CFV Labs

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20125 Test Report: IAM and NMOT Testing of LG LG320N1K-A5 Module

Report Number: 20125-PR-E-002

Report Date: 2020-12-17

Test Period: 2020-05-29 to 2020-12-10

Project ID: 20125 (CFV), 2156362 (Customer PO)

Customer: Joshua Stein / Sandia National Laboratories / PO Box 5800 MS0951 / Albuquerque, NM 87185-0951

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Project Summary

CFV Labs conducted Nominal Module Operating Temperature (NMOT) and Incident Angle Modifier (IAM) testing file testing on one **LG320N1K-A5** module produced by **LG**. NMOT testing was conducted in accordance with IEC 61853-2:2016. Incident angle modifier (IAM) testing was conducted using an outdoor method in accordance with IEC 61853-2:2016 and a method based on the Sandia procedure SAND2016-5284 was used.

Summary of Results

NMOT Results

Module Type	Sample Size	U0 [W m^{-2} °C^{-1}]	U1 [W s m^{-3} °C^{-1}]	NMOT [°C]
LG320N1K-A5	1	24.229	7.182	45.47
U (k=2)		*±7.5%*	*±7.5%*	*±3.0°C*

IAM Results

Angle	**0°**	**10°**	**20°**	**30°**	**40°**	**45°**	**50°**
IAM	1.0000	1.0003	1.0005	1.0002	0.9943	0.9904	0.9819
U (k=2)	*±0.0002*	*±0.003*	*±0.004*	*±0.005*	*±0.005*	*±0.005*	*±0.006*
Angle	**55°**	**60°**	**65°**	**70°**	**75°**	**80°**	**85°**
IAM	0.9719	0.9557	0.9299	0.8843	0.8026	0.6817	0.4846
U (k=2)	*±0.006*	*±0.010*	*±0.011*	*±0.016*	*±0.021*	*±0.033*	*±0.057*

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1 Sample Information

Labeling

Module ID	SNL ID	Manufacturer	Module Type	Serial Number
20125-002	00003879	LG	LG320N1K-A5	710K3TA1V4KK

Constructional Details

Module Type	Length [m]	Width [m]	Thickness [mm]
LG320N1K-A5	1.646	1.016	40

Nameplate Values

Module Type	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmp [W]	Max Sys Volt [V]	Fuse Rating [A]
LG320N1K-A5	10.19	40.80	9.62	33.30	320	1000	20

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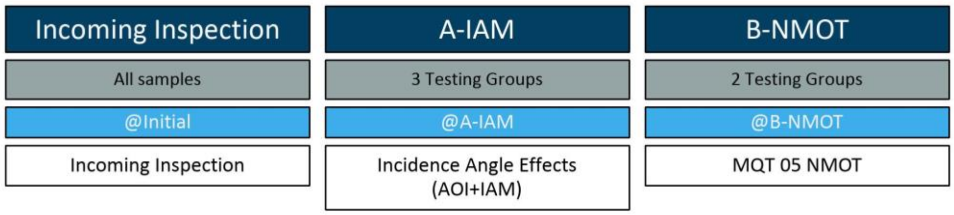
Photographs

LG LG320N1K-A5

2 Test Flow

2.1 Project Test Flow

The overall test flow for the project is shown in the figure below.



2.2 Test Flow Assignment

A total of nine modules were provided to CFV Labs for testing. The test flow assignment for each of the modules is provided in the table below. The modules were subjected to the test legs in the order listed.

Module ID	Test Leg(s)	Notes
20125-001	Incoming Inspection, A-IAM, B-NMOT	Results in separate report
20125-002	***Incoming Inspection, A-IAM, B-NMOT***	***Results in this report***
20125-003	Incoming Inspection, A-IAM, B-NMOT	Results in separate report
20125-004	Incoming Inspection, B-NMOT, A-IAM	Results in separate report
20125-005	Incoming Inspection, B-NMOT, A-IAM	Results in separate report
20125-006	Incoming Inspection, B-NMOT, A-IAM	Results in separate report
20125-007	Incoming Inspection, A-IAM, B-NMOT	Results in separate report
20125-008	Incoming Inspection, B-NMOT, A-IAM	Results in separate report
20125-009	Incoming Inspection, B-NMOT, A-IAM	Results in separate report

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3 Procedures

3.1 Receiving and Incoming Inspection

The modules were unpacked, inspected for shipping damage, labeled, and photographed per an internal procedure. The module IDs and the manufacturer's serial numbers are provided §1. Any shipping damage was noted and photographed. This process is carried out per an internal CFV procedure and is not included in CFV's scope of ISO 17025 accreditation.

