Journal of Hydrology: Regional Studies 12 (2017) 378–395

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

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

Reconstructing hydro-climatological data using dynamical downscaling of reanalysis products in data-sparse regions – Application to the Limpopo catchment in southern Africa

Ditiro B. Moalafhi[a], Ashish Sharma[b,*], Jason P. Evans[c]

[a] Department of Environmental Science, University of Botswana, Gaborone, Botswana
[b] School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW, Australia
[c] Climate Change Research Centre, University of New South Wales, Sydney, Australia

ARTICLE INFO

Keywords:
Reanalyses
Dynamical downscaling
Hydrological applications
Limpopo basin
Southern Africa

ABSTRACT

This study is conducted over the data-poor Limpopo basin centered over southern Africa using reanalysis downscaled to useful resolution.

Reanalysis products are of limited value in hydrological applications due to the coarse spatial scales they are available at. Dynamical downscaling of these products over a domain of interest offers a means to convert them to finer spatial scales in a dynamically consistent manner. Additionally, this downscaling also offers a way to resolve dominantatmospheric processes, leading to improved accuracy in the atmospheric variables derived. This study thus evaluates high-resolution downscaling of an objectively chosen reanalysis (ERA-I) over the Limpopo basin using Weather Research and Forecasting (WRF) as a regional climate model.

The model generally under-estimates temperature and over-estimates precipitation over the basin, although reasonably consistent with observations. The model does well in simulating observed sustained hydrological extremes as assessed using the Standardized Precipitation Index (SPI) although it consistently under-estimates the severity ofmoisture deficit for the wettest part of the year during the dry years. The basin's aridity index (I) is above the severe drought threshold during summer and is more severe in autumn. This practically restricts rain-fed agriculture to around 3 months in a year over the basin. This study presents possible beneficial use of the downscaled simulations foroptimal hydrologic design and water resources planning in data scarce parts of the world.

1. Introduction

Africa is a data-poor continent, with significant gaps characterizing the rainfall and streamflow records across its major river basins. While a regional reanalysis for the continent offers an excellent means of addressing this limitation, computational expense and lack of high quality ground observations make this a difficult task. An alternative to this is the dynamical downscaling of coarser scale reanalyzed datasets to interpolate it to finer spatial scales that are relevant to hydrological studies. We investigate here the viability of such an approach for hydrological applications with reference to the Limpopo catchment of southern Africa.

The Limpopo basin (Fig. 1), which covers an area of approximately 412 938 km^2, falls within four countries: Botswana, Mozambique, South Africa and Zimbabwe. The basin has a diverse water use in which its middle to lower parts are dominated by

* Corresponding author.
E-mail address: a.sharma@unsw.edu.au (A. Sharma).

http://dx.doi.org/10.1016/j.ejrh.2017.07.001
Received 15 June 2016; Received in revised form 24 March 2017; Accepted 4 July 2017
Available online 18 July 2017

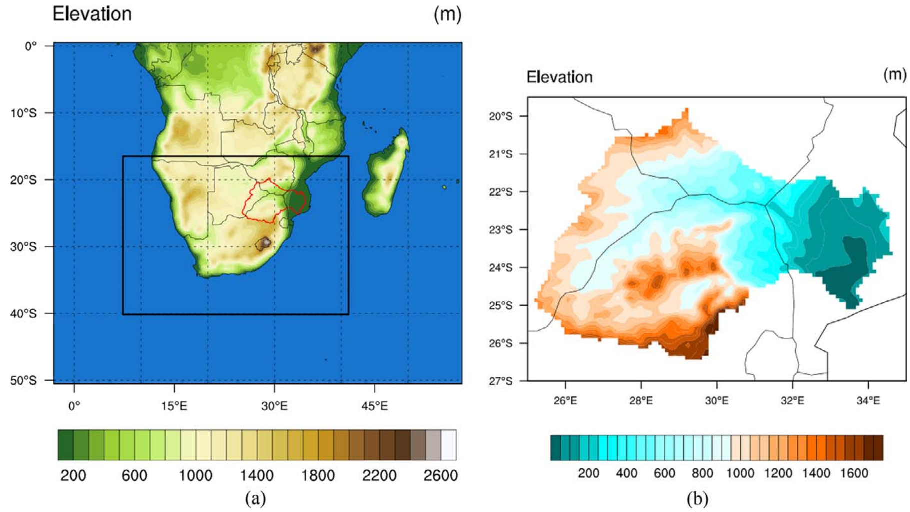

Fig. 1. Elevation (m) of (a) all domains of the simulation, and (b) Limpopo basin within the inner domain.

