Modeling Thermal Fatigue in CPV Cell Assemblies

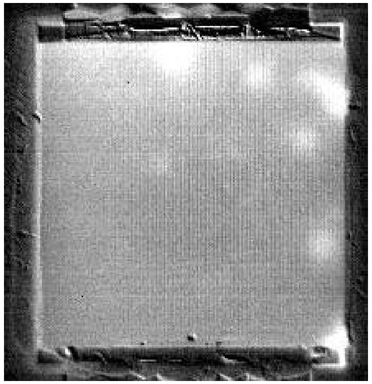
NREL PV Module Reliability Workshop

Nick Bosco,
Dhananjay Panchagade,
and Sarah Kurtz

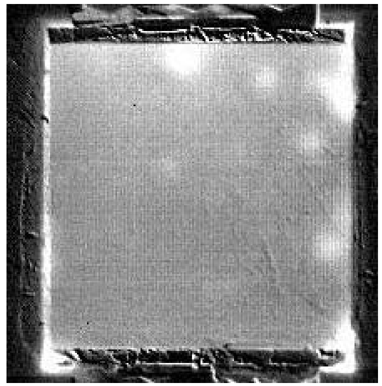
February 16, 2011

NREL/PR-5200-51247

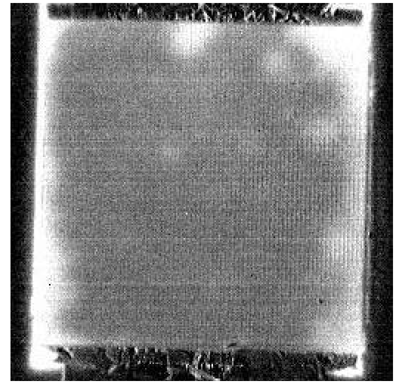
quantifying thermal fatigue



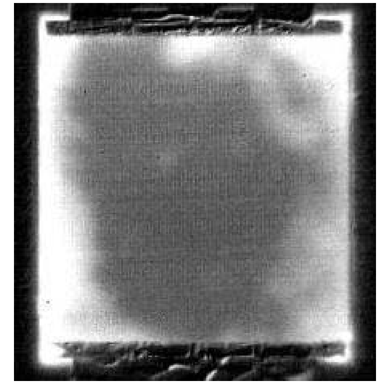
initial



500 cycles



1000 cycles



1500 cycles

- Thermal fatigue will cause die-attach failure.
- How can we model this failure?
- Will this model result in a lifetime prediction?

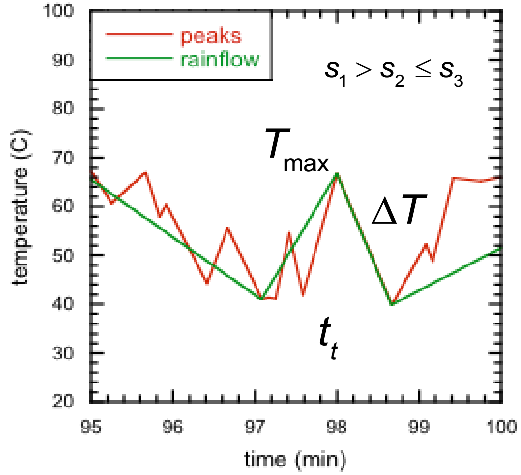
review: rainflow counting

1: CPV cell temperature modeling

$$T_{\text{mod}} = T_{amb} + E\exp(a + bW)$$

$$T_{cell} = \overline{T}_{\text{mod}} + \frac{E}{E_o}\Delta T$$

2: rainflow cycle counting



3: damage calculation

$$N_f = \frac{1}{2}\left(\frac{\Delta\gamma_p}{2\varepsilon_f}\right)^{\frac{1}{c}}$$

$$c = -0.422 - 6\cdot 10^{-4} T_{mean} + 1.74\cdot 10^{-2}\ln\left(1 + \frac{360}{t_d}\right)$$

