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Quantifying Risk to California's Energy Infrastructure from Projected Climate Change

Jayant A. Sathaye
Larry L. Dale
Peter H. Larsen
Andre F. P. Lucena

Lawrence Berkeley National Laboratory

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Quantifying Risk to California's Energy Infrastructure from Projected Climate Change

Background to study

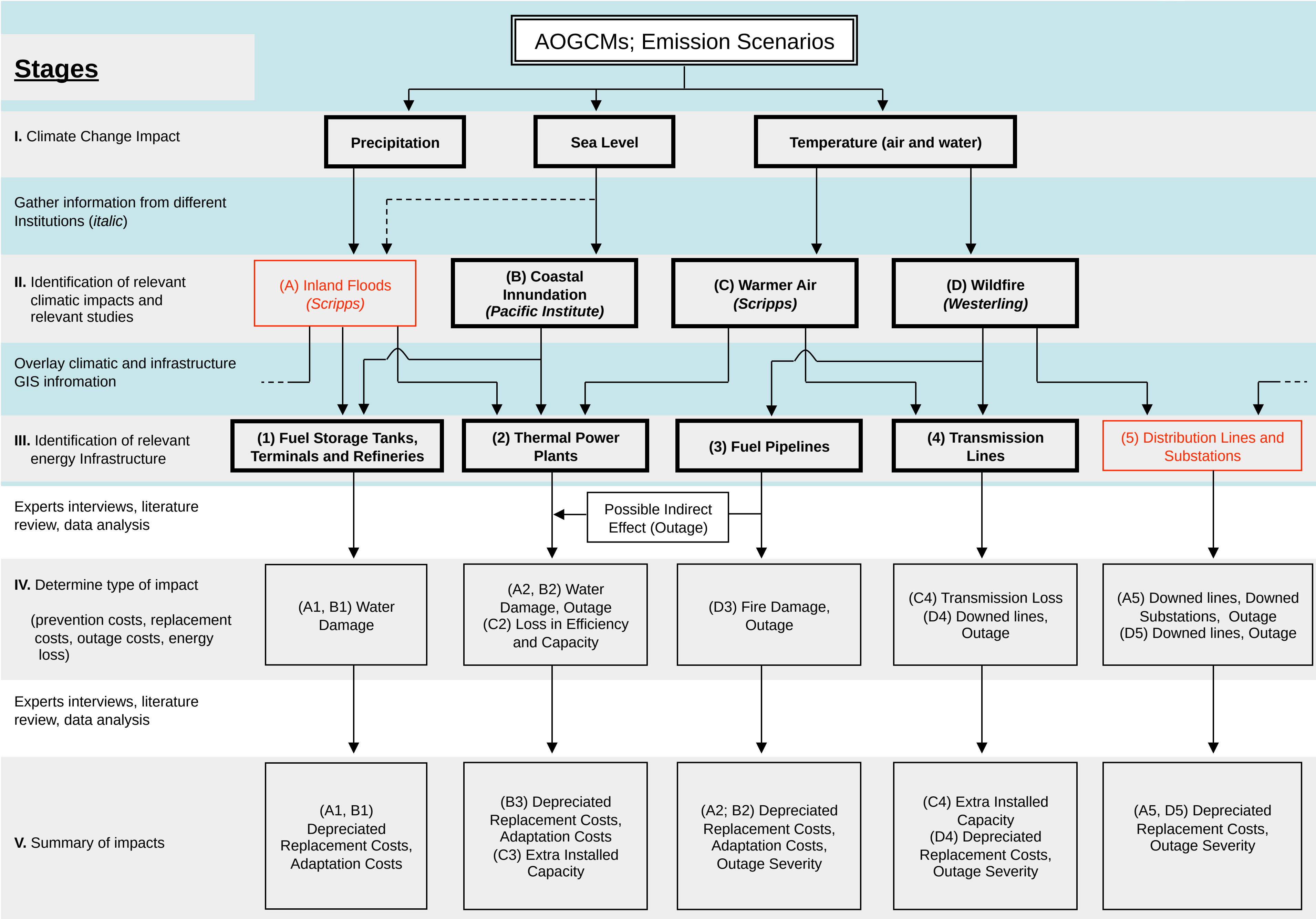
- PIER studies focused on climate risks to the broader economy
- State's energy infrastructure also directly at risk
- Deliverables to include white paper this fall and report early next year

This presentation

- Overview of the methodology (Larry Dale)
- Impacts of ambient temperature on power plants' efficiency and capacity (Peter Larsen)
- Impacts of coastal flooding on power plants (Peter Larsen)
- Impacts of wildfires on energy transportation (Peter Larsen)

Methodology Overview

1. What's covered?
   - Types of climate events
   - Energy infrastructure at risk
2. How to identify infrastructure at risk?
   - GIS mapping of climate and infrastructure.
   - Previous studies of some risks (fire and ocean level)
3. How to determine damage to infrastructure?
   - Past studies
   - Data collection, analysis
   - Energy and utility expert interviews
4. How to summarize damages?
   - Replacement costs (discounting, uncertainty)
   - Adaptation Assumptions?
   - Outages?
5. Principle data and analysis gaps
   - Extreme wind events.
   - Inland flooding events
   - Distribution system, substations, transformers.


Stages
AOGCMs; Emission Scenarios
I. Climate Change Impact
Precipitation
Sea Level
Temperature (air and water)
Gather information from different Institutions (italic)
II. Identification of relevant climatic impacts and relevant studies
(A) Inland Floods (Scripps)
(B) Coastal Innundation (Pacific Institute)
(C) Warmer Air (Scripps)
(D) Wildfire (Westerling)
Overlay climatic and infrastructure GIS infromation
III. Identification of relevant energy Infrastructure
(1) Fuel Storage Tanks, Terminals and Refineries
(2) Thermal Power Plants
(3) Fuel Pipelines
(4) Transmission Lines
(5) Distribution Lines and Substations
Experts interviews, literature review, data analysis
Possible Indirect Effect (Outage)
IV. Determine type of impact
(prevention costs, replacement costs, outage costs, energy loss)
(A1, B1) Water Damage
(A2, B2) Water Damage, Outage
(C2) Loss in Efficiency and Capacity
(D3) Fire Damage, Outage
(C4) Transmission Loss
(D4) Downed lines, Outage
(A5) Downed lines, Downed Substations, Outage
(D5) Downed lines, Outage
Experts interviews, literature review, data analysis
V. Summary of impacts
(A1, B1) Depreciated Replacement Costs, Adaptation Costs
(B3) Depreciated Replacement Costs, Adaptation Costs
(C3) Extra Installed Capacity
(A2; B2) Depreciated Replacement Costs, Adaptation Costs, Outage Severity
(C4) Extra Installed Capacity
(D4) Depreciated Replacement Costs, Outage Severity
(A5, D5) Depreciated Replacement Costs, Outage Severity

Useful Metrics to Evaluate Second-Order Climate Risk to Energy Infrastructure

I. Loss of effective *capacity* and *output (efficiency losses)* LBNL deliverable for this project.

II. Loss of infrastructure (increased capital and O&M costs) LBNL deliverable for this project (pending data and other constraints).

