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Does decadal climate variation influence wheat and maize production in the southeast USA?

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ABSTRACT

Linking decadal variability with short-term variability could be potentially exploited for improving seasonal climate forecasting for assisting crop management decisions. The objective of this study was to explore whether there are decadal variations in wheat (winter crop) and maize (summer crop) production and whether these decadal variations correlate with any known variations of climate. Over one hundred years of wheat and maize yields were simulated using process-based crop models with dynamically downscaled daily reanalysis data over four locations in the southeast USA. Using wavelet and cross-wavelet analysis, we found that winter crop yields were dominated by 10- and 22-year decadal oscillations; the decadal variations of winter crop yields were driven by decadal variations of winter temperature and spring precipitation; no decadal variations were detected for summer crop yields and summer precipitation and temperature. Cross-wavelet analysis showed that the decadal variations of winter crop yields were correlated with indices of the annual Atlantic Multi-decadal Oscillation (AMO), the annual Pacific Decadal Oscillation (PDO), and the winter North Atlantic Oscillation (NAO). Therefore, this knowledge of decadal climate variability could potentially be leveraged to predict winter seasonal yields of crops.

1. Introduction

Climate factors have a major influence on crop production (Hoogenboom, 2000). Variability of climate from one year to another poses risks on decision-making of crop management. For example, higher or lower than normal precipitation (drier or wetter season type) can cause damages or bring benefits to farmers. If these climate conditions can be forecasted in advance, decision-makers can benefit from using this information to change their strategies to adapt to the upcoming season type. For example, a forecast of the season type (e.g., wet or dry) before the start of the season could potentially be used to adjust crop management strategies to save input costs in dry seasons and to increase inputs in wet seasons to get higher achievable yields (Asseng et al., 2012a,b).

Teleconnections refer to statistical associations among different climatic variables among large distances. Recent studies have focused on using the teleconnection of large-scale climate patterns with local climate to improve seasonal crop management (e.g., Bannayan et al., 2010; Brown, 2013; Jarlan et al., 2013; Maxwell et al., 2013; Royce et al., 2011; Vizard and Anderson, 2009). In the southeast USA, agricultural yields have found to be influenced by the El Niño South Oscillation (ENSO) (e.g., Hansen et al., 1998, 1999; Royce et al., 2011), as well as other large-scale climate indices including Pacific/North American teleconnection pattern, tropical North Atlantic and eastern tropical Pacific sea surface temperature (SST), and Bermuda high indices (Martinez et al., 2009; Martinez and Jones, 2011). However, most of these studies were based on correlation or regression approaches that assumed the teleconnection relationships did not change through time, but the variability of large-scale climate patterns are often non-stationary processes (e.g., Coulibaly and Burn, 2004) and their relationships with crop yields may change over time. Besides using observed climate teleconnections, GCM-based seasonal forecast tools have

