# SENSEable Design Lab

UCF

IST, School of Modeling, Simulation and Training

# Predicting clear sky energy with machine learning *

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## Abstract

At least 40% of energy use in the U.S. is spent on residential and commercial buildings (more internationally, and much more if manufacturing is considered). In the field of sustainable design and building performance, we strive to empower architects, builders and maintenance professionals with the tools needed to design, build and maintain energy efficient buildings. Natural light (sky radiance) and its impact on building lighting and heating is often oversimplified. For physically accurate calculations with skies, spectral distributions of energy are needed. And unlike wide-area values like temperature and humidity, they should be available for every point in the sky, since the angle of incidence is paramount to radiative transfer and lighting models. In this work, we used machine learning models to estimate spectral sky radiance for clear skies for the entire skydome. We identify useful machine learning training and prediction features and experiment with various regression models. Whole sky radiance estimation is achieved within 8% RMSD (1nm spectral resolution, 350-1750nm range).

## Why Is This Important?

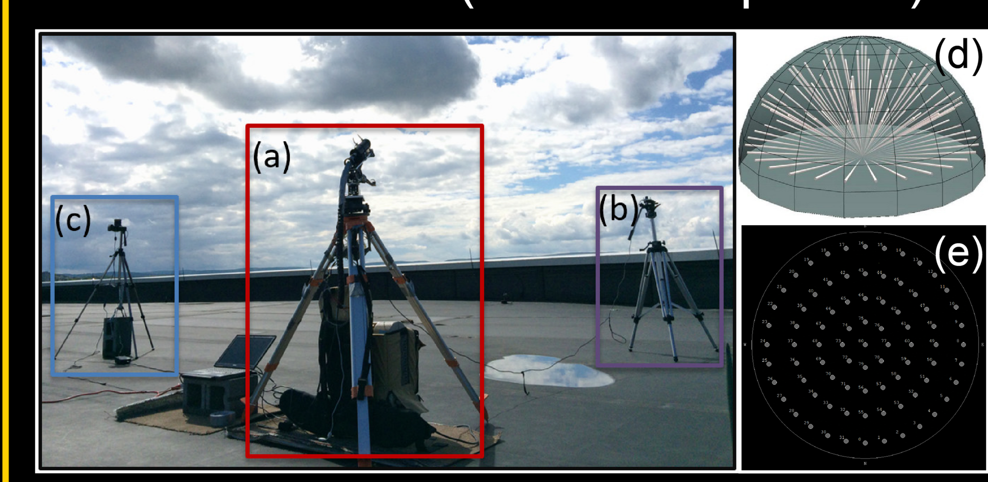
Building performance:
- Angle of incidence of incoming radiance
- Radiative transfer through different materials
- Dynamic building control systems
- Simulation BEFORE build = better design


Solar PV alignment:
- Maximum irradiance = more power

Physically based rendering (PBRT):
- Wavelength scattering & absorption
- Bidirectional reflectance distribution functions
- Natural light transport

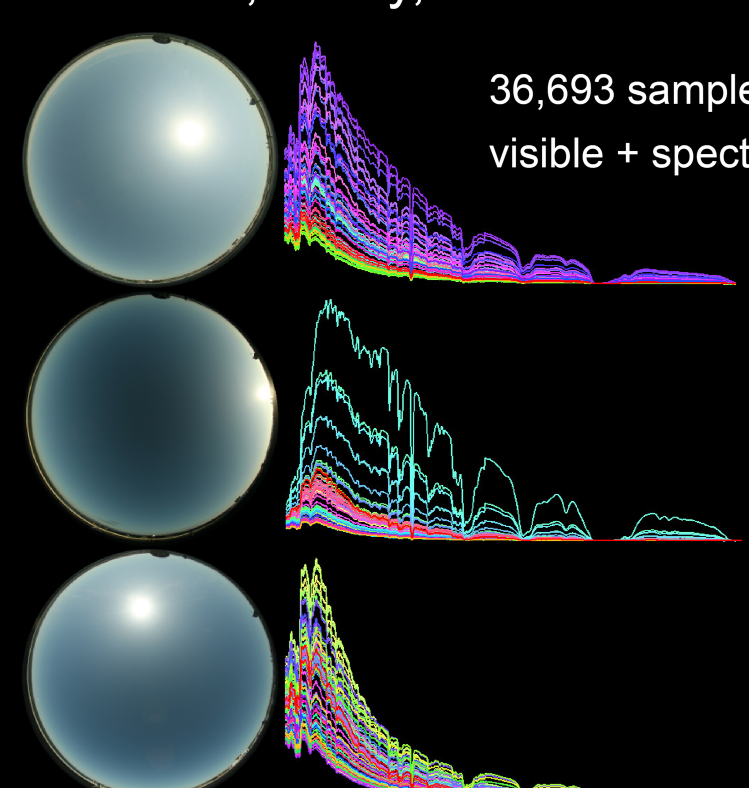

## Method

### Measure Data (Visible + Spectral)




(a) Spectroradiometer (350–2500nm)
(b) Pyranometer for irradiance reference
(c) Digital camera + 8mm fish-eye lens
(d) 1° steridian measurements
(e) 81 point sky sampling pattern

