On the Path to Energy Independence and a Clean Power Future – LED Lighting Retrofit and Solar Power Generation for the CTUIR Science and Engineering Laboratory and Public Transit Center

Final Project Report

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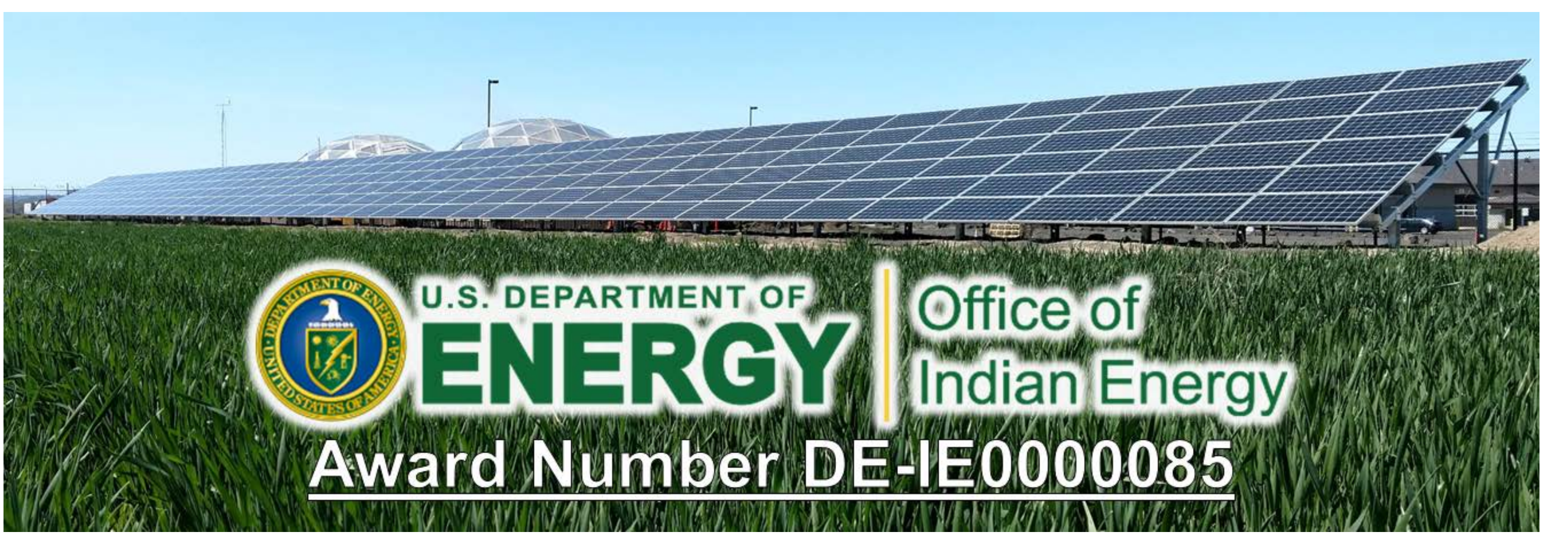

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1 Executive Summary

This project supports the goals of the Energy Policy for the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) through the implementation of an energy efficiency measure (LED lighting retrofit) and construction of a fixed rack (stationary) ground-mounted solar photovoltaic (PV) array energy generation system.

The project objective was to eliminate the net demand for grid-based utility energy at two tribal facilities: the CTUIR Field Station and the Public Transit Center (consisting of bus barn and maintenance shop buildings). A total of 332 lighting fixtures were retrofitted with high efficiency LEDs at the three buildings within the project scope. The solar PV array constructed adjacent to the Field Station (46330 Timine Way, Pendleton, OR 97801) has a nameplate capacity of 97.98 kW_{DC}. The project was managed by staff from the CTUIR Energy & Environmental Sciences Program within the Department of Natural Resources and the final budget was $288,206.

Data was collected during a 12 month monitoring period following construction of the aptly named Ántukš–Tín̓qapapt Solar PV Array and assessed to determine project results. During this time, the solar PV system generated 125,580 kWh of energy according to SolrenView solar PV system monitoring service. In contrast, the total realized utility energy and cost savings due to the project were estimated by comparing 24 months of consecutive utility billing data. Results of this comparison indicate that grid-based utility energy demand was reduced by 121,280 kWh, or roughly 80% of the total electricity consumed by both facilities. The cost savings associated with this energy demand reduction were $11,104 and a payback period of 5.7 years was estimated for recovering the CTUIR's investment. However, it should be noted that these figures are not representative of the savings that could be obtained under normal, error-free (i.e. faultless) conditions.

Several undesirable events occurred during the 12 month monitoring and evaluation period, the effects of which were quantified using available data so that results under a "Faultless Scenario" could be estimated. Annual energy and cost savings estimated for the Faultless Scenario were approximately 166,289 kWh and $15,225, respectively. These figures should prove to be more representative of the long-term average annual results achieved in response to the project and suggest a payback period closer to 4.5 years for the CTUIR.

2 Scope of Work

All activities included in the project scope of work were organized under a four task work breakdown structure and are discussed in the following sections, except for those completed during project initiation. Several of the activities completed during project initiation were a professional energy audit of the three buildings within the project scope to determine the most viable energy efficiency measure to implement; an approved aggregated net metering agreement with the utility was obtained; a solar PV system installer and lighting replacement company were selected; funding from the Energy Trust of Oregon was secured through two separate incentive reservations; and grant proposals for other funding sources were prepared.

2.1 Task 1: Project Management

The Project Manager, Patrick Mills, was responsible for project initiation, planning, execution, monitoring, and closing. This included fundraising, procurement, resource coordination, budget management, scope management, schedule management, and the preparation of all written deliverables. The Project Manager also contributed technical expertise to support the project and served as the focal point for project communications.

2.2 Task 2: LED Lighting Retrofit

The CTUIR awarded Gordon's Electric with the contract to complete the LED lighting retrofit task. A total of 332 lighting fixtures in three tribally owned buildings were retrofitted with high efficiency LEDs. Prior to work commencing, funding was secured through an approved incentive reservation specifically for covering the cost of this task.

2.3 Task 3: Solar PV Array Installation

A fixed rack (stationary) ground-mounted solar PV array was constructed on the south end of the Field Station Science and Engineering Laboratory property as shown in Figure 2-1. The CTUIR awarded Elemental Energy with the contract to complete this task. Elemental Energy is a registered trade ally with the Energy Trust of Oregon.

Figure 2-1: Satellite image showing the Nixyáawii Governance Center complex and the three buildings included in the project scope (Field Station Science and Engineering Laboratory, Public Transit Center Maintenance Shop and Public Transit Center Bus Barn). Also displayed are the solar PV array (shown in yellow) and solar PV array system interconnect location.

2.3.1 Subtask 3.1: Design and Permitting

A geotechnical survey was first completed to provide data necessary for system design. The core sample retrieval process utilizing a specialized drill rig is depicted in Figure 2-2.

Figure 2-2: Onsite core sample retrieval using a specialized drill rig. Core samples were assessed to complete the geotechnical survey report that informed system design specifications.

Initially it was proposed that SolarWorld SW 350 XL MONO solar modules would be used. However, due to SolarWorld filing for bankruptcy and the concern that product warranties would become voided, a no-cost change request for Hyundai model HiS-S355RI modules was processed, effectively increasing the DC-nameplate capacity of the array from 96.6 kW to 97.98 kW.

Two construction plan sets were prepared under this subtask, each adhering to respective codes adopted and enforced by the permitting authority within the CTUIR Tribal Planning Office. With support from the Project Manager, Elemental Energy staff completed the wiring design plan set according to the 2017 National Electric Code. The racking design plan set was completed by Elemental Energy in collaboration with RBI Solar according to the 2015 International Building Code with the addition of several site specific standards. Final plan sets were approved and stamped prior to construction taking place.

2.3.2 Subtask 3.2: Construction

The first activity that took place under this subtask was solar PV array installation site preparation. Trees and shrubs were removed by staff from the CTUIR Public Works Department. An existing fence was relocated by Doherty Fence to accommodate the footprint of the solar PV array (approximately 300 ft by 20 ft). The utility transformer closest to the system interconnect point was also upgraded by the utility, Pacific Power (PacifiCorp), the scale of which was selected to match that of the proposed energy generation system.

The array racking was manufactured by RBI Solar and constructed by first augering holes into the ground as shown in Figure 2-3. Grade 301 stainless steel posts used for the array footings were dropped into place, adjusted and then secured in concrete. Concrete was poured with precision using the concrete pumping truck with articulating boom delivery system shown in Figure 2-4

Figure 2-3: Excavation of holes via hydraulic auger. The holes, having a depth of 10 ft, were used to secure solar PV array footings.

Figure 2-4: Solar PV array footings were secured in place using concrete poured with precision from a concrete pumping truck with articulating boom delivery system.

Following the completion of the racking, a total of 276 Hyundai model HiS-S355RI solar modules with a nominal power output of 355 W each at Standard Test Conditions (STC) were mounted. The solar modules were connected to inverters through a total of 16 strings (12 strings with 17 modules each and four strings with 18 modules each) wired in series. Two Yaskawa Solectria Solar PVI 50/60TL three-phase grid-tied inverters were installed for the system as shown in Figure 2-5. One 150 KVA Federal Pacific Model 36B transformer was also installed inline before the grid interconnect point to reduce electrical voltage produced by the inverters from 480 VAC to commercial 208 VAC. To satisfy utility requirements for customer owned generation systems and grid protection, a grounding bank transformer and shunt trip system were also installed. Conductors between the equipment rack and transformer were installed underground. Also installed underground, separate from the conductors, was an Ethernet cable connecting the inverters to the internet inside the Field Station. The Ethernet cable was used to transmit system performance data from the inverters to SolrenView solar PV system monitoring service. See Task 4, System Performance Monitoring and Verification, for more information on system performance monitoring. Following the completion of these activities, the power meter for the Field Station was upgraded to a net meter by the utility so that excess energy (energy delivered to the grid due to solar PV system energy generation exceeding Field Station energy consumption) could be monitored for billing adjustment purposes. Figure 2-6 shows the solar PV array prior to the completion of final construction activities.

Final construction activities included the installation of a locking gate and fencing on the ends of the array. The locking gate was installed in the section of fence between the solar array and system DC disconnects (one on each inverter) to meet code requirements. Fencing was installed on the ends of the array to prevent wildlife and unauthorized personnel from accessing areas with high voltage wiring underneath the array for safety purposes and to satisfy Energy Trust of Oregon cost reimbursement criteria.

Figure 2-5: Equipment rack for the solar PV array system showing Yaskawa Solectria Solar PVI 50/60TL inverters (left), associated switchgear and meter (right).

Figure 2-6: The constructed solar PV array located adjacent to the Field Station Science and Engineering Laboratory (46330 Timine Way, Pendleton, OR 97801).

2.3.3 Subtask 3.3: System Commissioning

The system commissioning process involved initialization of the solar PV array system and verification that it was functioning nominally. Technical issues associated with the networking interface for the array inverters prevented the use of SolrenView solar PV system monitoring service for this. However, the display on each inverter (showing real-time AC power generation) and the net meter (indicating the direction and magnitude of energy flow) were available for use and the activities under this subtask were completed by the afternoon of June 29, 2018.

Additionally, to incorporate a valuable cultural and educational component into the project, the CTUIR Language Program was asked to name the solar PV system in the native languages of the peoples of the CTUIR. The name selected was Ántukš–Tíṅqapapt Solar PV Array, where Ántukš (Umatilla language) and Tíṅqapapt (Cayuse/Nez Perce) essentially mean "Sun Trap."

2.4 Task 4: System Performance Monitoring and Verification

Solar PV array system performance was monitored for 12 months immediately following system commissioning. The primary data collection platform used for performance monitoring was SolrenView solar PV system monitoring service which was successfully established on July 26, 2018 after inverter networking interface technical issues had been resolved. The service was purchased for a term of five years by the CTUIR and can be accessed using the internet[1]. Solar PV system performance data retrieved from SolrenView can be found in Appendix A.

A secondary data collection platform consisting of a meteorological tower with a data logger and various sensors located adjacent to the solar PV system installation site was used primarily for system performance verification and troubleshooting purposes. Solar radiation was measured using a Hukseflux LP02 ISO-9060 second class pyranometer[2] and solar PV array module temperature was measured using a CS240 PT-1000 Class A back-of-module temperature sensor secured using Kapton tape. Both sensors are pictured in Figure 2-7.

[1] Ántukš–Tíṅqapapt Solar PV Array system performance data and other metrics are available online at: https://solrenview.com/SolrenView/mainFr.php?siteId=5347

[2] The pyranometer was mounted horizontally level so that solar radiation data indicative of normal site conditions could be collected and used for scientific research purposes (e.g. botanical studies) beyond the project.

Figure 2-7: Hukseflux LP02 ISO-9060 second class pyranometer (left) and CS240 PT-1000 Class A back-of-module temperature sensor (right).

Ambient air temperature, wind speed, wind direction and precipitation data was also collected. All data was recorded at 30 second intervals using a custom script written by the Project Manager for the data logger system in the CRBasic computer programming language. The Campbell Scientific CR1000 data logger was used to record all sensor response data and was interfaced with the CTUIR computer network using the NL-120 Ethernet Module. This connection made it possible to effortlessly download and save large amounts of high resolution data to computers for manipulation in Microsoft Excel.

Two methods of comparison utilizing three separate datasets were employed to verify system performance. The first method involved corrected solar radiation data while the second used the results of a PVWatts Calculator[3] model updated to match the final solar PV array system design (having a nameplate capacity of 97.98 kW_{DC} rather than the initially proposed 96.6 kW_{DC}). Details of both methods are discussed below.

In the first performance assessment method, data from SolrenView solar PV system monitoring service was regularly compared to corrected solar radiation data. Power output of individual solar modules is a function of solar radiation per unit time (i.e. solar irradiance) and module temperature[4]. Therefore, measuring these three parameters allowed for the theoretical performance of the solar PV system to be estimated and any suspected performance discrepancies (as indicated by SolrenView) could be investigated. This method led to the detection of an unknown system faulting issue that began occurring prominently in January 2019, although data analysis indicates the first event ironically took place on December 25, 2018 but was unnoticed due to poor weather conditions and low lighting. The system faulting issue intensified overtime and appeared to correlate with meteorological data (precipitation and

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[3] For more information on the PVWatts Calculator developed by the National Renewable Energy Laboratory, visit: https://pvwatts.nrel.gov/

[4] A temperature-power coefficient of -0.42 %/K is reported in the datasheet for the Hyundai HiS-S355RI solar module where K denotes the difference between actual module temperature from the Standard Test Conditions reference temperature of 25 °C (298.15 °K). This can be interpreted as a module power output loss of 1% for every degree above the reference temperature, or a module power output increase of 1% for every degree below the reference temperature. The temperature-power coefficient was used to correct solar radiation data (collected onsite via pyranometer) before being compared to actual system performance data. In doing so, one-sided temperature effects (which only impact actual solar system performance) could be eliminated from the dataset.

solar radiation) trends. Later in the winter, the project site was inundated with unusually high amounts of snow followed by a rapid and prolonged increase in ambient air temperature which caused significant flooding in the area. This information aided Elemental Energy staff who, after several months of failed troubleshooting attempts, began conducting onsite system diagnostics that led to the successful identification of the root cause. A small flaw with the underground conductors had allowed water to short the system causing the inverters to temporarily cease operations while reporting a faulting error code. The flawed section of conductor was promptly replaced at no cost to the CTUIR in May 2019. Since being repaired, the system has performed flawlessly.

The second performance assessment method used on a regular basis was a side-by-side comparison of SolrenView data with data from the updated PVWatts model. This approach was more straightforward than the first method but did not account for site specific meteorological conditions effecting actual solar PV system performance. As such, only significant performance deviations from modeled PVWatts results were cause for investigation. Results of the PVWatts model are presented in Appendix D.

It should also be noted that the solar array modules were cleaned on August 1, 2018 at a cost of $675. As a result, system AC energy generation increased by approximately 4%[5]. To date, this has been the only operations and maintenance related expense. Based on the farming practices employed at the field adjacent to the solar array, cleaning is expected to take place approximately every other year.

3 Project Results

The first full day of solar PV array energy generation was June 30, 2018. According to SolrenView solar PV system monitoring service, 125,580 kWh had been generated by the system as of the end of June 30, 2019. This amount is greater than the result predicted using the updated PVWatts Calculator model for the same timeframe (124,810 kWh). It is also greater than the baseline annual energy generation predicted by the solar PV system installer during project initiation (125,568 kWh) which was included in the grant proposal for DE-FOA-0001660.

To evaluate realized cost and energy savings attributed to the project, 24 consecutive months of billing data obtained from the utility was compared. The first 12 months of data covered the timeframe from June 12, 2017 to June 12, 2018 and was not influenced by the solar PV array system. The latter 12 months of data was influenced by the solar PV system and LED lighting retrofit and covered the timeframe from June 12, 2018 to June 12, 2019. Data used in the evaluation was scaled to utility billing service periods to maintain symmetry and is presented in Tables 3-1 and 3-2 for primary and subordinate meters, respectively. Results indicate that total grid-based utility energy demand was reduced by 121,280 kWh, or roughly 80% of the total electrical energy (i.e. electricity) consumed by both facilities during the 2018-19 evaluation period[6]. This corresponds to roughly 18.5 tons of reduced fossil-fuel-generated greenhouse gas emissions. Cost savings of $11,104 were associated with this energy demand reduction, but

[5] The effect of cleaning on solar PV system performance was determined by comparing the average of output energy (AC energy generated) to input energy (temperature corrected solar radiation) ratios for the four days immediately before (July 28-31) and after (August 2-5) cleaning took place.

