Urban Africa Risk Knowledge

Nairobi Climate Profile: Full Technical Version

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Nairobi Climate Profile

Summary

Nairobi has a subtropical highlands climate. It is located close to the eastern edge of the East African Rift Valley at an altitude of roughly 1800 metres above sea level which strongly influences its climate. Nairobi receives just over 610 mm of rainfall a year occurring primarily in two rainfall season. The long rains from March and May, which generally records around 310 mm, and the short rains during November – December, where around 200 mm is recorded. Rainfall does also occur during January and February but is much less than the two core seasons (80 mm). A relatively dry period lasts from June – October (Figure 1 below).

Rainfall varies quite strongly from year to year. The annual (July-June) total rainfall varies from around 300 - 900mm/year, though during the extreme years it can be much higher, such as the 1997/8 year which recorded 1400mm of rainfall (Figure 2). Rainfall over Nairobi exhibits variability on the multi-year timescale. Some of which is related to large scale remote forcings such as the El Nino Southern Oscillation (ENSO), with El Nino conditions generally being associated with above average rainfall and La Nina conditions to below average rainfall during the short rains (Figure 3). There is little evidence of clear or statistically significant trends in the rainfall over the last 30 years (Figure 10 – 12).

Temperature at Nairobi displays variability at a number of time-scales. The most obvious being the daily, or diurnal, cycle where temperature varies by almost 12 °C. Temperature also changes though the year, but because of Nairobi's location just south of the equator, the seasonal cycle is relatively small with daily maximum temperature varying by about 6 °C and daily minimum temperature varying by around 5 °C. The long term (1981-2010) average daily maximum temperature is warmest during January – March (27.5 °C) with a secondary peak during September – November (26 °C), which correspond to the start of the rainy seasons. Daily maximum temperature is coolest during June – August (22.5 °C). The seasonality of long-term (1981-2010) average daily minimum temperature generally follows that of rainfall, with warmest night-time temperatures occurring during March – May (15 °C) and November – December (14.5 °C) and coldest night-time temperatures occurring during July (11.4 °C) (Figure 1).

Year to year differences in the average annual temperature are small, varying by only around 1 °C. Some of this is related to El Nino Southern Oscillation where temperatures are generally warmer during the El Nino phase and cooler during the La Nina phase (Figure 3).

Daily maximum and minimum temperature show clear and statistically significant warming trends over the last 30 or so years (Figure 4 and 5). The warming trend is seen during all seasons and in the mean temperature as well as in the frequency and duration of extreme temperature events (Figure 6 – 9).

The climate of Nairobi is projected to get warmer into the future. Using an ensemble of 15 Global Climate Models (GCMs) the daily maximum temperature is projected to increase by 0.5 °C to + 2 °C by 2040s, and by +2 °C to + 5 °C by the end of the century (Figure 13). Similarly daily minimum temperature is projected to increase by +1 °C to +1.5 °C by the 2040s, and between +3°C and +5 °C by the end of the century (Figure 14). This warming is expected to increase the frequency and severity of heat waves into the future (Figure 15 – 16). The message for rainfall is less certain with the ensemble of GCMs generally projecting no change, or a slight increase in rainfall by the end of the century (Figure 17 – 20). Similar results are obtained for both temperature and rainfall from an ensemble of 11 statistically downscaled GCM projections (Figure 21 – 28).

Historic Climate

Rainfall

Rainfall varies on a number of time scales from sub-daily to decadal or even longer:

The seasonal cycle of rainfall in Nairobi is strong with two core rainy seasons and a single dry season (Figure 1). This seasonality of rainfall is driven by the north-south migration of the Inter-Tropical Convergence Zone (ITCZ) over the region: The short rains occur during November – December as the ITCZ migrates southwards over the region. This season generally receives around 200 mm of rainfall. During January and February the ITCZ is located to the south of the region, but some rainfall still does occur in Nairobi (80 mm). During the long rains (March – May) the ITCZ migrates back north over the region and the long rains record around 310 mm of rainfall. During June – October the ITCZ is located to the north and little rainfall occurs in Nairobi.

Year-to-year or interannual variability in rainfall is large for Nairobi, with some years recording over 750 mm above or 370 mm below the long-term average (615 mm)(Figure 2). Rainfall totals within the two rainfall seasons fluctuate independently of each other (Figure 10 – 12). The long rains (March – May) vary by as much as 260 mm above or below the long-term average (310 mm). The short rains (November – December) vary by as much as 250 mm above or below the long-term average (200 mm) and with at least 1 year recording no rainfall during this season at all. The frequency of rainfall events, or number of rain days, also exhibits strong interannual variability which is closely linked to rainfall totals. The intensity of rainfall, or the daily mean rainfall amount, exhibits strong interannual variability in both rainy seasons, but does not appear to be strongly linked to the seasonal totals or frequency of rain events.

Rainfall over Nairobi exhibit variability on the multi-year timescale. Some of this is related to large scale remote forcings such as the El Nino Southern Oscillation (ENSO), with El Nino conditions generally being associated with above average rainfall and La Nina conditions to below average rainfall during the short rains (figure 3). Rainfall over Nairobi may also display decadal variability, however the 35-year length of the record does not provide sufficient time to clearly identify variability at this scale using this dataset.

The length of the climate record is just long enough to determine if there has been a long-term trend in rainfall. Each of the rainfall seasons is explored separately since they vary independently of each other. Looking at the period 1981-2016 there has not been a clear or significant linear trend in the seasonal total rainfall for the long rains (March – Mach). There has also not been a clear trend in the average daily rainfall intensity, the frequency of heavy rainfall events or the average wetspell or dryspell duration. The only statistic that does show a statistically significant trend is the frequency of rainfall events (-1.8 days per decade), but this may be influenced by the very high value at the beginning of the record. A similar message is seen for the short rains where the only statistically significant trend is found in the rainfall frequency (-1.7 days per decade) and the average wetspell duration (-0.2 days per decade) (Figure 10 – 12).

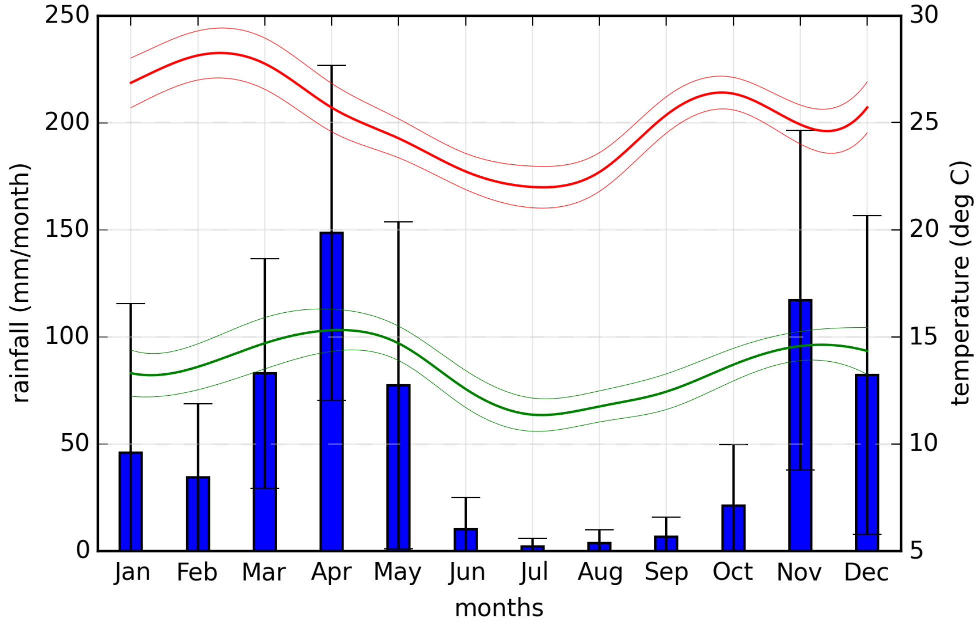

Figure 1: 1981-2010 historical average climate seasonality for the gridcell over Nairobi. Mean monthly total rainfall (mm/month) from CHIRPS dataset depicted as blue bars, whiskers show +- 2 standard deviations. Monthly mean daily maximum and minimum temperature from the WFDEI dataset presented by the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

Temperature

Temperature also shows clear variability on a range of time scales.

The diurnal temperature range – or difference between the maximum temperature and the minimum temperature within a 24-hour period – is an important mode of variability. Nairobi has an average diurnal temperature range of almost 12 °C within a day. The range is largest during January and February (14 °C) and smallest during the end of the long rains into the core of the dry season and also during November (between 9.5 – 10.6 °C)(Figure 1).

The seasonal cycle of temperatures - or the difference between the temperatures during the hottest and coldest time of the year - is relatively weak, averaging only around 6° and 5 °C for daily maximum and minimum temperature respectively (1981-2010). The long-term average (1981-2010) daily maximum temperatures are warmest during January – March (27.5 °C) with a secondary peak during September – November (25.9 °C), which corresponds to the start of the rainy season, and is coolest during June – August (22.5 °C). The long-term (1981-2010) average daily minimum temperature generally follows the seasonality of rainfall, with warmest night-time temperatures occurring during March – May (15 °C) and November – December (14.5 °C) and coldest night-time temperatures occurring during July (11.4 °C). This means that the difference between the average day-time and night-time temperatures within a season are generally larger than the difference in temperature between the hottest and the coldest time of the year for either daily maximum or minimum temperature (Figure 1).

Temperatures show low variability from year to year in terms of the average monthly or seasonal temperature, varying by less than 1 °C from the long-term mean in almost all months (Figure 2). What interannual variability does exist appears to be related to the El Nino Southern Oscillation, where temperatures are generally warmer during the El Nino phase and cooler during the La Nina phase (Figure 3).

The daily maximum and minimum temperatures in Nairobi display a clear and statistically significant linear warming trend in in all season of the year of between 0.3 and 0.4 °C per decade over the period 1979 - 2015. Looking more closely at how the temperature changed over time, daily maximum temperatures generally decreased slightly during the 1980s after which the trend is positive and most strongly positive during the 1990s especially during the warmest time of the year (January and February)(Figure 4). For daily minimum temperature there was a slight cooling trend in the 1980s during January and February before increasing from the 1990s to the present. The trend was positive for minimum temperature throughout the period for all other seasons (Figure 5).

Extreme daytime hot events which are classified as being those days where the temperature falls above the 90th percentile (tmax > 28.9 °C), mostly occur during February and March, but do occur from December to April and also in October. Extreme night-time temperatures (tmin > 15.8 °C) occur primarily from February to May and also during October to December. These events have become far more common over the period of the record (1979 – 2014) (Figure 6 and 7). The number of days where the maximum temperature exceeded the 90th percentile (28.9 °C) increased by 12 days per decade and the average length of these heat spells increased by 0.3 days per decade (or by 1 day over the full period). Within this period, the first 10 years actually showed a decrease in both the frequency and duration of these hot days, but the subsequent period from the early 1990s to 2014 showed a strong positive trend. A strong trend is also evident in the number of nights exceeding the 90th percentile (tmin > 15.8 °C) which increased by almost 22 days per decade and the average duration increased by half a day per decade. No clear trend is evident during the first 15 years of record after which a strong positive trend occurred in both the frequency and duration of the extreme warm nights.

Extreme cold events (tmax < 21.4 °C and tmin < 11 °C) occur primarily from June to August, but do also sometimes occur during January and February and other months. The frequency and duration of cold events has decreased over time (Figure 8 and 9). The number of days with extreme cold daily maximum temperatures (tmax < 21.4 °C) decreased by almost 8 days per decade and the duration by -0.1 days per decade. Similarly the frequency of extreme cold nights (tmin < 11 °C) has decreased by 7.6 days per decade and the average duration by -0.2 days per decade. The strongest rate of change occurred during the 1990s with more gradual decrease during the earlier and later decades.

