Protected Areas Resilient to Climate Change, PARCC West Africa

Projections of Change in Ecosystem Services under Climate Change

ENGLISH

Andrew Hartley, Richard Jones, and Tamara Janes

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219 Huntingdon Road, Cambridge CB3 0DL, UK
Tel: +44 1223 277314; Fax: +44 1223 277136
Email: protectedareas@unep-wcmc.org
URL: http://www.unep-wcmc.org

Table of Contents

Executive Summary

In this report, we analyse the combined and separate future impact of land use change and climate change on ecosystem services in West Africa, including carbon storage, water provision and vegetation productivity. We use the ensemble of regional climate projections developed for the PARCC project to run a model that simulates exchanges of carbon, energy and moisture between the land surface and the atmosphere, using three different scenarios of future land use change. These scenarios account for different levels of human disturbance of the land surface, and different levels of protection of primary forests. In the companion report on regional climate projections for West Africa the findings from the latest assessment report (AR5) from the Intergovernmental Panel on Climate Change (IPCC) are referred to in order to provide guidance on the how these results should be interpreted. They should be viewed either as:

(a) results we have confidence in because we have high agreement between the models and a physical understanding of why the change has been projected; or

(b) results which are plausible because we cannot exclude them as being wrong but we have low confidence in them because results from other models are different but also plausible .

The key findings for the region are:

- Carbon storage of forests is projected to increase under the effects of climate change, however, forest degradation would restrict this increase.
- Generally, vegetation productivity is projected to increase in most parts of West Africa. The exceptions to this are in southern Nigeria, where land use scenarios estimate a high level of human activity, and in the western Sahel, where a drying signal (considered plausible but low confidence) is found in the climate projections.
- In central and eastern West Africa, ecosystems are projected to shift northwards. This includes increase in tree fraction of ecosystems in Cameroon and Central African Republic, increases in shrub fraction in the savannah grasslands of southern Chad and northern Nigeria, and increases in grass fraction on the edge of the Sahara desert in Chad and Niger.

For individual PARCC countries, the key findings are:

Chad

The whole of Chad is projected to experience a northward shift of ecosystems.

This includes increases in shrub and tree cover in southern woody savannah ecosystems which are related to temperature change and thus confident projections. Increases in vegetation coverage (grassland) in arid and semi-arid ecosystems of central Chad on the edge of the Sahara are related to precipitation change and thus are plausible but not confident projections. Vegetation productivity increases in central and southern Chad, indicating stronger vegetation growth, and potentially larger crop yields are related to both temperature and precipitation change so again are plausible but not confident projections. Similarly, increases in surface run off, suggesting more water available for ecosystems and agriculture, are related to precipitation change and thus plausible but not confident projections.

Mali

In the south of Mali, projections are for an increase in the bare soil fraction, replacing grass cover, and a reduction in vegetation productivity in arid and semi-arid parts of the country. These are related to a projection of decreased western Sahelian precipitation and thus are plausible but not confident. Projections for change in grass and bare soil fractions in southern Mali show these are highly sensitive to precipitation variability, indicated by both year-to-year variability and decade-to-decade variability in vegetation cover.

Togo

Under a scenario of no human disturbance to natural vegetation (as found in protected areas), small increases in vegetation productivity are projected in Togo, resulting in an increase in vegetation carbon in woody savannah ecosystems, and are related to temperature change and thus confident. Including human disturbance, however, leads to a reduction in vegetation carbon in central Togo (high confidence). A small increase in the fraction of broadleaf tree cover over most of Togo is projected in some, but not all, regional climate model projections so should be considered plausible but not confident.

Sierra Leone

Increases in the fraction of broadleaf tree cover are projected to occur throughout Sierra Leone, although human disturbance would restrict this increase (high confidence). Vegetation productivity is also projected to increase as broadleaf tree cover increases, and consequently vegetation carbon storage increases. This is related to increases in minimum temperature, since photosynthesis is not limited by water availability in this region, and it thus a confident projection. There is a large variability in the projections of change in surface runoff with increases towards the end of the century related to precipitation change and thus plausible but not confident. It should be noted that estimates of human disturbance are most likely inaccurate for this region, although one scenario does provide a useful example of how long it might take natural ecosystems to revert to normal following disturbance. In this scenario, all human disturbance stops after 2000, but the ecosystem model projects that it would take until 2100 for vegetation carbon to return to 'natural' levels.

Gambia

In Gambia, the projections are for an increase in the bare soil fraction, replacing grass cover, as well as a small reduction in vegetation productivity. These are related to a projected decrease in western Sahelian precipitation and thus are plausible but not confident. Projections for change in grass and bare soil fractions in Gambia are also highly sensitive to precipitation variability, indicated by both year-to-year variability and decade-to-decade variability in vegetation cover.

1. Introduction

Protected areas provide ecosystem services that maintain the balance of natural systems and provide economic benefit way beyond their boundaries (Costanza et al., 1997). In many cases, these services can have a direct impact on human populations, such as in the provision of food security, or a clean, reliable supply of drinking water. In other cases, human populations may receive indirect benefits, such as the sequestration of carbon by forests that limits future global climate change. The identification of these services is an important step in the recognition of the value of protected areas, and therefore helps to identify the role they play in providing services that maintain human systems, such as agriculture or water and sanitation.

Landscapes and ecosystems in West Africa, however, have undergone large changes in recent decades (Mayaux et al., 2013). The rate of tropical deforestation in the region is an indication of the pressures facing ecosystems (e.g. Lawton et al., 1997). The most recent estimates of tropical forest deforestation from satellite observations show that deforestation rates in West Africa have slowed between 1990 and 2010, but are still considerably higher than the continental average (Mayaux et al., 2013). Between 1990 and 2000, it was estimated that annually, 1.09% of West African tropical forest was being deforested, compared to a continental rate of 0.33%. This rate decreased to 0.35% per year between 2000 and 2010, but still remains more than double the continental rate (0.15%).

Indirectly, the loss of tropical forest reduces the amount of carbon stored by the land and releases it into the atmosphere as carbon dioxide (CO_2) which potentially further enhances global climate change (Cox, Betts, Jones, Spall, & Totterdell, 2000). However, there are also direct impacts of tropical forest deforestation on local and regional ecosystem services. Tree cover allows the land to intercept, recycle, and retain rain water during the wet season, reducing the impact of heavy rain events, and maintaining a regular and clean supply of water during the dry season. Therefore, tree cover is a good example of an ecosystem service, because the water it provides can be have many uses such as irrigated agriculture, clean drinking water for human populations, or watering holes for cattle and wild life. Often, the value of ecosystem services is only realised after they are removed. Costs can be bourn through societal impacts, such as increased poverty or threat to life, or through economic impacts such as loss of revenue or increased demand for government services. For example, forest removed from slopes may lead to landslides during the wet season, which threatens life, housing and infrastructure. An example of economic costs related to deforestation may include an increase in siltation of reservoirs for drinking water, requiring greater investment to remove sediment, or lower quality drinking water, requiring greater investment in water purification.

