

Connecting Climate to Weather Extremes to Damages:

Lessons from Large Power Transformers to the Utility-Scale

ESIG SUMMER WORKSHOP: DAMAGE PREDICTION
FROM EXTREME WEATHER EVENTS

DENVER, CO
JUNE 15, 2026

POTENTIAL IMPACTS OF CLIMATE WARMING AND INCREASED SUMMER
HEAT STRESS ON THE ELECTRIC GRID: A CASE STUDY FOR A LARGE POWER
TRANSFORMER (LPT) IN THE NORTHEAST UNITED STATES: X. GAO, C. A.
SCHLOSSER AND E. MORGAN, CLIMATIC CHANGE,
[HTTPS://DOI.ORG/10.1007/S10584-017-2114-X](https://doi.org/10.1007/s10584-017-2114-x)



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with Xiang Gao and Eric Morgan

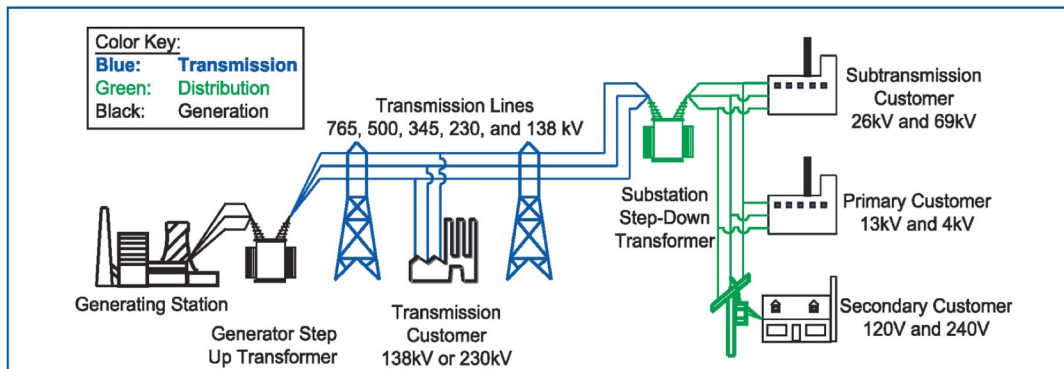
Along with colleagues and support from:



Center for
Sustainability Science
and Strategy



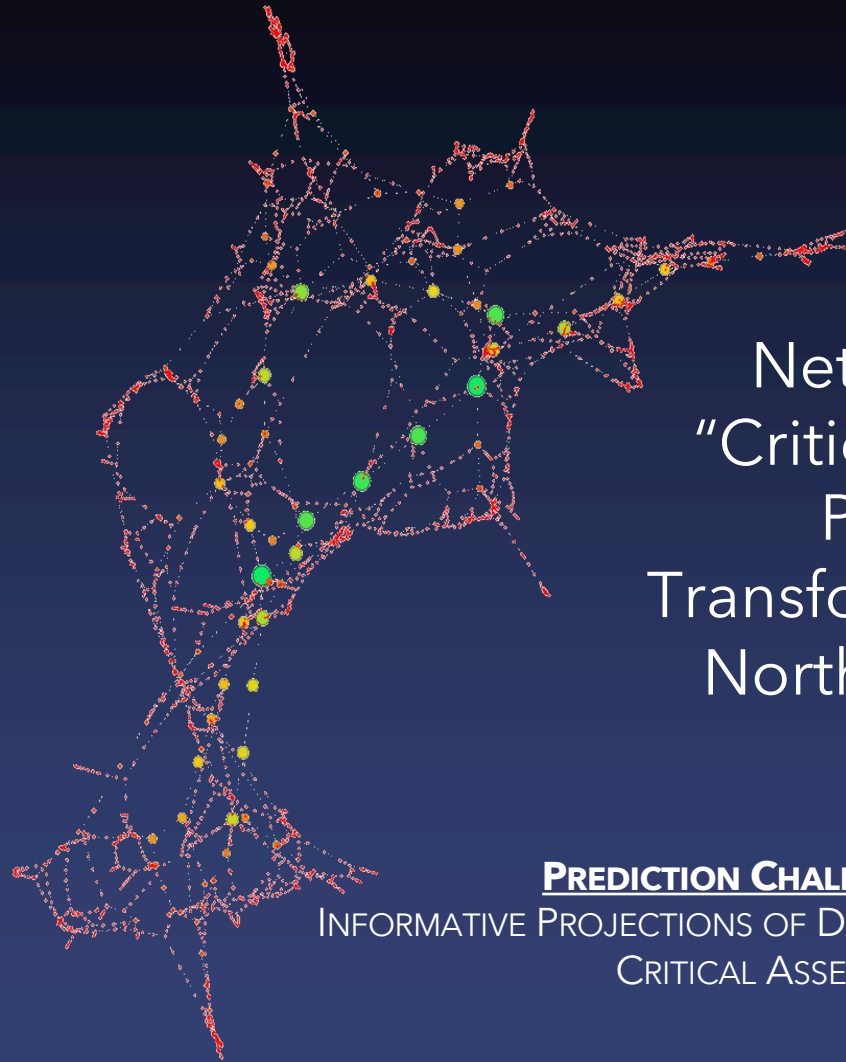
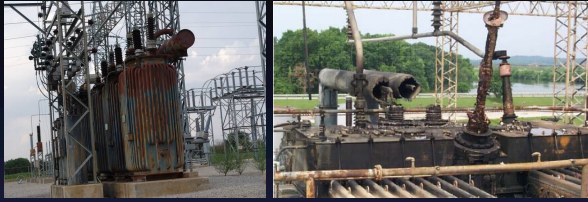
Why Large Power Transformers?



