Wildfire Webinar Series: Webinar 2

Situational Awareness

April 15, 2021

Michael Pesin

Deputy Assistant Secretary

Advanced Grid Research and Development

Office of Electricity

U.S. DEPARTMENT OF ENERGY
OFFICE OF ELECTRICITY

Tech: Multi-Source Multi-Time-Scale Wildfire Data Warehouse and Visualization Platform

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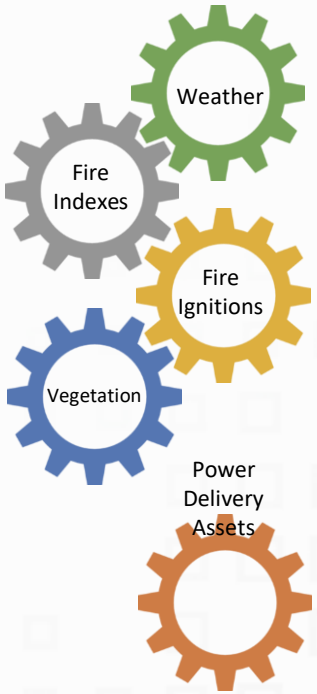
Apr 15, 2021

Overview

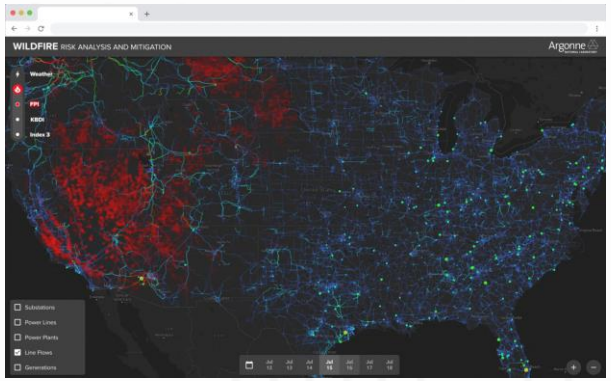
A risk assessment and mitigation framework for fire hazards caused by power delivery infrastructure

- Data warehouse & visualization
- Wildfire risk analysis & modeling
- Wildfire risk mitigation support

Data collection



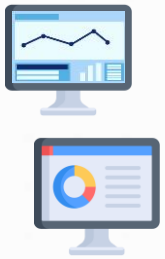
Data processing



Data Warehouse & Visualization

Wildfire Risk Analysis & Modeling

- Understanding wildfire
- Wildfire prediction
- Consequence study
- Trend analysis



Wildfire Risk Mitigation Support

Operation stage
- *Optimal de-energization*
- *Disaster response*

Planning stage
- *Temporary microgrids to mitigate PSPS*
- *Mobile generation*

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Capability Summary

Wildfire Data Warehouse and Visualization Platform

- **Purpose**
  - Provide a complete set of data and a visualization tool to study wildfire risks caused by power delivery
- **Features**
  - A data management system consisting of a set of data for power delivery – incurred wildfire risk analysis
    - grid assets, wildfire danger indices, vegetation data, weather and climate, fire incidents reports ……
    - Multi-time-scale, automatically updated
  - A visualization platform
    - Multiple layers, automatic updates, historical and future data
- **Potential users**
  - Research communities, utilities that do not have dedicated wildfire applications policy makers, community/infrastructure developers, etc.

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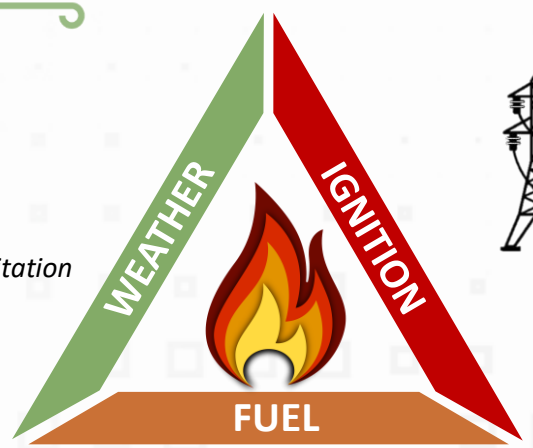
Contributing Factors: Wildfire Ignitions by Power Delivery

- Three categories of factors for a wildfire ignition by power system infrastructure

- *Wind Speed*
- *Wind Gust*
- *Temperature*
- *Humidity*
- *Total/Rate Precipitation*

Static and Dynamic Power System Modeling



Spark from power system infrastructure caused by:

Fire Incident Reports

- Equipment failure
- Contact by
  - Vegetation
  - Animal
  - Other

Fire Danger Indices

Vegetation Type

Area filled with dried out or dead vegetation

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Fire Danger Indices

Fire danger indices provide an estimation of the **wildfire risk**. We have developed the capability to determine the following commonly-used indices for a range of time scales, from near **real-time** to a week, to seasonal outlook, to the longer-term projection over the next decades at high spatial (4km and 12km) resolutions.

a) **KBDI** (Keetch-Byram Drought Index) [3,4]

- Applied by U.S. Forest Service (USFS), Texas Forest Service, U.S. Army

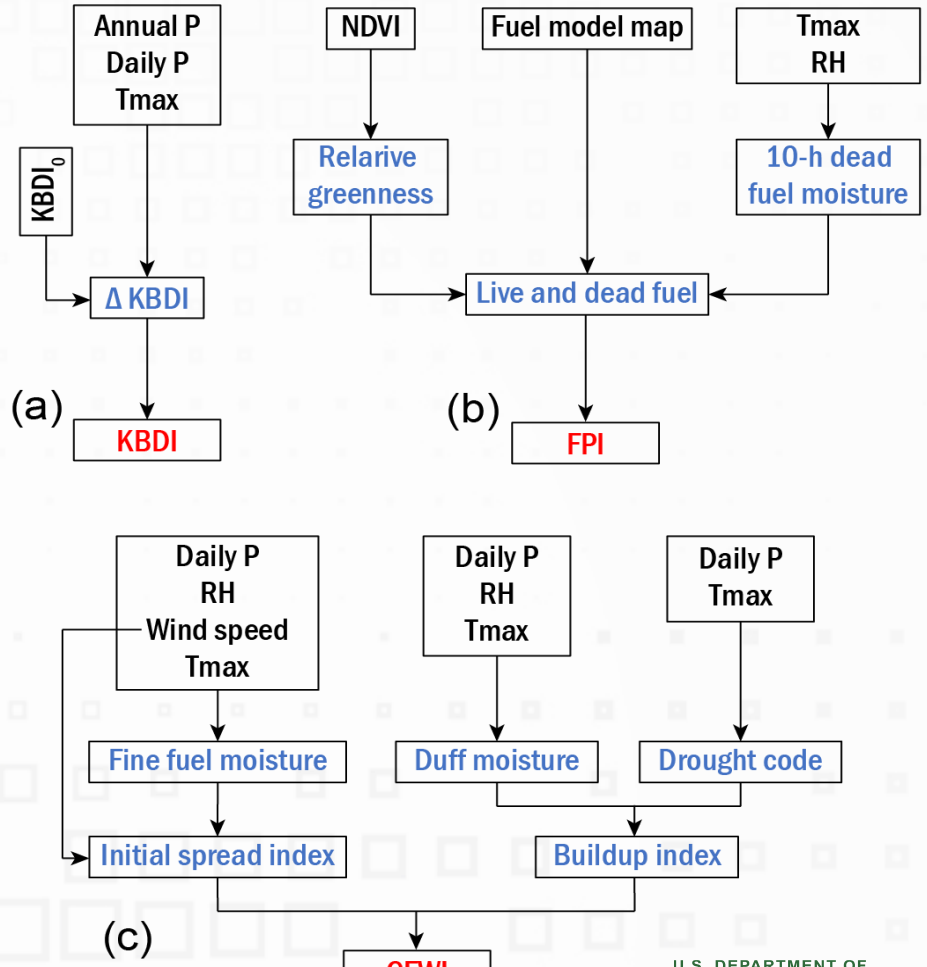
b) **FPI** (Fire Potential Index) [5,6]

- Applied by USFS, United States Geological Survey (USGS)
- Proprietary versions of FPI are being used by power utilities (e.g., PG&E, SCE)

c) **CFWI** (Canadian Fire Weather Index) [6,7]

- Applied by the Canadian Forest Service and variations have been adopted by Australia, France, and Croatia.

- **d)** A machine-learning fire danger model is being developed



[3] Keetch J. J. and Byram G. M. (1968). A Drought Index for Forest Fire Control SE-38 U.S.D.A. For. Serv. Res. Pap
[4] Brown, E.K., J. Wang, and Yan Feng. 2021. U.S. wildfire potential: a historical view and future projection using high-resolution climate data. Environmental Research Letters.
[5] Burgan R.E., Klaver R. W., and Klarer J.M. (1998). Fuel models and fire potential from satellite and surface observations. International Journal of Wildland Fire, 8(3), 159 – 170
[6] Yu, G., J Wang, Y. Feng, E. Brown, and D. Wright. 2021. The performance of fire danger indices and its utility in predicting future wildfire danger over the conterminous United States. To be submitted
[7]Turner, J.A. and Lawson, B.D. (1978). Weather in the Canadian Forest Fire Danger Rating System. A user guide to national standards and practices. Environment Canada, Pacific Forest Research Centre, Victoria, BC

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Future Projection of US Wildfire Potential for Infrastructure Planning

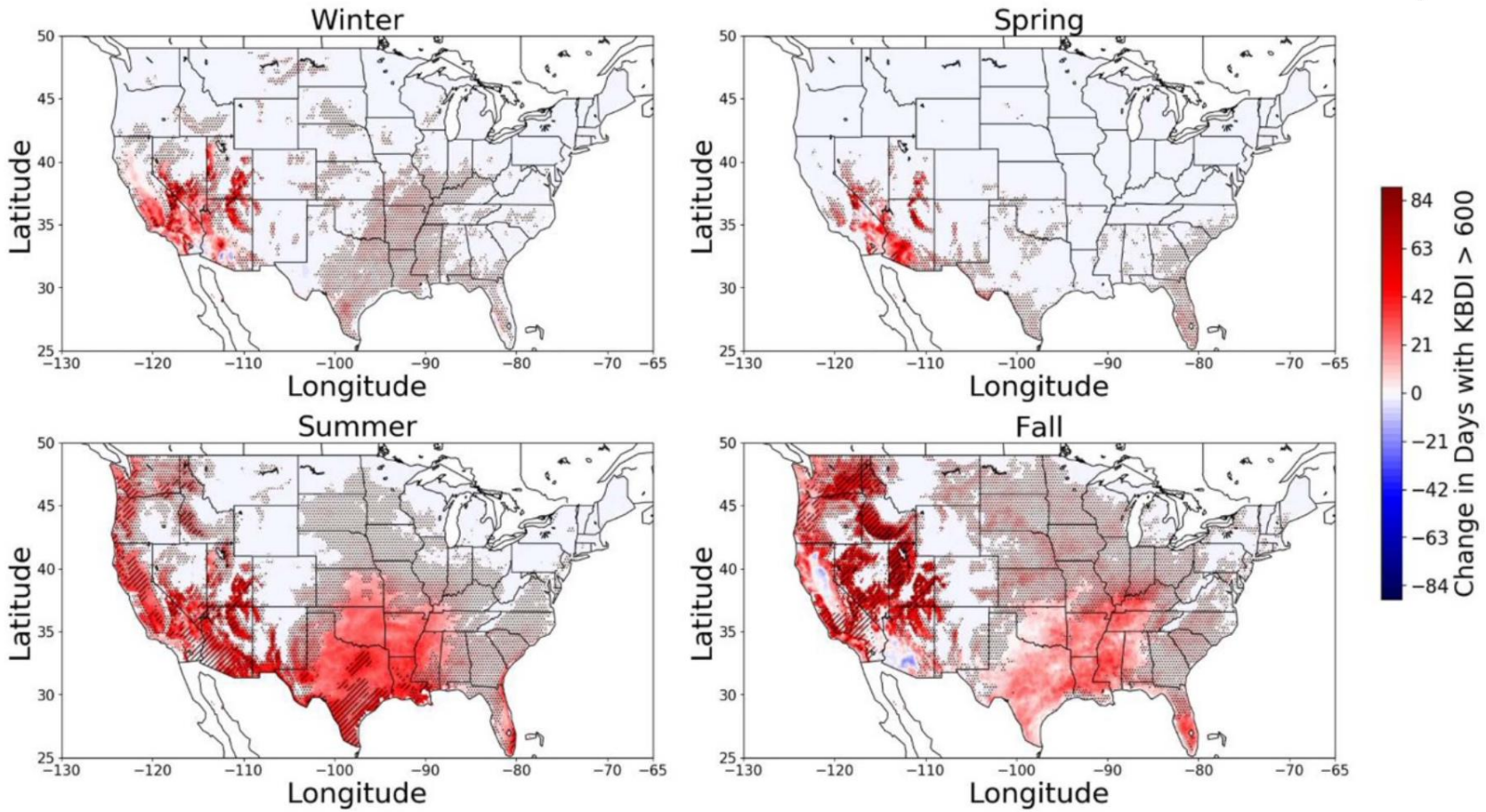

Figure 4. Change in the number of days and area with KBDI > 600 from the historical period to late 21st century using WRF-CCSM4. Shading indicates changes in the number of days; significant changes (signal-to-noise ratio larger than 2) are hashed. Dots indicate that a grid cell has a KBDI value greater than 600 only in the future. Areas without dots indicate that a grid cell either has KBDI > 600 in both periods or does not have KBDI > 600 in either period.

A significant increase is projected in the number of days (red color) and area (dotted) with large fire danger potential

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Vegetation Type

The **existing vegetation type** (EVT) information represents the current distribution of the terrestrial ecological systems classification [6].

Information can be accessed in a 30 m spatial granularity and a yearly time granularity if available, including:

a) Fuels EVT class name.

b) EVT Lifeform.

c) EVT Physiognomy.

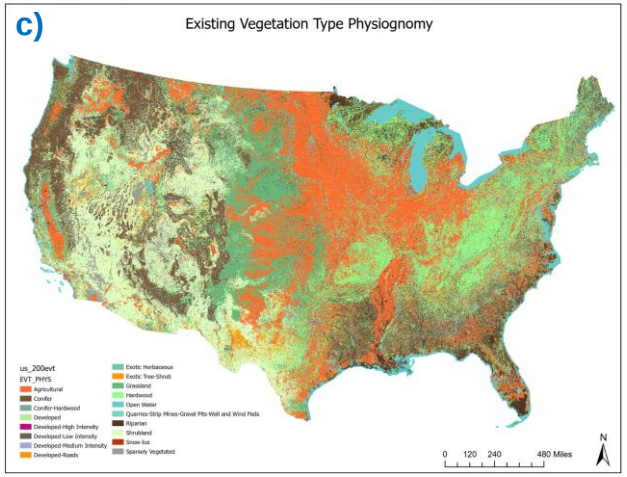
d) EVT Group name.

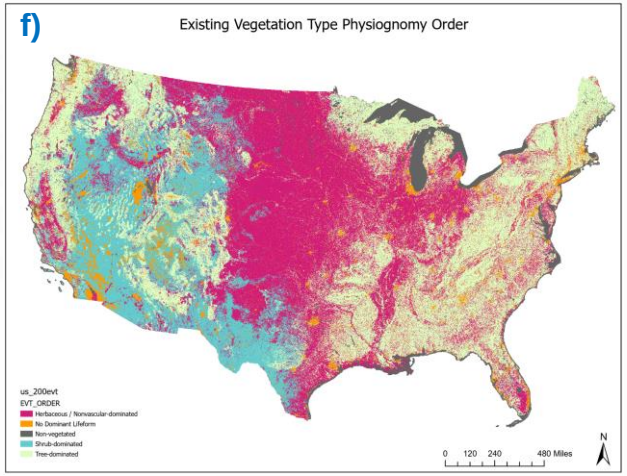
e) Crosswalk to Society of American Foresters and Society for Range Management cover type.

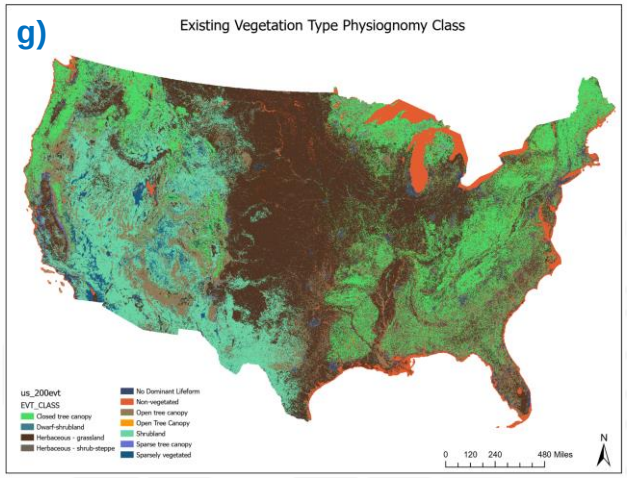
f) EVT Physiognomic Order from Federal Geographic Data Committee classification system.

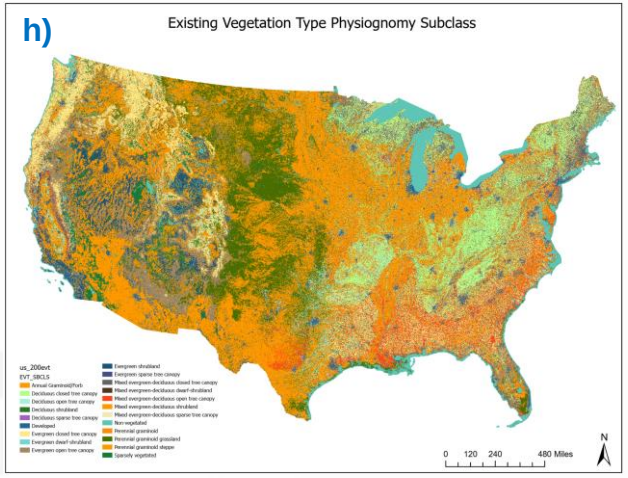
g) EVT Physiognomic Class from Federal Geographic Data Committee classification system.

h) Physiognomic Subclass from Federal Geographic Data Committee classification system.









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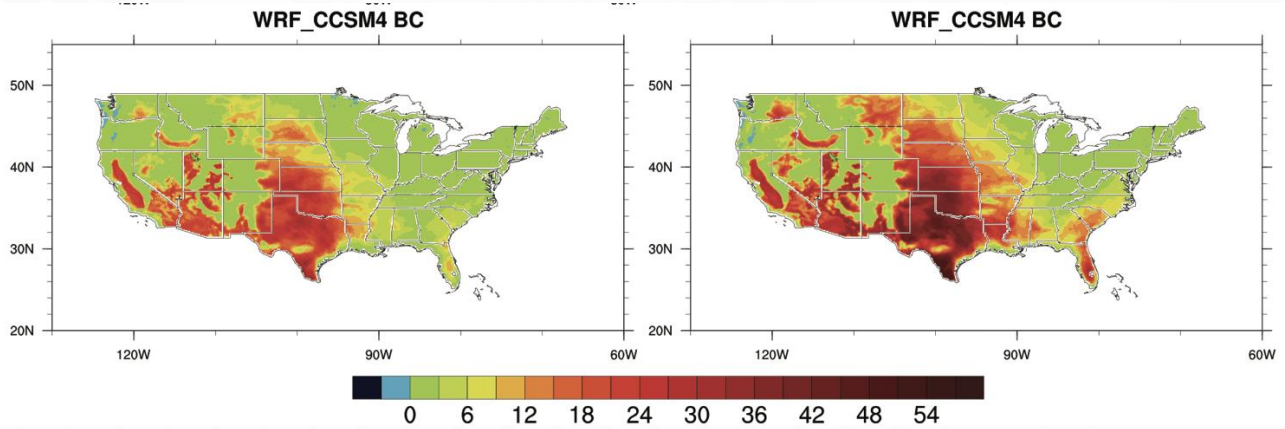
[6] LANDFIRE. LANDFIRE: Existing Vegetation Type, U.S. Department of Agriculture and U.S. Department of the Interior. Available at https://www.landfire.gov

Weather and Climate Variables

- **Wind speed/wind gust** - Unit (m/s): 10m above ground
- **Relative humidity** - Unit (%) 2m above ground
- **Air Temperature (daily maximum)** - Unit (K): 2m above ground
- **Precipitation (total, rate)** - Unit (mm, mm/s) surface level

Increase of Extreme Hot Days



Changes in number of days greater than 95 degF at each grid point in period of 2045-2054 under RCP4.5 (left) and RCP8.5 (right). Changes are shown as number of days per year (Zobel et al. 2017)

- **Soil moisture/soil temperature** – unitless (kg/kg), 2m deep below the ground
- **Geopotential height at 500hPa/ Sea level pressure:** provide large scale weather circulations

Available in:

- Near real-time 3-km resolution, hourly updated, with radar data being assimilated every 15 min over a 1-h period [7,8];
- Ten-year time slices for 1995-2004, 2025-2034, 2045-2054, and 2085-2094 under the business-as-usual and mitigation scenarios [9]

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[7] HRRR data archive: doi: 10.7278/S5JQ0Z5B
[8] Blaylock B., J. Horel and S. Liston, 2017: Cloud Archiving and Data Mining of High-Resolution Rapid Refresh Model Output. Computers and Geosciences. 109, 43-50. doi: 10.1016/j.cageo.2017.08.005
[9] Zobel, Z., J. Wang, D. J. Wuebbles, and V. R. Kotamarthi. 2017: High Resolution Dynamical Downscaling Ensemble Projections of Future Extreme Temperature Distributions for the United States. Earth's Future

Fire Incident Reports

The California Public Utilities Commission (CPUC) provides the **Fire Incident Data Reports** from 2014 – 2019 for the following power utilities [9]:

- Pacific Gas and Electric (PG&E)
- Southern California Edison (SCE)
- San Diego Gas & Electric (SDG&E)

These reports provide information of fire incidents ignited by power system infrastructure including:

Fire start

- Date
- Time

Location

- Latitude
- Longitude
- Material at origin
- Land use at origin

Fire

- Size
- Suppressed by
- Utility facility
- Facility identification
- Voltage
- Equipment involver
- Type (overhead/subsurface/underbuild)

Outage

- Date
- Time

Field observations

- Suspected initiating event
- **Equipment failure**
- **Contact from object**

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[9] California Public Utilities Commission (CPUC), available at https://www.cpuc.ca.gov/wildfires/

Power Infrastructure

Power Infrastructure [10]

- Power substations

  Electric power substations primarily at voltages equal to, or greater than, **69 kilovolts**. Substations with a maximum operating voltage less than 69 kilovolts may be included, depending on the availability of authoritative sources. Geographic coverage includes the United States and the U.S. Territories.

- Power transmission lines

  Includes lines operated at relatively high voltages varying from **69 kV up to 765 kV**. Underground transmission lines are included where sources were available. Geographic coverage includes the United States and the U.S. Territories.

- Power plants

  All power plants that are operating, on standby, or short- or long-term out of service with a combined nameplate capacity of **1 MW** or more in the United States

Dynamic Power Operation

- Power flows, voltages
- Power generated / consumed at each substations
- Calculated through **Argonne's dynamic power operation models**.

