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A Web Application for Managing Regional Crop Production: The West Texas Mesonet Agro-Climate Monitor

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ABSTRACT

Although dependent on rainfall and other climate factors to produce crops, West Texas crop consultants, extension agents, and agricultural producers have few tools that allow them to track the current growing season's climate conditions and determine how current conditions compare with those of past years. The West Texas Mesonet Agro-Climate Monitor (ACM), a JavaScript web application based on daily data from Texas Tech University's mesonet weather station network, was designed to meet this need. By displaying continuously updated information on variables such as soil temperature, cumulative growing degree days (GDD), cumulative precipitation, and first freeze dates, the ACM allows producers to monitor planting conditions, track crop development, and compare current conditions with those during the previous 10 yr's growing seasons. In illustrating how mesonet data might be used as an operational climate data resource, the ACM might also serve as a conceptual model for other high resolution climate tools that estimate measures of current climate using continuously updated daily data sets.

Core Ideas

- A web-based JavaScript tool for continuous monitoring of West Texas agro-climate.
- High resolution operational climatology.
- Mesonet meteorological data as an agro-climate data resource.

Dense networks of meteorological stations such as the Oklahoma (www.mesonet.org: Brock et al., 1995) and West Texas Mesonets (www.mesonet.ttu.edu: Schroeder et al., 2005) can be important sources of current weather information for crop consultants, extension agents, and producers. Mesonets provide information relevant to agriculture that other meteorological networks, for example, the U.S. National Weather Service's cooperative network (Robinson, 1990) or the U.S. Historical Climatology Network (USHCN: Menne et al., 2012, 2015), do not. In addition, these networks provide data at time and spatial resolutions that are typically more useful to most farming or ranching operations.

In the course of attending bi-weekly meetings of the Plains Cotton Advisory Group (www.plainscotton.org) it becomes clear that producers and agricultural decision makers rely on West Texas Mesonet (WTM) data to monitor soil temperature, air temperature, wind, radiation, humidity, and rainfall. But although mesonets are usually not designed to answer questions regarding climate, users also pose climatological questions about WTM data. Although some of these questions might be answered with daily cooperative or USHCN data, others require soil temperature or hourly air temperature records that those data sources do not provide. For example: When do soil temperature conditions normally rise to levels suitable for planting? When can I expect the onset of hard freeze conditions and for how long? West Texas summer rainfall can be spatially random, that is, certain areas receiving ample rainfall while nearby areas receive none. As a result, answering a producer's questions regarding how total precipitation during the current growing season compares with totals from past seasons may require a spatially dense meteorological network. A dense network may also be necessary to resolve the effects of a region's topography on precipitation, temperature, and growing degree days (GDD).

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Abbreviations: ACM, agro-climate monitor; Ajax, Asynchronous JavaScript and XML; DTR, daily temperature range; DPCP, daily precipitation; FRHR, daily freeze hours; GUI, graphical user interface; GDD, growing degree days; HDD, heating degree days; JSON, JavaScript object notation; LDM, local data manager; QC, quality control; ST20, soil temperature at 20 cm; TMIN, daily minimum temperature; TMAX, daily maximum temperature; PSWCL, USDA Plant Stress and Water Conservation Laboratory; USHCN, U.S. Historical Climatology Network; WTM, West Texas Mesonet.

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The WTM has been operational since June 2000 and currently consists of 102 automated surface stations located across West Texas. The network provides data at high time and spatial resolution, but, as of early 2017, has also been collecting data at many stations for over a decade. Although no WTM data records are of the 30 yr length traditionally used to define climate normals (Guttman, 1989; WMO, 1989), an emerging view in climatology is that statistics calculated over a recent 30-yr period may not be the most representative measure of current climate (Livezey et al., 2007; Trewin, 2007; Arguez and Vose, 2011). As summarized by Trewin (2007), climate normals of periods shorter than 30 yr have been found to be more skillful in forming seasonal persistence forecasts. Over the United States the Climate Prediction Center's Optimal Climate Normal method (Huang et al., 1996; O'Lenic et al., 2008) uses annually updated means calculated over 10-yr periods to predict mean seasonal temperature, and 15-yr periods to predict total seasonal precipitation. Angel et al. (1993) found that 11-yr winter heating degree day (HDD) means provided the most skillful forecasts of winter HDD in Illinois with a 1-yr lead time. Trewin (2007) proposes predictive ability as a leading criteria for defining the most suitable periods over which climate statistics might be estimated, and recommends the use of "operational" normals that might be calculated with 10 or fewer years of recent data. Thus valid, high resolution, and arguably more representative climate information might be derived from mesonet records as short as 10 yr long. To be clear, the main purpose of the agro-climate web application described here is not predictive. However, these studies suggest that the decadal data sets provided by the WTM and other regional mesonets may be useful if untapped operational climate data resources.

Although mesonet data records might provide smaller statistical samples over time, their dense spatial sampling may allow for increasing sample rates by aggregating or averaging data over groups of adjacent stations. In addition to providing representative estimates of current climate conditions, mesonet data may also provide information about a wider range of climate variables than that provided by most mesoscale meteorological networks. Web applications based on such data might be used by producers to monitor a current growing season's key climate variables over arbitrary seasonal periods and with high spatial resolution. Moreover, such applications might be used to address one of the more general and common questions posed by producers: How do the current growing season's conditions compare with those of previous years? A dynamic web application designed to provide such information- the West Texas Mesonet Agro-Climate Monitor (ACM)-is described here. The following description's objectives are twofold: First, to describe the WTM data used in the ACM and the U.S. Historical Climatology Network version 2.5 data used to estimate quality control parameters for the daily WTM temperature and precipitation values; second, to provide a functional overview of the ACM, including the interaction between Local Data Managers (LDM) and web servers, the daily calculation, quality control, and storage of data, basic client-server interaction, and a description of the graphical user interface (GUI).

