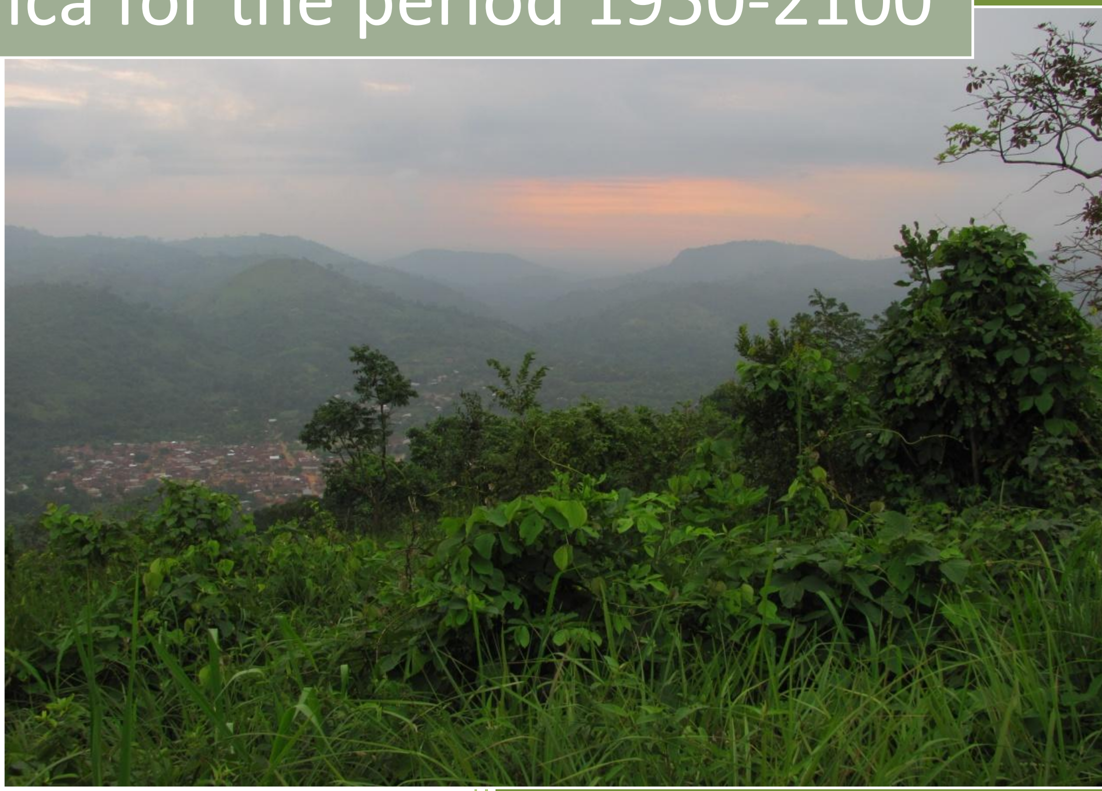
Protected Areas Resilient to Climate Change, PARCC West Africa

2012

Deriving high resolution climate data for West Africa for the period 1950-2100



English

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Met Office Hadley Centre

2012

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Executive Summary

This report summarizes the experimental design of the ensemble regional model simulations which the Met Office Hadley Centre (MOHC) have run to provide high resolution baseline and future climate data for the PARCC project. The model simulations are run from December 1949 to December 2100 using the MOHC regional climate modelling system, PRECIS, with the MOSES2.2 tiled land-surface scheme and the A1B SRES scenario, on the 50km resolution Africa CORDEX (Giorgi et al, 2009) domain. They provide a comprehensive dataset of surface and atmospheric climate variables including minimum and maximum temperatures and precipitation at the daily and monthly timescale and at a spatial resolution of 50km.

The lateral boundary data for the simulations is taken from a sub-set of 5 members sampled from the Hadley centre's QUMP[1] perturbed physics ensemble. The model selection is primarily based on regional analysis of global climate simulations for Africa and its sub-regions with a focus on several regions including West and Central Africa. Members of the QUMP ensemble are selected in order to capture the spread in outcomes produced by the full ensemble, whilst excluding any members that do not represent the African climate realistically. The methodology that the Met Office has used to make these judgements is also provided.

The main points from the regional analysis for West Africa are:

- In general the large scale geographical distribution of the temperature and precipitation of the African climate are captured, however the magnitudes do not always compare well with the observations. We select a sample subject to the requirement that it captures the full range of outcomes produced by the QUMP ensemble and captures the annual variation for as many of the sub-regions as possible.
- For the whole of West Africa, Q0 and Q2 represent the cooler end of the range of projected temperature changes and Q13 and Q14 represent the warmer end of the range to provide the spread in temperature, while Q0 and Q9 capture the spread in projected precipitation changes.
- Therefore, the spread of outcomes produced by the ensemble is captured by: Q0, Q2, Q9 Q13, and Q14.

[1] QUMP stands for `Quantifying Uncertainty in Model Predictions' and refers to the 17-member perturbed-physics ensemble, based on the HadCM3 GCM. Ensemble members are labelled from Q0 to Q16.

1. Introduction

General Circulation Models (GCM) provide a physically-based projection of how climate may change in the future. GCM projections may be adequate up to a few hundred kilometres or so, however they do not capture the local detail often needed for impact assessments at national and regional levels. One widely applicable method for adding this detail to global projections is to use a regional climate model (RCM). RCMs, like GCMs, are physically based and resolve the processes, interactions and feedbacks between the climate system components dynamically, but are run at higher resolution for a limited area, driven by a GCM at its lateral boundaries.

In general RCMs do not model oceans, as this would substantially increase the computing cost yet, in many cases, would make little difference to the projections over land where most impact assessments are conducted. However, dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all described in the RCM, in this case PRECIS (Jones et al. 2004). RCMs are limited area models and therefore need to be driven at their boundaries by time-dependent large scale fields (e.g., wind, temperature, water vapour and surface pressure and sea-surface temperature at model sea grid-boxes); here this information is provided by the GCM, HadCM3 (Gordon et al. 2000; Pope et al. 2000; Collins et al. 2001). More information on the RCM configuration is given in Section 2.

A single model simulation provides one representation of climate but with no indication of uncertainty. Using a range of different model simulations provides a better understanding of how the difference in model formulation can lead to uncertainty in the projections. Two possible ways of producing an ensemble of climate models are currently used; one is to use a multi-model ensemble (MME) where many modeling centres contribute their GCM simulations, for a particular emissions scenario, to generate a range of future climates. Another approach is to perturb physical parameters and produce a range of future climates based only on one climate model; this is called a Perturbed Physics Ensemble (PPE).

The PPE approach enables modeling uncertainties to be sampled systematically by perturbing uncertain parameters (Collins et al, 2006). The Met Office Hadley Centre has run a 17-member perturbed physics ensemble called 'Quantifying Uncertainties in Model Projections' (abbreviated as QUMP) based on the HadCM3 global model (Gordon et al. 2000; Pope et al. 2000; Collins et al. 2001); this was done as part of the UK Climate Projections (UKCP09, Murphy et al, 2009). This project aimed to make a full assessment of the climate uncertainty around adaptation options in the UK.

