Quality Assurance Of Weather Parameters For Determining Daily Evapotranspiration In The Humid Growing Environment Of The Mid-South

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ABSTRACT

Producers increasingly rely on irrigation to enhance yields and improve return on investment. The greater demand for ground water to support irrigation in the Mississippi River Alluvial Flood Plain has resulted in a decline in the aquifer, and a subsequent implementation of more stringent regulations for well permits. Given the concerns of ground water depletion, producers can clearly benefit from a tool that would indicate when they need to irrigate and how much. However, no easy to use irrigation scheduling tools have been developed and calibrated for the humid, high-rainfall environment of Mississippi. Researchers at USDA-ARS and Mississippi State University are developing a daily irrigation scheduling tool that calculates reference evapotranspiration (ET) from weather data to establish a crop water balance which will indicate when irrigation is needed. The weather parameters required for the calculation of ET include temperature, vapor pressure (determined from relative humidity and temperature), wind, and solar radiation. Rainfall and irrigation are also needed to track water balance in the field. Accurate determination of ET requires weather data that are consistent, accurate, and reliable. Errors in archived weather records are introduced from several sources, including sensor limitations and failures, instrument siting and deployment issues, lack of timely cleaning or re-calibration of instruments, data logger failures or programming errors, data transmission problems, and human errors. Further errors in the calculation of ET can result from mixing units in the calculations (e.g, degrees Fahrenheit and Centigrade), incorrectly converting units, or failing to adjust wind measurements to a common height. Since the archived data has not undergone any systematic assessment of data quality, potential users must conduct their own rigorous quality assurance before using the data to calculate ET. The research described here identifies common sources of errors in the available Mississippi weather station data, and develops statistical and range limit tests to identify erroneous records. Such quality assessment and control procedures are essential to ensure that values produced by the daily irrigation scheduling tool are reasonable and useful for decision support. The protocols described here will establish accurate data needed for calculation of reference crop ET for irrigation scheduling and crop management. Developing technologies to manage agricultural water resources of the humid Mid-South United States will provide means for agricultural producers to increase water use efficiency and mitigate ground water depletion.

INTRODUCTION

There is a growing and substantial need for water management technologies for crop production in humid areas. Historically, humid regions have had plentiful ground water resources and rainfall with some locations receiving precipitation in excess of 100 cm (40 inches) per year. While rain-fed agriculture has been profitable in the past, yields and profits from non-irrigated crops are typically lower than for irrigated fields (Wesley et al., 1993; Pringle and Martin, 2003; Balkcom et al., 2007). Increasing economic risks have enhanced the reliance on supplemental irrigation to secure adequate yields and reduce production risks (Gollenhon and Quinby, 2006; Vories and Evett, 2010). Irrigated acres have increased steadily for nearly all farm sizes over the past 15 years, resulting in nearly one-fourth of all Mississippi farms being irrigated (NASS, 2009).

Increasing use of agricultural irrigation, particularly in the Mississippi Delta, has resulted in extensive drawdown of the alluvial aquifer. As a result, implementation of water conservation measures for permits on new wells is required (YMD, 2010). Beginning in January, 2011, new and renewal well permit applications require implementation of water conservation measures or permission to withdraw water may be terminated. One acceptable water conservation measure is documented use of an irrigation scheduling program.

Water management practices and irrigation scheduling tools have been extensively developed for arid regions in response to water shortages. While some of these tools and practices are relevant to humid areas, most have not been developed and calibrated for the unique environmental conditions and crops in the area. As a result, methods of scheduling irrigation based on crop water use have not been used regularly in Mississippi.

Many methods have been developed to determine crop water use for scheduling irrigation. Direct measurements rely on sensors placed in the soil or on the plant to track soil or crop water status through the growing season. This requires calibration, installation, and regular maintenance of the instrumentation followed by downloading and interpretation of the information by the end-user. Alternatively, crop water use can be estimated from calculations of reference evapotranspiration (ET) from weather parameters. The reference ET calculated from weather data is then adjusted for the specific crop of interest with a crop coefficient. As an example, the Arkansas Scheduler has been developed for humid growing conditions, using regressions from daily climatic data at six locations throughout the Mid-South to estimate ET from maximum temperature (Vories and Tacker, 2006). The Arkansas Scheduler has been used for more than twenty years, but requires users to input data and perform model runs to track crop water use for irrigation scheduling, limiting its utility for many producers.

Several algorithms have been developed to estimate ET from weather parameters. The modified Penman-Montieth (MPM) has been established as the standard equation for calculating ET from weather parameters for estimation of crop water use (Allen et al., 1998; ASCE-EWRI, 2004). This robust algorithm requires inputs of air temperature, vapor pressure, solar radiation, and wind speed.

Researchers at the USDA Agricultural Research Service and Mississippi State University have developed a daily irrigation scheduling tool for Mississippi crop producers based on the modified Penman-Montieth algorithm. In order to apply this algorithm, accurate, reliable, and complete weather data for each irrigation site is needed (Allen, 1996).

Weather networks and quality assurance procedures have been established in other states for collecting and quality assuring weather data for agricultural production (Shafer et al., 2000; Fiebrich et al., 2010). These procedures consist of a series of checks and tests to insure that sensor readings are consistent, reliable and accurate. Because each sensor responds to climatic conditions and degrades in a different fashion, separate procedures are required for the different sensors. The automated assurance procedures flag potentially erroneous entries, which are then firther checked by meteorologists. The net result is an accurate and detailed record of daily climatological conditions that can be used for multiple purposes.

