WILDFIRE STATISTICS
AND THE USE OF POWER LAWS
FOR POWER LINE FIRE PREVENTION

Prepared for:
Mussey Grade Road Alliance
S-MAP II Phase 1 Track 1 Technical Working Group

February 3, 2021

Joseph W. Mitchell, Ph. D
M-bar Technologies and Consulting, LLC
jwmitchell@mbartek.com

Prepared by M-bar Technologies and Consulting

- Power Laws
- Power Laws and Wildfire
- Power Laws, Wildfire, and Utilities
- Building a Risk Model
- Incorporating Extreme Events into MAVF
- Next Steps

Goal: Safe Utility Operation

The purpose of utility wildfire mitigation is to raise the fire weather severity limits at which utility equipment can be safely operated.

Critical Phenomena & Power Laws

- Landslides
- Earthquakes
- Species Extinction
- Wildfires
- 1/f Noise
- Etc…

Accumulation, Instability, Cascade

Per Bak

"self-organized criticality"

"complex behavior in nature reflects the tendency of large systems with many components to evolve into a poised, 'critical' state, way out of balance, where minor disturbances may lead to events, called avalanches, of all sizes. **Most of the changes take place through catastrophic events** rather than by following a smooth gradual path"

Power Laws

- Self-organized critical events show “power law” behavior

$$y = Cx^{-\alpha}$$

- Extreme events dominate the result. “Fat-tailed”
- For $\alpha < 1$, can’t even predict average from past events. This is important.

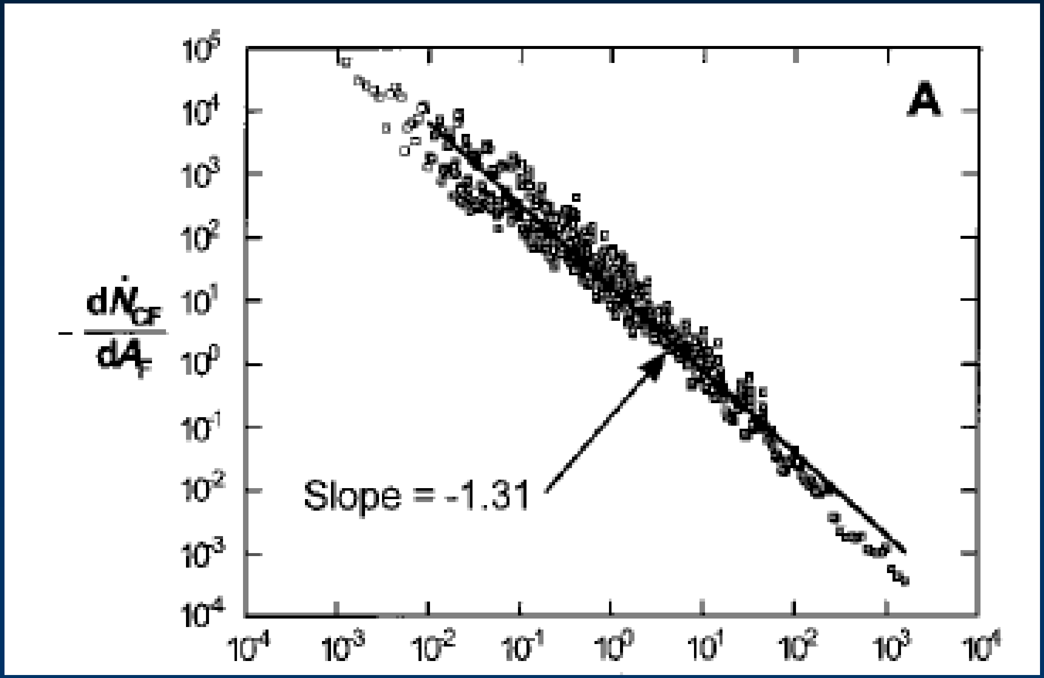
Wildfire and Power Laws

Malamud et. al, 1998

US Fish & Wildlife wildfires 1986-1995

Simple models reproduce behavior

<u>Shows as linear on log-log plot</u>



Malamud, B.D., Morein, G., Turcotte, D.L., 1998. Forest Fires: An Example of Self-Organized Critical Behavior. Science 281, 1840–1842.

