

FORGESOLAR GLARE ANALYSIS

Project: **Bonsmara SEF**

Site configuration: **with mitigation 27 Mar 2023-temp-1**

Created 27 Mar, 2023

Updated 27 Mar, 2023

Time-step 1 minute

Timezone offset UTC2

Site ID 87051.15142

Category 10 MW to 100 MW

DNI constant at 2,200.0 W/m²

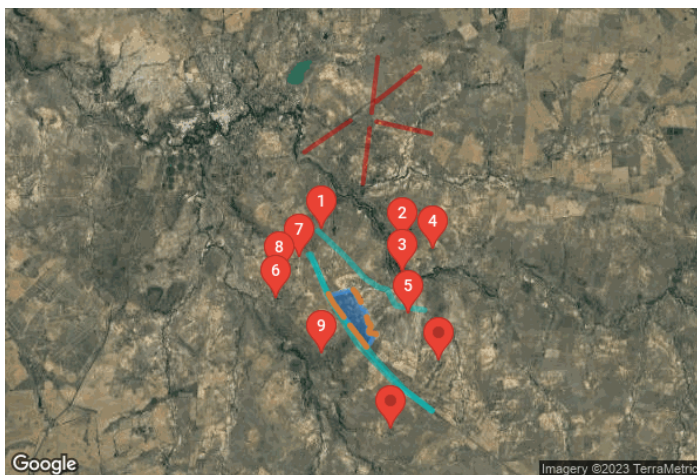
Ocular transmission coefficient 0.5

Pupil diameter 0.002 m

Eye focal length 0.017 m

Sun subtended angle 9.3 mrad

PV analysis methodology V2



Summary of Results Glare with potential for temporary after-image predicted

PV Array	Tilt °	Orient °	Annual Green Glare		Annual Yellow Glare		Energy kWh
			min	hr	min	hr	
Bonsmara PV Array	SA tracking	SA tracking	4,390	73.2	20,731	345.5	-

Total annual glare received by each receptor; may include duplicate times of glare from multiple reflective surfaces.

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
R76	182	3.0	10,014	166.9
Railway	169	2.8	3,570	59.5
Unnamed Dirt Road	509	8.5	975	16.2
FP 1	0	0.0	0	0.0
FP 2	0	0.0	0	0.0
FP 3	0	0.0	0	0.0
FP 4	0	0.0	0	0.0
FP 5	0	0.0	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	423	7.0	728	12.1
OP 4	382	6.4	1,318	22.0
OP 5	930	15.5	1,979	33.0
OP 6	1,488	24.8	993	16.6
OP 7	0	0.0	0	0.0

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
OP 8	307	5.1	1,154	19.2
OP 9	0	0.0	0	0.0
OP 10	0	0.0	0	0.0
OP 11	0	0.0	0	0.0

Component Data

PV Arrays

Name: Bonsmara PV Array
Axis tracking: Single-axis rotation
Backtracking: Instant
Tracking axis orientation: 0.0°
Tracking axis tilt: 28.0°
Tracking axis panel offset: 0.0°
Max tracking angle: 60.0°
Resting angle: 0.0°
Rated power: -
Panel material: Smooth glass without AR coating
Reflectivity: Vary with sun
Slope error: correlate with material



Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-27.756036	27.296470	1428.88	2.50	1431.38
2	-27.755622	27.297011	1426.61	2.50	1429.11
3	-27.753333	27.307293	1405.56	2.50	1408.06
4	-27.753368	27.309666	1398.76	2.50	1401.26
5	-27.754864	27.311002	1393.69	2.50	1396.19
6	-27.757606	27.312982	1395.65	2.50	1398.15
7	-27.759947	27.314007	1392.83	2.50	1395.33
8	-27.760636	27.314011	1392.12	2.50	1394.62
9	-27.762750	27.314887	1392.02	2.50	1394.52
10	-27.763384	27.316702	1390.83	2.50	1393.33
11	-27.765200	27.317764	1390.69	2.50	1393.19
12	-27.765782	27.317717	1390.67	2.50	1393.17
13	-27.766483	27.317095	1394.91	2.50	1397.41
14	-27.770522	27.318037	1397.26	2.50	1399.76
15	-27.771159	27.318328	1395.25	2.50	1397.75
16	-27.771262	27.319241	1395.25	2.50	1397.75
17	-27.772129	27.319260	1394.19	2.50	1396.69
18	-27.773943	27.318032	1404.80	2.50	1407.30
19	-27.774996	27.317962	1417.25	2.50	1419.75
20	-27.776043	27.318814	1422.49	2.50	1424.99
21	-27.776037	27.322000	1421.21	2.50	1423.71
22	-27.776758	27.321991	1418.13	2.50	1420.63
23	-27.777355	27.321772	1425.11	2.50	1427.61
24	-27.778082	27.321202	1423.45	2.50	1425.95
25	-27.780639	27.319890	1427.89	2.50	1430.39
26	-27.781888	27.318335	1441.75	2.50	1444.25
27	-27.782403	27.317667	1442.25	2.50	1444.75
28	-27.780621	27.316062	1440.79	2.50	1443.29
29	-27.779528	27.315240	1438.24	2.50	1440.74
30	-27.776531	27.312607	1439.75	2.50	1442.25
31	-27.774787	27.310996	1441.67	2.50	1444.17
32	-27.773633	27.310132	1438.40	2.50	1440.90
33	-27.760696	27.298857	1442.01	2.50	1444.51
34	-27.758707	27.297605	1434.71	2.50	1437.21
35	-27.757006	27.296373	1431.28	2.50	1433.78

Route Receptors

Name: R76
Path type: Two-way
Observer view angle: 50.0°



Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-27.815423	27.355934	1453.43	1.00	1454.43
2	-27.811096	27.349668	1454.70	1.00	1455.70
3	-27.808363	27.345548	1450.62	1.00	1451.62
4	-27.805630	27.341342	1444.96	1.00	1445.96
5	-27.804340	27.339626	1442.95	1.00	1443.95
6	-27.801151	27.336278	1439.12	1.00	1440.12
7	-27.796671	27.331300	1435.49	1.00	1436.49
8	-27.792495	27.326837	1425.29	1.00	1426.29
9	-27.788395	27.322460	1440.67	1.00	1441.67
10	-27.782396	27.317224	1419.99	1.00	1420.99
11	-27.778295	27.313791	1421.41	1.00	1422.41
12	-27.773815	27.309671	1429.54	1.00	1430.54
13	-27.769410	27.305894	1435.46	1.00	1436.46
14	-27.765385	27.302375	1441.86	1.00	1442.86
15	-27.761512	27.298942	1441.92	1.00	1442.92
16	-27.758473	27.296796	1442.14	1.00	1443.14
17	-27.746396	27.290531	1422.17	1.00	1423.17
18	-27.741611	27.288213	1419.51	1.00	1420.51
19	-27.734698	27.285038	1412.98	1.00	1413.98

