Dynamical Downscaling of GCM out puts *to Determine Impacts of Climate Change and Variability on the Hydrologic Sensitivity of Blue Nile Basin Surface Water Resource Potential*

Haileselassie G. Weldemariam (PhD candidate –AAU)

***Advisors:** Gizaw Mengistu (PhD) Associate Professor (AAU , Physics Department) , Tsegay Tadesse (PhD) Associate professor (UNL - NDMC) , Robert Oglesby (Professor) (UNL - School of Natural Resources*

1. Background and Motivation

Dynamical downscaling is emerging as the best climate downscaling approach in bridging the gap between Global Circulation Model (GCM) resolutions and finer resolutions required for climate impact analysis. Dynamical downscaling nests a regional climate model (RCM) into the GCM to represent the atmospheric physics with a higher grid box resolution within a limited area of interest. Subgrid-scale climate information are critical to understand and forecast incidences of extreme hydro-meteorological events such as floods, droughts and daily minimum and maximum temperatures. Moreover understanding the spatial and temporal variability of surface water resource on a basin level is a key step to water resource planning and management.

This ongoing research attempts to explore the potential impacts of climate change and variability on the surface water resource potential of Blue- Nile basin using the Weather Research and Forecasting (WRF) model for dynamical downscaling under RCP4.5 and RCP 8.5 greenhouse gas emission seniors.

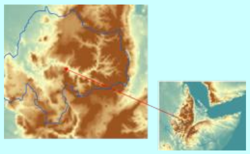
2. Research Objectives

1. Determine the skill of dynamically downscaled GCM outputs in detecting trends of climate change and variability over the central high lands of Ethiopia using precipitation and temperature anomalies under the RCP4.5 and RCP8.5 emission scenarios.
2. Determine the spatial and temporal variability and sensitivity of the surface water resource over the central high lands of Blue Nile basin using physical based distributed hydrological models coupled with the dynamically downscaled GCM outputs.

3. Research Methods and Models

3.1 Study area

Blue Nile basin, locally known as "Abay" basin; covers a catchment area of 199, 812- km^2, contributes about 53% alone to the total annual runoff in Ethiopia with 54.852.6 Bm^3 annual runoff. It supports for 25 % of the population and for over 40 % of agricultural production. Together with "Baro – Akobo" and "Tekeze rivers", the Blue Nile contributes between 80 and 90 per cent of the Nile's flow.



.

Figure-1: Geographic location of the study area (Blue Nile Basin on the top left)

The dominant synoptic and regional weather patterns that influence the main rainy season or 'kiremt' (June –September) which occurs during the northern hemisphere summer include; the ITCZ, development of quasi-permanent high-pressure systems over the South Atlantic (the St. Helena high pressure) and south Indian Oceans (the Maskaran high pressure), development and persistence of the Arabian and the Sudan thermal lows along 20 °N latitude (Seleshi Y. and Zanke U. 2004) ; the Congo air boundary and the Tropical Easterly Jet. The southern hemisphere anticyclones at the Maskarin and St. Helena areas (Figure -2) are the main source for moisture-carrying winds to Ethiopia and give rain in the highlands.

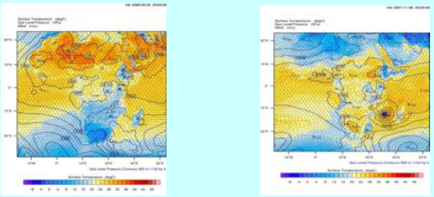


Figure-2 Sea Level pressure, surface temperature and wind across the 36-Km domain of a typical (a) Northern summer day (2008 -08 -01) and Northern winter (2006-01-01) respectively.

3.2 WRF Model set up and physics options

Advanced Weather Research and Forecasting (WRFV3.6.1) is used for the dynamical downscaling using initial and boundary conditions from the Community Climate System Model version-4 (CCSM4) and the ERA-Interim Global Reanalysis data set of the European Center for Medium range Weather Forecasting (ECMWF). WRF is designed for both research and operational applications in two dynamical (computational) cores; the Advanced Research WRF (ARW) and Non-hydrostatic Mesoscale Model (NMM).

The Non -hydrostatic ARW core or solver ($\frac{\partial w}{\partial t} + u_j \frac{\partial w}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g + F_z$) *is in use for this dynamical downscaling experiment for the domain configurations depicted below under the different physics options.*

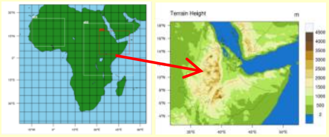


Figure-3: WPS configuration of the domains (a) 36-Km outer domain and (b) 4-Km inner domain

For the ERA-Interim (2001-2010) simulations the USGS 24 classification category of land-use data is used for interpolating topography and land use with spatial resolution of (5-m, 2-m and 30s'). One -way nesting, with 38 vertical levels in the atmosphere and 10 soil layers are used in downscaling the ERA-Interim reanalysis to the desired resolutions.

parameterizations	Physics options in use	Description of schemes
Microphysics (cloud processes)	mp_physics=4 WRF single-moment five-class microphysics	Sophisticated version that allows for mixed-phase processes and super-cooled water. It has terrain-following sigma coordinate in the vertical domain.
Cumulus	*Kain-Fritsch scheme (cu_physics=1)*	Deep and shallow convective sub-grid scheme using a mass flux approach with downwards and CAPE removal time scale
SW Radiation	*(ra_sw_physics = 1) Dudhia scheme*	*Computes clear sky and cloudy solar fluxes, including annual and diurnal solar cycles taking* absorption and scattering processes into account.
LW Radiation	*(ra_lw_physics = 1)*	*Rapid Radiative Transfer Model (RRTM) computes long wave or* IR radiation absorbed and emitted by gases and the surface.
PBL physics	*bl_pbl_physics = 1*	*Yonsei University scheme:* Non-local-K scheme with explicit entrainment layer and parabolic K profile in unstable mixed layer.
Land Surface Parameterization	*sf_surface_physics =5* Noah Land Surface Model	Unified NCEP/NCAR/AFWA scheme with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics.

