U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

# Modeling Receiver Flux of Commercial Power Tower Concentrating Solar Power Plants Using Ray Tracing: A Round-Robin Comparison of SolTrace, Solstice, and TieSOL


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conceptual design • components • integration • mass production • heliostat field

# Ray Trace Collaboration Team

NREL Transforming ENERGY

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## *SolTrace*

- Developer: NREL
- Language: C++
- Software type: Open-source, CPU

## *Solstice*

- Developer: CNRS-PROMES, Meso-Star
- Language: C
- Software type: Open-source, CPU

## *TieSOL*

- Developer: Tietronix
- Language: CUDA, C++, C#
- Software type: Commercial, GPU

# Why Conduct a Ray Trace Comparison Study?

- Previous study baselined ray trace tools for small case studies
  - Y. Wang et al., “Verification of optical modelling of sunshape and surface slope error for concentrating solar power systems,” Solar Energy, vol. 195, pp. 461–474, Jan. 2020, doi: 10.1016/j.solener.2019.11.035.No validation for simulation of a commercial-scale field with multi-facet heliostats
- Examination of blocking/shading
- Comparison of simulation of a commercial scale field with multi-facet heliostats with examination of canting and focusing
  - Are single facet heliostats sufficient for a simulation of a field with multi-facet heliostats?
- Accuracy of ray trace simulations can not be taken for granted
- This effort to set the stage for a larger collaborative ray-trace comparison study

# Ray Trace Comparison Methodology and Test Cases

## Test Cases

- Single heliostat baseline cases, flat target
- Commercial field comparison cases, surround cylindrical target
  - Single heliostat, blocking neighboring heliostats
  - Full-field

Created this test case after first full-field attempt

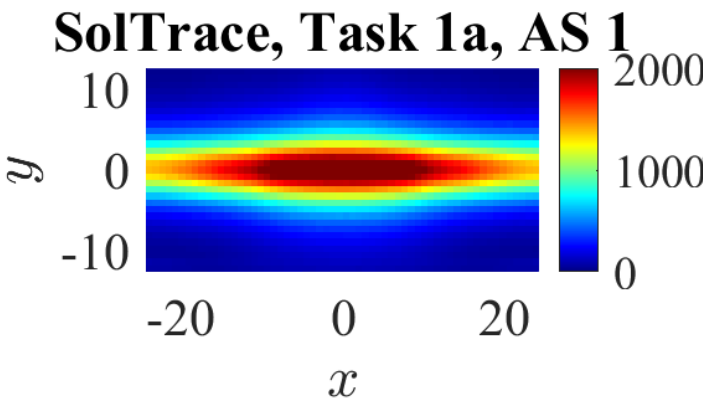
## Comparison Metrics

- 2D plots of flux distribution
- 1D radial flux plots along flux distribution axes
- Peak flux (kW/m$^2$)
- Total power (kW)

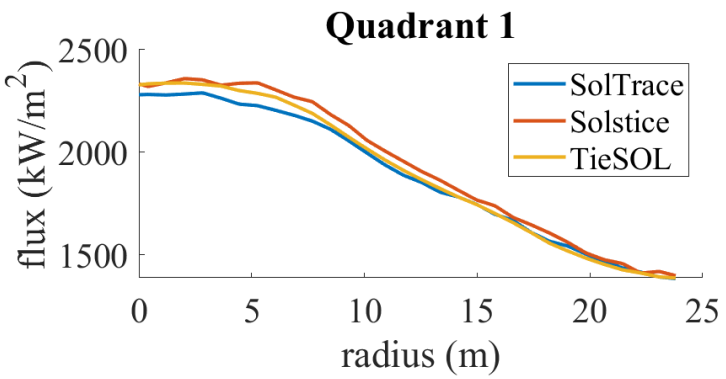
## Model parameters

- Fixed parameters
  - No atmospheric attenuation
  - 90% reflectance
  - 2 mrad slope error
  - 4.56 mrad Pillbox sunshape
  - Day of the year
  - Target shape
- Varied parameters
  - Single facet and multi-facet heliostats
  - Canting and facet focusing
  - Heliostat location
  - Sun position
  - Aimpoint strategy (full-field)

