Influence Of Climate Change On The Future Precipitation Pattern In The Region Of Ghana

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Summary

- Model predictions for the Ghana region are highly uncertain and in most cases do not show any significant trend within the 95% confidence interval.
- Over western West Africa, the monsoon system and rainfall started to strengthen from 1998 indicating a new inter-decadal variation.
- Ghana displayed a negative annual trend of precipitation ranging from -50 to -100 mm/year for the period 1951-2010.
- By the end of the 21st century a small delay in the monsoon season and an intensification of late-season precipitation events are projected across West Africa.
- The implications for future changes in Ghanaian mean rainfall are uncertain primary due to the inability of global climate models to resolve convective rainfall and due to the lack of available historical data.
- In Accra city and in the broader area of Ghana, seasonal rainfall averages are anticipated to increase (0.2 mm day^{-1}) with a 1.5°C of global warming under the RCP 8.5 high GHG-forcing scenario. Projections for consecutive wet days (CWT) show a reverse pattern with CWT being reduced by one day or two days.
- According to the RCP 4.5 mid-level and to the RCP 2.6 low-level GHG scenarios a small increase in precipitation is projected during the rainy season (i.e. 0.1-0.2 mm day^{-1} precipitation changes per changes of global annual mean surface-air temperature in °C) and a small decrease of precipitation during the dry season (0-0.1 mm day^{-1} $°C^{-1}$) across Ghana. For the same area, under the SRES A1b scenario it is also projected a small increase of annual precipitation (0-0.1 mm day^{-1} $°C^{-1}$).
- Under RCPs 4.5 and 8.5 scenarios, recent studies projected an increase in the frequency and intensity of extreme rainfall events over West Africa.
- Based on physical reasoning it could be suggested that projected increases in heavy precipitation and sea level extremes would contribute to increases in local flooding, although there is low confidence in projections of changes in fluvial floods because the causes of regional changes (e.g., soil moisture gradients and topographic particularities) are complex.
- Under the A1F1 scenario sea level may rise up to 0.79 m along the coastline of Accra leading to a shoreline recession of 200 m by the year 2100.
- The southwestern part Volta basin and Oti basin in Ghana will probably experience increases in runoff by 2050 under the SRES A1b scenario. The fluctuations in runoffs, particularly in the Volta River, may increase the risk of floods and/or droughts.

Regional impact of climate change

Large sections of African coastal cities' population are at risk from flooding (Awuor et al., 2008; Adelekan, 2010) while the region of sub-Saharan Africa has been identified as a climate-change hotspot with negative impacts on crop yields and production under the scenario of 1.5°C warming by 2030 (IPCC, 2018; Palazzo et al., 2017). In the absence of adaptation, there is high confidence that locations currently experiencing adverse effects, such as coastal erosion and inundation, will continue to do so in the future (Seneviratne et al., 2012). The exposure of Sub-Saharan African countries to drought and floods account for 80 % of loss of life and 70 % of economic losses (African Union et al., 2008) while there is a chance up to 50% for a drought event to cause food security stresses (World Bank, 2010).

Recent studies indicate that socio-economic conditions will exacerbate flood impacts more than global climatic change, and that the magnitude of these impacts could be larger in some regions (Winsemius et al., 2016; Alfieri et al., 2018). Differences in flood risks among regions reflect the balance among the magnitude of the flood, the populations, their vulnerabilities, the value of assets affected by flooding, and the capacity to cope with flood risks, all of which depend on socio-economic development conditions, as well as hydro-climatic conditions and topography (Tanoue et al., 2016).

Even if the global temperature increase is constrained to 1.5°C, West Africa is likely to experience more frequent heatwaves and increases in the number of hot nights, with further increases expected under 2°C of global warming (Weber et al., 2018).

However, the projected increases of daily rainfall intensity and runoff towards 1.5°C and 2°C of global warming exhibit higher uncertainty compared to the projections of temperature (Schleussner et al., 2016; Diedhiou et al., 2018). Some models predict a significant increase in rainfall, others a decrease, yet others no significant change (UNFCCC, 2008). The uncertainty can be attributed to various sources including: i) the partial lack of literature and historical data; ii) the lack of consistency in reported patterns (Seneviratne et al., 2012); and iii) the vastly different model responses to greenhouse gases forcing (Cook, 2008). In either case, precipitation extremes including precipitation intensity and consecutive dry days are likely to increase at higher rates than those of mean precipitation (IPCC, 2013).

