Assessment of Photovoltaic Module Backsheets as a Critical Indicator of Degradation, and Modeling of Module Durability in Different Climatic Zones

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Project Focus

- **The objective of this project is to develop predictive tests and modeling for photovoltaic (PV) module backsheets as a critical indicator of PV module health.**
- **The testing methodologies and models are based on assessing fielded PV modules and using accelerated laboratory testing techniques to obtain equivalent results.**
- **The tests and models are supplemented with meteorology, climatic and similar data to understand the differences in module responses in different installation and operation conditions.**
- **The predictive tests and models specify indoor/outdoor exposure and evaluation data and temporal duration/variation to predict backsheet performance in various climatic zones based on defined backsheet failures in the field.**

Streams of work

- **Identify different PV modules with various common backsheets that have been in use in different Koppen-Geiger climate zones**

- **Evaluate fielded modules for actual degradation through gloss measurement, yellowness index, and delamination assessments**

- **Perform accelerated weathering exposures of backsheets to compare to degradation profiles of fielded modules, using various parameters of UV, heat, humidity, water exposure, etc. and destructive/non-destructive assessments**

- **Address data cross-correlation and develop and refine Stress/Response (S/R) and Stress/Mechanism/Response (S/M/R) models**

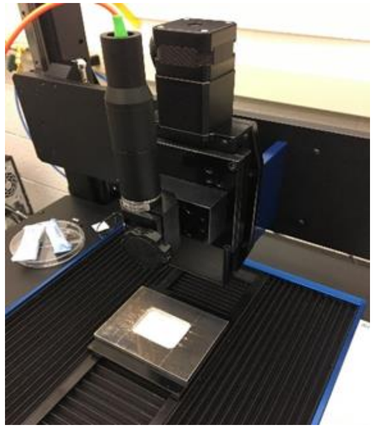
Outdoor Field Survey Information

Site Location	Climatic Zone	Capacity	Backsheet Material	Ground Cover	Install Configuration	Rack Length	Rack Height	Note
Napanee, ON; Belleville, ON, Canada	Dfb	10.5 MW; 14 MW	PVDF; PA	Grass	Landscape	80; 82	4; 5	
Cleveland, OH, USA	Cfa		PET	Grass	Portrait	24, 36, 78	2	
Dover, NJ, USA	Dfb		PET	Roof	Portrait	3 - 28	1	Low angle, backsheet is covered
Gaithersburg, MD, USA	Dfa		PEN	Rock	Landscape	48	4,5	
Taiwan, China	Cwb	4.6 MW	PVDF, PVF, PET	Concrete and grass	Landscape			

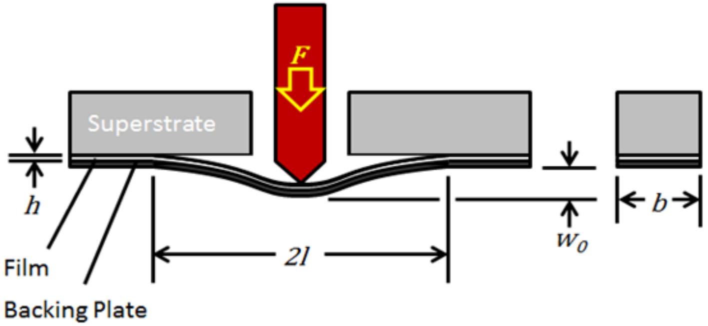
Study the degradation of PV panel backsheets (AAA, FPE, PPE, PVDF/PET/EVA, PVF/PET/EVA) in real-world conditions

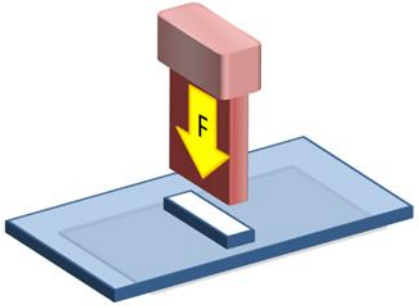
- effect of installation factors:
  - climatic zone, backsheet material
  - install location in the rack
  - ground cover
- influence the rear-side irradiance and temperature near backsheet

Assessments



<u>Non-destructive evaluations</u>:
Colorimetry
Gloss meter
Fourier transform infrared spectroscopy
UV-Visible Spectroscopy
Profilometer: crack quantification





