The climate change scenarios for impact assessment on water resources in the River Nile basin

NYEKO PAUL OGIRAMOI[186] **and WILLEMS PATRICK**[187]

ABSTRACT

The global climate is changing and this may potentially affect the frequency, quantity, location and duration of hydrological extremes. It indicates an intensification of the hydrological cycle affecting both ground and surface water supply. Changed hydrological extremes will have significant implications on the design of civil structures and general water resources management. Such changes when on the surplus side may affect the magnitude and timing of runoff but drought-like situations when on the deficit side. Regional and local projection of future climate change impacts on water resources, in the River Nile basin, is very crucial for hydrological and transboundary planning. This means that climate change scenarios need to be scrutinized, identified and unified for impact studies in the basin. In order to guide the future climate change impact study in the River Nile basin, MAGICC/SCENGEN (a coupled gas-cycle/climate model that drives a spatial climate-change to produce spatial patterns of change from a data base of atmosphere/ocean GCM (AOGCM) data from the CMIP3/AR4 (Climate Model Inter-comparison/IPCC Fourth Assessment Report) archive, was applied to assess precipitation changes over the River Nile basin using the pattern scaling method. Appropriate reference and policy scenarios were selected. The annual-mean precipitation projected up to 2100, with respect to 1990 (for the A1T emissions scenario, and - best guess climate model parameters in MAGICC) averaged over all 18 selected AOGCMs, shows a positive change, of up to a maximum of 24% for the upper Nile basin given a projected global mean temperature change of 2.48°C. This change is projected to be less than the global change with a maximum of 58.5% under the same scenario. This implies that there will be a decrease and an increase in precipitation for the downstream and upstream of the River Nile basin, respectively. There is higher inter-modal uncertainty as compared to uncertainty in the scenario chosen. It is therefore better to use the results from several GCMs than from limited ones in order to reduce on the sensitivity in precipitation changes from a single or few models. For a complete climate change impact research the four SRES scenarios, the COMMIT, B1, A1B, and A2 should be used in order to cover regional information on the range of possible future climates. Credible and recommended regional climate change scenarios for the River Nile basin is therefore recommended to be developed.

Key words *climate change, climate change impacts, climate change projection, Lake Victoria, River Nile, water resources, scenarios*

---

[186] Directorate of Water Development, Rural Water Division, TSU1, Ministry of Water & Environment, PO Box 20026, Kampala, Uganda, E-mail: nyeko_ogiramoi@yahoo.co.uk

[187] Katholieke Universiteit Leuven, Laboratory for Hydraulics, Civil Engineering building, Kasteelpark 40, 3000 Heverlee, Leuven Belgium E-mail: Patrick.Willems@bwk.kuleven.be

INTRODUCTION

Physical and biological systems on all continents and in most oceans are already being affected by recent climate changes, particularly regional temperature increases systems to anthropogenic climate change is complicated by the effects of natural climate variability and non-climate drivers (e.g., land-use change), (Trenberth, et al., 2001). Detection of climate change is the process of demonstrating that an observed change is significantly different (in a statistical sense) from what can be explained by natural variability. The detection of a change, however, does not necessarily imply that its causes are understood. Attribution of climate change to anthropogenic causes involves statistical analysis and the assessment of multiple lines of evidence to demonstrate, within a pre-specified margin of error, that the observed changes are (i) unlikely to be due entirely to natural internal climate variability; (ii) consistent with estimated or modelled responses to the given combination of anthropogenic and natural forcing; and (iii) not consistent with alternative, physically plausible explanations of recent climate change. Extending detection and attribution analysis to observed changes in natural and managed systems is more complex. Detection and attribution of observed changes and responses in systems to anthropogenic forcing is usually a two-stage process. First, the observed changes in a system must be demonstrated to be associated with an observed regional climate change within a specified degree of confidence. Second, a measurable portion of the observed regional climate change, or the associated observed change in the system, must be attributed to anthropogenic causes with a similar degree of confidence. Joint attribution involves both attribution of observed changes to regional climate change and attribution of a measurable proportion of either regional climate change or the associated observed changes in the system to anthropogenic causes, beyond natural variability (Stott et al., 2000). This process involves statistically linking climate change simulations from climate models with the observed responses in the natural or managed system. Confidence in joint attribution statements must be lower than the confidence in either of the individual attribution steps alone, due to the combination of two separate statistical assessments. Once the climate change has been detected and attributed, predicting its impacts on environments is significant in understanding how future environments will change. Projecting future climate change and its impacts on natural and managed systems is not an obvious process and will not give any exact or perfect results. Predicting impacts of climate change on a local environment is basically done by using sets of climate change scenarios often constructed from results of Global Circulation Models (GCM) in order to drive impact models. Selection and construction of climate change scenarios for climate change impacts, especially on water resources at local scale, is the key component in such a process. The recommended climate change scenarios, by Intergovernmental Pannel on Climate Change (IPCC), for impact studies, are the Special Report on Emission Scenarios (SRES) (Carter et al, 2007). Several of the GCM have applied SRES scenarios to carry out global climate change projections for different time spans and their results were used by IPCC in its Fourth Assessment Report (AR4).

The impacts of climate change on hydrology and water resources system and their management are mainly due to the observed and projected increases in temperature, evaporation, sea level and precipitation variability. Water resources planning has traditionally viewed climate as stationary, a position that is increasingly untenable given that infrastructure can be in place for many decades, even centuries. Climate change may potentially affect the frequency, quantity, location and duration of hydrological extremes. Changed hydrological extremes will have significant implications on the design of civil structures and general water resources management. The changes could exacerbate periodic and cyclic shortfalls of water, particularly in arid and semi-arid areas of the world (Yanjun et al., 2008; Christensen et al., 2007; Hamlet and Lettenmaier, 1999; Jeong, 2005; Kundzewicz et al., 2007). Developing countries are highly vulnerable to climate change because many are located in arid and semi-arid regions, and most derive their water resources from single-point systems such as bore holes or isolated reservoirs (Boko et al., 2007). Even in the absence of climate change, present population trends and patterns of water use signal that more developing countries, especially in Africa, will exceed limits of their 'economically usable, land-based water resources before 2025 (Kundzewicz et al., 2008). These systems, by their nature, are vulnerable because there is no redundancy in the system to provide resources, should the primary supply fail. Also, given the limited technical, financial and management resources possessed by developing countries, adjusting to shortages and/or implementing adaptation measures will impose a heavy burden on their national economies (Kundzewicz et al., 2007). The population at risk of increased water stress in Africa, for the full range of SRES scenarios, is projected to be 75-250 million and 350-600 million people by 2020s and 2050s, respectively (Arnell, 2004). The climate change impacts on water resources will therefore not be uniform. Analysis of six climate models and the SRES scenarios (Arnell, 2004) shows a likely increase of people who could experience water stress by 2055 in northern and southern Africa. More people in eastern and western Africa will be likely to experience a reduction rather than increase in water stress. These estimations are at macro-scale and may mask a range of complex hydrological interactions and local-scale difference. More local-scale impact assessments are needed to ascertain these findings because water is managed at catchment scale and adaptation is local.