Table 1: Summary of trends in temperature and rainfall attributes. The rainfall trends are calculate from the gridcell value over Nairobi from the CHIRPS dataset (1981-2016) and the temperature trends were calculated from the WFDEI dataset. The long-term mean values are included in brackets. Statistically significant temperature trend are coloured red if they are upward trends. Statistically significant rainfall trends are coloured brown if they are drying trends and green if they are wetting trends.

Temperature	**Jan – Feb**	**Mar – May**	**Jun – Oct**	**Nov – Dec**
Tmax [°C/decade]	**+0.4** (27.5)	**+0.4** (25.9)	**+0.3** (23.8)	**+0.4** (25.3)
Tmin [°C/decade]	**+0.4** (13.5)	**+0.4** (14.9)	**+0.3** (12.4)	**+0.4** (14.5)
	Annual (July – June)			
Tmax extreme hot events [days]	Frequency: **+12.1**	Duration: **+0.3**	Threshold: 28.9 °C	
Tmin extreme hot events [days]	Frequency: **+21.7**	Duration: **+0.5**	Threshold: 15.8 °C	
Tmax extreme cold events [days]	Frequency: **-7.9**	Duration: **-0.1**	Threshold: 21.4 °C	
Tmin extreme cold events [days]	Frequency: **-7.6**	Duration: **-0.2**	Threshold: 11.0 °C	

Rainfall	**Jan - Feb**	**Mar - May**	**Nov - Dec**
Total rainfall [mm/decade]	+3.6 (79)	-11.0 (308)	-3.1 (199)
Rain intensity [mm/day]	-0.3 (26.5)	+2.7 (76.7)	**-1.7** (75.3)
Rain day frequency [days/decade]	+0.4 (5.4)	**-1.8** (15.3)	+5.2 (6.6)
Heavy rain day frequency [days/decade]	no trend (3.0)	no trend (10.9)	no trend (4.5)
Wet spell [consecutive days]	**+0.2** (2.7)	-0.1 (6.1)	**-0.2** (2.8)
Dry spell [consecutive days]	**-3.3** (76.2)	+2.1 (91.6)	+4.8 (88.2)

Climate change projections

Global Climate Models

Projections of future climate, based on 15 CMIP5 GCM simulations[1] under the RCP8.5 pathway[2] show a clear and statistically significant increase in both minimum and maximum temperature into the future (Figure 13 and 14). By 2040 the mean daily maximum temperatures may be between 0.5 - 2 °C warmer than the current climate, while daily minimum temperatures are projected to warm by between +0.7 °C to +2 °C by 2040. The models suggest that the warming due to anthropogenic climate change may begin to be distinguished from that of natural variability within this current decade. This is supported by the observations which already show evidence of record breaking warming.

The frequency of heat spells is projected to increase into the future. However models disagree on the exact change with the frequency of days where the maximum temperature is over the 90th percentile ranging from a 100% increase to over 400% increase by the end of the century (Figure 15), and the increase in the frequency of nights over the 90th percentile ranging from almost 200% to 600% (Figure 16).

Annual rainfall totals are projected to remain within the historic range of variability, or to increase slightly in the second half of the century (Figure 17. However two outlier models disagree with the rest, the one projecting a decrease while the other projecting a very significant increase in rainfall into the future. A number of models project that the change in rainfall due to global warming may become discernable from that of natural variability in the 2040s but the rest do not project any clear trend due to global warming. A similar overall message is shown in the projected change in rainfall daily intensity, the frequency of rain days and heavy rain days (Figure 18 – 20). Table 3 below provides a summary.

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[1] The fifth iteration of the Couple Model Inter-comparison Project (CMIP) is a coordinate activity amongst international modeling centers 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)

[2] 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 its commitments remain to be shown.

Table 2: Summary of projected climate changes messages for key climate variables from an ensemble of 15 Global Climate Models for Nairobi.

Statistic	Annual (July – June)
Average Tmax [°C]	**Increasing:** +0.5 °C to +2 °C by 2040s, and by +2° to + 5°C by the end of the century. Warming generally becomes distinct from natural variability in this or the next decade.
Average Tmin [°C]	**Increasing:** +0.7 °C to +2 °C by 2040s, and by +2.5° to +6.5 °C by the end of the century. Warming generally becomes distinct from natural variability in this or the next decade.
Frequency of daytime heat spells (days)	**Increasing:** +10 to +130 days by 2040, and by +60 to 270 days by the end of the century. Strong disagreement in the rate of change between models. Increase in frequency discernable from that of natural variability within this decade for most models, but only in the second half of the century for all models.
Frequency of nighttime heat spells (days)	**Increasing:** +20 to +160 days by 2040, and by +100 to 300 days by the end of the century. Increase in frequency discernable from that of natural variablility from the beginning of this decade for most models. Note: nighttime heat spells increasing much more than daytime heat spells
Rainfall Totals [mm/year]	**Normal to increasing rainfall**, ranging from no change to moderate increase from 2040 (with 2 outlying models, one showing very strong increase while the other moderate decrease).
Rainfall daily intensity [mm/day]	**No change to strong positive change:** half the models project no clear change into the future, with one model showing a decrease and the rest projecting an increase in intensity especially towards the end of the century.
Rainfall frequency [days]	**No change to decreasing or increasing frequency:** roughly half of the models show no change in frequency into the future, while a couple show a decrease and the rest an increase in frequency from the 2020s onwards.
Heavy rainfall frequency (over 10 mm) [days]	**No change to increasing or decreasing frequency:** roughly half of the models show no change in frequency until after 2040. One shows a decrease and the rest an increase in frequency from the 2020s and especially after 2050.

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 (Figure 21 and 22). By 2040 the daily maximum temperatures may be between 1 °C to 1.5 °C warmer than the current climate and by the end of the century it may increase by between 2.5 °C and 4.5 °C, depending on the model selected. Similarly daily minimum temperate is also project to increase into the future by between 1 °C and 1.5 °C by 2040 and by 3 °C to 5 °C by the end of the century. The models suggest that the warming due to anthropogenic climate change may begin to be distinguished from that of natural variability within this current decade. This is supported by the observations which already show evidence of record breaking warming.

The frequency of heat spells is projected to increase into the future. However models disagree on the exact change. Daytime extreme heat events are projected to increase by between 20 to 50 days by 2050 and by 75 to 180 extra days by the end of the century (this equates to a 100% to almost 300% increase from the historical norm)(Figure 23). Nighttime extreme heat events are projected to increase by between 70 to 110 days by 2040 and by 210 to 310 extra days by the end of the century (this equates to an increase of between 600% and 850% from the historical norm)(Figure 24).

Annual total rainfall is projected to remain within the historic range of variability during most of the 21st Century, but could increase towards the end of the century (2070s onwards)(Figure 25). A similar message is projected for rain day and heavy rain (>10mm/day) frequency, but no change is projected in the daily intensity of rainfall (Figure 26 – 28).

Table 3: Summary of projected climate changes messages for key climate variables from an ensemble of 11 statistically downscaled Global Climate Models for Nairobi.

Statistic	Annual
Average Tmax [°C]	**Increasing** +1 to +1.5 °C by 2040, and between +2.5 to +4.5 °C by the end of the century. Warming trend may already be discernable from that of natural variability.
Average Tmin [°C]	**Increasing** +1 °C to +1.5 °C by 2040s, and between +3 and +5 °C by the end of the century. Warming trend may already be discernable from that of natural variability.
Daytime extreme heat events [days]	**Increasing**, +20 to 50 extra days by 2040, and between +75 to +180 extra days by the end of the century. Warming trend may already be discernable from that of natural variability in this decade.
Nighttime extreme heat events [days]	**Increasing**, +70 to 110 extra nights by 2040, and between +210 to +310 extra nights by the end of the century. Warming trend may already be discernable from that of natural variability.
Total rainfall [mm/year]	**Normal to increasing rainfall**, ranging from slight drying to significant wetting from 2070 onwards.
Rain intensity [mm/day]	**No change in daily intensity.**
Rain day frequency [days]	**No change to increasing rain day frequency**, ranging from no change to significant increase from 2070 onwards
Heavy rain day frequency [days]	**No change to increasing rain day frequency**, ranging from no change to significant increase from 2070 onwards.

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 Nairobi 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)[3] where the WATCH Forcing Data methodology is applied to ERA-Interim data (Weedon et al. 2014)[4]. 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)[5] (Funk et al. 2015)[6]. 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).

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

[4] 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.

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

[6] 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.

Table 4: CMIP5 modelling centres and models used in the analysis (those 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*

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[7]). 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.

A time series for the gridcell covering Nairobi 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.

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 Nairobi 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 Nairobi.

[7] 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.

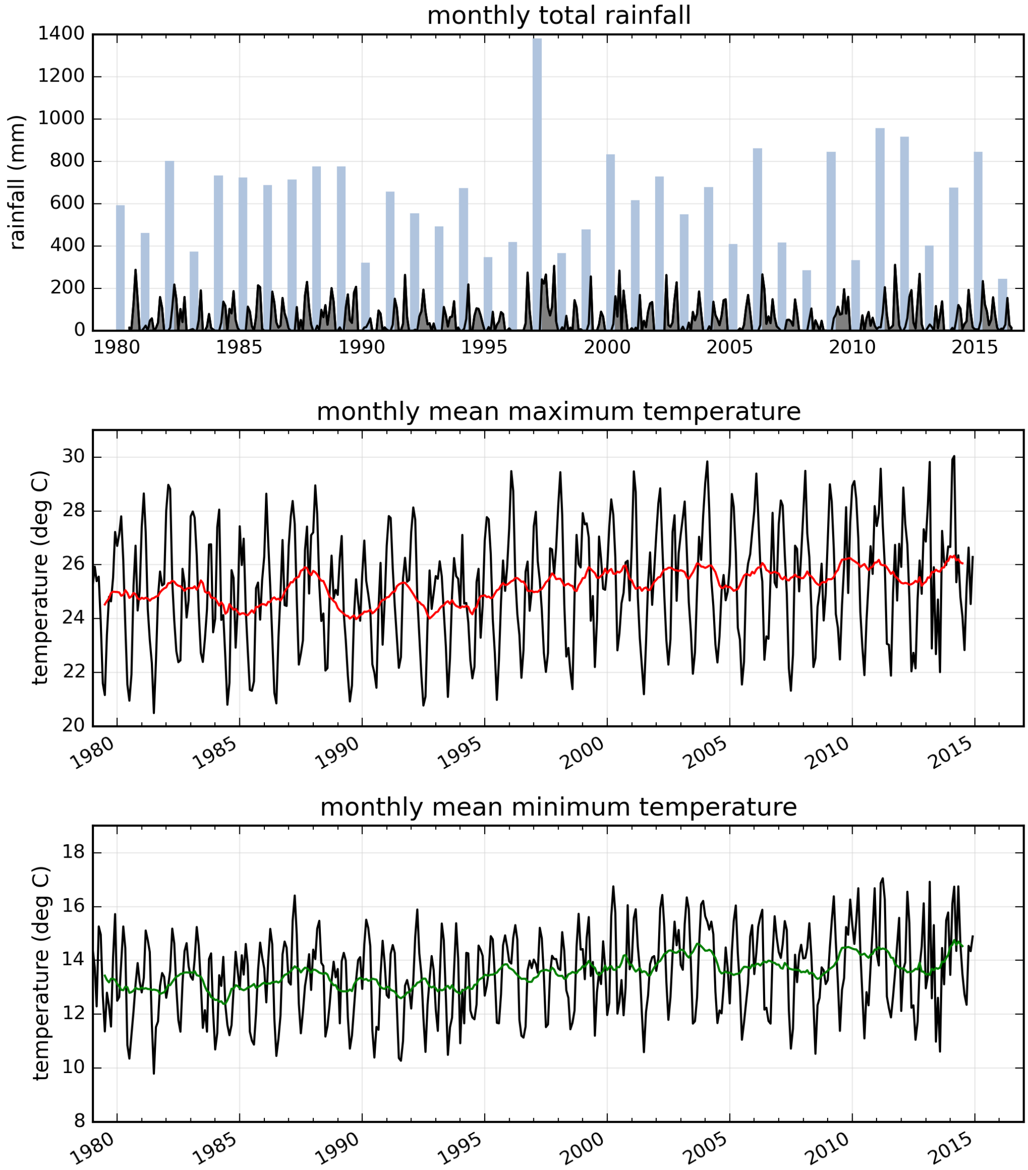

Figure 2: Time series of monthly mean maximum and minimum temperature and total rainfall for Nairobi, red and green coloured lines represent a 12 month running average for maximum and minimum temperature respectively. Light blue bars present the annual (July – June) total rainfall.

