Evaluation of NASA Satellite- and Model-Derived Weather Data for Simulation of Maize Yield Potential in China

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Agroclimatology

ABSTRACT

Use of crop models is frequently constrained by lack of the required weather data. This paper evaluates satellite-based solar radiation and model-derived air temperature (maximum temperature, T_{max}; minimum temperature, T_{min}) from NASA and their utility for simulating maize (*Zea mays* L.) yield potential at 39 locations in China's major maize-producing regions. The reference data in this evaluation were the corresponding ground-observed weather data and simulated yield using these data. NASA weather data were closely correlated with data from ground weather stations with an $r^2 > 0.8$, but a systematic underestimation of air temperature was found (T_{max} of −2.8°C; T_{min} of −1.4°C). As a result, use of NASA data alone for yield simulation gave poor agreement with simulated yields using ground weather data ($r^2 = 0.2$). The simulations of yield potential using satellite-derived solar radiation, coupled with temperature data from ground stations, agreed well with simulated results using complete ground weather data in three of the five regions ($r^2 > 0.9$). The agreement in the other two regions was relatively poor ($r^2 = 0.62$ and 0.64). Across all 710 site-years evaluated, the agreement was shown with a mean error (ME) = 0.2 t ha^{-1}, a root mean square error (RMSE) = 0.6 t ha^{-1}, and $r^2 = 0.9$. Our results indicate that combining NASA solar radiation with ground-station temperature data provides an option for filling geospatial gaps in weather data for estimating maize yield potential in China.

Daily weather data are required to run most crop simulation models. Data quality varies depending on the source, which can introduce uncertainty in crop simulation results unless the weather data are carefully vetted (Aggarwal, 1995; Rivington et al., 2006). Among weather variables, daily total solar radiation and air temperature (T_{max} and T_{min}) have the greatest influence on crop phenology and yield potential when biotic and abiotic stresses are absent. However, these data are not always available for regional simulation studies because of spatial gaps in weather station coverage (Prihodko and Goward, 1997; Rivington et al., 2005). Solar radiation data are scarce (Thornton and Running, 1999; Chen et al., 2004) and require careful quality assurance (Fodor and Kovacs, 2005; Fritschen and Fritschen, 2007). To fill gaps in the data, the required weather variables are often estimated from existing weather station networks by spatial interpolation (Stahl et al., 2006) or by deriving missing variables, such as daily total solar radiation, from more commonly measured weather variables, such as sunshine hours (Lin and Lu, 1999; Almorox and Hontoria, 2004) or temperature (Mahmood and Hubbard, 2002; Donatelli et al., 2003; Mavromatis and Jagtap, 2005). Because most of the estimation methods are empirical, their accuracy across a wide range of environments and geographic regions is uncertain. For example, Chen et al. (2004) concluded that temperature-based models were unsuitable for solar radiation estimation in China, and they found substantial variability in the empirical coefficients used to make these estimates (Chen et al., 2006).

Satellite-sensed weather data have been proposed as an alternative when weather station data are not available (Pinker et al., 1995; Lakshmi and Susskind, 2000). Satellite weather data have been used for crop yield simulations (de Wit and van Diepen, 2008) and evapotranspiration estimation (Bois et al., 2008). NASA has recently established an online database of satellite- and model-derived weather data (Stackhouse, 2006). The database provides complete daily weather variables, including total solar radiation, T_{max}, T_{min}, average temperature, precipitation, dew point, and relative humidity, which are all required to run crop simulation models. The NASA data used in our study were obtained from the Prediction of Worldwide Energy Resources (POWER) at the NASA Langley Research Centre (Stackhouse, 2006), which provides global coverage at a spatial resolution of 1° latitude by 1° longitude. For most variables, data are available for the past 25 yr and are continually updated to within 1 to 2 wk of the present time. In the current study, we used data from 1984 through the end of 2003.

China is one of the largest countries in the world, but there are only 122 weather stations nationwide that measure a complete set of daily weather variables, including solar radiation, required for running crop simulation models (CMDSSS, 2005). Crop modeling for nationwide studies is only possible at very coarse resolution. Maize is one of China's major crops and

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Abbreviations: DOY, day of year; ME, mean error; NC, North-Central China region; NE, Northeast China region; NW, Northwest China region; RMSE, root mean square error; SW, Southwest China region; T_{max}, maximum temperature; T_{min}, minimum temperature; YHR, Yellow-Huai River Valley.

is grown in six agroecological zones, including the Northeast (NE), North-Central (NC), Northwest (NW), Yellow-Huai River Valley (YHR), Southwest (SW), and South China regions (Meng et al., 2006; Fig. 1). Diverse maize cropping systems have been developed to adapt to the diverse climatic conditions (from cold temperate in NE to subtropical in SW) and geographical environments (from large plains in NE to hilly regions in SW). The total maize area in the five major maize-producing regions (excluding South China) is about 24 million ha, which represents 90% of total maize production in China, and about 18% of global maize production.

