Identifying Threats, Predicting Vulnerabilities, and Assessing the Risks

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Resilience Training for States – Western Region

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Presentation Outline

Uncertainty, Risks, and Vulnerability

- Introduction to Uncertainty & Risk
- Integrating Threat Information into Risk-Based Assessments
- Assessing Infrastructure Vulnerability

Climate Change Impacts

- Climate Science & Modeling 101
- Climate Impact Data Resources

Wrapping Up

- Questions to Ask

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Uncertainty, Risks, and Vulnerability

Introduction to Uncertainty & Risk

Uncertainty

"…any departure from the unachievable ideal of complete determinism."
Walker et al. (2003)

- Randomness in events (aleatoric uncertainty)
- Limited knowledge (epistemic uncertainty)



Images: unsplash.com

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Introduction to Uncertainty & Risk

Risk

- Historical definition:

  …derives from random adverse events with probabilities of occurrence that can be statistically calculated.
  ~Knight, 1921 (paraphrased)

  - This suggests that risk can be viewed as a subset of uncertainty that can be quantified by statistical probability

- Modern definition:

  "…a measure of the probability and severity of adverse effects" from some event.
  ~Lowrance,1976, in Haimes, 2004

  - Risk is a function of (1) the likelihood (i.e., probability) of an event's occurrence, and (2) the consequences of that event.

Introduction to Uncertainty & Risk

- Quantitative approaches to risk & uncertainty
  - Risk = Likelihood X Consequence
  - Easiest to do when likelihood can be statistically quantified…
  - …and/or consequences can be quantified
    - E.g., Risk = 10% probability X $1M in losses
  - Frequently incorporated into engineering design standards
- Qualitative approaches to risk & uncertainty
  - Risk matrices
  - Scenario analysis (can also be used in quantitative analysis)

		Impact			
		Catastrophic	Major	Moderate	Minor
Likelihood	Very Likely	High	High	Med	Med
	Likely	High	High	Med	Low
	Medium	High	Med	Med	Low
	Unlikely	Med	Med	Low	Low
	Very Unlikely	Med	Med	Low	Low

Source: (MacArthur et al. 2012)

Functional Classification	Allowable Backwater, Annual EP	Roadway Serviceability, Annual EP	Service-ability Freeboard *	Bridge, Allowable Velocity, Annual EP	Culvert, Allowable Velocity, Annual EP
Freeway	1%	1%	2 ft	1%	2%
Ramp	1%	1%	0 ft	1%	2%
Non-Freeway, 4 or More Lanes	1%	1%	2 ft	1%	2%
Two-Lane Facility, AADT > 3000	1%	1%	1 ft	1%	2%
Two-Lane Facility, 1000 < AADT ≤ 3000	1%	4%	0 ft	1%	4%
Two-Lane Facility, AADT ≤ 1000	1%	10%	0 ft	1%	10%
Drive	1%	10%	0 ft	1%	10%

* Required serviceability freeboard is based on the difference between the edge-of-pavement and the structure-headwater elevations throughout the floodplain or watershed. Roadway serviceability should consider backwater effects from a larger downstream waterway.

DESIGN-STORM FREQUENCY FOR BRIDGE OR CULVERT

Source: (Indiana Department of Transportation, 2013

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Introduction to Uncertainty & Risk

Systematically Thinking About Risk

- ISO 31000:2018 – “Risk Management – Guidelines”
- Risk Assessment
  1. Risk Identification – Find, recognize and describe risks
  2. Risk Analysis – Model, quantify, measure level of risk
  3. Risk Evaluation – Prioritize; compare with the established risk criteria to determine what actions, if any at all

Image: https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en

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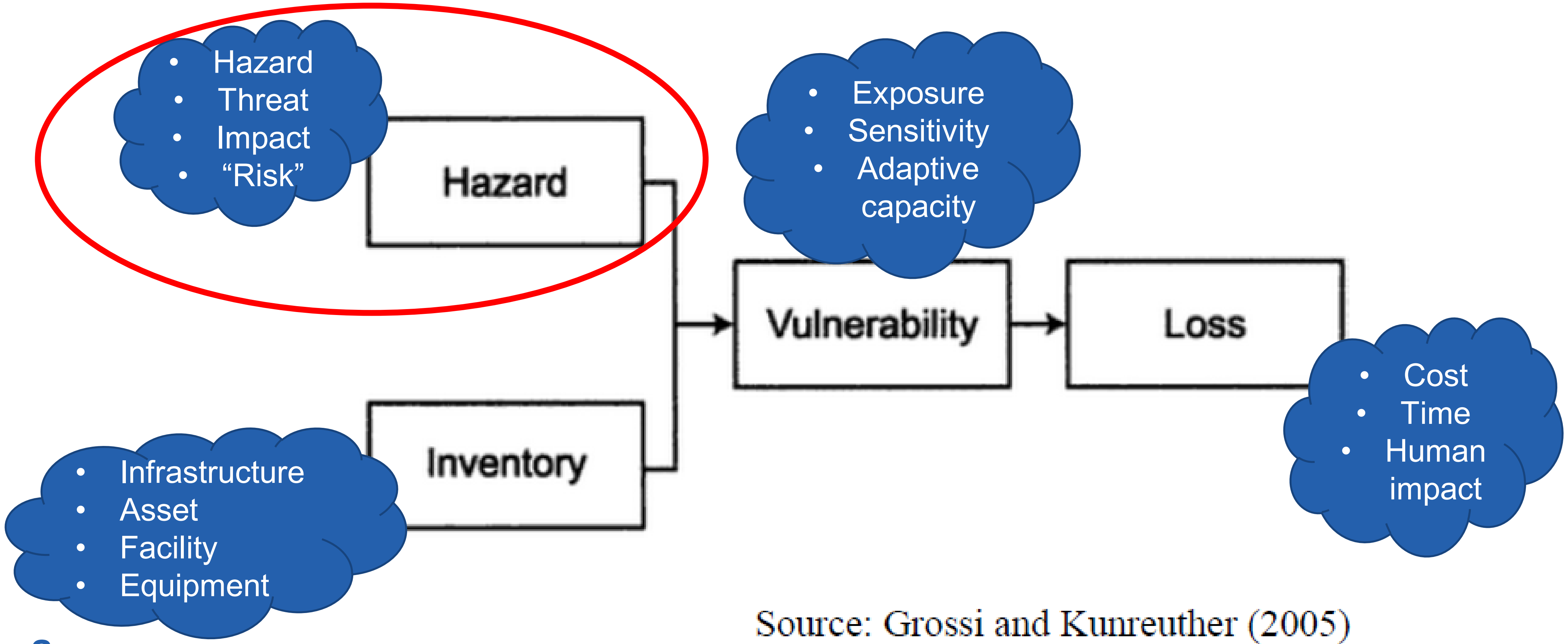
Integrating Threat Information into Risk-Based Assessments (1)

Infrastructure Risk – Catastrophe Model

- How does threat and hazard information fit into the construct of risk?



Source: Grossi and Kunreuther (2005)

Integrating Threat Information into Risk-Based Assessments (2)

Probabilistic vs. Deterministic Hazard Information

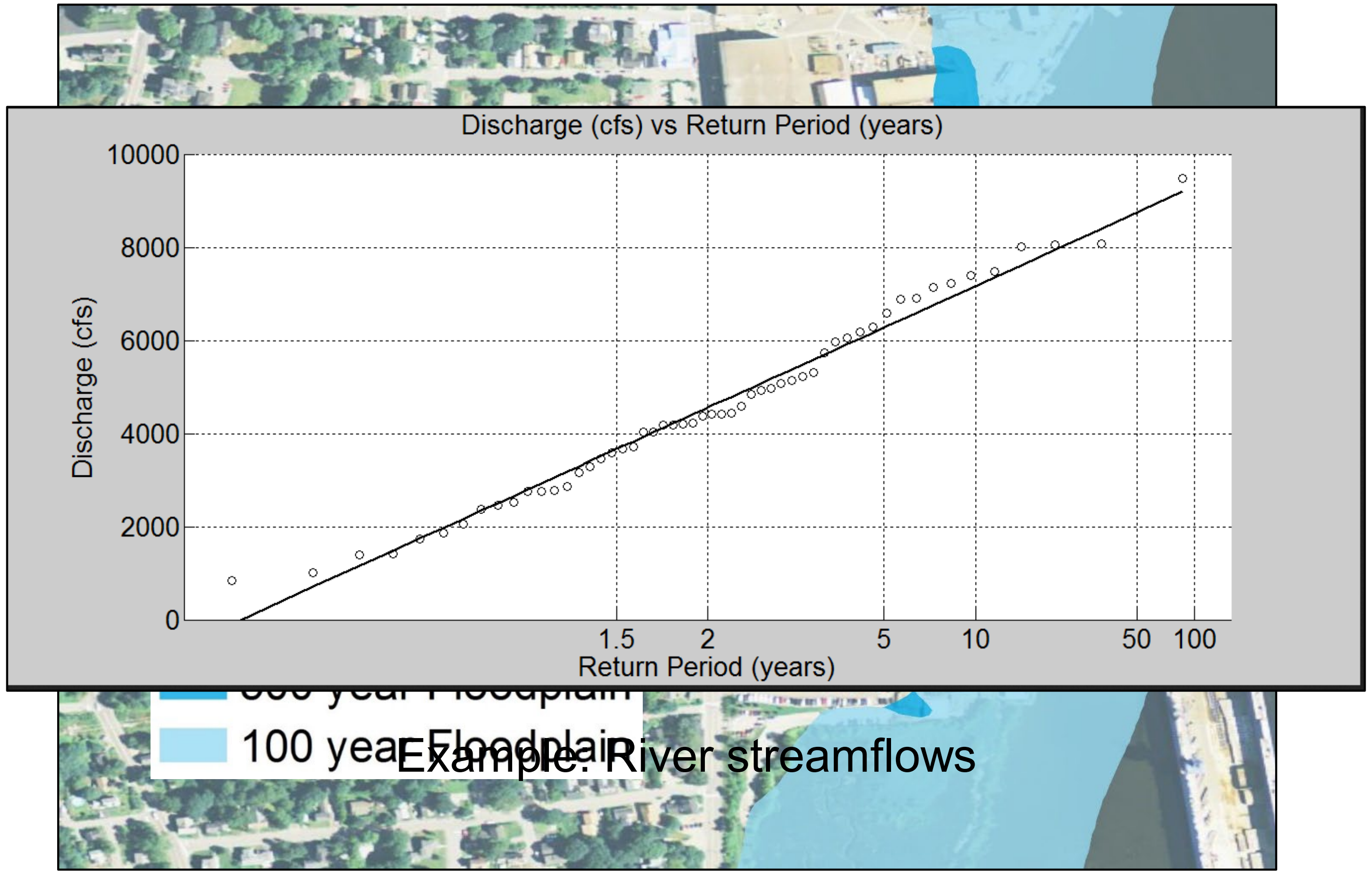
- Likelihood or probability based threat information
- Deterministic/scenario-based threat information

Example

Probability: Return intervals (e.g., flooding, storms, etc.)

$$T = N/n$$

Recurrence interval (**T**) is the number of years in record (**N**), divided by number of events (**n**)



Example: River streamflows

Image: https://serc.carleton.edu/hydromodules/steps/168500.html; Argonne National Laboratory

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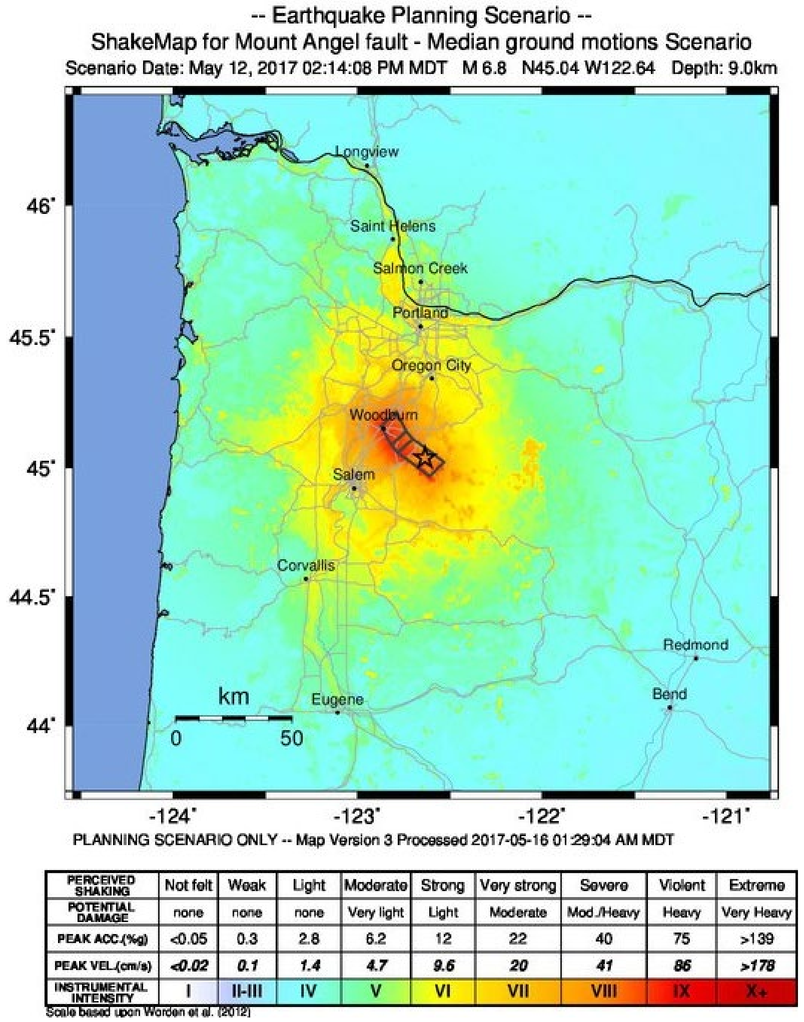
Integrating Threat Information into Risk-Based Assessments (3)