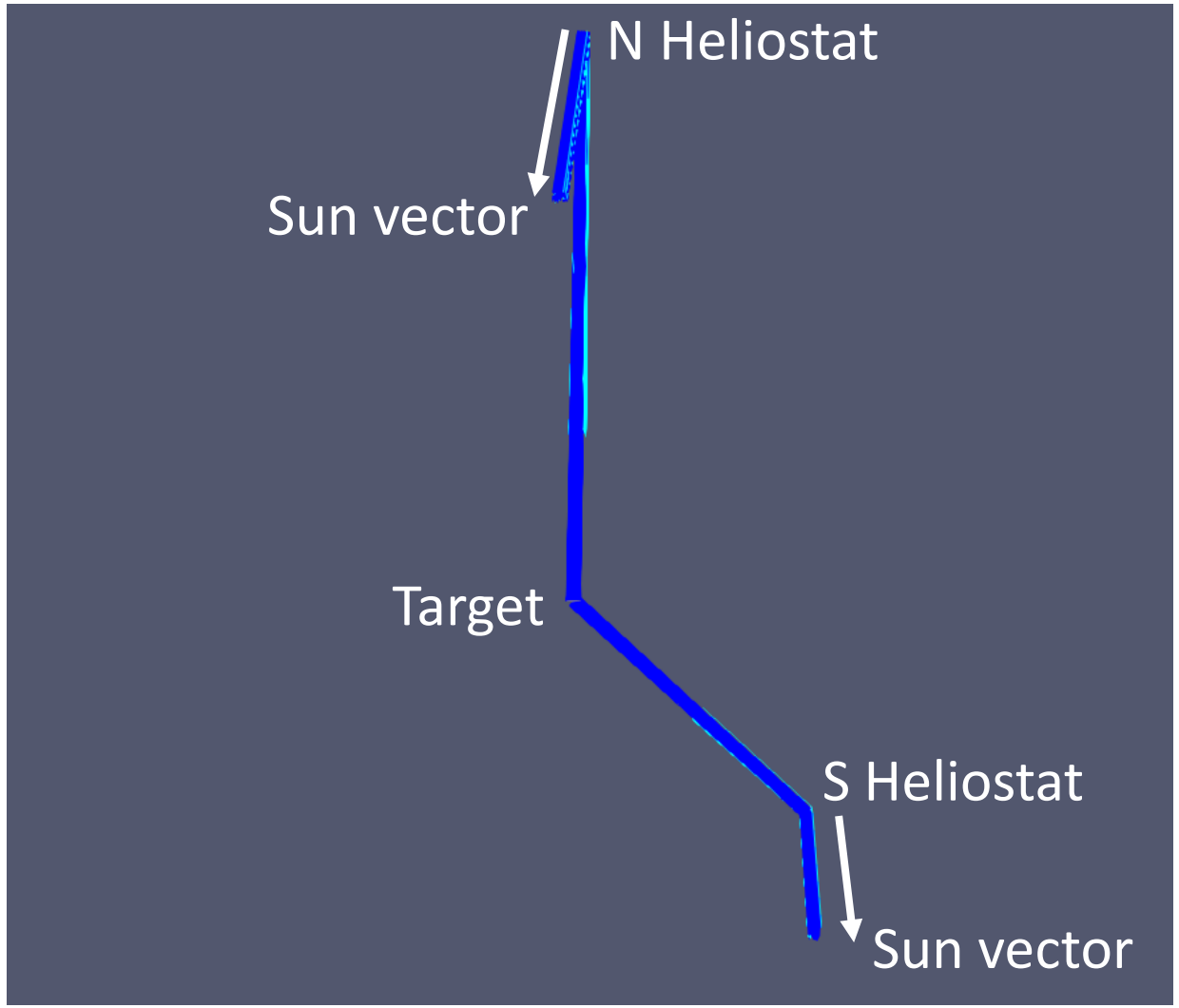
Example 2D flux plot




Example 1D radial flux plot



# Single Heliostat Test Cases




## Model Parameters

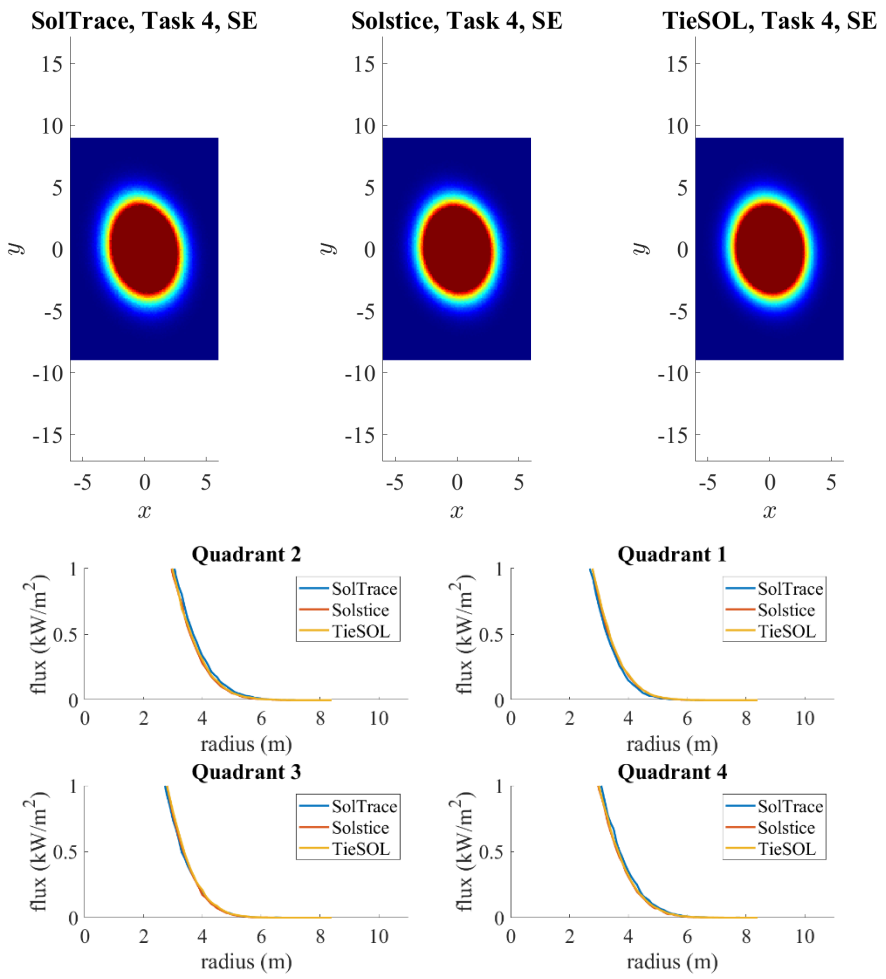
- Located in Nevada (Crescent Dunes location)
- Heliostats based on Crescent Dunes design (5 x 7)
- Solar noon on 8/31
- North (500 m) and Southeast (200 m E, 200 m S) heliostat locations
- Flat rectangular target

## Test Cases

- Single facet
  - Flat
  - Curved to slant range
- Multi facet
  - No canting, flat facets
  - Canted to slant range, flat facets
  - Canted to slant range, facets curved to slant range