The individual members of the QUMP ensemble are referred to as HadCM3Q0-16, where HadCM3Q0 is the unperturbed member (the parameters values are the same as those used by the standard HadCM3 GCM) and the perturbed members Q1-16 are numbered according to the value of their global climate sensitivity, thus Q1 has the lowest global average temperature response to a given increase in atmospheric CO_2, and Q16 the highest. From hereon, these models are referred to simply as 'Q0-Q16'.

Downscaling a GCM ensemble of this size with an RCM would be highly resource intensive. We therefore employ a method outlined in McSweeney et al (2012) to sample from the ensemble in order to select a subset which represents a similar range of outcomes as the full ensemble.

The experimental set-up for the regional model simulations is described in section 2, including an account of some adjustments made to ancillary files in order to improve the representation of the African great lakes in the model. The method and subsequent selection of ensemble members for Africa is given in Section **Error! Reference source not found.** and 4 respectively nd the final selection is provided in Section **Error! Reference source not found.**.

2. The Africa Regional Climate Model Simulations

The regional configuration of the Met Office Hadley Centre Climate model, PRECIS (Jones et al. 2004) is run for the period from December 1949 to December 2100 for the whole of Africa using the domain defined by the Coordinated Regional climate Downscaling Experiment (CORDEX) project (Giorgi et al, 2009); this is shown in
Figure 1. The configuration for these simulations has a resolution of 50km, with 19 vertical atmospheric levels and includes MOSES 2.2 (Met Office Surface Exchange Scheme version 2.2), a tiled land surface scheme (Essery et al. 2001) with 4 soil levels. The chosen global QUMP ensemble members using the methodology outlined in Section **Error! Reference source not ound.** provide the boundary conditions for the RCM simulations.

In all of the ensemble members the SRES A1B scenario (Nakićenović et al. 2000) is used to represent future emissions; this scenario contains no mitigation and represents only one of several possible futures considered in the 4th assessment report of the IPCC (Meehl et al, 2007).

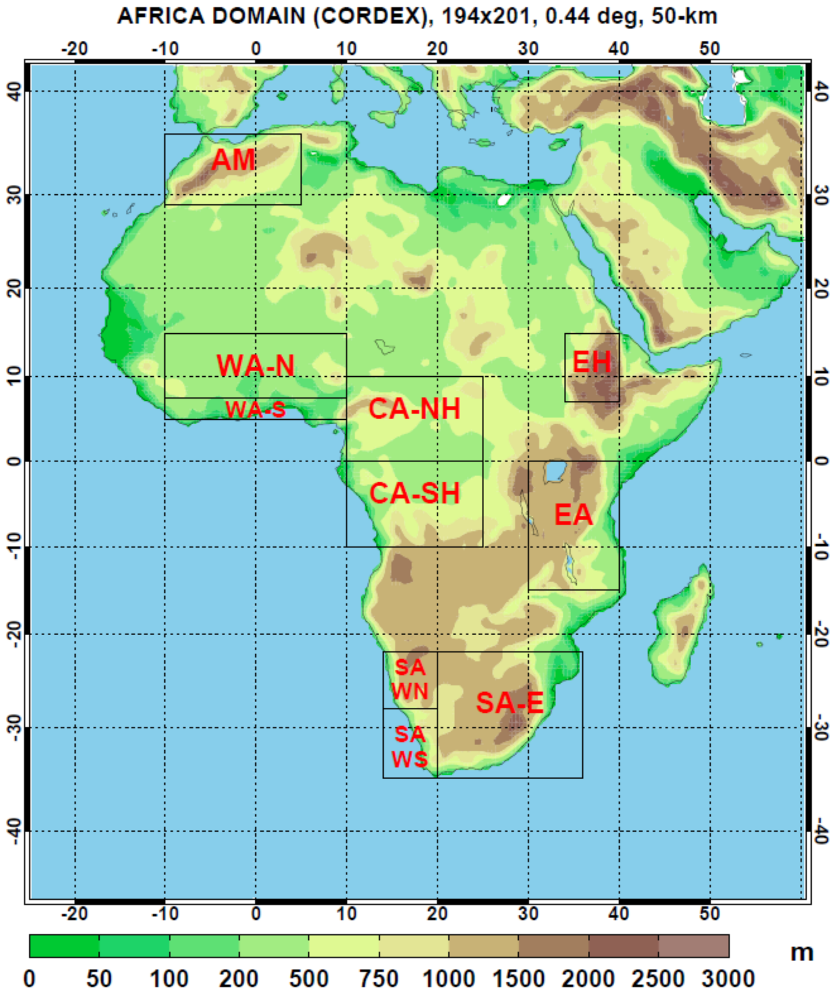

Figure 1. Domain used in the simulations from the CORDEX project.

2.1 *The African Great Lakes*

The African Great Lakes are an important feature of Africa and influence the climate of the region. In the MOSES2.2 configuration of PRECIS there is no specific lake model and therefore the model makes certain assumptions when the lakes are set to be inland water or sea points. A limitation of this particular configuration of the regional model is that lakes are assumed to be at sea level, and lake surface temperatures are interpolated from the nearest sea point. This results in a warm bias in the lake surface temperatures, and subsequently excessive evaporation. In order to alleviate the problem in these simulations, two actions are taken; first the Great Lakes are set to land points in the domain orography which means that they are at the correct height above sea level, but are maintained as water by the land-sea mask. Secondly, the lake surface temperatures are corrected from the values that were interpolated from sea points, using lake surface temperature observations.

The observations used to correct biases in the model sea surface temperatures are those from the ARCLake project (MacCallum and Merchant, 2010, 2011). The lake mean temperatures for three of the Great Lakes in the Africa domain are used to estimate the annual cycle of temperatures for Lake Nyasa (Malawi), Tanganyiki and Victoria. The biases are calculated using the observed lake mean; this is then used to nudge the lake surface temperatures in the model towards the ARCLake mean observations. This process is illustrated in Figure 2; the black curve shows the annual cycle of observations and the orange and yellow curves show the annual cycle of the original ancillaries. Once bias corrected to the observations the model lake-surface temperatures are much closer to the observed ARCLake mean temperatures. A key assumption made here is that the bias correction applied will remain relevant into the future, i.e. that the difference between the true lake mean temperatures (as provided by ARCLake) and the temperatures interpolated from the nearest sea point will remain the same in a future climate. However, given that the bias between the model ancillaries and the lake mean temperatures from ARCLake is large, almost 3°C in some cases, the application of the bias correction is necessary to ensure that the current and near future climate is represented correctly. For the West African domain, only lakes Aby and Ebrie in southern Cote d'Ivoire were available in the ARCLake database.