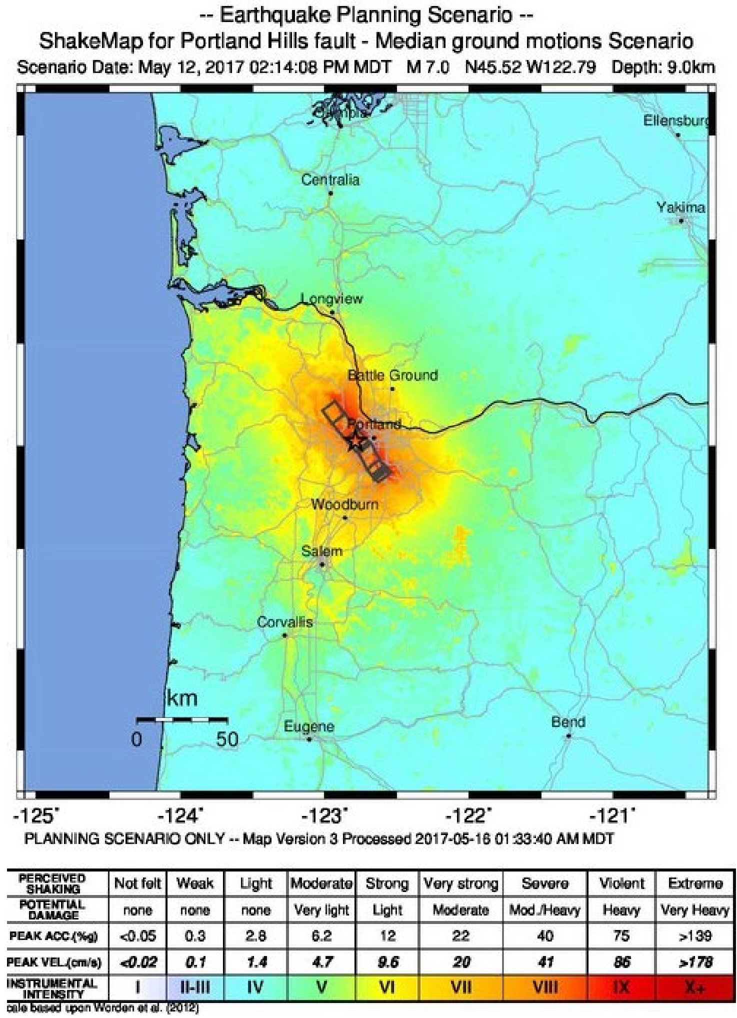
Probabilistic vs. Deterministic Hazard Information

- Likelihood or probability based threat information
- Deterministic/scenario-based threat information

Example

Scenario: Earthquake planning scenarios





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Images: https://earthquake.usgs.gov/scenarios/eventpage/bssc2014877_m7p05_se/executive; https://earthquake.usgs.gov/scenarios/eventpage/bssc2014873_m6p8_se/executive

Integrating Threat Information into Risk-Based Assessments (4)

Probabilistic vs. Deterministic Hazard Information

- Likelihood or probability based threat information
- Deterministic/scenario-based threat information

Hybrid Approach – Ensemble Scenarios

- Key feature of techniques like Robust Decisionmaking (RDM)
- Examining large numbers of scenarios moves ***toward*** a more comprehensive characterization of hazard impacts, or risk

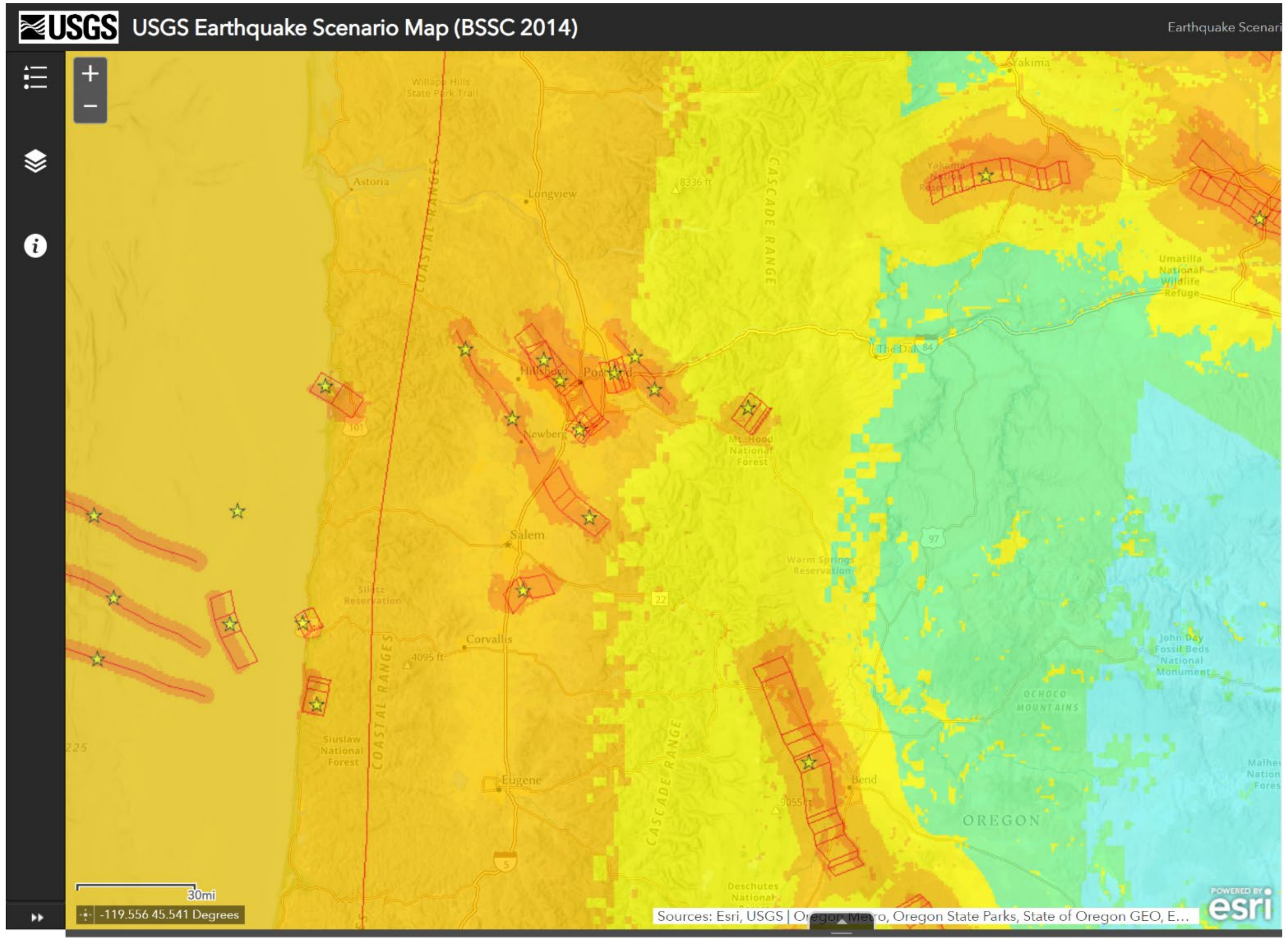

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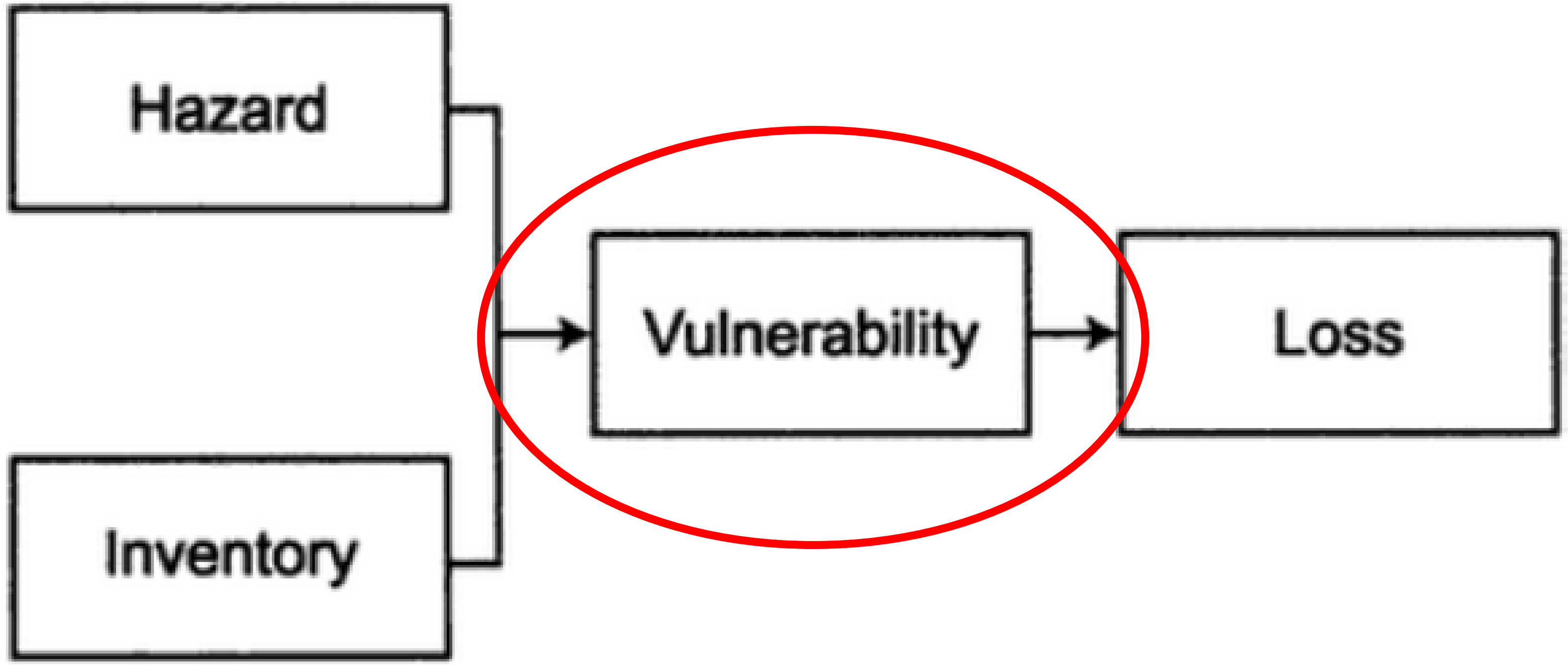
Image: https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=14d2f75c7c4f4619936dac0d14e1e468

Assessing Infrastructure Vulnerability

The Importance of Place-Based Information & Data



Source: Grossi and Kunreuther (2005)

Assessing Infrastructure Vulnerability

The Importance of Place-Based Information & Data

- UN Intergovernmental Panel on Climate Change (IPCC) definition of vulnerability

