



# ENERGY SECTOR RESILIENCE: FROM DATA AND TOOLS TO SOLUTIONS

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23 June 2016

# AGENDA

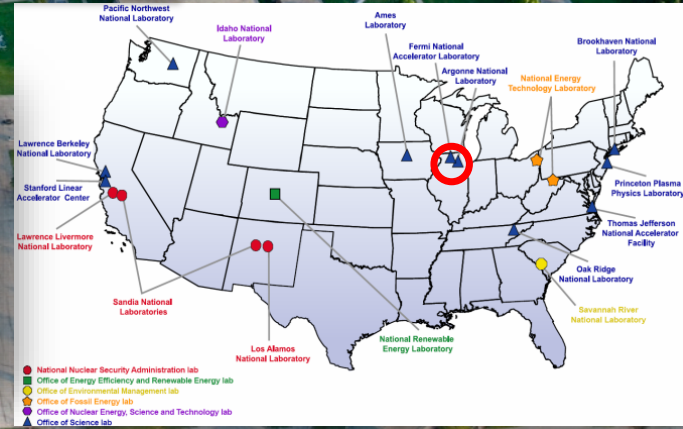
- Introduction and Background
- Why is resilience a concern
- Resilience definition and resilience modeling
- Tools and data used for resilience analysis
- Examples of recent U.S. applications
- Model applications in Asia
- Questions





# Argonne Campus

- Founded in 1943, designated a national laboratory in 1946
- Part of the U.S. Department of Energy (DOE) laboratory complex
  - 17 DOE National Laboratories
- Managed by UChicago Argonne, LLC
  - About 3,400 full-time employees
  - 5,000+ facility users
  - About \$800M budget
  - Main site: 1500-acre site in Illinois, southwest of Chicago





# ENERGY RESILIENCE IS PART OF ARGONNE RESILIENCE INITIATIVE

<http://www.anl.gov/egs/group/resilient-infrastructure>



## ARGONNE RESILIENT INFRASTRUCTURE INITIATIVE

Argonne will reduce the risk to lives and property by

- Advancing the science and technology needed to enable the resilient design of future critical infrastructure systems
- Leading an integrated, national effort to create resilient infrastructure that is adaptable and robust to respond to future demands

# ARGONNE HAS BROAD ENERGY RESILIENCE CAPABILITIES

## From Development of Advanced Algorithms and Models to Commercialization and Deployment

### Advanced Algorithms

- Predictive modeling
- Advanced math/solvers
- Scalable solutions for optimization
- Integrative Frameworks

### Model Development

- Resource optimization
- Stochastic UC/operations
- Power market tools
- Large-scale grid tools

### Model Applications

- Integration studies
- Power market design
- Long-term investment dynamics
- Grid resilience, cascading failures power system restoration
- Storage value/impacts
- Climate change impacts

### Deployment

- EPPFAST/NGFAST/POLFAST
- HEADOUT, RESTORE, EGRIP
- GTMax/ EMCAS/CHEERS
- EISPC

Useful

Useable

USED



# ARGONNE HAS BROAD ENERGY RESILIENCE CAPABILITIES

## From Scenario Definition to System Restoration: EXAMPLE for Electric Power

### Scenario Definition

- Describe plausible triggering event, such as weather/climate (hurricanes, ice storms, tornados), earthquakes, cyber, others



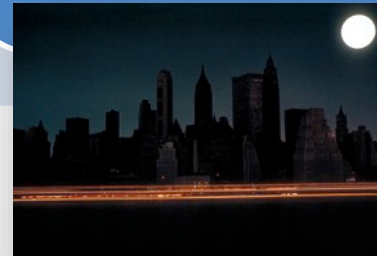
### Physical Impact Assessment

- Using fragility curves, assess physical damage to relevant infrastructure, including generators, towers/poles, wires, substations, fuel infrastructure (natural gas, coal, petroleum, etc.)



### System Modeling

- Model impact of loss of fueling infrastructure
- Model impact of loss of multiple grid assets
- Determine potential islanding and extent of blackout

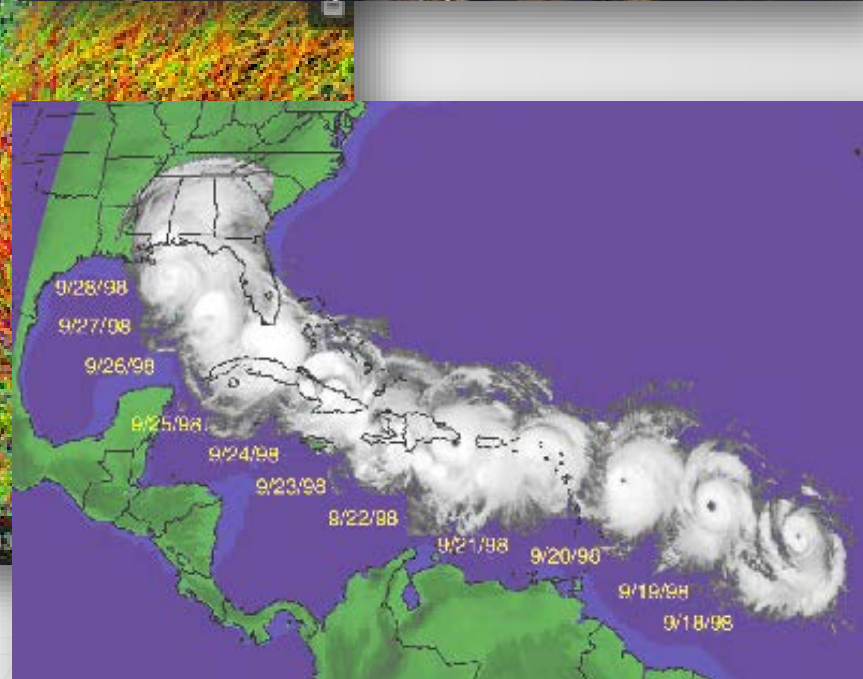
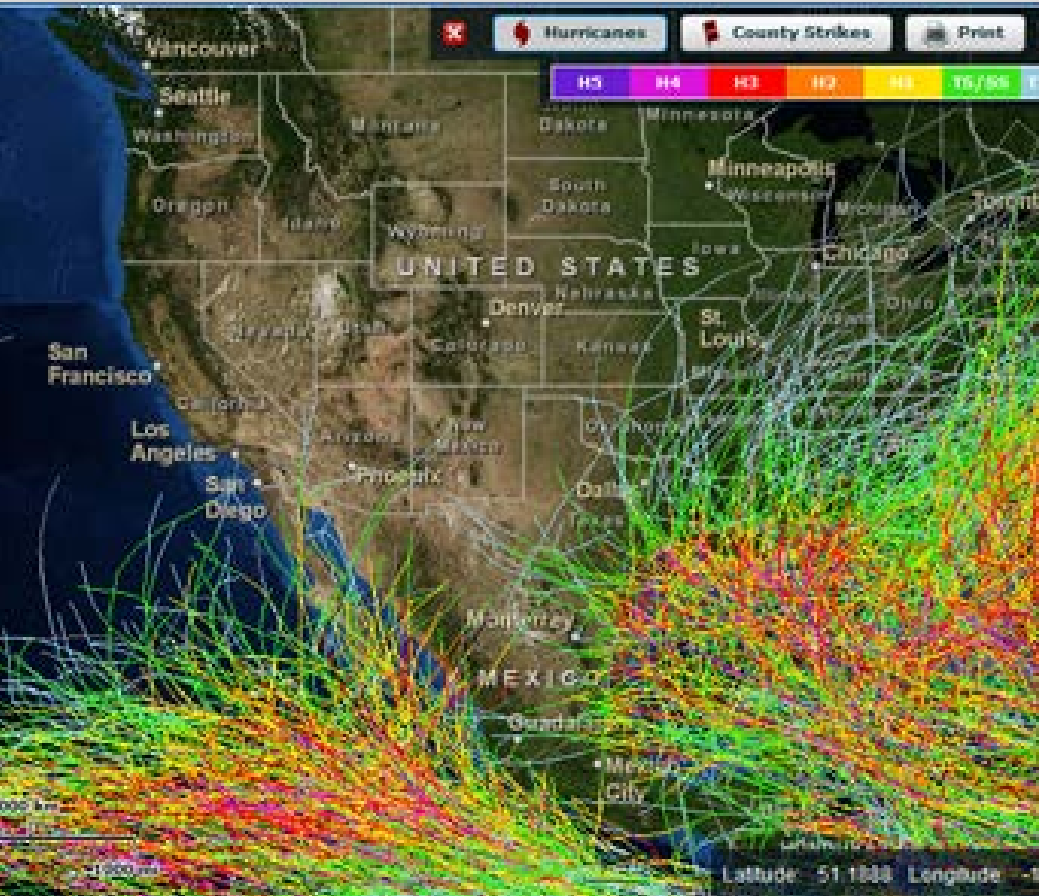