For a populous country like China, it is important to predict spatial trends in crop production capacity. Crop simulation models provide a means to assess such trends and to perform ex-ante evaluation of crop and soil management options to improve productivity across a wide range of soil and climatic conditions. This is important for maize in China given the diversity of cropping systems and environments in which this crop is grown. When suitable weather data are available, simulation models such as the Hybrid-Maize model provide powerful tools for interpreting geospatial patterns in crop yield potential and its variability (Grassini et al., 2009), and the interactive effects of various crop and soil management options in relation to year-to-year climate variation (Yang et al., 2004, 2006). The objectives of this study were to (i) evaluate differences between NASA satellite- and model-derived weather data and ground station data, and (ii) quantify the impact of such differences on simulated yield potential of maize at 39 locations in the five major maize-producing agroecological zones in China.

MATERIALS AND METHODS

Site Selection and Sources of Weather Data

We selected 39 weather stations maintained by the China Meteorological Administration (CMA) across the five maize-planting regions based on the criterion of having at least 10 yr of daily weather records for total solar radiation, T_{max} and T_{min}, and good geographical coverage of the maize production area within each zone (Fig. 1 and Table 1). Based on each site's coordinates and elevation, corresponding daily weather data for

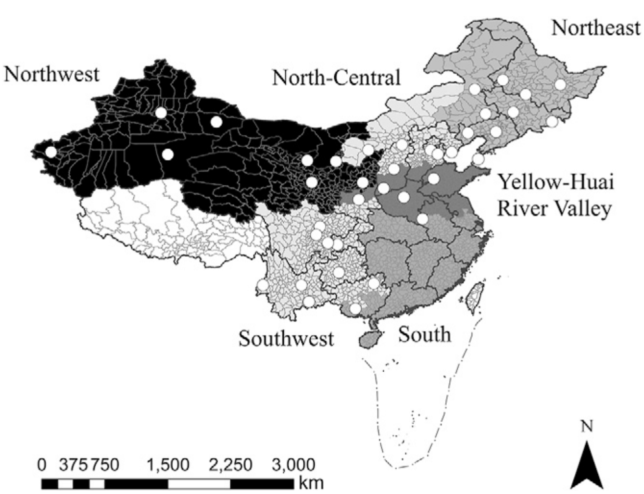

Fig. 1. Major agroecological regions for maize production in China (Meng et al., 2006), and the locations of the 39 selected sites (white circles) used in this study.

the same periods were downloaded from the NASA POWER database (Stackhouse, 2006).

In the POWER database, the solar radiation data are derived from an ensemble of global satellite observations of cloud parameters and reflected shortwave radiation emerging from the earth's atmosphere. These data are obtained from the NASA International Satellite Cloud Climatology Project (ISCCP) DX data product (Travis, 2007). The surface solar radiation is estimated from the ISCCP data and other supporting atmospheric data according to the procedure described by (Gupta et al., 2006). Currently, through the NASA POWER

Table 1. Location, elevation, and general topography of the 39 selected weather stations in major maize-growing areas of China.

Region and site	Latitude	Longitude	Elevation	Topography†
			m	
Northeast				
Jimushi	46°49′ N	130°17′ E	81	2
Harbin	45°45′ N	126°46′ E	142	2
Fuyu	47°48′ N	124°29′ E	163	2
Changchun	43°54′ N	125°13′ E	237	2
Yanji	42°53′ N	129°28′ E	177	1
Suolun	46°36′ N	121°13′ E	500	2
Tongliao	43°36′ N	122°16′ E	179	2
Shenyang	41°44′ N	123°27′ E	45	2
Chaoyang	41°33′ N	120°27′ E	170	1
Dalian	38°54′ N	121°38′ E	92	1
North-Central				
Dosheng	39°50′ N	109°59′ E	1460	3
Beijing	39°48′ N	116°28′ E	31	2
Tianjin	39°05′ N	117°04′ E	3	1
Datong	40°06′ N	113°20′ E	1067	3
Taiyuan	37°47′ N	112°33′ E	778	2
Leting	39°26′ N	118°53′ E	11	2
Northwest				
Wulumuqi	43°47′ N	87°37′ E	918	4
Hami	42°49′ N	93°31′ E	737	2
Kashi	39°28′ N	75°59′ E	129	2
Ruoqiang	39°02′ N	88°10′ E	888	2
Yinchuan	38°29′ N	106°13′ E	1111	3
Mingqing	38°38′ N	103°05′ E	1367	3
Lanzhou	36°03′ N	103°53′ E	1517	3
Yanan	36°36′ N	109°30′ E	959	2
Yellow-Huai River Valley				
Jinan	36°41′ N	116°59′ E	52	2
Houma	35°39′ N	111°22′ E	434	2
Xian	34°18′ N	108°56′ E	398	2
Zengzhou	34°43′ N	113°39′ E	110	2
Gushi	32°10′ N	115°40′ E	57	2
Southwest				
Mianyang	31°28′ N	104°41′ E	471	4
Chongqing	29°35′ N	106°28′ E	259	4
Chengdu	30°40′ N	104°01′ E	506	2
Luzhou	29°53′ N	105°26′ E	335	4
Guiyang	26°35′ N	106°43′ E	1074	3
Kunming	25°01′ N	102°41′ E	1892	3
Tengchong	25°01′ N	98°30′ E	1655	3
Mengzi	23°23′ N	103°23′ E	1301	3
Guilin	25°19′ N	110°18′ E	164	4
Nanning	22°49′ N	108°21′ E	73	2

† The topography of each site is classified by the following definitions: 1, coastal plain (within 100 km of the coast); 2, low elevation plain (<1000 m); 3, high altitude plain (>1000 m); and 4, hilly or mountainous.

database, the daily solar radiation data spans the time period from 1 July 1983 to within 2 to 3 wk of current time.

