Development of Agricultural Information System (AIS): Comparison of TRMM and Climate Division Rain Rates over Oklahoma

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Abstract
To evaluate the use of high spatial and temporal resolution TRMM products for crop yield assessment and agricultural management in the development of an Agricultural Information System, TRMM algorithm monthly rain rates are compared with gauge analyses in the climate divisions of Oklahoma. 3B43 and 3B42 shows the highest correlation with gauge data with annual biases of -11% and 33%, respectively. The GPCC is consistently lower by 15-20% for all seasons. Large seasonal variations of the biases require that they be accounted for in operational applications.

1. INTRODUCTION

Monitoring global agricultural crop conditions during the growing season and estimating potential seasonal production are critically important for market development of U.S. agricultural products and for global food security. The Goddard Space Flight Center Earth Sciences Data and Information Services Center (GES DISC) is developing an Agricultural Information System (AIS) in collaboration with the USDA/Foreign Agricultural Service and the United Nations World Food Program. The AIS is based on an existing TRMM Online Visualization and Analysis System (TOVAS) and will operationally provide satellite remote sensing data products, such as rainfall and vegetation indices, and services to the operational users for crop yield forecasting and monitoring. AIS outputs will be integrated into existing operational decision support systems for global crop monitoring, such as those of the USDA Foreign Agricultural Service and the U.N. World Food Program (Teng et al., 2004)

To develop and test the crop yield models, field experiments will be carried out in Oklahoma (OK), USA and Argentina. In addition to the Moderate-Resolution Imaging Spectroradiometer (MODIS) data, rainfall data are required to support the model development.

The Tropical Rainfall Measuring Mission (TRMM), jointly cosponsored by NASA and JAXA of Japan, has collected data since November 1997 (Kummerow et al., 2000). TRMM has developed a daily $1^0 x 1^0$ microwave calibrated IR rain estimate (TSDIS 3B42). This product will be useful in computing 10-day average rain rates currently used in the FAS crop yield forecast.

The purpose of this study is to examine the utility of the TRMM products for providing improved service to the operational users. Specifically, the objectives of this study are to (1) examine TRMM algorithm performance in Oklahoma (2) quantify relative TRMM biases (3) examine seasonal dependence of these biases (4) check the consistency of the variability within data sets (5) evaluate their utility for agricultural management/crop yield assessment.

2. DATA

The TRMM products examined include TRMM Microwave Imager rain profile (TMI), the Precipitation Radar (TPR), the TRMM Combined Instrument (TCI), TRMM calibrated IR rain estimate (3B42) and TRMM merged satellite and gauge analyses (3B43). An initial assessment of the algorithm performance has been given by Kummerow et al. (2000). Algorithm updates are available via the TSDIS web site (URL: http://trmm.gsfc.nasa.gov/data_dir/ProductStatus.html). Briefly, the TMI uses a Bayesian approach that matches the observed brightness temperature to a database of observed or modeled cloud profiles. The TPR converts the observed reflectivity profile to a rain rate distribution via a Z-R relation. The TCI combined the TMI and PR measurements to derive the vertical rain profile constrained by passive microwave measurements. 3B42 uses the infrequent microwave rain estimates to calibrate IR rain rates that have better temporal sampling to produce a daily product. The 3B42 is then merged with gauge analysis, such as GPCC or CAMS to produce a monthly rain product. To minimize diurnal sampling biases (Negri et al., 2002), seasonal averages over the whole state are compared.

Monthly TMI, TPR and TCI data are computed from the TRMM product 3G68 which contains 0.5 degree gridded swath rain rates of all three algorithms. Monthly gauge analyses from GPCC and the OK climate divisions are used for comparison. The climate division rainfall data and GPCC data are available from NCDC (URL: http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/main.html) and http://www.dwd.de/en/FundE/Klima/KLIS/int/GPCC/G

PCC.htm), respectively. Climate divisions are relative homogeneous regions within a state and have 5-10 gauges. Each state in the US is divided into 1-10 climate divisions

3. RESULTS AND DISCUSSIONS

Figure 1 shows the climate division (CD) of OK. For each CD, the corresponding 1 degree grids are identified. The CD average rain rates are computed as a weighed sum of the CD rain rates by its areas.

