Modelling the changing water balance in West Africa

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JULES meeting, 27th June 2017

The BRAVE2 Project

"BRAVE: Building understanding of climate variability into planning of groundwater supplies from low storage aquifers in Africa – second phase"

Funded under the NERC/DFID/ESRG Unlocking the Potential of Groundwater for the Poor (UPGro) Program

Investigators from the University of Reading, the British Geological Survey, and a large number of water resources research, governance, and (international) aid agency partners in Ghana and Burkina Faso

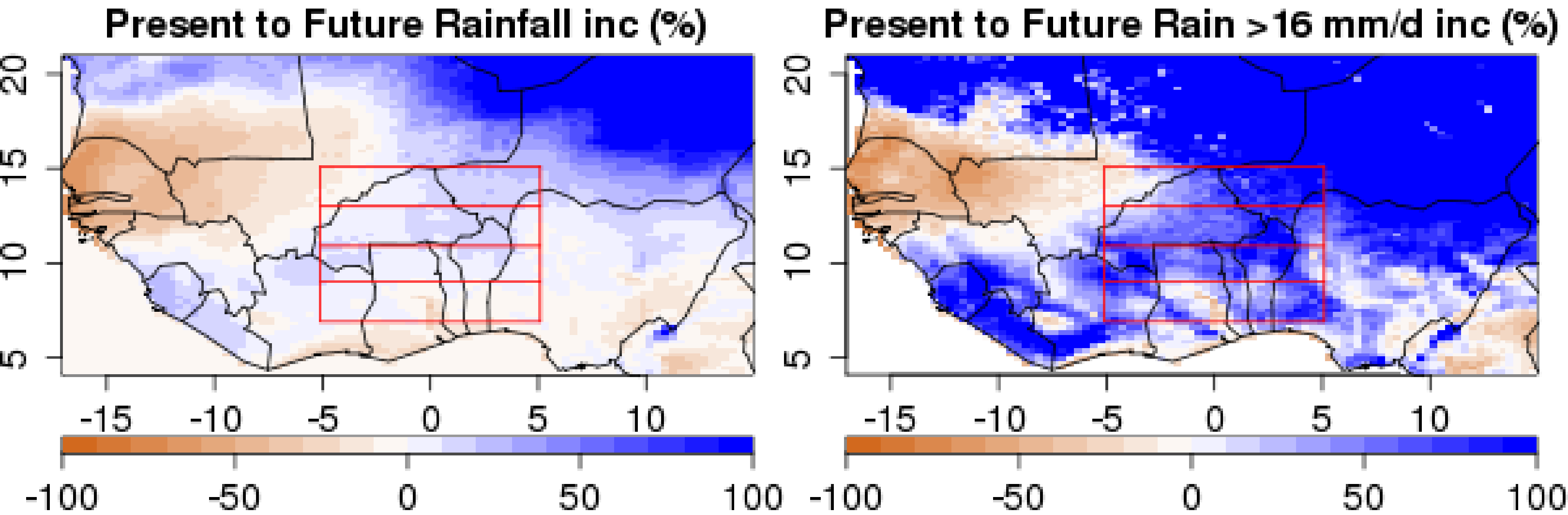
Emphasis is on water balance extremes and how these may change in the future, in relation to the management of water resources

Modelling Study

Data are derived from the Met Office Unified Model (GA3) ensemble of high resolution (N512) atmosphere-only model runs (UPSCALE)

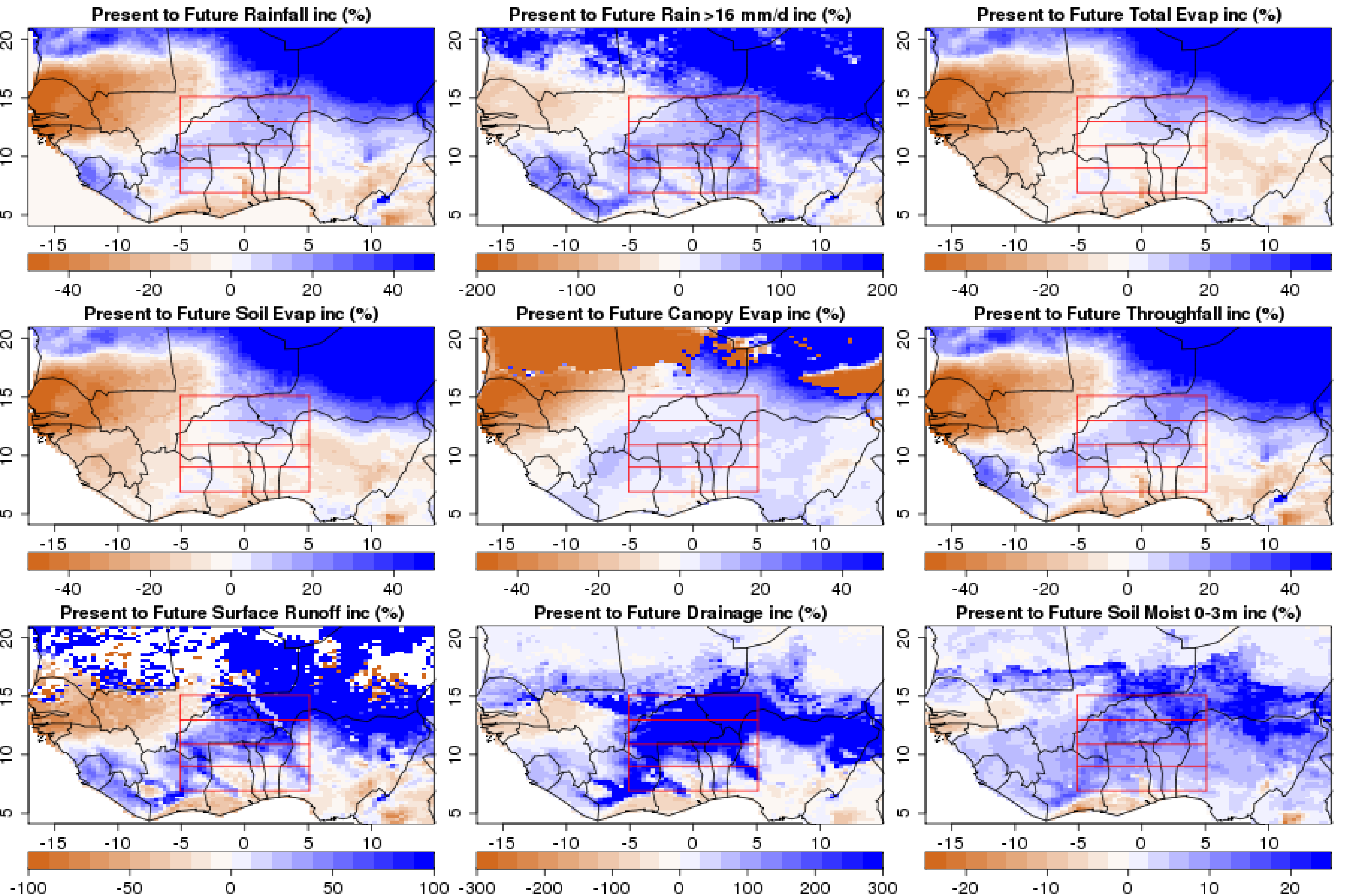
These simulations were forced with OSTIA SSTs for present climate (5 runs of 1985-2011), and with OSTIA + the SST change between 2000-2100 (RCP8.5) for future climate (3 runs also of 27 years)

