SUSTAINABILITY AND RESILIENCE OF CRITICAL INFRASTRUCTURE SYSTEMS
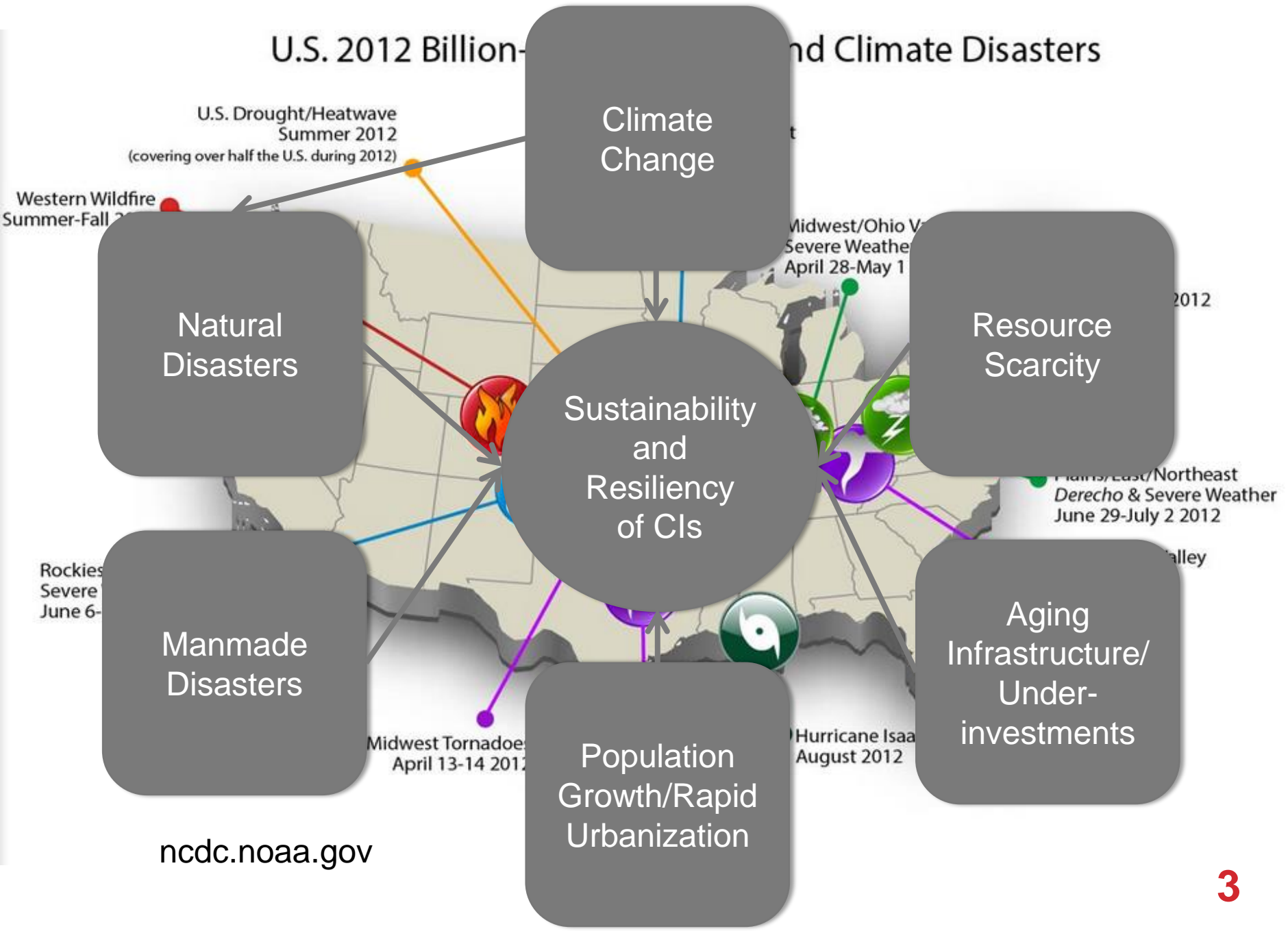

Posted by Yellow Cab NYC on October 30, 2012

ROSHI NATEGHI
IE & EEE
PURDUE UNIVERSITY, JUNE 2016

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RESEARCH OVERVIEW

U.S. 2012 Billion-[Dollar Weather a]nd Climate Disasters

Climate Change

Natural Disasters

Resource Scarcity

Sustainability and Resiliency of CIs

Manmade Disasters

Aging Infrastructure/ Under-investments

Population Growth/Rapid Urbanization

ncdc.noaa.gov

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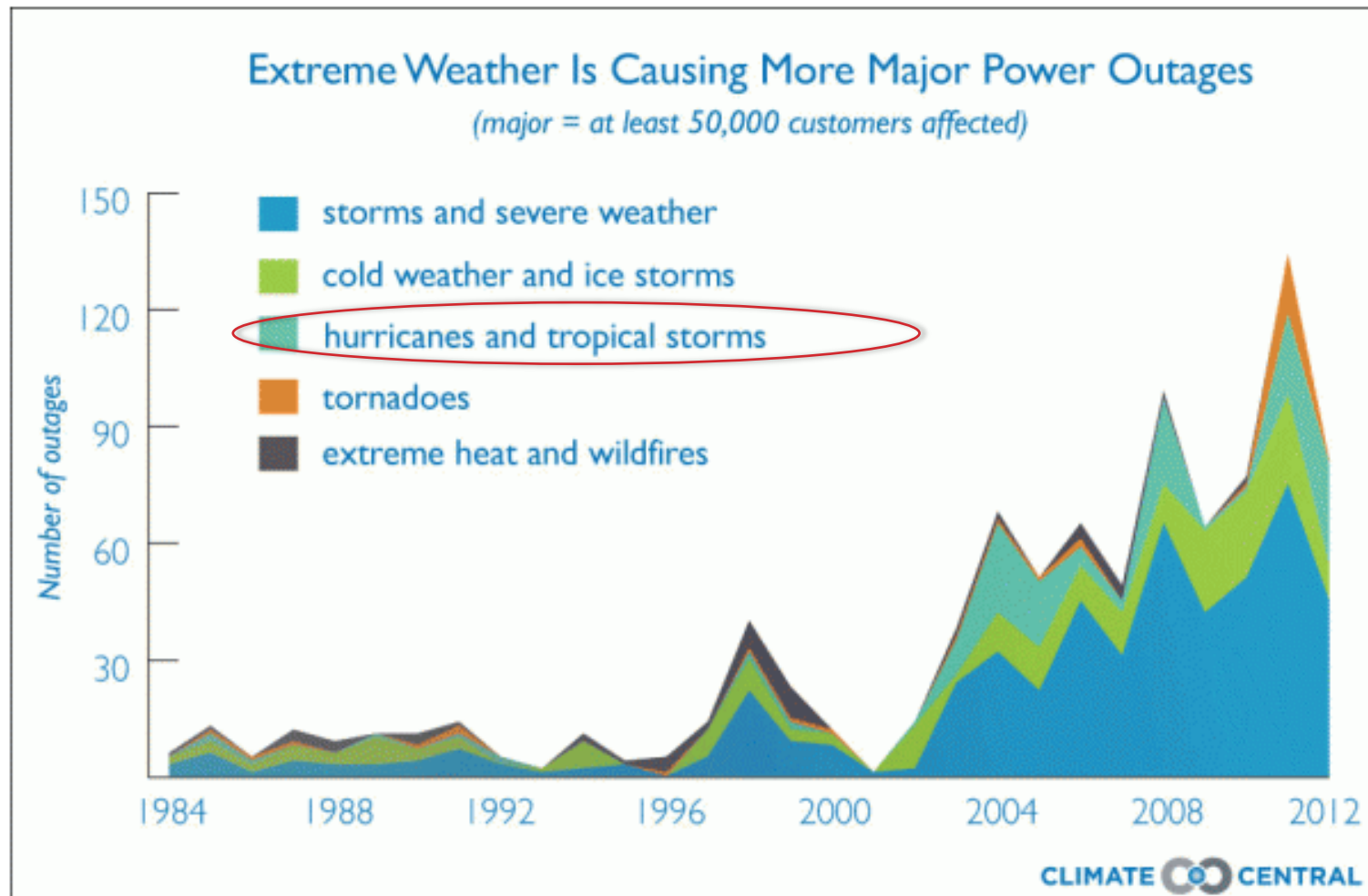# GOAL: DESIGNING SUSTAINABLE ADAPTATION TOOLS TO ENSURE RESILIENT CIS

USES:

- ❖ Planning at various temporal scales
- ❖ Hardening and mitigation decisions at various spatial scales

Methods:

- ❖ Data Analytics
- ❖ Complex Systems Theory
- ❖ Risk and Decision Analysis

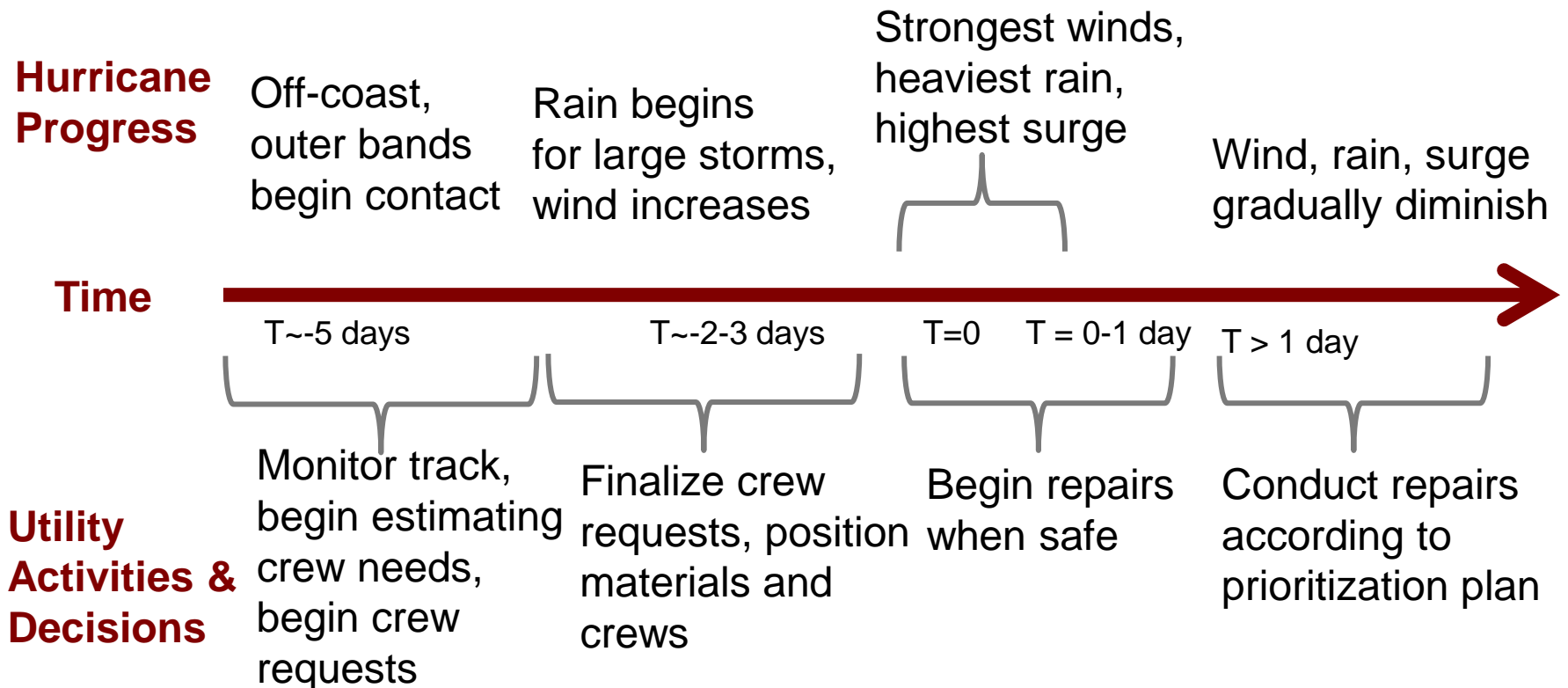# HURRICANES, POWER SYSTEMS AND CLIMATE CHANGE

EXTREME WEATHER INDUCED OUTAGES

Extreme Weather Is Causing More Major Power Outages

(major = at least 50,000 customers affected)

- storms and severe weather
- cold weather and ice storms
- hurricanes and tropical storms
- tornadoes
- extreme heat and wildfires

HURRICANE-INDUCED OUTAGE FORECASTING

A TYPICAL UTILITY RESPONSE CYCLE

Hurricane Progress

Off-coast, outer bands begin contact

Rain begins for large storms, wind increases

Strongest winds, heaviest rain, highest surge

Wind, rain, surge gradually diminish

Time →

T~-5 days   T~-2-3 days   T=0   T = 0-1 day   T > 1 day

Utility Activities & Decisions

Monitor track, begin estimating crew needs, begin crew requests

Finalize crew requests, position materials and crews

Begin repairs when safe

Conduct repairs according to prioritization plan

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CURRENT PRACTICES

MODEL DEVELOPMENT

Forecast for approaching hurricane & assess performance → Collect data → Estimate hurricane winds → Train, test & validate statistical predictive models → (back to Forecast)
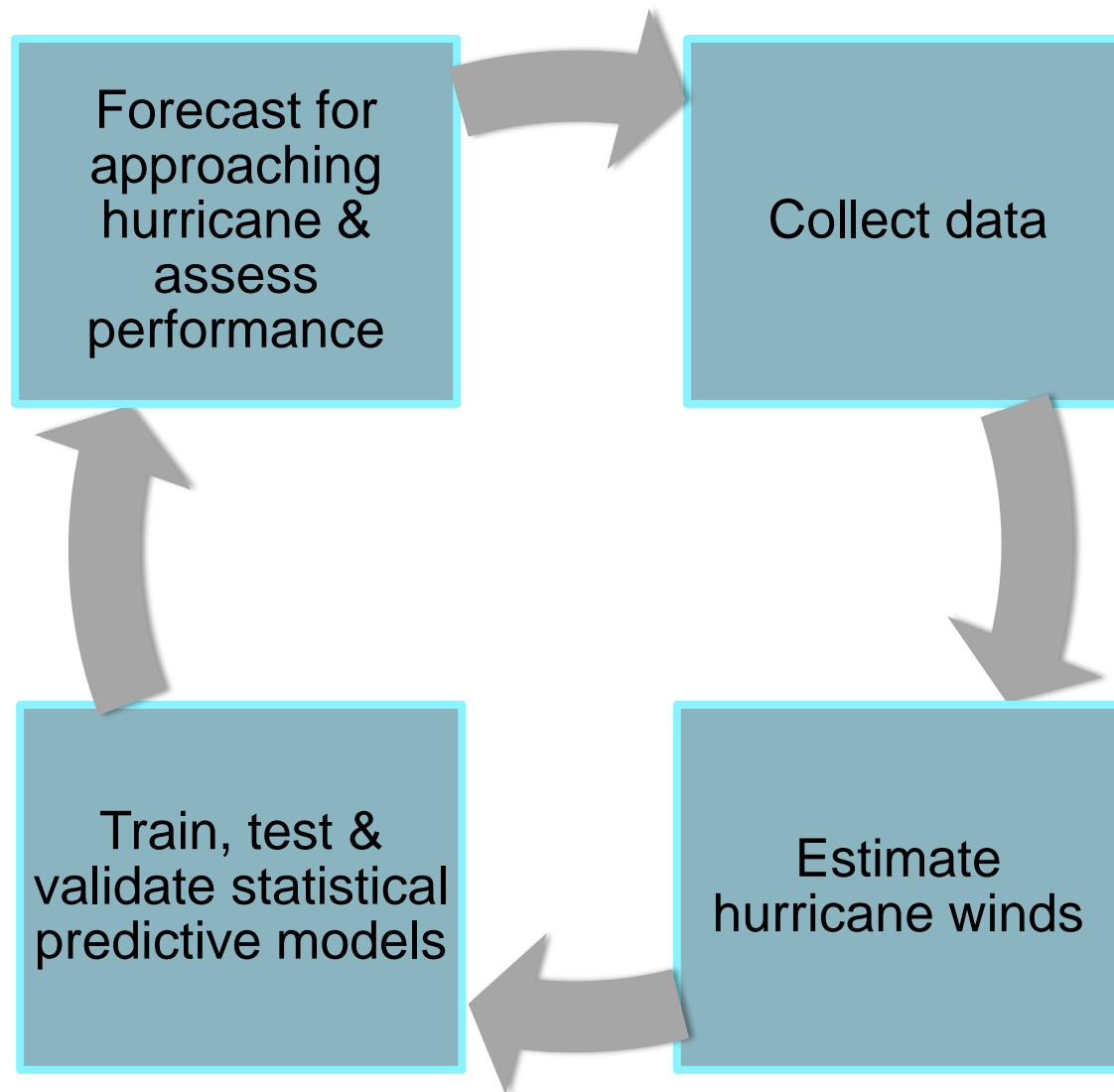
METHODOLOGY

Ensemble Tree-based Method of:

Random Forest
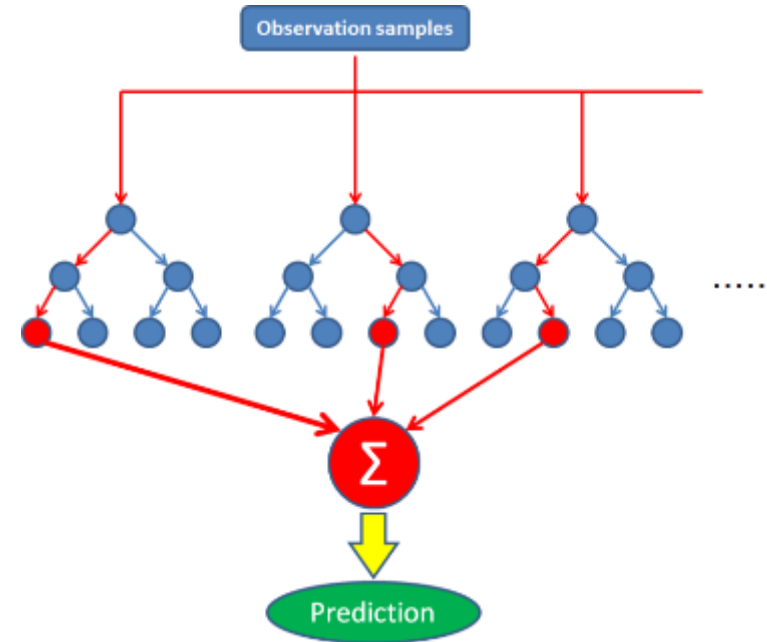
Validation:

- Critical to bias-variance trade-off especially for complex methods;

