ORASECOM Document No. 007/2010

SUPPORT TO PHASE 2 OF THE ORASECOM BASIN-WIDE INTEGRATED WATER RESOURCES MANAGEMENT PLAN

Work Package 4:

Climate Change in the Orange-Senqu River Basin

Downscaling Methodology and Ongoing Climate Modelling Initiatives

February 2010

ORASECOM

The *Support to Phase 2 of the ORASECOM Basin-wide Integrated Water Resources Management Plan* Study was commissioned by the Secretariat of the Orange-Senqu River Basin Commission (ORASECOM) with technical and financial support from the German Federal Ministry for Economic Cooperation and Development (BMZ) in delegated cooperation with the UK Department for International Development (DFID) and the Australian Agency for International Development (AusAID). The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) implemented the study.

On behalf of
Federal Republic of Germany
The Federal Government

from the Department for International Development

Prepared by

A Miya Group Company

in association with

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ORASECOM Document No.	007/2010
Date of Publication:	February 2010

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Status:	Final Report

APPROVALS

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Study Name	**Support to Phase 2 of the ORASECOM Basin-wide Integrated Water resources Management Plan**		
Report Title:	***Downscaling Methodology and Ongoing Climate Modelling Initiatives***		
Submitted by:	WRP Consulting Engineers in association with Golder Associates, DMM, PIK, RAMBOLL and WCE		
REPORTS, WPS AND OTHER DELIVERABLES SUBMITTED		**TYPE**	**No.**
Overall Study			
	Inception Report	Report	004/2010
	Overall Project Executive Summary	Report	013/2011
Work Package 1: WATER RESOURCES MODELLING OF THE ORANGE-SENQU BASIN			
	Strengths and Weaknesses of Existing Models	WP	005/2010
	Setting up and Testing of the Final Extended and Expanded Models; Changes in Catchment Yields and Review of Water Balance	Report & WP	001/2011
	Modelling software and datasets	Software	None
	Capacity Building and Setting up the Models in each Country; Process of Continuous Review	WP	003/2011
Work Package 2: EXTENSION AND EXPANSION OF HYDROLOGY OF ORANGE-SENQU BASIN			
	Improvements to Gauging Network and Review of Existing Data Acquisition Systems	WP	005/2011
	Extension of Hydrological Records	Report	006/2011
	Hydrological Database	Database	None
Work Package 3: INTEGRATED WATER RESOURCES QUALITY MANAGEMENT PLAN			
	Development of Water Quality Monitoring programme and Data Management Framework	Report	007/2011
	Development of Specifications for the Water Quality Model	WP	006/2010
Work Package 4: CLIMATE CHANGE IN THE ORANGE-SENQU RIVER BASIN			
	Downscaling Methodology and Ongoing Climate Modelling Initiatives	***WP***	***007/2010***
	GCC Downscaling for the Orange-Senqu River Basin	Report	008/2011
	Projection of impacts and Guidelines on Climate Change Adaptation Strategies	WP	009/2011
Work Package 5: ASSESSMENT OF ENVIORNMENTAL FLOW REQUIREMENTS			
	Literature survey and Gap Analysis	WP	008/2010
	Delineation of Management Resource Units	WP	009/2010
	Desktop Eco Classification Assessment	Report	016/2010
	Goods and Services Report	WP	010/2010
	Environmental Flow Requirements	Report	010/2011
Work Package 6: WATER CONSERVATION AND WATER DEMAND IN THE IRRIGATION SECTOR			
	The Promotion of WC WDM in the Irrigation Sector	Report	011/2011
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1 INTRODUCTION

1.1 Global Circulation Models

The starting point for most regional climate projections is a climate simulation using a global circulation model (GCM) 6277, based on a specific greenhouse gas emission scenario. Climate in particular, refers to the entirety of weather phenomena during a quasi-stationary period. Based on past weather records, it was defined by WMO, that “climate” constitutes a time frame of 30 years and 1961-1990 was declared as being a climatological reference period for the recent past.