In this report, we will use the results of the 5 regional climate model (RCM) simulations for the PARCC project (Jones, Hartley, McSweeney, Mathison, & Buontempo, 2012) to study the effect of future changes in climate on ecosystems and some of the services they provide. Furthermore, we use three different scenarios of future land use to show the effects of different land use compared to regional climate change. Two of these scenarios are based on land use change projections used in the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5), and a third assumes no historical or future human disturbance of natural vegetation. By comparing these scenarios we separate the effects of different future land use and climate change on changes in ecosystem services.

2. Methodology

Regional climate projections have been created for the PARCC project using a methodology described in more detail in Jones et al. (2012). These simulations provide future projections for regional climate change in West Africa at 50km spatial resolution for the period 1950 to 2099, using the A1b greenhouse gas emissions scenario, which is a 'business as usual' greenhouse gas emissions scenario. We used the PRECIS (Providing REgional Climates for Impacts Studies) Regional Climate Model (RCM) to downscale 5 different global climate simulations from an ensemble of uncertainty in the HadCM3 (Hadley Centre Climate Model 3) global climate model (GCM). Each of these 5 GCMs were chosen for downscaling because they provided realistic simulations of the historical climate, and represented the full range of IPCC 4th Assessment Report (AR4) future projections for temperature and precipitation. In the case of West Africa as a whole, projections for mean annual temperature change range from 2.5 to 5.5°C, and for changes in precipitation, projections range from –60% to +50%, by the end of the century relative to a 1971-2000 baseline, indicating larger uncertainty in projections of precipitation change. A more detailed analysis of how the 5 member RCM ensemble compares to the latest projections from the IPCC AR5 can be found in the climate assessment report (Janes, Jones, & Hartley, 2015).

The Joint UK Land Environment Simulator (JULES) was used to make projections of changes to ecosystem services, based on the 5 member ensemble of regional climate change projections and three different land use scenarios. Using this approach makes it possible to compare the effects of both uncertainty in the regional climate simulations (5 member RCM), and uncertainty in the future land use scenario. JULES is a land surface model that simulates exchanges of carbon, heat, moisture, and momentum between the land surface and the atmosphere. The main inputs to these JULES simulations were climate data at 3 hourly time steps, annually changing atmospheric CO_2 concentrations (taken from the A1b scenario greenhouse gas emissions scenario), and land use change. For a given RCM ensemble member, JULES was run to reach equilibrium with the historical climate (1950-1970), using observed historical CO_2 concentrations for the same period. Once equilibrium was reached in the exchange of carbon between the land and the atmosphere, the model was allowed to run for the full 1950-2099 period, using updates to the climate every 3 hours, and annual updates to atmospheric CO_2.

To understand the relative effects of human activity (via agriculture or deforestation) compared to climate-induced change in vegetation characteristics, 3 scenarios of land use were used:

i. MINICAM (RCP4.5). In this scenario, preservation of existing carbon stored in forest was available as a climate change mitigation strategy. This leads to the preservation of existing forests, and an expansion of forest area throughout the 21st Century.
ii. AIM (RCP6.0). In this scenario, land use was treated as a production factor for agriculture, livestock, forestry and biomass energy, leading to a reduction of grasslands in favour of croplands. In West Africa, human disturbance of forest remains largely unchanged.
iii. No Land Use Change. Here, no human disturbance was assumed in both the historical and future periods. This simulation was run so that climate-induced changes in ecosystem services could be separated from anthropogenic causes. Potentially, this is the most realistic scenario for ecosystems in protected areas where no human disturbance has occurred since 1950 and will not occur in the future.

The land use scenarios from MINICAM and AIM, as shown in figure 1, were used to estimate the fraction of human disturbance that occurs within each grid cell for the historical period (based on observations), and the future period (based on the AIM and MINICAM socio-economic models). Human disturbance is a measure of how much human influence there is on the land cover of a given grid cell. It is used by JULES to adjust fractions of natural vegetation in accordance with how humans modify the landscape. For example, the MINICAM scenario assumes that human disturbance in Chad will continue at existing levels into the far future, whereas the AIM scenario assumes that it will reduce from 60-90% in the historical period to 30-50% in the far future (Figure 1). These projections should be viewed as potential future outcomes that are affected by global decisions on climate change mitigation, rather than an attempt to predict changes in a particular location, such as a protected area.