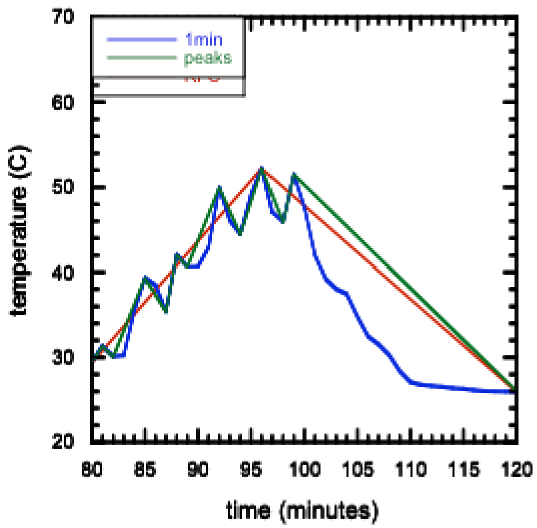
$$\Delta\gamma_p = \frac{\sqrt{2}FL}{2h}\Delta\alpha\Delta T$$

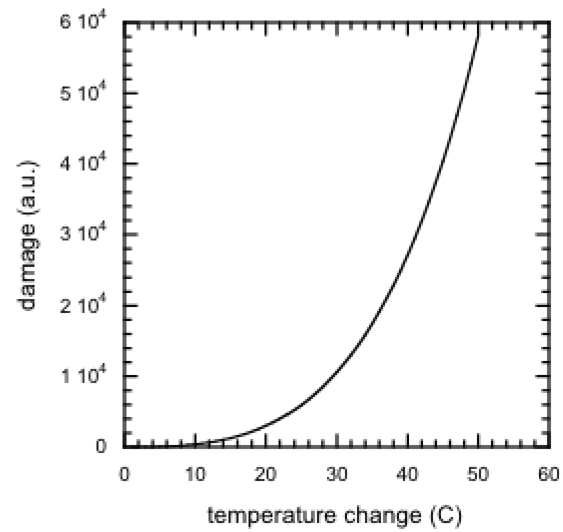
$$D = \sum_i \frac{n_i}{N_i}$$

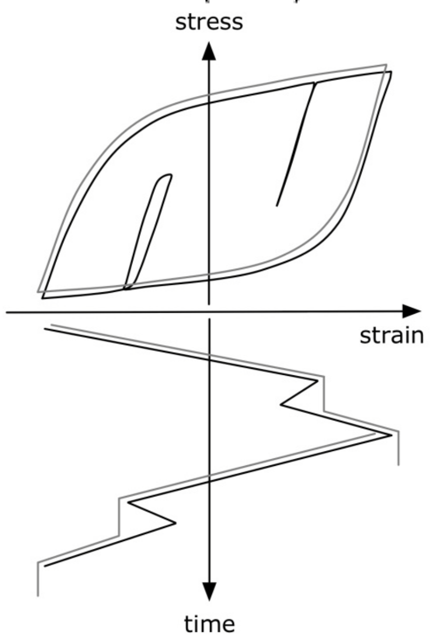
$$D = \sum_i \Delta T_i^{-\frac{1}{c_i}}$$

- Method can quickly analyze long time histories
- Several sources of error exist
- Not capable of differentiating between materials and designs*

