

ASME 2011 5th International Conference on Energy Sustainability

Washington, DC, August 7-10, 2011

A Flux Mapping Method for Central Receiver Systems

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Overview

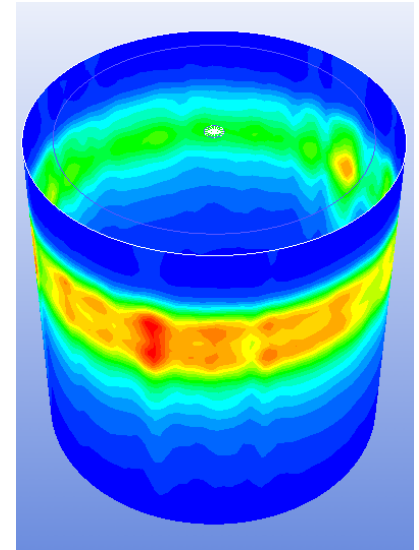
- **Introduction**
- **PHLUX Method**
- **Testing and Validation**
- **Web-Based PHLUX Tool**
- **Summary**

Introduction

- **Need tools for industry and R&D to characterize concentrated solar flux on receiver**
 - Monitor receiver performance
 - Assess heliostat tracking
 - Improve designs



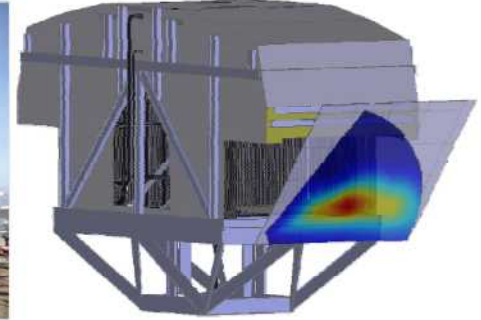
Receiver testing at the National Solar Thermal Test Facility at Sandia National Laboratories



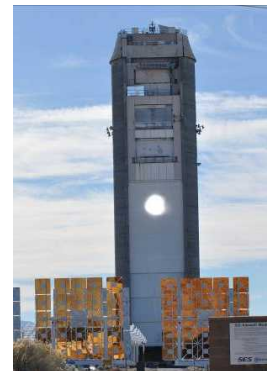
Simulated flux on a cylindrical receiver

Background

- **Existing methods can be costly and difficult to implement**
 - Flux gauges, mechanical wands, or costly infrared cameras
- **Scaling digital images with known power**
 - Complex for non-planar surfaces or when spillage occurs



from Yogeve et al., eSolar (SolarPACES 2009)



Projecting a beam from a heliostat onto the face of the tower



Objective

- **Develop accurate flux-mapping tool that is less expensive and simpler than existing methods**
- **PHLUX Method**
 - Photographic Flux Mapping Tools



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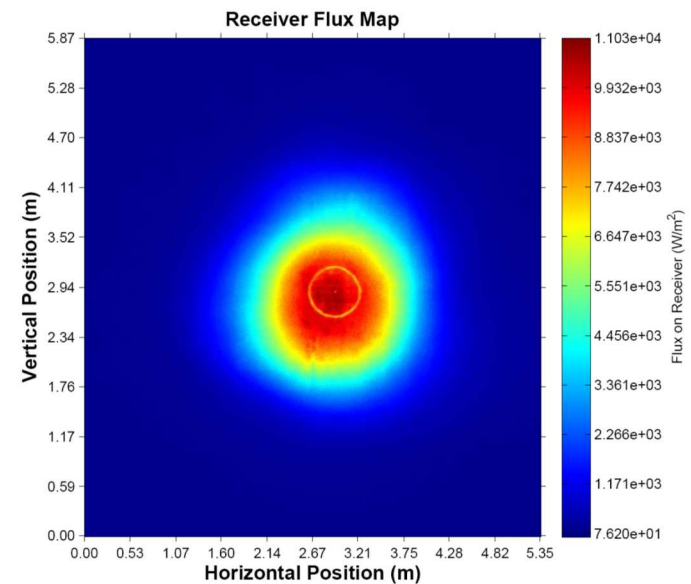
PHLUX Method