Name: Railway
Path type: Two-way
Observer view angle: 50.0°



Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-27.815615	27.355778	1452.41	2.00	1454.41
2	-27.811401	27.349405	1454.92	2.00	1456.92
3	-27.808611	27.345242	1450.48	2.00	1452.48
4	-27.805831	27.341240	1444.42	2.00	1446.42
5	-27.803781	27.338204	1440.24	2.00	1442.24
6	-27.800697	27.333634	1436.57	2.00	1438.57
7	-27.799482	27.332121	1437.89	2.00	1439.89
8	-27.793968	27.326091	1435.76	2.00	1437.76
9	-27.789269	27.321027	1440.05	2.00	1442.05
10	-27.783498	27.314751	1437.32	2.00	1439.32
11	-27.782094	27.313185	1439.33	2.00	1441.33
12	-27.775686	27.308335	1436.15	2.00	1438.15
13	-27.769900	27.304296	1438.32	2.00	1440.32
14	-27.765676	27.301463	1442.09	2.00	1444.09
15	-27.761660	27.298760	1441.84	2.00	1443.84
16	-27.758584	27.296678	1441.77	2.00	1443.77
17	-27.755897	27.294908	1435.72	2.00	1437.72
18	-27.750580	27.292290	1429.39	2.00	1431.39
19	-27.746450	27.290338	1422.52	2.00	1424.52
20	-27.741398	27.287956	1419.88	2.00	1421.88
21	-27.740253	27.287410	1418.81	2.00	1420.81
22	-27.739280	27.286822	1417.34	2.00	1419.34
23	-27.737986	27.285902	1416.08	2.00	1418.08
24	-27.734774	27.283539	1416.55	2.00	1418.55

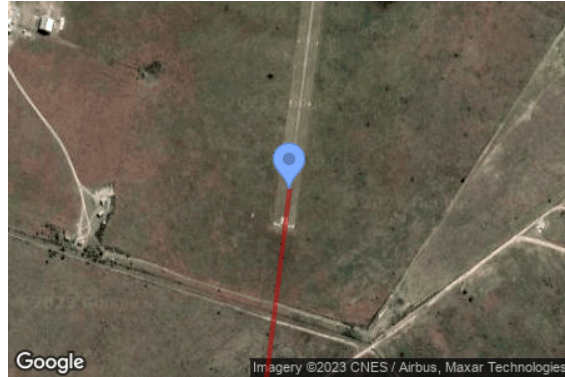
Name: Unnamed Dirt Road
Path type: Two-way
Observer view angle: 50.0°



Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-27.722596	27.289100	1399.34	1.00	1400.34
2	-27.726167	27.293564	1387.85	1.00	1388.85
3	-27.731106	27.299400	1380.72	1.00	1381.72
4	-27.734600	27.303692	1396.73	1.00	1397.73
5	-27.736044	27.305322	1402.65	1.00	1403.65
6	-27.739842	27.309185	1415.35	1.00	1416.35
7	-27.742824	27.312425	1409.22	1.00	1410.22
8	-27.745900	27.315429	1396.67	1.00	1397.67
9	-27.747590	27.317575	1393.34	1.00	1394.34
10	-27.749337	27.320686	1383.56	1.00	1384.56
11	-27.751616	27.324205	1371.63	1.00	1372.63
12	-27.752319	27.326887	1369.77	1.00	1370.77
13	-27.752604	27.328475	1369.36	1.00	1370.36
14	-27.753059	27.329870	1364.75	1.00	1365.75
15	-27.756173	27.331501	1365.86	1.00	1366.86
16	-27.758224	27.332702	1370.38	1.00	1371.38
17	-27.760427	27.334162	1369.73	1.00	1370.73
18	-27.761262	27.335106	1371.66	1.00	1372.66
19	-27.761661	27.337251	1370.88	1.00	1371.88
20	-27.761813	27.339762	1366.27	1.00	1367.27
21	-27.762501	27.342959	1370.39	1.00	1371.39
22	-27.762734	27.345073	1364.07	1.00	1365.07
23	-27.762981	27.347562	1364.14	1.00	1365.14
24	-27.763484	27.351521	1366.90	1.00	1367.90

Flight Path Receptors

Name: FP 1
Description:
Threshold height: 15 m
Direction: 7.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



Point	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
Threshold	-27.669479	27.319394	1434.25	15.24	1449.49
Two-mile	-27.698176	27.315411	1359.17	259.01	1618.17

Name: FP 2
Description:
Threshold height: 15 m
Direction: 186.3°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



Point	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
Threshold	-27.661488	27.320583	1435.77	15.24	1451.01
Two-mile	-27.632750	27.324169	1397.48	222.22	1619.70

Name: FP 3
Description:
Threshold height: 15 m
Direction: 282.4°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



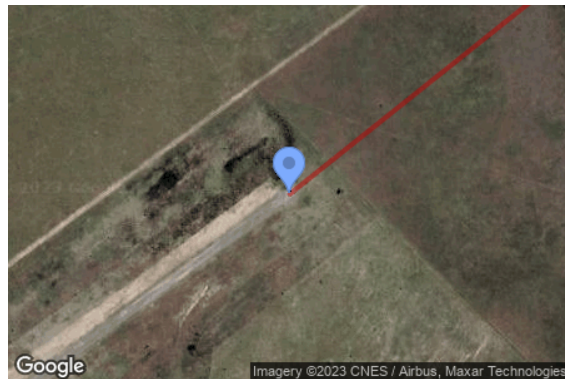
Point	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
Threshold	-27.666040	27.323427	1434.75	15.24	1449.99
Two-mile	-27.672238	27.355350	1404.25	214.43	1618.68

Name: FP 4
Description:
Threshold height: 15 m
Direction: 55.6°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



Point	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
Threshold	-27.665468	27.308129	1424.42	15.24	1439.66
Two-mile	-27.681790	27.281153	1353.11	255.23	1608.34

Name: FP 5
Description:
Threshold height: 15 m
Direction: 231.5°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



Point	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
Threshold	-27.655790	27.323130	1433.73	15.24	1448.97
Two-mile	-27.637780	27.348695	1447.75	169.91	1617.66