[6] The total energy consumed by both facilities during the 2018-19 project evaluation period was calculated to be 152,003 kWh by summing actual Transit Center energy usage (55,680 kWh) with the estimated total energy usage of the Field Station (96,323 kWh). Since energy is generated onsite by the solar PV system, total Field Station energy usage was estimated using the energy balance equation shown in footnote “d” of Table 3-1.

when factoring in maintenance (i.e. cleaning) expenses, the realized cost savings for the CTUIR during this period were $10,429.

As an alternative approach to understanding savings as a result of the project, the total amount of net metered energy used during the 2018-19 evaluation period[7] was calculated to be 37,840 kWh and summed with the grid-based energy demand reduction previously reported. The result of 159,120 kWh is equal to the total amount of electrical energy consumed by both facilities during the 2017-18 reference period[8], 100% of which was grid-based.

[7] The total amount of net metered energy used during the 2018-19 evaluation period was calculated as the sum of actual Transit Center energy usage (55,680 kWh of grid-based utility energy) and Field Station net metered energy usage (-17,840 kWh; the negative sign indicating more energy was generated onsite than consumed).
[8] In the absence of the solar PV system, 100% of the electricity consumed by both facilities during the 2017-18 reference period was grid-based and could be calculated directly from Field Station and Transit Center utility billing data.

Table 3-1: 24 consecutive months of utility billing data for the primary meter located at the Field Station Science and Engineering Laboratory (46330 Timine Way, Pendleton, OR 97801).

	2017-18 (Reference Period)		2018-19 (Evaluation Period)							Realized Savings[f]	
Utility Billing Service Period	**Utility Energy Used (kWh)**	**Final Billing Amount Due**	**Generated Energy[b] (kWh)**	**Utility Energy Used[c] (kWh)**	**Excess Metered Energy[d] (kWh)**	**Net Metered Energy[e] (kWh)**	**New Charges**	**Adjustments**	**Final Billing Amount Due**	**Utility Energy (kWh)**	**Billing Costs**
June 12 to July 12[a]	7,720	$804.75	8,758	4,160	6,400	-2240	$171.78	$0.00	$171.78	9,960	$632.97
July 12 to August 13	9,920	$995.59	19,694	3,400	14,360	-10960	$177.66	$0.00	$177.66	20,880	$817.93
August 13 to September 12	9,680	$965.60	15,763	3,560	10,760	-7200	$336.16	-$158.50	$177.66	16,880	$787.94
September 12 to October 11	6,000	$671.58	11,742	2,760	8,440	-5680	$154.81	$0.00	$154.81	11,680	$516.77
October 11 to November 9	5,800	$685.78	10,039	3,680	7,520	-3840	$154.14	$0.00	$154.14	9,640	$531.64
November 9 to December 13	7,360	$839.71	6,471	5,520	4,000	1520	$154.14	$0.00	$154.14	5,840	$685.57
December 13 to January 15	10,360	$1,039.35	3,705	8,240	1,440	6800	$280.18	$0.00	$280.18	3,560	$759.17
January 15 to February 13	13,640	$1,340.11	3,699	8,400	1,640	6760	$737.00	$0.00	$737.00	6,880	$603.11
February 13 to March 15	11,720	$1,189.00	5,793	7,280	2,720	4560	$540.69	$0.00	$540.69	7,160	$648.31
March 15 to April 12	6,440	$756.96	7,175	4,200	4,600	-400	$206.99	$0.00	$206.99	6,840	$549.97
April 12 to May 13	5,240	$641.94	9,009	4,840	6,720	-1880	$189.34	$0.00	$189.34	7,120	$452.60
May 13 to June 12	6,200	$715.16	12,317	3,840	9,120	-5280	$67.65	$0.00	$67.65	11,480	$647.51
Totals	*100,080*	*$10,645.53*	*114,163*	*59,880*	*77,720*	*-17840*	*$3,170.54*	*-$158.50*	*$3,012.04*	*117,920*	*$7,633.49*

[a] Solar PV array commissioned afternoon of June 29, 2018.

[b] Solar PV array energy generation according to SolrenView solar PV system monitoring service (https://solrenview.com/SolrenView/mainFr.php?siteId=5347).

[c] Utility energy used when solar PV system energy generation < site energy consumption (predominantly at night).

[d] Excess metered energy generated by the solar PV system and delivered to the utility (during the day when solar PV system energy generation > site energy consumption). All values are based on actual utility power bill data except for July 12 to September 12, 2018 service periods. Values for these service periods had to be estimated due to an incorrect meter reading by the utility. The method of estimation utilized correct meter readings before and after the incorrect reading so the total amount of excess metered energy could be calculated. The total amount of excess metered energy (calculated to be 25,120 kWh) was then distributed across both billing service periods following the energy consumption trend exhibited during the reference period (i.e. prior year). Doing so required the use of an energy balance equation [$E_{In} – E_{Out} = E_{Consumed}$ or in terms of the system at hand $(E_{GenPV} + E_{GenUtility}) – E_{Excess} = E_{Consumed}$] to account for the energy generation system, GenPV, that didn't exist during the reference period.

[e] Net metered energy calculated as difference between utility energy used (when site energy consumption > solar PV system energy generation) and excess metered energy. Negative values represent an overall surplus of energy being pushed back to the grid.

[f] Realized savings attributed to LED lighting retrofit and solar PV system energy generation while neglecting facility occupational and environmental factors that may change energy usage. Amounts were calculated from differences between reference period and evaluation period utility invoices, i.e., utility energy savings were calculated by subtracting evaluation period net metered energy (Column 7 values) from utility energy used during the reference period (Column 2 values). Billing costs were calculated similarly.

Table 3-2: 24 consecutive months of utility billing data for the subordinate meter located at the Public Transit Center Bus Barn and Maintenance Shop (46322 Timine Way, Pendleton, OR 97801).

	2017-18 (Reference Period)		2018-19 (Evaluation Period)					Realized Savings[c]	
Utility Billing Service Period	Utility Energy Used (kWh)	Final Billing Amount Due	Utility Energy Used (kWh)	Adjusted Utility Energy Usage[a] (kWh)	New Charges	Adjustments[b]	Final Billing Amount Due	Utility Energy (kWh)	Billing Costs
June 12 to July 12	3,840	$450.70	3,280	3,280	$387.08	-$239.58	$147.50	560	$303.20
July 12 to August 13	4,400	$516.05	3,680	3,680	$423.87	-$359.25	$64.62	720	$451.43
August 13 to September 12	4,720	$528.95	3,440	3,440	$405.89	-$398.18	$7.71	1,280	$521.24
September 12 to October 11	3,680	$441.34	2,960	2,960	$356.75	-$322.66	$34.09	720	$407.25
October 11 to November 9	5,680	$625.80	3,040	-	$34.09	$0.00	$34.09	2,640	$591.71
November 9 to December 13	7,440	$792.27	7,200	-	$39.92	$0.00	$39.92	240	$752.35
December 13 to January 15	7,760	$826.34	7,440	7,440	$769.72	$0.00	$769.72	320	$56.62
January 15 to February 13	5,760	$620.26	6,240	6,240	$646.33	$0.00	$646.33	(480)	-$26.07
February 13 to March 15	5,760	$620.26	7,360	7,360	$733.24	$0.00	$733.24	(1,600)	-$112.98
March 15 to April 12	3,680	$424.06	4,080	3,680	$404.82	$0.00	$404.82	(400)	$19.24
April 12 to May 13	3,040	$364.98	3,600	1,720	$216.41	$0.00	$216.41	(560)	$148.57
May 13 to June 12	3,280	$387.12	3,360	-	$29.15	$0.00	$29.15	(80)	$357.97
Totals	*59,040*	*$6,598.13*	*55,680*	*39,800*	*$4,447.27*	*-$1,319.67*	*$3,127.60*	*3,360*	*$3,470.53*

[a] Adjusted utility energy usage is the amount of utility energy used minus an amount subtracted by the utility (if at all) in response to either 1) a surplus of net metered energy measured by the primary meter, or 2) a different reason warranting this form of account credit (such as during Oct. 11 to Dec. 13, 2018 billing periods). The utility's method for calculating adjustments changed over the course of the evaluation period. Initially, cost adjustments (not energy usage adjustments) were applied to bills. Starting in 2019, energy usage adjustments limited to the amount used as measured by the subordinate meter were applied. This approach has compromised the CTUIR's ability to obtain the maximum savings possible.

[b] During 2018 only, aggregated net metering invoice expenses were adjusted with an account credit proportional to the amount of net metered energy measured by the primary meter the prior billing service period (negative values represent account credits). In 2019, this adjustment method was replaced with a method that offsets energy consumption measured by the subordinate meter with net metered energy measured by the primary meter.

[c] Savings attributed to LED lighting retrofit and solar PV system energy generation while neglecting facility occupational and environmental factors that may change energy usage. Amounts were calculated from differences between reference period and evaluation period utility invoices, i.e., utility energy savings were calculated by subtracting evaluation period utility energy used (Column 4 values) from utility energy used during the reference period (Column 2 values). Billing costs were calculated similarly.

3.1 Results Achievable Under Faultless Scenario

As discussed in Section 2.4, a faulty section of underground conductor caused the solar PV array system to short-to-ground and shutdown, interrupting energy generation on 58 days over six months. The amount of energy that would have been generated in the absence of this issue was estimated to be 22,567 kWh as shown in Table 3-3. The method of estimation required the use of SolrenView data in conjunction with solar radiation data collected onsite and corrected to account for temperature related system performance losses, similar to the procedure outlined in Section 2.4. Actual and estimated energy generation data on each day that faulting related downtime occurred is presented in Table 3-3.

Table 3-3: Actual and estimated energy generation on each day that faulting related solar PV system downtime occurred (58 days total).

Date	Actual Energy Generated (kWh_{AC})	Estimated Energy Generation (kWh_{AC})	Date Cont.	Actual Energy Generated (kWh_{AC})	Estimated Energy Generation (kWh_{AC})
2018-Dec-25	29	76	2019-Mar-22	260	488
2019-Jan-21	0	176	2019-Apr-09	18	236
2019-Jan-23	0	65	2019-Apr-15	356	578
2019-Feb-04	0	71	2019-Apr-17	282	553
2019-Feb-05	13	188	2019-Apr-18	0	549
2019-Feb-06	155	357	2019-Apr-19	0	473
2019-Feb-10	102	268	2019-Apr-20	0	234
2019-Feb-11	12	130	2019-Apr-21	0	667
2019-Feb-14	0	81	2019-Apr-22	9	539
2019-Feb-17	45	131	2019-Apr-23	146	437
2019-Feb-20	43	149	2019-Apr-29	401	715
2019-Feb-21	0	245	2019-Apr-30	0	689
2019-Feb-24	16	138	2019-May-01	0	574
2019-Feb-25	6	180	2019-May-02	0	672
2019-Feb-26	6	319	2019-May-03	0	617
2019-Feb-27	28	385	2019-May-04	0	638
2019-Feb-28	159	454	2019-May-05	0	638
2019-Mar-01	162	277	2019-May-06	0	638
2019-Mar-02	124	213	2019-May-07	0	622
2019-Mar-03	127	215	2019-May-14	135	423
2019-Mar-04	198	335	2019-May-15	0	262
2019-Mar-06	34	275	2019-May-16	0	213
2019-Mar-07	237	503	2019-May-17	0	283
2019-Mar-16	13	451	2019-May-18	0	670
2019-Mar-17	14	453	2019-May-19	0	271
2019-Mar-18	10	499	2019-May-20	0	585
2019-Mar-19	11	505	2019-May-21	0	324
2019-Mar-20	14	410	2019-May-22	0	326
2019-Mar-21	10	427	2019-May-23	198	678
Subtotals	*1,568*	*7,975*	*Subtotals*	*1,805*	*14,592*
			Grand Totals	***3,373***	***22,567***

Approximately 19,194 kWh of additional energy would have been generated by the solar PV system if faulting hadn't occurred. The root cause of the issue was successfully identified and resolved, and since no more incidents related to it are anticipated, a reasonable estimate for the total average energy generated by the system could be upwards of 144,774 kWh annually. The results of the first data evaluation period for the project (ending Nov. 9, 2018) indicated that savings directly attributed to the LED lighting retrofit would be roughly 21,515 kWh annually, which aligned relatively well with the theoretical estimate of 23,635 kWh provided in the grant proposal for DE-FOA-0001660 during project initiation. Therefore, the average cumulative energy savings due to the project could in all actuality prove to be upwards of 166,289 kWh annually or greater, equating to about 25.4 tons of reduced fossil-fuel-generated greenhouse gas emissions. Under this scenario, annual cost savings are estimated to be $15,225 and the payback period for the CTUIR's investment is about 4.2 years (or 18.9 years for the total project) neglecting maintenance and operations expenses which are minimal due to the location and design of the solar PV array system.

It's important to note that, regardless of the quantity of energy generated by the solar PV system, achieving maximum cost savings is impossible if the energy is incorrectly valued by the utility. This has been an ongoing issue and is discussed further in Section 5.

4 Budget Narrative

Project funding was provided by the sponsors shown in Table 4-1. Funding from the Energy Trust of Oregon was secured first through two separate incentive reservations; one for the LED lighting retrofit task and the other for the construction of the solar PV array system. With the intent to submit a proposal in response to DE-FOA-0001660 for up to 50% of eligible expenses, the project was brought before the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) Board of Trustees to request final approval which was granted through Resolution No. 17-011.

The project budget initially proposed was insufficient due to unplanned project soft costs[9] and $20,000 of supplemental funding was required to finish. This final amount was provided by the Wildhorse Foundation following the acceptance of an additional grant proposal that was submitted during the execution phase of the project. The final project budget is presented in Table 4-1.

[9] Project soft costs included unplanned expenses associated with construction site preparation, the installation of a gate and additional fencing around the solar PV array, cultural monitoring services, additional project management support, application fees, and hardware to support project Task 4 activities.

Table 4-1: The final project budget showing respective line item amounts.

REVENUES	Amount	Percent of Total
Grant/Contract Income (USDOE-OIE)	$133,705	46.4%
Grant/Contract Income (Energy Trust of Oregon)	$71,088	24.7%
Grant/Contract Income (Wildhorse Foundation)	$20,000	6.9%
Match Funds (CTUIR)	$63,413	22.0%
TOTAL REVENUES	**$288,206**	**100.0%**
EXPENSES		
PART I - PERSONNEL		
SALARIES	$10,483	3.6%
FRINGE BENEFITS	$2,771	1.0%
TOTAL PART I	**$13,254**	**4.6%**
PART II - TRAVEL, EQUIPMENT, ETC.		
TRAVEL	$1,614	0.6%
OTHER EXPENSES	$3,395	1.2%
TOTAL PART II	**$5,009**	**1.7%**
PART III - PASS THROUGH COSTS		
SUB-CONTRACT (Solar PV Array System Installation)	$236,911	82.2%
SUB-CONTRACT (LED Lighting Retrofit)	$9,912	3.4%
SUB-CONTRACTS (Other)	$15,489	5.4%
TOTAL PART III	**$262,312**	**91.0%**
SUB-TOTAL: PARTS I-III	**$280,575**	**97.4%**
PART IV - OVERHEAD COSTS		
INDIRECT Applied to Parts I+II	$7,631	2.6%
TOTAL PART IV	**$7,631**	**2.6%**
TOTAL EXPENSES	**$288,206**	**100.0%**

5 Issues Encountered with the Utility

A number of issues were encountered with the utility that hindered project progress and reduced the total amount of realized cost savings for the CTUIR. The solar PV array system inverters have features built-in that provide effective grounding, ensuring that other system components and the grid are protected in the event of a line-to-ground fault. Despite this, the installation of a grounding bank was required by the utility. A custom transformer had to be ordered and installed to satisfy the utility which delayed system commissioning by more than a month.

Several months after solar PV array system commissioning, Register 24 (excess metered energy) of the primary power meter located at the Field Station was incorrectly read by utility personnel following the September 12, 2018 billing service period. The mistake was identified by the Project Manager and the utility was contacted to correct it. This led to a series of account credits applied to invoices month after month that when combined still fell short of equitably compensating the CTUIR for energy it delivered to the grid.

Other billing discrepancies were caused when the utility changed its method for estimating account credits and how they were applied to invoices in response to the amount of net metered energy measured at the primary meter. This is apparent when comparing earlier 2018 billing adjustments to more recent 2019 billing adjustments. Additional information on this issue can be found in footnotes “a” and “b” of Table 3-2. An example of how the 2019 method is leading to reduced cost savings for the CTUIR can be seen in the May 13 to June 12, 2019 service period where 5,280 kWh of net metered energy delivered to the grid resulted in a reduction of only 3,360 kWh on the subordinate meter’s power bill, essentially meaning the CTUIR was not credited for 1,920 kWh of energy. The amount of uncredited energy rose to 7,240 kWh during the June 12 to July 12, 2019 service period. If this trend continues and nothing is done, the cost savings lost overtime could add up significantly.

