How well do climate models represent rainy season- and heat-related indices in Africa?

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The strongly rain-fed African agriculture is highly vulnerable to changing rainfall amounts and patterns induced by climate change. Additionally, an increase of heatwaves negatively affects the growth of crops. Thus, the WASCAL WRAP2.0 project LANDSURF (project partners: Fig. 1) aims to make reasonable statements of the future changes of these factors and its effects on African agriculture with a focus on West Africa.

To reach this aim, it is necessary to know how well regional climate models (RCMs, here: REMO2015, RegCM4-7, and CCLM5-0-15) from CORDEX-CORE and their forcing global models (GCMs, here: MPI-ESM-LR/MR, NorESM1-M) from CMIP5 are able to simulate the occurrence of rainfall and heatwaves in the past (1981-2010). In this framework, we mainly use ERA5Land as the benchmark, for the rainy season we consider CHIRPS. As African agriculture strongly depends on the rainy season, its simulation by climate models is very important. Knowing the onset of the rainy season, it is possible to calculate and validate the representation of agricultural and crop-specific indices like crop water need (CWN), irrigation requirement (IR), and water availability (WA) in the models as well. Additionally, we compared the performance of the models regarding the heat wave duration index (HWDI).

Fig. 1: Logos of the cooperation partners of the WASCAL WRAP2.0 project LANDSURF.

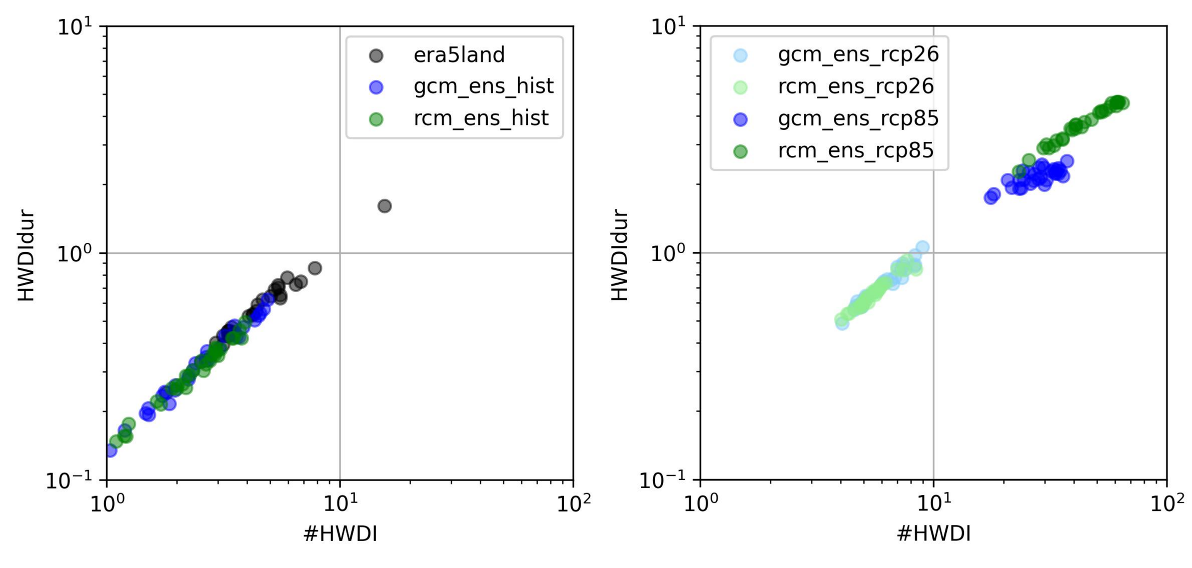


Fig. 2: #HWDI and HWDIdur spatial mean values (domain see Fig. 4) for different observation and model data sets for the historical (1981-2010) and a future time period (2071-2100) under RCP2.6 and RCP8.5 (mark: plot has logarithmic axes!).