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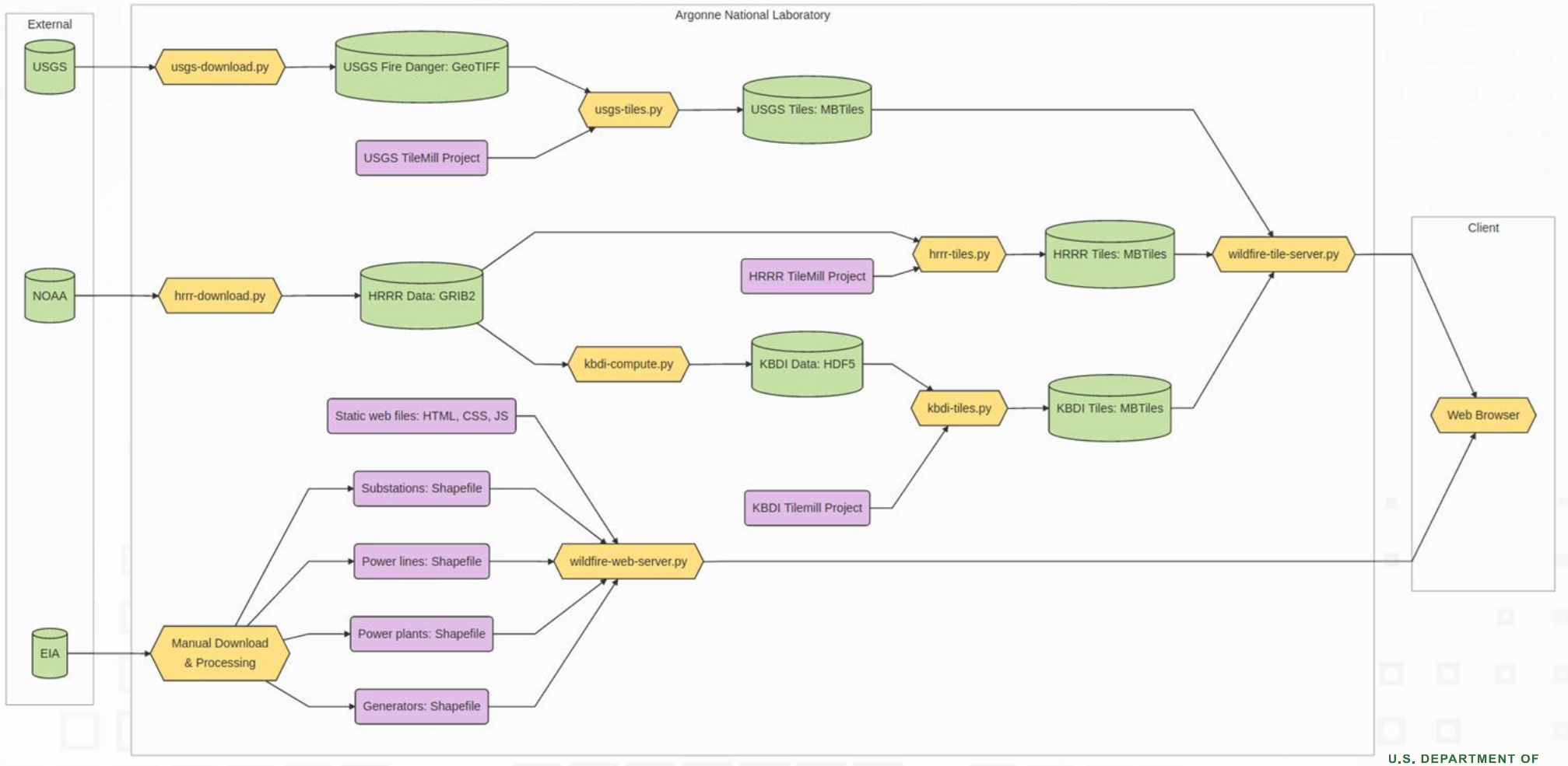
[10] U.S. Energy Information Administration (EIA). U.S. Energy Mapping System. Available at https://www.eia.gov/state/maps.php

Data Warehouse and Visualization

Wildfire: Data Flow



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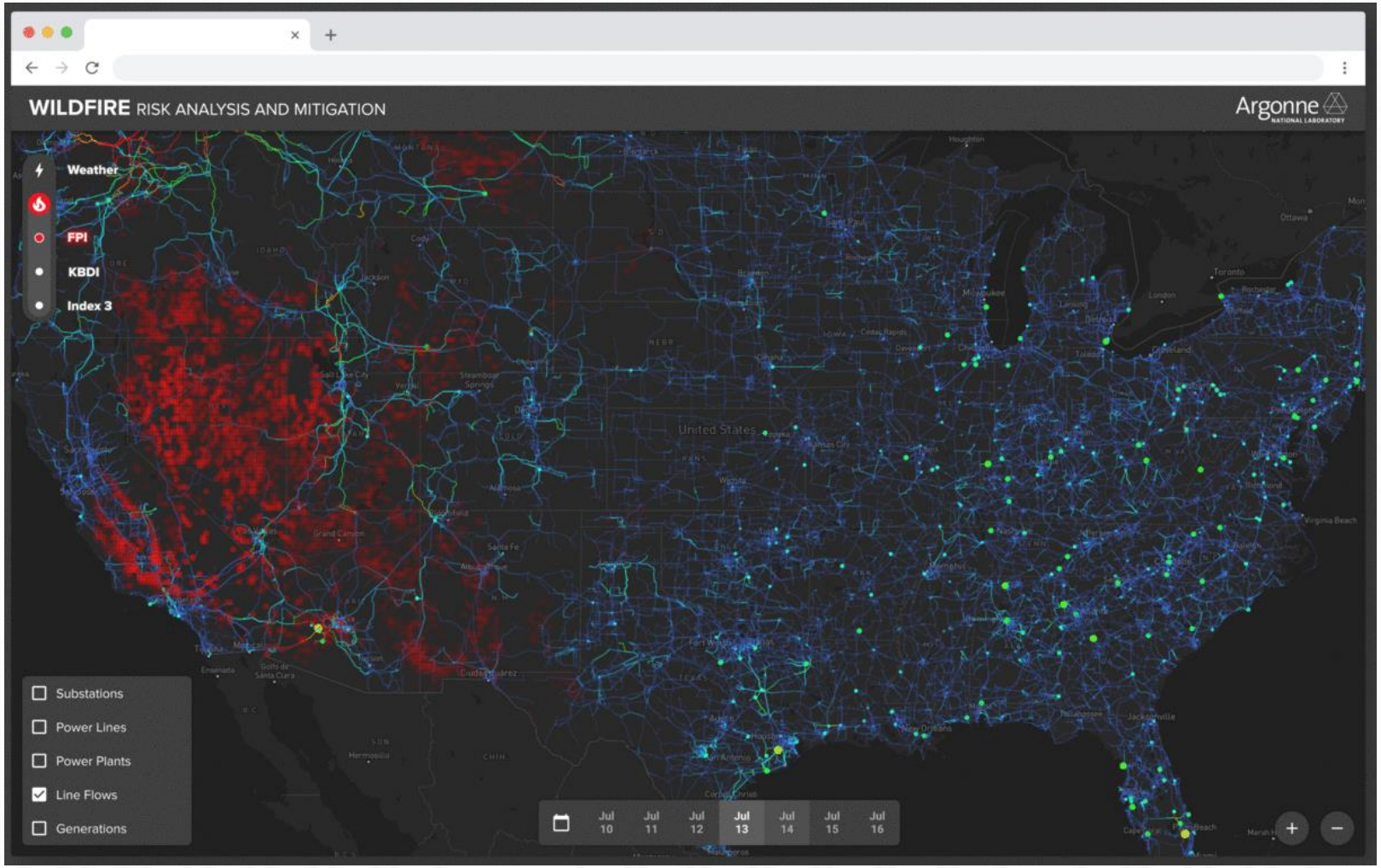
Visualization



Fire Potential Index & Power Flow

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Argonne's Wildfire Team

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Acknowledgement

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The advisory support from California's electricity utility, **Southern California Edison** (SCE), is acknowledged and appreciated.

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RISK & CRISIS COMMUNICATION FOR WILDFIRE RESPONSE

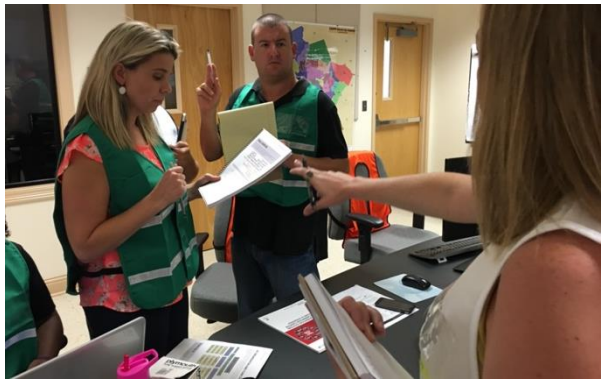
BRETT HANSARD
Risk & Crisis Communication Program
Public Affairs Science and Technology (PAST) Fusion Cell

April 15, 2021

PAST FUSION CELL & ACADEMY

Who we are and what we do

- Public Affairs Science and Technology (PAST) Fusion Cell & National Public Affairs Academy
- Part of Argonne's National Preparedness Analytics Center
- Engage with forward-thinking public affairs professionals and social scientists to improve all aspects of communication as it relates to emergency management
- Advanced training programs, exercise support and technical assistance for emergency management and communication professionals
- Wide range of emergency public information training topics
- Dynamic news media and social media simulations for training and exercises



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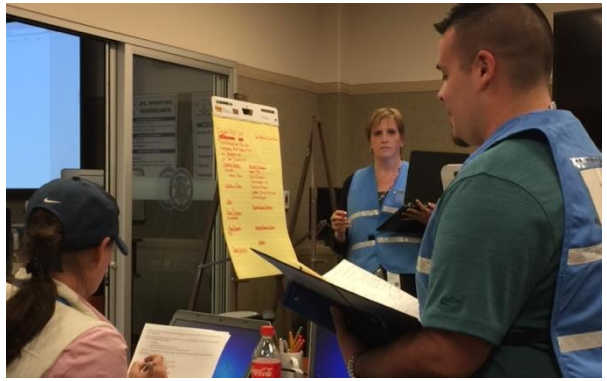
PAST FUSION CELL & ACADEMY

Who we work with

Including:

- Department of Energy
- National Nuclear Security Administration
- Chemical Stockpile Emergency Preparedness Program
- Federal Emergency Management Agency
- Department of Homeland Security
- Department of the Army
- Department of Defense
- Multi-Jurisdictional First Responders
- Multi-Jurisdictional Public Information Officers/Public Affairs Officers
- Spokespersons/Subject-Matter Experts/Leadership



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2021 COURSE CATALOG

Best practices for PIO/PAOs

The Public Affairs Science and Technology (PAST) Fusion Cell Academy offers virtual/In-person learning on a wide range of emergency management and public affairs topics, plus realistic virtual/in-person drills to test and reinforce skills.

https://pastfusion.egs.anl.gov/wp-content/uploads/2021/02/2021-PAST-Fusion-Cell-Academy-Course-Catalog.pdf

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2021 COURSE CATALOG

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PAST FUSION CELL & ACADEMY

Sampling of relevant courses for wildfire response

- Joint Information System/Center (JIS/JIC) Operations & Strategy
- Building and Maintaining a Resilient JIS
- Improving Emergency Communications for Vulnerable Populations
- Identifying and Addressing False Information in the Digital Era
- Social Media for Situational Awareness & Social Media Monitoring and Reporting
- Mapping GIS Tools & Techniques for PIOs/PAOs
- Spokesperson for PIOs/PAOs, Subject-Matter Experts and Leadership
- Go Live – Livestreaming Technology

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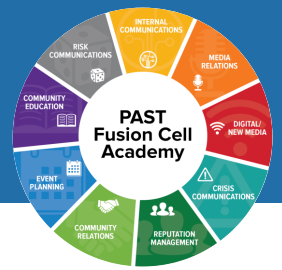
ALERT AND WARNING TECHNICAL ASSISTANCE



Why is getting alerts and warnings right so important?

CASE STUDIES

Camp Fire (2018)
Used opt-in system but 1/3 not reached

Gatlinburg Fire (2017)
Power outages meant messages not verified – not sent

Oroville Dam Spillway (2017)
Evacuation caused hours of bumper-to-bumper traffic

AUDIENCE

Those with role in communicating protective action guidance to public immediately preceding and during event:

- Emergency managers
- PIOs/PAOs
- Social media communicators

TA OUTCOMES

- Faster dissemination of effective messages
- Greater public understanding and response to A&W messages

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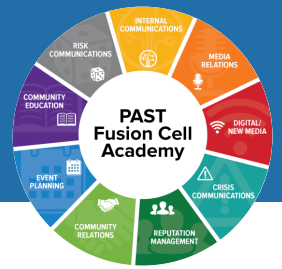
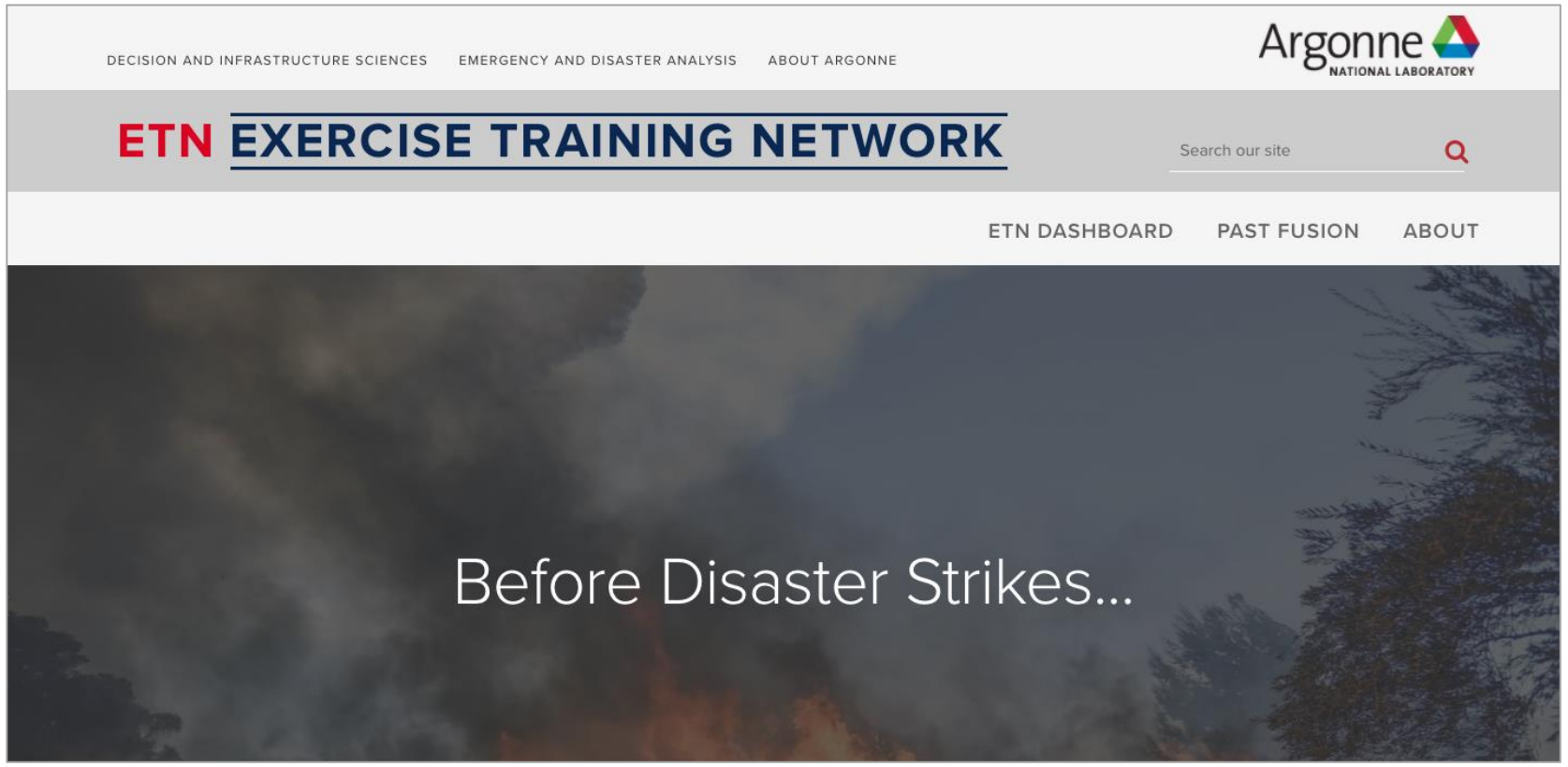
VIRTUAL TRAINING PLATFORM



Exercise Training Network site

PASSWORD-PROTECTED



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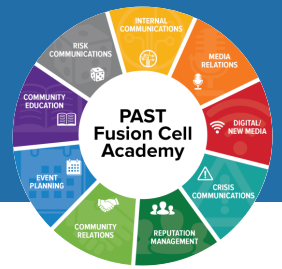
ETN MULTIMEDIA DASHBOARD



Real-time television, print and radio news stories for exercises

CSEPP BlueGrass20

September 16, 2020

TELEVISION

PRINT

THE DAILY GRIND

HOME WORLD NEWS SPORTS TRAVEL

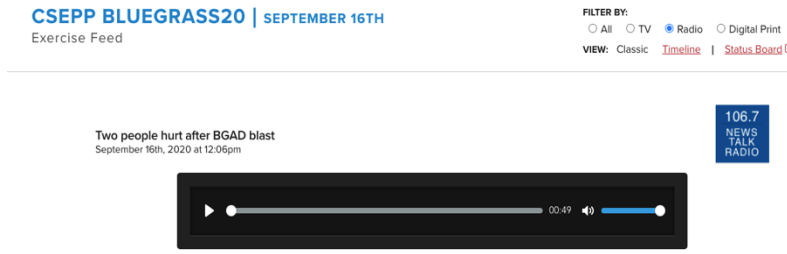
RICHMOND, Ky. – An incident of some kind has occurred this morning at a highly-secure military installation in central Kentucky where the U.S. Army stores some of the world's most deadly and dangerous chemical weapons.

No details have been released yet by the Blue Grass Army Depot, but coming just days after the 9/11 anniversary there are fears this might be more than an accident.

Initial reports indicate that emergency crews are responding in an area of the depot where toxic chemicals have been stored since 1944.

The depot is home to an aging stockpile of projectiles and rockets, with more than 500 tons of GB, VX and mustard agent stored there. GB and VX are nerve agents and just a few drops can be lethal. In fact, VX is the mostly deadly chemical agent known to man.

RADIO



FOR EXERCISE PURPOSES ONLY

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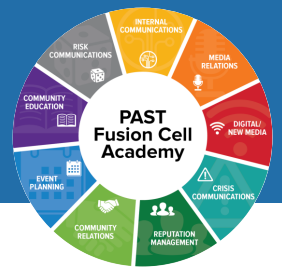
EXERCISE TRAINING NETWORK



Example of mock media news report

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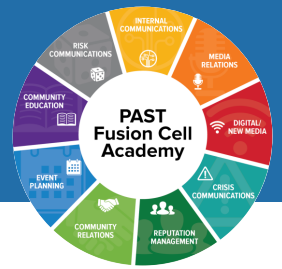
VIRTUAL STUDIO



Example of live interview training

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PAST FUSION CELL & ACADEMY

What we offer

- Identify and address training gaps in risk and crisis communication
- Establish best practices for PIO/PAOs and spokespersons
- Courses constantly evolving to reflect latest trends in communication
- Customized to meet specific needs and goals of training audience
- Maximize efficacy of critical messaging
- Challenging and realistic classroom and field training simulations
- Instructors with extensive real-world experience, familiar with wide range of hazards and training strategies

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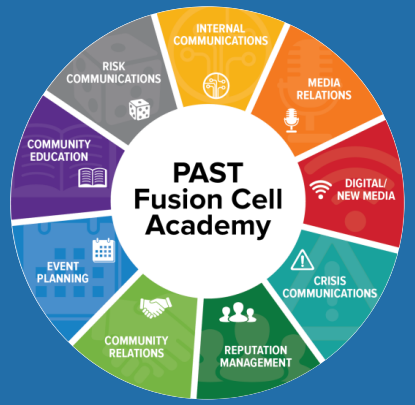

QUESTIONS?

Brett Hansard
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EAGLE-I

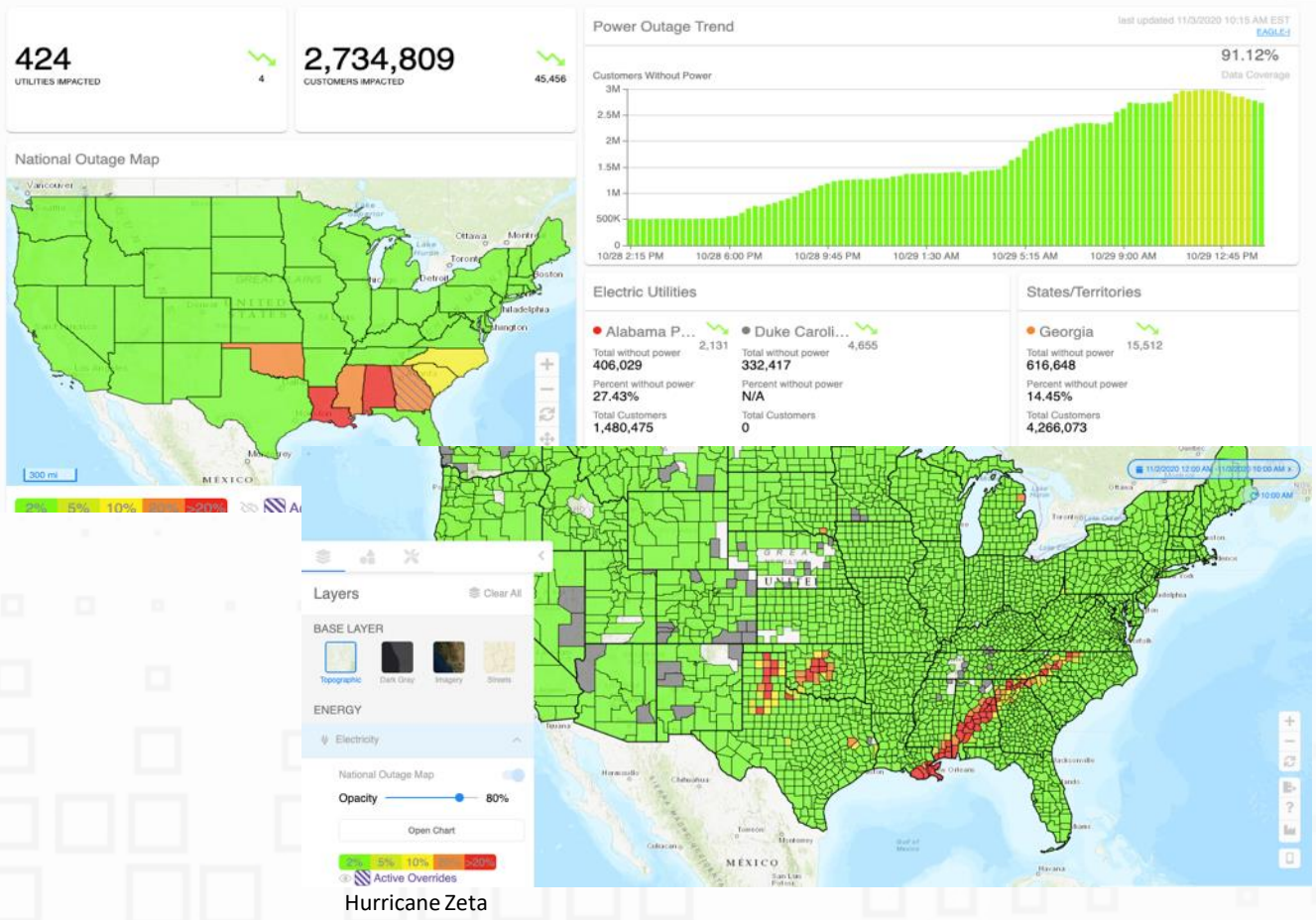
Environment for Analysis of Geo-Located Energy Information

Aaron Myers, Geospatial Systems Architect, Geoinformatics
Engineering Group, Geospatial Science And Human Security Division

April 15, 2021

Overview

- US DOE's operational and scalable data and information platform for real-time wide-area situational awareness of the energy sector
- Data science approaches to provide a centralized platform for monitoring power distribution outage for over 144 million customers; 92% coverage of US States and Territories
- Users from across the Federal Government including DOE, DHS, NGA, DOD, FEMA, and USDA along with state and other emergency responders.
- Supports the ESF#12 function within the National Response Framework (NRF)
- Providing modern framework for the future capabilities for emergency response and recovery support



Hurricane Zeta

OAK RIDGE National Laboratory

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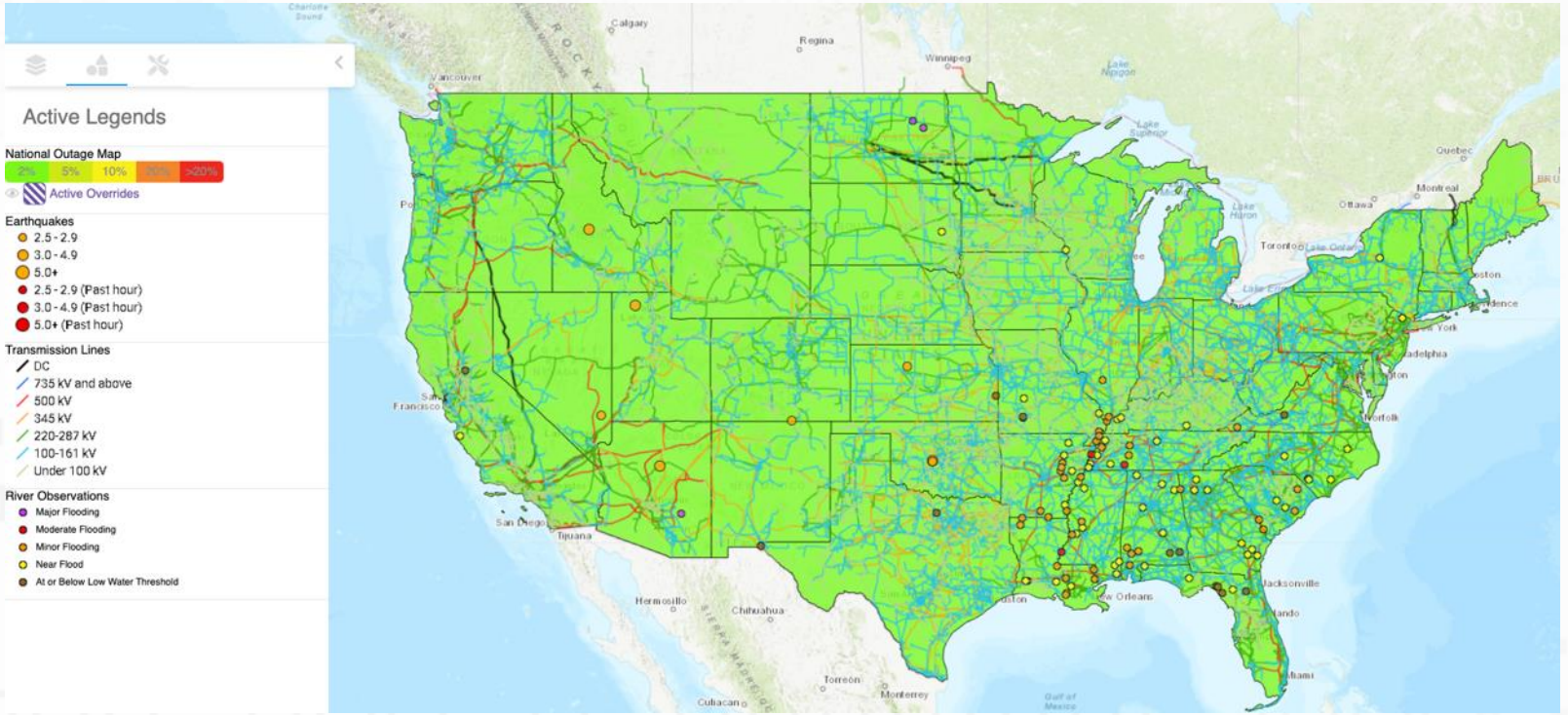
Wildfire and Critical Infrastructure Data

- National Interagency Wildfire Center
  - Wildfire Perimeters
- Homeland Infrastructure Foundation Level Data (HIFLD)
  - 23 Layers
    - Transmission Lines
    - Power Plants
    - Natural Gas Pipelines
  - Updated Annually
- Other Hazard Information
  - Earthquakes
  - Tropical Cyclone Tracks
  - River Observations
  - Weather Watches/Warnings
- Social Media Layer
  - Filtered Tweets by Utility Companies



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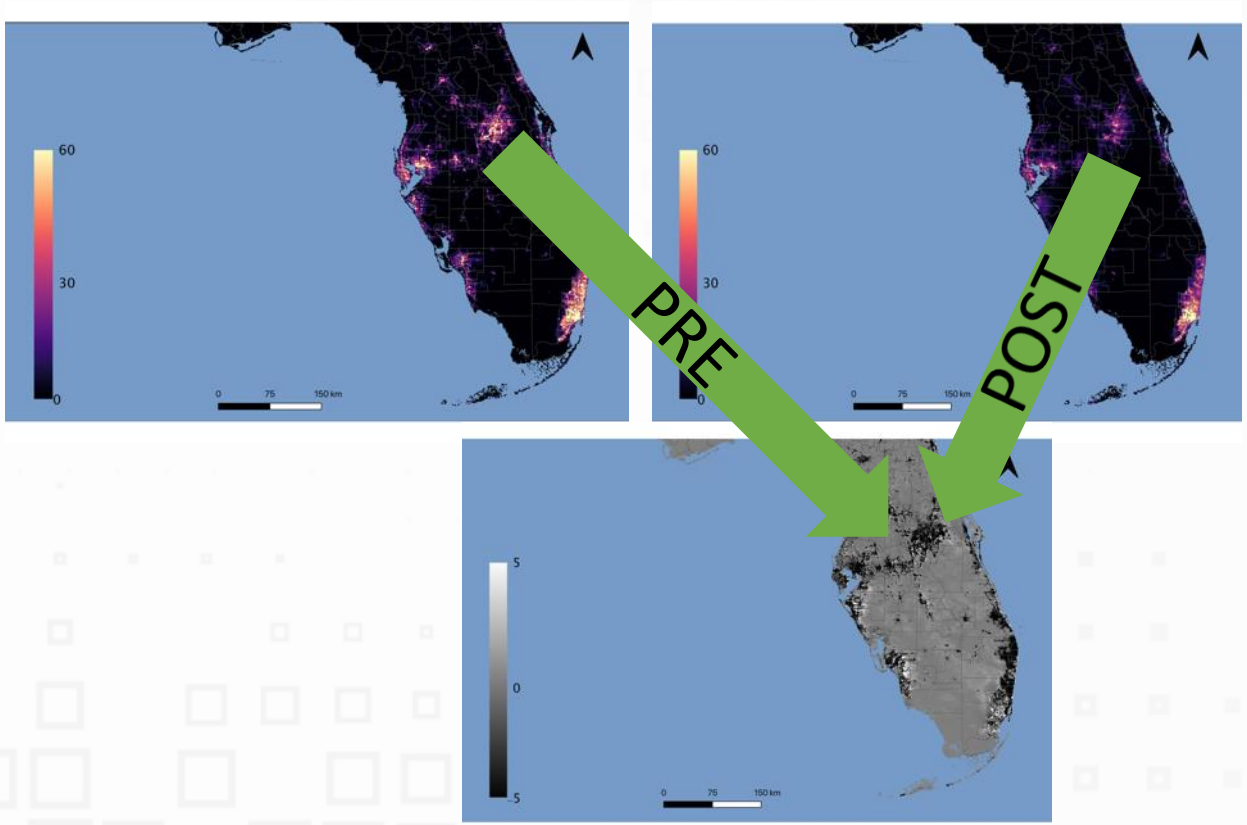
EAGLE-I Analytic Capabilities

Energy Infrastructure Damage Identification and Assessment Utilizing Imagery from Satellites and Airborne Systems

Project Overview:

- Generate scalable damage assessment and outage products to integrate and deploy through EAGLE-I to support response and recovery of energy infrastructures.