6 Lessons Learned and Recommendations

The following is a list of the more important lessons learned during the project and are provided for reader consideration.

1. The request for proposals document used during contractor selection should be comprehensive covering all applicable topics and containing a checklist with all required proposal components (e.g. record of relevant experience; bid, performance, and payment bond information as applicable; acknowledgment of Tribal Employment Rights Office requirements; acknowledgement of permitting authority procedures and applicable code requirements; etc.).
2. Incentivize contractors to complete work on schedule. This can be accomplished several ways (e.g. rewards for completing tasks on schedule, penalties for falling behind schedule or finishing late, etc.). Whatever the approach may be, it should be expressly stated in the contract with the service provider.
3. Provide ample time for the permitting authority to review and approve construction plan sets with the expectation that revisions will be required. A reasonable time allocation to do so, based on project scale and complexity, should be written into construction service provider contracts as a requirement.
4. All possible risks should be considered and managed across all phases of the project, especially during the construction phase when valuable goods are more susceptible to damage or theft.
5. For projects involving the construction of solar PV arrays, plan on establishing an annual service agreement with a solar array cleaning service provider. The number of cleanings per year and schedule should be based on dust loading and other site specific environmental factors that contribute to solar module fouling.
6. Include contingency funding in the project budget, the amount of which should be estimated based on project risks, complexity, and certainty associated with other budgetary estimates.
7. To ensure that final products of construction meet specific funding source requirements for reimbursement, it is recommended that language specifying this be included in construction service provider contracts.
8. The data collection systems employed for solar PV array system performance monitoring proved to be invaluable and are highly recommended, especially for supporting troubleshooting and data assessment/correction activities.

7 Conclusion

In conclusion, the project was completed successfully despite a number of undesirable events ranging from solar PV system faulting due to a flawed section of underground conductor, to an increased project budget and need for supplemental funding, to an incorrect utility power meter reading that led to a series of billing discrepancies skewing project cost savings data in the process. Project expenses exceeded initial budgetary limits, but an additional sponsor was identified and provided the funding needed to finish the project. The total final cost of the project was $288,206.

The Ántukš–Tíṅqapapt Solar PV Array surpassed initial estimates by generating 125,580 kWh of energy during its first full 12 months of operation. That value is expected to increase to approximately 144,774 kWh annually on average for the remainder of its lifetime in the absence of the short-to-ground faulting issue that was resolved in May 2019. A faultless operating scenario is assumed for the remainder of the systems lifetime and upwards of 166,289 kWh of energy, presently valued at nearly $15,225, could be saved annually on average when combined with savings from the LED lighting retrofit activity. This equates to roughly 25.4 tons of reduced fossil-fuel-generated greenhouse gas emissions annually. Under this scenario, a payback period of roughly 4.5 years is estimated for the CTUIR.

The data collection systems employed for monitoring solar PV system performance proved to be convenient, reliable, and highly effective for aiding system troubleshooting and data analysis. These systems will remain in use for the foreseeable future, not only for continued solar PV system monitoring, but also for serving in other applications beyond the scope of this project.

8 Acknowledgments

This project was made possible with generous support from the US Department of Energy Office of Indian Energy under award DE-IE0000085, the Energy Trust of Oregon, the Wildhorse Foundation and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR). The Project Manager would like to thank Lizana Pierce, Tweedie Doe, and Jami Alley for their assistance during the project.

Additional thanks are in order for the CTUIR staff who supported the project from within the Department of Public Works, Cultural Resources Protection Program, Language Program, Tribal Employment Rights Office, and the many other departments and programs that provided administrative resources to support the project. Finally, Dr. Rodney S. Skeen, PE deserves a special thanks for his invaluable experience, advice, and other critical contributions provided during project initiation, planning and execution. His support and mentoring of the Project Manager is also greatly appreciated and will not be forgotten.

9 Appendices

Appendix A, Data from SolrenView Solar PV System Monitoring Service

SolrenView Data

Date/Period	Inverter 1 [1013821742309 PVI 60TL] - AC Energy (kWh)	Inverter 2 [1013821743037 PVI 60TL] - AC Energy (kWh)	Period Total (kWh)
June 29 to July 25, 2018	8596	8595	17191
2018-Jul-26	228	228	456
2018-Jul-27	312	311	623
2018-Jul-28	319	317	636
2018-Jul-29	314	314	628
2018-Jul-30	280	280	560
2018-Jul-31	221	220	441
2018-Aug-01	341	340	681
2018-Aug-02	346	346	692
2018-Aug-03	328	329	657
2018-Aug-04	338	337	675
2018-Aug-05	328	328	656
2018-Aug-06	312	311	623
2018-Aug-07	298	299	597
2018-Aug-08	296	295	591
2018-Aug-09	291	290	581
2018-Aug-10	285	284	569
2018-Aug-11	318	316	634
2018-Aug-12	339	337	676
2018-Aug-13	285	285	570
2018-Aug-14	294	293	587
2018-Aug-15	256	255	511
2018-Aug-16	212	211	423
2018-Aug-17	265	264	529
2018-Aug-18	316	314	630
2018-Aug-19	274	273	547
2018-Aug-20	170	169	339
2018-Aug-21	300	298	598
2018-Aug-22	293	291	584
2018-Aug-23	245	244	489
2018-Aug-24	321	317	638
2018-Aug-25	227	225	452
2018-Aug-26	113	112	225
2018-Aug-27	195	193	388
2018-Aug-28	320	316	636
2018-Aug-29	302	297	599
2018-Aug-30	200	198	398
2018-Aug-31	286	279	565
2018-Sep-01	322	315	637
2018-Sep-02	318	311	629
2018-Sep-03	306	299	605
2018-Sep-04	307	300	607
2018-Sep-05	265	263	528
2018-Sep-06	253	252	505
2018-Sep-07	277	276	553
2018-Sep-08	302	300	602
2018-Sep-09	295	293	588
2018-Sep-10	262	260	522
2018-Sep-11	161	161	322
2018-Sep-12	243	241	484
2018-Sep-13	257	256	513
2018-Sep-14	285	285	570
2018-Sep-15	175	175	350
2018-Sep-16	288	288	576
2018-Sep-17	264	264	528
2018-Sep-18	285	284	569

2018-Sep-19	283	283	566
2018-Sep-20	280	280	560
2018-Sep-21	230	229	459
2018-Sep-22	79	79	158
2018-Sep-23	293	292	585
2018-Sep-24	288	288	576
2018-Sep-25	276	275	551
2018-Sep-26	265	264	529
2018-Sep-27	266	266	532
2018-Sep-28	264	263	527
2018-Sep-29	204	203	407
2018-Sep-30	133	133	266
2018-Oct-01	154	153	307
2018-Oct-02	71	72	143
2018-Oct-03	264	262	526
2018-Oct-04	141	141	282
2018-Oct-05	115	114	229
2018-Oct-06	33	33	66
2018-Oct-07	175	175	350
2018-Oct-08	118	117	235
2018-Oct-09	20	21	41
2018-Oct-10	116	114	230
2018-Oct-11	268	269	537
2018-Oct-12	273	271	544
2018-Oct-13	273	271	544
2018-Oct-14	281	280	561
2018-Oct-15	268	266	534
2018-Oct-16	267	267	534
2018-Oct-17	257	255	512
2018-Oct-18	242	242	484
2018-Oct-19	250	248	498
2018-Oct-20	233	233	466
2018-Oct-21	217	215	432
2018-Oct-22	230	230	460
2018-Oct-23	174	173	347
2018-Oct-24	109	109	218
2018-Oct-25	94	93	187
2018-Oct-26	36	36	72
2018-Oct-27	217	217	434
2018-Oct-28	39	39	78
2018-Oct-29	133	132	265
2018-Oct-30	179	177	356
2018-Oct-31	18	17	35
2018-Nov-01	32	33	65
2018-Nov-02	184	182	366
2018-Nov-03	95	95	190
2018-Nov-04	194	191	385
2018-Nov-05	84	85	169
2018-Nov-06	122	120	242
2018-Nov-07	123	123	246
2018-Nov-08	228	227	455
2018-Nov-09	92	91	183
2018-Nov-10	131	131	262
2018-Nov-11	210	210	420
2018-Nov-12	29	29	58
2018-Nov-13	30	30	60
2018-Nov-14	72	72	144
2018-Nov-15	200	199	399
2018-Nov-16	53	53	106

2018-Nov-17	182	181	363
2018-Nov-18	207	206	413
2018-Nov-19	195	195	390
2018-Nov-20	47	46	93
2018-Nov-21	28	27	55
2018-Nov-22	105	105	210
2018-Nov-23	26	27	53
2018-Nov-24	177	176	353
2018-Nov-25	182	181	363
2018-Nov-26	43	42	85
2018-Nov-27	14	14	28
2018-Nov-28	131	131	262
2018-Nov-29	114	114	228
2018-Nov-30	61	61	122
2018-Dec-01	88	87	175
2018-Dec-02	22	23	45
2018-Dec-03	183	181	364
2018-Dec-04	122	121	243
2018-Dec-05	26	26	52
2018-Dec-06	186	184	370
2018-Dec-07	27	28	55
2018-Dec-08	65	65	130
2018-Dec-09	25	24	49
2018-Dec-10	86	86	172
2018-Dec-11	13	13	26
2018-Dec-12	71	71	142
2018-Dec-13	90	89	179
2018-Dec-14	13	14	27
2018-Dec-15	133	131	264
2018-Dec-16	10	9	19
2018-Dec-17	147	146	293
2018-Dec-18	29	28	57
2018-Dec-19	25	25	50
2018-Dec-20	24	24	48
2018-Dec-21	101	99	200
2018-Dec-22	105	104	209
2018-Dec-23	16	16	32
2018-Dec-24	33	33	66
2018-Dec-25	14	15	29
2018-Dec-26	40	39	79
2018-Dec-27	18	18	36
2018-Dec-28	55	55	110
2018-Dec-29	63	63	126
2018-Dec-30	30	29	59
2018-Dec-31	189	185	374
2019-Jan-01	76	75	151
2019-Jan-02	93	91	184
2019-Jan-03	27	27	54
2019-Jan-04	45	45	90
2019-Jan-05	28	28	56
2019-Jan-06	35	35	70
2019-Jan-07	151	150	301
2019-Jan-08	18	18	36
2019-Jan-09	43	43	86
2019-Jan-10	153	151	304
2019-Jan-11	22	22	44
2019-Jan-12	23	24	47
2019-Jan-13	25	24	49
2019-Jan-14	22	22	44

2019-Jan-15	21	21	42
2019-Jan-16	33	32	65
2019-Jan-17	32	33	65
2019-Jan-18	86	85	171
2019-Jan-19	19	20	39
2019-Jan-20	17	16	33
2019-Jan-21	0	0	0
2019-Jan-22	24	24	48
2019-Jan-23	0	0	0
2019-Jan-24	176	174	350
2019-Jan-25	177	176	353
2019-Jan-26	191	190	381
2019-Jan-27	176	174	350
2019-Jan-28	36	36	72
2019-Jan-29	24	24	48
2019-Jan-30	36	36	72
2019-Jan-31	37	37	74
2019-Feb-01	38	37	75
2019-Feb-02	109	109	218
2019-Feb-03	19	19	38
2019-Feb-04	0	0	0
2019-Feb-05	6	7	13
2019-Feb-06	93	62	155
2019-Feb-07	237	224	461
2019-Feb-08	102	102	204
2019-Feb-09	68	69	137
2019-Feb-10	54	48	102
2019-Feb-11	5	7	12
2019-Feb-12	52	52	104
2019-Feb-13	38	38	76
2019-Feb-14	0	0	0
2019-Feb-15	123	121	244
2019-Feb-16	64	63	127
2019-Feb-17	22	23	45
2019-Feb-18	131	129	260
2019-Feb-19	70	70	140
2019-Feb-20	22	21	43
2019-Feb-21	0	0	0
2019-Feb-22	185	184	369
2019-Feb-23	154	153	307
2019-Feb-24	8	8	16
2019-Feb-25	3	3	6
2019-Feb-26	3	3	6
2019-Feb-27	12	16	28
2019-Feb-28	84	75	159
2019-Mar-01	89	73	162
2019-Mar-02	68	56	124
2019-Mar-03	69	58	127
2019-Mar-04	109	89	198
2019-Mar-05	136	114	250
2019-Mar-06	14	20	34
2019-Mar-07	122	115	237
2019-Mar-08	198	194	392
2019-Mar-09	116	113	229
2019-Mar-10	107	98	205
2019-Mar-11	274	252	526
2019-Mar-12	119	118	237
2019-Mar-13	244	235	479
2019-Mar-14	297	298	595

2019-Mar-15	209	211	420
2019-Mar-16	2	11	13
2019-Mar-17	4	10	14
2019-Mar-18	3	7	10
2019-Mar-19	2	9	11
2019-Mar-20	5	9	14
2019-Mar-21	3	7	10
2019-Mar-22	128	132	260
2019-Mar-23	126	125	251
2019-Mar-24	69	70	139
2019-Mar-25	129	128	257
2019-Mar-26	280	281	561
2019-Mar-27	65	65	130
2019-Mar-28	300	298	598
2019-Mar-29	151	151	302
2019-Mar-30	310	309	619
2019-Mar-31	314	309	623
2019-Apr-01	203	203	406
2019-Apr-02	191	190	381
2019-Apr-03	122	122	244
2019-Apr-04	196	197	393
2019-Apr-05	178	177	355
2019-Apr-06	90	90	180
2019-Apr-07	62	62	124
2019-Apr-08	82	82	164
2019-Apr-09	9	9	18
2019-Apr-10	227	226	453
2019-Apr-11	144	144	288
2019-Apr-12	147	146	293
2019-Apr-13	134	134	268
2019-Apr-14	192	191	383
2019-Apr-15	174	182	356
2019-Apr-16	186	188	374
2019-Apr-17	141	141	282
2019-Apr-18	0	0	0
2019-Apr-19	0	0	0
2019-Apr-20	0	0	0
2019-Apr-21	0	0	0
2019-Apr-22	1	8	9
2019-Apr-23	72	74	146
2019-Apr-24	314	311	625
2019-Apr-25	313	314	627
2019-Apr-26	317	315	632
2019-Apr-27	337	335	672
2019-Apr-28	323	322	645
2019-Apr-29	201	200	401
2019-Apr-30	0	0	0
2019-May-01	0	0	0
2019-May-02	0	0	0
2019-May-03	0	0	0
2019-May-04	0	0	0
2019-May-05	0	0	0
2019-May-06	0	0	0
2019-May-07	0	0	0
2019-May-08	290	290	580
2019-May-09	357	356	713
2019-May-10	346	345	691
2019-May-11	342	342	684
2019-May-12	229	238	467

2019-May-13	307	307	614
2019-May-14	68	67	135
2019-May-15	0	0	0
2019-May-16	0	0	0
2019-May-17	0	0	0
2019-May-18	0	0	0
2019-May-19	0	0	0
2019-May-20	0	0	0
2019-May-21	0	0	0
2019-May-22	0	0	0
2019-May-23	99	99	198
2019-May-24	168	168	336
2019-May-25	336	336	672
2019-May-26	276	274	550
2019-May-27	219	219	438
2019-May-28	352	352	704
2019-May-29	244	243	487
2019-May-30	225	226	451
2019-May-31	337	337	674
2019-Jun-01	339	338	677
2019-Jun-02	343	344	687
2019-Jun-03	353	351	704
2019-Jun-04	365	364	729
2019-Jun-05	311	311	622
2019-Jun-06	155	155	310
2019-Jun-07	324	322	646
2019-Jun-08	305	306	611
2019-Jun-09	335	335	670
2019-Jun-10	342	341	683
2019-Jun-11	345	346	691
2019-Jun-12	335	335	670
2019-Jun-13	340	339	679
2019-Jun-14	362	361	723
2019-Jun-15	347	348	695
2019-Jun-16	340	340	680
2019-Jun-17	342	342	684
2019-Jun-18	350	348	698
2019-Jun-19	372	370	742
2019-Jun-20	207	208	415
2019-Jun-21	156	156	312
2019-Jun-22	329	329	658
2019-Jun-23	235	234	469
2019-Jun-24	363	363	726
2019-Jun-25	296	298	594
2019-Jun-26	192	191	383
2019-Jun-27	259	260	519
2019-Jun-28	357	356	713
2019-Jun-29	345	346	691
2019-Jun-30	350	351	701
Totals	*62950*	*62630*	*125580*