review: rainflow counting



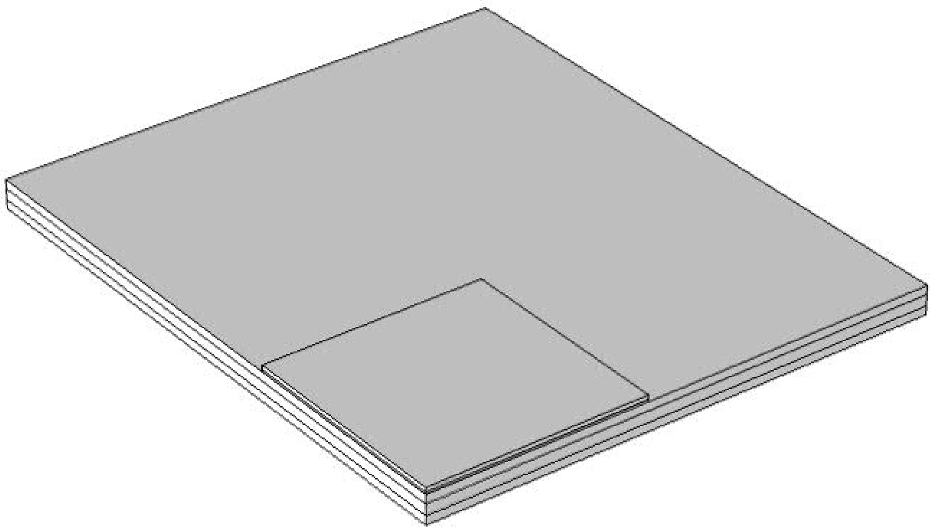




- Algorithm distills time history of temperature into discrete segments.
- Attempts to count only the "significant" segments.
- Damage is exponential with temperature change.