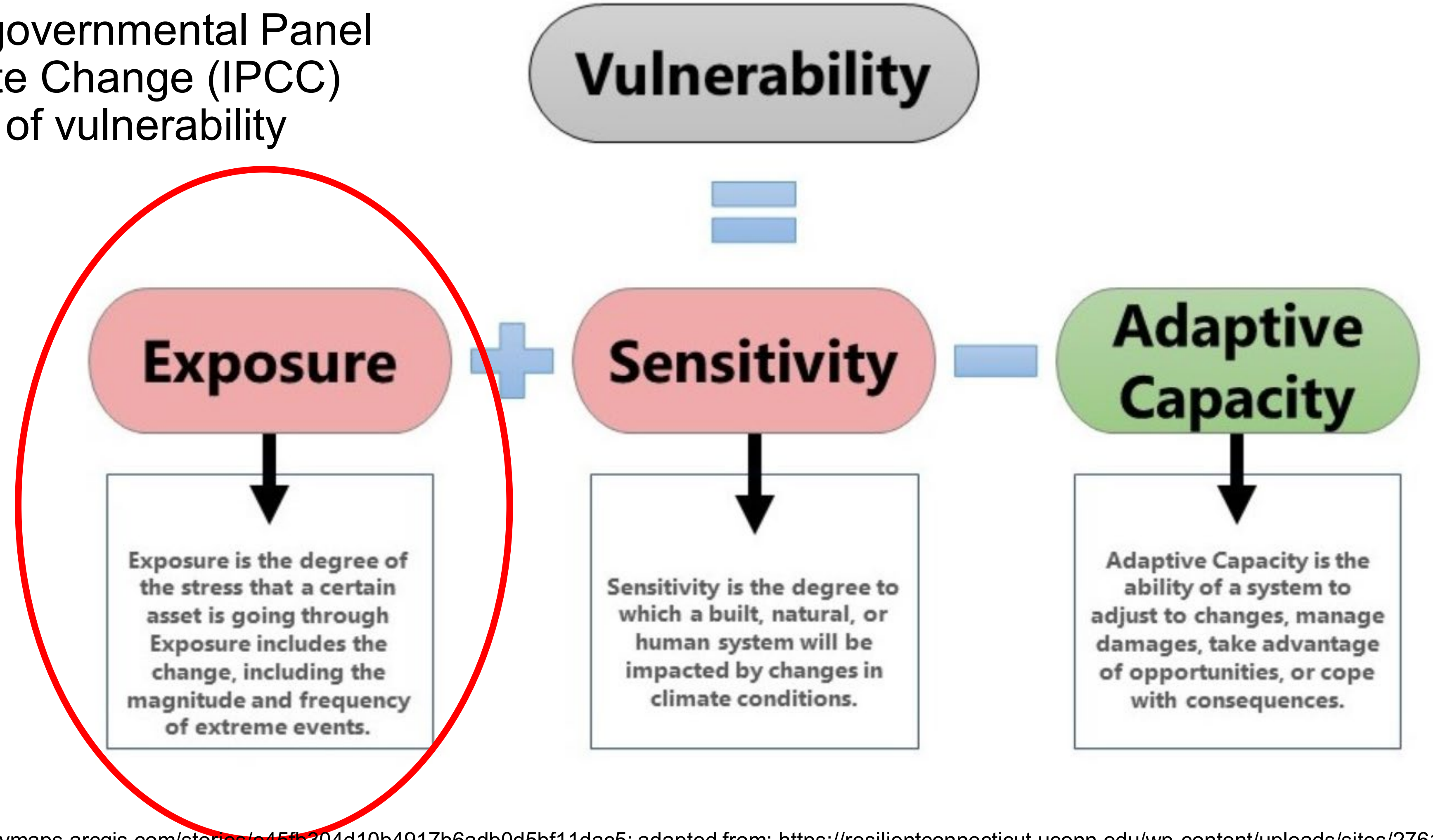


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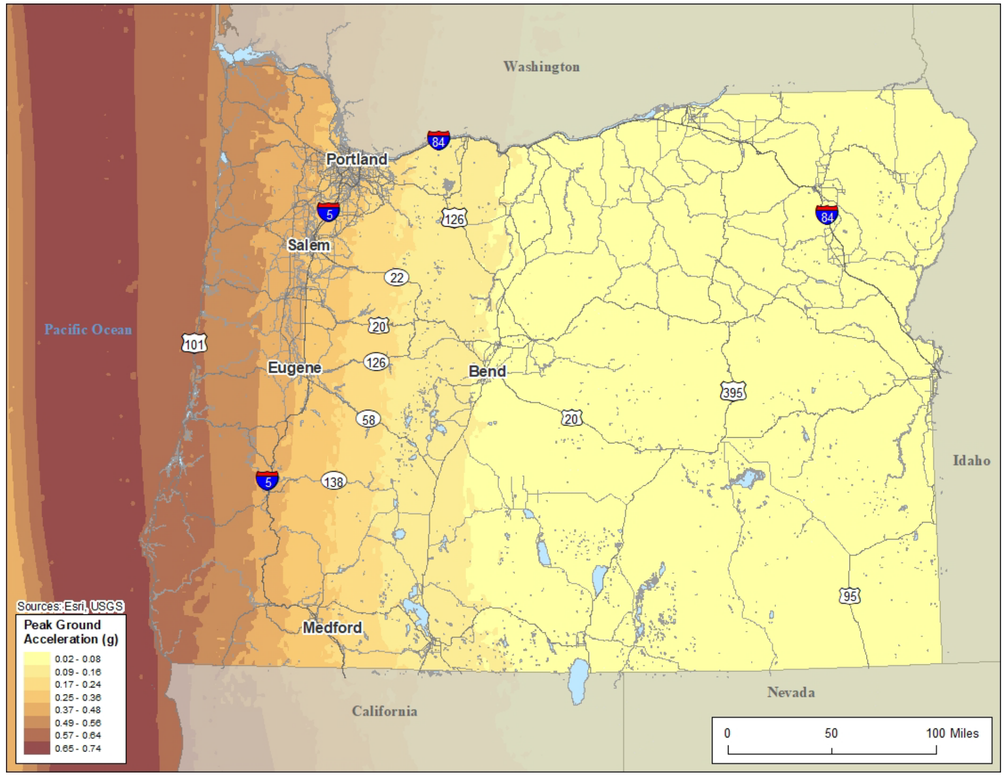
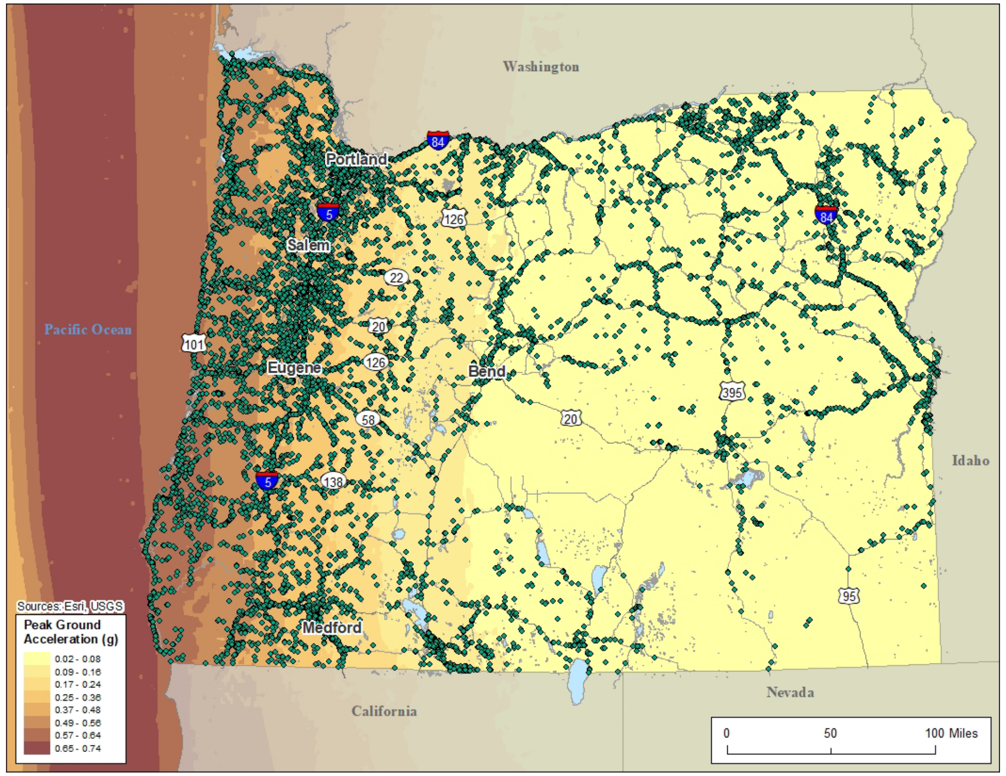
Image: https://storymaps.arcgis.com/stories/e45fb304d10b4917b6adb0d5bf11dac5; adapted from: https://resilientconnecticut.uconn.edu/wp-content/uploads/sites/2761/2021/10/CCVI-Fact-Sheet-2.pdf

Assessing Infrastructure Vulnerability

The Important Role of GIS and Mapping Tools

- Exposure: the ***degree*** to which an asset or facility will be subjected to a certain type of hazard, threat or impact
- Hazard severity is extremely place-based, and depending on the type of hazard, may vary widely across regions





Images: Argonne National Laboratory

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Assessing Infrastructure Vulnerability

The Important Role of GIS and Mapping Tools

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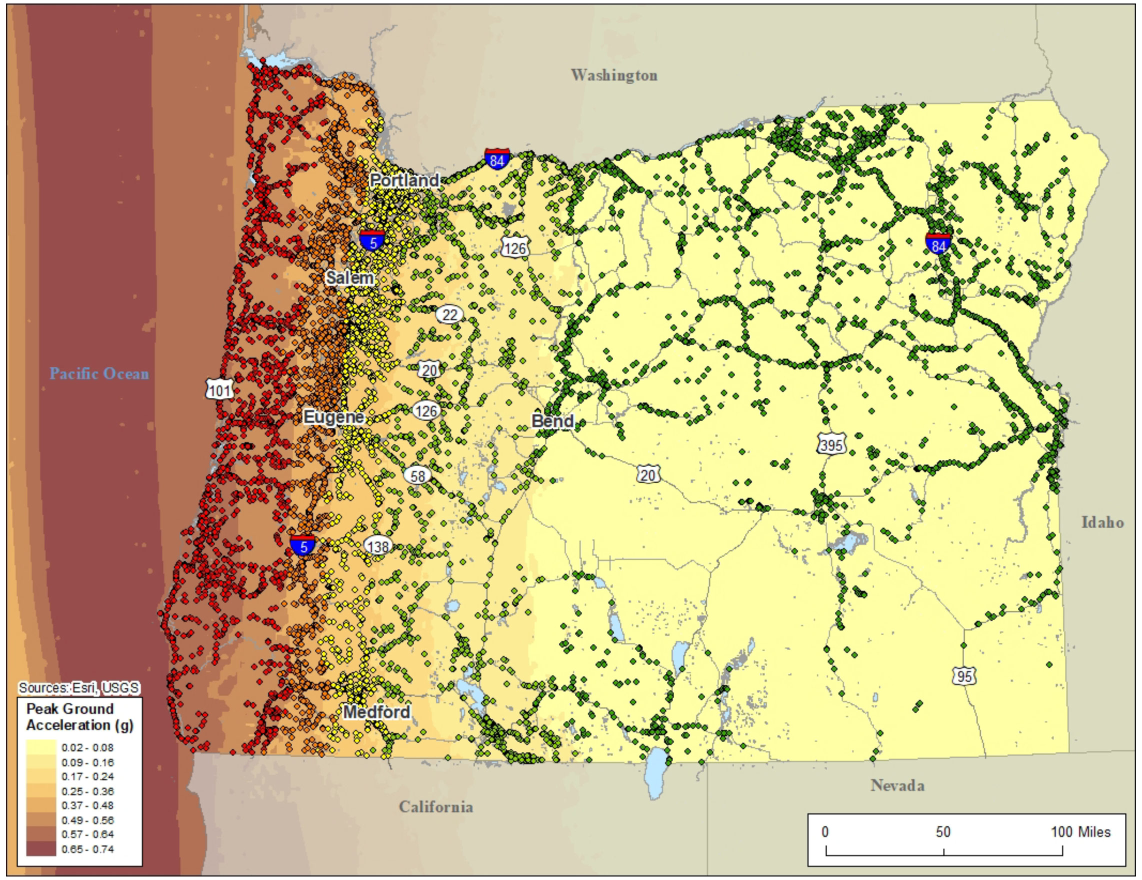


Images: Argonne National Laboratory

- Recall: Per ISO31000:2018, *risk analysis* concerns modeling, quantifying, or measuring level of risk

Assessing Infrastructure Vulnerability

Infrastructure Sensitivity Information

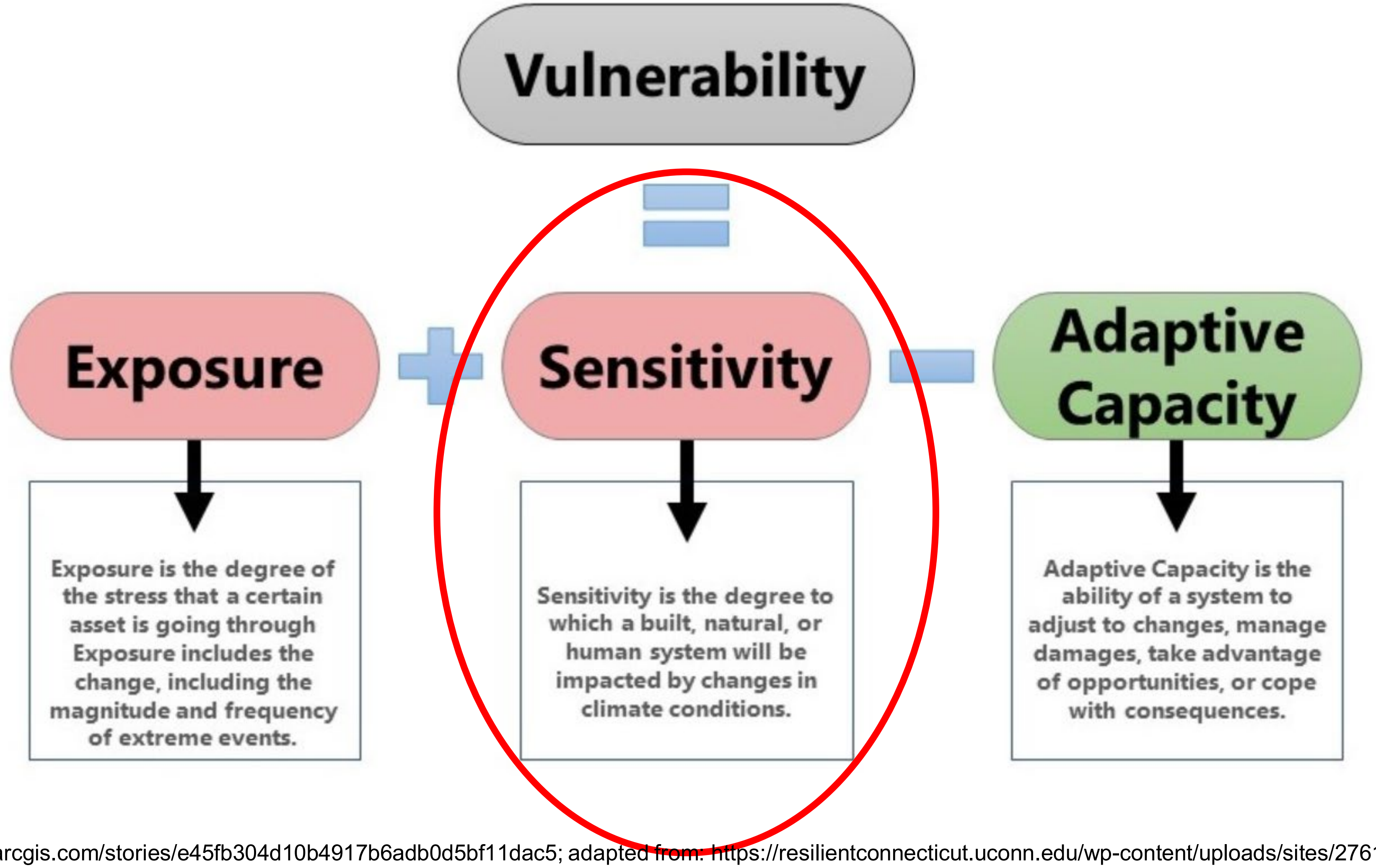


Image: https://storymaps.arcgis.com/stories/e45fb304d10b4917b6adb0d5bf11dac5; adapted from: https://resilientconnecticut.uconn.edu/wp-content/uploads/sites/2761/2021/10/CCVI-Fact-Sheet-2.pdf

Assessing Infrastructure Vulnerability

Infrastructure Sensitivity Information

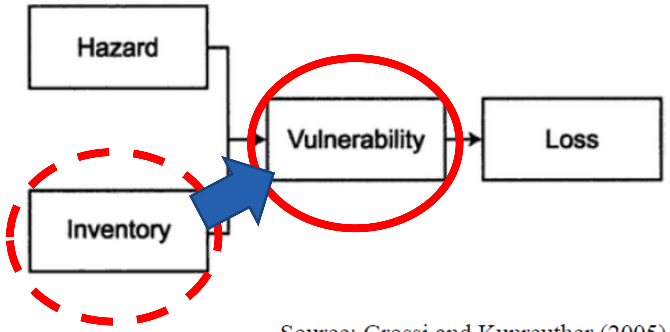
- Sensitivity: the ***degree*** to which built, natural, or human systems will be affected by a change or impact
- Not all assets or facilities, even if they are co-located, will be equally affected by an impact