Atmospheric variables from UPSCALE are used to drive the JULES land-surface model over West Africa in distributed fashion, individual grid boxes between 17W-15E 4-21N, considering the soil and vegetation processes including the vegetation seasonal cycle, to calculate the water balance

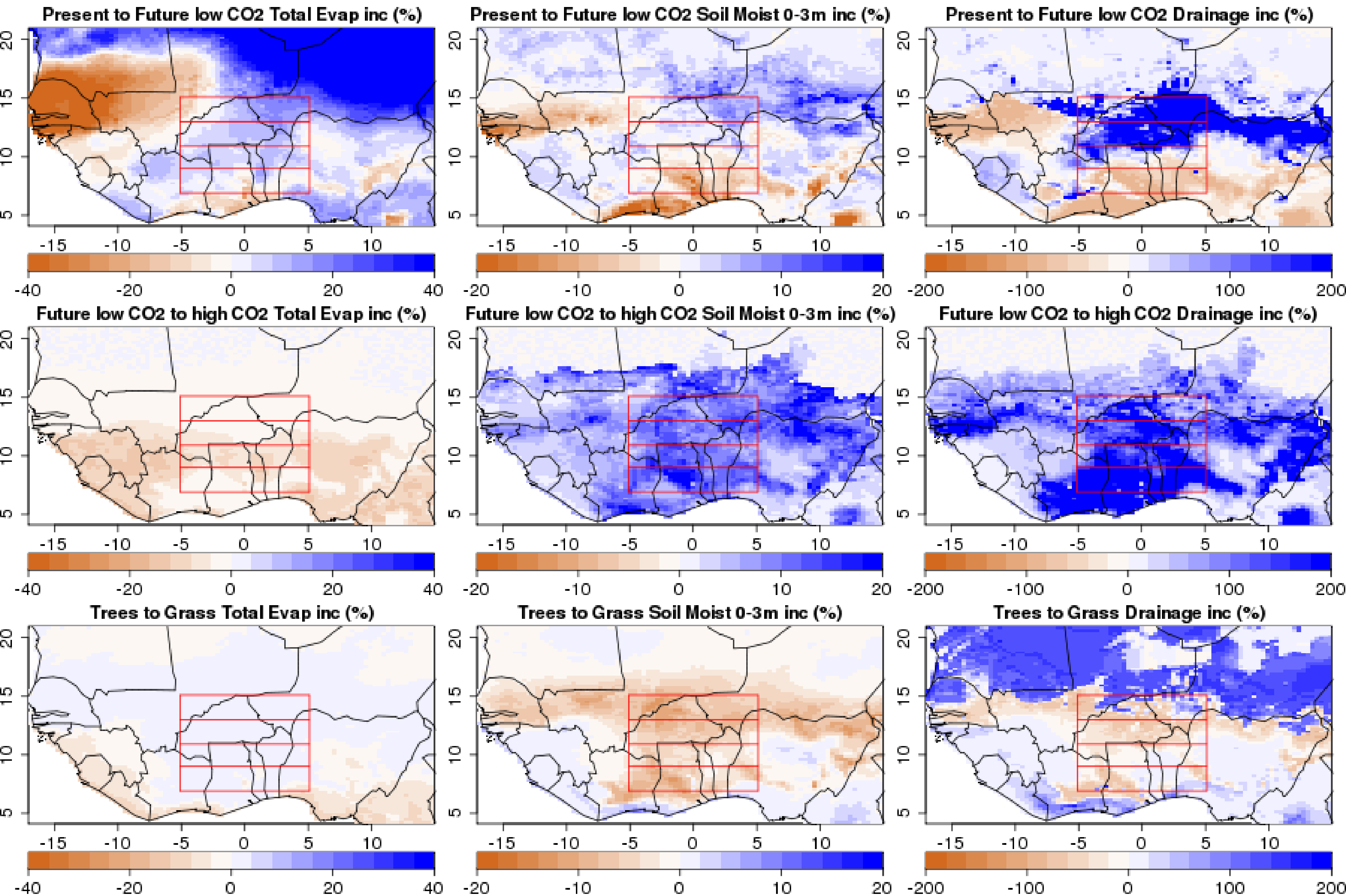


Changes are seen in the annual distribution of rainfall and also have increased daily rainfall intensity between the present and future climate

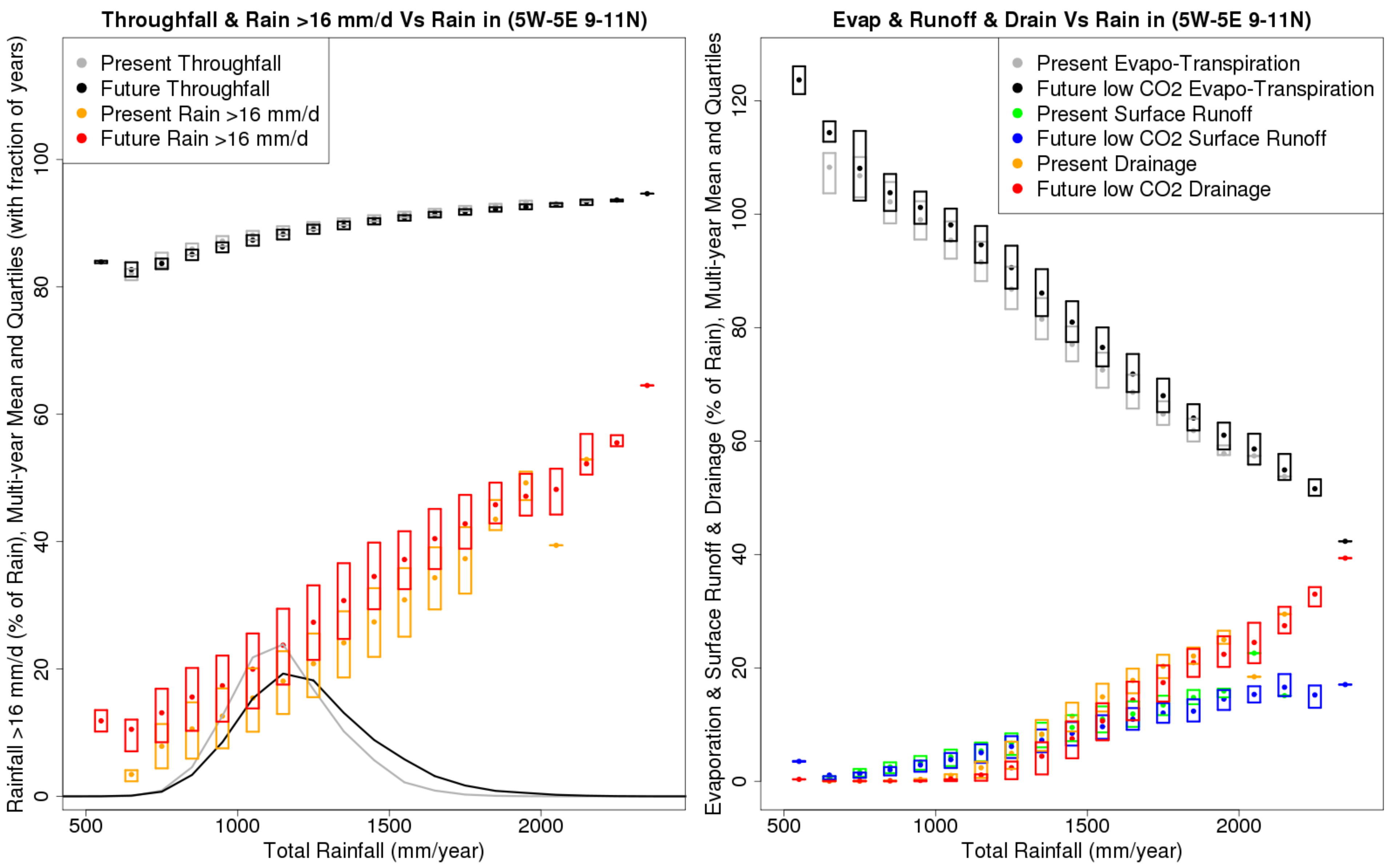
The resulting water balance will be affected by the rainfall intensity, but also by increased CO_2 concentration in the future climate, and by changes in the vegetation coverage