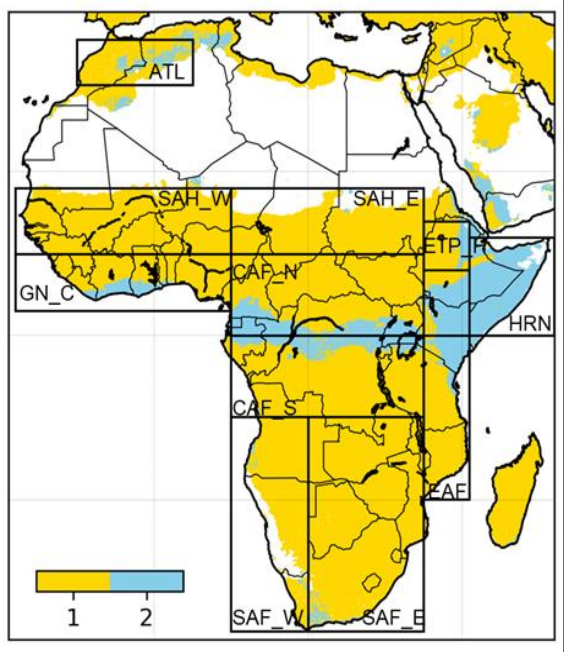
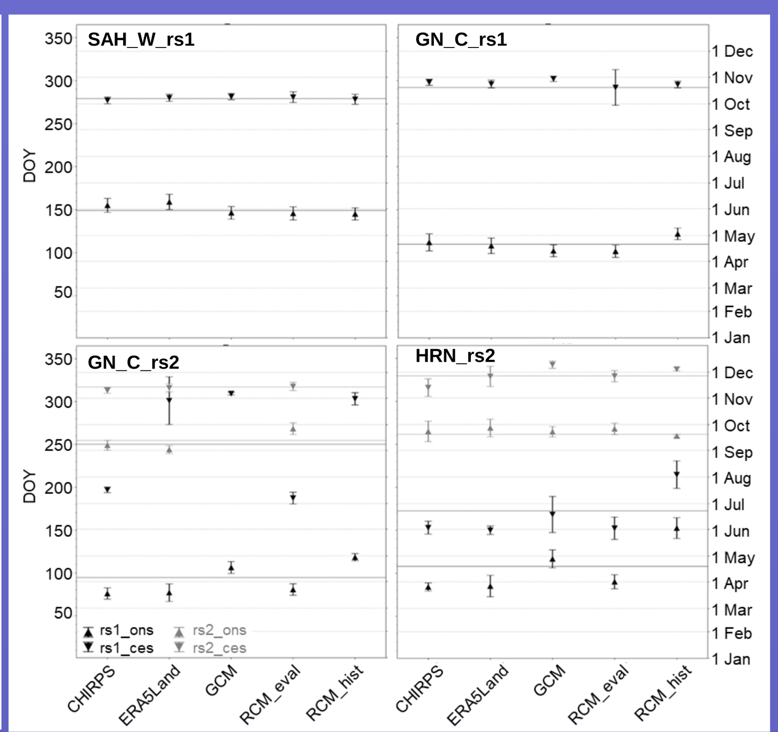


Fig. 3a: Climatological number of rainy season (RS) derived from CHIRPS data of 1981-2010.

Fig. 3b: Comparison of (first=black/ second=grey) onset and cessation for three subregions (see Fig. 3a) for the validation and model data from 1981-2010 (center of arrow = median of all grid points, bars = spatial standard deviation over the area; horizontal line = mean of the five data sets; RCM_eval = RCMs driven by ERA-Interim reanalysis, RCM_hist = driven by GCM data).



Analysis

The rainy season mask is calculated based on CHIRPS precipitation data after [1] – with some modifications following [2]. The resulting map for 1981-2010 is shown in Fig. 3a.

Using the first onset of the climatological RS as starting day for crop development phase, the CWN, WA, and IR are calculated based on the formula and values from [3]. Here, we present the results for the four different growing stages of maize grain (long).

Two variables (HWDIdur, #HWDI) were calculated with the recommended version of the IPCC by using the daily maximum temperature of each observational or model data set:

- First, the TX_{ref} was extracted as the daily mean value of the five-day running mean value of the maximum temperature from the reference period (1981-2010).
- Then, we counted how often the daily maximum temperature of one year surpasses the daily TX_{ref} + 5°C for six or more days in a row.

The resulting #HWDI is the number of the heat wave events that fulfill these conditions, while HWDIdur is the length of the longest heat wave per year in days.

Results

- HWDI: The spatial mean of GCM and RCM ensembles underestimates duration and number of heat waves compared with ERA5Land in the historical period. There is a remarkable extreme event in 2010 for ERA5Land (Fig. 2). For the future, RCP2.6 represents a stable warmer climate during the 21st century, while RCP8.5 represents an extraordinary, exponential, and extreme increase of heat waves over entire Africa. The RCMs show even higher HWDI values than the GCMs, with up to 10 days duration and nearly 100 heat waves per year (as spatial mean). This becomes even more for some regions (not shown). GCMs loose the relation between number and duration of heat waves in RCP8.5 during 2071-2100, while RCMs are still able to show it. The extreme event of 2010 (ERA5Land) will be ‘cold‘ in the future.
- Rainy Season: Three types of subregions with clearly one (I) or two (II) RS or mixed areas (III). For each type, one result is shown in Fig 3b. While all models represent a nearly perfect fit for I and ons1/ces1 for III, the ons2/ces2 in III cannot be represented well. Also for type II, big differences between model types for ons1/ces1 occur, while ons2/ces2 are in line with the observations.
- Crop-Indices: The highest errors occur for CDS and MSS, where absolute values are also the highest. RCMs generally reduce the bias compared to GCMs. Similar results are calculated for IR and WA (not shown).