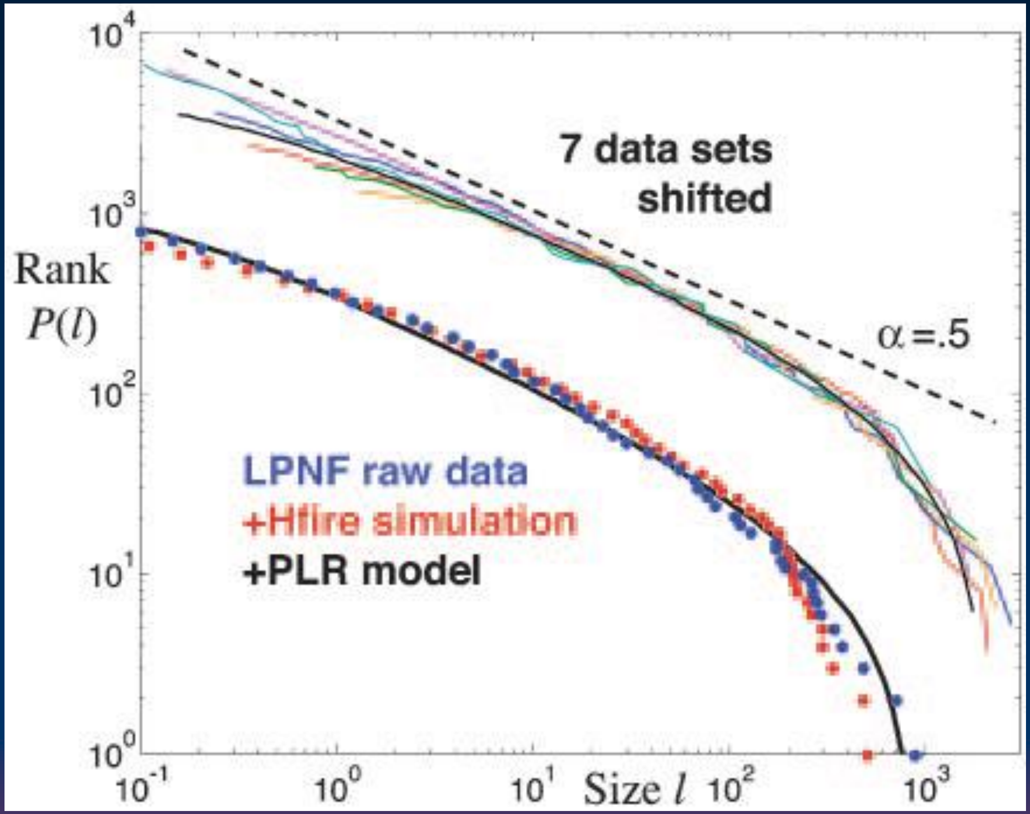
Power Law with Cutoff

Moritz et. al. 2005

- Larger data set
- PLR/HOT model

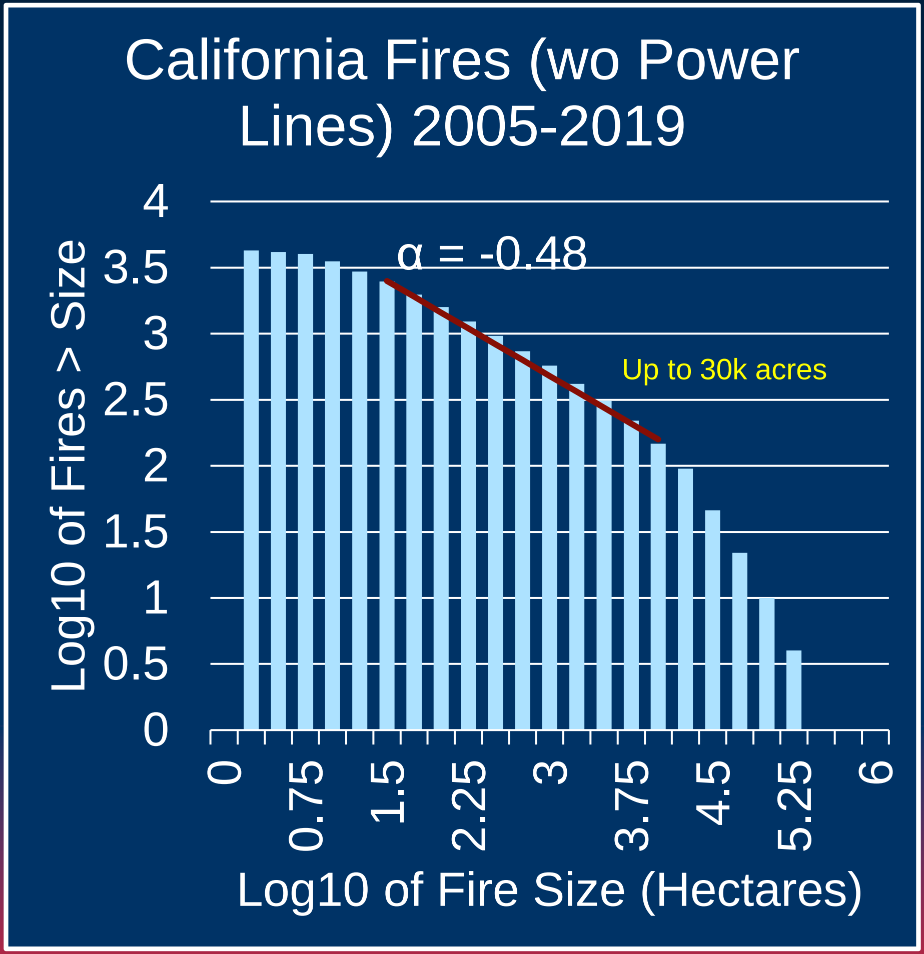
$$y = C[(a+x)^{-\alpha} - (a+L)^{-\alpha}]$$

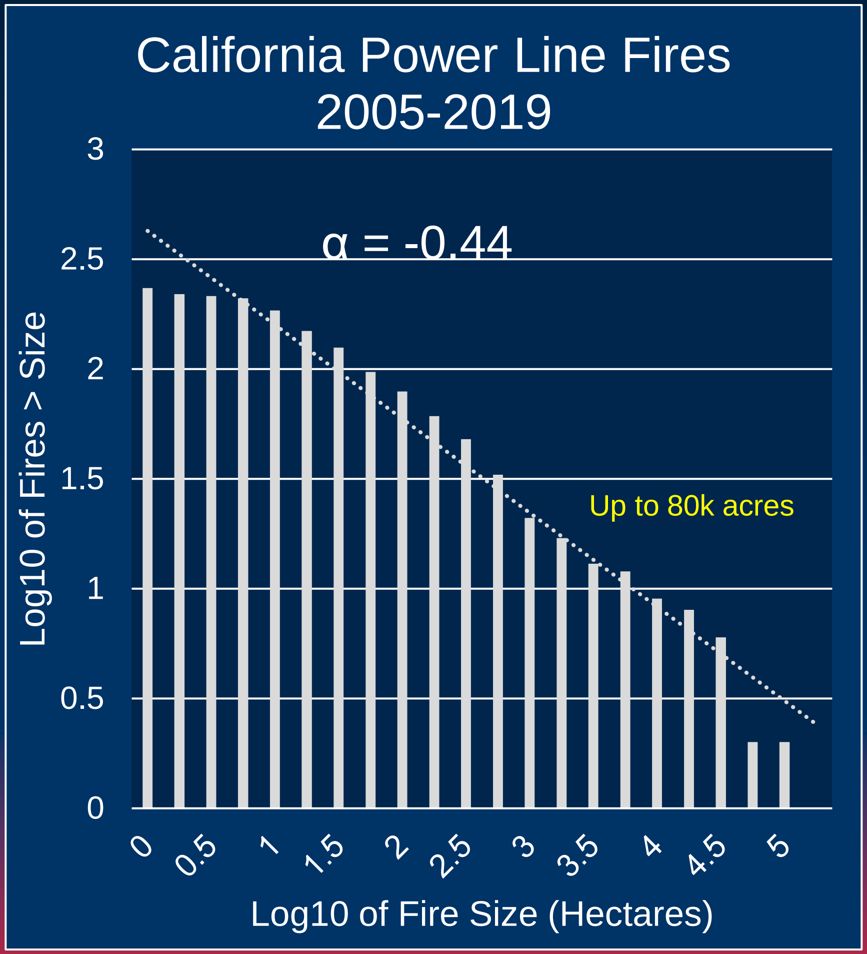
- Cutoff at large sizes (everything burns)
- **α < 1 (!!!!!)**



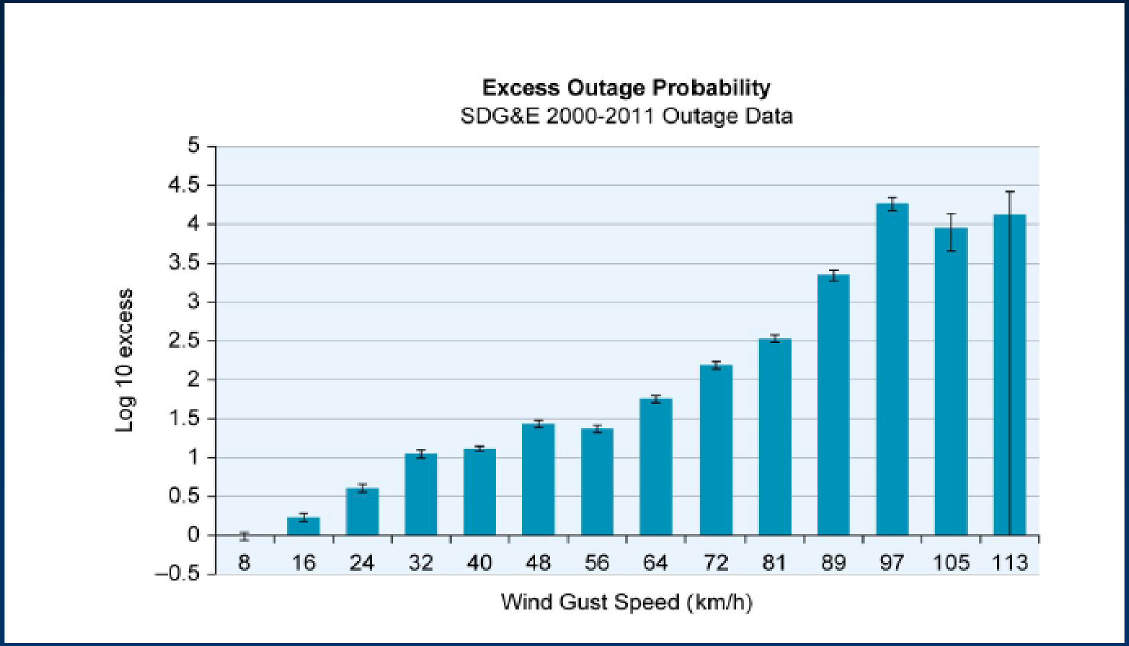
Moritz, M.A., Morais, M.E., Summerell, L.A., Carlson, J.M., Doyle, J., 2005. Wildfires, complexity, and highly optimized tolerance. Proceedings of the National Academy of Sciences 102, 17912–17917. https://doi.org/10.1073/pnas.0508985102

