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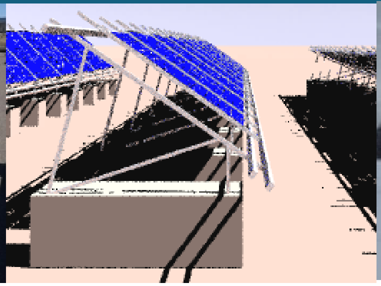
Sandia National Laboratories

Solar Transposition Modeling via Deep Neural Networks with Sky Images



PRESENTED BY

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U.S. DEPARTMENT OF ENERGY NNSA

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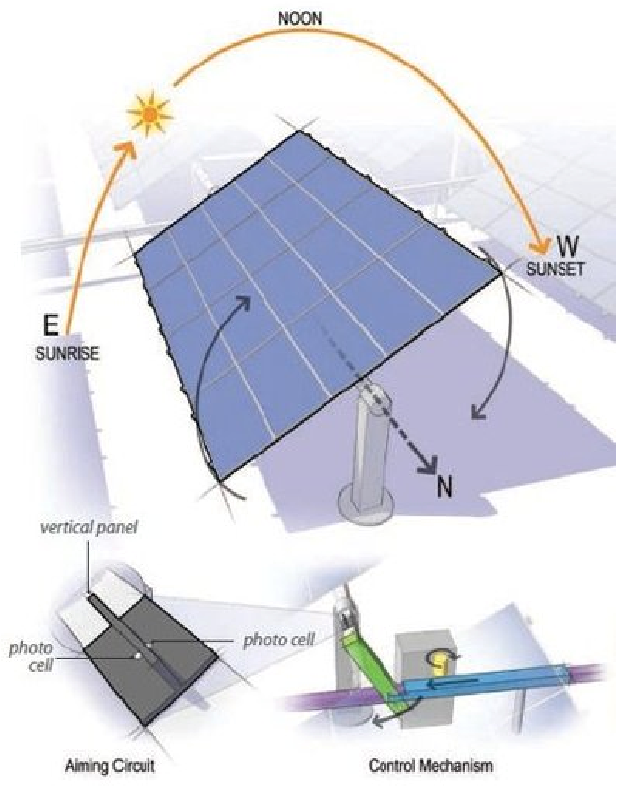
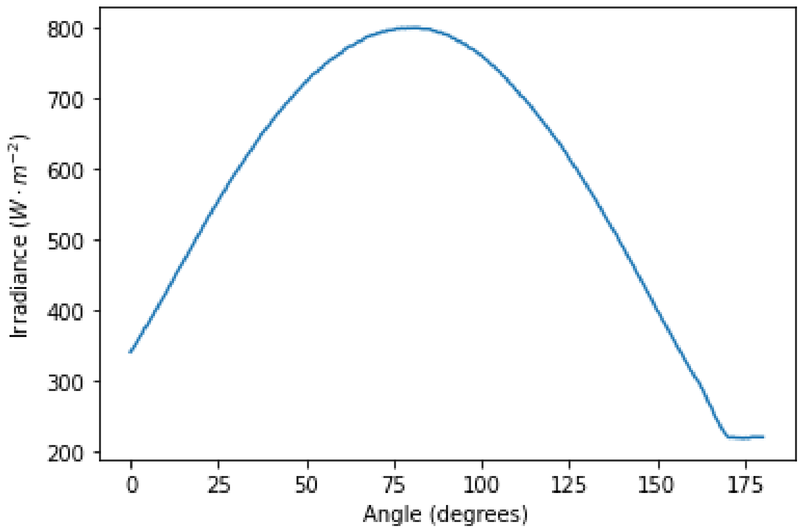
Introduction/premise

- Objective of the project: make single axis tracking more efficient
- Align solar panels with Sun
- Current approach merely follows where Sun should be, not current conditions
- When clouds are in front of the Sun, panel should be more horizontal



What models need to do:

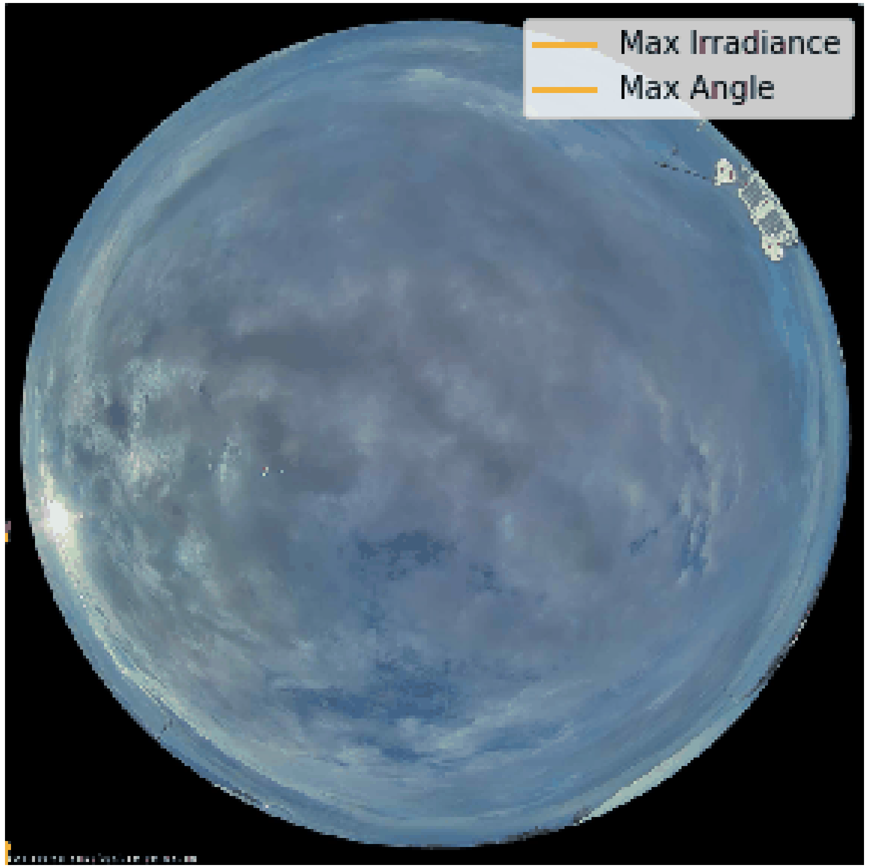
1. **Estimate angular irradiance profiles**
2. Find optimal *movement != angle of max. irrad.* of the tracking system



Data Sources

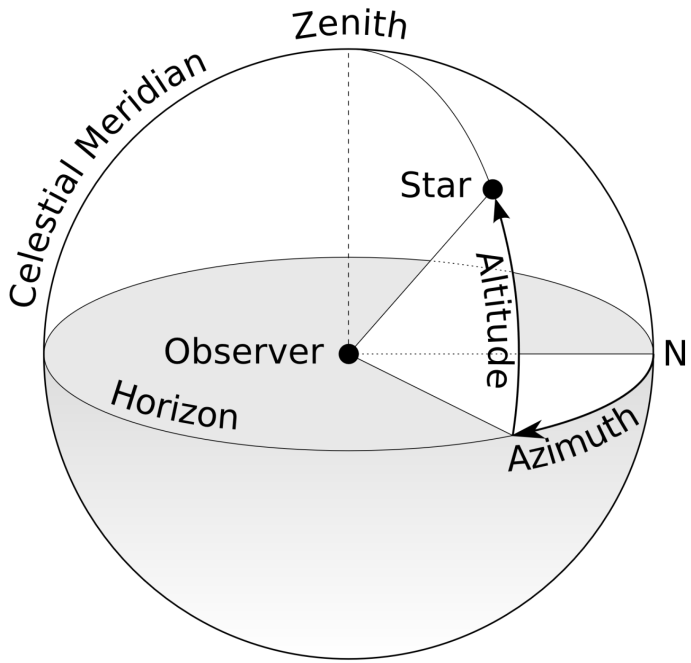
The (custom) MPIS sensor

ASI-16 Sky Camera



Model Input: Solar Position + Sky Images

- The Sun moves **predictably,** and its position can be easily **calculated**
  - This is useful to know when the Sun is obstructed by clouds
- This calculation is already implemented in **pvlib**
  - But not with respect to the **image**
  - This may be part of what the model learns
  - Or just a simple irradiance calculation



