

Climate Projections for United Republic of Tanzania

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Introduction

The United Republic of Tanzania covers an area of 885,800 km² and extends from the Indian Ocean coastline to more than 1000km inland. The topography ranges from sea level to over 1,600m altitude in the west. Kilimanjaro is at 5,895m altitude. Much of the country lies above with 1000m altitude with many areas above 1500m in the centre and north. The coastal areas and southern areas are generally lower altitude. The northern borders lie almost on the equator while the southern border is at around 12°S. This places Tanzania directly in the tropics climatologically and hence the climate is entirely driven by tropical processes. However, the range in altitude and associated climate impacts result in significant climate gradients across the country. In addition, the presence of Lake Tanganyika to the west and Lake Victoria to the north are potential sources of moisture to surrounding areas.

The ocean coastline is warm and generally wet with Dar es Salaam experiencing a mean of over 1000mm/year of rainfall daily maximum temperatures ranging between 29°C and 32°C. This is in contrast to Tabora in the centre which experiences a mean annual rainfall of less than 500mm/year and average daily maximum temperatures slightly cooler, ranging from 27°C and 31°C. Mwanza, on the coast of Lake Victoria experiences around 700mm/year which is higher than Tabora, most likely a result of the moisture supplied by Lake Victoria, however mean daily maximum temperatures are lower hovering between 27°C and 28°C.

Being in a tropical location the seasonality is tied to the movement of the Inter-tropical Convergence Zone (ITCZ) which moves north and south during the year. Additionally the ITCZ often splits into two branches over East Africa. The ITCZ in the tropics often results in a double rain season which can be seen at a number of locations in Tanzania. This double season occurs as the ITCZ moves southwards at the beginning of summer and then northwards at the end of summer. Rainfall is associated with the shift in the ITCZ, hence an early summer and a late summer rainfall season. However, regional expressions of this effect are varied.

It is always important to consider current climate inter-annual variability when one investigates the climate of a region. This gives an indication of the range of variability currently being experienced which is critical when one considers future changes. It is often the case that the current inter-annual variability of precipitation is very large compared to future projected changes, particularly for the near future (50 years). This is an important consideration for end users depending on the sector and the type of vulnerability under question.

The observed climate for a number of stations is presented below in the form of graphs and summary tables. The stations were selected in order to cover the general range of the climate over Tanzania extending from the coastline inland and from the lower altitude south to the higher altitude north. A map of the station locations is

presented in figure 1 with station names of the selected stations.

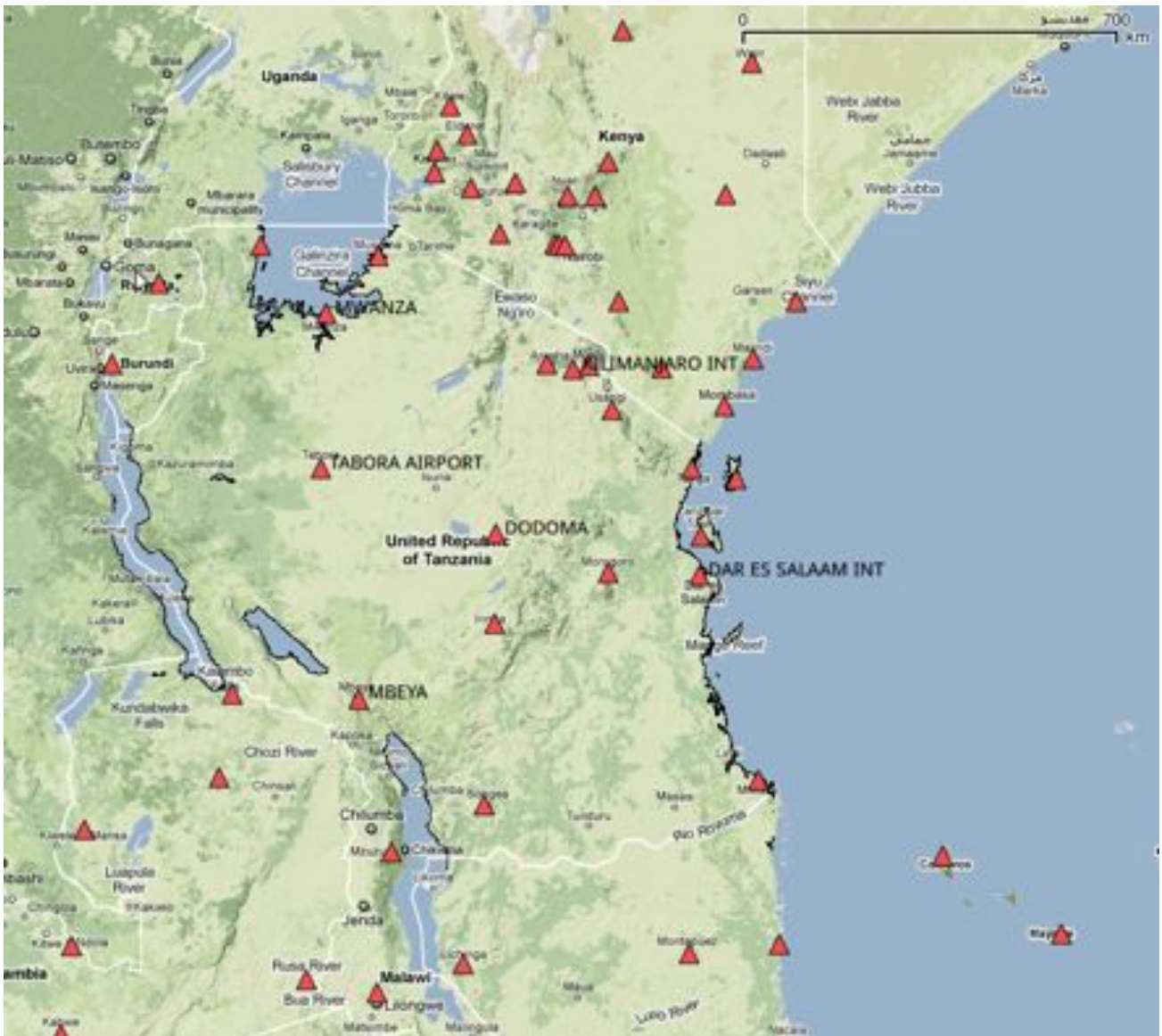
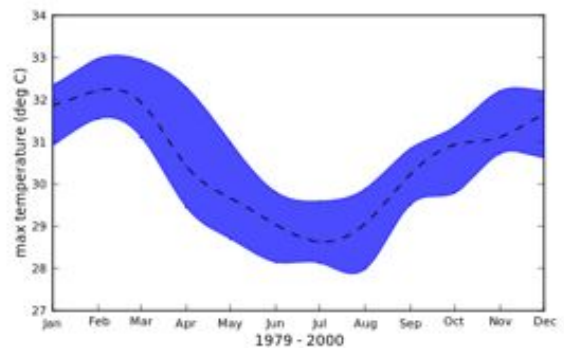
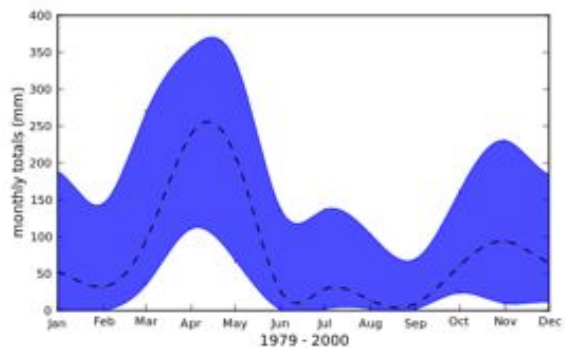
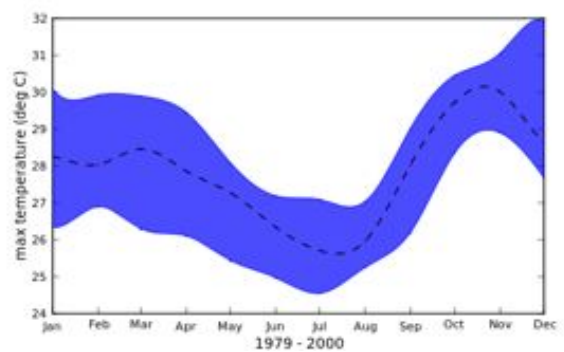
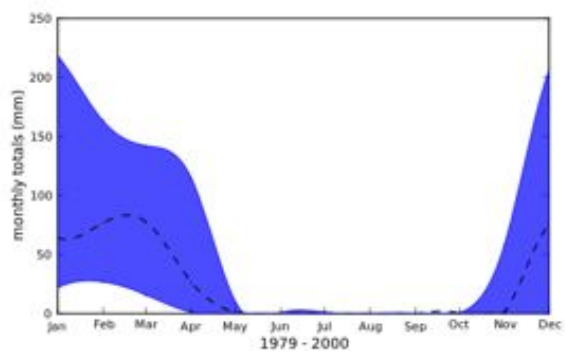


Figure 1: Weather station locations with analysis stations labelled

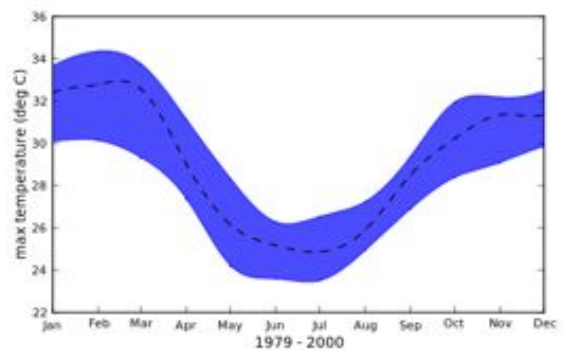
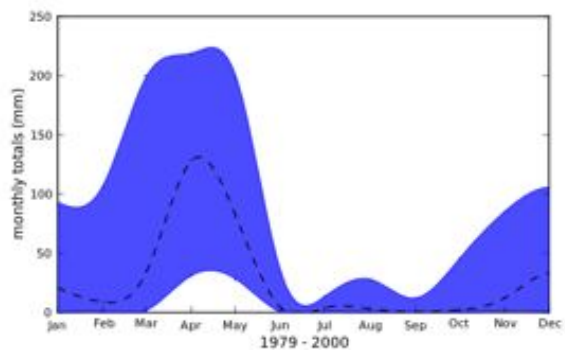
<i>Climatology of monthly total precipitation</i>	<i>Climatology of monthly mean maximum temperatures</i>
Dar es Salaam	



Dodomo



Kilimanjaro



Climatology of monthly total precipitation

Climatology of monthly mean max temperatures

Mbeya

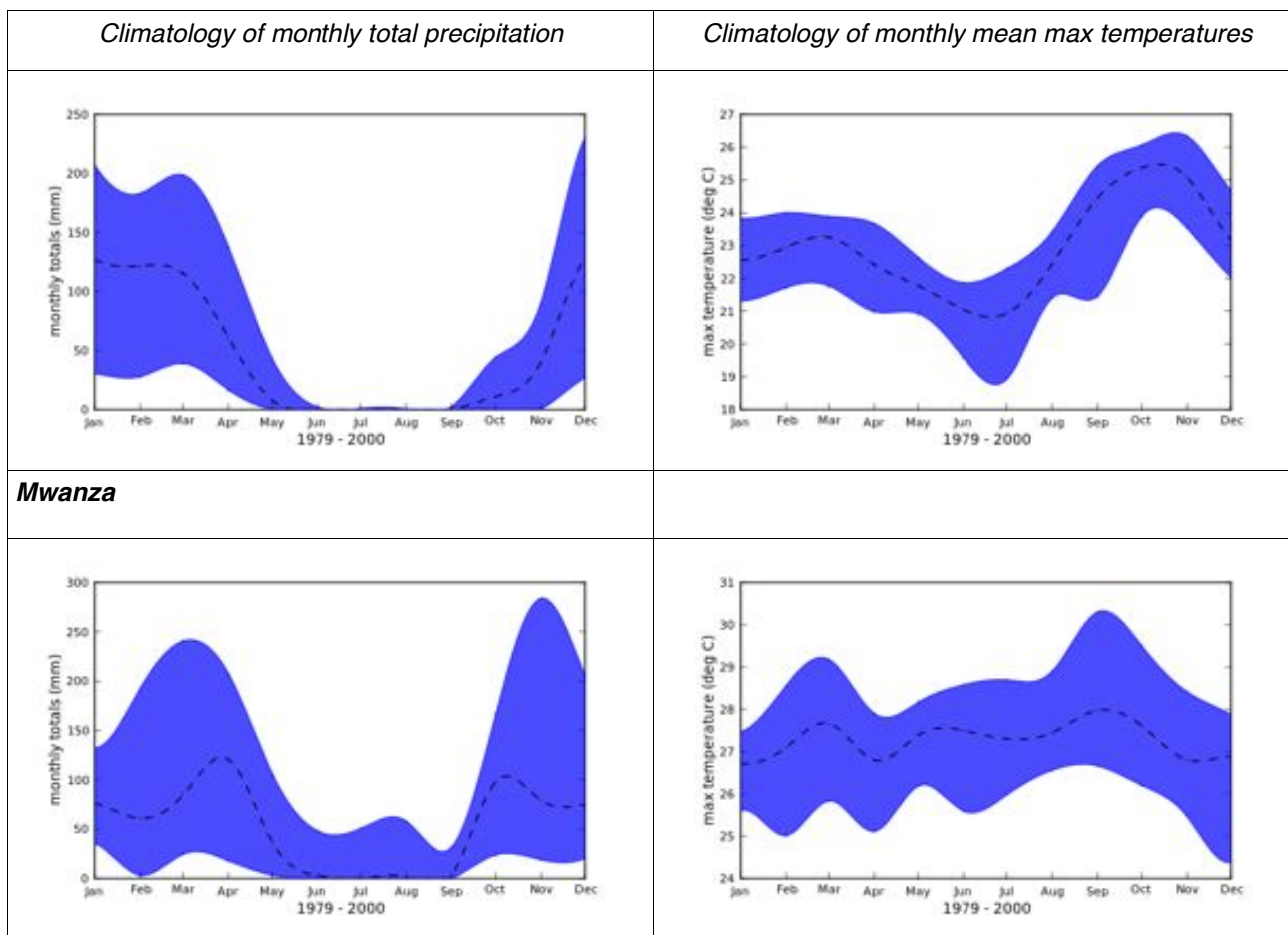
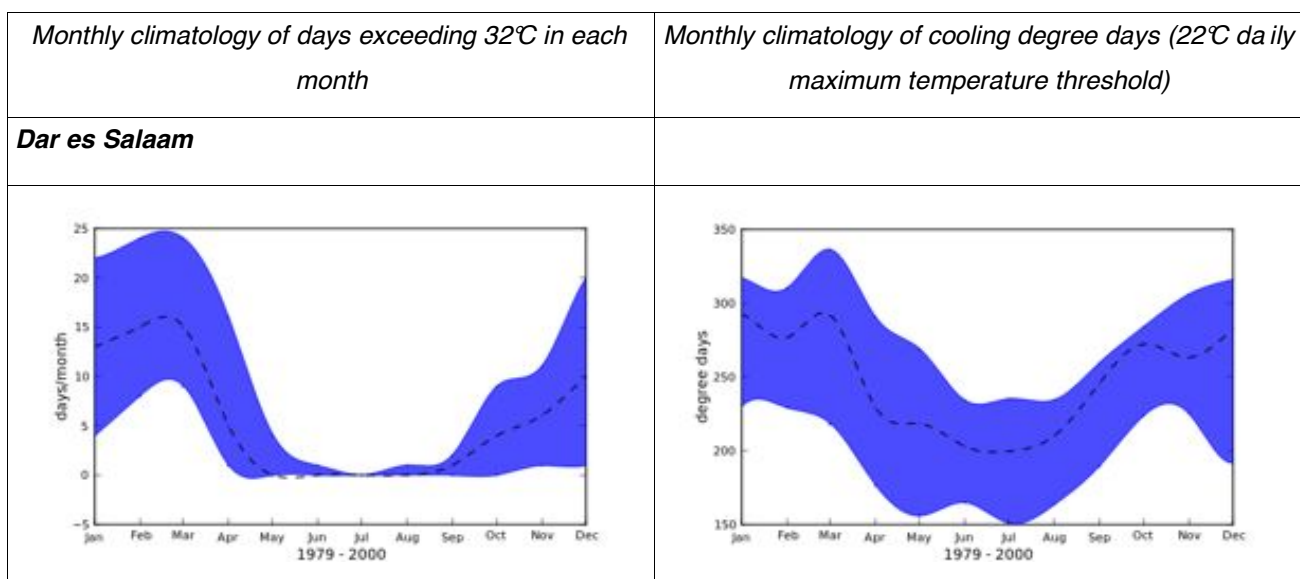
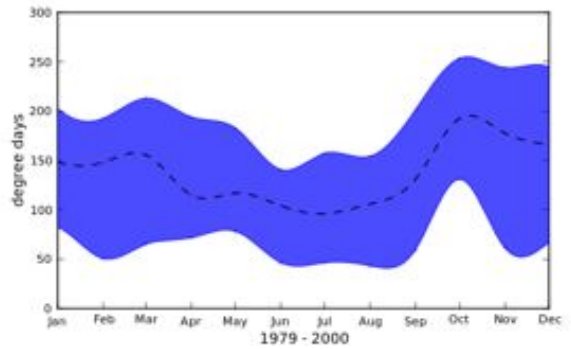
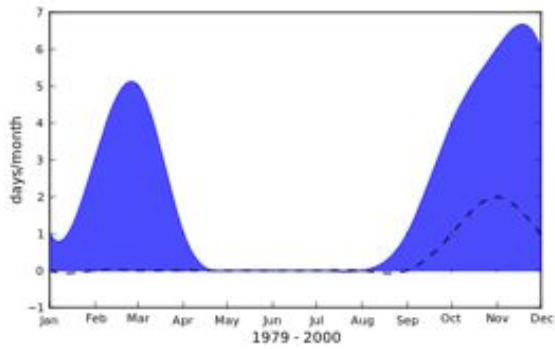