- **PHLUX Tool consist of:**

- A digital SLR camera
 - Photo of the sun
 - Scaling (size, power)
 - Photo of the desired image

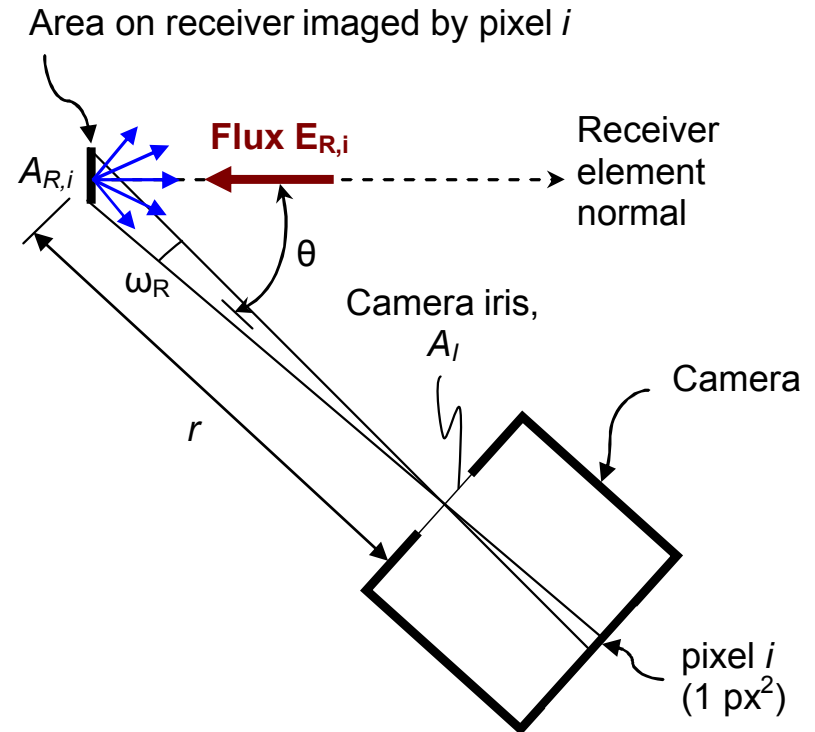
- **Algorithms/Software**

- Determines length scales and angles
- Processes irradiance distributions of the receiver



PHLUX Theory

- Assumes a diffuse (Lambertian) receiver
- Each pixel value of the camera corresponds to an elemental receiver irradiance
- Sun image is used to scale size and power for irradiance calculations
- Paper contains rigorous derivation



PHLUX Theory

$$E_{R,i} = \frac{V_{CCD,i} E_{DNI}}{\rho_{R,i} \tan^2(\gamma / 2)} \frac{\pi r_{sun_pixels}^2}{\sum_{sun} V_{CCD_sun,i}}$$

