Protected Areas Resilient to Climate Change,
PARCC West Africa

Regional Climate Projections for West Africa

ENGLISH

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Glossary

AR5	Fifth Assessment Report
CMIP5	Coupled Model Intercomparison Project Phase 5
GCMs	Global Climate Models
HadCM3	Hadley Centre climate prediction model 3
IPCC	Intergovernmental Panel on Climate Change
RCP	Representative Concentration Pathway
RCM	Regional Climate Model
SRES	Special Report on Emissions Scenarios

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Executive Summary

This report summarises climate projections derived from global and regional climate model experiments to assist in informing country-level decision making and adaptation activities in five focus countries: Chad, Mali, the Gambia, Sierra Leone and Togo. The climate of West Africa has been observed to be changing in recent decades, with some of these changes clearly attributable to global climate change. Combined with the need for local decision-making and adaptation strategies, projections of future regional climate change are increasingly being used as a tool to inform adaptation, policy and decision making activities.

For the purpose of this project, five high resolution regional climate modelling experiments were performed to assess the potential changes in temperature and rainfall across West Africa at a spatial scale relevant to assessing impacts of these changes. These regional experiments all suggest a general warming trend, in agreement with wider global climate experiments used to inform the Intergovernmental Panel on Climate Change Fifth Assessment Report (herein denoted as IPCC AR5). In conjunction with this warming, an increase in variability is also apparent within the regional climate results, and could result in a greater frequency of unusually hot events. The high level of agreement across global and regional climate models for West Africa allows us to say, with high confidence, that a projected increase in temperature is very likely to occur (consistent with findings in the IPCC AR5 reports). This could have large impacts on ecosystems and livelihoods across the West African region which implies that adaptation of these systems would be required in order to make them resilient in the face of any negative consequences.

With regards to rainfall in the five focus countries the projections with both regional and global climate modelling experiments are highly variable, and contain little to no consensus on either the direction or magnitude of potential changes in rainfall. Within the set of global model results presented in the IPCC AR5, over much of the region both significant increases and decreases are projected. This is also the case for the regional climate model projections in parts of the five focus countries, though in other parts there is a general consensus in either increases or decreases in rainfall. However, given the wide spread of results within the IPCC context, these results may not fully encapsulate the spread of possible outcomes, and should not be considered reliable. Thus, the best advice currently is to build robust resilience to current

climate variability as either the drier or wetter modes of this variability could be enhanced in the future.

1. Introduction

It is widely accepted that observed climate change is already having a negative impact on African livelihoods and ecosystems (Niang *et al.*, 2014). With climate change expected to continue through the 21st century, it is crucial to better understand how changing climate may impact the resilience of these ecosystems across the African continent. To date, much of the adaptation activities occurring across the continent have been a reactive response to short-term stresses, and often lack the support of government stakeholders (Vermuelen *et al.*, 2008; Ziervogel *et al.*, 2008; Berrang-Ford *et al.*, 2011; Niang *et al.*, 2014). With potential climate change threatening a range of sectors and livelihoods, such as fisheries, food security, health and well-being, and socio-economic activity, a clear understanding and appreciation of climate model projections for West Africa has the potential to inform adaptation activities and management of climate risks, as well as guide development opportunities within West Africa.

This report summarizes recent and projected climate trends from the IPCC AR5 (Niang *et al.*, 2014). It also shows results from an ensemble of regional climate model simulations (designed to generate spatially detailed future climate information suitable for countries in West Africa) in the wider context of findings from the IPCC AR5 global climate model projections over the region. Section 2 outlines the observed trends of climate change during recent decades for the African continent, and summarizes the key messages of climate change from the IPCC AR5. Following this summary, projections from our regional climate model experiments are highlighted in section 3 for each of the five focus countries (Chad, Mali, Gambia, Sierra Leone and Togo), along with a comparison of how these high-resolution projections fit in the context of the wider IPCC AR5 results. The report concludes with a summary of the results, along with potential implications for adaptation strategies in the countries of interest.

2. Observed Trends and Global Climate Projections from IPCC AR5

To provide context for the analysis and application of the future climate projections derived from regional climate model experiments, we first present information on how the climate has changed over the recent past, as well as develop an appreciation for current scientific consensus and modeling limitations for future model projections. An understanding on both of these topics will allow us to appropriately interpret the projections from the high-resolution regional climate experiments described in section 3.

The climate of Africa has already been observed to be changing, through recorded alterations in surface temperatures and rainfall patterns during the 20th century (Niang *et al.*, 2014). With the impacts of climate change already being observed across the continent, projections of future climate scenarios are increasingly being used as a tool to inform decision-making in a range of sectors, including biodiversity conservation and sustainable development, such as livelihoods of communities who depend on ecosystems services. For the future, there is high agreement that continuing changes in rainfall and temperature patterns associated with human-induced climate change are very likely to drive important future changes in terrestrial ecosystems through Africa (Niang *et al.*, 2014). This section aims to highlight observed and projected climate change impacts, as summarized in the IPCC AR5, for the key climate variables of temperature and precipitation.

Temperature

Figure 1 (adapted from Figure 22-1 in Ch 22 of the WGII report in AR5: Niang *et al.,* 2014) depicts an increase in mean annual temperature over the past century across much of the African continent (CDKN: *IPCC Fifth Assessment Report: What's in it for Africa?)*. In West Africa and the Sahel region, observed climate change has been recorded through increased surface temperatures over the last 50 years, with statistically significant warming of between 0.5˚C and 0.8˚C during 1970 to 2010 (Collins 2011, Niang *et al.*, 2014).

Temperatures over Africa are expected to rise faster than globally averaged temperatures during the 21st century (Christensen *et al.*, 2007; Joshi *et al.*, 2011; Sanderson *et al.*, 2011; James and Washington, 2013; IPCC WG2 Ch22), with West Africa projected to experience unprecedented and increasingly variable climates with respect to current climate conditions much earlier in the century. The top-right panel of Figure 1 shows projected temperature increases based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) ensemble, which is an internationally coordinated set of global climate model experiments to help improve our understanding of uncertainty associated with climate model design and set-up (Taylor *et al.*, 2012). Within this ensemble of global climate experiments, four scenarios called 'Representative Concentration Pathways' (or RCPs) are used to simulate a range of plausible future greenhouse gas concentration pathways, with some assuming various steps are taken to mitigate emissions in the future. There are four pathways: RCP2.6 (representing the lowest emission pathway requiring the most mitigation), RCP4.5, RCP6.0, and RCP8.5 (representing the highest emission pathway, and typically denoted as ‘business as usual’). The number in each pathway name (i.e. 2.6, 8.5) represent the amount of additional radiative forcing or ‘heating’ resulting from the increased greenhouse gas concentration in the atmosphere at the end of the 21st Century.

