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Which Models Matter: Uncertainty and Sensitivity Analysis for Photovoltaic Power Systems

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Outline

- Uncertainty and Sensitivity Analysis
- Methodology
- Models and uncertainty quantification for each model
- Analysis results
- Next steps

Uncertainty and Sensitivity Analysis

- If we have perfect data X and an exact model $F(X)$:

$$X \longrightarrow \boxed{F(X)} \longrightarrow Y \text{ is known exactly}$$

- But we don’t have perfect information or exact models:

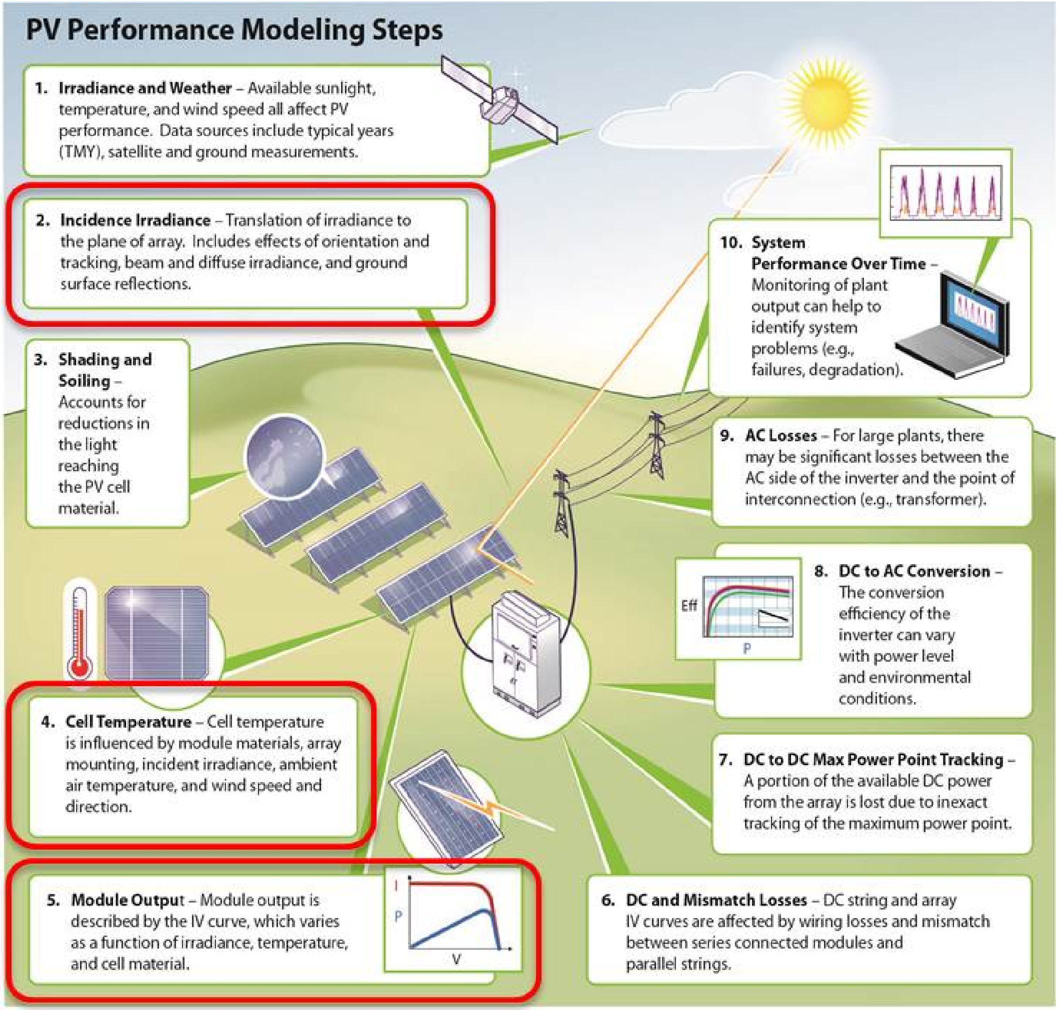
$$X_i \longrightarrow \boxed{F(X_i)} \longrightarrow Y_{F,\, i}\,,\ i = 1, \ldots,$$

$$X_i \longrightarrow \boxed{G(X_i)} \longrightarrow Y_{G,\, i}\,,\ i = 1, \ldots,$$