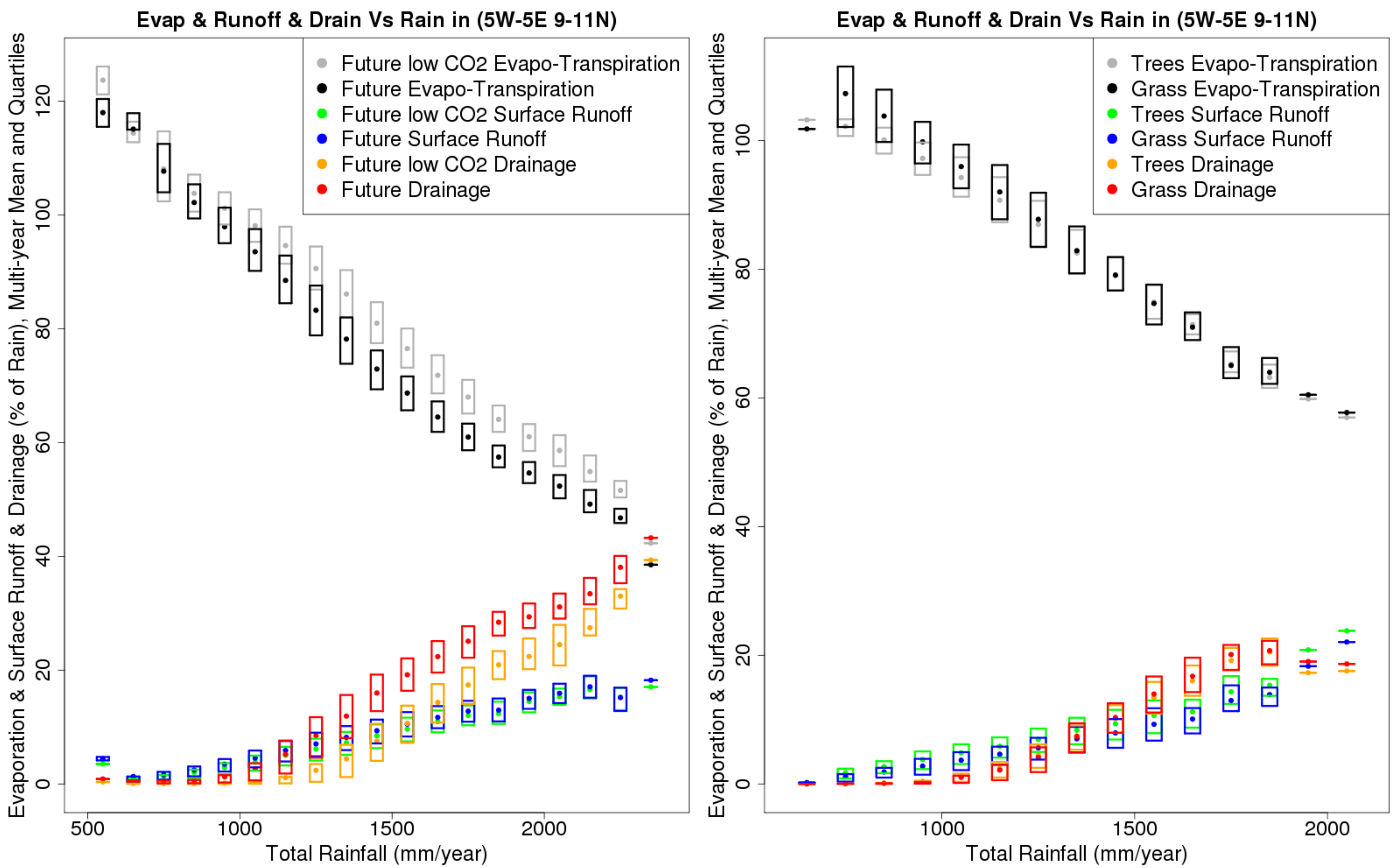


The changes due to increased rainfall and increased CO_2



Increased rainfall, increased CO_2, or change in vegetation


Throughfall & Rain >16 mm/d Vs Rain in (5W-5E 9-11N)
Present Throughfall
Future Throughfall
Present Rain >16 mm/d
Future Rain >16 mm/d
Rainfall >16 mm/d (% of Rain), Multi-year Mean and Quartiles (with fraction of years)
Total Rainfall (mm/year)
Evap & Runoff & Drain Vs Rain in (5W-5E 9-11N)
Present Evapo-Transpiration
Future low CO2 Evapo-Transpiration
Present Surface Runoff
Future low CO2 Surface Runoff
Present Drainage
Future low CO2 Drainage
Evaporation & Surface Runoff & Drainage (% of Rain), Multi-year Mean and Quartiles
Total Rainfall (mm/year)


Evap & Runoff & Drain Vs Rain in (5W-5E 9-11N)
Future low CO2 Evapo-Transpiration
Future Evapo-Transpiration
Future low CO2 Surface Runoff
Future Surface Runoff
Future low CO2 Drainage
Future Drainage
Evaporation & Surface Runoff & Drainage (% of Rain), Multi-year Mean and Quartiles
Total Rainfall (mm/year)
Evap & Runoff & Drain Vs Rain in (5W-5E 9-11N)
Trees Evapo-Transpiration
Grass Evapo-Transpiration
Trees Surface Runoff
Grass Surface Runoff
Trees Drainage
Grass Drainage
Evaporation & Surface Runoff & Drainage (% of Rain), Multi-year Mean and Quartiles
Total Rainfall (mm/year)

