



COUNTRY CLIMATE BRIEF

October 2017

ANNEX: Future climate projections for Malawi

This annex provides the methods and extra figures to support the brief on future climate projections for Malawi¹, which provides an overview of future climate change for the country using the latest available climate model simulations. A two-page summary² is also available highlighting key findings.

Data

Observed data

The observations used in the briefs included gridded rainfall and temperature data. We used the CHIRPS v2.0 (Climate Hazards group Infrared Precipitation with Stations) dataset³ for daily rainfall at a resolution of \sim 5 km (0.05° x 0.05°) for the period 1981-2016. CHIRPS is a combination of satellite-based rainfall estimates and station observations and has been used for various analyses for Africa^{4,5,6}. For temperature, we used the Climate Research Unit (CRU) TS v. 3.24.017 monthly data at a resolution of \sim 50 km (0.5° x 0.5°) for the period 1901-2015, which has been widely used for Africa^{8,9,10}.

About FCFA

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent.

www.futureclimateafrica.org

Historical and future climate data

We used the daily temperature and rainfall simulations for historical (1950-2005) and future (2006-2099) periods from 34 General Circulation Models (GCMs) listed in Table 1. These models are from the Coupled Model Inter-comparison Project 5 (CMIP5) corresponding to the Fifth Assessment Report of the Intergovernmental Panel for Climate Change (AR5 IPCC). The historical simulations represent simulated climate variability from the mid-19th century to early 21st century, driven by anthropogenic and natural forcings. As the level of present emissions is just above the **Representative Concentration Pathway** (RCP) 8.5, we used climate simulations based on the high-emission business as usual pathway, RCP8.5^{11,12}. Other lower emission RCPs are available in the CMIP5 database, but we only show results for RCP8.5 here.

Methods

Figure 1 shows the elevation and location map of Malawi. For developing the climate briefs, both temperature and rainfall variables have been extracted over a domain – 8.25°S-17.75°S latitude and 32.25°E-36.75°E longitude for covering the geographical extent of Malawi.

Downscaling of climate data

To analyse variations in future rainfall and temperature at a fine spatial resolution, we used the delta change method^{13,14}. This method is widely used for downscaling coarse resolution GCM projections to derive information at finer spatial scale¹⁵ for climate change impact modelling (e.g. hydrological and crop modelling) studies, which require temperature and rainfall changes at higher resolution^{16,17,18}. In this method, a change factor is applied to the observed climatology of temperature and rainfall. This change factor represents the climate change signal as derived from the climate models, and is calculated as a difference of mean changes in the future and historical climate simulations of a GCM (Equation 1)¹⁹. The derived time series provides higher resolution information consistent with future projections of a changing climate²⁰.

$$\mathbf{P}_{\text{new}} = \mathbf{P}_{\text{Obs}} + (\mathbf{P}_{\text{futr}} - \mathbf{P}_{\text{hist}})$$
(1)

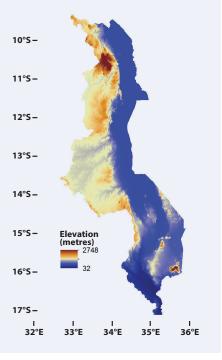
where, P_{new} , P_{obs} , P_{futr} and P_{hist} represents the new time series, observations in the historical period, raw GCM output for the future period and raw GCM output for the historical period, respectively. P_{futr} - P_{hist} represents the change factor.

Like other downscaling methods, there are advantages and limitations of using the delta change method. While it preserves the general climate change signal, it does not capture change in variance^{21,22} or account for local climatic variations^{23,24}. The method requires observations for the representative period²⁵, which can be challenging in data scarce regions. For this study, the 30-year period from the historical simulations used in Equation 1 (1976-2005) is different from the available observations (1981-2010).

We present results for change in mean annual rainfall and temperature for all 34 CMIP5 models separately, and the Multi-Model Ensemble (MME) of historical and future simulations of temperature and rainfall from 34 CMIP5 models to show spatial patterns of change. We averaged monthly rainfall and temperature over the period 1976-2005 for historical simulations, medium-term (2021-2050), long-term (2070-2099) for future simulations and observed rainfall and temperature over the period 1981-2010. We obtained monthly change factors (12 each) for medium and long-term periods. The change factors were interpolated using bi-cubic interpolation and were added to CHIRPS and CRU observations for preparing new time series for medium and long-term future periods for rainfall and temperature, respectively. Using the monthly change factors we derived annual and seasonal change factors to address seasonal climatic specificities of Malawi.

We used well-defined seasons for Malawi; March to May (MAM), September to November (SON) and December to February (DJF). These seasons were considered important in terms of water resource availability at the time of planting and crop growth stages by the Malawi Department for Climate Change and Meteorological Services (DCCMS).