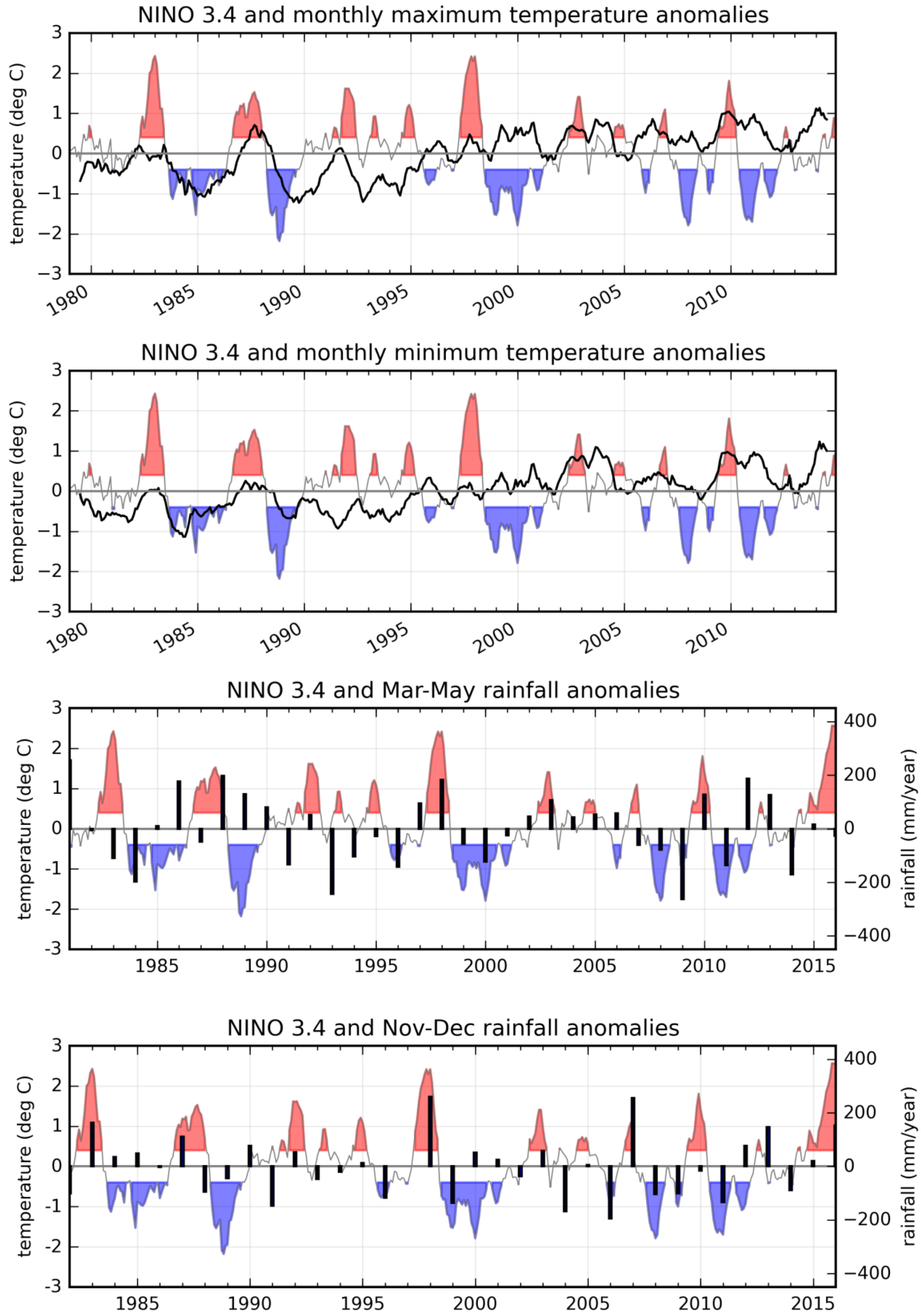

Figure 3: Association between ENSO and the climate at Nairobi through time. Time series of the NINO 3.4 SST monthly anomalies is presented as the grey line; positive (El Nino) phases are coloured red, while negative (La Nina) phases are shaded in blue. Black line in top panel shows the monthly mean maximum temperature anomalies smoothed with a 12-value running mean. The second panel shows the same as above, but for minimum temperature. The black bars in the bottom panel show the annual (July-June) total rainfall anomalies (mm/year).

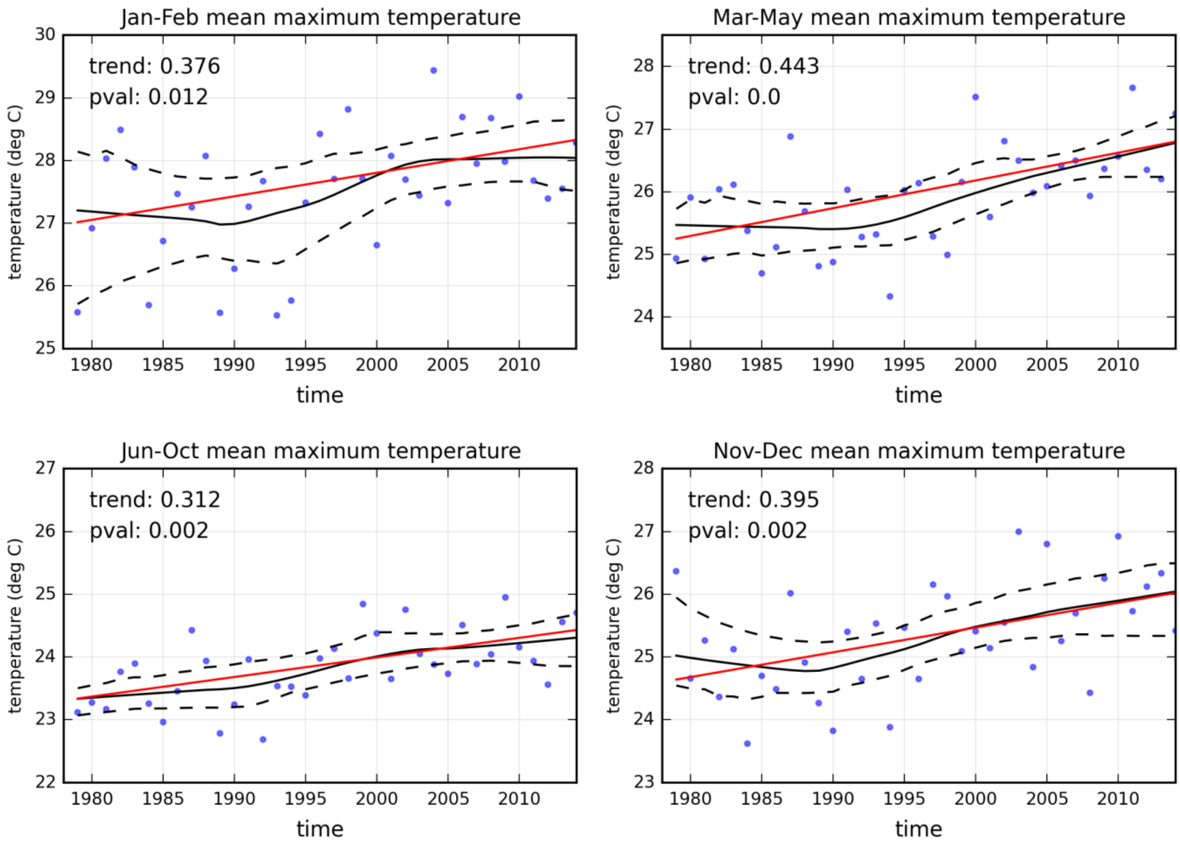

Figure 4: Time series and trend in seasonal average maximum temperature for the gridcell over Nairobi from the WFDEI dataset. Time series of seasonal mean maximum temperature (blue dots). Theil-Sen trend (red line) and the Lowess smooth (black line) and 95th confidence interval (dashed lines)

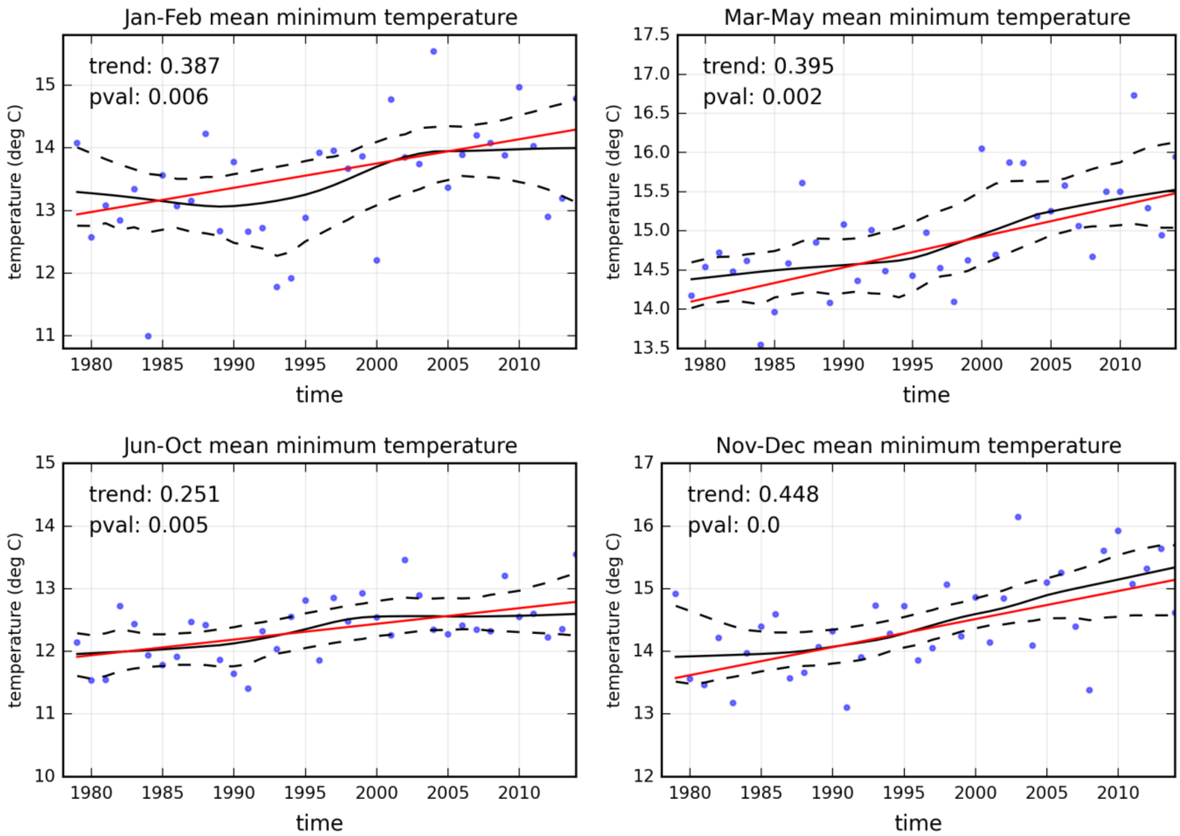

Figure 5: Time series and trend in seasonal average minimum temperature for the gridcell over Nairobi from the WFDEI dataset. Time series of seasonal mean maximum temperature (blue dots). Theil-Sen trend (red line) and the Lowess smooth (black line) and 95th confidence interval (dashed lines)

