DOE Solar Energy Technologies Program Peer Review

Technical Track: Concentrating Solar Power

Project Name: Advanced CSP Systems Analysis

Principal Investigator: Clifford K. Ho (SNL)

Denver, Colorado

March 9-10, 2009

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Overview

- Quality, Productivity, Accomplishment
- Scientific/Technical Approach
- Relevance/Impact of Research

Work performed from 6/08 through 2/09

1. Review of CSP codes
2. Probabilistic Modeling
3. Solid Particle Receiver Modeling
4. Coupled Processes/Heliostat Modeling
5. Glint and Glare Analyses

Budget received from DOE for FY08/FY09 (to date)

- $400 K for advanced CSP systems analysis; ~$140K spent
- $100 K for solid particle receiver modeling (Hydrogen program); ~$50K spent

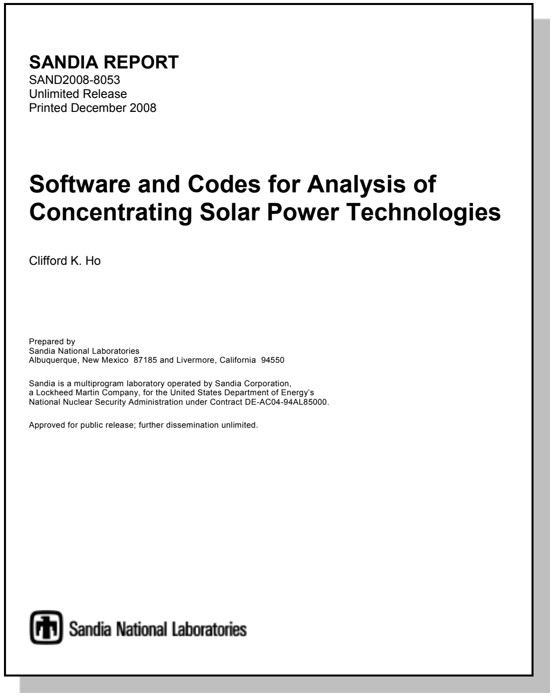
Quality, Productivity, Accomplishment

- Sandia R&D Team
  - Clifford K. Ho
  - Gregory J. Kolb
  - Nathan P. Siegel
  - Cheryl M. Ghanbari
- Publications
  - Ho, C.K., Software and Codes for Analysis of Concentrating Solar Power Technologies, SAND2008-8053, Sandia National Laboratories, Albuquerque, NM.
  - Ho, C.K., and G.J. Kolb, Probabilistic Modeling of a Solar Thermal Power Plant, submitted to SolarPACES 2009, Berlin, Germany, September 15-18, 2009.
  - Ho, C.K., and C.M. Ghanbari, Hazard Analyses of Glint and Glare from Solar Thermal Power Plants, submitted to SolarPACES 2009, Berlin, Germany, September 15-18, 2009.
  - Ho, C.K., and G.J. Kolb, Incorporating Uncertainty into Probabilistic Performance Models of Concentrating Solar Power Plants, submitted to the 2009 ASME 3rd International Conference on Energy Sustainability, San Francisco, CA, July 19-23, 2009.
  - Ho, C.K., S.S. Khalsa, and N.P. Siegel, Modeling a Solid Particle Receiver for Concentrating Solar Power Processes and Storage, submitted to the 2009 ASME 3rd International Conference on Energy Sustainability, San Francisco, CA, July 19-23, 2009.
  - Ho, C.K., S.S. Khalsa, and N.P. Siegel, Modeling and Optimization of a Prototype Solid-Particle Solar Receiver, submitted to SolarPACES 2009, Berlin, Germany, September 15-18, 2009.

Scientific/Technical Approach

1. Review of CSP Codes

- Identified cross-cutting tools, deficiencies, and needs
- Provides framework for total-system modeling (e.g., SAM, SOLERGY)
- Introduced need for probabilistic modeling to honor uncertainties



SANDIA REPORT
SAND2008-8053
Unlimited Release
Printed December 2008

Software and Codes for Analysis of Concentrating Solar Power Technologies

Clifford K. Ho

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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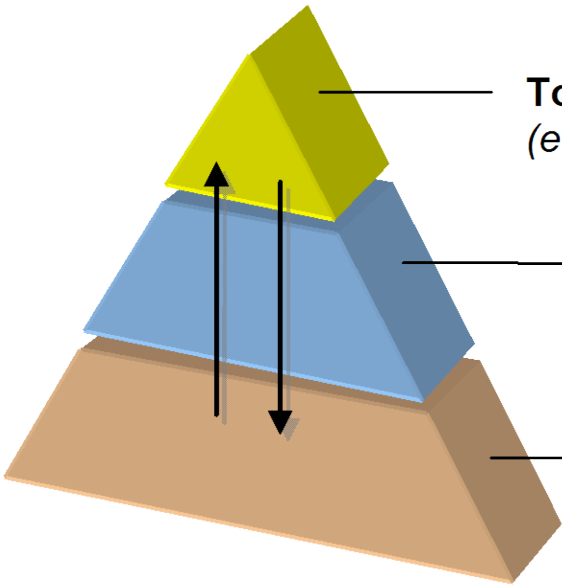
Sandia National Laboratories