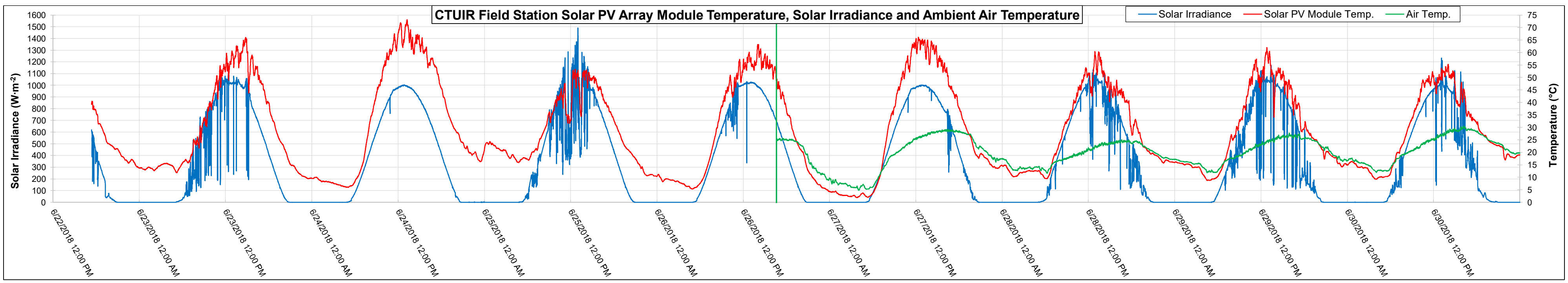
Appendix B, Solar Radiation Data Collected during 12 Month System Monitoring Period

Solar Radiation Data Collected Onsite Using ISO-9060 Second Class Pyranometer

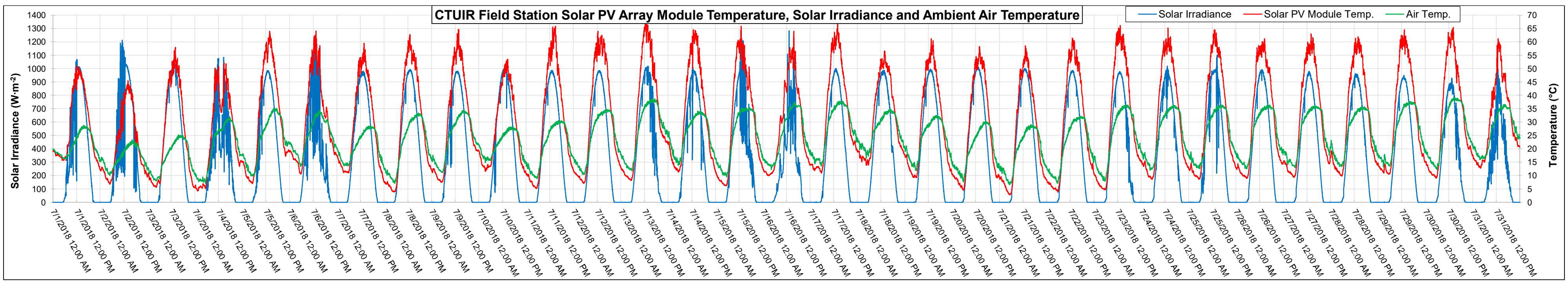
Date (mm/dd/yy)	Solar Radiation (kJ/m^2)	Date (mm/dd/yy)	Solar Radiation (kJ/m^2)	Date (mm/dd/yy)	Solar Radiation (kJ/m^2)
06/23/18	3.11E+04	10/26/18	2.67E+03	02/28/19	1.56E+04
06/24/18	3.21E+04	10/27/18	1.13E+04	03/01/19	9.82E+03
06/25/18	2.98E+04	10/28/18	2.92E+03	03/02/19	7.36E+03
06/26/18	3.29E+04	10/29/18	7.46E+03	03/03/19	7.40E+03
06/27/18	3.23E+04	10/30/18	9.44E+03	03/04/19	1.17E+04
06/28/18	3.11E+04	10/31/18	1.26E+03	03/05/19	1.35E+04
06/29/18	2.93E+04	11/01/18	2.34E+03	03/06/19	9.34E+03
06/30/18	2.81E+04	11/02/18	9.31E+03	03/07/19	1.84E+04
07/01/18	3.12E+04	11/03/18	6.00E+03	03/08/19	1.67E+04
07/02/18	2.92E+04	11/04/18	9.66E+03	03/09/19	1.07E+04
07/03/18	3.23E+04	11/05/18	5.17E+03	03/10/19	9.33E+03
07/04/18	2.50E+04	11/06/18	6.81E+03	03/11/19	1.94E+04
07/05/18	3.09E+04	11/07/18	6.98E+03	03/12/19	9.64E+03
07/06/18	2.66E+04	11/08/18	1.05E+04	03/13/19	1.51E+04
07/07/18	3.11E+04	11/09/18	5.34E+03	03/14/19	1.83E+04
07/08/18	3.14E+04	11/10/18	6.48E+03	03/15/19	1.88E+04
07/09/18	3.05E+04	11/11/18	9.54E+03	03/16/19	1.72E+04
07/10/18	3.17E+04	11/12/18	1.88E+03	03/17/19	1.75E+04
07/11/18	3.11E+04	11/13/18	2.22E+03	03/18/19	1.97E+04
07/12/18	3.11E+04	11/14/18	4.21E+03	03/19/19	1.99E+04
07/13/18	2.99E+04	11/15/18	8.86E+03	03/20/19	1.62E+04
07/14/18	3.08E+04	11/16/18	3.57E+03	03/21/19	1.72E+04
07/15/18	2.74E+04	11/17/18	8.07E+03	03/22/19	1.95E+04
07/16/18	1.87E+04	11/18/18	8.85E+03	03/23/19	8.99E+03
07/17/18	3.07E+04	11/19/18	8.39E+03	03/24/19	5.28E+03
07/18/18	3.07E+04	11/20/18	2.40E+03	03/25/19	8.97E+03
07/19/18	3.12E+04	11/21/18	1.67E+03	03/26/19	1.83E+04
07/20/18	3.17E+04	11/22/18	5.20E+03	03/27/19	4.76E+03
07/21/18	3.12E+04	11/23/18	1.81E+03	03/28/19	2.04E+04
07/22/18	3.06E+04	11/24/18	7.37E+03	03/29/19	1.08E+04
07/23/18	2.92E+04	11/25/18	7.67E+03	03/30/19	2.09E+04
07/24/18	3.02E+04	11/26/18	2.87E+03	03/31/19	2.12E+04
07/25/18	3.04E+04	11/27/18	1.00E+03	04/01/19	1.45E+04
07/26/18	3.05E+04	11/28/18	5.89E+03	04/02/19	1.35E+04
07/27/18	2.93E+04	11/29/18	5.39E+03	04/03/19	9.16E+03
07/28/18	2.91E+04	11/30/18	3.38E+03	04/04/19	1.41E+04
07/29/18	2.84E+04	12/01/18	4.40E+03	04/05/19	1.31E+04
07/30/18	2.50E+04	12/02/18	1.64E+03	04/06/19	6.71E+03
07/31/18	1.90E+04	12/03/18	7.55E+03	04/07/19	4.64E+03
08/01/18	2.94E+04	12/04/18	5.32E+03	04/08/19	6.13E+03
08/02/18	2.93E+04	12/05/18	1.85E+03	04/09/19	8.44E+03
08/03/18	2.74E+04	12/06/18	7.47E+03	04/10/19	1.62E+04
08/04/18	2.83E+04	12/07/18	2.01E+03	04/11/19	1.05E+04
08/05/18	2.76E+04	12/08/18	3.71E+03	04/12/19	1.07E+04
08/06/18	2.62E+04	12/09/18	1.67E+03	04/13/19	9.84E+03
08/07/18	2.51E+04	12/10/18	4.29E+03	04/14/19	1.42E+04
08/08/18	2.50E+04	12/11/18	9.69E+02	04/15/19	2.25E+04
08/09/18	2.47E+04	12/12/18	4.07E+03	04/16/19	1.68E+04
08/10/18	2.40E+04	12/13/18	4.82E+03	04/17/19	2.12E+04
08/11/18	2.57E+04	12/14/18	7.85E+02	04/18/19	2.29E+04
08/12/18	2.77E+04	12/15/18	5.62E+03	04/19/19	1.98E+04
08/13/18	2.30E+04	12/16/18	6.02E+02	04/20/19	8.61E+03
08/14/18	2.40E+04	12/17/18	5.99E+03	04/21/19	2.70E+04
08/15/18	2.10E+04	12/18/18	1.48E+03	04/22/19	2.18E+04
08/16/18	1.75E+04	12/19/18	1.74E+03	04/23/19	1.68E+04
08/17/18	2.14E+04	12/20/18	1.67E+03	04/24/19	2.56E+04
08/18/18	2.58E+04	12/21/18	4.66E+03	04/25/19	2.40E+04
08/19/18	2.21E+04	12/22/18	4.85E+03	04/26/19	2.42E+04
08/20/18	1.42E+04	12/23/18	1.15E+03	04/27/19	2.52E+04
08/21/18	2.38E+04	12/24/18	2.23E+03	04/28/19	2.49E+04
08/22/18	2.37E+04	12/25/18	2.03E+03	04/29/19	2.77E+04

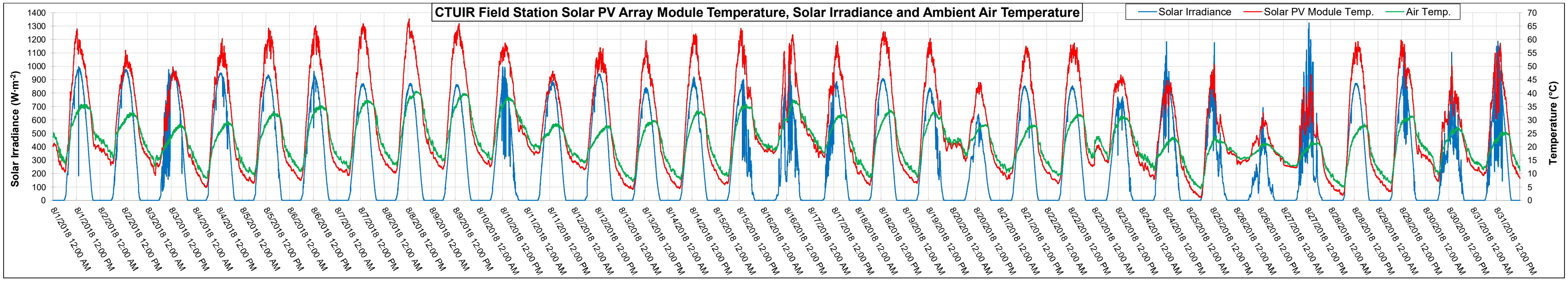
08/23/18	1.99E+04	12/26/18	2.40E+03	04/30/19	2.70E+04
08/24/18	2.50E+04	12/27/18	1.25E+03	05/01/19	2.48E+04
08/25/18	1.78E+04	12/28/18	3.41E+03	05/02/19	2.87E+04
08/26/18	9.37E+03	12/29/18	3.65E+03	05/03/19	2.76E+04
08/27/18	1.51E+04	12/30/18	2.08E+03	05/04/19	2.86E+04
08/28/18	2.45E+04	12/31/18	6.96E+03	05/05/19	2.86E+04
08/29/18	2.33E+04	01/01/19	3.82E+03	05/06/19	2.88E+04
08/30/18	1.60E+04	01/02/19	4.61E+03	05/07/19	2.75E+04
08/31/18	2.19E+04	01/03/19	1.92E+03	05/08/19	2.85E+04
09/01/18	2.42E+04	01/04/19	3.08E+03	05/09/19	2.96E+04
09/02/18	2.40E+04	01/05/19	1.99E+03	05/10/19	2.94E+04
09/03/18	2.30E+04	01/06/19	2.45E+03	05/11/19	2.96E+04
09/04/18	2.28E+04	01/07/19	6.48E+03	05/12/19	2.73E+04
09/05/18	1.97E+04	01/08/19	1.20E+03	05/13/19	2.63E+04
09/06/18	1.91E+04	01/09/19	2.76E+03	05/14/19	1.79E+04
09/07/18	2.07E+04	01/10/19	6.41E+03	05/15/19	1.09E+04
09/08/18	2.21E+04	01/11/19	1.62E+03	05/16/19	8.55E+03
09/09/18	2.15E+04	01/12/19	1.67E+03	05/17/19	1.14E+04
09/10/18	1.94E+04	01/13/19	1.76E+03	05/18/19	2.98E+04
09/11/18	1.23E+04	01/14/19	1.57E+03	05/19/19	1.12E+04
09/12/18	1.80E+04	01/15/19	1.46E+03	05/20/19	2.59E+04
09/13/18	1.83E+04	01/16/19	2.36E+03	05/21/19	1.35E+04
09/14/18	2.00E+04	01/17/19	2.38E+03	05/22/19	1.36E+04
09/15/18	1.29E+04	01/18/19	4.98E+03	05/23/19	3.02E+04
09/16/18	2.03E+04	01/19/19	1.41E+03	05/24/19	1.33E+04
09/17/18	1.82E+04	01/20/19	1.12E+03	05/25/19	2.72E+04
09/18/18	1.95E+04	01/21/19	5.55E+03	05/26/19	2.34E+04
09/19/18	1.98E+04	01/22/19	1.64E+03	05/27/19	1.84E+04
09/20/18	1.97E+04	01/23/19	2.00E+03	05/28/19	3.06E+04
09/21/18	1.63E+04	01/24/19	8.31E+03	05/29/19	2.08E+04
09/22/18	6.40E+03	01/25/19	8.11E+03	05/30/19	1.90E+04
09/23/18	1.97E+04	01/26/19	8.71E+03	05/31/19	2.97E+04
09/24/18	1.92E+04	01/27/19	8.65E+03	06/01/19	3.02E+04
09/25/18	1.87E+04	01/28/19	2.66E+03	06/02/19	3.10E+04
09/26/18	1.86E+04	01/29/19	1.75E+03	06/03/19	3.12E+04
09/27/18	1.82E+04	01/30/19	2.63E+03	06/04/19	3.32E+04
09/28/18	1.78E+04	01/31/19	2.70E+03	06/05/19	2.77E+04
09/29/18	1.44E+04	02/01/19	2.67E+03	06/06/19	1.29E+04
09/30/18	9.82E+03	02/02/19	6.14E+03	06/07/19	2.71E+04
10/01/18	1.12E+04	02/03/19	1.32E+03	06/08/19	2.69E+04
10/02/18	5.11E+03	02/04/19	2.21E+03	06/09/19	2.99E+04
10/03/18	1.62E+04	02/05/19	5.88E+03	06/10/19	3.04E+04
10/04/18	9.85E+03	02/06/19	1.18E+04	06/11/19	3.16E+04
10/05/18	7.83E+03	02/07/19	1.14E+04	06/12/19	3.03E+04
10/06/18	2.44E+03	02/08/19	6.11E+03	06/13/19	3.15E+04
10/07/18	1.14E+04	02/09/19	4.99E+03	06/14/19	3.31E+04
10/08/18	8.22E+03	02/10/19	8.69E+03	06/15/19	3.23E+04
10/09/18	1.55E+03	02/11/19	4.12E+03	06/16/19	3.18E+04
10/10/18	1.11E+04	02/12/19	3.70E+03	06/17/19	3.16E+04
10/11/18	1.56E+04	02/13/19	3.64E+03	06/18/19	3.23E+04
10/12/18	1.53E+04	02/14/19	2.56E+03	06/19/19	3.33E+04
10/13/18	1.51E+04	02/15/19	9.21E+03	06/20/19	1.78E+04
10/14/18	1.55E+04	02/16/19	4.76E+03	06/21/19	1.32E+04
10/15/18	1.46E+04	02/17/19	4.19E+03	06/22/19	2.97E+04
10/16/18	1.45E+04	02/18/19	8.66E+03	06/23/19	2.10E+04
10/17/18	1.39E+04	02/19/19	5.03E+03	06/24/19	3.23E+04
10/18/18	1.33E+04	02/20/19	4.72E+03	06/25/19	2.62E+04
10/19/18	1.35E+04	02/21/19	7.93E+03	06/26/19	1.71E+04
10/20/18	1.26E+04	02/22/19	1.06E+04	06/27/19	2.26E+04
10/21/18	1.16E+04	02/23/19	8.94E+03	06/28/19	3.18E+04
10/22/18	1.22E+04	02/24/19	4.37E+03	06/29/19	3.07E+04
10/23/18	1.03E+04	02/25/19	5.63E+03	06/30/19	3.17E+04
10/24/18	7.13E+03	02/26/19	1.00E+04	*Total*	*2.53E+06*
10/25/18	6.37E+03	02/27/19	1.22E+04		
Total	*2.69E+06*	*Total*	*5.85E+05*		

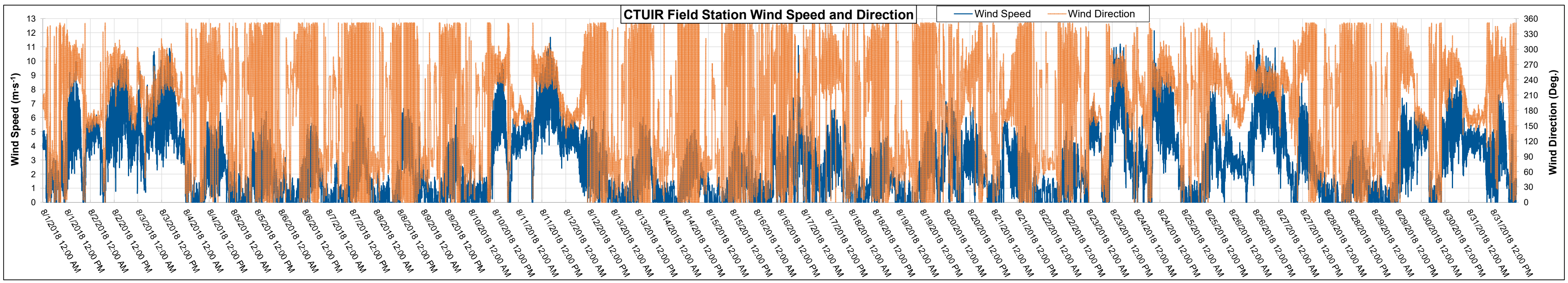
Appendix C, Meteorological Data Vs Time Plots for 12 Month System Monitoring Period

