# Solar Optical Codes Evaluation for Modeling & Analyzing Complex Solar Receiver Geometries


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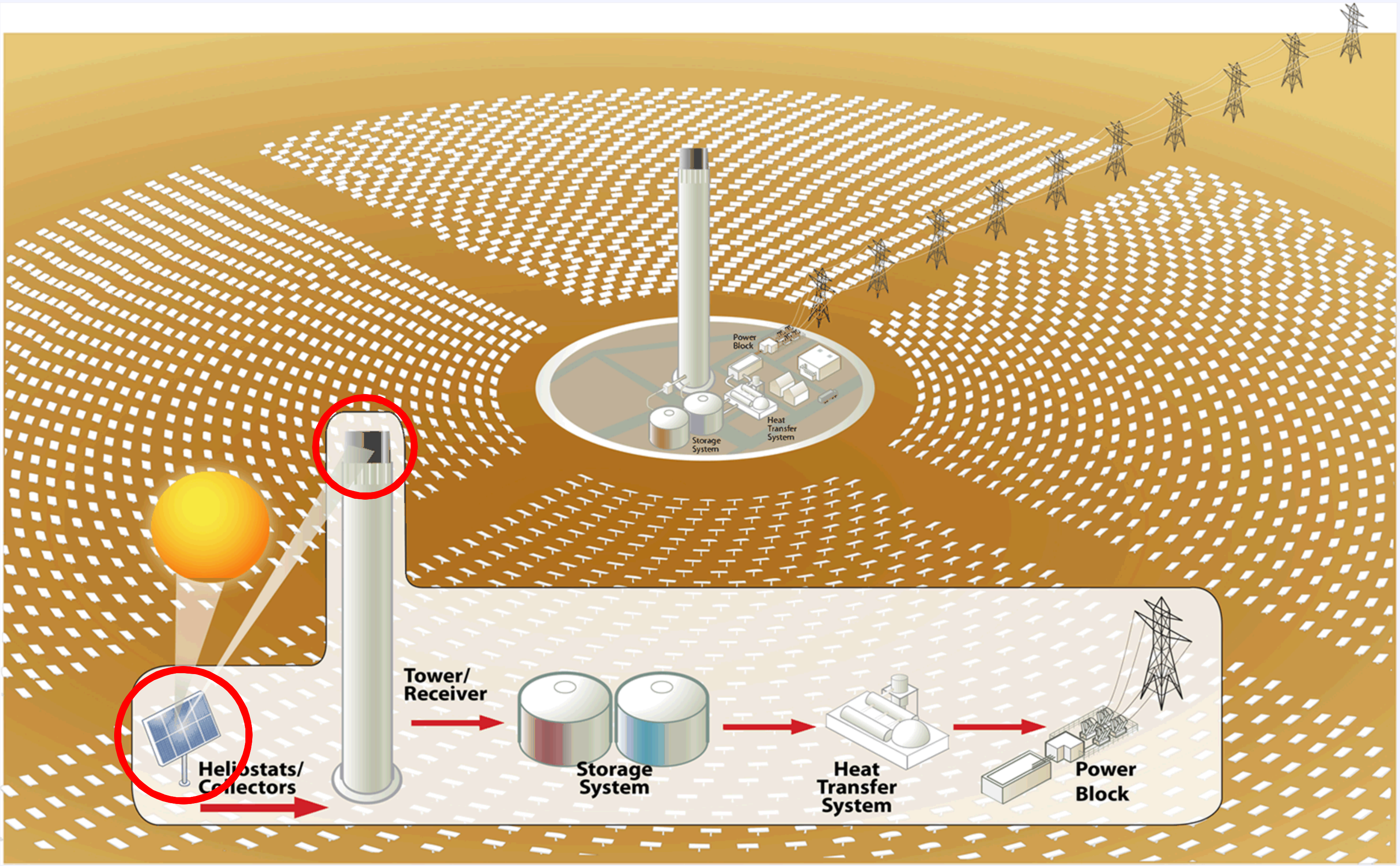
# Outline

- Background
- Motivation for this work
- Optical tools review
- Modeling of non-conventional receiver geometries
- Conclusion & future work

# Background: Power Tower System



# Background cont'd

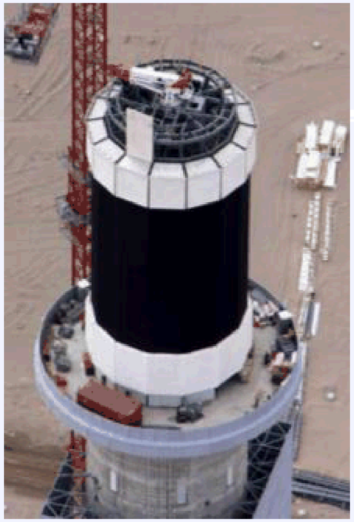
- Optical design tools are needed to model and analyze the performance of complex optical systems such as a CSP optical system

- Optical tools comparisons studies have been done in the past for solar applications – typically for a general need

Garcia, P., Ferriere, A., & Bezian, J-J. Codes for solar flux calculation dedicated to central receiver system applications: A comparative review. Solar Energy, Volume 82, Issue 3, March 2008, pp. 189-197.

