WCRP REPORT

World Climate Research Programme

Climate Observations and Regional Modeling in Support of Climate Risk Management and Sustainable Development[1]

Report of Workshop 2: Regional modeling for the GHA region

21-25 February 2011, Nairobi, Kenya

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GFDRR Global Facility for Disaster Reduction and Recovery

THE WORLD BANK Working for a World Free of Poverty

GCOS GLOBAL CLIMATE OBSERVING SYSTEM

IGAD CLIMATE PREDICTION AND APPLICATIONS CENTRE ICPAC

World Meteorological Organization Weather • Climate • Water

[1] Supported under World Bank/GFDRR Project (Grant No. TF092496)

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1. Background

Reliable and detailed regional climate information, including current and future assessments of climate variability and change, is essential in the design of effective strategies for managing risks and adapting to climate variability and change. Such information critically depends on the availability of good quality climate observations with sufficient spatial coverage over an extended period of time, on the adequacy of climate predictions from numerical models to depict current and future regional climate, and on a thorough understanding and appreciation of the uncertainties and constraints associated with the use of both data and regional and global models.

1.1 Project Description

To assist the developing and least developed countries of the Greater Horn of Africa (GHA) region to undertake and appropriately use climate projections in climate risk management and adaptation planning, the World Climate Research Programme (WCRP), the Global Climate Observing System (GCOS), the World Meteorological Organization (WMO) and the World Bank, along with the Nairobi-based IGAD (Inter-Governmental Authority on Development) Climate Prediction and Applications Center (ICPAC) are collaborating to develop and implement a programme of three linked workshops to demonstrate the key elements of an effective climate risk management strategy for the GHA region. The overall objectives of the workshop programme are to:

- Help ensure that attention is given by countries in the GHA region to observation and data needs,
- Demonstrate the use and value of regional models and provide advice on model limitations,
- Improve capabilities across the GHA for using data records and model projections for adaptation planning, in particular for the agriculture/food security and water resources sectors,
- Involve decision makers with the climate experts to facilitate the inclusion of climate information into national, regional, and local planning processes, as well as within economic sectors (i.e., "Begin mainstreaming now", and.
- Develop an initial set of "best practices" for the overall processes of developing climate indices and of 'downscaling' global climate predictions to provide reliable data on the future climatic conditions over the regional, national and local areas.

The ten ICPAC countries of the Greater Horn of Africa (i.e. Burundi, Djibouti, Ethiopia, Eritrea, Kenya, Rwanda, Somalia, Sudan, Tanzania, and Uganda) are participating in the project (Figure 1).

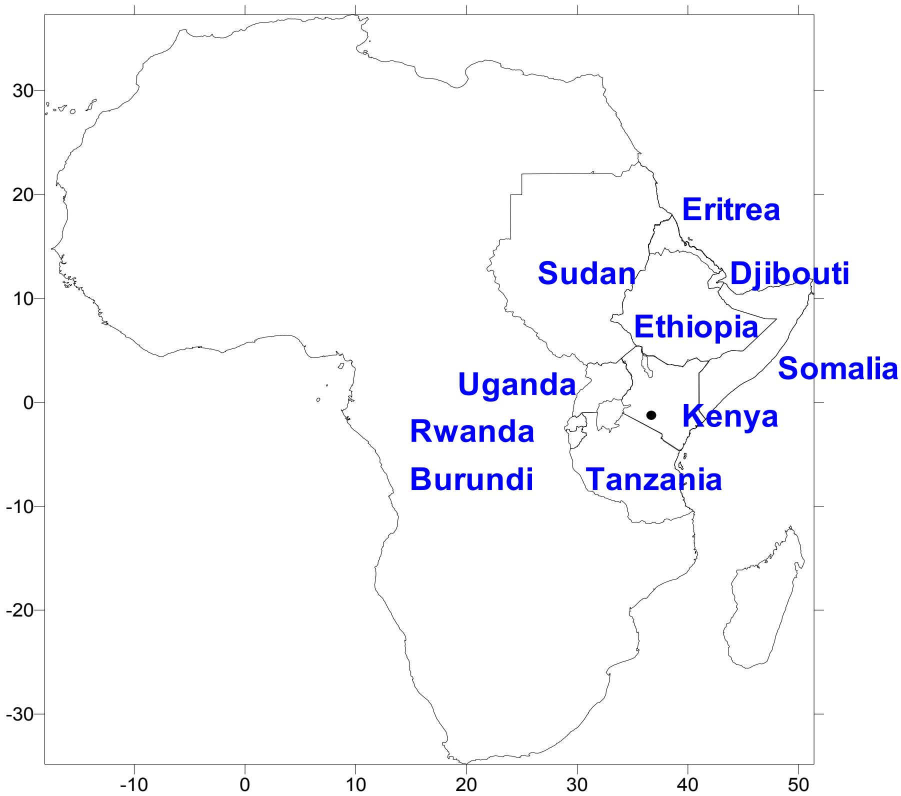

Figure 1: Participating ICPAC countries of the Greater Horn of Africa

The overall programme consists of three interrelated workshops that focus on (i) developing a process to produce quality controlled national data sets and regional climate indices based on national meteorological station data for temperature and rainfall; (ii) utilizing this data and other analyses (e.g., using satellite observations) to compare with regional model predictions (or projections) of future climatic conditions over regional, national, and local areas (i.e., validate the predictions of past climate in the model), and (iii) demonstrating how climate data can be utilized within regional, national, local planning processes, in particular for benefiting the agriculture/food security and water resources sectors.

2. Implementation of the Second Workshop

The Second Workshop of GFDRR integrated project was held from 21-25 February 2011 at ICPAC in Nairobi Kenya. The agenda, given in Annex 1, shows a mixture of briefing on a range of topics related to regional modeling and projecting future changes in climate conditions (i.e., constructing climate change scenarios). There were 19 participants from the GHA countries who worked directly on the data, while a total of 40 including facilitators were at the workshop on regional modeling (see the listing of attendees in Annex 2). The specific objectives of this workshop, focusing on regional modeling, were to:

- Evaluate the baseline simulations of the regional climate model representing the current climate, through comparison with the observations and reanalysis-based results from the first workshop. Also use the same models to make one or more projections of future climate in the region for a time period of interest for adaptation;
- Provide the participants with hands-on training in data processing and in analyzing regional model output to enable them to complete such analyses in the future within their countries;

- By using the results obtained by these sample climate projection(s), familiarize workshop participants with the additional steps that would be needed to undertake further analysis after the workshop (e.g., to develop improved estimates of uncertainty); and
- Make the participants aware of both the benefits and limitations in using and interpreting regional model simulations in climate applications.