3.2 Electroluminescence Imaging

EL imaging was performed in conformity with IEC TS 60904-13:2018. CFV is ISO 17025-accredited to perform the test. EL images were taken with a Sensovation HR-830 camera that has a resolution of 8.3 MPixels. A long pass filter blocked incoming light with wavelength below 850 nm. A constant DC bias was applied to the modules while the imaging was performed in the dark.

3.3 Incident Angle Modifier (IAM)

Angle of Incidence test was conducted following a procedure that CFV has developed jointly with the Sandia National Laboratories (SAND2016-5284) and further improved in house. The goal of this procedure is to obtain the incident angle modifier (IAM) profile that is also the aim of the procedure in IEC 61853-2:2016 §7.3. The IAM values were obtained at 14 points in the AOI range of 0 to 85 degrees. The global irradiance at the test plane was measured with a calibrated pyranometer having an uncertainty of ±1.6%. The direct normal irradiance was measured with a calibrated pyrheliometer having an uncertainty of ±0.8%. The temperature of the module was measured with calibrated thermocouples having uncertainties of ± 0.50°C.

One key difference between the SAND2016-5284 and IEC 61853-2:2016 procedures is that the IEC standard requires the test to be carried out at solar noon, whereas we carry out the tests once before noon and once after noon to average out possible errors from the alignment. To account for the spectral effects from the air mass change over the course of the test, a reference module on the sun-tracking tracker provides more accurate measurement of the effective irradiance. The temperature and broadband irradiance corrected Isc of the reference module is used to apply corrections to any spectrally induced changes to the DNI component of the POA irradiance incident on the test modules.

The table below shows the estimated uncertainty (k=2) of the IAM measurement at the 95% confidence level.

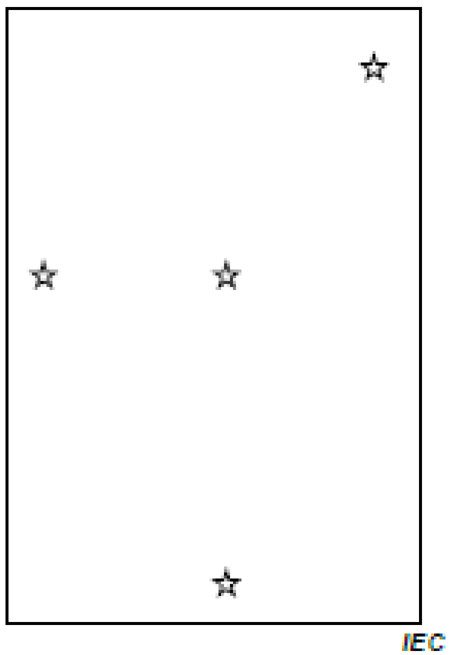
Angle	**0°**	**10°**	**20°**	**30°**	**40°**	**45°**	**50°**
U (k=2)	±0.0002	±0.003	±0.004	±0.005	±0.005	±0.005	±0.006
Angle	**55°**	**60°**	**65°**	**70°**	**75°**	**80°**	**85°**
U (k=2)	±0.006	±0.010	±0.011	±0.016	±0.021	±0.033	±0.057

3.4 Nominal Module Operating Temperature (NMOT)

NMOT (Nominal Module Operating Temperature) testing was carried out per IEC 61853-2:2016. This test is within the scope of CFV's ISO 17025 accreditation.

The test module(s) were installed on our NMOT test stand as shown in the figures below.