The air temperature data in the POWER database are obtained from the Goddard Earth Observing System global assimilation model version 4 (GEOS-4). Temperatures from the GEOS-4 assimilation model are estimated via an atmospheric analysis performed within a data assimilation context that combines information from irregularly distributed atmospheric observations with a model state obtained from a forecast initialized from a previous analysis (Bloom et al., 2005). The GEOS-4 analysis provides global estimates of the vertical distribution of a range of atmospheric parameters at 3-h intervals. The daily ground-level maximum and minimum temperature from the NASA POWER database are based on 3-h interval estimates for an elevation of 2 masl. Both the temperature and solar radiation data from the NASA POWER database represent averaged values over a 1-degree grid.

The degree of agreement between corresponding weather variables from the NASA and ground stations was evaluated for the typical maize growing season at each location in zones with a single maize crop per year {from beginning of April [Day of Year (DOY) 92] to the end of October (DOY 304)}, or for the entire year in the SW where maize is grown year-round. All weather data were examined for missing values. A given year at a site was excluded from the evaluation if, during the growing season, it had missing values for (i) more than 30 d total, or (ii) more than 6 d within a month, or (iii) more than three consecutive days within a month. Single missing values were replaced by average values of adjacent days. For ground stations that had consecutive missing weather data of <4 d per month, the gaps were filled using the NASA data. For solar radiation, missing values represented only 0.05 to 2.4% of all daily observations for individual sites, and only 19 yr out of 729 total site-years were excluded from the analysis.

Simulation of Maize Yield Potential

We chose the Hybrid-Maize model because it combines the strength of different maize modeling approaches and has been validated against field data for irrigated maize grown under nonstress conditions that allow expression of yield potential (Yang et al., 2004, 2006; Liu et al., 2008; Grassini et al., 2009). For the purpose of this study, we define yield potential following Evans (1993), namely, the yield of a cultivar when grown in an environment to which it is adapted, with nonlimiting nutrients and water, and effective control of pests, diseases, weeds, lodging, and other stresses. The Hybrid-Maize model requires daily total solar radiation, T_{max}, and T_{min} to simulate yield potential. Other model inputs include hybrid maturity, date of planting, and plant population. Selections of these input values were based on farmer's practices in each region, including choice of cultivar maturity and planting date (Meng et al., 2006). Plant population was set according to "best management practice" recommendations given by district agronomists, with 50,000 plants ha^{-1} for NE, North, and NW regions, 60,000 plants ha^{-1} for the YHR, and 55,000 plants ha^{-1} for the Southeast.

For each site in our study, maize grain yield potential (at 15.5% moisture content) was simulated using all years for which weather data from both a ground station and the NASA database were available. Simulations were performed using three approaches: (i) the ground station weather data; (ii) the NASA weather data; and (iii) the ground station data for T_{max} and T_{min}, and solar radiation from NASA.

Statistical Analysis

The ME, RMSE, and r^2 were used to evaluate the NASA weather data and its use in yield potential simulation for each site or region. The reference data used for such evaluation were ground-observed weather data and simulated yield potential, accordingly.

The ME, a measure of accuracy, is calculated as

$$\mathrm{ME} = \frac{1}{n}\sum(Q_{est} - Q_{obs}) \qquad [1]$$

where Q_{est} is the NASA weather data (MJ m^{-2} d^{-1} or °C) or the simulated yield in t ha^{-1} using the NASA weather data or the combination of T_{max} and T_{min} from the ground station and solar radiation from NASA database; Q_{obs} is the ground-observed weather data or the simulated yield using the ground station weather data; and n is the number of paired values. In addition, the ME was plotted against DOY to evaluate the temporal distribution of the agreement.

The RMSE, a measure of precision, is calculated as

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum(Q_{est} - Q_{obs})^2} \qquad [2]$$

The coefficient of determination (r^2) was obtained from regressions of Q_{est} against Q_{obs}.

Weiss et al. (2001) evaluated the effect of three different daily solar radiation data (the ground station data and the estimated data by two algorithms) on the crop yields simulated by EPIC (Erosion Productivity Impact Calculator; Williams et al., 1984) for three crops and eight sites in the U.S Great Plains. In their study, ANOVA performed in PROC MIXED has been used to analyze the response of simulated yield to the fixed effects of site, crop, and solar irradiance. In our study, to test if the simulated yield potential differed when based on solar radiation from NASA versus solar radiation from ground weather stations and if the magnitude of difference varied across sites in China's five major maize-producing regions, PROC GLM in SPSS 13.0 for Windows statistical software (SPSS, 2004) was used to analyze the response of simulated yield to the fixed effects of site and source of solar radiation data, either from ground or satellite-based measurements in different regions. The response variable was simulated yield and a full two-way factorial ANOVA for site and solar radiation was evaluated in whole and partial regions.

