Working Paper

Selection of climate model simulations for the DECCMA project

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About DECCMA Working Papers

This series is based on the work of the Deltas, Vulnerability and Climate Change: Migration and Adaptation (DECCMA) project, funded by Canada’s International Development Research Centre (IDRC) and the UK’s Department for International Development (DFID) through the **Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA)**. CARIAA aims to build the resilience of vulnerable populations and their livelihoods in three climate change hot spots in Africa and Asia. The program supports collaborative research to inform adaptation policy and practice.

Titles in this series are intended to share initial findings and lessons from research studies commissioned by the program. Papers are intended to foster exchange and dialogue within science and policy circles concerned with climate change adaptation in vulnerability hotspots. As an interim output of the DECCMA project, they have not undergone an external review process. Opinions stated are those of the author(s) and do not necessarily reflect the policies or opinions of IDRC, DFID, or partners. Feedback is welcomed as a means to strengthen these works: some may later be revised for peer-reviewed publication.

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1. Introduction

This report describes the selection of climate model simulations for use in the DECCMA project. Data from the simulations selected are being used as input to modelling activities assessing the impact of climate change on the Ganges-Brahmaputra-Meghna (GBM), Mahanadi and Volta deltas.

The global and regional future climate projections in the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC, 2013) were produced from a set of Global Climate Model (GCM) simulations contributed to the Coupled Model Intercomparison Project phase 5 (CMIP5) (Taylor et al., 2012). While suitable as a basis for an overall narrative for future regional climate changes, these coarse-resolution simulations, on their own, do not provide a basis for the detailed assessments of the impacts of climate change using impact models (e.g. hydrological and agricultural models) required in the DECCMA project. The GCM output, which typically has grid cells hundreds of kilometres across, must first be downscaled to finer resolutions to provide input to impact models. The DECCMA project has chosen to downscale the CMIP5 GCM output dynamically using Regional Climate Model (RCM) simulations. These are capable of representing fine-scale atmospheric processes and physiographic effects influencing regional weather and climate, which are not well-represented in GCMs. They provide internally consistent datasets of numerous impact-relevant climate variables at a finer resolution than GCMs.

The CMIP5 GCMs provide simulations of the future climate forced with different scenarios for “radiative forcing”, the energy imbalance of the climate system due changing greenhouse gas and aerosol concentrations in the atmosphere. These scenarios are known as Representative Concentration Pathways (RCPs) (Moss et al., 2010; van Vuuren et al., 2014). The CMIP5 dataset includes simulations of four different RCPs, as shown in Table 1) and over 40 GCMs (although simulations are not available for every RCP-GCM combination) and is considered to provide reasonable sampling of uncertainties in future climate conditions on large spatial scales. However, since running RCM simulations is computationally expensive, it is not possible to downscale all of the CMIP5 simulations. Even if it was, it would not be possible for the impact modelling component of the DECCMA project to use data from so many simulations.

RCP	Description of greenhouse gas emissions and radiative forcing trajectories during the 21st century	Radiative forcing and approximate atmospheric greenhouse gas concentration in 2100
RCP8.5	Rising: *High emission scenario; a fast and high increase in emission up to around 2070, followed by a slow growth in emissions later in the century; rising and high radiative forcing throughout the century*	8.5 W/m^2 (~1370 ppm CO_2 equivalent)
RCP6.0	Stabilisation without overshoot: *Emissions remain at current levels until 2030, then peak around 2080 before a sharp delayed reduction; radiative forcing stays below RCP4.5 up to 2060, followed by significant increase through the remaining part of the century*	6.0 W/m^2 (~850 ppm CO_2 equivalent)
RCP4.5	Stabilisation without overshoot: *Moderate emission growth up to 2040 followed by gradual reduction before levelling around 2080; radiative forcing stabilises around 2060*	4.5 W/m^2 (650 ppm CO_2 equivalent),
RCP2.6	Peak and decline: *Lowest overall emissions and forcing; strict emission abatement starts around 2020; peak in radiative forcing at 3 W/m^2 before mid-century; effective emissions are reduced to zero around 2080*	2.6 W/m^2 (~490 ppm CO_2 equivalent)

Table 1: Characteristics of the four RCPs used in CMIP5 (adapted from van Vuuren et al., 2014). Greenhouse gas concentrations are given in terms of concentration, in parts per million (ppm), of carbon dioxide (CO_2) that would have the same global warming potential.