Relation between global change in precipitation and heavy precipitation patterns

A global increase in precipitation intensity could lead to an offsetting global decrease in the frequency or duration of precipitation events, though some regions could experience different patterns of precipitation. The change in the pattern of global precipitation in the observations and in model simulations is consistent with the theoretical understanding, related to the Clausius -Clapeyron equation (Trenberth et al., 2005), which describes the water-holding capacity of the atmosphere as a function of temperature, and typical values are about 7% change of water-holding capacity for 1°C change in temperature. In other words, higher global temperatures can increase the average precipitation and/or its intensity and amplify net evaporation. In a warming world; wet regions become overall wetter and dry regions drier. However, this picture may be an oversimplification and effects are likely to manifest in unforeseen ways (Cook et al., 2014) and some regions display shifts in climate regimes. Why have there not been increased trends of precipitation extremes everywhere? Probably because changes in precipitation extremes with temperature also depend on changes in the moist adiabatic temperature lapse rate, in the upward velocity, and in the temperature when precipitation extremes occur (Sugiyama et al., 2010). However, taking into account that human influence is the primary driver for global warming and about 18% of the moderate daily precipitation extremes over land are attributable to the observed temperature increase (Fischer and Knutti, 2015), it could be suggested that changes in precipitation extremes are attributed to anthropogenic activities as well. Further, since there are evidence of anthropogenic influence on the global hydrological cycle (Min et al., 2011) that, in turn, is directly relevant to extreme precipitation changes, it could be advocated with a medium confidence that human activities have a positive contribution to the intense of precipitation extremes

Observed Trends in annual precipitation over West Africa

Over western West Africa on the whole, precipitation decreased observably since the middle to late years of 1960s but began to increase from 1998 (Li et al., 2012).

As obtained by the AR4, Figure 1 presents the spatial variability of recent trends (1951–2010) in annual precipitation using the Global Precipitation Climatology Centre V6 (GPCC) data sets interpolated to a 5° × 5° latitude/longitude grid (Becker et al., 2013) over West Africa. Trends were calculated for each grid box with greater than 70% complete records and more than 20% data availability in first and last decile of the period. The patterns of these absolute trends (in mm yr^{-1} per decade) were found to be broadly similar to the trends (in percent per decade) relative to local climatology (IPCC, 2013). As it can be observed from Figure 1, the grid including the country of Ghana displayed a significant negative annual trend of precipitation for the period 1951-2010.

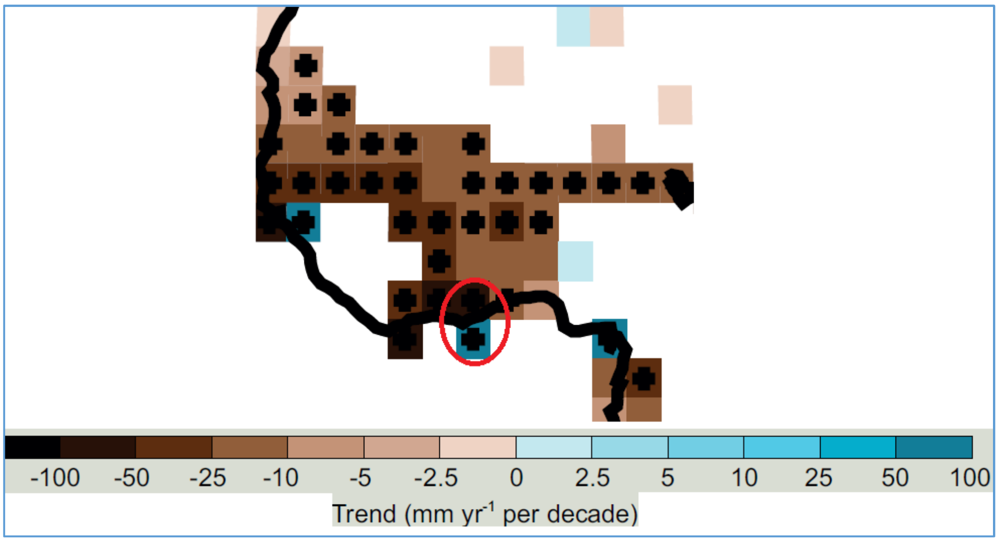

Figure 1. Trends in annual precipitation over land from the GPCC data sets for 1951–2010. Black plus signs (+) indicate grid boxes where trends are significant (i.e., a trend of zero lies outside the 90% confidence interval) (Adopted from IPCC, 2013).

