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Effects of meteorological droughts on agricultural water resources in southern China

Houquan Lu [a,*], Yihua Wu [b,c], Yijun Li [a], Yongqiang Liu [d]

[a] National Meteorological Center, Beijing 100081, China
[b] Environmental Model Center, National Centers for Environmental Prediction, 5830 University Research Court, College Park, MA, USA
[c] IMSG at NCEP/EMC, 5830 University Research Court, College Park, MA, USA
[d] Center for Forest Disturbance Science, USDA Forest Service, Athens, GA 30602, USA

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ABSTRACT

With the global warming, frequencies of drought are rising in the humid area of southern China. In this study, the effects of meteorological drought on the agricultural water resource based on the agricultural water resource carrying capacity (AWRCC) in southern China were investigated. The entire study area was divided into three regions based on the distributions of climate and agriculture. The concept of the maximum available water resources for crops was used to calculate AWRCC. Meanwhile, an agricultural drought intensity index (ADI), which was suitable for rice planting areas, was proposed based on the difference between crop water requirements and precipitation. The actual drought area and crop yield in drought years from 1961 to 2010 were analyzed. The results showed that ADI and AWRCC were significantly correlated with the actual drought occurrence area and food yield in the study area, which indicated ADI and AWRCC could be used in drought-related studies. The effects of seasonal droughts on AWRCC strongly depended on both the crop growth season and planting structure. The influence of meteorological drought on agricultural water resources was pronounced in regions with abundant water resources, especially in Southwest China, which was the most vulnerable to droughts. In Southwest China, which has dry and wet seasons, reducing the planting area of dry season crops and rice could improve AWRCC during drought years. Likewise, reducing the planting area of double-season rice could improve AWRCC during drought years in regions with a double-season rice cropping system. Our findings highlight the importance of adjusting the proportions of crop planting to improve the utilization efficiency of agricultural water resources and alleviate drought hazards in some humid areas.

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1. Introduction

Climate warming and increased climate variability have led to a greater number of drought events in many river basins around the globe, particularly at intermediate and high latitudes (Mishra et al., 2009; IPCC, 2013; Zhao et al., 2016). Climate change has increased the frequency of droughts (Gleick, 1987; Karl and Riebsame, 1989; Lettenmaier and Gann, 1990; Panagoulia, 1992; Vimal et al., 2010). Moreover, future climate change may lead to more frequent and severe droughts (Quiring, 2015). Droughts are now a major threat to crop production in many areas of the world. In recent years, droughts have been a focus of study for environmentalists, ecologists, hydrologists, meteorologists and agricultural scientists (Wilhite, 2000; Bola et al., 2014; Zhao et al., 2016).

Agriculture, which strongly depends on water resources, will be affected by climate change and increasing drought frequency. Droughts are caused by a precipitation deficiency. Studying the effects of droughts on the carrying capacity is important to optimize crop management and agricultural planning. The term "carrying capacity" has been used since the late 1880s (Seidl et al., 1999) and was clearly defined by Park and Ernest (1921). Carrying capacity has been typically defined as the maximum population size that can be supported indefinitely by a given environment. This concept has since been widely used in many fields. Meadows et al. (1972) built a model of the world for economy growth by using the concept of carrying capacity. This research was the first indirect study of water resource carrying capacity. Harris and Scott (1999) studied agricultural production and regional agricultural water resource carrying capacity. These authors investigated the yield growth patterns of major cereal crops, soil degradation, water overdraft, and other ecosystem stressors and concluded that the

* Corresponding author.
E-mail address: lvhq@cma.gov.cn (H. Lu).

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world was close to its agricultural carrying capacity and that specific resource and ecological constraints were very importance at the regional level. Many studies on water resource carrying capacity have been incorporated into strategies for sustainable development. The definition of water resource carrying capacity varies (Hixon, 2008). In this study, the agricultural water resource carrying capacity (AWRCC) is defined as the maximum crop production that a regional water resource can support without environmental degradation. If deficits in precipitation and soil moisture continue, these phenomena can reduce AWRCC. When agricultural water needs are not met by precipitation, AWRCC will be overloaded without changes in agricultural structure or the introduction of blue water with water (Falkenmark, 1995). Although irrigation is an effective way to reduce agricultural drought, research of Leng et al. (2015a) showed that irrigation would increase vulnerability to drought, and the combined effect of increased irrigation water demand and amplified temporal-spatial variability of water supply may lead to severe local water scarcity for irrigation. Therefore, the role of adjustment of agricultural planting structures for increasing AWRCC to adapt to climate change needs investigation.

Southern China, located in the humid subtropical climate zone (Peel et al., 2007), is an important agricultural region. Water resources are relatively abundant here, but seasonal droughts can drastically affect crop growth (Xu et al., 2012) and dramatically affect the AWRCC. Climate warming is projected to continue along with more frequent droughts in China (Gao et al., 2012). In the future, agricultural drought in southern China tends to increase with severe intensity, longer duration and higher frequency (Leng et al., 2015b). Southern China is especially at risk (Chen et al., 2013) for two major reasons. First, Global Climate Models generally indicate that precipitation will decrease at low and mid-latitudes and will be less than evapotranspiration in mid-continent regions. Therefore, more severe, longer-lasting droughts may occur in these areas. Second, the temperatures in southern China are now at the upper limit of the optimal temperature for plant growth, whereas the temperatures in other regions of China are at the middle point of the optimal temperature for plant growth, which provides more buffer space. Therefore, continued global warming may induce more detrimental effects on crops in southern China than on crops in other regions.

