

# Analysis of Existing Weather and Climate Information for Malawi

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## List of Acronyms

CCA	Canonical Correlation Analysis
CIP	Climate Information Platform
CMIP-5	Climate Model Intercomparison Project-5
CORDEX	Coordinated Regional Climate Downscaling Experiment
CPC	Climate Prediction Centre
CPT	Climate Predictability Tool
CSAG	Climate Systems Analysis Group (University of Cape Town)
CSIR	Council for Scientific and Industrial Research
DCCMS	Department of Climate Change and Meteorological Services
ECMWF	European Centre for Medium-Range Forecasting
ENSO	El Niño Southern Oscillation
GCM	Global Climate Model
ITCZ	Inter-Tropical Convergence Zone
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
LIA	Lilongwe International Airport
MECCM	Ministry of Environment and Climate Change Management
MOS	Model Output Statistic
PCR	Principal Component Regression
RCP	Representative Concentration Pathways
SADC	Southern African Development Community
SARCOF	Southern African Regional Climate Outlook Forum
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperatures
TRMM	Tropical Rainfall Measuring Mission
UCT	University of Cape Town
WCRP	World Climate Research Programme

## **1. Introduction**

The paper reviews the scope of weather and climate information available for Malawi, taking into account both southern African and international sources of information. It also provides an overview of Malawi's current climate, nature of recent observed changes, and projected future changes based on a combination of Global Climate Model (GCM) ensembles (under the Representative Concentration Pathways, RCP, scenarios) as cited in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, including both statistically- and dynamically-downscaled projections.

## **2. Sources of weather and climate information relevant to Malawi**

There are several southern African regional sources of weather and climate information. The National Meteorological and Hydrological Agency in Malawi is the Department of Climate Change and Meteorological Services (DCCMS), which is institutionally located within the Ministry for Environment and Climate Change Management (MECCM). Significant capacity-building attempts have taken place to support the generation of more robust weather and climate information in Malawi. For example, the World Bank funded a major "training of trainers" initiative based on a capacity building needs assessment led by the University of Cape Town (UCT) in 2013 (Daron, 2013). UCT is also providing on-going support to DCCMS in the development of their climate atlas, which is still underway.

In South Africa, the Council for Scientific and Industrial Research (CSIR) generates medium-term weather forecasts (seasonal forecasts) for southern Africa, and dynamically downscales GCMs to give longer term climate projections. The Climate Systems Analysis Group (CSAG) at UCT statistically downscales GCMs to give longer term climate projections as part of the Coordinated Regional Climate Downscaling Experiment (CORDEX), an initiative of the World Climate Research Programme (WCRP). Regional seasonal forecasts are discussed at Southern Africa Regional Climate Outlook Forum meetings (e.g. SARCOF-17 held in August 2013 provided a consensus climate forecast for the October 2013 – March 2014 period). Scientific input to these meetings is also provided by the Southern Africa Development Community (SADC) Climate Services Centre, the International Research Institute for Climate Prediction (IRI, based in the USA), European Centre for Medium Range Weather Forecasting (ECMWF, based in the UK) and Climate Prediction Centre (CPC, based also in the USA).

### **2.1 Climate data availability**

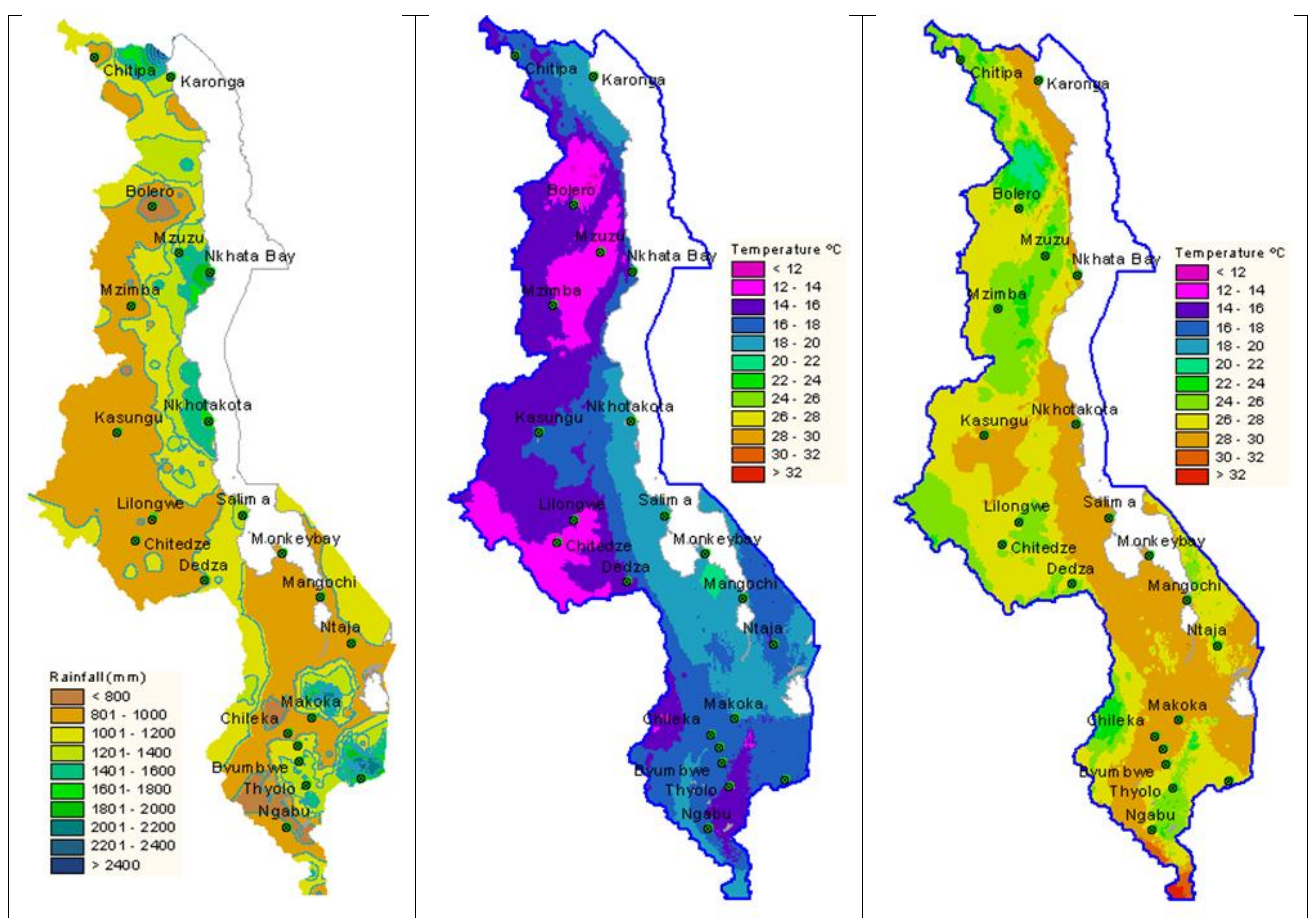
The most accessible source of climate data on Malawi is the Climate Information Platform (CIP) hosted at the CSAG. This portal has historical records of TRMM satellite rainfall, namely total monthly rainfall, total monthly rainy days, and total monthly heavy rain days (useful to identify particular climate events such as floods or droughts, as well as observing long term variability and trends and observed average seasonality) covering Malawi from 1998 to 2012. Observational records from Lilongwe International Airport (LIA) are available from 1982 to 2000 and include total monthly rainfall, total monthly rainy days, total monthly heavy rain days (>10mm), average maximum temperature, and average minimum temperature.

