Assessment of satellite-derived weather data system (NASA/POWER) for some Brazilian regions and their impact on sugarcane yield simulations[1]

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ABSTRACT: Long-term weather series are widely used as input data for crop simulation models. The virtual weather stations from NASA/POWER are still not intensively used for studies related to climatic risk analysis for agricultural planning in Brazil. The objectives of this study were a) to use INMET observed and NASA/POWER estimated weather data to estimate sugarcane yield by a simple agrometeorological model in order to quantify the errors caused by NASA/POWER data on yield estimates; and b) to test a combined dataset composed by NASA/POWER data with rainfall data from ANA in order to evaluate their impact on sugarcane yield estimates. The yield model was run for 10 growing seasons (2003 to 2013) considering a cane plant cycle with 12 months. Planting dates were simulated in a ten-day time scale, during all year long, totalizing 36 growing seasons per year. Potential yield (Yp) and attainable yield (Yatt) were simulated with observed and gridded weather datasets. The statistical errors and indices showed a satisfactory agreement between observed and estimated weather data. When these data were used to estimate Yp high accuracy was observed. For Yatt, the simulations with NASA/POWER data presented $R^2 = 0.73$, ME = 5.8 Mg ha^{-1}, d = 0.84 and MAPE = 26.5%. Such estimates were improved when NASA/POWER rainfall data was replaced by local data from ANA, with R^2 increasing to 0.82, ME decreasing to 1.1 Mg ha^{-1}, d going to 0.90 and MAPE to 19.1%. These results suggest that the NASA/POWER system allows to Yp and Yattsimulation with high accuracy, since with rainfall data from local databases.

Key words: gridded weather data, climatic variability, sugarcane yield.

INTRODUCTION

The use of long-term weather data for agricultural analysis is usually employed for determine the most appropriated strategies at regional and national scales (ZHAO et al., 2015). The quality of yield simulations by crop models is strongly affected bymodel input data, mainly the weather data (MEINKE et al., 1995). Ground weather stations representthe most common source of meteorological data for agricultural studies and, more specifically, for crop modelling applications.Although, these data are not available for all regions of interest or they can present missing or erroneous data, making impossible to investigate the climatic risks associated to agricultural activities (WHITE et al., 2011; RAMIREZ-VILLEGAS; CHALLINOR, 2012). On the other hand, the use of weather data estimated by weather generators or even by interpolation from many sources such as satellites, radar imagery, meteorological balloons, and even ground weather stations have becoming an alternative to increase the spatial density of meteorological stationsfor crop modelling applications.NASA/POWER is a system that provides weather data mainly for agricultural applications and has a total global coverage in a spatial grid of 1° x 1° of geographic coordinates (latitude and longitude) (STACKHOUSE, 2010).Therefore, studies about the quality of this kind of weather data for crop yield modeling are of high importance. So, the objectives of this study were: to test the weather variables from a gridded system (NASA/POWER) in comparison with observed weather data from INMET; to use observed and NASA/POWER estimated weather data to estimate sugarcane yields by an agrometeorological model in order to quantify the errors caused by NASA/POWER data on yield estimates; and to test a combined dataset composed by NASA/POWER data with rainfall data provided by National Water Agency (ANA) in order to evaluate the impact of them on sugarcane yield estimates.

MATERIAL AND METHODS

A south-north transect was established across Brazil for selection of10 weather stations(Figure 1) to evaluate the performance of gridded weather databases from NASA/POWER.The followingweather variables provided by INMET and NASA/POWER database systems were compared: average air temperature (Tavg); sunshine hours (n); reference evapotranspiration (ETo); and rainfall (P). Table 1 presentsa summary of the weather variables provided by NASA/POWER, with their respective satellite and period of coverage for each weather variable.