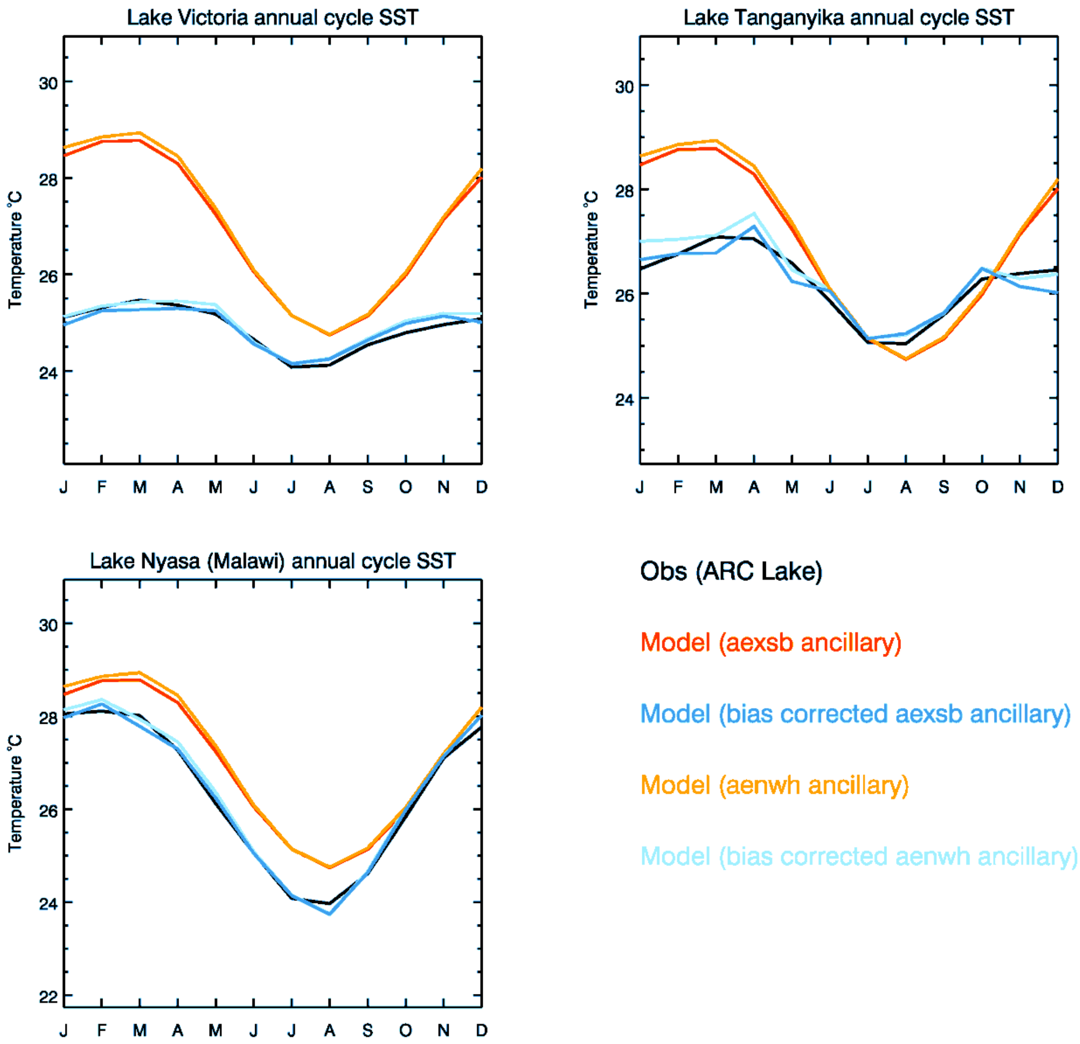

Figure 2. The annual variation of the ARCLake observations (black); the original lake surface temperature ancillaries for two of the model ensemble members (red and yellow); and the lake surface temperature ancillaries after bias corrected to observations (blue and light blue).

3. Selection Procedures

In order to provide a range of plausible climate outcomes while minimising the resource requirement, a sub-set of the17-member QUMP ensemble is selected to downscale from the global scale to obtain region specific information. The aim is to select a sample that characterises the range of climate projections for important regions of Africa including West Africa. In order to select the most appropriate sample the broad range of climatic regimes that occur across Africa must be considered. For this reason, as well as validating the QUMP ensemble projections against temperature and precipitation data for the whole of Africa, we also present results for 2 geographical sub-regions that were chosen to represent the different climatic regimes across Africa. The climatic regions are listed below and shown in Figure 3:

1. All Africa
2. West Sahel
3. Western Tropical Africa

The coordinates that have been used to define the Africa region and the other climatic sub-regions are illustrated in Figure 3 are given in Table 1.

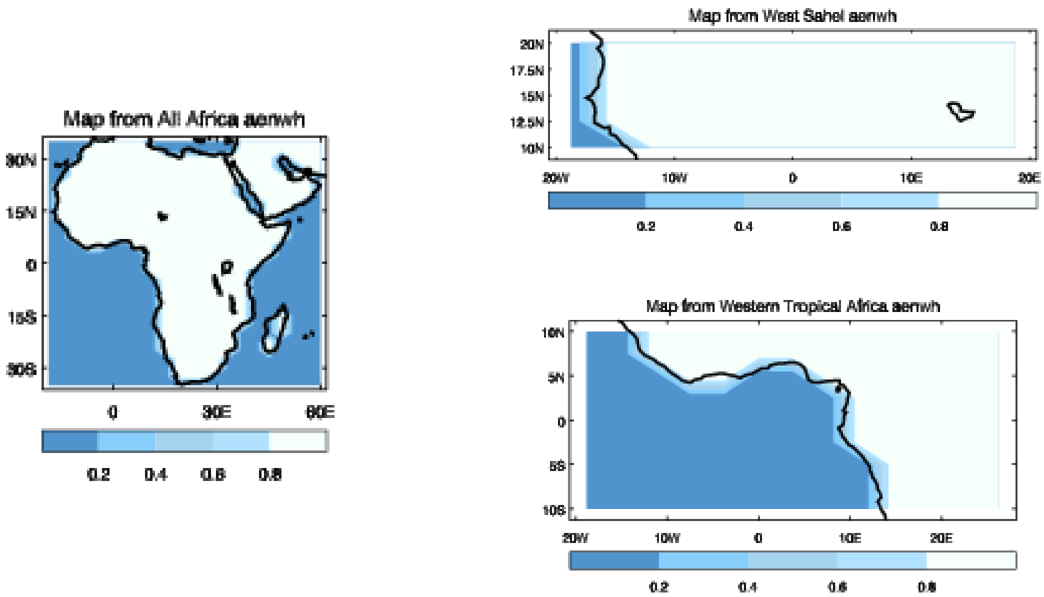

Figure 3 regions selected for validating QUMP ensemble members across different climatic regions of Africa. Moving left to right along each row, the panels show: Africa, Western Tropical Africa and West Sahel.