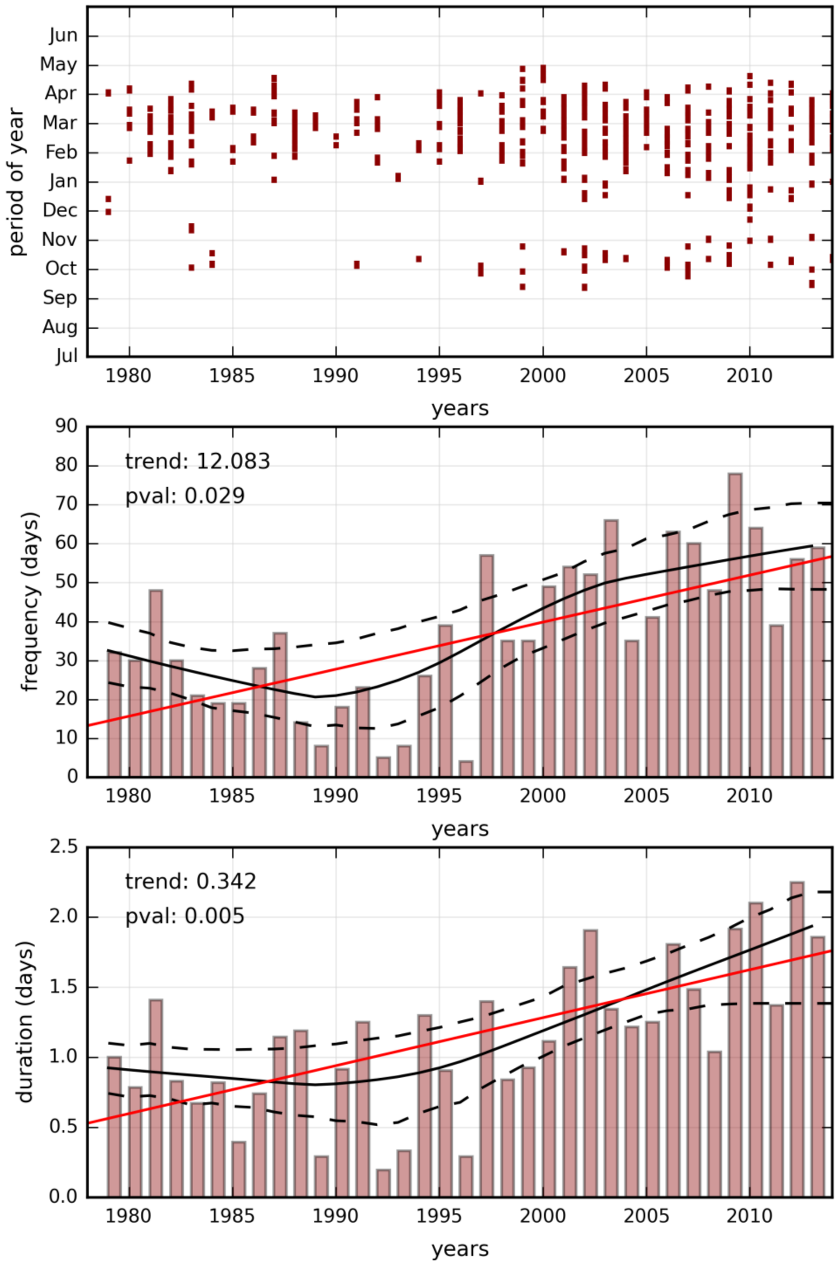

Figure 6: Time series of the timing of extremely hot days (tmax > 90th percentile (28.9°C)) for the gridcell over Nairobi from the WFDEI dataset. Top panel displays the timing and length of hot spells. Bottom panel displays the total number of days which exceed this threshold for each July – June calendar year (pink bars). The Theil-Sen linear trend (red line) and the Lowess smooth interpolation (black line) and 95th confidence interval (dashed lines).

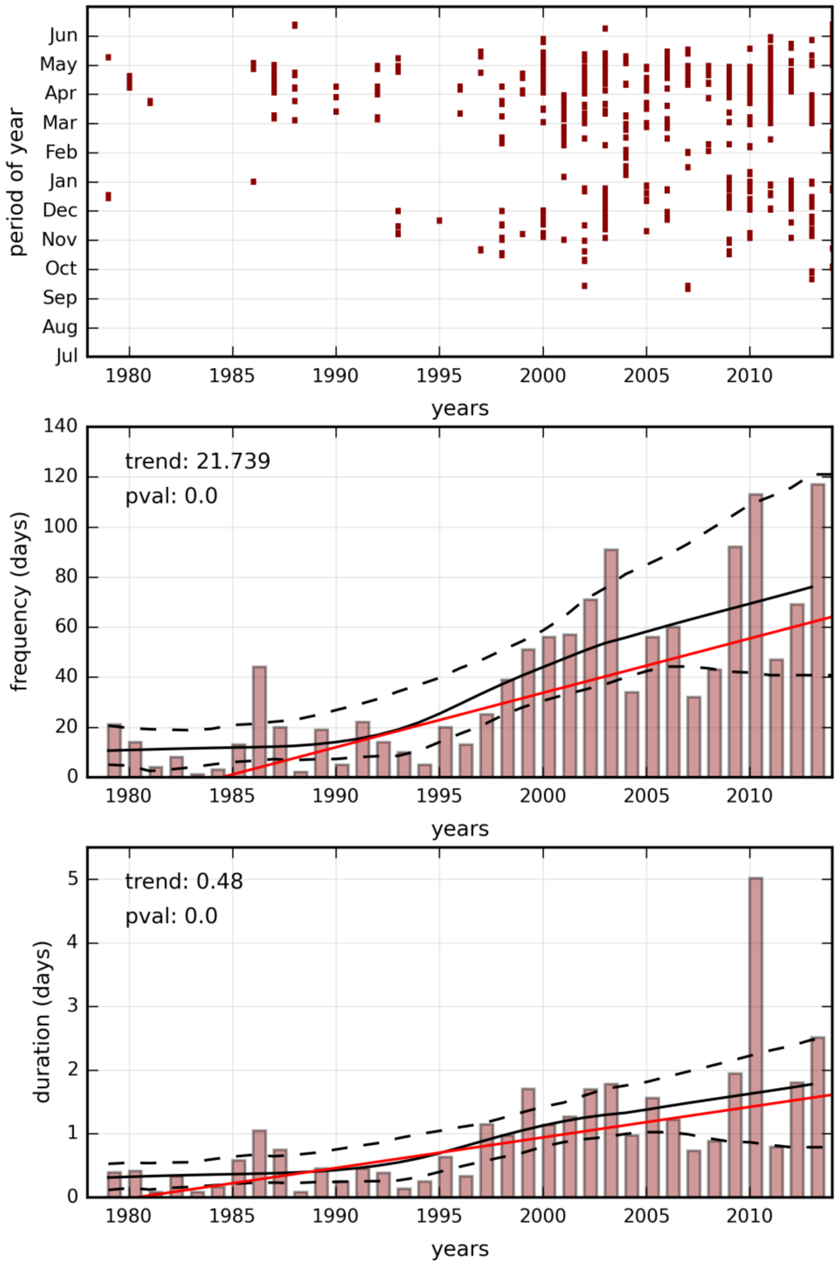

Figure 7: Time series of the timing of extremely hot nights (tmin > 90th percentile (21.4°C)) for the gridcell over Nairobi from the WFDEI dataset. Top panel displays the timing and length of hot spells. Bottom panel displays the total number of days which exceed this threshold for each July – June calendar year (pink bars). The Theil-Sen linear trend (red line) and the Lowess smooth interpolation (black line) and 95th confidence interval (dashed lines).

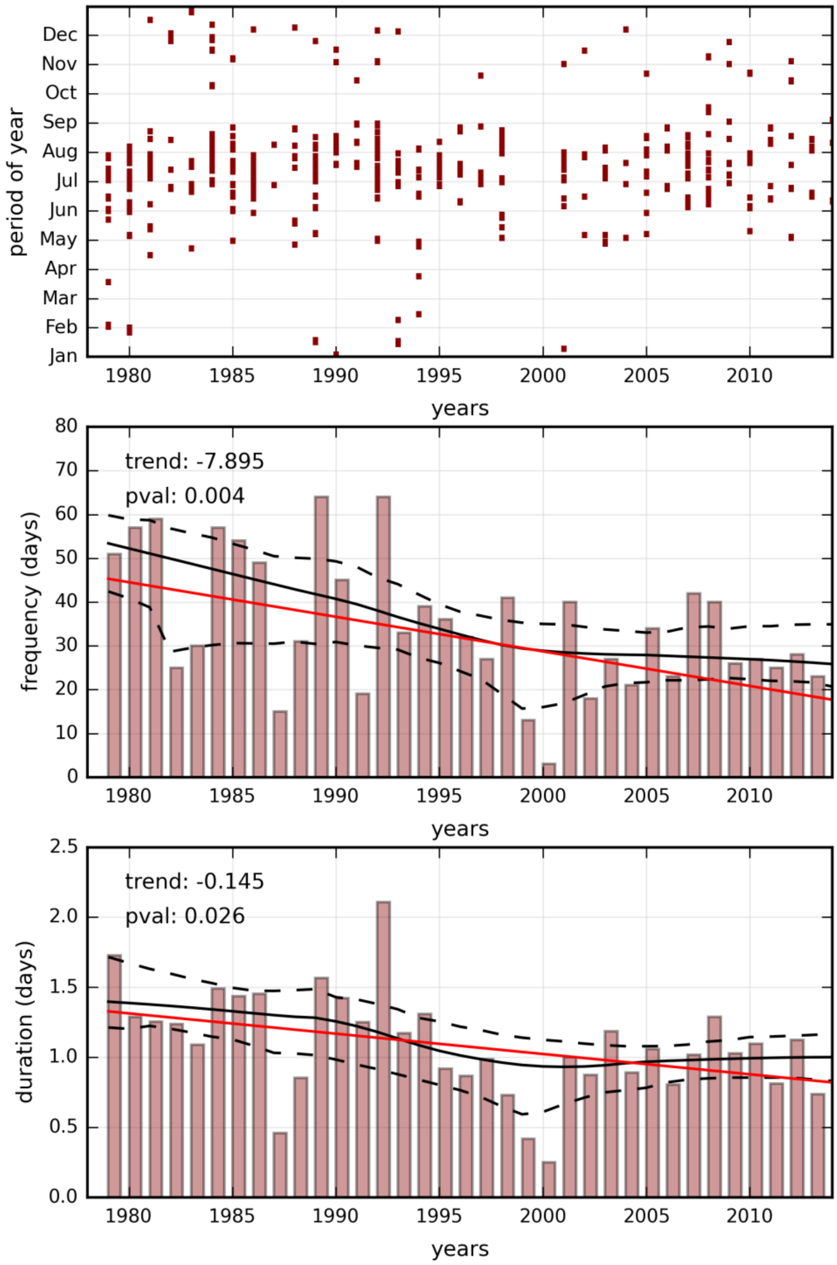

Figure 8: Time series of the timing of extremely cold days (tmax < 10th percentile (15.8°C)) for the gridcell over Nairobi from the WFDEI dataset. Top panel displays the timing and length of hot spells. Bottom panel displays the total number of days which exceed this threshold for each July – June calendar year (pink bars). The Theil-Sen linear trend (red line) and the Lowess smooth interpolation (black line) and 95th confidence interval (dashed lines).