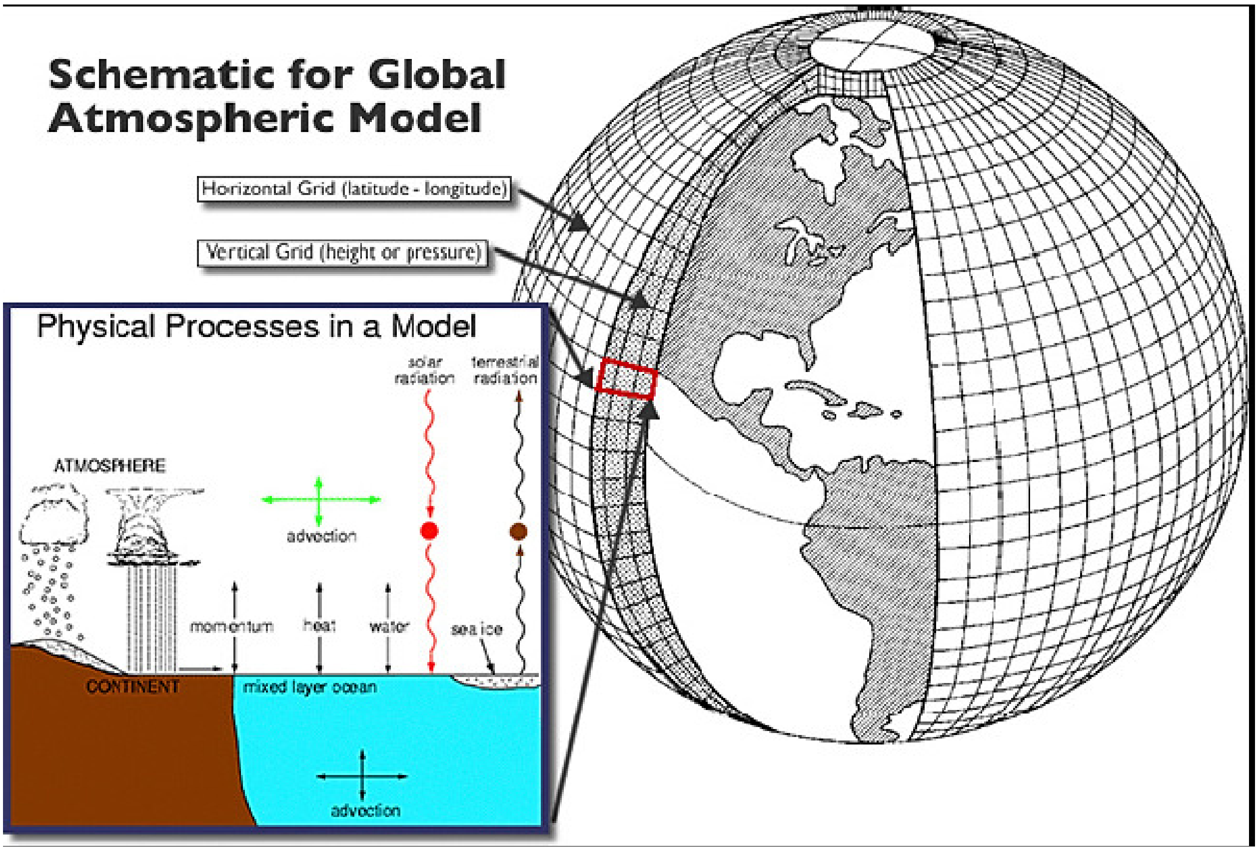

Figure 1: Schematic for Global Atmospheric Model

GCMs are numerical models that simulate the large-scale circulation of the atmosphere for the entire earth, based on physical laws, such as Newton’s equations of motion, the basic laws of thermodynamics etc. Since the ocean, vegetation and soil are particularly pertinent to the climate (as opposed to weather, where only changes on shorter time scales are considered), all these aspects need to be included in GCMs as specific components of the climate system. Today’s GCMs therefore constitute complete climate system models. Due to the complexity of the modelled processes and constraints of CPU power, GCMs typically manage to resolve the earth’s surface down to about 80 km to 500 km. The exact grid cell size depends on the mesh type chosen, as well as the position on earth. e.g., if a grid cell is chosen as fixed longitude/latitude size, grid cells at the equator will be larger in area than the ones close to the North Pole.