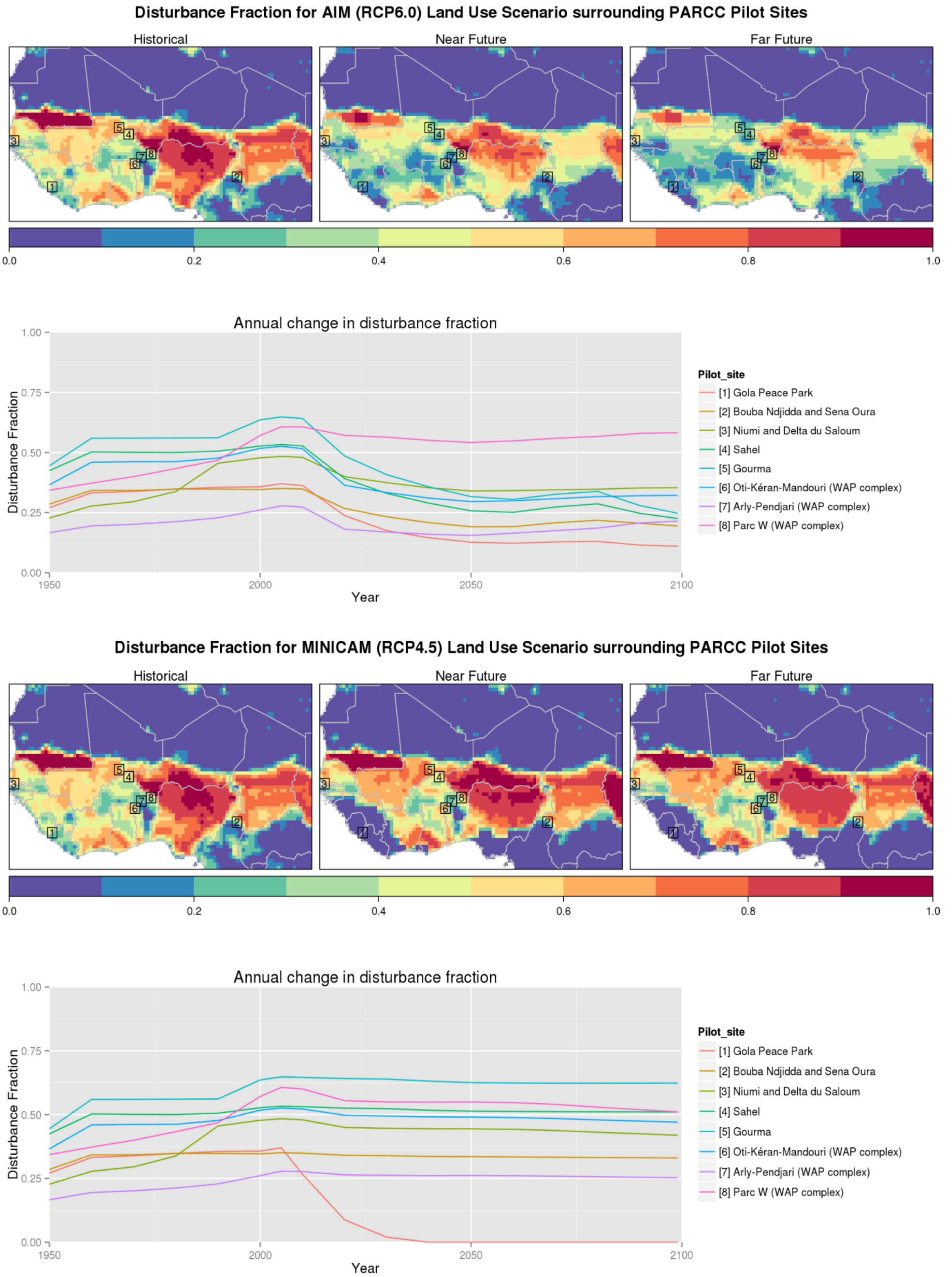

Figure 1. Land use change scenarios used in this report. The AIM scenario used in RCP 6.0 is shown on the top panel, and the MINICAM scenario used in RCP 4.5 is shown on the bottom panel. In each panel, the maps show human disturbance at historical (1971-2000), near future (2020-2049) and far future (2070-2099) time periods, and the line plots below show change in human disturbance at each of the 8 protected areas involved in the 5 PARCC pilot sites

between 1950 and 2100.

3. Ecosystem Shifts

Over a long period of time, the distribution of the main vegetation types is influenced by the prevailing climatic conditions. The PARCC regional climate projections show a change in mean annual temperature in West African countries of between 2.5 and 5.5°C and change in precipitation between -60% and +50% by the end of the century relative to a 1971-2000 baseline. Such changes would be expected to have an impact on the ecosystem types and species distributions. The JULES land surface model uses the PARCC regional climate change projections (Jones et al., 2012) to provide projections of how key vegetation types may shift according to climate. These vegetation types can be used to give an indication of how the existing vegetation within a protected area may change. Land use scenarios (Figure 1) are used from the IPCC AR5 to show the effect of different global and regional climate change mitigation decisions.

The plots below show a summary of changes in vegetation and bare soil fractions (Figures 2 to 5) across the climate ensemble and land use scenarios. Results were obtained for each of the 5 RCM ensemble members, but ensemble members Q2 (most broadleaf tree change) and Q13 (least broadleaf tree change) are presented below because they represent the most extreme changes. Generally, across the whole of West Africa, there is a climate-induced increase in the fraction of the land surface that is vegetated. This is the case in tropical biomes, where an increase in forest fractional cover is found (replacing shrubs), in savannah regions where an increase in fractional shrub cover is found (replacing grass), and in arid zones, where an increase in grass cover is found (replacing bare soil). Generally speaking, these changes are due to increases in atmospheric CO_2 concentration (high confidence), temperature (high confidence) and, in some parts of West Africa, increases in precipitation (low confidence), creating conditions that are more favourable for photosynthesis and the retention of water within plants. Increases in bare soil fraction in the Western Sahel are found across all land use scenarios, indicating a climate-induced desertification in this sub-region (related to precipitation, therefore low confidence).

When interpreting figures 2 – 5, it should be noted that the vegetation types in JULES are a simplification of true vegetation that is found in situ. Therefore, when interpreting these results, the user should put the changes shown below in the context of the vegetation that currently exists in that location. For example, the woody vegetation in savannah ecosystems is characterised as shrub cover rather than tree cover, so increases in shrub cover can be interpreted as an increase in woody vegetation.

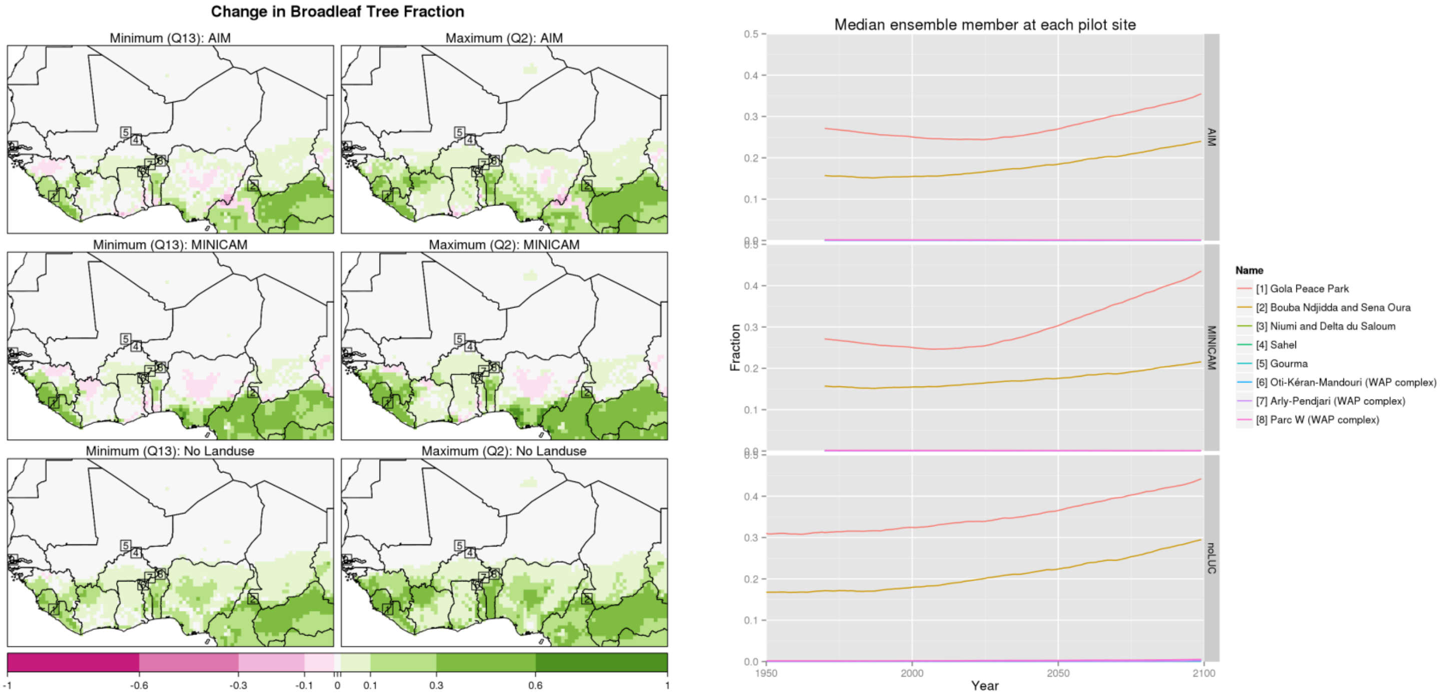

Figure 2. Change in projected broadleaf tree fraction. The left column of maps show the RCM ensemble member with the minimum fractional change in broadleaf tree cover (Q13), and the right map column shows the ensemble member with the largest fractional change in broadleaf tree cover. The three rows of maps show the three different land use scenarios: AIM (RCP6.0), MINICAM (RCP4.5), and no land use. The time series plots on the right show the projected mean annual fractional coverage at each of the 8 pilot sites. In savannah regions, such as the WAP complex and Sahel-Gourma, woody vegetation is represented in JULES as shrub cover.