Discrete Observation Point Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (m)	Height (m)
OP 1	1	-27.721825	27.291660	1394.09	1.53
OP 2	2	-27.727956	27.338656	1376.14	1.53
OP 3	3	-27.744477	27.338527	1356.52	1.53
OP 4	4	-27.731998	27.356670	1394.54	1.53
OP 5	5	-27.765833	27.342031	1386.90	1.53
OP 6	6	-27.757445	27.264430	1377.83	1.53
OP 7	7	-27.736240	27.278521	1415.08	1.53
OP 8	8	-27.745483	27.266667	1403.74	1.53
OP 9	9	-27.786305	27.291727	1391.94	1.53
OP 10	10	-27.824830	27.332011	1415.60	1.53
OP 11	11	-27.789886	27.359884	1412.86	1.53

Obstruction Components

Name: Eastern Berm / Trees

Top height: 1.5 m



Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	-27.753059	27.309820	1395.73
2	-27.754103	27.310742	1394.52
3	-27.754995	27.311536	1394.57
4	-27.756030	27.312244	1393.08
5	-27.756866	27.312856	1392.35
6	-27.758024	27.313575	1392.13
7	-27.758869	27.313961	1392.05
8	-27.759410	27.314143	1391.84

Name: Eastern Berm / Trees 2

Top height: 1.5 m



Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	-27.767022	27.317599	1397.04
2	-27.770250	27.318564	1397.87
3	-27.770478	27.319465	1396.65
4	-27.770895	27.319852	1395.77
5	-27.772338	27.319980	1396.75
6	-27.773990	27.319058	1401.95
7	-27.774958	27.318993	1404.53
8	-27.775395	27.319723	1403.48
9	-27.775737	27.323006	1398.75
10	-27.776116	27.323113	1399.13

Name: Western Berm / Trees

Top height: 2.0 m



Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	-27.782515	27.317562	1421.43
2	-27.778263	27.314000	1420.50
3	-27.775424	27.311436	1425.87
4	-27.773801	27.310041	1428.73
5	-27.773383	27.309677	1428.85
6	-27.772887	27.309175	1428.40
7	-27.771387	27.307845	1429.77

Name: Western Berm / Trees

Top height: 2.0 m



Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	-27.755162	27.295161	1432.86
2	-27.757916	27.296813	1441.46
3	-27.760270	27.298380	1441.57
4	-27.762017	27.299818	1442.17
5	-27.764310	27.301845	1442.64
6	-27.767172	27.304259	1441.90

Glare Analysis Results

Summary of Results Glare with potential for temporary after-image predicted

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	°	°	min	hr	min	hr	kWh
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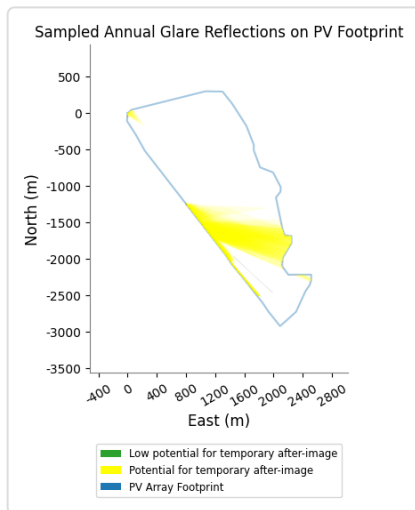
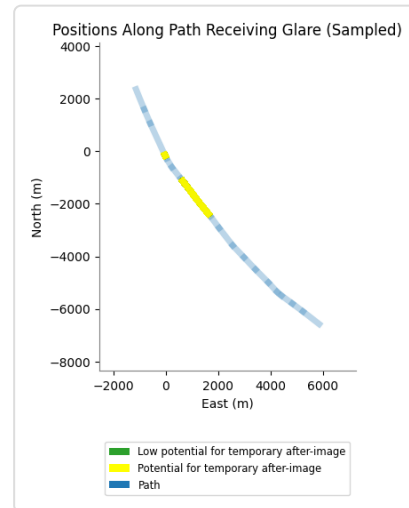
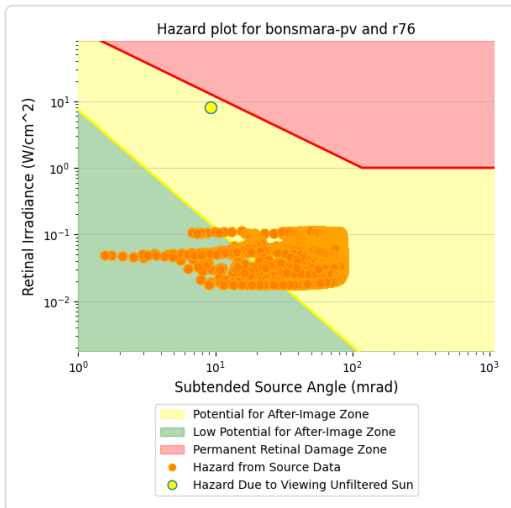
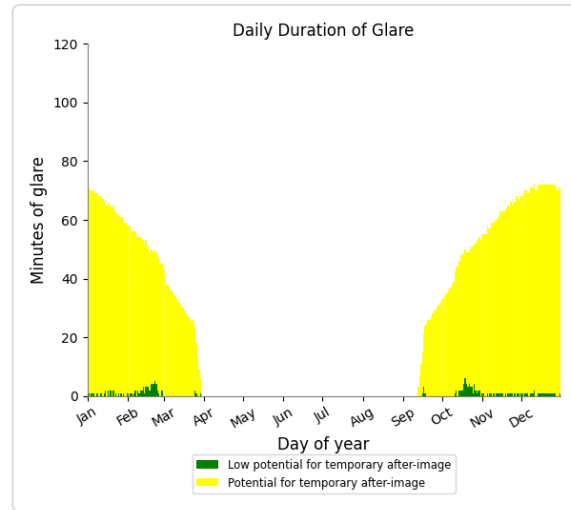
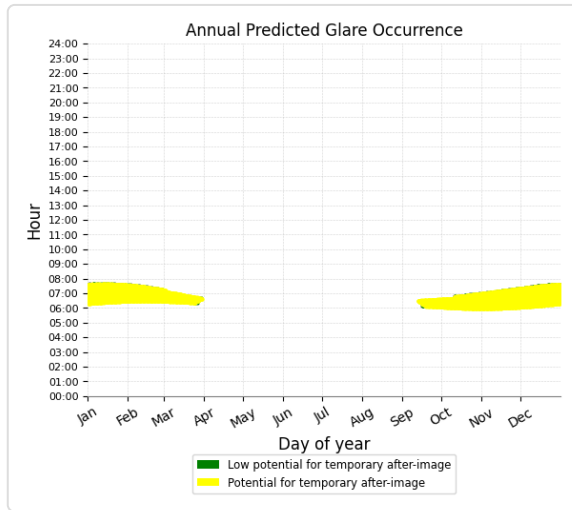
PV: Bonsmara PV Array potential temporary after-image