The Delta Research and Extension Center of Mississippi State University in Stoneville, MS has been collecting weather data since the early 1900's (DAWC, 2011). As sensor technologies advanced, additional climatological parameters were measured and weather stations were installed in more locations. The weather information has been used for tracking crop growth and maturity (growing degree days, e.g. DD50's, DD60's; Pringle and Ebelhar, 2009), modeling and decision support tools for agricultural crop production (e.g. Gossym/Comax; McKinion et al., 1989), and management of natural resources (e.g. AnnAGNPS; Bosch et al., 1998). The USDA NRCS has also implemented a series of weather stations throughout Mississippi through their Soil Climate Atmosphere Network (Hu et al., 2002; NRCS, 2012). However, there has not been a systematic, published assessment of the entire DAWC or SCAN data set gathered in Mississippi to determine if the available weather data is of sufficient quality aud continuity to support accurate calculations of ET using the MPM algorithm.

The research reported here describes the weather data available in Mississippi for use in agricultural decision support tools, in particular the MPM calculations of ET; assesses the availability, consistency, reliability, and accuracy of the reported data; and delineates the most critical and accurate measurements that are needed. Establishment of quality control and quality assurance procedures for measuring and processing weather data is a necessary preliminary step, and will contribute substantially to agricultural production and water management.

METHODS

Data Sources

Historical weather data was downloaded from the Delta Agricultural Weather Center (DAWC, 2011) and the NRCS SCAN web site (NRCS, 2012) for weather stations located throughout the state (Figure 1). Standard procedures have been developed for establishing mesoscale weather collection networks, and for assessing data quality (Allen, 1996; Fiebrich et al., 2010). However, the process of quality assuring weather and climate data is an expensive and laborious process, requiring not only continuously running algorithms to flag suspicious or missing data, but frequent critical assessment by scientists familiar with the phenomenology, sensors, networks, and IT aspects of weather and climate data archives. Costs are significant and ongoing, and very few funding agencies are willing to support data quality assurance or even data archival efforts. Consequently, with the exception of a few research networks (e.g., the Oklahoma Mesonet, and the Department of Energy's ARM/CART sites), data quality assurance is not conducted routinely. It is a safe assumption that the majority of weather and climate data available via internet has not been quality assured. This state of affairs is well known within the weather and climate communities, and initial data quality assurance is a necessary preliminary step for all research and development. Unfortunately, other research communities that are now seeking out weather and climate data are often not aware of the potential problems, and too often erroneous data is used with bad results.

Proper site selection is a critical aspect of network creation to ensure representative weather data. The weather stations installed and maintained by the DAWC and NRCS are all located in agricultural areas, most with minimal neighboring disturbance that would interfere with sensor readings. The sensors used are standard meteorological instruments and the stations are maintained and sensors calibrated regularly. A metadata analysis of the recorded data was performed using Excel to establish the integrity of each data set by station and year. All recorded entries were counted and the percent of data entries recorded were determined for each year.

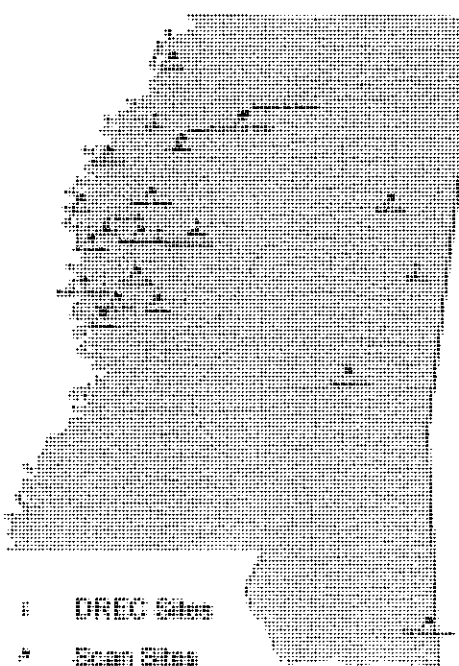

Figure 1. Map of locations of DREC-MSU Delta Agricultural Weather Center and the NRCS Soil Climate Atmosphere Network stations in Mississippi.

Data Checking

Following the initial tests for data availability, quality assurance tests were performed on daily data from all years and all locations to assess data consistency and reliability (following Fiebrich et al., 2010). These include a sensor range test, climate range test, step (spike or dip) test and persistence test, which flagged potentially incorrect values. Thirty-one years of data from Stoneville were used as the standard, as this weather station has received the longest and most extensive sensor calibration and quality control efforts. Maximum and minimum values, standard deviation, and coefficient of variation were determined for all measured data. Erroneous data were determined as that outside of the physically acceptable ranges. The flagged values were manually inspected and erroneous data removed based on established ranges or statistical deviation from normal. Once climate range limitations were identified for the Stoneville location, these were used as a baseline to correct the data from other stations.

Identification of steps (spikes or dips) in the data was performed by taking the difference between the current reading and the reading on the preceding day. Readings that exceeded one standard deviation were eliminated (Hubbard et al., 2005). Maximum and minimum differences between consecutive days were averaged across all years for each sensor and used for the maximum and minimum limits of the step test. The Stoneville location was used as the standard, averaging across the thirty-one years of data for temperature, wind speed, and solar radiation. Fifteen years of data were used for the relative humidity test. The temporal variability of rainfall (i.e., air always has a temperature, but most days are rain-free) precluded development of a step test function for rainfall data.

The revised records were then recounted to determine the percentage of days of data available at each location. Climate range tests were established for each location from the corrected data. These climate range tests will be used in quality assurance of future weather for estimation of crop reference ET with the irrigation scheduling tool

RESULTS

Weather Data Sources

The Weather Center in Stoneville has historical weather data on precipitation dating back to 1915 (Pringle and Ebelhar, 2009; DAWC, 2012). In 1930, addition of temperature measurements allowed determination of DD50 and DD60 for plant growth tracking. In 1959, soil temperature, wind speed, solar radiation, and pan evaporation were added, although pan evaporation, recorded manually, was only measured during the growing season. Relative humidity measurements were begun in 1996. The Delta Agricultural Weather Center supports eight weather stations that are automatically downloaded to the station and upload through the MSUCares webpage for public use (Figure 1). All sensors are maintained, cleaned, and calibrated yearly or as needed. Because the information is used by crop producers, all recordings are reported in English units of measure. We have continued that convention here for consistency.

