U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-TR-193

SWATS: Diurnal Trends in the Soil Temperature Report

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June 2017

ARM CLIMATE RESEARCH FACILITY

DOE/SC-ARM-TR-193

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June 2017

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
DOE	U.S. Department of Energy
DQR	Data Quality Report
cm	centimeter
EBBR	Energy Balance Bowen Ration Station
EF	Extended Facility
SEBS	Surface Energy Balance System
SGP	Southern Great Plains
STAMP	Soil Temperature And Moisture Profiles
SWATS	Soil Water and Temperature System
UTC	Coordinated Universal Time
VAP	value-added product

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1.0 Problem Definition

During the processing of data for the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility 2-dimensional gridded surface (ARMBE2DGRID) value-added product (VAP), the developers noticed that the SWATS soil temperatures did not show a decreased temporal variability with increased depth with the new E30+ Extended Facilities (EFs), unlike the older EFs at ARM's Southern Great Plains (SGP) site. The instrument mentor analyzed the data and reported that all SWATS locations have shown this behavior but that the magnitude of the problem was greatest at EFs E31-E38. The data were analyzed to verify the initial assessments of:

1. 5 cm SWATS data were valid for all EFs and 15 cm soil temperature measurements were valid at all EFs other than E31-E38,

2. Use only nighttime SWATS soil temperature measurements to calculate daily average soil temperatures,

3. Since it seems likely that the soil temperature measurements below 15cm were affected by the solar heating of the enclosure at all but E31-38, and at all depths below 5cm at E31-38, individual measurements of soil temperature at these depths during daylight hours, and daily averages of the same, can ot be trusted on most (particularly sunny) days.

2.0 Background

The first SWATS was installed at E13 on 2/5/1996 with subsequent installations occurring, in no particular order, at E10, E11, E12, E15, E16, E18, E19, E20, E22, E24, E25, E27, E2, E31, E33, E34, E35, E36, E37, E38, E3, E4, E5, E6, E7, E8, and E9. Normally, the effect of heating on soil temperature due to the sun would taper off the farther down the measurements are taken and would be relatively constant below 15 cm (Figure 1). The present problem is the opposite, in that all depths are showing a diurnal temperature variation (Figure 2). The problematic temperatures show a sharp drop in the morning and rise throughout the day.

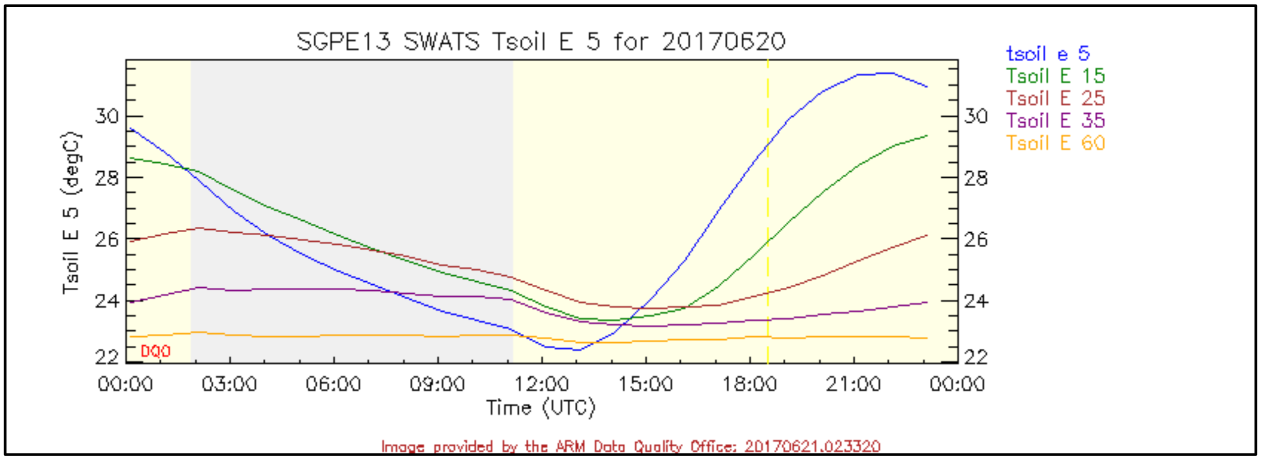


Figure 1. Plot of how the SWATS data should trend, although there is a slight diurnal trend at greater depths.