Climate change poses a major conceptual challenge to water managers, in addition to the challenges caused by population and land-use change. It is no longer appropriate to assume that past hydrological conditions will continue into the future (the traditional assumption or business as usual) and, due to climate change uncertainty, of the future. It will also be difficult to detect a clear climate change effect within the next couple of decades, even with an underlying trend (Wilby, 2006; Murphy et al., 2004). Global climate projections work on large spatial grids but water is managed at the catchment scale and adaptation is local. A scenarios driven projection of climate change is thus required in order to provide water managers with the baseline knowledge and tool to assess future risks associated with water resources and thereby draw a strategy for adaptation. Quantification of future impact of climate change on water resources at a local catchment is one of the current challenges facing climate change impact research including the Nile basin. The problem is more complicated when looking at catchments located in a region with no regional climate projection, where local studies have to entirely depend on global climate projection with temporal and spatial resolution quite bigger than what is required at local scale.

Assessment of climate change is often done using climate change scenarios. Scenarios are based on the narrative storylines (Nakicennovic et al., 2000) describing the relationships between the forces driving GHG and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each scenario represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways and result in different levels of GHG emissions. This work looks at observed and projected changes in precipitation over the River Nile basin as defined by global climate change model.

DESCRIPTION OF METHODOLOGY

Observed and projected changes in climatic variables, such as rainfall and temperature, over

GCM and SRES scenarios were explored to determine their data availability from the international database for this study and beyond. A number of GCM results were then analyzed using MAGICC/SCENGEN model, described in the next section, to assess the future states and changes in precipitation over the River Nile basin for selected a policy and a reference scenario. Comparisons were then made between models average and selected individual GCM to assess consistency in precipitation changes over the River Nile basin. Precipitation changes considered were percentages increases and decreases from the observations, changes in standard deviation, errors between observations and model outputs and standard deviation signal-to-noise ratio.

A1T-MES was selected and used as the reference scenario, and WRE450 as the Policy scenario. A1T-MES is one of the six illustrative scenarios from the SRES (Nakićenović and Swart, 2000) set. Meanwhile the WRE450 uses CO2 emissions that lead to CO2 concentration stabilization at 450 ppm along the WRE (Wigley et al., 1996) pathway, with compatible non-CO2 gas emissions that follow the extended MiniCAM (Mini Climate Assessment Model) Level 2 stabilization scenario (Wigley et al., 2008; Clarke et al., 2007).

The first and last years for model outputs selected were 1990 and 2100; and because of the fact that the output year of most emissions scenarios in the library run only to 2100. Analysis was done to assess the different model results for changes in the spatial patterns of annual-mean precipitation over the River Nile basin using normalized precipitation parameters for the different selected Atmosphere-Ocean Global Circulation Models (AOGCMs). A crucial and unique aspect of SCENGEN is that averages across models are based on normalized results (following the original implementation of this idea in Santer et al. (1990)). Using normalized results ensures that each model pattern of change receives equal weight and the average is not biased towards models with high climate sensitivity.

THE MAGICC/SCENGEN MODEL

MAGICC/SCENGEN is a coupled gas-cycle/climate model (MAGICC; **M**odel for the **A**ssessment of **G**reenhouse-gas **I**nduced **C**limate **C**hange) that drives a spatial climate-change **SCEN**ario **GEN**erator (**SCENGEN**). MAGICC has been one of the primary models used by IPCC since 1990 to produce projections of future global-mean temperature and sea level rise. The climate model in MAGICC is an upwelling-diffusion, energy-balance model that produces global- and hemispheric-mean temperature output together with results for oceanic thermal expansion. The MAGICC climate model is coupled interactively with a range of gas-cycle models that give projections for the concentrations of the key greenhouse gases. Climate feedbacks on the carbon cycle are therefore accounted for. Global-mean temperatures from MAGICC are used to drive SCENGEN. SCENGEN uses a version of the pattern scaling method described in Santer et al. (1990) to produce spatial patterns of change from a data base of atmosphere/ocean GCM (AOGCM) data from the CMIP3/AR4 (Climate Model Inter-comparison/IPCC Fourth Assessment Report) archive. The pattern scaling method is based on the separation of the global-mean and spatial-pattern components of future climate change, and the further separation of the latter into greenhouse-gas and aerosol components. Spatial patterns in the data base are - normalized and expressed as changes per 1°C change in global-mean temperature. These normalized greenhouse-gas and aerosol components are appropriately weighted, added, and scaled up to the global-mean temperature defined by MAGICC for a given year, emissions scenario and set of climate model parameters. For the SCENGEN scaling component, the user can select from a number of different AOGCMs for the patterns of greenhouse-gas-induced climate.

SCENGEN has the ability to remove spatial drift from a model (under the justifiable assumption that the drift is approximately common to both the perturbed and control runs) and this was applied. Since the grid box is big, a spatial smoothing option was used and this replaces all output fields by an area-weighted 9-box smoothed field. The smoothing is done simply by area averaging of the nine 2.5 by 2.5 cells surrounding a given grid box. Visually, the effect of this smoothing on the displayed maps is minor. However, smoothed results for individual grid boxes can be significantly different from unsmoothed data.