The DECCMA project has two regional domains of interest:

1) South Asia (covering the GBM and Mahanadi deltas)
2) West Africa (covering the Volta delta)

Initial estimates suggested that the resources devoted to the climate and impact modelling components of the project would be sufficient for five RCM simulations covering each domain to be considered. However, after further consideration of the complexities of the impact modelling and the need for Met Office resources to be devoted to the distribution and provision of advice on RCM usage, it was suggested that the project consider three RCM simulations per domain. To reduce the number of RCM simulations to three, the following selections have been made.

1) Selection of RCPs to consider
2) Selection of RCMs to be used for downscaling
3) Selection of GCMs to downscale

Early in the DECCMA project, it was decided to focus only on climate model simulations of the RCP8.5 scenario (Nicholls et al., 2017). This report describes the selection process for the climate models, both RCMs and GCMs, for the two DECCMA domains.

2. Selection for South Asia

For South Asia, covering the GBM and Mahanadi deltas, simulations of the HadGEM2-ES, CNRM-CM5 and GFDL-CM3 GCMs have been downscaled to 25km with the HadRM3P RCM.

Although different RCMs will simulate different climate conditions for the same GCM forcing data, it was anticipated that greater uncertainty in future climate conditions would be contributed by differences between GCMs. Hence a single RCM was selected to generate a consistent set of simulations sampling across as much of the uncertainty range of the CMIP5 GCM ensemble as could be spanned with three GCMs.

A large ensemble of pre-existing RCM simulations downscaling CMIP5 GCMs over South Asia was not available to the DECCMA project. It was therefore necessary for the project to run its own RCM simulations. The Met Office has the capability to run a number of different RCMs. Of these, the HadRM3P RCM was selected as it has proved to be a reliable tool for downscaled GCM simulations to a resolution of 25km in previous projects, including those concerning South Asia (e.g. Bhaskaran et al., 2012; Caesar et al., 2015; Manasa and Shivapur, 2016).

For South Asia, the domain used for the downscaling experiments within DECCMA, shown in Figure 1, is the same domain used in previous Met Office downscaling experiments in the region (Bhaskaran et al., 2012). A considerable amount of research has been done to assess the appropriate domain choice for capturing monsoon dynamics over India. In addition, the choice of this domain will allow the information produced within the DECCMA project to be applicable to a number of current and future research and collaboration opportunities in the region.