2.1 Opening Plenary

Professor Laban Ogallo, ICPAC Director, opened the workshop, held at the ICPAC Auditorium/Training Room, by noting the uniqueness of this project, which links observations, modeling and application to user needs into a single integrated programme. He thanked the World Bank's Global Fund for Disaster Risk Reduction (GFDRR) for its pioneering support for the project and noted the support for the workshop from local partners and workshop staff (get list) and the strong participation by:

- Dr. Fred Semazzi (North Carolina State University) – Chair of the Project Advisory Group (PAG)
- Dr. Joseph Instiful (UNDP African Adaptation Programme) – Lead Scientist for the Second Workshop
- Drs. John Caesar, Winfried Moufouma-Okia, Erasmo Buonomo – Climate scientists from the UK Met Office
- Dr. Ogallo then requested some opening comments by key participants:
- Mr. Carl Dingel, representing the World Bank's GFDRR, stressed the effects of disasters on African economies (e.g., Malawi) and the importance of climate related risk reduction
- Ms. Valery Detemmerman, as the WMO project manager from the World Climate Research Program, emphasized the critical role of using both modeling and observations in making climate change projections;
- Ms Stella Aura, Principal, Institute of Meteorological Training and Research Kenya Met Department, who welcomed and extended the hospitality of the KMA to the participants;

In setting the tone for the workshop, Dr. Ogallo reviewed the aims of the project to "support sector specific applications to reduce risks associated with climate variability and change for poverty alleviation, environmental management and sustainable development" and emphasized the highly variable climate over the GHA region. He stressed the importance of understanding and applying climate data and information to assist the countries of the GHA in dealing with the stresses from climate variability and change in the region. Without use of climate information to understand climate effects, economic investments are not likely to achieve their anticipated benefits. This project will assist countries in meeting their development goals by developing the tools to analyze the effects of future climate conditions on economic and societal activities with attention to agriculture and water.

He then noted that the third workshop in Arusha, Tanzania from 1-4 March 2011 will bring together users and providers to examine the usefulness of the outputs of the first workshop on observations (April 2010) and this second workshop on regional modeling in assessing the impacts of climate on economic activities. He opined that without good data, it will be difficult, if not impossible, to analyze the impacts of climate on economies and societies. Finally he noted the regional data challenges (e.g., as assessed in the GCOS Regional Action Plan for eastern and southern Africa (Oct 2001)) and several current opportunities to improve the regional situation (e.g., use and calibration of satellite data (AMESH)).

2.2 Workshop Perspectives

2.2.1 Impacts and vulnerability of climate change in Africa

Dr. Christopher Oludhe (University of Nairobi) provided a perspective on climatic factors in the GHA region by reviewing the "Indicators of Climate Change". Some climate signals that are becoming apparent in the GHA region, include (1) rising temperatures; (2) decreasing trends in rainfall; (3) melting and retreating mountain glaciers; and (4) increasing frequency of extreme climate events, such as ENSO events and the occurrence of droughts and floods;

These climate signals have been associated with observed impacts, such as (1) rising sea level; (2) resurgences of some diseases; (3) river flows becoming more seasonal or disappearing altogether; (4) decreasing lake levels and areal extent; and (5) shifts in seasonal rainfall.

Dr. Oludhe concluded that since the potential impacts from climate change may undermine and even, undo progress made in improving the socio-economic well-being of many African countries, reducing the risks associated with the current climate variability and extremes is a critical step in adapting to future changes in climate.

Since climatic conditions are regional in extent, a regional perspective is essential if individual countries are to make informed national decisions on disaster risk management and adaption to changing climate conditions. The application of regional models to climate change analysis and projection is a key link between the analysis of the observations and data available in the GHA countries and their application to needs of policy and sectoral users. The techniques discussed in this workshop also offers a unique way to test the adequacy of the regional (and thus the national) climate data bases and to identify the primary gaps in existing data sets and related observing systems. It is hoped that action by the governments and users more generally can be taken to remedy these shortcomings.

A driving force behind these efforts to apply climate data and models to inform policy and economic decisions in the GHA region can be seen in Figure 1 below which shows that the GDP of four countries (Kenya, Uganda, Tanzania and Ethiopia), are highly dependent on the crop yield within their country and thus on the seasonal rainfall for their rain-fed agriculture.

