Working with Climate Change Data for South Africa

A Guide to Analysis in ArcGIS

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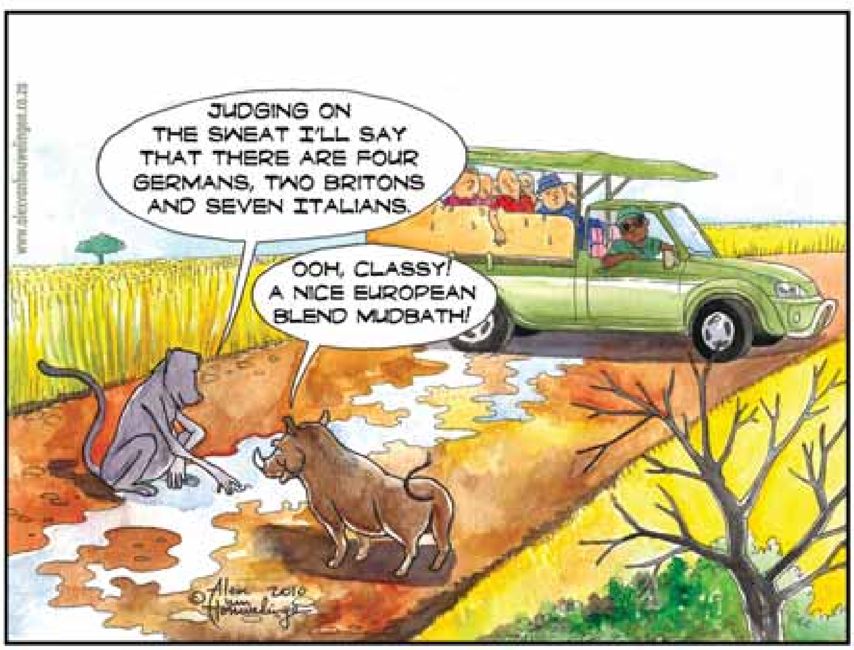
Contents


JUDGING ON THE SWEAT I'LL SAY THAT THERE ARE FOUR GERMANS, TWO BRITONS AND SEVEN ITALIANS.
OOH, CLASSY! A NICE EUROPEAN BLEND MUDBATH!

1. Introduction

The purpose of this manual is to present a GIS-based methodology that can be utilised in analysing downscaled climate change models. This methodology provides a platform for initial interaction and analysis, which can be expanded and adapted to suit different research objectives. The manual outlines the techniques utilised in ArcMap. Other GIS programmes such as DIVA GIS (an example of freeware GIS) can also be used. There are, however important limitations when using a programme such as DIVA, which should be noted before proceeding. Firstly, the climate projections are provided in raster format, which DIVA GIS does not recognise. As a result, these raster files need to be converted into shape-files or ASCii files which can be imported into the programme. Secondly, spatial analysis techniques are limited.

Future temperature projections from two dynamic regional climate models (PRECIS and MM5) and future precipitation projections from ten statistically downscaled GCMs (IPSL_CM4, GFDL_CM2_0, CCMA_CGCM3_1, MRI_CGCM2_3_2A, CSIR0_MK3_0, CSIR0_MK3_5, MPI_ECHAM5, GISS_MODEL_E_R, CNRM_CM3, MIUB_ECHO_G), are utilised in this manual and provided on the disc. These downscaled models were made available by the Climate System Analysis Group at the University of Cape Town (for more information visit www.csag.uct.ac.za). Updated climate change projections are continuously being provided both by CSAG, and through the Weather and Climate portal of the Risk and Vulnerability Atlas (www.rvatlas.org).

A brief overview of Global Climate Models and the two processes of downscaling; namely empirical and dynamical are provided in the beginning of the manual.

2. Background Information

2.1. General Circulation Model (GCMs)

A **General Circulation Model** (or **Global Climate Model**) is defined according to the IPCC as a numerical (quantitative) representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes (IPCC, 3rd Assessment Report Glossary). Climate models are applied as a research tool to study and simulate climate. More recently, however, they are being used in the construction and application of climate change scenarios for impact and adaptation studies. GCMs are the tools that provide regional predictions of future climate change; through various downscaling techniques (detailed in the next section).

GCMs consider the interaction between the ocean and the atmosphere (called coupled Ocean-Atmosphere General Circulation Models; AOGCMs) and are the basis for model predictions of future climate. AOGCMs account for the complex set of processes that cause climate change and thus attempt to provide a comprehensive representation of the climate system. They simulate future climate by considering various scenarios of human emissions of greenhouse gases (GHG), which can be idealistic or more realistic.

Future projections of climate variables are calculated by models that are run under various scenarios. A 'scenario' is a logical, credible account of a potential condition of the world in the future. The **Special Report on Emissions Scenarios** (SRES) details four main possible scenarios based on differences in the future economy, technology and world population if no action is taken to mitigate climate change. To estimate climatic changes in the future, variations in continental and regional rainfall and average temperatures during each season are obtained using observed climate change data over the last 100 years. These are used to project possible temperature and rainfall variations in the next 100 years.

The most probable future scenario, in terms of atmospheric carbon dioxide concentration, is currently uncertain. What is known, however, is that even were emissions to be cut today, the earth is still committed to a certain degree of climatic change.

There is confidence in certain estimates of future climate change provided by the climate models, however confidence in model estimates is higher for some climate variables (temperature) than for others (precipitation). This confidence in the climate models derives from their ability to reproduce observed features of current as well as past climate. Climate models are able to effectively represent many important climate features, such as the large-scale distributions of atmospheric temperature, precipitation, radiation and wind, and of oceanic temperatures, currents and sea ice cover (IPCC 2007). Models still show significant errors, however, which generally occur at the regional scale. This is partly due to limitations in computing power as well as limitations in scientific understanding of some physical processes. In addition, future scenarios do not consider stochastic events such as volcanic eruptions or changes in solar forcing as these effects are minimal in comparison to GHG forcing.

