

Adapting Together, Thriving Tomorrow



Downscaled Temperature and Precipitation Scenarios Report

Enhancing Multi-Sector Planning and Capacity for Effective Adaptation in Ghana



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Planning and Capacity for Effective Adaptation in
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Table of Contents

Acronyms	14
Executive Summary	16
Background	16
Delineation of Homogenous Climate Zones	16
Analysis of Climate Change Scenarios for Ghana	18
Overall Summary of Climate Scenario Results	18
Joint Scenario Climate Change Pathways for Ghana	20
Summary of Results for the Four Climate Zones	21
1. Introduction	27
1.1. Background and Context	27
1.2. Previous Downscaled Climate Scenarios for Ghana	27
1.2.1. Climate Change Studies Assistance Program (NCCSAP)	27
1.2.2. Second National Communication Climate Risk Assessments	28
1.2.3. Forth National Communication (4NC) and Updated NDCs	28
1.2.4. IPCC CIMP6 climate models and analysis of uncertainty	28
1.3. Purpose of this Report	28
2. Approach and Methodology	30
2.1. Overview of Global Emissions Scenarios	30
2.2. Analysis of uncertainty in future climate scenarios.	34
2.3. Overview of the Approach to Analysis of Uncertainty	35
2.4. Data used for the SOMs and Plume Plots Analysis	36
2.5. Overview of Self Organising Maps (SOMs)	37
2.5.1. Areas used in the SOMs analysis	37
2.5.2. The Self-Organising Maps (SOMs) Calculations	38
2.5.3. Identification of Regional Climate Models (RCMs)	39
2.6. Overview of Plume Plots Analysis	39
2.7. Downscaled Climate Scenarios for Individual MMDAs	40
2.8. Development of an Updated Climate Risk Narrative	40
3. Results	41

3.1.	Selection of priority MMDAs	41
3.2.	Defining Homogenous Climate Zones	43
3.3.	Results of Initial Analysis of CMIP5 Ensembles	47
3.3.1.	Climate Change Impacts on Temperature and Rainfall	47
3.3.2.	Future Trends in Return Period Values	48
3.3.3.	Future Trends in Likelihood of Exceedance Thresholds	50
3.4.	Results of SOMs Analysis	56
3.4.1.	Overall Summary of SOMs Analysis Results	56
3.4.2.	Summary Results for RCP2.6 (All Climate Zones)	56
3.4.3.	Summary Results for RCP 4.5 (All Climate Zones)	58
3.4.4.	Summary Results for RCP 8.5 (All Climate Zones)	60
3.5.	Selection of the Representative Climate Scenarios	63
3.5.1.	Representative Scenarios for RCP 2.6	63
3.5.2.	Representative Scenarios for RCP4.5	64
3.5.3.	Representative Scenarios for RCP8.5	65
3.5.4.	Identifying GCM/RCM pairings from CORDEX for downscaling	67
3.6.	Plume Plots Analysis for Climate Zones	73
3.6.1.	Historical Simulations vs. Observations	73
3.6.1.1	Air temperature	73
3.6.1.2	Rainfall	74
3.6.2.	Results for RCP 2.6/SSP1 2.6	74
3.6.2.1	Air Temperature	74
3.6.2.2	Rainfall	75
3.6.3.	Results for RCP 4.5/SSP2 4.5	78
3.6.3.1	Air Temperature	78
3.6.3.2	Rainfall	78
3.6.4.	Results for RCP 8.5/SSP5 8.5	81
3.6.4.1	Air Temperature	81
3.6.4.2	Rainfall	81
3.7.	Plume Plot Summaries for Priority MMDAs	83

4. Summary of Future Climate Scenarios	84
4.1. Overall Summary of Climate Scenario Results	84
4.2. Summary Results for Individual Climate Zones	84
4.2.1. Northern Climate Zone:	84
4.2.2. Central Climate Zone:	84
4.2.3. Southwestern Climate Zone:	85
4.2.4. Coastal Climate Zone:	85
4.3. Summary Results for Individual MMDAs	86
4.3.1. West Mamprusi Municipal MMDA	86
4.3.2. Tamale Metro MMDA	87
4.3.3. Wenchi District MMDA	88
4.3.4. Asuogyaman (Akosombo) District MMDA	89
4.3.5. Keta Municipal MMDA	90
4.3.6. Kumasi Metro MMDA	91
4.3.7. Enchi (Aowin) District MMDA	91
4.3.8. Ellembelle Municipal MMDA	92
4.3.9. Sekondi Takoradi Metro MMDA	93
4.3.10. Tema Metro MMDA	94
5. Additional Points of Discussion	96
5.1. Why CMIP6 models were <u>not</u> used in the analysis?	96
5.2. Why use Ensembles?	98
5.2.1. The generation of ensembles	98
5.2.2. A visual example of the justification for using ensembles	99
5.2.3. The interpretation of ensemble results	102
6. Conclusions and the Way Forward	104
References	105
Appendix A I Additional Results: The Self-	107
Organising Maps analyses and identification of appropriate RCMs to be used for downscaling:	107
The section on the self-organising maps	107
The section on identifying appropriate RCMs for downscaling	109

Appendix A1: RCP 2.6 SOMs Analysis Results	111
RCP2.6 Central Zone – 4 nodes – used in defining the scenarios	111
RCP2.6 Central Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios	112
RCP2.6 Coastal Zone – 4 nodes – used in defining the scenarios	113
RCP2.6 Coastal Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios	115
RCP2.6 North Zone – 4 nodes – used in defining the scenarios	116
RCP2.6 North Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios	117
RCP2.6 Southwest Zone – 4 nodes – used in defining the scenarios	118
RCP2.6 Southwest Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios	119
Appendix A2: RCP 4.5 SOMS Analysis Results	130
RCP4.5 Central Zone – 4 nodes – used in defining the scenarios	130
RCP4.5 Central Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios	131
RCP4.5 Coastal Zone – 4 nodes – used in defining the scenarios	132
RCP4.5 Coastal Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios	133
RCP4.5 North Zone – 4 nodes – not used as 6 nodes preferred	134
RCP4.5 North Zone – 6 nodes – used in defining the scenarios	135
RCP4.5 Southwest Zone – 4 nodes – used in defining the scenarios	136
RCP4.5 Southwest Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios	138
Appendix A3: RCP 8.5 SOMS Analysis Results	148
RCP8.5 Central Zone – 4 nodes – not used in defining the scenarios	148
RCP8.5 Central Zone – 6 nodes – not used in defining the scenarios	149
RCP8.5 Central Zone – 8 nodes – used in defining the scenarios	150
RCP8.5 Coastal Zone – 4 nodes – not used in defining the scenarios	151
RCP8.5 Coastal Zone – 6 nodes – not used in defining the scenarios	152
RCP8.5 Coastal Zone – 8 nodes – used in defining the scenarios	153
RCP8.5 North Zone – 4 nodes – not used in defining the scenarios	154

RCP8.5 North Zone – 8 nodes – used in defining the scenarios	156
RCP8.5 Southwest Zone – 4 nodes – not used in defining the scenarios	158
RCP8.5 Southwest Zone – 6 nodes – not used in defining the scenarios	159
RCP8.5 Southwest Zone – 8 nodes – used in defining the scenarios	160
Appendix B I Plume plots at MMDA Level	170
Appendix B1: RCP 2.6/SSP1 2.6	170
Appendix B2: RCP 4.5/SSP2 4.5	174
Appendix B3: RCP 8.5/SSP5 8.5	178

List of Figures

Figure e1 Approach to analyses of climate change scenarios for Ghana and ten priority MMDAs	16
Figure e2 Change in mean annual rainfall and mean annual temperature in the 2040-2071 period compared to 1981-2010 period as projected by the median of the CORDEX ensemble	17
Figure e3 Resulting four homogeneous climate zones identified for Ghana (left) and comparison (right) with existing ecological regions for Ghana (source: Kemausuer et al. 2013).	17
Figure e1 Projected change in mean annual temperature for all climate zones – RCP4.5 – SSP 2	24
Figure e2 Projected change in total annual precipitation for all climate zones – RCP4.5 - SSP 2	25
Figure e4 Projected change in mean monthly precipitation by mid-century for the climate zones.	26
Figure e5 Projected change in mean monthly temperature by mid-century for the climate zones.	26
Figure 1 Spatial scale of key deliverables	29
Figure 2 Emissions of Carbon Dioxide under different scenarios for different generations of projections	33
Figure 3 The CORDEX Africa Domain (left) and the CORDEX MENA Domain (Right)	35
Figure 4 The four climate zones used in the SOMs calculations. From top to bottom these are North, Central, Southwest, and Coastal.	38
Figure 5 Explanation of the elements of a plume plot. The shaded areas show the range (10 th percentile to 90 th percentile) of the different model ensembles including both CIMP5 and CIMP6 results.	40
Figure 6 Priority MMDAs for downscaled climate scenarios	42
Figure 7 Mean annual rainfall and mean annual temperature based on ERA5 datasets	43
Figure 8 Change in mean annual rainfall and mean annual temperature in the 2040-2071 period compared to 1981-2010 period as projected by the median of the CORDEX ensemble	44
Figure 9 Results of clustering of time series of CORDEX ensemble median of mean annual temperature (coded as TG) - standardized values. That clustering captures similarity in terms of year-to-year variability of temperature, without consideration given to magnitudes.	45
Figure 10 Results of clustering of time series of CORDEX ensemble median of annual rainfall (coded as PRCPTOT)- standardized values. That clustering captures similarity in terms of year-to-year variability of rainfall, without consideration given to magnitudes.	45
Figure 11 Recommended climate zones for synthesizing climate change projections in Ghana	46
Figure 12 Time series of temperature (top) rainfall (bottom) changes across the Central zone (see Figure 7) for RCP2.6. RCP4.5 and RCP8.5 up to 2100 using the full CMIP5 ensemble. Results for the other three zones are similar.	47
Figure 13 Expected changes in probability of exceedance of temperature and rainfall thresholds (defined for the base period) under different emissions scenarios for the North Zone	52
Figure 14 Expected changes in probability of exceedance of temperature and rainfall thresholds (defined for the base period) under different emissions scenarios for the Central Zone	53

Figure 15 Expected changes in probability of exceedance of temperature and rainfall thresholds (defined for the base period) under different emissions scenarios for the Southwest Zone	54
Figure 16 Expected changes in probability of exceedance of temperature and rainfall thresholds (defined for the base period) under different emissions scenarios for the Coastal Zone	55
Figure 17 Pathways identified for RCP2.6 – North Zone	57
Figure 18 Pathways identified for RCP2.6 – Central Zone	57
Figure 19 Pathways identified for RCP2.6 – Southwest Zone	57
Figure 20 Pathways identified for RCP2.6 – Coastal Zone	58
Figure 21 Pathways identified for RCP4.5 – North Zone	59
Figure 22 Pathways identified for RCP4.5 – Central Zone	59
Figure 23 Pathways identified for RCP4.5 – Southwest Zone	60
Figure 24 Pathways identified for RCP4.5 – Coastal Zone	60
Figure 25 Pathways identified for RCP8.5 – North Zone	61
Figure 26 Pathways identified for RCP8.5 – Central Zone	62
Figure 27 Pathways identified for RCP8.5 – Southwest Zone	62
Figure 28 Pathways identified for RCP8.5 – Coastal Zone	62
Figure 29 Joint scenarios for RCP2.6	64
Figure 30 Joint scenarios for RCP4.5	65
Figure 31 Joint scenarios for RCP8.5	67
Figure 32 Example of an ellipse diagram used to identify representative GCM/RCM pairs for each scenario	68
Figure 33 Plume plots illustrating the evolution of mean annual temperature in Ghana homogeneous climate zones in simulations of historical and future climate under rcp26/ssp126 scenarios	76
Figure 34 Plume plots illustrating the evolution of total annual rainfall in Ghana homogeneous climate zones in simulations of historical and future climate under rcp2.6/ssp126 scenarios	77
Figure 35 Plume plots illustrating the evolution of mean annual temperature in Ghana homogeneous climate zones in simulations of historical and future climate under RCP 4.5/SSP2 4.5 scenarios	79
Figure 36 Plume plots illustrating the evolution of total annual rainfall in Ghana homogeneous climate zones in simulations of historical and future climate in under RCP 4.5/SSP2 4.5 scenarios	80
Figure 37 Plume plots illustrating the evolution of mean annual temperature in Ghana homogeneous climate zones in simulations of historical and future climate under rcp8.5/ssp585 scenarios.	82
Figure 38 Plume plots illustrating the evolution of total annual rainfall in Ghana homogeneous climate zones in simulations of historical and future climate under RCP85/SSP585 scenarios.	83
Figure 39 Change in mean annual temperature (deg C) for West Mamprusi	87

Figure 40 Change in total annual rainfall (%) for West Mamprusi	87
Figure 41 Change in mean annual temperature (deg C) for Tamale Metropolitan relative to the base period	88
Figure 42 Change in total annual rainfall (%) for Tamale Metropolitan relative to the base period	88
Figure 43 Change in mean annual temperature (deg C) for Wenchi District	89
Figure 45 Change in mean annual temperature (deg C) for Asuogyaman (Akosombo) District	90
Figure 46 Change in total annual rainfall (%) for Asuogyaman (Akosombo) District	90
Figure 47 Change in mean annual temperature (deg C) for Keta Municipal	90
Figure 48 Change in total annual rainfall (%) for Keta Municipal	91
Figure 49 Change in mean annual temperature (deg C) for Kumasi Metro	91
Figure 50 Change in total annual rainfall (%) for Kumasi Metro	91
Figure 51 Change in mean annual temperature (deg C) for Enchi (Aowin) District	92
Figure 53 Change in mean annual temperature (deg C) for Ellembelle Municipal	93
Figure 54 Change in total annual rainfall (%) for Ellembelle Municipal	93
Figure 55 Change in mean annual temperature (deg C) for Sekondi Takoradi Metro	93
Figure 56 Change in total annual rainfall (%) for Sekondi Takoradi Metro	94
Figure 57 Change in mean annual temperature (deg C) for Tema Metro	94
Figure 58 Change in total annual rainfall (%) for Tema Metro	95
Figure 59 North Zone under RCP4.5	97
Figure 60 North Zone under SSP2-45	97
Figure 61 Distributions of relatively warm average years projected for the Coastal Zone under RCP2.6	100
Figure 62 Distributions of relatively dry and wet annual rainfall totals projected for the Coastal Zone under RCP2.6	101
Figure B1-1a Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp26/ssp126 scenarios. All lines represent 20-year running averages calculated on annual values.	170
Figure B1-1b Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp26/ssp126 scenarios. All lines represent 20-year running averages calculated on annual values.	171
Figure B1-2a Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp26/ssp126 scenarios. All lines represent 20-year running averages calculated on annual values.	172
Figure B1-2b Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp26/ssp126 scenarios. All lines represent 20-year running averages calculated on annual values.	173

Figure B2-2a Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp45/ssp245 scenarios. All lines represent 20-year running averages calculated on annual values.	174
Figure B2-1b Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp45/ssp245 scenarios. All lines represent 20-year running averages calculated on annual values.	175
Figure B2-2a Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp45/ssp245 scenarios. All lines represent 20-year running averages calculated on annual values.	176
Figure B2-2b Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp45/ssp245 scenarios. All lines represent 20-year running averages calculated on annual values.	177
Figure B3-1a Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp85/ssp585 scenarios. All lines represent 20-year running averages calculated on annual values.	178
Figure B3-1b Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp85/ssp585 scenarios. All lines represent 20-year running averages calculated on annual values.	179
Figure B3-2a Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp85/ssp585 scenarios. All lines represent 20-year running averages calculated on annual values.	180
Figure B3-2b Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp85/ssp585 scenarios. All lines represent 20-year running averages calculated on annual values.	181
Figure B3-3 Comparison of selected climate model scenario results for MMDAs – temperature	182
Figure B3-3 Comparison of selected climate model scenario results for MMDAs – rainfall	183

List of Tables

Table e1 Overall trends in climate for the remainder of the century in °C/decade and %/decade	19
Table e2 Results of joint pathways analysis across the four climate zones under RCP2.6	20
Table e3 Joint pathways across the four climate zones under RCP4.5	20
Table e4 Joint pathways across the four zones under RCP8.5	21
Table 1 Approaches taken sequentially in generating climate scenarios using Global Climate Models	30
Table 2 Summary of the storylines used in the SRES Scenarios	31
Table 3 Summary of the storylines used in the SSP Scenarios	32
Table 4 Initial shortlist of potential priority MMDAs	41
Table 5 Final list of priority MMDAs	41
Table 6 Overall trends in climate for the remainder of the century in °C/decade and %/decade	48
Table 7 Highest annual average temperatures for different return periods under RCP2.6. RCP4.5 and RCP8.5 showing the absolute value (in deg C) and the percentage change from historical.	49
Table 8 Return period values of lowest annual rainfall under RCP2.6. RCP4.5 and RCP8.5.	49
Table 9 Return period values of highest annual rainfall under RCP2.6. RCP4.5 and RCP8.5.	50
Table 10 Results of joint pathways analysis across the four climate zones under RCP2.6	64
Table 11 Joint pathways across the four climate zones under RCP4.5	65
Table 12 Joint pathways across the four zones under RCP8.5	66
Table 13 Summary of recommend GCM/RCM pairing for representative scenarios of downscaled climate information for RCP2.6	70
Table 14 Summary of recommend GCM/RCM pairing for representative scenarios of downscaled climate information for RCP4.5	71
Table 15 Summary of recommend GCM/RCM pairing for representative scenarios of downscaled climate information for RCP8.5	72
Table 16 Priority MMDAs and Climate Zones	86
Table A1-1 RCP2.6 Annual Central using 4 SOMs – used in defining the scenarios	111
Table A1-2 RCP2.6 Annual Central using 6 SOMs – not used in defining the scenarios	113
Table A1-3 RCP2.6 Annual Coastal using 4 SOMs – used in defining the scenarios	114
Table A1-4 RCP2.6 Annual Coastal using 6 SOMs – not used in defining the scenarios	115
Table A1-5 RCP2.6 Annual North using 4 SOMs – used in defining the scenarios	116
Table A1-6 RCP2.6 Annual North using 6 SOMs – not used in defining the scenarios	118
Table A1-7 RCP2.6 Annual Southwest using 4 SOMs – used in defining the scenarios	118
Table A1-8 RCP2.6 Annual Southwest using 6 SOMs – not used in defining the scenarios	120
Table A1-9 Results of joint pathways analysis across the four hydroclimatic zones under RCP2.6	121

Table A2-1 RCP4.5 Annual Central using 4 SOMs – used in defining the scenarios	130
Table A2-2 RCP4.5 Annual Central using 6 SOMs – not used in defining the scenarios	132
Table A2-3 RCP4.5 Annual Coastal using 4 SOMs – used in defining the scenarios	133
Table A2-4 RCP4.5 Annual Coastal using 6 SOMs – not used in defining the scenarios	134
Table A2-5 RCP4.5 Annual North using 4 SOMs – not used in defining the scenarios	135
Table A2-6 RCP4.5 Annual North using 6 SOMs – used in defining the scenarios	136
Table A2-7 RCP4.5 Annual Southwest using 4 SOMs – used in defining the scenarios	137
Table A2-8 RCP4.5 Annual Southwest using 6 SOMs – not used in defining the scenarios	138
Table A2-9 Results of joint pathways analysis across the four hydroclimatic zones under RCP4.5	140
Table A3-1 RCP8.5 Annual Central using 4 SOMs – not used in defining the scenarios	148
Table A3-2 RCP8.5 Annual Central using 6 SOMs – not used in defining the scenarios	149
Table A3-3 RCP8.5 Annual Central using 8 SOMs –used in defining the scenarios	150
Table A3-4 RCP8.5 Annual Coastal using 4 SOMs – not used in defining the scenarios	152
Table A3-5 RCP8.5 Annual Coastal using 6 SOMs – not used in defining the scenarios	153
Table A3-6 RCP8.5 Annual Coastal using 8 SOMs –used in defining the scenarios	154
Table A3-7 RCP8.5 Annual North using 4 SOMs – not used in defining the scenarios	155
RCP8.5 North Zone – 6 nodes – not used in defining the scenarios	155
Table A3-8 RCP8.5 Annual North using 6 SOMs – not used in defining the scenarios	156
Table A3-9 RCP8.5 Annual North using 8 SOMs –used in defining the scenarios	157
Table A3-10 RCP8.5 Annual Southwest using 4 SOMs – not used in defining the scenarios	158
Table A3-11 RCP8.5 Annual Southwest using 6 SOMs – not used in defining the scenarios	159
Table A3-12 RCP8.5 Annual Southwest using 8 SOMs –used in defining the scenarios	160
Table A3-13 Results of joint pathways analysis across the four hydroclimatic zones under RCP8.5	162

Acronyms

AR	Assessment Report of the IPCC (AR4 published in 2007; AR5 published 2013-4; AR6 2021-2)
CCRA	Climate Change Risk Assessment
CERES	Crop Environment Resource Synthesis
CORDEX	Coordinated Regional Downscaling Experiment
CORE	Coordinated Output for Regional Evaluations
CROPWAT	Crop Water and Irrigation Requirements Program
CSPG	Cross Sectoral Policy Group
CMIP	Climate Model Intercomparison Project; CMIP5 was used extensively in the IPCC AR5 and CMIP6 in the AR6
ENSO	El Niño/Southern Oscillation
EPA	Environmental Protection Agency
GCF	Green Climate Fund
GCM	Global Climate Model
GHG	Greenhouse Gas
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LE	Lower Extreme
MENA	Middle East/North Africa
MESTI	Ministry of Environment, Science, Technology and Innovation
MMDAs	Metropolitan, Municipal and District Assemblies
NAP	National Adaptation Plan
NCCSAP	Netherlands Climate Change Studies Assistance Programme
PSC	Project Steering Committee
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
SOM	Self-Organising Map, an artificial intelligence technique used to analysis the CMIP ensembles
SRES	IPCC Special Report on Emissions Scenarios
SSP	Shared Socioeconomic Pathways
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme
UE	Upper Extreme
WATBAL	Watershed Response Model for Forest Management

Executive Summary

Background

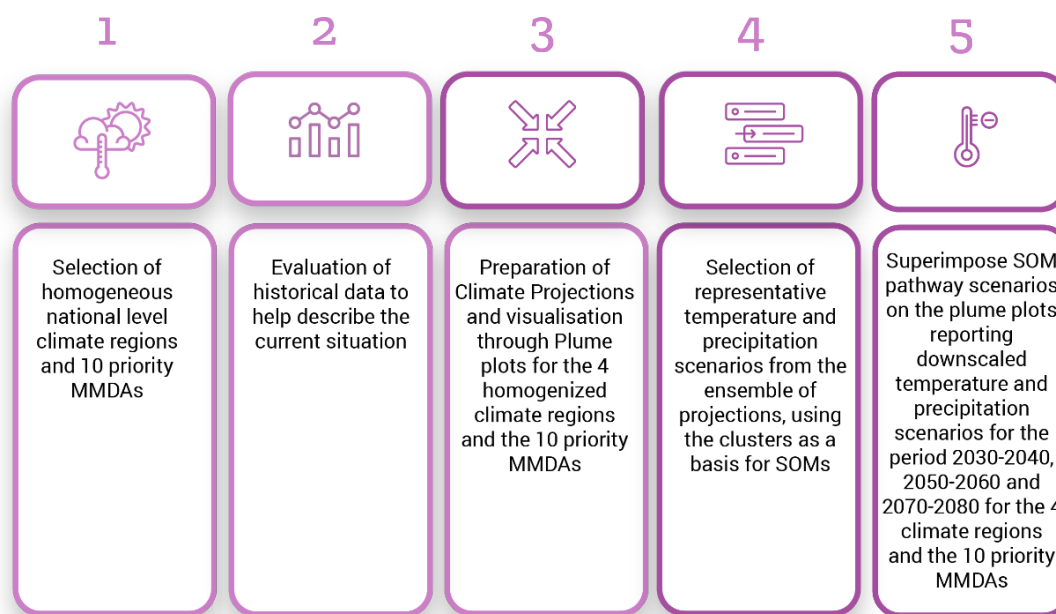
The Government of Ghana, through the Environmental Protection Agency (EPA), under the auspices of the Ministry of Environment, Science, Technology, and Innovation (MESTI), has obtained a grant from the Green Climate Fund (GCF) to build capacity to advance National Adaptation Plan (NAP) process in Ghana. The United Nations Environment Programme (UNEP) is the Delivery Partner for the project, with the role of supporting and overseeing the project implementation.

The specific activities to be undertaken under this project, supported by UNEP, are as follows:

- **Task 1:** Develop a methodology for producing national climate change scenarios.
- **Task 2:** Develop downscaled/area-based climate change projections for Ghana,
- **Task 3 & 4:** Develop national and sub-national level climate risk assessments for two MMDAs
- **Task 5:** Summary for Policy Makers, Training and Capacity Building.

The report presents the results of **Task 2**, developing downscaled national climate change projections for Ghana and for ten priority MMDAs. The overview of the approach is shown in the figure below.

Figure e1 | Approach to analyses of climate change scenarios for Ghana and ten priority MMDAs

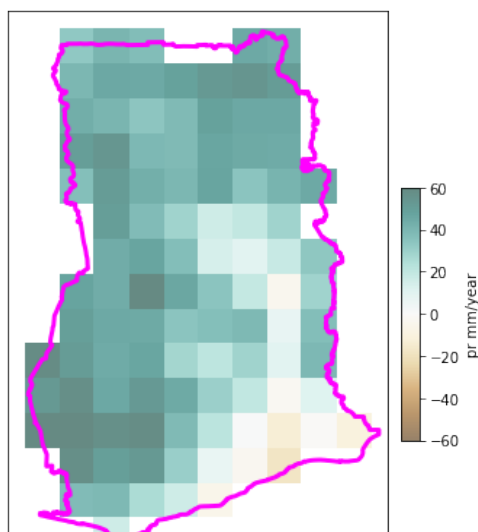


Delineation of Homogenous Climate Zones

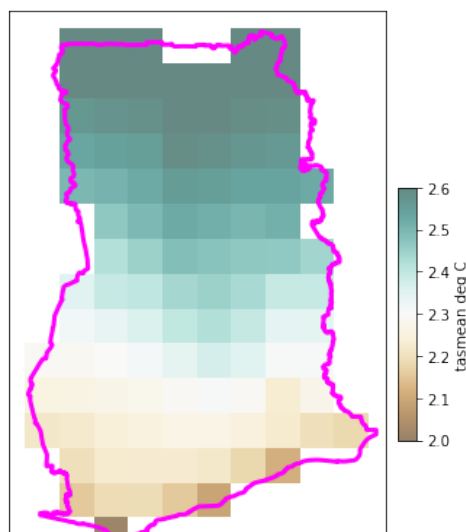
Clustering of current climate and expected changes in climate variables based on the latest downscaled climate scenarios from the CORDEX data set were used to identify four homogeneous climate zones for Ghana used in describing the regional impacts of climate change.

Figure e2 | Change in mean annual rainfall and mean annual temperature in the 2040-2071 period compared to 1981-2010 period as projected by the median of the CORDEX ensemble

change in pr between 2040-2071 and 1981-2010
ensemble median in cordex data

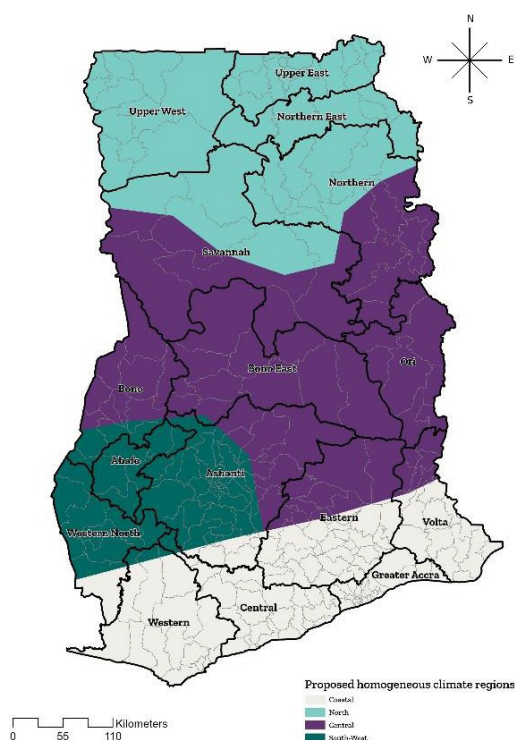


change in tasmean between 2040-2071 and 1981-2010
ensemble median in cordex data



The resulting four homogenous climate zones identified for Ghana are shown in figure below and are compared with the identified ecological regions for Ghana (Kemausuer et al, 2013).

Figure e3 | Resulting four homogeneous climate zones identified for Ghana (left) and comparison (right) with existing ecological regions for Ghana (source: Kemausuer et al. 2013).



Analysis of Climate Change Scenarios for Ghana

For the analysis of future climate change scenarios, two different but complementary approaches were used, and results were presented for the four homogenous climate zones and the ten priority MMDAs.

- **Self-Organising Map (SOM)** these types of analyses are intended to identify, firstly, the characteristic “trajectories” of future climate thus schematizing the broad uncertainty of projections in the form of several distinct scenarios, and secondly, individual projections (or models) that are representative to the broad range of projected future climate. The SOMs analysis were based on the downscaled climate scenarios from the CIMP5 ensemble and considered three different global emissions scenarios namely, RCP 2.6, RCP 4.5, and RCP 8.5.
- **Plume plots:** These are intended to visualize the evolution of the historical and future climate, with explicit presentation of uncertainty of projections across three different ensembles, i.e., CORDEX, CMIP5 and CMIP6. These figures are the basis for evaluation of robustness of the downscaled (CORDEX) projections against GCM ensembles, as well as visualization of the range (and thus uncertainty) of future climates as projected by the analysed ensembles.

The SOMs analysis resulted in the identification of 16 individual climate scenarios and the RCM that most closely replicates the temperature and rainfall changes in each scenario was identified from the available CORDEX data set (using root-mean-square distances). The selected CORDEX scenarios can then be used to provide downscaled climate variables to support the national and sub-national level climate risk and vulnerability assessments dependent on what is relevant for the identified risk domains.

Overall Summary of Climate Scenario Results

The overall messages about future climate in Ghana emerging from the analyses are as follows:

- **strong confidence** message of **strong increases in air temperatures** manifested in all scenarios and all zones. Those increases amount to **0.5 - 1.5 °C**, **1.5 - 2.5 °C** and **2.5 - 4.5 °C** above historical mean at the end of 21st century under **RCP 2.6/SSP126**, **RCP 4.5/SSP245** and **RCP 8.5/SSP585**, respectively.
- **moderate to low confidence** message of **weak changes** (comparable to or only slightly stronger than the level of variability simulated for the past) in the overall “**wetness**” of the climate **without a clearly defined direction** of future changes in total annual rainfall, independently on emission scenario. That **low confidence** is partly caused by the lack of consistency in historical rainfall trends between observational data and model simulations.
- **Higher annual average temperature** values occur, as expected, with increasing emissions. For the North Zone, the 100-year return value under RCP8.5 increases by approaching 6°C.
- There are **no clear trends in return values for the driest annual events**, suggesting limited, if any, change in drought occurrences and magnitudes, although when combined with an increasing trend in average annual temperatures, could result in an increasing risk of drought.
- There is a **possible trend, although not significant, towards increased return values for the wettest years**, *perhaps* indicating the prospects of increased flood risks.
- There is an expected increase in the maximum one-day rainfall across all regions of around 25% (ensemble mean) by 2035 increasing to 42% by 2085 under RCP4.5 and 66% under RCP 8.5.

- There is **limited variation across the zones**, with greater **increases in temperatures** expected over the northern region and a greater potential for **wetting** in the coastal zone.
- The latest **CIMP6 model results** suggest more **significant “wetting”**, particularly over the Northern region of Ghana, but **further analysis is required** to clarify these results.

Overall trends in expected climate change for the remainder of the century are summarised in the table following in terms of the degree Celsius (°C) change per decade for annual average temperature and the percentage change per decade in annual rainfall, with significance at the 5% level in bold italics.

Table e1 | Overall trends in climate for the remainder of the century in °C/decade and %/decade

	Temperature °C/decade			Rainfall %/decade		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
North	<i>+0.09</i>	<i>+0.24</i>	<i>+0.57</i>	-0.1	+0.1	<i>+0.6</i>
Central	<i>+0.08</i>	<i>+0.23</i>	<i>+0.55</i>	-0.0	+0.0	<i>+0.6</i>
Southwest	<i>+0.08</i>	<i>+0.23</i>	<i>+0.52</i>	+0.1	+0.1	<i>+0.6</i>
Coastal	<i>+0.08</i>	<i>+0.22</i>	<i>+0.50</i>	-0.1	<i>+0.3</i>	<i>+0.8</i>

Note: Analysis based on average across all CIMP5 climate models, significance at the 5% level in italics.

Temperature changes in all four zones are similar, with most trends, other than under RCP2.6, statistically significant. Under RCP2.6 the increases tend to plateau after mid-century; there is also some plateauing in the final two or so decades under RCP4.5 but temperatures increase throughout the century under RCP8.5, reaching an average rise of almost 4°C. Projected temperature trends are strongest in the North Zone, but only under RCP 8.5 with little difference for RCP 2.6 and RCP 4.5.

Only non-significant trends in changes in **rainfall** are present for most zones under RCP2.6 and RCP4.5, with statistically significant positive trends under RCP8.5 across all four zones. The strongest trends in rainfall are for the Coastal Zone which is significant under RCP 4.5 and RCP 8.5.

In terms of the results of the analysis of changes in extreme events (i.e. floods and droughts):

- **Higher annual average temperature** values occur, as expected, with increasing emissions. For the North Zone, the 100-year return value under RCP8.5 increases by approaching 6°C.
- There are **no clear trends in return values for the driest annual events**, suggesting limited, if any, change in drought occurrences and magnitudes, although when combined with an increasing trend in average annual temperatures, could result in an increasing risk of drought.
- There is a **possible trend, although not significant, towards increased return values for the wettest years**, *perhaps* indicating the prospects of increased flood risks.

Estimates have been made of the **changes in likelihoods of 2- and 3-year sequences** of average annual temperatures and rainfall totals exceeding certain thresholds, based on climate during the base period of 1986 to 2005. For temperatures, the thresholds are for 2- and 3-year successive breaches of 2 and 3 standard deviations defined annually historically. For dry events, the thresholds are the driest 10% and 25% of years historically. For wet events, the thresholds are the wettest 10% and 25% of years during the base period. The results of this analysis are summarised below:

- In all zones, likelihoods under RCP 8.5 reach 100% by mid-century for 2-year sequences of temperatures above the 2 standard deviation thresholds, with 3-year sequences close behind. In other words, **the results point to certainty that there will be multi-year sequences with average annual temperatures of magnitudes currently in the warmest 16% and 2.5% of years.** Results are similar under RCP4.5 but reach 100%, or close by, only towards the end of the century. For RCP2.6 likelihoods approach around 50% in mid-century but reduce somewhat later. In summary, **it is certain that multi-year sequences with temperatures in the upper ranges of those currently experienced will occur, the more so with higher emissions.**
- For both the dry 10th and 25th percentiles there are **statistically significant positive trends**, indicating extended dry annual sequences, particularly for the 25th percentile metric (Note: the return values analysis suggested that overall, there is little risk of increased overall drought occurrences and magnitudes defined in terms of changes in mean annual precipitation only, but these results are not contradictory). **Positive trends** are present also for the wet 75th and 90th percentile metrics, more so for the former. All trends are **most prominent under RCP8.5** and in the Southwest and Coastal Zones. **These results suggest a widening of the range of annual rainfall totals under climate change, more so towards wetter years**

Joint Scenario Climate Change Pathways for Ghana

The SOMs analysis was used to identify a set of four joint scenario pathways representing the expected change in temperature and precipitation in each of the four climate zones and under the three emission scenarios RCP 2,6, RCP 4.4 and RCP 8.5. Two additional scenarios, representing an upper extreme (UE) and a lower extreme (LE) scenario were also identified. The resulting probability of each of these scenarios and the expected impact over the future time periods are shown in the table below. The scenarios indicated in red were used in the identification of individual RCMs from the CORDEX data set that could be used to represent each of these scenarios in providing additional downscaled data.

Table e2 | Results of joint pathways analysis across the four climate zones under RCP2.6

Scenario	Likelihood of Individual Scenarios				Expected Temperature (°C) and Rainfall (%) Impacts		
	North	Central	Southwest	Coastal	2035	2060	2080
A26	1 35%	1 30%	2 30%	1 35%	0.5/1.05	0.5/1.05	0.5/1.05
B26	2 25%	3 25%	3 20%	3 20%	1.5/1.05	1.5/1.05	2.0/1.05
C26	3 25%	2 30%	1 40%	4 15%	1.0/1.00	1.0/1.00	1.0/1.00
D26	4 15%	4 15%	4 10%	2 30%	1.0/0.95	1.5/0.95	1.0/0.95
UE A26	✓	✓	X	X	0.5/1.15	1.0/1.15	1.5/1.10
UE B26	X	X	✓	✓	1.0/1.10	1.5/1.10	1.5/1.05
LE A26	✓	✓	✓	✓	1.0/0.95	1.0/0.95	1.5/0.90

Table e3 | Joint pathways across the four climate zones under RCP4.5

Scenario	Likelihood of Individual Scenarios				Expected Temperature (°C) and Rainfall (%) Impacts		
	North	Central	Southwest	Coastal	2035	2060	2080
5	1 50%	1 50%	2 40%	X	1.0/1.00	1.5/1.00	2.5/1.00
B45	X	X	X	2 40%	1.0/1.00	1.5/1.05	1.5/1.05
C45	2 40%	2 30%	1 45%	1 45%	1.0/0.95	1.5/0.95	2.0/0.90

D45	3 10%	3 20%	3 15%	3 15%	1.0/1.10	1.5/1.10	1.5/1.10
UE A45	✓	✓	✓	✓	1.0/1.15	1.0/1.15	2.0/1.15
LE A45	✓	✓	✓	✓	1.0/0.90	2.0/0.90	1.5/0.85

Table e4 | Joint pathways across the four zones under RCP8.5

	Likelihood of Individual Scenario				Expected Temperature (°C) and Rainfall (%) Impacts		
Scenario	North	Central	Southwest	Coastal	2035	2060	2080
A85	1 40%	1 40%	1 30%	3 30%	1.0/1.05	2.0/1.05	3.5/1.05
B85	2 35%	4 10%	3 25%	2 30%	1.5/0.95	2.5/0.95	4.5/0.90
C85	X	2+3 50%	4 15%	1 40%	1.5/1.00	2.5/1.00	3.5/1.00
D85	3 25%	X	2 30%	X	1.5/1.10	2.0/1.10	3.5/1.15
UE A85	✓	✓	✓	✓	1.0/1.10	2.0/1.15	3.5/1.20
LE A85	✓	✓	✓	✓	1.0/0.90	3.5/0.90	5.0/0.85

Summary of Results for the Four Climate Zones

Individual SOMs analysis and comparison of climate models and scenarios using plume plots were undertaken for each of the four climate zones. The summary results for each zone are described below.

Northern Climate Zone

In general, there is greater likelihood for larger increases in temperature in the North (and the Central) than the other two zones. This zone will see **temperature** increases from between 1.5 °C under RCP

2.6 to 3.5/4 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 °C. As usual RCP 8.5 represents a step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of another 0.5 °C. In short there is a **risk of significantly higher temperatures even at lower GHG concentration scenarios**.

Precipitation does not vary as much as other regions in Africa. There is a slightly greater chance of **small increases** in annual average precipitation compared to the base years. Typically, around 5% increase. There is also a relatively significant chance of **decreases** in precipitation to a similar degree.

The extremes suggest that a change in precipitation is possible of up to +/-15/20%. The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP

4.5 or RCP 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

Central Climate Zone

In general, there is a greater likelihood that there is a greater increase in temperature in the Central Zone than in the Southern Zones, but less than in the North. This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3.5/5 °C under RCP 8.5 (possible an even greater change than in the North) with RCP 4.5 suggesting a mid-point of about 2.5 deg. As usual RCP 8.5 represents a step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest and even greater increase of temperature of at least another 2.0 °C. In short there is a risk of significantly higher temperatures in the Central area even at lower GHG concentration scenarios.

There is a slightly greater chance of small increases in annual average **precipitation**. Typically, around 30% chance of a decrease of around 10%. However, it is almost as likely that a similar increase in precipitation occurs. The extremes suggest that the change is possible of up to 15/20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

Southwestern Climate Zone

This zone will see **temperature** increases from between 1.5/2.0 °C under RCP 2.6 to 3/4 °C under RCP

8.5 with RCP 4.5 suggesting a mid-point of about 2/2.5 °C. As usual RCP 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of at least another 0.5 °C. In short there is a risk of significantly higher temperatures in the Southwest zone even at lower GHG concentration scenarios under CMIP 6.

Precipitation does not vary as much as other regions in Africa. In this zone there is roughly equal chance of a small decrease in precipitation as there is an increase. This contrasts with the other the regions where the tendency is for a greater likelihood of an increase. The decrease is projected to be around 10% as is the increase. The extremes suggest that the change is possible of up to 15/20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at 2.6 but not 4.5 or 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

Coastal Climate Zone

This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3 /4.5 °C under RCP

8.5 with RCP 4.5 suggesting a mid-point of about 2.0 °C. As usual RCP 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of at least another 0.5 °C. In short there is a risk of significantly higher temperatures in the Coastal Zone even at lower GHG concentration scenarios under CMIP 6.

There is a roughly equal chance of small increases and decreases in annual average **precipitation** compared to the base years. Typically, around a 10% increase or decrease in mean annual precipitation (MAP). The extremes suggest that the change is possible of up to +/- 20% in MAP. The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP

4.5 or 8.5 where there is chance of significant increases in rainfall - possibly 20-30% greater increases.

Selection of Representative Climate Scenarios

Based on the results of the SOMs analysis, representative climate scenarios have been identified for each of the four climate zones in Ghana under three global emission scenarios: RCP 2.6, 4.5 and 8.5.

Out of the possible 64 representative pathways, 16 have been identified that represent multiple future scenarios and across the different zones. The likelihood of each of these pathways has been determined based on the SOMs analysis. In addition, an Upper Extreme (UE) and Lower Extreme (LE) pathway have also been identified. For each representative pathway, a single representative climate model/scenario combination has been identified from the CORDEX dataset which can then be used to provide additional information on specific climate variable required to support the risk assessments.

Summary Climate Scenarios for Priority MMDAs.

Individual plume plots have been produced for each of the ten priority MMDAs along with a short narrative of the potential impacts under the different climate scenarios. In general, the results are similar to that of the climate zone in which they are located, but with a few exceptions. Additional details and downscaling of specific climate variables will be undertaken as part of the individual risk assessments.

Conclusion and Recommendations

In general, the results of the analysis have shown that there is not a significant range of potential climate change impacts across the different zones and MMDAs for Ghana. While temperatures are expected to increase across all zones, these are not as significant as in other regions of the globe, and there appears to be only limited impact in terms of changing precipitation, with possibly even some evidence of a general increase in precipitation. It is important to note that under the CIMP6 scenarios there did appear to be a significant increase in precipitation in the North Zone, but this required more analysis.

Plume plots for the four climate zones reflecting the expected change in average annual temperature and total annual precipitation under the RCP 4.5–SSP2 are shown in the figures below. Results for additional global emission scenarios (i.e. RCP2.6-SSP1 and RCP8.5-SSP5) are shown in the report.

Figure e1 | Projected change in mean annual temperature for all climate zones – RCP4.5 – SSP 2

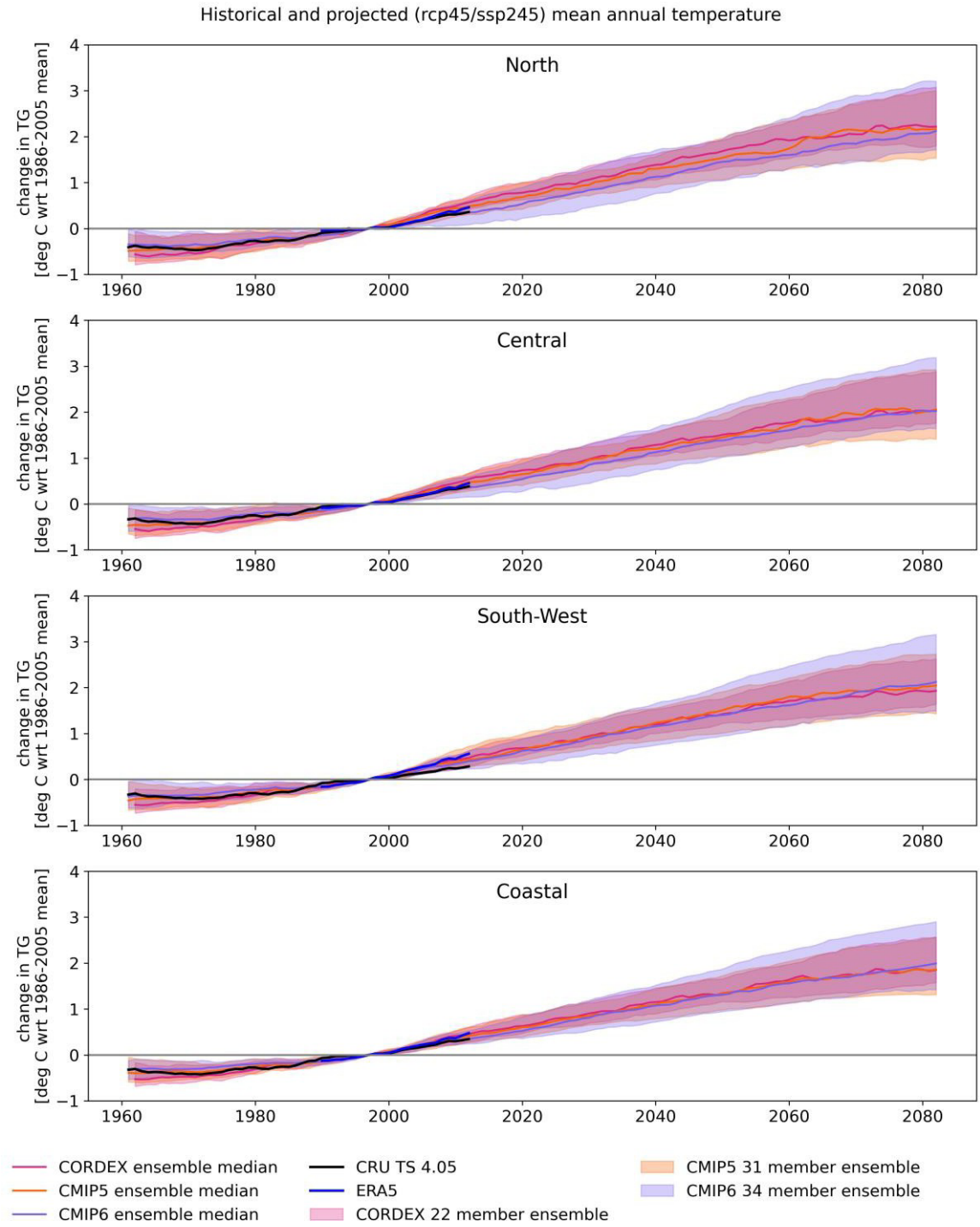


Figure e2 | Projected change in total annual precipitation for all climate zones – RCP4.5 - SSP 2

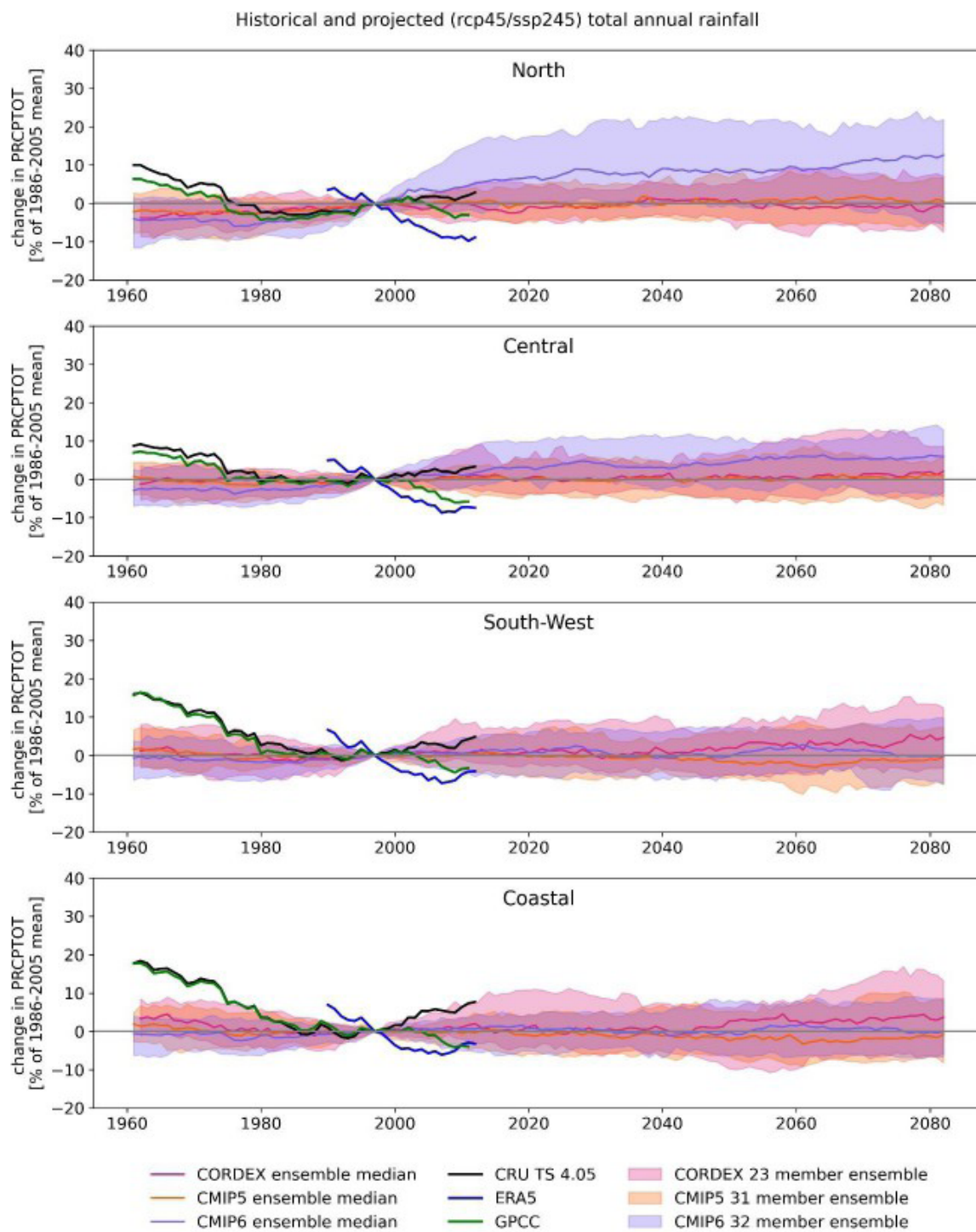


Figure e4 | Projected change in mean monthly precipitation by mid-century for the climate zones.

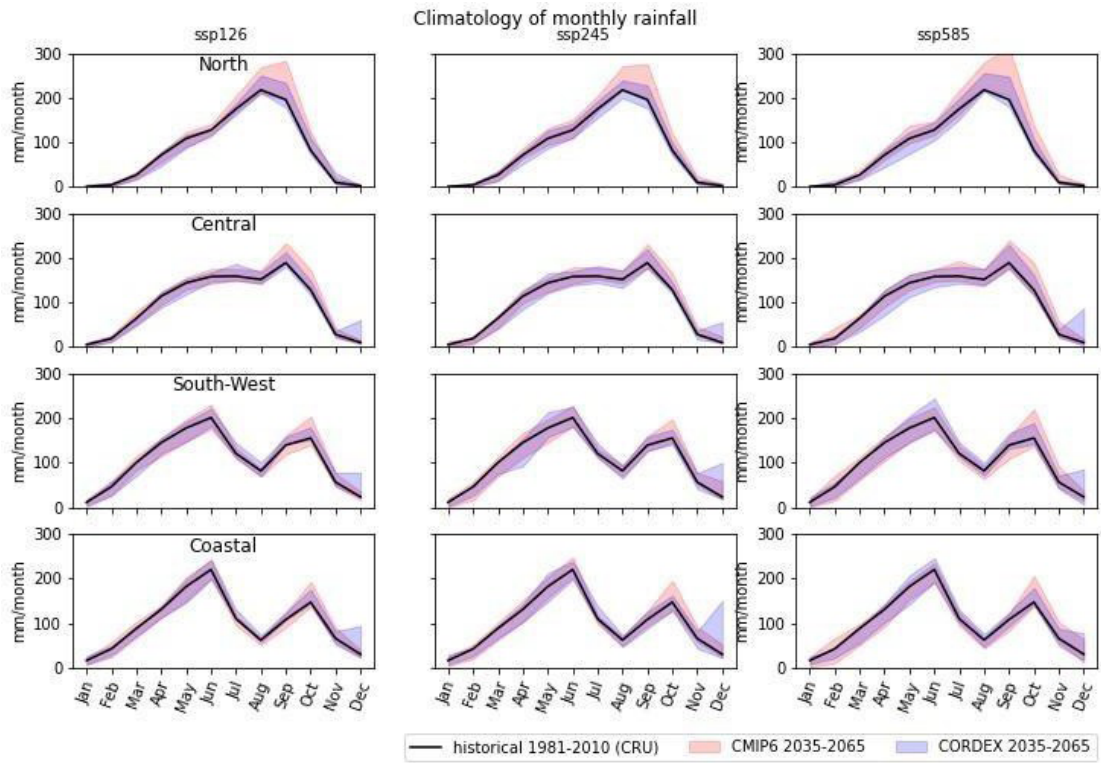
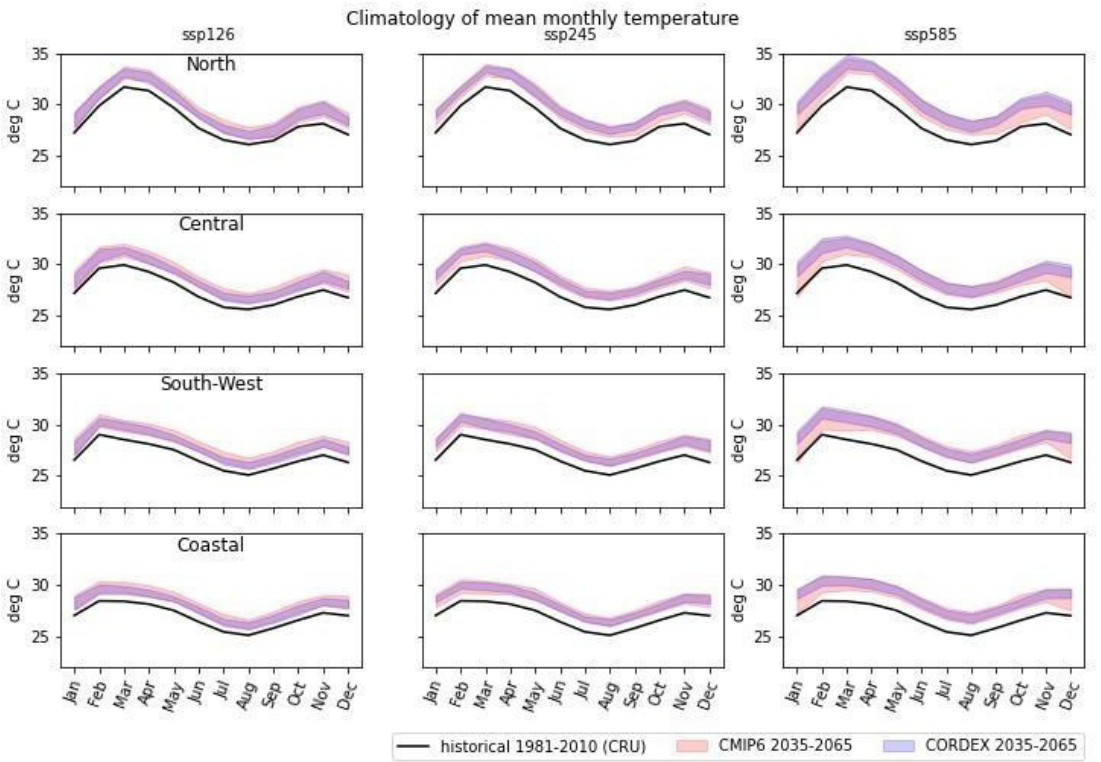


Figure e5 | Projected change in mean monthly temperature by mid-century for the climate zones.



1. Introduction

1.1. Background and Context

The Government of Ghana, through the Environmental Protection Agency (EPA), under the auspices of the Ministry of Environment, Science, Technology, and Innovation (MESTI), has successfully obtained a grant from the Green Climate Fund (GCF) for a three-year project to build capacity to advance National Adaptation Plan (NAP) process in Ghana. The United Nations Environment Programme (UNEP) is the Delivery Partner, supporting and overseeing the project implementation.

The project entitled “**Enhancing multi-sector planning and capacity for effective adaptation in Ghana**” is being implemented by a small project team headed by a National Coordinator. The NAP project seeks to support multi-sectoral, medium- to long-term adaptation planning and budgeting in Ghana and promote the integration of climate change adaptation issues into development planning processes and policies. Systems for developing and sharing climate risk and vulnerability information will be reinforced, and sustainable financing mechanisms for climate change adaptation initiatives are set to be developed. This specific study is intended to support multiple objectives of the NAP program.

Outcome 1 of the NAP project which is “Central level systems and processes for the development of the NAP developed” and Outcome 2 “District level systems and processes for the NAP developed” and specifically output 1.3 “Ghana’s downscaled sectoral climate change risk scenario analysis including socio-economic modelling developed” - the first activity is “Develop temperature and precipitation scenarios for the period 2020, 2040, and 2080 in line with best practice” and this is therefore fundamental to the risk assessments as well as Output 2.1 “Downscale sectoral climate change risk and vulnerability scenario analysis including socio-economic modelling developed in 5 climate zones”

Central to the preparation of effective climate change risk assessments (CCRAs) is the ability to understand the science behind the projections, manage the inherent uncertainty associated with them, analyse them using a variety of techniques and then communicate the impact risks clearly and concisely in an actionable format for decision makers and wider non-technical stakeholders and users.

This work is intended to support several national initiatives in Ghana, including the updated NAP. However, it must also be able to underpin the climate rationales necessary to secure international climate finance. This requires an understanding of the past and current climate impacts, the potential impact of future climate, with and without climate change and the disaggregation of other changes that are occurring in the area covered by the risk assessment, so that the impact of climate change can be isolated, analysed and presented in the form of a robust and clear climate risk narrative for Ghana.

1.2. Previous Downscaled Climate Scenarios for Ghana

1.2.1. Climate Change Studies Assistance Program (NCCSAP)

The first set of climate change projections and climate impact assessments developed for Ghana were in 2008 with support from the Netherlands Climate Change Studies Assistance Programme (NCCSAP).

These results were reported in the Second National Communications (2011) and in the Third national Communications (TNC). The scenario analysis used statistical downscaling approach using the results of nine combinations of global climate models (GCMs) and regional climate models (RCMs) projections generated for each of the twenty-two weather stations used in the downscaling. The Special Report on Emissions Scenarios (SRES) A1B emissions projection was used. Downscaled monthly averages of

rainfall and temperature for each of the twenty-two weather stations used in the baseline analysis were created for the period 1981-2010, 2021-2040, 2041-2060 and 2061-2080. Zonal change projections were created by averaging the results by climatic zone for each of the projected time periods.

Spatial flood and drought risk maps were created using geographic information system (GIS) techniques for a selected five Districts in the country spread across five ecological zones in the country.

1.2.2. Second National Communication Climate Risk Assessments

Climate risk assessments were carried out for fishing and health sectors during the Second National Communications (2011). Climate change risk assessments in the water, agriculture and coastal resources sectors were carried out during the preparation of the Initial National Communication (2000) using modelling [Watershed Response Model for Forest Management (WATBAL) for water balances, Crop Water and Irrigation Requirements Program (CROPWAT) and Crop Environment Resource Synthesis (CERES) models for crop impact modelling and spatial analysis for coastal impacts].

These previous downscaling studies and climate risk and vulnerability assessments were derived from previous generation climate model scenarios and require updating using latest best practice methods.

1.2.3. Forth National Communication (4NC) and Updated NDCs

Subsequently, additional downscaled scenarios have been derived for all Metropolitan, Municipal and District Assemblies (MMDAs) in Ghana as input to the Fourth National Communication (EAP, 2020) using data from the Coordinated Global Downscaling Experiment (CORDEX) which are based on the available CIMP5 climate models. These downscaled climate scenarios were then used to determine and overall level of exposure to the likely impacts of climate change for each MMDA, which was then combined with an assessment of the adaptive capacity of each MMDA in order to determine an overall climate change related risk for each MMDA in Ghana.

The 4NC considered the results from only five regional climate models (RCMs) selected from the CORDEX data but did consider both Representative Concentration Pathways, RCP4.5 and RCP8.5 emissions scenarios. As a result, they did not consider the full range of possible climate change futures necessary to inform decision making.

1.2.4. IPCC CIMP6 climate models and analysis of uncertainty

The IPCC released the results of the latest generation of climate models (CIMP6) in 2021. These results are available for each of the six administrative regions in Ghana and can be viewed by way of the World Bank Climate Knowledge Portal. As will be discussed later, however, these results are still only available at the scale of the GCMs and have not yet been downscaled to be used at more local level of analysis.

1.3. Purpose of this Report

This report is the deliverable from Task 2.1 of the Study and provides a description of future changes in climate for Ghana as an input to the process of development of climate risk and vulnerability assessments (CRVAs) and climate adaptation plans at national and sub-national levels. This study presents the results of analysis of downscaled temperature and precipitation scenarios for the periods 2030-2040, 2050-2060 and 2070-2080 in line with best practice at the national level initially and then applied to ten priority MMDAs as shown in Figure 1.

The resulting downscaled climate scenarios will also be used to support Climate Change Risk Assessments (CCRA) for two of the MMDAs shown in Figure 1, namely Tamale and Sekondi-Takoradi.

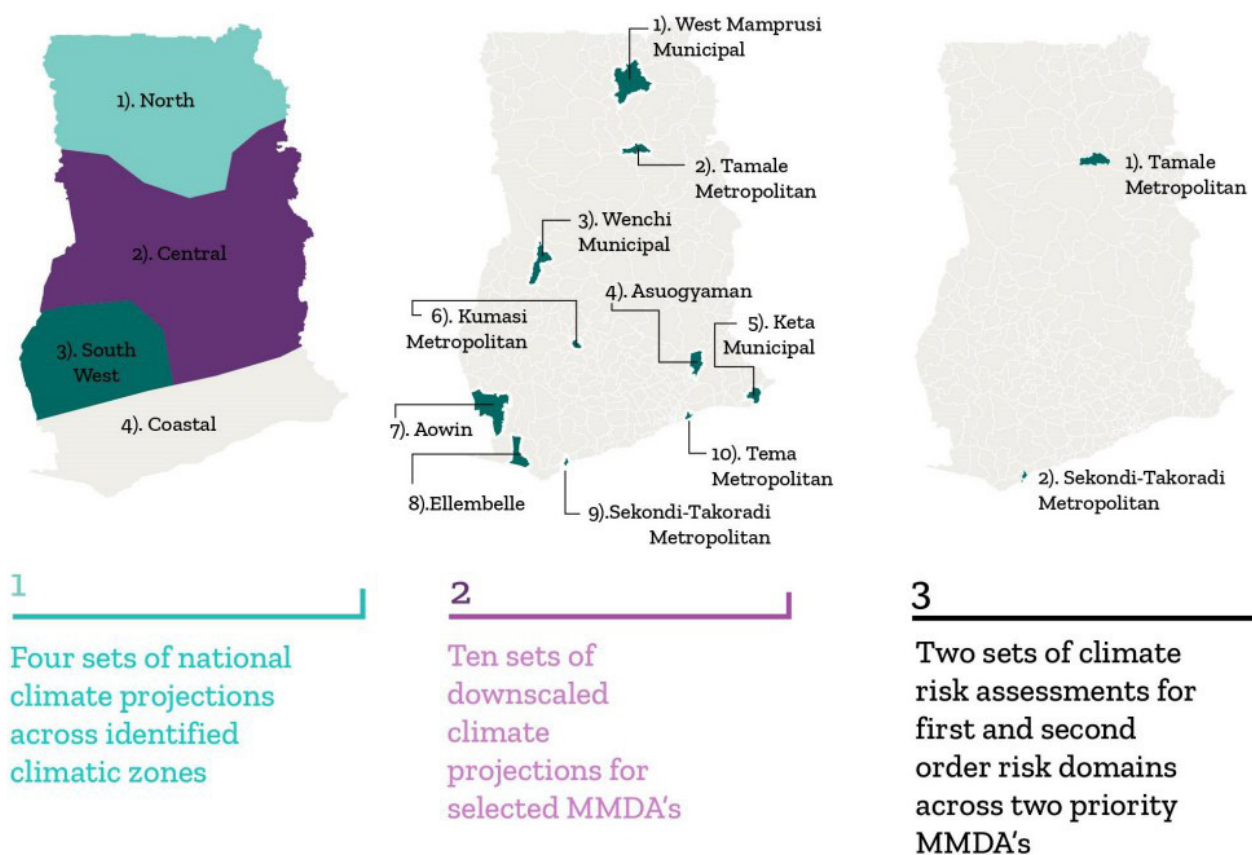


Figure 1 | Spatial scale of key deliverables

2. Approach and Methodology

2.1. Overview of Global Emissions Scenarios

The International Panel on Climate Change (IPCC) has used several greenhouse gas (GHG) scenarios for the six Assessment Reports to date, reflecting the state of the science at each stage. Early projections, including before the IPCC commenced work, simply used two model runs, one with GHG concentrations set at historical, pre-industrial, values, the second with a doubling of that value. Models were run over sufficiently long periods to achieve simulated climatic steady state and differences between the two runs assessed. A slightly more sophisticated approach was to increase GHG concentrations by 1% per year, normally until reaching doubling. Both approaches were required in order that projections might be made in lieu of any information in the early research on possible future GHG concentrations, but both are still in use as straightforward methods to inter-compare models and to assess impacts of changes in model formulations. All approaches to date are shown in Table 1.

Table 1 | Approaches taken sequentially in generating climate scenarios using Global Climate Models

CO ₂ Doubling (Steady State simulations)	Early work and used in all IPCC Assessments
1% increase in CO ₂ per annum (Transient simulations)	Early work and used in all IPCC Assessments
SA90 – Scenario A of 1990 (Business as Usual) (there was also SB90, SC90 and SD90)	First IPCC Assessment Report and its Supplement
IS92 – IPCC Scenario (there was IS92a to IS92f)	Second and Third Assessment Reports
SRES – Special Report on Emissions Scenarios (to 2100) (see Table 2)	Third, Fourth, Fifth, and Sixth Assessment Reports
RCPs – Representative Concentration Pathways (to 2100, but have been extended to 2300)	Fifth and Sixth Assessment Reports
SSPs – Shared Socioeconomic Pathways (see Table 3)	Sixth Assessment Report

The first attempts at a more realistic view of future GHG concentrations were prepared for the First IPCC Assessment Report of 1990 – SA90 (Scenario A 1990), SB90, SC90 and SD90, the latter three being modifications around the Business-As-Usual estimate of SA90 on which most modelling research was focused (for pragmatic reasons – limitations of computer time). An improved set was developed for the Supplement to the First Assessment Report of 1992 and for the Second Assessment Report of 1995 – IS92a, IS92b, ..., IS92f (IPCC Scenario 1992a, etc.), but it was in preparation for the Third Assessment Report of 2001 that a major step forward was made by developing storylines quantified through the use of Integrated Assessment Models (complex computer models covering industry, commerce, economics, population, etc., including relatively simple climate modules), published in 2000 in the Special Report on Emissions Scenarios (SRES). The main SRES Scenarios are shown in Table 2, which includes a brief summary of the related storylines. In principle highest emissions are to be expected under A2, in which the objective is to promote economic growth within a competitive environment (regional decision making) as opposed to B1, lowest emissions, with globally coordinated decision making focussed on environmental protection. In practice emissions were greater under A1FI than under A2 through most of the 21st Century. Again, for reasons of limited computer time, most projections and results reviewed in the Third Assessment Report (AR3) focused on A1B, A2 and B1.

Table 2 | Summary of the storylines used in the SRES Scenarios

SRES Scenario	Basis of storyline
A1FI (fossil fuel intensive)	Global decision making; economic growth priority
A1T (technology-based generation)	
A1B (balanced between fossil fuels and technology)	
A2	Regional decision making; economic growth priority
B1	Global decision making; environmental protection priority
B2	Regional decision making; environmental protection priority

A new approach was taken in the Fifth Assessment Report (AR5) of 2013/14, in which Relative Concentration Pathways (RCPs) were used; RCPs are based on future radiative properties of the atmosphere under various GHG concentrations but without an underlying storyline, in other words from a pure scientific perspective. Four RCPs have been used to create projections in CMIP5, namely RCP2.6, RCP4.5, RCP6.0 and RCP8.5. These RCPs reflect progressively higher numbers indicating greater GHG emissions and concentrations. In straightforward terms:

- RCP8.5 is roughly equivalent to A1FI
- RCP6.0 is roughly midway between A2 and B1
- RCP4.5 is roughly equivalent to B1
- RCP2.6 introduces lower emissions than in any SRES Scenario, with net anthropogenic emissions ceasing by about 2070.