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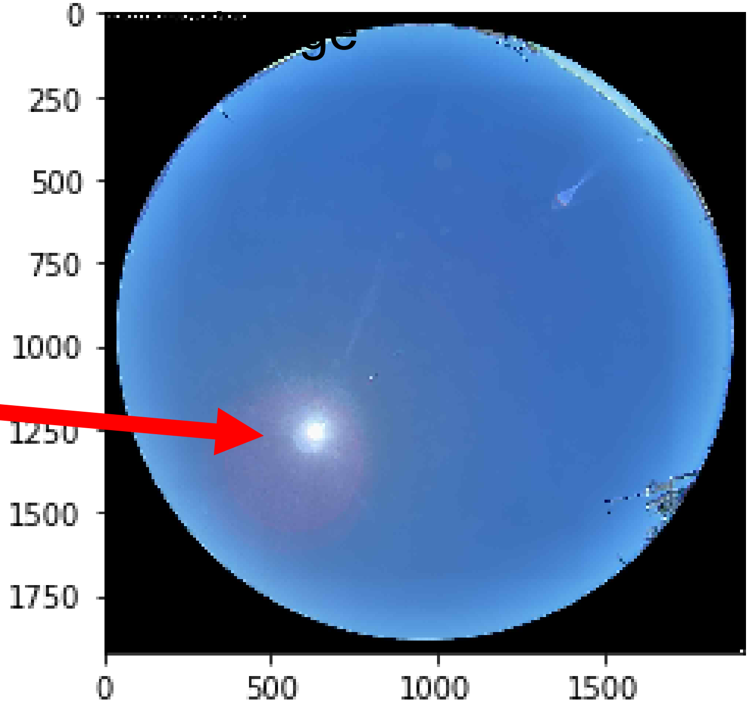
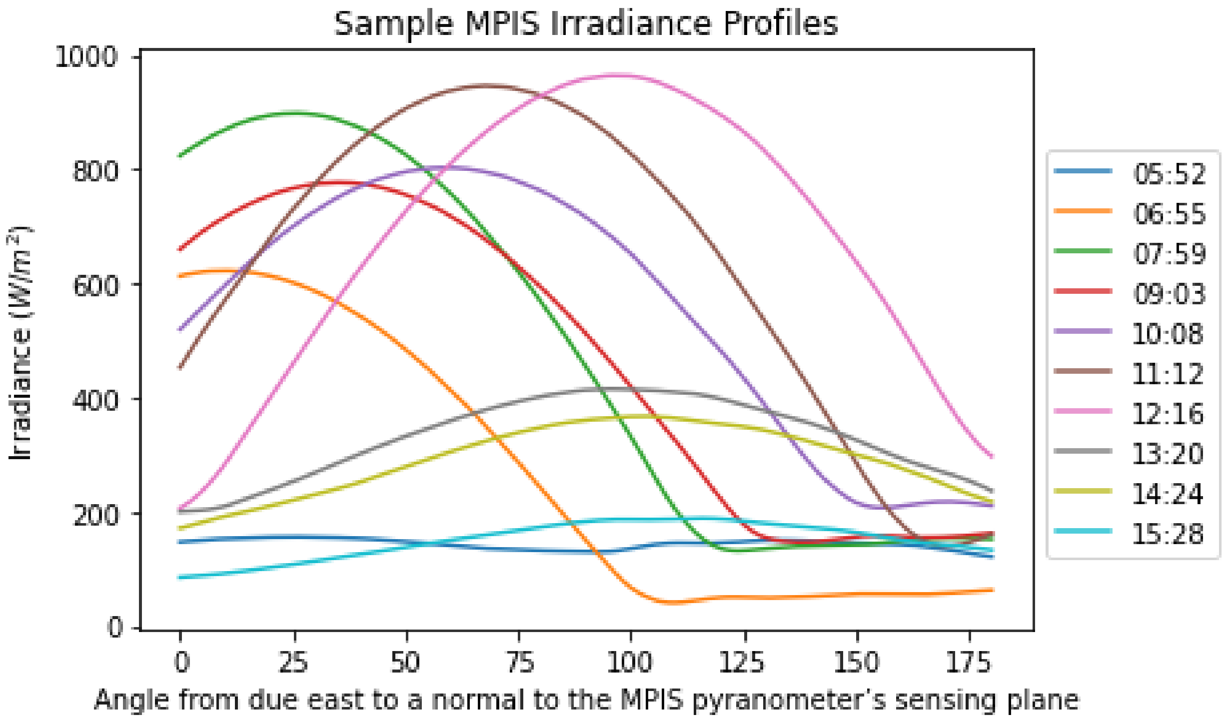
“Fisheye” sky



Model Output: Multi Planar Irradiance Sensor (MPIS)

- Sensor rotates from east to west over about a second
- Measures in half-degree increments from horizon to horizon
  - 0-180 degrees
- Developed by Augustyn & Company, Berkeley, California
- US Patent #1028155