- Good fit doesn't necessarily lead to strong predictive accuracy
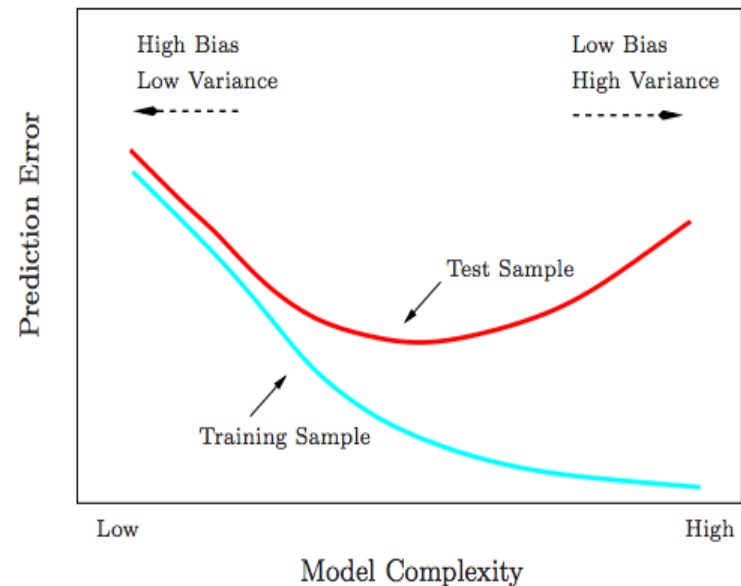
SPATIALLY DETAILED MODEL

INPUT VARIABLES:

Antecedent conditions affecting tree strength, stability, and type of development

Climatic & Geographic Data
- Soil Moisture
- Long-term mean precipitation
- Short-term deviations from long-term precipitation
- Land use/land cover type
- Topographic data

Exposure to high winds

Power System Data
- Number of poles, transformers, switches & miles of line (OH, UG)
- Tree trimming

Hazard to the system

Hurricane Data
- Local wind field (via physics-based model)

ALSO-> Number of customers per grid-cell

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VARIABLE SELECTION

Model Development:

Iterative process based on variables' contribution to out-of-sample accuracy

Final Input variables

- ❖ Number of customers
- ❖ 3-second gust wind speed
- ❖ Duration of wind above 20 m/s
- ❖ Soil moisture at different depths
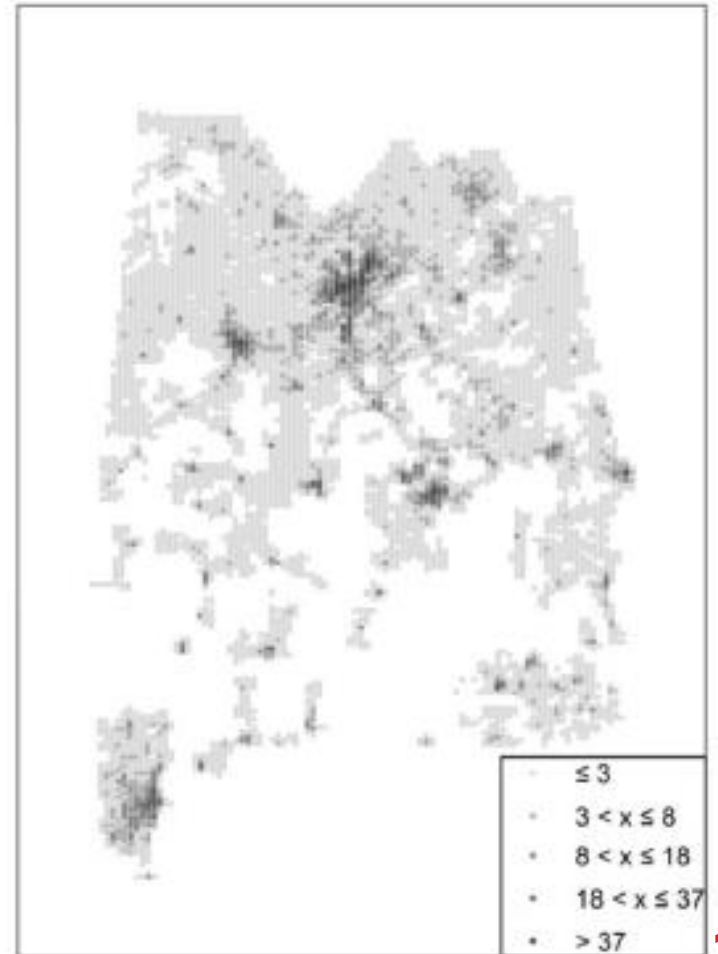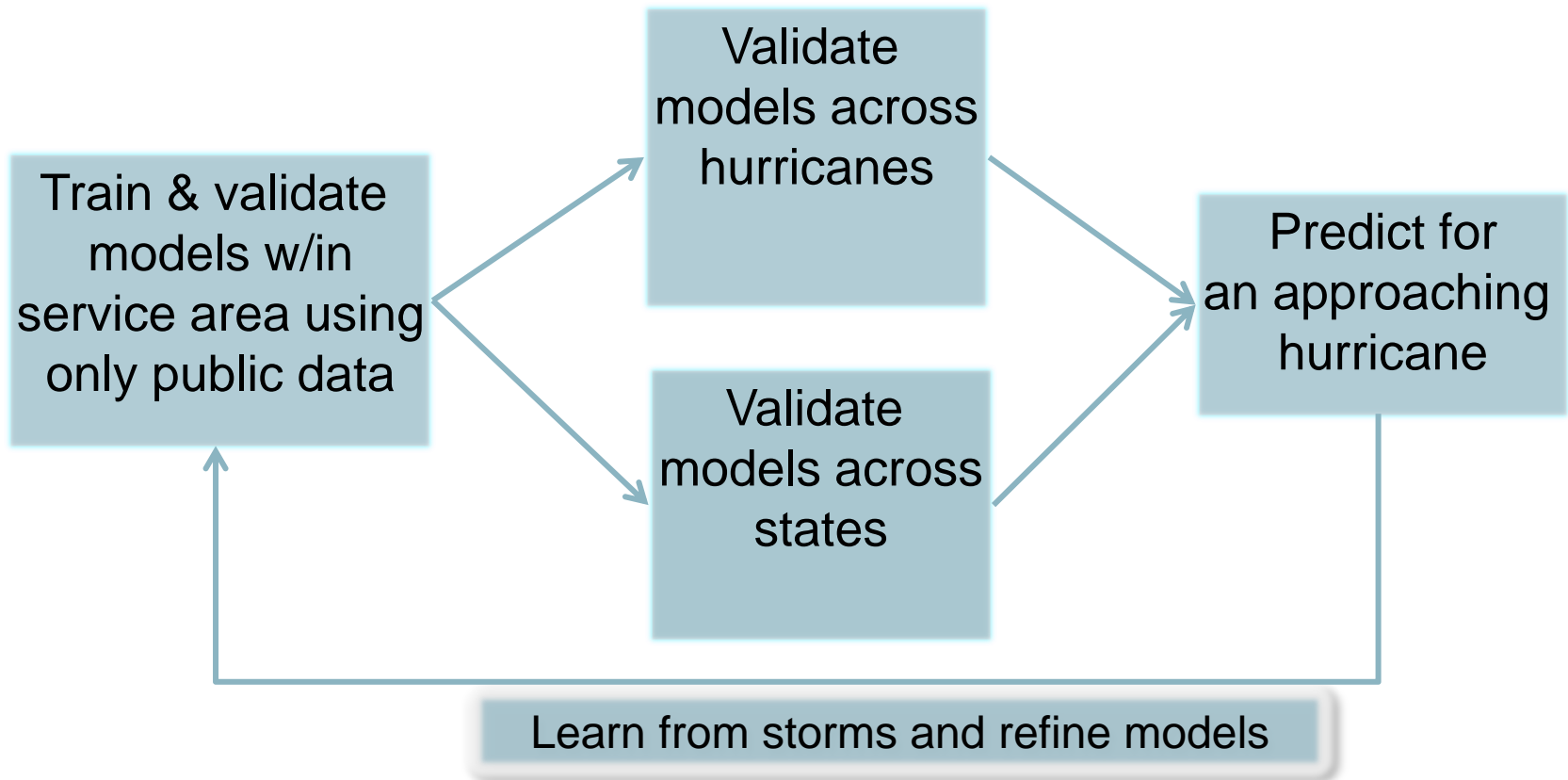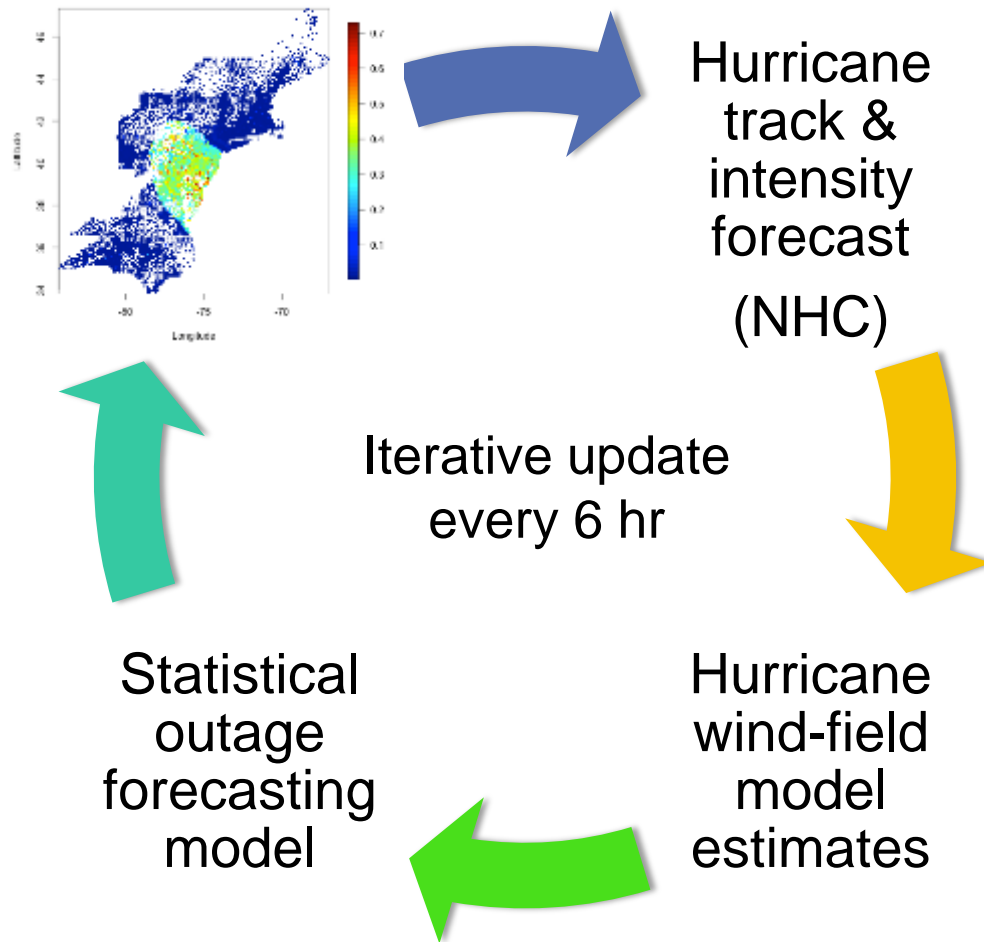- ❖ Tree trimming practices

