

Supplementary information

Long-Term Outdoor Performance of a Solar Farm enabled by Graphene-Perovskite Panels: Investigating Degradation Mechanisms, Dark Storage Recovery, and Visual Defects

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Meteo data at solar farm from July '21 to November '22

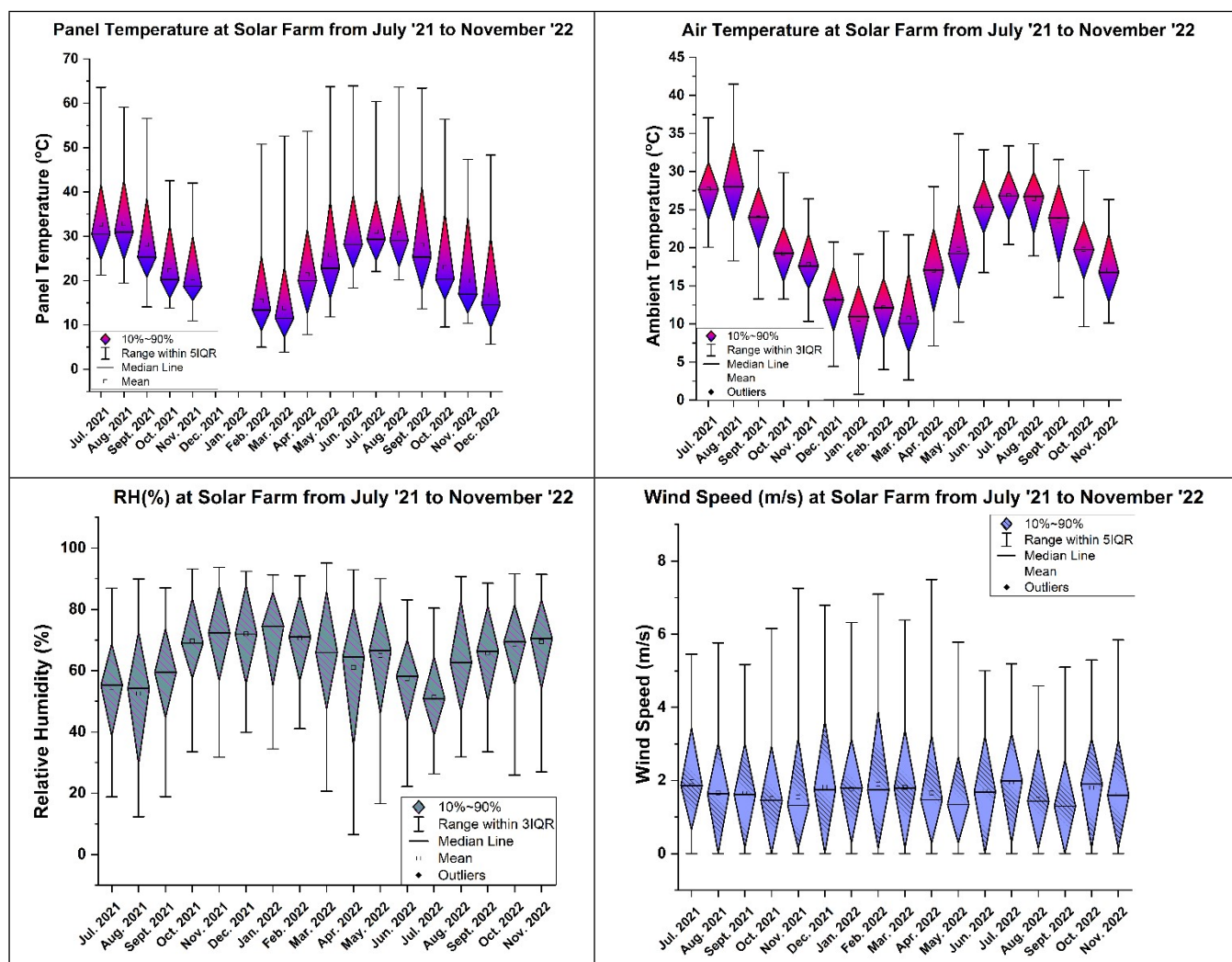


Figure 1 Meteo data at solar farm from July '21 to November '22. a) Panel Temperature, b) Air temperature, c) Relative Humidity, d) Wind Speed