Step-up and step-down transformers are critical junctures within the system to deliver electricity to consumers. Failure of units represent substantial collateral risks to grid operation.

Voltage Rating (Primary-Secondary)	Capability MVA Rating	Approximate Price (\$)	Approximate Weight & Dimensions
Transmission Transformer			
Three Phase			
230–115kV	300	\$2,000,000	170 tons (340,000 lb) 21ft W–27ft L–25ft H
345–138kV	500	\$4,000,000	335 tons (670,000 lb) 45ft W–25ft L–30ft H
765–138kV	750	\$7,500,000	410 tons (820,000 lb) 56ft W–40ft L–45ft H
Single Phase			
765–345kV	500	\$4,500,000	235 tons (470,000 lb) 40ft W–30ft L–40ft H
Generator Step-Up Transformer			
Three Phase			
115–13.8kV	75	\$1,000,000	110 tons (220,000 lb) 16ft W–25ft L–20ft H
345–13.8kV	300	\$2,500,000	185 tons (370,000 lb) 21ft W–40ft L–27ft H
Single Phase			
345–22kV	300	\$3,000,000	225 tons (450,000 lb) 35ft W–20ft L–30ft H
765–26kV	500	\$5,000,000	325 tons (650,000 lb) 33ft W–25ft L–40ft H

- Up to tens of thousands of LPT's (≥ 100 MVA) in America,
- LPTs are aging – increase risk in failure and replacement.
- Manufacturing custom designed, lengthy, and costly.
- Units heavy and increasingly built outside U.S.



Network of "Critical" Large Power Transformers over Northeast U.S.

PREDICTION CHALLENGE:
INFORMATIVE PROJECTIONS OF DAMAGING EVENTS TO
CRITICAL ASSETS

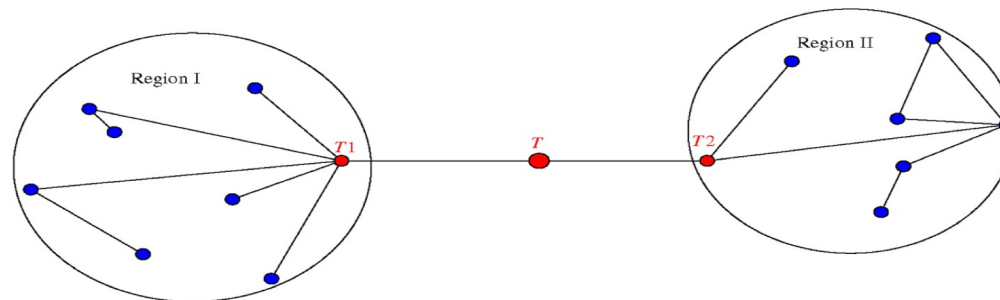
NEEDS TO BE RISK-BASED...

NORTHEAST U.S. POWER GRID: DETERMINE CRITICAL JUNCTURES VIA "BETWEENNESS" DIAGNOSES

United States electric grid is among the largest connected networks of machines on the planet, consisting of over 50,000 substation locations and connected by over 200,000 miles of transmission lines.