MAE_State A

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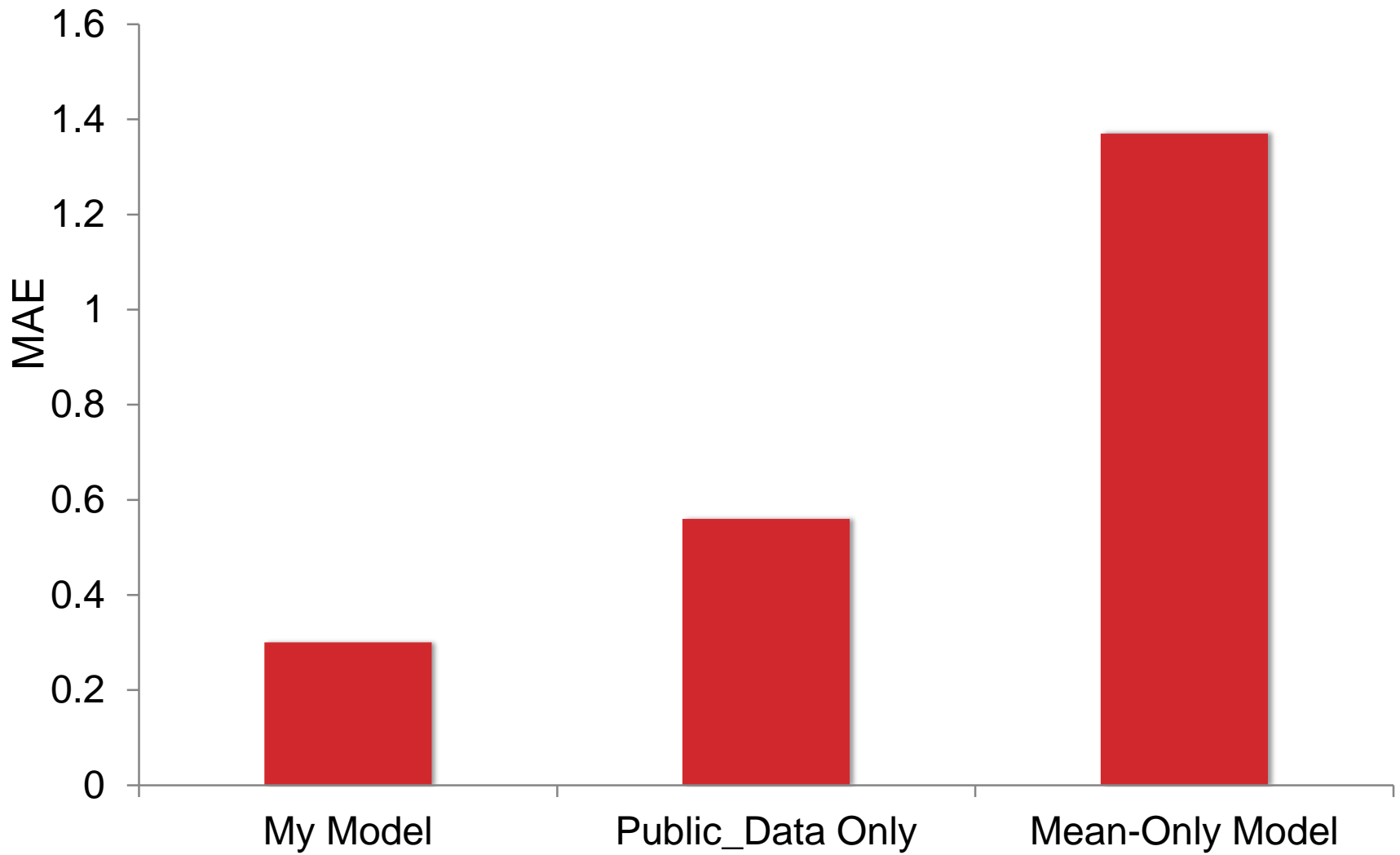
OUTAGE MAPS

Ivan - Actual

Ivan - Predicted

Legend:
- ≤ 3
- 3 < x ≤ 8
- 8 < x ≤ 18
- 18 < x ≤ 37
- > 37

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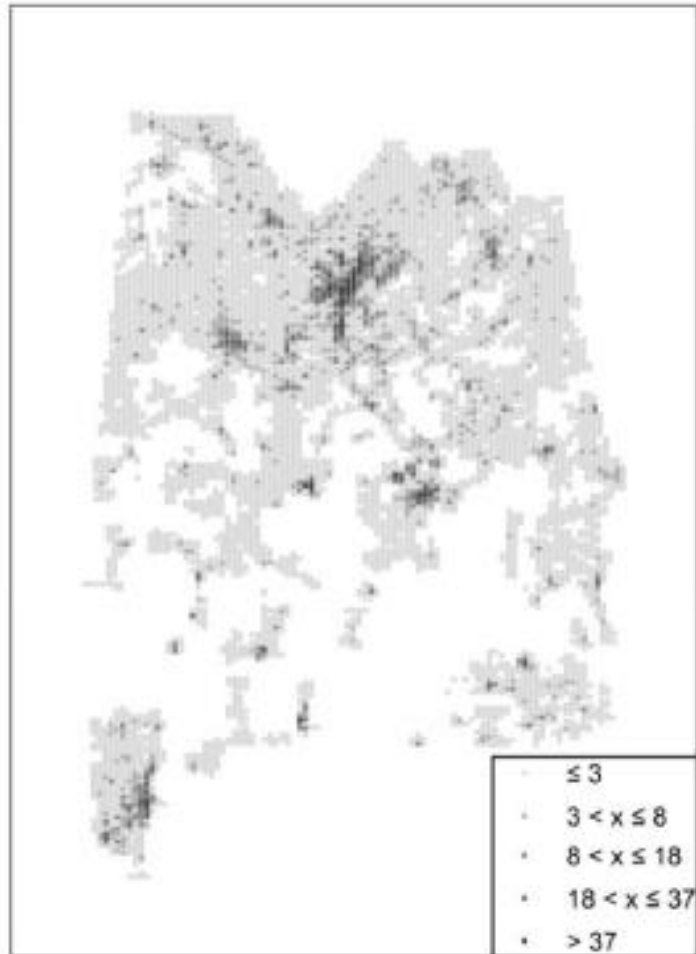
SPATIALLY GENERALIZED MODEL

INPUT VARIABLES:

Antecedent conditions affecting tree strength, stability, and type of development

Exposure to high winds

Geographic Data
- Soil Moisture
- Long-term mean precipitation
- Short-term deviations from long-term precipitation
- Land use/land cover type
- Topographic data

Power System Data
- Number of poles, transformers, switches & miles of line (OH, UG)

Hazard to the system

Hurricane Data
- Local wind field (via physics-based model)

Customers->Population per census tract

MODEL DEVELOPMENT:

Train & validate models w/in service area using only public data

Validate models across hurricanes

Validate models across states

Predict for an approaching hurricane

Learn from storms and refine models

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FORECASTING PROCESS

Hurricane track & intensity forecast

(NHC)

