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From grid to field: Assessing quality of gridded weather data for agricultural applications

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ABSTRACT

High quality measured weather data (MWD) are not available in many agricultural regions across the globe. As a result, many studies that dealt with global climate change, land use, and food security scenarios and emerging agricultural decision support tools have relied on gridded weather data (GWD) to estimate crop phenology and crop yields. An issue is the agreement of GWD with MWD and the degree to which this agreement may influence the utility of GWD for agricultural research. The objectives of this study were: (i) to compare the agreement of two widely used gridded weather databases (GWDs) (Daymet and PRISM) and MWD, (ii) to evaluate their robustness at simulating maize growth and development, and (iii) to examine how GWD compare relative to weather data interpolated from existing meteorological stations for which MWD are available. The U.S. Corn Belt, a region that accounts for 43 and 34% of respective global maize and soybean production, was used as a case of study because of its dense weather station network and high-quality MWD. Historical daily MWD were retrieved from 45 locations across the region, resulting in *ca.* 1300 site-years. To test the accuracy of GWDs, separate simulations of maize yield and development were performed, separately for the two GWDs and MWD, using a well-validated maize crop model. For both GWDs, small biases were observed for temperature and growing degree-days in relation with MWD. However, accuracy was much lower for relative humidity, precipitation, reference evapotranspiration, and degree of seasonal water deficit. There was close agreement in duration of vegetative and reproductive phases between GWD and MWD, with root mean square error (RMSE) ranging from 3 to 7 days for the different crop phases and GWDs. However, robustness of GWDs to reproduce maize yields simulated using MWD was lower as indicated by the RMSE (18 and 24% of average yield for Daymet and PRISM, respectively). There was also a high proportion of site-years (20 and 32% for Daymet and PRISM, respectively) exhibiting a yield deviation >15% in relation to the yield simulated using MWD. Data interpolation using a dense weather station network resulted in lower RMSE% for simulated phenology and yields relative to GWDs. Findings from this study indicate that GWD cannot replace MWD as a basis for field-scale agricultural applications. While GWD appear to be robust for applications that only require temperature for prediction of crop stages, GWD should not be used for applications that depend on accurate estimation of crop water balance, crop growth, and yield. We propose that the evaluation performed in this study should be taken as a routinary activity for any research or agricultural decision tool that relies on GWD.

1. Introduction

Lack of measured daily weather data (MWD) at appropriate spatial resolution is a serious constraint to forecast current and future effect of weather on crop yields and to develop and use agricultural decision-support tools for crop and inputs management (Van Wart et al., 2013, 2015; Grassini et al., 2015). This phenomenon seems to be ubiquitous, even for important agricultural regions in developed countries such as the US Corn Belt (Fig. 1A). A fairly dense station network (2125 weather stations) has been established in this region (Fig. 1B). However, many of these stations are located at airports and cities and, therefore, MWD cannot reliably be used for agricultural applications. Likewise, most of these stations only measured rainfall and sometimes temperature but do not include other important variables for crop growth and yield such as solar radiation and humidity. When only weather stations

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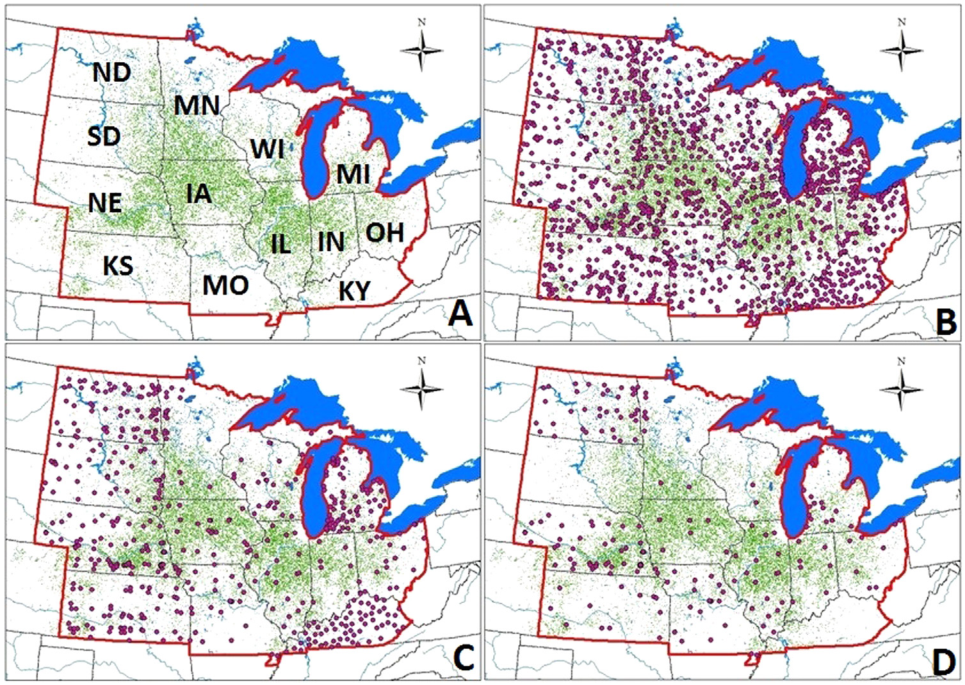