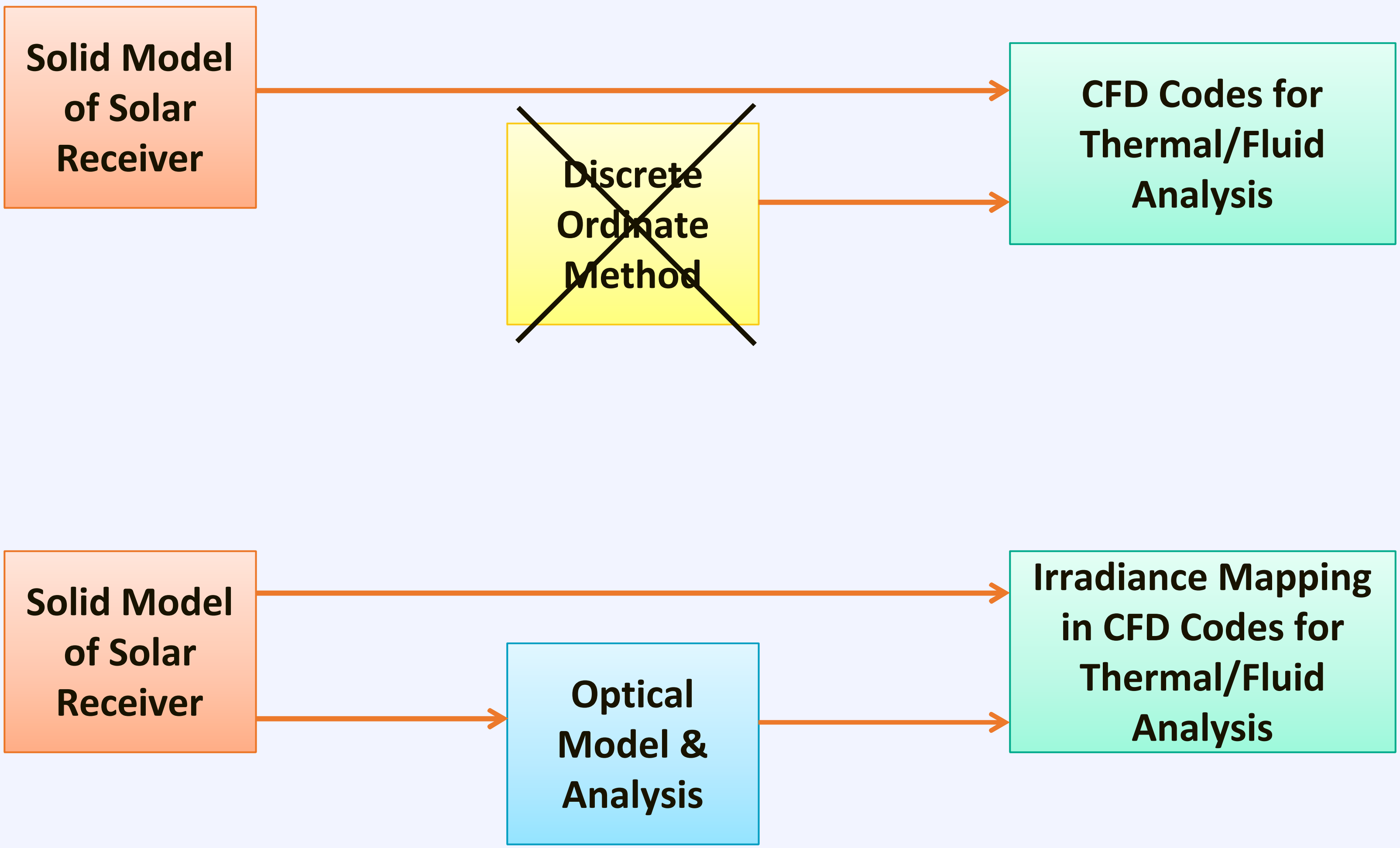
Bode, S-J & Gauche, P. (2012). Review of optical software for use in concentrating solar power systems. Proc. SASEC, Stellenbosch, South Africa, May 21-23.