### **2.2 Climate characteristics of Malawi**

Malawi has a sub-tropical climate which is characterized by seasonal changing wet (November to April) and dry (May to October) conditions. The general climate pattern is altered by altitude, relief and lake influence (Figure 1). In general mean temperatures range between 18°C and 27°C.

Rainfall fluctuates with the movements of the Inter-Tropical Convergence Zone (ITCZ) which may vary slightly between different years. For southern Malawi the rainy season normally lasts from November to February with between 150mm and 300mm in rainfall per month. In general, rainfall increases with altitude up the escarpments (McSweeney et al., 2010).

Inter-annual variability in the wet season rainfall in Malawi is influenced by the Indian Ocean Sea Surface Temperatures (SST), which vary from year to year, mainly due to the El Niño Southern Oscillation (ENSO) phenomenon. The influences of ENSO on the climate of Malawi can be difficult to predict as Malawi is located between two regions of opposing climatic response to El Niño. Eastern equatorial Africa tends to receive above average rainfall in El Niño conditions, whilst south-eastern Africa often experiences below average rainfall. The opposite response pattern occurs during La Niña conditions.

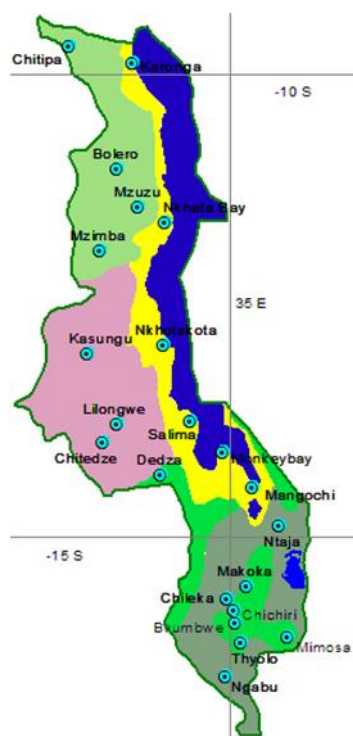


**Figure 1: Average annual rainfall, minimum temperature and maximum temperature across Malawi**  
(source: www.metmalawi.com, accessed 10th April 2014)

### 2.3 Short-term weather forecasting

Short-term deterministic weather forecasts (1-10 day time period) are issued by DCCMS in Malawi. DCCMS maintains 22 full meteorological stations (see Figure 2) where fully trained Meteorological Assistants collect observations at 0500, 0600, 0800, 0900, 1100, 1400 and 1700, with the minimum number of observations per station sitting at two (for one man stations) and only one on Sundays. Currently two stations take observations 24 hours per day.

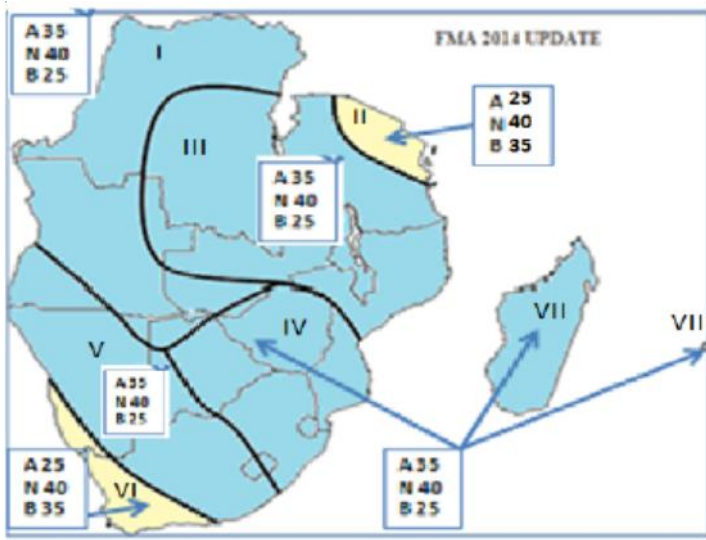
Additionally, there are 21 agrometeorological stations and 761 rainfall stations, although of the latter, less than half have more than 10 years of information, and so their use in forecasting and projections is limited. DMCCS issues daily weather forecasts, which are variously disseminated through the media, as well as agrometeorological bulletins.



**Figure 2: Location of Malawi's full Meteorological stations**  
 (source: [www.metmalawi.com](http://www.metmalawi.com), accessed 10th April 2014)

#### 2.4 Medium-term weather forecasting

Medium-term forecasts cover a time period of up to 6 months and the main format is probabilistic seasonal forecasts. Consensus regional seasonal forecasts are issued by the Southern African Climate Outlook Forum (SARCOF) in August and December (to cover the main rainy season), to which all SADC member National Meteorological and Hydrological Services, including DMCCS, contribute. SARCOF was first held in 1997 and takes place under the auspices of the SADC Climate Services Centre (the successor to the Harare-based Drought Monitoring Centre), whose role is to develop and disseminate meteorological and hydro-meteorological products and provide training in climate prediction for meteorological staff in member states. Figure 3 shows the 2014 mid-season updated SARCOF seasonal forecast, showing Malawi (like the majority of the region) was projected to have normal to above-normal rainfall.