Figure 1: Elevation map of Malawi based on 30-metres Shuttle Radar Topography Mission data²⁶



1 ACCESS1-0 2 ACCESS1-3 3 Bocc sam1-1 4 Bocc sam1-1 5 BNU-ESM 6 CanESM2 7 CCSM4 7 CCM4 7 CCM4 7 CCM4 7 CCM4 7 CCM4 7		Model	Modelling Centre/Group
2 ACCESS1-3 ACCESS1-3 3 bcc-sm1-1 Beljing Climate Center, China Meteorological Administration, China 4 bcc-sm1-1 Beljing Climate Center, China Meteorological Administration, China 5 RNLESM College of Global Change and Earth System Science, Beljing Normal University, China 6 CanESM2 Canadian Centre for Climate Modelling and Analysis, Canada 7 CCSM4 University of Mami – RSMAS, United States 8 CESM1-CAMS Community Earth System Model Contributors, NSF-DOE-NCAR, United States 9 CESM1-CAMS Centre Curo. Hediterraneo per I Cambiamenti Climatici, Italy 10 CMCC-CMS Centre National de Recherches Météorologiques, France 11 CMCC-CMS Centre National de Recherches Météorologiques, France 12 CAGA-Sys2 LASG, Institute of Amospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China 15 EC-FARTH Irish Centre for High-End Computing (ICHEC), Iteland 16 FGOL-SM32 NAGA Geophysical Fluid Dynamics Laboratory, United States 17 GFDL-CSM2 National Institute of Meteorological Research/Korea Meteorological Administration, South Korea 13 HadGEM2-AO National Institute of Meteorolog	1	ACCESS1-0	Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia
Instruct of the section of t	2	ACCESS1-3	
4 bcccam1-1-m 5 BUL-ESM College of Global Change and Earth System Science, Beijing Normal University, China 6 GanESM2 Canadian Centre for Climate Modelling and Analysis, Canada 7 CCSM4 University of Miami – RSMAS, United States 8 CESM1-EGC Community Earth System Model Contributors, NSF–DOE–NCAR, United States 9 CESM1-CAMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 10 CMCC-CM Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 11 CMCC-CMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 12 CMCC-CMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 13 CMRM-CMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 14 CSIRO-VA3-c6 CSIRO-Queensland Climate Change Centre of Excellence, Australia 15 EC-EMRTH Itals Centre of High-End Computing (ICHEC), Iteland 16 FGOL-S92 LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China 17 GFDL-ESM2M NAAA Geophysical Fluid Dynamics Laboratory, United States 19 GFDL-ESM2M NAtto an	3	bcc-csm1-1	Beijing Climate Center, China Meteorological Administration, China
6 CanESM2 Canadian Centre for Climate Modelling and Analysis, Canada 7 CCSM4 University of Miami – RSMAS, United States 8 CESM1-BGC Community Earth System Model Contributors, NSF–DOE–NCAR, United States 9 CESM1-CAMS Centro Euro -Mediterraneo per I Cambiamenti Climatici, Italy 10 CMCC-CMS Centro Euro -Mediterraneo per I Cambiamenti Climatici, Italy 11 CMCC-CMS Centro Euro -Mediterraneo per I Cambiamenti Climatici, Italy 12 CMCC-CMS Centro Euro -Mediterraneo per I Cambiamenti Climatici, Italy 13 CNRNO-MS-6-0 CSIRO - Queensland Climate Change Centre of Excellence, Australia 14 CSIRO-MA3-6-0 CSIRO - Queensland Climate Change Centre of Excellence, Australia 15 EC-EARTH Irish Centre for High-End Computing (ICHEC), Ireland 16 FGOLLSJ2 LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China 17 GFDL-ESM2M NoAA Geophysical Fluid Dynamics Laboratory, United States 18 GFDL-ESM2M National Institute of Meteorological Research/Korea Meteorological Administration, South Korea 12 HadGEM2-CC Met Office Hadley Centre, United Kingdom 13 INM-CM4 Institut Flerre-Simon Laplace, France 14 Institut Pierre-Simon Laplace, France 15	4	bcc-csm1-1-m	
7 CCSM4 University of Miami – RSMAS, United States 8 CESM1-BGC Community Earth System Model Contributors, NSF–DOE–NCAR, United States 9 CESM1-CAMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 10 CMCC-CM Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 11 CMCC-CMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 12 CMCC-CMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 13 CNRM-CMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy 14 CSIRO-MK3-6-00 CSIRO - Queensland Climate Change Centre of Excellence, Australia 15 ECFARTH trish Centre for High-End Computing (ICHEC), Ireland 16 FGOAL5-g2 LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China 17 GFDL-CMSA MAGEM2-ACO National Institute of Meteorological Research/Korea Meteorological Administration, South Korea 12 HadGEM2-EC Met Office Hadley Centre, United Kingdom Met Office Hadley Centre, United Kingdom 13 INM-CM4 Institute For Numerical Mathematics, Russia Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan 14 IPSL-CMSA-LR Japan Agency for Marine-Earth Science a	5	BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University, China