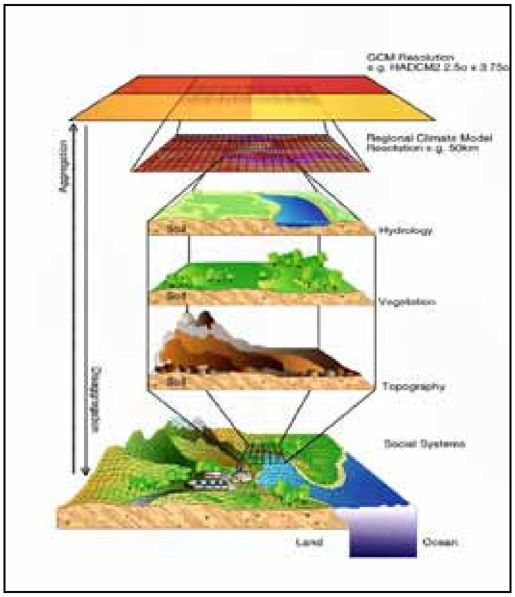
2.2. GCM Downscaling

GCM's have levels of uncertainty attached, being found to be too coarse in regional scale application (200-300 km grid). This has led, in part, to the development of two downscaling methods:

- **Empirical** (Statistical): large scale climate features are statistically related to fine scale climate for a region. Historical data records are utilised.

- **Dynamical** (Regional Climate Models – RCMs): high resolution regional climate model with a better representation of local terrain simulate future climate over a region.

Downscaling thus refers to the process whereby GCMs are converted to a finer spatial scale that is more meaningful in the context of local and regional impacts, adaptation and the development of policy. This is done by obtaining local-scale surface weather from regional-scale atmospheric variables. A key limitation of downscaling is that the performance of the model is highly dependent on the quality of the input data, and that the downscaled models may inherit the assumptions and errors made in global model simulations.



Both downscaling approaches are useful but empirical is easier to generate for many global models.

	Statical Downscaling	RCMs
Advantages	**Available for more GCMs and this allows you to assess the probabilities and uncertainties**	**All physical interactions are accounted for and local fine-scale feedback process (not anticipated with statistical methods) can be simulated**
Limitations	**May not account for some of the interactions, such as between the land and the atmosphere**	**RCMs are far more computationally demanding**

3. The Data

Data provided on the disc were obtained from two different downscaling techniques:

- Statistical downscalings of 7+ GCMs (CSIRO, ECHAM, HadCM3, GFDL, MRI_CGCM, CGCM3, CNRM, ECHO, GISS) for two future periods (2046-2065 and 2070-2100). The reason for the use of 2 periods is that one set of GCMs (CSIRO MK11, ECHAM4.5 and HadCM3) were used as part of the IPCC Third

Assessment Report, data from which were not available for the earlier 2046-2065 period, as was the case for the other GCMs which were used as part of the later IPCC Fourth Assessment Report. These downscalings are from the second set of downscalings disseminated by the Climate System Analysis Group at the University of Cape Town, namely version 2.

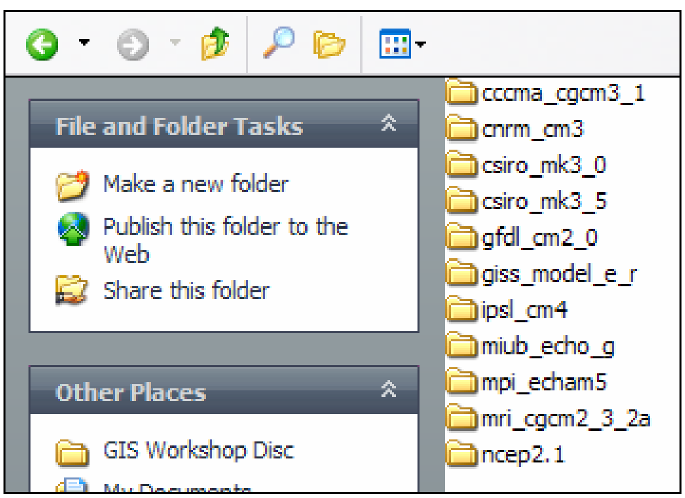
- 2 Regional Climate Models (RCM) of the same GCM (HasAM3P); MM5 and PRECIS were used to obtain future temperature projections. These downscalings are from the first set of downscalings, namely version 1.

The downscaled simulations all assumed a future **A2 SRES emissions scenario**. The A2 storyline and scenario describes a very heterogeneous world, assuming a moderate to high growth in greenhouse gas concentration.

These downscalings represent a comprehensive range of climate change projections and a range of possible estimates. It is thus important to note that each RCM has different biases and used together they span the range of the observed climate cycle. You should always use data from all available downscalings to test the uncertainty of range of difference model projections and you should always compare the widest range of models/downscalings for which data is available.

3.1. Rainfall

There are 11 **statistical downscalings** (from the version 2 downscalings)

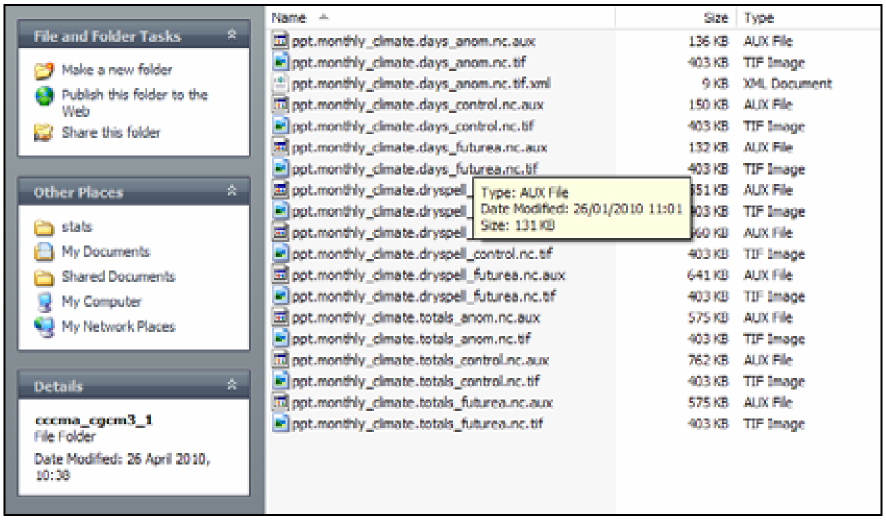


Each model has data for three different variables:

