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Management outweighs climate change on affecting length of rice growing period for early rice and single rice in China during 1991–2012

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ABSTRACT

Whether crop phenology changes are caused by change in managements or by climate change belongs to the category of problems known as detection-attribution. Three type of rice (early, late and single rice) in China show an average increase in Length of Growing Period (LGP) during 1991–2012: 1.0 ± 4.8 day/decade (±standard deviation across sites) for early rice, 0.2 ± 4.5 day/decade for late rice and 2.0±6.0 day/decade for single rice, based on observations from 141 long-term monitoring stations. Positive LGP trends are widespread, but only significant ($P < 0.05$) at 25% of early rice, 22% of late rice and 38% of single rice sites. We developed a Bayes-based optimization algorithm, and optimized five parameters controlling phenological development in a process-based crop model (ORCHIDEE-crop) for discriminating effects of managements from those of climate change on rice LGP. The results from the optimized ORCHIDEE-crop model suggest that climate change has an effect on LGP trends dependent on rice types. Climate trends have shortened LGP of early rice (−2.0 ± 5.0 day/decade), lengthened LGP of late rice (1.1 ± 5.4 day/decade) and have little impacts on LGP of single rice (−0.4 ± 5.4 day/decade). ORCHIDEE-crop simulations further show that change in transplanting date caused widespread LGP change only for early rice sites, offsetting 65% of climate change induced LGP shortening. The primary drivers of LGP change are thus different among the three types of rice. Management are predominant driver of LGP change for early and single rice. This study shows that complex regional variations of LGP can be reproduced with an optimized crop model. We further suggest that better documenting observational error and management practices can help reduce large uncertainties existed in attribution of LGP change, and future rice crop modelling in global/regional scales should consider different types of rice and variable transplanting dates in order to better account impacts of management and climate change.

1. Introduction

The Length of the Growing Period (LGP), defined as the interval in days from the day of planting/transplanting to the day of maturity, is an integrated indicator of crop development that has been related to production (Bassu et al., 2014; Zhang and Tao, 2013). Shortening LGP caused by warmer climate is recognized as a key emerging response through which climate change may impact agricultural production (Bassu et al., 2014; Estrella et al., 2007; Lin et al., 2005; Porter et al., 2014). However, historical change in LGP has been reported diversely across different crops and regions. Some studies found shortening LGP over the past decades (Chmielewski et al., 2004; He et al., 2015; Siebert and Ewert, 2012; Tao et al., 2014b; Xiao et al., 2013). For example, oat in Germany was found to have shorter LGP over the past five decade with rates of change

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ranging from −0.1 to −0.4 day/decade (Siebert and Ewert, 2012). On the other hand, there are also studies finding little change or even a lengthening in LGP (Liu et al., 2012, 2010; Sacks and Kucharik, 2011; Tao et al., 2013; Zhang et al., 2013). For example, maize in the US Corn Belt shows lengthening LGP during 1981–2005 with an average positive trend of 5 day/decade (Sacks and Kucharik, 2011).

The LGP change of China's rice (*Oryza sativa*), which is the staple food resource for more than half of Chinese population and the crop with the largest growing area in the country, has attracted research interest. Observed trends of rice LGP across different stations vary largely from −2 day/decade to more than 7 day/decade over the past 2–3 decades, the majority of the field-scale observations showing either non-significant change or a lengthening of LGP (Liu et al., 2010; Tao et al., 2006, 2013). One hypothesis explaining the lack of evidence for shortening trend of rice LGP was that management practices has counterbalanced the effects of climate change (e.g. Liu et al., 2012; Tao et al., 2013; Zhang et al., 2013). However, large uncertainties remain on the relative contributions of climate change, shifts in transplanting date and other management practices (e.g. use of longer-duration cultivar), which limits our ability to understand the past trends and project the near term evolution of LGP and its possible consequences for future crop production.

Attribution of the observed trend of LGP from past observations remains challenging because both changes in climate and in management practices have taken place simultaneously. Recent studies used statistical models to characterize the interannual sensitivity of rice LGP to temperature and to separate the contribution of the temperature trend to LGP trend for rice and maize crops over the period 1981–2009 (Tao et al., 2014a, 2013; Zhang et al., 2013). This approach has some limitations: first, statistical models built from interannual LGP variations cannot isolate the impact of changing planting dates from the effects of climate change; second, statistical analyses usually assume linear and constant response to climatic variations (Zhang et al., 2013), but several studies showed that the response is neither linear (Lobell et al., 2013) nor constant with time (Lobell et al., 2014; Burke and Emerick, 2015). On the other hand, crop models can provide an alternative mean to further understand mechanisms and quantify the attributions of different drivers (e.g. Lobell et al., 2012). Therefore, a question to ask in complement of the statistical models is whether crop models can be used as an independent method to separate climate change impacts from management. Using crop models factorial simulations where each driver is varied at a time, or combined, instead of statistical models based on historical data can overcome the limitations by having mechanistic representation of climate change impacts (Gregory and Marshall, 2012), but earlier application of crop models for the attribution of rice LGP trends were criticized for lack of validation for the study region (Tao et al., 2013).