Total-System Modeling Pyramid



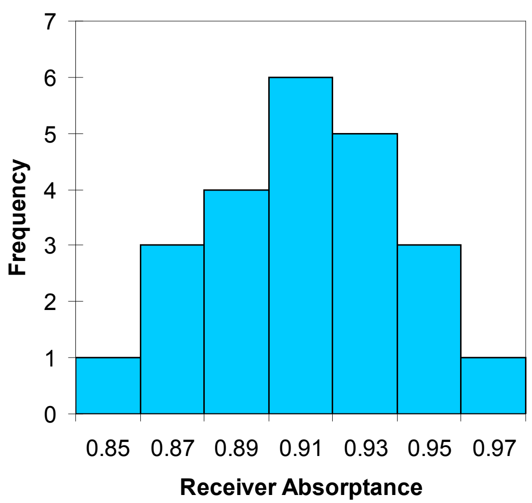
Total system models – performance and cost
(e.g., SAM, SOLERGY)

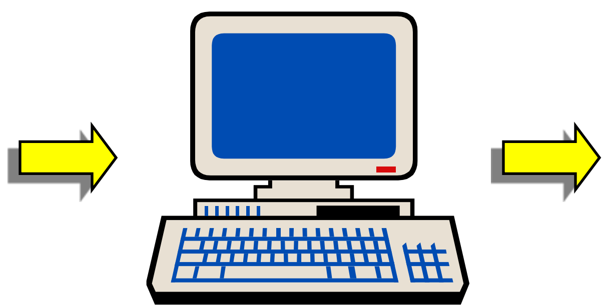
Component and process models
(e.g., collector/reflector optics, receiver performance, thermal storage processes, power output)

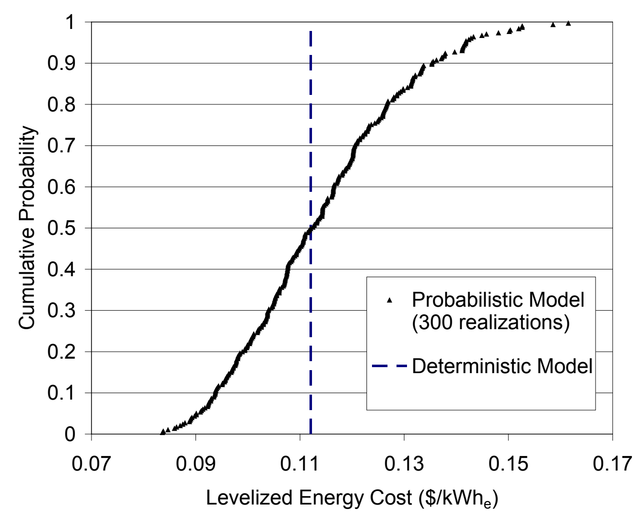
Input parameters and distributions
(e.g., geometry, reflectivity, solar radiation, temperature, flow rates, efficiencies, costs)

Need to honor uncertainties in component and process models to improve reliability of total-system models

2. Probabilistic Modeling





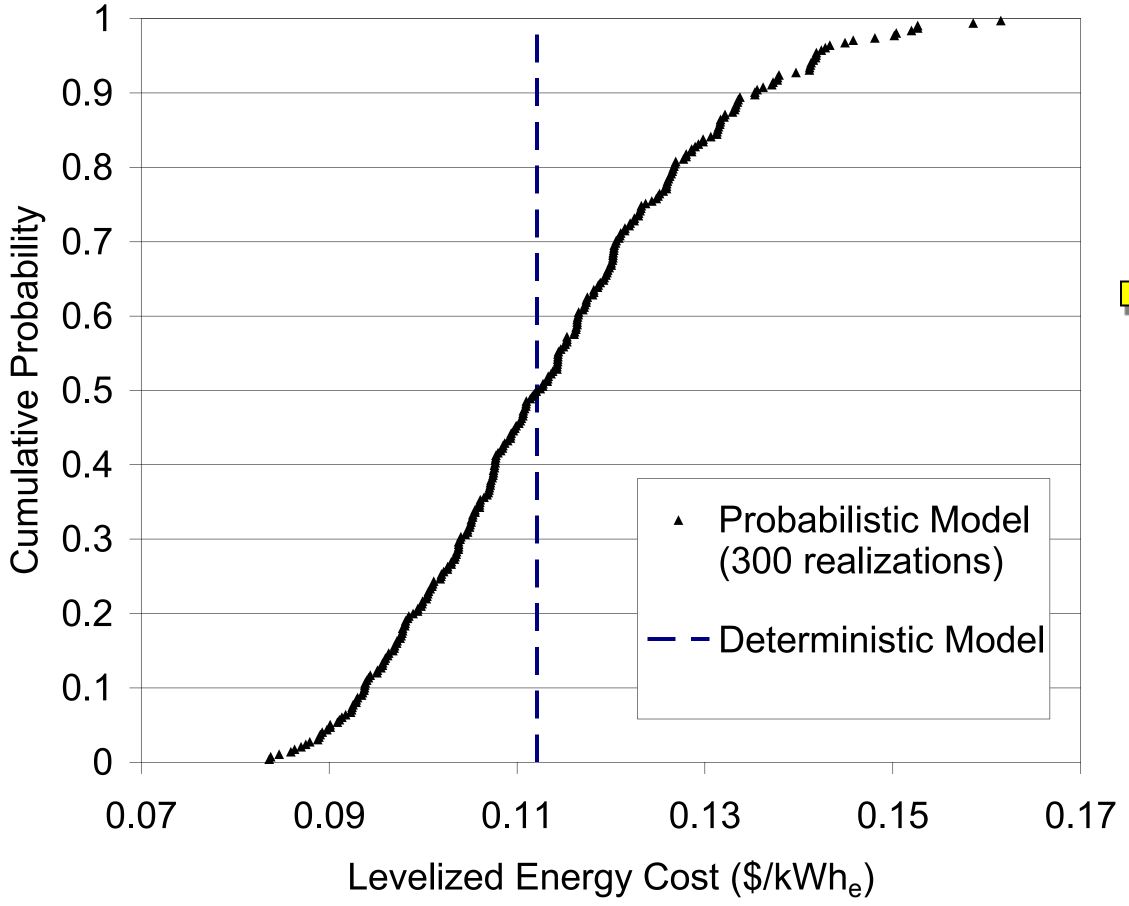


Stochastic Inputs
(Latin Hypercube Sampling)