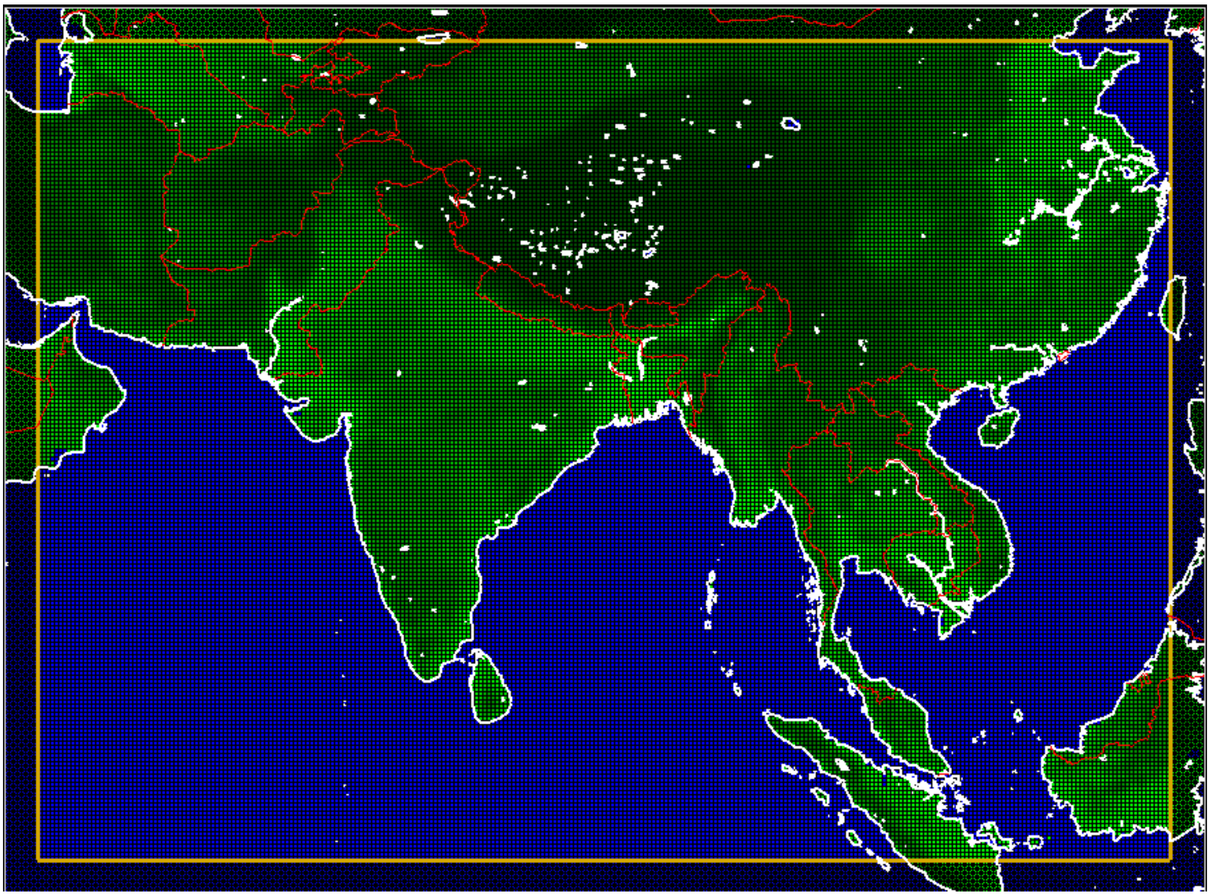

Figure 1: Downscaling domain for South Asia.

Due to the short timescales of the DECCMA project, along with the developing capability at the Met Office to downscale all CMIP5 driving models, the selection of CMIP5 GCMs for downscaling was limited to the 10 models downscaled for a recent collaborative project with the Met Service Singapore (Marzin et al., 2015). These 10 models included HadGEM2-ES, ACCESS1-0, bcc-csm-1-1-m, CanESM2, CMCC-CM, CNRM-CM5, CSIRO-Mk3-6-0, GFDL-CM3, GFDL-ESM2G, and IPSL-CM5A-LR.

To select GCMs to downscale from these 10 CMIP5 GCMs, we followed McSweeney et al. (2015). They selected GCMs for downscaling based on two criteria:

1. All selected GCMs should have a satisfactory simulation of relevant aspects of the recent climate of the region of interest.

2. Future climate changes in the region of interest simulated by the ensemble of selected GCMs should span the range of future climate changes spanned by the full ensemble of satisfactory GCMs.

In addressing the first criterion, a number of models were immediately eliminated from the selection due to either a) a lack of robust monsoon dynamics as described in McSweeney et al. (2015), or b) incorrect climate characteristics or responses identified in the project with the Met Service Singapore. No additional GCM assessment specific to the South Asia region was performed due to limitations on resources and it was assumed that the assessments performed by McSweeney et al. (2015) and the Met Service Singapore project were applicable to the region.

To address the second criterion, we examined climate changes between the 1961-1990 time period and the 2080s in the RCP8.5 simulations of the different CMIP5 GCMs. Changes in annual and seasonal mean temperature and precipitation averaged over a region covering the Mahanadi and GBM basins (15-30˚N, 80-95˚E) were examined. Inspection of Figures 2 and 3 was used to select GCMs that spanned as much as possible of the range of future climate changes simulated by the full CMIP5 ensemble, for both the annual timescale (Figure 2) as well as for the June, July, August season, which includes most of the monsoon season (Figure 3). The three GCMs chosen for downscaling within the DECCMA project were:

1) HadGEM2-ES
2) CNRM-CM5
3) GFDL-CM3

Seasons outside of the monsoon season may be of interest to those assessing climate change impacts and are important to the regional climate dynamics of the region. Note, however, that it was not possible to sample the full range of changes in annual and seasonal mean temperature and precipitation with just these three GCMs selected from those that it was possible to downscale. Most obviously, the selected GCMs did not span much of the uncertainty in CMIP5-simulated future changes in seasonal mean precipitation for the March, April, May season (Figure 3). In this season, all three selected GCMs simulate future increases in seasonal mean precipitation of 0.5mm/day or less. However, some CMIP5 GCMs simulate future decreases in seasonal mean precipitation for this season and some simulate increases of greater than 0.5mm/day. In this case, the GCMs simulating the most extreme future climate changes were not among the 10 that could be downscaled following the project with the Met Service Singapore.

