Identifying Threats, Predicting Vulnerabilities, and Assessing the Risks

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Clean Energy Innovator Fellows Training

September 26, 2024

Presentation Outline

Uncertainty, Risks, and Vulnerability

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

Climate Impact Data Resources

- Climate Impact Data Resources

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Uncertainty, Risks, and Vulnerability

Introduction to Uncertainty & Risk

Images: unsplash.com

Uncertainty

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

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

Risk

"…derives from random adverse events with probabilities of occurrence that can be statistically calculated."

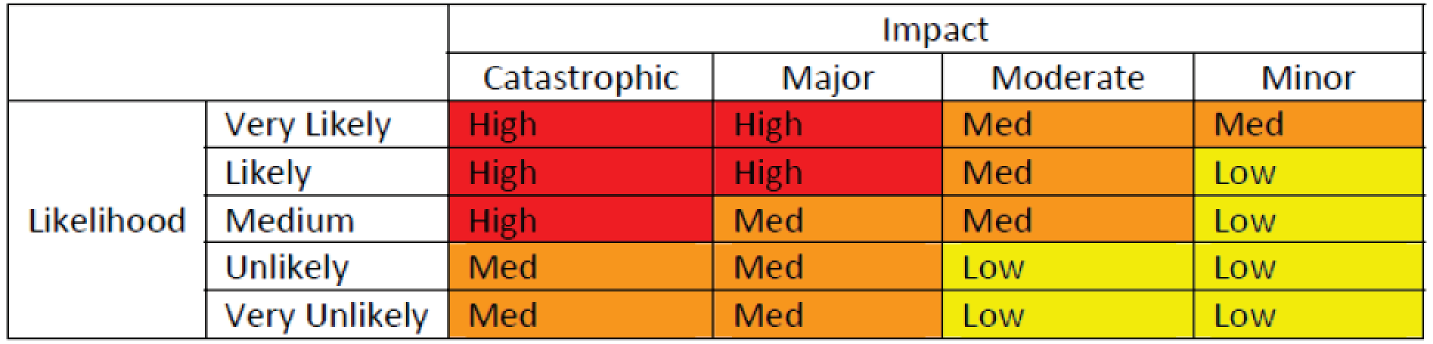
~Knight, 1921 (paraphrased)

"…a measure of the probability and severity of adverse effects" from some event."

~Lowrance,1976, in
Haimes, 2004

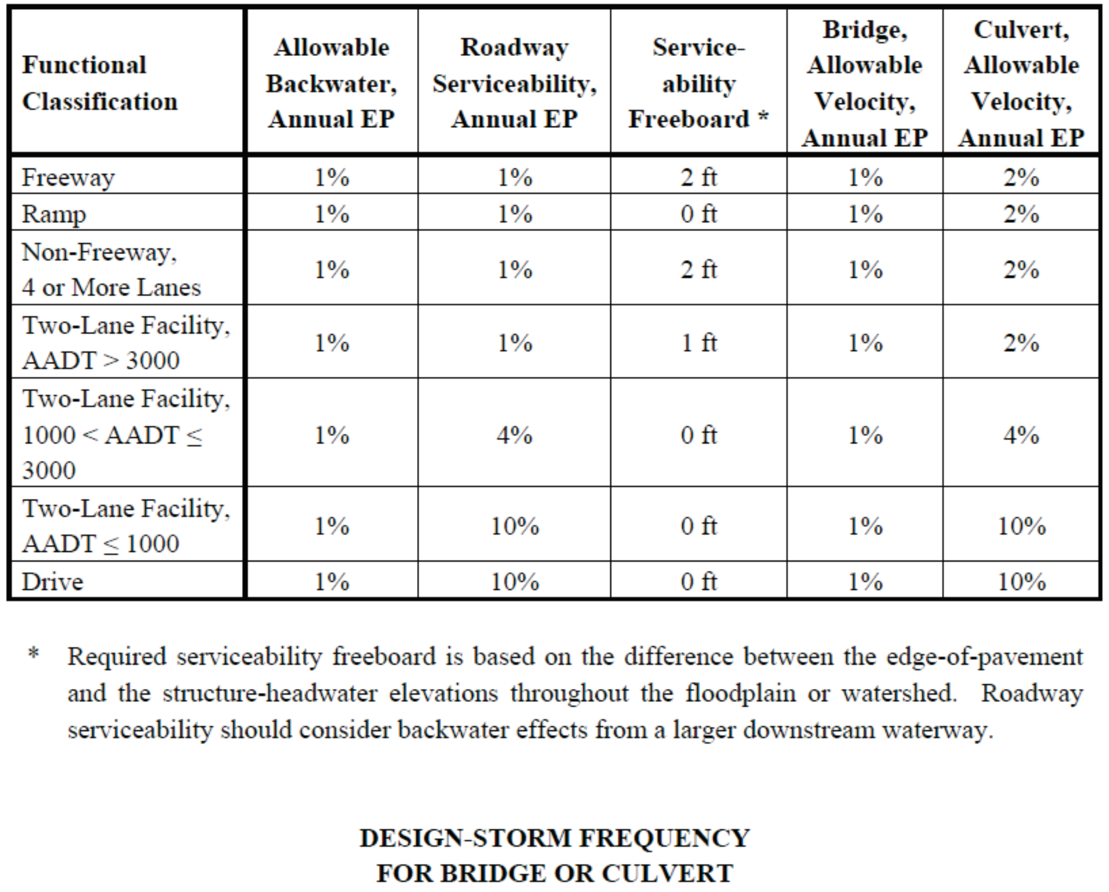
Introduction to Uncertainty & Risk

- Quantitative approaches to risk & uncertainty
  - **Risk = Likelihood X Consequence**
  - Frequently incorporated into engineering design standards
  - Easiest when likelihood can be statistically quantified and/or consequences can be quantified
    - E.g., Risk = 10% probability X $1M in losses
- 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

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


Risk Management Process

Scope, context, criteria

Risk assessment

Risk identification

Risk analysis

Risk evaluation

Risk treatment

Recording & reporting

Communication & consultation

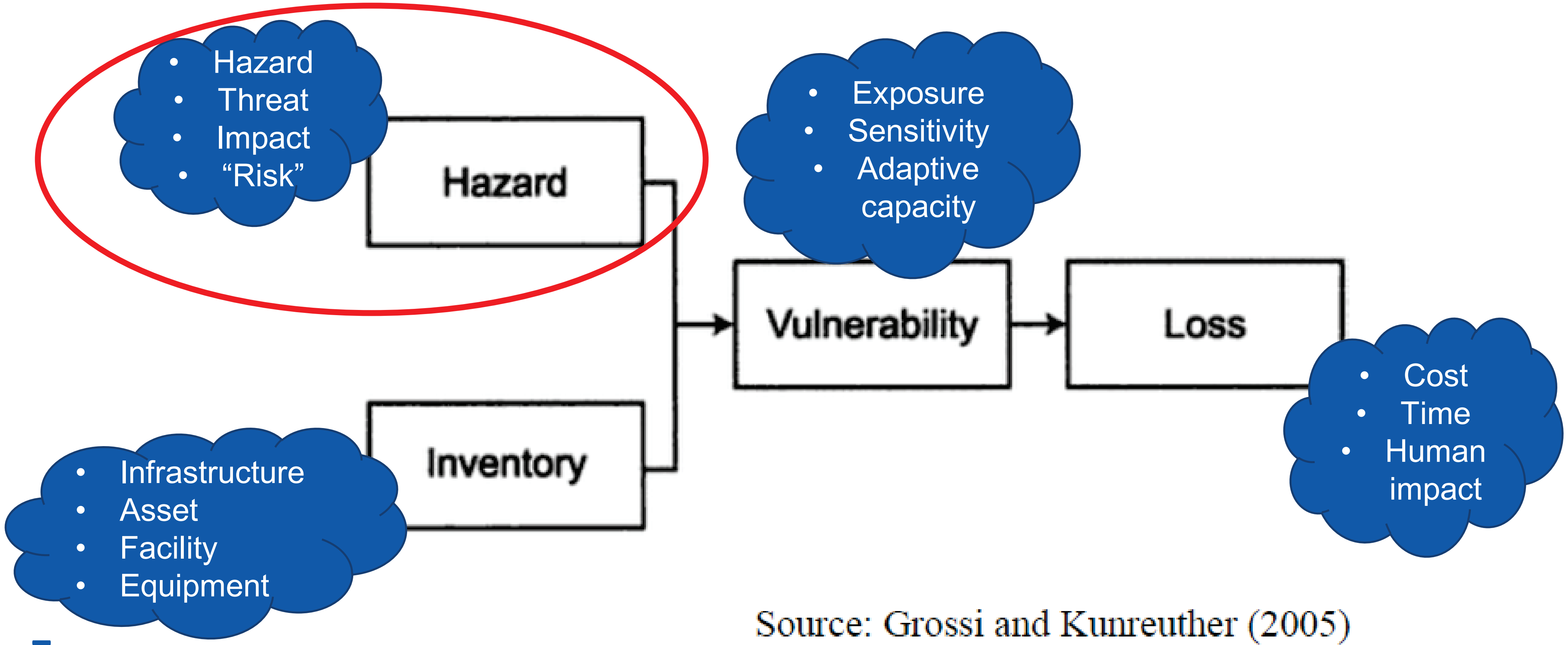
Monitoring & review

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

Integrating Threat Information into Risk-Based Assessments (1)

Infrastructure Risk – Catastrophe Model

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



- Hazard
- Threat
- Impact
- “Risk”

- Infrastructure
- Asset
- Facility
- Equipment

- Exposure
- Sensitivity
- Adaptive capacity

- Cost
- Time
- Human impact

Source: Grossi and Kunreuther (2005)

Integrating Threat Information into Risk-Based Assessments (2)

Probabilistic vs. Deterministic Hazard Information

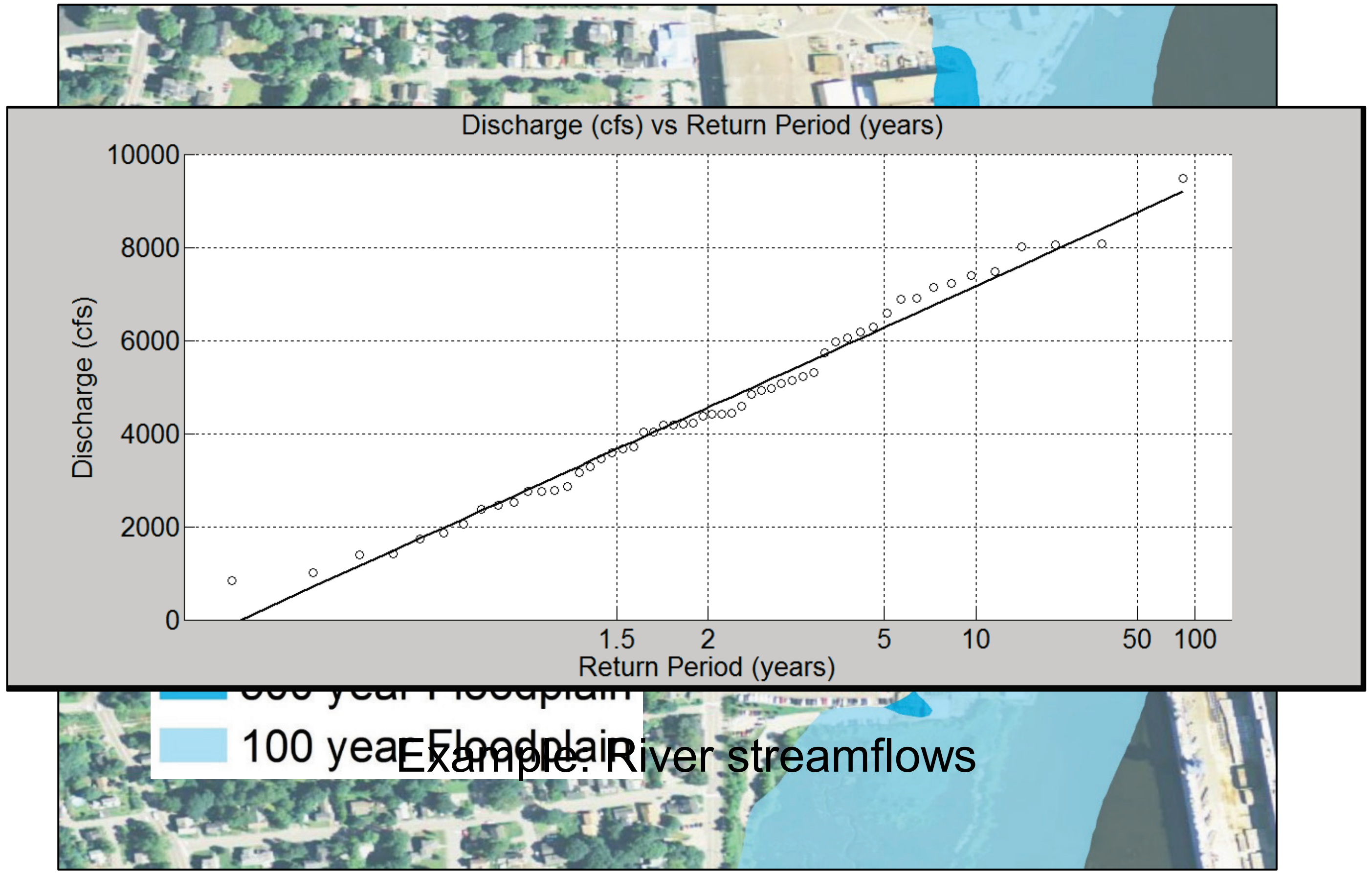
- Likelihood or probability based threat information
- Deterministic/scenario-based threat information

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

Integrating Threat Information into Risk-Based Assessments (3)