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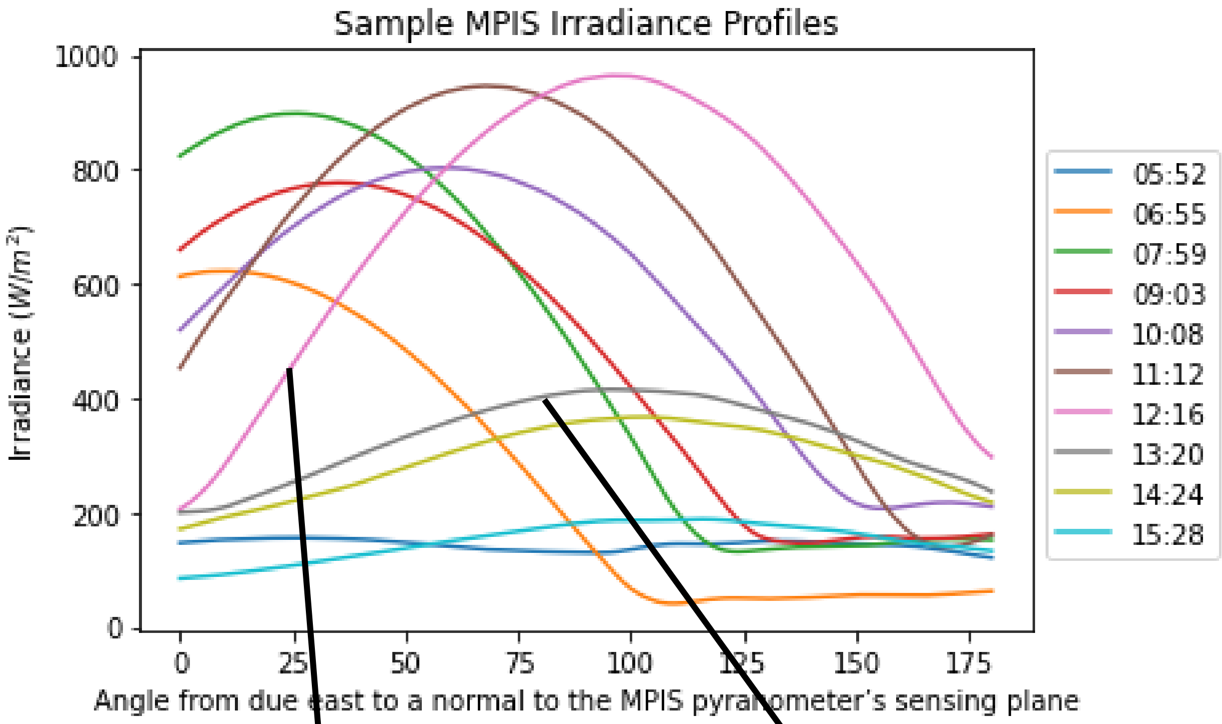
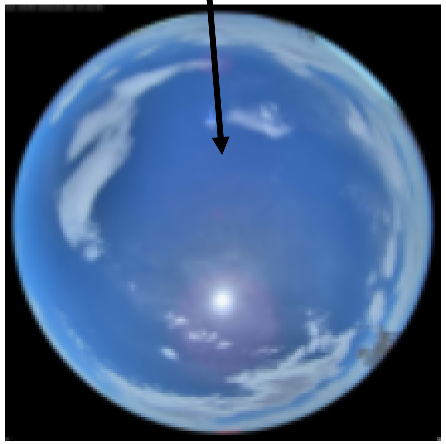
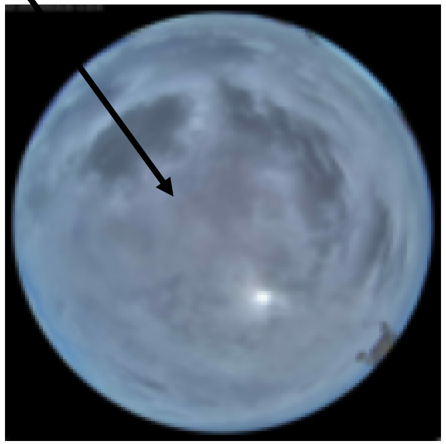
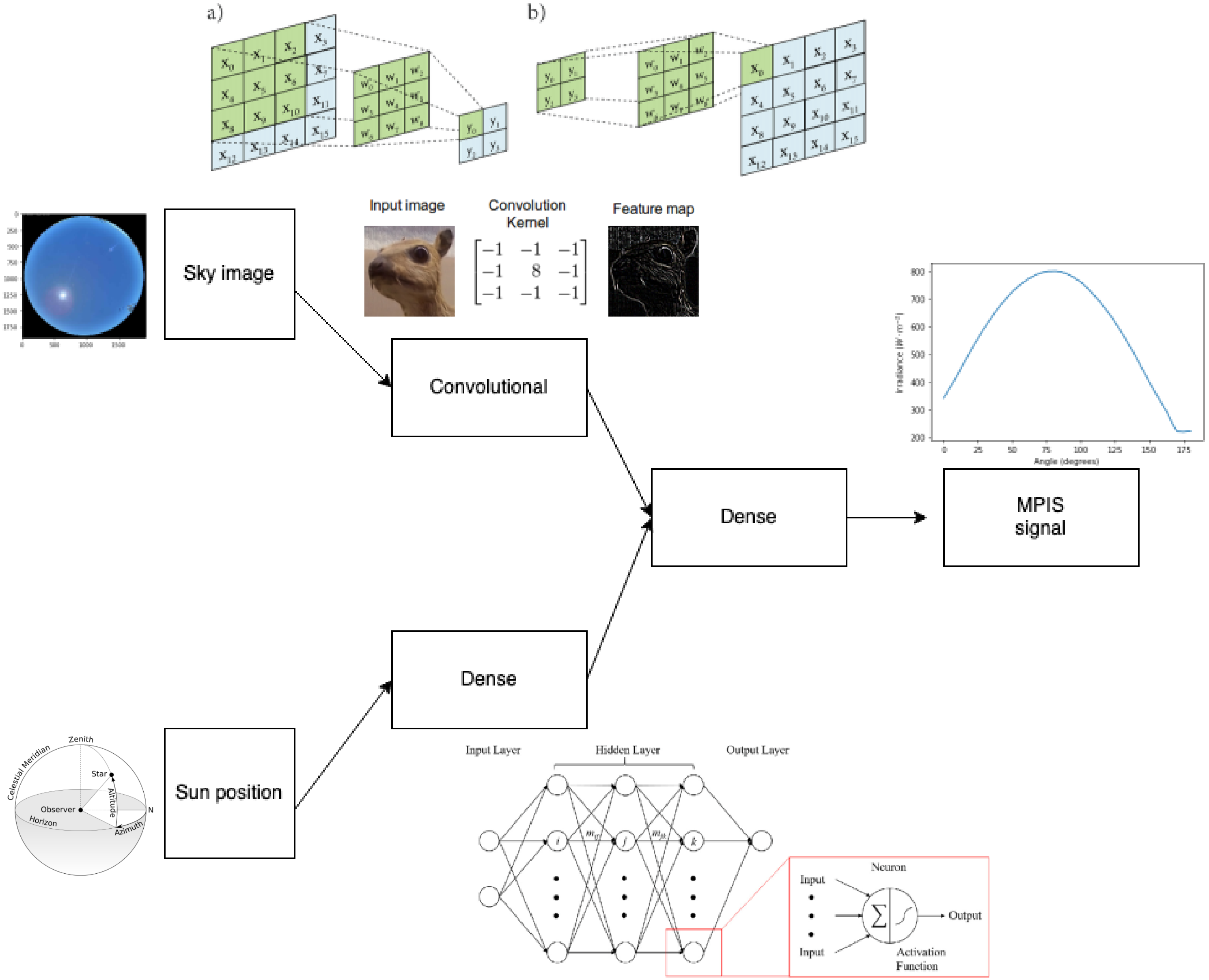