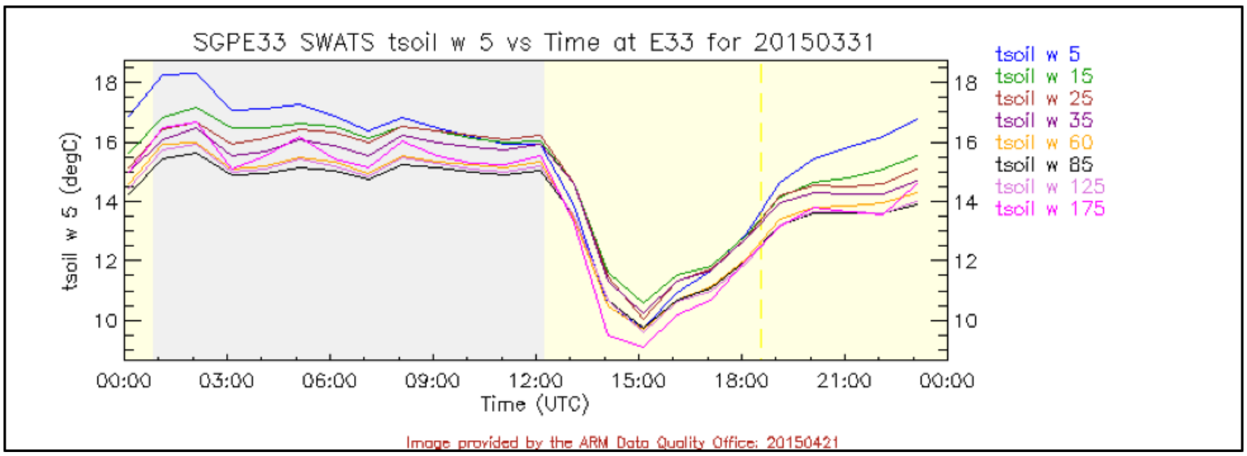


Figure 2. Problematic SWATS data at E33 showing the diurnal trend at all depths.

The SWATS were eventually removed and replaced with the Soil Temperature And Moisture Profiles (STAMP) instrument at all EFs except E13 starting in February 2016. E13 is the only facility where both instruments were operated at the same time. All other EFs have either an Energy Balance Bowen Ratio Station (EBBR) or Surface Energy Balance System (SEBS) that take an integrated soil temperature measurement from 0-5 cm. This is not exactly a one-to-one comparison with the SWATS, but the two instrument systems should show similar trends.

The EBBR soil temperatures should normally be higher than the SWATS since temperatures above 5 cm are normally warmer than at 5 cm for most solar conditions. The SEBS probes are placed in a crop area that can change throughout the year from bare soil in the winter to full crop coverage in the summer. Since the SWATS and EBBR soil temperature measurements are made in soil beneath short grass, one would expect to see larger deviations in the SEBS soil temperature measurements at different times of the year.

3.0 Results

3.1 Validity of the 5 cm Measurements

Data were analyzed from January 1, 2015 to the end of the SWATS deployment at each EF. Each of the 5 EBBR and/or 3 SEBS soil temperature measurements were compared with the SWATS 5 cm data (Figure 3). Data known to be incorrect and flagged by Data Quality Reports (DQRs) were removed from the analysis along with any obvious outliers.