4. Preliminary Results

Time series plots for 36-Km, 12-Km and 4-km resolutions against observed station data

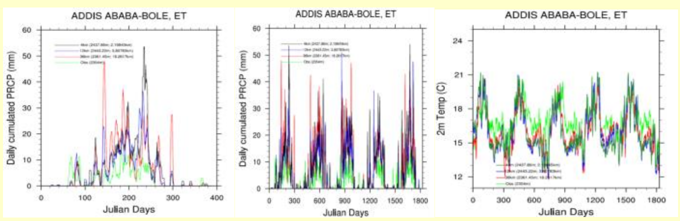


Figure-4 Observed versus model output of daily precipitation for a meteorological station at Bole International airport (a) one year simulation and (b) Five years simulation.

4. Preliminary Results ....cont'd

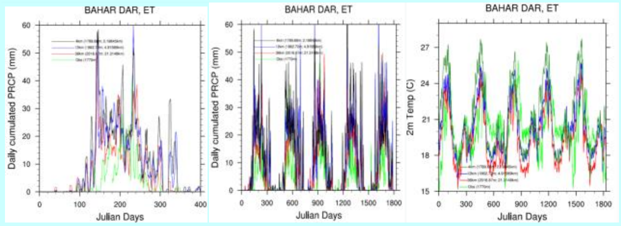


Figure-5 Observed versus model outputs of daily precipitation for a meteorological station at Bahir-Dar: (a) one year simulation and (b) Five years simulations.

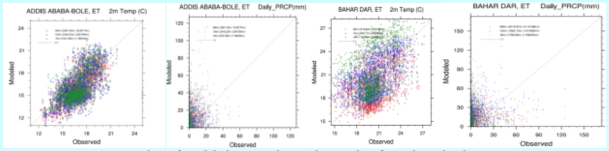


Figure –6: Scatter plots of modeled versus observed point data for Bole and Bahir-Dar met stations

5. Summary and the way forward

Time series and scatter plot results of this dynamical downscaling experiment demonstrate reasonable fit of seasonality and occurrences of extreme precipitation and temperature events with the station data records examined. Overestimation of precipitation is persistently observed in both the stations considered . Temperature on the other hand is slightly cold biased for the station at Bole International airport. Unlike the patterns observed for Bole International airport, high variability of modeled versus observed data is observed for the meteorological station at Bahir-Dar.

In summary, the preliminary results of WRF simulations examined so far indicate promising out puts of great importance for the hydrological impact detection. With the inclusion of more number of stations in the basin, the bias, RMS and correlation of modeled data will be determined using Taylor diagram for each resolution compared to the observed station data. Rigorous analysis of CCSM4 and WRF-hydro simulations for both baseline and projection will be the major tasks ahead to come up with sensible research output.

Acknowledgments

My advisors Dr. Gizaw Mengistu (AAU), Dr. Tsegay Tadesse (NDMC-UNL), and Prof Robert Oglesby (UNL – SNR), deserve my sincere and deepest gratitude for their continuous follow up and guidance to work on this fascinating research topic. Meanwhile Dr. Tsegay , and Prof Oglesby deserve my special thanks for their concern and extra commitment to realize my research visit to the university of Nebraska - USA.

It is also my pleasure to express my appreciation to all NDMC and HCC staff of UNL for providing me unlimited access to the supercomputing facilities to work on WRF simulations and hosting me with great concern and hospitality. I am grateful to AAU and MU graduate program offices as well for sponsoring part of my research visit to UNL. My final thanks also go to Prof Clinton M. Rowe and Cynthia for providing me continuous professional feedbacks and NCL scripts.

References

1. Seleshi Y. and. Zanke U (2004): changes in Rainfall and Rainy Days in Ethiopia, Int. J. Climatol. 24: 973–983.
2. Syktusa J. Jeffreya S, Rotstaynb L., Wonga K. ,Toombsa N., Dravitzkib S., Collierb M., Hamalainena C., and Moesenederb C. (2011) :The CSIRO-QCCCE contribution to CMIP5 using the CSIRO Mk3.6 climate model, 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011,http://mssanz.org.au/modsim201.
3. Skamarock W.C., Klemp J.B., Dudhia J., Gill D.O., Barker M.B., Duda M.G., Huang X.Y., Wang Y., Powers J.G., et al (2008) A description of the advanced research WRF version 3. NCAR tech. note TN-475+STR; National Center for Atmospheric Research Boulder, Colorado, USA
4. P. Dee et al (2011): The ERA-Interim reanalysis: configuration and performance of the data assimilation system; Q. J. R. Meteorol. Soc. 137: 553 – 597 (2011).