SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Agricultural decision-tailored (sub)seasonal drought forecasting for Sub-Saharan Africa (AGENDA-SSA)
Computer Project Account:	spde4l
Start Year - End Year :	2022 - 2024
Principal Investigator(s)	Dr. Patrick Laux
Affiliation/Address:	Karlsruhe Institute of Technology (KIT) Institute of Meteorology and Climate Research Department of Atmospheric Environmental Research (IMK-IFU)
Other Researchers (Name/Affiliation):	

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

Agricultural productivity and food security in sub-Saharan Africa heavily depend on uncertain rainfall. The exposure to climate risk characterizes the livelihood of the majority of the region's population: high rainfall variability impedes the farmers' efforts to intensify agricultural production and negatively affects the level of food security. The overall goal of this Special Project (SP) is to contribute to improving agricultural management strategies across the Greater Horn of Africa (GHAF) with sufficient lead time by optimizing water usage for agriculture. In this SP, optimized and seasonal drought forecast products based on the SEAS5 data shall be developed. This shall be achieved by dynamical downscaling of preselected representative perturbed initial condition SEAS5 members. The preselection of representative SEAS5 members and configuration of the regional climate model WRF was the focus of this study.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

- Technical problems to write monthly WRF restart files using I/O quilting due to their large size.
- Initial problems to compile the WPS on ATOS.
- For the last year (2024), we did not have staff member available for this project work, and due to this the work could not be continued.

Experience with the Special Project framework

Our experience with the administrative aspects of the Special Project framework was always positive. The application procedure was clear and well-structured, with comprehensive guidance provided at each step. Communication with the administrative and technical support team was always efficient and supportive, which greatly facilitated the overall process. Progress reporting requirements were reasonable, allowing us to maintain a focused and productive research workflow.

Summary of Results

The first step comprised the review of drivers of rainfall variability in selected African regions. During this first phase of the project, the focus has been set to the GHAF as well as the short rainy season (OND) in East Africa (EA). Based on the SEAS5 retroforecasts (1986-2015) and observational data, an Indian Ocean Diploe (IOD) and East African Rainfall (EAR)-related approach has been developed to select most promising perturbed initial conditions (PICs) members of the SEAS5 retroforecast ensemble.

IOD is considered on the basis of the Dipole Mode Index (DMI), introduced by Saji et al. (1999). It depicts the SST anomaly difference between the western pole of East Africa (WEA) and the eastern pole of Sumatra (EPS), see Figure 1 (left). The EAR anomaly is calculated as deviation of the mean field precipitation of the 2021 OND season (black box, Fig. 1 right) and the SEAS5 retroforecasts (1986-2015, PIC member #0) in the same region.