1.2 Scenarios

Another major factor in determining the outcome of a GCM simulation, is the scenario which is fed into the simulation. A scenario is an assumption of future greenhouse gas emissions. It is usually based on certain lines of development, with respect to economy and various types of governance and political actions, including adaptation and mitigation strategies.

Until the last (fourth) assessment report of the Intergovernmental Panel on Climate Change (IPCC), the so-called SRES (Special Report on Emission Scenarios) scenarios have become the de facto standard when assuming different futures of our planet. There are basically 4 scenario families: A1, A2, B1 and B2. The A scenarios refer to a mainly economically driven future, while the B scenarios assume a future that seriously takes environmental issues into account. Scenarios labelled 1, assume governance with a global point of view, whereas scenarios labelled 2, expect governance to be driven mainly by local interest. In some sense, B1 is the most desirable future with respect to the climate. A2 on the other hand is a worst case scenario. The IPCC further distinguishes scenarios for the A1 family: A1T (advanced technology, predominantly non-fossil fuel), A1B (balanced) and A1FI (fossil intensive). These are listed in order of increasing greenhouse gas emissions.

In the preface of the next IPCC assessment report, new scenarios are defined based on representative concentration pathways (RCP scenarios), accounting for new economic and political developments.

1.3 GCM Predictions for Africa

The outcome of 21 different GCMs for the climate on the African continent is shown in **Figure 2**. In particular, the figures indicate the temperature and precipitation projections based on scenario A1B, averaged for 2080 to 2099, and compared to the climatological mean for the years 1980-1999. The left column indicates annual averages, while the middle and right columns provide the averages over the December/January/February and June/July/August periods respectively. The top row indicates that, on average, the Orange-Senqu river basin is expected to deal with higher temperatures throughout the year. The middle row indicates that, on average, precipitation is expected to decrease. This effect is mainly due to a relatively strong decrease in precipitation in summer.