Additionally, the Center assists personnel from NRCS in maintaining the NRCS SCAN weather stations. In 1991, the Natural Resources Conservation Service (NRCS) established the Soil Climate Analysis Network (SCAN) to provide nationwide assessment of soil and climate information (NRCS, 2012). The data are used to support natural resource assessments and conservation activities, primarily concentrated in agricultural areas. In Mississippi, the NRCS maintains 15 SCAN weather stations, fourteen of which are still active (Figure 1). The SCAN stations use the same sensor technologies as the DAWC weather stations.

Most of the agricultural production in Mississippi is in the alluvial flood plain colloquially referred to as the Delta. The rich, alluvial soils of this region and flat topography make it ideal for crop production. Production in the region relies on the relatively shallow alluvial aquifer for ground water resources for agricultural irrigation. Most of the well permits in the state are located in the Delta region (Wax et al., 2009). The extensive agricultural activities concentrated in the Delta have led to the establishment of most of the weather stations in this region of the state as well.

The current weather stations use data loggers and sensors from Campbell Scientific (Logan, UT). Data loggers (CR10X) take measurements every 2 seconds. Rainfall and solar radiation are summed hourly; temperature and relative humidity are averaged hourly. Rain gauges record each tip of the "bucket", an increment of 0.01". Data are then summarized or averaged daily, and reported on the website. Hourly information is available on the SCAN sites, and for the DAWC stations by request. Temperature and relative humidity are measured with a Vaisala HMP45C in a solar radiation shield (Table 1). The temperature sensor is a platinum resistance temperature detector and can be reported in either degrees Fahrenheit or Centigrade. The relative humidity sensor is a HUMICAPR 180 capacitance relative humidity sensor, and is reported as percent relative humidity. Wind speed is measured with a 3-cup anemometer; a wind vane records wind direction (03002 Wind Sentry Set). Prior to March 21, 1997, wind speed was reported in knots. Currently, total wind run per day is measured in miles per hour and reported in miles per day. Hourly wind data is reported as miles per hour. Wind speed is measured in 15 min increments at certain sites for use in estimating agricultural chemical drift information for aerial applicators. Rainfall is measured using TE525 Texas Electronics tipping bucket rain gauges with a 6" orifice. Rainfall is recorded in hundredths of an inch or millimeters, depending on the station, and summed for each day (Table 2). A silicon photovoltaic detector mounted in a cosine-corrected head (LI200X) is used to record total incoming solar radiation, and reported in total Langleys/day. The pyranometer is calibrated for the daylight spectrum (400 to 1100 nm). By positioning the sensor to view the entire sky, the instrument measures incoming direct solar radiation and diffuse sky (solar) radiation.

For establishing the procedures to determine reference crop evapotranspiration with the MPM, the datasets must be robust. For the purposes of irrigation scheduling, robust data sets contain accurate daily climatic information from all of the parameters needed in the calculation: maximum and minimum temperature, vapor pressure deficit (can be measured directly, or calculated from temperature and relative humidity), wind speed, and solar radiation (Table 2). Precipitation and irrigation is not needed in the MPM, but is essential to track water balance in the field. Of the required parameters, the most common parameter not recorded is relative humidity (Table 2). Several of the SCAN stations also do not report solar radiation. The DAWC stations generally have the most complete and robust historical data records, but several of the SCAN sites also have lengthy and reasonably complete records. Additional SCAN sites have been added recently in agricultural areas near Mayday, North Issaquena, Onward, Perthshire, Sandy Ridge, Starkville, Scott, Silver City and Tunica. While these have fewer than 10 years of historical records, they will be useful in establishing climatic variables for crop management.

Table 1. Summary of weather station details for the DREC-MSU Delta Agricultural Weather Center and the NRCS Soil Climate Atmosphere Network stations.

Weather Station DAWC-AMS	Location			Location Description	Start Date	End Date	Years Reported
	Latitude	Longitude	Elevation				
Catfish (Stoneville)	33° 27'	-90° 54'	121'	grass, catfish pond	9/14/1996	present	14
Lyon	34° 13'	-90° 33'	172'	grass, ag field	5/11/1997	present	13
Macon	33° 7'	-90° 34'	178'	grass, ag field	9/29/2001	present	8
Sidon	33° 25'	-90° 14'	123'	grass, ag field	8/19/1998	present	12
Stoneville	33° 26'	-90° 55'	127'	grass, ag field	1/1/1996	present	15
Stoneville	33° 26'	-90° 55'	127'	grass, ag field	1/1/1980	12/31/1995	16
Thighman Lake	33° 21'	-90° 30'	115'	grass, ag field	3/6/1998	present	13
Tribbett	33° 21'	-90° 48'	118'	grass, ag field	4/23/2001	present	10
Verona	33° 12'	-90° 43'	321'	grass, ag field	7/26/2000	present	10
Weather Station NRCS SCAN	**Location**			**Location Description**	**Start Date**	**End Date**	**Years Reported**
	Latitude	**Longitude**	**Elevation**				
Beasley Lake	33° 23'	-90° 39'	115'	grass, ag field	9/20/1999	present	11
Goodwin Creek Pasture	34° 15'	-89° 52'	320'	grass	1/27/1999	present	9
Goodwin Creek Timber	34° 14'	-89° 54'	320'	grass, near trees	1/29/1999	present	11
Mayday	32° 52'	-90° 31'	108'	grass, ag field	9/23/2005	5/10/2011	5
Newton	32° 20'	-89° 05'	300'	grass, ag field	1/1/1997	7/7/2003	4
North Issaquena	32° 60'	-91° 4'	112'	grass, ag field	2/10/2004	present	6
Onward	32° 45'	-90° 57'	100'	grass, ag field	11/4/1997	present	9
Perthshire	33° 58'	-90° 54'	200'	grass, ag field	4/18/2002	5/6/2011	8
Sandy Ridge	33° 40'	-90° 34'	138'	grass, ag field	9/24/2005	present	5
Scott	33° 37'	-91° 6'	165'	grass, ag field	8/14/2002	4/5/2011	8
Silver City	33° 5'	-90° 31'	115'	grass, ag field	2/10/2004	present	7
Starkville	33° 28'	-88° 47'	340'	grass, ag field	4/21/2002	4/26/2011	9
TNC Fort Bayou	30° 28'	-88° 44'	43'	grass, near trees	1/1/2004	present	7
Tunica	34° 41'	-90° 25'	260'	grass, edge of field	9/17/1999	present	9
Vance	34° 4'	-90° 21'	150'	grass, ag field	9/18/1999	present	11