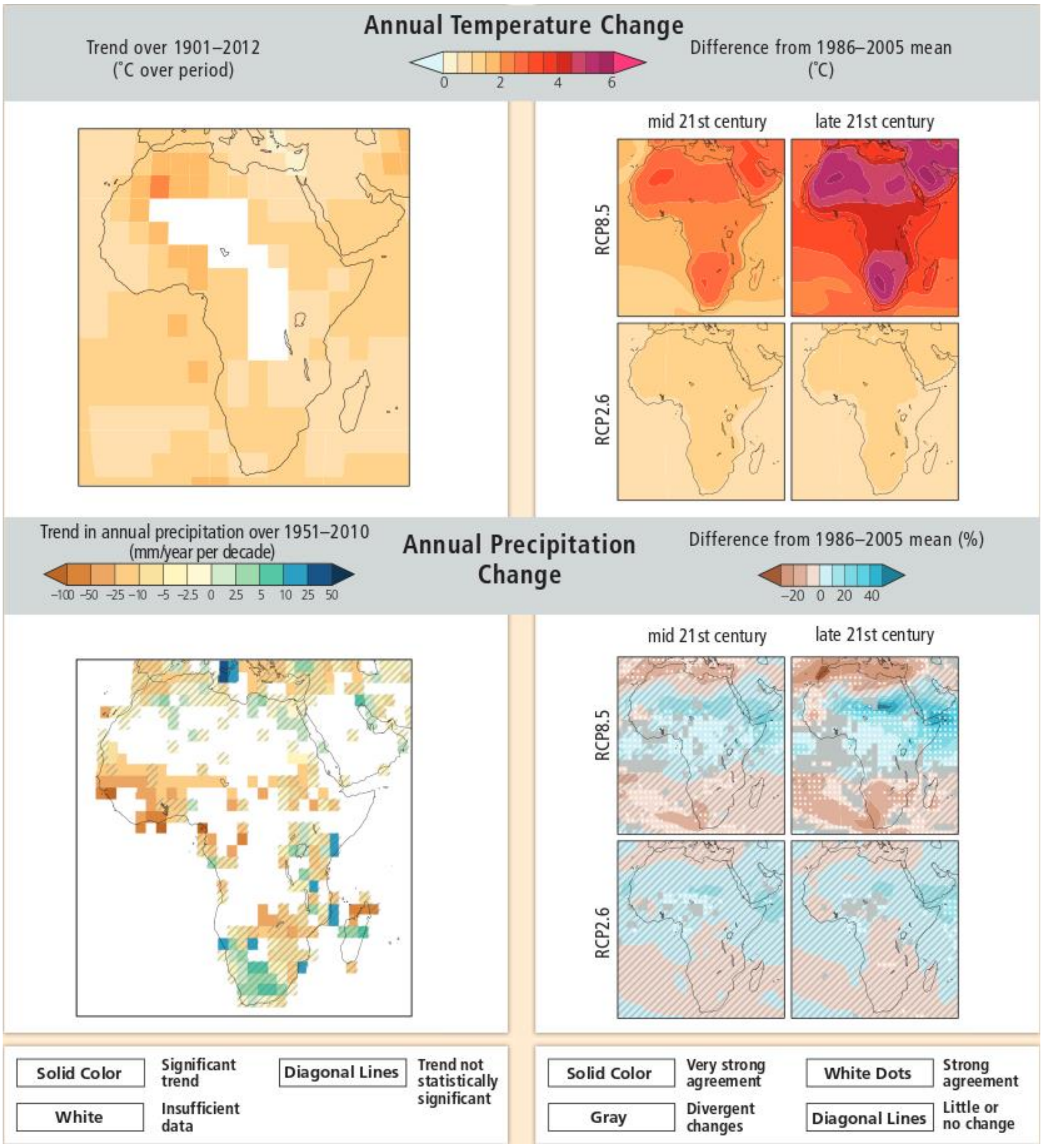


Figure 1: Observed and projected changes in annual average temperature and precipitation. (Top panel, left) Observed annual average temperature trend from 1901-2012. [WGI AR5 Figures SPM.1 and 2.21] (Bottom panel, left) Map of observed annual precipitation change from 1951-2010, derived from a linear trend. [WGI AR5 Figures SPM.2 and 2.29] For observed temperature and precipitation, white areas depict regions which lack sufficient observational data for analysis. Solid colours indicate areas where trends are significant at the 10% level. Diagonal lines indicate areas where trends are not significant. (Top and bottom panel, right) CMIP5 multi-model mean projections of annual average temperature changes and average percent changes in annual mean precipitation for two time periods (2046-2065 and 2081-2100) under two RCP emissions scenarios. Sold colours indicate very strong agreement amongst models (≥90% of models agree), white dots represent strong agreement (≥66% of models agree), grey areas depict divergent changes (<66% of models agree on sign of change), and diagonal lines represent areas with little or no change with respect to current climate variability (although there may be significant changes at shorter timescales). Entire figure from WG2 AR5 Fig 22-1.

Each RCP contains a set of starting values and the estimated emissions up to the end of the 21st century, based on assumptions about economic activity, energy sources, population growth and other socio-economic factors. While socio-economic projections were drawn from the literature in order to develop the concentration pathways, the database does not include socio-economic data (van Vuuren *et al.*, 2011).

It is clear from Figure 1 that the results from CMIP5 suggest an increase in mean annual temperature over the African land mass during the mid- and late-21st century, with high model consensus and high confidence in this projection. Stronger temperature increases, exceeding 2˚C for the mid-century and 4˚C for the late-century, are associated with the 'more extreme' RCP8.5 emissions scenario. Specifically for West Africa, temperature projections under the RCP8.5 emissions scenario are reaching 6˚C, leading to the identification of the Sahel and tropical West Africa as hotspots of climate change (Diffenbaugh and Giori, 2012; Niang *et al.*, 2014).

In Figure 2, which compares the expected responses of temperature and precipitation to both human-induced and natural forcing, we can see that a clearly identifiable increase in observed and projected temperature is attributed to human-influenced forcing, and are therefore a very likely climatic response to future increases in greenhouse gas emissions under 'business as usual' activities.

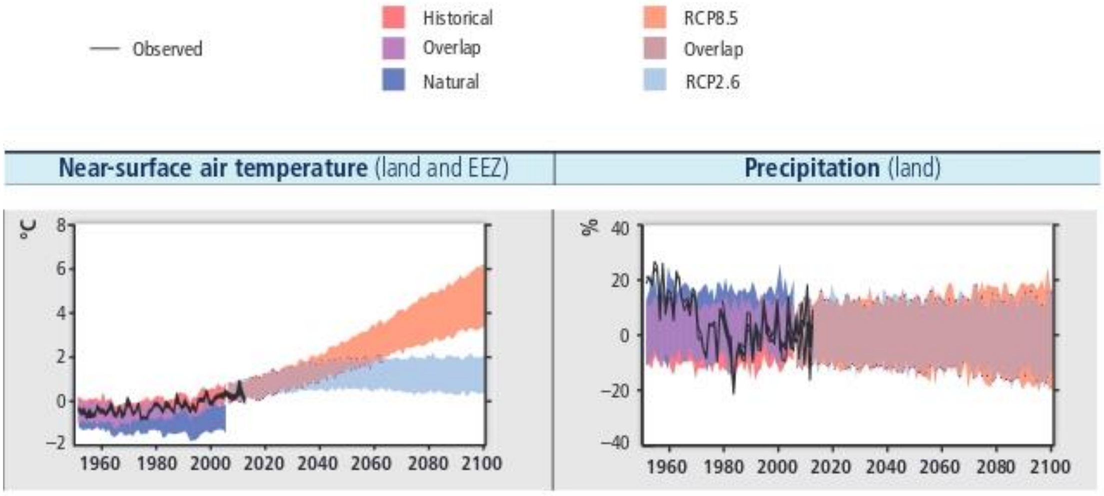


Figure 2: Observed and simulated variations in past and projected future annual average temperature and precipitation for the Economic Community of West Africa States (ECOWAS). Black lines show various estimates from observational measurements. Shading denotes the 5th – 95th percentile range of climate model simulations driven with historical changes in anthropogenic and natural drivers (63 simulations), historical changes in natural drivers only (34), the RCP2.6 emissions scenario (63) and the RCP8.5 emissions scenario (63). Data shown here are differences from the 1986-2005 average.

Precipitation

Due to both the lack of sufficient observational data and discrepancies amongst available datasets, it is difficult to draw many conclusions on observed trends in annual precipitation across the African continent from the IPCC AR5 (see Figure 1, bottom left panel). Areas which have sufficient data for analysis include parts of the Sahel region in West Africa, where observations suggest very likely decreases in annual precipitation during the last century (Niang *et al.*, 2014). This decrease has not been a consistent feature during the last century, as decadal variability has resulted in both the occurrence of large-scale droughts in the Sahel during the 1970s and 1980s, along with a general recovery of rainfall more recently (Biasutti and Giannini, 2006; Biasutti *et al.*, 2008; Greene *et al.*, 2009; Niang *et al*, 2014).

Projections for precipitation within the CMIP5 ensemble are much more uncertain than those for surface temperatures (Rowell, 2012). As can be seen in Figure 1, most areas of the African continent do not exhibit changes outside of current climate variability (denoted by diagonal lines). In West Africa and the Sahel, the situation is further complicated with areas of both significant decrease and increase in precipitation (for coastal regions and further in-land regions, respectively) and only moderate agreement amongst climate models in other areas. Near the Gulf of Guinea, there is a lack of agreement across models as to the nature of precipitation changes, giving low confidence in any future rainfall projections. The right-hand panels of Figure 1 offer a clear depiction of uncertainty in climate model projections across the continent, the limitations of which will be referred to in subsequent sections.

This high level of uncertainty is further confirmed in Figure 2, as there is no clear response of precipitation to anthropogenic forcing only, suggesting that future projections of precipitation under increasing greenhouse gas concentrations are highly uncertain. Therefore, it is important that the projections of rainfall described in this report are interpreted with caution.

3. Downscaled Regional Climate Projections

While the global climate models (or GCMs) used in producing the IPCC AR5 report represent a wide-ranging, set of climate model experiments, their resolutions are often too low to accurately capture the local and regional scales details that influence regional climate. In order to better capture regional climate characteristics, it is important to implement climate model simulations at an appropriate resolution. Therefore, we use a technique called ‘dynamical downscaling' approach to create higher-resolution regional climate information through implementing a regional climate model (or RCM).

For the purpose of this project, we have used results from a set of 5 RCM simulations over Africa, run at a horizontal resolution of 50 km and driven by versions of the HadCM3 (Hadley Centre Climate prediction Model 3) GCM whose representations of atmospheric processes were modified to capture uncertainty in future climate projections. Results from 17 versions of the GCM were analyzed to select a subset of five model configurations, based on both their capability to represent the current climate of West Africa (including accurate simulation of the West African Monsoon climate), and their projected temperature and rainfall change responses by the end of the 21st century. By selecting global model configurations which span both warmer/cooler and drier/wetter possible future climate scenarios, we seek to appropriately capture a wide range of plausible future climate scenarios, without the computational expense of running a large number of RCM experiments.