Receptor results ordered by category of glare

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
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Unnamed Dirt Road	509	8.5	975	16.2
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FP 2	0	0.0	0	0.0
FP 3	0	0.0	0	0.0
FP 4	0	0.0	0	0.0
FP 5	0	0.0	0	0.0
OP 3	423	7.0	728	12.1
OP 4	382	6.4	1,318	22.0
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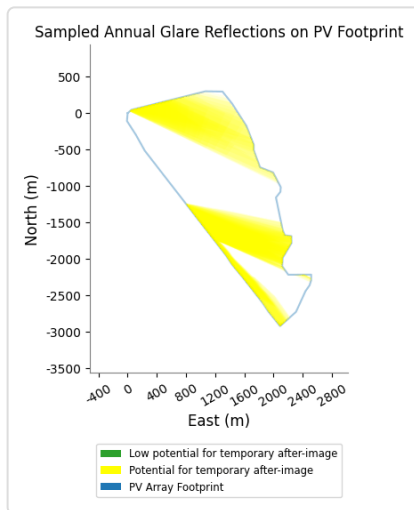
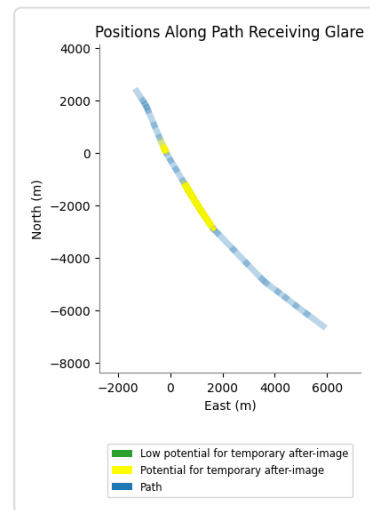
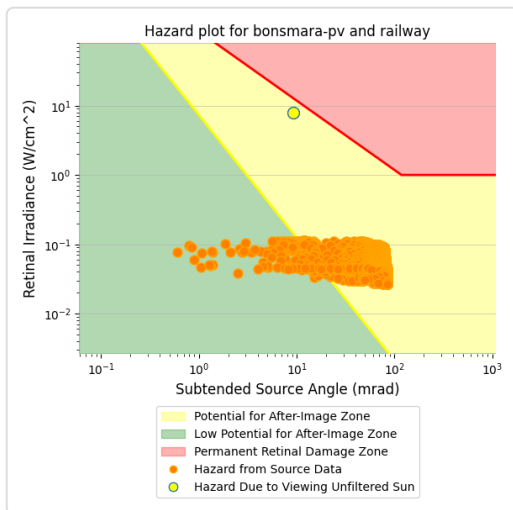
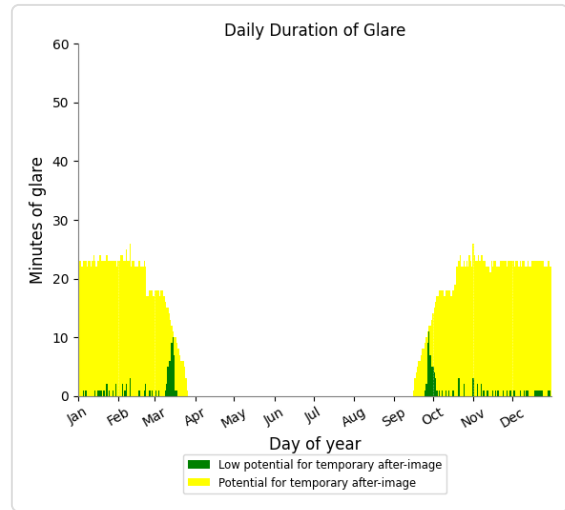
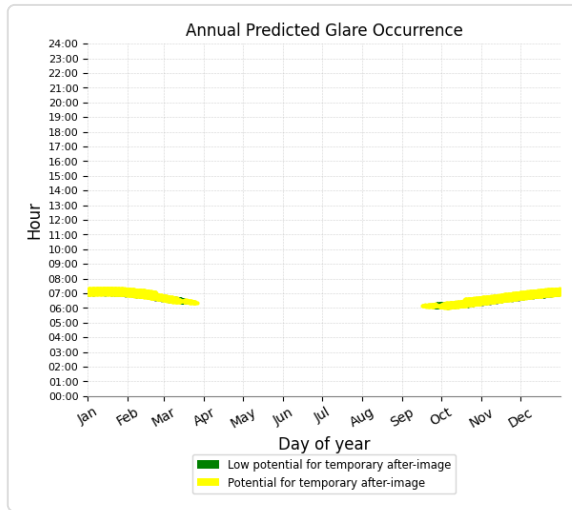
Bonsmara PV Array and R76