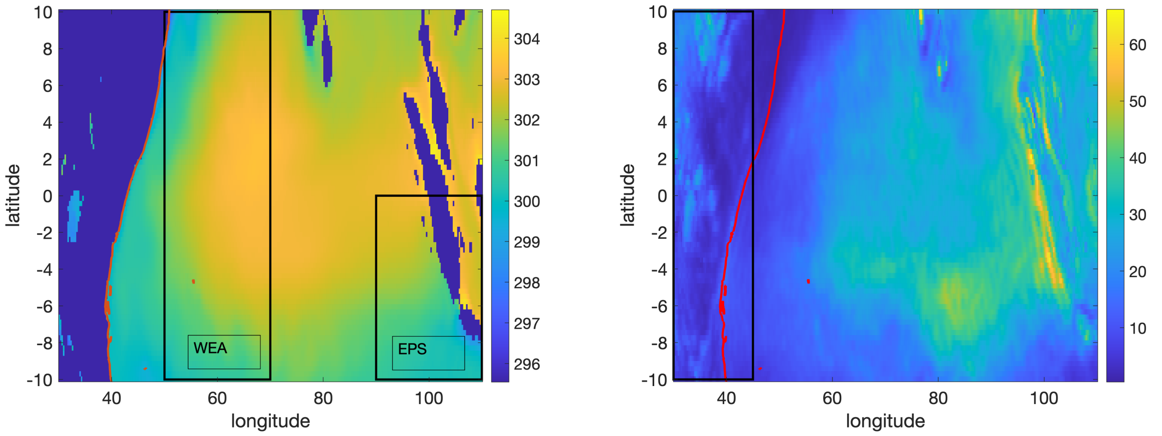

Fig.2: Left: schematic illustration of the Dipole Mode Index (DMI), calculated as SST anomaly difference between the western pole of East Africa (WEA, left big black box) and the eastern pole of Sumatra (EPS, right big black box), i.e., WEA minus EPS. Right: East African Rainfall (EAR) anomaly [mm d^{-1}] is calculated for the Greater Horn of Africa region (black box). Red line represents the coastline. Both indices represent the forecasted average 2021 OND season using a lead time of 4 months (i.e., forecasts issued in June).

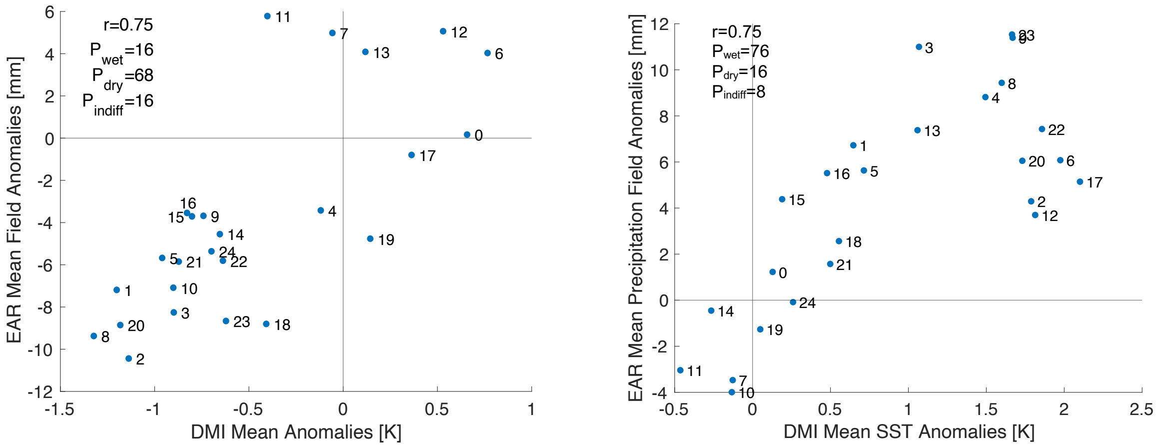

Fig.2: Left: Scatter plot of 25-members ensemble predictions by the SEAS5 reforecasts between the Dipole Mode Index (DMI) (x-direction, K) and the East African rainfall (EAR) index (y-direction, mm day −1) for the 2021 October-December (OND) average issued on early June (blue dots). Right: same as for the left figure, but for the 'wet year' 2019. Based on the long-term retroforecast statistics (1986-2015), the inter-ensemble scatter plot can be split into 4 quadrants, whereas the lower left represents anomalously dry and the upper right anomalously wet conditions.

It is found that the correlation among the different PIC SEAS5 reforecasts members between the DMI and the EAR index for mean 2021 OND season is highest for a lead time of 4 months (i.e., forecasts issued in June). The relative high correlation (r=0.75) enables a statistical linear regression model to estimate the OND EAR anomaly based on the OND DMI anomaly with a lead time of 4 months (Fig. 2).

Similar observations have been made for the 'wet' OND 2019 season. This approach does not only provide opportunities to assess the quality of the raw SEAS5 retroforecast product (compared to observation), but will facilitate the HPC intensive dynamical downscaling of suitable PIC members for high-impact climate extreme events (droughts and floods) using the operational SEAS5 data with sufficient lead time. Depending on the strategies of the users, suitable candidates for downscaling could be from the anomalously dry quadrant (based on the high drought probability), such as #8 or #2 to simulate the most extreme droughts, candidates around the centre of the dry PIK could be e.g., #10 or #21, or #8 or #2 to reflect the range of a possible drought.

