CLIMATE AND HYDROLOGIC CHANGE ASSESSMENT FOR GEORGIA

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Abstract. This article describes a climate change and hydrological impact assessment for several basins in Georgia. First, a new statistical technique, Joint Variable Spatial Downscaling (JVSD), is developed to produce high resolution gridded hydrological datasets for the Southeast US from 13 different Global Circulation Models (GCMs). A lumped conceptual watershed model (Georgakakos et al., 2010) is then employed to characterize the hydrologic responses under the historical climate and the future climate scenarios. The historical (baseline) assessment is based on climatic data for the period 1901 through 2009. It consists of running the hydrological models under historical climatic forcing (of precipitation and temperature) for the 109 year period from 1901 to 2009 (in monthly steps). The future assessment consists of running the Georgia watershed models under all A1B and A2 climate scenarios for the period from 2000 through 2099 (100 years) in monthly time steps. For the baseline scenarios and each of the 26 future climate scenarios (i.e., 13 A1B scenarios and 13 A2 scenarios), this study assesses the changes of both climate variables (i.e., precipitation and temperature) and hydrologic variables (i.e., soil moisture, evapotranspiration, and runoff) for each watershed. The results show that: (1) the 26 IPCC future climate scenarios (2000-2099) do not indicate any long term change in average precipitation; (2) the precipitation distribution is expected to "stretch" becoming wetter and drier than that of the historical climate; (3) temperature and potential evapotranspiration (PET) show consistently increasing historical and future trends; (4) soil moisture storage exhibits a declining trend historically and for future climates; and (5) watershed runoff, and thus river flow, exhibits a similar historical decline across all Georgia watersheds.

INTRODUCTION

Current water resources planning and management practices in the Southeast US may be vulnerable to the potential impacts of future climate changes on both water quantity and water quality. These are largely due to the hydrological stationarity assumption among policy and decision makers who are often unconcerned about climate and environmental changes over the coming decades. An integrative approach to assessing climate change impacts on water resources by following a well-defined assessment framework is crucial to regional water resources managers (Georgakakos et al., 1998).

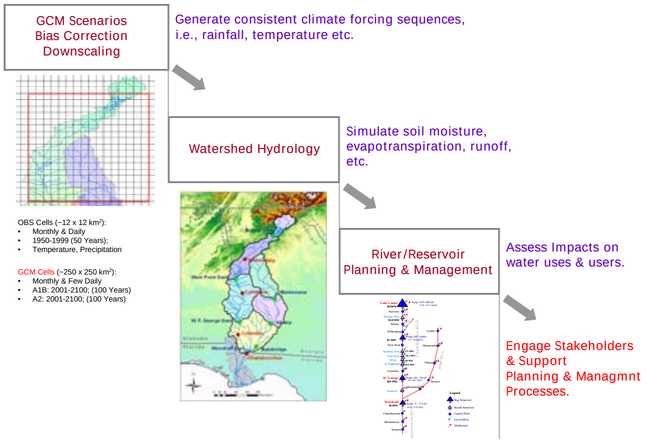


Figure 1. Integrated Modeling Framework

The aim of this study is to develop an integrated climate change assessment framework and to generate reliable data and information to support the on-going regional water resources planning and management efforts in Georgia and the southeast US. **Figure 1** illustrates the integrated modeling framework comprising three main components: (1) processing of general circulation model (GCM) scenarios for bias correction and downscaling (climate component); (2) developing physically based conceptual models for all ACF sub-watersheds (hydrology component); and (3) representing all ACF regulation infrastructure and water uses within an adaptive river and reservoir regulation and assessment model (water resources component).

CLIMATE CHANGE SCENARIOS

Many researchers have demonstrated the physical science basis, impact, adaptation and vulnerability of our changing climate and environment. The climate change issues have been addressed in a couple of literatures for the impact on water resources (Lettenmaier and Rind, 1992; Stamm et al., 1994; Conway, 1998; Wood et al., 2004;). Among these studies, as an important tool for qualitative impact assessment, general circulation models (GCMs) are broadly used.

General circulation models (GCMs) are scientific tools used to assess the future global climate response associated with various greenhouse gas emission scenarios (IPCC WGI, 2007). The GCMs represent (through a large system of partial differential equations) the coupled atmospheric and oceanic processes currently understood to govern the Earth's climate. Climate scenarios are generated by the numerical integration of the underlying equations over space and time. Thirteen different GCMs, selected scenarios from which (corresponding to emission scenarios 20CM3, SRESA2, and SRESA1B) are utilized in this study (Georgakakos, Zhang, and Yao, 2010).