**Figure 3: SADC seasonal forecast for February - April 2014**  
 (source: <http://www.sadc.int/sadc-secretariat/services-centres/climate-services-centre/>)

CSIR and IRI also produce probabilistic seasonal forecasts, together with projections on El Niño for Southern Oscillation (ENSO) for the coming months. CSIR-generated information is updated more frequently than that provided by SADC, and is available online through the weather and climate section of the South Africa Risk and Vulnerability Atlas spatial data portal ([www.rvatlas.org](http://www.rvatlas.org)); whilst IRI seasonal forecasts are also made available through their website (<http://iri.columbia.edu/our-expertise/climate/forecasts/seasonal-climate-forecasts/>). Even though CSIR and IRI make their information freely available for use by anyone DCCMS is mandated to use the consensus-based SADC seasonal forecast, to which it also contributes as a SADC member country.

In support of national meteorological services, IRI has produced a Climate Predictability Tool (CPT), which is a Windows-based package for constructing a seasonal climate forecast model, performing model validation, and producing forecasts given updated data. Its design has been tailored for producing seasonal climate forecasts using model output statistic (MOS) corrections to climate predictions from general circulation models (GCMs), or for producing forecasts using fields of sea-surface temperatures. Although the software is specifically tailored for these applications, it can be used in more general settings to perform canonical correlation analysis (CCA) or principal components regression (PCR) on any data, and for any application.

### 3. Climate projections

Climate projections that cover Malawi are produced globally by a number of different actors, the most comprehensive of which are the Global Climate Model ensembles produced under the Climate Model Intercomparison Project-5 (CMIP-5) using the recently-released Representative Concentration Pathways (RCP). These are outlined in the IPCC Fifth Assessment Report (IPCC, 2013) and summarised below.

Regional downscaling of Global Climate Models for the southern African region has been recently undertaken by CSIR, projecting to the period 2046-2065 (relative to 1961-2000) using 6 GCMs based on the A2 SRES scenario (a fairly high emissions scenario that reflects the current path of our emissions). CSAG has undertaken statistical downscaling using 10 GCMs, projecting through



to the same time period. These projections have been published in the *Climate Risk and Vulnerability: A Handbook for Southern Africa* (Davis, 2011) and are presented below.

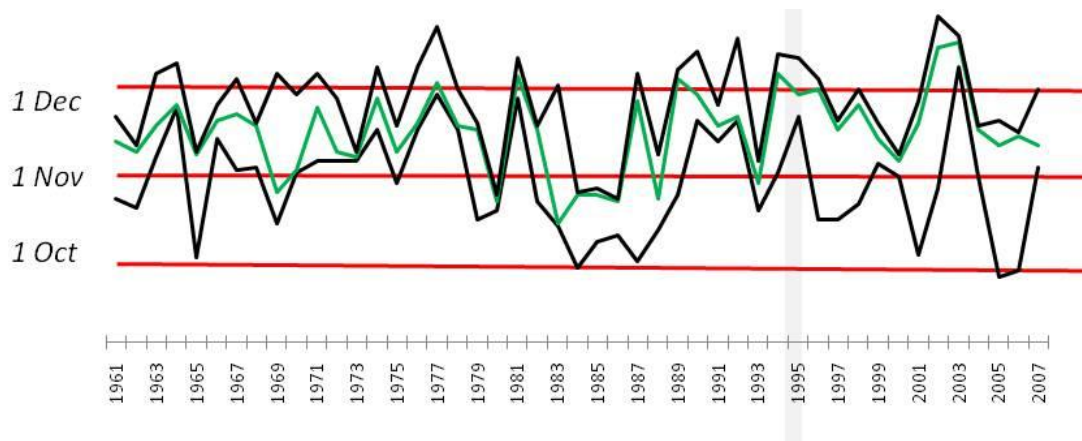
Using the LIA meteorological station data, CSAG has also statistically downscaled CMIP3 projections (across 10 different GCMs) producing total monthly rainfall anomalies under A2 and B1 SRES scenarios; for 2046-2065 and 2081-2100 relative to 1979-2000.

Although DCCMS does not make climate projections publicly available, a USAID-funded project supported the assessment of current climate conditions and the provision of future climate projections under different emissions scenarios, making explicit the uncertainty ranges around future climate projections, undertaken by CSAG, and the results of this analysis is on the Climate Information Platform. Projected changes using data from 20 Malawi meteorological stations under the CMIP-5 shows the range of projected future changes across 10 different statistically-downscaled CMIP5 GCMs for two different RCP pathways (RCP 4.5 and RCP 8.5), deriving anomalies relative to the historical period 1980-2000. Particular projections available include total monthly rainfall; count of wet days, count of wet days >5mm; count of wet days >20 mm; count of wet days >95th percentile of observed wet days; maximum daily rainfall; mean dry spell duration; average maximum temperature; average minimum temperature; hot days >32°C; hot days >36°C; hot days (tmax >95th percentile of observed days); heat spell duration 95th percentile threshold; frost days (<0°C).