Iterative update every 6 hr

Statistical outage forecasting model

Hurricane wind-field model estimates

SANDY

FORECASTS AT 84, 60, 36, 12, AND 0 HRS BEFORE LANDFALL. CENSUS TRACT LEVEL
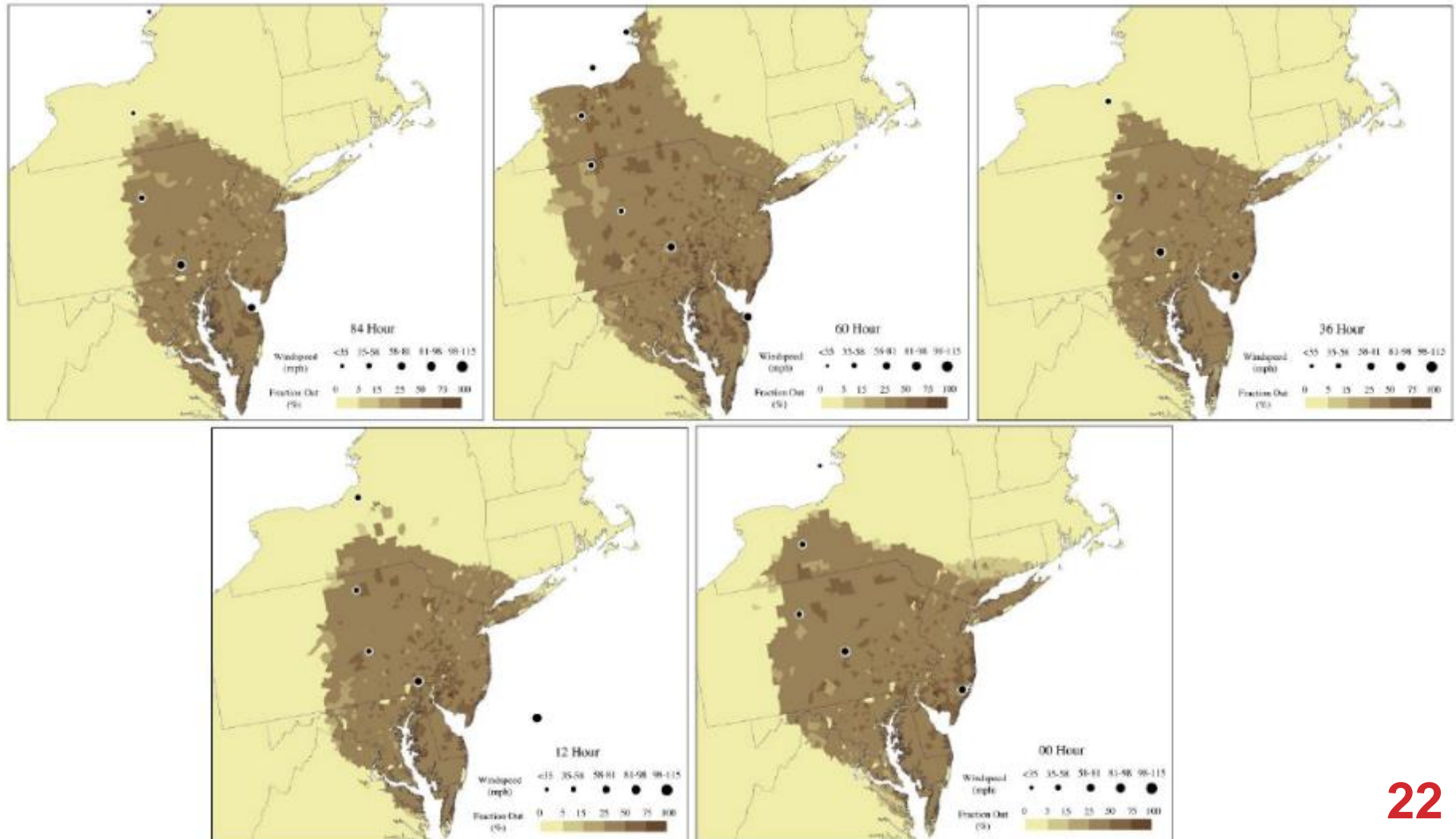
CHALLENGES OF SANDY

- **We predict cumulative outages, utilities generally report peak outages**

- **No reliable source of actual outage data at the same scale as our predictions**

Katrina
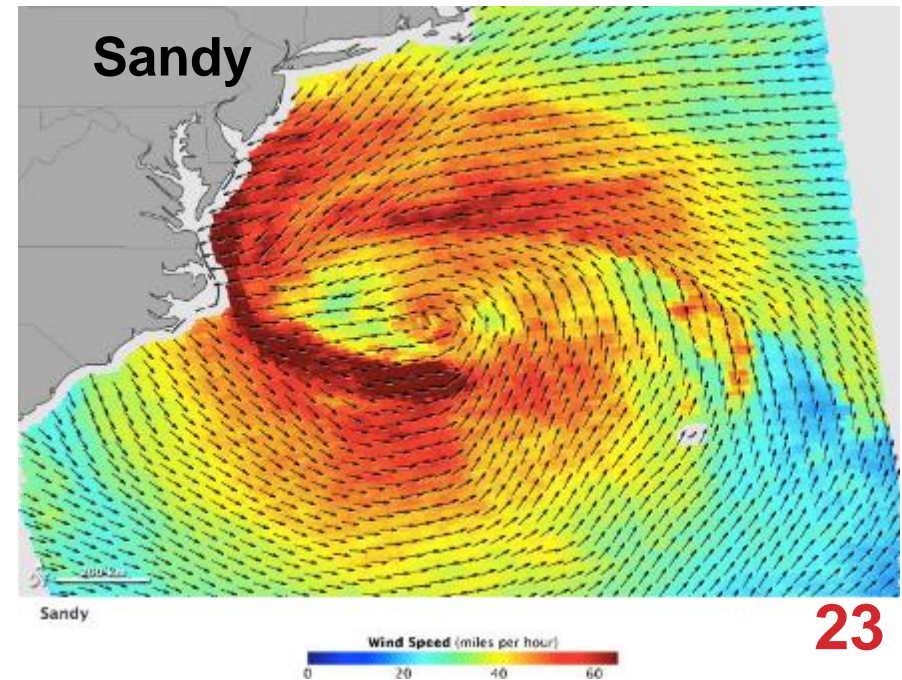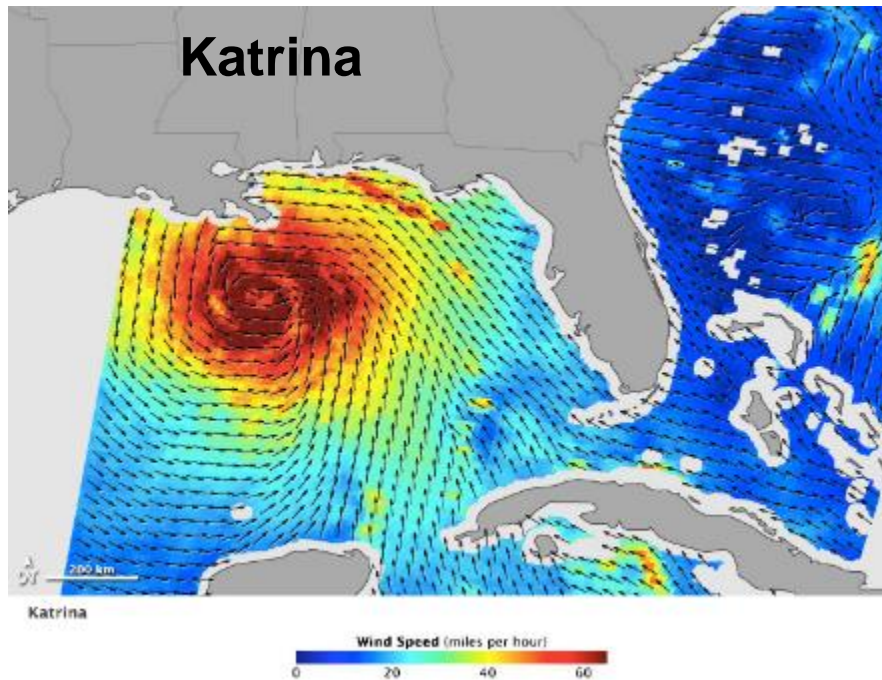
Sandy

RESULTS OF SANDY

- DOE estimate: 8.5 million customers out at peak
- Our forecast estimate: 8 -10 million out:
    - within 8% of DOE's estimates for NY, PA, MA, RI, VA
    - overestimated outages for MD and DE
    - underestimated outages for CT

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WHAT IF ANALYSIS

Assessing impacts of hypothetical storm events

Haiyan Storms

Windspeed (mph): 23-35, 35-69, 69-115, 115-161, 161-196

Fraction Out (%): 0 5 15 25 50 75 100
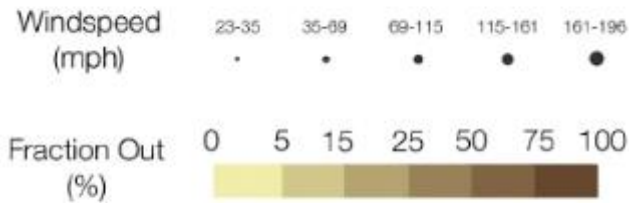
Haiyan - Andrew