Receptor type: Route
 10,014 minutes of yellow glare
 182 minutes of green glare



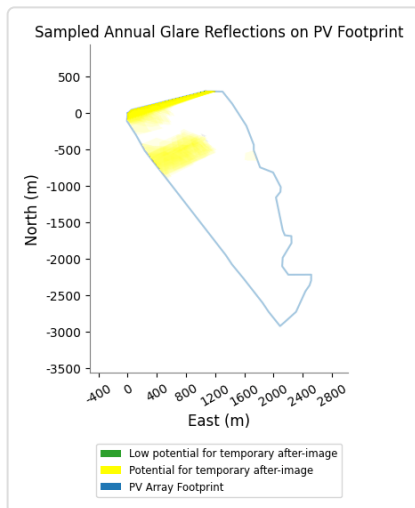
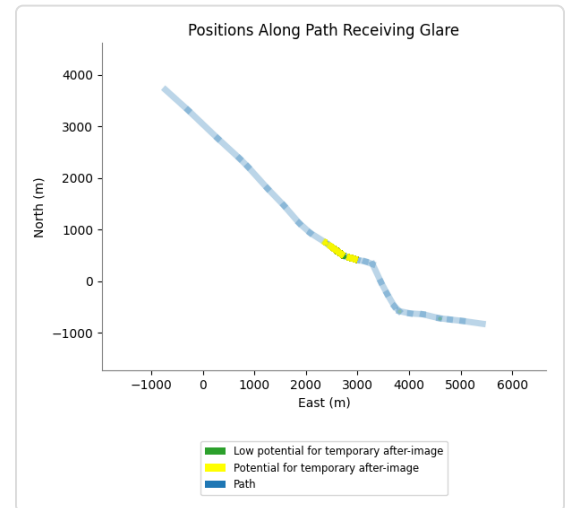
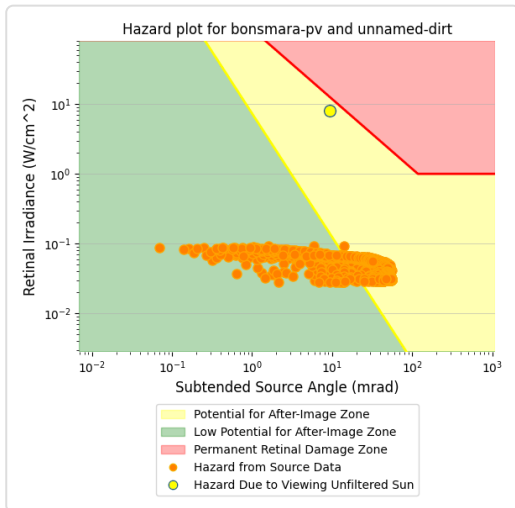
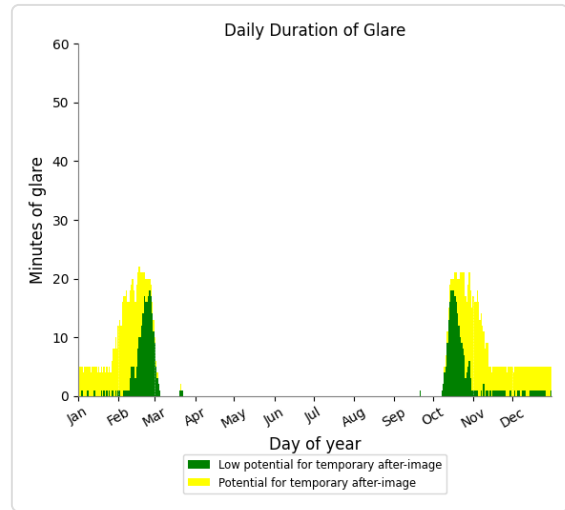
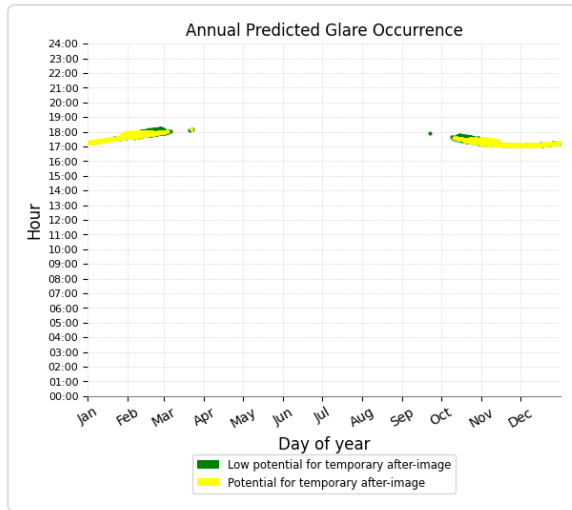
Bonsmara PV Array and Railway

Receptor type: Route
 3,570 minutes of yellow glare
 169 minutes of green glare



Bonsmara PV Array and Unnamed Dirt Road

Receptor type: Route
 975 minutes of yellow glare
 509 minutes of green glare



Bonsmara PV Array and FP 1

Receptor type: 2-mile Flight Path
 No glare found

Bonsmara PV Array and FP 2

Receptor type: 2-mile Flight Path
 No glare found

Bonsmara PV Array and FP 3

Receptor type: 2-mile Flight Path
 No glare found

Bonsmara PV Array and FP 4

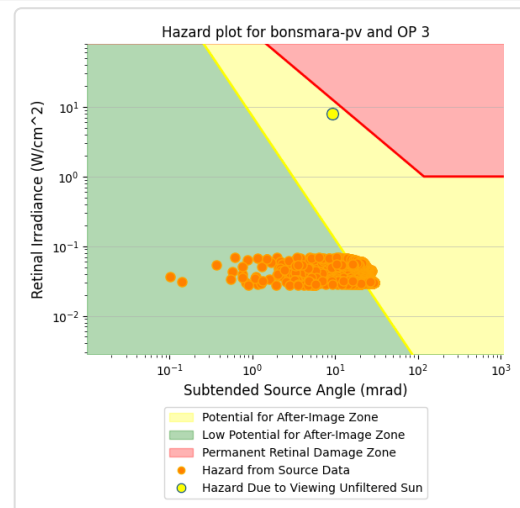
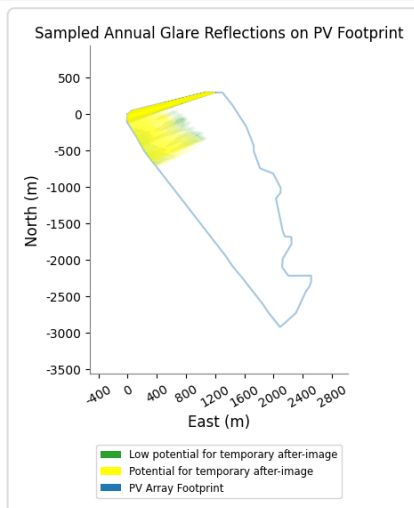
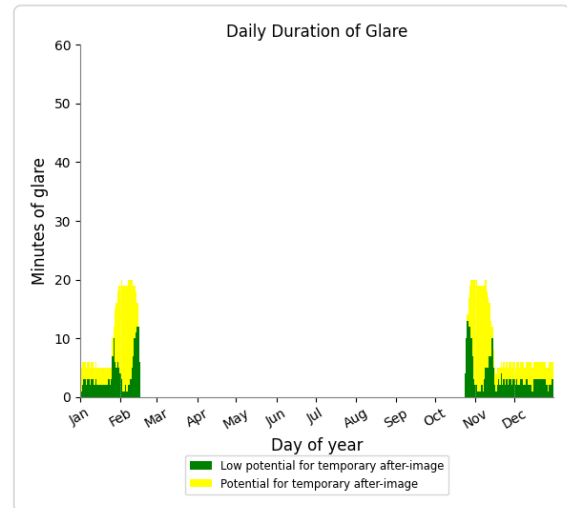
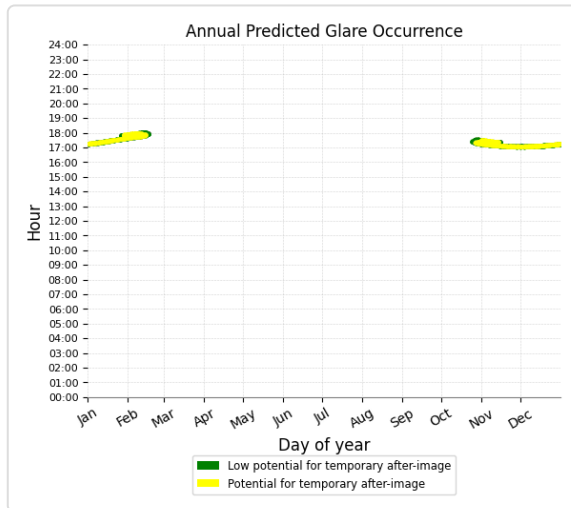
Receptor type: 2-mile Flight Path
 No glare found