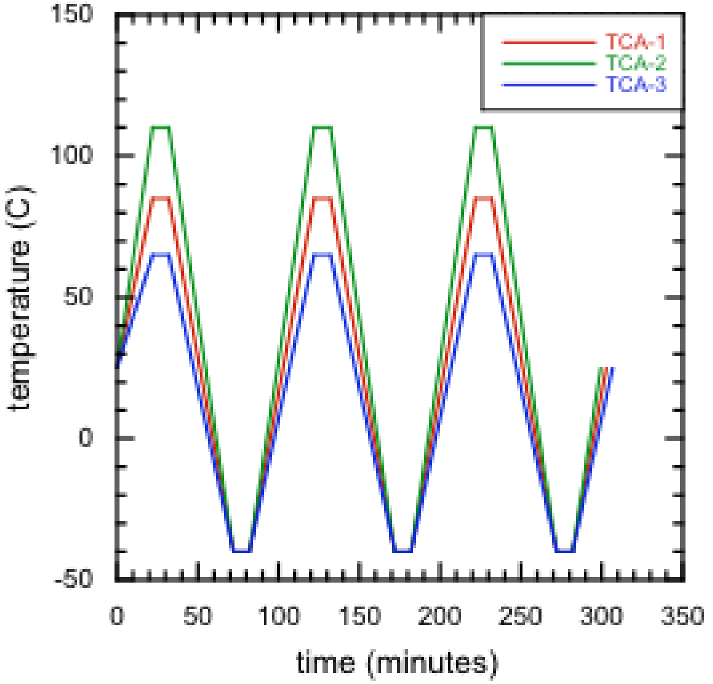
finite element modeling

FEM: CPV Cell Assembly



¼ model
1 cm^2 x 100 µm Ge die
50 µm eutectic Pb-Sn solder
650 µm DBC

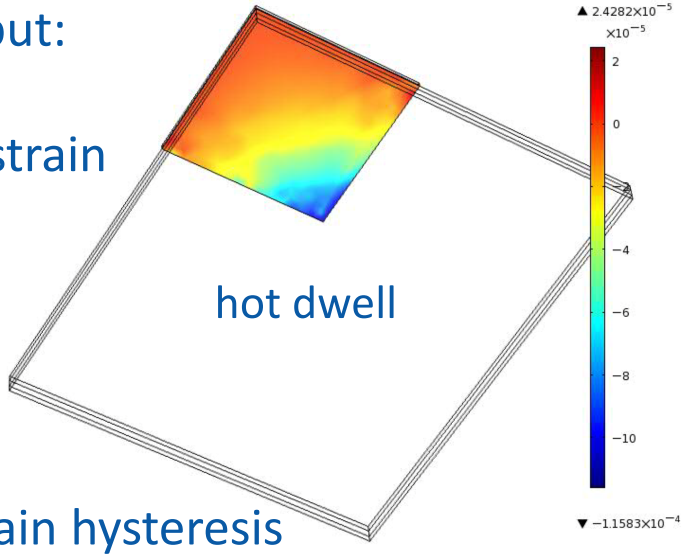
simulation: IEC 62108 thermal cycles

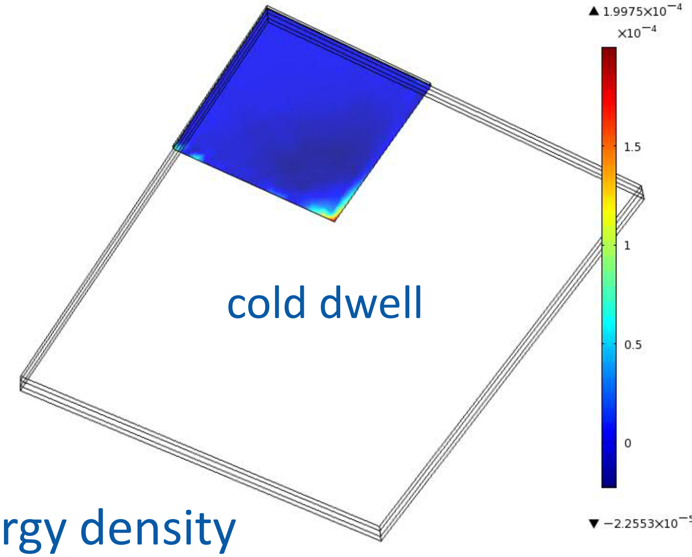


finite element modeling

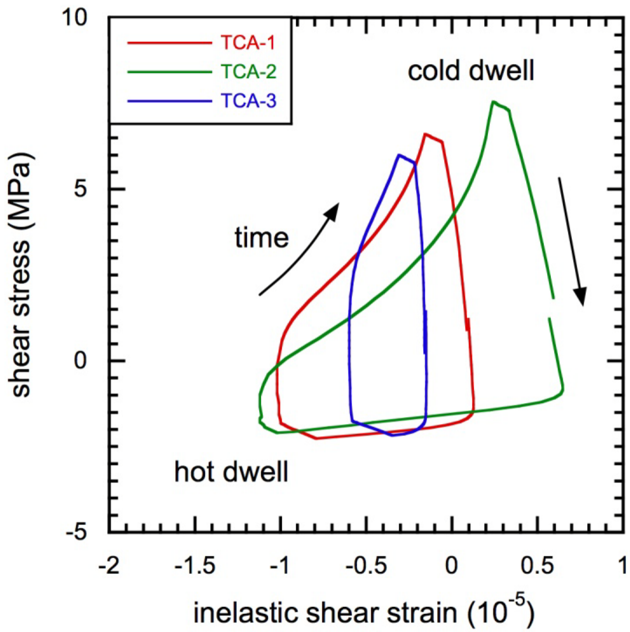
FEM output:

inelastic strain

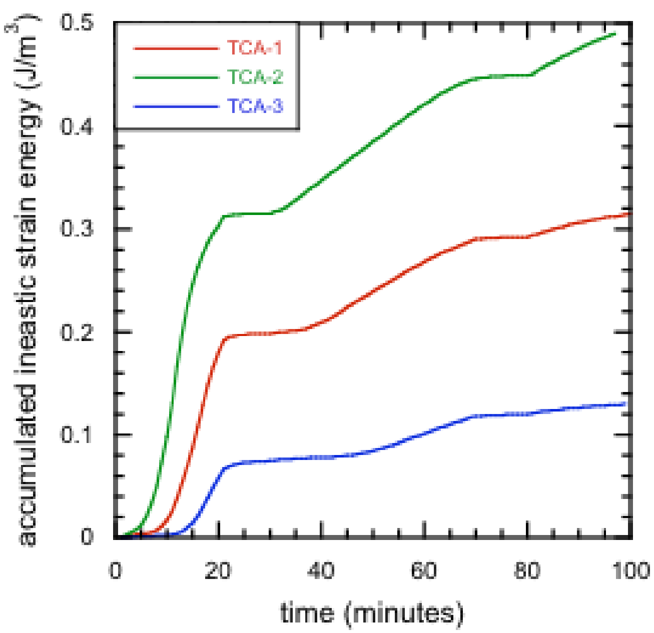




stress-strain hysteresis

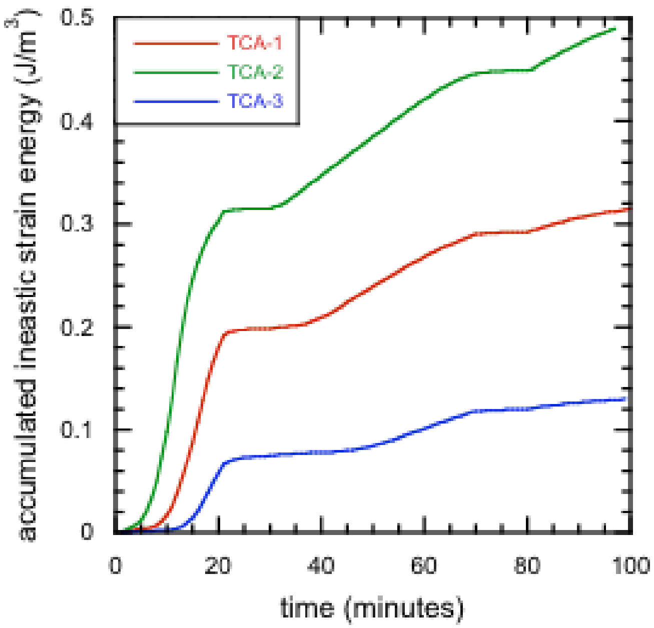


energy density



finite element modeling

damage calculation



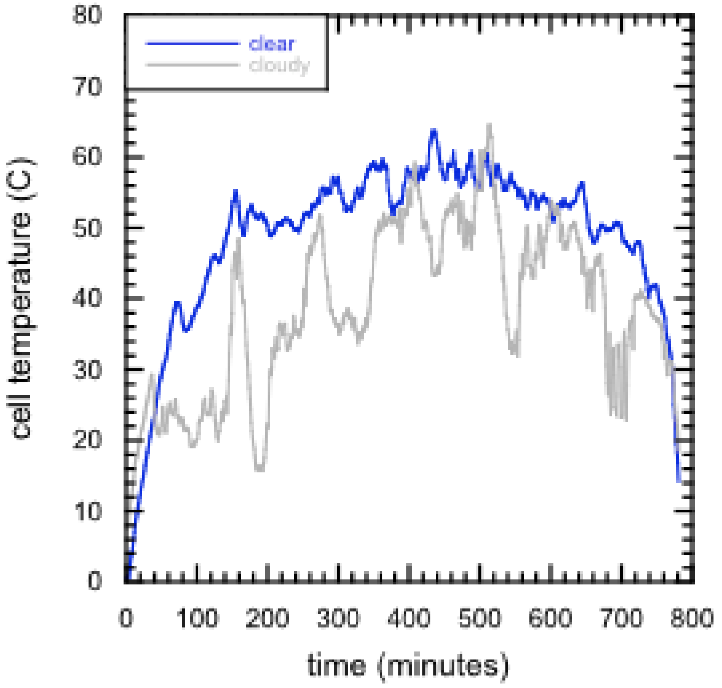
crack initiation: $N_o = K_1 \Delta W_{ave}^{\alpha}$

crack growth: $\dfrac{da}{dN} = K_2 \Delta W_{ave}^{\beta}$

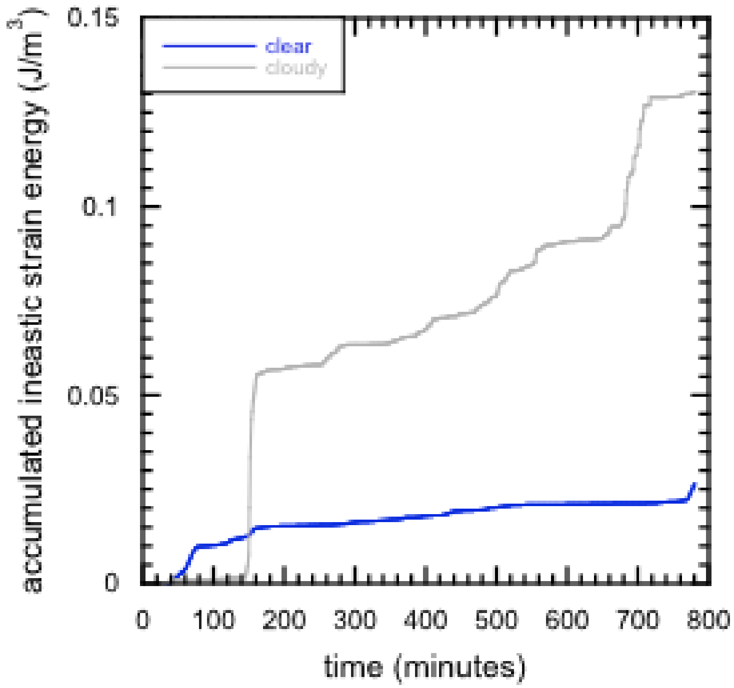
$$D = \frac{\Delta W_{acc}}{\Delta W_f}$$