The modules were MPP-tracked with DC optimizers, which were in turn operated with a string inverter. The plane-of-array irradiance was measured with a pyranometer on the test stand. The wind speed and the ambient temperature were measured with sensors installed on the test stand. Four T-type thermocouples were attached to each test module at the approximate positions shown in the figure below.



Two methods of data filtering were used in the analysis.

<u>Method 1:</u>

Default filtering as described in the IEC 61853-2:2016 test standard. Each test day must have a minimum of 10 data points from before solar noon and 10 data points after solar noon. This method exactly follows the procedure defined in IEC 61853-2:2016

<u>Method 2:</u>

Default filtering as described in the IEC 61853-2:2016 test standard. Each test day must have a minimum of 10 data points irrespective of time of day. Method 2 is a small modification to the procedure defined in IEC 61853-2:2016. This modification was explored to reduce test completion time especially for instances when the weather conditions are such that filtered data conditions exist in before or after solar noon, but rarely both because due to location or seasonality reasons. An initial comparison of Method 2 to Method 1 (defined above) showed a maximum NMOT difference of less than 0.5 °C across a group of 5 test modules for a case when Method 1 resulted in a minimum of 10 valid test days. Method 2 was performed on the same entire data set and resulted in a larger number of valid test dates.

The test setup is shown in the images below. The test module is outlined in yellow. The pyranometer and windspeed sensor can be seen near the top of the test array. The ambient temperature sensor was mounted behind the test array.

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4 Results

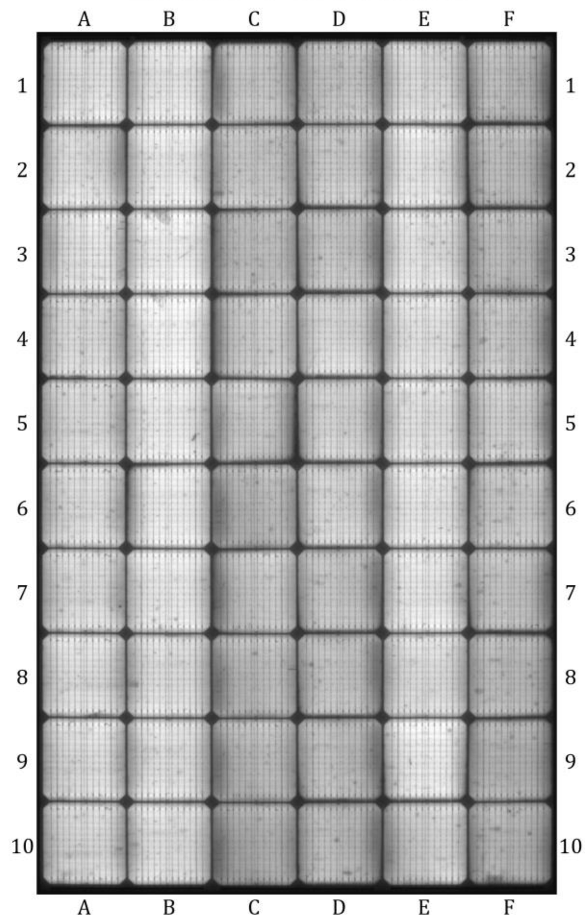
4.1 Receiving and Incoming Inspection

No issues were observed during receiving or the incoming inspection.

4.2 Electroluminescence Imaging

The module was imaged in the dark while a constant DC bias current ($1.0 \times Isc$) was applied to the module. EL images of the test modules were originally taken as part of project 19074 and carried over for this report.

20125-002: Initial



4.3 Incident Angle Modifier (IAM)

Measured Data

The following table shows the measured IAM data for the 20125-002 test module compared to the default IAM profiles in PVsyst for both the Non-ARC and ARC configurations.