RESULTS

Comparisons of Weather Data

Nationally, NASA daily solar radiation values were reasonably well correlated with the ground station data (Table 2). The r^2 value was 0.8, and the RMSE was 3.4 MJ m^{-2} d^{-1}, or 21% of the absolute ground-measured value. However, NASA solar radiation values were larger than ground station measurements (represented by a positive bias) from weather stations in most of the major maize-producing areas. Among all sites, 72% showed a positive bias and 85% of the sites had a difference between

Table 2. Regional summary of the degree of agreement between weather variables estimated by a NASA satellite and model system and ground-based measurements at existing weather stations at 39 sites in China. Weather variables include daily total solar radiation, maximum temperature (T_{max}), and minimum temperature (T_{min}).

Region	n	Total solar radiation ME	Total solar radiation RMSE	Total solar radiation r^2	T_{max} ME	T_{max} RMSE	T_{max} r^2	T_{min} ME	T_{min} RMSE	T_{min} r^2
		$MJ\ m^{-2}\ d^{-1}$			°C			°C		
NE	38,766	0.7	3.3	0.8	–1.9	3.1	0.9	0.1	2.4	0.9
NC	21,087	1.1	3.2	0.8	–1.6	3.2	0.8	–0.4	2.4	0.9
NW	31,950	–1.1	3.7	0.8	–4.6	6.0	0.7	–2.7	4.8	0.7
YHR	19,809	1.9	3.6	0.8	–1.4	3.8	0.7	–1.1	3.1	0.8
SW	67,937	1.4	3.5	0.8	–3.9	5.0	0.9	–2.8	4.0	0.9
All regions	179,549	0.7	3.4	0.8	–2.8	4.0	0.9	–1.4	3.2	0.9

–2.0 and 2.0 MJ m^{-2} d^{-1} (Fig. 2a). The sites with a negative bias were mostly located in the arid and semiarid NW region (Fig. 2a and Table 1). The difference between the NASA and ground station data varied during the maize growth season tested in our study (Fig. 3a). A larger difference happened between November (304 d) and March (92 d). The difference was smallest in the 50-d period of peak grainfilling, from 190 to 250 d (July and August).

Similar to daily solar radiation, NASA temperature data correlated well with the ground station temperature with an overall $r^2 = 0.9$ for both T_{max} and T_{min} (Table 2). However, both NASA T_{max} and T_{min} were consistently lower than the ground station measurements for about 90% of all sites under study (Fig. 2b and 2c). The overall difference in T_{max} (–2.8°C) was nearly two-fold greater than for T_{min} (–1.4°C). While this systematic negative bias for T_{max} and T_{min} was consistent over the entire maize growing season, the bias was greatest from November to March (Fig. 3b and 3c).

The degree of correlation between NASA and ground station values for solar radiation was similar across regions and at national level (Table 2). NASA daily solar radiation was consistently greater than ground measurements in all but the NW region. The best agreement between NASA and ground-measured solar radiation was found in the NE region, which had smaller ME and RMSE, and largest r^2. The NW region ranked highest in absolute RMSE, on a relative basis the NW region RMSE was 19% of the mean solar radiation, which was comparable with that of NE (20%) and NC (19%), and smaller than that of YHR (24%) and SW (31%) regions. For air temperature, the negative bias for T_{max} and T_{min} existed in all regions except for a small positive bias of T_{min} in the NE (Table 2). Across regions, RMSE ranged from 3.1 to 6.0°C for T_{max}, and 2.4 to 4.8°C for T_{min}.

Comparisons of Simulated Maize Yield Potential

Maize yield potential simulated with at least 10 yr of ground station weather data varied widely across the five regions (Fig. 4). Site averages ranged from 5.3 t ha^{-1} at Jimushi at high N latitude and short growing season in the NE to 11.7 t ha^{-1} at Kashi (NW), an arid location where solar radiation levels are relatively high (Table 1). Mean yield potential was 9.3 t ha^{-1} across all 710 site-years under evaluation.

Using only NASA weather data resulted in higher simulated maize yield potential (overall ME = 1.4 t ha^{-1}, RMSE = 2.6 t ha^{-1}) than simulations based on ground station data except for four sites (Fig. 5a). Correlations between simulations using NASA versus ground weather data were very poor ($r^2 = 0.2$ across all sites, Fig. 5b). At two sites in NW, the simulated crop never reached maturity due to early frost because the much lower NASA air temperatures extended the simulated growth period into late fall. No pronounced regional differences were found for performance of yield simulation using NASA data comparing with that using ground-measured data (Fig. 5a and 5b).