Multiple Computer Simulations
(e.g., SOLERGY, SAM)

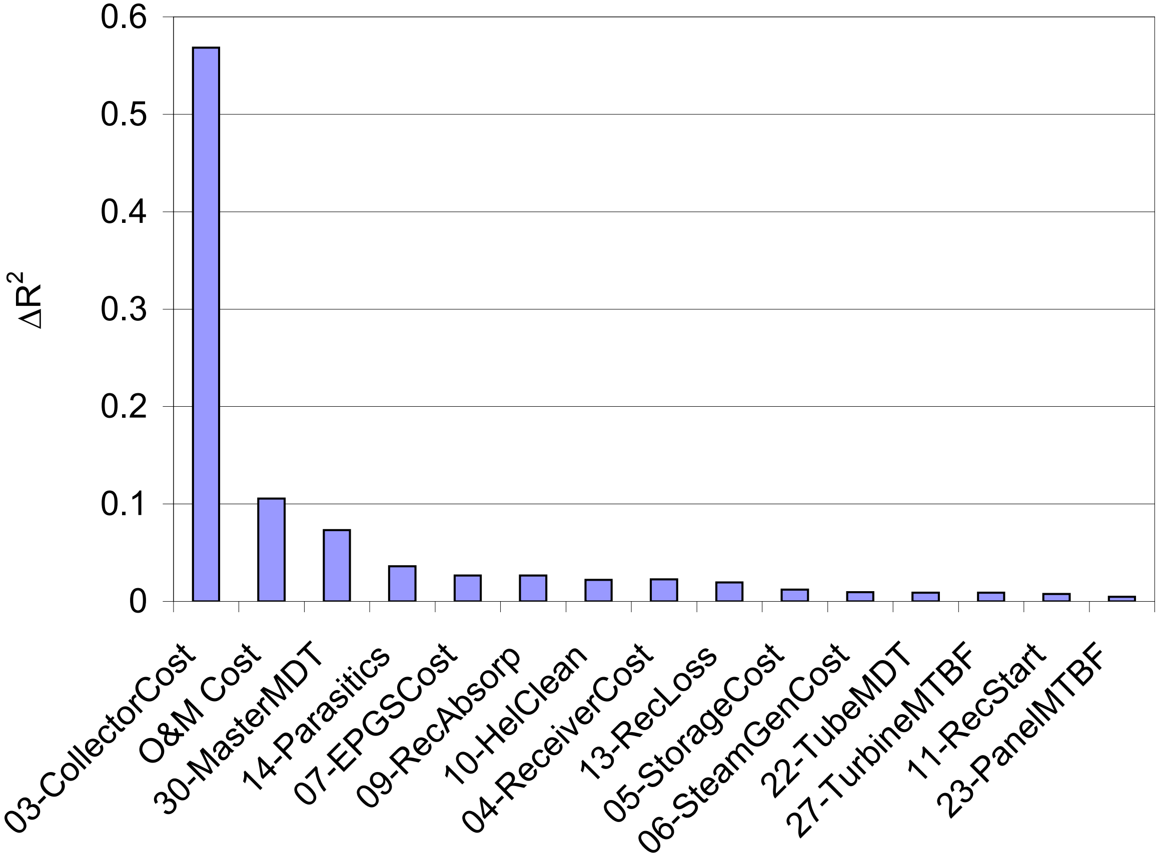
Distribution of Results
(Multiple Simulations)

Benefit #1: Quantifies Uncertainty



Provides estimate of confidence in model results

Benefit #2: Identifies system components most important to performance or cost metric