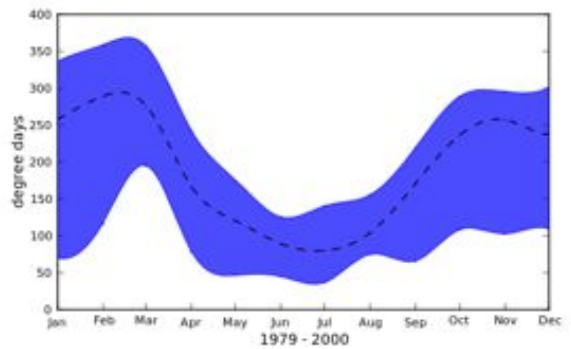
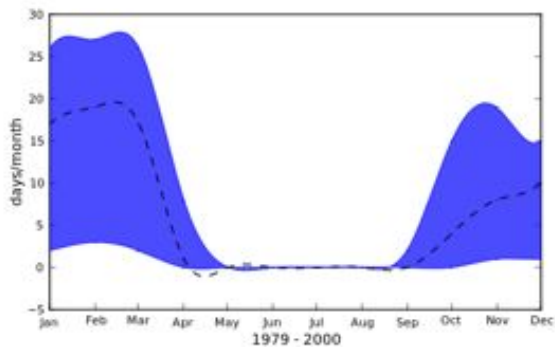
Table 1: Observed rainfall and maximum temperature climatologies for selected stations between 1979 and 2000. Blue envelope represents the range between the 10th percentile values and the 90th percentile values for each month. Dashed line represents the median value for each month



Dodomo



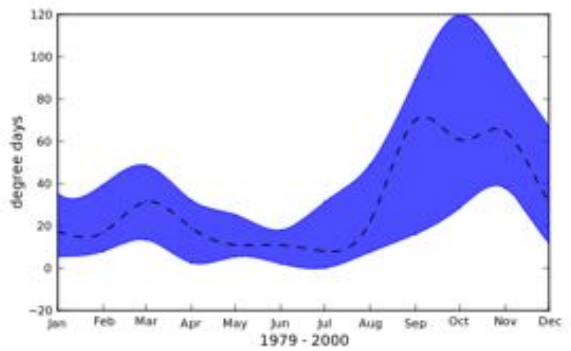
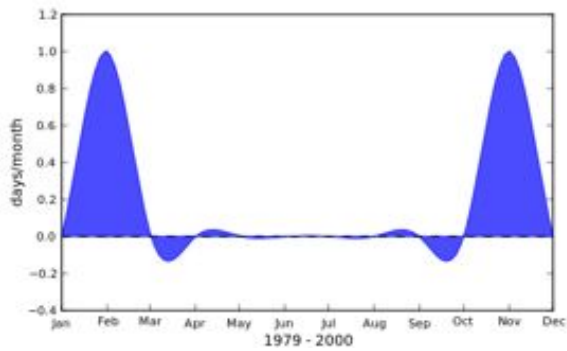
Kilimanjaro



Monthly climatology of days exceeding 32°C in each month

Monthly climatology of cooling degree days (22°C daily maximum temperature threshold)

Mbeya



Mwanza

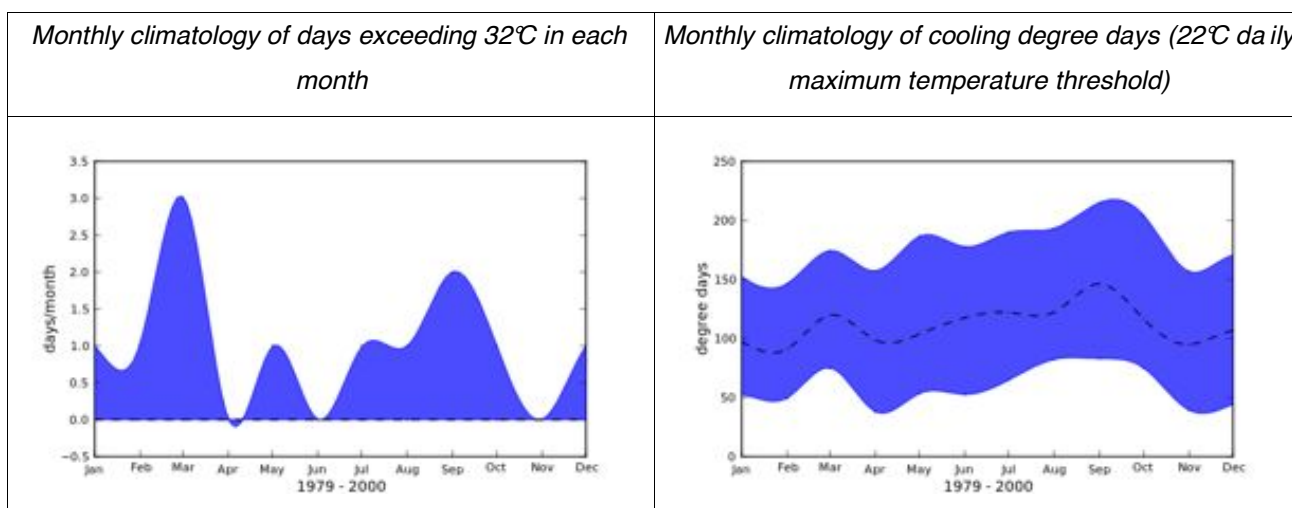


Table 2: Observed climatologies of days/month exceeding 32°C and cooling degree days (22°C threshold) for selected stations between 1979 and 2000. Blue envelope represents the range between the 10th percentile values and the 90th percentile values for each month. Dashed line represents the median value for each month

Observed climate discussion

The observed climatologies in Tables 1 and 2 identify a number of climate regimes with Tanzania. Dar es Salaam and Mwanza both show a distinct double rainfall season with both early summer rains and late summer rains. It is likely that this is a result of the proximity to large water bodies (Indian Ocean and Lake Victoria) and hence the availability of moisture. The other locations show a much more uniform rainfall season. It is important to note the high variability in the monthly rainfall totals (indicated by the filled envelope). The area experiences high rainfall variability in the rainy seasons with differences as high as 250mm/month between the 10th percentile and 90th percentile values.

Observed climatologies of temperature show a normal seasonal cycle of temperature. Most locations have a fairly small seasonal temperature variation of around 3°C to 4°C which is not uncommon in tropical areas. Kilimanjaro International Airport shows the strongest cycle which is most likely related to its altitude. Mwanza is unique in having an extremely constant temperature throughout the year but this is most likely a result of the lake proximity which would strongly moderate the temperature in the vicinity.

Exceedence of the 32°C threshold represents the average number of days per month where the maximum recorded temperature exceeded 32°C. It is an indication of heat stress on human populations as well as some crops. Human heat stress indices generally include some measure of humidity which was not available for these locations. The exceedence measure is therefore used as a reasonable proxy of heat stress. Most of the results are as expected with high exceedence in warmer locations such as Dar es Salaam and Kilimanjaro. Cooler locations such as Mbeya and Mwanza show almost no exceedence throughout the year.

Cooling degree days (CDD) is used as a proxy for the amount of energy required to cool buildings when the temperature rises above a certain level. The threshold used in this study is 22°C. A simple version of the calculation is used in this study that just uses the difference between the daily maximum temperature and the threshold temperature. The calculation is as follows:

$$CDD = \sum (T_{max} - T_{threshold}) \text{ [for all } T_{max} > T_{threshold}]$$

It must be noted that the use of the daily maximum temperature is not accurate and other more sophisticated methods can be used given more data for the location. Minimum temperature is available for these locations but the timing of the measurements is suspect and hence the values are not reliable. The method used here primarily provides a baseline climatology with which to compare future projections.

The CDD figure understandably shows a strong correspondence to the maximum temperature figures and the same explanations apply.

Climate Projections

Global Climate Models (GCMs) are the foundation of climate change projections. These models attempt to simulate the global climate system by integrating known atmospheric physical processes through time. The models simulate the heating effect of the sun, the heat and moisture fluxes from the oceans, the effect of the land surface and vegetation, as well as the effect of green house gases on the atmospheric temperature profile. However, many processes occur at scales that cannot be resolved by the GCM numerics. These processes are approximated through parameterisations. Parameterised processes included cloud radiative effects, convection and precipitation, boundary layer mixing and many aspects of surface heat and moisture fluxes. Many differences between GCMs are a result of the different approaches to these parameterizations, particularly cloud radiative effects and precipitation processes. Another consequence of importance is that the skill of a GCM to simulate a particular region varies. Each GCM has better skill in some areas than others.

Multi-model selection

The temptation is to pick the GCM that best represents the climate of your region of interest. However this is not a valid approach because when generating climate change projections we are looking for an accurate response to changes in GHG concentrations. A GCM that accurately simulates observed climate does not necessarily accurately respond to changes in GHGs. Of course we do not know what an accurate response should be so we have to assume that all models represent an equally likely response. This is the basis of the development of climate projection envelopes which represent the range of responses produced by the GCMs.

Model Bias

It is acknowledged that each GCM has a particular bias for a particular variable in a particular region. This bias can be significant in the case of precipitation. When developing future projections it is therefore important not to look at the raw GCM output fields only, but to also look at the anomalies between the GCM 20th century simulation and the future simulation. These anomalies are calculated for each GCM and represent the GCM response or delta given the GHG forcing. In the figures below both the absolute downscaled GCM projection envelopes and the anomaly envelopes are presented. The absolute values are still useful to show the GCM seasonality as well

as the agreement between GCMs.

Downscaling

The resolving scale of GCMs has improved significantly in the last 10 years with many state of the art GCMs able to resolve at a scale of around 100km. The CMIP3 archive 1 GCMs are typically of lower resolution than 100km with resolution ranging between 200km and 400km. However, while the native resolution of GCM may be 200km, the skill of the model at this resolution is typically low due to the GCMs simplified topography and representation of regional processes. GCM skill is much higher when aggregated up to large scales such 500km to 1000km.

The problem is that these scales are far too coarse for most users who are dealing with regional issues such as water management and agriculture. Society and ecosystems typically operate at much finer scales.

Downscaling is the concept based on the observation that local scale climate is largely a function of the large scale climate modified by some local forcing such as topography. There are two main types of downscaling, dynamical and empirical. Dynamical downscaling utilises a higher resolution, limited domain, dynamical model that follows the same principles as a GCM but because of the limited domain is able to be run at much higher spatial resolutions with moderate computation costs. Dynamical downscaling offers a physically based regional response to the large scale forcing. However dynamical modelling is complicated by similar problems to those of GCMs, namely bias and error.

Empirical downscaling utilises various statistical methods to approximate the regional scale response to the large scale forcing. Various methods have been developed. The method used in this report is called SOMD (Self Organising Map based Downscaling) ² developed at the University of Cape Town. Details of the method can be found in the referenced paper. The method recognises that the regional response is both stochastic as well as a function of the large scale synoptics. As such it generates a statistical distribution of observed responses to past large scale observed synoptic states. These distributions are then sampled based on the GCM generated synoptics in order to produce a time series of GCM downscaled daily values for the variable in question (typically temperature and rainfall). An advantage of this method is that the relatively unskilled grid scale GCM precipitation and surface temperature are not used by the downscaling but rather than relatively highly skilled large scale circulation (pressure, wind and humidity) fields are used.