In contrast, when NASA solar radiation was used in combination with ground station T_{max} and T_{min}, simulated maize yield potential agreed reasonably well with simulations using only ground station data (Fig. 5c and 5d). Whereas the overall ME was 0.2 t ha^{-1} with an RMSE of 0.6 t ha^{-1} and $r^2 = 0.89$ across all sites (Fig. 4), there were regional differences in the degree of agreement between the estimates of yield potential (Table 3, Fig. 4). The ANOVA was conducted for the simulated yields using NASA or ground-measured solar radiation in combination with ground-measured temperature for all sites in each region (Table 3). This ANOVA confirmed the significance of regional differences in estimates of yield potential and also the lack of a significant site × solar radiation data source interaction for all regions except the SW. For the NE, NC, and NW regions where the radiation effect and radiation × site interaction was not significant, differences in simulated yields using ground-measured solar radiation or satellite-based radiation were similar across locations. For the YHR and SW regions, the simulated yield using NASA solar radiation data was different from that using ground-based data due to consistent differences between yield estimates using these different sources of radiation data, a highly significant interaction between the site and the source of solar radiation data, or both (Table 3).

DISCUSSION

NASA satellite-derived daily solar radiation values and the NASA modeled temperature data that are required for simulating crop yield potential were compared with corresponding ground-observed weather data across 39 sites that are representative of the major maize-producing regions in China. The uncertainties of weather data comparison between site- or regional-average satellite observations and local point-measurements has been evaluated in detail elsewhere (Pinker et al., 1995; Zelenka et al., 1999). Both data sources have inherent errors and uncertainties. Uncertainties related to satellite parameters include pixel size, sensor resolution, navigation time, algorithm accuracy, and geographical coincidence of instantaneous information recorded by a satellite with measurements on the ground. For example, Pinker and Laszlo (1992) showed that the difference between ground-based

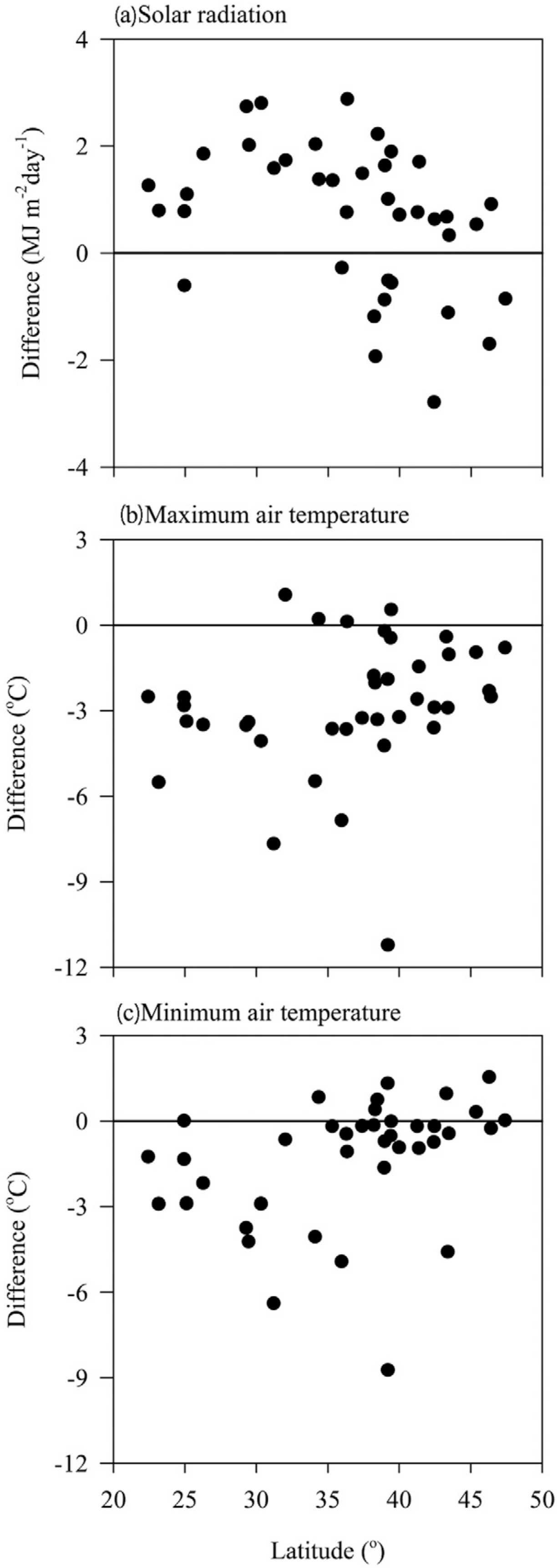

Fig. 2. Differences between daily weather variables estimated by a NASA satellite and model system and ground-based measurements at existing weather stations at 39 sites in China: (a) total solar radiation; (b) maximum air temperature (T_{max}); (c) minimum air temperature (T_{min}). Zero bias is indicated by a horizontal line in each panel.