MATERIALS AND METHODS

Data

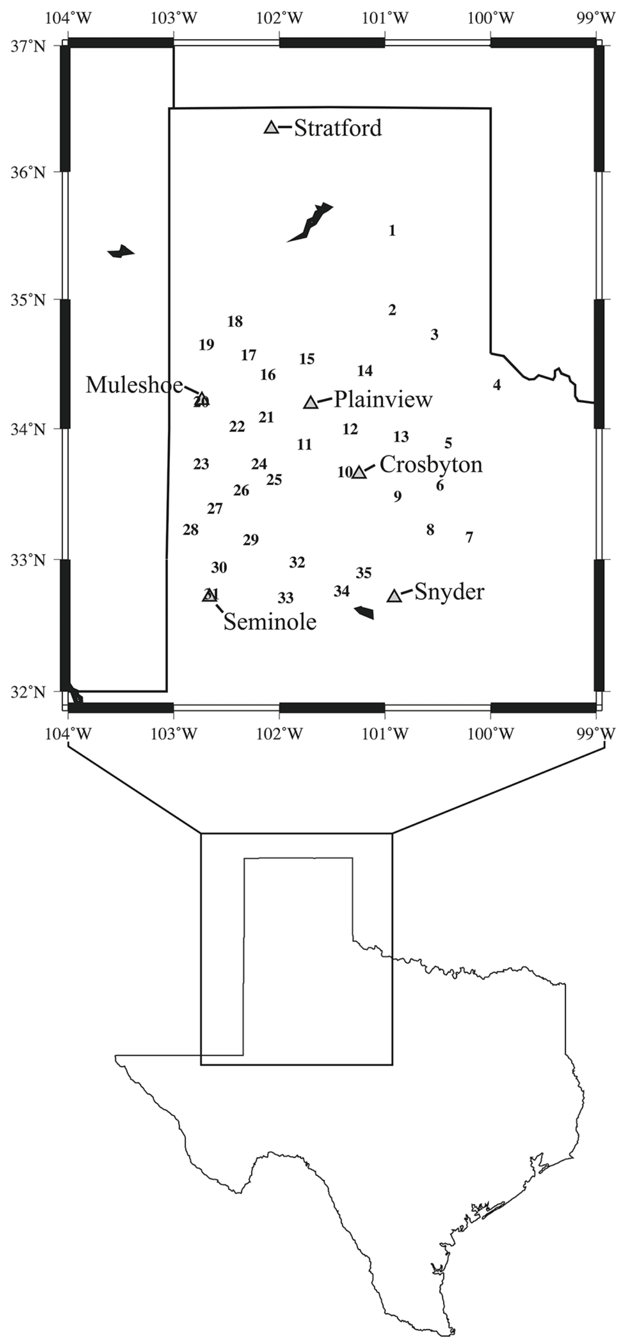
The ACM displays data from a subset of 35 WTM Stations (Fig. 1) that have been in operation since 1 Jan. 2005 or before. In addition to providing at least 10 yr of data, these stations also provide dense spatial coverage over the upland cotton (*Gossypium hirsutum* L.)-producing regions of West Texas. Each WTM station provides measurements of meteorological data at 5-min increments. Agricultural data, that is, measurements of soil temperature, soil water content, and leaf wetness, are recorded every 15 min. Most of the Fig. 1 WTM stations are sited in rural areas: the southern High Plains cotton production region to the West is very flat, while the Rolling Plains area to the East is dominated by ranching. The network's station siting was guided by the need for maintaining an approximate 35 km station separation, line-of-sight radio access, uniform wind exposure and site slope, and obtaining permission for siting and accessing stations on private land. Site design was modeled after that of the Oklahoma Mesonet, and each site is maintained every 2 mo. While a full description of a typical site's equipment suite and the variables that are recorded can be found in Schroeder et al. (2005), the ACM's variables are based on precipitation, 2.0 m air temperature, and soil temperature measurements at 20 cm. Although a summary of quality control (QC) procedures applied to archived data is outlined in Schroeder et al. (2005), the 5 and 15 min data reports used here to estimate the most recent calendar day's precipitation and air and soil temperature values are not quality controlled. The procedures used here to conduct QC tests on this daily data are described in a following section. The daily data available from the USHCN version 2.5 dataset has undergone quality control (Menne et al., 2012), and is used here to calculate QC parameters for the daily WTM data values. These parameters were derived using 1981 to 2010 daily maximum and minimum temperature and precipitation data from the USHCN stations at Stratford, Plainview, Muleshoe, Crosbyton, Seminole, and Snyder, TX (Fig. 1).

FUNCTIONAL DESCRIPTION

The transfer of 5 and 15 min WTM station data to the USDA web server hosting the ACM is accomplished via an upstream LDM server at Texas Tech University (TTU) and a downstream USDA LDM server (Fig. 2). The TTU LDM server is maintained by the TTU Atmospheric Science Department, while both USDA servers are located at the Agricultural Research Service's (ARS) Plant Stress and Water Conservation Laboratory (PSWCL) in Lubbock, TX. Files containing WTM data for the previous 48-h period are transferred to the PSWCL LDM server every 30 min. Every day at 0210 h CST, the most recent file is transferred from the PSWCL LDM server to the PSWCL web server.

