Solar Glare Hazard Analysis Tool (SGHAT)

Clifford K. Ho and Cianan A. Sims
Sandia National Laboratories
Concentrating Solar Technologies Dept.
Albuquerque, New Mexico
ckho@sandia.gov, (505) 844-2384

SAND2015-XXXX
SGHAT Overview

- Why do we need it?
- What does it do?
- Improvements and future plans
Glint and Glare

- **Glint and glare may cause unwanted visual impacts**
  - Pilots, air-traffic controllers, workers, motorists

- **Potential visual impacts**
  - Distraction
  - Temporary after-image (flash blindness)
  - Veiling
  - Retinal burn

**Definitions**

- **Glint:** Momentary flash of light
- **Glare:** Continuous source of excessive brightness

Road sign on Massachusetts State Route 2
Examples of Glare from Solar Technologies

**Photovoltaics**

- Images of photovoltaic panels showing glare.

**Concentrating Solar Power**

- Images of heliostats and central receiver setup at Sandia Labs, Albuquerque, NM.
- Images of dish collectors at Sandia.
- Images of parabolic trough collectors at Kramer Junction, CA.
Examples of Glare from Solar Technologies

Glare observations from C-12 cockpit at Kramer Junction, CA (from Air Force Flight Test Center 412 TW at Edwards AFB, approval #13166)

Glare observed from airport traffic control tower at Manchester-Boston Regional Airport (May 2012). The $3.5M array had to be tarped.
Types of Reflection

Specular Reflection
Polished Surfaces (e.g., mirrors, smooth glass)

Diffuse Reflection
Rough Surfaces (e.g., receivers, textured glass, snow, pavement)
Reflectivity

Percentage of Sunlight Reflected

<table>
<thead>
<tr>
<th>Material</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow</td>
<td>80</td>
</tr>
<tr>
<td>White Concrete</td>
<td>70</td>
</tr>
<tr>
<td>Bare Aluminum</td>
<td>60</td>
</tr>
<tr>
<td>Vegetation</td>
<td>50</td>
</tr>
<tr>
<td>Bare Soil</td>
<td>40</td>
</tr>
<tr>
<td>Wood Shingle</td>
<td>30</td>
</tr>
<tr>
<td>Water</td>
<td>20</td>
</tr>
<tr>
<td>Black Asphalt</td>
<td>10</td>
</tr>
<tr>
<td>Mirrors</td>
<td></td>
</tr>
<tr>
<td>PV Solar Panels</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from ACRP Synthesis 28 “Investigating Safety Impacts of Energy Technologies on Airports and Aviation”
Impact of Light Entering the Eye

- Need to calculate
  - Power entering eye
    - Function of irradiance at the cornea (front of eye)
  - Subtended angle of glare source (size / distance)
Potential Ocular Impacts

Potential for Permanent Eye Damage (retinal burn) (0.15 s exposure)

- Brumleve (1977) [1]
- Sliney and Freasier (1973, Table III) [3]
- Metcalf and Horn (1958) [12]
- Severin et al. (1962) [13]
- Saur and Dobrash (1969) [14]

Equations and analysis methods detailed in Ho et al. (2010, 2011)
New Federal Policy

- U.S. Department of Transportation, Federal Aviation Administration (78 FR 63276, October 23, 2013)
  - “...the FAA requires the use of the SGHAT to demonstrate compliance with the standards for measuring ocular impact stated above for any proposed solar energy system located on a federally-obligated airport.”
  - “All sponsors of federally-obligated airports who propose to install or to permit others to install solar energy systems on the airport must attach the SGHAT report, outlining solar panel glare and ocular impact, for each point of measurement to the Notice of Proposed Construction Form 7460-1.”
DoD issued guidance in June 2014 requiring the use of SGHAT for renewable energy projects near DoD Aviation Operations.
SGHAT Used at DoD Sites

- 106th Rescue Wing
- 374th Civil Engineer Squadron
- AF/A3O-BA (Bases & Ranges)
- Air Force Material Command
- Andersen Air Force Base (Guam)
- Eglin AFB
- Eielson Air Force Base (AK)
- Fairchild AFB
- Fort Detrick (Army, Maryland)
- Hanscomb AFB
- Hickam Air Force Base (HI)
- Joint Base Anacostia Boling
- Laughlin AFB
- Naval Air Station Fort Worth
- Reserve Base
- Naval AS Pensacola
- Naval Facilities Engineering Command Midwest
- Nellis AFB
- Osan Air Base (South Korea)
- Patuxent River Naval Air Station
- Pearl Harbor Naval Station
- Travis AFB
- Tyndall AFB
- USAF Air Mobility Command
- USAF CEC, Strategic Asset Util.
- Wake Island Airfield
- Yokota Air Base (Japan)
SGHAT Overview