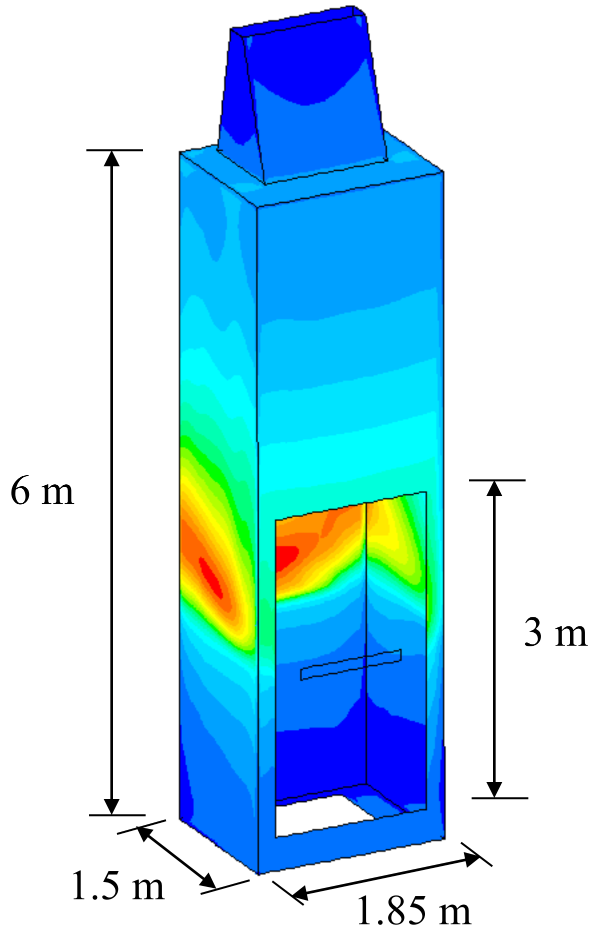


Prioritize R&D to improve components that matter the most

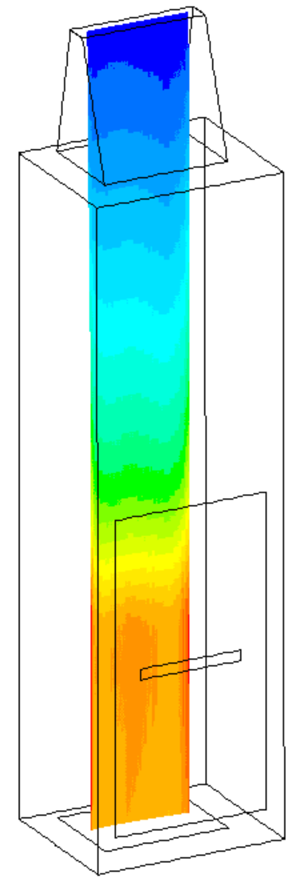
3. Solid Particle Receiver Modeling

- Can achieve higher temperatures via direct particle irradiation for thermochemical processes and storage
- 3-D model in FLUENT
  - Irradiation from heliostat field
  - Two-band reradiation and emission within cavity
  - Discrete-phase particle transport and heat transfer
  - Gas-phase convection and interaction with particles
  - Wall conduction
  - Radiative and convective heat losses

On-sun testing (Siegel and Kolb, 2008)