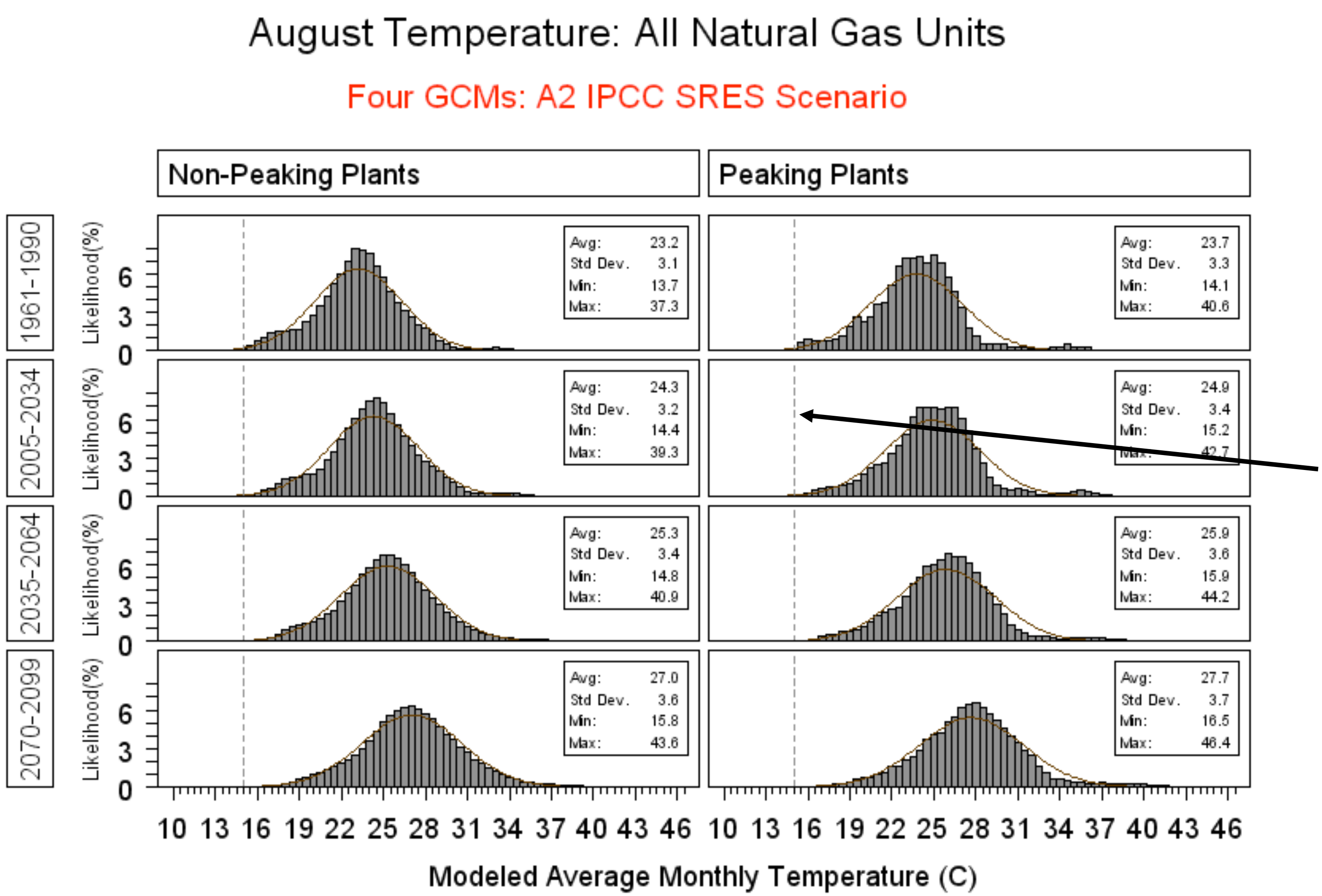
III. Risk to other economic activity (secondary costs from outages, etc.)

Impacts of Ambient Temperature on Plant Efficiency and Output (Peter Larsen)

Future Temperature Likelihood Estimates

- Scripps provided monthly downscaled climate projections for four general circulation models (GFDL, CCSM, CNRM, and PCM) and two future emissions scenarios (A2 & B1).
- LBNL/UC-Berkeley matched monthly downscaled climate projections to every piece of energy infrastructure in California.
- LBNL/UC-Berkeley are studying impacts for the following date ranges: 1961-1990 (base), 2005-2034, 2035-2064, and 2070-2099.
- In addition to average and maximum monthly climate projections, LBNL/UC-Berkeley were provided the standard deviation (or spread) of the monthly projections.
- A Monte-carlo simulation of future temperatures was run at every natural gas plant in California for two emissions scenarios (A2 and B1).
- We are considering new methods for estimating likelihoods of extreme events based on research by N. Miller, K. Hayhoe, M. Auffhammer, J. Walsh, and others….

Future Average Temperature Likelihood Estimates



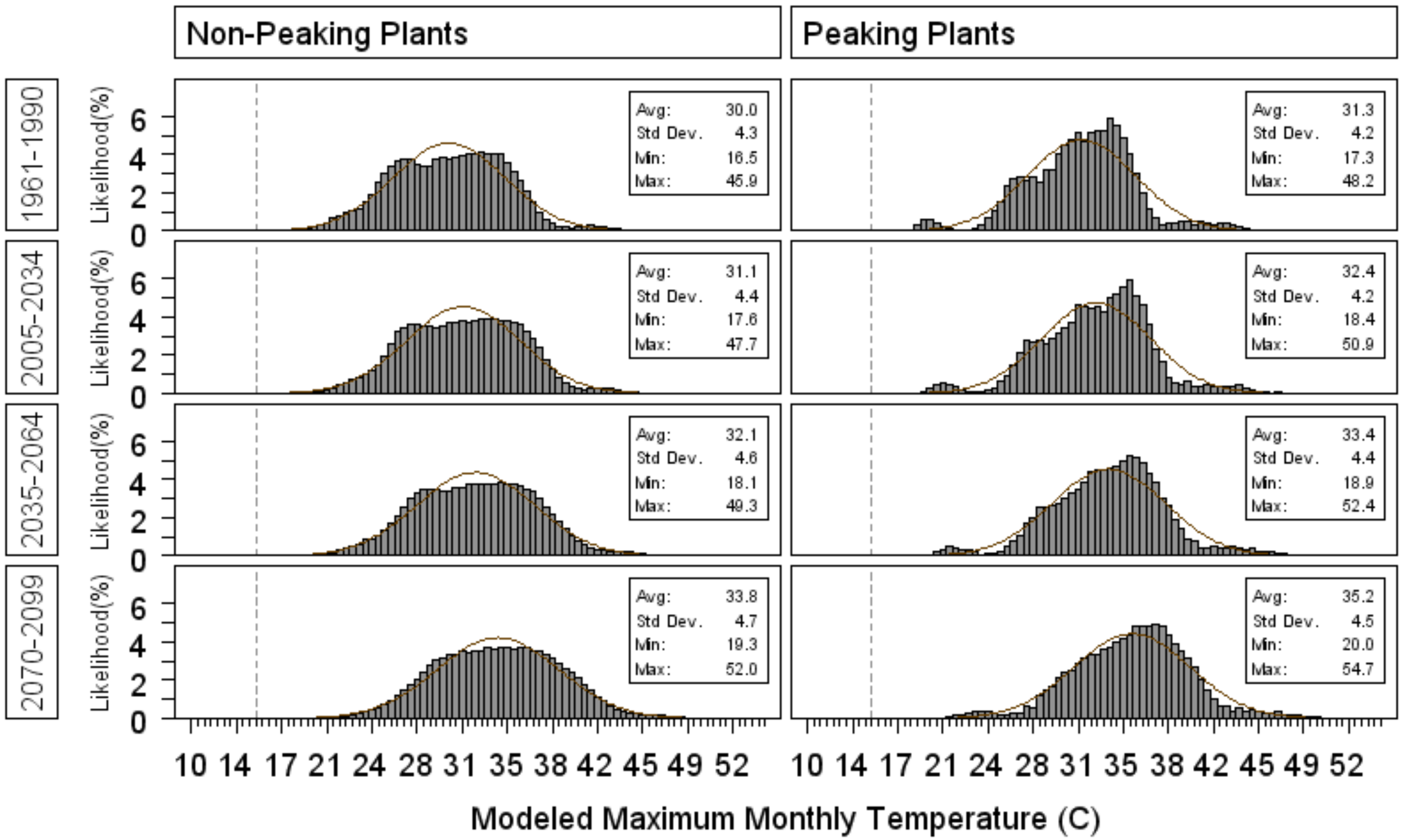
- ***Monthly average temperatures are assumed to be normally distributed.***
- ***Efficiency losses are assumed above 15C.***
- **Plant-level probability distributions for each SRES scenario.**