### System Restoration Modeling

- Physical restoration/repair time; optimized repair crew scheduling and staging
- Electrical restoration at transmission-level
- Electrical restoration at distribution level



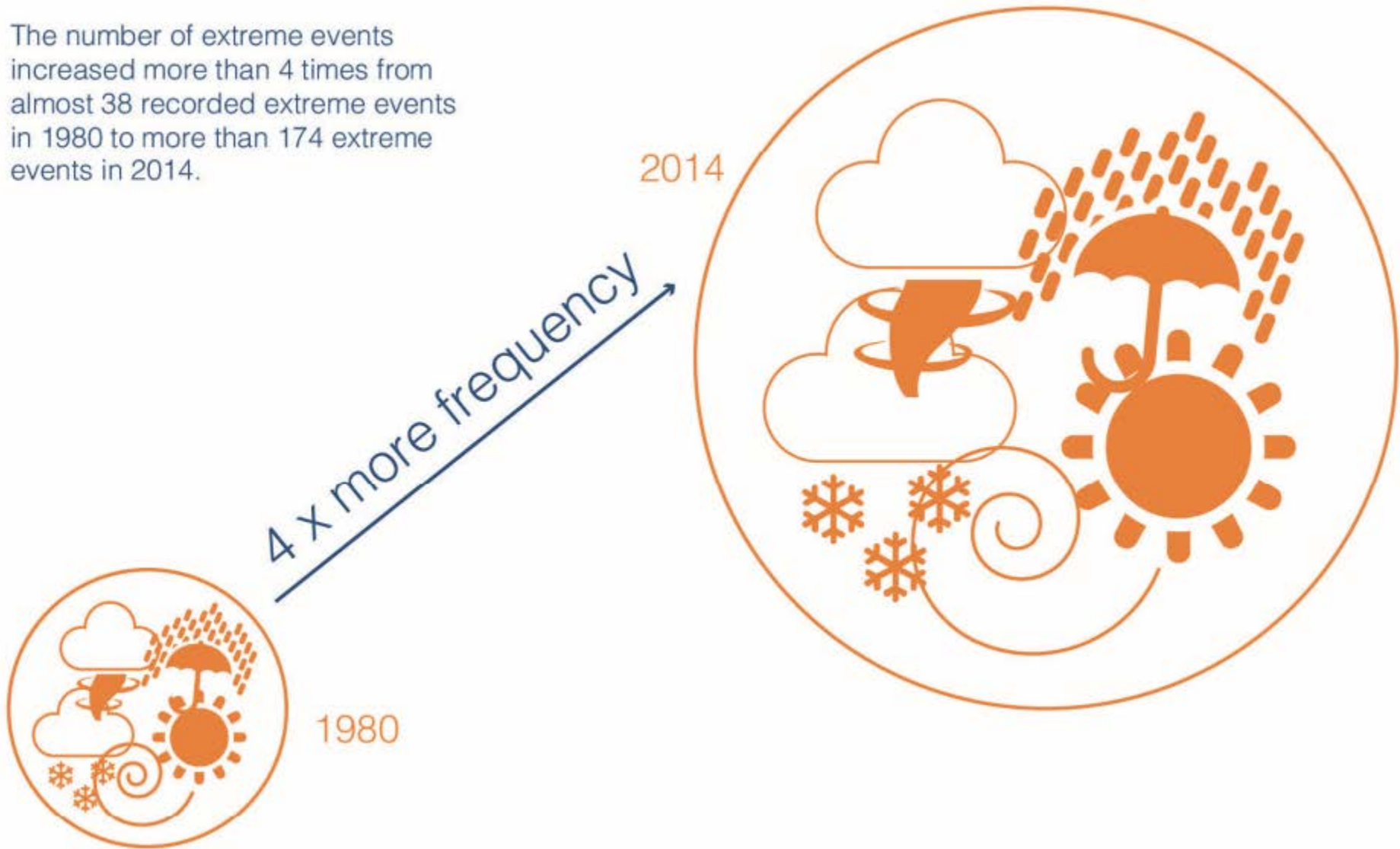
# OUR ENERGY SYSTEMS ARE INCREASINGLY THREATENED BY EXTREME EVENTS





# FREQUENCY OF EXTREME EVENTS HAS INCREASED

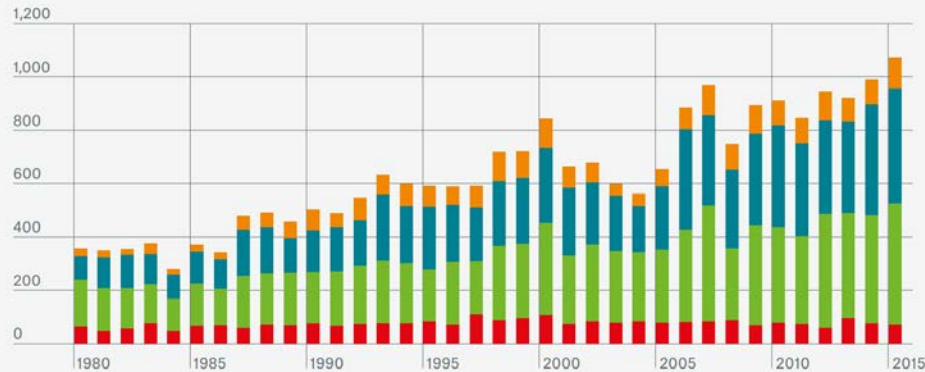
The number of extreme events increased more than 4 times from almost 38 recorded extreme events in 1980 to more than 174 extreme events in 2014.





# GLOBAL NUMBER/VALUE OF LOSSES FROM NATURAL CATASTROPHES

Number of loss events 1980-2015



**Geophysical events:**

Earthquakes, tsunamis, volcanic activity

**Hydrological events:**

Flood, mass movement

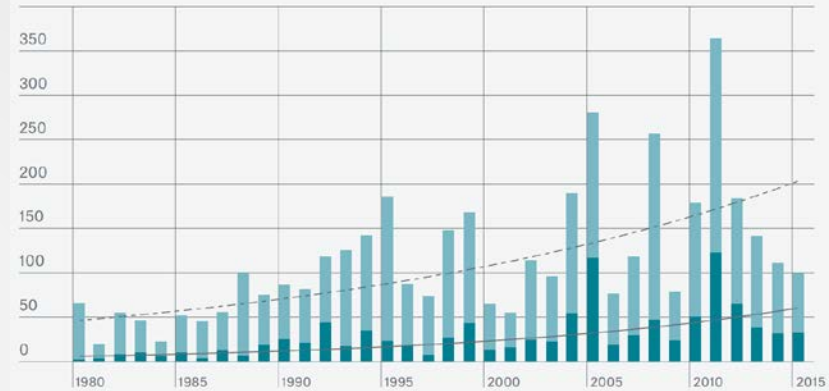
**Meteorological events:**

Tropical storm, extratropical storm, convective storm, local storm

**Climatological events:**

Extreme temperatures, drought, wildfire

Overall and insured losses 1980 to 2015 (in US\$ bn)



Overall losses\* (2015 values)

Trend overall losses  
Trend insured losses

Of which insured losses\* (2015 values)

\*Values adjusted for inflation using the Consumer Price Index (CPI) of each country and taking into account fluctuations in exchange rates



1,060 natural hazard events, thereof  
50 major events (detail's overview)

- Geophysical events: Earthquake, tsunami, volcanic activity
- Meteorological events: Tropical storm, extratropical storm, convective storm, local storm
- Hydrological events: Flooding, mass movement
- Climatological events: Extreme temperatures, drought, wildfire

# DEFINITION OF RESILIENCE

*The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions (U.S. Presidential Executive Order 13653)*