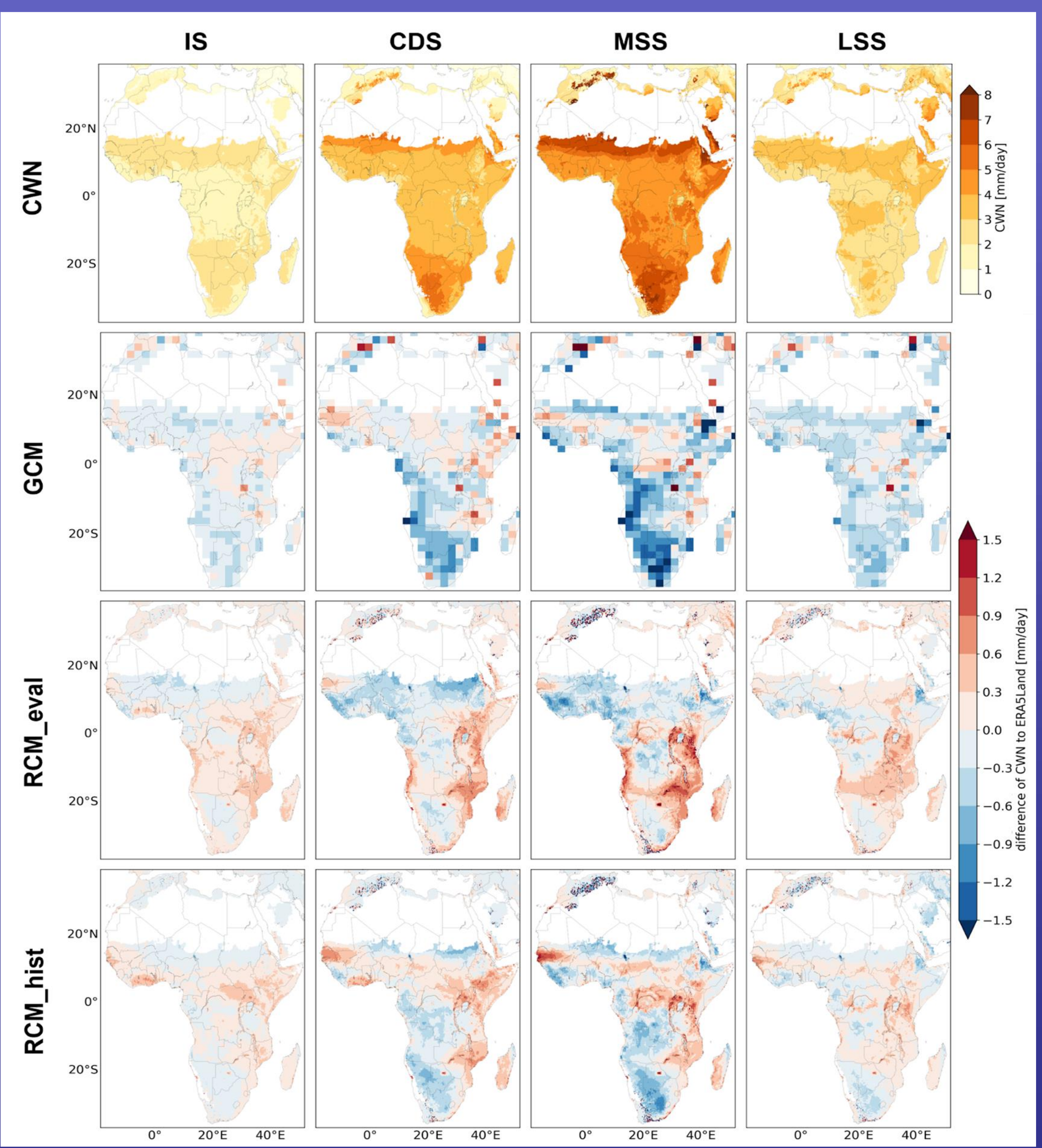


Fig. 4: Absolute CWN temporal mean values for ERA5Land (1981-2010) and difference from the ensemble mean of the used RCM and GCM model data sets to ERA5Land for the four crop growing stages (IS=initial stage, CDS=crop development stage, MSS=mid season stage, and LSS=late season stage) of maize grain (long).

Conclusion and Outlook

Nevertheless, we already see that temperatures are rising, and heat waves and a potential shift of rainy season could become a big problem for Africa depending on the emission scenario. Next steps are the analysis of the future index behaviour und different RCP-scenarios.

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