On-Sun Evaluation of the PHLUX Method for Heliostat Beam Characterization

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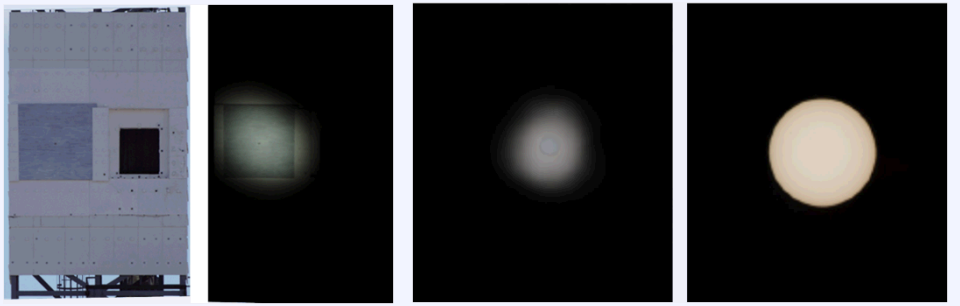

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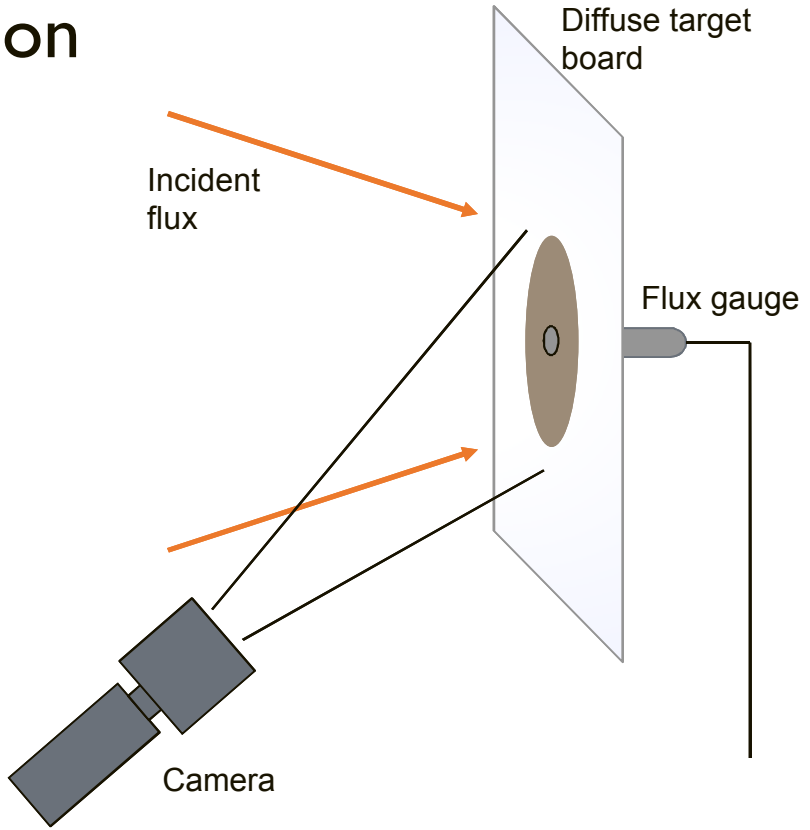
Outline

- Background
- Motivation for this work
- Approach
- Results & Discussion
- Conclusions