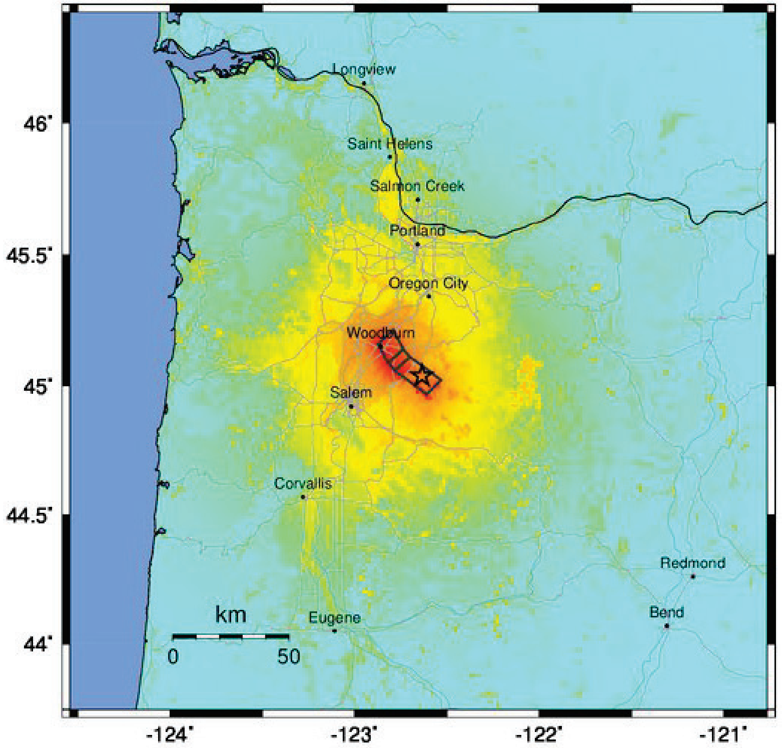
Probabilistic vs. Deterministic Hazard Information

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

Example

Scenario: Earthquake planning scenarios

-- Earthquake Planning Scenario --
ShakeMap for Mount Angel fault - Median ground motions Scenario
Scenario Date: May 12, 2017 02:14:08 PM MDT M 6.8 N45.04 W122.64 Depth: 9.0km

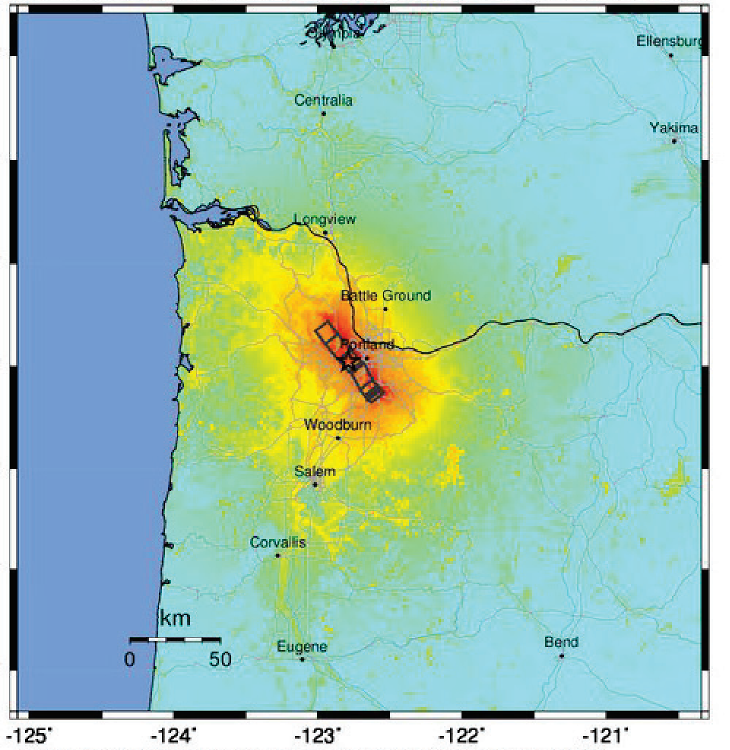


PLANNING SCENARIO ONLY -- Map Version 3 Processed 2017-05-16 01:29:04 AM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

-- Earthquake Planning Scenario --
ShakeMap for Portland Hills fault - Median ground motions Scenario
Scenario Date: May 12, 2017 02:14:08 PM MDT M 7.0 N45.52 W122.79 Depth: 9.0km



PLANNING SCENARIO ONLY -- Map Version 3 Processed 2017-05-16 01:33:40 AM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
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cale based upon Worden et al. (2012)

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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

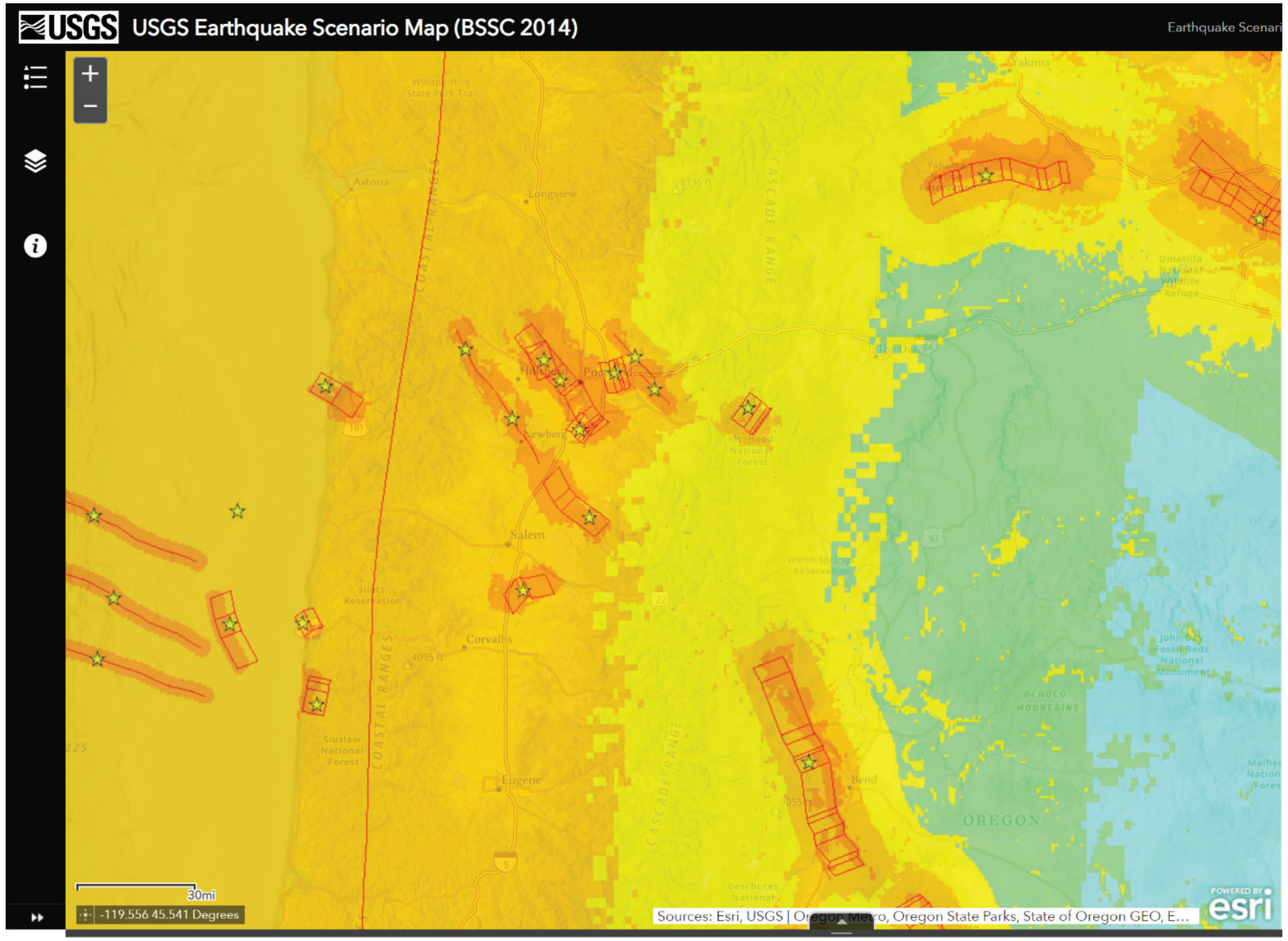


Image: https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=14d2f75c7c4f4619936dac0d14e1e468

Poll Question

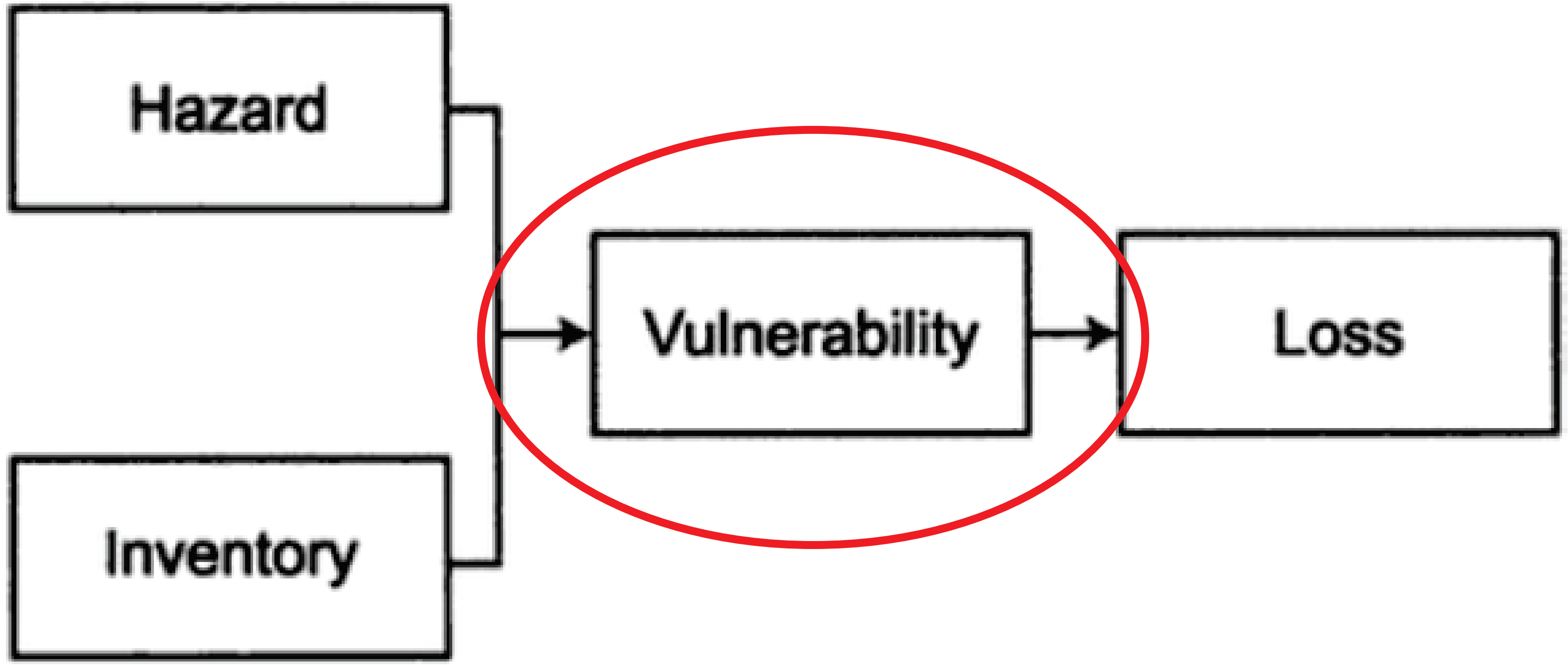
Over the last decade in the U.S., every year we saw at least ten “billion dollar events,” where overall damages/costs for each event reached or exceeded $1 billion. In 2023 we saw 28 such events!

One disaster type accounted for the greatest number of events in every single year – which of the following disaster types do you think it was?

A) Winter storm
B) Wildfire
C) Drought
D) Severe storm
E) Hurricane

Assessing Infrastructure Vulnerability

The Importance of Place-Based Information & Data

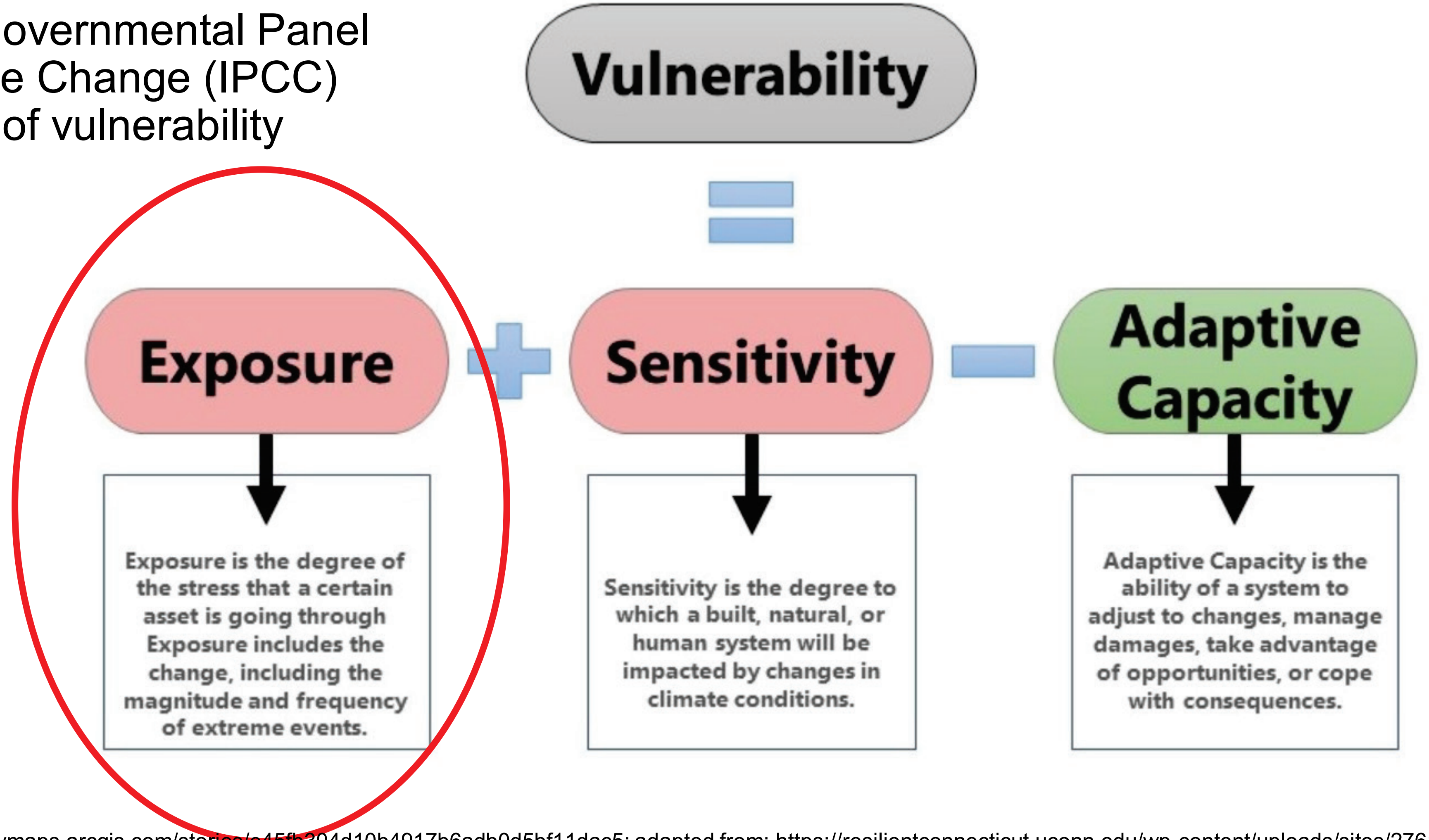


Source: Grossi and Kunreuther (2005)

Assessing Infrastructure Vulnerability

The Importance of Place-Based Information & Data

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



Exposure is the degree of the stress that a certain asset is going through Exposure includes the change, including the magnitude and frequency of extreme events.