Power Line Fires





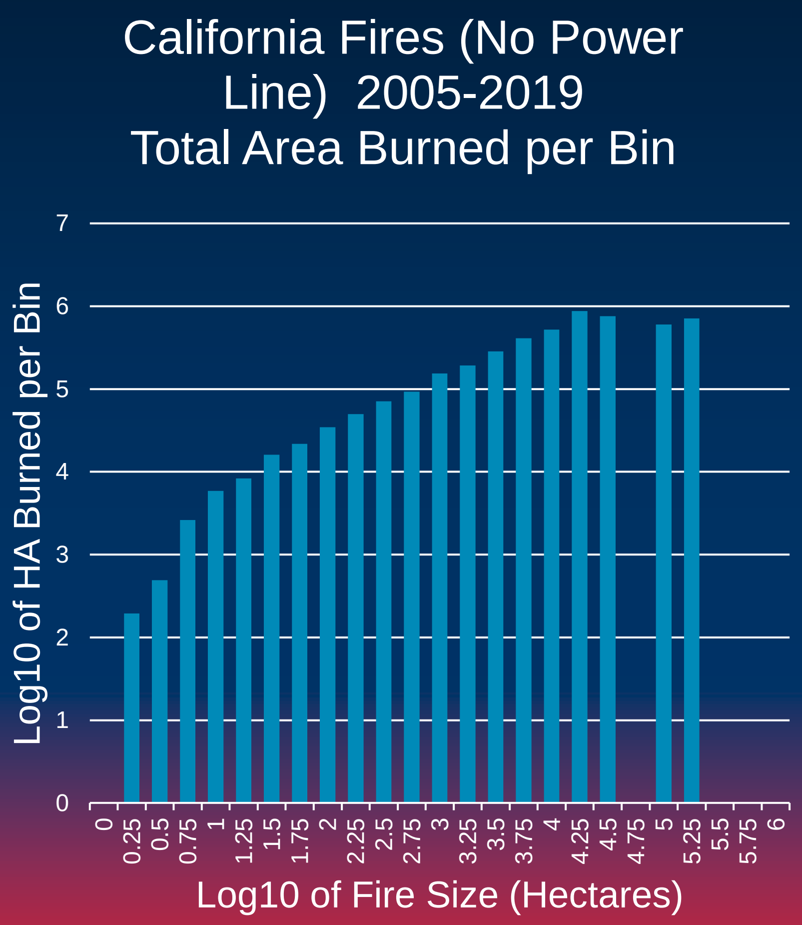
Power Lines and Wind

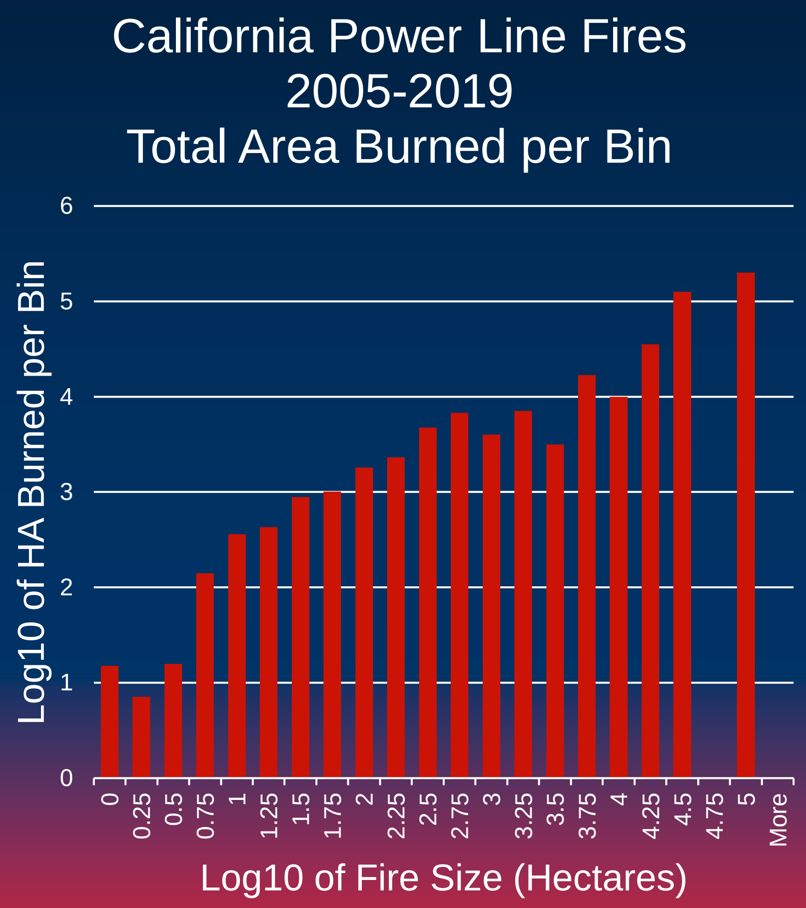


- Outages as proxy for ignition
- Wind gusts from nearest weather station
- Exponential growth with wind speed.

Mitchell, J.W., 2013. Power line failures and catastrophic wildfires under extreme weather conditions. Engineering Failure Analysis, Special issue on ICEFA V- Part 1 35, 726–735. https://doi.org/10.1016/j.engfailanal.2013.07.006

