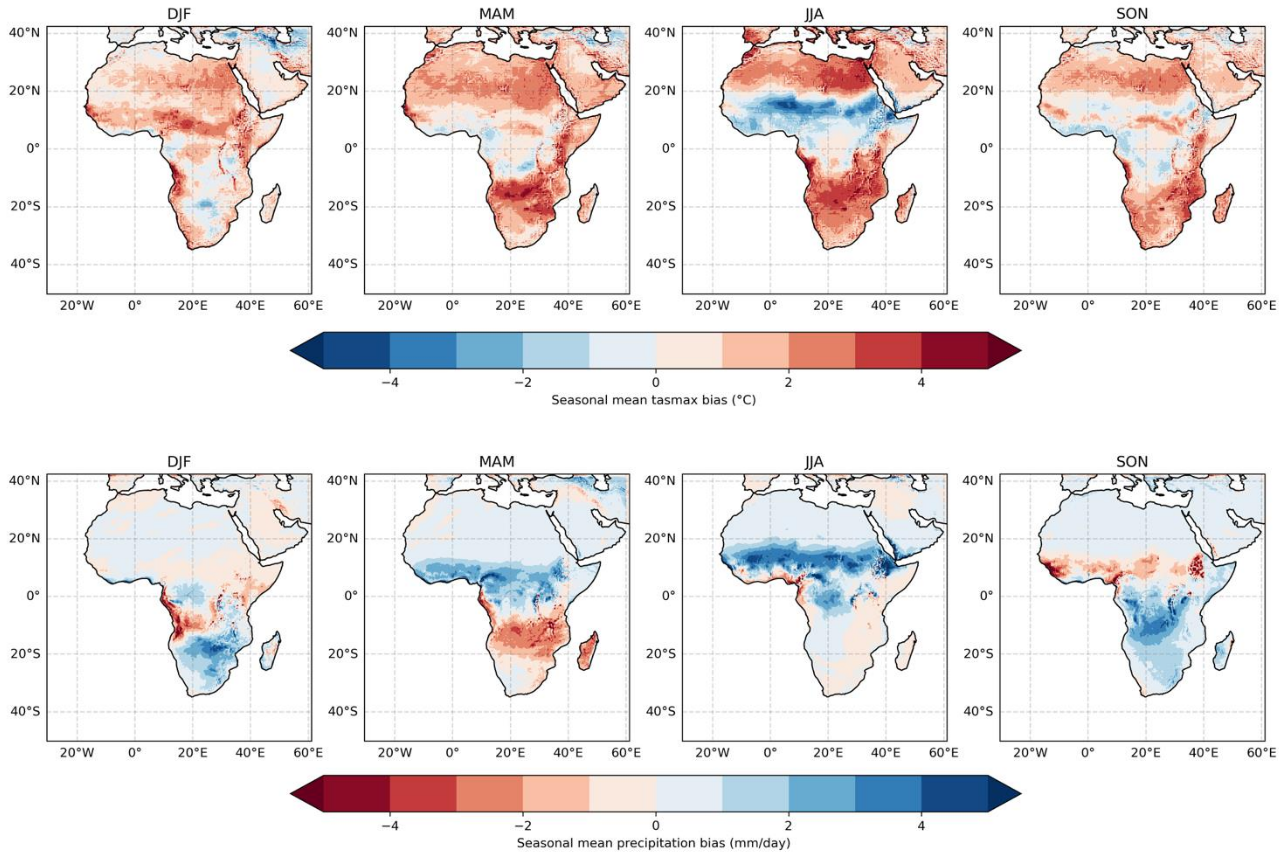

Figure 3. *HCLIM model output bias for seasonal averaged (left set of subplots) daily maximum temperature, and (right set of subplots) precipitation with respect to ERA5 outputs based on period 2001-2005. Units are in in ℃ for maximum temperature bias and mm/day for precipitation bias.*

At seasonal level, Fig 3 shows the evaluation of the maximum temperature and precipitation model outputs against ERA5. The seasons considered are summer (December, January, February – DJF), autumn (March, April, May – MAM), winter (June, July, August – JJA), and spring (September, October, November – SON) in the context of Southern Hemisphere. The model simulation overestimated maximum temperature in most parts of the continent especially in the subtropics in all the seasons as was the case at annual level. The largest model underestimation is observed over the Sahel region. The spatial patterns and evaluation of minimum temperature are consistent with those found in the annual analysis; therefore, the corresponding plots are not shown here for brevity. For precipitation, biases are different across the seasons and the continent. In SON and DJF which are together typically the rainfall period in Southern Africa, there is a slight wet bias of the model in Southern Africa while in JJA and MAM, the wet bias is in the tropical regions and in the Sahel region during which also the region receives most of its rain.

