Climate risk report for the West Africa region
Supplementary Document: Appendices

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Contents

Appendix A: Methods and Data

Climate in context methodological approach

The key stages in the methodology and division of responsibilities across the project team are presented in a schematic in Figure A1 and described in more detail below.

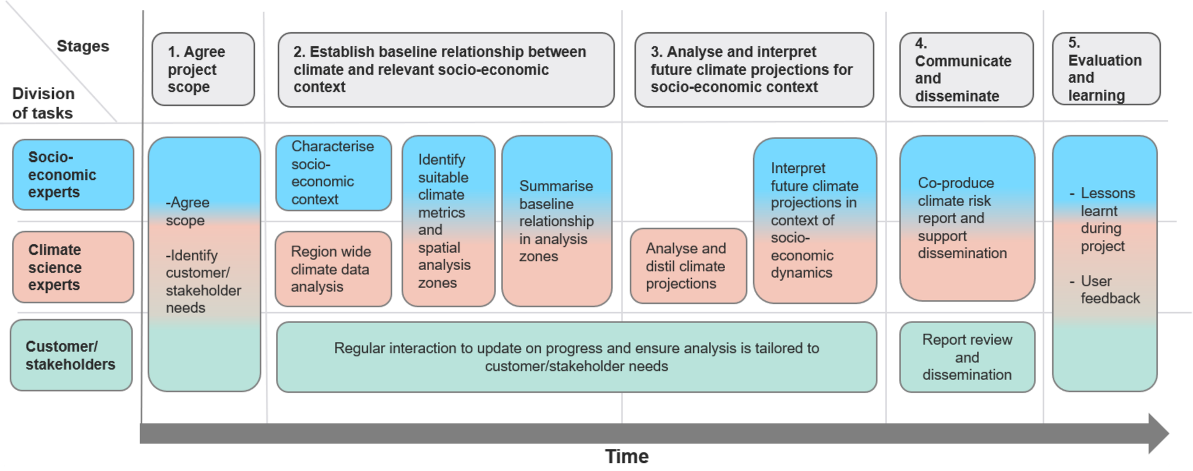

Figure A1 – Schematic diagram of the key stages of the methodology and division of tasks between the socio-economic experts (ODI), climate science experts (Met Office) and customer (FCDO) roles of the project team. This diagram is an initial draft of the Climate in Context methodology[1] currently being developed.

Stage 1 involves agreement on the scope of the work and the format of the outputs through iterative discussions across the project team. Consultations with the customer (FCDO) are conducted to identify the socio-economic themes relevant to their decision context.

Stage 2 involves establishing the baseline relationship between climate and the key socio-economic themes identified in Stage 1. This includes:

- Preliminary analysis is conducted to characterise the regional socio-economic context and regional climate through a combination of literature review and processing climate reanalysis data by the relevant experts.
- Identification of suitable climate metrics and spatial analysis zones via an iterative process between the experts, drawing on the outcomes of the preliminary analysis.
- Characterisation of the baseline climate, the key climate-related vulnerabilities and exposure to climate-related hazards in each of the spatial analysis zones.

Stage 3 involves analysis of future climate projections and interpretation in the context of the key vulnerabilities and baseline assessments developed in Stage 2. This includes:

- Selection of appropriate climate model simulations for the region and quantitative analysis of projected changes in relevant climate variables in each of the spatial analysis zones.

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[1] A report documenting the Met Office Climate in Context methodology is in preparation and due to be published in 2021.

- Distillation of the future climate projections into narrative summaries for the relevant climate metrics in each spatial analysis zone.
- Translation of the future climate summaries into climate risk impacts with a focus on the key socio-economic themes.

Stage 4 involves the co-production of a report summarising the analysis and outcomes, tailored to the needs of the customer.

Finally, **Stage 5** involves evaluation and learning of the process to support future applications of the methodology.

Climate data and analysis methods

The climate projections in this report came from an ensemble of 30 CMIP5 global climate model simulations (see Table A1), 20 CMIP6 global climate model simulations (see Table A2) and 20 regional climate model simulations (from the CORDEX project, see Table A3). The models selected are those that were available to access at the time of analysis. Model simulations were assessed for their suitability in simulating the climate of the region by comparing the baseline periods from the model simulations with the reanalysis. The results from this assessment were taken into consideration when interpreting the future projections from the model simulations. More detail on evaluation of these model simulations and known biases is available in IPCC (2013), Ntoumos et al., (2020), Oztuek et al., (2018), Syed et al., (2019).

Table A1 – GCM simulations from CMIP5 used in the climate data analysis, from https://pcmdi.llnl.gov/mips/cmip5/availability.html.

Modelling Centre	**Model**	**Institution**
BCC	BCC-CSM1-1	Beijing Climate Center, China Meteorological Administration
	BCC-CSM1-1	
CSIRO-BOM	ACCESS1-0	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
	ACCESS1-3-m	
CCCma	CanESM2	Canadian Centre for Climate Modelling and Analysis
CMCC	CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici
	CMCC-CMS	
CNRM-CERFACS	CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
CSIRO-QCCCE	CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
EC-EARTH	EC-EARTH	EC-EARTH consortium
GCESS	BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University
INM	INMCM4	Institute for Numerical Mathematics
IPSL	IPSL-CM5A-LR	Institut Pierre-Simon Laplace

	IPSL-CM5A-MR	
	IPSL-CM5B-LR	
MIROC	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
	MIROC-ESM	
	MIROC-ESM-CHEM	
MOHC	HadGEM2-CC	Met Office Hadley Centre
	HadGEM2-ES	
MPI-M	MPI-ESM-LR	Max Planck Institute for Meteorology
	MPI-ESM-MR	
MRI	MRI-CGCM3	Meteorological Research Institute
NCAR	CCSM4	National Center for Atmospheric Research
NCC	NorESM1-M	Norwegian Climate Centre
NIMR/KMA	HadGEM2-AO	National Institute of Meteorological Research/Korea Meteorological Administration
NOAA-GFDL	GFDL-CM3	NASA Goddard Institute for Space Studies
	GFDL-ESM2G	
	GFDL-ESM2M	
NSF-DOE-NCAR	CESM1-CAM5	National Science Foundation, Department of Energy, National Center for Atmospheric Research

Table A2 – GCM simulations from CMIP6 used in the climate data analysis, from https://pcmdi.llnl.gov/mips/cmip5/availability.html.

Modelling Centre	**Model**	**Institution**
BCC	BCC-CSM2-MR	Beijing Climate Center, China Meteorological Administration
CCCma	CanESM5	Canadian Centre for Climate Modelling and Analysis
CNRM-CERFACS	CNRM-CM6-1	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
	CNRM-CM6-1-HR	
	CNRM-ESM2-1	
CSIRO	ACCESS-ESM1-5	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia)
EC-EARTH consortium	EC-Earth3	EC-EARTH consortium
	EC-Earth3-Veg	
INM	INM-CM4-8	Institute for Numerical Mathematics
	INM-CM5-0	
	INM-CM6A-LR	
MIROC	MIROC6	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MOHC	HadGEM3-GC31-LL	Met Office Hadley Centre
MOHC	UKESM1-0-LL	
MPI-M	MPI-ESM1-2-LR	Max Planck Institute for Meteorology
MRI	MRI-ESM2-0	Meteorological Research Institute
NCC	NorESM2-MM	Norwegian Climate Centre
NOAA-GFDL	GFDL-ESM4	NASA Goddard Institute for Space Studies

	GFDL-CM4	
NUIST	NESM3	Nanjing University of Information Science and Technology

Table A3 – RCM simulations from CORDEX AFR-44 used in the climate data analysis. These are downscaled simulations of a subset of the CMIP5 models in Table A1 at ~50km resolution.

Modelling centre	**Institution**	**RCM**	**Driving GCM**
CLMcom	Climate Limited-area Modelling Community (CLM-Community)	CCLM4-8-17	CNRM-CM5
			MPI-ESM-LR
			EC-EARTH
			HadGEM2-ES
DMI	Danish Meteorological Institute	HIRHAM5	EC-EARTH
GERICS	Helmholtz-Zentrum Geesthacht, Climate Service Center Germany	REMO2009	IPSL-CM5A-LR
			MIROC5
			HadGEM2-ES
MPI-CSC	Helmholtz-Zentrum Geesthacht, Climate Service Center, Max Planck Institute for Meteorology	REMO2009	EC-EARTH
			MPI-ESM-LR
SMHI	Swedish Meteorological and Hydrological Institute	RCA4	CNRM-CM5
			CSIRO-Mk3-6-0
			CanESM2
			HadGEM2-ES
			EC-EARTH
			MPI-ESM-LR
			IPSL-CM5A-MR
			NorESM1-M
			MIROC5
			GFDL-ESM2M

Appendix B: Climate plots

Additional plots of the baseline climate and projected climate changes for annual and seasonal timescales, in each spatial analysis zone are included in the following sections.