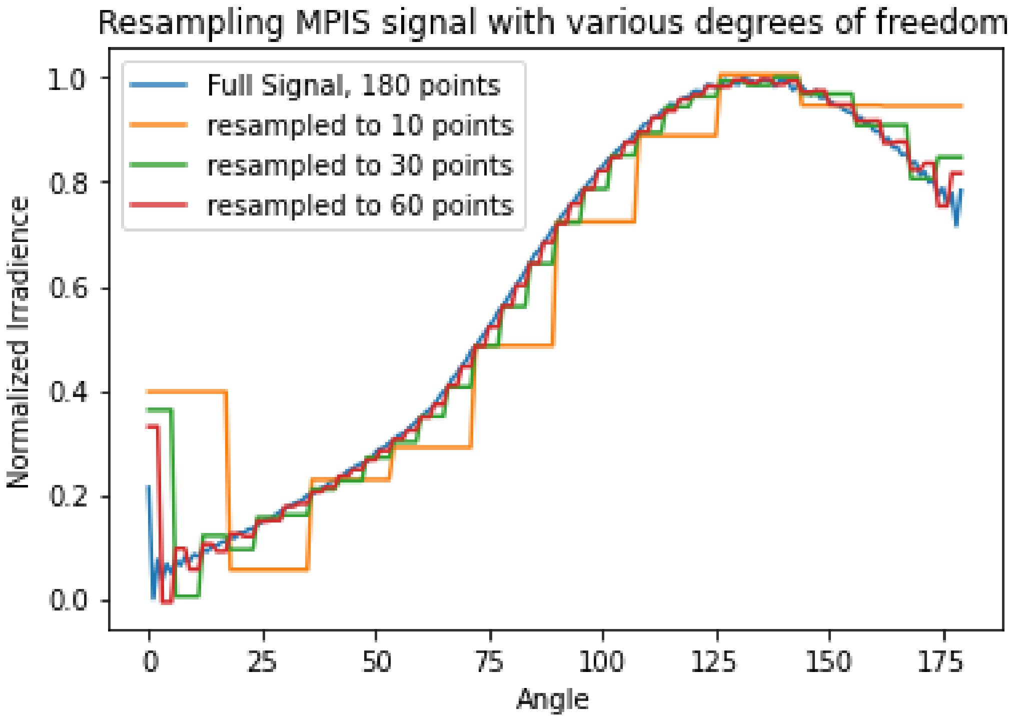
Multi-Input Convolutional Neural Network