Uncertainty in climate projections for monsoon over the West Africa

Overall, confidence in the projected precipitation changes in Africa is at best medium. This is owing to the overall modest ability of models to capture the West African monsoon system (WAM) that has a strong control on African climate. The WAM alternates between wet (most of the rain between May/June and September) and dry seasons as the rainfall belt follows the migration of inter-tropical discontinuity (Polcher et al., 2011). Factors influencing the WAM include : i) interannual to interdecadal variations, ii) land processes and iii) oceanic change, but their mechanisms and interactions are highly complex.

From an interdecadal time scale, the monsoon flow and moistening of the boundary layer are influenced by the cross-equatorial tropical Atlantic sea surface temperature (SST) patterns, so that a colder northern tropical Atlantic induces negative rainfall anomalies (Rowell, 2011). Figure 2 shows that the WAM weakened first and from 1998 strengthened while the boreal spring North Atlantic Oscillation (NAO) changed after 1995 from strong to weak indicating the occurrence of a new interdecadal variation over western West Africa (Li et al., 2012). It has been documented that the WAM (Vizy and Cook, 2012) is affected by the Atlantic Niño variability as well where its amplitude has weakened by 40% from 1960 to 1999, associated with a weakening of the equatorial cold tongue (Tokinaga and Xie, 2011).

Since the Atlantic multi-decadal variability (AVM) drives interannual variability in precipitation over the West Africa (van Oldenborgh et al., 2012), it can be speculated that the non-statistically significant skill of climate models in hindcasting precipitation over this region (with a 95% confidence level) is associated with the low confidence in predicting changes for the tropical Atlantic (Gaetani and Mohino, 2013).

The positive skill of AVM's in hindcasting precipitation can be attributed mostly to variable external forcing (i.e., changes in natural and/or anthropogenic atmospheric composition) (Goddard et al., 2013). For the country of Ghana, the root mean square skill score for rainfall hindcasts for the forecast time 2 to 5 years from the multi-model ensemble mean of the Coupled Model Intercomparison Project Phase 5 (CMIP5) experiment over the period 1960–2005 was estimated to be positive and ranging from 1.05 to 1.1 (Adapted from Doblas-Reyes et al., 2013). Therefore, the implications for future changes in Ghanaian mean precipitation according to the CMIP3 and CMIP5 simulations are uncertain, reflected by considerable model deficiencies and spread in the projections partially attributed to the inability of Global Climate Models (GCMs) to resolve convective rainfall (Roehrig et al., 2013).

In either case, it is worth mentioned that CMIP3 models projected a decrease in rainfall across the West Africa in the early part but an increase towards the end of the rainy season, implying a small delay in the monsoon season and an intensification of late-season rains (Seth et al., 2010). Many of the latest generation of climate models from the CMIP5 indicated a small delay to rainy season by the end of the 21st century (Biasutti, 2013).

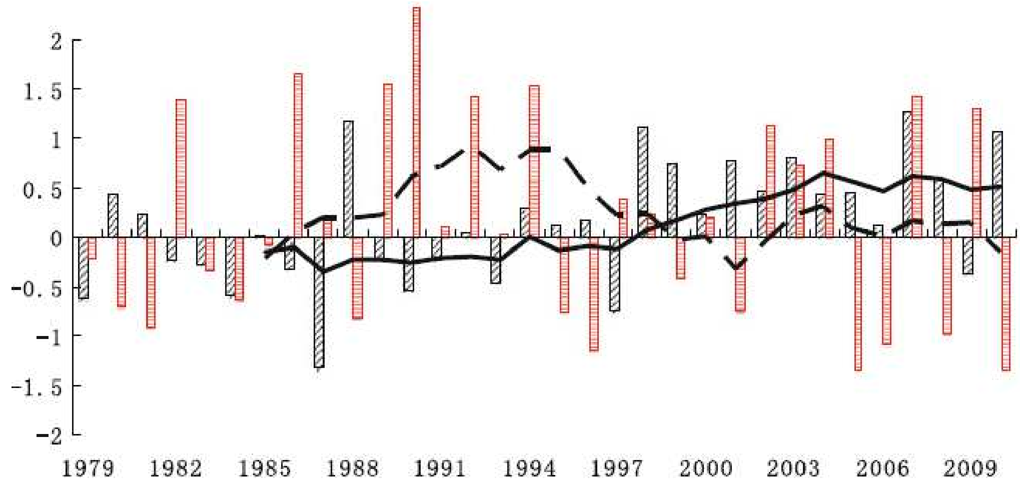

Figure 2. Time series from 1979 to 2010 of the boreal spring North Atlantic Oscillation index (red histogram) and WAM index (black histogram) defined as the difference between the standardized module of horizontal wind at 925 hPa and zonal wind at 200 hPa. The solid and dashed lines are 7-year running mean (After Li et al., 2012).