# Motivation



- Conventional power tower receivers (i.e. cylindrical receivers) have view factors of 1
- Need optical modeling of non-conventional receiver geometries with reduced view factors to study their optical and thermal performance
- Commercial optical tools are sufficient, but are typically costly; we evaluated freely available tools

# Motivation cont'd



# Optical Tools We Evaluated

| Code | DELSOL | HELIOS | SolTrace | Tonatiuh |
|---|---|---|---|---|
| **Method** | Convolution (truncated Hermite polynomials) | Convolution (cone optics) | Ray tracing (Monte Carlo) | Ray tracing (Monte Carlo) |
| **CSP System** | Power tower | Power tower | General CSP | General CSP |
| **Main Features** | Optimization and annual performance calculations | NSTTF heliostat field is pre-defined | Can incorporate measured surface data;<br>can import/ export geometry files | Open source code |
| **Developer** | Sandia National Labs | Sandia National Labs | National Renewable Energy Labs | CENER |

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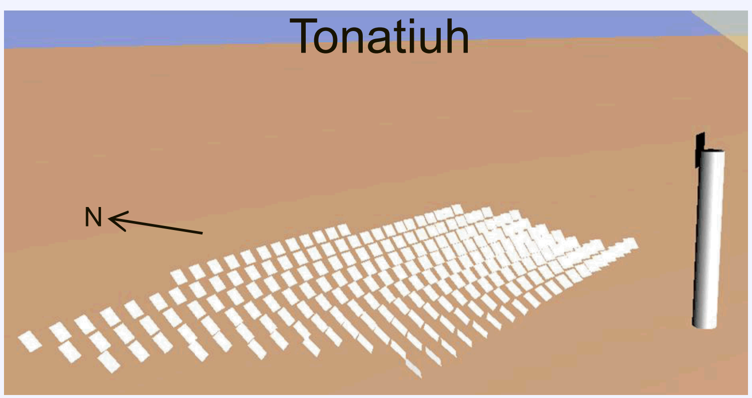
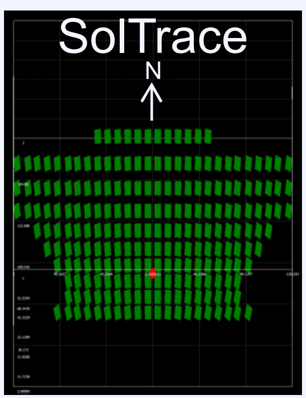
# Baseline System for Tools Comparison

| Sun Parameters | Heliostat Field Parameters | Target Parameters |
|---|---|---|
| • Buie sunshape<br>• Day 80 at solar noon<br>• Latitude = 34.96°<br>• Insolation = 1000 W/m$^2$ | • NSTTF heliostat field of 218 heliostats<br>• Flat heliostats – modeled as one facet with 1 mrad RMS slope error<br>• Heliostat size = 6.1 x 6.1 m<br>• Reflectance = 0.96 | • Flat plate facing North (no tilt)<br>• Size = 11 m x 11 m<br>• Aimpoint is the geometrical center of the plate |

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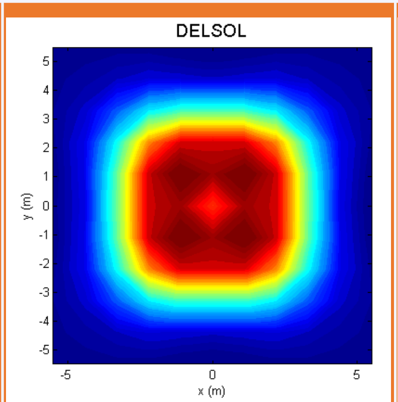
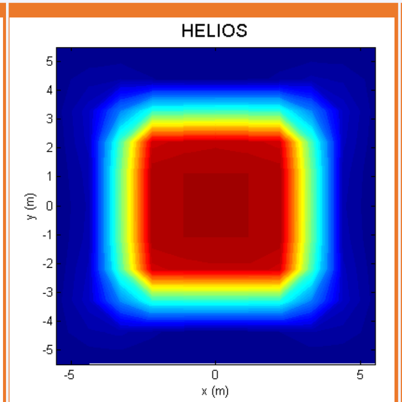
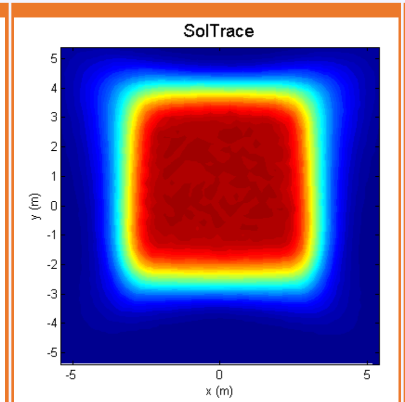
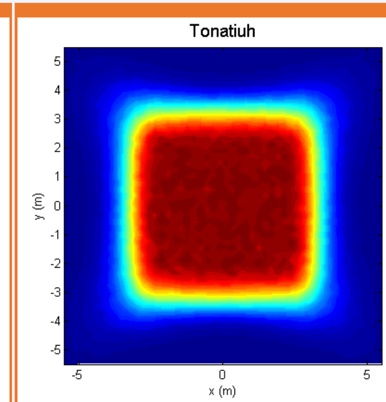
# Output Flux Evaluation