Project Technology:

- Satellite-based Broad area outage and restoration mapping using satellite-based (VIIRS) nighttime lights
- Machine learning from airborne UAS imagery for automated distribution pole and substation damage assessment

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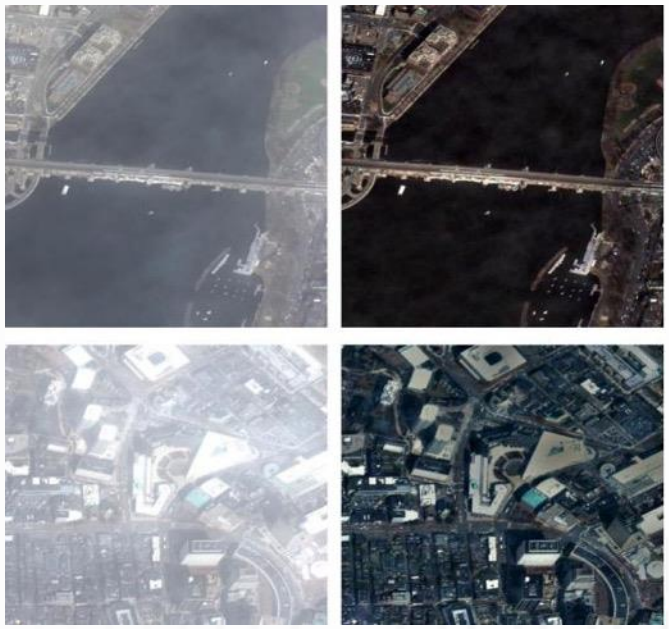
Image Quality: Enhancement for Damage Assessment

Automated Analyst Assist Tools

DeHaze

Original | Corrected



Reduce the appearance of haze in imagery to improve clarity without negatively impacting image content.

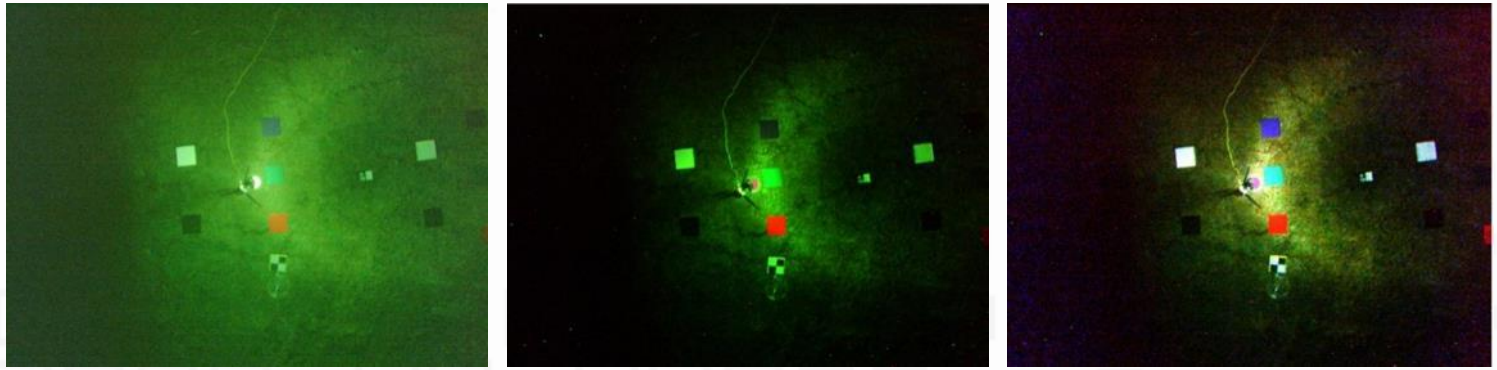
Shadow Mitigation

Original | Mitigated | Original | Mitigated

Mitigate the reduction in brightness resulting from cloud shadow, which is generally undesirable, to achieve more consistent contrast that will aid analysis.

Light Enhancement

Original RGB, Logarithmic Stretch | Lime RGB Processing, No Stretch | Lime RGB with Source Weighted Processing, No Stretch



Enhance the image based on automatic extraction and identification of illumination information from the image itself while maintaining color fidelity.

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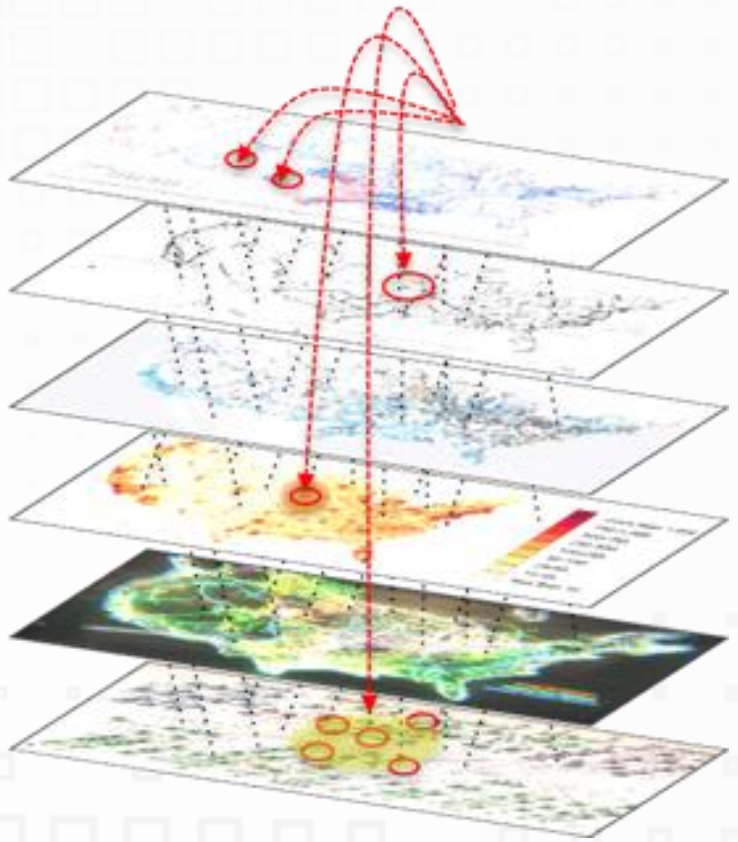
Urban-Net: *Predicting Propagation Consequences Using Synergistically Interacting Infrastructure Networks*

Project Overview:

- ORNL develops URBAN-NET system that quantifies vulnerability & importance of critical infrastructure system (CIS) components across multiple CI networks
- URBAN-NET will analyze propagation of effects based on given “what-if” scenarios
  - (e.g. disaster preparedness exercises)
- Identify at risk infrastructure and downstream dependencies for wildfires and other events



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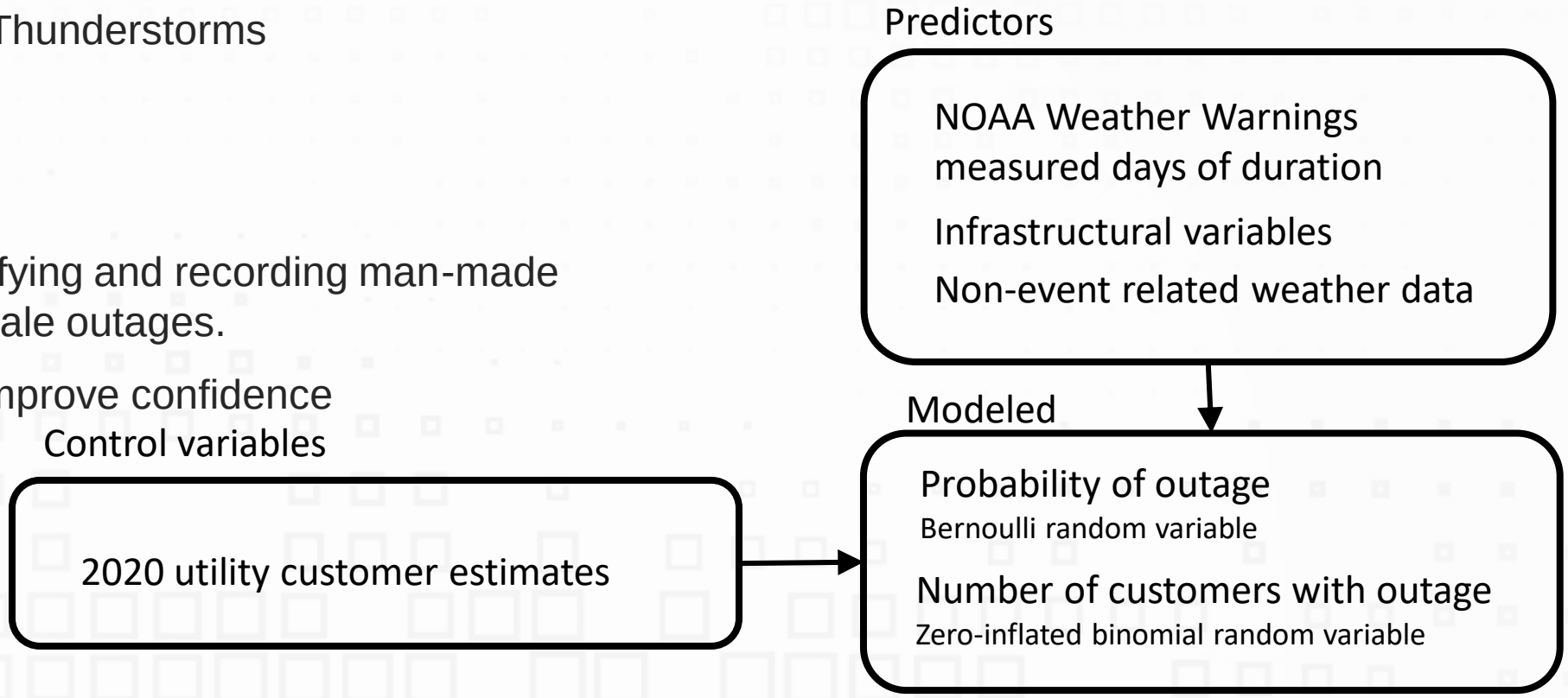
Power Outage Event Monitoring

- Create a near real-time information overlay that associates power outages with severe non-notice events
  - Severe Weather and Thunderstorms
  - Tornados
  - Wildfires
  - Earthquakes
- Explore methods for identifying and recording man-made events that create large scale outages.
- Verified Data Sources to improve confidence



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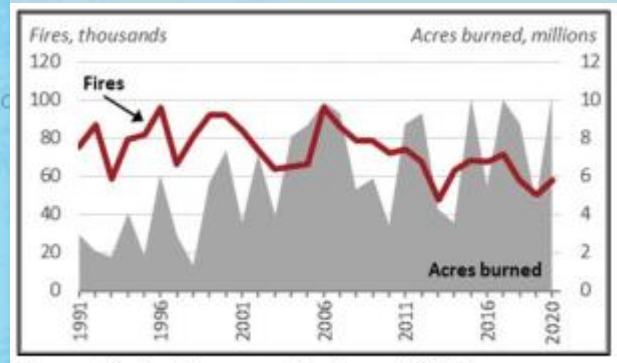
ForWarn: Satellite-Based Change Recognition and Tracking

Jitendra (Jitu) Kumar (kumarj@ornl.gov)
Environmental Sciences Division
Oak Ridge National Laboratory

April 15, 2021

Wildfires in United States

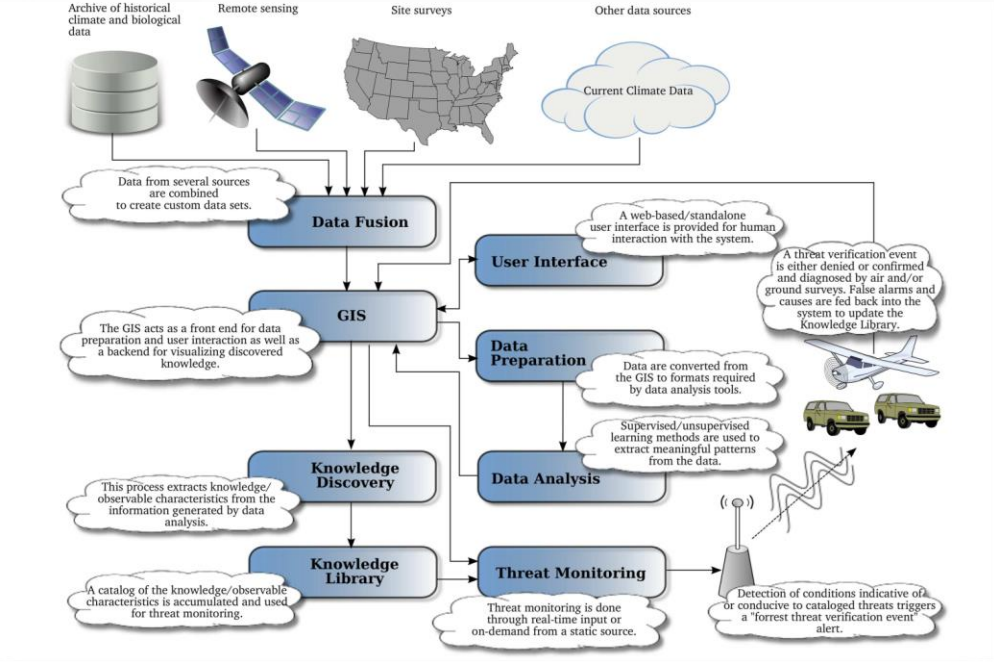
- Since 2000, an average of 70,685 fires have burned an annual average of 7.1 million acres
- In 2020, over 58,250 fires burned 10.3 million acres. 40% of these were in California.
- Wildfire management is carried out by USDA Forest Service and Department of Interior on federal lands, and states on non-federal lands.
- A number of agencies/entities monitor and record historical and active fire information, but in different ways.
- However, a synoptic wall-to-wall examination of wildfires in US is still missing.



Source: National Interagency Fire Center (NIFC).

ForWarn: Satellite-Based Change Recognition and Tracking

- **ForWarn** provides near-real-time tracking of vegetation changes across landscapes in the United States.
- Led and supported by USDA Forest Service and used operationally within the agency.
- ORNL is a contributing partner supporting development of remote sensing and data analytics algorithms and technologies, high performance computing tools and software.



https://forwarn.forestthreats.org/

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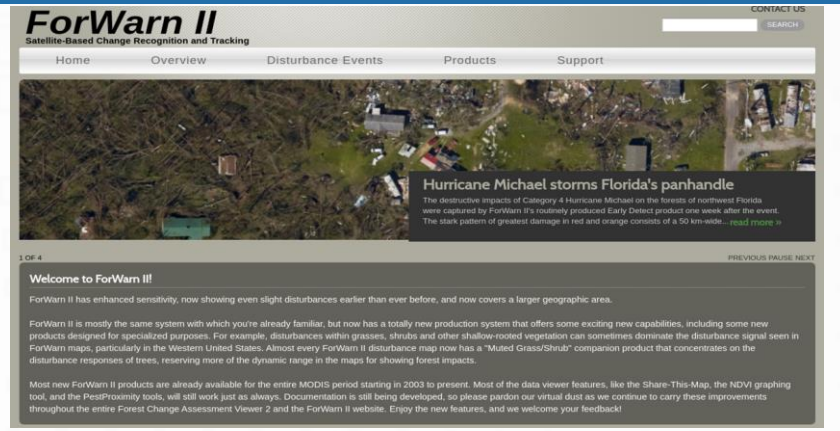
ForWarn: Satellite-Based Change Recognition and Tracking

- **ForWarn** provides near-real-time tracking of vegetation changes across landscapes in the United States**.**
- Based on MODIS Normalized Difference Vegetation Index (NDVI) data stream from NASA's MODIS instruments on board Aqua and Terra satellites.
- **ForWarn** monitors all lands all the all time for all potential change (disturbance and recovery) due to natural or anthropogenic disturbance agents (such as wildfires, droughts, floods, hurricanes etc.).
- Spatial resolution: ~250m Temporal update frequency: 8 days
- Designed for enhanced sensitivity to detect subtle changes in vegetation.
- Uses multiple baselines to detect ecosystem/disturbance specific changes.



https://forwarn.forestthreats.org/

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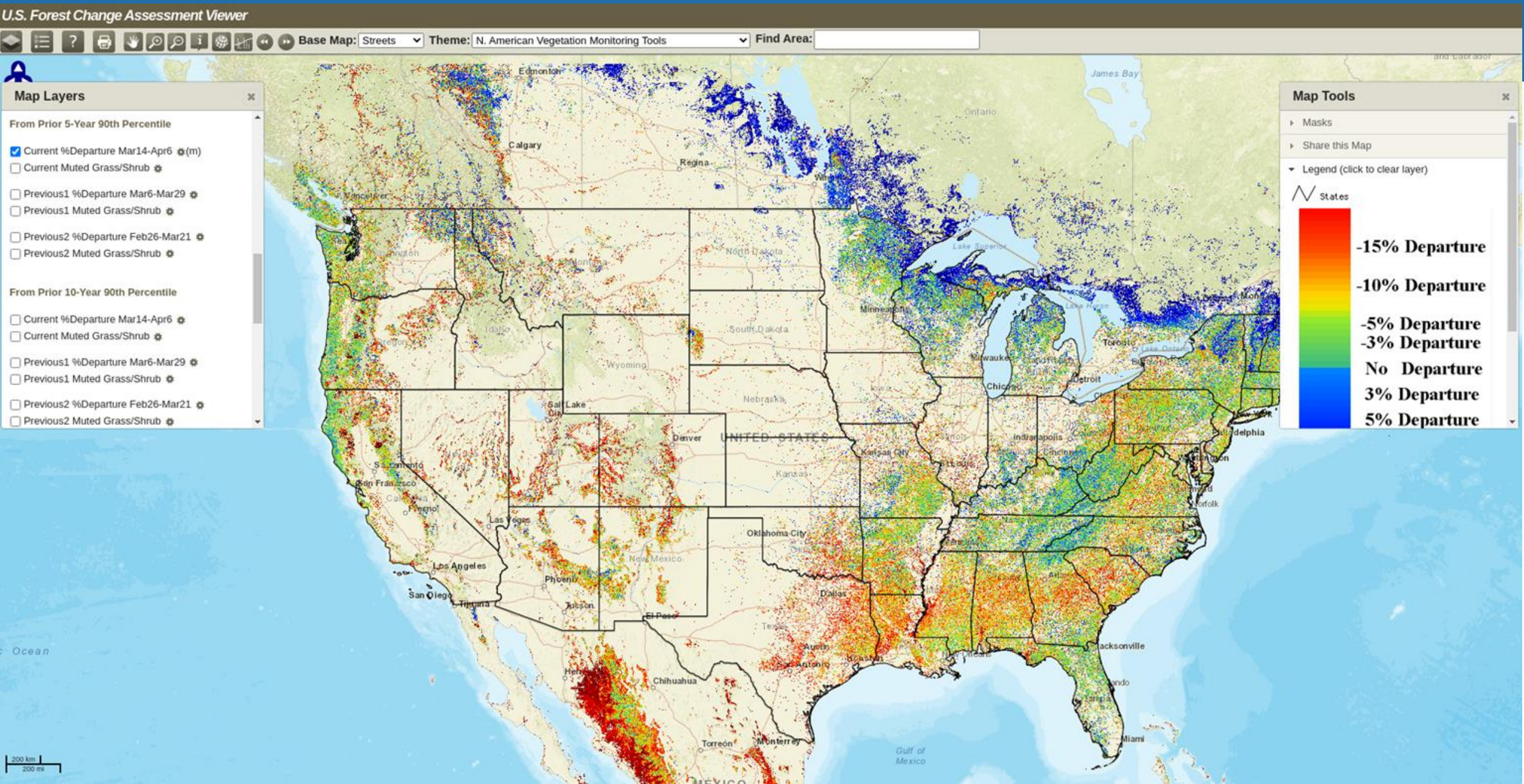
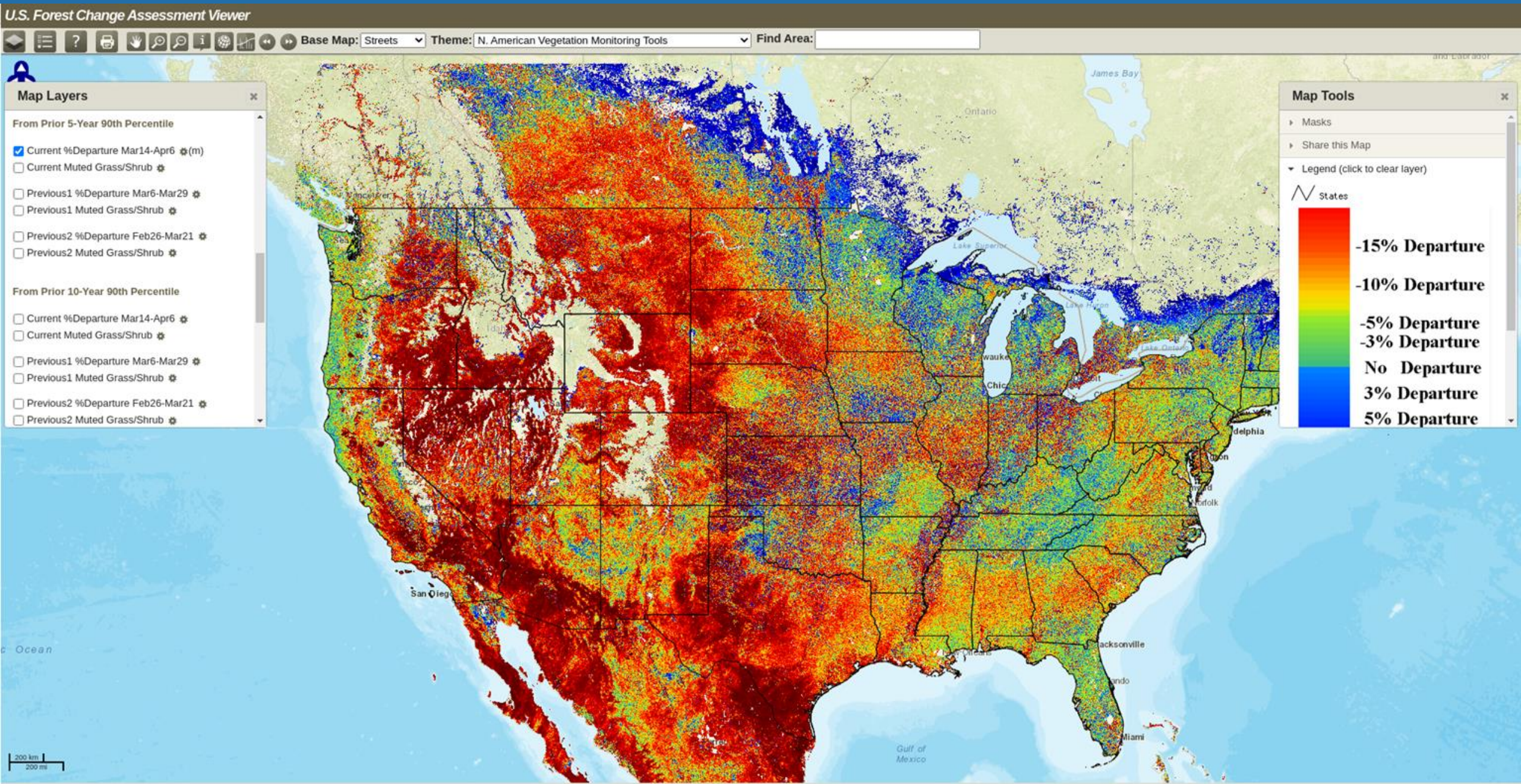
ForWarn focuses primarily on forest lands



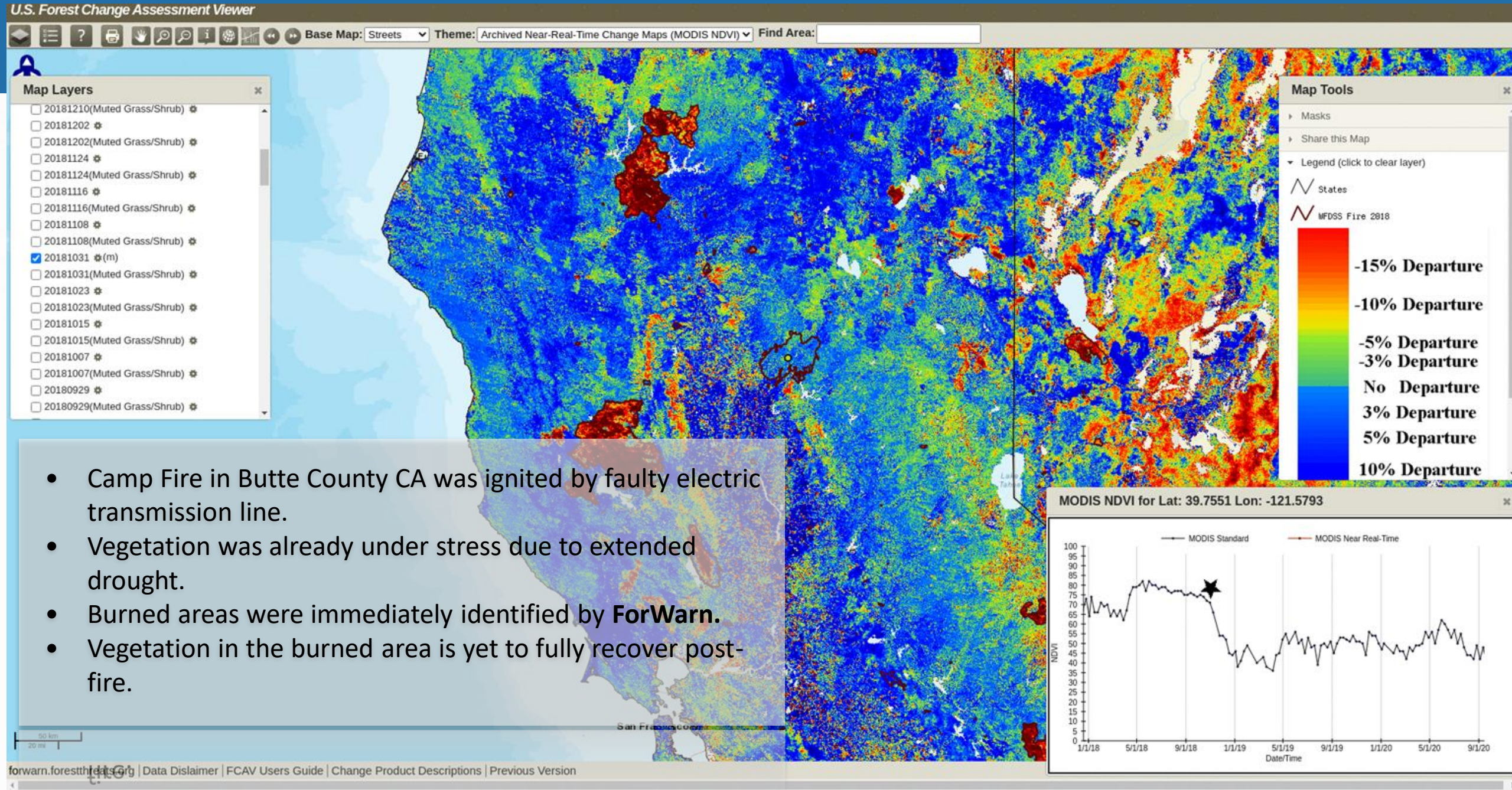
But it monitors and provides data for all vegetation types



Continuous monitoring of both disturbance and vegetation/fuel regrowth

- **ForWarn** provides a fast turn around assessment of disturbance as well as vegetation/fuel regrowth patterns.
- **Forest Change Assessment Viewer (FCAV)** is designed to see fine distinctions in all severe negative departures across CONUS, but can be optimized to focus on wildfires.
- ForWarn is the only system that monitors departure of current vegetation/fuel conditions from normal.
- In 10 years ForWarn has been operational, we have noticed that shallow roots vegetation (grasses and shrubs) respond to dry conditions rapidly and also rewet quickly when drought is over.
- These light fuels are susceptible to ignition, thus a near-real-time system is necessary to monitor these rapid changes in condition of grasses and shrubs.