RESULTS AND DISCUSSION

Observed and projected changes

The climate of the River Nile basin, including the Lake Victoria region, the principal source of the River Nile, has already changed over the last century. The observed changes are with respect to the most dominant climatic drivers for water availability which include precipitation, temperature, and evaporative demand (dependent on net radiation at ground level, atmospheric humidity, wind speed, and temperature). The monthly mean air temperature records show a warming of (0.68-0.77°C) for the last decades of the 20th century. The AR4 by IPCC indicates that there has been a general increase in precipitation from the year 1925-1965 and observed decrease thereafter to 1980 and again an increase trend to 1998 for the east African region. The reversed decreasing trend, again from 1999, had led to dramatic decrease in Lake Victoria level by 2005 and the pattern is believed to be driven by El Nino phenomenon or localized forcing (Anyah et al., 2007). The regional projected change in annual runoff by 2041-60, relative to 1900-70, for the Lake Victoria sub-basin of the bigger River Nile basin is expected to be by about 20% (Milly et, al., 2005). In terms of lake level, Lake Victoria would initially fall as increases in evaporation offset changes in precipitation, but subsequently rise as the effects of increased precipitation overtake the effects of higher evaporation. The observed changes, in the last 10 years, in extreme events, in the region, have been characterized by high temperature, floods and droughts suggesting a negative impact of climate change (Mills, 2006). Floods depend on precipitation intensity, volume, timing and antecedent conditions of rivers and their drainage basins. Meteorological and hydrological droughts are due to precipitation well below average and low river flows (or water levels in rivers, lakes and ground water), respectively. In general, the region has seen global mean temperatures increase since 1970s, increased precipitation associated with increases in cloud and surface wetness, and thus increased evapotranspiration (Boko et al., 2007).

Furthermore the SRES-based projection, using the multi-model data set (MMD) derived from the Programme for Climate Model Diagnosis and Intercomparison (PCMDI) of climate change indicates that Lake Victoria region will have a monotonic increase in temperature referenced from the year 2000 to 2090, which will result into an intensification of hydrologic cycle in the region (Christensen et al., 2007). The projection further indicates that rainfall will increase in most parts of east Africa although the local variability will not be uniform (Anyah et al., 2007). The projection gives the direction of change regionally but, under secondary climatic response, intra-regional (local) trends differ significantly (Song et al., 2004).

The paucity of climate change impact assessments is contingent on available climate change scenarios at time and space scales of relevance to the regional or local issues of importance. These scales are commonly far finer than even the native resolution of the Global Climate Models (GCMs) (the principal tools for climate change research), let alone the skilful resolution (scales of aggregation at which GCM observational error is acceptable for a given application) of GCMs. Several scenarios exist but SRES-based climate change scenarios and their descriptions that have been extensively used and are sufficient for impact study are provided in Table 1. The scenarios can capture possible range of anticipated changes in natural systems. Other scenarios such as the Millennium Ecosystem Assessment scenarios to 2100 (Alcamo et al., 2005), Global Scenarios Group scenarios to 2050 (Raskin et al., 1997) and Global Environment Outlook scenarios to 2032 (UNEP-United Nations Environment Programme, 2002) are quite similar to SRES scenarios because many applied similar assumptions to those used in SRES scenarios.

Table 1 Relevant potential climate change SRES scenarios

Name of the IPCC scenarios	Data set	Description	Duration
20C3M	Climate of the 20^{th} century (20c3m)	Atmospheric CO_2 concentrations and other input data are based on historical records or estimates beginning around the time of the Industrial Revolution.	1870-200
COMMIT	Year 2000 CO_2 maximum (COMMIT)	Atmospheric CO2 concentrations are held at year 2000 levels. This experiment is based on conditions that already exist (e.g. 'committed' climate change).	2001-210
SRES B1	550 ppm CO_2 maximum (SRES B1)	Atmospheric CO_2 concentrations reached 550 ppm in the year 2100 in a world characterized by low population growth, high GDP growth, low energy use, high land-use changes, low resource availability and medium introduction of new and efficient technologies.	2001-210
SRES A1B	720 ppm CO_2 maximum (SRES A1B)	Atmospheric CO_2 concentrations reach 720 ppm in the year 2100 in a world characterized by low population growth, very high GDP growth, very high energy use, low land-use changes, medium resource availability and rapid introduction of new and efficient technologies.	2001-210
SRES A2	850 ppm CO_2 maximum (SRES A2)	Atmospheric CO_2 concentrations reach 850 ppm in the year 2100 in a world characterized by high population growth, medium GDP growth, high energy use, medium/high land-use changes, low resource availability and slow introduction of new and efficient technologies.	2001-210

COMMIT: committed, GPD: gross domestic product, ppm: parts per million

GCM with daily rainfall results

Potential Global Climate Change scenarios for the indicated GCMs, shown in Table 2 show how difficult are to derive concrete conclusion from climate change impact studies if only few models are selected. This is because of the fact that some scenarios outputs are not available for certain GCMs, the spatial resolution varies from one model to another and not all models have data that have similar temporal resolution. This implies that the data would undergo a number of transformations before they can be used for impact study. This imposes a big challenge in carrying out climate change impact study for region without regional climate model. The choice of model and scenarios to use will then be based on how convenient to use the data and it becomes a subjective approach. Using long term daily equally long term daily observed records are not available. It is then recommended to use as much as possible the available global information in order to arrive at reasonable conclusion or reduce the data to reasonable information. Scenarios such as preindustrial and/or control, scenario and time horizons need to be explained clearly beforehand for use. This is because it is important to identify what parameters are relevant for hydrological impact assessments. The choice of the optimum variables is influenced by data (readily available) and time constraints (simple hydrological conceptual models).

Table 2. Potential Global Climate Change scenario

No.	Model Name	SCENARIO							Resolution	
		PIcntrl	20C3M	SRESA2	SRESA1B	SRESB1	1%to2x	Commit	lon	latitude
1	BCCR-BCM2.0, Bjerknes Centre for Climate Research, Norway Norway	×	×	×	×	×	×	×	2.812500	2.790611
2	Cccma CGCM3.1(T63) Canadian Centre for Climate Modelling & Analysis, Canada	×	×	×	×	×			3.750000	3.711136
3	CCSM3.0/NCAR, Community Climate System ModellingNational Center for Atmospheric Research, USA	×	×	×				×	1.405280	1.400767
4	CSIRO-Mk3.5, Australia's Commonwealth Scientific and Industrial Research Organisation Australia	×		×	×	×			1.875000	1.865200
5	ECHAM4, Max-Planck-Institut for Meteorology,GERAMNY	×		×		×			3.750000	3.711136
6	Max-Planck-Institut for Meteorology ECHAM5/MPI-OM, Germany	×	×	×	×	×			1.875000	1.865001
7	Geophysical Fluid Dynamics Laboratory GFDL-CM2.1, USA	×		×	×	×			2.500000	2.022471
8	Goddard Institute for Space Studies, GISS-ER, USA	×	×	×	×	×	×	×	5.000000	4.000000
9	Institute for Numerical Mathematics, INM-CM3.0, Russia	×		×	×				5.000000	4.000000
10	Institut Pierre Simon Laplace, IPSL-CM4.1, France	×		×	×	×			3.750000	2.535210
11	Meteorological Research Institute, MIROC3.2(medres), Japan	×		×	×	×			2.812500	2.790608
12	Meteorological Research Institute, MRI-CGCM2.3.2a, Japan	×		×	×	×			2.812500	2.790611

For the GCM data archived at PCMDI, daily series represent a grid as shown in Figure 1. This determines whether validation is against rainfall stations or against areal averaged rainfall.