Bonsmara PV Array and FP 5

Receptor type: 2-mile Flight Path
 No glare found

Bonsmara PV Array and OP 3

Receptor type: Observation Point
 728 minutes of yellow glare
 423 minutes of green glare

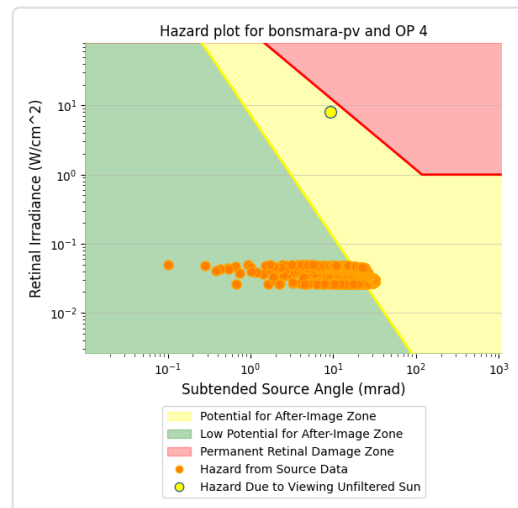
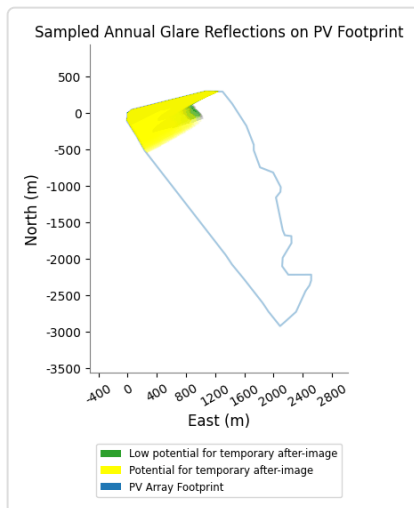
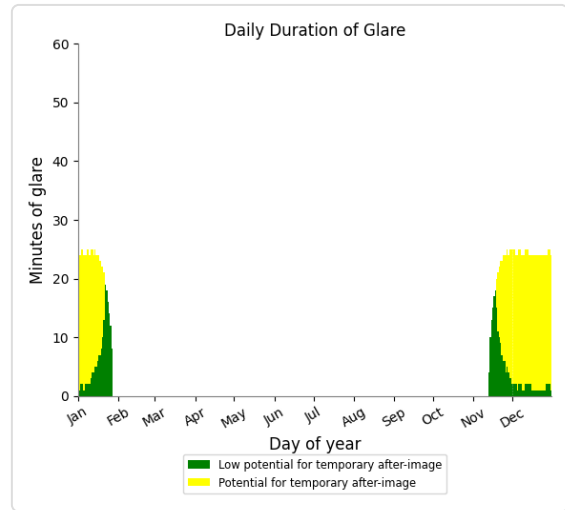
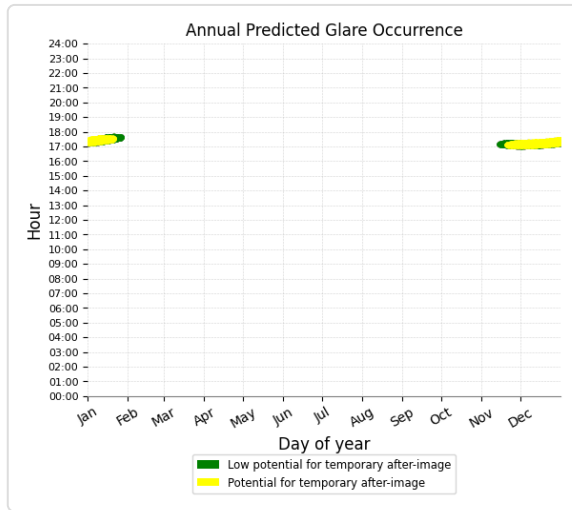