Region	Western longitude (W)	Eastern longitude (E)	Northern latitude (N)	Southern latitude (S)
Africa	-20°	60°	36°	-35°
West Sahel	-20°	20°	20°	10°
West Tropical Africa	-20°	27.5°	10°	-10°

Table 1. The coordinates of the sub-regions of Africa.

To select a representative sample from the QUMP ensemble appropriate for Africa and West Africa, we adopt the procedure outlined in McSweeney et al. (2012):

1. Eliminate ensemble members that perform poorly in simulating the key features of the current African regional climate.
2. Select, from those remaining, a sub-set that captures the range of responses in temperature and precipitation simulated by the 17 QUMP ensemble members.

3.1 Validation of the African climate simulations

To validate the performance of the models, we compare the observed and simulated annual cycles of temperature and precipitation and the geographical patterns of precipitation and 850hpa winds (both speed and direction) in the simulations to those in observed datasets. The observed datasets used are detailed in Table 2.

Dataset	Variables used	Resolution	Source	Reference
CRU 3.0	1.5m Temperature	0.5° monthly, 1900-2006 land only	Gridded station data	Mitchell and Jones 2005
ERA40	850hPa Winds	2.5° monthly 1979-1993	Reanalysis	Uppala et al, 2005
CMAP	Precipitation	2.5° monthly 1979-2002	Gridded station data merged with satellite data	Xie and Arkin, 1997

Table 2. Observational datasets used for validation of regional model simulations for Africa.

The annual cycles for each of the sub-regions are shown in Figure 4. The annual cycle of temperature for the whole of Africa suggests that the models capture the seasonal cycle of temperature realistically, although the majority of members slightly over-estimate temperatures between May and September (Figure 4, top left), and there is a wide spread of results in both of the sub-regions.

Most of the models also capture the different seasonal temperature cycles in the sub-regions similarly. Model Q16 tends to be consistently the warmest model, and lies apart from the other models, and Q4 the coolest. The temperatures for the West Sahel, Figure 4 (middle left) are generally under-estimated by most of the models for the period between April and June.

In general the ensemble members capture the annual cycle of rainfall for the regions of Africa shown here (in Figure 4, right column), however there are differences in spread between ensemble members for different regions and in how close the simulations are to observations. The models capture the main rainy season in the West Sahel region in JAS, although the rainy season begins too early in most of the models, and the range of magnitudes of wet-season rainfall is large. Rainfall in the western Tropical region (Figure 4, bottom right) arrives in the correct seasons, but is systematically too large, to a varying degree depending on the particular model.

However, there are two aspects to the analysis of precipitation that should be noted; firstly modelling the climate of Africa is a challenge in itself, this is highlighted in the IPCC 4^{th} assessment, which shows the systematic errors that occur in and around Africa in many of the GCMs included in the assessment. In 90 percent of IPCC 4^{th} assessment models there is excessive rainfall (by on average 20 percent) for southern Africa and the Inter-Tropical Convergence zone is displaced towards to equator. In fact several of the IPCC GCMs have no representation of the West African Monsoon at all (Meehl et al, 2007). So it is not surprising that there is some difference in the HadCM3 model ensemble studied here compared with observations and therefore in this context, this model does reasonably well. Secondly the amounts of precipitation that occur in Sahelian West Africa are very small therefore errors in the simulations could appear more significant than they actually are. In this case it is helpful to refer also to the geographical patterns of precipitation and compare these with observations to establish if the ensemble members capture the observed synoptic picture.

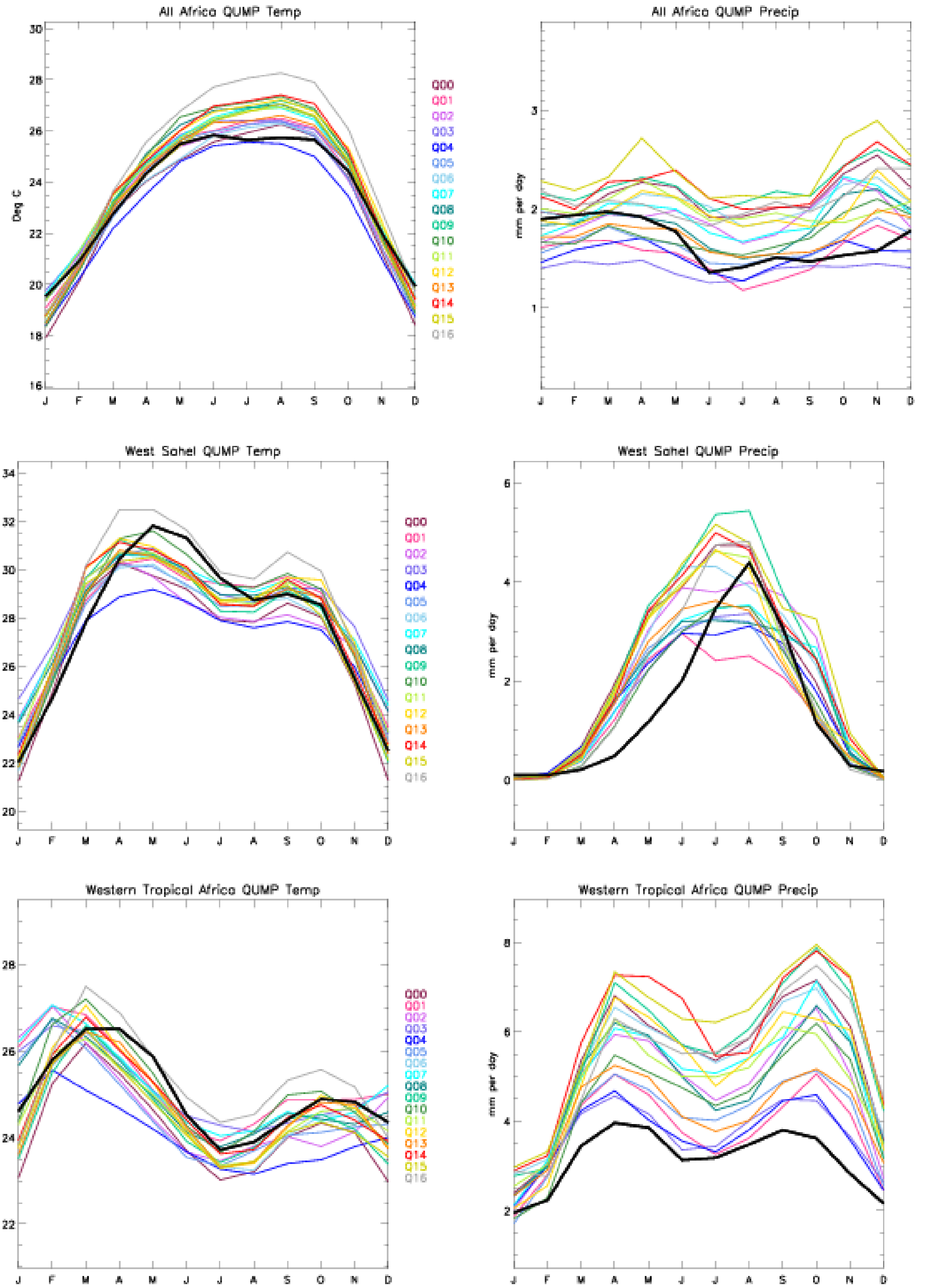

Figure 4. The annual variation of temperature (left) and precipitation (right) for Africa, West Sahel and Western Tropical Africa. The black line shows the observed values while the coloured lines show the model outcomes.