1. 'Climate Days': this refers to the number of rain days per month
2. 'Climate Dryspell': this refers to the number of dry days per month

3. 'Climate Totals': this refers to the amount of rainfall per month

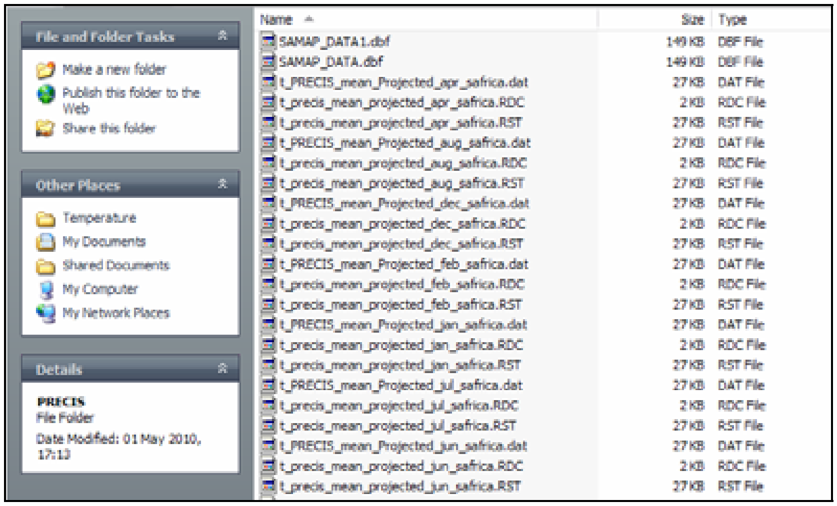
For each of these variables there is a **control** (based on observed climate conditions averaged over the period 1961-2000), **future** (projected climate conditions for the period 2046-2065 and 2070-2100) and **anomaly** (the difference between the future and control).



3.2. Temperature

The reference (or control) climate period for the PRECIS downscaling is 1960-1980 and for the MM5 downscaling is 1975-1985. The future climate period for the PRECIS downscaling is 2070-2090 and for the MM5 downscaling is 2070-2080.

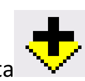
Projections for mean day temperature, minimum day temperature and maximum temperature are available on the disk for both regional climate models. This data is expressed as a projected future value and not as an anomaly. It should be noted here that at the time of writing, interim version 2 temperature downscalings will be shortly available, and should be used in real analysis.



4. Analysing the Downscaled Climate Models: Using ArcMap

4.1. Displaying the Rainfall Data

Create a New Empty Map

In ArcMap Add Data  or main menu File > Add Data

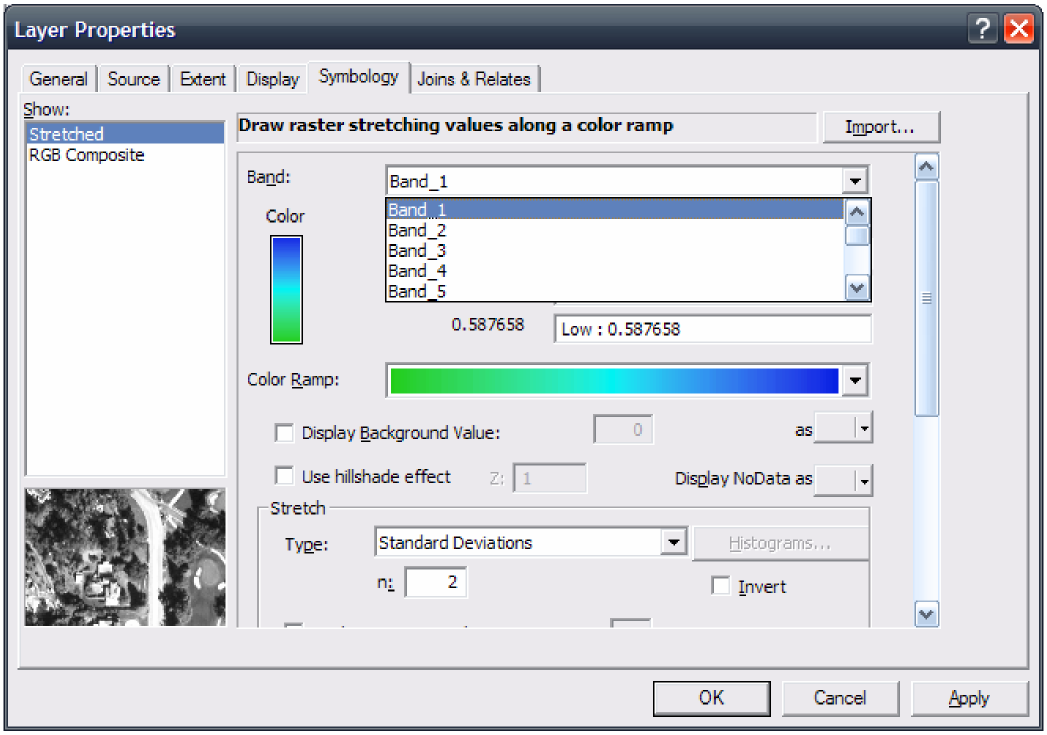
In the dialog box navigate to the cccma_cgcm_3_1 folder and add