Table 2. Summary of station sensors used, degrees reported, and complete years' data available. Height of wind sensor is recorded in m. Summary of station sensors used, units reported, and number of years of complete data in the archive. Height of wind sensors is reported because all wind data will need to be normalized to a reference height.

Weather Station DAWC-AMS	Parameter							
	Air Temperature		Relative Humidity (%)	Precipitation (inches-day^{-1})	Wind Speed			Solar Radiation (Langley-day^{-1})
	HMP45C			tipping bucket	3-cup anemometer			pyranometer
	Years	Units	Years	Years	Years	Sensor Height (m)	Units	Years
Catfish (Stoneville)	14	^{0}F	14	12	14	2.13	miles/day	14
Lyon	14	^{0}F	9	14	14	1.68	miles/day	14
Macon	8	^{0}F	8	8	8	3.00	miles/day	8
Sidon	11	^{0}F	10	11	11	2.74	miles/day	11
Stoneville, 1996 - present	15	^{0}F	15	15	15	2.0 & 10.0	miles/day	15
Stoneville, 1980 - 1995	16	^{0}F	16	16	16	2.0 & 10.0	miles/day	16
Thighman Lake	12	^{0}F	11	12	12	3.26	miles/day	12
Tribbett	9	^{0}F	9	9	9	3.29	miles/day	9
Verona	10	^{0}F	9	10	10	1.74	miles/day	10

Weather Station NRCS SCAN	Parameter							
	Air Temperature		Relative Humidity (%)	Precipitation (inches-day^{-1})	Wind Speed			Solar Radiation (Langley-day^{-1})
	HMP45C			tipping bucket	3-cup anemometer			pyranometer
	Years	Units	Years	Years	Years	Sensor Height (m)	Units	Years
Beasley Lake	11	^{0}F	11	11	9	2.93	miles/day	9
Goodwin Creek Pasture	8	^{0}C	NA	6	8	3.68	avg mph	NA
Goodwin Creek Timber	11	^{0}C	NA	5	10	3.68	avg mph	NA
Mayday	5	^{0}F	5	5	5	3.00	miles/day	5
Newton	6	^{0}C	NA	3*	NA	NA	NA	NA
North Issaquena	7	^{0}F	7	7	7	2.87	miles/day	7
Onward	9	^{0}F	9	9	8	3.00	miles/day	9
Perthshire	9	^{0}F	9	9	9	3.28	miles/day	9
Sandy Ridge	5	^{0}F	5	5	5	3.07	miles/day	5
Scott	8	^{0}C	8	8	8	2.93	miles/day	8
Silver City	7	^{0}F	7	7	7	2.90	miles/day	7
Starkville	9	^{0}F	9	9	8	2.84	miles/day	9
TNC Fort Bayou	6	^{0}C	NA	6	6	3.25 & 8.23	avg mph	NA
Tunica (1999-2004)	4	^{0}C	5	5	3	2.74	miles/day	3
Tunica (2005 - present)	5	^{0}F	5	4	5	2.74	miles/day	5
Vance	11	^{0}F	11	11	9	2.74	miles/day	9

* Newton reports precipitation accumulated since first day of year.
Stoneville began reporting relative humidity in 1996.
Tunica changed from reporting temperature in Centrigrade in 2004.

Identification and Elimination of Erroneous Entries

Error checking of the reported weather data is critical to identify erroneous data. However, care must be taken to prevent the elimination of good readings due to incorrect identification of extreme values as erroneous (Hubbard et al., 2005).

To quickly identify potential problems in data records, the number of entries recorded were counted and averaged across all years for each location (Table 3 & 4). Duplicate daily data entries were apparent from recorded counts in excess of 365 (or 366 in leap years) resulting in recorded percentages in excess of 100% (e.g., at Verona, Newton, and TNC Fort Bayou). A common problem with the SCAN sites was insertion of a duplicate record on September 30. In some years, duplicate daily entries were negated by missing data from other days. To insure removal of all duplicate entries, daily records were checked against calendar days. Another infrequent error occurred when entire blocks of records were duplicated. For example, at the Thighman Lake station, the entire period from May 27 through June 14 was reported twice in 2010. This type of error more likely results from a problem with the downloading and transfer to the web page rather than a system error at the weather station.

The quality assurance procedures outlined in Table 5 quickly correct common errors, such as entries of -99.9 or -6999 commonly entered as flags to indicate faulty or missing sensor readings (Hu et al., 2002). These readings are obviously outside of the range of either the sensor or the climate. The sensor and climate range limit tests identified additional errors such as temperature readings of 257°F. More subtle errors also exist, such as a recorded temperature of 9°F, which is possible but unlikely in Mississippi. Performing a step test on the temperature data from previous and subsequent days indicated that this temperature reading fell outside the acceptable range and it was concluded that the value was erroneous.