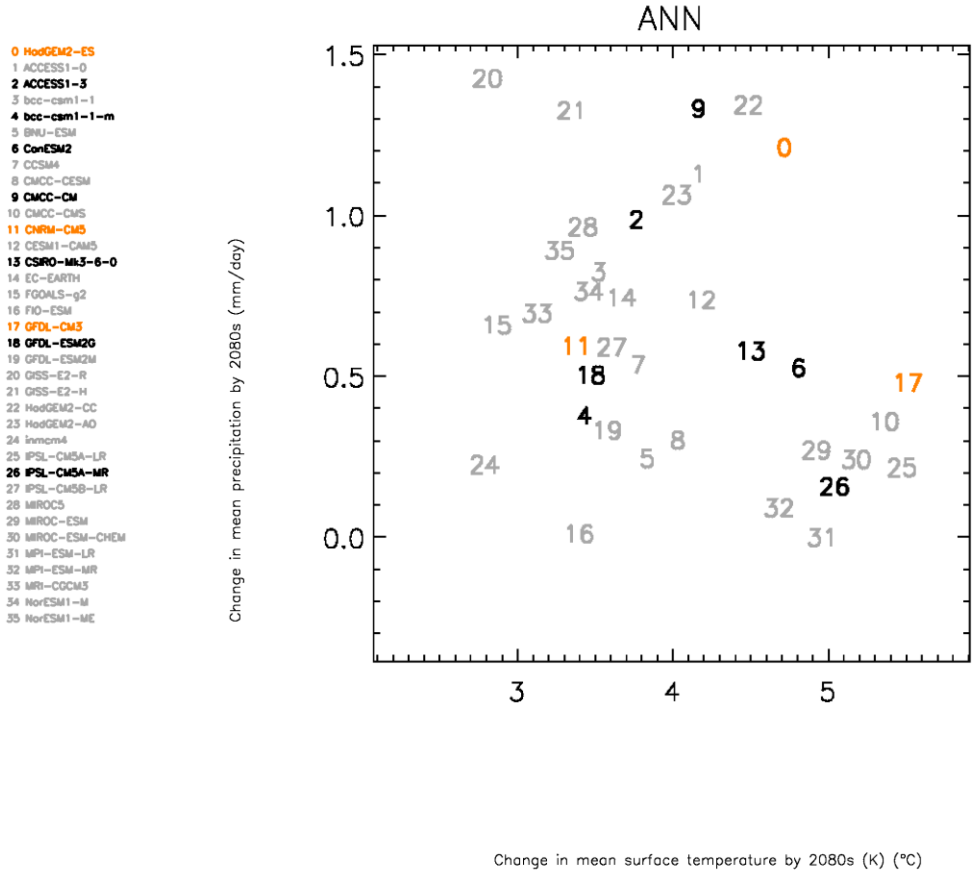

Figure 2: CMIP5-simulated future climate changes for RCP8.5 for a region covering the Mahanadi and GBM basins (15-30˚N, 80-95˚E). Changes in annual mean temperature and precipitation between 1961-1990 and the 2080s are shown. Grey numbers represent GCMs that could not be downscaled due to a lack of output suitable for input to an RCM. Orange numbers indicate the three GCMs that were selected for downscaling in the DECCMA project.