JOINT VARIABLE SPATIAL DOWNSCALING

GCM outputs are usually inadequate to capture the spatial variability at regional or local scales necessary for hydrological applications. Such conclusion is corroborated by the large uncertainties arising from using different models driven by the same scenarios (Tebaldi, 2005; Mitchell and Hulme, 1999; Mujumdar and Ghosh, 2008). To overcome the limitation of directly using GCM outputs, and to produce high resolution gridded hydrological datasets suitable for regional watershed modeling and assessments, a new statistical downscaling technique, Joint Variable Spatial Downscaling (JVSD), was developed by Zhang and Georgakakos (2011).

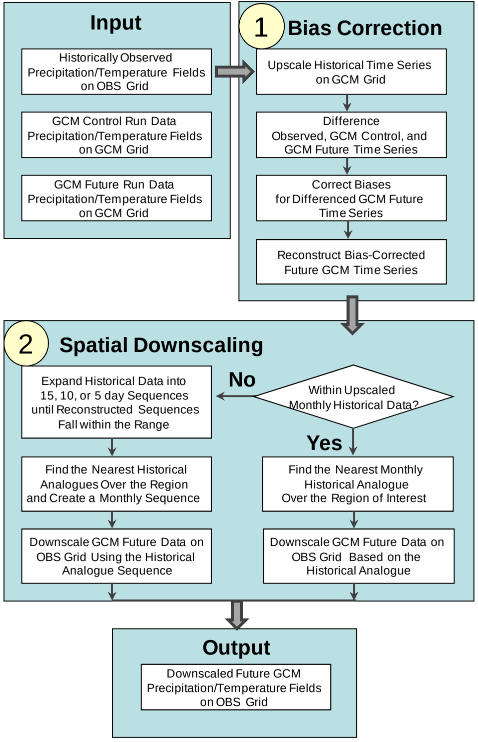
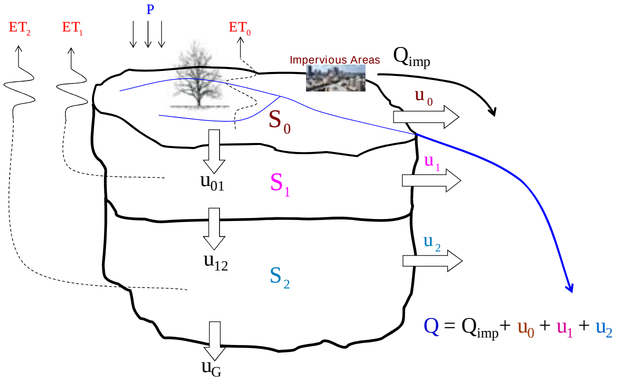


Figure 2. JVSD Procedure Flowchart

The new downscaling approach differs from other existing statistical downscaling methods in that multiple climatic variables are downscaled simultaneously and in a consistent way to produce realistic climate projections. Figure 2 shows the flow chart of the JVSD procedure.It starts with a bias correction step: it uses a differencing process to create stationary time series and the joint variables quantile-based mappings (also known as joint empirical cumulative density functions) to adjust differentiated time sequences for Global Circulation Model (GCM) outputs. Then, in the next step, spatial disaggregating, JVSD uses the historical analogue approach and the historical analogues are identified simultaneously for all atmospheric fields being downscaled.

HYDROLOGIC MODELS

A lumped conceptual watershed model for hydrologic impact assessment of climate changes has been developed by Georgakakos *et al.* (2010). The watershed model includes several water balance elements with nonlinear storage-release functions at monthly time resolution. The model formulation is similar to that of a lumped parameter Sacramento model type, and is intended to simulate the hydrologic processes of infiltration/percolation, evapotranspiration, and surface and subsurface runoff (Figure 3).



Available Observations: P, T, PET, Q, Area, Terrain, Land Cover.
Model Calibration: Storage capacities, runoff functions, and percolation functions.
Model Outputs: S_0, S_1, S_2, ET_0, ET_1, ET_2, u_0, u_1, u_2, Q.