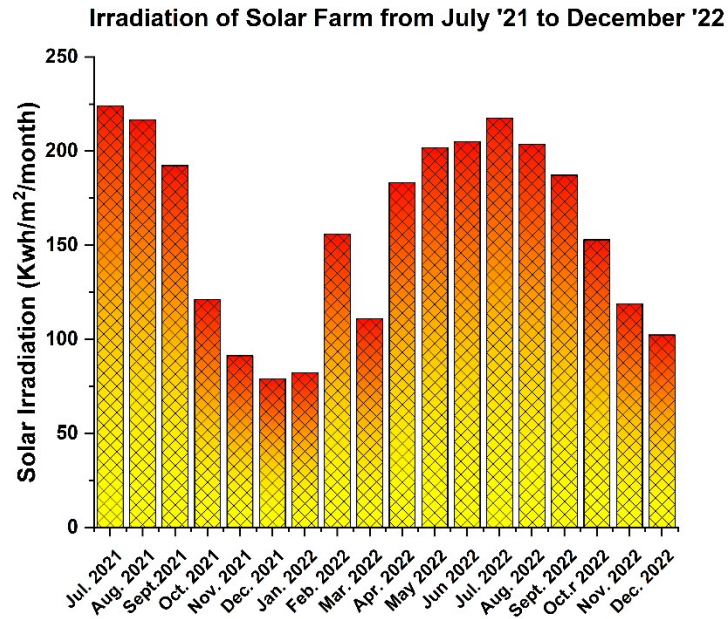


Figure 2 solar Irradiation values of Solar Farm from July '21 to December '22

Two days comparison of electrical characteristics for all panels

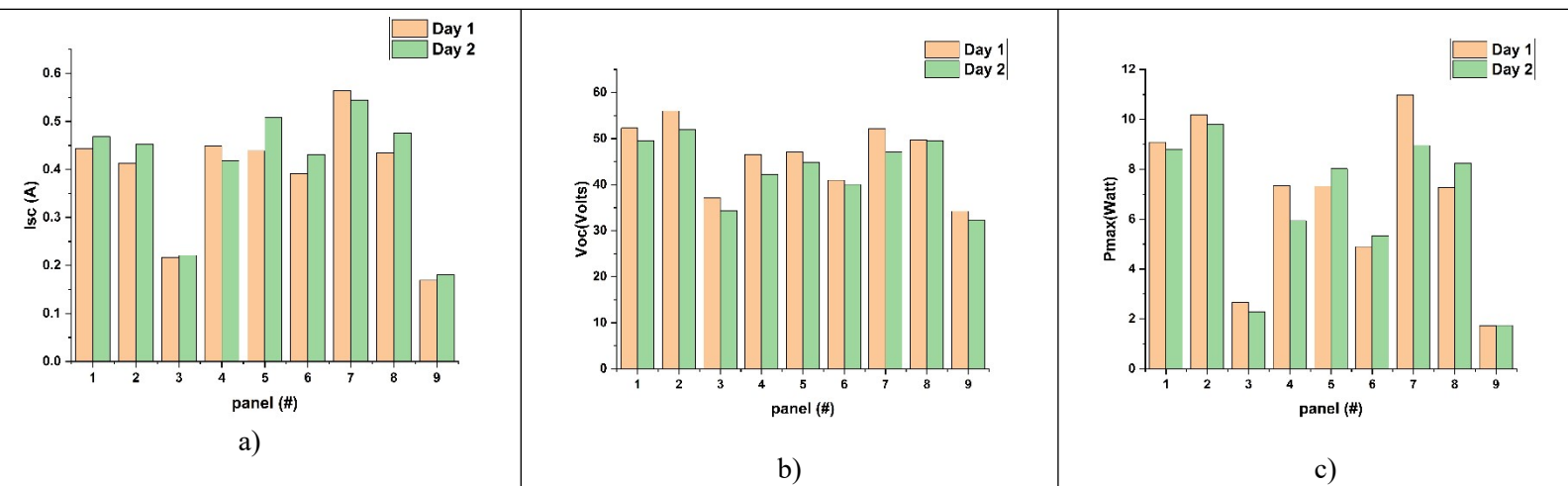


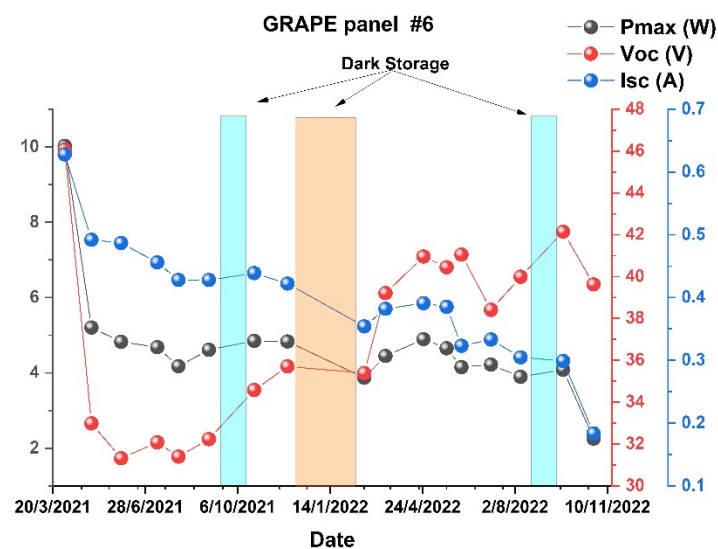
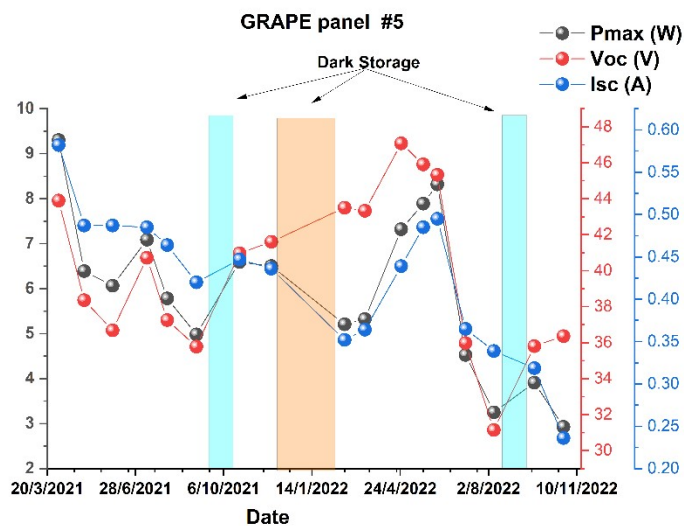
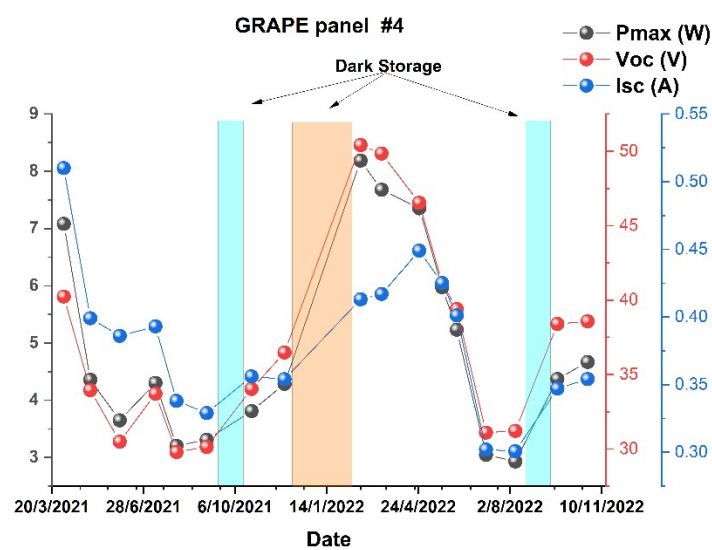
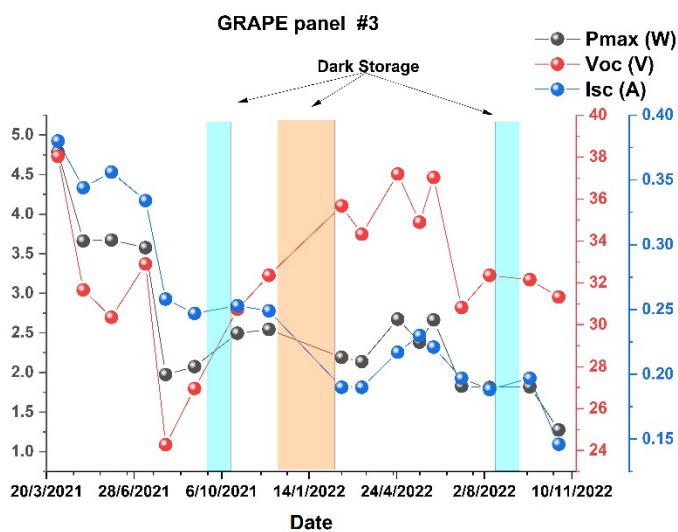
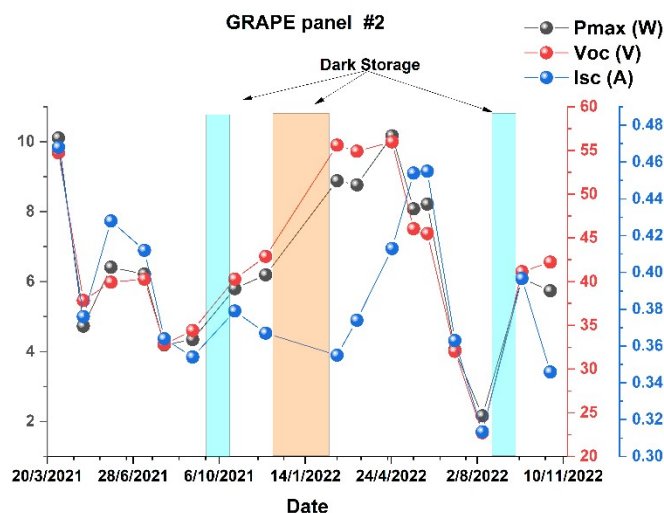
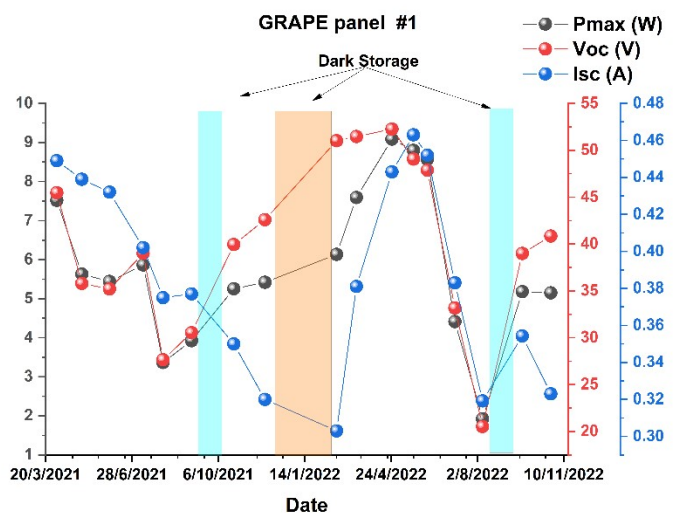
Figure 3 Data exported from I-V Measurements performed in two Consecutive Days at 1000 W/m2 for all grape panels. a) Isc, b) Voc, c) Pmax

From these measurements, it appears that some panels had reduced electrical properties, as expected based on LID, which has a greater effect on the open circuit voltage and by extension the FF. Thus, the open circuit voltage was reduced for all panels on day 2.

The current was increased for panels #1,2,3,5,6,8 on day 2 and the maximum Power was increased only for panels #5,6,8.

Table S1: Voltage Mismatch in GRAPE panels of Solar Farm

Date	SolarFarm (9 panels)	Panels' average value	Panel #1	Panel #2	Panel #3	Panel #4	Panel #5	Panel #6	Panel #7	Panel #8	Panel #9	Deviation of SolarFarm's Voc from average value of panels	Deviation of SolarFarm's Voc from minimum value of panels
	Voc (V)											%	
Feb-22	46.05	45.52	51.02	55.62	35.67	50.41	43.50	35.39	53.45	48.58	36.05	1.17	23.15
Mar-22	47.48	45.33	51.47	54.92	34.32	49.84	43.33	39.21	52.23	50.07	32.61	4.73	31.31
Apr-22	47.94	46.23	52.26	55.99	37.19	46.53	47.08	40.96	52.17	49.71	34.21	3.69	28.64
May-22	44.67	43.21	49.06	46.06	34.89	41.14	45.91	40.45	47.44	49.95	34.00	3.39	23.90
Jun-22	43.65	42.99	47.88	45.50	37.02	39.39	45.33	41.05	45.28	48.84	36.59	1.54	16.17
Jul-22	34.13	33.80	33.17	32.03	30.83	31.09	35.97	38.41	34.39	34.12	34.21	0.97	9.68



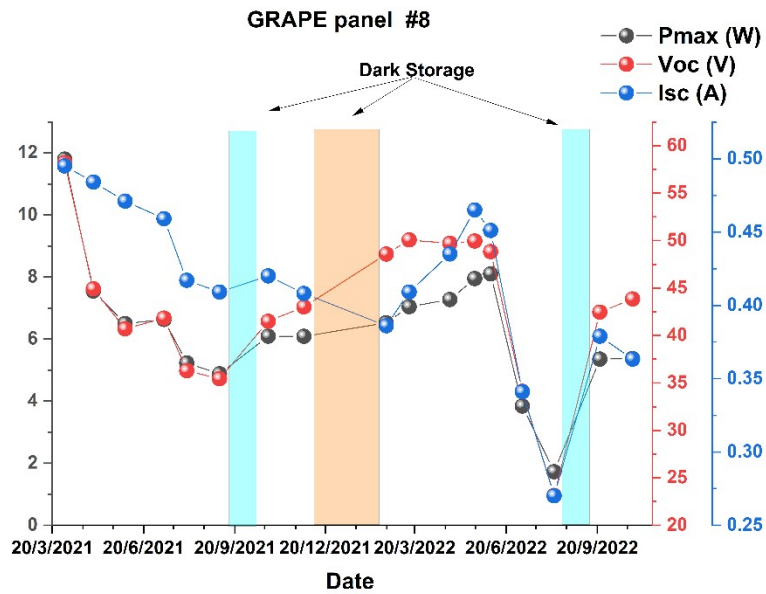


Figure 4 . Electrical parameters (P_{max} , I_{sc} , and V_{oc} extracted from the I-V characteristics of GRAPE panels #1, #2, #3, #4, #5, #6, #8 for the period 2021-2022. In all graphs, dark storage periods are highlighted with a) cyan (1 month D.S. period applied twice), b) orange (3 months D.S. period applied once)

Table S2: The table below presents the percentage (%) increase or decrease in the electrical characteristics of each panel observed during each dark storage (D.S.) period.

