Solar Glint and Glare Study for the CBSS Project

The solar glare assessments in Canada typically utilize Sandia National Laboratories' Solar Glare Hazard Analysis Tool (SGHAT) through ForgeSolar's GlareGauge software. This software has been used to conduct a solar glint and glare study for the Cambridge Bay Solar + Storage project.

1. Assessment Input Parameters

The photovoltaic arrays, point receptors, flight path receptors, and transportation route receptors were plotted using an interactive Google map, and site-specific data was entered into the software before modeling. The details of the input parameters specified for the analysis are described in the following.

1.1. PV Array

The PV array area, named **PV array 1**, for the proposed 3 MW AC solar system design has been plotted on the interactive Google map and can be seen in Figure 1. The details of the solar system design are presented in Table 1.

Figure 1: PV array 1 on the interactive Google map.

Table 1: PV Array Specified Parameters

Input Parameter	Specified Value	Description
Axis tracking	None (fixed)	Modules are mounted on fixed tilt racking.
Orientation	180°	Azimuthal position measured from true north.
Panel tilt	35°	Tilt angle of modules.
Module surface material	Smooth glass with anti-reflective coating	Surface material of modules.
Reflectivity varies with the incidence angle	Yes	Reflectivity is calculated as a function of module surface material and incidence angle between the panel normal and sun position.
Correlate slope error with module surface type	Yes	Slope error specifies the amount of scatter that occurs from the PV module.
Height above ground	1 m	Height of PV panels.

1.2. Flight Paths

Two two-mile (3.2km) long flight paths approaching Cambridge Bay Airport from both sides have been included in this solar glare study, representing the landing approaches to the runway. These two paths, named **FP1** and **FP2**, utilize a typical glide slope of 3°, ending 50 feet (15m) above the runway threshold. The study considers flight paths with a maximum downward viewing angle of 30° from horizontal, accounting for obstructions in the cockpit below the windshield. This analysis has set the Azimuthal viewing angle for airplane pilots to ±50° from the center (100° total field of view). These two flight paths are shown in Figure 2.

Figure 2: FP1 and FP2 on the interactive Google map.

1.3. Route Paths

In this study, we have identified two routes with the highest probability of being affected by glint and glare from the solar system, referred to as **Route 1** and **Route 2**. Both are two-way routes with a horizontal viewing angle of 50 degrees for motorists. **Route 1**, approximately 1.35 km in length, is the existing route adjacent to the solar system site. **Route 2**, approximately 1.92 km long, is located within the community and runs alongside the bay. These two routes are indicated in Figure 3.