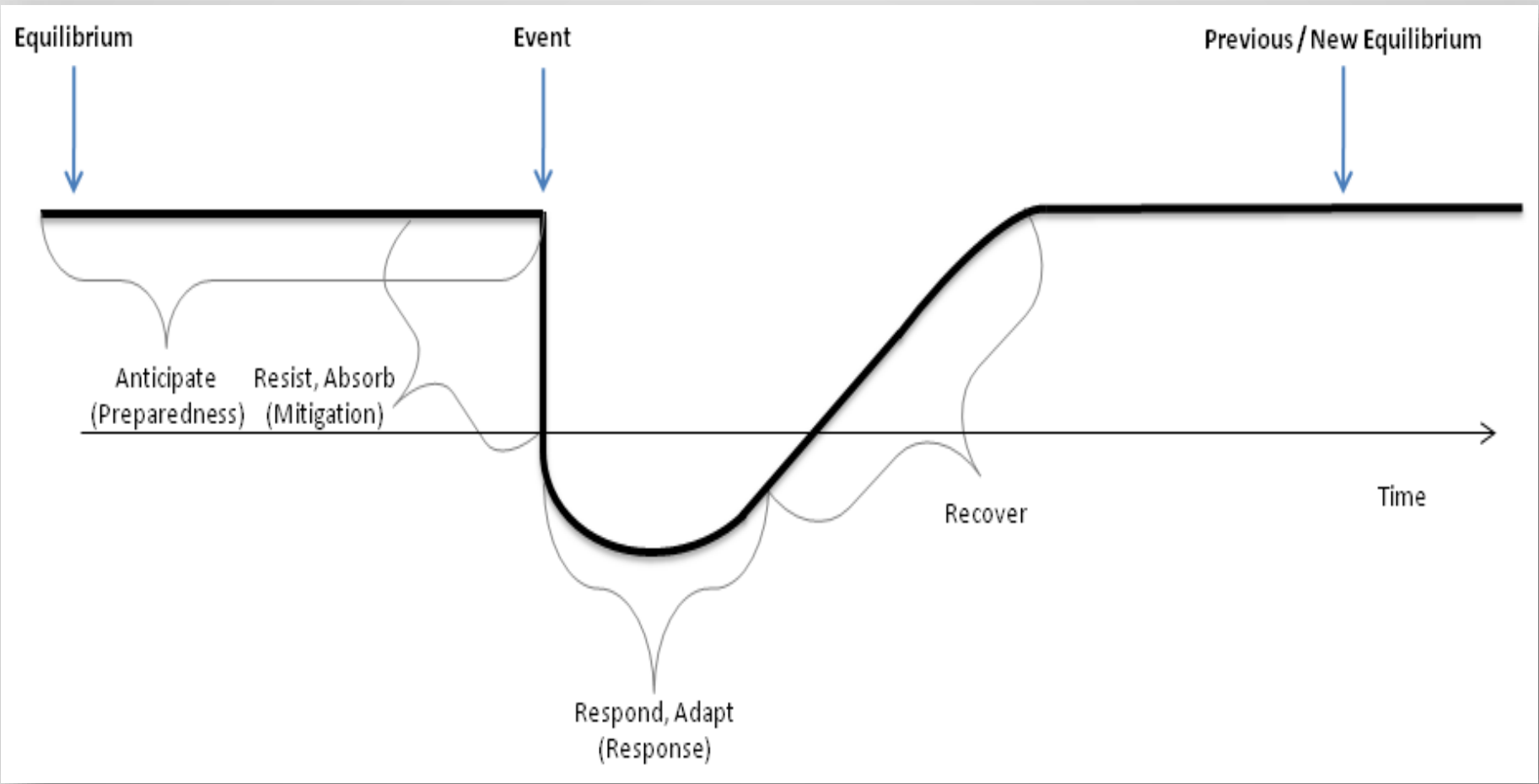
*The ability to maintain normal (or near-normal) service or status of the system through planning, prevention, mitigation, response, and recovery efforts (NRECA 2016)*

*Ability of an entity — asset, organization, community, region — to anticipate, resist, absorb, respond to, adapt to, and recover from a disturbance (Argonne Resilience Measurement Index)*



*When you bend with the wind, but don't break in the storm  
— the Ability to Bounce Back*

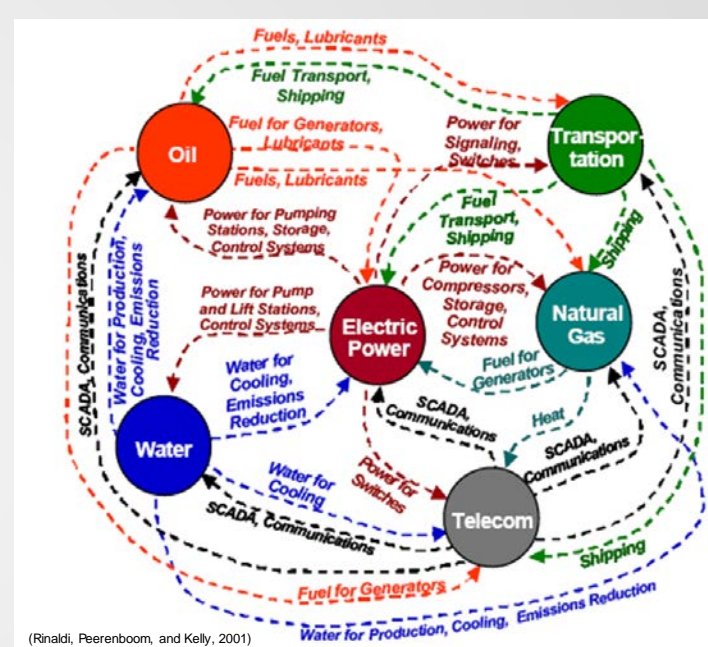
# DEFINITION OF RESILIENCE





# INFRASTRUCTURE MODELING AND RESILIENCE

- Infrastructure modeling can be used to estimate the degree of infrastructure impact and the potential outage duration
  - Can incorporate interdependencies that can prolong outages or increase impacts
  - Can account for cascading impacts from one sector that affects the resilience of a second sector
- Infrastructure modeling aids stakeholders in understanding previous and future crises in order to promote resilience
  - Can be used to determine which systems in previous incidents proved resilient and why
  - Aids in determining recommendations for effective planning to increase critical infrastructure resilience



# FROM DATA TO RESILIENT AND ECONOMIC/RELIABLE OPERATIONS



## Enabling Data Analysis

- Hazards (e.g., climate)
- Infrastructure (public, restricted)

## TOOLS for Resilient Operations

- Tools to assess vulnerabilities and develop mitigation/response options
- Tools cover full spectrum
  - Prepare
  - Mitigate
  - Respond
  - Recover

## TOOLS for Economic/Reliable Operations

- Tools to determine short and long-term operations of resilient system
- Tools address economic reliability, revenue sufficiency, affordability, environmental concerns, etc.

# DOWN-SCALED CLIMATE DATA FOR REGIONAL ASSESSMENTS



- Generated high-resolution (12-km) climate projections/probability distributions of downscaled climate variables for North America (1980-2010, 2045-2054, 2085-2095, in 3-hour time steps, 200 TB of data)
- Allows comprehensive analysis of uncertainty of climate projections at regional scale and ability to quantify/plan for impacts of future climate change at specific locations
- Publically available; used in regional U.S. resiliency assessments
- Currently developing next-generation data (4x4km resolution) available next year
- Can be developed/provided for Asia



# DOWN-SCALED CLIMATE DATA FOR REGIONAL ASSESSMENTS

- Provides information for selecting climate information and downscaled climate products
- Describes how to incorporate these into vulnerability and impact assessments, climate resilience and preparedness, and adaptation planning, at an actionable, impact-relevant scale
- <https://www.serdp-estcp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Climate-Change/>



Scale	Statistical Downscaling Methods							Dynamic Downscaling	GCM
	Delta Corrections	Empirical Quantile Mapping	Bias correction	Percentile Quantile Mapping	Canonical Correlation Analysis	Wx generate	ANALOGUE CORRELATION	Convective parameterization	
Global scale -> 3,000 km or more, weeks to months (general circulation structure, jet stream position)									
Synoptic scale: 100-3,000 km, days to weeks (high and low, midlatitude cyclones, mesoscale, atmospheric teleconnections)									
Course mesoscale - a, $\beta$ 10-100 km, hours to days (diabatic winds, weather fronts, mesoscale convective systems, tropical cyclones, sea breeze circulations)									
Fine mesoscale - $\gamma$ , 1-10 km, hours to minutes (supercell thunderstorms, tornadoes, pain fronts, air mass thunderstorms, mountain-valley winds, mountain mist/fog)									

# COMPREHENSIVE INFRASTRUCTURE DATA



- For the United States, ongoing work by National Geospatial Intelligence Agency to prepare and deliver infrastructure datasets for various energy sectors
- For the United States, new efforts by Department of Energy to develop synthetic grid datasets for transmission and distribution

# ARGONNE RESILIENCE AND RESTORATION TOOLS

## Prepare

Self-assessment/  
maturity  
(ERAP-D)

Emergency  
planning (**onVCP/  
SyncMatrix,  
SpecialPop, LPAT**)