Projections

The CMIP3 archive GCMs are used in this study. The downscaling methodology requires daily archive fields which limited the number of suitable GCMs to a total of 9 out of a possible 21. Each GCM has a number of simulations. The first is a simulation of the 20th Century climate (1961 to 2000) forced by observed GHG concentrations. This simulation is the GCMs representation of the observed climate period. It is important to note that there is no correspondence between real years and the years of the 20th Century simulations. This means one can expect no likeness between a particular year in the 20th Century simulation and that year in the

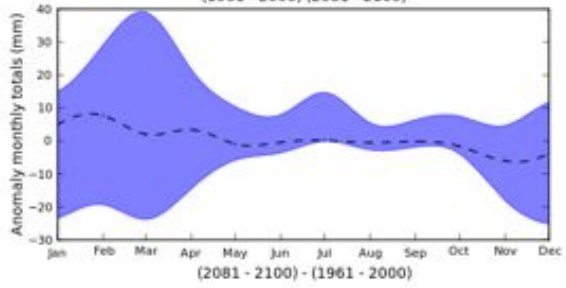
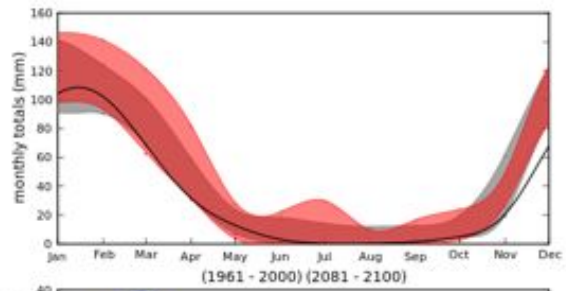
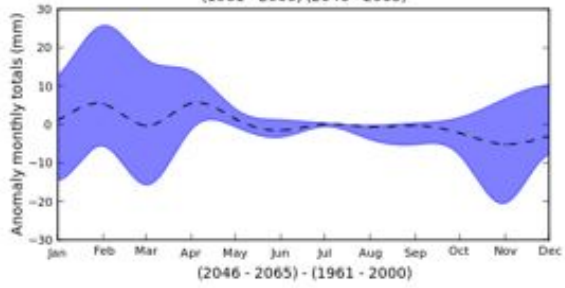
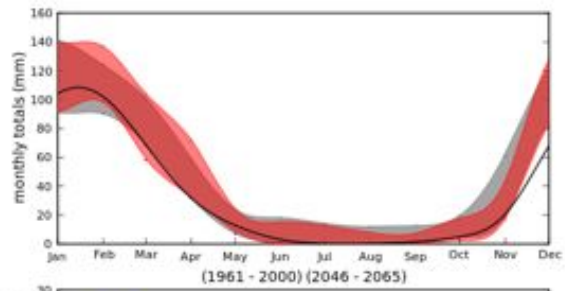
1 Climate Model Intercomparison Project <http://cmip-pcmdi.llnl.gov>

2 Hewitson and Crane, International Journal of Climatology, (2006)

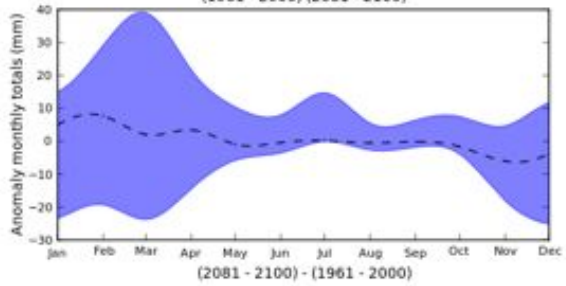
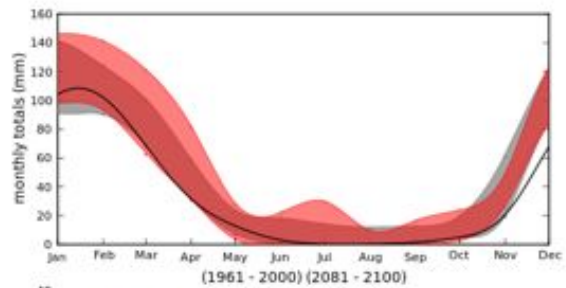
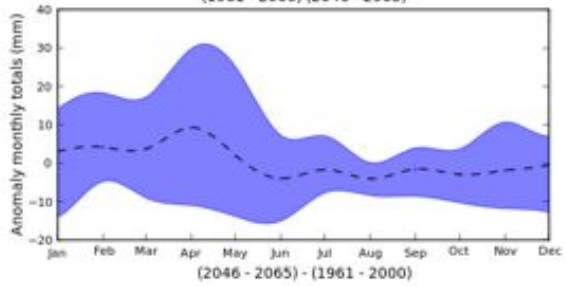
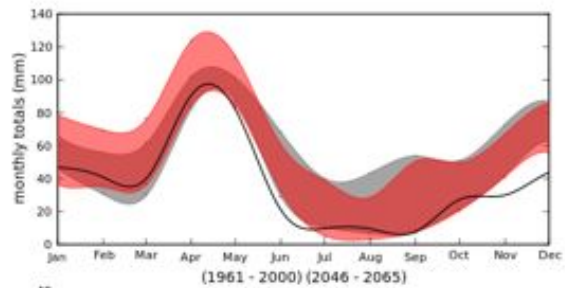
observational record.

Then follows a number of simulations of future periods and GHG concentration scenarios. For this study the two future periods of 2046 – 2065 and 2081 – 2100 were selected and the two future development scenarios of B1 and A2. The B1 development scenario results in a lower GHG concentrations than the A2 scenario. A total of 5 GCM simulations, one 20th Century period and 4 future periods are therefore analysed for each particular GCM. Each GCM simulation was downscaled to a number of regional locations within Tanzania and various appropriate climatological summary statistics were produced. These are presented below in the form of climate projection envelopes. As mentioned above, projection envelopes capture the range of GCM responses to GHG forcing and represent the level of agreement or disagreement between the GCMs.

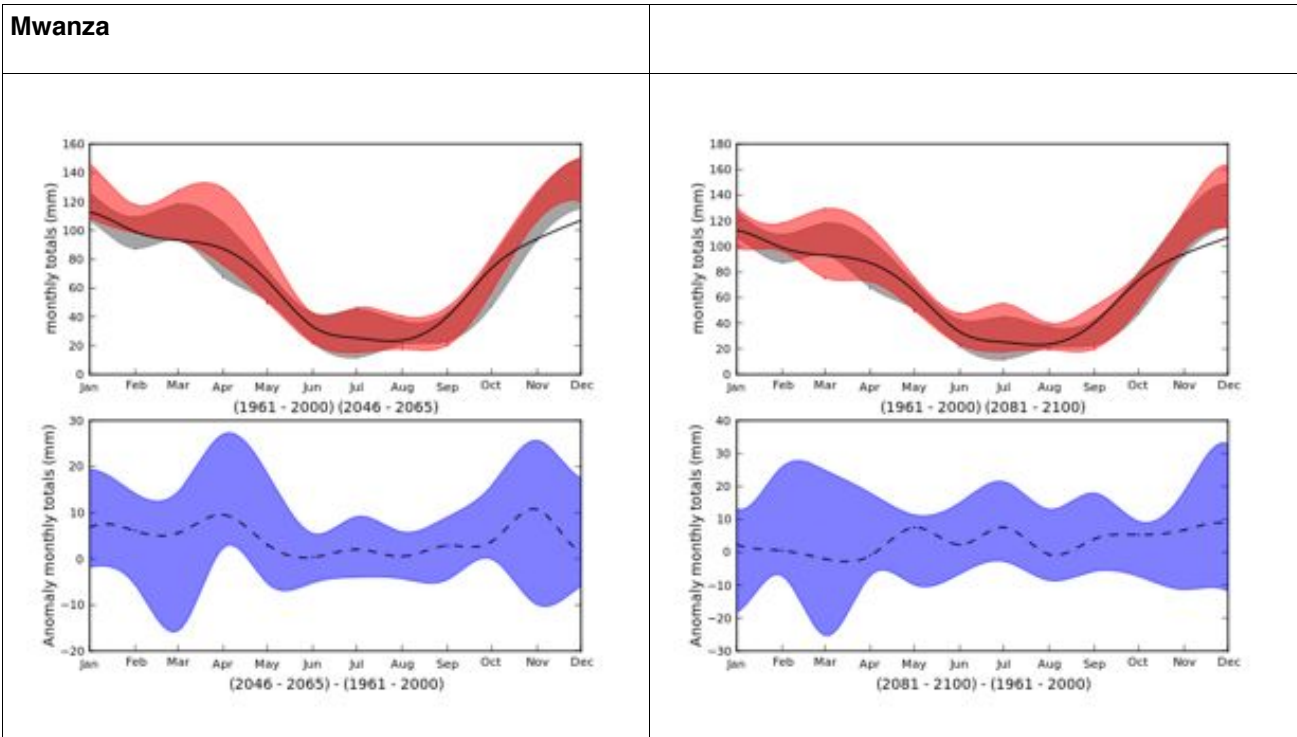
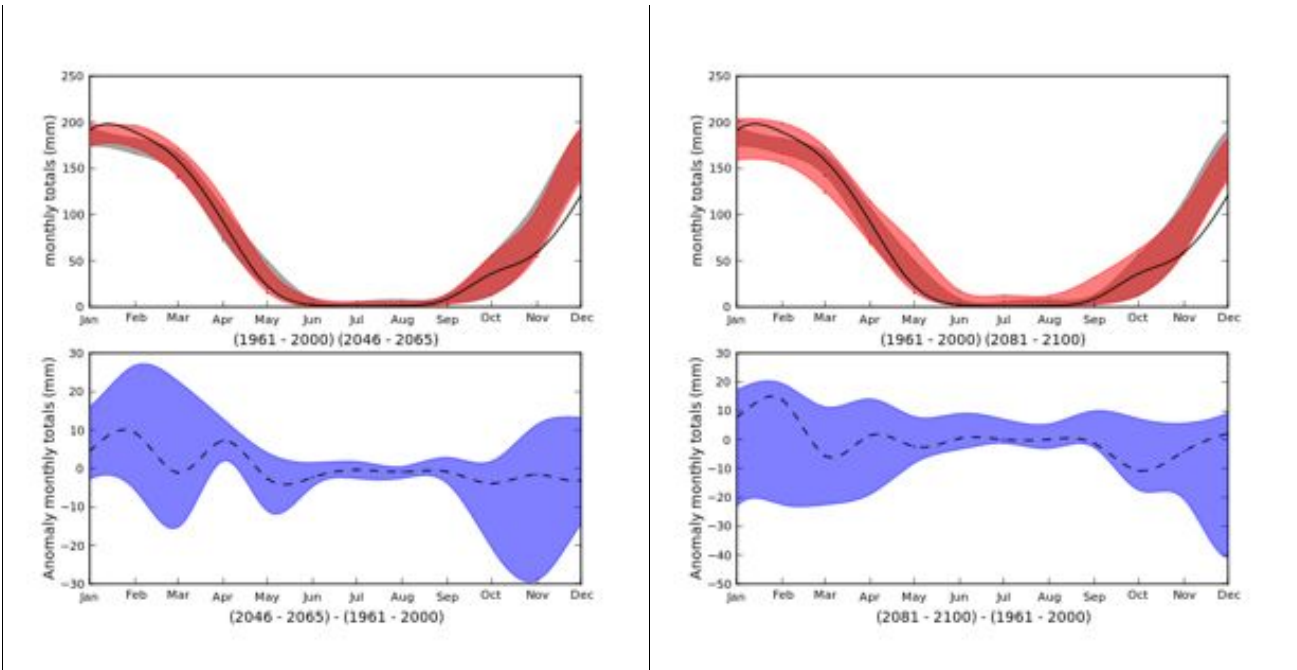
<i>B1 Scenario, Projections and anomalies of monthly precipitation (2046 - 2065)</i>	<i>B1 Scenario, Projections and anomalies of monthly precipitation (2081-2100)</i>
<p>Dar es Salaam</p>	
Dodomo	



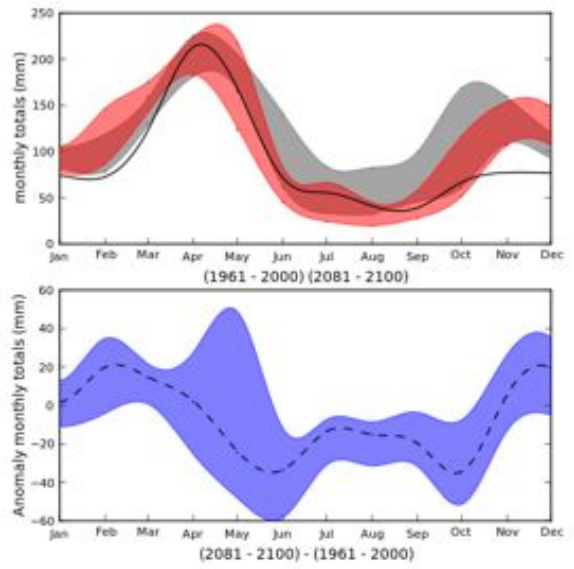
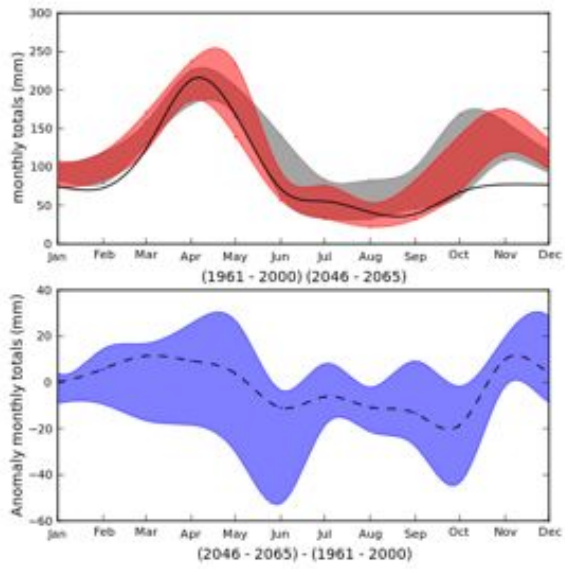
Kilimanjaro



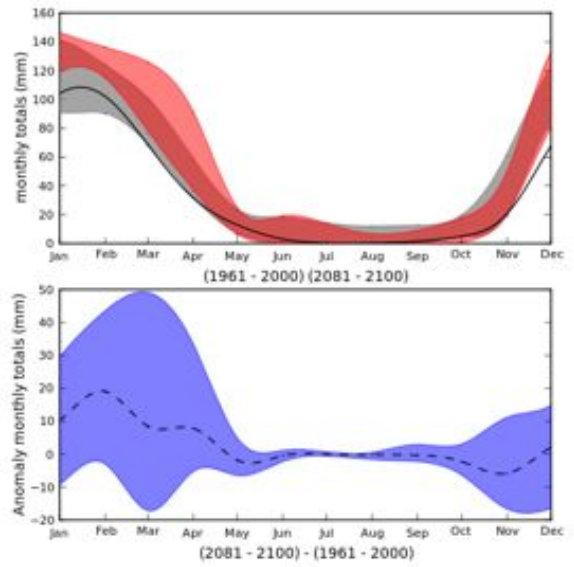
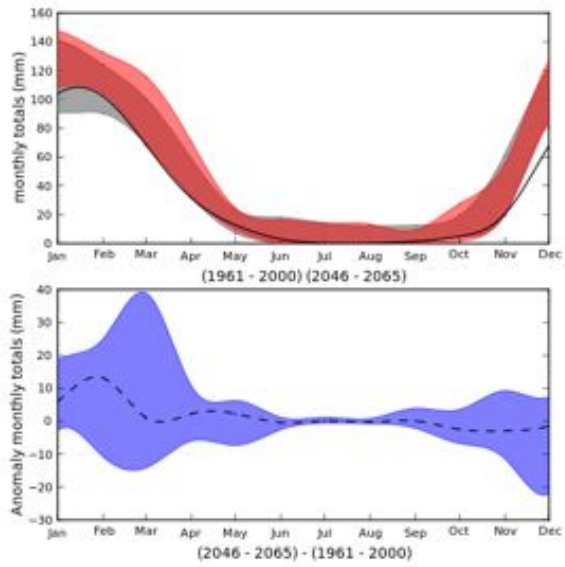
Mbeya