ppt.monthly_climate.totals_futurea.nc.tif

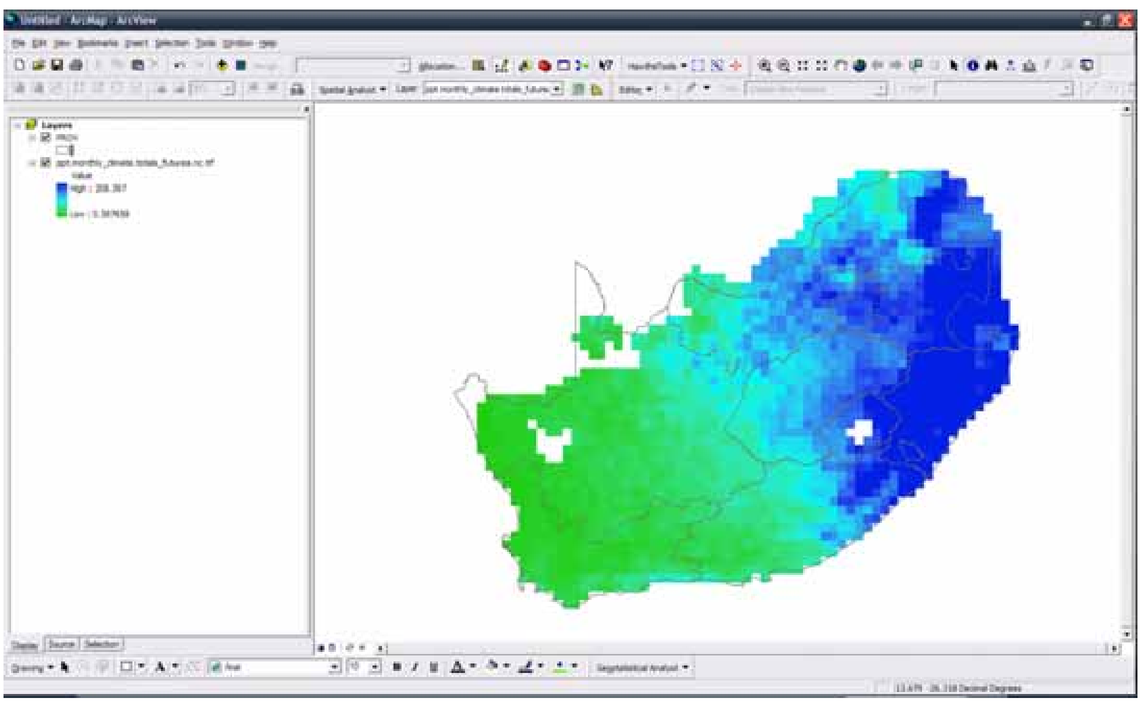
Also add the Province Shape File as this will be required in later analysis.

The climate data will be displayed in RGB Composite with Red displaying Band_1 (January) and Green displaying Band_2 (February) and Blue displaying Band_3 (March).

To change the display right click on the layer and select Properties. Select the Symbology tab and change the display from RGB Composite to Stretched. Under the band drop down menu you will see that there are twelve bands each representing the 12 months of the year.



The **projected rainfall for January** should look like this.

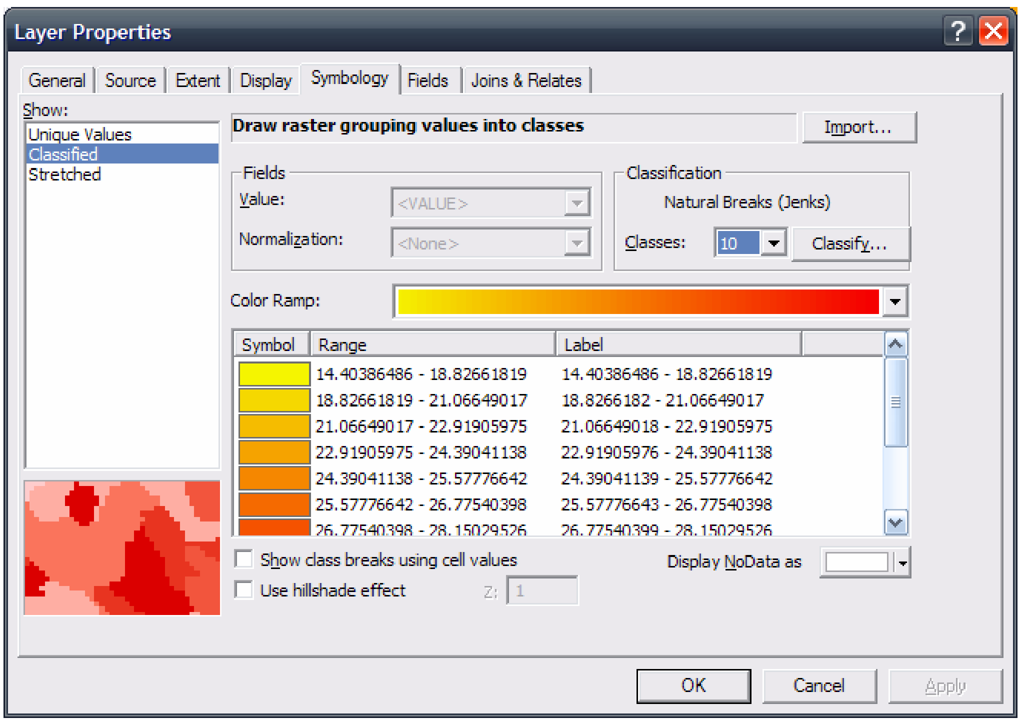


4.2. Displaying the Temperature Data

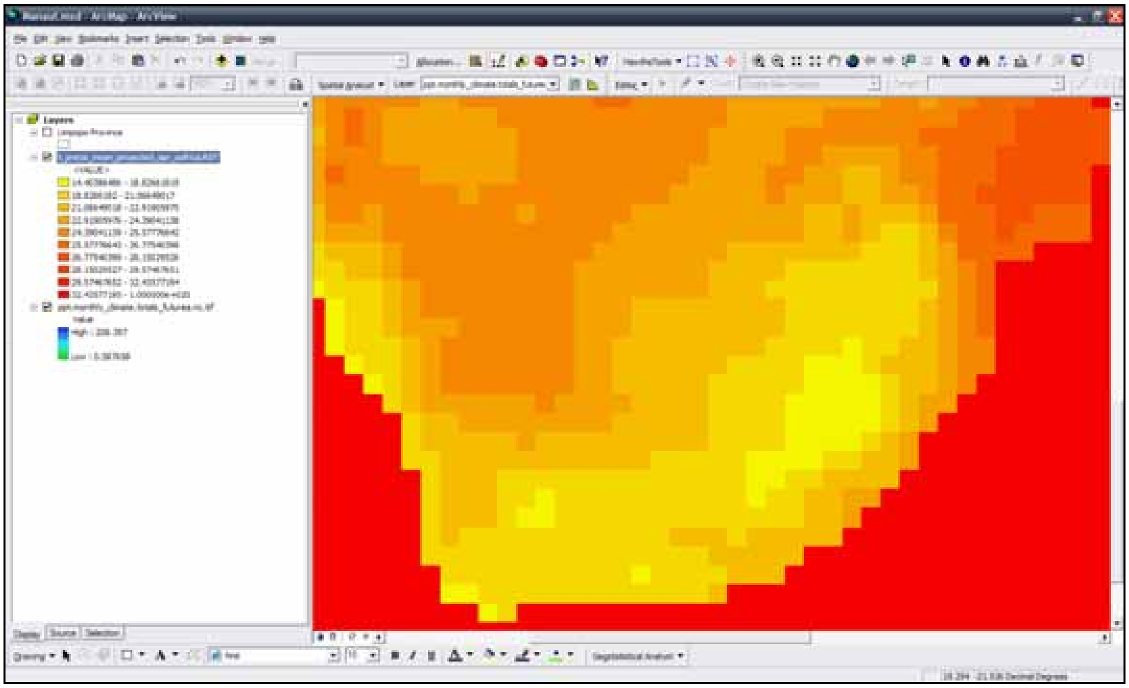
File > Add Data and in the dialog box navigate to the folder Temperature/PRECIS and add