The sections below summarize the results of the five RCM experiments we have performed (herein denoted as Q0, Q2, Q9, Q13, and Q14 – the number denoting specific members of the GCM ensemble used to drive the RCM), alongside the results derived from the CMIP5 ensemble, for each of the five focus countries in the PARCC West Africa project. The RCM experiments and their driving GCMs used greenhouse gas concentrations from the SRES A1B emissions scenario (IPCC 2000) whose closest analogue amongst the RCPs is RCP6.0 (a full description of RCP scenarios can be found in the previous section). Thus the RCM results are compared with CMIP5 RCP6.0 results to allow us to depict our RCM results in the context of IPCC AR5.

This comparison with the CMIP5 results is essential as it helps to assess the level of confidence that we have in the regional model projections of climate change over the region and thus the projected ecosystems services changes resulting from these. For this reason we display the RCM results in each of the following country sub-sections in a way that acknowledges this context and so we can draw out clear messages on their reliability. 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.

Chad

The results of the five RCM experiments suggest an overall increase in annual mean surface temperatures, ranging from 3-5˚C by the end of the 21st century (Figure 3, bottom left panel). Spatially, this temperature increase is expected to be highest near the Tibesti Mountains in the north and southeastern regions of the country, with smaller increases in central areas (Figure 3, top panels). The bottom left panel of Figure 3 depicts the evolution of surface temperature for the median of our five RCM experiments, and clearly shows that projected increases in temperature for the near future (2020-2049) and far future (2070-2099) fall outside simulated climate variability in the baseline period (1971-2000), suggesting that future temperatures for Chad will be considerably warmer than experienced now. This is derived from assessing the 30-year mean of surface temperature across these three time periods (blue lines), and comparing the range associated with ± 1 standard deviation from this mean (red lines). The fact that the ranges between these red lines do not overlap in the three chosen time periods suggests that the projected increase in temperature is clearly a climate change response, and not a factor of current climate variability. The projections also show a clear increase in the variability within these 30-year time periods, as the distance between the two red lines becomes larger through time. This is a key result, and suggests that Chad may experience an enhanced increase in the frequency of extreme warm events, due to increasing climate variability, over that which would results from the general warming expected with climate change. In the far future, increasing temperatures will likely have negative effects on biodiversity, agriculture and food security, with the likelihood of diminished crop yield potential of key livelihood crops (Schlenker and Lobell, 2010; Sultan *et al.*, 2013; Niang *et al.*, 2014). Alternative crops, which are more resistant to increasing temperatures, may need to be implemented to ensure minimal loss of livelihood for subsistence farmers in the region.

When compared to the CMIP5 ensemble, it is clear that the range of projected temperature increases simulated by our five RCM experiments is within the upper limits of the CMIP5 range (Figure 3, bottom right panel). This suggests a high degree of confidence in the prediction of warmer temperatures for Chad during the 21st century.

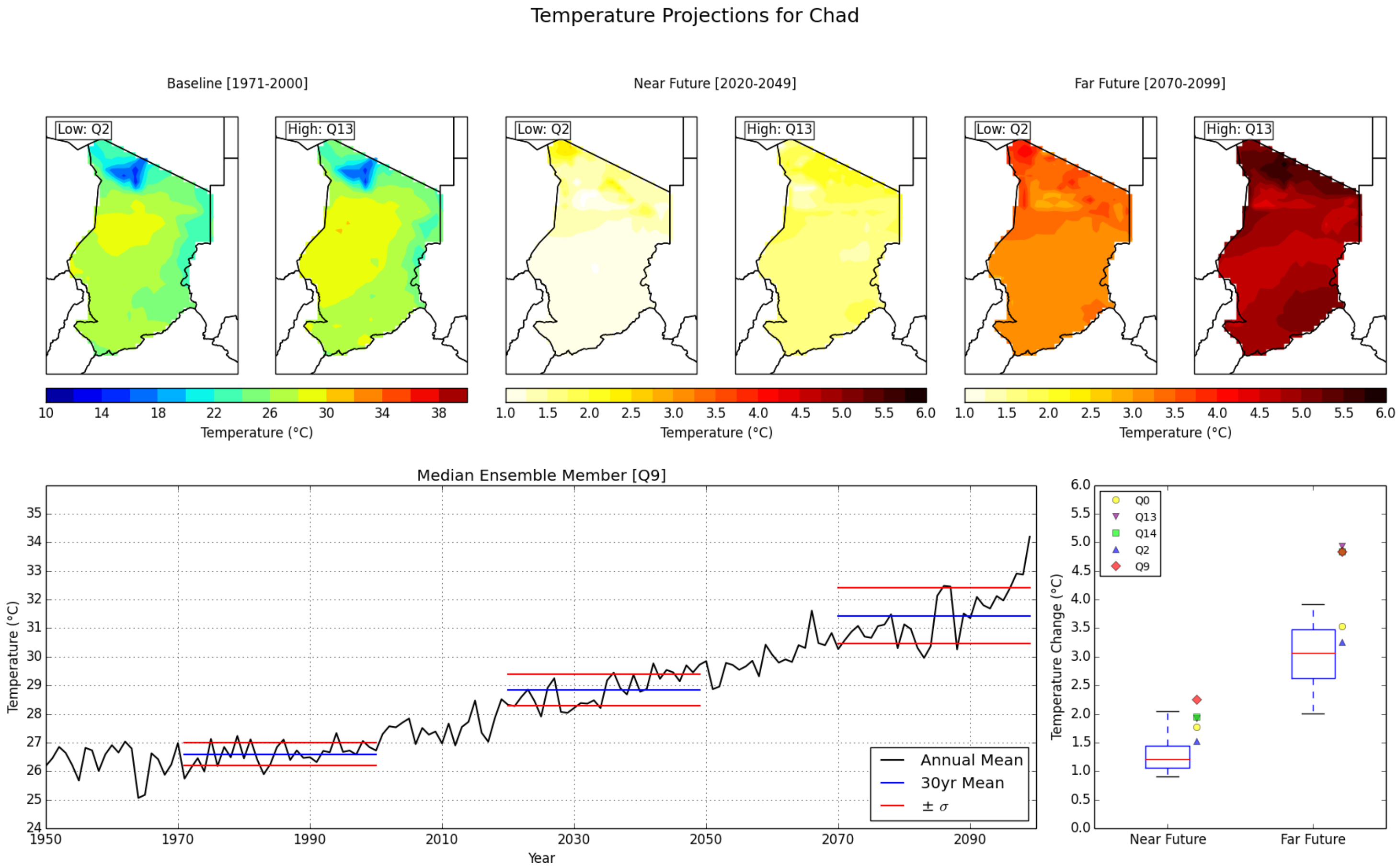


Figure 3: Temperature projections for Chad. (Top 6 panels) Annually averaged surface temperature (˚C) for the baseline period (1971-2000), and projected changes for the near future (2020-2049) and far future (2070-2099), for the RCM models with the lowest and highest projected sensitivities in the far future time period (for Chad, these are Q2 and Q13 respectively). (Bottom left panel) Evolution of annual mean surface temperature from 1950-2100 for the median ensemble member of the five models (Q9), as well as the 30-year mean and associated standard deviations for the baseline, near and far future periods defined above. (Bottom right panel) Annually averaged temperature changes for the near and far future time periods, for the five RCM experiments as well as 18 CMIP5 GCM experiments using RCP6.0.

For precipitation, the results of the five RCM experiments project an increase in total rainfall amount during the months of July, August and September (herein denoted as JAS), ranging from roughly 20-50% by the end of the 21st century (Figure 4, bottom right panel). Here, JAS is the chosen time period for analysis as this typically represents the timing of the West African Monsoon, a key driver of weather and climate in this region of the world. This increase in rainfall is highest in northern regions, with small areas of little/no change or potentially decreasing precipitation across the country (Figure 4, top panels). For the purpose of this analysis, results are displayed from the two RCMs which define the range of projected RCM changes based on their projected changes in the far future time period (2070-2099). For precipitation, this range can involve just positive or negative values or both. There is very little model agreement amongst the five RCM experiments on the spatial distribution of rainfall changes for Chad (top panels of Figure 4). The evolution of JAS rainfall accumulation for the median of our five RCM experiments highlights the level of uncertainty associated with rainfall projections in this region. This variability within the three distinct time periods (depicted by the range within the red lines) is quite wide and over-lapping in time, suggesting that future rainfall for Chad during the JAS months could be more variable than currently experienced. This could imply more frequent flash-flooding and drought events, particularly for northern regions, with resultant impacts on agriculture, health and water resource management.

When compared to similar results from the CMIP5 ensemble, as shown in the bottom right panel of Figure 4, the range of projected rainfall increases simulated by our five RCM experiments is within the CMIP5 range (Figure 4, bottom right panel). However, it is clear from the CMIP5 range that GCMs within this ensemble disagree on the magnitude and direction of projected changes in rainfall, as the range spans large positive and negative percentage changes. This reiterates the high level of uncertainty associated with rainfall projections in this region and demonstrates why the RCM projections for Chad used in this project, though plausible, should not be considered as having low confidence.