Image: Segmet and Seg	6	CanESM2	Canadian Centre for Climate Modelling and Analysis, Canada
CESM1-CAMS Control High Splein Hoder Control United Splein 10 CMCC-CESM 11 CMCC-CESM 12 CMCC-CMS 13 CNRM-CMS 14 CSIRO-MK3-6-0 15 EC-EARTH 16 FGOALS-g2 17 GFDL-CM3 18 GFDL-ESM2G 19 GFDL-ESM2G 10 NOAA Geophysical Fluid Dynamics Laboratory, United States 19 GFDL-ESM2G 10 NOAA Geophysical Fluid Dynamics Laboratory, United States 10 HadGEM2-AQ 11 HadGEM2-AC 12 HadGEM2-AC 14 Institute for Numerical Mathematics, Russia 12 HadGEM2-ES 13 INM-CM4 14 Institute for Numerical Mathematics, Russia 15 IPSL-CMSA-LR 16 FSL-CMSA-LR 17 MIROCS 18 MIROC-ESM-CE 19 MIROC-ESM-CE 10 Institute for Numerical Mathematics, Russia 12 HadGEM2-ES 19 MIR	7	CCSM4	University of Miami – RSMAS, United States
Int CMCC-CESM Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy Int CMCC-CMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy Int CMCC-CMS Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy Int CMCC-CMS Centre National de Recherches Météorologiques, France Int CSIRO-MIA3-6-0 CSIRO-Queensland Climate Change Centre of Excellence, Australia Int EC-EARTH Irish Centre for High-End Computing (ICHEC), Ireland Int FGOALS-g2 LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China Int GFDL-ESM2A MAdeophysical Fluid Dynamics Laboratory, United States Int HadGEM2-CQ MAtoinal Institute of Meteorological Research/Korea Meteorological Administration, South Korea Int HadGEM2-CC Met Office Hadley Centre, United Kingdom Institute for Numerical Mathematics, Russia Institut For Numerical Mathematics, Russia Institut Pierre-Simon Laplace, France Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan Institut Pierre-Simon Laplace, France Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and Nation	8	CESM1-BGC	Community Earth System Model Contributors, NSF–DOE–NCAR, United States
11CMCC-CMCentro Euro-Mediterraneo per l Cambiamenti Climatici, Italy12CMCC-CMS13CMCM-CMSCentre National de Recherches Météorologiques, France14CSIRO-MIA-6-0CSIRO - Queensland Climate Change Centre of Excellence, Australia15EC-EARTHIrish Centre for High-End Computing (ICHEC), Ireland16FGOALS-g2LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China17GFDL-CM3Mational Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China18GFDL-ESM204NAtional Institute of Meteorological Research/Korea Meteorological Administration, South Korea20HadGEM2-CQMational Institute of Meteorological Research/Korea Meteorological Administration, South Korea21HadGEM2-CCMet Office Hadley Centre, United Kingdom22HadGEM2-CCInstitute for Numerical Mathematics, Russia23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CMSA-LR25IPSL-CMSA-LR26IPSL-CMSA-LR27MIROCS28MIROC-ESM29MIROC-ESM-CHEM30MPI-ESM-LR31MPI-ESM-LR32MRI-CSM33MRI-CSM334Marchanal Institute for Meteorology, Germany31MPI-ESM-LR32MRI-CSM333MRI-ESM134MRI-ESM135MRI-CSM336MRI-CSM337MRI-CSM3	9	CESM1-CAM5	
12CMCC-CMS13CMR-CMSCentre National de Recherches Météorologiques, France14CSIRO-MA3-6-0CSIRO - Queensland Climate Change Centre of Excellence, Australia15EC-EARTHIrish Centre for High-End Computing (ICHEC), Ireland16FGOALS-g2LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China17GFDL-CM318GFDL-ESM2GNOAA Geophysical Fluid Dynamics Laboratory, United States19GFDL-ESM2A20HadGEM2-CCMet Office Hadley Centre, United Kingdom21HadGEM2-CCMet Office Hadley Centre, United Kingdom23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CMSA-LRMet Office Hadley Centre, United Kingdom25IPSL-CMSA-LRInstitut Pierre-Simon Laplace, France26MIROCSJapan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan29MIROCJapan Agency for Marine-Earth Science and Technology, Germany31MPI-ESM-LRMax Planck Institute for Meteorology, Germany32MRI-CGCM3Max Planck Institute, Japan33MRI-CSM3Meteorological Research Institute, Japan	10	CMCC-CESM	Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy
11CNRM-CMSCentre National de Recherches Météorologiques, France12CSIRO-MK3-6-0CSIRO - Queensland Climate Change Centre of Excellence, Australia13EC-EARTHIrish Centre for High-End Computing (ICHEC), Ireland14FGOALS-g2LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China17GFDL-CM3MOAA Geophysical Fluid Dynamics Laboratory, United States19GFDL-ESM2AMNAA Geophysical Fluid Dynamics Laboratory, United States20HadGEM2-CCMet Office Hadley Centre, United Kingdom21HadGEM2-CCMet Office Hadley Centre, United Kingdom23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CMSA-LRInstitute Pierre-Simon Laplace, France25IPSL-CMSA-LRJapan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan29MIROC-ESMMax Planck Institute for Meteorology, Germany31MPI-ESM-LRMax Planck Institute for Meteorology, Germany32MRI-CGM3Meteorological Research Institute, Japan33MRI-ESM1	11	CMCC-CM	
14 CSIR0 - Queensland Climate Change Centre of Excellence, Australia 15 EC-EARTH Irish Centre for High-End Computing (ICHEC), Ireland 16 FGOALS-g2 LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China 17 GFDL-CM3 18 GFDL-ESM2G 19 GFDL-ESM2G 10 HadGEM2-AO 11 National Institute of Meteorological Research/Korea Meteorological Administration, South Korea 12 HadGEM2-CC Met Office Hadley Centre, United Kingdom 12 HadGEM2-ES 13 INM-CM4 14 Institute for Numerical Mathematics, Russia 14 IPSL-CM5A-LR 15 IPSL-CM5A-MR 16 Institute Pierre-Simon Laplace, France 17 MIROC-ESM 18 MIROC-ESM 19 MIROC-ESM-CHEM 10 MPI-ESM-LR 11 May Planck Institute for Meteorology, Germany 12 MRI-CGCM3 13 MRI-CGCM3 14 MIR-CGCM3 15 MIR-CGCM3 16	12	CMCC-CMS	
15EC-EARTHIrish Centre for High-End Computing (ICHEC), Ireland16FGOALS-g2LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China17GFDL-CM3PAGEophysical Fluid Dynamics Laboratory, United States18GFDL-ESM2GNOAA Geophysical Fluid Dynamics Laboratory, United States19GFDL-ESM2MNational Institute of Meteorological Research/Korea Meteorological Administration, South Korea20HadGEM2-AONational Institute of Meteorological Research/Korea Meteorological Administration, South Korea21HadGEM2-CCMet Office Hadley Centre, United Kingdom22HadGEM2-ESInstitute for Numerical Mathematics, Russia23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CMSA-LRInstitut Pierre-Simon Laplace, France25IPSL-CMSB-LRJapan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan29MIROC-ESM-CHEMMar Planck Institute for Meteorology, Germany31MPI-ESM-LRMateorological Research Institute, Japan32MRI-CGCM3Meteorological Research Institute, Japan33MRI-ESM1	13	CNRM-CM5	Centre National de Recherches Météorologiques, France
16 FGOALS-g2 LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China 17 GFDL-CM3 AGEOPHYSICal Fluid Dynamics Laboratory, United States 18 GFDL-ESM2G NOAA Geophysical Fluid Dynamics Laboratory, United States 19 GFDL-ESM2M Autional Institute of Meteorological Research/Korea Meteorological Administration, South Korea 20 HadGEM2-AO National Institute of Meteorological Research/Korea Meteorological Administration, South Korea 21 HadGEM2-CC Met Office Hadley Centre, United Kingdom 22 HadGEM2-ES Met Office Hadley Centre, United Kingdom 23 INM-CM4 Institute for Numerical Mathematics, Russia 24 IPSL-CMSA-LR Institut Pierre-Simon Laplace, France 25 IPSL-CMSB-LR Institut Pierre-Simon Laplace, France 26 IPSL-CMSB-LR Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan 29 MIROC-ESM Max Planck Institute for Meteorology, Germany 31 MPI-ESM-LR Max Planck Institute for Meteorology, Germany 32 MRI-CGCM3 Meteorological Research Institute, Japan 33 <td>14</td> <td>CSIRO-Mk3-6-0</td> <td>CSIRO - Queensland Climate Change Centre of Excellence, Australia</td>	14	CSIRO-Mk3-6-0	CSIRO - Queensland Climate Change Centre of Excellence, Australia
17 GFDL-CM3 18 GFDL-ESM2G 19 GFDL-ESM2M 20 HadGEM2-AO 21 HadGEM2-CC 22 HadGEM2-CC 23 INM-CM4 24 IPSL-CMSA-LR 25 IPSL-CMSA-LR 26 IPSL-CMSA-LR 27 MIROC5 28 MIROC-ESM 29 MIROC-ESM-CHEM 30 MPI-ESM-LR 31 MPI-ESM-LR 32 MAX Planck Institute for Meteorology, Germany 31 MPI-ESM-MR 32 MR-CGCM3 33 MRI-ESM1	15	EC-EARTH	Irish Centre for High-End Computing (ICHEC), Ireland
18GFDL-ESM2GNOAA Geophysical Fluid Dynamics Laboratory, United States19GFDL-ESM2MNational Institute of Meteorological Research/Korea Meteorological Administration, South Korea20HadGEM2-CCMet Office Hadley Centre, United Kingdom22HadGEM2-ESMet Office Hadley Centre, United Kingdom23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CMSA-IRInstitute Pierre-Simon Laplace, France25IPSL-CMSB-LRInstitut Pierre-Simon Laplace, France26MIROC-ESMAgana Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan29MIROC-ESM-CHEMMax Planck Institute for Meteorology, Germany31MPI-ESM-LRMax Planck Institute for Meteorology, Germany31MRI-CGCM3Meteorological Research Institute, Japan33MRI-ESM1Meteorological Research Institute, Japan	16	FGOALS-g2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University, China