Sensitivity is the degree to which a built, natural, or human system will be impacted by changes in climate conditions.

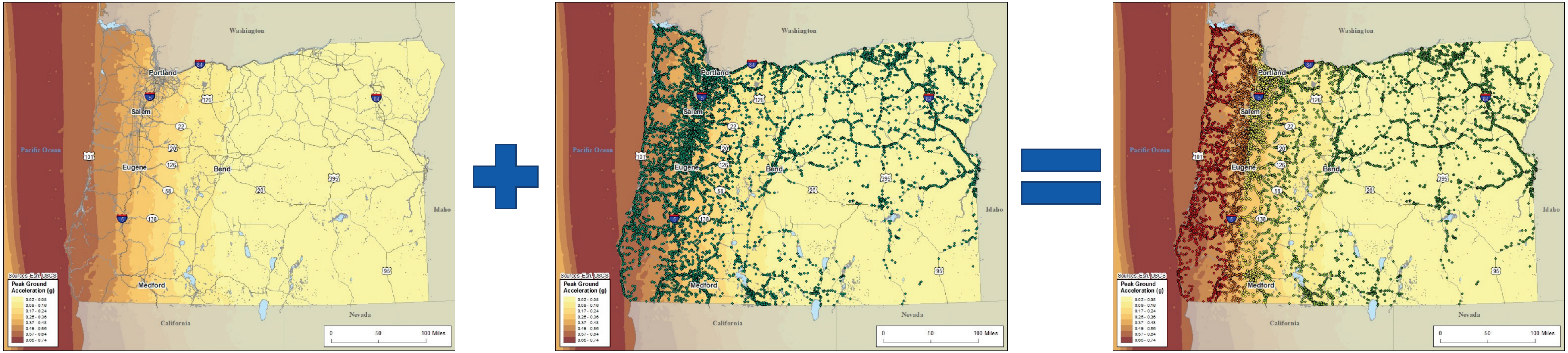
Adaptive Capacity is the ability of a system to adjust to changes, manage damages, take advantage of opportunities, or cope with consequences.

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

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

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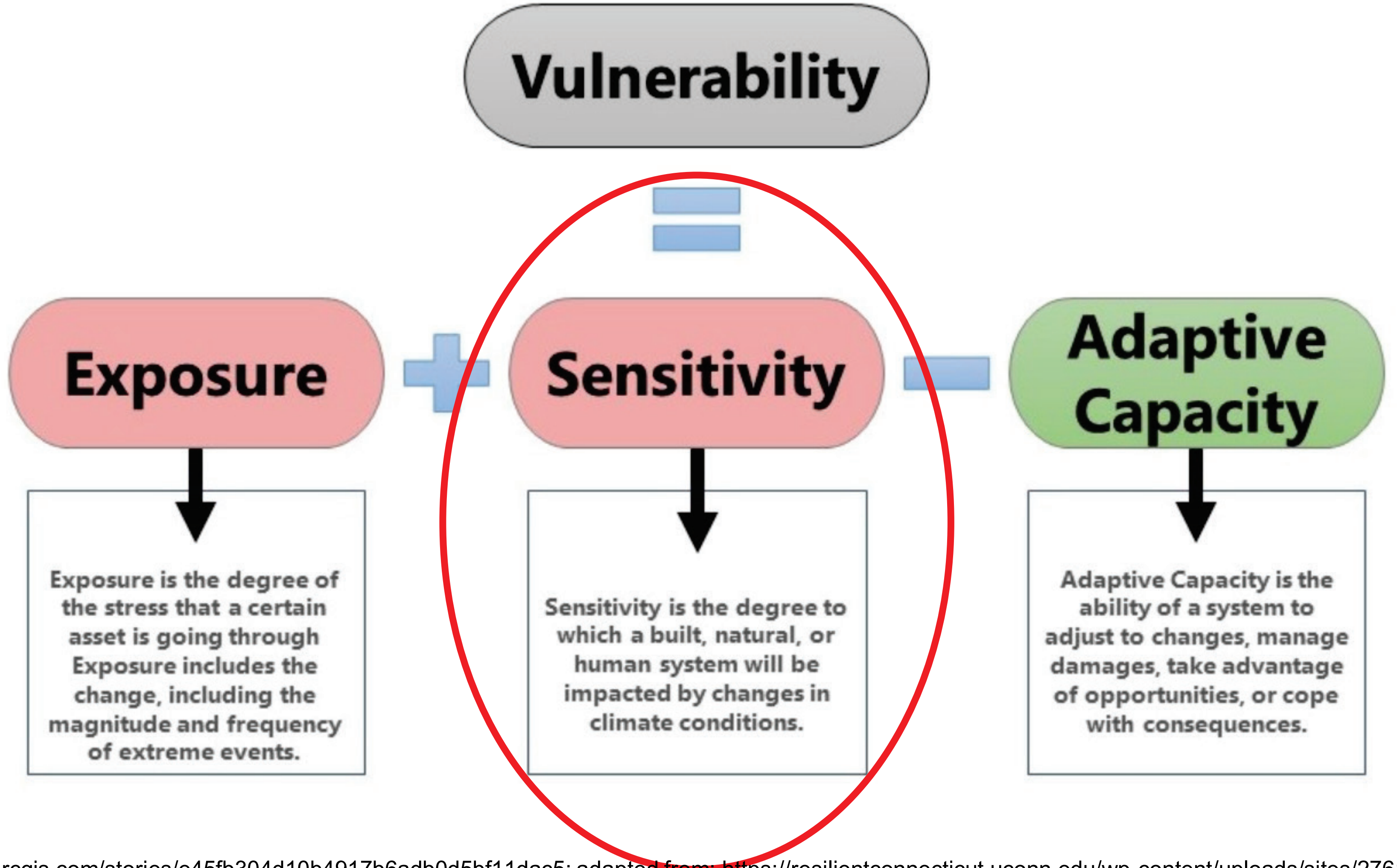
Assessing Infrastructure Vulnerability

Infrastructure Sensitivity Information



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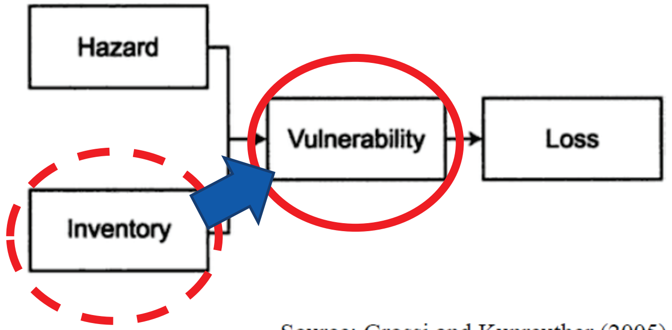
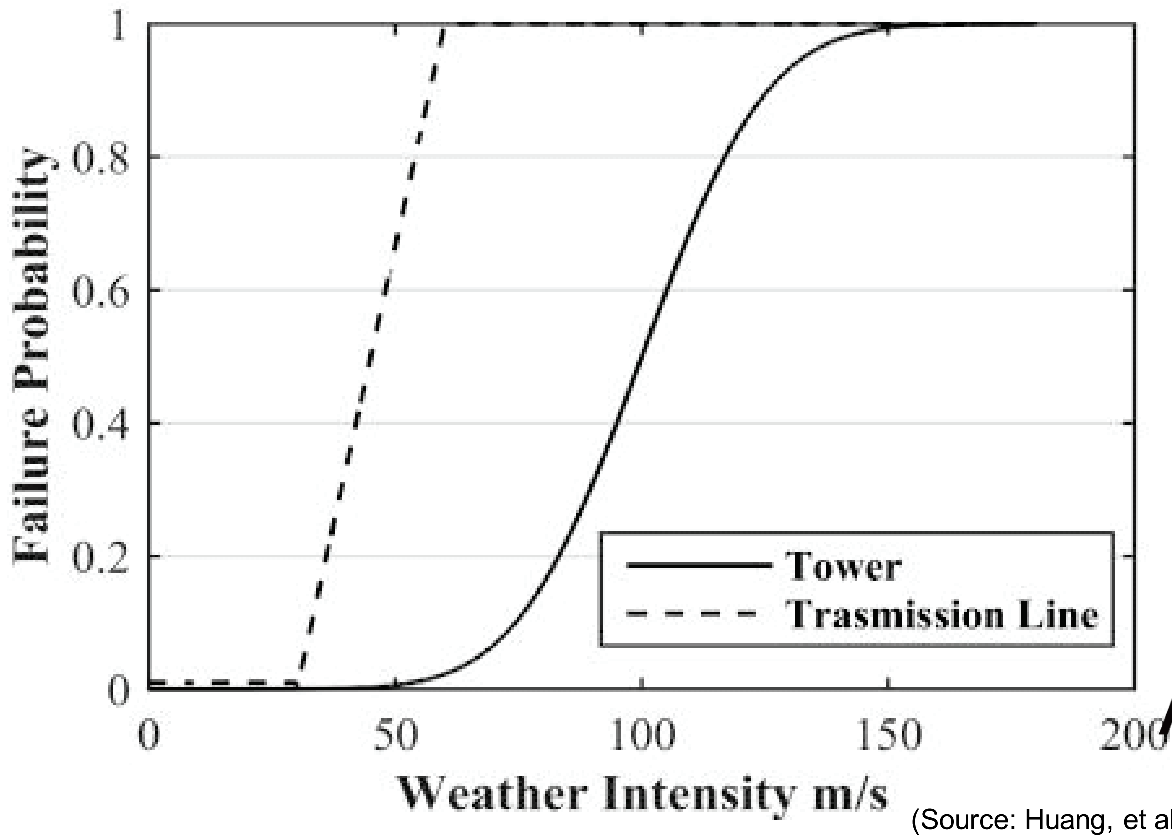
Assessing Infrastructure Vulnerability

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



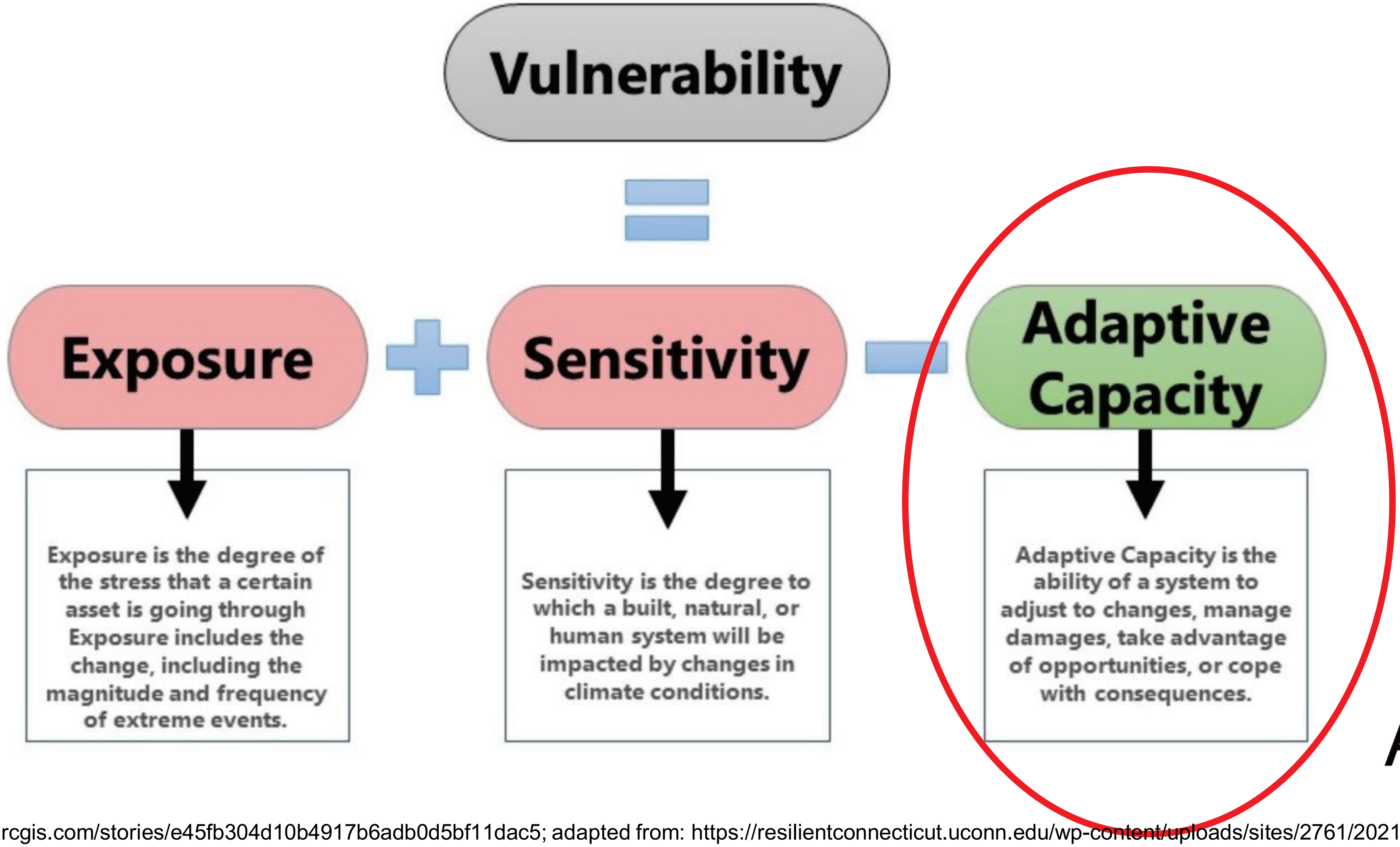
Source: Grossi and Kunreuther (2005)