- Why do we need it?
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Solar Glare Hazard Analysis Tool

- Free web-based software that predicts impacts of glare and annual energy production from photovoltaic arrays

- Uses interactive Google Maps
- Very fast annual simulations
Approach to Runway 24

Observation points approaching Runway 24 from the northeast.
Data Entry for PV Tilt/Orientation, Reflectance, DNI, and Elevations

PV Array

Array name
PV array 1

Description

Axis tracking
None

Panel tilt
20 deg

Orientation (Calculate declination)
110 deg

Rated power
530 kW

Module surface material
Smooth glass without ARC

Slope error
10 mrad

Correlate slope error to module surface type (view data)

Analysis configuration

Height units
feet

Time interval
1 min

Sun angle
9.3 mrad

Peak DNI
1000 W/m²

DNI varies?

Ocular transmission coefficient
0.5

Pupil diameter
0.002 m

Eye focal length
0.017 m

Okay
Glare Occurrence Plot

3-minute time interval. All times are in standard time. For Daylight Savings Time add one hour.

Legend:
- Green: Glare beyond 50 deg from pilot line-of-sight
- Dark Green: Low potential for temporary after-image
- Yellow: Potential for temporary after-image
- Red: Potential for permanent eye damage
Glare Animation Feature
Mitigation of glare while maximizing energy production

<table>
<thead>
<tr>
<th>Azimuthal Angle (degrees)</th>
<th>Elevation Angle (degrees)</th>
<th>Relative Annual Energy Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>43</td>
<td>100.0%*</td>
</tr>
<tr>
<td>200</td>
<td>20.6</td>
<td>93.9%**</td>
</tr>
<tr>
<td>120</td>
<td>40</td>
<td>88.9%</td>
</tr>
<tr>
<td>120</td>
<td>60</td>
<td>87.2%</td>
</tr>
<tr>
<td>110</td>
<td>20.6</td>
<td>82.4%</td>
</tr>
<tr>
<td>110</td>
<td>30</td>
<td>81.0%</td>
</tr>
<tr>
<td>110</td>
<td>40</td>
<td>84.7%</td>
</tr>
<tr>
<td>120</td>
<td>60</td>
<td>83.7%</td>
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<tr>
<td>110</td>
<td>50</td>
<td>82.8%</td>
</tr>
<tr>
<td>130</td>
<td>70</td>
<td>81.5%</td>
</tr>
<tr>
<td>100</td>
<td>30</td>
<td>80.9%</td>
</tr>
<tr>
<td>100</td>
<td>20</td>
<td>80.8%</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
<td>79.9%</td>
</tr>
<tr>
<td>110</td>
<td>60</td>
<td>79.3%</td>
</tr>
<tr>
<td>120</td>
<td>70</td>
<td>78.3%</td>
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<tr>
<td>100</td>
<td>50</td>
<td>77.6%</td>
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<tr>
<td>90</td>
<td>20</td>
<td>77.5%</td>
</tr>
<tr>
<td>210</td>
<td>80</td>
<td>76.9%</td>
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<tr>
<td>90</td>
<td>30</td>
<td>76.4%</td>
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<tr>
<td>220</td>
<td>80</td>
<td>75.8%</td>
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<tr>
<td>90</td>
<td>40</td>
<td>74.5%</td>
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<td>110</td>
<td>70</td>
<td>74.2%</td>
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<td>100</td>
<td>60</td>
<td>74.1%</td>
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<tr>
<td>130</td>
<td>80</td>
<td>74.0%</td>
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<td>90</td>
<td>50</td>
<td>71.8%</td>
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<td>120</td>
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<td>100</td>
<td>70</td>
<td>69.2%</td>
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<tr>
<td>90</td>
<td>60</td>
<td>68.1%</td>
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<td>110</td>
<td>80</td>
<td>67.7%</td>
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<tr>
<td>90</td>
<td>70</td>
<td>63.4%</td>
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<tr>
<td>100</td>
<td>80</td>
<td>63.2%</td>
</tr>
<tr>
<td>90</td>
<td>80</td>
<td>57.8%</td>
</tr>
</tbody>
</table>

- Use SGHAT to identify PV array configurations that produce no glare
- Choose design that maximizes energy production

*Maximum energy production; produces glare to ATCT
**Current configuration; produces glare to ATCT
SGHAT Overview

- Why do we need it?
- What does it do?
- Improvements and future plans
SGHAT Enhancements since 1.0

- **2013 Q3:**
  - Flight path analysis tool
  - Component persistence (save site configurations on server)
  - Updated look-back algorithm to account for elliptical beam spread

- **2013 Q4:**
  - Editable flight path elevation
  - Expanded .csv output
  - Vary panel reflectivity based on panel material type

- **2014 Q1:**
  - Multiple PV arrays per analysis
  - Generate glare hazard plots for selected day
  - Account for glare visibility along flight paths
  - Editable viewing angle restriction along flight paths
  - Single- and dual-axis tracking with angle limit
SGHAT Enhancements since 1.0 (cont.)