Image: http://hyperphysics.phy-astr.gsu.edu/Nave-html/S09/flood.html

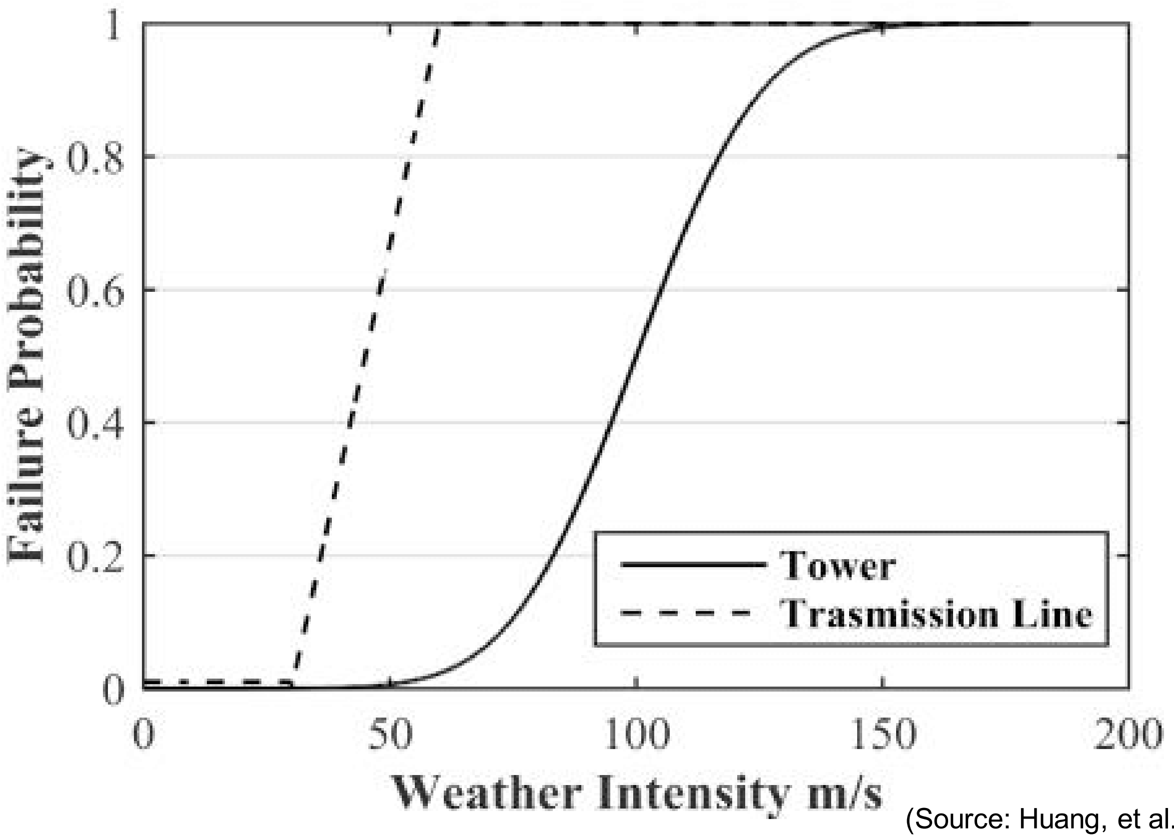
Assessing Infrastructure Vulnerability

Infrastructure Sensitivity Information

- Sensitivity: the ***degree*** to which built, natural, or human systems will be affected by a change or impact
- Not all assets or facilities, even if they are co-located, will be equally affected by an impact
- Fragility curves or response curves are a commonly used way to assess asset sensitivity to an impact



Source: Grossi and Kunreuther (2005)



(Source: Huang, et al. 2018)

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Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity

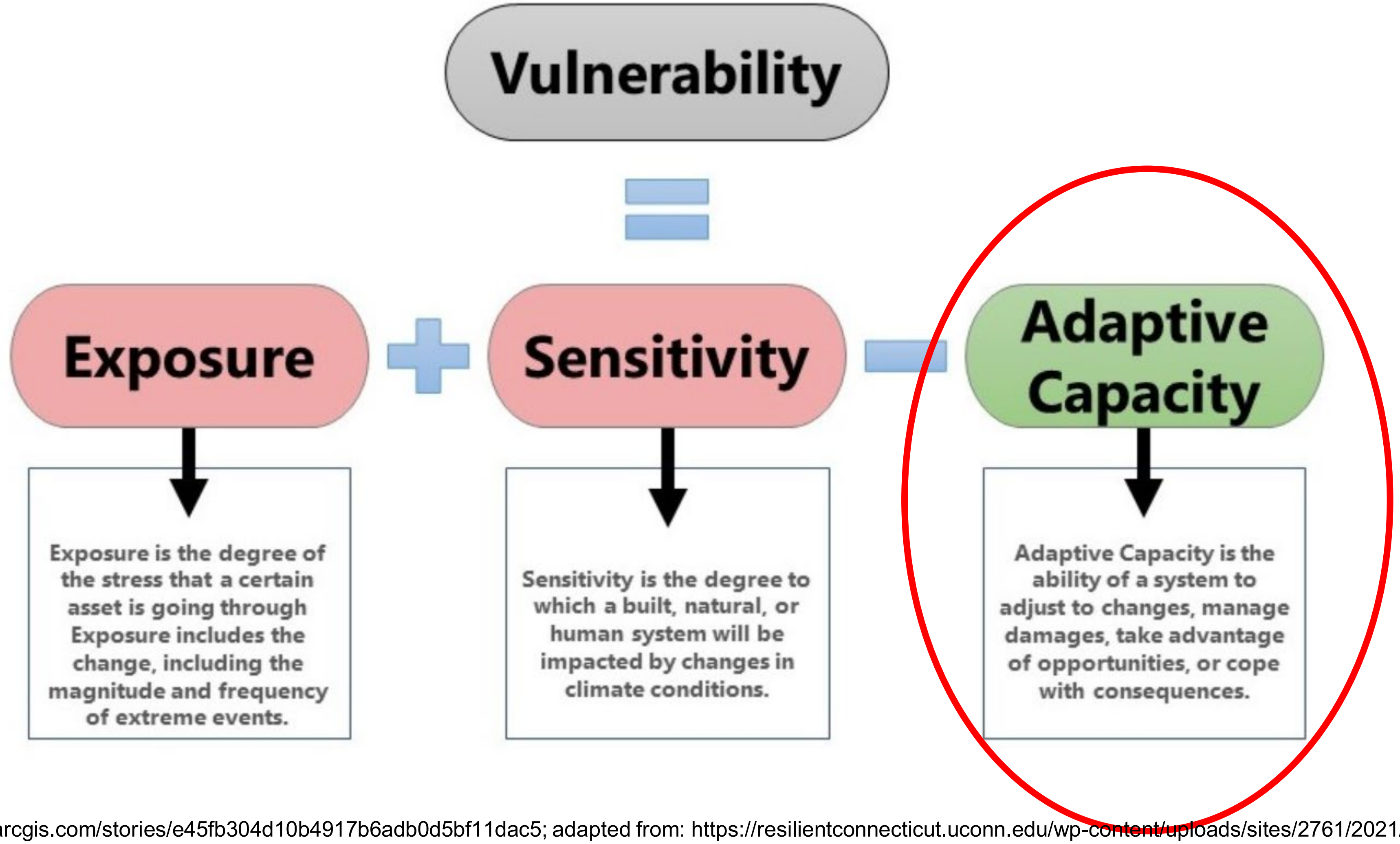

Image: https://storymaps.arcgis.com/stories/e45fb304d10b4917b6adb0d5bf11dac5; adapted from: https://resilientconnecticut.uconn.edu/wp-content/uploads/sites/2761/2021/10/CCVI-Fact-Sheet-2.pdf

Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity

- Adaptive Capacity: the ***ability*** of a system to adjust to changes, manage damages, take advantage of opportunities, or cope with consequences

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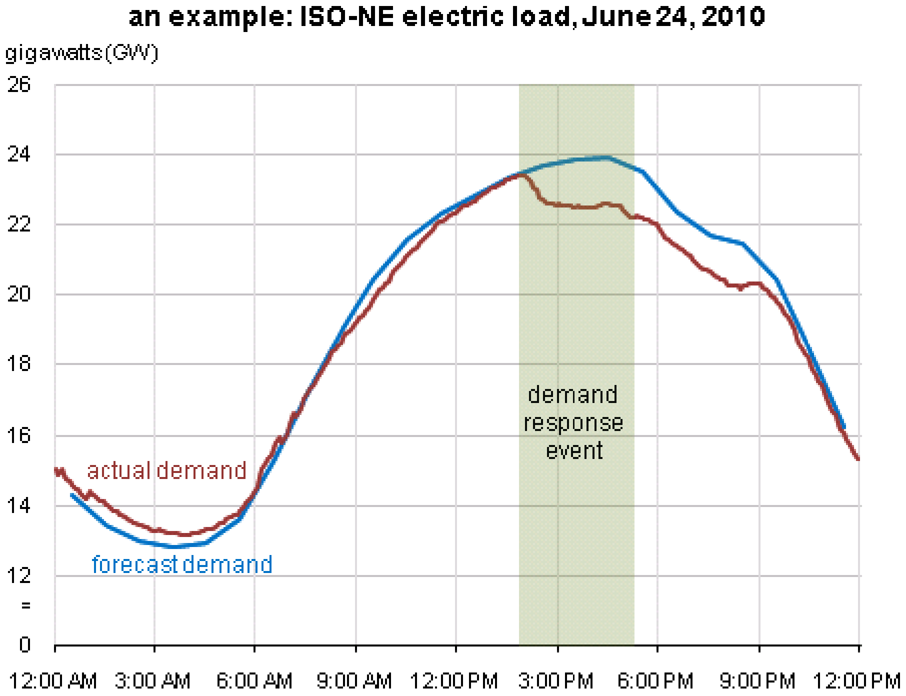
Images: https://en.wikipedia.org/wiki/Ponte_Milvio; https://en.wikipedia.org/wiki/Puente_Romano

Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity

- Adaptive Capacity: the ***ability*** of a system to adjust to changes, manage damages, take advantage of opportunities, or cope with consequences
- This is not exclusively an engineering challenge/solution; concerns operations, emergency response, others solutions



Images: Unsplash; https://www.eia.gov/todayinenergy/detail.php?id=130

Assessing Infrastructure Vulnerability

Thinking About Vulnerability and Risk through the Lens of Resiliency

RESILIENCE

The ability to **prepare** for and **adapt** to changing conditions and **withstand** and **recover** rapidly from disruptions.

Source: The White House, PPD-21

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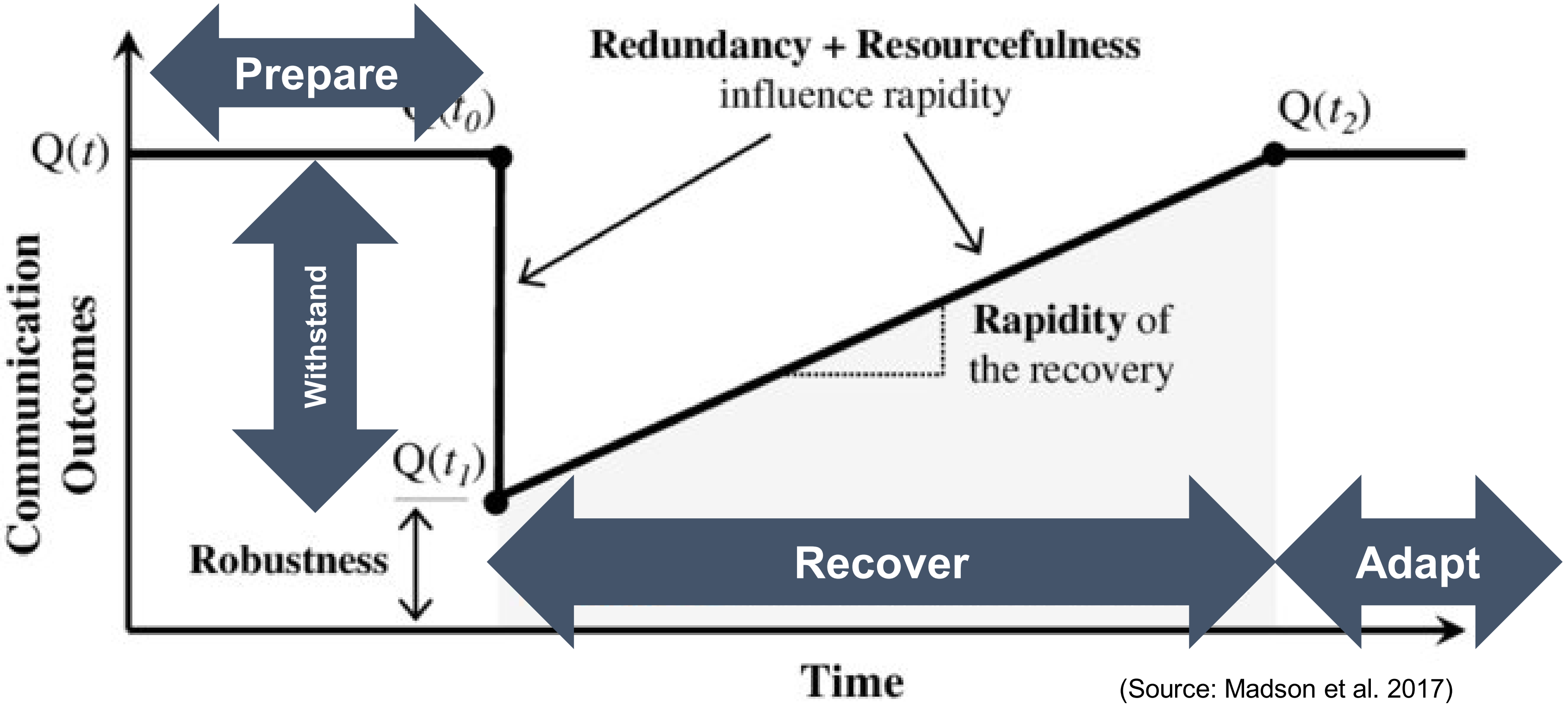
Assessing Infrastructure Vulnerability