(Source: Huang, et al. 2018)

Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity



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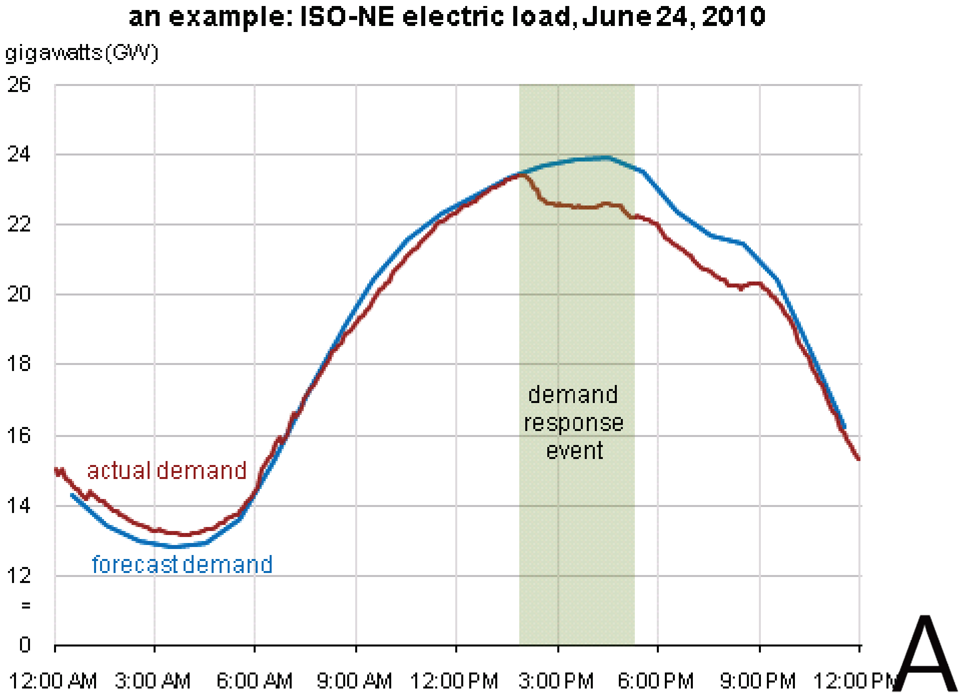
Assessing Infrastructure Vulnerability

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

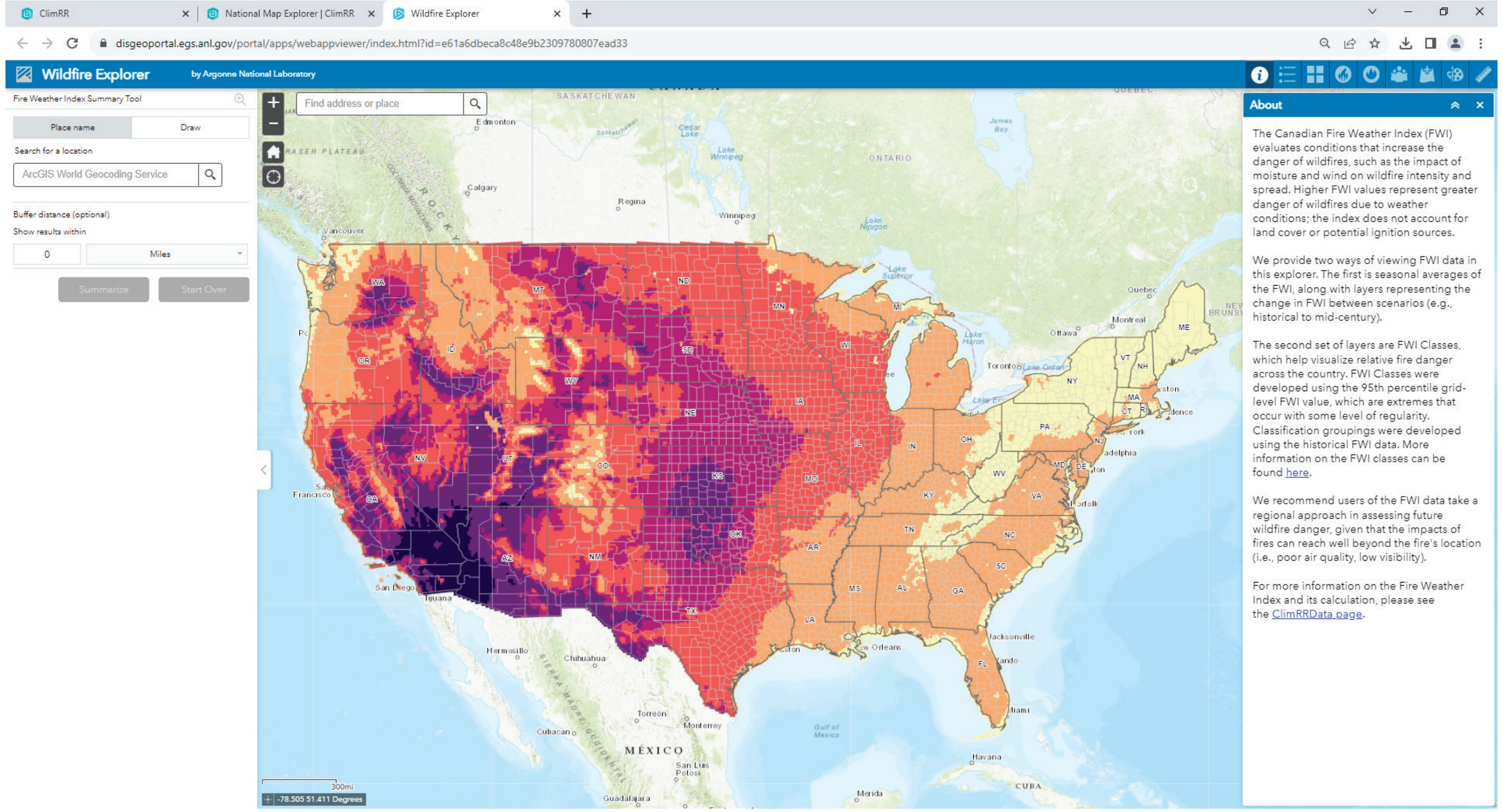


Images: Unsplash; https://www.eia.gov/todayinenergy/detail.php?id=130

Climate Impact Data Resources

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



About

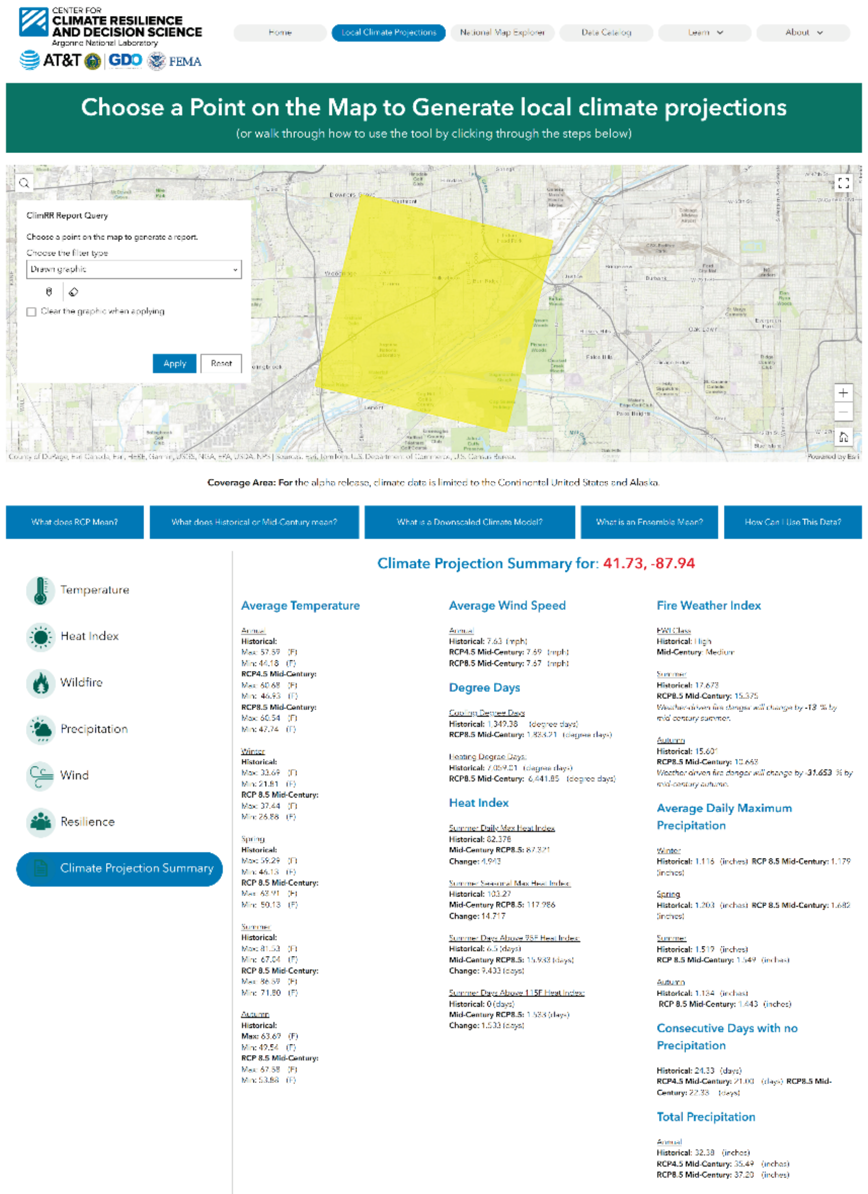
The Canadian Fire Weather Index (FWI) evaluates conditions that increase the danger of wildfires, such as the impact of moisture and wind on wildfire intensity and spread. Higher FWI values represent greater danger of wildfires due to weather conditions; the index does not account for land cover or potential ignition sources.

We provide two ways of viewing FWI data in this explorer. The first is seasonal averages of the FWI, along with layers representing the change in FWI between scenarios (e.g., historical to mid-century).

The second set of layers are FWI Classes, which help visualize relative fire danger across the country. FWI Classes were developed using the 95th percentile grid-level FWI value, which are extremes that occur with some level of regularity. Classification groupings were developed using the historical FWI data. More information on the FWI classes can be found here.

We recommend users of the FWI data take a regional approach in assessing future wildfire danger, given that the impacts of fires can reach well beyond the fire's location (i.e., poor air quality, low visibility).

For more information on the Fire Weather Index and its calculation, please see the ClimRRData page.



Choose a Point on the Map to Generate local climate projections

(or walk through how to use the tool by clicking through the steps below)

Coverage Area: For the alpha release, climate data is limited to the Continental United States and Alaska.

Climate Projection Summary for: 41.73, -87.94

Average Temperature

Average Wind Speed

Annual
Historical: 7.63 (mph)
RCP4.5 Mid-Century: 7.69 (mph)
RCP8.5 Mid-Century: 7.67 (mph)

Degree Days

Heat Index

Fire Weather Index

FWI Class
Historical: High
Mid-Century: Medium

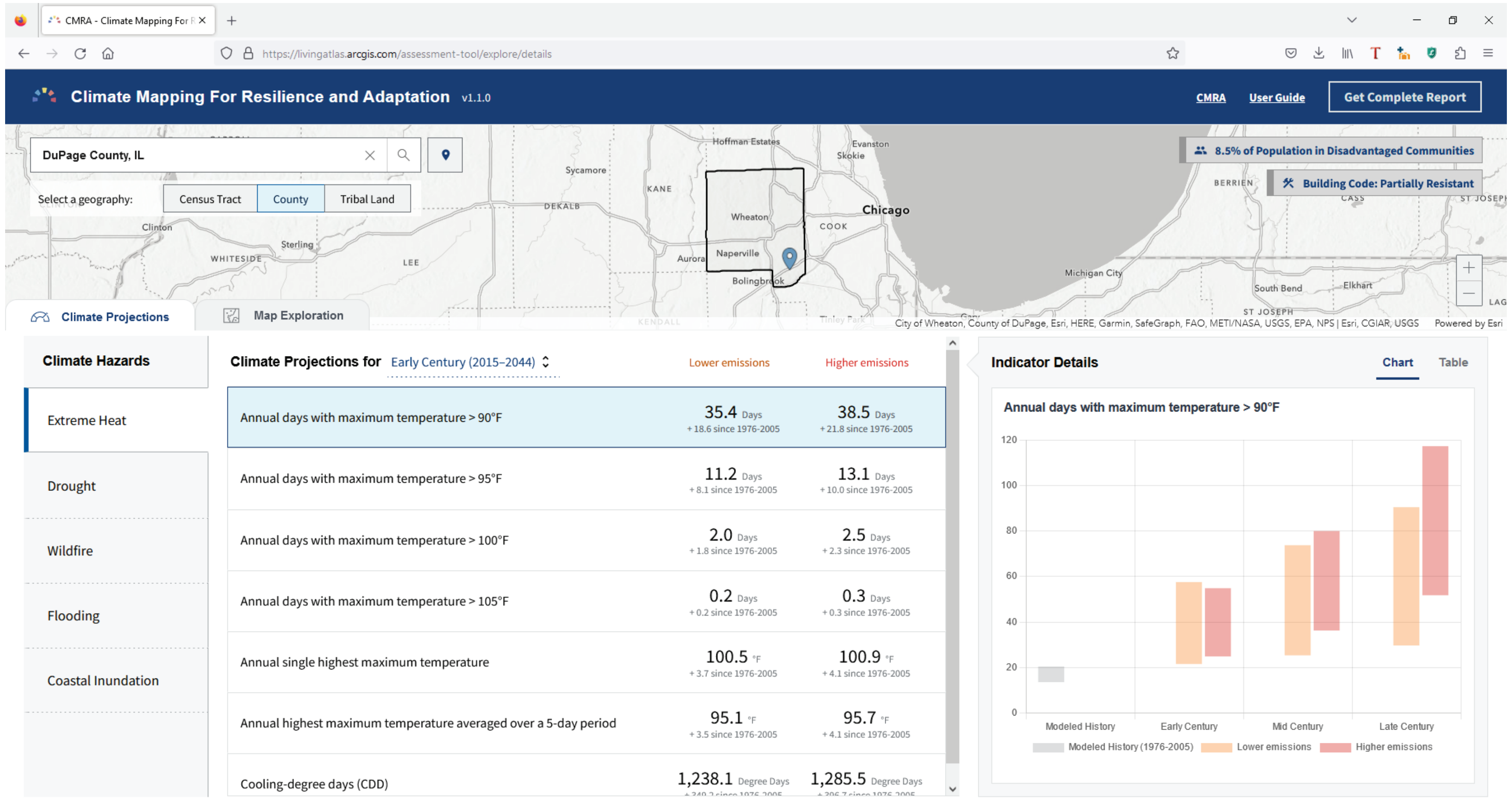
Average Daily Maximum Precipitation

Consecutive Days with no Precipitation

Total Precipitation

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)