<u>Destructive evaluations</u>:
Tensile test
Cantilever beam test
V-peel test

Field Survey Result & Temporal Spatial Model Development

Measured parameters

- **Module location**
  - **Divide the PV module according to the Si cells location**
    - **6 x 10 or 6 x 12**
    - **Column index and height index of measured position**
    - **Take module install configuration into consideration**
  - **Module location in the rack**
    - **height and column number of module**
- **Yellowness index and gloss**
- **FTIR**
  - **confirm the material of outer layer backsheet**

Observations

- **Edge effect**
  - **backsheet in the 2 ends of rack degrades faster**
- **Effect of height and elevation height**
  - **rear-side irradiance distribution**
- **Ground cover**
  - **affects the albedo**
- **Backsheet material**
  - **degradation sensitive**

Model development

- **Approach: response surface method**
  - **Identify factors that affect the response**
  - **Determine the setting for these factors that result in the optimum value of the response**
  - **Examine the “surface” or the relationship between the response and the factors affecting the response**
- Model pattern
  - First order
    - $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$
    - Screening Response Model

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \varepsilon$$

  - **Second order**
    - $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \varepsilon$

Indoor Exposure Conditions

Samples

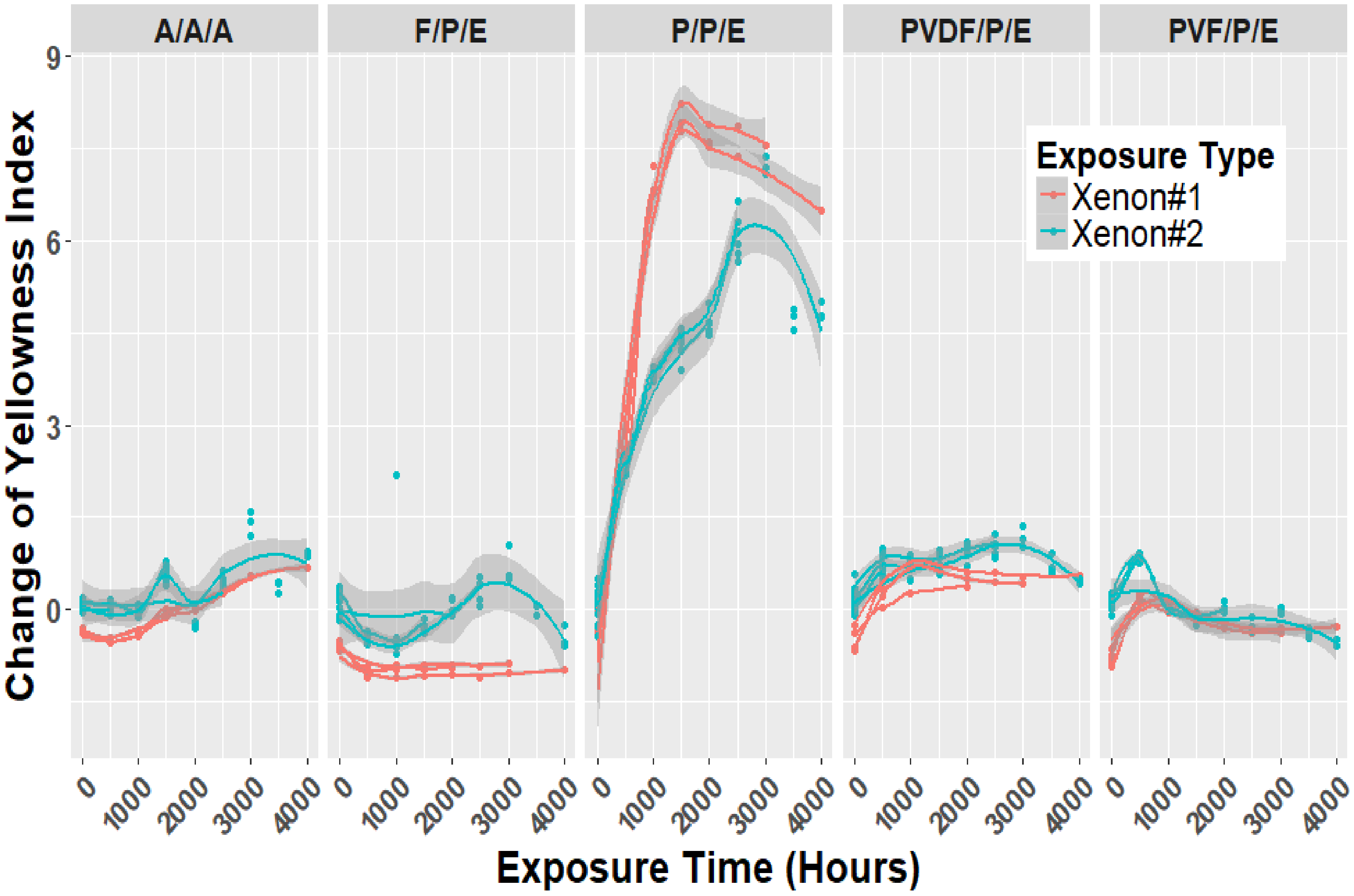
- 5 laminated backsheets
- AAA, FPE, PPE, PVDF/P/E, PVF/P/E