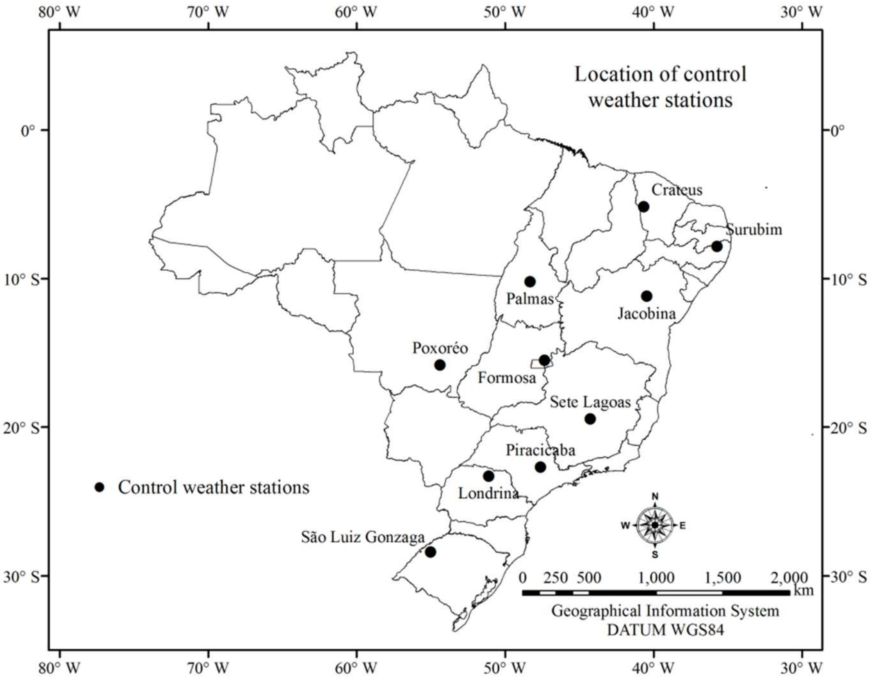

Figure 1 - Spatial location of the weather stations employed to evaluate the NASA/POWER gridded weather database

Table 1- Detailed information of weather variables provided by satellite-derived NASA/POWER project and their respective temporal coverage

Weather variable	Satellite	Temporal coverage
SR	GEWEX SRB 3.0 FLASHFlux	July 1, 1983 - Dec 31, 2007 Jan 1, 2008 - near present
Tmax, Tmin, Tavg	GEOS-4 GEOS-5	July 1, 1983 - Dec 31, 2007 Jan 1, 2008 - nearpresent
RH, U10, Tdew	GEOS-4 GEOS-5	July 1, 1983 - Dec 31, 2007 Jan 1, 2008 - nearpresent
Precipitation	GPCP	Jan 1, 1997 - nearpresent

SR = global solar radiation (MJ m^{-2} d^{-1}), Tmax = maximum air temperature (°C), Tmin = minimum air temperature (°C), Tavg = average air temperature (°C), RH = average relative humidity (%), U10 = wind speed at 10-m height (m s^{-1}), Tdew = dew point temperature (°C). **Global Energy and Water Exchanges Project Surface Radiation Budget (GEWEX SRB 3.0 – http://eosweb.larc.nasa.gov/project/srb/srb_table); Fast Longwave and Shortwave Radiative Fluxes (FLASHFlux – http://flashflux.larc.nasa.gov/); Goddard Earth Observing System model version 4 and 5 (GEOS-4 and GEOS-5 – http://gmao.gsfc.nasa.gov/), Global Precipitation Climate Project (GPCP – http://precip.gsfc.nasa.gov/)

For comparing INMET and NASA/POWER data, the following indices and errors were evaluated:R^2, dindex (Willmott et al., 1985); root mean square error(RMSE); mean absolute percentage error (MAPE); and mean error (ME). In addition, the weather data from both databases were employed as input in a sugarcane yield model. The agrometeorological yield model employed was previously calibrated and validated considering 12 operational fields in Brazil, with very good performance in both phases (R^2 between 0.65 and 0.79; d between 0.70 and 0.80; and RMSE between 13.2 and 13.8 Mg ha^{-1}).

For the simulations, a plant cane with a growing season of 12 months was considered. The planting dates were simulated every 10 days, from January 1st to December 21st, totaling 36 cycles per year, during ten years, from 2003 to 2013.

The sugarcane yield simulations were performed with three sources of weather data as the inputs for the crop yield model. In the first, the model was run with the weather data from the National Institute of Meteorology (INMET). In the second, data from NASA/POWER system was used. Finally, in the third, weather data from NASA/POWER, with exception to rainfall, which was replaced by observed locally data from the rainfall stations belonging to National Water Agency (ANA). The statistical coefficients of precision (R^2), accuracy (d) and errors were also analyzed.

