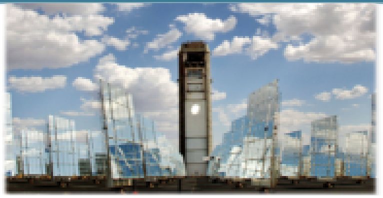
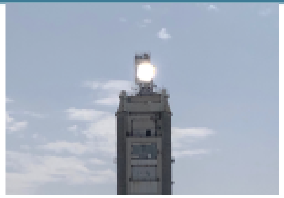
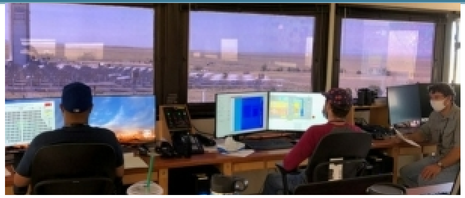
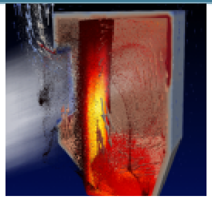
SAND2021-11558C

Sandia National Laboratories

Model Validation of Falling Particle Receivers with On-sun Experiments

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Presentation Content

- Introduction and Background
- Objectives and Motivation
- NSTTF Receiver Test Campaign
- Falling Particle Receiver Models
- Model Validation Study
- Conclusions and Summary

Particle-Based Concentrating Solar Power

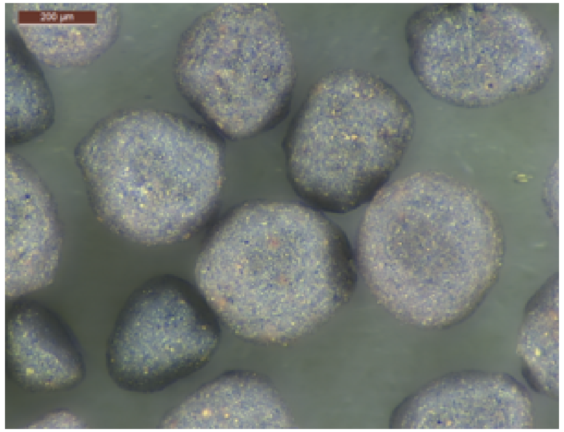
Particle technology is a leading candidate to couple with next-generation concentrating solar power (CSP) systems

Advantages of particles in CSP:

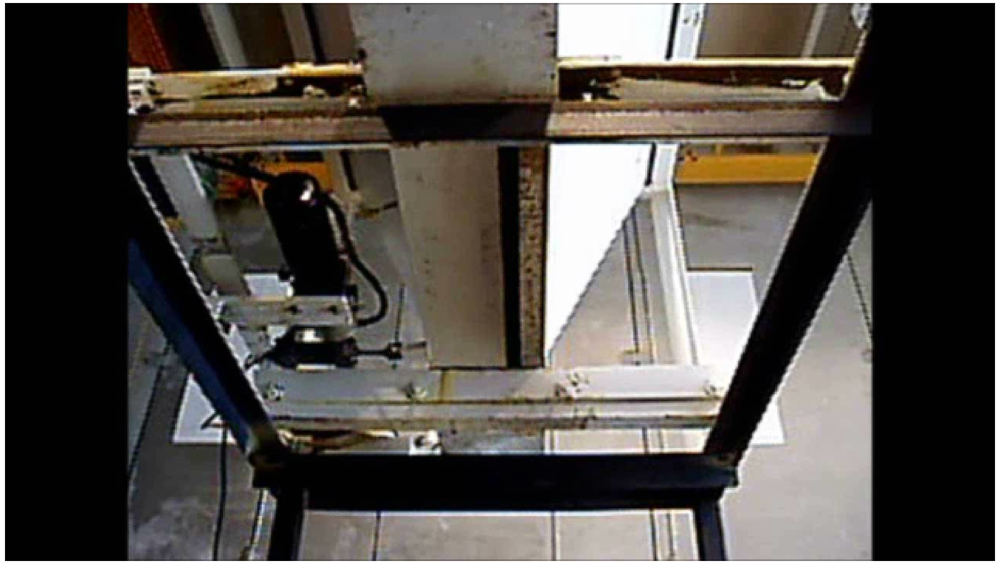
- Able to achieve high temperatures (>800°C)
- Low parasitics (gravity driven)
- Low cost heat transfer medium
- Efficient storage
- Direct irradiation (absence of flux limitations)
- No trace heating is necessary