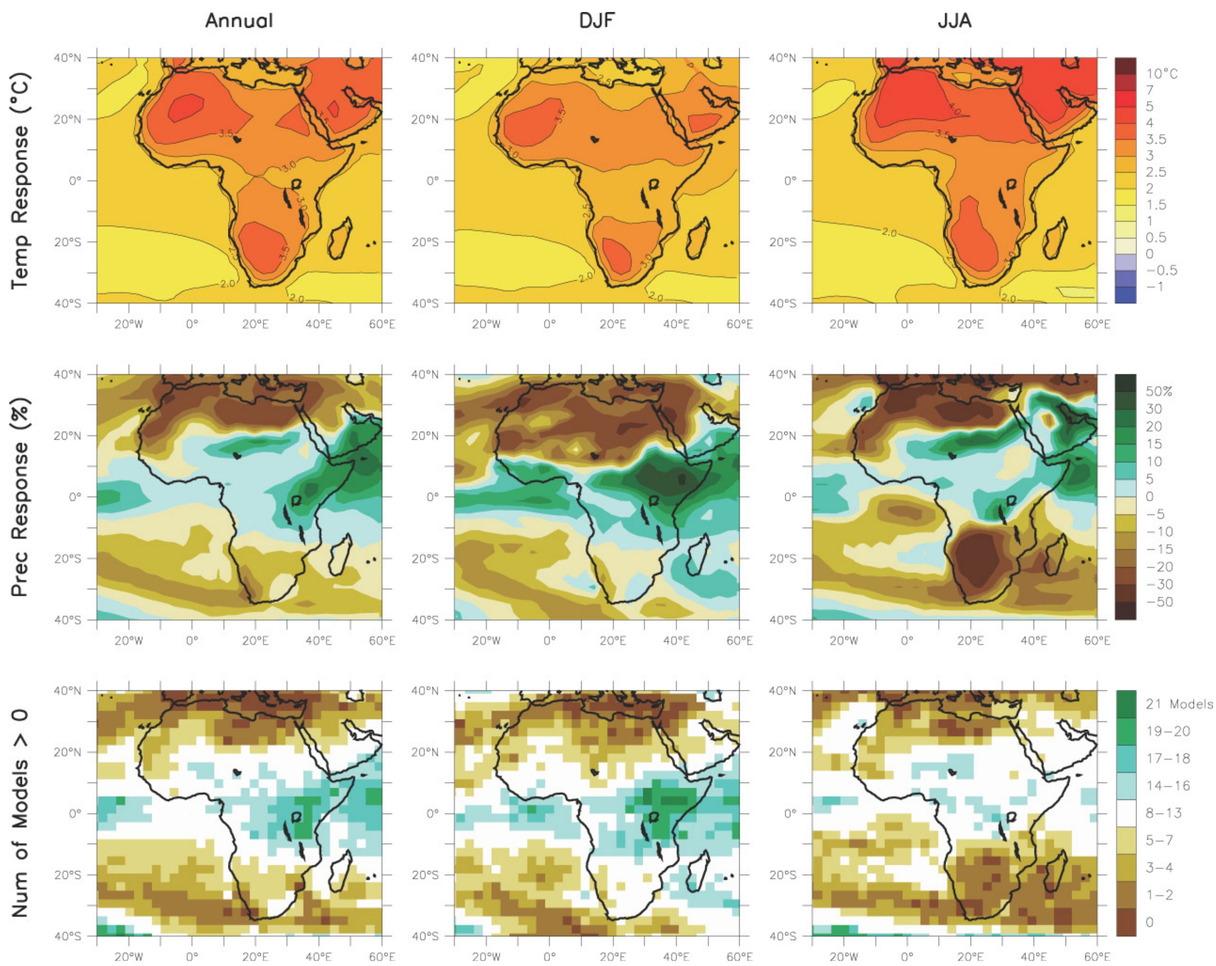

Figure 2: Predictions of Climate Change over the African Continent from 21 different GCMs. Average values for 2080-2099 compared to 1980-1999 (A1B Emissions scenarios)

When analysing the third row of **Figure 2**, it can be seen that all models predict a general decrease in precipitation in the Orange-Senqu River Basin in winter. On the other hand, in summer, there is no consistency between the GCMs in predicting if there will be an increase or decrease in precipitation in the Orange-Senqu region. This is particularly unfortunate since this is the season when most of the runoff feeding the Orange-Senqu region is generated.

2 DOWNSCALING

2.1 Overview

In our downscaling, we intend to employ the data generated by the GCM ECHAM-5/MPIOM. This model is developed at the Max-Planck Institute for Meteorology in Hamburg, Germany. It is one of the most prominent GCMs. We intend to downscale the ECHAM5 results based on the A1B IPCC emission scenario. In particular, we will downscale the ECHAM5 projections up to 2060.