According to calculations based on CMIP5, net emissions must cease at some stage during the 21st Century if the below 2°C target set by the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) as defining dangerous anthropogenic interference in the climate system is not to be breached. There is perhaps also a marginal possibility under RCP4.5. The recent IPCC AR6 indicates that cessation should be achieved sooner than under RCP2.6, and a growing number of countries are now announcing plans to achieve net-zero emissions by 2050, or earlier. Subsequently a more aspirational target of keeping global temperatures to below 1.5°C has been emphasised at the 2021 Glasgow meeting of the IPCC.

A further update that combines both the scientific perspective of the RCPs with socioeconomic considerations has been introduced for CMIP6, with results appearing in the AR6. Shared Socioeconomic Pathways (SSPs) build on the RCPs by re-incorporating socioeconomic considerations through pathways; the scientific perspective remains in the RCPs. There are 5 SSPs, summarised in the Table 3 below, each of which in principle can be combined with one of the RCPs, although in practice high emissions RCPs will not be combined with low emissions SSPs and *vice versa*. Each combination of SSP and RCP is entitled by SSP-RCP, for example SSP1-2.6. Three new RCPs have been included in the mix, a high emissions RCP7.0, a low middle-of-the-road emissions RCP3.4, and an ultra-low emissions RCP1.9. Priority projections for CMIP6, Tier 1, have been defined for most SSPs, together with some Tier 2 priorities as listed in Table 3.

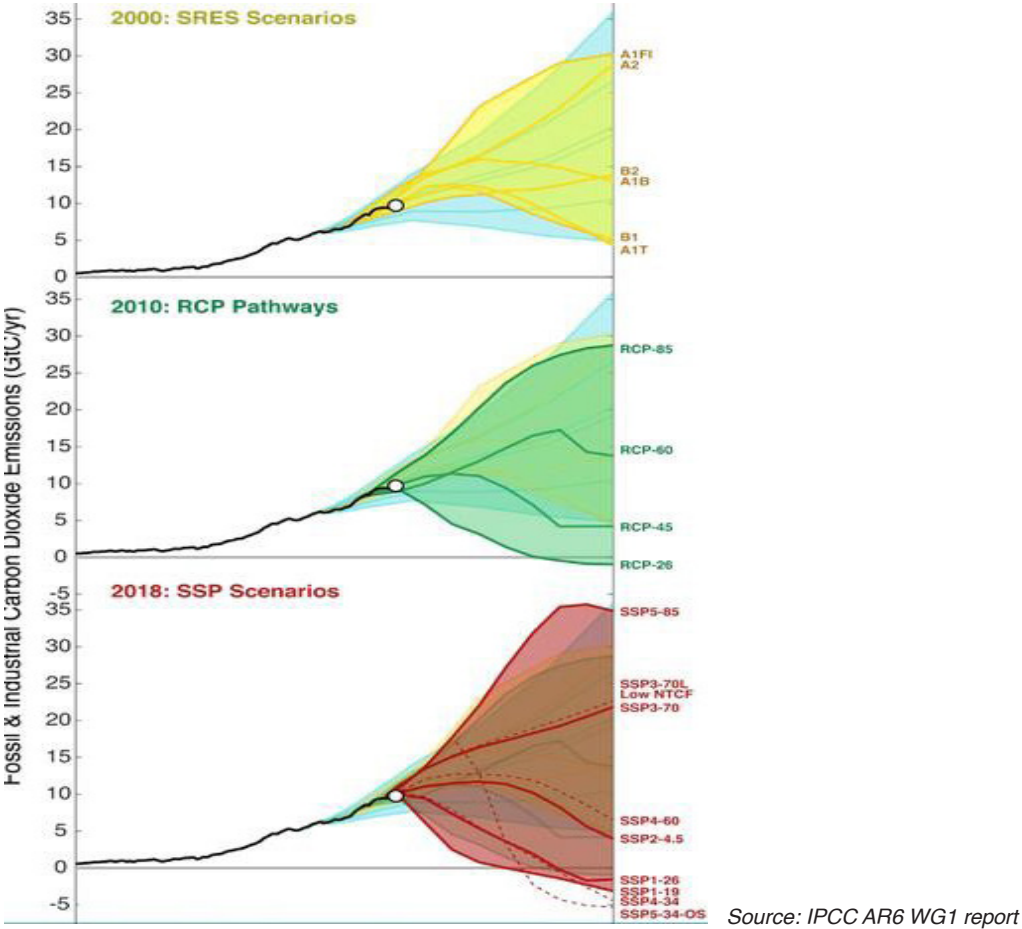
Table 3 | Summary of the storylines used in the SSP Scenarios

SSP Scenario	Basis of storyline	Tier 1	Tier 2
SSP 1	Sustainability (Taking the Green Road): Low challenges for mitigation (resource efficiency) and for adaptation (rapid development)	SSP1-2.6	SSP1-1.9
SSP 2	Middle of the Road: with intermediate changes for both mitigation and adaptation	SSP2-4.5	-
SSP 3	Regional Rivalry (A Rocky Road): High challenges for mitigation (regionalised energy/land policies) and for adaptation (slow development)	SSP3-7.0	-
SSP 4	Inequality (A Road Divided): Low challenges for mitigation (global high-tech economy) but high challenges for adaptation (regional low-tech economies)	-	SSP4-3.4; SSP4-6.0
SSP 5	Fossil-Fuelled Development (Taking the Highway): High challenges for mitigation (resource/fossil fuel intensive) but low challenges for adaptation (rapid development)	SSP5-8.5	SSP5-3.4

There is no objective manner in which an 'optimal' emissions scenario might be selected, much depending on international agreements and national actions. The pessimistic view, based on currently observed emissions, is that the higher scenarios are likely to be followed. The optimistic view is that negotiations under the UNFCCC will succeed in meeting the 2°C (or preferably the 1.5°C) target, and thus RCP2.6 currently is the most appropriate on which to base planning (all SRES Scenarios are too high from the perspective of the 2°C target), unless it is assumed the target will be missed.

Source: IPCC AR6 WG1 report

Figure 2 | Emissions of Carbon Dioxide under different scenarios for different generations of projections



2.2. Analysis of uncertainty in future climate scenarios.

The context and objectives of this study, as well as the character of available data and information impose several implications to the methods and the overall framing of the analyses presented in this report. The issue of uncertainty is crucial to understanding past and future climate change, especially when designing adaptation strategies that will benefit both present and future socioeconomic situations.

The most recent climate report from the IPCC, IPCC AR6 (2021) has concluded that it is certain that human activities are contributing to increases in global warming. How fast global warming and how global warming will translate into changes in *local scale* is far more difficult to foresee due to uncertainties involved in prediction of future climate, but also of future greenhouse gas emissions and the extent of societal response and mitigation activities. Any information related to the future conditions of natural and social systems has uncertainties that users of this information should be aware of.

The IPCC (Chen et al., 2021) define four sources of uncertainty that limit the detail of regional climate projections:

- a) **Radiative forcing uncertainty or scenario uncertainty:** Future radiative forcing is uncertain due to as-yet-unknown societal choices that will determine future greenhouse gas emissions;
- b) **Climate response uncertainty or model uncertainty:** structural differences between models and how they respond to external forcing, arising from choices made by individual modelling centres during the construction and tuning of their model;
- c) **Natural and internal climate variations:** the fact that a projection of climate is uncertain at any given point in the future because of unpredictable natural factors such as variations in solar activity and volcanic eruptions
- d) **Interactions between variability and radiative forcings:** the fact that there are interactions between radiative forcings and climate variations, such as influences on the phasing or amplitude of internal or natural climate variability.

The adopted practice of accounting for these uncertainties is through considering a range of possible future emission scenarios associated with different socio-economic trajectories (source a above), considering an ensemble of climate models instead of individual ones (sources b and c), and continuous improvement of climate models (source b, c and d). The framework of model equiprobability that considers that different climate models generate equally plausible future climates is commonly accepted (McSweeney et al. 2015; Creese, Washington and Munday, 2019), although frameworks based on model evaluation and screening are also used. Those frameworks centre around rejecting “bad” models or projections rather than attempting to identify the “best” ones, but face problems of lack of objectivity of acceptance-rejection criteria and limited reduction of uncertainty in the “screened” ensemble of models/projections (Hawkins and Sutton, 2011; McSweeney and Jones, 2016).

Considering the above, the approach of using all available models for evaluating future climate is increasingly being adopted. In addition to that, projections of the “multi-model multi-method multi-generation” “grand” ensemble (CORDEX, CMIP5 and CMIP6, which capture different generations and different nature of model) are evaluated, in an effort to distinguish interpretations and conclusions that are robust across a range of sources from those that are method specific. In case of differences –the final interpretation is made based on expert knowledge of the nature of the considered methodologies and their ability to simulate climate processes in the region derived from literature studies.

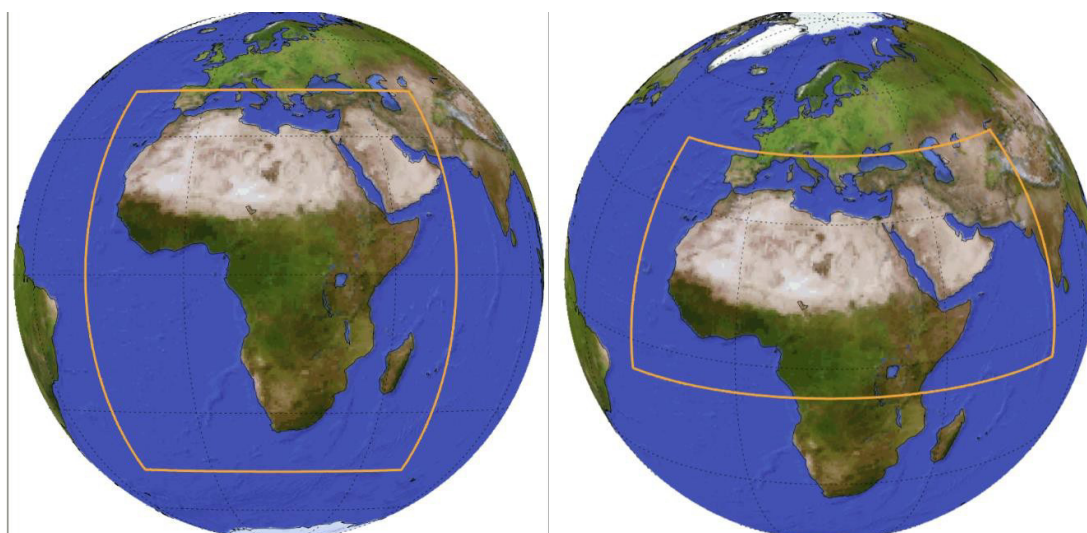
Finally, while in the context of the broad overview of the robustness of climate projections three ensembles are analysed, considering CORDEX data to be *downscaled*, i.e. appropriate for expressing climate signals at *spatial scales relevant to local impacts and adaptation actions*. This is so, because CORDEX data, in contrast to the CMIP5 and CMIP6 ensembles, are technically the output of the dynamical downscaling process, where climate projections of CMIP5 GCM ensemble of spatial resolution in the order of 1 to 2.5 deg (~100-250km)

are used to force regional climate models (RCMs) operating at spatial resolution of 0.22deg (~25km) and 0.44deg (~50 km).

It is worth noting in this context that while CORDEX data downscale the previous generation of climate projections, i.e. CMIP5 ensemble, there is currently no dynamically downscaled projections available for the most recent generation of climate projections, i.e. CMIP6. In view of the above, the approach adopted here, i.e. the “multi-model, multi-method, multi-generation” approach provides means of using CORDEX data as a basis for adaptation measures in an informed and defensible manner.

The CORDEX projections, of necessity covering smaller areas than the global CMIP projections, have been developed for several individual continental areas, with two of these, Africa, and Middle East/North Africa (MENA), including Ghana (Figure 3). The selection process of representative models, described later, used all projections from both CORDEX domains (although in the event only RCMs from the Africa domain were selected).

Figure 3 | The CORDEX Africa Domain (left) and the CORDEX MENA Domain (Right)



2.3. Overview of the Approach to Analysis of Uncertainty

For the analysis of future climate projections, two different, but related approaches have been used:

- **Self-Organising Map (SOM)** these types of analyses are intended to identify, firstly, the characteristic “pathways” of future climate thus schematizing the broad uncertainty of projections in the form of several distinct scenarios and the probability that these might be realised, and secondly, to identify individual projections (or models) that are representative of these pathways.
- **Plume plots:** These are intended to visualize the evolution of the historical and future climate, with explicit presentation of uncertainty of projections across three different ensembles, i.e., CORDEX, CMIP5 and CMIP6. These figures are the basis for evaluation of robustness of the downscaled (CORDEX) projections against GCM ensembles (CMIP5 only), as well as visualization of the range of future climates as projected by the analysed ensembles.

These two approaches have been combined to provide a better understanding of the uncertainty associated with climate projections for the different hydro-climatic zones and MMDAs across Ghana.

Based on this analysis individual climate model projections are identified which describe each of the possible future scenario pathways. These can then be used to provide additional downscaled climate scenarios from the CORDEX dataset to support the national and sub-national level risk assessments.

2.4. Data used for the SOMs and Plume Plots Analysis

The following observational and reanalysis datasets are used to evaluate the agreement of the model ensemble with historical climate:

- CHIRPS – a blended satellite-station rainfall dataset providing daily rainfall over the period of 1981-present at 0.25 deg spatial resolution
- CRU 4.05 – gridded station-based data products including monthly rainfall, minimum and maximum air temperature over the period of 1901-2021 at 0.5 deg spatial resolution
- GPCC 2021 – gridded station-based rainfall dataset providing monthly rainfall over the period of 1900-2021 at 0.5 deg resolution
- ERA5 – the latest high resolution atmospheric reanalysis from ECMWF and represents the state of the art in observational assimilation coupled to dynamical modelling. ERA5 provides a set of 3-hourly atmospheric variables including rainfall and air temperature at spatial resolution of 31 km over the period of 1979 to present.

Out of the above, CRU and GPCC have data at monthly resolution and contain data spanning a long-term period (~1900-present) and are thus suitable for the analyses of long-term variability patterns.

These are also datasets that are based on interpolation of data from stations and thus reflect only the quality and spatial coverage of the available information which is limited in many regions of the global including Africa. Both datasets were considered suitable for analyses in the context of climate change (Atiah, Amekudzi et al. 2020). CHIRPS rainfall data, in contrast, are satellite-based (although with station input) and cover only the recent, post-1981 period. It has been shown, however, that CHIRPS is superior to other available satellite-based rainfall data products in capturing rainfall seasonality and interannual trends (Atiah, Amekudzi et al. 2020) and rainfall extremes (Atiah, Tsidu et al. 2020)

The following datasets are used for evaluation of future climate uncertainty using the Plume Plots:

- CMIP6 ensemble of GCM projections. It is the primary basis of the climate projections analysed under the IPCC 6th assessment report released in 2021/2022.
- CMIP5 ensemble of GCM projections. It is the primary basis of the climate projections analysed under the IPCC 5th assessment report released in 2013-2014
- CORDEX-Africa ensemble of dynamically downscaled projections. CORDEX regional climate models provide all relevant atmospheric data at a grid resolution of around 0.44° horizontally (~50km) and CORDEX-Core ensemble at a grid resolution of around 0.22° horizontally (~25km). The CORDEX models are driven by CMIP5 GCMs and are used in the IPCC AR5 report.

In these analyses plume plots are prepared only for 0.44° CORDEX-Africa, as this ensemble includes a relatively large number of members (13-22). CORDEX-Core (0.22°) has much fewer members (e.g. RCP4.5

has only 1 member), as so is not include in the plume plots. It is to be noted, however, that “representative” models identified through the SOM analyses may include CORDEX-Core models.

The CMIP5 (and consequently CORDEX) experiment utilised RCPs (Van Vuuren et al., 2011) to describe different future global emission scenarios and their associated radiative forcing scenarios. Here is included the RCP 4.5, which represents a middle of the road scenario with fairly strong mitigation action culminating in an increase of 4.5W/m^2 in radiative forcing by 2100, as well as RCP 8.5 (increase of $\sim 8.5\text{W/m}^2$ of radiative forcing by 2100) which represents a very pessimistic scenario with very little mitigation of emissions into the future, and the RCP 2.6 (increase of $\sim 2.6\text{W/m}^2$ of radiative forcing by 2100) which represents an optimistic scenario with intensive mitigation that has increased probability of achieving targets of the Paris Agreement, i.e. global warming at 1.5 deg C at the end of 2100.

While deploying a different approach to future emissions scenarios, called Shared Socio-economic Pathways (SSPs, O'Neill et al. 2014), SSPs are aligned with the CMIP5 RCPs in terms of the expected level of radiative forcing but based on specific socio-economic storylines. In this case we analyse SSP5-8.5, SSP2-4.5 and SSP1-2.6 as equivalent to RCP 8.5 and RCP 4.5 and RCP 2.6 respectively.

2.5. Overview of Self Organising Maps (SOMs)

Self-organising maps (SOMs) is a technique using Artificial Intelligence (AI) approaches that groups similar values within the full set of possibilities as laid out in a data set such as the ones in the CMIP5 projections. It is a type of neural network but in the manner in which it is used in this report it might be easier to think of it as a clustering technique but with the important difference that no assumptions regarding inherent statistical distributions are made. A typical clustering approach is designed to identify a group of similar values within a dataset and to separate these from other equivalent groupings within the data set, which is exactly the objective here inasmuch as it is to identify one or more future pathways of the climate each supported by the larger numbers of projections.

SOMs has been in frequent use in recent decades to explore distributions of values within large data sets. The main reason that SOMs analyses may be used in preference to clustering is that most clustering techniques assume a fundamental underlying statistical distribution of the data within a set, normally Gaussian. That assumption immediately constrains the manner in which the groupings are identified in way that might be inappropriate for a particular data set. Certainly, examination of regional rainfall distributions across the CMIP5 projections indicates that these are not necessarily Gaussian. With SOMs no assumptions are made regarding underlying statistical distributions, and the approach allows the dataset itself to define the groupings within, something appropriate for the examination of CMIP5 rainfall (and probably other variables, such as evaporation and wind speeds) distributions.

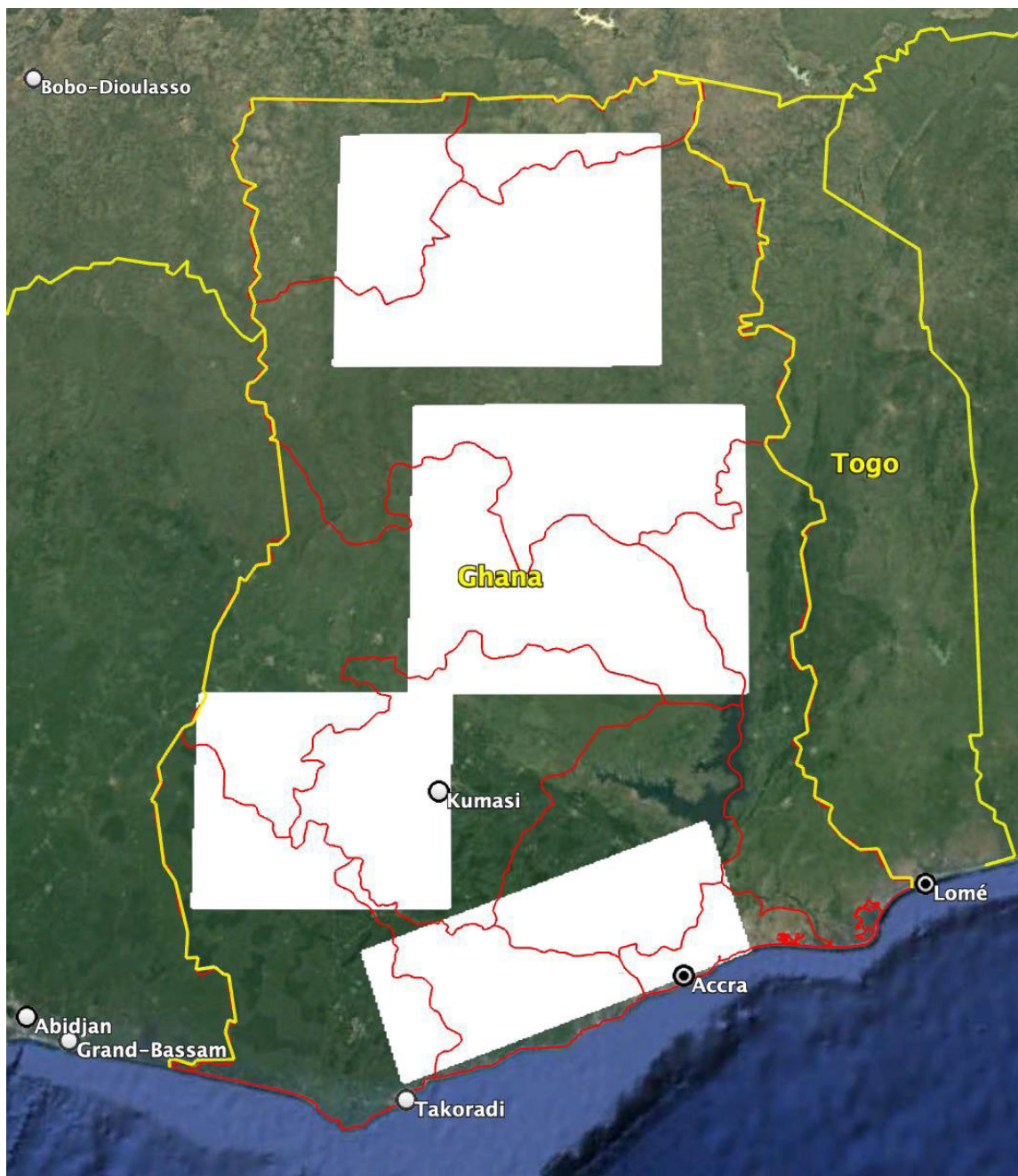
The resulting outputs of the SOMs analyses require interpretation, and that interpretation may differ between analysts. For that reason, all direct results from the analyses are presented in **Appendix A** in order that the interpretations offered might be assessed by the reader and alternate interpretations considered where appropriate. Note that the SOMs are calculated using data from three sub-periods across the remaining 21st Century within a single analysis (for each RCP independently), as the objective is to identify pathways of climate change through the coming Century and not just for the individual sub-periods. This also results to differences in the representativeness of individual pathways and ultimately the individual models selected, at different time periods in the analysis.

2.5.1. Areas used in the SOMs analysis

The country was separated into four homogenous climate zones based on an analysis of rainfall patterns, with each zone having a common rainfall climatology. In order to calculate the SOMs, rectangular domains were defined as shown in Figure 4 to represent each of these four homogenous climate zones across Ghana; the domains were selected to be as large as reasonable to maximise statistical stability in the calculations while at the same time being as small as possible so as not to cross any boundaries in terms of rainfall climatology. The four domains used for the SOMs analysis were based on the regional clustering analysis described later and are shown in Figure 4. These four homogenous climate zones were identified through the analysis of trends in observed climate data as well as similarity in the expect

changes due to climate change. As a result, they are expected to respond in a similar what to future climate change under the different global emission scenarios which can then be translated to expected changes at the level of individual MMDAs or for individual eco-region.

Figure 4 | The four climate zones used in the SOMs calculations. From top to bottom these are North, Central, Southwest, and Coastal.



2.5.2. The Self-Organising Maps (SOMs) Calculations

Two types of climate model have been used in the SOMs analysis:

- the GCMs run using common background conditions, including emissions scenarios, and stored in the CMIP (Climate Model Intercomparison Project) data sets; and
- the RCMs stored in the CORDEX data set.

For each of the four zones SOMs were calculated independently using 4, 6 or 8 nodes¹, the larger numbers of nodes used when necessary to help clarify results. Only GCM projections from the CMIP5 set (used extensively in preparing the 2013-14 IPCC AR5) were included in these calculations.

Independent calculations were made for the three emissions scenarios, for RCP2.6, for RCP4.5 and for RCP8.5. RCP6.0 was not used as no CORDEX RCMs are available for this specific emission scenario.

Either three or four climate scenarios were identified for each emissions scenario for each of the four climate zones (Figure 5) that represent the pathways most supported by CMIP5 projections, and therefore the pathways most likely to occur.

To each an estimated likelihood has been attached based on the number of model scenarios in each of the clusters. Calculations were carried out in terms of projected annual temperature and rainfall changes for each domain averaged across three future periods centred on 2035, 2060 and 2080.

In addition to the most-supported pathways, two further pathways have been added that represent the reasonable upper and lower extremes (UE and LE) across all of the CMIP projections which thus, in combination with the other pathways, provide a total of five or six climate change scenarios for each zone and for each RCP, that cumulatively cover the major possibilities according to the CMIP5 projections. The logical outcome of this would be around 66 scenarios, but by identifying scenarios common to one or more zones or scenario, these have been reduced to a total of only 16 scenarios.

2.5.3. Identification of Regional Climate Models (RCMs)

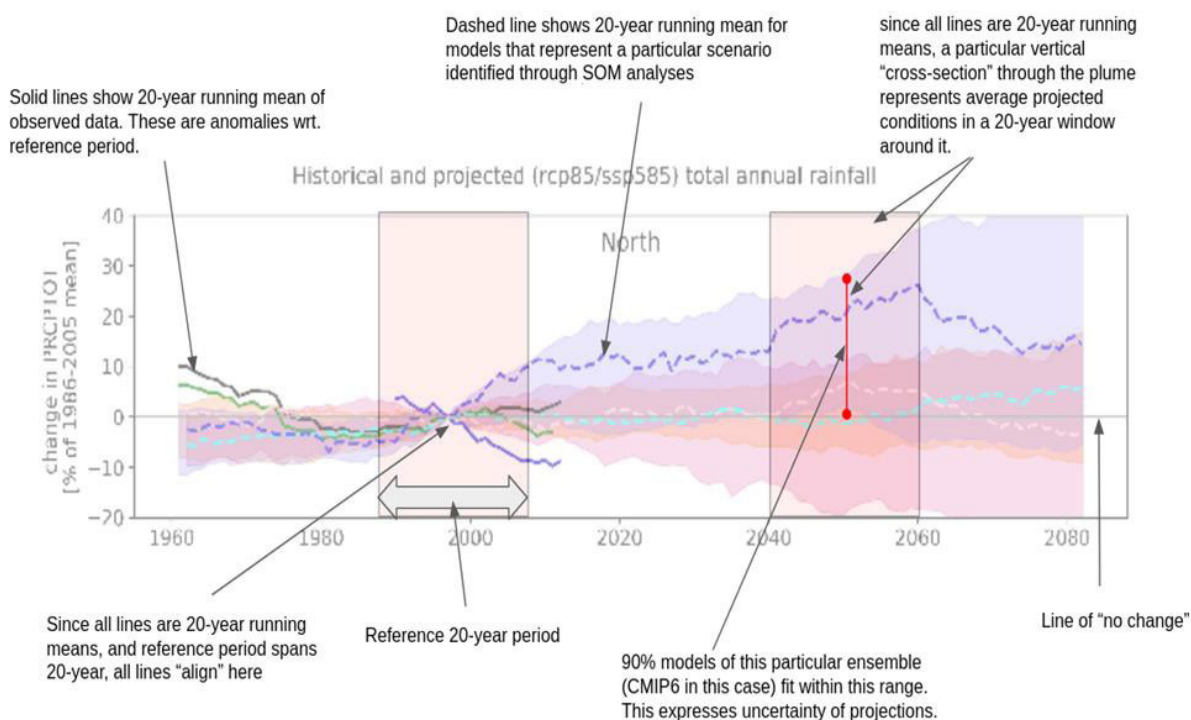
Once the representative pathways have been determined for each climate zone, the RCM that most closely replicates the temperature and rainfall changes in each scenario was identified from the CORDEX data set (using root-mean-square distances). CORDEX projections, of necessity covering smaller areas than the global CMIP projections, have been developed for several individual continental areas, with two of these, Africa, and MENA, including Ghana. The selection process used all projections from both CORDEX domains (although in the event only RCMs from the Africa domain were selected).

2.6. Overview of Plume Plots Analysis

Plume plots (example shown in Figure 5) visualise the evolution of the historical and future climate, with explicit presentation of uncertainty of projections across all three analysed ensembles, i.e., CORDEX, CMIP5 and CMIP5. These figures are the basis for evaluation of robustness of the downscaled projections against the full range of the GCM ensembles, as well as visualisation of the range of future climates as projected by the analysed ensembles. In addition to the ensemble projections and historical time series of observations (or using re-analysis data) data, the “representative” climate model scenarios identified through the SOM analyses, described above, are also presented in plume plots. Those scenarios are illustrated through the “trajectory” of the model that represents the given scenario.

1 Node – the arbitrarily-selected starting point used to seed the SOMs calculations

Figure 5 | Explanation of the elements of a plume plot. The shaded areas show the range (10th percentile to 90th percentile) of the different model ensembles including both CIMP5 and CIMP6 results.



Individual plume plots have been prepared for two sets of regions within Ghana:

- **Four broad climate zones** that are characterised by a relative homogeneity of climate in terms of its interannual variability, as such units are likely capturing different climate drivers and thus different responses to anthropogenic forcing. The process is described in the Results section.
- a set of **ten priority MMDAs** selected through a consultative process between stakeholders.

2.7. Downscaled Climate Scenarios for Individual MMDAs

Individual plum plots and comparison of the climate scenarios are produced for each of the priority MMDAs. The results of the selection of representative models can then be used to derive information on any other relevant climate related variable that is needed to support the climate risk assessments for individual priority MMDAs and also to information analysis of other sectors in support of the NAP.

2.8. Development of an Updated Climate Risk Narrative

Based on the results of the SOMs and the Plum Plot analysis, summaries of the expected impacts are prepared, and these are included in the form of short climate risk narratives for each region. In addition, the resulting climate risk narrative for each of the four regions is then applied to the priority MMDAs located within in each region and adjusted slightly based on the specific results for that MMDAs. The results of both the regional and individual MMDAs are then used to inform initial climate risk narratives which consider the potential implications for communities and key economic sectors in each MMDA.

The updated Climate Risk Narratives for Ghana will be included in a subsequent report and summary for policy makers (Task 3.1) as well as the individual climate risk assessments for the two priority MMDAs (namely Tamale Metro and Takoradi) to be produced under Task 3.4 and Task 4.1 respectively.

3. Results

3.1. Selection of priority MMDAs

A selection committee was put up by the NAP PMU to select the 10 MMDAs for the consideration of the project steering committee (PSC). Members of the Committee were carefully selected and was chaired by the NAP Project Coordinator. The Committee made an initial shortlist of 18 MMDAs based on a relevant selection criterion. The initial list was further trimmed down to 10 by the PSC.

The NAP working group consisted of the following members:

- Mr. Kingsley Amoako (MOFA)- Mmember
- Mr. Eric Afornope (MLGRD)- Member
- Ms. Angela Kwashie (UNCDF/LoCAL)- Mmember
- Dr. Daniel Benefoh (UNFCCC FP/EPA)- Member
- Dr. Antwi-B. Amoah (NAP PC/EPA)- Chairman

This initial shortlist of potential priority MMDAs are given in Table 4.

Table 4 | Initial shortlist of potential priority MMDAs

#	MMDA	#	MMDA
1	Tema Metro	10	Asuogyaman (Akosombo) District
2	Ahanta West	11	Nzema east
3	Ellembelle Municipal	12	Sekondi Takoradi Metro
4	Offinso north	13	West Mamprusi Municipal
5	Keta Municipal	14	Sissala East
6	Sogakope	15	Enchi (Aowin) District
7	Kumasi Metro	16	Wenchi District
8	Tamale Metro	17	Kintampo
9	Awutu	18	Nkrunza

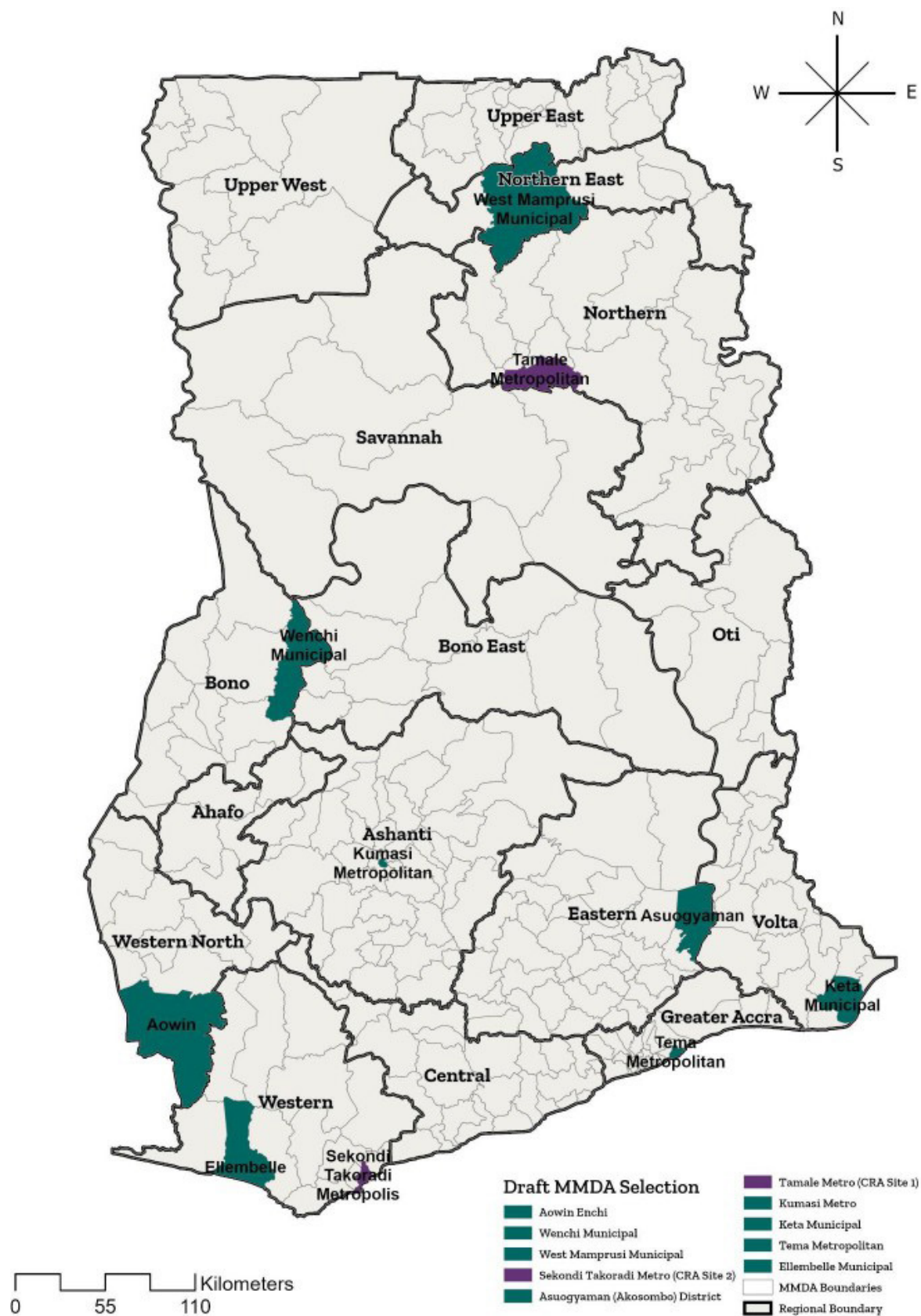
From this list of eighteen shortlisted MMDAs, it was further refined following a NAP PSC meeting on Tuesday the 22nd of March 2022. The shortlist and refined list of ten was then presented to the Cross Sectoral Policy Group (CSPG) at a workshop on the 23rd of March 2022. This presentation was led by Dr Antwi-Boasiako Amoah from the Environmental Protection Agency. Dr Amoah went through each of the eighteen MMDA's and explained the rational for the final refined list of ten MMDA's. Following some debate from CSPG members, the final list of ten priority MMDAs was decided upon and given in Table 5 and in Figure 6.

Table 5 | Final list of priority MMDAs

#	MMDA	#	MMDA
1	Tema Metro	6	Asuogyaman (Akosombo) District
2	Ellembelle Municipal	7	Sekondi Takoradi Metro
3	Keta Municipal	8	West Mamprusi Municipal
4	Kumasi Metro	9	Enchi (Aowin) District

5	Tamale Metro	10	Wenchi District
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Figure 6 | Priority MMDAs for downscaled climate scenarios

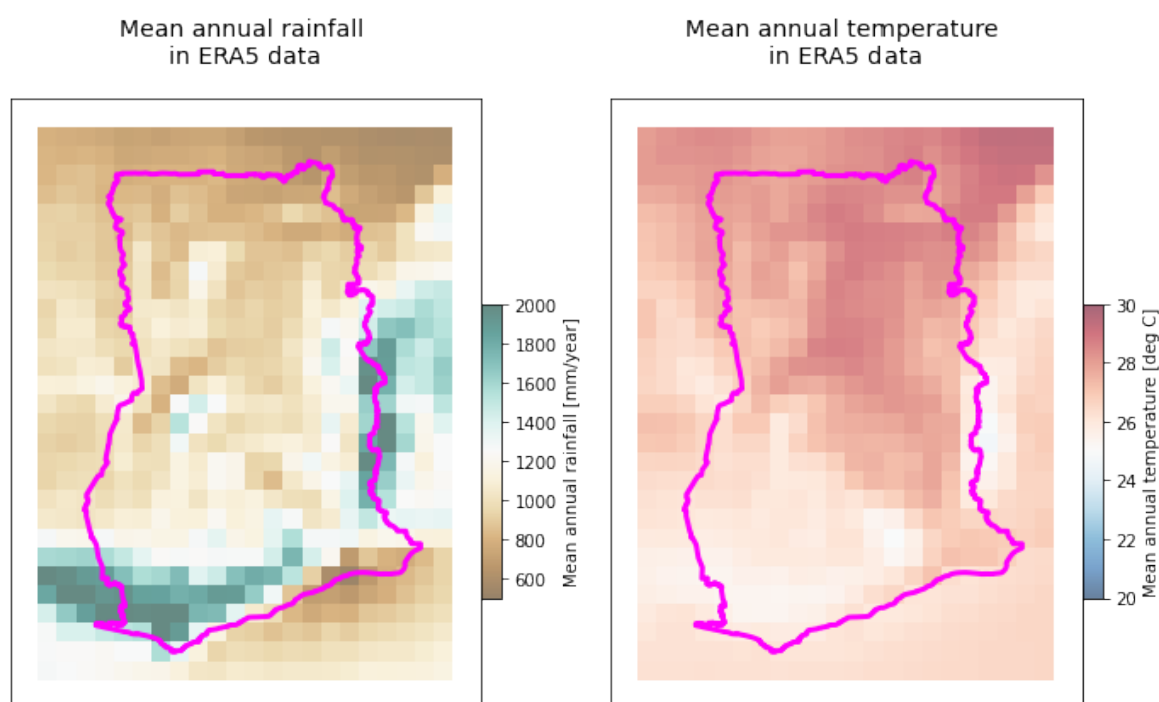


3.2. Defining Homogenous Climate Zones

Preliminary analyses of distribution of climatic zones were carried out based on historical ERA5 and downscaled CORDEX climate simulations and projections data. The majority of Ghana falls into Koppen-Geiger Tropical Savannah category, while its south-west has Tropical Monsoon climate. The climate is characterised by a high mean annual rainfall, with a general south-north gradient, with south-west of the country which is strongly influenced by the west African monsoon receiving in excess of 1800 mm/year and north-west of the country receiving 800-1000 mm/year (Figure 7).

Additionally, there is a narrow region of lower rainfall along the south-east coast.

Figure 7 | Mean annual rainfall and mean annual temperature based on ERA5 datasets



The northern part of the country experiences a unimodal May-September rainfall season whereas the southern part is characterised by a bi-modal distribution of rainfall with the major rainfall season from April to July and minor rainfall season from September to November. Mean annual temperature is characterised by a slightly different pattern to that of rainfall – a south-west to north-east, with lowest temperatures in the south-west. Apart from the general regional patterns, rainfall and temperature reflect the main geographical regions of Ghana:

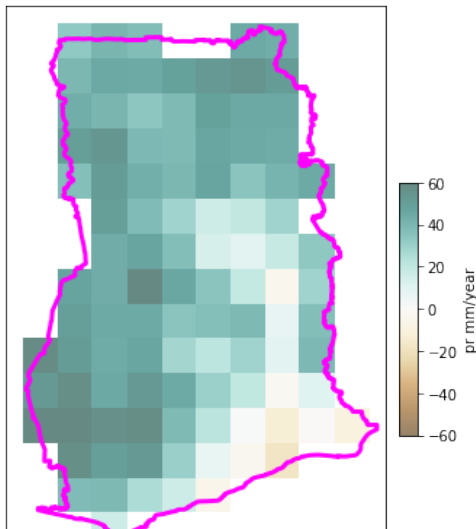
- coastal belt is characterized by lower rainfall in the east and higher in the south-west
- Ashanti Plateau in the south-west, that is characterized by higher rainfall and lower temperatures than the Volta basin located to the north-east of it in central-east Ghana
- Akwapim-Togo mountain range on the border with Togo, characterized by higher rainfall
- high plains in the north characterized by drier and hotter climate than the rest of the country.

Homogeneity of climate change signal was analysed by hierarchical clustering of time series of annual rainfall and temperature in CORDEX data, using the standardized 24-model ensemble median for each of the two

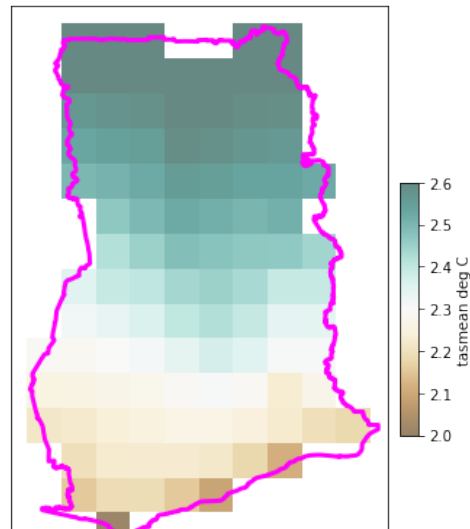
variables. This approach identifies homogeneity in terms of temporal pattern (pace and direction) of change rather than the magnitude of change (Figure 8).

Figure 8 | Change in mean annual rainfall and mean annual temperature in the 2040-2071 period compared to 1981-2010 period as projected by the median of the CORDEX ensemble

change in pr between 2040-2071 and 1981-2010
ensemble median in cordex data



change in tasmean between 2040-2071 and 1981-2010
ensemble median in cordex data



Results are presented in Figure 9 and in Figure 10 for various numbers of clusters.

Figure 9 | Results of clustering of time series of CORDEX ensemble median of mean annual temperature (coded as TG) - standardized values. That clustering captures similarity in terms of year-to-year variability of temperature, without consideration given to magnitudes.

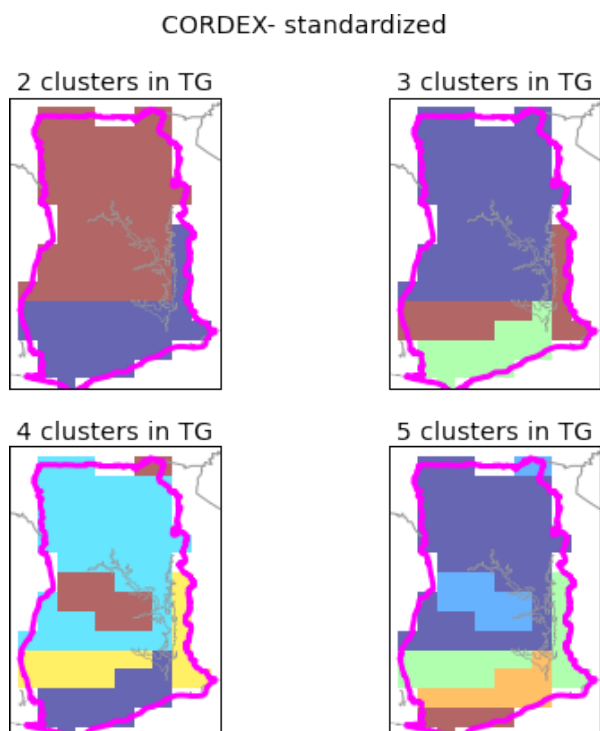
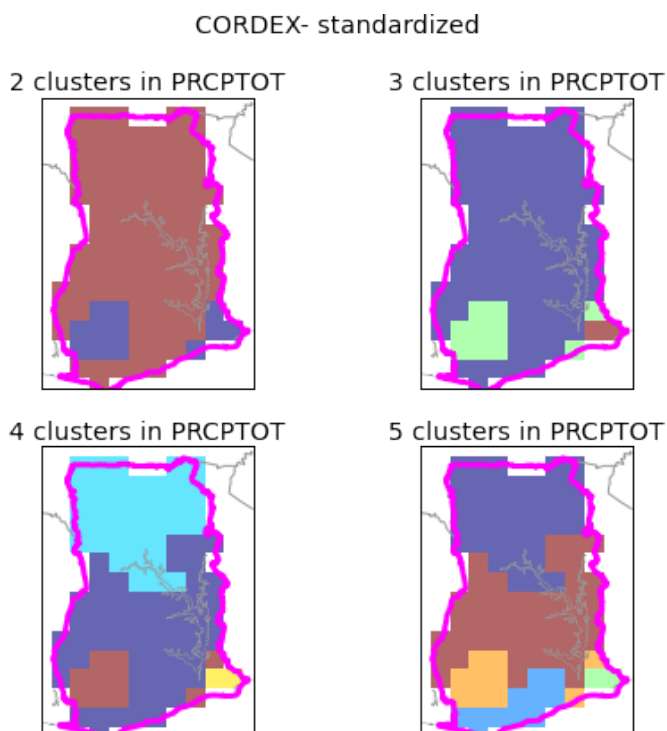
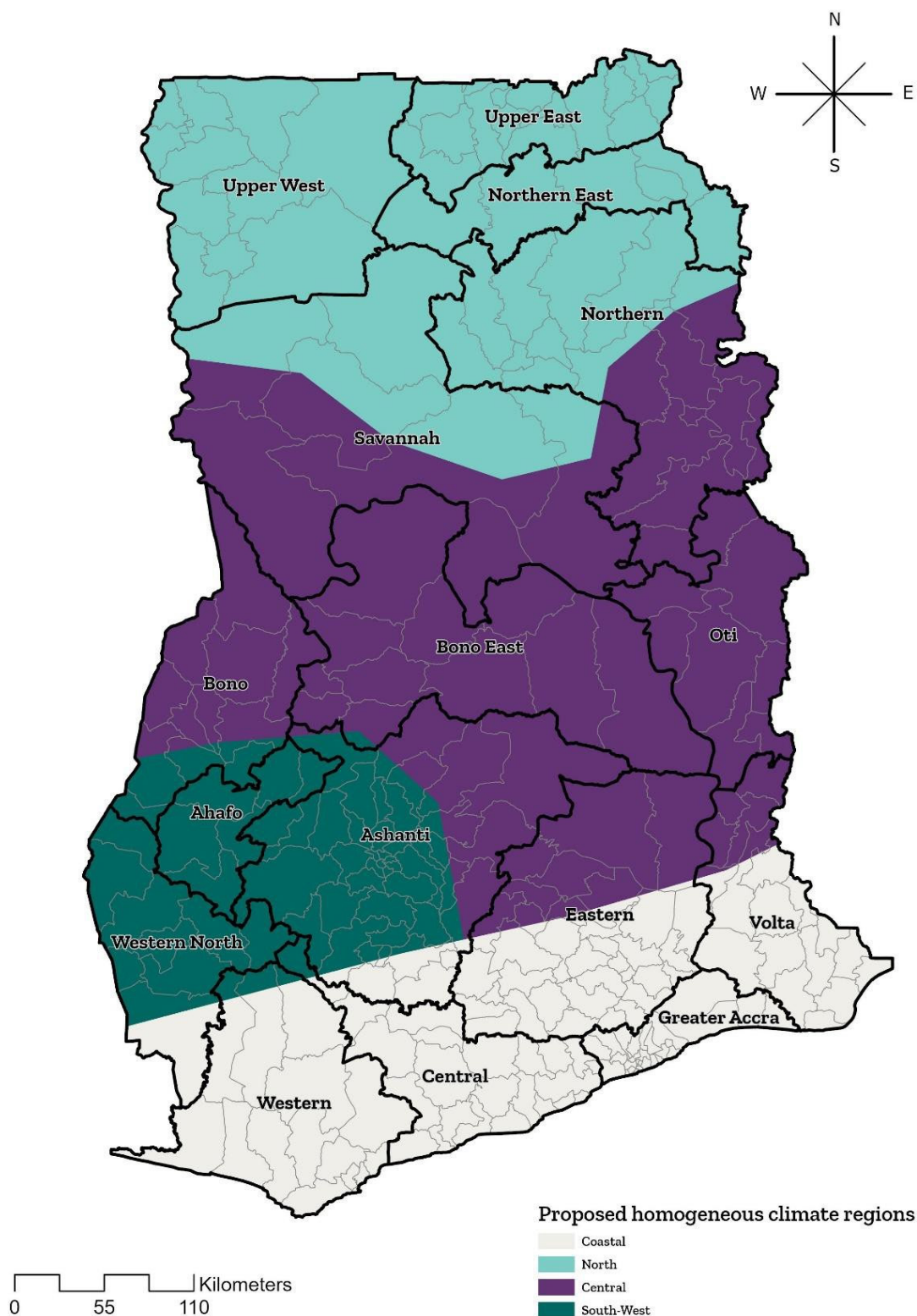


Figure 10 | Results of clustering of time series of CORDEX ensemble median of annual rainfall (coded as PRCPTOT)- standardized values. That clustering captures similarity in terms of year-to-year variability of rainfall, without consideration given to magnitudes.



Clustering of rainfall identifies zones that align with the main geographic regions, i.e. the coastal region, Ashanti plains, Volta basin and northern plains. Clustering of temperature identifies zonal patterns (bands aligning with latitudes) but maintains the main tenets of the geographical regions described above. Based on these analyses, four climate zones – North, Central, Southwest and Coastal – were identified for the analyses of climate change impacts. The four climate zones are presented in Figure 11.

Figure 11 | Recommended climate zones for synthesizing climate change projections in Ghana

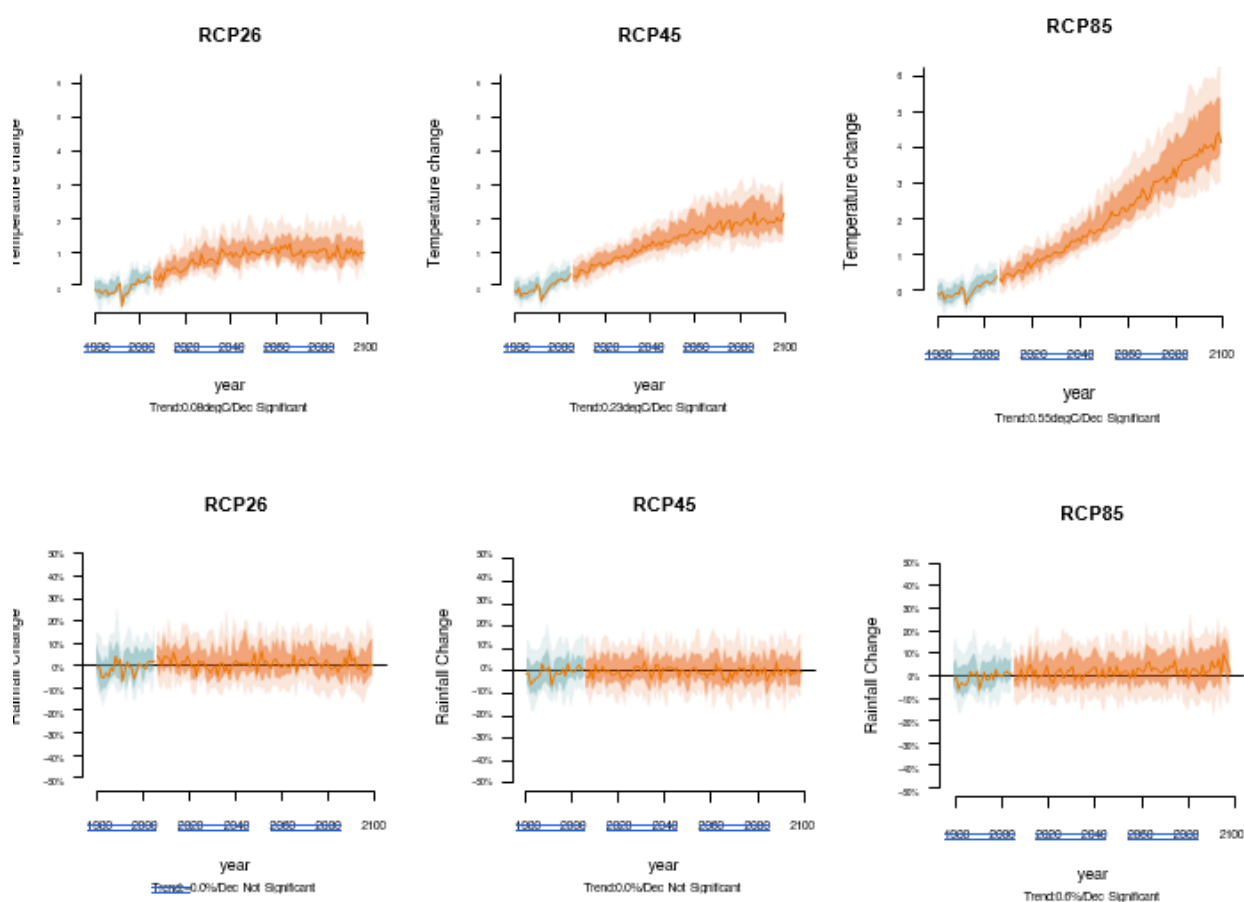


3.3. Results of Initial Analysis of CMIP5 Ensembles

3.3.1. Climate Change Impacts on Temperature and Rainfall

Time series of temperature and rainfall changes across each of the four climate zones have been calculated for RCP2.6, RCP4.5 and RCP8.5 up to 2100 using the full CMIP5 ensemble. The results, however, are so similar for all climate zones that only those for the Central Zone are illustrated in the figures below.

Figure 12 | Time series of temperature (top) rainfall (bottom) changes across the Central zone (see Figure 7) for RCP2.6, RCP4.5 and RCP8.5 up to 2100 using the full CMIP5 ensemble. Results for the other three zones are similar.



*Note: All changes have been calculated individually by model against simulations for the base period of 1986 to 2005, with those for temperatures in °C and those for rainfall as a proportional increase or decrease. Heavy shading indicates the 10th to 90th percentile ranges across the ensemble and light shading the two outer 5th percentiles, in blue for the base period, in orange for the projections. Central red lines indicate ensemble means. Trends to the end of the century have been assessed using the non-parametric Mann-Kendall statistic; all temperature trends are significant at the 5% level but mainly only those for RCP8.5 in rainfall trends (increasing trends) as summarised in the table below, with statistically significant trends in **bold italics** (temperature trends in °C/decade and rainfall trends in %/decade).*

The overall trends for the remainder of the century for each zone are summarised in Table 6.

Table 6 | Overall trends in climate for the remainder of the century in °C/decade and %/decade

	Temperature °C/decade			Rainfall %/decade		
North	<i>+0.09</i>	<i>+0.24</i>	<i>+0.57</i>	-0.1	+0.1	<i>+0.6</i>
Central	<i>+0.08</i>	<i>+0.23</i>	<i>+0.55</i>	-0.0	+0.0	<i>+0.6</i>
Southwest	<i>+0.08</i>	<i>+0.23</i>	<i>+0.52</i>	+0.1	+0.1	<i>+0.6</i>
Coastal	<i>+0.08</i>	<i>+0.22</i>	<i>+0.50</i>	-0.1	<i>+0.3</i>	<i>+0.8</i>

Note: Analysis based on average across all CIMP5 climate models, significance at the 5% level in italics.

The following observations are derived from the analysis of basic trends shown in the table above:

- **Temperature**

Temperature changes in all four zones are similar, all trends are statistically significant.

Under RCP2.6 the increases tend to plateau after mid-century; there is also some plateauing in the final two or so decades under RCP4.5 but temperatures increase throughout the century under RCP8.5, reaching an average rise of almost 4°C by the end of the century.

Projected temperature trends are strongest in the North Zone.

- **Rainfall:**

Only non-significant trends in rainfall are present for most zones under RCP2.6 and RCP4.5, with statistically significant positive trends only under RCP8.5

The strongest and most significant trends in increasing rainfall are in the Coastal Zone.

3.3.2. Future Trends in Return Period Values

Values of the highest annual average temperatures and of lowest and highest annual rainfall totals with specific return periods (i.e. probabilities) have been determined for the historical base period of 1986 to 2005 and for the remainder of the century under RCP2.6, RCP4.5 and RCP8.5 and for each climate zone. The return periods considered are for 1 in 25, 50, and 100 years. Given the relatively limited data points available the values should be viewed as indicators rather than interpreted as precise values.

No statistical tests for significance have however been applied to data in any of the tables given below.

In terms of the change in the return period values for average annual temperature (Table 7), the highest average annual temperature values are in the Northern Zone, decreasing southwards in the Central and Southwestern Zones, but with a slight rise in the Coastal Zone. The average annual temperature values for all return periods increase with increasing emission scenarios, with increases approaching 6°C (or +20%) for the 100-year return period average temperature in the Northern Zone under RCP8.5.

Table 7 | Highest annual average temperatures for different return periods under RCP2.6, RCP4.5 and RCP8.5 showing the absolute value (in deg C) and the percentage change from historical.

Period	Climate Zone	Average Annual Temperature (°C)			Relative Change (%)		
		25 Years	50 years	100 years	25 Years	50 years	100 years
Historical	North	28.2	28.5	28.8			
	Central	27.5	27.7	28			
	Southwest	26.7	26.9	27.2			
	Coastal	27.1	27.3	27.5			
RCP2.6	North	29.4	29.7	30.1	4.3%	4.2%	4.5%
	Central	28.6	28.9	29.2	4.0%	4.3%	4.3%
	Southwest	27.8	28.1	28.4	4.1%	4.5%	4.4%
	Coastal	28.1	28.3	28.6	3.7%	3.7%	4.0%
RCP4.5	North	30.5	31	31.5	8.2%	8.8%	9.4%
	Central	29.6	30.1	30.5	7.6%	8.7%	8.9%
	Southwest	28.8	29.2	29.6	7.9%	8.6%	8.8%
	Coastal	29	29.4	29.8	7.0%	7.7%	8.4%
RCP8.5	North	32.7	33.6	34.5	16.0%	17.9%	19.8%
	Central	31.8	32.6	33.4	15.6%	17.7%	19.3%
	Southwest	30.8	31.6	32.4	15.4%	17.5%	19.1%
	Coastal	31	31.7	32.4	14.4%	16.1%	17.8%

Changes in the return period values for dry years (i.e. lowest annual rainfall anomaly) are shown in Table 8 in terms of the percentage of the historical mean annual rainfall. For example, in the Northern Zone historically 22% of average might occur once in 25 years, and 18% once in 100 years. There is no clear trend in values with increasing emissions, any changes likely being within the noise, suggesting that the lowest totals during drier years are unlikely to differ much in future compared to the recent past.

Table 8 | Return period values of lowest annual rainfall under RCP2.6, RCP4.5 and RCP8.5.

Period	Climate Zone	Lowest Annual Rainfall Anomaly (%)	Relative Change (%)				
		25 Years	50 years	100 years	25 Years	50 years	100 years
Historical	North	22%	21%	18%			
	Central	20%	19%	17%			
	Southwest	20%	19%	17%			
	Coastal	23%	21%	18%			
RCP2.6	North	22%	20%	18%	0.0%	-4.8%	0.0%
	Central	19%	17%	15%	-5.0%	-10.5%	-11.8%
	Southwest	21%	20%	17%	5.0%	5.3%	0.0%
	Coastal	22%	20%	18%	-4.3%	-4.8%	0.0%
RCP4.5	North	22%	20%	18%	0.0%	-4.8%	0.0%

	Central	20%	18%	16%	0.0%	-5.3%	-5.9%
	Southwest	21%	19%	17%	5.0%	0.0%	0.0%
	Coastal	23%	21%	18%	0.0%	0.0%	0.0%
RCP8.5	North	22%	20%	18%	0.0%	-4.8%	0.0%
	Central	20%	18%	15%	0.0%	-5.3%	-11.8%
	Southwest	22%	20%	17%	10.0%	5.3%	0.0%
	Coastal	24%	21%	19%	4.3%	0.0%	5.6%

Changes in the return period values for wet years (i.e. highest annual rainfall anomaly) are shown in Table 9 in terms of the percentage of the historical annual rainfall. In this case there is a trend of a few per cent towards wetter years as emissions increase. For example, for the Northern Zone the historical 100-year return values has been estimated as 140% of average but increases to 148% under RCP8.5

Table 9 | Return period values of highest annual rainfall under RCP2.6, RCP4.5 and RCP8.5.

Period	Climate Zone	Highest Annual Rainfall Anomaly (%)			Relative Change (%)		
		25 Years	50 years	100 years	25 Years	50 years	100 years
Historical	North	126%	133%	140%			
	Central	124%	130%	136%			
	Southwest	123%	129%	136%			
	Coastal	125%	132%	138%			
RCP2.6	North	129%	136%	143%	2.4%	2.3%	2.1%
	Central	126%	132%	138%	1.6%	1.5%	1.5%
	Southwest	126%	132%	138%	2.4%	2.3%	1.5%
	Coastal	129%	136%	143%	3.2%	3.0%	3.6%
RCP4.5	North	128%	135%	142%	1.6%	1.5%	1.4%
	Central	124%	131%	137%	0.0%	0.8%	0.7%
	Southwest	125%	132%	138%	1.6%	2.3%	1.5%
	Coastal	128%	136%	143%	2.4%	3.0%	3.6%
RCP8.5	North	132%	140%	148%	4.8%	5.3%	5.7%
	Central	128%	135%	142%	3.2%	3.8%	4.4%
	Southwest	128%	135%	142%	4.1%	4.7%	4.4%
	Coastal	133%	141%	149%	6.4%	6.8%	8.0%

3.3.3. Future Trends in Likelihood of Exceedance Thresholds

The sequence of diagrams given below illustrate changes in likelihoods by decade through the coming century, according to the full CMIP5 ensemble, of annual average temperatures and of annual rainfall totals exceeding specific thresholds established over the base period of 1986 to 2005.

The diagrams are ordered first for the Northern Zone, then the Central Zone, the Southwestern Zone and the Coastal Zone. For each zone, temperature results are placed ahead of those for rainfall.

Temperature likelihoods indicate chances of exceeding two standard deviations (SD) above the historic average in the left-hand side, and three standard deviations (SD) on the right-hand side.

Rainfall likelihoods in the top left are for annual total being below the 25th percentile, top right below the 10th percentile, bottom left above the 75th percentile, and bottom right above the 90th percentile.

In all diagrams:

- Decades are indicated along the horizontal axes and likelihoods given along the vertical axes
- Solid curves give likelihoods for the specific threshold being exceeded in two successive years and dashed curves for three successive years
- Curves for RCP2.6 are in black, for RCP4.5 in purple, and for RCP8.5 in red
- Legends at the left indicate the trends in likelihoods for the two-year periods (three-year trends are in general similar), together with “true” if the trend is statistically significant at the 5% level according to the Mann-Kendall statistic.

The results for the analysis of annual temperature likelihoods are similar for all four climate zones:

- Most likelihood trends in the exceedance of annual average temperature thresholds are statistically significant, except for certain zones for two standard deviations under RCP2.6
- Likelihoods peak for two standard deviations over two successive years under RCP2.6 at around 70% in mid-century before declining somewhat through the rest of the century.
- Under RCP8.5 the likelihoods of exceeding the relevant thresholds reach 100% by mid-century (slightly later for three standard deviations), meaning that two successive years (and also three successive years) with annual temperatures in the current top ~16% and ~2.5% are almost certain every year (for two and three standard deviations respectively) from around mid-century.
- Similar curves of exceedance thresholds under RCP4.5 only reach 100%, or close to, for the Coastal and Southwestern Zones by the end of the century, but still reach >90% for the other two zones by the end of the century and between 80% and 90% for all zones by mid-century.

The results for the analysis of rainfall likelihoods may be summarised as:

- For the 10th percentile, i.e. the driest years, there are several statistically significant trends, all positive and suggesting an increased likelihood of 2-year sequences; the changes are most prominent later in the century in the Coastal and Southwestern Zones and under RCP8.5.
- Similar trends to those for the 10th percentile exist for the 25th percentile (less dry years), suggesting an increase in likelihoods of these lesser, but still significant, dry sequences in all climate zones, and again these are more prominently in the Coastal and Southwestern Zones.
- Conversely trends are generally positive in most climate zones for the wetter years within the 75th and 90th percentiles, again most prominently and significant under the RCP8.5 scenario.
- In general, the expected increase in both wetter and dryer years is relatively low for the first part of the century and only increasing towards the end of the century and general below 10% in total.
- In total the results suggest that the distribution of annual rainfall totals may widen across all climate zones, i.e. an increasing likelihood of both dryer and wetter years than the current climate

particularly under higher emissions and more so towards the wetter years (a result not inconsistent with those above for the return period values representing wetter and drier years).