It has been found that the correlation between OND EAR and the OND DMI anomaly decreases with decreasing lead time. However, the probability of getting a dry 2021 OND season is increasing at the same time (Table 1, top). While the probability to get a dry season was 68% (16% probability of a wet and an indifferent season, respectively) based on the forecasts issued in June, it increased to 94% for August and September (probabilities of indifferent season is 4%). Similar observations have been made for the 'wet' OND 2019 season (Table 1, bottom). Table 1 suggests that the predictability for high-impact events based on raw SEAS5 works well. Further analyses for dry and wet years supported this conclusion.

Table 1: Summary statistics of 25-members ensemble SEAS5 reforecasts for the year 2021 (top) and 2019 (bottom). The Pearson correlation coefficient (r) is demonstrating the linear dependency between the OND EAR anomaly and the OND DMI anomaly.

Lead time [month]	r	Probability Wet OND [%]	Probability Dry OND [%]	Probability Indifferent OND [%]
June (lead 4)	0.75	16	68	16
July (lead 3)	0.4	0	68	32
August (lead 2)	0.54	0	96	4
September (lead 1)	0.33	0	96	4

Lead time [month]	r	Probability Wet OND [%]	Probability Dry OND [%]	Probability Indifferent OND [%]
June (lead 4)	0.75	76	16	8
July (lead 3)	0.56	88	0	12
August (lead 2)	0.65	96	0	4
September (lead 1)	0.39	100	0	0

During the reporting period, the WRF test simulation phase on Atos HPC has been finished. Based on conducted speedup performance tests using different compiler settings, i.e., different domain settings (nested vs single nest simulations) as well as different number of nodes, a reasonable WRF setup has been identified. Scalability on Atos is found to be much higher for a single nest and a big domain and using OpenMPI.

A set of sensitivity experiments have been performed based on predefined parameterization schemes (e.g., Laux et al., 2021) for microphysics (MP) and planetary boundary layer (PBL). The following experiments have been conducted:

CP_WSM6_YSU_RRTMG/
CP_Thom_YSU_CAM/
CP_MOR_MYNN_RRTMG/

However, due to unforeseen circumstances out of our control such as missing human resources the simulation data for these three sensitivity experiments was unintentionally deleted.

List of publications/reports from the project with complete references

None (so far)

Future plans

Due to limited human resources, several of the envisaged tasks could not be completed during the project duration. In the next phase, provided that a follow-up SP is approved, the planned WRF parameterization sensitivity experiments will be conducted for selected seasons and SEAS5 PIC members of the reforecast product. A comprehensive validation using various datasets—including station observations for the GHOF—and diverse validation strategies will also be carried out following Laux et al., 2021.

The performance of SEAS5 data will be assessed in an operational setting, i.e., using forecasts for upcoming seasons. Moreover, downscaled operational SEAS5 forecasts will be used to drive agricultural models.

By leveraging additional resources (personnel and data) from ongoing projects such as the *Development and Transfer of a Seamless Prediction System for Decision Support in Transboundary Water Management of the Blue Nile* (SPS Blue Nile), the chances of successfully completing a follow-up project will be significantly improved.

At least two scientific publications are expected to result from a follow-up SP.

References:

Laux, P., D. Dieng, T. C. Portele, J. Wei, S. Shang, Z. Zhang, J. Arnault, C. Lorenz, and H. Kunstmann (2021). A High-Resolution Regional Climate Model Physics Ensemble for Northern Sub-Saharan Africa. Frontiers in Earth Science, 9:1–16. doi: 10.3389/feart.2021.700249.

Saji, N., Goswami, B., Vinayachandran, P. et al. A dipole mode in the tropical Indian Ocean. Nature 401, 360–363 (1999). https://doi.org/10.1038/43854