Urban Africa Risk Knowledge

Dar es Salaam Climate Profile: Full Technical Version

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Dar es Salaam climate profile

Historic climate

Dar es Salaam is located on the Tanzanian coast and has a tropical climate with relatively high temperatures, high humidity and annual rainfall over 1000 mm. Rainfall occurs all year round but primarily during two rainy seasons: the short rainy season from October to December and the main / long rainy season from March to May. Less rainfall occurs during January and February, and there is a long and relatively dry season from June to September. The warmest time of year is during January and February, and the coolest time of the year occurs during July and August; however, the season cycle is very small. More details are provided in Figure 1 below.

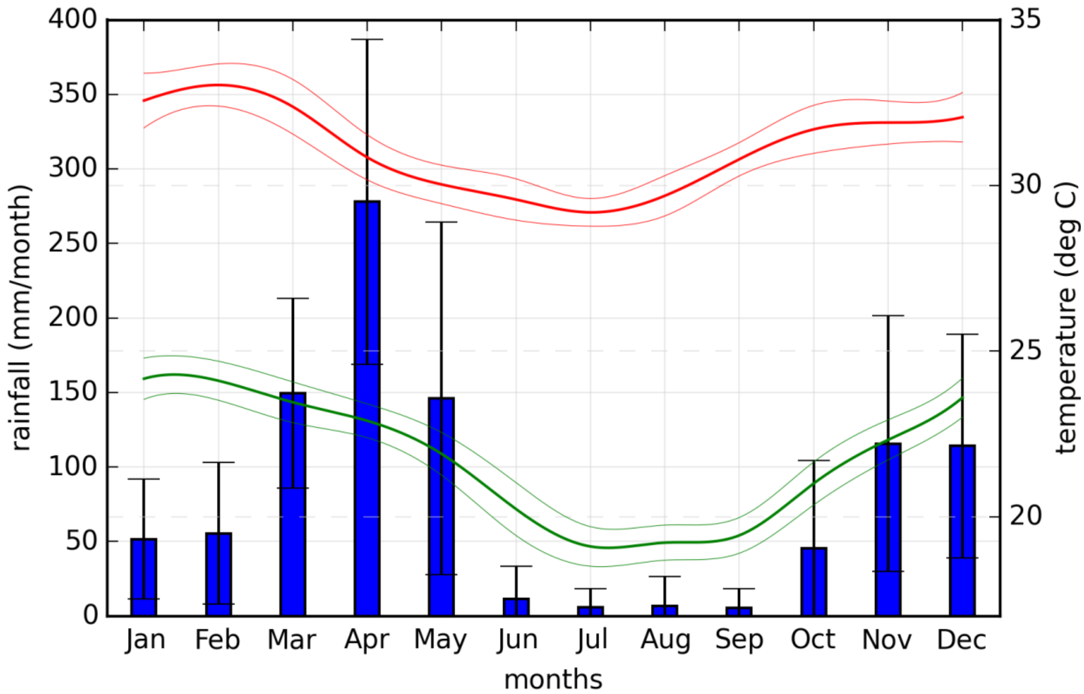

Figure 1: 1981 to 2010 historical average seasonality for gridcell over Dar es Salaam. Mean monthly total rainfall (mm/month) from the CHIRPS dataset depicted as blue bars, whiskers show +- 2 standard deviations. Monthly mean daily maximum and minimum temperature from the WFDEI dataset presented by the red and green lines respectively. Dashed lines represent the +- 2 standard deviation around these means.

The climate is not static, and rainfall and temperature display variability on a number of different time scales, from daily to decadal. On top of this, there may also be evidence of long-term trends in the climate; however, it can sometimes be difficult to distinguish between a trend and variability at a longer timescale, unless a very long historical record is used.

Rainfall

Rainfall varies on a number of time scales, from sub-daily to decadal. The diurnal cycle is an important mode of variability for rainfall. Over this region, rainfall is predominantly convective in nature (thunderstorms) and occurs during the late afternoon – early evening, but some storms may also develop over the ocean at night.

Rainfall in Dar es Salaam occurs during all months of the year, however the bulk of the rain takes place during two rainy seasons (Figure 1). This bimodal rainfall pattern is due to the migration of the Inter-Tropical Convergence Zone (ITCZ) over the region. During January and February the ITCZ is located to the south of the region and the rainfall during this period averages around 110 mm. The ITCZ moves north passing over the region during March – May, resulting in the long rains during where roughly 610 mm of rain falls. During the austral winter (June – September) the ITCZ is situated north of the region and little rainfall falls (less than 100mm during this period). The ITCZ shifts back south passing over the region during October to November resulting in the short rains, where roughly 350mm of rainfall falls on average.

The average annual (July-June) total rainfall is around 1200mm, however the year-to-year or interannual variability is large (Figure 2). Some years record as little as 950mm while others record more than 180mm. On multi-year to decadal time scales Dar es Salaam also experiences clear rainfall variability (Figure 3). Much of this is related to large scale remote forcings such as the El Nino Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). Over the northern coastal areas of Tanzania the positive phase (El Nino) of ENSO is generally associated with above-average rainfall during the short rains (OND). The opposite is true during the cool phase (La Nina) which is generally associated with below-average rainfall. The increased rainfall associated with El Nino conditions is generally due to a longer-than-normal rainfall season and more specifically an earlier onset. La Nina conditions tend to be associated with later-than-normal onset of the rainy season[1]. The positive phase of the IOD generally leads to increased rainfall during the short rains, and the cooler phase to drier-than-normal conditions. The long rains act independently to the short rains, and do not exhibit any consistent relationship to either ENSO or IOD.

Rainfall in Dar es Salaam has changed over time (Figure 4). The annual (July to June) rainfall has decreased in magnitude by -26mm/decade, and the frequency of wet days has decreased by over -6.5 days per decade. However, the rainfall within the two primary rainy seasons has changed independently of each other. The long rains (March to May) (Figure 6) show an increase in magnitude or seasonal total rainfall amount, and this is linked to a statistically significant increase in the daily intensity which has increased by nearly 6mm/day per decade. In contrast to the daily intensity, the frequency of rain days has seen a decreasing trend through time of almost 4 days per decade. A negative trend is also seen in the average duration of wetspells, which have decreased by almost 0.3 days per decade. This decrease in wetspell duration is mirrored by an increase in the average dryspell duration, with some years showing very long periods between rain events. The rate

[1] Kijazi, A. & Reason, C. (2005) Relationships between intraseasonal rainfall variability of coastal Tanzania and ENSO. Theoretical and Applied Climatology 82: 153-176.

of change was generally highest during the 1980s and 1990s for most of these rainfall statistics, after which the rate of change generally decreased.

The short rains (October to December)(Figure 7) show a different picture. There is a negative trend in the seasonal total rainfall of -15 mm/decade. The strongest decreases occurred during the 1980s and 1990s after which there has been a slight recovery in rainfall totals. The frequency of rain days shows a similar pattern, with a negative trend overall, of just under 2 days per decade. The average wetspell duration has decreased by 0.1 days per decade which is mirrored by the average dryspell duration which has increased by almost 11 days per decade. Heavy rainfall frequency also shows a negative trend of almost 1 day per decade. All these statistics show that the strongest negative change for both rainy seasons occurred during the 1980s and 1990s, and that there has been a slight recovery from around 2000 to the present. The one statistic not in line with these general trends is that of daily average rainfall intensity, which shows an increase through time and especially during the first two decades (1980s and 1990s). A summary of these results can be found in Table 1 below)

Temperature

Temperature also shows clear variability on a range of time scales. The diurnal temperature range – or difference between the maximum and minimum temperature within a 24-hour period – is an important mode of variability for Dar es Salaam. At Dar es Salaam it averages just over 9 °C, but varies between seasons; the largest differences occur in the second half of the dry season, especially September (11.3 °C), and the smallest differences occur in April (7.9 °C), which is the wettest month of the year (Figure 1).

The seasonal cycles of daily maximum and minimum temperature are relatively small, averaging 3.5 °C and 5 °C respectively (Figure 1). The warmest temperatures occur during January and February (~32.5 °C maximum and 24 °C minimum) and the coolest temperatures occur during the winter dry season (~29.5° and 19 °C). This small season cycle is due to Dar es Salaam being located very close to the equator and on the coast of a warm ocean which modulates the temperature through the year.

Temperatures show little interannual variability, with annual average daily maximum and minimum temperatures generally varying by less than half a degree from year to year(Figure 2). The variability for a specific month or season is generally larger than that for annual average temperature, varying by as much as 1 °C from the long term mean. This interannual variability is often linked to the ENSO signal, with warmer temperatures generally being associated with El Nino conditions, and cooler temperatures being associated with La Nina conditions. See figure 3 for further details.

Focussing on the longer-term multi-decadal timescale, Dar es Salaam shows a slight positive trend in daily maximum temperature throughout the year, but the trend is only statistically significant during the cooler dry season (+0.1 °C per decade)(Figure 8). Extreme hot days (days where the temperature exceeds 34.6 °C) occur historically from October through to April of the following year. These daytime hot events have seen a slight decrease in frequency (of number of hot events) and duration (of number of consecutive hot days), especially during the 1980s (Figure 9).

There is a stronger warming trend for average night-time temperatures from 1979-2014, and this warming trend is statistically significant in all seasons except during the long rains (Figure 10). Extreme warm nights (i.e. nights where the minimum temperature is > 24.5°) historically occur from December to March, and there has been a very clear increase in the frequency (+11 days per decade) and duration (of number of consecutive hot nights; +0.2 days per decade)(Figure 11).

“Extreme cold” days (which for Dar es Salaam means days where the maximum temperature is < 28 °C) historically occur during June to August, but occasionally occur during other times of the year. The frequency of these cold days has decreased over the last 30 years by almost 8 days per decade and the duration of “extreme cold” spells (i.e. back-to-back “extreme cold” days) has decreased, now averaging just a single day per year (Figure 12). “Extreme cold” nights (which for Dar es Salaam means nights where the minimum temperature is < 18.8 °C) historically occur primarily during July to September, and the frequency and duration of “extreme cold” night-time spells have also experienced a statistically significant decrease of -7.6 and -0.2 days per decade respectively, with the sharpest decrease occurring during the 1990s (Figure 13).

Table 1: Summary of trends in temperature and rainfall attributes, Dar es Salaam. The Theil-Sen linear trend slope (per decade) is provided along with the climatological mean value (in brackets). The rainfall is from the Dar es Salaam weather station and the temperature trends are calculated from the gridcell value over Dar es Salaam from the WFDEI dataset. Values in bold indicate a statistically significant change. Red(blue) colour indicates a warming(cooling) temperature trend. Green(brown) colour indicates a wetting(drying) precipitation trend.

Temperature	**Jan – Feb**	**Mar – May**	**Jun – Sep**	**Oct – Dec**
Tmax [°C/decade]	+0.05 (mean = 32.8)	+0.1 (mean = 31.1)	**+0.1** (mean = 29.8)	+0.1 (mean = 31.9)
Tmin [°C/decade]	**+0.3** (mean = 24.1)	(+0.1) (mean = 22.7)	**+0.2** (mean = 19.5)	**+0.3** (mean = 22.3)
	Annual (July – June)			
Tmax extreme hot events [days]	Frequency: -3.3	Duration: **-0.1**	Threshold: 34.6 °C	
Tmin extreme hot events [days]	Frequency: **+11**	Duration: **+0.2**	Threshold: 24.5 °C	
Tmax extreme cold events [days]	Frequency: **-7.9**	Duration: **-0.1**	Threshold: 28.0 °C	
Tmin extreme cold events [days]	Frequency: **-7.6**	Duration: **-0.2**	Threshold: 18.8 °C	
Rainfall	**Jan – Feb**	**Mar - May**	**Oct - Dec**	
Total rainfall [mm/decade]	-1.7 (mean = 105.4)	+24.2 (mean = 573.5)	-15.6 (mean = 275)	
Rain intensity [mm/day]	+0.8 (mean = 11.9)	**+5.8** (mean = 36.3)	+4.8 (mean = 37.7)	
Rain day frequency [days/decade]	**-0.2** (mean = 9.7)	**-3.8** (mean = 23.6)	**-1.9** (mean = 10.6)	
Heavy rain day frequency [days/decade]	no trend (mean = 4.3)	no trend (mean = 16.5)	**-1.0** (mean = 7.8)	
Wet spell [consecutive days]	no trend (mean = 1.5)	**-0.3** (mean = 2.0)	-0.1 (mean = 1.2)	
Dry spell [consecutive days]	-0.3 (mean = 14.2)	**+2.8** (mean = 22.9)	+10.9 (mean = 53.9)	

Climate change projections

Global climate models

Projections of future climate, based on 15 CMIP5 Global Climate Models (GCMs) simulations[2] under the RCP8.5 pathway[3], show a clear and statistically significant increase in both daily maximum and minimum temperature into the future (figure 14 & 15). By 2040 temperatures may be between 0.5 - 1 °C (for maximum temperatures) and 0.75 - 1.75 °C (for minimum temperatures) warmer than the current climate, depending on the GCM. Note that two models simulate an unrealistic decadal variability in daily maximum temperature, but do not change the overall message (please refer to Figure 14). The number of extreme hot days is projected to increase linearly through time, but there is large disagreement on the rate of change (Figure 16). Some models project just a small change, while others project that up to half the days per year will exceed the historical 90th percentile by 2040. The number of extreme hot nights is also projected to increase into the future and there is more agreement on the rate of change compared to daily maximum temperature (Figure 17). By 2040 the frequency of these hot nights is projected to occur on between 100 and 200 days per year depending on the GCM.