Figure 13 | Expected changes in probability of exceedance of temperature and rainfall thresholds (defined for the base period) under different emissions scenarios for the North Zone

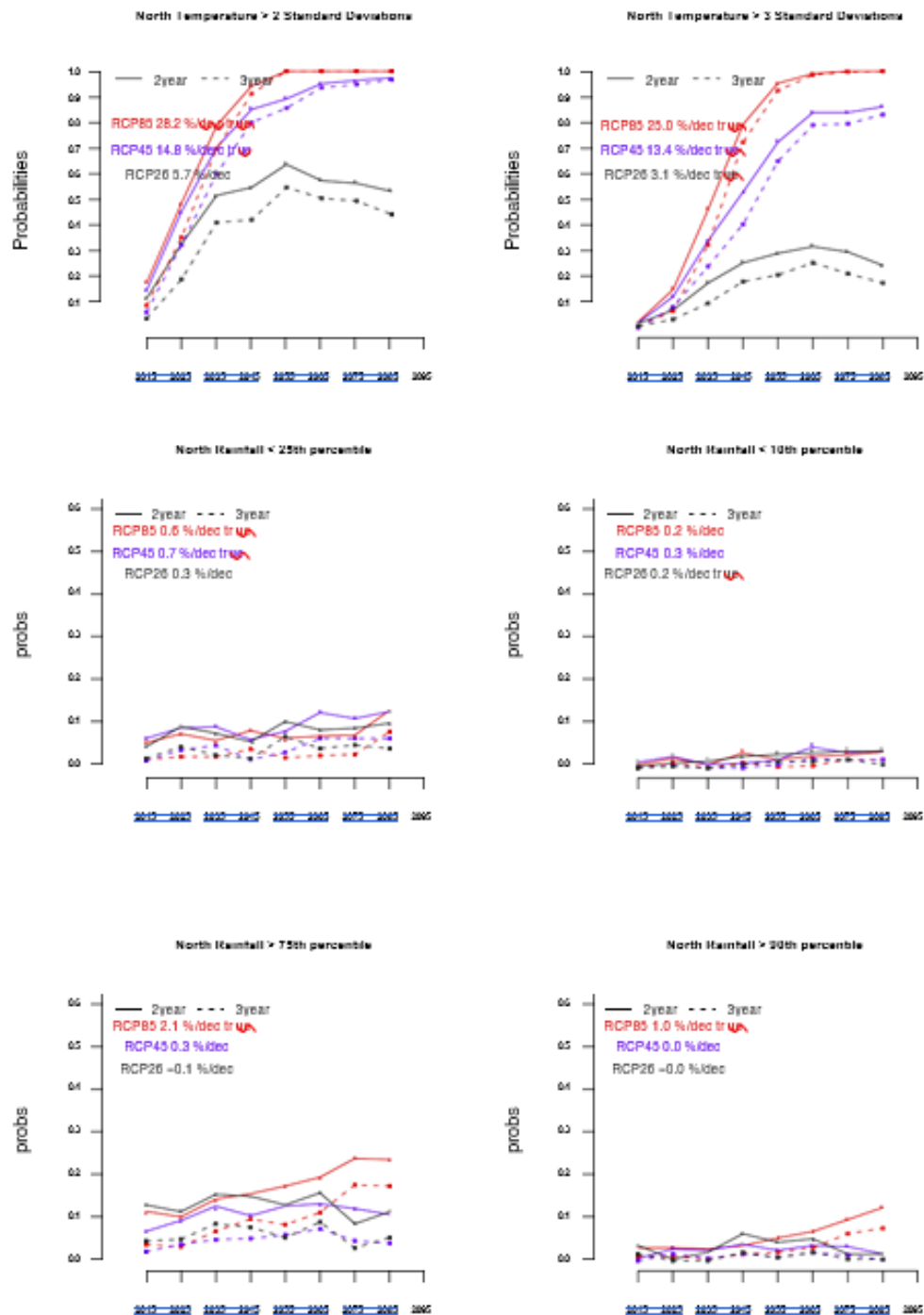


Figure 14 | Expected changes in probability of exceedance of temperature and rainfall thresholds (defined for the base period) under different emissions scenarios for the Central Zone

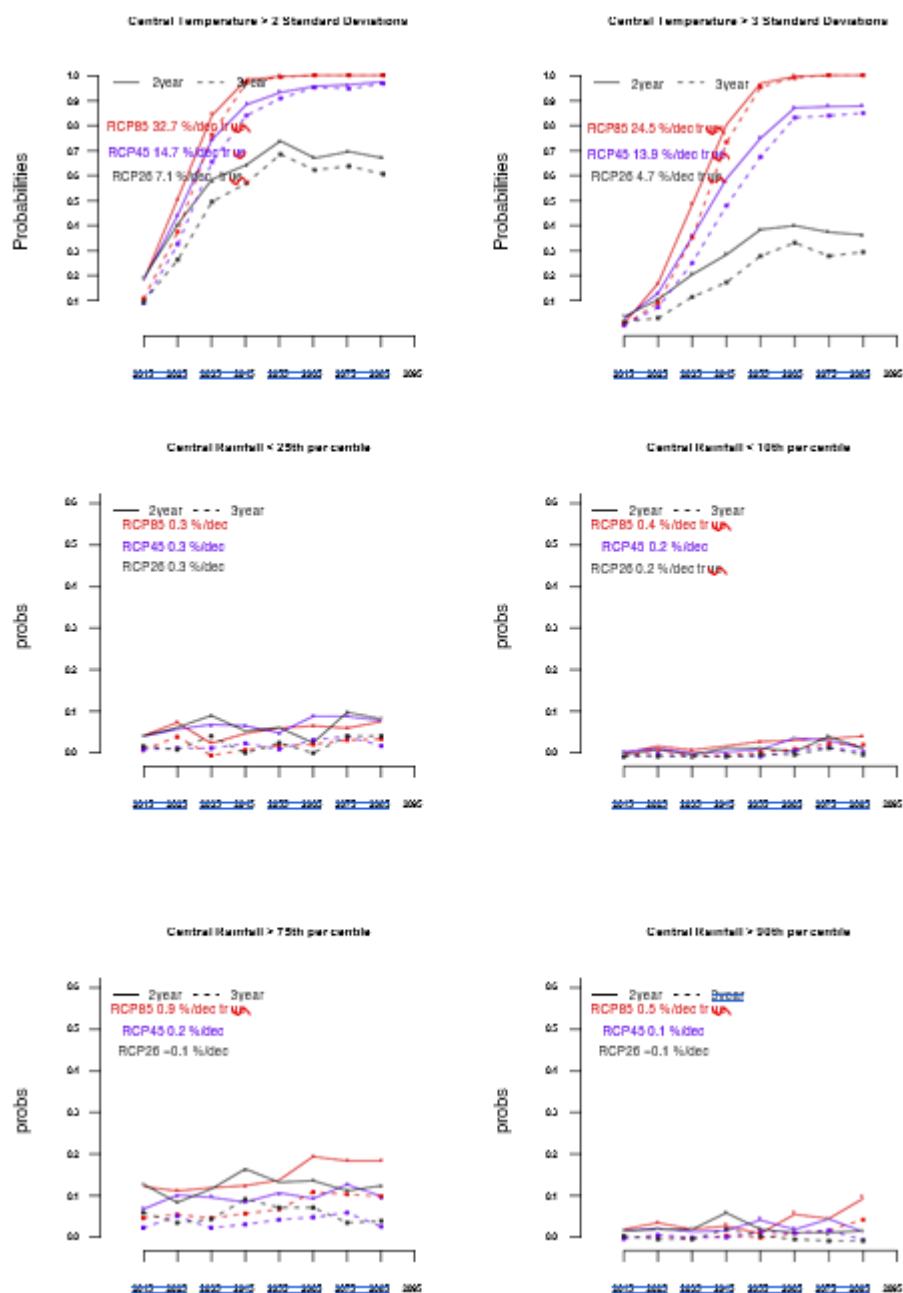


Figure 15 | Expected changes in probability of exceedance of temperature and rainfall thresholds (defined for the base period) under different emissions scenarios for the Southwest Zone

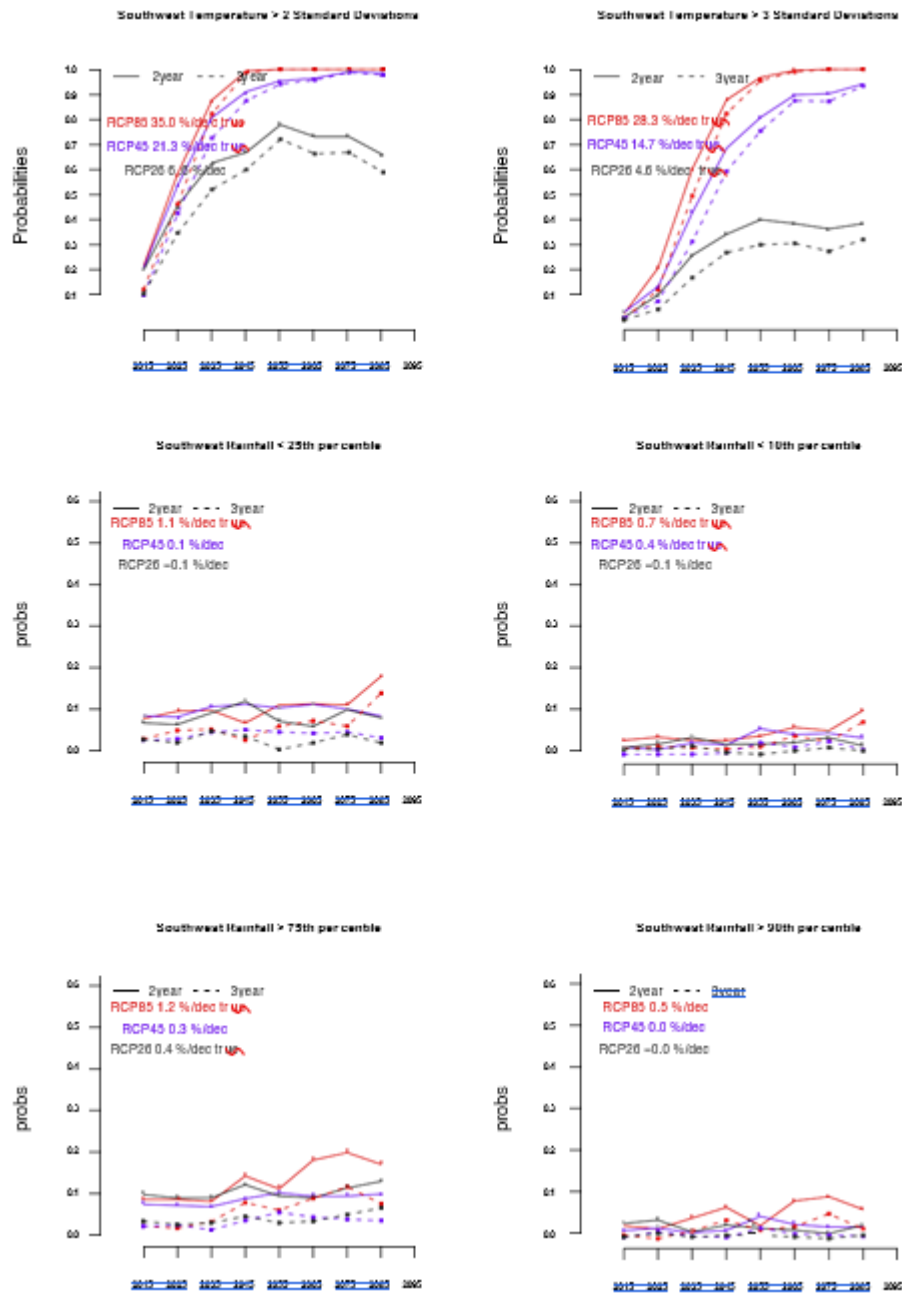
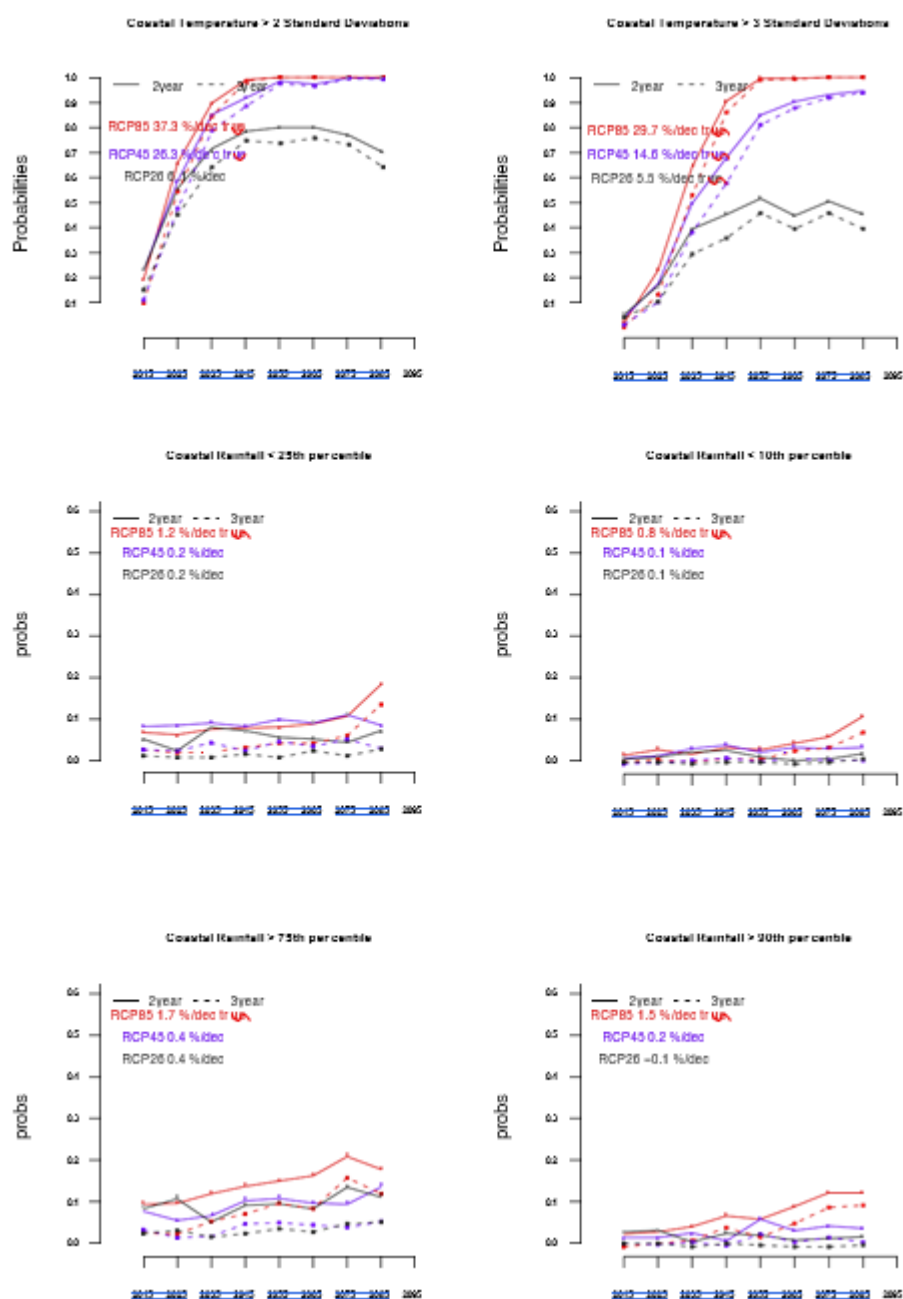


Figure 16 | Expected changes in probability of exceedance of temperature and rainfall thresholds (defined for the base period) under different emissions scenarios for the Coastal Zone



3.4. Results of SOMs Analysis

3.4.1. Overall Summary of SOMs Analysis Results

Following is a summary of the individual SOMs results, for different emission scenarios and for the four identified homogenous climate zones for Ghana, namely North, Central, Southwest and Coastal.

One word of caution in interpreting the results. In defining the pathways temperatures, have been assessed to the nearest 0.5°C change, rainfall to the nearest 5% change, and likelihoods to the nearest 5%. Readers may wish to review the recommendations to determine whether alternate judgments might have been made. Given this approach it is possible that one or two individual projections might suggest alternate pathways, but where so these tend to be outliers that do not support the majority of projections as summarised in the pathways. Because of the rounding of values, it is possible that likelihoods of specific events, such as a decrease in rainfall, might differ between the pathways and values estimated directly from the original projections. Also note that in determining the upper and lower extremes, UE and LE, of the CMIP5 projections, priority is given to outlying changes in rainfall. Had the focus been on outlying changes in temperatures different UE and LE pathways may have resulted.

3.4.2. Summary Results for RCP2.6 (All Climate Zones)

There are a total of 19 projections available for RCP2.6. In each case, all using 4 nodes, four separate pathways were produced. Using 6 nodes made no difference to the results in terms of pathways.

Temperature Impacts

Even by late century most pathways suggest average annual temperature increases up to about 1.5°C.

An increase of +2.0°C is suggested in single pathways for the North and Southwest Zones, but in both cases, this is related to little change in annual rainfall.

None of the UE and LE suggest temperature changes exceeding +1.5°C by the end of the century.

Rainfall Impacts

Most of the pathways point to either no change or to an increase in annual rainfall. The likelihoods of decreases in rainfall were assessed as 15% (about a 10% decrease) in the North and Central Zones and 10% (about a 5% decrease) in the Southwest Zone

The highest likelihood of a decrease, 30%, is for the Coastal Zone, but only for a decrease of 5%. None of the main pathways point to increases of more than about 5% in rainfall.

At most the UE and LE pathways indicated increases up to 10% and decreases up to 15% respectively with the latter in the North Zone only but otherwise 5% to 10%

Overall Summary

Under RCP2.6, the only emissions scenario offering a reasonable possibility of achieving the Paris Agreement, both annual temperature increases, and rainfall departures are relatively modest. Nevertheless, even a 1.5°C increase in temperature might lead to substantial impacts, for example on health, agriculture, water resources, etc. Perhaps the good news is that the likelihood of future decreases in annual rainfall totals is relatively low, but naturally not out of the question.

In total, 24 individual pathways have been identified for RCP2.6 as illustrated in the figures below.

Figure 17 | Pathways identified for RCP2.6 – North Zone

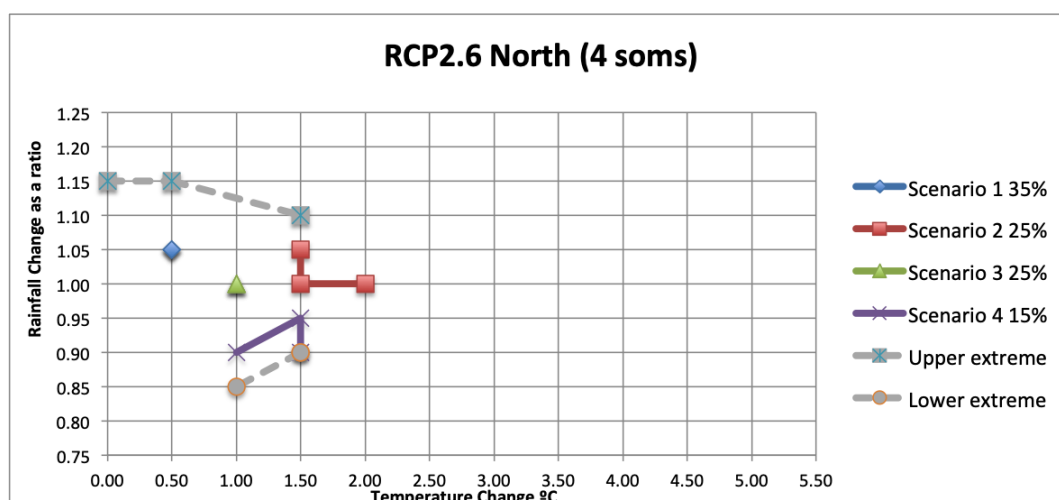


Figure 18 | Pathways identified for RCP2.6 – Central Zone

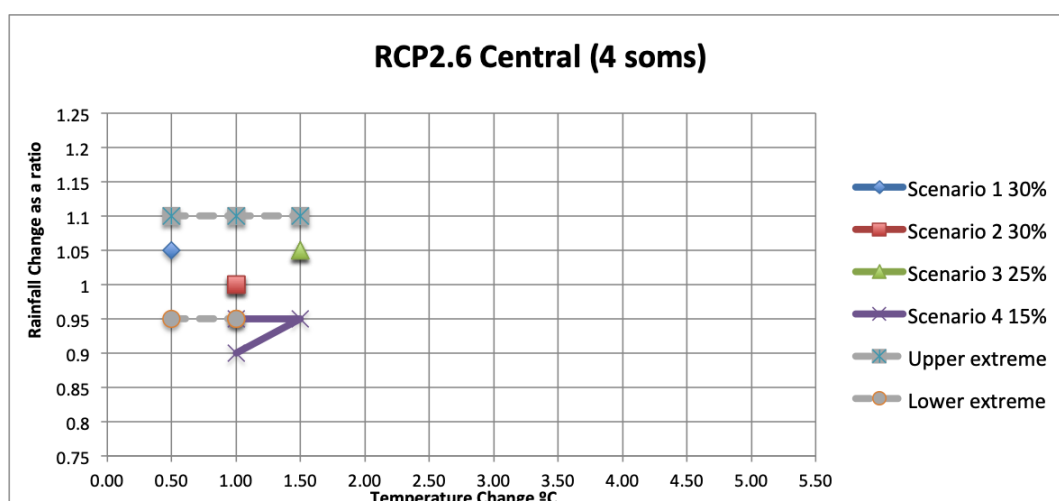


Figure 19 | Pathways identified for RCP2.6 – Southwest Zone

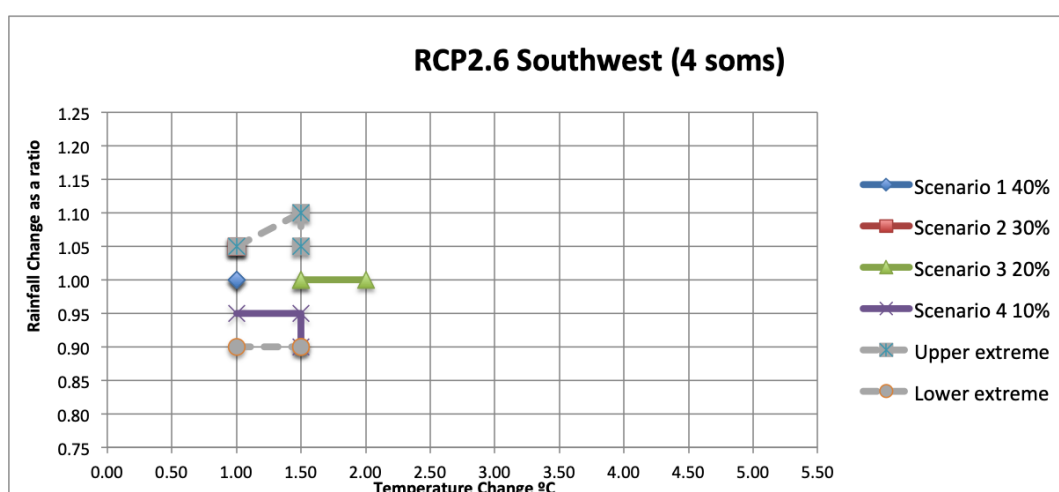
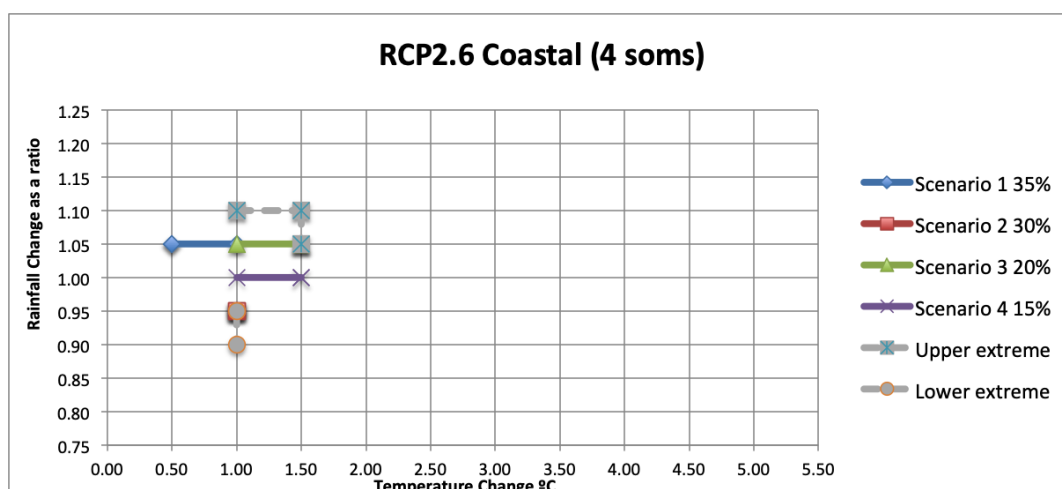


Figure 20 | Pathways identified for RCP2.6 – Coastal Zone



3.4.3. Summary Results for RCP 4.5 (All Climate Zones)

There are a total of 37 projections available for RCP4.5. In most cases using 6 nodes provided no additional information over 4 nodes, the exception being the North Zone. When using 4 nodes for the North Zone two scenarios resulted with equal likelihoods for pathways that towards century end gave annual rainfall adjustments of plus and minus 5%. However, using 6 nodes resulted in three pathways, judged to provide clearer separation than those from just 4 nodes, and in this case was used to provide the final selection for the North Zone. For the remaining three zones, 4 nodes were used. In all cases there are 3 pathways (plus UE and LE), and thus 20 individual pathways in total.

Temperature Impacts

As would be expected, projected annual temperature increases under RCP 4.5 exceed those according to RCP2.6 by the end of the century, but still less than for RCP 8.5. In general, these do not exceed 2.5°C, with the exception of a relatively low-likelihood (20%) pathway for the Central Zone (+3.0°C)

There is perhaps a suggestion of possible greater warming in the drier northern parts (North and Central Zones), but the signal does not appear to be strong, while certainly the lowest increases in temperature are projected for the Coastal Zone

Rainfall Impacts

As for RCP2.6, annual rainfall changes in the pathways are typically restricted to the range of plus/minus 10%, although for UE and LE the range increases to plus/minus 20%, particularly in the Coastal Zone

The likelihoods of a decrease in rainfall are somewhat higher than under RCP2.6 with a 45% likelihood) in the Coastal and Southwest Zones (the most likely pathway in the latter) and 40% in the North Zone but just 20% in the Central Zone.

Overall Summary

RCP4.5 represents the upper bound on emissions if the Paris Agreement is to be met according to the IPCC AR5, although the chances of achieving that target are minimal given such emissions

Temperatures naturally are projected to be higher than under RCP2.6, perhaps by around +0.5 to

+1.0°C, sufficient to increase any impacts significantly, but lower than for the higher emission scenario.

Also, in comparison to RCP2.6, there is an increased risk of future reductions in annual rainfall totals over all climate zones, although in all cases the overall likelihood remains below 50%

In total, 20 individual pathways have been identified for RCP4.5 and summarised in the figures below.

Figure 21 | Pathways identified for RCP4.5 – North Zone

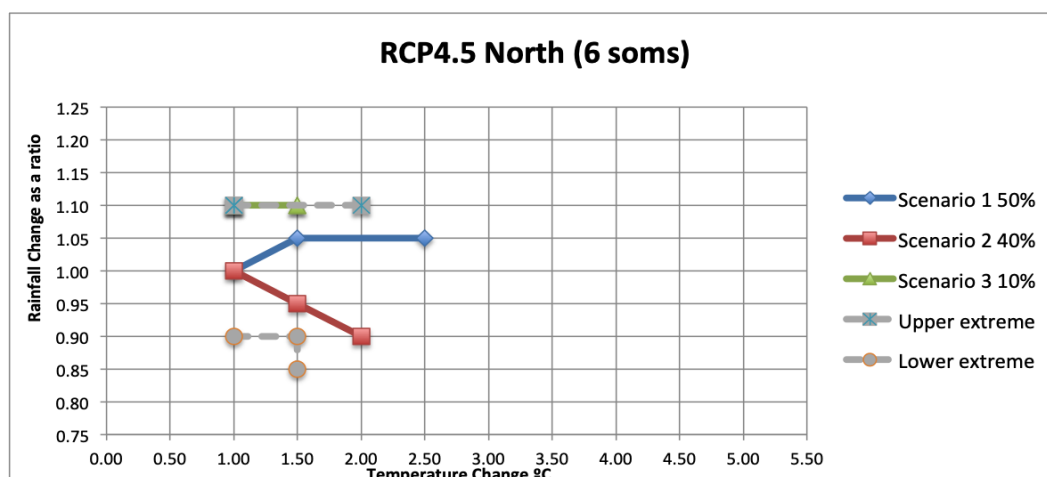


Figure 22 | Pathways identified for RCP4.5 – Central Zone

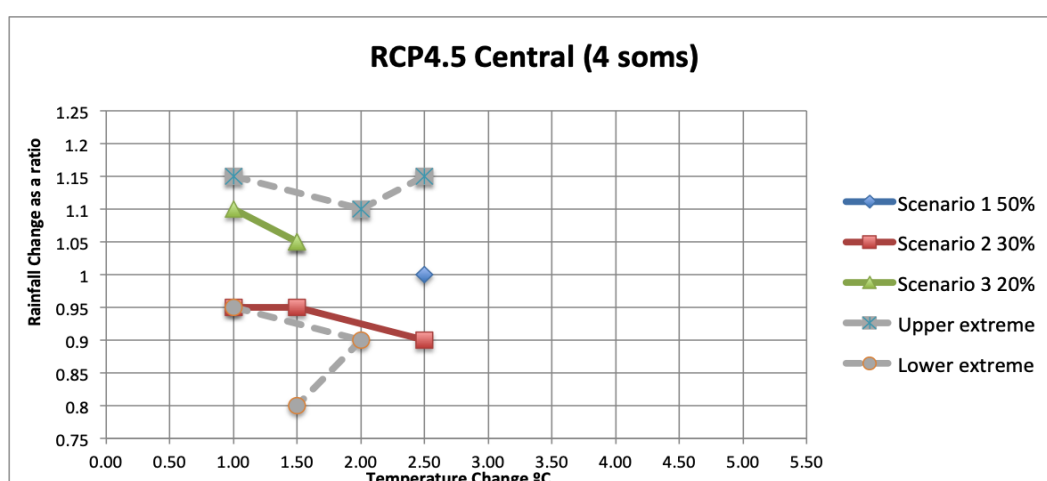


Figure 23 | Pathways identified for RCP4.5 – Southwest Zone

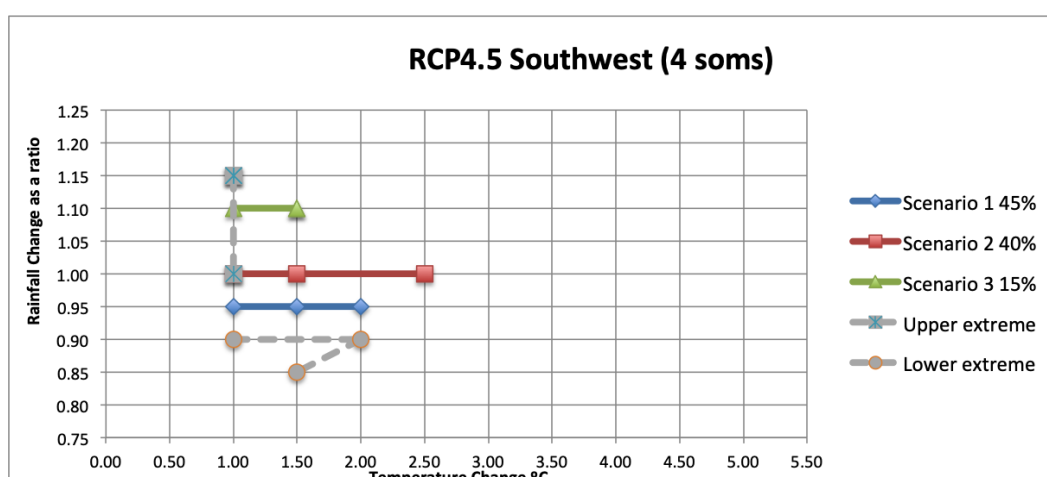
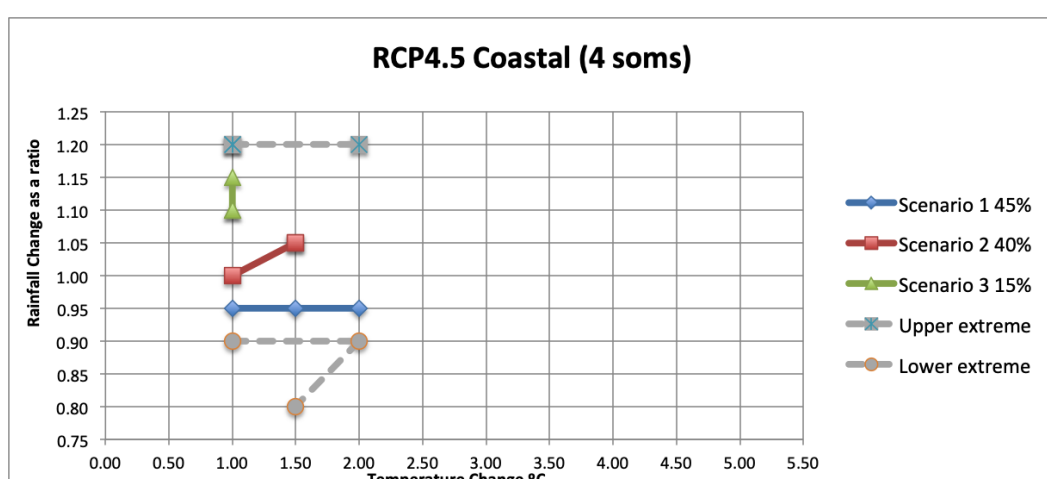


Figure 24 | Pathways identified for RCP4.5 – Coastal Zone



3.4.4. Summary Results for RCP 8.5 (All Climate Zones)

There are a total of 39 projections for RCP8.5, the most for any emissions scenario in CMIP5.

For all climate zones of Ghana, the use of 8 nodes provided improved clarity of pathways as compared to both 4 and 6 nodes, and thus 8 nodes have been used in all final results. The numbers of pathways identified for the different climate zones varies from 3 (North and Coastal) to 4 (Central and Southwest).

Temperature Impacts

Highest temperature projections for any of the pathways are, of course, reached under RCP8.5, with maxima of 4.5°C in the three southernmost zones (4.0°C in the North Zone); the possibility of 5.0°C is noted for LE in each of the three northernmost zones. That said, many of the pathways peak at relatively cooler, but nevertheless impactful, temperatures

Rainfall Impacts

As for RCP2.6 and RCP4.5, projected changes in annual rainfall tend to be modest in global terms, often within 5%, occasionally 15%, but reaching 20% (or even a 25% increase in the North Zone) for UE and LE

Again in general the likelihood of rainfall decreases according to the pathways is below 50%, with the exception of the Southwest Zone where it is, at 50%, the most likely pathway. Perhaps UE pathways are wetter in the north and LE pathways drier in the south

Overall Summary

RCP8.5 represents a “Business-as Usual” scenario, i.e. a continuation of the use of fossil fuels as in recent decades without moderation in terms of environmental considerations. It is now thought to be too high in pragmatic terms, and a new RCP7.0 has been included in CMIP6. RCP 8.5 has however remained in regular use by modellers for technical reasons. It goes without saying that the impacts of the projected temperature increases will surpass those of any of the other emissions scenarios, and, though this might be too high an emissions scenario, even replacing the current results with those that might be obtained using RCP7.0 will result in significant impacts

One observation that might be made here regarding the rainfall projections has been replicated in probably all of the previous SOMs analyses for other parts of the globe, namely that, while temperatures increase with emissions scenarios, there is only limited, if any, change in rainfall projections based on the pathways. Some individual outlying GCMs might provide stronger rainfall changes but this does not appear to be a major feature with the most common projections as revealed through the SOMs. In total, 22 individual pathways have been identified for RCP8.5

Figure 25 | Pathways identified for RCP8.5 – North Zone

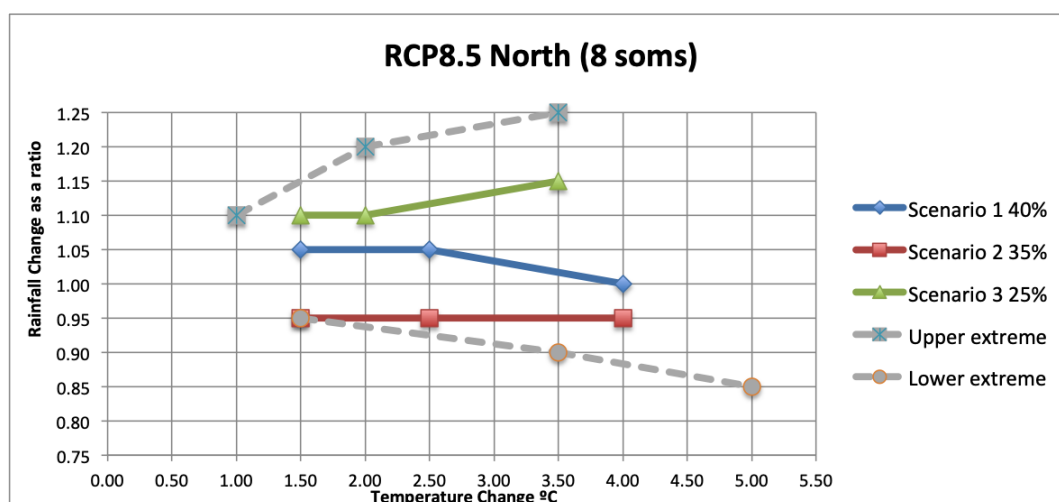


Figure 26 | Pathways identified for RCP8.5 – Central Zone

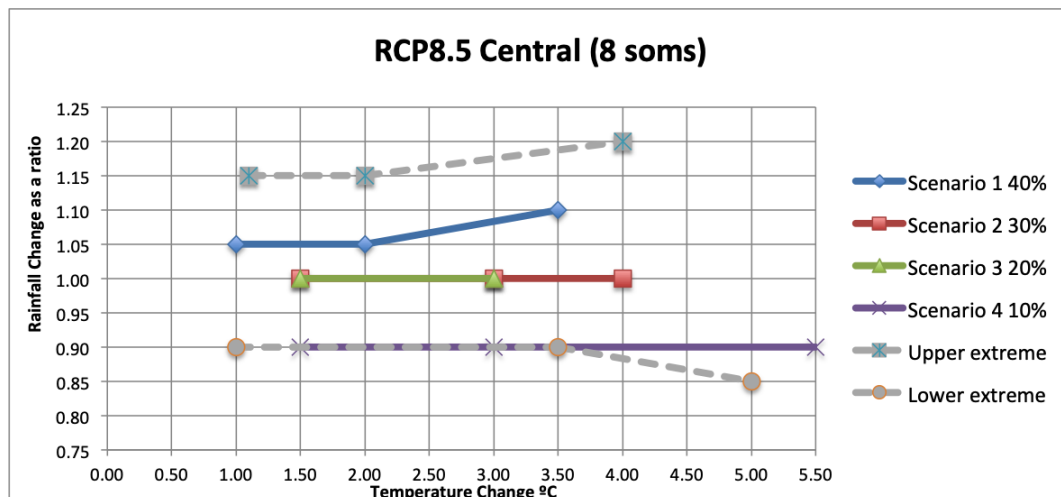


Figure 27 | Pathways identified for RCP8.5 – Southwest Zone

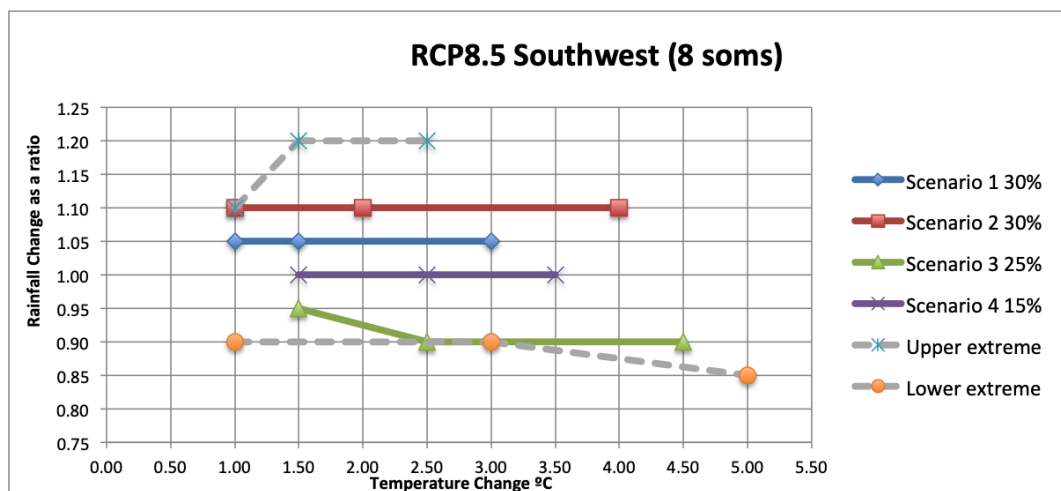
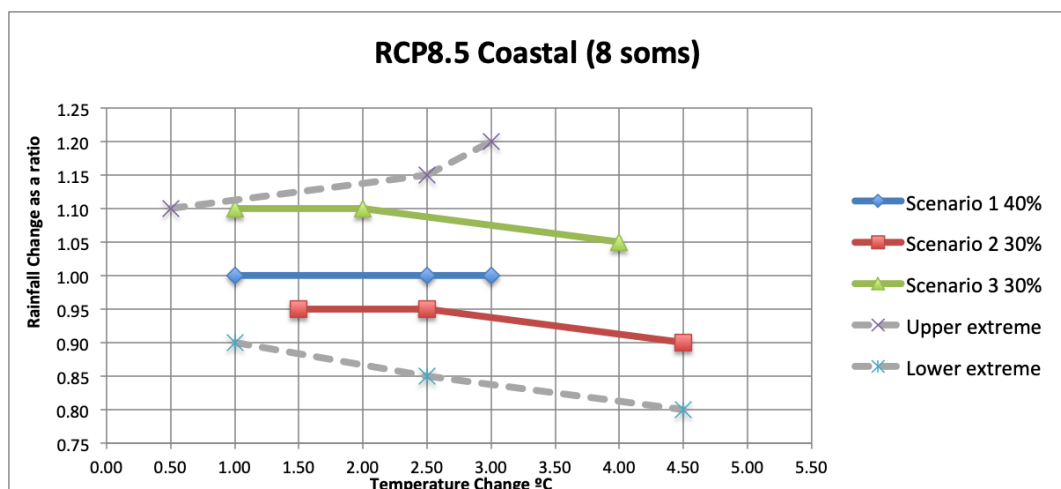


Figure 28 | Pathways identified for RCP8.5 – Coastal Zone



3.5. Selection of the Representative Climate Scenarios

A total of 66 individual pathways were identified across the three RCPs and the four climate zones, rather more than can be handled in practice. To reduce the number, a search was made by RCP for joint pathways across the four climate zones that were broadly similar in terms of annual both temperature and rainfall changes through the three future periods, bearing in mind the relative imprecisions of the values.

The individual pathways have been named Scenario 1, Scenario 2, ... and Upper and Lower Extreme (UE and LE); to distinguish these individual pathways from the joint pathways the latter are referred to as (examples for RCP2.6) Scenario A26, Scenario B26, ..., UE A26, UE B26, ..., (allowing for multiple scenarios for UE and LE). In the summary tables given below, the original individual pathways are identified as '1 35%', denoting the original pathways (in this example Scenario 1) and the accompanying likelihood (in this example 35%). The ranges of temperature and rainfall changes captured in the individual scenarios are listed to the right. The naming of Scenario A etc. is roughly alphabetical in reducing order of likelihoods, but as likelihoods may vary by region this ordering may not be exact.

3.5.1. Representative Scenarios for RCP 2.6

In the SOMs analysis each zone was given 4 individual scenarios (plus UE and LE) under RCP2.6, using 4 nodes in all climate zones. The 4 joint scenarios reflect these, although the order of likelihoods differs somewhat between zones. Values in the joint scenarios represent, as far as possible, the majority changes amongst the related individual scenarios. Otherwise, expert judgment was used.

Scenarios highlighted in red are those selected to be used in the next step in choosing a GCM/RCM pairing from the CORDEX data set that should be used for downscaling. The selection being made based on the closeness of individual scenarios to each joint scenario in combination with the likelihoods for each climate zone higher likelihoods being given priority.

The results of the joint pathways analysis shown in Table 10, can be summarised as follows:

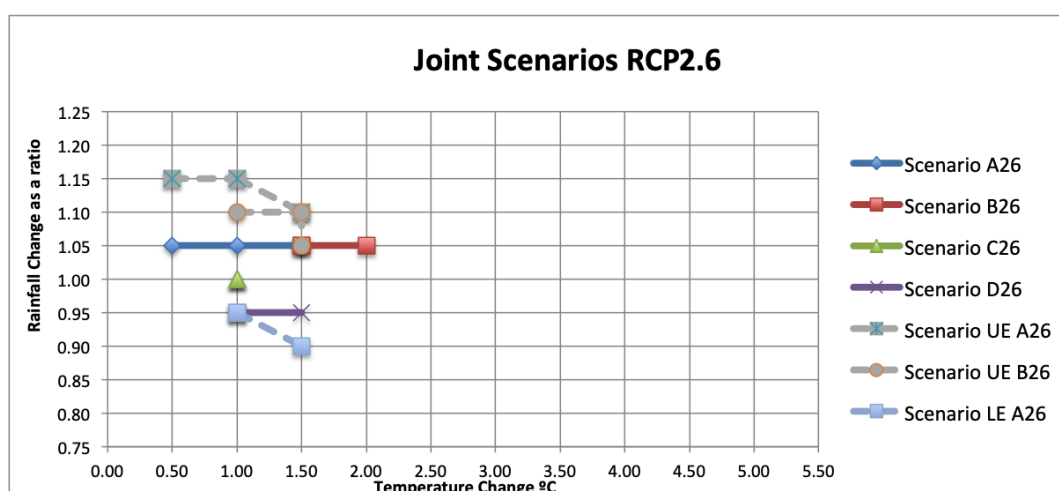
- *Scenario A26* has roughly similar likelihoods (30-35%) in all zones; it is the most likely in three zones and second in the Southwest. Temperature increases are of the order 0.5°C, with rainfall increasing by about 5%
- *Scenario B26* also has similar likelihoods in all climate zones (20-25%), is second most likely in the North and third in the other zones. It is warmer than A26 (to 1.5-2.0°C), but with similar increases in rainfall (by about 5%)
- *Scenario C26* is more complex than the two above, with the likelihood in the Coastal Zone (15%) rather lower than elsewhere (25-40%), with temperature increases of 1.0°C but no change in rainfall
- *Scenario D26* has reduced rainfall (by about 5%), combined with temperature increases of 1.0-1.5°C, in all zones, with likelihoods of 10-15% except in the Coastal Zone (30%)
- *Scenario UE A26* relates to the two northern zones only, North and Central, as the UE temperature increases tend to be lower here (0.5-1.5°C) than further south (1.0-1.5°C) and rainfall increases are consistently higher (10-15%) than further south (5-10%)
- *Scenario UE B26* covers the Southwest and Coastal Zones (see UE A26 above for details)

- *Scenario LE A26* applies to all four zones with temperature increases in the range 1.0-1.5°C and rainfall decreases generally 5-10%

Table 10 | Results of joint pathways analysis across the four climate zones under RCP2.6

Likelihood of Individual Scenarios					Expected Temperature (°C) and Rainfall (%) Impacts.		
Scenario	North	Central	Southwest	Coastal	2035	2060	2080
A26	1 35%	1 30%	2 30%	1 35%	0.5/1.05	0.5/1.05	0.5/1.05
B26	2 25%	3 25%	3 20%	3 20%	1.5/1.05	1.5/1.05	2.0/1.05
C26	3 25%	2 30%	1 40%	4 15%	1.0/1.00	1.0/1.00	1.0/1.00
D26	4 15%	4 15%	4 10%	2 30%	1.0/0.95	1.5/0.95	1.0/0.95
UE A26	✓	✓	✗	✗	0.5/1.15	1.0/1.15	1.5/1.10
UE B26	✗	✗	✓	✓	1.0/1.10	1.5/1.10	1.5/1.05
LE A26	✓	✓	✓	✓	1.0/0.95	1.0/0.95	1.5/0.90

Figure 29 | Joint scenarios for RCP2.6



3.5.2. Representative Scenarios for RCP4.5

Each zone was given 3 individual pathways in the SOMs analysis (plus UE and LE) under RCP4.5. Nevertheless, there are 4 joint scenarios because of relatively cooler temperatures in the Coastal Zone, albeit with similar rainfall changes, in one set of individual pathways.

Again, values in the joint scenarios represent, as far as possible, the majority changes amongst the related individual scenarios; otherwise judgment was used; red highlighting indicates chosen joint scenarios for further downscaling as outlined in Section 3.5.4.

In summary:

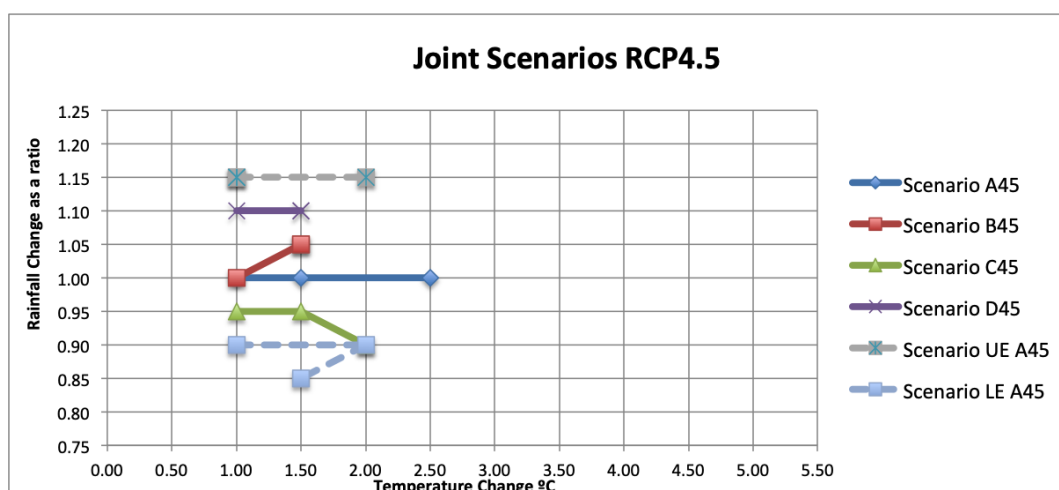
- *Scenario A45* covers only the three northernmost zones, with equivalent results for the Coastal Zone placed in Scenario B45. A45 is the dominant joint scenario, with likelihoods of 50% in the North and Central Zones, and of second importance (40%) in the Southwest Zone. Temperature increases reach 2.5°C and but rainfall remains roughly unchanged (but is unlikely to decrease)

- *Scenario B45* is the equivalent of A45 but covering only the Coastal Zone (with 40% likelihood). Temperature rises up to 1.5°C are lower than for A45 but with increases in rainfall by 5%.
- *Scenario C45* covers all four zones and is the most important in the Southwest and Coastal (45%) Zones, and second in the North (40%) and Central (30%) Zones. There are temperature increases to 2.0°C and rainfall reductions reaching 5-10%.
- *Scenario D45* has the lowest likelihoods in all zones (10-20%) with increased temperatures in the range 1.0-1.5°C and of rainfall to 10%
- *Scenario UE A45* covers rainfall increases to 15% combined with temperature increases to 2.0°C
- *Scenario LE A45* includes rainfall reductions up to 15% and temperature increases up to 2.0°C

Table 11 | Joint pathways across the four climate zones under RCP4.5

Likelihood of Individual Scenarios					Expected Temperature (deg °C and Rainfall (% Impacts.		
Scenario	North	Central	Southwest	Coastal	2035	2060	2080
A45	1 50%	1 50%	2 40%	X	1.0/1.00	1.5/1.00	2.5/1.00
B45	X	X	X	2 40%	1.0/1.00	1.5/1.05	1.5/1.05
C45	2 40%	2 30%	1 45%	1 45%	1.0/0.95	1.5/0.95	2.0/0.90
D45	3 10%	3 20%	3 15%	3 15%	1.0/1.10	1.5/1.10	1.5/1.10
UE A45	✓	✓	✓	✓	1.0/1.15	1.0/1.15	2.0/1.15
LE A45	✓	✓	✓	✓	1.0/0.90	2.0/0.90	1.5/0.85

Figure 30 | Joint scenarios for RCP4.5



3.5.3. Representative Scenarios for RCP8.5

Difficulties like those found in some previous analyses for countries other than Ghana analysed using SOMs for RCP8.5 resulted, initially, in 6 nodes being required over 4 nodes to identify reasonable pathways in all four zones. Nevertheless, further inspection suggested that greater clarity would be gained using 8 nodes, the first time this has been done, and that has resulted in the identification of 4 realistic joint scenarios. The more likely two joint scenarios cover all four zones, but for the third joint scenario two individual scenarios for the Central Zone were included within a single joint scenario (they differ only in the third period in terms of temperatures but not in terms of rainfall) and includes just three

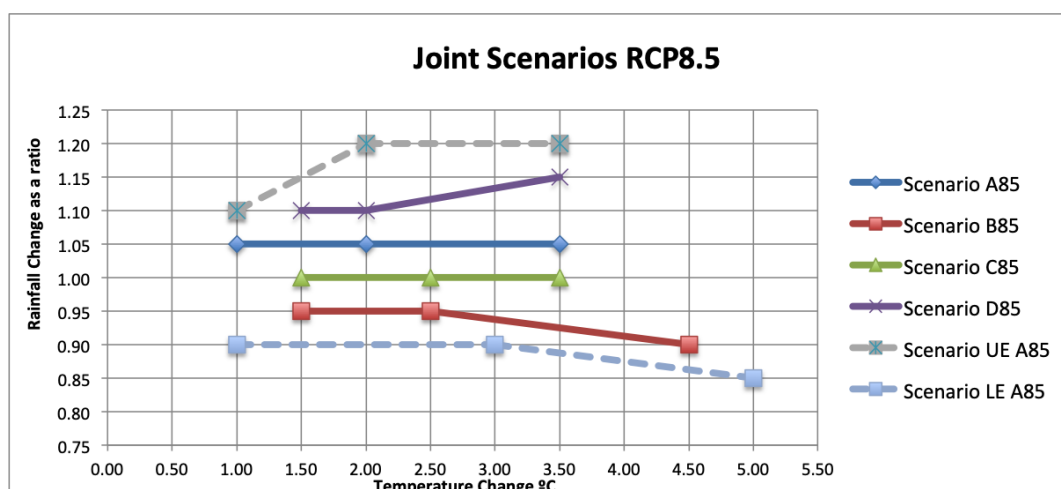
zones, while the final joint scenario covers only two. As before, values in the joint scenarios represent, as far as possible, the majority changes amongst the related individual scenarios; otherwise judgment was used; red highlighting indicates chosen joint scenarios for further downscaling as outlined in Section 3.5.4. In summary:

- *Scenario A85* covers all four zones, and is the most likely (30-40%) in all except the Coastal Zone (30%). Temperature increases reach 3.5°C with rainfall about 5% higher
- *Scenario B85* also covers all four zones, with likelihoods varying between 35% (North) through 30% (Coastal) and 25% (Southwest) to 10% (Central). This is a drying scenario with rainfall reductions to 10% accompanied by temperature increases to 4.5°C
- *Scenario C85* omits the North Zone and has a likelihood of 50% when the two individual scenarios with similar rainfall projections in the Central Zone are joined; elsewhere it is the most likely in the Coastal Zone (40%) but least likely in the Southwest (15%)
- *Scenario D85* applies only to the North (25% likelihood) and Southwest (30%) Zones with temperatures rising by 3.5°C and rainfall by 10-15%
- *Scenario UE A85* includes increases in temperatures of up to 3.5°C and in rainfall of up to 20%
- *Scenario LE A85* has the highest temperature increases of any joint scenario of up to 5.0°C combined with rainfall decreases to 15%

Table 12 | Joint pathways across the four zones under RCP8.5

Scenario	Likelihood of Individual Scenario				Expected Temperature (deg C) and Rainfall (%) Impacts.		
	North	Central	Southwest	Coastal	2035	2060	2080
A85	1 40%	1 40%	1 30%	3 30%	1.0/1.05	2.0/1.05	3.5/1.05
B85	2 35%	4 10%	3 25%	2 30%	1.5/0.95	2.5/0.95	4.5/0.90
C85	X	2+3 50%	4 15%	1 40%	1.5/1.00	2.5/1.00	3.5/1.00
D85	3 25%	X	2 30%	X	1.5/1.10	2.0/1.10	3.5/1.15
UE A85	✓	✓	✓	✓	1.0/1.10	2.0/1.15	3.5/1.20
LE A85	✓	✓	✓	✓	1.0/0.90	3.5/0.90	5.0/0.85

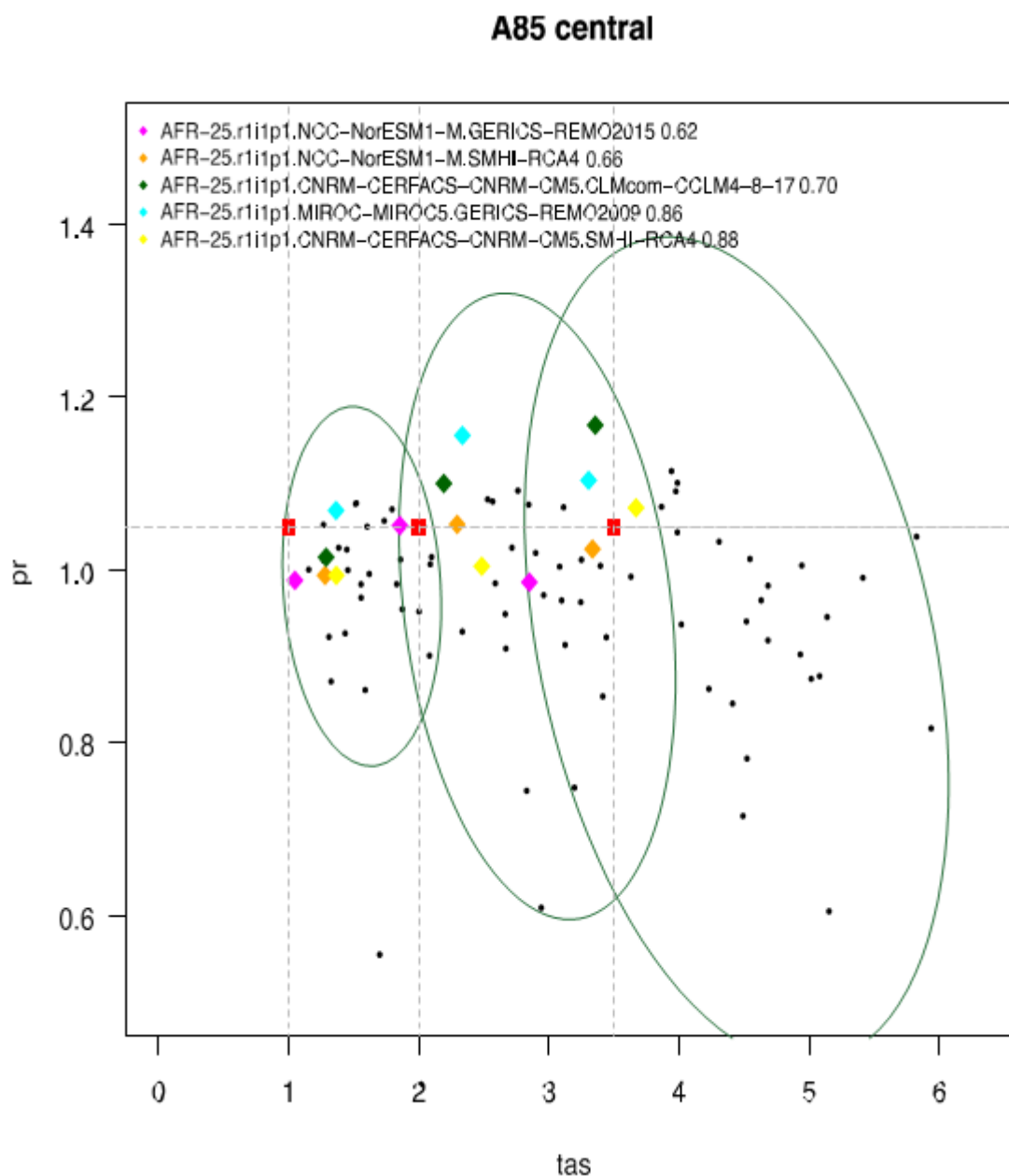
Figure 31 | Joint scenarios for RCP8.5



3.5.4. Identifying GCM/RCM pairings from CORDEX for downscaling

For each of the joint scenarios presented above an assessment was made using root-mean square (RMS) distances between each CORDEX GCM/RCM pairing's projections of temperature and rainfall changes for the same three periods used in the SOMs analyses and from those of each joint scenario. CORDEX pairings from both the Africa and the MENA domains were used, but only those from the Africa domain emerged as the closest. An example of the resulting ellipse diagram is shown in Figure 32 (for A85 Central) with all the ellipse diagrams for each joint scenario given in **Appendix B**.

Figure 32 | Example of an ellipse diagram used to identify representative GCM/RCM pairs for each scenario



In each ellipse diagram information is provided regarding the closest 5 GCM/RCM pairings, in all cases the individual closest being selected for providing the downscaled results. Further detail might be obtained by using the closest two, or more, pairings to produce a mini-ensemble, but this approach has not been used here. The ellipses, drawn from the centroid of projections for each period so as to include 90% of those projections, themselves are also informative in terms of determining likely climate impacts.

The ellipses remain similar for all scenarios under each RCP but vary a little for each zone:

- The ellipses for RCP2.6 overlap to a large extent, indicating that there is minimal differentiation between projections for the three periods, with most temperature projections within the range 0.5 to 2.0°C and rainfall projections $\pm 10\%$.

- Under RCP4.5 the ellipses shift to the right in time, indicating relatively high differentiation in temperature projections for the three periods, but more so between the first and the second and third periods. There is limited differentiation in rainfall projections, which are mainly in the range -10% to +20%.
- There is a marked differentiation in temperature projections under RCP8.5 and there is also a comparatively wider spread of rainfall projections, although this appears to result from a small number of outliers with the majority of projections in the range $\pm 20\%$.
- These results appear to be consistent with those found using similar analyses for other parts of the world that, while there is marked differentiation in temperature projections as emissions increase, there is less, if any, in rainfall projections

The tables below include the details of the final selected GCM/RCM pairing recommended for use in providing additional downscaled climate information. The tables include details of the modelling house origins of the GCM/RCM pairings selected to represent the joint scenarios and the estimated likelihood in each of the four climate zones together with a subjective assessment of how well each pairing reproduces each joint scenario. In some cases, the GCM/RCM selection covers more than a single joint scenario, thus reducing the numbers of models required for downscaling, the final totals being 6 for RCP2.6, 4 for RCP4.5, and 5 for RCP8.5. In using the downscaled information from each of the GCM/RCM pairings it is recommended that the information provided in **Appendix B** and in the sections above are reviewed to identify to which zone and with what likelihood each scenario refers.

In the tables:

- Joint scenario names include the RCP (e.g. A26 is from RCP2.6)
- Scenarios with '*' or '\$' following the names have the same closest GCM/RCM pairings and therefore may be treated as the same scenarios as far as the downscaling is concerned (e.g. C26 and D26)
- Likelihoods are listed by zone in the order North/ Central /Southwest/Coastal; the symbol '-' is used where a joint scenario is not appropriate to a particular zone
- Distances are the root-mean-square (RMS) distances as described earlier.

Table 13 | Summary of recommend GCM/RCM pairing for representative scenarios of downscaled climate information for RCP2.6

Scenario	Likelihood	RMS	Focus Region	CORDEX Domain	Host GCM	RCM	Comments
A26	35%/30%/30%/35%	0.35	North	Africa	NorESM Climate Modelling Consortium	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	A good fit to the scenario
B26	25%/25%/20%/20%	0.76	Central	Africa	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC)	Swedish Meteorological and Hydrological Institute (SMHI)	Reasonable for the first two periods but fails to capture, as do all the models, the warmth and increased rainfall of the third period
C26*	25%/30%/40%/15%	0.36	Southwest	Africa	Max Planck Institute in Germany (MPI)	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	A good fit to the scenario
D26*	15%/15%/10%/30%	0.61	Central	Africa	Max Planck Institute in Germany (MPI)	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	Reasonable for first two periods but does not capture warmth of third period
UE A26	Applies to North and Central	1.44	Central	Africa	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC)	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	Simulation generally too warm and too dry throughout
UE B26	Applies to Southwest and Coastal	0.78	Coastal	Africa	Institute Pierre-Simon Laplace in France (IPSL)	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	Model too dry throughout and too warm in first period

LE A26	Applies to all regions	0.81	Coastal	Africa	Max Planck Institute in Germany (MPI)	Abdus Salam International Centre for Theoretical Physics (ICTP)	Good for first two periods but does not capture the warmth of the third period
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Note:

* The same GCM/RCM combination provides the closest fits to both C26 and D26 (but a different RCM for UE B26)

Table 14 | Summary of recommend GCM/RCM pairing for representative scenarios of downscaled climate information for RCP4.5

Scenario	Likelihood	RMS	Focus Region	CORDEX Domain	Host GCM	RCM	Comments
A45	50%/50%/40%/-	0.70	Central	Africa	Centre National de Recherches Météorologiques in France (CNRM)	Swedish Meteorological and Hydrological Institute (SMHI)	A good fit but model too cool in the third period
B45*	-/-/40%	0.56	Coastal	Africa	NorESM Climate Modelling Consortium	Swedish Meteorological and Hydrological Institute (SMHI)	Model becomes too warm in the second period, but rainfall captured reasonably well
C45*	40%/30%/45%/45%	1.20	North	Africa	NorESM Climate Modelling Consortium	Swedish Meteorological and Hydrological Institute (SMHI)	Simulation is generally warmer and wetter than the scenario, but the scenario lies close to the edges of the ellipses in all three periods
D45\$	10%/20%/15%/15%	0.82	Southwest	Africa	European GCM collaboration (ICHEC)	Climate Limited-Area Modelling Community (CLM) in association with KIT in Germany	In the third period the simulation is markedly warmer than the scenario
UE A45\$	Applies to all regions	1.26	Coastal	Africa	European GCM collaboration (ICHEC)	Climate Limited-Area Modelling Community (CLM) in association with KIT in Germany	Captures the rainfall better than the temperatures

LE A45	Applies to all regions	1.69	Southwest	Africa	Max Planck Institute in Germany (MPI)	Climate Limited-Area Modelling Community (CLM) in association with KIT in Germany	The scenario lies outside the GCM/RCM cloud, and this is the best option
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Notes:

* The same GCM/RCM combination provides the closest fits to both B45 and C45

\$ The same GCM/RCM combination provides the closest fits to both D45 and UE A45

Table 15 | Summary of recommended GCM/RCM pairing for representative scenarios of downscaled climate information for RCP8.5

Scenario	Likelihood	RMS	Focus Region	CORDEX Domain	Host GCM	RCM	Comments
A85*	40%/40%/30%/30%	0.62	Central	Africa	NorESM Climate Modelling Consortium	Helmholtz Centre for Polar and Marine Research (GERICS)	The simulation is too cool and too dry in the third period
B85	35%/10%/25%/30%	0.56	North	Africa	European GCM collaboration (ICHEC)	Max Planck Institute in Germany (MPI)	The model follows the scenario temperature changes well but is too dry in the third period
C85	-/50%/15%/40%	0.48	Coastal	Africa	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC)	Helmholtz Centre for Polar and Marine Research (GERICS)	Reasonable for temperatures but too wet in the second and third periods
D85	25%/-/30%/-	0.61	Southwest	Africa	National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory (GFDL)	Swedish Meteorological and Hydrological Institute (SMHI)	The main issue is the simulation being too warm in the second period
UE A85*	Applies to all regions	0.60	North	Africa	NorESM Climate Modelling Consortium	Helmholtz Centre for Polar and Marine Research (GERICS)	Likely the best fit to the scenario available but generally too cool and too dry in comparison; scenario lies close to the edges of the ellipses throughout

LE A85

Applies to all regions

1.39

Southwest

Africa

UK Met Office (MOHC)

Helmholtz Centre
for Polar and Marine
Research (GERICS)

Despite the high RMS distance it is a reasonable
simulation for the later two periods, but too warm
in the first.

*Note: * The same GCM/RCM combination provides the closest fits to both A85 and UE A85*

3.6. Plume Plots Analysis for Climate Zones

3.6.1. Historical Simulations vs. Observations

This section includes the description of the agreement between historical observations and simulations by the multi-method multi-model ensemble. Analyses of projected climate are presented separately for each of the considered RCP/SSP scenarios in sections below based on a set of plume plots.

Of note is that in the plume plots, data for the historical period, i.e., the period till 2010 for CORDEX and CMIP5 models, and till 2015² for CMIP6 ensembles are always identical, irrespective of the RCP/SSP scenario, and reflect results of model simulations under observed, historical GHG forcing.

The historical simulations by GCMs are not time-synchronous with observations, i.e., GCM simulations are not designed to replicate observed sequences of dry and wet years. In spite of this, GCM simulations should replicate historical trends and low-frequency variability, although within statistical uncertainty bounds. In other words, at a conceptual level, one can consider that GCMs represent all possible “trajectories” of climate under historical GHG forcing, while the observations represent a particular trajectory the climate system has actually taken.

In view of that, model simulations have to be statistically compatible with observations.

An issue that arises when performing such a comparison is the uncertainty of observations, which manifests as differences between various observational or “pseudo-observational” datasets. We consider here four different observational datasets (see Data section above).

The evaluation presented below is not based on the strict statistical evaluation of the agreement between the observations, but rather on qualitative, generic observations.

3.6.1.1 Air temperature

There is a good consistency between the three model ensembles in terms of overall trend in air temperature in the historical period. All three ensembles indicate an increase in air temperature, with a very similar range of uncertainty (the plume plots overlap in the pre-2020 period).

There is a very good consistency between trends in the two historical observational datasets and historical model simulations, with observations falling close to the middle of model range³.

The overall consistency between models and observations as well as between individual model ensembles indicates a high confidence in air temperature projections over the region.

3.6.1.2 Rainfall

There is little difference between the three model ensembles in terms of historical trends⁴ in all the regions, apart from in the Coastal region. In general, historical shape and location of the plumes indicate that both weak drying and weak wetting were simulated by models. In the Coastal region, CORDEX and CMIP5 ensembles simulate tendency towards historical decline in rainfall, while the CMIP6 ensemble does not simulate consistent trends (i.e. simulates both drying and wetting).

There is a strong disparity between trends in the long-term historical observational datasets (CRU and GPCC) and historical model simulations, with observations indicating strong rainfall declines in the pre-1980 period, while models of all three ensembles, as illustrated above, simulate varying and weak trends. This disparity is indicated by the observational time series falling well outside of the model ensemble plumes.

In the post-1980 period, however, the agreement between model simulations and observations is better. ERA5 reanalysis data shows strong decline in rainfall which falls outside of the model ranges, but CRU and GPCC show weaker downward trend that falls within the range of the model ensembles (apart from the Central Zone where the observed trend is stronger). CHIRPS data, in contrast to the other datasets, show weak increase in rainfall in the post-1981 period, but that increase is, again, compatible with the modelled range of historical rainfall changes.

That trend is in contrast with the drying manifested over that period in the three remaining datasets but has been detected in dedicated analyses of station data by Baidu et al. (2017).

Overall, there is a limited consistency between models and observations, which indicates a reduced confidence in rainfall projections over the region and requires further investigation.

3.6.2. Results for RCP 2.6/SSP1 2.6

3.6.2.1 Air Temperature

Projections of future air temperature under rcp26/ssp126 scenario indicate a gradual increase until the 2040s, and then stabilisation, with the end of the 21st century anomalies projected to fall in 0.5 - 1.5 °C above historical mean, although the CMIP6 ensemble projects somewhat higher increases reaching 2 °C in 2100. The differences between regions are minimal, although there is a somewhat larger spread (uncertainty) of projected temperature in the North compared to the other regions.

3 Note that for clarity we do not plot ensemble median in the plume plots, so it is difficult to judge how the median behaves. However, exploration of details of plume plots not presented here, indicates that the plumes are typically symmetrical with median roughly in its central location

4 Note that historical trends are not analysed here explicitly. Instead, we evaluate the “trends” through the overall “tendency” of the plume of a given ensemble. Plume centred over or symmetrical around the 0 or “not change” line, will indicate no overall “trend”. A “sloping” plume will indicate propensity of ensemble members towards either upward or downward trend.

There is a good consistency between the CMIP5 and the dynamically downscaled CORDEX projections. That effect is visible in all regions. Overall, dynamical downscaling (from the CORDEX projections) does not seem to change the climate change signal compared to parent GCMs.

The disparity between the CMIP6 and CMIP5/CORDEX ensembles might result from the increased climate sensitivity of the new generation of climate models as indicated above.