Bonsmara PV Array and OP 4

Receptor type: Observation Point

1,318 minutes of yellow glare

382 minutes of green glare

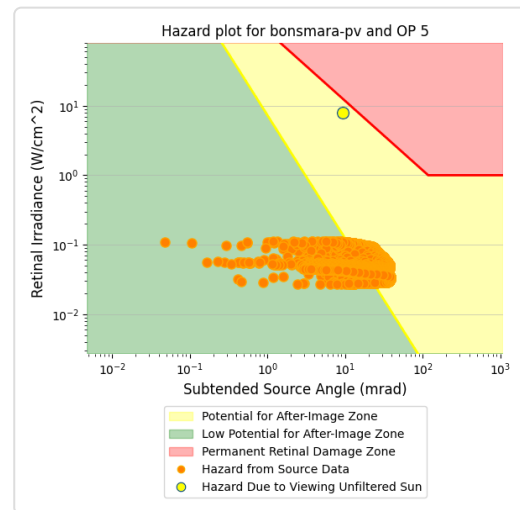
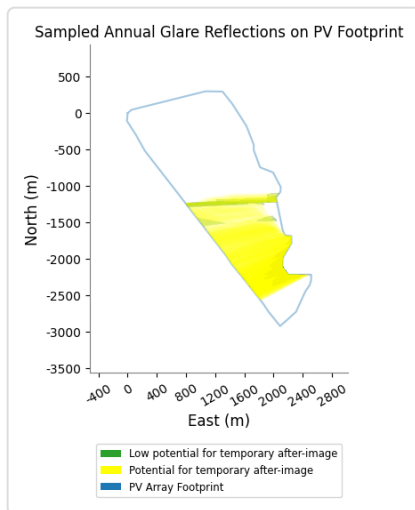
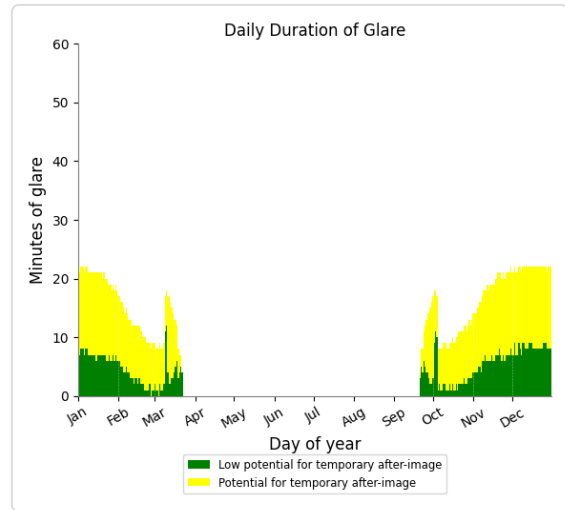
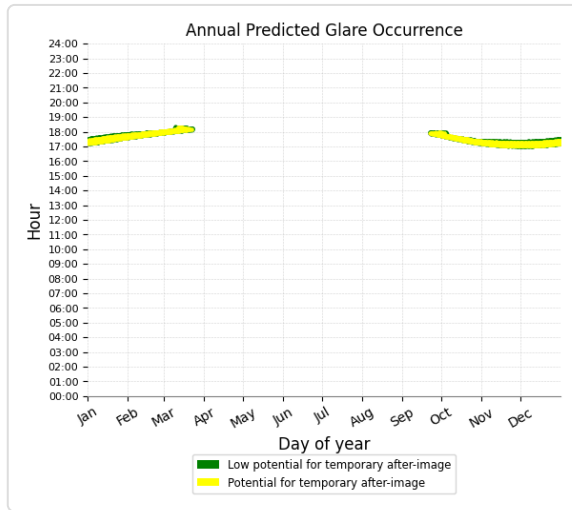


Bonsmara PV Array and OP 5

Receptor type: Observation Point

1,979 minutes of yellow glare

930 minutes of green glare

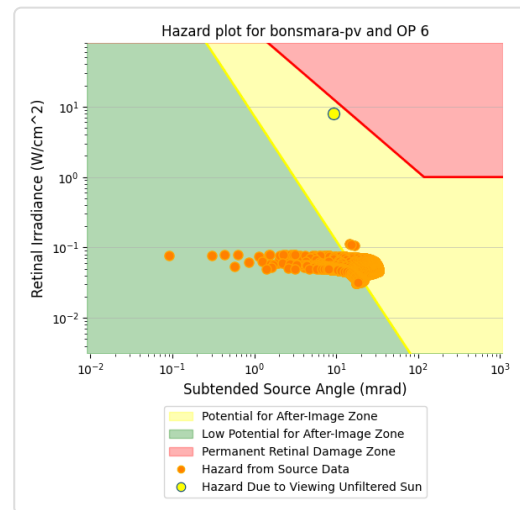
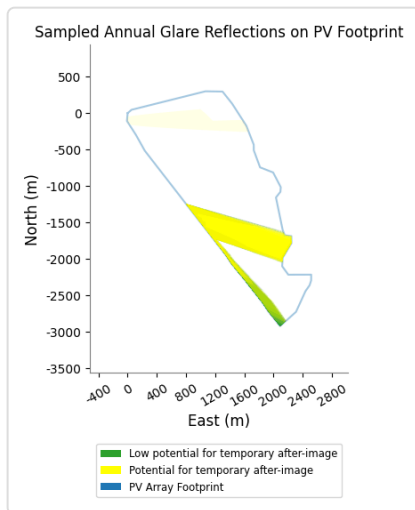
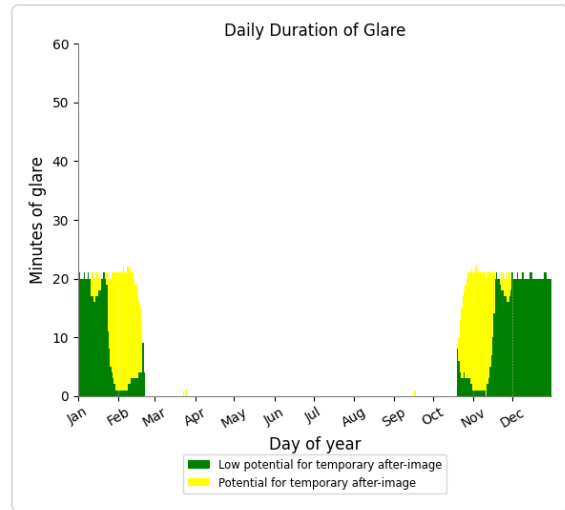
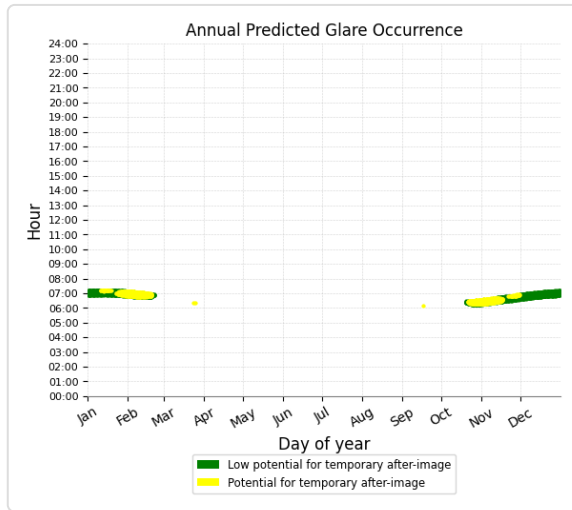