Figure 5 and Figure 6 show the precipitation for Africa for the seasons June, July, August and September (JJAS) and December, January, February (DJF) respectively. The large scale patterns are generally captured by all the ensemble members, however many over-estimate the magnitude of the precipitation over central southern Africa particularly during DJF. In Figure 6 the lower sensitivity models (Q1-Q5) tend to match the magnitude of the observed DJF precipitation climatology more closely than the higher sensitivity models (Q15 and Q16). The timings, and geographical location of wet periods and regions, however, are realistic.

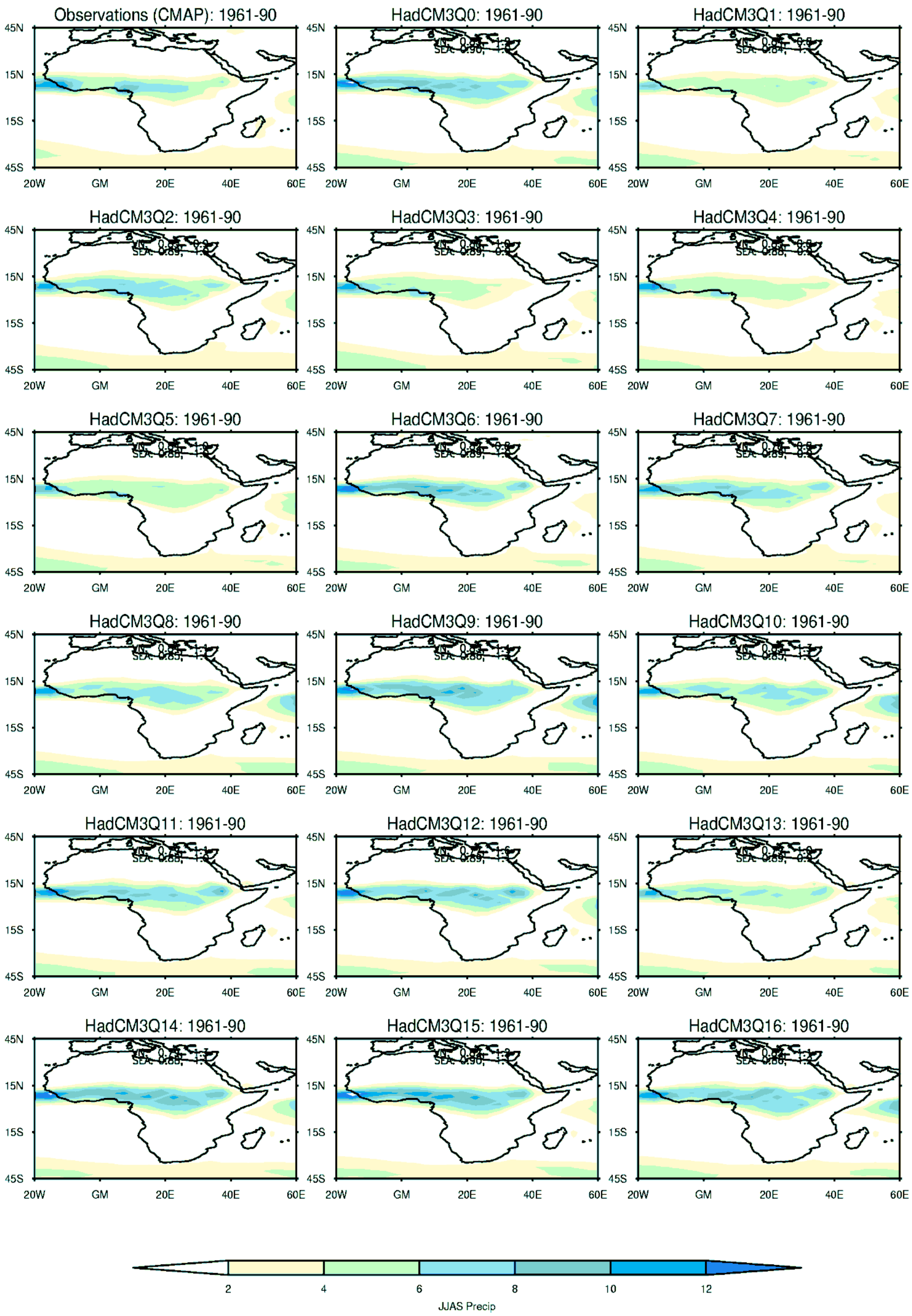

Figure 5. Comparison of observed and simulated precipitation for Africa during JJAS. The observations were taken during the period 1979-1998 and the simulation data during the period 1961-1990.