# Single Heliostat Results and Lessons Learned

Good agreement (not perfect) across all test cases




## Key Challenges and Learnings

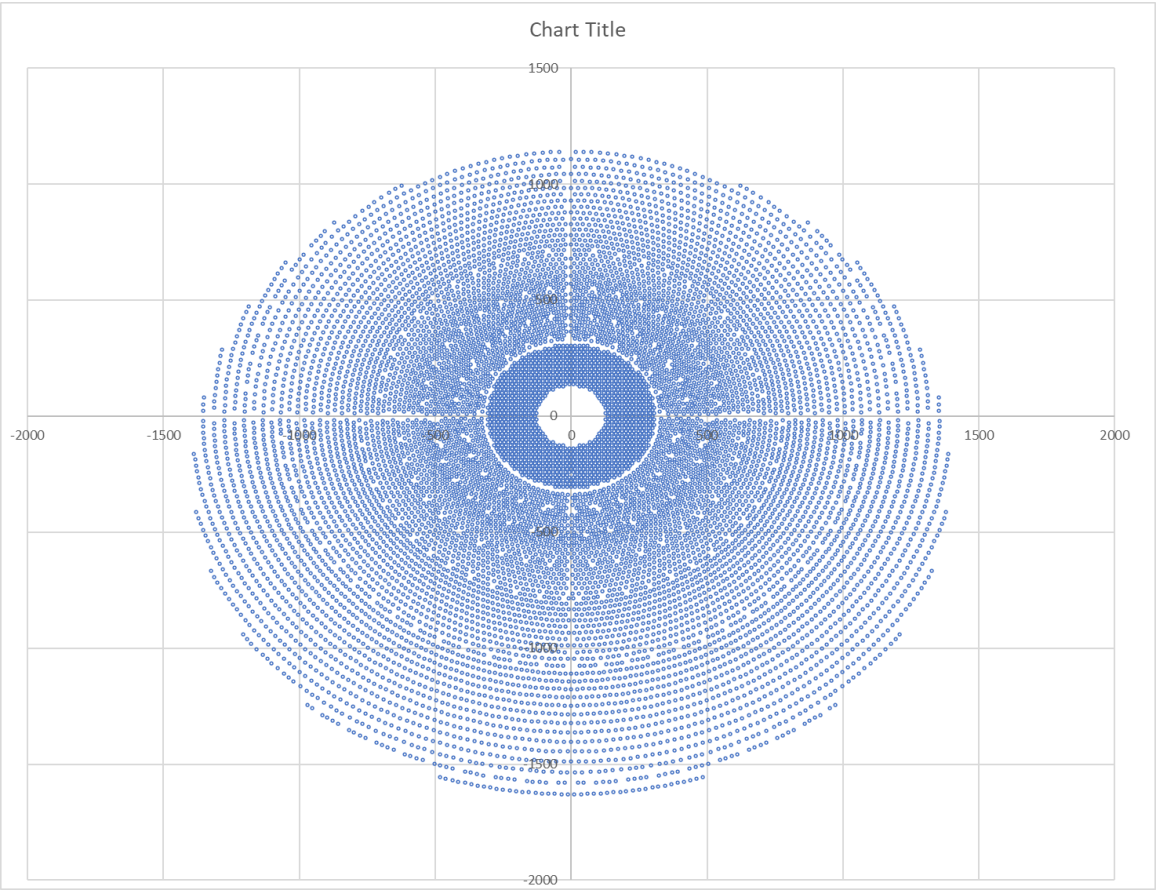
*Expected this to go quickly and it did not…*