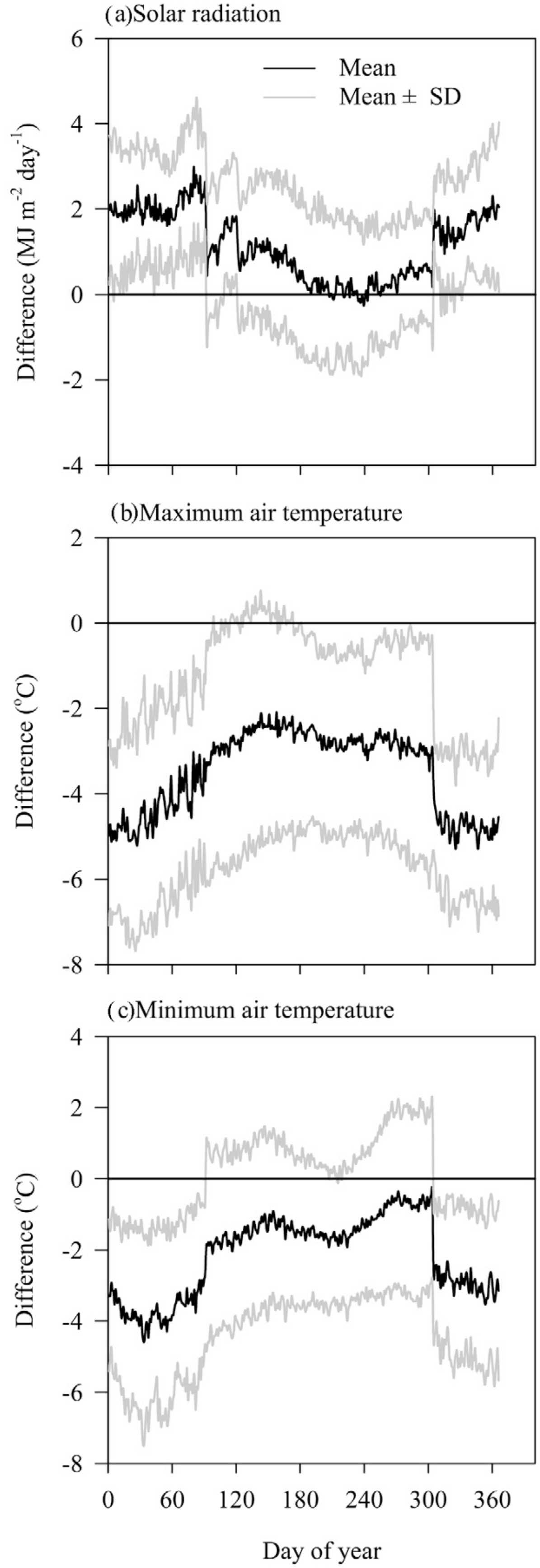

Fig. 3. Intraannual variability in the differences between NASA satellite- and model-derived weather data compared with ground data for (a) solar radiation, (b) maximum temperature, and (c) minimum temperature. The mean and standard deviation data are showed in the graph.