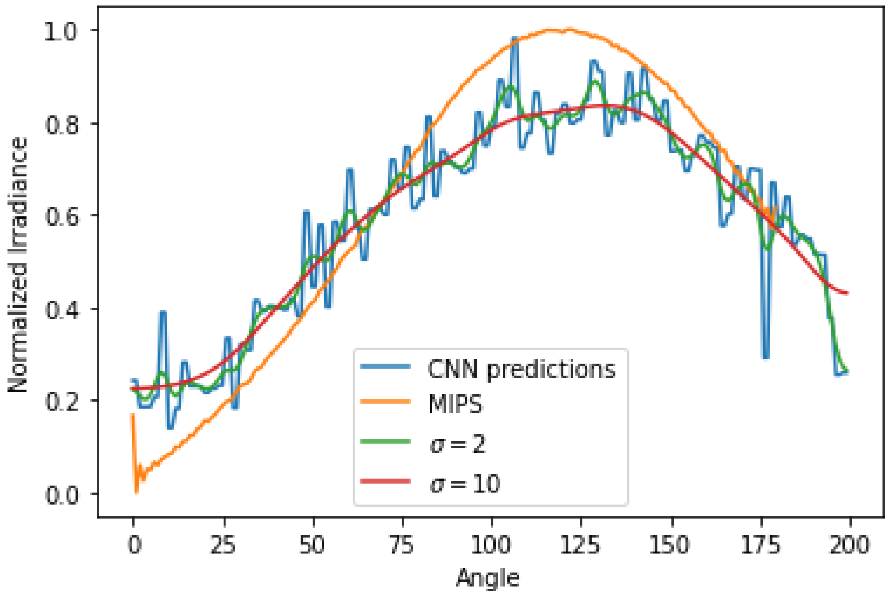
- This neural network takes **two** inputs
  - Sky image from **ASI 16**
  - Solar position (vector of length 6) from **pvlib**
- And **vector** output (**regression**)
  - Trained on the **MPIS** sensor readings as the ground truth
- Full model structure shown in paper
- Primarily consists of convolutional and dense layers
- ANN: learns arbitrary function given data



Resampling and Smoothing

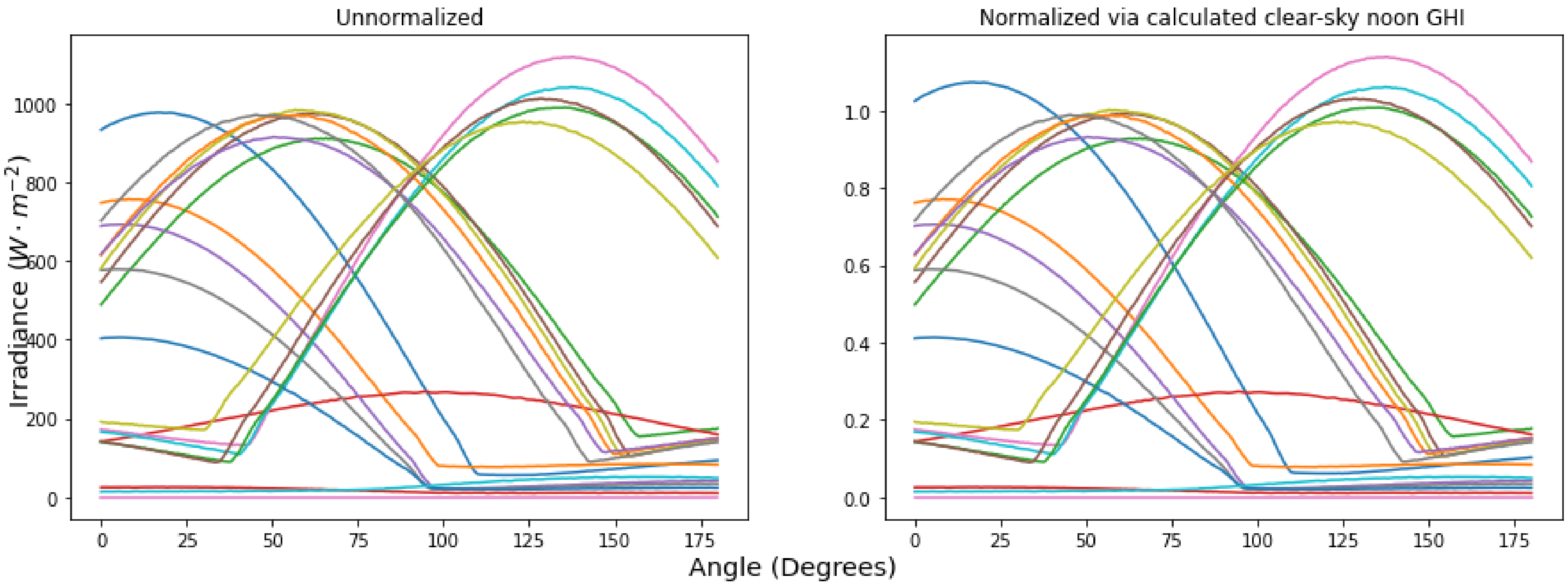
- It is difficult to model a high dimensional regression problem
  - Curse of dimensionality
- However, the MPIS signal is very smooth
  - Variance between angles is locally small
- Solution: downsample signal
  - Using Fourier method
  - Remove mirrored middle band frequencies
- This introduces additional source of error/jaggedness
  - That can be smoothed with Gaussian kernel
  - Also reduces natural error in model