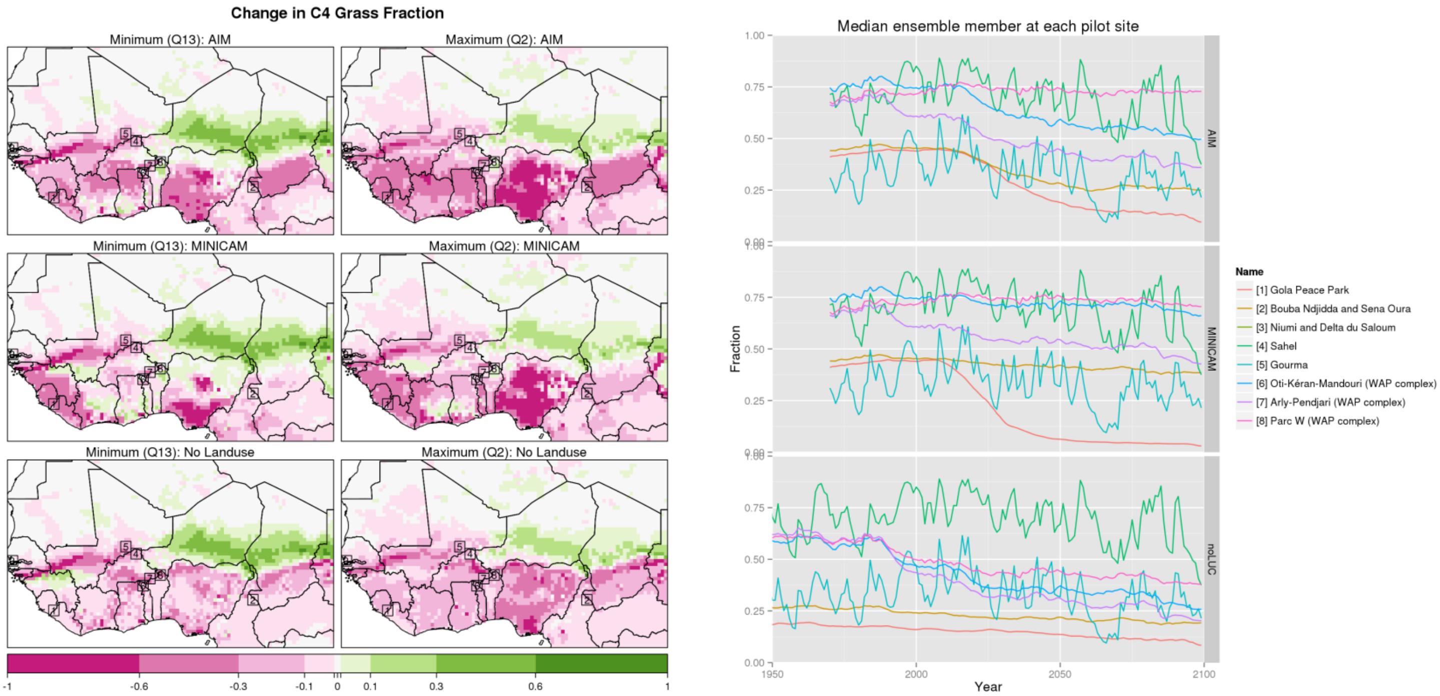

Figure 3. As above, but for C4 grass fractional cover. C4 describes the photosynthetic pathway that is common in grass cover in West Africa. Such plants have evolved to have a competitive advantage over C3 plants under

conditions of drought, high temperatures, and nitrogen or CO_2 limitation. Crops such as maize, millet, sorghum and sugar cane use the C4 photosynthetic pathway.