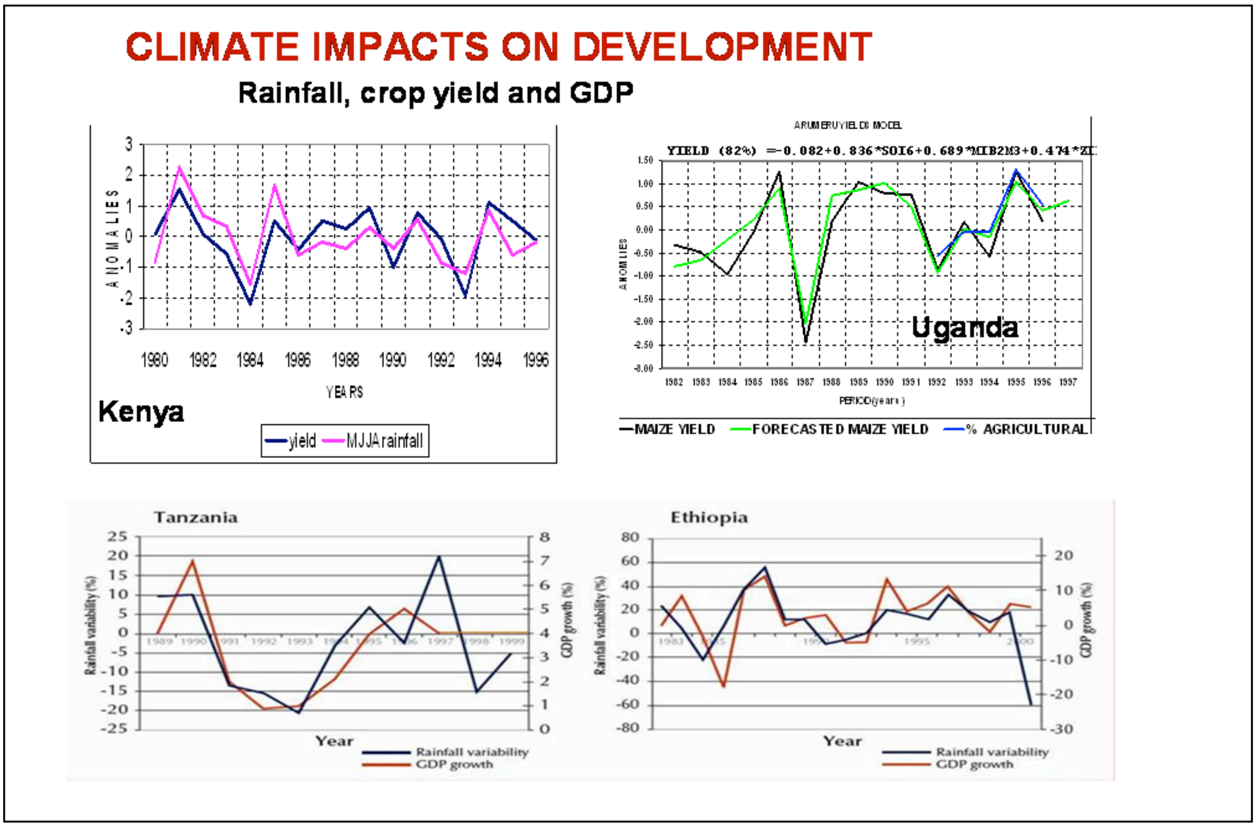

Figure 1: Shows strong correlations between rainfall (climate) and crop yield or GDP for four GHA countries (Kenya, Uganda, Tanzania, and Ethiopia.

2.2.2 Participants' perspectives of the workshops

The participants were asked to write down their expectations on what information and techniques they wished to gain from the workshop. Their comments are summarized in Annex 3. Also the participants completed a questionnaire after the workshop in order to assess what was accomplished and what follow-up activities might be needed as well to ascertain what lessons could be learned for future use. A section of conclusions, recommendations, and lessons learned is included in a final section of this report.

The participants had an overall positive view of the workshops 1 & 2 especially with the quality of the presentations and the basic support (computers, software, etc.). However, they had a number of recommendations for improvements, including the need for:

- More time at workshops 1 & 2 (or back-to-back workshops) to use the software and to master the analysis techniques;
- Follow-up workshops (and training) to master skills and sustain capacity building,
- Continuity of participants throughout the 3 workshop project;
- Regional support through ICPAC and UNDP AAP for assistance in developing and interpreting indices and model outputs.

3. Constructing Climate Change Scenarios

To assist in the development of adaptation analyses and response plans, government policies and sectoral decisions will need to be informed on future climate conditions and how they might impact economic sectors, societal activities, and national well-being security. To define or to project these future climate conditions will require that climate change scenarios that consider not only the climate system, but also global economic, demographic, societal and environmental conditions as well as the needs of users to adapt to changed conditions.

a. The process of constructing climate change scenarios for use in analyzing the impacts of future climate conditions can be visualized as a multi-staged process, as shown below. At each stage, uncertainties are introduced so that the uncertainty in the outputs from one stage becomes an uncertainty in the input to the next stage. Thus in this 5 stage process there is a cascade of uncertainties that must be carefully analyzed and used carefully in using these climate change scenarios. The participants received a briefing on the "uncertainties in the development of climate scenarios" from Dr. E. Buonomo, which is summarized in section 3.4 (f) below.

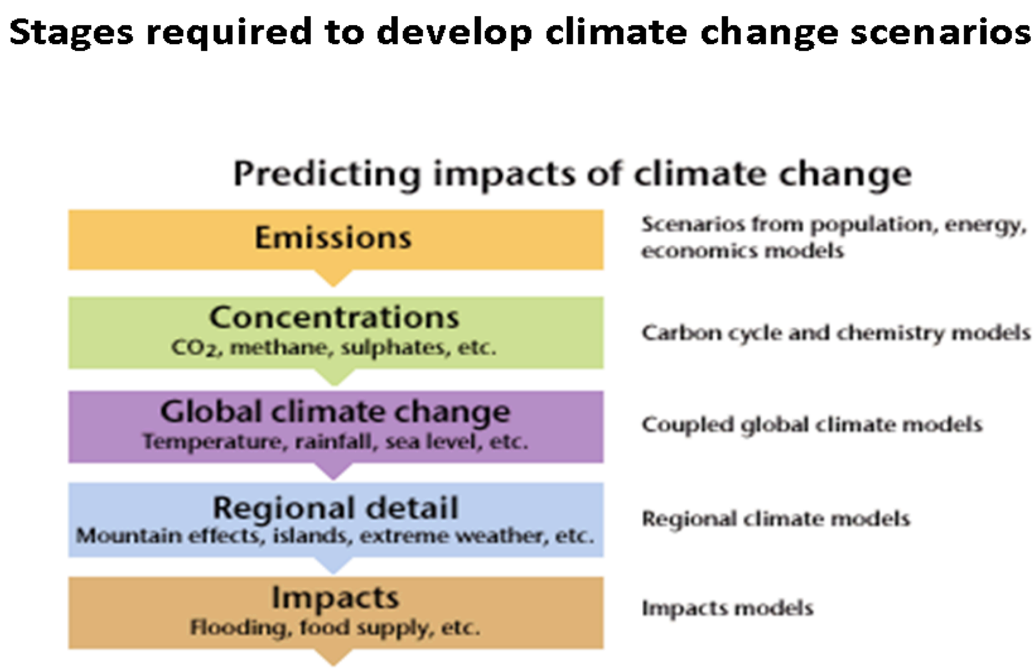

Figure 2: Conceptual Model for Constructing Climate Change Scenarios.

The workshop presented the participants from the GHA countries with a series of lessons and hands-on training exercises (discussed in section 4) that addressed the 5 stages of the conceptual model above. The greatest emphasis in the workshop was placed on the last 2 stages, since these were the focus of the training and hands-on exercises for the participants and their professional development.

3.1 Emission scenarios

"A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold." Prof. R Odingo (University of Nairobi) discussed the "Concept of Climate Change Scenarios", which project future conditions, either as "business as usual" or as a future that accounts for potential global actions to change future conditions. Scenarios are developed as a function of socioeconomic conditions, such as population (growth), energy availability and efficiency of use, rate of development globally, etc. and consider other socioeconomic data sources, such as global GDP, income ratios between countries. The IPCC gas uses SRES[2] climate scenarios that show a 25-90% increase of GHG emissions in 2030 relative to 2000. Thus emissions are continuing to grow despite the proposed mitigation actions under the UNFCCC and will lead to at least a 2 deg C rise in global temp by 2100. Risks to the environment and economies will increase.

In the IPCC assessment process, the SRES scenarios have been used particularly for analyzing options for the mitigation of climate change, e.g., in reducing emissions directly or in actions related to limiting deforestation and encouraging reforestation. Under UNFCCC, non Annex 1[3] countries are not required to mitigate their greenhouse emissions. However, Prof. Odingo stressed that common sense mitigation should be undertaken if there are some economic and policy advantages, e.g., opportunities for carbon trading and CDM[4] projects. He discussed a number of ways to reduce emissions, including energy efficiency, renewable energy, energy self sufficient buildings, more efficient means of transport (e.g., modal shifts in commuting, more efficient vehicles) in light of the growing energy use in Africa (9% per year). Finally he stressed the co-benefits of mitigation, such as health improvements due to reduced air pollution.