NOTES: Distribution based on 100 random temperature draws per unit per GCM.

Future Max. Temperature Likelihood Estimates (cont.)

August Temperature: All Natural Gas Units

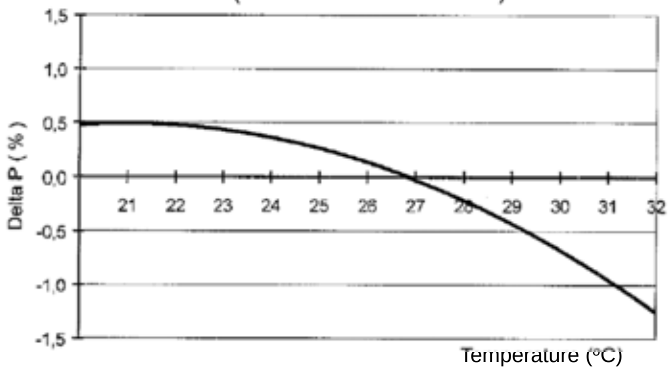
Four GCMs: A2 IPCC SRES Scenario



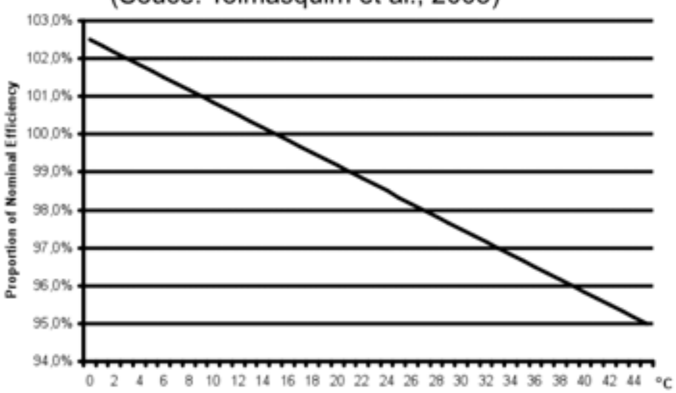
NOTES: Distribution based on 100 random temperature draws per unit per GCM.

Warmer Air and Water Impacts on Power Plant Efficiency and Capacity

Change in power as function of sea temperature at the Angra 2 Nuclear Power Plant
(Source: Eletronuclear)



Influence of atmospheric temperature on the efficiency of gas turbines
(Souce: Tolmasquim et al., 2003)



Change in Power as function of temperature
(Source: CEC-500-2006-034)

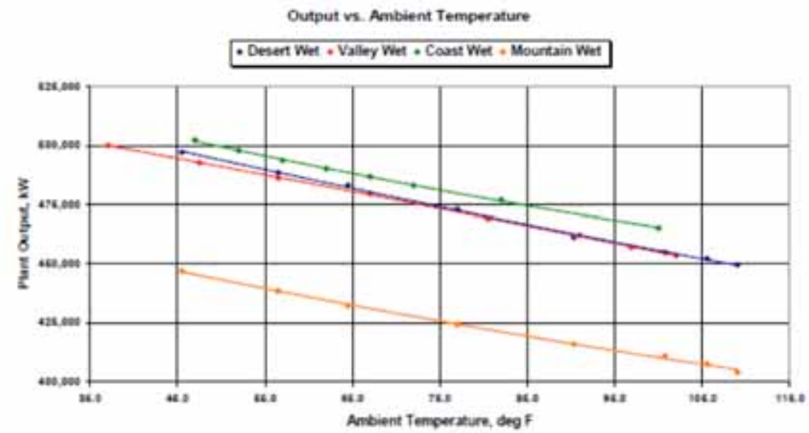


Figure 7. Output vs. ambient temperature—wet-cooled plants

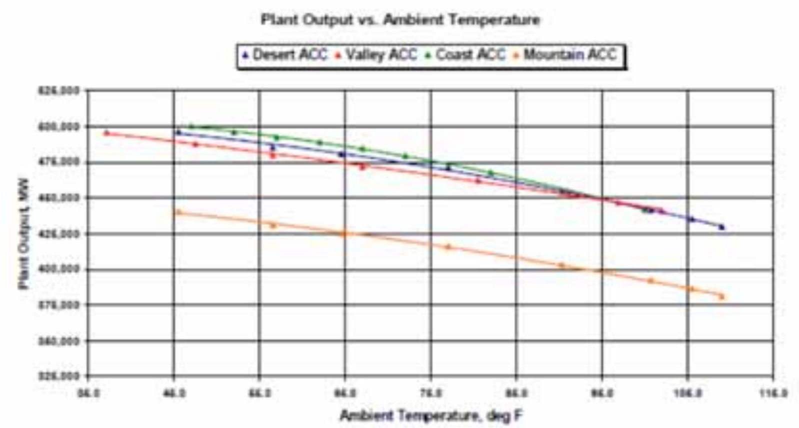
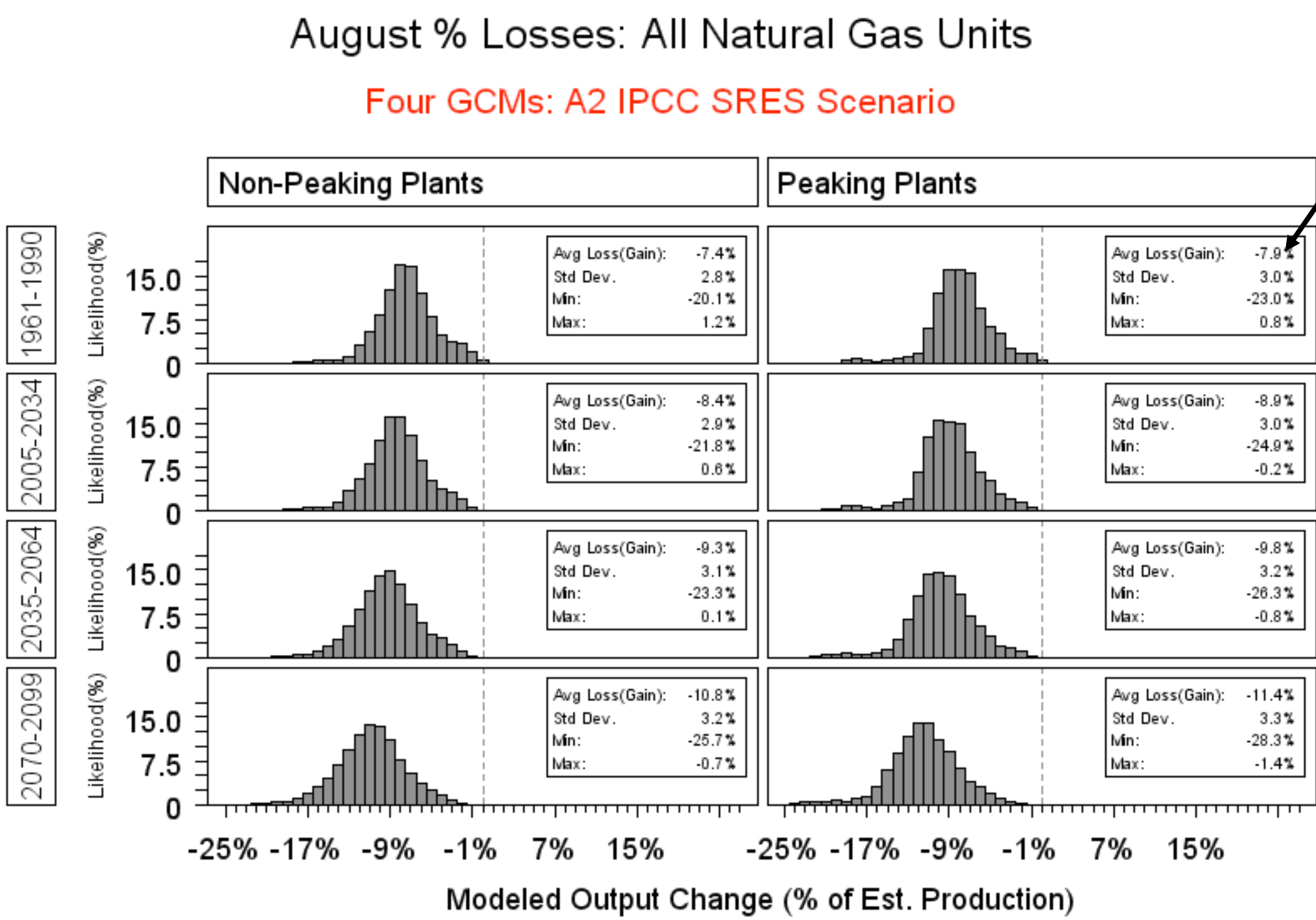