DuPage County, IL

Select a geography: County

Climate Projections for Early Century (2015–2044)

	Lower emissions	Higher emissions
Annual days with maximum temperature > 90°F	35.4 Days + 18.6 since 1976-2005	38.5 Days + 21.8 since 1976-2005
Annual days with maximum temperature > 95°F	11.2 Days + 8.1 since 1976-2005	13.1 Days + 10.0 since 1976-2005
Annual days with maximum temperature > 100°F	2.0 Days + 1.8 since 1976-2005	2.5 Days + 2.3 since 1976-2005
Annual days with maximum temperature > 105°F	0.2 Days + 0.2 since 1976-2005	0.3 Days + 0.3 since 1976-2005
Annual single highest maximum temperature	100.5 °F + 3.7 since 1976-2005	100.9 °F + 4.1 since 1976-2005
Annual highest maximum temperature averaged over a 5-day period	95.1 °F + 3.5 since 1976-2005	95.7 °F + 4.1 since 1976-2005
Cooling-degree days (CDD)	1,238.1 Degree Days	1,285.5 Degree Days

Climate Impact Data Resources

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

Explore projected long-term (30 year) Annual Average Maximum Temperature

Mid–Century Medium Emissions (RCP 4.5)

Maps of Projected Change

Change in Temperature (°C)

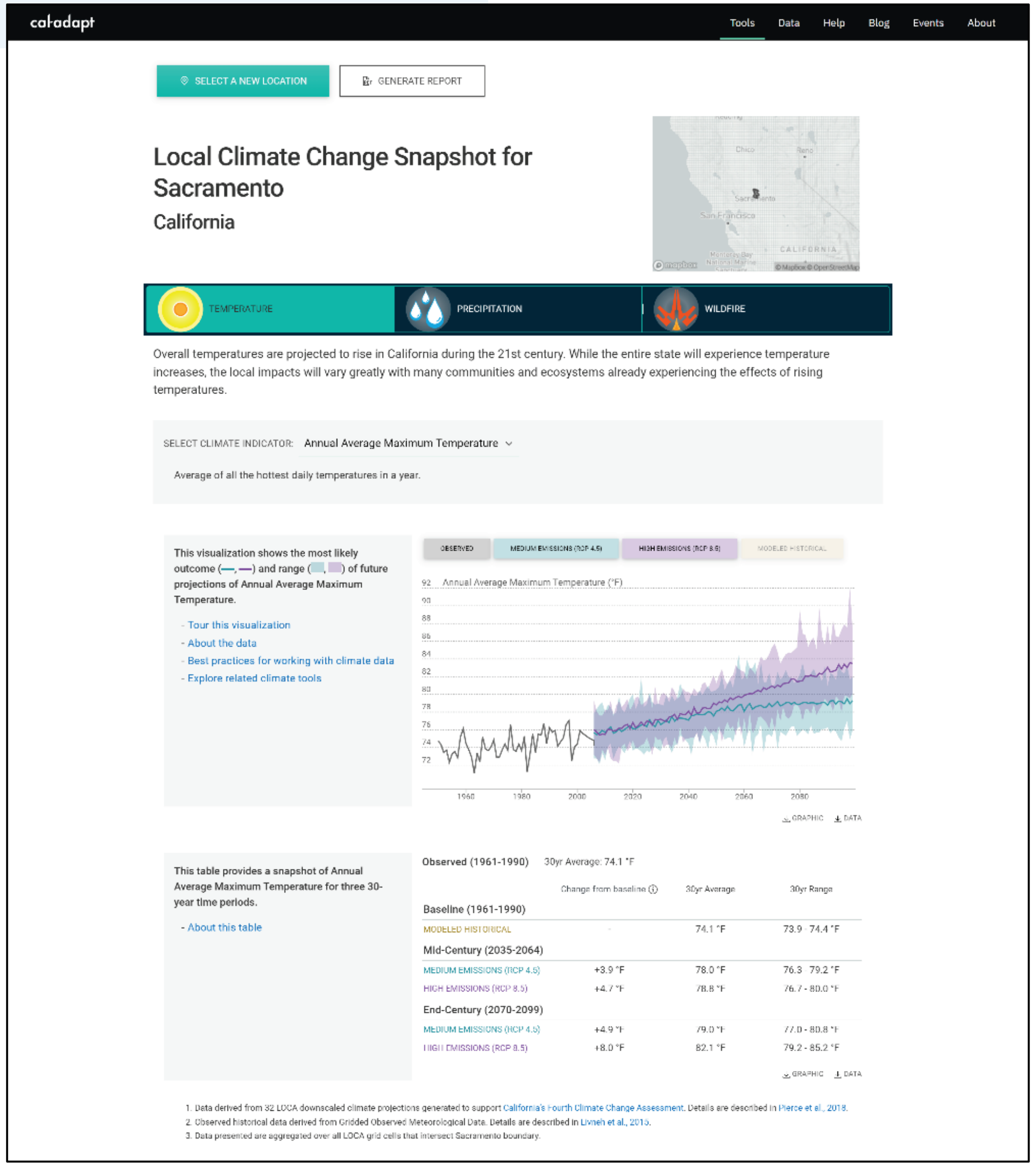
Change units: Metric

Select boundary: None

Select map view: SINGLE SWIPE

Download: IMAGES DATA

ABOUT THE TOOL



Local Climate Change Snapshot for Sacramento

California

Overall temperatures are projected to rise in California during the 21st century. While the entire state will experience temperature increases, the local impacts will vary greatly with many communities and ecosystems already experiencing the effects of rising temperatures.

SELECT CLIMATE INDICATOR: Annual Average Maximum Temperature

Average of all the hottest daily temperatures in a year.

This visualization shows the most likely outcome (—, —) and range (🟦, 🟪) of future projections of Annual Average Maximum Temperature.

- Tour this visualization
- About the data
- Best practices for working with climate data
- Explore related climate tools

This table provides a snapshot of Annual Average Maximum Temperature for three 30-year time periods.

- About this table

Observed (1961-1990) 30yr Average: 74.1 °F

	Change from baseline ⓘ	30yr Average	30yr Range
Baseline (1961-1990)			
MODELED HISTORICAL	-	74.1 °F	73.9 - 74.4 °F
Mid-Century (2035-2064)			
MEDIUM EMISSIONS (RCP 4.5)	+3.9 °F	78.0 °F	76.3 - 79.2 °F
HIGH EMISSIONS (RCP 8.5)	+4.7 °F	78.8 °F	76.7 - 80.0 °F
End-Century (2070-2099)			
MEDIUM EMISSIONS (RCP 4.5)	+4.9 °F	79.0 °F	77.0 - 80.8 °F
HIGH EMISSIONS (RCP 8.5)	+8.0 °F	82.1 °F	79.2 - 85.2 °F

GRAPHIC DATA

1. Data derived from 32 LOCA downscaled climate projections generated to support California's Fourth Climate Change Assessment. Details are described in Pierce et al., 2018.
2. Observed historical data derived from Gridded Observed Meteorological Data. Details are described in Livneh et al., 2015.
3. Data presented are aggregated over all LOCA grid cells that intersect Sacramento boundary.

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Contact

✉ **Tom Wall, Ph.D.** twall@anl.gov

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Supplemental Material

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

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.

Poll Question - Figure

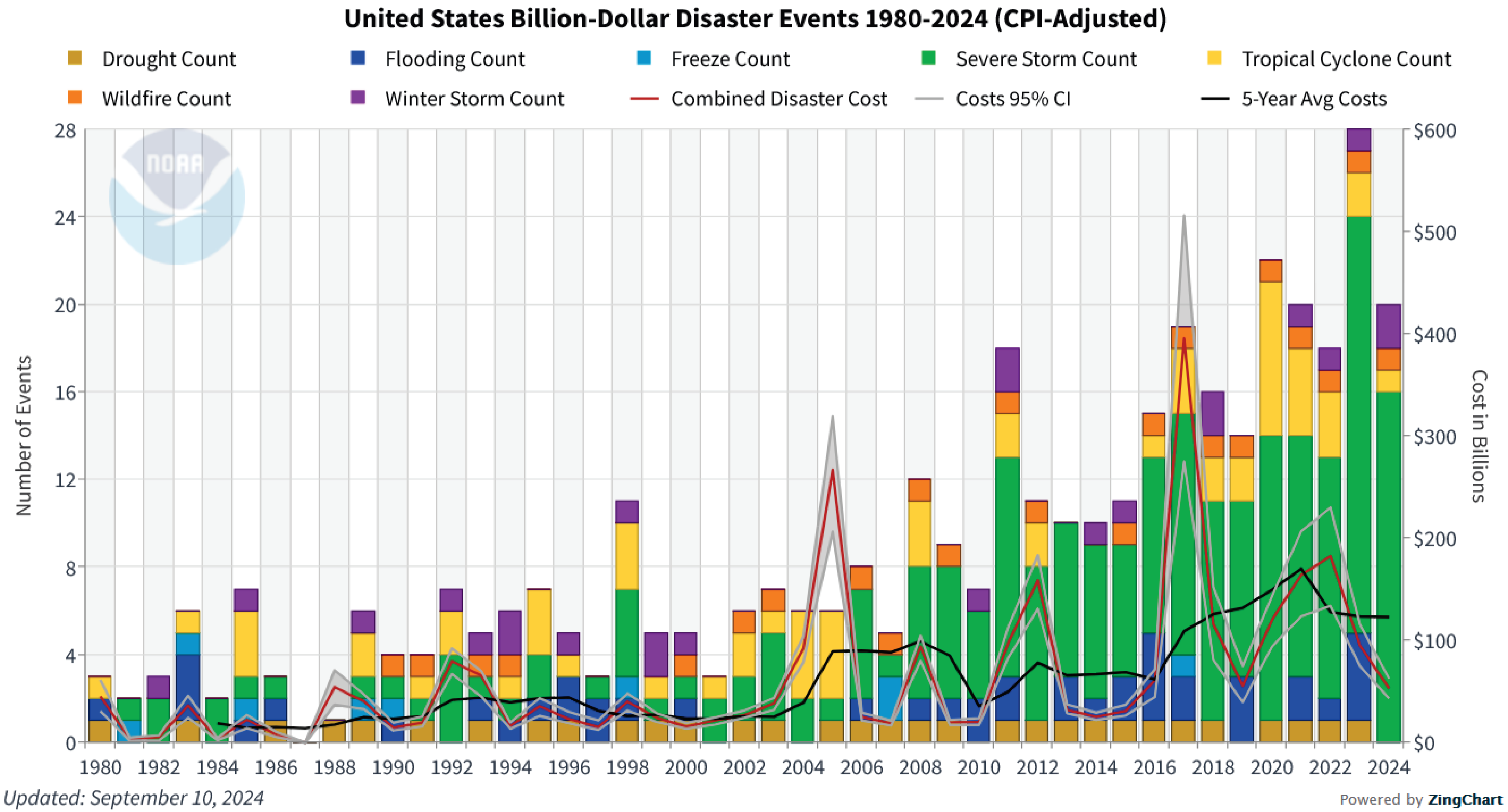


Image: https://www.ncei.noaa.gov/access/billions/time-series

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

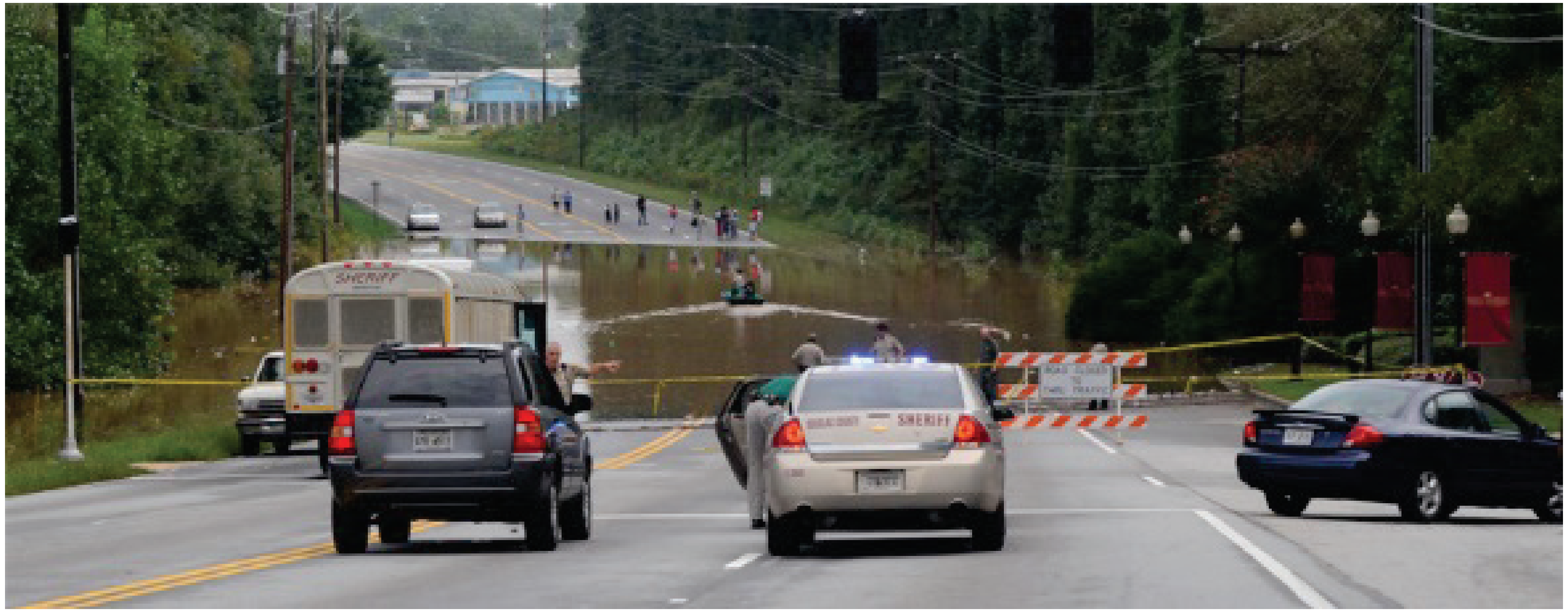


Image: http://hyperphysics.phy-astr.gsu.edu/Nave-html/S09/flood.html

Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity

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

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

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.