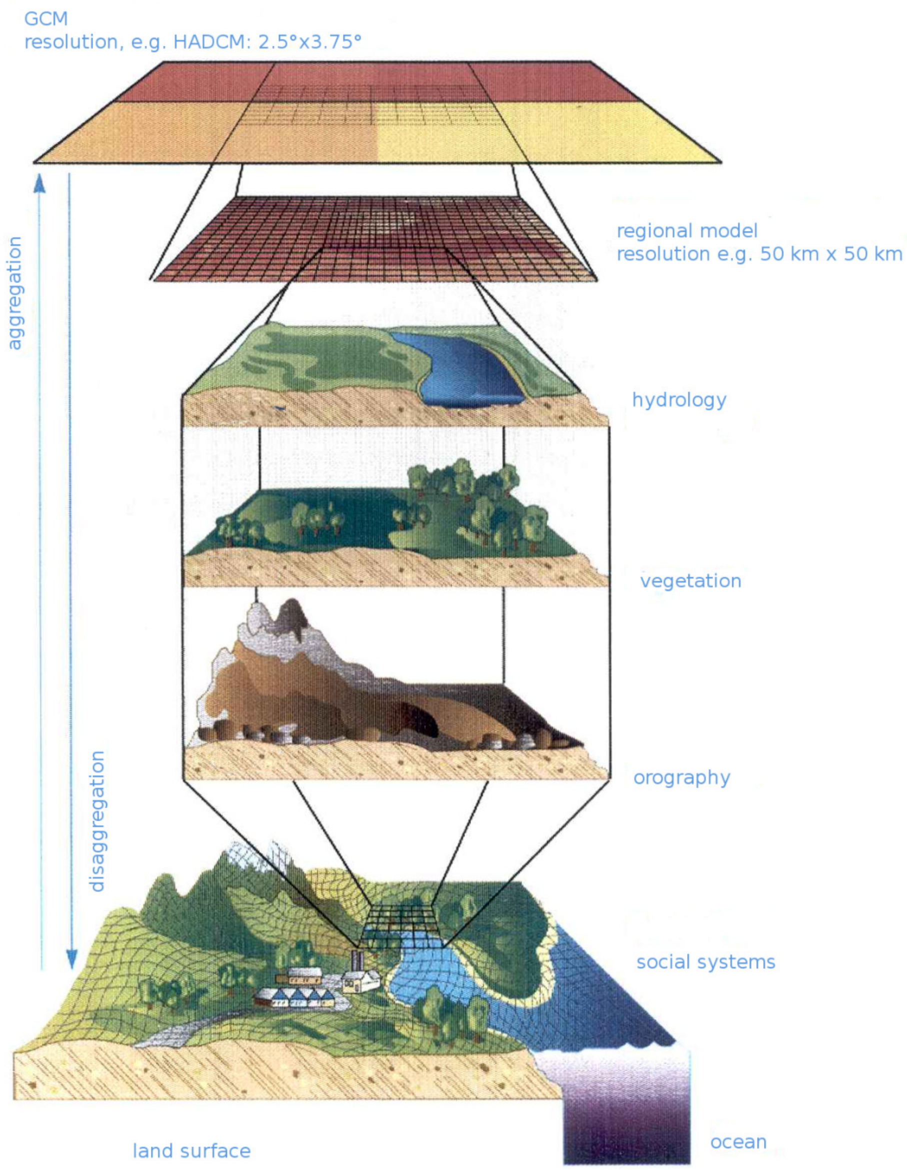

Figure 3: Downscaling; going from a coarse resolution Mapping of the World to a finely grained Model

Apart from the intrinsic errors of GCMs, as indicated by the partially contradicting results of the GCMs, the coarse resolution of the earth's surface renders their prediction useless for particular intents and purposes. The GCMs neglect the fine orographic structures or land use patterns specific to a particular region, in our case the Orange-Senqu basin. Other features not resolved by GCMs are, for instance, land-sea winds, cloud clusters, gust lines and cyclones. Figure 3 schematically depicts some features only apparent on the fine-scale. The breaking down of the large-scale GCM predictions to the mesoscale (20km – 2000km), is commonly referred to as “downscaling”. At the Potsdam Institute for Climate Impact Research (PIK), two complementary climate models are used to achieve this feat. One model is based on a statistical approach by re-sampling previous weather observations. This model is called statistical regional model (STAR). The second approach to downscaling is based on physical laws, commonly denoted as “dynamical downscaling”. The model employing this technique is named climate mode COSMO Lokalmodell (CCLM). It is intended to use both of these models to derive future climate predictions which can then be compered with each other to assess the areas of agreement and disagreement.

After having downscaled the future climate for a region covering the Orange-Senqu basin, future precipitation and temperature conditions, together with further meteorological drivers, are fed into a river model. At PIK the Soil Water Integrated Model (SWIM) is used. This is an ecohydrological model simulating the water and nutrition cycle and various land uses. It must be adjusted for the assessment of the Orange-Senqu river basin using information derived from land use maps, vegetations maps and soil maps. Combining this with future climate realizations by STAR/CCLM, yields a hydrograph for any point in the river desired. This can then be integrated with the available water resource management models, since the Orange-Senqu hydrograph is heavily influenced by the many dams located within the river basin (such as the Gariep Dam or the Vanderkloof Dam).

2.2 Statistical Downscaling using STAR II

STAR was developed to generate regional climate projections for the near future (for the next 50 – 60 years). It operates on the basis of taking a temperature trend, provided by the GCM for a particular region, such as the Orange-Senqu basin. It is not strictly necessary to use the temperature for the trend, and any available climatic variable, such as precipitation, can be used. Temperature is the most commonly used variable, and it is intended to use the temperature in the case of the Orange-Senqu river basin. Then weather observations from a previous time span (called “observation period”) are shuffled and randomly drawn to assemble a future weather timeline. These timelines are then subject to a distance function, which measures how accurately the prescribed (temperature) trend has been met. If the distance is too large, the generated timeline of weather events is simply discarded. In practice, various means are used to improve timelines and reduce the distance from the prescribed trend, but if these fail, the generated climate is still discarded. Effectively, this is a Monte Carlo approach in which the generated climates then include predictions for climate variables previously measured.