*SolTrace target was upside down*

*New capabilities created in Solstice for canted multi-facet heliostats*

Thanks to Ye Wang's "solsticepy" wrappers

# Full Field Test Cases




## Model Parameters

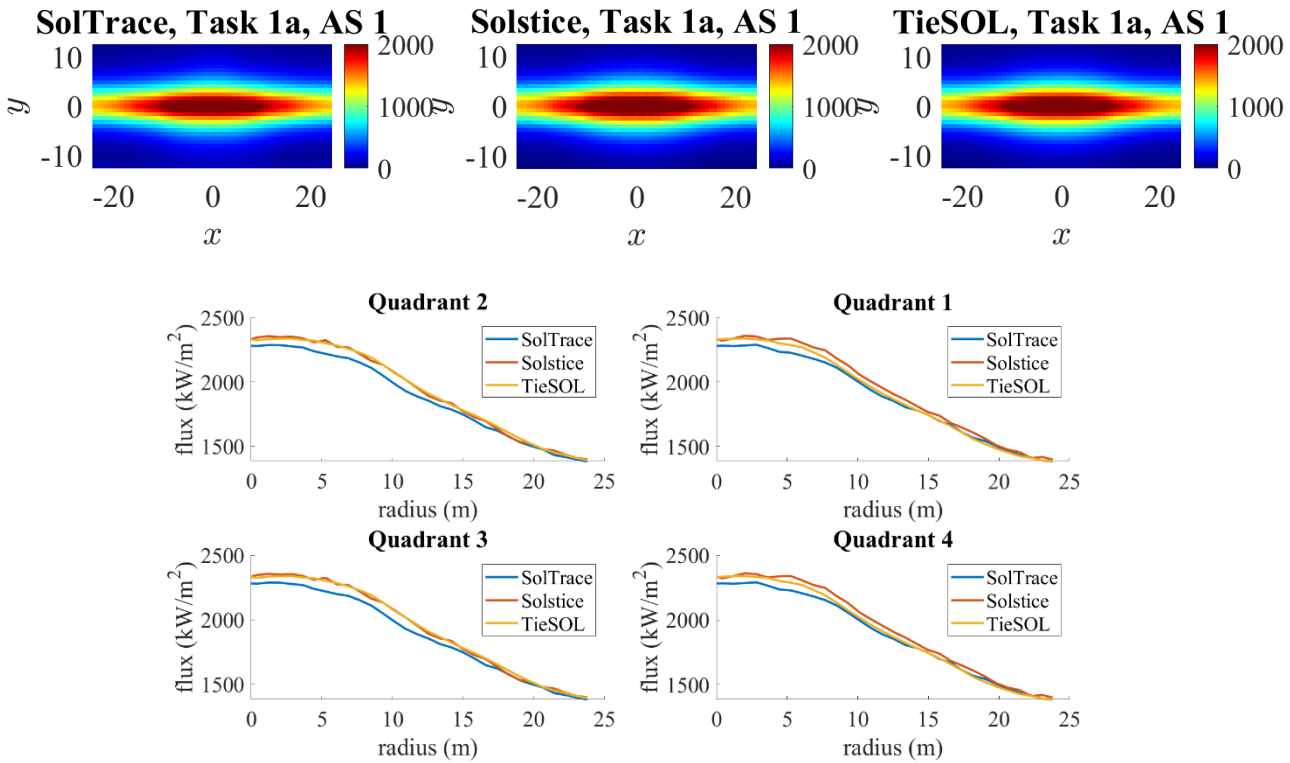
- Located in Port Augusta, Australia based on planned plant
- Heliostats with 30 facet layout (6 x 5)
- Solar noon and 8 on the spring solstice (9/22)
- Cylindrical target
- Aimpoint strategy (none or scattered in elevation)

## Test Cases

- Single facet
  - Curved to slant range
  - Curved according to 4 canting bands
- Multi facet, flat facets
  - Canted to slant range
  - Canting according to 4 canting bands
- Multi facet, curved facets
  - Canted to slant range, facets curved to slant range
  - Canting according to 4 canting band, facets curved according to 4 focusing bands

# Full Field First Attempt

Nothing agreed at all




## Key Challenges and Learnings

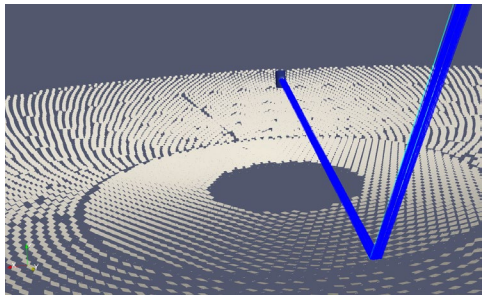
*Too complex a leap, could not identify sources of discrepancy*