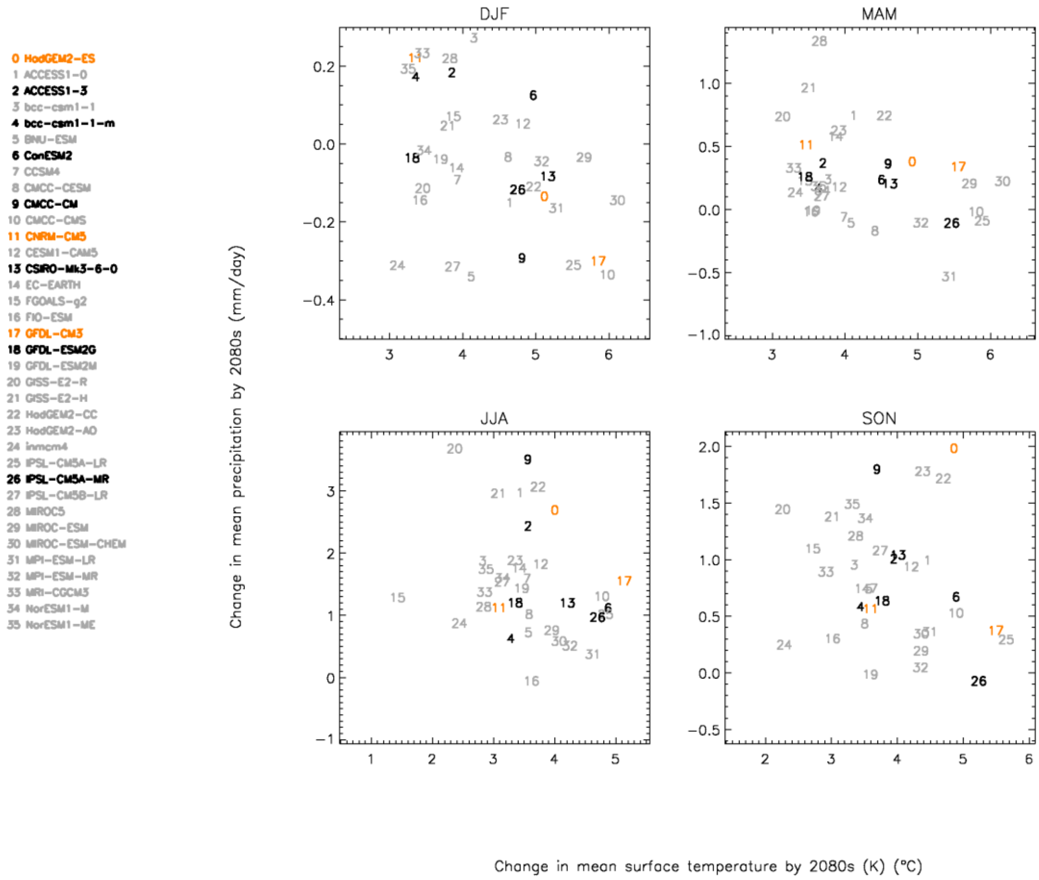

Figure 3: As Figure 2, but for changes in seasonal means (DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November).

3. Selection for West Africa

For West Africa, covering the Volta delta, the DECCMA project is using RCP8.5 simulations of the HadGEM2-ES, CNRM-CM5 and CanESM2 GCMs downscaled to 50km with the RCA4 RCM as part of the CORDEX project.

For the Volta region in West Africa, the DECCMA project has not performed any new dynamical downscaling experiments, and instead is using results from the ongoing CORDEX-Africa collaboration, which collates RCM experiments over Africa from a number of climate modelling centres around the world.

SMHI-RCA4 CORDEX simulations (SMHI, Rossby Centre)

AFRICA (AFR-44)							
ID	Rean/GCMs	Exp.	Res.	Period	Status/Progress	netcdf	Comments
201106	ERA-INTERIM	eval	0.44	1979-2010	done	done	
201107	CanESM2	hist	0.44°	1950-2005	done	done	
201108	CanESM2	rcp45	0.44°	2006-2100	done	done	
201109	CanESM2	rcp85	0.44°	2006-2100	done	done	
201110	CNRM-CM5	hist	0.44°	1950-2005	done	done	
201111	CNRM-CM5	rcp45	0.44°	2006-2100	done	done	
201112	CNRM-CM5	rcp85	0.44°	2006-2100	done	done	
201113	HadGEM2-ES	hist	0.44°	1950-2005	done	done	
201114	HadGEM2-ES	rcp45	0.44°	2006-2099	done	done	
201115	HadGEM2-ES	rcp85	0.44°	2006-2099	done	done	
201423	HadGEM2-ES	rcp26	0.44°	2006-2099	done	done	
201124	NorESM1-M	hist	0.44°	1950-2005	done	done	
201126	NorESM1-M	rcp45	0.44°	2006-2100	done	done	
201125	NorESM1-M	rcp85	0.44°	2006-2100	done	done	
201527	NorESM1-M	rcp26	0.44°	2006-2100	done		
201140	EC-Earth	hist	0.44°	1950-2005	done (**LBCs**)	done	
201141	EC-Earth	rcp45	0.44°	2006-2100	done (**LBCs**)	done	
201142	EC-Earth	rcp85	0.44°	2006-2100	done (**LBCs**)	done	
201148	EC-Earth	rcp26	0.44°	2006-2100	done	done	
201202	MIROC5	hist	0.44°	1950-2005	done (**LBCs**)	done	
201203	MIROC5	rcp45	0.44°	2006-2100	done (**LBCs**)	done	
201204	MIROC5	rcp85	0.44°	2006-2100	done (**LBCs**)	done	
201526	MIROC5	rcp26	0.44°	2006-2100	done		
201235	GFDL-ESM2M	hist	0.44°	1950-2005	done	done	
201239	GFDL-ESM2M	rcp45	0.44°	2006-2100	done	done	
201240	GFDL-ESM2M	rcp85	0.44°	2006-2100	done	done	
201236	MPI-ESM-LR	hist	0.44°	1950-2005	done	done	
201237	MPI-ESM-LR	rcp45	0.44°	2006-2100	done	done	
201238	MPI-ESM-LR	rcp85	0.44°	2006-2100	done	done	
201407	MPI-ESM-LR	rcp26	0.44°	2006-2100	done	done	
201404	IPSL-CM5A-MR	hist	0.44°	1950-2005	done	done	
201405	IPSL-CM5A-MR	rcp45	0.44°	2006-2100	done	done	
201406	IPSL-CM5A-MR	rcp85	0.44°	2006-2100	done	done	
201420	CSIRO-Mk3-6-0	hist	0.44°	1950-2005	done	done	
201421	CSIRO-Mk3-6-0	rcp45	0.44°	2006-2100	done	done	
201422	CSIRO-Mk3-6-0	rcp85	0.44°	2006-2100	done	done	

Table 2: SMHI RCA4 simulations for CORDEX-Africa

In order to replicate the methodology for the South Asia region (i.e. different GCMs being downscaled by the same RCM), it was necessary to choose experiments from the available CORDEX inventory that had all been downscaled by the same RCM. This limited the selection of available RCM experiments. Of the RCMs used to create the CORDEX-Africa ensemble, RCA4 (run by SMHI – see Table 2 for more info on the simulations performed by SMHI) provided the greatest choice of GCMs.