Haiyan - Irene

Haiyan - Ike

Haiyan - Katrina

Historic Storms

Windspeed (mph): 23-35, 35-69, 69-115, 115-161, 161-198

Fraction Out (%): 0, 5, 15, 25, 50, 75, 100
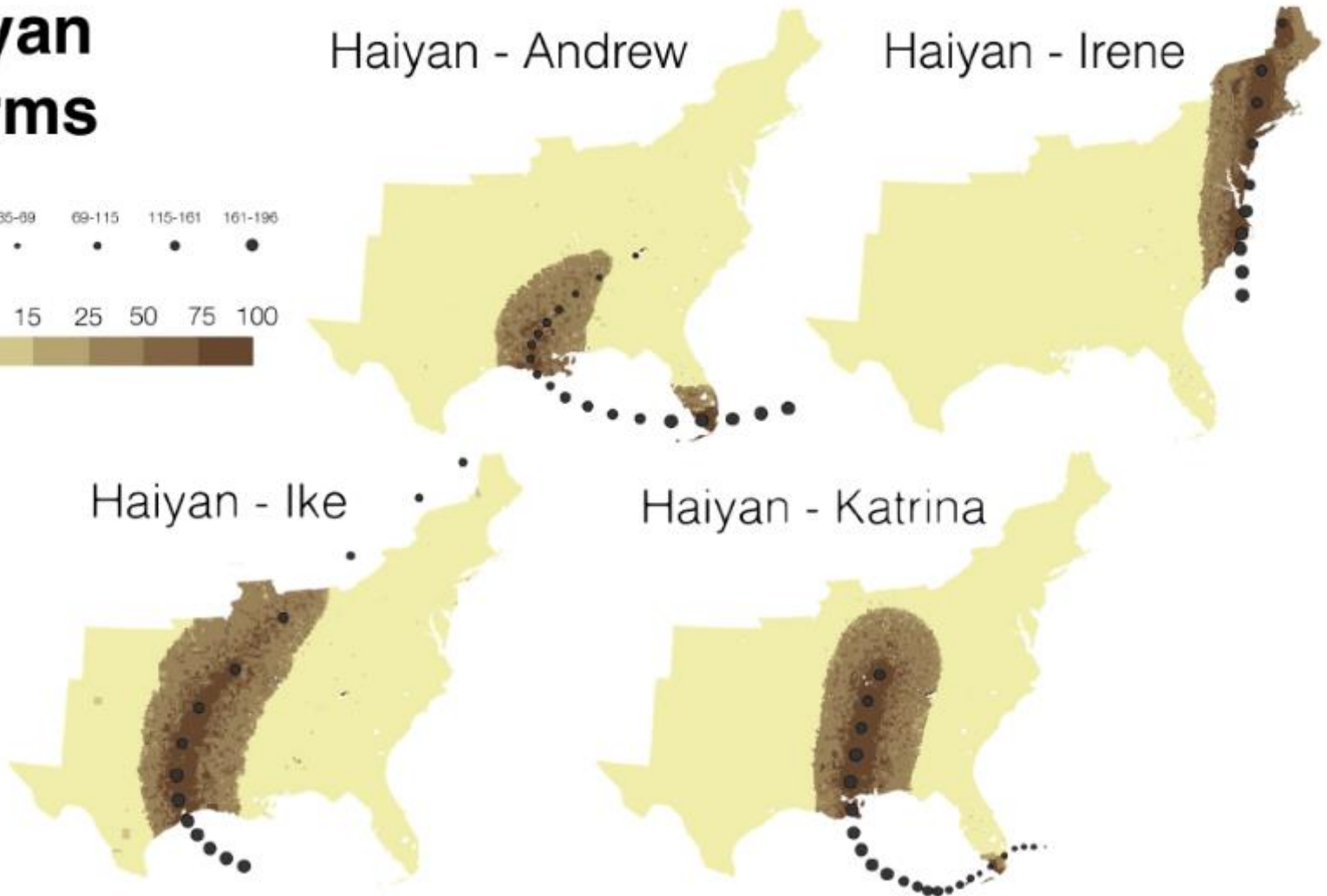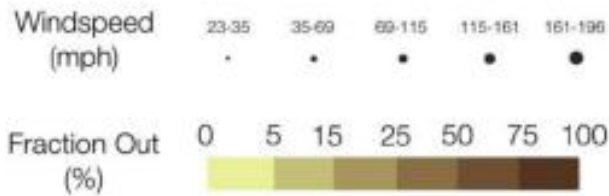
Andrew

Camille

Galveston

Ike

Irene

Isabel

Ivan

Katrina

Rita

Sandy

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LONG-TERM SIMULATION

SIMULATION STRUCTURE
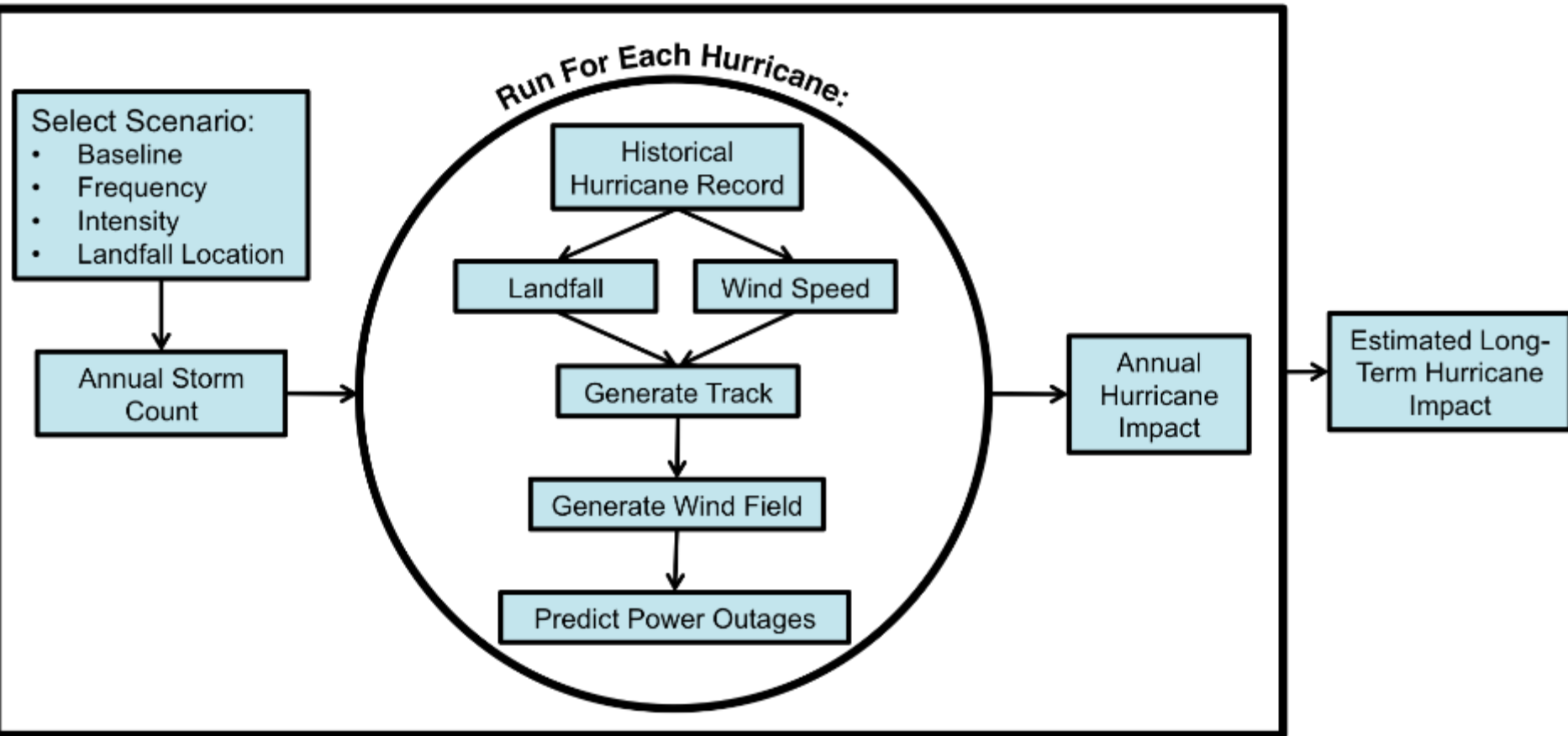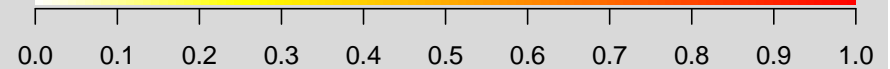
BASELINE RESULTS

100-Year Wind Speed [m/s]
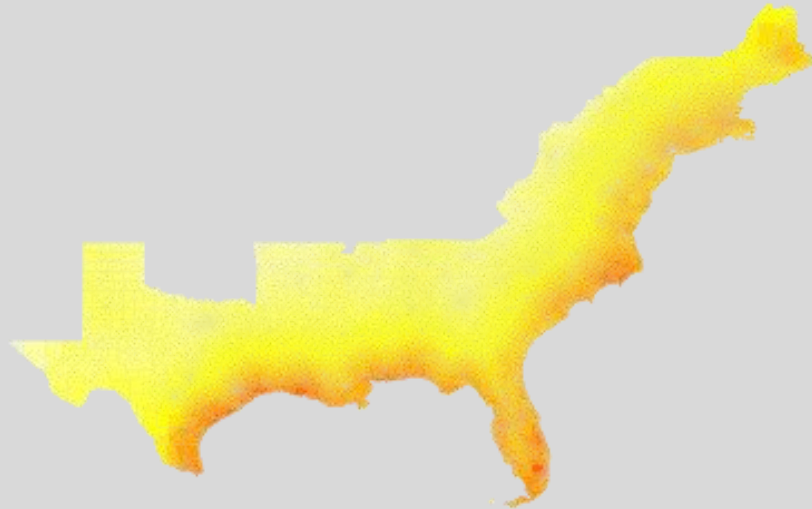
3-sec Gust Wind Speed [m/s]

| 0 | 11 | 22 | 33 | | 55 | 66 | 77 | 88 | | 110 |

100 mph   224 mph

100-Year Fraction of Customers without Power

| 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
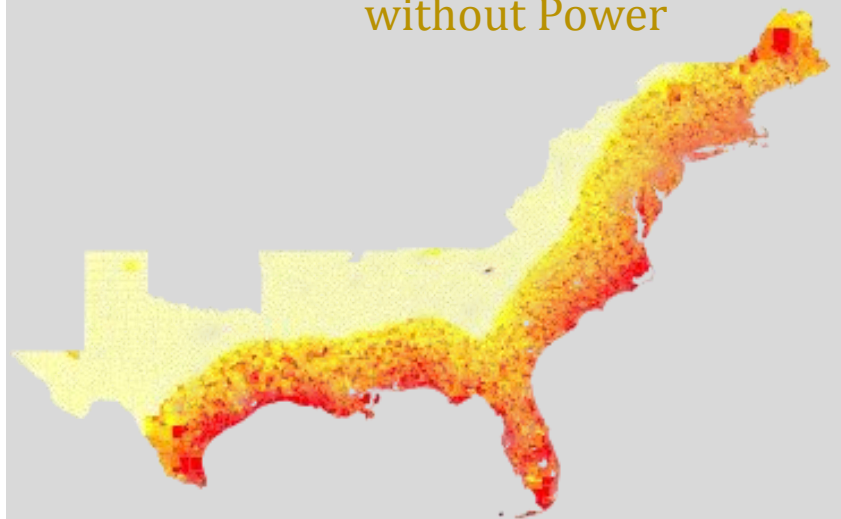
100-YEAR WIND SPEED

Plotting **Difference** From Baseline:

Intensity = 0.8   Intensity = 1.2   Intensity = 1.4

Change in Wind Speed [m/s]

-60   -48   -36   -24   -12   0   12   24   36   48   60

Plotting **Difference** From Baseline:

Intensity = 0.8   Intensity = 1.2   Intensity = 1.4

Change in Fraction Out

-1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0

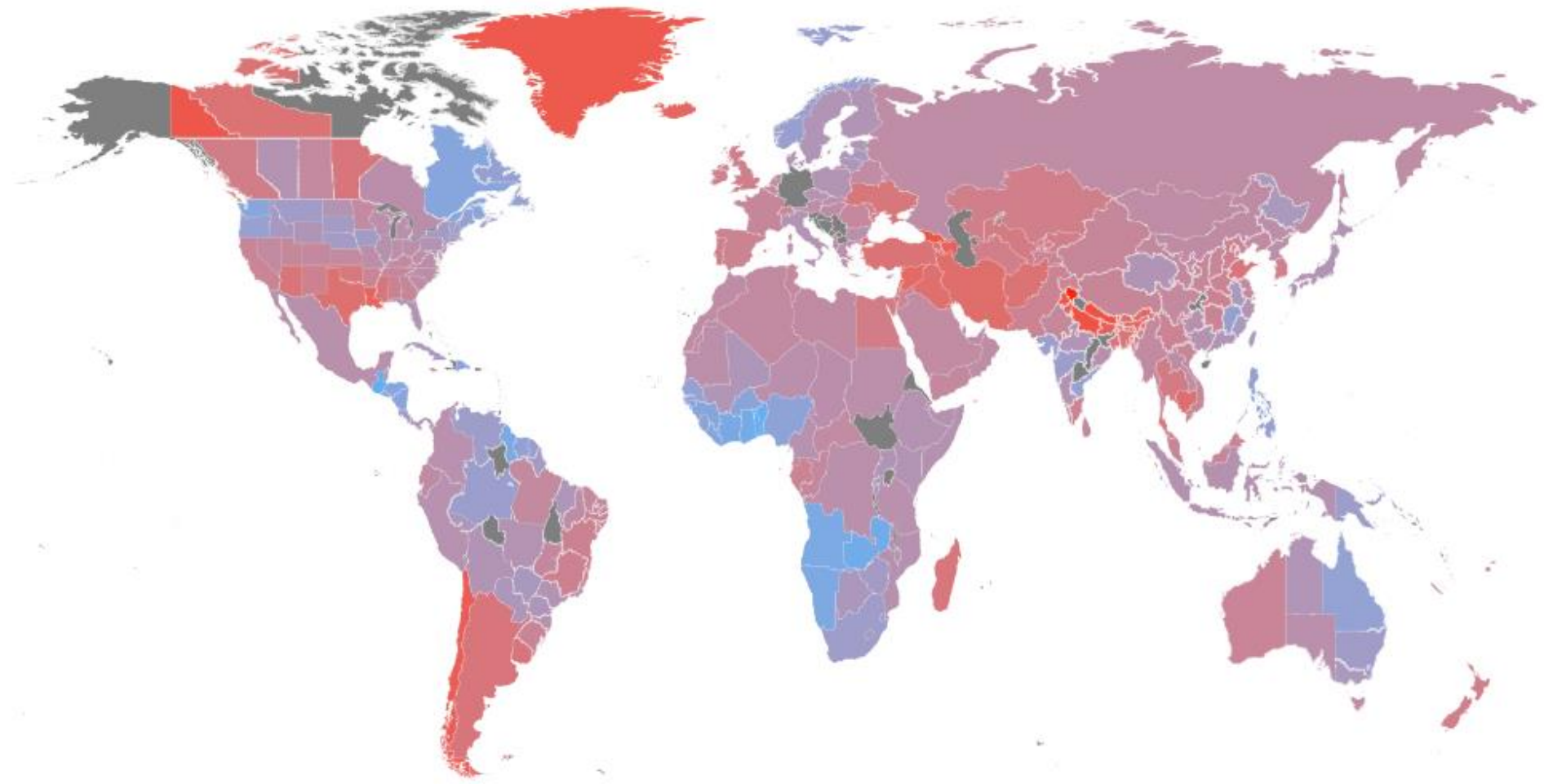**32**
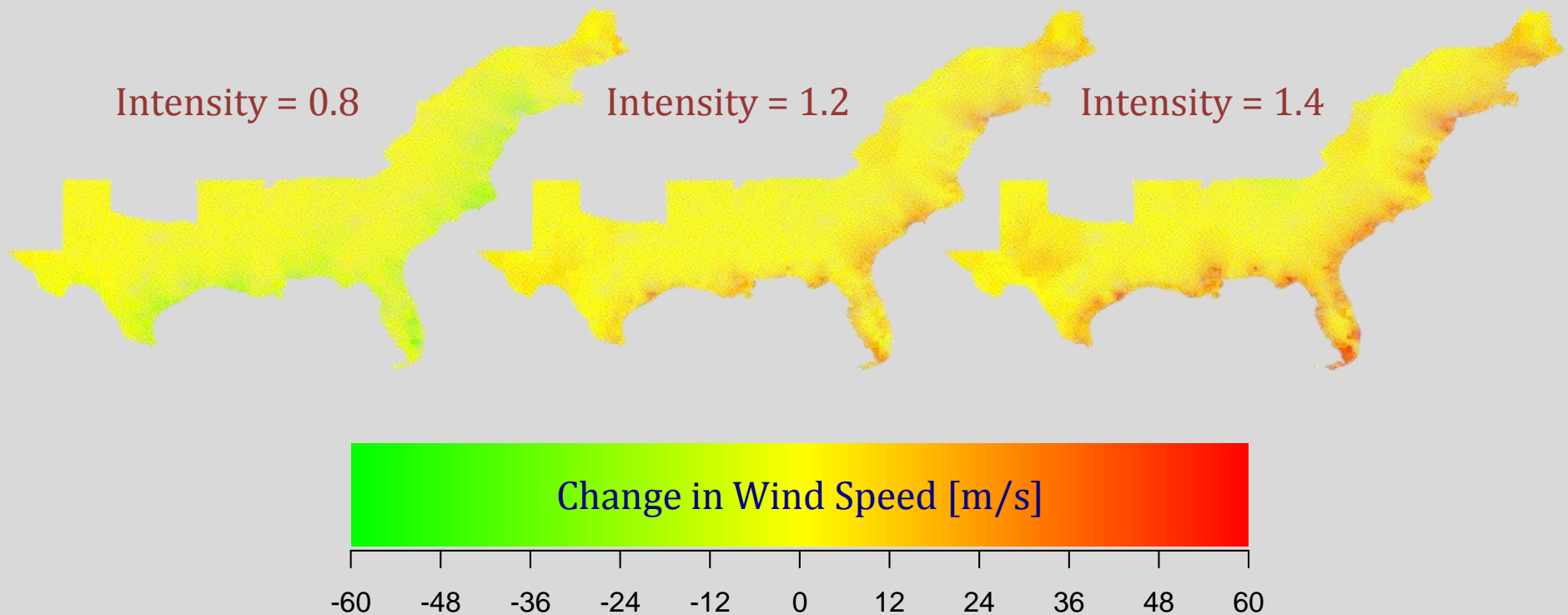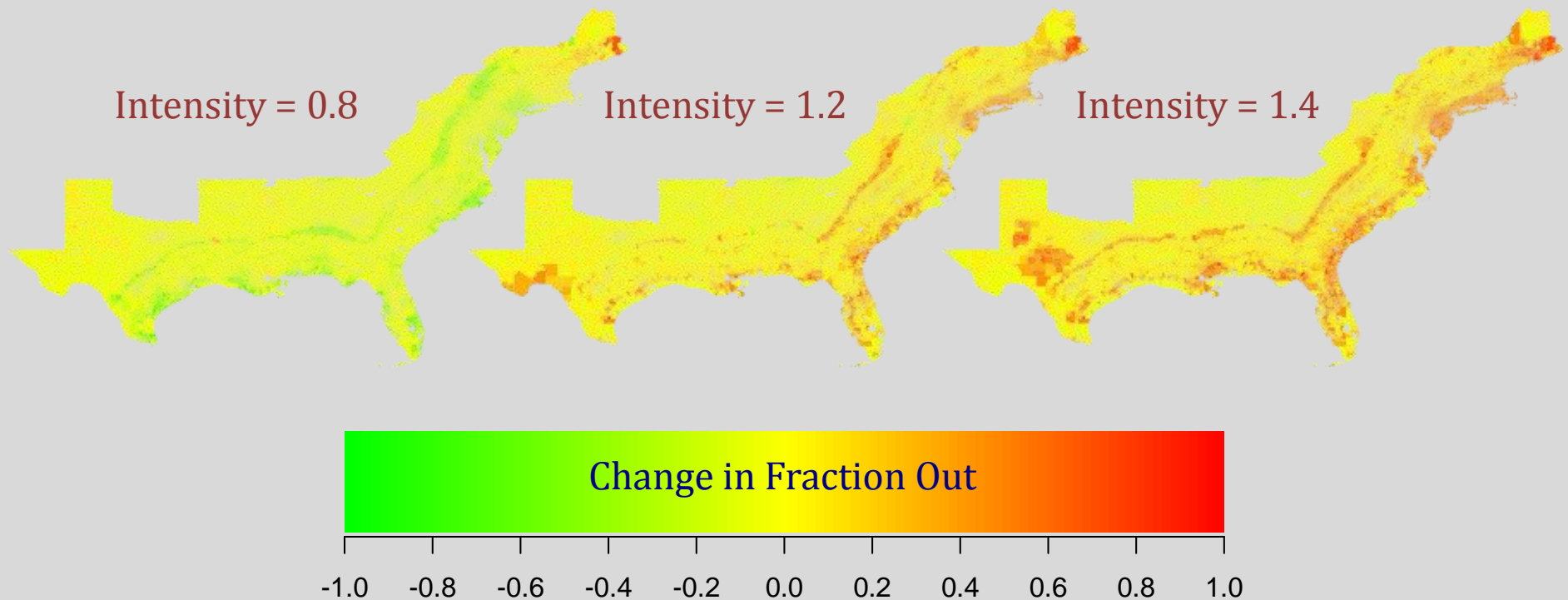
ELECTRICITY ADEQUACY PLANNING