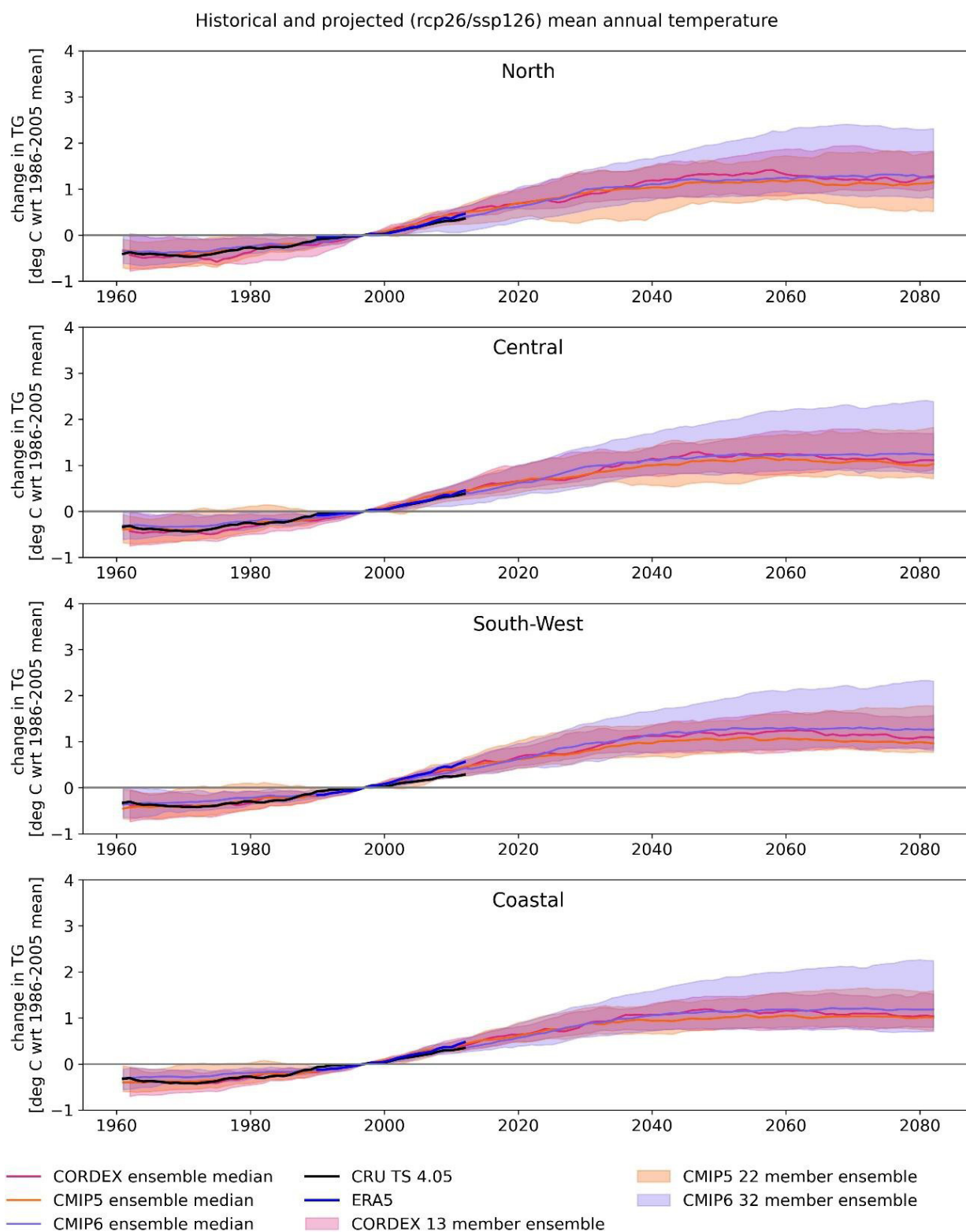
3.6.2.2 Rainfall

Projections of the future rainfall under rcp26/ssp126 scenario span both wetter and drier future in each of the regions, with the end of the 21st century anomalies projected to fall in the +10% to -10% range by each of the three ensembles, although the CMIP6 ensemble projects somewhat wetter future in the Northern and Central Zones than the other ensembles.

There is a good consistency between the CMIP5 and dynamically downscaled CORDEX projections, although the CMIP5 ensemble range spans somewhat larger reductions of rainfall than those of the CORDEX ensemble. That effect is visible in all regions. Overall, dynamical downscaling does not seem to alter the climate change signal of parent GCMs. The disparity between the CMIP6 and CMIP5/CORDEX ensembles might result from the increased climate sensitivity of the new generation of climate models (Zelinka et al. 2020; Seneviratne and Hauser, 2020; Wyser et al. 2020).

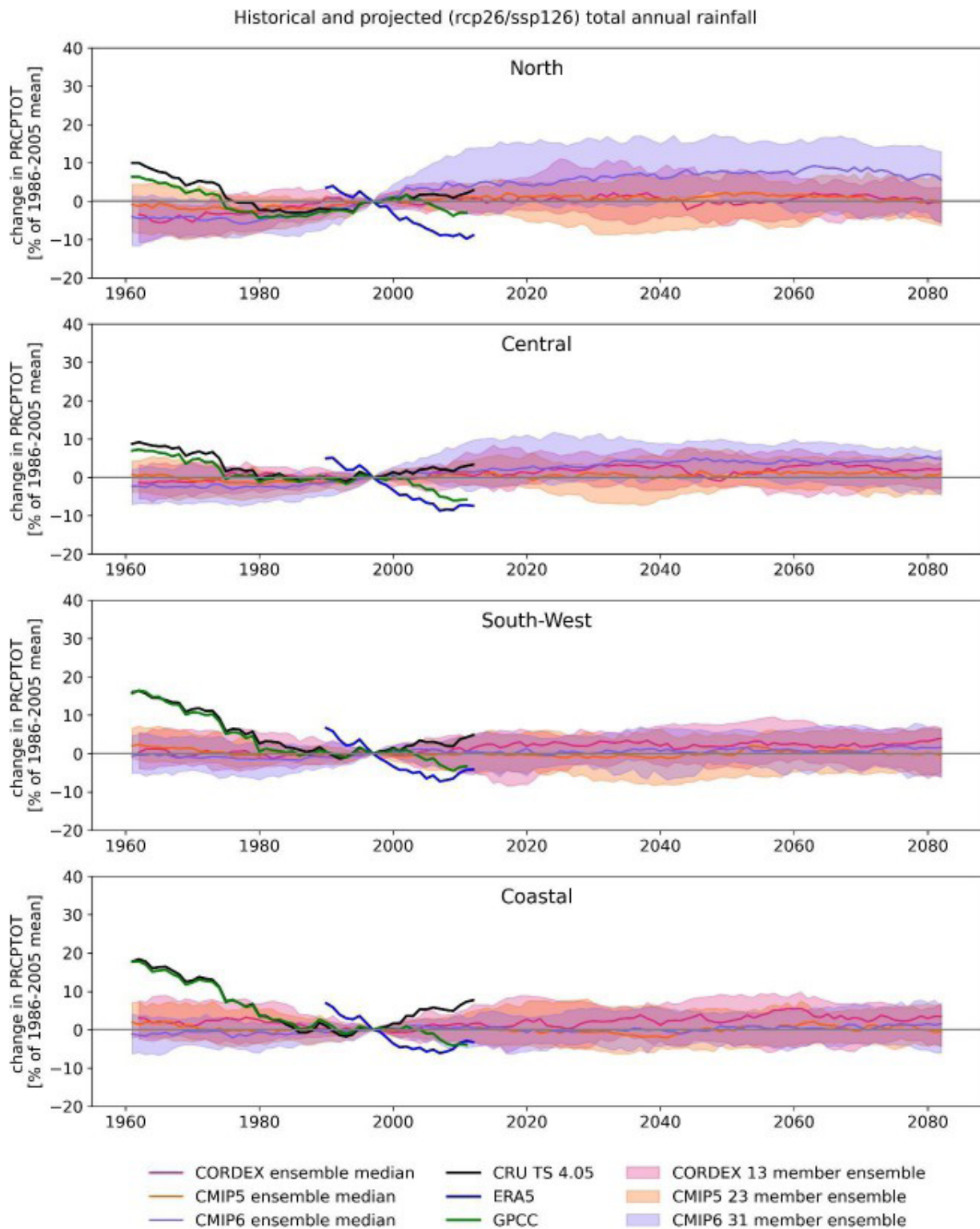
In general, projections do not indicate any strong and consistent departures from the historical rainfall levels and the spread of the ensembles seem to reflect climate variability of magnitude similar to that simulated in the historical period. This gives some confidence in terms of the expected future scenarios.

Figure 33 | Plume plots illustrating the evolution of mean annual temperature in Ghana homogeneous climate zones in simulations of historical and future climate under rcp26/ssp126 scenarios



All lines represent 20-year running averages calculated on annual values. Shaded areas show the range 10th to 90th %.

Figure 34 | Plume plots illustrating the evolution of total annual rainfall in Ghana homogeneous climate zones in simulations of historical and future climate under rcp2.6/ssp126 scenarios



All lines represent 20-year running averages calculated on annual values. Shaded areas show the range 10th to 90th %.

3.6.3. Results for RCP 4.5/SSP2 4.5

3.6.3.1 Air Temperature

Projections of the future air temperature under the rcp45/ssp245 scenarios indicate a gradual increase continuing throughout the 21st century, although with a slight reduction of the rate of increase towards the 2080s. The end of the 21st century anomalies are projected to fall in the range 1.5 - 2.5 °C above historical mean, although the CMIP6 ensemble projects somewhat higher increases reaching 3 °C in 2100. The differences between regions are minimal.

There is a good consistency between the CMIP5 and dynamically downscaled CORDEX projections. That effect is visible in all regions. Overall, dynamical downscaling does not seem to change the climate change signal compared to parent GCMs. The disparity between the CMIP6 and CMIP5/CORDEX observed in rcp26/ssp126 scenario is weaker, with CMIP6 projecting the upper envelope of temperature only 0.5 °C higher in 2100 than the CMIP5 and CORDEX ensembles.

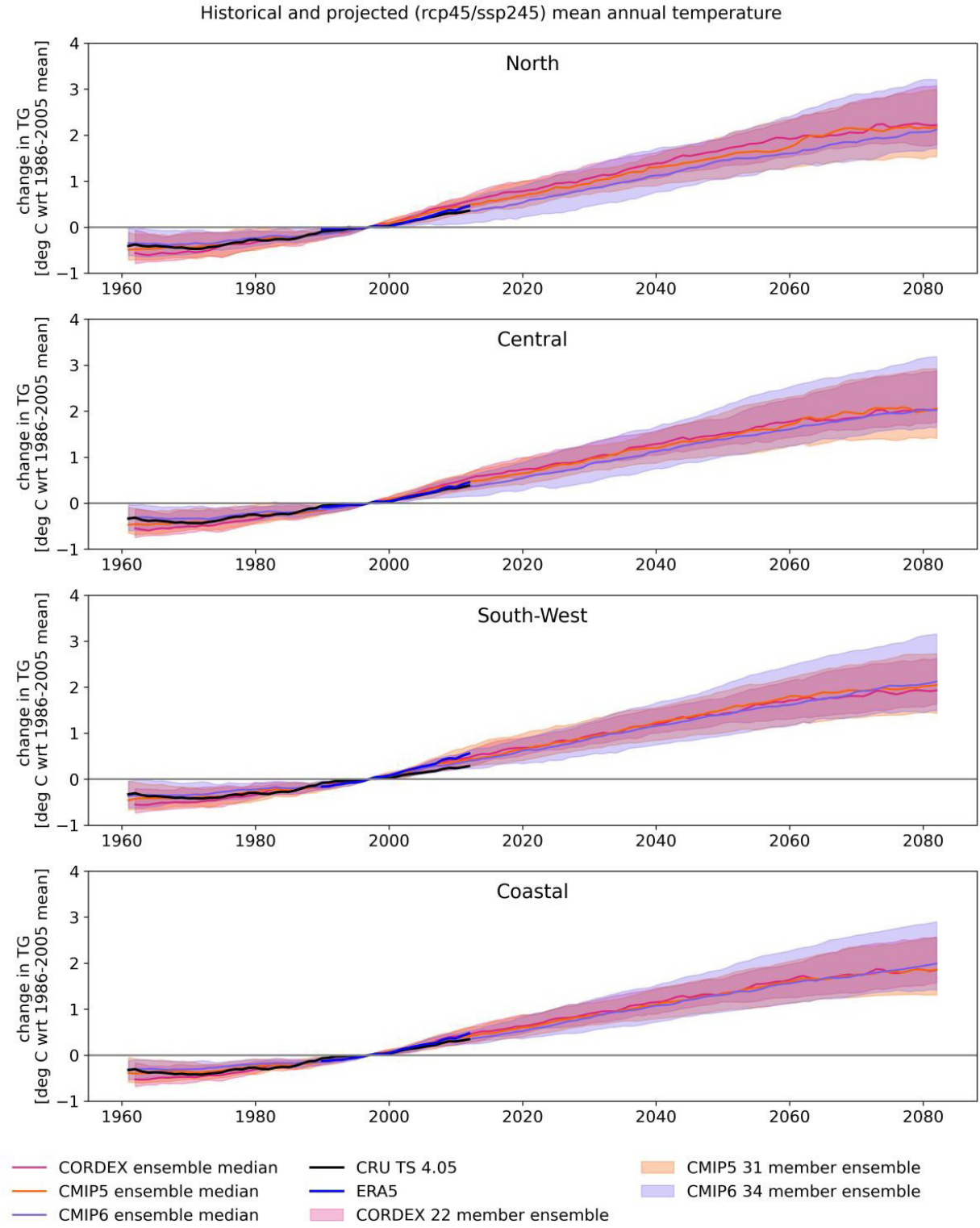
3.6.3.2 Rainfall

Projections of the future rainfall under rcp45/ssp245 scenario span both wetter and drier future in each of the regions, with the end of the 21st century anomalies projected to fall in the +10% to -10% range by each of the three ensembles, although the CMIP6 ensemble projects somewhat wetter future in the Northern and Central Zones than the other ensembles.

There is a good consistency between the CMIP5 and the dynamically downscaled CORDEX projections, although CMIP5 ensemble range spans somewhat larger reductions of rainfall than those of CORDEX ensemble. That effect is visible in all regions. Overall, the dynamical downscaling does not seem to change the climate change signal compared to parent GCMs.

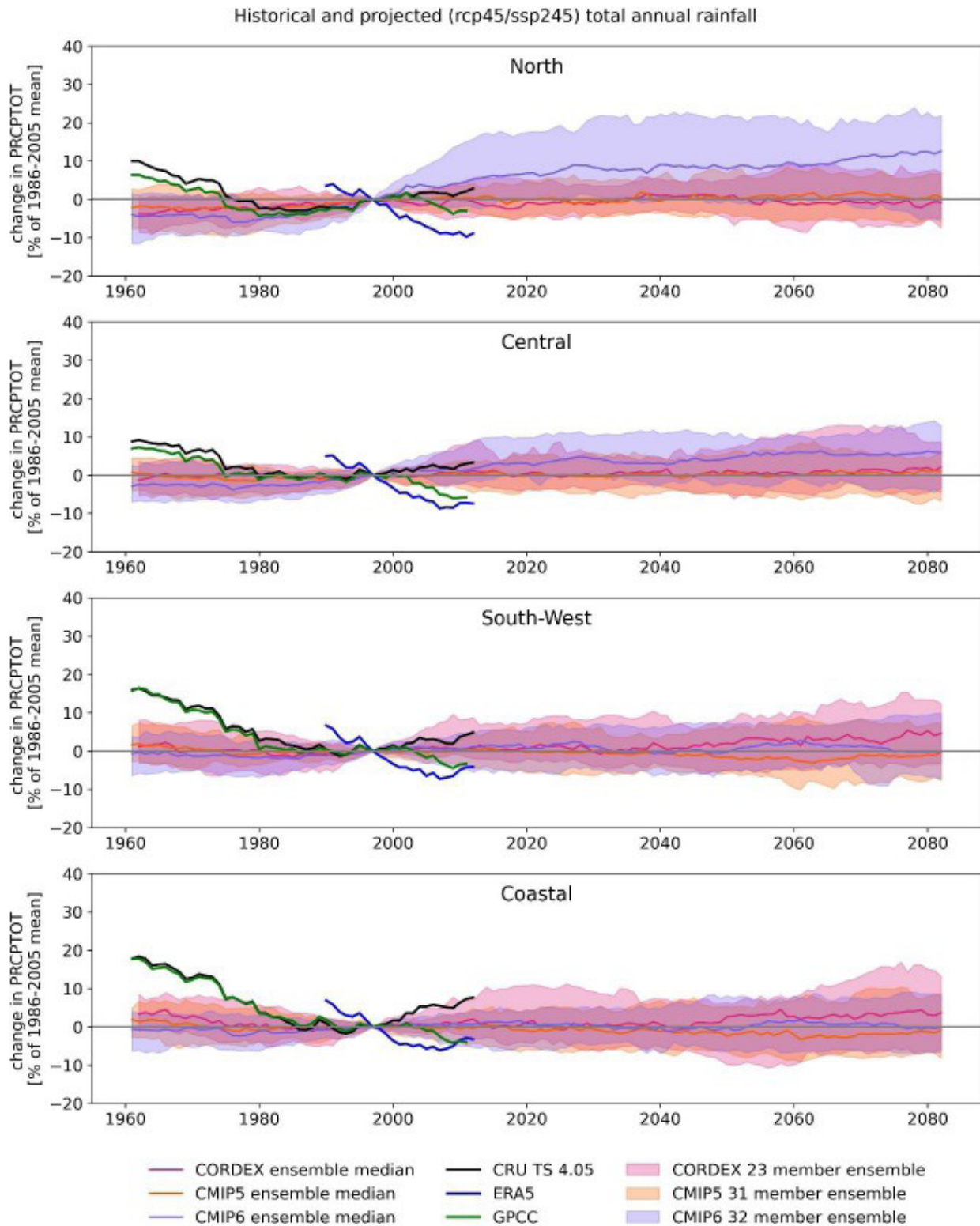
Overall, projections do not indicate any strong and consistent departures from the historical levels of total annual rainfall and the spread of the ensembles seem to reflect climate variability of magnitude similar to that simulated in the historical period. Only the CMIP6 ensemble projects a possible range of future rainfall that is larger than that simulated by models in the past.

Figure 35 | Plume plots illustrating the evolution of mean annual temperature in Ghana homogeneous climate zones in simulations of historical and future climate under RCP 4.5/SSP2 4.5 scenarios



All lines represent 20-year running averages calculated on annual values. Shaded areas show the range 10th to 90th %.

Figure 36 | Plume plots illustrating the evolution of total annual rainfall in Ghana homogeneous climate zones in simulations of historical and future climate in under RCP 4.5/SSP2 4.5 scenarios



All lines represent 20-year running averages calculated on annual values. Shaded areas show the range 10th to 90th%.

3.6.4. Results for RCP 8.5/SSP5 8.5

3.6.4.1 Air Temperature

Projections of the future air temperature under the rcp85/ssp585 scenario indicate a gradual increase continuing throughout the 21st century, with a rate that accelerates throughout the entire period. The end of the 21st century anomalies are projected to fall in the range 2.5 - 4.5 °C above historical mean. Unlike for projections under rcp26/ssp126 and rcs45/ssp245, the CMIP6 ensemble envelope includes lower projected temperatures, as low as 2 °C in 2100. The differences between regions are minimal.

There is a good consistency between the CMIP5 and dynamically downscaled CORDEX projections. That effect is visible in all regions. Overall, the dynamical downscaling does not seem to change the climate change signal compared to parent GCMs.

The four “representative” scenarios capture only certain aspects of the entire analysed ensemble (as mapped by the plumes). The scenarios seem to capture only the lower and middle part of the envelope, not reflecting cooler projections by CMIP6 and hotter projections by all three ensembles.

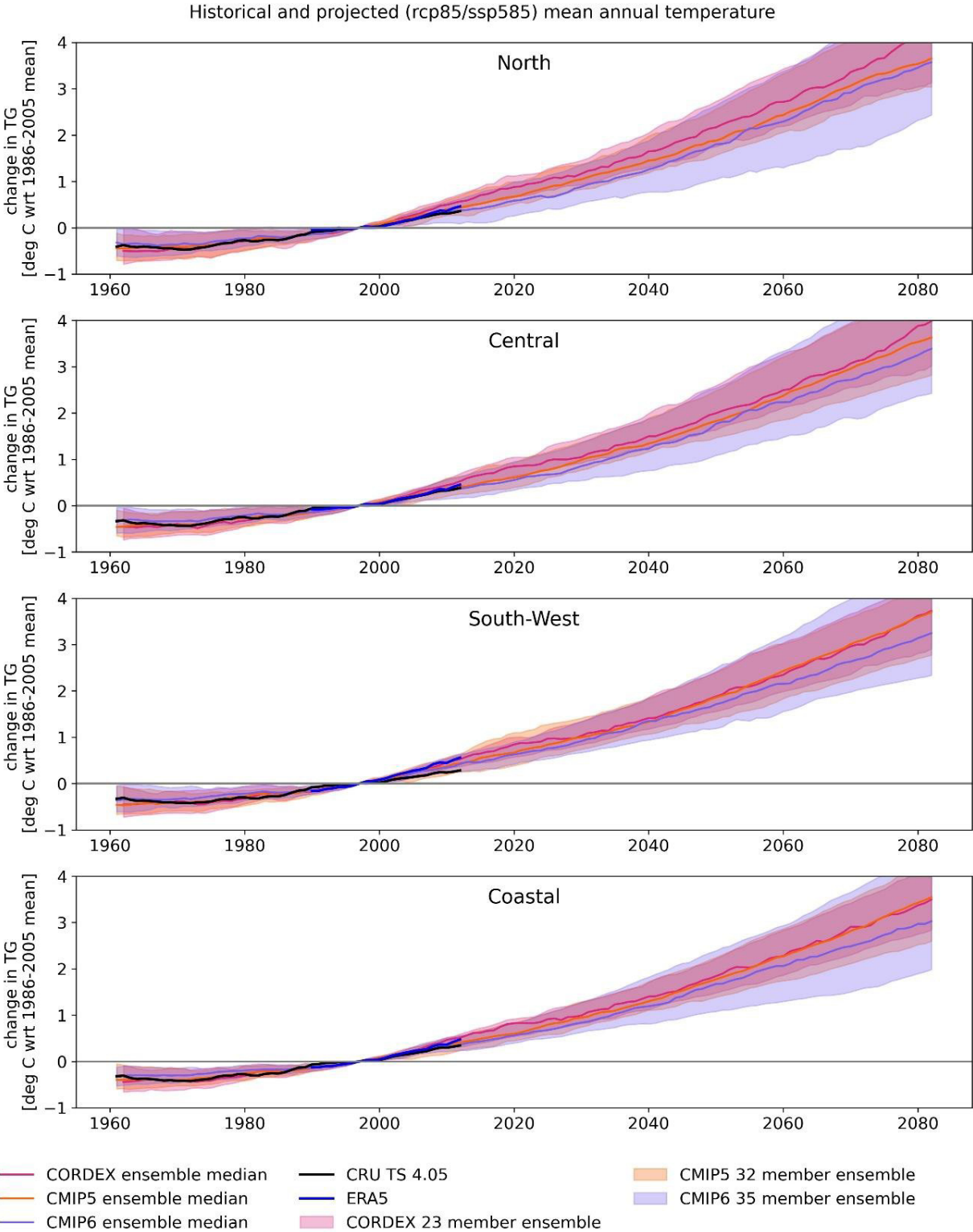
3.6.4.2 Rainfall

Projections of the future rainfall under rcp85/ssp585 scenario span both wetter and drier future in each of the regions, with the end of the 21st century anomalies projected to fall within a broad range of values -15% to 40% depending on the ensemble and region.

There is a good consistency between the different ensembles, apart from in the North, where CMIP6 ensemble projects a considerably wetter future compared to that projected by the other two ensembles.

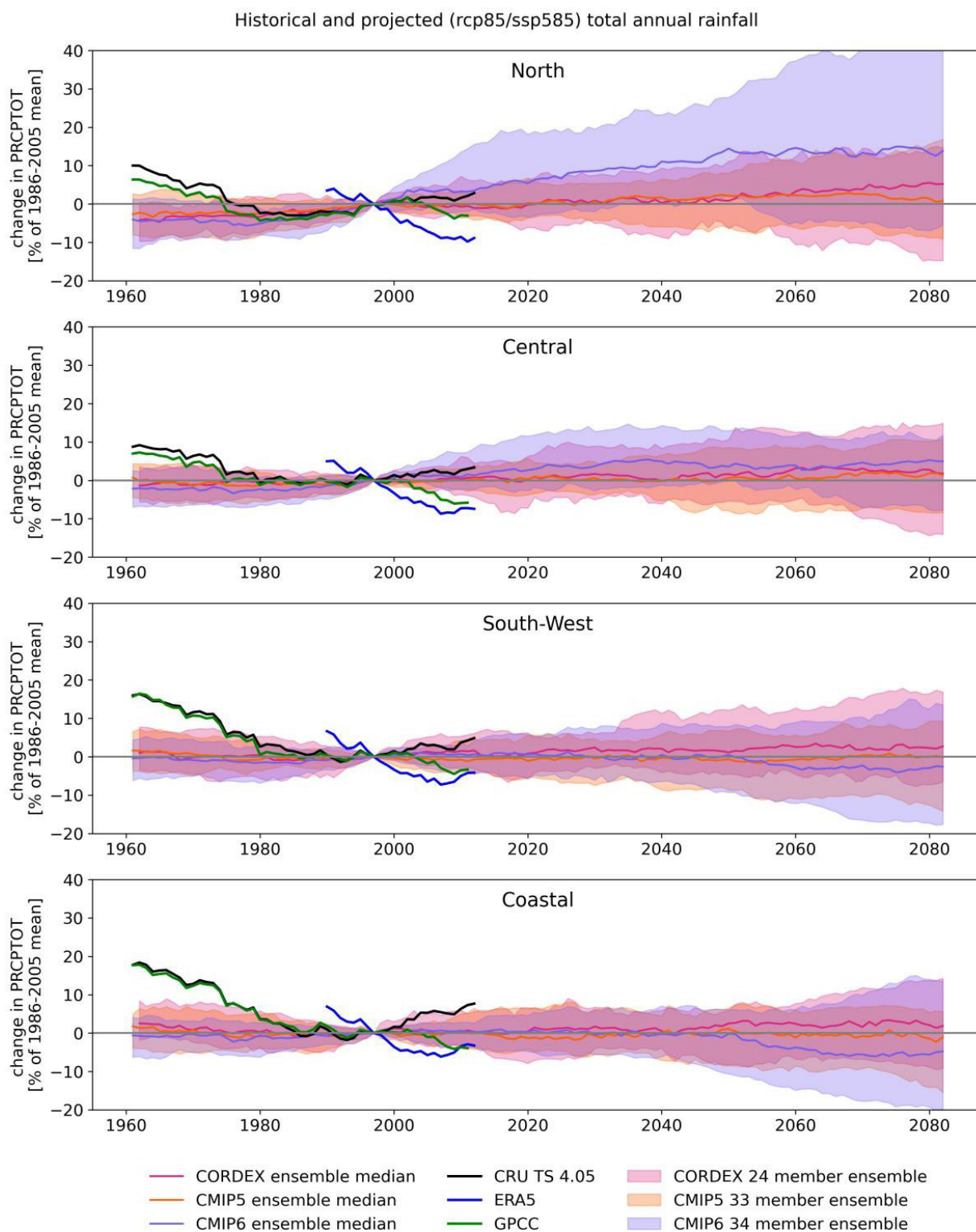
The four “representative” scenarios capture only certain aspects of the entire analysed ensemble (as mapped by the plumes). Individual simulations (scenarios) manifest quite strong levels of decadal and longer variability, and “criss-cross” each other, thus not maintaining the relative position throughout the future, with the consequence that the driest scenario over a certain period is not necessarily the driest over another. This reflects the high levels of long-term variability in rainfall in Ghana, and highlights its role in the uncertainty of rainfall projections. The overall envelope of projections is captured by the four scenarios relatively well in all regions, however.

Figure 37 | Plume plots illustrating the evolution of mean annual temperature in Ghana homogeneous climate zones in simulations of historical and future climate under rcp8.5/ssp585 scenarios.



All lines represent 20-year running averages calculated on annual values. Shaded areas show the range 10th to 90th %.

Figure 38 | Plume plots illustrating the evolution of total annual rainfall in Ghana homogeneous climate zones in simulations of historical and future climate under RCP85/SSP585 scenarios.



All lines represent 20-year running averages calculated on annual values. Shaded areas show the range 10th to 90th %.

3.7. Plume Plot Summaries for Priority MMDAs

Individual plume plots are included in **Appendix B** and the results summarised in the section below.

4. Summary of Future Climate Scenarios

4.1. Overall Summary of Climate Scenario Results

The overall messages about future climate in Ghana emerging from the analyses are as follows:

- **strong confidence** message of **increases in air temperatures** manifested in all scenarios. Those amount to **0.5 to 1.5 °C**, **1.5 to 2.5 °C** and **2.5 to 4.5 °C** above historical mean at the end of 21st century under **RCP26/SSP126**, **RCP45/SSP245** and **RCP85/SSP585** respectively.
- **moderate to low confidence** message of **weak changes (+/-5%)** (comparable to or only slightly stronger than the level of variability simulated for the past) in the overall “**wetness**” of the climate **without a clearly defined direction** of future changes in total annual rainfall, independently of emission scenario. That **low confidence** is partly caused by the lack of consistency in historical rainfall trends between observational data and model simulations and requires further analysis.
- there is **some variation across the regions**, with greater **increases in temperatures** expected over the northern region and a greater potential for **wetting** in the coastal zone under **CIMP5**.
- the latest **CIMP6 model results** suggest more **significant “wetting”**, particularly over the Northern and Central regions of Ghana, but **further analysis is required** to clarify these results.

4.2. Summary Results for Individual Climate Zones

A summary of the results of the analysis of future climate scenarios for the identified four homogenous climate zones across Ghana (i.e. Northern, Central, Southwestern, and Coastal) are given below.

4.2.1. Northern Climate Zone:

Generally speaking, there is greater likelihood for larger increases in temperature in the north (and the Central) than the other 3 zones. This zone will see **temperature** increases from between 1.5 deg under RCP 2.6 to 3.5/4 deg under 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 deg. As usual 8.5 represents a comparative step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of at least another 0.5 deg. In short there is a risk of significantly higher temperatures in the North compared to further south even at lower GHG concentration scenarios.

Precipitation does not appear to change significantly in the future. There is a slightly greater chance of small increases in annual average precipitation compared to the base years. Typically, around 5% increase there is also a relatively significant chance of decreases in precipitation to a similar degree. The extremes suggest that a change in precipitation is possible of up to 15/20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at 2.6 but not 4.5 or 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

4.2.2. Central Climate Zone:

Generally speaking, there is a greater likelihood that there is a greater increase in temperature here than in the southern zones. This zone will see **temperature** increases from between 1.5 deg under RCP 2.6 to 3.5/5 deg under 8.5 (possible greater change than in the North) with RCP 4.5 suggesting a mid-point of about 2.5 deg. As usual 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest and even greater increase of temperature of at least

another 2.0 deg. In short there is a risk of significantly higher temperatures in the Central area even at lower GHG concentration scenarios.

There is a slightly greater chance of small increases in annual average **precipitation** compared to the base years. Typically, around 30% chance of a decrease of around 10%. However, it is almost as likely that a similar increase in precipitation occurs. The extremes suggest that the change is possible of up to 15/20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at 2.6 but not 4.5 or 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

4.2.3. Southwestern Climate Zone:

This zone will see **temperature** increases from between 1.5/2.0 deg under RCP 2.6 to 3/4 deg under 8.5 with RCP 4.5 suggesting a mid-point of about 2/2.5 deg. As usual 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest and even greater increase of temperature of at least another 0.5 deg. In short there is a risk of significantly higher temperatures in the Southwest even at lower GHG concentration scenarios.

Precipitation does not vary as much as other regions in Africa. In this zone there is roughly equal chance of a small decrease in precipitation as there is an increase. This contrasts with the other the zones where the tendency is for a greater likelihood of an increase. The decrease is projected to be around 10% as is the increase. The extremes suggest that the change is possible of up to 15/20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at 2.6 but not 4.5 or 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

4.2.4. Coastal Climate Zone:

This zone will see **temperature** increases from between 1.5 deg under RCP 2.6 to 3 /4.5 deg under 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 deg. As usual 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of at least another 0.5 deg. In short there is a risk of significantly higher temperatures in the North even at lower GHG concentration scenarios.

There is a roughly equal chance of small increases and decreases in annual average **precipitation** compared to the base years. Typically, around 10% increase and decrease. The extremes suggest that the change is possible of up to 20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at 2.6 but not 4.5 or 8.5 where there is chance of significant increases in rainfall - possibly 20-30% greater increases.

4.3. Summary Results for Individual MMDAs

Below is a short summary of the likely impacts for each MMDA based on the relevant climate zone.

Table 16 | Priority MMDAs and Climate Zones

#	MMDA	Climate Zone
1	West Mamprusi Municipal	North
2	Tamale Metro	North / Central
3	Wenchi District	Central
4	Asuogyaman (Akosombo) District	Central / Coastal
5	Keta Municipal	Coastal
6	Kumasi Metro	Southwest / Central
7	Enchi (Aowin) District	Southwest
8	Ellembelle Municipal	Coastal
9	Sekondi Takoradi Metro	Coastal
10	Tema Metro	Coastal

4.3.1. West Mamprusi Municipal MMDA

The West Mamprusi Municipal MMDA is located in the **North Climate Zone** of Ghana.

In general, there is greater likelihood for larger increases in temperature in the North (and the Central) than the other two climate zones. This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3.5 to 4 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 deg. As usual RCP 8.5 represents a step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of another 0.5 °C. In short there is a **risk of significantly higher temperatures even at lower GHG concentration scenarios**.

Precipitation does not vary as much as other regions in Africa. There is a slightly greater chance of **small increases** in annual average precipitation compared to the base years. Typically, around 5% increase. There is also a relatively significant chance of **decreases** in precipitation to a similar degree. The extremes suggest that a change in precipitation is possible of up to +/-15/20%. The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP

4.5 or RCP 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

The latest **CMIP6 model results** suggest **greater climate sensitivity** and more **significant “wetting”**, particularly over the Northern region of Ghana, but **further analysis is required** to clarify these results.

Figure 39 | Change in mean annual temperature (deg C) for West Mamprusi

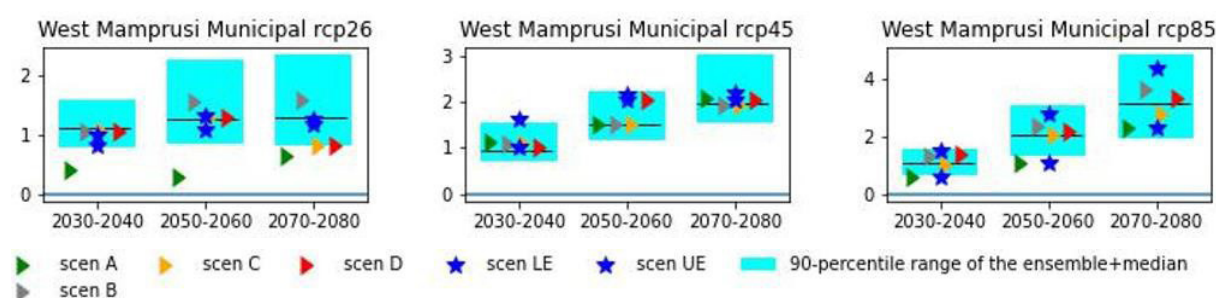
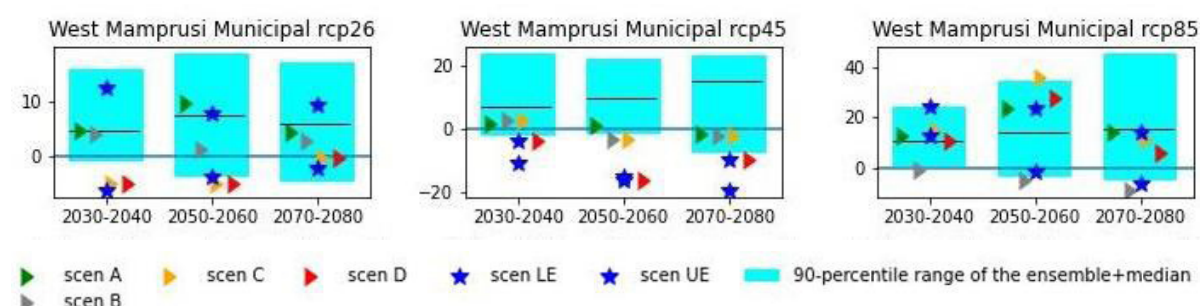


Figure 40 | Change in total annual rainfall (%) for West Mamprusi



4.3.2. Tamale Metro MMDA

The Tamale Metro MMDA is located on the border of the **Northern** and **Central Climate Zones**.

In general, there is greater likelihood for larger increases in temperature in the North (and the Central) than the other two climate zones. This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3.5 to 4 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 °C. As usual RCP 8.5 represents a step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of another 0.5 °C. In short there is a **risk of significantly higher temperatures even at lower GHG concentration scenarios**.

Precipitation does not vary as much as other regions in Africa. There is a slightly greater chance of **small increases** in annual average precipitation compared to the base years. Typically, around 5% increase. There is also a relatively significant chance of **decreases** in precipitation to a similar degree. The extremes suggest that a change in precipitation is possible of up to +/-15/20%. The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

The latest **CMIP 6 model results** suggest **greater climate sensitivity** and more **significant “wetting”**, particularly over the Northern region of Ghana, but **further analysis is required** to clarify these results.

Figure 41 | Change in mean annual temperature (deg C) for Tamale Metropolitan relative to the base period

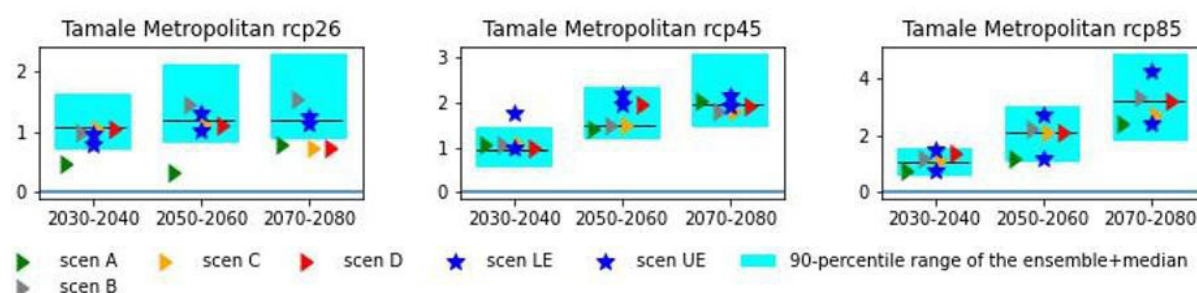
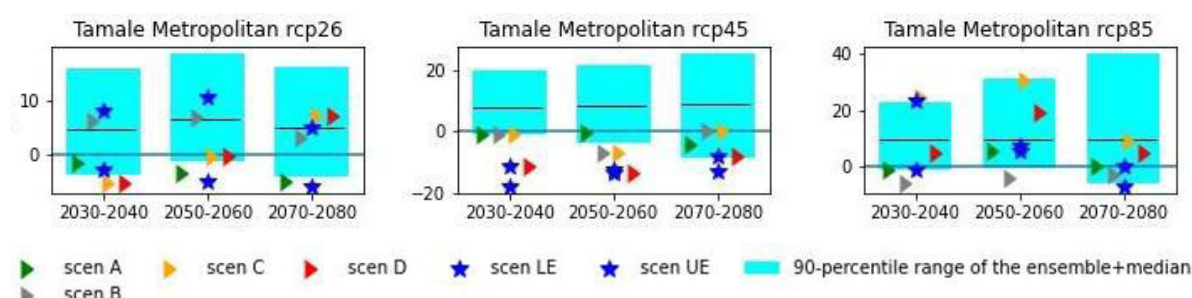


Figure 42 | Change in total annual rainfall (%) for Tamale Metropolitan relative to the base period



4.3.3. Wenchi District MMDA

The Wenchi District MMDA is located in the **Central Climate Zone**.

In general, there is a greater likelihood that there is a greater increase in temperature here than in the southern zones. This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3.5 to 5 °C under RCP 8.5 (possible greater change than in the North) with RCP 4.5 suggesting a mid-point of about 2.5 °C. As usual RCP 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest and even greater increase of temperature of at least another 2.0 °C. In short there is a risk of significantly higher temperatures in the Central area even at lower GHG concertation scenarios.

There is a slightly greater chance of small increases in annual average **precipitation** compared to the base years. Typically, around 30% chance of a decrease of around 10%. However, it is almost as likely that a similar increase in precipitation occurs. The extremes suggest that the change is possible of up to 15/20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

Figure 43 | Change in mean annual temperature (deg C) for Wenchi District

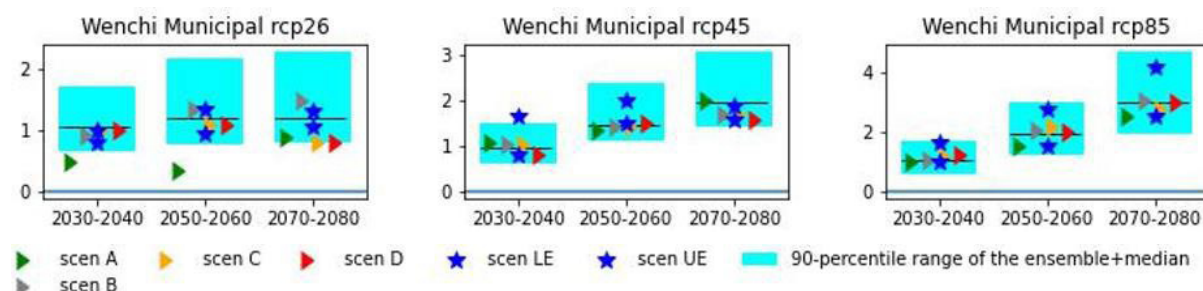
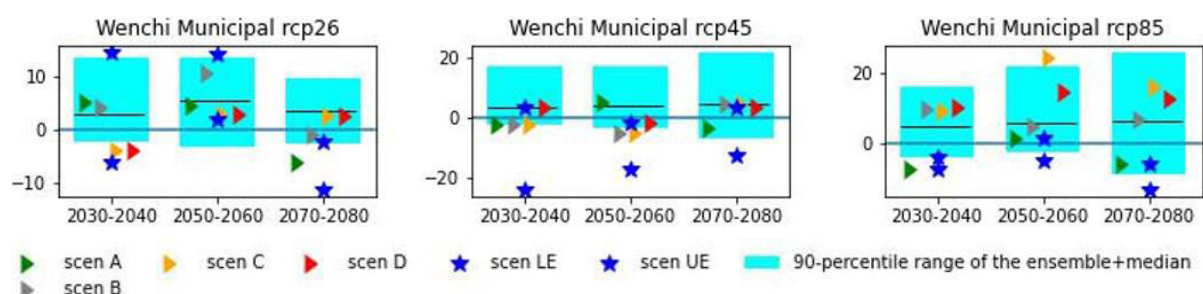


Figure 44 | Change in total annual rainfall (%) for Wenchi District



4.3.4. Asuogyaman (Akosombo) District MMDA

The Asuogyaman (Akosombo) District MMDA is located on the border between the **Central** and the **Coastal Climate Zones**.

In general, there is a greater likelihood that there is a greater increase in temperature here than in the southern zones. This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3.5/5

°C under RCP 8.5 (possible greater change than in the North) with RCP 4.5 suggesting a mid-point of about 2.5 °C. RCP 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of at least another 2.0 °C. In short there is a risk of significantly higher temperatures in the Central area even at lower GHG concentration scenarios.

There is a slightly greater chance of small increases in annual average **precipitation** compared to the base years. Typically, around 30% chance of a decrease of around 10%. However, it is almost as likely that a similar increase in precipitation occurs. The extremes suggest that the change is possible of up to 15/20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

Figure 45 | Change in mean annual temperature (deg C) for Asuogyaman (Akosombo) District

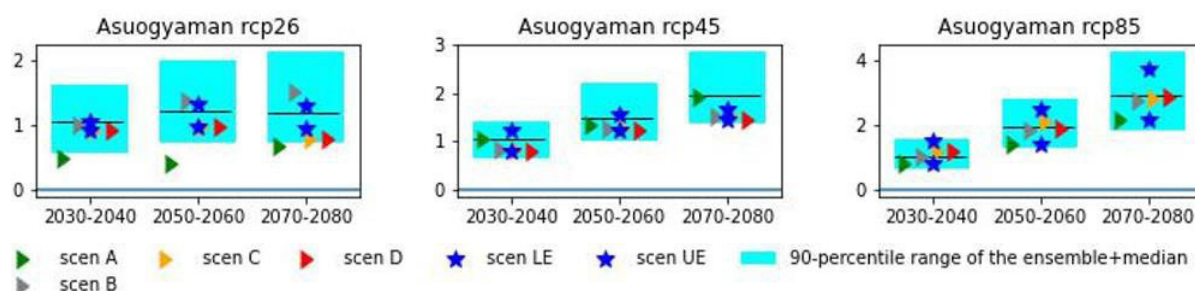
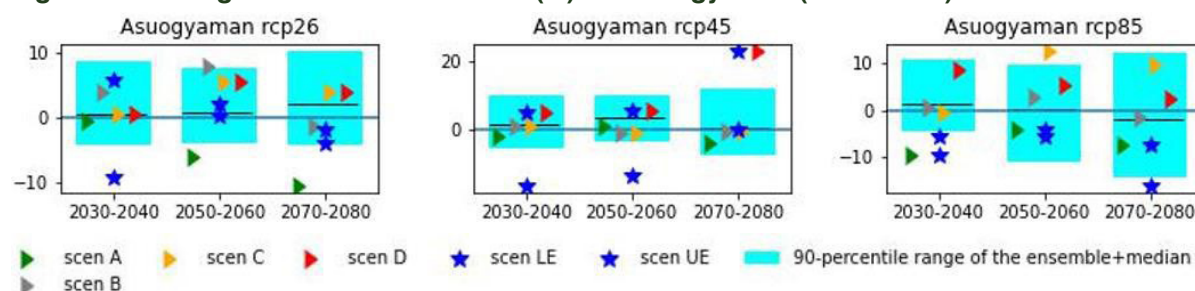


Figure 46 | Change in total annual rainfall (%) for Asuogyaman (Akosombo) District



4.3.5. Keta Municipal MMDA

The Keta Municipal MMDA is located in the **Coastal Climate Zones**.

This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3 to 4.5 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 °C. As usual RCP 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of at least another 0.5 °C. In short there is a risk of significantly higher temperatures in the North even at lower GHG concentration scenarios.

There is a roughly equal chance of small increases and decreases in annual average **precipitation** compared to the base years. Typically, around 10% increase and decrease. The extremes suggest that the change is possible of up to 20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall - possibly 20-30% greater increases.

Figure 47 | Change in mean annual temperature (deg C) for Keta Municipal

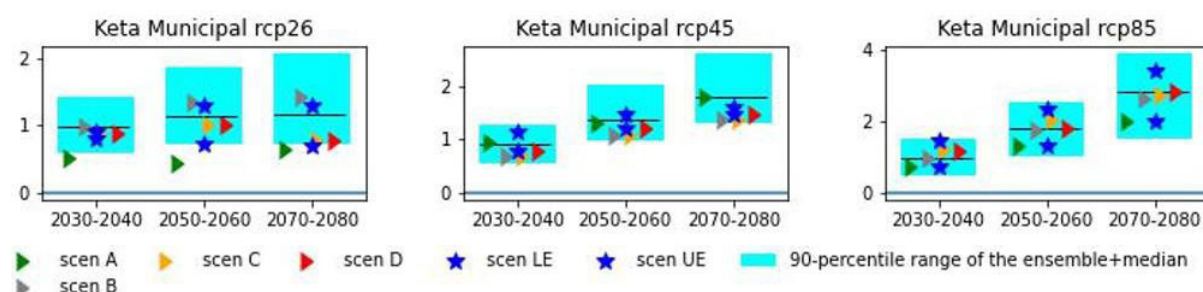
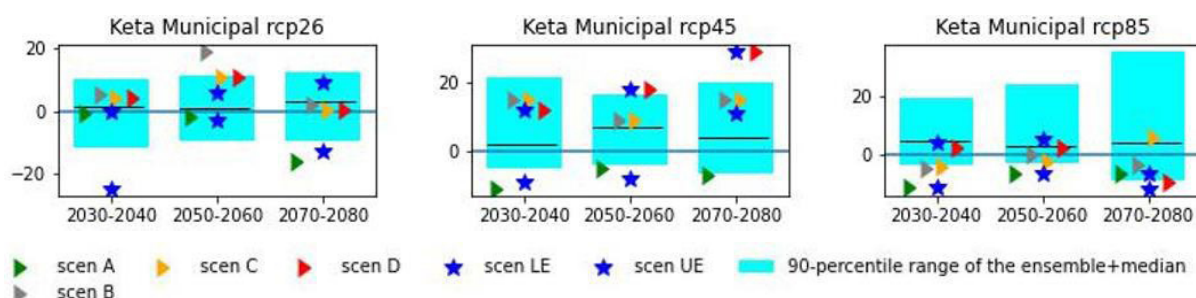


Figure 48 | Change in total annual rainfall (%) for Keta Municipal



4.3.6. Kumasi Metro MMDA

The Kumasi Metro MMDA is located on the border between the **Southwest** and **Central Climate Zones**.

This zone will see **temperature** increases from between 1.5 to 2.0 °C under RCP 2.6 to 3 to 4 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2 to 2.5 °C. As usual RCP 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP6 suggest even greater increase of temperature of at least another 0.5 °C. In short there is a risk of significantly higher temperatures in the Southwest even at lower GHG concentration scenarios.

Precipitation does not vary as much as other regions in Africa. In this zone there is roughly equal chance of a small decrease in precipitation as there is an increase. This contrasts with the other the zones where the tendency is for a greater likelihood of an increase. The decrease is projected to be around 10% as is the increase. The extremes suggest that the change is possible of up to 15/20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP

2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

Figure 49 | Change in mean annual temperature (deg C) for Kumasi Metro

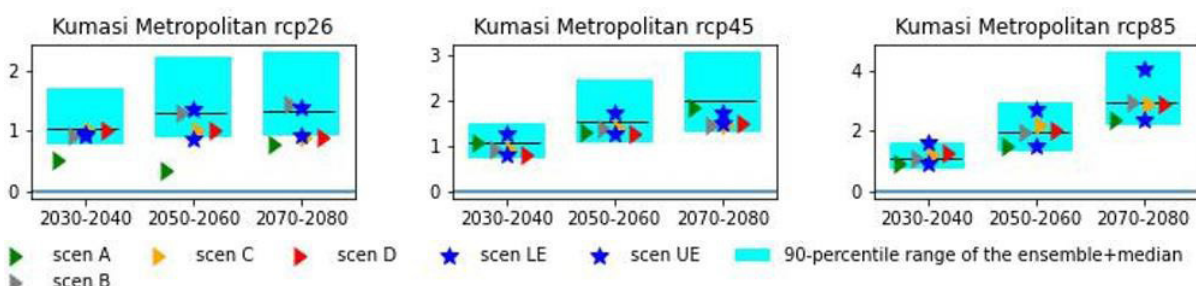
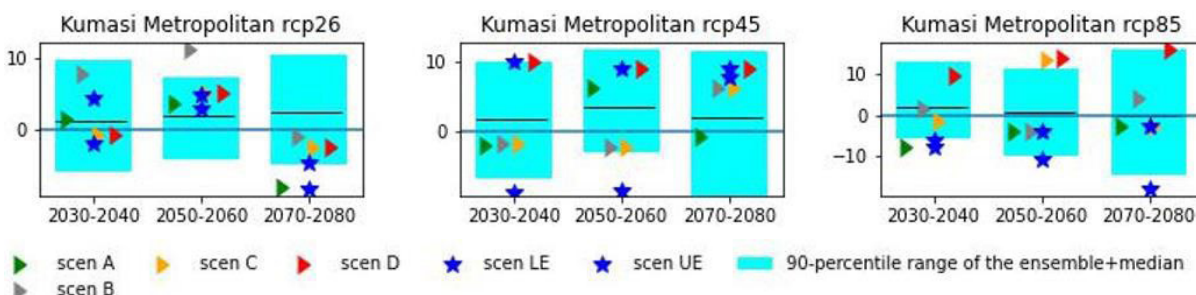


Figure 50 | Change in total annual rainfall (%) for Kumasi Metro



4.3.7. Enchi (Aowin) District MMDA

The Enchi (Aowin) District MMDA is located in the **Southwest Climate Zone**.

This zone will see **temperature** increases from between 1.5/2.0 °C under RCP 2.6 to 3 to 4 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2/2.5 deg. As usual RCP 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP6 suggest and even greater increase of temperature of at least another 0.5 deg. In short there is a risk of significantly higher temperatures in the Southwest even at lower GHG concertation scenarios.

Precipitation does not vary as much as other regions in Africa. In this zone there is roughly equal chance of a small decrease in precipitation as there is an increase. This contracts with the other the zones where the tendency is for a greater likelihood of an increase. The decrease is projected to be around 10% as is the increase. The extremes suggest that the change is possible of up to 15/20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP

2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall possibly 20% greater increases.

Figure 51 | Change in mean annual temperature (deg C) for Enchi (Aowin) District

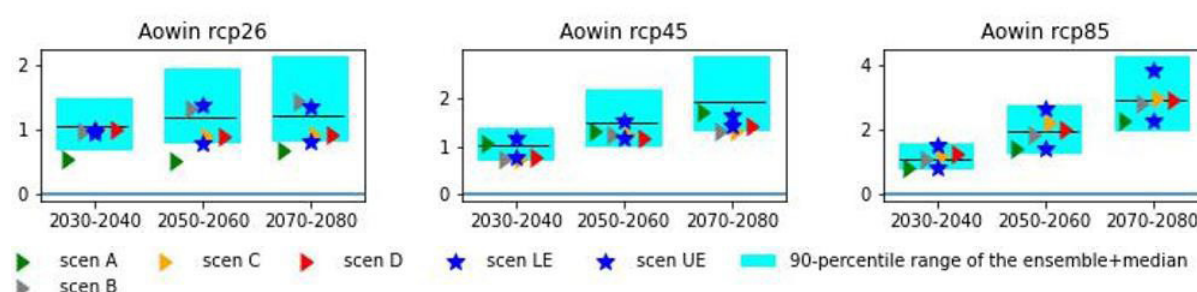
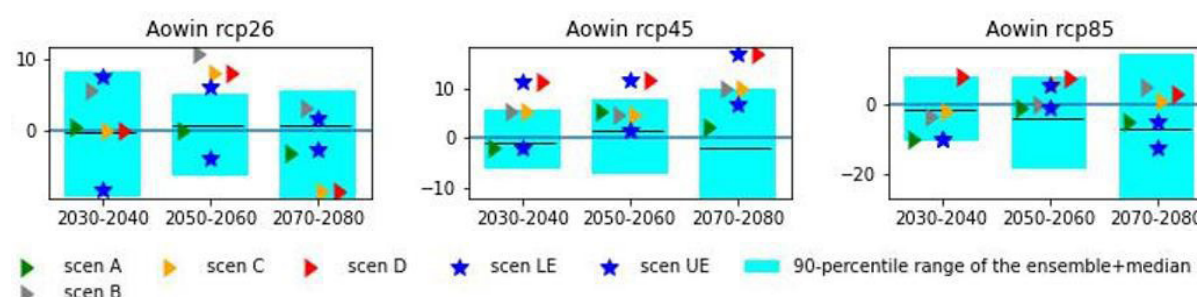


Figure 52 | Change in total annual rainfall (%) for Enchi (Aowin) District



4.3.8. Ellembelle Municipal MMDA

The Ellembelle Municipal MMDA is located in the **Coastal Climate Zone**.

This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3 to 4.5 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 °C. As usual RCP 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of at least another 0.5 °C. In short there is a risk of significantly higher temperatures in the North even at lower GHG concertation scenarios.

There is a roughly equal chance of small increases and decreases in annual average **precipitation** compared to the base years. Typically, around 10% increase and decrease. The extremes suggest that the change is possible of up to 20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job

of capturing the possible variation at RCP 2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall - possibly 20-30% greater increases.

Figure 53 | Change in mean annual temperature (deg C) for Ellembelle Municipal

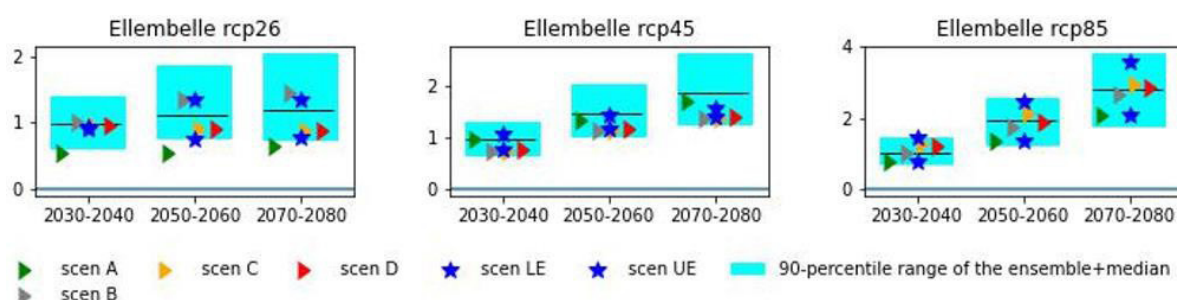
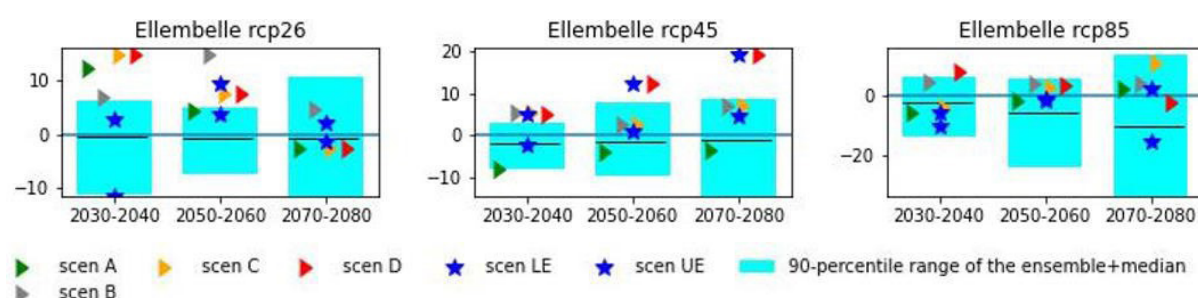


Figure 54 | Change in total annual rainfall (%) for Ellembelle Municipal



4.3.9. Sekondi Takoradi Metro MMDA

The Sekondi Takoradi Metro MMDA is located in the **Coastal Climate Zone**.

This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3 to 4.5 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 °C. As usual 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP6 suggest an even greater increase of temperature of at least another 0.5 deg. In short there is a risk of significantly higher temperatures in the North even at lower GHG concertation scenarios.

There is a roughly equal chance of small increases and decreases in annual average **precipitation** compared to the base years. Typically, around 10% increase and decrease. The extremes suggest that the change is possible of up to 20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall - possibly 20-30% greater increases.

Figure 55 | Change in mean annual temperature (deg C) for Sekondi Takoradi Metro

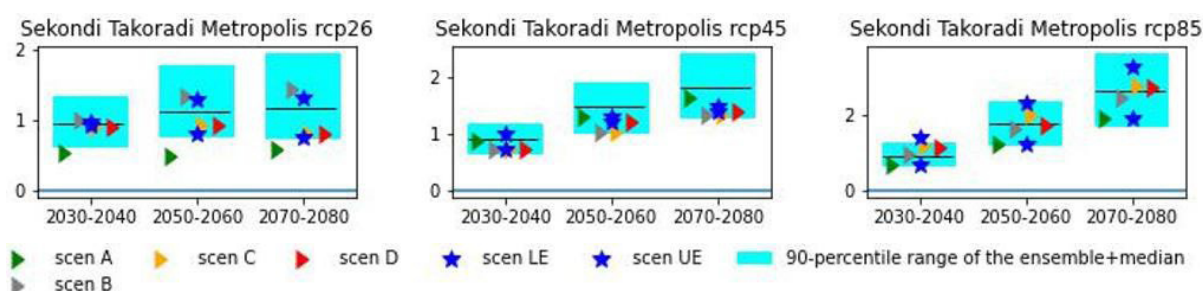
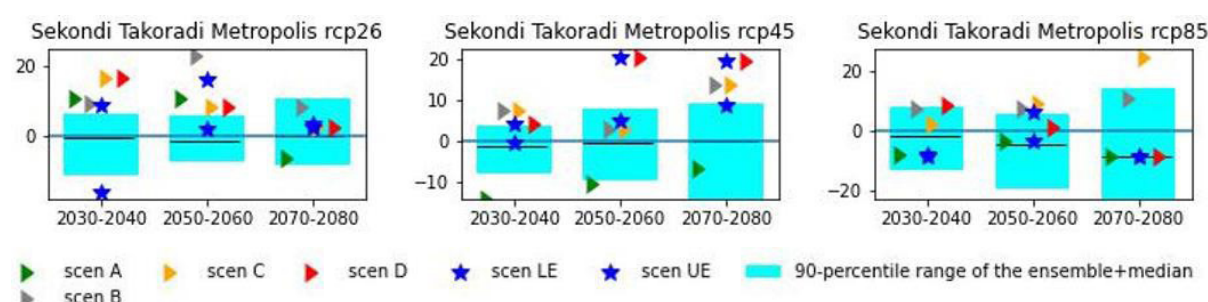


Figure 56 | Change in total annual rainfall (%) for Sekondi Takoradi Metro



4.3.10. Tema Metro MMDA

The Tema Metro MMDA is located in the **Coastal Climate Zone**.

This zone will see **temperature** increases from between 1.5 °C under RCP 2.6 to 3 to 4.5 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 °C. As usual RCP 8.5 represents step change in temperature. However, the plume plots particularly when incorporating CMIP 6 suggest an even greater increase of temperature of at least another 0.5 °C. In short there is a risk of significantly higher temperatures in the North even at lower GHG concentration scenarios.

There is a roughly equal chance of small increases and decreases in annual average **precipitation** compared to the base years. Typically, around 10% increase and decrease. The extremes suggest that the change is possible of up to 20% +/- . The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall - possibly 20-30% greater increases.

Figure 57 | Change in mean annual temperature (deg C) for Tema Metro

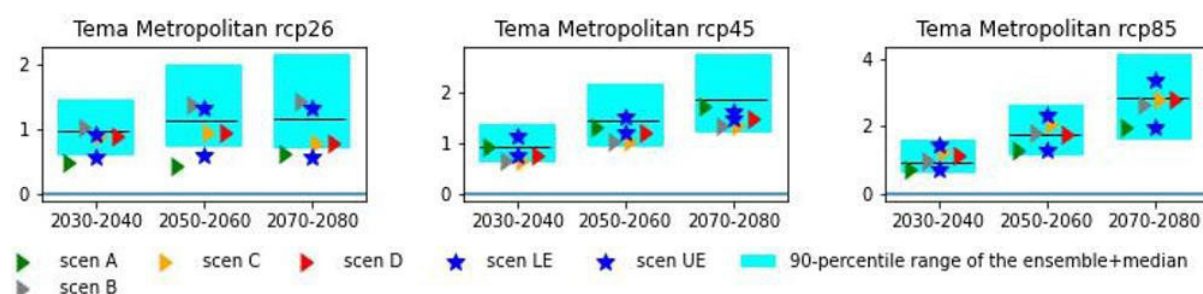
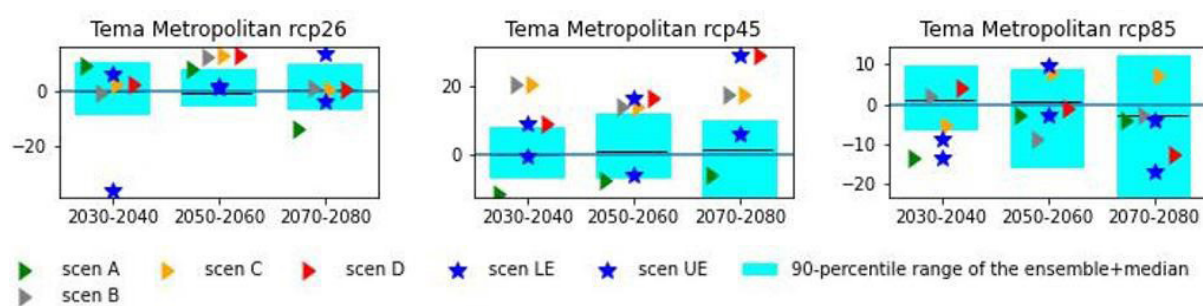


Figure 58 | Change in total annual rainfall (%) for Tema Metro



5. Additional Points of Discussion

Two additional points of discussion have been identified during the analysis and are discussed below.

5.1. Why CMIP6 models were not used in the analysis?

CMIP6, although still in the process of being developed, is the latest in the series of CMIP data sets, contains projections from the most sophisticated climate models yet developed, and forms much of the basis for the Working Group I (WGI) report in the latest IPCC assessment report, IPCC AR6, released in late 2021. Further, the design of CMIP6, using the SSP emissions scenarios, incorporates the RCPs within the SSPs with the intention of producing projections within both CMIP5 and CMIP6 that can be analysed together to create a larger joint ensemble.

So why have CMIP6 projections not been used rather than CMIP5 projections, either alone or in combination with CMIP5?

The *simplest* answer is that, at present, available CORDEX downscaling offers only CMIP5 host GCMs together with the RCMs, although development of CORDEX using CMIP6 hosts is under way.

A *second argument* for not incorporating the additional complexities associated with including CMIP6 is based on the statement on page 1-83 of the draft IPCC WGI Report: “*Despite the documented progress of higher resolution, the model evaluation carried out in subsequent chapters shows that improvements between CMIP5 and CMIP6 remain modest at the global scale*”. Further details are provided in Section 3.8.2 of the Report, and in particular in Figure 3.42 it is indicated that improvements from CMIP5 to CMIP6 for some of the variables of interest to Ghana do not occur with all models.

Nevertheless the arguments above are not conclusive, so an analysis using SOMs has been made for the four climate zones of Ghana (North, Central, Southwest and Coastal), but representative results from the North Zone using 4 nodes only will be presented, for RCP4.5 to represent CMIP5 (in Figure 59) and the equivalent SSP2-45 to represent CMIP6 (in Figure 60).

Figure 59 | North Zone under RCP4.5

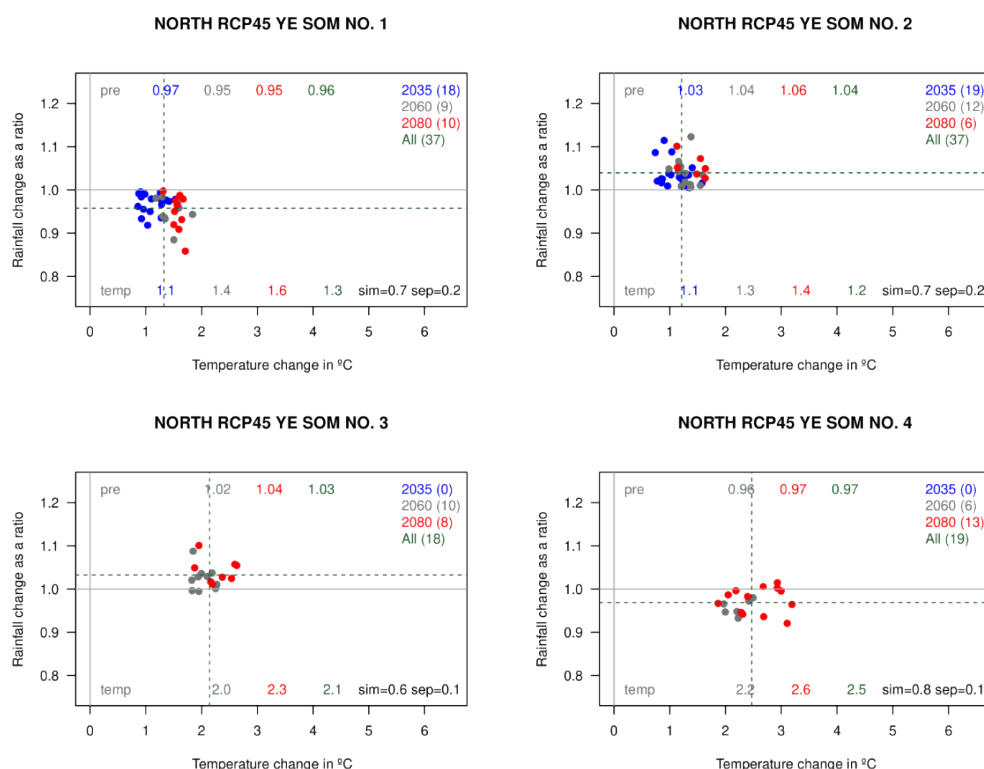
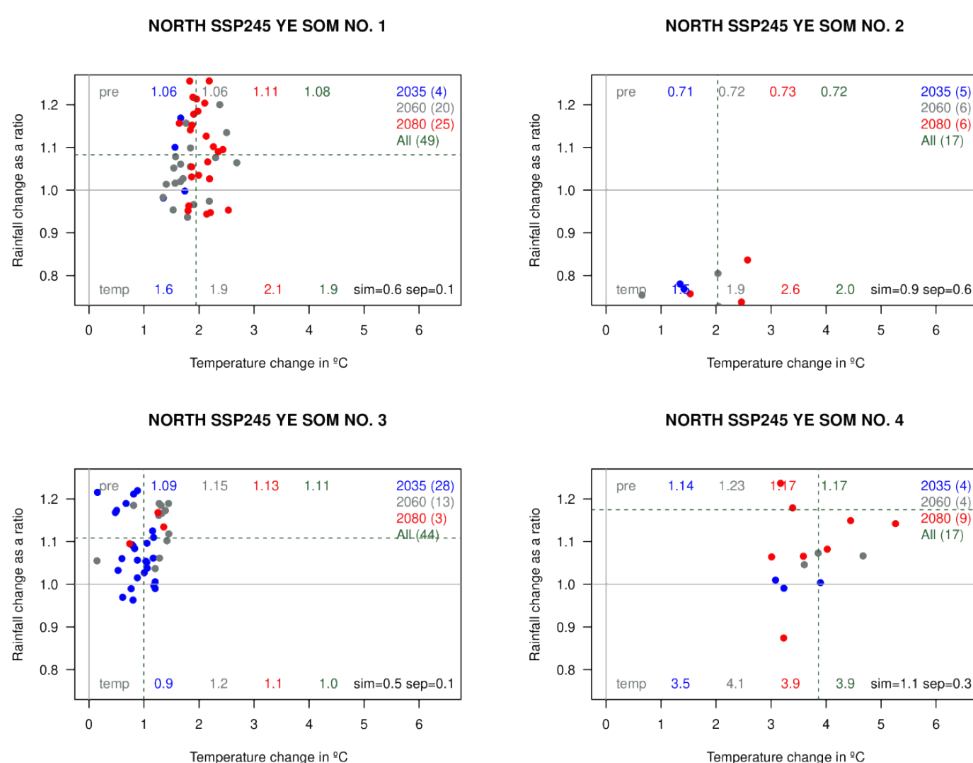


Figure 60 | North Zone under SSP2-45



It is evident immediately by comparison of the two Figures that the distribution of points differs substantially between CMIP5 and CMIP6, one key aspect being that the distribution of rainfall projections is notably wider in CMIP6 than in CMIP5. The use of SOMs to study differences between the two data sets appears to be a powerful technique, although further analysis is beyond the scope of this project.