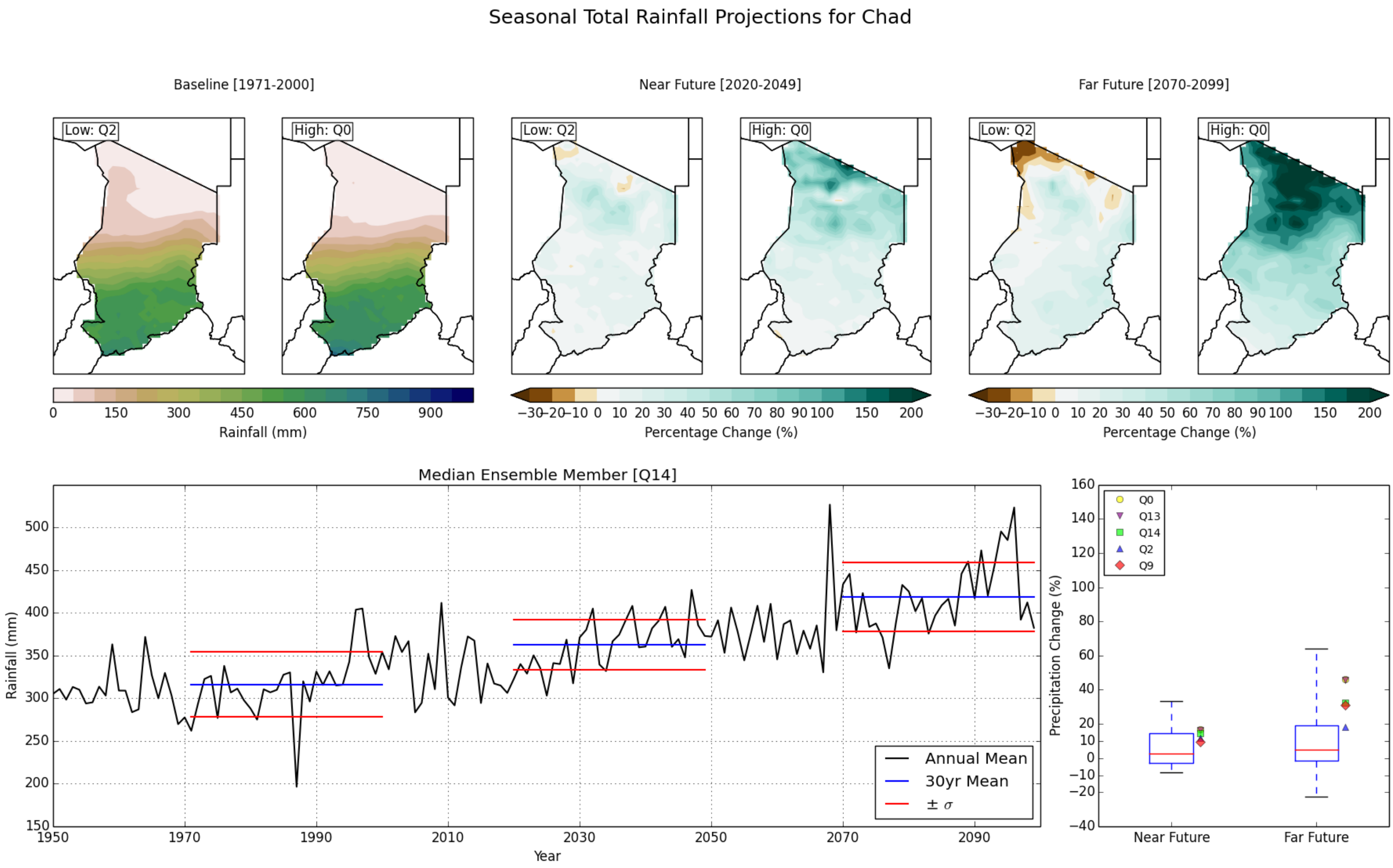


Figure 4: Precipitation projections for Chad. (Top 6 panels) Seasonal total rainfall (mm) in the JAS season, for the baseline period (1971-2000), and projected changes for the near future (2020-2049) and far future (2070-2099), for the RCM models with the lowest and highest sensitivities in the far future time period (for Chad, these are Q2 and Q0 respectively). (Bottom left panel) Evolution of JAS seasonal total rainfall from 1950-2100 for the median ensemble member of the five models (Q14), as well as the 30-year mean and associated standard deviations for the baseline, near and far future periods defined above. (Bottom right panel) Projected percentage changes for JAS seasonal total rainfall, for the near and far future time periods, for the five RCM experiments as well as 18 CMIP5 GCM experiments using RCP6.0. NOTE: High and low sensitivity models are identified through absolute value anomalies, rather than raw anomalies as in Figure 3.

Mali

For Mali, the five RCM experiments suggest an overall increase in annual mean surface temperature, ranging from 4˚C to nearly 6˚C by the end of the 21st century (Figure 5, bottom left panel). This temperature increase is mostly uniform across the country, with slightly larger increases expected in central regions (Figure 5, top panels). The evolution of surface temperature for the median of the five RCM experiments depicts a strong climate change response, with temperature increases in the near and far future falling outside the range of current climate variability. Again there is a clear amplification of climate variability through time, which suggests an enhanced increase in the frequency of extreme warm events, due to increasing climate variability, over that which would result from the general warming associated with climate change. As with Chad, higher temperatures by the end of the 21st century could have detrimental impacts on current agricultural practices, particularly within the agricultural regions in southern Mali.

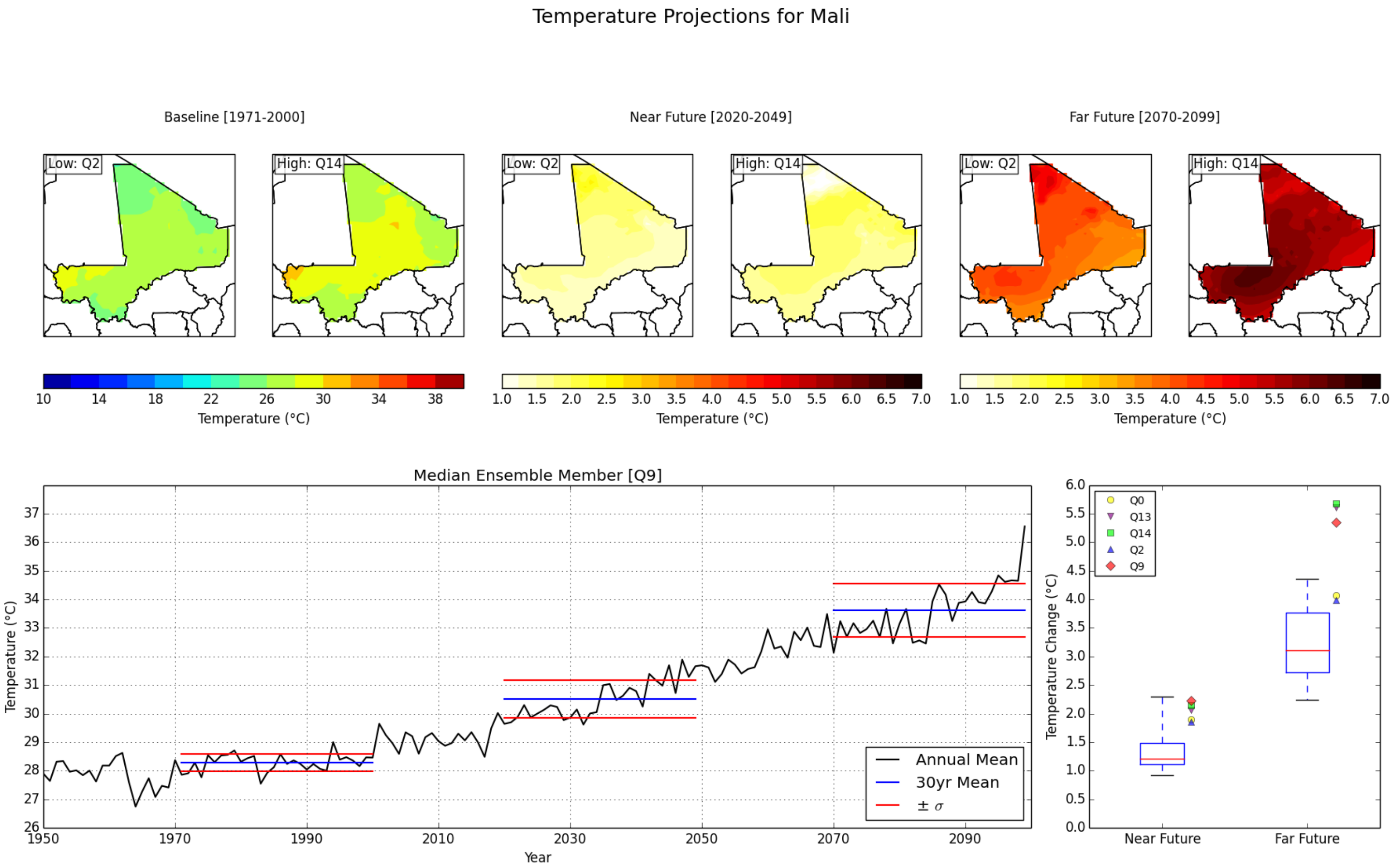


Figure 5: As in Figure 3, but for Mali.