Pixel value

DNI value at time sun image was recorded

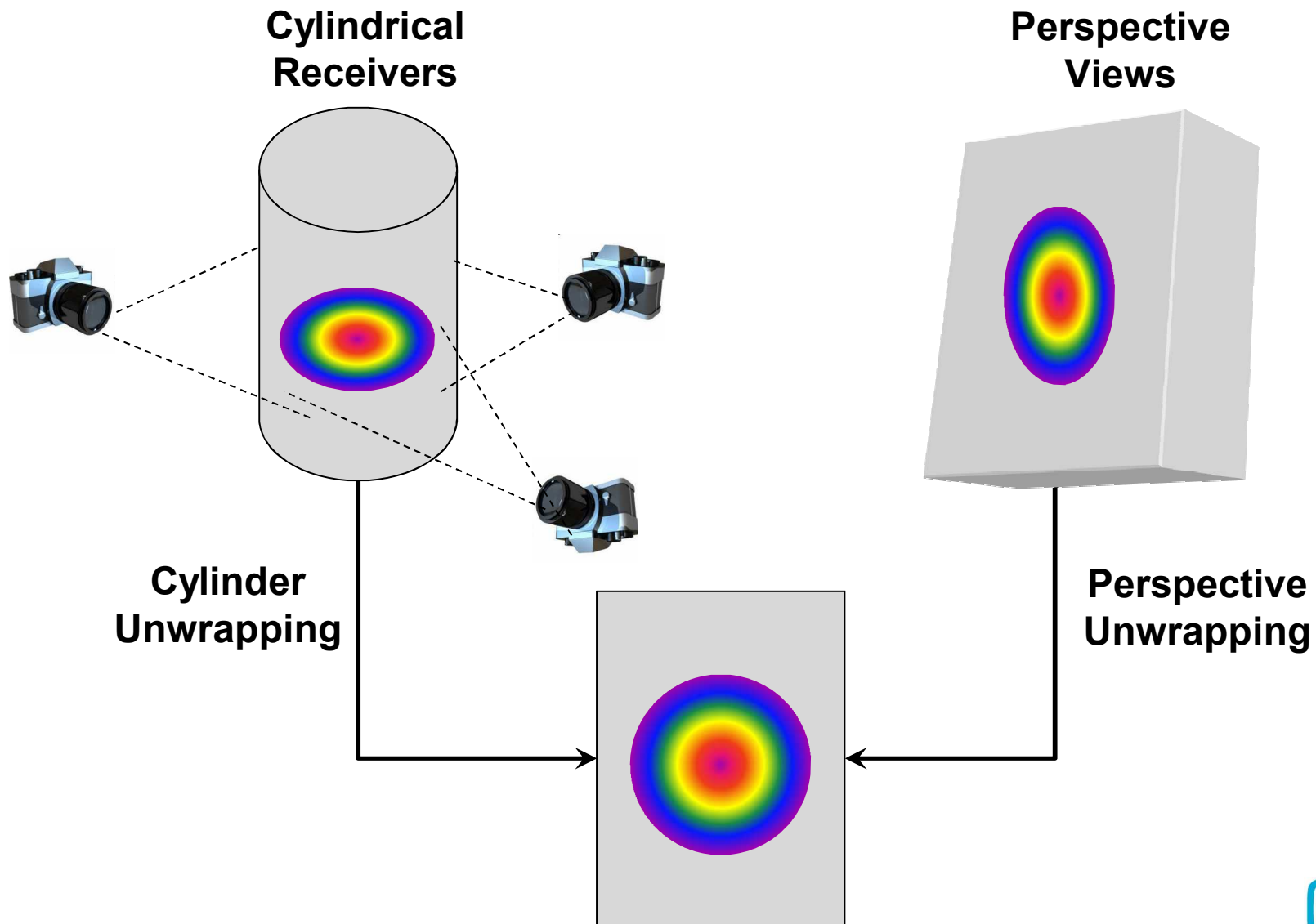
Average pixel value in sun image

Receiver irradiance corresponding to each pixel value

Reflectivity of receiver element corresponding to pixel i^*

Subtended angle of the sun (~9.3 mrad)