Wildfire example: Camp Fire, CA 2018 (2018/11/08 - 2018/11/26)



- Camp Fire in Butte County CA was ignited by faulty electric transmission line.
- Vegetation was already under stress due to extended drought.
- Burned areas were immediately identified by **ForWarn.**
- Vegetation in the burned area is yet to fully recover post-fire.

ForWarn data availability

- ForWarn products are publicly available for free at https://forwarn.forestthreats.org/.
- All near-real-time and historical products (since 2000) are readily accessible via Web Mapping Service (WMS) and Web Coverage Service (WCS).

Information relevant for electrical infrastructure

- Specific focus on wildfire disturbance
- Before wildfire:
  - Quantification of potential fire risk, and fire spread potential in regions around infrastructure of interest
- During wildfire:
  - High spatial resolution relevant for decision making
  - High temporal resolution (and low latency) for planning, readiness, and response

Opportunities for wildfire warning system for electrical infrastructure

Zooming in to high threat areas

- High resolution imagery from public (such as ESA Sentinel-2/3) and commercial (such WorldView, PlanetLabs etc.) satellite platforms can improve the spatial resolution and enable a more effective monitoring and management of critical infrastructure.
- A telescoping strategy -- Tier 1: Leverage existing **ForWarn** ~250m product to identify regions of interest (ROI); Tier 2: Use high resolution imagery for finer look within the ROIs.
- Current 8 day frequency (and 8 day latency) can be improved for fewer days by fusing data from multiple satellite platforms.

Opportunities for wildfire warning system for electrical infrastructure

Customized to show fire risk to electrical infrastructure

- Occurrence of an wildfire event requires three things: i) Availability of the fuel; ii) Weather conditions; iii) Ignition source;
- "Potential risk" of wildfire at any region of interest can be quantified by assessment of ecosystem wildfire regime, fuel characteristic [i], and prevailing weather conditions [ii].
- Overlaid with power grid infrastructure, can offer a wildfire early warning system for critical power grid infrastructure.
- Quantified risk can inform strategy and planning for wildfire mitigation and management. Help prioritize of efforts on the ground to protect critical infrastructures.

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Opportunities for wildfire warning system for electrical infrastructure

Modeling Wildfire spread

- Understanding spread of wildfire is critical in a connected ecosystem. For ex.
  - Wildfire may start at a power infrastructure and spread out OR
  - Wildfire started elsewhere may reach a power infrastructure
- Spread of wildfire is driven by weather conditions (highly variable and non-deterministic) and fuels and connectivity (deterministic/quantifiable).
- By assessing fuels on the ground and their potential connectivity can help develop probabilistic fire spread scenarios.
- Model can be used to explore and assess pre-fire mitigation strategies such as controlled/prescribed burns, fire breaks etc.
- Combined with fire risk model can aid monitoring and mitigation planning.

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PlanetSense Program

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GridSense

Incorporating Citizen Science in Predictive Modeling of Impacts on Energy Infrastructure

Presented by:

Dr. Gautam Thakur

thakurg@ornl.gov | gautamthakur.ornl.gov

Staff Scientist,
National Security and Sciences
ORNL

April 15, 2021

Smokies Wildfire: A Tragedy of Unparallel Scale

GreatSmokyNPS ✓
@GreatSmokyNPS

A 0.25 acre wildfire burning near the summit of Chimney Tops has trails closed in that area through Tuesday, November 15th.

3:55 PM · Nov 14, 2016 · Twitter Web Client

GreatSmokyNPS ✓
@GreatSmokyNPS

Great Smoky Mountains National Park officials have closed all facilities in the park due to the extensive fire activity, and downed trees.

8:30 AM · Nov 29, 2016 · Twitter Web Client

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One of the largest natural disasters in Tennessee's History

Tragedy

14 Killed
190 Injured
14,000 Evacuated

Date(s)

November 14, 2016 –
December 22, 2016

Cost, Buildings destroyed

US$2 billion in damages

2,460 destroyed

Burned area,

17,900 acres (28 mi^2)

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The Timeline of Power Outage

14 Nov 2016

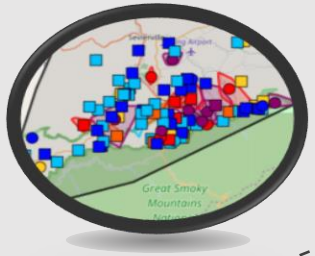
NPS tweeted Chimney Top 1 Fire spread in 0.25 acre

23 Nov 2016

NPS responded to Chimney Top 2 Fire spread in 1.5 acre. WBIR tweeted!

28 Nov 2016 (AM)

GSMNP maintenance discovered fire spreading



28 Nov 2016 (5-8 PM)

City of Gatlinburg began experiencing intermittent power outages

28 Nov 2016 (8:20 PM)

widespread losses of power started across Gatlinburg. Sevier County Electric System to kill downtown power

28 Nov 2016 (10:20 PM)

Tennessee Valley Authority power transmission lines were lost

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Learning from Crowd Intelligence

Due to fires in the surrounding areas over the past week, the air in Gatlinburg and the Smokies has been filled... fb.me/WkGCPwTv

12:16 PM · Nov 14, 2016 · Facebook

So the mtn fire is now so smokey you can't see the mtns guess that's why it's called the smokies

8:14 PM · Nov 14, 2016 · Twitter for iPhone

East TN pk gusts (until power outages)...Gaitlinbu FD: 63mph (6:17pm). Pigeon Forge CH: 48mph (8:14pm), Sevierville: 57mph (8:44pm) #tnwx

10:41 PM · Nov 28, 2016 · Twitter Web Client

Numerous power outages reported in Sevier cty in #Tennessee due to high winds. Might be problems due to the fires as well #TNwx #Gatlinburg

11:36 PM · Nov 28, 2016 · TweetDeck

Numerous power outages reported in Sevier cty in #Tennessee due to high winds. Might be problems due to the fires as well #TNwx #Gatlinburg

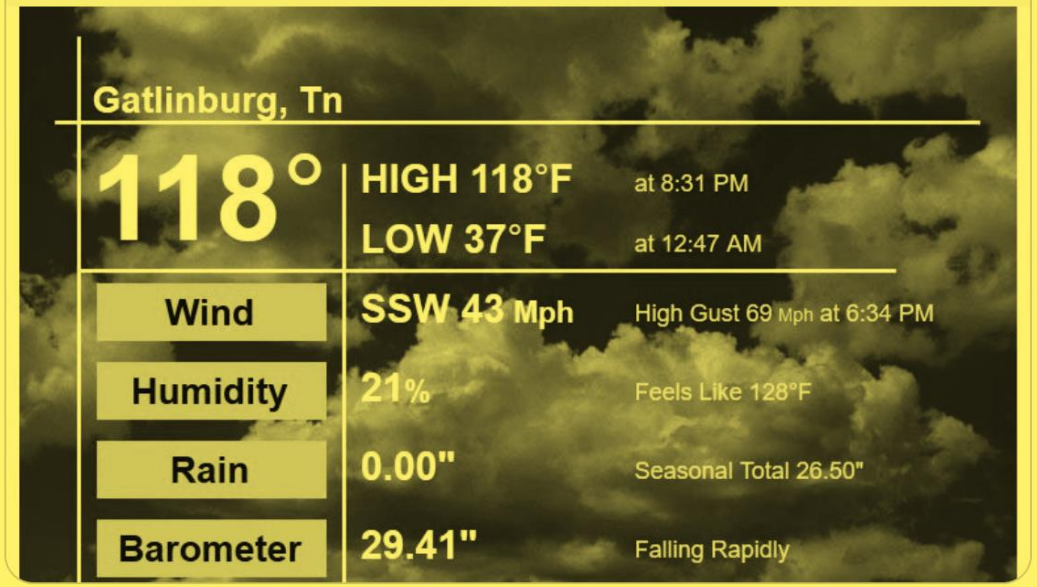
11:37 PM · Nov 28, 2016 · Twitter for Android

Rapidly spreading fire west of Gatlinburg, TN

This is a weather station near the Gatlinburg fire, just minutes before it went out. Either melted, or power outage...or both.

Scott Dimmich @ScottDimmich · Nov 28, 2016

This was a (last) reading from a weather station on the east side of Gatlinburg at 8:34pm. Very telling. @lucky13wxman @Hinkmologist



9:49 AM · Nov 29, 2016 · Buffer

Today: the Blue Ridge. Saturday: the Smokies uper extra smokey right now on account

, 2016 · Twitter Web Client

2,000+ power outages in Sevier county

, 2016 · Twitter for iPad

own on Ravens den way, but Sevierville ing hard to bring power back & are being cleared #wearsvalley 2/3

, 2016 · Twitter for iPhone

er forward trucks being sent out to help rg and Sevierville Tennessee they're batteries

2016 · Twitter Web App

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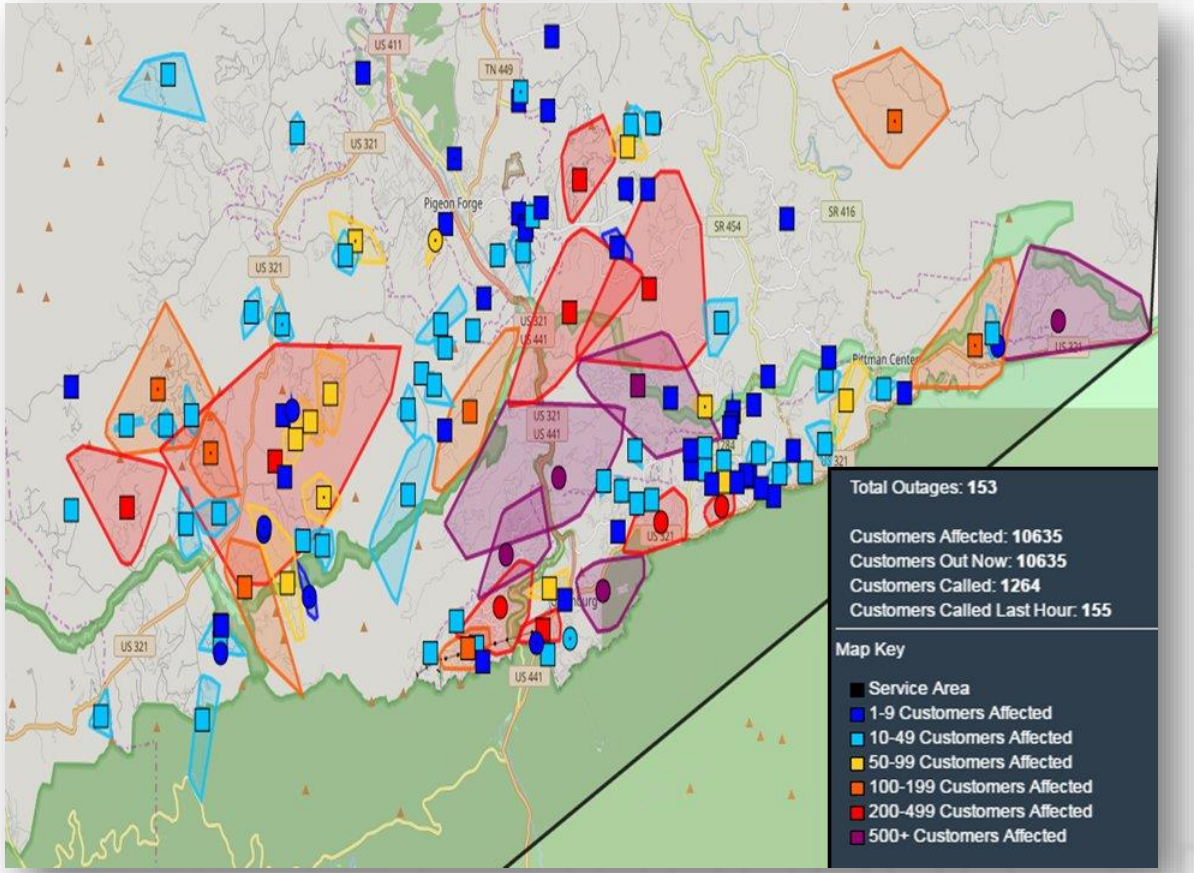
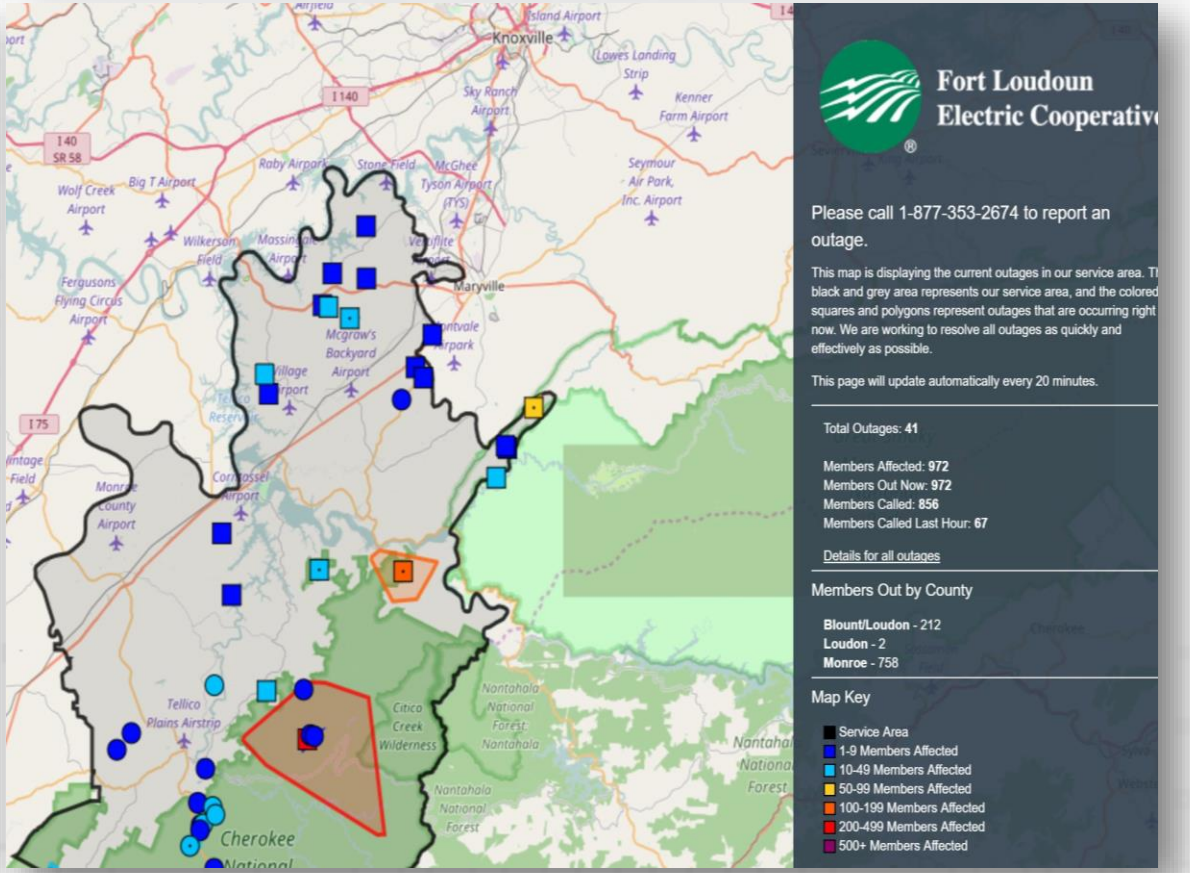
Power Outage Affected 11,000 Customers



Sevier County Electric System



Fort Loudoun Electric Cooperative

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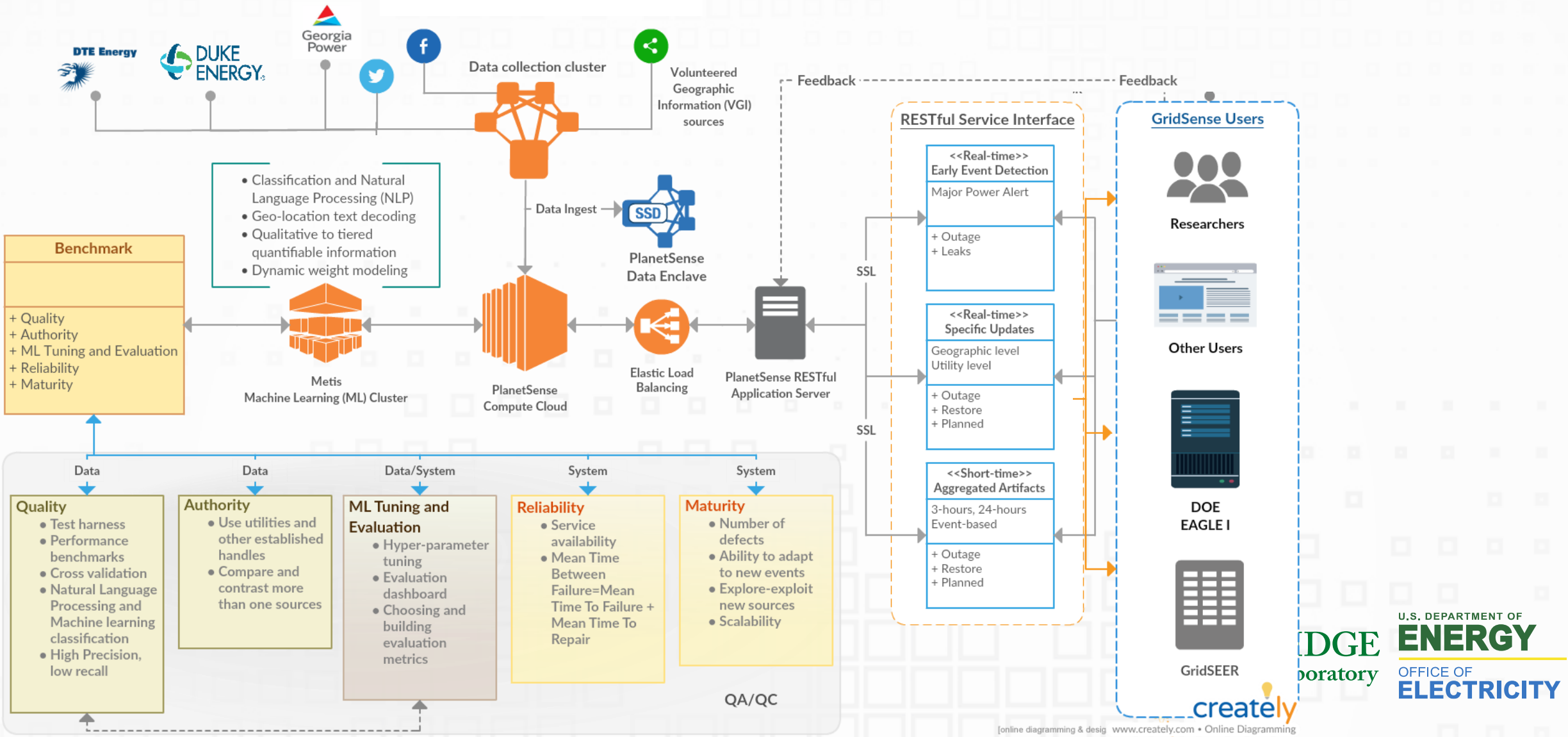
GridSense Architecture



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Capability at a Glance

Curate outage, restoration, critical infrastructure, sensor/IoT support, location-based intelligence

Computational social analysis, community and network analysis, vulnerabilities assessment

Few shot learning driven crowd-sourced ground-level imagery analysis for mapping disaster zones, urban analytics, fire, etc.

Semantic Ontology for coherent features from disparate sources or notations

Events and activity detection in near real-time

operationalize *non-authoritative* information for Energy Security

create an abstraction for DOE and utilities for policy guidance

focused on the entire planet

Social media

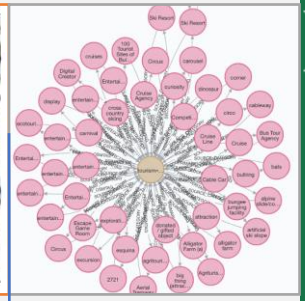
Blogs and medium

Ground–level Imagery (ImageSense)

Maps, Transportation, and Location Services

News and Events

Sensors, Environment, Weather



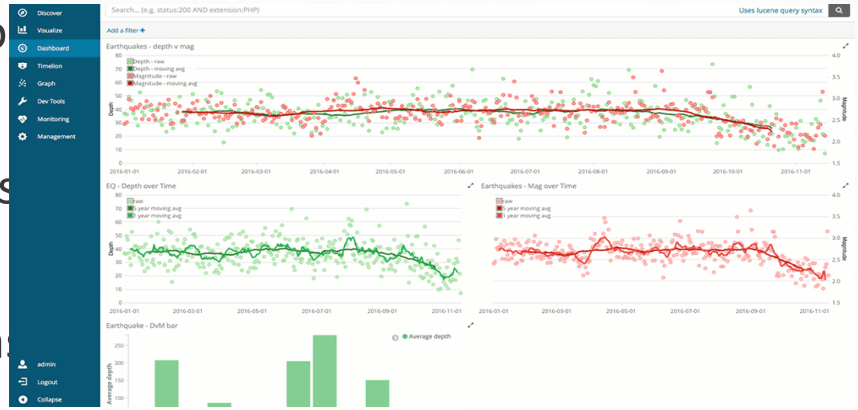
Semantic Ontology

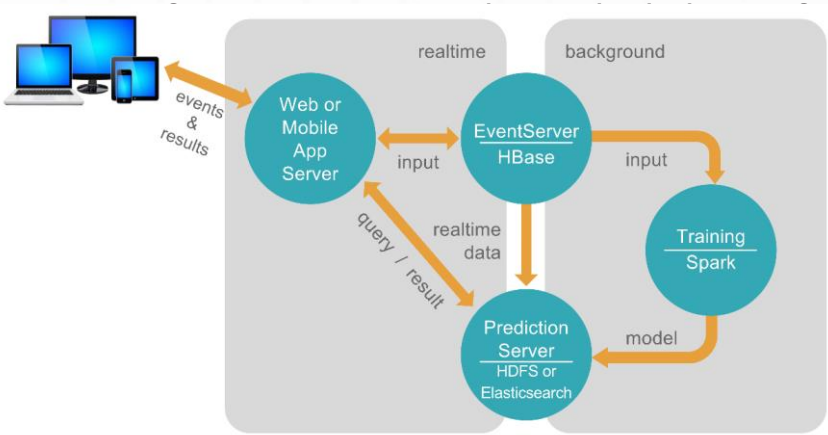
ACTIVE RESEARCH

- Population Modeling
- Landuse Characterization
- Detection Special Events
- Activity Intelligence
- Urban Dynamics

Technical Approach

- Design, develop, and deploy citizen science platform for the collectio
  non-authoritative data
- Develop and deploy models and services that understand and utilizes
  traditional models
- Develop in-situ calibration and resolution benchmarks for accurate a
  a quantifiable measure
- Implement multi-sourced data fusion, verification and validation tech
  crowd-sourced data
- Develop and deploy interactive and real-time feedback-based machi
  would integrate with sensor data
- Capability Maturity: Used during Smokies wildfire, Puerto Rico outag
  - Full maturity and operational deployment: 24-36 months effort
  - Stand-alone and third-party integration





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Water Extreme Lookup Library

David R. Judi, PhD

April 15, 2021

Background: Tool Develop for Infrastructure Response to Extreme Events

Objective: Develop and apply state of the art infrastructure analytics needed to support infrastructure stakeholder requirements. These analytics are used to characterize:

- Infrastructure system fragility, stability, and resilience
- Infrastructure dependencies on natural systems
- Infrastructure interdependencies
- Economic and community interoperability with infrastructure

WEATHER EXTREMES ARE THE MOST FREQUENT AND SIGNIFICANT CAUSES OF WIDESPREAD INFRASTRUCTURE DISRUPTION

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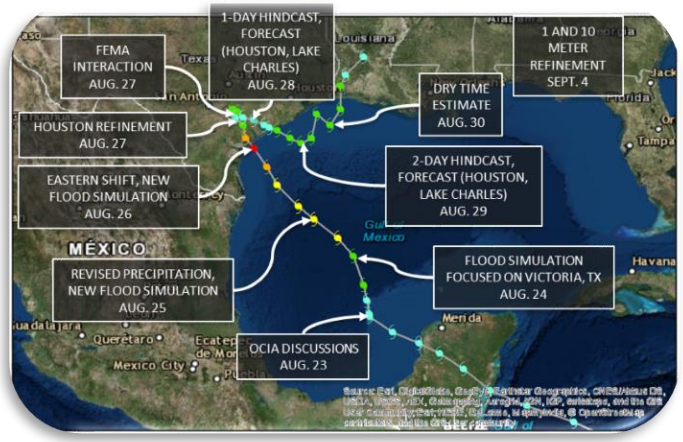
Enhancing Situational Awareness in Extreme Events: Flood Example