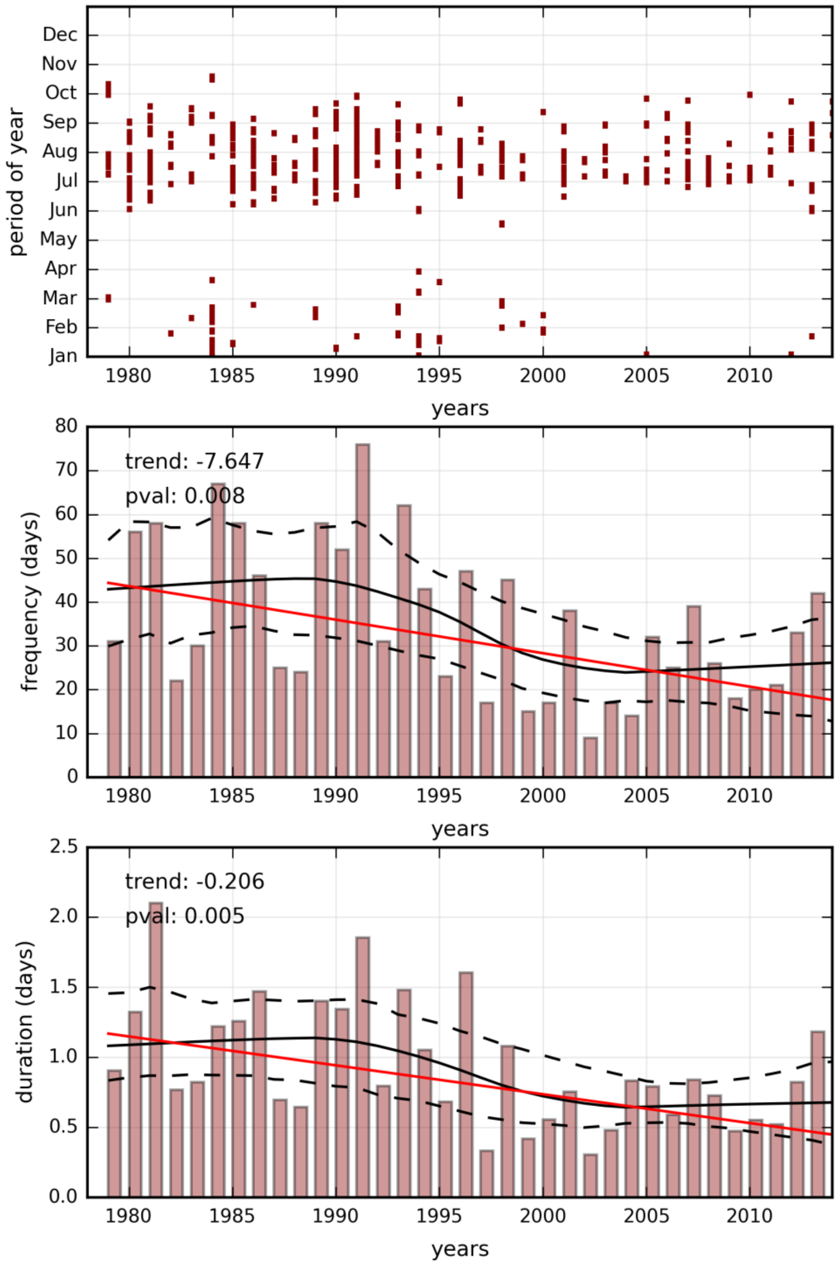

Figure 9: Time series of the timing of extremely cold nights (tmin < 10th percentile (11°C)) for the gridcell over Nairobi from the WFDEI dataset. Top panel displays the timing and length of hot spells. Bottom panel displays the total number of days which exceed this threshold for each July – June calendar year (pink bars). The Theil-Sen linear trend (red line) and the Lowess smooth interpolation (black line) and 95th confidence interval (dashed lines).

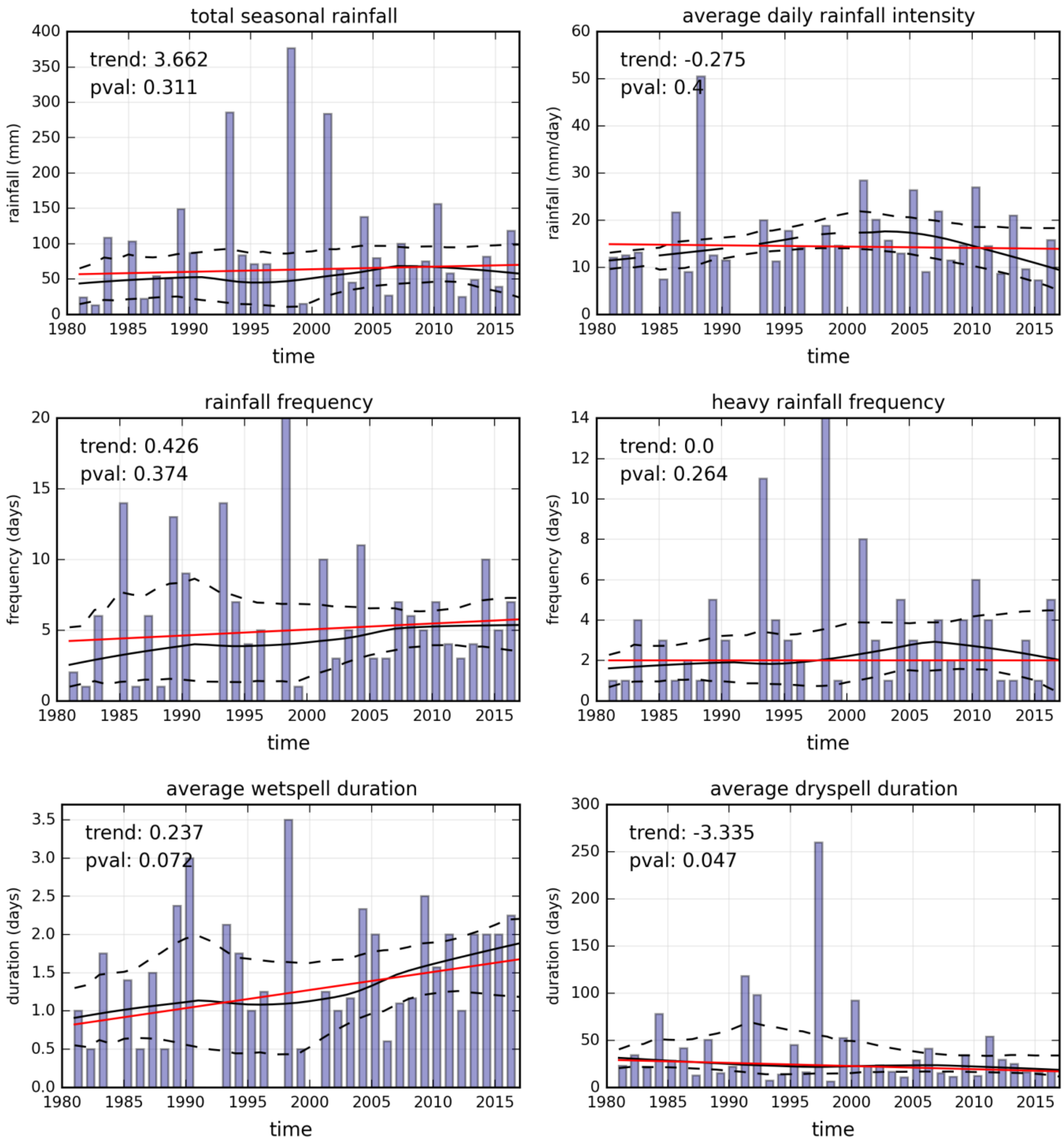

Figure 10: Time series and trend in the short dry season (January-February) rainfall statistics for Nairobi. Blue bars depict the time series of the annual statistic. The Theil-Sen linear trend line is show in red along with the trend (per decade) and pvalue. The median (solid black line) and 95th confidence interval (dashed line) from a 1000 member ensemble of the Lowess regression.

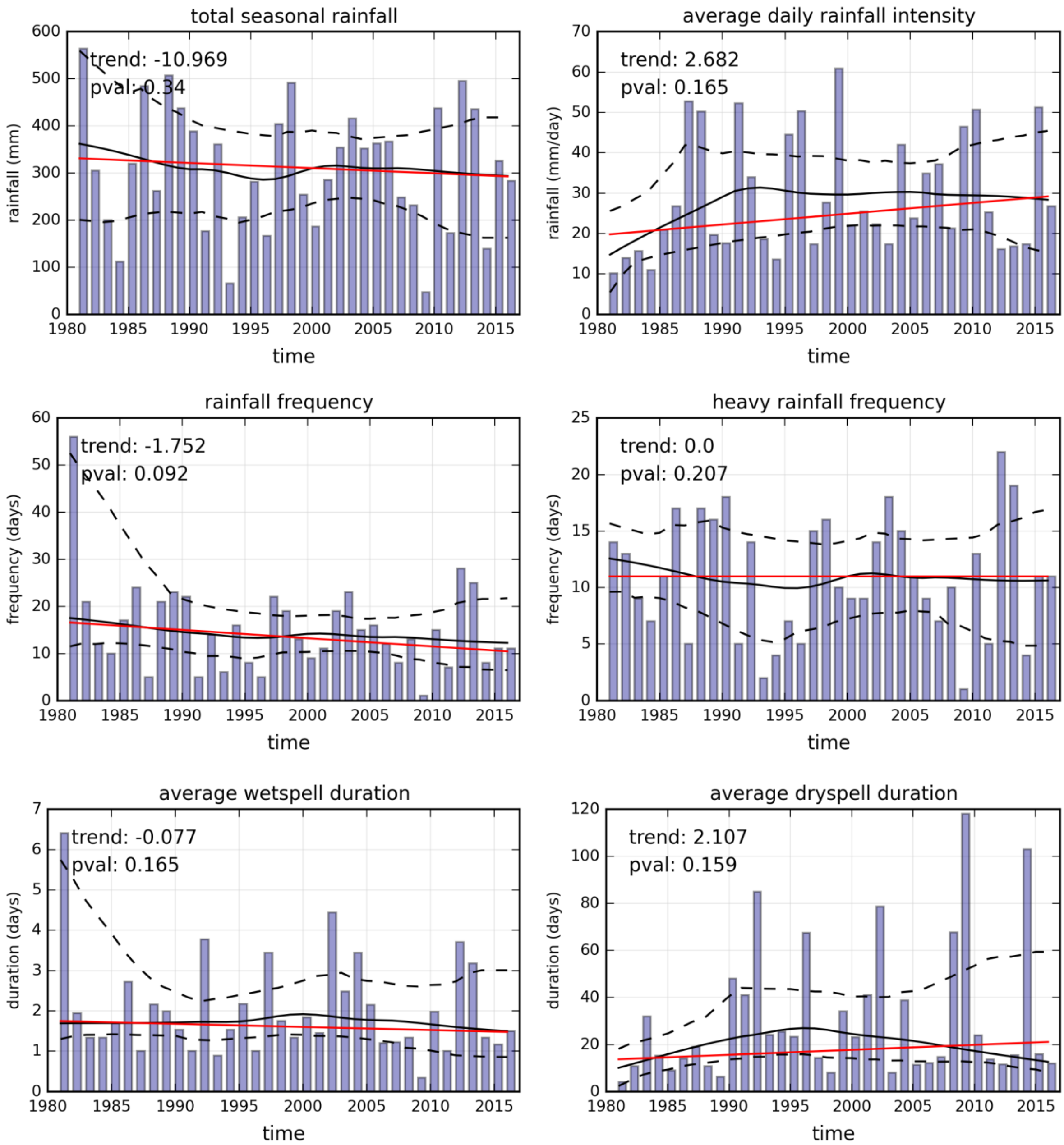

Figure 11: Time series and trend in the long rains season (March – May) rainfall statistics for Nairobi. Blue bars depict the time series of the annual statistic. The Theil-Sen linear trend line is show in red along with the trend (per decade) and pvalue. The median (solid black line) and 95th confidence interval (dashed line) from a 1000 member ensemble of the Lowess regression.