In theory, it would have been possible to examine the output of the RCM simulations listed in Table 2 and select three simulations based on their performance and range of simulated future climate changes. However, resources were not available to perform such an assessment and a more time-efficient model selection was done based on GCM output. A GCM-based model selection process similar to that used for South Asia was used for West Africa. The assumption was made that the RCM simulations are well constrained by their driving GCMs and so analysis of the RCM output on large spatial scales would return similar results to analysis of the driving GCM simulations.

As for South Asia, guidance from McSweeney et al. (2015) was followed to eliminate certain GCMs that performed 'poorly'. In this case, GCMs with an inferior simulation of the West African monsoon and associated teleconnections were eliminated. Further details of this assessment are described by McSweeney et al. (2015). As for South Asia, we examined climate changes between 1961-1900 and the 2080s in the RCP8.5 simulations of the different CMIP5 GCMs. Changes in annual and seasonal mean temperature and precipitation averaged over the Volta region (1-12˚N, 17˚W-12˚E), shown in Figures 4 and 5, were examined. Inspection of Figures 4 and 5 was used to select GCMs that spanned as much as possible of the range of future climate changes simulated by the full CMIP5 ensemble, for both the annual timescale (Figure 4) as well as for four seasons (Figure 5). The three GCMs chosen for downscaling within the DECCMA project were:

1) HadGEM2-ES
2) CNRM-CM5
3) CanESM2

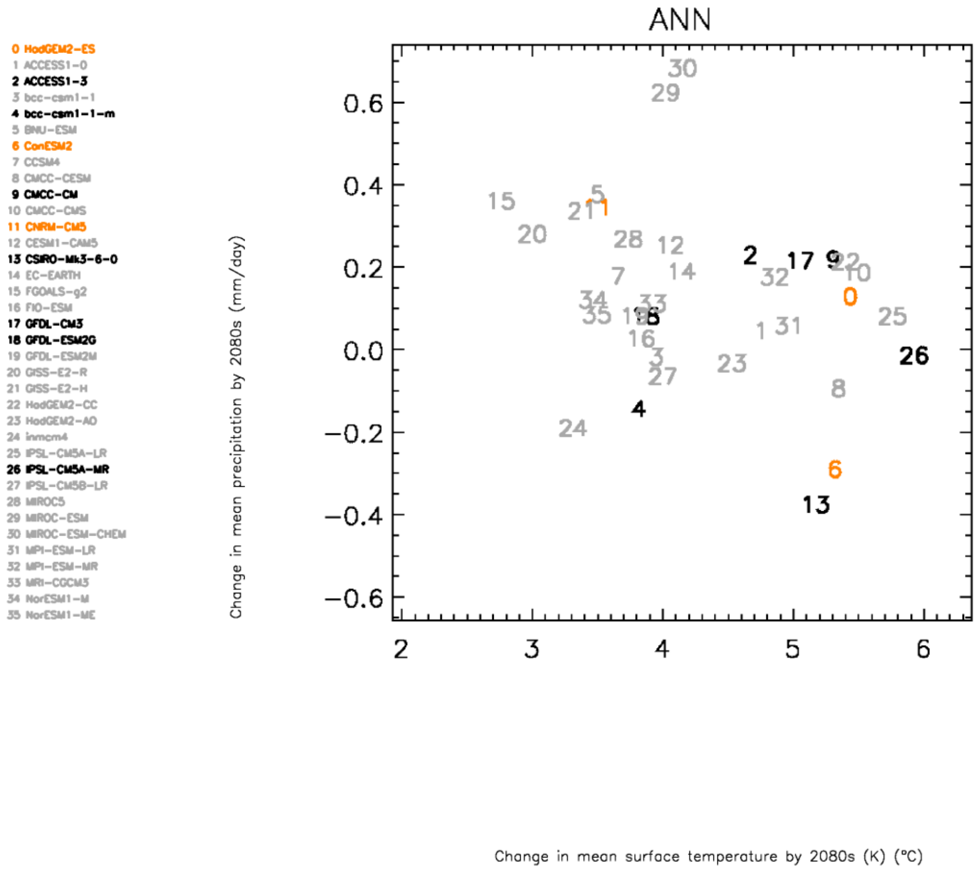

Figure 4: As Figure 2, but for the Volta region (1-12˚N, 17˚W-12˚E)