EP/PSR exercise/  
drill (**Scenarios,  
Threat-Damage,  
Impact Models**)

## Mitigate

Mitigation  
assessment  
(**EPfast, NGfast,  
POLfast, others**)

Resource mitigation  
measures,  
dependencies  
(**IST-RMI**)

Power system  
restoration  
planning (**EGRIP**)

Blackstart  
resource planning  
(**EGRIP**)

## Respond

Impact  
assessment  
(**Threat-Damage,  
Impact Models**)

Hurricane  
assessment  
(**HEADOUT**)

Emergency  
management/resp  
onse (**onVCP,  
vBEOC**)

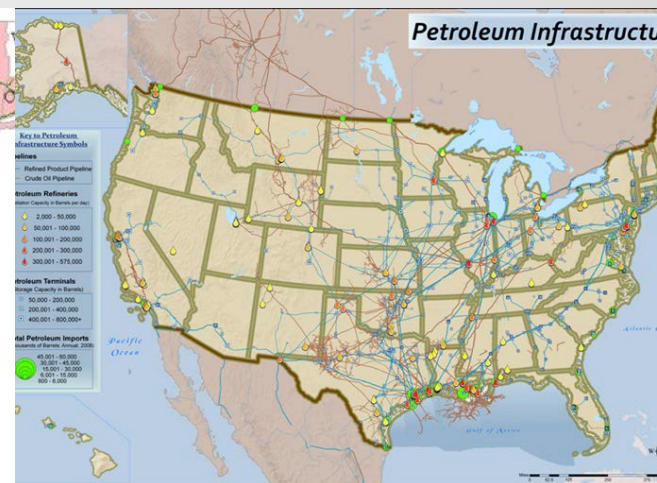
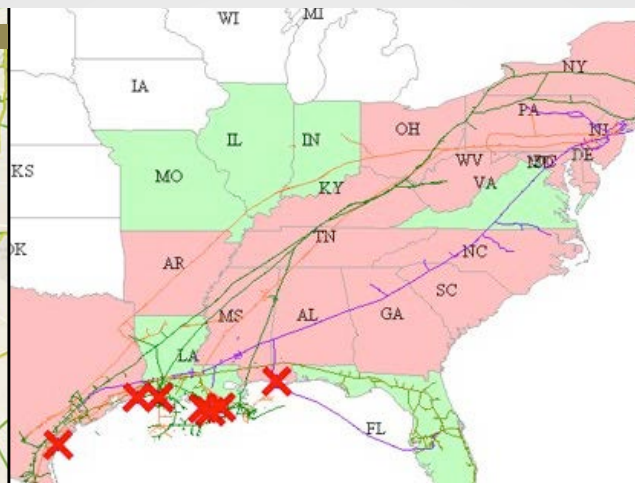
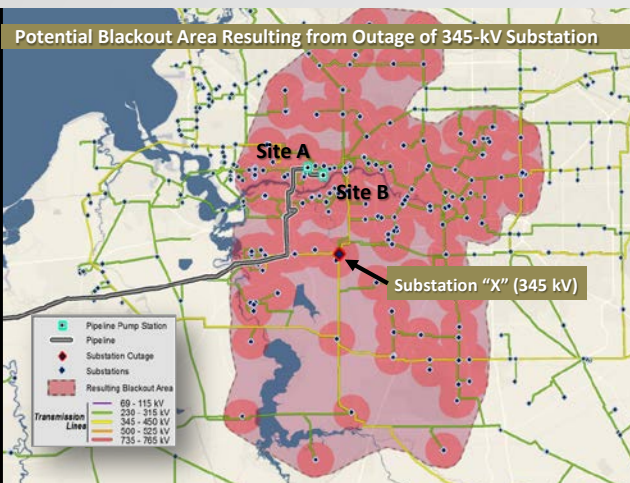
## Recover

Real-time PSR  
analysis (**EGRIP**)

Emerge-Manage.,  
Communication,  
Collaboration  
(**onVCP/vBEOC**)



# ARGONNE'S ENERGY SECTOR RESILIENCE MODELING TOOLS

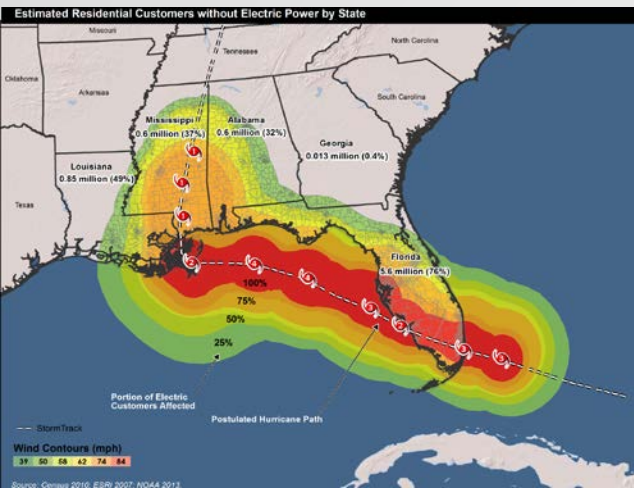


- **EPFAST** examines the impacts of power outages on large electric grid systems
- Models the tendency of power systems to “island” after either man-made or natural disturbances, which can lead to regional power disruptions

- **NGfast** is a natural gas – electric interdependency tool
- Estimates impacts to natural gas sector from user-defined hazards and determines gas-fired power plants at-risk of fuel disruptions

- **POLfast** estimates impacts to petroleum sector (crude oil and refined products) from disruptions in production, storage, and transportation

# ARGONNE'S ENERGY SECTOR RESILIENCE MODELING TOOLS



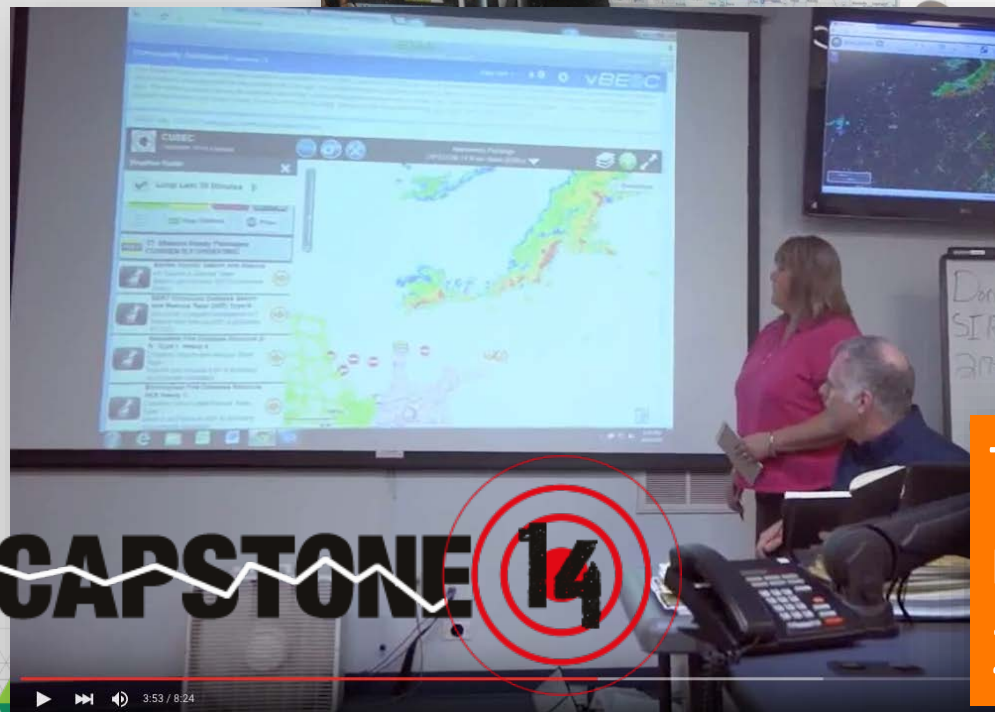
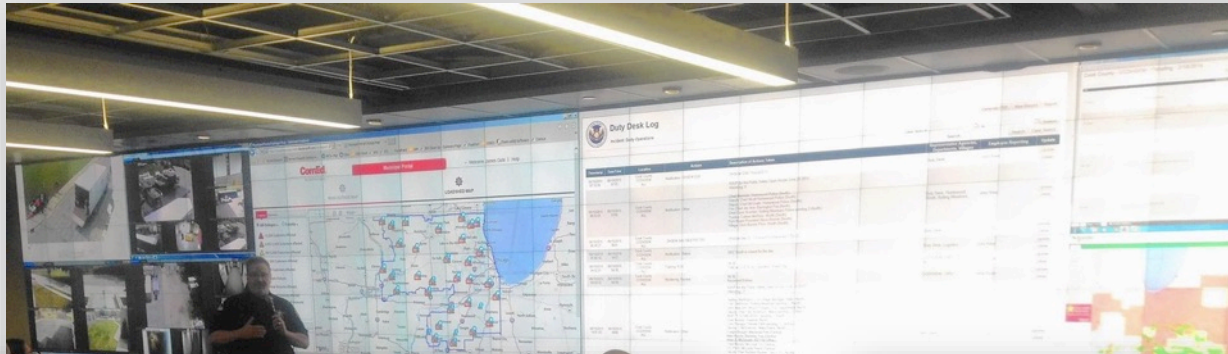
- **HEADOUT** produces an estimation of the potential number of electric customers that will experience a loss of commercial electrical power as a tropical cyclone makes landfall