*Disagreement of all 3 tools, could not determine if anyone was correct*

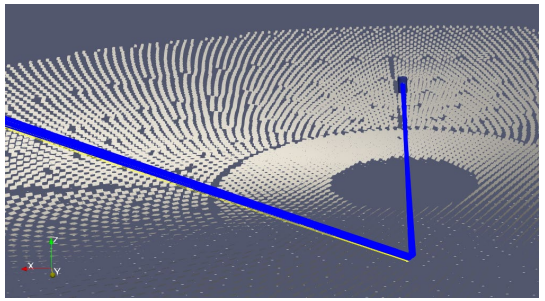
*Designed a simpler test case: isolated heliostats with blocking neighbors*

# Isolated Heliostats With Blocking Neighbors

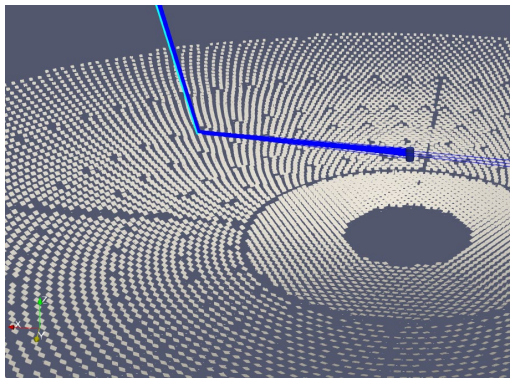
North heliostat, noon



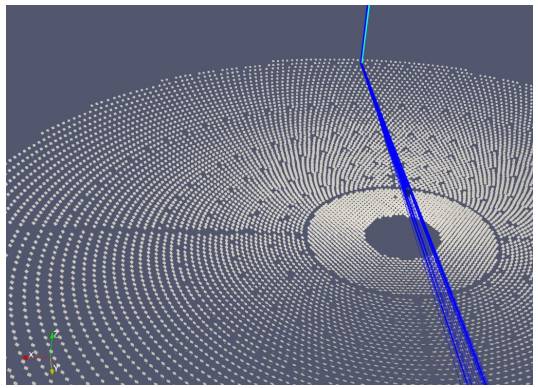
North heliostat, 8am

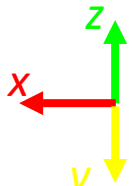


South-east heliostat, noon



South heliostat, noon






## Model Parameters

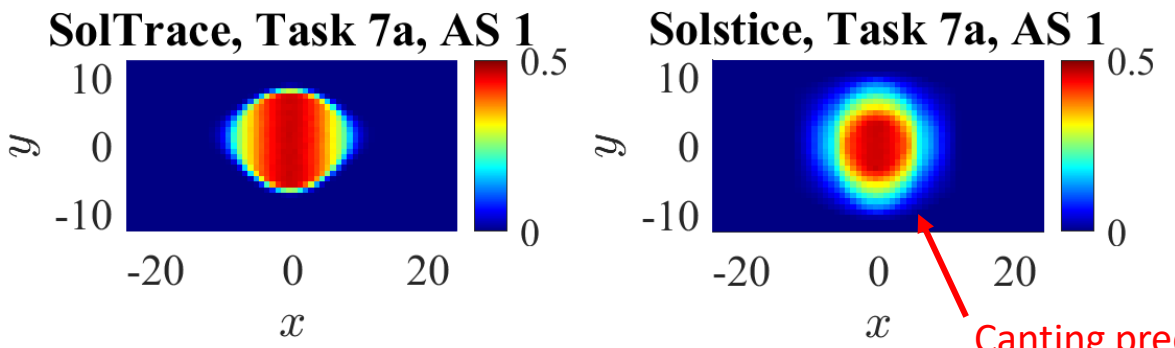
- Heliostats chosen at N, SE, and S locations in the field with selected neighbors that would create blocking
- Removed slope error in selected cases to troubleshoot