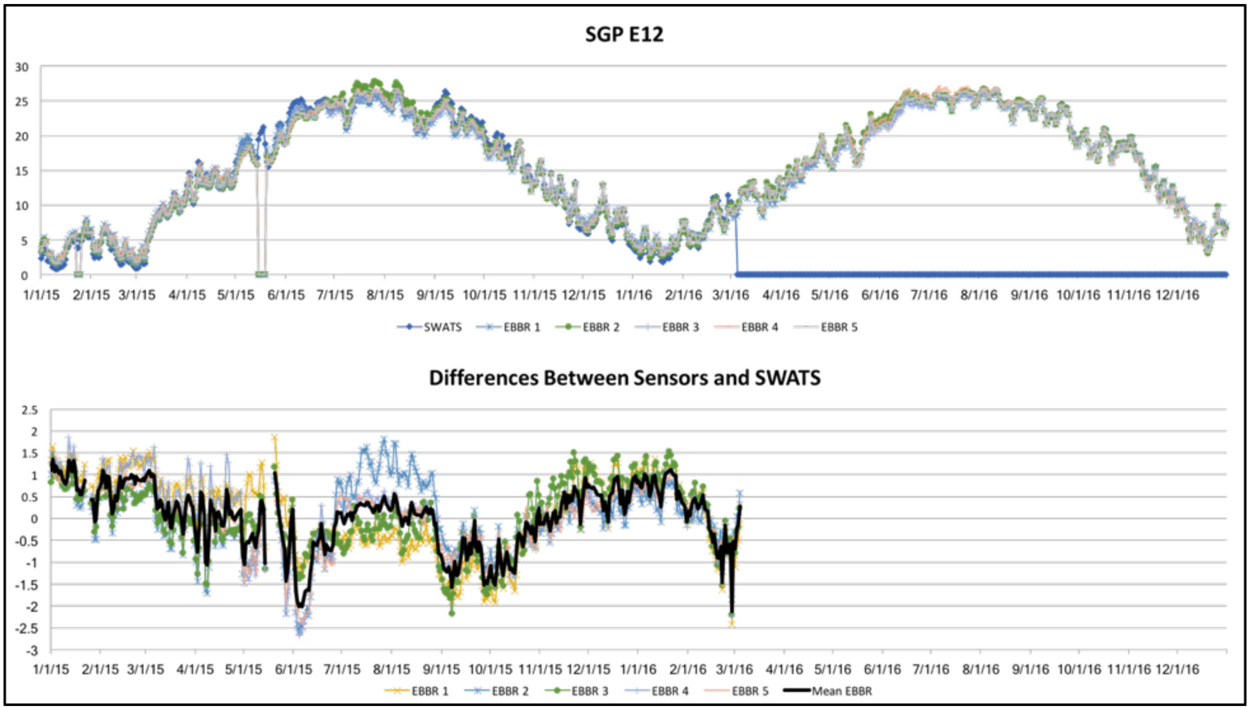
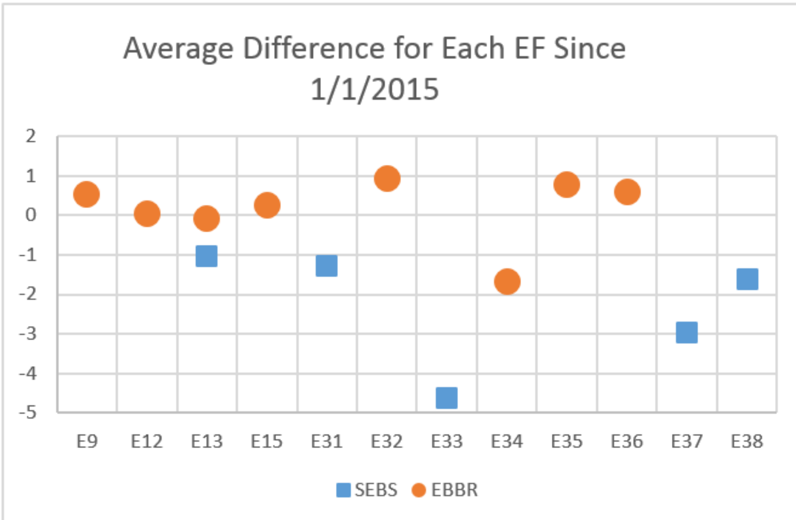


Figure 3. Time series of SWATS and EBBR soil temperatures (top). The bottom plot shows the corresponding differences. The thick black line in the difference plot is the average difference for all EBBR sensors.