- **RESTORE** offers insights into physical outage restoration times at critical infrastructure facilities
- Identifies the dependencies of the affected infrastructure and its impact on the restoration process

- **EGRIP** is an AC power flow based cascading failure/outage and integrated power system restoration optimization tool
- The electric restoration module supports restoration planning and operational decision-making in both T&D



# ARGONNE TOOLS PROVIDE SITUATIONAL AWARENESS AND COMMON OPERATING PICTURE



**Operation Power Play**  
June 2015

**Working Together to Prepare Illinois**

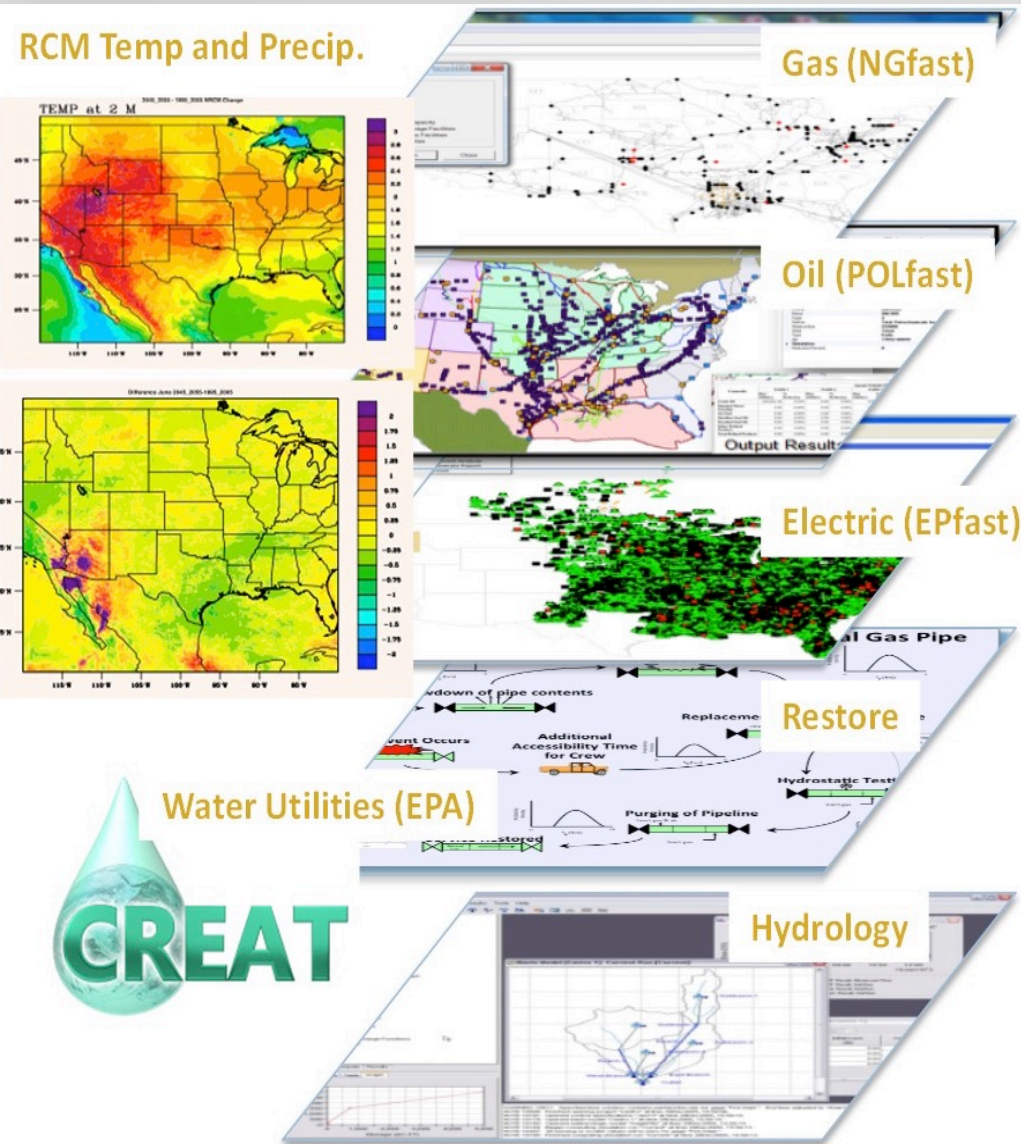
Please join us for Operation Power Play, a statewide emergency exercise bringing together over 30 Federal, State, County, municipal and private entities to better prepare for a significant weather event in Illinois.

Tools used in large regional exercises in 2014 and 2015

CAPSTONE 14



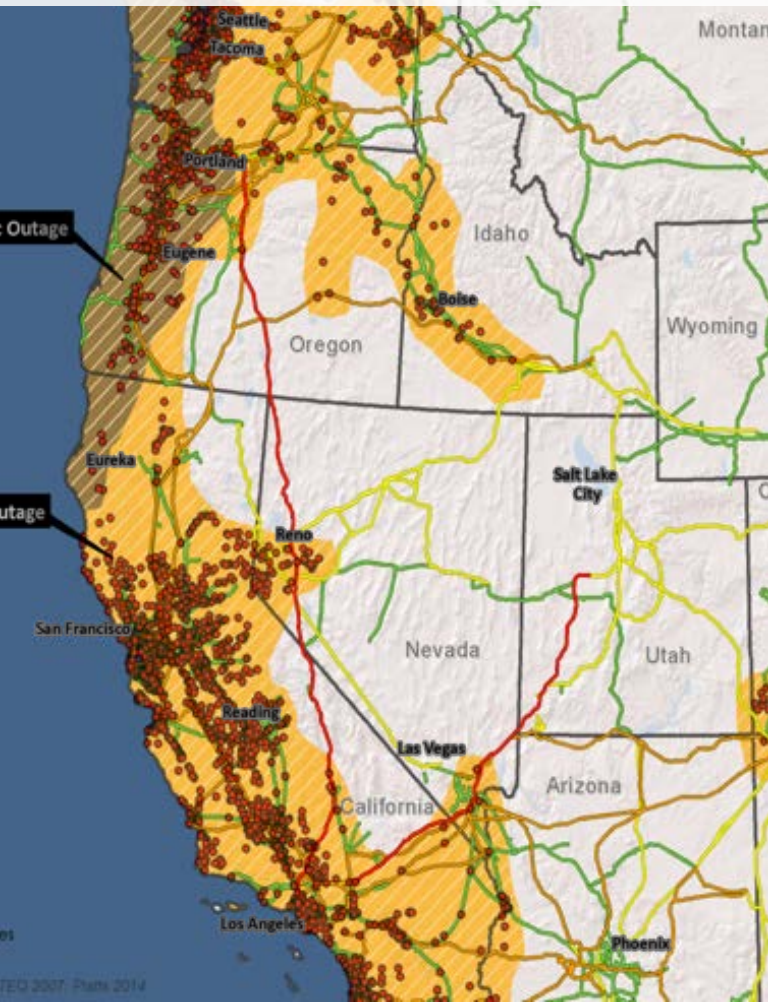
# TOOL APPLICATION: REGIONAL ENERGY RESILIENCE



- Regional Resilience Assessment Program (RRAP)
- RRAP process identifies critical infrastructure security and resilience gaps; dependencies; interdependencies; cascading effects; and State, local, tribal, and territorial government capability gaps
- Argonne completed 56 RRAPs (2009-2015)
- RRAPs include multiple infrastructure assessment tools (oil, gas, electric, water, service restoration)