Thinking About Vulnerability and Risk through the Lens of Resiliency

Resilience Elements

1. Prepare
2. Adapt
3. Withstand
4. Recover



(Source: Madson et al. 2017)

- Recall: Per ISO31000:2018, *risk evaluation* determining if/what actions
- Nichole Hanus will cover some of this in her talk later today

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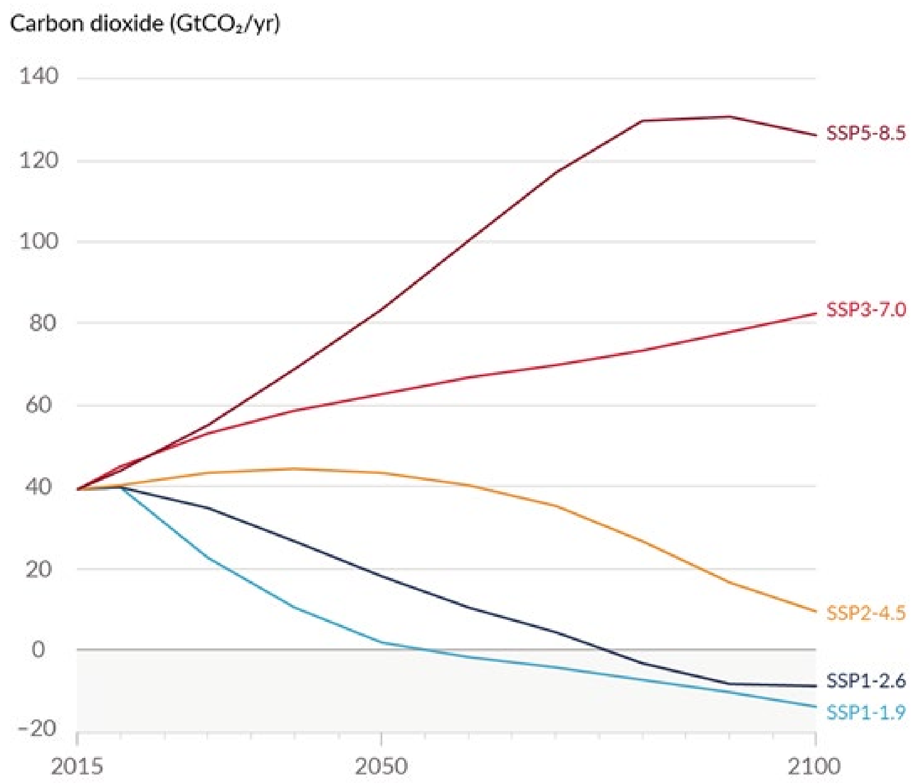
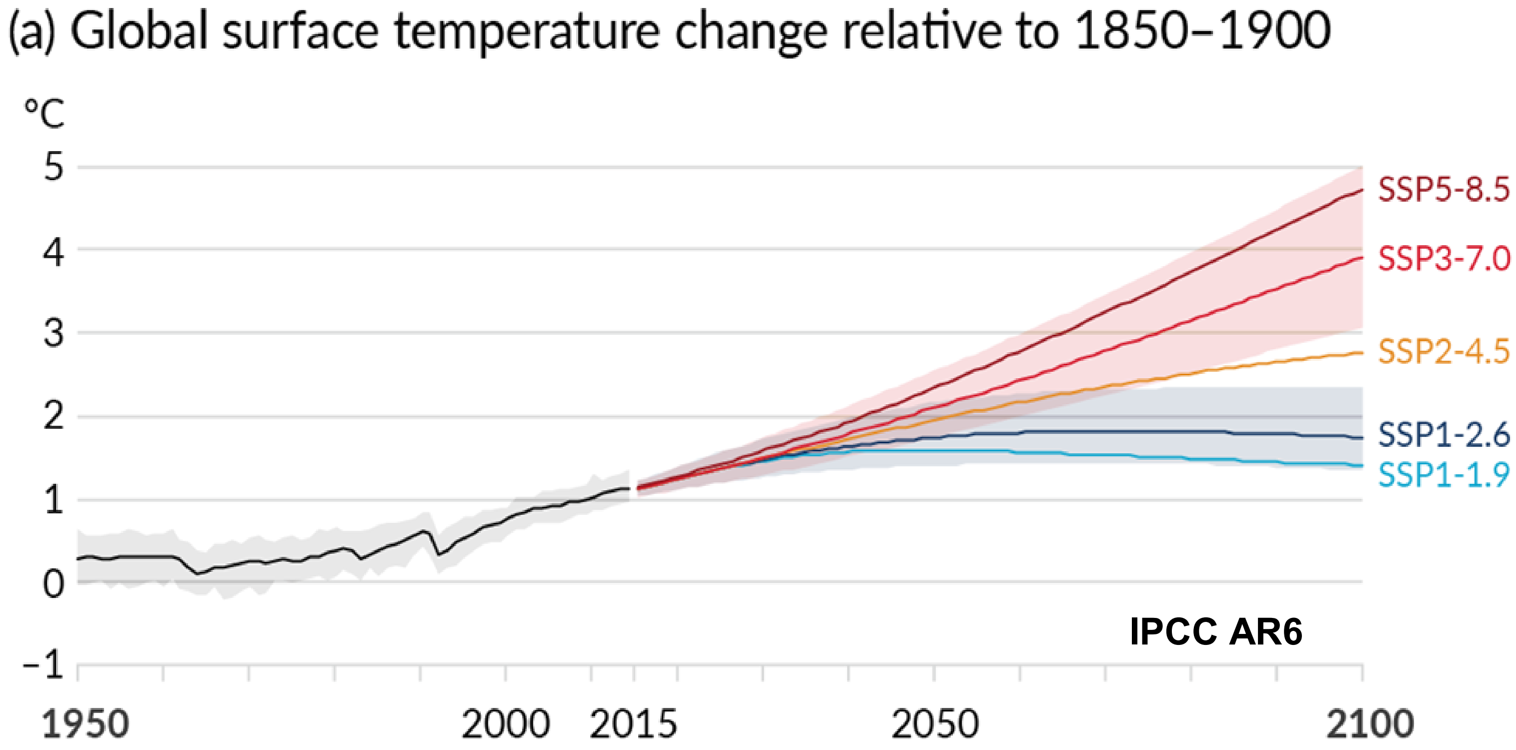
Climate Change Impacts

Climate Science & Modeling 101

Greenhouse Gas (GHG) Emission Scenarios

- Plausible future scenarios for atmospheric greenhouse gas concentrations, and the pathways to get there
  - Current Generation: Shared Socioeconomic Pathway (SSP)
  - Prior Generation: Representative Concentration Pathway (RCP)
- No probabilistic likelihood is assigned to any individual scenario



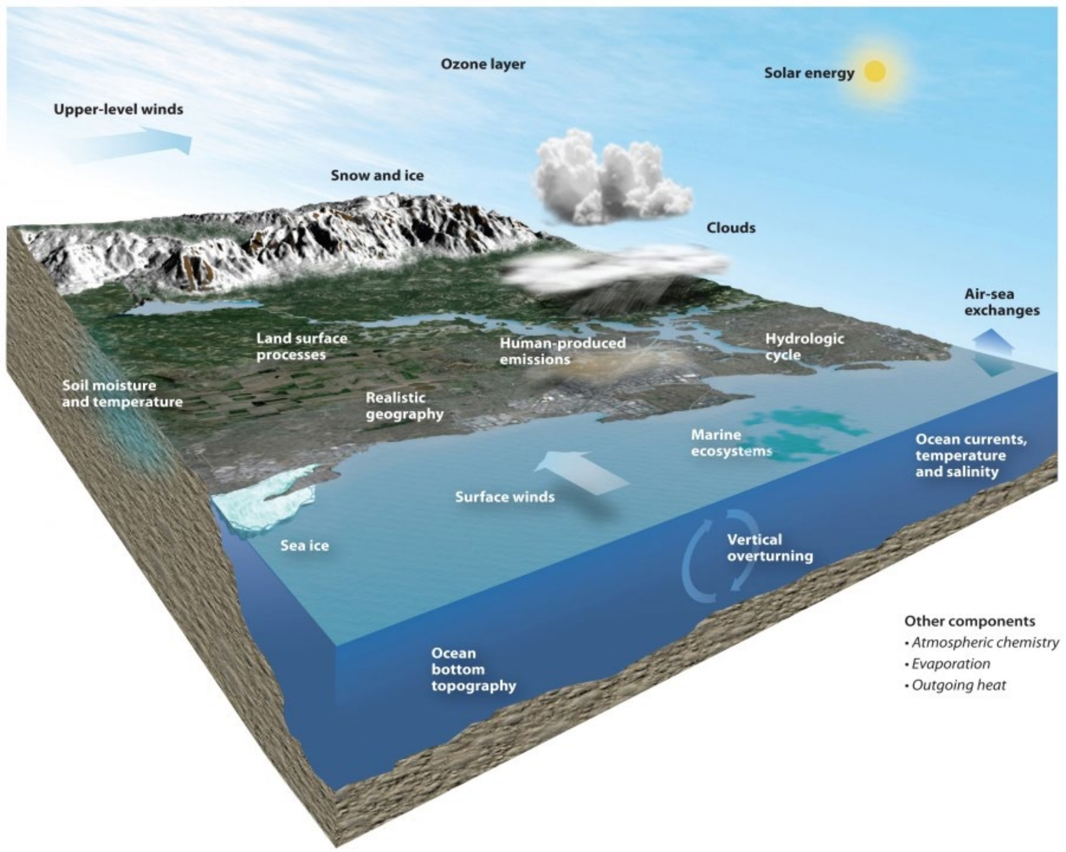


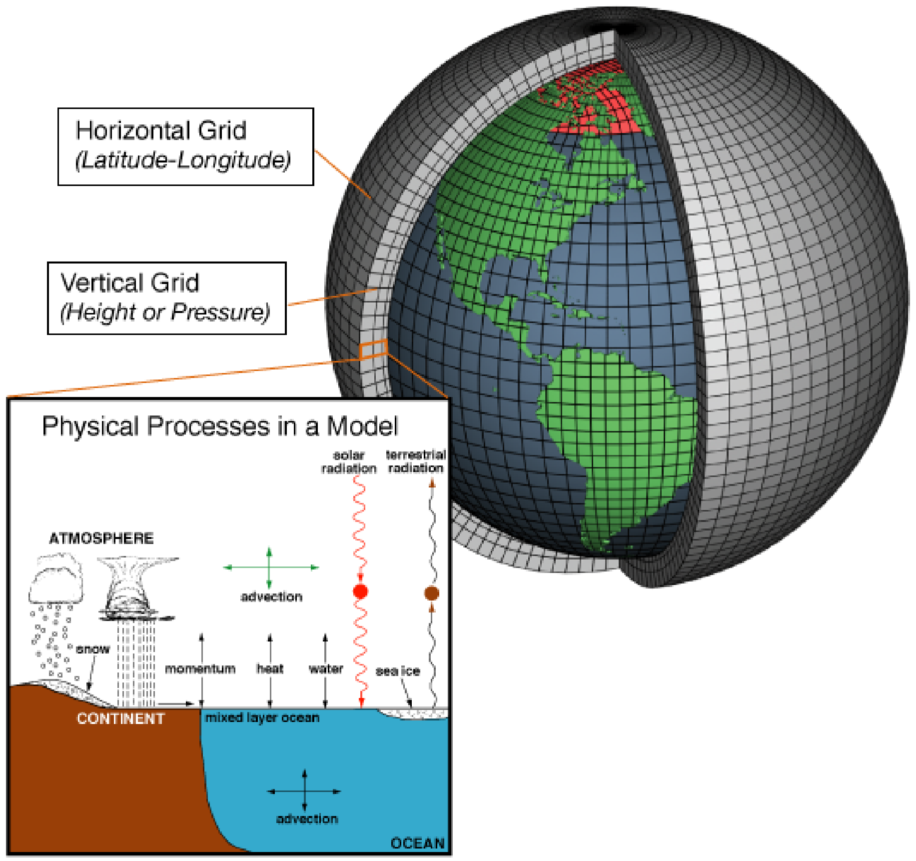
Images: https://www.ipcc.ch/report/ar6/wg1/figures/summary-for-policymakers

Climate Science & Modeling 101

Global Climate Models

Mathematical representations of the climate system based on physical laws and understanding of processes





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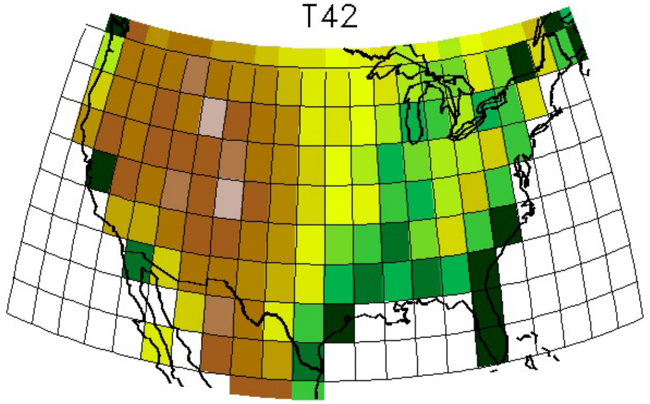
Images: https://scied.ucar.edu/image/community-earth-system-model; https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-models