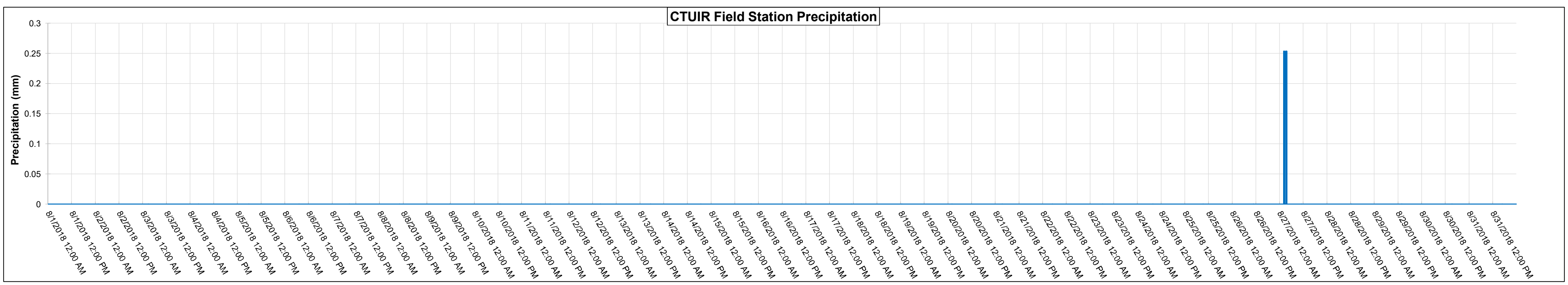


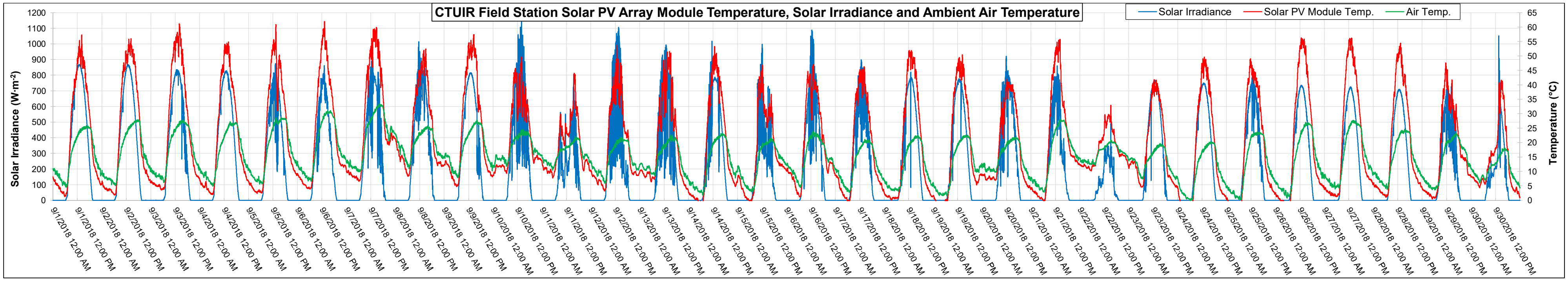
CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m-2)
Temperature (°C)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
6/22/2018 12:00 PM
6/23/2018 12:00 AM
6/23/2018 12:00 PM
6/24/2018 12:00 AM
6/24/2018 12:00 PM
6/25/2018 12:00 AM
6/25/2018 12:00 PM
6/26/2018 12:00 AM
6/26/2018 12:00 PM
6/27/2018 12:00 AM
6/27/2018 12:00 PM
6/28/2018 12:00 AM
6/28/2018 12:00 PM
6/29/2018 12:00 AM
6/29/2018 12:00 PM
6/30/2018 12:00 AM
6/30/2018 12:00 PM

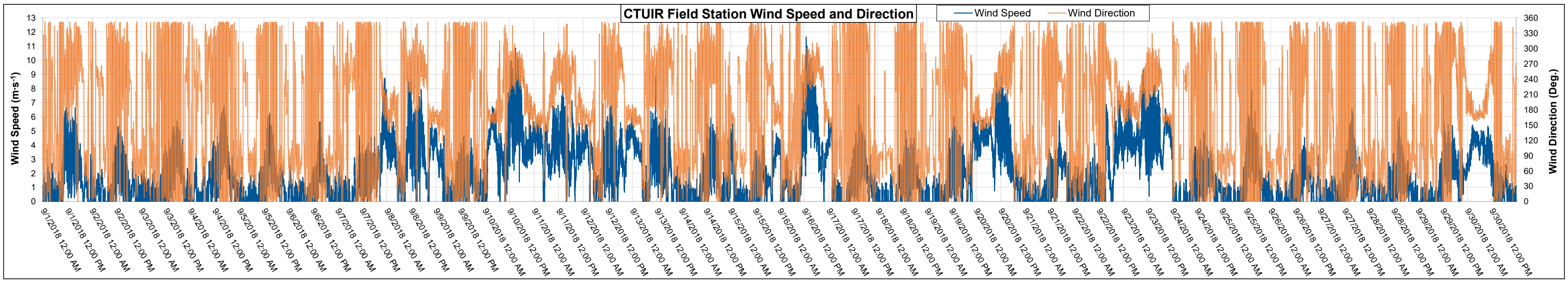

CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m-2)
Temperature (°C)

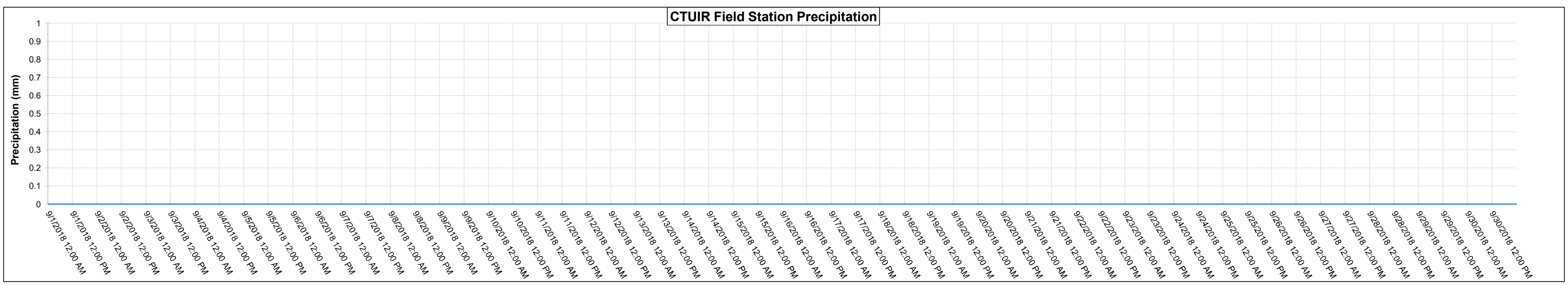

CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

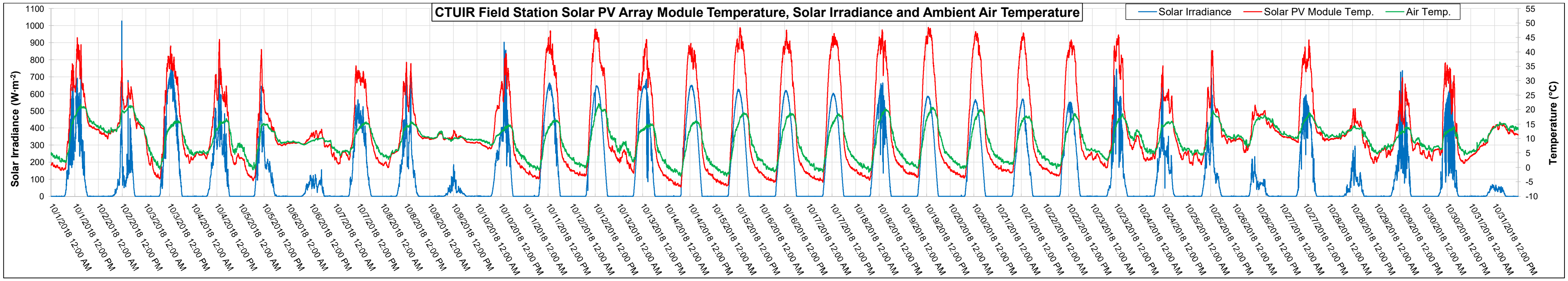

CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
360
330
300
270
240
210
180
150
120
90
60
30
0

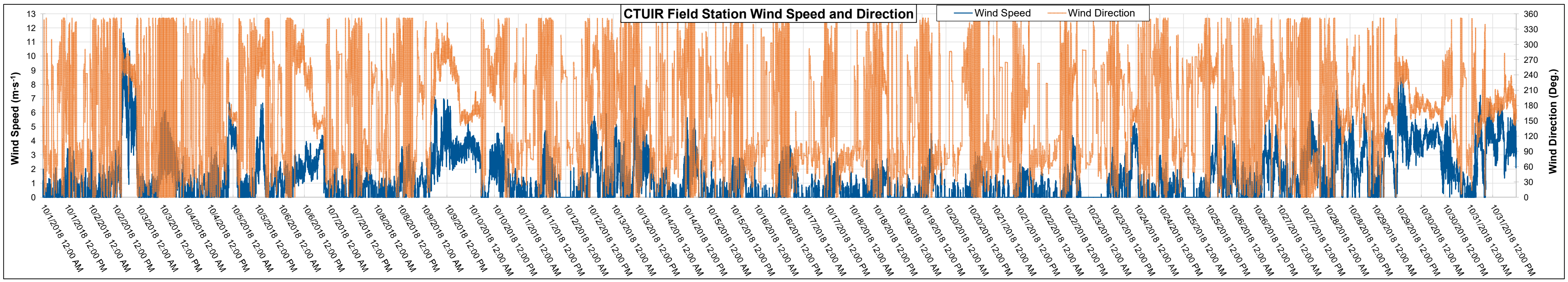

CTUIR Field Station Precipitation
Precipitation (mm)
0.3
0.25
0.2
0.15
0.1
0.05
0

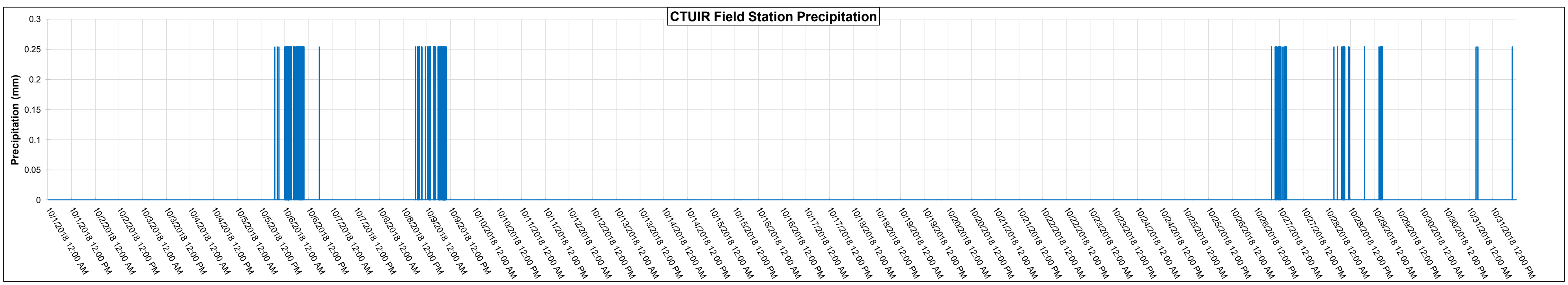

CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
0 5 10 15 20 25 30 35 40 45 50 55 60 65

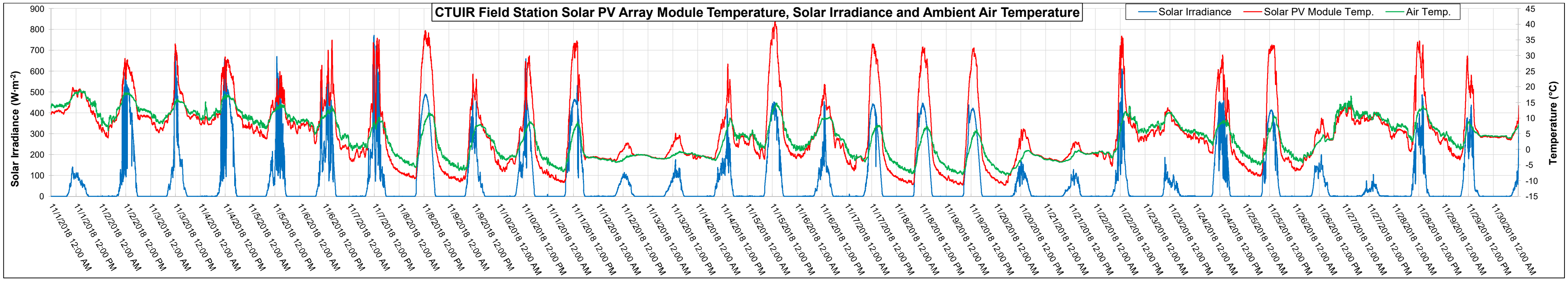

CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)
0 1 2 3 4 5 6 7 8 9 10 11 12 13
0 30 60 90 120 150 180 210 240 270 300 330 360

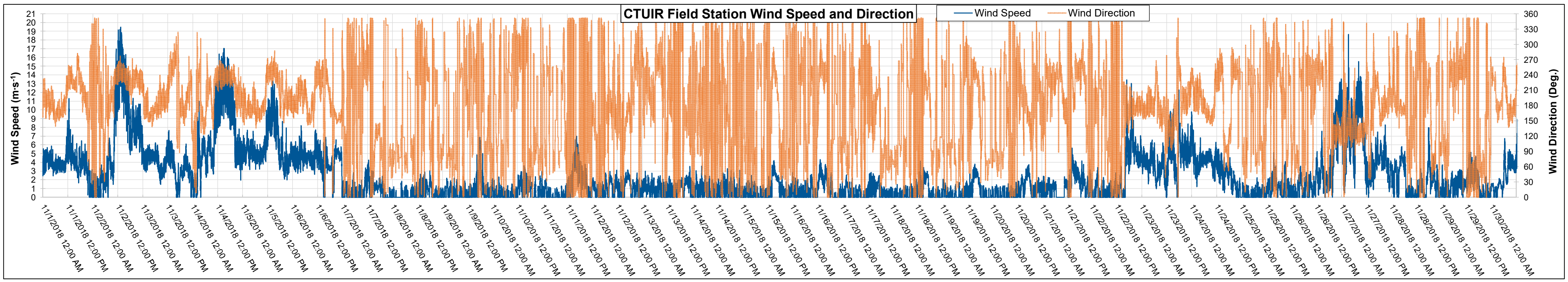

CTUIR Field Station Precipitation
Precipitation (mm)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

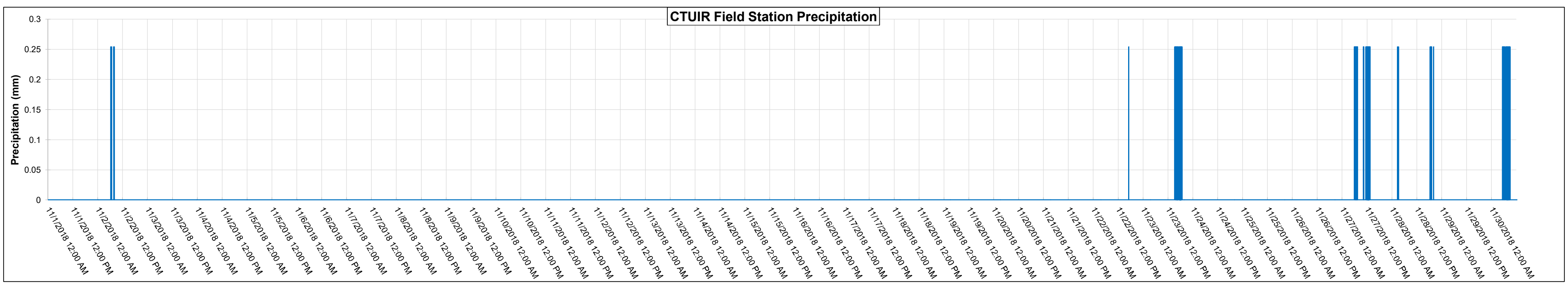

CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)
1100
1000
900
800
700
600
500
400
300
200
100
0
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10