Figure 3. Hydrologic Modeling System

Model inputs include precipitation and potential evapotranspiration demand (PET) averaged over the watershed area. The model includes one surface and two subsurface moisture storage layers, with water contents S0, S1, and S2 respectively. Water enters the top model layer as precipitation, P, and, after some losses to surface retention, it infiltrates/percolates to the lower storage layers. Precipitation falling on impervious areas contributes immediately to runoff (QImp). Storage layers may be depleted by evapotranspiration ET0, ET1, and ET2, or runoff to the stream u0, u1, and u2. Evapotranspiration depends on PET as well as storage. Runoff depends on storage through the storage-runoff functions u0(S0), u1(S1), and u2(S2). Total runoff, Q, to the stream is the sum of all runoff contributions:

$$Q = QImp + u0(S0) + u1(S1) + u2(S2).$$

The infiltration/percolation functions u01 and u12 are key model elements and depend on various model variables. In addition to the evapotranspiration, storage-runoff, and infiltration/percolation functions, model parameters include storage capacities. These functions and parameters are calibrated from contemporaneous observations of precipitation, PET, and total watershed runoff. The ACF watershed models developed in this study have a monthly time resolution.

The function forms and parameters of the model are data driven and they are estimated using a recursive identification methodology suitable for multiple, interlinked modeling components. By using such method, each watershed is calibrated by using area averaged precipitation, PET and unimpaired flow sequences:

(1) Monthly precipitation sequences for each ACF watersheds are generated by aggregating of gridded data over watershed areas. The gridded dataset were obtained from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) climate mapping system (Daly et al., 1997).
(2) Monthly average ground air temperature sequences are also obtained from the PRISM dataset. The Hamon method discussed by Lu (2005) is used.
(3) Unimpaired flows are the river flows that would have been observed in the absence of human water use and regulation. The unimpaired flow sequences used in this study were initially developed by the U.S. Army Corps of Engineers (USACE) as part of the ACF Comprehensive Study for the period from 1939 to 1993. This dataset was extended to 2001 by USACE Mobile District in September 2003. A further extension to 2007 was carried out recently by the Georgia EPD as part of the Georgia Water Plan.

CLIMATE AND HYDROLOGIC ASSESSMENT

The calibrated hydrologic models are employed to characterize the hydrologic responses under the historical climate and the future climate scenarios for all Georgia watersheds. We will take the Apalachicola-Chattahoochee-Flint (ACF) River Basin as an example for the assessment.

The historical (baseline) assessment is based on climatic data for the period 1901 through 2009. It consists of running the hydrologic models under historical climatic forcing (of precipitation and temperature) for the 109 year period from 1901 to 2009. The future assessment consists of running the Georgia watershed models under all A1B and A2 climate scenarios for the period from 2000 through 2099 (100 years).

For the historical scenarios and each of the 26 future climate scenarios (i.e., 13 A1B scenarios and 13 A2 scenarios), this study assesses the changes of climate and hydrologic variables (i.e., soil moisture, evapotranspiration, and runoff) for each watershed. The results show that: (1) the 26 IPCC future climate scenarios (2000-2099) do not indicate any long term change in average precipitation; (2) the precipitation distribution is expected to "stretch" becoming wetter and drier than that of the historical climate; (3) temperature and potential evapotranspiration (PET) show consistently increasing historical and future trends; (4) soil moisture storage exhibits a declining trend historically and for future climates; and (5) watershed runoff, and thus river flow, exhibits a similar historical decline across all ACF watersheds.

As an example, Figure 4 shows the frequency curves of precipitation, temperature, potential evapotranspiration, and runoff for Buford watershed under A1B scenario. The figure leads to the following observations:

(1) While on average (i.e., in the vicinity of the 50% percentile), Buford precipitation is not expected to change relative to the historical baseline, the precipitation distribution is expected to "stretch" becoming wetter and drier than that of the historical climate.
(2) Most future scenarios result in higher PET, evapotranspiration, and lower soil moisture storage. This effect is especially pronounced in dry years (those that fall below 75% of the distribution values).
(3) In the wettest 20% of the years, runoff is expected to be higher than historical. However, the rest of the future ensemble distributions portend drier than historical runoff conditions. Thus, the coming decades are likely to usher in more severe floods and droughts than those experienced in the historical past.
(4) The previous results and conclusions are typical of all watersheds. However, they are based on frequency comparison with all data. To examine the potential changes on a monthly basis, box plots of the historical and future scenarios were developed for each month of the year, watershed, climate scenario type (A1B or A2), and hydrologic process (precipitation, PET, soil moisture storage, and runoff).