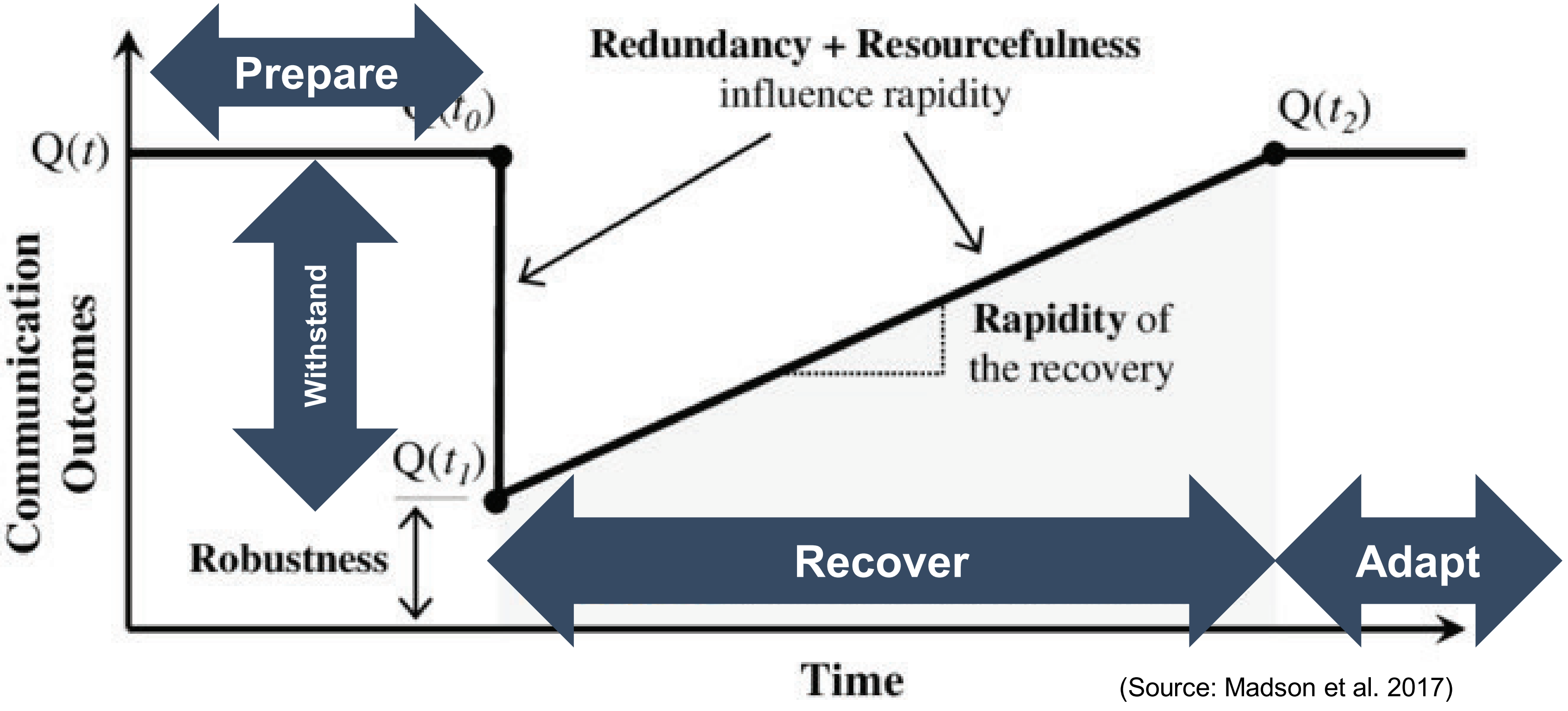
Source: The White House, PPD-21

Assessing Infrastructure Vulnerability

Thinking About Vulnerability and Risk through the Lens of Resiliency

Resilience Elements

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



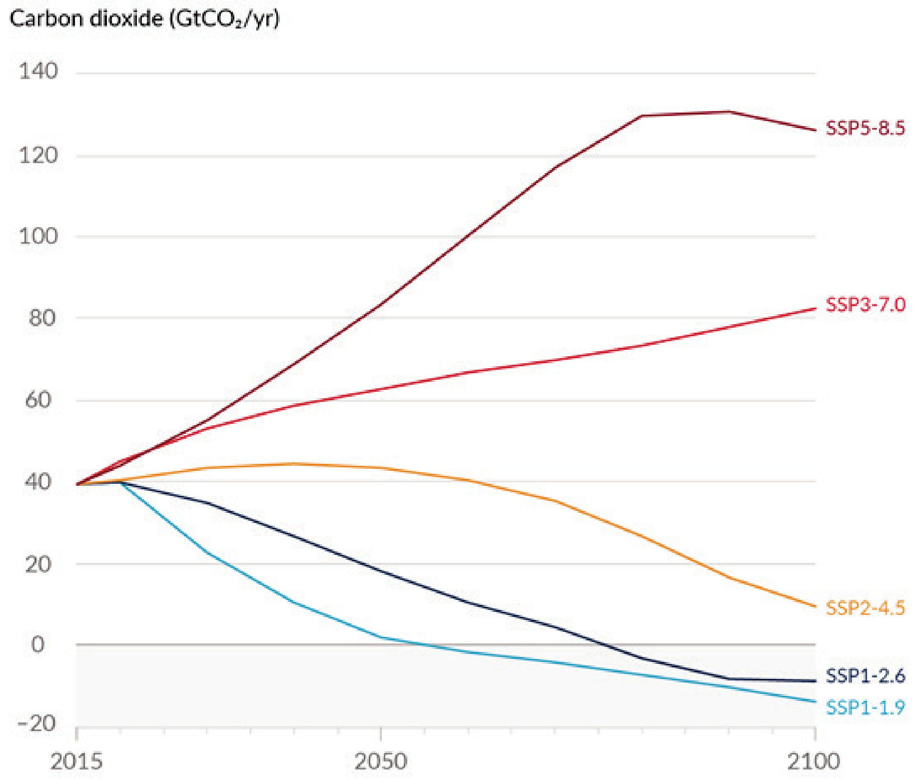
(Source: Madson et al. 2017)

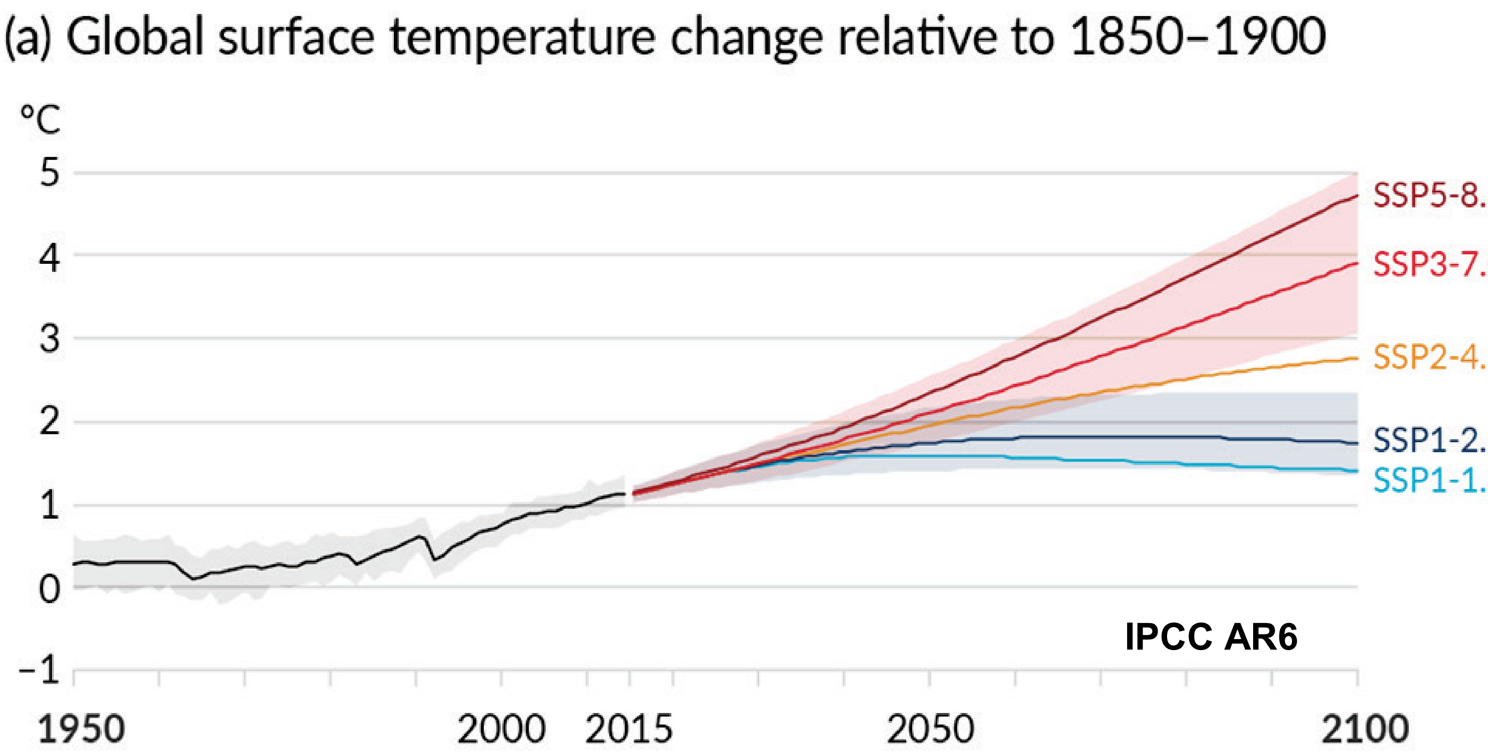
- Recall: Per ISO31000:2018, *risk evaluation* determining if/what actions
- Nichole Hanus will cover some of this in her talk later today