Figure 2 shows the monthly average CD rain rates and sample standard deviations. Over the six year period, there are rain rate maxima in June and October. There are interannual variations in the month of the maxima. The late summer minimum is evident. Figure 3 shows the time series of monthly CD, 3B42 and 3B43 rain rates

There are correlations among the algorithms at the monthly scale. Correlation analyses are performed between the time series of all the algorithms and the results are summarized in Table 1. TPR and TCI show the strongest correlation (0.99), which is consistent with earlier results (Shin et al., 2001). This is followed by the high correlation between CD and 3B43 (0.91), and between 3B42 and 3B43 (>0.8). There are also good correlation between among the satellite swath products of TMI, TPR and TCI. The good correlations between these monthly level 2 products are attributed to the satellite sampling, at least partially. The good correlation between 3B42 and TMI, TPR and TCI (>0.75) probably reflects the fact that 3B42 is a merged satellite rain rate with input from all algorithms.

Table 2 shows the biases between the monthly TRMM algorithms and CD gauge analyses. Most algorithms show a positive bias (algorithm > CD) except 3B43. However, 3B43 shows the lowest bias and root mean square difference (RMSD). Regression analyses (Table 3) also shows that slope of the regression associated with 3B43 is close to unity, with an intercept close to zero. It also has the highest R square value. Since 3B43 is a merged produce of 3B42 and GPCC, we include GPCC in the following analysis.

Seasonal averages of the algorithm, CD and GPCC rain rates are shown in Figure 4. While all algorithms show high MAM rainfall, TMI shows the highest JJA rainfall and the lowest in DJF.

The scatter plots of CD gauge, 3B43 and GPCC monthly rain rates are shown in Figure 5. The scatters between these rain products are relatively small, except for 3B43 October 2000. The same outliner was also noted in an analysis of climate division data over New Mexico (Chiu et al., 2004). Examination of the CD data shows that relatively high rain was prevalent in all water divisions, both in New Mexico and Oklahoma in October 2000. It is thus concluded that the outliner is probably due to the input data used in creating 3B43. Regression analyses of both 3B43 and CD gauge vs. GPCC show reasonable fits.

To examine the seasonal dependence of the biases, regression analyses were performed separately for each season and the results are summarized in Table 4. There are large seasonal differences in the slope and intercept of the regression. Over all, the slopes for 3B43 and GPCC are close to unity and they show the largest R square. The seasonal changes are especially large for TMI, from 0.37 in JJA to 0.89 in DJF. The R square are also low for TMI in JJA and DJF and for TPR and TCI in JJA (< 0.5).

Figure 6 shows the histograms of the rain rate difference between the algorithms and CD. The histogram of GPCC difference is tightly clustered around zero. Same is true for 3B43, except for an outliner of -4 mm/day. This data point corresponds to the October 2000 data, as discussed earlier. The difference histograms of TCI and TPR are quite similar, with maximum differences of up to 6mm/day. The highest scatter is between TMI and DC, the maximum difference exceeds 6 mm/day.

Table 5 summarizes the annual and seasonal biases of the different algorithms. 3B43 shows the lowest (-11%) bias and the 3B42 a high positive bias (33%). TMI in JJA shows the largest seasonal variation of the bias, with 89% in JJA and -52% in DJF. The biases for 3B42 are highest in summer (47%) and lowest in the fall. The lowest bias for 3B43 is in winter (-1.6%) and highest in the fall. GPCC are consistently lower the CD rain rates for all seasons by 15 to 20%.

Ten-day average rain rates are currently used for assessing crop yield. These averages are computed based on calendar months, i.e. each month consists of three “10-day” averages, and the first 10-day averages are based on the first 10 days, and the last “10-day” average of the month is the accumulation from the 21^{st} to the last day of the month. Our results show that there are large seasonal biases (compared to gauge analyses) in the TRMM algorithms. Hence the use of 10-day averages computed from daily 3B42 in agricultural management and crop yield assessment must consider these biases. A case can be made if these rainfall accumulations are tied to the start of the growing season, which are dependent on the season, region and the crop type. These 10-day averages can be easily generated from the daily data.