When compared to similar results from the CMIP5 ensemble, the range of projected temperature within our five RCM experiments falls within the range of CMIP5 models for the near future time period, but extends above this range for the far future time period (Figure 5, bottom right panel).

For precipitation, the results of the five RCM experiments suggest varying outcomes in total rainfall accumulation during JAS, ranging from little/no change to a decrease of 20% by the end of the 21st century (Figure 6, bottom right panel). This decrease tends to occur in central and western regions of the country, but with the possibility of rainfall increases in the northwest (Figure 6, top panels). Note that in the top six panels of Figure 6, we can clearly see strong decadal variability across time periods, particularly in the low sensitivity model (Q0) which projects a slight increase in precipitation during the near future time period, but reverts to little/no change by the end of the century (this can be further confirmed by the location of the symbol for Q0 in the bottom right panel of Figure 6). Similar to the results for Chad, the evolution of JAS rainfall accumulation for the median of our five RCM experiments again highlights the level of uncertainty associated with rainfall projections in this region, as variability within the three distinct time periods (depicted by the range within the red lines) does not indicate a robust climate change response. A potential decrease in rainfall for this region could negatively impact biodiversity, but also water availability, crop productivity, and lead to the degradation of ecosystems and livelihoods.

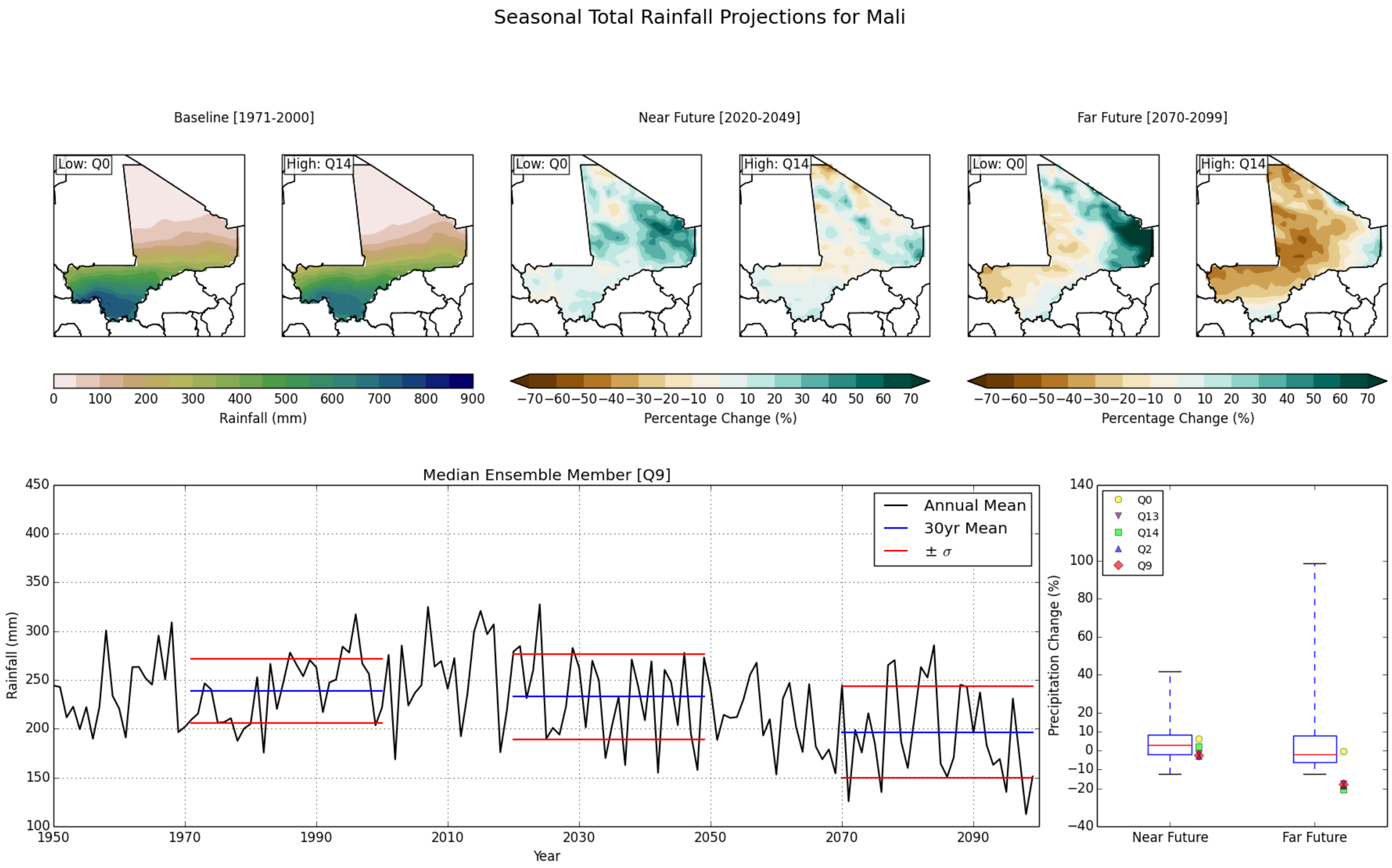


Figure 6: As in Figure 4, but for Mali.

When compared to similar results from the CMIP5 ensemble, the range of projected rainfall change within the five RCM experiments is within the limits of the CMIP5 range during the near future time period, but extends out of this range in the far future, with stronger decreases in projected in the RCMs. However, it is again clear from the CMIP5 range that the majority of GCMs within this ensemble disagree on the magnitude and direction of projected changes in rainfall with most projecting small positive or negative changes.

Sierra Leone

Similar to both Chad and Mali, the five RCM experiments suggest an overall increase in annual mean surface temperatures for Sierra Leone, ranging from just below 3˚C to over 4˚C by the end of the 21st century (Figure 7, bottom left panel). The magnitude of these projected changes is slightly lower than previous countries, as Sierra Leone's climate is somewhat regulated by its proximity to the ocean. This temperature increase is highest within the furthest inland regions of the country, again linked to oceanic influences (Figure 7, top panels). As we have consistently seen already, the evolution of surface temperature for the median of our five RCM experiments depicts a clear climate change response, with temperature increases in the far future falling outside the range of current climate variability, as well as the potential range of climate variability widening through time (Figure 7, bottom left panel). Again, this increase in temperature during the 21st century could have negative impacts on the subsistence agricultural activities that provide a livelihood for much of the population.

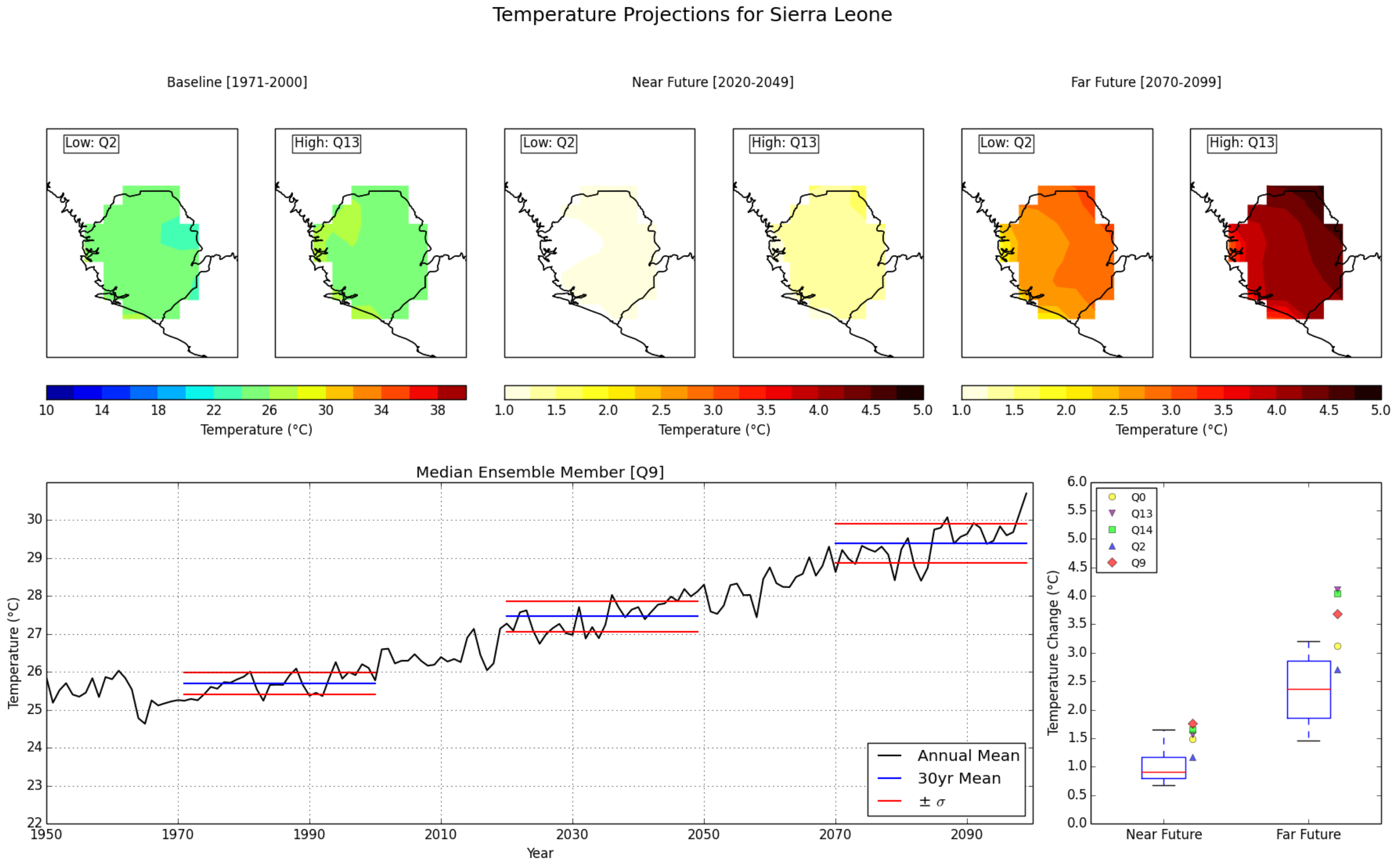


Figure 7: As in Figure 3, but for Sierra Leone.