Solar Farm	D.S Period	Voc	Isc	Pmax
		±%	±%	±%
	1 m	26.12	9.09	46.71
	3 m	19.79	-5.31	13.15
	1 m	47.19	18.65	102.54

PANEL #5	D.S Period	Voc	Isc	Pmax
		±%	±%	±%
	1 m	14.52	6.43	32.33
	3 m	4.55	-19.27	-19.92
	1 m	14.96	-6.01	20.21

PANEL #1	D.S Period	Voc	Isc	Pmax
	1 m	30.82	-7.16	33.85
	3 m	19.79	-5.31	13.15
	1 m	90.06	10.99	169.36

PANEL #6	D.S Period	Voc	Isc	Pmax
	1 m	7.28	2.57	5.12
	3 m	-0.89	-16.11	-19.89
	1 m	5.39	-1.86	4.77

PANEL #2	D.S Period	Voc	Isc	Pmax
	1 m	17.1	7.06	33.57
	3 m	29.67	-3.27	43.49
	1 m	81.12	26.59	182.09

PANEL #7	D.S Period	Voc	Isc	Pmax
	1 m	16.1	7.6	32.64
	3 m	31.06	9.98	64.13
	1 m	76.18	24.13	159.44

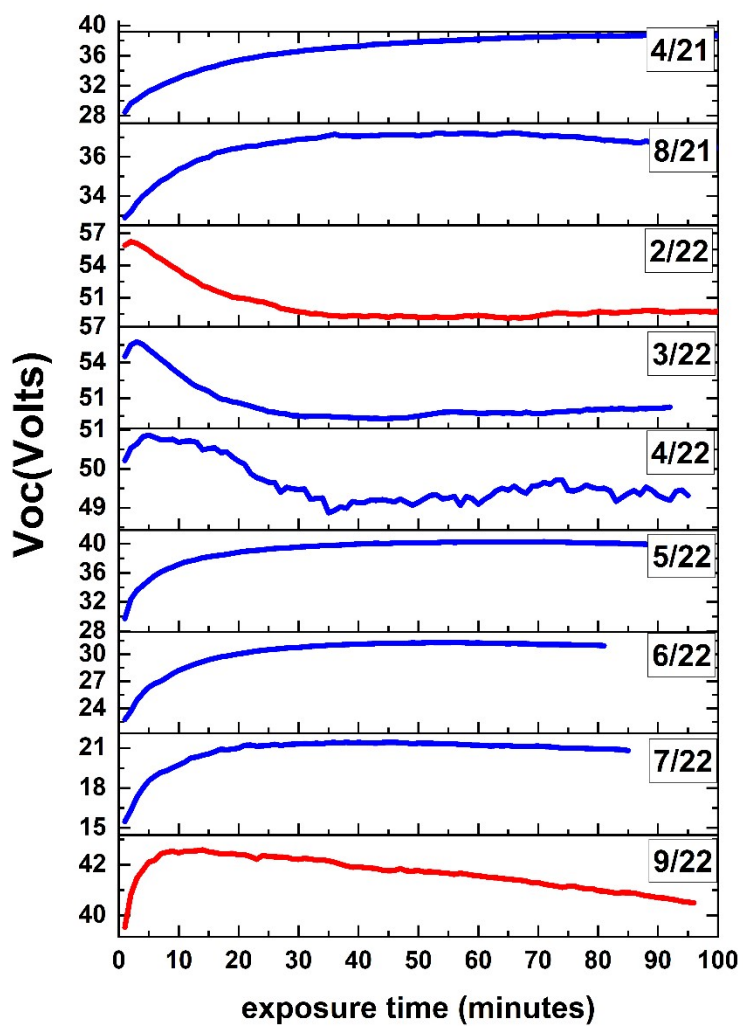
PANEL #3	D.S Period	Voc	Isc	Pmax
	1 m	14.01	2.43	20.27
	3 m	10.27	-23.69	-13.84
	1 m	-0.64	4.52	0.51

PANEL #8	D.S Period	Voc	Isc	Pmax
	1 m	17.04	2.69	24.8
	3 m	12.93	-5.39	7.22
	1 m	83.57	40.29	209.71

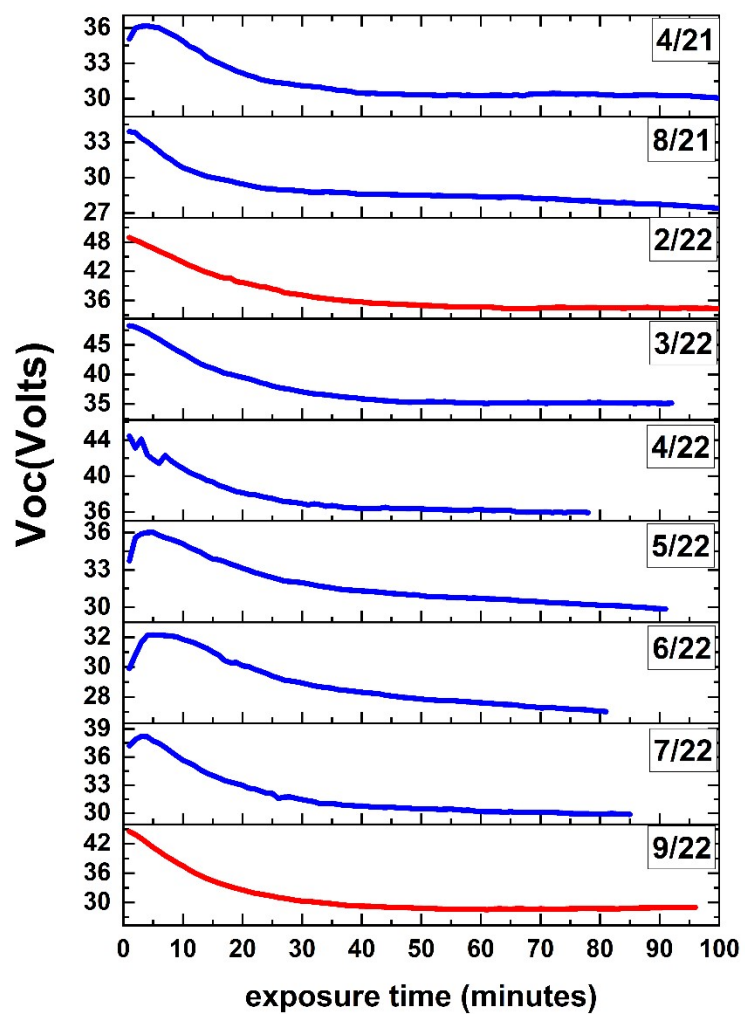
PANEL #4	D.S Period	Voc	Isc	Pmax
	1 m	12.92	8.21	15.08
	3 m	38.22	16.67	91.04
	1 m	23.02	15.4	49.09

PANEL #9	D.S Period	Voc	Isc	Pmax
	1 m	5.58	-11.17	-3.45
	3 m	-18.31	-37.5	-54.7
	1 m	24.33	45.28	87.43