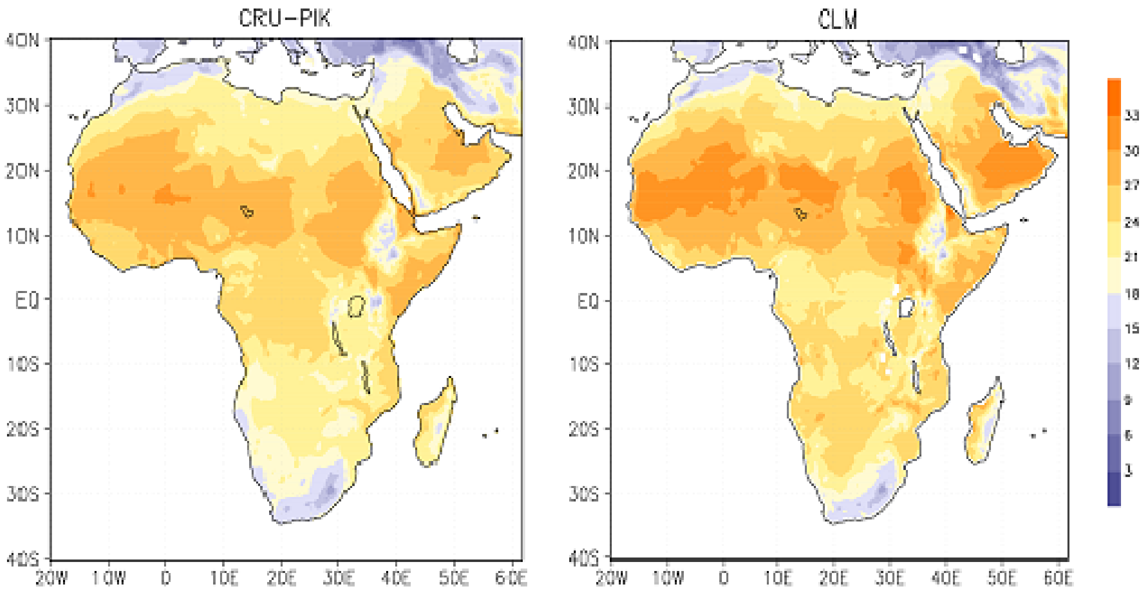

Figure 4: Results of a validation Run for CCLM (1970-1999)

In **Figure 4** the temperature (at 2m elevation) is shown. On the left the observations data (CRU-PIK) is plotted while the right side displays the simulation results.

2.3 Dynamic Downscaling using CCLM

The second approach to climate modelling, dynamic downscaling, as used in CCLM, is similar to the one used in GCMs. Here we again use physical laws. In particular, CCLM is based on Newton's second law, the continuity equation (matter is neither destroyed nor created), on energy conservation and on the laws of an ideal gas. In contrast to a GCM, however, these equations are applied over a smaller area at a higher resolution which should typically be in the order of no larger than blocks of up to a few thousand km on each side. Therefore, dynamical regional climate models are also named LAMs (Limited Area Models). Current supercomputers allow for grid cell sizes of a few kilometers. This high resolution requires detailed assumptions on the future state of soil, vegetation/land use and orography. With all these issues in place, the CCLM can then be applied at the (lateral) boundaries, with input from the GCM for the time period in question. **Figures 4 and 5** show the results of CCLM validation runs for the temperature and the precipitation respectively.