19GFDL-ESM2M20HadGEM2-AONational Institute of Meteorological Research/Korea Meteorological Administration, South Korea21HadGEM2-CCMet Office Hadley Centre, United Kingdom22HadGEM2-ESMet Office Hadley Centre, United Kingdom23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CM5A-LRInstitute for Numerical Mathematics, Russia25IPSL-CM5A-LRInstitut Pierre-Simon Laplace, France26IPSL-CM5B-LRJapan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan29MIROC-ESMJapan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan30MPI-ESM-LRMax Planck Institute for Meteorology, Germany31MPI-ESM-MRMateorological Research Institute, Japan32MRI-CGCM3Meteorological Research Institute, Japan	17	GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory, United States
20HadGEM2-AQNational Institute of Meteorological Research/Korea Meteorological Administration, South Korea21HadGEM2-CCHadGEM2-ES22HadGEM2-ESHatGEM2-ES23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CM5A-LRHatture for Numerical Mathematics, Russia25IPSL-CM5A-LRInstitute Pierre-Simon Laplace, France26IPSL-CM5B-LRInstitut Pierre-Simon Laplace, France27MIROC5Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan29MIROC-ESM-CHEMMax Planck Institute for Meteorology, Germany31MPI-ESM-MRMateorology, Germany32MRI-CGCM3Meteorological Research Institute, Japan33MRI-ESM1Meteorological Research Institute, Japan	18	GFDL-ESM2G	
21HadGEM2-CCMet Office Hadley Centre, United Kingdom22HadGEM2-ESInstitute for Numerical Mathematics, Russia23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CMSA-LRInstitut Pierre-Simon Laplace, France25IPSL-CMSB-LRInstitut Pierre-Simon Laplace, France26IPSL-CMSB-LRJapan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan29MIROC-ESM-CHEMMax Planck Institute for Meteorology, Germany31MPI-ESM-MRMax Planck Institute for Meteorology, Germany32MRI-CGCM3Meteorological Research Institute, Japan33MRI-ESM1	19	GFDL-ESM2M	
22HadGEM2-ESMet Office Hadley Centre, United Kingdom23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CMSA-LRInstitute for Numerical Mathematics, Russia25IPSL-CMSA-MRInstitut Pierre-Simon Laplace, France26IPSL-CMSB-LRInstitut Pierre-Simon Laplace, France27MIROC5Image Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan29MIROC-ESM-CHEMImage Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan30MPI-ESM-LRImage Agency for Metheorology, Germany31MRI-ESM-MRMateorological Research Institute, Japan32MRI-CGCM3Image Agency for Matine, Japan33MRI-ESM1Image Agency for Matine, Japan	20	HadGEM2-AO	National Institute of Meteorological Research/Korea Meteorological Administration, South Korea
22HadGEM2-ES23INM-CM4Institute for Numerical Mathematics, Russia24IPSL-CM5A-LR25IPSL-CM5A-MRInstitut Pierre-Simon Laplace, France26IPSL-CM5B-LR27MIROC528MIROC-ESM30MPI-ESM-LR30MPI-ESM-LR31MPI-ESM-MR32MRI-CGCM333MRI-ESM1	21	HadGEM2-CC	Met Office Hadley Centre, United Kingdom
24IPSL-CM5A-LR25IPSL-CM5A-MR26IPSL-CM5B-LR27MIROC528MIROC-ESM29MIROC-ESM-CHEM30MPI-ESM-LR31MPI-ESM-MR32MR-CGCM333MRI-ESM1	22	HadGEM2-ES	
25IPSL-CM5A-MRInstitut Pierre-Simon Laplace, France26IPSL-CM5B-LR	23	INM-CM4	Institute for Numerical Mathematics, Russia
26IPSL-CMSB-LR27MIROC528MIROC-ESM29MIROC-ESM-CHEM30MPI-ESM-LR31MPI-ESM-MR32MR-CGCM333MRI-CSM1	24	IPSL-CM5A-LR	Institut Pierre-Simon Laplace, France
27MIROC528MIROC-ESM29MIROC-ESM-CHEM30MPI-ESM-LR31MPI-ESM-MR32MRI-CGCM333MRI-CSM1	25	IPSL-CM5A-MR	
NIROC-ESMJapan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan10MPI-ESM-LRMax Planck Institute for Meteorology, Germany11MPI-ESM-MRMax Planck Institute for Meteorology, Germany12MRI-CGCM3Meteorological Research Institute, Japan13MRI-ESM1Meteorological Research Institute, Japan	26	IPSL-CM5B-LR	
 MIROC-ESM MIROC-ESM-CHEM MIROC-ESM-CHEM MPI-ESM-LR MPI-ESM-MR MRI-CGCM3 MRI-CGCM3 MRI-ESM1 	27	MIROC5	
29 MIROC-ESM-CHEM 30 MPI-ESM-LR 31 MPI-ESM-MR 32 MRI-CGCM3 33 MRI-ESM1	28	MIROC-ESM	
MPI-ESM-MR Max Planck Institute for Meteorology, Germany 32 MRI-CGCM3 33 MRI-ESM1	29	MIROC-ESM-CHEM	
31 MPI-ESM-MR 32 MRI-CGCM3 33 MRI-ESM1	30	MPI-ESM-LR	Max Planck Institute for Meteorology, Germany
33 MRI-ESM1 Meteorological Research Institute, Japan	31	MPI-ESM-MR	
33 MRI-ESM1	32	MRI-CGCM3	Meteorological Research Institute, Japan
34 NorESM1-M Norwegian Climate Centre, Norway	33	MRI-ESM1	
nonegan cinter control froma	34	NorESM1-M	Norwegian Climate Centre, Norway