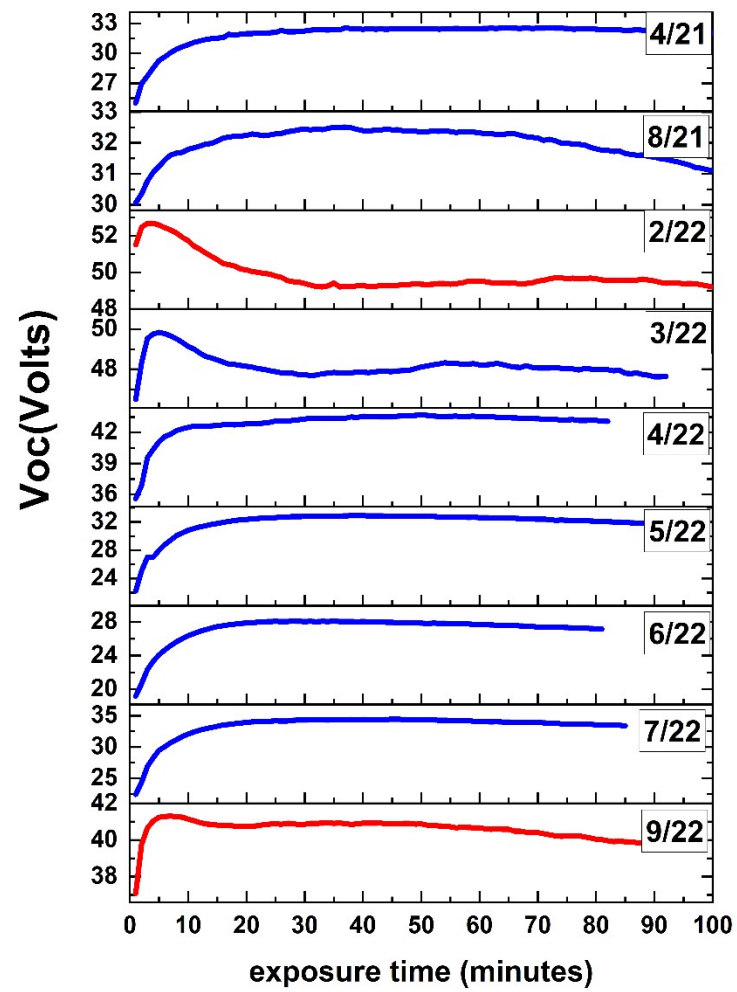
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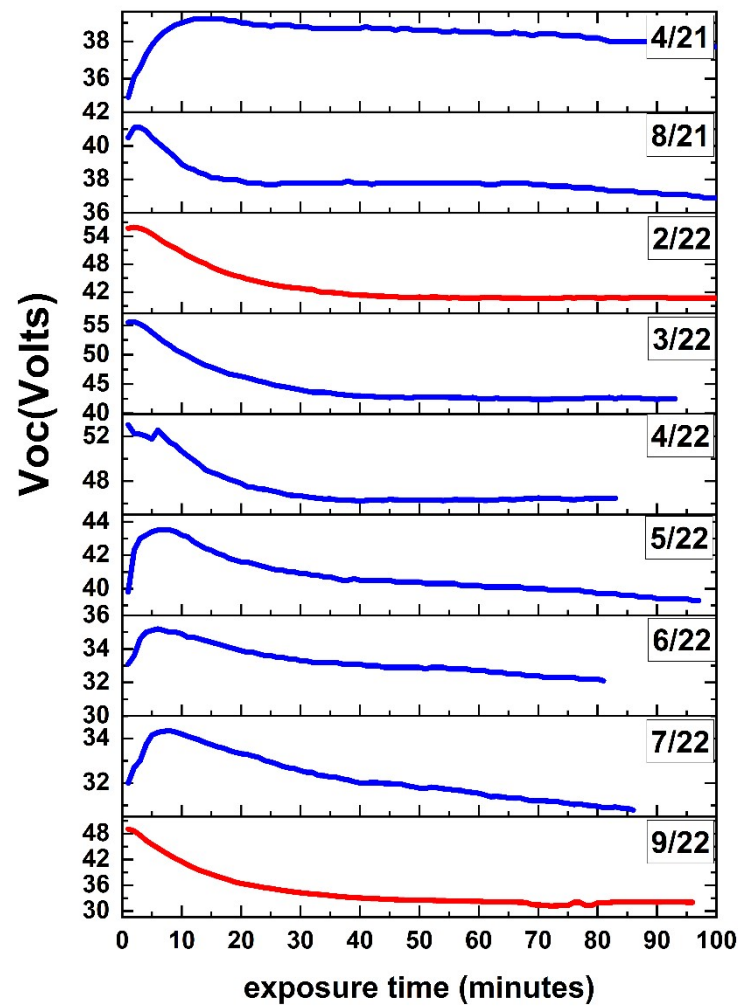
panel # 3



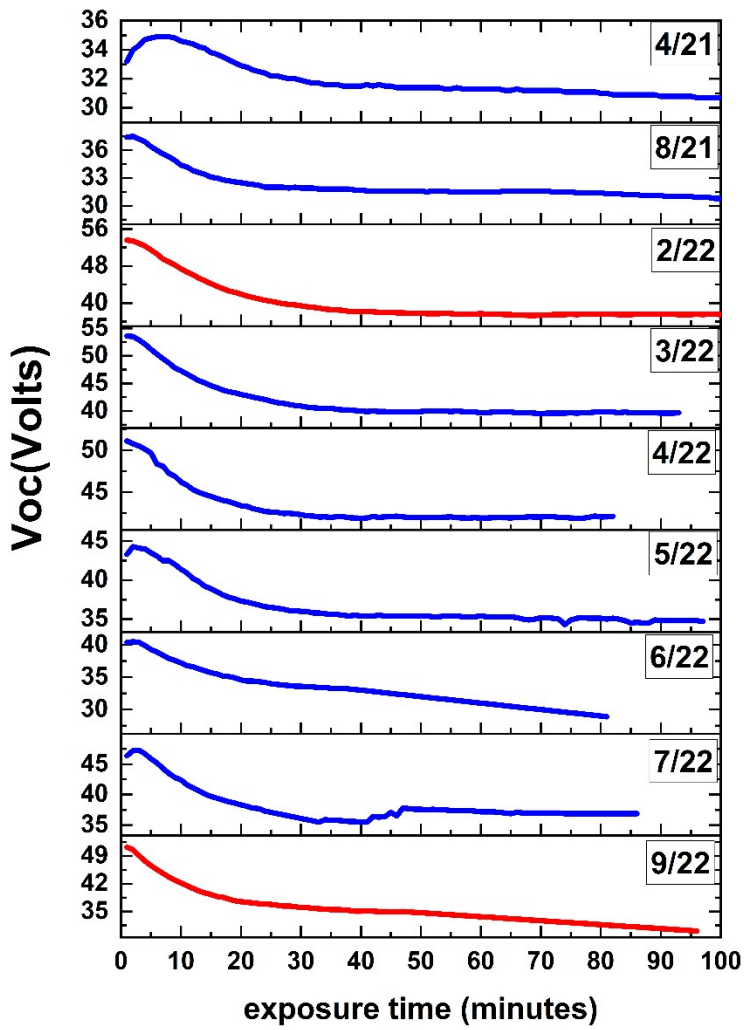
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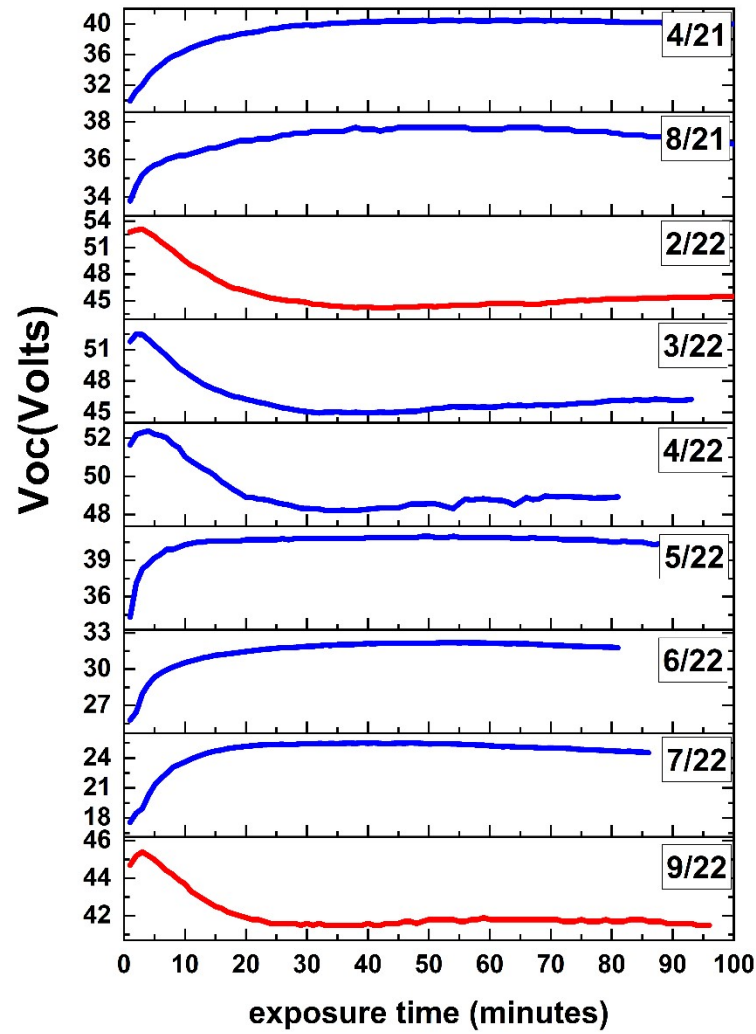
panel # 5