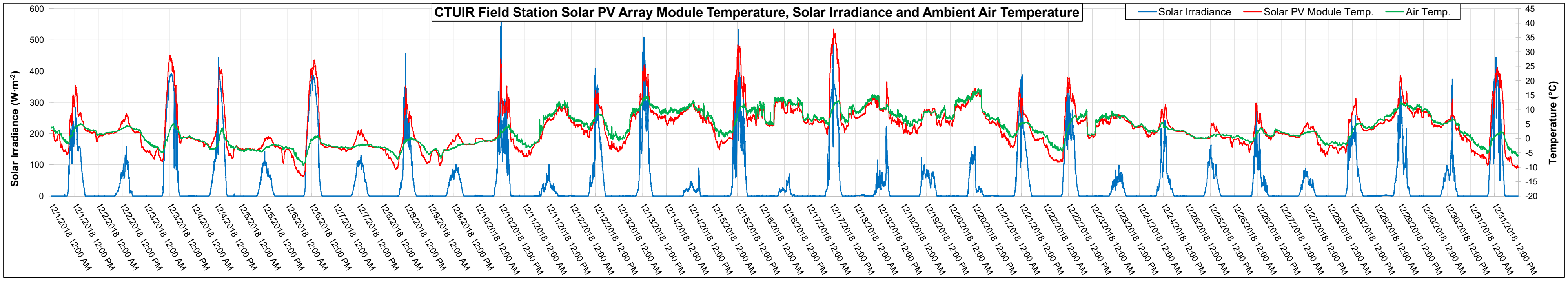

CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
360
330
300
270
240
210
180
150
120
90
60
30
0

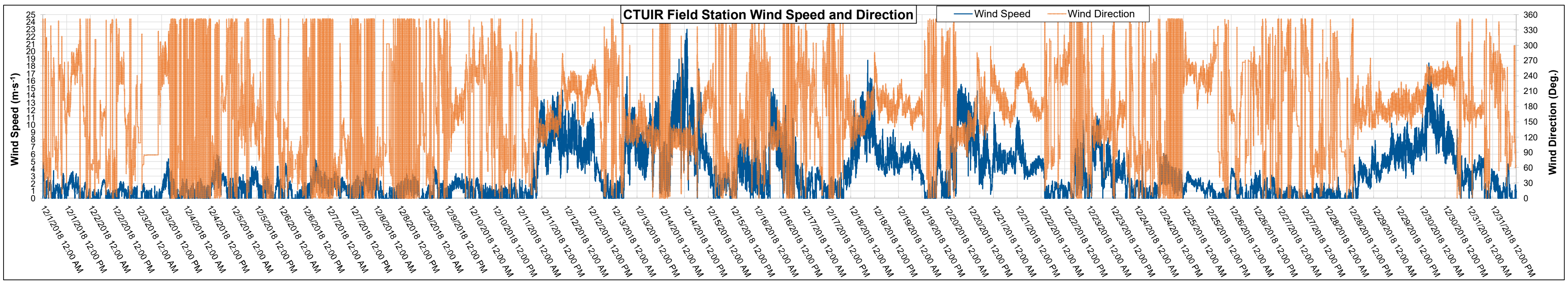

CTUIR Field Station Precipitation
Precipitation (mm)
0.3
0.25
0.2
0.15
0.1
0.05
0

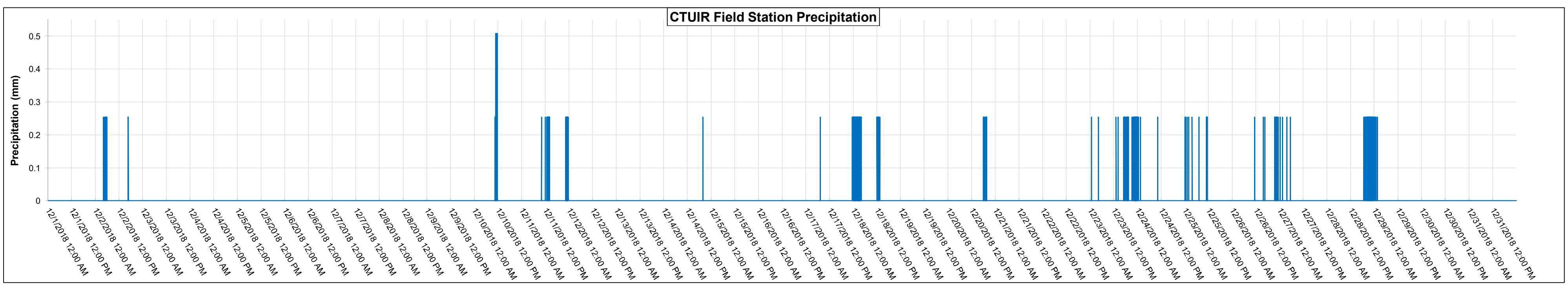

CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)

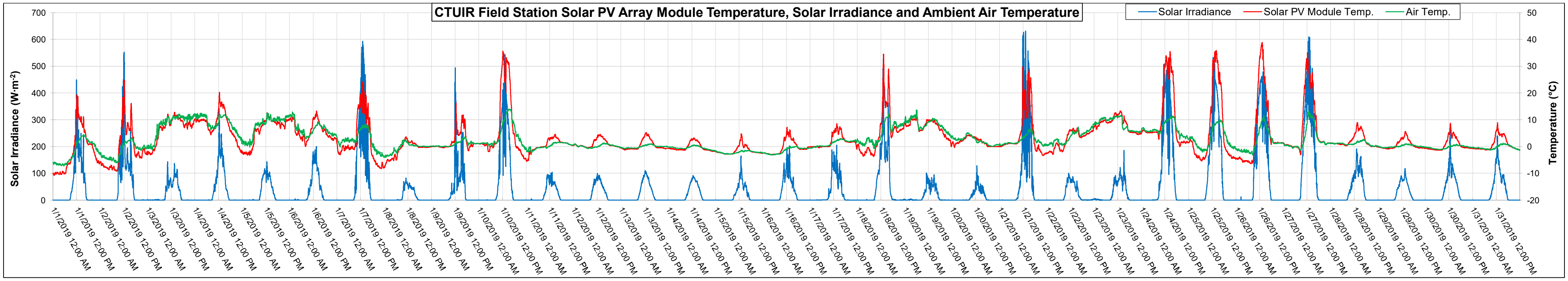

CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)

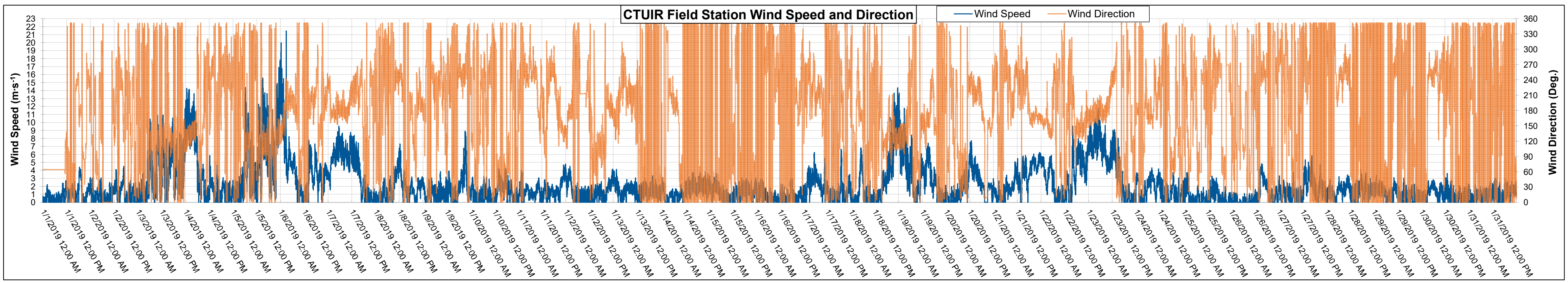

CTUIR Field Station Precipitation
Precipitation (mm)

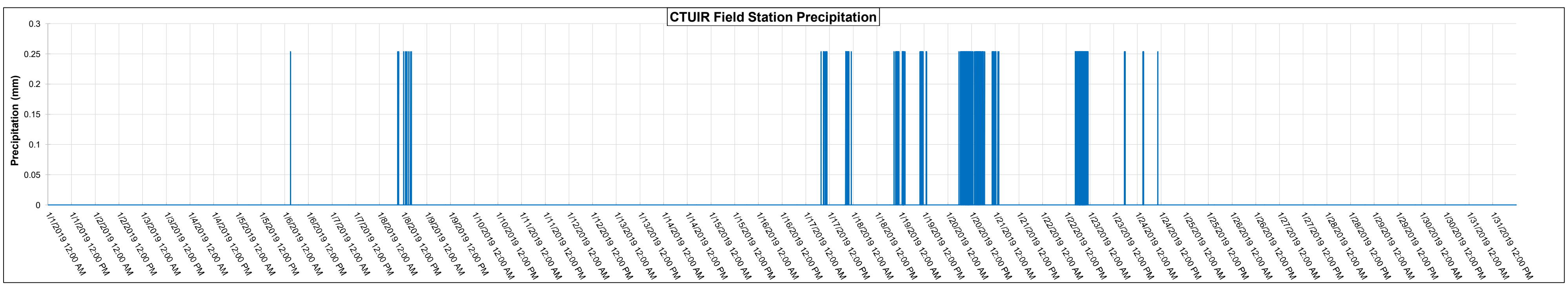

CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)

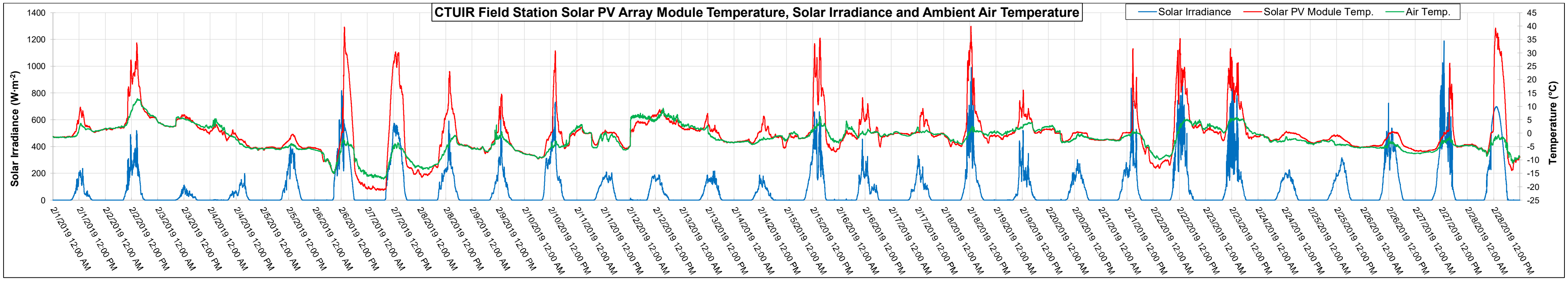

CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)


CTUIR Field Station Precipitation
Precipitation (mm)

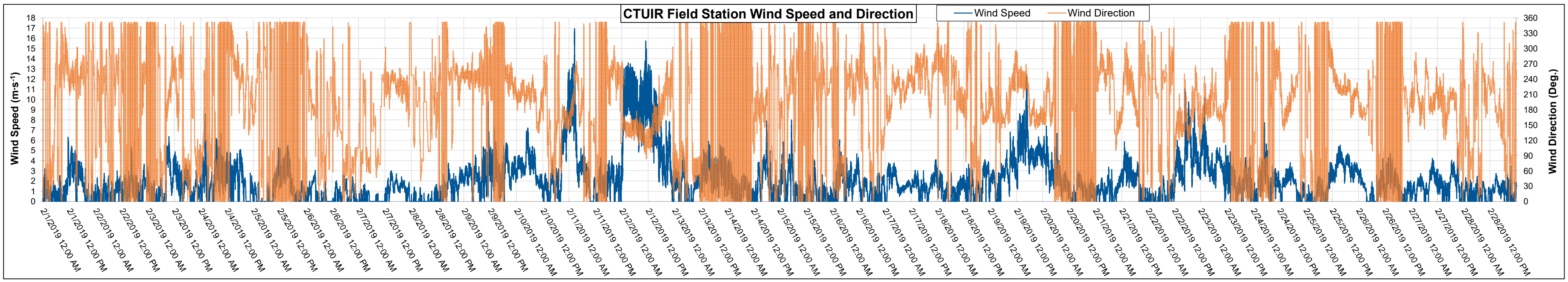

CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m-2)
Temperature (°C)


CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s-1)
Wind Direction (Deg.)

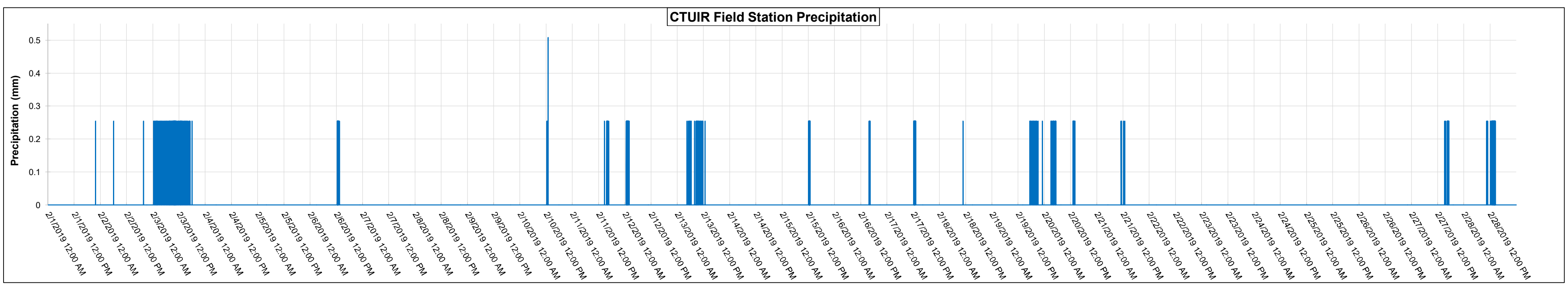

CTUIR Field Station Precipitation
Precipitation (mm)



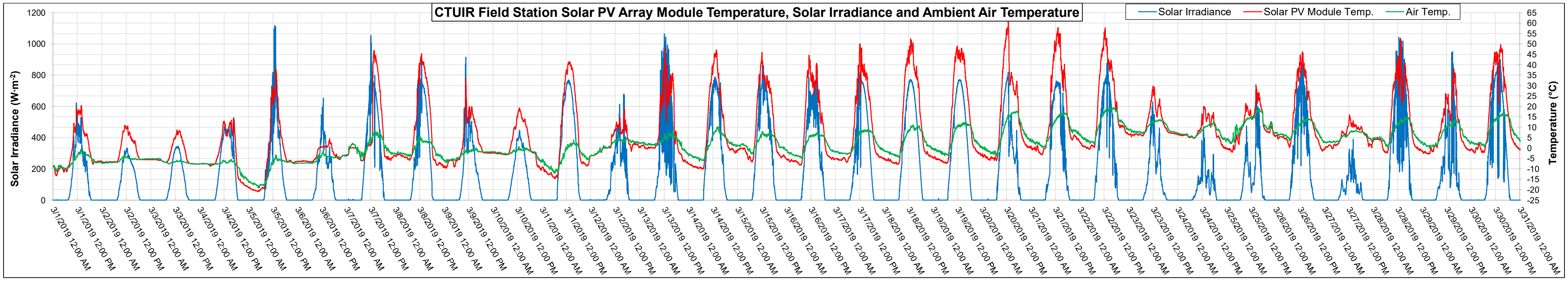
CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)
0
200
400
600
800
1000
1200
1400
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
2/1/2019 12:00 AM
2/1/2019 12:00 PM
2/28/2019 12:00 AM
2/28/2019 12:00 PM

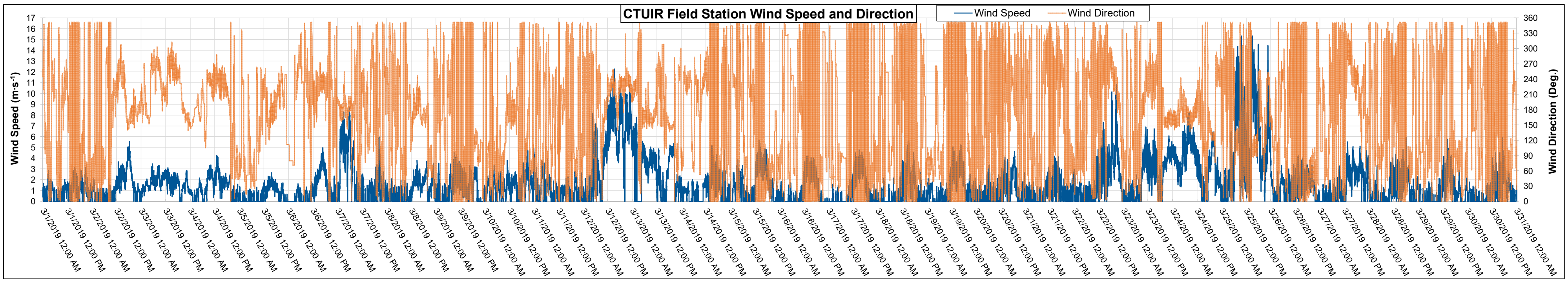


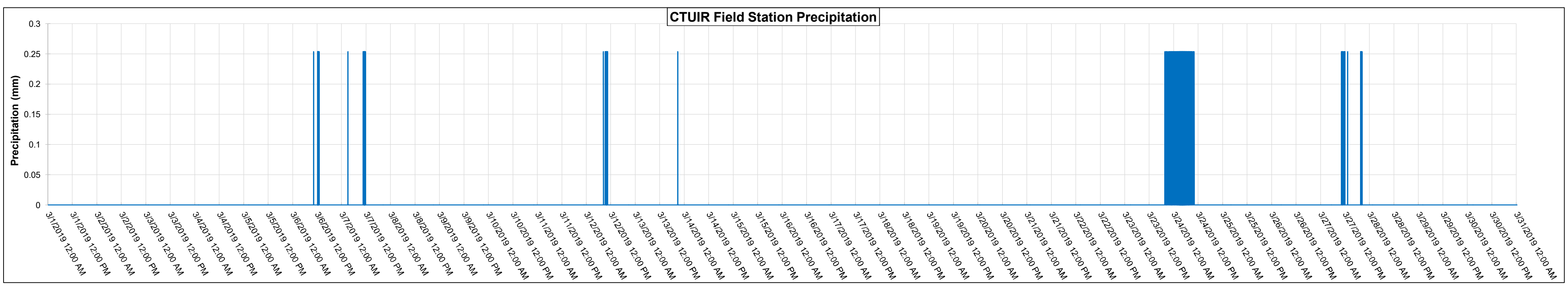
CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
0
30
60
90
120
150
180
210
240
270
300
330
360
2/1/2019 12:00 AM
2/1/2019 12:00 PM
2/28/2019 12:00 AM
2/28/2019 12:00 PM