No equivalent study was made in earlier analyses when the work moved from CMIP3 to CMIP5⁵, but the results from the SOMs on the two data sets did not appear to show disparities in a similar way to those illustrated above. It is known that some of the newer model versions in CMIP6 project greater and faster temperature increases than their equivalents in CMIP5, and it has been argued that this may also be more realistic, and this might in part account for the differences revealed above in the rainfall projections.

Nonetheless, what the two Figures reveal is the *main reason* for not including CMIP6 (independent of the relative validities of the two CMIP data sets) is that any scenarios developed from CMIP6 may not be represented with any validity in CORDEX projections that use CMIP5 host GCMs only.

Thus, only CMIP5 has been used in the SOMs analysis.

5.2. Why use Ensembles?

Both CMIP and CORDEX provide ensembles of projections, i.e. a set of individual projections from a number of different models, although all use certain common rules and boundary conditions, not least common emissions scenarios (the RCPs for CMIP5, the SSPs for CMIP6). For RCP8.5 the CMIP5 ensemble, as used in the IPCC AR5, contains 39 individual projections, and so 39 possibly different solutions, each suggesting diverse responses in terms of planning both adaptation and mitigation. For the decision maker this is clearly excess information, so why do we focus on ensembles?

5.2.1. The generation of ensembles

There are several approaches to creating ensembles, an aspect explored in more detail in CMIP6 and in the IPCC AR6 than in earlier Reports from the IPCC. Nevertheless, the basic, pragmatic, approach within CMIP6, for the main results as presented in the AR6, remains the same as previously (including in CMIP5), an open house for any modelling group interested in submitting their projections provided they follow the agreed guidelines. A similar democratic process is used for CORDEX, except that in this case each RCM requires projections from a host GCM, and that process reduces the numbers of both GCMs and of RCMs used.

One significant issue is that it is not possible to undertake a detailed examination of the performance of climate change ensembles until, perhaps, the end of this century. While lessons can be learned from the use of ensembles on shorter time scales for which full validation is possible, there is still a desire amongst both modellers and decision makers to identify the “best” model(s) to use. The issues are summarised in Box 4.1 of the AR6 (Chapter 4). It is beyond the scope of this project to undertake the steps used in the AR6 with the CMIP6 ensembles, and thus the raw CMIP5 ensembles, for which no such adjustments are immediately available, have been analysed. Nevertheless, it is useful to summarise a selection of the issues listed in AR6’s Box 4.1.

- In Box 4.1 is a list of three uncertainties involved in modelling. No details need be given here but it is these uncertainties that lead to the requirement to produce ensembles, i.e. the projections from any individual model are uncertain and inevitably contain errors. In order to attempt to reduce and to measure these uncertainties ensembles are created with a number of models, all scientifically valid but different in their approaches and each giving diverse, to greater or lesser extent, projections. There is no approach currently available to identifying any single “best” projection, and therefore the processes described below in Section 5.2.2 are used.
- Independence is a fundamental aspect of the theoretical requirements for producing a valid ensemble. This means that each projection is independent of each other, a condition that

5 There was no CMIP4 to avoid confusion with a then-extant climate modelling project with a similar name

does not, and likely never will, hold in CMIP5/6 or CORDEX. In CMIP some modelling houses contribute projections from two or more generations of the same model, which thus share portions of code and result in non-independence. There is also some code sharing between models of different houses, which eliminates independence. Attempts are made in some areas of the AR6 to identify and remove models lacking independence. The situation in CORDEX is, from the theoretical perspective, worse than in CMIP6 as the fewer numbers of modelling houses working with downscaling often repeatedly use a small number of GCM hosts with one or two generations of the same RCM. No attempt to adjust for lack of independence has been made in the analyses for Ghana, an examination beyond the scope of this project.

- Historical performance has frequently been used to select specific projections to reduce the complexities of interpreting an ensemble, and is used in part in the AR6, but again assessment of historical performance is beyond the scope of this project. Historical performance comes in via at least two scales: a) the local scale, as used frequently in many National Contributions to the UNFCCC; b) the large-scale environment within which the local scale sits (such as in simulating El Niño/Southern Oscillation – ENSO). One issue is which metrics to use in both cases, as alternate choices are likely to produce different selections. Approaches specifically mentioned within the AR6 include large-scale analysis (e.g., simulation of summer Arctic ice coverage) and assessment from a project for decadal projection.

The above is not a complete list of all issues, but one additional aspect to be noted is that, even with perfect ensemble, there is a likelihood that the “answer” lies fully outside the ensemble, in one direction or another, that likelihood reducing as the ensemble grows in size (for a 40-member ensemble, as for RCP8.5 in CMIP5, the likelihood is ~5%). It might be noted that events such as the melting of Arctic Sea ice have tended to occur more quickly than suggested by the models, leading to the possibility that the CMIP ensembles are insufficiently wide with the “answer” on the warm side; this issue has been considered in some detail in the AR6. There is no way of correcting for this, although the IPCC AR5 assumed that the 5% to 95% temperature range based directly on the ensembles should be interpreted more reasonably as the 17% to 83% range to accommodate this issue.

Another often perhaps over-looked aspect of uncertainties in using ensembles in climate projections is the issue of emissions scenarios. Three scenarios have been used here, RCP2.6, RCP4.5 and RCP8.5. These emissions scenarios cover a range of reasonable futures, but no selection can be made of which is the more likely to reflect the future (although subjected judgments, based on various assumptions, have often been used to eliminate one or more emissions scenarios from consideration). Projections under different emissions scenarios are typically considered independently of each other because of the issues of mitigation and of the UNFCCC negotiations but given only limited ability to select between these scenarios it is not unreasonable to treat the combination of projections for all three as an ensemble. In the AR6 the IPCC has started to adopt this approach by combining projections at common levels of global warming into common ensembles regardless of emissions scenario.

5.2.2. A visual example of the justification for using ensembles

The following diagrams illustrate the justification for using ensembles for the Coastal Zone under RCP2.6; equivalent diagrams can be provided on request for the other three climate zones and for all RCPs.

Figure 61 | Distributions of relatively warm average years projected for the Coastal Zone under RCP2.6



In Figure 61 heavy blue blocks indicate years in which each model projects for specific years (along the horizontal axis) average temperatures exceeding two (top diagram) and three (bottom diagram) standard deviations (i.e., the warmest ~16% and ~2.5% respectively) calibrated over the base period of 1986 to 2005. Each individual projection occupies a row, with the rows ordered from the most (top row) to the least (bottom row) frequent occurrences exceeding the thresholds.

Figure 62 | Distributions of relatively dry and wet annual rainfall totals projected for the Coastal Zone under RCP2.6

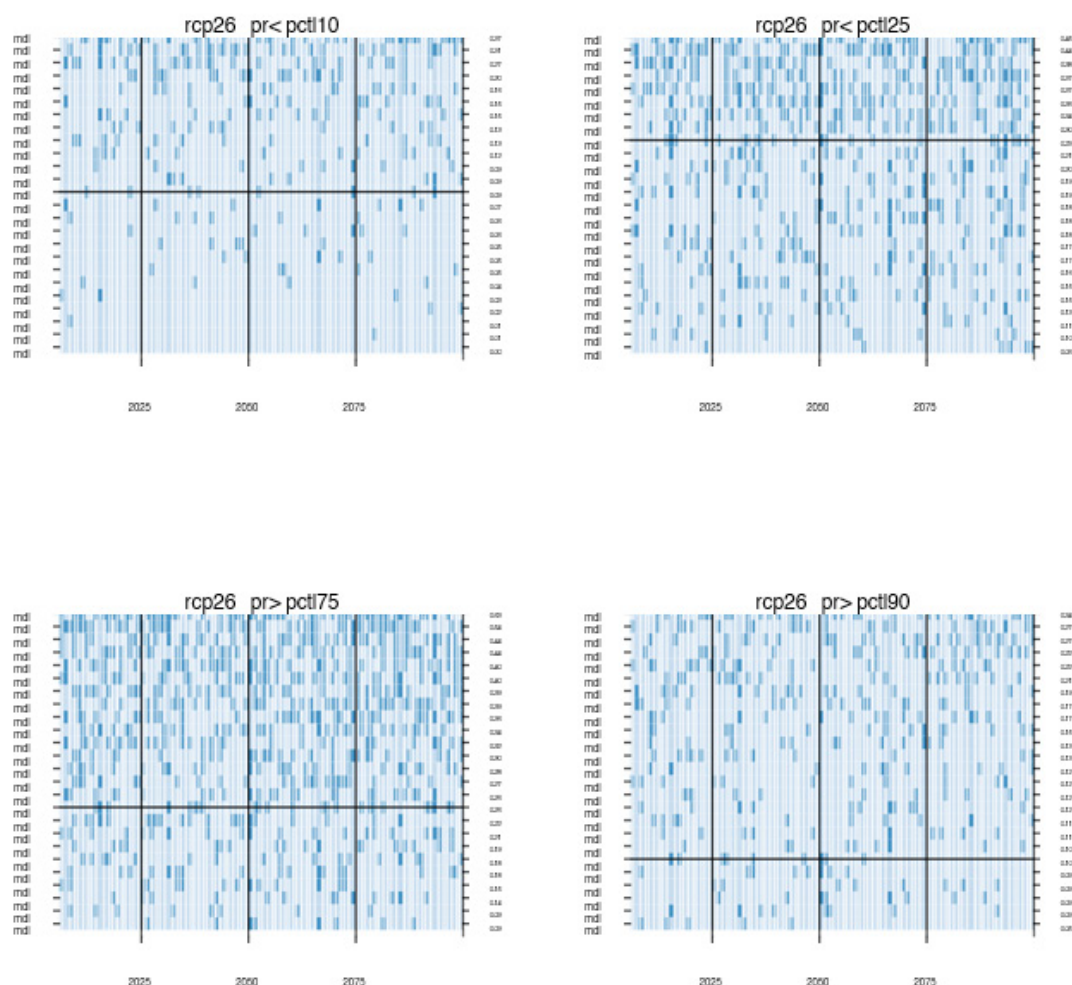


Figure 62 is similar to Figure 61 but illustrates, using heavy blue blocks, years with projections for annual rainfall totals, as calibrated over the base period, under the 10th percentile (top left), under the 25th percentile (top right), over the 75th percentile (bottom left), and over the 90th percentile (bottom right).

Looking at Figure 61 and Figure 62, some of the models project more frequent exceedances of both the temperature and the rainfall thresholds than others. Indeed, taking the temperature case in Figure 61, there are some models that project almost continuous seasonal temperatures above the 2 standard deviations threshold, starting nearly immediately in the sequence, whereas some near the bottom row project only a handful of such cases. The contrast between projections is even starker using 3 standard deviations. Different models warm the atmosphere at different rates in response to growing greenhouse gas concentrations, with the true rate in the atmosphere not known precisely. Thus, those models warming more quickly will produce more events exceeding the thresholds than those with slower responses. It has been a feature of successive versions of CMIP projections, as summarised in the IPCC ARs, that each is on average a little warmer than the preceding, an observation equally true of the AR6 (CMIP6) as compared to the AR5 (CMIP5).

The link between temperature and rainfall is complex, but again it is apparent from Figure 62 that some models produce more drier years below the 10th and 25th percentiles thresholds and wetter years exceeding the 75th and 90th thresholds than others (no attempt is made here to identify how models respond individually to all the temperature and rainfall thresholds). Rainfall is often critical in adaptation planning and these diagrams clearly illustrate the limitation of the CMIP projections in this regard.

There is no specific conclusion to be drawn from these two figures other than that any selection of, perhaps, just one, maybe two, perhaps more, individual models raise the risk of using projections that *may* prove inaccurate and that *might* lead to maladaptation. Clearly selection of an individual model does not cover all uncertainties involved. Some of the models tend to project more frequent events than others, with some suggesting almost annual events while others few, if any, events. Creation of ensembles helps identify the uncertainties associated with climate change projections but at the expense of creating a more complex information set to interpret.

5.2.3. The interpretation of ensemble results

Given numerous GCMs in the case of CMIP, or GCM/RCM pairings in the case of CORDEX, used to produce an ensemble of individual projections, none the same, there is an issue of how to interpret the broad spread of information produced. Several approaches have been used:

- At the simplest level is the selection of a preferred single model, as mentioned above. Unfortunately, there is no evidence to guide appropriate selection, while predictability theory is clear in indicating the limitations of this approach. Published papers, nevertheless, frequently use this approach. It is quite valid as an examination of the performance of a particular model, but caveats are needed if this approach is used to prepare scenarios for planning purposes. It is certainly not recommended as a basis for adaptation planning, although it has been used.
- At the next level is the selection of a small number of preferred models from the complete ensemble. However, there is no more justification in predictability theory for selecting a subset of models than there is for selecting a single model. Nevertheless, this approach has been used frequently in adaptation planning and in National Communications to the UNFCCC (as has the single model approach), and, as touched on above, the approach has been considered through a complex decision chain in the IPCC AR6.
- The only approach that begins to satisfy predictability theory is to create and interpret as large an ensemble as possible, as has been discussed. Most, if not all, National Communications do not use ensembles of anywhere near the size available to the IPCC.

With the full AR4, AR5 and AR6 ensembles running to 30 or 40 or more projections, various interpretive approaches have been used both by the IPCC and elsewhere:

- The simplest approach, and most popular technique, is to take mean values (sometimes median values) across all individual projections within the ensemble, as it permits a straightforward deterministic interpretation to be provided. It is used commonly throughout IPCC reports and elsewhere. According to predictability theory taking an ensemble mean is an appropriate technique to use, as it averages out those aspects that are 'unpredictable' leaving behind a summary of the 'predictable' elements. However, two caveats underlie this theory. The first is that values across all projections within the ensemble have a normal distribution. Experience indicates that often this is not so, particularly for rainfall. The second caveat is that the ensemble is formed 'properly'. In effect this means that the ensemble is assumed to provide a complete distribution

of all realistically possible future states with each given its correct probability of occurring. No tests have ever been made on the IPCC projections of this second caveat for entirely pragmatic reasons, as mentioned previously, but experience with ensembles at shorter timescales indicate that the IPCC ensembles are unlikely to be proper. Considerable research was required before this caveat could be addressed at the shorter time scales. Use of the ensemble mean as the sole basis for planning, therefore, however straightforward, is not recommended; whenever it is used appropriate measures of uncertainty should be added.

- The next approach is to provide a range of possibilities based on the ensemble, with the range typically expressed around the ensemble mean or as upper and lower bounds. This approach is also used by the IPCC and provides a limited degree of advice about the uncertainties involved as suggested by an ensemble. Nevertheless, the two caveats mentioned above remain an issue. In fact the caveats need to be broadened with the issue of the possibility that the “answer” might lie outside the ensemble. This possibility can be reduced in principle by increasing the ensemble size, but how large is large enough for an ensemble? However, adding members eventually becomes a matter of decreasing returns in some regards, although the point at which this applies with climate projections is unknown at present. With current technology it is probably best to assume that the larger the ensemble size the better. Nevertheless, inherent biases still remain in the IPCC ensembles, partly as not all models included are independent (as explained above).
- The only approach that provides all information inherent within an ensemble is to calculate probability distributions for each variable at each point and time of interest (with the assumption that the ensemble is properly formed). While the IPCC provides some information along these lines, it focuses principally on the average/range approaches outlined above. Probability distributions are often not popular amongst users who may find them difficult to interpret. In addition, not all published probability distributions consider the fact that the “answer” may lie outside the ensemble; none are able to consider that the ensemble may not be proper. One major disadvantage of this approach is that the vast amount of information produced can readily overwhelm the user.

In developing downscaled projections for Ghana an advanced approach to selection has been used, based on the concept of Self Organising Maps (SOMs) which reduces the number of projections to be considered to a representative few while retaining information on the uncertainties involved. Other approaches to selection have been tried, including accuracy of historical simulations (some limitations of which have been mentioned above) and statistical clustering of projections. Clustering normally uses approaches that make assumptions about statistical distributions within the ensemble, and that become constrained after the first step in the process has been completed. SOMs analysis, a popular technique in many areas beyond meteorology and climatology, makes no such assumptions, and, as the name implies, permits the data themselves to determine the formation of the groupings (maps) used.

6. Conclusions and the Way Forward

Based on the results of the SOMs and the Plum Plot analysis, summaries of the expected impacts are prepared, and these are included in the form of short climate risk narratives for each region. In addition, the resulting climate risk narrative for each of the four regions is then applied to the priority MMDAs located within in each region and adjusted slightly based on the specific results for that MMDAs. The results of both the regional and individual MMDAs are then used to inform initial climate risk narratives which consider the potential implications for communities and key economic sectors in each MMDA.

The updated Climate Risk Narratives for Ghana will be included in a subsequent report and summary for policy makers (Task 3.1) as well as the individual climate risk assessments for the two priority MMDAs (namely Tamale Metro and Takoradi) to be produced under Task 3.4 and Task 4.1 respectively

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Appendix A | Additional Results: The Self-Organising Maps analyses and identification of appropriate RCMs to be used for downscaling:

Self-organising maps results and identification of RCMs are presented below in a continuous stream of graphics and tables ordered in terms of emissions scenarios, RCP2.6, then RCP4.5 and RCP8.5.

In summary, all SOMs analyses for each climate zone are shown first, prior to tables and graphs that collate all results, then the identification of common pathways across two or more zones and determination of zones used to identify the appropriate GCM/RCM pairings.

Ellipse diagrams, explained below, follow for each pathway and tables outlining the final results.

The section on the self-organising maps

All results are separated into those for 4 nodes, and, where appropriate, for 6 nodes and for 8 nodes; the number of nodes used in the analyses are flagged both in the headers and in the tables. To assist all tables are colour-coded: orange for RCP2.6; cyan for RCP4.5; purple for RCP8.5.

For each set of nodes the SOMs maps are presented first, with:

- Each map has a title indicating the climate zone and the RCP, plus that the analyses were made on annual data (YE = year), and a number for each map (e.g. SOM No. 1); the numbering of maps is along the rows across the top then downwards and is *entirely arbitrary* – the numbering is for identification purposes only and has no bearing on the analyses themselves
- The title indicates also whether the analysis was or was not used in defining the scenario pathways
- Temperature changes are in °C along the horizontal axes and rainfall changes as a proportion (1.1 represents a 10% increase, 0.9 a 10% decrease) along the vertical axes, all calculated individually by model against simulations for the base period 1986 to 2005, as per the legends top right with, in brackets, the numbers of projections included
- Individual projections for the period centred on 2035 are in blue, on 2060 in grey and on 2080 in red
- Similarly, values for all projections in each map are in green
- Solid grey lines indicate no change from the base period
- Dashed green lines indicate the average changes across all time periods in each map, with actual values given in green along the bottoms and tops of the maps for, respectively, temperature and rainfall changes
- Similarly average changes for each future period are indicated in colour coding along the bottoms and tops of the maps

Below each map is a brief summary of the analyses; where 6 nodes and 8 nodes are used there is also a charting of the maps from the lower number of nodes, i.e. 4 or 6 respectively, on to the higher number, 6 or 8 as appropriate

Next a table is given outlining the proposed resulting scenarios:

- Main headers indicate the RCP, the climate zone, the number of modes, and whether or not the details were used in defining the scenario pathways
- Right-hand columns indicate estimated likelihoods for each scenario *based on the assumption*, consistent with theory, that likelihoods are given by the proportionate numbers of projections within each scenario; likelihoods have been estimated to 5% and corrected to total 100%
- Map numbers are provided in the second columns linking to the numbers in each maps' titles; when a scenario is contained within only a single map a single number is provided, but where scenarios extend over one map all map numbers are indicated separated by □ to indicate chronological order within the scenario
- The remaining columns indicate the scenarios for each period as centred on 2035, 2060 and 2080 in the format temperature/rainfall, where the temperature change is in °C and the rainfall change as a proportion (1.1 represents a 10% increase, 0.9 a 10% decrease), all calculated individually by model against simulations for the base period 1986 to 2005; temperature changes have been estimated to 0.5°C and rainfall changes to 5%
- Scenarios are listed in rows in decreasing orders of likelihoods
- UE and LE are the “Upper” and “Lower Extreme” scenarios that reasonably cover the outer limits of all CMIP5 projections, with the interpretations focussed on rainfall changes – different results might have emerged had the focus been on temperature changes
- Note that UE and LE are not affected by the number of nodes used

Following each table is a graphic of the recommended scenarios from the table:

- As for the SOMs maps, the graphics are presented with temperature changes in °C along the horizontal axis and rainfall changes as a proportion (1.1 represents a 10% increase, 0.9 a 10% decrease) along the vertical axes, all calculated individually by model against simulations for the base period 1986 to 2005
- A consistent scaling of both axes is used to permit easier intercomparison of scenarios across all RCPs and climate zones
- Titles indicate the emissions scenario and the climate zone, together with the number of nodes used
- Legends on the right-hand sides indicate the Scenario numbers and their graphical representations; the Scenarios are numbered “Scenario 1”, etc., in order of reducing likelihoods as indicated in the tables above and as listed in the legends; no likelihoods can be attached to UE and LE
- Main scenarios use solid lines while UE and LE are indicated by grey dashed lines (note that given the focus on rainfall in assessing UE and LE it is possible that individual scenarios might, on occasion, suggest greater rainfall changes than in the extremes)
- Graphics are presented only for those nodes used in defining scenario pathways
- These graphics are discussed in more detail in the “Review of the Climate Scenarios”
- At the end of each RCP section the tables for those nodes used in defining scenarios are repeated to enable easier intercomparison, together with some brief comments based on the pathways, with

the presentation from North, through Central and Southwest, to Coastal (i.e. moving southwards); the graphics are repeated similarly for intercomparison in Sections 3.4, 3.5 and 3.5.4.

The section on identifying appropriate RCMs for downscaling

The joint scenarios table and graphic:

- The final joint scenarios for each RCP are summarised in a table and a graphic, both following the summary tables for each zone; given the large total number of individual scenarios identified for each zone it is necessary to reduce the number of scenarios by identifying those common to two or more climate zones
- For each RCP 6 or 7 joint scenarios were identified by seeking common temperature and rainfall changes across the three periods used in the SOMs analyses; these searches were successful, often, but not always, revealing pathways common to all four climate zones
- The joint scenarios have been named A26, B26,..., A45, B45, etc. and UE A26, etc. depending on RCP; the ordering is in approximate order of likelihood across all four climate zones, an ordering that might not match likelihoods for individual zone
- Next, a key zone was identified for each joint scenario to be used in the following stage, giving priority to those zone in which each joint scenario had a relatively high likelihood
- In the joint scenarios tables:
 - Joint scenario names are listed in the first column
 - Details for each zone are provided in the next four columns:
- For the main joint scenarios details are given in “position likelihood”; e.g. ‘1 35%’ means that for this zone the joint scenario was taken from the individual scenario based on the SOMs that had a 35% likelihood and was first in likelihood ordering
- For the UE and LE joint scenarios a ‘√’ indicates valid for the zone, an ‘X’ not valid
- Zones identified as for use in the next stage to select RCMs are indicated in red
 - The final three columns indicate, for each of the periods used in the SOMs analyses, the temperature/rainfall changes representing each joint scenario in the format as used previously for the SOMs tables
 - The graphics following illustrate the joint scenarios in similar format to the SOMs graphics
 - The ellipse diagrams and the selection of RCMs:
- The ellipse diagrams are used to illustrate and to select the RCMs to be used in the downscaling; each is titled with its appropriate joint scenario and with the zone used for the selection, with the horizontal temperature and vertical rainfall axes as in previous diagrams
- CORDEX RCMs from both the Africa and MENA domains were used, but all selected RCMs are from Africa only
- Joint scenarios are indicated as red squares for the three SOMs periods. Most projections from the host GCM/RCM pairings for both Africa and MENA are indicated simply as black dots for all three periods, but coloured diamonds identify the five closest pairings for each period to the joint scenarios;

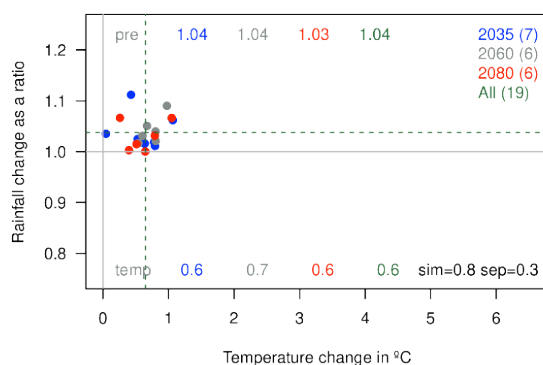
distances were calculated using root-mean-squares from the three temperature and rainfall values. Grey dotted lines link the (red) scenario squares to the axes.

- The legends top left identify the closest five GCM/RCM pairings together with the colours of their associated diamonds – the closest is shown always in purple, then successively in orange, dark blue, cyan and yellow. Short-hand coding is used in the legends to identify the host GCM/RCM pairings; the CORDEX domain (always Africa as it has turned out) occupies the first part, the host GCM the second part and the RCM the third part, the parts separated by dashes and periods. The legends are sorted with the closest at the top.
- Ellipses have been drawn based on the centroid of all projections from the GCM/RCM pairings for each period, covering 90% of the projections. Note that these ellipses change a little for each individual zone for a given RCP, but are always the same for the same zone and RCP. In general the ellipses shift towards the right of the diagrams for subsequent periods, 2035–2060–2080, as temperature increases; no equivalent directional shift is present necessarily for rainfall changes. The ellipses were discussed further in Section 3.5.4.
- Two tables follow the ellipse diagrams and complete the information for each RCP:
 - The first table lists the joint scenario name, the focus zone used in the process to identify the closest GCM/RCM pairing, the CORDEX domain for the closest GCM/RCM pairing (always Africa as MENA does not appear), the organisations responsible for, first, the GCM and, second, the RCM, and finally the root-mean-square distance of the GCM/RCM pairing from the joint scenario
 - Some modelling centres have provided data to CORDEX from more than one version of a model; this detail may be determined, if required, from the legends in the ellipse diagrams
 - In some cases the same GCM/RCM pairing is the closest to two joint scenarios (thus helping reduce the downscaling requirements); these are indicated by ‘**’ and ‘\$’ against the joint scenario names and are noted below the table
 - The final tables provide lists of the recommended joint scenarios to be used in the downscaling, with columns:
 - Joint scenario names plus ‘**’ and ‘\$’ to indicate same GCM/RCM pairings
 - For the main scenarios the likelihoods for each zone in the order North/ Central / Southwest/Coast; for UE and LE the zones to which they apply
 - The root-mean-square distance
 - Comments on the validity of the GCM/RCM pairing in terms of their closeness to the joint scenarios together with colour coding to represent:
 - Green: Close representation of the scenario
 - Orange: Reasonable representation of the scenario
 - Yellow: Best possible representation but some distance from the scenario; use with caution
 - From examination of the distances in conjunction with the ellipse diagrams it would appear that a rule of thumb is that distances below, perhaps, 1.2 tend to be reasonable representations while those above 1.2 need to be used with care.

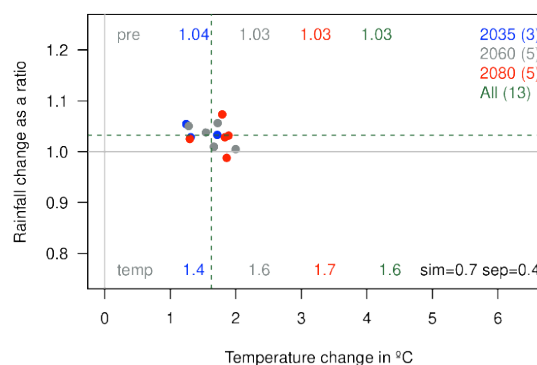
Appendix A1: RCP 2.6 SOMs Analysis Results

RCP2.6 Central Zone – 4 nodes – used in defining the scenarios

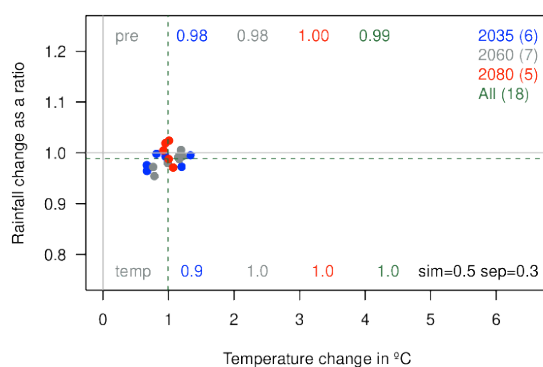
CENTRAL RCP26 YE SOM NO. 1



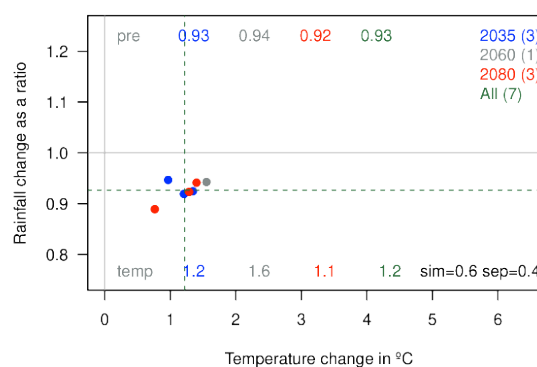
CENTRAL RCP26 YE SOM NO. 2



CENTRAL RCP26 YE SOM NO. 3



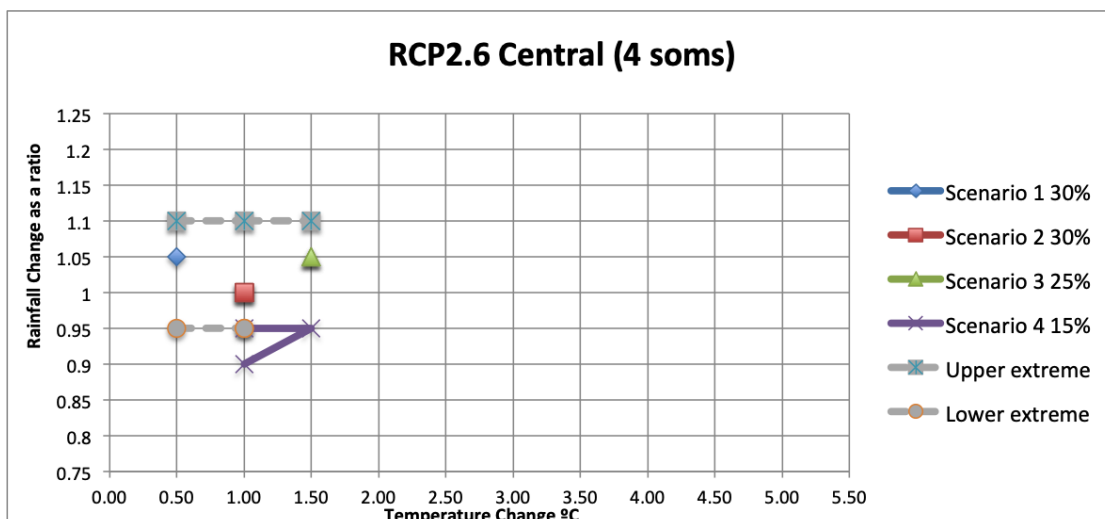
CENTRAL RCP26 YE SOM NO. 4



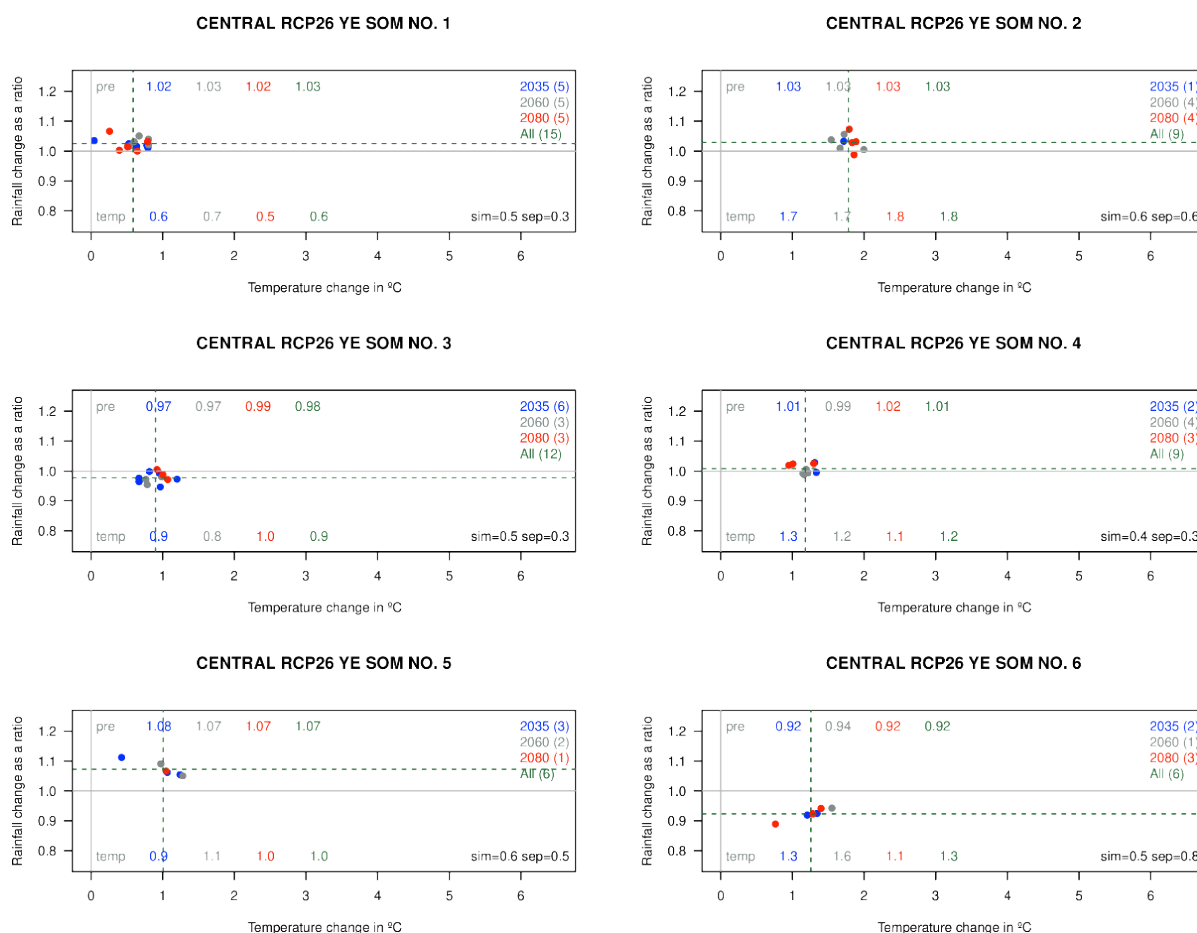
19 projections. Separates readily into 4 scenarios, 1 per som. Contributions to UE from som1 and som2 and to LE from som3 and som4. Re-checked using 6 SOMs but no adjustments to these scenarios.

Table A1-1 | RCP2.6 Annual Central using 4 SOMs – used in defining the scenarios

Likelihood	som	2035	2060	2080
30%	1	0.5/1.05	0.5/1.05	0.5/1.05
30%	3	1.0/1.00	1.0/1.00	1.0/1.00
25%	2	1.5/1.05	1.5/1.05	1.5/1.05
15%	4	1.0/0.95	1.5/0.95	1.0/0.90
UE		0.5/1.10	1.0/1.10	1.5/1.10
LE		0.5/0.95	1.0/0.95	1.0/0.95



RCP2.6 Central Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios



- 19 projections.
- Mapping of 4 nodes □ 6 nodes
 - som1 □ som1 + som5 [5 is warmer and a little wetter]
 - som2 □ som2 + som5 [5 separates cooler projections]

- som3 $\square$ som3 + som4 [3 is slightly cooler drier compared to som4]
- som4 $\square$ som6 + som3 [mainly all in som6]

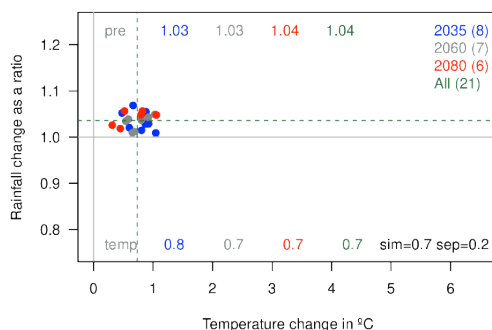
Re-checked using 6 SOMs but no adjustments to these scenarios; already the 4 scenarios are sufficient – the further complications possible are unnecessary in terms of scenario development.

Table A1-2 | RCP2.6 Annual Central using 6 SOMs – not used in defining the scenarios

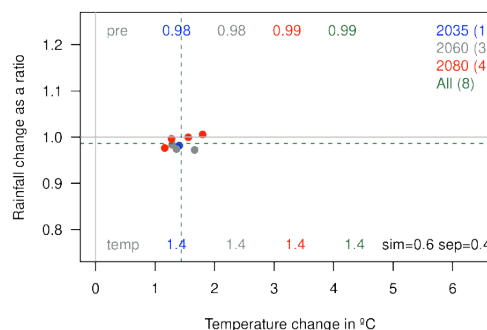
Likelihood	som	2035	2060	2080
30%	1	0.5/1.05	0.5/1.05	0.5/1.05
30%	3	1.0/1.00	1.0/1.00	1.0/1.00
25%	2	1.5/1.05	1.5/1.05	1.5/1.05
15%	4	1.0/0.95	1.5/0.95	1.0/0.90
UE		0.5/1.10	1.0/1.10	1.5/1.10
LE		0.5/0.95	1.0/0.95	1.0/0.95

RCP2.6 Coastal Zone – 4 nodes – used in defining the scenarios

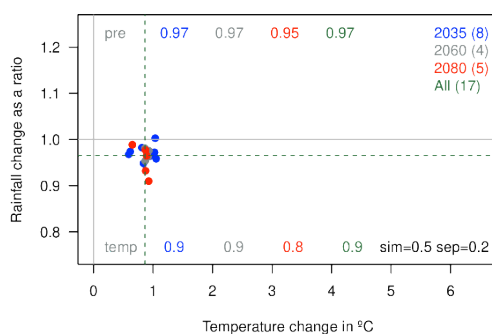
COASTAL RCP26 YE SOM NO. 1



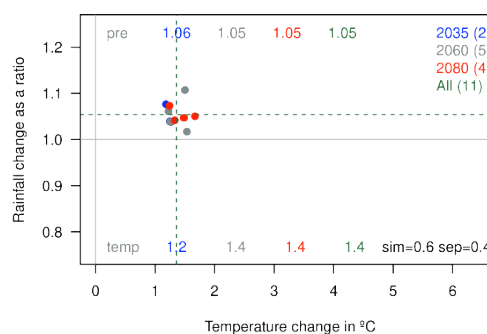
COASTAL RCP26 YE SOM NO. 2



COASTAL RCP26 YE SOM NO. 3



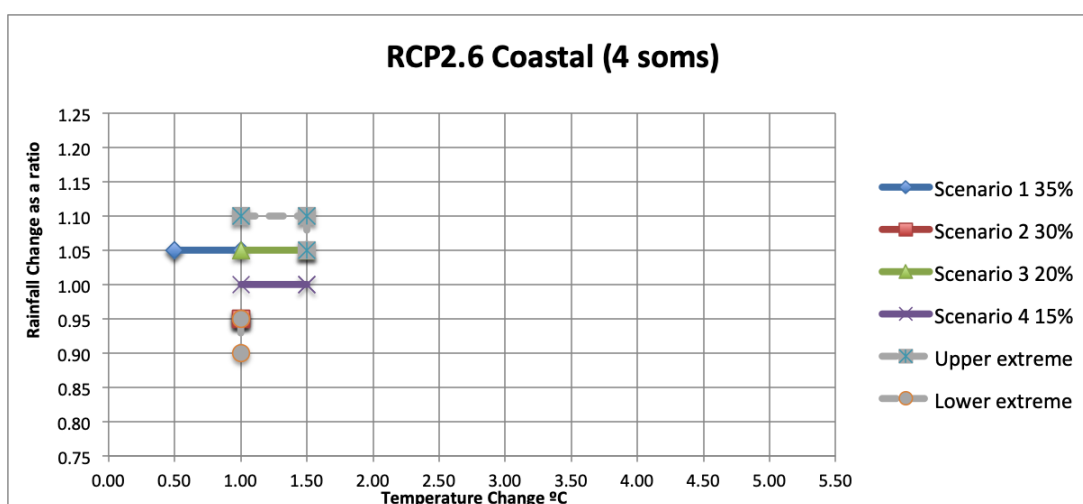
COASTAL RCP26 YE SOM NO. 4



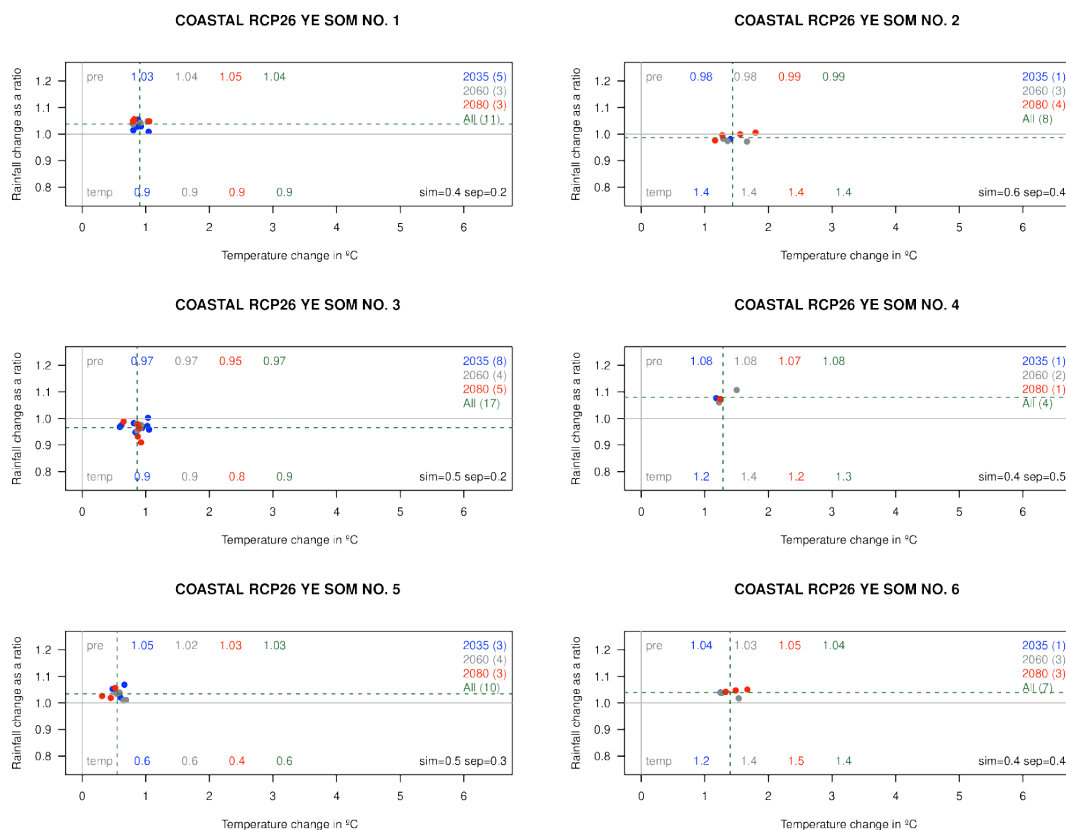
19 projections. Separates readily into 4 scenarios, 1 per som. Contributions to UE from som4 and to LE from som3. Re-checked using 6 SOMs but no adjustments to these scenarios.

Table A1-3 | RCP2.6 Annual Coastal using 4 SOMs – used in defining the scenarios

Likelihood	som	2035	2060	2080
35%	1	1.0/1.05	0.5/1.05	0.5/1.05
30%	3	1.0/0.95	1.0/0.95	1.0/0.95
20%	4	1.0/1.05	1.5/1.05	1.5/1.05
15%	2	1.5/1.00	1.5/1.00	1.0/1.00
UE		1.0/1.10	1.5/1.10	1.5/1.05
LE		1.0/0.95	1.0/0.95	1.0/0.90



RCP2.6 Coastal Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios



- 19 projections.
- Mapping of 4 nodes □ 6 nodes
 - som1 □ som1 + som5 [1 is a little warmer]
 - som2 □ som2 [no difference]
 - som3 □ som3 [no difference]
 - som4 □ som4 + som6 [4 is warmer]

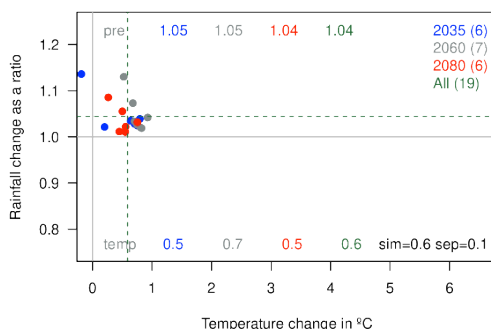
Re-checked using 6 SOMs but no adjustments to these scenarios; 4 scenarios are sufficient – the further complications possible are unnecessary in terms of scenario development.

Table A1-4 | RCP2.6 Annual Coastal using 6 SOMs – not used in defining the scenarios

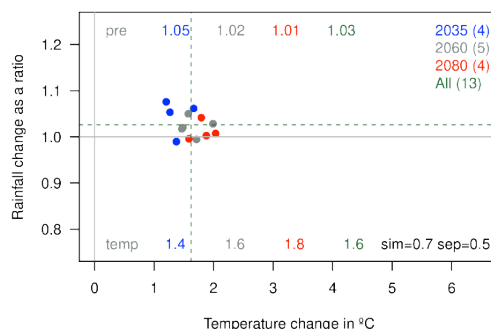
Likelihood	som	2035	2060	2080
35%	1	1.0/1.05	0.5/1.05	0.5/1.05
30%	3	1.0/0.95	1.0/0.95	1.0/0.95
20%	4	1.0/1.05	1.5/1.05	1.5/1.05
15%	2	1.5/1.00	1.5/1.00	1.0/1.00
UE		1.0/1.10	1.5/1.10	1.5/1.05
LE		1.0/0.95	1.0/0.95	1.0/0.90

RCP2.6 North Zone – 4 nodes – used in defining the scenarios

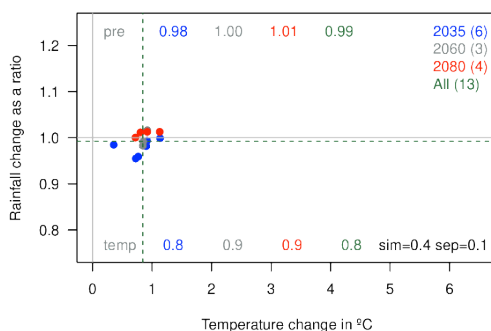
NORTH RCP26 YE SOM NO. 1



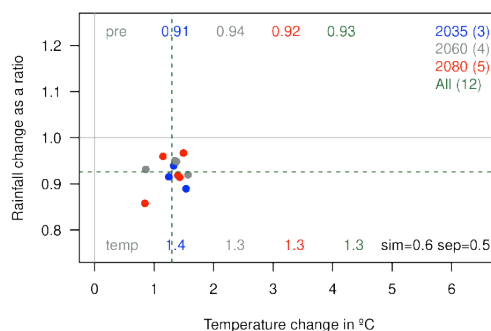
NORTH RCP26 YE SOM NO. 2



NORTH RCP26 YE SOM NO. 3



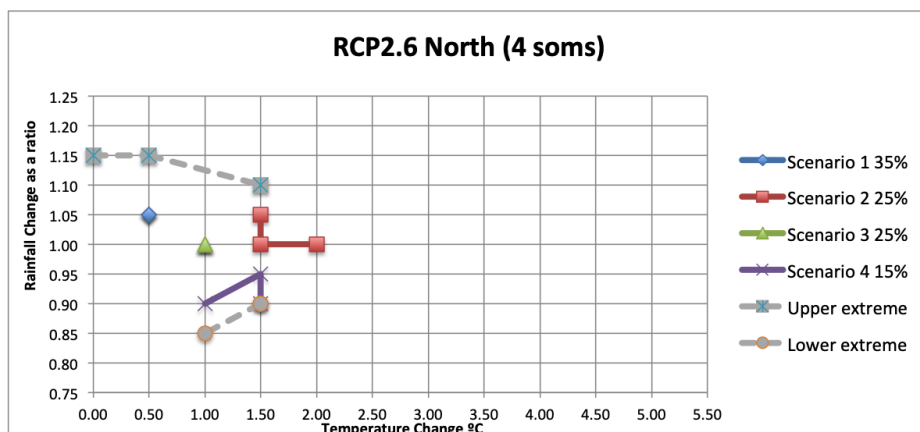
NORTH RCP26 YE SOM NO. 4



19 projections. Separates readily into 4 scenarios, 1 per som. Contributions to UE from som1 and to LE from som4. Re-checked using 6 SOMs but no adjustments to these scenarios.

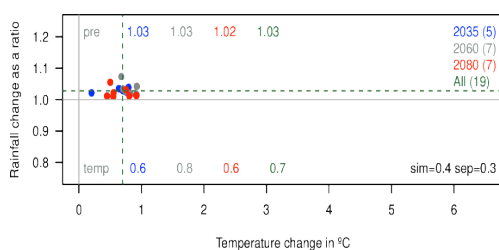
Table A1-5 | RCP2.6 Annual North using 4 SOMs – used in defining the scenarios

Likelihood	som	2035	2060	2080
35%	1	0.5/1.05	0.5/1.05	0.5/1.05
25%	2	1.5/1.05	1.5/1.00	2.0/1.00
25%	3	1.0/1.00	1.0/1.00	1.0/1.00
15%	4	1.5/0.90	1.5/0.95	1.0/0.90
UE		0.0/1.15	0.5/1.15	0.5/1.10
LE		1.5/0.90	1.5/0.90	1.0/0.85

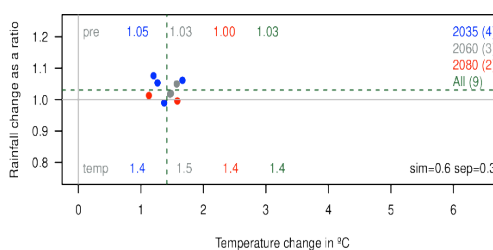


RCP2.6 North Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios

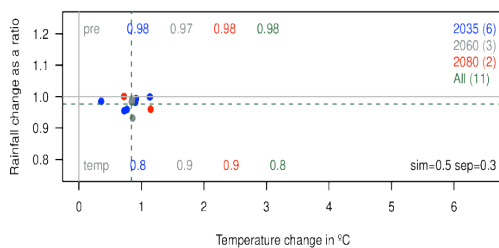
NORTH RCP26 YE SOM NO. 1



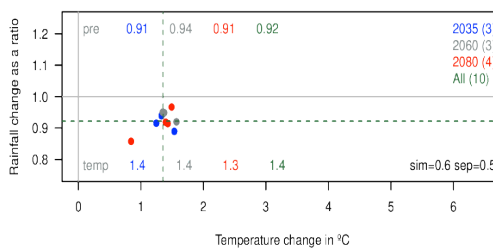
NORTH RCP26 YE SOM NO. 2



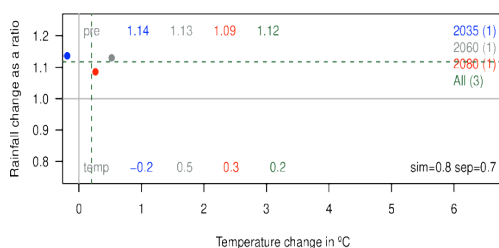
NORTH RCP26 YE SOM NO. 3



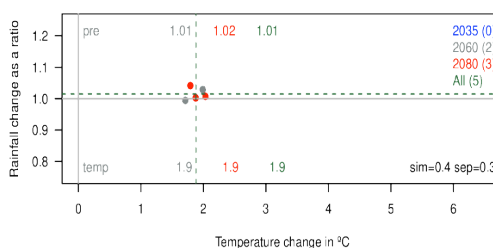
NORTH RCP26 YE SOM NO. 4



NORTH RCP26 YE SOM NO. 5



NORTH RCP26 YE SOM NO. 6



- 19 projections.
- Mapping of 4 nodes □ 6 nodes
 - som1 □ som1 + som5 [5 is a clearly warmer, drier outlier]
 - som2 □ som2 + som6 [6 is warmer but no p3]
 - som3 □ som3 + som1 [som3 is drier]

- som4 □ som4 + som3 [mostly som4]

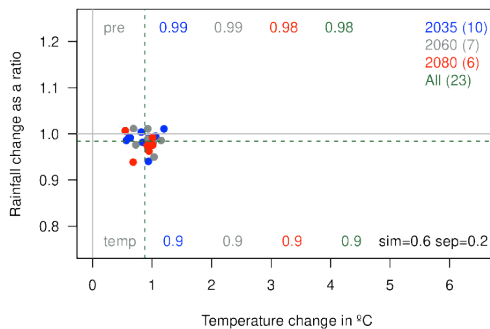
Re-checked using 6 SOMs but no adjustments to these scenarios; 4 scenarios are sufficient – the further complications possible are unnecessary in terms of scenario development§.

Table A1-6 | RCP2.6 Annual North using 6 SOMs – not used in defining the scenarios

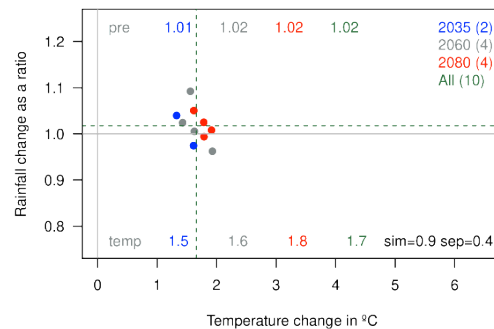
Likelihood	som	2035	2060	2080
35%	1	0.5/1.05	0.5/1.05	0.5/1.05
25%	2	1.5/1.05	1.5/1.00	2.0/1.00
25%	3	1.0/1.00	1.0/1.00	1.0/1.00
15%	4	1.5/0.90	1.5/0.95	1.0/0.90
UE		0.0/1.15	0.5/1.15	0.5/1.10
LE		1.5/0.90	1.5/0.90	1.0/0.85

RCP2.6 Southwest Zone – 4 nodes – used in defining the scenarios

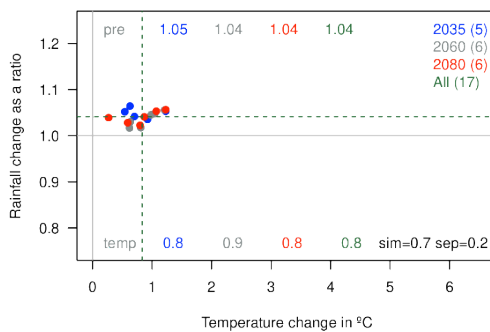
SOUTHWEST RCP26 YE SOM NO. 1



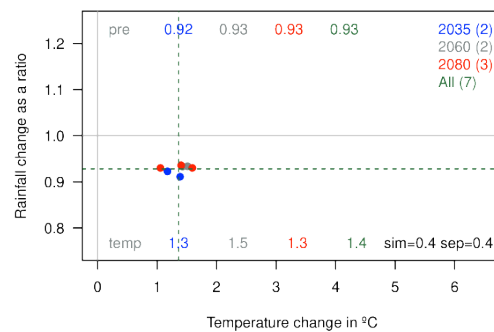
SOUTHWEST RCP26 YE SOM NO. 2



SOUTHWEST RCP26 YE SOM NO. 3



SOUTHWEST RCP26 YE SOM NO. 4

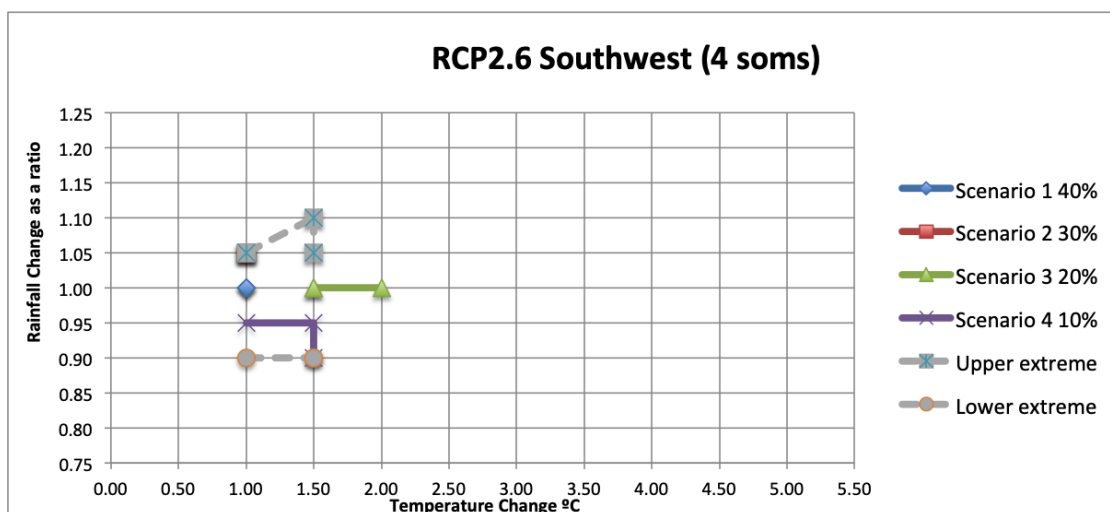


19 projections. Separates readily into 4 scenarios, 1 per som. Contributions to UE from som2 and to LE from som4. Re-checked using 6 SOMs but no adjustments to these scenarios.

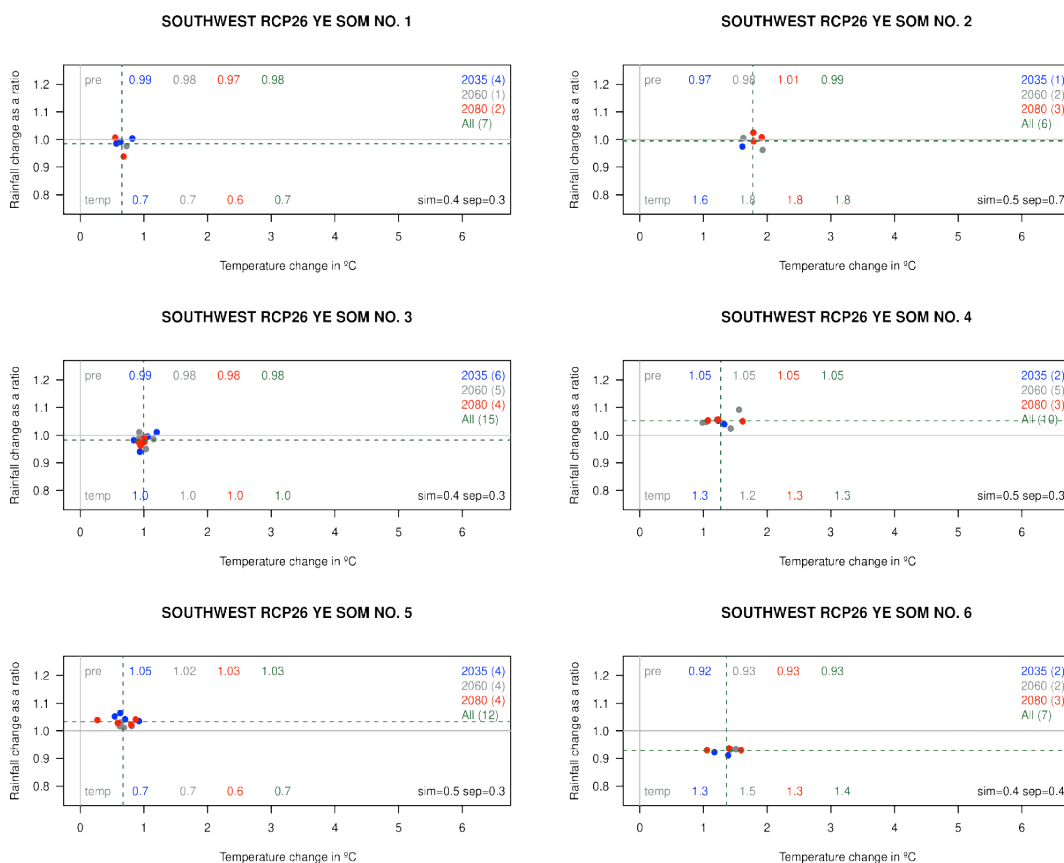
Table A1-7 | RCP2.6 Annual Southwest using 4 SOMs – used in defining the scenarios

Likelihood	som	2035	2060	2080
40%	1	1.0/1.00	1.0/1.00	1.0/1.00
30%	3	1.0/1.05	1.0/1.05	1.0/1.05
20%	2	1.5/1.00	1.5/1.00	2.0/1.00

10%	4	1.5/0.90	1.5/0.95	1.0/0.95
UE		1.0/1.05	1.5/1.10	1.5/1.05
LE		1.0/0.90	1.5/0.90	1.5/0.90



RCP2.6 Southwest Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios



- 19 projections.
- Mapping of 4 nodes □ 6 nodes
 - som1 □ som3 + som1 [3 is warmer]

- som2 □som2 + som4 [2 is warmer and possibly drier]
- som3 □ som5 + som4 [a few in 4 which is warmer, wetter]
- som4 □som6 [all som6]

Re-checked using 6 SOMs but no adjustments to these scenarios; 4 scenarios are sufficient – the further complications possible are unnecessary in terms of scenario development.