- <u>Uncertainty analysis</u> quantifies the uncertainty in Y resulting from uncertainty in data X and models F, G, …
- <u>Sensitivity analysis</u> explores the relationship between uncertainty in Y and uncertainty in data X

Models considered

- GHI, DNI and DHI to POA:
  - Isotropic sky, Hay and Davies, Perez, Sandia
- POA to effective irradiance:
  - Accounts for spectral mismatch, reflections and soiling
  - Polynomial in AM
- Cell temperature:
  - Sandia model
- Module DC output:
  - Sandia model
- cSi and CdTe modules
- Meteorological data from Albuquerque and Golden, CO



Limitations

- We deliberately do NOT consider uncertainty in measured irradiance
  - Uncertainty in irradiance translates proportionally to uncertainty in power and energy
  - Would obscure effects of other uncertainties, which we want to understand
- We do not consider effect of measurement error in other quantities (e.g., temperature, voltage)
  - Would add greatly to complexity of analysis
  - But they are anticipated to have small effects
- We do not consider uncertainty in calibration of models
  - Most models used for PV system analysis (e.g., Hay and Davies sky diffuse model) are calibrated to a specific set of historic data
  - A different 'Hay and Davies' model would result from different data

Methodology

- Obtain measured inputs X and concurrently measured output Y for each model f(X)
- Define model residuals, e.g., : $\varepsilon_f(X) = f(X) - Y$

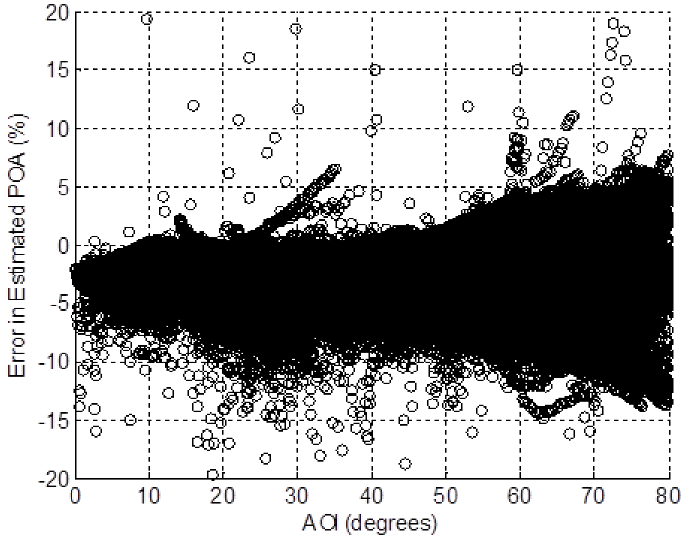
The distributions of $\varepsilon_f(X)$ characterize the aggregate uncertainty in f(X) over the range of X

- Build a probability model for each ε_f
- Need to detrend and account for correlations
- Generate samples $\varepsilon_{f,i}(X)$
- Propagate samples through the sequence of models:

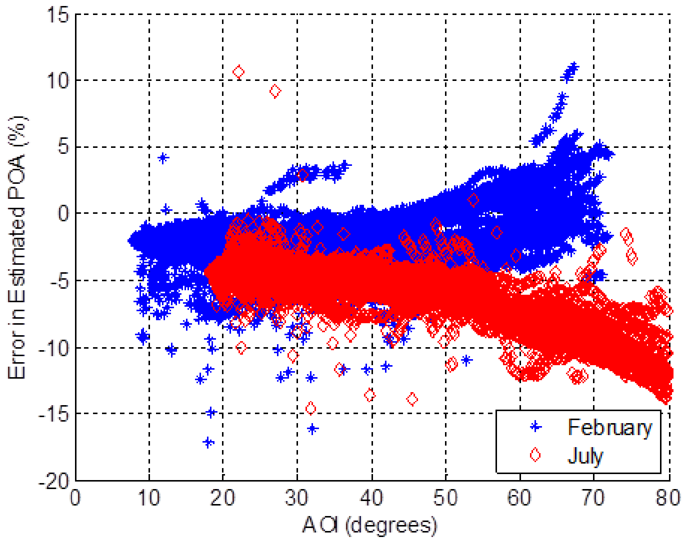
$$P_{DC}(X) = P_{DC}(Ee(X) + \varepsilon_{Ee,i}(X), Tc(X) + \varepsilon_{Tc,i}(X))$$

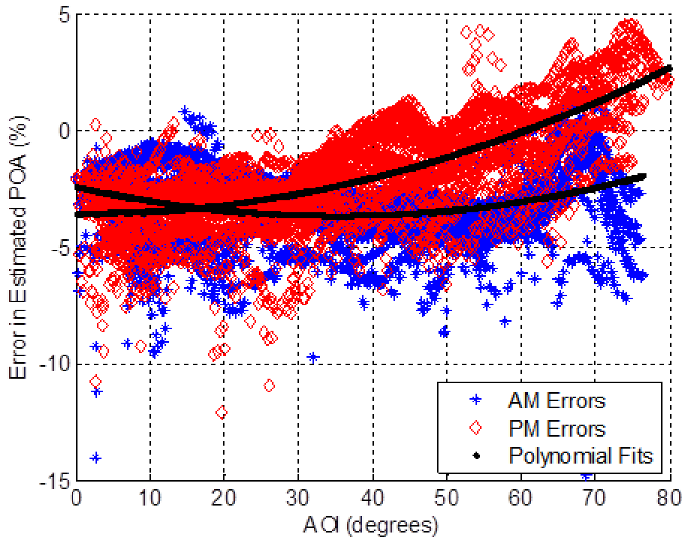
$$= \ldots$$

Uncertainty Quantification: Isotropic sky diffuse model



- Partition residuals by month, sky condition and time of day; detrend
- Create and sample stochastic process model for detrended residuals