Zone 1: Senegambia

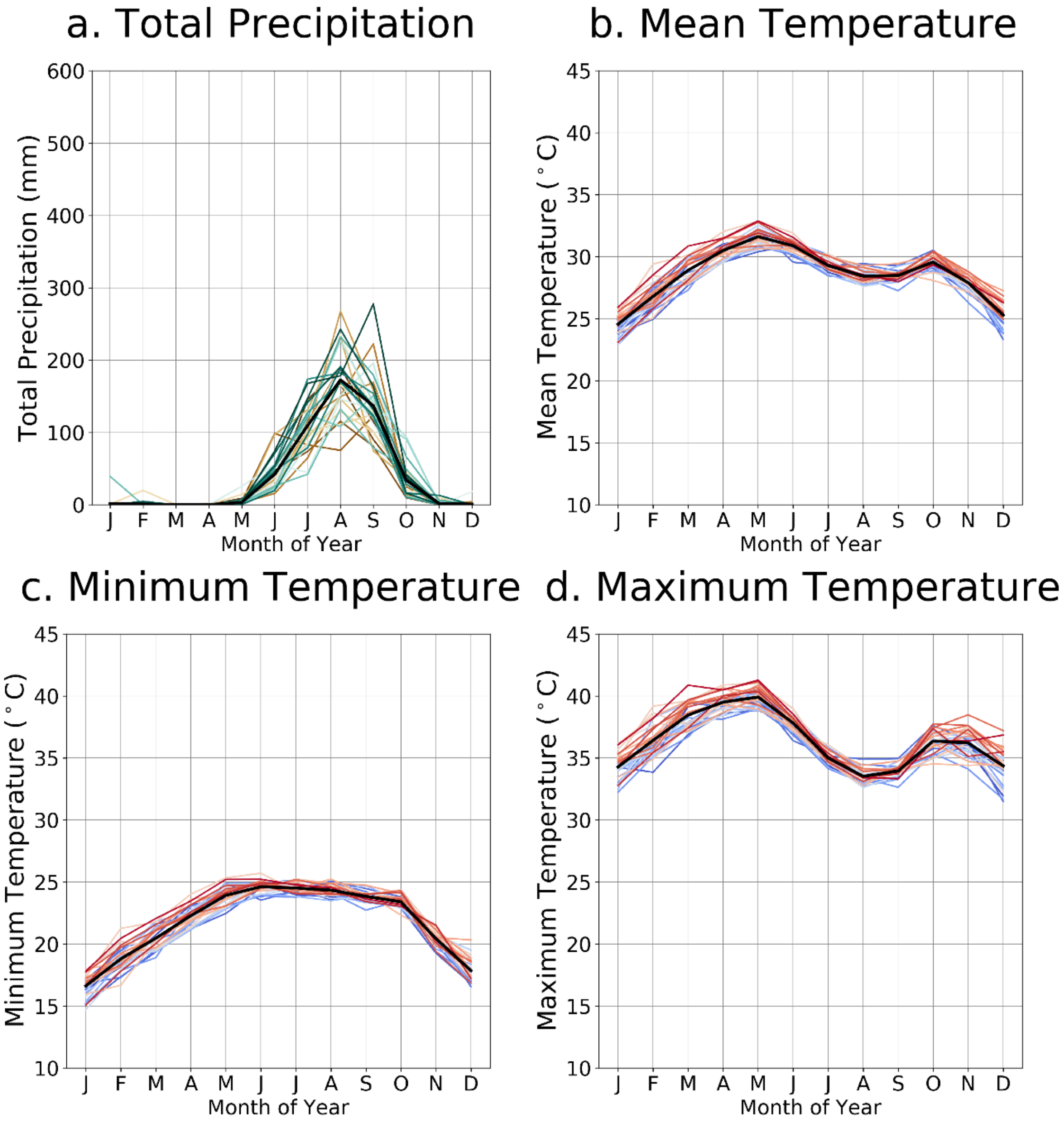


Figure B1: Observations for Zone 1 of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) from the WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset. Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

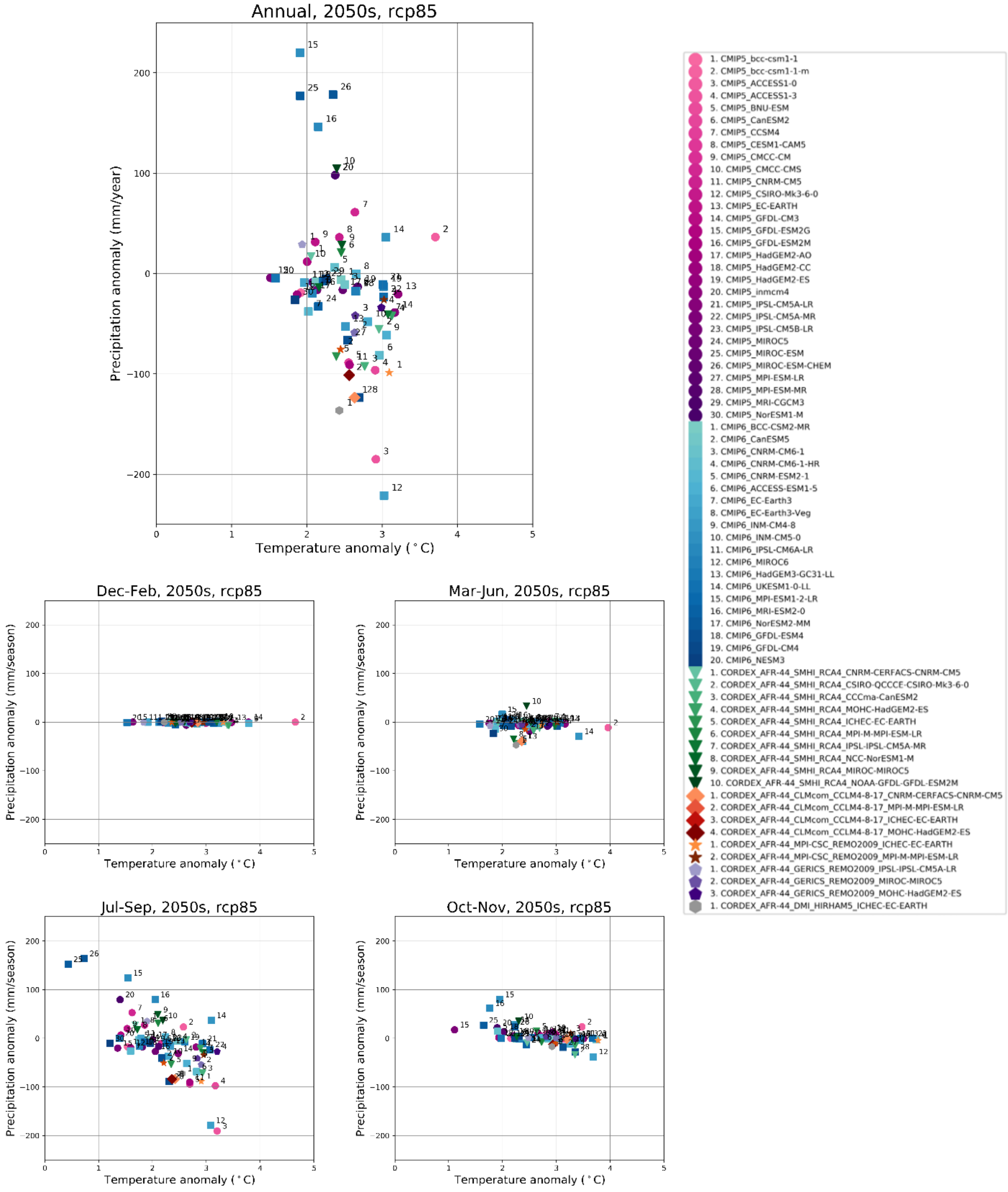


Figure B2: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 1. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Zone 2: Northern Nigeria