Rainfall is projected to remain within the historic range of variability until the second half of the century, when some models project an increase, while a couple project a decrease in rainfall; half the models project that it will remain within the current range of natural variability up to the end of the century (Figure 18). The models project no change or a slight increase in daily rainfall intensity toward the end of the century (Figure 19). The frequency of heavy and extreme rainfall days is projected to remain within the range of natural variability for the first half of the century (Figure 20 & 21). By the end of the century some models project an increase while a few project a decrease in frequency. Table 2 below provides a summary of these projected climate changes for Dar es Salaam.

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[2] The fifth iteration of the Couple Model Inter-comparison Project (CMIP) is a coordinated activity amongst international modelling centres to produce a suite of climate simulations using common experimental parameters. CMIP5 is currently the primary source of global to regional scale climate projections and extensively informed the IPCC Fifth Assessment Report (AR5)

[3] Although this emissions/development pathway represents the “worst-case scenario” amongst the pathways simulated by the IPCC CMIP5 models, at this stage it is the most realistic reflection of the recent progression of anthropogenic emissions. It is presented here, in spite of the Paris Agreement, as effects of the latter’s commitments remain to be shown.

Table 2: Summary of GCM projected climate changes for key climate variables, Dar es Salaam

Statistic	Annual
Average Tmax [°C]	**Increasing** +0.5 °C to +1 °C by 2040s, and by between 2 - 4 °C by the end of the century, but changes evident in next decade (note: two models show unexpected decadal variability)
Average Tmin [°C]	**Increasing:** +0.75 °C to +1.75 °C by 2040s, and by between 2 – 4.5 °C by the end of the century, but changes evident in next decade
Tmax extreme hot events [days over the model's historical 90th percentile]	**Increasing:** linear increase of number of extreme hot days into the future, with very large spread in the rate of increase depending on the model. The frequency by 2040 ranges between small change (a small increase in the number of extreme hot days per year), to half the days per year exceeding the model's historic 90th percentile. Frequency by the end of the century ranges between less than doubling, to all days per year exceeding the threshold.
Tmin extreme hot events [nights over the model's historical 90th percentile]	**Increasing:** steady rate of increase in number of extreme hot nights from present to the 2070s, after which there is a slightly slower increase. Relatively small intermodel spread compared to daily extreme hot events. By 2040 the frequency of extremely hot nights (i.e. nights over the model's historic 90th percentile) increases to between 100 and 200 days per year, and by the end of the century it varies between 220 to all days per year.
Rainfall totals [mm]	**Normal to increasing or decreasing rainfall**, by 2040 most models show no change, but by the end of the century the intermodel spread ranges from wetting to drying of around 200mm/year.
Rain intensity [mm/day]	**Normal to slightly increasing rainfall intensity**, by 2040 most models show no change, but by the end of the century a few models show a slight increase in rainfall intensity.
Heavy rainfall frequency [days of rainfall > 10mm]	**Normal to increasing or slightly decreasing heavy rainfall frequency**, by 2040 most models show no change or a slight increase, but by the end of the century more models show an increase and a few show a decrease in frequency.
Extreme rainfall frequency [days of rainfall > the model's historical 90th percentile]	**Normal to increasing or slightly decreasing extreme rainfall frequency**, by 2040 most models show no change or a slight increase, but by the end of the century more models show an increase and a few show a decrease in frequency.

Statistically downscaled projections

Projections of future climate, based on 11 statistically downscaled CMIP5 GCM simulations under the RCP8.5 pathway, show a clear and statistically significant increase in both minimum and maximum temperature into the future and the changes should already be starting to become evident (Figure 22 & 23). By 2040 the daily maximum and minimum temperatures may be between 1 – 1.75 °C and 1 – 1.5 °C warmer than the current climate, respectively, and up to 2.75 – 4.5 °C and 2.5 – 4.25 °C warmer by the end of the century, depending on the model selected. The frequency of days and nights exceeding the historical extreme temperature threshold (90th percentile) is projected to increase (Figure 24 & 25), however the extreme daily minimum temperatures are expected to increase more rapidly than the extreme daily maximum temperatures, especially before the 2060s.

Rainfall is projected to remain within the historic range of variability or decrease over the first half of the 21st century; by the end of the century, all but two models project a drying trend (Figure 26). This is also seen in the magnitude, intensity and frequency of rainfall and extreme rainfall (Figure 27 – 29). Table 3 below provides a summary of these projected climate changes.

Table 3: Summary of statistically downscaled GCMs projected climate changes for key climate variables, Dar es Salaam

Statistic	Annual
Average Tmax [°C]	**Increasing** +1 °C to +1.75 °C by 2040s, and by between 2.75 – 4.5 °C by the end of the century, but changes may already be evident (note: models separate into two groups with 6 more conservative and 5 more extreme projections
Average Tmin [°C]	**Increasing** +1 °C to +1.5 °C by 2040s, and by between 2.5 – 4.25 °C by the end of the century, but changes may already be evident (note: models separate into two groups with 6 more conservative and 5 more extreme projections.
Tmax extreme hot events [days over the model's historical 90th percentile	**Increasing:** gradual increase in frequency up until 2060, by which time the frequency increases by 50% to 100%. Then more rapid increase to the end of the century, where the frequency ranges between 120 to 225 days per year.
Tmin extreme hot events [nights over the model's historical 90th percentile]	**Increasing:** steady rate of increase from present to the end of the century, frequency doubles to triples by 2040, and reaches between 150 and 275 days per year by the end of the century.
Rainfall totals [mm]	**Normal to decreasing rainfall**, by 2040 most models show no change, but by the end of the century all but two models project significant drying.
Rain intensity [mm/day]	**Normal to decreasing rainfall intensity**, by 2040 most models show no change, but by the end of the century all but two models project significant decrease in rainfall intensity.
Rainfall frequency [days]	**Normal to decreasing rainfall frequency**, by 2040 most models show no change, but by the end of the century all but three models project significant decrease in rainfall frequency.
Extreme rainfall frequency [days of rainfall > the model's historical 90th percentile]	**Normal to decreasing rainfall frequency**, by 2040 most models show no change, but by the end of the century all but three models project significant decrease in extreme rainfall frequency.

Supporting evidence

The above summary information is supported by rigorous analysis of observed and model projections data. More details of this analysis and supporting figures can be found below.

Data

This study focuses on how the climate for Dar es Salaam has changed in the past and how it may change in the future due to anthropogenic climate change. Ideally one would like to base the historical analysis on data from a number of weather stations to obtain a detailed understanding of the local climates in the different parts of the city. Unfortunately the only publicly-available weather station data for Dar es Salaam are of insufficient length and quality to use in this analysis. Instead this analysis relies on temperature data from a gridded product call the WATCH Forcing Data ERA-Interim (WFDEI)[4] where the WATCH Forcing Data methodology is applied to ERA-Interim data (Weedon et al. 2014)[5]. It provides data for the global land surface at 0.5° x 0.5° covering the period 1979-2014. The daily rainfall data used in the historical analysis is obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)[6] (Funk et al. 2015)[7]. CHIRPS incorporates 0.05° resolution satellite imagery with station data to create a gridded rainfall time series for most of the globe. The version 2.0 is used in this analysis which provides data on a 0.05° grid.

Two different sets of climate change data are used to explore the possible future changes in the climate due to anthropogenic climate change. The first set is an ensemble of 15 Global Climate Models (GCMs) from the Climate Model Intercomparison Projection version 5 (CMIP5) (a list of the models and modelling groups is provided in table 4 below). Daily rainfall, maximum and minimum temperature from the historical experiment (1960-2005) and the RCP8.5 future emission experiment (2006-2100) were used to explore how these variables are projected to change into the future. The second set of climate change data is an ensemble of 11 statistically downscaled CMIP5 GCMs. Circulation fields from the GCMs were used as predictor variables, while the WFDEI daily rainfall, maximum and minimum temperature data were used as predictant datasets in a statistical downscaling methodology called Self-Organising Map based Downscaling (SOMD) developed by the Climate System Analysis Group (CSAG) (Hewitson & Crane 2006[8]). The downscaling provides daily rainfall, maximum and minimum temperature for each GCM for the historical (1960-2005) and RCP8.5 future (2006-2100) experiment at a 0.5° resolution.

[4] EU WATCH – Data for Researchers: http://www.eu-watch.org/data_availability

[5] Weedon, G.P., Balsamo, G., Bellouin, N., Gomes, S., Best, M.J. & Viterbo, P. (2014) The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data. Water Resources Research, 50: 7505–7514.

[6] CHG – Data – CHIRPS: http://chg.geog.ucsb.edu/data/chirps/

[7] Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. & Michaelsen, J. (2015) The climate hazards infrared precipitation with stations – a new environmental record for monitoring extremes. *Scientific Data* 2, Article number: 150066.

[8] Hewitson, B.C. & Crane, R.G. (2006) Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. International Journal of Climatology 26: 1315-1337.

A time series for the gridcell covering Dar es Salaam was extracted from each of the observed datasets and also from all of the GCM and statistically downscaled data. These data were used in all the analyses.

Table 4: CMIP5 modelling centres and models used in the analysis. Models in italics are also used in the statistical downscaling

MODELING CENTRE (OR GROUP)	INSTITUTE ID	MODEL NAME
Beijing Climate Center, China Meteorological Administration	BCC	*BCC-CSM1.1*
College of Global Change and Earth System Science, Beijing Normal University	GCESS	*BNU-ESM*
Canadian Centre for Climate Modelling and Analysis	CCCMA	*CanESM2*
Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en CalculScientifique	CNRM- CERFACS	*CNRM-CM5*
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	LASG-IAP	*FGOALS-s2*
NOAA Geophysical Fluid Dynamics Laboratory	NOAA GFDL	*GFDL-ESM2G* *GFDL-ESM2M*
Institut Pierre-Simon Laplace	IPSL	IPSL-CM5A-MR IPSL-CM5B-LR
Institute for Numerical Mathematics	INM	INM-CM4
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC	*MIROC5*
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC	*MIROC-ESM* *MIROC-ESM-CHEM*
Max Planck Institute for Meteorology (MPI-M)	MPI_M	MPI-ESM-LR
Meteorological Research Institute	MRI	*MRI-CGCM3*

Historical trends and variability analysis

The analysis of historical trends and variability of key climate variables is presented below. This analysis uses daily maximum and minimum temperature data obtained from the WATCH which covers the period 1979 - 2014. The rainfall dataset used is the CHIRPS dataset covers the period January 1981 – December 2016. These gridded datasets were used since the quality and length of the weather station record for Dar es Salaam was too poor to be used in this analysis. Derived statistics were calculated at the seasonal and annual time scale. These were used to explore the long term trends and variability of the climate at Dar es Salaam.