panel # 6



panel # 8



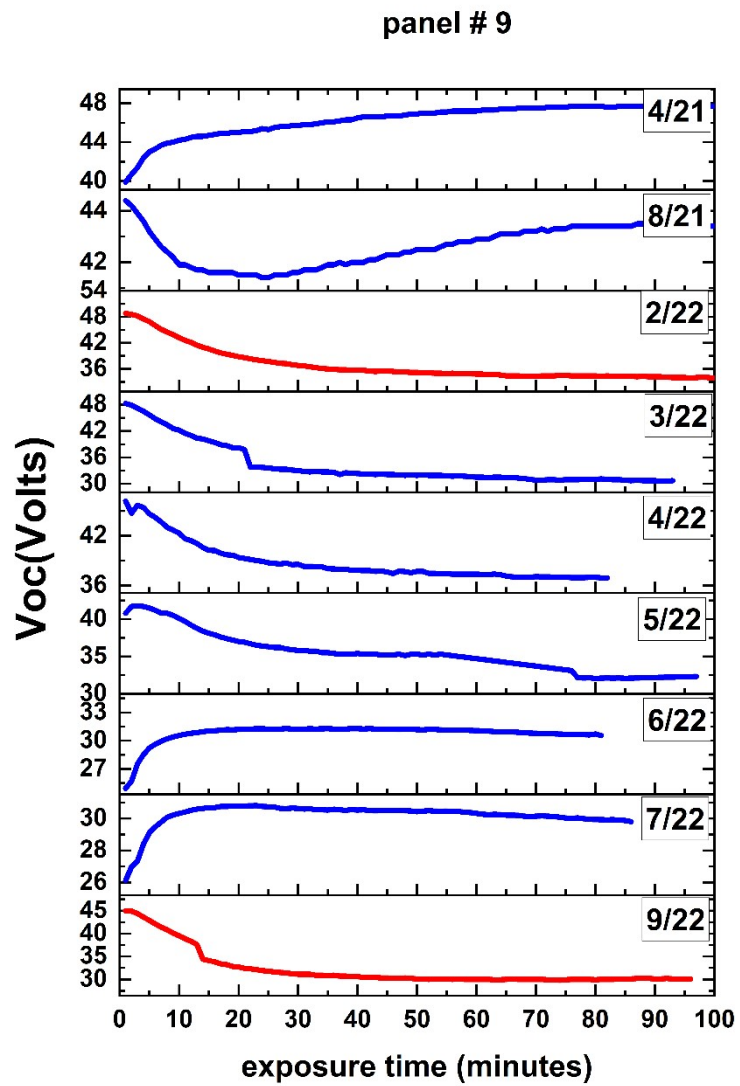
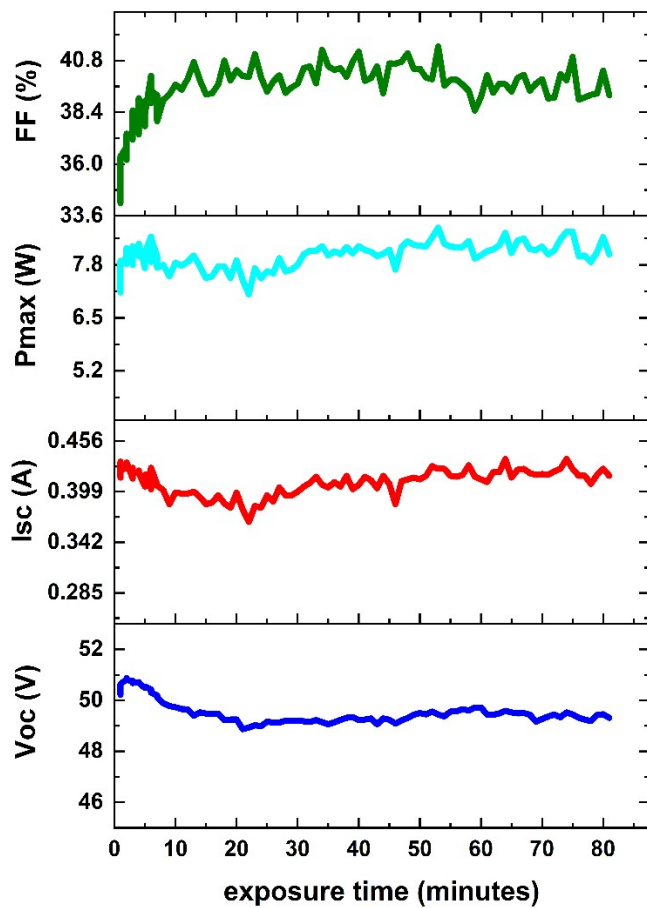


Figure 5 . Light soaking effect behavior change for each month after the 3 months dark storage and relevant recover observed (D.S) period for panels #1, #3, #4, #5, #6, #8, #9. Red color represents the behavior trend during LSP after D.S recovery occurred.

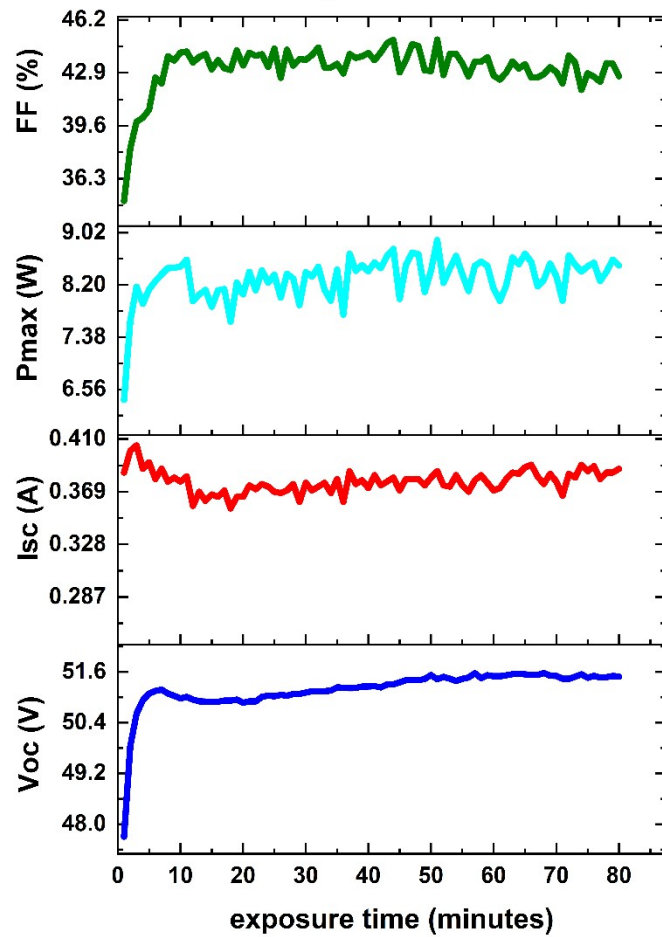
Table S3: Statistical Analysis of Voc Variations ($\bar{x} \pm y$) Induced by Light Soaking across different periods

Pan el #	4/2021	8/2021	2/2022	3/2022	4/2022	5/2022	6/2022	7/2022	9/2022
	Voc (V)	Voc(V)	Voc(V)	Voc(V)	Voc(V)	Voc(V)	Voc(V)	Voc(V)	Voc(V)
Sola r Far m	-	-	-	46.92±0. 99	-	-	35.07± 1.07	-	42.7±1. 05
pan el #1	37.39± 1.90	36.58± 0.88	50.23± 1.65	50.46±1. 60	49.62± 0.54	39.19± 1.85	30.22± 1.78	20.79± 1.08	41.64± 0.64
pan el #2	39.67± 2.90	36.63± 1.78	53.64± 1.39	53.36±1. 17	51.19± 0.48	35.77± 2.82	30.27± 2.11	23.79± 1.54	44.39± 0.55
pan el #3	30.41± 1.70	28.9±1. 39	36.56± 3.6	37.47±3. 60	37.57± 2.15	31.76± 1.75	28.84± 1.60	31.78± 2.38	30.97± 3.94
pan el #4	31.56± 1.07	31.99± 0.48	49.71± 0.90	48.15±0. 53	42.9±1. 27	31.92± 1.68	27.21± 1.56	33.35± 2.04	40.54± 0.57
pan el #5	37.6±1. 104	37.91± 0.86	42.7±3. 86	44.64±3. 51	47.4±1. 89	40.69± 1.15	33.26± 0.85	32.3±1. 01	35.06± 4.51
pan el #6	30.84± 1.55	32.14± 1.51	39.51± 3.94	41.73±3. 57	43.22± 2.36	36.5±2. 56	33.17± 2.96	38.14± 2.86	35.58± 4.58
pan el #7	43.5±3. 47	35.17± 2.19	49.87± 1.11	49.63±0. 65	49.24± 0.86	30.8±1. 30	31.50± 1.19	27.6±1. 90	44.62± 0.72
pan el #8	39.12± 1.62	37.16± 0.68	45.77± 2.01	46.32±1. 79	49.17± 1.16	40.49± 0.84	31.5±1. 18	24.65± 1.51	42.07± 0.95
pan el #9	46.63± 1.31	42.64± 0.78	36.26± 3.59	34.13±4. 743	38.79± 2.36	35.36± 2.66	30.77± 1.05	30.2±0. 76	32.12± 3.96

