Mid-21st Century Changes in Extreme Events over Northern and Tropical Africa

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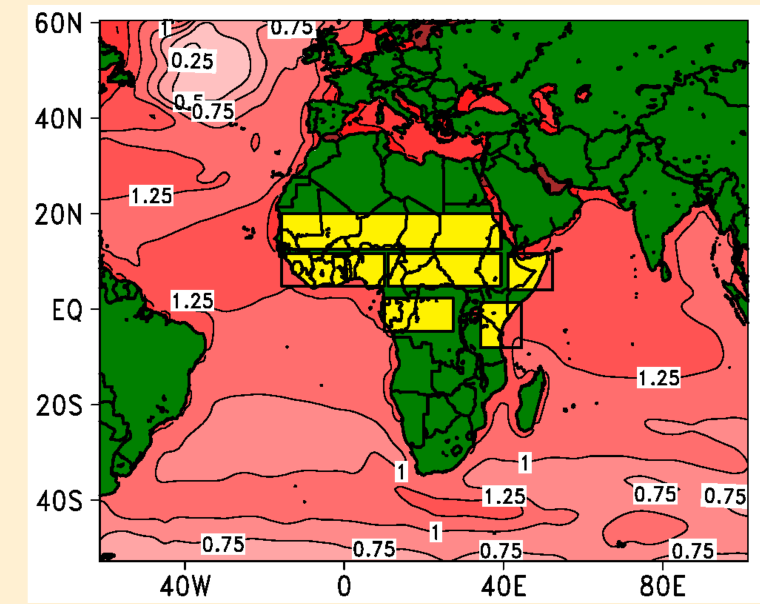
Introduction

Future changes in extreme events, including droughts and intense rainfall, will have significant impacts on the environment and society. This is especially true over Africa, as the continent is thought to be particularly susceptible given a high vulnerability to climate variability and relatively low adaptive capacity. Mid-21st century climate projections on regional space scales are needed to improve our understanding of future changes and allow for better planning to help mitigate impacts over Africa. Coupled atmosphere-ocean global circulation models (AOGCMs) being run in advance of the Fifth Assessment report of the Intergovernmental Panel on Climate Change (IPCC AR5) are one source of information, but the horizontal space scales of these models, generally about 200 km, may not be ideally suited to evaluate changes in extreme events locally. Regional climate modeling can increase this resolution to capture extreme events more accurately. The purpose of this study is to evaluate changes in temperature and precipitation extremes over northern and tropical Africa for the mid-21st century due to increased CO_2 forcing/global warming using a regional climate model, and to evaluate confidence in those predictions.

Methodology

The Weather Research and Forecasting Model version 3.1.1 (WRF) is optimized and used to produce two ensembles. One represents 1981-2000, called " 20C", and the other 2041-2060 under the SRES A1B emissions scenario, called "21C". Each ensemble consists of 6 integrations run through the full year. The model is run at 90-km resolution with 32 vertical levels and a model time step of 180 seconds.



Model domain and 21C annual SSTAs (K). Boxes denote averaging regions used in the analysis.

The Ensemble Simulations

The large model domain (left) is selected to minimize the effects of lateral boundary constraints in the analysis over Africa and to provide ample space for the development of subtropical anticyclones over the oceans.

20C

Initial, lateral, and surface boundary conditions, including SSTs, for all six ensemble members are derived from the 1981-2000 monthly climatology in the National Centers for Environmental Prediction reanalysis 2 (NCEP2) and interpolated onto the regional model grid. Lateral boundary conditions are updated every 6 hours using NCEP2 climatological values. The monthly means are assumed to represent the middle of the month, and linear interpolation is used to generate boundary conditions every 6 hours.