Table 3. Average values over 8 common years (2002-2009) of key statistics from quality controlled weather information available from DAWC weather stations. These 6 stations had the highest percentage of reported data. The other DAWC station in Mississippi (Macon and Tribbett) had insufficient time continuity to be used in this analysis. *Temperature and relative humidity not included for 2009 because of insufficient data during the growing season

Weather Station DAWC-AMS		Catfish (Stoneville)	Lyon	Sidon	Stoneville	Thighman Lake*	Verona
T_{max} ^0F	maximum	99	101	101	101	101	99
	minimum	30	28	32	31	30	30
	standard deviation	16	17	16	17	16	16
	% valid readings	99	96	100	100	99	99
T_{min} ^0F	maximum	77	78	76	78	77	76
	minimum	19	17	20	18	19	15
	standard deviation	15	16	15	16	15	16
RH_{Max} Percent	maximum	98	101	100	99	98	99
	minimum	66	65	66	66	59	58
	standard deviation	5	6	5	5	6	6
	% valid readings	98	96	99	98	98	99
RH_{Min} Percent	maximum	94	99	100	94	93	93
	minimum	18	16	18	16	15	15
	standard deviation	16	17	17	17	17	16
Wind run Miles-day^{-1}	maximum	426	352	353	335	341	295
	minimum	39	14	9	15	11	9
	standard deviation	77	64	70	60	64	56
	% valid readings	100	97	100	99	98	100

Sunlight Langley-day^{-1}	maximum	663	730	672	691	674	725
	minimum	19	17	21	15	20	20
	standard deviation	171	189	173	178	173	183
	% valid readings	100	97	100	100	98	100
Precipitation inches-day^{-1}	maximum	4.04	3.13	3.58	4.01	3.06	3.23
	minimum	0.00	0.00	0.00	0.00	0.00	0.00
	standard deviation	0.40	0.34	0.38	0.42	0.37	0.38
	% valid readings	99.66	96.61	99.62	100.00	98.77	99.90

Table 4. Average values over 8 common years (2002-2009) of key statistics from quality controlled weather information available from NRCS weather stations in Mississippi. These 4 stations had the highest percentage of reported data. The other NRCS stations in Mississippi (Goodwin Creek (pasture and timber), Mayday, Newton, North Issaquena, Sandy Ridge, Scott, Silver City, TNC Fort Bayou, and Tunica) had insufficient time continuity to be used in this analysis.

Weather Station NRCS SCAN		Beasley Lake	Perthshire	Starkville	Vance
T_{max} ^{0}F	maximum	100	99	98	99
	minimum	30	28	33	28
	standard deviation	16	16	15	16
	% valid readings	99	95	88	96
T_{min} ^{0}F	maximum	76	77	77	76
	minimum	19	18	18	17
	standard deviation	15	15	15	15
RH_{Max} Percent	maximum	100	100	99	99
	minimum	63	61	61	62
	standard deviation	6	6	5	6
	% valid readings	99	95	87	96
RH_{Min} Percent	maximum	95	94	93	93
	minimum	15	16	13	16
	standard deviation	17	17	16	16
Wind run Miles-day^{-1}	maximum	358	363	254	302
	minimum	19	24	20	22
	standard deviation	69	67	41	52
	% valid readings	99	95	90	96
Sunlight Langley-day^{-1}	maximum	692	695	672	694
	minimum	19	17	18	17
	standard deviation	177	182	162	176
	% valid readings	97	95	88	96

	maximum	3.27	3.33	4.00	3.49
	minimum	0.00	0.00	0.00	0.00
Precipitation inches-day^{-1}	standard deviation	0.39	0.39	0.42	0.39
	% valid readings	99.42	94.21	86.92	95.38

When a value is flagged, it is important to examine the entire climatic record for weather patterns that may explain the apparent error. In determining if a particular point measurement is erroneous, it is helpful to determine if the reading fits in with the rest of the weather pattern during that period. The temporal shifts in weather patterns may account for seemingly high or low readings. For example, a recorded value of RH_{min} = RH_{max} = 100% for 11/22/04 at Beasley Lake was flagged as a possible error. Examination of RH values from previous days showed that RH_{min} values were as low as 39%. However, the entire climatic record showed that rain began four days previously and by November 24th, 1.4 inches of rain had been received. The rain continued for several more days. The reported RH_{min} of 100% was therefore realistic. Conversely, a high standard deviation flagged an RH_{max} reported value at the Catfish weather station in 2004. Examination of the record showed that 1.8" of rain had been received the previous day and another inch of rain was received that day. Low solar radiation levels corroborated the rainy weather, indicating that the RH_{max} = 51% was probably wrong. Closer examination revealed that RH_{max} dropped abruptly on day 95, and remained low through day 138, even though significant rainfall was received (Figure 2).

Extreme weather events lead to other problems with recorded data. Some of the sensors are susceptible to extreme weather, especially in the humid, high rainfall environment of Mississippi. The relative humidity sensors are particularly error-prone (Table 3 & 4). Rain also interferes with the solar radiation sensor, giving artificially low or high readings. Discrete weather events, such as thunderstorms, can often interrupt all sensors, possibly through electrical activity. Error checking should include a specific component to examine the integrity of all sensors during and after extreme and discrete weather events. If one sensor is reporting erroneous data, it is more likely that other sensors are also reporting incorrect values. Strong storms can interrupt data delivery, either through damage to the sensors, data logger, or the communications equipment. Occasionally, communication between the SCAN master station located in Stoneville, MS (one of only three in the U.S.) and individual SCAN stations is disrupted; for example, the master station has been hit by lightening. This is seen quite dramatically in the 2011 growing season when four weather stations were knocked out of service during severe spring storms (Table 1). The weather station at Mayday also had to be removed because of the flood hazard associated with the rising Mississippi River. These stations are being repaired and brought back on line.