Daily Data Calculation

At 0220 h CST minimum (TMIN) and maximum (TMAX) temperature, the number of hard freeze hours (FRHR), and total daily precipitation (DPCP) are calculated from the previous calendar day's 5 min meteorological data. The daily average soil temperature at 20 cm (ST20) are calculated from soil temperature values reported every 15 min. Before the calculation of TMIN, TMAX, and FRHR values, each station's 5 min 2.0



Station #	WTM Station Location
1	3.2 km E Pampa
2	3.2 km WSW Clarendon
3	1.6 km NE Memphis
4	4.8 km W Goodlett
5	16.0 km SW Paducah
6	16.0 km WSW Guthrie
7	4.8 km NE Aspermont
8	1.6 km SSE Jayton
9	1.6 km W Spur
10	1.6 km SE Ralls
11	8.0 km ENE Abernathy
12	3.2 km NNE Floydada
13	4.8 km N Roaring Springs
14	11.2 km ESE Silverton
15	3.2 km ENE Tulia
16	4.8 km N Hart
17	3.2 km NE Dimmitt
18	3.2 km NW Hereford
19	3.2 km NE Friona
20	3.2 km SSW Muleshoe
21	9.6 km S Olton
22	1.6 km NE Amherst
23	1.6 km ENE Morton
24	9.6 km SSW Anton
25	13.2 km W Lubbock
26	6.4 km S Levelland
27	12.8 km WSW Sundown
28	4.8 km N Plains
29	3.2 km S Brownfield
30	1.6 km SW Seagraves
31	3.2 km NNE Seminole
32	1.6 km N O'Donnell
33	3.2 km SE Lamesa
34	3.2 km ESE Gail
35	4.8 km WNW Fluvanna

Fig. 1. Locations of the Agro-Climate Monitor's 35 West Texas Mesonet (WTM) stations. Gray triangles mark the locations of the six U.S. Historical Climatology Network stations used to calculate quality control parameters for daily temperature and precipitation.

m temperature readings are submitted to preliminary quality control by comparing them with the World Meteorological Organization (WMO) global records for maximum (56.7°C) and minimum (-89.2°C) temperature. Non-null 5 min values that exceeded those thresholds are set to null. Similarly, running 1 and 12 h totals of the 5 min precipitation data were compared with WMO global records for 1 h (305 mm) and 12 h (1144 mm) rainfall. If those thresholds are exceeded during any 1- or 12-h period the 5 min precipitation values during that period were set to null. Daily data values for a station are calculated when at least 80% of the 5- and 15-min measurements during the previous day's 24 h were valid, non-null values. Otherwise, the corresponding daily value is set to a null value. The resulting daily values are then subjected to a simple quality control procedure that detects climatological outlier and instrument failure, and substitutes data from nearby stations for missing data and data values that fail any QC test.

Quality Control of Daily Data

As temperature distributions are generally Gaussian, outlier daily temperature values in the WTM daily data were checked using the Z-score based method used by Durre et al. (2010). Using the daily records from the six USHCN stations, the means and standard deviations of daily West Texas TMIN and TMAX were estimated for each day of the calendar year. As in Durre et al. (2010), these parameters were calculated over 15-d running