When compared to results from the CMIP5 ensemble, the range of projected temperature within our five RCM experiments falls at the upper end of the range of CMIP5 models for the near future time period, but extends well above this range for the far future time period (Figure 7, bottom right panel). The agreement amongst models on the projected increase in temperature for Sierra Leone again suggests a high level of confidence in a generally warmer future.

For precipitation, the results of the five RCM experiments suggest small to medium increases in total rainfall during JAS, ranging from below 10% to a 20% increase by the end of the 21st century (Figure 8, bottom right panel). These tend to occur in coastal regions of the country, extending further inland as the century progresses (Figure 8, top panels). Unlike other countries, there is some support for this being a robust signal as the majority of the CMIP5 models also project increases of similar magnitude. A slight increase in precipitation, as suggested by the five RCM experiments, could have both positive and negative effects, such as enhanced water availability and resource management, and increased risk of flooding events which could also result from the increased variability projected at the end of the century.

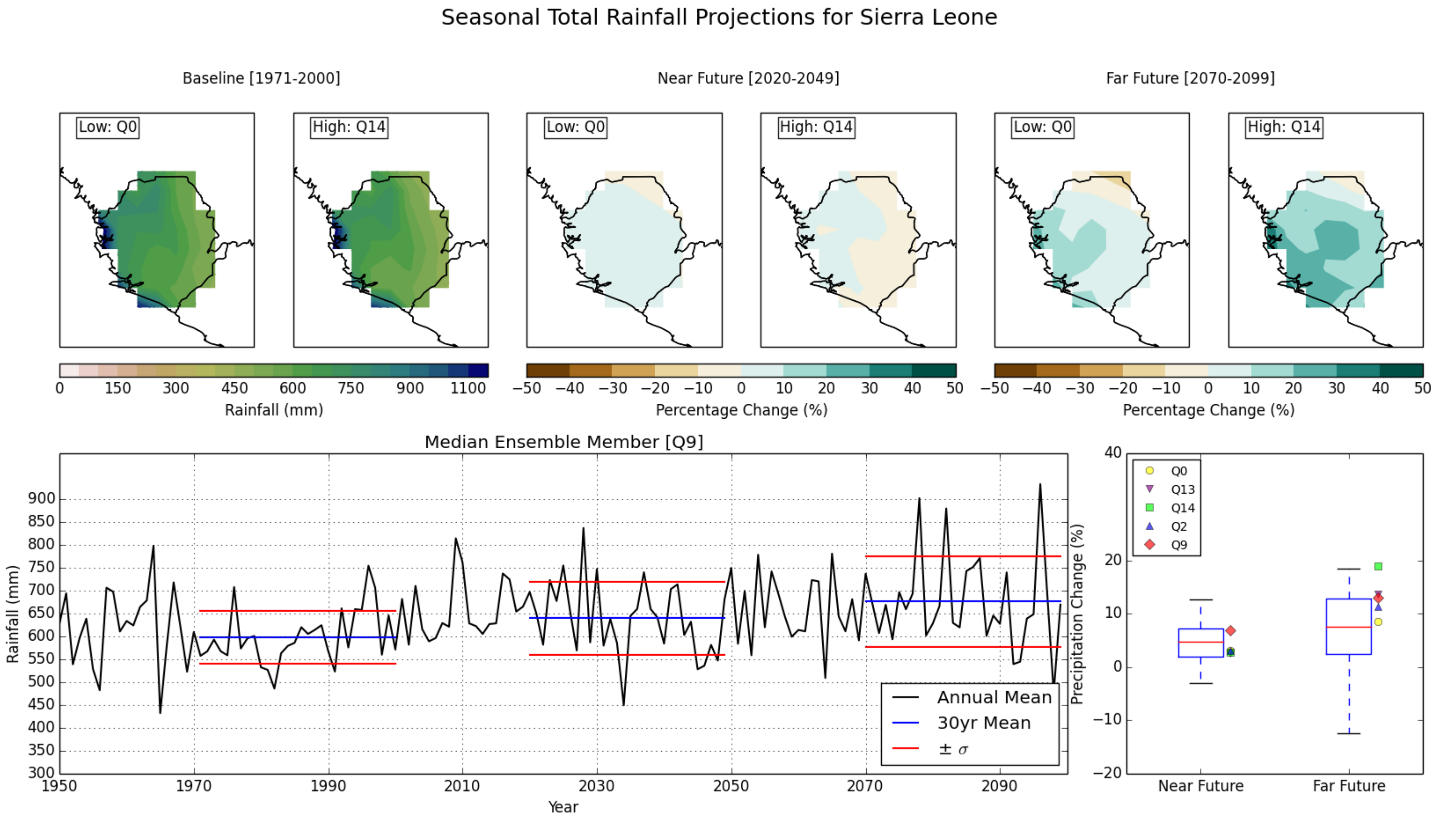
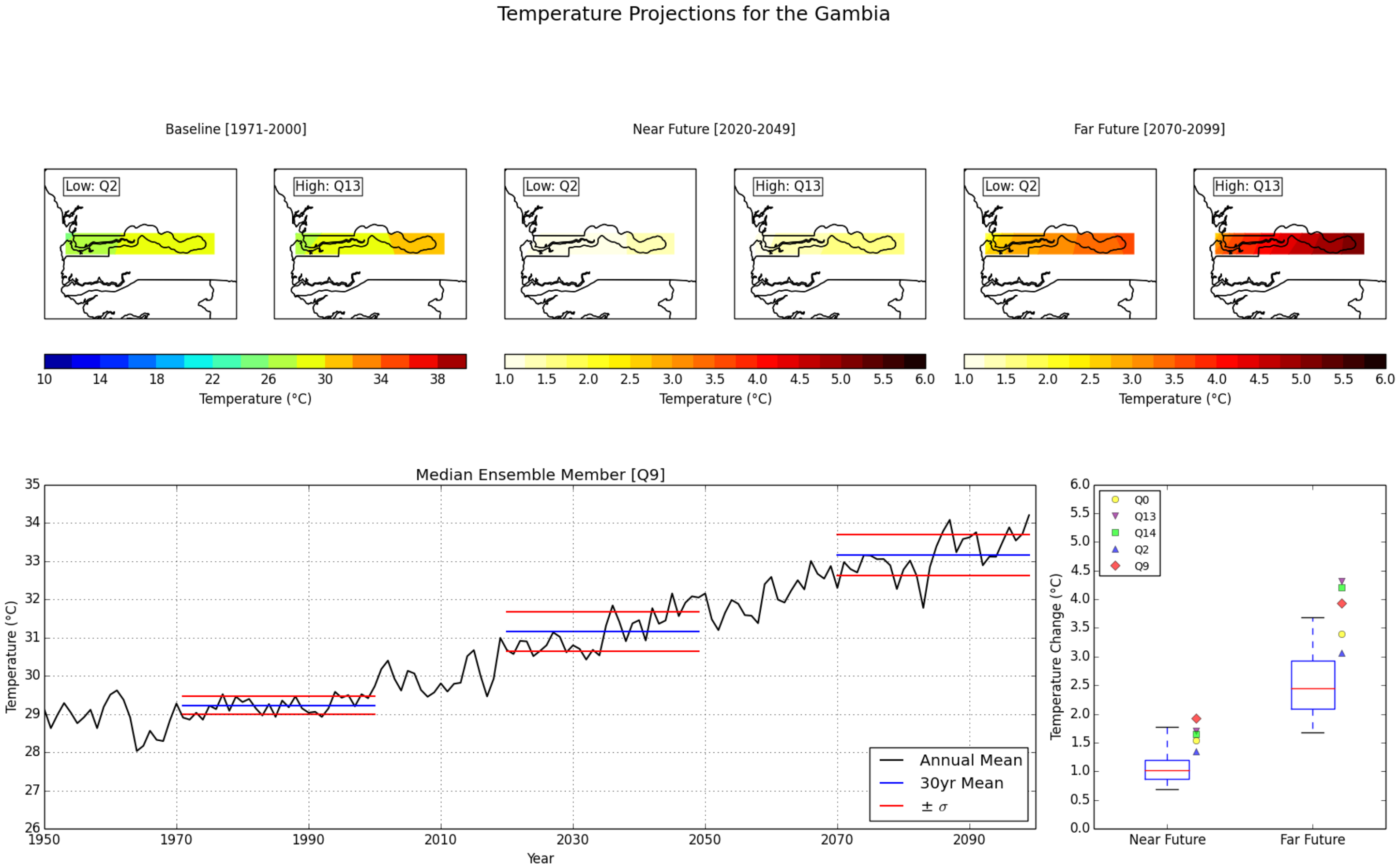


Figure 8: As in Figure 4, but for Sierra Leone.