2.4 Comparison of the two Downscaling Approaches

As stated previously, the statistical and the dynamical approach are complementary to each other. Each has its own distinct advantages and disadvantages. STAR works by reshuffling observations from the past. This also means, that only locations where an observation station exists, can be provided with a future climate realization. Also, only weather variables for which previous observations exist, can be predicted. Considering that the ultimate reason for generating a climate realization is to drive the hydrological model SWIM, the observed data matching the required input for SWIM is used. In particular, observations of precipitation, radiation, relative humidity, as well as the daily average, maximal and minimal temperature are normally used in the analyses. The dynamic modelling approach using the CCLM, allows for predicting arbitrary variables at any desired location, since the atmospheric processes themselves are taking place inside the model. It should be noted, however that, the statistical approach to climate modelling consistently outperforms dynamic climate modelling. Nevertheless, this conclusion should be treated with caution, as the validation periods for the models lie in the past, and a basic assumption in statistical climate modelling, is that large scale circulation pattern will largely remain the same as in the past. This can be viewed as an advantage, if the future climate is unlikely to deviate significantly from current conditions but may be a problem if the climate should change profoundly.

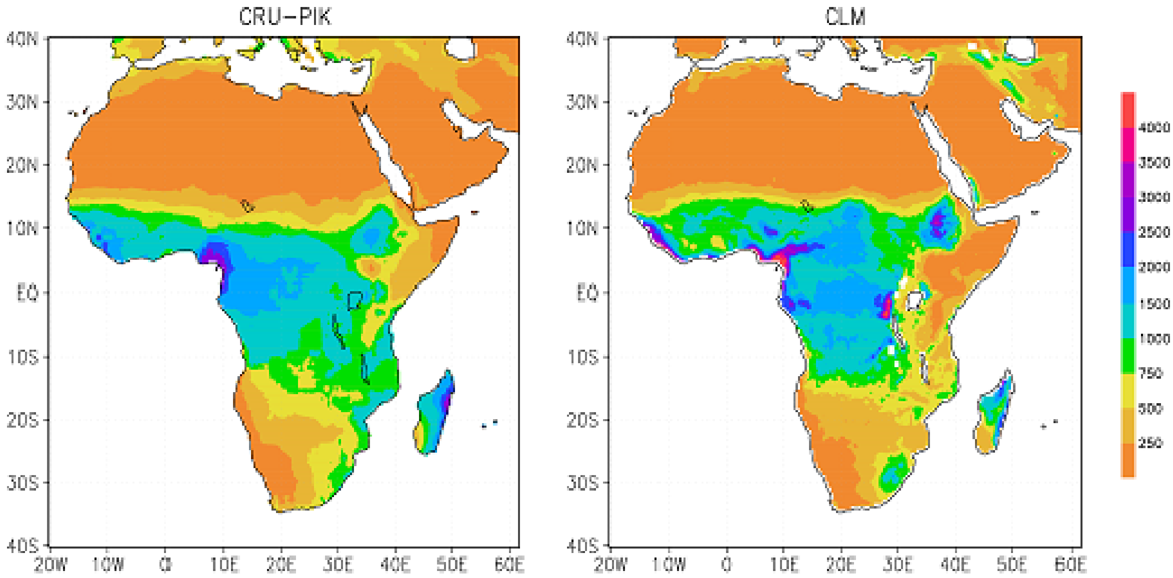

Figure 5: Results of a precipitation Validation Run for CCLM (1979-1999)

Figure 5 presents the results of a validation run for CCLM averaged over the years 1970 to 1999. In this figure, precipitation is displayed. Again, the left plot shows the observation, while the right-hand plot depicts the CCLM simulation results.

Another major difference between STAR and CCLM, is the required processing power. Whereas STAR can be run on a standard PC, running CCLM requires a tremendous amount of CPU effort. PIK's supercomputer (currently #389 in the top500 in the world) will therefore be used to model the future climate in the Orange-Senqu river basin. The difference in required computing power, as well as the Monte Carlo nature of the climate simulation, allows STAR to produce an ensemble of future climate realizations, typically around a few hundred. This provides all the advantages usually associated to an ensemble, such as a measurement of uncertainty and a high probability of a realistic spread in the results.

Furthermore, running CCLM requires detailed vegetation and soil maps, while STAR is free from such requirements. In the case of the Orange-Senqu assessment these data are also already required for SWIM in any case with the result that this is not a serious disadvantage.

In summary, STAR will be used as the key model for generating ensembles of future climate realizations, which will then be complemented by CCLM results, in order to fill apparent gaps and holes.

3 MODELLING OF IMPACTS

After having generated an ensemble of future climate realizations, which will be the most work-intensive part of WP4, we will then feed the results to SWIM.