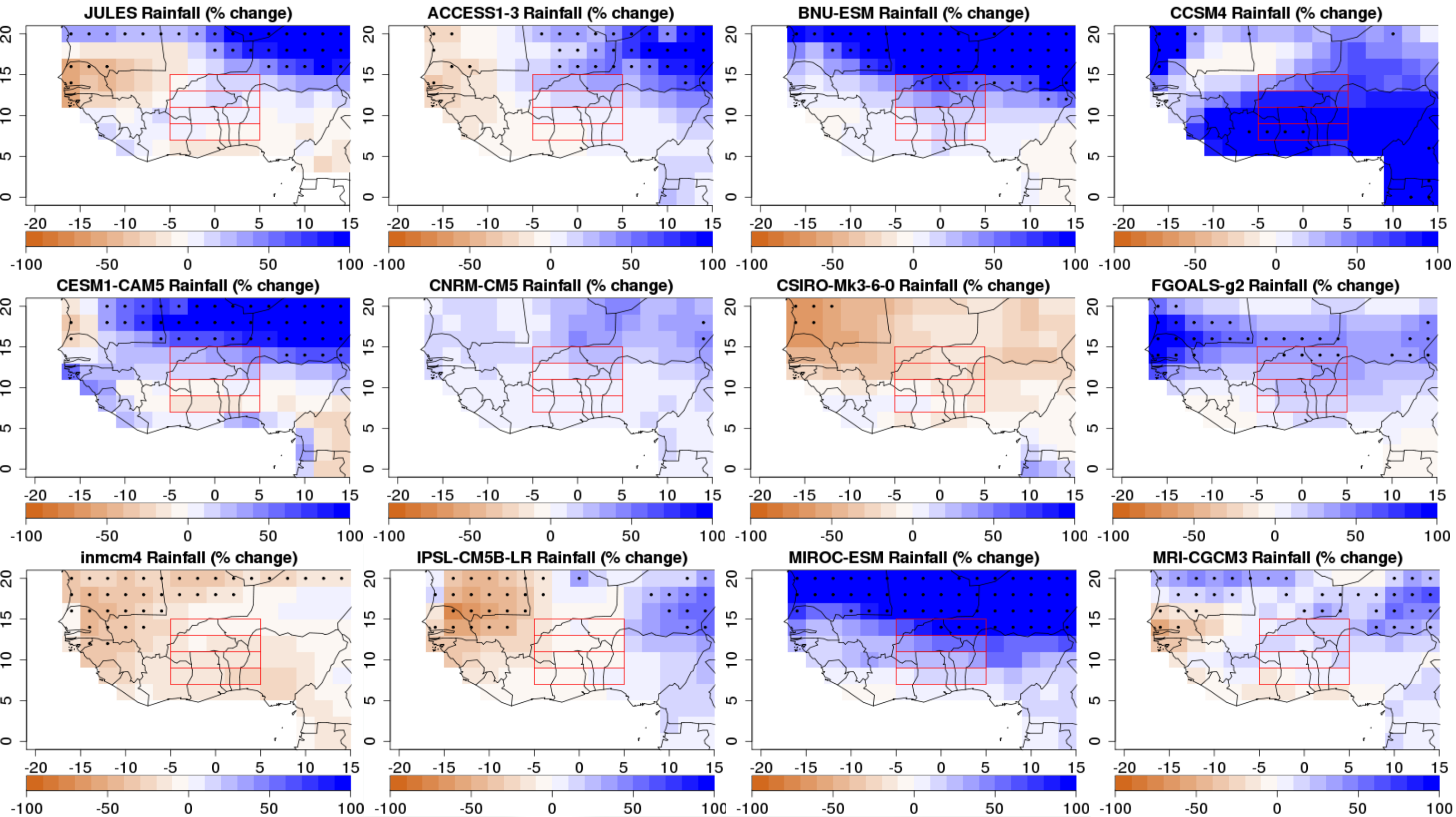
Results

UPSCALE predicts increased rainfall in central and northeast West Africa but reduced in the west and south, with greater percentages of rain >16 mm/day for the same annual rainfalls

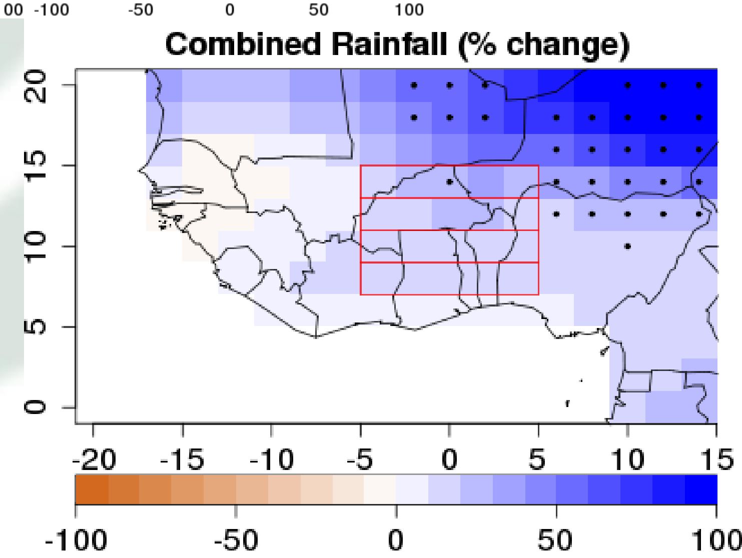
With the changes in rainfall, there is increased transpiration from the soil and vegetation, and some increases in surface runoff and drainage, with little change in soil moisture

However with the increased CO_2 as well, transpiration is reduced (due to the vegetation CO_2 response) while surface runoff, drainage and soil moisture are all increased

Going from vegetation coverage with all broadleaf trees to all c4 grass leads to increased evapo-transpiration but some reductions in surface runoff, drainage and soil moisture



JULES-UPSCALE rainfall change with results from 11 CMIP5 models, Historical (1986-2005) to RCP8.5 (2081-2100), and the overall mean percentage change