Area Burned as Risk Proxy





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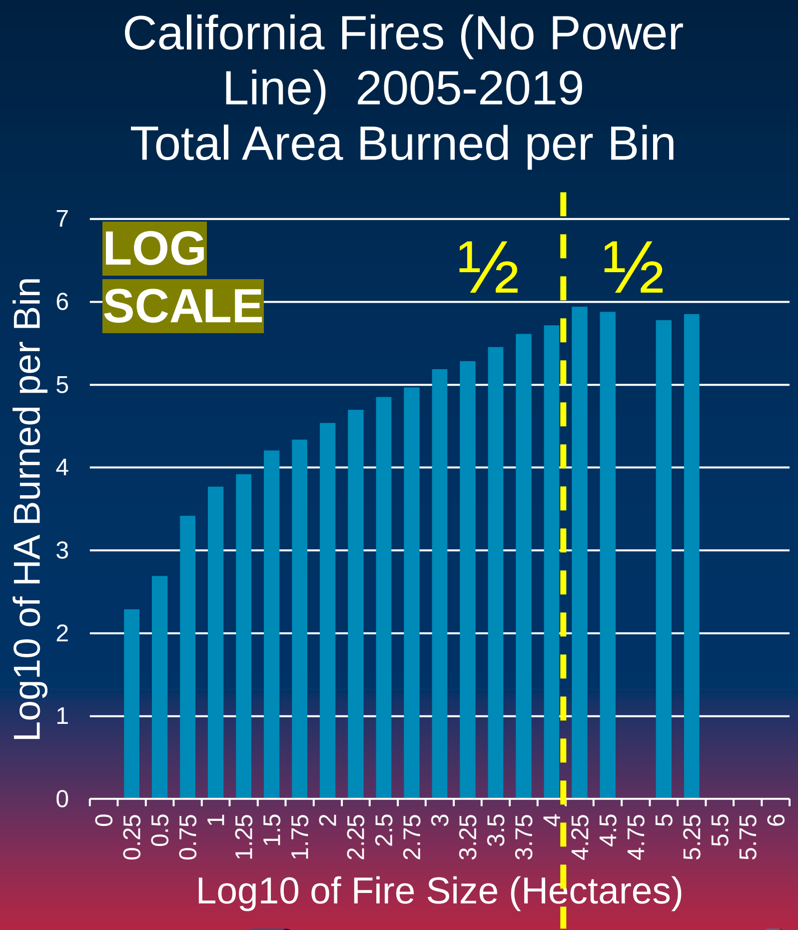
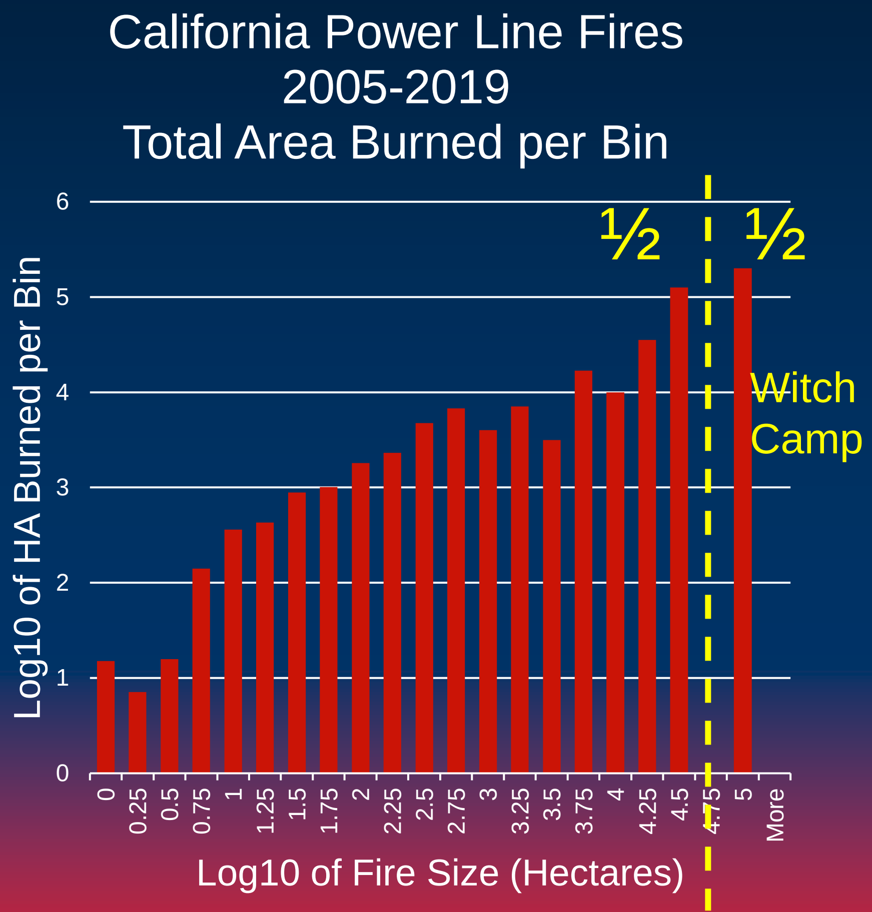
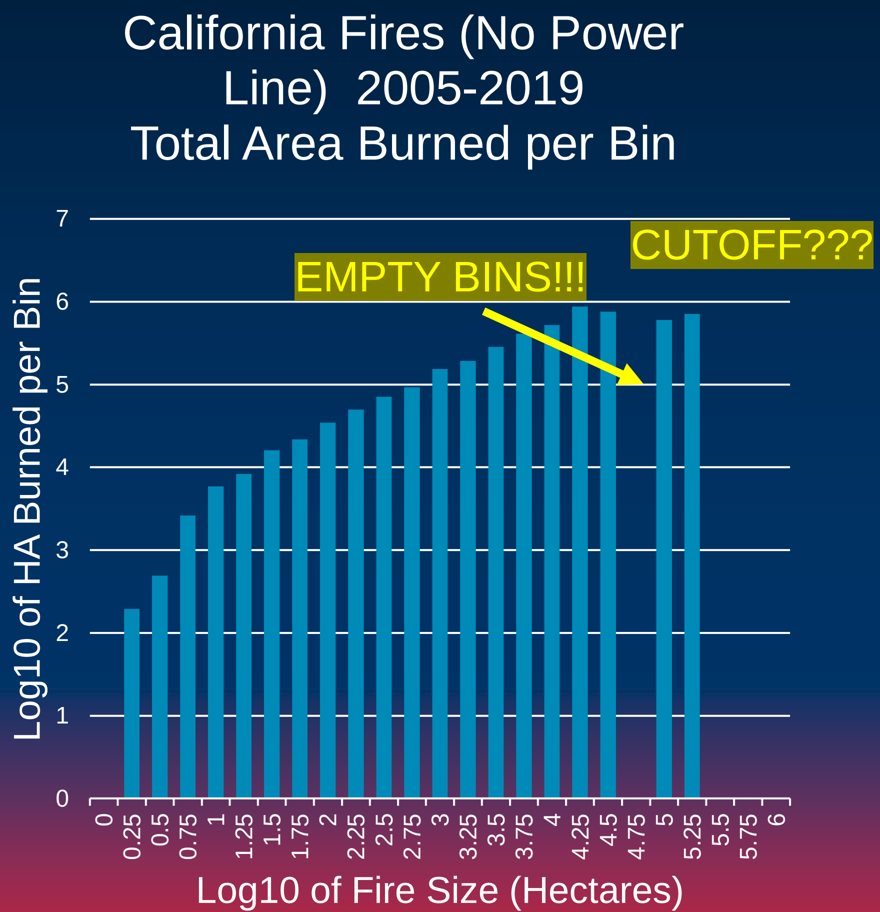
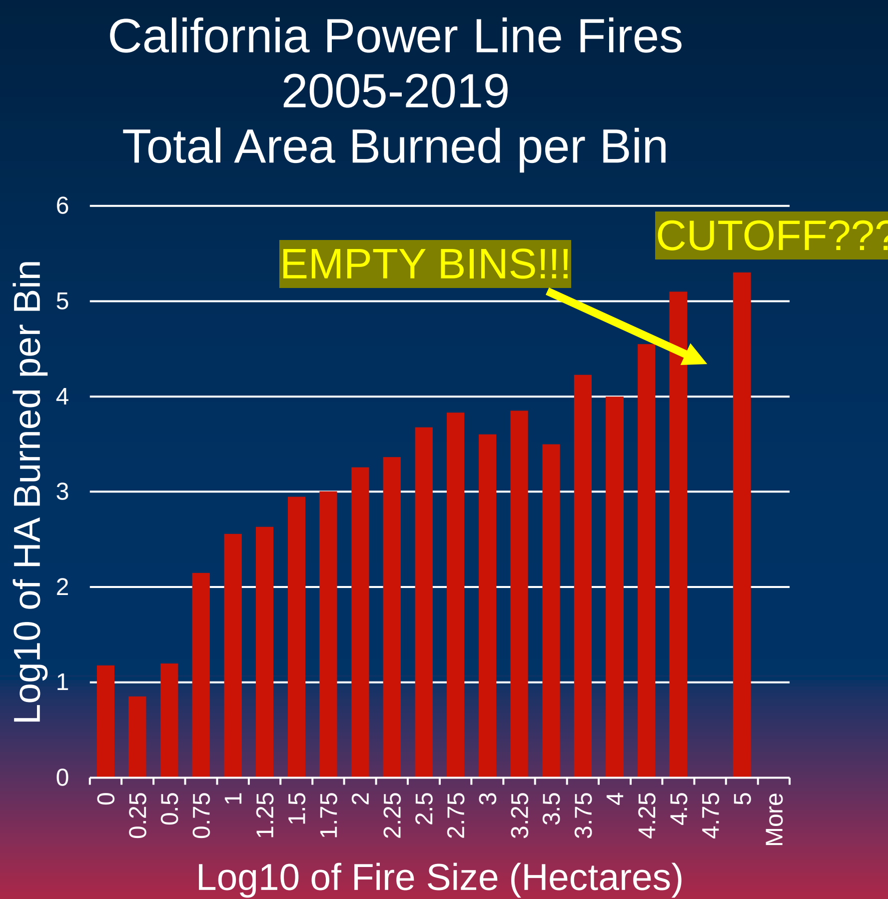




Uncertainty as Risk





Summary of Problem

- Power line fires are more likely to ignite under extreme weather conditions.
- The greatest amount of future damage will come from the most extreme events.
- We know little about maximum size or frequency of extreme fires, making risk estimates uncertain.