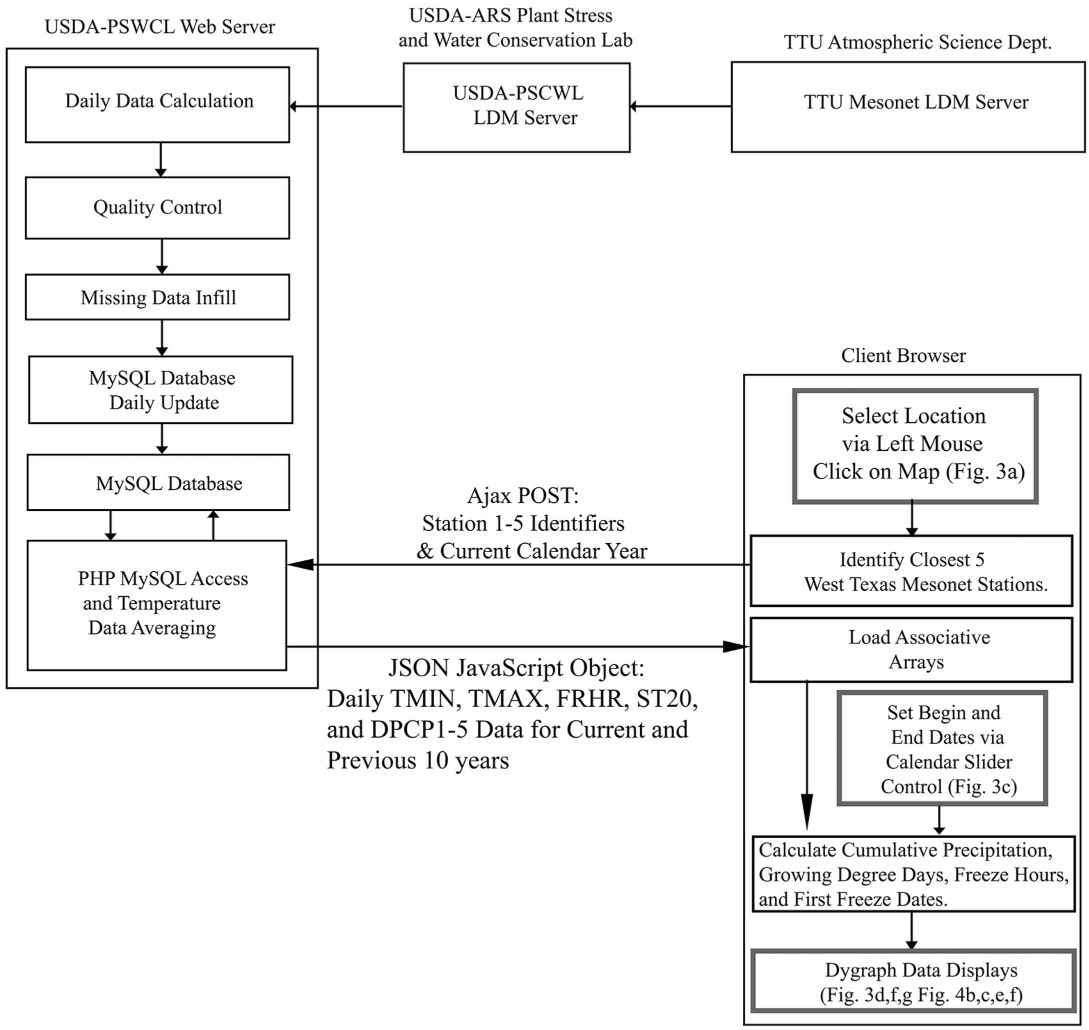


Fig. 2. Functional flow chart of the Agro-Climate Monitor's client-server configuration. Gray outlined elements indicate a user control or data display marked in Fig. 3 and 4.

windows, and were based on the six station's aggregate statistics during 1981 to 2010 for each day of the year. Thus, for example, the average maximum temperature for 8 July was the average of 1 to 15 July TMAX values estimated from the six stations during 1981 to 2010 (μ_T), and that day's TMAX standard deviation was estimated from the variance of the station's 1 to 15 July TMAX values about the 8 July mean. Similarly, the means and standard deviation of daily TMIN and temperature range (DTR = TMAX – TMIN) were also calculated for each day of the year.

As the USHCN network provides no soil temperature data, distribution parameters for daily ST20 values were estimated from a subset of WTM soil temperature records that were considered suitable as quality control standards. After visually inspecting a number of WTM station records for each year of 2005 to 2015, the data for Pampa, Hereford, Floydada, Levelland, and Lamesa, TX, were selected based on the absence of spikes, discontinuities, or runs related to instrument failure. The daily data from these five stations during 2006 to 2014 were used to estimate distribution mean and standard deviation parameters for ST20 for each calendar day using the same process used to generate mean (μ_T) and standard deviation (σ_T) temperature parameters for TMIN, TMAX, and DTR. Using the appropriate normalizing parameters for each T variable and each day of year (i), the WTM daily soil and air temperature variables are normalized into corresponding Z statistics,

$$Z_{T(i)} = \frac{T_i - \mu_{T(i)}}{\sigma_{T(i)}} \quad [1]$$

Following Durre et al. (2010) daily temperature values were considered as outliers and set to null when the absolute value of their corresponding Z statistic exceeded 5.0. DTR values of 0.0 are assumed to be due to instrument failure, and in those cases that day's TMIN, TMAX, and FRHR values are set to null. When the QC procedure detects or sets a daily temperature null value, the non-null and non-outlying TMIN, TMAX, FRHR, or ST20 temperature value from the nearest WTM station is substituted to ensure data continuity.

The recording of WTM temperature data every 5 min makes it possible to calculate the number of FRHR and identify first freeze dates. In the ACM hard freeze conditions are considered to exist when temperature falls below –2°C (28°F). However, given the lack of subdaily USHCN temperature measurements, QC parameters for daily FRHR values cannot be calculated. The approach taken here was to set a day's FRHR value to null whenever any of the same day's TMAX, TMIN, or DTR variables had been detected or set to null by the QC process. As with the other temperature variables, FRHR null values were replaced by a non-null FRHR value from the nearest WTM station.

Given the non-normality of daily precipitation data, WTM DPCP magnitudes were checked based on comparisons with estimates of the 95th percentile of wet-day rainfall totals derived from the six USHCN stations ($DPCP_{95}$). Days were defined as wet in the USHCN data when the daily rainfall total exceeded 2.54 mm (0.10 inch). Following Durre et al. (2010), percentiles were estimated using 29-d windows centered on each day of the year. Thus the 15 July $DPCP_{95}$ value was defined by the 95th percentile of the six station's 587 wet-day rainfall totals in the 1–29 July time window during 1981 to 2010. Each WTM station's daily rainfall total is expressed as a ratio of that day's 95th percentile,

$$Z_{P(i)} = \frac{\mathrm{DPCP}_{(i)}}{\mathrm{DPCP}_{95(i)}} \qquad [2]$$

and $DPCP_{(i)}$ values were considered outliers when the resulting $Z_{P(i)}$ ratio exceeded 5.0. When outlying values are identified, or when a DPCP value is missing due to insufficient or absent data, a value is generated for that day using code adapted from the GEM6 weather generator (Hanson et al., 1994) and weather generator parameters estimated from the six USHCN precipitation records during 1981 to 2010. Overall, the QC procedure results in relatively few data replacements. During 1 Jan. 2005 and 31 Dec. 2015 the 35 stations contributing data to the ACM database could potentially produce 140,595 station-days of data. Over that period the procedures applied here to daily data derived from archived West Texas Mesonet records identified fewer than 100 missing or outlying station-days in the DPCP, TMIN, and TMAX variables, resulting in replacement rates of less than 0.07%. In the 35 station's daily ST20 records, 284 were replaced with values from nearby stations, resulting in a 0.20% replacement rate. After completion of each day's ongoing operational QC procedure at 0220 h, the previous calendar day's TMIN, TMAX, FRHR, ST20, and DPCP values for all 35 stations are added to a MySQL database on the PSWCL web server.