Table 1: List of 34 CMIP5 climate models used for analysing future climate change for Malawi

Recent climate variability and extremes from observations

Figure 2: CHIRPS observed annual and seasonal rainfall trend (linear trend by grid cell in mm/year) for 1981-2016. Seasons are March to May (MAM), September to November (SON) and December to February (DJF)

CHIRPS Annual trend 1981-2016 mm/yr

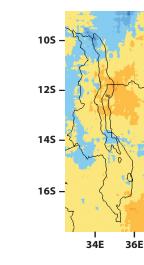
10S

125 -

14S

16S -

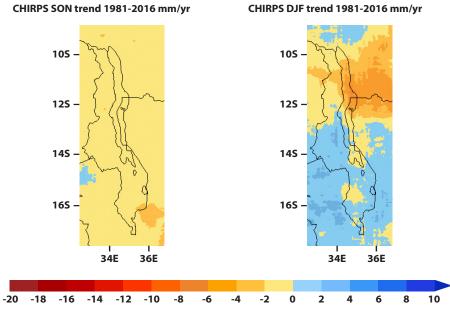
CHIRPS MAM trend 1981-2016 mm/yr



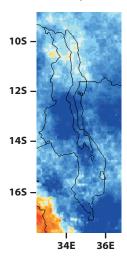
CHIRPS SON trend 1981-2016 mm/yr

34E

36E



CHIRPS MAM 1989 Anomaly wrt 1981-2016%



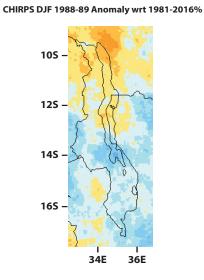
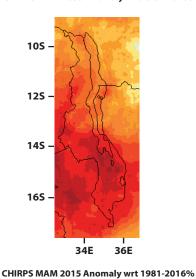
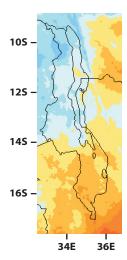


Figure 3: CHIRPS observed mean seasonal precipitation anomaly (%) for the wettest year 1989, driest year 2005 and recent dry year 2014/15 with respect to the mean for 1981-2016. Seasons are December to February (DJF) and March to May (MAM)

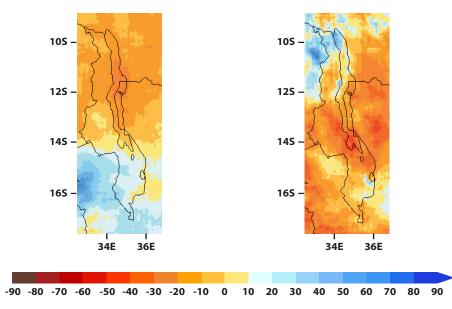
CHIRPS MAM 2005 Anomaly wrt 1981-2016%



CHIRPS DJF 2004-05 Anomaly wrt 1981-2016%



CHIRPS DJF 2014-15 Anomaly wrt 1981-2016%



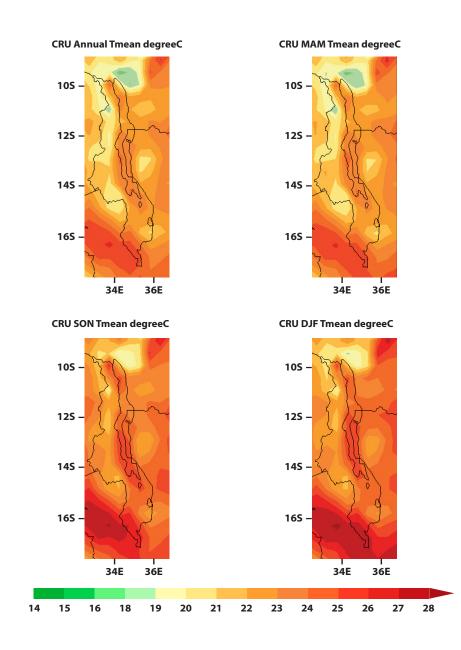


Figure 4: CRU observed annual and seasonal mean temperature (°C) for 1976-2005. Seasons are March to May (MAM), September to November (SON) and December to February (DJF)

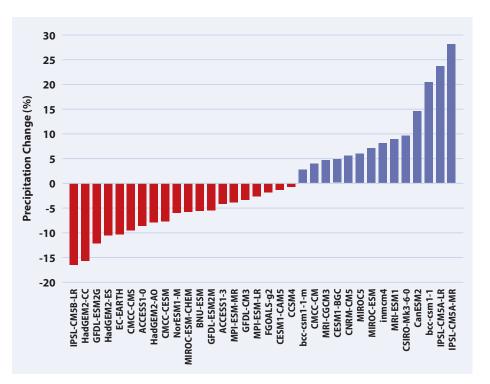
Projections of future climate

We use the daily temperature and rainfall simulations for historical (1950-2005) and future (2006-2099) periods from 34 global climate models from CMIP5 corresponding to the IPCC's AR5. We present climate simulations based only on a high greenhouse gas emission pathway, RCP8.5 (projections with other rates of emissions are available).

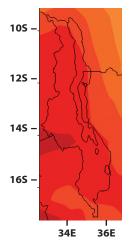
Rainfall

Figure 5: Per cent change in annual mean rainfall for all Malawi between the GCM simulated current period (1976-2005) and 2070-2099 for 34 GCMs

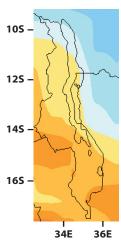
Figure 6: Per cent change in mean annual and seasonal precipitation change for the 2090s (2070-2099) compared to current period 1976-2005 using ensemble mean of 34 CMIP5 models for annual, March to May (MAM), September to November (SON) and December to February (DJF)



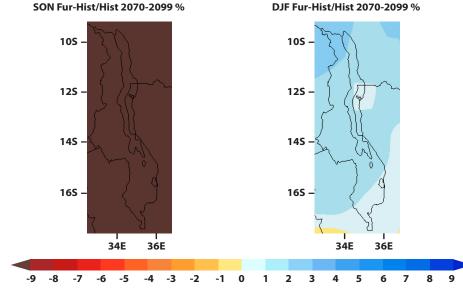
Annual Fur-Hist/Hist 2070-2099 %



MAM Fur-Hist/Hist 2070-2099 %



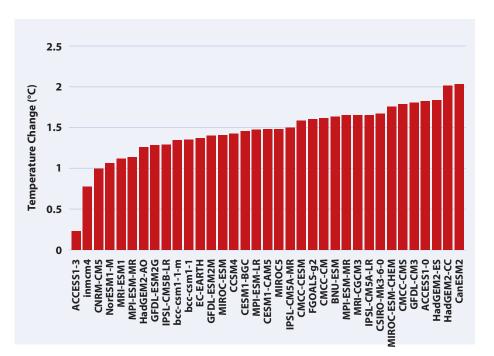
DJF Fur-Hist/Hist 2070-2099 %



Temperature

Figure 7: Change in annual mean temperature (°C) for all Malawi between the GCM simulated current period (1976-2005) and 2021-50 for 34 GCMs