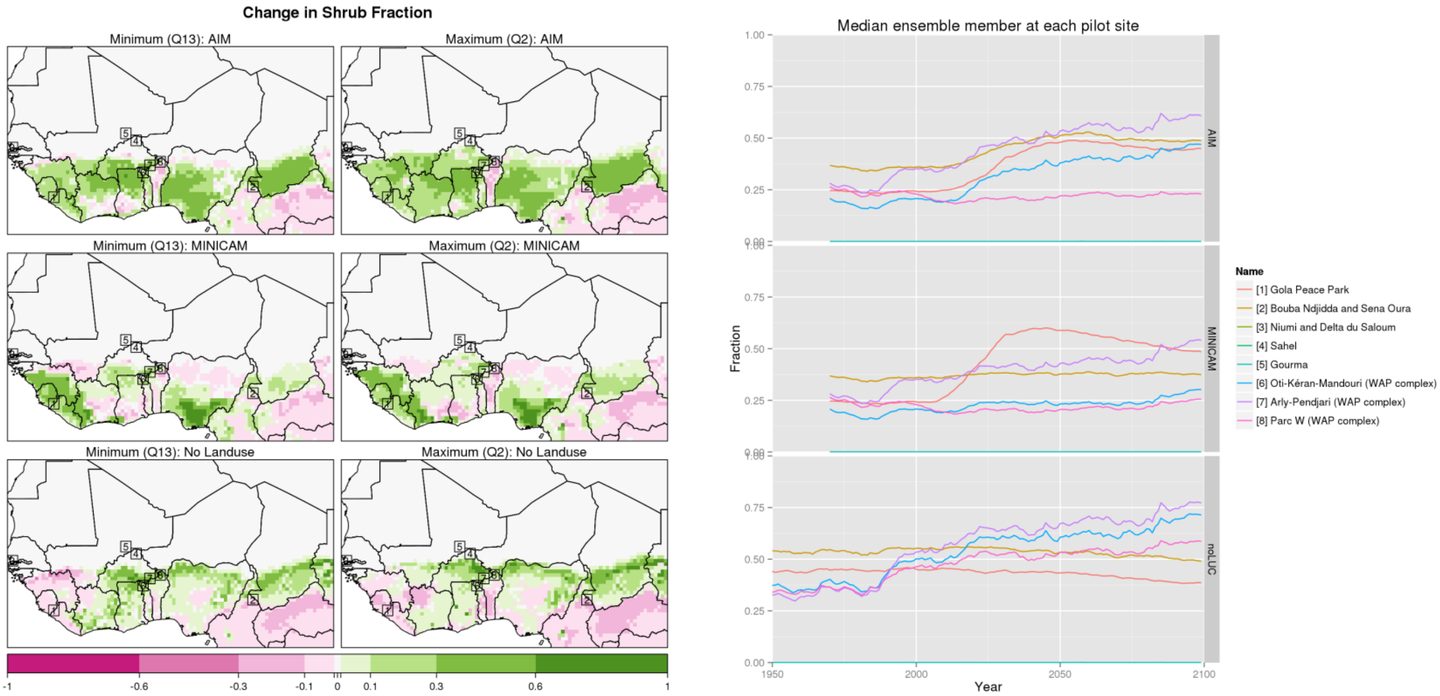

Figure 4. As above, but for shrub fractional cover

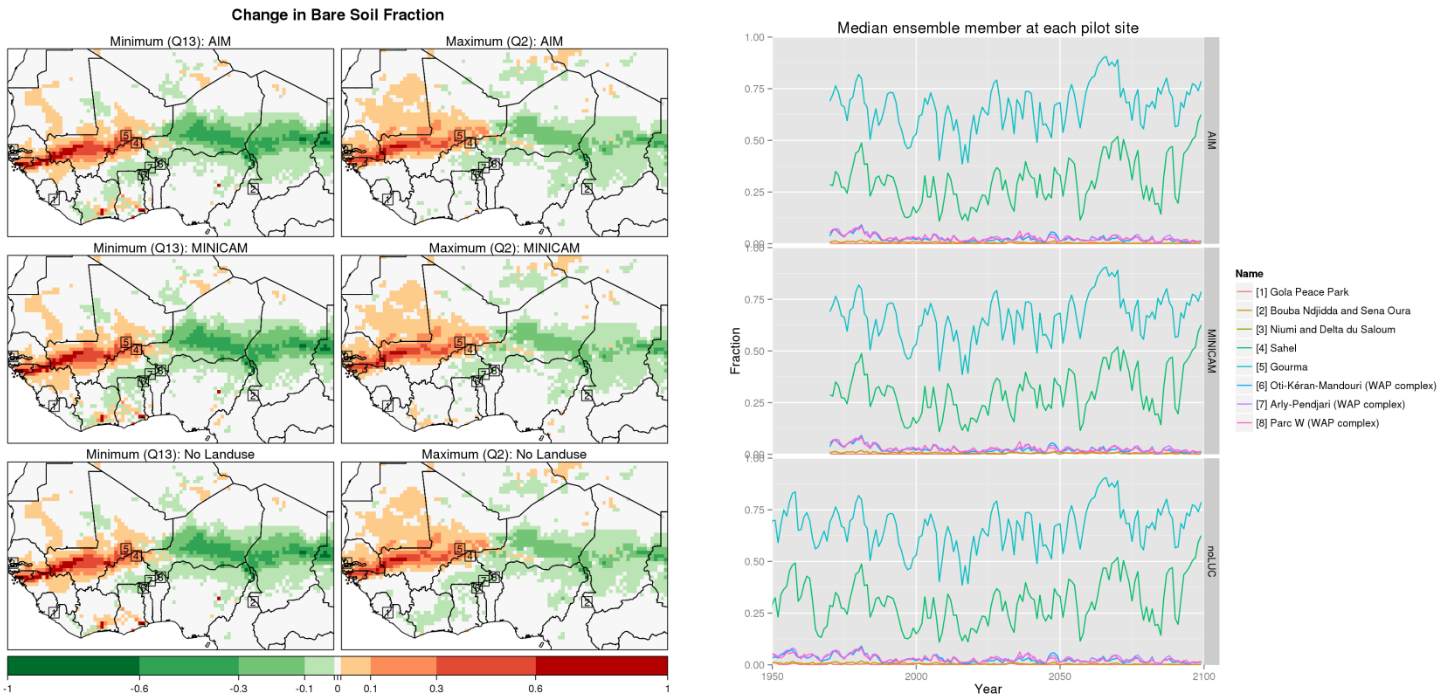

Figure 5. As above, but for bare soil fractional cover.

At the national level, the results for ecosystem shifts can be interpreted as follows:

Chad: In the vegetated south of the country, there is a reduction in bare soil fraction that is strongly related to climatic factors rather than land use decisions, and is evident in all RCM ensemble members. However, the bare soil is replaced by different vegetation types, depending on the land use scenario. More human disturbance in the MINICAM future land use scenario (historical disturbance continues unabated at 60-90% of the land surface) leads to a greater fraction of C4 grass as opposed to shrub cover. Lower amounts of disturbance in the AIM future land use scenario (reducing to 30-50% disturbance in the far future) leads to shrub cover reaching natural levels by 2050. For the PARCC pilot site in the South of Chad, Sena Oura National Park, which is transboundary with Bouba Ndjidda National Park in Cameroon, the land use scenarios are similar to Chad as a whole. Since the site is on the edge of the savannah woodlands surrounding the Congo Basin, the climate signal (under no anthropogenic land use) leads to an increase in the fraction of broadleaf tree cover, indicating a trend towards more closed woody savannah in the region.

Mali: Here, the predominant trend in Central and Southern Mali is towards an increase in bare soil fraction, replacing grasslands, related to climatic factors rather than different scenarios of land use. This result is plausible, but it has not been verified, therefore should be interpreted as not a confident projection since it is closely related to a highly uncertain drying signal from the regional climate model in the Western Sahel. The PARCC pilot site at *Réserve des éléphants du Gourma*, which is transboundary with the *Réserve partielle de faune du Sahel* in Burkina Faso, is on the edge of this area, therefore the projections for reductions in grass cover and increase in bare cover are much less pronounced. There is also considerable year-to-year and decade-to-decade variability in grass and bare soil fractions, providing further indication that the vegetation in this region is closely linked to precipitation variability and change.

Togo: Under the no land use scenario, the climate signal indicates a small increase in the broadleaf tree fraction across most of the country, along with reductions in grass cover. However, continuing historical land use patterns into the far future under the MINICAM scenario has the effect of reducing the gains in broadleaf tree that would be gained under climate change. In the north of Togo, and throughout the PARCC pilot site, made of the Oti-Kéran-Mandouri complex and the WAP transboundary conservation area, an increase in shrub cover is projected to replace grass cover. This would indicate that the climate conditions in the far future are more favourable to woody savannah than to grassy savannah.

Sierra Leone: An increase in the fraction of broadleaf tree cover is projected, related to increases in annual average minimum temperature (see Annex 1). However, in Sierra Leone, the land use scenarios used here do not concur with recent trends. They consider either a complete cessation of human disturbance (MINICAM), or a substantial reduction by 2100 (AIM). If these land use scenarios were to occur, the projections show that there would be a period of regrowth, and if deforestation were to be stopped in the near future (MINICAM scenario) tree cover fraction would revert to natural levels by 2100.

Gambia: Gambia is on the edge of a region where large increases in bare soil fraction have been projected related to projected reductions in precipitation, albeit with low confidence (see description for Mali). Only small increases in bare soil fraction are projected for Gambia (increase of 0-10%), replacing grass cover. Projections for the Niumi National Park pilot site, which is transboundary with the Parc National du Delta du Saloum in Senegal, were not possible due to the large coastal element of the site.

4. Vegetation productivity

Gross Primary Productivity (GPP) is a measure of the amount of carbon that is taken up by plants when they photosynthesize. GPP is a useful indicator because it can be directly influenced by climate, and so provides a link between the condition of the vegetation and the climate (see for example Annex 1). As plants photosynthesize, they absorb CO_2, sunlight and water. The process produces carbon-based sugars that are then fixed by the plant to either store as leaves, stems or roots, or to use as energy in respiration. This is the process by which plants store CO_2 from the atmosphere. Therefore, as atmospheric CO_2 is expected to continue to increase throughout the next century, it would be expected to enhance photosynthesis and increase the rate at which carbon is stored in the vegetation. The extent to which this is done depends on the physiology of the plant itself, and other limiting factors such as availability of sunlight and water, air and ground temperature, or nutrient availability.