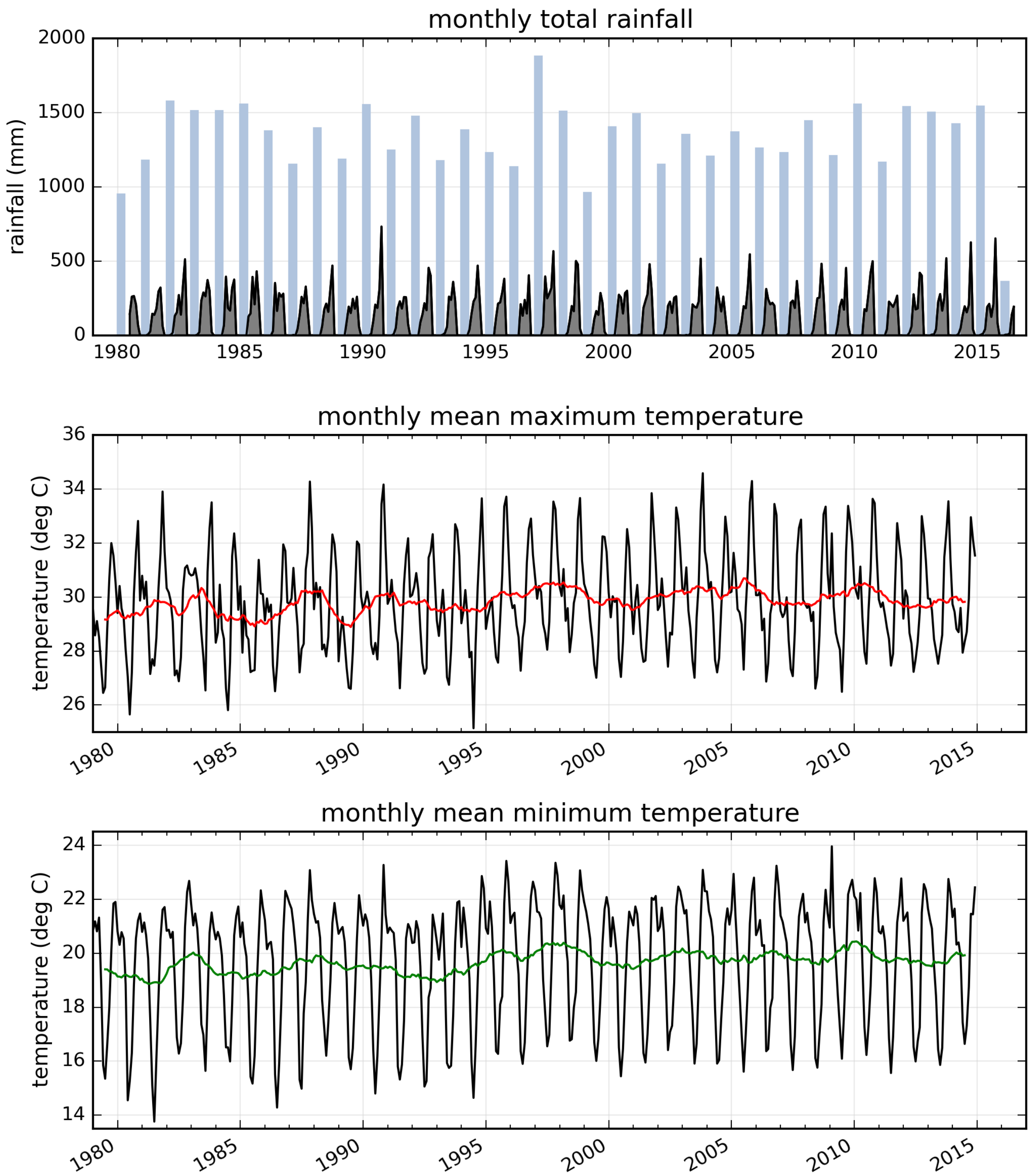

Figure 2: Time series of monthly mean maximum and minimum temperature and total rainfall for the gridcell over Dar es Salaam. Red and green coloured lines represent a 12-month running average for maximum and minimum temperature respectively from the WFDEI dataset. Light blue bars present the annual (July – June) total rainfall from the CHIRPS dataset.

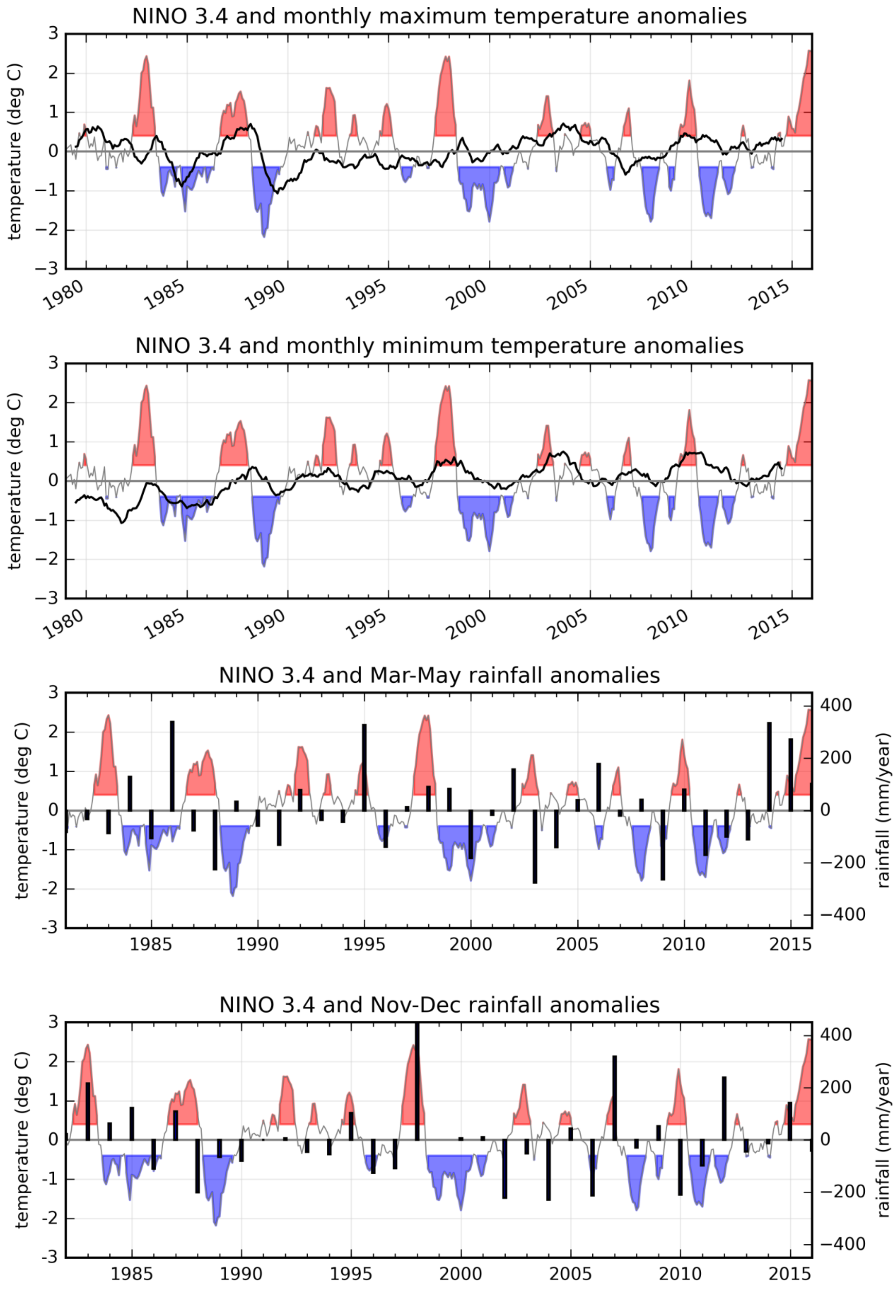

Figure 3: Association between ENSO and the climate at Dar es Salaam through time. Time series of the NINO 3.4 SST monthly anomalies is presented as the grey line; positive (El Nino) phases are coloured red, while negative (La Nina) phases are shaded in blue. The black line in the top panel shows the monthly mean maximum temperature anomalies smoothed with a 12-value running mean from the WFDEI dataset. The second panel shows the same as above, but for minimum temperature. The black bars in the bottom two panels show the March - May and October – December seasonal total rainfall anomalies (mm/season) from the CHIRPS dataset.

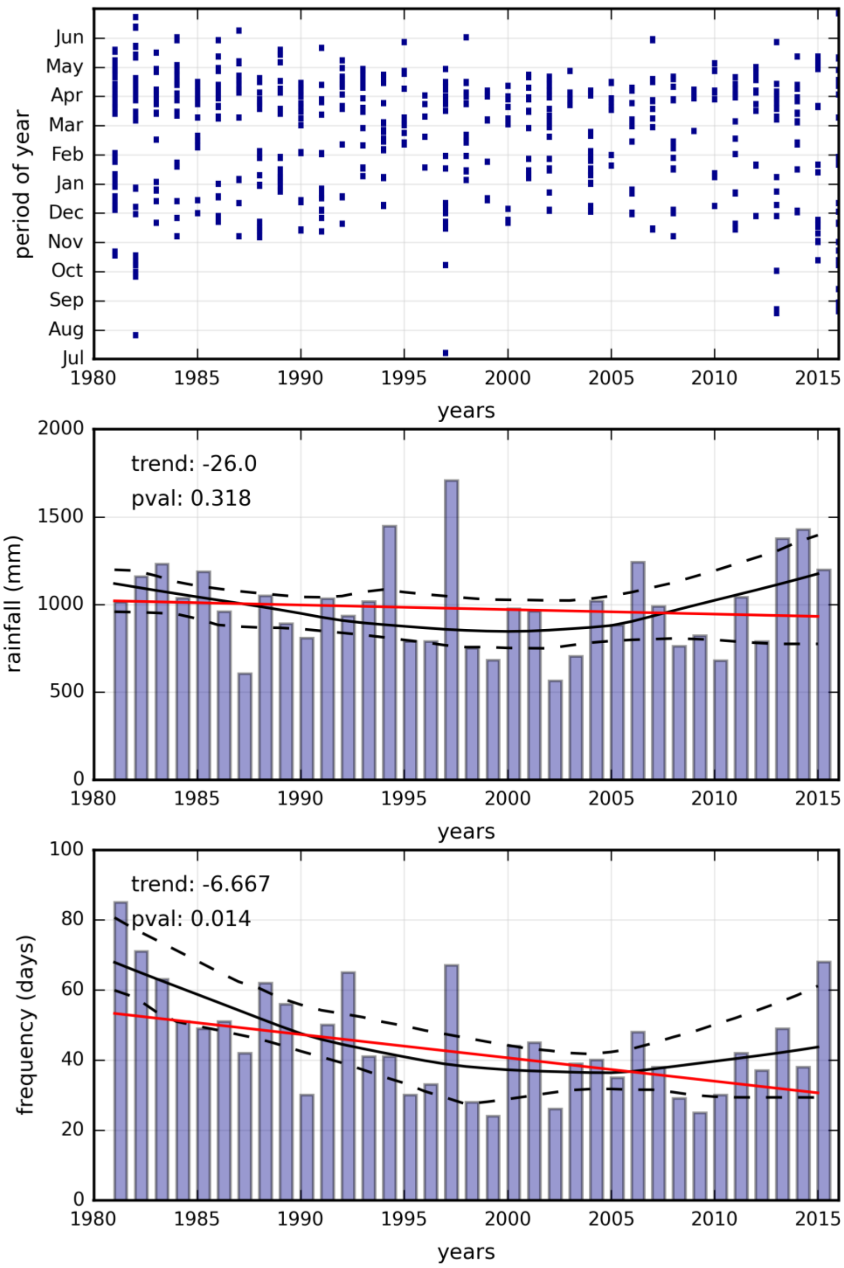

Figure 4: Time series and trend in daily rainfall (pr>0.2mm) for the gridcell over Dar es Salaam from the CHIRPS dataset. The top panel shows the timing and duration of rain events in each year (July-June) of the record. The middle panel shows the annual (July-June) total rainfall in blue bars along with the Theil-Sen trend (red line) and the Lowess smooth mean (black line) and 95th confidence interval (dashed line). The bottom panel shows the same as above but for the annual (July-June) frequency of rain days.

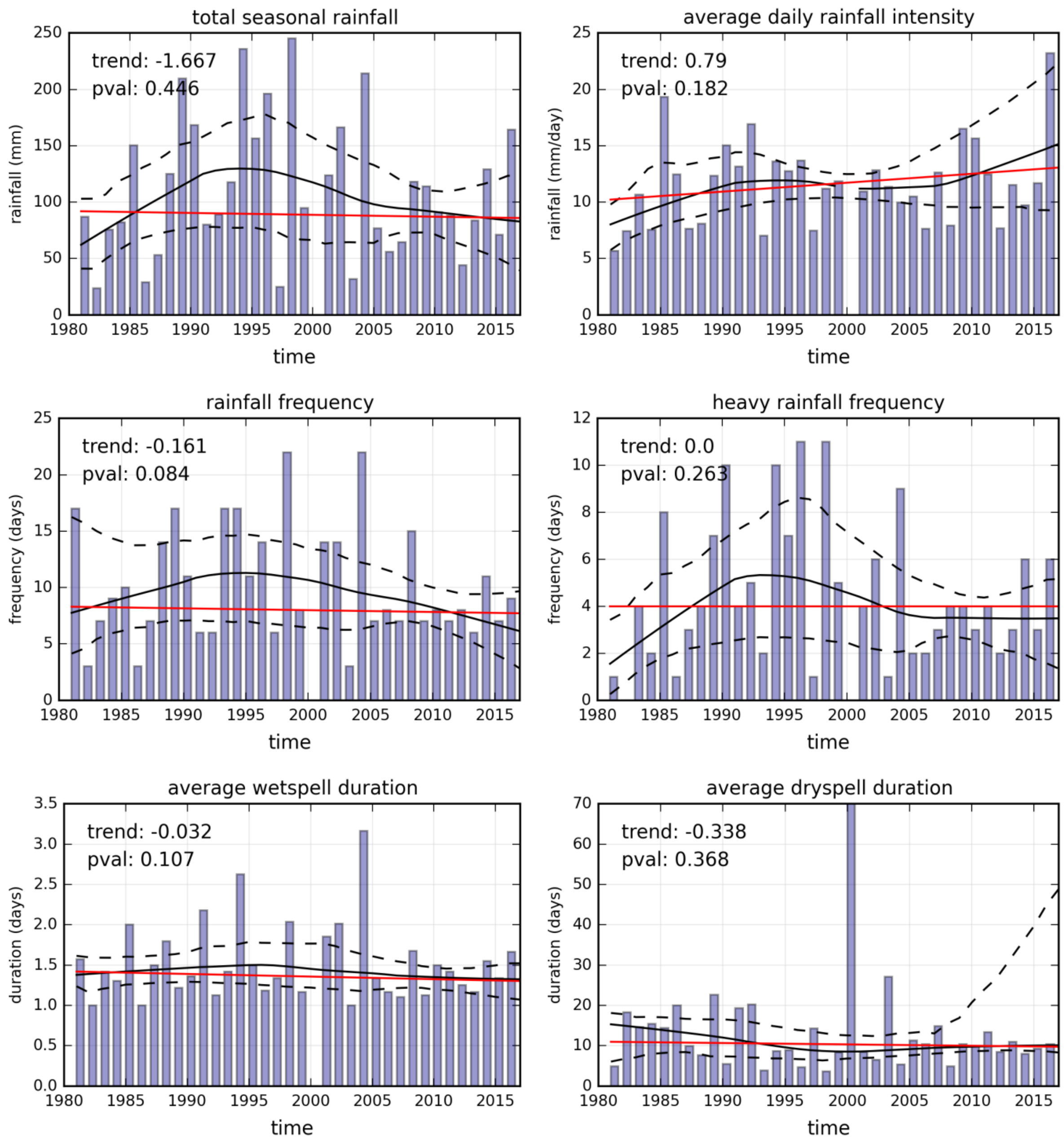

Figure 5: Time series and trend in January - February seasonal rainfall statistics for the gridcell over Dar es Salaam from the CHIRPS dataset. Each panel shows that statistic as a blue bars along with the Theil-Sen trend (red line) and the Lowess smooth mean (black line) and 95th confidence interval (dashed line).