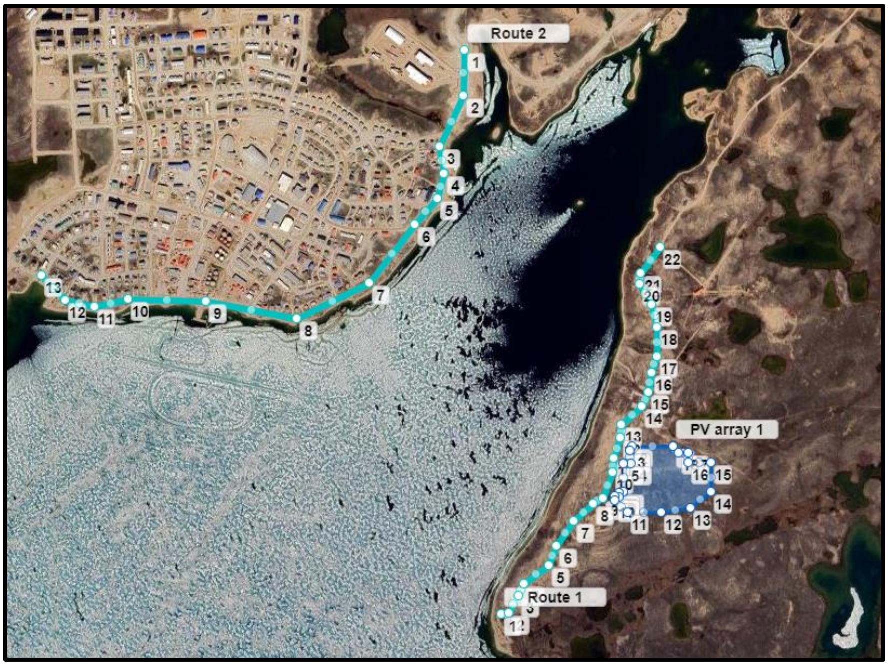


Figure 3: Route 1 and Route 2 on the interactive Google map.

1.4. Observation Points

Seven observation points have been considered in this analysis, covering existing buildings at various locations on both sides of the bay. Observation Point 1 (**OP1**) is located at the main building (control room) of Cambridge Bay Airport to assess the potential glint and glare effects on the staff. Since Cambridge Bay does not have an air traffic control tower (ATCT), this point is used as a generic observation point with a height of 4 meters to adapt to the building's structure. Another observation point, **OP7**, is situated near the airport's fuel tanks. Both of these points are illustrated in Figure 4.

Figure 4: OP1 and OP7 on the interactive Google map.

Two buildings on the east side of the bay, located near the solar system site, have been identified for this study. Observation points **OP2** and **OP6** have been placed at these buildings, representing the structures to the north and south of the solar system site, respectively. These observation points are illustrated in Figure 5.

Figure 5: OP2 and OP6 on the interactive Google map.

Additionally, three observation points have been placed at three dwellings situated at the corners of the community closest to the solar system site on the west side of the bay. These points, designated as **OP3**, **OP4**, and **OP5**, are intended to evaluate the effects of the solar system installation on the buildings in Cambridge Bay. Their locations are indicated in Figure 6.

Figure 6: OP3, OP4, and OP5 on the interactive Google map.

FORGESOLAR GLARE ANALYSIS

Project: **Cambridge Bay - 4.2 MWDC - Glare Study 1**

Solar Design: Design 3 - 1500 VDC - 4.2 MWDC - South Facing (row space 25 ft) Location: Cambridge Bay - New Site 1 (69.109607, -105.023212)

Site configuration: **Cambridge Bay - Site 1**

Client: High Latitude Energy Consulting

Created 02 May, 2024
Updated 02 May, 2024
Time-step 1 minute
Timezone offset UTC-7
Minimum sun altitude 0.0 deg
DNI peaks at 1,000.0 W/m^2
Site ID 118139.20293

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

Glare Policy Adherence

The following table estimates the policy adherence of this glare analysis according to the **2021** U.S. Federal Aviation Administration Policy:

Review of Solar Energy System Projects on Federally-Obligated Airports

This policy may require the following criteria be met for solar energy systems on airport property:

- No glare of any kind for Air Traffic Control Tower(s) ("ATCT") at cab height.
- Default analysis and observer characteristics, including 1-minute time step.

ForgeSolar is not affiliated with the U.S. FAA and does not represent or speak officially for the U.S. FAA. ForgeSolar cannot approve or deny projects - results are informational only. Contact the relevant airport and FAA district office for information on policy and requirements.

COMPONENT	STATUS	DESCRIPTION
Analysis parameters	PASS	Analysis time interval and eye characteristics used are acceptable
ATCT(s)	N/A	No ATCT receptors assessed

The referenced policy can be read at https://www.federalregister.gov/d/2021-09862

Component Data

This report includes results for PV arrays and Observation Point ("OP") receptors marked as ATCTs. Components that are not pertinent to the policy, such as routes, flight paths, and vertical surfaces, are excluded.