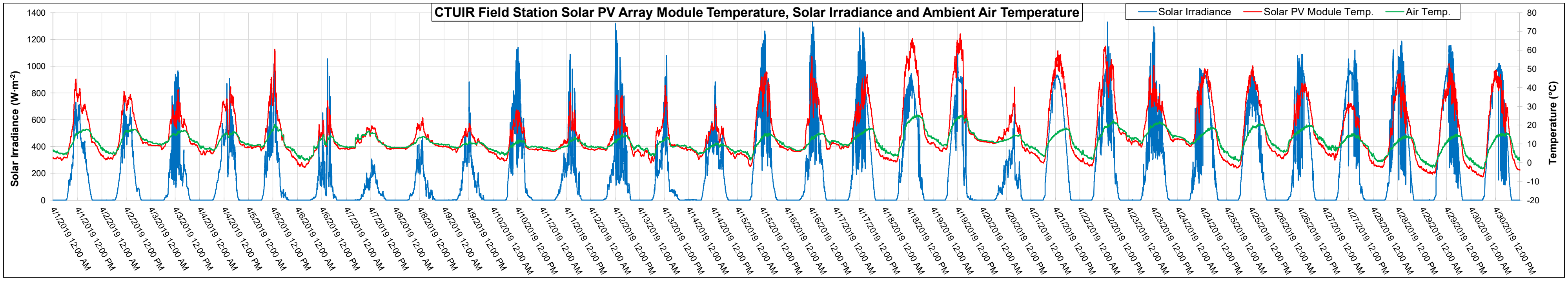


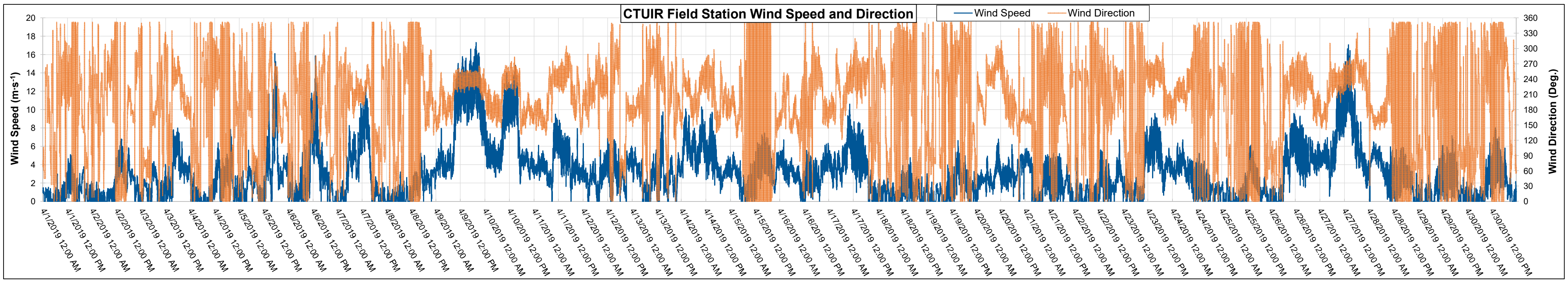
CTUIR Field Station Precipitation
Precipitation (mm)
0
0.1
0.2
0.3
0.4
0.5
2/1/2019 12:00 AM
2/1/2019 12:00 PM
2/28/2019 12:00 AM
2/28/2019 12:00 PM

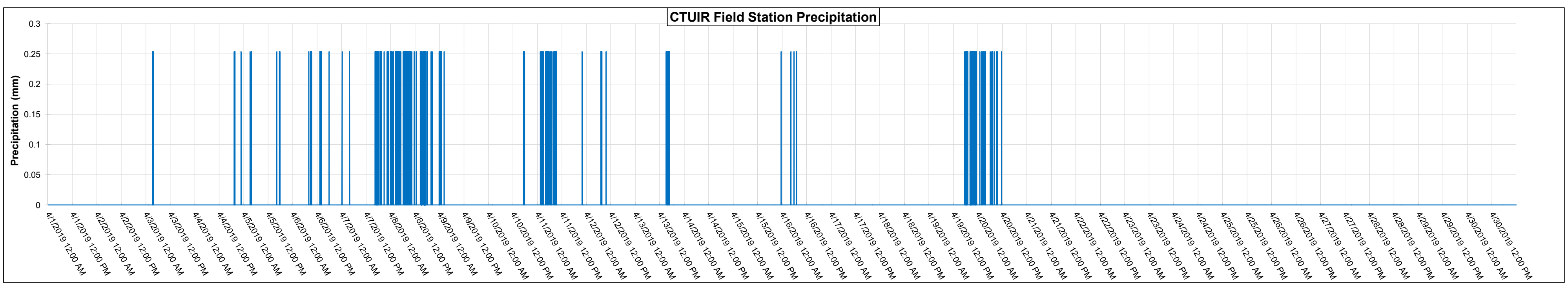

CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)

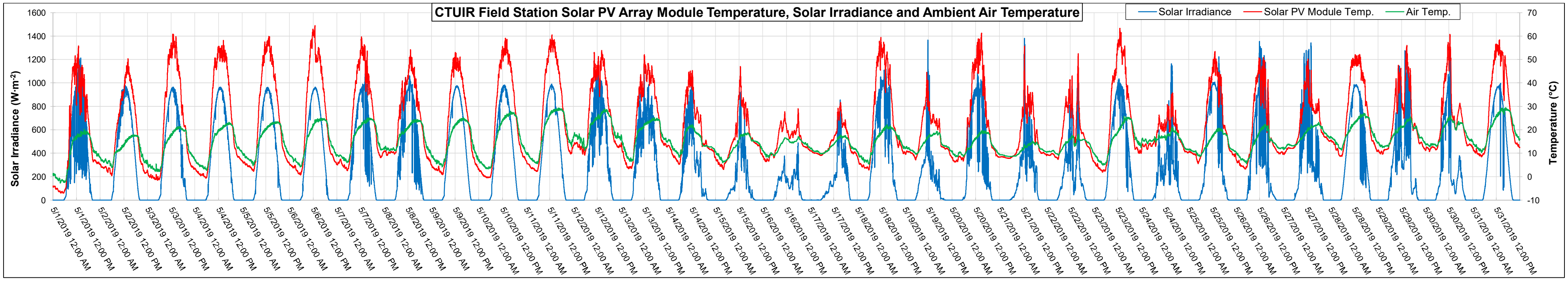

CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)

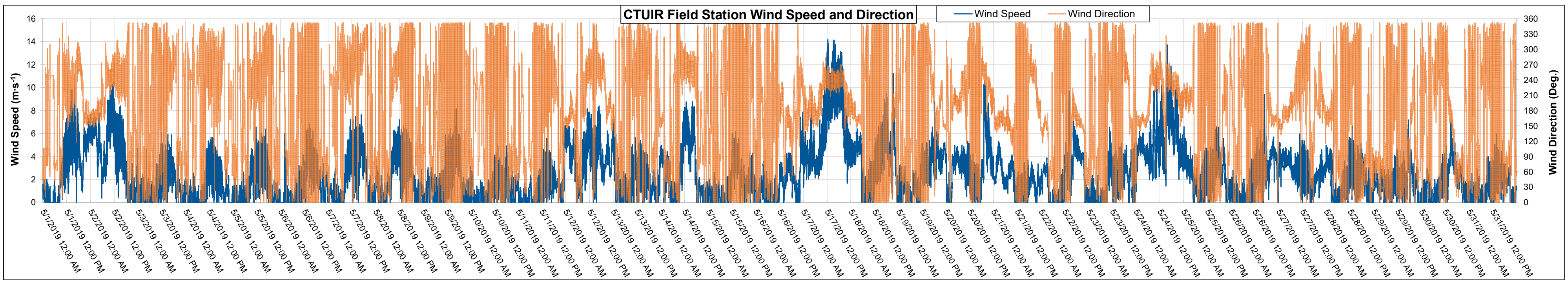

CTUIR Field Station Precipitation
Precipitation (mm)

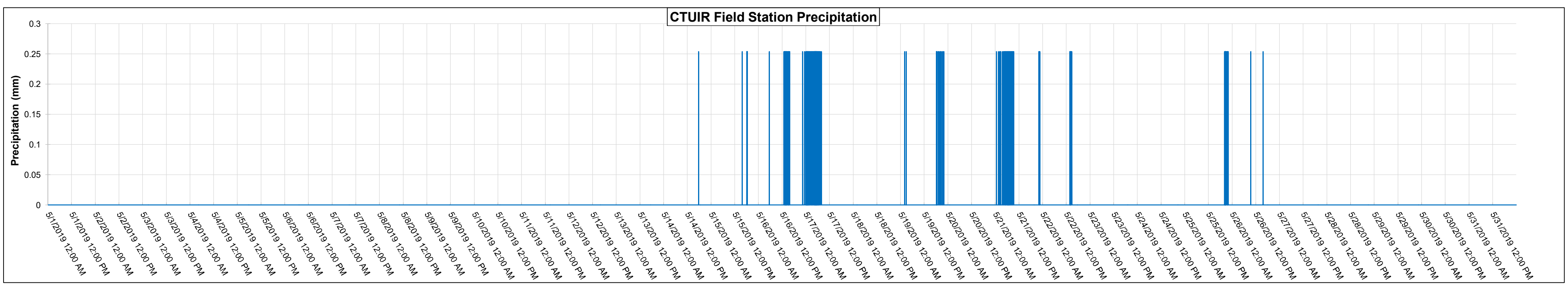

CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)

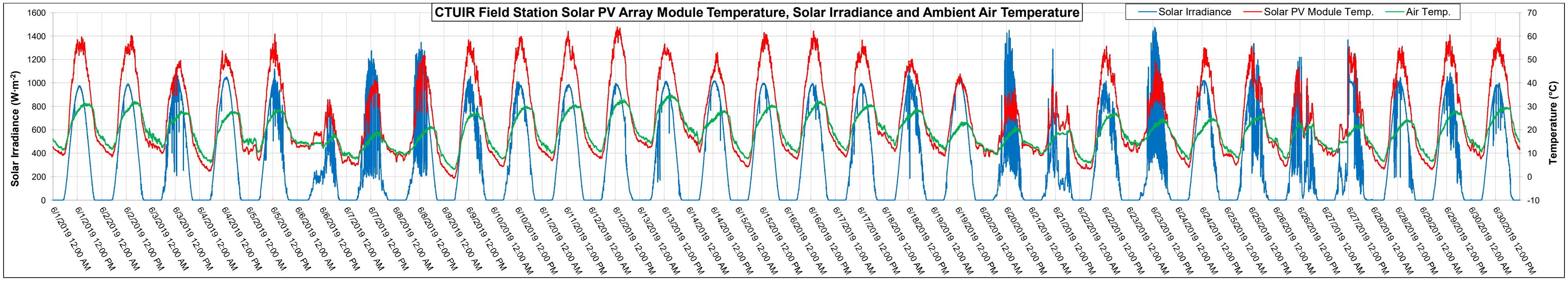

CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)


CTUIR Field Station Precipitation
Precipitation (mm)


CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)


CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)


CTUIR Field Station Precipitation
Precipitation (mm)


CTUIR Field Station Solar PV Array Module Temperature, Solar Irradiance and Ambient Air Temperature
Solar Irradiance
Solar PV Module Temp.
Air Temp.
Solar Irradiance (W·m⁻²)
Temperature (°C)
1600
1400
1200
1000
800
600
400
200
0
70
60
50
40
30
20
10
0
-10
6/1/2019 12:00 AM
6/1/2019 12:00 PM
6/2/2019 12:00 AM
6/2/2019 12:00 PM
6/3/2019 12:00 AM
6/3/2019 12:00 PM
6/4/2019 12:00 AM
6/4/2019 12:00 PM
6/5/2019 12:00 AM
6/5/2019 12:00 PM
6/6/2019 12:00 AM
6/6/2019 12:00 PM
6/7/2019 12:00 AM
6/7/2019 12:00 PM
6/8/2019 12:00 AM
6/8/2019 12:00 PM
6/9/2019 12:00 AM
6/9/2019 12:00 PM
6/10/2019 12:00 AM
6/10/2019 12:00 PM
6/11/2019 12:00 AM
6/11/2019 12:00 PM
6/12/2019 12:00 AM
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6/21/2019 12:00 AM
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6/22/2019 12:00 AM
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6/24/2019 12:00 AM
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6/25/2019 12:00 AM
6/25/2019 12:00 PM
6/26/2019 12:00 AM
6/26/2019 12:00 PM
6/27/2019 12:00 AM
6/27/2019 12:00 PM
6/28/2019 12:00 AM
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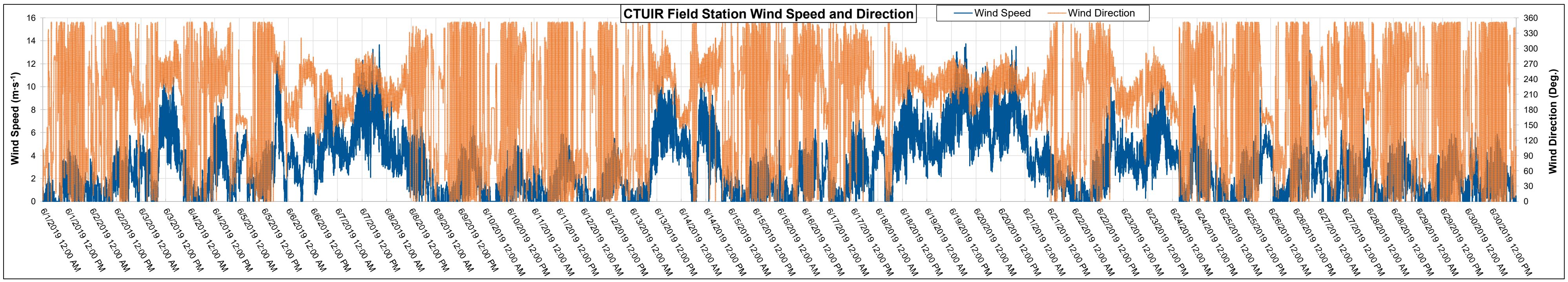
6/30/2019 12:00 PM


CTUIR Field Station Wind Speed and Direction
Wind Speed
Wind Direction
Wind Speed (m·s⁻¹)
Wind Direction (Deg.)
16
14
12
10
8
6
4
2
0
360
330
300
270
240
210
180
150
120
90
60
30
0
6/1/2019 12:00 AM
6/1/2019 12:00 PM
6/2/2019 12:00 AM
6/2/2019 12:00 PM
6/3/2019 12:00 AM
6/3/2019 12:00 PM
6/4/2019 12:00 AM
6/4/2019 12:00 PM
6/5/2019 12:00 AM
6/5/2019 12:00 PM
6/6/2019 12:00 AM
6/6/2019 12:00 PM
6/7/2019 12:00 AM
6/7/2019 12:00 PM
6/8/2019 12:00 AM
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6/9/2019 12:00 AM
6/9/2019 12:00 PM
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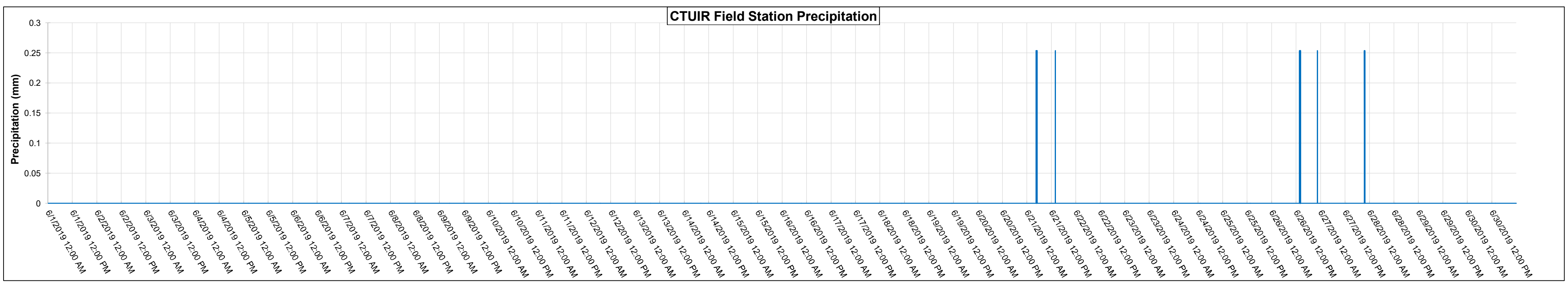
6/30/2019 12:00 PM


CTUIR Field Station Precipitation
Precipitation (mm)
0.3
0.25
0.2
0.15
0.1
0.05
0
6/1/2019 12:00 AM
6/1/2019 12:00 PM
6/2/2019 12:00 AM
6/2/2019 12:00 PM
6/3/2019 12:00 AM
6/3/2019 12:00 PM
6/4/2019 12:00 AM
6/4/2019 12:00 PM
6/5/2019 12:00 AM
6/5/2019 12:00 PM
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6/29/2019 12:00 AM
6/29/2019 12:00 PM
6/30/2019 12:00 AM
6/30/2019 12:00 PM

Appendix D, Revised PVWatts Calculator Model Results

Caution: Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules. Both NREL and private companies provide more sophisticated PV modeling tools (such as the System Advisor Model at https://sam.nrel.gov) that allow for more precise and complex modeling of PV systems.