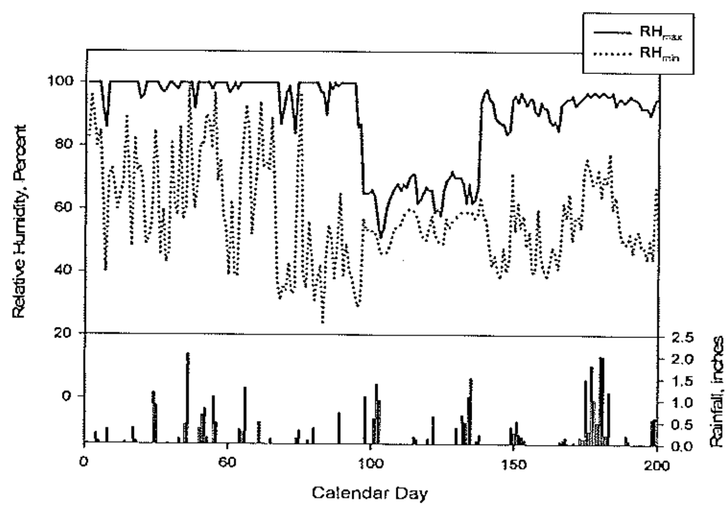

Figure 2. An example of a sensor integrity error (roughly day 95 through 140), possibly the result of storm-related damage to the sensor, data logger, or reporting network.

0Instrument error can also result in incorrect readings. Incorrect calibration of a sensor can lead to recording incorrect values (Figure 3). Alternatively, drift in instrument calibration slowly introduces error into the recorded data, making frequent and complete calibration of instrumentation critical. This is particularly important for the relative humidity and solar radiation sensors, which seem most prone to calibration error and drift. To check for accuracy of the solar radiation readings, the recorded solar radiation values were compared to the maximum possible clear-sky values based on latitude and day of year (Figure 4). The solar radiation values recorded in spring and fall that rise slightly above the calculated maximums are the result of increased scattering from intermittent, bright clouds. Long periods of low solar radiation may indicate that the sensor dome has become dirty or clouded, or that the interior of the dome has accumulated moisture (Fiebrich et al., 2010). Degradation of a pyranometer was evident by the declining solar radiation values over several years (Figure 5). After recalibration, however, the solar radiation readings were greater than those possible based on latitude and clear-sky conditions. This could have resulted from improper calibration or positioning of the pyranometer.

Another type of error apparently results from calculation errors in data logger programming (Figure 6). In this instance, the recorded solar radiation increases ten-fold on 7/14/04 and remains high for several months. The month-to-month trend in the data follows readings expected from the annual change in total sunlight, though at a level ten times that previously recorded. The recorded value falls abruptly after 11/30/2005. An examination of the historical record indicates no sensors recorded during the time period from 11/30/05 – 12/12/05, after which time the correct solar radiation was regained.

Errors that are more difficult to detect can result from poor or improper placement of the weather station. Large trees or other obstructions can shade the radiation sensor, and greatly alter the wind dynamics. These obstructions may be temporary, such as a crop or agricultural implement. Seasonal changes can also greatly impede proper collection of weather data, such as locating a weather station too near an irrigation system, resulting in irrigation water accumulating in the rain gauge and being recorded as precipitation. Human and animal activity near the weather station can also impact weather data collection. One particularly high temperature reading led to the discovery that a neighboring field of wheat stubble had been burned, melting the wind sensor. These errors can best be identified by regular site visits; barring that, continuous application of quality assurance algorithms is the next best line of defense.

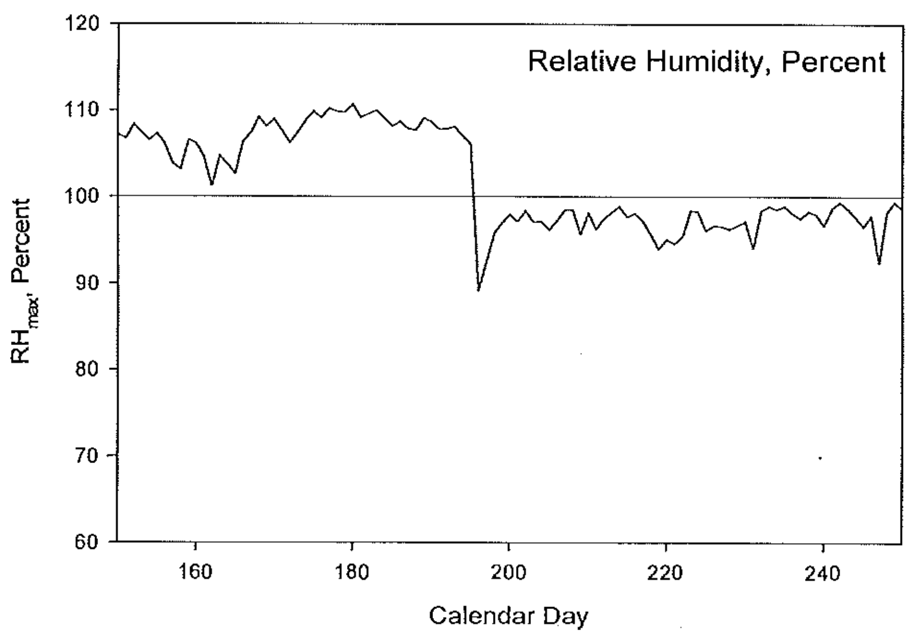

Figure 3. An example of erroneous data before recalibration (day 196) of the humidity sensor