Exposures

- Damp Heat (85°C and 85% RH)
- Xenon #1: Full Spectrum, 60°C, 20%RH
- Xenon #2: Full Spectrum, 60°C, 20%RH, and water spray
- Xenon #3: 80°C, 20%RH, cycle full spectrum/water spray in light
- Xenon #4: 80°C, 20%RH
- Xenon #5: 80°C, 20%RH cycle low irradiance/water spray in light

Evaluations

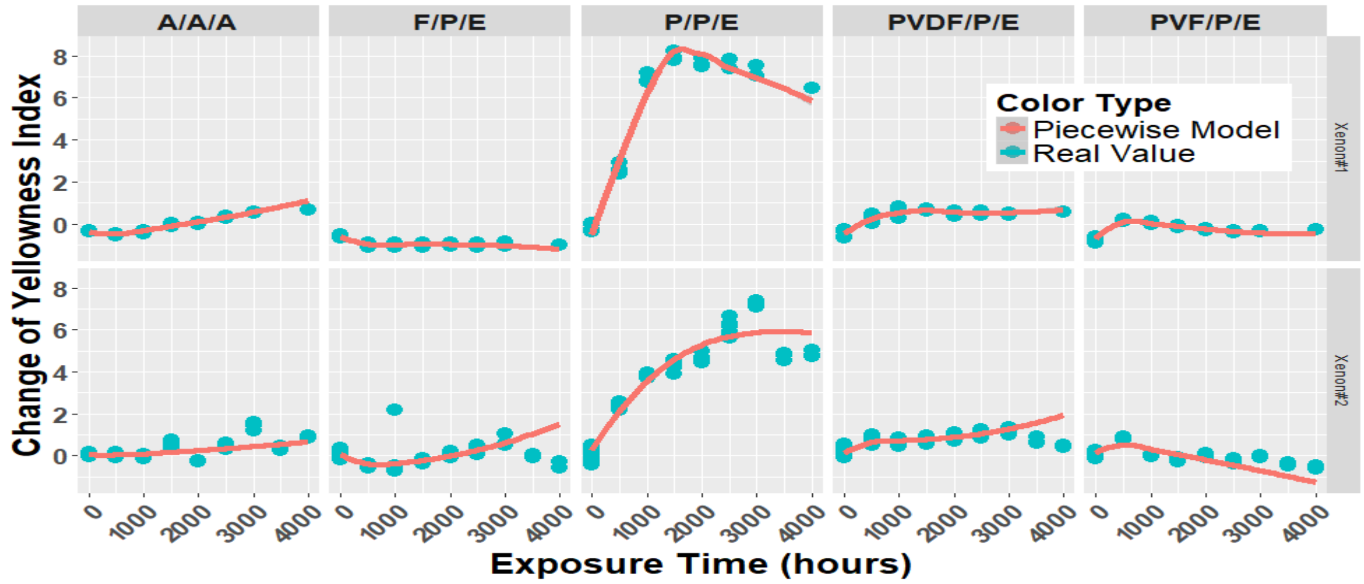
- Color
- Gloss
- FTIR
- Images
- Crack Quantification
- SEM



