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Multidecadal changes in moisture condition during climatic growing period of crops in Northeast China

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ABSTRACT

Investigating the spatiotemporal dynamics of agricultural water status during crop growth season can provide scientific evidences for more efficient use of water resources and sustainable development of agricultural production under climate change. In this study, the following were used to evaluate the multidecadal changes in moisture condition during climatic growth period of crops in Northeast China from 1961 to 2010: (1) the daily climate variables gathered from 101 meteorological stations in Northeast China for 1961–2010; (2) FAO (Food and Agriculture Organization) Penman–Monteith equation; (3) 80% guaranteed probability for agro-climatic indicators; and (4) the daily average temperature stably passing 0 °C, which is the threshold temperature of climatic growth period for crops. Reference crop evapotranspiration (ET_0) and relative moisture index were further calculated. The results showed that Northeast China's climate in the main agricultural areas over the past 50 years was warmer and drier in general, with a growing range and intensity of drought. From 1961 to 2010, when the daily average temperature stably passed 0 °C, the average annual total precipitation (*P*) and ET_0 with 80% guaranteed probability in Northeast China both emerged as decreasing trends with averages of 555.0 mm and 993.7 mm, respectively. However, the decline in *P* was greater than that of annual total ET_0. As a result, the annual relative moisture indices sharply decreased with an average of −0.44, mostly fluctuating from −0.59 to −0.25. As far as spatial distributions were concerned, the inter-regional reductions in *P* and relative moisture index over the past 50 years were conspicuous, especially in some agricultural areas of central Heilongjiang Province, northeastern Jilin Province and northeastern Liaoning Province. On the contrary, ET_0 obviously increased in some agricultural areas of central and northwestern Heilongjiang Province (eg. Qiqiha'er, Shuangyashan, Hegang, Suihua, etc.), and northeastern Jilin Province (eg. Baicheng). This indicated that drought existed and was unfavorable for crop growth and development, especially during the period of 2001–2010. This finding revealed that drought was still one of the most important agricultural meteorological disasters in Northeast China. Some countermeasures should be formulated to adapt to climate change. Our findings have important implications for improving climate change impact studies, for breeding scientists to breed higher yielding cultivars, and for agricultural production to cope with ongoing climate change.

1. Introduction

Agriculture is heavily impacted by climate change (Olesen and Bindi, 2002; IPCC, 2007; Bocchiola et al., 2013; Zhao et al., 2015a, b). There is significant concern about the impacts of climate change on agriculture both for policymakers and scientists (Gregory and Ingram, 2000; Sanchez et al., 2000; Fuhrer, 2003; Lobell and Field, 2007; Lobell et al., 2008; Zhao et al., 2013). On the other hand, global warming drives the complex water cycle to change, resulting in a shift in the distribution of water resources spatially and temporally. More and more scientists have been paying close attention to changes in water regimes caused by climate change, making the issue of regional moisture status another hot topic (Chen et al., 2006; Xie and Wang, 2007; Yao et al., 2013).

Under climate change, with the temperature increasing, other climatic variables such as vapor pressure deficit, evaporation from the surface, and transpiration from vegetation surfaces, reference crop evapotranspiration (ET_0) and moisture from coupled plant/-soil interface can be significantly affected, because they have strong direct and/or implicit links to temperature. On a large scale,

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many other climatic variables such as precipitation, wind speed and direction, and relative moisture are also directly or indirectly impacted by changes in atmospheric temperature due to its effect on atmospheric circulation. These factors have a marked influence on most of natural phenomena and ecological functions. They interact with each other producing the moisture status of land surface. Generally speaking, the moisture status are characterized by relative moisture index, which reflects the two most important surface water components: precipitation and ET_0. ET_0 is a basis for computation of water requirements of crops, depending only on climatic parameters and providing the evapotranspiration of an ideal and well-watered grass surface (Zhang et al., 2010). ET_0 is affected by the changes in air temperature, sunshine duration, wind speed, and so on. Changes in air temperature can alter the saturation vapor pressure, which in turn changes the evaporation and ET_0 rate. As integral parts of climate change, ET_0 and moisture status represent heat and moisture within a region in the agro-hydrological systems (Liang et al., 2010).