Proposal:

Optimized mitigation with heuristic kill-switch

- Weather event as risk event
- Extreme event risks and uncertainties managed by PSPS
- Reduce PSPS for lower risk tiers
- i.e.: What’s happening now except formalized to improve:
  - Customer experience
  - Regulatory supervision
  - Spending priorities

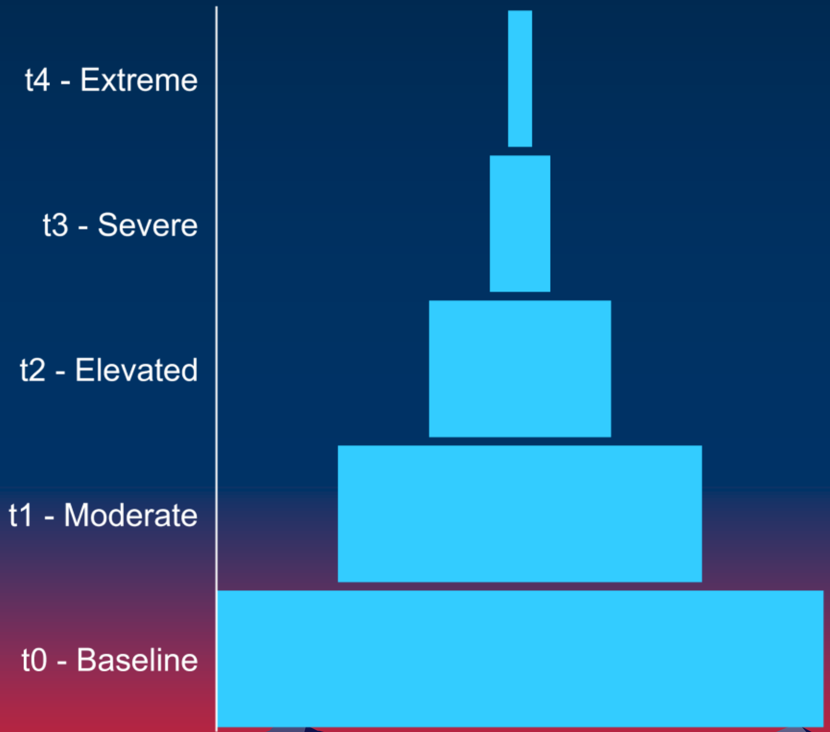
Proposal:

Optimized mitigation with heuristic kill-switch

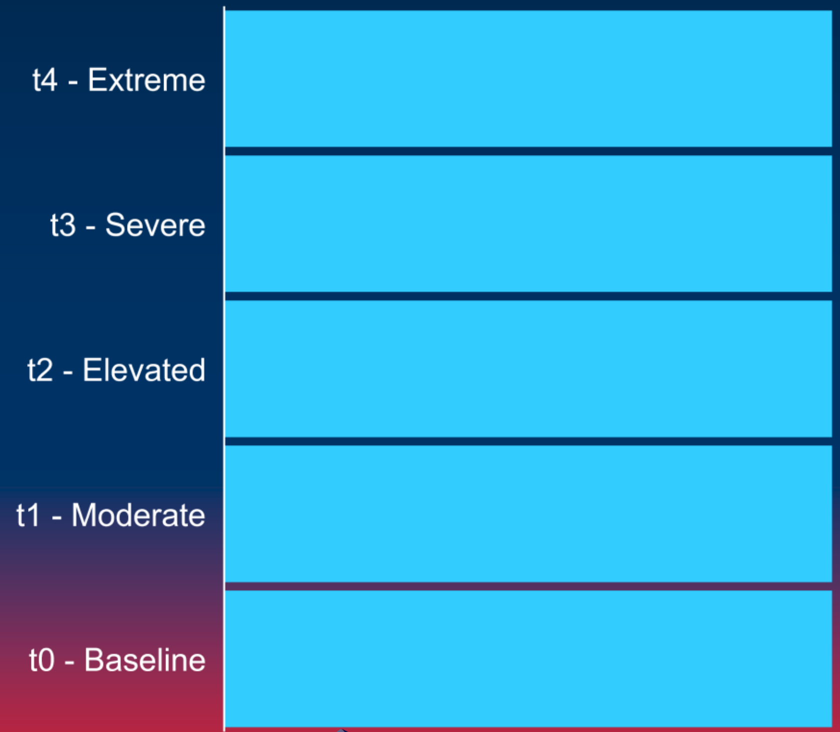
- Can be done in MAVF framework
- Weather Risk Event Advantages:
  – Allows PSPS risks to be treated in same way as wildfire risks
  – Captures increased risk of utility ignitions
  – Allows clear mitigation goals to be set
  – Allows straightforward use of climate inputs

Fire Weather Tranches

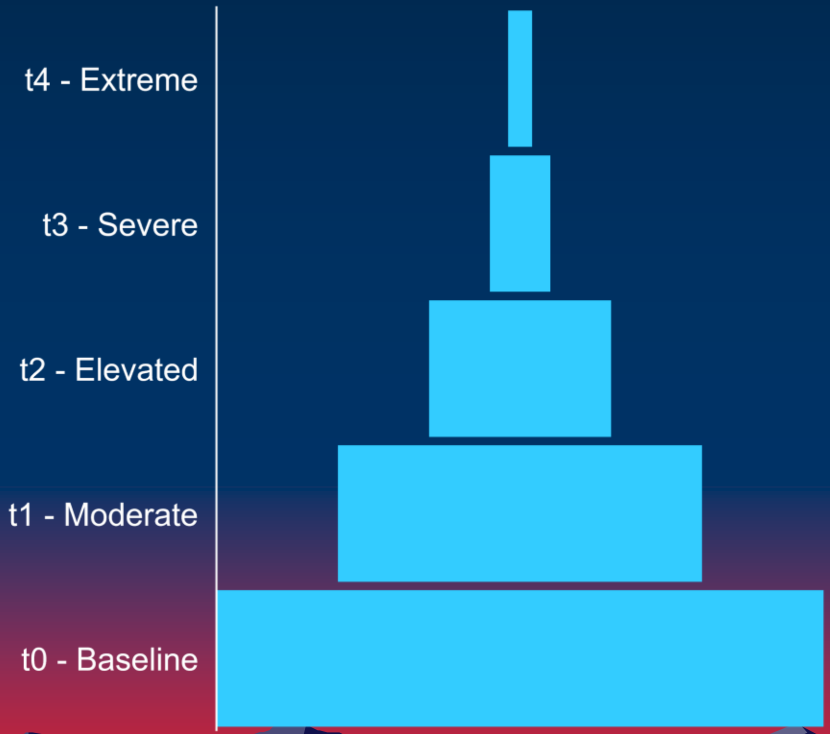
Wildfire weather intensity tranches, based on frequency



Wildfire weather intensity tranches, based on risk



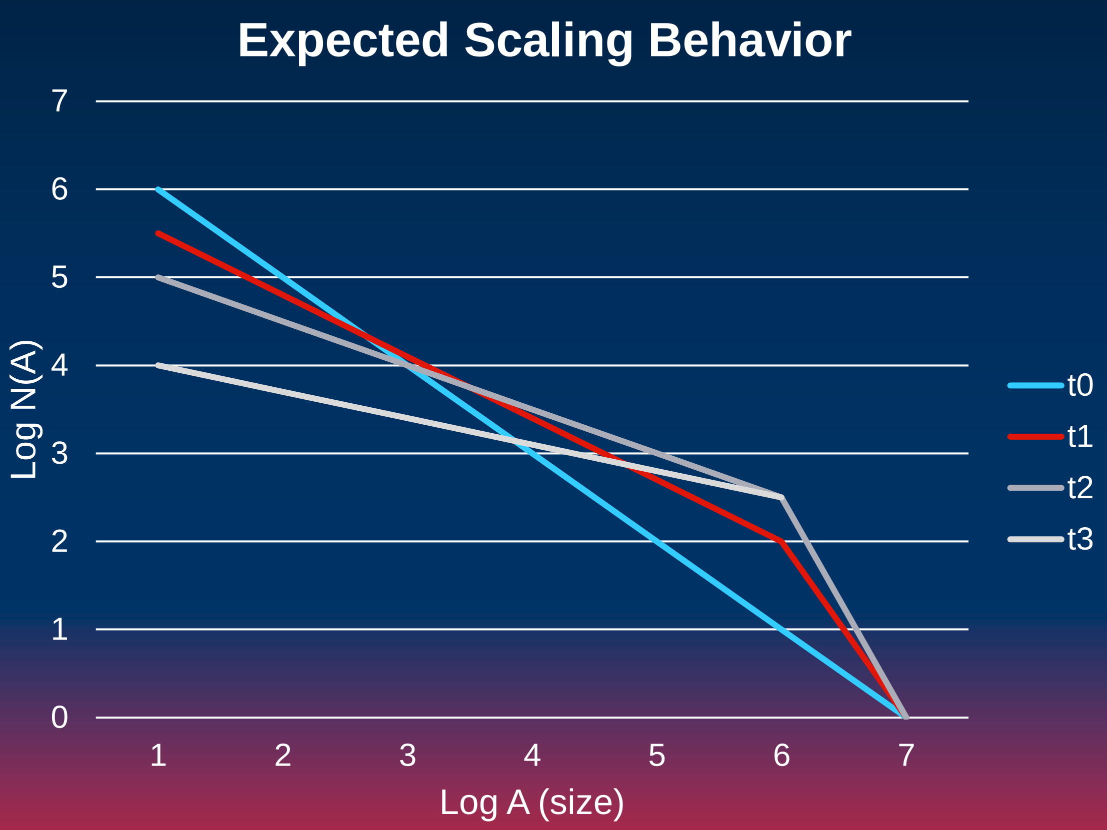
Fire Weather Tranches



- Weather events
  - Meteorological (Abatzoglou)
  - Fosberg Fire Weather Index
  - SAWTI
  - FPI
  - Measured