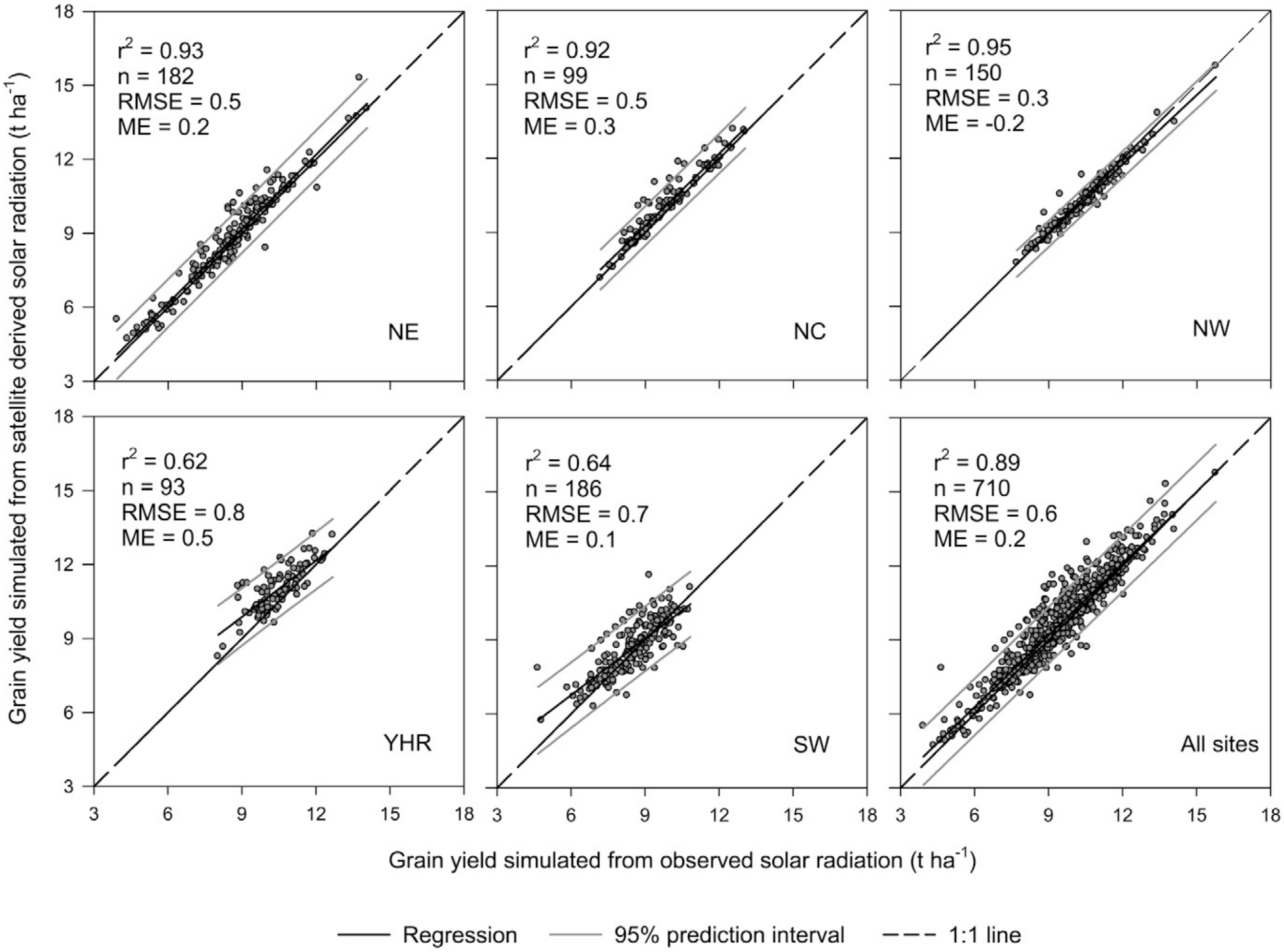

Fig. 4. Simulated maize grain yield potential using NASA solar radiation along with ground-measured maximum and minimum temperature (*y* axis) regressed on yield potential simulated using ground station weather data only (*x* axis). Each point represents one site-year. The black line depicts the linear regression for panel. The gray lines show the confidence interval at 95% (95% prediction interval). The gray dashed linear line represents the 1:1 reference line. The r^2, numbers of site-year pairs (*n*), root mean square error (RMSE, t ha^{-1}), and mean error (ME, t ha^{-1}) are shown at upper left of each panel. Region names are given in the lower right corner of each panel. Significances of regressions are all significant at $P < 0.001$.

and satellite-derived values could be reduced by using higher resolution satellite data. In their study, the RMSE decreased from 3.9 MJ m^{-2} d^{-1} with ISCCP B3 data (50 km × 50 km) to 1.6 MJ m^{-2} d^{-1} with NOAA/NESDIS data (8 km × 8 km).

Table 3. Analysis of variance for regressions comparing simulated maize yield using NASA-derived versus ground-observed solar radiation in different agroecological regions of China.

Agroecological region†	df	Source of variation (*P* > *F*)‡ Site	Radiation	Site × radiation
NE	364	0.000	0.170	0.734
NC	198	0.000	0.098	0.804
NW	300	0.000	0.227	0.991
YHR	186	0.000	0.000	0.161
SW	372	0.000	0.046	0.001
Over all regions	1420	0.000	0.002	0.056

† NC, North-Central China region; NE, Northeast China region; NW, Northwest China region; SW, Southwest China region; YHR, Yellow-Huai River Valley.

‡ Source of variation means source of variation of ANOVA of difference between simulated maize yield potential using NASA solar radiation along with ground-measured maximum and minimum temperature and yield potential simulated using ground station weather data only; *P* > *F* means probability of a significant *F* value.

Atmospheric conditions and topography within the 1-degree grid area of NASA values is also a possible source of bias. White et al. (2008) reported largest differences in air temperature from NASA versus ground stations measurements at 855 locations across the United States in areas with mountainous topography or coastal zones.

Our results are comparable with those published by NASA (2007). For example, comparisons of satellite data with solar radiation estimates using data from the high-quality Baseline Surface Radiation Network (BSRN) from 1 Jan. 1992 to 30 June 2006 as the reference showed that the difference in daily solar radiation had an RMSE of 3.0 MJ m^{-2} d^{-1}, which was nearly the same as the 3.4 MJ m^{-2} d^{-1} in our study across China's Maize Belt. It should also be noted, however, that the error in estimating daily solar radiation from satellite data is typically comparable or smaller than errors obtained with other estimation methods. Ball et al. (2004) tested a range of solar radiation prediction models at 13 sites in North America. The results showed the Hargreaves-Samani model applied in that study for daily solar radiation estimation with site-specific parameters gave RMSE value of 3.5 MJ m^{-2} d^{-1} and r^2 of 0.68.

For comparison of NASA model-derived temperatures versus ground measurements, White et al. (2008) found an RMSE value across 885 U.S. ground stations of 4.1°C for T_{max} and 3.7°C for T_{min}, which is also consistent with the findings we report here. The greatest discrepancy between our findings for China and those of White et al. (2008) for the United States is that the ME for T_{min} was positive in the United States but negative in China; that is, the NASA model-derived temperatures in China tended to be significantly lower than ground station temperatures, and this bias was not due to site-specific or seasonal variation. Further investigation is required to understand the reasons for these differences. It should be noted, however, that many ground weather stations tend to be located close to urban areas in China, where temperature is normally higher than surrounding rural areas due to the *heat island* effect (Zhou et al., 2004). For example, Ren et al. (2007) found evidence of urbanization-induced warming at two national meteorological stations in China (Beijing and Wuhan cities). If this situation is widespread, use of ground station temperature data for regional yield simulations may not necessarily be better than using the NASA model-derived weather data.