Additional Considerations



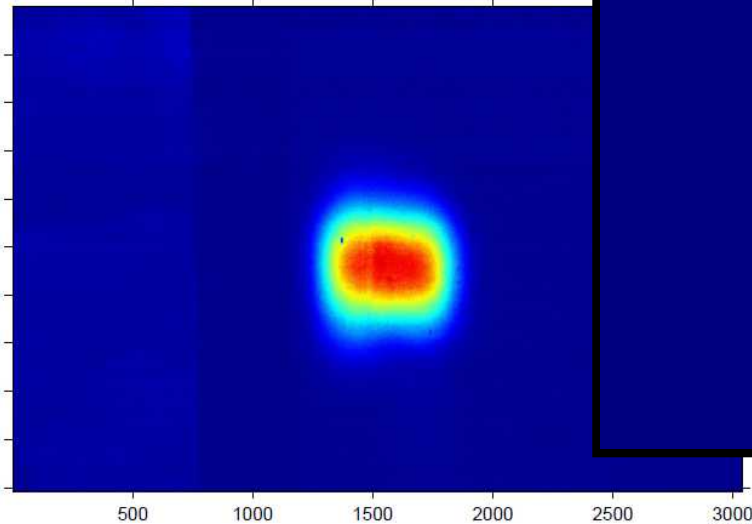
PHLUX Procedure



Receiver Flux Map

Vertical Position (m)
13.5
12.0
10.5
9.0
7.5
6.0
4.5
3.0
1.5
0.0

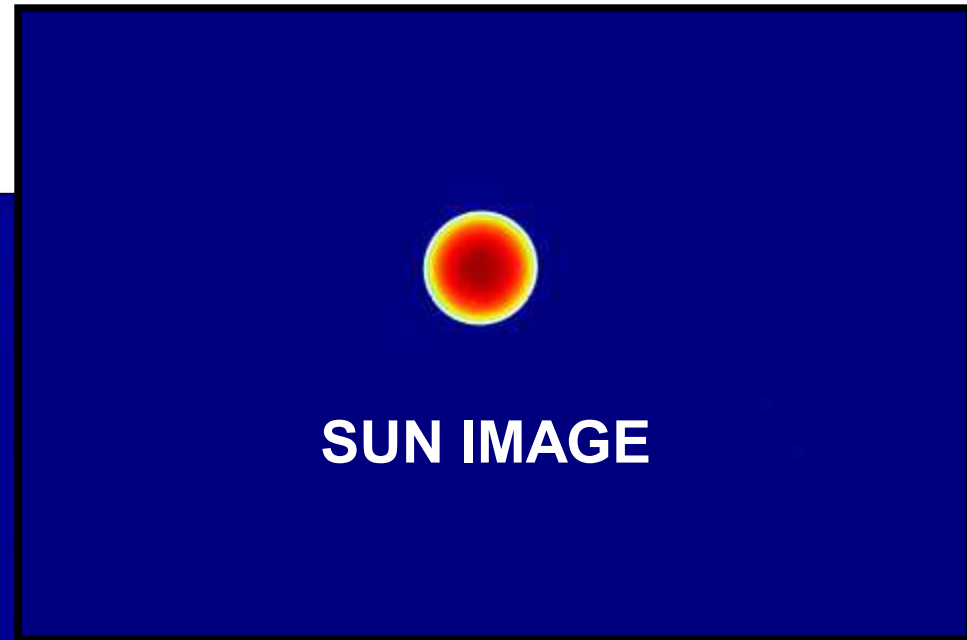
Vertical Position (pixels)
200
400
600
800
1000
1200
1400
1600
1800
2000



Horizontal Position (pixels)
500 1000 1500 2000 2500 3000



Angle on Receiver (°)
-80 -20 0 20 80



SUN IMAGE

360

180

3445.93

1722.97



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Testing and Validation

- **Applied PHLUX method to heliostat beams projected onto face of tower**
 - National Solar Thermal Test Facility, Sandia National Labs, Albuquerque, NM