PV Arrays

Name: PV array 1
Description: Design 3 - 1500 VDC - 4 MWDC - South Facing - row space 25 ft
Axis tracking: Fixed (no rotation)
Tilt: 35.0°
Orientation: 180.0°
Rated power: 4220.0 kW
Panel material: Smooth glass with 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	69.110251	-105.022017	1.00	1.00	2.00
2	69.110247	-105.025290	0.00	1.00	1.00
3	69.110144	-105.025408	0.00	1.00	1.00
4	69.109753	-105.025386	0.00	1.00	1.00
5	69.109757	-105.025934	0.00	1.00	1.00
6	69.108973	-105.025944	0.00	1.00	1.00
7	69.108950	-105.026298	0.00	1.00	1.00
8	69.108831	-105.026298	0.00	1.00	1.00
9	69.108835	-105.026642	0.00	1.00	1.00
10	69.108713	-105.026631	0.00	1.00	1.00
11	69.108395	-105.025633	0.00	1.00	1.00
12	69.108391	-105.022929	0.12	1.00	1.12
13	69.108521	-105.020644	0.50	1.00	1.50
14	69.108961	-105.019013	1.00	1.00	2.00
15	69.109788	-105.019013	1.00	1.00	2.00
16	69.109784	-105.020784	1.00	1.00	2.00
17	69.110069	-105.020811	1.00	1.00	2.00
18	69.110073	-105.021588	1.00	1.00	2.00

Observation Point ATCT Receptors

No ATCT receptors were included in the analysis.

Glare Analysis Results

Summary of Results No glare predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
PV array 1	35.0	180.0	0	0.0	0	0.0	5,726,000.0

No ATCT receptors were included in the analysis.

PV: PV array 1

No ATCT receptors assessed.

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

FORGESOLAR GLARE ANALYSIS

Project: **Cambridge Bay - 4.2 MWDC - Glare Study 1**

Solar Design: Design 3 - 1500 VDC - 4.2 MWDC - South Facing (row space 25 ft) Location: Cambridge Bay - New Site 1 (69.109607, -105.023212)

Site configuration: **Cambridge Bay - Site 1**

Client: High Latitude Energy Consulting

Created 02 May, 2024
Updated 02 May, 2024
Time-step 1 minute
Timezone offset UTC-7
Minimum sun altitude 0.0 deg
DNI peaks at 1,000.0 W/m^2
Category 1 MW to 5 MW
Site ID 118139.20293

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
	°	°	min	hr	min	hr	kWh
PV array 1	35.0	180.0	1,101	18.4	1,889	31.5	5,726,000.0

Total 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
Route 1	143	2.4	1,889	31.5
Route 2	0	0.0	0	0.0
FP 1	0	0.0	0	0.0
FP 2	0	0.0	0	0.0
OP 1	421	7.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	537	8.9	0	0.0

Component Data

PV Arrays

Name: PV array 1
Description: Design 3 - 1500 VDC - 4 MWDC - South Facing - row space 25 ft
Axis tracking: Fixed (no rotation)
Tilt: 35.0°
Orientation: 180.0°
Rated power: 4220.0 kW
Panel material: Smooth glass with 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	69.110251	-105.022017	1.00	1.00	2.00
2	69.110247	-105.025290	0.00	1.00	1.00
3	69.110144	-105.025408	0.00	1.00	1.00
4	69.109753	-105.025386	0.00	1.00	1.00
5	69.109757	-105.025934	0.00	1.00	1.00
6	69.108973	-105.025944	0.00	1.00	1.00
7	69.108950	-105.026298	0.00	1.00	1.00
8	69.108831	-105.026298	0.00	1.00	1.00
9	69.108835	-105.026642	0.00	1.00	1.00
10	69.108713	-105.026631	0.00	1.00	1.00
11	69.108395	-105.025633	0.00	1.00	1.00
12	69.108391	-105.022929	0.12	1.00	1.12
13	69.108521	-105.020644	0.50	1.00	1.50
14	69.108961	-105.019013	1.00	1.00	2.00
15	69.109788	-105.019013	1.00	1.00	2.00
16	69.109784	-105.020784	1.00	1.00	2.00
17	69.110069	-105.020811	1.00	1.00	2.00
18	69.110073	-105.021588	1.00	1.00	2.00