Table A1-8 | RCP2.6 Annual Southwest using 6 SOMs – not used in defining the scenarios

Likelihood	SOM	2035	2060	2080
40%	1	1.0/1.00	1.0/1.00	1.0/1.00
30%	3	1.0/1.05	1.0/1.05	1.0/1.05
20%	2	1.5/1.00	1.5/1.00	2.0/1.00
10%	4	1.5/0.90	1.5/0.95	1.0/0.95
UE		1.0/1.05	1.5/1.10	1.5/1.05
LE		1.0/0.90	1.5/0.90	1.5/0.90

RCP2.6 Annual North using 4 SOMs				
Likelihood	SOM	2035	2060	2080
35%	1	0.5/1.05	0.5/1.05	0.5/1.05
25%	2	1.5/1.05	1.5/1.00	2.0/1.00
25%	3	1.0/1.00	1.0/1.00	1.0/1.00
15%	4	1.5/0.90	1.5/0.95	1.0/0.90
UE		0.0/1.15	0.5/1.15	0.5/1.10
LE		1.5/0.90	1.5/0.90	1.0/0.85

Drier conditions are the least likely scenarios except in Coastal Zone (15%, 15%, 10%, 30%)

2°C by 2080 reached only in North and Southwest

No scenario has 10% rainfall increase except UE

Highest UE in terms of rainfall in North and Central

RCP2.6 Annual Central using 4 SOMs				
Likelihood	SOM	2035	2060	2080
30%	1	0.5/1.05	0.5/1.05	0.5/1.05
30%	3	1.0/1.00	1.0/1.00	1.0/1.00
25%	2	1.5/1.05	1.5/1.05	1.5/1.05
15%	4	1.0/0.95	1.5/0.95	1.0/0.90
UE		0.5/1.10	1.0/1.10	1.5/1.10
LE		0.5/0.95	1.0/0.95	1.0/0.95

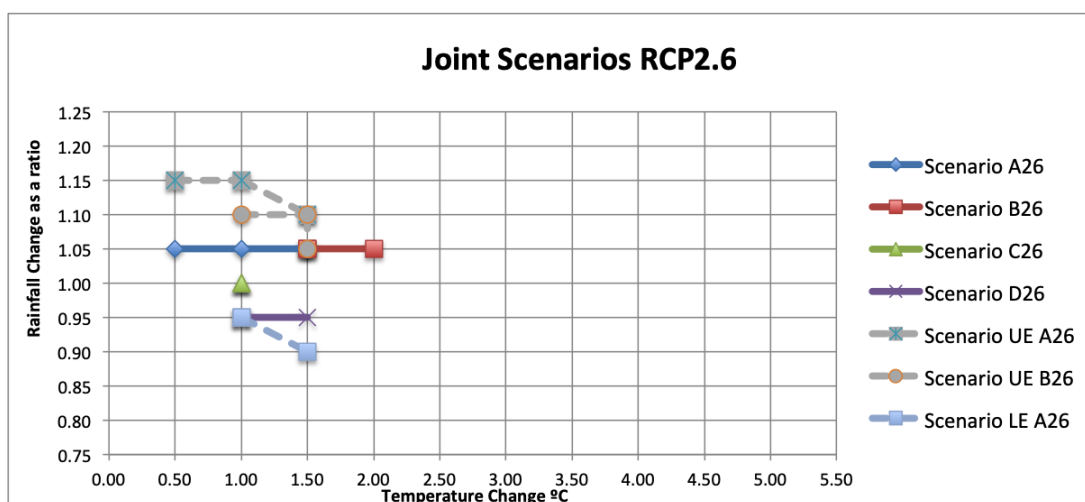
All LE have 10% rainfall reductions except Central; a 15% reduction only in North

RCP2.6 Annual Southwest using 4 SOMs				
Likelihood	SOM	2035	2060	2080
40%	1	1.0/1.00	1.0/1.00	1.0/1.00
30%	3	1.0/1.05	1.0/1.05	1.0/1.05
20%	2	1.5/1.00	1.5/1.00	2.0/1.00
10%	4	1.5/0.90	1.5/0.95	1.0/0.95
UE		1.0/1.05	1.5/1.10	1.5/1.05
LE		1.0/0.90	1.5/0.90	1.5/0.90

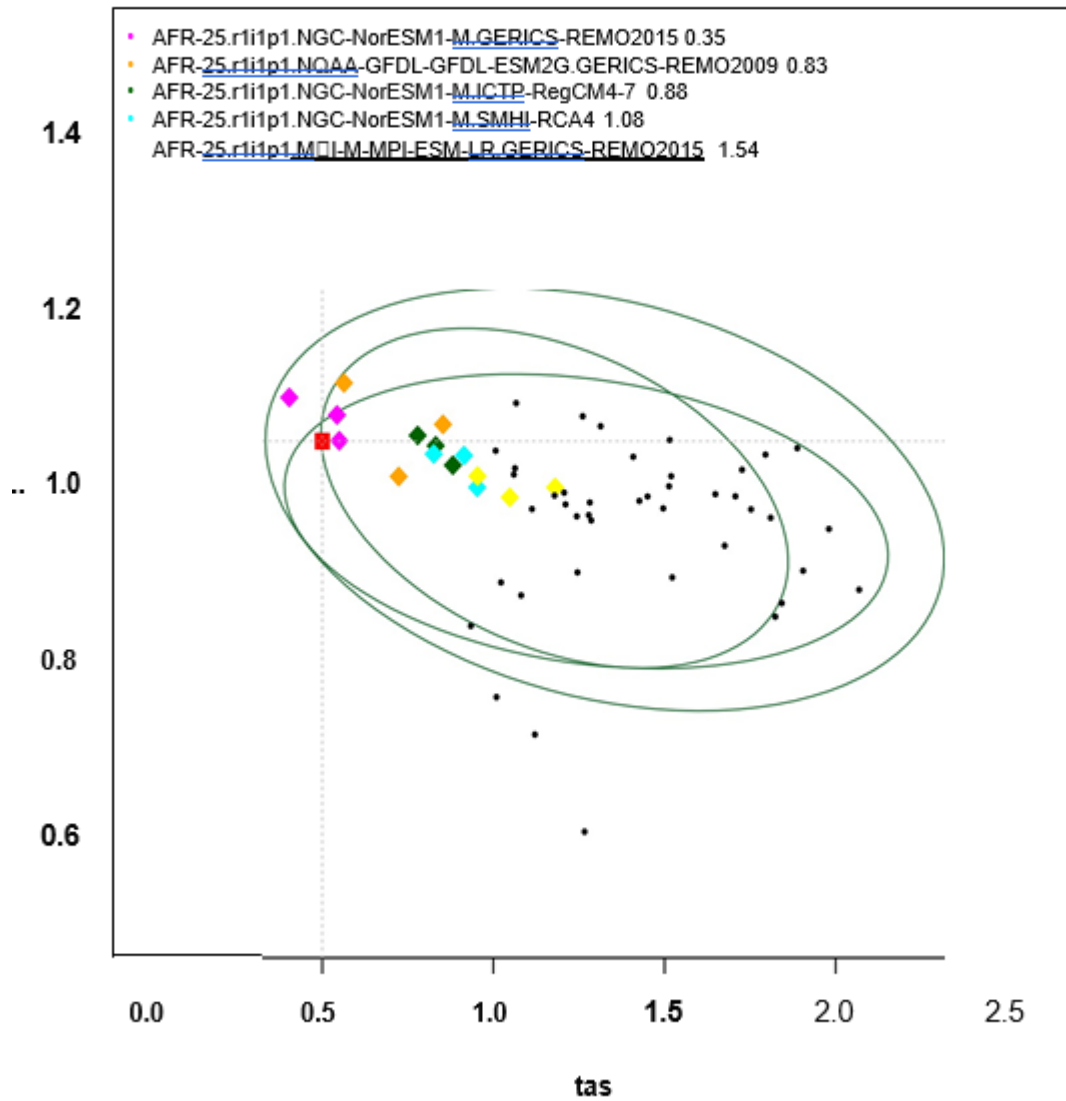
RCP2.6 Annual Coastal using 4 SOMs				
Likelihood	SOM	2035	2060	2080
35%	1	1.0/1.05	0.5/1.05	0.5/1.05
30%	3	1.0/0.95	1.0/0.95	1.0/0.95
20%	4	1.0/1.05	1.5/1.05	1.5/1.05
15%	2	1.5/1.00	1.5/1.00	1.0/1.00
UE		1.0/1.10	1.5/1.10	1.5/1.05
LE		1.0/0.95	1.0/0.95	1.0/0.90

Table A1-9 | Results of joint pathways analysis across the four hydroclimatic zones under RCP2.6

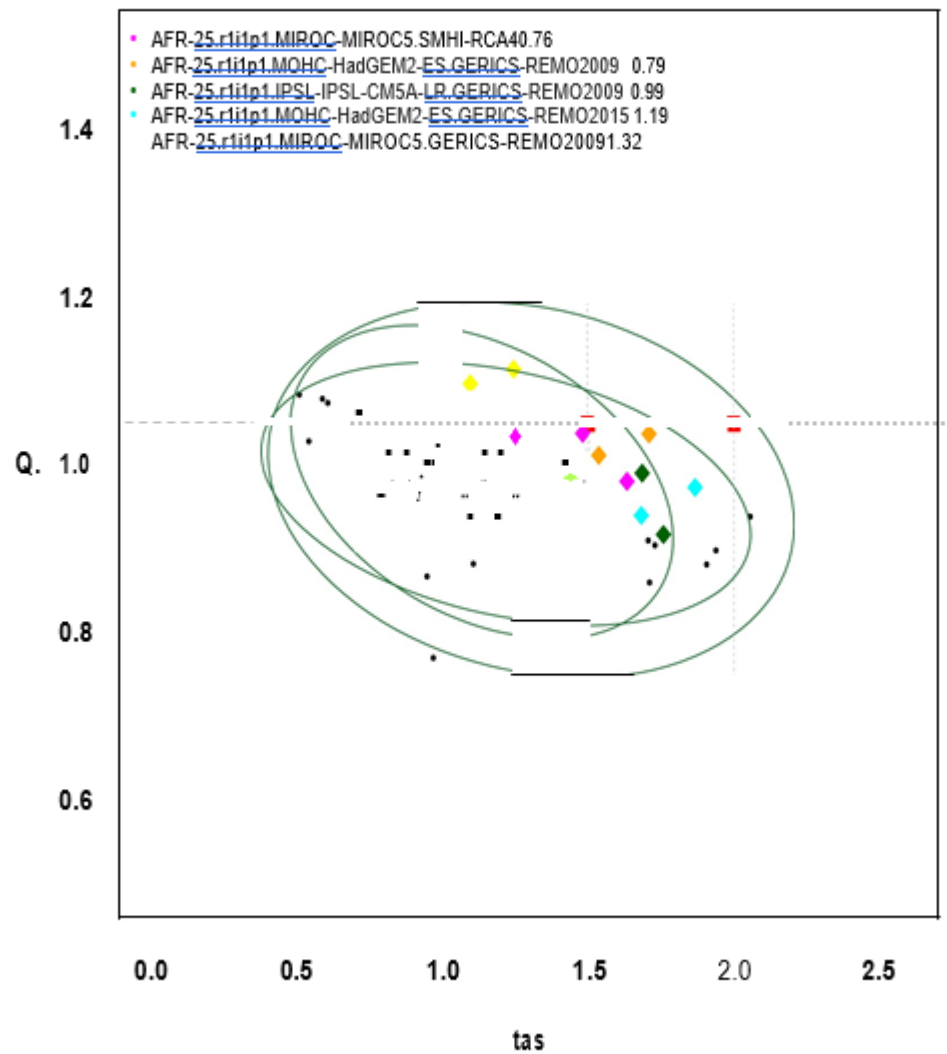
Likelihood of Individual Scenario					Expected Temperature (deg C) and Rainfall (%) Impacts.		
Scenario	North	Central	Southwest	Coastal	2035	2060	2080
A26	1 35%	1 30%	2 30%	1 35%	0.5/1.05	0.5/1.05	0.5/1.05
B26	2 25%	3 25%	3 20%	3 20%	1.5/1.05	1.5/1.05	2.0/1.05
C26	3 25%	2 30%	1 40%	4 15%	1.0/1.00	1.0/1.00	1.0/1.00
D26	4 15%	4 15%	4 10%	2 30%	1.0/0.95	1.5/0.95	1.0/0.95
UE A26	✓	✓	✗	✗	0.5/1.15	1.0/1.15	1.5/1.10
UE B26	✗	✗	✓	✓	1.0/1.10	1.5/1.10	1.5/1.05
LE A26	✓	✓	✓	✓	1.0/0.95	1.0/0.95	1.5/0.90



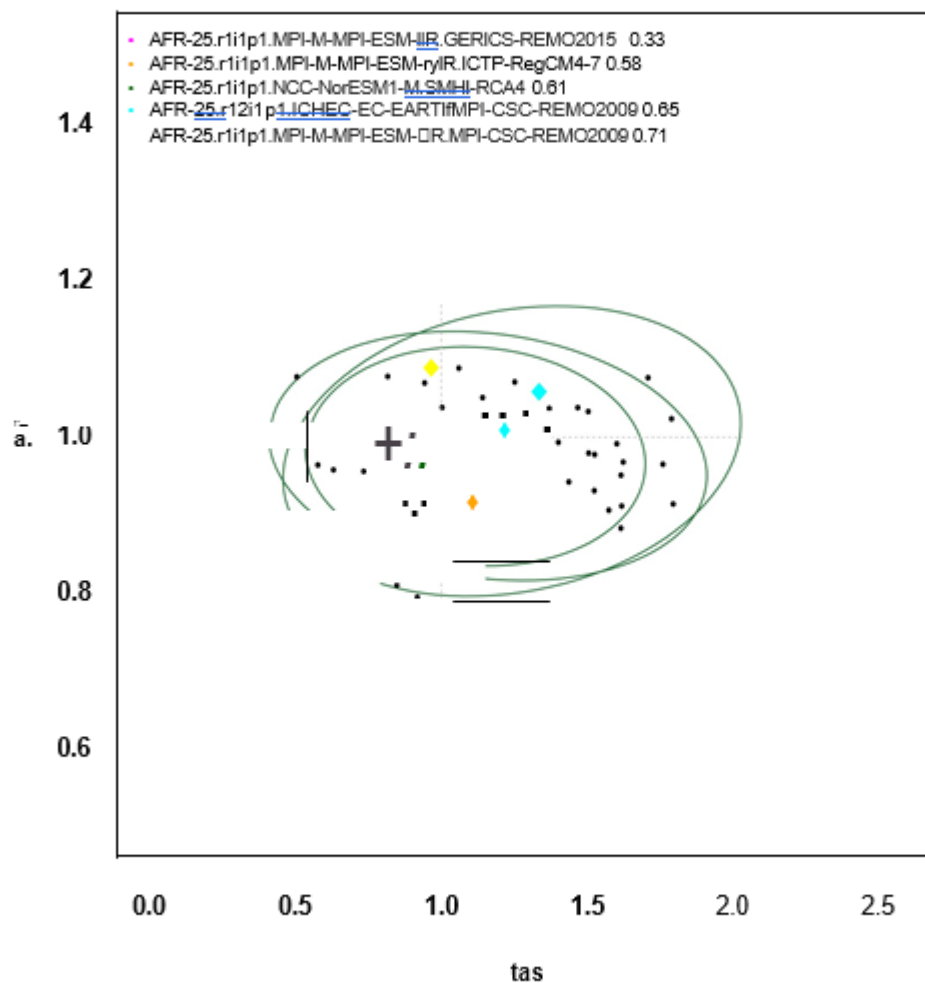
A26 north



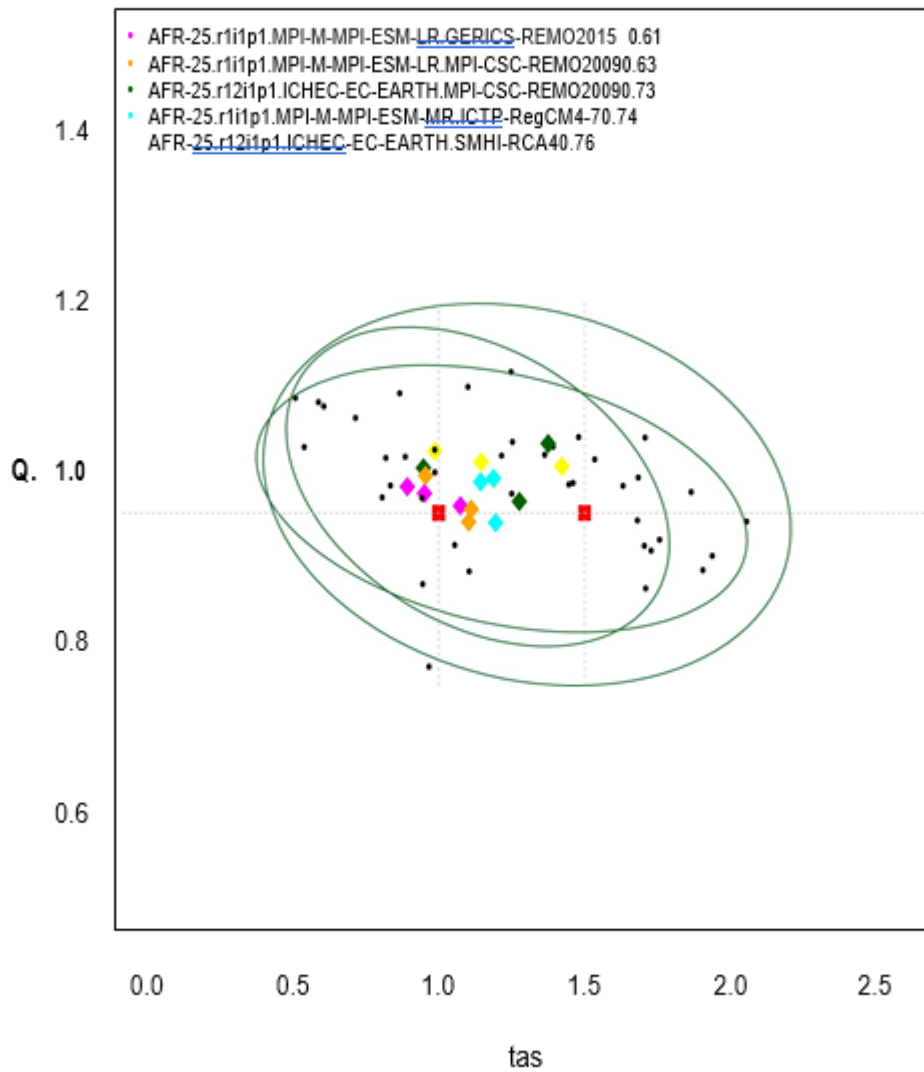
826 central



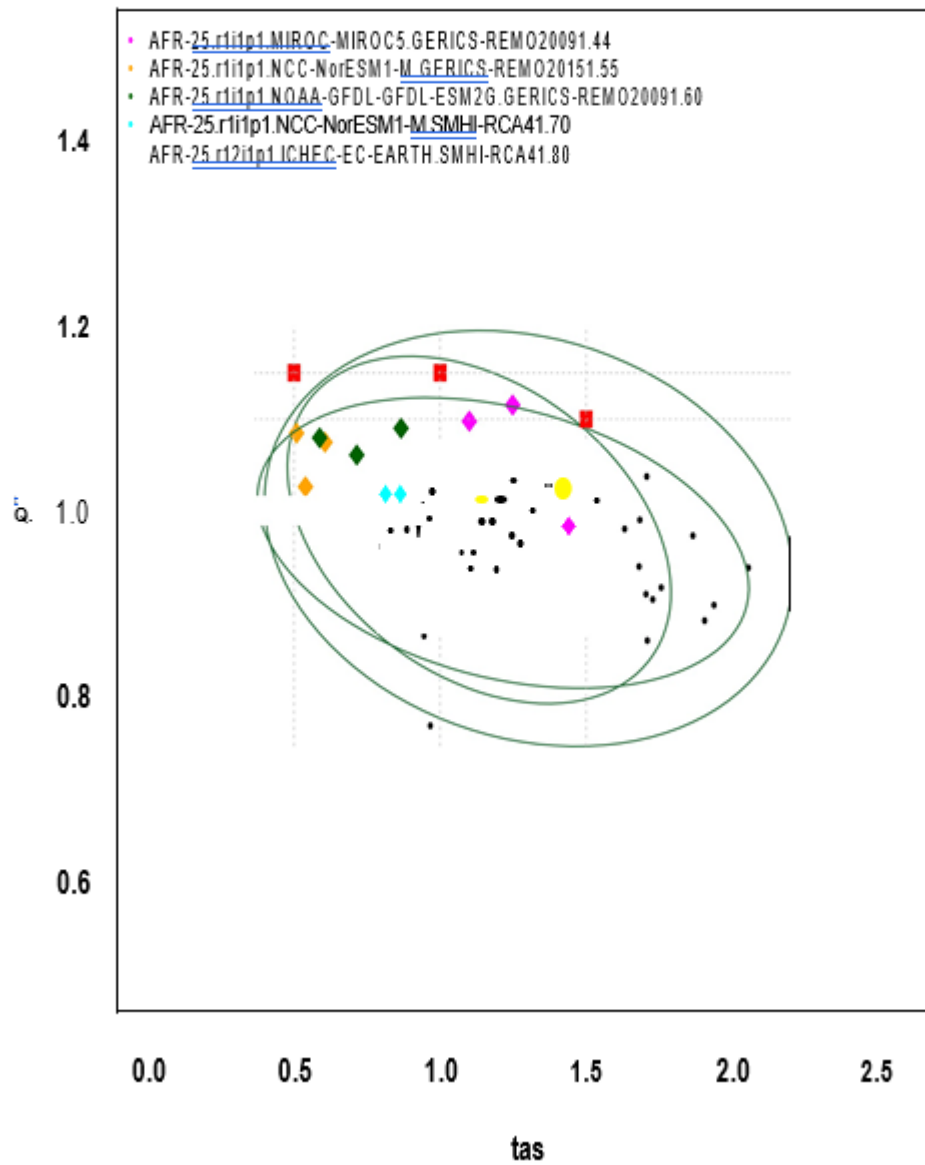
C26 swest



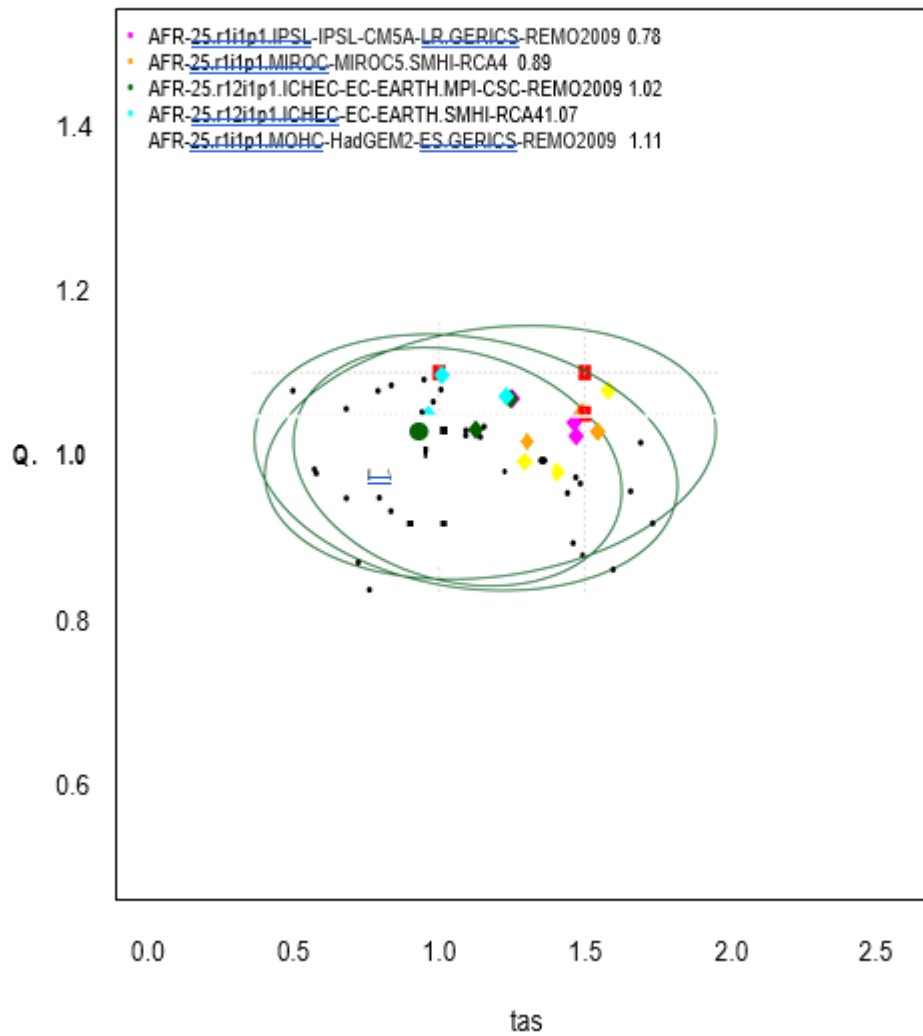
D26 central



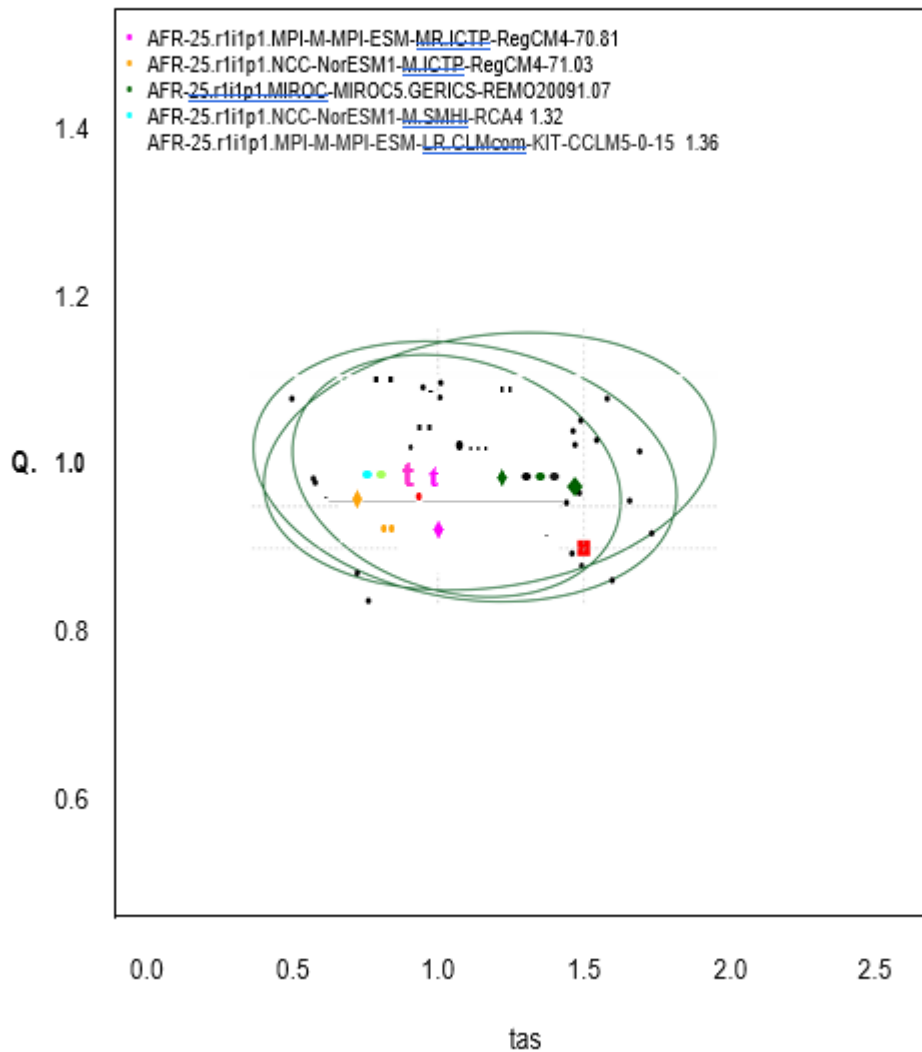
UEA26 central



UEB26 coastal



LEA26 coastal



Scenario	Focus Zone	CORDEX Domain	Host GCM	RCM	RMS
A26	North	Africa	NorESM Climate Modelling Consortium	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	0.35
B26	Central	Africa	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC)	Swedish Meteorological and Hydrological Institute (SMHI)	0.76

C26*	Southwest	Africa	Max Planck Institute in Germany (MPI)	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	0.33
D26*	Central	Africa	Max Planck Institute in Germany (MPI)	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	0.61
UE A26	Central	Africa	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC)	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	1.44
UE B26	Coastal	Africa	Institut Pierre-Simon Laplace in France (IPSL)	Helmholtz Centre for Polar and Marine Research in Germany (GERICS)	0.78
LE A26	Coastal	Africa	Max Planck Institute in Germany (MPI)	Abdus Salam International Centre for Theoretical Physics (ICTP)	0.81

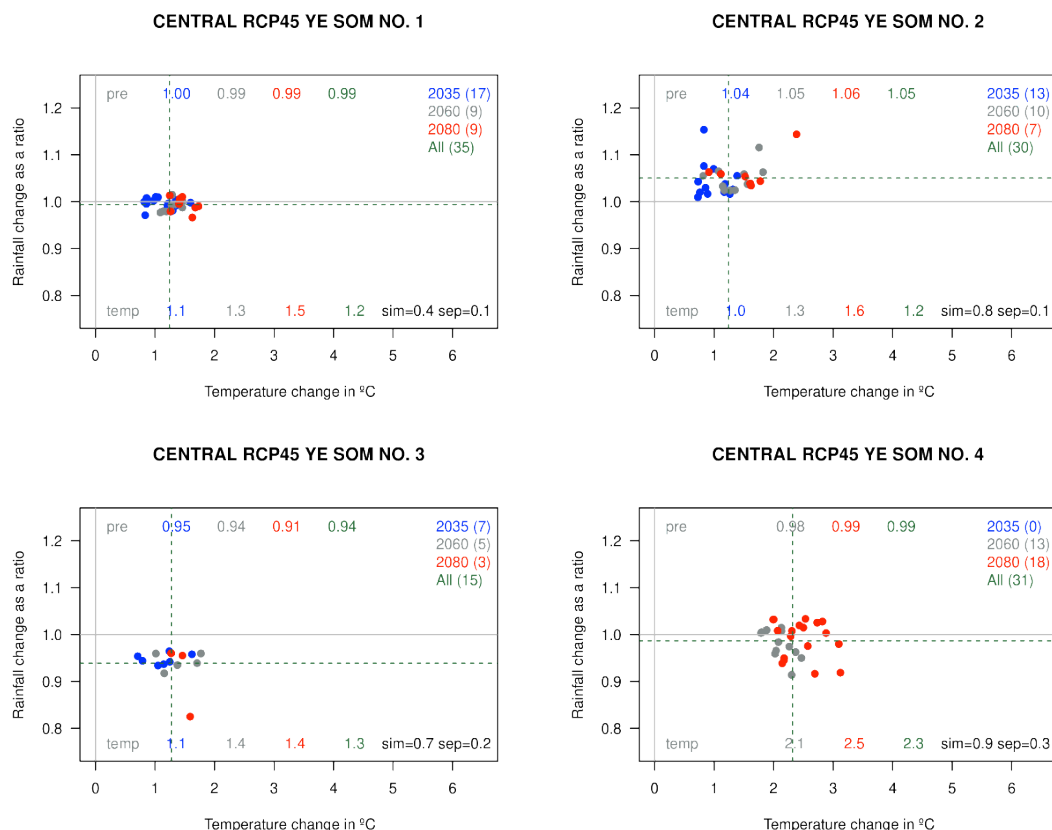
Note:

* The same GCM/RCM combination provides the closest fits to both C26 and D26 (but a different RCM for UE B26)

Scenario	Likelihood	Distance	Comments
A26	35%/30%/30%/35%	0.35	A good fit to the scenario
B26	25%/25%/20%/20%	0.76	Reasonable for the first two periods but fails to capture, as do all the models, the warmth and increased rainfall of the third period
C26*	25%/30%/40%/15%	0.36	A good fit to the scenario
D26*	15%/15%/10%/30%	0.61	Reasonable for first two periods but does not capture warmth of third period
UE A26	Applies to North and Central	1.44	Simulation generally too warm and too dry throughout
UE B26	Applies to Southwest and Coastal	0.78	Model too dry throughout and too warm in first period
LE A26	Applies to all zones	0.81	Good for first two periods but does not capture the warmth of the third period

Appendix A2: RCP 4.5 SOMS Analysis Results

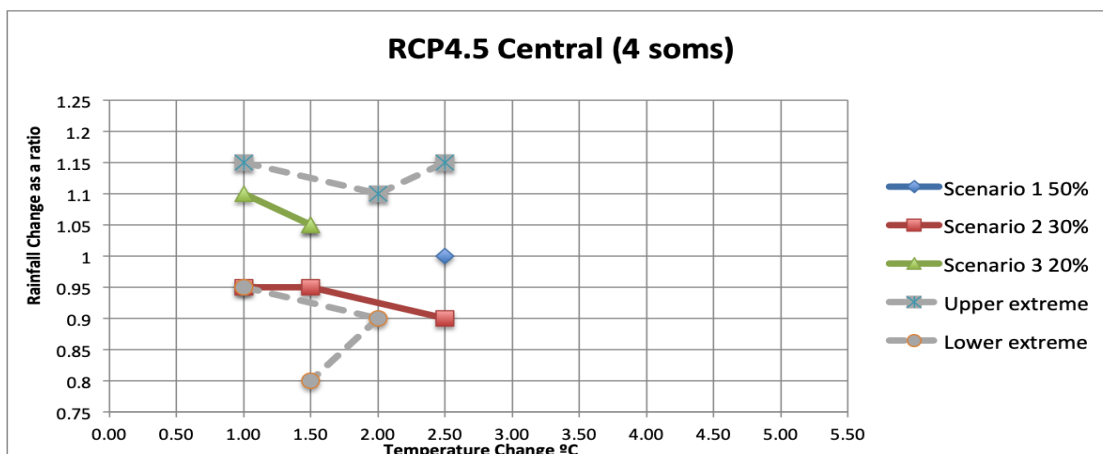
RCP4.5 Central Zone – 4 nodes – used in defining the scenarios



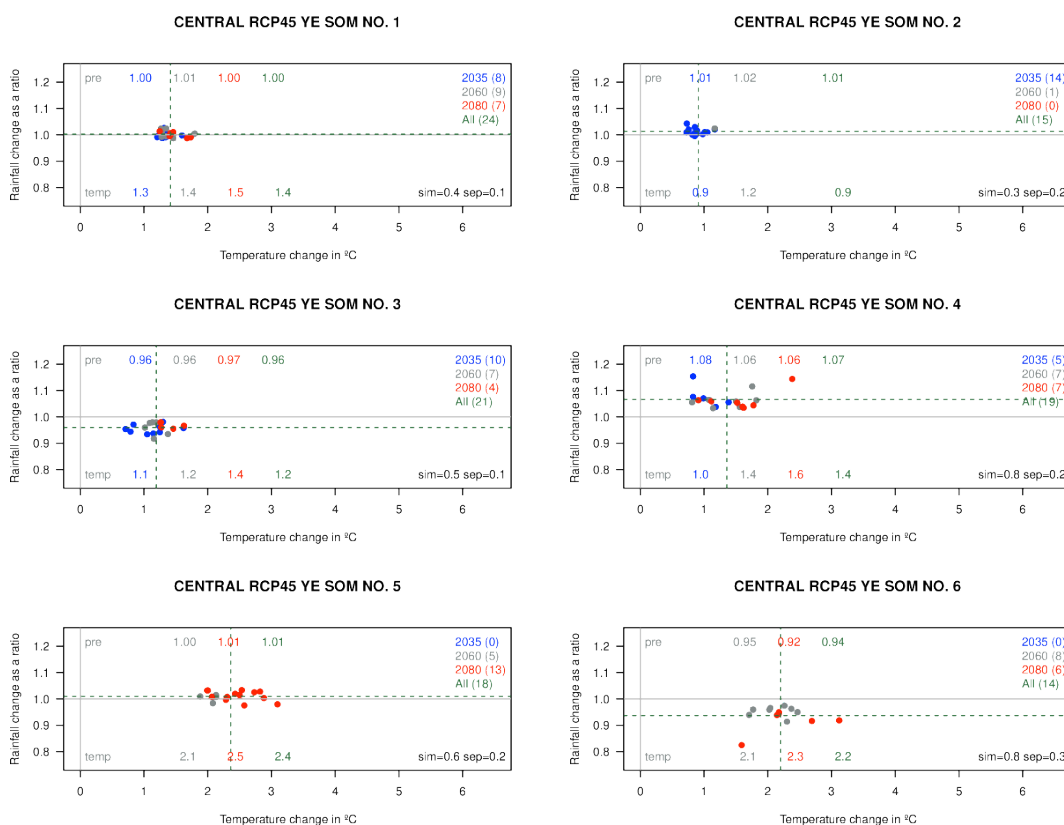
37 projections. Most of the p1 are in 1 and 2, p2 in 2 and 4, and p3 in 4. Not straightforward – final solution is som2 on its own because of relatively high projected temperatures, and remainder ending in som4 with som3 representing drying. Contributions to UE from som2 and to LE from som3 and som4. Re-checked using 6 SOMs with some adjustments to these scenarios, mainly likelihoods – see notes under 6 nodes.

Table A2-1 | RCP4.5 Annual Central using 4 SOMs – used in defining the scenarios

Likelihood	SOM	2035	2060	2080
50%	1□4	1.0/1.00	1.5/1.00	2.0/1.00
30%	2	1.0/1.05	1.5/1.05	1.5/1.05
20%	3□4	1.0/0.95	1.5/0.95	3.0/0.95
UE		1.0/1.15	2.0/1.10	2.5/1.15
LE		1.0/0.95	2.0/0.90	1.5/0.80



RCP4.5 Central Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios



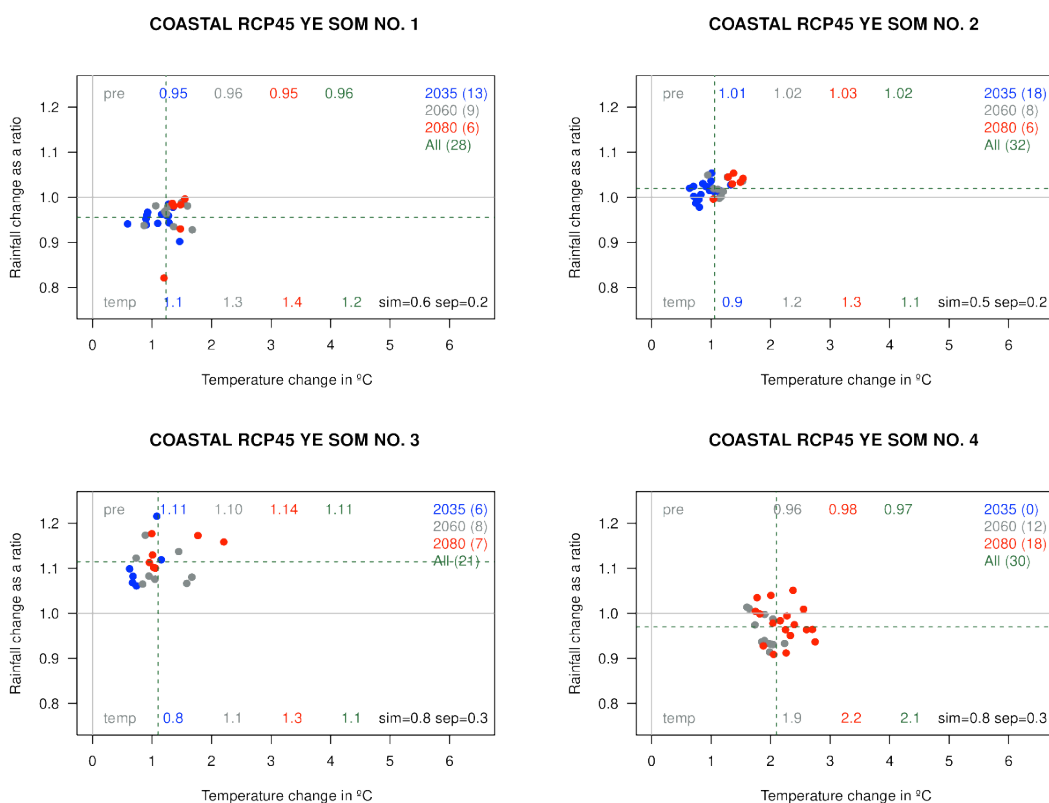
- 19 projections.
- Mapping of 4 nodes $\square$ 6 nodes
 - som1 $\square$ som1 + som2 [2 almost all relatively cool p1]
 - som2 $\square$ som2 + som4 [2 is cooler and drier]
 - som3 $\square$ som3 + som6 [6 captures the cooler projections]
 - som4 $\square$ som5 + som6 [6 captures the drier projections]

Differentiation above is not perfect as there is some intermingling between SOMs. The main difference is that the likelihoods of the lesser two scenarios reverse – should they be 25% each? Otherwise perhaps a little warmer by p3. Either could be used, especially if likelihoods are made 25%.

Table A2-2 | RCP4.5 Annual Central using 6 SOMs – not used in defining the scenarios

Likelihood	SOM	2035	2060	2080
50%	2□1□5	1.0/1.00	1.5/1.00	2.5/1.00
30%	3□6	1.0/0.95	1.5/0.95	2.5/0.90
20%	4	1.0/1.10	1.5/1.05	1.5/1.05
UE		1.0/1.15	2.0/1.10	2.5/1.15
LE		1.0/0.95	2.0/0.90	1.5/0.80

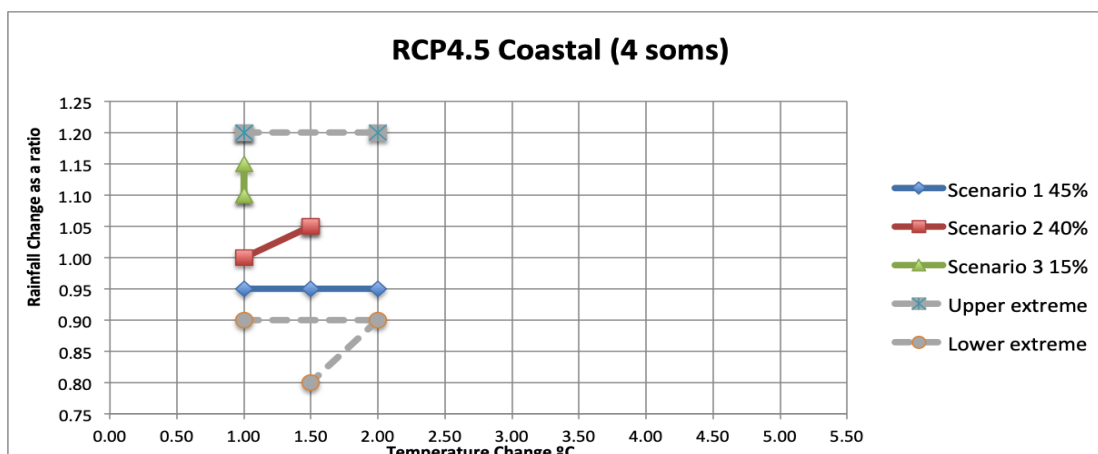
RCP4.5 Coastal Zone – 4 nodes – used in defining the scenarios



37 projections. Most of the p1 are in 1 and 2, p2 in 4, and p3 in 4som3 stands on its own, with two similar-likelihood scenarios, wetter 2□4 and drier 1□4. Contributions to UE from som3 and to LE from som1 and som4; clearly a few outlying projections. Re-checked using 6 SOMs with some adjustments to these scenarios, mainly likelihoods – see notes under 6 nodes.

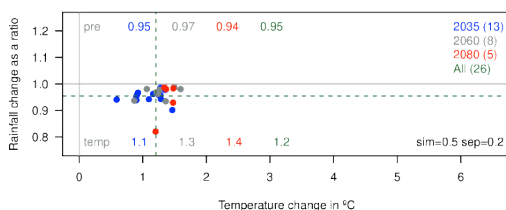
Table A2-3 | RCP4.5 Annual Coastal using 4 SOMs – used in defining the scenarios

Likelihood	SOM	2035	2060	2080
55%	2□4	1.0/1.00	1.5/1.00	2.0/1.05
45%	1□4	1.0/0.95	1.5/0.95	2.0/0.95
20%	3	1.0/1.10	1.0/1.10	1.5/1.15
UE		1.0/1.20	1.0/1.20	2.0/1.20
LE		1.0/0.90	2.0/0.90	1.5/0.80

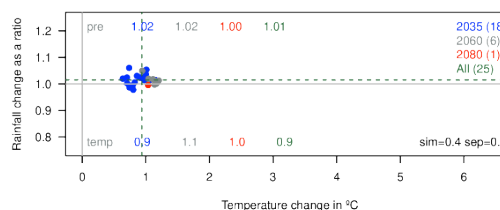


RCP4.5 Coastal Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios

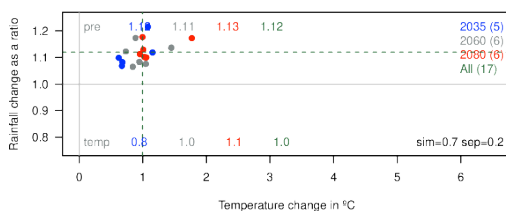
COASTAL RCP45 YE SOM NO. 1



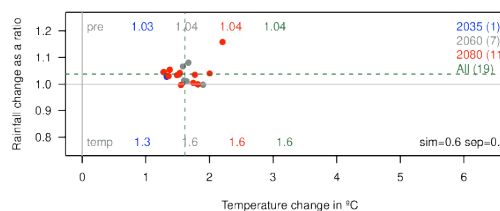
COASTAL RCP45 YE SOM NO. 2



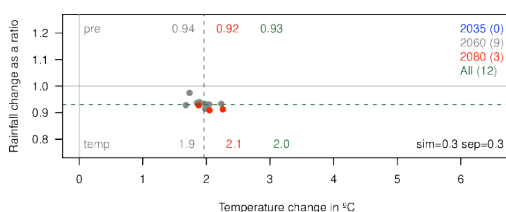
COASTAL RCP45 YE SOM NO. 3



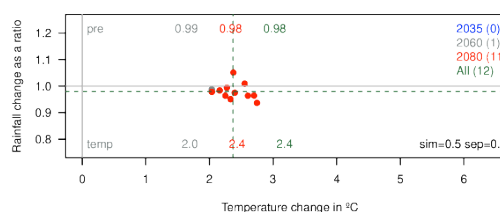
COASTAL RCP45 YE SOM NO. 4



COASTAL RCP45 YE SOM NO. 5



COASTAL RCP45 YE SOM NO. 6



- 37 projections.
- Mapping of 4 nodes □ 6 nodes
 - som1 □ som1 [a couple of unidentified projections elsewhere]
 - som2 □ som2 + som4 [p1 and p2 mainly in 2, p3 in the cooler part of 4]
 - som3 □ som3 [a couple of unidentified projections elsewhere]
 - som4 □ som4 + som5 + som6 [mainly separates out p3]

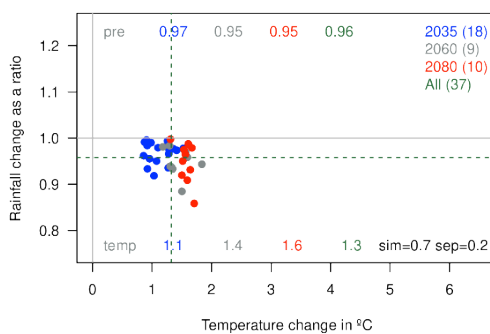
Differentiation above is not perfect as there is some intermingling between SOMs. The main difference is that the likelihoods of the lesser two scenarios reverse with slight changes in likelihoods. Otherwise not as warmer by p3. Either could be used.

Table A2-4 | RCP4.5 Annual Coastal using 6 SOMs – not used in defining the scenarios

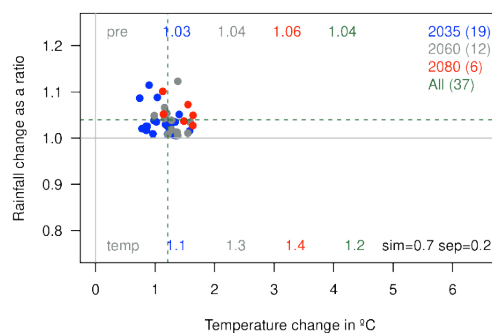
Likelihood	SOM	2035	2060	2080
45%	1□5□6	1.0/0.95	1.5/0.95	2.0/0.95
40%	2□4	1.0/1.00	1.5/1.05	1.5/1.05
15%	3	1.0/1.10	1.0/1.10	1.0/1.15
UE		1.0/1.20	1.0/1.20	2.0/1.20
LE		1.0/0.90	2.0/0.90	1.5/0.80

RCP4.5 North Zone – 4 nodes – not used as 6 nodes preferred

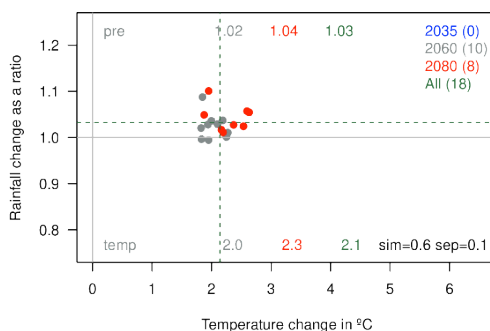
NORTH RCP45 YE SOM NO. 1



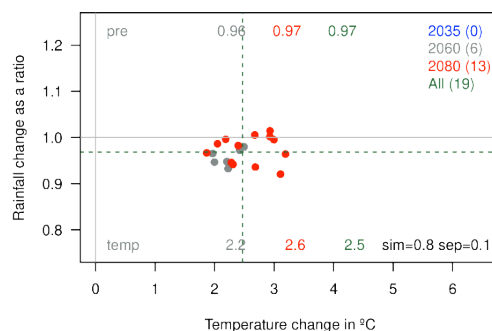
NORTH RCP45 YE SOM NO. 2



NORTH RCP45 YE SOM NO. 3



NORTH RCP45 YE SOM NO. 4

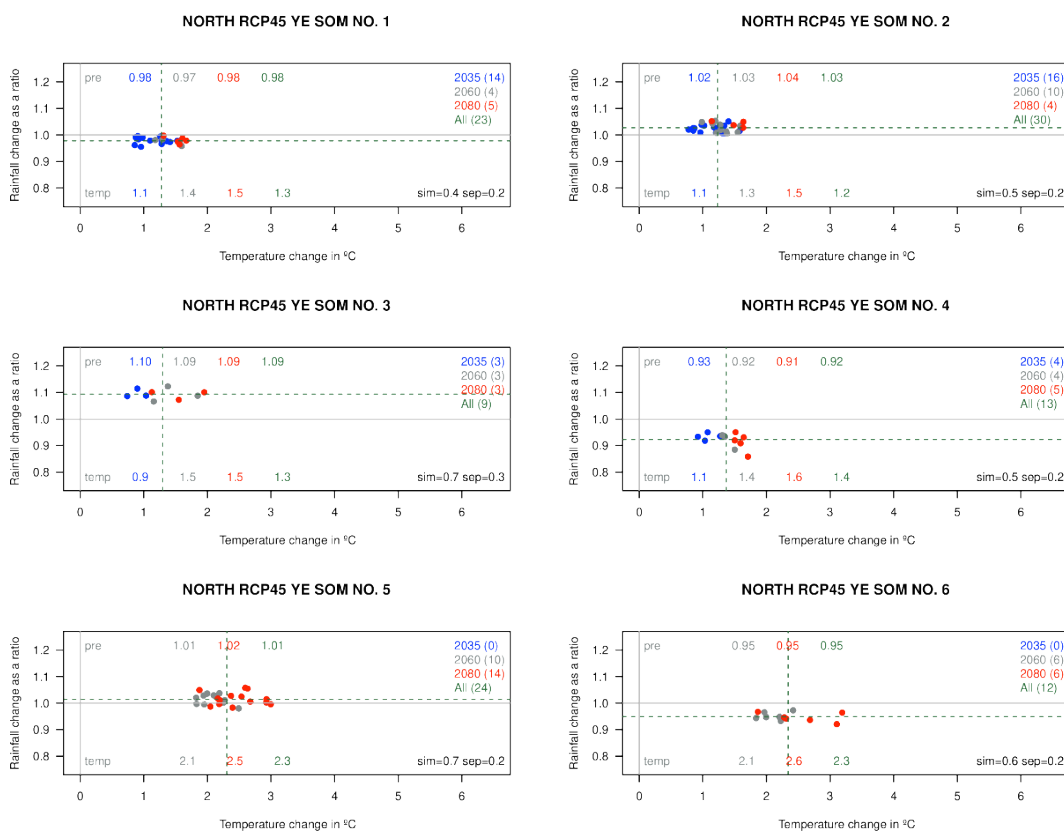


37 projections. Splits easily into 2 scenarios, both with similar likelihoods. Contributions to UE from som2 and som3 and to LE from som1; clearly a few outlying projections. Re-checked using 6 nodes with some adjustments to these scenarios, mainly likelihoods; results from 6 nodes judged to provide the clearer scenarios.

Table A2-5 | RCP4.5 Annual North using 4 SOMs – not used in defining the scenarios

Likelihood	SOM	2035	2060	2080
50%	1□4	1.0/0.95	1.5/0.95	2.0/0.95
50%	2□3	1.0/1.05	1.5/1.05	2.0/1.05
UE		1.0/1.10	1.0/1.10	2.0/1.10
LE		1.0/0.90	1.5/0.90	1.5/0.85

RCP4.5 North Zone – 6 nodes – used in defining the scenarios

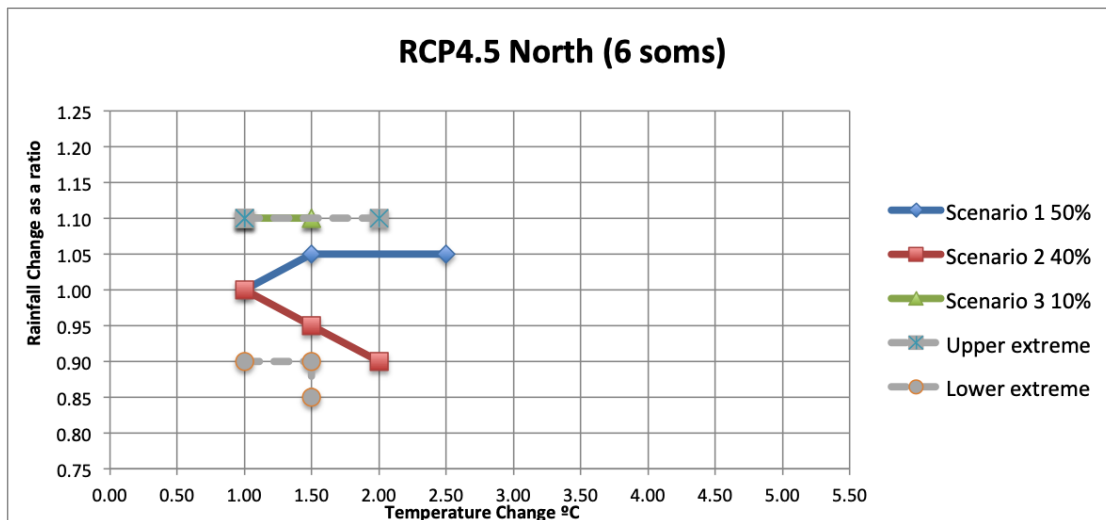


- 37 projections.
- Mapping of 4 nodes □ 6 nodes
 - som1 □ som1 + som4 [almost exact; warmer and drier in som4]
 - som2 □ som2 + som3 [almost exact; drier in som3]
 - som3 □ som5 [some warmer projections added in 5 from 4 in 4 nodes]
 - som4 □ som6 [with some p3 lost to 5]

Basically similar to 4 nodes, with roughly even split between wetter and drier. Some temperature change in the 2080 period. Either could be used, but recommend 6 nodes.

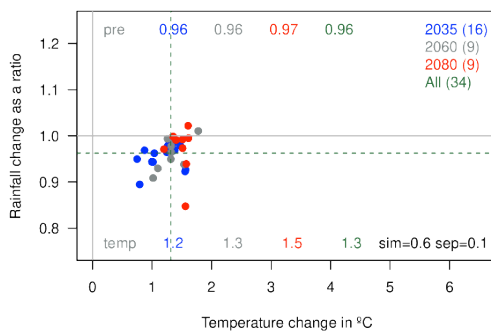
Table A2-6 | RCP4.5 Annual North using 6 SOMs – used in defining the scenarios

Likelihood	SOM	2035	2060	2080
50%	2□5	1.0/1.00	1.5/1.05	2.5/1.05
40%	1□4□6	1.0/1.00	1.5/0.95	2.0/0.90
10%	3	1.0/1.10	1.5/1.10	1.5/1.10
UE		1.0/1.10	1.0/1.10	2.0/1.10
LE		1.0/0.90	1.5/0.90	1.5/0.85

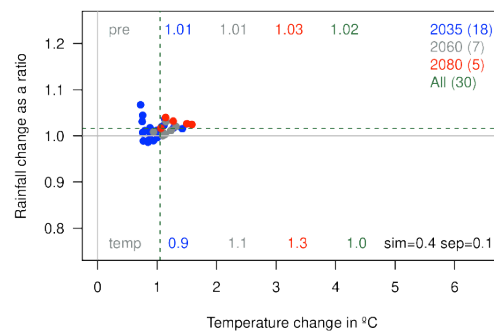


RCP4.5 Southwest Zone – 4 nodes – used in defining the scenarios

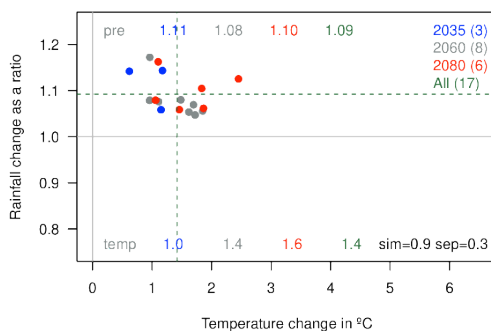
SOUTHWEST RCP45 YE SOM NO. 1



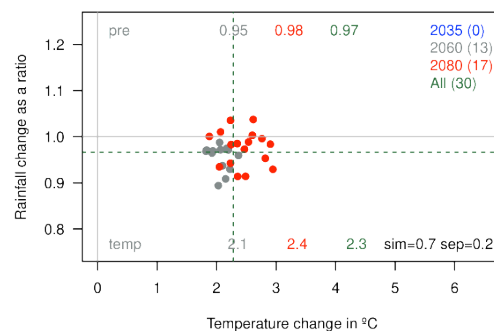
SOUTHWEST RCP45 YE SOM NO. 2



SOUTHWEST RCP45 YE SOM NO. 3



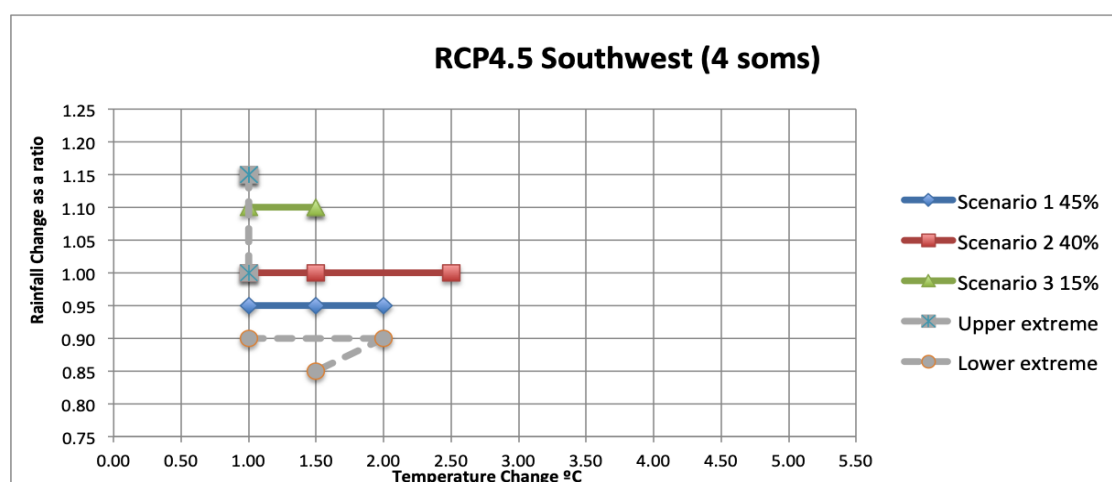
SOUTHWEST RCP45 YE SOM NO. 4



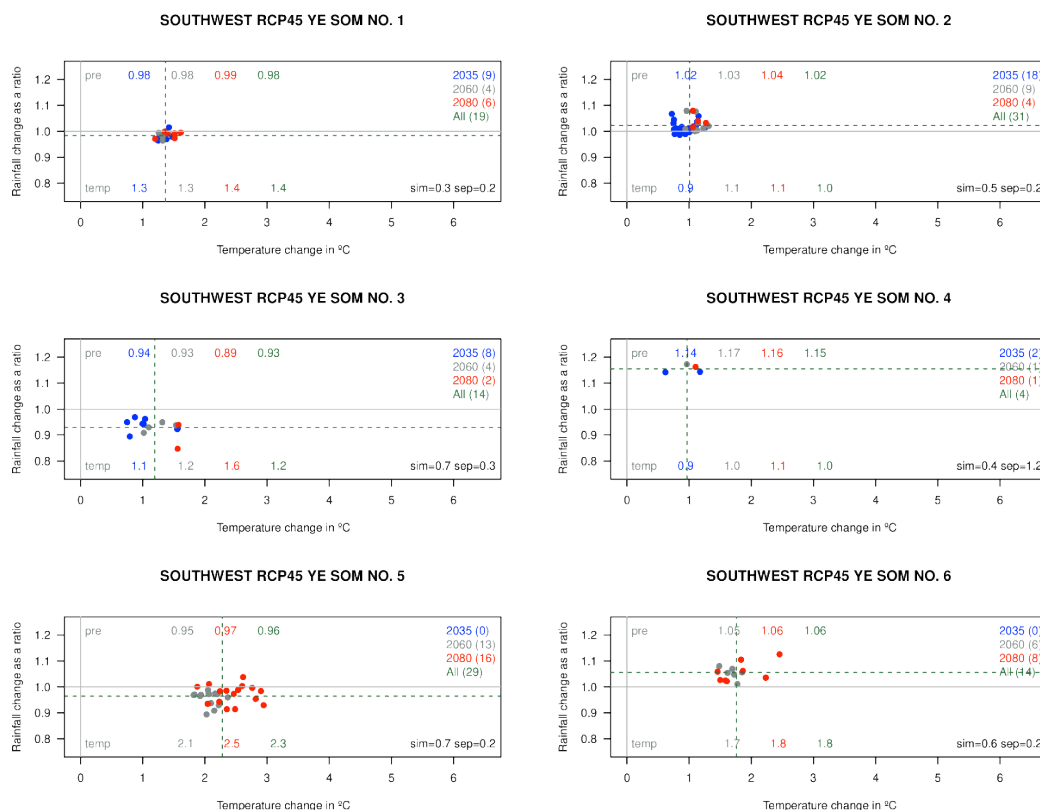
37 projections. Not straightforward: majority of 2080 period in som4, with both som1 and som2 feeding to som4, but is som3 a separate scenario or does it include some from som2? In the recommended solution som3 is kept separate. Contributions to UE from som3 and to LE from som1 and som4; clearly a few outlying projections. Re-checked using 6 SOMs with some adjustments to these scenarios, mainly likelihoods – see also notes under 6 nodes.

Table A2-7 | RCP4.5 Annual Southwest using 4 SOMs – used in defining the scenarios

Likelihood	SOM	2035	2060	2080
45%	1□4	1.0/0.95	1.5/0.95	2.0/0.95
40%	2□4	1.0/1.00	1.5/1.00	2.5/1.00
15%	3	1.0/1.10	1.5/1.10	1.5/1.10
UE		1.0/1.15	1.0/1.15	1.0/1.10
LE		1.0/0.90	2.0/0.90	1.5/0.85



RCP4.5 Southwest Zone – 6 nodes – used only to confirm the scenarios from 4 nodes and not used in defining the scenarios



- 37 projections.
- Mapping of 4 nodes $\square$ 6 nodes
 - som1 $\square$ som1 + som3 [almost exact; warmer and rather drier in som3]
 - som2 $\square$ som2 [almost exact, but a couple extra]
 - som3 $\square$ som2 + som4 + som6 [distributed across several with a new pattern]
 - som4 $\square$ som5 [almost exact]

New high rainfall scenario introduced with low likelihood, but similar to UE. Otherwise some movement in terms of likelihoods, but overall proportions of positive and negative remain similar. Either could be used, but probably 4 nodes to remove complication of the 4th scenario with 6 nodes being similar to UE.

Table A2-8 | RCP4.5 Annual Southwest using 6 SOMs – not used in defining the scenarios

Likelihood	SOM	2035	2060	2080
40%	2 $\square$ 6	1.0/1.00	1.5/1.05	1.5/1.05
30%	1 $\square$ 5	1.5/1.00	2.0/0.95	2.5/0.95
25%	3 $\square$ 5	1.0/0.95	2.0/0.95	2.5/0.95
5%	4	1.0/1.15	1.0/1.15	1.0/1.15
UE		1.0/1.15	1.0/1.15	1.0/1.10
LE		1.0/0.90	2.0/0.90	1.5/0.85

RCP4.5 Annual North using 6 SOMs				
Likelihood	SOM	2035	2060	2080
50%	2□5	1.0/1.00	1.5/1.05	2.5/1.05
40%	1□4□6	1.0/1.00	1.5/0.95	2.0/0.90
10%	3	1.0/1.10	1.5/1.10	1.5/1.10
UE		1.0/1.10	1.0/1.10	2.0/1.10
LE		1.0/0.90	1.5/0.90	1.5/0.85

RCP4.5 Annual Central using 4 SOMs				
Likelihood	SOM	2035	2060	2080
50%	1□4	1.0/1.00	1.5/1.00	2.0/1.00
30%	2	1.0/1.05	1.5/1.05	1.5/1.05
20%	3□4	1.0/0.95	1.5/0.95	3.0/0.95
UE		1.0/1.15	2.0/1.10	2.5/1.15
LE		1.0/0.95	2.0/0.90	1.5/0.80

RCP4.5 Annual Southwest using 4 SOMs				
Likelihood	SOM	2035	2060	2080
45%	1□4	1.0/0.95	1.5/0.95	2.0/0.95
40%	2□4	1.0/1.00	1.5/1.00	2.5/1.00
15%	3	1.0/1.10	1.5/1.10	1.5/1.10
UE		1.0/1.15	1.0/1.15	1.0/1.10
LE		1.0/0.90	2.0/0.90	1.5/0.85

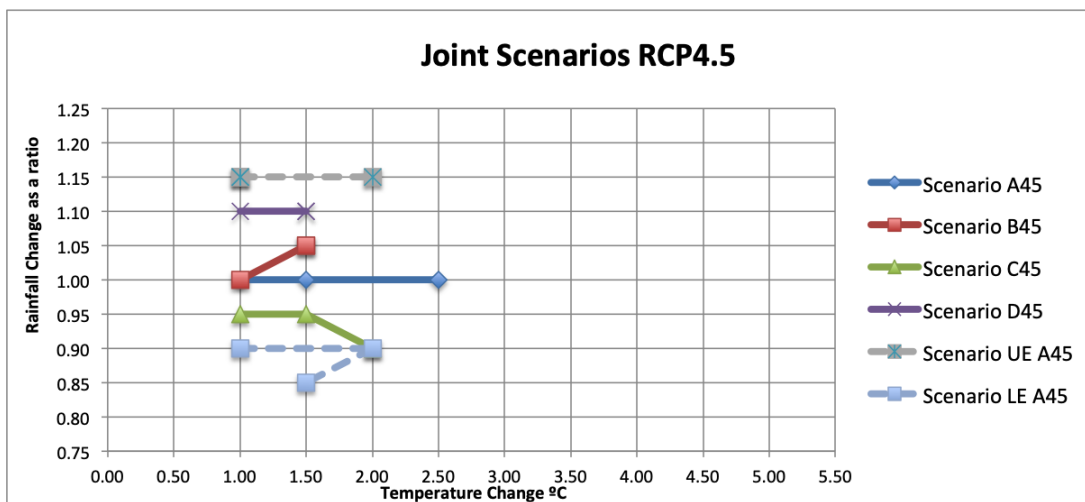
RCP4.5 Annual Coastal using 4 SOMs				
Likelihood	som	2035	2060	2080
55%	2□4	1.0/1.00	1.5/1.00	2.0/1.05
45%	1□4	1.0/0.95	1.5/0.95	2.0/0.95
20%	3	1.0/1.10	1.0/1.10	1.5/1.15
UE		1.0/1.20	1.0/1.20	2.0/1.20
LE		1.0/0.90	2.0/0.90	1.5/0.80

No changes in rainfall for the recommended scenarios exceeding 10% in either direction

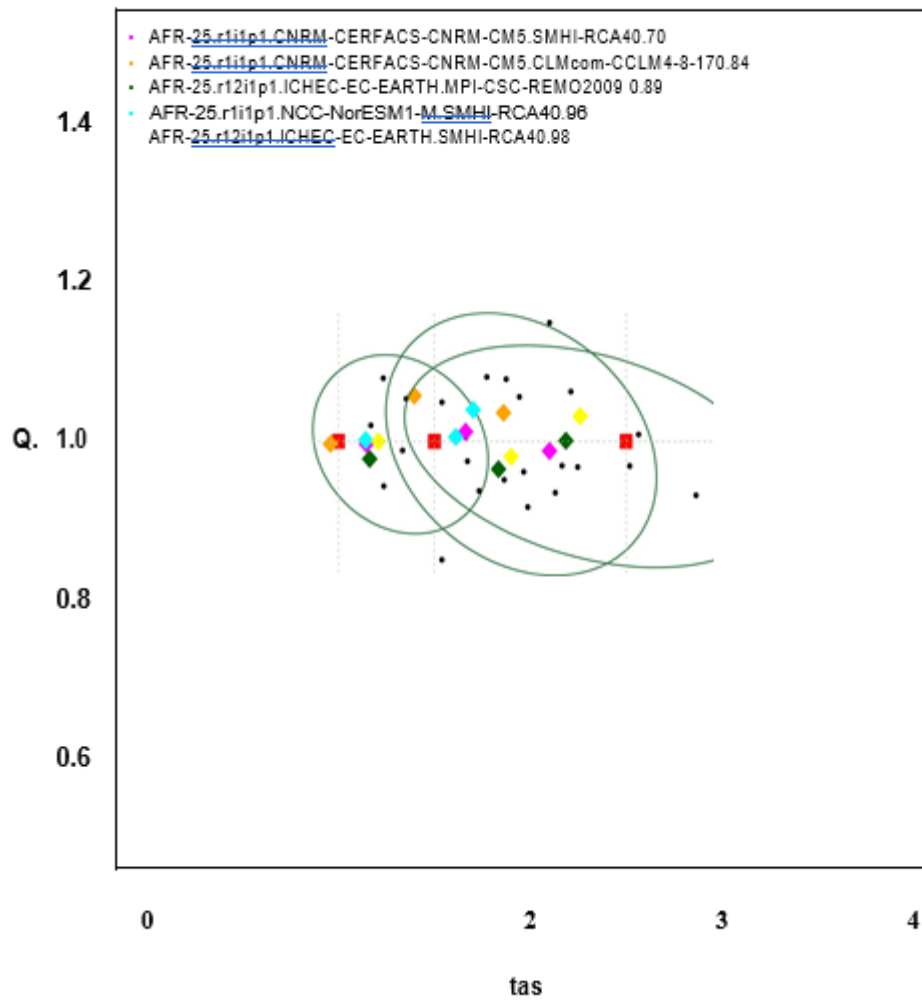
Likelihoods of increases and decreases in rainfall are similar Greater warming possible in the 2 northern areas

Table A2-9 | Results of joint pathways analysis across the four hydroclimatic zones under RCP4.5

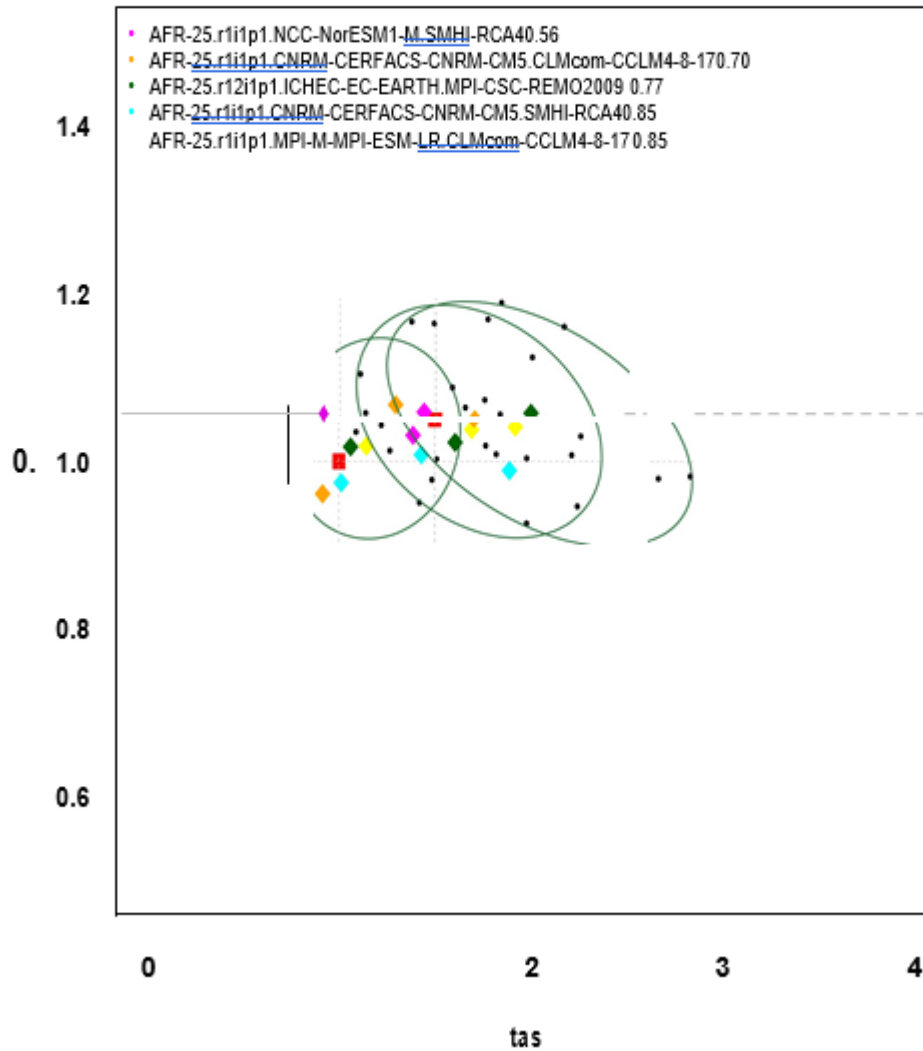
Likelihood of Individual Scenario					Expected Temperature (deg C) and Rainfall (%) Impacts.		
Scenario	North	Central	Southwest	Coastal	2035	2060	2080
A45	1 50%	1 50%	2 40%	X	1.0/1.00	1.5/1.00	2.5/1.00
B45	X	X	X	2 40%	1.0/1.00	1.5/1.05	1.5/1.05
C45	2 40%	2 30%	1 45%	1 45%	1.0/0.95	1.5/0.95	2.0/0.90
D45	3 10%	3 20%	3 15%	3 15%	1.0/1.10	1.5/1.10	1.5/1.10
UE A45	✓	✓	✓	✓	1.0/1.15	1.0/1.15	2.0/1.15
LE A45	✓	✓	✓	✓	1.0/0.90	2.0/0.90	1.5/0.85