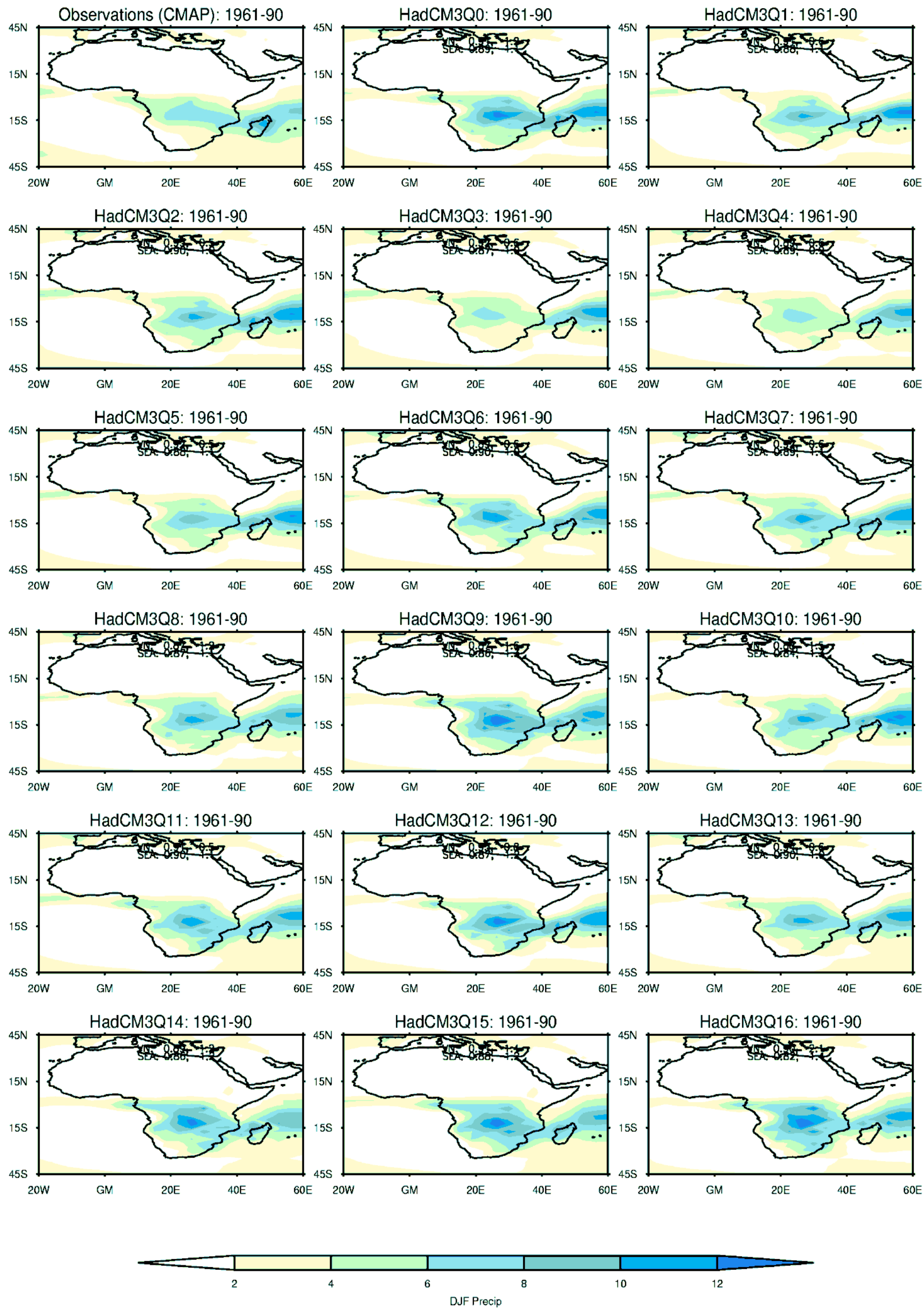

Figure 6. Comparison of observed and simulated precipitation for Africa during DJF. The observations were taken during the period 1979-1998 and the simulation data during the period 1961-1990.

Figure 7 and Figure 8 compare the simulated 850hPa winds during JJAS and DJF months respectively with ERA40 (Uppala et al 2005). As with the precipitation maps (Figure 5 and Figure 6), the models generally reproduce prevailing circulation patterns, including the direction of the trade winds (both north-east and south-east). During JJAS the region of higher wind-speeds over the Horn of Africa (referred to as the 'Somali Jet') are also captured. However there is some variation between the ensemble members in the magnitude of the Somali Jet, with Q2, Q3, Q6 and Q7 matching the observations more closely than the other ensemble members. The direction of the DJF trade winds are also captured in most of the ensemble members e.g. Q8, Q9, Q11 and Q13; however the magnitude of the winds over the Sahel and southern Africa are slightly over-estimated in most of the ensemble members. Of all the ensemble members Q3 is the closest match to the observed climatology for the magnitude of DJF wind-speed.

The surface temperature and sea surface temperature patterns (not shown here) in general compare well with the CRU observations and HadISST datasets respectively. However some of the ensemble members, particularly the higher sensitivity ones (Q9- Q16) do overestimate the temperatures in regions where temperatures are high. The mean sea level pressure patterns (also not shown) for the ensemble members also compare well with observations.

Our validation of the 17 models shows that while all the models capture the broad seasonal and geographical pattern in key climate features, the range in magnitudes of features such as seasonal rainfalls, and the realism of those magnitudes, varies from across the models. However, it is not straightforward to identify a subset of models that perform better or worse across the whole region – models that do least well in some regions tend to be the most realistic in another.

Our approach, therefore, is to select the sub-set based mainly on representing the spread of future climate outcomes across the regions. When making this decision, however, we take into account the shortcomings of some of the models. For example, where two models project similar characteristics of change in the future, we can use the validation information to choose to include the better performing model.

On the basis of the analysis shown Q1, Q3, Q4, and Q16 are not considered further in this analysis because the seasonal cycle of both precipitation and temperature do not compare as well with observations as other ensembles in the largest number of regions. In the following analysis we consider the spread of models with respect to temperature and precipitation changes to make the final selection of ensemble members (see Section 0).