| | DELSOL | HELIOS | SolTrace | Tonatiuh |
|---|---|---|---|---|
| Peak Flux ($kW/m^2$) | 178 | 164 | 168 | 176 |
| AVG Flux ($kW/m^2$) | 53.4 | 49.3 | 62.4 | 61.2 |
| Total Power Incident (kW) | 7.17e+03 | 7.24e+03 | 7.34e+03 | 7.37e+03 |

# Optical Tools Comparison

| Tool | DELSOL | HELIOS | SolTrace | Tonatiuh |
|---|---|---|---|---|
| Strengths | • Computation speed<br>• Optimizes on heliostat layout, tower height, receiver size, storage size<br>• Annual performance calculations | • Computation speed<br>• NSTTF field is pre-defined | • Graphical display<br>• Multiple surface shapes<br>• Import/export geometry files<br>• Importation of measured surface data<br>• Multiple ray reflections | • Graphical display<br>• Open source code<br>• Relatively fast ray tracing |
| Deficiencies | • Limited on surface shapes<br>• Flux is smoothed out due to approximations<br>• Exportation of flux data needed for analysis | • Limited on surface shapes<br>• Input deck very sensitive to formatting<br>• Exportation of flux data needed for analysis | • Reduced accuracy for # of rays < 1,000,000<br>• Slow computation speed | • Reduced accuracy for # of rays < 1,000,000 |

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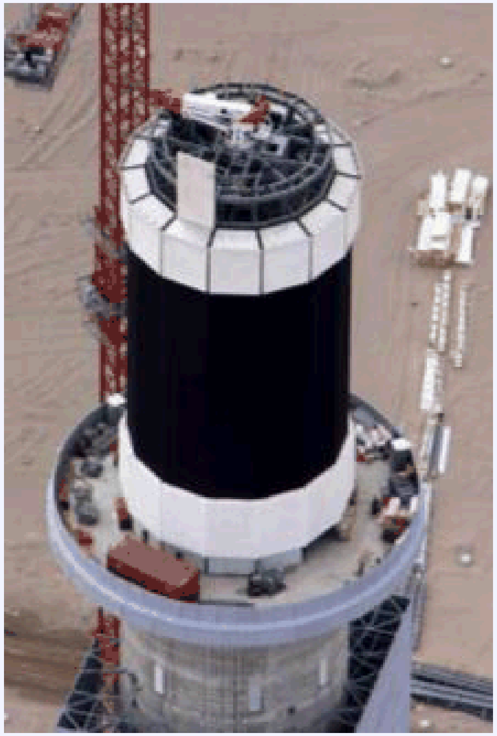
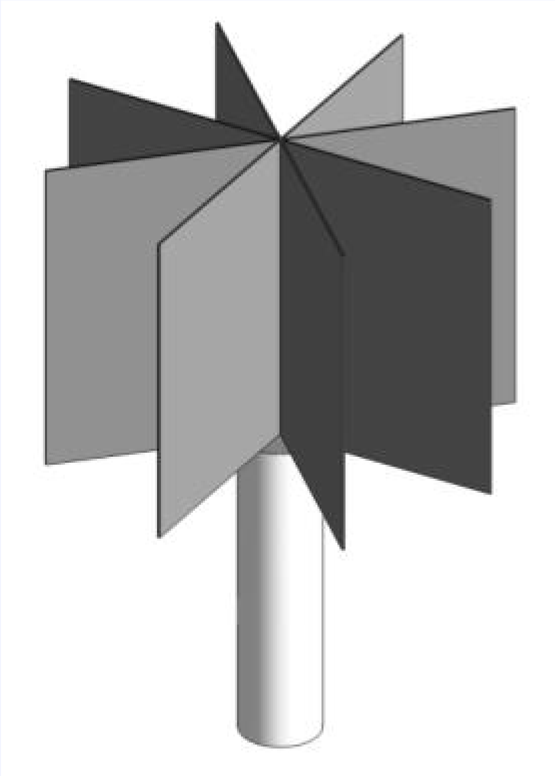
# Example of a Non-Conventional Receiver