## Test Cases

- Single facet, curved to slant range, no blocking or shading
- Canted to slant range, facets curved to slant range, no blocking or shading
- Canting bands, facets curved to slant range, blocking and shading from neighbors

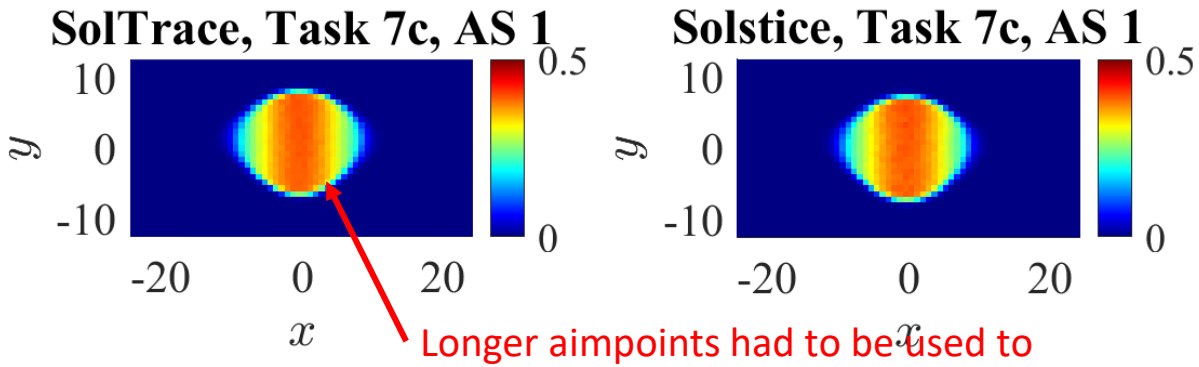
# Isolated Heliostat Key Discoveries

Canting precision in Solstice




Canting precision had to be increased (from 10e-6 to 10e-12) for far field heliostats (1500 m)

Aimpoint precision in SolTrace



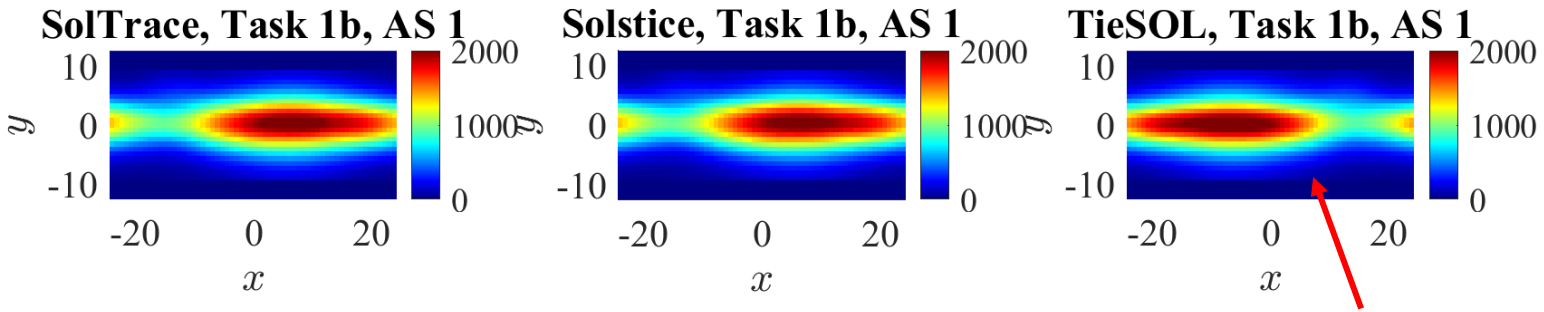

Longer aimpoints had to be used to avoid beam offset from precision loss from decimal truncation