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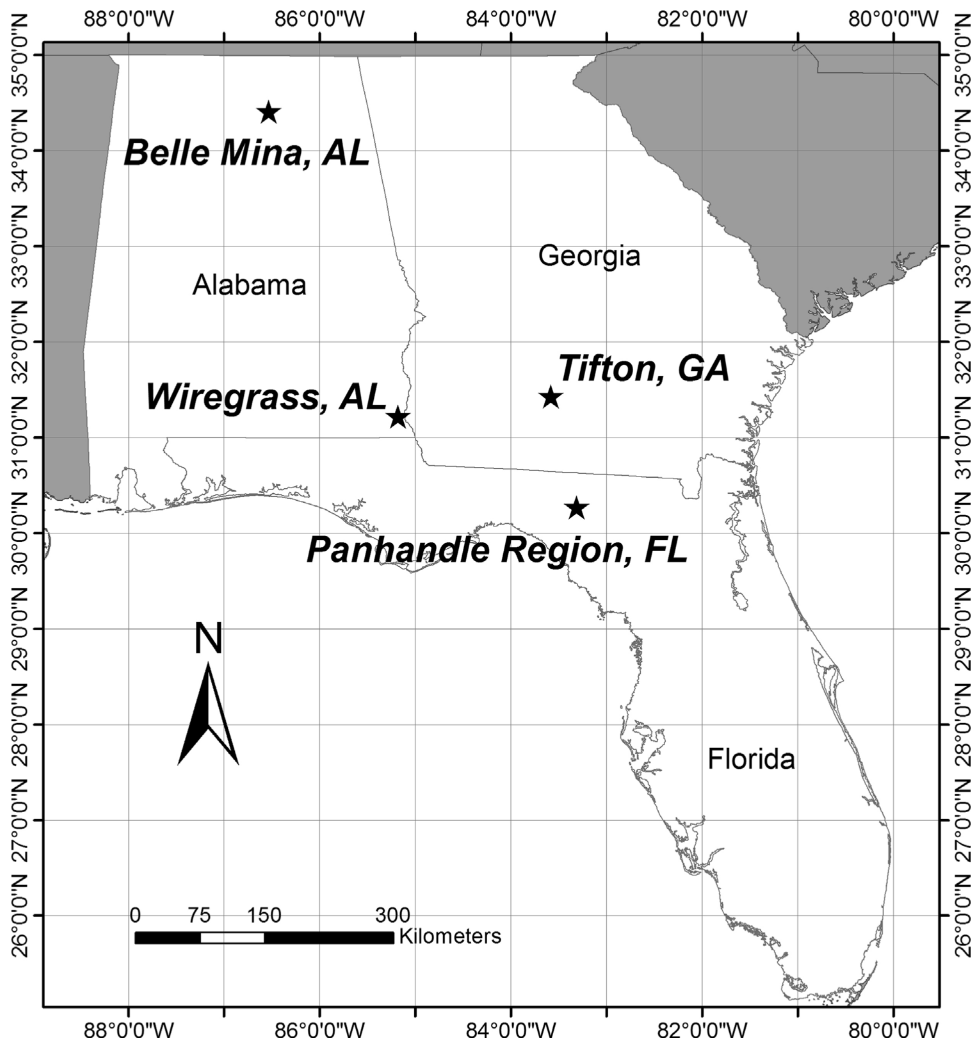

Fig. 1. Study locations in three states of the Southeast USA.

also been used to improve crop management systems in different regions (e.g., Asseng et al., 2012a,b; Baigorria et al., 2010, 2008a,b; Cantelaube and Terres, 2005). However, since the skills of GCMs were still marginal, any crop management improvements from this strategy are limited by the forecast skill of a GCM.

Decadal climate variability information can be potentially combined with the information of short-term climate variability and GCM-based forecasts to further improve seasonal forecasting for crop management. To make use of decadal climate information, the prerequisite step is to know whether there are decadal variations in historical crop production and whether these decadal variations correlate with any known variations of climate. Crop yield and climate data over multiple decades or even a century can be used to investigate the impact of decadal climate on crop yields. Since variation in crop yields is driven by numerous factors not only including fluctuations of climate but also agronomic management (e.g., sowing date, cultivar choice, fertilizer amount, plant density), in this study, dynamic crop simulation models (CSMs) were used as a tool to study the response of crop yields to climate variations by keeping all other factors constant over time. CSMs allow simulating the growth and development of crops beyond a single experimental site, and thus can be used to conduct regional climate impact studies. Climatic inputs such as daily precipitation, temperature, and solar radiation are particularly important for CSMs to simulate crop growth and development (van Ittersum et al., 2003). Since complete sets of these observed weather variables are difficult to obtain over a period of multiple decades at a regional scale, reanalysis data, which provides a temporally and spatially consistent representation of the observed weather, can be used as a surrogate for inputs into CSMs (e.g., Cammarano et al., 2013; Challinor et al., 2005).

This study is aimed to assess the decadal variability of crop yields and the possible links to dominant climatic patterns. Most previous assessment studies were based on correlation- or regression-based analysis between crop yields and the teleconnection pattern indices by assuming stationary time series. However, wavelet analysis has revealed that climatic patterns are non-stationary processes, since their variance, frequency, and duration changes through time (Grinsted et al., 2004; Torrence and Compo, 1998). The time series of climate-driven simulated crop production may also exhibit non-stationarity. Therefore, using wavelet analysis as opposed to traditional stationary approaches can capture the intermittent features of the relationship between time series of simulated crop production and climate factors and can enhance the understanding and potential predictability of crop yields. While in recent years, wavelet analysis has been widely used in detecting non-stationary features and correlations in geophysical time series such as climate and hydrology (e.g., Carey et al., 2013; Liang et al., 2010), this method has not yet been used in assessing the impact of climate variability on crop yields. To the authors' knowledge, this study is the first to introduce wavelet methods to climate impact assessment of crop production.