Climate change scenarios: Representative Concentration Pathways

In order to assess projections of future climate change, the IPCC Fifth Assessment Report (AR5; IPCC, 2013) used the so-called Representative Concentration Pathways (RCP) to describe different climate scenarios, all of which are consistent with a wide range of possible changes in future anthropogenic greenhouse gas (GHG) emissions, and aim to represent their atmospheric concentrations (Figure 3). The four RCPs are labelled after a possible range of radiative forcing values (W/m2) in the year 2100 relative to pre-industrial value. The RCP8.5 is representative of the high range of non- climate policy scenarios. Most non-climate policy scenarios predict emissions of the order of 15 to 20 GtC by the end of this century, which is close to the emission level of the RCP6. The forcing pathway of the RCP4.5 scenario is comparable to a number of climate policy scenarios and low-emissions reference scenarios such as the SRES B1 scenario (IPCC, 2007). It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level. The RCP2.6 emission pathway represents the range of lowest GHG emission scenarios that would lead to very low GHG concentration levels. Its radiative forcing level first reaches a value of around 3.1 W/m2 by mid-century, and returns to 2.6 W/m2 by 2100 (van Vuuren et.al. 2011).

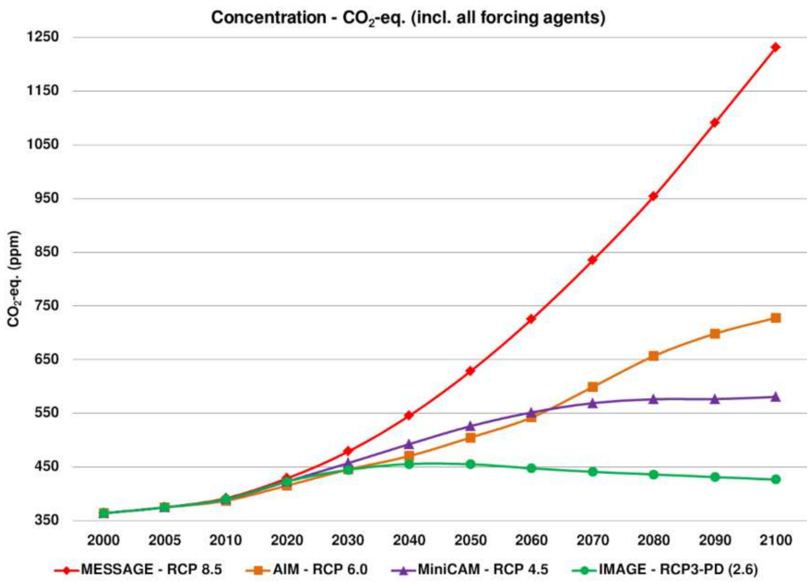

Figure 3. Forcing agents' atmospheric CO_2-equivalent concentrations (ppmv) according to the four RCPs which are all considered possible depending on how much GHG are emitted in the years to come. RCP 2.6 assumes that global annual GHG emissions peak between 2010–2020, with emissions declining substantially thereafter. Emissions in RCP 4.5 peak around 2040, RCP 6, emissions peak around 2080 and in RCP 8.5, emissions continue to rise throughout the 21st century (IPCC, 2013).

Projections for mean precipitation under the Representative Concentration Pathway 8.5

Local Perspective

The high GHG-forcing scenario RCP 8.5 (~3.5°C above pre-industrial levels by 2060–80) may be considered as a realistic business-as-usual scenario given the current trajectory of GHG emissions.

Using the RCP 8.5 and Coordinated Regional Climate Downscaling Experiment (CORDEX; Jones et al., 2011,) scenarios from 25 simulations from 12 regional climate models (RCMs) forced with 10 CMPI5 GCMs, a recent study predicted a decrease in mean rainfall over West Africa in models at 1.5°C of global warming (Klutse et al., 2018). According to Figure 4 seasonal precipitation averages will increase by about 0.2 mm day^{-1} until 2013 in Accra city and in the broader area of Ghana under an enhanced warming regime.

Projections for consecutive wet days (CWD) show a reverse pattern with CWD being reduced by one day or two days.

