Journal of Hydrology 495 (2013) 94–112

Contents lists available at SciVerse ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Hydrological climate change projections for Central America

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ARTICLE INFO

Article history:
Received 9 November 2012
Received in revised form 27 February 2013
Accepted 4 May 2013
Available online 13 May 2013
This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief

Keywords:
Hydrometeorology
Surface water hydrology
Variable Infiltration Capacity Model
Intertropical Convergence Zone (ITCZ)
Mid-Summer Drought (MSD)
Caribbean Low-Level Jet (CLLJ)

SUMMARY

Runoff climate change projections for the 21st century were calculated from a suite of 30 General Circulation Model (GCM) simulations for the A1B emission scenario in a 0.5° × 0.5° grid over Central America. The GCM data were downscaled using a version of the Bias Correction and Spatial Downscaling (BCSD) method and then used in the Variable Infiltration Capacity (VIC) macroscale hydrological model. The VIC model showed calibration skill in Honduras, Nicaragua, Costa Rica and Panama, but the results for some of the northern countries (Guatemala, El Salvador and Belize) and for the Caribbean coast of Central America was not satisfactory. Bias correction showed to remove effectively the biases in the GCMs. Results of the projected climate in the 2050–2099 period showed median significant reductions in precipitation (as much as 5–10%) and runoff (as much as 10–30%) in northern Central America. Therefore in this sub-region the prevalence of severe drought may increase significantly in the future under this emissions scenario. Northern Central America could warm as much as 3 °C during 2050–2099 and southern Central America could reach increases as much as 4 °C during the same period. The projected dry pattern over Central America is consistent with a southward displacement of the Intertropical Convergence Zone (ITCZ). In addition, downscaling of the NCEP/NCAR Reanalysis data from 1948 to 2012 and posterior run in VIC, for two locations in the northern and southern sub-regions of Central America, suggested that the annual runoff has been decreasing since ca. 1980, which is consistent with the sign of the runoff changes of the GCM projections. However, the Reanalysis 1980–2012 drying trends are generally much stronger than the corresponding GCM trends. Among the possible reasons for that discrepancy are model deficiencies, amplification of the trends due to constructive interference with natural modes of variability in the Reanalysis data, errors in the Reanalysis (modeled) precipitation data, and that the drying signal is more pronounced than predicted by the emissions scenario used. A few studies show that extrapolations of future climate from paleoclimatic indicators project a wetter climate in northern Central America, which is inconsistent with the modeling results presented here. However, these types of extrapolations should be done with caution, as the future climate responds to an extra forcing mechanism (anthropogenic) that was not present prehistorically and therefore the response could also be different than in the past.

1. Introduction

In Central America (Fig. 1), droughts and floods are a consequence of the high spatial and temporal variability of climate (Westerberg, 2011). Such climate variability is the result of various naturally occurring phenomena at different spatial and temporal scales (Amador et al., 2006; Waylen et al., 1996), and the interaction between the predominant flow and the complex terrain of the region (Amador et al., 2010). The start and end date of the rainy season and the Mid-Summer Drought (MSD; Magaña et al., 1999) for example, are subject to interannual variability associated with the temperature anomalies of the east-equatorial Pacific and the Tropical North Atlantic (Enfield and Alfaro, 1999). The climate variability at seasonal and interannual scales, in particular those associated with El Niño-Southern Oscillation (ENSO), has significant socioeconomic impacts on the countries of Central America (IPCC, 1997; Waylen et al., 1996). In addition, climate change could significantly affect the hydrological cycle, altering the intensity and distribution of precipitation, runoff and recharge, producing diverse impacts in different natural ecosystems and human activities (IPCC, 1997). Just in the last 5 years or so, the economies of the

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http://dx.doi.org/10.1016/j.jhydrol.2013.05.004

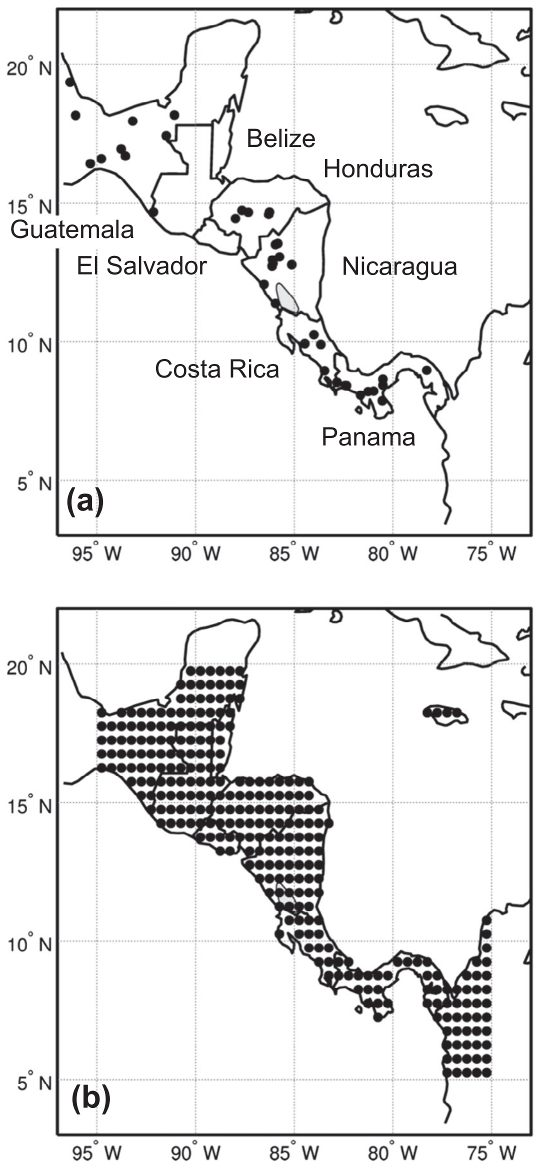

Fig. 1. Study area and locations of the stream-gages (top) and meteorological gridded data (bottom).