### Visualize, Verify, Correlate Data

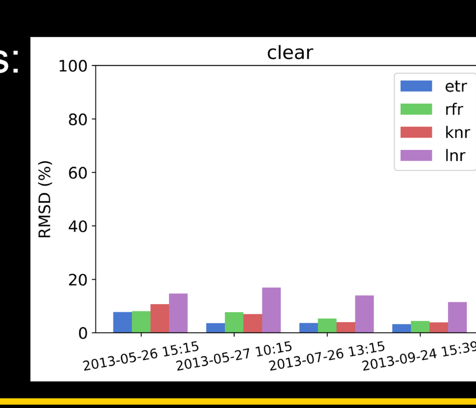


36,693 samples of visible + spectral

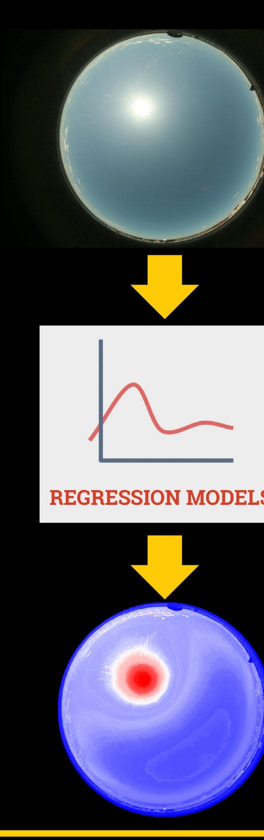
### Machine Learning (Offline)

"Binning" was performed on date+time of captures to engineer additional features. Exploratory data analyis was done on all input features: quarter, month, week, day, hour, sun loc., point loc., sun-point-angle, RGB. Scikit-learn was used for ML. 10+ regression models investigated.

Final Regression Models:
- (ETR) Extra Trees
- (RFR) Random Forest
- (KNR) KNN
- (LNR) Linear




### Prediction (Real-Time)

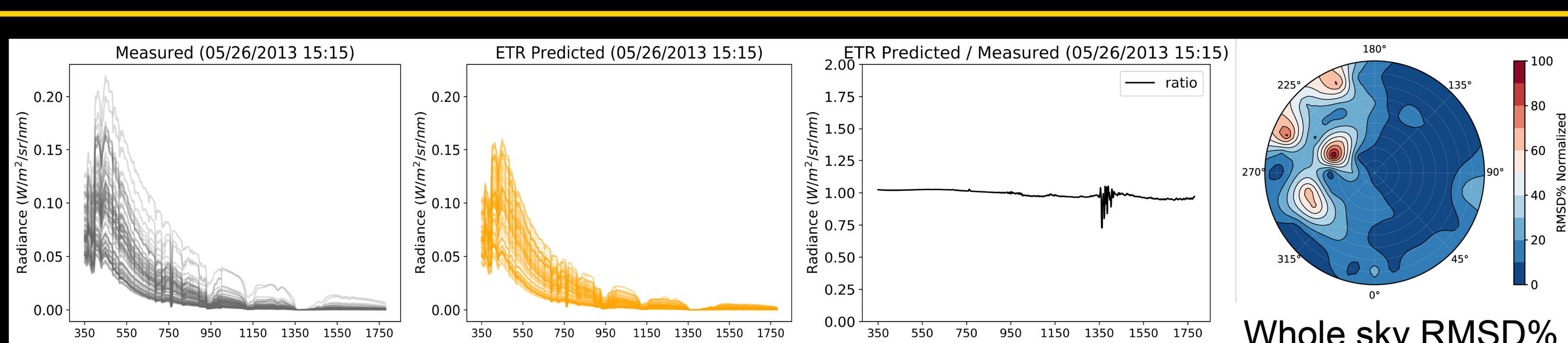



Visible data (RGB per pixel)