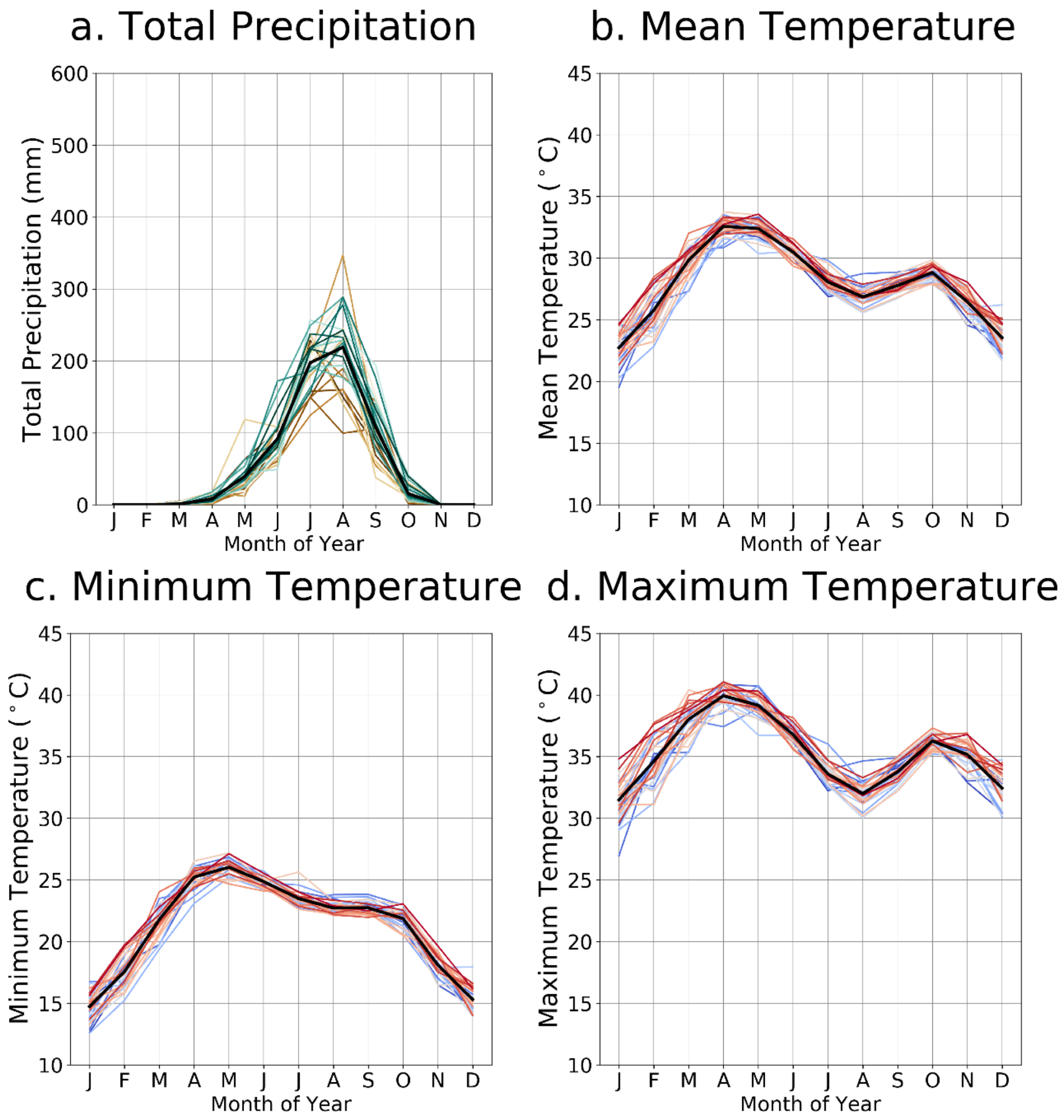


Figure B3: Observations for Zone 2 of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) from the WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset. Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

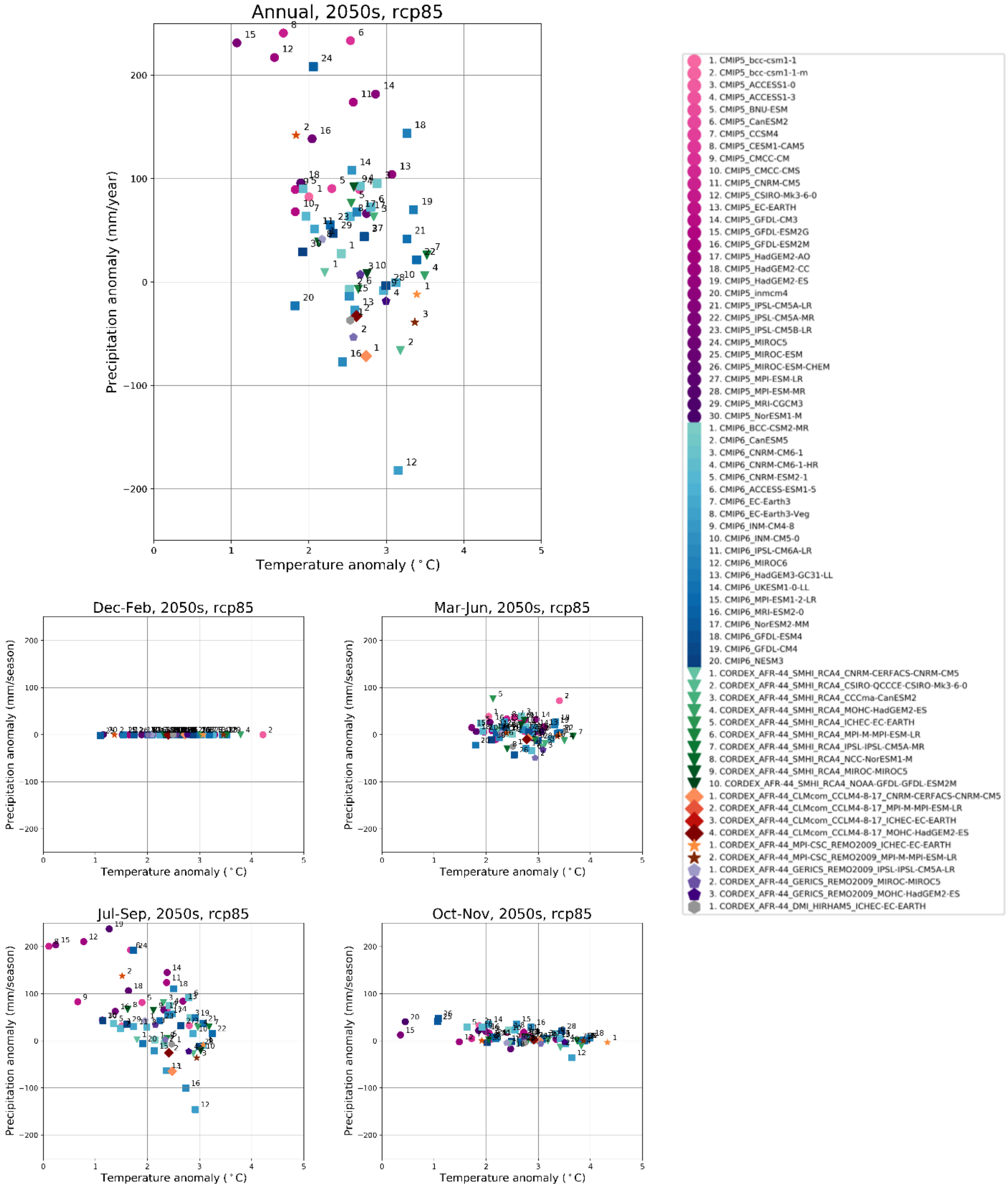


Figure B4: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 2. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Zone 3: Central Western West Africa