Sandia National Laboratories has a long history of researching particles for CSP technologies with renewed interest over the past decade

CARBO-HSP Particles



Yue, L., et al. (2019)



Falling Particle Receivers

Falling particle receivers (FPRs) are cavity receivers where particles are released in a curtain and fall via gravity past the beam of concentrated light

Sandia has been experimentally testing FPRs at the National Solar Thermal Test Facility (NSTTF) for years (**>800°C** outlet temperatures)

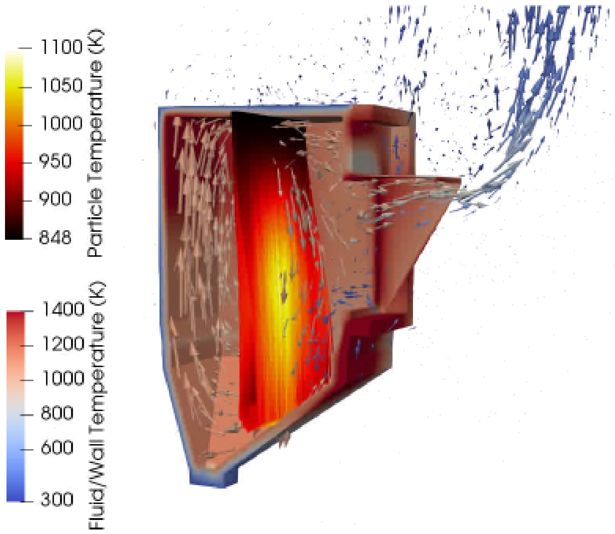
Advantages of FPRs:

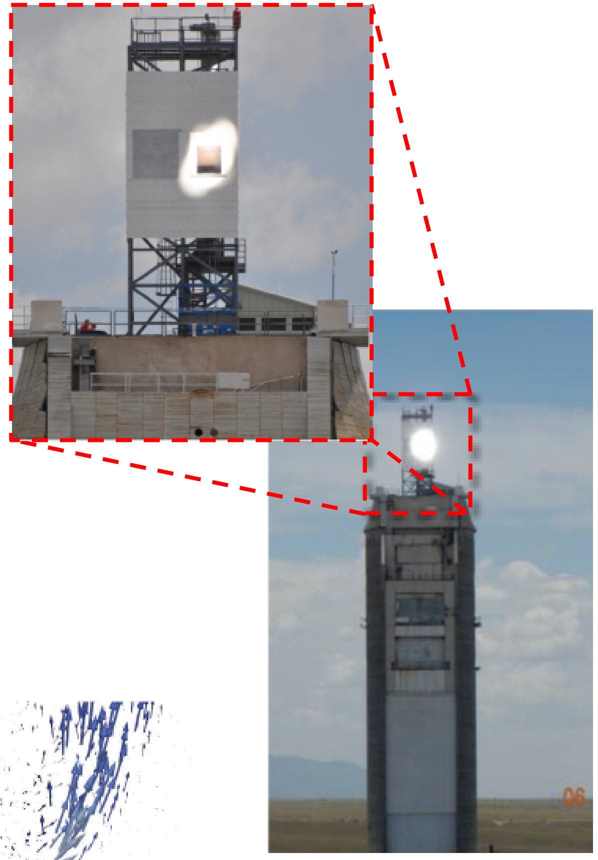
- Direct irradiance of the particles (fast response; absence of flux limitations)
- Experimental evidence of reaching requisite temperatures
- Low parasitics; only a single slide gate for control
- Conceptually simple and inexpensive

Disadvantages of FPRs:

- Sensitive to advective losses through the aperture
- Open aperture increases susceptibility to wind