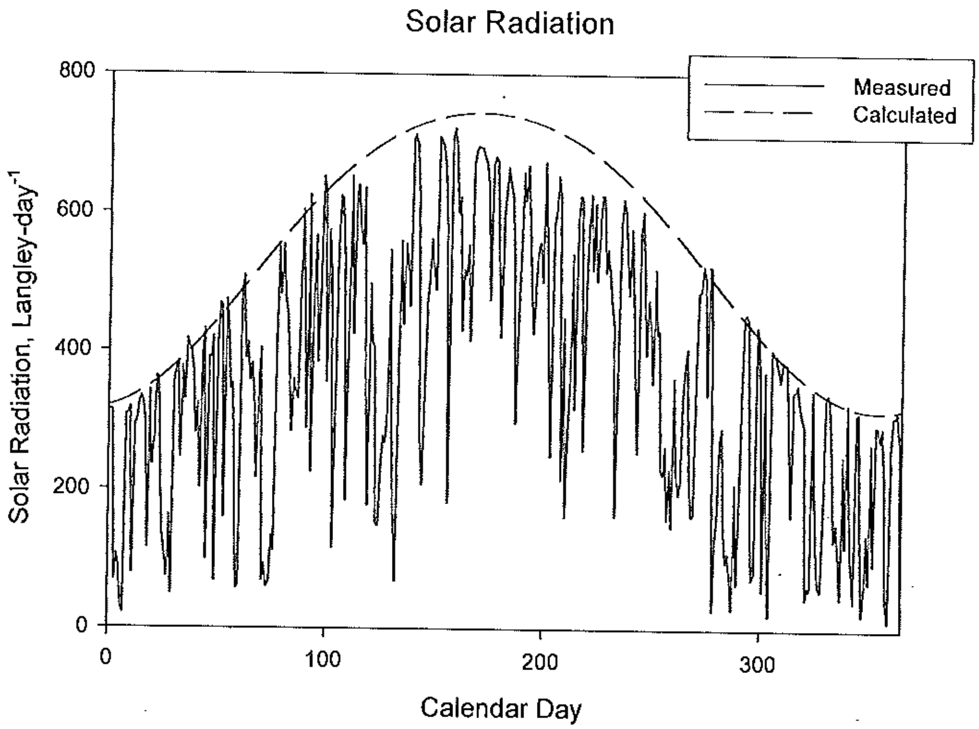

Figure 4. Error checking of solar radiation by comparison of measured solar radiation against maximum clear-sky solar radiation calculated for latitude and time of year.

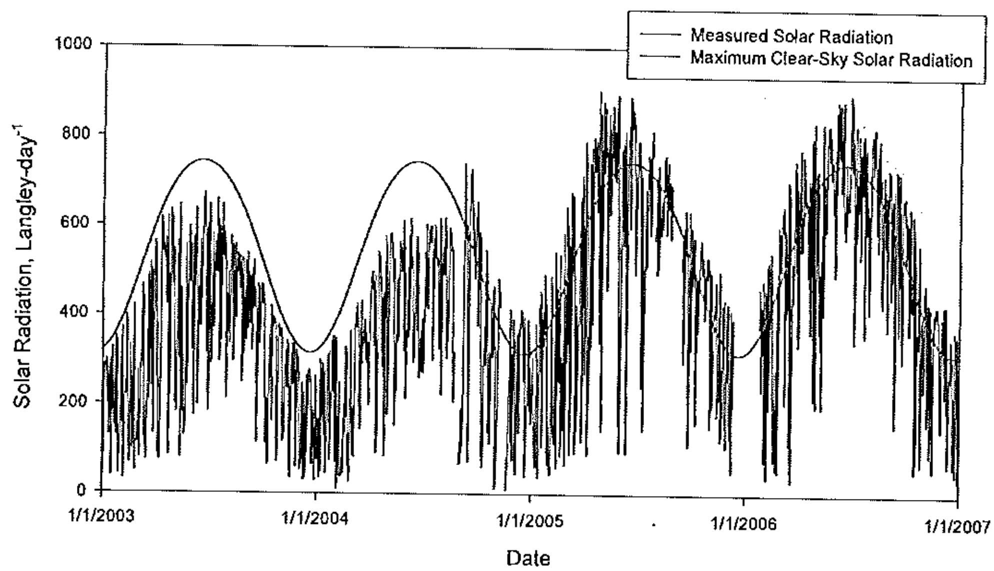

Figure 5. Solar radiation sensor prior to and following recalibration, and maximum clear-sky radiation.