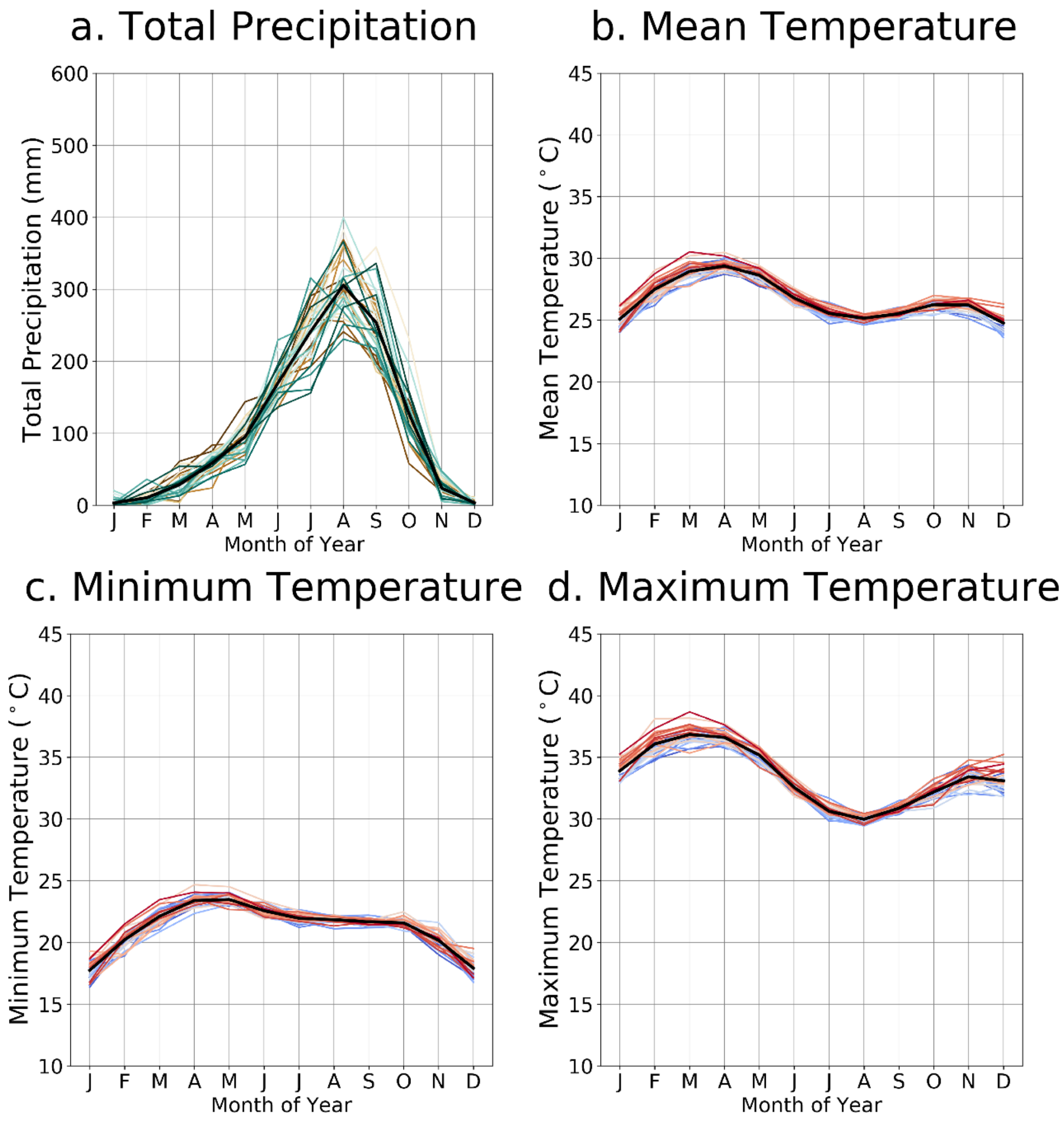


Figure B5: Observations for Zone 3 of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) from the WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset. Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

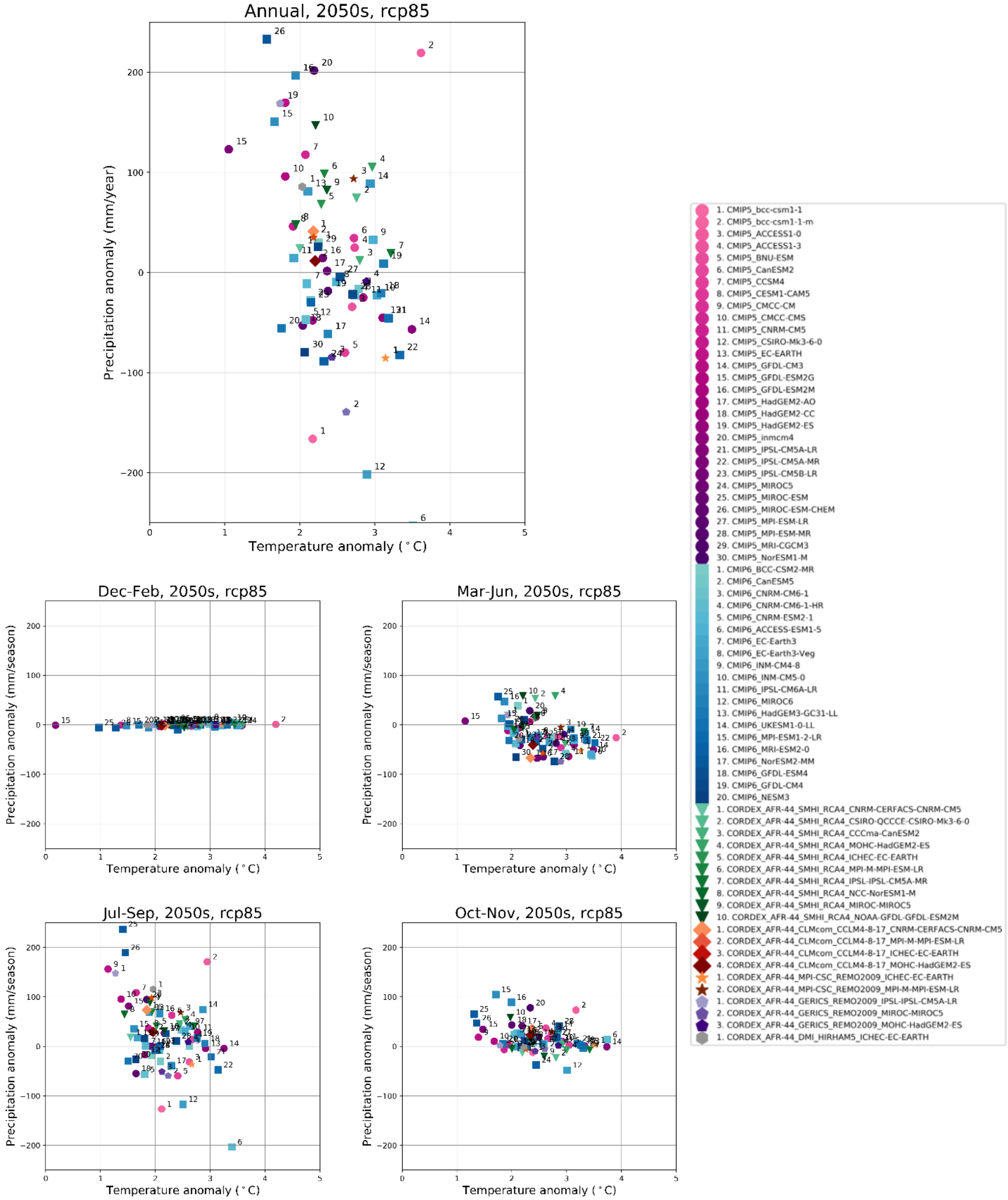


Figure B6: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 3. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Zone 4: Central Eastern West Africa

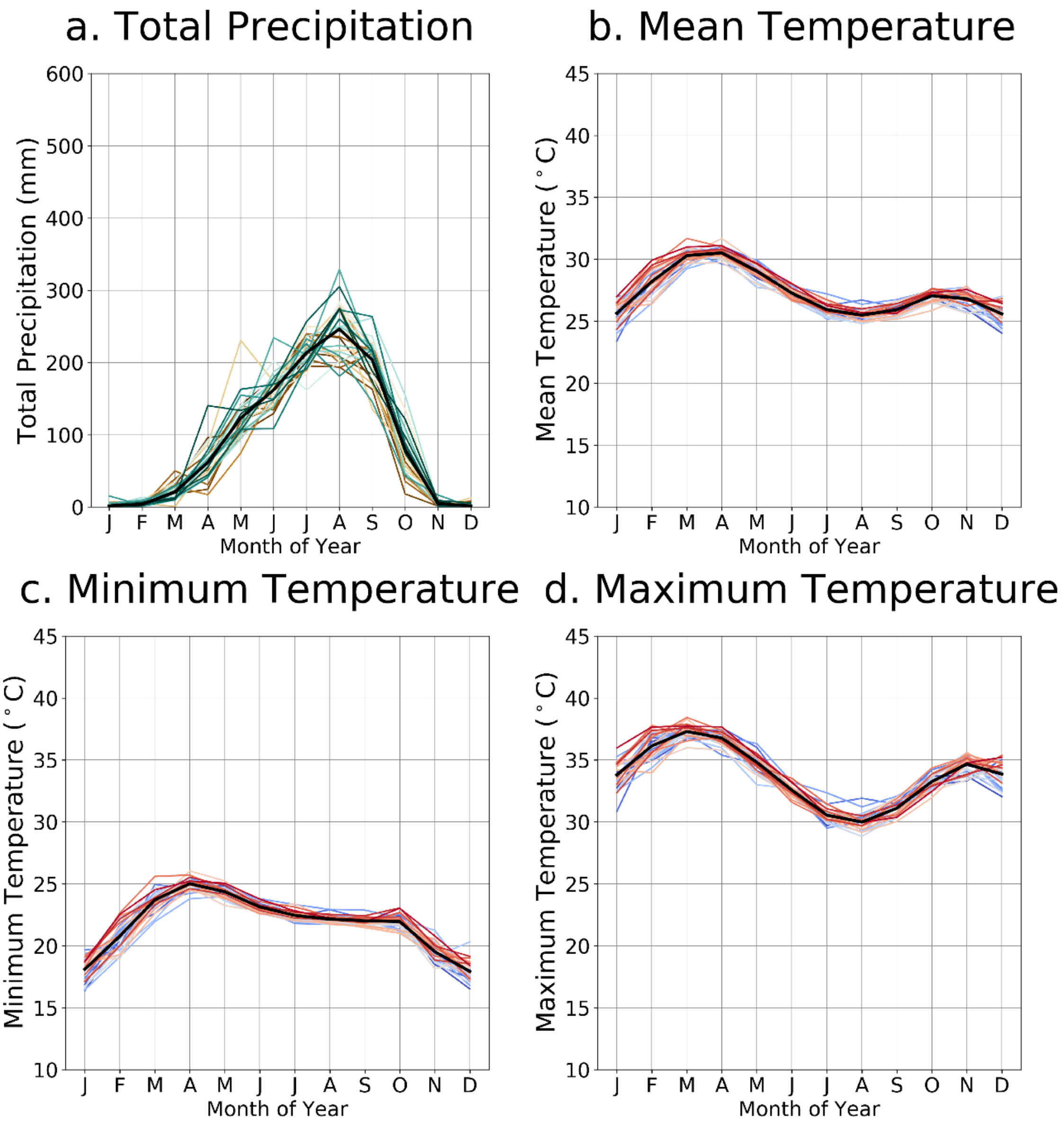


Figure B7: Observations for Zone 4 of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) from the WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset. Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