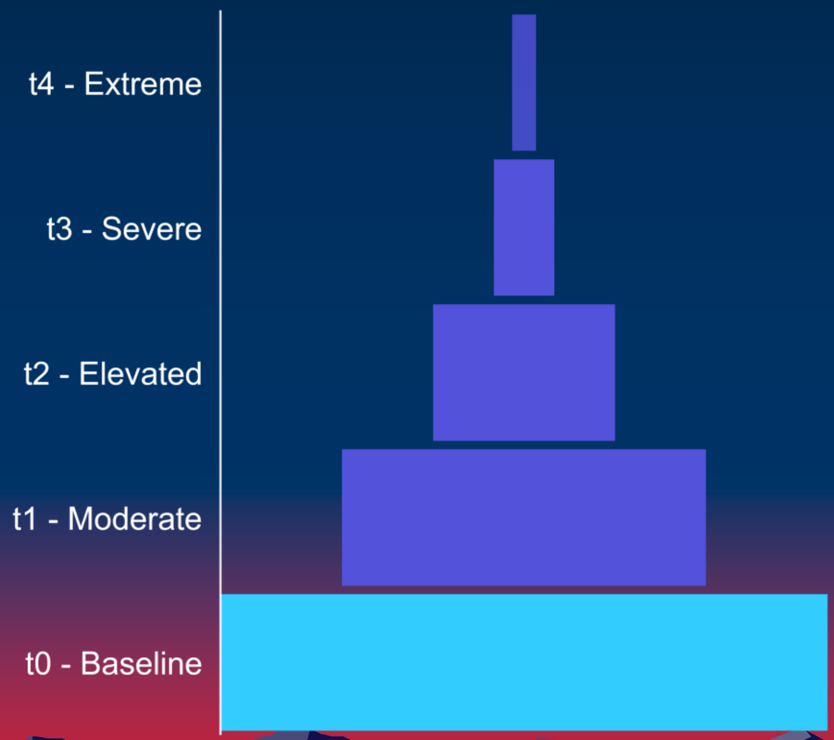
Wildfire Sizes vs. Weather Event Severity

- Group all wildfires into weather tranches
- "Baseline" tranche t0 – no weather effects
- Tranches t1,t2,t3 from moderate to extreme



Fire Weather Tranches

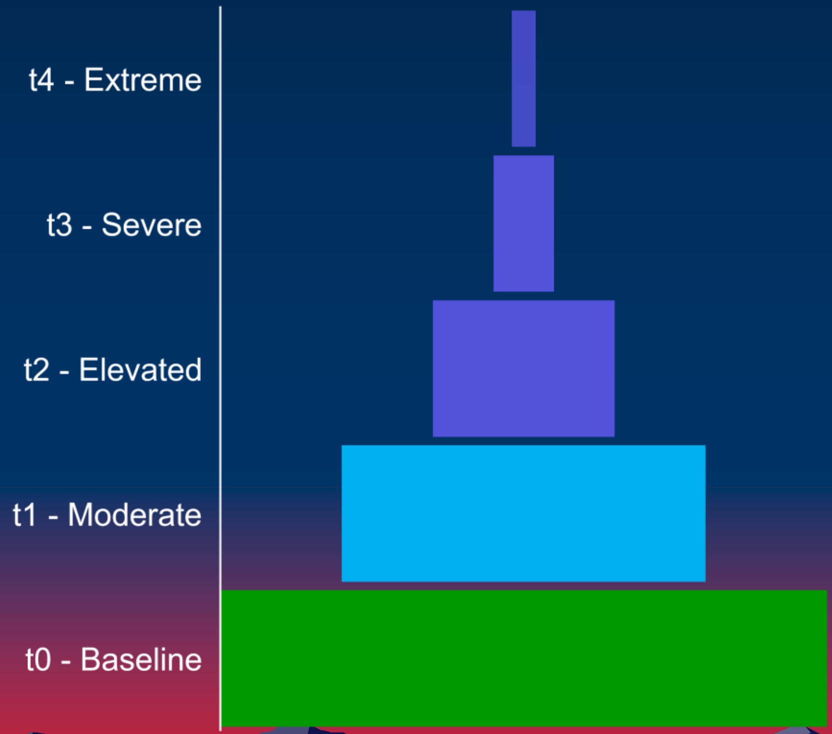
Current Utility Response



--- PSPS for elevated wildfire risk

--- Mitigation for baseline risk

Fire Weather Tranches



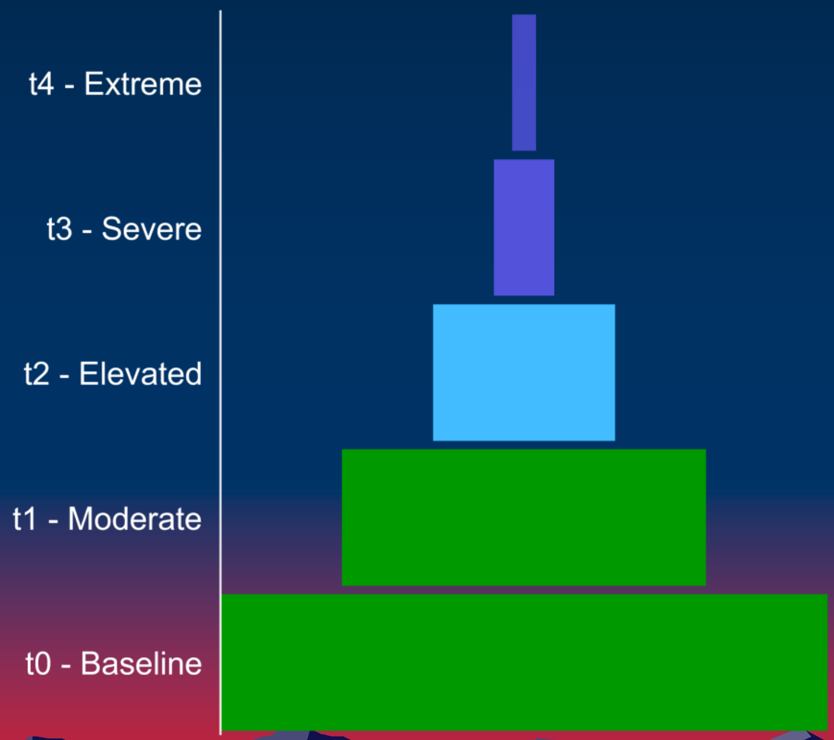
Short-Term Goal

--- PSPS for severe wildfire risk

--- Mitigation for moderate tranche, raise PSPS threshold

--- Safe operation for baseline risk

Fire Weather Tranches



Medium-Term Goal (example)