21C

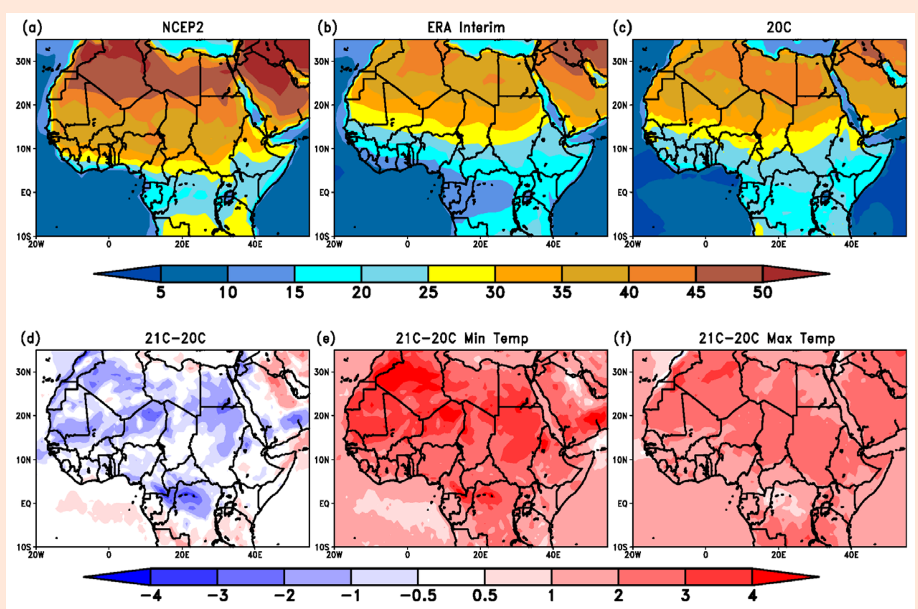
The second ensemble, 21C, represents mid-21st c. (2041-2060) conditions under the IPCC AR4 A1B emissions scenario. The atmospheric CO_2 concentration is increased to 536 ppmv, the 2041-2060 average in the A1B scenario. Effects of other greenhouse gases and aerosols are not included. Boundary conditions are anomalies for 2041-2060 calculated from 9 AOGCM simulations. They are averaged and applied as anomalies to the NCEP2 20C boundary conditions.

Temperature

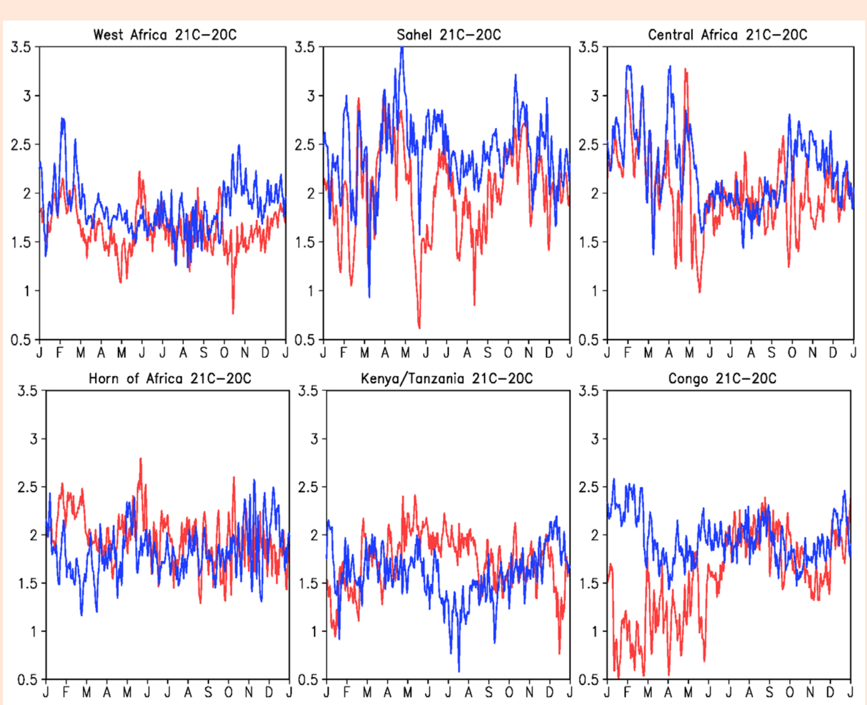
Annual Extreme Temperature Range

(warmest maximum daily temperature of the year - coldest minimum daily temperature of the year)

- **Model projects a widespread decrease in the annual extreme temperature range ranging from 0.5 – 1 K over West Africa, to 2 – 3 K over the Sahel and up to 4 K over the Congo.**
- **Both 21C minimum and maximum temperatures are projected to increase, but the magnitude of the increase is greater for the minimum temperature.**



Average annual extreme temperature range from the (a) NCEP2, (b) ERA-I, and (c) 20C (6-member ensemble mean). Also shown are the 21C - 20C average annual (d) extreme temperature range, (e) minimum temperature, and (f) maximum temperature differences. Units are K.