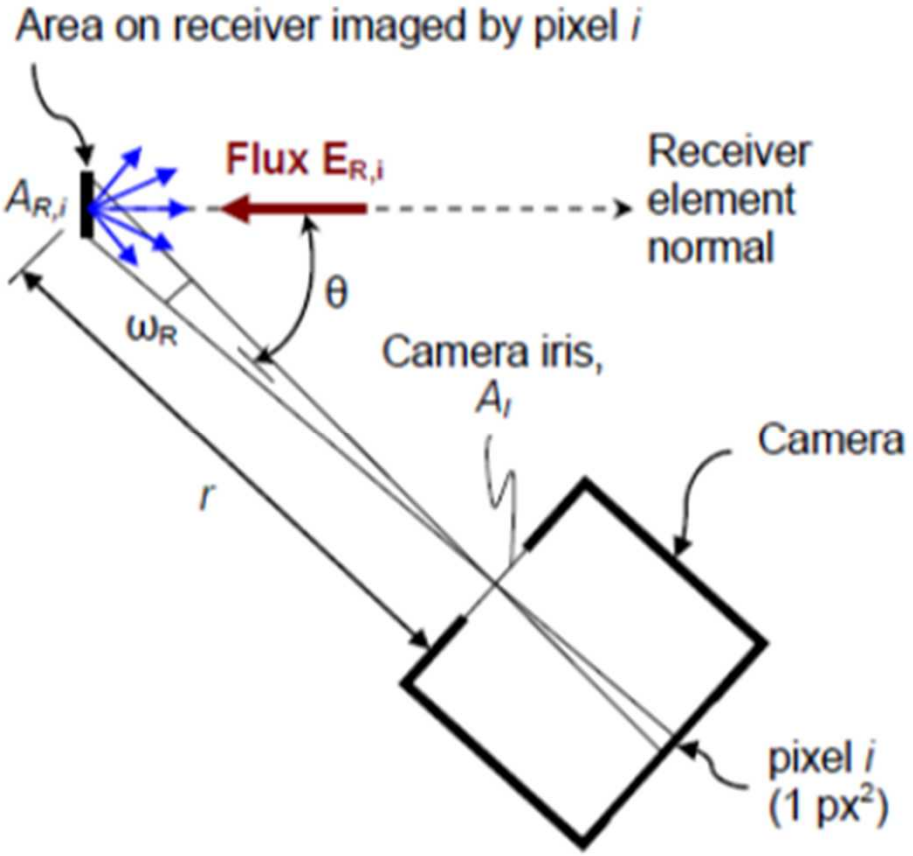
Background – Traditional Fluxmapping

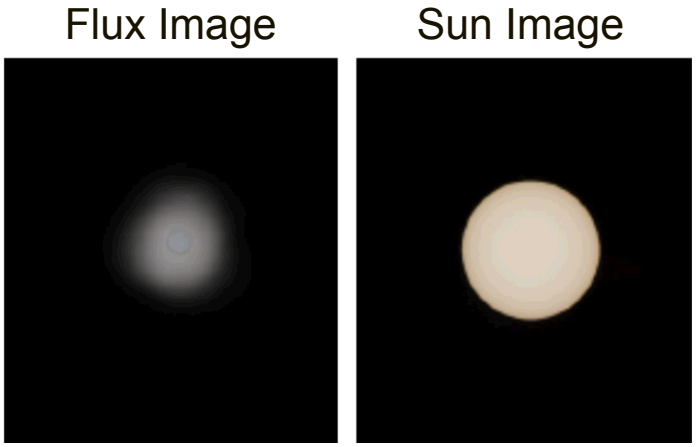
- Fluxmapping is needed to characterize flux distribution on a receiver

- Digital camera
- Diffuse target board
- Water-cooled flux gauge, Kendall radiometer, or calorimeter



Background – PHLUX (Photographic Flux)





The sun image is used to scale the flux image pixels.

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

Ho, C.K. and S.S. Khalsa, 2012, A Photographic Flux Mapping Method for Concentrating Solar Collectors and Receivers, *Journal of Solar Engineering*, 134(4).

Motivation

- Typical BCS requires hardware (camera, water-cooled target board & flux sensor) and computer including code to process and analyze the flux images
- PHLUX serves the same purpose using a DLSR camera without the expensive auxiliary instrumentation, and receiver surface with known reflectance
  - Analysis code has been developed and can be accessed online (https://share.sandia.gov/phlux)
- Evaluate PHLUX (using 2 DSLR cameras) and compare to Kendall radiometer measurements

Method – Camera Specs

Table 1. Specifications[a] of the Nikon D90 and D3300 DSLR cameras for comparison.

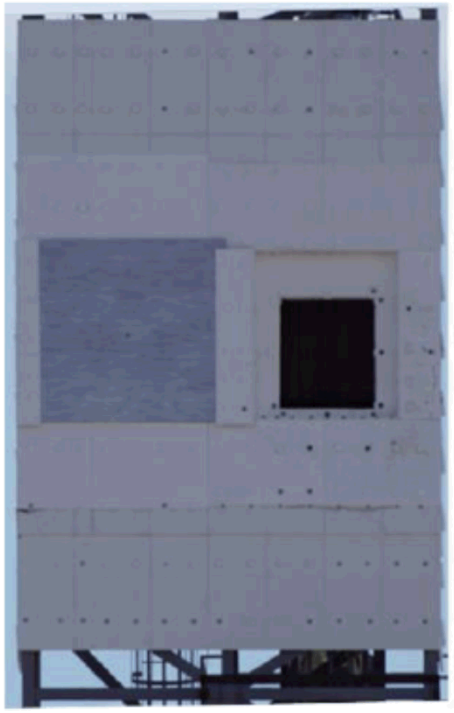
Camera Parameter	Nikon D90	Nikon D3300
Sensor array size	2868 x 4310 (12.3 Mpix)	4016 x 6016 (24.2 Mpix)
Sensor size	372.88 mm^2	357.28 mm^2
Pixel pitch (approx.)	5.5 um	3.87 um
Filter thread (for 300 mm focal length zoom lens)	67 mm	67 mm
Date introduced	09/2008	02/2014