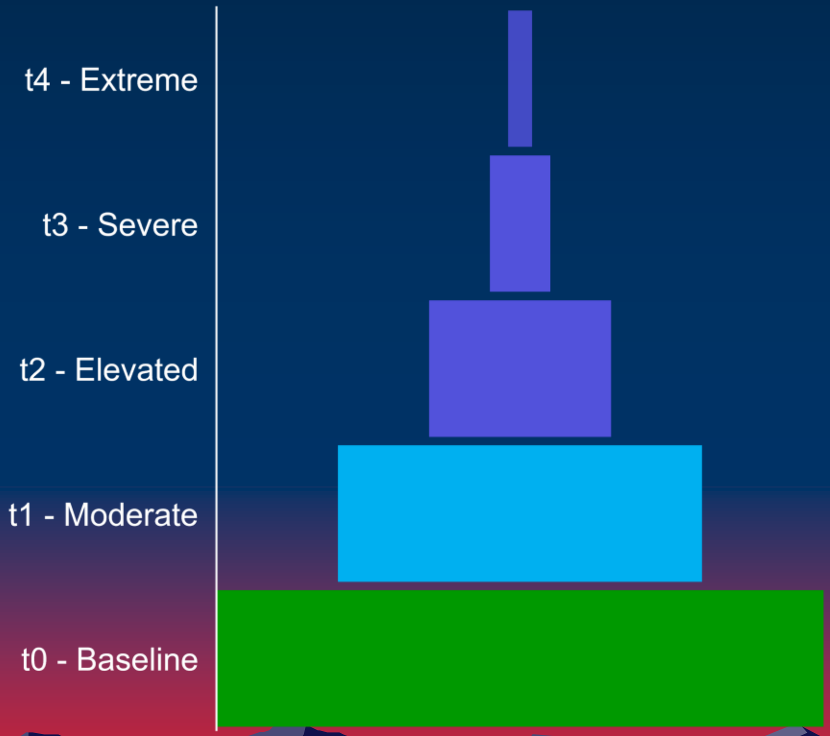
--- PSPS for severe wildfire risk

--- Mitigation for severe tranche,

--- Safe operation for moderate and baseline risk

Fire Weather Tranches

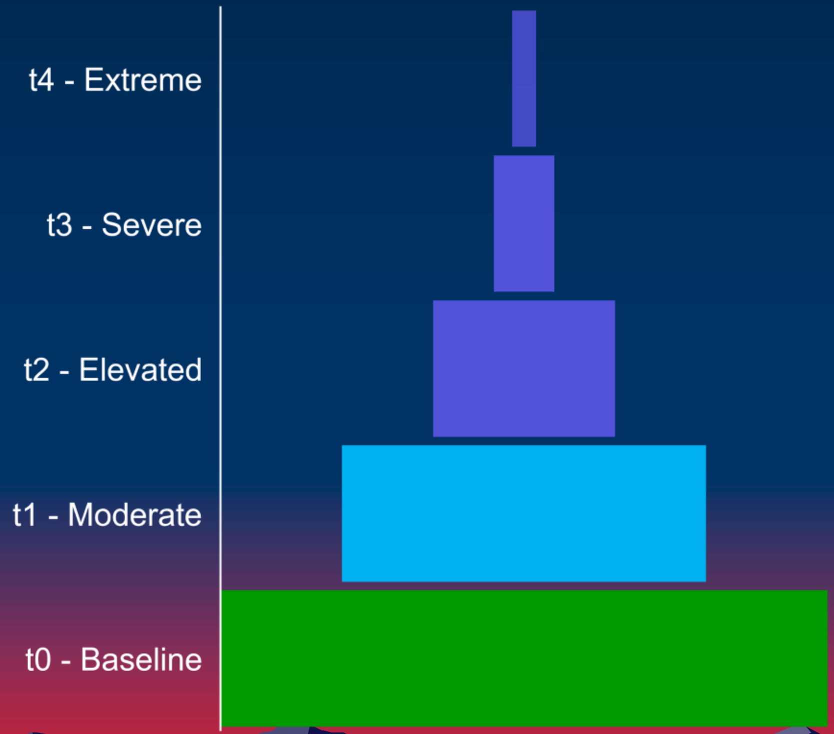
Risks



--- PSPS risks (reliability, safety risks)

--- Residual wildfire ignition after mitigation

Fire Weather Tranches



Mitigations

--- PSPS mitigations (notification, microgrid, restoration)

--- Weather-sensitive ignition

--- Wildfire ignition risks

PSPS – Dangers on Both Ends

PSPS Hazards
(w. alleged examples)

- Economic Losses
- At-risk Individuals
- Loss of Communications (San Anselmo house fire fatality)
- Generator fires (Thief fire)
- Cooking fires (Tick fire)
- Auto accidents (PG&E claims)

Wildfires Before/During/After PSPS
(w. alleged electrical involvement)

Fire	Date	Utility
Camp	November 8, 2018	PG&E
Kincade	October 23, 2019	PG&E
Zogg	September 27, 2020	PG&E
Silverado	October 26, 2020	SCE
Cornell	December 7, 2020	SCE

Elements of the MAVF

- **Tranches: $t_i \ldots t_N$**
- **Baseline Tranche: t_0**
- **Baseline Wildfire Rate: F_0**
- **Fire Weather Event Frequency: f_i**
- **Fire Multiplier: π_i**

  Fires per weather event

- **Tranche Wind Speed: v_i**

  Not ideal. Will be broad range of wind speeds

Elements of the MAVF

- **Power Line Frequency Multiplier: P_i**
  Increase of ignition rate for each severity ranking
- **Wildfire Consequence Distribution: dW_i/dA_i**
  Probability distribution – used for Monte Carlo
- **Wildfire Consequence Mean: $\overline{W}_i$**
- **Cutoff Size: $A_{max,i}$**
- **Minimum Reliable Size: A_{min}**
- **Power Law Exponent: α_i**

Elements of the MAVF

- **De-energization Severity:** d_i, $i > 0$

  How extensive is PSPS, geographically & in time?

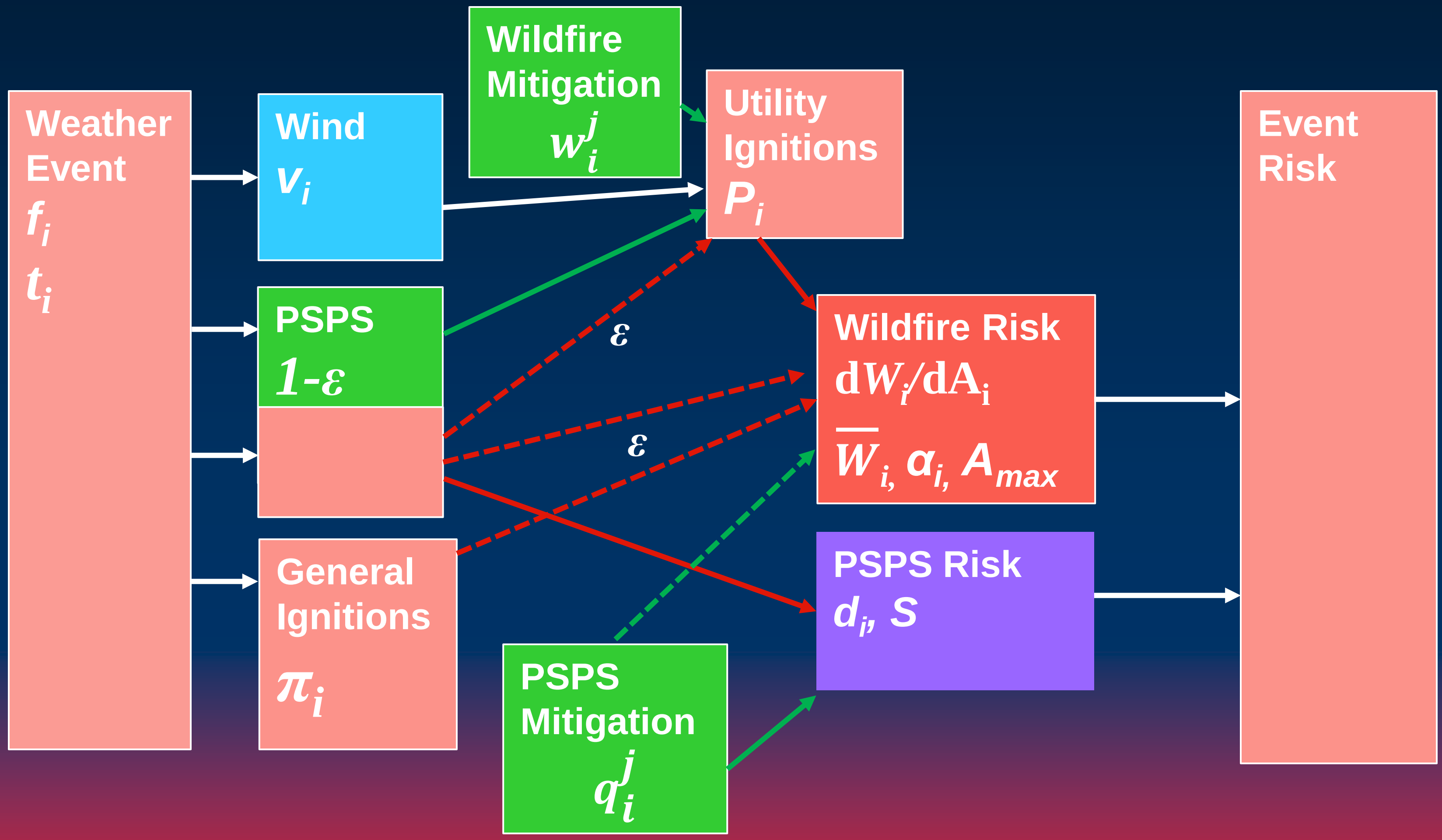
- **De-energization Consequences:** $D_i = Sd_i$