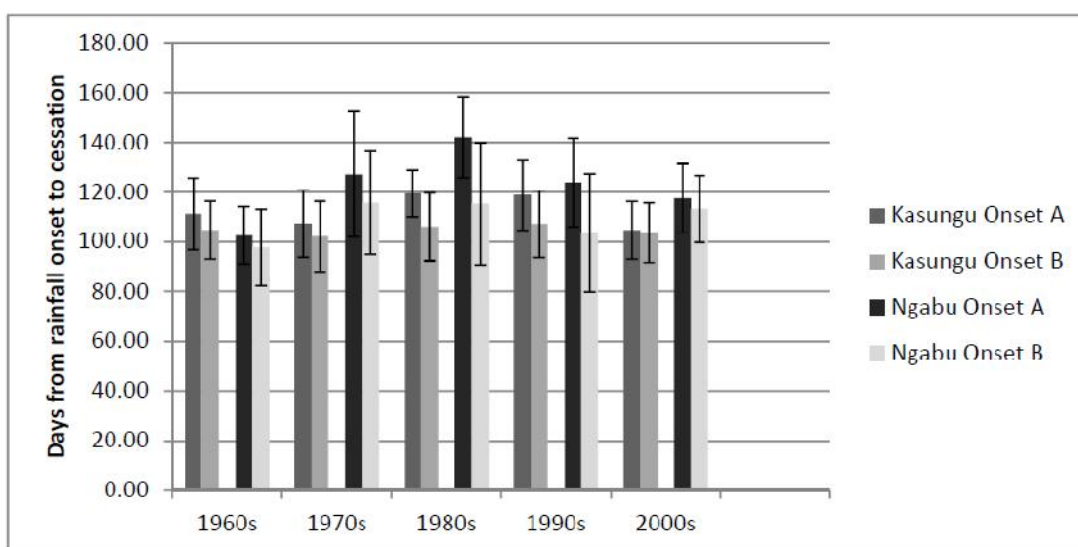
### 3.1 Recent climate trends

Since climate change is already occurring, it is important to assess the nature of observation records before looking at how this is projected to change into the future. Recent climate trends are best observed by averaging observed station data over larger areas in order to minimize local effects. Increased temperatures of 0.9°C between 1960 and 2006 were observed, an average rate of 0.21°C per decade. The increase in temperature has been most rapid in December-February (mid-summer) and slowest during September-November (early summer). Evaporation has increased in line with temperature increases.

Longer term trends in precipitation are more difficult to discern given the nature of the underlying variability (Simelton et al., 2013). Observations of rainfall over Malawi do not show statistically significant trends either in terms of total amount, the date of rainfall onset (Figure 4), or the length of the wet season (Figure 5). Wet season (December-February) rainfall over Malawi in 2006 was particularly low, causing an apparent decreasing trend in December-February rainfall, but there is no evidence of consistent decreases. Dry spells early in the wet season are particularly important given their impact on maize production (Tadross et al., 2009). There are also no statistically significant trends in the extremes indices calculated using daily precipitation observations (McSweeney et al., 2010).



**Figure 4: Interannual variability in the agronomic onset of rain in Malawi, classified as first 3 days with at least 10mm rainfall in a day at Bvumbwe Meteorological Station**  
 (source: Simelton et al., 2013)



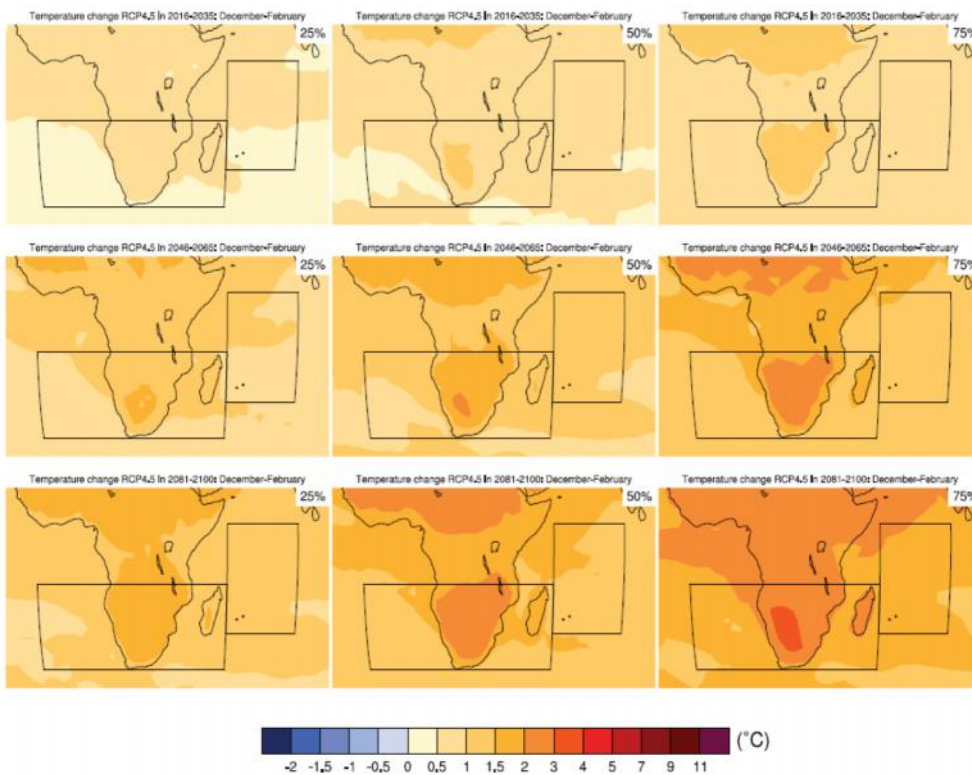
**Figure 5: Length of maize growing season defined as days from rainfall onset to cessation across 5 decades for Kasungu and Ngabu Meteorological Stations, Malawi**  
 (source: Sutcliffe, 2014)

### 3.2 Future climate projections from GCMs

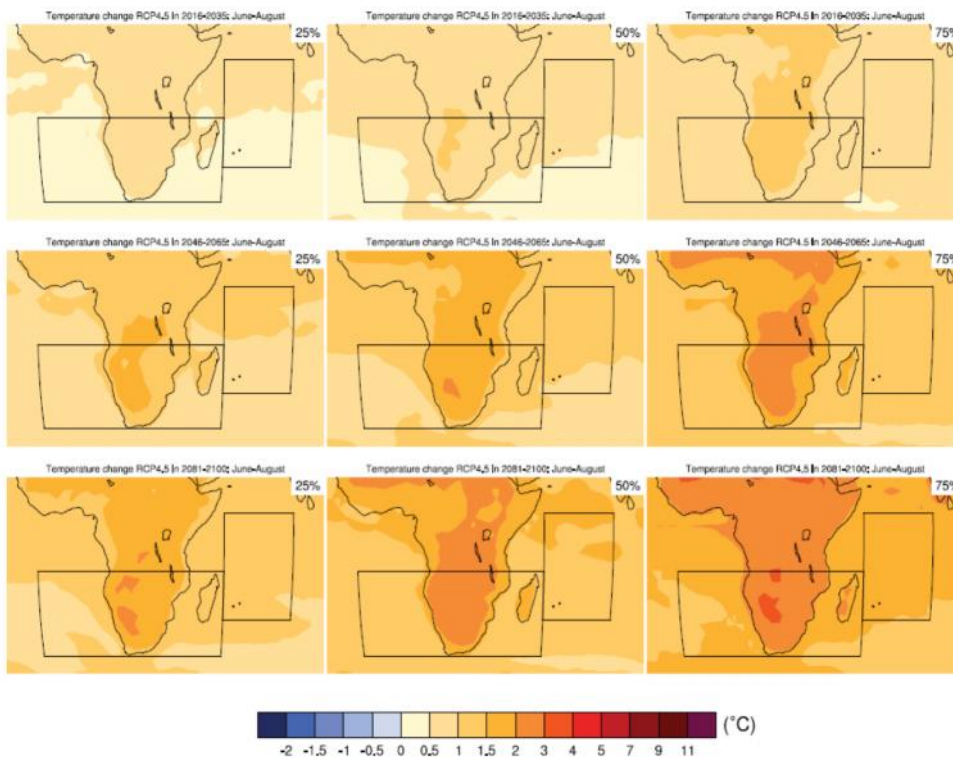
Figure 6 shows the regional temperature projections for southern Africa under the RCP4.5 for December-January-February (i.e. summer). The top row of the diagram shows the period 2016-35; the middle row shows 2046-65; and the bottom row shows 2081-2100. As with the downscaled projections above, the percentage figures (25%, 50% and 75%) are percentiles because these are combined from sets of models, known as ensembles, which all provide slightly different outputs when run under the same conditions. Country level change is difficult to discern from the maps, but broadly speaking Malawi, like other southern countries, is projected to get warmer in the summer; and the extent of warming will increase as time goes on, such that summer temperatures are likely to be more than 2°C warmer by the end of the century.