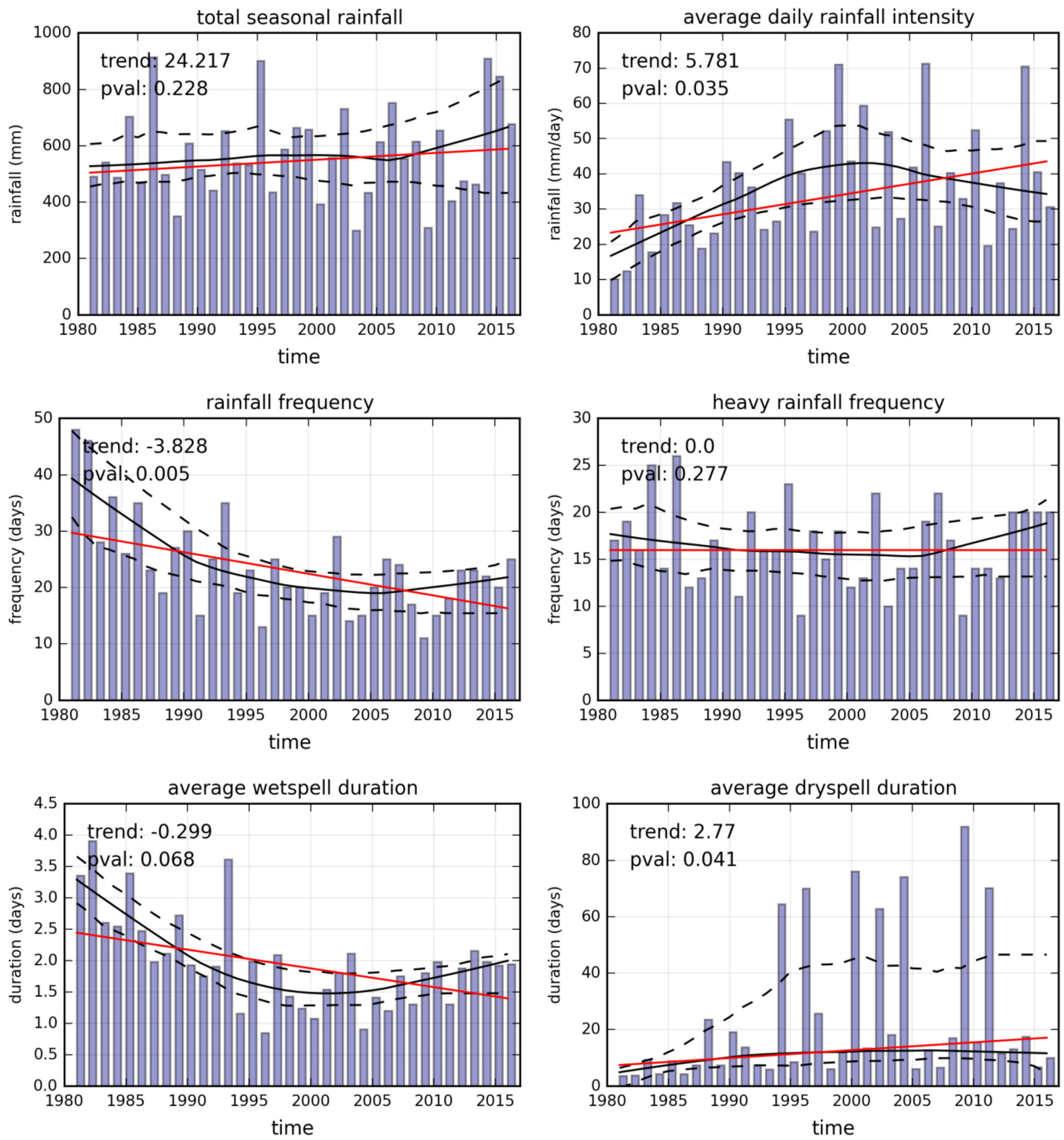

Figure 6: Time series and trend in March-May seasonal rainfall statistics for the gridcell over Dar es Salaam from the CHIRPS dataset. Each panel shows that statistic as a blue bars along with the Theil-Sen trend (red line) and the Lowess smooth mean (black line) and 95th confidence interval (dashed line).

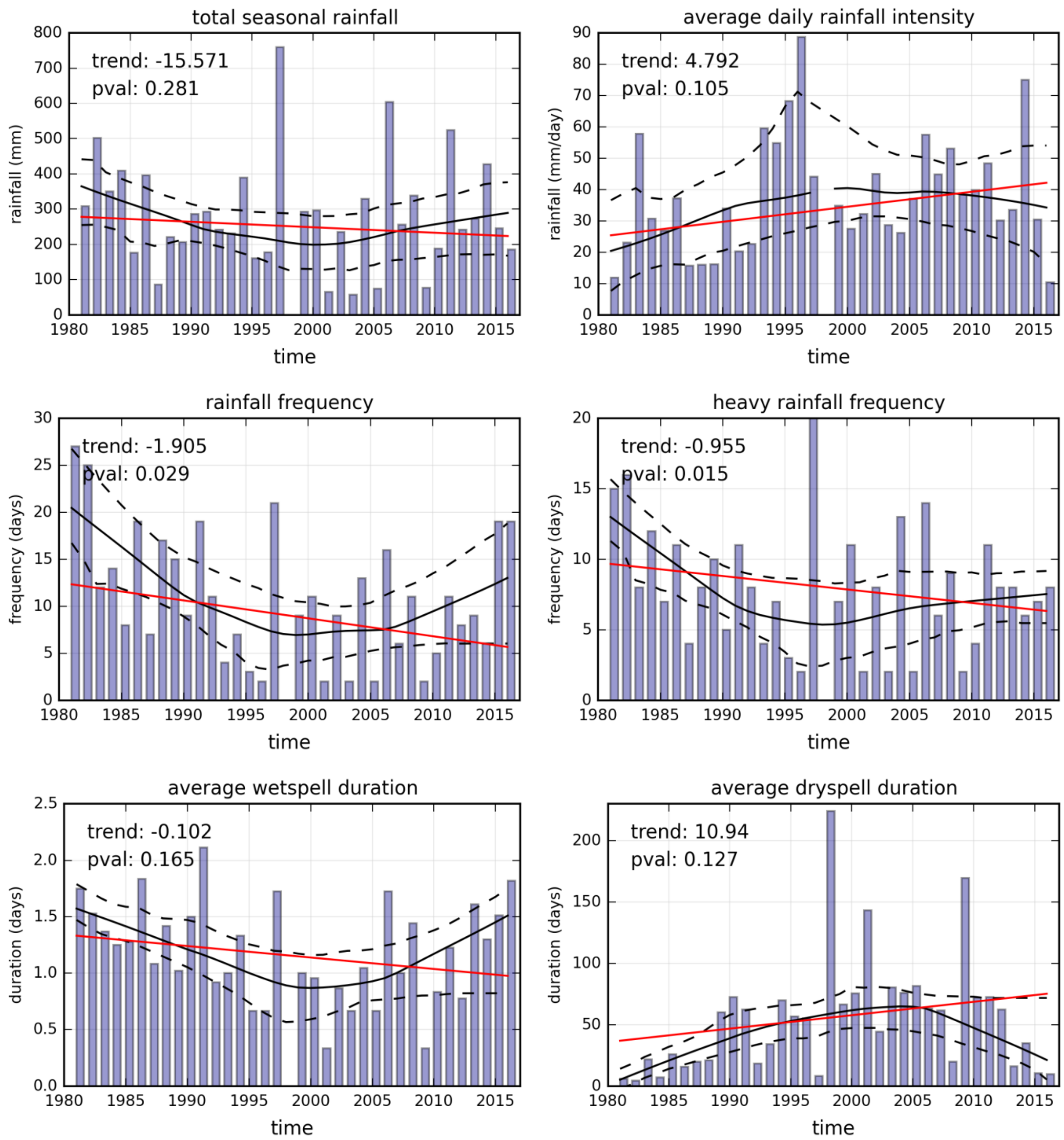

Figure 7: Time series and trend in March-May seasonal rainfall statistics for the gridcell over Dar es Salaam from the CHIRPS dataset. Each panel shows that statistic as a blue bars along with the Theil-Sen trend (red line) and the Lowess smooth mean (black line) and 95th confidence interval (dashed line).

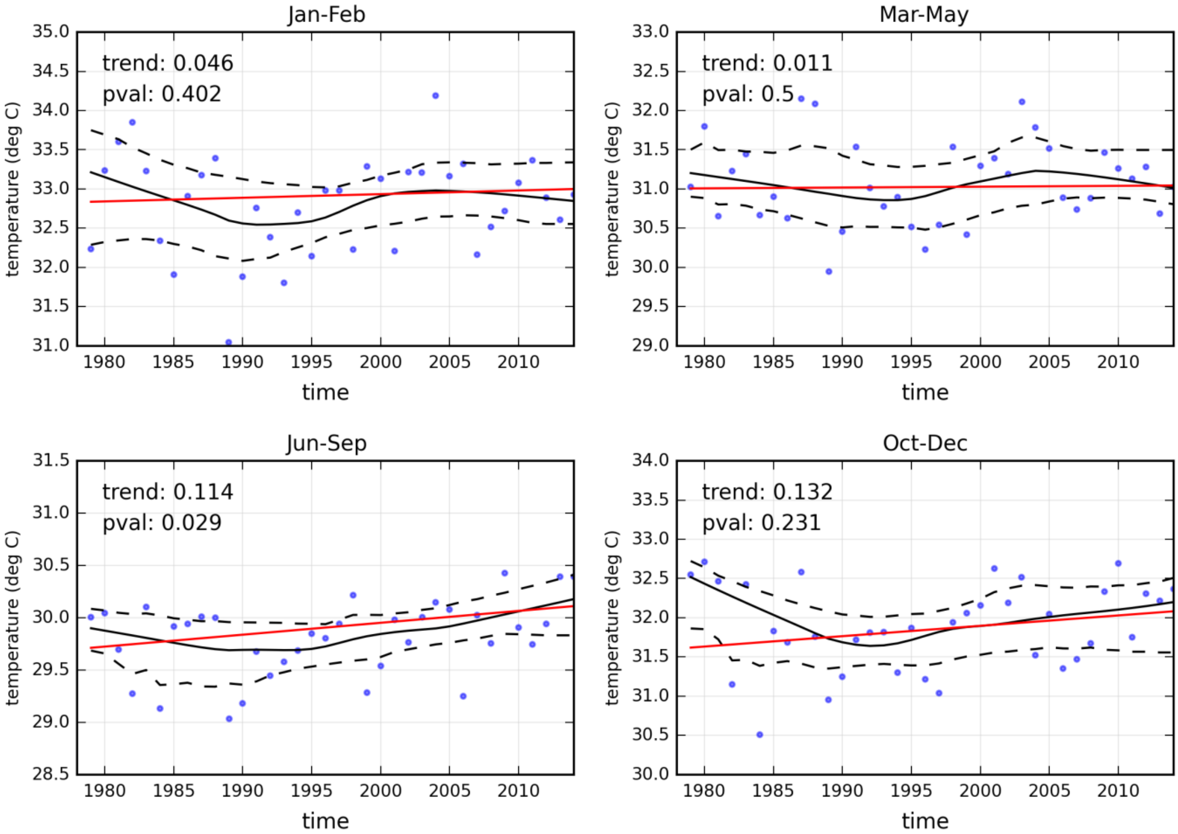

Figure 8: Time series and trend in seasonal average maximum temperature for the gridcell over Dar es Salaam from the WFDEI dataset. Time series of seasonal mean maximum temperature (blue dots); Theil-Sen trend (red line), the Lowess smooth (black line), and 95th confidence interval (dashed lines).