Route Receptors

Name: Route 1
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	69.105520	-105.035610	0.00	0.00	0.00
2	69.105531	-105.035057	0.00	0.00	0.00
3	69.106023	-105.034290	0.00	0.00	0.00
4	69.106368	-105.033883	0.00	0.00	0.00
5	69.106899	-105.031866	0.00	0.00	0.00
6	69.107450	-105.031308	0.00	0.00	0.00
7	69.108147	-105.029913	0.00	0.00	0.00
8	69.108640	-105.028325	0.00	0.00	0.00
9	69.108786	-105.027615	0.00	0.00	0.00
10	69.109509	-105.026821	0.00	0.00	0.00
11	69.109919	-105.026735	0.00	0.00	0.00
12	69.110493	-105.026209	0.00	0.00	0.00
13	69.110875	-105.026081	0.00	0.00	0.00
14	69.111384	-105.024493	0.31	0.00	0.31
15	69.111785	-105.023947	0.30	0.00	0.30
16	69.112351	-105.023753	0.04	0.00	0.04
17	69.112787	-105.023303	0.22	0.00	0.22
18	69.113613	-105.023260	0.00	0.00	0.00
19	69.114278	-105.023743	0.00	0.00	0.00
20	69.114847	-105.024666	0.00	0.00	0.00
21	69.115149	-105.024612	0.00	0.00	0.00
22	69.115872	-105.023024	0.00	0.00	0.00

Name: Route 2
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	69.121442	-105.038557	0.00	0.00	0.00
2	69.120157	-105.038685	0.00	0.00	0.00
3	69.118735	-105.040531	0.00	0.00	0.00
4	69.117955	-105.040187	0.00	0.00	0.00
5	69.117251	-105.040702	0.00	0.00	0.00
6	69.116532	-105.042548	0.00	0.00	0.00
7	69.114865	-105.046110	0.00	0.00	0.00
8	69.113855	-105.051903	0.00	0.00	0.00
9	69.114344	-105.059070	0.00	0.00	0.00
10	69.114406	-105.065293	0.00	0.00	0.00
11	69.114191	-105.067911	0.00	0.00	0.00
12	69.114375	-105.070271	0.00	0.00	0.00
13	69.115079	-105.072116	0.00	0.00	0.00

Flight Path Receptors

Name: FP 1
Description:
Threshold height: 15 m
Direction: 127.0°
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	69.112452	-105.153765	1.15	15.24	16.39
Two-mile	69.129852	-105.218605	26.42	158.65	185.08

Name: FP 2
Description:
Threshold height: 15 m
Direction: 307.0°
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	69.103841	-105.122359	0.88	15.24	16.12
Two-mile	69.086441	-105.057545	1.00	183.81	184.81

Discrete Observation Point Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (m)	Height (m)
OP 1	1	69.107240	-105.121614	1.36	4.00
OP 2	2	69.114655	-105.020007	0.82	0.00
OP 3	3	69.114115	-105.051924	0.00	0.00
OP 4	4	69.117399	-105.041345	0.00	0.00
OP 5	5	69.114644	-105.069732	0.00	0.00
OP 6	6	69.105545	-105.035769	0.00	0.00
OP 7	7	69.103725	-105.094500	0.00	0.00

Glare Analysis Results

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

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
PV array 1	35.0	180.0	1,101	18.4	1,889	31.5	5,726,000.0

Total 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
Route 1	143	2.4	1,889	31.5
Route 2	0	0.0	0	0.0
FP 1	0	0.0	0	0.0
FP 2	0	0.0	0	0.0
OP 1	421	7.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	537	8.9	0	0.0