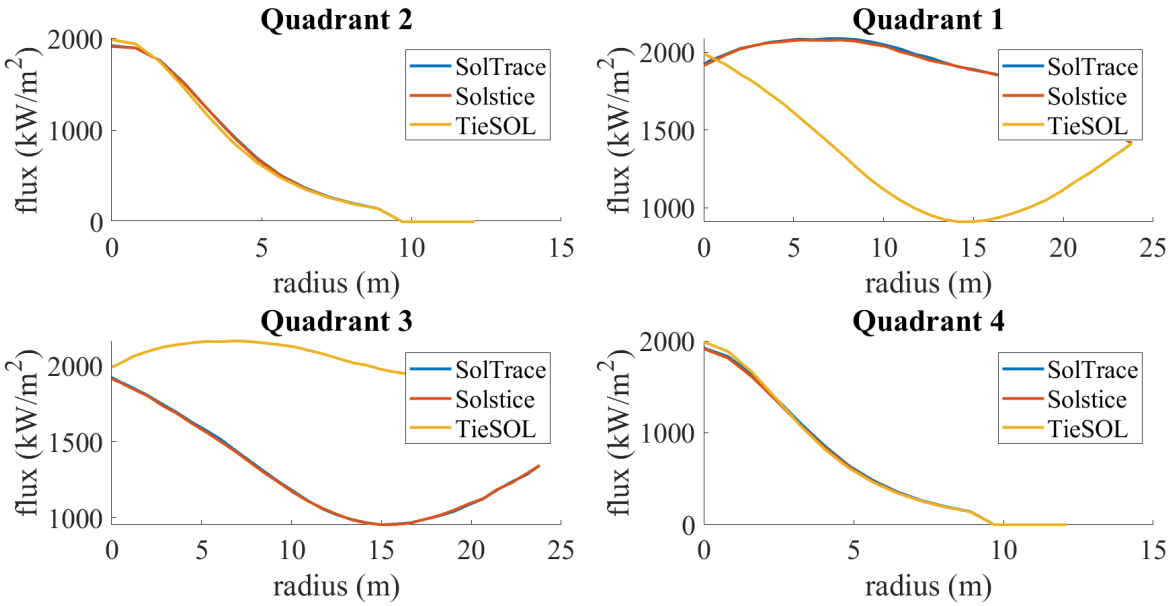
## Other Discrepancies Resolved

- *Canting focusing band definitions*
- *Target height and aperture*
- *Atmospheric attenuation*
- *Slant range distance*
- *Different heliostats ☹*

# Full Field Second Attempt

Agreement of 2 out of 3 tools




Coordinate system discrepancy became apparent at a different time of day (8 am)

>300K facets
350M rays

## Key Challenges and Learnings

*Comparison of at least 3 tools is key*

*Beams from different parts of the field key to identifying coordinate system discrepancies*

*Had not verified agreement of new cylindrical target*

*Computation Multi-facet full-field cases difficult for SolTrace and Solstice*

# Top Learnings

- Best practices:
  - Accuracy of ray trace simulations cannot be assumed; standardized/benchmark tests are necessary for validation
  - Comparison of at least three tools with incrementally increasing complexity
  - Coordinate systems need to be defined clearly and verified
  - Isolate and verify each model parameter
  - Establish/evaluate software performance (computation time and # of rays)
- Key discoveries:
  - Multi-facet canting capabilities introduced for Solstice (thank you Ye Wang)
  - Canting precision must be defined carefully for far-field heliostats in Solstice
  - Aimpoints should be specified at long distances (1000 m) to avoid precision truncation error in SolTrace

TieSOL is the clear winner

# Next Steps

- Resolve remaining discrepancies and complete full field comparison
  - Stay tuned for the conclusion at SolarPACES…
- Establish confident benchmark tests to be shared as open source for the benefit of the CSP community
- Expand ray-trace round robin to additional ray trace tools
  - Want to be involved in the next phase? Contact rebecca.Mitchell@nrel.gov