Test Angle	20125-002 (LG320N1K-A5)	Default PVsyst Non-ARC	Default PVsyst ARC
0°	1.0000	1.0000	1.0000
10°	1.0003	0.9955	0.9965
20°	1.0005	0.9966	0.9975
30°	1.0002	0.9980	0.9990
40°	0.9943	0.9946	0.9968
45°	0.9904	0.9894	0.9931
50°	0.9819	0.9810	0.9870
55°	0.9719	0.9683	0.9775
60°	0.9557	0.9480	0.9620
65°	0.9299	0.9154	0.9364
70°	0.8843	0.8620	0.8920
75°	0.8026	0.7760	0.8160
80°	0.6817	0.6360	0.6810
85°	0.4846	0.4030	0.4400

A weighted ($\cos AOI$) fit of the IEC 61853-2:2016 IAM function to the test module IAM profile in the 0-85° range was also performed yielding an **a_r value of 0.1590 ± 0.0018 for the LG320N1K-A5 module type**. The function is repeated below for the convenience of the reader:

$$\tau(\theta) = \frac{1 - e^{-\frac{\cos(\theta)}{a_r}}}{1 - e^{-\frac{1}{a_r}}}$$

Data Plots

The top plot below shows the measured IAM profile of the 20125-002 test module and the default PVsyst models for both the ARC and Non-ARC constructions. The bottom plot shows the difference in IAM values relative to the default Non-ARC PVsyst model, which indicates how the test module performs relative to the baseline Non-ARC configuration.

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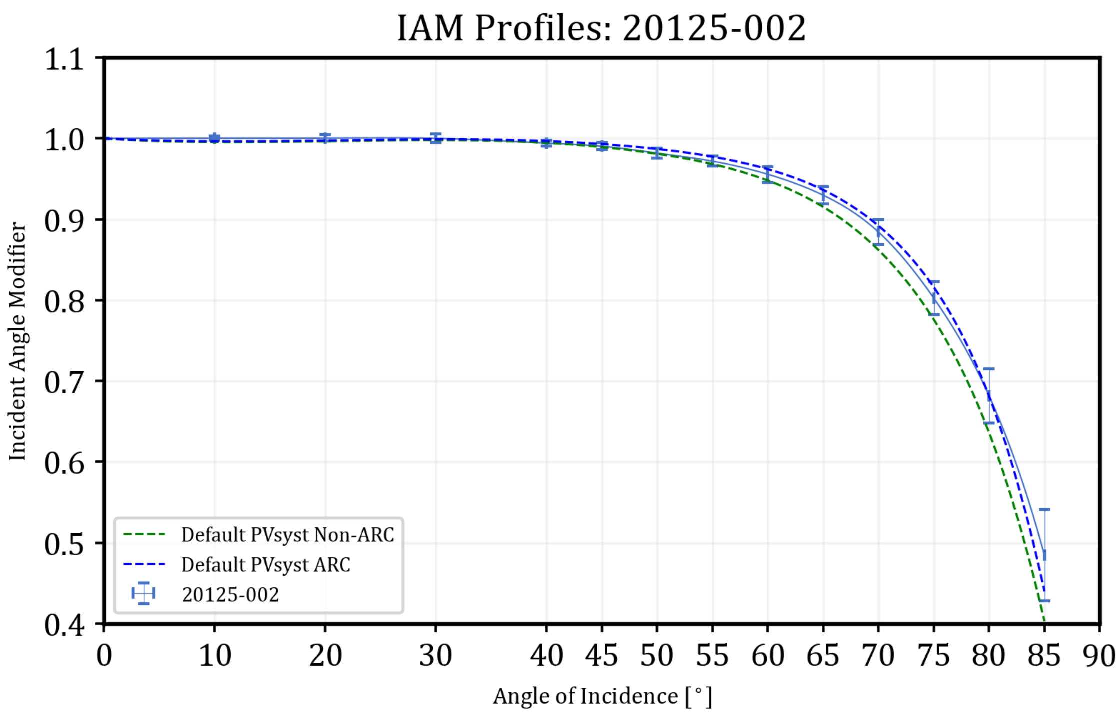
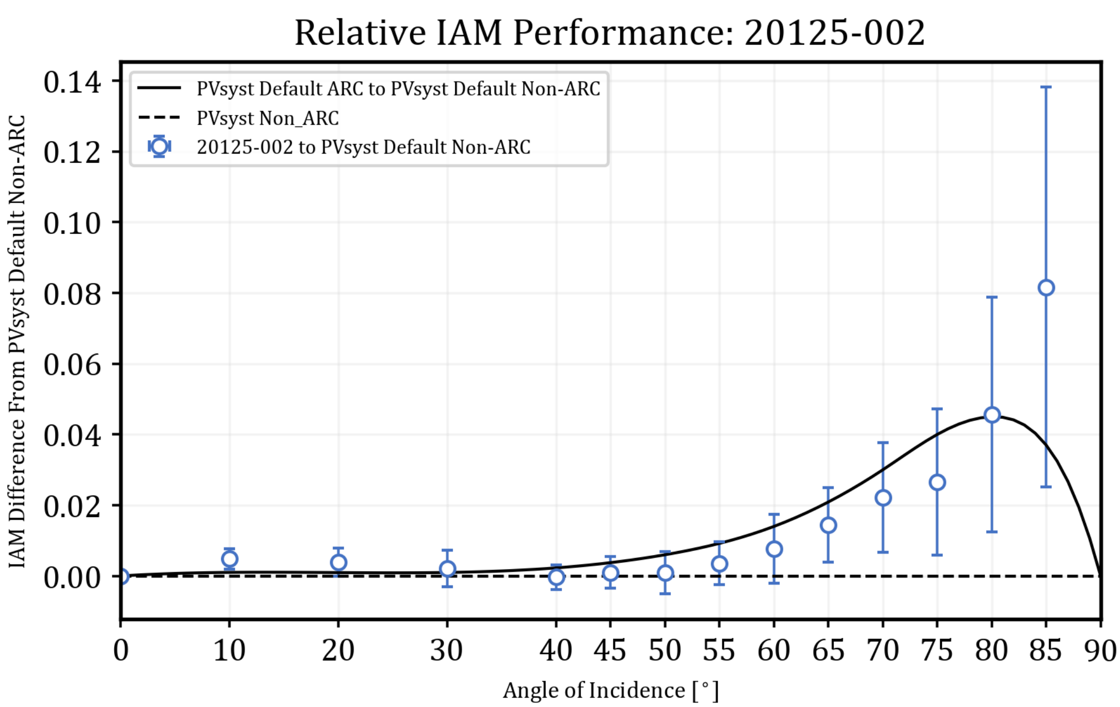




