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Investigating drought over the Central Highland, Vietnam, using regional climate models

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SUMMARY

The Standardized Precipitation Index (SPI) has been computed based on the monthly precipitation for different observed and modelled datasets over the Central Highland, Vietnam during the period 1990–2005. Station data from a total of 13 stations were collected from the study region and used for benchmarking to compare gridded observation data and two regional climate models (RCMs). Various characteristics of drought across the study region were analyzed using spatial and temporal distributions, number of drought events, their frequency and their deficit. The RCMs were able to capture the SPI temporal distributions of station data fairly well. The analysis from RCMs showed close estimation for the number of drought events to station data and gridded observations. In terms of Drought Deficit and frequency, the RCMs matched the station data better than gridded observations. The drought trend was carried out using a Modified Mann–Kendall trend test which yielded no clear trends that suggested the need for longer records of data. The results also highlight uncertainties in gridded data and the need for robust station data quality and record lengths. The regional climate models proved to be appropriate tools in assessing drought over the study area as they can serve as good proxies over data sparse regions, especially in developing countries, for studying detailed climate features at sub regional and local scales.

1. Introduction

Drought is a natural feature of the climate cycle that quietly wreaks havoc in most regions of the globe (American Meteorological Society, 2013). The United States Environment Protection Agency (EPA) also listed severe drought as a natural disaster (USEPA website). In the statistics of natural disasters by Obasi (1994), the World Meteorological Organization (WMO) has observed that during 1967–1991, drought accounted only for 7.3% of all events for all type of natural disasters but it led to 38% number of people killed, one of the highest among all natural hazards. Drought affects natural habitats, ecosystems and many economic and social sectors, from the foundation of civilization – agriculture – to transportation, urban water supply and the modern complex industries (Heim, 2002). Understanding drought and modelling its components have drawn the attention of ecologists, hydrologists, meteorologists and agricultural scientists (Mishra and Singh, 2011).

A common tool utilized to monitor current drought conditions is a drought index expressed by a numeric number, which is believed to be far more functional than raw data during decision-making (Belayneh and Adamowski, 2012). Two widely used indices for drought are the Palmer Drought Severity Index (Palmer, 1965) and the Standardized Precipitation Index (McKee et al., 1993). The PDSI requires information such as precipitation, temperature and available water content from soil to study the wet and dry conditions using water balance technique. Guttman (1999) strongly suggested that users of the Palmer indices consider the Standardized Precipitation Index (SPI) as either a primary drought index or as an equal companion to the Palmer indices. Applying SPI requires only monthly precipitation data to yield a better representation of abnormal wetness and dryness, than using PDSI which is more demanding in terms of ground data and hence problematic in regions where good ground data do not exist.

The SPI is both a standardized index and a probabilistic drought index. Standardization of a drought index ensures independence from geographical position as the index in question is calculated

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with respect to the average precipitation (Bordi and Sutera, 2007). The SPI is considered as the most appropriate index for monitoring the variability of droughts since it is easily adapted to local climate, has modest data requirements and can be computed at almost any time scale (Ntale and Gan, 2003). In Asia, many researches have adapted SPI as an effective tool for their countries' drought monitoring. Yusof et al. (2014) applied SPI to assess rainfall characteristic over Peninsular Malaysia and concluded that the whole peninsula is predicted to have an increasing trend during drought events. Zhang et al. (2014) used SPI of 3 months to monitor winter wetness and dryness in Southeast China. Vu et al. (2013) also compared SPI with the de Martonne J index (de Martonne, 1926) and the Ped index (Ped, 1975) to monitor drought for the whole Vietnam from 50 meteorological stations. Lyon et al. (2009) evaluated drought in Sri Lanka using 3, 6, 9 and 12-month cumulative drought index SPI and found out the 9-month SPI provided the strongest relationships overall. In the "Lincoln Declaration on Drought Indices", 54 experts from all regions agreed on the use of a universal meteorological drought index for more effective drought monitoring and climate risk management (WMO, 2009). Thus, experts participating in the Inter-Regional Workshop on Indices and Early Warning Systems for Drought, held at the University of Nebraska-Lincoln, USA in 2009, made a significant step through a consensus agreement that the SPI should be used to characterize meteorological droughts by all National Meteorological and Hydrological Services around the world (WMO, 2009). To this end, this study makes use of the results from a Regional Climate Model and SPI index to assess drought over a climate vulnerable region in Vietnam.