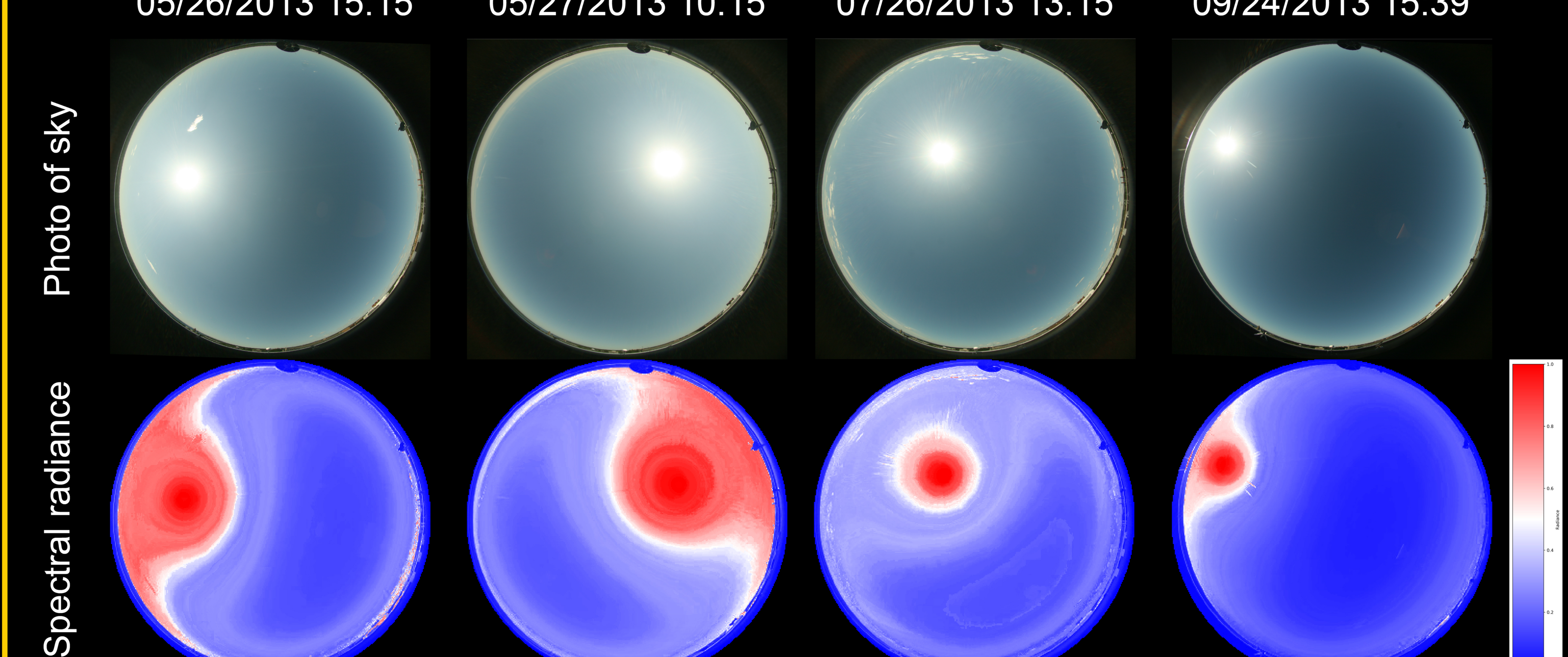
Only 1 model needed to predict

Spectral data (curve per pixel)

## Results




05/26/2013 15:15 05/27/2013 10:15 07/26/2013 13:15 09/24/2013 15:39




## Conclusions

We set out to develop a machine learning method for estimating sky radiance distributions (including VIS, VNIR, and SWIR spectra) from photos captured with a hemispherical commercial digital camera. We feel this project was a success in that regard. We showed that spectral radiance can be predicted down to 1nm resolution from machine learned regression models using features such as: sun position, point position, sun-to-point-in-sky angle, time and day of year, and pixel color (visible color). Only simple regression models were experimented with and yet results were promising, tree-based regressors performing the best. Applications include: real-time dynamic building control systems driven by ML models and photos of sky, rendering tools and pipeline with support for more realistic clear sky natural lighting, photovoltaic (PV) alignment optimization to maximize irradiance, etc.

## Future Work

Improving & validating:
- Using GOES satellite data
- Comparing color models
- Use available HDR photos
- Different ML approaches
- Cloudy & overcast skies
- Validating w/ known models
- Validating other sites
- Speed-space tradeoff study

Usages & integrations:
- E-glass controller
- Spectral renderers
- PV alignment study
- Ladybug Tools

* Portions of this work were presented at SPIE Optics and Photonics for Information Processing XII: "Learning and estimating whole sky visible, VNIR, SWIR radiance distributions from a commercial camera," Proc. SPIE 10751, Optics and Photonics for Information Processing XII, 107510F (7 September 2018); doi: 10.1117/12.2321295