3.2 Concentrations of atmospheric constituents

Once the scenarios are defined, the atmospheric concentrations of CO2, CH4 and N2O resulting from the six SRES scenarios can be computed with current methodology. Using carbon cycle and chemistry models, the atmospheric radiative forcing can be determined for use in the global climate models to project their effect on future climate conditions. These carbon cycle / chemistry models, due to their imperfect physics and other processes, produce a number of uncertainties in converting emissions to concentrations. By coupling a carbon cycle-chemistry module to an atmospheric-ocean GCM some of the uncertainties can be reduced through the internal feedback in the model, e.g., interaction between water vapour and the concentration of chemical species or the feedback between biosphere and atmospheric climate changes.

The UK Met Office's Hadley Centre model accounts for these feedbacks to reduce the uncertainty in the conversion of emissions to concentrations, though the overall uncertainty in calculating concentrations from emission scenarios is large. The net effect of land and ocean climate feedbacks as indicated by models is to further increase projected atmospheric CO2 concentrations by reducing both the ocean and land uptake of CO2.

[2] The Special Report on Emissions Scenarios (SRES) was commissioned by IPCC to provide a new set of scenarios for use in the Third Assessment Report. These are referred to as the IS92 scenarios.

[3] The UNFCCC defines 42 countries as Annex 1 Parties while the remaining countries are referred to as non-Annex 1 Parties.

[4] The CDM or clean development mechanism allows emission-reduction projects in developing countries to earn certified emission reduction credits, which can be traded and sold to industrialized countries to a meet a part of their emission reduction targets under the Kyoto Protocol. The CDM is the main source of income for the UNFCCC Adaptation Fund, which finances adaptation projects in developing country Parties to the Kyoto Protocol that are particularly vulnerable to the adverse effects of climate change.

3.3 Global Models (and Regional Models)

Climate change scenarios must be constructed to provide the "best possible" definition of future conditions as well as the uncertainties associated with these projected conditions. This will require high quality climate and other related observations in adequate numbers and the development and application of validated climate modeling systems with sufficient resolution to project current climate conditions into the future. Currently these modeling systems consist of:

- Global climate models (GCMs) – Currently these models tend to be coupled atmospheric-ocean models (AOGCMs) with a fixed (or time varying) land surface boundary and a defined initial state for the atmosphere and ocean.
- Regional climate models (RCMs) are limited area models with largely the same internal physics but have greater spatial resolution that can better define climate conditions at the regional to local levels to meet the needs of users.

Global climate models (GCMs) calculate the future evolution of the climate system in response to the internal natural variability of the climate system as well as the influence of human activities on the atmosphere, ocean, and terrestrial environment. Currently most global models do not have fine enough areal resolution to allow for the comparison of model outputs with observational data sets and/or climate indices. However global models are essential to calculate the future changes in the global environment due to changes in global forcing (e.g., from increasing GHG and changes in cloud processes). These models then serve to determine the boundary conditions for regional models.

3.4 Regional Details: Regional Climate Models and Regional Data

There are a number of regional models that have been developed worldwide, but this project will utilize the regional model called PRECIS (for **P**roviding **RE**gional **C**limates for **I**mpact **S**tudies), which has been developed and tested by the UK Met Office. As an introduction, Dr. W. Moufouma-Okia stressed that PRECIS can provide detailed projections of future climate conditions over any regional area of the globe with estimates of uncertainty due both to different emission scenarios and to climate variability. PRECIS output consists of hourly and daily data as well as longer timescale averages for the atmosphere and land-surface with 50 kilometre resolution (25km for small areas).

PRECIS was developed to assist Annex 1 Parties to meet the UNFCCC requirement to assess national vulnerability and report on their plans for adaptation in their National Communications. Determining vulnerability to, and the economic and societal impacts from, climate change requires the development of detailed scenarios of future climate that PRECIS can provide. Further the UNFCCC requires Annex 1 parties to assist developing and least developed economies in capacity building and technology transfer, which was one of the motivations in developing PRECIS.

PRECIS was selected for use in this project because it is a physically-based and computationally accessible regional climate model for downscaling GCM projections and because of the long experience of the UK Met Office in developing this model and associated training modules for capacity building. The model can be run on a PC with driving data supplied on a DVD and set up by the users to run over a particular region, in this case, the GHA, thus providing them with the capacity to locally construct scenarios of climate change. They then will be able to conduct useful vulnerability and adaptation studies and climate research within their countries.

The workshop further provided the participants with detailed information on the following topics[5]

a. Downscaling Techniques and Regional Climate Modeling – E. Buonomo

Since current GCMs do not provide adequate local detail, downscaling techniques are used to derive fine scale (local) details from GCM output. Assessing vulnerability and impacts of climate change require such fine scale information to account for local and regional details like mountains or water

[5] See full briefings on the WCRP home page at (http://backup.wcrp-climate.org/GFDRR/)

bodies. Several downscaling techniques (e.g., statistical methods, regional models) are available, but they each have their own strengths and weaknesses.

- Statistical methods – derive a function from past statistical relationships between observations of fine-scale conditions and large scale variables and then use this function to adjust future GCM projections to estimate the fine scale or local conditions, e.g., for temperatures or rainfall. The major weakness is that these methods cannot account for possible systematic future changes in regional forcing conditions or feedbacks and thus it is difficult to assess the uncertainty in the projections.
- Regional climate model (RCMs) – are driven at the boundaries by GCM output or observed data at the lateral (side) boundaries by wind, temperature, water, pressure, and aerosols data and at the bottom by sea and land surface conditions. The strengths of RCMs are that they provide more realistic simulations of climate conditions, more geographic details, and simulate climate extremes (e.g., heavy rainfalls and storm systems) more realistically, while the weakness is that they are highly dependent on their boundary conditions which may not be satisfactorily consistent with GCM output and cannot exist without them.

PRECIS is a physically-based and computationally accessible regional climate model for downscaling GCM projections'

b. <u>Data Storage System, Model Output & Analysis Tools</u> – E. Buonomo

The presentation provided technical guidance on how to run PRECIS, such as data locations, STASH[6] codes, file naming convention, and analysis utilities that used to convert model data formats to other more useful formats[7] for analysis. Possible utilities include **GrADs**, **Ferret** and **CDAT**. See full presentation (footnote 2) for more information.

c. <u>Coordinated Regional Downscaling Experiment (CORDEX)</u> – W. Moufouma-Okia

CORDEX (for **Co**ordinated **R**egional **D**ownscaling **Ex**periment) is a WCRP-sponsored activity to provide an ensemble of coordinated Regional Climate Scenarios for 1950-2100 and to make this data available at worldwide archives and useable to users through a common diagnostic set and format. CORDEX will provide a framework for coordinating and testing regional climate models and downscaling techniques for the recent past and future scenarios while encouraging participation in developing countries. This effort will provide simulation data to support the IPCC AR5 for many land-regions of the globe. Africa will be an initial focus for constructing future climate scenarios for use in IPCC AR5 assessments. Investigating the uncertainty in downscaling techniques will be another area of emphasis for CORDEX.