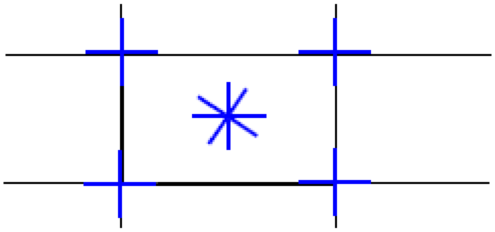

Fig. 1 Grid and point data representation

However, if the GCM data represent a grid data we might need areal reduction factors for the higher time scales like monthly the impact of areal reduction factors is reduced so it may be ignored. Some inconsistencies within the models should be ferreted out: e.g. simulated convective precipitation values are mainly negatives. This implies that most GCM cannot reasonably represent convective precipitation as compared to large scale precipitation.

From table 1, it can be seen that the grid resolution, for each GCM model is not the same at the other and this signifies that interpolation is necessary to ensure uniformity of the grid sizes and for a more reliable spatial representation of the climate change impact.

Changes in annual precipitation

Change in annual-mean precipitation projected up to 2100 with respect to 1990 (for the A1T emissions scenario, and - best guess climate model parameters in MAGICC) averaged over all 18 selected AOGCMs is shown in Figure 2. Positive change, up to a maximum of 24%, is projected for the upper Nile basin given a projected global mean temperature change of 2.48°C. This change is projected to be less than the global change with a maximum of 58.5% under the same scenario. This implies that there will be a decrease and an increase in precipitation for the downstream and upstream of the River Nile basin, respectively as indicated by the legend given in Figure 2. When a Standard Deviation (SD) is considered, then it can be seen that most part of the basin will experience negative change as shown in Figure 3. For the same scenario, it can be seen from Figure 4 that the actual precipitation will spatially varies significantly over the basin.

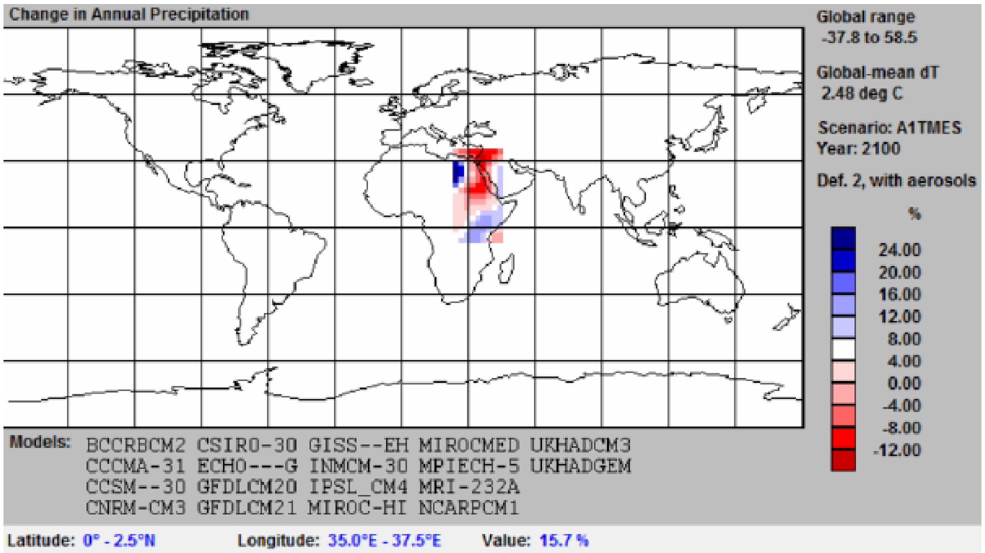

Figure 2 Change in annual precipitation

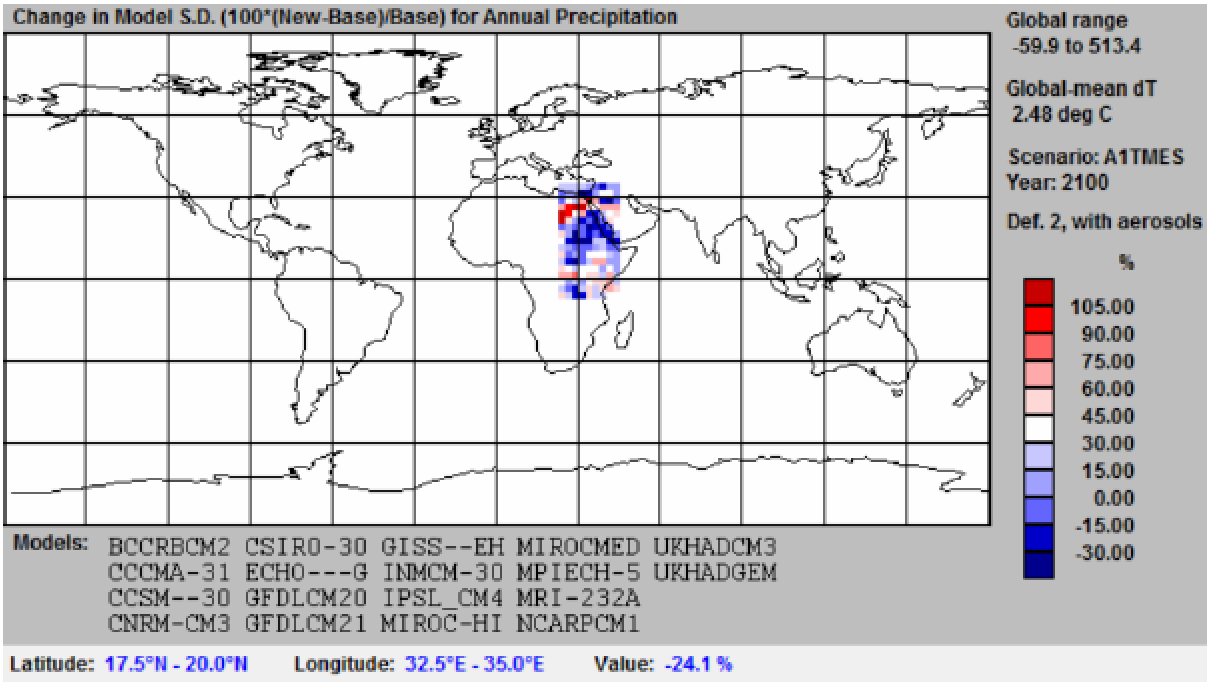

Figure 3 Change in annual precipitation standard deviation

Higher values are around Lake Victoria sub basin meanwhile lower values will be in the semi-arid and arid regions, which are mainly in the downstream of the basin. This is consistent with the finding in AR4 of the IPCC.