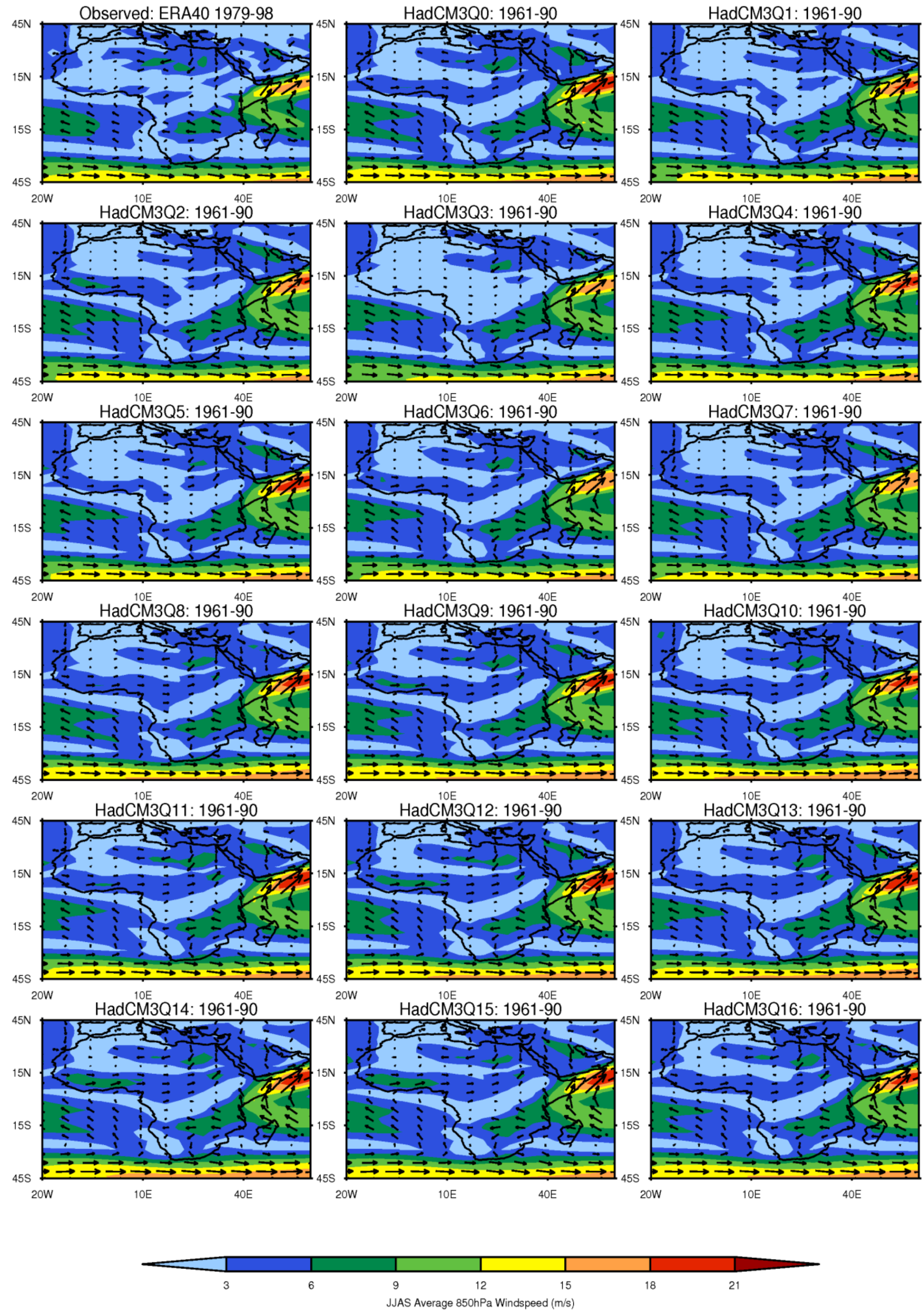

Figure 7. Comparison of observed and simulated 850 hPa winds for Africa duringJJAS. The observations were taken during 1978-1998, and the simulated outcomes during the period 1961-1990.

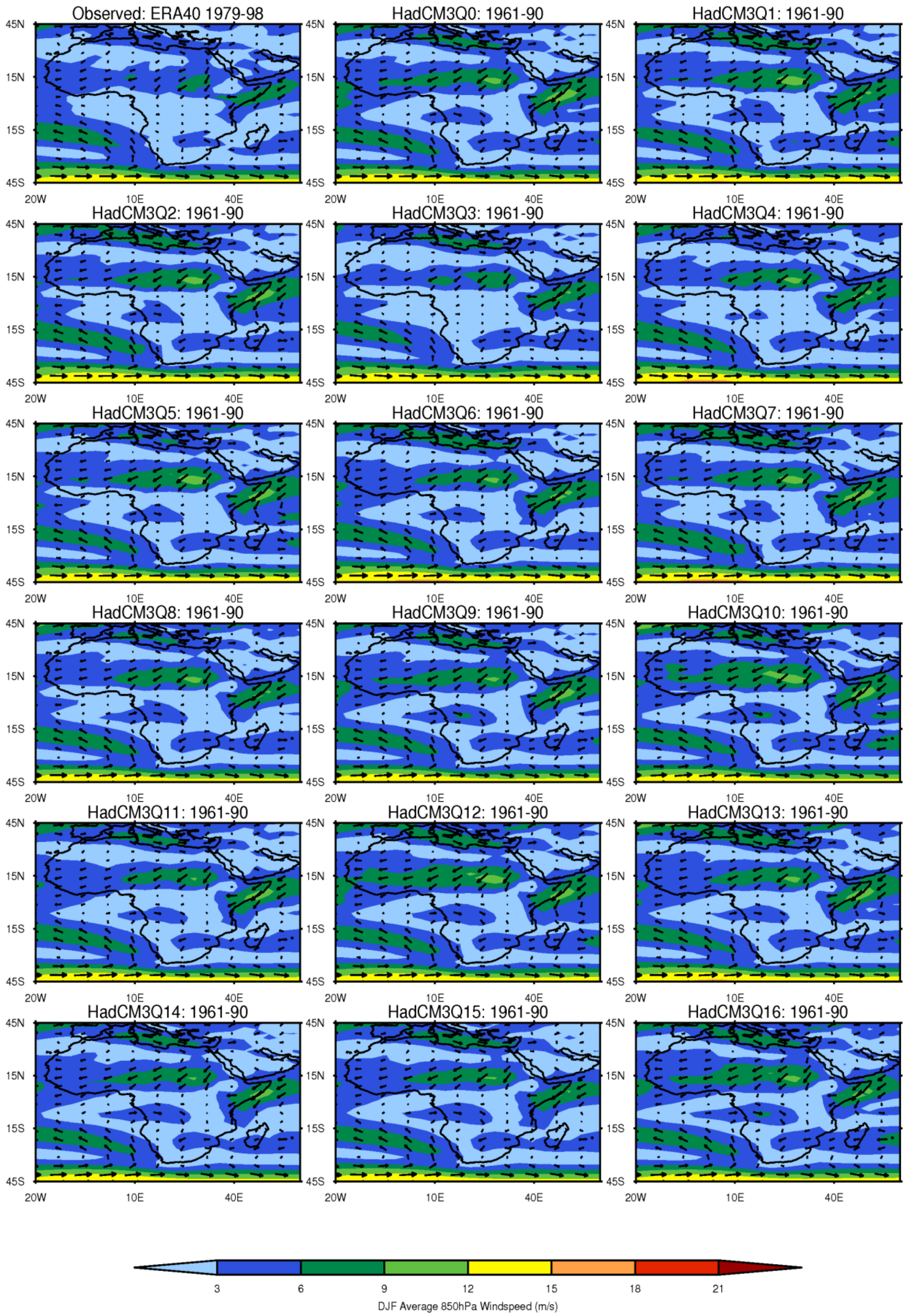

Figure 8. Comparison of observed and simulated 850 hPa winds for Africa during DJF. The observations were taken during 1978-1998, and the simulated outcomes during the period 1961-1990.

3.2 Selection for Africa

The final selection of ensemble members for Africa involves identifying the models that represent the range of the full ensemble in their change in precipitation (ΔP) and temperature (ΔT) for Africa and the key climatic sub-regions (see Table 1).

This analysis takes the form of scatter plots that are shown for each region and season in Figure 9. There is no particular model that consistently shows the largest change in precipitation for all regions throughout the year. For example, in Western Tropical Africa in DJF (Figure 9, top) the largest change in precipitation is seen in Q9, but this model is not always the wettest model for the other seasons for this region. Also, Q14 is one of the driest models for some sub-regions, as shown in some seasons (MAM, JJA, SON) in the West Sahel (Figure 9, middle column). On this basis the extremes of the ensemble distribution are classified in terms of which models consistently have the largest positive or negative change in precipitation across all the sub-regions and seasons. Therefore using this scoring system Q9 represents one of the wettest and Q0 represents one of the driest models in the range of the ensemble (but this does not mean these are the wettest and driest models in all sub-regions and all seasons).