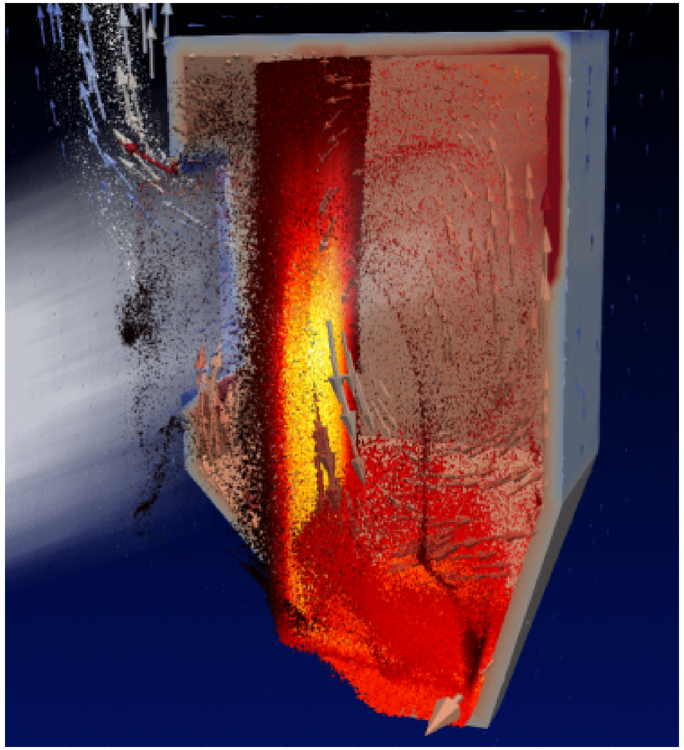
Advanced models of FPRs are used to predict the thermal performance in various designs





Prototype FPR at the top of the existing tower at the NSTTF

Objectives and Motivation



Visualization of the FPR at the NSTTF

Objective:

Utilize data collected at the NSTFF for FPRs to validate corresponding models and predictions of the thermal performance (*i.e.* thermal efficiency)

Motivation:

A validated FPR model will yield better predictions for the performance of the receiver in conditions that can't be experimentally tested

A validated FPR model will provide more confidence in modeled performance of larger receivers in utility scale facilities

Accelerates FPR development by allowing features to be evaluated quickly

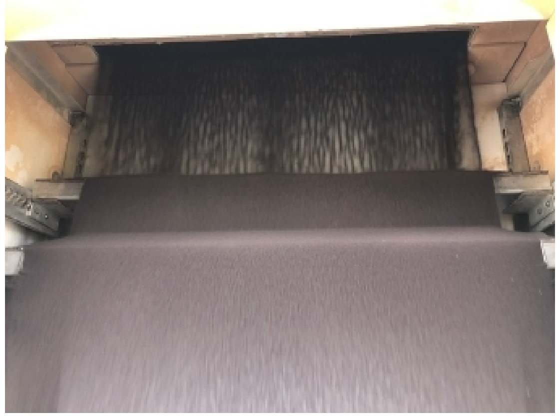
Existing model validation studies have left considerable room for improvement:

- Additional data collected for wind in the recent 2020–2021 test campaign offer more information for effective comparisons

NSTTF 2020-21 FPR Test Campaign

A FPR test campaign was performed at the NSTTF to mitigate risks during the development of the Generation 3 Particle Pilot Plant (G3P3)

- Among the objectives, the **thermal efficiency** of the existing FPR was quantified for different design features aimed at improving receiver performance
- The receiver featured a truncated design **with and without multistage features**



Multistage particle curtain

Wind speed and direction were also measured around the receiver module for additional validation metrics

A total of **27 cases** were selected from the dataset

Criteria for omitting cases included:

- Missing data (e.g. missing of wind measurements)
- Low power (<350 kW incident power)
- Issues with particle temperature/mass flow rate measurements

FPR Models

A steady-state **Lagrangian-Eulerian approach** is used to model particles falling through air inside a FPR within ANSYS Fluent®

Falling particles are coupled with the air continuum through **drag forces, heat transfer, and turbulent interactions**

- Spherical particles are assumed (CARBO-HSP)