Graphical User Interface Description

The ACM's main purpose is to provide up-to-date, localized, and representative agro-climate data. Given the relatively high spatial density of stations in the WTM network, this is accomplished by calculating and displaying statistics based on daily data from stations closest to a user's location. Users can select their location by left clicking on the map in the upper left of the GUI (Fig. 3a). The JavaScript client then determines the five closest WTM stations to the latitude–longitude coordinate of the selected map location, lists those stations on the GUI (Fig. 3b), and submits an asynchronous JavaScript (Ajax) POST request to the ACM server.

In response to the clients's Ajax request, the server retrieves the TMIN, TMAX, FRHR, ST20, and DPCP daily data for each of the five stations for the 10 calendar years prior to the current year, and the data for the current year up to the previous day, from the web server's MySQL database. Given the relative lack of temperature variability between station records in closely adjacent stations on a particular day, the application's server-side PHP code averages the daily values of the four temperature variables into single records. As a result, for example, the five station records for daily TMIN data are averaged into a single TMIN record that can contain as much as 11 yr of daily data. Repeating this averaging for the TMAX, FRHR, and ST20 variables reduces the volume of temperature data returned to the client by 80%. As daily precipitation totals can vary significantly between nearby stations, similar server-side averaging was not conducted on the five station's DPCP records. After temperature averaging, the resulting TMIN, TMAX, FRHR, and ST20 average temperature records, and the DPCP records of the five nearest stations, are returned to the client web browser encoded in JavaScript Object Notation (JSON).

Once the client browser receives the JSON encoded data for the five closest stations, the records for the four mean temperature variables, and the precipitation records for each station (DPCP1-5) are loaded into JavaScript associative arrays keyed by year. An additional array is loaded with the average of the DPCP1-5 records, which is used to calculate and display average cumulative precipitation for the current year and the previous 10 yr. Sections of these associative arrays are accessed based on the setting of a calendar year slider control (Fig. 3c) which defines the beginning and end dates of data display and calculation periods. Left clicking and dragging the slider's date markers changes the period over which data is displayed on the Mesonet Precipitation (Fig. 3d, 3e, 3f) and Mesonet Temperature (Fig. 4a, 4b, 4c, 4d) tabs. This has a visual zooming effect, but for variables such as accumulated precipitation (Fig. 3d), GDD (Fig. 4b), and hard freeze hours (Fig. 4c) also changes the period over which the accumulation is calculated. So, for example, changing the date markers to 15 May and 15 September would show precipitation totals summed from rainfall events after 15 May. For weather variables that are not summed, for example, daily TMIN, TMAX, and soil temperatures, adjusting the date markers only has a visual zooming effect. Left clicking directly on the graphs on the Mesonet Precipitation and Mesonet Temperature Tabs and dragging to the left or right also produces a zoom-only effect that does not change the accumulation period defined by the calendar slider control. Subsequent double clicking on the graph returns the graph to the display period defined by the current setting of the calendar control.

On the Mesonet Precipitation Tab the "Select Precipitation Variable' dropdown control (Fig. 3g) allows the user to plot three variables:

- The average of the cumulative precipitation for the five nearest mesonet stations calculated for the current year (plotted in white) and for each of the previous 10 yr (Fig. 3d).
- The current year's cumulative precipitation traces for each of five nearest stations, and the average of those traces (Fig. 3e).
- The total precipitation for the period defined by the calendar control date markers for each of the five nearest stations, during the current year and each of the previous 10 yr (Fig. 3f). If either of the calendar slider date markers are set for a day after the current date, the rainfall totals for the current year are not displayed.

Hovering the mouse over any of the graphs causes the numeric values of the plotted data, and their dates or years, to be displayed in a table to the right of the graph.