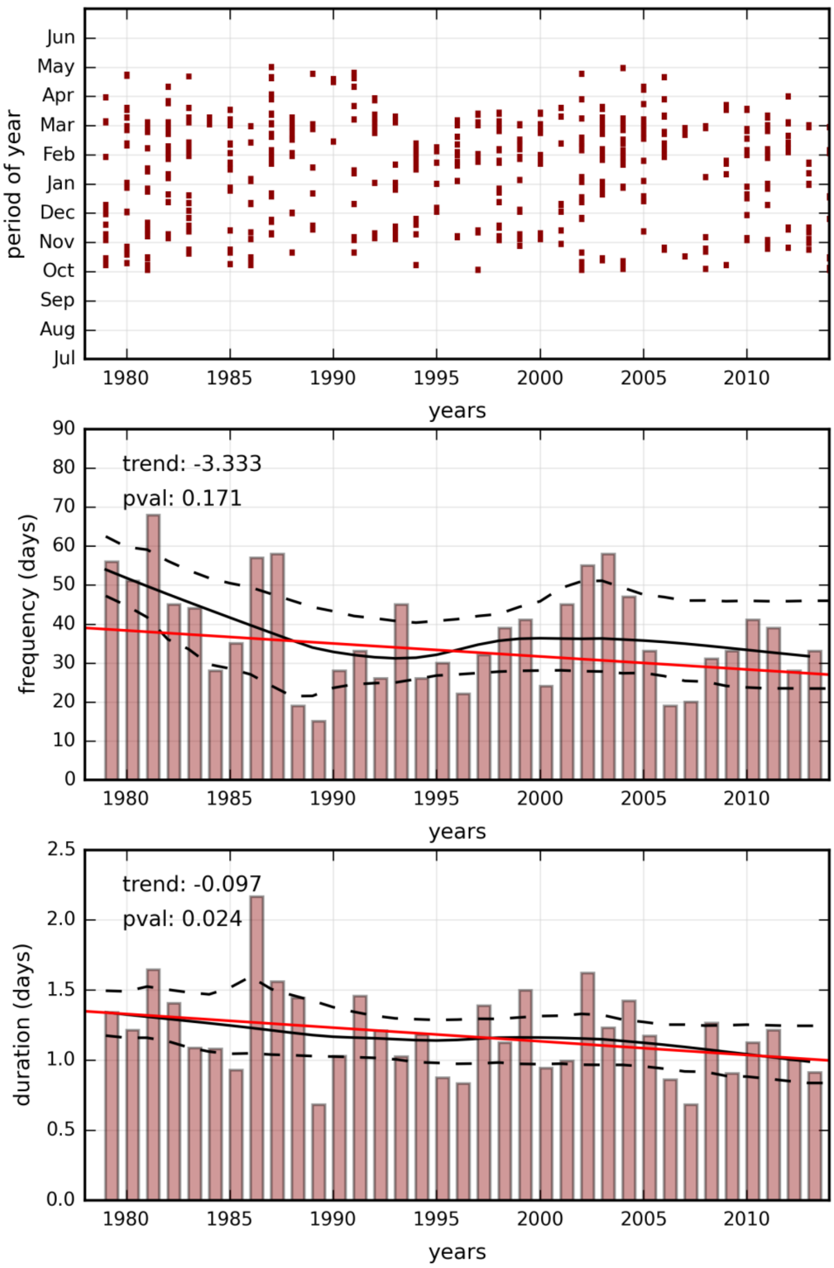

Figure 9: Time series and trend in the frequency of hot days (Tmax > 34.5) for the gridcell over Dar es Salaam from the WFDEI dataset. The top panel shows the timing and duration of these events in each year (July-June) of the record. The middle panel shows the heat spell frequency or number of days per year (July – June) in the red bars along with the Theil-Sen trend (red line) and the Lowess smooth (black line) and 95th confidence interval (dashed lines). The bottom panel shows the same as above but for the average spell duration or number of consecutive days per year (July-June).

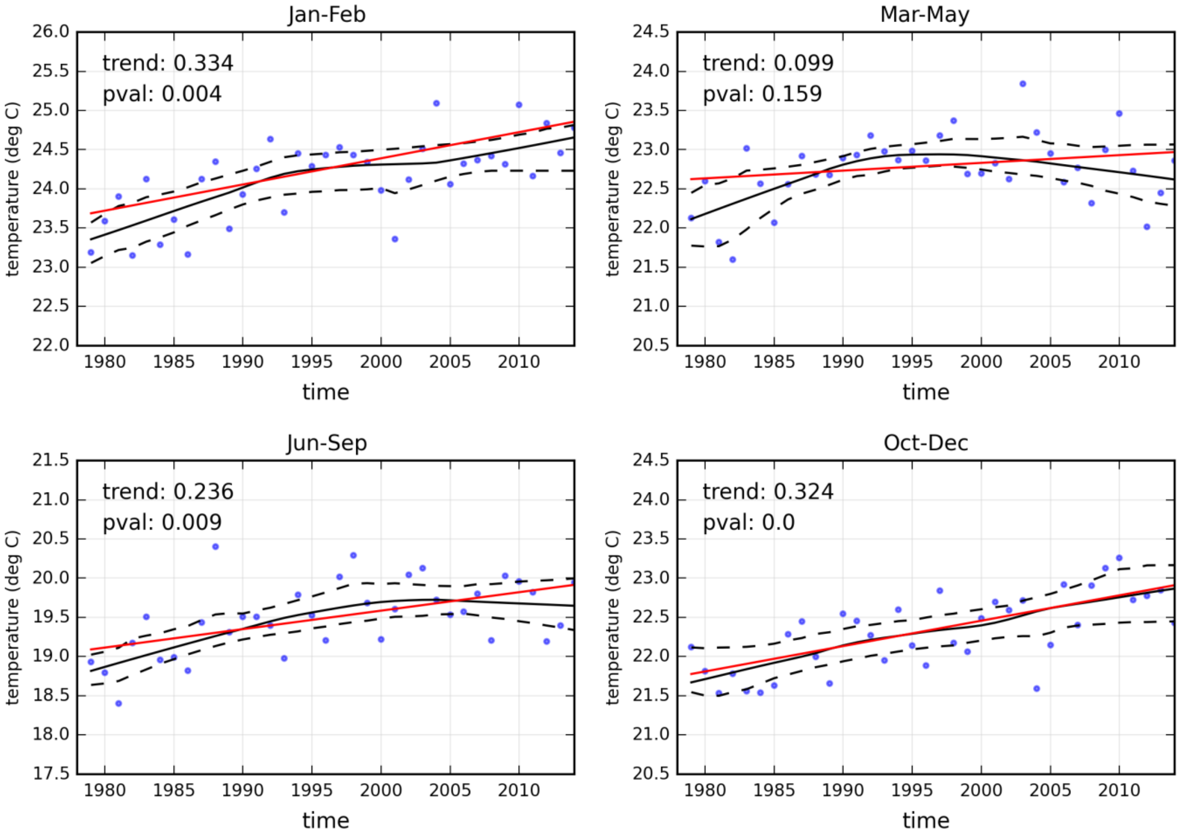

Figure 10: Time series and trend in seasonal average minimum temperature for the gridcell over Dar es Salaam from the WFDEI dataset. Time series of seasonal mean minimum temperature (blue dots); Theil-Sen trend (red line), the Lowess smooth (black line) and 95th confidence interval (dashed lines).

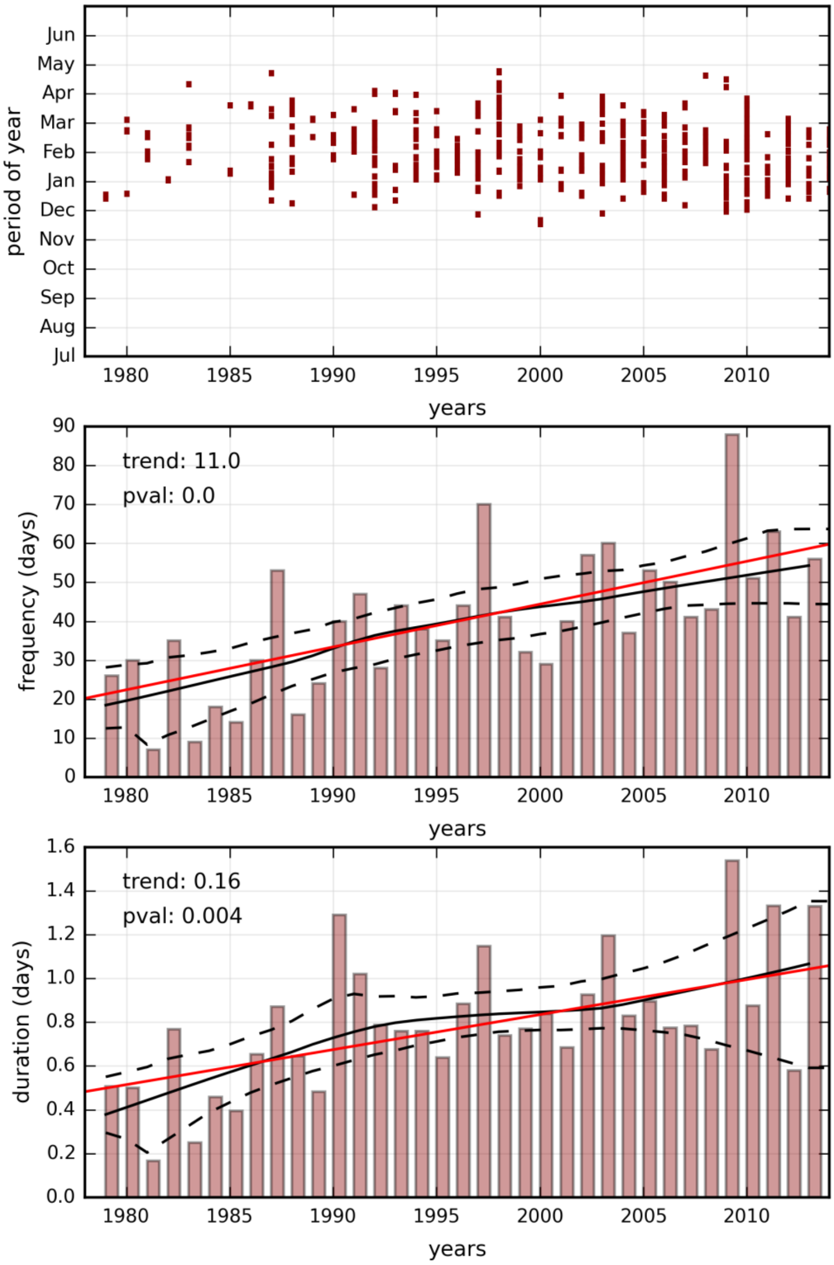

Figure 11: Time series and trend in the frequency of hot nights (tmin > 24.5) for the gridcell over Dar es Salaam from the WFDEI dataset. The top panel shows the timing and duration of these events in each year (July-June) of the record. The middle panel shows the heat spell frequency or number of days per year (July – June) in the red bars along with the Theil-Sen trend (red line) and the Lowess smooth (black line) and 95th confidence interval (dashed lines). The bottom panel shows the same as above but for the average spell duration or number of consecutive days per year (July-June).