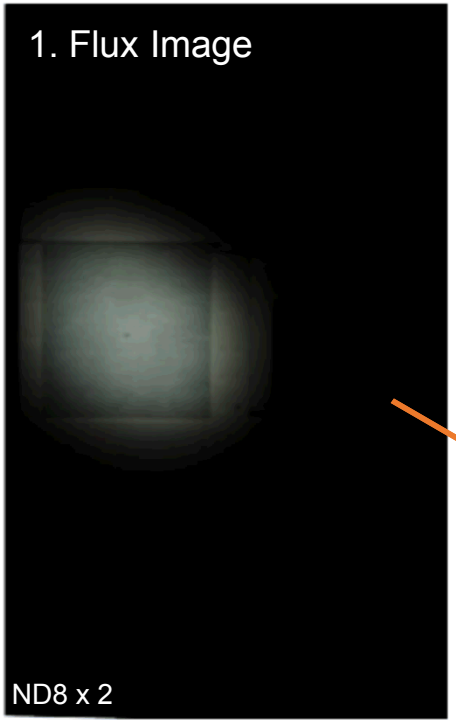
a) Specifications retrieved from Nikon website.

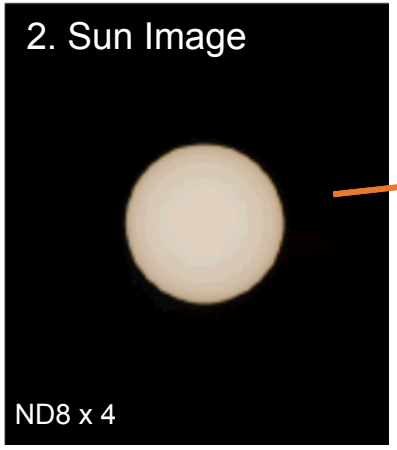
Table 2. Camera settings used during the flux image collection.

Parameter	D90	D3300
Lens focal length	300 mm	300 mm
Shutter speed	1/4000	1/4000
f-number	f/32	f/22 – f/32
Image format	RAW (NEF)	RAW (NEF)
White balance	Direct Sunlight	Direct Sunlight

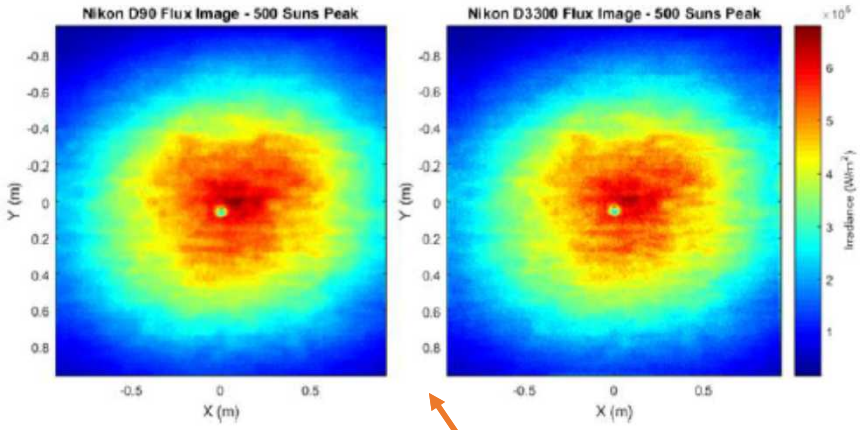
Method – Image Capture & Analysis







Scaled Fluxmaps



Measurement Parameters

PHLUX Code (online)