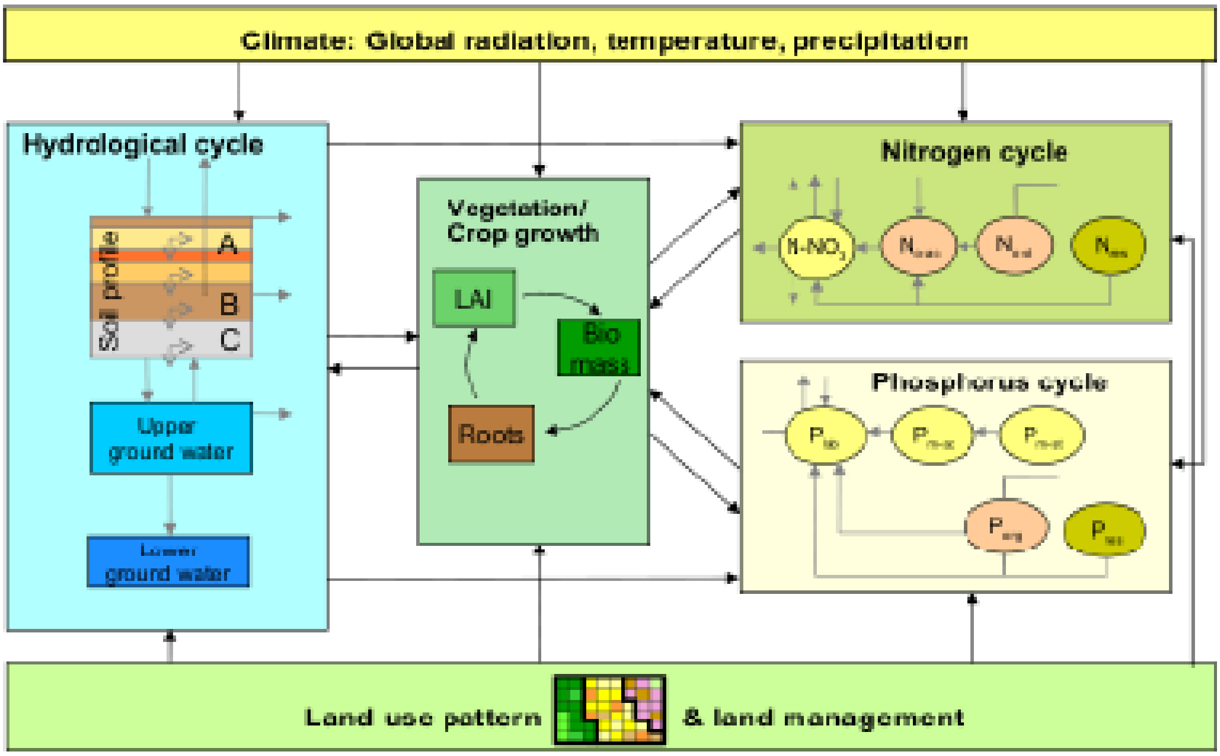

Figure 6: Scematic showing the Workings of the SWIM Model

The results (precipitation, temperature and radiation data) of the downscaling (regional climate model) will be used to drive the ecohydrological model SWIM. SWIM integrates hydrology, vegetation, erosion and nutrient dynamics at the watershed scale. In particular, SWIM features:

- a detailed mapping of the most relevant hydrological processes;
- a phosphorus, nitrogen and carbon cycle;
- a detailed crop model; and
- a land use/land management model.

Figure 6 provides a schematic overview of the main SWIM modules.

As SWIM requires minor alterations for the specifics of the Orange-Senqu river basin, a natural annual hydrograph will also be required. This may pose some difficulty, due to the fact that the Orange-Senqu is already heavily managed and used for irrigation and mining, in addition to the numerous inter-basin transfers. Fortunately the basin has already been modelled using highly sophisticated water resource models developed over a period of more than 20 years. The water resource models have been used to create natural hydrology at many points within the river basin and therefore the availability of a natural flow record at the river mouth should pose no serious problem or delay. After obtaining the natural hydrograph, the SWIM can be calibrated for the Orange-Senqu, which, in turn will enable an ensemble of runoffs and hydrographs to be generated, providing expected averages and uncertainties.

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