Predication: Accelerated Data

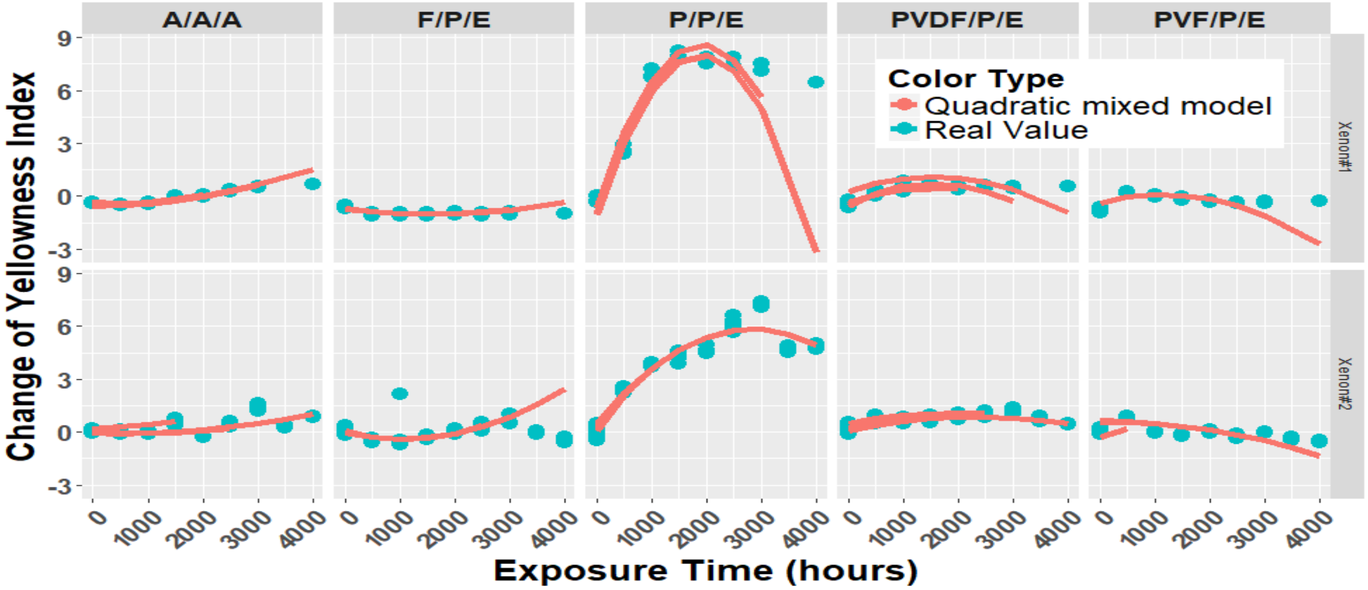
Predict Future Accelerated Data

- With different Models
- Two exposures



Piecewise & Quadratic Models

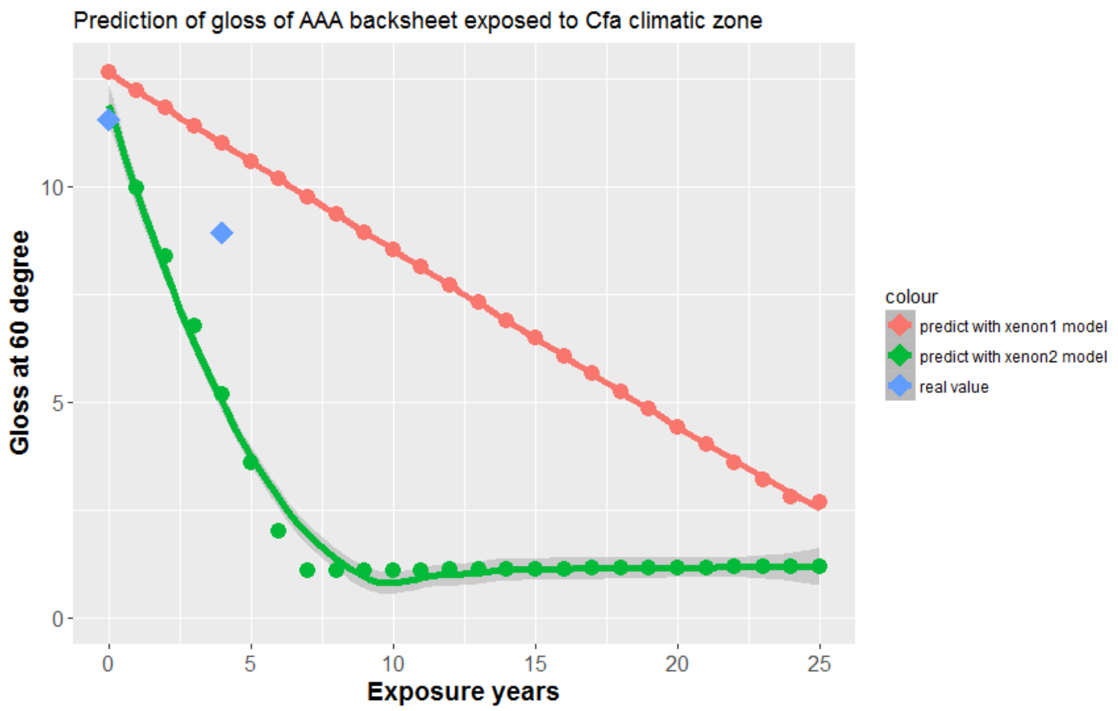
- Developed With 2500 hrs data
- Predict 4000 hrs value
- Compare with real value