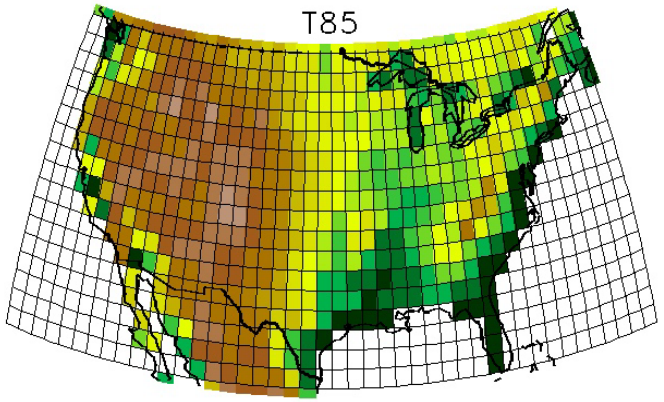
Climate Science & Modeling 101

Global Climate Models

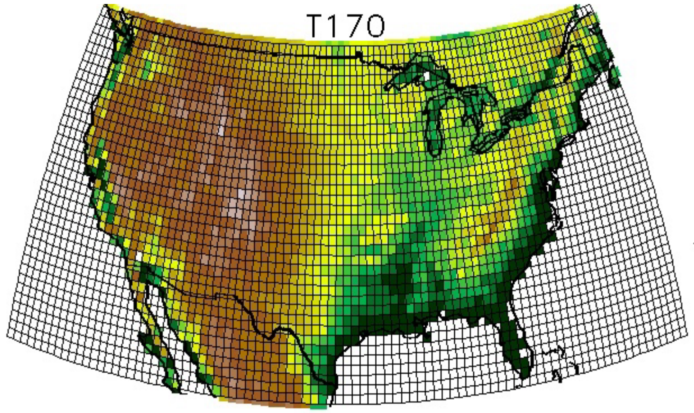
- As computing resources have improved over time, models have become increasingly complex and more detailed
- Smaller grid squares or “pixel sizes” enable more place-specific and detailed projections of locally relevant climate



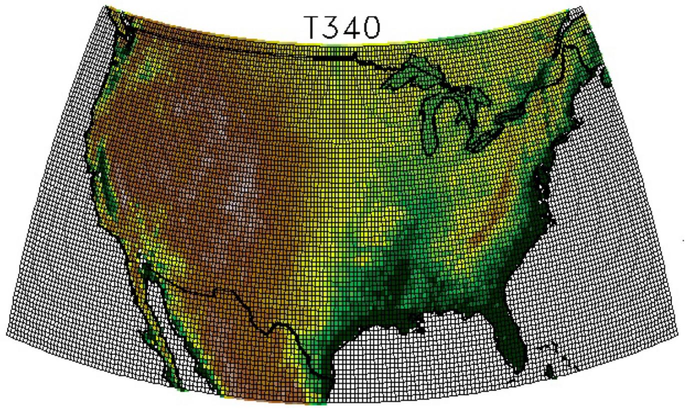
Mid-1990s 200~300 kms



2000s 100~150 kms



Current 50~100 kms



Future. 25~40 kms

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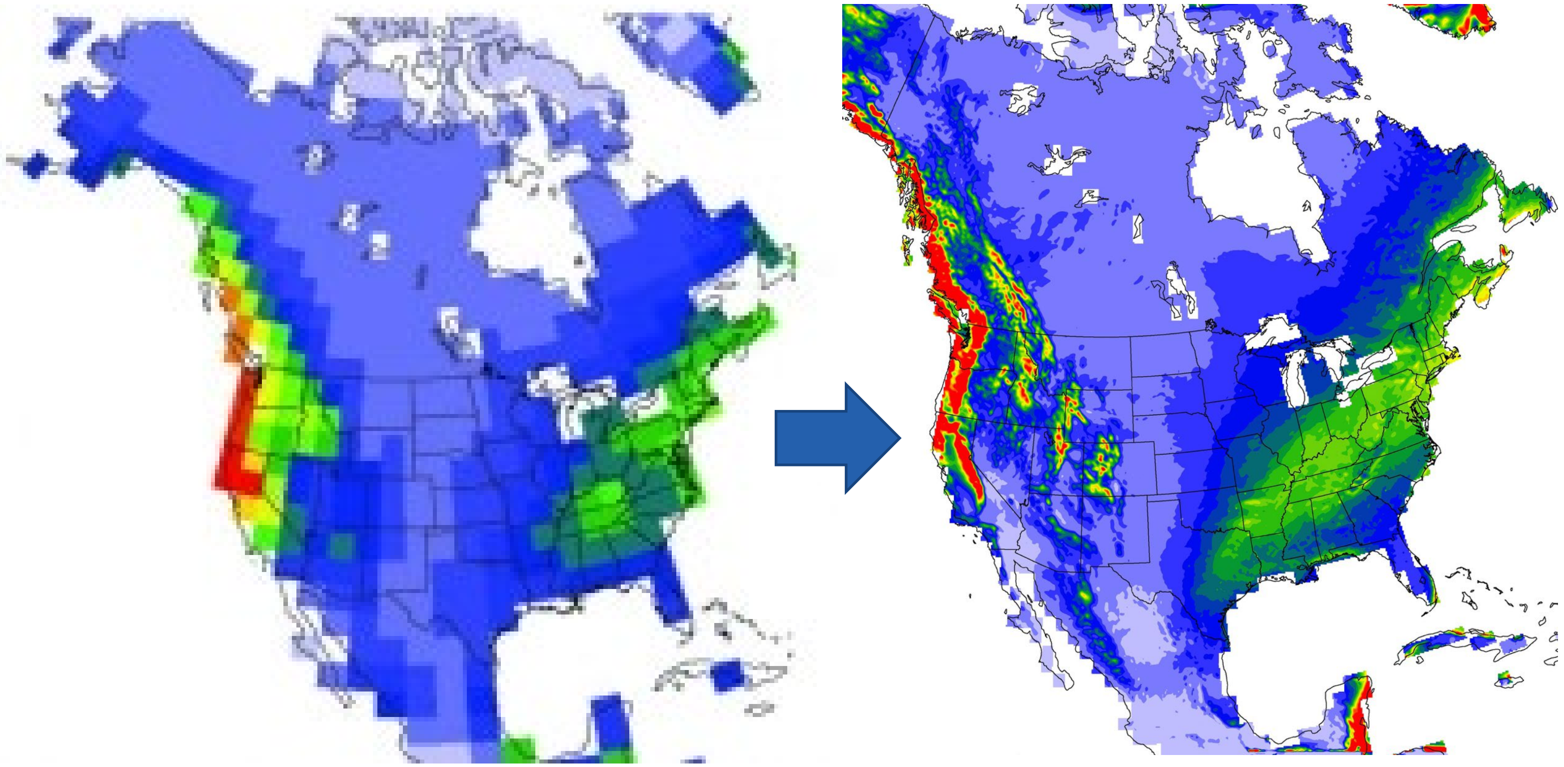
Climate Science & Modeling 101

Downscaling Techniques to Increase Model Resolution

- **Statistical Downscaling**: A statistical relationship is developed between historical observed climate data and the output of a global climate model that has been run for the same historical period. That historically-based statistical relationship is then applied to forward-looking global climate model projections to develop higher-resolution future climate data. Essential for statistical downscaling is the availability of local weather data.

- **Dynamical Downscaling**: A higher resolution regional climate model (RCM) uses lower resolution climate models as boundary conditions and physical principles to reproduce local climate. Essential for dynamical downscaling is the availability of large computing resources.



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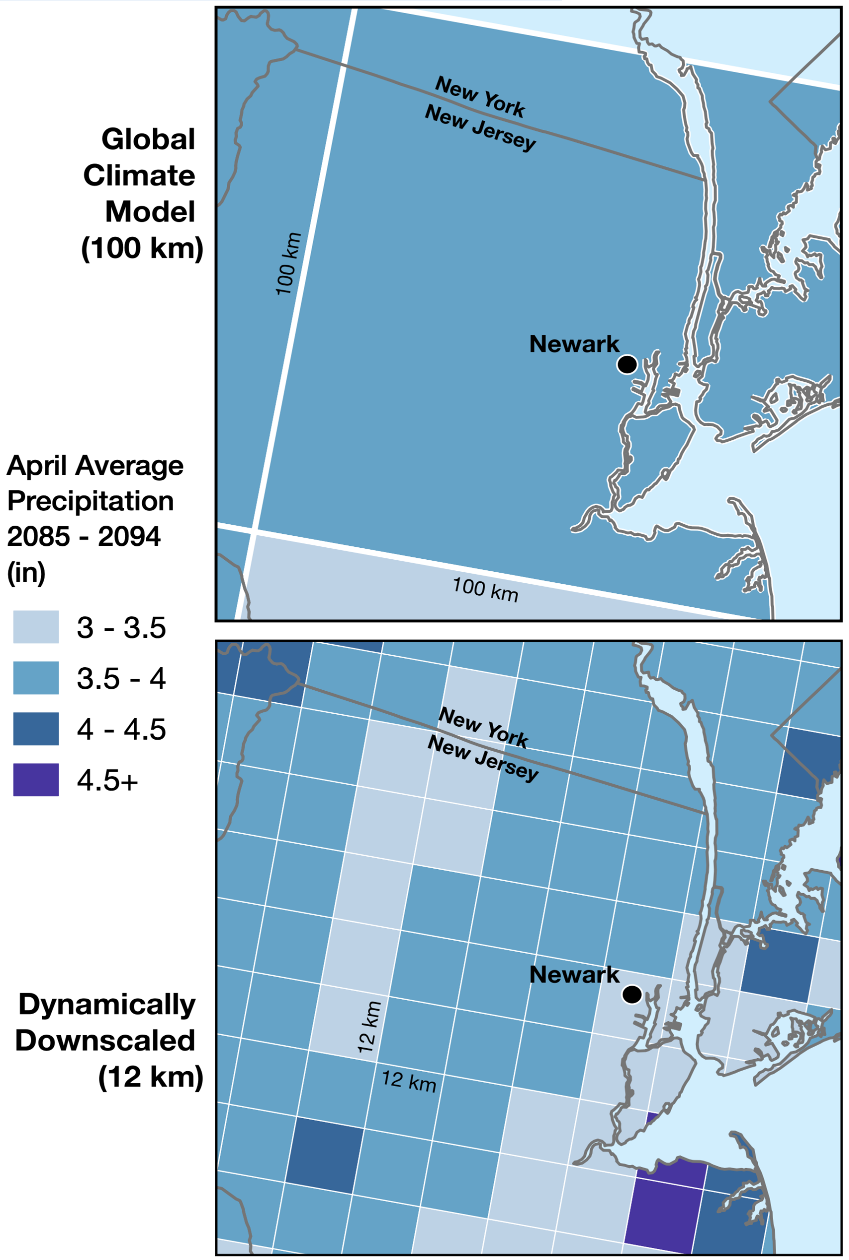
Source: Copernicus.EU, Undated
Images: Argonne National Laboratory

Climate Science & Modeling 101

Example: Dynamical downscaling at Argonne National Laboratory

- From coarse resolution (100-200km) to high resolution, community-level data (12km)
- Physics-based models that incorporate local geography & features (e.g., mountains, waterbodies)
- Downscaled data from three different global climate models
- Two GHG emission pathways: RCP8.5 (high emissions) + RCP4.5 (mid-century peak)
- Three timeframes: historical (1995-2004), mid-century (2045-2054), and end-of-century (2085-2094)
- Scientific transparency: widely published and peer reviewed modeling and outcomes



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Images: Argonne National Laboratory