These differences were averaged out for each site (Figure 4). As expected, the EBBR shows a slight high bias compared to the SWATS at most sites with E34 being a major outlier. The SEBS differences were slightly larger and negative with E33 being a largely negative outlier. The SEBS differences do make sense in that there were more data from winter months in this analysis than from the summer. There would be more measurements from bare soil in the winter, which would bias the SEBS lower.

The results from E33 and E34 did require further examination. These sites are in the upper NE quadrant of the ARM footprint and are close to E9 and E12. The maximum soil temperature during the 2015 summer was roughly 27 ºC while the SWATS at E33 and E34 were maxing out at around 32 ºC and 30ºC, respectively. This lines up with the larger difference in the SEBS at E33.



	SEBS	EBBR
E9		0.52
E12		0.038
E13	-1.02	-0.097
E15		0.25
E31	-1.27	
E32		0.938
E33	-4.62	
E34		-1.676
E35		0.765
E36		0.58
E37	-2.959	
E38	-1.615	

Figure 4. Average difference for each site and the corresponding instrument type (left). Table of corresponding difference values for each site (right).

For the most part, the differences between the 5 cm SWATS soil temperature and the EBBR/SEBS soil temperature are within reason and lend credit to the validity of the SWATS 5 cm soil temperature measurement. This does not apply to the SWATS at E33 and E34 where there is a noticeable high bias in the SWATS soil temperature of 3-5 ºC.

3.2 Using the Nighttime SWATS Data to Calculate a Daily Average

One would expect that the heating due to solar radiation would not affect the soil temperature at night and that measurements from sunset to sunrise would be valid. Figure 5 shows that the soil temperature peaks at sunset and then decreases overnight until ~0600-0700 UTC. It appears that for a period the soil temperatures reach an equilibrium. This slow decrease could potentially bias the overnight average soil temperature by ~1 ºC, depending on the severity of the problem.