At the regional scale, as expected, GPP tends to increase over most parts of West Africa mostly influenced by climatic factors, as opposed to land use scenario, as shown by the third column of maps in Figure 6. The trend in GPP is strongly related to changes in precipitation over most of the savannah ecosystems in the region, although in the tropical forest region, temperature appears to be the main driver of GPP changes (see details in Annex 1). In all RCM ensemble members, the largest increases in GPP are found in the tropical forest areas, and in parts of Chad that experience a northward movement of vegetation. Reductions in GPP are projected for the Western part of the Sahel, where a highly uncertain climate signal of precipitation reductions is projected by the RCM ensemble. Notably, there are several locations where the impact of human land use is expected to reverse the climate-related positive trend in GPP. These locations are found in mostly coastal West Africa, in southern Nigeria, and to a lesser extent Cote d'Ivoire and Ghana.

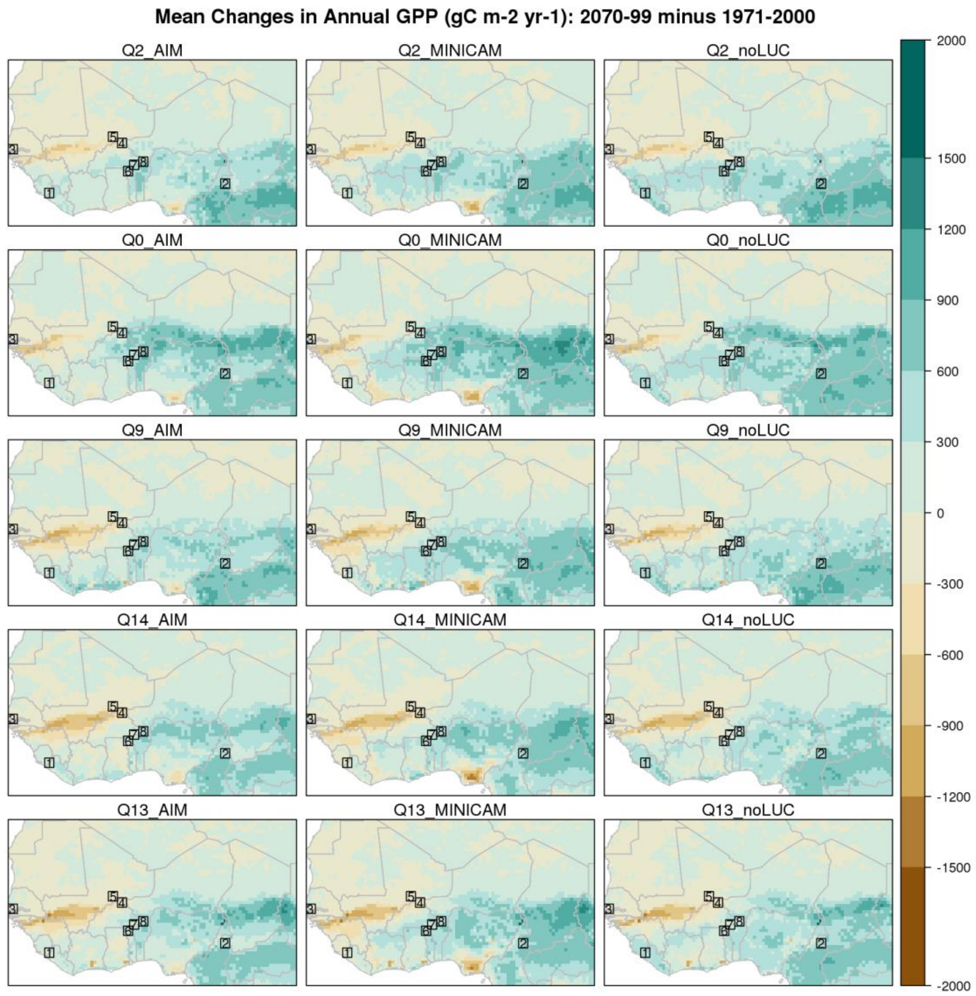

Figure 6. Spatial change in Annual GPP from 5 different regional climate projections (rows) and 3 different land use scenarios (columns, see description in figure legends above). Results are shown for all simulations in order to aid visual comparison of the relative effects of RCM ensemble member and land use scenario.

At the national level, results for change in vegetation productivity can be interpreted as follows:

Chad: Increases in GPP in the south of Chad are strongly correlated with changes in temperature, giving greater confidence to this result. Further north, into the Sahel, increases in vegetation growth are limited by the availability of water. Consequently, projections for increases in vegetation productivity in this region are plausible, but have a lower level of confidence. This result indicates that in locations where increases in C4 grass are projected (Figure 3), increases in the productivity crops such as maize, sorghum or millet may occur.

Mali: Reductions in vegetation productivity in arid and semi-arid parts of Southern Mali is related to a projected decrease in western Sahelian precipitation, and to a lesser extent increases in air temperature in some ensemble members (see Annex 1 for more details).

Togo: Generally, small increases in vegetation productivity are projected, related to changes in both precipitation and temperature (and thus plausible but not confident). The woody savannah ecosystems of central and northern parts of Togo are projected to see the largest increases in productivity.

Sierra Leone: Relatively large increases in vegetation productivity are projected in Sierra Leone by the far future, related to projected increases in minimum temperatures (high confidence), and projected increases in the broadleaf tree fraction.

Gambia: Projections are for a small reduction in vegetation productivity, which is related to a projected decrease in western Sahelian precipitation (plausible, but not confident). Projections for changes in vegetation productivity show highly sensitive to precipitation variability, indicated by both year-to-year variability and decade-to-decade variability in vegetation cover.

5. Carbon storage

In the tropical forests of West Africa, large amounts of carbon are held in the vegetation above and below ground. In the context of REDD (Reducing Emissions from Deforestation and Degradation), the amount of vegetation stored within the vegetation of protected areas could have important financial implications. In the region as a whole, we found that carbon stored in vegetation is projected to increase, especially in tropical rainforest and woody tropical savannah ecosystems (Figure 7). This is related to projected increases in vegetation productivity and the fractional cover of trees and shrubs. Regionally, most of the changes in vegetation carbon storage occur in the tropical forests of the region. These areas mostly coincide with locations where temperature is more strongly correlated with GPP (see more details in Annex 1), meaning that there is a higher confidence in this result. It should be emphasized that human land use can have a large negative impact on these increases, emphasising the importance of protecting existing stands of tropical forest.

