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Improving the timeliness of winter wheat production forecast in the United States of America, Ukraine and China using MODIS data and NCAR Growing Degree Day information

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ABSTRACT

Wheat is the most important cereal crop traded on international markets and winter wheat constitutes approximately 80% of global wheat production. Thus, accurate and timely production forecasts are critical for making informed agricultural policies and investments, as well as increasing market efficiency and stability. Becker-Reshef et al. (2010) developed an empirical generalized model for forecasting winter wheat production. Their approach combined BRDF-corrected daily surface reflectance from Moderate resolution Imaging Spectroradiometer (MODIS) Climate Modeling Grid (CMG) with detailed official crop statistics and crop type masks. It is based on the relationship between the Normalized Difference Vegetation Index (NDVI) at the peak of the growing season, percent wheat within the CMG pixel (area within the CMG pixel occupied by wheat), and the final yields. This method predicts the yield approximately one month to six weeks prior to harvest. In this study, we include Growing Degree Day (GDD) information extracted from NCEP/NCAR reanalysis data in order to improve the winter wheat production forecast by increasing the timeliness of the forecasts while conserving the accuracy of the original model. We apply this modified model to three major wheat-producing countries: the Unites States (US), Ukraine and China from 2001 to 2012. We show that a reliable forecast can be made between one month to a month and a half prior to the peak NDVI (meaning two months to two and a half months prior to harvest), while conserving an accuracy of 10% in the production forecast.

1. Introduction

Following the food price spikes in recent years, there has been increased international demand for more accurate and timely crop production forecasts at national to global scales. Such information is essential to making informed national and international agricultural policies, stabilizing markets, enhancing market access and averting food shortages. The utility of remotely sensed methods for timely crop monitoring and forecasting has been demonstrated extensively across a variety of crops and geographic scales (Delécolle, Maas, Guérif, & Baret, 1992; Idso, Hatfield, Jackson, & Reginato, 1979; Johnson, 2014; Lobell, Asner, Ortiz-Monasterio, & Benning, 2003; Maselli, Moriondo, Angeli, Fibbi, & Bindi, 2011; Mkhabela, Mkhabela, & Mashinini, 2005; Moriondo, Maselli, & Bindi, 2007; Huang et al., 2015). Atzberger (2013) recently provided an extensive review of existing remote sensing based agriculture monitoring systems. He highlighted four key challenges addressed to the remote sensing scientific community for supporting the agricultural sector: (i) yield estimation, (ii) stress monitoring, (iv) crop phenology monitoring, (iv) land-cover mapping and land-cover change monitoring.

Several remote sensing forecasting methods are based on deriving empirical relationships between vegetation indices during a specific phenological stage, and final yields (Dente, Satalino, Mattia, & Rinaldi, 2008; Kouadio et al., 2012; Wit, Duveiller, & Defourny, 2012). Pioneering work carried out in this field, such as by Fischer (1975), found that wheat yields could be forecasted as a function of the leaf area at the onset of the reproductive stage, which corresponds to the timing of maximum crop green leaf area. In the case of wheat, studies have found a strong correlation between the peak of the Normalized Different Vegetation Index (NDVI, Rouse, 1974), which corresponds closely to the reproductive stage, and final wheat yields (Groten, 1993; Mahey et al., 1993; Rasmussen, 1992; Smith, Adams, Stephens, & Hick, 1995; Tucker, Holben, Elgin, & McMurtrey, 1980). Nevertheless, one of the challenges in crop forecasting over large areas, such as at the state or national scale using remote sensing data, is the variability in climatic zones, which can result in different timing of crop development. This means that in cooler parts of a country, wheat will reach the reproduction stage later than in warmer areas. This, therefore, presents a challenge to producing a timely national scale forecast prior to the NDVI peak of the croplands in the cooler areas.