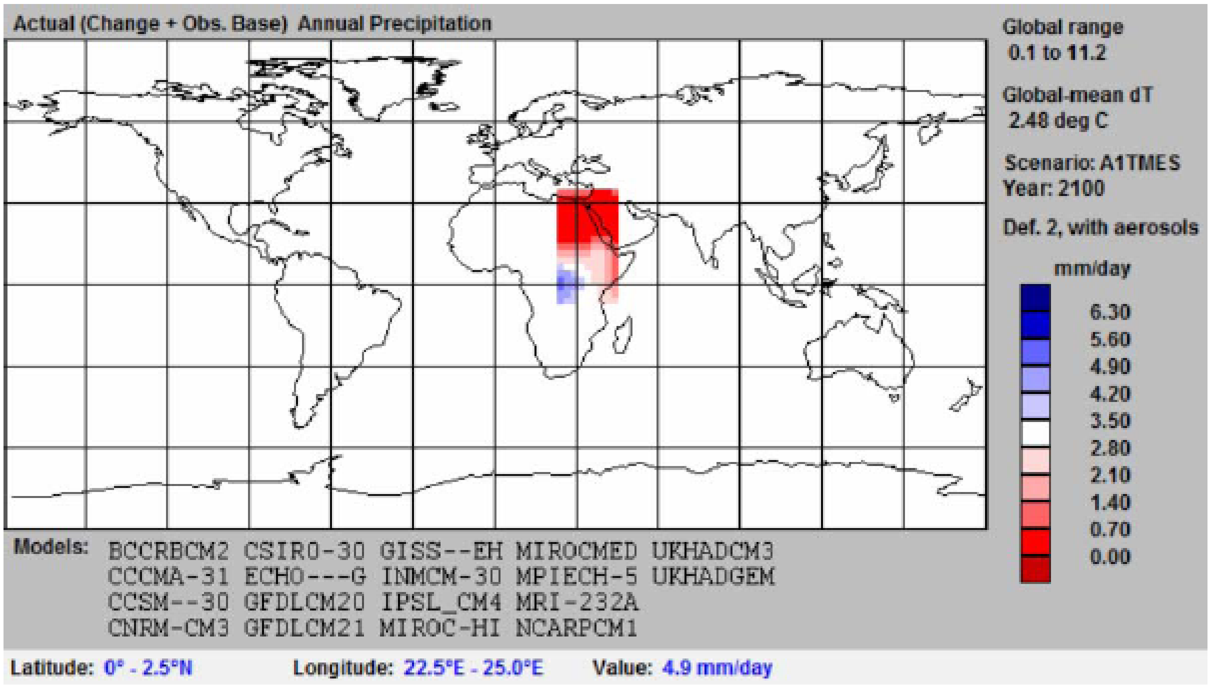

Figure 4 Actual annual precipitations

The values, minimum and maximum, are lower than that of the global values, indicating that the basin will greatly experience water stress as compared with global values. The probability chances of flood related disaster in the upstream basin and drought related disaster in the downstream regions of the basin. The changes are the average values of the selected eighteen GCMs but when compared with the average of two models (CSIRO and MPIECH-5) it can be seen that the average percentage change over these two models are consistent with the average values over eighteen models. The changes in annual precipitation, average over the two models are less sensitive compared to that averaged over eighteen models. This indicates that the two models may well represent the region than the other eighteen models.