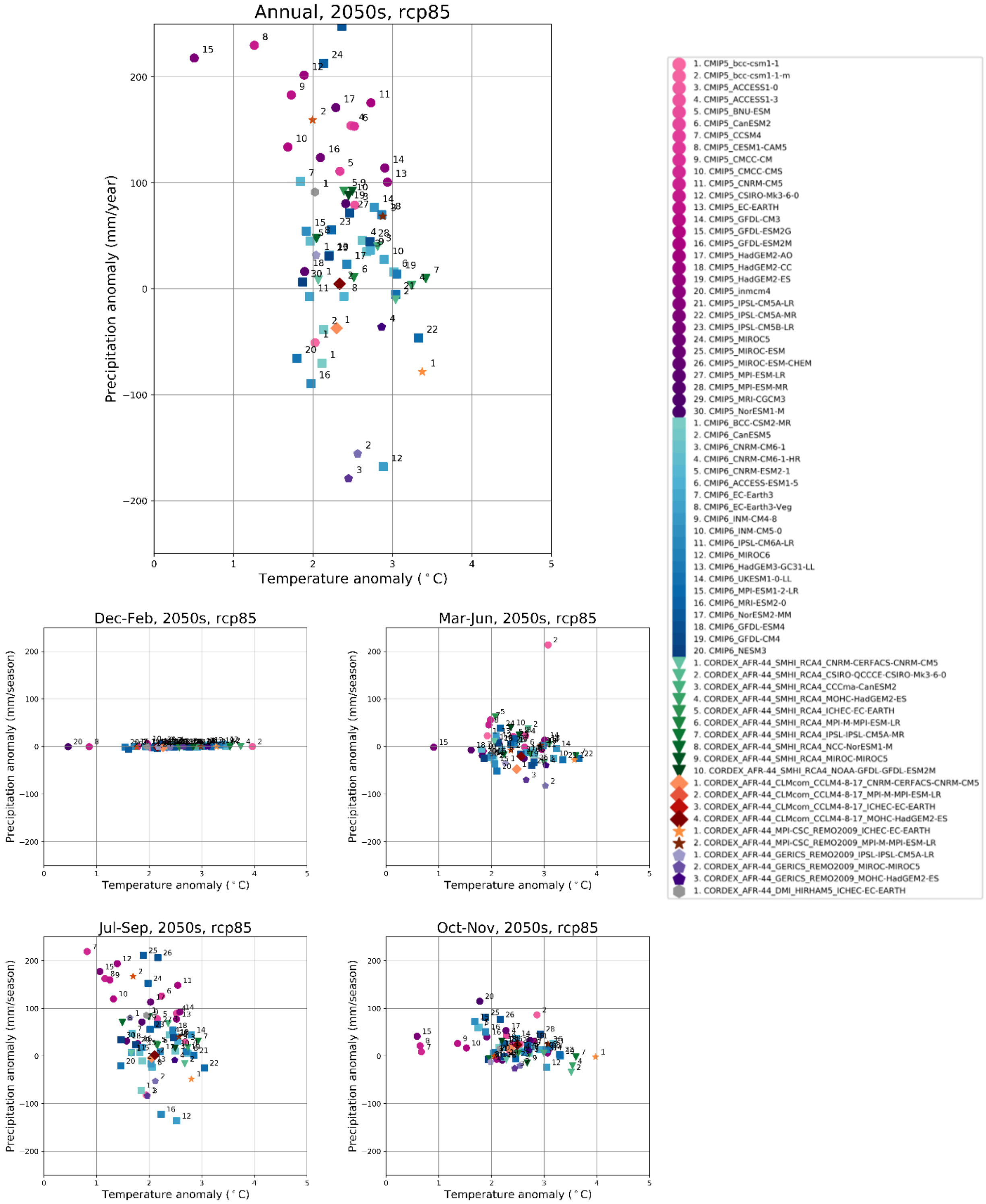


Figure B8: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 4. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Zone 5: South Western Coastal Zone

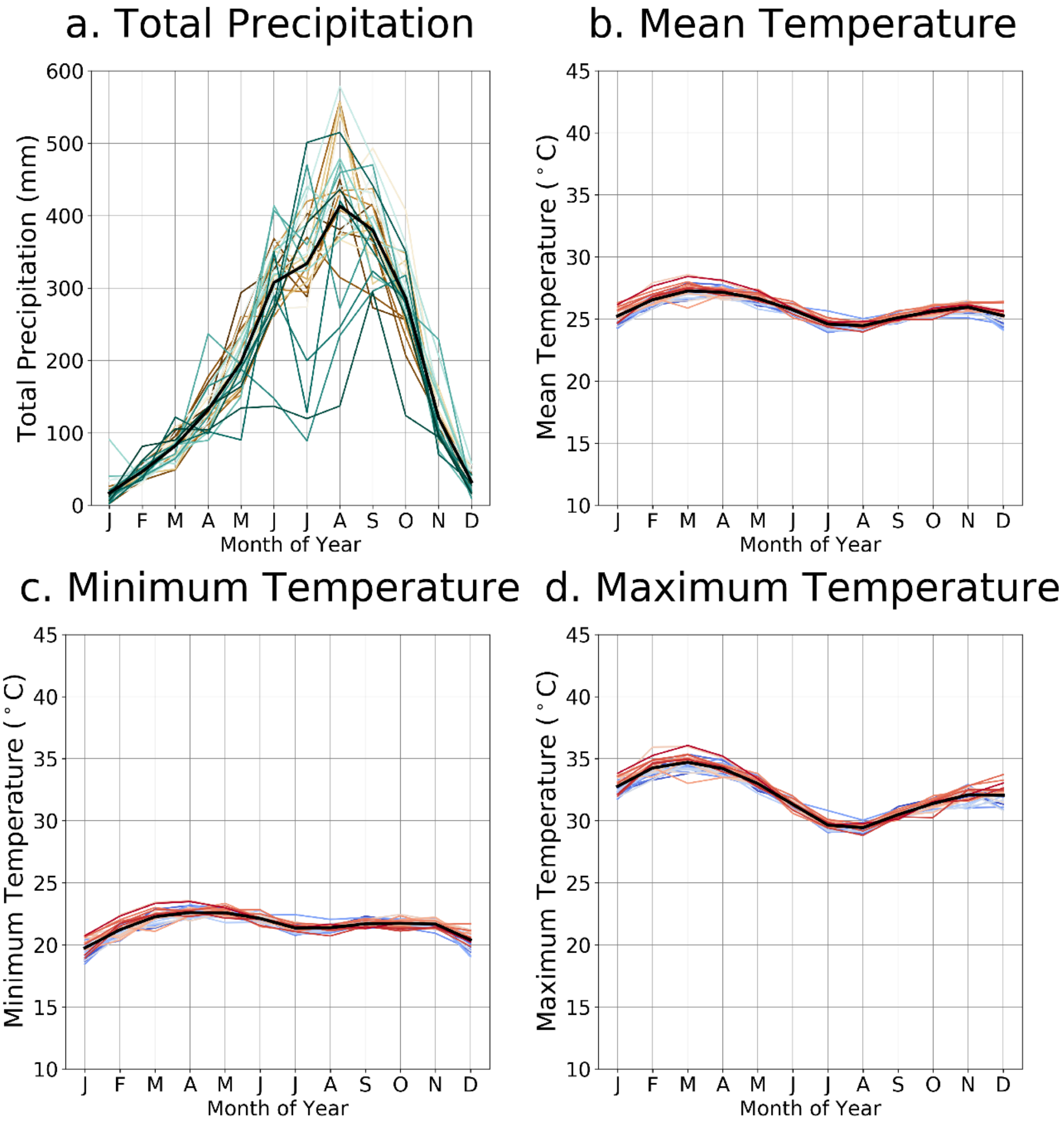


Figure B9: Observations for Zone 5 of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) from the WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset. Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