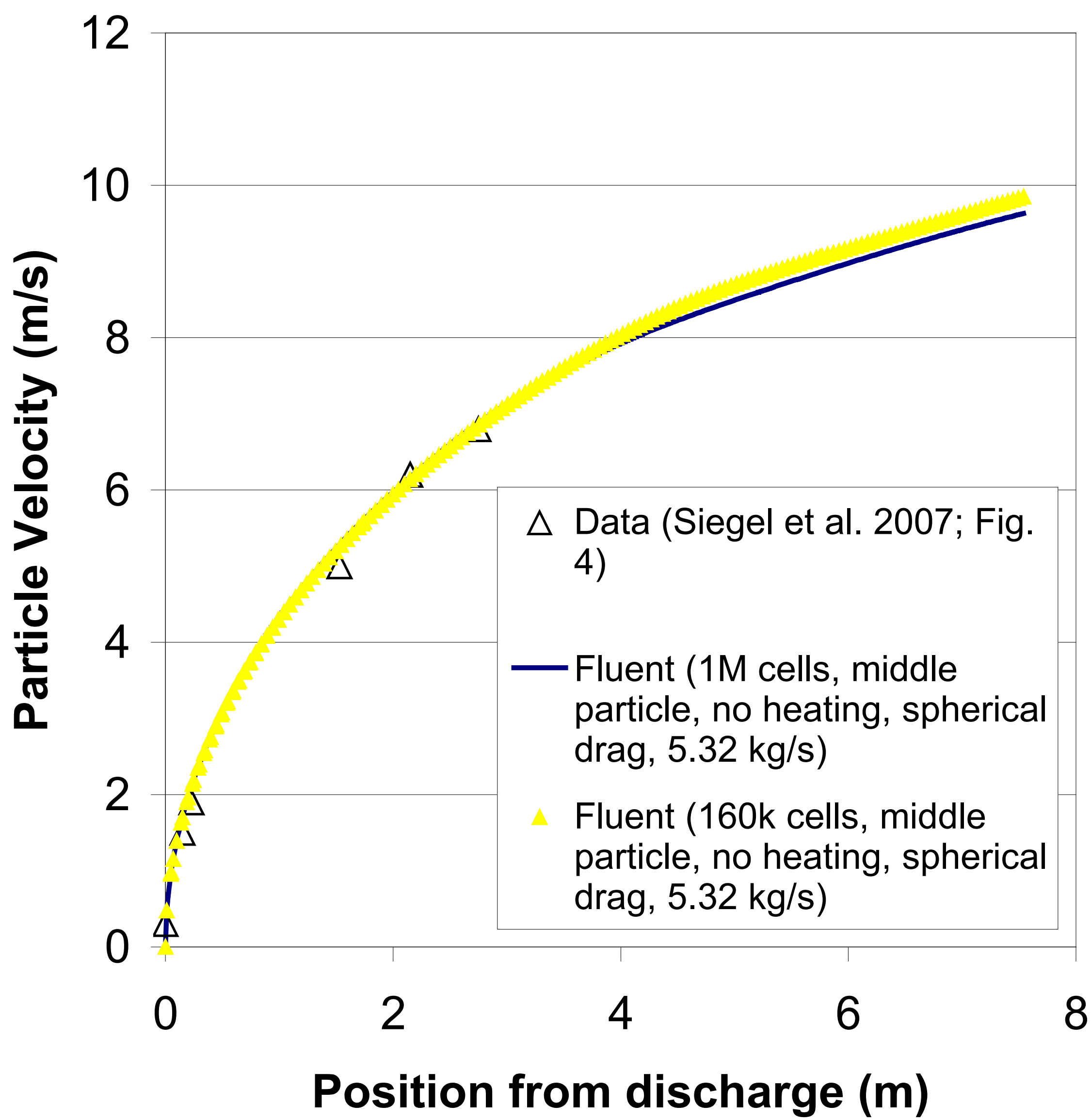


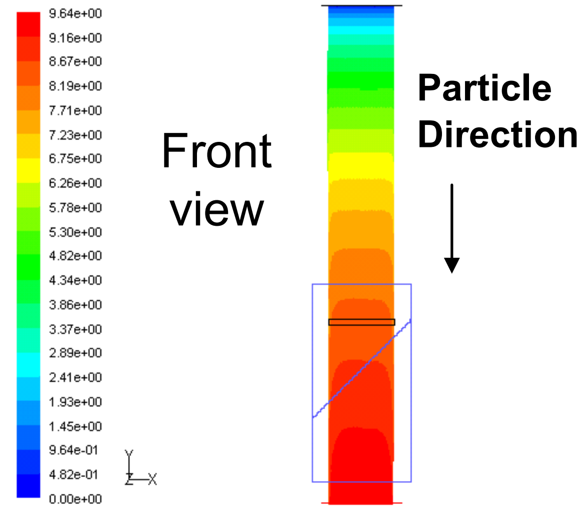
Simulated Wall Incident Radiation



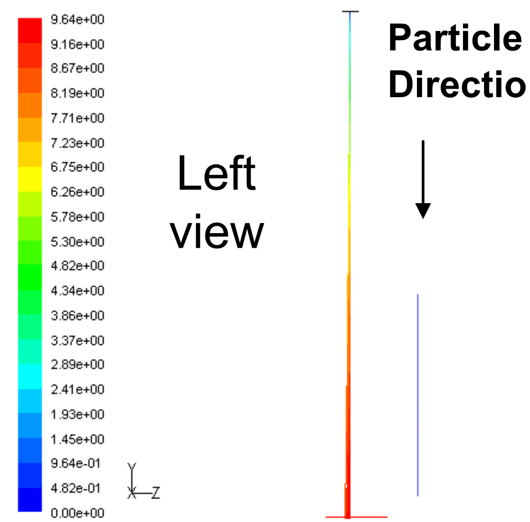
Simulated Particle Tracks Colored by Temperature