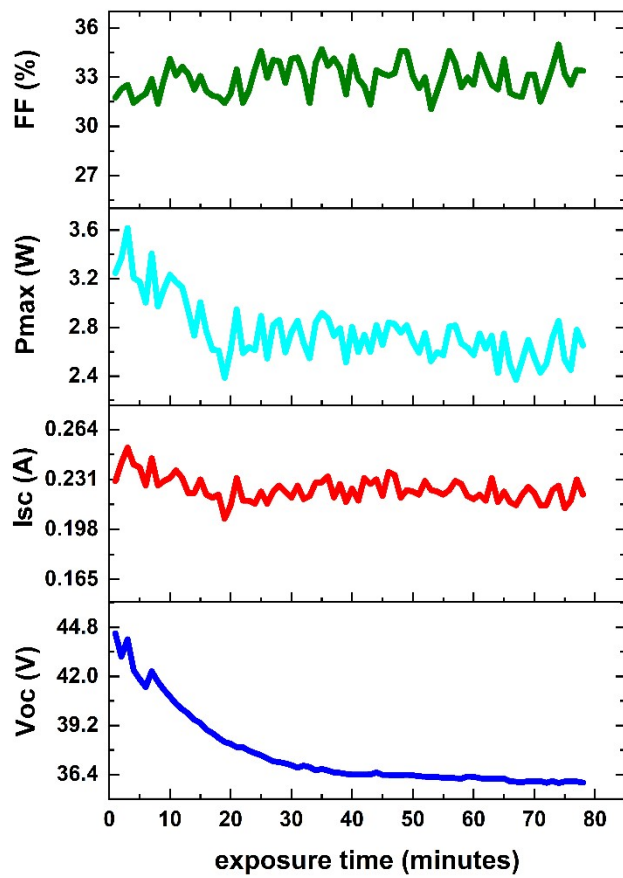
panel #1



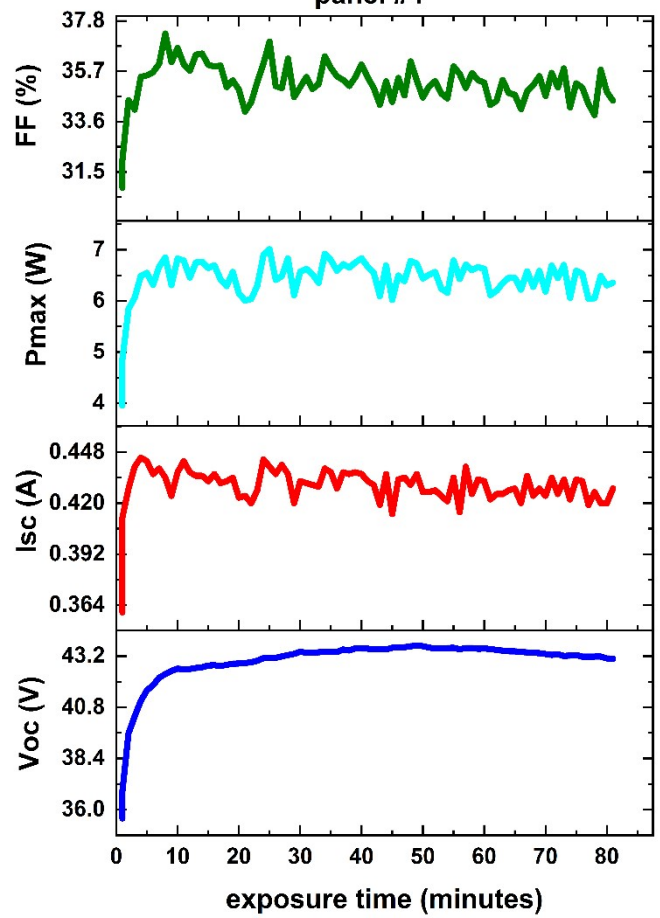
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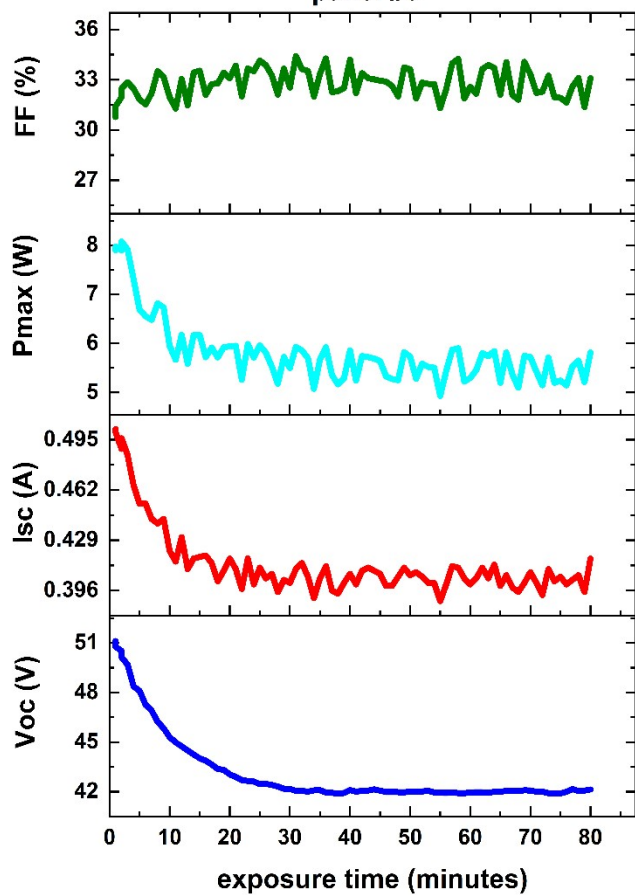
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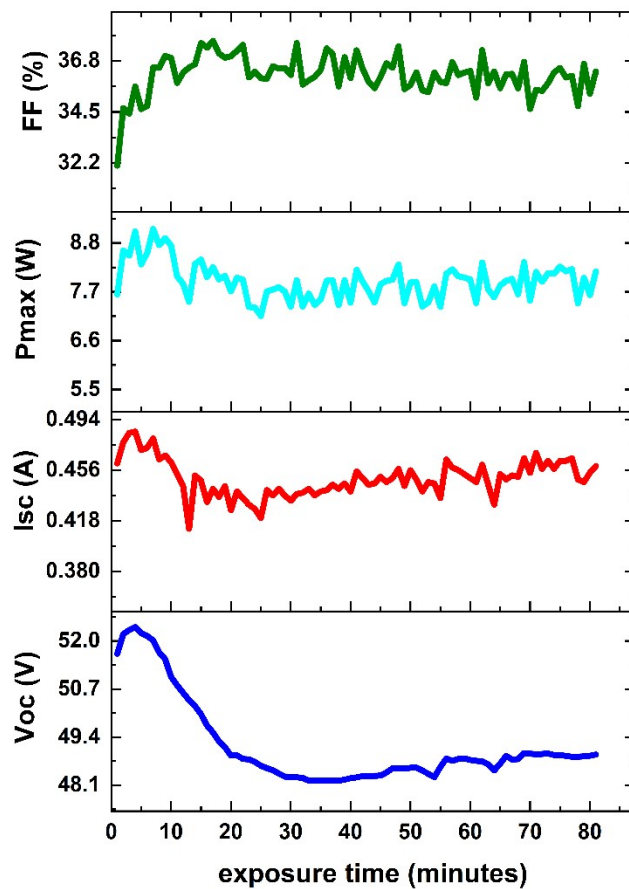
panel #4



panel #6



panel #8



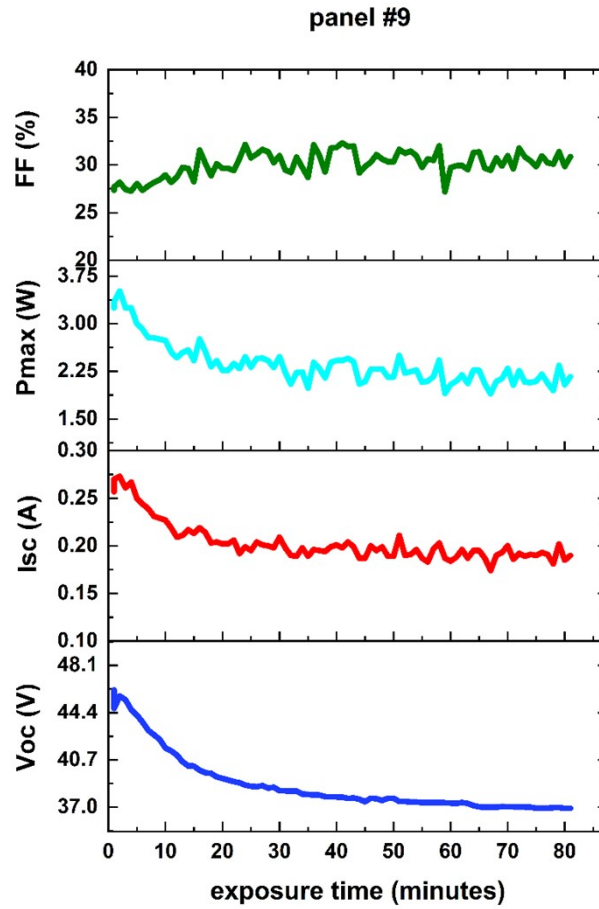


Figure 6. All electrical characteristics during light soaking effect for GRAPE solar farm, panel #1,2,3,4,6,8,9

Table S4: Quantification of Electrical Parameters Changes Due to Light Soaking Under 1000 W/m²

Panel #	Voc	Isc	Pmax	FF
	(V)	(A)	(W)	(%)
Solar Farm	47.00±1.04	3.170±0.177	52.87±3.90	35.41±0.59
panel #1	49.62±0.54	0.410±0.014	8.03±0.31	39.46±1.44
panel #2	51.19±0.48	0.377±0.008	8.30±0.34	43.19±1.60
panel #3	37.57±2.15	0.224±0.008	2.76±0.24	32.93±0.99
panel #4	42.93±1.27	0.429±0.010	6.43±0.41	35.17±0.99
panel #5	47.41±1.89	0.512±0.022	9.05±0.88	37.52±0.71
panel #6	43.22±2.36	0.414±0.024	5.82±0.68	32.78±0.85
panel #7	49.25±0.84	0.549±0.013	9.82±0.55	36.67±1.25
panel #8	49.17±1.16	0.449±0.013	7.93±0.42	36.17±0.93
panel #9	38.79±2.35	0.203±0.021	2.36±0.33	30.05±1.45