2. Study region

The study region is the Central Highland of Vietnam, which is located southeast of the Indochina Peninsula, between longitudes 11°N to 15°N and latitudes 107°E to 109°E. The region has complex topography: (1) high mountains that range from 1000 m to 2500 m, located in the northeast and in the southeast of the study region. (2) Plateau topography is most prominent spreading westerly from Da Lat highland (1000 m) to the border with Cambodia (100 m). (3) Valley topography with a small area lying over western side of the region, distributed along the river basin (shown in Fig. 1).

The soil in the study region has 1.7 million ha of basaltic area (comprising 90% total basaltic area in Vietnam) and 3 million ha of forest (22% total forested land). Therefore, the region is suitable for planting perennial plants like coffee, rubber or annual plants like cocoa, pepper, sugar cane and cashew. The cultivated area is about 800,000 ha with major crops in the region. Coffee is the most important crop in the Central Highland and Vietnam is the world's second largest coffee exporter after Brazil.

The population is about four million people and 80% of the population live in rural and mountainous areas. Two main tributaries of the Mekong river also come from this region: Sesan and Srepok, which serve as the main source of water supply for agricultural activities. The total annual rainfall ranges from 1500 to 2400 mm. Rainy season occurs from May to October which account for 80% of the annual rainfall. Dry season is from November to the following year April that coincides with winter–spring crop seasons.

With climate change, the frequency and magnitude of droughts are very likely to increase and the poor nations are very vulnerable to such changes (IPCC, 2014). Vietnam is prone to drought in addition to being susceptible to floods. The climate in Vietnam is strongly affected by monsoons and its complex topography. The total precipitation amount in the dry season accounts for approximately 15–25% of the annual precipitation. There are limited statistical figures of sectors affected by drought events since the 1980s in Vietnam. During the 1997–1998 El Niño event, most regions in Vietnam, especially regions from central to south, were significantly affected by severe drought. According to a drought assessment by the Ministry of Agriculture and Rural Development (MARD), Vietnam, in 1997–1998, about three million people were affected and the total losses in terms of agricultural production were estimated to be about 400 million US dollars. The country being so vulnerable, very few studies on droughts have been made over Vietnam (Vu et al., 2013; Dao, 2002; Nguyen, 2005). In Vietnam, the Central Highland area is important for perennial plantation and has been known to be largely drought prone. The Central Highland suffers from severe drought. Nguyen et al. (2007) found that the precipitation in Central Highland, during October, November and April, is highly related to the El Nino Southern Oscillation (ENSO). Nguyen (2005) characterized drought over the Central Highland whose studies pointed out that 1998 and 2005 were the two typical severe drought events over this region, especially during the winter–spring crop season. A study by Dao (2002) indicated a series of drought events in this area from 1994 to 1998 during the winter–spring season. Tran (1999) pointed out that the wide spread drought in 1997–1998 was related to a strong El Nino year. In a recent study comparing different drought indices for Vietnam, Vu et al. (2013) suggested that no particular meteorological drought indices would be the best to represent the drought conditions in Vietnam and it remains a challenge to better understand the relationship between drought and climate. This study, therefore, attempts to assess the regional climate model's ability to simulate drought characteristics over this region, so that future drought conditions using the model can be assessed with more confidence.

3. Methodology, model and data

3.1. Drought characterization indices

3.1.1. Standardized Precipitation Index (SPI)

The SPI was first introduced by McKee et al. (1993) by analyzing historical monthly precipitation. A set of averaging periods are selected on a moving window basis to determine a set of time scale of period 'i' months ($i = 3, 6, 12, 24, 48$). A 3-month SPI can be very effective in showing seasonal trends in precipitation while SPI 12 reflects long-term precipitation patterns (Belayneh and Adamowski, 2012). In this study $i = 12$ is selected in order to assess meteorological drought because it is more suitable for water resources management purposes (Raziei et al., 2009) and more appropriate for identifying the persistence of dry periods (Gocic and Trajovic, 2013; Tabari et al., 2012). Each dataset is fitted to the Gamma distribution that has the probability density function as:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta}, \quad \text{for } x > 0 \tag{1}$$

where $x > 0$ is the amount of accumulated precipitation. Based on each data set, a set of shape parameter $\alpha > 0$ and shape parameter $\beta > 0$ is estimated. $\Gamma(\alpha)$ is the Gamma function that is defined by the integral:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \tag{2}$$

After estimating coefficients α and β, an expression for the cumulative probability $G(x)$ can be obtained that represents a certain amount of rain that is observed for a given month at time scale i:

$$G(x) = \int_0^{\infty} g(x) dx \tag{3}$$