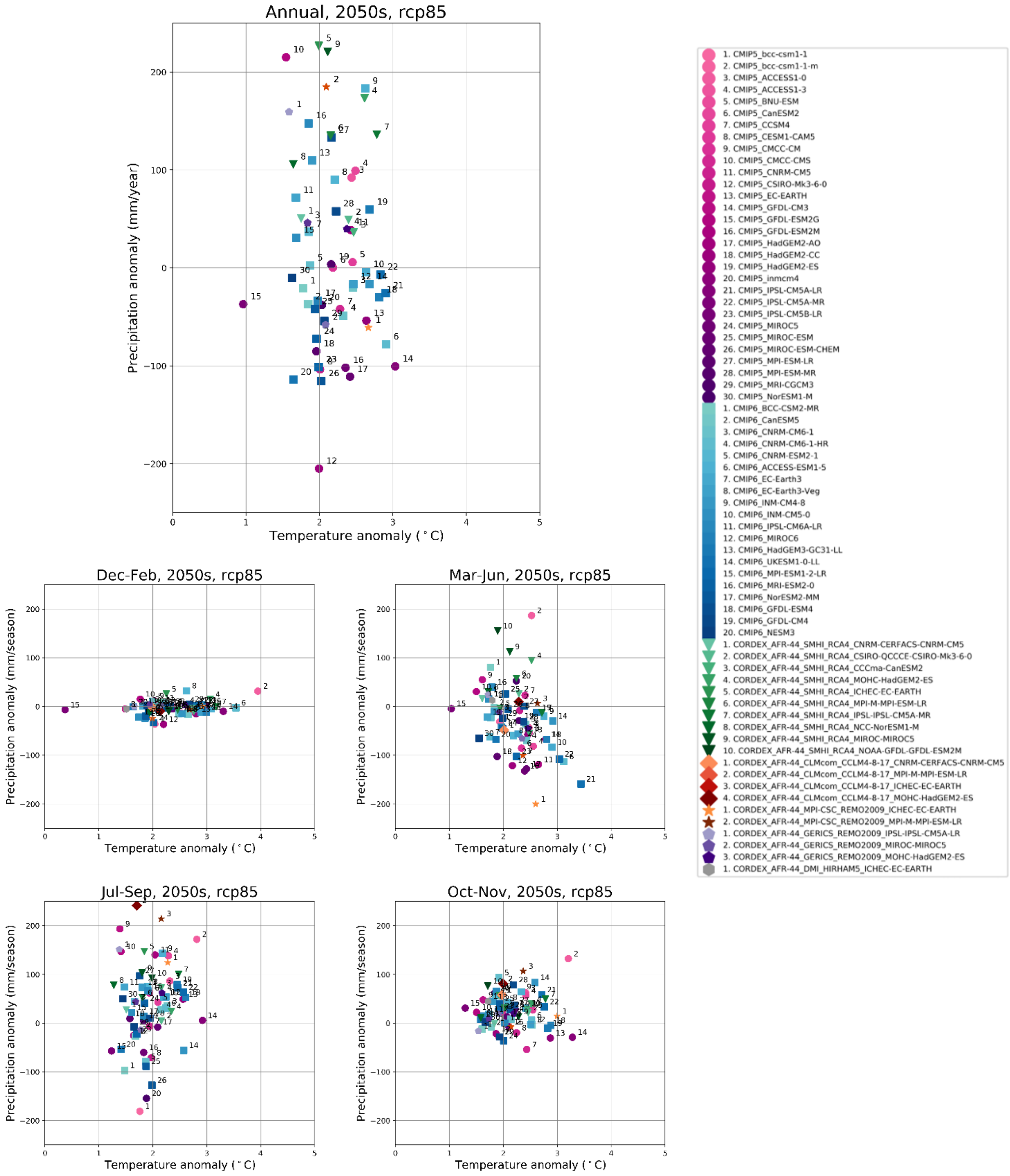


Figure B10: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 5. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Zone 6: South Eastern Coastal Zone

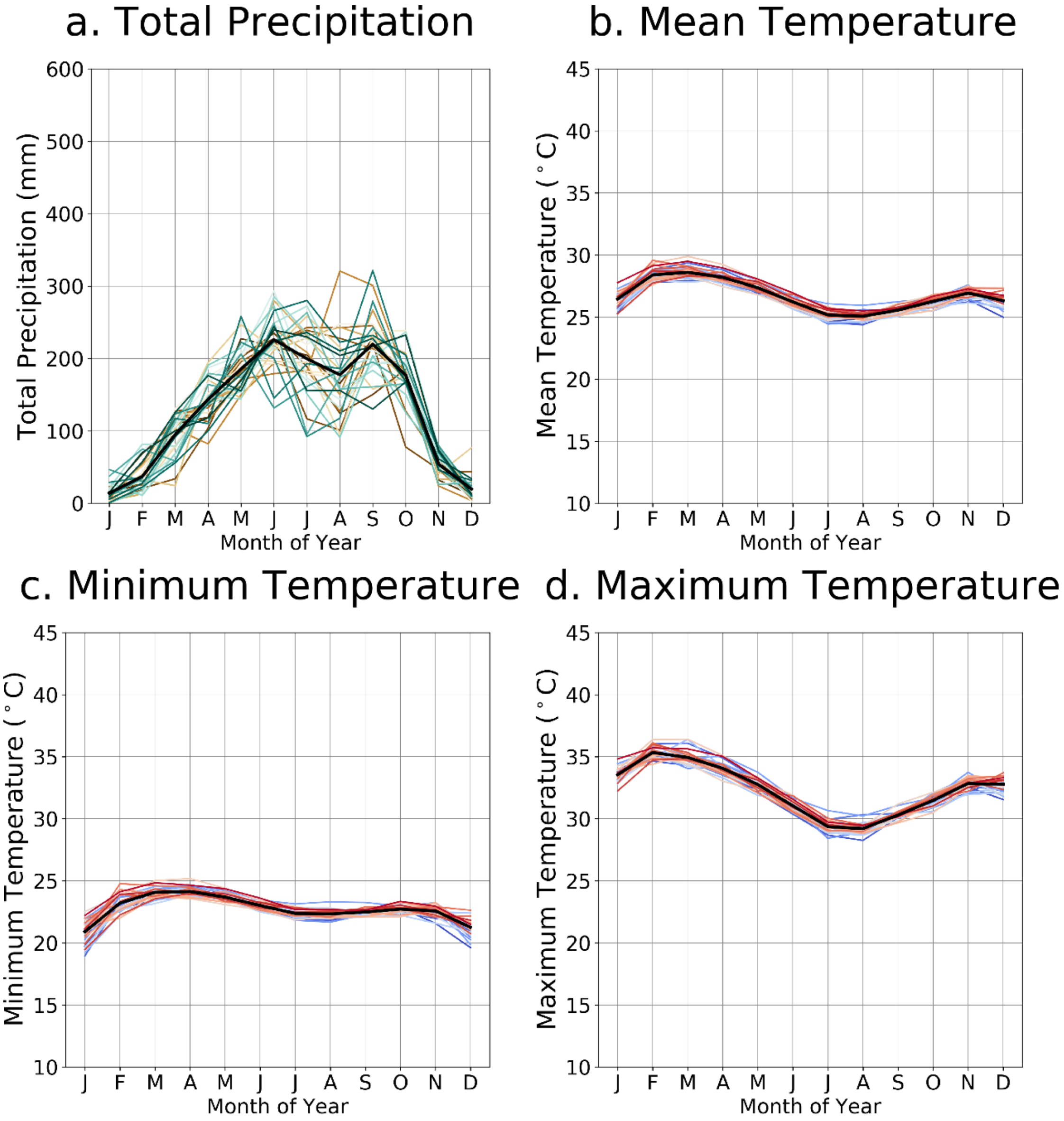


Figure B11: Observations for Zone 6 of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) from the WFDEI-CRU (WATCH Forcing Data methodology applied to ERA-Interim data, adjusted using CRU TS3.101 precipitation totals) dataset. Each line is one individual year. Colours show the ordering of years from brown to blue (total precipitation) and blue to red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline period. The bold black line indicates the average of the 30-year period.