t_precis_mean_projected_apr_safrica.RST

When it opens it will display as a black image. In order to correct this you need to change the Symbology. Click on classified and request to calculate histogram. The number of classes can be changed and the breaks can be manually adjusted by clicking Classify. The temperature data is not displayed in bands, as with the rainfall (described above) but rather individual raster files, which need to be added to ArcMap individually.

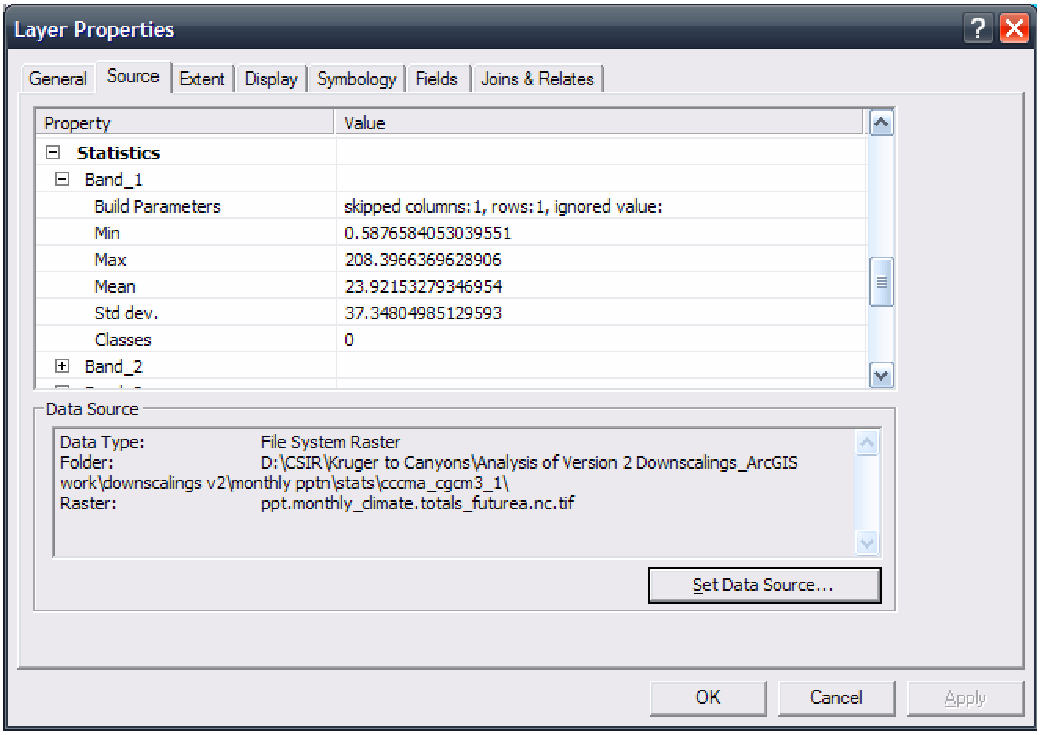


The **projected mean temperature for April** should look like this (depending on your choice of class breaks and colour).

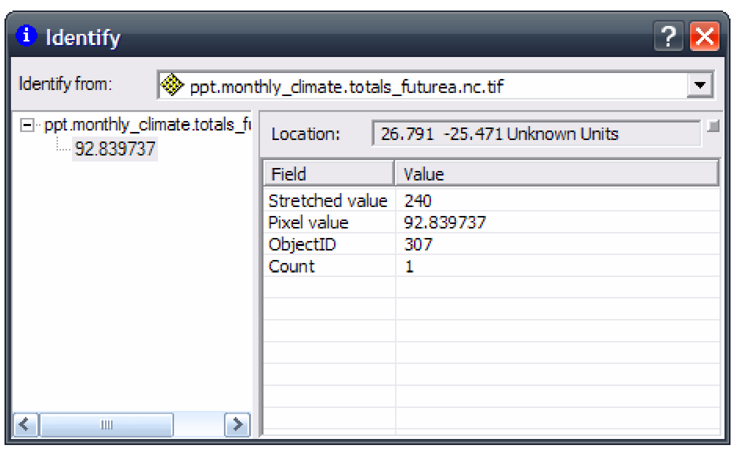


4.3. Querying the Data

The data can be explored in a number of ways. It is important to note that there is no attribute file associated with the data file and consequently you are unable to select by attributes or location and are unable to use the statistics function under the Selection menu (refer to section 1.4 which outlines how to create your own attribute file). The general statistics for each band can be viewed under the Source tab in the Layer Properties dialog box.



Identify  provides information for the specific spatial feature in the location you click. For example, if Band_1 is selected in the layer properties the identify dialog box would display the pixel values for January for a specific location.



4.4. Extracting the Data for further Analysis

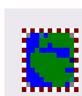
A non-spatial analysis can be performed on the data by creating a database file (.dbf).