21C – 20C ensemble mean regional daily maximum (red) and minimum (blue) temperature differences (K).

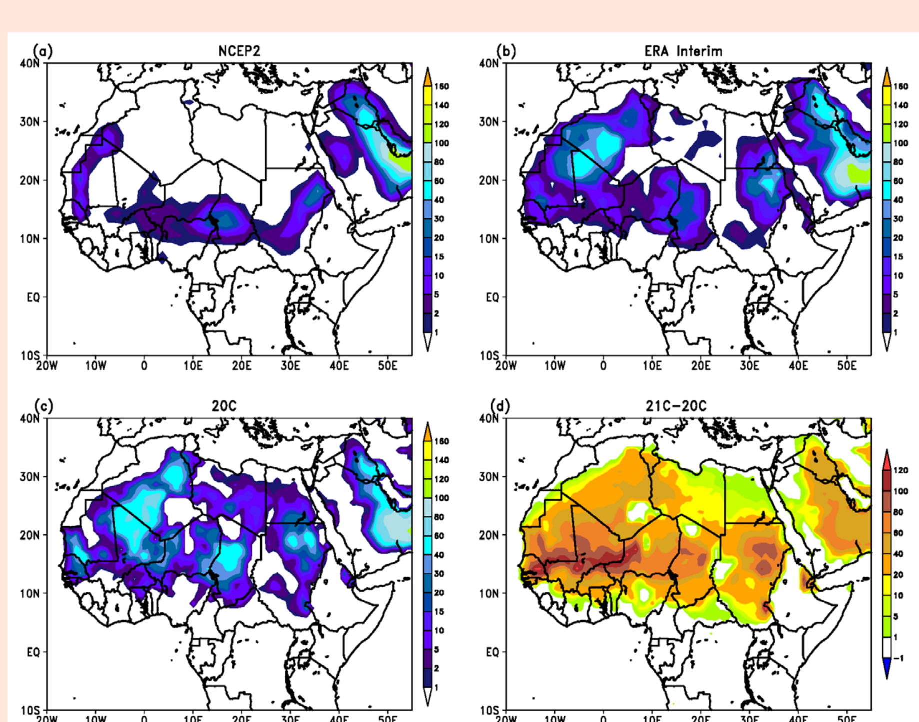
Daily Maximum and Minimum Temperatures

- **Daily maximum and minimum temperatures are projected to increase in all regions analyzed, but there are regional and seasonal variations.**
- **The daily diurnal temperature range decreases over West Africa and Central Africa by 0.3 – 1.2 K during the boreal spring and fall, over the Sahel by 0.5 – 1.2 K in summer, and over the Congo by 0.5 – 2.0 K during the boreal winter and spring.**
- **The daily diurnal temperature range increases over the Horn of Africa by 0.3 – 1.2 K during the boreal winter and over Kenya/Tanzania by 0.2 – 1.5 K during the boreal summer.**

Heat Wave Days

(# of days when the maximum daily apparent temperature, which factors in RH, exceeds the danger level of 41°C for at least 3 consecutive days)

- **5 – 120 day increase in the number of heat wave days predicted over the Sahel and Saharan Africa. The largest changes are projected to occur over the western Sahel.**
- **Projected increase in the number of heat wave days over the northernmost West Africa and Central Africa averaging regions.**