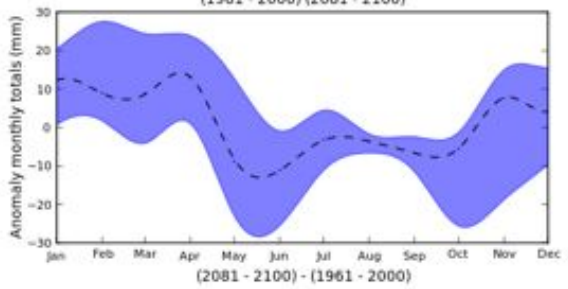
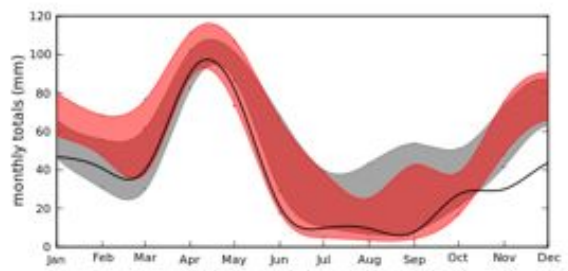
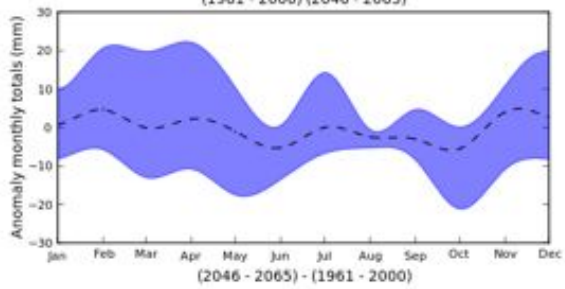
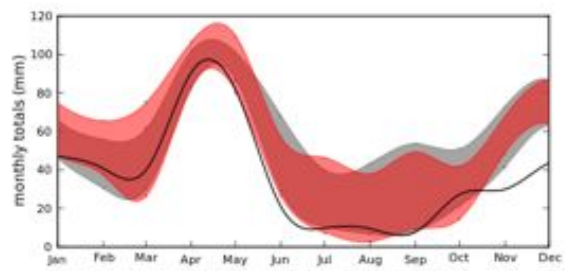
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<p>Dar es Salaam</p>	



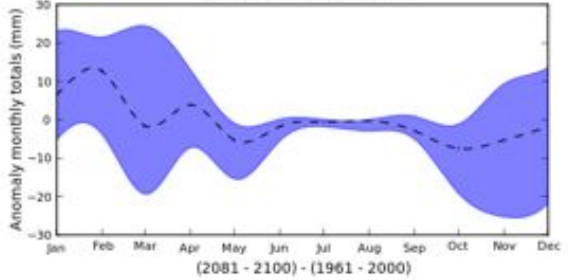
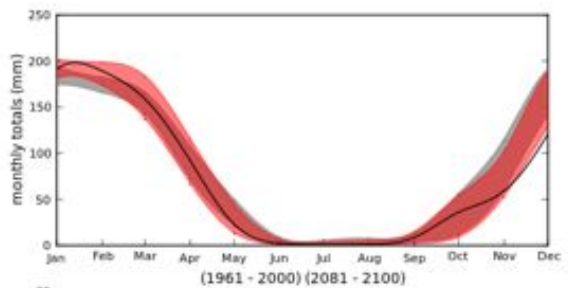
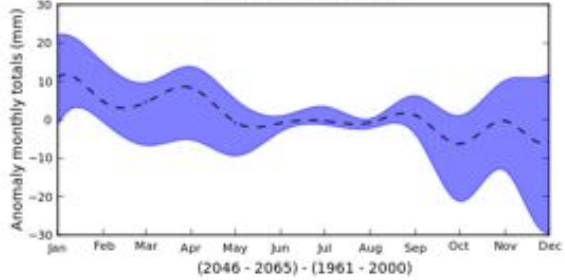
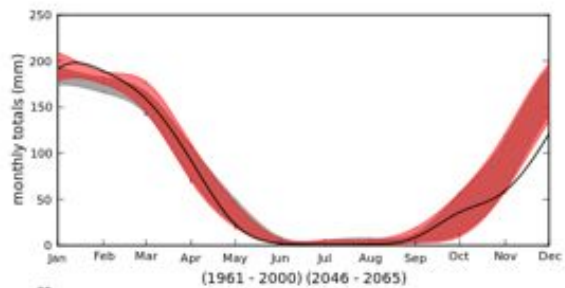
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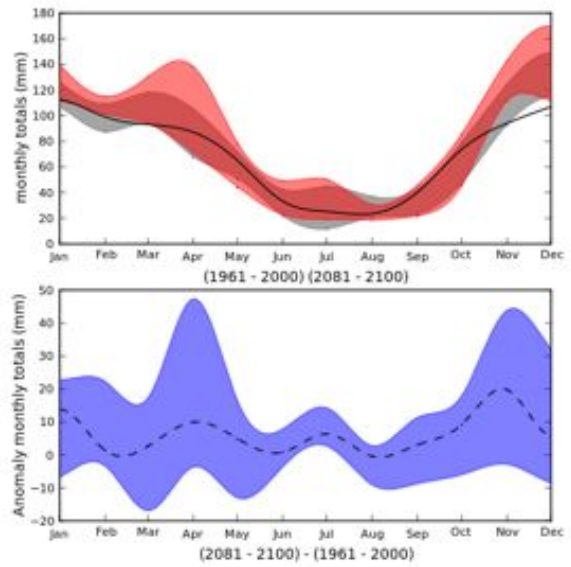
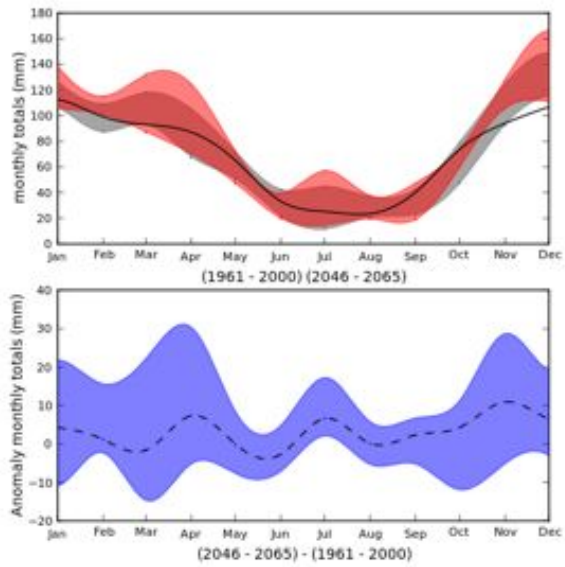
Kilimanjaro



Mbeya



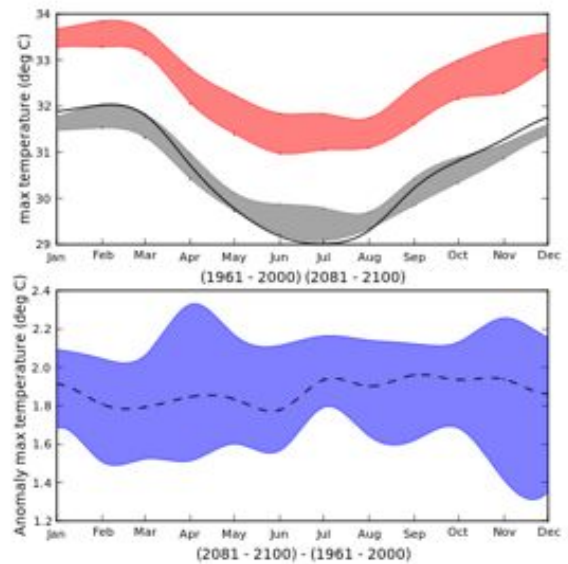
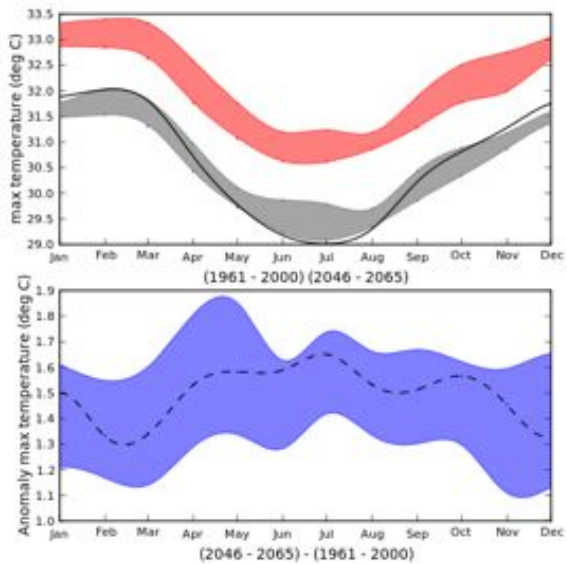
Mwanza



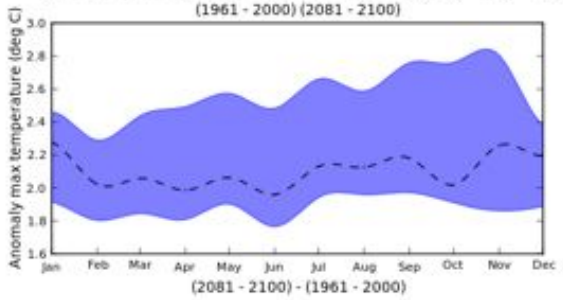
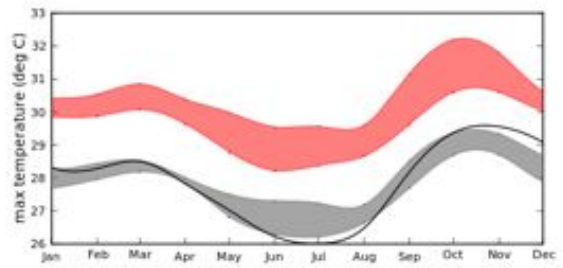
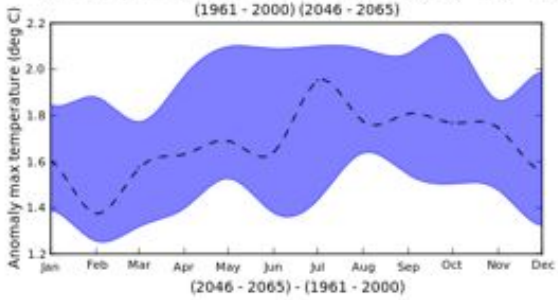
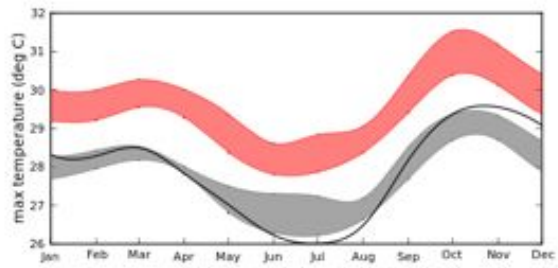
B1 Scenario, Projections and anomalies of monthly mean maximum temperature (2046 - 2065)

B1 Scenario, Projections and anomalies of monthly mean maximum temperature (2046 - 2065)

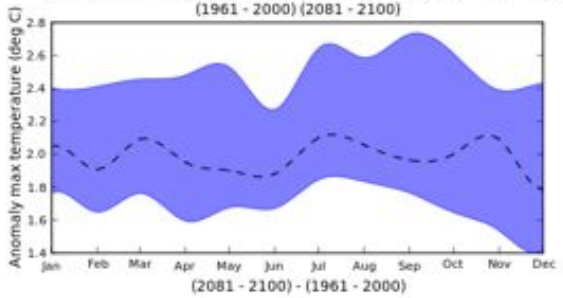
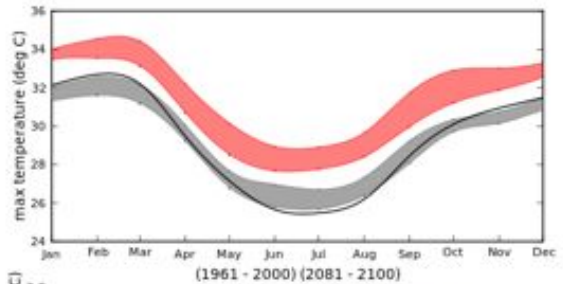
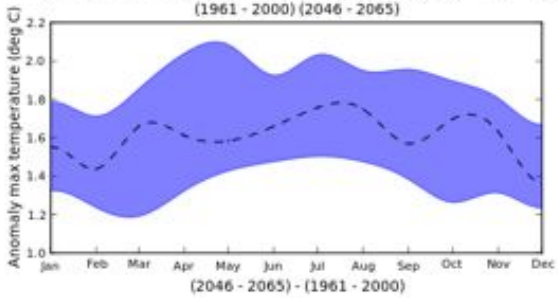
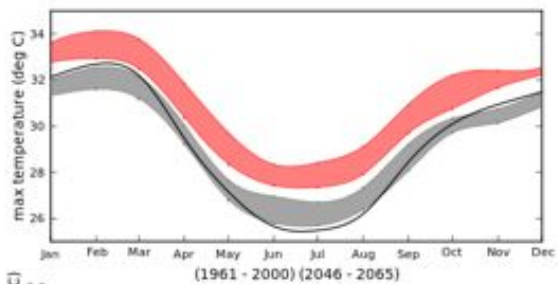
Dar es Salaam



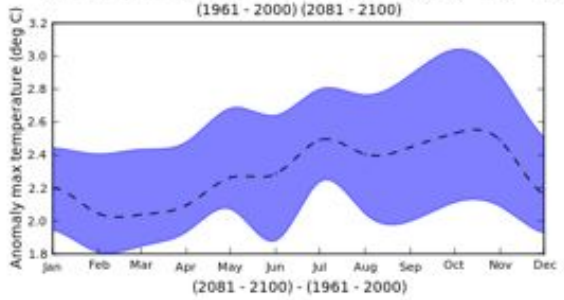
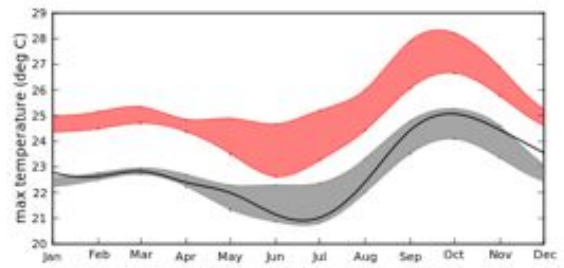
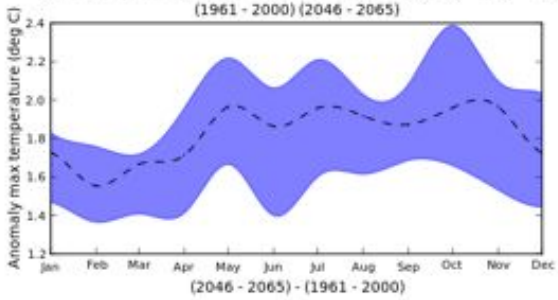
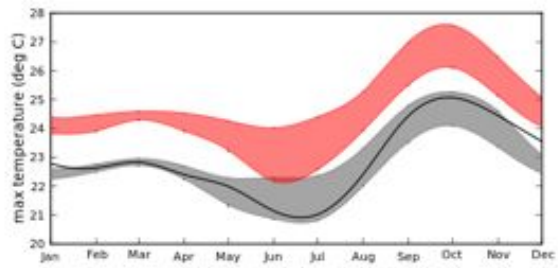
Dodomo