Figure 8. Output vs. ambient temperature—dry-cooled plants

Climate Impacts on Efficiency/Output

- Used temperature likelihood estimation to simulate efficiency and output losses/gains at each natural gas plant in California.
- "Strawman" assumption is that natural gas plants *lose* 0.9% output for each degree above 15C (59F) and *gain* 0.9% output for each degree below 15C.
- Multiplied output losses/gains (%) against assumed monthly production (MWh) to determine impacts for each time period.
- Monthly production was estimated by multiplying an assumed capacity factor against nameplate capacity for each plant.
- We are in the process of estimating relationship between temperature and efficiency at specific natural gas plants and will use these numbers in the final paper.
- Relationship between efficiency and plant output isn't necessarily linear….

Average Monthly Temperature Impacts on Efficiency/Output



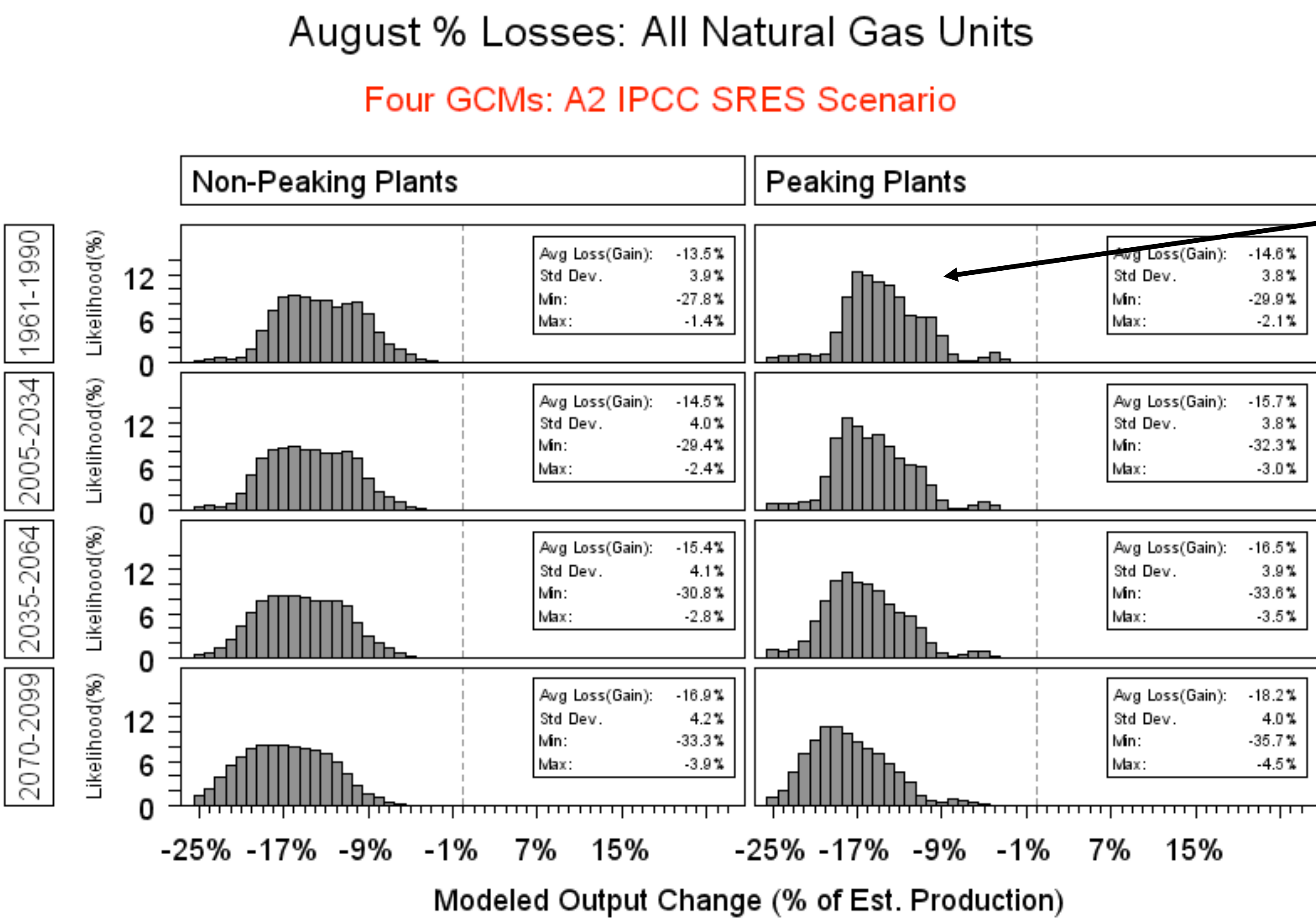
- ***Average losses of 7-8% were estimated in base period for August.***

- **This simple method implies that climate change may reduce monthly average output by an additional 3-4% for both peakers and non-peakers by the end of the century.**

- **There may already be excessively low reserve margins….**

NOTES: Distribution based on 100 random temperature draws per unit per GCM.
ASSUMPTIONS: Base temperature=15C. Peaking capacity factor=10%. Non-peaking capacity factor=60%.