4.4 Nominal Module Operating Temperature (NMOT)

The results of the NMOT analysis for each method described in §3.4 are provided in the tables below.

Test Details

Method	Test Period	Total Days	Valid Days	Tamb Avg [°C]	WS Avg [m/s]	WS Min[1] [m/s]	WS Max [m/s]	WS Range [m/s]
1	2020-10-24 to 2020-12-10	42	4	13.13	2.02	1.00	3.56	2.56
2		42	24	12.52	3.10	1.00	7.99	6.99

IEC 61853-2:2016 Thermal Model Coefficients

Module ID	Module Type	Method	U0 [W m^{-2} °C^{-1}]	U1 [W s m^{-3} °C^{-1}]	NMOT [°C]
20125-002	LG320N1K-A5	1	24.903	7.011	45.07
		2	24.229	7.182	45.47
Estimated Uncertainty (k=2)[2]			*±7.5%*	*±7.5%*	*±3.00°C*

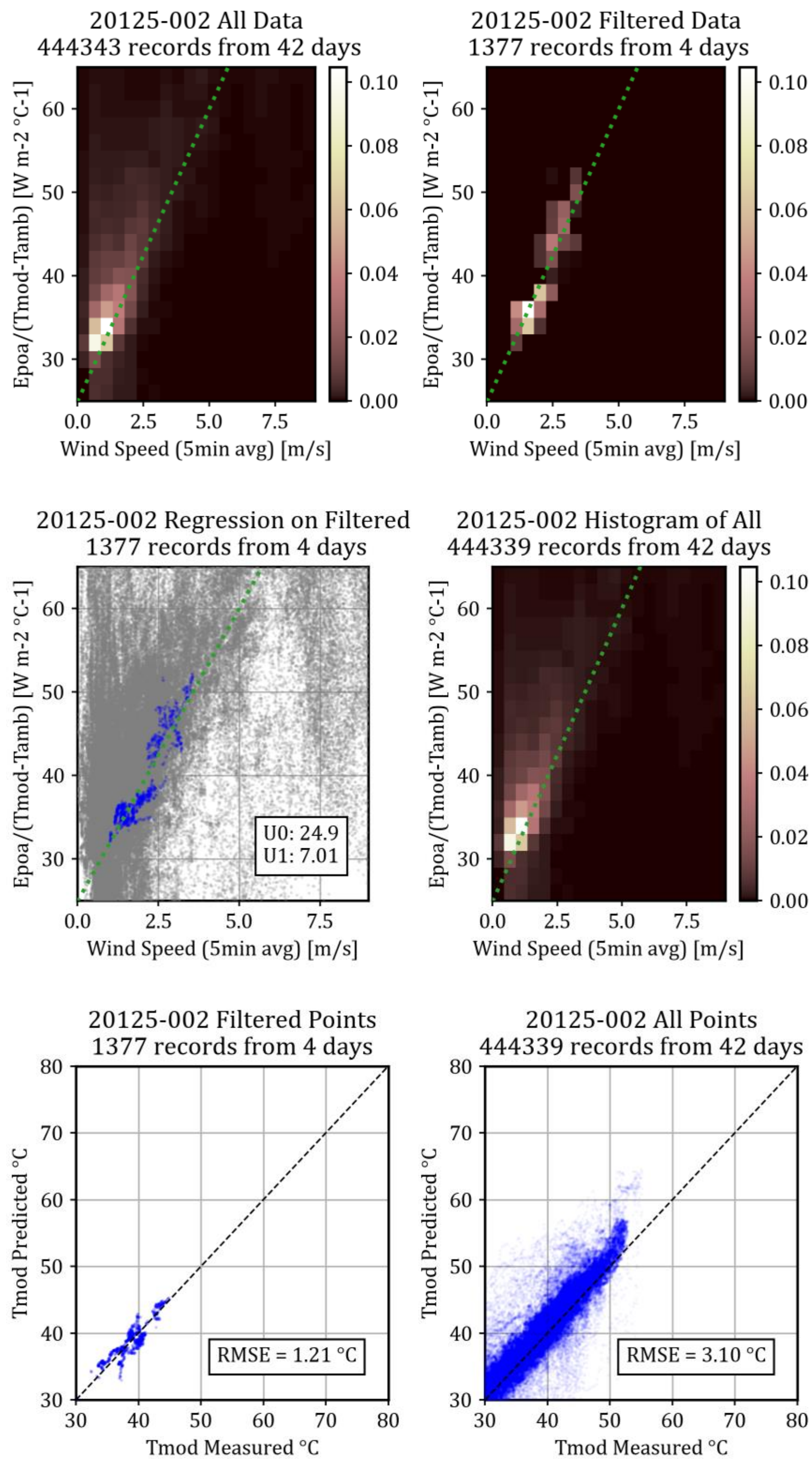
Residual Analysis

			Model Mean Bias Error [°C] on		
Module ID	**Method**	**Number of Qualifying Records**	**Qualifying Records**	**All Hourly Records from All Days (659)**	**All Records (444339)**
20125-002	1	1377	-0.05	1.05	1.41
	2	5937	-0.01	1.33	1.70

			Model RMS Error [°C] on		
Module ID	**Method**	**Number of Qualifying Records**	**Qualifying Records**	**All Hourly Records from All Days (659)**	**All Records (444339)**
20125-002	1	1377	1.21	1.70	3.10
	2	5937	1.14	1.92	3.30

[1] The wind data filter in IEC 61853-2:2016 filters out all the points with wind speed running average (5 minute duration) below 1 m/s, and so by definition the minimum wind speed running average is always 1 m/s.
[2] The estimated uncertainty includes contributions from uncertainties in the measurements of irradiance, module and ambient temperatures and wind speed. The estimated uncertainty does not include estimates of seasonal effects.