For the user, CORDEX has developed a framework for making results freely available for subsequent access and use, including an initial CORDEX archive at Danish Meteorological Institute and an Africa diagnostic & evaluation panel, led by the University of Cape Town.

d. <u>Evaluating Regional Climate Models</u> – E. Buonomo

Dr. Buonomo emphasized the importance of assessing how closely a model is able to simulate the present-day, observed climate. Such an assessment would lead to a familiarity with the model characteristics and an understanding of the most credible aspects of the model simulation. This then indicates how to make the best use of the model output in analyzing climate vulnerability, impacts and adaptation strategies. He noted that the types of uncertainties in the output of the model arise from systematic model bias (i.e., errors in the model's physical formulation), spatial sampling issues (e.g., differences in resolution of model and observations) and observational errors (e.g., missing or inaccurate data, instrument errors).

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[6] Each variable (e.g., temperature, precipitation) has a 5-digit STASH code.

[7] Formats such as NetCDF format and ArcInfo ascii (e.g. for GIS/spreadsheets).

Models can be assessed in 4 ways: (1) GCM vs. observations; (2) RCM, driven by GCM vs. GCM; (3) RCM, driven by GCM vs. observations: and (4) RCM, driven by observations vs. observations. However, it was stressed that individual model years cannot be directly compared with their corresponding observed years, since a models response to external forcing (e.g. SST, CO2) will not match that of the real atmosphere, except possibly when using observed lateral boundary conditions which are an additional constraint to reality. When using observations it is important to use as many as datasets as possible for validating the regional model (e.g., station data and gridded datasets, such as CRU[8] for land surface, ERA40[9] for the atmosphere.

e. Uncertainties in the Development of Climate Scenarios – E. Buonomo

This session was aimed at understanding the cascade of uncertainties through the process of constructing climate change scenarios, providing detail on the uncertainties in emissions scenarios (see section 3.2), and providing detail on the uncertainties in regional climate change predictions. Areas of significant uncertainty include:

- Incorrect or incomplete description of key processes and feedbacks in the climate system e.g., representation of clouds, complexity of sea-ice model. and feedback from land-use change and
- Internal (natural) variability of the climate system within the model.

Climate change scenarios for impacts studies can be derived by combining climate model and observed data or by using climate model data directly.

f. Climate Scenario Construction for Impacts Assessment – J. Intsiful/ E. Obuobie

A scenario was defined in section 3.1 earlier. There are many types of scenarios, such as incremental scenarios for climate sensitivity studies, analogue scenarios and climate models output scenarios. Analogue scenarios are based on past recorded climate regimes (e.g., palaeoclimatic analogues) which may resemble the future climate in a given region. Downscaled climate model scenarios are the most commonly used.

In using downscaled climate models with impact models, it is necessary to establish a baseline scenario, e.g., by running an impact model with baseline (current) climate information from a climate model or from observations. An example was shown where a climate model was used with a runoff impact model to calculate the water balance. Two ways were discussed on how to calculate the water balance in the future. The simplest conceptually was to use the climate model to project future conditions and then use these conditions as input to a water balance model. The second method, used particularly when systematic errors in a climate model are large, is to calculate a model change factor based on the difference of the climate model output in the future compared to the baseline climate model output. Then this change factor is applied to the baseline impact model output to calculate the future impact model result. The role of the climate model is to provide climate scenarios which are plausible and self consistent. For all method of climate scenario construction, a further uncertainty is added in assessing impacts of climate change

g. A Regional Approach to Climate Change Analysis – J. Caesar

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8 Climate Research Unit at the UK University if east Anglia

9 ERA40 is a project at the European Center for Medium Range Weather Forecasts (ECMWF) to reanalyze data for the period from mid-1957 to 2001 with the purpose of promoting the use of global analyses of the state of the atmosphere, land and surface conditions over the period. The analysis used satellite data, starting in 1972 and cloud motion winds from 1979 onwards. It further used data from past research experiments such as the 1974 Atlantic Tropical Experiment of the Global Atmospheric Research Program and the more recent 1992-1993 TOGA-COARE. ERA-40 provides a means for studying longer term trends and fluctuations such as El Nino / La Nina.

Dr. Caesar summarized the background on the development of climate indices and the Rclimdex software[10], noting that "*better knowledge of climate change requires a knowledge of climate extremes derived from daily data".* Regional workshops to prepare sets of regional indices were motivated by the need to provide better regional data for the IPCC forth Assessment Report in light of the reluctance of many countries to share their climate data.

The first workshop in this project was a proven mixture of seminars, participant presentations and hands-on work, that was geared to provide (a) a description of climate change in the region; (b) country presentations by participants, including user needs; (c) quality control and homogeneity analysis of daily data series brought to the workshop; and (d) calculation of a core set of indices for climate extremes in the GHA region. These indices calculate moderate extremes (i.e. 90th percentile rather than the 99th percentile) in order to obtain "a few occurrences each year" instead of "a few occurrences each decade", so trends are easily detected. He showed examples from other workshops of changes in precipitation over the last decades as well as trends in temperatures. For the GHA region he showed a regional map with trends in TXx (monthly maximum value of daily maximum temperature) and total precipitation plotted where data was available.

Finally he stated that daily station data from large collections (such as US National Climatic Data Center) when supplemented with daily data or indices from regional workshops, can fill in gaps in the global assessment of changing climate extremes (e.g., IPCC AR4) and are a very useful resource for research into the impacts of a changing climate.

h. Major Outputs from Workshop 1: Climate Indices and Regional Climate Extremes – Dr. Nelson D. Pyuzza

Workshop 1, "On Exploring Changes in Temperature and Precipitation Extreme Indices for the GHA Region", was held from 19-23 April 2010, Nairobi, Kenya. This presentation summarized the results from the 10 GHA countries, noting that the participants:

- Quality controlled their country's digital long-term daily station data of precipitation, maximum and minimum temperature. Most of these stations have observations in digital form starting from 1961 until end of 2009, while some were from 1971 to 2009.
- Then produced 16 Temperature indices and 11 Precipitation indices, using the Rclimdex software. Particular attention was placed on those indices that reflected climate extremes due to the fact that the vulnerability of society to climate variability and change is likely to depend more on changes in the intensity and frequency of extreme weather and climate events than on changes in the mean climate.