RESULTS AND DISCUSSION

A global analysis from average annual records during the period evaluated (2003 to 2013) and the respective comparisonsbetween thedata from INMET (observed) and from NASA/POWER (gridded) indicated a potential use of estimated weather databases, mainly for average air temperature and solar radiation (mentioned here as effective sunshine hours) (Table 2).

Table 2 -Comparison of annual average air temperature (Tavg), sunshine hours (n), accumulated reference evapotranspiration (ETo) and rainfall (P), and their respective standard deviations (between brackets), provided by INMET (OBS) and NASA/POWER (NP) databases in the locations considered in this study

Location (state)	Data source	Tavg	n	ETo	P
SLG (RS)	OBS	21.4 (±4.5)	6.4 (±1.9)	1252.9 (±17.1)	1803.5 (±52.4)
	NP	20.5 (±4.7)	7.0 (±1.9)	1190.8 (±17.2)	1879.5 (±50.7)
LON (PR)	OBS	22.6 (±3.2)	6.8 (±1.8)	1423.9 (±13.7)	1594.9 (±46.7)
	NP	22.4 (±3.2)	6.7 (±1.7)	1276.1 (±14.1)	1575.1 (±40.8)
PIR (SP)	OBS	22.3 (±2.8)	6.7 (±1.7)	1232.5 (±10.2)	1269.2 (±39.3)
	NP	21.8 (±2.9)	6.8 (±1.8)	1307.2 (±13.0)	1556.3 (±43.2)
STL (MG)	OBS	22.6 (±2.1)	7.2 (±2.1)	1419.0 (±11.3)	1338.4 (±53.4)
	NP	22.0 (±2.6)	7.0 (±1.9)	1354.0 (±10.9)	1444.3 (±48.2)
POX (MT)	OBS	25.9 (±1.9)	6.2 (±2.2)	1590.5 (±8.4)	1740.7 (±52.8)
	NP	25.5 (±2.1)	6.2 (±2.0)	1368.0 (±9.5)	1763.5 (±50.0)
FOR (GO)	OBS	23.1 (±1.6)	7.3 (±2.4)	1450.1 (±9.6)	1401.6 (±51.8)
	NP	23.3 (±2.1)	7.0 (±2.1)	1384.1 (±9.5)	1339.3 (±43.4)
JAC (BA)	OBS	24.9 (±2.0)	6.9 (±1.7)	1630.9 (±9.5)	696.4 (±31.0)
	NP	24.0 (±1.7)	6.1 (±1.5)	1529.1 (±8.7)	537.7 (±26.4)
PAL (TO)	OBS	28.1 (±1.4)	6.9 (±2.3)	1679.5 (±6.8)	1841.6 (±57.6)
	NP	27.0 (±2.1)	6.3 (±2.2)	1511.7 (±7.3)	1798.3 (±49.6)
SRB (PE)	OBS	25.1 (±1.7)	7.7 (±1.7)	1856.1 (±9.6)	606.1 (±22.0)
	NP	24.9 (±1.4)	6.1 (±1.2)	1692.7 (±7.6)	805.6 (±31.1)
CRT (CE)	OBS	28.2 (±1.4)	7.6 (±1.8)	1712.6 (±6.0)	711.6 (±39.0)
	NP	26.4 (±2.0)	7.0 (±1.6)	1646.3 (±5.3)	777.8 (±35.3)

SLG = São Luiz Gonzaga; LON = Londrina; PIR = Piracicaba; STL = Sete Lagoas; POX = Poxoréo; FOR = Formosa; JAC = Jacobina; PAL = Palmas; SRB = Surubim; CRT = Crateus.

The results presented in table 2show a high agreement between observed and gridded annualaverages for air temperature and sunshine hours. Moreover, these meteorological variables are the main input weather data to sugarcane potential yield (Yp) estimation.Concerning about these variables, the annual differences in all locations werelower than 2°C and 2 hours, respectively, forTavg and effective sunshine hours. On the other hand, forETo and P, the differences were more pronounced, mainly for rainfall.The employment ofprecipitation dataprovided by NASA/POWER should be done carefully or even avoided,since the differences can be of more than 100 mm year^{-1}in some places (Table 2).

White et al. (2008; 2011) tested theNASA/POWER against automatic weather stations across the United States of America for air temperature and solar radiationand highlighted the power of thatsystemto provide weather data for crop modelling application mainly at large spatial scales.Under Brazilian conditions, Sentelhas et al. (2001) tested two weather generators, indicating the use of alternative systems as a potential tool to be used for filling data or even to generate long data series inlocations with restrictor even too short meteorological datasetsfor most confidence agricultural planning.