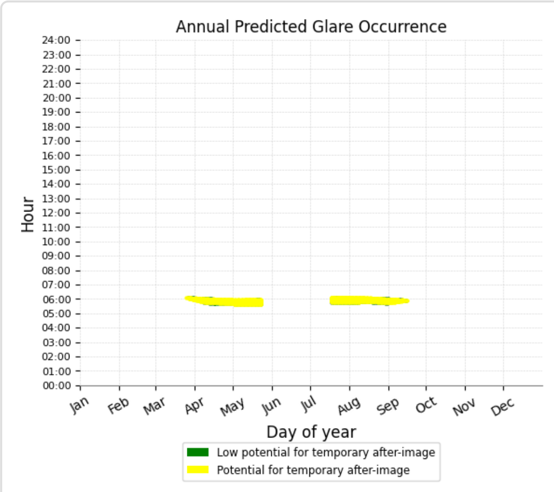
PV: PV array 1 potential temporary after-image

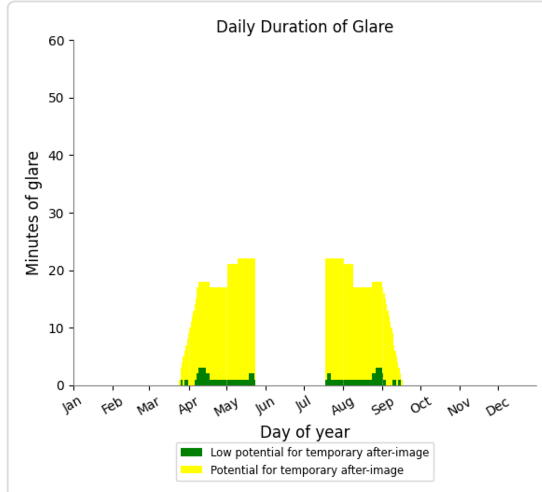
Receptor results ordered by category of glare

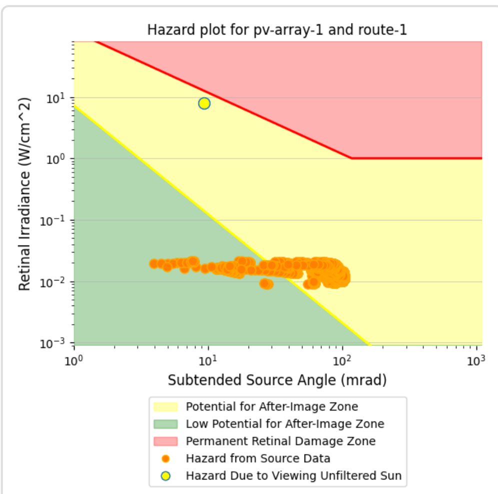
Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Route 1	143	2.4	1,889	31.5
Route 2	0	0.0	0	0.0
FP 1	0	0.0	0	0.0
FP 2	0	0.0	0	0.0
OP 1	421	7.0	0	0.0
OP 7	537	8.9	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0

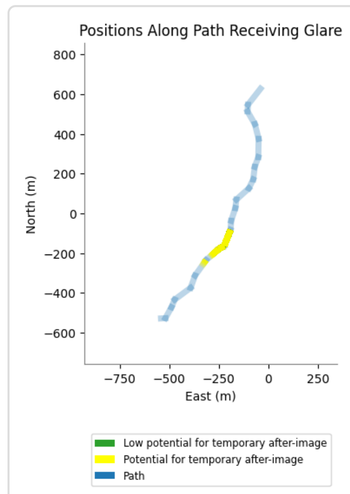
PV array 1 and Route: Route 1

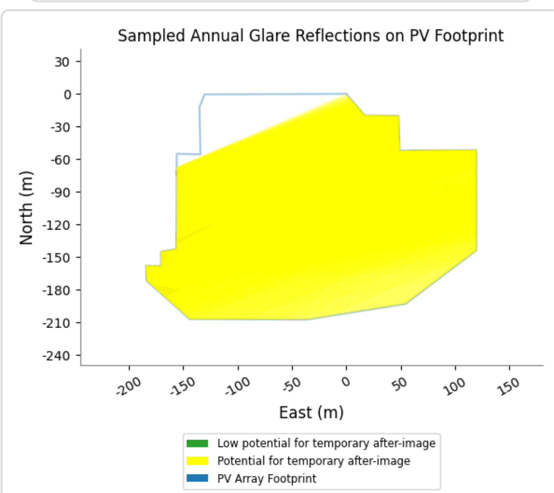
Yellow glare: 1,889 min.
Green glare: 143 min.