Figure 5 shows the plots for Buford under A1B scenarios: the historical box-plots are denoted "H1 through H12" while next to them are the future scenario box-plots denoted "F1 through F12." The future box-plots include data from all 13 future scenarios, while the historical box-plots include only historical data. This figure indeed shows that climate change impacts are not uniform across the months of the year.

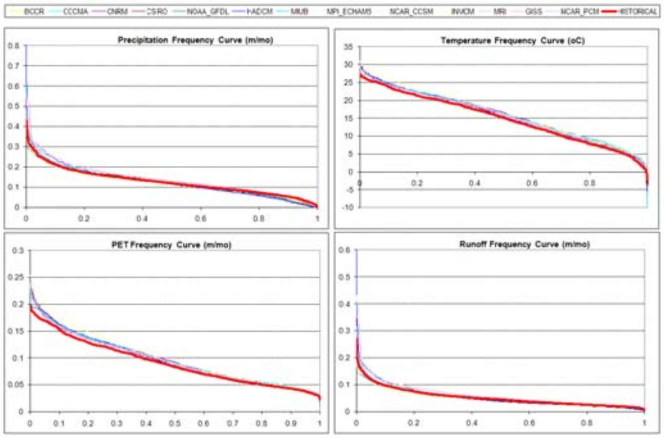


Figure 4. Frequency Curves for Buford Watershed under A1B Scenario

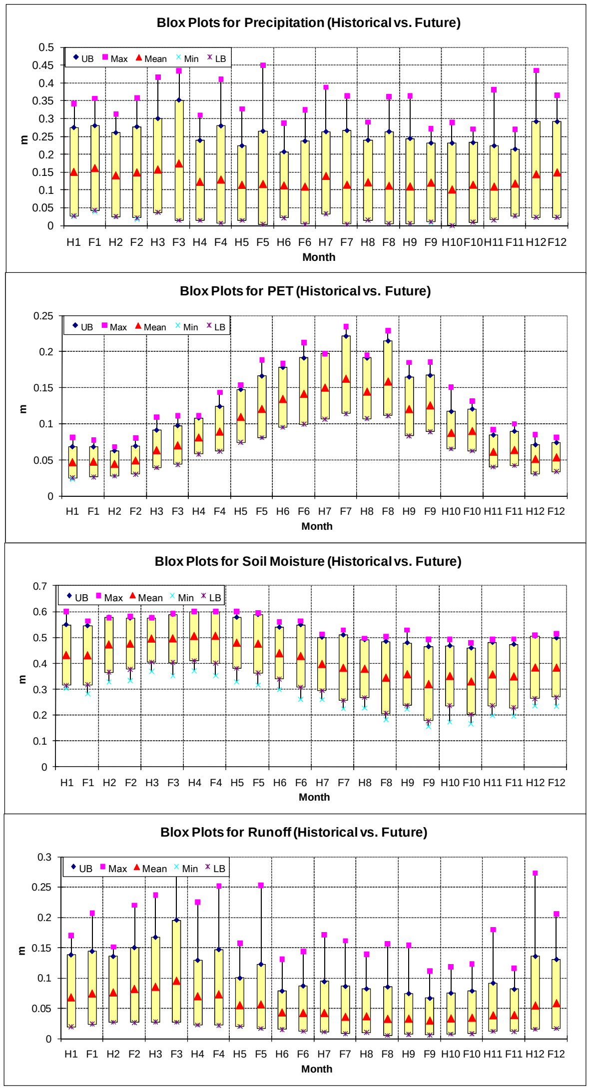


Figure 5. Monthly Historical vs. Future (A1B) Watershed Response, Buford

CONCLUSIONS

This paper describes an integrated climate assessment for river basins in Georgia. The study combines (1) downscaling and assessment of future precipitation and temperature scenarios for six ACF sub-watersheds, (2) hydrologic assessments for each sub-watershed, and (3) water resources assessments for the entire basin (Yao and Georgakakos, same issue). The climate and hydrology changes are assessed based on the integrated assessment framework.

ACKNOWLEDGMENTS

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