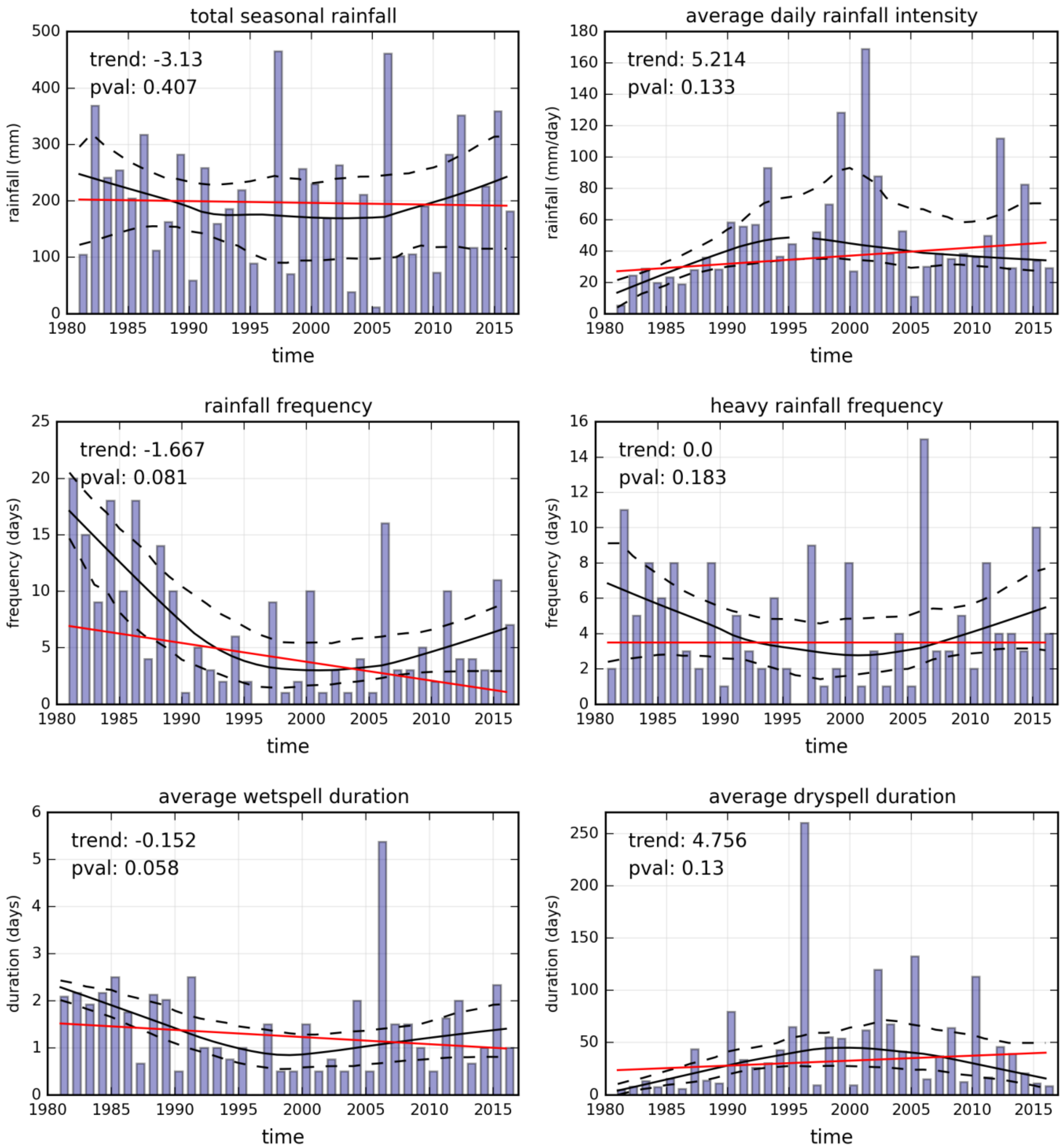

Figure 12: Time series and trend in the short rains season (November – December) rainfall statistics for Nairobi. Blue bars depict the time series of the annual statistic. The Theil-Sen linear trend line is show in red along with the trend (per decade) and pvalue. The median (solid black line) and 95th confidence interval (dashed line) from a 1000 member ensemble of the Lowess regression.

Global Climate Models

The plots below (Figures 13 to 20) 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 Nairobi produces 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 differs between GCMs and it is possible that different messages would be obtained at smaller spatial scales and if various forms of downscaling are performed.

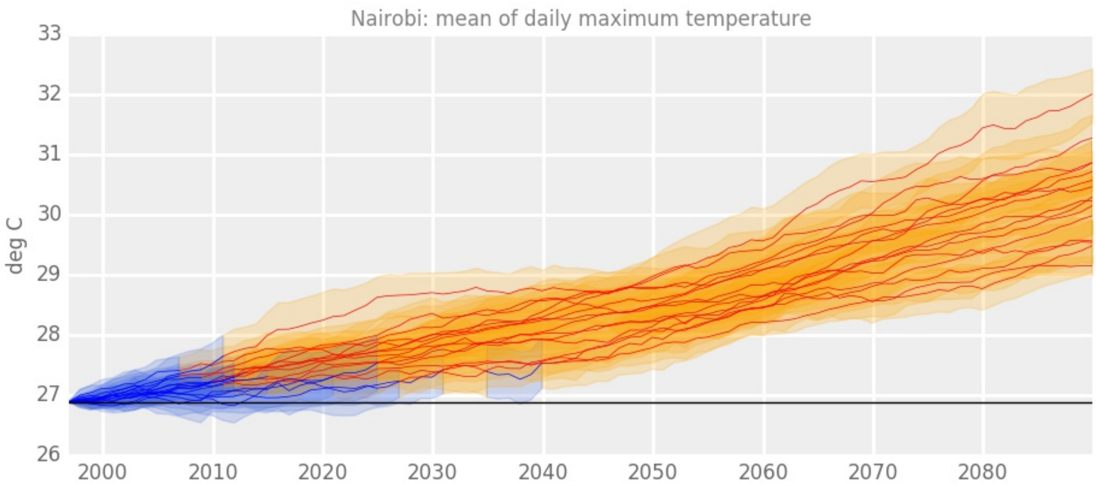

Figure 13: CMIP5 projected changes in seasonal mean daily maximum temperature under the RCP 8.5 concentration pathway for Nairobi. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of results from each 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 indicates when 20-year moving average moves outside of the 95% confidence range of the reference period.

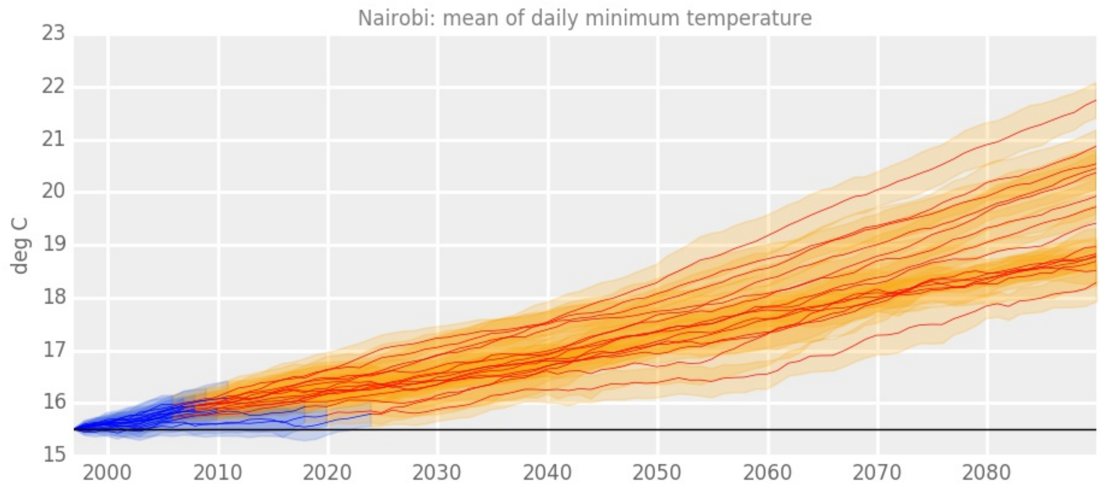

Figure 14: CMIP5 projected changes in annual mean daily minimum temperature under the RCP 8.5 concentration pathway for Nairobi (refer to figure 13 for further details).

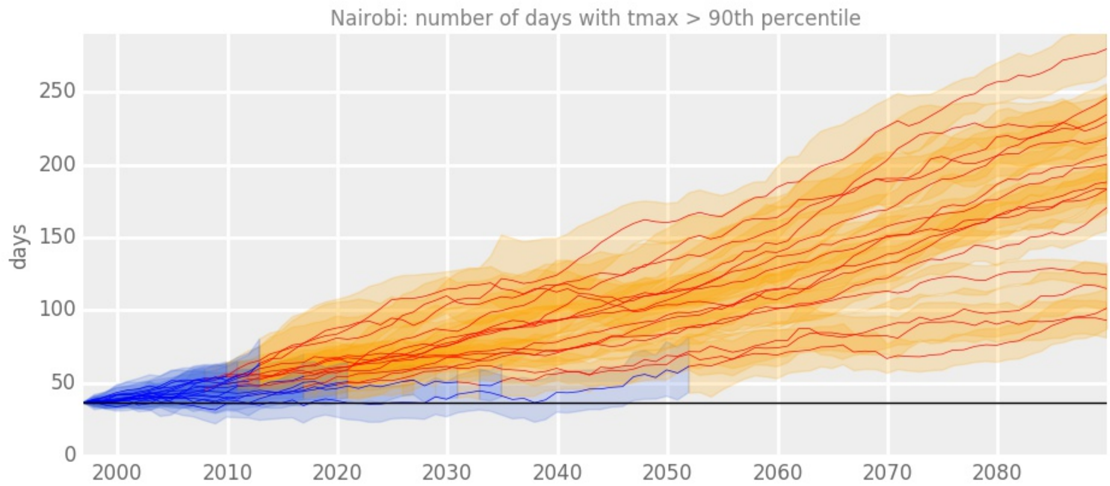

Figure 15: CMIP5 projected changes in annual frequency of days exceeding the 90th percentile for maximum temperature under the RCP 8.5 concentration pathway for Nairobi (refer to figure 13 for further details).

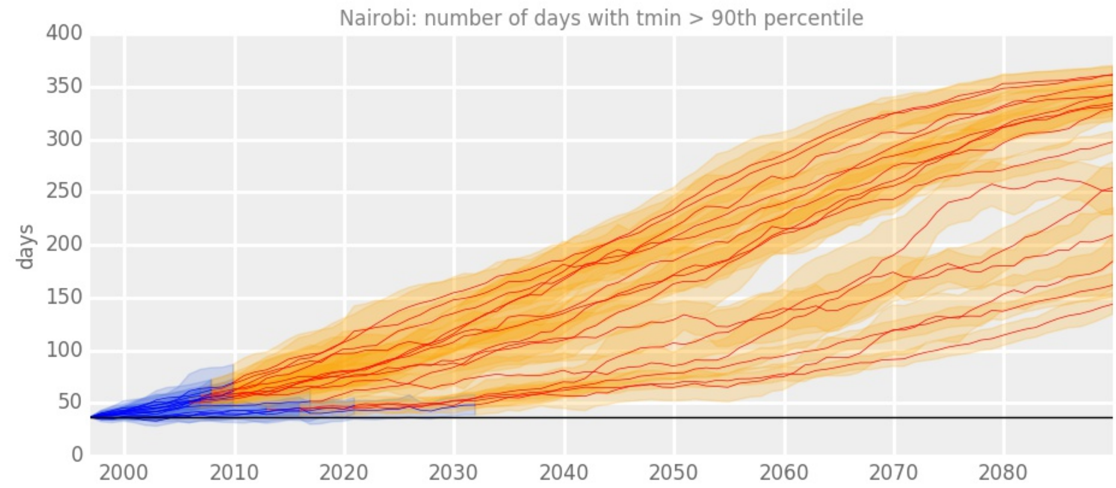

Figure 16: CMIP5 projected changes in annual frequency of nights exceeding the 90th percentile for minimum temperature under the RCP 8.5 concentration pathway for Nairobi (refer to figure 13 for further details).