PV array 1 and Route: Route 2

No glare found

PV array 1 and FP: FP 1

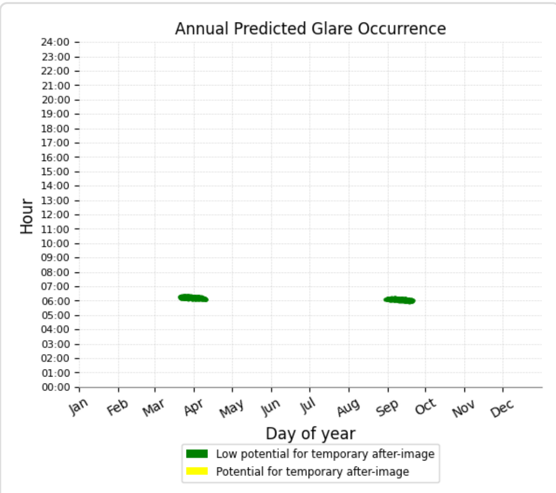
No glare found

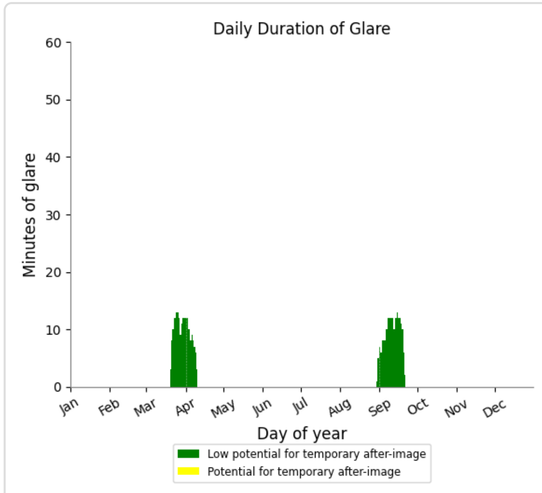
PV array 1 and FP: FP 2

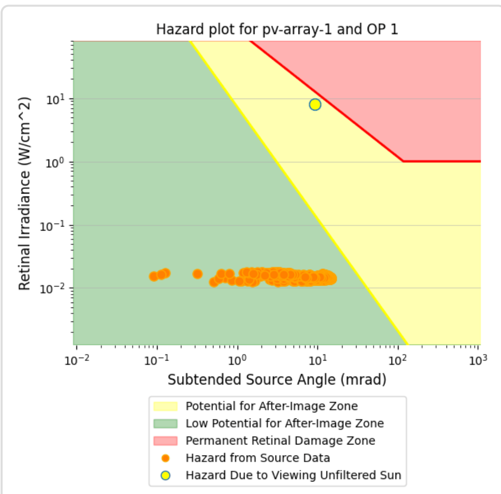
No glare found

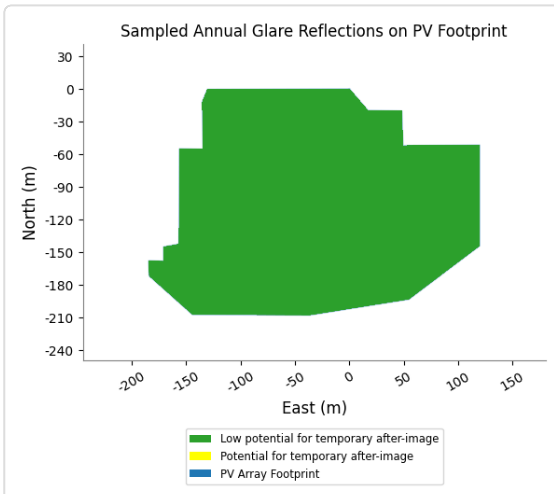
PV array 1 and OP 1

Yellow glare: none
Green glare: 421 min.