- Capability Development is Guided by the EOC/Infrastructure Mission and Relevant Questions:
  - *What is the spatial extent of flooding?*
  - *When will the flood arrive?*
  - *How long will the flood remain?*
  - *How many people are at risk?*
  - *Which infrastructure assets are at risk?*
- How Do We Support Flood Events?
  - Predictive modeling and simulation (real-time, near real-time)
  - Imagery-based damage analytics
  - **<u>Access and leverage previously simulated events- Go to the WELL!</u>**



Hurricane Harvey Flood Simulation Timeline

Oroville Spillway Failure, 2017

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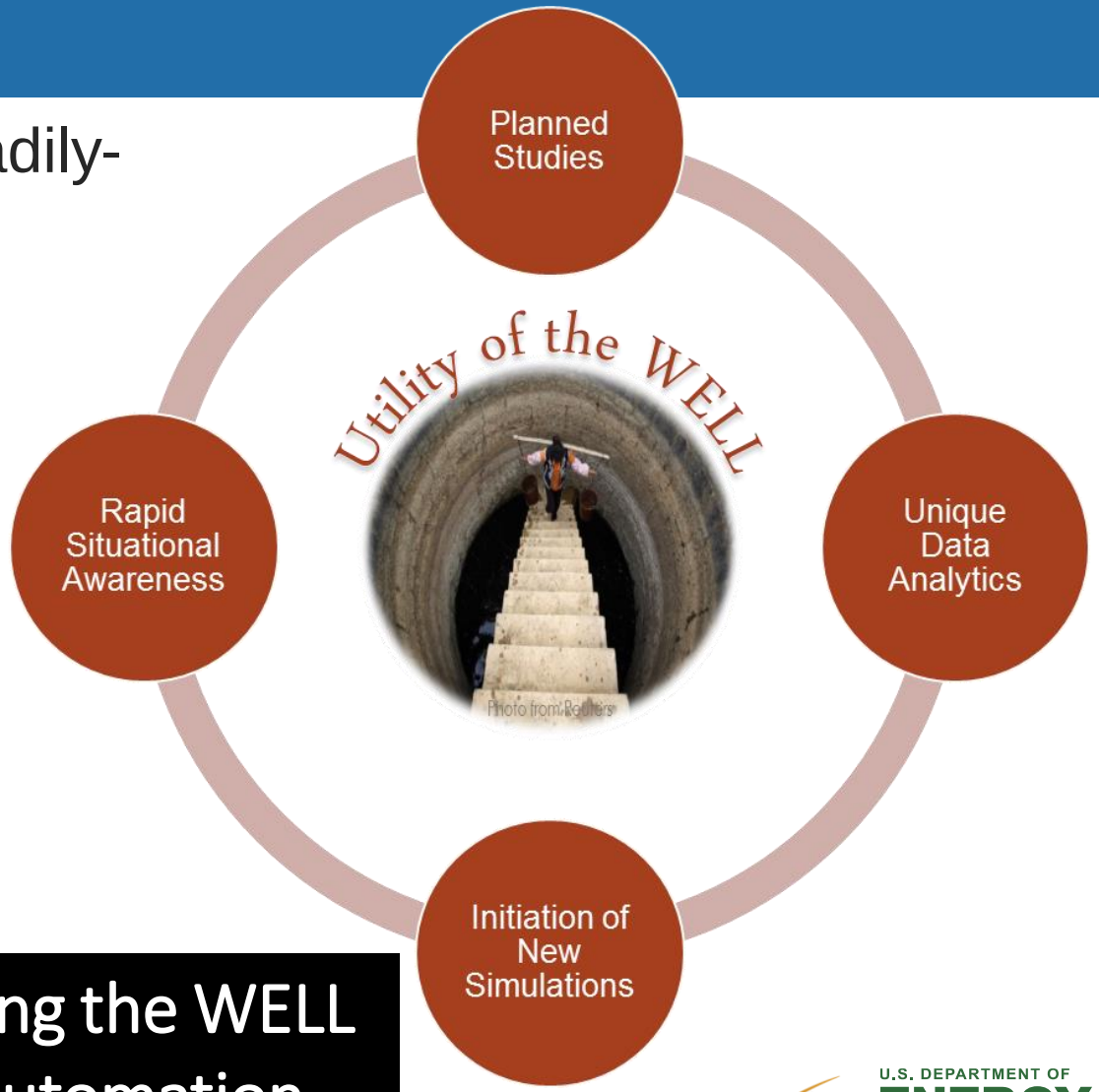
What is the WELL?

Water Extreme Lookup Library (WELL) is readily-accessible archive of flood simulations

Requirements Document

The Archive Shall:

- ✓ Be accessible from anywhere
- ✓ Not require software installation
- ✓ Have efficient searching (spatial and text query)
- ✓ Provide geospatial visualization
- ✓ Be responsive to map-based movements
- ✓ Be flexible to include multiple flood types
- ✓ Contain simulation metadata
- ✓ Provide access to downloadable simulation data
- ✓ Be ingestible into other web-based platforms (rest services)
- ✓ Protect information



The Key to Filling the WELL is Simulation Automation

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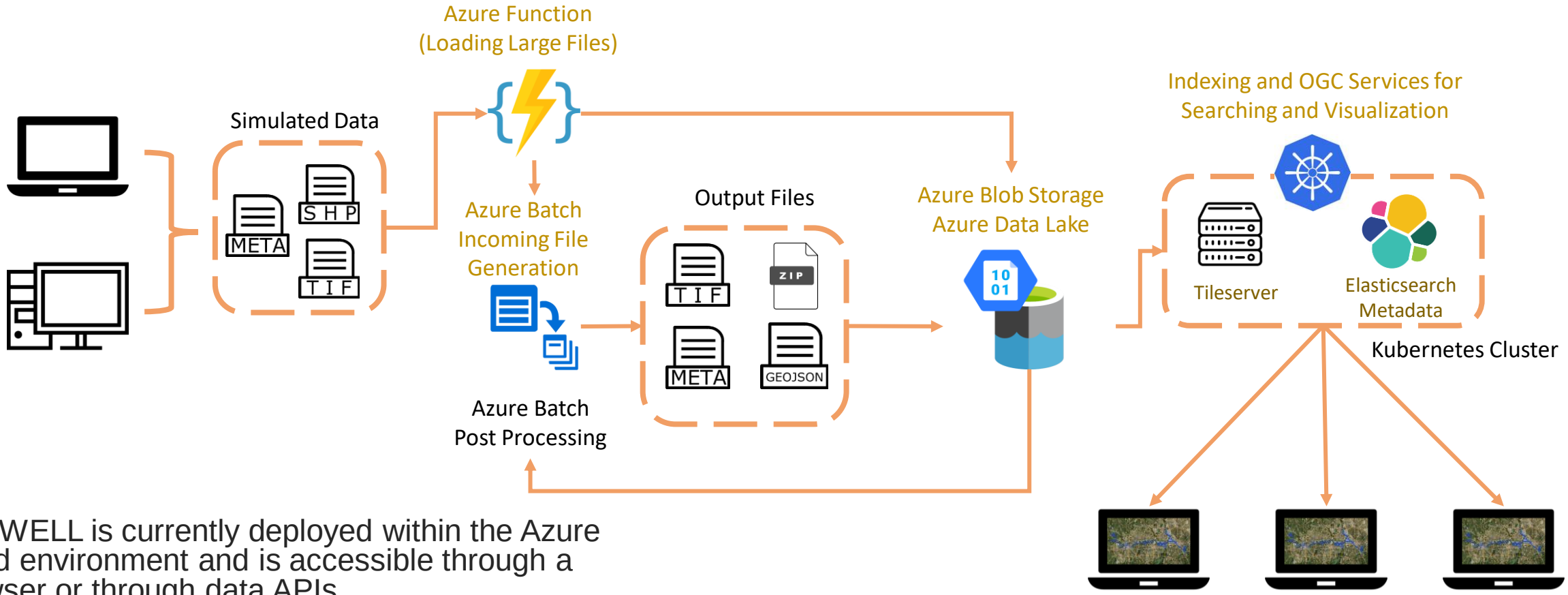
Implementation of the WELL



The WELL is currently deployed within the Azure cloud environment and is accessible through a browser or through data APIs

- Searchable (text, visual)
- Interactive
- Downloadable

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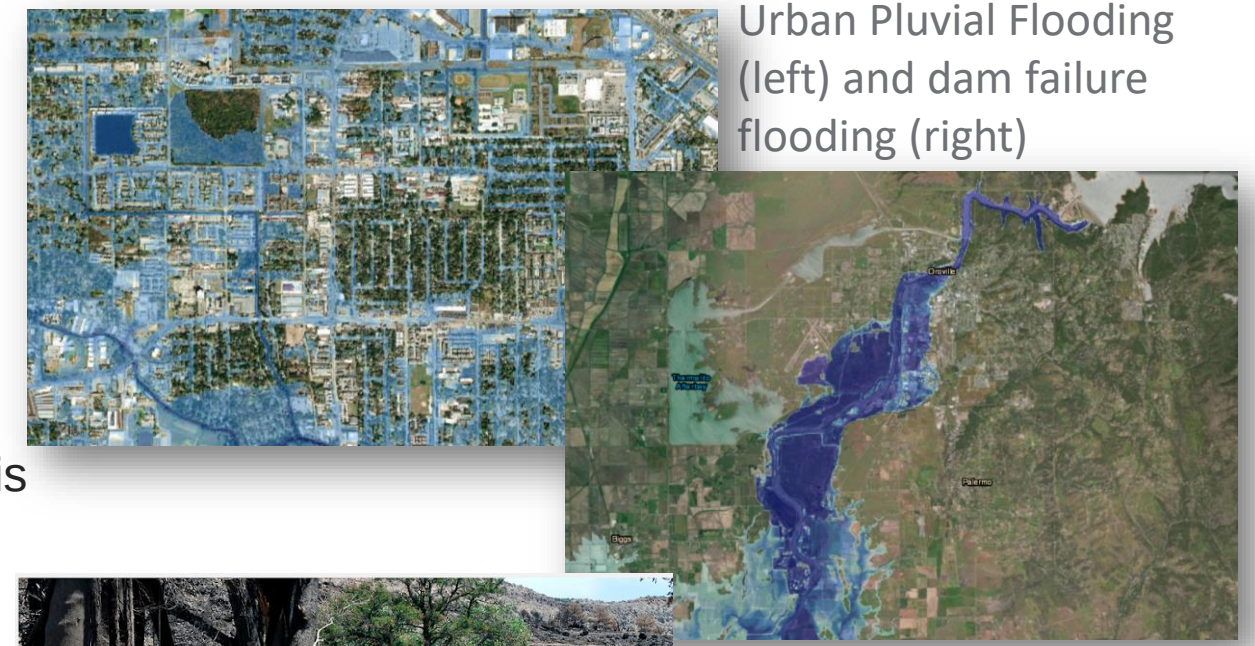
What's in the WELL?

Flood Types Currently Automated

- CONUS-Wide Dam Failure Simulations
  - National Inventory of Dams (NID)
  - Sunny-day failure events, catastrophic failure
- Riverine Flooding Events
  - National Hydrography Data (NHD)
  - USGS gage locations, historical frequency analysis
- Urban Area Extremes (Pluvial)
  - Urban-area footprints
  - NOAA Atlas 14

Working Towards More Automation

- Hurricanes and Compound Flooding
- **Post-Fire Extreme Runoff!?**



Urban Pluvial Flooding (left) and dam failure flooding (right)

Post-fire rainfall-runoff can result in significant floods

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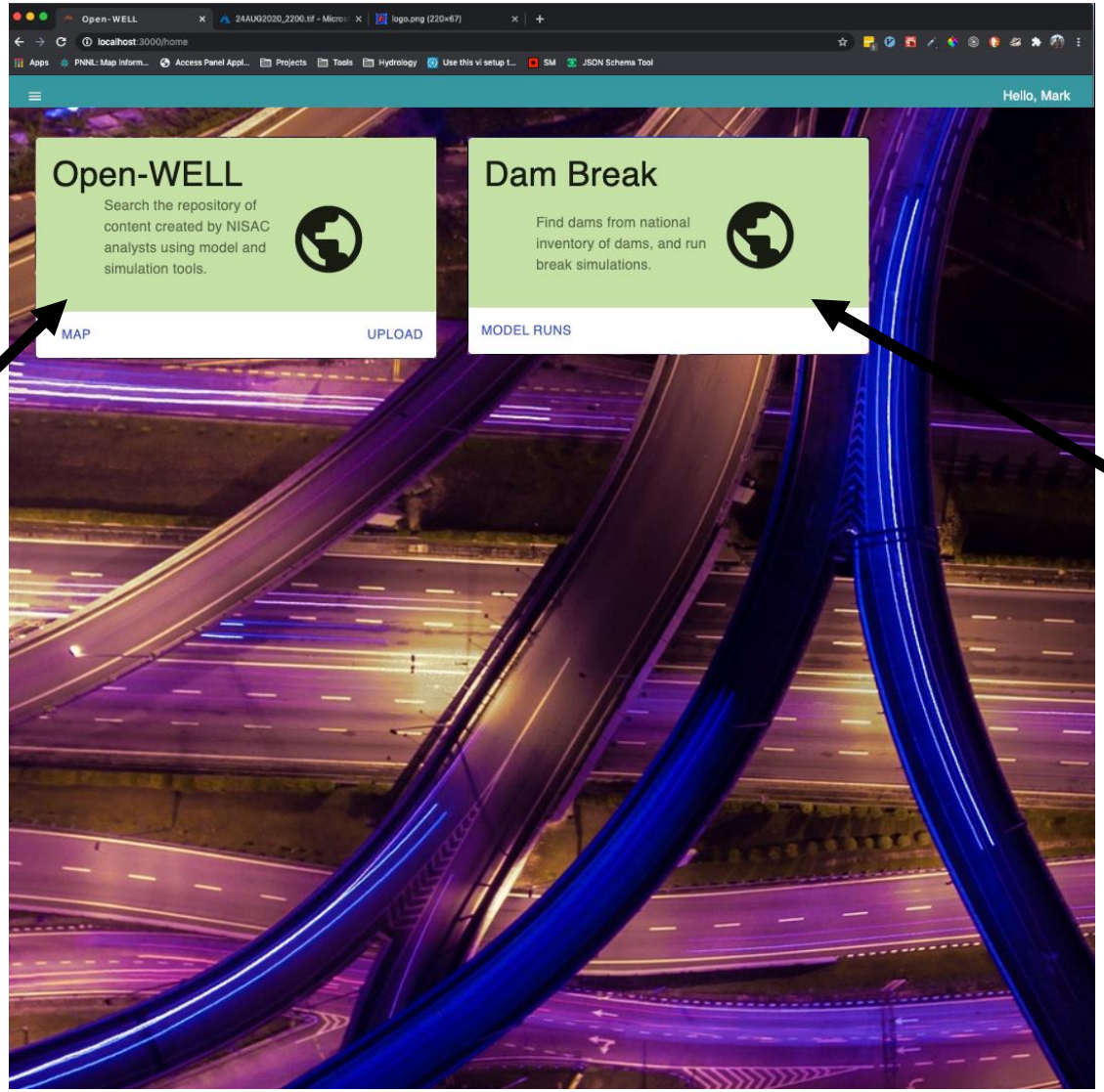
A Peek Into the WELL



Archived Simulations

Run a New Simulation

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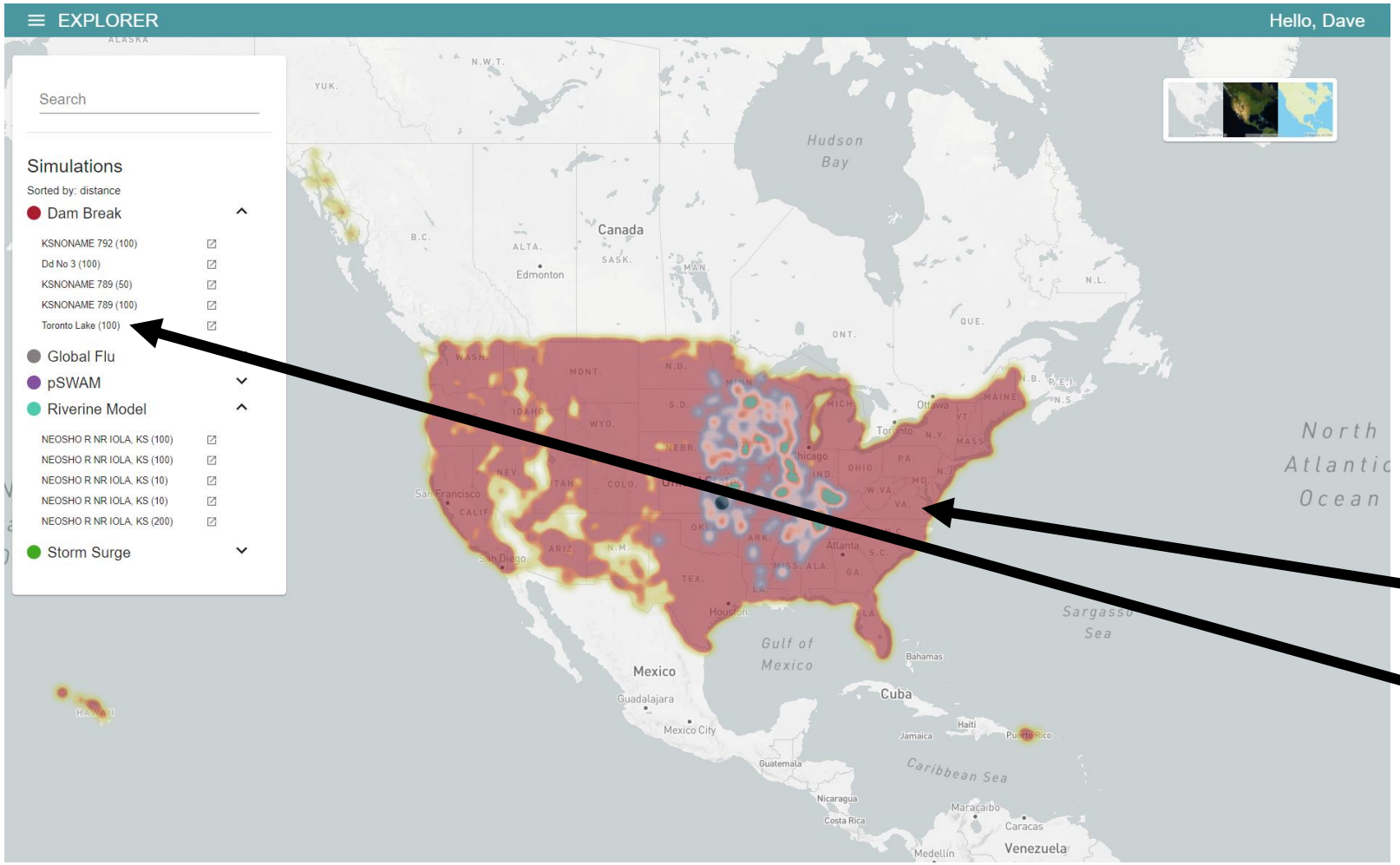
A Peek Into the WELL



Interactive Visual Search for Available Simulations

- Filter by type, location (click)
- Search by name

Select a simulation of interest

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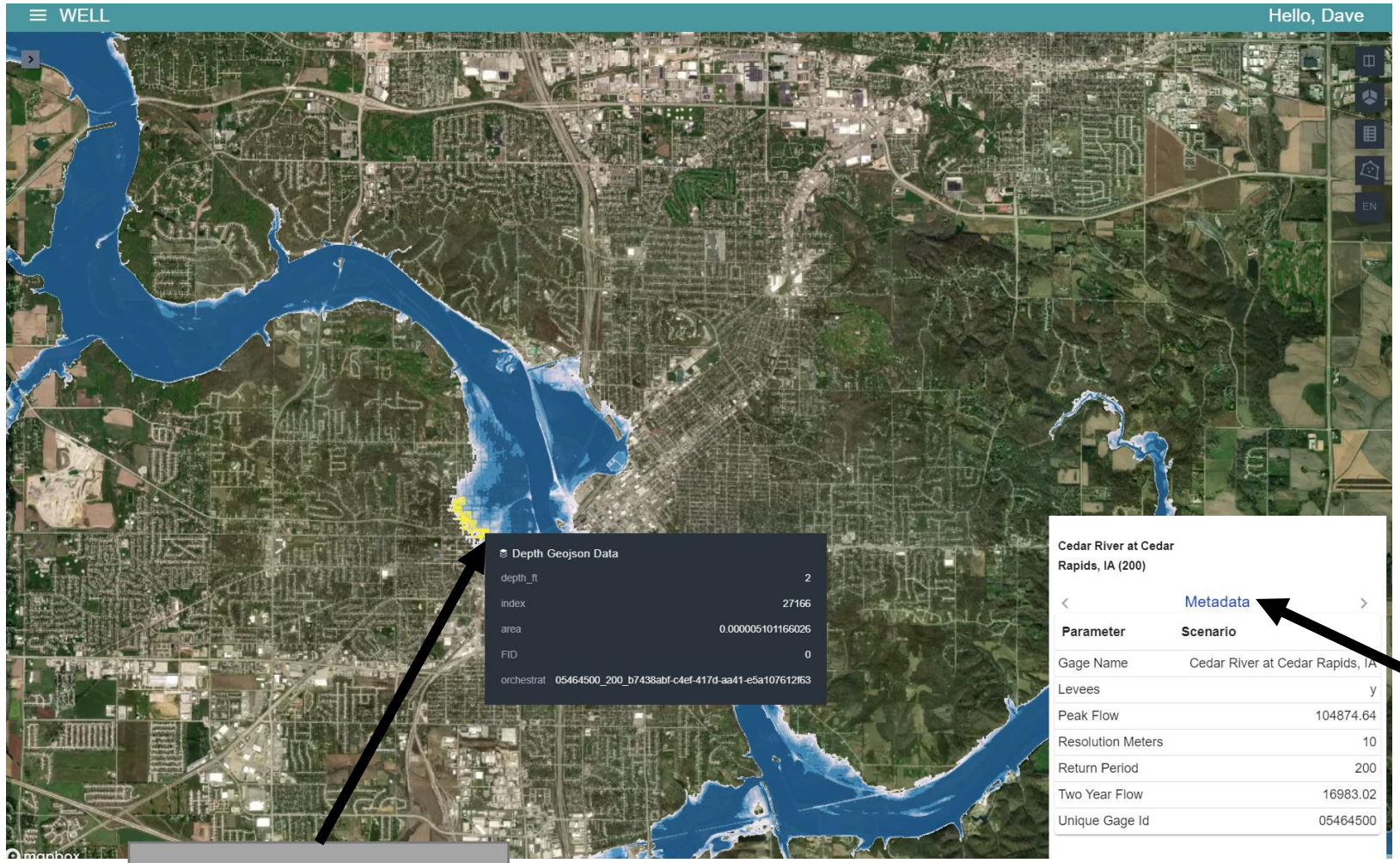
A Peek Into the WELL



Each individual simulation is readily viewed in a geospatial map using a web browser

All data can be downloaded and ingested into standard geospatial platforms and workflows

View the simulation metadata

Interrogate the extreme event data

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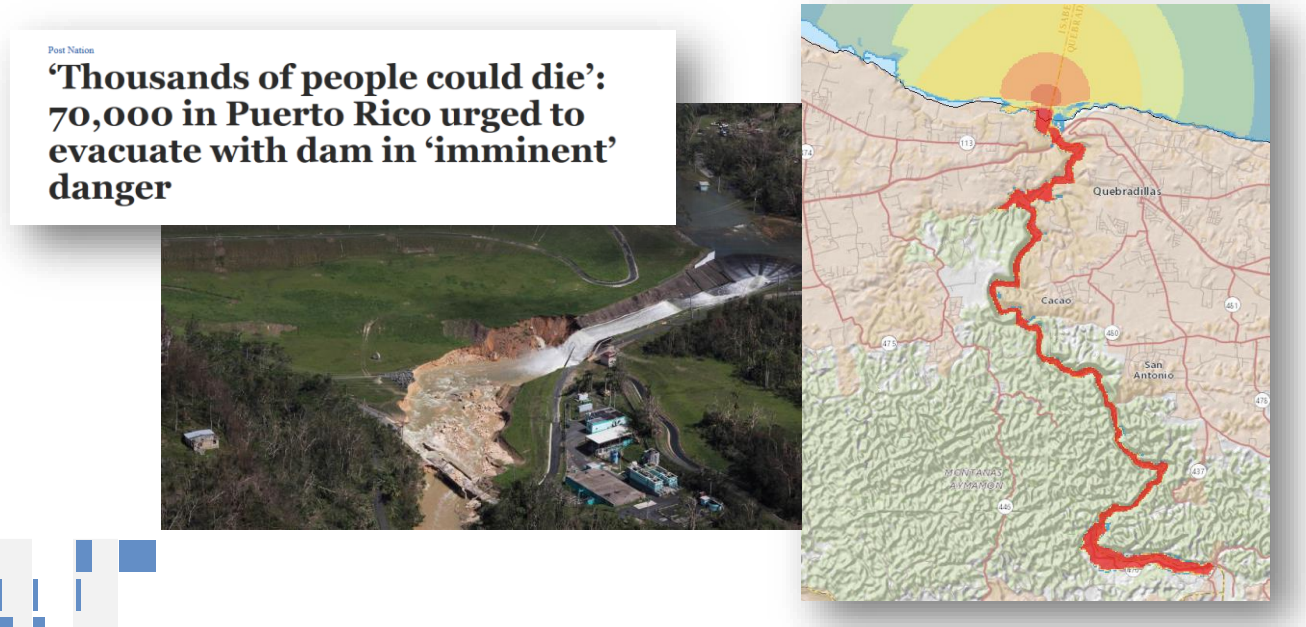
Examples of How the WELL is Used

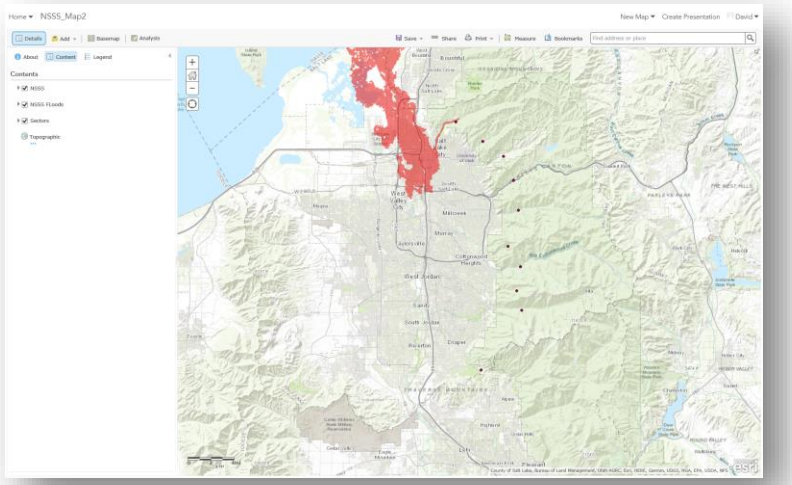
WELL has been used to provide rapid insight into potential flood threats for a variety of events, including US landfalling hurricanes and extreme precipitation. Many of these are related to dam failure events.