Figure 7 shows the projected temperature changes in winter. The key regional message is that winter temperatures will get warmer as time goes on, they will warm more in the interior of the

sub-continent (including Malawi), and by the end of the century we can expect over 2°C increase compared to current winter temperatures.

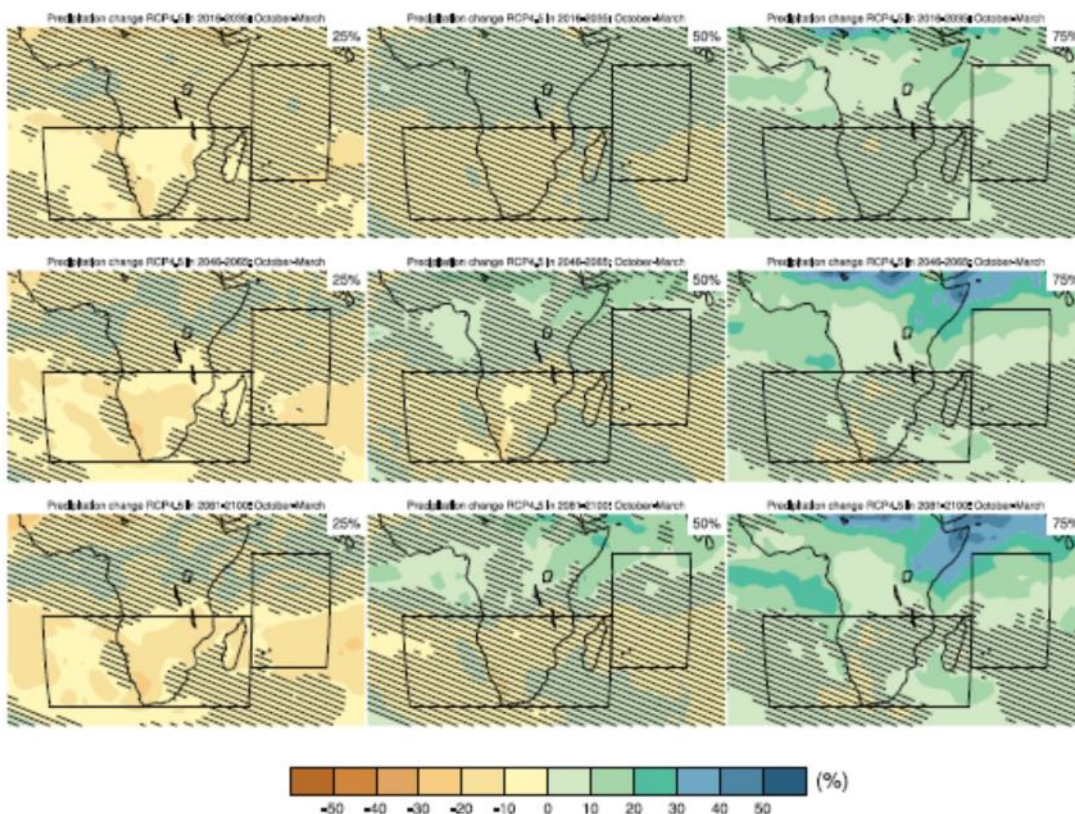


**Figure 6: Regional temperature projections for December-January-February in Southern Africa under RCP4.5** (source: IPCC, 2013)



