Regional-scale climate change projections of annual, seasonal and monthly near-surface temperatures and rainfall in Uganda

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Major forces that modulate Earth’s climate system – heat as a driver for atmospheric flow;

Uganda climate within a global atmospheric circulation system;

Earth’s radiation budget and Representative Concentration Pathways for greenhouse gases;

Modelling of the atmospheric system and experimental design of the regional dynamical downscaling simulations;

Future projections of near-surface temperature and rainfall in Uganda;

“Correcting” model results according to observations – regional statistical downscaling
The atmosphere behaves like a fluid with components of chaos in its propagation.

However, atmospheric mass (and therefore flow) is partially modulated by forces:
- Gravitation
- Temp & Pres gradients
- Rotation
- Friction and others

The influence of such forces results in some identifiable flow patterns or distinct rainfall zones.
PLANETARY-SCALE atmospheric flow is considerably modulated by two drivers or forces:

- **Temperature gradients** between the equator (higher T) towards the poles (lower T), as a result of surface HEAT radiation gradients. More heat radiation at the equator results in lower surface pressures which initiate surface flow from higher pressures regions (convergence). This leads to convection at the equator and subsidence at the poles (Hadley Circulation).

- The **rotation of the Earth**, at one revolution in 24-hours, results in a surface velocity gradients from the equator (higher surface velocities) towards the poles (lower surface velocities).
PLANETARY-SCALE atmospheric flow is characterised by convection (lift of air mass) at equatorial regions (in reality above the HEAT equator) associated with easterly flow. As a result, Uganda is located in an area of convection, with easterly surface flow (trade winds) which results in moisture advection from the Indian Ocean.
Continental HEAT (Sensible Heat Flux – shaded in W.m\(^{-2}\)) has a noticeable influence on surface pressure patterns (Mean Sea Level Pressure – contours in hPa). Note how troughs develop during summer months over areas of high continental HEAT radiation.

ERA-Interim Reanalyses data: monthly sensible heat flux (W.m\(^{-2}\)) and mean sea-level pressure (hPa) as calculated over the 20-year period 1986-2005.
Averaged (1986 to 2005) seasonal mean sea level pressure (hPa) and 850 hPa streamlines with specific humidity from ERA Interim Reanalysis data.
Averaged (1986 to 2005) seasonal mean sea level pressure (hPa) and 850 hPa streamlines with specific humidity from ERA Interim Reanalysis data.
Estimated average (1981 to 2010) seasonal rainfall totals (mm.season$^{-1}$) as derived by the Global Precipitation Climatology Centre (GPCC).
Averaged (1986 to 2005) seasonal near-surface (2m above surface) temperatures (°C) as captured by ERA Interim Reanalysis data.
It is all about \textbf{HEAT} (W.m$^{-2}$) = Energy

Global Anthropogenic Radiative Forcing for the \textbf{high RCP8.5}, the \textbf{medium-high RCP6}, the \textbf{medium-low RCP4.5} and the \textbf{low RCP3-PD}.

In addition, two supplementary extensions are shown, connecting RCP6.0 levels to RCP4.5 levels by 2250 (SCP6TO45) or RCP45 levels to RCP3PD concentrations and forcings (SCP45to3PD).

Reference:
Modelling of the Atmosphere:

- Conservation of momentum:
  \[
  \bar{F} = m\ddot{\bar{U}} = m\frac{\partial \bar{U}}{\partial t} = -2\Omega \times \bar{U} - \frac{1}{\rho} \bar{\nabla} p + \bar{g} + \bar{F}_r
  \]

- Conservation of mass;
- Conservation of energy.

Models are computer programmes developed to “solve” the atmospheric equations.
EXPERIMENTAL DESIGN

Results from an ensemble of four European based ocean-atmosphere Coupled Global Circulation Models (CGCMs), which were accommodated with the IPCC AR5, were considered for generating historical and future climate projections.

**HadGEM2-ES ocean-atmosphere CGCM**
United Kingdom (UK) Hadley Centre (Caesar et al., 2013);

**CNRM-CM5 ocean-atmosphere CGCM**
National Centre for Meteorological Research (CNRM), Climate Modelling and Global Change team, France - Meteo France (Voldoire et al., 2011)

**EC-EARTH ocean-atmosphere CGCM**
EC-Earth consortium, coordinated by the Royal Netherlands Meteorological Institute (KNMI) (Hazeleger et al., 2012);

**MPI-ESM-LR ocean-atmosphere CGCM**
Max-Planck-Institut für Meteorologie (Giorgetta et al., 2013).

**COoRdinated Downscaling EXperiment (CORDEX)**
Grid resolution of 44º x 0.44º (≈50km x 50km).

Dynamical downscaling: The four ocean-atmosphere CGCMs provided lateral boundary input to the COnsortium for Small-scale MOdeling-climate mode (COSMO) (version 4.8) model of the Climate Limited-area Modelling (CLM) community, known as the COSMO-CLM 4.8 or CCLM 4.8 Regional Climate Model.
2 x 150-year simulations, each with a different CO₂ concentration pathway, were completed by each one of the four models. 20-year periods (historical, +50 and +80 years from present) of averaged temperature and rainfall were considered for analyses.
<table>
<thead>
<tr>
<th>RCP 4.5: Annual temperature change (ºC) relative to 1985-2005</th>
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**Projected change of the MEDIAN**

- **2046 – 2065 (+50 years)**
- **2076 – 2095 (+80 years)**
Projected change of the MEDIAN – RCP4.5

Seasonal temperature change (ºC) for 2046 – 2065 (+50 years) - relative to 1985-2005

DJF | MAM | JJA | SON

Seasonal temperature change (ºC) for 2076 – 2095 (+80 years) - relative to 1985-2005

DJF | MAM | JJA | SON
Projected change of the MEDIAN – RCP4.5

Seasonal rainfall change (mm/month) for 2046 – 2065 (+50 years) - relative to 1985-2005

DJF | MAM | JJA | SON

Seasonal rainfall change (mm/month) for 2076 – 2095 (+80 years) - relative to 1985-2005

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Projected change of the MEDIAN – RCP8.5

Seasonal temperature change (ºC) for 2046 – 2065 (+50 years) - relative to 1985-2005

Seasonal temperature change (ºC) for 2076 – 2095 (+80 years) - relative to 1985-2005
Projected change of the MEDIAN – RCP8.5

Seasonal rainfall change (mm/month) for 2046 – 2065 (+50 years) - relative to 1985-2005

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Projected percentage (%) change – RCP4.5

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Seasonal rainfall change (mm/month) for 2076 – 2095 (+80 years) - relative to 1985-2005

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The Kampala, Uganda domain (dashed square: 32.56°E – 33.00°E ; 0.0°N – 0.44°N) with the position of the four model grid points nearest to the metro pole. The average of rainfall and near-surface temperature values at these grid points were regarded as representative for Kampala, from where **statistical downscaling** will be performed.
Kampala (Uganda) annual rainfall totals (mm) for the moderate RCP 8.5 greenhouse gas concentration pathway as simulated over the historical period 1951 to 2005, and projected for the period 2006 to 2099 by the CCLM 4.8 Regional Climate Model (RCM) forced across its lateral boundaries by the 1) CNRM-CM5(red thin line), 2) HadGEM2-ES (thin blue line), 3) EC-EARTH (orange thin line) and 4) MPI-ESM-LR. The ensemble mean between these CGCMs are indicated by thick blue lines, and the linear trend in the ensemble projection is indicated by a thick dashed line.
Delegates who attended the Climate Change Development and Knowledge sharing workshop that took place earlier this week at Makerere University
Thank you

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