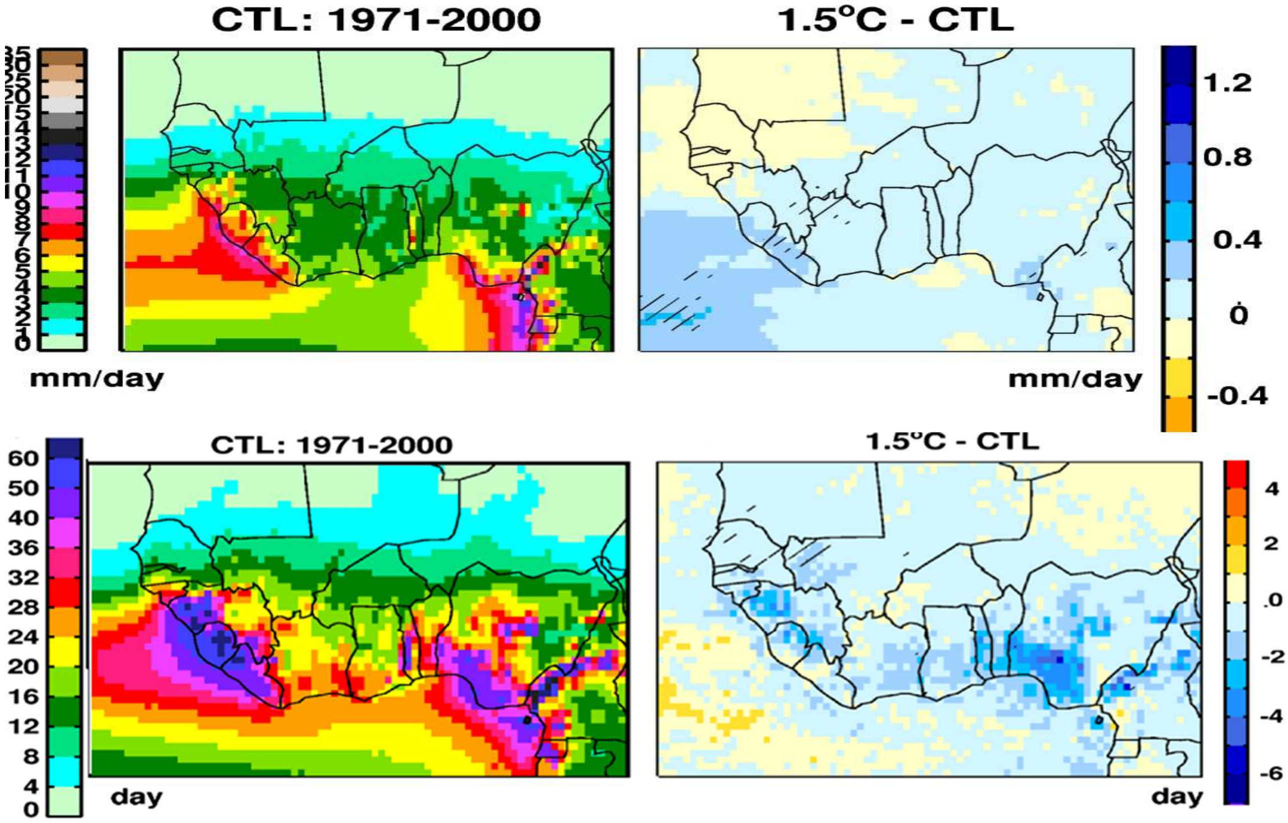

Figure 4. The CORDEX Africa ensemble average in the annual mean precipitation (upper left column) and in the consecutive wet days (lower left column) for the control period (CTL) 1971−2000 which is used as a baseline to extract RCM simulations for a 30-year period under the scenario of 1.5 °C global warming level. The corresponding projected changes at the 1.5 °C global warming level with respect to 1971−2000 are displayed in the upper and lower right column (after Klutse et al., 2018).

Other simulations of future rainfall changes in West Africa by regional climate models (RCMs) subject to coupled model-derived boundary conditions (Patricola and Cook, 2010), noted a wetting response of the Sahel to increased GHG in the absence of other forcing. This observation indicate that local soil moisture gradients can trigger convective systems and that these surface contrasts are as important as topography for generating these systems, which bring most of the rain (Taylor et al., 2011). Sylla et al. (2015) noticed that the pre-monsoon season experiences the largest changes in daily precipitation, particularly toward an increased risk of drought associated with a decrease in mean precipitation and frequency of wet days and an increased risk of flood associated with very wet events. Such patterns can produce significant stresses on the water sector especially during the monsoon onset.