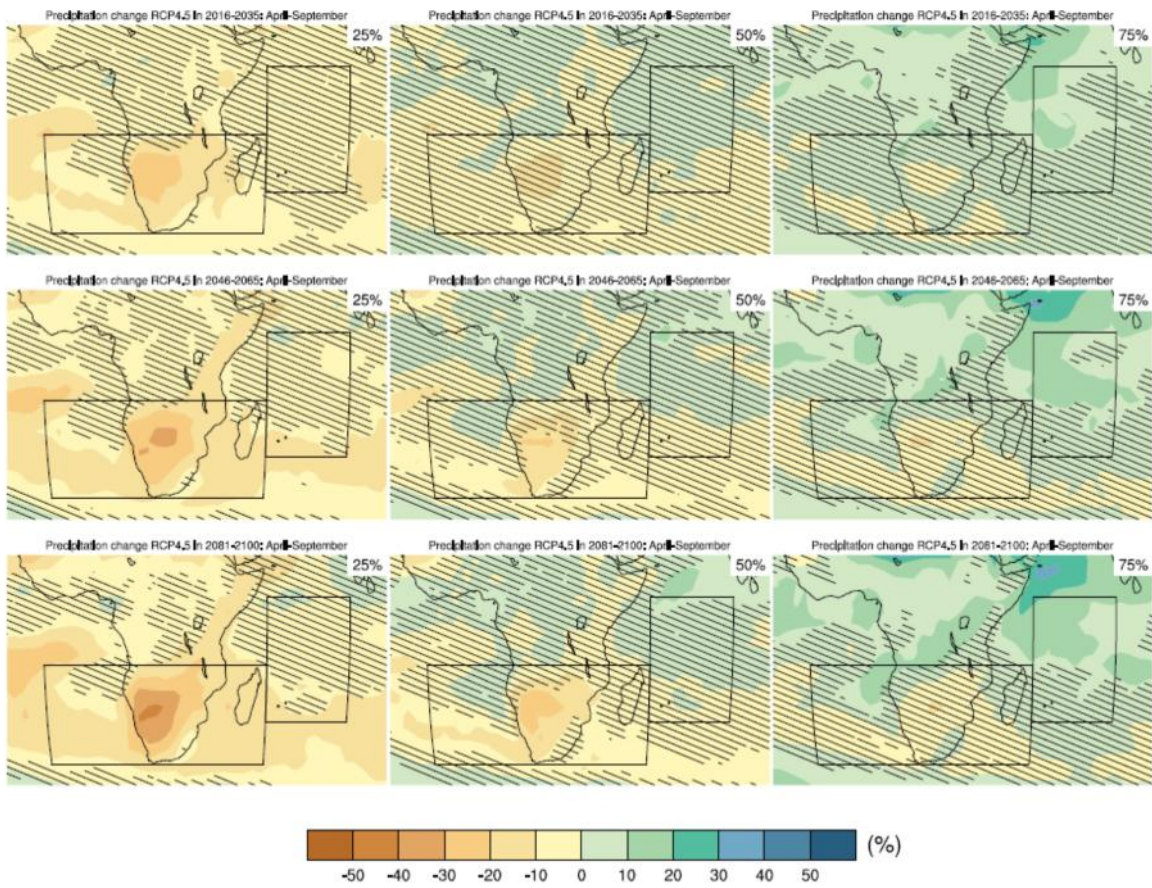
**Figure 7: Regional temperature projections for June-July-August in Southern Africa under RCP4.5** (source: IPCC, 2013)

As with previous models, rainfall projections are subject to greater uncertainties than temperatures. Some models project Malawi will become drier in the summer months (Figure 8), and others, wetter – but the uncertainty is emphasised by the fact that the presence of lines over the colours (covering Malawi in all except the 25% percentile) show that the differences are less than one standard deviation from the current situation of variability. In terms of winter rainfall (Figure 9) there is a drying trend in all but the 75% percentile but, again, the presence of lines over the colours shows that the degree of different is not more than one standard deviation from current variability.



**Figure 8: Regional rainfall projections for October-November-December-January-February-March under RCP4.5**  
 (source: IPCC, 2013)



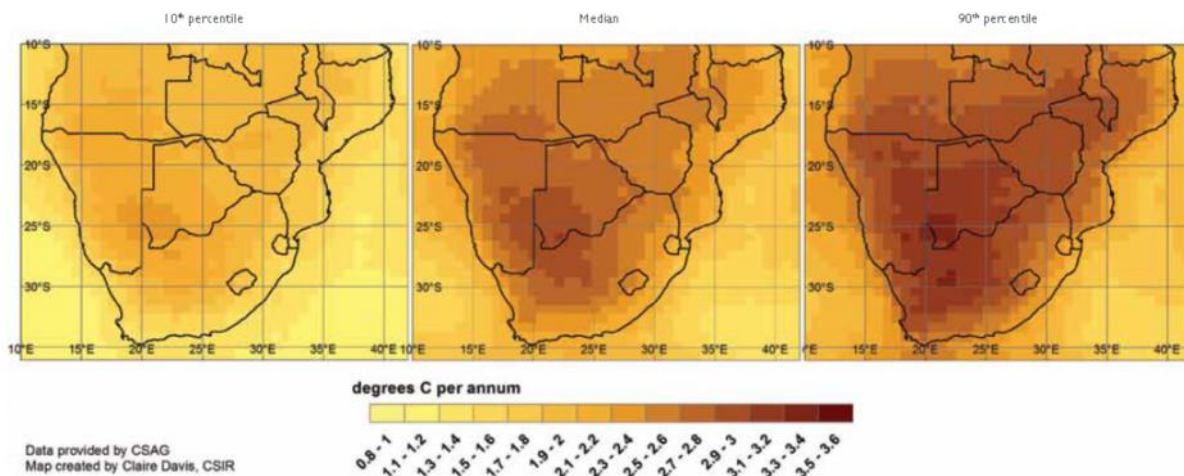


**Figure 9: Regional rainfall projections for April-May-June-July- August-September under RCP4.5**  
 (source: IPCC, 2013)

### 3.3 Future regional climate projections from statistical downscaling

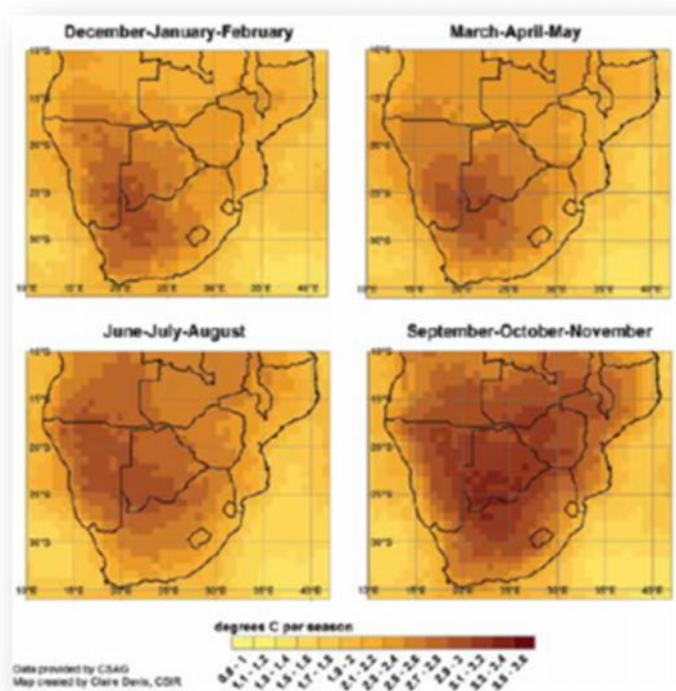
Figures 10 and 11 show projected mean annual maximum temperature change and projected seasonal temperature change, respectively. What we can say from these diagrams is that we are 90% certain that annual maximum temperature change will exceed the 10<sup>th</sup> percentile, and 90% certain that it will be less than the 90<sup>th</sup> percentile. So there is 90% likelihood that mean annual maximum temperatures in southern Malawi will exceed 1.6-1.8<sup>o</sup>c increase (the far left diagram); and 90% chance they will be less than 2.7-2.8<sup>o</sup>C.