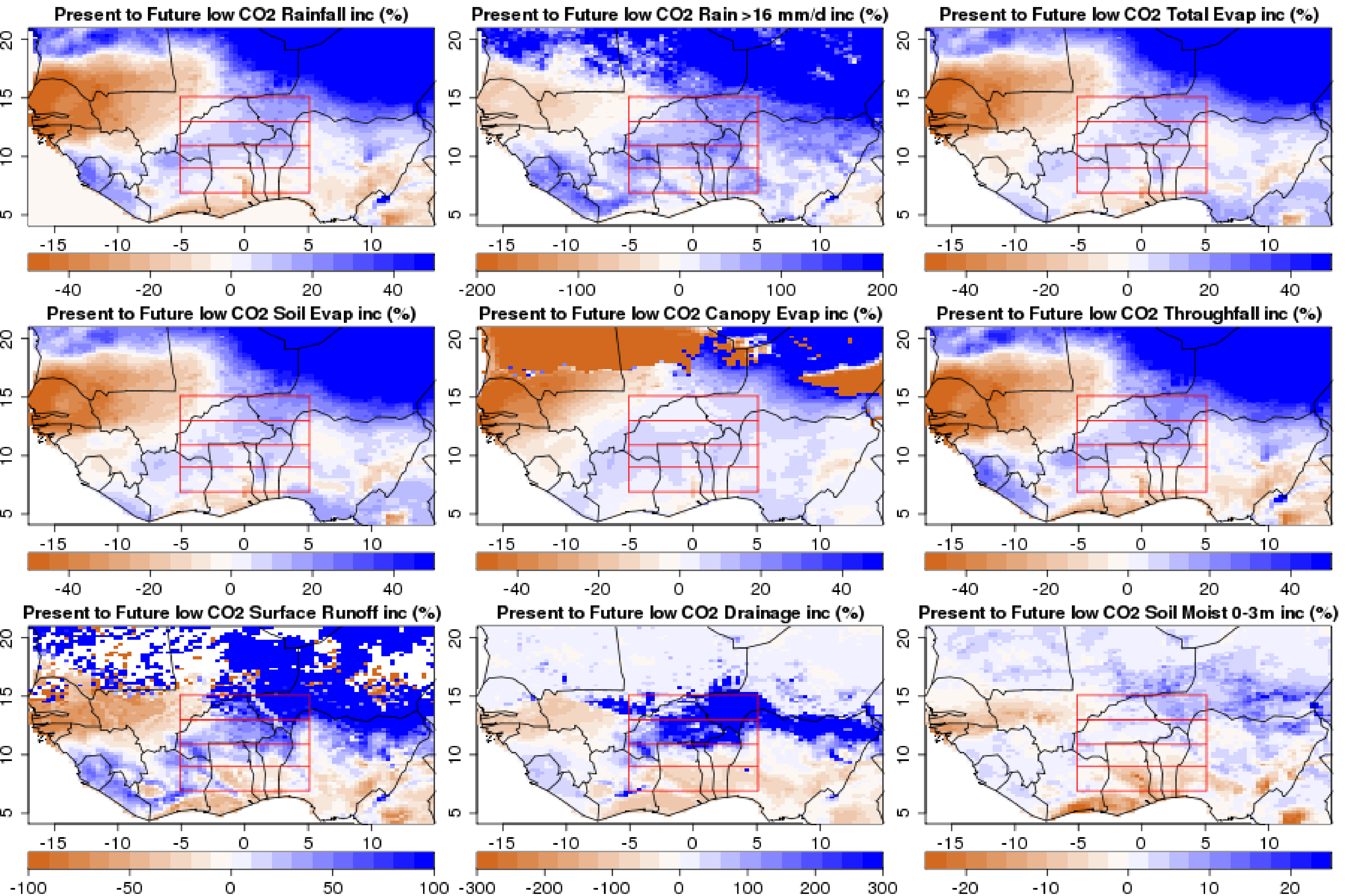


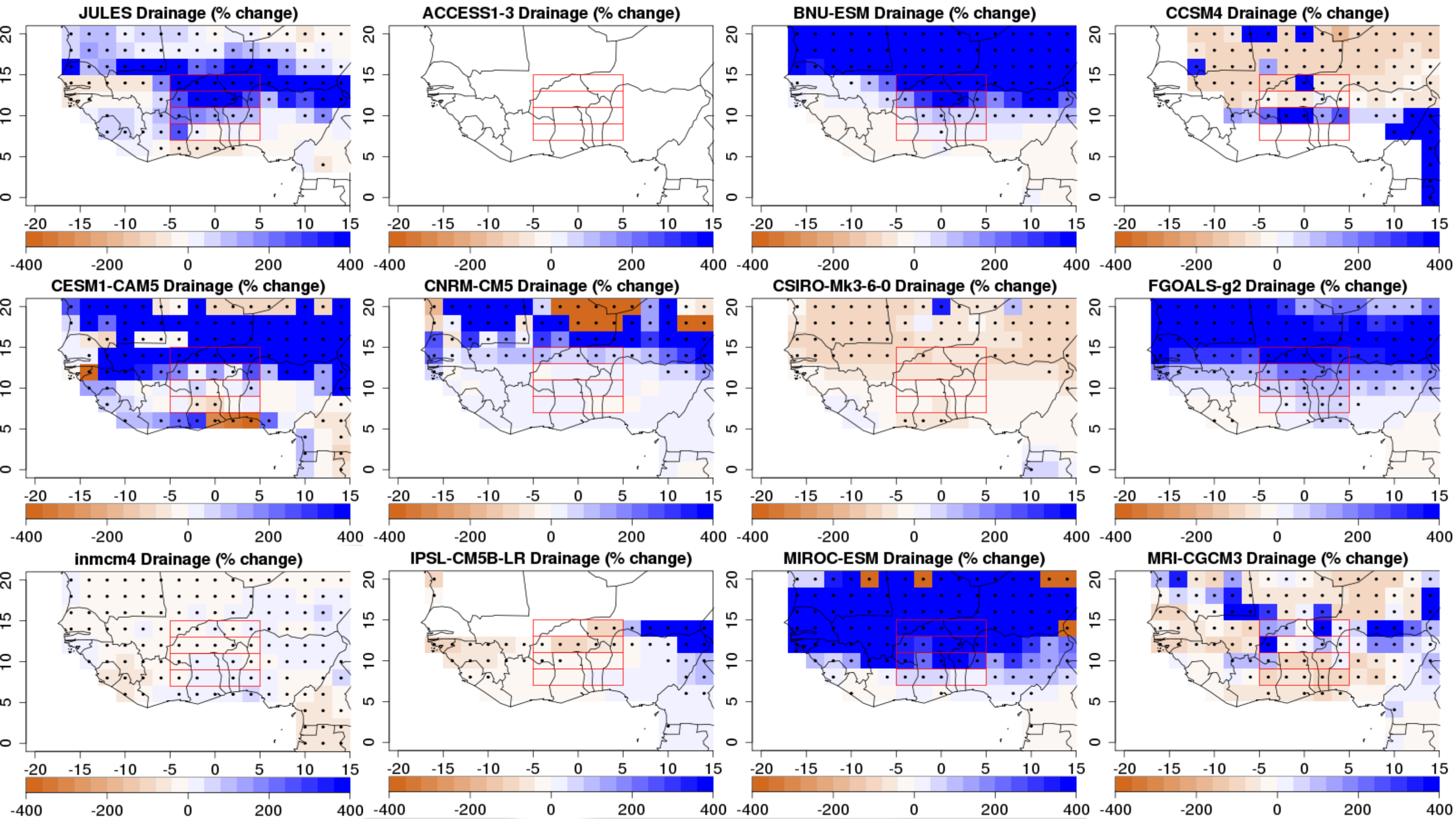
Summary

This study using JULES driven by daily meteorological data from UPSCALE predicts significant changes for the West African monsoon in the future climate (similar to the predictions from the CMIP5 models)

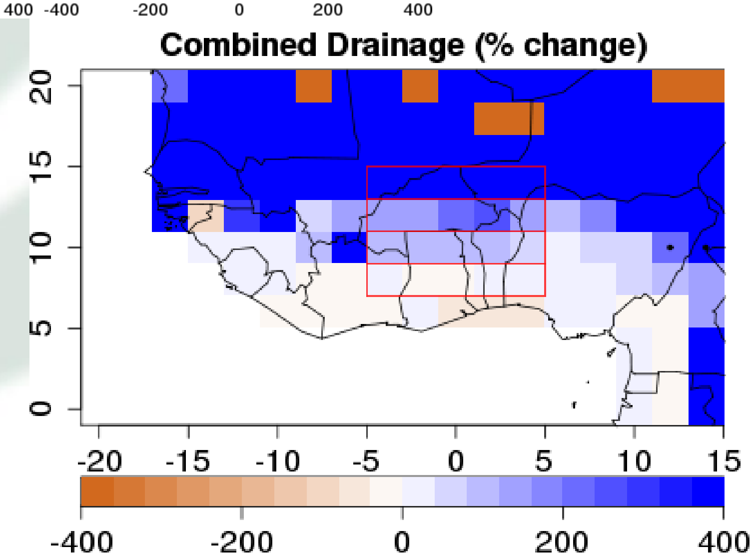
A number of different factors influence the surface water balance and here we have examined the effects of increased rainfall, increased CO_2 (the vegetation CO_2 response), and changing vegetation coverage