Projections for mean precipitation under the Representative Concentration Pathway 4.5 and SRES A1b

As presented in Figure 5, CMIP3 models under the SRES A1b scenario projected a small increase of annual precipitation (0-0.1 mm d^{-1} $^{o}C^{-1}$) in the 21st century across Ghana. For the same area, CMIP5 models simulated a higher increase in precipitation during the rainy season (0.1-0.2 mm d^{-1} $^{o}C^{-1}$) and a small decrease of precipitation (0-0.1 mm d^{-1} $^{o}C^{-1}$) for the RCP 4.5 scenario.

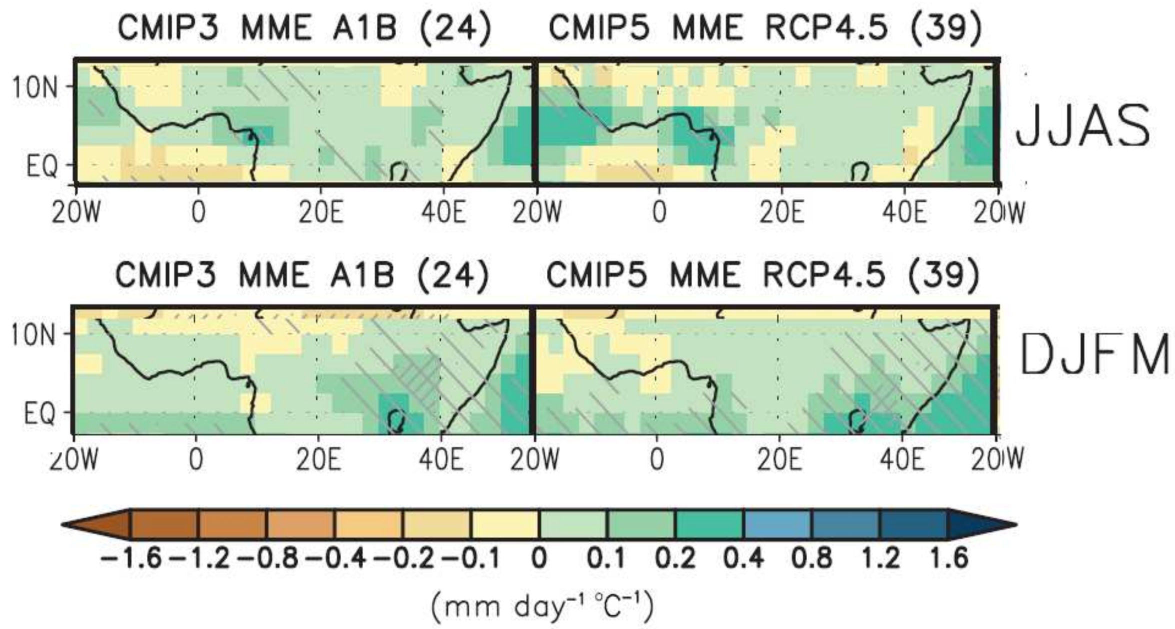

Figure 5. Maps of precipitation changes for West Africa in 2080–2099 with respect to 1986–2005 in June to September (above) and December to March (below) in the SRES A1B scenario with 24 CMIP3 models (left), and in the RCP4.5 scenario with 39 CMIP5 models (right). Precipitation changes are normalized by the global annual mean surface air temperature changes in each scenario (IPCC, 2013).

In Table 1, as adopted from the IPCC (2013), are displayed precipitation projections as a percent change by a set of 42 CMIP5 models for the RCP 4.5 scenario. The area-mean precipitation responses were averaged for each model over the 1986–2005 period and the 2016–2035 and 2081–2100 periods of the RCP4.5 experiments. Based on the difference between these two periods, the table shows the 50th percentiles and the highest response among the 42 models. According to the RCP 4.5 mid-level GHG-forcing scenario it is projected an enhancement of summer precipitation in West Africa by the end of the 21st century.