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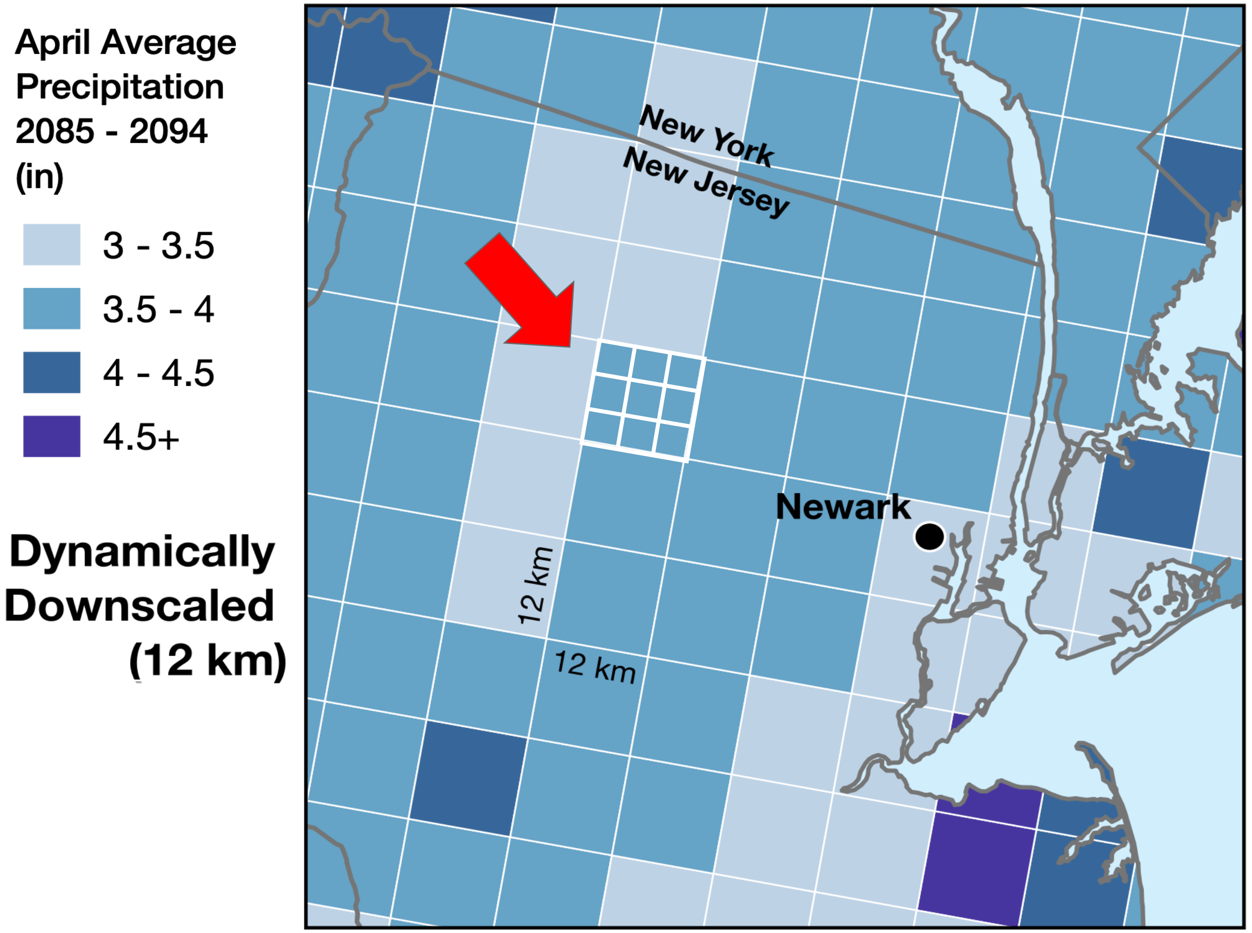
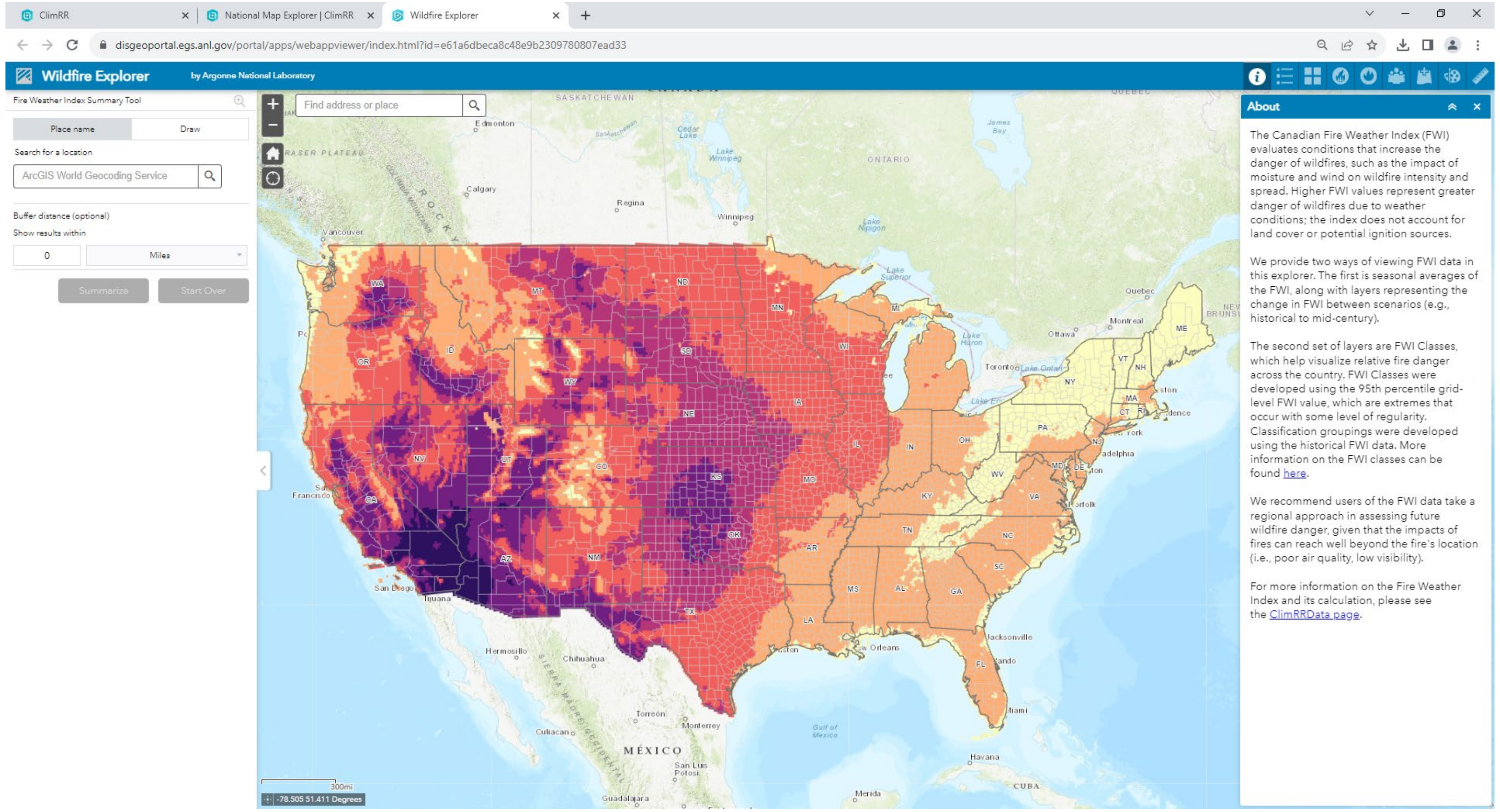
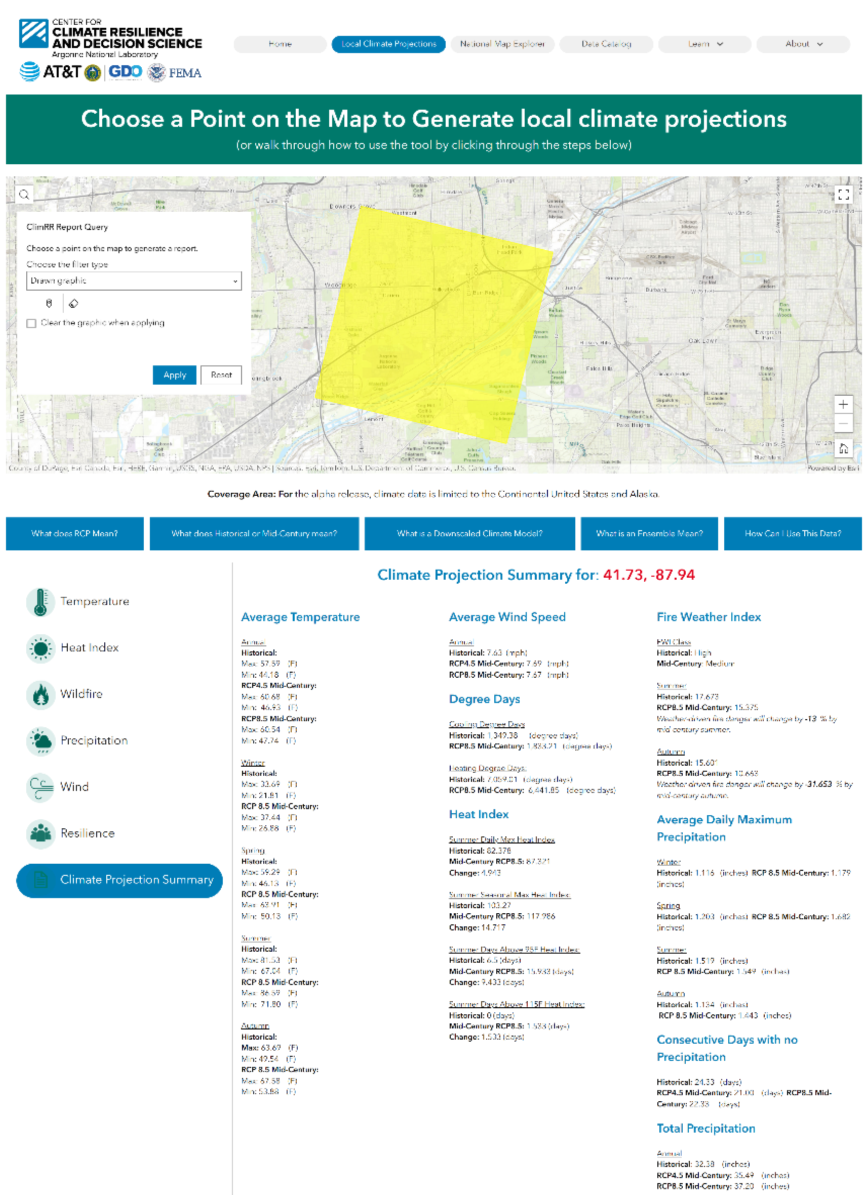


Images: Argonne National Laboratory

Climate Impact Data Resources

- Climate Risk and Resilience Portal (ClimRR) – Argonne National Laboratory, Federal Emergency Management Agency, DOE Grid Deployment Office, AT&T
- https://climrr.anl.gov





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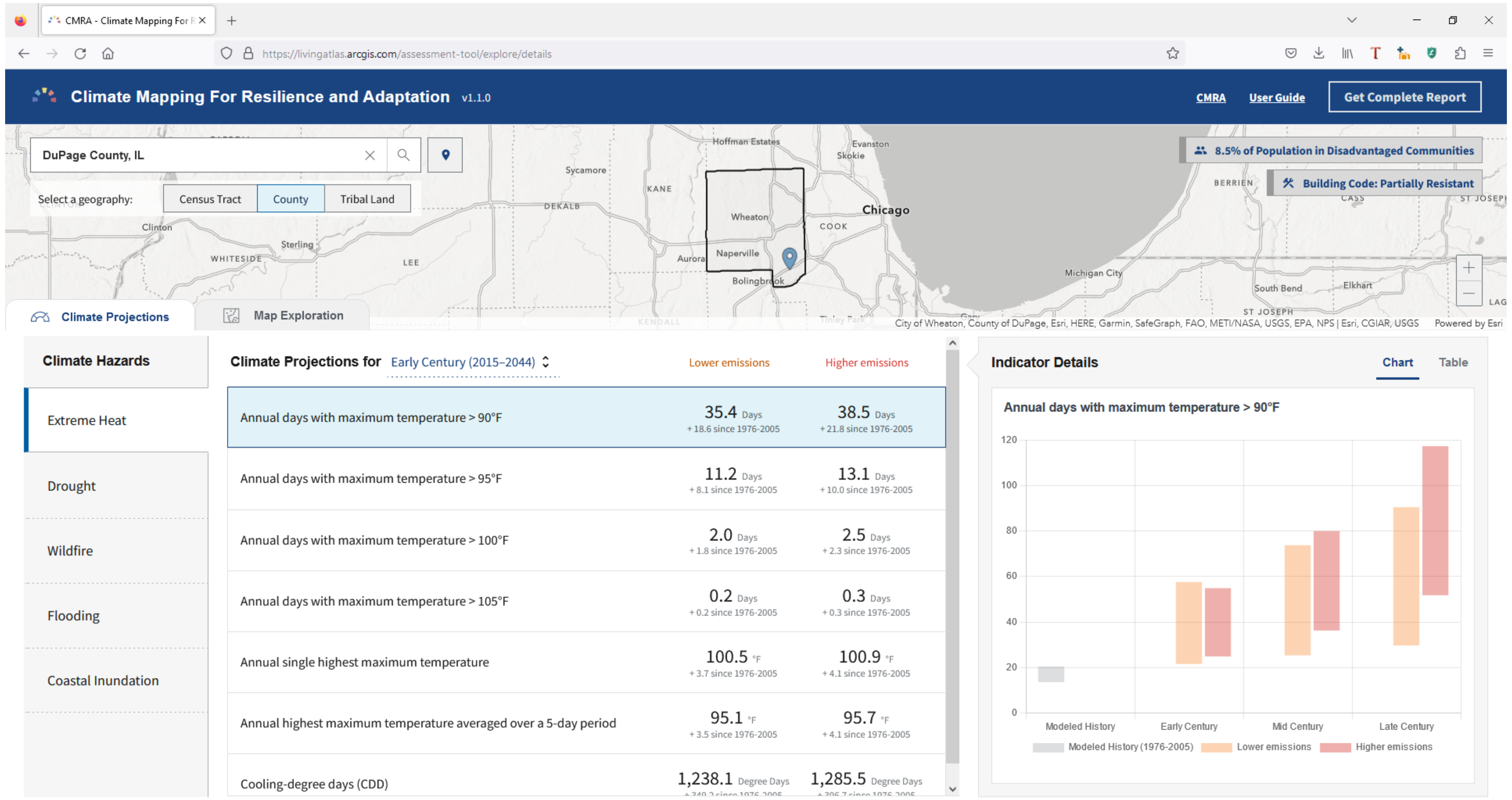
Climate Impact Data Resources

- Climate Mapping for Resilience and Adaptation (CMRA) Assessment Tool - NOAA, Esri
- https://livingatlas.arcgis.com/assessment-tool/home (find at https://resilience.climate.gov)