Maximum Monthly Temperature Impacts on Efficiency/Output



- ***Average losses of <u>14-15%</u> were estimated in base period for August.***

- **An additional <u>3-4%</u> of lost output due to climate change could *severely* impact an already stressed power system…..**

NOTES: Distribution based on 100 random temperature draws per unit per GCM.
ASSUMPTIONS: Base temperature=15C. Peaking capacity factor=10%. Non-peaking capacity factor=60%.

Next Steps for Quantifying Efficiency Losses

- Determine quantitative relationship between water/ambient temperature and plant/transmission efficiency for multiple infrastructure classes.
- Revisit estimating probabilities of extreme events.
- Incorporate other meteorological variables that influence infrastructure efficiency/output (e.g., humidity, pressure, etc.)?
- Determine average structure replacement/maintenance costs and downtime.
- Gather information on how much it typically costs to improve plant/line efficiency against meteorological losses.
- Work closely with our Technical Advisory Committee (TAC)….

Impacts of Coastal Flooding on Power Plants

Sea Level Rise Impacts on Coastal Power Plants

- 30 power plants totaling over 10,000 MW vulnerable to a 100-year coastal flood with a 1.4 meter sea level rise.
- In some cases whole piece of infrastructure is at risk, whereas in other cases, only portions of structure are at risk (e.g., intake or other peripheral structures are exposed to flood risk).
- There are estimation caveats….

Power plants vulnerable to a 100-year coastal flood with a 1.4 meter sea-level rise

(Source: Pacific Institute – http://www.pacinst.org/reports/sea_level_rise/maps/)

Example of Power Plant Exposed to 100-year Flood Event (2000 sea level and 1.4m rise)

Source: Pacific Institute; CEC

- **Pittsburg may be at risk to current 100 year flood, but also additional risk from sea-level rise.**
- **Levies and other protective measures were not accounted for in the original Pacific Institute analysis.**
- **Vertical resolution of digital elevation data may be too course in some locations….**

Power Plants Exposed to 100-year Flood Event (2000 sea level)

Source: Pacific Institute; CEC

Some power plants may already be at risk from a 100-year flood event.

Power Plants Exposed to 100-year Flood Event (1.4m sea level rise)

Source: Pacific Institute; CEC

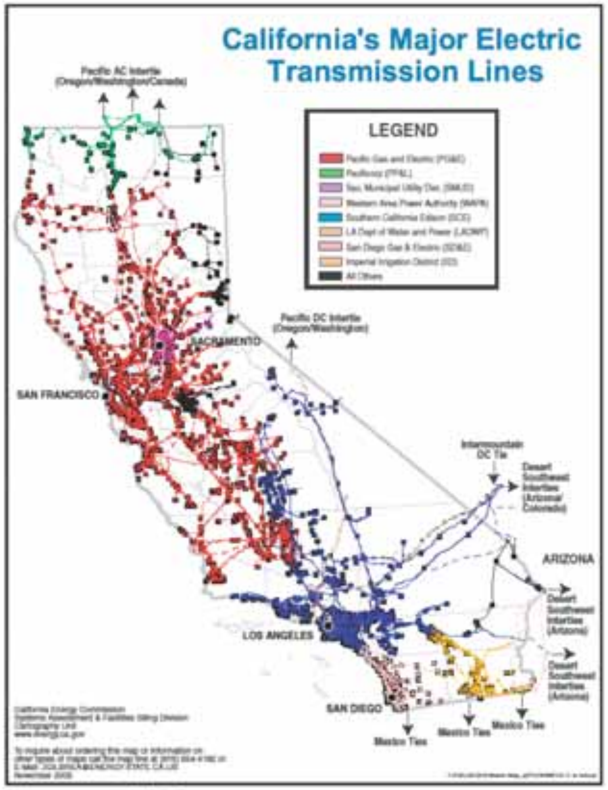
Assuming sea level rise, some plants may also be affected. Others, may be affected to a greater extent.

Next Steps for Estimating Flooding Impacts

- How does storm surge with sea level rise specifically affect selected power plants?
- Misc. Information Needs:
  - What are the consequences (and costs) to each specific power plant that might be impacted?
  - What is the expected useful life span of each specific power plant?
  - Are there levies already in place that protect these structures?
  - Are there adaptation measures being taken (or proposed) to prevent (or reduce) damages from projected flooding? At what costs?
- Oil terminals, transmission, and refineries were also investigated.

Impacts of Wildfires on Energy Transportation Infrastructure

California's Energy Transportation Infrastructure

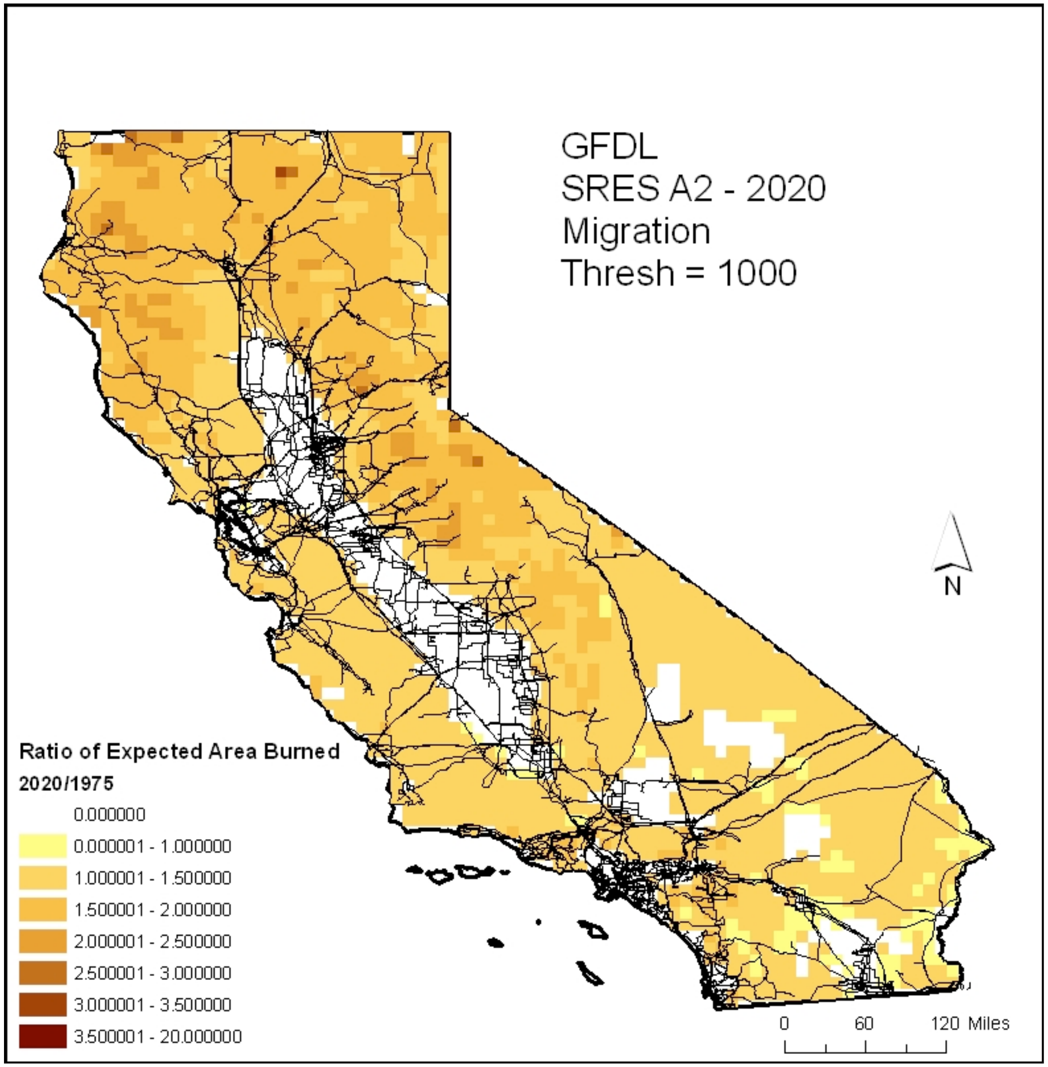


Source: CEC

GIS crossing of energy infrastructure with expected area burned scenarios:

