Journal of Arid Environments 158 (2018) 35–42

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Does the Drakensberg dehydrate southwestern Africa?

Shunya Koseki[a,*], Teferi Demissie[b]

[a] Geophysical Institute, University of Bergen, Bergen/Bjerknes Centre for Climate Research, Bergen, Norway
[b] Uni Research Climate/Bjerknes Centre for Climate Research, Bergen, Norway

ABSTRACT

We have investigated the impacts of the high-elevated orography of the Drakensberg on the hydro-meteorological climate in the southwestern Africa, which is characterized by an annual aridity. The focus has been in the summer season (November to March), which contributes 70% of the annual rainfall of the region. A sensitivity experiment performed using a regional climate modeling, in which the Drakensberg is eliminated from the lower boundary condition, shows that precipitation is significantly enhanced over the southwestern Africa and its amplification exceeds 200% in a benchmark experiment. Without the Drakensberg, the lower-tropospheric easterly, associated with the subtropical anti-cyclone over the Indian Ocean, is allowed to penetrate and transport the moisture more westward. Correspondingly, a regime of the intense upward motion also shifts westward to Namibian coastal region and instead, the weak subsidence is formed around the Drakensberg in southeastern Africa. The westward-shifted upward motion is attributed to the enhanced rainfall, which is generated by local daily-anomaly circulation with the help of the enriched moisture. Consequently, the aridity over the southwestern Africa changes from severe arid/arid to semi-arid based on a traditional aridity index. We conclude that the Drakensberg partially contributes to the dry climate over the southwestern Africa.

1. Introduction

The western coast of the tropical-to-subtropical continents is characterized by arid and sub-arid climate. The dry climate is induced by subtropical high-pressure system and cool sea surface temperature (SST) due to equatorward ocean current and coastal upwelling, which are observed ubiquitously over the global ocean (e.g., Goubanova et al., 2013). The stabilized atmospheric boundary layer due to the underlying cool SST is a favorable condition for stratocumulus formation (e.g., Klein and Hartmann, 1993) and inhibits cumulus convection and precipitation, which eventually leads to the formation of deserts along the western coast.

In general, the southwestern Africa is one of the arid climate regions (e.g., Wu and Liu, 2003; Hartmann, 2013) characterized, for example, by the Namib Deserts (Viles, 2005) associated with the divergent flows of St. Helena high-pressure system (anti-cyclone) and the Benguela Current in the South Atlantic Ocean. On the other hand, the hydro-meteorological climate in southeastern Africa is dominated by a clear contrast between dry winter and wet summer (e.g., Dieppois et al., 2016). The wet condition in southeastern Africa is generated by several factors, e.g., the South Indian Convergence Zone (SICZ, Cook, 2000) and the warm SST due to the Agulhas Current (e.g., Jury et al., 1993; Rouault et al., 2013; Nkwinkwa Njoudo et al., 2018). In addition to these key players, the high-elevated terrain of the Drakensberg (up to 3482 m) is responsible for the occurrence and variability of the local precipitation (Potter et al., 2017; Koseki et al., 2018, submitted) by activating local mountain-valley breeze and orographic uplifting effect during summer (November to March). As witnessed in Fig. 1a and c, southeast Africa is moist and southwest Africa is arid in summer and consequently, a west-eastward gradient of moisture is formed. From the figures, it is natural for us to imagine that the Drakensberg blocks the moisture transport westward.

Impacts of orography on the climate system have been investigated for several decades with general circulation and regional climate models (e.g., Manabe and Terpstra, 1974; Koseki et al., 2008; Simpson et al., 2015; de Campos and Barreto Carvalho, 2018). Over our region of interest, southern Africa, Richter and Mechoso (2004) and Potter et al. (2017) concluded that the southern African orography including the Drakensberg plays a key role for the formation of low-level stratocumulus and Inter-tropical Convergence Zone over the South Atlantic Ocean. On the other hand, there is relatively less attention paid to exploring how the local and regional climate in the southwestern continental Africa is influenced by the Drakensberg highland. This work uses a regional climate modeling approach to assess whether the high topography of the Drakensberg lying over southeastern Africa affects the spatial variation of the hydro-meteorological climate over the southwestern continental Africa.

The rest of this paper is structured as follows: the details of data and model are given in Section 2. The results of numerical simulations will be presented in Section 3. Finally, we summarize the paper in Section 4.

* Corresponding author. Allégate 70, 5007, Bergen, Norway.
E-mail address: Shunya.Koseki@gfi.uib.no (S. Koseki).

https://doi.org/10.1016/j.jaridenv.2018.08.003
Received 22 May 2018; Received in revised form 10 August 2018; Accepted 21 August 2018
Available online 01 September 2018
0140-1963/