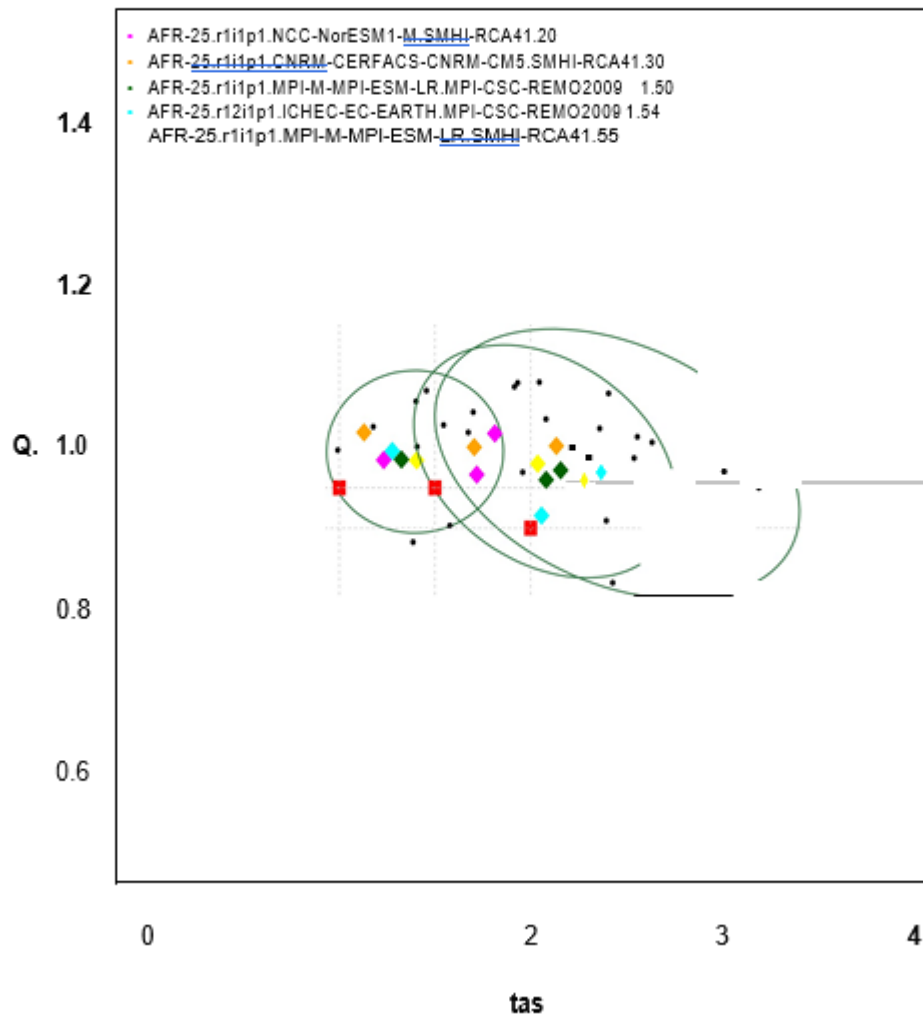
A45 central



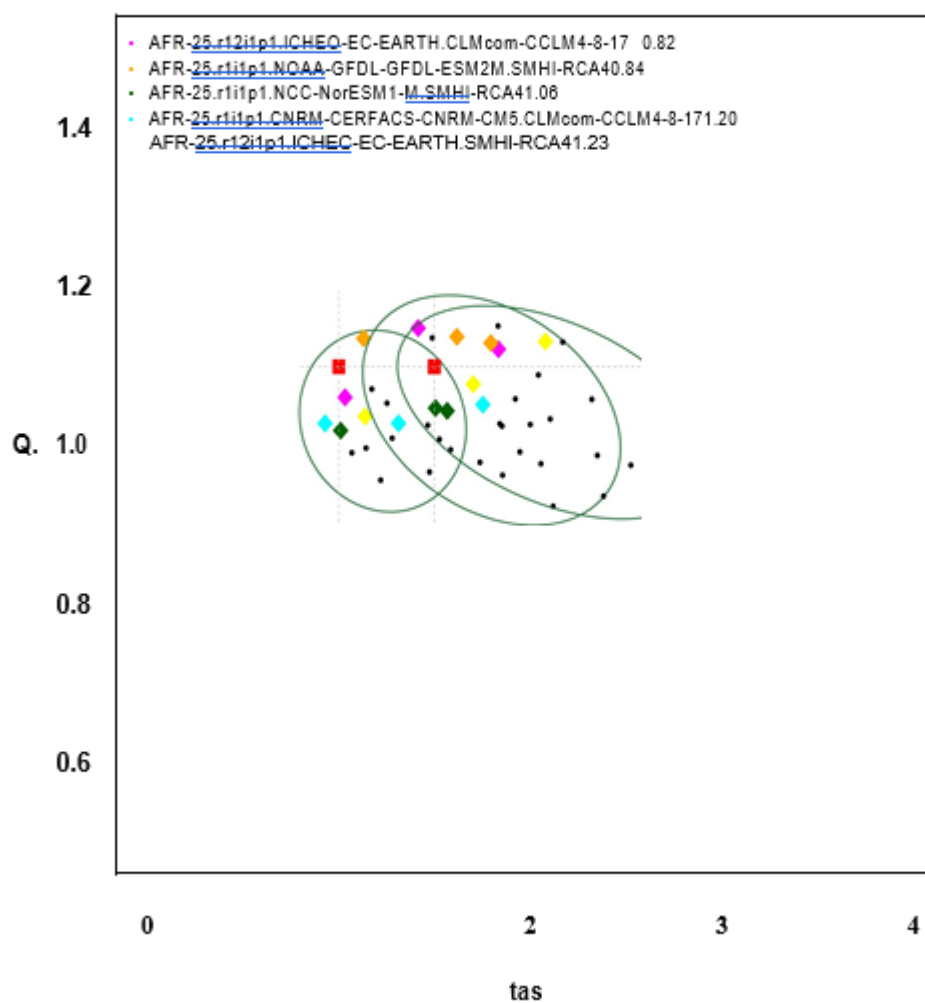
845 coastal



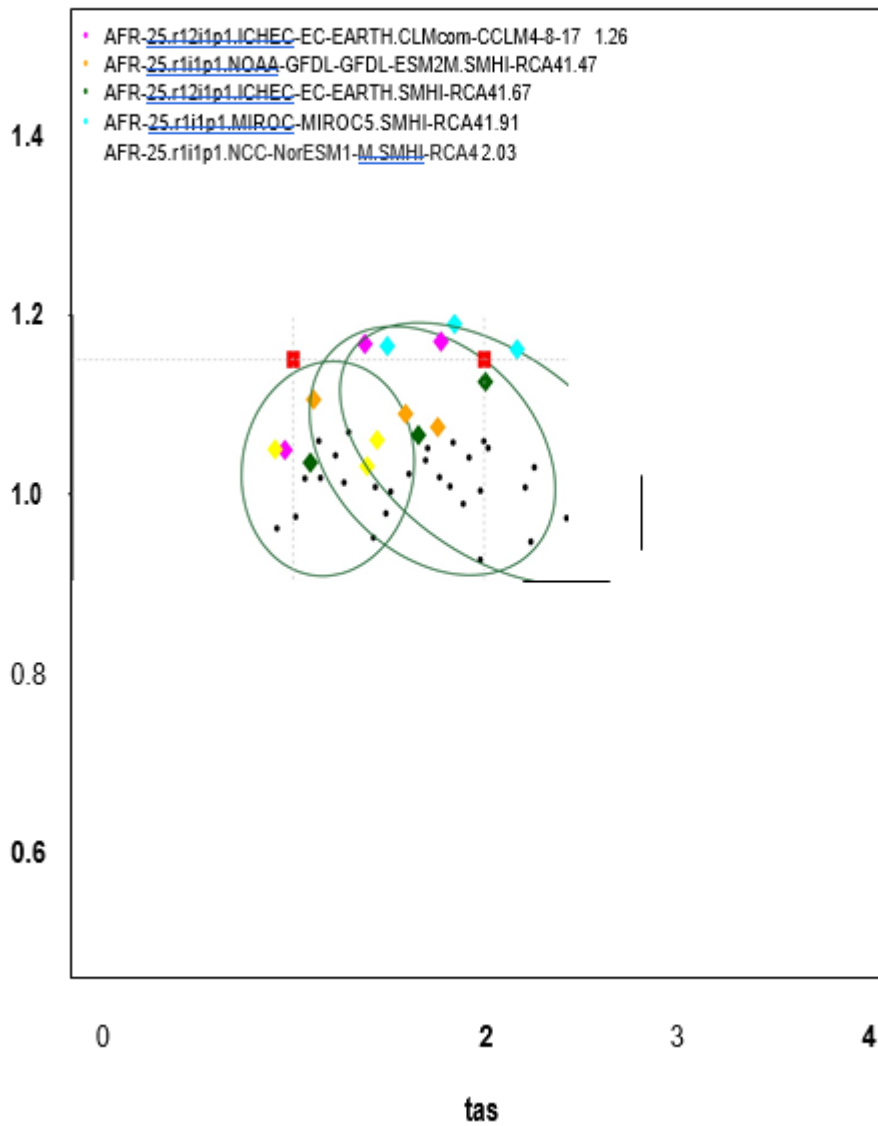
C45 north



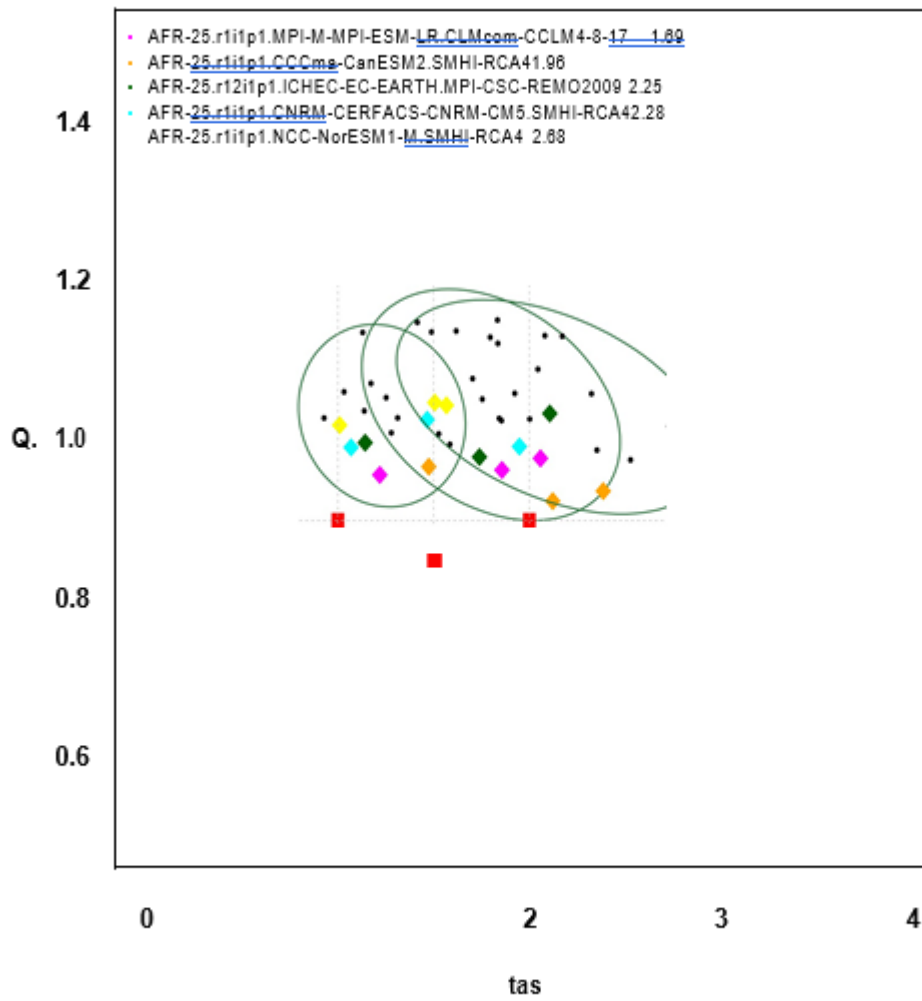
D45 swest



UEA45 coastal



LEA45 swest



Scenario	Focus Zone	CORDEX Domain	Host GCM	RCM	RMS
A45	Central	Africa	Centre National de Recherches Météorologiques in France (CNRM)	Swedish Meteorological and Hydrological Institute (SMHI)	0.70
B45*	Coastal	Africa	NorESM Climate Modelling Consortium	Swedish Meteorological and Hydrological Institute (SMHI)	0.56
C45*	North	Africa	NorESM Climate Modelling Consortium	Swedish Meteorological and Hydrological Institute (SMHI)	1.20
D45\$	Southwest	Africa	European GCM collaboration (ICHEC)	Climate Limited-Area Modelling Community (CLM) in association with KIT in Germany	0.82
UE A45\$	Coastal	Africa	European GCM collaboration (ICHEC)	Climate Limited-Area Modelling Community (CLM) in association with KIT in Germany	1.26
LE A45	Southwest	Africa	Max Planck Institute in Germany (MPI)	Climate Limited-Area Modelling Community (CLM) in association with KIT in Germany	1.69

Notes:

* The same GCM/RCM combination provides the closest fits to both B45 and C45

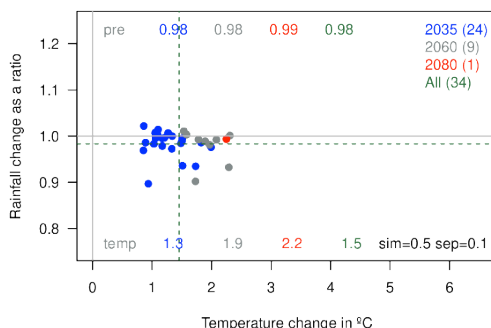
\$ The same GCM/RCM combination provides the closest fits to both D45 and UE A45

Scenario	Likelihood	Distance	Comments
A45	50%/50%/40%/-	0.70	A good fit but model too cool in the third period
B45*	-/-/40%	0.56	Model becomes too warm in the second period, but rainfall captured reasonably well
C45*	40%/30%/45%/45%	1.20	Simulation is generally warmer and wetter than the scenario, but the scenario lies close to the edges of the ellipses in all three periods
D45\$	10%/20%/15%/15%	0.82	In the third period the simulation is markedly warmer than the scenario
UE A45\$	Applies to all zones	1.26	Captures the rainfall better than the temperatures
LE A45	Applies to all zones	1.69	The scenario lies outside the GCM/RCM cloud, and this is the best option

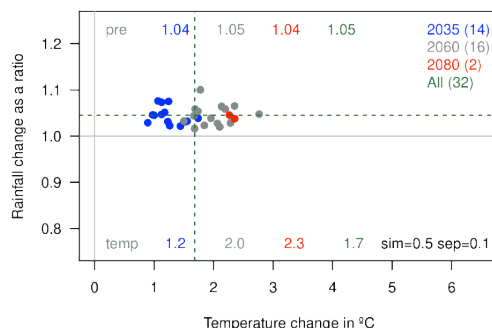
Appendix A3: RCP 8.5 SOMS Analysis Results

RCP8.5 Central Zone – 4 nodes – not used in defining the scenarios

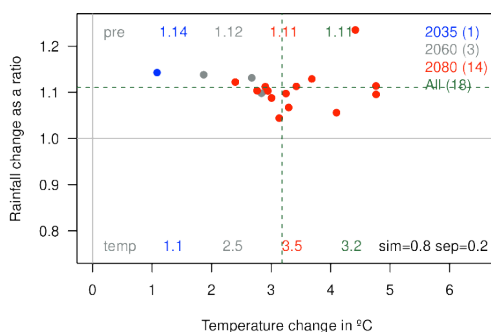
CENTRAL RCP85 YE SOM NO. 1



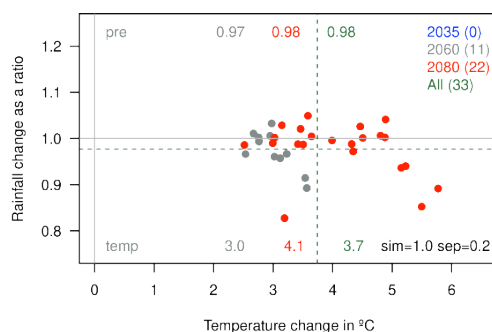
CENTRAL RCP85 YE SOM NO. 2



CENTRAL RCP85 YE SOM NO. 3



CENTRAL RCP85 YE SOM NO. 4

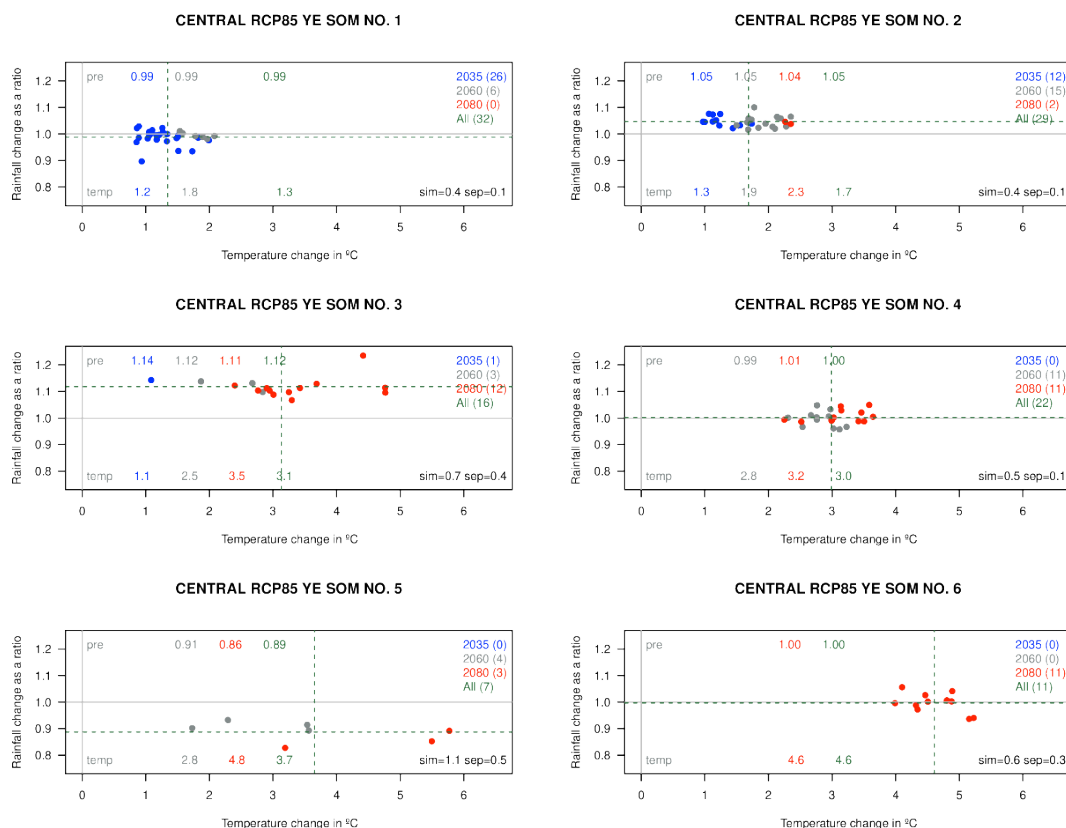


39 projections. Splits readily into 2 scenarios. Contributions to UE from som3 and to LE from som1 and som4; clearly a few outlying projections.

Table A3-1 | RCP8.5 Annual Central using 4 SOMs – not used in defining the scenarios

Likelihood	SOM	2035	2060	2080
60%	1□4	1.5/1.00	2.5/1.00	4.0/1.00
40%	2□3	1.0/1.05	2.0/1.05	3.5/1.10
UE		1.1/1.15	2.0/1.15	4.0/1.20
LE		1.0/0.90	3.5/0.90	5.0/0.85

RCP8.5 Central Zone – 6 nodes – not used in defining the scenarios



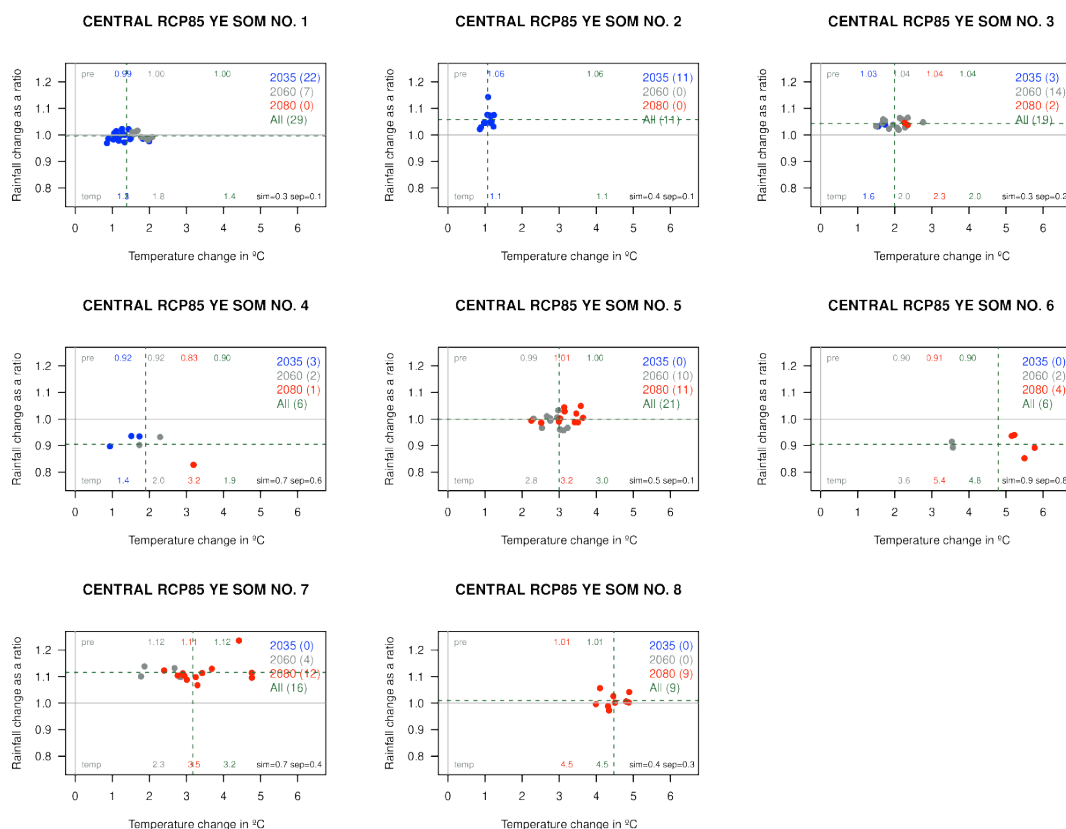
- 39 projections.
- Mapping of 4 nodes $\square$ 6 nodes
 - som1 $\square$ som1 + som5 [mainly som1]
 - som2 $\square$ som2 [almost exact]
 - som3 $\square$ som3 [almost exact; hence the 40% scenario from 4 nodes stays the same]
 - som4 $\square$ som4 + som5 + som6 [effectively a split into 3 groupings]

Scenario using som2 $\square$ som3 remains as with 4 nodes, with same likelihood. Scenario from som1 splits to som4 and som6, with part of som4 continuing to SOMs5; likelihoods estimated from proportion remaining after taking out of the calculations the 40% scenario.

Table A3-2 | RCP8.5 Annual Central using 6 SOMs – not used in defining the scenarios

Likelihood	SOM	2035	2060	2080
40%	2 $\square$ 3	1.0/1.05	2.0/1.05	3.5/1.10
30%	1 $\square$ 4 $\square$ 6	1.5/1.00	2.5/1.00	4.0/1.00
20%	1 $\square$ 4	1.5/1.00	2.5/1.00	3.0/1.00
10%	1 $\square$ 5	1.5/1.00	2.0/0.95	4.5/0.90
UE		1.1/1.15	2.0/1.15	4.0/1.20
LE		1.0/0.90	3.5/0.90	5.0/0.85

RCP8.5 Central Zone – 8 nodes – used in defining the scenarios



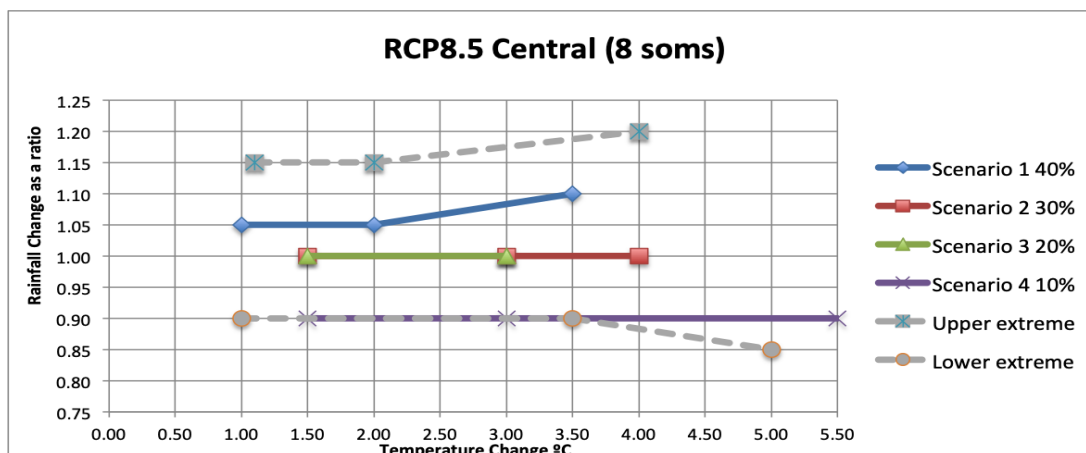
- 39 projections.
- Mapping of 6 nodes $\square$ 8 nodes
 - som1 $\square$ som1 + som4 [mainly som1]
 - som2 $\square$ som2 + som3 $\square$
 - som3 $\square$ som7 [almost exact; hence the 40% scenario from 4 nodes stays the same]
 - som4 $\square$ som4 + som5 [almost exact]
 - som5 $\square$ som4 + som6 $\square$
 - som6 $\square$ som8 [almost exact]

In the table below the 4 scenarios from 6 nodes have been mapped to the 8 nodes; because of the splitting of some of the SOMs there are some changes in the details of the scenarios, with some warmer and some drier estimates. No adjustments made to the likelihoods from 6 nodes have been made but this could be reviewed.

Table A3-3 | RCP8.5 Annual Central using 8 SOMs –used in defining the scenarios

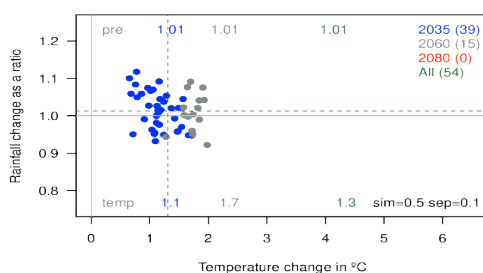
Likelihood	som	2035	2060	2080
40%	2□3□7	1.0/1.05	2.0/1.05	3.5/1.10
30%	1□5□8	1.5/1.00	3.0/1.00	4.5/1.00
20%	1□5	1.5/1.00	3.0/1.00	3.0/1.00
10%	4□6	1.5/0.90	3.0/0.90	5.5/0.90

UE		1.1/1.15	2.0/1.15	4.0/1.20
LE		1.0/0.90	3.5/0.90	5.0/0.85

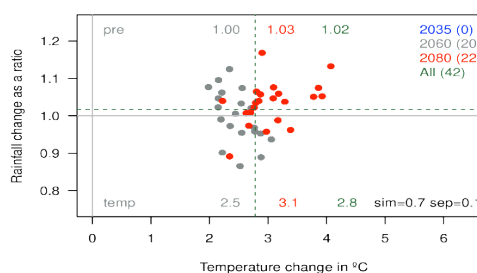


RCP8.5 Coastal Zone – 4 nodes – not used in defining the scenarios

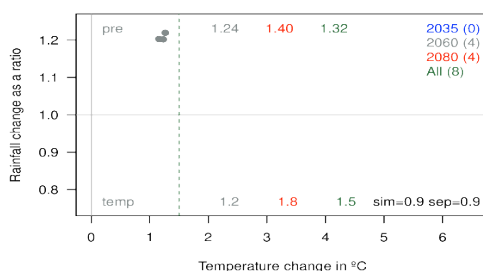
COASTAL RCP85 YE SOM NO. 1



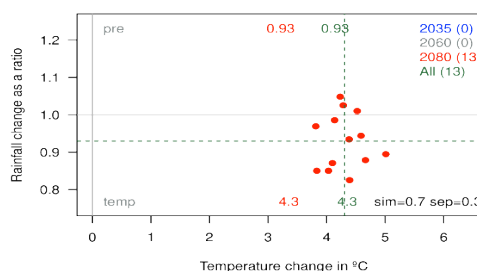
COASTAL RCP85 YE SOM NO. 2



COASTAL RCP85 YE SOM NO. 3



COASTAL RCP85 YE SOM NO. 4

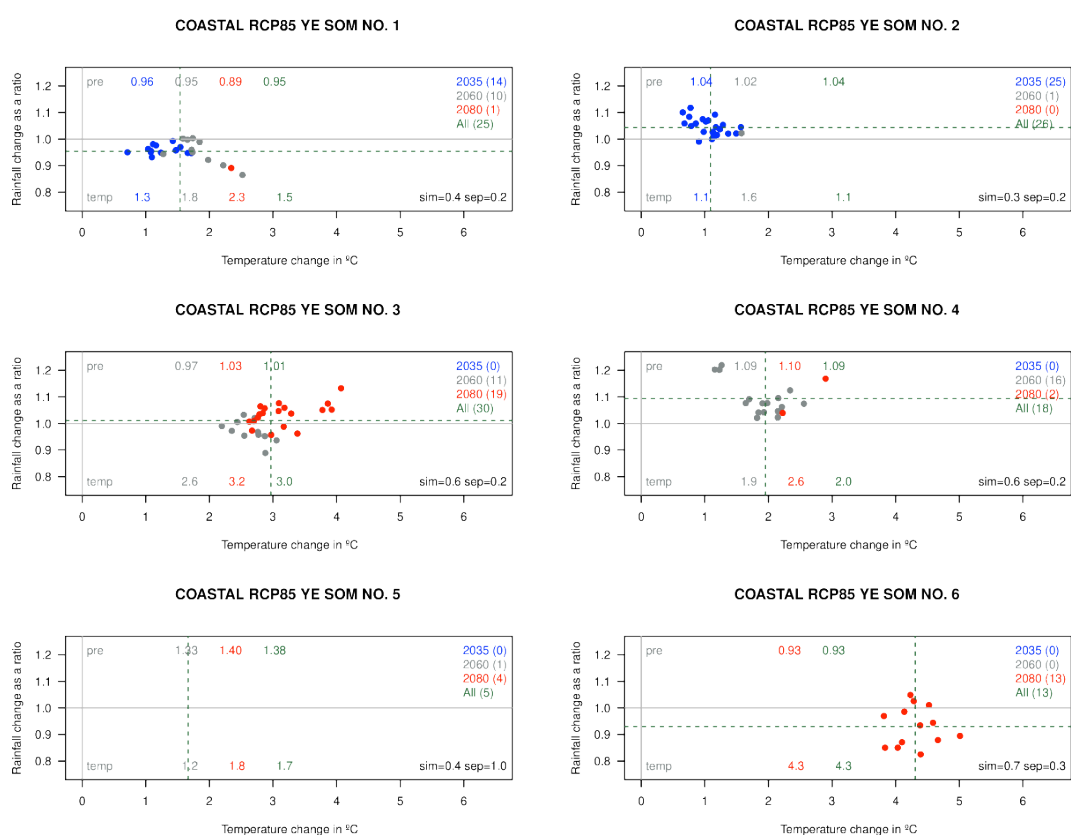


39 projections. Not straightforward: all 2035 points in som1, most 2060 values split roughly equally between som1 and som2, and similarly 2080 values between som2 and som4 – som3 is outlying 2060 and 2080 values. If scenarios were defined from this then the result would be ones with limited rainfall change – this has happened before, but resolved to an extent using 6 nodes, but more so with 8 nodes. Hence no scenarios defined from 4 nodes. Contributions to UE from som1 and som2 and to LE from som1 and som2 and som4; projections in som3 were ignored in defining UE.

Table A3-4 | RCP8.5 Annual Coastal using 4 SOMs – not used in defining the scenarios

Likelihood	som	2035	2060	2080
UE				
		0.5/1.10	2.5/1.15	3.0/1.20
LE		1.0/0.90	2.5/0.85	4.5/0.80

RCP8.5 Coastal Zone – 6 nodes – not used in defining the scenarios



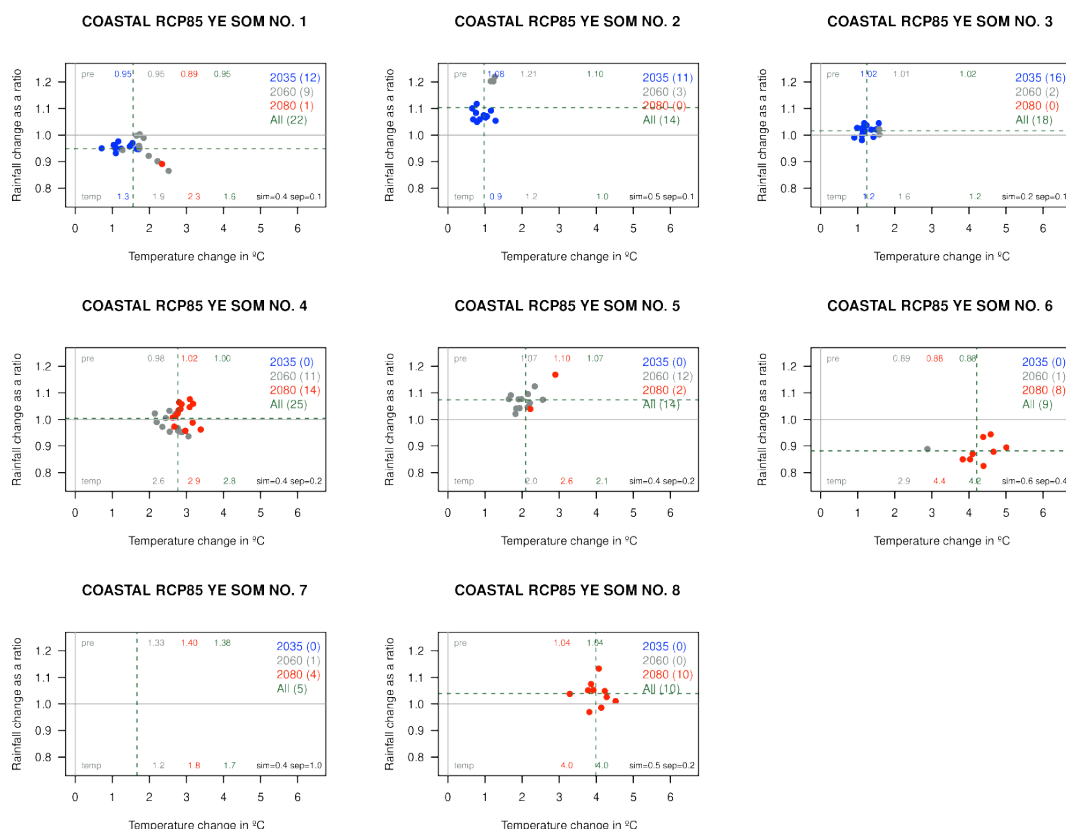
- 39 projections.
- Mapping of 4 nodes □ 6 nodes
 - som1 □ som1 + som2 [exact, but one p3 in som1]
 - som2 □ som3 + som4 [almost exact, but perhaps includes some from som3]
 - som3 □ som5 [but 3 p2 have gone elsewhere]
 - som4 □ som6 [exact]

Scenarios defined without supporting information from 4 nodes; in this case the split into two scenarios is reasonable. Note that som5 has not been used as per som3 with 4 nodes.

Table A3-5 | RCP8.5 Annual Coastal using 6 SOMs – not used in defining the scenarios

Likelihood	som	2035	2060	2080
65%	2□4□3	1.0/1.05	2.0/1.10	3.0/1.05
35%	1□6	1.5/0.95	2.0/0.95	4.5/0.95
UE		0.5/1.10	2.5/1.15	3.0/1.20
LE		1.0/0.90	2.5/0.85	4.5/0.80

RCP8.5 Coastal Zone – 8 nodes – used in defining the scenarios

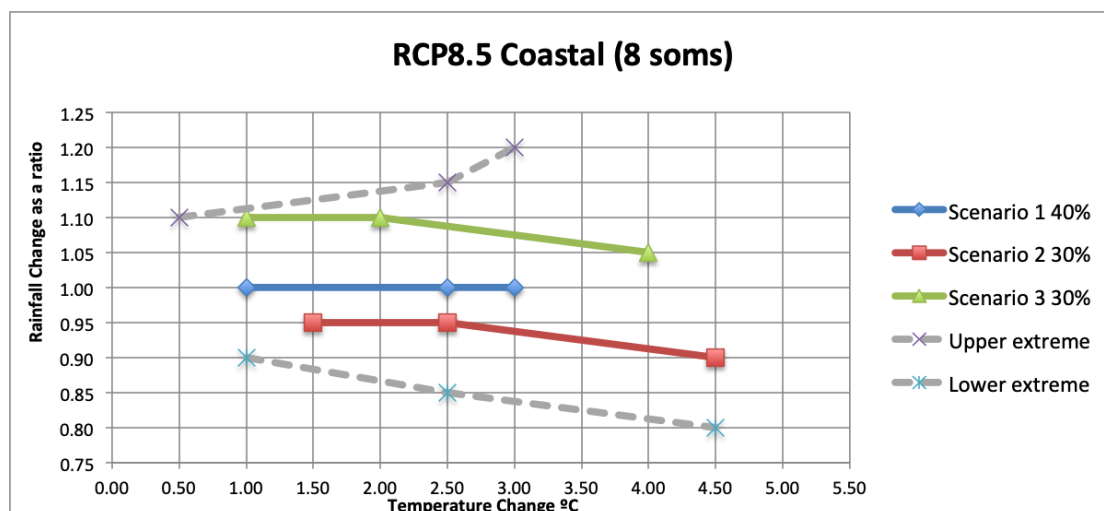


- 39 projections.
- Mapping of 6 nodes □ 8 nodes
 - som1 □ som1 [almost exact]
 - som2 □ som2 + som3 [an important p1 split to cooler/wetter and warmer/drier]
 - som3 □ som4 + som8 [mostly into som4]
 - som4 □ som5 + som2 [mostly into som5]
 - som5 □ som7 [exact but retains the outliers suggesting 40% increase]
 - som6 □ som6 + som8 + som3 [the second important split, for p3]

Using 8 nodes clarifies substantially over 6 nodes, leading to 3 rather than 2 scenarios. Note that som7, equivalent to som5 with 6 nodes, has not been used – it has for the 2080 period 4 projections with rainfall change average of +40%.

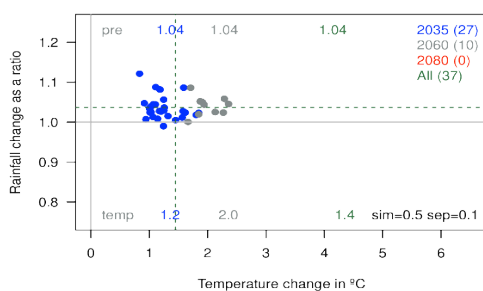
Table A3-6 | RCP8.5 Annual Coastal using 8 SOMs –used in defining the scenarios

Likelihood	som	2035	2060	2080
40%	3□4	1.0/1.00	2.5/1.00	3.0/1.00
30%	1□4□6	1.5/0.95	2.5/0.95	4.5/0.90
30%	2□5□8	1.0/1.10	2.0/1.10	4.0/1.05
UE		0.5/1.10	2.5/1.15	3.0/1.20
LE		1.0/0.90	2.5/0.85	4.5/0.80

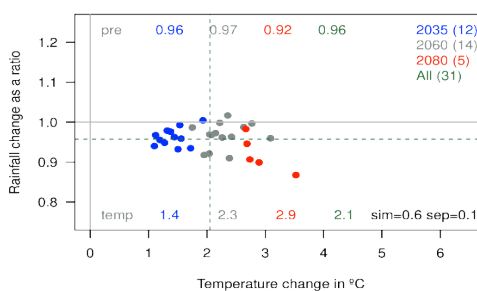


RCP8.5 North Zone – 4 nodes – not used in defining the scenarios

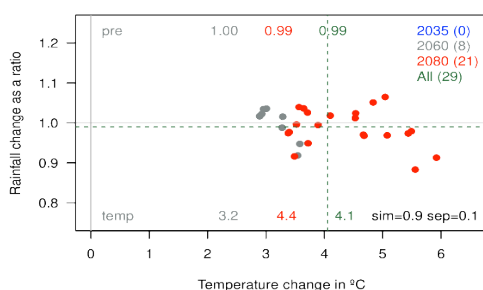
NORTH RCP85 YE SOM NO. 1



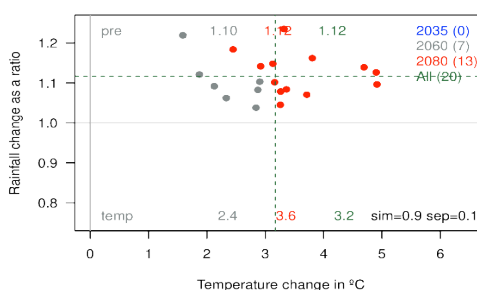
NORTH RCP85 YE SOM NO. 2



NORTH RCP85 YE SOM NO. 3



NORTH RCP85 YE SOM NO. 4

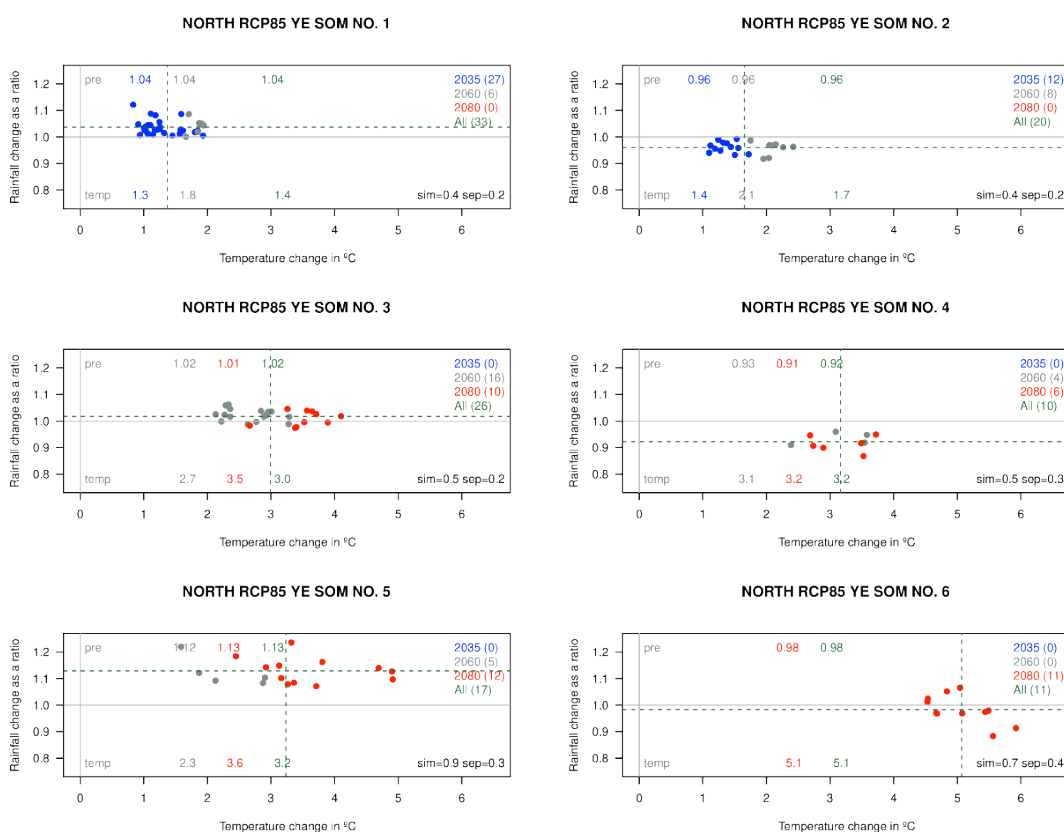


39 projections. Basically a straightforward split into 2 equi-likely scenarios, but the distributions of some of the points suggests that more scenarios might be preferable. UE from som1 and som4; LE from som2 and som3.

Table A3-7 | RCP8.5 Annual North using 4 SOMs – not used in defining the scenarios

Likelihood	som	2035	2060	2080
50%	2□3	1.5/0.95	2.5/1.00	4.5/1.10
50%	1□4	1.0/1.05	2.0/1.05	3.5/1.10
UE		1.0/1.10	2.0/1.20	3.5/1.25
LE		1.5/0.95	3.5/0.90	5.0/0.85

RCP8.5 North Zone – 6 nodes – not used in defining the scenarios



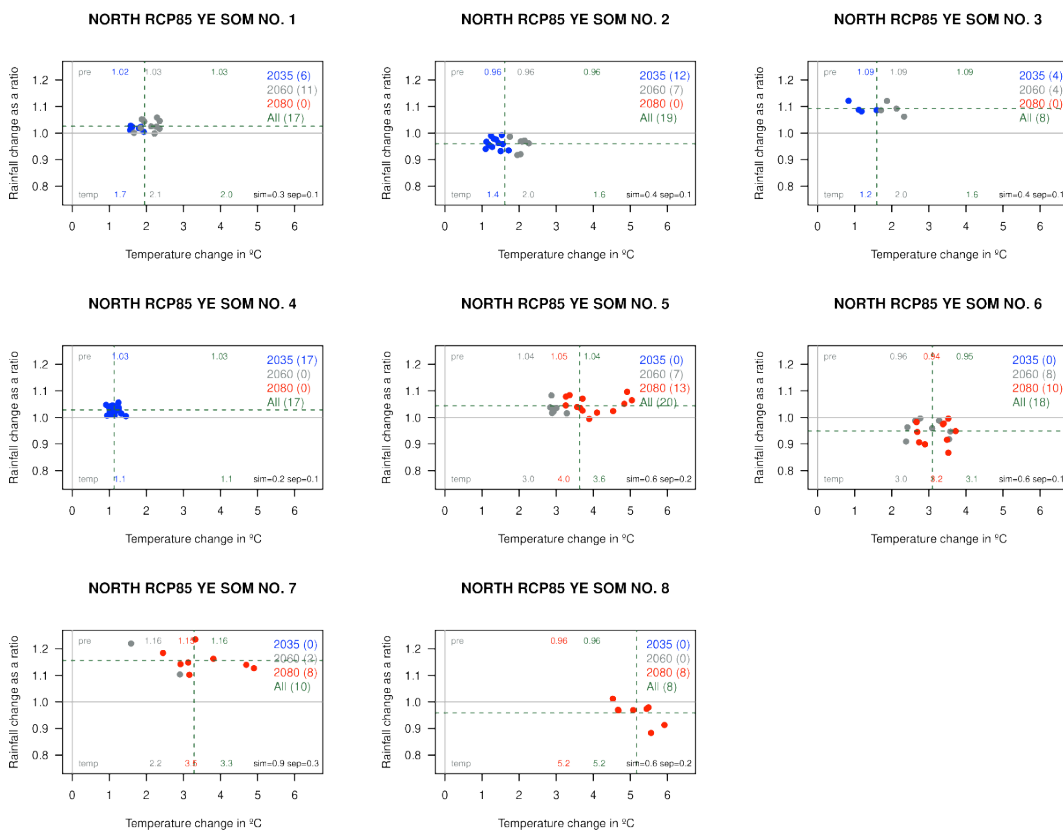
- 39 projections.
- Mapping of 4 nodes □ 6 nodes
 - som1 □ som1 [a few p2 elsewhere]
 - som2 □ som2 + som3 + som4 [with redistribution of projections]
 - som3 □ som4 + som6 [included in redistribution]
 - som4 □ som5 [almost exact]

Somewhat different set of scenarios compared to 4 nodes – Probably the better choice.

Table A3-8 | RCP8.5 Annual North using 6 SOMs – not used in defining the scenarios

Likelihood	SOM	2035	2060	2080
40%	1□3	1.5/1.05	2.5/1.00	3.5/1.00
35%	2□4□6	1.5/0.95	2.5/0.95	4.0/0.95
25%	1□5	1.5/1.05	2.0/1.10	3.5/1.15
UE		1.0/1.10	2.0/1.20	3.5/1.25
LE		1.5/0.95	3.5/0.90	5.0/0.85

RCP8.5 North Zone – 8 nodes – used in defining the scenarios

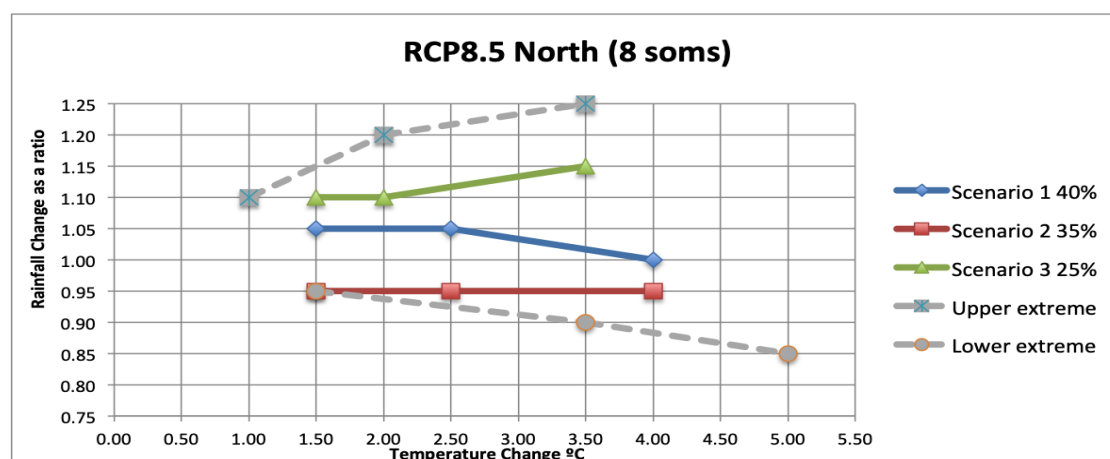


- 39 projections.
- Mapping of 6 nodes □ 8 nodes
 - som1 □ som1 + som4 [mainly separates p1 in som4 from p2 in som1]
 - som2 □ som2 [almost exact]
 - som3 □ som5 + som6 + som1 for p2 []
 - som4 □ som6 [part of som6]
 - som5 □ som7 + som3 [mainly 7 but some p2 from 3]
 - som6 □ som8 [mainly exact]

A similar set of scenarios to 6 nodes, with slightly adjusted values in a few cases. Likelihoods not yet changed from 6 nodes, but could be reviewed.

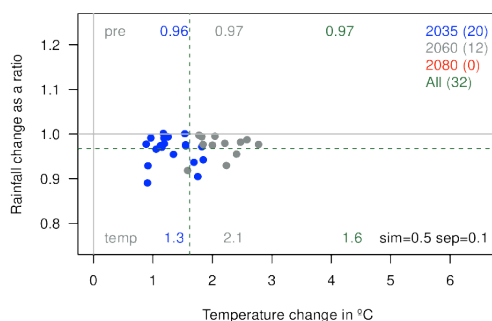
Table A3-9 | RCP8.5 Annual North using 8 SOMs –used in defining the scenarios

Likelihood	SOM	2035	2060	2080
40%	4□1□5	1.5/1.05	2.5/1.05	4.0/1.00
35%	2□6□8	1.5/0.95	2.5/0.95	4.0/0.95
25%	3□7	1.5/1.10	2.0/1.10	3.5/1.15
UE		1.0/1.10	2.0/1.20	3.5/1.25
LE		1.5/0.95	3.5/0.90	5.0/0.85

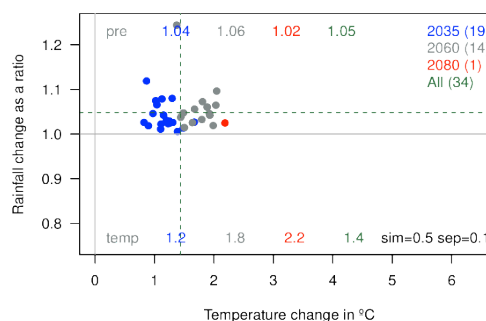


RCP8.5 Southwest Zone – 4 nodes – not used in defining the scenarios

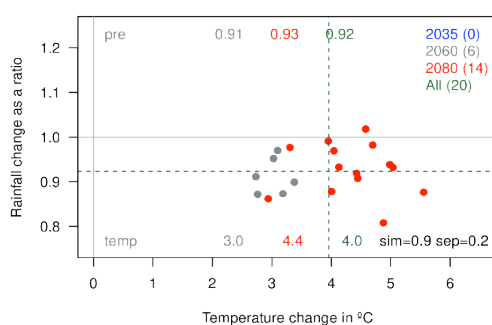
SOUTHWEST RCP85 YE SOM NO. 1



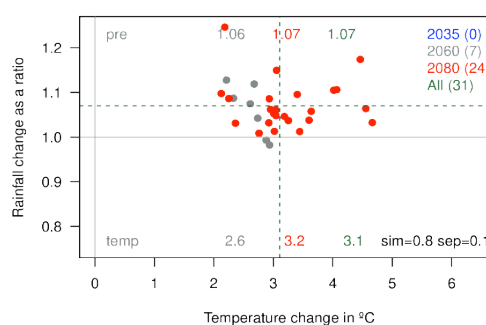
SOUTHWEST RCP85 YE SOM NO. 2



SOUTHWEST RCP85 YE SOM NO. 3



SOUTHWEST RCP85 YE SOM NO. 4

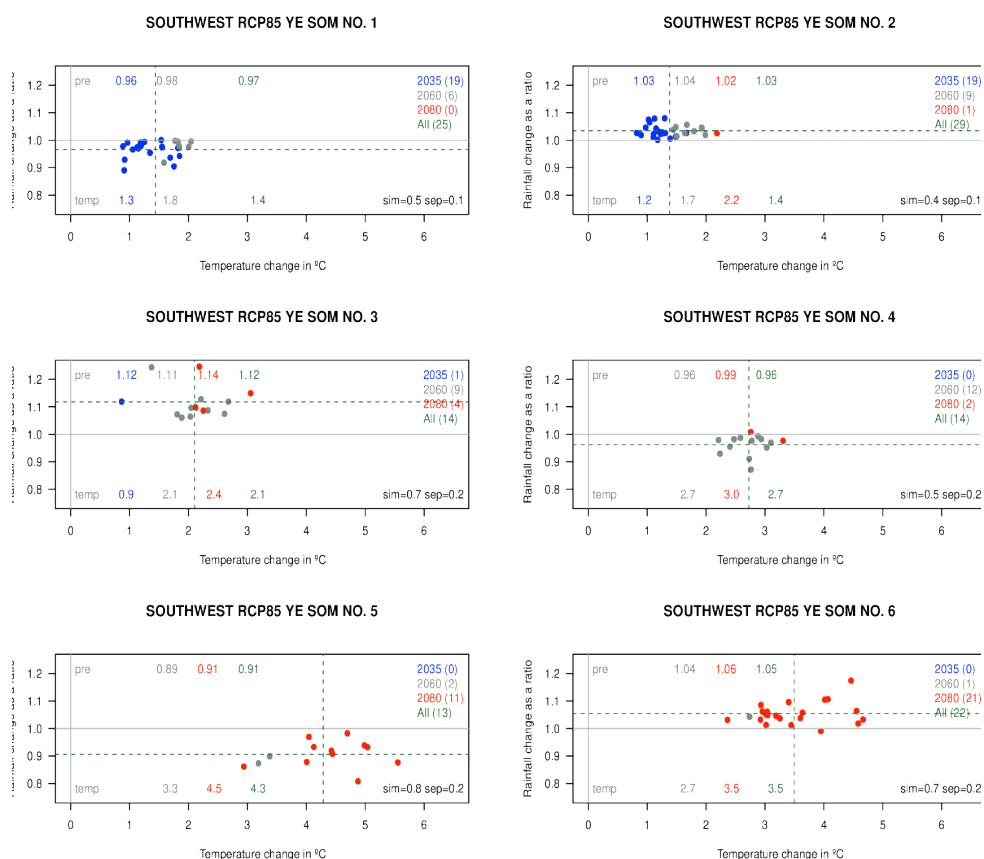


39 projections. Basically a straightforward split into 2 equi-likely scenarios, but the distributions of some of the points suggests that more scenarios might be preferable. UE from som2 and som4; LE from som1 and som3.

Table A3-10 | RCP8.5 Annual Southwest using 4 SOMs – not used in defining the scenarios

Likelihood	SOM	2035	2060	2080
55%	2□4	1.0/1.05	2.0/1.05	3.0/1.05
45%	1□3	1.5/0.95	2.5/0.95	4.5/0.95
UE		1.0/1.10	1.5/1.20	2.5/1.20
LE		1.0/0.90	3.0/0.90	5.0/0.85

RCP8.5 Southwest Zone – 6 nodes – not used in defining the scenarios



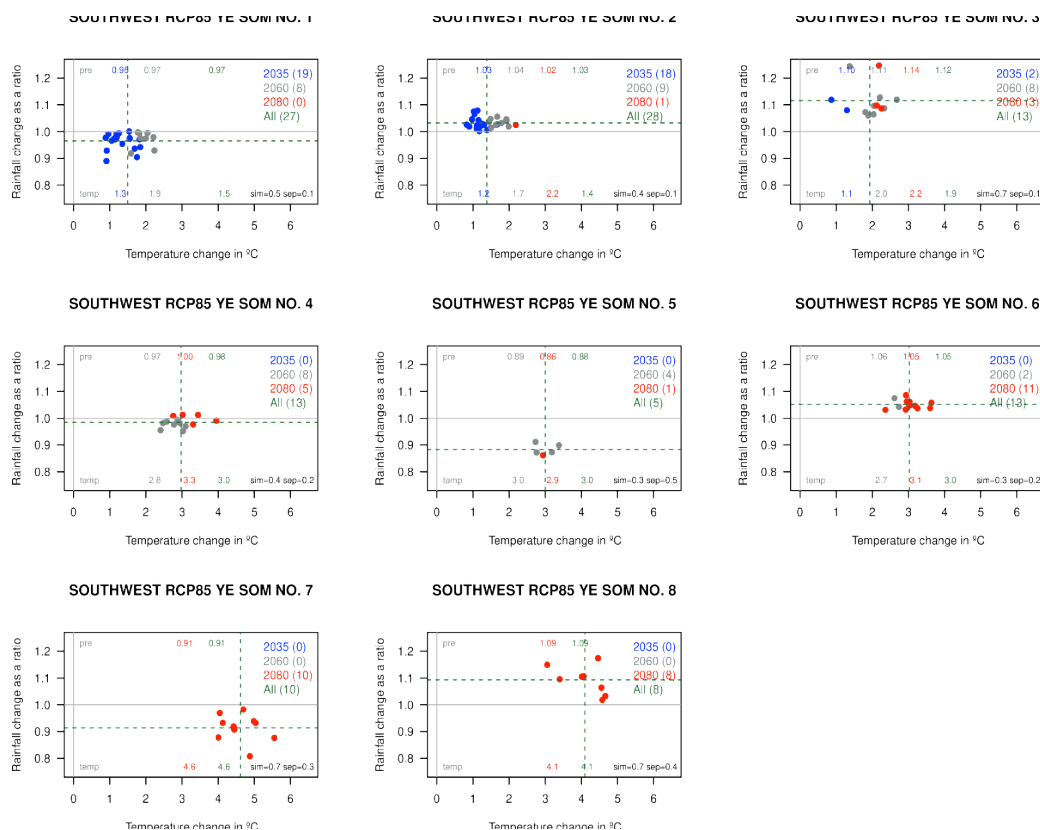
- 39 projections.
- Mapping of 4 nodes $\square$ 6 nodes
 - som1 $\square$ som1 + som4 [a few p3 added]
 - som2 $\square$ som2 + som3 [almost exact]
 - som3 $\square$ som4 + som5 [close split]
 - som4 $\square$ som6 + som3 [almost exact]

Somewhat different set of scenarios compared to 4 nodes – probably the better choice but results using 8 nodes preferred.

Table A3-11 | RCP8.5 Annual Southwest using 6 SOMs – not used in defining the scenarios

Likelihood	SOM	2035	2060	2080
50%	1 $\square$ 4 $\square$ 5	1.5/0.95	2.5/0.95	4.5/0.90
30%	2 $\square$ 6	1.0/1.05	1.5/1.05	3.5/1.05
20%	2 $\square$ 3	1.0/1.05	2.0/1.10	2.5/1.15
UE		1.0/1.10	1.5/1.20	2.5/1.20
LE		1.0/0.90	3.0/0.90	5.0/0.85

RCP8.5 Southwest Zone – 8 nodes – used in defining the scenarios

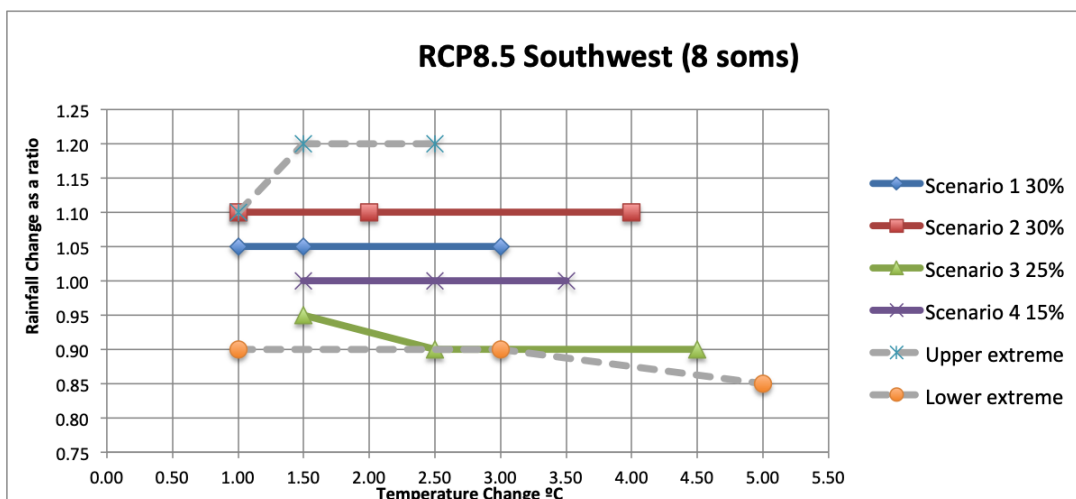


- 39 projections.
- Mapping of 6 nodes $\square$ 8 nodes
 - som1 $\square$ som1 [almost exact]
 - som2 $\square$ som2 [almost exact]
 - som3 $\square$ som3 [almost exact]
 - som4 $\square$ som4 + som5 [almost exact for p2]
 - som5 $\square$ som7 [almost exact for p3]
 - som6 $\square$ som6 + som8 $\square$

Some rejigging compared to 6 nodes and an increase to 4 scenarios – looks the more realistic choice.