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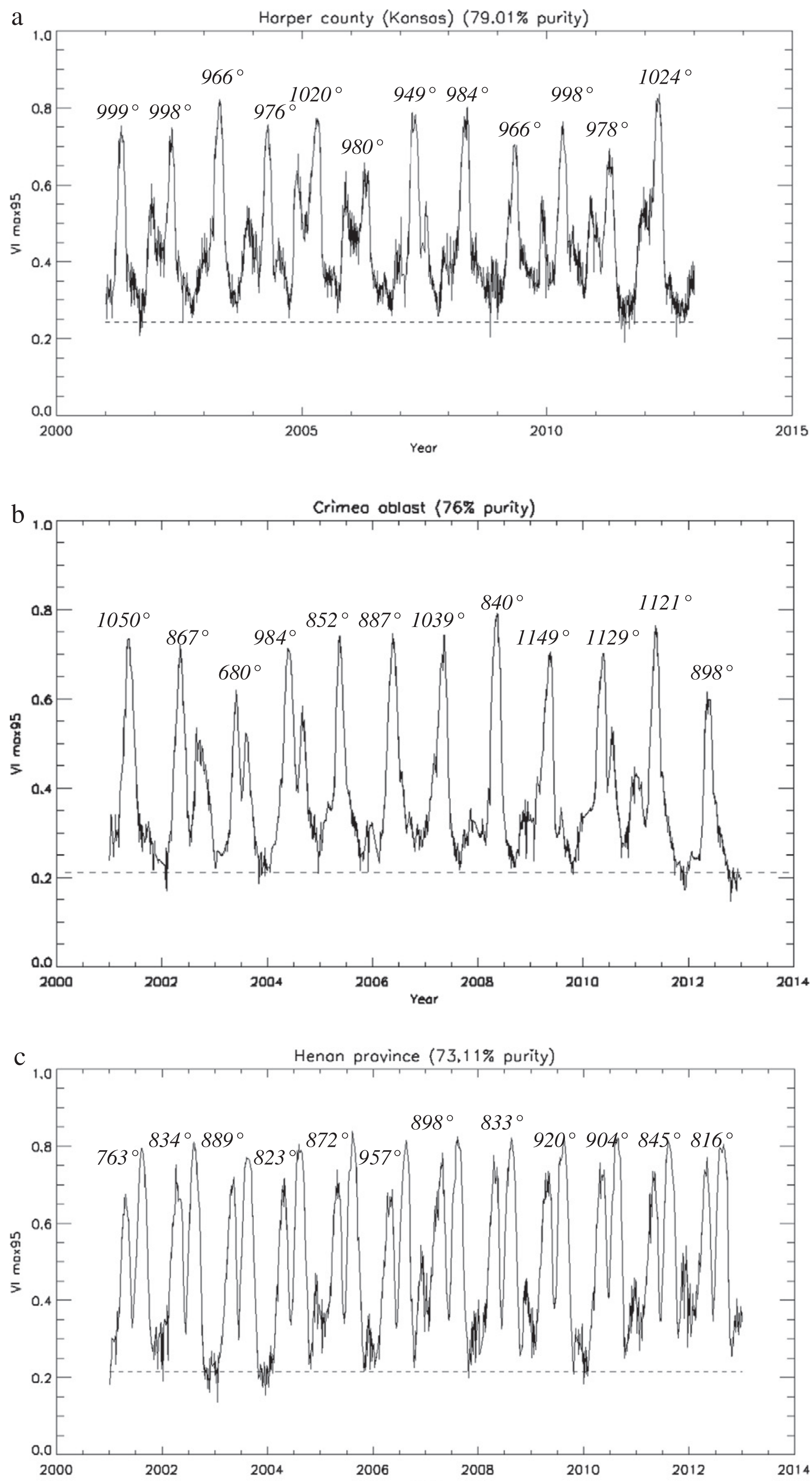

Fig. 1. Example of the $ANDVI_{day,year}$ time-series for a) the Harper county (Kansas, US), b) the Autonomous Republic of Crimea (Ukraine) and c) the Henan province (China), which are the top wheat producing administrative units in each country analyzed. The numbers in italics are the accumulated GDD during the NDVI peak.