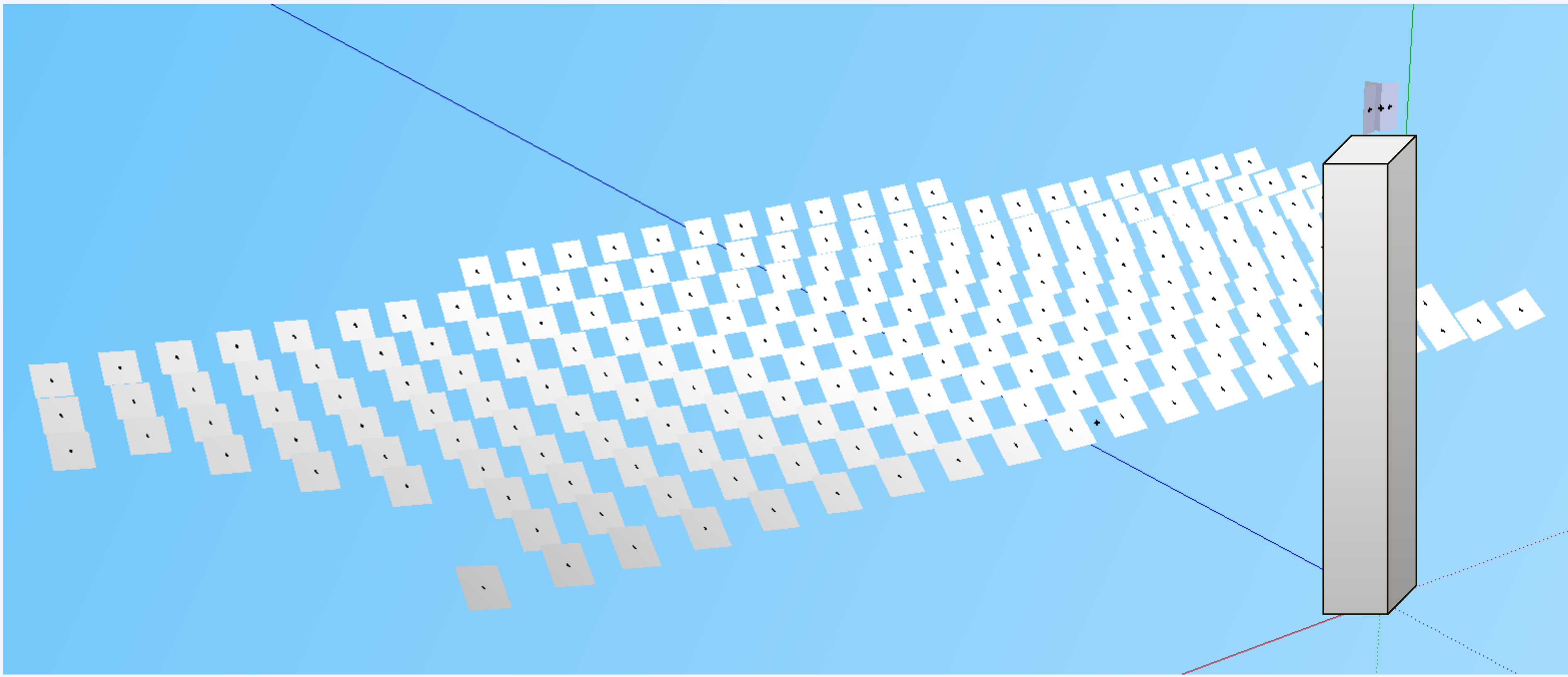


View factor = 1

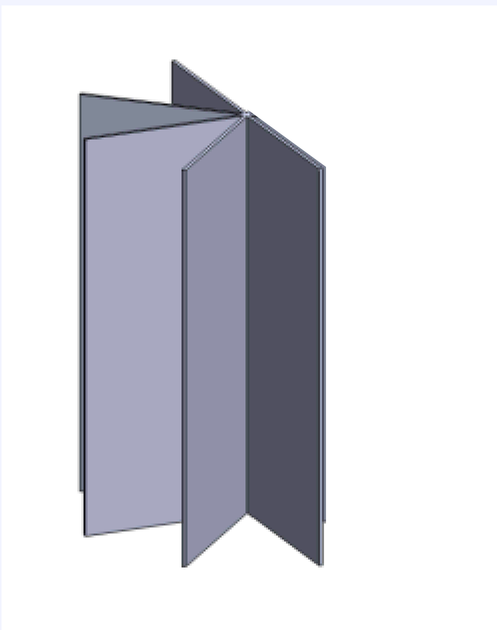


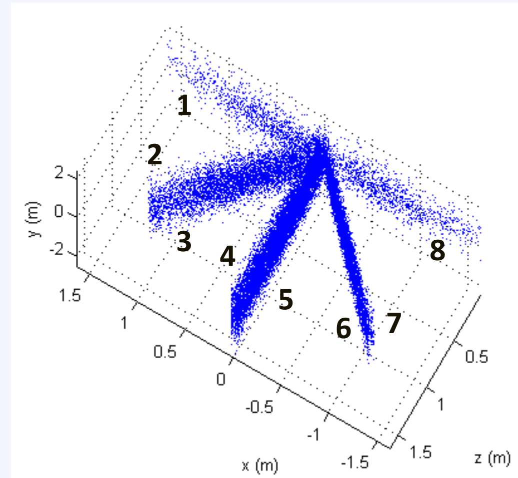