Precipitation (%)			
Period	**Year**	**50%**	**max**
December, January, February	2035	2	9
	2100	4	11
June, July, August	2035	1	6
	2100	2	9
Annual	2035	1	8
	2100	3	8

Table 1. Projections of precipitation in West Africa for 2035 and 2100 as a percent change compared to the baseline period 1986-2005, under the RCP 4.5 scenario. (after IPCC, 2013)

Projections for mean precipitation under the Representative Concentration Pathway 2.6

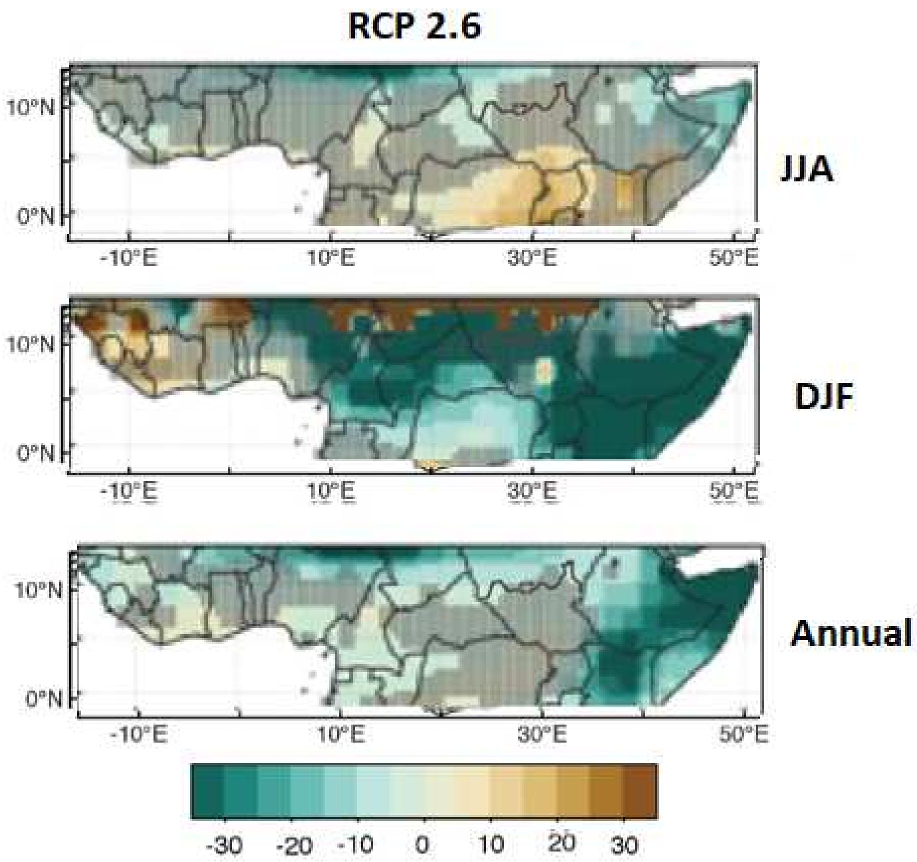

Figure 6. Eight-model mean of the percentage change in summer (JJA top), winter (DJF-middle), and annual precipitation for RCP2.6 for Sub-Saharan Africa by 2071–99 relative to 1951–1980. Grey areas indicate uncertainty regions with two out of five models disagreeing on the direction of change compared to the remaining three models (after World Bank, 2013).

The projections for seasonal and annual changes of mean precipitation over the south part of Ghana under the RCP 2.6 and as displayed in Figure 6 (World Bank, 2013), are similar with the respective projections noted in the AR4 for the RC 4.5 scenario. The precipitation during the rainy season is expected to remain withinthe same levels as the recent trends or increase by a percentage of 5 by the end of the 21st century. Further, the winter season will likely exhibit an up to 10% decrease of mean precipitation resulting in a rather small increase in the annual mean precipitation by the 2099 for RCP 2.6.

Projections for heavy precipitation over West Africa

Based on CMIP3 GCMs there was low to medium confidence in projected changes of heavy precipitation by the end of the 21st century over West Africa (IPCC, 2014).

It has been suggested that downscaling global climate model output with regional climate models (RCM) could potentially improve spatial and temporal information that is more meaningful in the context of local and regional impact assessments (e.g., Giorgi et al, 2014) from certain extreme conditions such as floods (Seneviratne et al., 2012). However, RCM uncertainty can be large (Dosio and Panitz 2016). Accounting the ability of RCMs to resolve complex topography compared to GCMs, regional model studies suggested an increase in the number of extreme rainfall days over West Africa during May and July (Vizy et al., 2013). Under RCPs 4.5 and 8.5 scenarios, Egbebiyi (2016) used RCMs that projected an increase in the frequency and intensity of extreme rainfall events over West Africa with increasing temperature. Using coordinated Regional Downscaling Experiment (CORDEX) model output, Abiodun et al (2017) recently showed that climate change would lead to an increase in extreme rainfall events, resulting in more flooding over four coastal cities in Africa.