The presentation discussed the results country-by-country. (See also the country reports completed by the participants, which are documented in Annex F in the first workshop report.

General conclusions from this analysis include:

- Total annual rainfall (PRCPTOT) showed a decreasing trend for many of the stations except for Khartoum in Sudan and over the northern stations of Ethiopia. Generally, consecutive wet days (CWD) showed a decreasing trend while the consecutive dry days (CDD) showed an increasing trend.
- Temperature indices vary from station to station, but the dominant features seem to be an increasing trend for TN10p (cold nights) and a decreasing trend for TN90p (warm nights)

[10] The Rclimdex software calculates 27 indices to monitor climate extremes change for hands-on work and can be found at: http://cccma.seos.uvic.ca/ETCCDI. The software was developed under the guidance of the WMO/WCRP Expert Team on Climate Change Detection and Indices (ETCCDI).

leading to a decreasing diurnal temperature range (i.e. Dagoretti) and vise versa for Lodwar and Makindu.

- A decreasing trend for TX10p (cold day times) with an increasing TX90p (warm day times) leading to an increasing diurnal temperature range (i.e. Mombasa, Lodwar, Makindu and Asmara/Djibouti

i. Analysis and Display Techniques – several presenters

The participants were briefed on and then practiced using a number of analysis and display techniques, including use of:

- TRENDS software for statistical analysis (J. Intsiful),
- Geographical information systems (GIS) and visualization techniques for spatial information (E. Obuobie / Olang), and
- Stochastic weather generator LARS-WGE to create climate scenarios (Obuobie)

The participants utilized these techniques in their analysis of climate indices calculated from their country data and from the PRECIS output. Several participants showed the results in their presentations and added clarity to the discussions.

3.5 Climate Change Impacts

The impacts of changing climate conditions were discussed in two presentations.

1. Climate Change Impacts and Vulnerability Assessment – C. Oludhe (University of Nairobi)

This presentation discussed the nature of potential climate changes (e.g., changes in means or standard deviation of climate variables) and indicators of climate change, especially changes in temperature and rainfall. He observed that current data seems to show an increasing trend in temperature over the GHA region and a decreasing trend in seasonal rainfall in recent years. Examples of current impacts include decreases in river flow and glacier size due to rising temperatures. These changes will affect many sectors, such as health, agriculture, forests, water resources, coastal areas, species, and natural areas.

The briefing discussed the vulnerability assessment process, which emphasizes assessing current vulnerabilities first and related possible adaptations and then assessing projected future vulnerabilities and possible adaptation actions. These assessment must consider “non-climate drivers“, which include a wide range of environmental, economic, social, demographic, technological, and political factors that can affect the sensitivity of a system to changing climatic conditions.

He concluded that “The African continent is particularly vulnerable to the impacts of climate change due to factors such as widespread poverty, weak institutions, limited infrastructure, lack of technology and information, poor access to resources, recurrent droughts, inequitable land distribution, armed conflicts and overdependence on rain-fed agriculture among others”.

2. Impacts of future climate change in agriculture – E. Komutunga

A second presentation on climate change impacts on agriculture discussed the temperature effects on plant growth, such as effect of increased temperatures ion photosynthesis, respiration, transpiration, and flowering as well as on the length of the growing season. In contrast, as carbon dioxide levels increase, crops may benefit by increasing the rate of photosynthesis. However, the purported benefits of elevated carbon dioxide concentrations are “likely to be far lower than previously estimated” when factors such as increasing ground-level ozone are taken into account[11].

[11] From a two-day international meeting, entitled "Food Crops in a Changing Climate", at the Royal Society in London in 2005.

Other potential effects include:

- Lower protein content of grains under combined increases of temperature and CO2[12], which primarily affects inhabitants of poorer countries who are less able to compensate by eating more food, more varied diets, or possibly taking supplements.
- CO2 Increases and albedo changes due to land use practices, such as deforestation
- Climate projections indicate that climate change may result in increased frequency (or intensity) of droughts in parts of Africa. Droughts have significant environmental, agricultural, health, economic and social consequences. Dr. Komutunga presented the correlations between rainfall (climate) and crop yield or GDP for four GHA countries (Kenya, Uganda, Tanzania, and Ethiopia), as shown in Figure 1. The effect varies according to vulnerability, but for subsistence farmers, this may lead to migration to find alternative food sources. Drought can also reduce water quality, because lower water flows reduce dilution of pollutants and increase contamination of remaining water sources. Finally war can break out over natural resources, including water and food.

4. Hands-on Exercises

There were 3 hands-on exercises within the workshop agenda, which allowed the participants to practice the key aspects involved in using a regional model to project and downscale climate conditions into the future and to analyze the outputs from the model and to display and visualize the results of the analyses. For each exercise, there was a worksheet prepared to guide the training and to explain the procedures.

4.1 Exercise 1: Climate model data and data manipulation tools

The Hands-on Exercises aim to demonstrate some of the tools available for PRECIS data analyses and to teach how to prepare PRECIS outputs for additional analysis.

All the simulations used in the exercises here are driven by a Hadley Centre ensemble and in particular, demonstrate some techniques to manipulate the data over a sample region (over Egypt) designed for assessments. The examples in this training module utilize the tools of PRECIS's data post processing package, utilizing Linux software. The participants were taught to identify and list the names of PRECIS output data in the appropriate format, using standard Linux commands for sample datasets in the period 1970-2049. One application is to prepare and extract PRECIS data in a format for input to the Rclimdex software to calculate climatic indices from time series of daily precipitation, the maximum daily temperature (Tmax) and minimum daily temperature (Tmin).

Validation of model results by comparison with observed data is essential and is the measure by which one can assess the quality of the model and the appropriate uses of the data. An example of types of analyses undertaken as part of a model validation, include creating and comparing mean annual cycles for precipitation for the period 1971 to 2000 averaged over a box containing Kenya.

4.2 Exercise 2: Climate model validation and projections with Rclimdex

Validation of model results by comparison with observed data is essential and is the measure by which one can assess the quality of the model and the appropriate uses of the data. An example of types of analyses undertaken as part of a model validation, include creating and comparing mean annual cycles for precipitation for the period 1971 to 2000 averaged over a box containing Kenya.

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[12] Ziska, E., Fraser, D., Falcon, P. 1997. Assessing risks of climate variability and climate change for rice. *Science* **240**: 996-1002.