agriculture while the upper parts are dominated by urban, industrial and mining water use sectors. The major urban centres for the countries that make up the basin are situated either within or in the vicinity of the headwaters. A significant percent of the population is rural and poor and hence socio-economically challenged (FAO, 2004). The basin has characteristic recurrent droughts that have socio-economic implications on its resident population. The characteristically unreliable low rainfall accompanied with high evaporation rates makes water availability an ever present challenge. Also, water abstraction rates over most of the sub-basins of the Limpopo are increasing and becoming unsustainably high as population continues to grow. As a consequence, a number of inter-basin water transfer schemes (at potentially high costs and with politically risky debates for buy-ins from all concerned parties) continue to dominate Southern African Development Community (SADC) forums facilitated through the regional bloc's protocol on shared river systems. Although reasonable efforts are being made to address the relatively severe water shortage in the Limpopo River Basin through such schemes, water demand management is being promoted over water supply management. A common need for optimizing such schemes is the availability of spatio-temporal hydrologic data records, which are of poor quality and coverage for the basin, consistent with similar issues in many African catchments.

The present study assesses the possibility of using dynamical downscaling of selected reanalysis products as a means of formulating climate and hydrologic records over data sparse regions such as the Limpopo. Reanalysis is described as a climate or weather model simulation of the past that includes data assimilation of historical observations (Bengtsson et al., 2007). The use of reanalysis products has increasingly been used in the field of climate research due, in part, to the lack of globally and temporally complete direct observations (Qian et al., 2006; Zhang et al., 2013). Reanalysis products have been used to drive land surface models, study the climate system and provide lateral boundary forcing for regional climate models (Decker et al., 2012). Although reanalyses use some common station data, the products differ in various ways. They use different vertical and horizontal resolutions, data assimilation methods, physical parameterizations and sea surface temperature prescriptions for boundary conditions. Mesinger et al. (2006) and Kanamitsu and Kanamaru (2007) argue that global reanalysis products can be usefully downscaled to provide greater regional detail. A RCM with a relatively high fidelity is a useful tool in describing regional scale climate conditions and in producing high-resolution meteorological data (Bastola and Misra, 2014). The choice of which reanalysis to use has been left to the convenience of individuals' and their research team's preferences and familiarity. This could then result in less than optimum meteorological forcing that may be limited in resolving the complex inter-play between processes at basin scale. The resultant inaccuracies will subsequently propagate through any applications of the downscaled products and have consequences for water resources planning. Therefore, to use the high-resolution climate model simulations for hydrological and related enterprises, the global reanalysis being downscaled should have been carefully chosen to make sure that the most accurate lateral boundary conditions (LBCs) are used. Although improved simulations depend on various factors, starting with the most accurate LBCs is the first step in the right direction. This is desired for sustainable development of water resources where reliable and high resolution hydro-climatic data are necessary for making optimal decisions and planning.

Use of reliable, skillful and high resolution data at basin scale cannot be overemphasized for semi-arid regions where understanding the interplay of dynamic hydrologic processes continues to present a challenging task. Precipitation over semi-arid southern Africa, for example, exhibits significant inter-annual variations with frequent droughts. Cyclones that bring intense rainfall, and often associated floods, are increasingly common over the area. Droughts and floods account for 80% of loss of life and 70% of economic losses that are linked to natural hazards in Sub-Saharan Africa (Vicente-Serrano et al., 2012; World Bank, 2010). Persistent drought conditions are found to be the most significant climate influence on GDP per capita growth across the African continent (Brown et al., 2011).

This study undertakes a high resolution (10 km) downscaling of European Centre for Medium-Range Forecasts Reanalysis Interim (ERA-I) which is one of the two (2) reanalysis datasets that were recommended for the same domain using a 4-D evaluation of