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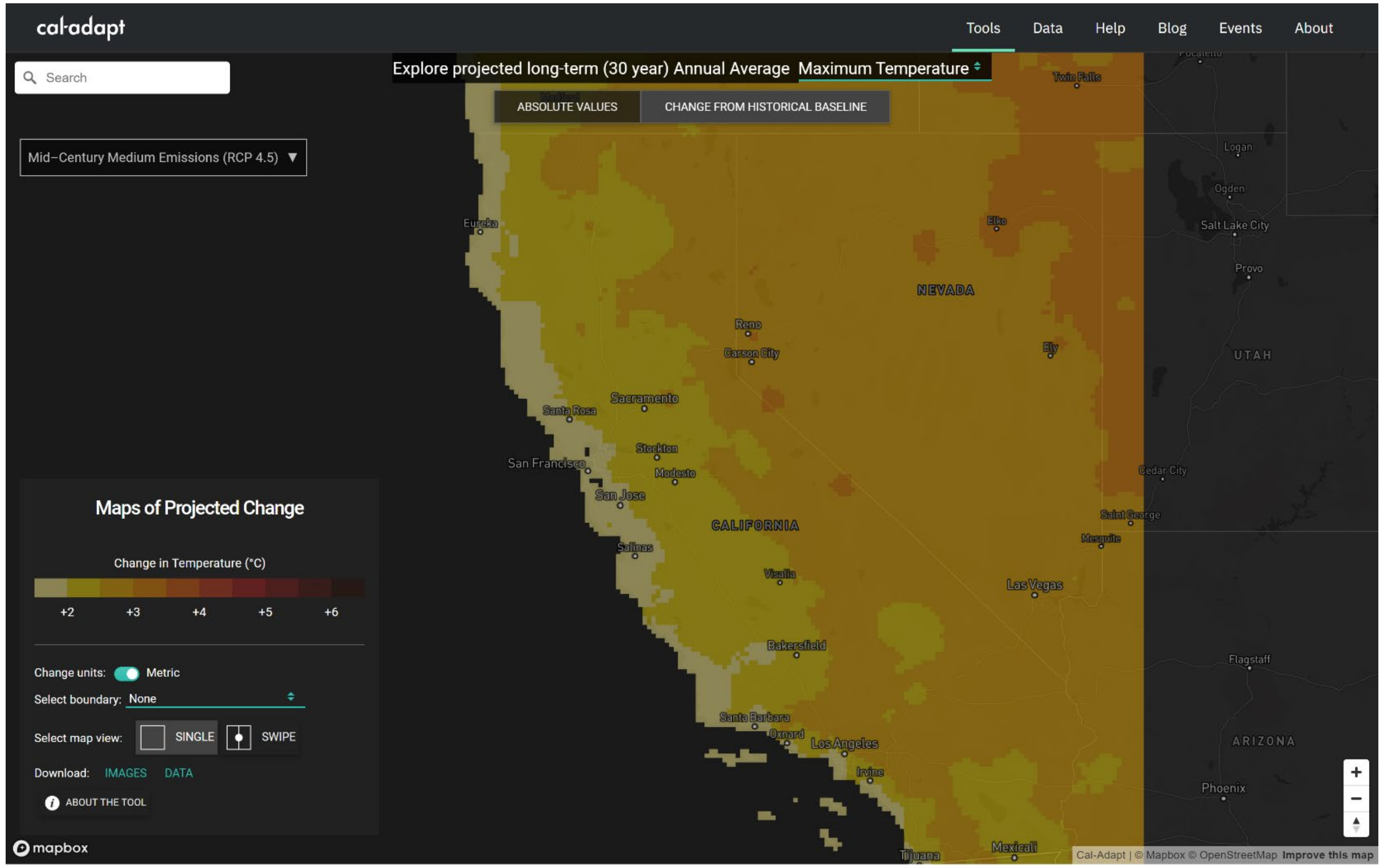
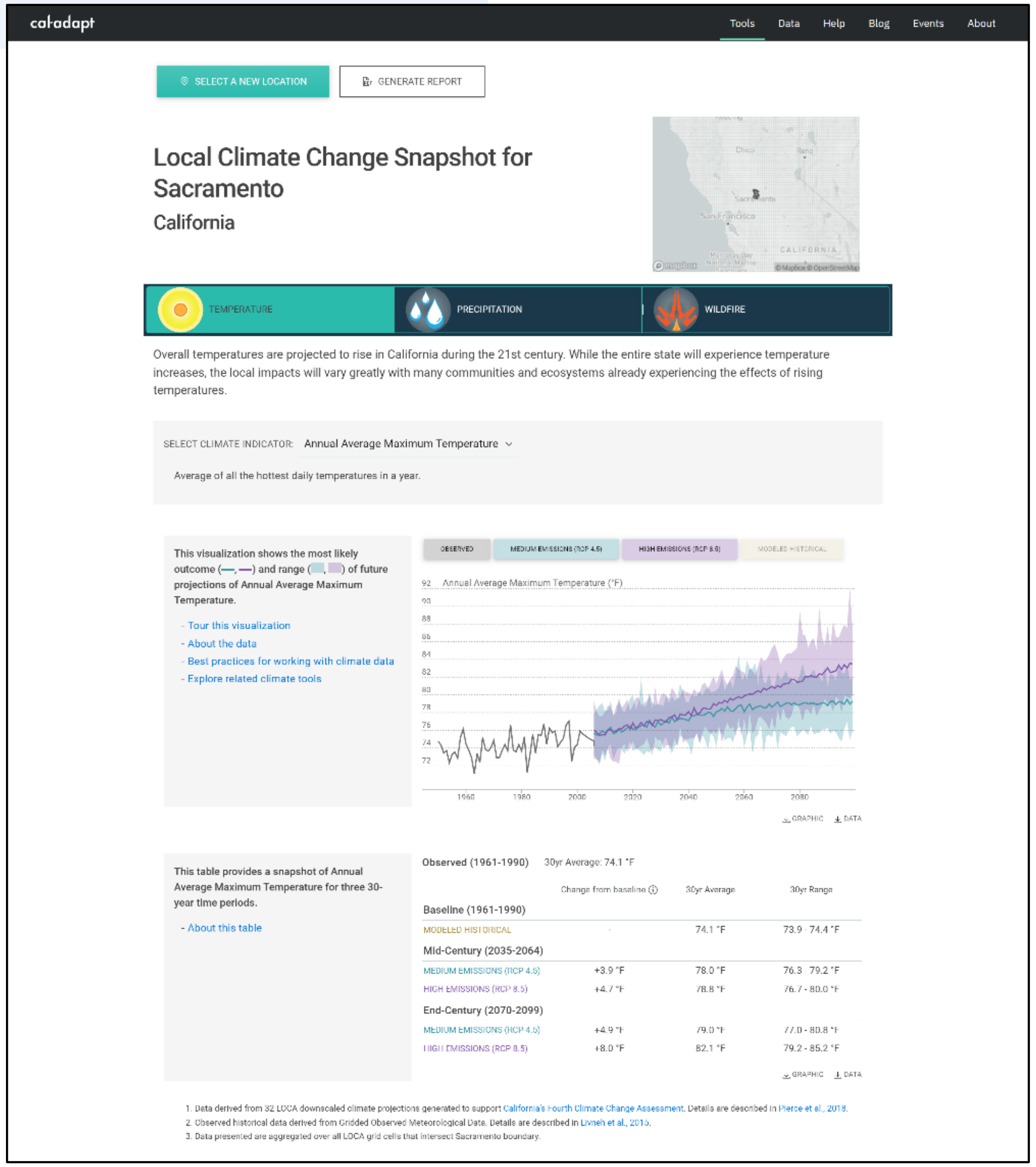
Climate Impact Data Resources

- Cal-Adapt – California Energy Commission, California Strategic Growth Council, UC-Berkeley
- https://cal-adapt.org





Risk-Based Climate Vulnerability Assessments

How is Climate Change Affecting the Electric Grid?

- Literature review of academic and industry studies
- https://www.osti.gov/biblio/1900595

Asset Type	Hazards	Effect	References[8]
Distribution Poles	Cold	Freeze expansion (concrete)	[21]
	Wind	Toppling, debris fall	[2]
	Flooding	Toppling, maintenance route closure	[2]
	Stream Flow	Earth destabilization, toppling	[4]
	Ice	Toppling, debris fall, freeze expansion	[21]
	Overgrowth	Debris fall, maintenance interference	[22]
DERs (SOLAR), Community Microgrid	Heat	Self-islanding, overloading, battery derating	[23]
	Cold	Self-islanding, overloading, photovoltaic (PV) icing	[23]
	Wind	Debris fall, unseating/destruction	[23]
	Flooding	Destruction, grounding	[23]
	Humidity	HVAC demand (depletion)	[15], [17], [18]
	Ice	PV and battery icing, maintenance prevention	[23]

Images: https://oklahoma.gov/oem/emergencies-and-disasters/2005/january-2005-winter-weather-event.html; https://www.energy.gov/eere/articles/let-it-snow-how-solar-panels-can-thrive-winter-weather

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Image: https://commons.wikimedia.org/wiki/File:Underwater_substation,_Cedar_Rapids,_June_12_2008.jpg

Asset Type	Hazards	Effect	References[5]
Transmission Lines	Heat	Sagging, ampacity derating	[7], [8]
	Humidity	Insulation derating, flashover	[2], [3]
	Wind	Cross-whipping, snapping, grounding contact	[7]
	Ice	Snapping, flashover faults	[9], [10]
	Flooding	Buried asset damage	[11]
	Overgrowth	Debris fall, arcing contact	[12]
Transmission Structures	Wind	Toppling	[2]
	Flooding	Maintenance route closure	[13]
	Ice	Toppling	[25], [10]
	Stream Flow	Earth destabilization (on embankments)	[4]
Transformers	Heat	Derating, loss of asset life, overloading	[14], [15]
	Humidity	Insulation derating, loss of asset life, heating, ventilation, and air-conditioning (HVAC) demand	[16], [15], [17], [18]
	Flooding	Destruction, faulting	[19]
	Cold	Overloading, HVAC demand	[15]
Switchgear	Cold	Freezing, gas pressure loss	[20]
	Ice	Freezing	[20]
Other Substation Assets	Humidity	Grounding impedance, HVAC demand	[2], [15], [17], [18]
	Heat	Overloading	[15]
	Flooding	Destruction, maintenance route closure	[2], [19]
Distribution Lines	Wind	Cross-whipping, snapping, grounding contact	[7]
	Heat	Sagging, ampacity derating, overloading	[6]
	Ice	Snapping, debris fall	[10]
	Overgrowth	Debris fall, arcing contact	[12]
	Flooding	Buried asset damage, maintenance route closure	[11]
	Humidity	Insulator derating, HVAC demand	[2], [15], [17], [18]

Risk-Based Climate Vulnerability Assessments

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Asset Type	Hazards	Effect	References[2]
Gas Lines	Cold	Supply pressure collapse	[1]
	Ice	Supply pressure collapse, fuel leak	[1]
	Flooding	Destruction	[2]
	Fire	Destruction, ignition	[3]
	Stream Flow	Earth destabilization (on banks), destruction at crossing	[4]
Generation	Cold	Water supply icing, equipment freeze	[24], [1]
	Heat	Cooling water shortage, cooling water inefficacy, ambient cooling impacts	[5]
	Ice	Structural damage, water supply icing	[24]
	Wind	Structural damage, hydroelectric overflow	[24], [6]
	Stream Flow	Water supply overflow	[24]
	Flooding	structural damage, maintenance route closure	[25]

- A California Energy Commission study found that capacity of natural gas combined-cycle power plants decreases by 0.3-0.5 percent for each 1C increase above a reference temperature of 15C (59F)
- Power transformer average power output decreases 0.7% to 1% per 1C increase in air temperature, above a reference temperature (usually 20C, or 68F)

(Source: Allen-Dumas et al. 2019)

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Image: https://en.wikipedia.org/wiki/List_of_natural_gas_power_stations_in_the_United_States#/media/File:Chehalis_Power_Plant,_September_2020.jpg

Wrapping Up

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Questions to Ask

Questions to set that set the stage for understanding how utilities are assessing climate impacts and risks

- Scope, context, criteria
  - What GHG emission/concentration scenarios form basis of the assessment? RCP/SSP8.5? RCP/SSP4.5?
  - What is your assessment timeframe? Mid-century? End-of-century?
  - What models and data will you use? A single model? A multiple model ensemble?
  - How can the state ensure consistency across multiple utilities' assessments?
- Risk Identification
  - What are the climate impacts of greatest concern and why? (This will be different by region/location)
  - What aspects of these impacts are of greatest concern? Averages? Extremes? Highs/lows? How does emission scenario affect this?
  - Does the assessment examine chronic (reliability) problems as well as catastrophic (resiliency) problems?

Image: https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en

Questions to Ask

- Risk Analysis
  - How are risks different according to various climate impacts and asset/equipment/facility types?
  - What are critical planning/operational thresholds?
  - Are there gaps in climate data/information that prevent certain risk analyses? Are there work-around solutions?
- Risk Evaluation
  - How will you determine risk levels and compare/prioritize?
  - What metrics and criteria will you use to assess risk?
    - Disruption time?
    - Economic impacts? Capital, customer, etc.?
  - How will you identify and prioritize risk treatments?
  - How will you reconcile/align climate impact risks with other risks and opportunities? Transition risk? Asset management? Decarbonization?

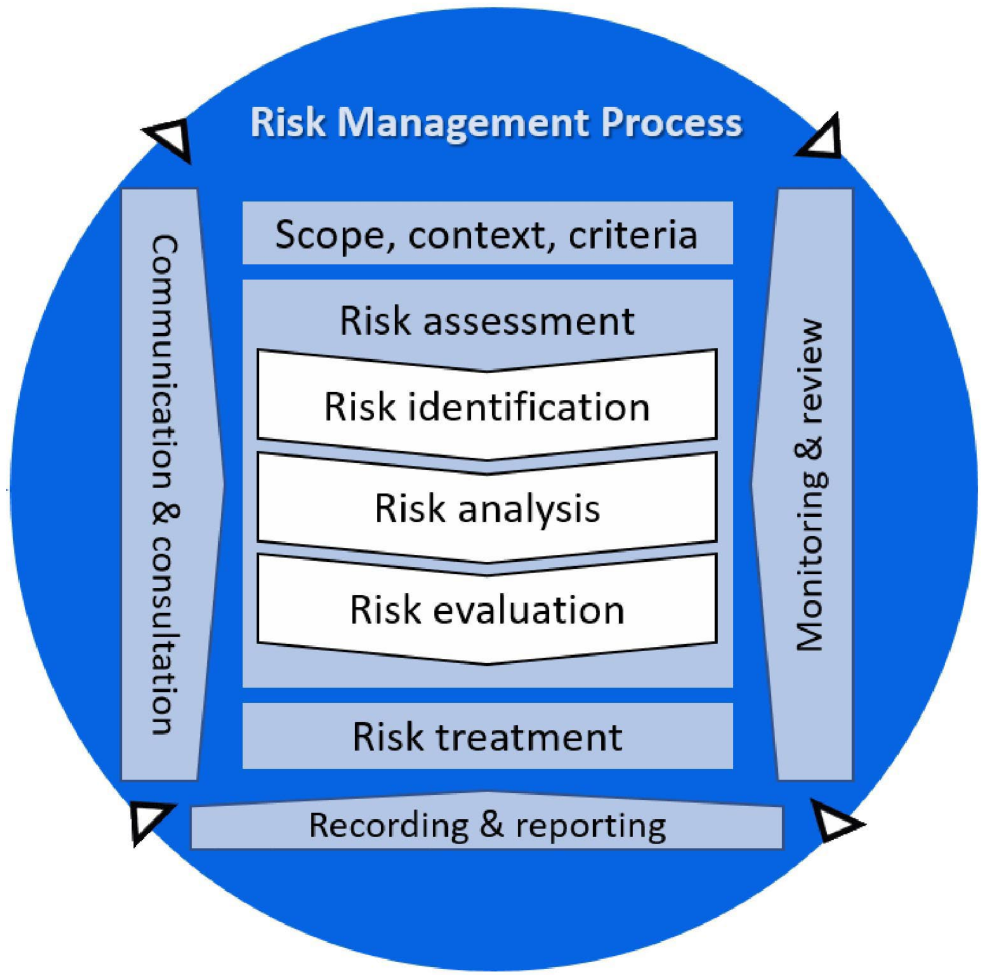

Image: https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en

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Contact

https://www.energy.gov/gdo/grid-deployment-office

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Thank You