Figure 8: Change in annual mean temperature (°C) between the GCM simulated current period (1976-2005) and 2070-99 for 34 GCMs



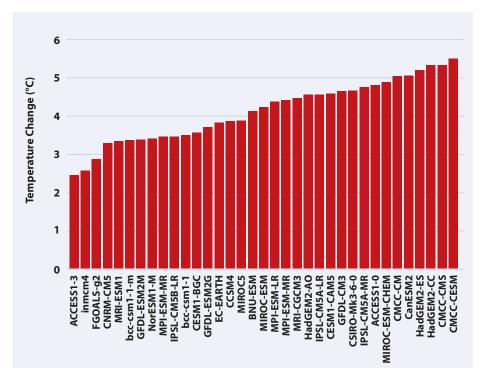


Figure 9: Mean seasonal temperature change (°C) for near-term 2021-2050 compared to current period 1976-2005 using ensemble mean of 34 CMIP5 models for annual, March to May (MAM), September to November (SON) and December to February (DJF)

Tmean Annual 2021-2050 wrt 1976-2005 %

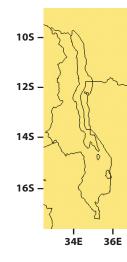
10S

12S -

14S

16S

Tmean MAM 2021-2050 wrt 1976-2005 %



34E Tmean SON 2021-2050 wrt 1976-2005 %

36E

Tmean DJF 2021-2050 wrt 1976-2005 %

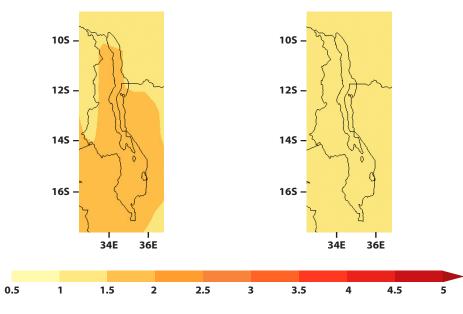
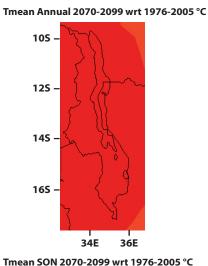
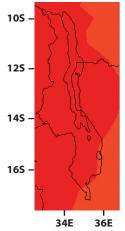


Figure 10: Mean seasonal temperature change (°C) for the long-term 2070-2099 compared to current period 1976-2005 using ensemble mean of 34 CMIP5 models for annual, March to May (MAM), September to November (SON) and December to February (DJF)







Tmean DJF 2070-2099 wrt 1976-2005 °C

34E

36E

10S

12S

14S -

16S -

Figure 11: Time series of mean annual temperature (°C) for 34 CMIP5 models and their ensemble (bold red line) for the period 1950-2099 and CRU observations (bold black line) for the period 1950-2014

10S

3 3.5 4 4.5 5 period 1950-2014 CCSM4 CESM1-BGC CESM1-CAM5 EC-EARTH FGOALS-g2 MPI-ESM-MR ACCESS1-0 ACCESS1-3 bcc-csm1-1 bcc-csm1-1-m BNU-ESM CanESM2 CSIRO-Mk3-6-0 CMCC-CESM CMCC-CM CMCC-CMS CNRM-CM5 GFDL-CM3 GFDL-ESM2G GFDL-ESM2M HadGEM2-A0 HadGEM2-CC HadGEM2-ES inmcm4 IPSL-CM5A-LR IPSL-CM5A-MR IPSL-CM5B-LR MIROC5 **MIROC-ESM MIROC-ESM-CHEM** NorESM1-M MME - MPI-ESM-LR MRI-CGCM3 MRI-ESM1 Observed 32 32 30 30 Mean annual Temperature (°C) 28 28 26 26 24 24 22 22 20 20 18 18

10

Endnotes

- 1 FCFA (2017a) Country climate brief. *Future climate projections for Malawi*. Cape Town: Future Climate for Africa. www. futureclimateafrica.org/resource/futureclimate-projections-for-malawi
- 2 FCFA (2017b) Summary: *Future climate* projections for Malawi. Cape Town: Future Climate for Africa. www.futureclimateafrica. org/resource/future-climate-projections-formalawi/
- 3 Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. and Michaelson, J. (2015) The Climate Hazards Infrared Precipitation with Stations-A new environmental method for monitoring extremes. *Scientific Data*, 2, p. 150066
- 4 Badr, H.S., Dezfuli, A.K., Zaitchik, B.F. and Peters-Lidard, C.D. (2016) Regionalising Africa: Patters of precipitation variability in observations and global climate models. *Journal of Climate*, 29(24), p. 9027-9043
- 5 McNally, A., Arsenault, K., Kumar, S., Shukla, S., Peterson, P., Wang, S., Funk, C., Peters-Liard, C.D. and Verdin, P. (2012) A land data assimilation system for sub-Saharan Africa food and water security applications. *Scientific Data*, 4, p. 170012
- 6 Sossa, A., Liebmann, B., Bladé, I., Allured, D., Hendon, H.H., Peterson, P. and Hoell, A. (2017) Statistical connection between the Madden-Julian Oscillation and large daily precipitation events in West Africa. *Journal of Climate*, 30(6), p. 1999-2010.
- 7 Harris, I.P.D.J., Jones, P.D., Osborn, T.J. and Lister, D.H. (2014) Updated high resolution grids of monthly climatic observations-the

CRU TS3.10 dataset. *International Journal of Climatology*, 34(3), p. 623-642.