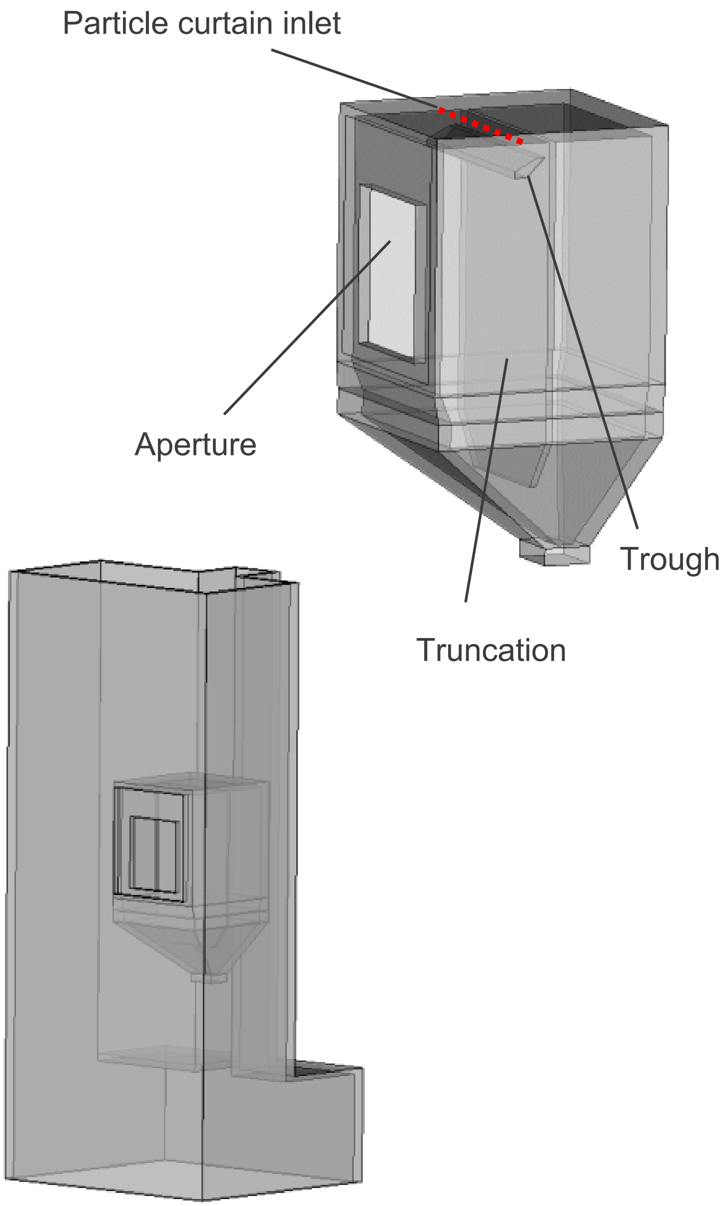
A **non-grey, discrete-ordinates** model is applied to model radiative heat transfer in three bands

- 0.1 – 2.5 μm; 2.5 – 4.5 μm; 4.5 – 100 μm
- Radiation enters the domain in the smallest wavelengths

Conduction through the receiver walls is also modeled

Reduced-order models are used to model particles interacting with a trough (*i.e.* multistage)

- Shaeffer, R., et al. (2020). Evaluation of Performance Factors for a Multistage Falling Particle Receiver. ASME ES 2020 Conference



Wind measurements and Validation

Five **3D anemometers** were placed around the receiver module to measure speed and direction

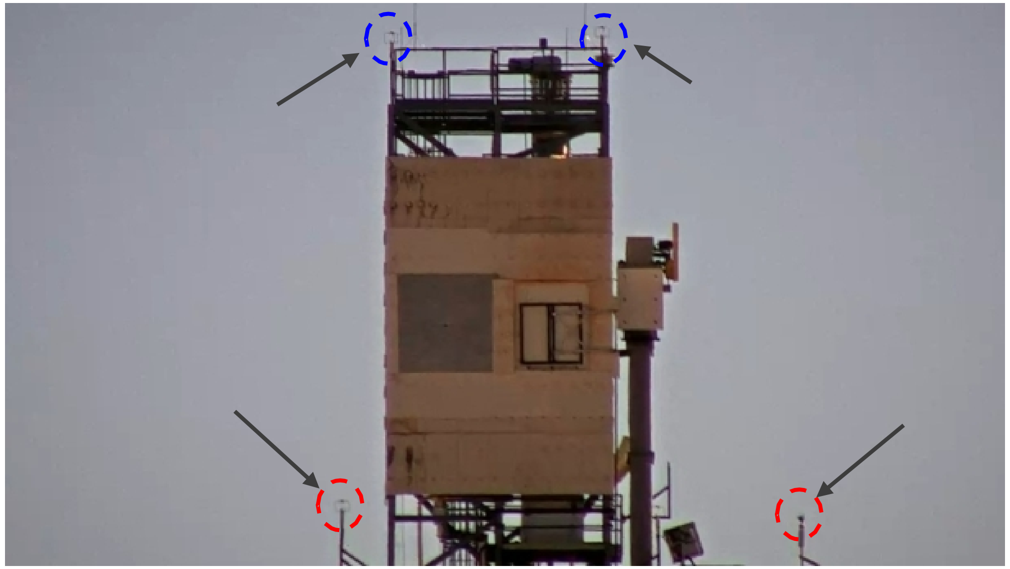
- Top two anemometers (blue circles) quantified free stream wind conditions
- Bottom three anemometers (red circles) were used for validation metrics