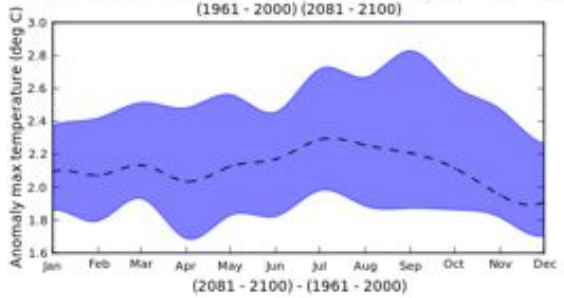
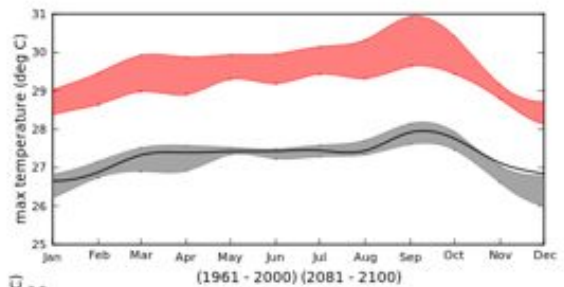
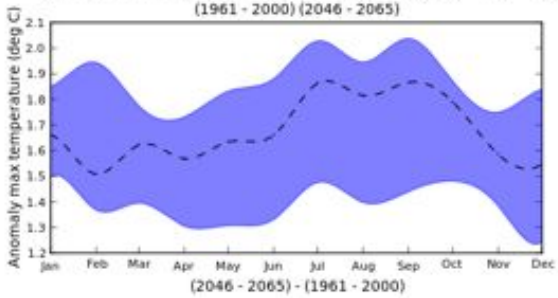
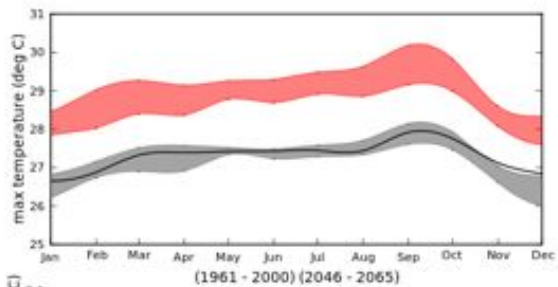
Kilimanjaro



Mbeya



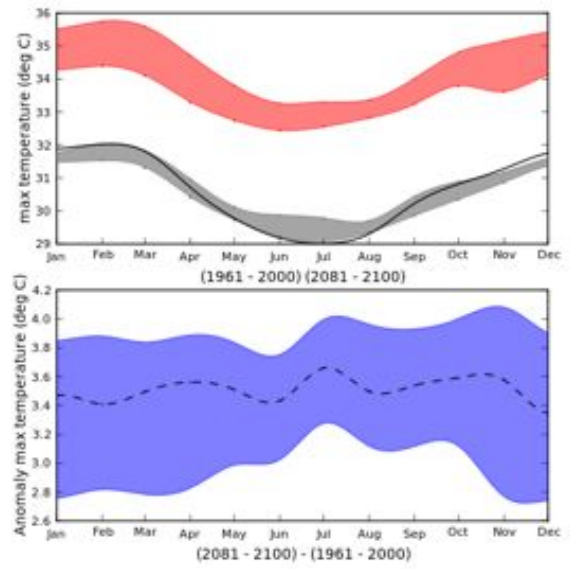
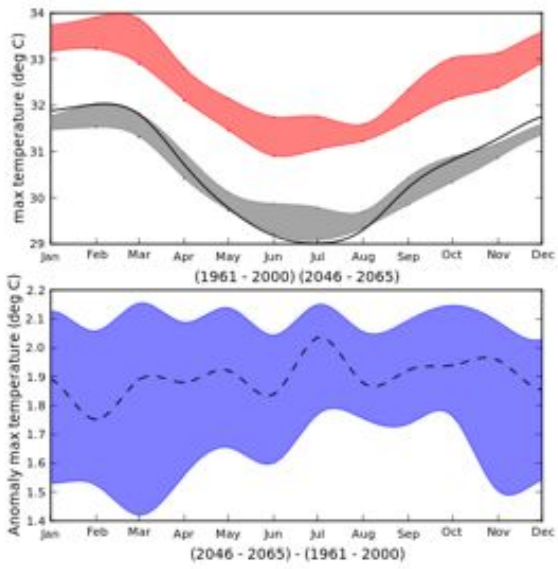
Mwanza



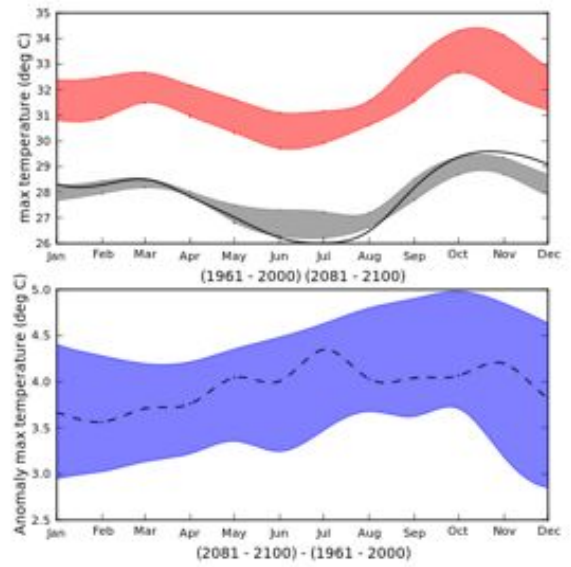
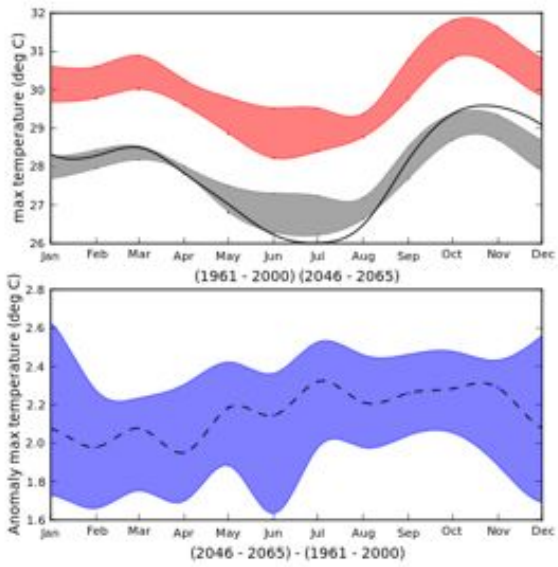
A2 Scenario, Projections and anomalies of monthly mean maximum temperature (2046 - 2065)

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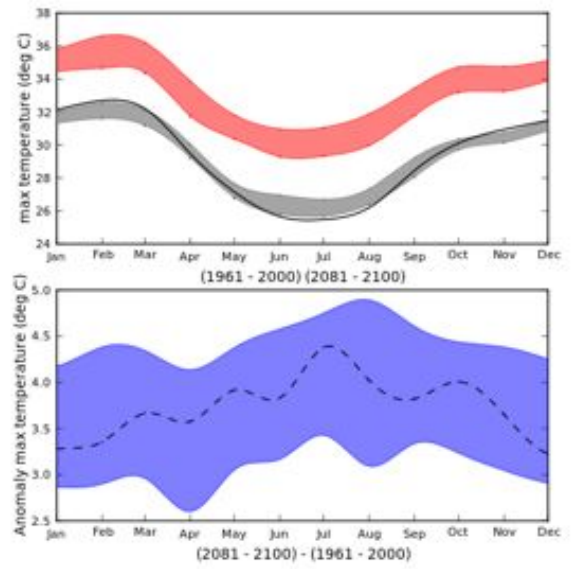
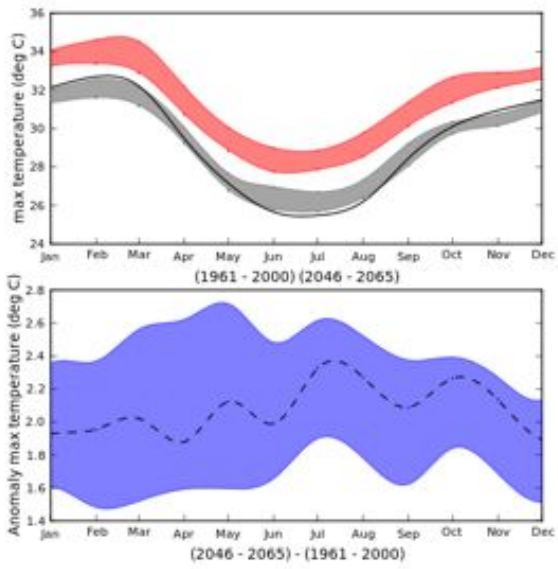
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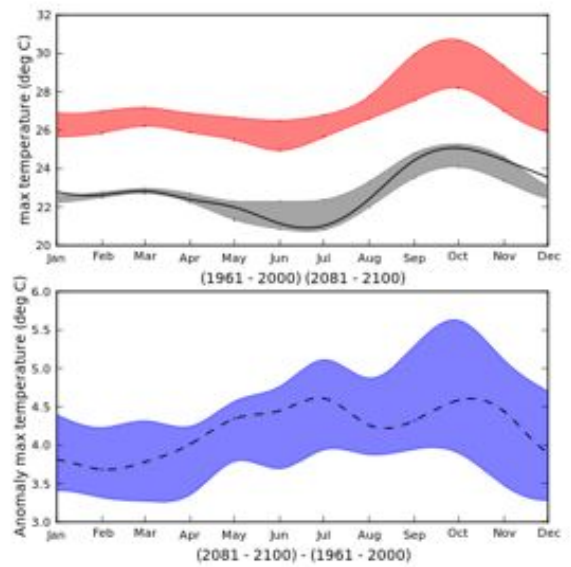
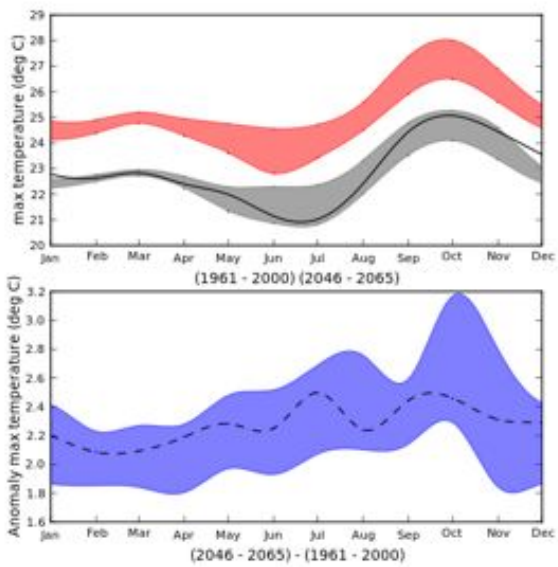
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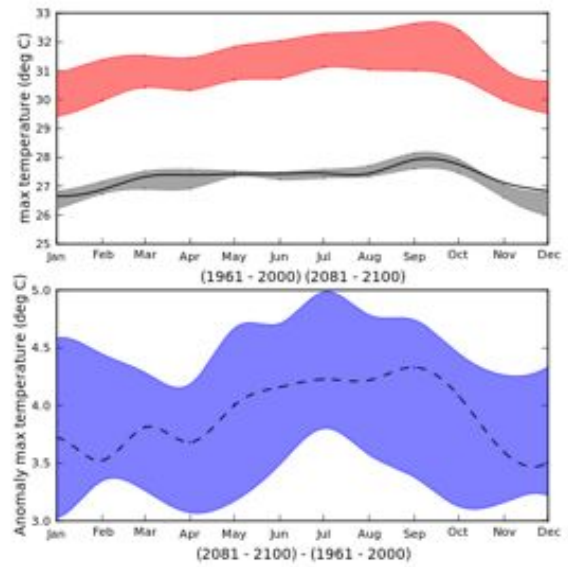
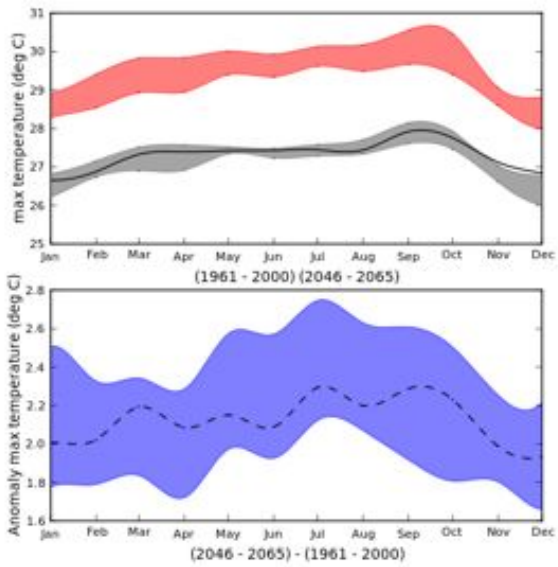
Kilimanjaro



Mbeya



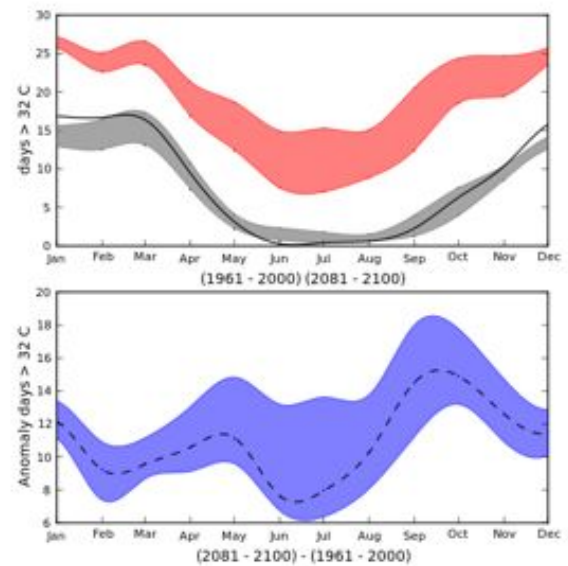
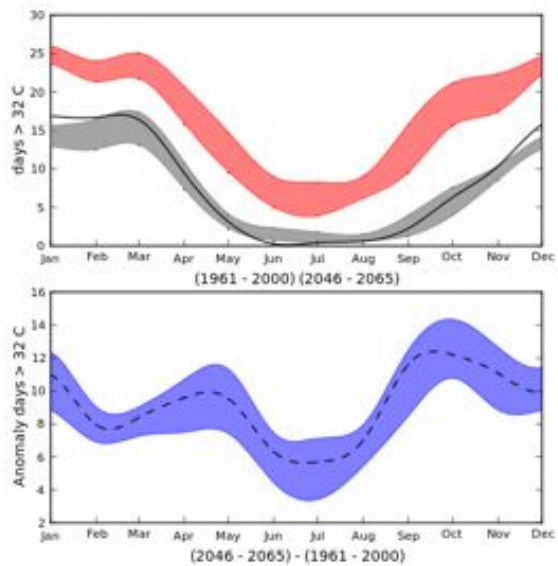
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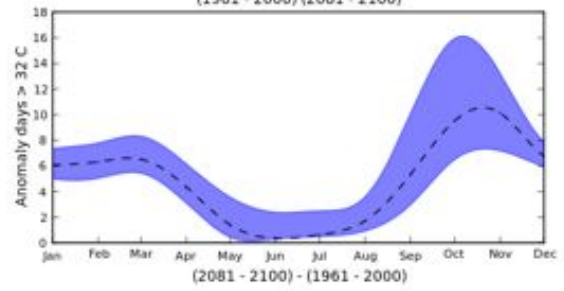
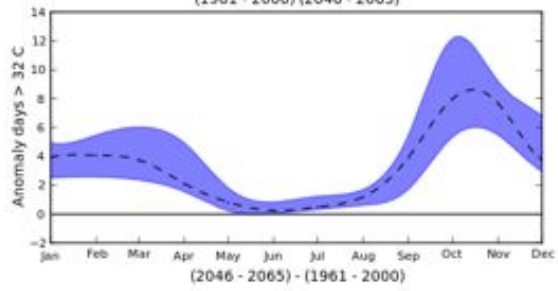
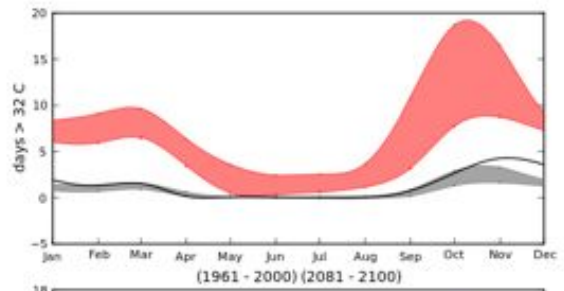
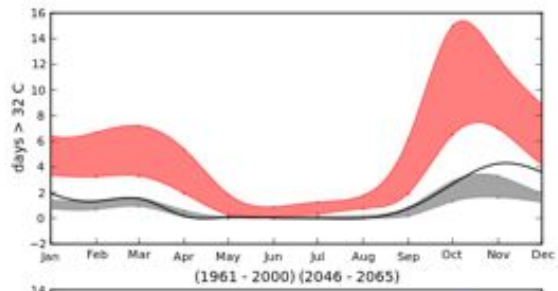
B1 Scenario, Projections and anomalies of monthly days exceeding 32°C (2046 - 2065)