The potential influence of sea level rise in coastal erosion and flood events in Accra

Based on robust tide gauge records from the 1970s onwards global analyses support that the magnitude of extreme sea level events (i.e., coastal flooding, storm surge etc.) has increased in all regions studied since that time (e.g., Woodworth et al., 2011). According to the AR4 (IPCC, 2013) extremes in sea level are increasing since the 1950s in most regions of the world, caused mainly by increasing mean sea level. The expansion of warming ocean water and the addition of melting ice may alter ocean currents leading to changes in sea level that vary along different places. Higher regional extremes may also be attributed to large interannual and multi-decadal variations in sea level associated with climate fluctuations such as ENSO, the NAO and the Atlantic Multi-decadal Oscillation (Haigh et al., 2010).

Currently, it is unclear to what extent extreme sea levels will affect the magnitude and the frequency of flood events along the coastline of the West Africa. It could be expected though, that sea level extremes will exacerbate flooding tide and erosion in low-lying coastal environments, such as Accra, since rising sea levels act as a swelling tide that allows waves to act further up the beach profile and permits larger waves to reach the coast (Zhang et al., 2004). By projecting alterations of sea level rise along the coastline of Dansoman of Accra for two SRES scenarios Addo et al. (2011) reported that there might be a shoreline recession of 200 m for 0.79 m of sea level rise by the year 2100 under the SRES A1F1 scenario (Table 2). It is mentioned that for the same area observational data indicated that the shoreline has already migrated significantly inland for the period 2005-2009.

	Year	Min (cm)	Mean (cm)	Max (cm)	Shoreline position (m)
SRES A1F1	2025	2.97	6.77	11.39	−63.88
	2050	7.25	15.73	26.45	−105.49
	2100	21.22	46.41	79.71	−202.06
SRES B2	2025	3.18	7.17	12.05	−64.24
	2050	6.46	14.86	25.6	−104.96
	2100	14.04	33.74	60.27	−189.63

Table 2. Projections for sea level rise (cm) along the coastline of Dansoman, Acrra for the 21st century under SRES A1F1 and B2. The baseline was 1970–1990 (after Addo et al., 2011).

Projections for flood events over West Africa and Ghana

Precipitation is projected to be concentrated into more intense events, with longer periods of little precipitation in between. Therefore, intense and heavy rainfall events with high runoff amounts are interspersed with longer relatively dry periods with increased evapotranspiration, particularly in the subtropics. Based on physical reasoning it could be suggested that projected increases in heavy precipitation would contribute to increases in local flooding, although there is low confidence in projections of changes in fluvial floods because the causes of regional changes are complex. Projections of increased or decreased risk of flooding seems to depend mostly on the model analyzed (after Seneviratne et al., 2012) since flood magnitude and extent have a strong dependency on local topography, soil moisture status and land use change.

In an effort to assess the magnitude and frequency of river floods under scenarios of 1.5∘C, 2∘C, and 4∘C global warming Alfieri et al. (2018) used downscaled climate projections from an ensemble of seven GLMs to derive streamflow simulations. According to their hydrological simulations atmospheric warming and future flood risk exhibit a clear positive correlation under the RCP 8.5 scenario. However, changes in flood risk for most countries in Africa were not statistically significant for all considered warming levels.

Using the simulations from two GCMs (NCAR and CSIRO) with SRES A1b and SRES B1 as emission forces, the wettest parts of Ghana over the period 2010-2050 are expected to be the Forest (Ashanti and Western regions) and the coastal zone (Volta, Eastern, Central, and Greater Accra), see figure 7 (World Bank, 2010).

According to the report the areas around Volta basin will experience significant reduction in runoff while the southwestern part will experience increases in runoff by 2050 under both scenarios. Oti basin will experience a small increase in runoff for the A1b scenario with highest moisture index and 29 % reduction in the B1 scenario with the lowest moisture index. The fluctuations in stream flows and runoffs, particularly in the Volta River, may increase the risk of floods and/or droughts in urban and rural areas.

Estimating and understanding such seasonal and sub-seasonal changes is important for the formulation of adaptation and mitigation strategies. If an increase in high-intensity rainfall events is concurrent with the peak of the rainy season, widespread flooding may result (Sylla et al. 2015). In the case of pre-monsoon high-intensity precipitation events, early deployment of flood-control measures may be required.

Figure 7. Districts in Ghana

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