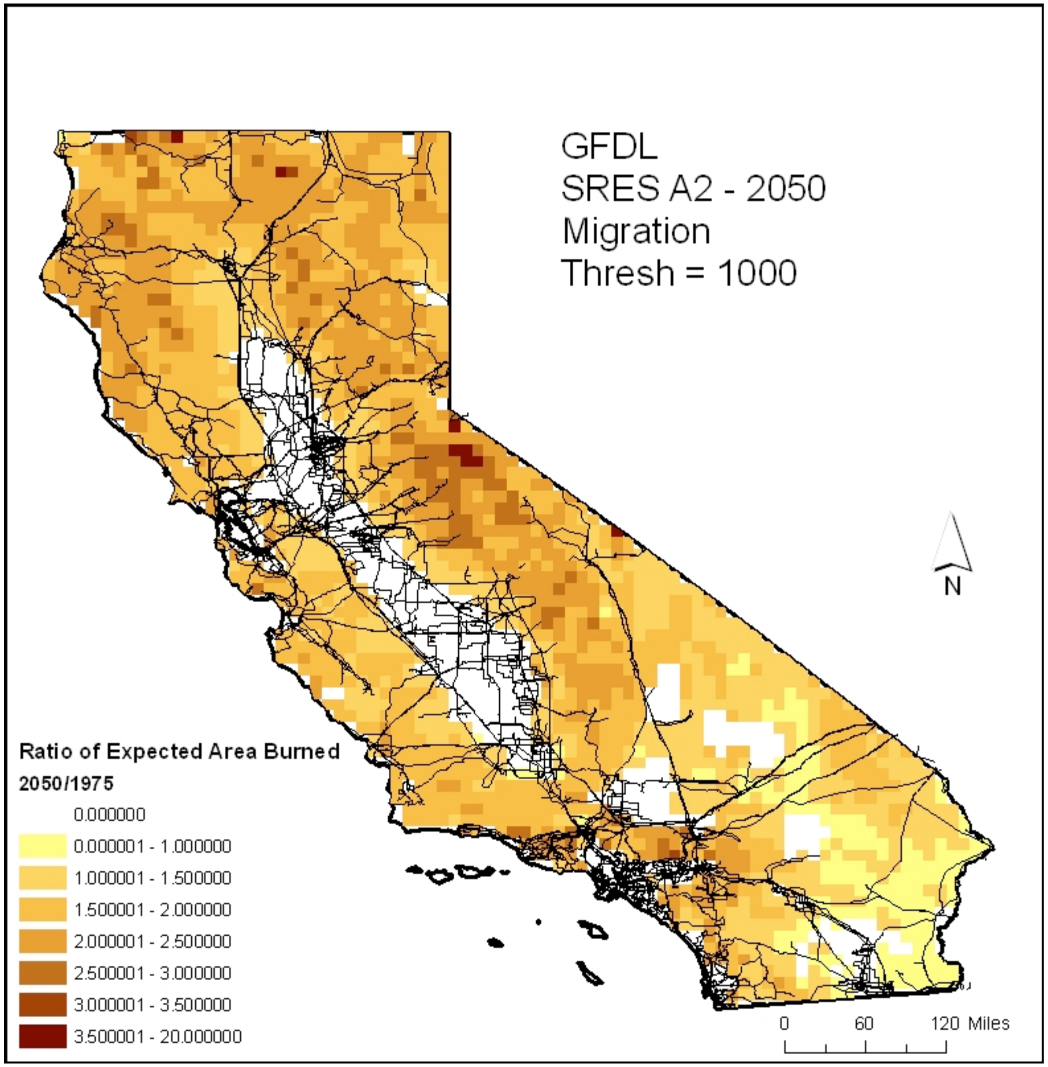
- **Transmission Lines**
- **Natural Gas Pipelines**
- **Oil Pipelines**

2020: Expected Area Burned vs. Transmission Lines (projection to baseline ratio)



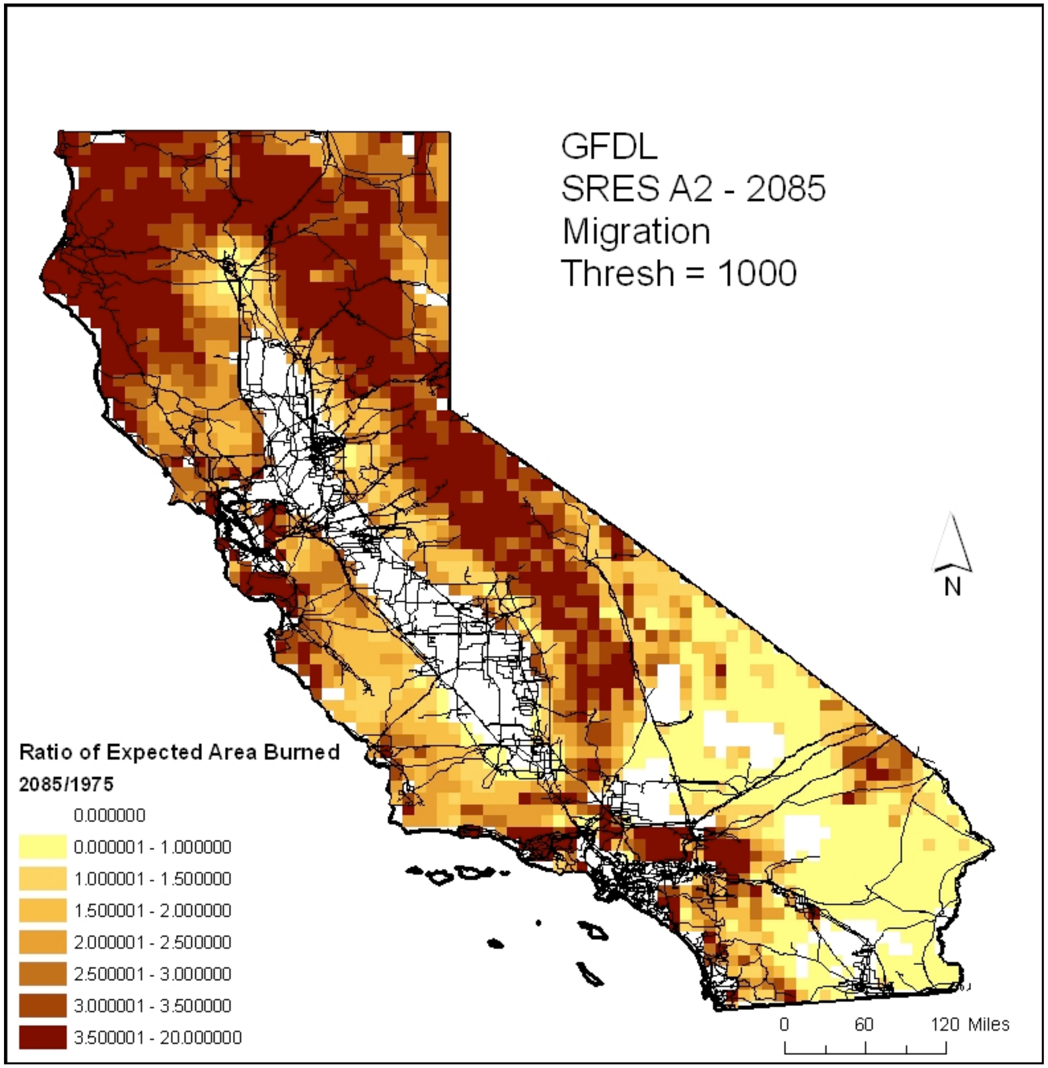
Source: A. Westerling

2050: Expected Area Burned vs. Transmission Lines (projection to baseline ratio)



