



CLIMATE
CHANGE
AGRICULTURE AND
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**CGIAR Research Program on
Climate Change, Agriculture and Food Security (CCAFS)**

**Climate Change in CCAFS Regions:
Recent Trends, Current Projections, Crop-
Climate Suitability, and Prospects for Improved
Climate Model Information**

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Part 1, West Africa (Richard Washington & Matt Hawcroft)

Part 2, East Africa (Richard Washington & Helen Pearce)

**Part 3, The Indo-Gangetic Plain (Mark New, Muhammad Rahiz &
Jagadishwor Karmacharya)**

**Part 4, Progress in Climate Science Modelling: A Look Forward (Richard
Washington)**



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Acronyms

AR5	IPCC's Fifth Assessment Report
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CMIP5	Coupled Model Intercomparison Project Phase 5
CORDEX	COoRdinated Downscaling EXperiment
ENSO	El Niño-Southern Oscillation
GCMs	General Circulation Models
IGP	Indo-Gangetic Plain
ITCZ	Intertropical Convergence Zone
RCMs	Regional Climate Models

Executive Summary

This report investigates the climate of three target regions of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The report assesses the implications of climate change for agriculture, with a particular focus on those aspects of climate change that will have greatest impact on the crops currently grown in each region. The study investigated the ability of General Circulation Models (GCMs) to reproduce already observed climates, to establish the reliability of future climate projections, as well as projections of how associated crops might grow under future conditions.

The climate of **West Africa** is dominated by the monsoonal cycle and high spatial and temporal variability in precipitation. The high annual precipitation and bimodal precipitation regime on the Gulf of Guinea gives way to a unimodal summer precipitation peak towards the continental interior associated with the monsoon. The precipitation gradient is steep and the precipitation highly variable, on daily to decadal timescales. The influences and interactions that control the climate of the region are complex and models have difficulty in simulating the observed climate. Temperature climatologies, variability and trends are generally robustly reproduced. GCMs do not perform as adequately in their simulation of regional precipitation patterns, with biases in the model climatologies, further uncertainty in the reproduction of trends, and under-estimation of climatic variability.

Model projections of the future in the region are highly uncertain. Temperature trends, including extreme indices, are all positive, though the models vary in the magnitude of the projected increases under the various forcing scenarios. Precipitation projections vary from significant decreases in precipitation and extended droughts in certain models in some regions, particularly the Sahel (the GFDL model), to increases in precipitation and decreased frequency and length of droughts (the MIUB model). The ensemble precipitation projections, which are generally neutral, are not so useful as they represent the average of a wide spread and are not constrained by the physical mechanisms which control the model scenarios. The temperature and precipitation trends produced in the models are mostly non-linear in both directions, indicating that the response of the climate system to external forcing will become more pronounced as the 21st century continues.

The projections for change in crop cultivation limits are highly variable over space and time. The individual models produce spatially consistent changes in the crop domains under continued anthropogenic climate forcing, but the inter-model spread is wide. For crops with lower precipitation growth thresholds, the growth domain projections produced by the end members of the ensemble having little overlap. Projected increases in temperature indices have varying impact on crops, depending on their particular climatic limits of growth. The outlook for agriculture is highly uncertain, particularly in the vulnerable Sahel region. Insufficient observational records constrain the accuracy of reanalysis and gridded data, making the verification of models and identification of local trends and mechanisms challenging. This initial uncertainty is compounded by the wide divergence in model projections for the region's climate by the end of this century, providing a significant challenge to the design of agricultural adaptation strategies.

The climate of **East Africa** is dominated by convective precipitation associated with the seasonal migration of the Intertropical Convergence Zone (ITCZ) across the equator. Most of the region has a bimodal regime with precipitation falling mostly in boreal spring (March to May, the long rains) and autumn (October to December, the short rains); to the north of the region, one rainy season from June to September coincides with the peak of northwards migration of the ITCZ; and in the south, the primary rainy season runs from December to March. Inter-annual variability is strongly linked to El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole patterns. Climate models are generally able to simulate temperatures adequately, although many exhibited a slight cool bias, including the ensemble. Precipitation is less well represented, and model biases are greater than for temperature. The ensemble captures precipitation more robustly than any single model, although precipitation retreats southwards too early in boreal autumn. Generally, the models have an annual cycle that migrates too far north and covers too great an area.

The climatological growth limits of ten crops that are important in the region were investigated using observed and reanalysis datasets. The simulated spatial distributions of these crops were generally similar to observed, with some key differences due to the inadequate simulation of climatological precipitation patterns by the climate models. Pigeon pea may have significantly greater potential for development in the region than is currently the case, if cultivation is not restricted by other factors. Under anthropogenic climate change a

warmer future is projected in all models, with the most significant changes over Ethiopia and Sudan. East Africa is one of the few regions where average precipitation projections converge, in this case to a wetter future. This wet trend is mainly projected to occur during the short rains (most models) with evidence to suggest that the long rains may decrease by up to 2 mm per day (CCCMA, CSIRO, GFDL and MPI models). Such changes will have highly variable impacts on agriculture. The rainfall projections may not alter current crop distribution ranges that much: more likely, future crop distribution will be more closely related to temperature increases. Some crops such as bananas, cassava, pigeon pea and rice may see an expansion of optimally suitable areas as a result of relatively high temperatures being optimal for their growth. In contrast, crops with cooler optimal thresholds such as maize, millet, potato, sorghum, sweet potato and wheat may be less suited to a warmer climate, and higher temperatures may adversely affect yields. There is significant uncertainty as to changes in severity and frequency of extreme events in the region, which could have substantial impacts on crop yields and food production.