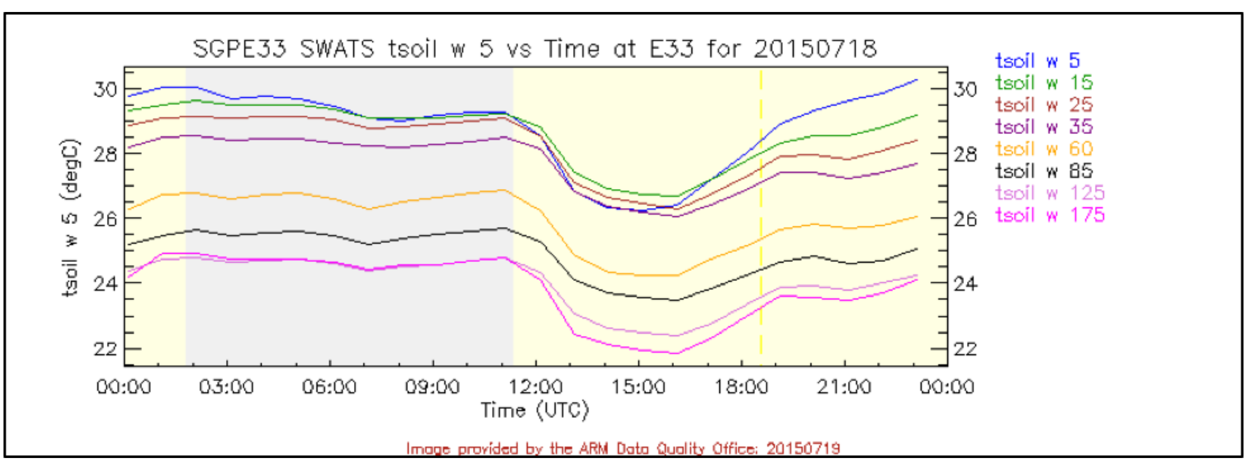


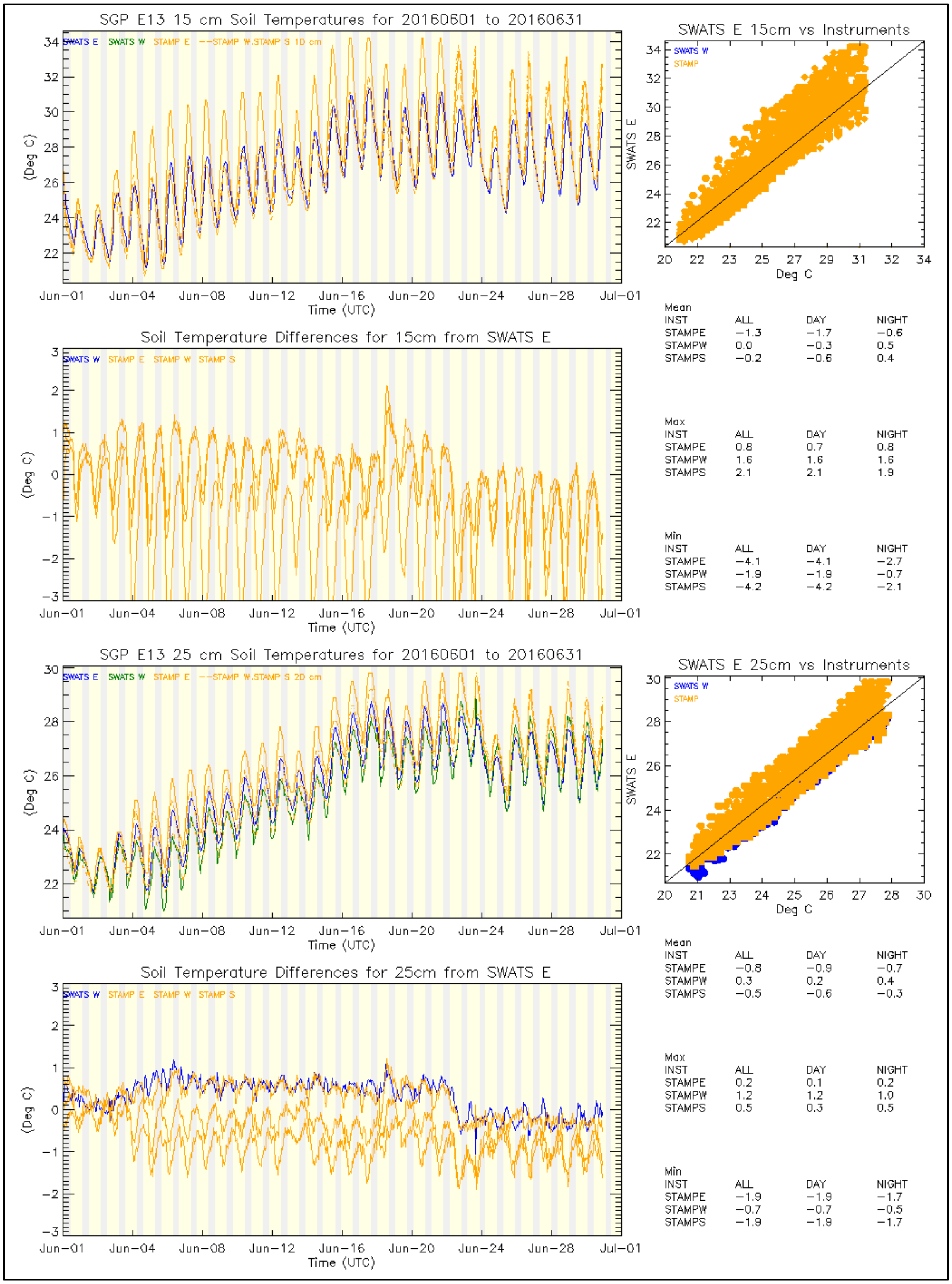
Figure 5. SGP E33 SWATS temperature for 20150718.

3.3 Validity of Data at Lower Depths

Figure 6 shows a comparison of soil temperature at different depths for the instrument systems at the Central Facility in June 2016. The 15 cm SWATS data are compared with the 10 cm STAMP data. The SWATS data look reasonable and are lower than the STAMP, which is expected due to the depth difference. The 25 cm SWATS data also look reasonable when compared to the 20 cm STAMP measurements. This lends validity to the 15 and 25 cm SWATS measurements at E13. The 35 cm SWATS soil temperatures are compared with the 20 cm STAMP soil temperatures and show similar trends; however, with a 15 cm difference, it is not certain whether these trends in the SWATS data are real or not. The last comparison is the 60 cm SWATS data to the 50 cm STAMP data. The diurnal cycle in the SWATS data is present below 60cm but is not visible in the STAMP data.