The software Rclimdex calculates climatic indices from daily precipitation, the maximum daily temperature (Tmax) and minimum daily temperature (Tmin) and was used in workshop 1 to calculate indices from observational data from the participants' countries. In exercise 2, Rclimdex is used to calculate climatic indices from PRECIS output, in particular for the indices:

- TN90p → warm nights
- Percentage of days when TN>90th percentile.
- TX90p → warm days.
- Percentage of days when TX>90th percentile.
- PRCPTOT → annual total wet-day precipitation.
- Number of indices related to precipitation amounts and extent.

These PRECIS results are compared with the indices calculated from observations in workshop 1 and provide projections for the future evolution of these indices. Both indices calculated from observations and from the model output are plotted on the same graph to see if there is a good agreement. The PRECIS model runs were based on GCM boundary conditions and therefore year-to-year comparison would not be meaningful for the reasons outlined in 3.4e. In follow-up post-workshop activities, the participants were strongly encouraged to undertake further comparison using PRECIS based on reanalysis boundary conditions, which would permit year-to-year comparisons with the observed indices.

Since the grid box values represent the average values of a 50 km squared area, they should show less variability than observations from a point source. Participants present their findings to the group. In addition since the PRECIS indices are available for the full period 1970-2049, future projections are viewed in the combined observational and PRECIS climate indices data sets.

4.3 Exercise 3: Summarizing multi-model simulations and projections

This exercise presented simple ways to summarize the main results from a set of climate model integrations and was designed to reach two objectives to:

1. Get an initial understanding of the accuracy of climate models in reproducing the climatology at local scales (This was done using regional model data driven by boundary conditions from coupled atmospheric and oceanic Global Climate Models (AOGCMs)) and
2. Estimate the range of climate responses that can be obtained by using different models.

This tutorial uses a set of five integrations in which different RCMs have been driven by a set of physically consistent GCMs with slightly different sub-grid scale physics. The strategy and the methods in this worksheet can be used on any set of model integrations; however, the outcome of the analysis and its interpretation will depend on the experimental design used to select the set of model simulations.

Since all the climate simulations in this tutorial use the SRES A1B emission scenario, estimates of uncertainty will be mainly determined by the differences in the parameters plus an additional contribution due to the multi-decadal variability. Estimates of variability can be obtained by designing a new set of integrations in which the same AOGCM is started from a different initial state. However, since we know from previous research that this component is smaller than the model uncertainty, it is a good approximation to attribute all the differences to the model uncertainty.

In the first worksheet, model data was compared to observation to understand how well the model integration compares with observations. This exercise uses the full set of model integrations to estimate, for example, how large is the typical model error and how different is the climate change signal extracted from climate projections using different models. This exercise also shows how to plot model biases and climate change responses for several different models.

5. Participant Country Reports

The participants were asked to prepared "country reports" summarizing their results from workshops 1 and 2. Additionally, representatives from each country made a final presentation at workshop 3 summarizing their work. They were also asked to address the following questions:

1. What type of extreme events does your country experience?
3. What is the evidence of climate change in your country?
4. How adequate are climate change models for your country?
5. What adaptation strategies do you recommend for your country based on the climate model projections, in addition to any ongoing activities?
6. What are the main limitations you anticipate in the implementation of the adaptation and mitigation you have recommended for your country?

A compilation of these country reports is published in a separate document.

6. Conclusions, Lessons Learned, and Recommendations

Conclusions from Workshops 1 and 2

The main conclusions from the participants were that:

- The first two workshops of this project provide the tools and techniques for analyzing past variability and trends in climate and for projecting future trends in climate conditions. Workshop 1 focused on the quality control of national data and the calculation of climate indices using the Rclimdex software. In workshop 2, the participants learned how to develop climate scenarios using the PRECIS regional model, to compare the variability and trends in their past data with those from the PRECIS model, using a variety of analytic techniques, to project climate conditions for their countries into the future, and to develop an awareness of the uncertainties in these techniques.
- More time was needed for Workshops 1 & 2 to gain better command of the complexities of the analytic and computer based techniques. This could be accomplished either by adding additional days to the workshops and/or holding the workshops on consecutive weeks allowing for weekend discussions and hands-on sessions.
- The lack of continuity of participation by some national participants in the two workshops hindered the learning process, while additional benefits could be gained if there was more preparatory work before workshops
- There was general agreement on the need for additional regional and sector specific indices and for specific real world examples of the use of indices and downscaled model projections as input to assessing impacts in climate-sensitive sectors.
- Requiring oral reports on the climate analyses was viewed as a very useful exercise to encourage dialogue between the users and providers of climate information.

Lessons Learned from Workshops 1 and 2

There was general agreement that many lessons emerged from the two workshops.

- Having a capacity nationally to analyze climate variability and change should help in mainstreaming climate change into national policies, including Disaster Risk Reduction and Climate Change Adaptation.
- Additional preparatory work prior to workshops could usefully allow the development of background guidance and relevant materials for use in workshops.
- The participants agreed that the one week workshops were good to demonstrate capabilities but were not sufficient to be fully trained to the desired level of proficiency.
- Key national project participants (and contacts) should be identified prior to implementation of the workshops to assist in planning, implementation and assessment of the overall project. They should participate in all three workshops and be actively involved in all project implementation discussions.
- There is an overall need for a commitment in GHA countries to data sharing for regional analyses and to provide more time series for consideration at the workshops. This may require data rescue and digitization as well as improving national observing systems.
- Having a regional capacity on climate data, modeling and analysis is most useful in supporting the national efforts in planning and policy development in disaster risk reduction and climate change adaptation. This should include producing aggregated products, downscaled projections, as well as region-wide capabilities and training on climate.

Recommendations for Future Work from Workshops 1 and 2

Based on the above conclusions and lessons learned, the following recommendations need attention from the participants, regional partners and other organizations, users, and the international community.

- Workshops 1 and 2 are initial steps in a capacity building process that should include additional efforts, such as long-term training and practice; refresher courses and distance learning; and access to on-line assistance, particularly through the Regional Climate Centre (RCC)
- It was strongly recommended that the time for workshop 1 and 2 be extended either by adding additional days to each workshop and/or by holding them on consecutive weeks allowing for weekend discussions and hands-on efforts.
- In light of the limitations on available national data, efforts must be initiated to rescue, digitize, and quality control all existing data and to utilize data from reanalyses to fill the many gaps in time series for stations in the region. Adding stations in major gap areas should be considered also.
- Specific attention should be directed at defining what indices would be of particular value to the GHA region for national application in climate resource management, disaster risk reduction and climate change adaptation. Possible indices, such as length of growing period and the onset and cession of seasonal rainfall, were mentioned.
- Activities should be undertaken to locate specific real world examples of the use of indices and downscaled model projections as input to assessing impacts in climate-sensitive sectors.
- There is a need to quantify uncertainties in projections by using multiple models with multiple forcing. It was noted that CORDEX runs should be useful in this regard and will be in the public domain.
- There is a need to identify what activities regional centers will provide vis-à-vis those at national and international centers. This could include provision of aggregated data sets and products, downscaled projections, as well as region-wide capabilities and training on climate.