SPR Model Validation: Particle Velocity

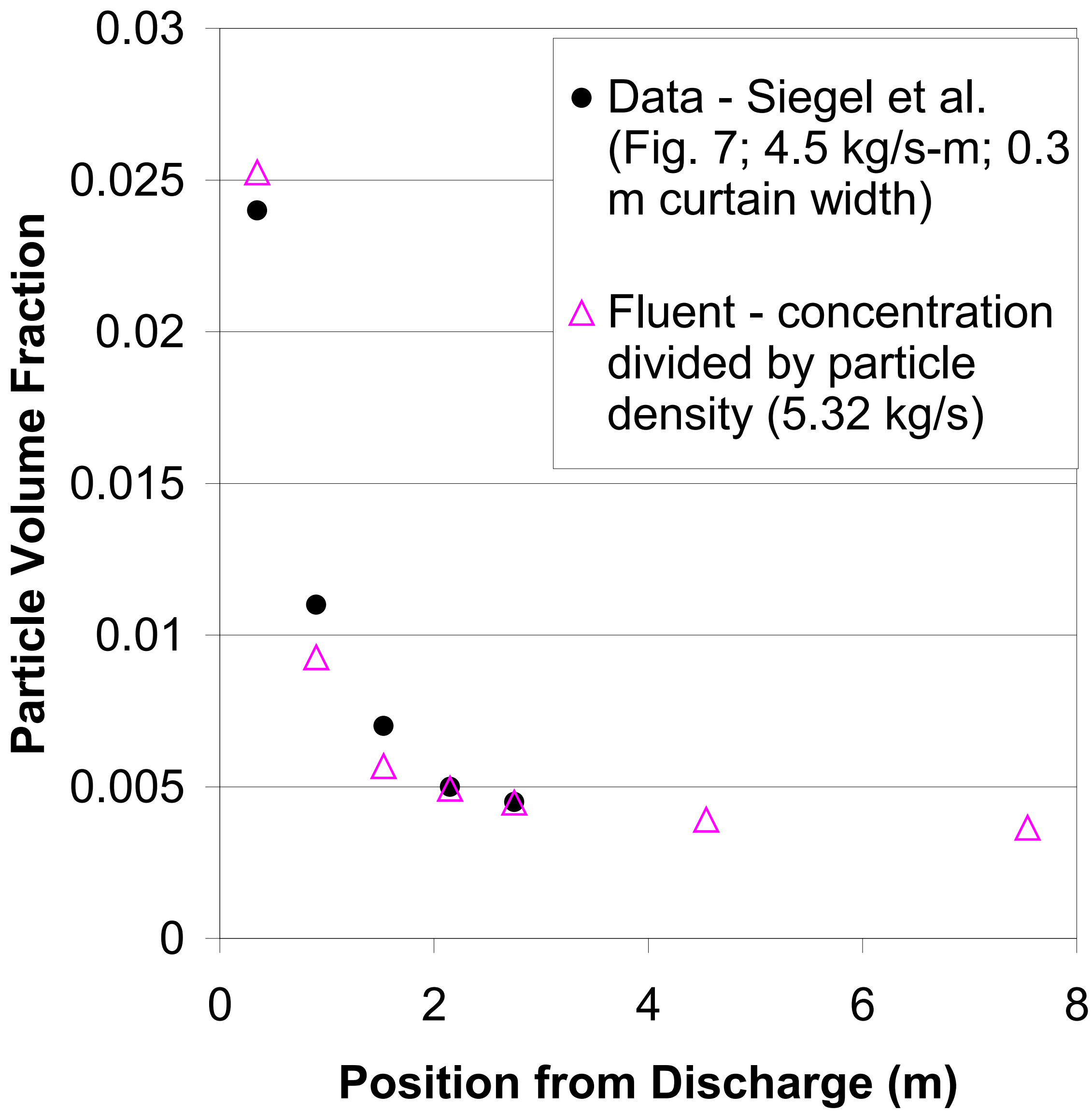


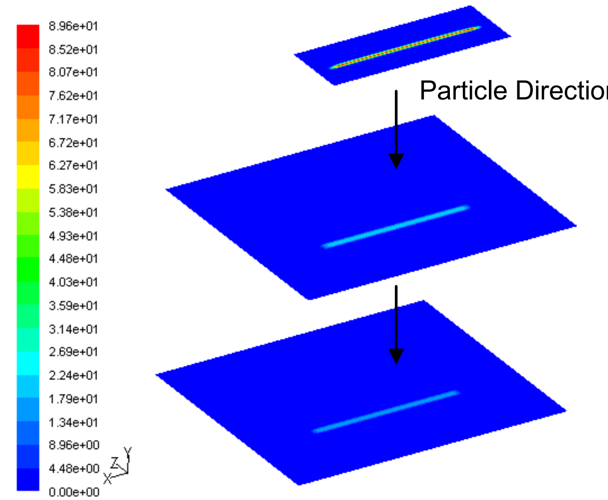


Fluent particles colored by velocity magnitude (m/s).