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



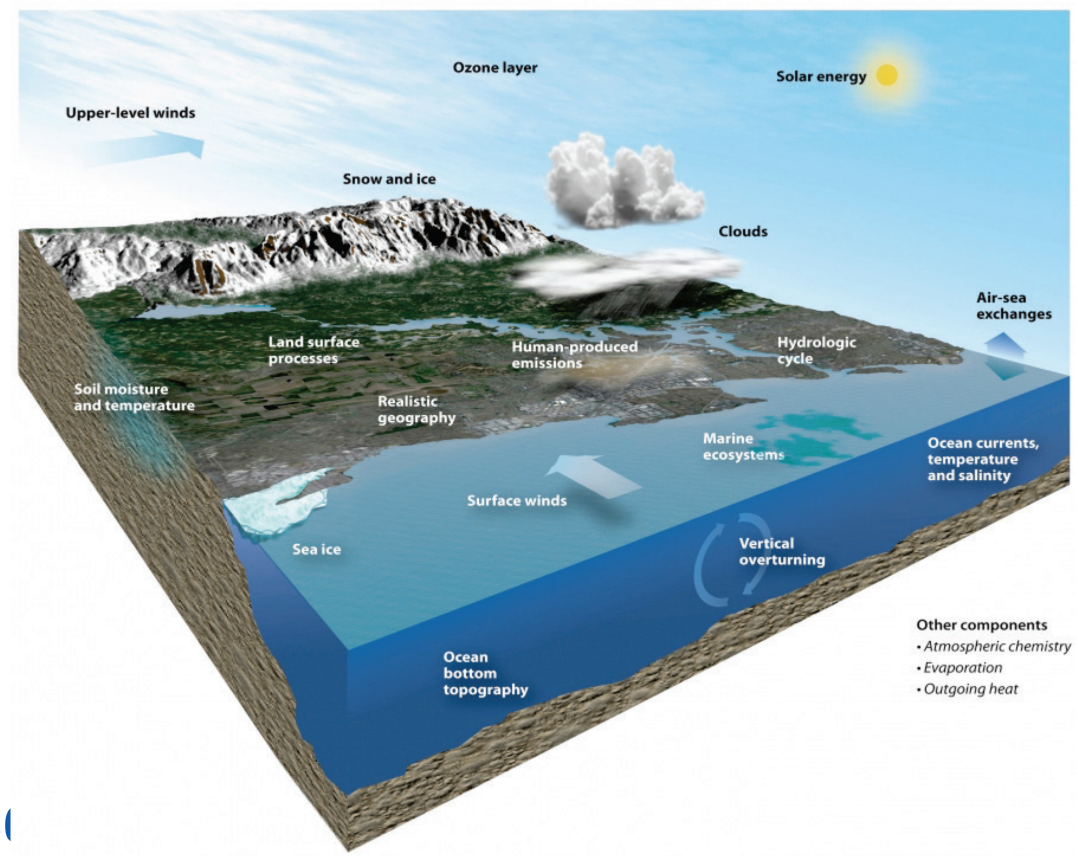


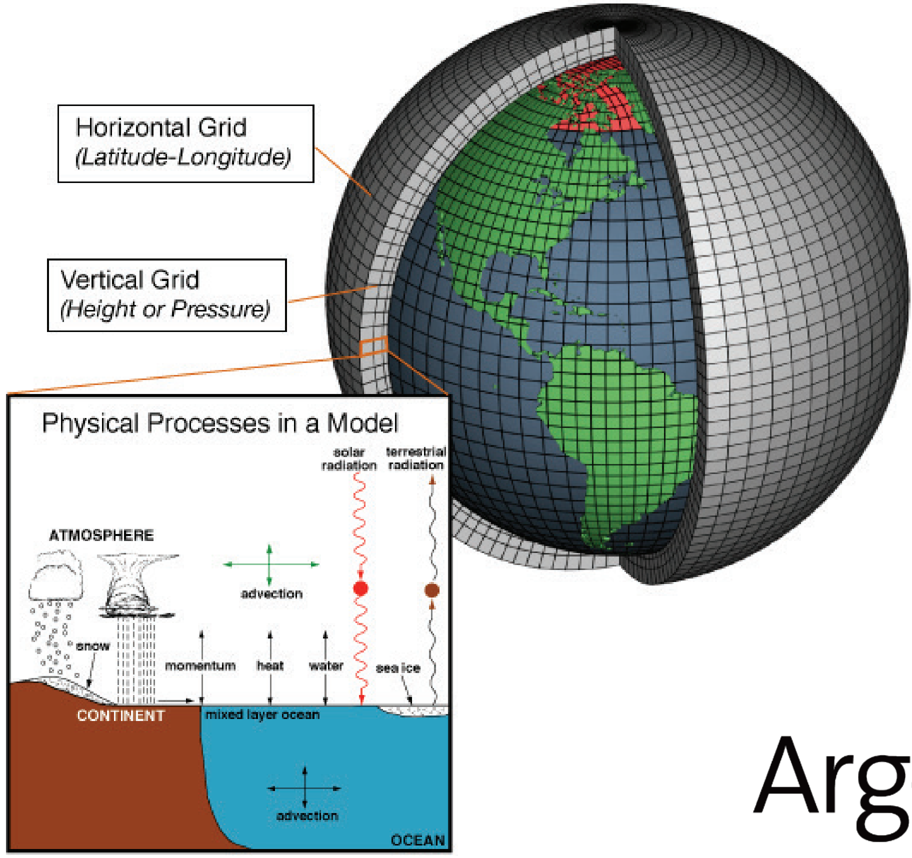
Images: https://www.ipcc.ch/report/ar6/wg1/figures/summary-for-policymakers

Climate Science & Modeling 101

Global Climate Models

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



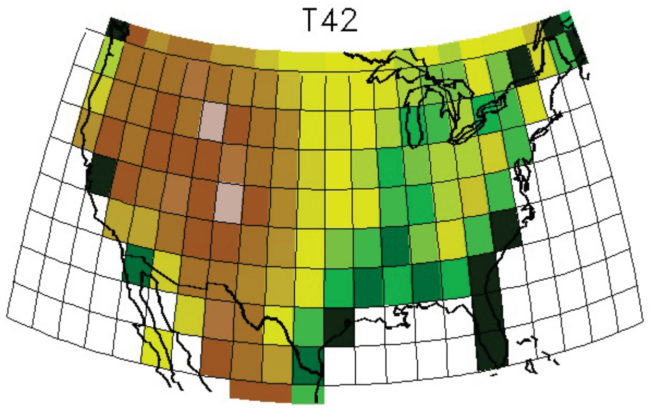


Images: https://scied.ucar.edu/image/community-earth-system-model; https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-models

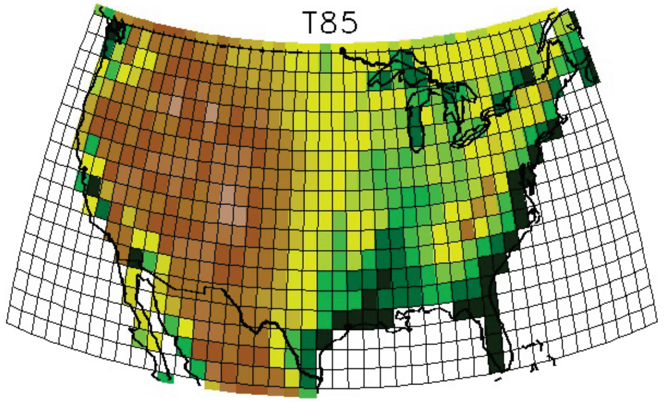
Climate Science & Modeling 101

Global Climate Models

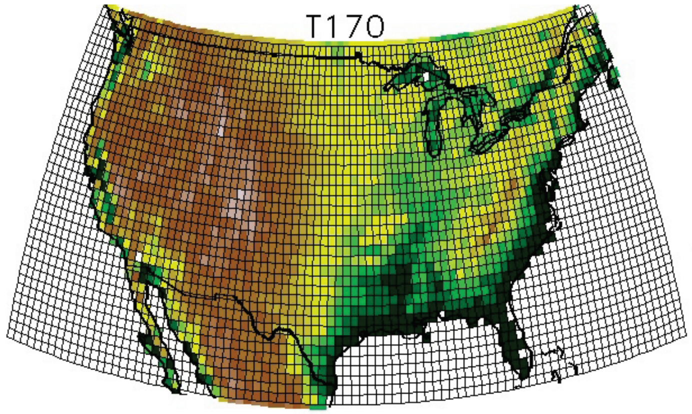
- As computing resources have improved over time, models have become increasingly complex and more detailed
- Smaller grid squares or “pixel sizes” enable more place-specific and detailed projections of locally relevant climate



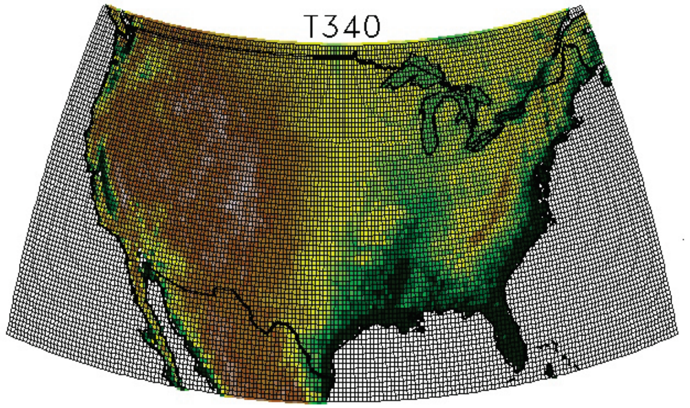
Mid-1990s 200~300 kms



2000s 100~150 kms



Current 50~100 kms



Future. 25~40 kms

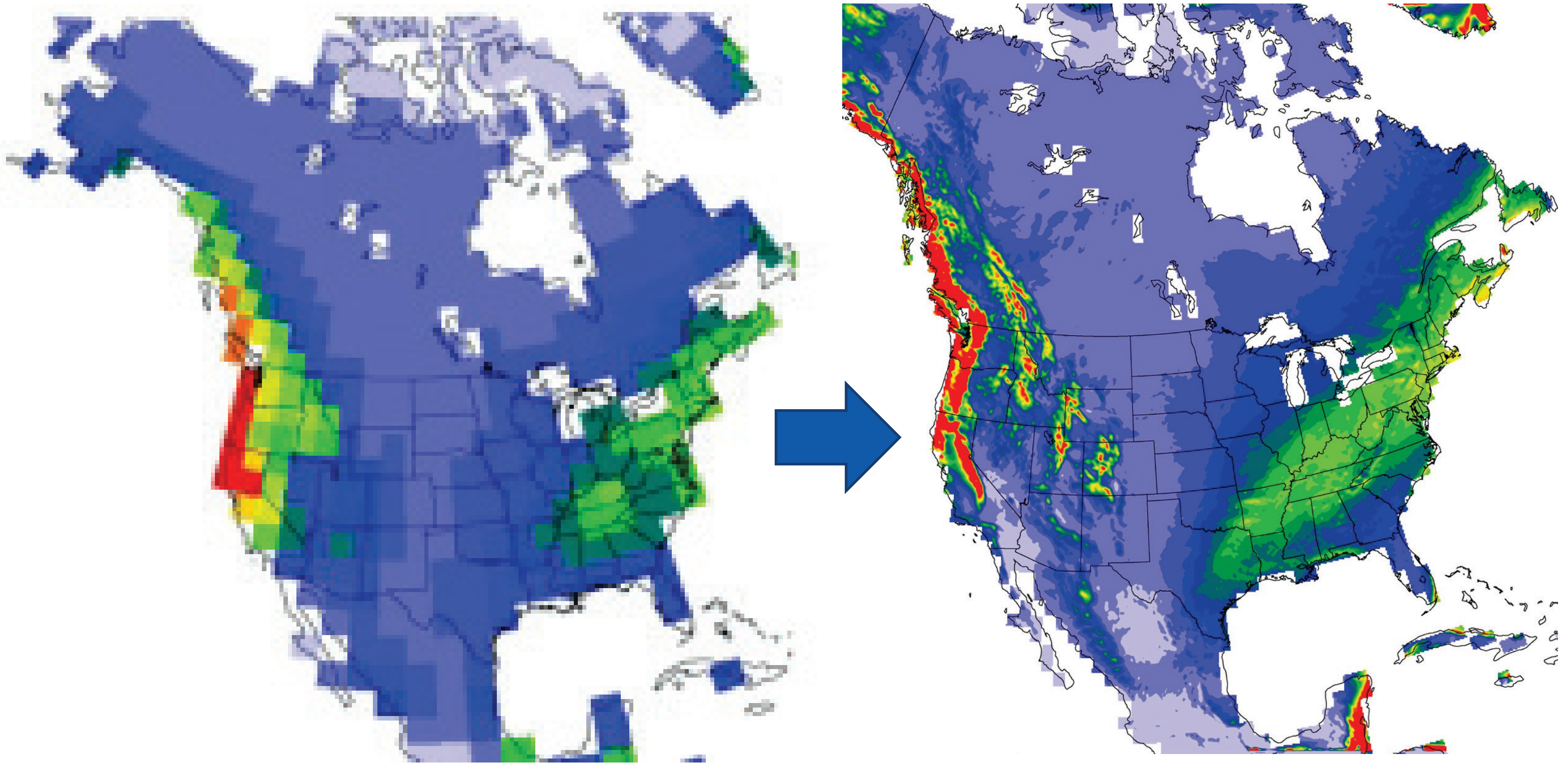
Image: https://eo.ucar.edu/staff/rrussell/climate/modeling/climate_model_resolution.html

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.