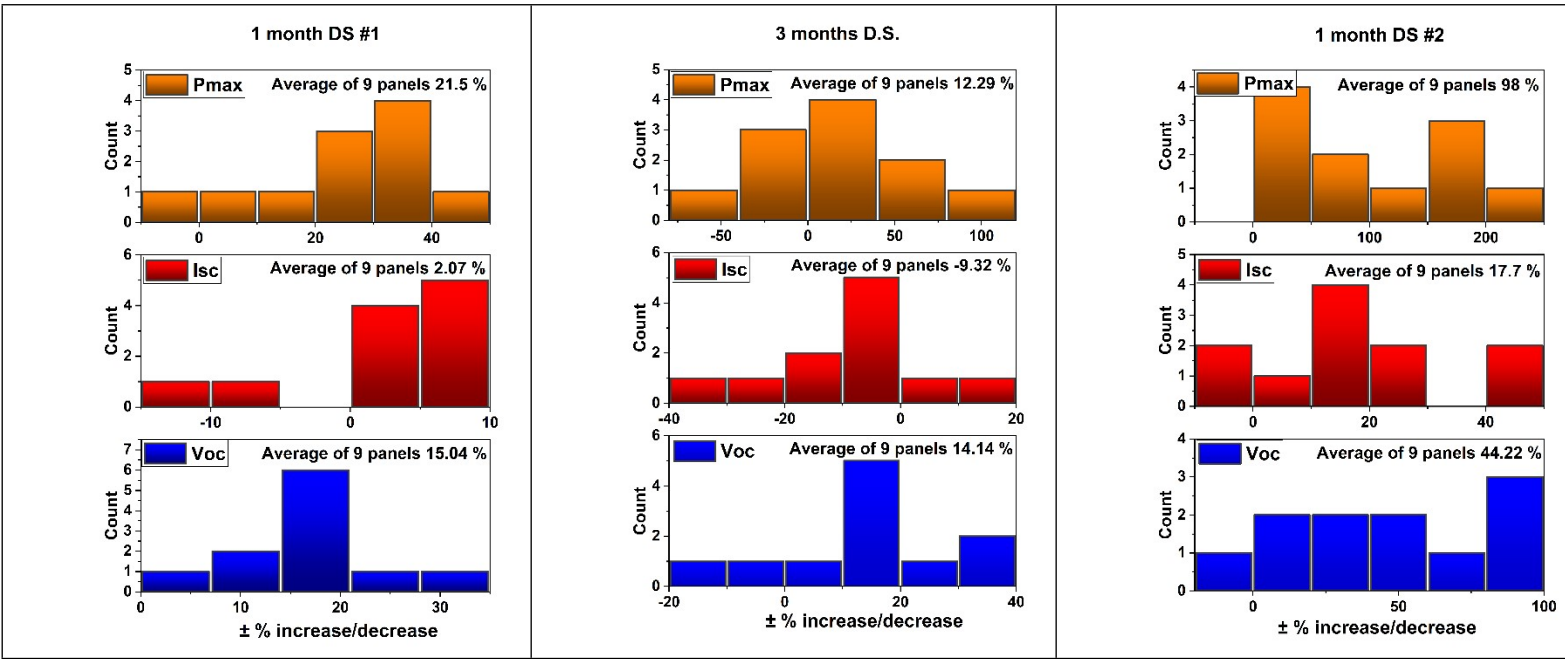


Figure 7. Histograms presenting the $\pm$ % increase/decrease of the main figures of merit (Pmax, Isc, and Voc) during each D.S period for the nine panels of solar farm. For each electrical parameter (Pmax, Isc, and Voc) the average of all 9 panels is presented in their corresponding figure.

Front & Back side view of a grape panel

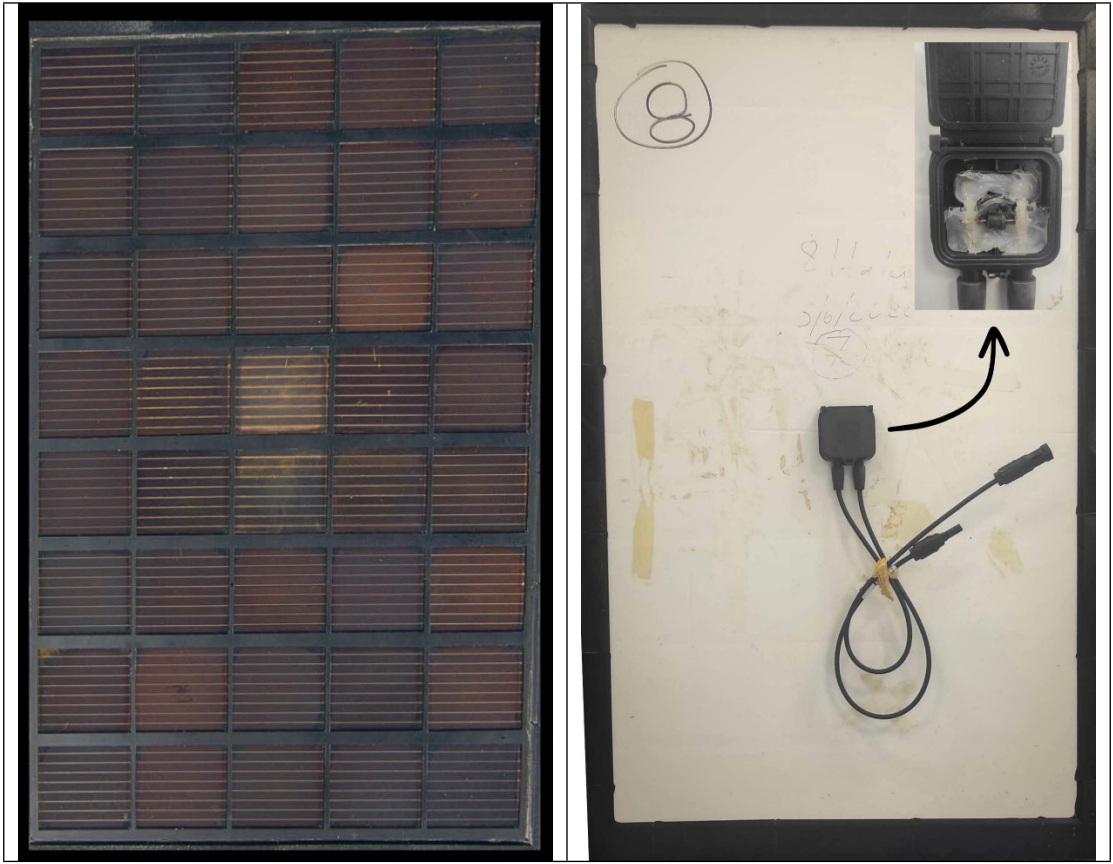
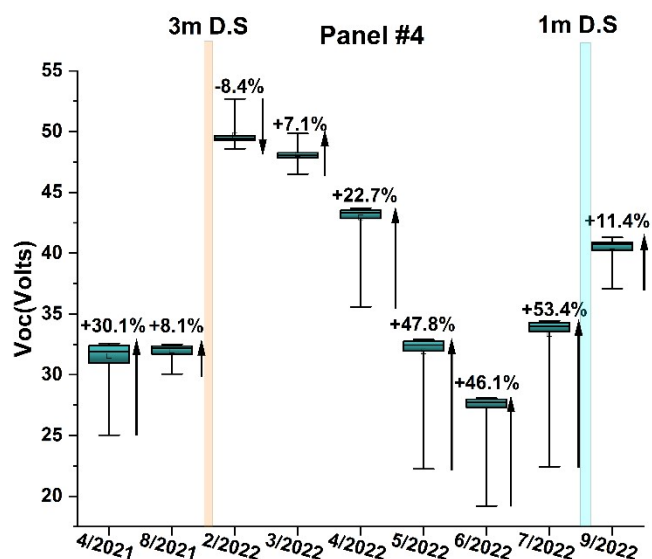
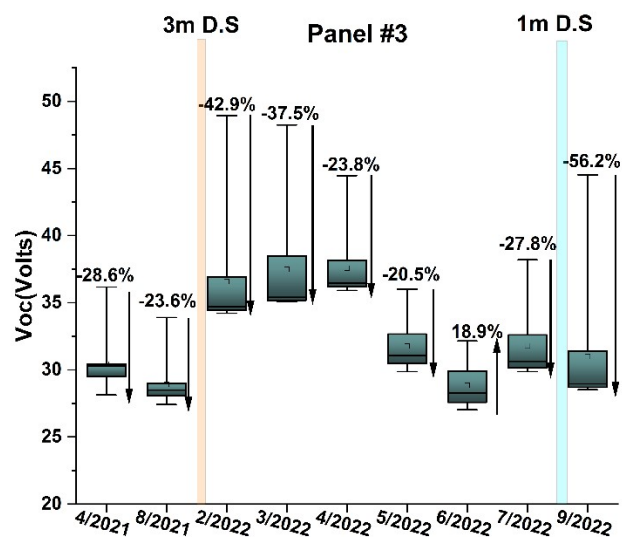
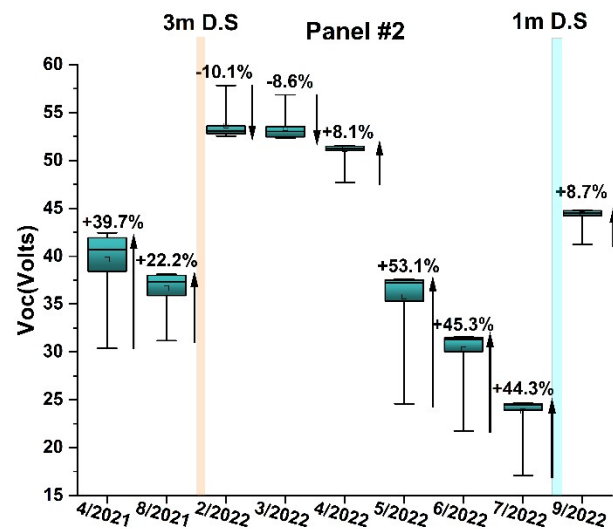
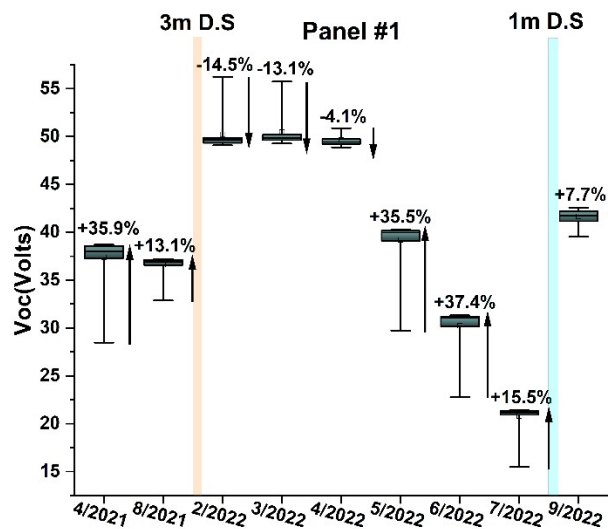