Huang and Yang et al. (2010) studied the evolutionary characteristics of seasonal droughts in southern China during the past 58 years based on a standardized precipitation index. Huang (2011) evaluated the characteristics and causes of droughts in China from 1949 to 2007. Fang et al. (2011) studied the trends and distributive characteristics of agrometeorological disasters in China over the past 30 years. Sui et al. (2012a, 2012b) documented changes in precipitation and the spatiotemporal characteristics of droughts for wintering grain and oil crops in southern China based on a crop water deficit index. Consequently, the need for drought assessment is crucial to minimize socio-economic losses. To date, however, the potential effects of meteorological droughts on the agricultural water resources in the humid regions of southern China have not been uniformly evaluated.

This study was designed to 1) establish the agricultural drought intensity index (ADI), which was suitable for rice planting areas for agricultural drought evaluation in southern China; 2) investigate the effects of meteorological droughts on the agricultural water resource carrying capacity (AWRCC) in different regions in southern China from 1961 to 2010; 3) explore the effects of meteorological droughts on agricultural water resource in southern China; and 4) present countermeasures for drought prevention and provide a scientific basis for sustainable agricultural production in southern China to adapt to future climate change.

2. Materials and methods

2.1. Study area

The southern China study area is located between 20–30° N and 100–120° E (Fig. 1). This area has a warm temperate climate with hot summers (climate type C, temperature type a, Koppen-Geiger climate classification; Kottek et al. 2006). The seasonal distribution of precipitation differs in the eastern and western portions. The eastern portion is mainly affected by the East Asian summer monsoon, which originates from the Pacific Ocean, while the western portion is mainly affected by the South Asian monsoon, which originates in the Indian Ocean. The South Asian monsoon begins significantly later than the East Asian monsoon. The most obvious characteristic of a monsoon climate is the simultaneous rainy and hot season. Winter and summer have distinctive climate characteristics. Monsoon climates are conducive to good crop growth and high yields, but monsoon climates can vary greatly. The onset of the summer monsoon determines the length of the rainy season,

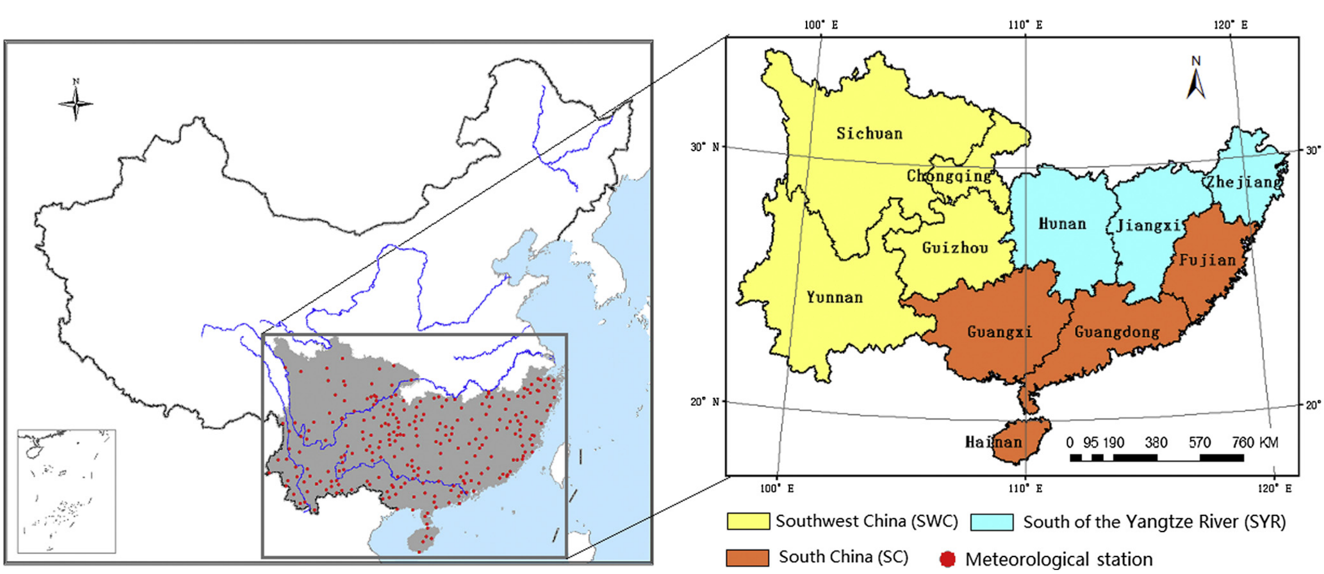

Fig. 1. Study area, distribution of meteorological stations and the three sub-regions of southern China.

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