# TOOL APPLICATION: IMPACT OF EARTHQUAKE (WEST)

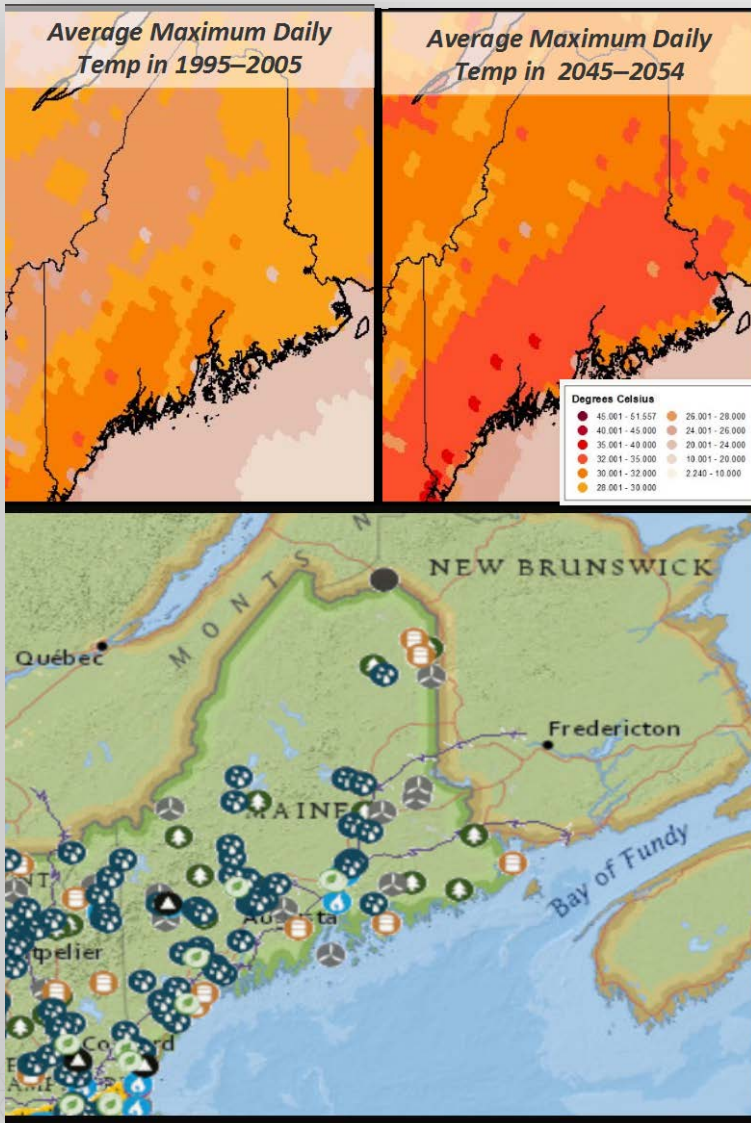
Application of *EPfast* Tool to Cascadia Subduction Zone (CSZ) Earthquake – Summer Conditions (2013)



- Performed for Columbia Basin Regional Resilience Study (2013)
  - Examined short- and long-term impacts
  - Considered summer and winter peak-day conditions
- 9.0 CSZ earthquake scenario would have a significant impact on the electric system in the Columbia Basin:
  - Could permanently damage up to 23 power plants, 170 substations, and 250 transmission lines in Columbia Basin area
  - Long-term impacts to Washington, Oregon, and California
  - Projected blackout lasting from weeks to months



# TOOL APPLICATION: CLIMATE CHANGE IMPACTS IN MAINE

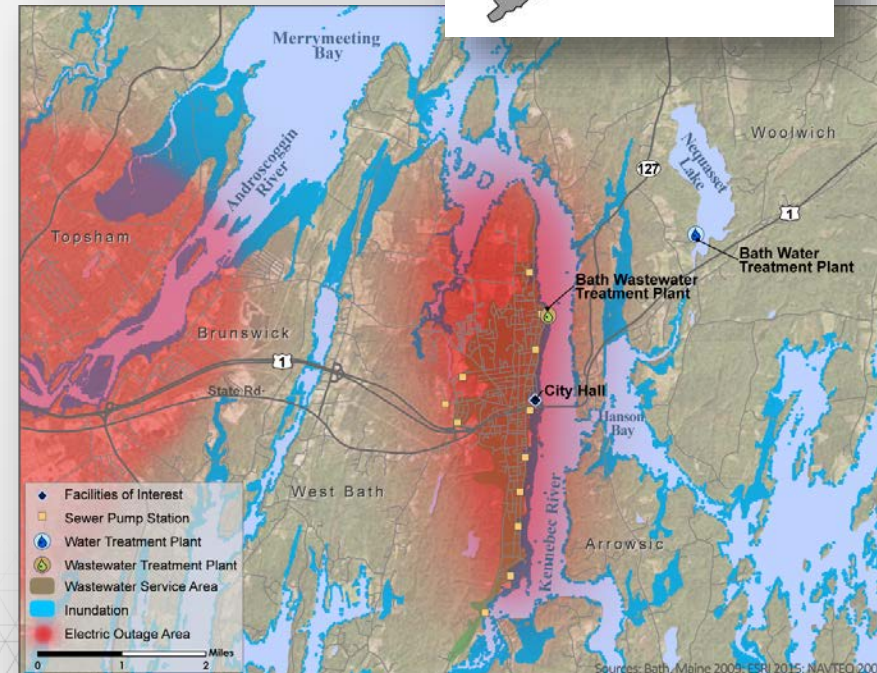


- Investigate the impacts to Maine's electric system from climate change hazards, including higher storm surge and increased ambient temperatures
- Impose 2050 storm surge and ambient temperature projections on the 2011 electric system in Maine
- Identify impacts on capacity of power plants, transmission lines, transformers and growth in demand
- Determine implications on overall grid performance via load-flow simulation



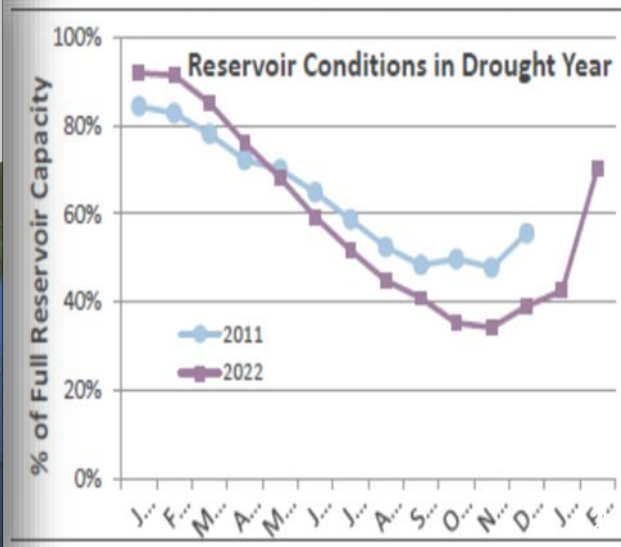
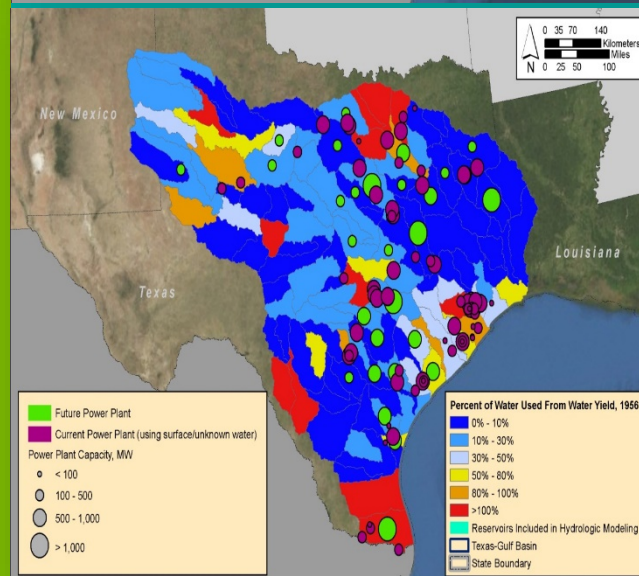
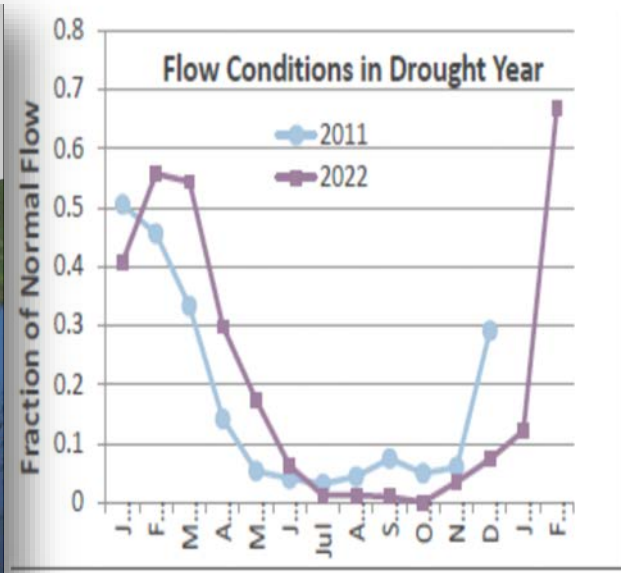
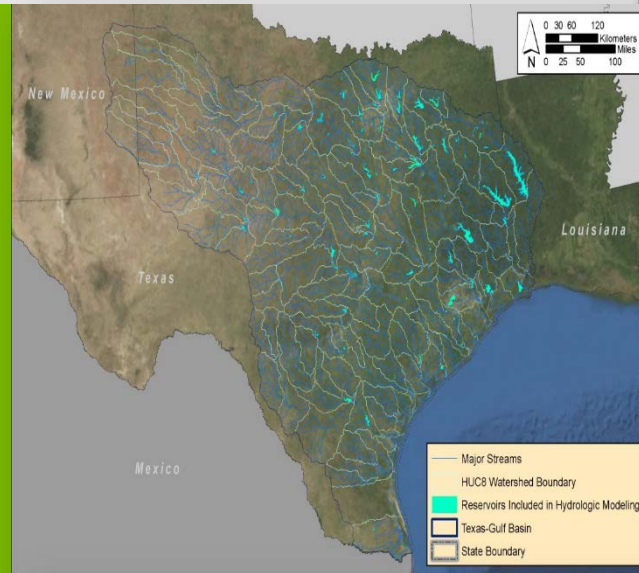
# TOOL APPLICATION: CLIMATE CHANGE IMPACTS NEW ENGLAND