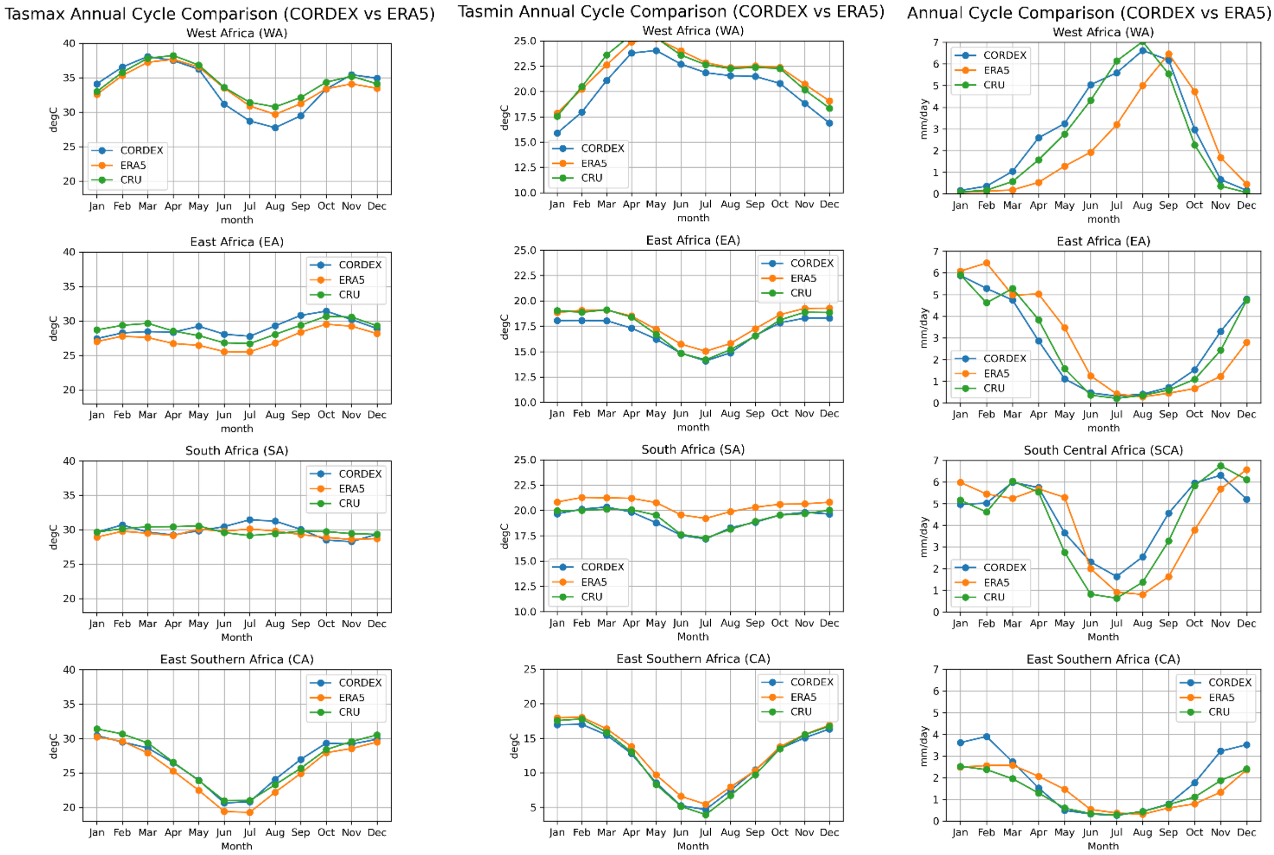

Figure 4. *HCLIM model annual cycle of (left panel) maximum temperature, (middle panel) minimum temperature, and (right panel) precipitation for the African regions West Africa, East Africa, South Central Africa and East Southern Africa shown from top to bottom respectively. Blue, orange and green lines are from CORDEX, ERA5 and CRU datasets respectively averaged over the period 2001-2005. Temperature and precipitation values are in ℃ and mm/day, respectfully.*

Annual cycle of monthly mean precipitation over four African subregions (West Africa, East Africa, South Central Africa, and East Southern Africa) from the HCLIM simulation compared with ERA5 reanalysis and CRU observations is shown in Fig 4. The ERA5 driven HCLIM outputs for maximum and minimum temperature are relatively good at recreating the annual cycle of temperature in all the regions studied, predominantly varying within less than 1 °C of the ERA5 reanalysis data (Fig 4). Some previous analysis has shown that RCMs are better able to represent annual cycles in Southern Africa (Nikulin et al., 2012; Buontempo et al., 2015; Dosio et al., 2015) hence these results are encouraging. On precipitation, the datasets show broadly consistent seasonal precipitation patterns, although differences are evident in the timing and magnitude of peak rainfall across regions. The HCLIM simulations generally captures the annual cycle but exhibits regional biases relative to ERA5 and CRU.

Following this evaluation, we are confident in the model's performance over the region and can proceed with the production simulations.

In the coming months, we expect to make extensive use of the high-performance computing (HPC) and storage resources. From July to September, we will run three simulations concurrently, resulting in a substantial increase in computational and storage demands. Following this period, the post-processing and analysis of the simulation outputs will begin. Given the large volume of data produced, this stage is expected to take several months and will continue to require significant storage and computational resources.

References

1. *Buontempo, C., Mathison, C., Jones, R., William, K., Wang, C., Mcsweeney, C., 2015. An ensemble climate projection for Africa. Clim. Dyn. 44, 2097–2118*
2. *Dosio, A., Panitz, H.-J., Schubert-Frisius, M., Lüthi, D., 2015. Dynamical downscaling of CMIP5 global circulation models over CORDEX-Africa with COSMO-CLM: evaluation over the present climate and analysis of the added value. Clim. Dyn. 44, 2637–2661.*
3. *Harris, I., Jones, P.D., Osborn, T.J., Lister, D.H., 2014. Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 dataset. Int. J. Climatol. 34, 623–642*
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5. *Wu, M., Nikulin, G., Kjellström, E., Belušić, D., Jones, C., & Lindstedt, D. (2020). The impact of regional climate model formulation and resolution on simulated precipitation in Africa. Earth System Dynamics, 11(2), 377-394.*