SPR Model Validation: Volume Fraction

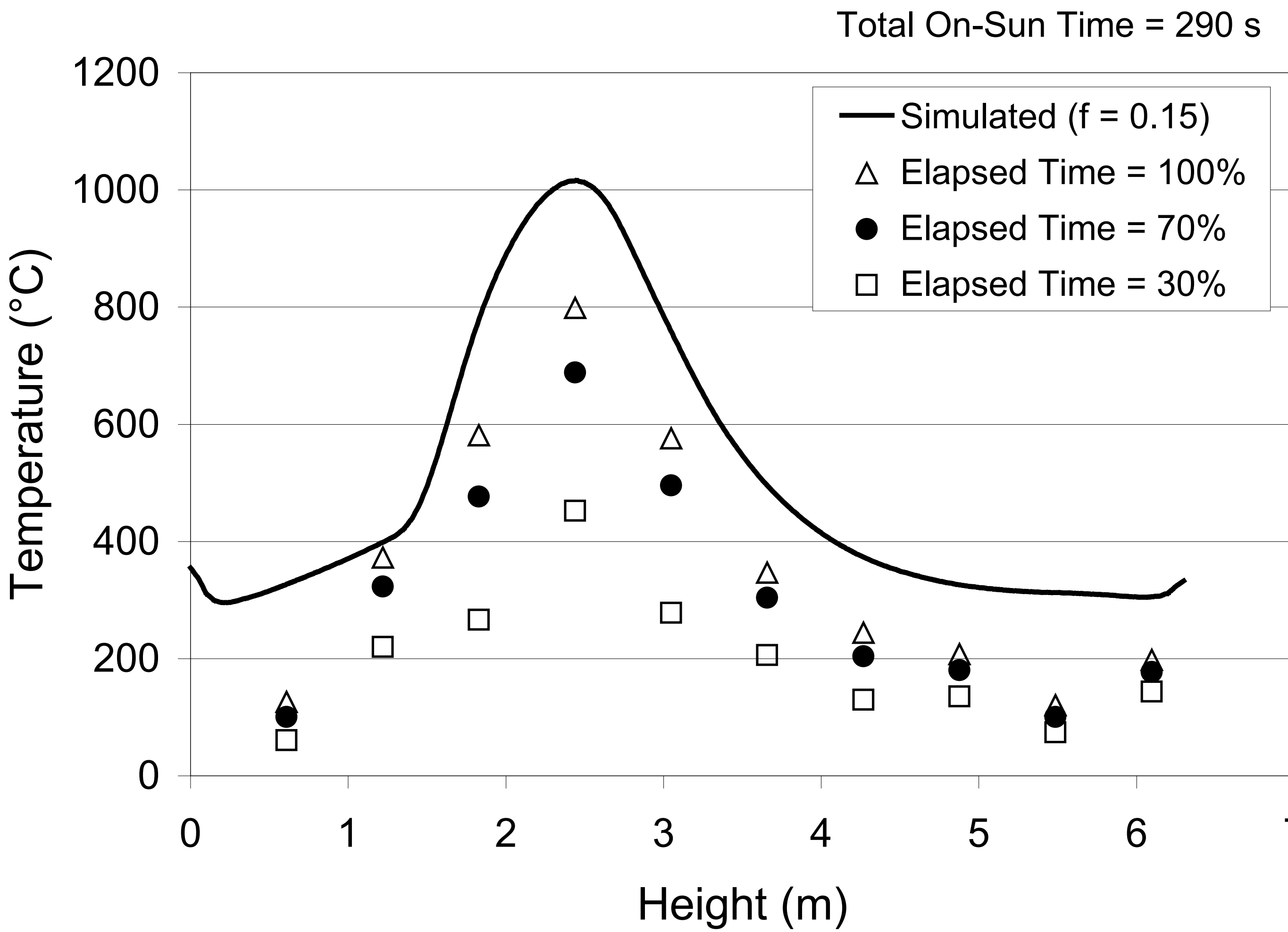




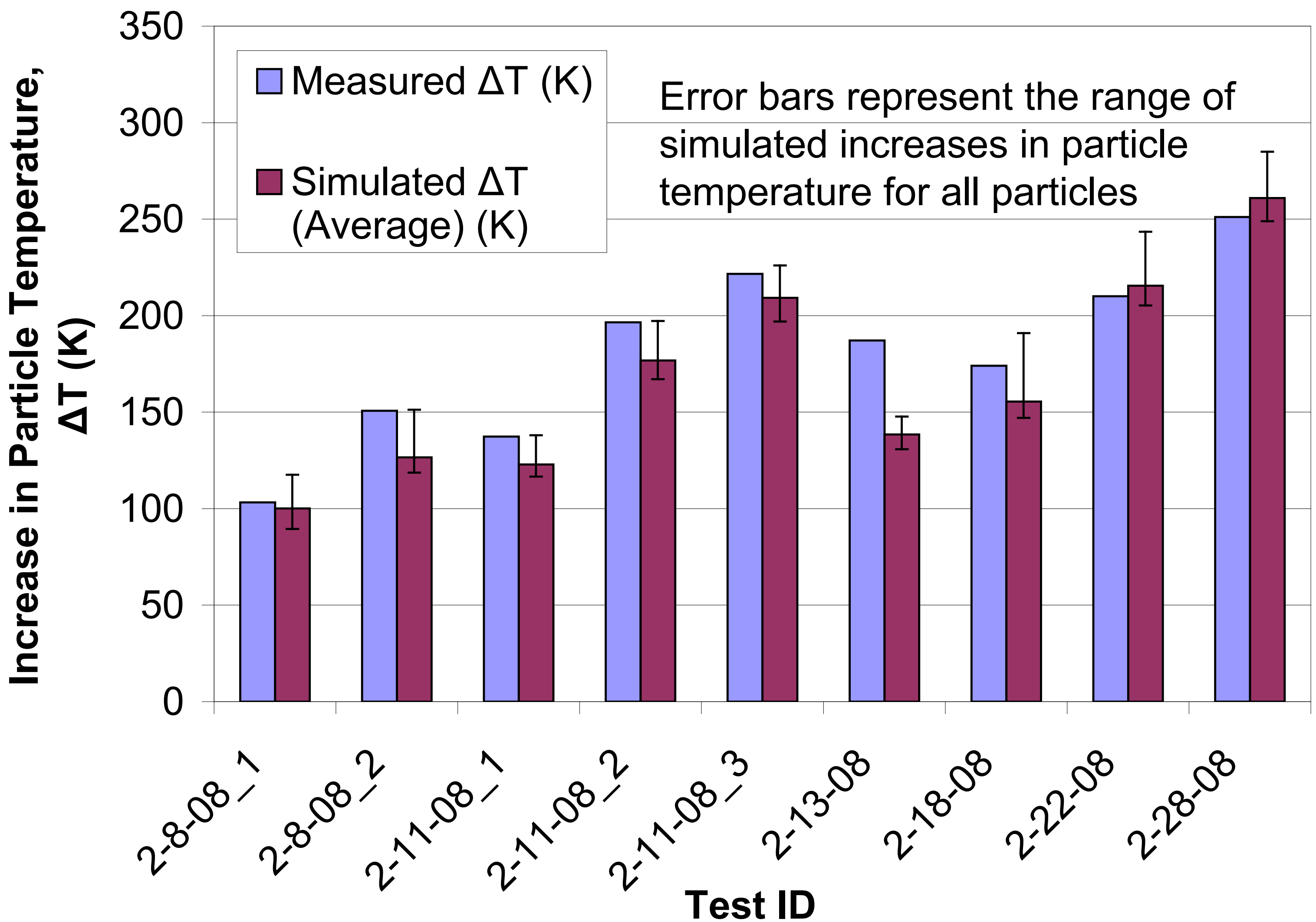
Particle concentrations (kg/m^3) along horizontal planes at y=7.19m (drop=0.35m), y=6.01m (drop=1.53m),y=4.79 m (drop=2.75m). The concentration divided by the particle density (3550 kg/m^3) is the particle volume fraction.