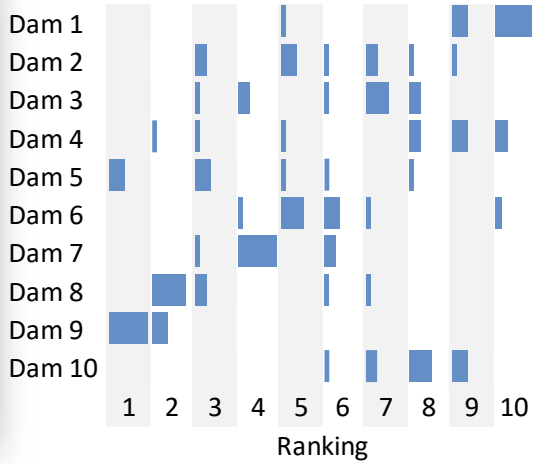
The WELL has also been used as a platform for infrastructure operations/management training

Hurricane Maria – Guajataca Dam



WELL immediately informed the probable area of inundation from a catastrophic dam failure.





The WELL data has been used to assist in the training of infrastructure analysts

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Transitioning the WELL to the Open-WELL

- The WELL was developed in support of the federal infrastructure protection mission
- The WELL has broad applicability to federal, state, and local emergency planners and responders
- Current Open-WELL efforts include:
  - Investigating **cost-effective approaches for broader cloud-based scaling** of the WELL
  - Opening the WELL to ingest **third-party simulated data**
  - Developing approaches to support **'community-based ensemble'** analysis to embrace a multi-model approach to extreme event decision making and response

The WELL architecture and implementation is generally applicable to other types of extreme event data, including wildfire

Team WELL

Mark Jensen

Data Scientist

Cindy Rakowski

Computational Scientist

Dan Corbiani

Data Scientist

Tim Seiple

Computer Scientist

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Thank You!

Hotspot Analysis Tool

Scalable Spatial Data and Analysis

Dan Corbiani
Dan.Corbiani@pnnl.gov

April 15, 2021

Agenda

- What is the Hotspot Analysis Tool?
- Results
- Challenges and Technical Approach
- Implemented Algorithms

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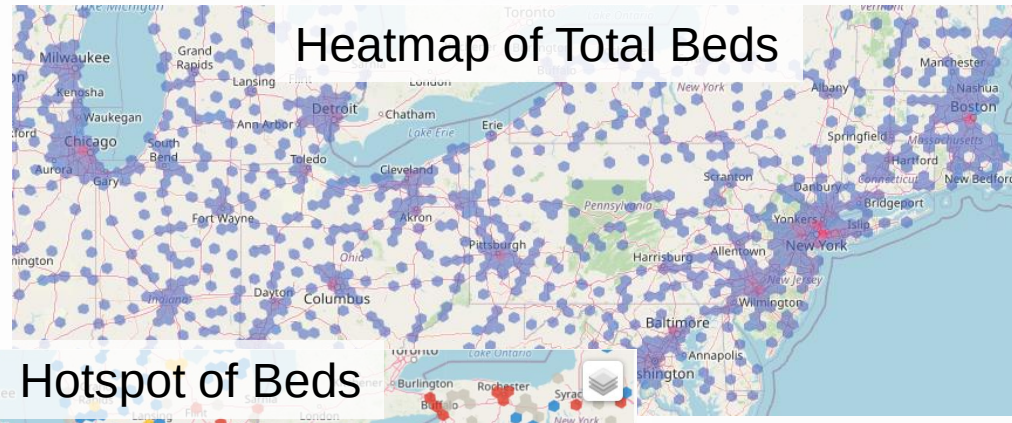
Hotspot Analysis Tool

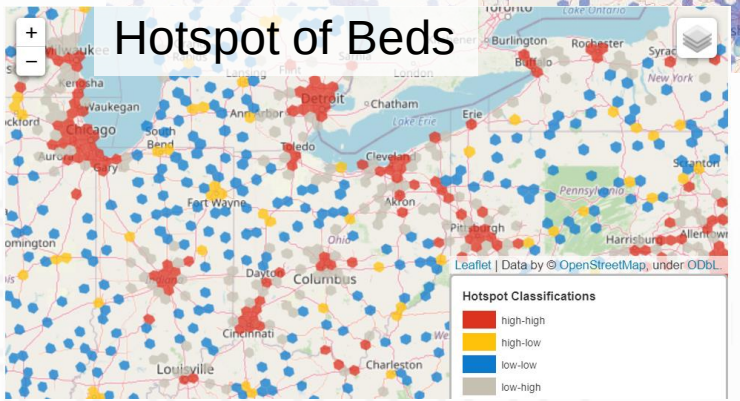
- **Find spatially concentrated industries at risk of disruption from hazards.**

- Requirements:
  - Deploy the tool to multiple environments, both connected and disconnected from the internet.
  - Do not create a framework or UI, this tool should be integrated in other places.
  - Simplify the deployment and validation of research code.

- Can’t we just use a heatmap?
  - Heatmaps show concentration based on global information.
  - Hotspot takes spatial information into consideration.

- Example:
  - A small hospital may be very important to a region.





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Results

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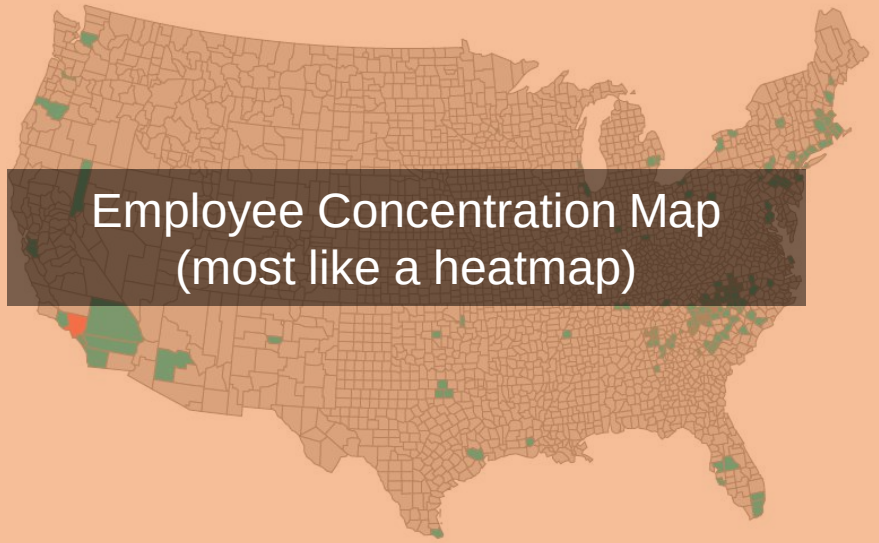
Average Percentile

Textile Mills

Cluster Ranking Map

Employee Concentration



Employee Concentration Map
(most like a heatmap)

Average Percent

0.00 0.17

Average Weighted Percent

0.00 0.17

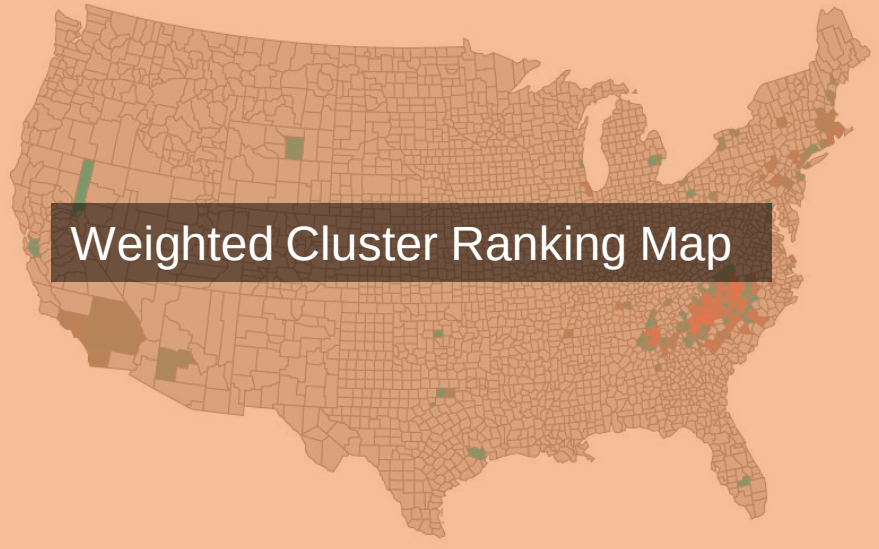
Employees

1.00 4,979.00

Overall Cluster Metrics

Based on an average value of other cluster rankings.

Average Weighted Percentile

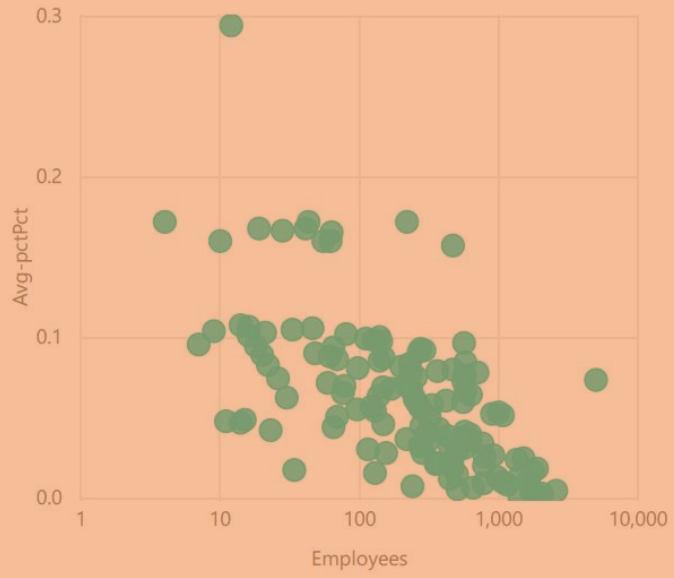


Weighted Cluster Ranking Map

County Name	Avg-pctPct	Avg-weightedPct	EMP
Los Angeles County, California	0.07	0.07	4,979.00
Gaston County, North Carolina	0.00	0.00	2,579.00
Spartanburg County, South Carolina	0.00	0.00	2,040.00
Rockingham County, North Carolina	0.00	0.00	1,888.00
Anderson County, South Carolina	0.02	0.01	1,876.00
Walker County, Georgia	0.02	0.02	1,758.00
Cherokee County, South Carolina	0.01	0.01	1,675.00
Alamance County, North Carolina	0.01	0.01	1,639.00
Yadkin County, North Carolina	0.02	0.02	1,502.00
Gordon County, Georgia	0.01	0.01	1,420.00
Guilford County, North Carolina	0.00	0.01	1,403.00
Burke County, North Carolina	0.02	0.01	1,341.00
Whitfield County, Georgia	0.01	0.00	1,150.00
McDuffie County, Georgia	0.05	0.05	1,069.00
Greenville County, South Carolina	0.01	0.01	1,063.00
Providence County, Rhode Island	0.05	0.05	996.00
Catawba County, North Carolina	0.01	0.01	977.00

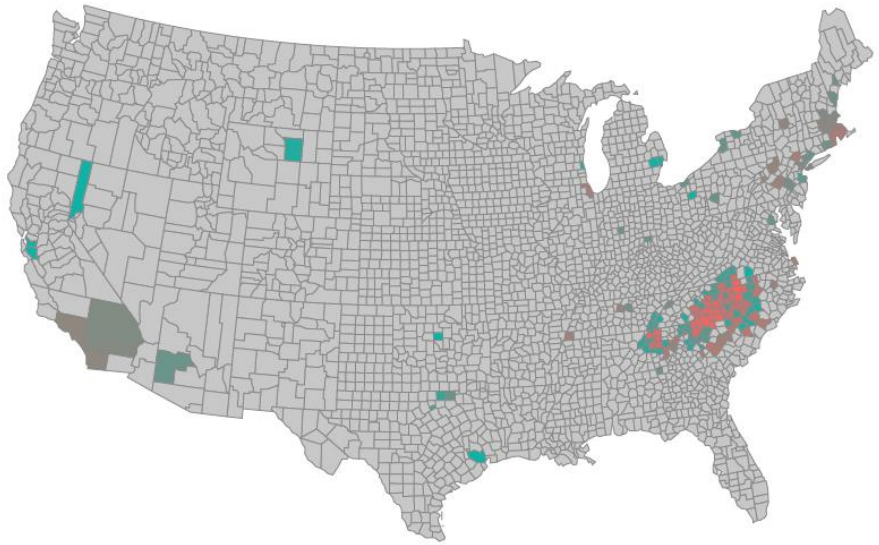
County Listing for Validation

Percentile vs Log Employees

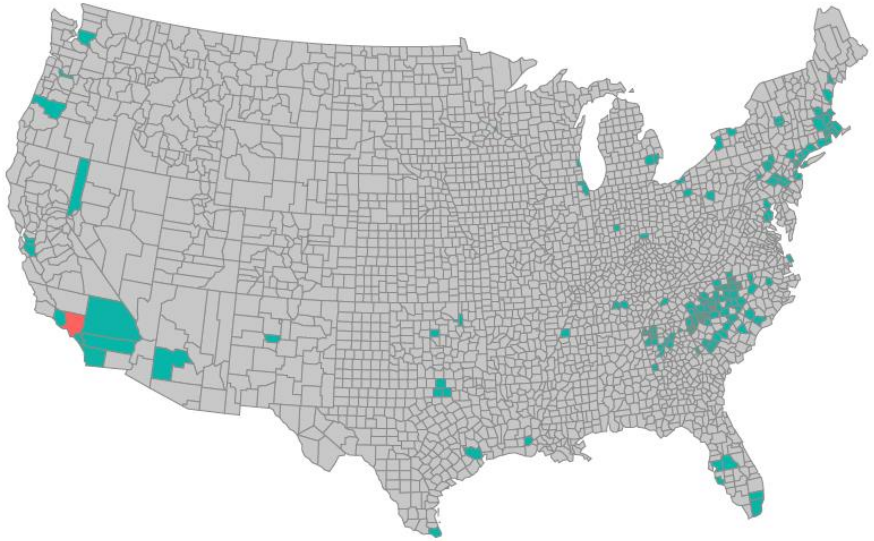


Textile Mills

Average Percentile



Employee Concentration



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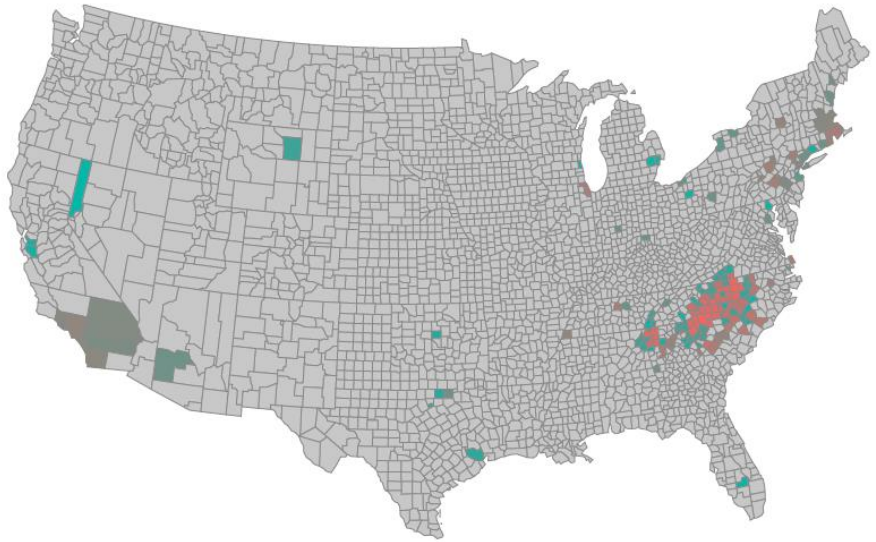

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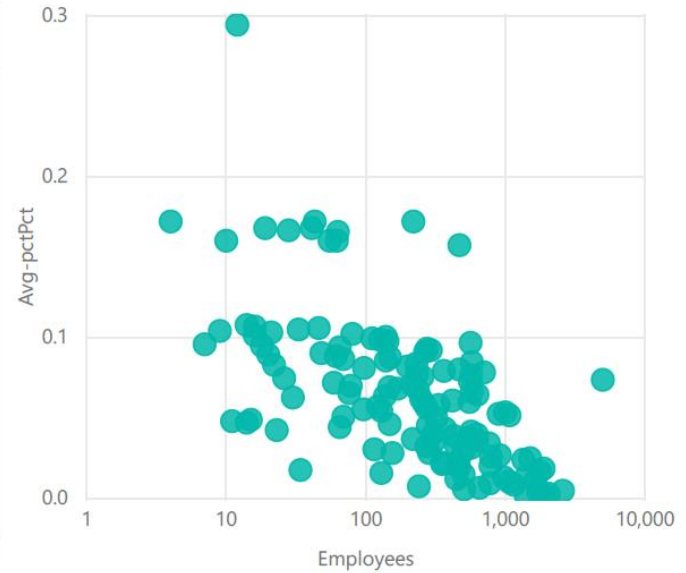
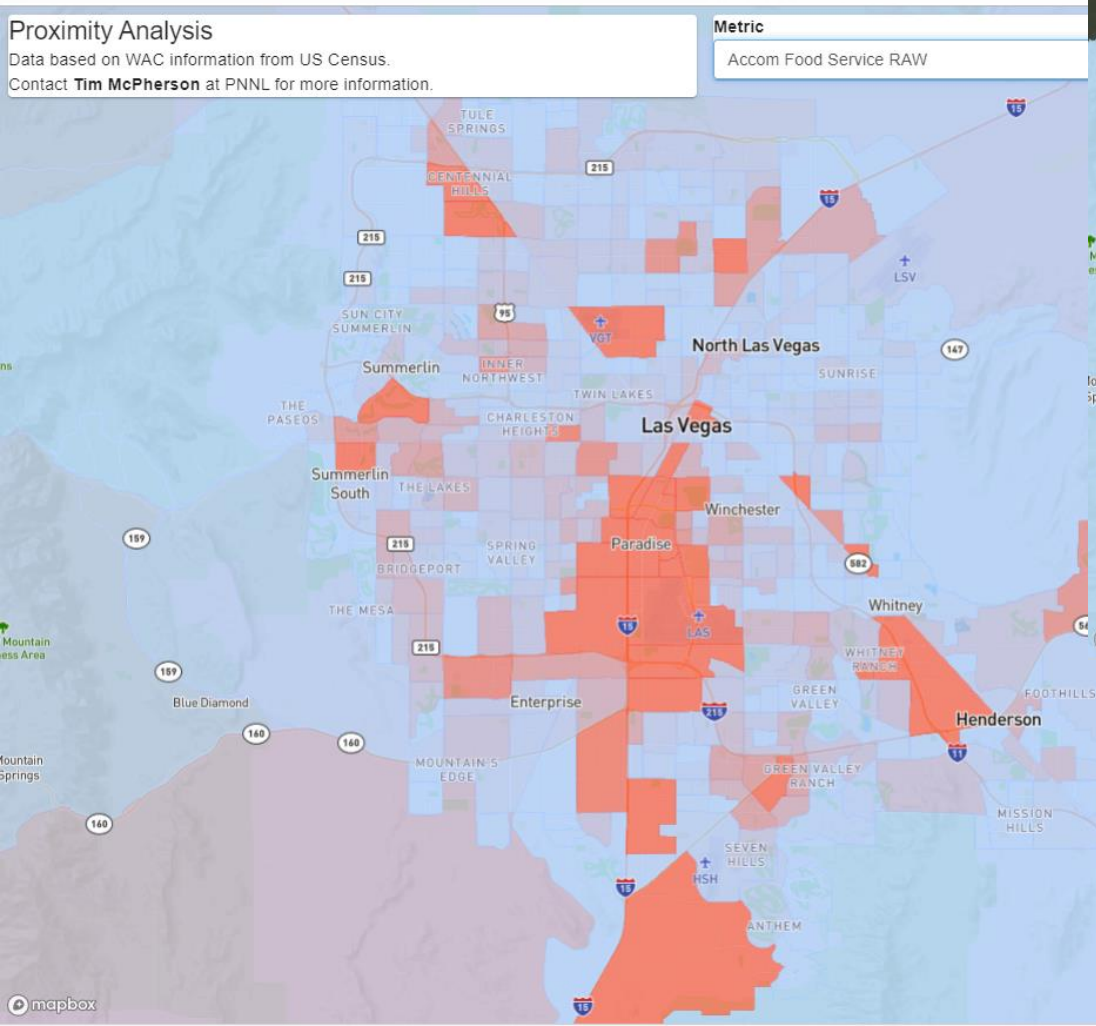
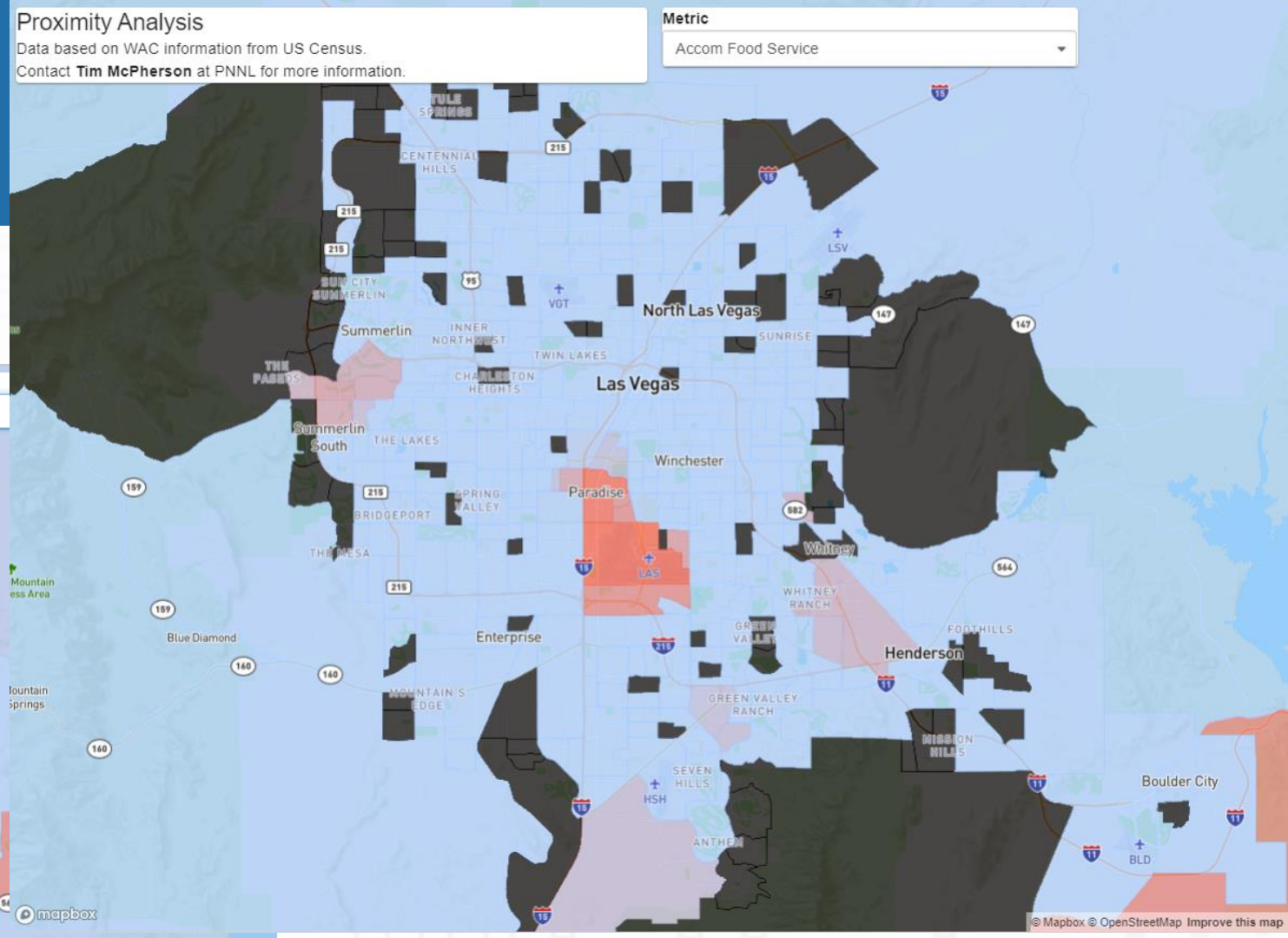
Percentile vs Log Employees



Block Level Data





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Why is this hard?

Geospatial Data Challenges

- Geospatial datasets are available in many formats / projections.
  - Team members often re-write ETL scripts.
- Datasets are fragmented across services.

Geospatial Library Implementation Challenges

- Algorithms are written against specific datasets or dataframes.
- Documentation for algorithms and methods is often shoddy.
- Explanations are often contained in PowerPoints / papers that rot in relationship to code.
- Few algorithms are designed for scaling.

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Hotspot Components

User Focused APIs

- Dataset
- Workflows
- Algorithms
- Visualizations / Output Connectors

Developer Building Blocks

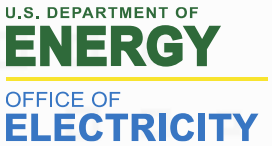
- Supporting Libraries and Environment
- Data Loader / Base Classes / Hashing
- File Management

Deployment Guardrails

- API Docs / Examples
- Tests
- Linters
- Integration Tests

amazon EMR

databricks



This architecture facilitates deployment to a variety of environments.

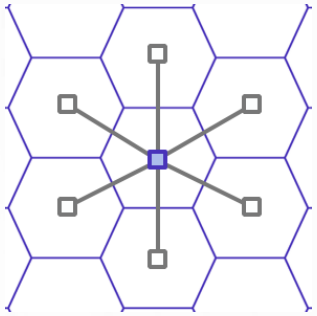
Algorithms

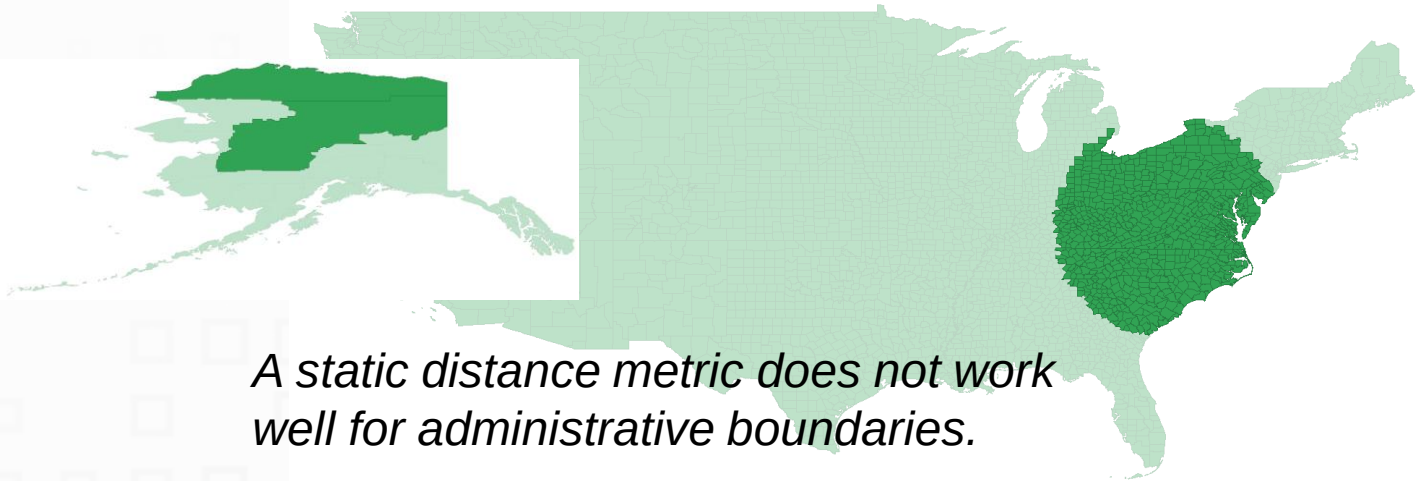
Administrative Boundaries to Constant Size

What does “near” mean?