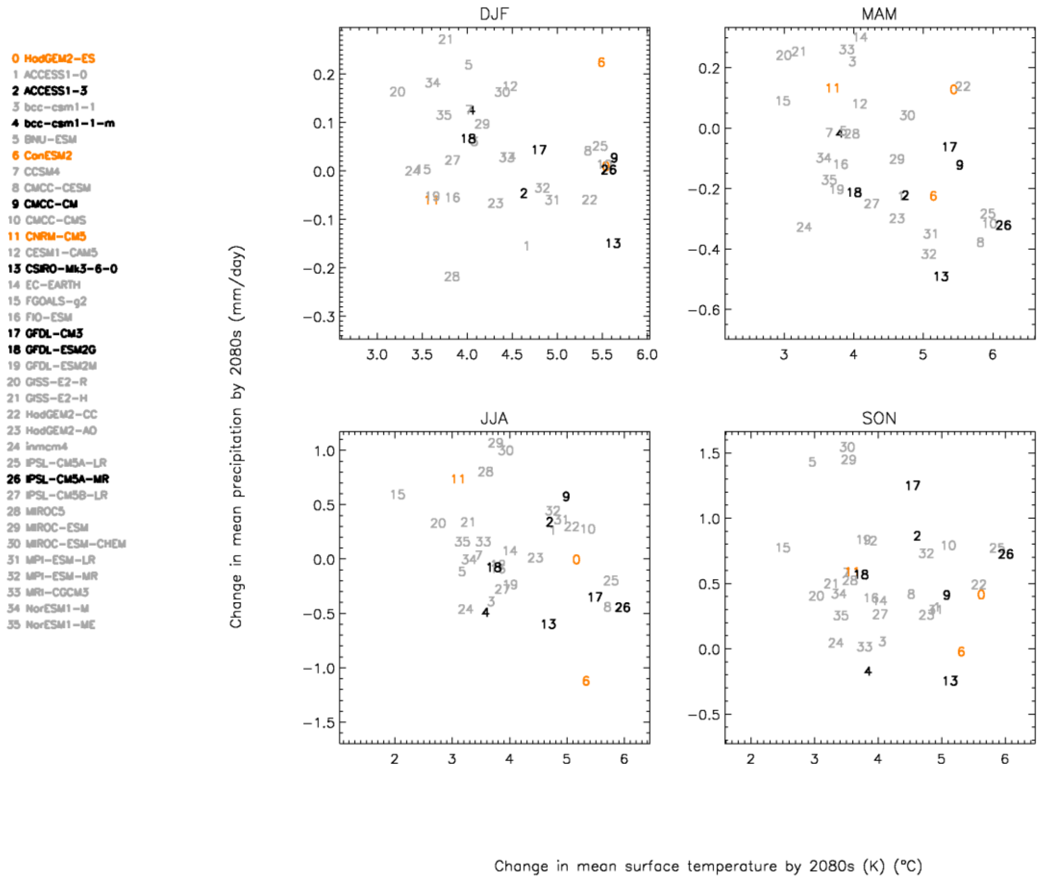

Figure 4: As Figure 3, but for the Volta region (1-12˚N, 17˚W-12˚E)

Note that, as for South Asia, it was not possible to sample the full range of changes in annual and seasonal mean temperature and precipitation with just these three GCMs. For example, in all four seasons, some CMIP5 GCMs simulate future increases in seasonal mean precipitation that are greater than that simulated by any of the three selected GCMs and, in all seasons except June, July, August, some CMIP5 GCMs simulate future decreases in seasonal mean precipitation that are greater than that simulated by any of the three selected GCMs (Figure 5).

4. Conclusion

The DECCMA project is using downscaled data from three CMIP5 GCM simulations of RCP8.5 for each of South Asia and West Africa. For South Asia, simulations of the HadGEM2-ES, CNRM-CM5 and GFDL-CM3 GCMs have been downscaled to 25km with the HadRM3P RCM. For West Africa, covering the Volta delta, the project is using CORDEX simulations of the HadGEM2-ES, CNRM-CM5 and CanESM2 GCMs downscaled to 50km with the RCA4 RCM.