Projected change in mean annual maximum temperature based on 10 statistically downscaled GCMs



**Figure 10: Projected mean annual maximum temperature change based on statistical downscaling.**  
 (source: Davis, 2011)

As well as increase in mean annual maximum temperatures, it is also important for natural resource-based livelihoods (and their effects on land and resource management) to assess how those changes will manifest themselves on a seasonal basis. Figure 11 shows that the season with the greatest increase in temperature will be September-October-November (i.e. early summer). This has implications since it is the traditional planting season in Malawi. June-July-August will also increase in temperature – meaning that winters will be warmer than they are at present.



**Figure 11: Projected seasonal temperature change based on statistical downscaling**  
(source: Davis, 2011)

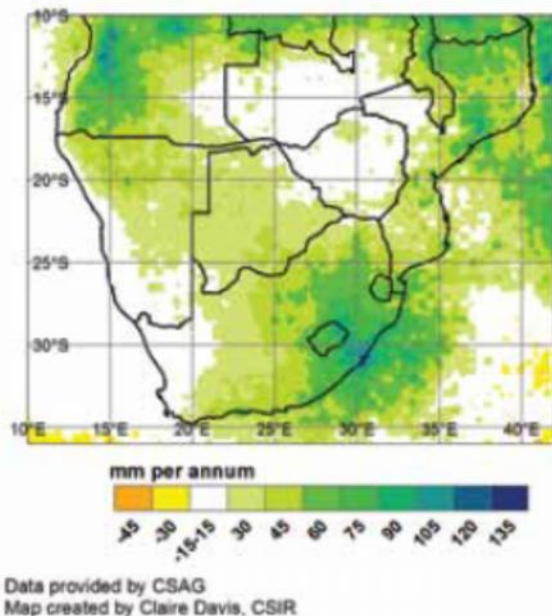
Figure 12 shows projected change in mean annual rainfall based on statistical downscaling. Since downscalings are based on GCMs, the same limitations apply. Since there is such variation in GCMs for rainfall, it is important to interpret this as a representation of the direction of change as opposed to the extent of change (since if 5 models project an increase, and 5 project a decrease, the median figure will show no change). As a result, median figures here should only be used to show direction of change (because they are the median of a range which may include less rain to more rain within the same model). This means that the areas shown in white in Figure 11 are those where the average change is close to 0 – which is often due to disagreement in the models (i.e. some project an increase, and others project a decrease).

Figure 12 shows that an increase in rainfall is likely for Malawi, to the order of more than 45mm per annum (and in some parts more than 60mm). Figure 13 looks at the seasonal distribution. Whilst models do not agree on whether there will be an increase or decrease in winter and early summer, they do project an increase in rainfall in the second part of summer (January, February and March) and March-April-May. This will have implications for rain-fed agriculture, for example, as planting may need to occur later than it does currently. However, whilst breaking



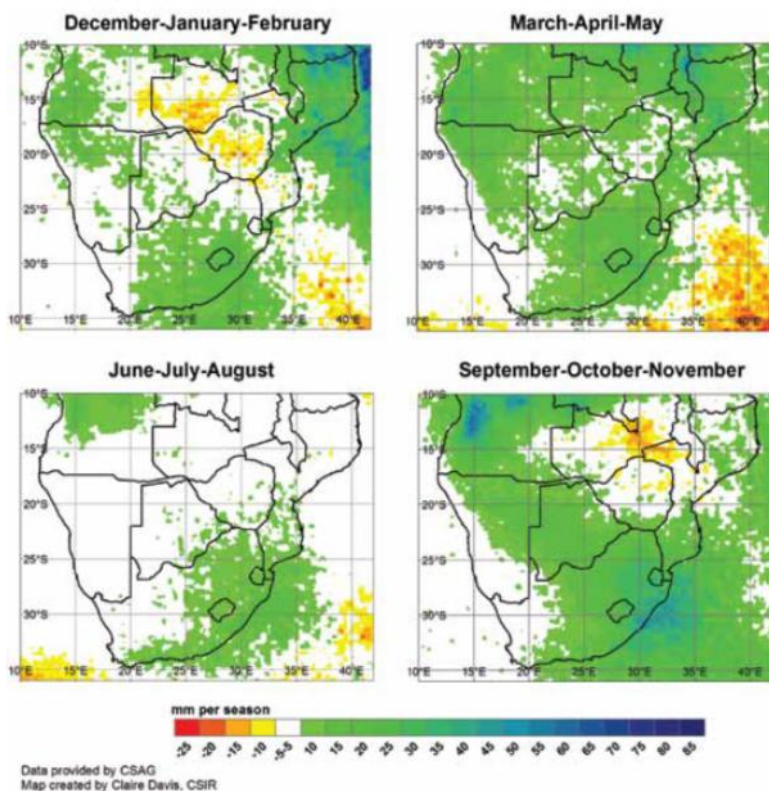
down the increase by season, these maps still do not show the extent of distribution within each season – and there is a big difference for natural resources between regular, low intensity rain and high frequency events.

**Projected change in mean annual rainfall based on 10 statistically downscaled GCMs**



**Figure 12: Projected change in mean annual rainfall based on statistical downscaling**  
(source: Davis, 2011)

**Projected change in seasonal rainfall based on 10 statistically downscaled GCMs**



**Figure 13: Projected change in seasonal rainfall based on statistical downscaling**  
(source: Davis, 2011)

### 3.4 Future regional climate projections based on dynamical downscaling

As Figure 14 illustrates, dynamical downscaling also shows temperature increase is projected throughout Malawi; there is 90% chance that mean annual maximum temperature will exceed 1°C in the south of the country; and a 90% chance that the mean annual maximum temperature increase will be less than 2.4-2.6°C. As with statistical downscaling, dynamical downscaling therefore also shows an increase in mean annual maximum temperature throughout Malawi.