SPR Model Validation: Wall Temperature

2-22-08 Back Wall:
Flow Rate = 5.32 kg/s-m, Input Power = 2.56 MW



SPR Model Validation: Particle Temperature

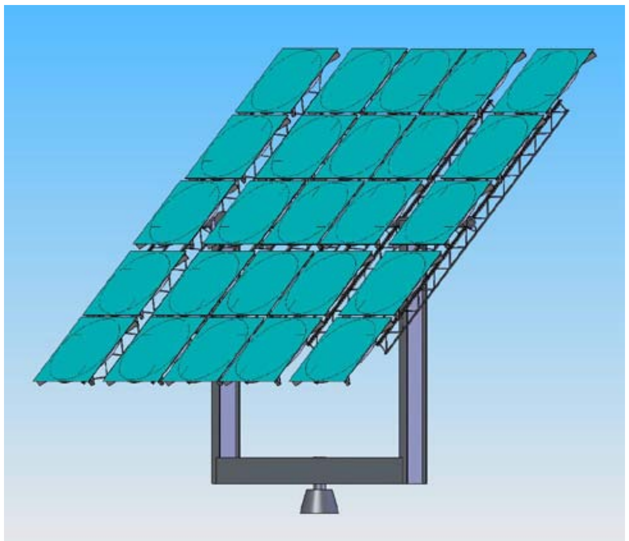


Perform parametric analyses to optimize design and performance

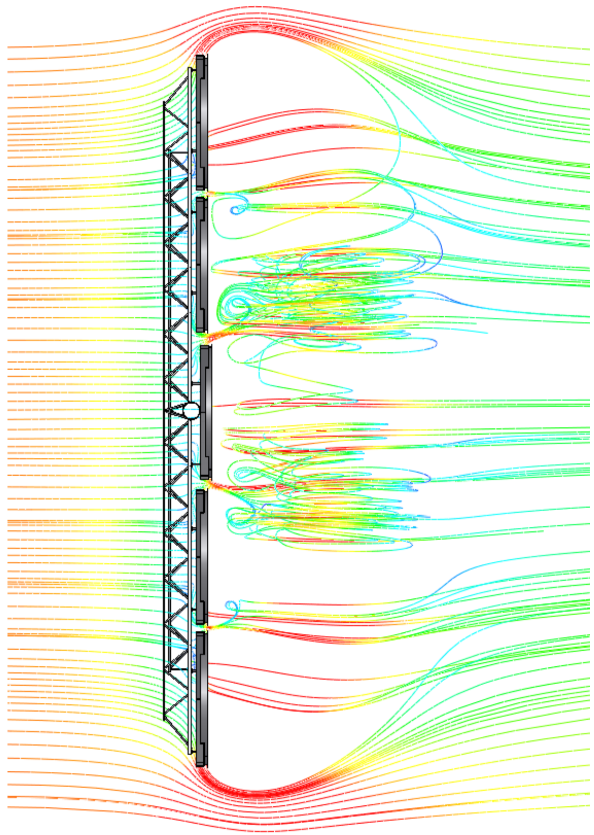
- Particle-drop position
- Particle size
- Particle mass flow rate
- Solar flux

4. Coupled Processes/Heliostat Modeling

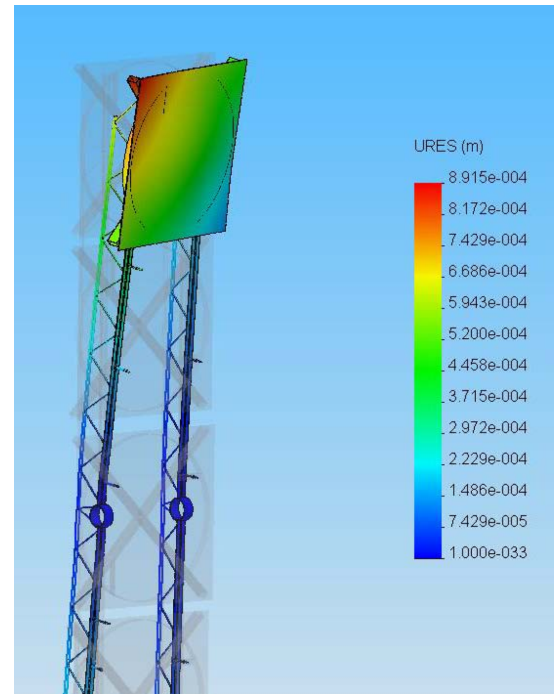
- Understand impact of wind and gravity loads on optical performance of heliostats and other collector systems
- Optimize structural design
- Characterize uncertainties



3D Solidworks model of heliostat at Sandia



CFD simulations of flow over heliostat



FEA analysis of loads on facet

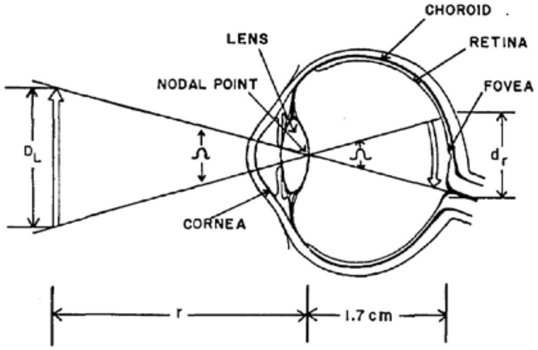
5. Glint and Glare Analyses

- Develop unified and rigorous method to assess solar-reflection hazards from solar power plants
- Needed in applications for certification
  - (e.g., California Energy Commission)

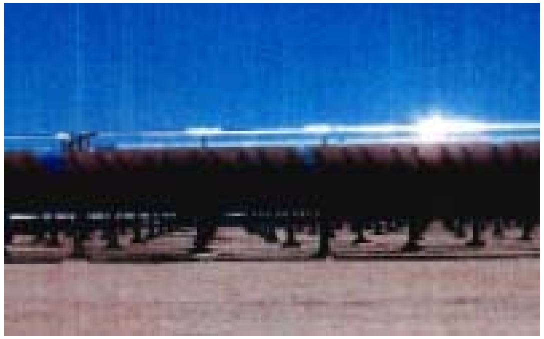
- Evaluate retinal irradiance from specular and diffuse reflections
  - Disability glare metrics
    - Flash blindness
    - Irreversible retinal burn

SES Dish Collectors, Sandia National Laboratories, NM

Solar One, 10 MW_e Power Tower, Daggett, CA



Sliney and Freasier, 1973



Kramer Junction, 150 MW_e Parabolic Trough, Mojave Desert, CA

Relevance/Impact of Research

Relevance/Impact of Research

- Probabilistic modeling
  - Uncertainty analyses will provide companies with more confidence and reliability in their cost/performance models
  - Sensitivity analyses will prioritize R&D to focus on system components that have the most impact
- Solid particle receiver modeling
  - Optimize designs to advance next-generation power cycles, thermochemical fuel-production processes, and storage media

Relevance/Impact of Research

- Coupled Processes/Heliostat Modeling
  - Enable better structural designs and/or procedures to minimize deviations caused by wind/gravity loading
  - Improve characterization of uncertainties
- Glint and Glare Analyses
  - Provide rigorous cross-cutting analyses that can be used by applicants seeking certification for solar thermal power plants

Future Directions

Future Directions

- Implement probabilistic modeling into existing tools (e.g., SOLERGY, SAM)
- Optimize design for next-generation solid particle receiver
- Develop integrated models to optimize system design and performance under normal and off-normal conditions (CAD/fluid/thermal/structural/optical)
- Complete glint and glare analyses