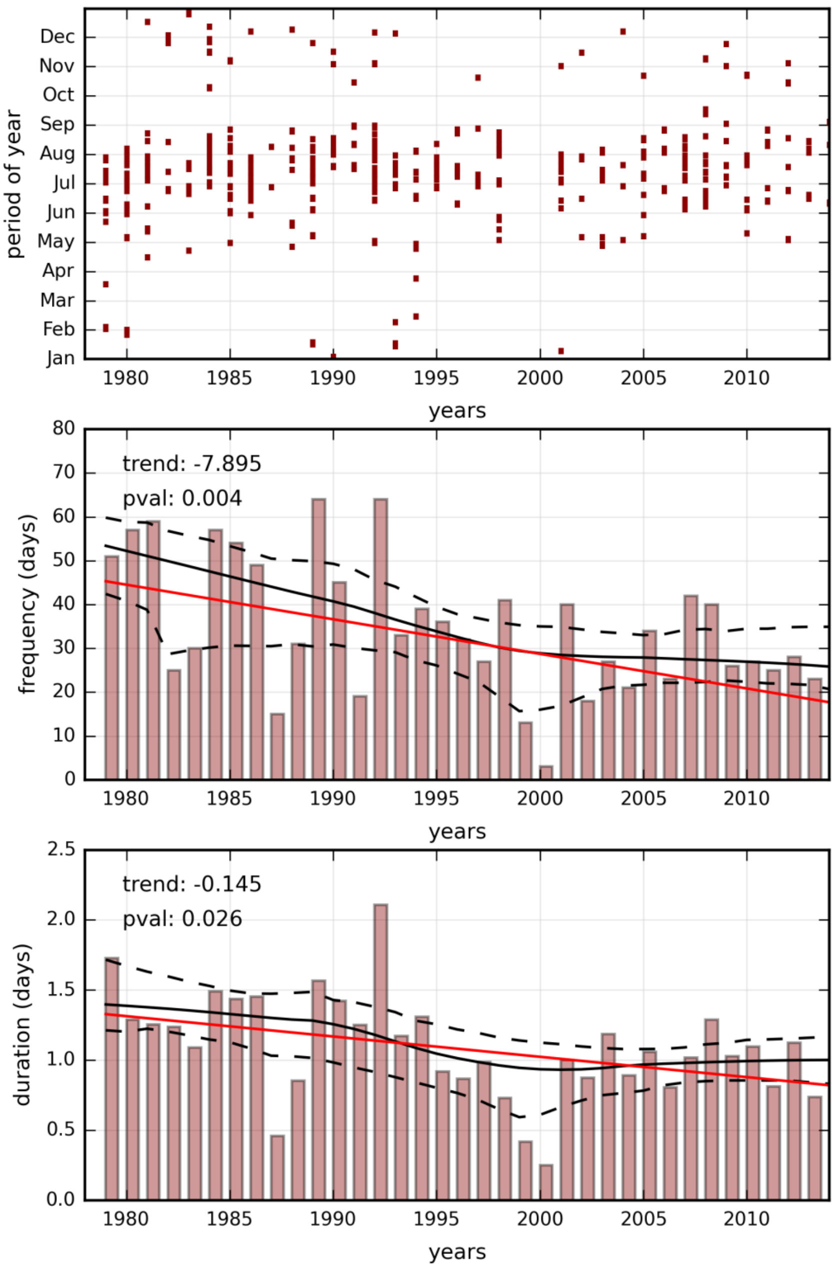

Figure 12: Time series and trend in the frequency of cool days (Tmax < 28) for the gridcell over Dar es Salaam from the WFDEI dataset. The top panel shows the timing and duration of these events in each year (July-June) of the record. The middle panel shows the heat spell frequency or number of days per year (Jan – Dec) in the red bars along with the Theil-Sen trend (red line) and the Lowess smooth (black line) and 95th confidence interval (dashed lines). The bottom panel shows the same as above but for the average spell duration or number of consecutive days per year (July-June).

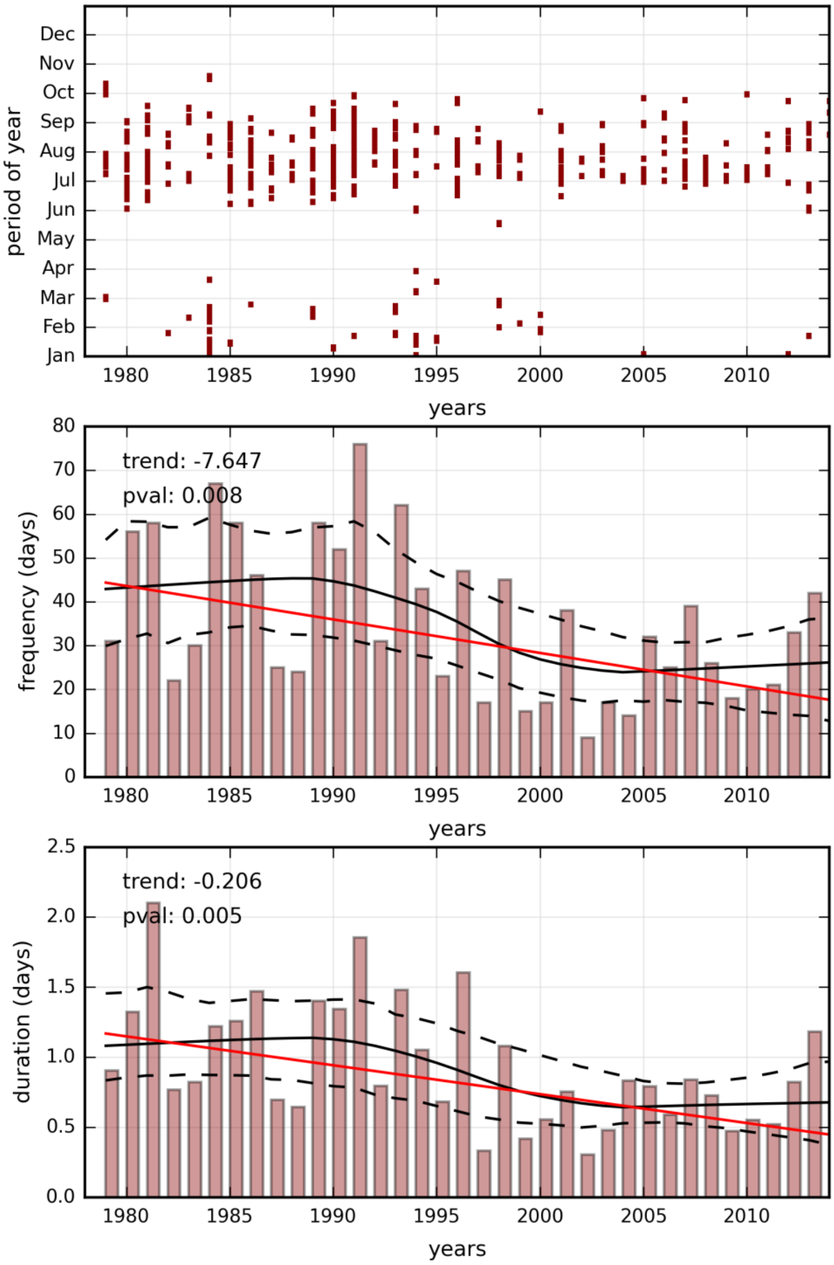

Figure 13: Time series and trend in the frequency of cold nights (Tmin < 18.8) for the gridcell over Dar es Salaam from the WFDEI dataset. The top panel shows the timing and duration of these events in each year (July-June) of the record. The middle panel shows the heat spell frequency or number of days per year (Jan – Dec) in the red bars along with the Theil-Sen trend (red line) and the Lowess smooth mean (black line) and 95th confidence interval (dashed lines). The bottom panel shows the same as above but for the average spell duration or number of consecutive days per year (July-June).

Climate projections visualizations

Global Climate Models

The plots below (Figures 14 to 29) are called plume plots and they are used to represent the different long-term projections across the multiple climate models in the CMIP5 model archive used to inform the IPCC AR5 report. The plots show projected variations in different variables for the gridcell over Dar es Salaam produced by an ensemble of 15 models. The blue colours indicate variations that would be considered within the range of natural variability, so in other words, not necessarily the result of climate change. The orange colours indicate projection time series where the changes would be considered outside of the range of natural variability and so likely a response to climate change.

It is important to note that these are Global Climate Model (GCM) projections and so likely do not capture local scale features such as topography and land-ocean boundary dynamics. They also may not capture small-scale features such as severe thunderstorms that can have important societal impacts. Finally, these projections are averages over relatively large spatial area which differ between GCMs and it is possible that different messages would be obtained at smaller spatial scales and if various forms of downscaling were performed.

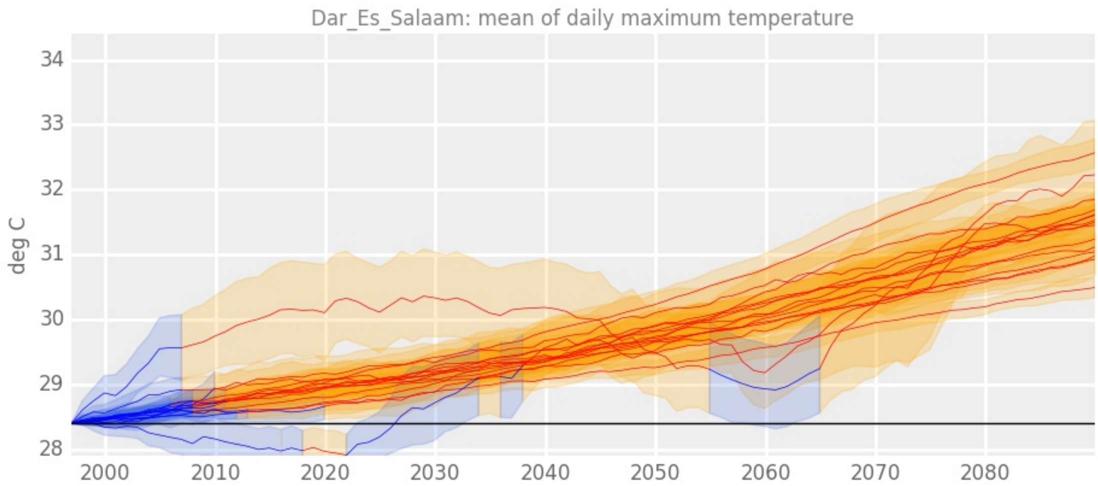

Figure 14: CMIP5 projected changes in annual mean daily maximum temperature under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

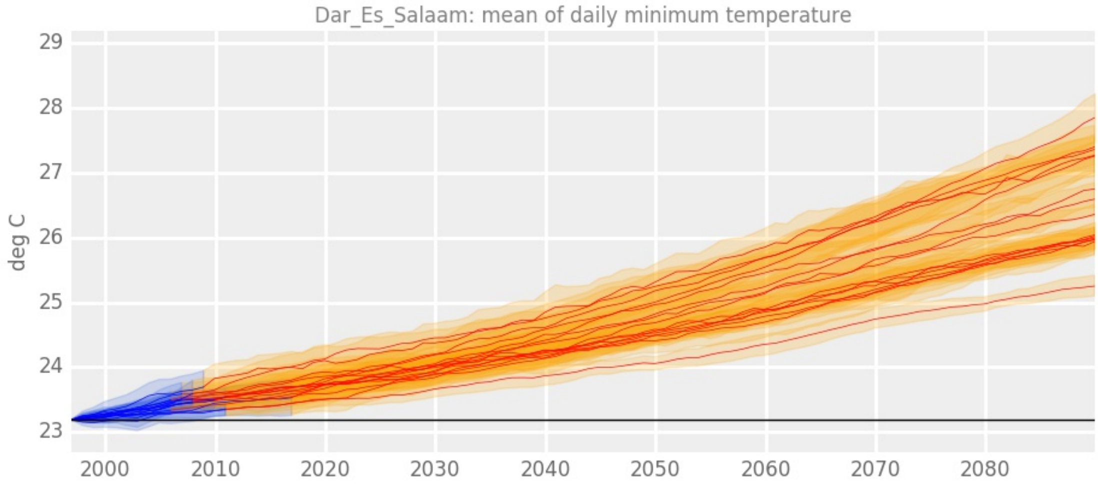

Figure 15: CMIP5 projected changes in annual mean daily minimum temperature under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

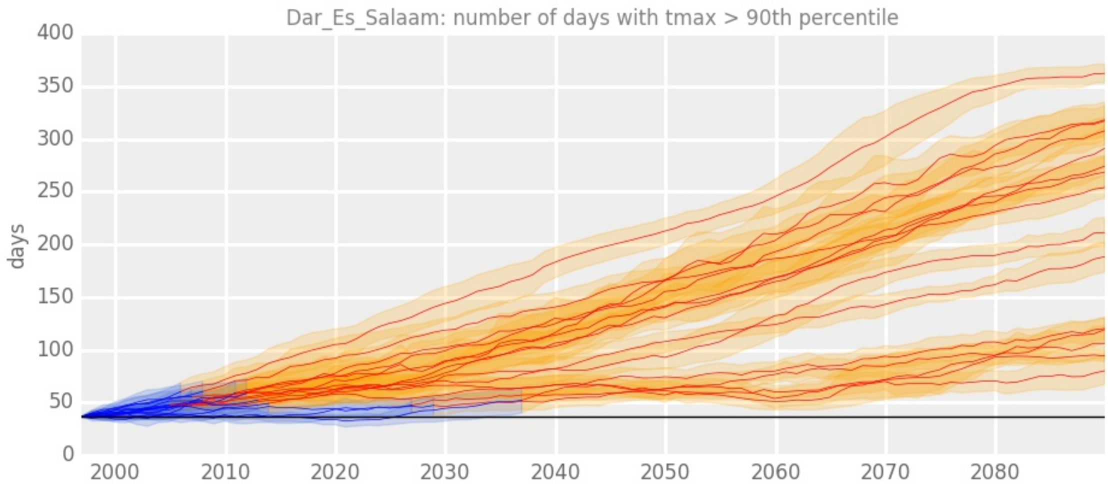

Figure 16: CMIP5 projected changes in annual hot days (daily maximum temperature > 33.4 °C) under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