ACKNOWLEDGMENT
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Table 1. Temporal correlations among gauge and TRMM rain rates over Oklahoma (1998-2003).

Algorithm	CD	3B42	3B43	TMI	TPR
3B42	0.82	1.00			
3B43	0.91	0.80	1.00		
TMI	0.62	0.77	0.60	1.00	
TPR	0.65	0.75	0.63	0.79	1.00
TCI	0.67	0.75	0.66	0.76	0.99

Table 2. TRMM algorithms biases and root mean square error (RMSE) against CD rain rates (unit: mm/day).

Algorithm	Average_bias (mm/day)	RMSD
3b42	0.81	1.41
3b43	-0.28	0.65
3G68-TMI	0.60	2.22
3G68-TPR	0.82	2.01
3G68-TCI	0.78	1.84

Table 3. Regression analysis for TRMM algorithms with the gauge measurements for Oklahoma (1998-2003)

Algorithm (X)	a	b	R-Squared
3B42	0.58	0.54	0.68
3B43	1.02	0.24	0.83
TMI	0.33	1.44	0.39
TPR	0.38	1.18	0.41
TCI	0.42	1.07	0.45

Regression form CD = a X + b, Degrees of freedom = 69.

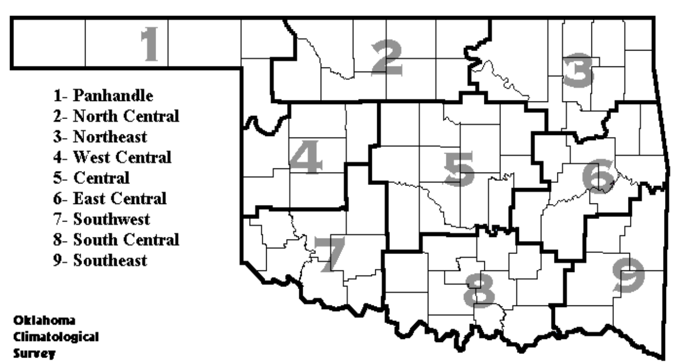
Table 4. Regression analyses for TRMM algorithms and GPCC with the gauge measurements for Oklahoma (1998-2003) for summer and winter.

	Summer	Winter
Algorithm	(a, b, [R**2])	(a, b, [R**2])
3B42	0.69, – 0.02, [0.83]	0.50, 0.54 [0.68]
3B43	1.10, 0.09 [0.96]	0.89, 0.21 [0.96]
TMI	0.37, 0.74 [0.44]	0.89, 0.99 [0.33]
TPR	0.36, 1.11 [0.29]	0.41, 0.93 [0.51]
TCI	0.43, 0.97 [0.35]	0.43, 0.80 [0.61]
GPCC	1.19, 0.08 [0.97]	1.13,0.14 [0.97]

Table 5. Percent bias to CD rain rate for TRMM algorithms and GPCC rain rates

	3B42	3B43	TMI	TPR	TCI	GPCC
Annual	33.4	-11.4	24.9	34.0	32.1	-17.5
MAM	42.9	-8.9	35.4	51.8	46.8	-17.8
JJA	47.1	-12.7	88.5	48.9	38.2	-18.9
SON	6.8	-19.5	1.1	13.1	15.0	-14.9
DJF	36.2	-1.6	-52.6	11.1	22.2	-18.9

Figure 1. Location of Oklahoma climate divisions



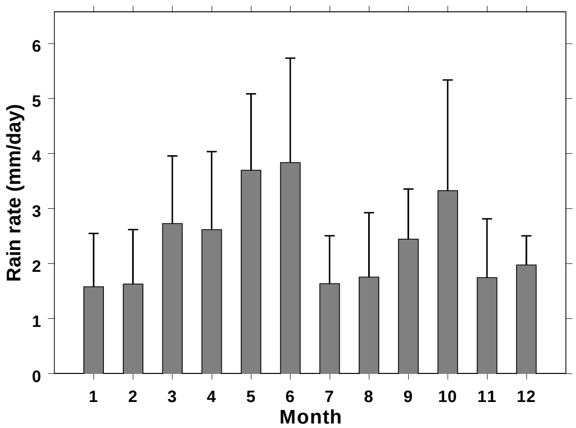


Figure 2. Monthly average (1998-2003) gauge rain rate (unit: mm/day) over Oklahoma. Error-bar is sample standard deviation.