"Betweenness centrality" of a node - a measure of the network's connectivity. Use this for transformers since high betweenness has been shown to be a meaningful parameter for cascading failures in the North American power grid.

Treat electrical grid as a series of nodes (transformers) and edges (transmission lines) so that basic mathematical analysis can be performed.



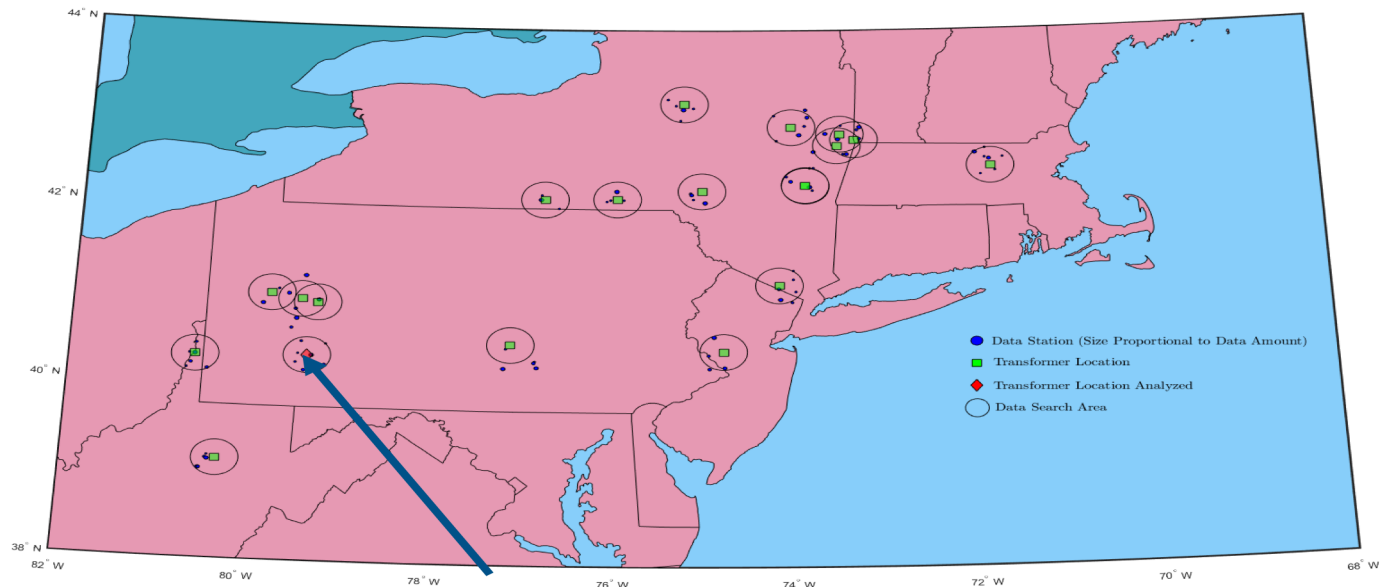
In the above example, node "T" has high betweenness even though it has only a few direct neighbors. Removing "T" severs the network between the subnetworks

Formally speaking, the betweenness of any node, v , measures the fraction of shortest paths flowing through that node, or:

$$g(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

where σ_{st} is the total number of shortest paths between nodes s and t and $\sigma_{st}(v)$ is the total number of shortest paths from s to t via v .

