Modelling the changing water balance in West Africa

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iLEAPS Conference, 11th September 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 from the Met Office Unified Model (GA3) ensemble of high resolution (N512) atmosphere-only runs (UPSCALE)

These simulations were forced with OSTIA SSTs and low CO$_2$ for present climate (5 runs of 1985-2011), and with OSTIA + the SST change between 2000-2100 (RCP8.5) and high CO$_2$ 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

Also JULES simulations with different vegetation coverage
• Changes are seen in the annual distribution of rainfall
• Also, increased daily rainfall intensity between the present and future climate

The resulting water balance is affected by the atmospheric driving variables, but also by the increased CO₂ concentration between present and future climate, and by any changes in the vegetation coverage
Changes due to future climatic variables and increased CO$_2$
Changes due to future climatic variables alone, to increased $CO_2$ in future climate, or due to land use change in present
Results

UPSCALE predicts increased rainfall in central and northeast West Africa but reduced in the west and south, with greater fractions of heavy rain (>16 mm/day) in the future climate.

With the changes in meteorology evapotranspiration is increased, but also a greater fraction of the rainfall reaches the surface leading to some increases in runoff and drainage.

However with the increased CO$_2$ as well, transpiration is reduced (due to the vegetation CO$_2$ response) leaving more water in the soil so again runoff and drainage are increased.

Going from vegetation coverage consisting of all broadleaf trees to all c4 grass leads to increased evapotranspiration but some reductions in runoff, drainage and soil moisture.
Water balance in North Ghana for present climate (blue), and future climate with low (red) or high (black) CO$_2$. 

**Drainage (5W-5E 9-11N)**

- Present, low CO$_2$
- Future, low CO$_2$
- Future, high CO$_2$

**Evaporation (5W-5E 9-11N)**

**Runoff (5W-5E 9-11N)**
Water balance in South Burkina Faso for present climate (blue), and future climate with low (red) or high (black) CO₂.
Water balance in North Ghana for all broadleaf trees (dark green), all C4 grass (light green) or all bare soil (orange)
Water balance in South Burkina Faso for all broadleaf trees (dark green), all C4 grass (light green) or all bare soil (orange).
Results 2

Both drainage and surface runoff strongly depend on the monthly rainfall (and particularly on the amount of heavy rain >16 mm/day) while evaporation is more constant.

The future meteorology alone (with higher temperatures) increases the evapotranspiration from the soil and vegetation, and the evaporation from the canopy.

However with the increased CO$_2$ as well, transpiration and overall evapotranspiration is reduced (vegetation CO$_2$ response) and drainage increased (less soil water removed).

100% broadleaf tree coverage leads to greater drainage and surface runoff than full c4 grass cover, whereas 100% bare soil has the greatest drainage and runoff as no vegetation
The annual cycle of rainfall in the present and future climate
The annual cycle of drainage in the present and future climate
Results 3

The West African monsoon is also predicted to progress further to the north and to occur later in the year, resulting in reduced drainage to the south of 8N but increased drainage to the north of 8N.
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 future climate driving data, increased CO$_2$ (the vegetation CO$_2$ response), and changing the vegetation coverage.

This work is ongoing, particularly into the subtle influences of soil conditions and vegetation coverage on the resulting water balance.
JULES-UPSACLE rainfall change with results from 11 CMIP5 models, Historical (1986-2005) to RCP8.5 (2081-2100), and the combined mean absolute change (mm/year)
JULES-UPSCALE drainage change with results from 11 CMIP5 models, Historical (1986-2005) to RCP8.5 (2081-2100), and the combined mean absolute change (mm/year)
Results 4

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.
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.
Changes due to future climatic variables (constant CO$_2$)
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.

\( \text{CO}_2 \) mass mixing ratio of 5.241e-4 for present climate, and 1.4217e-3 for future climate.