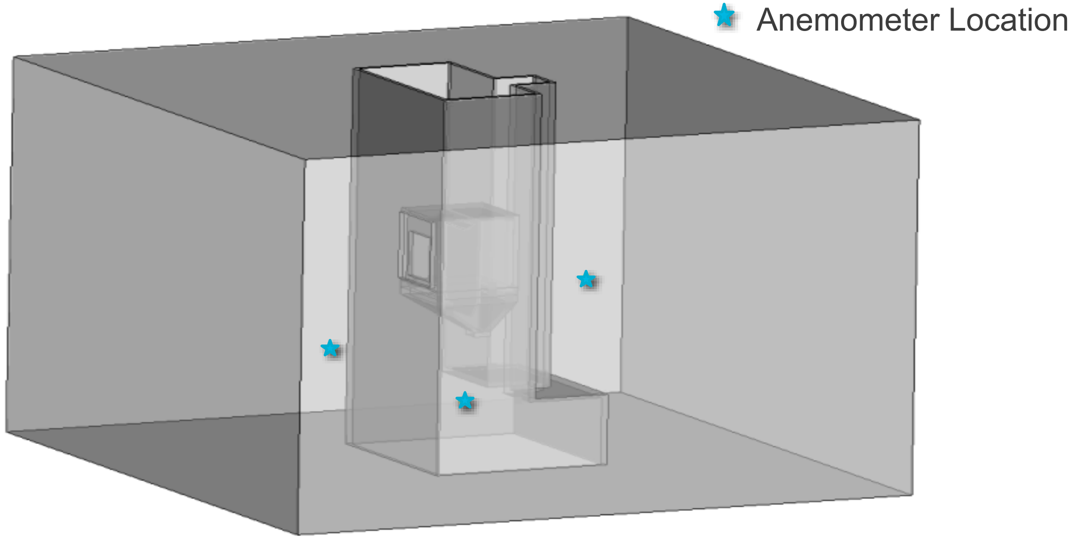
Parity plots were generated for **8 validation metrics**:

- Average Particle Temperature Increase, ΔT
- Receiver Thermal Efficiency, η
- Lower Anemometer Wind Speeds, v (3)
- Lower Anemometer Wind Directions, θ (3)

Linear fits of the parity plots targeted:

- $0.75 \leq$ slope ≤ 1.25 $R^2 \geq 0.75$





Thermal Efficiency and ΔT Parity Plots

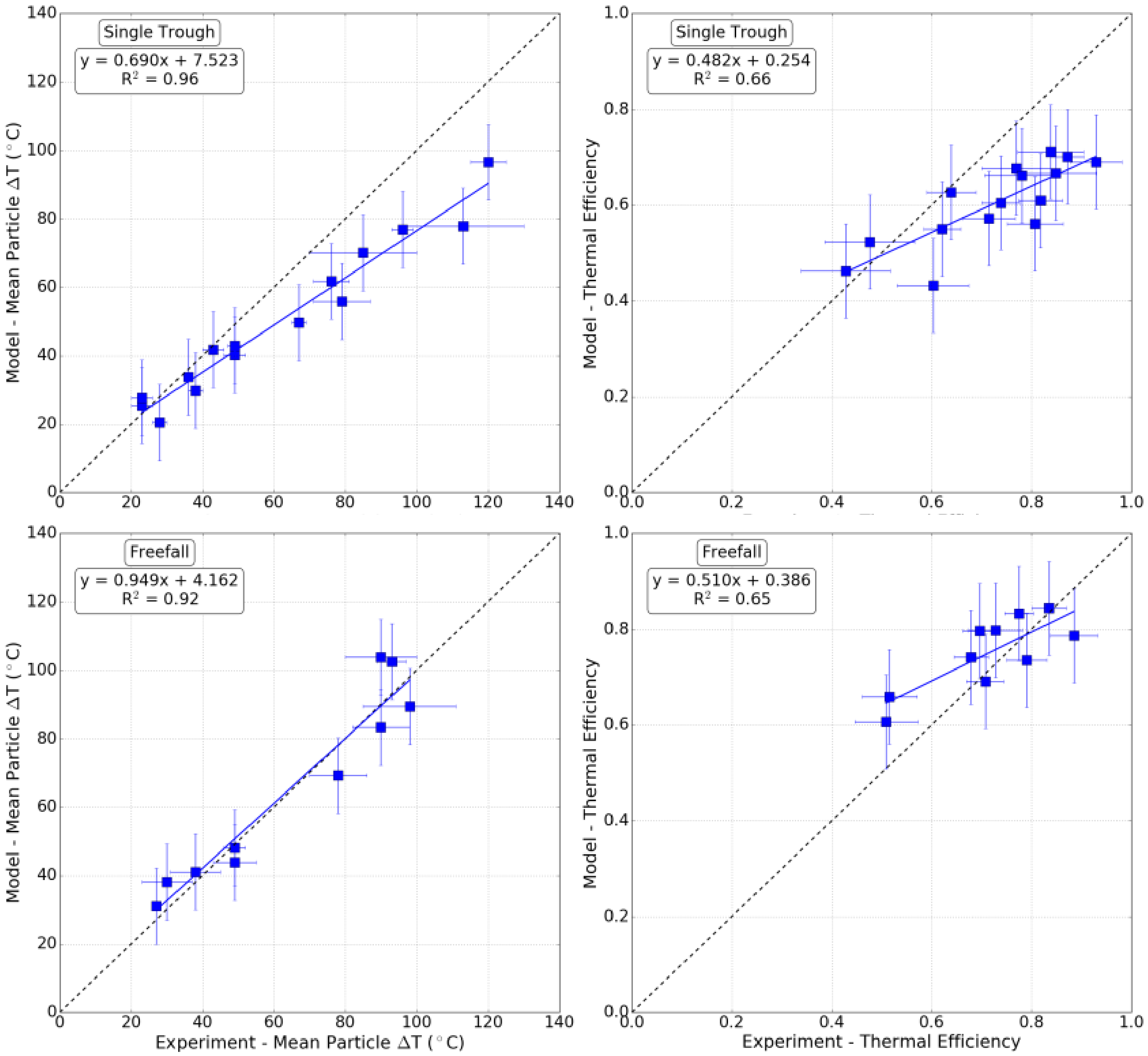
For the multistage receiver (single trough), the model **underpredicts *ΔT*** at the higher values

Likewise, the model does not predict the higher efficiencies measured

- slope < 0.75

For the freefall receiver, *ΔT* was well modeled but the scatter in the data resulted less agreement in the efficiency

Numerical uncertainty was quantified from a **probabilistic uncertainty analysis** using estimated uncertainties of various model inputs