The Gambia

For the Gambia, our five RCM experiments suggest an overall increase in annual mean surface temperatures, ranging from 3˚C to 4.5˚C by the end of the 21st century (Figure 9, bottom left panel). Consistent with results found in Sierra Leone, the magnitude of these projected changes is slightly lower than other focus countries (e.g. Chad and Mali) due to the climate-regulating influence of the ocean. This oceanic influence can be clearly seen in the spatial temperature projections for the Gambia, as the strongest temperature increase are projected to occur in the furthest inland eastern regions (Figure 9, top panels). Again, the evolution of surface temperature for the median RCM experiment suggests a strong climate change response, with both an upward shift and widening of the range of climate variability (Figure 9, bottom left panel). Both the warming temperatures and increased variability in the future could impact biodiversity and ecosystems within the Gambia, as adaptation to these warmer temperatures will be required.


Temperature Projections for the Gambia

Baseline [1971-2000]

Near Future [2020-2049]

Far Future [2070-2099]

Median Ensemble Member [Q9]

Figure 9: As in Figure 3, but for the Gambia.

When compared to results from the CMIP5 ensemble, the range of projected temperature change from the RCM experiments falls within the upper end of the CMIP5 range for the near future time period, but extends above this range for the far future time period (Figure 9, bottom right panel). This again suggests a high degree of confidence in a warmer future for the Gambia.

For precipitation, the RCM experiments project strong decreases in total rainfall during JAS, ranging from 40% to nearly 60% by the end of the 21st century (Figure 10, bottom right panel) but either increases or decreases in mid-century (Figure 10, top panels). It is worth noting that as the Gambia is a very small country it is only captured by a small number of grid points within the RCMs, and even fewer grid points within the CMIP5 GCMs, and so these statistics may be unreliable. The evolution of JAS rainfall for the median of our five RCM experiments depicts a high level of uncertainty with apparently little change in the mean but increased variability in mid-century. Precipitation decreases are projected by the end of the century, albeit with little change in variability, compared to the present day, by the end of the century (Figure 10, bottom left panel). A decrease in rainfall for the Gambia could affect biodiversity and potentially lead to prolonged drought events, decreased crop production and degraded ecosystems across the country.

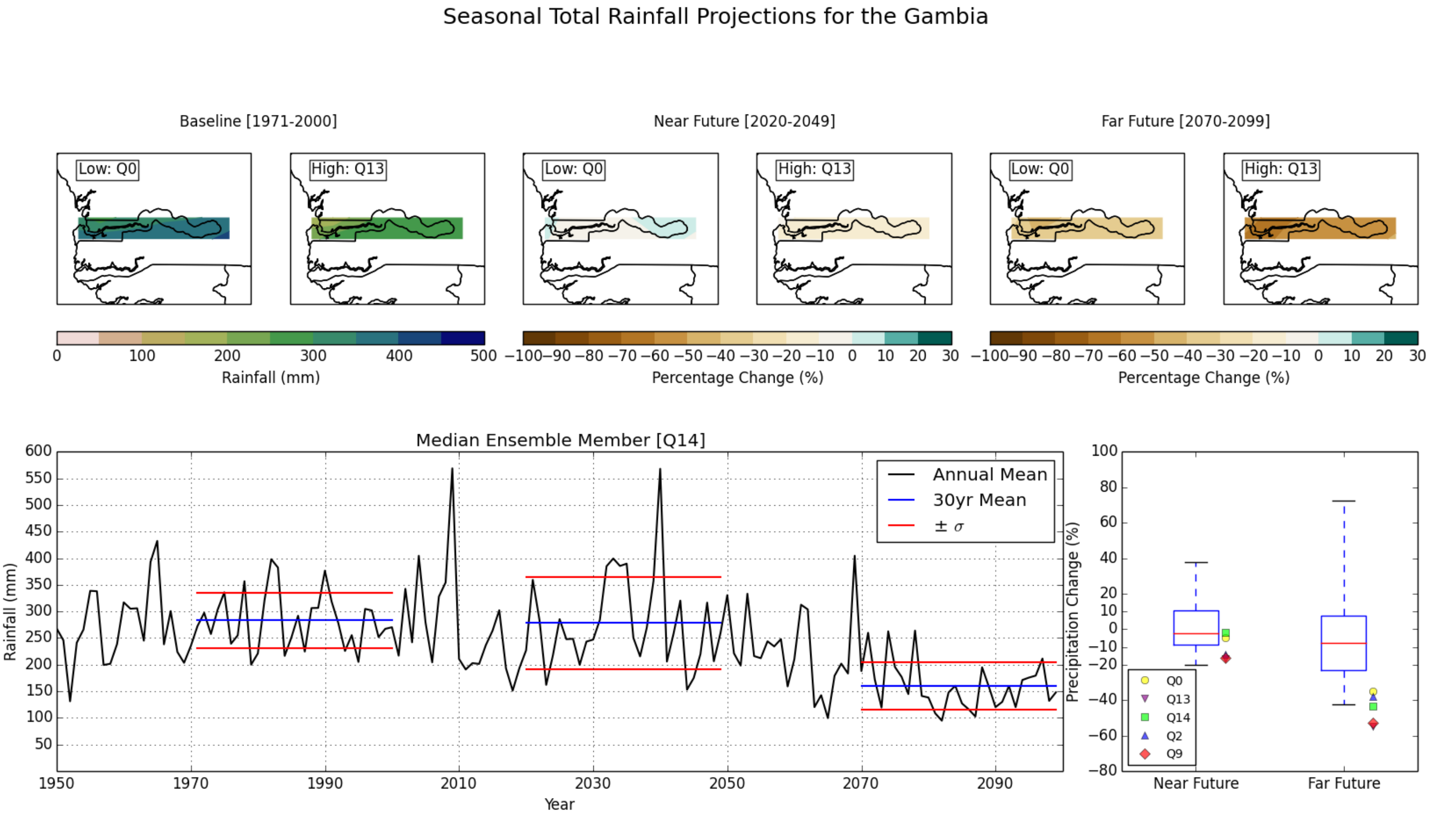


Figure 10: As in Figure 4, but for the Gambia.

However, while the RCMs suggest a strong end of century decrease in rainfall for the Gambia, the range of projected changes within CMIP5 shows very little model agreement in this area, with strong positive and negative changes projected during this season. Therefore, the results of the five RCM experiments should be interpreted with extreme caution.

Togo

The results from our five RCM experiments for Togo are consistent with findings for the other focus countries, and suggest an overall increase in annual mean surface temperature ranging from 3˚C to nearly 5˚C by the end of the 21st century (Figure 11, bottom left panel). Spatially, these projected changes in temperature are again slightly lower within the southern coastal regions of Togo, due to oceanic influences (Figure 11, top panels). As we have seen in the previous four countries, the evolution of surface temperature for the median RCM experiment suggests a strong climate change response, with both an upward shift and slight widening of the range of climate variability (Figure 11, bottom left panel). As with previous countries, a warming climate in the 21st century could have strong impacts on food security, ecosystems and livelihoods within the region.