- Administrative boundaries can have vastly different sizes.
  - Alaska counties vs Manhattan
  - Causes visual artifacts in maps.
- Makes analysis more complex.
  - What is a neighbor?
  - How do you calculate density?
- Focus heavily on “hashing” polygons and distributing the value to each cell.

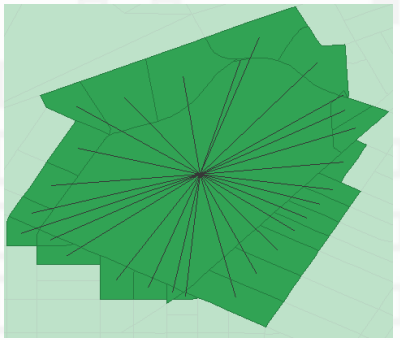
H3 Hexagons. Near constant size, distance, and number of neighbors.





A static distance metric does not work well for administrative boundaries.

Administrative polygons have different numbers of neighbors.



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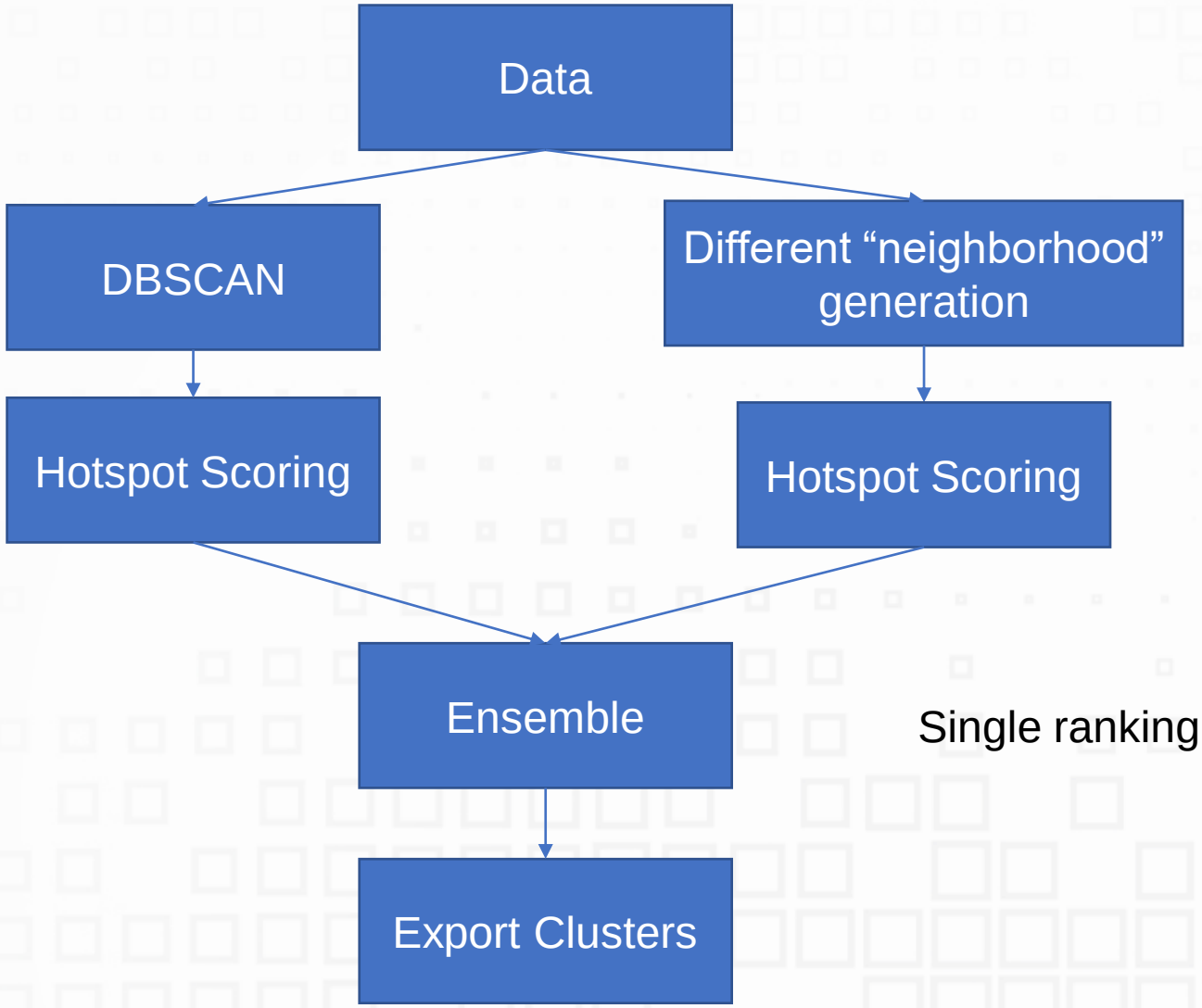
Algorithms

- We found two algorithms that worked well
  - DBSCAN and Getis Ord Gi* (Hotspot)

- These had challenges in a distributed environment
  - Building a weight matrix is challenging because of the full join of the dataset.
  - Capturing the data into standard formats without a database backend is complicated.
  - Determining the right epsilon value for DBSCAN is challenging for SMEs.

Clustering Process



Run any clustering algorithm permutations that may be useful.

Many rankings for each point / polygon

Single ranking for each point / polygon

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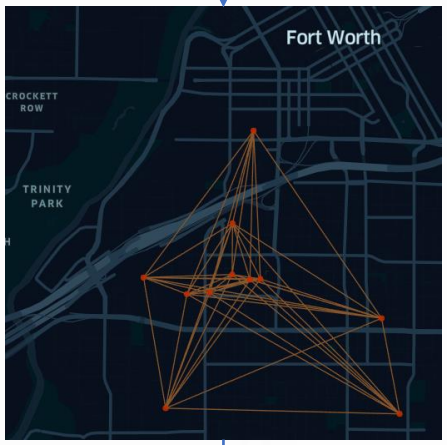
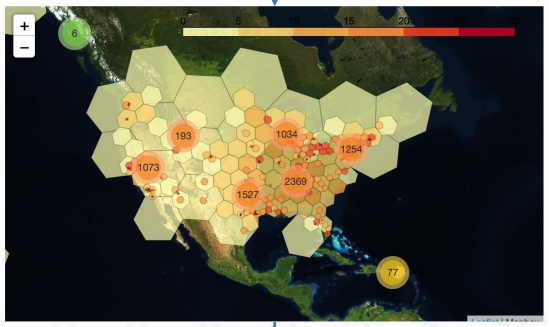
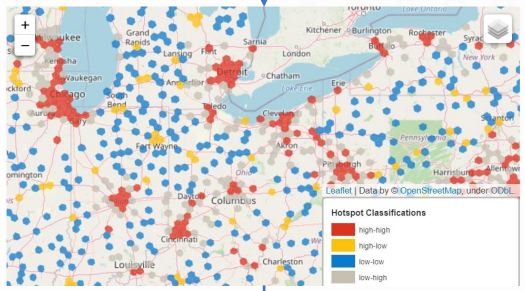
Clustering Process

Data







Many rankings for each point / polygon

Ensemble

Single ranking for each point / polygon

Export Clusters

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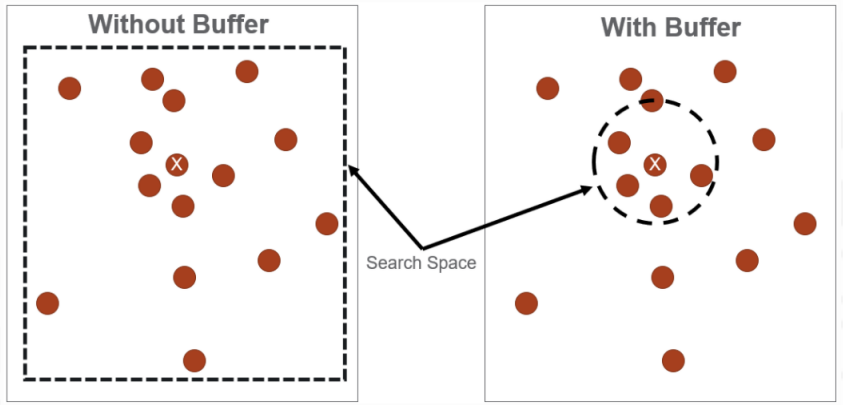
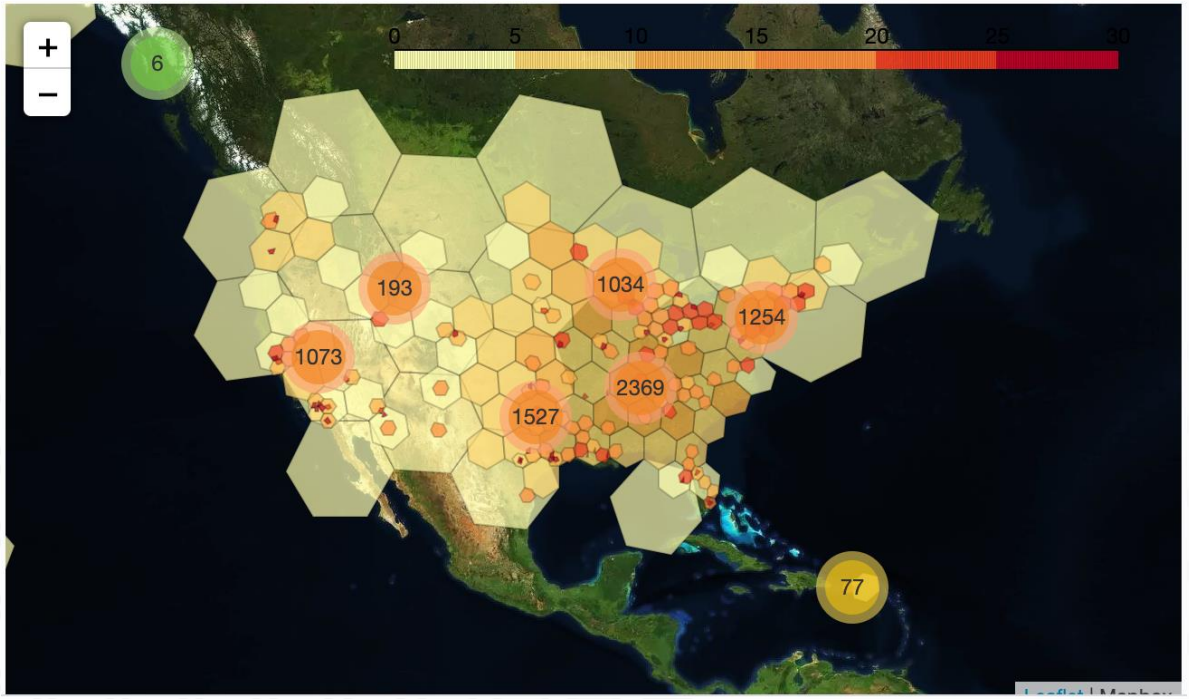
Scaling Spatial Algorithms

- Problem:
  - Spatial Clustering Algorithms have not been ported to distributed computing.
- Prior Efforts:
  - Large machine or database holding all data.
- Our solution:
  - Focus on efficiently building a weight matrix.



How do you determine an ideal buffer quickly?

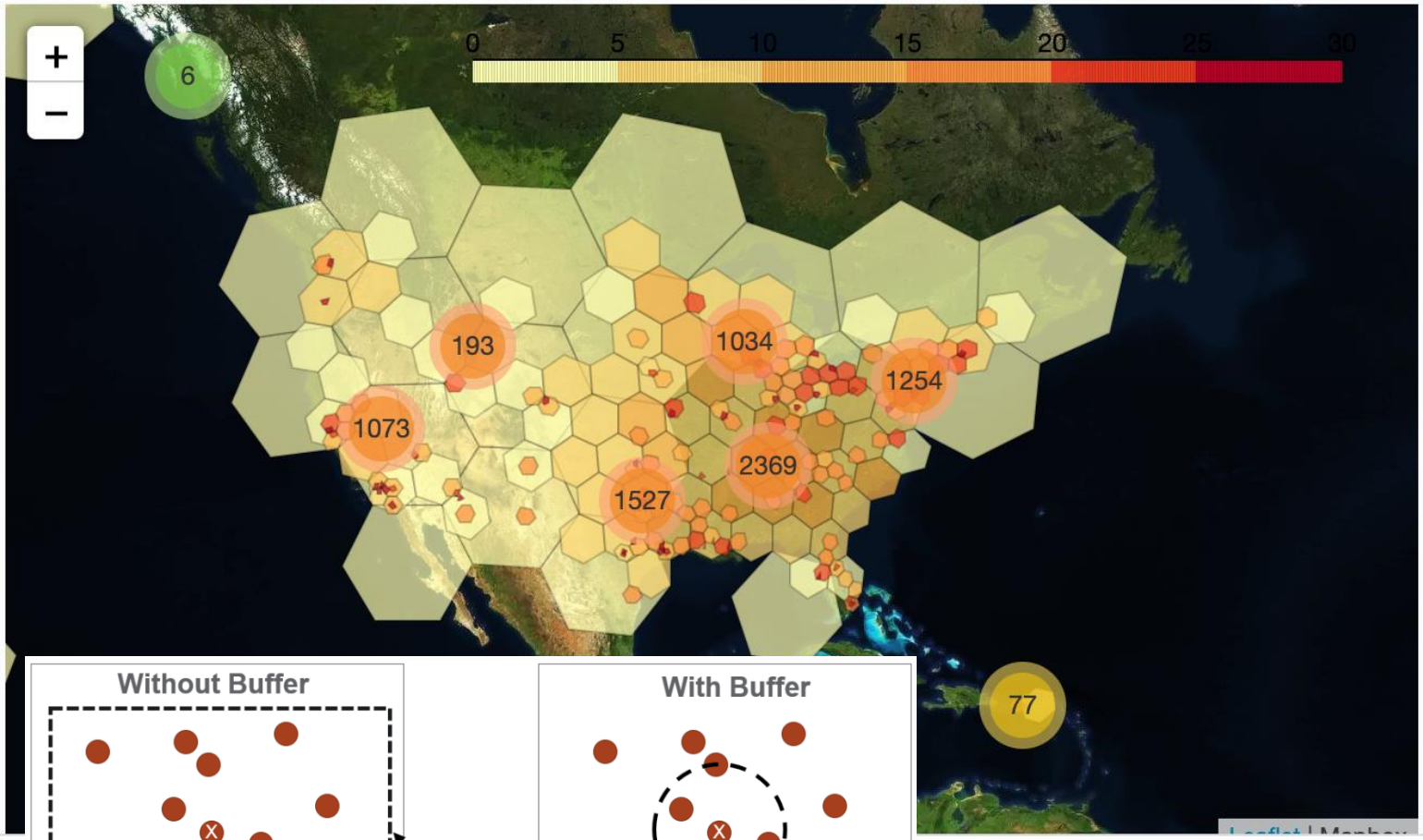
Kdtrees or r-trees or h3 aggregation.

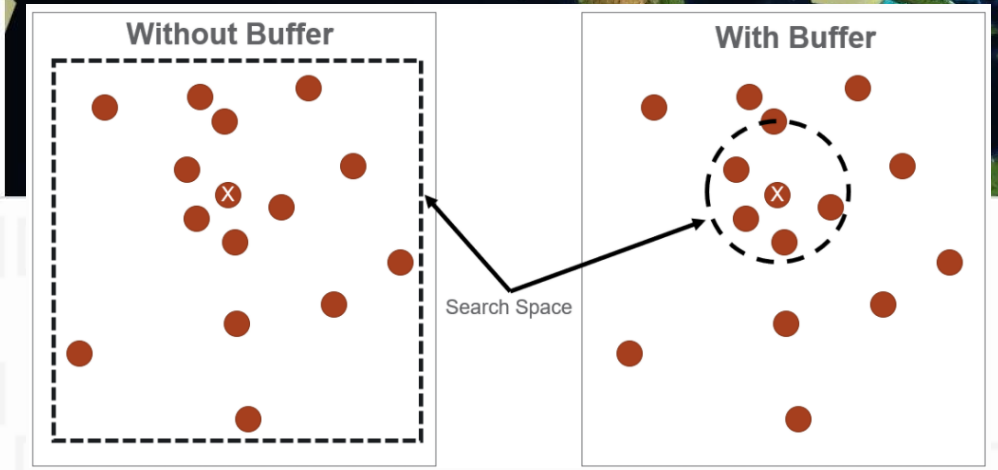


Algorithms (Adaptive KNN)

- Problem:
  - Distributed spark systems do not process k-nearest neighbors queries in parallel.

- Solution:
  - Hash each point using h3.
  - Coalesce points in hash until density is reached.
  - Create a “buffer” guess around a set of points based on hash where we believe K-nearest neighbors can be found.
  - Produces a “heat map” and allows us to parallelize the KNN query.
  - Generates a spatially relevant set of connections.





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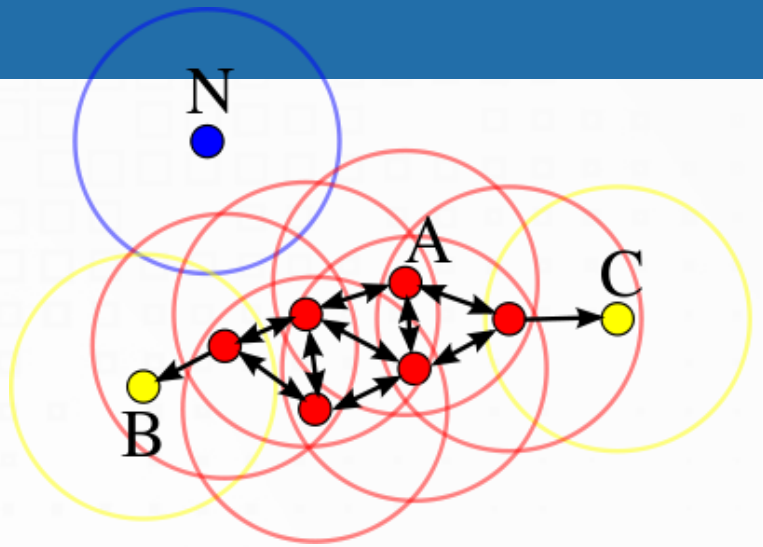
Algorithms (DBSCAN)

- Leverage the Adaptive KNN to find neighbors / distances.
- Create a Spark GraphFrame with the distance as the edges.
  - Use the maximum likely epsilon value.
- Filter the graph based on desired epsilon value.
- Run disconnected components to find clusters.
- Optionally perform graph-based analysis (connectedness, triangle count, etc.)
- Visualize output in kepler.

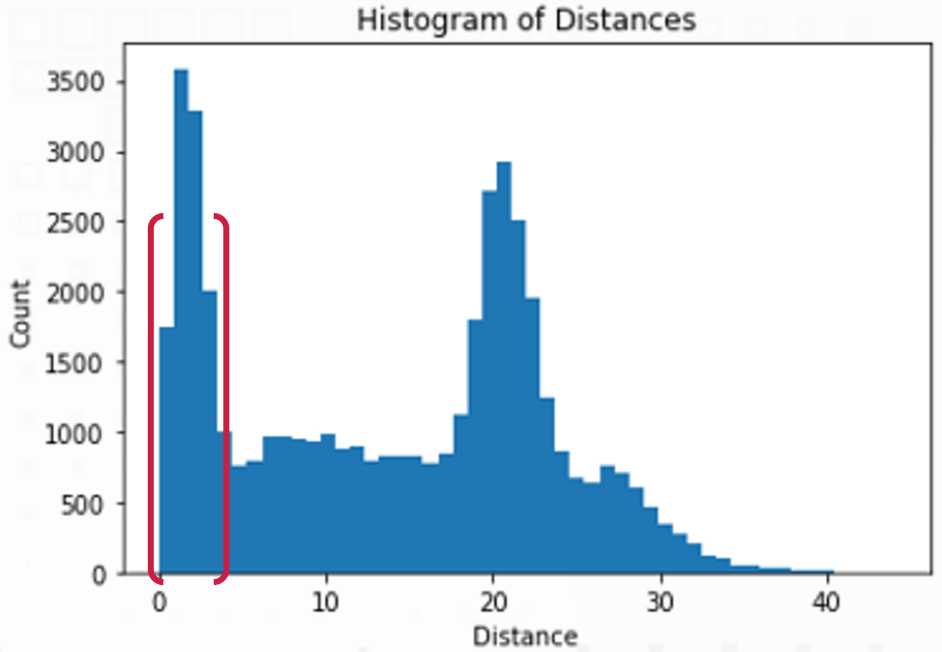


- DBSCAN is intended to be run multiple time across different epsilon ranges.

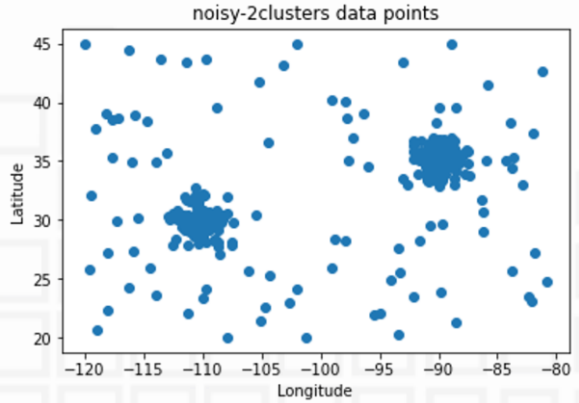
Algorithm (DBSCAN Range Finder)

- Problem:
  - DBSCAN requires a range (epsilon) for connected components.
  - There are permutations to dynamically determine this range (OPTICS, *DBSCAN, etc) but they introduce different complexities.

- Solution:
  - Use KNN distance information to determine a set of interesting epsilon values.
  - Run DBSCAN at values spaced along the determined interval.



Epsilon Range



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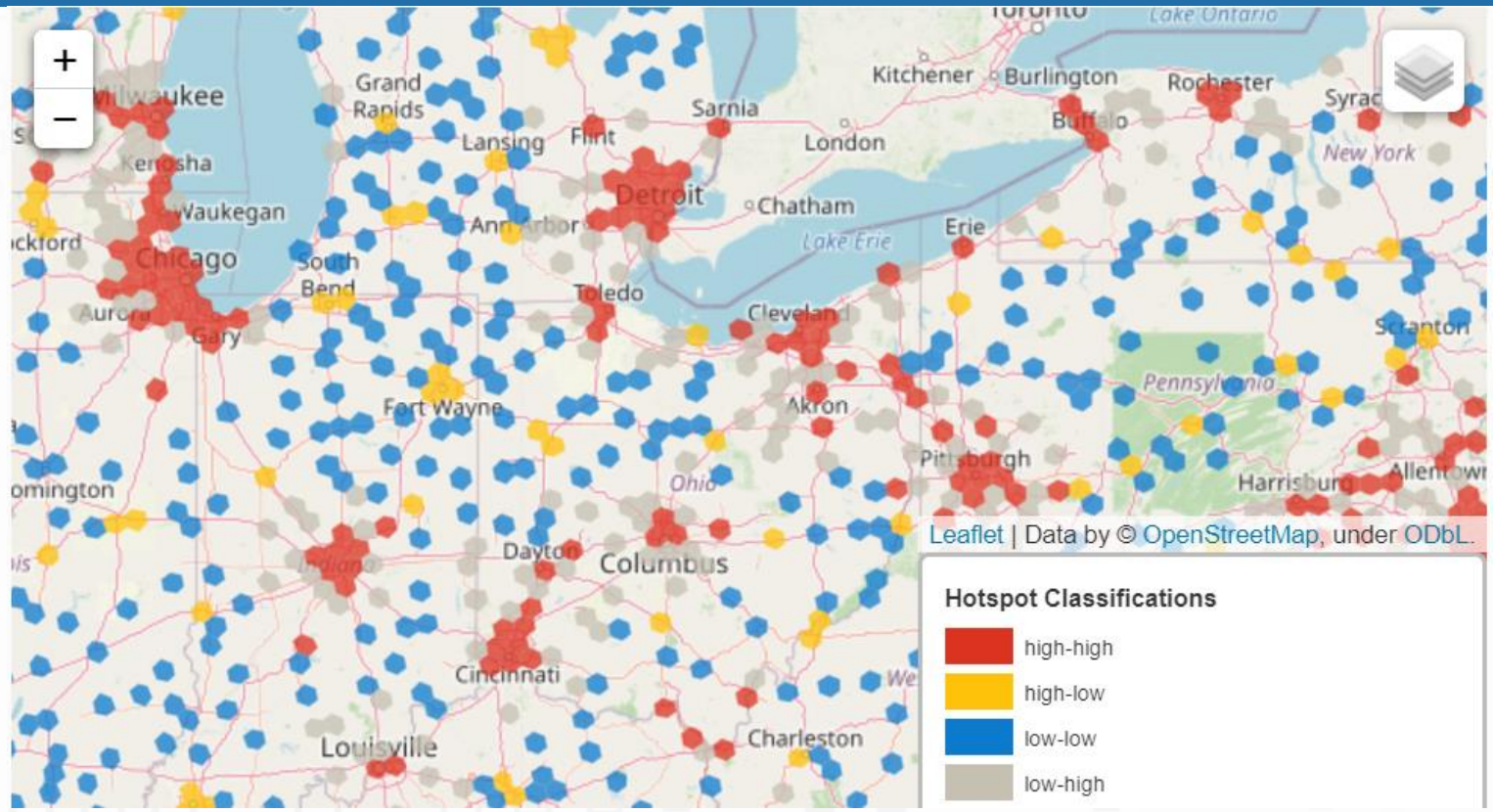
Algorithm (Hotspot)

- Extension of Getis Ord Gi *
- Leverages neighboring cells from H3 to find neighborhoods.

- Classification is
  - Neighborhood vs other neighborhoods
  - Point vs other points in the neighborhood

- Can vary the size of the neighborhood as well as the starting resolution.

- All results can be passed into an ensemble algorithm for ranking.