- Builds on Maine analysis, part of 2016 regional resilience study
- Assesses climate impacts on electric infrastructure throughout New England
- Considers flood risk due to sea level rise combined with more intense overland precipitation events
- Identifies high-consequence failure points and potential cascading failure scenarios within the region's electric infrastructure



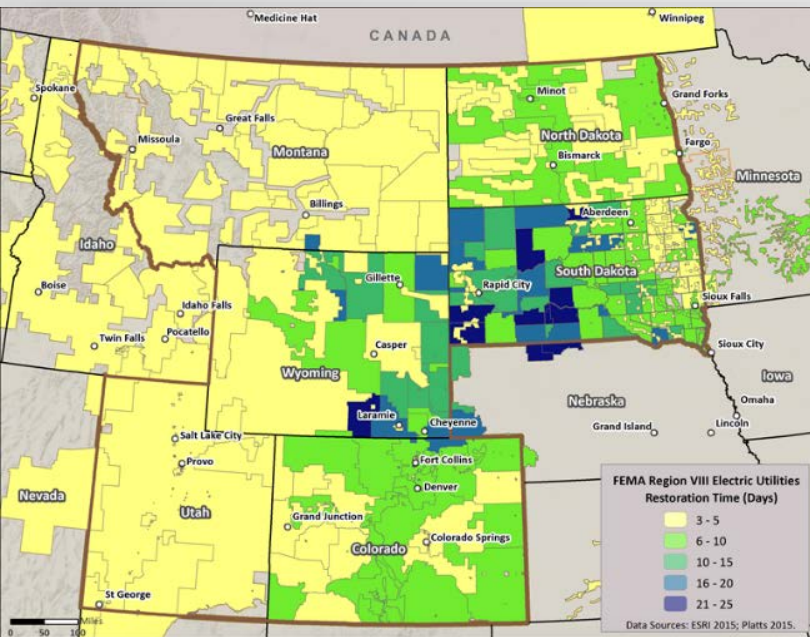
# TOOL APPLICATION: CLIMATE CHANGE/DROUGHT IMPACTS

- Using Argonne's downscaled climate data, examined climate variability impact on Texas power generation
  - Impacts on water availability
  - Potential reduction or curtailment of power generation
- Supports long-range transmission planning in Texas and Western U.S.



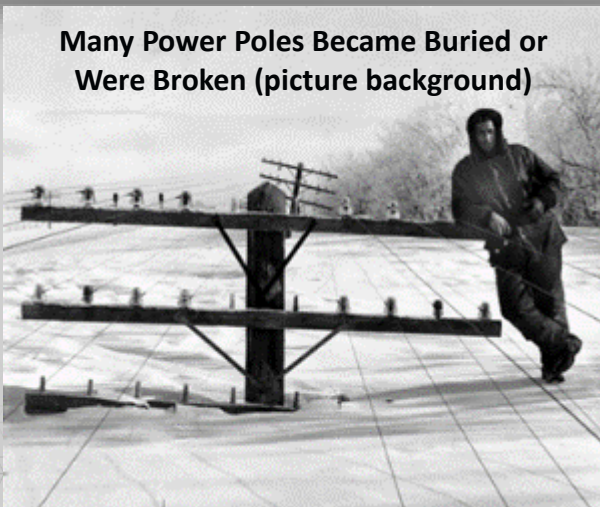


# TOOL APPLICATION: EXTENDED POWER OUTAGE PLANNING



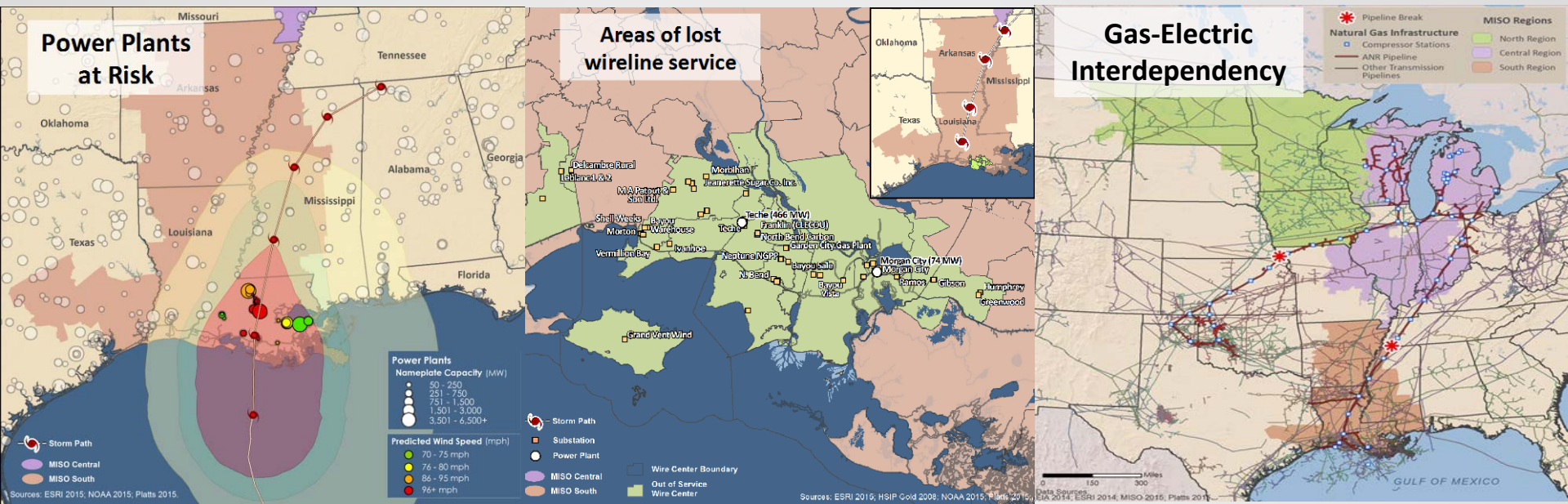
- Support Federal Emergency Preparedness Agency in planning for large, extended power outages
- Scenario development, grid impact modeling, and physical and electrical power system restoration
- Region 5: Initiating event is cyber attack
- Region 8: Initiating event is major blizzard (January 1949)
- Involves multitude of regional stakeholders and workshops

Many Power Poles Became Buried or Were Broken (picture background)