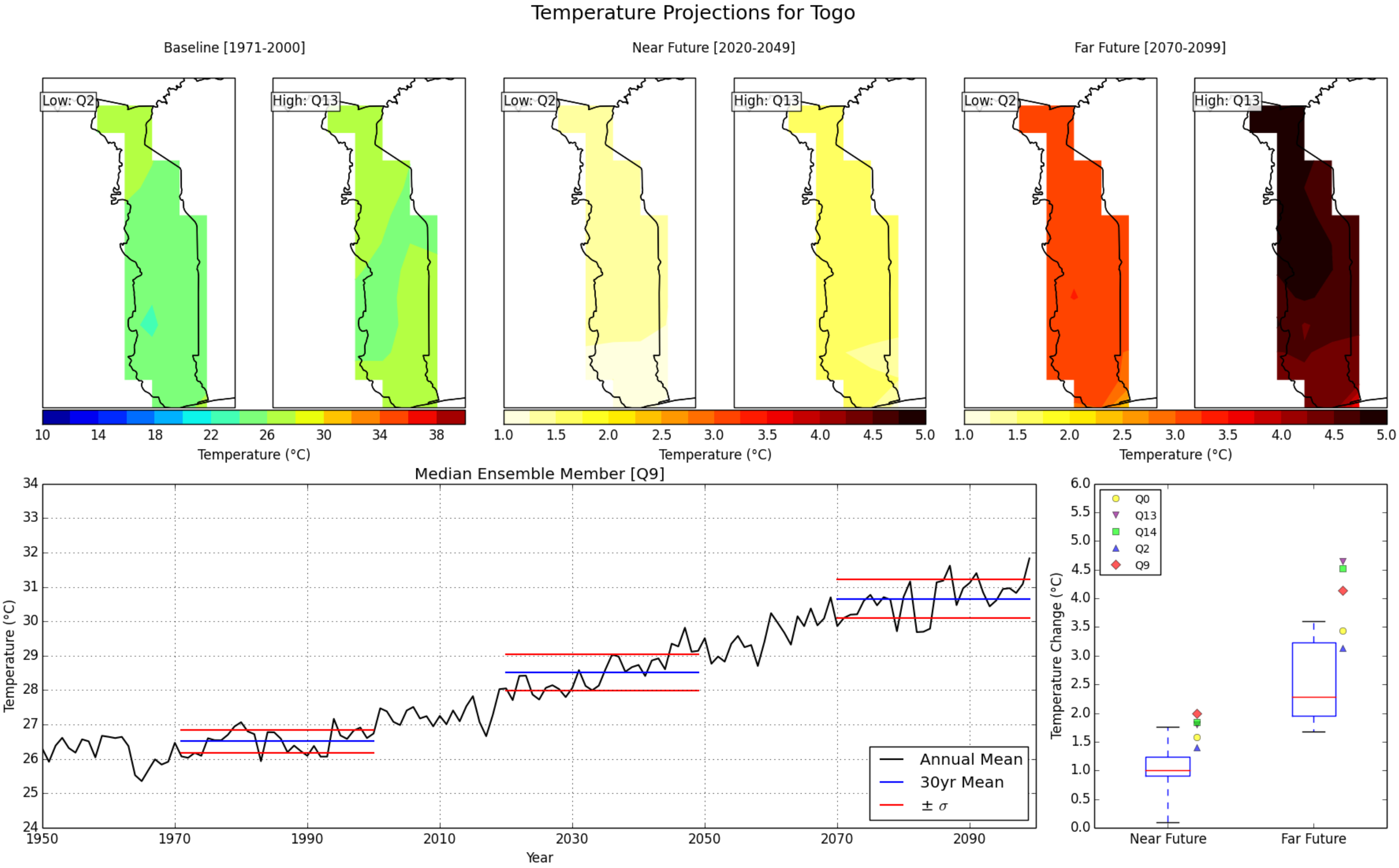


Figure 11: As in Figure 3, but for Togo.

When compared to similar results from the CMIP5 ensemble, the range of projected temperature from the RCM experiments extends slightly above the upper end of the range of

CMIP5 models for the near future time period, and extends even further above this range for the far future time period (Figure 11, bottom right panel). As discussed previously, this suggests a high level of confidence in a warmer climate for Togo during the 21st century.

For precipitation, the results of our five RCM experiments are highly uncertain, projecting a similar magnitude of both increases and decreases in total rainfall accumulation during JAS by the end of the 21st century (Figure 12, bottom right panel). Spatially, the RCM experiments project increases in rainfall within northern regions of the country and decreases in rainfall along the coast. The evolution of JAS rainfall accumulation for the median of our five RCM experiments further confirms the high level of uncertainty associated with rainfall projections in this region, as no clear climate response can be derived from the results (Figure 10, bottom left panel).

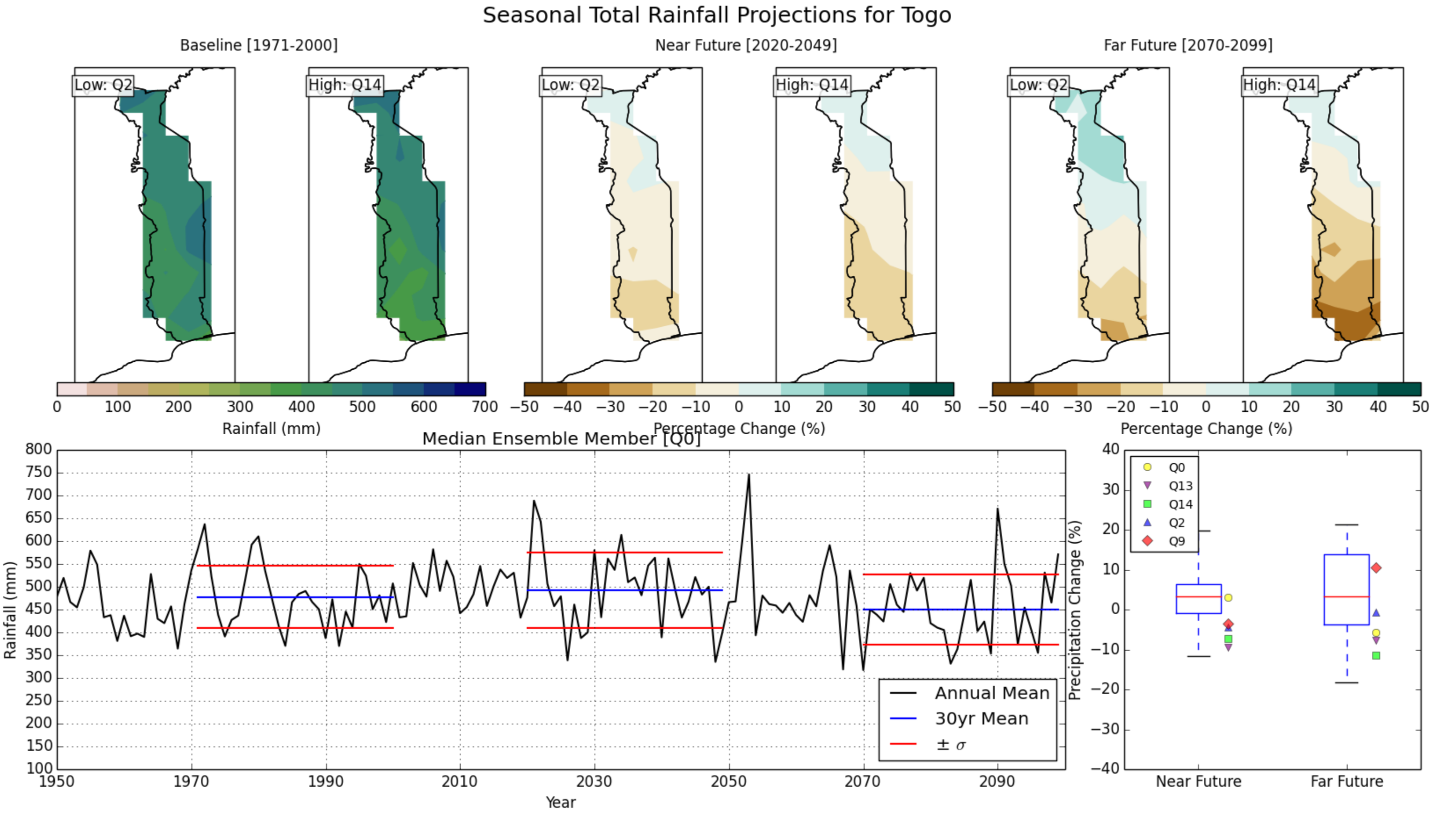


Figure 12: As in Figure 4, but for Togo.

The high level of uncertainty with our 5-member RCM ensemble is consistent with level of uncertainty within the CMIP5 ensemble, which again suggests very little model agreement in this region, with strong positive and negative changes in the percentage of rainfall during the JAS season.

4. Conclusion and Action Points

While the temperature and rainfall projections within IPCC AR5 are a useful source of information on potential future climate conditions, regional climate projections using high-resolution models can add value and bring more spatial detail to the climate information to be used in decision-making process.

The five innovative RCM experiments used to inform the PARCC West Africa project all suggest an increase in temperature over the five focus countries (Chad, Mali, Sierra Leone, the Gambia and Togo). A warmer climate in the future could have serious impacts on agricultural productivity, ecosystems and livelihoods across West Africa. In addition, the regional climate information suggests an increase in variability of temperature during the 21st century, which could result in even more frequent extreme hot events in the future than would be expected just from the increases in average temperatures. The high level of consensus across both global and regional climate model results in this region suggests that increase of surface temperature is very likely in all five focus countries. Adaptation, such as alternative crop selection and better protected area networks to ensure species survival, will be required in order to reduce the effect of an inevitably warmer climate in the future.

Results for precipitation across the five RCM experiments are widely varying and suggest slight decreases in JAS rainfall for Mali and the Gambia, potential increases for Sierra Leone and Chad. There is very little agreement across the five RCM experiments on projections of rainfall for Togo. While some of the results described above may suggest a clear response to climate change, when compared to similar results found in the CMIP5 ensemble, there is a high level uncertainty associated with rainfall projections in West Africa, with very little model agreement on both the direction (positive or negative) and magnitude of potential rainfall changes in the future. It is therefore recommended that adaptation activities occur in order to build robust resilience against the impacts of current climate variability, as this resilience will help species survive, protect ecosystem services, and ensure improved livelihoods for the coming years and decades, leading to improved capability to adapt to either wetter or drier conditions which will result from climate change.

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