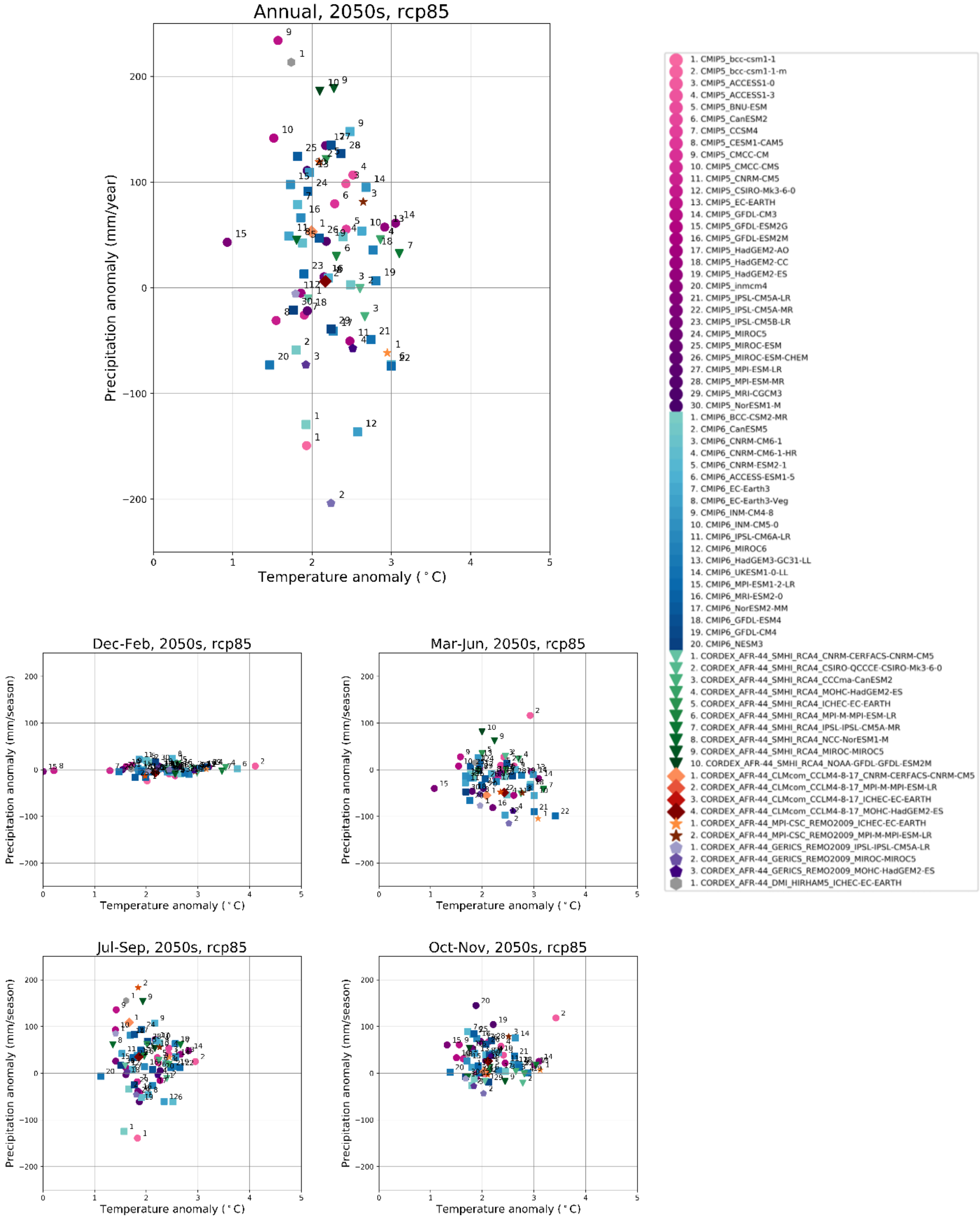


Figure B12: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 6. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Appendix C:

Crop T in West Africa

Table 1: Agro-ecology of a selection of West African cereal crops and climate risks

Crop	Current growing area (zones)	Growing conditions & thresholds	Climate risks
Cereals / Grains:			
Bulrush millet (pearl millet) - *Pennisetum glaucum*	Northern limit of growing around the 250mm isohyet. Zones 1 & 2 (especially), zones 3, 4 (northern areas).	Rain-fed crop in semi-arid regions; most important crop in Sahel; in Sudan zone (savanna) equal status with sorghum; short-cycle millet can be grown with less rainfall than sorghum. Even distribution of rainfall during growing season more important than total precipitation. Drought resistant and suited to drier and sandier areas than sorghum but requires a minimum amount of moisture for growth.	Too much rain at flowering can cause a crop failure. It cannot tolerate waterlogging. The climate risk is from flooding, which is projected to increase.
Finger millet (Tamba) - *Eleusine coracana*	Grown mainly at 1000m – 2000m altitude, e.g. on Jos Plateau in central Nigeria About 500 mm rainfall preferred.	It requires a well distributed rainfall during the growing season with an absence of prolonged droughts. In drier areas with unreliable rainfall, sorghum and bulrush millet are better suited than finger millet. It will not tolerate such heavy rainfall as rice or maize. Can tolerate temperatures down to 18C, hence suitable for highlands.	It cannot tolerate waterlogging, therefore is not suited to flood prone areas. Moderate temperatures preferred (optimum may be 27C); high temperatures could reduce yields.
Sorghum (guinea corn) - *Sorghum bicolor* and other varieties	Dry savannas and grasslands, 40 N and S of the equator.	Adapted to a wide range of ecological conditions; will produce useful yields of grain under conditions unfavourable to other cereals. It can tolerate hot and dry conditions but can also be grown in areas with high rainfall where waterlogging can occur. Grown in areas	Sorghum is well adapted to climate risks and will grow in importance.

	It was domesticated in Africa - a native crop.	that are too hot and dry for maize. Its physiology means evapotranspiration in sorghum is about half that of maize and it requires about 20% less water than maize to produce equivalent dry matter. It can remain dormant in drought and resume growth when conditions become favourable. Tolerates wide range of soil conditions. Optimum growth temperature about 30C. It is drought resistant. Can also survive physiological drought produced by waterlogging.	The main climate risk is from high temperatures. Sorghum is presently grown in conditions well above 30C in West Africa, but the projected temperature increases are extreme and far higher than optimal. This could reduce yields.
Maize – *Zea mays* and other varieties	A widely grown and consumed cereal crop in West Africa. Zones 3, 4, 5, 6, parts of 1 and 2.	Cultivars of maize in W. Africa suited to savanna areas, but the crop has become widespread in southern and some northern areas too. Preferred rainfall about 450-600mm and should not fall below 200mm, so is unsuited to semi-arid conditions. High yields of maize make a heavy drain on soil nutrients, and it has a high nitrogen requirement. In West Africa maize tends to be grown with chemical fertilisers.	Climate risks to maize are many. It is susceptible to erratic rainfall during wet season. Yields will decrease or the crop will be spoilt in extreme heat. Maize is grown in higher rainfall areas at the edges of the rainy season through early and late planting. Maize does not like waterlogging or degraded soil, so that is also a climate risk as rainfall changes.
Rice – *Oryza glaberrima* and other varieties	An important crop in West Africa, grown mainly in wetlands (riverine areas), and in some high rainfall areas. Present in all zones (1-6).	Wet habitats: swamp rice grows in flat lowlands, river basins and deltas with a high temperature and abundant sunshine and adequate water; and in monsoon regions with high rainfall. Hill or dryland rice requires high rainfall for successful cultivation.	Climate risk from drought periods caused by erratic or low rainfall. Changes in river flows and wetlands are a risk, as high temperatures will increase evaporation, exacerbating water extraction by increasing population. Rice paddies in coastal areas threatened by sea water inundation, e.g. in Casamance, where mangroves traditionally protect rice paddies, and in Bijagós Archipelago off coast of Guinea-Bissau where rice is grown on raised terraces.

Acha (Fonio / Hungry Rice) - *Digitaria exilis* (and varieties)	Savanna zone of West Africa from Senegal to Cameroon, but patchy distribution. Popular in Futa Djallon (highland area of Guinea), Jos Plateau (Nigeria), parts of Sierra Leone. Zones 3 and 4, parts of 5 and 6 (field research needed).	Rainfall exceeding 400mm. Acha has a very small grain and it is nutritious with a good flavour. It is an old, indigenous West African cereal. It can grow on poor, shallow, rocky soils. It is traditionally sown around June/July and harvested in Sept/Oct.	Acha could be well suited to the uncertain conditions of climate change, as it is a resilient crop and as a West African domesticate it is adapted to local ecologies. The rainfall requirement means it is more suited to savannah areas. Currently it is far less widespread than maize and sorghum and is not a common feature of West Africa diets in most areas, so it would need to be cultivated more widely to have more than specific local impacts on food security.
Wheat	Northern Nigeria (zone 2)	In West Africa wheat has been introduced in some areas to be grown in the dry season with irrigation. Particularly Northern Nigeria (state/donor sponsored schemes, not widespread). It can be grown in high temperatures with low humidity. Fertile soils with reasonable drainage and good water holding capacity are preferred. Such soils are not typical in savanna and semi-arid areas of the region, and where they are present other crops are more suitable.	There are misguided government efforts to increase wheat production in Nigeria, but it is not a suitable crop for the region. It would be vulnerable to climate risks posed by erratic rainfall and as a dry season crop irrigation of wheat would increase water insecurity.

Sources:

Purseglove, J. W. (1974) *Tropical Crops: Dicotyledons* (vols 1 & 2). London: Longman Publishing Group.

Purseglove, J. W. (1975) *Tropical Crops: Monocotyledons* (vols 1 & 2). London: Longman Scientific & Technical.