POWER ADEQUACY RISK

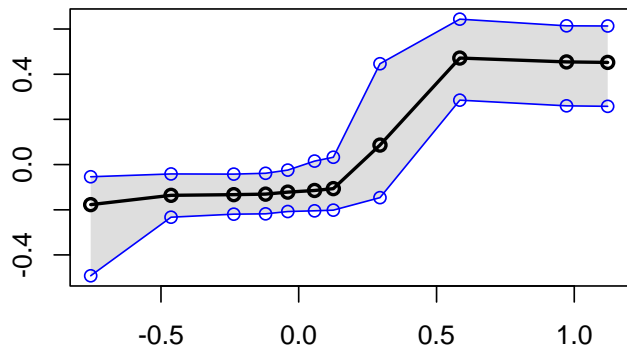**Predict US building stock energy use + identify the key drivers of demand at a spatially detailed level.**
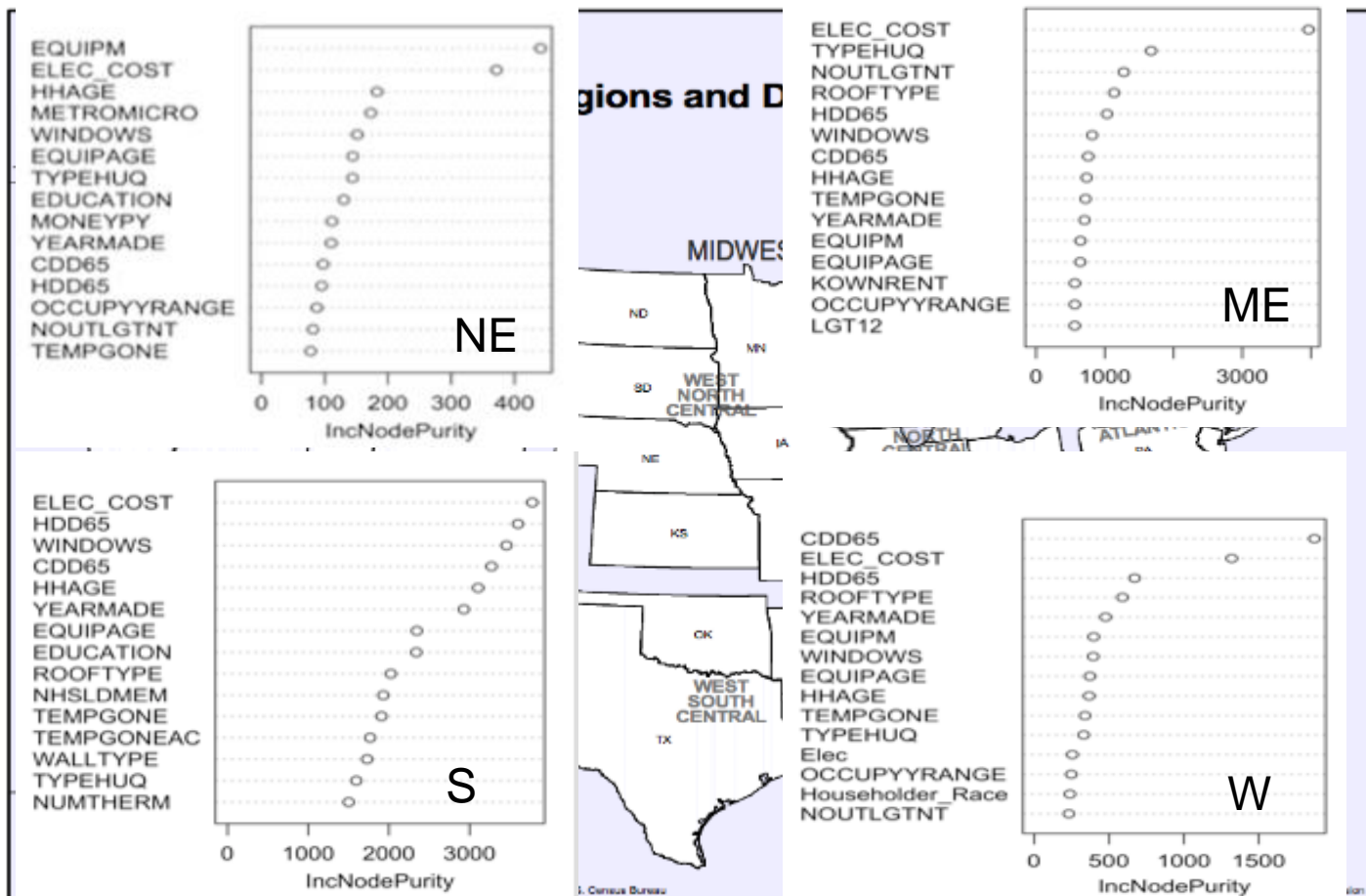
PREDICTIVE ANALYTICS IN WATER
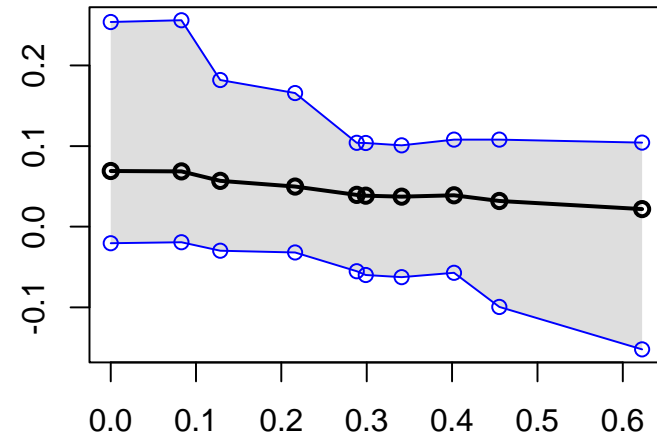
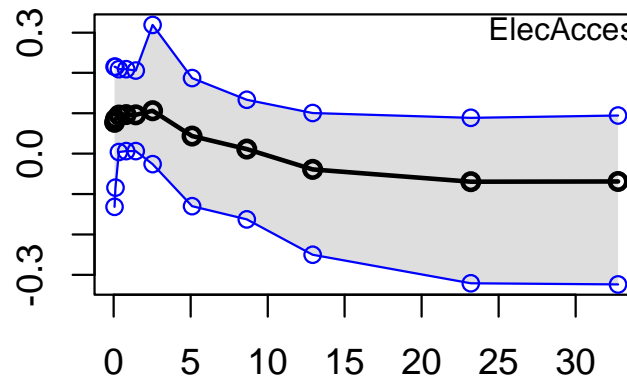# GREACE GROUNDWATER TRENDS

KEY STRESSORS GLOBALLY

- Industrialized agriculture

- Precipitation levels

- Power generation

season_trmm_trend plotted at specified quantiles
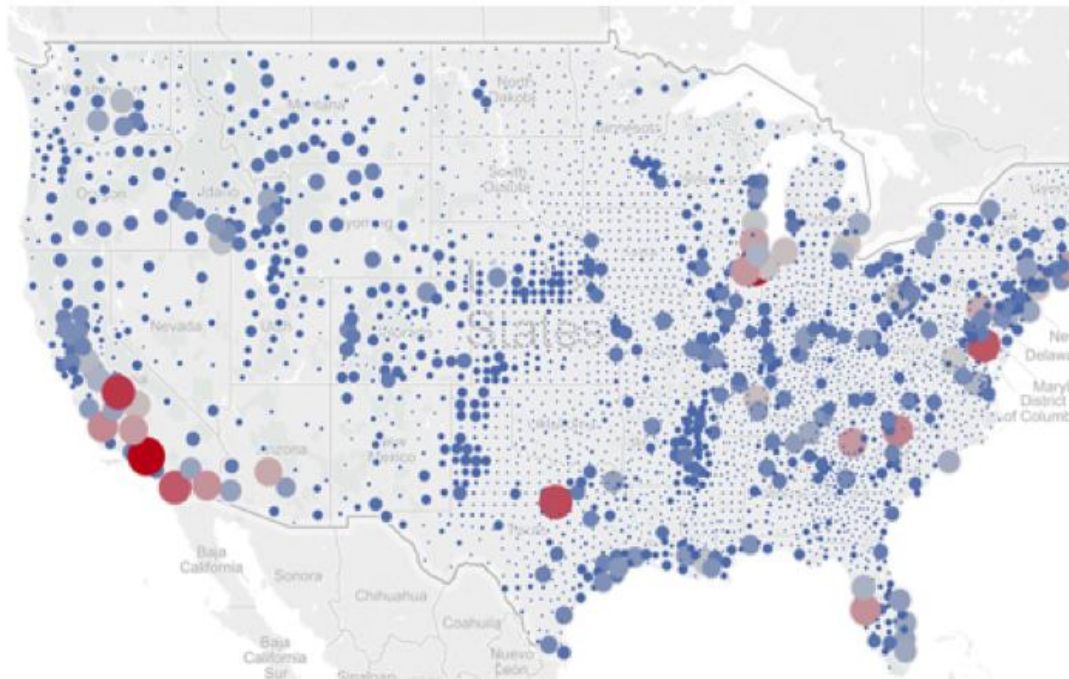
ElecAccessTrend plotted at specified quantiles

LEIDA plotted at specified quantiles

US WATER CONSUMPTION

Key drivers:

- Population size

- Irrigation size

- energy generation

- urbanization and climatic variables.

THANK YOU!

A little boy it Port-Au-Prince, Haiti wearing oversized rain boots after the storm. Photo: Reuters