Transformer Locations and Corresponding Weather Data

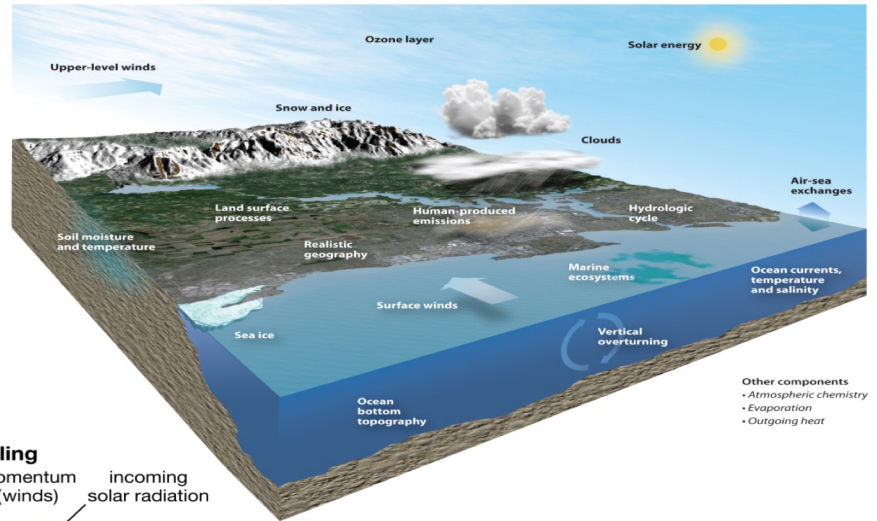
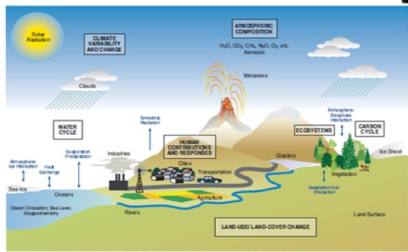
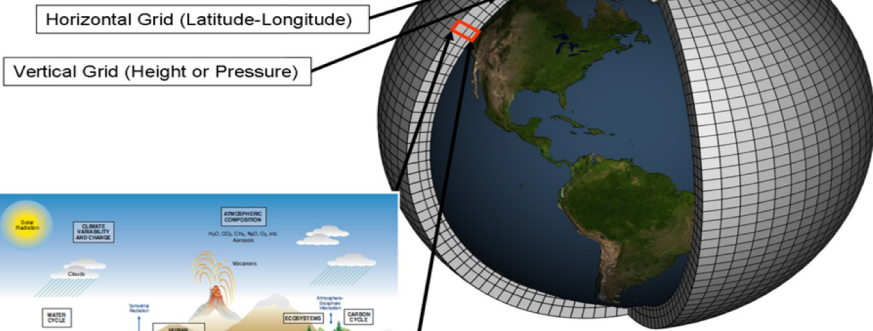


TRANSFORMER IN PA SELECTED FOR CASE STUDY

FOCUS ON OCCURRENCE OF 90+ °F MAX. TEMPERATURE DAYS

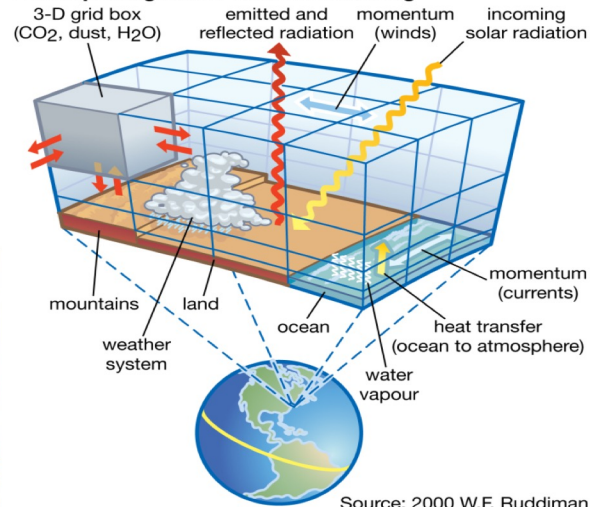
Extreme Events: The Prediction Challenge