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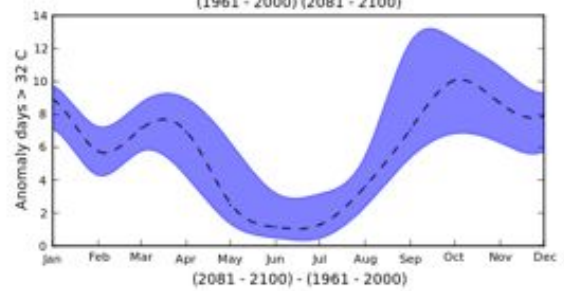
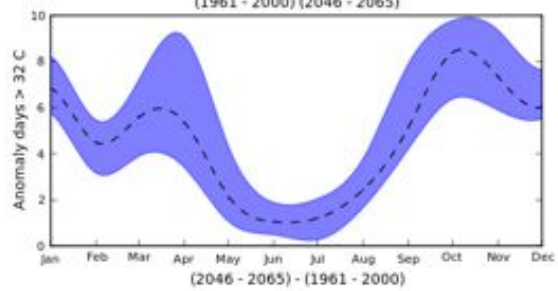
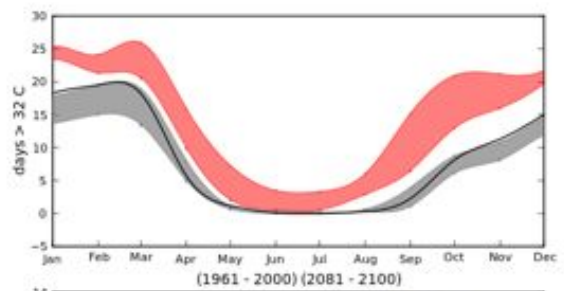
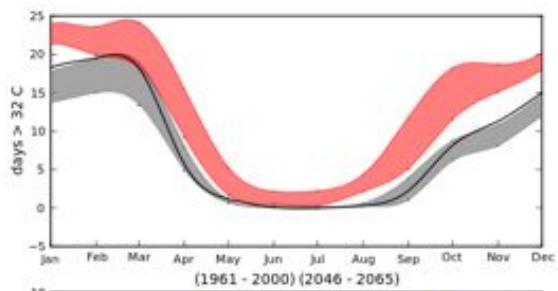
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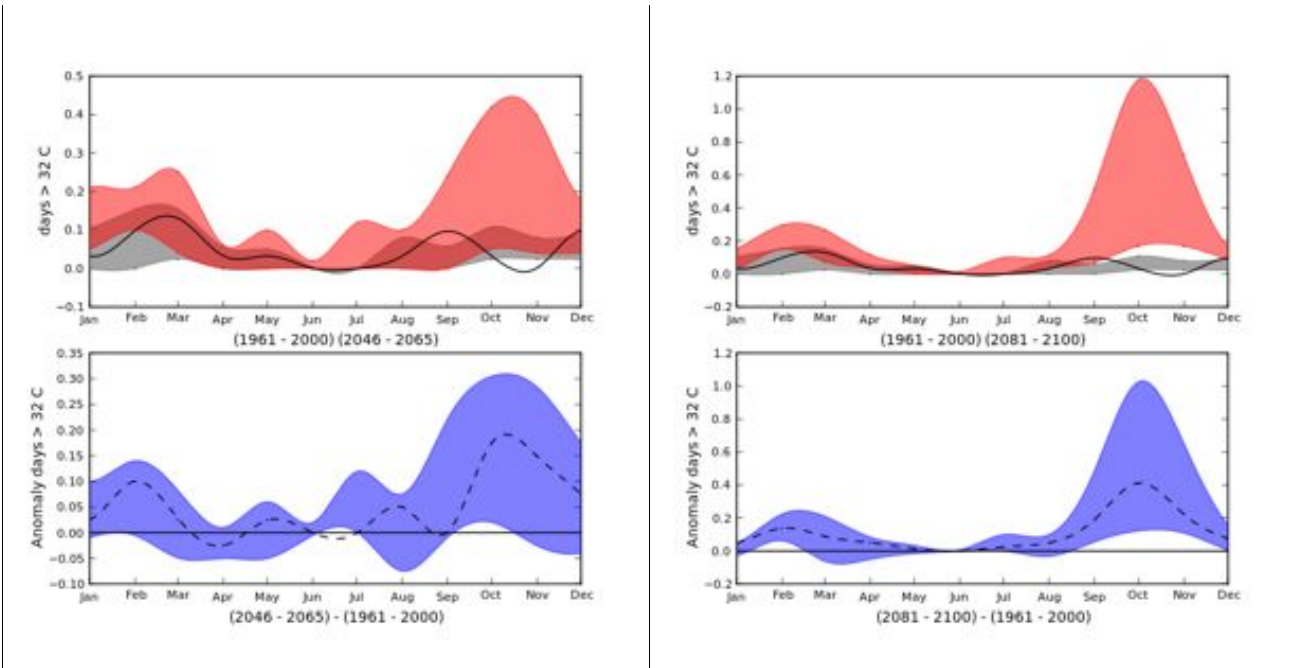
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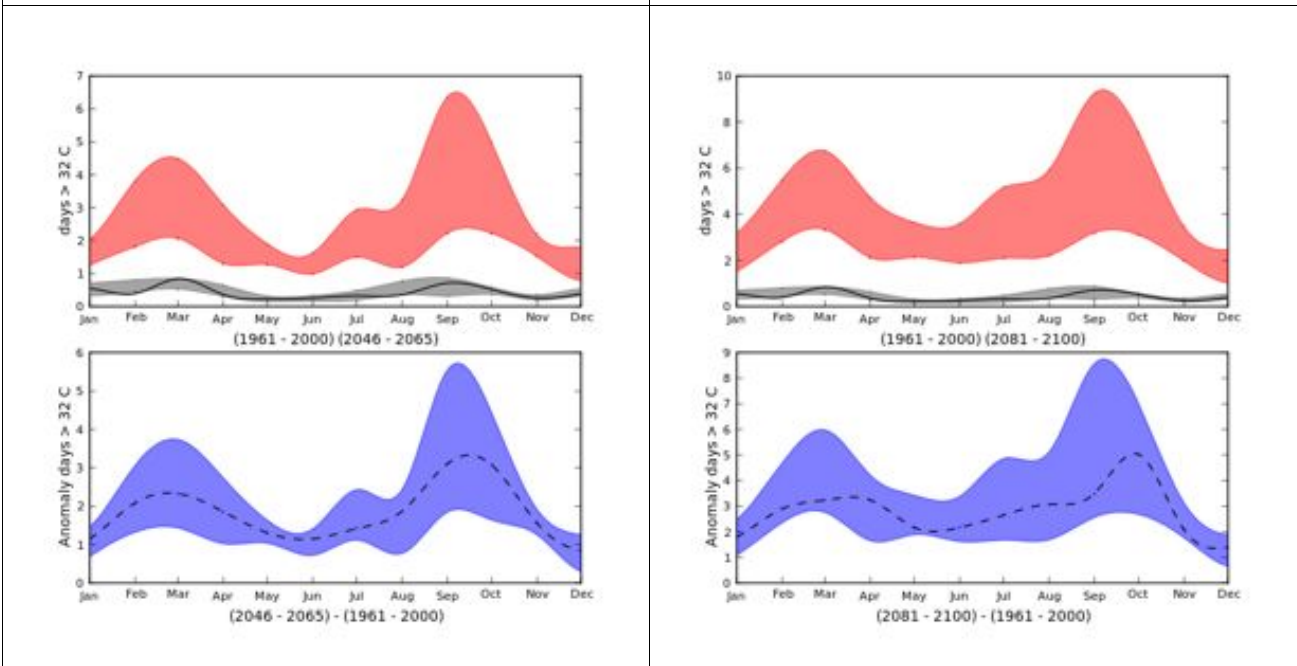
Kilimanjaro



Mbeya



Mwanza

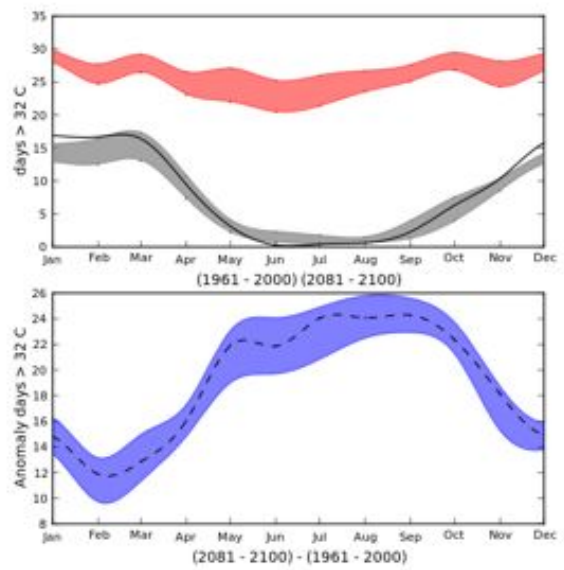
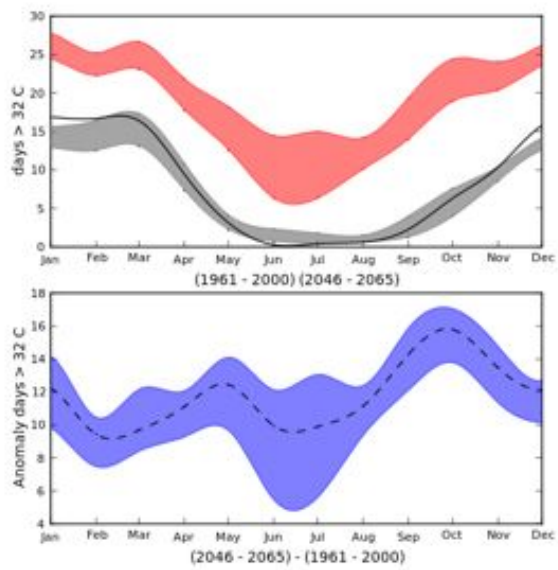


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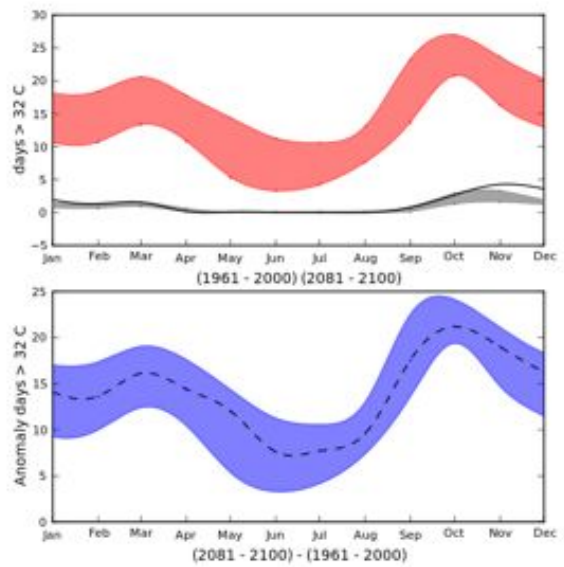
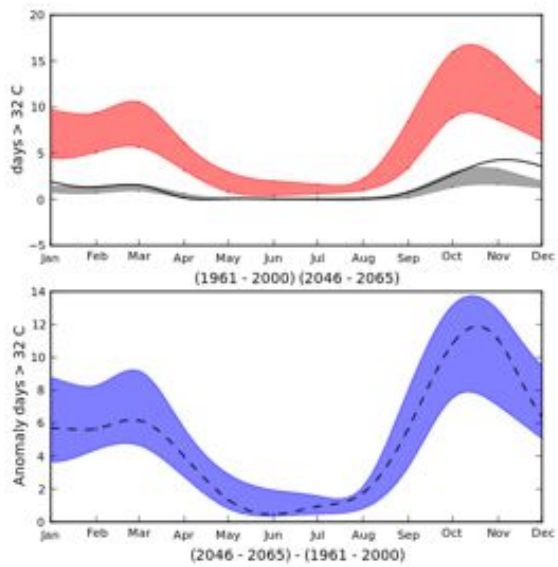
A2 Scenario, Projections and anomalies of monthly days exceeding 32°C (2046 - 2065)

Dar es Salaam

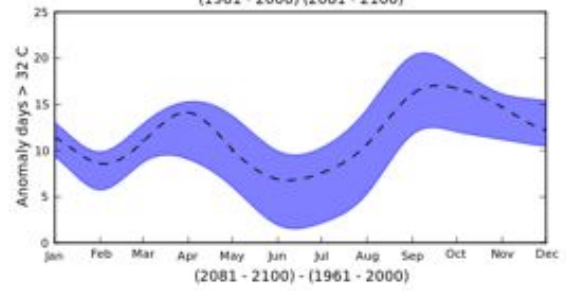
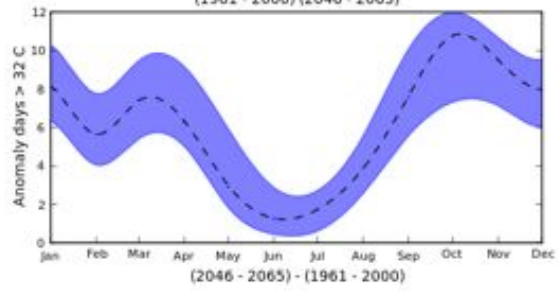
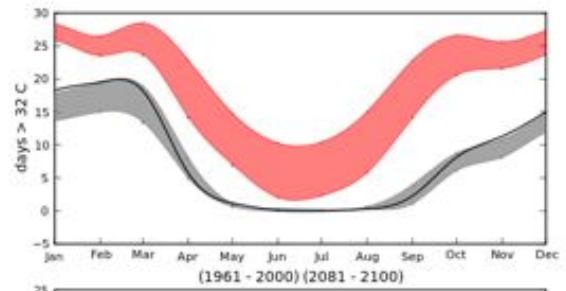
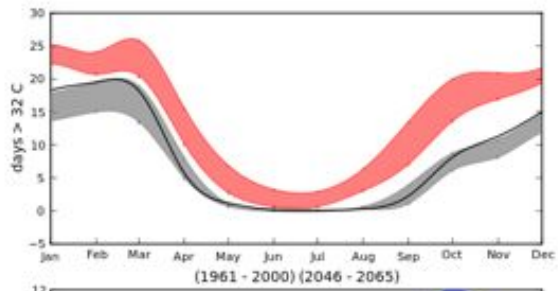