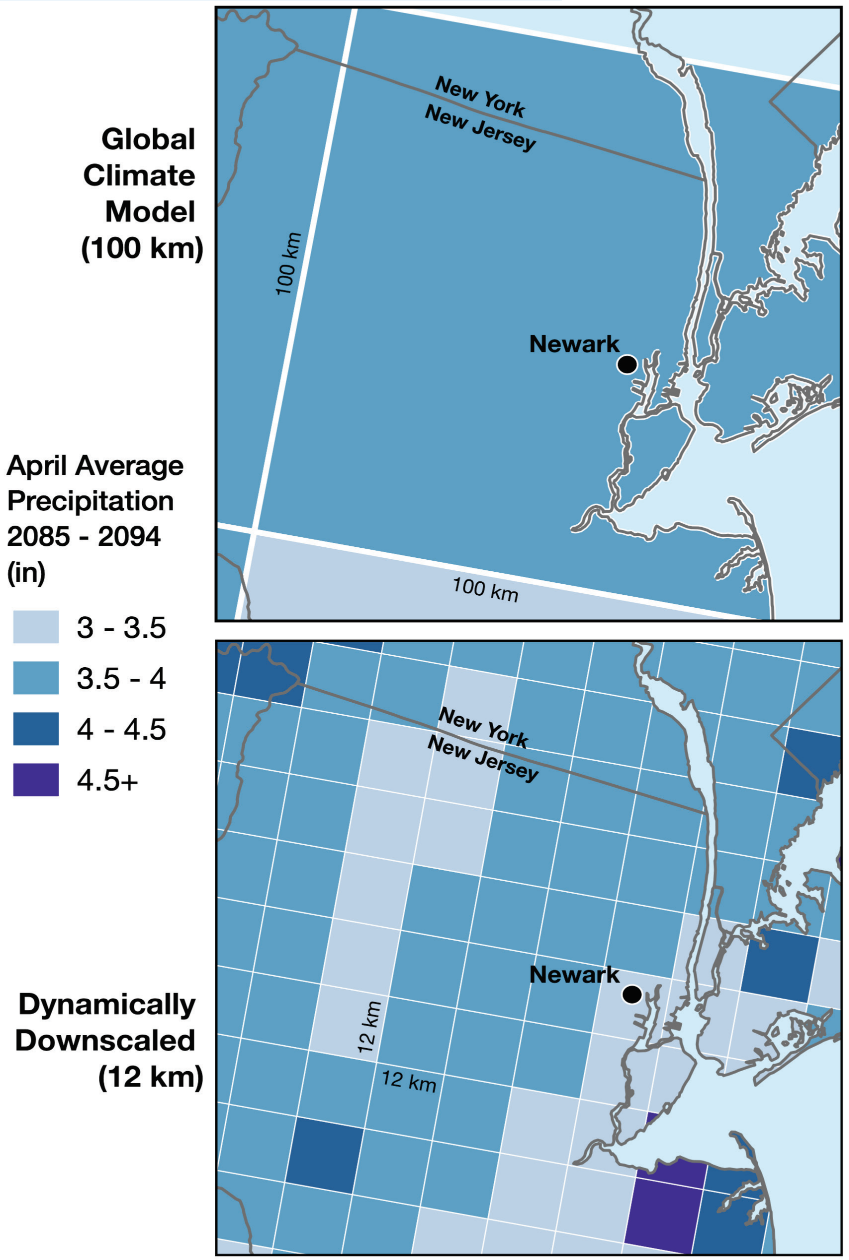


Source: Copernicus.EU, Undated
Images: Argonne National Laboratory

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



Images: Argonne National Laboratory

Climate Science & Modeling 101

Example: Dynamical downscaling at Argonne National Laboratory

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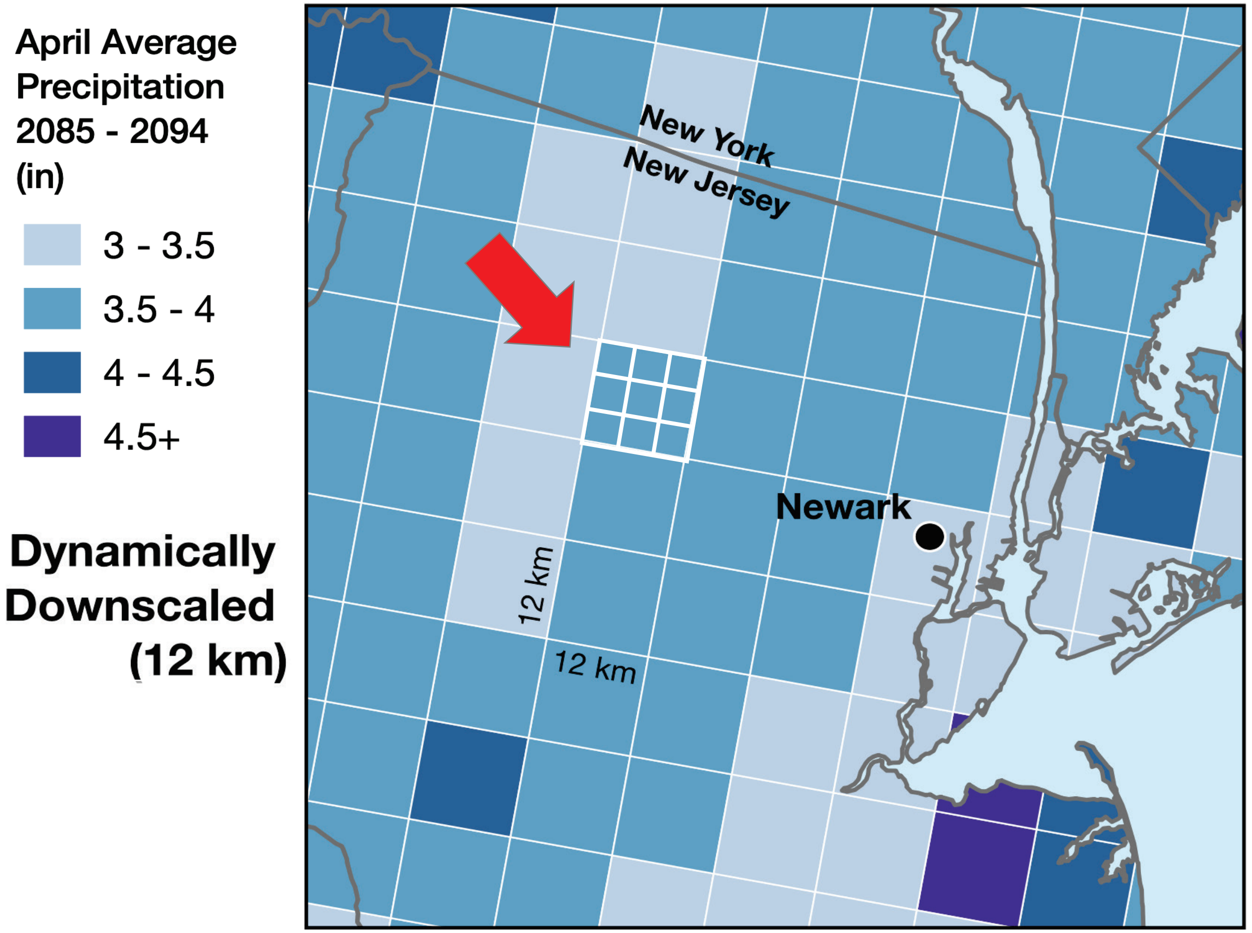
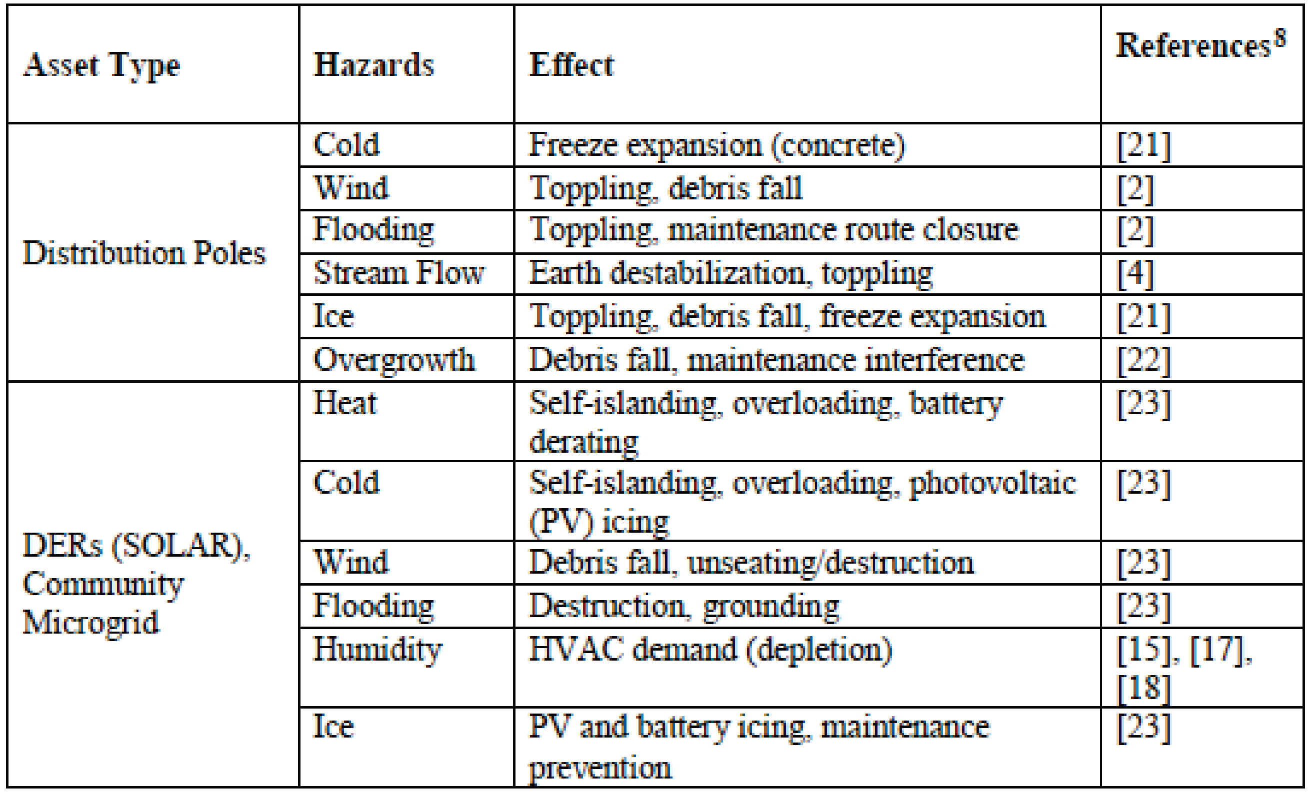


Images: Argonne National Laboratory

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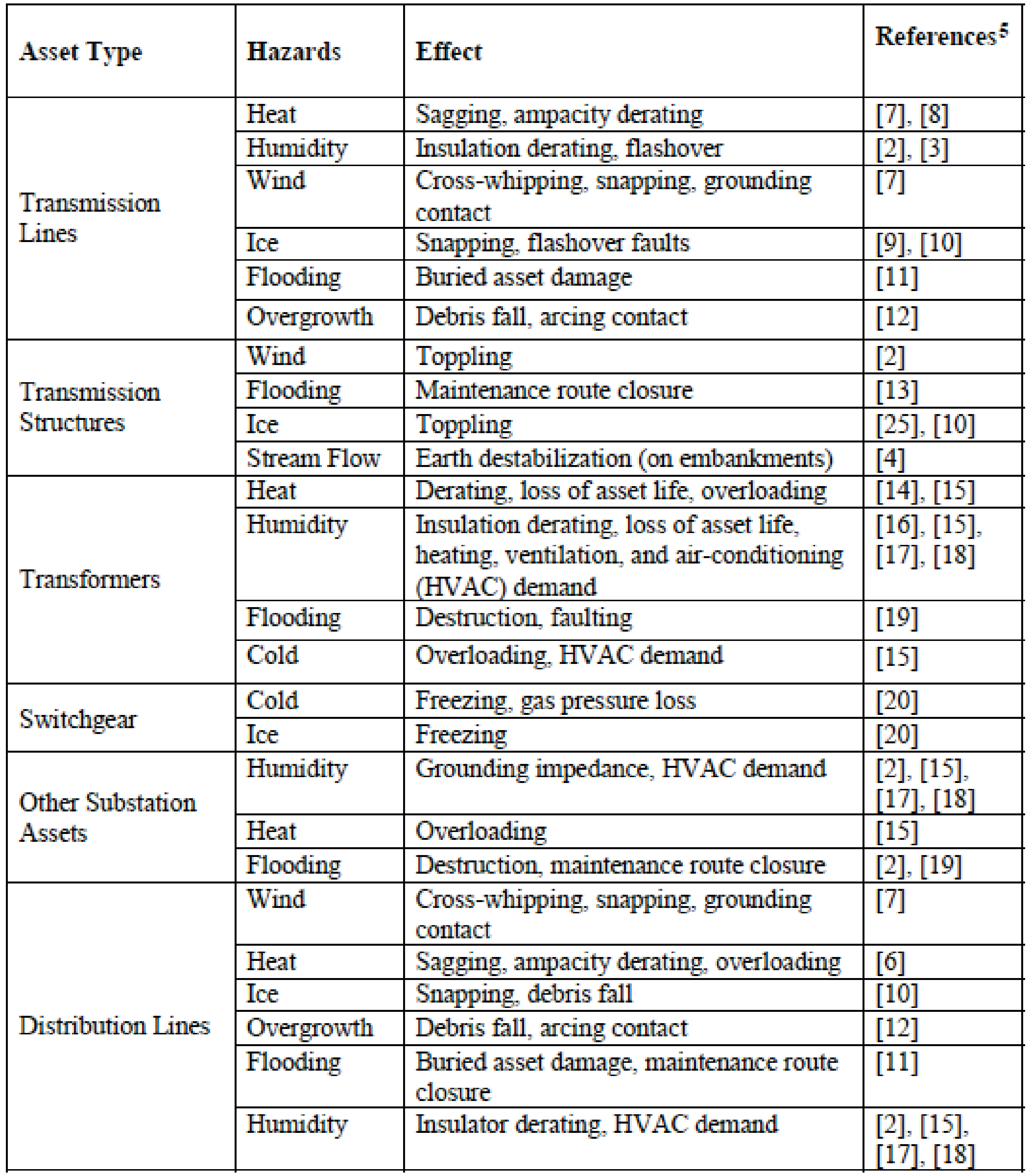
Image: https://commons.wikimedia.org/wiki/File:Underwater_substation,_Cedar_Rapids,_June_12_2008.jpg



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]

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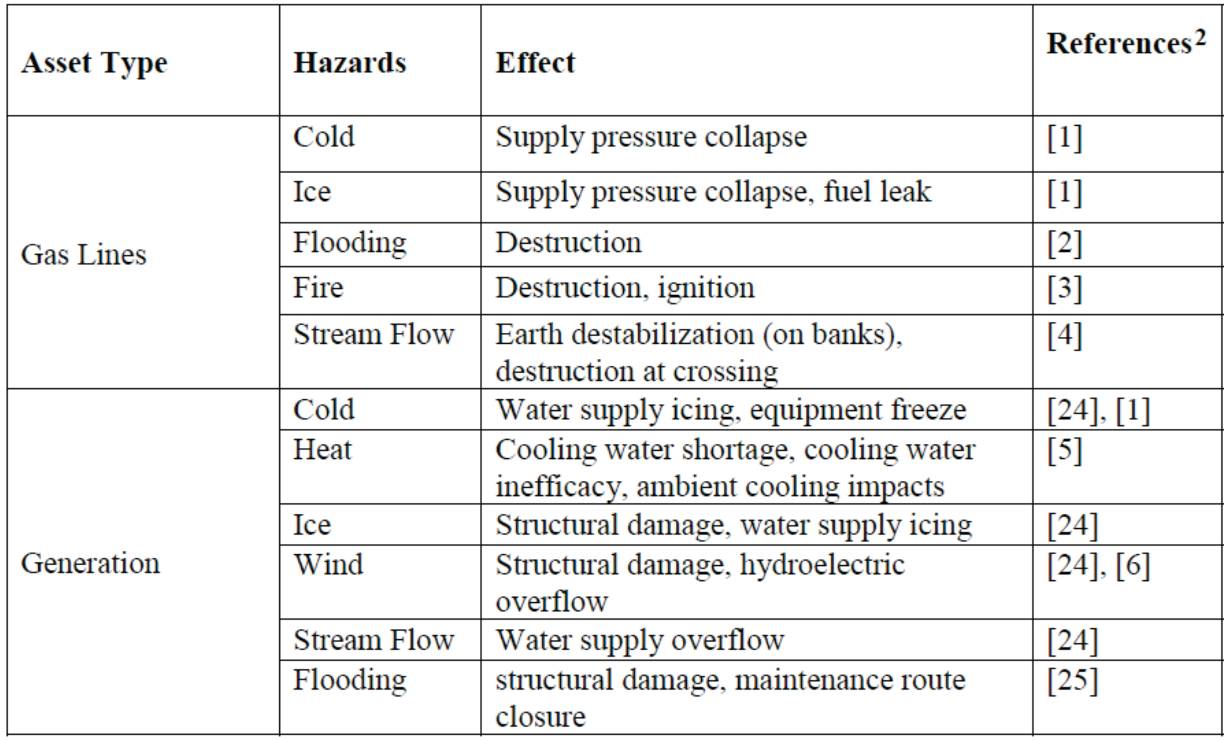

Asset Type	Hazards	Effect	References[2]
Gas Lines	Cold	Supply pressure collapse	[1]
	Ice	Supply pressure collapse, fuel leak	[1]
	Flooding	Destruction	[2]
	Fire	Destruction, ignition	[3]
	Stream Flow	Earth destabilization (on banks), destruction at crossing	[4]
Generation	Cold	Water supply icing, equipment 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)

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