  S is PSPS harm per customer per hour - TBD

Elements of the MAVF

- **De-energization Inefficiency:** ε
  - *Risk from PSPS fires (generators, cooking, etc.)*
  - *Risk from de-energizing in wrong place*
  - *Increased risk from all wildfires (communication, etc.)*
- **Wildfire Mitigation Efficiency:** w_i^j
- **De-energization Mitigation Efficiency:** q_i^j

Where Pieces Fit



And the Math

- Power line wildfire risk:

$$R_i = f_i \pi_i P_i \overline{W}_{\mathrm{I}}$$

- PSPS risk:

$$R_i = R_i^{PSPS} + R_i^{WF} = f_i(D_i + \pi_i \varepsilon_i P_i \overline{W}_i)$$

Safe Operation Threshold

- Safe operation without PSPS:

$$\pi_i(1-\varepsilon_i)P_i\overline{W}_i > D_i$$

- Safe operation with mitigation (ex. Tier 2):

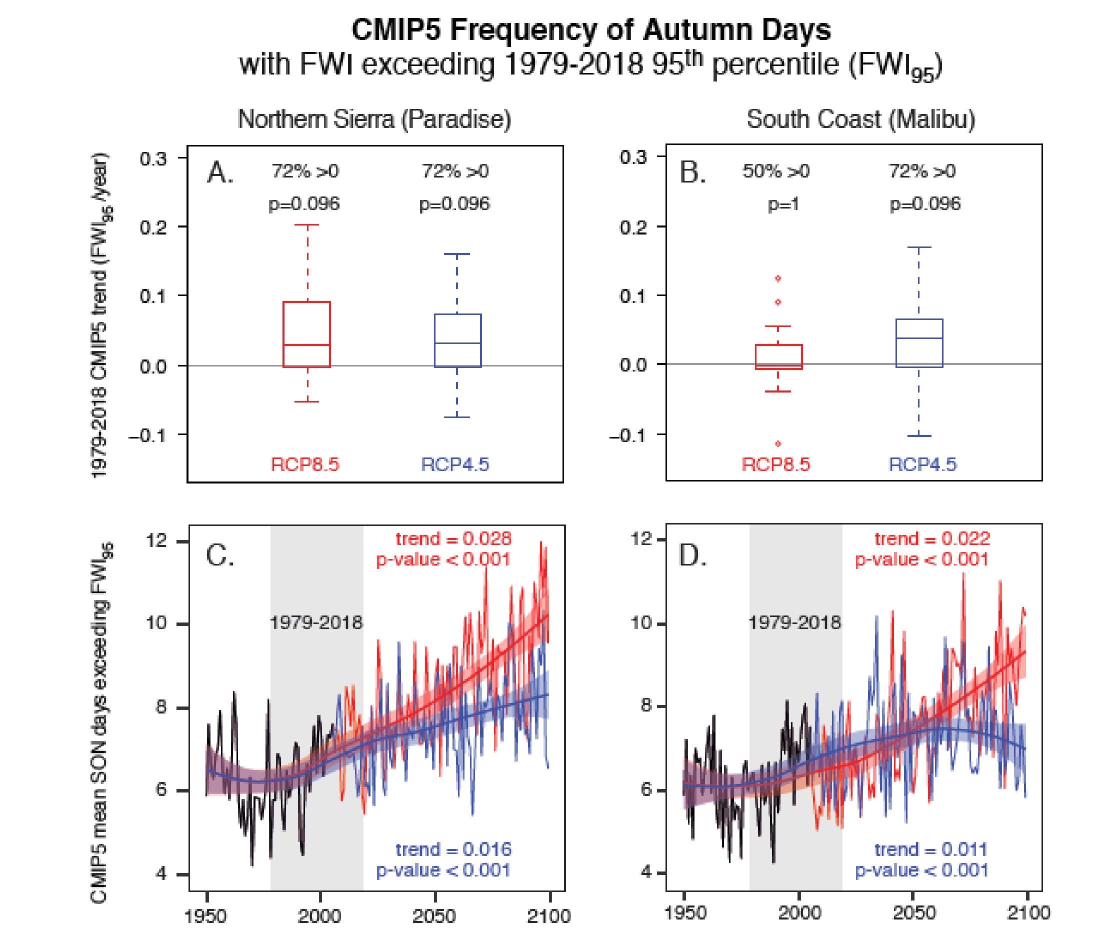
$$\prod_{j=1}^{W}(1-w_2^j)(1-\varepsilon_2)\pi_2P_2\overline{W}_2 < \prod_{j=1}^{Q}(1-q^j)D_2$$

Other issues

- Climate change
- Attributes
- Other Tranches

Increase in Extreme Fire Weather Frequency Due to Climate Change

Changes f_i



Goss, M., Swain, D.L., Abatzoglou, J.T., Sarhadi, A., Kolden, C., Williams, A.P., Diffenbaugh, N.S., 2020. Climate change is increasing the risk of extreme autumn wildfire conditions across California. Environ. Res. Lett. https://doi.org/10.1088/1748-9326/ab83a7

Other MAVF Questions

- How do we divide into attributes?
  - TBD but should be straightforward
- What about other tranche definitions?
  - Should be fine, subdivide each into fire weather severity tranches.
- Monte Carlo or Averages?
  - Monte Carlo can deal with correlated risks

Next Steps

Component	Symbols	Difficulty	Source	Comments
Wildfire weather tranches and event rates.	t_i, F_0, f_i	Moderate	Academic, CA fires	Methodology for fire weather event severity has been developed by several groups.
Wildfire consequence distributions and means	dW_i/dA, α_i	Moderate	Academic, CA fires	Methodology for fire size distributions has already been developed by several groups.
Fires per event	π_i		Academic, CA fires	Will come out of tranche analysis.
Power line frequency multiplier	P_i	Moderate	Utility data, weather	Existing utility data is sufficient to show increase in outage/damage rates as a function of wind speed.
PSPS event severity	d_i	Easy	Utility SME, PSPS history	Once tranches & severity are established, extent of associated PSPS event can be calculated.
PSPS consequences and efficiency	S, Di, ε	Hard	Utilities, consultants, CPUC, intervenors	CPUC or WSD needs to develop methodology for quantifying customer harm.
Mitigations for wildfire and PSPS	w_i, q_i	Easy	Utilities	Utilities have mitigation estimates already, need to divide them into weather severity tranches if they depend on wind.

Thank you

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SUPPLEMENTAL SLIDES

Frequency vs Probability