Data Plots – Regression Analysis
Method 1:



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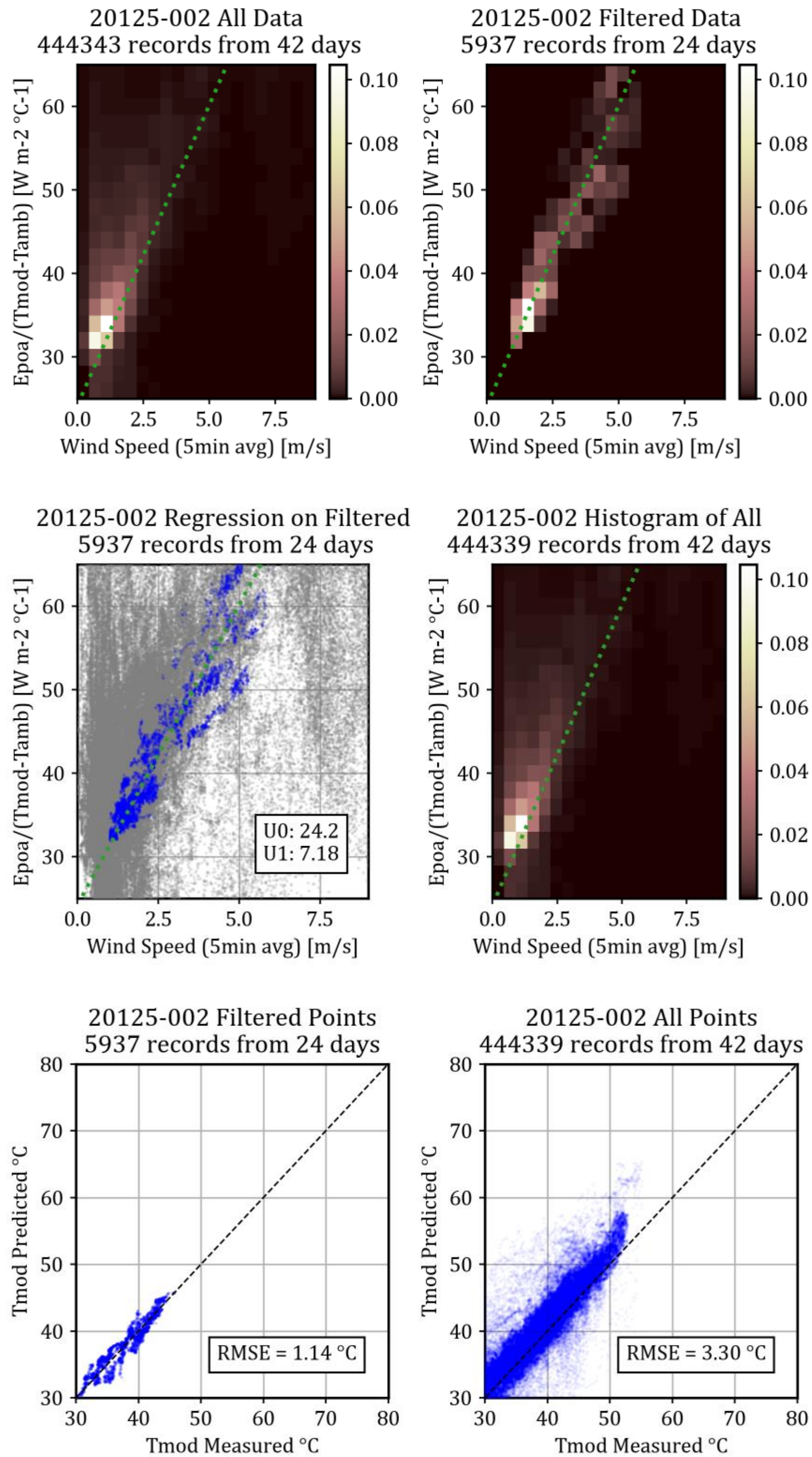
Method 2:



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5 Equipment and Calibration Information

Equipment and calibration information is available upon request.

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