View factor < 1

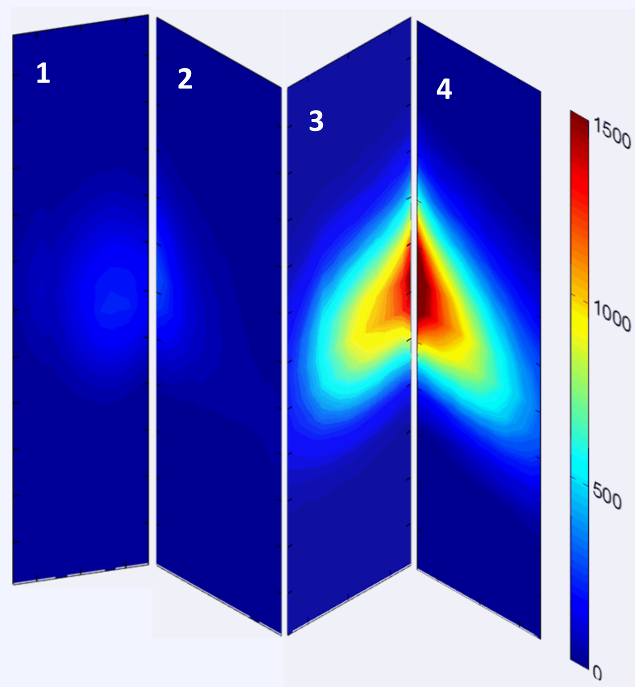
# SolTrace Model of the NSTTF Heliostat Field