Bonsmara PV Array and OP 6

Receptor type: Observation Point

993 minutes of yellow glare

1,488 minutes of green glare

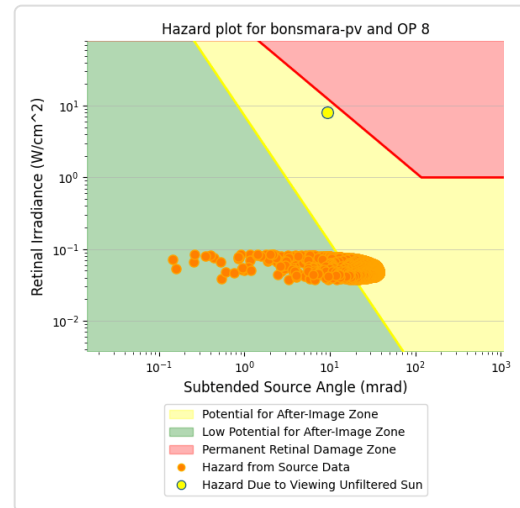
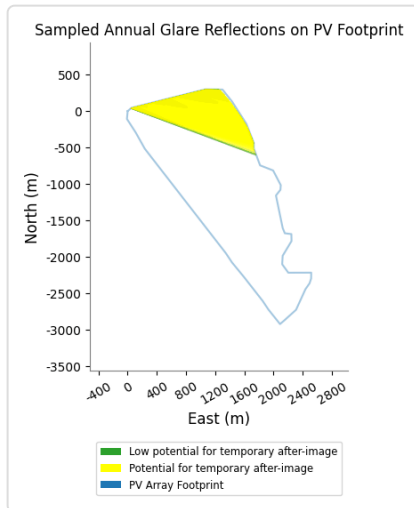
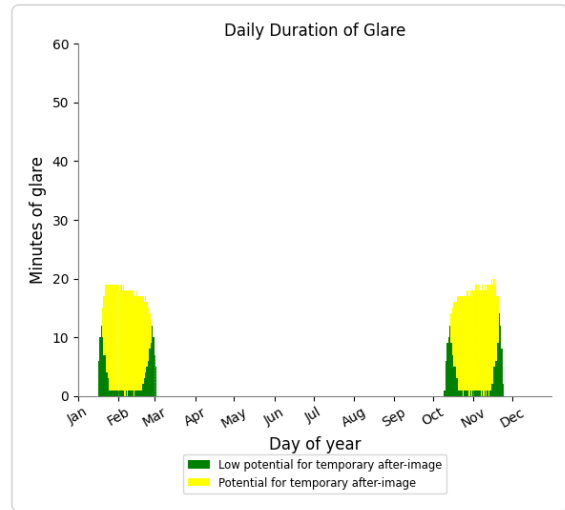
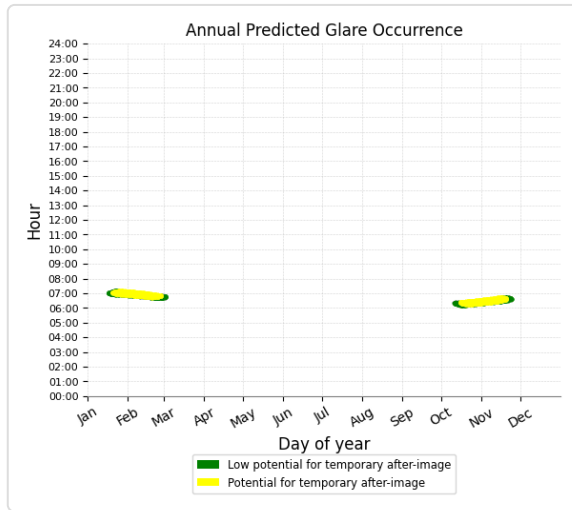


Bonsmara PV Array and OP 8

Receptor type: Observation Point

1,154 minutes of yellow glare

307 minutes of green glare



Bonsmara PV Array and OP 1

Receptor type: Observation Point

No glare found

Bonsmara PV Array and OP 2

Receptor type: Observation Point

No glare found

Bonsmara PV Array and OP 7

Receptor type: Observation Point

No glare found

Bonsmara PV Array and OP 9

Receptor type: Observation Point

No glare found

Bonsmara PV Array and OP 10

Receptor type: Observation Point

No glare found

Bonsmara PV Array and OP 11

Receptor type: Observation Point

No glare found

Assumptions

"Green" glare is glare with low potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.

"Yellow" glare is glare with potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.

Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.

The algorithm does not rigorously represent the detailed geometry of a system; detailed features such as gaps between modules, variable height of the PV array, and support structures may impact actual glare results. However, we have validated our models against several systems, including a PV array causing glare to the air-traffic control tower at Manchester-Boston Regional Airport and several sites in Albuquerque, and the tool accurately predicted the occurrence and intensity of glare at different times and days of the year.

Several V1 calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare. This primarily affects V1 analyses of path receptors.

Random number computations are utilized by various steps of the annual hazard analysis algorithm. Predicted minutes of glare can vary between runs as a result. This limitation primarily affects analyses of Observation Point receptors, including ATCTs. Note that the SGHAT/ ForgeSolar methodology has always relied on an analytical, qualitative approach to accurately determine the overall hazard (i.e. green vs. yellow) of expected glare on an annual basis.

The analysis does not automatically consider obstacles (either man-made or natural) between the observation points and the prescribed solar installation that may obstruct observed glare, such as trees, hills, buildings, etc.

The subtended source angle (glare spot size) is constrained by the PV array footprint size. Partitioning large arrays into smaller sections will reduce the maximum potential subtended angle, potentially impacting results if actual glare spots are larger than the sub-array size. Additional analyses of the combined area of adjacent sub-arrays can provide more information on potential glare hazards. (See previous point on related limitations.)

The variable direct normal irradiance (DNI) feature (if selected) scales the user-prescribed peak DNI using a typical clear-day irradiance profile. This profile has a lower DNI in the mornings and evenings and a maximum at solar noon. The scaling uses a clear-day irradiance profile based on a normalized time relative to sunrise, solar noon, and sunset, which are prescribed by a sun-position algorithm and the latitude and longitude obtained from Google maps. The actual DNI on any given day can be affected by cloud cover, atmospheric attenuation, and other environmental factors.

The ocular hazard predicted by the tool depends on a number of environmental, optical, and human factors, which can be uncertain. We provide input fields and typical ranges of values for these factors so that the user can vary these parameters to see if they have an impact on the results. The speed of SGHAT allows expedited sensitivity and parametric analyses.

The system output calculation is a DNI-based approximation that assumes clear, sunny skies year-round. It should not be used in place of more rigorous modeling methods.

Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid based on aggregated research data. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.

Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.

Refer to the Help page at www.forgesolar.com/help/ for assumptions and limitations not listed here.

Default glare analysis parameters and observer eye characteristics (for reference only):

- Analysis time interval: 1 minute
- Ocular transmission coefficient: 0.5
- Pupil diameter: 0.002 meters
- Eye focal length: 0.017 meters
- Sun subtended angle: 9.3 milliradians

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