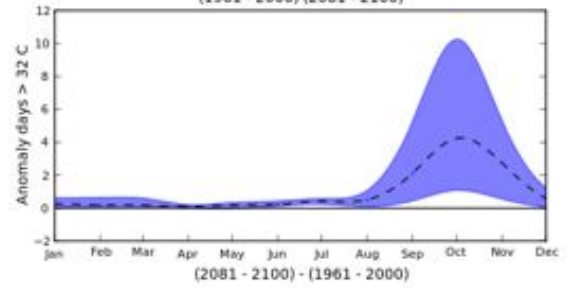
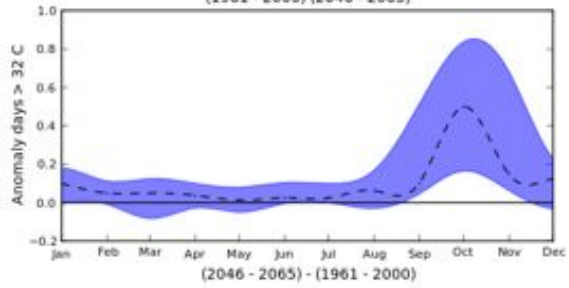
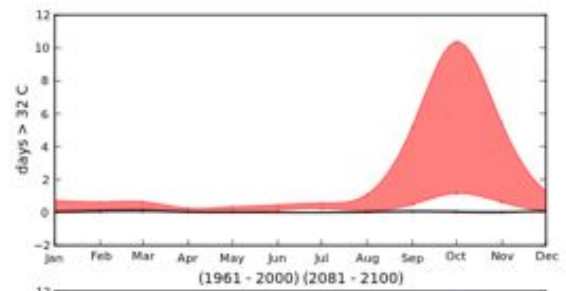
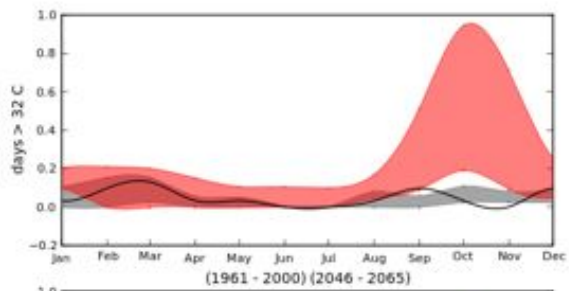
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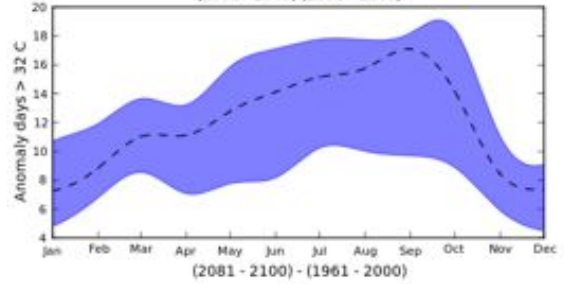
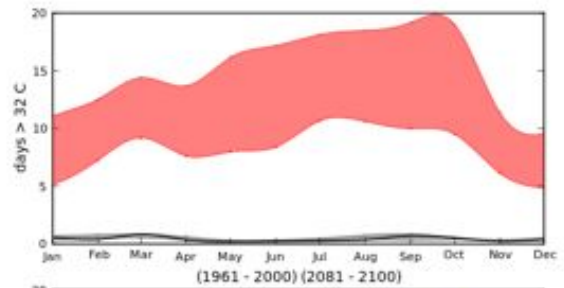
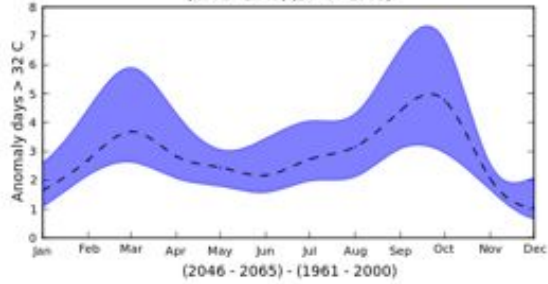
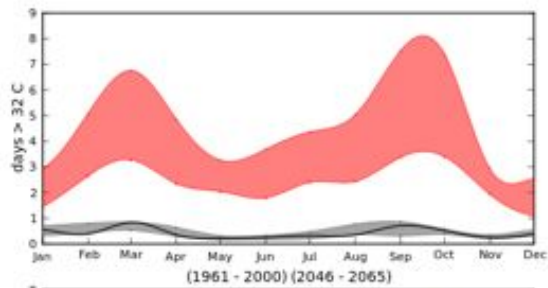
Kilimanjaro



Mbeya



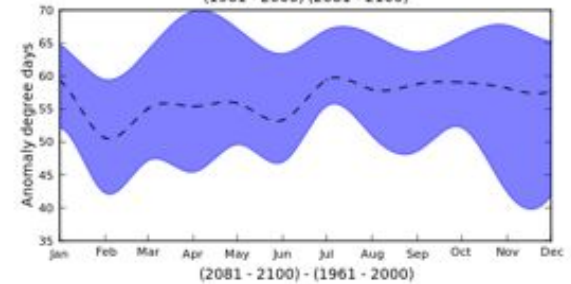
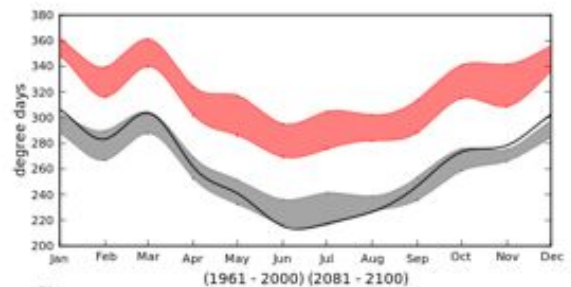
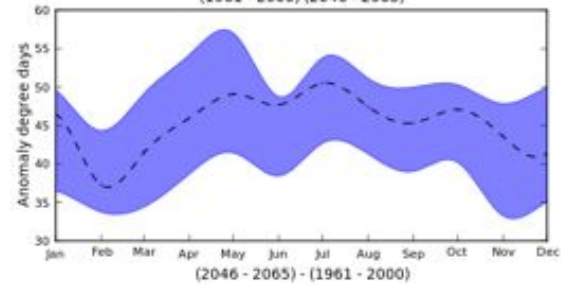
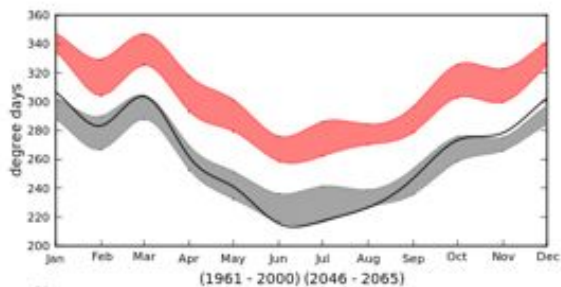
Mwanza



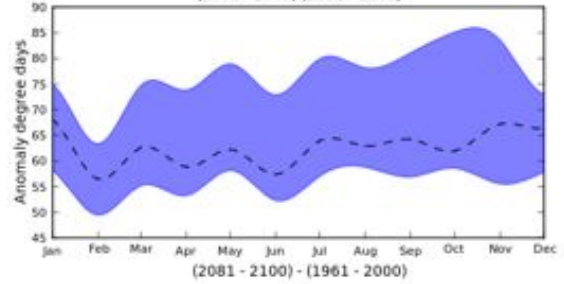
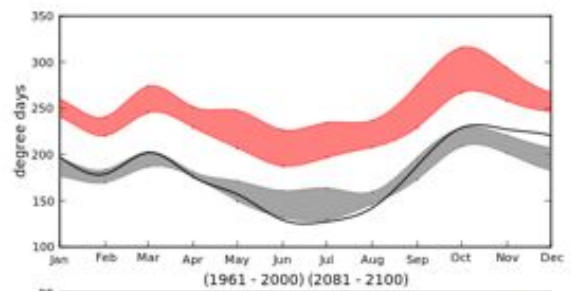
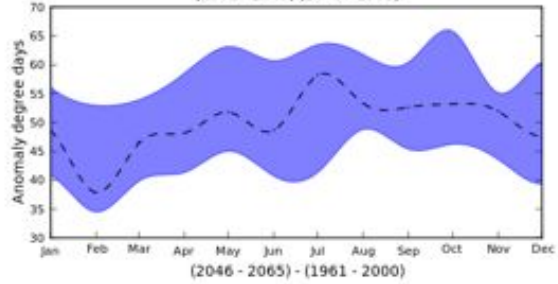
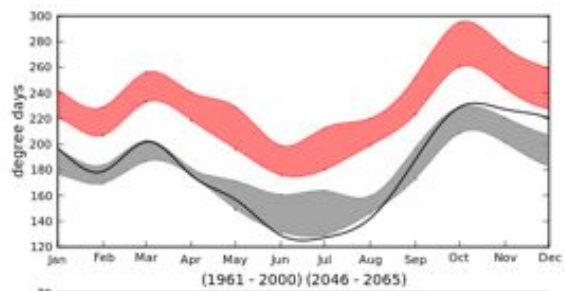
B1 Scenario, Projections and anomalies of monthly cooling degree days (2046 - 2065)

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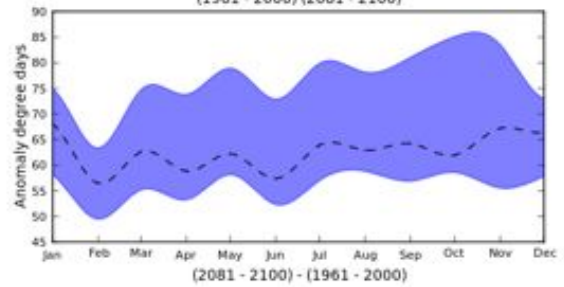
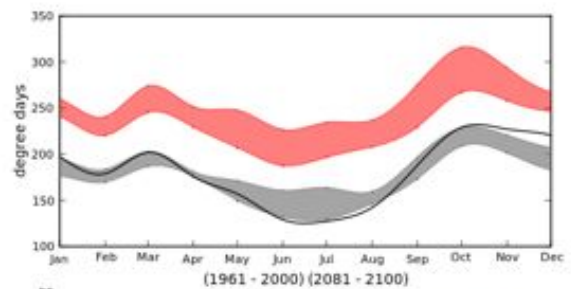
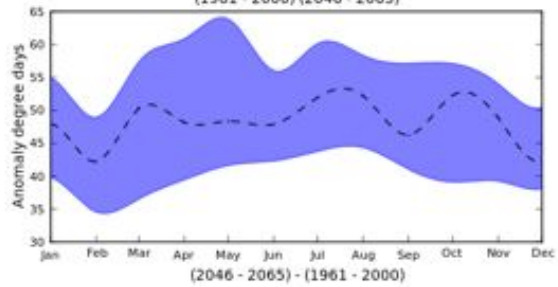
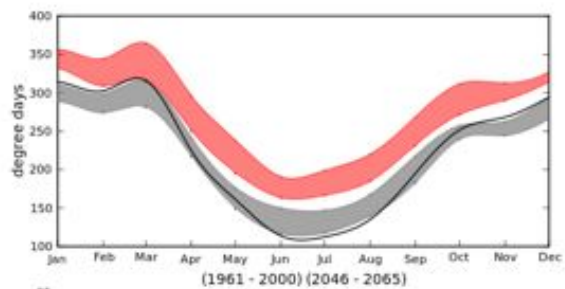
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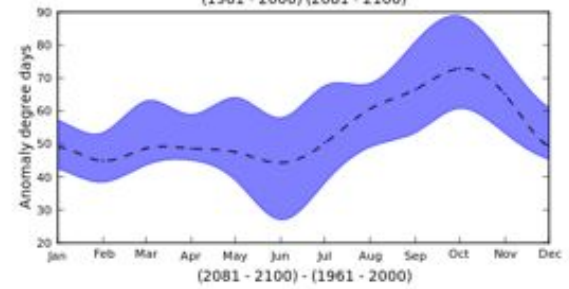
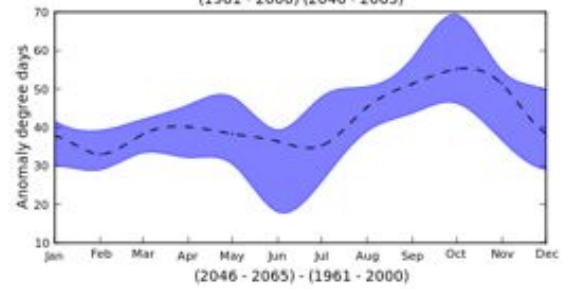
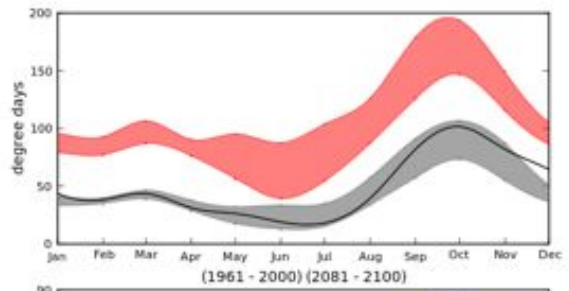
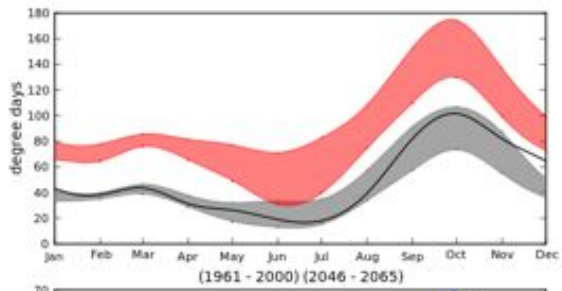
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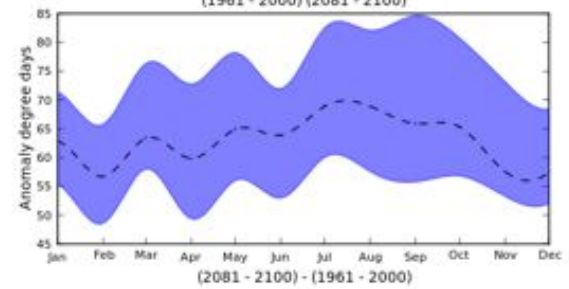
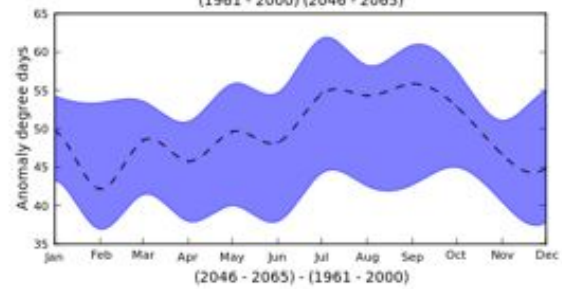
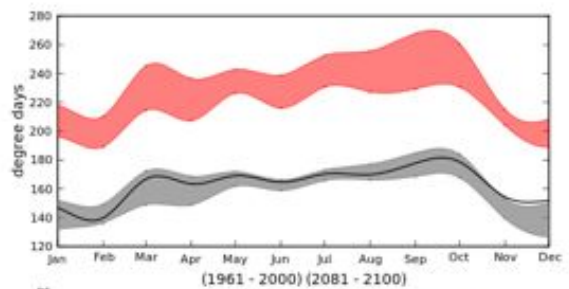
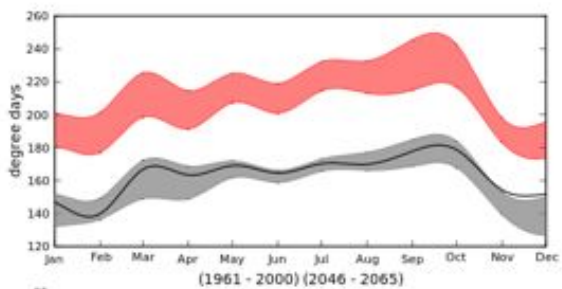
Kilimanjaro