This indicates that the 5 cm and 15 cm SWATS measurements are valid at the older SWATS sites and possibly even the measurements at 25 cm. However, without being able to compare similar periods at the other EFs, we cannot verify that measurements at these depths are OK, especially at the more severely affected E31-E38 EFs.

Looking at the 60 cm SWATS data, it does appear that applying smoothing or a daily average to the entire data set would closely mimic the STAMP data, but it would add to the uncertainty of the measurement. The size of the oscillations in the 60 cm SWATS data at E13 max out around 0.8 ºC. It may be feasible to perform this analysis at greater depths and at other sites, but without any semi-co-located measurements the uncertainty greatly increases.


SGP E13 15 cm Soil Temperatures for 20160601 to 20160631
SWATS E SWATS W STAMP E --STAMP W STAMP S 10 cm
(Deg C)
Jun−01 Jun−04 Jun−08 Jun−12 Jun−16 Jun−20 Jun−24 Jun−28 Jul−01
Time (UTC)
SWATS E 15cm vs Instruments
SWATS W
STAMP
SWATS E
Deg C
Soil Temperature Differences for 15cm from SWATS E
SWATS W STAMP E STAMP W STAMP S
Mean
INST ALL DAY NIGHT
STAMPE −1.3 −1.7 −0.6
STAMPW 0.0 −0.3 0.5
STAMPS −0.2 −0.6 0.4
Max
INST ALL DAY NIGHT
STAMPE 0.8 0.7 0.8
STAMPW 1.6 1.6 1.6
STAMPS 2.1 2.1 1.9
Min
INST ALL DAY NIGHT
STAMPE −4.1 −4.1 −2.7
STAMPW −1.9 −1.9 −0.7
STAMPS −4.2 −4.2 −2.1
SGP E13 25 cm Soil Temperatures for 20160601 to 20160631
SWATS E SWATS W STAMP E --STAMP W STAMP S 20 cm
SWATS E 25cm vs Instruments
Soil Temperature Differences for 25cm from SWATS E
Mean
INST ALL DAY NIGHT
STAMPE −0.8 −0.9 −0.7
STAMPW 0.3 0.2 0.4
STAMPS −0.5 −0.6 −0.3
Max
INST ALL DAY NIGHT
STAMPE 0.2 0.1 0.2
STAMPW 1.2 1.2 1.0
STAMPS 0.5 0.3 0.5
Min
INST ALL DAY NIGHT
STAMPE −1.9 −1.9 −1.7
STAMPW −0.7 −0.7 −0.5
STAMPS −1.9 −1.9 −1.7