finite element modeling

simulation: clear and partly cloudy days



FEM output: energy density



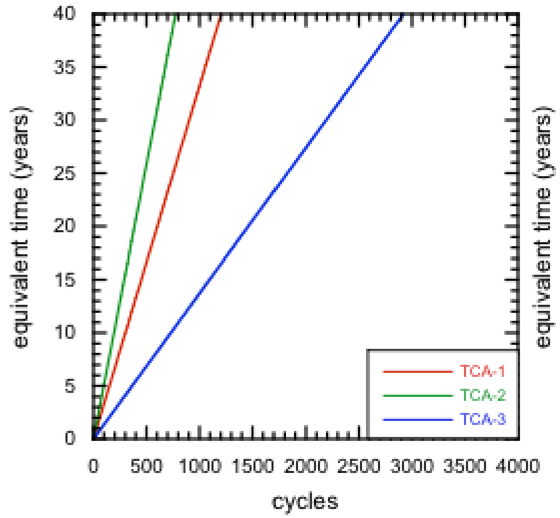
finite element modeling

Analysis:

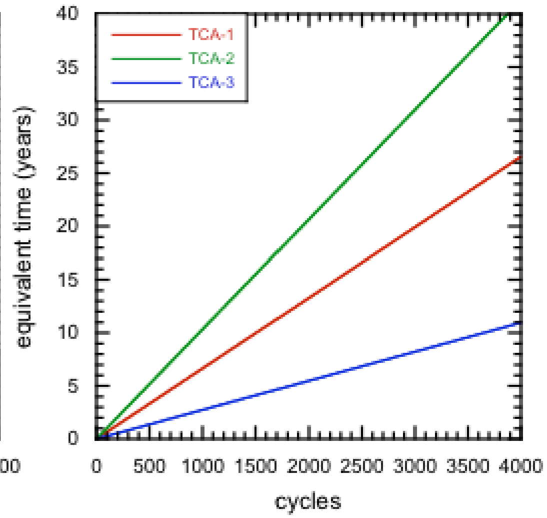
Comparison of energy accumulated through thermal cycling and out door exposure provides for the calculation of equivalent times (acceleration factors)