Schematic for Global Climate Model

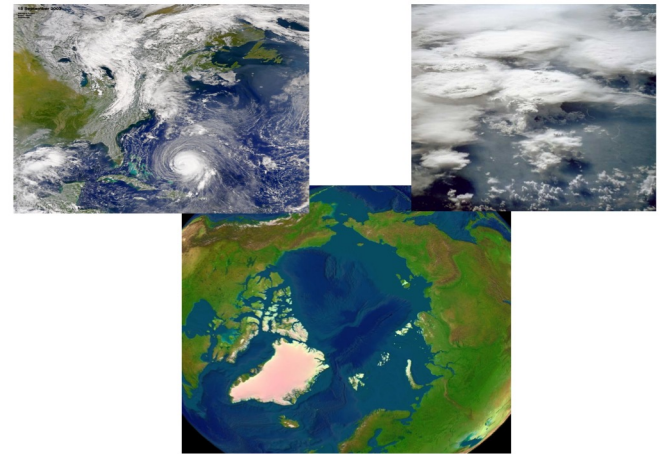


Other components
 • Atmospheric chemistry
 • Evaporation
 • Outgoing heat

Concept diagram of climate modeling



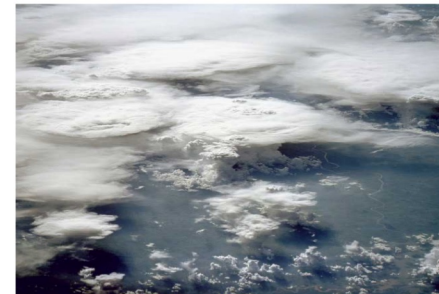
Source: 2000 W.F. Ruddiman



PROJECTION OF CHANGES IN EXTREME EVENTS THROUGH AN ANALOGUE LENS

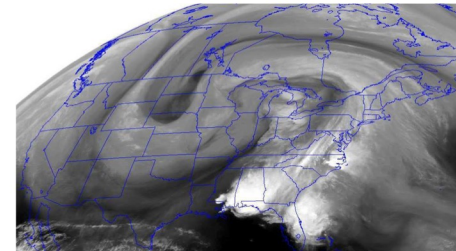
Analogue (or analog): *noun* - something seen as comparable to another; *adjective* - relating or using signals or information represented by a continuously variable physical quantity.

Focus more on event of concern or threat - rather than generalized description in space and time.



Gao X. and C.A. Schlosser, 2018: Mid-Western U.S. Heavy Summer-Precipitation in Regional and Global Climate Models: The Impact on Model Skill and Consensus Through an Analogue Lens, *Climate Dynamics* (online first doi: 10.1007/s00382-018-4209-0).

Gao, X., C. A. Schlosser, P. O’Gorman, E. Monier, and D. Entekhabi, 2017: 21st Century Changes in Heavy Precipitation Frequency Based on Resolved Atmospheric Patterns over the United States, *J. Climate*, doi: <http://dx.doi.org/10.1175/JCLI-D-16-0544.1>.