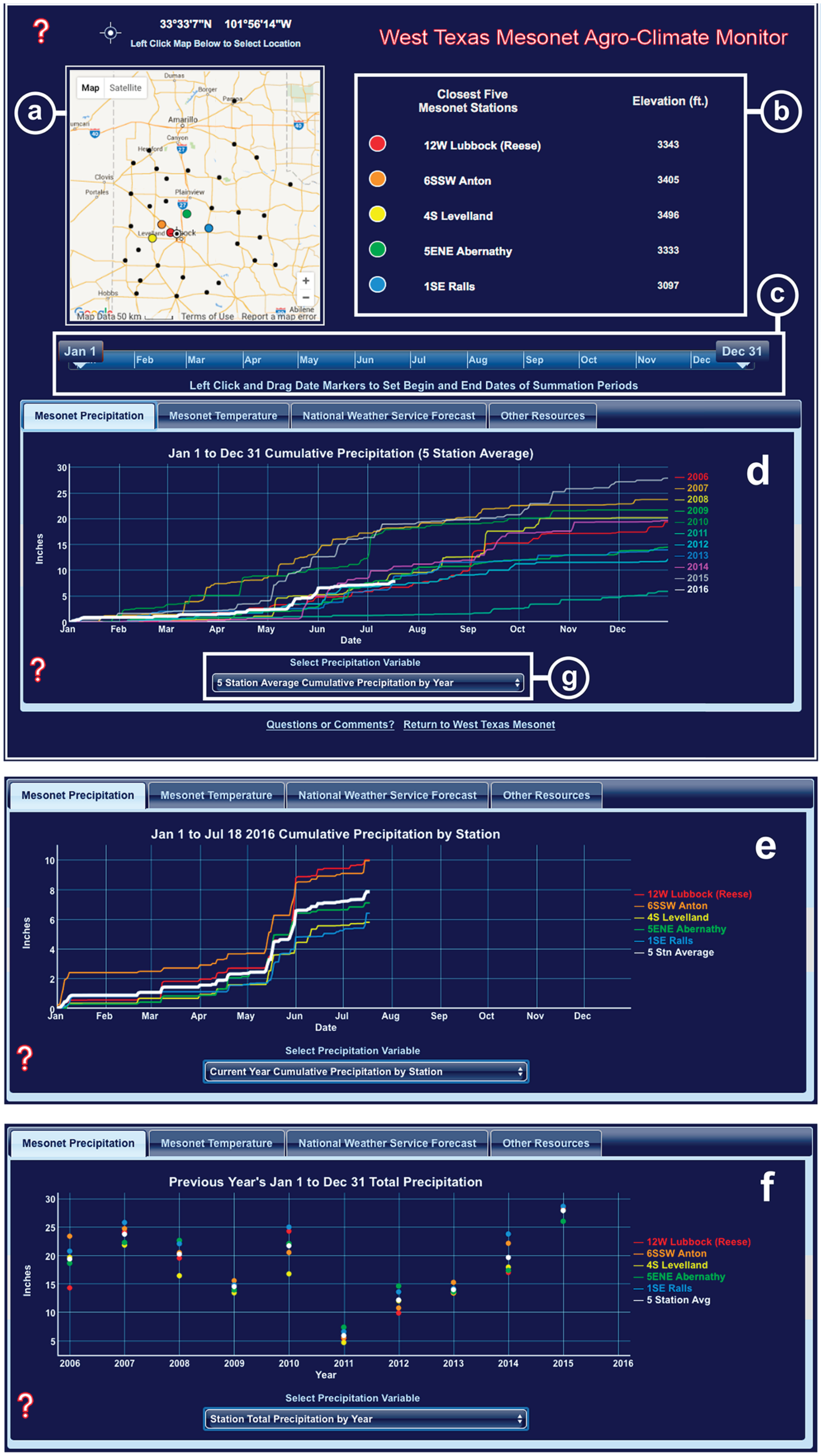


Fig. 3. (a) Agro-Climate Monitor Google Map interface showing user-selected location and locations of the closest five West Texas Mesonet stations. (b) Names and elevations of closest stations. (c) Slider control used to select beginning and end dates of integration periods for total precipitation, growing degree days, and hard freeze hours. (d) Precipitation Tab showing average total precipitation traces for the closest stations. (e) Precipitation Tab showing total precipitation traces for the closest stations during the current year, and the five station average. (f) Precipitation Tab showing closest station's precipitation totals during the period defined by the calendar slider control (c), for each of the previous 10 yr. (g) Drop down list for precipitation variable display selection.