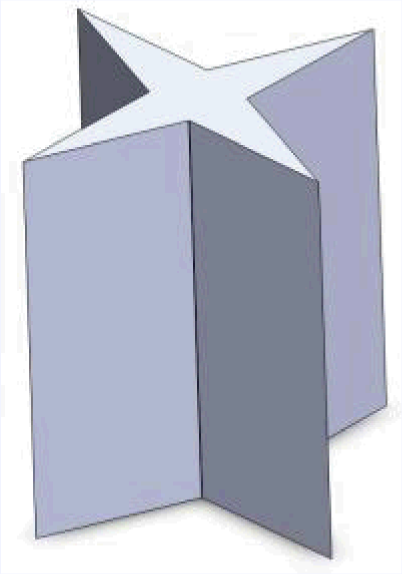
# SolTrace Modeling of Finned Receiver

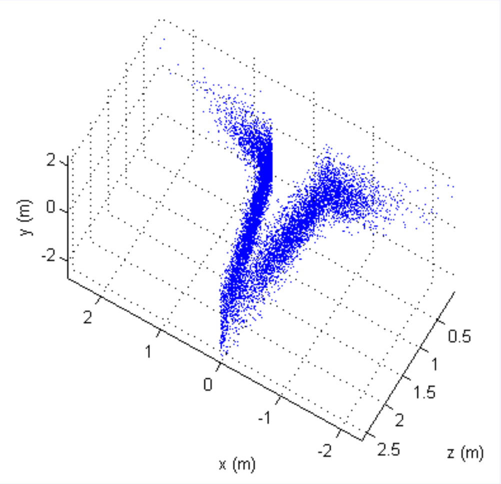


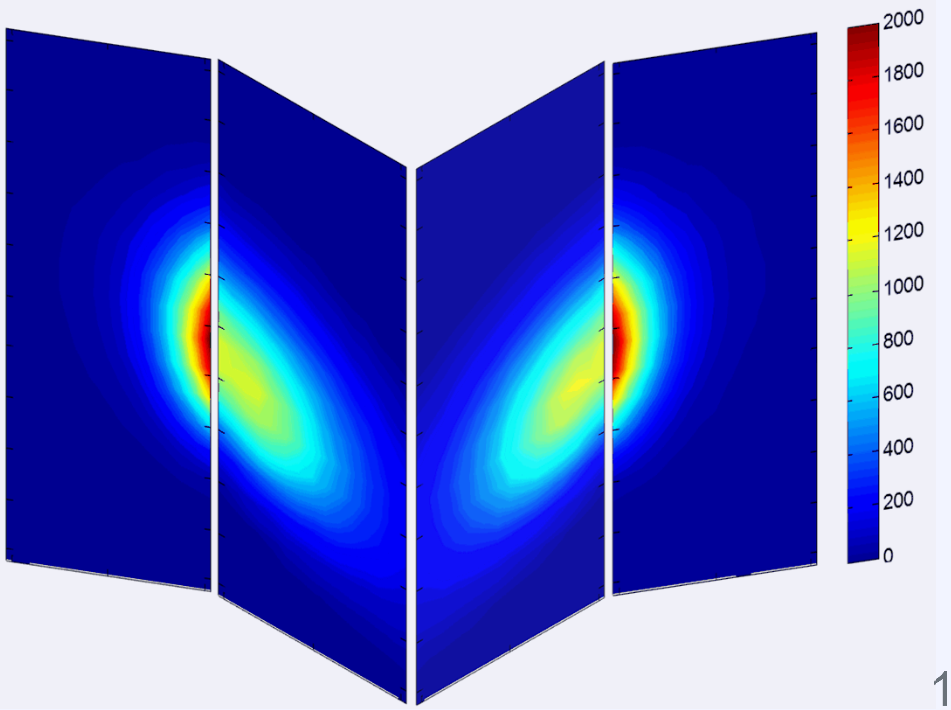


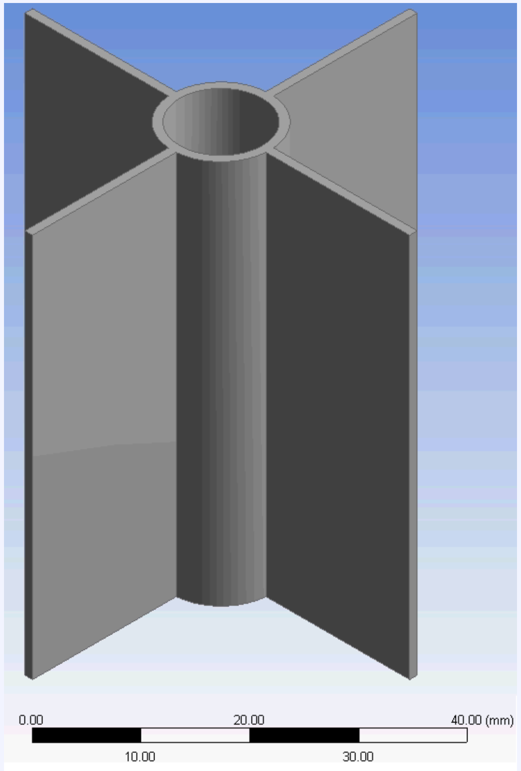
# SolTrace Modeling of Star Receiver





# Another Example of a Non-Conventional Receiver

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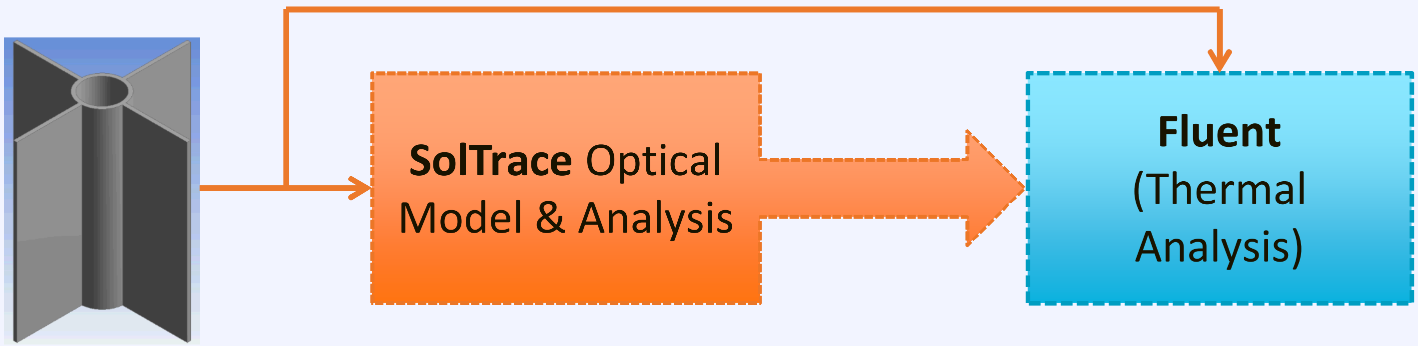
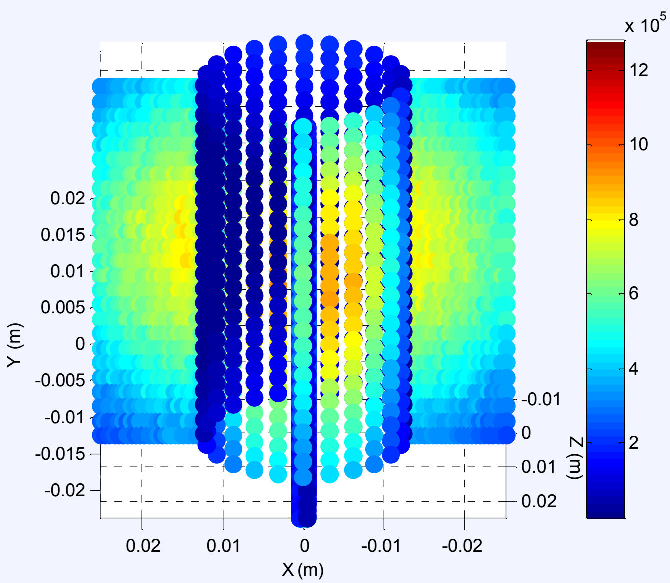
We can model this receiver with ray-tracing tools such as SolTrace.

# Ray-Tracing Model to Fluent for Analysis




## SolTrace Mapped Irradiance

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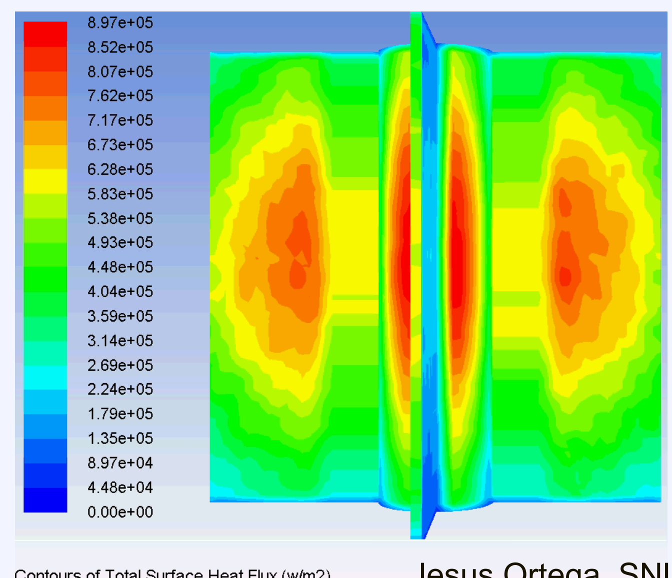
## Mapped Irradiance in Fluent

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# Conclusions

- We evaluated four optical modeling tools based on
  - User friendliness
  - Functionality
  - Flexibility
  - Ability to model complex and multiple shapes
- We modeled non-conventional receiver geometries with SolTrace and calculated the flux profiles on the receiver surfaces
  - Removes the DO radiative transport calculations

# On-Going Work

- Use SolTrace to model non-conventional receiver geometries and heliostat fields
  - The mapped flux will be used as boundary conditions for thermal analysis in ANSYS Fluent
- Export geometry files from CAD program and import directly into SolTrace and Fluent, and use Matlab for intermediate calculations

# Acknowledgements


- Supported by the Laboratory Directed Research and Development (LDRD) program at Sandia National Laboratories, a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

# National Solar Thermal Testing Facility

PV Regional Test Center

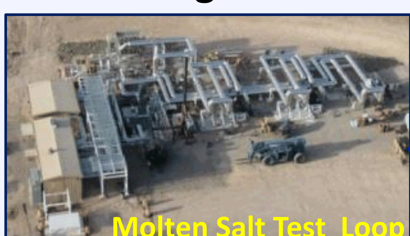
Dish Testing Facility

Rotating Platform for Parabolic Trough R&D

Optical Metrology Lab

Solar Furnace

Thermal Energy Storage R&D




Central Tower & Heliostat Field

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# Extra Slides

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# Extra Slides

Flux on STAR receiver with lower reflectance (same slope errors).