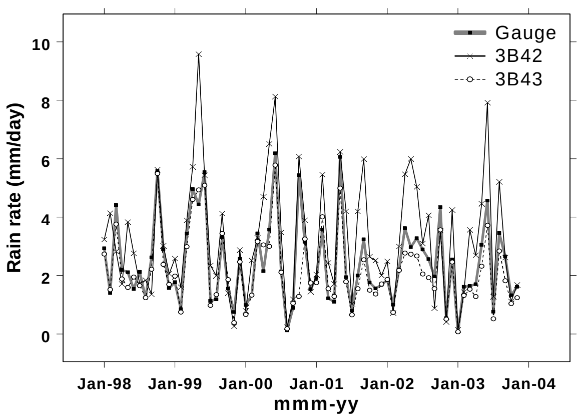


Figure 3. Monthly average TRMM and gauge rain rate January 1998 – November 2003 (unit: mm/day).

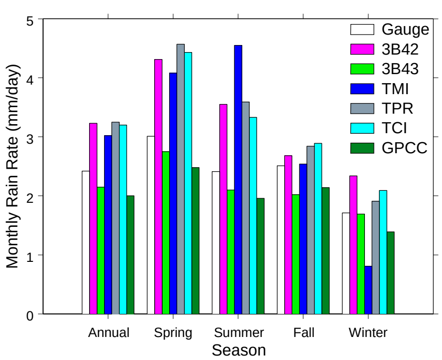


Figure 4. Annual and seasonal average of monthly gauge, TRMM and GPCC rain rates (unit: mm/day) for Oklahoma from 1998 January to 2003 November.

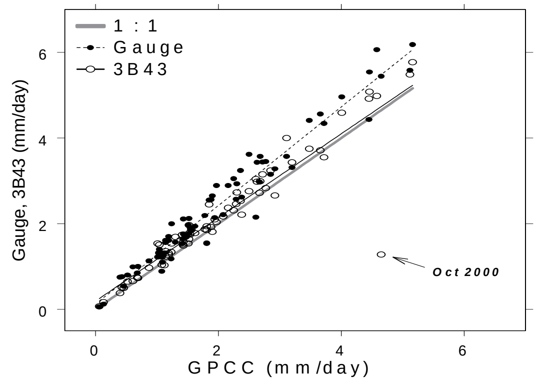


Figure 5. Monthly GPCC, gauge and TRMM 3B43 rain rate (unit: mm/day) for Oklahoma from January 1998 to November 2003**.**

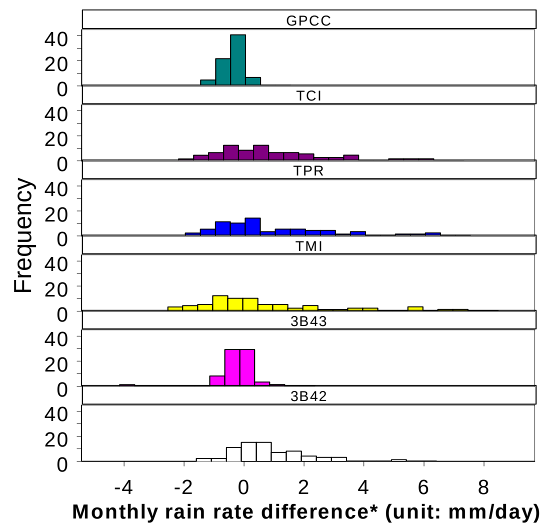


Figure 6. Histogram of monthly rain rate differences from gauge rain rate for TRMM and GPCC rain rates (unit: mm/day) for Oklahoma from January 1998 to November 2003.
* Monthly rain rate difference = Algorithm_rain_rate - Gauge_rain_rate