Receiver and Sun Images

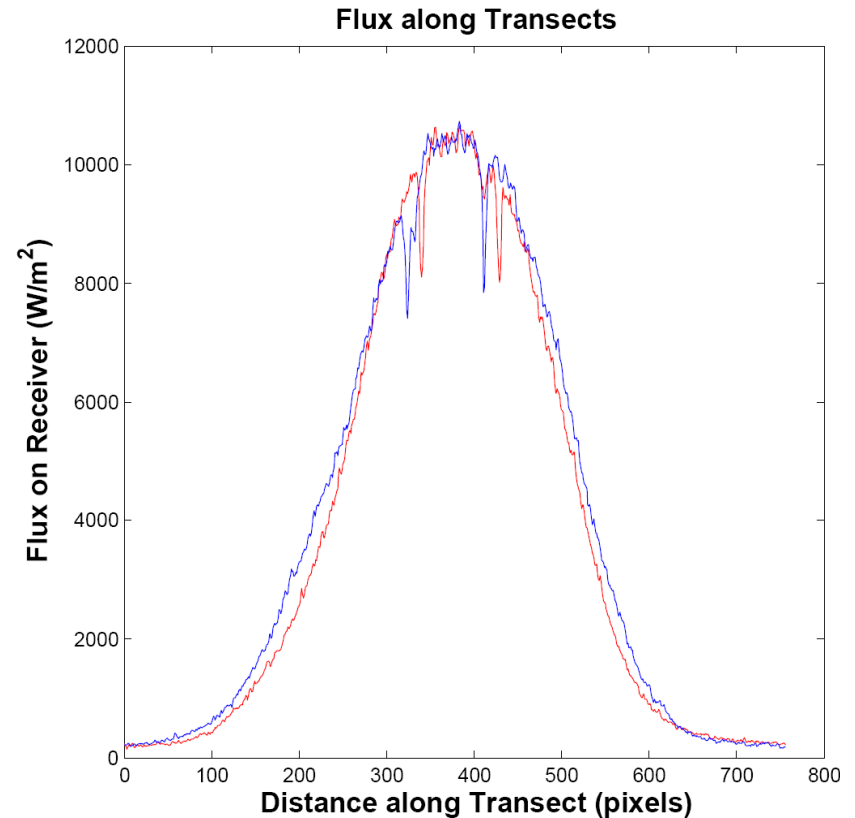
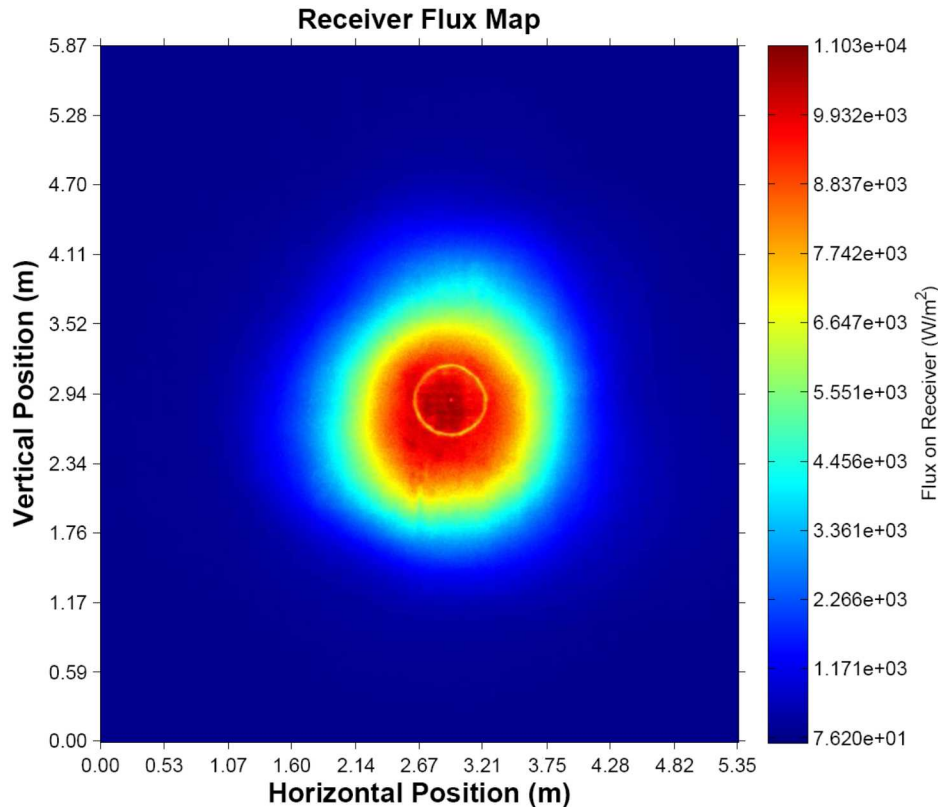


Image of beam on tower



Image of sun

PHLUX Map



- Peak flux using PHLUX method was within 2% of that measured by flux gauge
- Additional tests using multiple heliostats showed that the PHLUX method yielded results that were within 10% of that measured by flux gauge

PS10 (Spain)

- **PHLUX method was applied during tour of PS10 in Spain**
 - PHLUX-calculated irradiance on receiver was within the range measured by their sensors