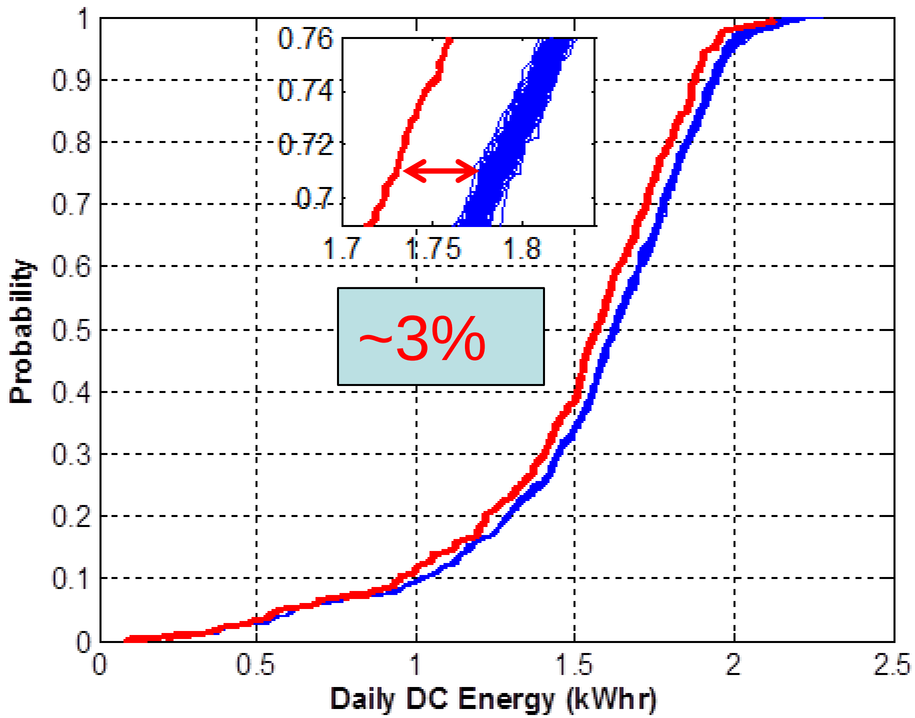


Uncertainty in daily energy

- Red curve is 'baseline' : model results without applying sampled errors
- 100 blue curves result from 100 error samples
- Shift indicates an overall bias toward overestimating energy
- But small variation among blue curves

Models are consistent but also consistently wrong

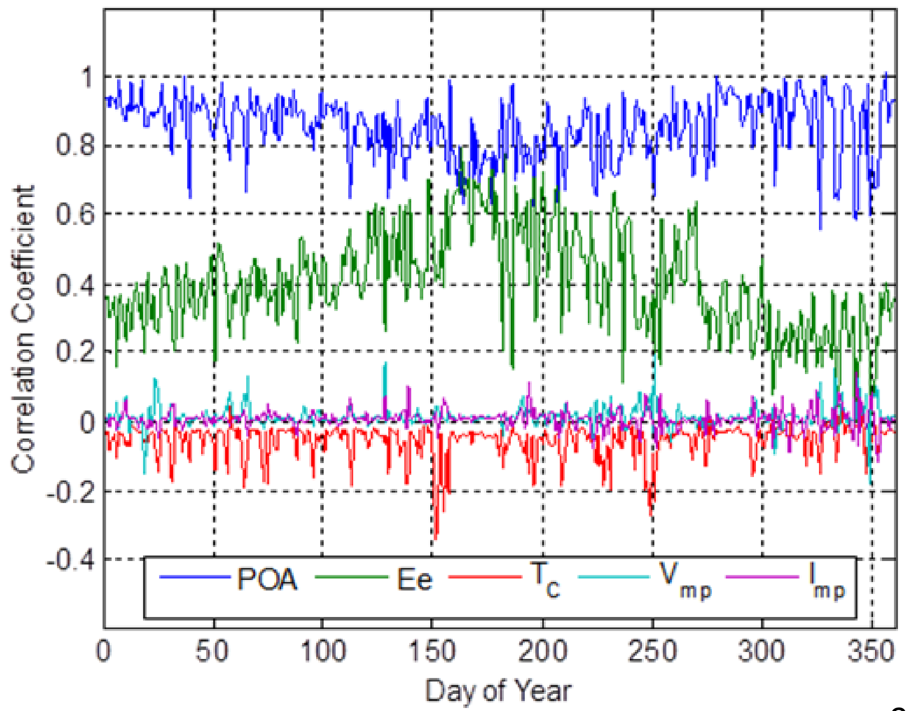
Distributions of daily energy: cSi module, isotropic sky model, Albuquerque data (<u>other module, models, and data similar</u>)



Which models drive uncertainty?

- Uncertainty in POA model dominates (relative to uncertainty in other models)
- Independent of module type, POA model and data source
- Uncertainty distributions for POA models aren’t that different

Stepwise rank regression of deviations in daily energy onto errors: cSi module, isotropic sky model, Albuquerque data (<u>other modules, models, and data similar</u>)



Conclusions

- Given what we have considered (POA, Ee, Tc, DC output), uncertainty in modeled energy is relative small ~3%
- Analysis indicates POA model uncertainty dominates
- POA model error appears to be systematic

See Lave, Hansen, Hayes, et al., PVSC 40, for analysis of POA models

Future work:

- Consider remaining modeling steps : e.g., effective irradiance separately broken down into reflection losses, spectral mismatch, soiling
- Research to improve POA models

Thank you