The first objective of this study is to optimize a process-based crop model to represent rice phenology in China. The second objective is to run the optimized model for attributing LGP change to climate change and change in various management practices during the last two decades. To achieve these goals, we first collected and harmonized observations of the rice LGP during 1991–2012 from an extensive station network in China (287 sites). Then, a random set of 80% of the sites is used to optimize the process-based crop model (ORCHIDEE-crop) under a Bayesian framework, by calibration of the parameters controlling rice phenology. The optimized model results are then evaluated against the remaining 20% of the site observations. Finally, contributions to LGP trends from climate change, transplanting date change and other management practices (including cultivar change) are separated by comparing the LGP observations and simulations of the optimized model driven by observed and fixed transplanting date.

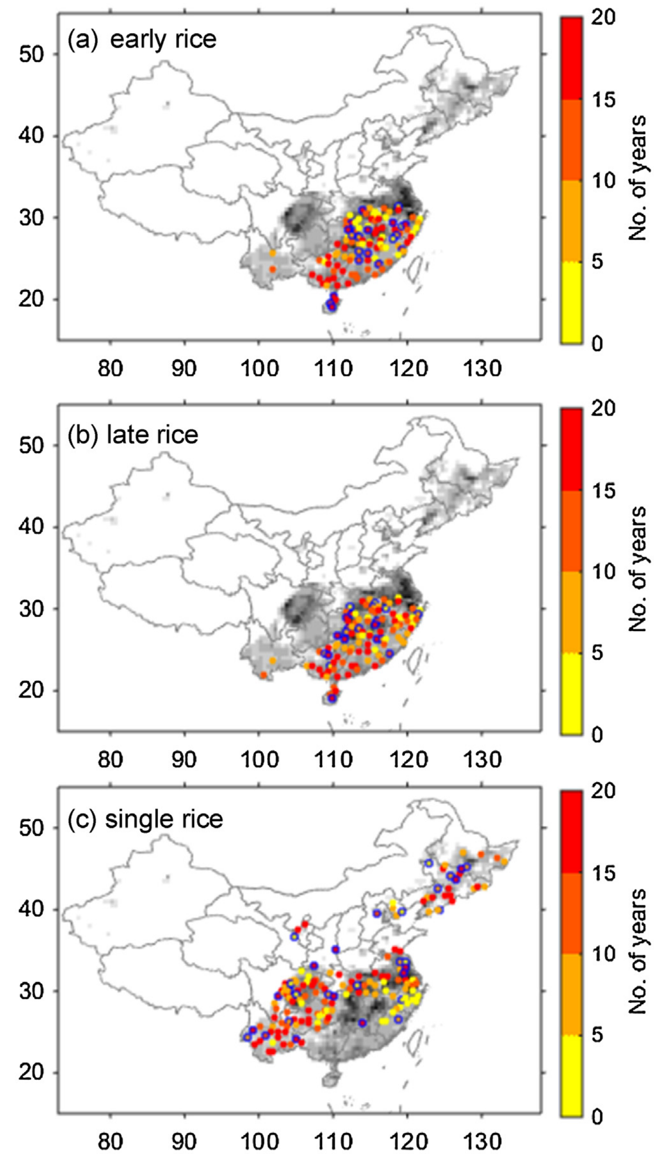

Fig. 1. Spatial distribution of agrometeorological stations in China for (a) early rice, (b) late rice, and (c) single rice. Color shows the number of years of available observations in each station. Blue circle indicates stations randomly selected to cross-validate the model. Grey shading indicates the fraction of rice growing area (Frolking et al., 2002) that darker pixel has larger area of rice croplands. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Methods

2.1. Rice phenology observations from agrometeorological stations

Transplanting and maturity date of rice in China during 1991–2012 were recorded over 287 agro-meteorological field stations by the Chinese Meteorological Administration, covering the entire rice growing area, from the northeast to the southwest and Hainan Island (Fig. 1). The length of These observations were made following a standardized protocol across sites (CMA, 1993). The dataset includes single rice (177 stations), early rice (110 stations) and late rice (110 stations). Early rice and late rice have the same number of stations because they are two consecutive crops on the same site comprising the double rice cropping system (i.e. rotation between early rice and late rice (Tao et al., 2013)). 80% of the 287