HEAT-WAVE DETECTION COMPOSITES FOR TRANSFORMER LOCATED IN CENTRAL PA

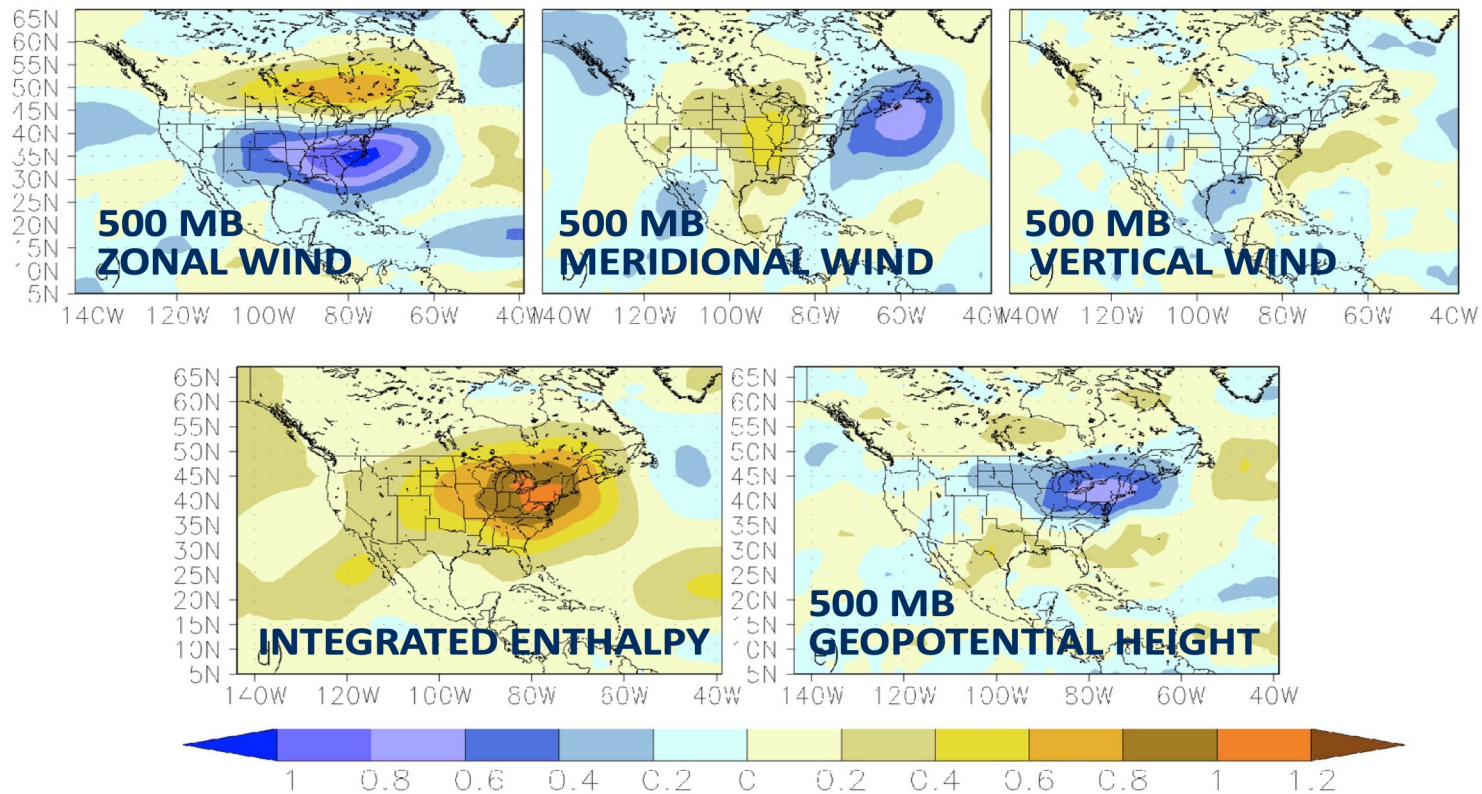
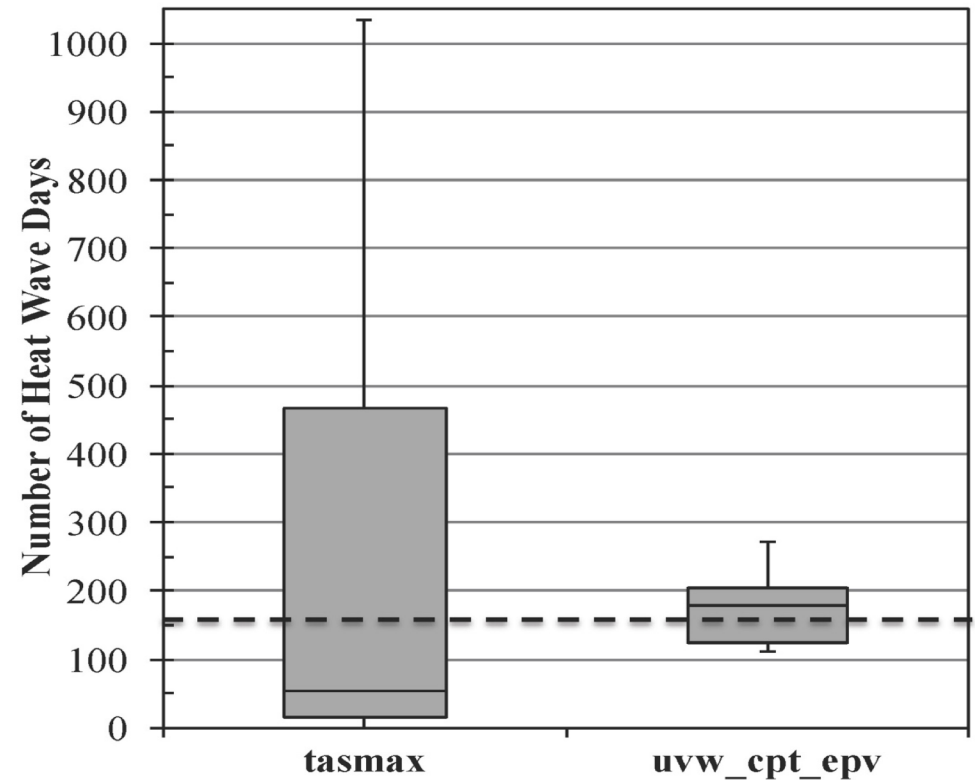


Fig. 6: Composite fields as normalized anomalies at $2.5^\circ \times 2^\circ$ for the transformer T2 in JJA: a) 500hPa zonal velocity (u_{500}); b) 500hPa meridional velocity (v_{500}); c) 500hPa vertical pressure velocity (w_{500}); d) vertically integrated enthalpy; and e) 500hPa based on 157 heat wave days.