This work is ongoing, particularly into the subtle influences of soil conditions and vegetation coverage on water balance


Present to Future low CO2 Rainfall inc (%)
Present to Future low CO2 Rain >16 mm/d inc (%)
Present to Future low CO2 Total Evap inc (%)
Present to Future low CO2 Soil Evap inc (%)
Present to Future low CO2 Canopy Evap inc (%)
Present to Future low CO2 Throughfall inc (%)
Present to Future low CO2 Surface Runoff inc (%)
Present to Future low CO2 Drainage inc (%)
Present to Future low CO2 Soil Moist 0-3m inc (%)



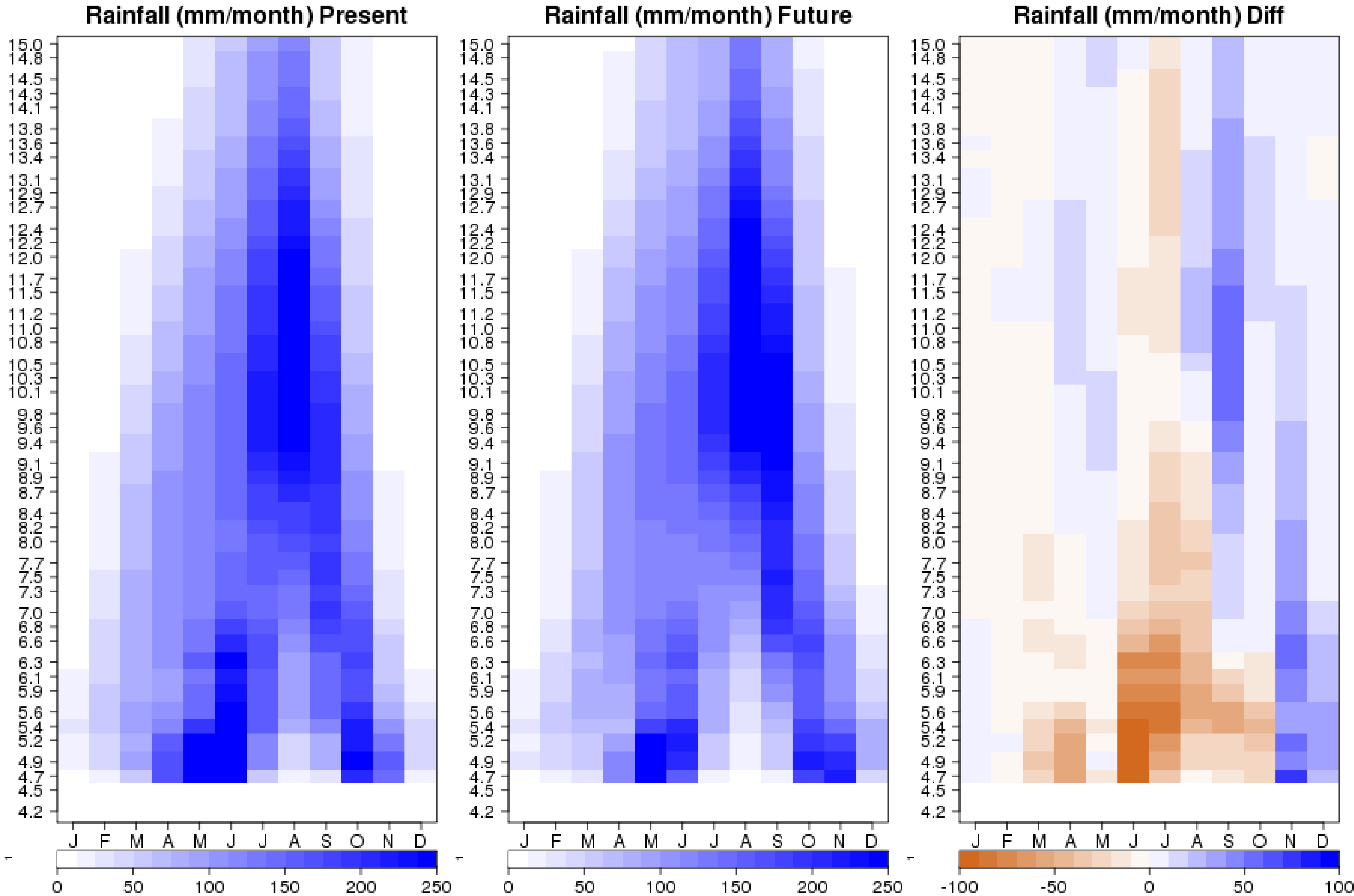
JULES-UPSCALE drainage change with results from 11 CMIP5 models, Historical (1986-2005) to RCP8.5 (2081-2100), and the overall mean percentage change