The DECCMA project is using RCM-generated downscaled data from a selection of CMIP5 GCM simulations of RCP8.5 as a basis for investigating the impacts of climate change. For South Asia, covering the GBM and Mahanadi deltas, the GCM simulations have been downscaled to 25km with the HadRM3P RCM. For West Africa, covering the Volta delta, the DECCMA project is using GCM data downscaled to 50km with the RCA4 RCM generated as part of the CORDEX project. The GCMs have been selected to sample as much of the uncertainty in changes in key climate variables over the 21st century spanned by the full set of CMIP5 GCMs as possible. Table 3 lists the GCMs selected and, for each, summarises the changes in annual mean temperature and precipitation simulated for RCP8.5.

Region	GCM	Temperature Change	Precipitation Change
West Africa	***CNRM-CM5***	*Small increase*	*Moderate increase*
	HadGEM2-ES	*Large increase*	*Small increase*
	CanESM2	*Large increase*	*Large decrease*
South Asia	***CNRM-CM5***	*Small increase*	*Moderate increase*
	GFDL-CM3	*Large increase*	*Moderate increase*
	HadGEM2-ES	*Large increase*	*Large increase*

Table 3: Summary of regional climate changes simulated by the CMIP5 GCMs considered for the DECCMA project. Changes in annual mean temperature and precipitation simulated over the 21st century for RCP8.5 are described. The magnitudes of the changes are described relative the magnitudes of the changes simulated by the full set of CMIP5 RCP8.5 simulations.

The process for selecting climate model simulations for the DECCMA project described in this report has a number of limitations. Some to these relate to the assessment of the performance of CMIP5 GCMs considered for downscaling. This relied on existing work by McSweeney et al. (2015) and the Met Service Singapore project involving assessments relevant to South Asia and West Africa that were part of broader multi-region assessments. An assessment of GCM performance targeted at South Asia and West Africa may have resulted in a different set of GCMs being excluded from consideration for downscaling. However, as the existing assessments used were targeted on excluding unrealistic models for regions including South Asia and West Asia, the models and projections used in DECCMA can still be regarded as plausible.

Other limitations relate to the sampling of the range of plausible future climate outcomes. The selection of climate models described here is focussed on sampling the range of future changes in the large-scale climate simulated by the CMIP5 GCMs. However, the CMIP5 ensemble has not been designed to comprehensively sample the range of plausible real world outcomes and it is possible that responses of some large-scale aspects of the real climate system to future greenhouse forcing may be beyond the range projected by CMIP5. If this is the case, then the DECCMA RCM simulations will only sample a portion of the range of plausible real world outcomes.

As noted in Sections 2 and 3, it has not been possible to sample the full range of CMIP5-simulated changes in annual and seasonal mean temperature and precipitation with just three GCMs selected from the limited number for which downscaled data could be provided. It should also be noted that the model selection does not directly address the sampling of future changes in aspects of the climate other than annual and seasonal mean temperature and precipitation. Future changes in some other variables relevant to climate change impacts are likely to be related to changes in these variables. For example, the Intergovernmental Panel on Climate Change reports a link between future changes in extreme and mean temperatures in climate models (Seneviratne et al., 2012). However, there may not be such links for other impact-relevant variables, such as measures of extreme precipitation. For these variables, it is possible that the DECCMA model selection may not sample future changes simulated by the CMIP5 ensemble well.

Another implication of the approach described in this report is that uncertainty due to the use of different RCMs is not considered by the DECCMA project. Indeed, the project uses only one RCM for each of West Africa and South Asia. Although this is unlikely to affect the sampling of future changes in climatological means on large spatial scales, uncertainty arising from the existence of multiple RCMs may contribute more significantly to uncertainty in more local climate changes and to uncertainty in climate extremes.

The focus on sampling future climate changes also leaves the issue of sampling biases in the climate model simulations unaddressed. It is common for climate models to output biased absolute values of climate variables. Biases generally become clear when climate model output and observations are compared for a historical time period. If a climate change impact assessment is sensitive to climate model biases, then the use of different climate models is likely to contribute uncertainty to the results as different climate models are likely to have different biases. Therefore, if it is not possible to remove relevant climate model biases, it may be desirable for the climate datasets considered to sample the range of different relevant climate model biases (e.g. including data from climate model simulations with warm biases as well as those with cool biases). Such sampling of biases has not been considered in the selection of climate model simulations for the DECCMA project and users of the output of the simulations are encouraged to carefully consider how biases in the DECCMA RCM simulations might affect their work. Some of these biases are discussed in more detail by Macadam and Janes (2017).

It is important that these limitations be considered by users of the output for the DECCMA RCM simulations. However, despite the limitations, the climate model simulations selected for the DECCMA project should yield a diverse set of future climate change scenarios that are consistent with results from the CMIP5 GCMs and provide a suitable climatological basis for exploring climate change impacts in the regions of interest.

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