CONTEMPORARY SYNTHESIS AND FUTURE PROJECTIONS USING CMIP5 MODELS

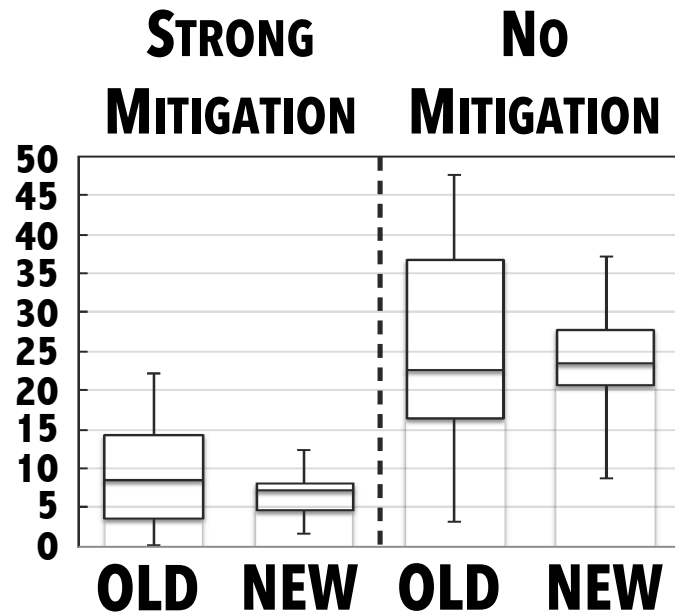
HISTORICAL EVALUATION:
ANALOGUE SHARPENS THE
REPRODUCTION OF HEAT-
WAVE OCCURRENCE
COMPARED TO THAT BASED ON
EXPLICIT SURFACE-AIR
TEMPERATURE (SAT)



WE ARE ADVANCING METHODS TO IMPROVE CONSENSUS AND SKILL IN CLIMATE PREDICTIONS OF "DAMAGING" (EXTREME) EVENTS

APPLY APPROACH TO LOCATION AND SPECIFICATIONS OF "CRITICAL" INFRASTRUCTURE AND INSTALLATIONS OF INTEREST.

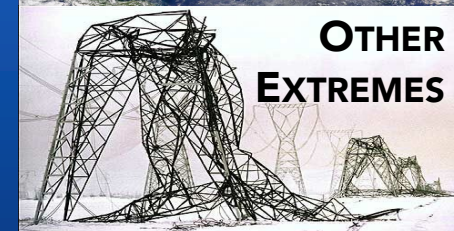
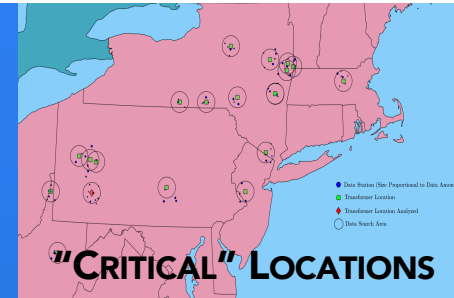
**Change in
"Damaging" Heat
Wave Frequency
Per Year
by late 21st
Century**



Case Study on Extreme Summer Heat and Large Power Transformers

MITIGATION - UNDERLYING RISK IS LIKELY TO BE DOUBLED.

NO ACTIONS - RISK COULD BE QUADRUPLED.





Key Results:

- Under the most aggressive mitigation pathways – the underlying risk from heat waves is likely to be doubled going into the latter decades of this century. If no actions taken the risk could be quadrupled.
- Analogue method complements central tendency of explicit simulation/prediction – most notably model consensus is substantially strengthened, with inter-quartile range reduced by a factor of 3.

Ongoing and Future Work and Long-Term Vision:

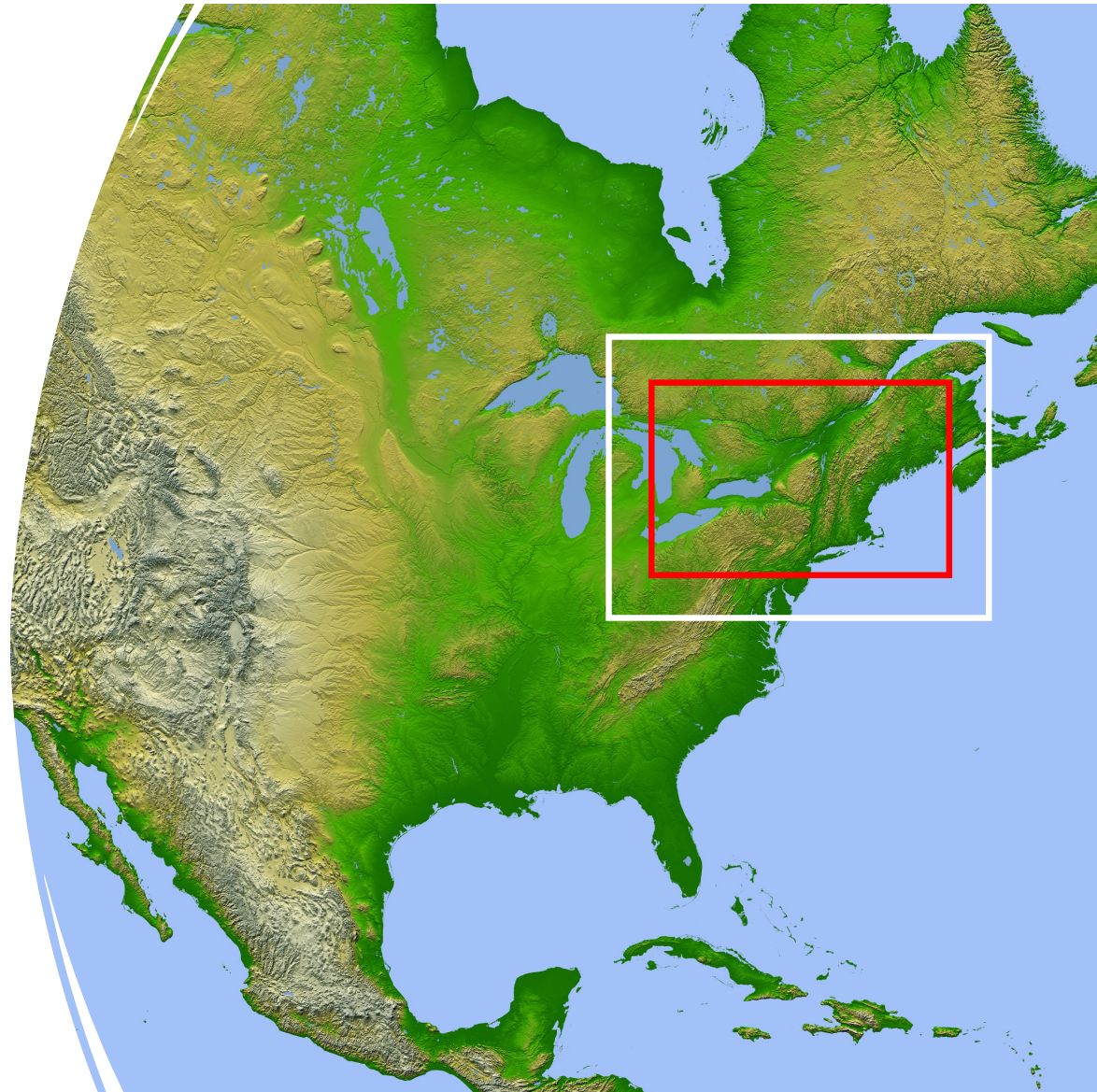
- Consider network of LPTs – as well as region and ISO aggregates.
- Consider additional attributes of LPTs and/or grid to identify “critical” locations/threats.
- More data(!), details, and additional extreme environmental threats (e.g. floods, storms, wildfires, etc.)
- Leverage AI/ML-based methods to improve precision and workflow.

An MIT/Joint-Utility Project
The Northeast United States Dynamically
Downscaled Data (NEUS-D3)

C. Adam Schlosser and Sandeep Chinta

Project Elements and Underpinning Aspects:

- Update prior 2021 study conducted
- Provide expanded set of outputs/metrics
- Accessibility of model outputs and analyses
- Address structural uncertainty in downscaling
- Establish capacity for further enhancements
- Historical and future simulations
- Innermost domain at 3km resolution
- AI-powered 1km detail in subsequent phases





GLOBAL-SCALE CHALLENGE : SUSTAIN THE CHANGING, GROWING, COMPLEX, AND LINKED SYSTEMS OF THE NATURAL, MANAGED, AND BUILT ENVIRONMENTS

INTEGRATION OF CLIMATE SCIENCE, ENGINEERING, ECONOMICS, MACHINE LEARNING, AI, DECISION-MAKING, TECHNOLOGY, POLICY, POLITICS, AND EDUCATION. **BRINGING THIS ALL TO SCALE...**



THANK YOU

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