Figure 8. Front & Back side view of a grape panel. The junction box placement is in the center of the panel's back side.



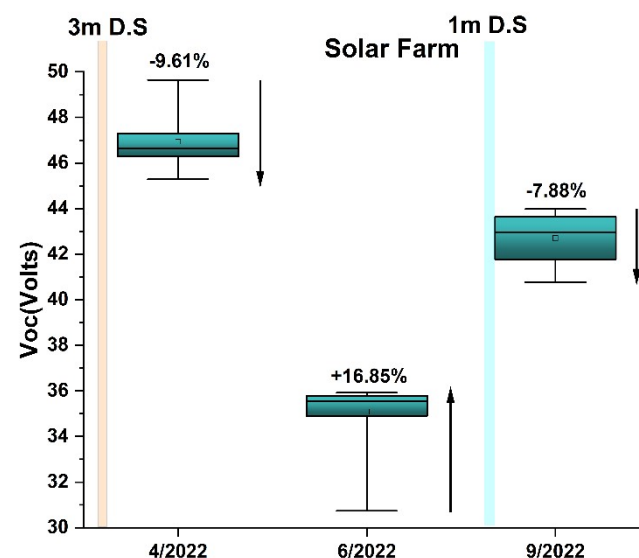
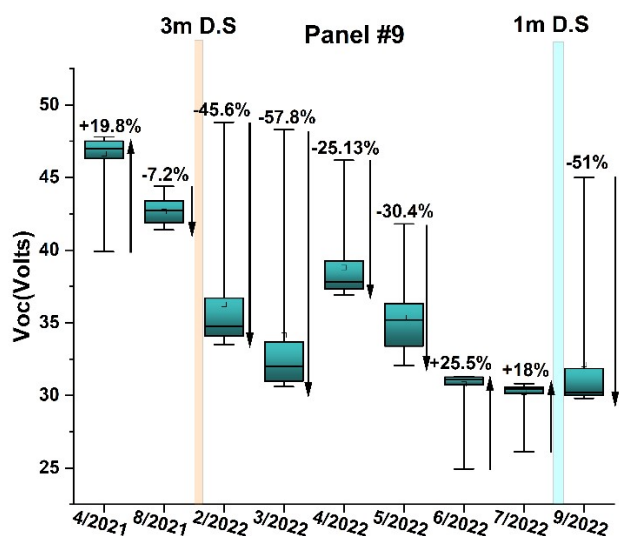
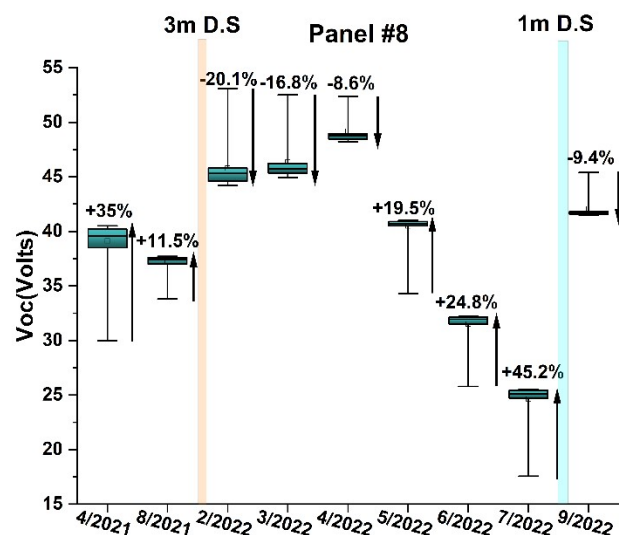
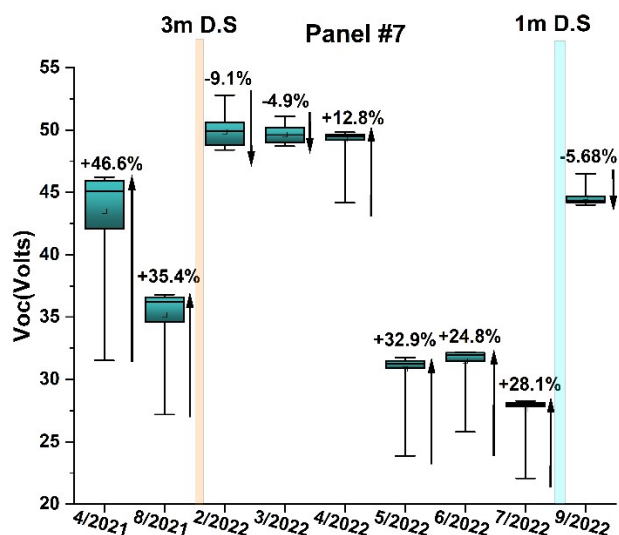
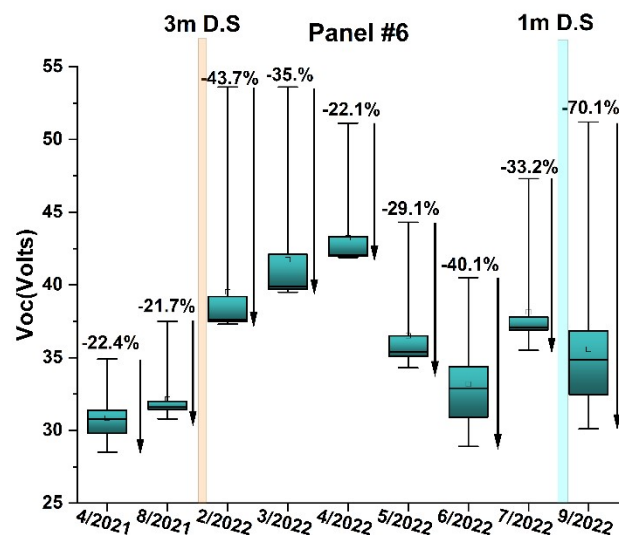
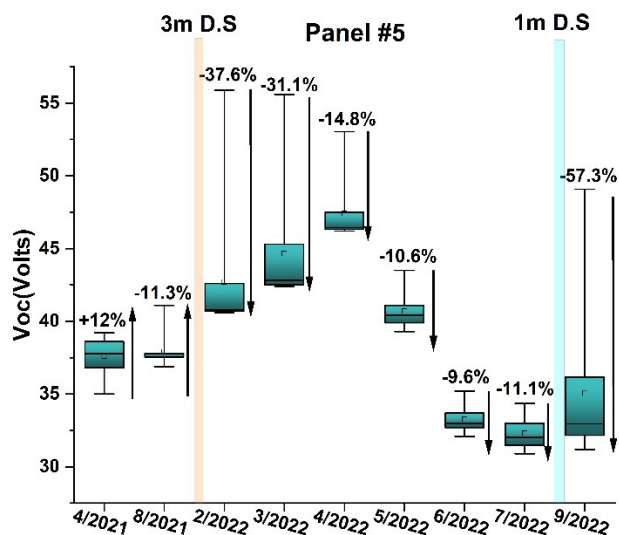


Figure 9 Detailed analysis of light soaking (L.S.) losses and gains under stable irradiance conditions of 1000 W/m², showing the variations $x \pm y \%$ in Voc across different time periods. Each box chart quantifies the percentage (%) of losses and gains observed during L.S.