Fig. 1. (A) Map of the US Corn Belt, including portions of the Central Great Plains region (ND-North Dakota, SD-South Dakota, NE-Nebraska, KS-Kansas, MN-Minnesota, IA-Iowa, MO-Missouri, WI-Wisconsin, IL-Illinois, MI-Michigan, IN-Indiana, OH-Ohio, and KY-Kentucky). Red line shows the extent of the region. Area sown with maize and soybean is shown in green. (B) Location of all active and inactive meteorological stations collecting daily weather data. (C) Distribution of stations located in agricultural areas and collecting data for all agronomically relevant variables. (D) Distribution of active weather stations with publicly available, long-term (>15 years) daily weather data records for all agronomically relevant weather variables and located in agricultural areas. Each circle indicates the location of a meteorological station. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

measuring all weather variables needed for agricultural applications (radiation, temperature, humidity, and wind speed) located in agricultural areas are considered, total number reaches 529 (including inactive stations) and average coverage reaches 4026 km^2 per station (Fig. 1C). Additionally, the distribution of the stations is uneven resulting in states with a dense network (*e.g.,* Kentucky, North Dakota, and Nebraska) and states with a sparse to almost non-existing network (*e.g.,* Minnesota and Wisconsin). Many stations have stopped to be operated in recent years or data are not publicly available (*e.g.,* South Dakota). Other stations have started to be operated in recent years *e.g.,* Kentucky; these stations are of limited used for agricultural applications that require long-term records to account for weather variability. Considering only active stations with complete long-term daily data (>15 years and missing observations <10%), the number for which is possible to obtain reliable, long-term daily weather data is only 184, which translates to an average coverage of 11,575 km^2 per station (Fig. 1D).

The current trend of increasingly higher volume of gridded weather data (GWD), in contrast to increasing scarcity of (or lack of access to) MWD, has led researchers to use GWD as basis for assessments on climate change, food security and land use (Mourtzinis et al., 2015, 2016; Overpeck et al., 2011; Van Wart et al., 2013 and references cited therein). Likewise, GWD have started to be used for agricultural-related research and decision-support tools to guide crop and input management (*e.g.,* https://www.ral.ucar.edu/solutions/decision-support-tools-farmers, https://ifdc.org/decision-support-tools/; Daly et al., 2012; Miner et al., 2013). GWD are typically generated from satellite images or interpolations from meteorological stations using a collection of tortuous and empirical algorithms to produce gridded estimates of daily weather parameters at the desired spatial and scale. Influence of the level of weather data spatial aggregation on crop simulations has been investigated in previous studies (Angulo et al., 2013; Zhao et al., 2014; Rezaei et al., 2015). However, very few studies have evaluated these GWDs on their agreement with MWD from stations located within the same grid have indicated lack of agreement and important biases (Ramirez-Villegas and Challinor, 2012; Van Wart et al., 2013, 2015). However, these previous evaluations have been based on GWDs with coarse spatial resolution (from 3000 to 70,000 km^2), such as NASA-POWER National Aeronautics & Space Administration; http://power.larc.nasa.gov/), NCEP (National Center for Environmental Prediction/Department of Energy; http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis2.html), and CRU (Climate Research Unit; http://badc.nerc.ac.uk/data/cru/). There is lack of a robust assessment of most recent GWDs, with more granular spatial resolution (<20 km^2), relative to their potential use for agricultural applications. And while some of these GWDs have been evaluated by comparing them against MWD, these previous evaluations can benefit from using a crop simulation model that integrates the effects of weather, management practices, soils, and crop cultivars on crop development, growth, and yield (Van Ittersum et al., 2013; Van Wart et al., 2013, 2015).

In the present study, we evaluated accuracy of state-of-art GWD containing daily weather data at high level of spatial resolution. We used the US Corn Belt as a case of study because it covers one of the most important agricultural areas of the world, with substantial spatial weather and soil variation, and has a fairly dense network of weather stations with long-term daily MWD including all the weather variables needed for agricultural applications. We assessed accuracy of GWD by comparing their agreement with high-quality MWD as well as associated simulated crop phenology and yields based on a well-validated crop model and using actual dominant soil and management practices for each location. As an alternative approach to GWD, we also evaluated the accuracy of weather data interpolated from nearby weather stations and how this accuracy depended upon the density of the weather station network.

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