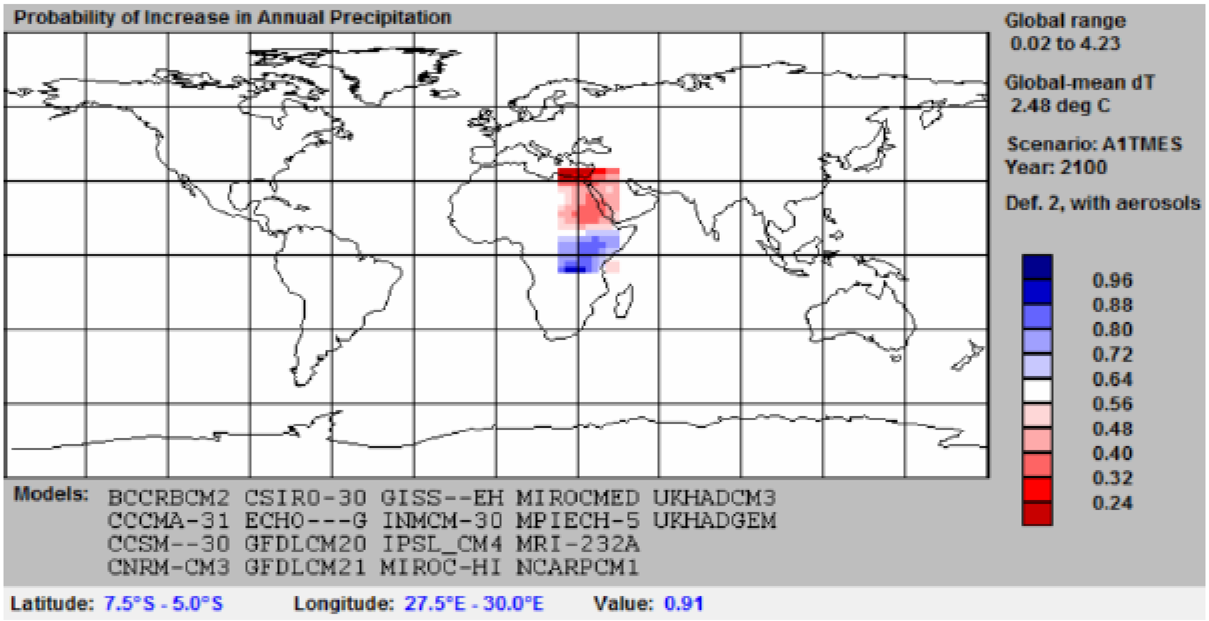

Figure 5 Probability of increase in annual precipitation

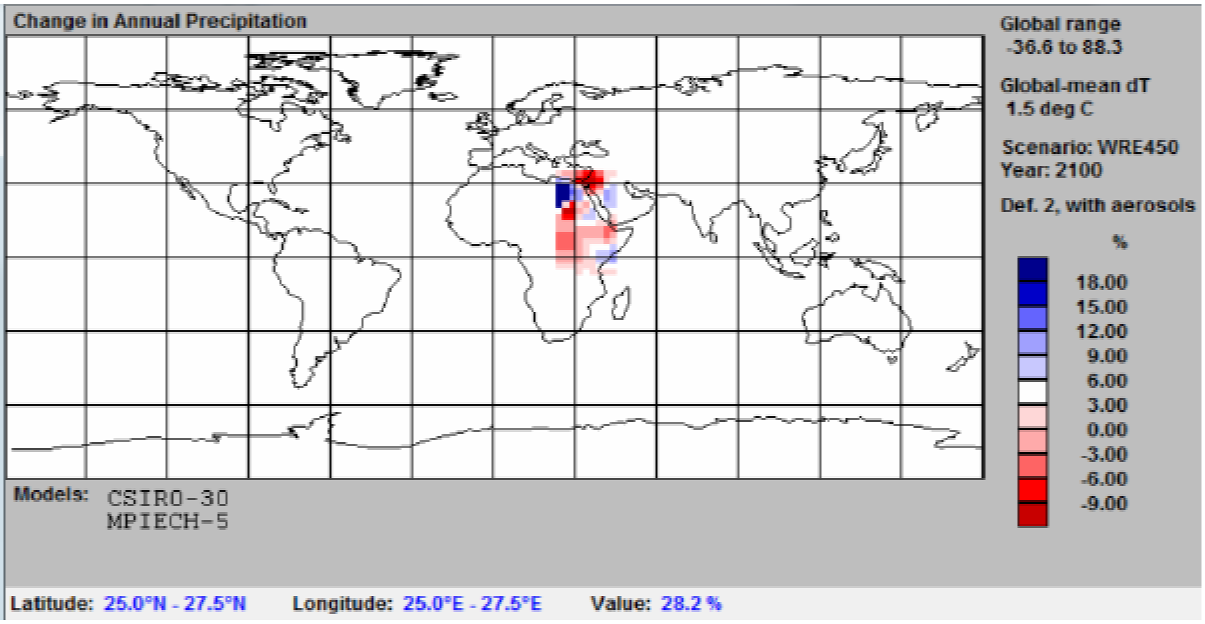

Figure 6 Change in annual precipitation

Model error

The accuracy with which the models can represent the region can be seen when error between and representativeness. Figure 7 shows that the model average tends to overestimate annual precipitation for the regions towards the Mediterranean Sea meanwhile they under estimate for most the remaining regions, mostly in the upstream of the basin.

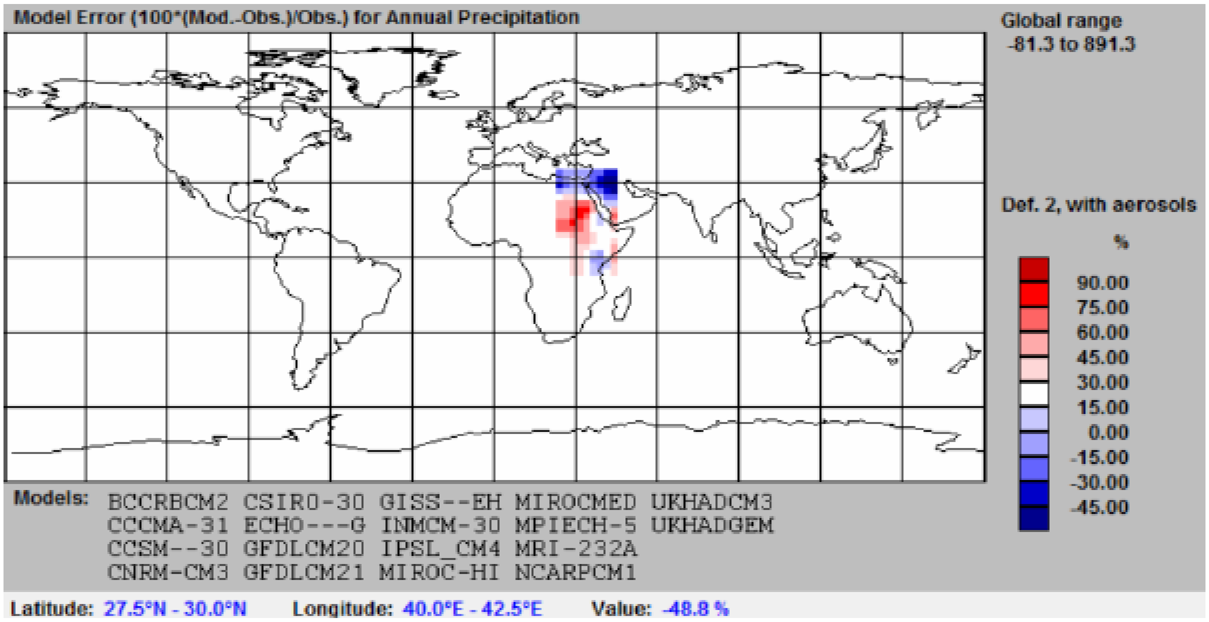

Figure 7 Model error for annual precipitation

The result from CSIRO and MPIECH-5 outputs (Figure 8) shows some consistency with the one in Figure 7, where several model outputs are used, but with a clear picture of the model tending to overestimate annual precipitation over the Nile basin in a general way. It is also clear that the deviation of the model results from the observations is much less for the region around Lake Victoria, which is upstream of the basin. Nevertheless, the sensitivity in model error is higher for the model results from CSIRO and MPIECH-5 compared the one from several models.