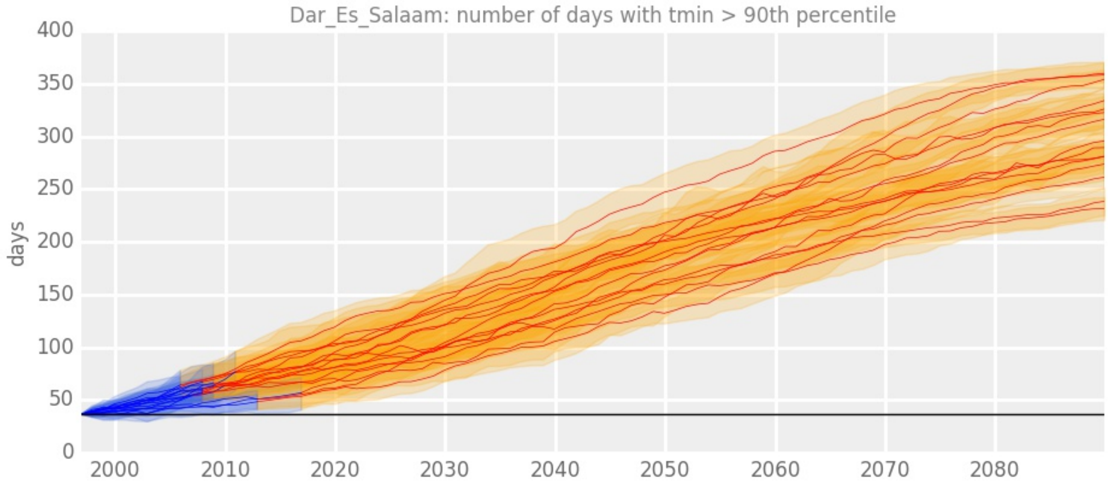

Figure 17: CMIP5 projected changes in annual hot nights (daily minimum temperature > 24 °C) under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

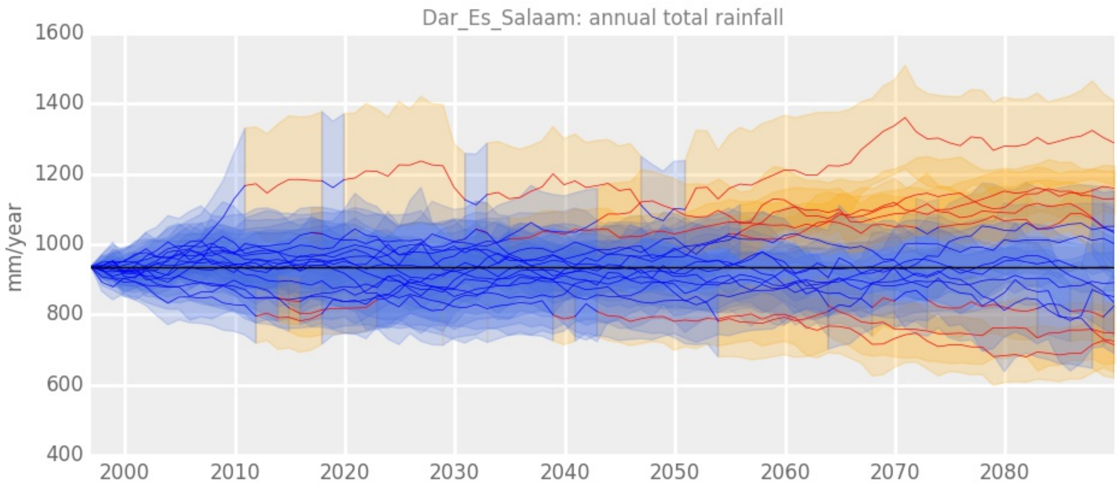

Figure 18: CMIP5 projected changes in annual total rainfall under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

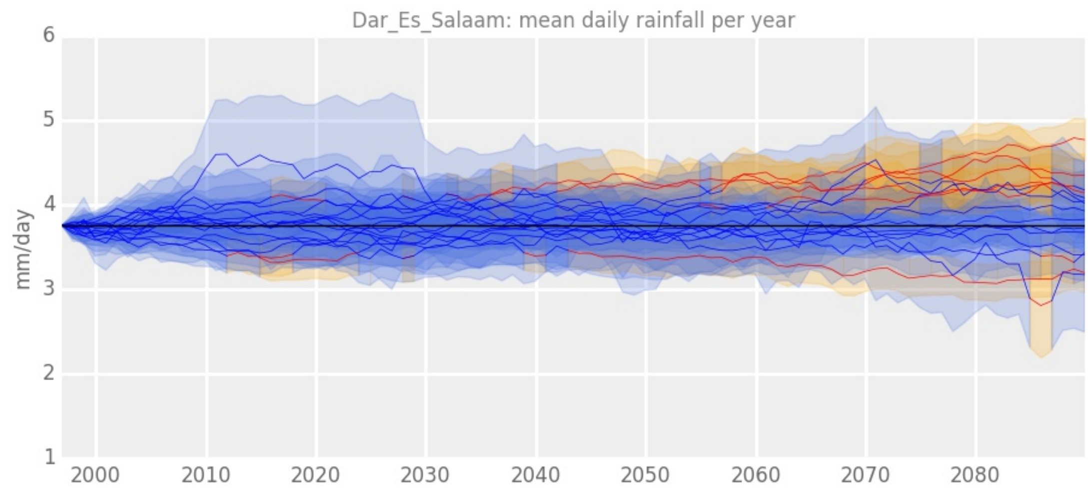

Figure 19: CMIP5 projected changes in rainfall daily intensity under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

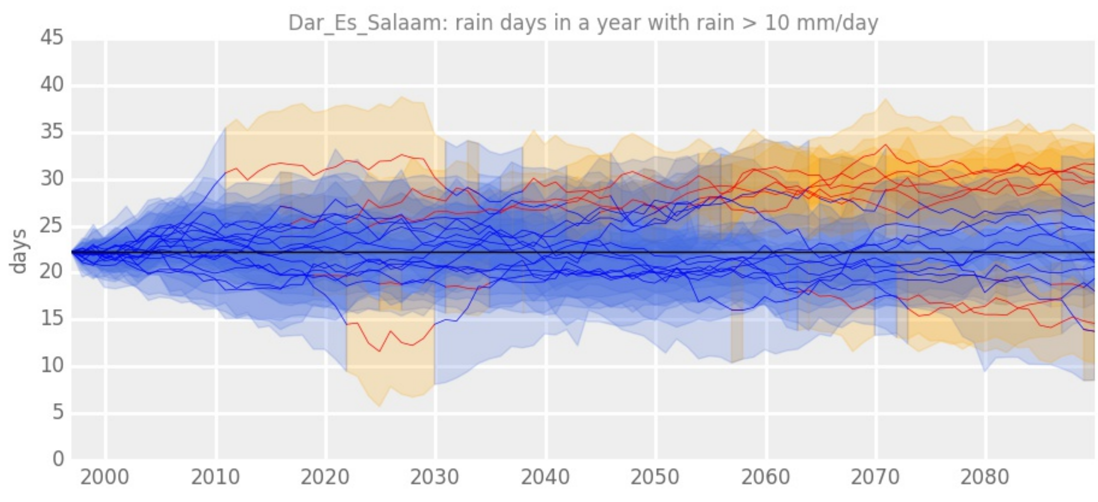

Figure 20: CMIP5 projected changes in annual frequency of heavy rainfall days under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

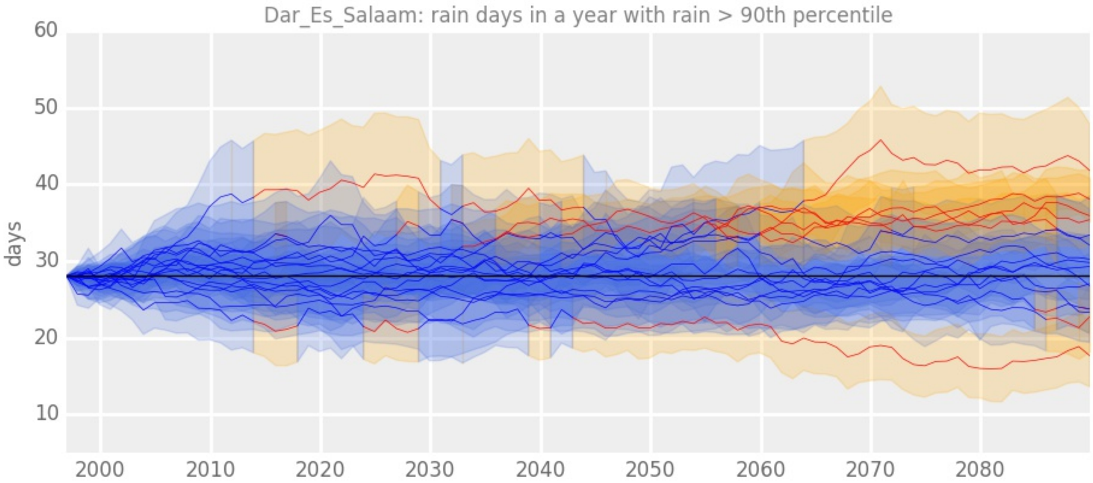

Figure 21: CMIP5 projected changes in annual frequency of extreme rainfall days under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

Statistically Downscaled Global Climate Models

The plots below (Figures 22 to 29) are called plume plots and they are used to represent the different long-term projections across the multiple statistically downscaled climate models in the CMIP5 model archive used to inform the IPCC AR5 report. The plots show projected variations in different variables for the gridcell over Dar es Salaam produced by an ensemble of 11 models. The blue colours indicate variations that would be considered within the range of natural variability, so in other words, not necessarily the result of climate change. The orange colours indicate projection time series where the changes would be considered outside of the range of natural variability and so are likely a response to climate change.

It is important to note that these are downscaled GCM projections, which have a spatial resolution of roughly 50 km. They provide higher resolution output than the raw GCM and depict the first order response to anthropogenic response. However they are unlikely to accurately capture local-scale features such as topography and land-ocean boundary dynamics. They also may not capture small-scale features such as severe thunderstorms that can have important societal impacts.

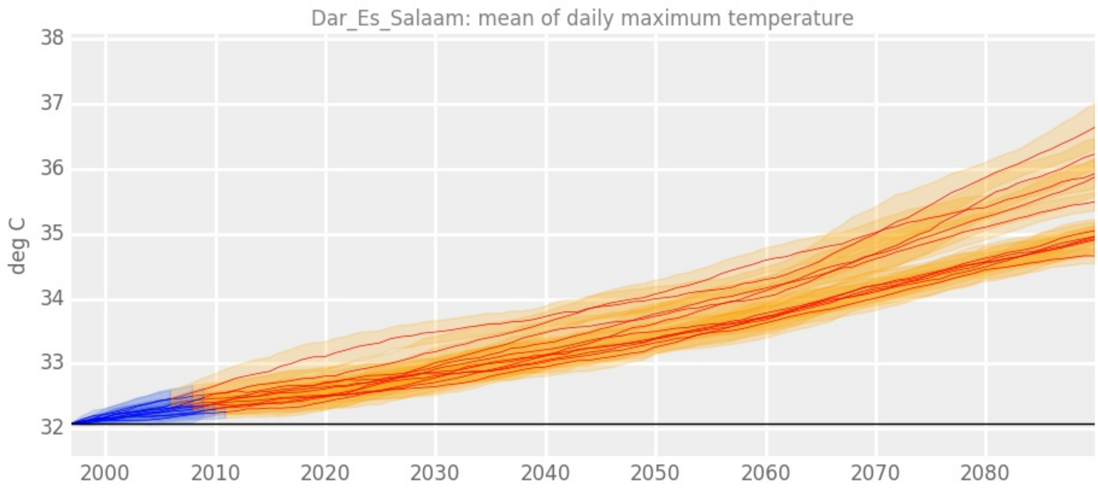

Figure 22: Statistically downscaled projected changes in annual mean daily maximum temperature under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