Table A3-12 | RCP8.5 Annual Southwest using 8 SOMs –used in defining the scenarios

Likelihood	SOM	2035	2060	2080
30%	2 $\square$ 6	1.0/1.05	1.5/1.05	3.0/1.05
30%	3 $\square$ 8	1.0/1.10	2.0/1.10	4.0/1.10
25%	1 $\square$ 5 $\square$ 7	1.5/0.95	2.5/0.90	4.5/0.90
15%	1 $\square$ 4	1.5/1.00	2.5/1.00	3.5/1.00
UE		1.0/1.10	1.5/1.20	2.5/1.20
LE		1.0/0.90	3.0/0.90	5.0/0.85



RCP8.5 Annual North using 8 SOMs

Likelihood	SOM	2035	2060	2080
40%	4□1□5	1.5/1.05	2.5/1.05	4.0/1.00
35%	2□6□8	1.5/0.95	2.5/0.95	4.0/0.95
25%	3□7	1.5/1.10	2.0/1.10	3.5/1.15
UE		1.0/1.10	2.0/1.20	3.5/1.25
LE		1.5/0.95	3.5/0.90	5.0/0.85

RCP8.5 Annual Central using 8 SOMs

Likelihood	SOM	2035	2060	2080
40%	2□3□7	1.0/1.05	2.0/1.05	3.5/1.10
30%	1□5□8	1.5/1.00	3.0/1.00	4.5/1.00
20%	1□5	1.5/1.00	3.0/1.00	3.0/1.00
10%	4□6	1.5/0.90	3.0/0.90	5.5/0.90
UE		1.1/1.15	2.0/1.15	4.0/1.20
LE		1.0/0.90	3.5/0.90	5.0/0.85

RCP8.5 Annual Southwest using 8 SOMs

Likelihood	SOM	2035	2060	2080
30%	2□6	1.0/1.05	1.5/1.05	3.0/1.05
30%	3□8	1.0/1.10	2.0/1.10	4.0/1.10
25%	1□5□7	1.5/0.95	2.5/0.90	4.5/0.90
15%	1□4	1.5/1.00	2.5/1.00	3.5/1.00
UE		1.0/1.10	1.5/1.20	2.5/1.20
LE		1.0/0.90	3.0/0.90	5.0/0.85

RCP8.5 Annual Coastal using 8 SOMs

Likelihood	SOM	2035	2060	2080
40%	3□4	1.0/1.00	2.5/1.00	3.0/1.00
30%	1□4□6	1.5/0.95	2.5/0.95	4.5/0.90
30%	2□5□8	1.0/1.10	2.0/1.10	4.0/1.05

Have used 8 nodes in all cases

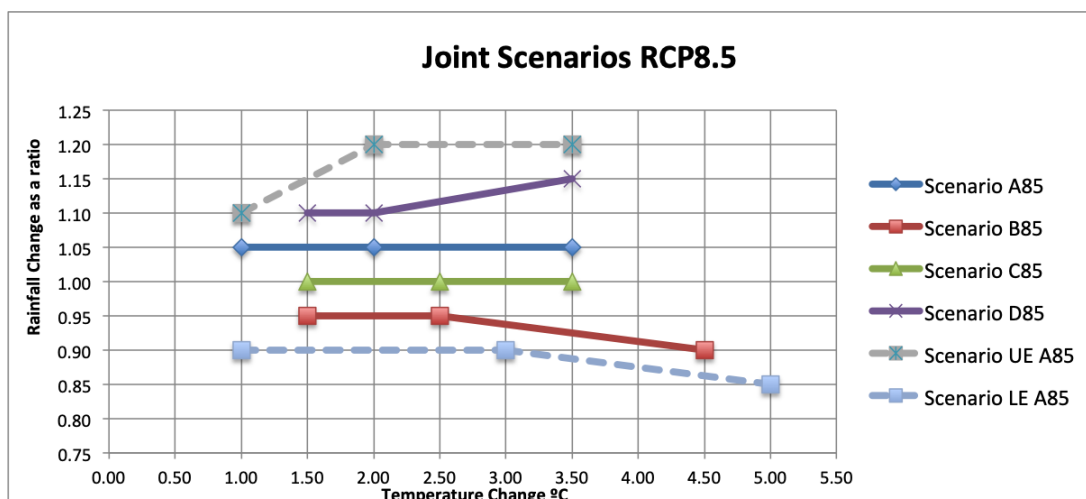
No indication of major differences in rainfall changes between zones according to main scenarios Perhaps UE wetter in north and LE drier in coastal

No differences in temperature changes between zones

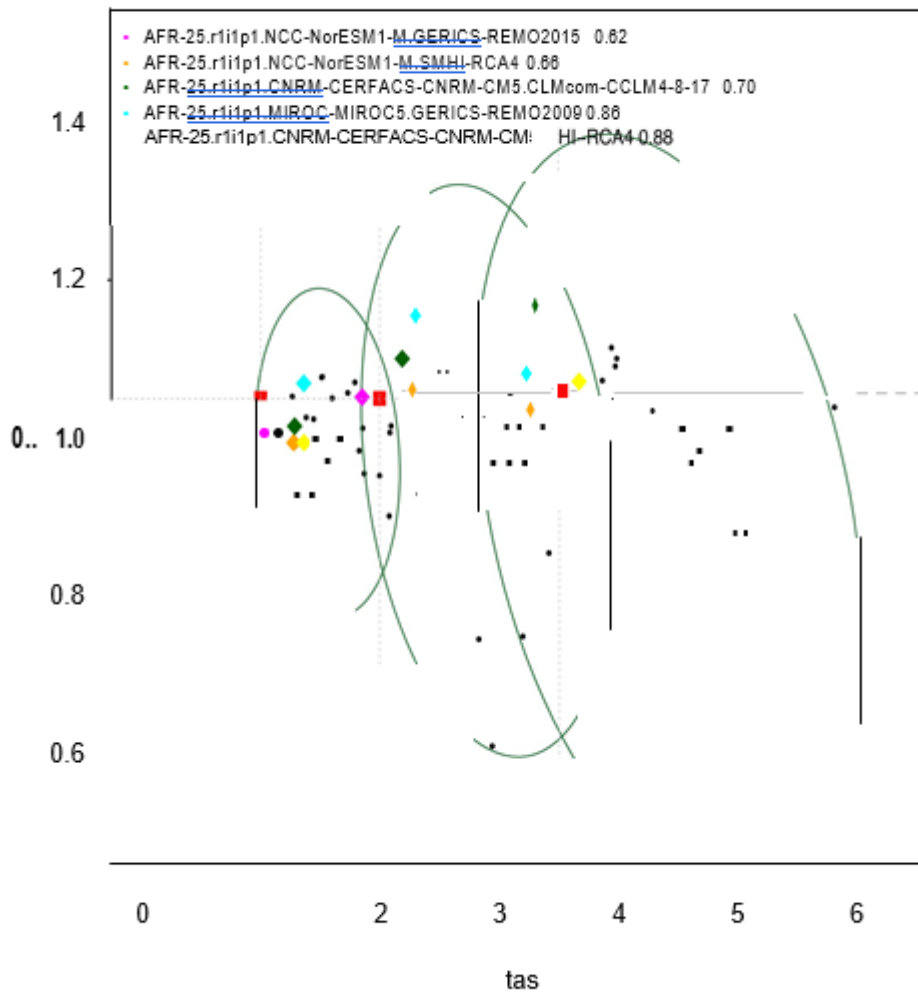
UE		0.5/1.10	2.5/1.15	3.0/1.20
LE		1.0/0.90	2.5/0.85	4.5/0.80

Table A3-13 | Results of joint pathways analysis across the four hydroclimatic zones under RCP8.5

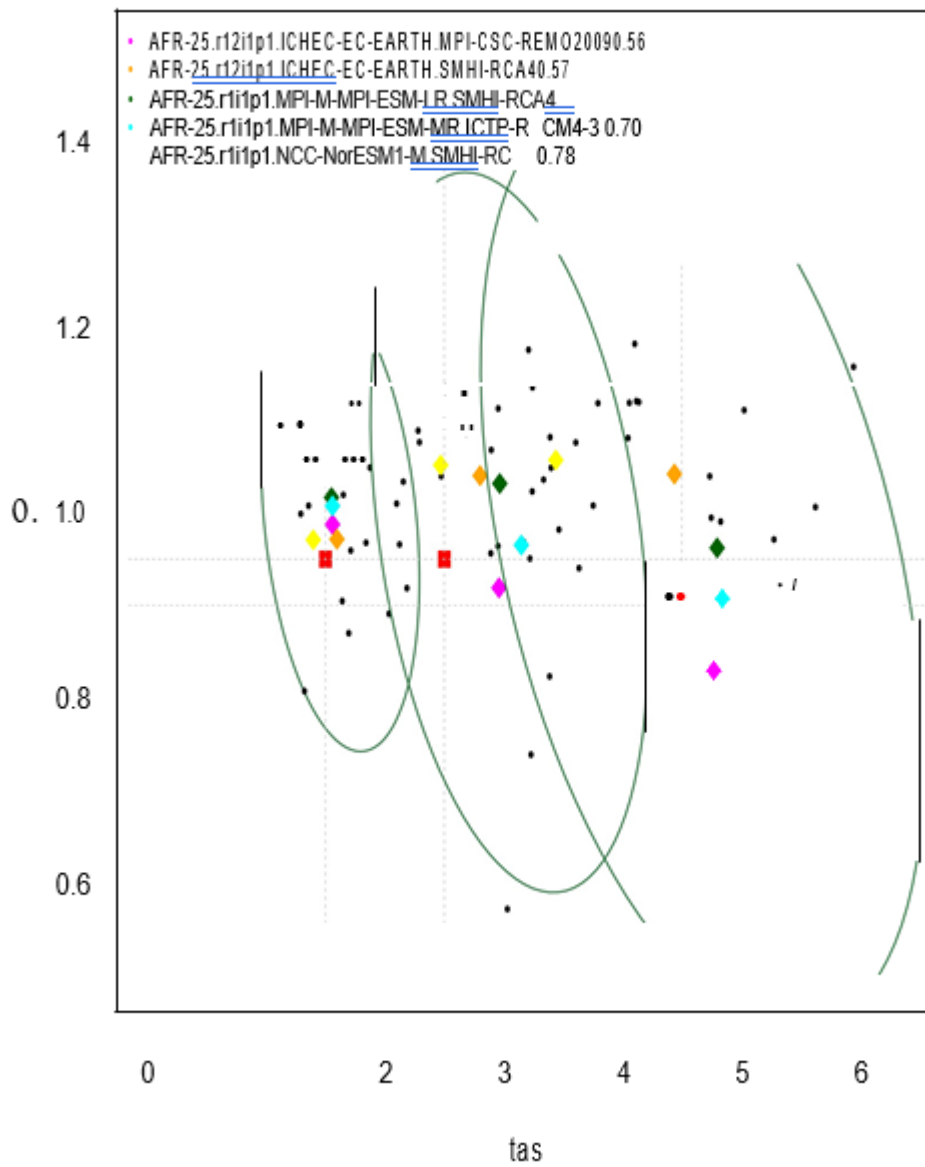
Scenario	Likelihood of Individual Scenario				Expected (deg C) and Temperature Rainfall (%) Impacts.		
Scenario	North	Central	Southwest	Coastal	2035	2060	2080
A85	1 40%	1 40%	1 30%	3 30%	1.0/1.05	2.0/1.05	3.5/1.05
B85	2 35%	4 10%	3 25%	2 30%	1.5/0.95	2.5/0.95	4.5/0.90
C85	X	2+3 50%	4 15%	1 40%	1.5/1.00	2.5/1.00	3.5/1.00
D85	3 25%	X	2 30%	X	1.5/1.10	2.0/1.10	3.5/1.15
UE A85	✓	✓	✓	✓	1.0/1.10	2.0/1.15	3.5/1.20
LE A85	✓	✓	✓	✓	1.0/0.90	3.5/0.90	5.0/0.85



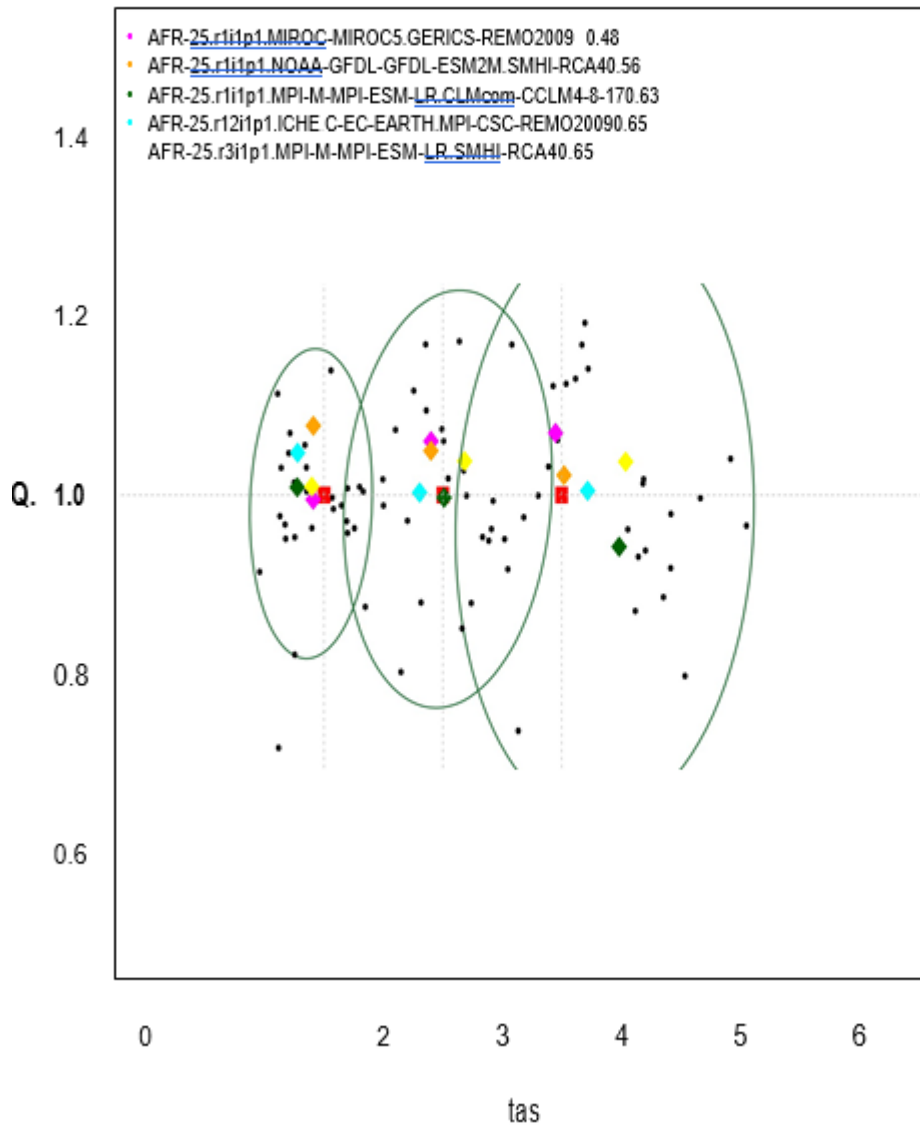
ASS central



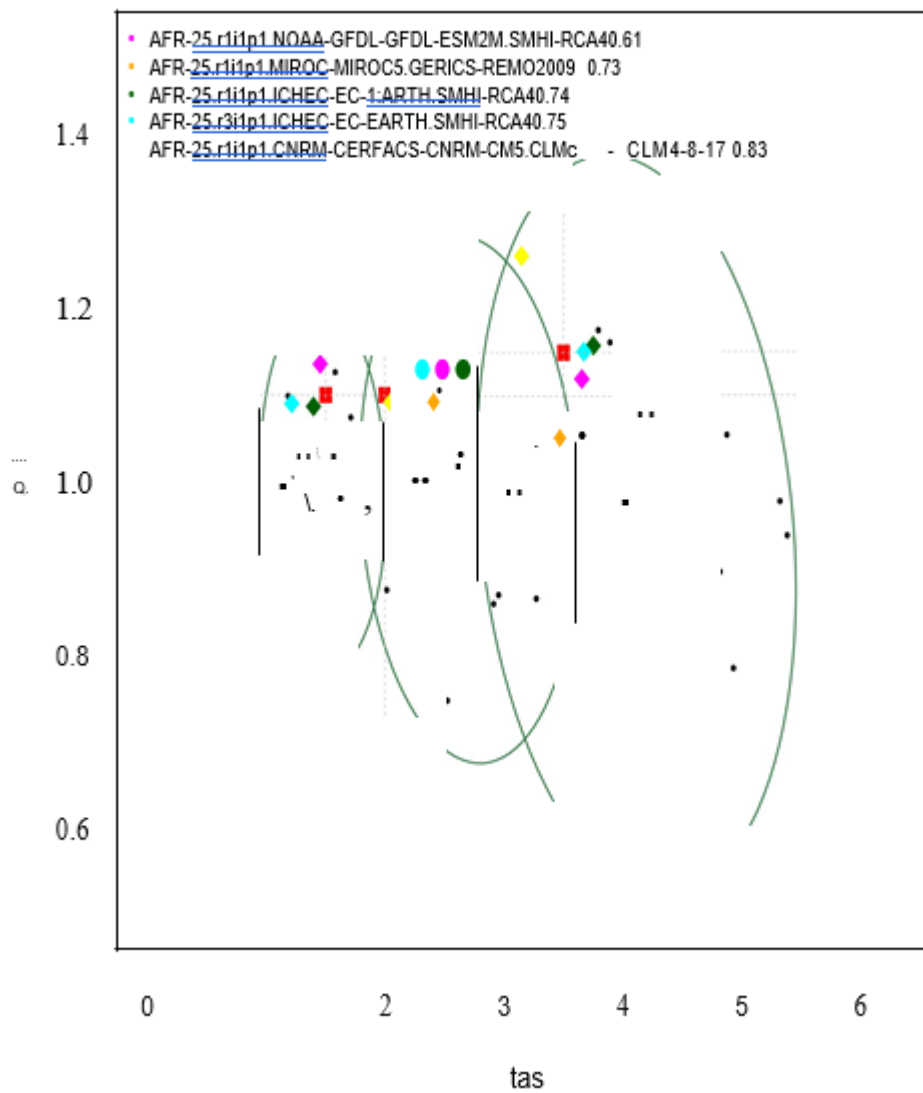
885 north



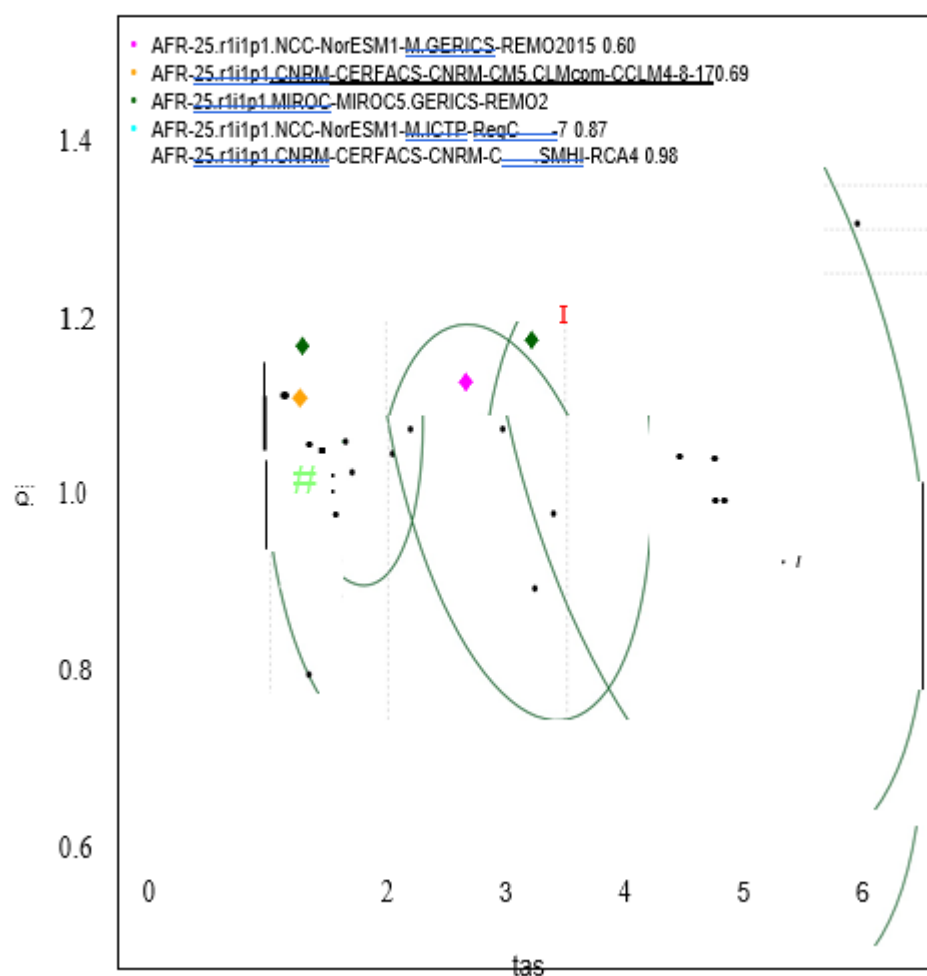
C85 coastal



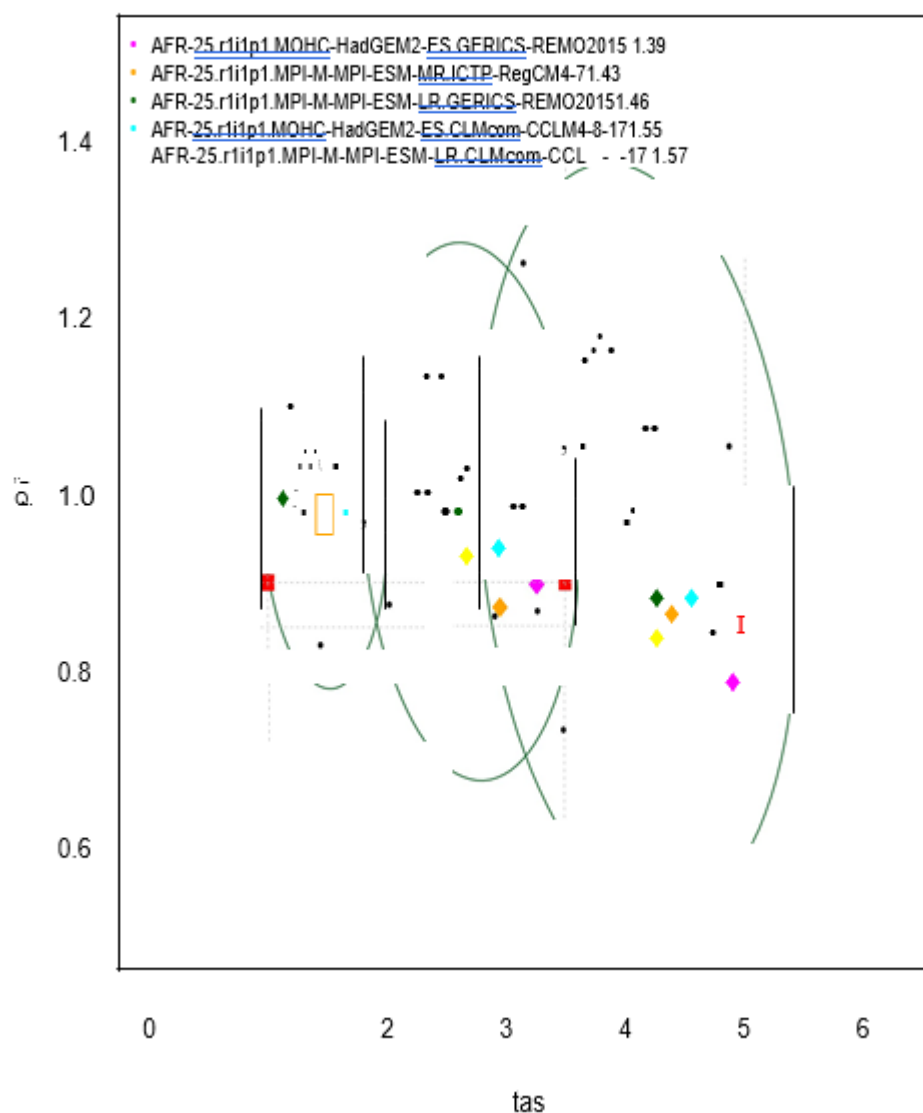
D85 swest



UEA85 north



LEA85 swest



Scenario	Focus Zone	CORDEX Domain	Host GCM	RCM	RMS
A85*	Central	Africa	NorESM Climate Modelling Consortium	Helmholtz Centre for Polar and Marine Research (GERICS)	0.62
B85	North	Africa	European GCM collaboration (ICHEC)	Max Planck Institute in Germany (MPI)	0.56
C85	Coastal	Africa	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (MIROC)	Helmholtz Centre for Polar and Marine Research (GERICS)	0.48

D85	Southwest	Africa	National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory (GFDL)	Swedish Meteorological and Hydrological Institute (SMHI)	0.61
UE A85*	North	Africa	NorESM Climate Modelling Consortium	Helmholtz Centre for Polar and Marine Research (GERICS)	0.60
LE A85	Southwest	Africa	UK Met Office (MOHC)	Helmholtz Centre for Polar and Marine Research (GERICS)	1.39

Note:

* The same GCM/RCM combination provides the closest fits to both A85 and UE A85

Scenario	Likelihood	Distance	Comments
A85*	40%/40%/30%/30%	0.60	The simulation is too cool and too dry in the third period
B85	35%/10%/25%/30%	0.56	The model follows the scenario temperature changes well but is too dry in the third period
C85	-/50%/15%/40%	0.48	Reasonable for temperatures but too wet in the second and third periods
D85	25%/-/30%/-	0.61	The main issue is the simulation being too warm in the second period
UE A85*	Applies to all zones	0.60	Likely the best fit to the scenario available but generally too cool and too dry in comparison; scenario lies close to the edges of the ellipses throughout
LE A45	Applies to all zones	1.39	Despite the high rms distance it is a reasonable simulation for the later two periods, but too warm in the first

Appendix B | Plume plots at MMDA Level

Appendix B1: RCP 2.6/SSP1 2.6

Figure B1-1a | Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp26/ssp126 scenarios. All lines represent 20-year running averages calculated on annual values.

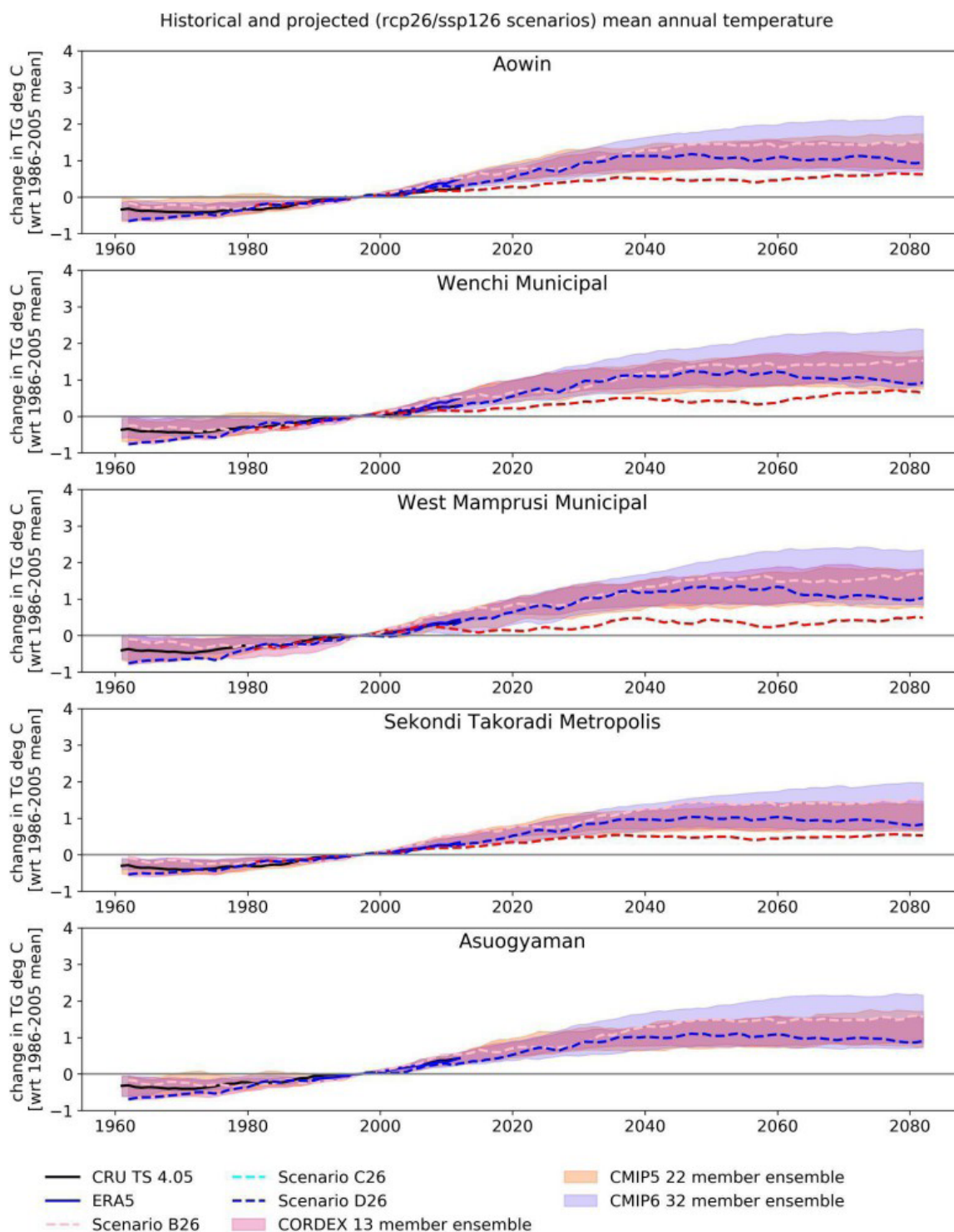


Figure B1-1b | Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp26/ssp126 scenarios. All lines represent 20-year running averages calculated on annual values.

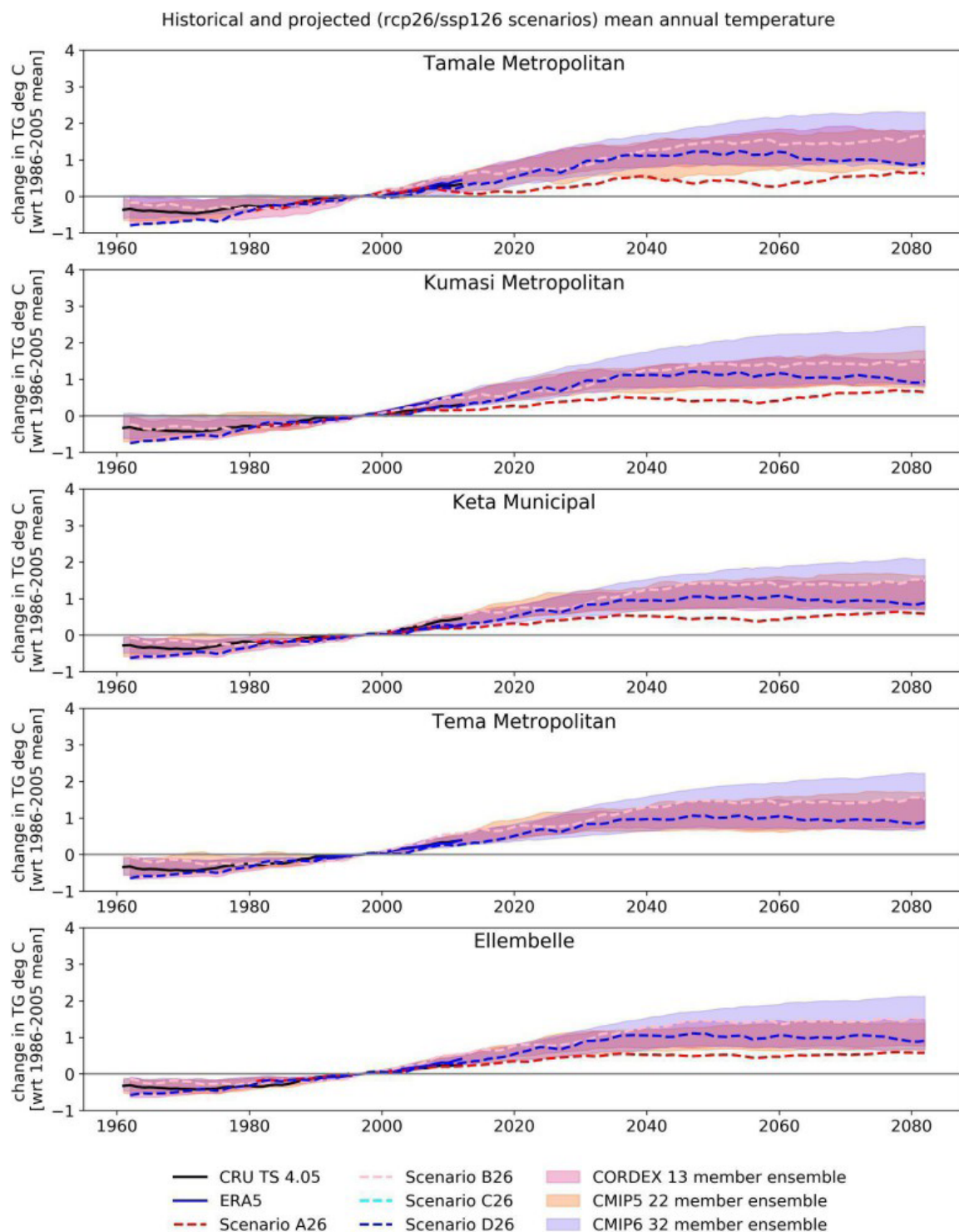


Figure B1-2a | Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp26/ssp126 scenarios. All lines represent 20-year running averages calculated on annual values.

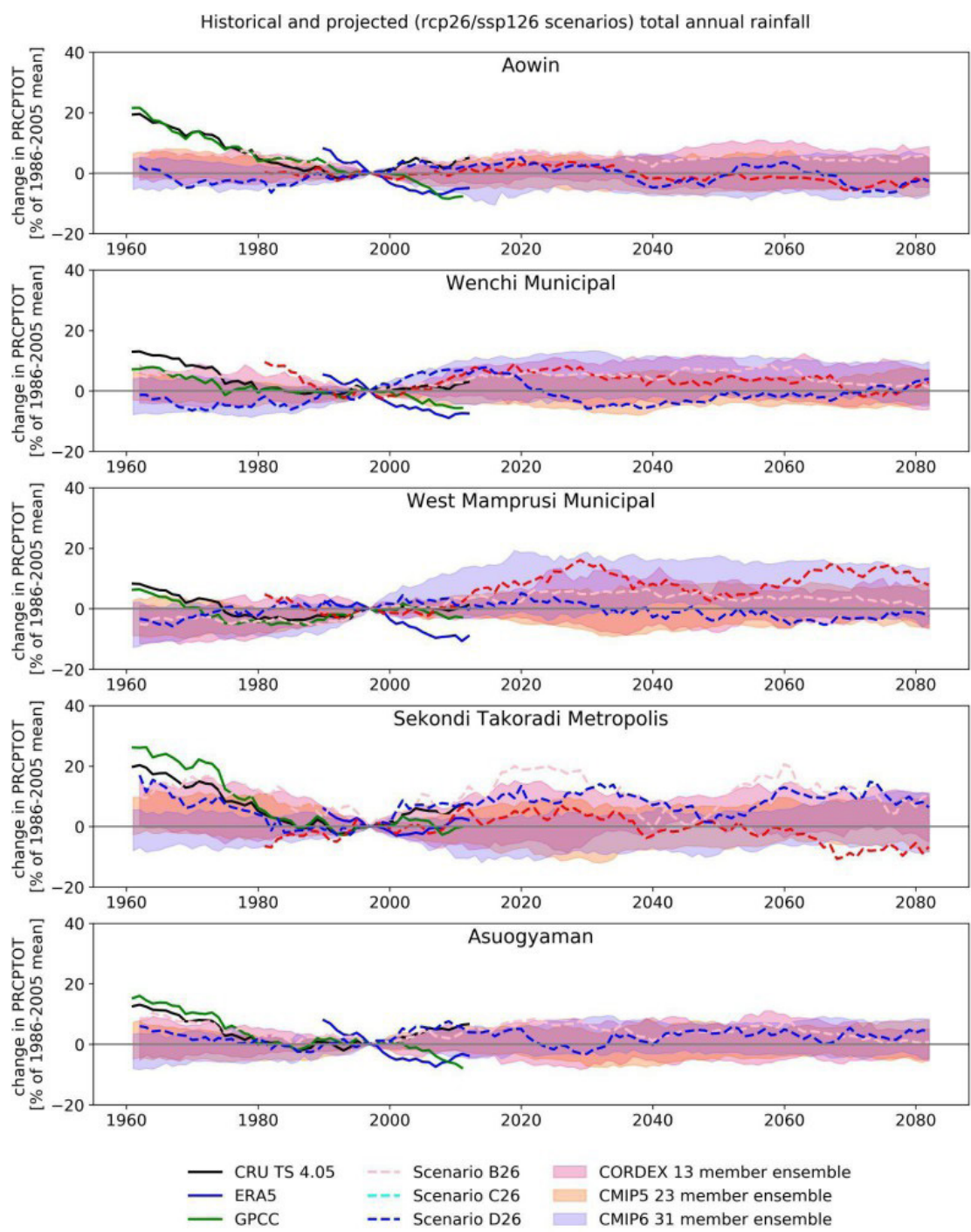
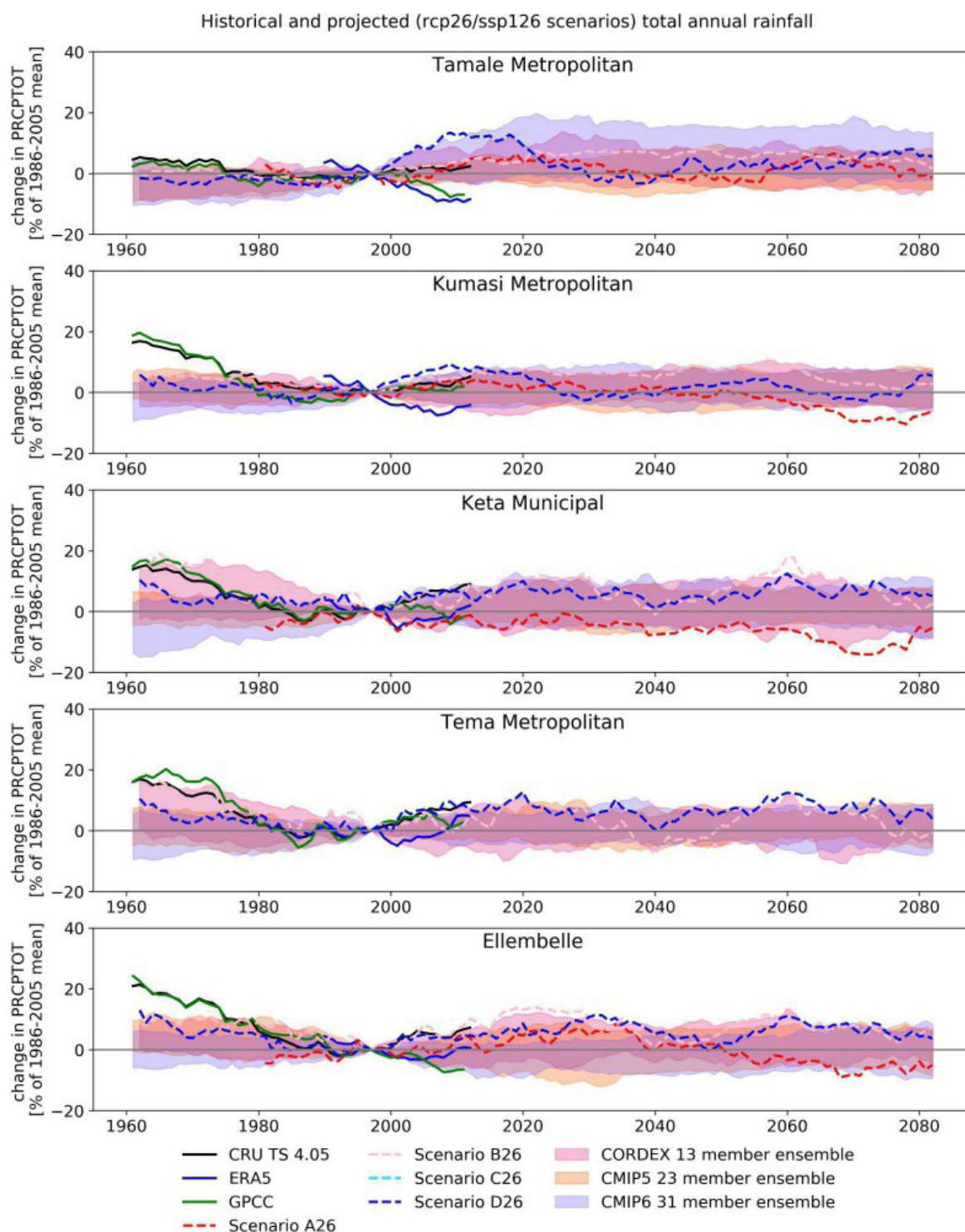


Figure B1-2b | Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAss in simulations of historical and future climate in three ensembles under rcp26/ssp126 scenarios. All lines represent 20-year running averages calculated on annual values.



Appendix B2: RCP 4.5/SSP2 4.5

Figure B2-2a | Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp45/ssp245 scenarios. All lines represent 20-year running averages calculated on annual values.

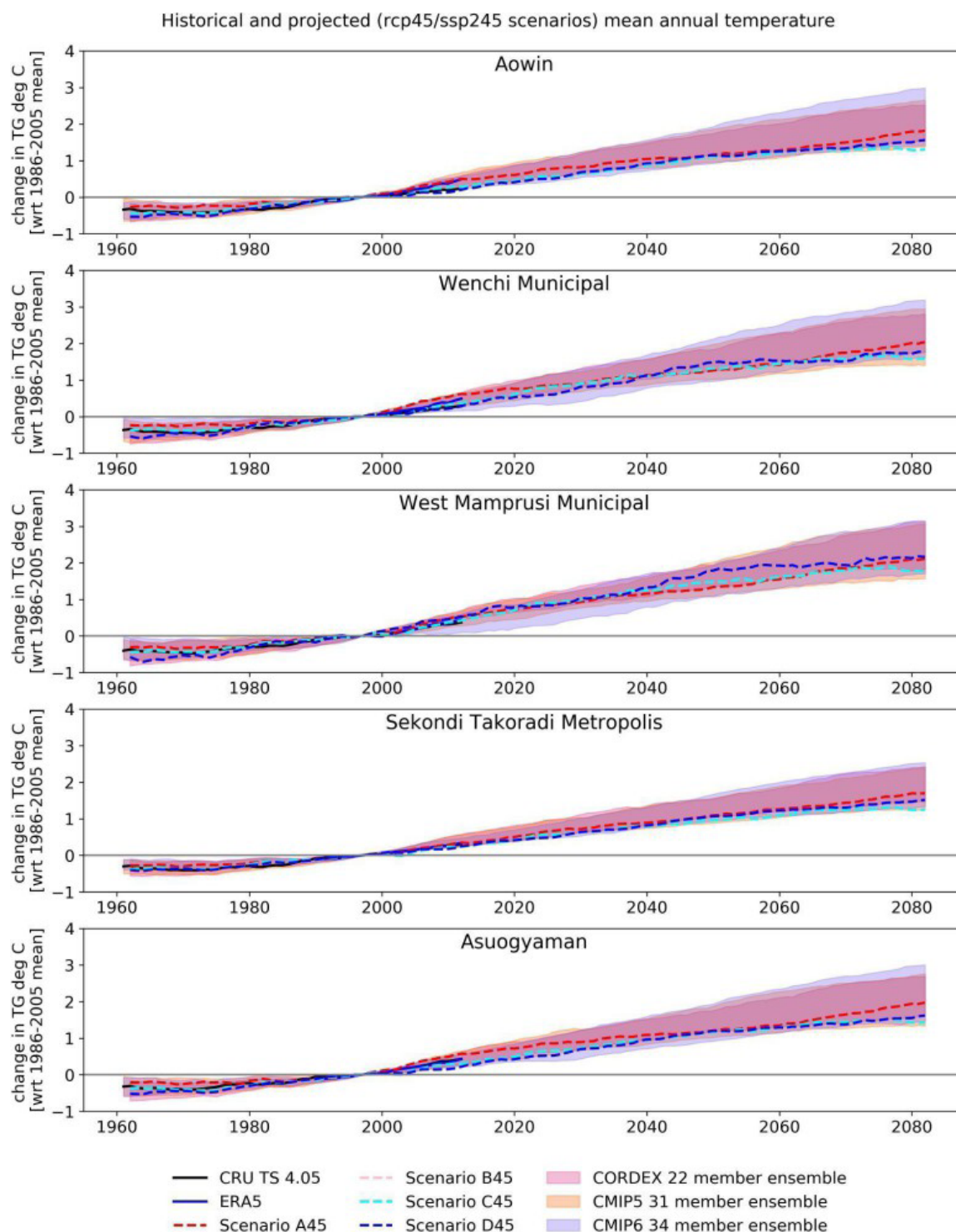


Figure B2-1b | Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp45/ssp245 scenarios. All lines represent 20-year running averages calculated on annual values.

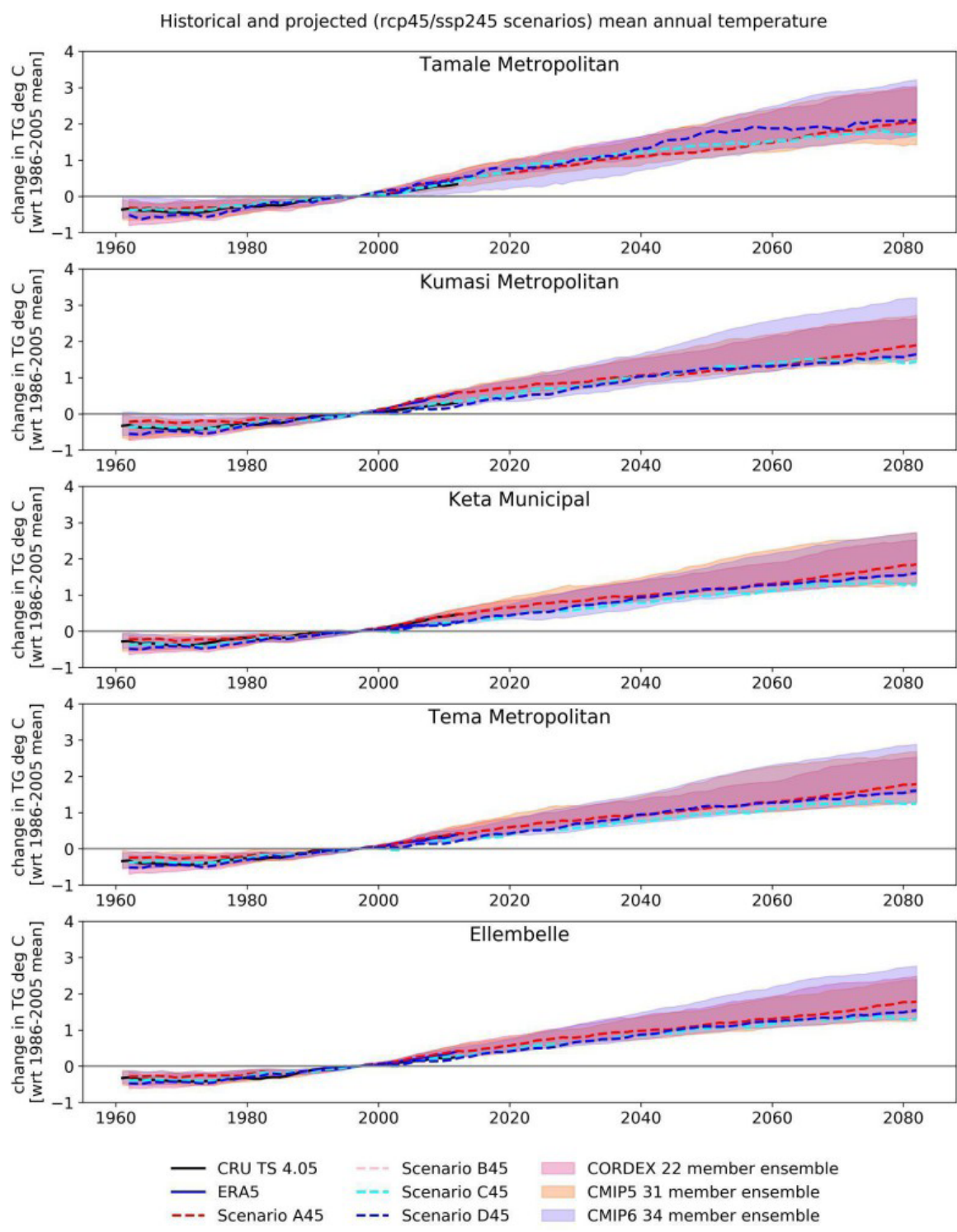


Figure B2-2a | Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAss in simulations of historical and future climate in three ensembles under rcp45/ssp245 scenarios. All lines represent 20-year running averages calculated on annual values.

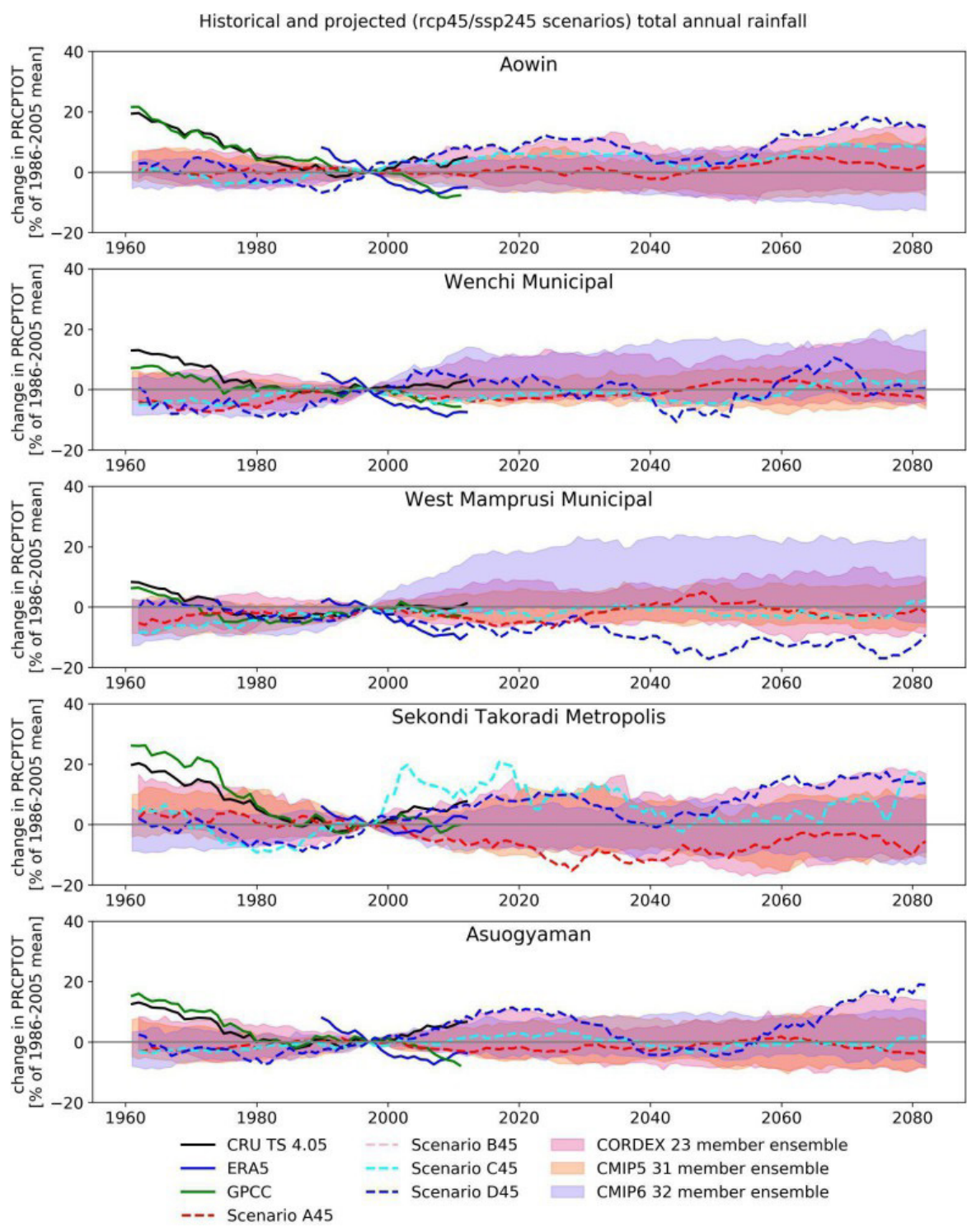
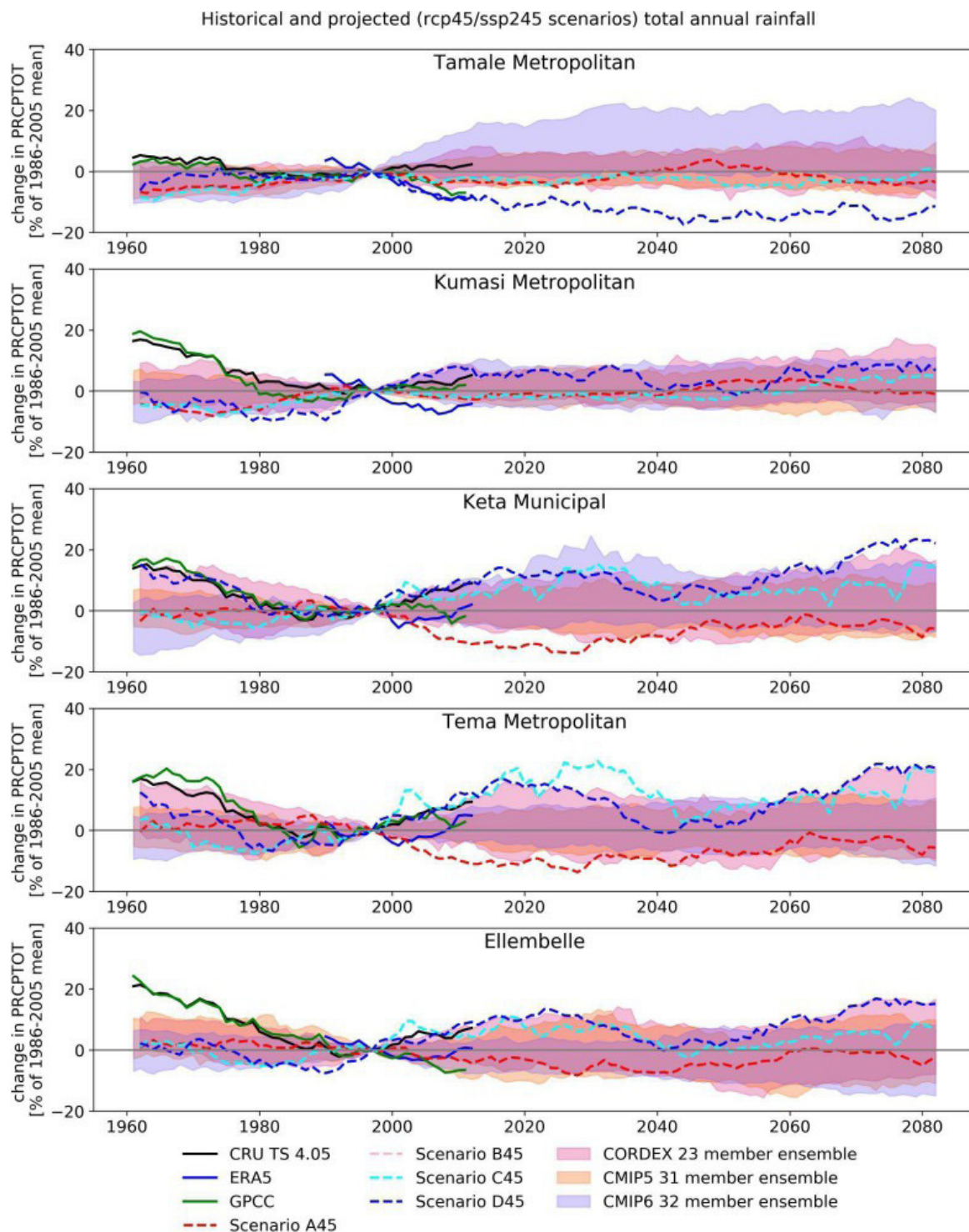


Figure B2-2b | Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAss in simulations of historical and future climate in three ensembles under rcp45/ssp245 scenarios. All lines represent 20-year running averages calculated on annual values.



Appendix B3: RCP 8.5/SSP5 8.5

Figure B3-1a | Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp85/ssp585 scenarios. All lines represent 20-year running averages calculated on annual values.

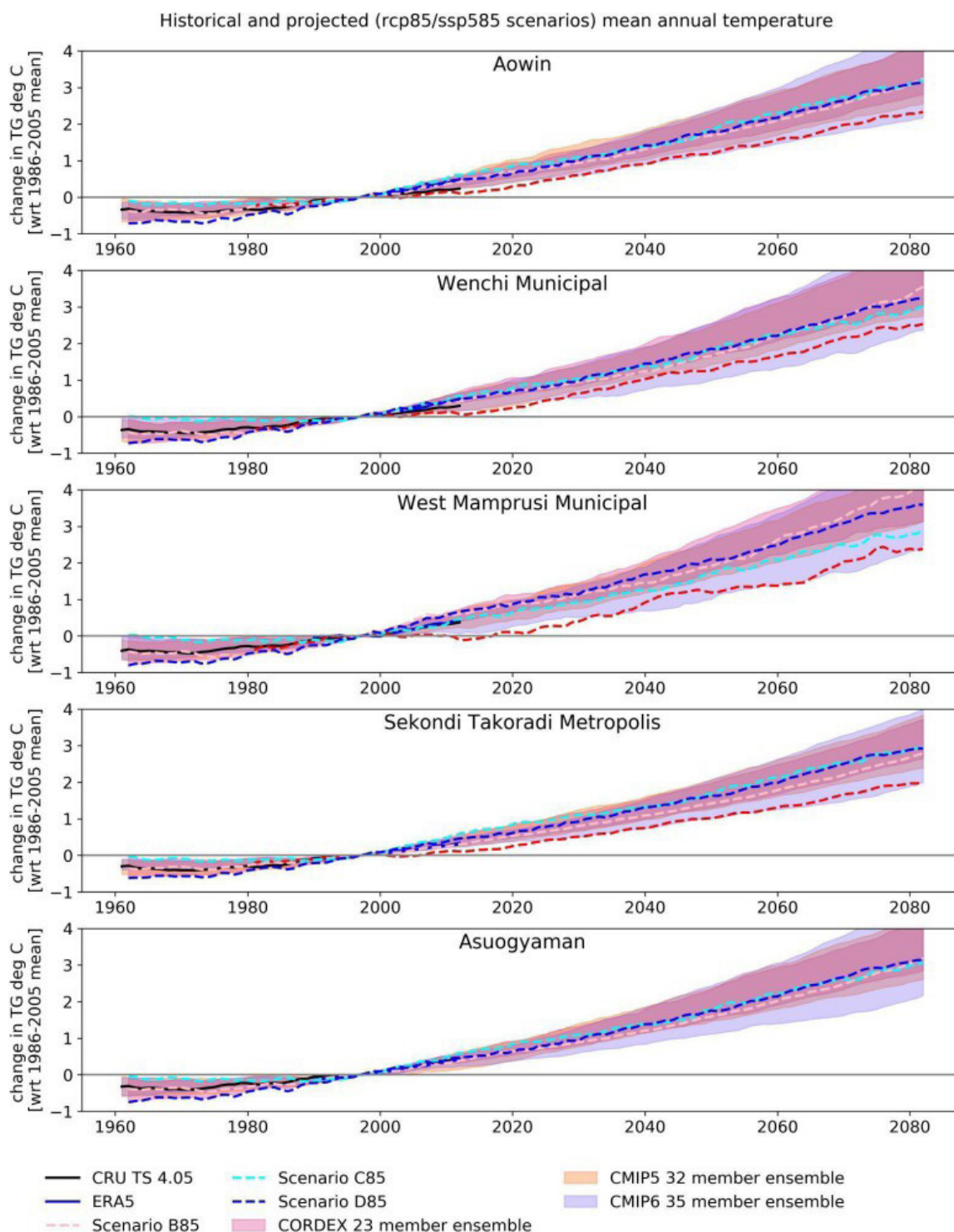


Figure B3-1b | Plume plots illustrating the evolution of mean annual temperature in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp85/ssp585 scenarios. All lines represent 20-year running averages calculated on annual values.

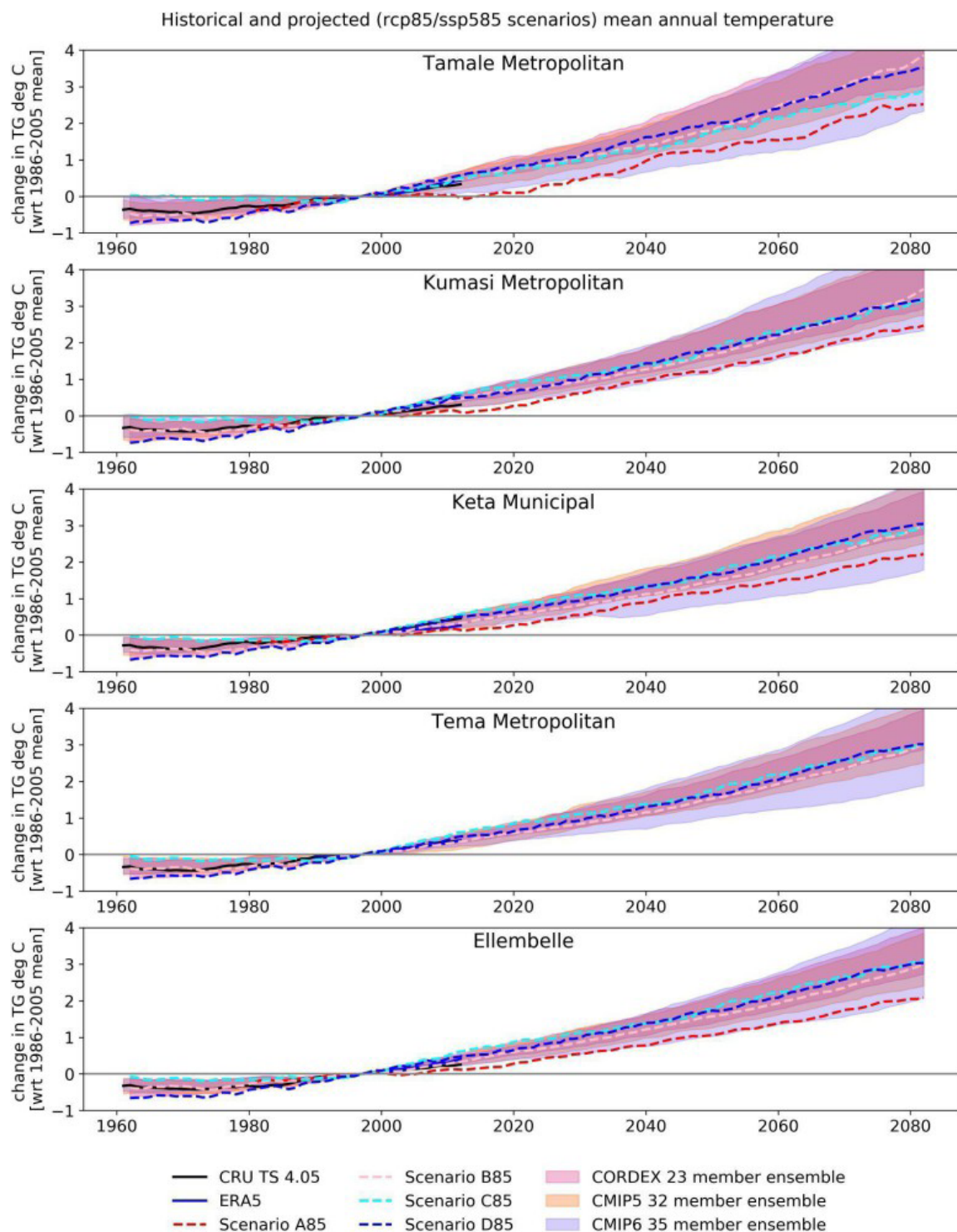


Figure B3-2a | Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp85/ssp585 scenarios. All lines represent 20-year running averages calculated on annual values.

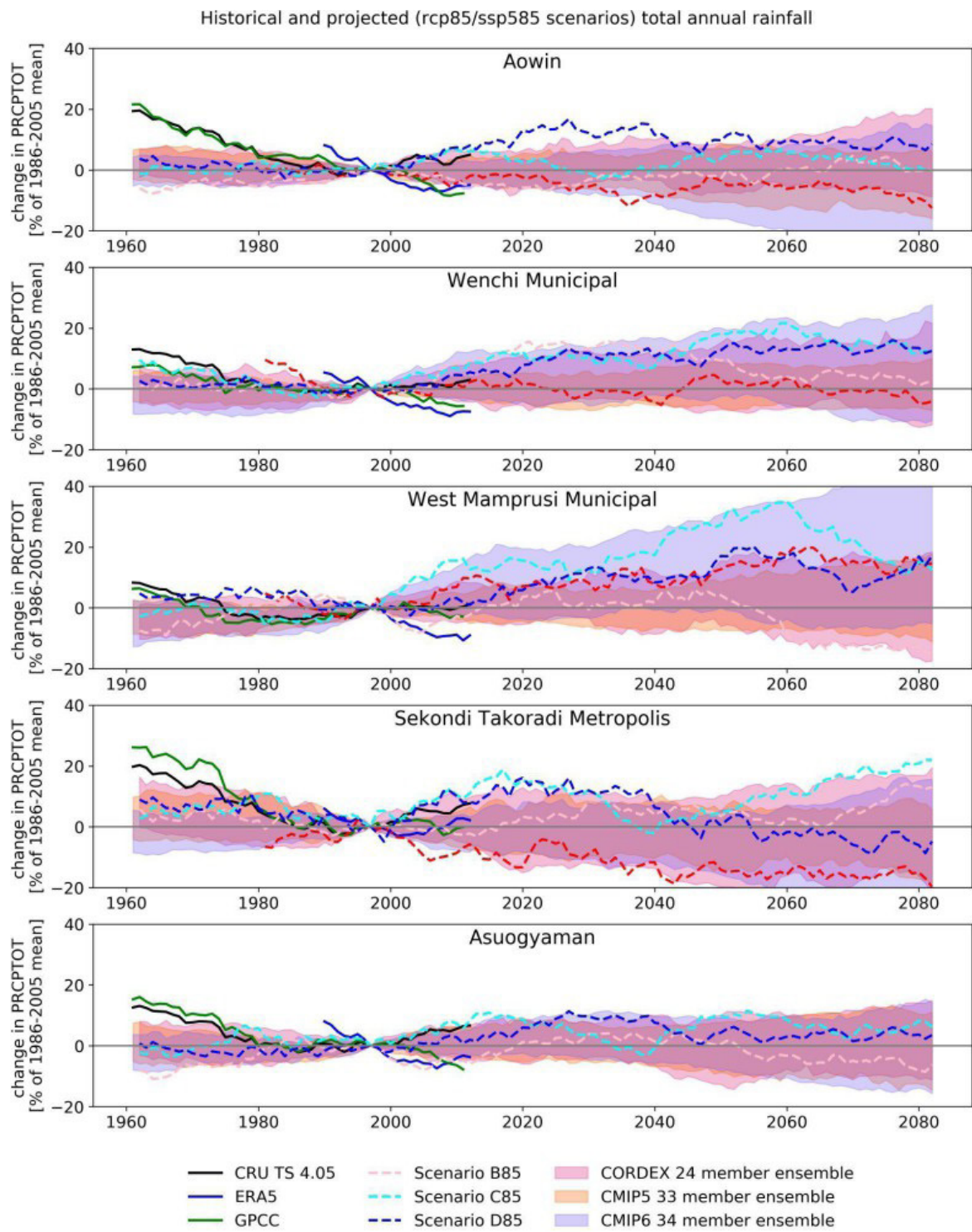


Figure B3-2b | Plume plots illustrating the evolution of total annual rainfall in Ghana MMDAs in simulations of historical and future climate in three ensembles under rcp85/ssp585 scenarios. All lines represent 20-year running averages calculated on annual values.

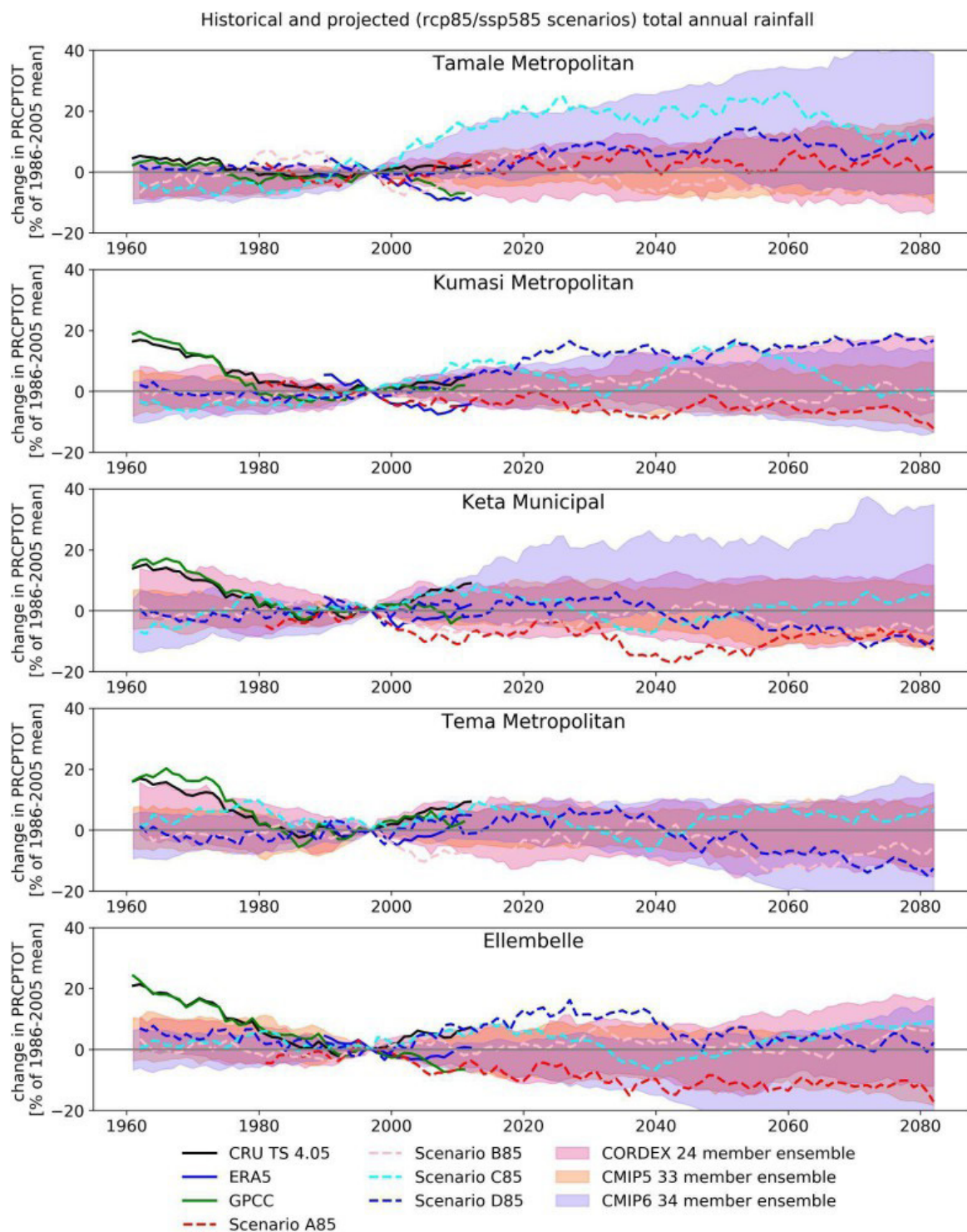


Figure B3-3 | Comparison of selected climate model scenario results for MMDAs – temperature

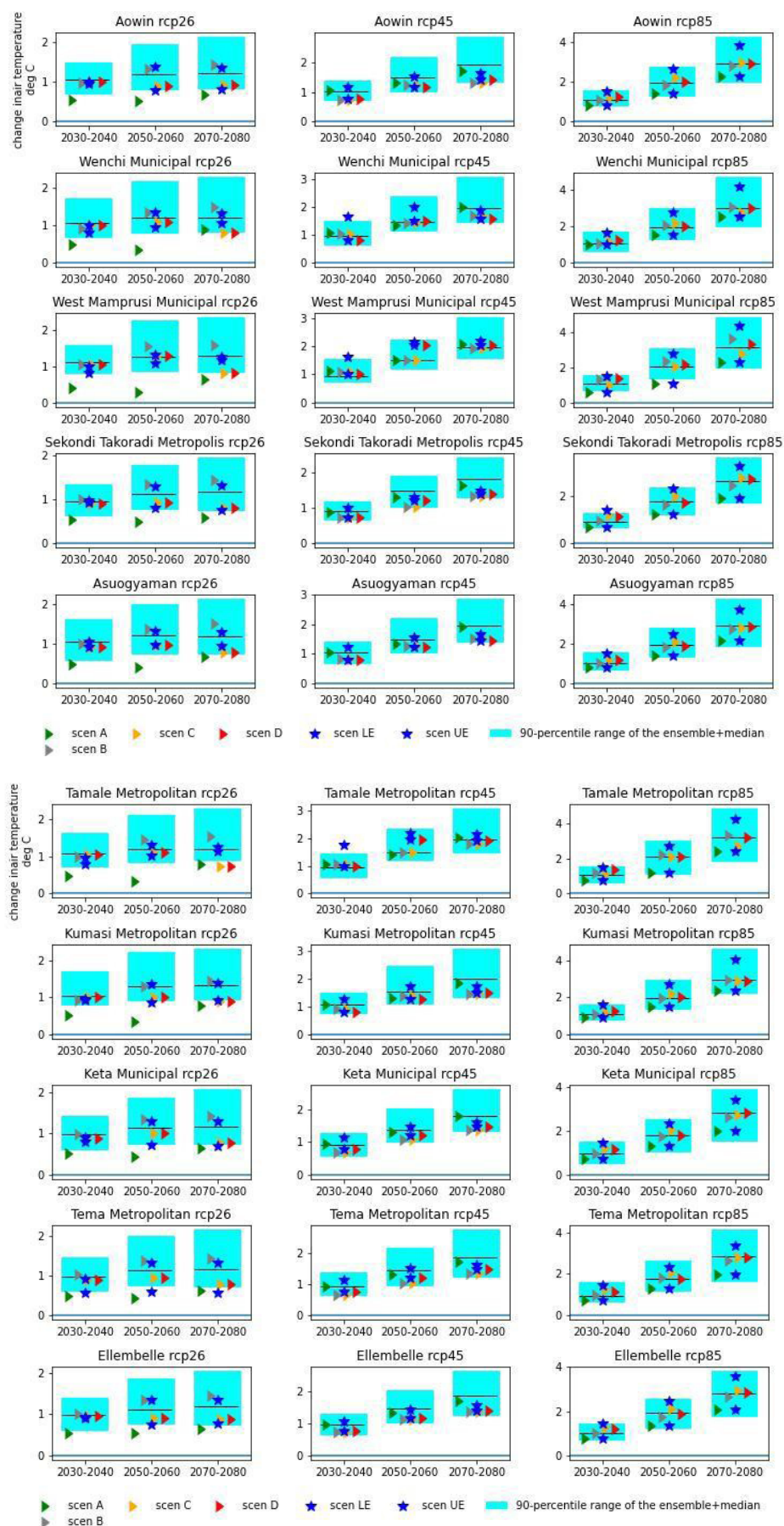


Figure B3-3 | Comparison of selected climate model scenario results for MMDAs – rainfall