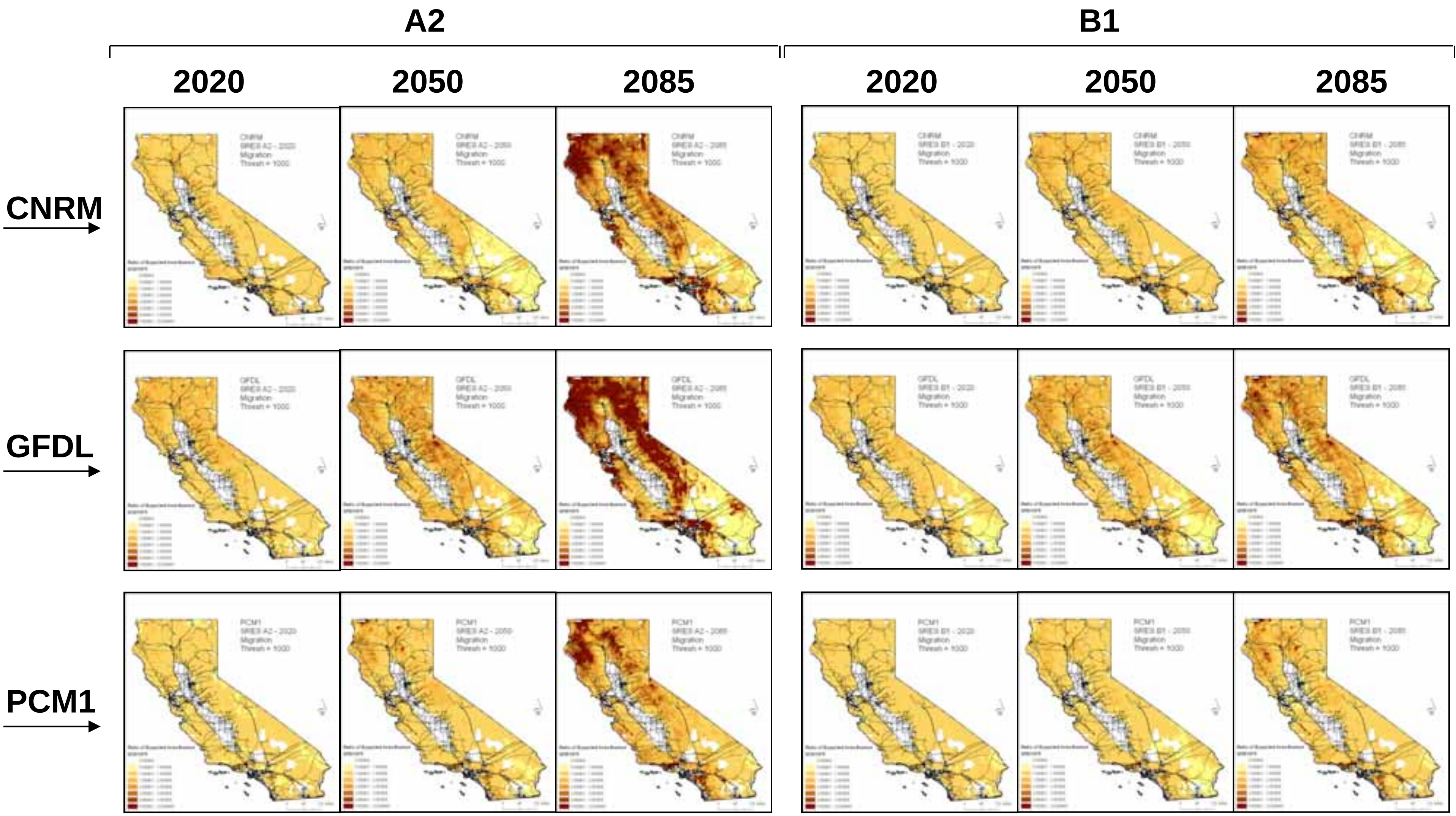
Source: A. Westerling

2085: Expected Area Burned vs. Transmission Lines (projection to baseline ratio)



Source: A. Westerling

Expected Area Burned vs. Transmission lines (projection to baseline ratio)



Source: A. Westerling

Expected Area Burned and Energy Infrastructure

- Based on the information provided by Professor Westerling:
  - By 2085, the greatest increase in fire activity may occur in northern California, Los Angeles, and in the Sierra Nevada;
  - Greater changes occur by the second half of the century;
  - SRES Scenario A2 is much more severe than B1, especially in the long term; and
  - GFDL model is the most pessimistic about future risk.

- Assuming uniformal distribution of fire at the subgrid level, we calculated the ***Expected Length of Lines Burned*** per year (disaggregated by line owner and type)

Length of Energy Transportation Infrastructure in Expected Burned Areas

(average km/year)

		Transmission Lines				Natural Gas Pipelines				Oil Pipelines			
GCM	**Scenario**	**1975**	**2020**	**2050**	**2085**	**1975**	**2020**	**2050**	**2085**	**1975**	**2020**	**2050**	**2085**
GFDL	**A2**	54.4	74.7	92.5	122.7	13.1	17.0	21.3	26.9	6.5	8.0	10.0	12.2
	B1	54.4	77.4	91.1	95.4	13.1	18.3	20.8	21.8	6.5	8.6	9.5	10.0
CNRM	**A2**	42.1	57.6	60.9	93.5	9.2	12.3	12.8	18.9	4.3	5.8	5.8	8.8
	B1	42.1	54.6	63.4	68.9	9.2	11.8	13.4	14.3	4.3	5.3	6.1	6.6
PCM1	**A2**	50.6	55.1	73.5	94.5	11.3	12.1	16.2	19.9	5.4	5.8	7.7	9.2
	B1	50.6	61.0	66.9	72.5	11.3	13.4	14.8	15.9	5.4	6.4	7.0	7.5

(ratio to baseline)