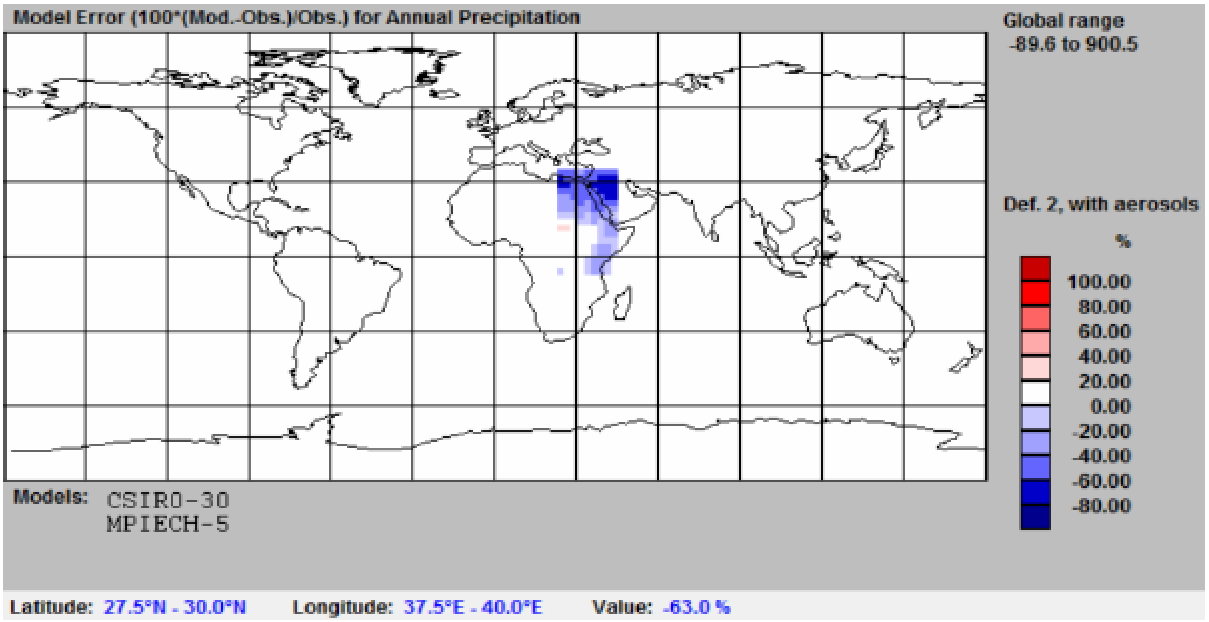

Figure 8 Model errors for annual precipitation (CSIRO and MPIECH-5)

Inter-model Signal-to-Noise Ratio

The result for the inter-model Signal-to-Noise Ratio (SNR) is shown in Figure 9. The SD change SNR (SDSNR), which shows an inter-model Signal-to-Noise Ratio for changes in variability (where -variability here is determined by the inter-annual standard deviation (s.d.) calculated over a 20-year period). SDSNR is defined as the model average of the normalized s.d. changes divided by the inter-model s.d. of these normalized s.d. changes. This is a time-independent quantity that shows the uncertainty in projections of s.d. relative to inter-model differences in these projections. SDSNR values, as shown in Figure 9, are invariably small, showing that projections of variability changes are highly uncertain. In other words there are large inter-model differences in projections of variability change in precipitation.

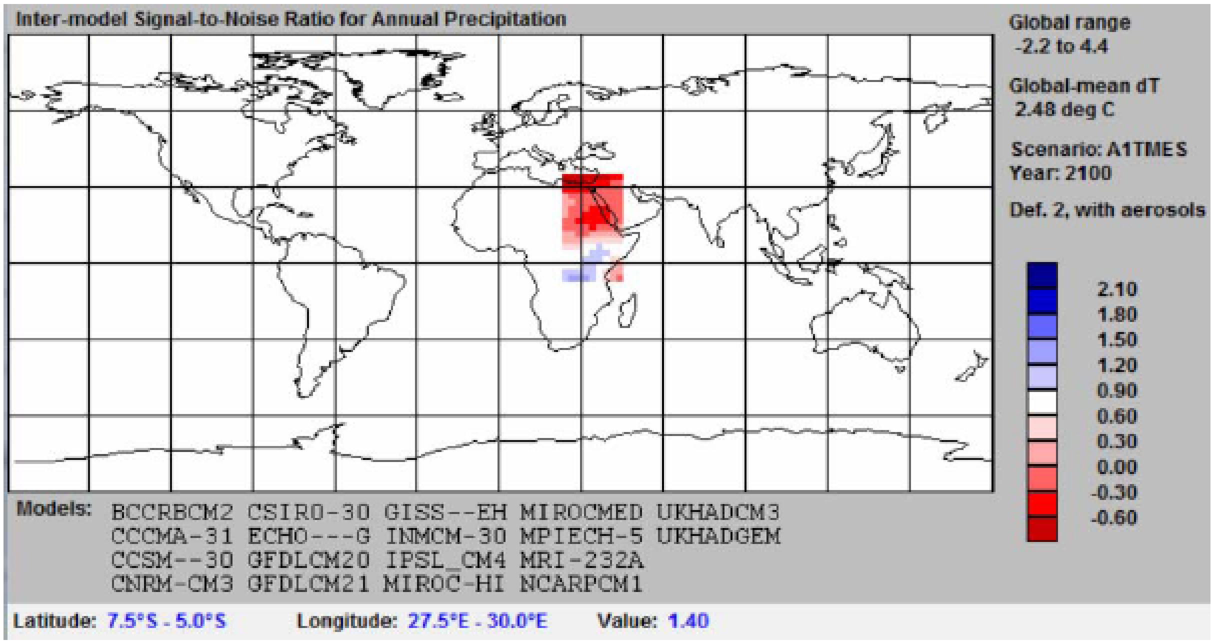

Figure 9 Inter-model Signal-to-Noise Ratio for annual precipitation

CONCLUSION

The Special Report on Emission Scenarios (SRES) is the current recommended climate change scenarios that need to be adopted for climate change impact research in the River Nile basin. Several GCMs have simulation results for the different SRES scenarios but vary in both spatial and temporal resolution. This imposes a challenge in selecting the GCM outputs required for impact analysis. For a complete climate change impact research the four SRES scenarios, the COMMIT, B1, A1B, and A2, that cover regional information on the range of possible future climates, may be selected and used until such a period when credible and recommended regional climate change scenarios for the River Nile basin is developed. Even though different downscaling approaches will be applied, the final outcome will be relative and comparative.

The annual-mean precipitation projected up to 2100, with respect to 1990 (for the A1T emissions scenario, and - best guess climate model parameters in MAGICC) averaged over all 18 selected AOGCMs, shows a positive change, of up to a maximum of 24% for the upper Nile basin given a projected global mean temperature change of 2.48°C. This change is projected to be less than the global change with a maximum of 58.5% under the same scenario. This implies that there will be a decrease and an increase in precipitation for the downstream and upstream of the River Nile basin, respectively. There is higher inter-modal results from several GCMs than from limited ones in order to reduce on the sensitivity in precipitation changes from a single or few models. The study shows very strong evidence in increase in precipitation in the upstream basin of River Nile while it is projected to decrease in the downstream basin by the year 2100. This is consistent with the finding of the IPCC as reported in AR4. The trend in changes in precipitation over the River Nile basin should be able to guide the results of an impact study for a catchment that can be taken at local scale.