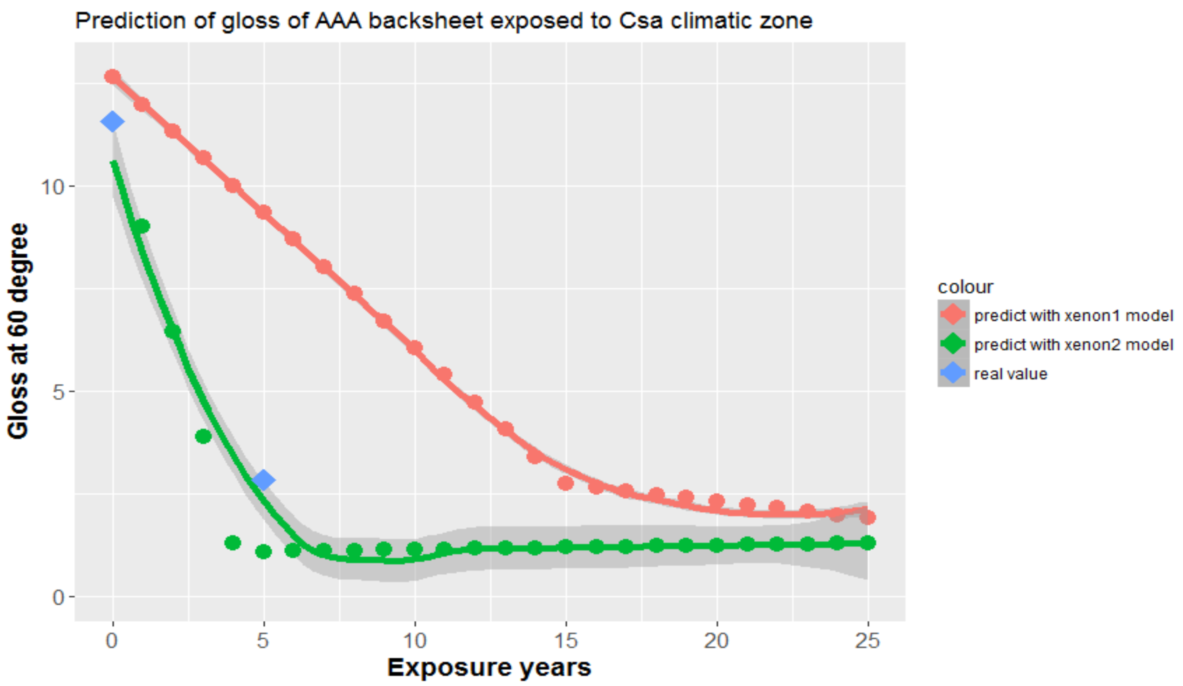


Better Prediction

- **Piecewise model**

Prediction: Real-World from Accelerated Data





Predict Csa with Xenon Exposure with humidity

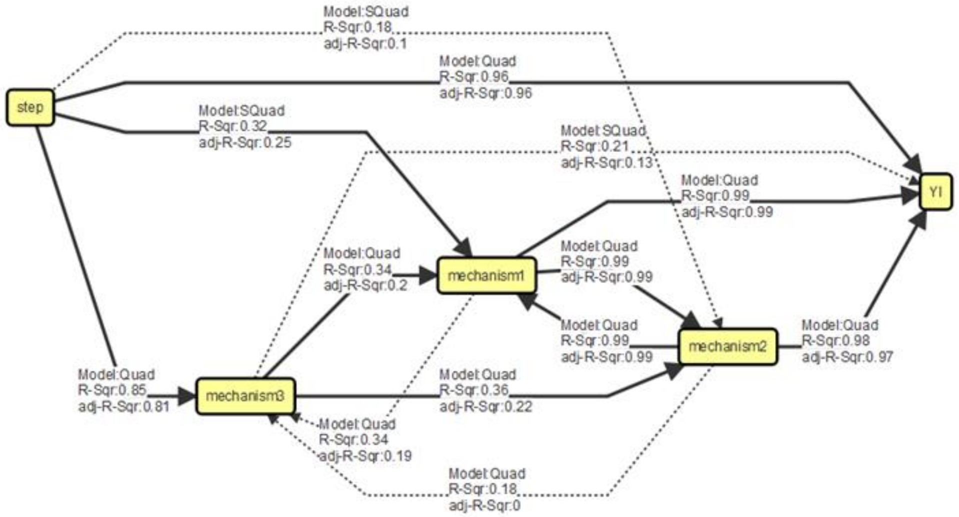
Prediction of Cfa climatic zone

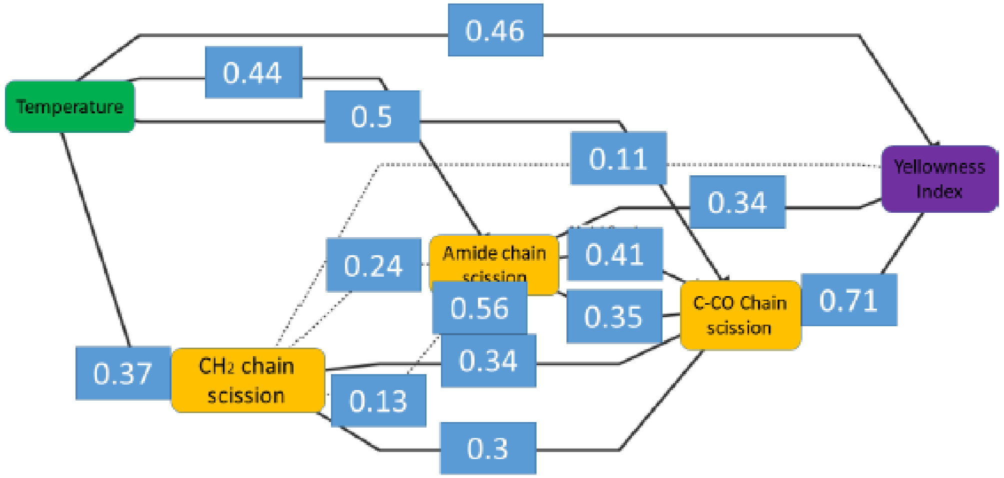
Prediction of Csa climatic zone

Gloss (Response)

- Shows surface roughening
- AAA backsheets have microcracks and large cracks
- After 4-5 years of exposure