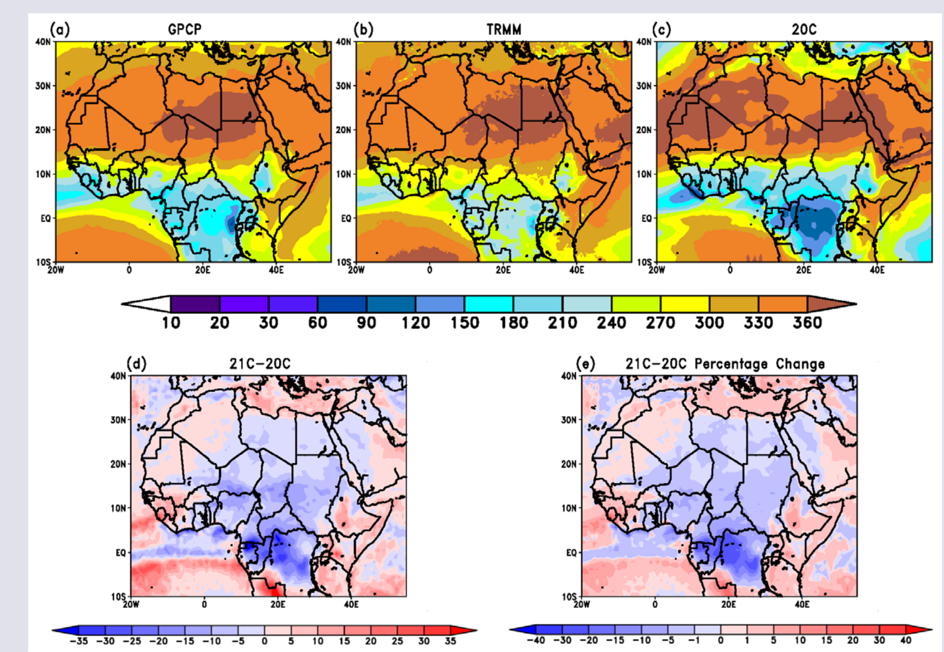
Average number of heat wave days per year from the (a) NCEP2, (b) ERA-I, and (c) 20C ensemble (6-member average). (d) 21C minus 20C difference in the average number of heat wave days per year.

Precipitation

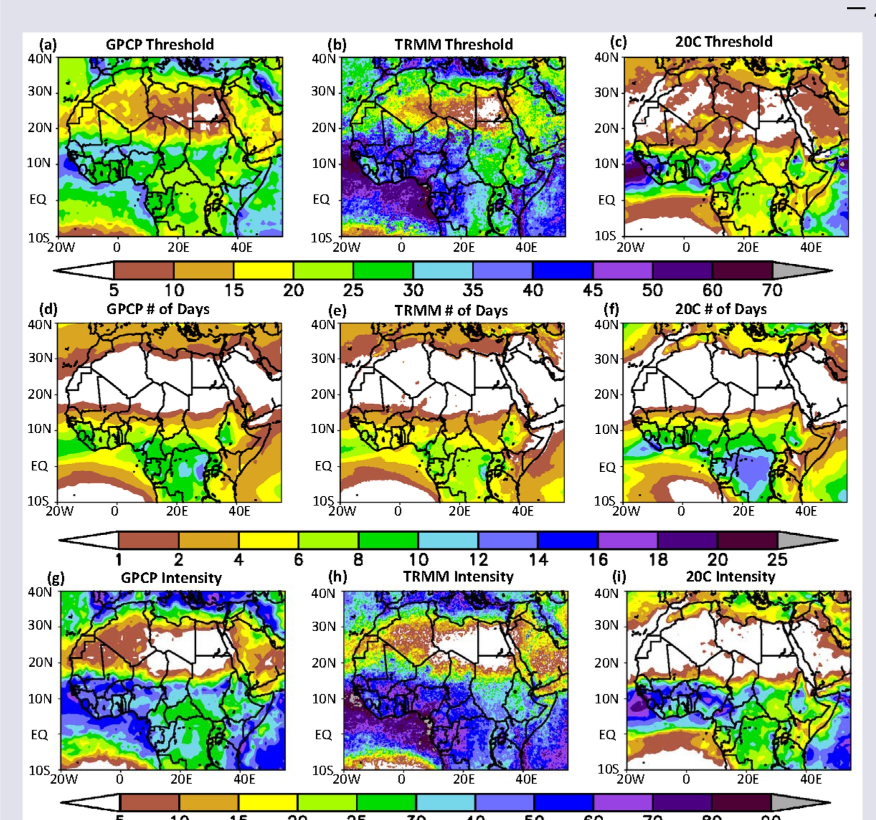
Number of Dry Days

(when daily rainfall is less than 1 mm/day)

- **The number of dry days is predicted to decrease by 15 – 25% over the Congo, 3 – 7% over Central Africa, and 3 – 7% over the Sahel east of 0°E.**
- **Over the Horn of Africa and Kenya/Tanzania, the number of dry days is projected to increase by 5 – 10 % associated with the weakening of the boreal spring long rains.**



Average number of dry days per year in the (a) GPCP, (b) TRMM, and (c) 20C ensemble (6-member average). Also shown are the (d) difference in the number of dry days for 21C – 20C and the (e) 21C – 20C percent change difference.