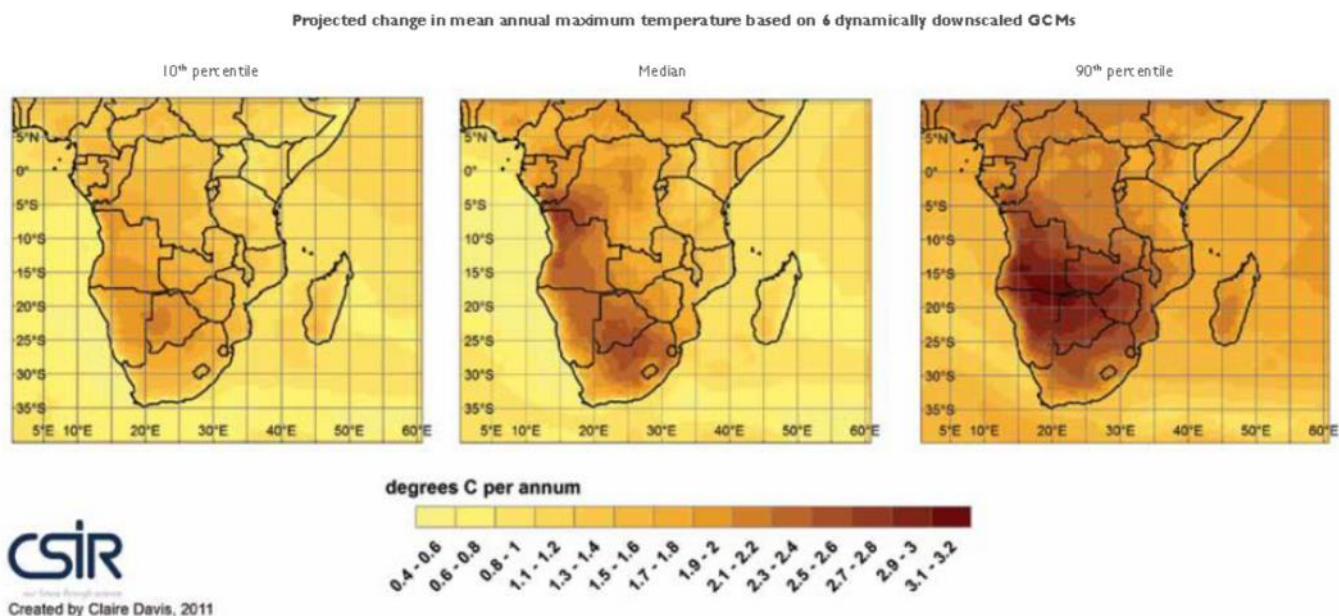


Figure 14: Projected mean annual maximum temperature increase based on dynamical downscaling (source: Davis, 2011)

Figure 15 shows projected change in annual rainfall based on dynamical downscaling. Much of Malawi is white, showing that some of the models project an increase, and others a decrease. Figure 16 shows the distribution of rainfall throughout the year and shows a high level of agreement with statistical downscaling: although there is uncertainty about winter rainfall, the second part of the summer (December-January-February) and then March-April-May will likely have increases in rainfall. However, whilst the statistical downscaling of the models is inconclusive on early summer, dynamical downscaling shows a definite decrease in rainfall in the early part of summer (September-October-November), i.e. the traditional planting time.



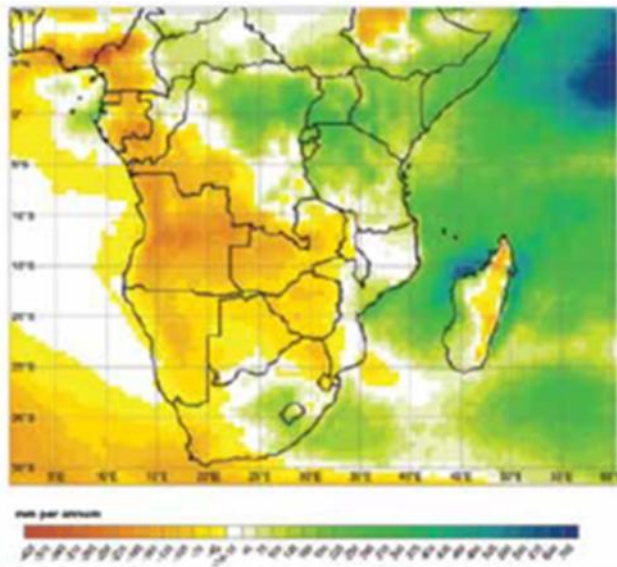


Figure 15: Projected change in annual rainfall based on dynamical downscaling (source: Davis, 2011)

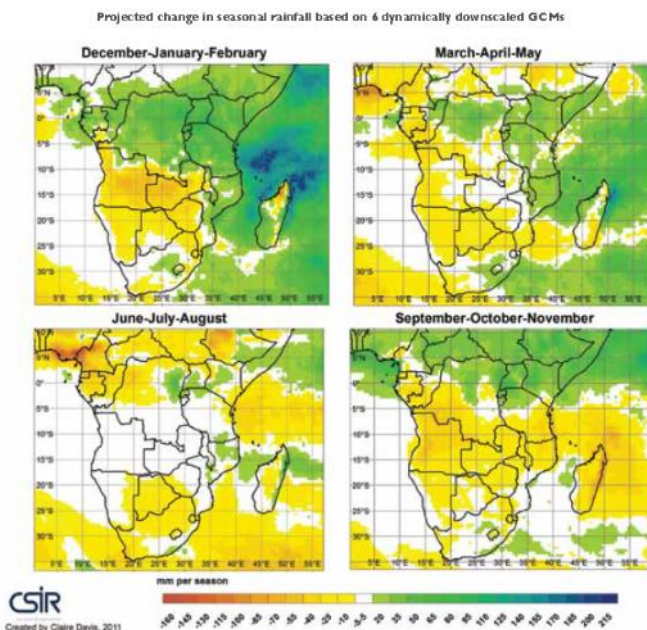


Figure 16: Projected seasonal change in rainfall based on dynamical downscaling (source: Davis, 2011)

#### 4. Conclusion

The paper has outlined the main sources of weather and forecast information in Malawi, ranging from short- to medium-term weather forecasts to longer term climate projections based on GCMs and two different methods of downscaling: statistical and dynamical. It has also summarised Malawi’s current climate and data availability from different sources, both within the country (the DCCMS), and outside (including CSAG and CSIR in South Africa; and various other institutions in Europe and the United States).

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