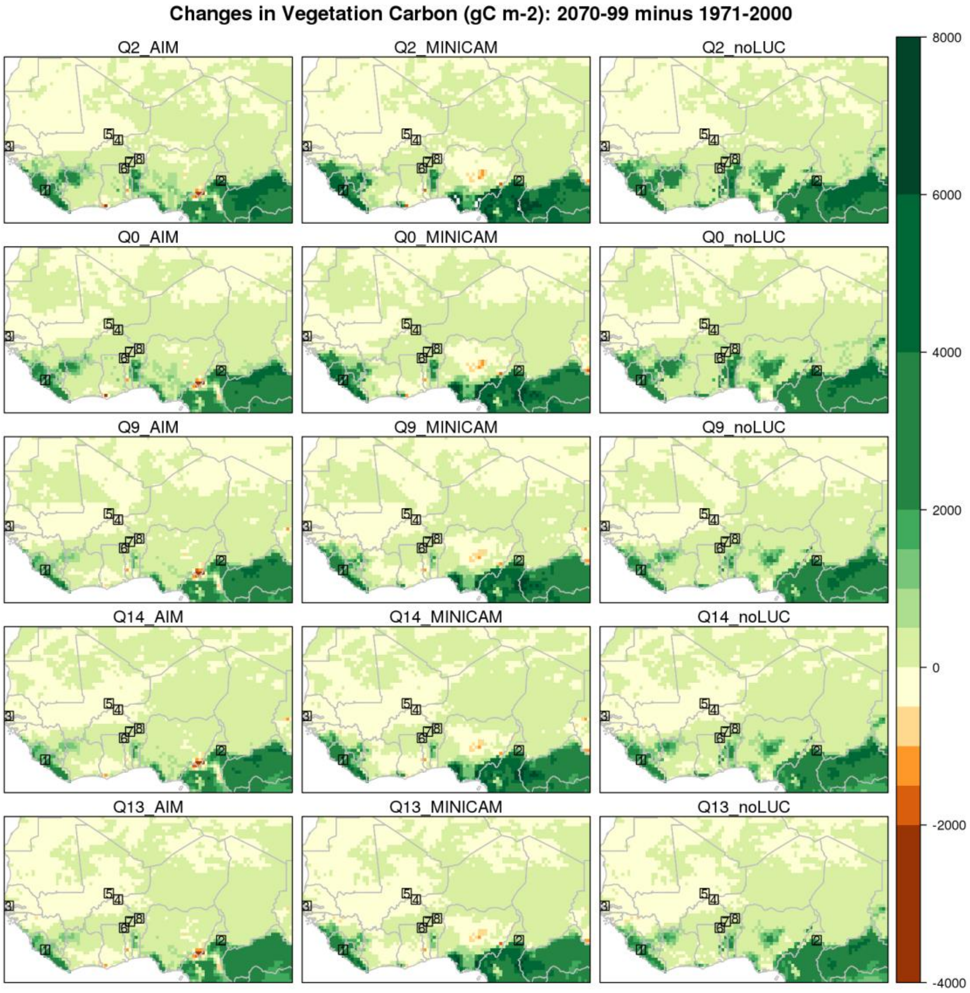

Figure 7. Changes in above ground vegetation carbon storage for 5 regional climate ensemble members (rows), and three land use scenarios (columns).

Vegetation carbon storage is by far the greatest at PARCC pilot sites found in tropical forests. At Gola Forest Peace Park, on the boundary between Sierra Leone and Liberia, most ensemble members project an increase in carbon storage of 25 to 35% more than in the historical period. In Bouba Ndjidda and Sena Oura national parks on the border of Chad and Cameroon, this increase is projected to be even greater (as much as 100% increase by the far future), as it is related to a northward shift of broadleaf tree cover.

6. Surface runoff

Water falling as precipitation can either be absorbed by the soil water stores, transpired through vegetation, evaporated from the soil (or the vegetation canopy) or run off into channels. The amount of surface runoff is an indication of how much water is available for drinking and irrigation in a given location. It is closely related to projections of change in the amount of precipitation (via input of water), and to projections of change in the amount and productivity of vegetation (via output of water due to evaporation and transpiration). We found that regionally, surface runoff is projected to increase, especially in savannah ecosystems, in the area between Northern Ghana and Central and Southern Chad, where we found up to 100% increase in surface runoff by the end of the century compared to 1961-1990. Small reductions are projected in the western Sahel (Figure 8; between 0 and 60%), although projections of reduced rainfall in this region currently have low confidence.

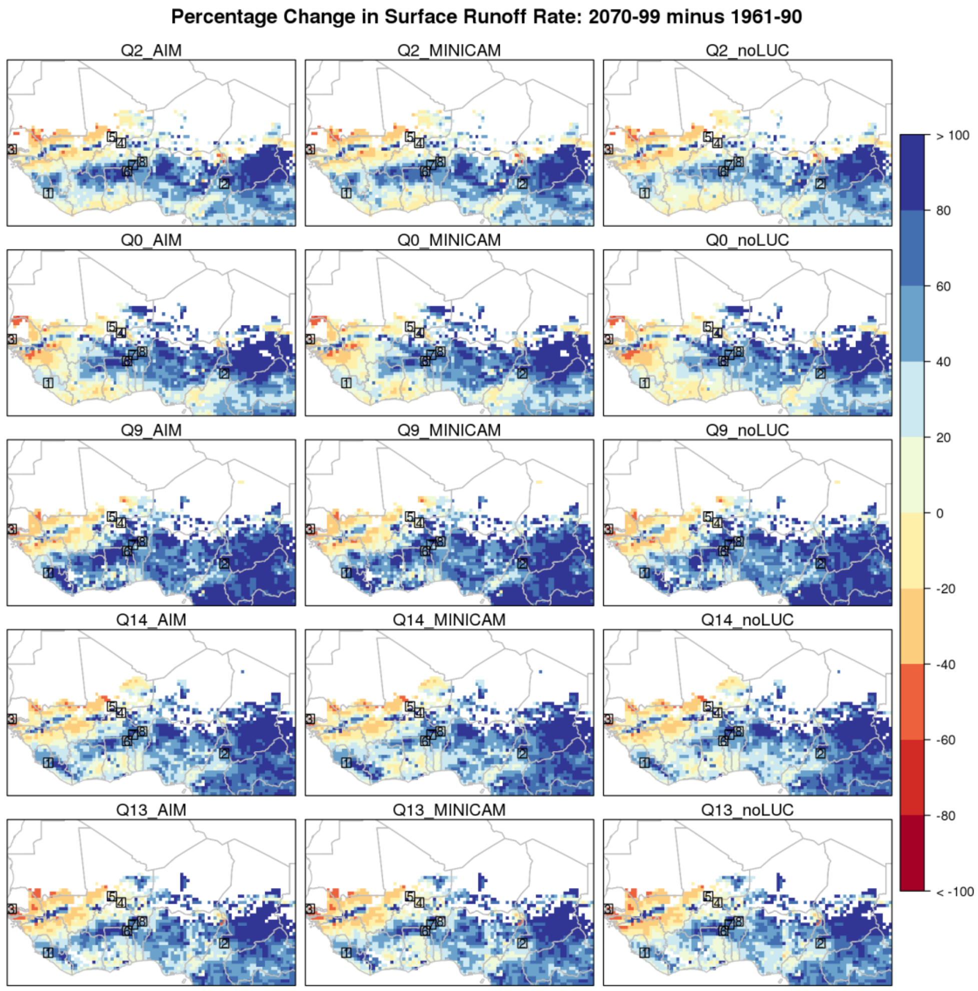

Figure 8. Percentage change in surface runoff for 5 regional climate ensemble members (rows), and three land use scenarios (columns). Arid areas (where surface run off is very low) are excluded from the analysis.