SMR Model Development

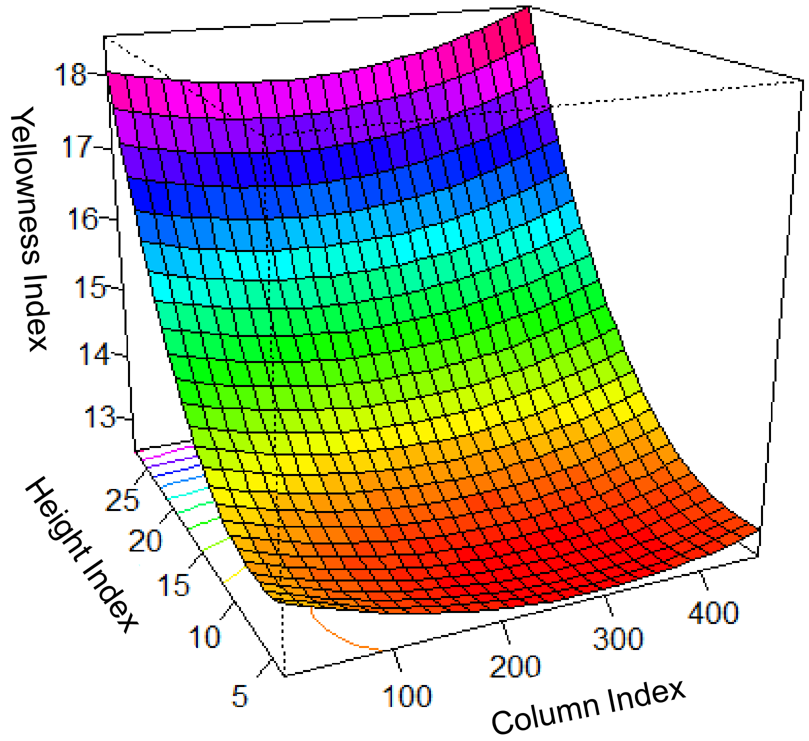




Temporal Spatial Models

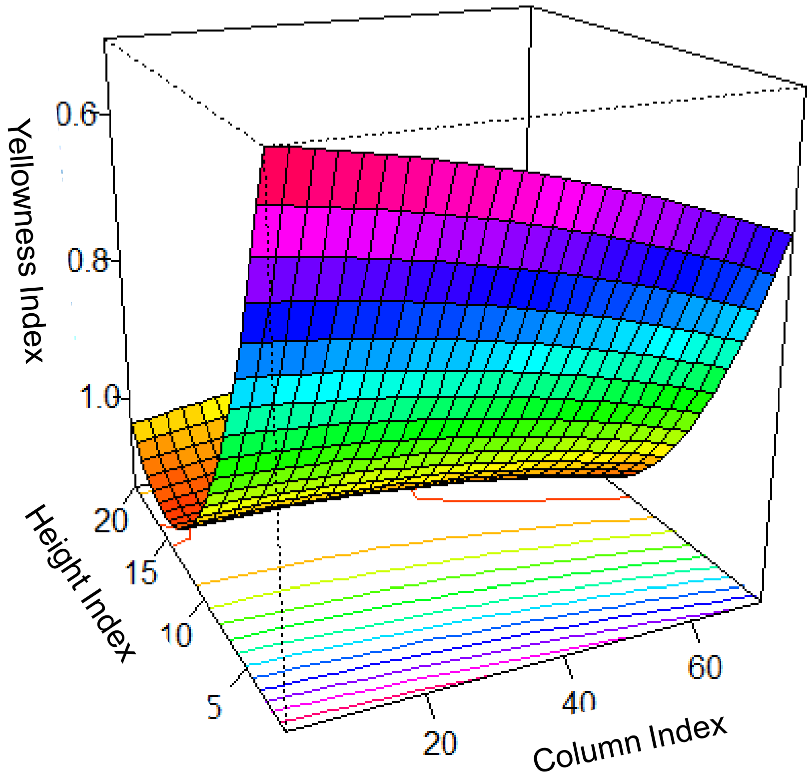
Data set: Gaithersburg, MD

- Strong edge effect
- Significant effect of height
- Edge effect decrease with increase of height
- Adjusted R^2 = 0.6819