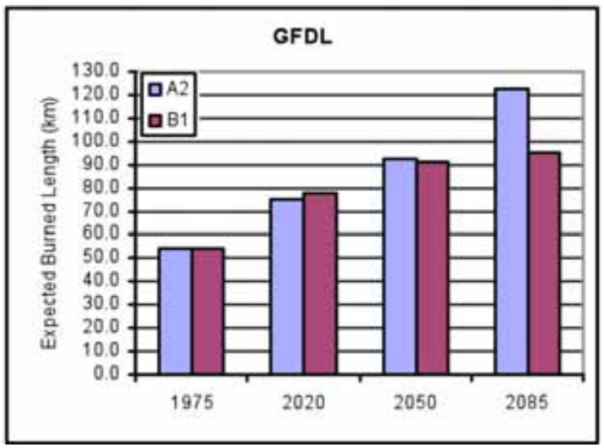
		Transmission Lines				Natural Gas Pipelines				Oil Pipelines			
GCM	**Scenario**	**1975**	**2020**	**2050**	**2085**	**1975**	**2020**	**2050**	**2085**	**1975**	**2020**	**2050**	**2085**
GFDL	**A2**	1.00	1.37	1.70	2.25	1.00	1.30	1.62	2.04	1.00	1.23	1.55	1.89
	B1	1.00	1.42	1.67	1.75	1.00	1.39	1.58	1.66	1.00	1.33	1.47	1.55
CNRM	**A2**	1.00	1.37	1.45	2.22	1.00	1.34	1.40	2.06	1.00	1.33	1.35	2.04
	B1	1.00	1.30	1.51	1.64	1.00	1.29	1.47	1.56	1.00	1.23	1.40	1.52
PCM1	**A2**	1.00	1.09	1.45	1.87	1.00	1.07	1.44	1.77	1.00	1.06	1.41	1.69
	B1	1.00	1.21	1.32	1.43	1.00	1.19	1.31	1.41	1.00	1.18	1.29	1.39

All columns are time periods.

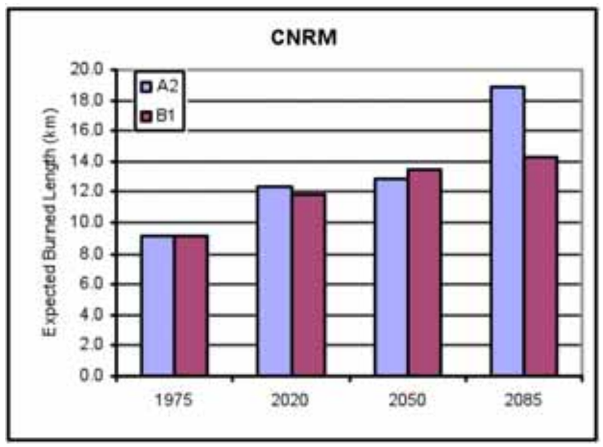
Sources: A. Westerling; CEC

Length of Energy Transportation Infrastructure in Expected Burned Areas (examples)

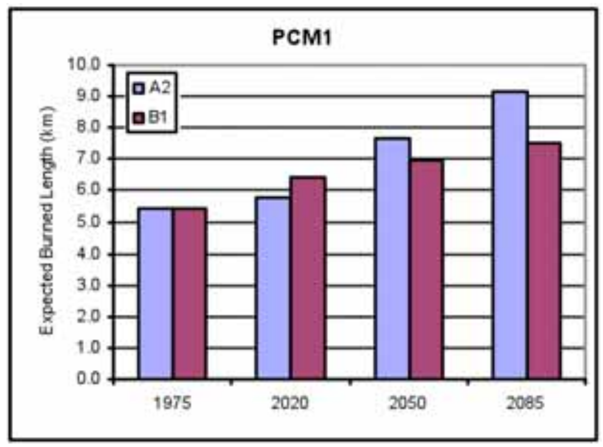
Transmission Lines



Natural Gas Pipelines

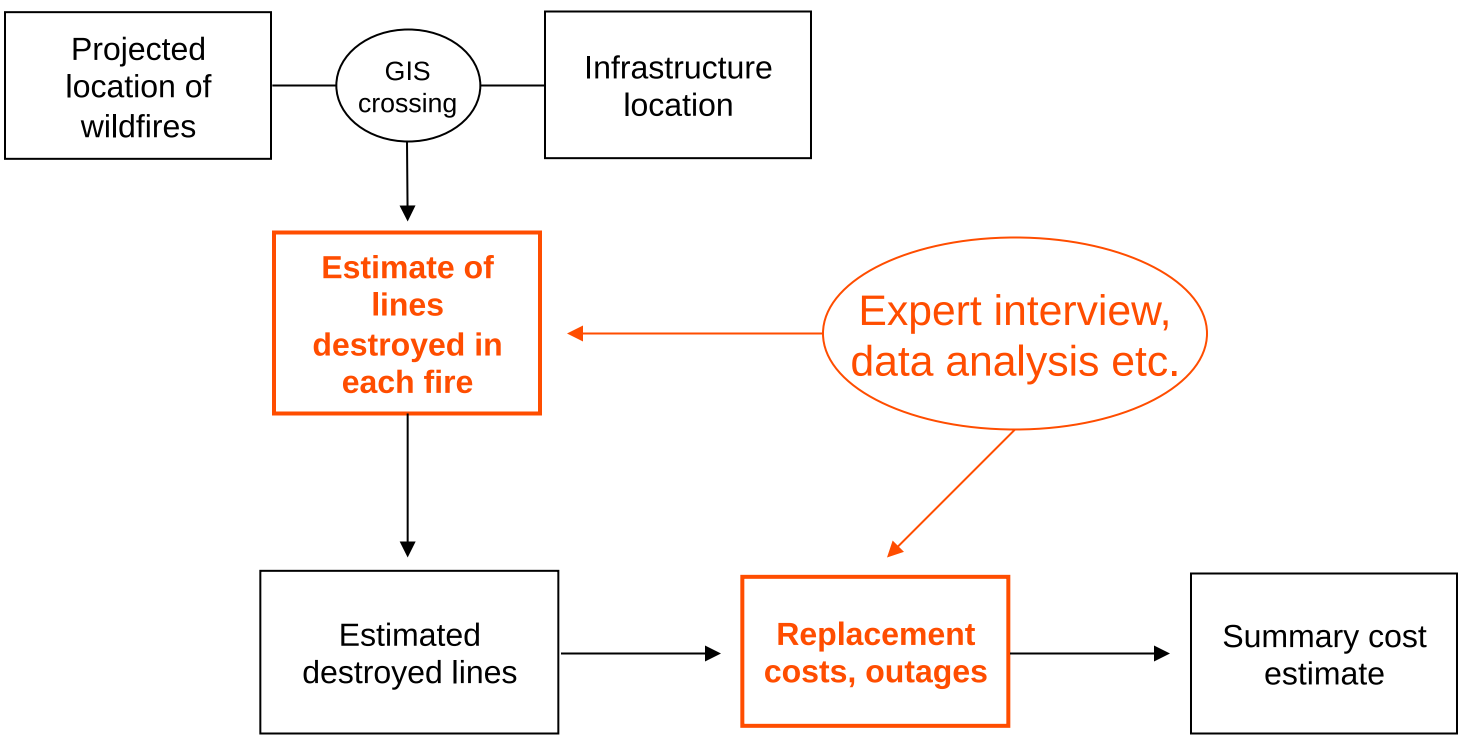


Oil Pipelines



Impacts of Increased Wildfire Activity on Transmission and Distribution Lines

- Similar methodology to Westerling and Bryant (2008)
  - Analyzed property damages due to wildfire



Next Steps on Estimating Fire Impacts

- Translate length of structure burned to structural damage (i.e., capital and maintenance costs).
- Need to gather historical information on past impacts of fire on transmission lines and pipelines:
  - Need more information about structural capital and maintenance impacts;
  - Need more information on costs and length of time of interrupted service; and
  - Identification of other key variables for impact assessment.

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Questions?