The savannah parts of West Africa are projected to have the largest percentage increases in surface runoff in the region, where increases of up to 100% are projected in parts of Northern Ghana, Northern Togo, Nigeria and Southern Chad (Figure 8). The absolute projected increase in surface runoff in these ecosystems is however lower than that projected for the Congo Basin (not shown). It should also be noted that the “no land use change” scenario projects smaller increases in runoff in savannah ecosystems, particularly in the transboundary WAP complex. This indicates that locations where historical land use change is likely to not have occurred (i.e. protected areas), smaller increases in surface runoff are projected compared to locations where there is a large amount of human disturbance. This difference is thought to be due to larger amounts of tree and shrub cover within protected areas, meaning that more water is intercepted and transpired by vegetation cover. In the Western Sahel, generally reductions in surface runoff are projected, related to projections of reduced precipitation in this region (low confidence). However, increases are also projected in the area surrounding the Niger River, where increases in bare soil fraction are projected, resulting in less interception of heavy rainfall by vegetation. In general however, the reduction in surface runoff in the Western Sahel may affect both human and natural systems that may be more sensitive to smaller surface runoff changes due to the relatively low annual precipitation.

Figure 8 also shows that there is considerable uncertainty in the magnitude and extent of the increases in surface run off. This can be seen by comparing the difference between ensemble members (rows) in Figure 8. For example, ensemble member Q9 shows increases in surface run off across many parts of West Africa, ranging from the tropical coastal regions of Sierra Leone, to the arid regions of Chad. In contrast, ensemble member Q0 shows relatively small changes in the area between Sierra Leone and Ghana, with increases in surface run off restricted to savannah ecosystems in the belt between Northern Ghana and Central Chad. These variations between ensemble members are an indication of how uncertainty in precipitation projections can affect projections of the surface water balance. It should be noted that each of these ensemble members are equally plausible. There is however, low confidence in precipitation projections because the mechanisms of change are still an active area of research.

Conclusions

In this report, we have used a land surface model (JULES) to make projections of change in ecosystem services across West Africa. This has involved analyzing the impacts of climate or land use scenario on services such as carbon storage, water provision and vegetation productivity.

The principal findings for West Africa as a whole are firstly that carbon storage of forests is projected to increase under the effects of climate change, however, forest degradation would restrict this increase. Generally speaking, this increase is related to a projected increase in minimum temperatures in tropical parts of West Africa, and precipitation in savannah ecosystems.

Secondly, vegetation productivity is projected to increase in most parts of West Africa. The exceptions to this are in southern Nigeria, where land use scenarios estimate a high level of human activity, and in the western Sahel, where a drying signal (low confidence) is found in the climate projections. This would be expected to lead to more productive ecosystems, and increases in crop yields.

Thirdly, in central and eastern West Africa, ecosystems are projected to shift northwards. This includes increases in tree fraction of ecosystems in Cameroon and Central African Republic, increases in shrub fraction in the savannah grasslands of southern Chad and northern Nigeria, and increases in grass fraction on the edge of the Sahara desert in Chad and Niger.

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Annex 1. Correlations between GPP and Climate Variables

Here, we show the relationship between changes in Gross Primary Production (GPP) of plants and climate drivers for the full 150 year period (1950-2099). Knowledge about how GPP is related to climate gives us information about which climate drivers are associated with vegetation productivity in different locations across the region. This allows us to establish a link between confidence in climate projections and confidence we have in projections of changes in ecosystem services.

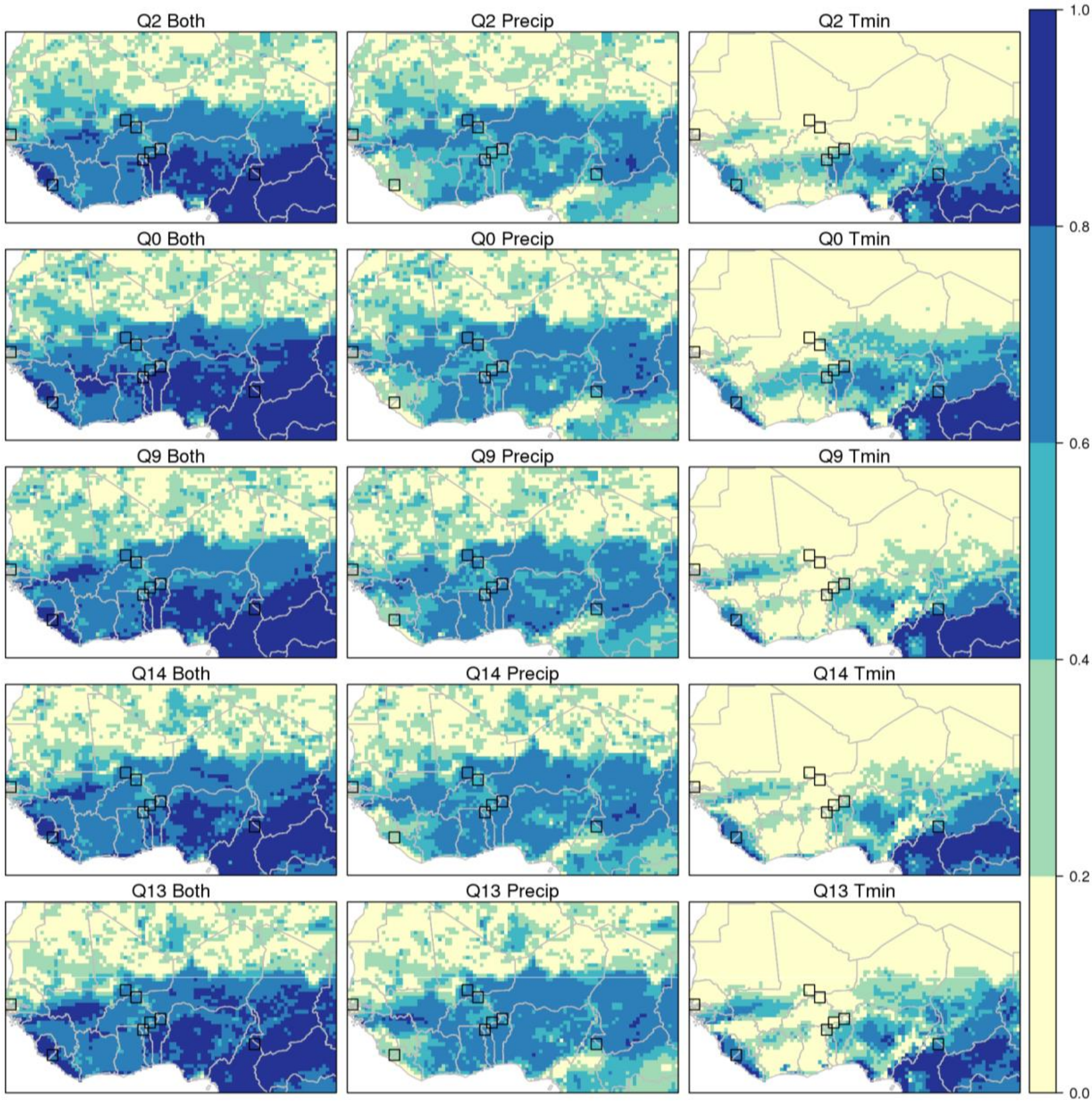

Figure 9. The extent to which minimum temperature (right), precipitation (middle), and both combined (left), explain the change in Gross Primary Production (GPP) from 1950 to 2099. Values are scaled between 0 (no relationship) and 1 (very strong relationship). A 1 year lag of precipitation was found to be most strongly correlated to GPP.