- **2014 Q3**
  - Account for pilot line-of-sight in flight path results (light green glare)

- **2015 Q1**
  - Correlate slope error with panel surface material

- **In-progress**
  - Optimization tool
  - Project-based layout
  - Vertical surface analysis
  - Improved glare prediction "envelope" algorithm

Developed simplified block-space analysis for PAX River in December 2015
Assessment of Solar Glare Hazard Analysis Tool (SGHAT) for Use at USAF Air Fields

Mr. Bill Timbs
Technical Lead
3 APR 14
### Table 1
Solar PV Compatibility Project Recommended Implementation Actions

<table>
<thead>
<tr>
<th>Recommendation/Tasks</th>
<th>Staff/CME Requirement (person hours)</th>
<th>Contract Requirement (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SGHAT Modifications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Establish capability to conduct block air space analysis of project site against multiple flight paths</td>
<td>40</td>
<td>$64,000</td>
</tr>
<tr>
<td>b. Provide import of batch files containing approach paths and closed loop patterns for block air space analysis</td>
<td>80</td>
<td>32,000</td>
</tr>
<tr>
<td>c. Advanced flight path drawing tool</td>
<td>32,000</td>
<td></td>
</tr>
<tr>
<td>d. Expand account permission beyond current limit to four project locations, eight observation points, and two flight paths</td>
<td>8,000</td>
<td></td>
</tr>
<tr>
<td>e. Establish customizable analysis options, permitting user to segment ocular hazards analysis or effective energy production calculations to optimize processing speed</td>
<td>40</td>
<td>32,000</td>
</tr>
<tr>
<td>f. Add user control for saving project reviews</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>g. Investigate Fee Based Review Service Options</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>h. Organize and staff User Technical Advisory Committee for modification guidance</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>i. Facilitate Contract Agreements and liaison/oversight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>j. Provide periodic briefs to designated Management Committee</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>2. Migrate and Operationalize Enhanced SGHAT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Provide for SGHAT Hosting using virtualized servers and balancing</td>
<td>60</td>
<td>8,200</td>
</tr>
<tr>
<td>b. Provide Technical Support and Maintenance for SGHAT Program</td>
<td>40</td>
<td>24,000</td>
</tr>
<tr>
<td>c. Updating and upgrading of existing features. Development of minor features, maintenance and bug fixes</td>
<td>20</td>
<td>40,800</td>
</tr>
<tr>
<td>3. SGHAT User Reach-back and Support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Prepare AF SGHAT User's Manual Supplement for special instructions and integration of modification features</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>b. Operate SGHAT User Hotline-Mailbox</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>c. Coordinate Processing Que</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>4. Prepare and Maintain On-line Training Module</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>5. Develop and Apply Prototype Glint/Glare Areawide Analysis as AICUZ Study Element</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>6. Support in the adoption and implementation of selected recommendations</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>a. Coordination with DoD Siting Clearinghouse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Integration of Glint/Glare Policy in AICUZ Program</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>870</td>
<td>$240,000</td>
</tr>
</tbody>
</table>
Conclusions

- Glint and Glare can cause unwanted visual impacts
  - Analytical models and safety metrics have been developed
  - Models have been validated with test data
  - Web tool has been developed

- SGHAT predicts when and where glare will occur from a prescribed PV array at user-defined observation points/paths
  - Google Maps is used for easy user interface
  - SGHAT can be used to produce analyses and reports to satisfy new federal (FAA, DoD) requirements for solar installations near airports

- SGHAT predicts annual energy production
  - Systems can be quickly optimized to mitigate glare while maximizing energy production

- Expected to save costs and increase public safety
  - FAA, DoD, regulatory agencies, airports, solar energy industries, consumers, cities, businesses, residences
Acknowledgments

- DOE Solar Technologies Soft Costs Subprogram
- Bill Petrak and Chris Hugunin, FAA
- Sandia Colleagues
  - Cianan Sims, Contractor (Programmer)
  - Julius Yellowhair, Ph.D., SMTS
  - James Yuan, SMTS
  - Evan Bush and Andrew Sharp, Students
  - Victoria Smith, Steve Arroyo, Jim Muntz (9329 – SNL Server/Software Support)
Questions?

Cliff Ho
(505) 844-2384
ckho@sandia.gov
Backup Slides
FAA Flight Simulator Tests

- Impact of angle and duration of glare