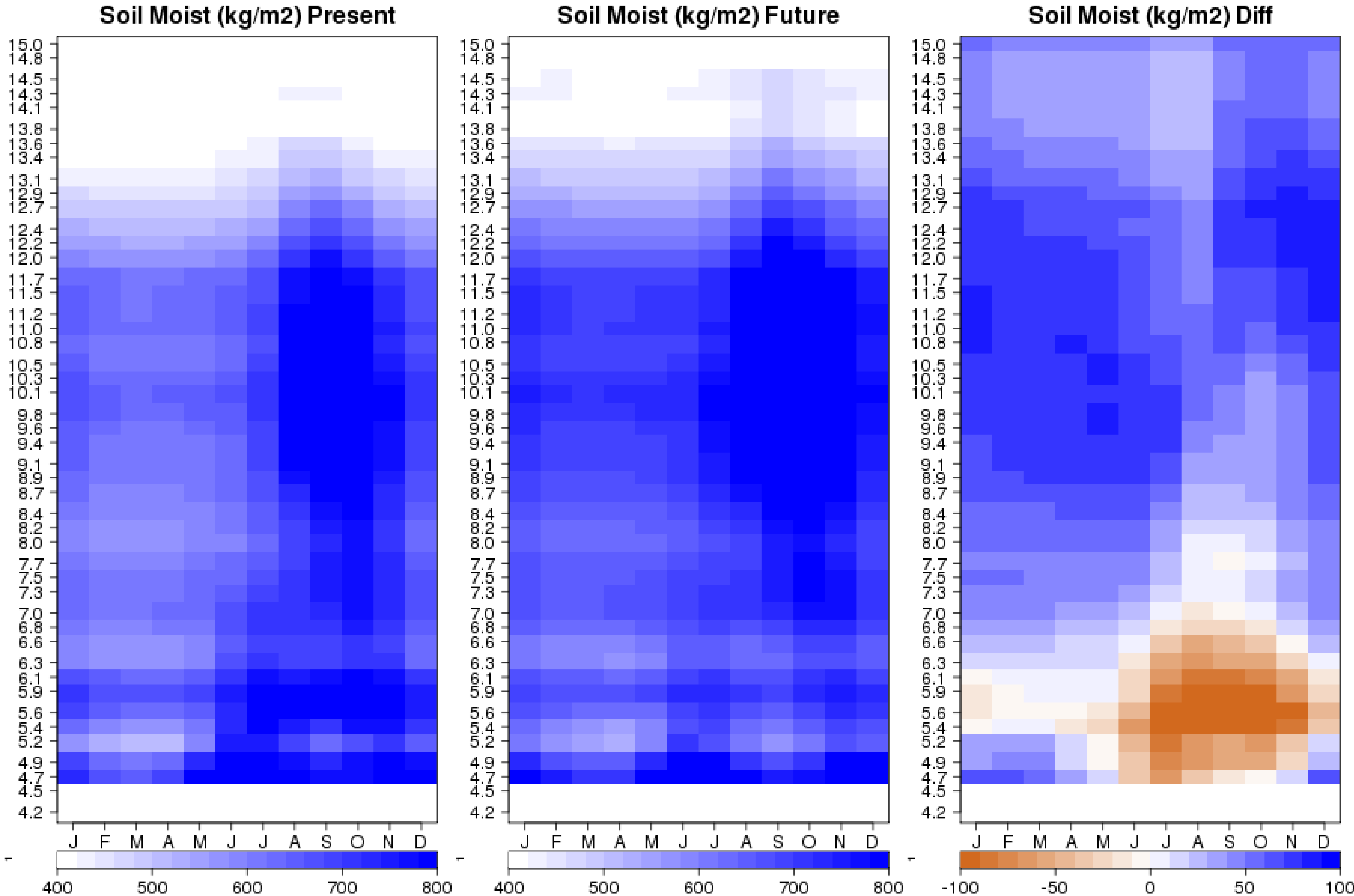


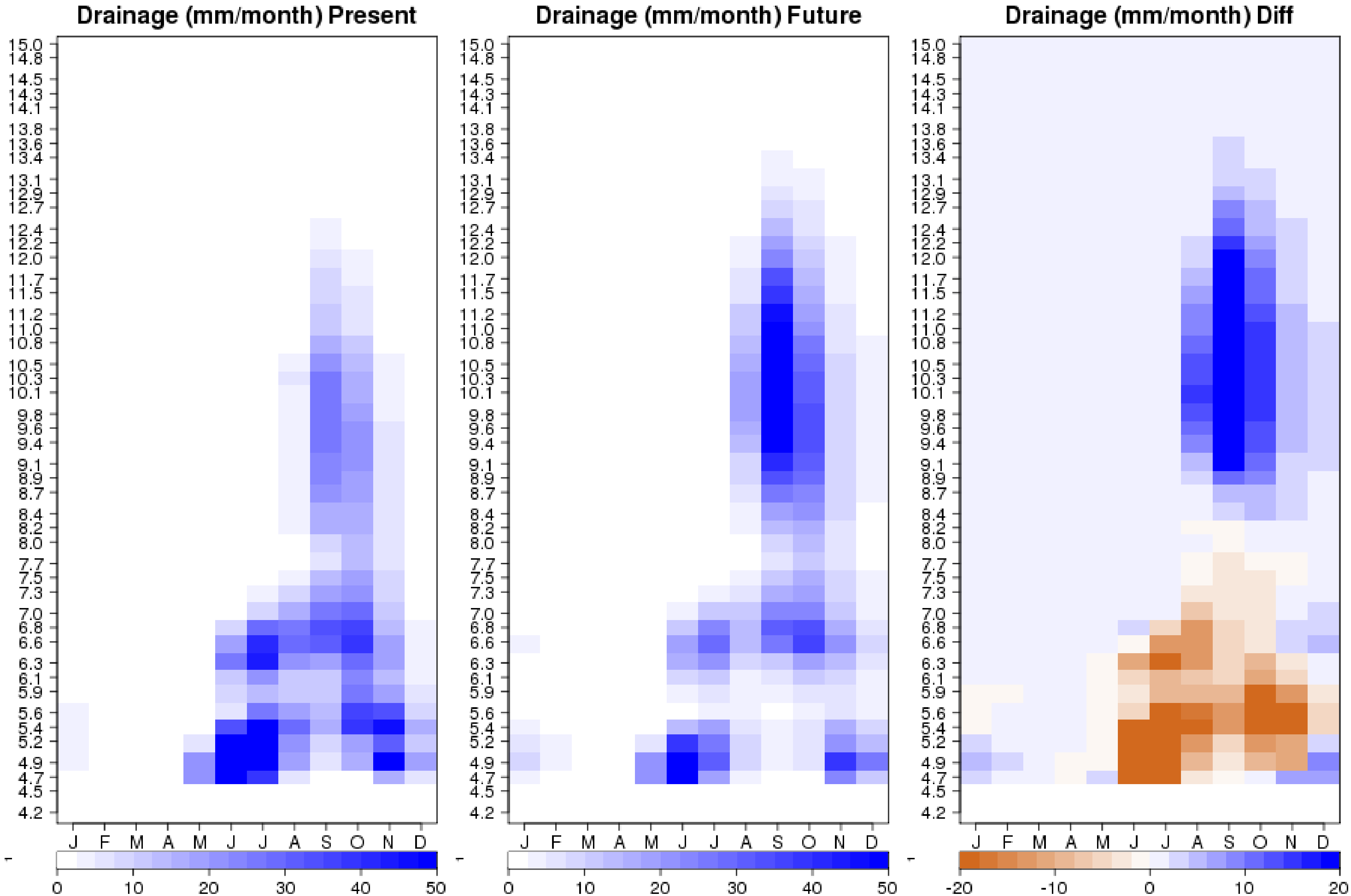
Results 3

The different CMIP5 models show a variety of changes in the West African monsoon from Historical runs (1986-2005) to RCP8.5 (2081-2100), but most of the models show wetter conditions in the North and East but drier conditions in the South and West

The models also show a variety of changes in the amount of drainage across West Africa, but most of the models show significant increases particularly in the North