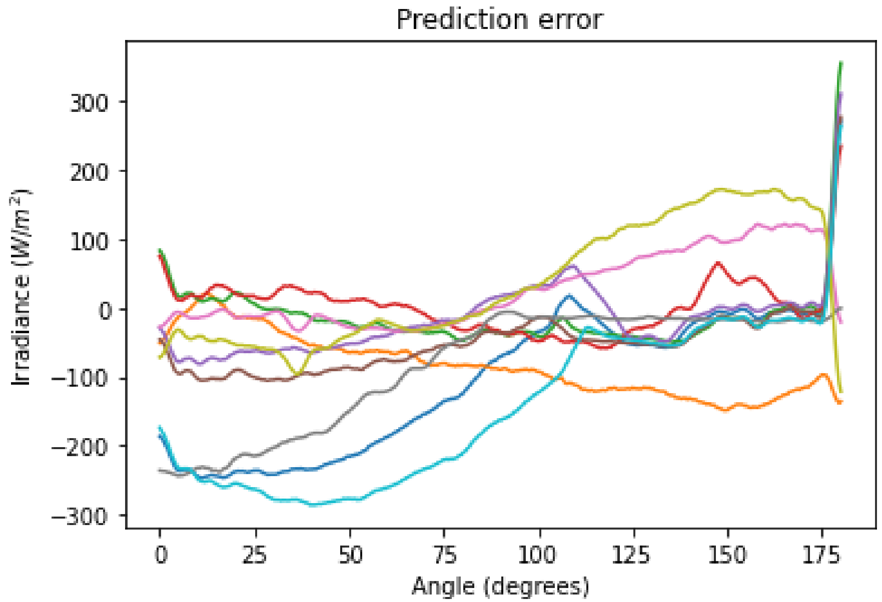
Normalization

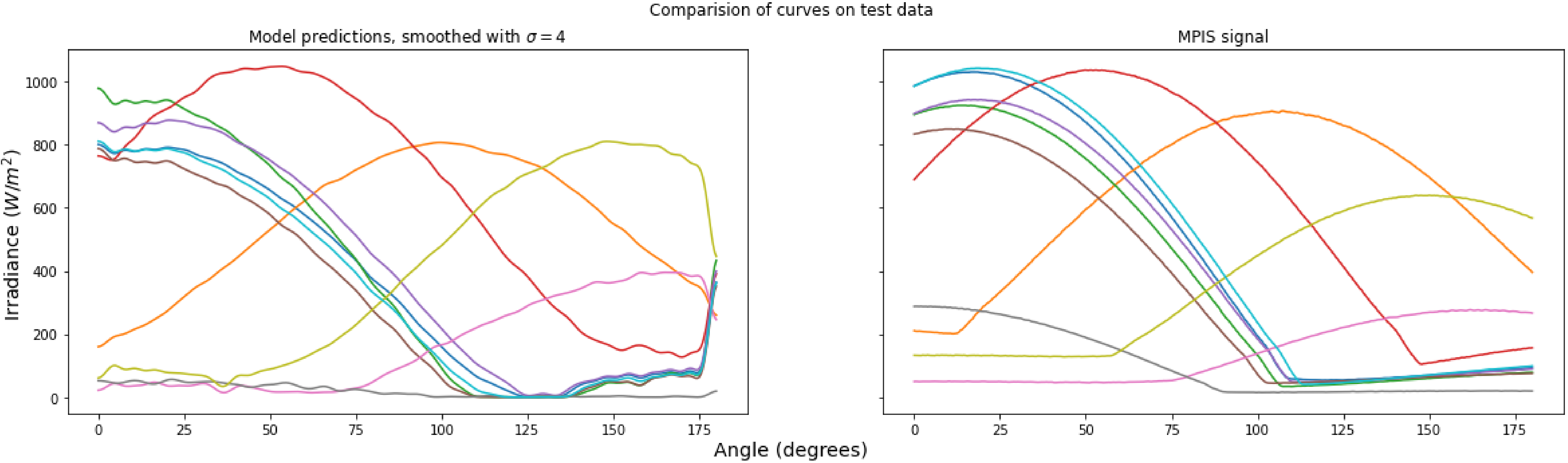
- The MPIS signal must be normalized in some way to account for seasonality/camera fluctuations
- Sky image is too qualitative to predict entire irradiance profile directly
  - But can predict *shape* of the curve
- Traditional min-max normalization fails to preserve relative magnitudes
- Solution: normalize by ideal clear-sky GHI at solar noon
  - Easily calculable with pvlib
  - Simple rescale operation for days within a week
  - Still preserves magnitudes as opposed to using true GHI at time *t*