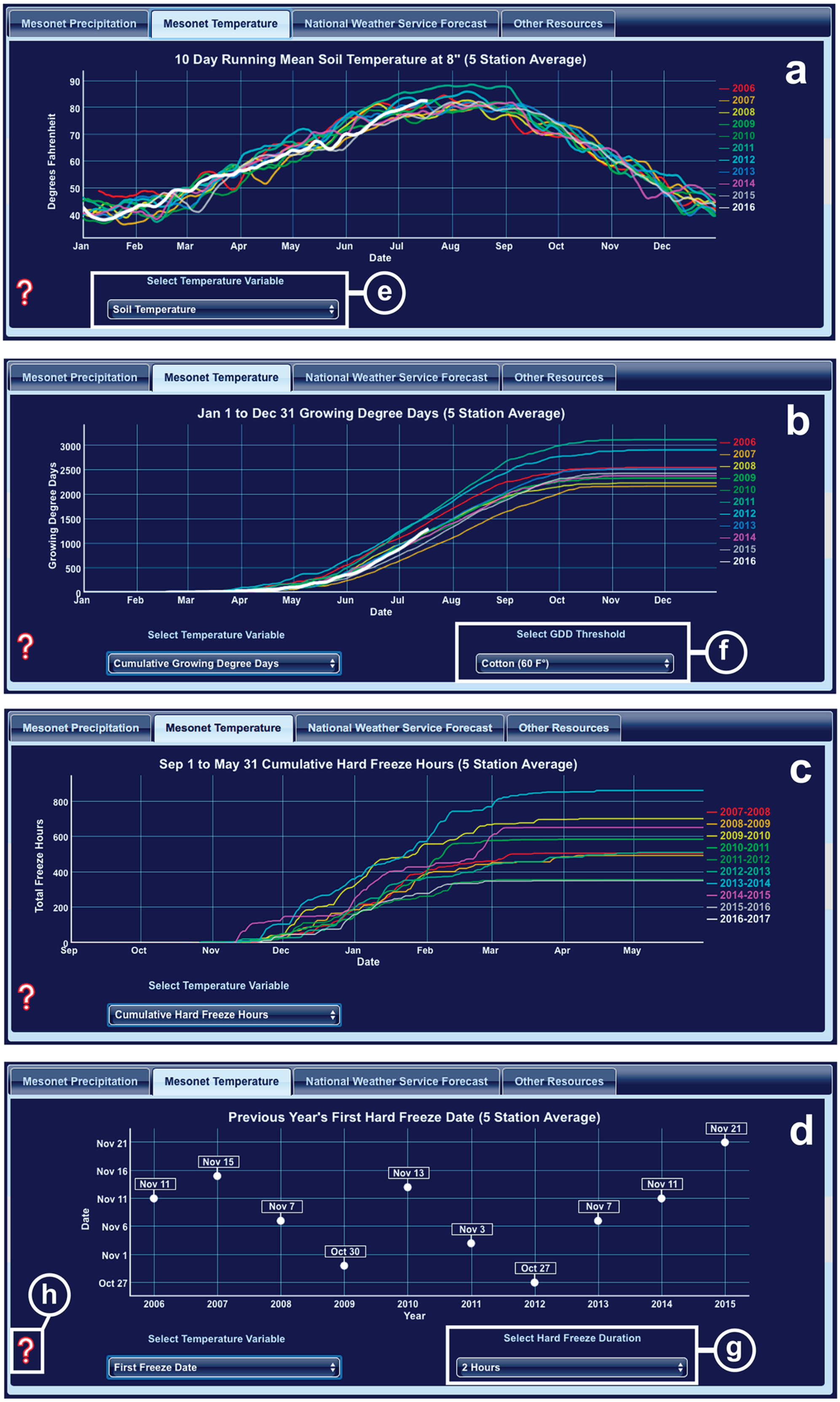


Fig. 4. (a) Temperature Tab showing traces of average soil temperature at 20-cm depth for the closest five stations during the current year, and the previous 10 yr. Each soil temperature trace is also smoothed using ten day trailing average. (b) Graph showing five station average growing degree days (GDD) for the current and previous 10 yr. (c) Graph of average cumulative hard freeze hours traces for the closest stations during the winters of 2005–2006 to 2015–2016. (d) Graph showing the date of the first hard freeze (T < –2°C (28°F) for greater than 2 h) for the years 2005 to 2015 based on the closest station's average number of daily freeze hours. (e) Temperature variable display selection list. (f) Crop GDD threshold selection list. (g) Drop down list allowing selection of 2, 4, 6, or 8 h hard freeze duration threshold. (h) Hovering the mouse over the "?" icons causes informational pop-ups to display that provide descriptions of displayed data and directions for use.

On the Mesonet Temperature Tab the “Select Temperature Variable” dropdown control (Fig. 4e) allows the user to plot six variables:

- The daily average soil temperature at 20 cm for the five nearest WTM stations during the current year, which is plotted in white, and ST20 series for the previous 10 yr (Fig. 4a). To monitor optimal soil temperature conditions for cotton planting (Boman and Lemon, 2005), these traces are also smoothed using a 10-d trailing average.
- The average daily TMIN records for the five closest WTM stations during the current year and the previous 10 yr (not shown).
- The average daily TMAX records for the five closest WTM stations during the current year and the previous 10 yr (not shown).
- The cumulative GDD for the five nearest WTM stations for the current year and for each of the past 10 yr (Fig. 4b). When this graph is displayed a second dropdown list becomes visible (Fig. 4f), which can be used to select a GDD display for cotton, corn (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], sunflower (*Helianthus annuus* L.), peanut (*Arachis hypogaea* L.), or winter wheat (*Triticum aestivum* L.). For winter wheat, this graph's accumulated degree day values only apply to the current calendar year, that is, periods after the crop emerges from dormancy in the spring. A day's growing degrees are calculated as the number of degrees Fahrenheit that a day's five-station mean temperature exceeds a specified threshold temperature. Given $TAVG_i = 0.5 \times (TMAX_i + TMIN_i)$ as an estimate of the daily mean station average for day *i*, then,

$$GDD_i = \mathrm{Max}(TAVG_i - T_o,\ 0.0) \qquad [3]$$

  is the day's growing degree accumulation. Cotton GDD are accumulated when $TAVG_i$ exceeds a T_o threshold of 16°C (60°F), while the T_o threshold for corn and sorghum is 10°C (50°F). Threshold values for peanut, wheat, and sunflower are 12.8°C (55°F), 0°C (32°F), and 6.7°C (44°F), respectively. When calculating corn GDD_i, $TMAX_i$ values are set to a 30°C (86°F) ceiling when calculating $TAVG_i$ on days when a five station mean $TMAX_i$ value rises above 30°C (Gibson, 2003). Similarly, a $TMAX_i$ ceiling is set to 38°C (Gerik et al., 2003) for sorghum GDD and 35°C (Rowland et al., 2006) for peanut GDD. The $TMIN_i$ values used to calculate sorghum GDD are also set to a floor value of 10°C (50°F) when a day's $TMIN_i$ falls below 10°C (Gerik et al., 2003).
- The average of cumulative hard freeze hours for the five nearest WTM stations for each of the past 10 winters and for the current year (Fig. 4c). When this plotting option is selected the calendar slider control's limits shifts from a 1 January to 31 December calendar year to a 1 September to 30 March winter period. In the ACM hard freeze conditions are considered to exist when temperature falls below −2°C (28°F).
- Estimated first freeze dates based on the first day that the average number of FRHR at the five stations exceeded 2 h during the past 10 yr (Fig. 4d). When this graph is displayed a second dropdown list becomes visible (Fig. 4 g), which can be used to change the first hard freeze duration threshhold to 4, 6, or 8 h.

With the exception of the first freeze date graph, hovering the mouse over any of the graphs on the Temperature Tab causes the numeric values of the plotted data, and their dates or years, to be displayed in a table to the right of the graph.