- The participants in other regional workshops to analyze climate indices have prepared a peer reviewed paper on their results. It is recommended that the GHA region, with leadership from ICPAC, also prepare and have published a peer reviewed paper on the results from workshops 1 and 2. This paper would also be useful in regional assessment of climate change, in national planning, and in IPCC regional assessments.
- Downscaling is a key element in constructing of climate scenarios and in mainstreaming climate into adaptation planning at the national level. It was recommended that ICPAC, along with the NMHSs, should strengthen their capacity in downscaling in order to play an important role in climate scenario construction nationally and in developing regional scenarios for the IPCC assessment process.

In conclusion, the first two workshops in the GFDRR project provided the participants with the:

- Tools and techniques for analyzing the quality of national data and calculating climate indices using the Rclimdex software,
- Knowledge to run regional climate models to constructed climate change scenarios using the PRECIS regional model
- Conduct analyses to compare the variability and trends in climate indices derived from past observational data with those from the PRECIS model, using a variety of analytic techniques,
- Investigate the projected climate conditions for their countries into the future and
- Develop an awareness of the uncertainties in these techniques.

With these tools and knowledge, the participants engaged a diverse group on users in the third workshop of the GFDRR project to better understand the needs of users for climate change information. They also were prepared through workshops 1 and 2 to become a core capability to perform climate change analyses within their countries as a part of national adaptation planning as well as to contribute to the National Adaptation Plans of Action (NAPA) as requested by the UNFCCC.

Annex 1 – Meeting Agenda

TIME	MONDAY 21 February 2011	TUESDAY 22 February 2011	WEDNESDAY 23 February 2011	THURSDAY 24 February 2011	FRIDAY 25 February 2011
08.30-10.30	❖ Workshop Registration and Opening Ceremony ❖ Brief on the World Bank/ICPAC/WMO project (Linking the first, second and third workshops) **Prof. Ogallo** ❖ Outcome Mapping – **Wayumba/Omondi**	❖ Concept of climate change scenarios – **Prof Odingo** ❖ The CORDEX initiative ❖ Validating climate model simulations - **W. Moufouma-Okia**	❖ Output from Workshop I - **Pyuzza** ❖ WMO Indices of climate extremes for climate change monitoring & Detection ❖ Detecting trends in climate data **- J. Caesar.**	❖ Mitigation and adaptation – **Prof Odingo** ❖ Hands-on exercises with worksheet 3 ❖ Creating climate scenarios using the stochastic weather generator LARS-WGE- **Obuobie**	❖ Workshop assessment – **Omondi/Wayumba** ❖ Participants projects
10.30-	**BREAK**	**BREAK**	**COFFEE**	**BREAK**	**COFFEE**
11.00-13.00	❖ Data challenges for Climate Change studies over the Greater Horn of Africa - **Prof. Ogallo** ❖ Evidence of climate change over GHA - **Oludhe** ❖ Climate Change detection and attribution methodology – **Prof Ogallo** ❖ Discussion	❖ Quantifying Uncertainties in Model Prediction - **E. Buonomo** ❖ Climate Scenario Construction for Impacts Assessment **- J. Intsiful/ E. Obuobie**	❖ Hands-on exercises with worksheet 2 ❖ Impacts of future climate change in Agriculture - **Komutunga**	❖ Hands-on exercises with worksheet 3 - ❖ Introduction to GIS/Visualization of spatial information - **E. Obuobie/Olang** ❖ Impacts of future climate change in water resource management- **Opere**	❖ Participants projects
13.00-	**LUNCH BREAK**	**LUNCH BREAK**	**LUNCH BREAK**	**LUNCH BREAK**	**LUNCH BREAK**
14.00-15.30	❖ Climate change impacts and vulnerability assessment – **Oludhe** ❖ Regionalisation techniques - **E. Buonomo** ❖ Introduction to Regional Climate Modeling - **W. Moufouma-Okia** ❖ Discussion	❖ Hands-on exercises with worksheet 2 “Climate model validation with RClimdex”	❖ Hands-on exercises with worksheet 2 “Summarising multi-model simulations and projections” **- E. Buonomo**	❖ Hands-on exercises with worksheet 3 ❖ Participants projects	❖ Presentation of participant projects ❖ Feedback on workshop from participants ❖ Discussion on third workshop
15.30-	**COFFEE**	**BREAK**	**COFFEE**	**BREAK**	**COFFEE**
16.00-18.00	❖ Hands-on exercises with worksheet 1 “Climate model data and data manipulation tools” ❖ Wrap up of days activities	❖ Hands-on exercises with worksheet 2 ❖ Statistical analysis using the TRENDS software - **J. Intsiful** ❖ Wrap up of day	❖ Participant presentations ❖ Allocation of participant country projects ❖ Wrap up of day	❖ Participants projects ❖ Wrap up of days activities	**CLOSING REMARKS Giving of certificates**

Annex 2 – List of Participants

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Annex 3 – Expectations of Meeting Participants

Participants' responses when queried at the beginning of workshop 2 about their expectations from the overall project included:

Indices/Observations

- To learn new tools and methods for analysis of trends in past climate data
- To calculate climate indices and to see if there is climate change
- To assess the accuracy of PRECIS model in the GHA region using past records
- To develop a project proposal on data rescue and digitization with met services in the region

Downscaling

- To understand climate change downscaling
- To learn how to use PRCIS software
- To assess the capability of regional models to simulate present and future climates
- To use regional climate models and observations to assess the climate change and variability in IGAD region
- To understand how models can help identify the cause and effect of climate change in the future
- To learn how to use raw data (non-gridded) to verify GCMs/RCMs for current climate simulations (which are gridded)
- To understand techniques of assessing model uncertainties and how to incorporate them in current and future climate analysis
- To evaluate if there is an added value in downscaling the global models

Applications

- To develop a model that gives reliable forecast of the future climate scenario for the country/region
- To give early warning to users based on model output
- To learn modeling to help in flood forecasting and the development of an early warning system
- To learn strategies on data acquisition, storage and manipulation to solve water related issues
- To get downscaled information to address climate-related challenges including applications in agriculture and environmental management

Regional Aspect

- Enable different countries to use the same models for efficient climate predictions
- Develop general consensus about climate modeling
- Share experiences with other participants on adaptation to climate variability and change

General

-To take home the project computers and the end of the workshop for operational work.

Responses to the detailed questionnaire distributed at the end of workshop 2 indicated that, for the most part, participant's expectations had been met. Section 6 of this report addresses lessons learned and how the workshops and overall approach could be improved.

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