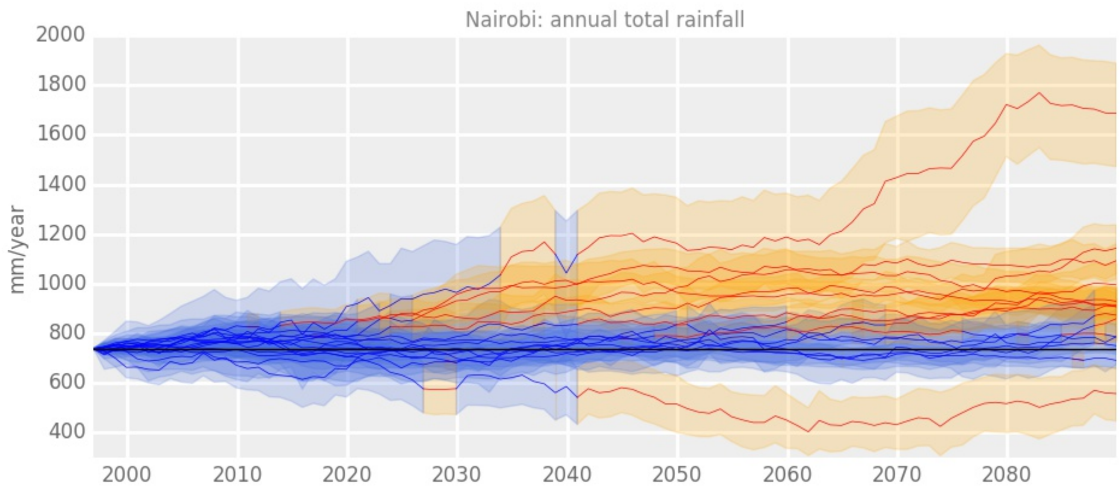

Figure 17: CMIP5 projected changes in annual total rainfall under the RCP 8.5 concentration pathway for Nairobi (refer to figure 13 for further details).

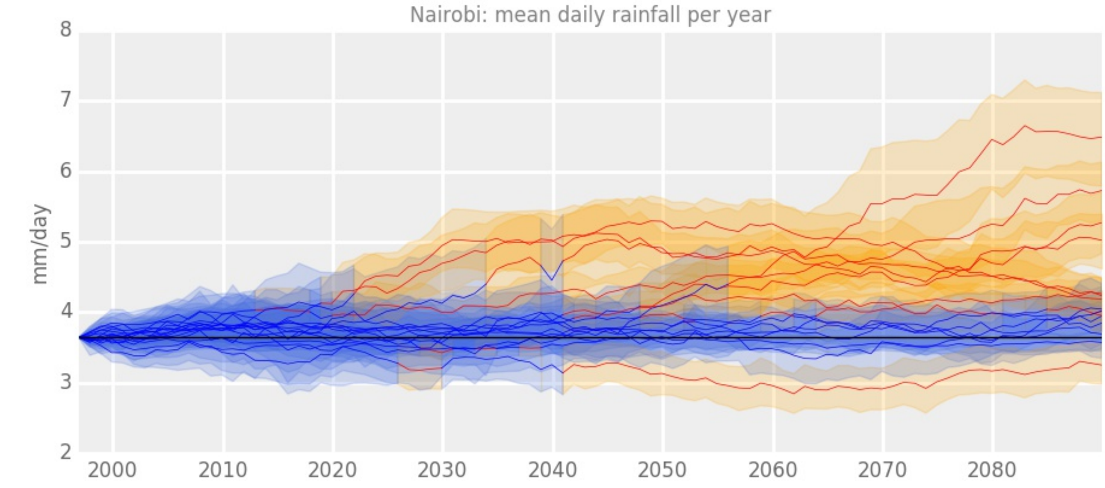

Figure 18: CMIP5 projected changes in annual average daily rainfall intensity under the RCP 8.5 concentration pathway for Nairobi (refer to figure 13 for further details).

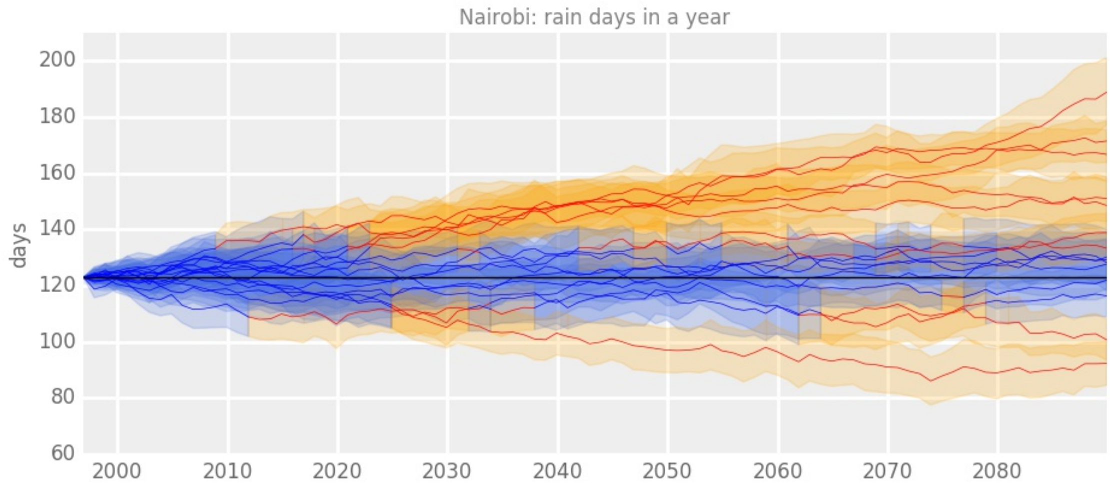

Figure 19: CMIP5 projected changes in annual rainfall frequency under the RCP 8.5 concentration pathway for Nairobi (refer to figure 13 for further details).

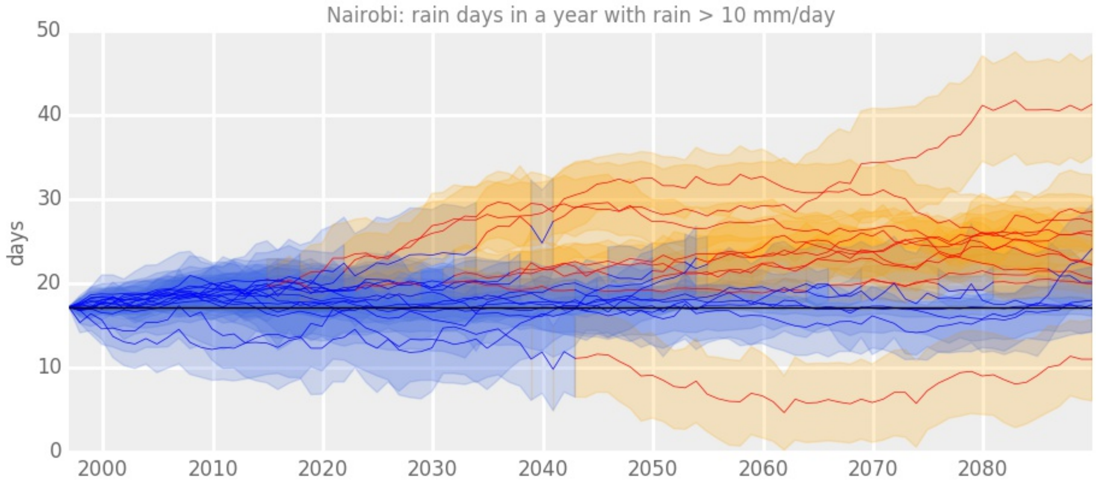

Figure 20: CMIP5 projected changes in annual heavy rainfall frequency under the RCP 8.5 concentration pathway for Nairobi (refer to figure 13 for further details).

Statistical downscaling

The plots below (Figures 21 to 28) 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 Nairobi produces 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 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.

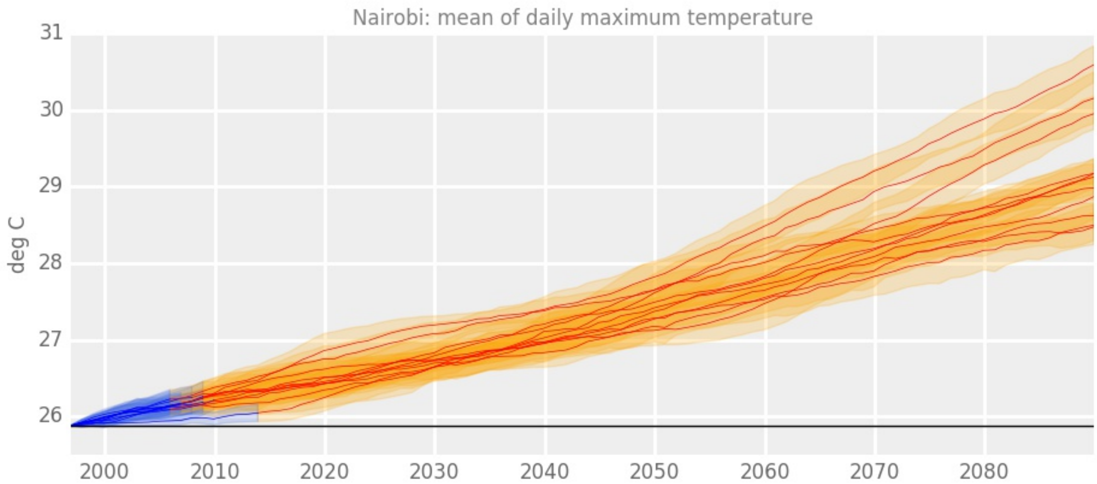

Figure 21: Statistically downscaled projected changes in annual mean daily maximum temperature under the RCP 8.5 concentration pathway for Nairobi. The black line shows the multi-model mean value across all models in the reference period 1986-2005. The coloured lines show the 20-year moving average of 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 indicates when 20-year moving average moves outside of the 95% confidence range of the reference period.

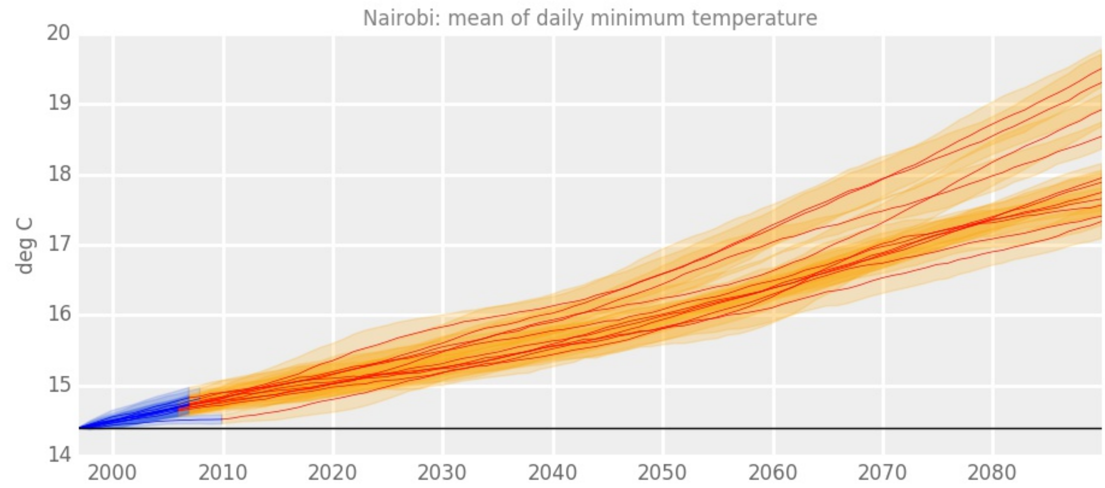

Figure 22: Statistically downscaled projected changes in annual mean daily minimum temperature under the RCP 8.5 concentration pathway for Nairobi (refer to Fig 21 for further details)