$$t_{eq} = \frac{nD_{TCA}}{365D_{day}}$$

clear day

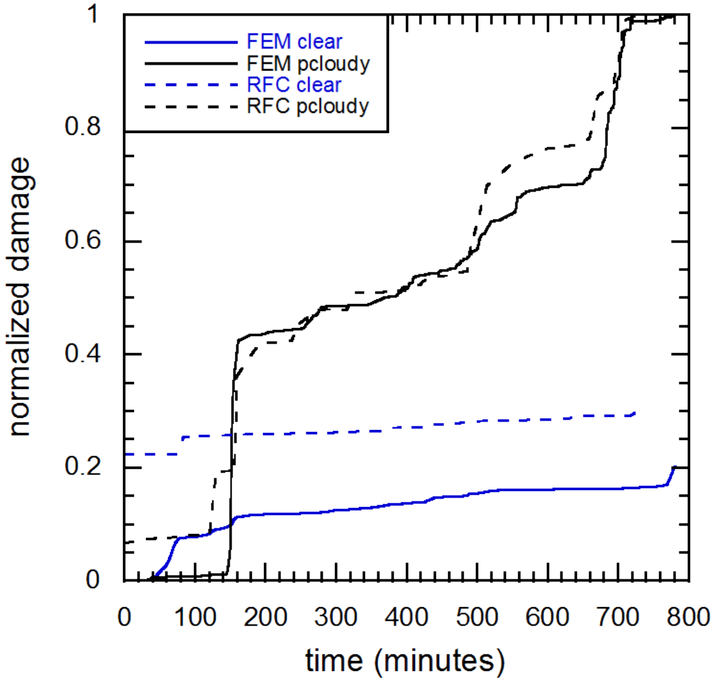


cloudy day



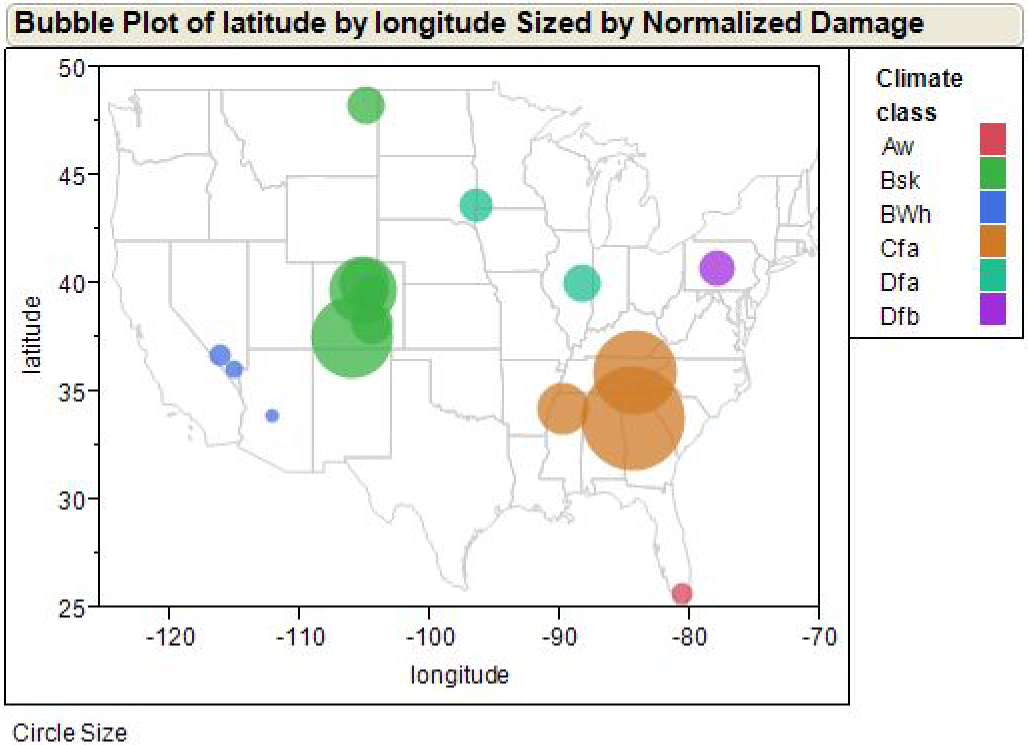
			FEM				RFC		
Standard	**Option**	**n**	**t_{eq} clear**	**t_{eq} cloudy**	**N_{25} clear**	**N_{25} cloudy**	**t_{eq} Golden** years	**t_{eq} Phoenix** years	**t_{eq} Miami** Years
IEC 62108	TCA-1	1000	33	6.5	750	3800	13.2	48	24
	TCA-2	500	26	5	480	2400	8.3	30	15
	TCA-3	2000	27	5.5	1800	9000	20.3	74	37

FEM vs. RFC



- All damage normalized with respect to the most damaging day.
- Only a 10% difference exists in the relative measurement.

RFC



- Bubble size: relative damage
- Bubble color: climate zone

thoughts and future work

- RFC method shows promise for comparative studies between locations.
- Algorithm is convenient to quickly handle long time histories.

- FEM is capable of accurately quantifying the damage that causes failure.
- Accuracy should not be dependent on stress level.
- Models can differentiate between materials and geometries.
- Simulations are slow and expensive.

- Use FEM as a tool to refine algorithm and damage analysis
- Understand sources and magnitudes of error
- Goal: a more accurate RFC method with life prediction capabilities.