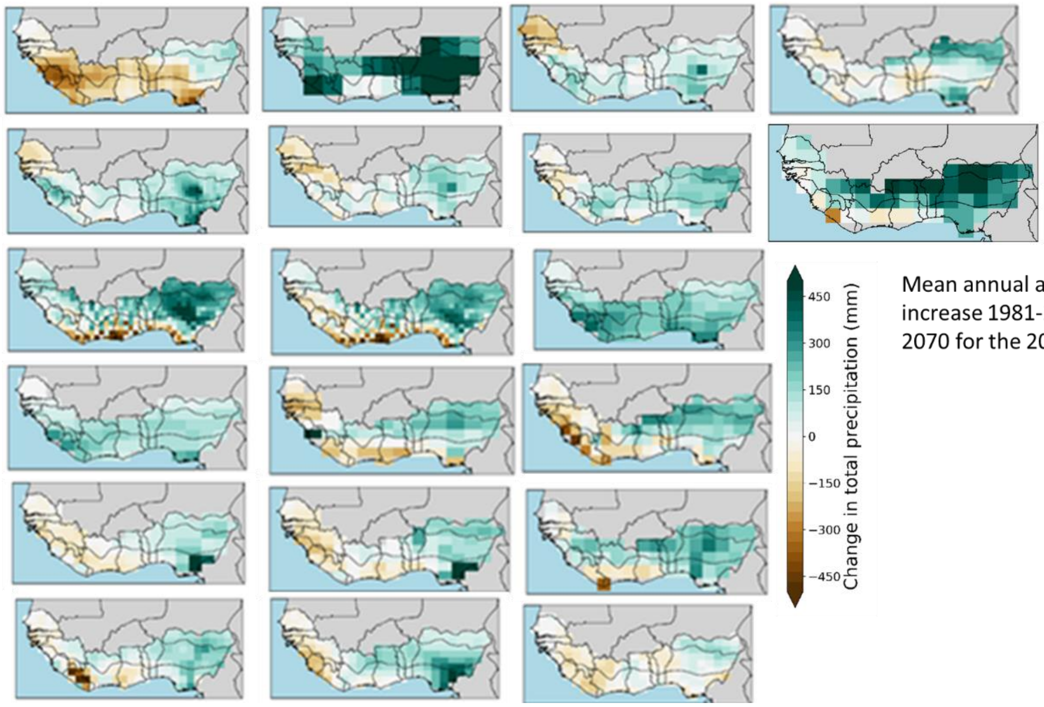
Appendix D: Climate projections overview

West Africa is a hot, wet region which will become hotter in the 2050s. Annual rates of rainfall will continue to be very variable, there is high confidence that heavy rain will be more frequent and intense and low confidence that dry spells will be longer and more frequent.

There is currently a narrow temperature range in West Africa, both year-to-year and throughout each year and this characteristic will not change. However, the temperatures will increase by 1-4°C on average across the region. This pushes future temperatures beyond the range currently observed – the lowest mean temperatures in the 2050s will be higher than the highest mean temperatures in the baseline period.

Year-to-year variability in seasonal precipitation amounts and timings will continue in the future climate as the larger-scale influences remain active. There is some evidence that ENSO events may become more frequent (Cai et al., 2021) which would increase inter-annual rainfall variability over time. This means an increase in both wetter and drier years relative to the mean.

Precipitation is currently highly variable, seasonally and inter-annually, and this will continue in the 2050s. Given the projected increase in atmospheric temperatures, there is confidence in more frequent intense precipitation events and long dry spells (Wang et al., 2021). There is some indication in the CMIP6 models that annual precipitation will increase in the east of the region (Nigeria) and decrease in the northwest (Senegal, The Gambia). The signal on the coast is less clear, but a similar west to east increasing gradient is indicated by some models (Figure 8) and significant drying along the coast of the Gulf of Guinea is a potential risk.



Mean annual average precip increase 1981-2010 to 2041-2070 for the 20 CMIP6 models

Figure 8: CMIP6 model precipitation projections

There is an indication from the models that the onset of the rainy season will be delayed, and the literature is in agreement with this, though this will vary across the region (Kumi & Abiodun, 2018).

Periods of unusually high temperature in such a humid region (especially in the south), will mean that heat stress will be a more prominent risk in the future and models agree in an increase to intensity and a decrease to frequency of precipitation during April-June over the Gulf of Guinea (Dosio et al., 2020).

From Figure 9 it can be seen that to the west of the region (zones 1, 3, 5 below) and to the south (zone 6) there is an indication of more dry days per year and a moderate increase in daily precipitation intensity. In the east of the region (zones 2 and 4) there is evidence for fewer dry days per year and an increase in daily precipitation intensity (see Figure 11 for climate zones).

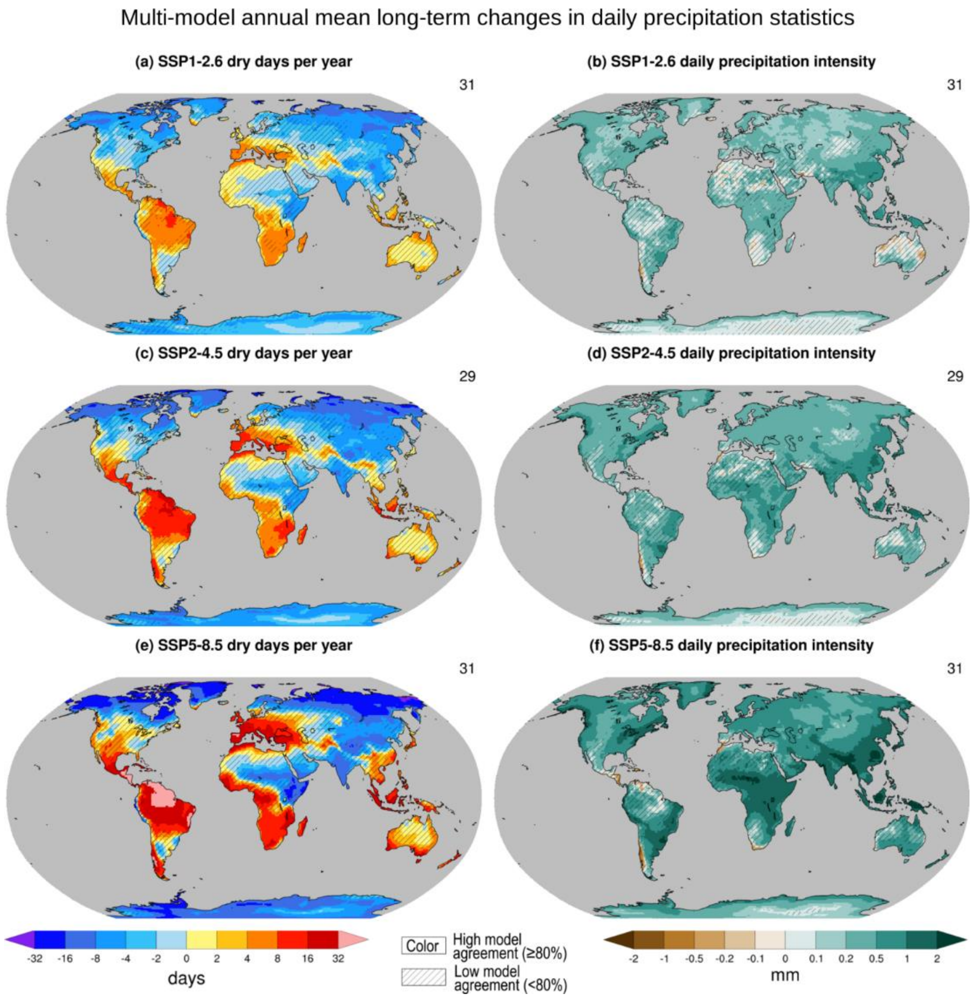


Figure 9: Projected long-term relative changes in daily precipitation statistics. Global maps of projected seasonal mean relative changes (%) in the number of dry days (i.e. days with less than 1 mm of rain) and daily precipitation intensity (in mm/day, estimated as the mean daily precipitation amount at wet days – i.e., days with intensity above 1 mm/day) averaged across CMIP6 models in the SSP1-2.6 (a,b), SSP2-4.5 (c,d) and SSP5-8.5 (e,f) scenario respectively. Uncertainty is represented using the simple approach: No overlay indicates regions with high model agreement, where ≥80% of models agree on sign of change; diagonal lines indicate regions with low model agreement, where <80% of models agree on sign of change. Source: IPCC, 2021

Atlantic circulation changes

The Guinea Current flows eastwards along the southern coast of West Africa. The Guinea Current plays a significant role in modulating the coastal upwelling in the northern Gulf of Guinea which extends along the West African coast from Côte d’Ivoire to Nigeria (Ukwe et al., 2006; Djakouré et al., 2017; Alory et al., 2021). This coastal upwelling brings colder, nutrient-rich waters to the surface and is vital in maintaining the productivity and biodiversity of the marine ecosystem in the region, including fisheries.

Future changes in circulation within the tropics remain unclear, however there is medium confidence that change in ocean circulation will contribute to continued change in tropical ocean temperature in the 21st century (IPCC, 2021).

The Canary Current runs south along the north-western coast of Africa and drives an upwelling zone along the north-western African coast, including a seasonal upwelling during winter along the coasts of Senegal and The Gambia (zone 1) at its lowest latitudinal extent (Gómez-Letona et al., 2017). Changes to the Canary Current trend over past decades is considered uncertain (IPCC, 2021). However, there is high confidence that overall eastern boundary upwelling systems, such as that associated with the Canary Current along the coast of West Africa will decrease at their lower latitude extents. However, there is also medium confidence that in the 21st century these changes will be within ±10-20% from present-day values (IPCC, 2021).

Image location: Accra, Ghana

www.metoffice.gov.uk