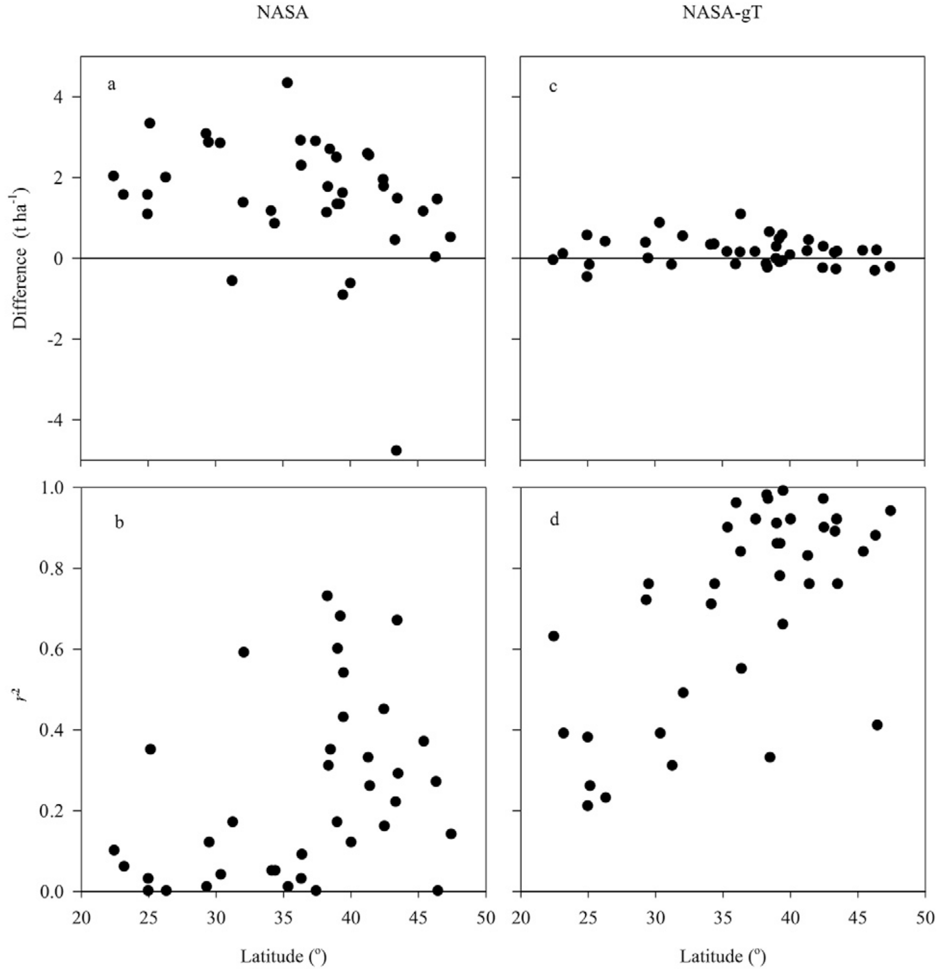

Fig. 5. Differences and coefficient of determination (r^2) for simulated maize yield potential using three different weather data sources at existing weather stations at 39 sites in China: (a, b) complete NASA data (NASA)–ground station data (reference); (c, d) NASA solar radiation along with ground-measured temperature (NASA–gT)–ground station data (reference). Due to low temperature restricting phonological development in Hybrid-Maize model simulations, Kashi and Lanzhou in NW and the last year (2003) of Houma in YHR were excluded from maize yield simulation with NASA data as model inputs.

Simulations based entirely on the NASA weather data, including both solar radiation and temperature, gave poor correlation with simulated yields using only ground-based weather data. The poor agreement was due to the large negative bias in air temperatures between NASA data and ground measurements, which resulted in simulation of slower crop development and a prolonged growing season.

Despite the uncertainties regarding agreement between NASA- and ground-based weather data mentioned above, we found that yield simulations using satellite-based data for solar radiation, in combination with ground-based temperature data, produced results in close agreement with simulations using only ground-based weather data in three of the five maize growing regions. Good agreement in the majority of regions suggests that NASA solar radiation data can be used with ground temperature data for maize yield simulation in much of China's maize-growing area. Because many more ground weather stations in China have long-term and real-time temperature and rainfall data, supplementation by NASA solar radiation can provide much greater spatial density to estimates of maize yield potential across China. Such an approach, however, is not recommended for the YHR and SW maize growing regions until the reasons for the relatively poor correlation between simulations with NASA solar radiation and ground-measured solar radiation are understood and corrected.

CONCLUSIONS

Simulated maize yields based on NASA satellite-derived weather data and ground station weather data were compared at 39 sites that represent the main maize-producing regions in China. We conclude that (i) NASA daily solar radiation showed good agreement with data from ground weather stations, but T_{max} and T_{min} was systematically underestimated comparing with ground measurements; (ii) using only NASA weather data resulted in simulated yields that were not in close agreement with yields simulated with ground station data (r^2 = 0.2); and (iii) yield simulation combining NASA satellite-derived solar radiation with ground station-based temperature gave a high correlation (r^2 = 0.9) with yields simulated with ground-station data only. Considering the advantage of continuous coverage and availability, use of NASA satellite solar radiation appears to be a promising option for regional and national simulation of maize yield potential, as well as for estimating the magnitude of existing gaps between yield potential and current average farm yields in China.

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