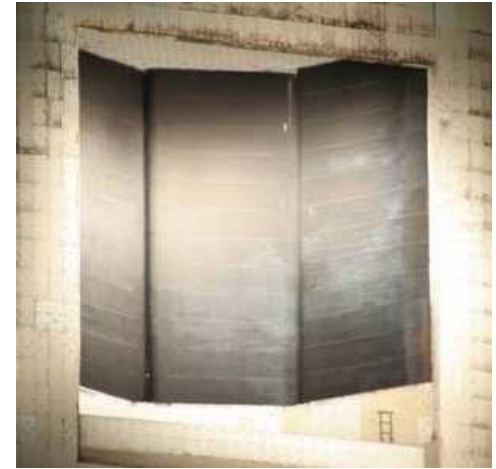
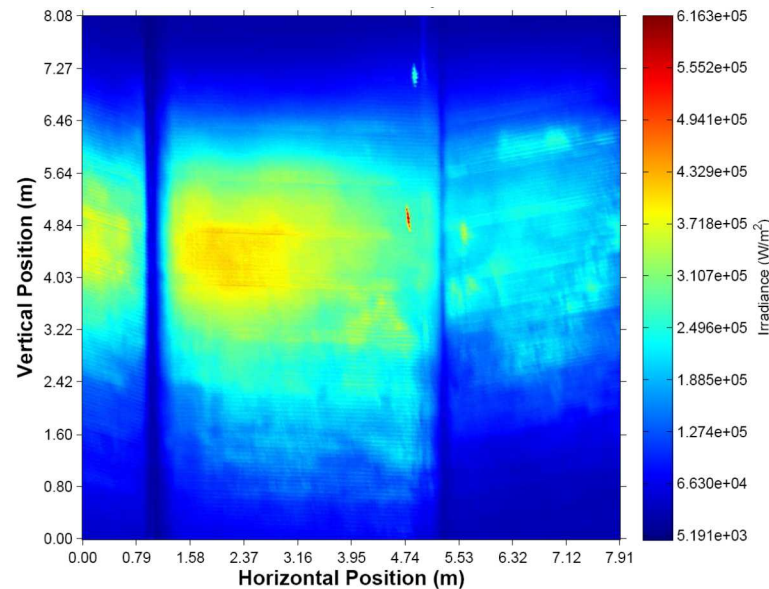


Photo from David Gill





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Web-Based PHLUX Tool

Sandia National Laboratories: Solar Glare and Flux Mapping Tools - Mozilla Firefox

File Edit View History Bookmarks Tools Help

Sandia National Laboratorie... +

http://www.sandia.gov/phlux

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Solar Glare and Flux Mapping Tools

Registration

Empirical Glare Analysis

PHLUX Mapping Analysis

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Solar Glare and Flux Mapping Tools

Measurement of reflected solar irradiance is receiving significant attention by industry, military, and government agencies to assess potential impacts of glint and glare from growing numbers of solar power installations around the world. In addition, characterization of the incident solar flux distribution on central receivers for concentrating solar power applications is important to monitor and maintain system performance.

This website provides tools to analytically and empirically quantify glare from reflected light and determine the potential impact (e.g., temporary after-image, retinal burn). In addition, tools are available to empirically determine the irradiance distribution on a central receiver. Empirical results are based on digital photographs uploaded by the user. Instructions are included in each of the links below.

To access these tools, please [register](#) by following the link or clicking the menu option on the left.

Empirical Glare Analysis
Upload Glare Photos

Flux Mapping Analysis
Upload Receiver Photos

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ories: Solar Glare and Flux Mapping Tools: PHLUX Mapping Analysis - Mozil

okmarks Tools Help

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share.sandia.gov/glare/fluxmap.html

Step 3: Outline Transect Calculation Area and Click Done

Ellipse Definition

Axis 1, Point 1, x (pixels): 369 Axis 1, Point 1, y (pixels): 255

Axis 1, Point 2, x (pixels): 519 Axis 1, Point 2, y (pixels): 438

Axis 2 Length (pixels): 237

Done

Image Adjustment

Contrast: Brightness:

Measurement Tools

Draw Ellipse Draw Circle Move Zoom In Zoom Out

Image Measurement

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Summary

- **PHLUX method provides simple and inexpensive flux mapping tool**
 - Only requires digital camera and reflectivity of receiver
 - Uses image of sun (and DNI) to scale power and size
 - Can be applied to arbitrary geometry
- **PHLUX method validated with testing**
- **Web-based tool developed**



Next Steps

- **Continue testing PHLUX method**
 - Evaluate impact of camera settings and filters
 - Evaluate impact of different receiver geometries
- **Resolve security issues for website before public release**
- **Demonstrate calculation of reflectivity map for receivers with non-uniform reflectivity**
- **Develop stand-alone software for PHLUX method**
 - Apply to video camera recordings