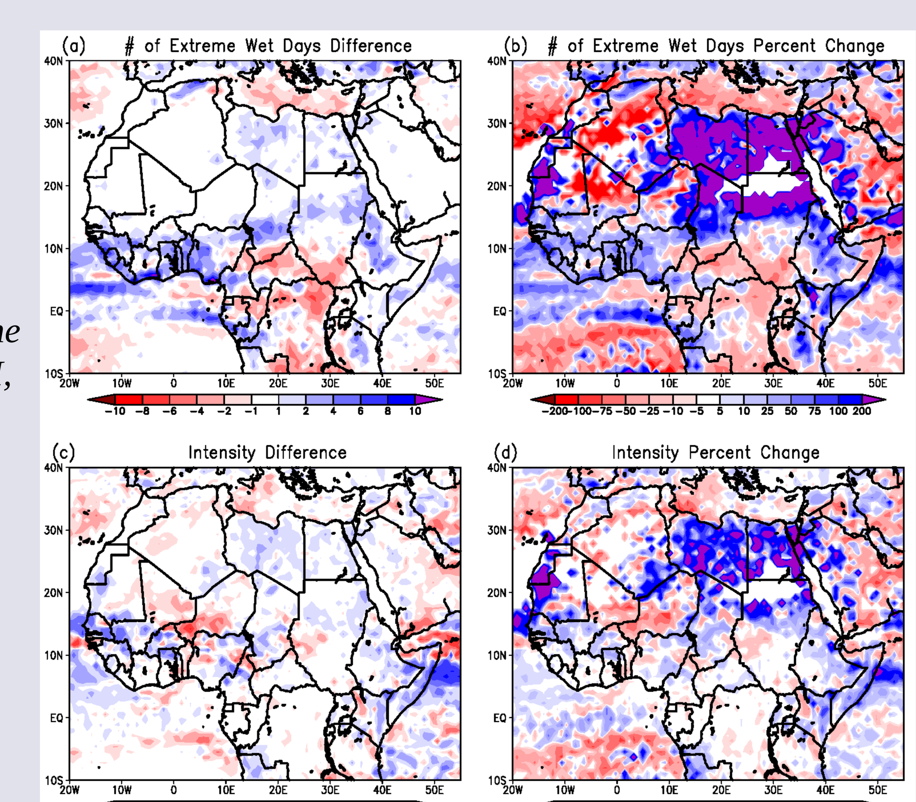


Extreme daily heavy rainfall threshold (mm day^{-1}) calculated from the (a) GPCP , (b) TRMM, and (c) 20C ensemble. Also shown are the average number of extreme heavy rainfall days per year for the (d) GPCP, (e) TRMM, and (f) 20C ensemble, and the average rainfall intensity per extreme wet day (mm day^{-1}) for the (g) GPCP, (h) TRMM, and (i) 20C ensemble.

Extreme Heavy Rainfall Days

(events that exceed the 95th percentile for wet days)