Mbeya



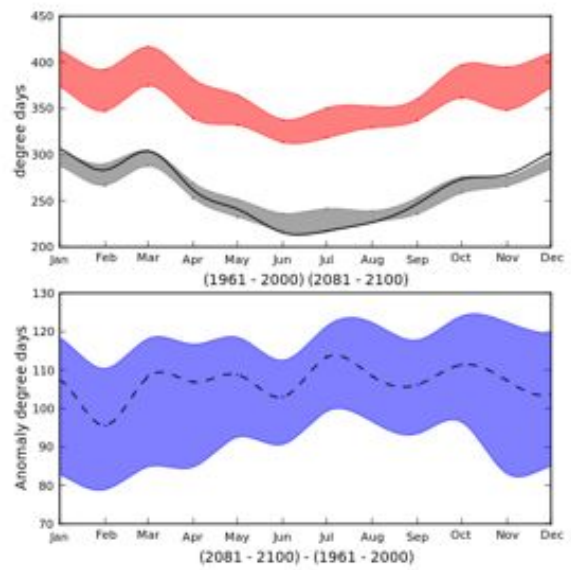
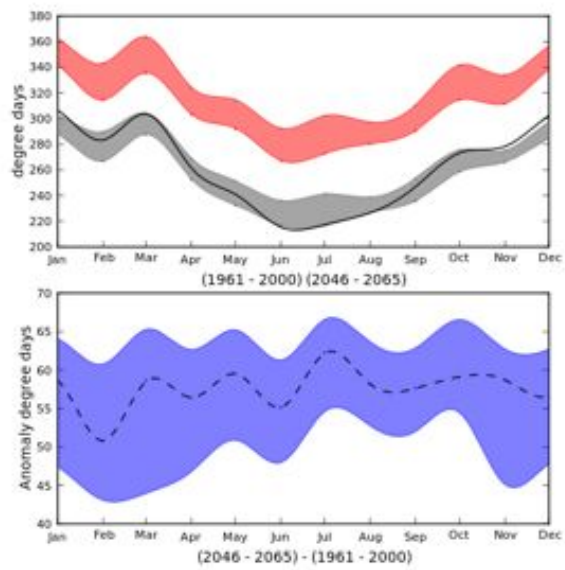
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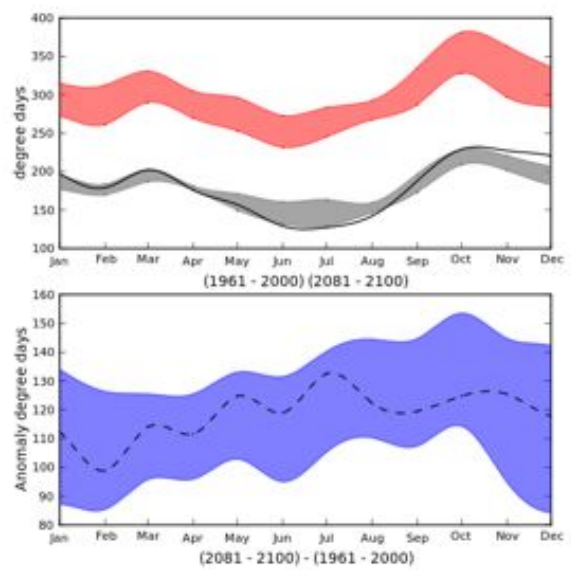
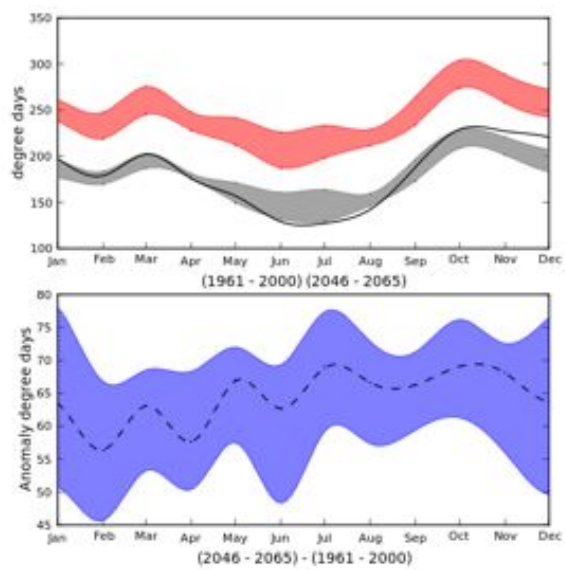
A2 Scenario, Projections and anomalies of monthly cooling degree days (2046 - 2065)

A2 Scenario, Projections and anomalies of monthly cooling degree days (2046 - 2065)

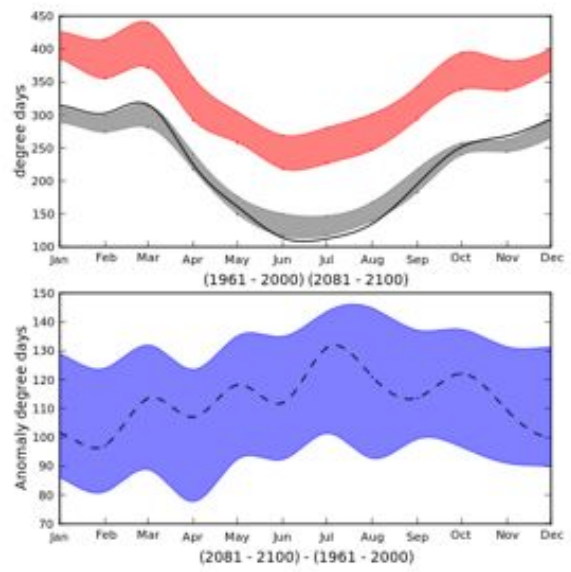
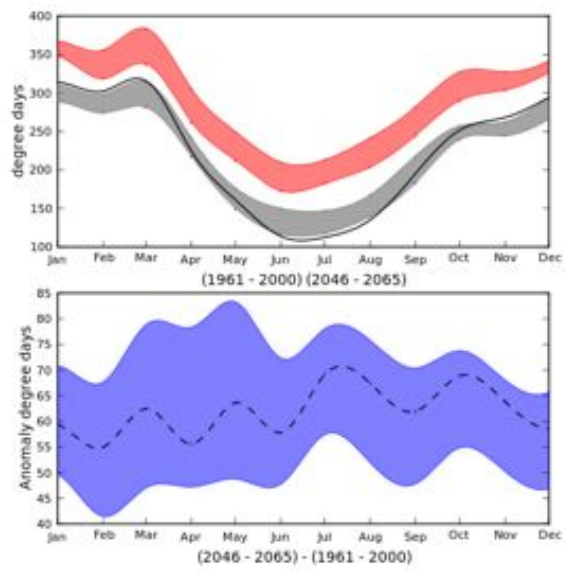
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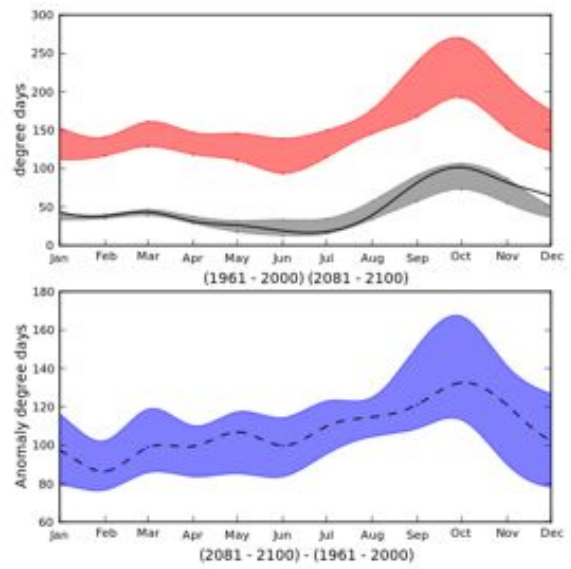
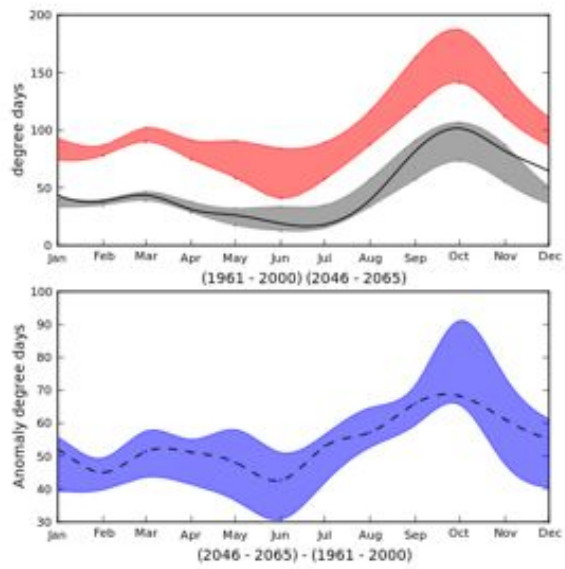
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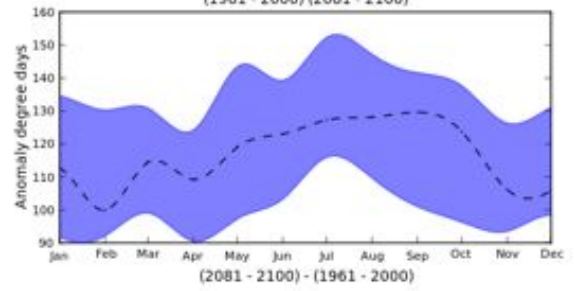
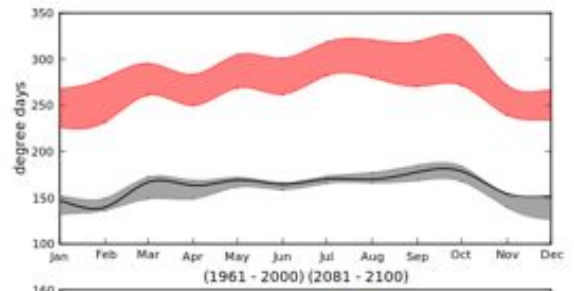
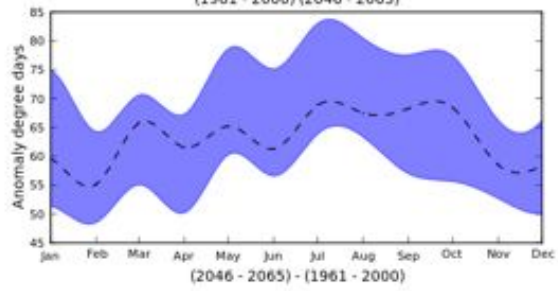
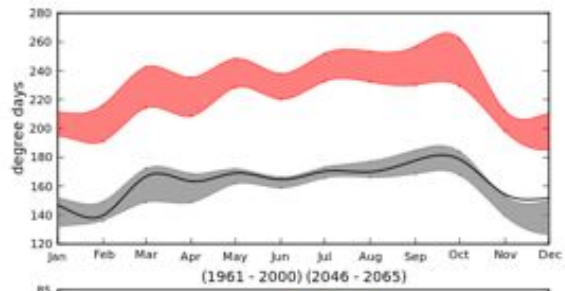
Kilimanjaro



Mbeya



Mwanza



Discussion

The projections presented broadly indicate the following changes under enhanced GHG concentrations.

Precipitation

Firstly, while projections of precipitation changes show large uncertainties, there is some agreement that precipitation will increase in the future during the late part of summer with some very slight signs of drying during the early summer. Such changes are indicative of a seasonal shift with weaker early season rains and stronger later season rains. Interestingly the far future projections (2081-2100) do not show significant wetting compared to the near future projections (2046-2065) suggesting that some limit on precipitation is being reached. This can be understood dynamically. Increases in precipitation in future climate projections is often related to increases in atmospheric moisture content. However in very wet regions it is likely that rainfall is not limited by moisture availability but by sources of uplift. In these areas changes in rainfall are often caused by changes in stability related to synoptic circulation. It is likely that the precipitation response to GHG increases in such locations is very complex and involves a number of dynamic and moisture related feedbacks.

Temperatures

Projections of temperature show much lower disagreement between the GCMs with all models showing significant temperature increases across the region. For the near future period temperature changes of around 1.5°C for the B1 scenario and 2°C for the A2 scenario are seen across most stations. Highest anomalies are seen during the winter period. This is most likely related to the initial increase in atmospheric moisture content in the near future period. Increases in humidity result in higher surface temperatures. However humidity during summer is already very high in tropical regions and it is likely that added moisture is precipitated out so the impact on surface temperature is reduced.

For the far future period temperature increases are higher ranging from around 2°C for the B1 scenario and as high as 4°C for the A2 scenario. In the far future period the temperature anomalies are much more constant through the year suggesting that increases in atmospheric humidity have reached some kind of equilibrium.

Exceedence of 32°C

Anomalies in the number of hot days per month show some interesting characteristics strongly tied to the 20th century temperature climatology and changes in mean maximum temperature. For warm locations such as Dar es Salaam, significant changes are seen during the shoulder seasons (autumn and spring) for the near future while for the far future the strongest changes occur during winter. Shoulder season changes are to be expected as for warm locations daily maximum temperatures during the 20th century climate generally exceed 32°C so future temperature increases do not change the exceedence index. It is during the shoulder seasons that there is a stronger increase in the number of days exceeding the threshold. During winter, even under future increased temperatures, for many locations daily maximums seldom exceed 32°C so there is very little change in exceedence.

Cooling Degree Days

The cooling degree days figures show much more consistent anomalies through the seasons. This is most likely because of the 22°C threshold used. For most locations during most seasons daily maximum temperatures exceed this threshold. The index therefore largely resembles the temperature anomalies presented earlier. The only locations that show significant seasonal variations are the cooler locations such as Mbeya and Mwanza.

B1 and A2 scenario differences

A full dissection of the differences between the B1 and A2 scenario projections is beyond the scope of this report beyond stating that the climate change signal for the A2 scenario is stronger than for the B1 scenario due to the increase GHG concentrations. The B1 scenario projections have a greater uncertainty attached to them as stochastic processes and natural variability will form a significant part of the results presented. Appropriate guidance would be to use the A2 scenarios in order to obtain a clearer picture of GHG induced changes while using the B1 scenarios to add some indication of the possible range of future projections under different emission scenarios.

Conclusions

We can therefore conclude that future changes in precipitation across the region are uncertain but with some indications of wetting for most locations. This wetting is largely concentrated during the late summer season with some drying in the early summer though for some locations the early summer is also wetter. Temperature increases across the region are in line with larger scale projections with some variations caused by the proximity to water bodies and altitude effects. Impacts of temperature on heat stress will be higher in cooler locations where the length of the period experiencing heat stress conditions will increase the most. Cooling degree days show consistent increases across the region.