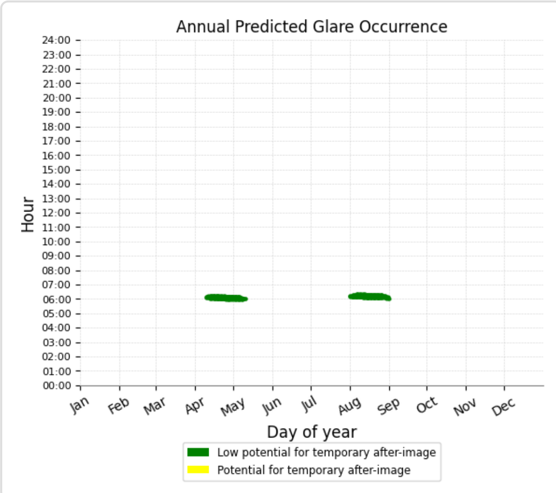


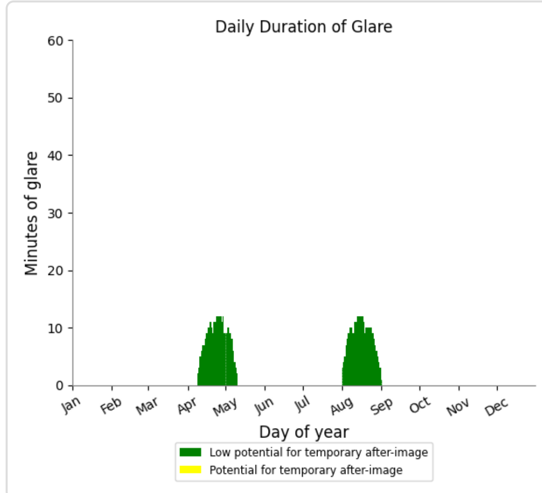


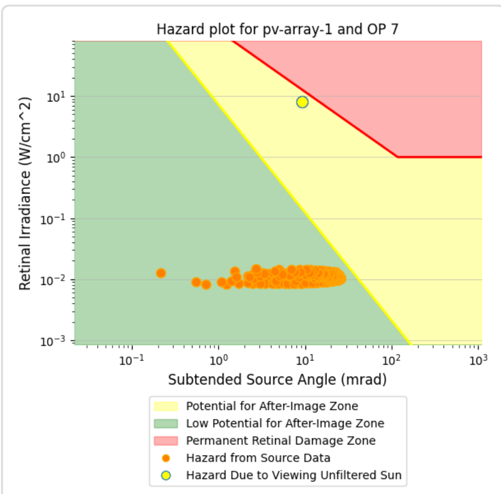


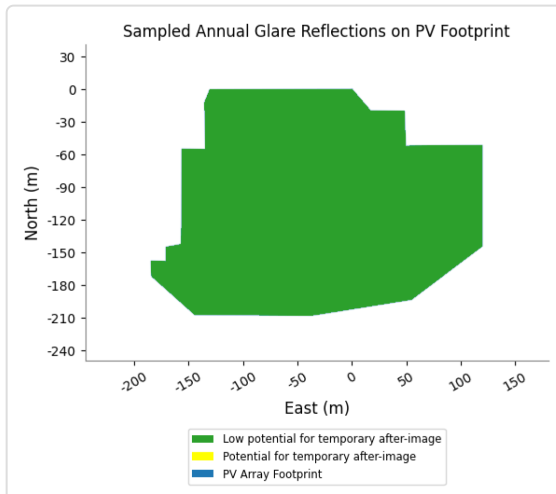
PV array 1 and OP 7

Yellow glare: none
Green glare: 537 min.









PV array 1 and OP 2

No glare found

PV array 1 and OP 3

No glare found

PV array 1 and OP 4

No glare found

PV array 1 and OP 5

No glare found

PV array 1 and OP 6

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