- 8 Fotso-Nguemo, T.C., Vondou, D.A., Tchawoua, C. and Haensler, A. (2016) Assessment of simulated rainfall and temperature from the regional climate model REMO and future changes over central Africa. *Climate Dynamics*, 48(11–12), p. 3685–3705
- 9 Camberlin, P. (2017) Temperature trends and variability in the Greater Horn of Africa: interactions with precipitation. *Climate Dynamics*, 48(1-2), p. 477-498
- 10 Sossa, A. et al. (2017) Op. cit.
- Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N. and Rafaj, P. (2011) RCP 8.5-A scenario of comparatively high greenhouse gas emissions. *Climatic Change*, 109(1-2) p. 33
- 12 Sanford, T., Frumhoff, P.C., Luers, A. and Gulledge, J. (2014) The climate policy narrative for a dangerously warming world. *Nature Climate Change*, 4(3), p. 164-166.
- 13 Tabor, K. and Williams, J.W. (2010) Globally downscaled climate projections for assessing the conservation impacts of climate change. *Ecological Applications*, 20(2), p. 554-565
- 14 Räty, O. Räisänen, J. and Ylhäisi, J.S.
 (2014) Evaluation of delta change and bias correction methods for future daily precipitation: intermodal cross-validation using ENSEMBLES simulations. *Climate Dynamics*, 42(9-10), p. 2287-2303.
- 15 Keller, D.E., Fischer, A.M., Liniger, M.A., Appenzeller, C. and Knutti, R. (2017) Testing a weather generator for downscaling climate change projections over Switzerland. *International Journal of Climatology*, 37, p. 928-942.

- 16 Teutschbein, C., Wetterhall, F. and Siebert, J. (2011) Evaluation of different downscaling techniques for hydrological climate change impact studies at the catchment scale. *Climate Dynamics*, 37(9-10), p. 2087-2105.
- 17 Hawkins, E., Osborne, T.M., Ho, C.K., and Challinor, A.J. (2013) Calibration and bias correction of climate projections for crop modelling: an idealised case study over Europe. *Agricultural and Forest Meteorology*, 170, p. 19-31.
- 18 House, A.R., Thompson, J.R., and Acreman, M.C. (2016) Projecting impacts of climate change on hydrological conditions and biotic responses in a chalk valley riparian wetland. *Journal of Hydrology*, 534, p. 178-192
- 19 Tabor, K. and Williams, J.W. (2010) Op. cit.
- 20 Räty et al. (2014) Op. cit.
- 21 Teutschbein, C., Wetterhall, F. and Siebert, J. (2011) Op. cit.
- 22 Addor, N., Rössler, O., Köplin, N., Huss, M., Weingartner, R. and Siebert, J. (2014) Robust changes and sources of uncertainty in the projected hydrological regimes of Swiss catchments. *Water Resources Research*, 50(10), p. 7541-7562.
- 23 Onyutha, C., Tabari, H., Rutkowska, A., Nyeko-Ogiramoi, P. and Willems, P.
 (2016) Comparison of different statistical downscaling methods for climate change rainfall projections over the Lake Victoria basin considering CMIP3 and CMIP5. *Journal* of Hydro-environment Research, 12, p. 31-45.
- 24 Keller, D.E. et al. (2017) Op. cit.
- 25 Hawkins, E. et al (2017) Op. cit.
- 26 DIVA GIS http://www.diva-gis.org/gdata

About Future Climate for Africa

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. This brief was written by Neha Mittal of the UMFULA research team. You can find out more about their work under 'research teams' on www.futureclimateafrica.org.



www.futureclimateafrica.org



e: info@futureclimateafrica.org



t: +2721 4470211

This document is an output from a project funded by the UK Department for International Development (DFID) and the Natural Environment Research Council (NERC) for the benefit of developing countries and the advance of scientific research. However, the views expressed and information contained in it are not necessarily those of, or endorsed by DFID or NERC, which can accept no responsibility for such views or information or for any reliance placed on them. This publication has been prepared for general guidance on matters of interest only, and does not constitute professional advice. You should not act upon the information contained in this publication without obtaining specific professional advice. No representation or warranty (expressed or implied) is given as to the accuracy or completeness of the information contained in this publication, and, to the extent permitted by law, the Climate and Development Knowledge Network's members, the UK Department for International Development ('DFID'), the Natural Environment Research Council ('NERC'), their advisors and the authors and distributors of this publication do not accept or assume any liability, responsibility or duty of care for any consequences of you or anyone else acting, or refraining to act, in reliance on the information contained in this publication based on it.

Copyright © 2017, Climate and Development Knowledge Network. All rights reserved.