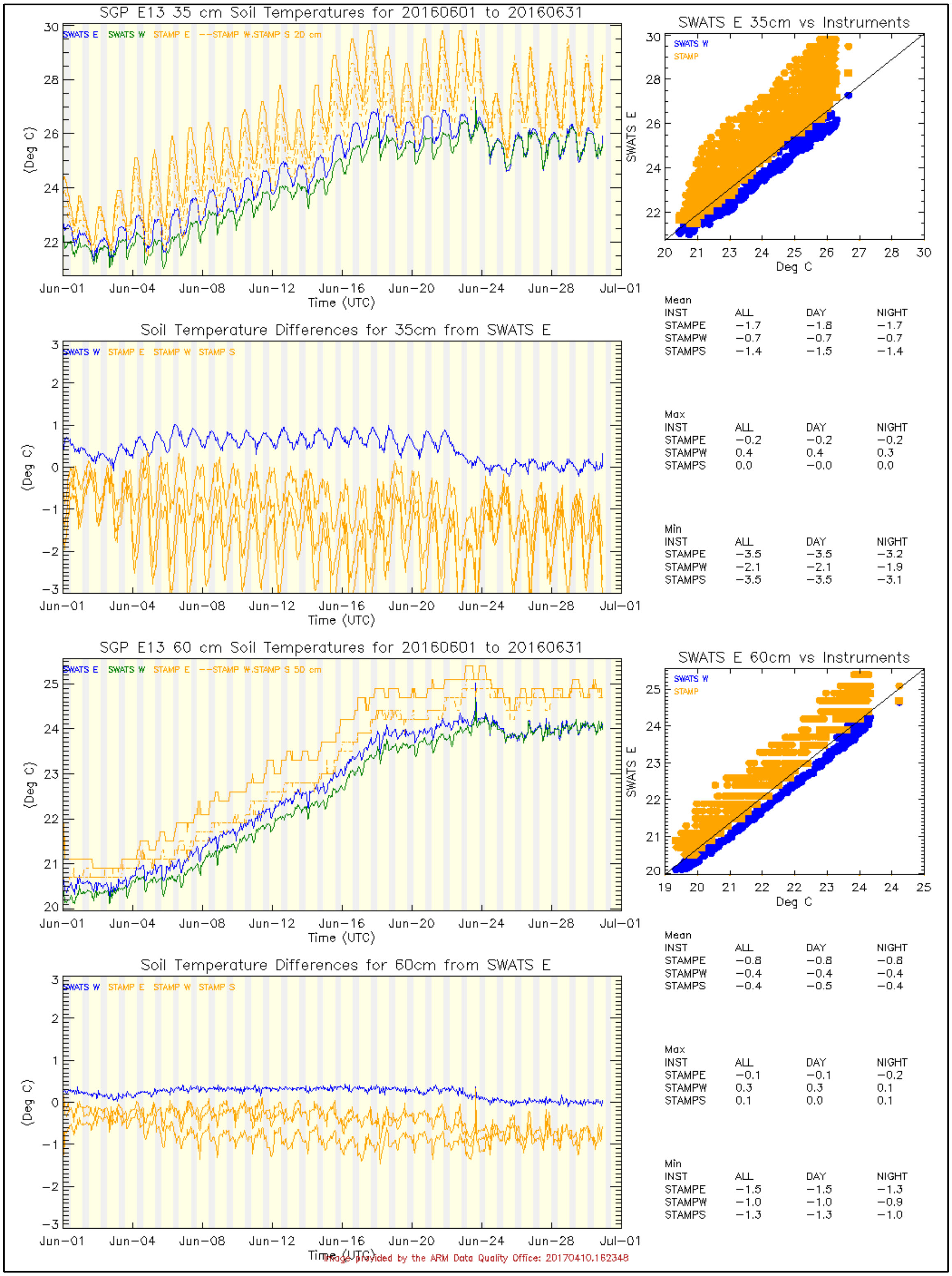


Figure 6. Comparison plots of SWATS/EBBR/STAMP data at depth 15cm-60cm for June 2016. The first panel is a time series of the soil temperatures followed by the differences between measurements. The scatter plot is the associated point-to-point comparison of the SWATS E soil temperatures to those of the other instruments. The statistics associated with each set of

plots are the MEAN/MAX/MIN values for the entire month and also only the daytime and nighttime values.

4.0 Discussion

This analysis shows that the 5 cm SWATS soil temperature data are valid at most sites, as the DQR indicates, with the exception of E33 and E34 where the SWATS showed a warm bias of 3-5 ºC. There appears to be a slight period of time overnight where the soil temperature sensors cool down and reach an equilibrium. Using averages of the data overnight to calculate a daily average could bias the measurement by up to 1 ºC, based upon the severity of the problem at the site. The 15 and possibly 25 cm SWATS soil temperature data at the E13 facility look reasonable when compared to similar STAMP measurements. However, a diurnal oscillation is evident in the lower depths and increases the uncertainty of the measurements. Without STAMP measurements at the rest of the EFs, there is no way to be certain that those measurements or the daily averages are valid.

It should be noted that there is a slight and opposite effect on STAMP soil water content and fractional water index; however, it is well within the error of the measurement.