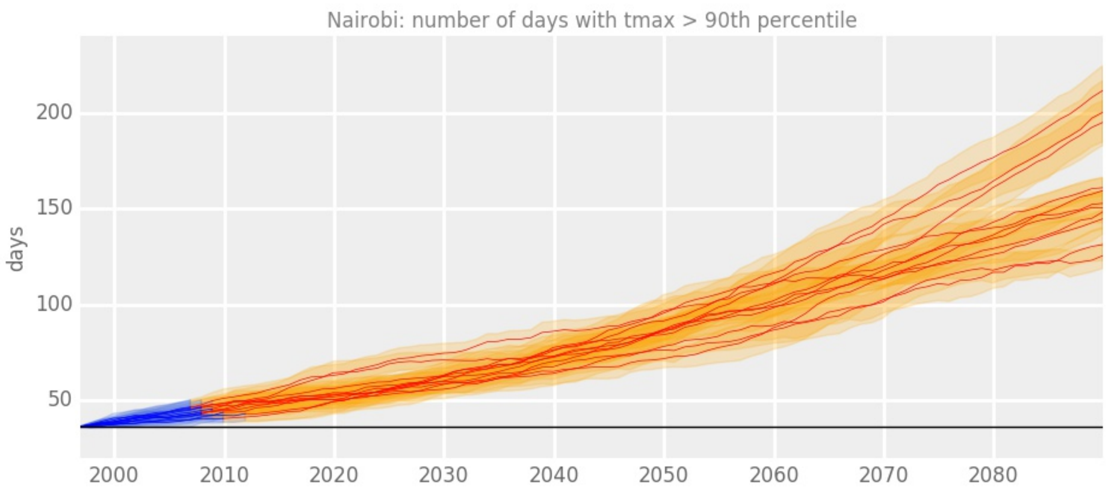

Figure 23: Statistically downscaled projected changes in annual frequency of days with maximum temperature above the 90th percentile of the historical period (1986-2005) under the RCP 8.5 concentration pathway for Nairobi (refer to Fig 21 for further details)

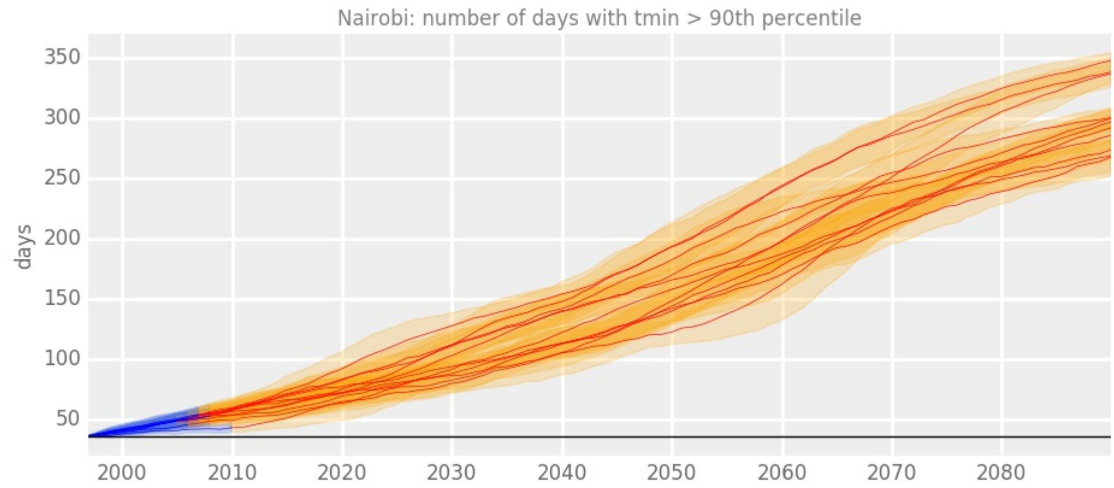

Figure 24: Statistically downscaled projected changes in annual frequency of nights with minimum temperature above the 90th percentile of the historical period (1986-2005) under the RCP 8.5 concentration pathway for Nairobi (refer to Fig 21 for further details)

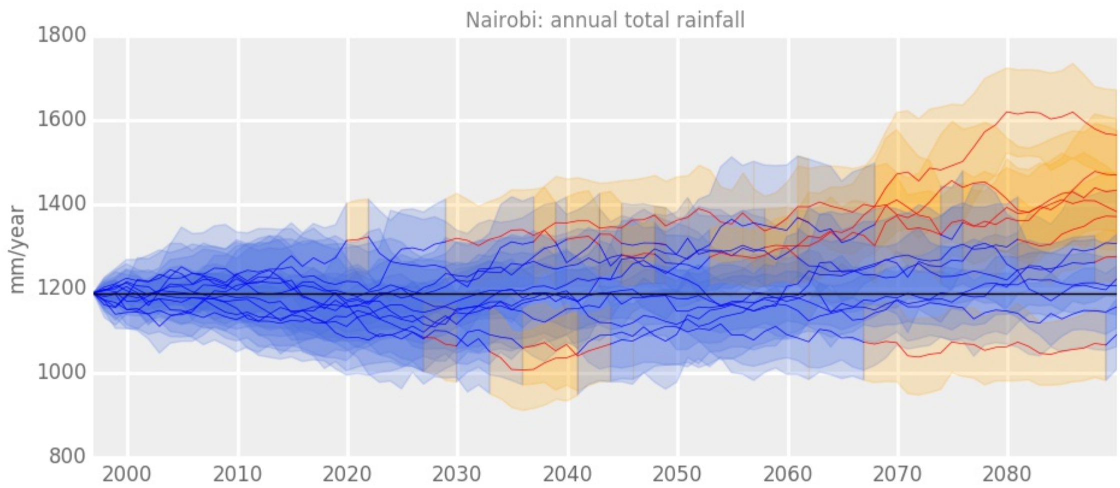

Figure 25: Statistically downscaled projected changes in annual total rainfall under the RCP 8.5 concentration pathway for Nairobi (refer to Fig 21 for further details)

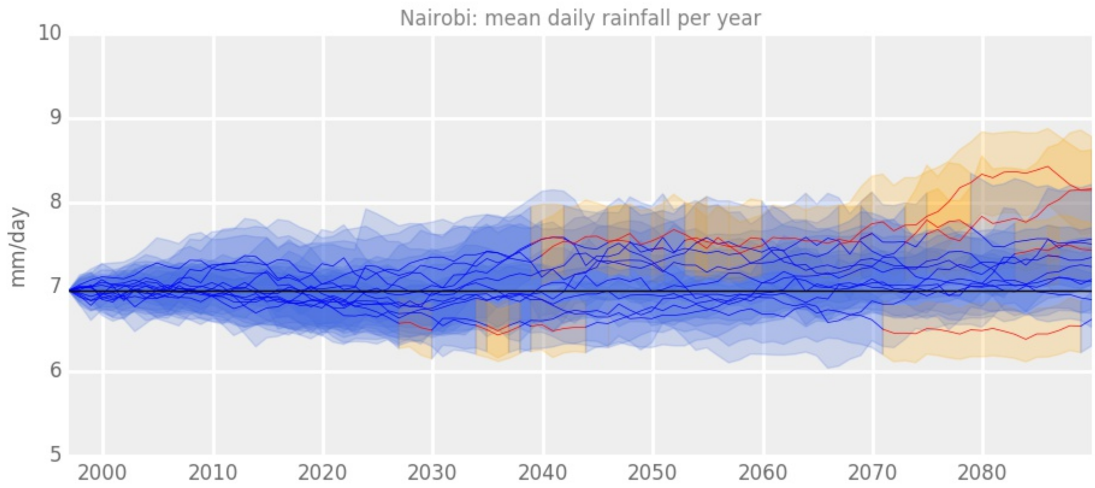

Figure 26: Statistically downscaled projected change in the daily intensity of rainfall under the RCP8.5 concentration pathway for Nairobi (refer to Fig 21 for further details)

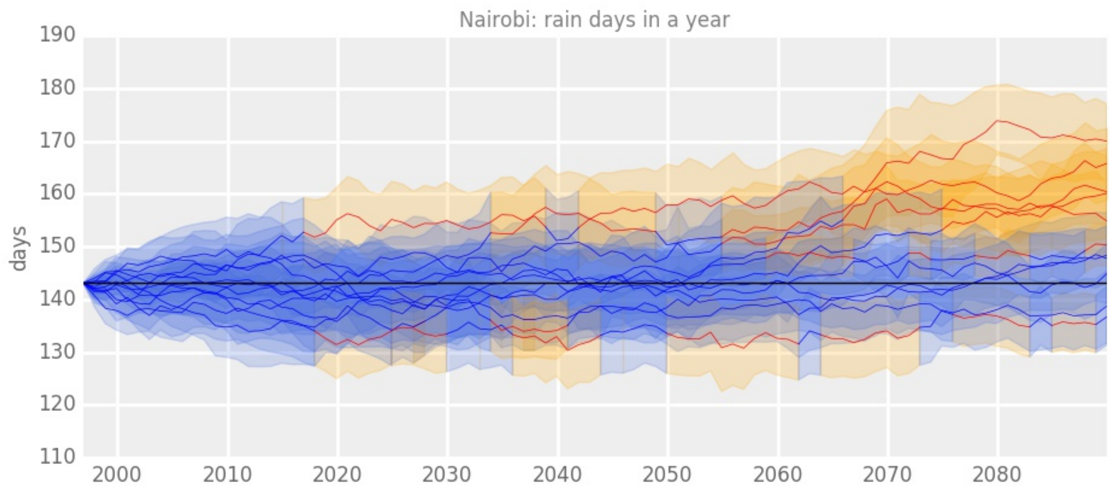

Figure 27: Statistically downscaled projected change in the frequency of raindays (rainfall > 0.02mm) under the RCP8.5 concentration pathway for Nairobi (refer to Fig 21 for further details)

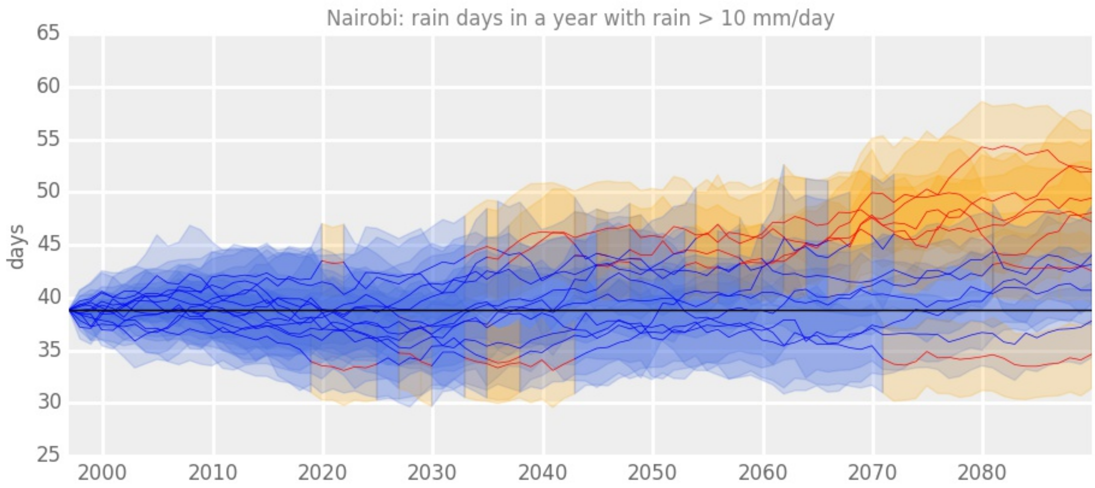

Figure 28: Statistically downscaled projected change in the frequency of heavy raindays (rainfall > 10mm) under the RCP8.5 concentration pathway for Nairobi (refer to Fig 21 for further details)

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

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