HawthsTools Extension (freely available off the web and provided on the disc with installation instructions) needs to be installed in order to undertake this analysis. This is also a useful tool that can be used to perform additional analysis not described here.

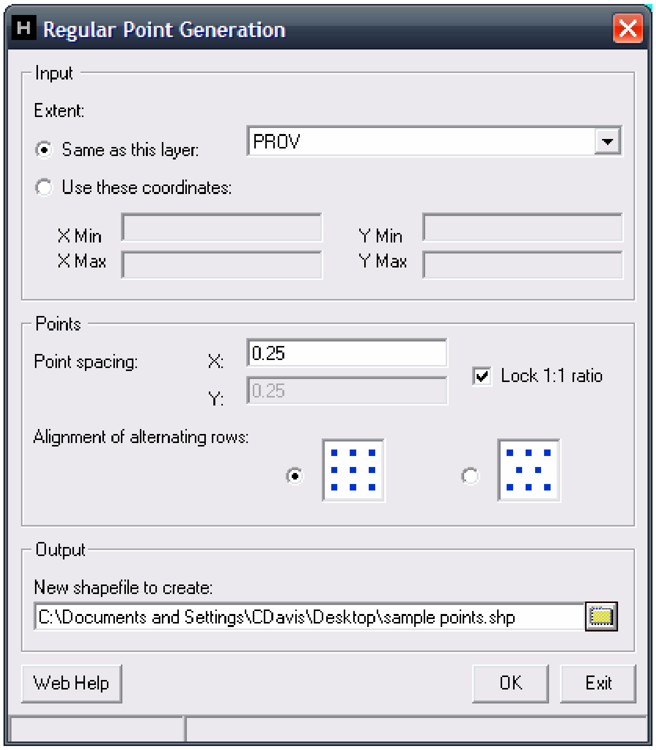
Example: determining the future rainfall for the Limpopo Province.

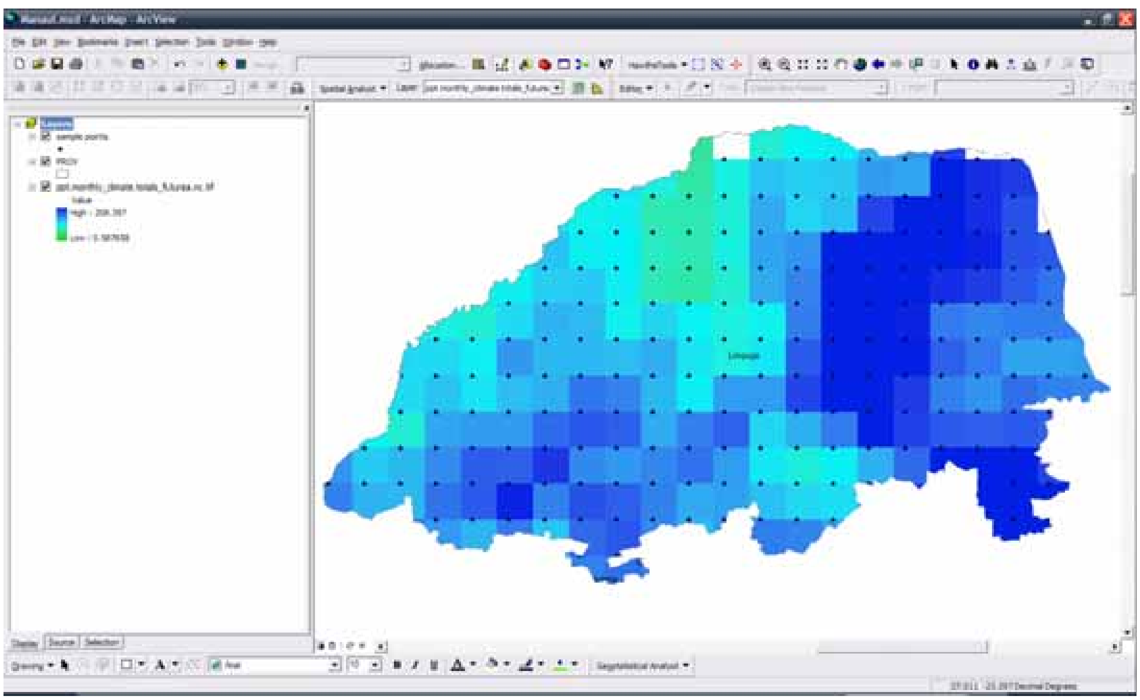
In order to extract the data for a single province or region, a layer file needs to first be created for the area. Before you change the attribute file you need to save the province layer so that the other province polygons are not lost.

To display the editor functions click on Tools > Editor toolbar. Click on the Editor tab and then Start Editing and a dialog box will appear with showing the Province layer file, click Start Editing. Open the attribute file of the Province layer and select the provinces you do not require and click on Delete Selected. Click on the Editor tab and then Stop Editing and save your changes. The province layer should now only display the Limpopo Province.

Use the Clip Data Frame  (you may need to add this to your toolbar under the command feature found in Tools > Customize) to reduce the extent of the map to the Limpopo province.

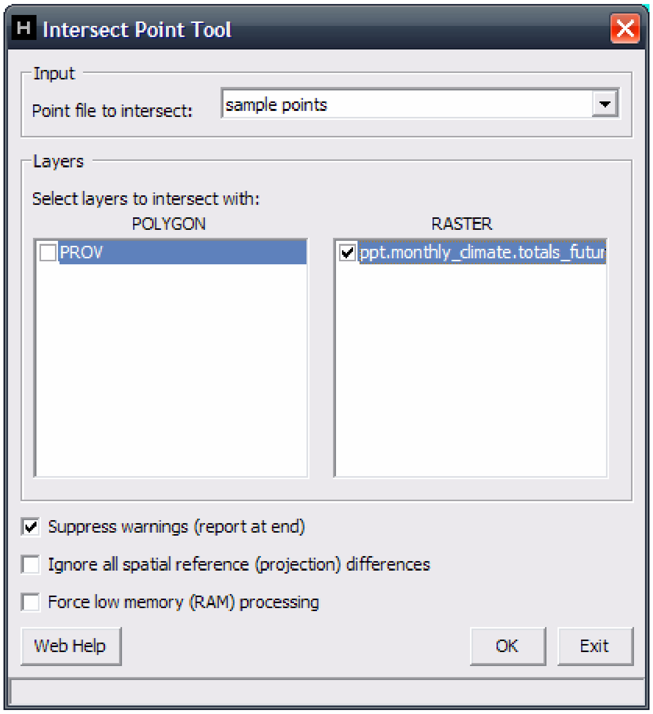
Click on the HawthsTools drop down menu and under Sampling Tools click on Generate Regular Points. The input layer should be the Province Shapefile. The point spacing should be 0.25 as the downscaled climate models have a resolution of 25 km^2 (the size of each grid cell is 25km). This will add a new layer in your window and dots (sample points) should appear on your map.