In addition to temperature and precipitation variables derived from WTM data, the ACM also contains tabs providing access to other useful web resources for West Texas producers. The National Weather Service Forecast Tab (Fig. 5a) links to a scrolling webpage that shows current 48 h forecast information for either Amarillo, Lubbock, or Midland, TX, depending on the latitude of the location selected by the user via the Fig. 3a map control. The “Other Resources” Tab (Fig. 5b) provides links to other web-based climate and crop management resources including the U.S. Drought Monitor, the U.S. Climate Prediction Center, a JavaScript tool for West Texas cotton irrigation management (Mauget et al., 2013a, 2013b), and the Visual Basic Ogallala Agro-Climate Tool.

SUMMARY AND DISCUSSION

The West Texas Agro-Climate Monitor (ACM) web application was described here. This included an overview of the application's client-server configuration and data quality control procedure, and a description of the application's graphical user interface. The ACM is based on a daily updated database containing weather data from the West Texas Mesonet (WTM: Schroeder et al., 2005). Using data from this spatially dense network of weather stations the application calculates and displays data up to the preceding day of the current year, and compares the current year's variation with that of the previous 10 yr based on data from stations closest to a user-selected location. These variables include records of daily minimum and maximum air temperature, 10 d trailing averages of soil temperature at 20 cm, accumulated precipitation and GDDs, first freeze dates, and freeze hours calculated over user-defined periods.

The application's features were designed to make it potentially useful over the course of a growing season. In addition to considering 5-d forecast conditions of daily TMAX and TMIN, Boman and Lemon (2005) suggest defining an optimal cotton planting date based on the previous 10-d average of soil temperature meeting or exceeding 18.3°C (65°F) at a 20-cm depth. Thus Fig. 4a's display of 20 cm average soil temperature can be used to track conditions suitable for planting during the spring. As the growing season progresses the cumulative precipitation (Fig. 3d) and growing degree (Fig. 4b) displays can be used to compare the current year's totals with those of the previous 10 yr. Using the date slider (Fig. 3c) these totals can be calculated over arbitrary periods. Although the ACM does not have an explicit predictive purpose, it can also be used to display the past 10-yr's outcomes over an upcoming seasonal period to display a range of values consistent with climatological persistence. For example, assuming the need to estimate expected total precipitation between the current day and a harvest date, the date slider's values could be set to those days to display the previous 10-yr's totals for each of the five nearest stations on the “Station Total Precipitation by Year” display (Fig. 3f). Those values would give a first order estimate of the possible range of total rainfall totals for the remainder of the current year's growing season based on recent climatology. Similarly, the range of possible GDD totals for the rest of the

Fig. 5. (a) Current National Weather Service 48 h forecast for Amarillo, Lubbock, or Midland, TX. (b) Links for other climate and cotton production management resources. (i) Drought outlook summary for the southern Plains region. (ii) U.S. Climate Prediction Center's extended range and long lead outlooks for U.S. precipitation and temperature. (iii) Cotton Irrigation Tool JavaScript web application for estimating profitability under dryland and center pivot production. (iv) Ogallala Agro-Climate Tool Visual Basic application that estimates irrigation demand, crop water use, and other climate variables over the Ogallala Aquifer region based on 1976 to 2005 data.

growing season might be estimated from the mean GDD traces displayed on the "Cumulative Growing Degree Day" display (Fig. 4b). By comparing traces of cumulative rainfall and degree days the user can also identify recent years with climate conditions that approximately track the current year's development. These analogous, or "analog" years (Elmore and Taylor, 2013) might be used to narrow the estimates of climate outcomes during the remainder of the current growing season. Finally, the end of the growing season can be estimated based on when GDD stop accumulating (Fig. 4b), and the onset of hard freeze conditions (Fig. 4c).

Although the ACM's purpose is to display agro-climatic information based on daily data over the cotton production areas of West Texas, it might also be considered as a conceptual demonstration of an approach with potentially broader applications. As discussed in the Introduction, although mesonets usually do not provide the 30-yr records used to calculate climate normals, useful climate information may be derived from 10 to 15 yr records (Angel et al. 1993; Trewin 2007). In addition to the calculation of decadally updated 30 yr normals, Trewin (2007) recommends the formation of continuously updated operational normals that might be based on as little as 4 to 5 yr when data from nearby stations are aggregated. This suggests the development of operational climate tools that are based on the idea that present climate conditions might be best characterized by recent decadal data. Although longer data records might be preferable from a statistical sampling standpoint, or more suited to calculate baseline normals against which the effects of long-term trends might be compared, trends or other non-stationary variability can introduce biases in climate statistics relative to what might be considered current conditions. Thus valid estimates of current regional climate might be derived from the decadal data records that some mesonets can provide. Given these network's high spatial resolution statistical sampling can be increased by aggregating or averaging data over groups of adjacent stations. Moreover, the higher resolution and wider range of meteorological variables recorded by mesonets would make it possible to resolve microclimate effects and seasonal and inter-annual variability in soil moisture, wind, radiation, and relative humidity.

ACCESS AND INSTRUCTIONS

The West Texas Mesonet Agro-Climate Monitor can be accessed directly at: http://www.csrl.ars.usda.gov/wewc/WestTXClimMonitor/index.php, and via the "USDA AGRO-CLIMATE Monitor" link under the Agricultural Data drop-down list on the West Texas Mesonet web page (http://www.mesonet.ttu.edu). Hovering the mouse over the "?" icons on the Temperature (Fig. 4h) and Precipitation Tabs, and on the upper left of the GUI (Fig. 3), causes informational pop-ups to display which provide descriptions of the data displayed and directions for use. The ACM has been tested on the Safari, Firefox, Google Chrome, and Opera web browsers. If using Internet Explorer, the ACM will not display properly in versions before IE9, or in compatibility mode in versions 9, 10, or 11.

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