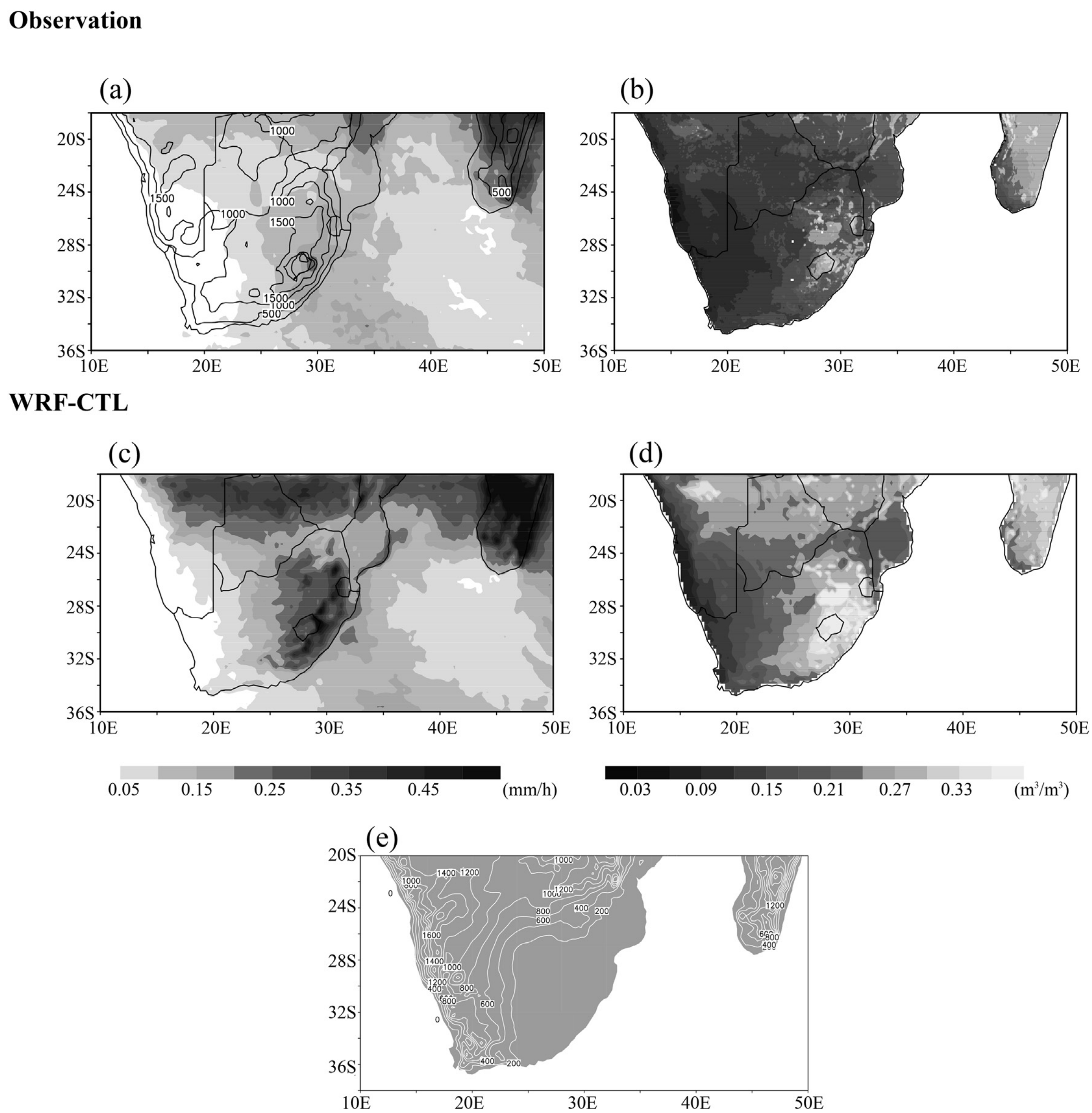

Fig. 1. Comparison of 5 years (2001–2005) NDJFM mean of (left) precipitation and (right) soil moisture at the first layer between (top) observation and (bottom) WRF-CTL. The precipitation is from TRMM-3B42 and soil moisture is from FLDAS-NOAH. On (a), the topographic height is superimposed as contours obtained from GTOPO. (e) Topography height for WRF-NODB.

2. Data and model

2.1. Observation and reanalysis

The 3-hourly Tropical Rainfall Measuring Mission (TRMM-3B42, 0.25° × 0.25°, Huffman et al., 2007) is used to evaluate the simulated precipitation and the 6-hourly ERA-Interim reanalysis (Dee et al., 2011) of 10 m horizontal winds (0.75° × 0.75°) for the lateral boundary condition of simulation are employed. In addition, the data of land data assimilation system of Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS, 0.1° × 0.1°) is also used. This system is based on the NOAH land surface model, which is forced by observed and reanalyzed meteorological boundary conditions. More details can be seen in McNally et al. (2017). For this study, we analyze the data for November to March from 2001 to 2005.

2.2. Weather Research and Forecast (WRF) model

The Weather Research and Forecast/Advanced Research (WRF, hereafter Skamarock et al., 2008) system version 3.7.1 is applied to investigate the dynamics of the diurnal cycle over eastern South Africa. The spatial resolution is 25 km by 25 km with 56 vertical eta-coordinate levels. WRF is forced laterally by ERA-Interim (0.75°, Simmons et al., 2007; Dee et al., 2011) 6-hourly reanalysis data and at the surface by the Optimum Interpolated Sea Surface Temperature (OISST, 0.25° × 0.25°, Reynolds et al., 2007) daily data. A relaxation zone is implemented in the first four lateral grid points to avoid discontinuity between forcing data and the model. The simulation extends from December 1st, 2000 to January 1st, 2006. The first month is considered as spin-up and only the remaining 5 years are analyzed. The domain of WRF simulations has 171 × 117 grids and covers 7.9638°E to 52.2985°E and 42.9037°S to 17.1558°S.

The selections of physical parameterizations used in WRF are as follow: the WRF Single-moment (WSM) 6-class for microphysics scheme (Hong and Lim, 2006) and the Yonsei University parameterization for the Planetary Boundary Layer (PBL; Hong et al., 2006). The longwave and shortwave radiative forcing are parameterized by the Rapid Radiative Transfer Model (Mlawer et al., 1997) schemes. These choices of physical parameterizations are based on Pohl et al. (2014) for their successful simulation of the diurnal cycle of rainfall in South Africa.