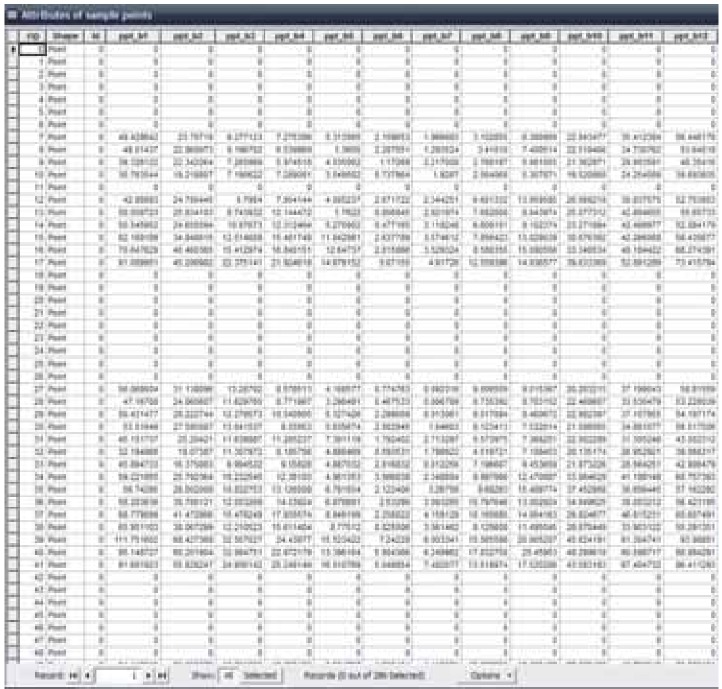




Click on the <u>HawthsTools</u> drop down menu and under <u>Analysis Tools</u> click on <u>Intersect Point Tool</u>.The point file to intersect is the Sample Points Layer you just created and the raster to intersect with is the climate layer. Once you click 'OK' you may get a warning regarding the coordinate reference system used for each layer – ignore this warning. Once complete, open the attribute file of the Sample Points layer. The attribute file should have values for each pixel for each month (1-12). Zero values refer to pixels with no data. Graphs of each month can be created by clicking Options > Create Graph.

To export this attribute table, click Options > Export. This creates a database file which can be opened in Microsoft Excel and other statistical programmes (such as R) where further analysis can be conducted.





4.5. Spatial Analysis of the Data

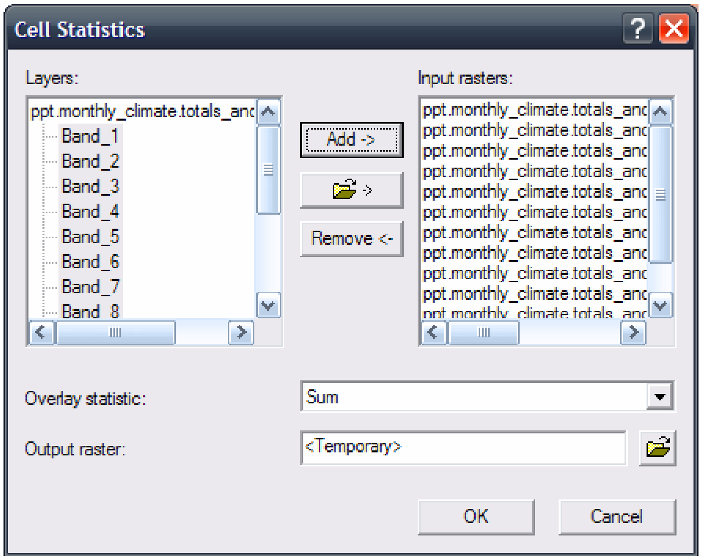
Spatial Analysis Extension[2] (an optional component of ArcGIS) is required to undertake this component of the analysis. A seasonal analysis using the Cell Statistics tool will be presented in the following section; however there are additional tools (such as the Raster Calculator) that can be used to perform advanced spatial analysis.

In the dialog box navigate to the cccma_cgcm_3_1 folder and add the rainfall anomaly layer:

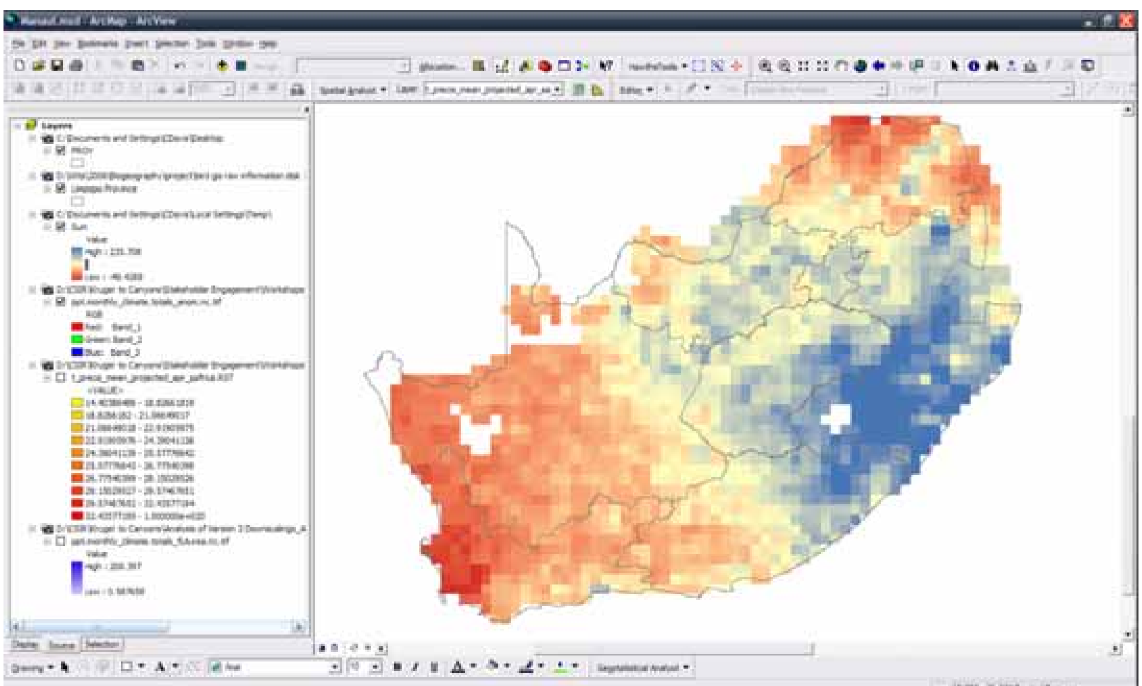
ppt.monthly_climate.totals_anom.nc.tif

Ensure that the layer is displayed in the RGB composite. Click on the Spatial Analyst toolbar and click Cell Statistics. Select all the Bands (all the months) and add them to the Input Rasters. Under the Overlay Statistic tab there is a range of mathematical functions. In this case we would like to determine the total change in rainfall for the whole calendar year and as such the Sum function is used. To determine the average change per annum the mean function can be used. Any combination of months can be analysed, such as the January and February Bands or May to July Bands depending on your months and/or seasons of interest. The orders in which the layers are added are not important.

[2] Before you can use this extension you need to ensure that is loaded into ArcGIS.
Click on Tools > Extension > Spatial Analyst

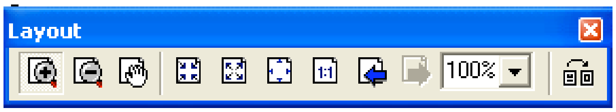


The map displayed will show the total change in rainfall per annum as projected by this particular model; CCCMA_CGCM. A clear west and east divide in rainfall change can be seen with the west of South Africa experiencing a decrease in rainfall and the eastern regions experiencing an increase in rainfall. The north-eastern region does not display a marked increase in rainfall and this demonstrates the importance of analysing more than one model and using a range of estimates from numerous models.



4.6. Exporting a Map

- Finish creating your map in ArcMap
- Go to View then select Layout View (it is currently in Data View)
- You will then see your map displayed on an A4 sheet much like the one in print preview in Microsoft Word
- A separate toolbar will also appear. On this tool bar there is an icon Change Layout, which will allow you to add different components to the map. Military Portrait adds coordinates onto your map



- To move your map around the page use the hand icon on the original toolbar you were using, usually found on the right of the page between the viewer and the display panel
- To add a title to the map go to Insert and select Title, then add your title
- You can also add north arrow, scale and legend in the same way.
- Go to File then select Export Map
- Select where you want the map to be saved

Acronyms

AR3	IPCC Third Assessment Report
AR4	IPCC Fourth Assessment Report
CO2	Carbon Dioxide
CGCM3	The Third Generation Coupled Global Climate Model
CNRM	Centre National de Recherche Meteorologique
CSAG	Climate System Analysis Group
CSIRO	Commonwealth Scientific and Industrial Research Organization
ECHAM	European Centre Hamburg Model
GCM	General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Green-house Gas
GIS	Geographic Information Systems
GISS	Goddard Institute for Space Studies
HadCM3	Hadley Centre Atmosphere Model
IPCC	Intergovernmental Panel on Climate Change
MIROC	Model for Interdisciplinary Research on Climate
MM5	Mesoscale Meteorological Model, Version 5
MRI_CGCM	Meteorological Research Institute Coupled General Circulation Model
PRECIS	Providing Regional Climates for Impacts Studies
RCM	Regional Climate Model
SDM	Statistically Downscaled Model
SAEON	South African Environmental Observation Network
SRES	Special Report on Emissions Scenarios
UCT	University of Cape Town

References and other Resources

ArcGIS Desktop Help, ESRI <www.esri.com>

Hewitson, B.C., and Crane, R.G., 2006 Consensus between GCM climate change projections with empirical downscaling, in press in Int. J. of Climatology.

Hewitson, B.C., Engelbrecht, F., Tadross, M. and Jack, C., 2005: General Conclusions on Development of Plausible Climate Change Scenarios for Southern Africa, *In*: Schulze, R.E. (Ed) *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation*, Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05, Chapter 5, 75 - 79.

IPCC, 2007: *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, In Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.), Cambridge University Press, Cambridge, 1-18. <http://www.ipcc.ch/WG1_SPM_17Apr07.pdf> (17 April 2007).

Joubert, A.M., 1994: Simulations of Southern African climate change by early generation general circulation models, *Water SA*, 20(4), 315-321.

Joubert, A.M., and Tyson, P.D., 1996: Equilibrium and fully coupled GCM simulations of future southern African climates, *South African Journal of Climat.,* 92(10), 471 – 485.

Joubert, A.M., and Hewitson, B.C., 1997: Simulating present and future climates of southern Africa using general circulation models, *Progress in Physical Geography*, 21 (1), 51 – 78.

Mason, S.J. and Joubert, A.M., 1997: Simulated changes in extreme rainfall over Southern Africa, *International Journal of Climatology*, 17, 291-301.

Tadross, M., *Downscaled climate scenarios for South and southern Africa*. SAEON Workshop on high-resolution climate change data for Southern Africa, 27 March 2007.

Tadross, M., Jack, C., and Hewitson, B., 2005: On RCM-based projections of change in Southern African summer climate, *Geophys. Res. Lett*., 32, 1-4.

Tyson, P.D. and Preston-Whyte, R.A., 2000: The prediction of future conditions, *In: The Weather and Climate of Southern Africa,* 2nd ed., Oxford University Press, Cape Town, Chapter 17, 339 – 355.