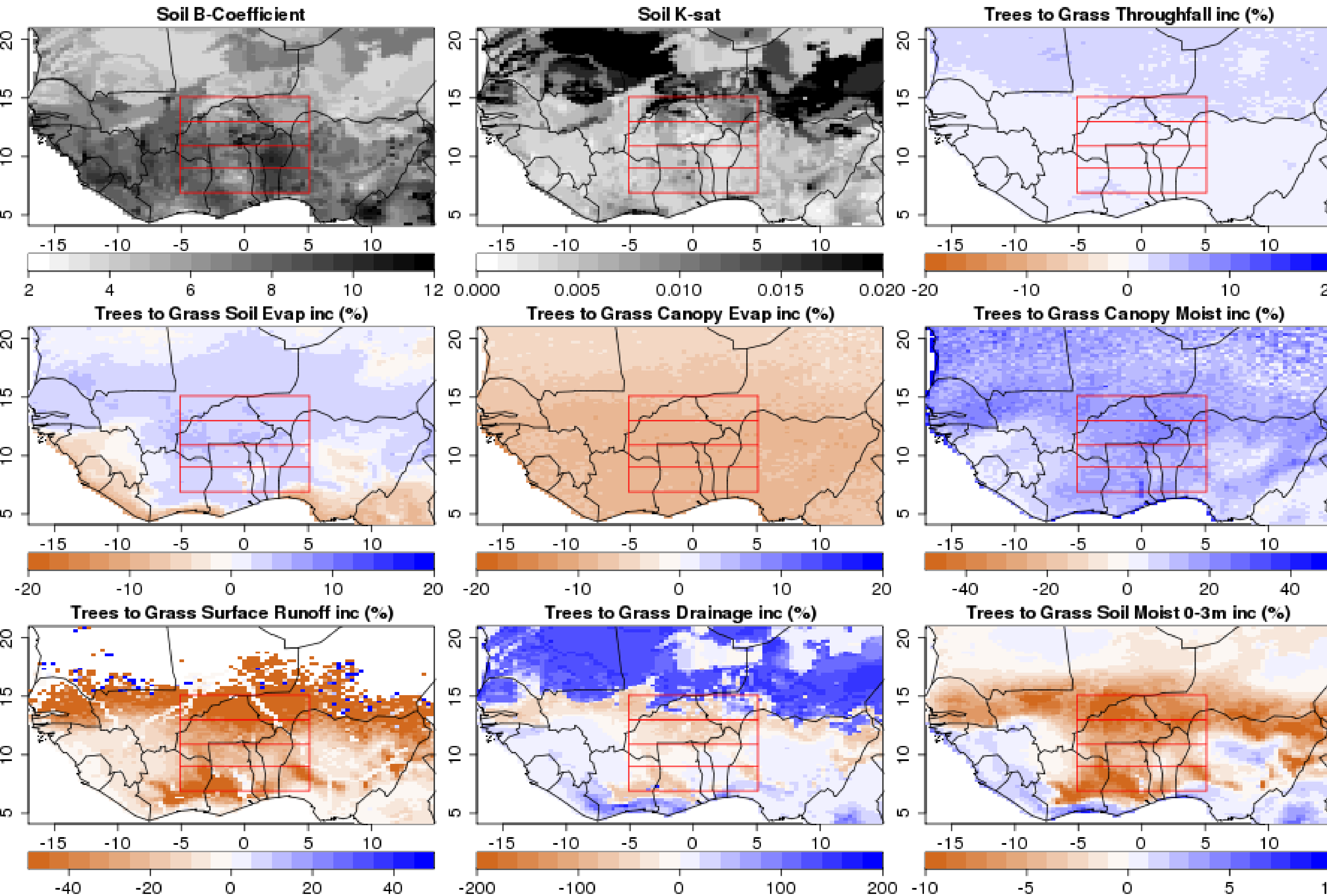

Rainfall (mm/month) Present
Rainfall (mm/month) Future
Rainfall (mm/month) Diff
15.0 14.8 14.5 14.3 14.1 13.8 13.6 13.4 13.1 12.9 12.7 12.4 12.2 12.0 11.7 11.5 11.2 11.0 10.8 10.5 10.3 10.1 9.8 9.6 9.4 9.1 8.9 8.7 8.4 8.2 8.0 7.7 7.5 7.3 7.0 6.8 6.6 6.3 6.1 5.9 5.6 5.4 5.2 4.9 4.7 4.5 4.2
J F M A M J J A S O N D
0 50 100 150 200 250
-100 -50 0 50 100


Soil Moist (kg/m2) Present
Soil Moist (kg/m2) Future
Soil Moist (kg/m2) Diff
15.0 14.8 14.5 14.3 14.1 13.8 13.6 13.4 13.1 12.9 12.7 12.4 12.2 12.0 11.7 11.5 11.2 11.0 10.8 10.5 10.3 10.1 9.8 9.6 9.4 9.1 8.9 8.7 8.4 8.2 8.0 7.7 7.5 7.3 7.0 6.8 6.6 6.3 6.1 5.9 5.6 5.4 5.2 4.9 4.7 4.5 4.2
J F M A M J J A S O N D
400 500 600 700 800
-100 -50 0 50 100


Drainage (mm/month) Present
15.0 14.8 14.5 14.3 14.1 13.8 13.6 13.4 13.1 12.9 12.7 12.4 12.2 12.0 11.7 11.5 11.2 11.0 10.8 10.5 10.3 10.1 9.8 9.6 9.4 9.1 8.9 8.7 8.4 8.2 8.0 7.7 7.5 7.3 7.0 6.8 6.6 6.3 6.1 5.9 5.6 5.4 5.2 4.9 4.7 4.5 4.2
J F M A M J J A S O N D
0 10 20 30 40 50
Drainage (mm/month) Future
15.0 14.8 14.5 14.3 14.1 13.8 13.6 13.4 13.1 12.9 12.7 12.4 12.2 12.0 11.7 11.5 11.2 11.0 10.8 10.5 10.3 10.1 9.8 9.6 9.4 9.1 8.9 8.7 8.4 8.2 8.0 7.7 7.5 7.3 7.0 6.8 6.6 6.3 6.1 5.9 5.6 5.4 5.2 4.9 4.7 4.5 4.2
J F M A M J J A S O N D
0 10 20 30 40 50
Drainage (mm/month) Diff
15.0 14.8 14.5 14.3 14.1 13.8 13.6 13.4 13.1 12.9 12.7 12.4 12.2 12.0 11.7 11.5 11.2 11.0 10.8 10.5 10.3 10.1 9.8 9.6 9.4 9.1 8.9 8.7 8.4 8.2 8.0 7.7 7.5 7.3 7.0 6.8 6.6 6.3 6.1 5.9 5.6 5.4 5.2 4.9 4.7 4.5 4.2
J F M A M J J A S O N D
-20 -10 0 10 20

Results 2

The West African monsoon is also predicted to progress further to the north and to occur later in the year, resulting in increased soil moisture and drainage to the north of 8N


Soil B-Coefficient
2 4 6 8 10 12
Soil K-sat
0.000 0.005 0.010 0.015 0.020
Trees to Grass Throughfall inc (%)
-20 -10 0 10 20
Trees to Grass Soil Evap inc (%)
-20 -10 0 10 20
Trees to Grass Canopy Evap inc (%)
-20 -10 0 10 20
Trees to Grass Canopy Moist inc (%)
-40 -20 0 20 40
Trees to Grass Surface Runoff inc (%)
-40 -20 0 20 40
Trees to Grass Drainage inc (%)
-200 -100 0 100 200
Trees to Grass Soil Moist 0-3m inc (%)
-10 -5 0 5 10
-15 -10 -5 0 5 10
5 10 15 20

The West African Monsoon

Rainfall in West Africa is strongly seasonal and at present many people have no other water for irrigation, so it is very important to determine the likely spatial and temporal changes in the monsoon from present (~2000) to future climate (~2100)

Also examining how changes in the amount of rain and in the rainfall intensity will affect the surface water balance, and hence the amount of drainage from the soil

Configuration of Model Experiments

Individual grid boxes (91x72) between 17W-15E and 4-21N

JULES driven by daily meteorological data from UPSCALE, the daily rainfall is disaggregated, with hourly time steps

4 soil levels (0.1, 0.25, 0.65, 2.0m) with 9 soil parameters (from file), and 9 values of vegetation fractional coverage (from file) with a monthly climatology of Leaf Area Index

Using Brooks and Corey soil hydraulic model, excess water is pushed up, and Cox et al. soil thermal conductivity model

CO_2 mass mixing ratio of 5.241e-4 for present climate, and 1.4217e-3 for future climate