REFERENCES

- Aavudai, A., Srinivas, V. V., Nanjundiah, R. S. and Nagesh, K. D. 2008. Downscaling precipitation to river basin in India for IPCC SRES scenarios using support vector machine. *Int. J. Climatol.* **28** 401–420.
- Alcamo, J., van Vuuren, D., Rosegrant, M., Alder, J., Bennett, E. M., Lodge, D., Masui, T., Morita, T., Ringler, C., Sala, O., Schulze, K., Zurek, M., Eickhout, B., M. Maerker, & K. Kok. 2005. Ch. 6. Methodology for developing the Millennium Ecosystem Assessment scenarios. In Millennium Ecosystem Assessment. Scenarios for the Future of Ecosystem Services. Washington, D.C.: *Island Press.*
- Anyah, R. O., Semazzib, F. H. M., 2007 Variability of East African rainfall based on multiyear
- RegCM3 simulations . *Int. J. Climatol.* 27: 357–371
- Arnell, N. W. (2004) Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global Environ. Change* 14, 31–52.
- Hamlet, A.F. & D.P. Lettenmaier, 1999. Effects of Climate Change on Hydrology and Water esources Objectives in the Columbia River Basin. *Water Resour. Bulletin* **35**(6):1597-1623.
- Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda, 2007: Africa. *Climate Change 2007*: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M. L., Canziani, O.F., Palutikof, J. P., Van Der Linden, P. J. & Hanson, C. E., Eds., *Cambridge University Press, Cambridge UK*, 433-467.
- Christensen, J.H., Carter, T.R. and Rummukainen, M. (2007) Evaluating the performance of regional climate models: the PRUDENCE project. *Climatic Change*. In press.
- Hantel, M., M. Ehrendorfer and A. Haslinger, 1999: Climate sensitivity of snow cover duration in Austria. *Int. J. Climatology*, 20, 615-640.
- Hewitson, B.C., 2003: Developing perturbations for Climate Change Impact Assessments, EOS,
- 84, No 35, 337-348.
- Jeong, C. S., Jun-haeng, H., Deg, H. B. & Konstantine, P. G., 2005. Utility of high-resolution climate model simulations for water resources prediction over the Korean Peninsula: a sensitivity study. *Hydrol. Sciences J.* 50(1).
- Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Döll, P., Jimenez, B., Miller, K., Oki, T., Sen, Z. & Shiklomanov, I., 2008. The implications of projected climate change for freshwater resources and their management. *Hydrol. Sciences J.* 53(1).
- Kundzewicz, Z. W., Mata, L. J., Arnell, N., Döll, P., Kabat, P., Jiménez, B., Miller, K., Oki, T., Şen, Z. & Shiklomanov, I., 2007. Freshwater resources and their management. *Climate Change* 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (ed. by M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden & C. E. Hanson), 173–210. *Cambridge University Press, UK.*
- Mills, G. 2006. Progress towards sustainable settlements: a role for urban climatology. *Theoretical and Applied Climatology*, 84, 69–76.
- Milly, P. C. D., Dunne, K. A. & Vecchia, A. V., 2005. Global pattern of trends in streamflow and water

- Mitchel TD, Carter TR, Jones PD, Hulme M, New M. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International J. Climatology* (**25**)693–712.
- Murphy, J. M., Sexton, D. M .H., Barnett, D. N., Jones, G. S., Webb, M. J. & Collins, M., 2004. Quantification of modeling uncertainties in a large ensemble of climate change simulations. *Nature*, 430, 768–772.
- Song, Y., Semazzi FHM, Xie L., Ogallo, L. A., 2004. A coupled regional climate model for Lake Victoria basin of East Africa. *International J. Climatology* 24, 57–75.
- Stott, P. A., Tett, S. F. B., Jones, G. S., Allen, M. R., Mitchell, J. F. B. & Jenkins, G. J., 2000. External control of 20th century temperature by natural and anthropogenic forcings. *Science* 290, 2133–2137.
- Trenberth, K. E. & Stepaniak, D. P., 2001. A Pathological Problem with NCEP Reanalyses in the stratosphere. *J. Climate*, 15, 690-695.
- UNEP, 2002. *Global Environment Outlook 3, EarthScan, London.*
- Wang Y, Leung, L. R., J. L. McGregor, D-K Lee, W-C Wang, Y Ding and F Kimura(2004):Regional climate modeling: Progress, Challenges and Prospects. *J. Metorol. Soc. Japan,*12,825-847
- Wilby, R. L., 2006. A Review of Climate Change Impacts on the Built Environment. *Built environment*, 33 (1). 31-45.
- Yanjun, S., Taikan, O., Nobuyuki, U., Shinjiro, K., & Naota H., 2008. Projection of future world water resources under SRES scenarios: water withdrawal. *Hydrol. Sciences J.*, **53**(1). In press.
- Carter, T.R., R.N. Jones, X. Lu, S. Bhadwal, C. Conde, L.O. Mearns, B.C. O'Neill, M.D.A. Rounsevell and M.B. Zurek, 2007: New Assessment Methods and the Characterisation of Future Conditions. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 133-171.
- Yanjun et al., 2008; Christensen et al., 2007; Hamlet and Lettenmaier, 1999; Jeong, 2005; Kundzewicz et al., 2007
- Nakićenović, N., & Swart, R., Eds., 2000. *Special Report on Emissions Scenarios*. Cambridge University Press, Cambridge, UK, 570.
- Wigley, T.M.L., Richels, R. & Edmonds, J.A., 1996. Economic and environmental choices in the stabilization of atmospheric CO2 concentrations. *Nature* **379**, 240–243
- Wigley, T.M.L., Clarke, L.E., Edmonds, J.A., Jacoby, H.D., Paltsev, S., Pitcher, H., Reilly, J.M., Richels, R., Sarofim, M.C. and Smith, S.J., 2008: Uncertainties in climate stabilization (submitted to *Climatic Change*).
- Clarke, L.E., Edmonds, J.A., Jacoby, H.D., Pitcher, H., Reilly, J.M. and Richels, R., 2007: *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Sub-report 2.1a of Synthesis and Assessment Product 2.1.* A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC, 154.
- Santer, B.D., Wigley, T.M.L., Schlesinger, M.E. and Mitchell, J.F.B., 1990: *Developing Climate Scenarios from Equilibrium GCM Results*. Max-Planck-Institut für Meteorologie Report No. 47, Hamburg, Germany, 29.
- Raskin, P., Gleick, P., Kirshen, P., Pontius, G. & Strzepek, K. (1997) Water futures: assessment of long-range patterns and problems. Comprehensive assessment of the freshwater resources of the world. Stockholm Environment Institute, Stockholm, Sweden.