Climatic conditions have significant implications for agriculture, because they determine crop yields and the types of crops that are suitable for specific geographic regions on longer time scales. There are strong interactions between climate variables and agro-ecosystems dynamics through various direct and indirect processes (Irmak et al., 2012). Under climate change, the moisture status will change and influence the sustainability and efficient use of agricultural climatic resources of crops in China. In the past few decades, a number of studies about moisture status in China have been conducted on large scale (Yang et al., 2002; Ma and Fu, 2006; Zhao et al., 2007; Shen et al., 2009; Zhao et al., 2010a,b), revealing intensified drought conditions in parts of China for nearly half a century, especially in the northern semi-arid regions. For example, Ma and Fu (2006) used the monthly precipitation and monthly mean air temperature data from 1951 to 2004, to calculate surface moisture index, Palmer drought index, and inversed soil moisture in the northern China. They pointed out that the frequency of extreme drought had a significant increase in the eastern part of northwest, north and northeast since 1980 in China. Similarly, Shen et al. (2009) demonstrated that in China the area of increasing wetness was larger than the area of increasing dryness although the course of aridity developed faster than that of humidification. Furthermore, Yao et al. (2013) further analyzed the spatiotemporal distributions of the terrestrial surface moisture conditions from 1961 to 2008 in the Loess Plateau of China, and found that drought gradually reduced from the interior region to the border region. Previous studies are important for understanding various aspects of agricultural production under climate change. However, very limited studies have been conducted to investigate the moisture status during climatic growing period of crops in Northeast China at a regional scale thus far.

Northeast China is a highly sensitive region to climate change due to its high latitude, where seasonality is distinct (Zhao et al., 2007). It is an important production base of commodity grain in China, mainly maize, soybean, wheat, rice and sorghum (Zhao et al., 2015a,b). Under climate change, the agricultural water resources in China will continuously change (IPCC, 2007), which will have major effects on sustainable development of crops and the efficient use of agricultural climatic resources in Northeast China. It is important to know how climate change affects moisture status in Northeast China during crop growth season in order to adapt to cropping systems accordingly.

The objectives of this study were to: (1) quantitatively evaluate the spatiotemporal changes of average annual total precipitation (*P*), reference crop evapotranspiration (ET_0) and relative moisture index from 1961 to 2010 based on 80% guaranteed probability, while daily average temperature stably passing 0 °C; (2) investigate the changes of moisture condition during climatic growth period of crops over the past 50 years in Northeast China; (3) provide scientific evidence for more efficient use of water resources and sustainable development of agricultural production in Northeast China under climate change.

2. Materials and methods

2.1. Study area

Northeast China is an important agricultural, forestry, animal husbandry and industrial production base in China. The region of interest extends from 38.9°N to 53.0°N and includes the entire Heilongjiang, Jilin, and Liaoning Provinces (Fig. 1) (Zhao et al., 2015a,b). The region's climate is characterized as semi-humid, with long cold winter and a windy drought spring. The mean annual air temperature ranges from −4.2 to 10.9 °C, decreasing from south to north. The annual precipitation increases from the northwest (450 mm) to the southeast (1070 mm). The precipitation is generally concentrated in the summer and autumn, and it coincides with the growing season of crops (May–September). The annual total sunshine hours ranged from 2220 to 2930 h, and tended to decrease at 40.6 h per decade ($p < 0.01$) (Liu et al., 2013).

2.2. Data

The data of daily climate variables (mean, maximal and minimal air temperature, precipitation, relative humidity and bright sunshine hours at 2 m height, and wind speed measured at 10 m height), taken at 101 meteorological stations in Northeast China during 1961–2010, were collected from the National Meteorological Information Center. These measured daily climate data were converted to standard input parameters for the ET_0 model (see the following section).

2.3. Threshold determination for climatic growth period of crops

Agricultural threshold temperature is an expression of agricultural heat resources. In agricultural meteorology, threshold temperature is of universal significance, marking the beginning of some important phenology or farming activities. This temperature above which development begins to occur varies between crops and with the stage of development of a single crop. Generally speaking, however, threshold temperatures of 0 °C (brussel sprouts, cabbage, parsley), 5 °C (peas, forages) and 10 °C (corn, soybeans, tomatoes) are considered appropriate for most agricultural crops. Climatic growth period is the potential growth period of crops within a year at a region. It is usually evaluated by the daily average temperature stably passed 0 °C. In this study, the method of 5-day moving average (Zhao et al., 2010a,b; Zhao et al., 2013) was used to determine the initial and final dates of stably passing 0 °C threshold temperature for climatic growth period of crops.

2.4. Reference crop evapotranspiration during climatic growth period of crops

There is a large number of available equations for estimating ET_0 (Penman, 1948; Blaney and Criddle, 1950; Deng, 1979; Allen et al., 1998; Xu et al., 2006; Yin et al., 2008; Valiantzas, 2013). Among these equations, the Penman–Monteith (FAO-56 PM) equation incorporates both energy balance and aerodynamic theory, and hypothesizes reference crop (height of 0.12 m, surface resistance of 70 s m^{-1} and albedo of 0.23). It is recommended as the standard method for estimating ET_0 from full climate records by the Food and Agriculture Organization of the United Nations (FAO) (Manabe, 1981; Zhang et al., 2010; Zhao et al., 2013).