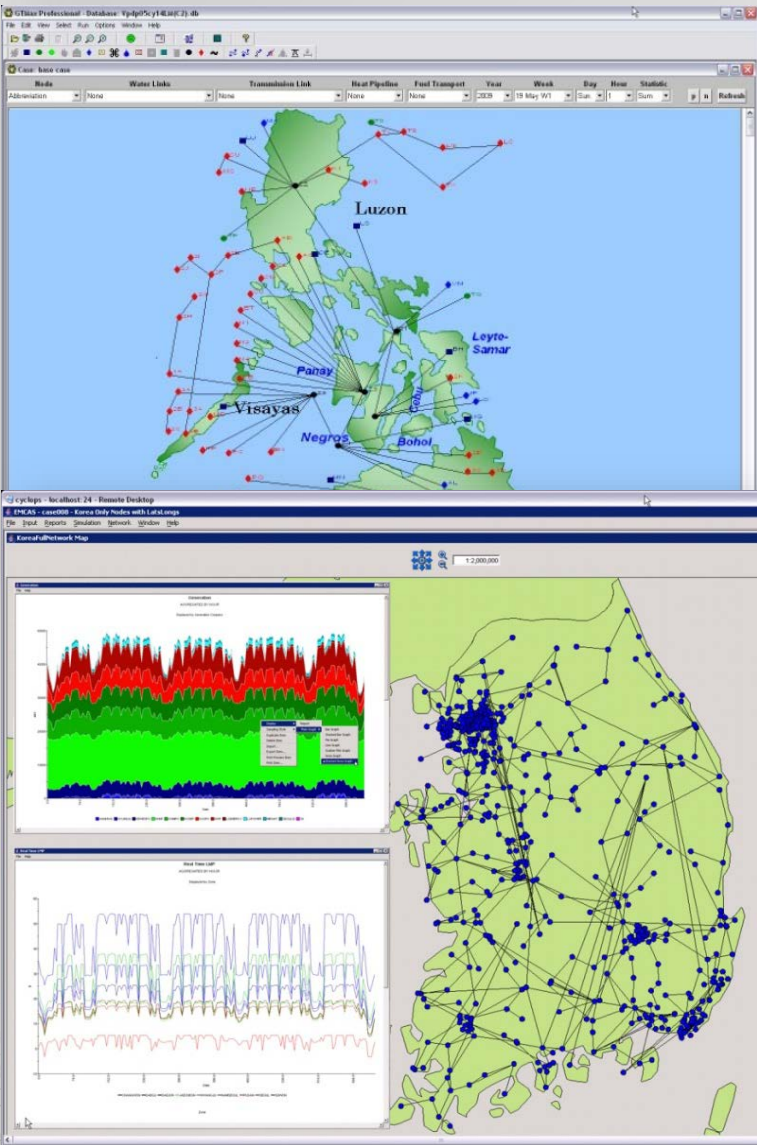


# TOOL APPLICATION: PREPARE GRID OPERATORS FOR STORMS



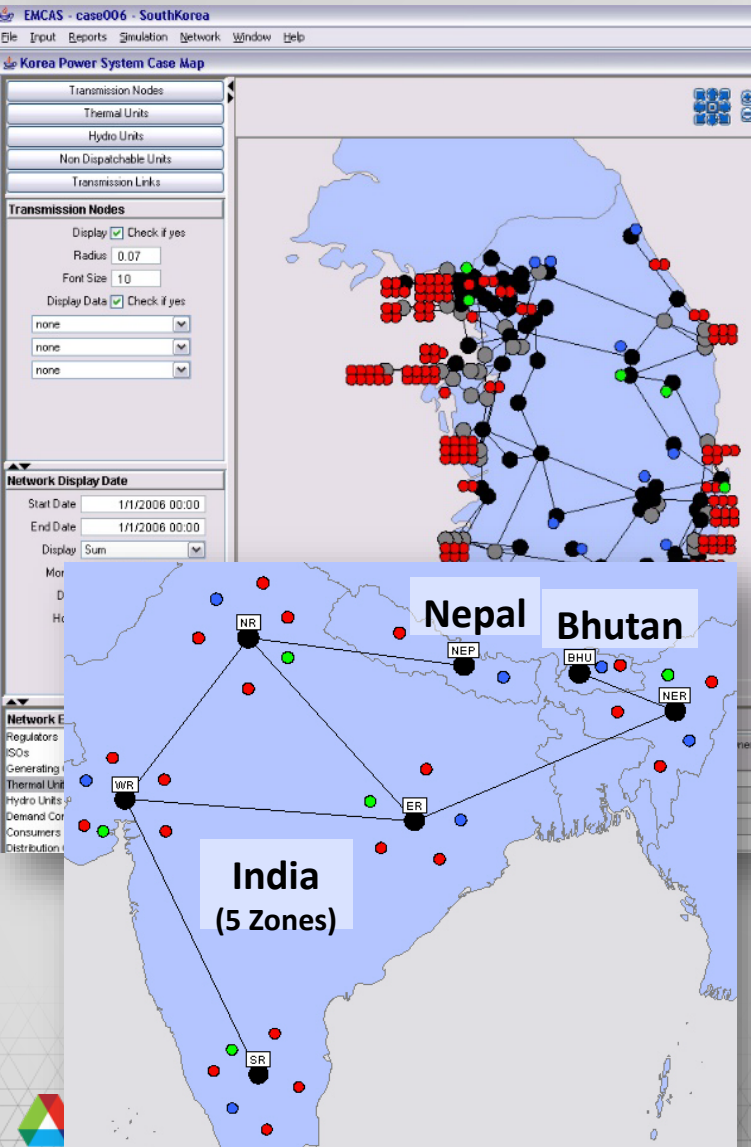
- Support for Midcontinent Independent System Operator (MISO) working group for Emergency Preparedness and Power System Restoration
- Recent 2016 spring drill and upcoming fall drill include hurricane scenario and impact estimation and interdependencies with telecommunications and natural gas

# ARGONNE MODELS USED IN ASIA TO STUDY GRID ISSUES



- Model implementations in Bangladesh, China, India, Indonesia, Kazakhstan, Korea, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam
- Feasibility analysis of geothermal power station in Indonesia in collaboration with Japanese consultants
- Long-term power system studies in Pakistan, Nepal, and Malaysia

# ARGONNE MODELS USED IN ASIA TO STUDY GRID ISSUES



- Analysis of benefits of inter-connections in the Philippines for Japan International Cooperation Agency in collaboration with Japan's Chubu Electric Power Company
- Providing modeling support for Korea Electric Power Research Institute, Korea Energy Economics Institute, and several universities
- Power market analysis for Korea Power Exchange

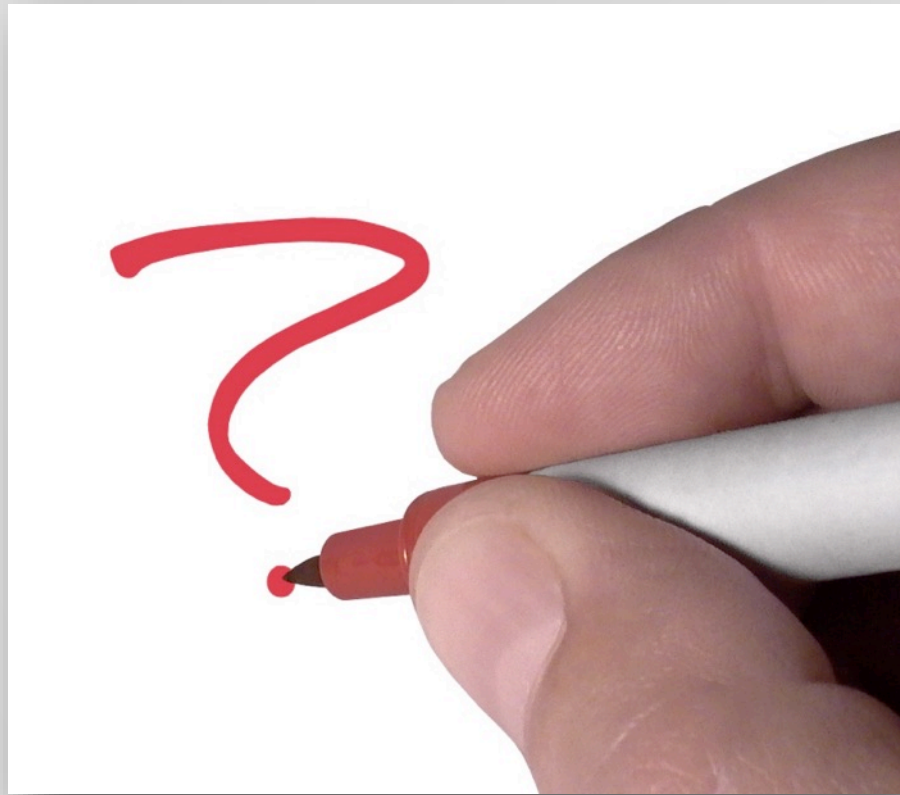


# ARGONNE HAS LONG HISTORY OF TRAINING GRID ANALYSTS



- Training programs can be customized
- Workshops can be conducted in-country/on-site or at Argonne
- Argonne has trained over 2000 analysts from 90+ countries in the use of energy planning and analysis tools

# FOR MORE INFORMATION PLEASE CONTACT:



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