In the **Indo-Gangetic Plain (IGP)**, the low-elevation, gently sloping middle and lower reaches of the Indus and Ganges river basins, most crops are grown in the rabi (October-March) and kharif (July-October) seasons. The key component that controls the climate is the southwest monsoon, which brings significant rainfall to the west coast of the Indian subcontinent and the north-eastern regions between June and September. Station-based data from 1960 indicate that temperatures are increasing by approximately 0.1 °C per decade, with a reduction in the diurnal temperature range. Temperature trends in the reanalysis data are less consistent, suggesting that not all the regional warming signal is captured well in the models. Trends in rainfall are inconclusive, as are trends in rainfall extremes, but with a tendency for increased dry-spell length and decreased wet-spell length. Very few if any climate models capture both monsoon rainfall amount and timing accurately over the region. All models except IPSL_CM4 exhibit a distinct monsoon rainfall season, but all have significant biases or mismatches between their simulated rainfall and temperature and that observed over the IGP. The most robust approach to assessing climate change over the IGP involves using all model projections available. Climate models all agree that mean temperature will rise, at a rate greater than the global mean. In general, temperatures in the monsoon period increase less than in the dry seasons. Projections for changes in precipitation are varied. For any period and season, the projected changes span zero, but the ensemble mean changes are generally

positive, and more consistently positive over the Ganges than the Indus. Changes in monsoon variability have not been assessed, but projections of such changes would have to be treated with extreme caution because of the difficulties climate models have in representing remote drivers of monsoon variability.

Scenarios for locations suitable for cultivation of key crops in the IGP show marked contrasts between irrigated and rain-fed situations. When using the ensemble mean projected changes in climate, rain-fed agricultural suitability of all crops increases in the future, due to the general increase in precipitation. Areas in the western Ganges and lower Indus that were previously unsuitable become suitable for at least one month, and those areas that are suitable in the present climate become suitable for longer. For irrigated agriculture, where temperature is the only constraint on crop suitability, maize, wheat and rice are not affected in terms of areas that are suitable for growth, except in the warmest scenarios in the 2090s; here temperature changes could start to limit the number of months in which a crop can be cultivated, especially in the lower Indus valley. However, the availability of water for irrigation will become an increasingly important factor in a warming world. The projections of increased rainfall for the Himalaya, the source of much of the surface irrigation water in the region, may ameliorate this stress, although there is considerable inter-model variability.

With regard to the **prospects for climate modelling**, the report shows clearly that there are considerable uncertainties in climate projections in all three regions from global models. These relate to issues such as climate sensitivity and representation of ENSO and other ocean-atmosphere processes. In the time since the IPCC's Fourth Assessment of 2007, most major modelling centres have developed newer versions of their global models. Each model typically includes improvements in the representation of physical processes, and usually increases in resolution, which can be important for representation of ocean-atmosphere interactions, and simulations of processes in areas with complex topography and land-sea geography. New simulations for the next IPCC assessment report are being undertaken through the Coupled Model Intercomparison Project Phase 5 (CMIP5). One set of experiments are long-term simulations, driven by a new set of radiative forcing scenarios (Representative Concentration Pathways) that represent a range of possible future greenhouse gas and aerosol concentrations. Other experiments are "decadal hindcast and prediction" simulations, to produce GCM simulations that are initialised using observations of the climate

system in 2005, and then predict climate evolution 10 and 30 years forward. Despite such developments, substantial increases in the reliability of projections from these models are not expected for the IPCC's Fifth Assessment Report (AR5). The model biases that exist tend to be stubborn and often persist from one model intercomparison to the next. Many such biases have important impacts on regional climate simulations.

For all the CCAFS regions, higher resolution simulations with Regional Climate Models (RCMs) have the potential to add considerable detail to the outputs from coarser resolution GCMs. CORDEX (COoRdinated Downscaling EXperiment) is an initiative to encourage the development of regionally downscaled climate projections in a consistent manner with a spatial resolution of 50 km. The results from CORDEX experiments should start to become available over the next two to three years, with an initial focus on Africa. Indeed, the hallmark of CMIP5 and AR5 from an impacts perspective is likely to be high-resolution climate model output derived from regional models. Whether the regional modelling effort provides benefits in terms of better constrained impact models remains to be seen. The performance of global models at regional scales has not improved drastically over the last ten years. In some cases, model errors have become more noticeable as the models themselves have become more complex. Careful evaluation of results will be required to identify both global and regional models that satisfy basic performance characteristics over the CCAFS regions. This is a heavy responsibility for the impacts modeller, and considerable creativity will be needed in handling model error and inter-model differences in all the impact methodologies that are used.