Central America countries have suffered losses by several hundred million United States (US) dollars due to hydrometeorological events. In fact, the Intergovernmental Panel on Climate Change (IPCC) determined that Mesoamerica (central Mexico, Guatemala, Belize, Honduras and El Salvador along with the Pacific coast of Nicaragua and northern Costa Rica) is a region of the world that could increase its vulnerability to extreme climatic events in the future (IPCC, 2007a, 2012). Moreover, Central America has been identified as a climate change "hot-spot" (Giorgi, 2006). Hydropower generation, cereal production and cattle ranching are just some examples of activities that are especially vulnerable to changes in the future availability of water, in particular in Costa Rica and Panama (IPCC, 2007a). Also vulnerable to such changes are the wetlands, which cover a significant part of the Central American territory and are known to help in mitigating some of the effects of climate change. Their destruction could have severe repercussions on both the environment and society (Rojas et al., 2003).

It is necessary to know which aspects of global climate change would affect more directly the hydrology and the water resources of the Central American region. In order to produce reliable projections of future climate it is necessary to depend on climatic and hydrological models, and downscaling techniques to obtain the required temporal and spatial coverage demanded by regional studies of (hydro) climatic change. These models are also very valuable in studies of climate change impacts in diverse sectors (e.g. ecosystems, agriculture, power generation, economy, public health).

The main objective of this article was to determine the impact of climate change in the regional hydrology of Central America. A secondary goal was to show the uncertainty in several models in the final downscaled runoff estimates associated with the differences in the precipitation and temperature of 21st century projections from 30 different runs of General Circulation Models (GCMs). For this reason in many parts of the study ensembles were not produced, but instead the results of individual models were kept apart, using boxplots that show the spread of the uncertainty associated with the different climate projections from the GCMs. In other words we did not work with aggregates or ensembles, but the 30 GCM runs were downscaled, resampled, and ran them through VIC. Sometimes we refer to the median climatic changes of all the models, but we considered these individual changes (2000–2099) from the 30 runs according to the individual corresponding baseline (1950–1999) runs. Models that were far from the general tendency of the group were identified as outliers and therefore were tagged as model runs that depict a future that is out of the range of the whiskers of the model-to-model variability. Another secondary objective was the determination of the impacts at monthly to annual time-scales. For example we were interested in verifying the changes in the MSD mentioned by Rauscher et al. (2008) in regard to future MSD behavior as part of the annual cycle of precipitation in the Pacific coast of Central America.

The data from the GCMs were downscaled using a modified version of the Bias Corrected and Spatial Downscaling Method (BCSD; Wood et al., 2004). The skill of the downscaling procedure is discussed in Maurer and Hidalgo (2008) and Maurer et al. (2010). Bias correction of the GCM data is a necessary step in downscaling, as GCMs are known to present considerable biases in the mean and standard deviation for both precipitation and temperature estimates (Hidalgo and Alfaro, 2012a; Maurer et al., 2010). This type of spatial downscaling consists of a process of interpolating GCM data or their anomalies into the finer resolution grid. A final process of resampling (described in a later section) transformed the downscaled monthly GCM data into daily estimates of precipitation and temperature. The downscaled estimates were then used as input in the Variable Infiltration Capacity (VIC) macroscale hydrological model (Liang et al., 1994) with the objective to obtain regional estimates of runoff at a resolution of $0.5^\circ \times 0.5^\circ$. Details on the VIC model are discussed in a latter section.

The procedure of downscaling GCM estimates and then using the input in hydrological models is common in studies of variability and climate change, (for examples see Barnett et al., 2008; Cloke et al., 2010; Das et al., 2011; Hidalgo et al., 2009; Maurer et al., 2009; Pierce et al., 2008). For example, in the particular case of Central America, Maurer et al. (2009) studied the climate change impacts in the Rio Lempa basin. The authors found precipitation reductions of 5–10% for the B1 and A2 scenarios respectively for the period 2070–2099 compared to the baseline scenario from 1961 to 1990. Median reservoir reductions for 2070–2099 were 10% and 13% for the B1 and A2 scenarios respectively.

Using a regional model, Karmalkar et al. (2011) found significant decreases in future precipitation in the dry season of Central America under the A2 emission scenario. Neelin et al. (2006) found an agreement between models in depicting a drying pattern over the Caribbean/Central American region at the end of the century (2077–2099). Data from stations (1950–2002) and satellite (1979–2003) showed decreasing precipitation trends over the