Results

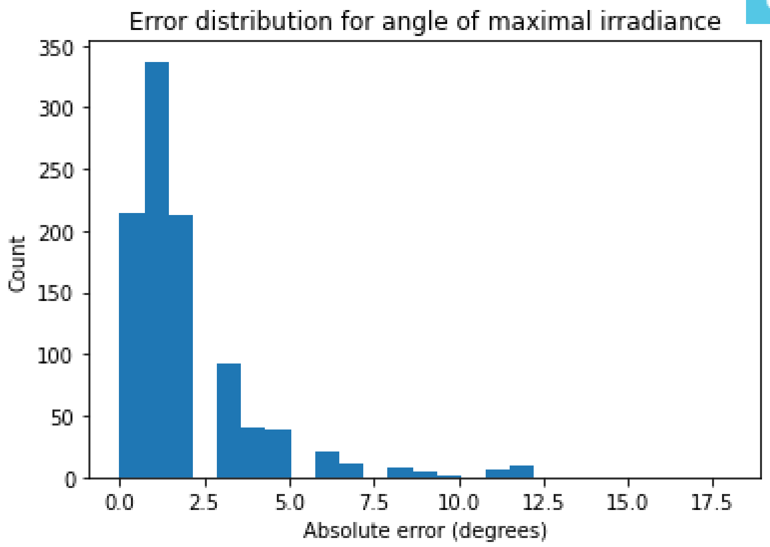
- Predictions for test samples shown below
- Model was not trained on these exact samples
- Most error occurs in less important regions

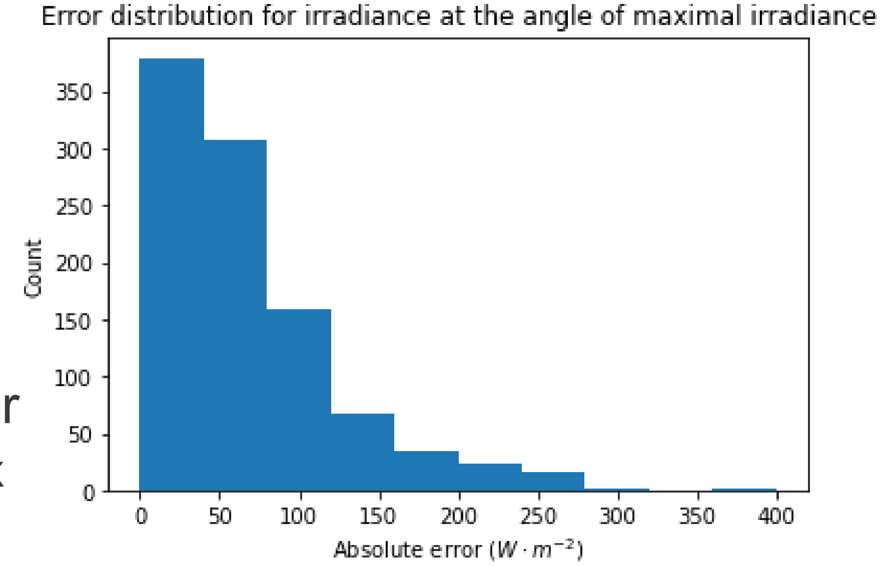




Conclusion/Future Work

- Through use of resampling, nonstandard normalization, and other techniques, this high dimensional regression problem becomes feasible
  - Model correctly learns shape of MPIS irradiance profile and can rescale to absolute irradiance values
- Overarching project goal: inform movement of single axis tracker
  - Most important quantity: angle of maximal irradiance
- Model accurately predicts (within error of 2.5 degrees) over 70% of 1000-sample test set
  - The remaining samples all fall within ~10 degrees
- In the future, we are developing algorithms to move a tracker
  - One prototype: move based on projected change of angle of max irradiance





Helping the neural network

- Values will be constrained in range [0, ϵ]
  - Due to normalization process
  - ϵ constant for dataset, calculated with max
- Use custom activation function to limit values to this range
  - Modified ReLu
  - Linear in range [0, ϵ]
- Gradient clipping
  - Truncate gradient when it gets too large
- Weight decay
  - "Complexity penalty"
- Dropout
  - Viewed as ensembling