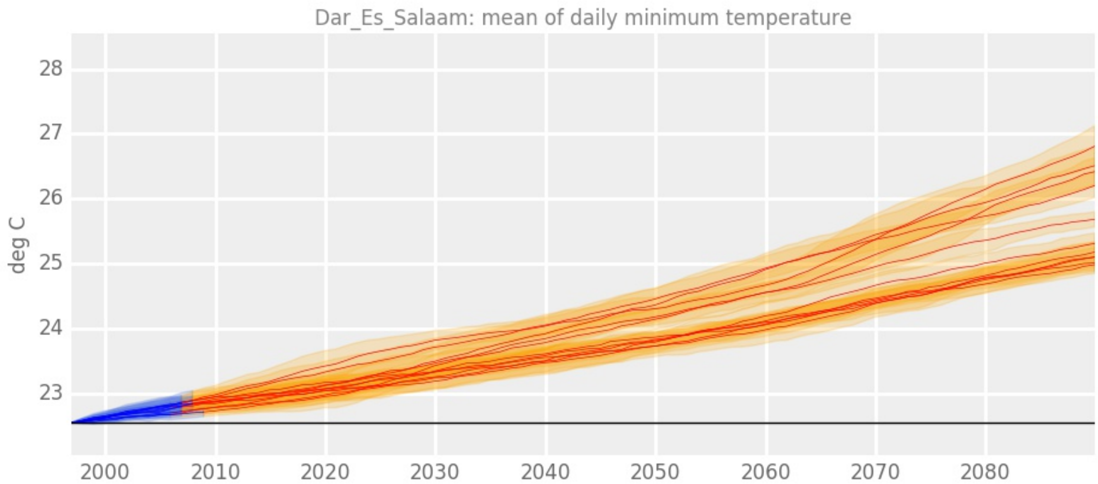

Figure 23: Statistically downscaled projected changes in annual mean daily minimum temperature under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

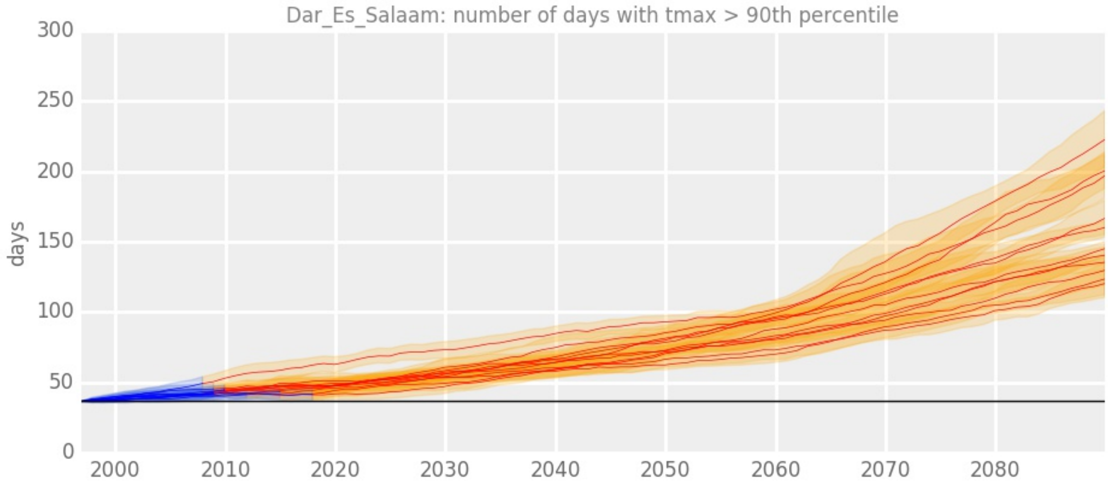

Figure 24: Statistically downscaled projected changes in the frequency of days with Tmax > 90th percentile of the historical period (1986-2005) under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

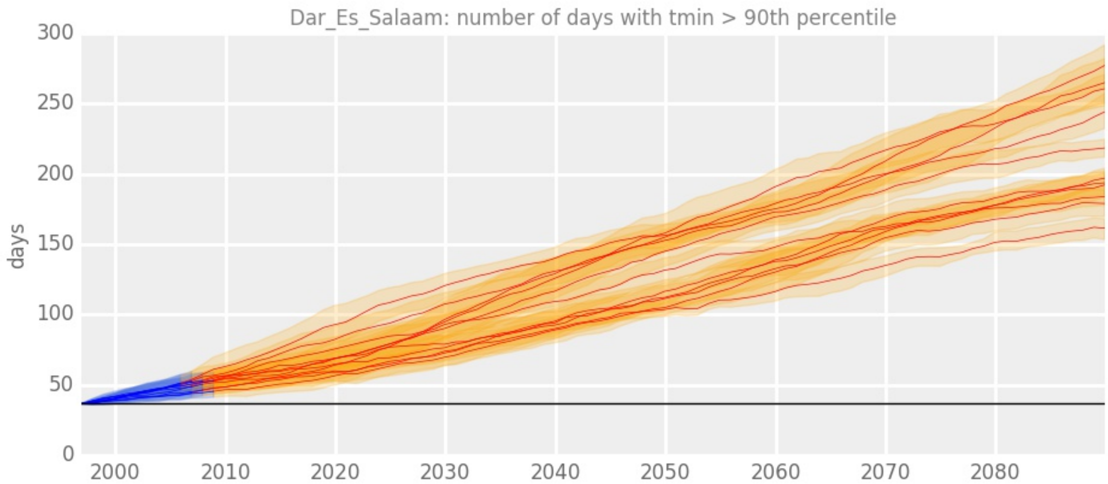

Figure 25: Statistically downscaled projected changes in the frequency of days with Tmin > 90th percentile of the historical period (1986-2005) under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

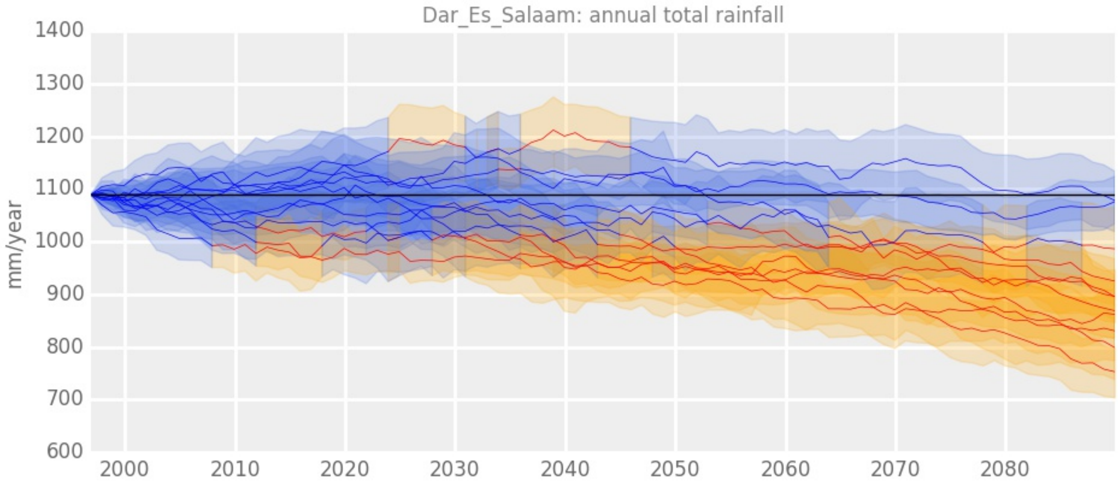

Figure 26: Statistically downscaled projected changes in annual total rainfall under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

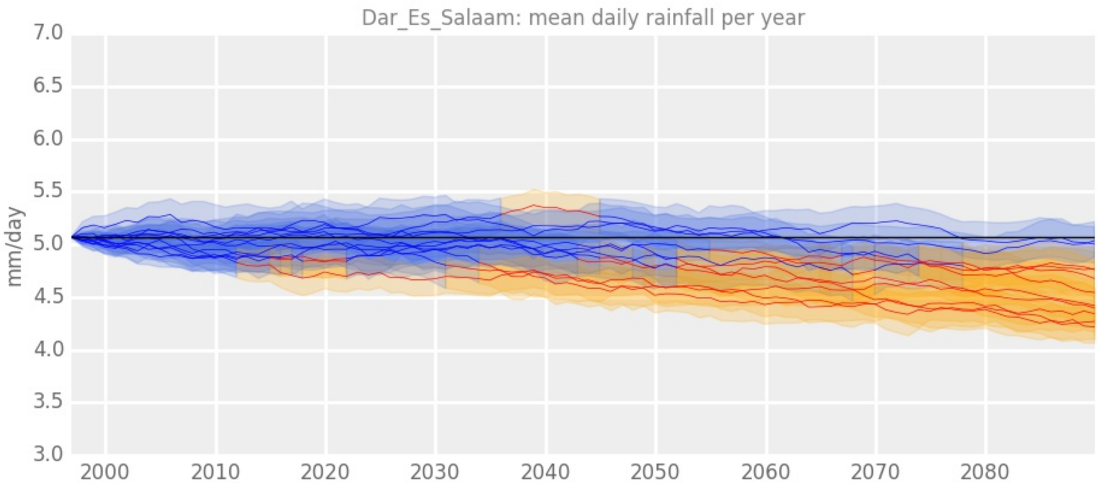

Figure 27: Statistically downscaled projected changes in the daily intensity of rainfall under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

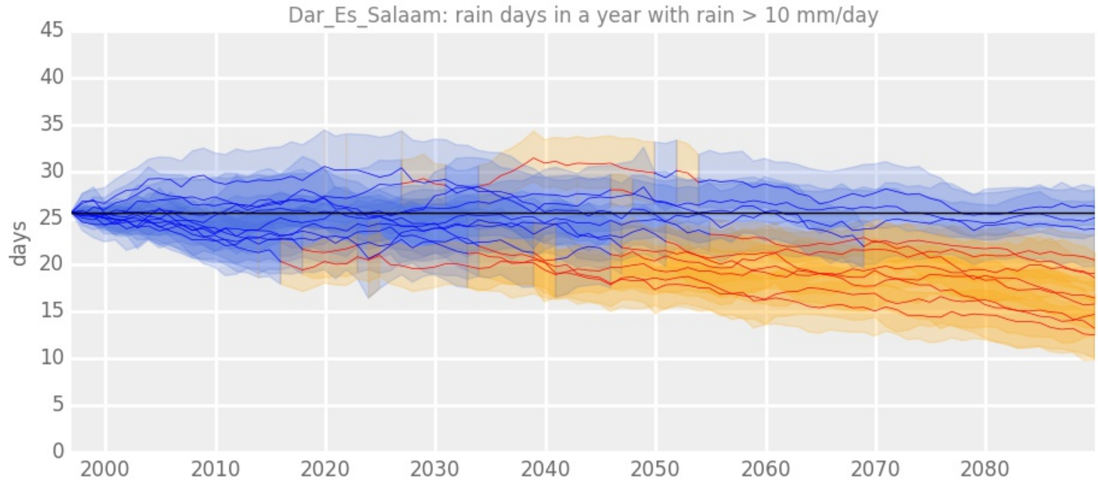

Figure 28: Statistically downscaled projected changes in the frequency of heavy rain days under the RCP 8.5 concentration pathway for Dar es Salaam. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

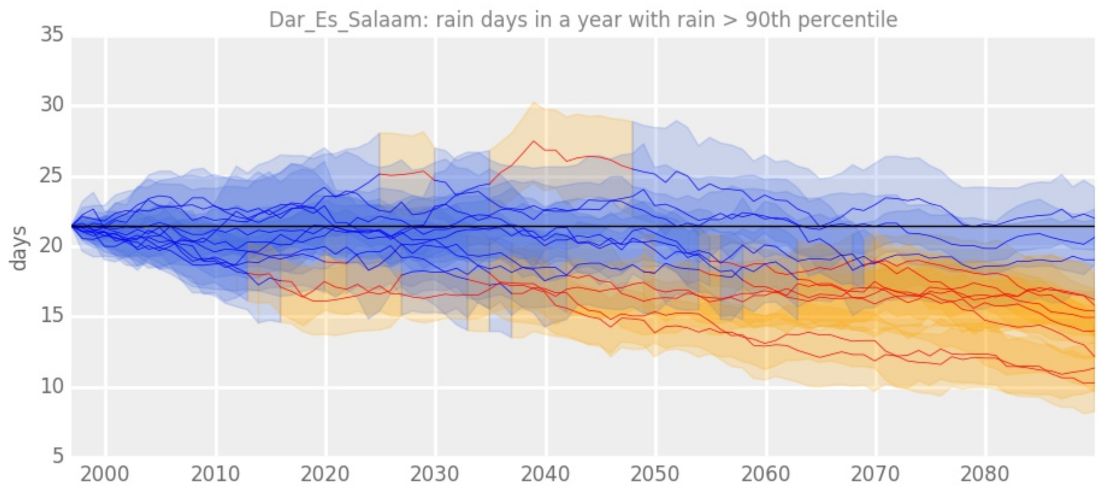

Figure 29: **Statistically downscaled projected changes in the frequency of days with rainfall > 90th percentile of the historical period (1986-2005) under the RCP 8.5 concentration pathway for Dar es Salaam.** The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each model and the shading around each line shows the 95% confidence range around those model results. Where the line and associated shading changes from blue to red/orange, this indicates when 20-year moving averages move outside of the 95% confidence range of the reference period.

Acknowledgements

We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modelling groups (listed in Table 4 of this report) for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals

The contents of this Working Paper reflect the views of the author only and not those of the UK Department for International Development or the Economic and Social Research Council.