Although the models are numbered 1-16 according to their global temperature response, regional responses will vary. Temperature response is more consistent across the regions and the seasons than the precipitation response, with the higher response models tending to capture the warmer end of the range (Q13, Q14, and Q16 tend to have the largest temperature response across the regions and seasons) while the lower-response models, tend to indicate smaller temperature responses (Q0, Q1, Q2, Q3 tend to be coolest). Therefore on the basis that, of the lower response models, Q1 and Q3 do not validate as well as Q0 and Q2 compared with observations; thus Q0 and Q2 are selected to represent the colder end of the range. At the hotter end of the range, Q16 has already been discounted on the basis of validation results, thus Q13 and Q14 are selected to represent this part of the range of the ensemble.

On the basis of this analysis we conclude that a sample which reproduces important characteristics of current the African and West Africa climates *and* represents the spread in projected outcomes produced by the QUMP ensemble consists of the following models: Q0, Q2, Q9, Q13 and Q14.

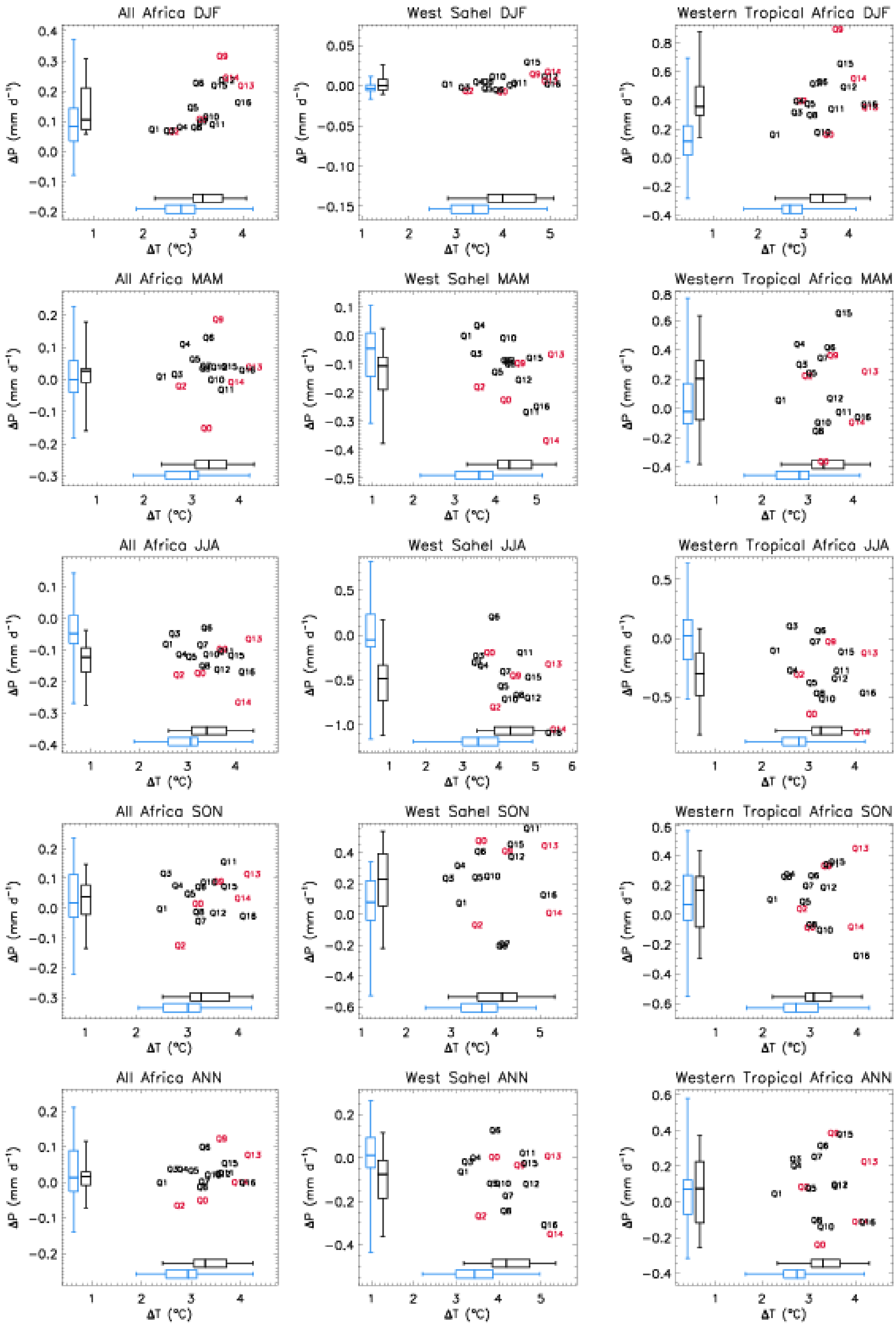

Figure 9. Plots for the QUMP ensemble showing projected change in precipitation versus change in the temperature for all Africa, West Sahel and Western Tropical Africa. The panels show the spread in projected outcomes during DJF, MAM, JJA, SON and annual (ANN). The data point labels (Q#) identify the models and the red data points indicate the selected sample.

4. Summary

This report summarizes the experimental design that underlies the ensemble regional model simulations for the West African PARCC project. The model simulations are run from December 1949 to December 2100 using the regional climate modelling system, PRECIS, with the MOSES2.2 tiled land-surface scheme and the A1B SRES scenario, on the 50km resolution Africa CORDEX domain. This domain includes representation of the African Great Lakes; however the configuration of PRECIS does not contain a lake model instead prescribing the lake surface temperatures as a lower boundary condition. In these simulations the lake surface temperatures are derived by interpolating SSTs from adjacent sea grid-boxes which are then bias-corrected using lake surface observations from the ARCLake project.

The lateral boundary data for the simulations is taken from a sub-set of 5 members sampled from the Hadley centre's QUMP perturbed physics ensemble. The model selection is primarily based on regional analysis of global climate simulations for Africa. Members of the QUMP ensemble are selected in order to capture the spread in outcomes produced by the full ensemble, whilst excluding any members that do not represent the African climate realistically.

The main points from the regional analysis are:

- The large scale geographical distribution of the temperature and precipitation of the African climate are captured, however the magnitudes do not always compare well with the observations. We select a sample subject to the requirement that it captures the full range of outcomes produced by the QUMP ensemble and captures the annual variation for as many of the sub-regions as possible.
- For both Africa as a whole and West Africa, Q0 and Q2 represent the cooler end of the range of future projections and Q13 and Q14 represent the warmer end of the range to provide the spread in temperature.
- There is no particular model that consistently shows the largest change in precipitation for all regions throughout the year. Q14 represents the wetter end of the range in future projections for Western Tropical Africa during December, January and February (DJF) but not during June, July, August (JJA) and annually in West Sahel it is actually the driest model. Overall, the analysis suggests that across all regions, seasons and annually, Q0 captures the drier end of the range of future projections and Q9 captures the wetter end of the range in future projections.

  Therefore, the subset of ensemble members selected is: Q0, Q2, Q9, Q13 and Q14.

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