The expected range is based on 30 years of actual weather data at the given location and is intended to provide an indication of the variation you might see. For more information, please refer to this NREL report: The Error Report.

The energy output range is based on analysis of 30 years of historical weather data for nearby , and is intended to provide an indication of the possible interannual variability in generation for a Fixed (open rack) PV system at this location.

RESULTS

140,664 kWh/Year*

System output may range from 133,082 to 142,901 kWh per year near this location.

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Value ($)
January	1.77	4,764	381
February	3.15	7,526	602
March	4.10	10,764	861
April	5.53	13,812	1,105
May	6.19	15,807	1,265
June	6.89	16,688	1,335
July	7.81	19,133	1,531
August	7.13	17,414	1,393
September	5.90	14,133	1,131
October	4.08	10,496	840
November	2.25	5,810	465
December	1.58	4,317	345
Annual	**4.70**	**140,664**	**$ 11,254**

Location and Station Identification

Requested Location	46411 timine way, pendleton, OR
Weather Data Source	Lat, Lon: 45.65, -118.7 1.2 mi
Latitude	45.65° N
Longitude	118.7° W

PV System Specifications *(Commercial)*

DC System Size	97.98 kW
Module Type	Premium
Array Type	Fixed (open rack)
Array Tilt	25°
Array Azimuth	180°
System Losses	10.51%
Inverter Efficiency	98.5%
DC to AC Size Ratio	1.2

Economics

Average Retail Electricity Rate	0.080 $/kWh

Performance Metrics

Capacity Factor	16.4%

Appendix E, Yaskawa Solectria Solar PVI 50/60TL Inverter Datasheet

YASKAWA

PVI 50TL & PVI 60TL

3-Ph Transformerless Commercial String Inverters

Features

- 55 & 66kVA Active Power ratings allow 0.91 PF leading/lagging
- NEC 2014 compliant (arc fault and rapid shutdown)
- Compliant with UL 1741SA
- 3 MPPTs with 5 inputs each
- Integrated DC and AC disconnects
- AC terminals compatible with copper and aluminum conductors
- Modbus communications
- Internal data logger
- 0 - 90° installation orientation
- Remote firmware upgrades
- Remote diagnostics

Options

- H4 wiring box
- Shade cover
- DC combiners bypass
- Web-based monitoring

Yaskawa Solectria Solar's PVI 50TL and PVI 60TL are grid-tied, transformerless three-phase inverters designed for ground mount, rooftop and carport arrays and can be installed from 0 - 90 degrees. The PVI 50/60TL inverters are NEC 2014 compliant and are the most reliable, efficient and cost effective in their class. They come standard with AC and DC disconnects, three MPPTs, a 15-position string combiner, remote diagnostics, remote firmware upgrades and various protection features. Options include H4 wiring box, shade cover, DC combiner fuse bypass, and web-based monitoring.

SOLECTRIA SOLAR

PVI 50TL & PVI 60TL

Specifications

	PVI 50TL	PVI 60TL
DC Input		
Absolute Maximum Open Circuit Voltage	1000 VDC	
Maximum Power Input Voltage Range (MPPT)	480-850 VDC	540-850 VDC
Operating Voltage Range	200-950 VDC	
MPP Trackers	3	
Maximum Operating Input Current	36 A per MPPT (108 A)	38 A per MPPT (114 A)
Maximum Available PV Current (Isc x 1.25)	60 A per MPPT (180 A)	
Maximum PV Power	75 kW (25 kW per MPPT)	90 kW (30 kW per MPPT)
Start Voltage	330 V	
AC Output		
Nominal Output Voltage	480 VAC, 3-Ph/PE/N	
AC Voltage Range (Standard)	-12/+10%	
Continuous Output Power	50 kW	60 kW
Maximum AC Apparent Power	55 kVA	66 kVA
Maximum Output Current	66.2 A	79.4 A
Nominal Output Frequency	60 Hz	
Output Frequency Range	57-63 Hz	
Power Factor	Unity, >0.99 (Adjustable 0.8 leading to 0.8 lagging)	
Fault Current Contribution (1 Cycle RMS)	55 A	
Total Harmonic Distortion (THD) @ Rated Load	<3%	
AC Surge Protection	Type II MOV, 1240Vc, 15kA Itm (8/20μ)	
Performance		
Peak Efficiency	99.0%	
CEC Efficiency	98.5%	
Tare Loss	< 2 W	
Ambient Temperature Range	-22°F to +140°F (-30°C to +60°C); Derating occurs over +122°F (+50°C)	
Storage Temperature Range	No low temp minimum to +158°F (+70°C)	
Relative Humidity (non-condensing)	0-95%	
Audible Noise	< 60 dba @ 1 m at room temperature	
Operating Altitude	13,123 ft (4,000 m) Derating occurs from 9,842.5 ft (3,000 m)	
Safety Listings & Certifications	UL 1741:2010, UL1699B, CSA-C22.2 #107.1, IEEE1547; FCC Part 15; UL 1741SA, CA Rule 21	
Testing Agency	ETL	
Mechanical		
15 Fused Positions (5 positions per MPPT)	15 A standard (20, 25, 30 A accepted*)	
AC/DC Disconnect	Standard, fully-integrated	
Enclosure Rating	NEMA Type 4X	
Enclosure Finish	Polyester Powder Coated Aluminum	
Mounting Method**	0-90° from horizontal (vertical, angled, flat)	
Dimensions (H x W x D)	39.4 in. x 23.6 in. x 10.2 in (1000 x 600 x 260 mm)	
Weight	Inverter: 123.5 lbs (56 kg); Wiring Box: 33 lbs (15 kg)	
Communications		
Data Logger Hardware	Standard, Internal	
SolrenView Web-Based Monitoring Service	Optional	
Revenue Grade Metering	Optional, External	
Communication Interface	RS-485 Modbus RTU	
Remote Firmware Upgrades	Standard	
Remote Diagnostics	Standard	
Features & Protections		
Arc-Fault Detection	Standard	
Smart Grid Features	L/HVRT, L/HFRT, Soft Start, Volt-Var, Frequency-Watt and Volt-Watt, Soft-Start, Soft-Step	
Warranty		
Standard	10 year	
Optional	15 or 20 year; Extended Service Agreement	

***Yaskawa Solectria Solar does not supply the optional fuses**
****Shade cover accessory required for installation of 75° or less**

SOLECTRIA SOLAR

Yaskawa Solectria Solar
360 Merrimack Street
Lawrence, MA 01843
solectria.com

1-978-683-9700
Email: inverters@solectria.com

DOCR-070642-K | January 2018

YASKAWA

Appendix F, Hyundai HiS-S355RI Solar Module Datasheet

www.hhi-green.com/solar/en

Hyundai Solar Module

Hyundai Heavy Industries was founded in 1972 and is a Fortune 500 company. The company employs more than 48,000 people, and has a global leading 7 business divisions with sales of 40.9 Billion USD in 2015. As one of our core businesses of the company, Hyundai Heavy Industries is committed to develop and invest heavily in the field of renewable energy.

Hyundai Solar is the largest and the longest standing PV cell and module manufacturer in South Korea. We have 800 MW of module production capacity and provide high-quality solar PV products to more than 3,000 customers worldwide. We strive to achieve one of the most efficient PV modules by establishing an R&D laboratory and investing more than 20 Million USD on innovative technologies.

RI-Series

Poly-crystalline Type

HiS-M310RI | HiS-M315RI | HiS-M320RI | HiS-M325RI

Mono-crystalline Type

HiS-S330RI | HiS-S335RI | HiS-S340RI | HiS-S345RI | HiS-S350RI | HiS-S355RI

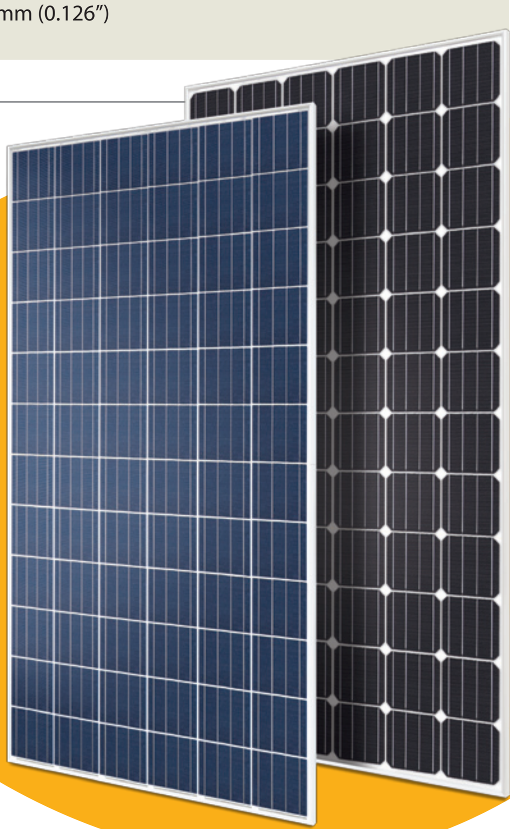
Mechanical Characteristics

※ Several models are under certification process.

Dimensions	998 mm (39.29")(W) × 1,960 mm (77.17")(L) × 40 mm (1.57")(H)
Weight	Approx. 22.9 kg (50.5 lbs)
Solar cells	72 cells in series (6 × 12 matrix) (Hyundai cell, Made in Korea)
Output cables	4 mm² (12AWG) cables with polarized weatherproof connectors, IEC certified (UL listed and UL 4703 certified), Length 1.2 m (47.2")
Junction box	IP67, weatherproof, IEC certified (UL listed)
Bypass diodes	3 bypass diodes to prevent power decrease by partial shade
Construction	Front : Anti-reflection coated glass (Anti reflection coated), 3.2 mm (0.126") Encapsulant : EVA Back Sheet : Weatherproof film
Frame	Clear anodized aluminum alloy type 6063

High Quality

- IEC 61215 (Ed.2) and IEC 61730 by VDE
- UL listed (UL 1703), Type 1 for Class A Fire Rating
- Output power tolerance +3/-0 %
- ISO 9001:2000 and ISO 14001:2004 Certified
- OHSAS 18001:2007 Certified
- Advanced Mechanical Test (5,400 Pa) Passed (IEC) / Mechanical Load Test (40 lbs/ft²) Passed (UL)
- IEC 62716 (Ammonia Corrosion Resistance Test) Passed
- IEC 61701 (Salt Mist Corrosion Test) Passed
- Potential-Induced Degradation (PID) Test Passed (85˚C / 85 % / 600 hr-PVEL)



Accredited Test Lab

- VDE (Test Data Acceptance Program)
- UL (Witness Test Data Program)

Limited Warranty

- 10 years for product defect
- 10 years for 90 % of warranted min. power
- 25 years for 80 % of warranted min. power

※ **Important Notice on Warranty**
The warranties apply only to the PV modules with Hyundai Heavy Industries Co., Ltd.'s logo (shown below) and product serial number on it.

HYUNDAI HEAVY INDUSTRIES

Electrical Characteristics

| Poly-crystalline Type |

		HiS-M□□□RI			
		310	315	320	325
Nominal output (Pmpp)	W	310	315	320	325
Voltage at Pmax (Vmpp)	V	36.0	36.2	36.4	36.6
Current at Pmax (Impp)	A	8.6	8.7	8.8	8.8
Open circuit voltage (Voc)	V	45.3	45.5	45.7	45.9
Short circuit current (Isc)	A	8.9	9.0	9.0	9.1
Output tolerance	%	+3/-0			
No. of cells & connections	pcs	72 in series			
Cell type	-	6" Poly-crystalline silicon (Hyundai cell, Made in Korea)			
Module efficiency	%	15.8	16.1	16.4	16.6
Temperature coefficient of Pmpp	%/K	-0.41			
Temperature coefficient of Voc	%/K	-0.32			
Temperature coefficient of Isc	%/K	0.039			

※All data at STC (Standard Test Conditions). Above data may be changed without prior notice.

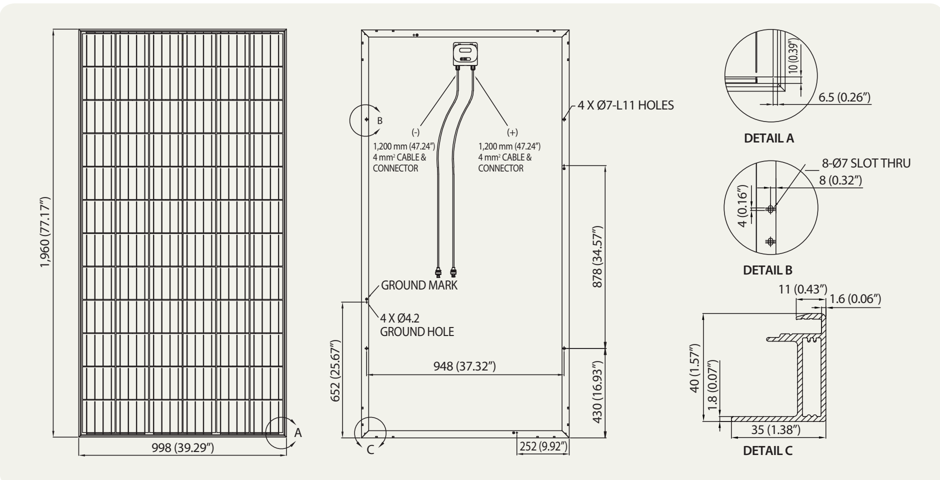
| Mono-crystalline Type |

		HiS-S□□□RI					
		330	335	340	345	350	355
Nominal output (Pmpp)	W	330	335	340	345	350	355
Voltage at Pmax (Vmpp)	V	38.0	38.2	38.4	38.6	38.7	38.9
Current at Pmax (Impp)	A	8.7	8.8	8.9	9.0	9.0	9.1
Open circuit voltage (Voc)	V	46.3	46.5	46.7	46.9	47.1	47.3
Short circuit current (Isc)	A	9.3	9.4	9.5	9.6	9.6	9.6
Output tolerance	%	+3/-0					
No. of cells & connections	pcs	72 in series					
Cell type	-	6" Mono-crystalline silicon (Hyundai cell, Made in Korea)					
Module efficiency	%	16.9	17.1	17.4	17.6	17.9	18.1
Temperature coefficient of Pmpp	%/K	-0.42					
Temperature coefficient of Voc	%/K	-0.30					
Temperature coefficient of Isc	%/K	0.047					

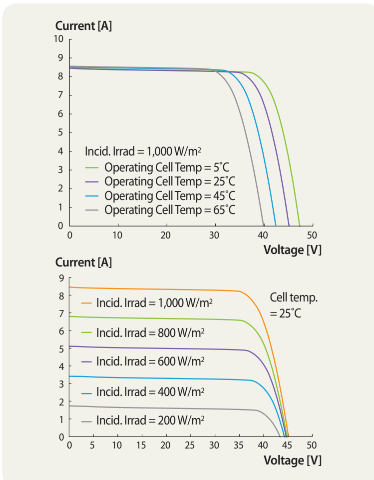
※All data at STC (Standard Test Conditions). Above data may be changed without prior notice.

| Module Diagram |

(unit : mm, inch)



| I-V Curves |



| Installation Safety Guide |

- Only qualified personnel should install or perform maintenance.
- Be aware of dangerous high DC voltage.
- Do not damage or scratch the rear surface of the module.
- Do not handle or install modules when they are wet.

Nominal Operating Cell Temperature	46˚C ± 2
Operating Temperature	-40 - 85˚C
Maximum System Voltage	DC 1,000 V (IEC) DC 1,000 V (UL)
Maximum Reverse Current	15 A

[Printed Date : December 2016]

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