The sugarcane yield model presented similar Yp estimates when datafrom INMET and NASA/POWER were used (Figure 2a). It can be associated with a reasonable precision and accuracyof air temperature and solar radiation estimative provided by gridded system.On the other hand, Figures 2b and 2c shows the Yatt estimates considering only NASA/POWER data as input and a combined dataset, in which the gridded rainfall was replaced for rainfall records from a local source, in this case, by National Water Agency (ANA).

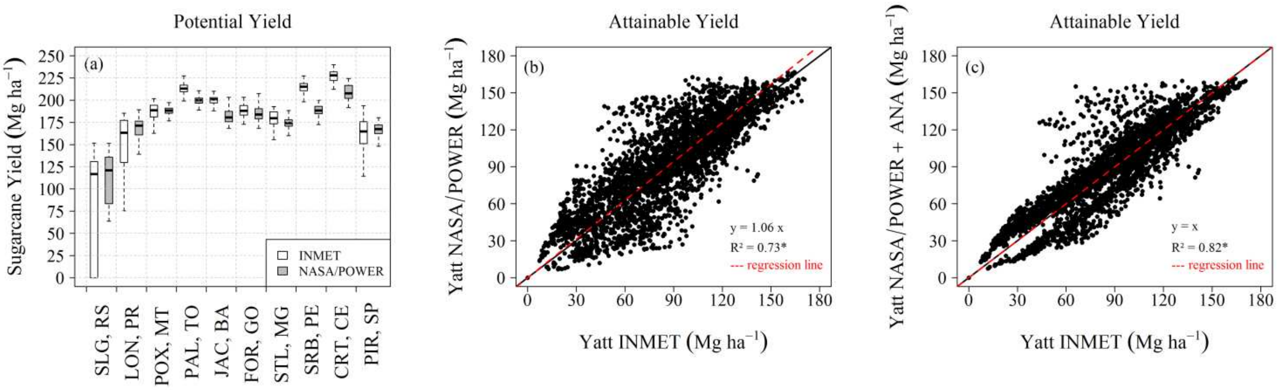

Figure 2. Potential yield estimated under observed (INMET) and gridded (NASA/POWER) weather databases (a); Attainable yield comparison employing INMET and NASA/POWER databases (b) and their comparisons with a combined dataset coupling NASA/POWER andrainfall from ANA (c) in the Brazilian locations evaluated in this study. *significance at 5% of confidence level.

The boxplots from Figure 2a allows to evaluateYp data and their respective variability. In the locations selected in south Brazil (SLG, RS and LON, PR), the variability is higher than the location upper north, mainly because in the southern locations the frost risk is higher, limiting cane yield. Moreover, in high latitudes the meteorological variables thatcontrollYp, such as incoming solar radiation, air temperature and photoperiod, have also high variability along the year.

When Yatt was estimated considering the input weather data fromNASA/POWER, the average yield was slightly overestimated of about 6% (y = 1.06 x),with a precision of 73% (R^2 = 0.73) and accuracy of 84% (d = 0.84). The statistical errors were RMSE = 21.3 Mg ha^{-1}, MAPE = 26.5% and ME = +5.8 Mg ha^{-1}. In contrast, when the model was run with combined dataset (NASA/POWER + ANA), a considerable improvement in the model performance wasobservedfor all statistical indices. In a global evaluation, there was almost notrend (ME = +1.1 Mg ha^{-1}),with R^2 = 0.82, d = 0.90, RMSE = 16.1 Mg ha^{-1}, and MAPE = 19.1%.

Similar results, with NASA/POWER was also obtained by Bai et al. (2010) in China, where the authors simulated maize potential yield, finding high crop yield estimated with observed and gridded weather data. These results are a promising option to estimate crop yield at a large spatial scales.

CONCLUSIONS

1 – Even with a relative huge gridded spatial coverage (1° x 1° of latitude and longitude), the NASA/POWER systemshowed a satisfactory performance when the weather variables mainly for air temperature and solar radiation were compared with those provided by INMET weather stations.

2 – The comparisons between sugarcane yields estimated with combined dataset (NASA/POWER + ANA) showed an improving performance in relation to the yield estimates done with all weather data from NASA/POWER system.

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