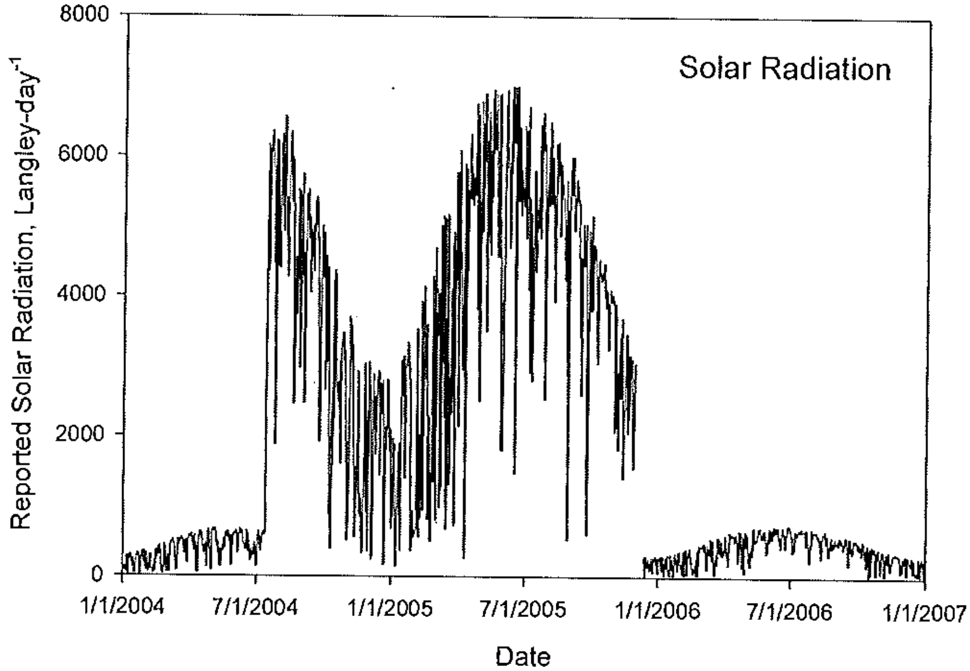

Figure 6. Apparent data logger error of solar radiation multiplication constant

Consistency Checking and Error Correction

After careful examination of all weather records from all sites, erroneous entries were removed based on the statistical variance. Quality assurance tests were then established by defining the climate range limits and step limits from the extremes in recorded, correct values (Table 5). While broad, the climate range limits give the maximum and minimum values for each of the parameters. The step limit is the most extreme one-day change observed for a particular value. This limit is used to identify dip or spike records in data. The persistence test identifies when a sensor has stopped responding but is reporting a value within acceptable range without varying.

After correction, the station parameters were recounted for completeness and counts averaged over all complete years of data available (Tables 3 and 4). The most complete and robust data sets have been recorded at the DAWC weather stations. While less complete, the agriculturally based SCAN sites will also be useful in providing weather parameters for calculating the reference crop evapotranspiration.

Additional rules are suggested to improve the error-checking process:

- RH_{min} must be < RH_{max}
- T_{min} must be < T_{max}
- If there is evidence that a measurement from a sensor is bad on a particular day, all other measurements from that sensor on that day are discarded.
- If a sensor records more than a threshold number of days of erroneous data, all subsequent data from that sensor should be flagged until the sensor is checked and the data are cleared by a technician.
- In the event of an extreme weather event (e.g. high rainfall), flag all sensor readings until the data are cleared by a technician.

For the purposes of the irrigation decision support tool, algorithms will need to be written and applied to daily data to flag and remove erroneous or questionable data as identified in the procedures outlined above, properly convert units, and adjust sensor readings to a common reference height before daily calculations of ET can be performed.

Table 5. Quality assurance tests established for range limits of sensors, climate, single day step increase or decrease, and day-to-day persistence.

Quality Assurance Test	Sensors									
	Air Temperature Degrees F		Relative Humidity Percent		Precipitation inches		Wind speed miles/day		Solar Radiation Langley/day	
Sensor Range Limits										
Maximum	140 F		100%		NA		100 mile/hr		258,120*	
Minimum	-40 F		0		0.01		0		0	
Climate Range Limits	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer
Maximum	86.0	106.0	100	100	601.0	743.0	265	192	350	782
Minimum	1.0	42.0	14.0	11.0	0	0	2	1	3	35
Step Test										
Maximum	31 F		68%		NA		224 mpd		630	
Minimum	-49 F		-75%		NA		-179 mpd		-607	
Persistence Test										
Minimum	0.1° in 60 min		0.1% in 360 min**		NA		0.1		0.1 Langley in 14 hrs	

* The listed solar radiation sensor maximum limit represents the upper limit for sensor response, and is several orders of magnitudes larger than would actually be observed. ** Because of the high relative humidity common to the Mid-South, the persistence test for relative humidity is based only on the minimum reading.

DISCUSSION

Development of timely, accurate crop management decision support tools requires consistent, reliable, accurate and complete information on climatic conditions to simulate crop growth and water use. Weather data is particularly susceptible to errors. Identification of errors and establishment of a protocol to flag and correct weather data will improve the ability to simulate crop development and the related water balance for irrigation decision support tools.

The environmental conditions in Mississippi make measurement of relative humidity particularly challenging. The high humidity conditions and frequent rain events erode sensor integrity, particularly that of the relative humidity sensors. While vapor pressure is needed to perform the MPM calculation of ET, a better approach may be to estimate this parameter from the minimum temperature (Allen et al., 1998).

The most critical parameters for accurate estimation of ET and crop water balance are T_{max}, T_{min}, precipitation, and irrigation. To develop a reference ET calculation that can be used by crop producers throughout Mississippi, missing data points and data from locations not near weather stations will both need to be interpolated. Interpolation of temperature across space and time is feasible. However, precipitation varies greatly in space and time, and interpolation methods produce less than satisfactory results. For this parameter, a more realistic measure may be the fine-scale daily precipitation radar data product developed by the National Weather Service (2012) from radar observations. This will provide daily rainfall data at the field scale for calculating a water balance for irrigation scheduling.

The online irrigation scheduler under development will require monitoring and error correcting of real-time weather data on a daily basis. The range tests and statistical limit tests developed here will be implemented in an automated error checking procedure to correct weather data prior to determination of reference ET for irrigation scheduling.

Developing reliable and accurate crop management tools for farmers is critically dependent on the quality of the data input. Developing an irrigation scheduling tool will be challenging based on the quality and continuity of the sparsely available weather data. By incorporating the error identification and correction protocols outlined here, the accuracy of the simulation can be greatly improved. Future studies will explore the spatial variability of weather parameters and develop interpolation protocols for realistic and feasible estimates of climatic conditions at remote locations. Additional research will explore alternative methods of measuring weather parameters and possible use of multiple sensors at each site (Allen, 1996). Although irrigation primarily occurs in the Delta region, interest in irrigation in other areas of the state necessitates addressing the paucity of weather information from other regions in Mississippi. This information will enhance the productive capacity of Mississippi agriculture.

DISCLAIMER

Mention of a trade name or proprietary product does not constitute an endorsement by the U.S. Department of Agriculture. Details of specific products are provided for information only, and do not imply approval of a product to the exclusion of others that may be available.

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