Wind Speed and Direction Parity Plots

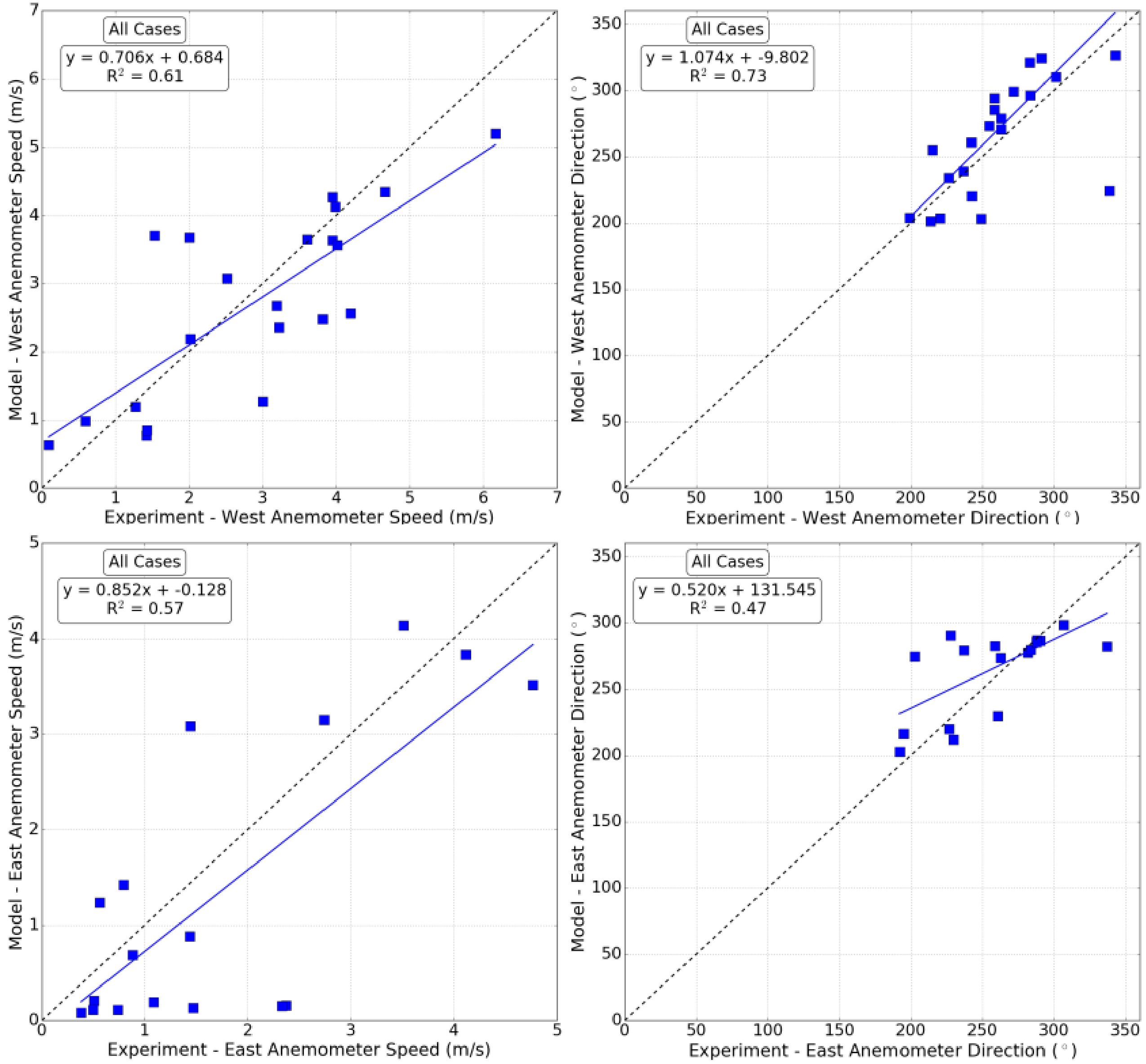
High scatter was observed in the wind speed

- Likely a function of a single point measurement for an anemometer

At the NSTTF, winds predominately originated from the West

- Explains the higher variability in the East anemometer which was often in the wake of the tower

The south anemometer (not depicted) also observed more variability from being in the wake of the tower



Validation Summary

Case	Variable	Slope	R^2
Single Trough	ΔT	0.69	**0.96**
	η	**0.48**	0.66
Freefall	ΔT	**0.95**	**0.92**
	η	0.51	0.65
All Cases	West An. Spd.	0.71	0.61
	West An. Dir.	**1.07**	0.73
	East An. Spd.	**0.85**	0.57
	East An. Dir.	0.52	**0.47**
	South An. Spd.	**0.97**	0.65
	South An. Dir.	0.54	0.50

Legend
< 0.5 or > 1.5
< 0.75 or > 1.25
> 0.75 and < 1.25

30% of the metrics listed above meet our targeted validation criteria, and **90%** are within 0.25

Although most metrics did not achieve targeted values, this represents the best validation to date with experimental data from FPRs

Summary and Conclusions

Model Validation Study Pursued Using Latest Experimental Dataset

Using the latest experimental data from the NSTTF 2020-21 FPR test campaign, a model validation study was pursued to build confidence in the modeling strategy used for FPRs

Validation of FPR Thermal Efficiency and Wind Around the Tower

For validation metrics including the thermal efficiency and wind around the tower, 30% met the target metric and 90% were near the target

Improved Model Validation Results over Previous Efforts

Although the validation presently falls below target metrics, the comparison presented here provides the best agreement to date with the experimental data

Thank You!

Questions?