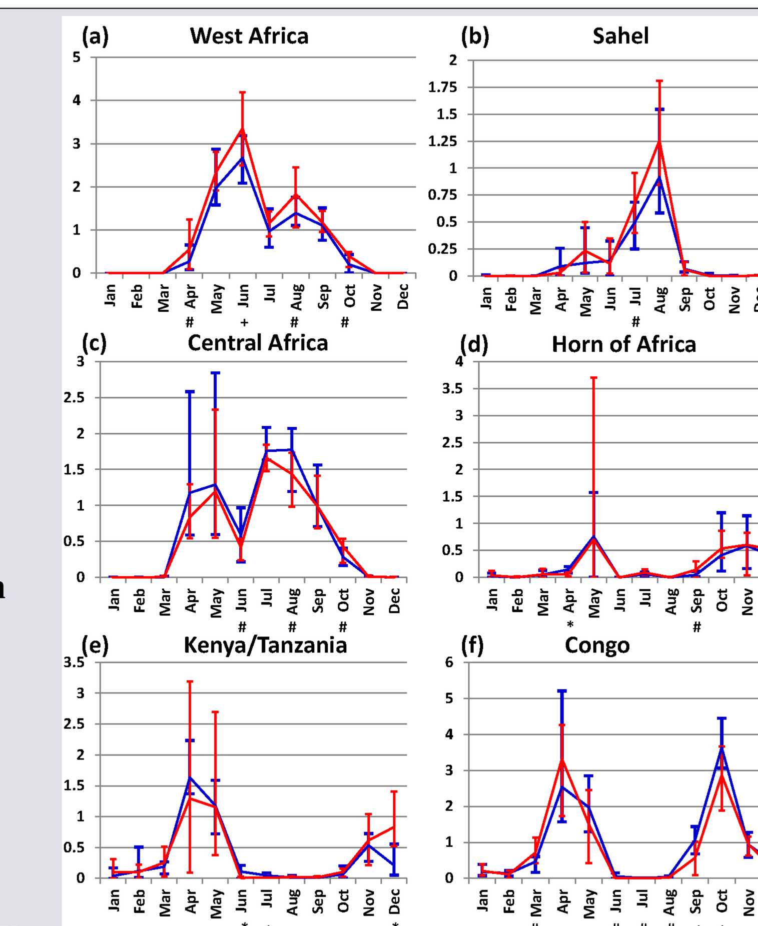
- **A percentile based approach is applied here as opposed to a fixed value threshold approach because it better allows for spatial comparison between the different datasets and model output as they sample the same part of the probability distribution.**



Ensemble mean 21C – 20C (a) difference and (b) percentage change in the number of extreme heavy rainfall days per year. Also shown is the ensemble mean 21C – 20C (c) difference (mm/day) and (d) percentage change in extreme heavy rainfall intensity per event.

- **Number of extreme heavy rainfall days is predicted to increase over West Africa by 40 – 60%, the southern Sahel by 50 – 90%, and the Ethiopian Highlands by 50 – 90%.**
- **Number of extreme heavy rainfall days is projected to decrease by 30 – 60% over the Congo**

- **The increase in extreme heavy rainfall days over the Sahel and West Africa is generally evenly distributed during the boreal summer months.**
- **The reduction in extreme heavy rainfall days over the Congo is due to a decrease in the number of events during the boreal fall short rains.**
- **Over Kenya/Tanzania the increase in extreme heavy rainfall events is associated with more boreal fall/early winter events, and is partially offset by a decrease in the number of events during the long rains of the boreal spring.**



*20C (blue) and 21C (red) ensemble mean average number of extreme heavy rainfall days per month. Vertical bars denote the spread of the individual ensemble members. Monthly statistical significance is denoted by the symbols under the x-axis. The #, +, and * denote statistical significance at the 80%, 90%, and 95% confidence intervals, respectively.*

Conclusions

- Results indicate a high likelihood that there will be a shift to warmer extreme temperatures by the mid-21st century over sub-Saharan and tropical Africa. The severity of these changes is not uniform across the annual cycle and is regionally dependent.
- Heat waves are likely to increase not only over the Sahara and Sahel, but also extend equatorward over tropical Africa into areas that currently do not experience such events.
- Changes in extreme rainfall are also regionally and seasonally dependent.
  - ***West Africa***: The number of dry days and extreme heavy rainfall days during the boreal summer are projected to increase indicating that the summer monsoon rainfall will be delivered in fewer, but more intense events.
  - ***Sahel***: The number of extreme dry days is projected to decrease while the number of extreme heavy rainfall days increases.
  - ***Tropical Africa***: Rainfall is projected to intensify during the boreal spring and weaken in the fall and winter over the Congo basin, with the opposite results to the east over Kenya and Tanzania.

More information about this study is available in the publication:

Vizy, E. K., and K. H. Cook, 2012: Mid-21st century changes in extreme events over northern and tropical Africa. *J. Climate*, doi:10.1175/JCLI-D-11-00693.1.

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