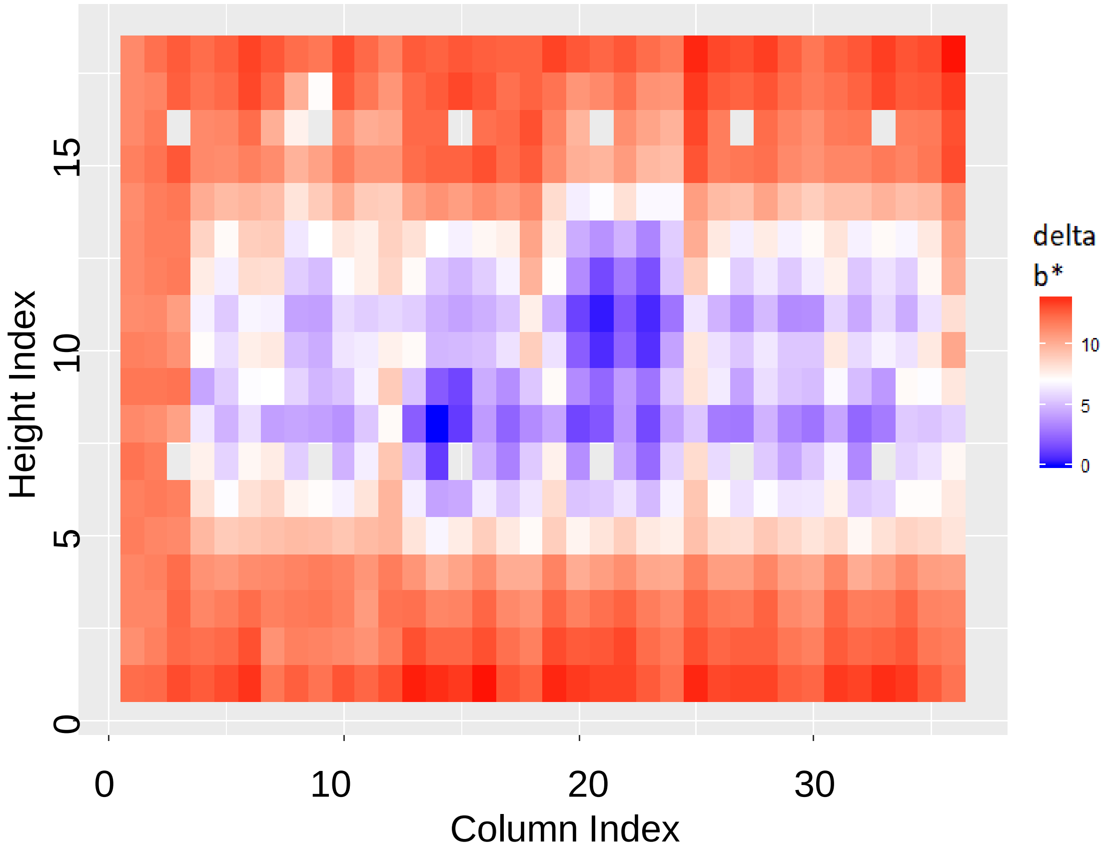
Data set: Cleveland, OH

- Low adjusted R^2 = 0.0582
  - Small variance with column and height
  - Short exposure years
  - Low albedo of ground cover (grass)
  - Minimal backsheet degradation (PET)



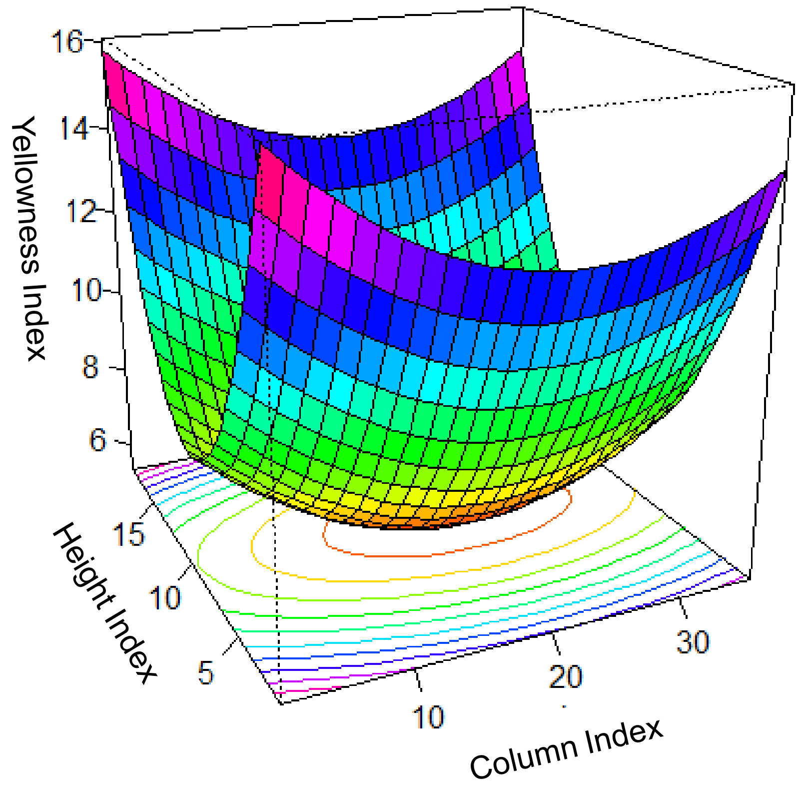
Temporal Spatial Models Evaluation on Published Data

- Roof mounted: 6 modules
  - 15 years
- PET outer layer
- ~150 mm from corrugation



Evaluation

- Use second order surface response model
- Adjusted R^2 = 0. 6962
- Significant p-value of each predictors
- Second order response surface model shows nice data fitting



Observations

UV Resistance of backsheet is critical for PV module degradation characterization

Physical placement of modules in array affects degradation – edge, height, albedo effects are noted

For low irradiance conditions, temperature becomes an important stressor

Pollution/NOx might be a relevant contributor to degradation

S/R & S/M/R models for responses of yellowing, gloss loss, delamination and cracks are increasingly correlating to field & lab data

Future work

Expanding analysis of more field modules exposed to different climatic zones

Conducting more field surveys at additional sites

Conducting new indoor lab exposures

Performing mechanistic evaluation experiments on retrieved submodules and indoor exposed coupons

Further develop and enhance the degradation models

Thank you.

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