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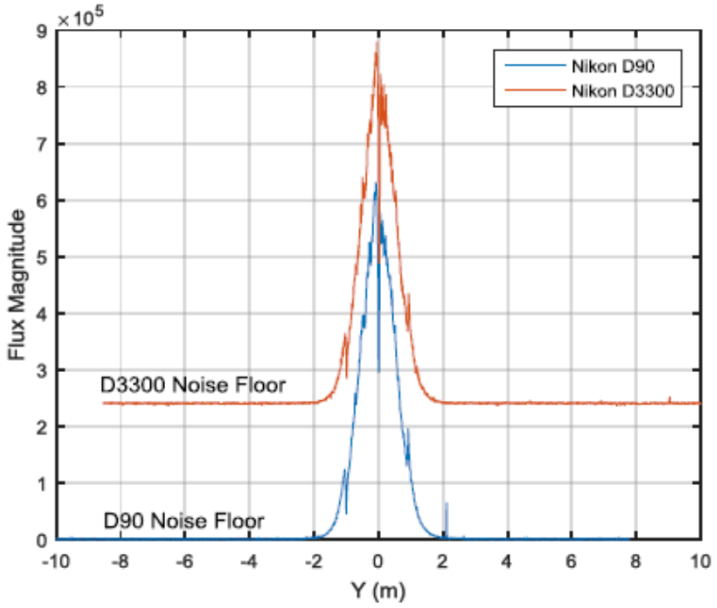
Results

Table 3. Measured peak flux values at different flux levels for comparison from the PHLUX tool and Kendall radiometer. Values in parentheses are % errors from the Kendall measurement.

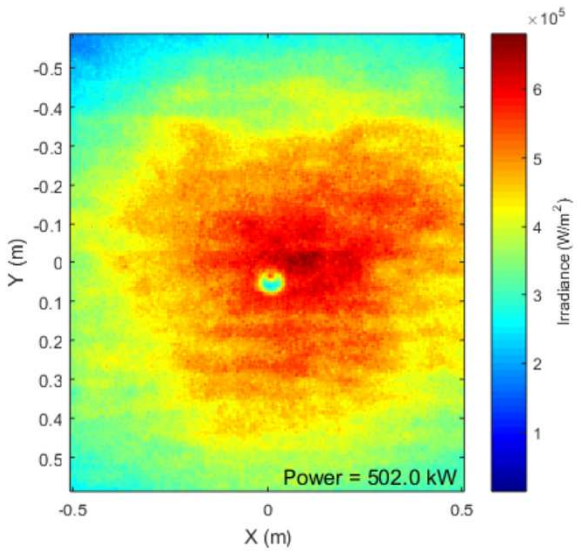
PHLUX Analyzed Images		Kendall Radiometer (kW/m^2)
D90 (kW/m^2)	D3300 (kW/m^2)	
107 (0.02)	109 (0.04)	105
350 (0.11)	294 (0.07)	315
564 (0.13)	547 (0.09)	500
1140 (0.10)	1051 (0.02)	1035

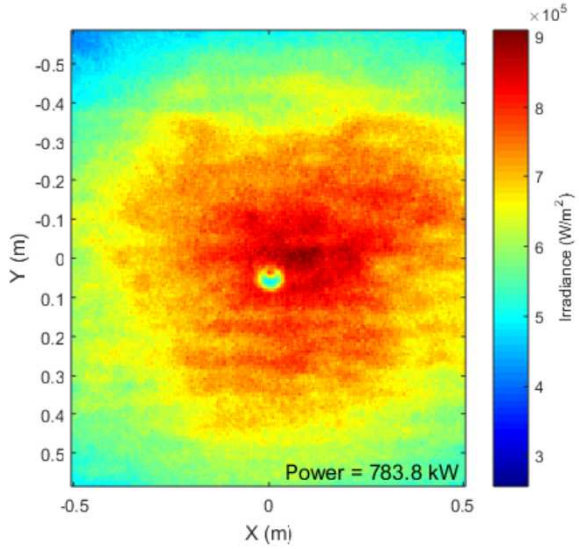
Correction for Noise Level or Ambient Light



Accounts for ambient lighting and/or sensor dark current noise

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





Conclusions

- PHLUX is a camera-based flux characterization system that uses a sun image to scale the flux image pixels
- PHLUX was evaluated using two cameras at 100-1000 suns peak flux levels on a target board
  - For the D90 camera the error was ~10% compared to a Kendall radiometer
  - For the D3300 the error was ~8% compared to a Kendall radiometer
- Impacts of uncertainties in the parameters were not studied – left for the future

Questions?