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Analysis Architecture

- Goal:
  - Provide structure to develop, test, and deploy algorithms.

- Why is this so hard?
  - Datasets are spread across systems.
  - Projections, formats vary.
  - Libraries are challenging to install
  - Geospatial workflows are easy to describe but challenging to implement / re-use

- Solution:
  - A library similar to pangeo.
  - Detailed instructions on install process.
  - Connections to other libraries when possible, porting when necessary for performance.
  - Full CI / CD pipeline to push the library to sponsors.

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Our Team

Development Team:

- Jenny Webster (co-lead)
- Dan Corbiani (co-lead)
- Mark Jensen
- Paige Maxwell
- Kate Miller
- Elise Saxon
- Lucas Tate
- Nile Wynar
- Katie Knobbs (advisor)

Join our Big Geospatial Data Meetup!

First Thursday at 1pm est.

Dan.Corbiani@pnnl.gov

or

Jenny.Webster@pnnl.gov

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High/Low Power R&D Arc & Ground-Fault Detection/Mitigation

Dr. Kenneth M. Armijo

Sandia National Laboratories

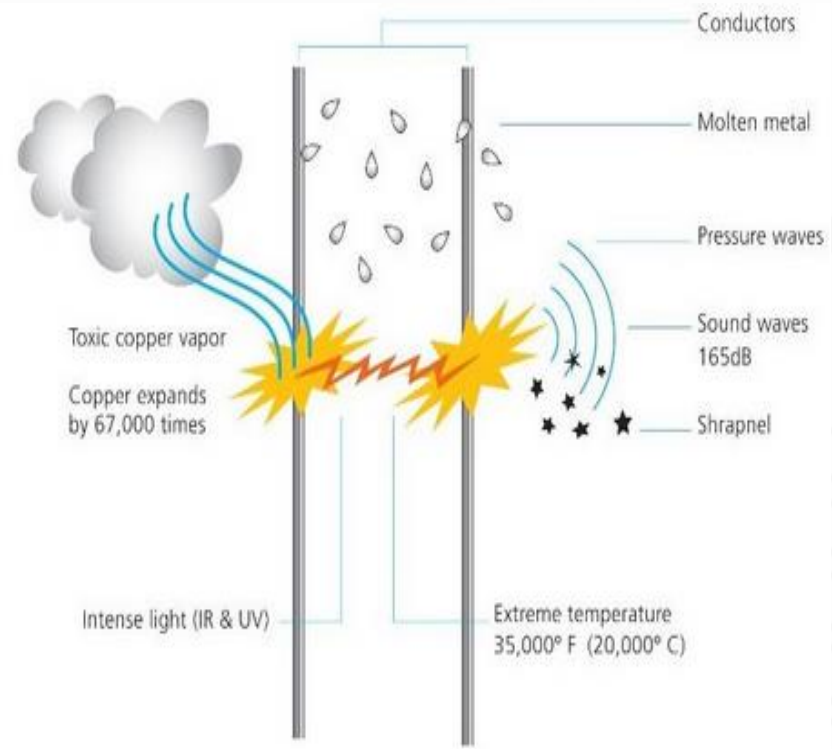
SAND2021-4288 PE

April, 15th 2021

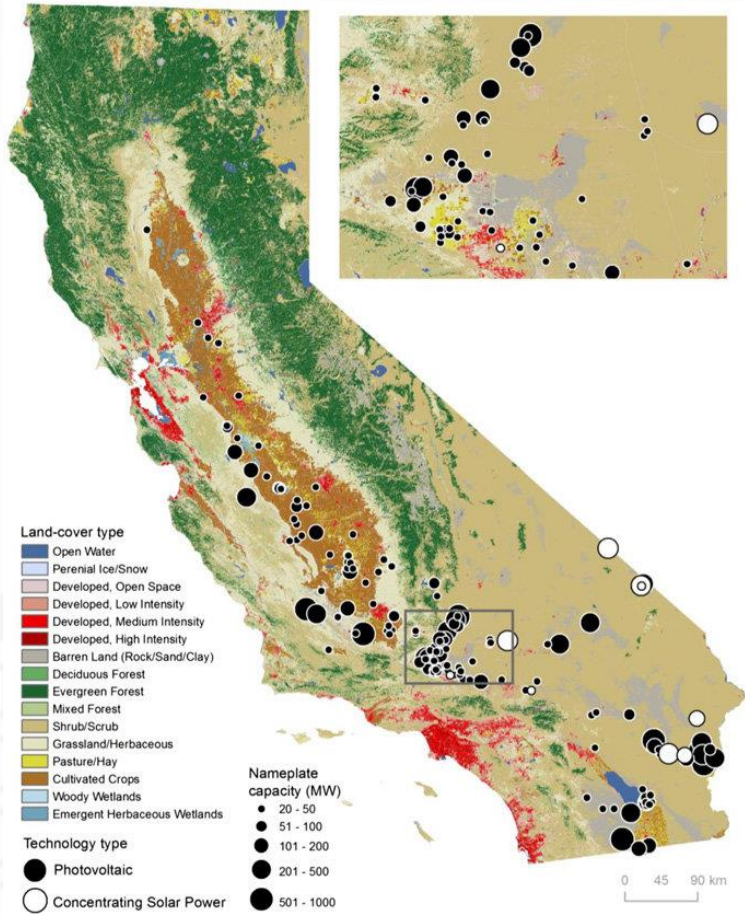
Thermal Arc/Ground Fault Research

- Arc & Ground Faults in PV & DC Systems Linked to Dozens of PV Fires Around the World.
- Direct Relevance Issue for Power Transmission-Scale Wiring & Forrest Fire Potential.
  - Future of Distributed PV in Forested Areas

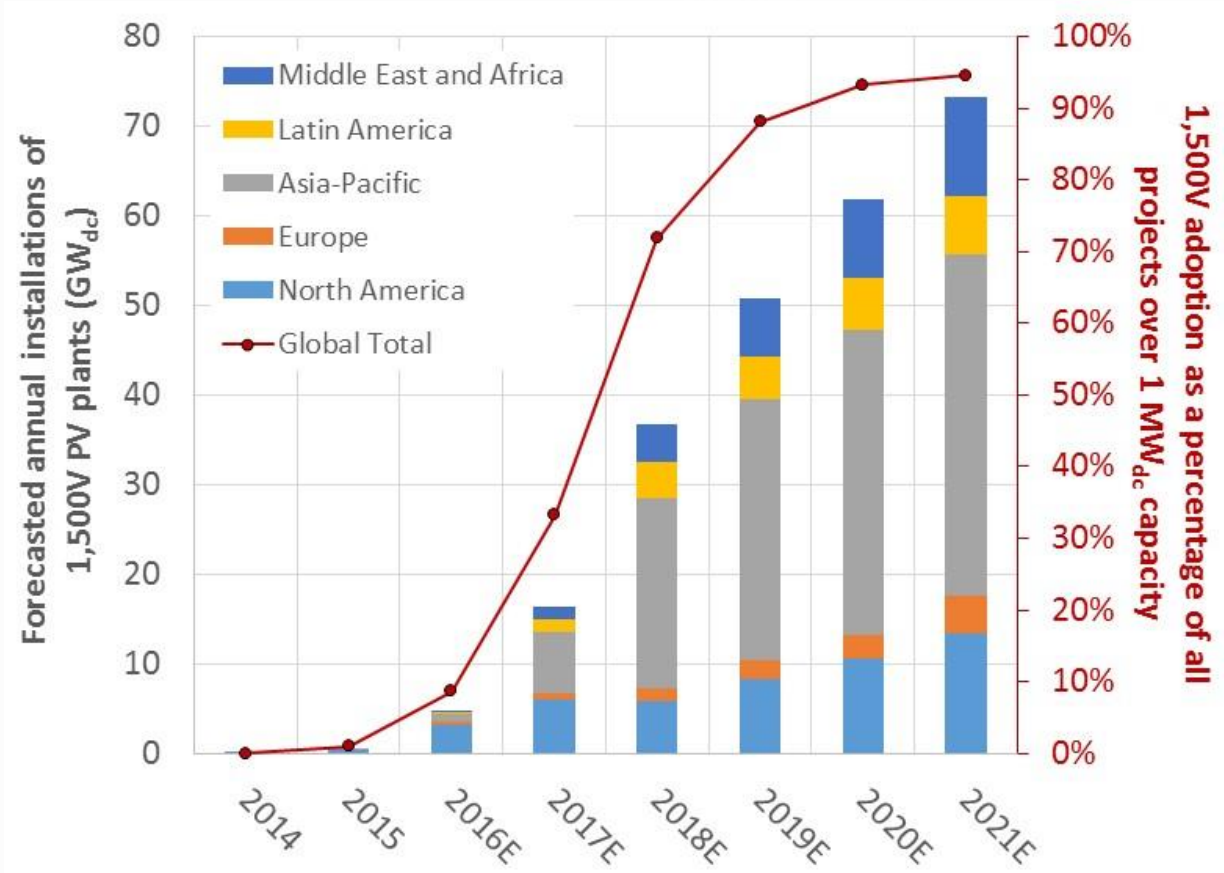
2015, Hernandez, R.R et al., "Solar energy development impacts on land cover change and protected areas", NAS, 112 (44)



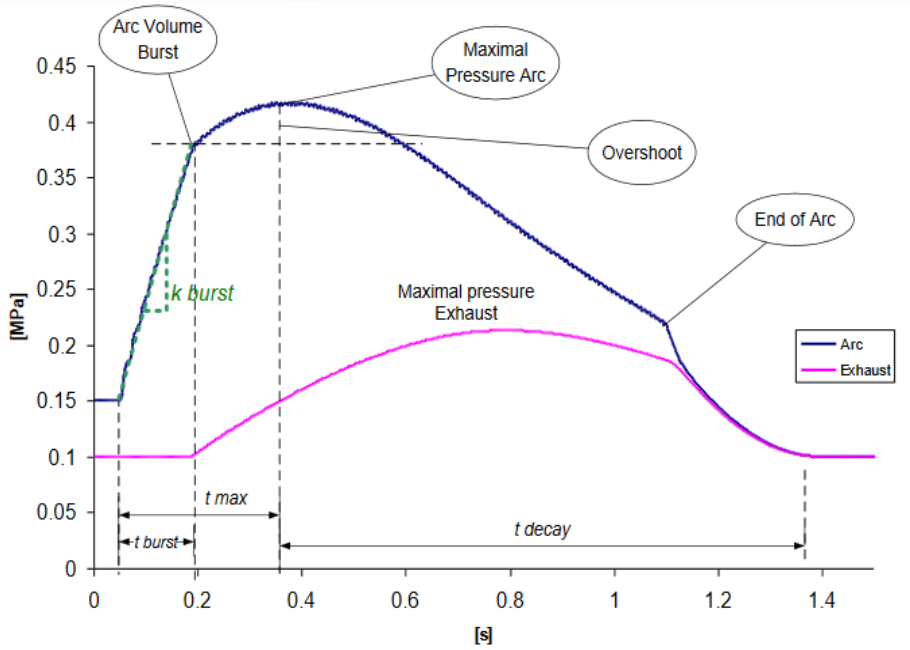
PV in Forested Lands



Increasing PV Voltage & Propensity for Fires



Forecasted capacity installation and percent adoption of 1,500V_{DC} utility-scale PV plants. Data: GTM Research



Commercial Bldg. Arc-Fault Fire

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Armijo, K.M., et al., "Localized Arc-Plasma Model for High-Voltage Photovoltaic Power Systems," *47th Photovoltaics Specialist Conference (PVSC)*, Calgary, Canada, 2020.

DC (PV) and AC (Nuclear Energy) High-Energy Arc-Fault (HEAF) events

Photovoltaics (600-1,500VDC)

Bakersfield CA, April 5 2009

"… the ground-fault protection device was unable to interrupt the current, **allowing arc faults to be formed**, spreading sparks to surrounding materials, **causing ignition.**"

-- Commercial Roof-Mounted Photovoltaic System Installation Best Practice Review and All Hazard Assessment, The Fire Protection Research Foundation, Feb. 2014

Nuclear Energy (480V, 410V, 6900V and 10kV)-AC

San Onofre Nuclear Generating Station, Feb. 3 2001

"There was a **failure of the main contacts** of a 25 year old 4.16 kV breaker to close fully, **causing a HEAF event**… the **fire persisted for three hours** until water was applied."

-- Brown et al., SAND2008-4820, High energy arcing fault fires in switchgear equipment, a literature review

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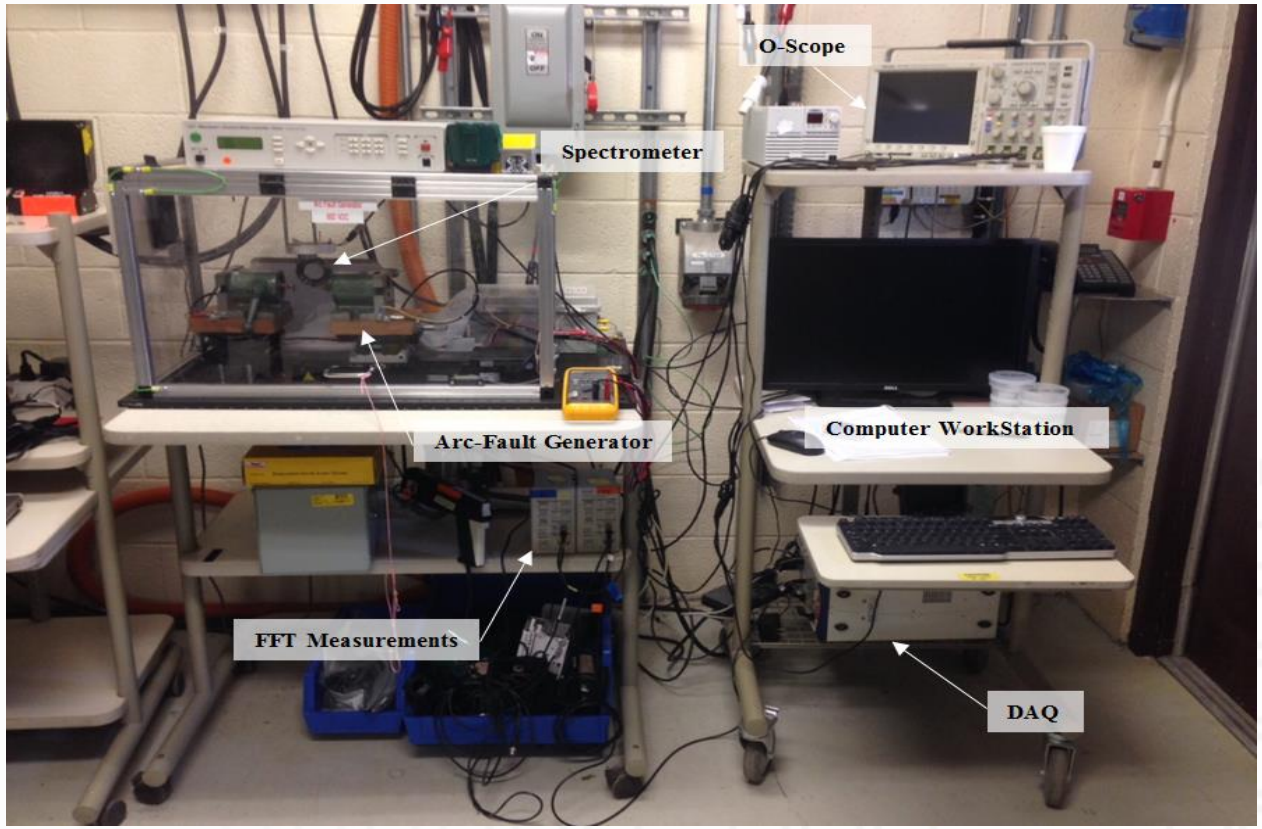
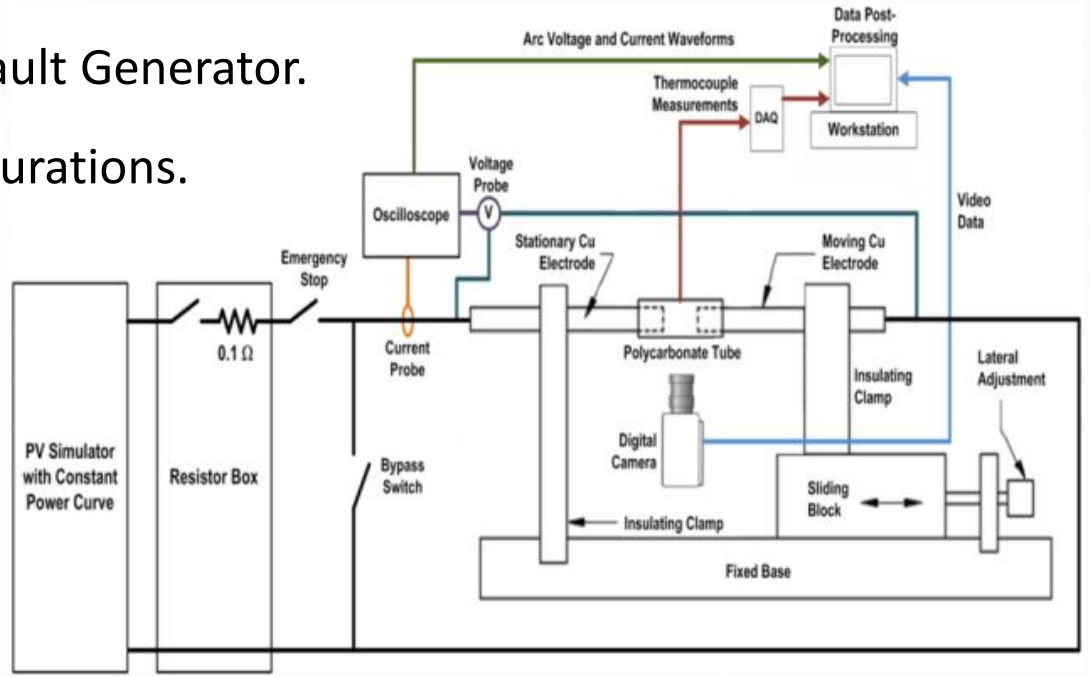
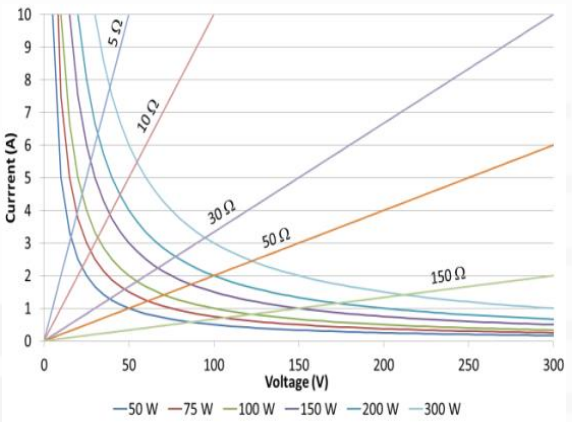
Experimental Low-Voltage (≤600V) Capabilities
Distributed Energy Technologies Lab (DETL)

- Customized PV Simulator provided power to a developed Arc-Fault Generator.
- PV DC & AC Simulators to evaluate varying power system configurations.



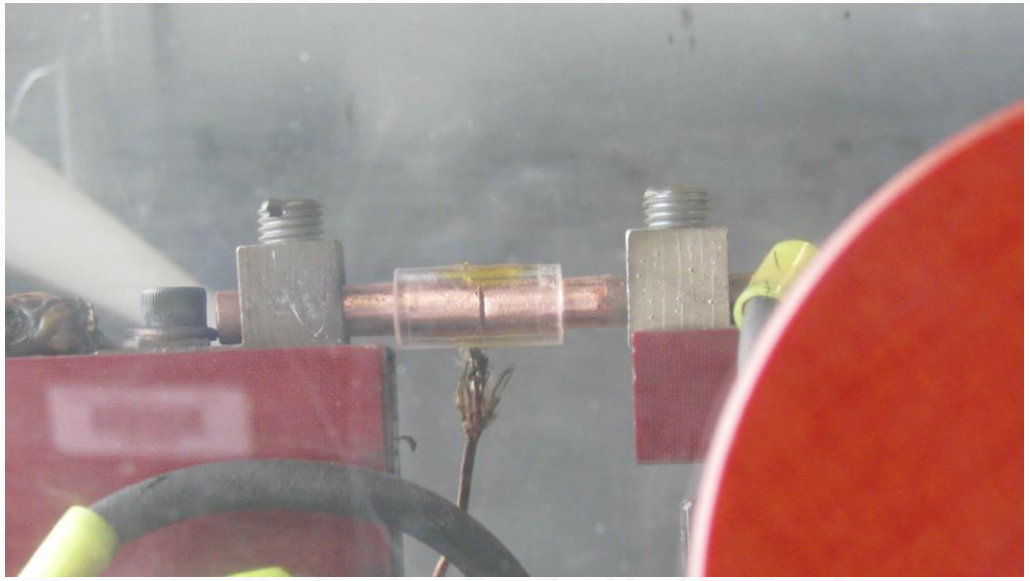




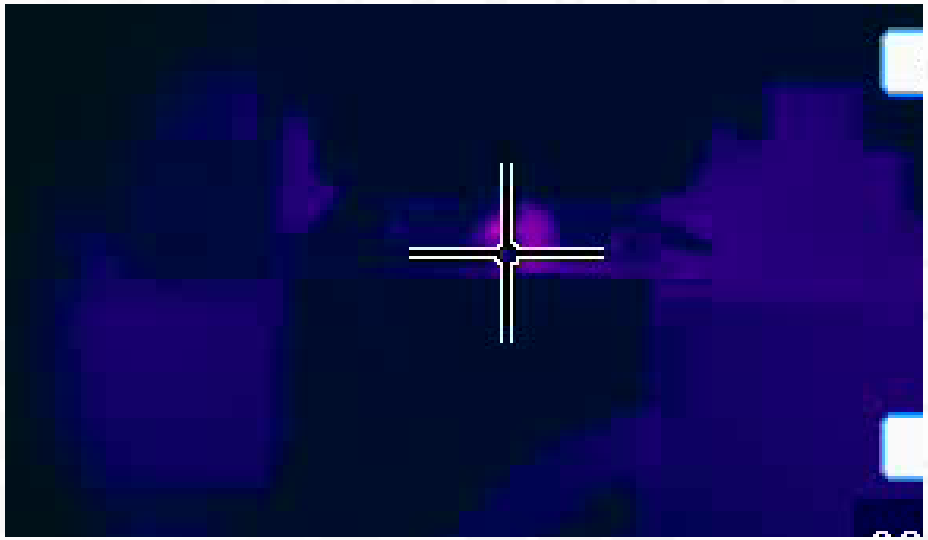
Schindelholz, E.J., Armijo, K.M., Johnson, J., Harrison, R.K. and Yang, B.B.Y., National Technology and Engineering Solutions of Sandia LLC, 2019. *Arc plasma-generating systems and methods thereof*. U.S. Patent 10,261,120.

Arc-Fault Characterization/Detection

Visual Video:



IR Video:



High-Speed Photography:

Armijo, K.M., Hibbs, M., Johnson, J. and Fresquez, A, "Characterizing fire danger from low power PV arc-faults", *40th PVSC Conference*, Denver, CO, 2014.

Experimental Development for High-Voltage Validation SNL Lightening Simulator Facility

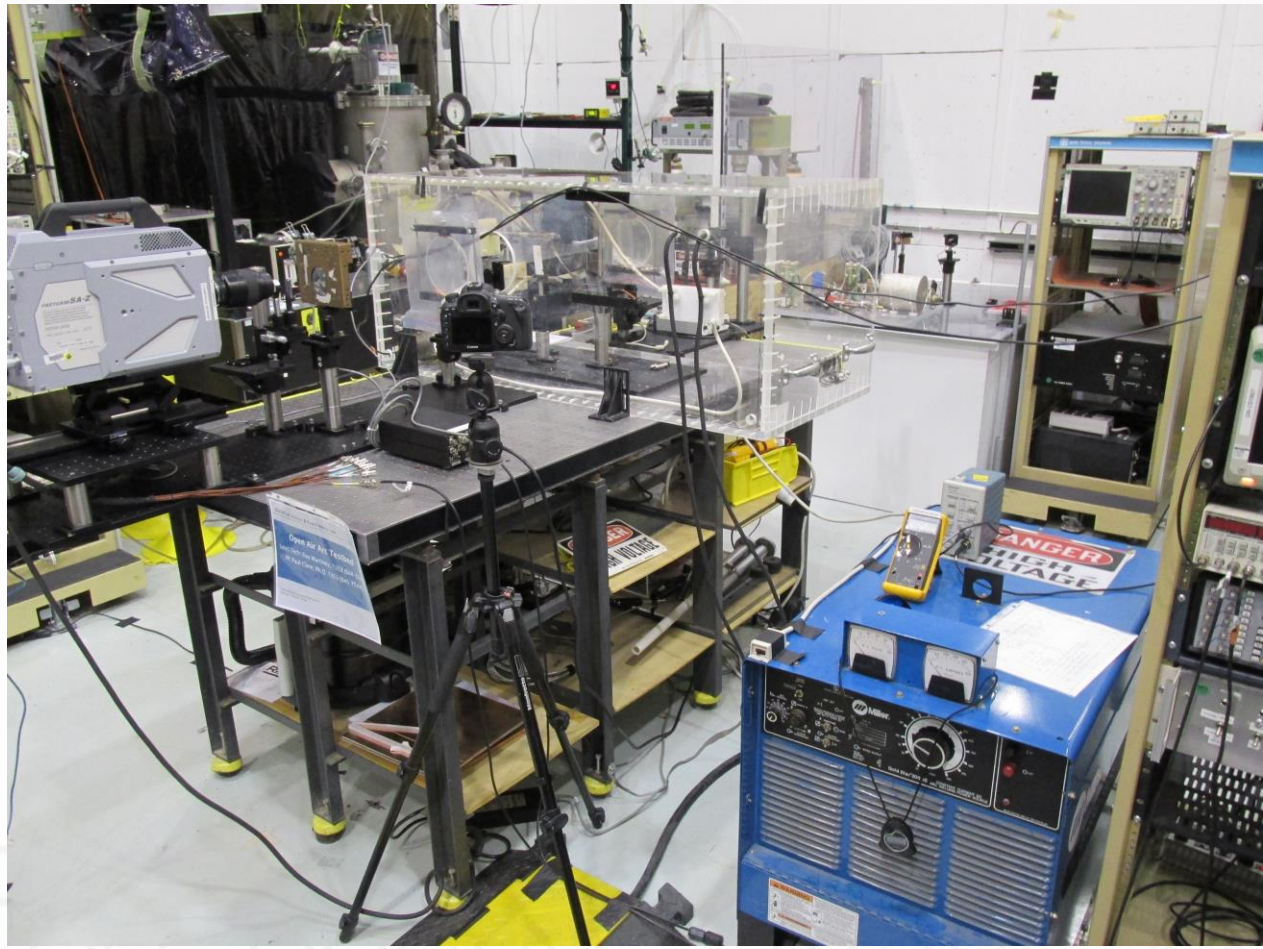
- Experimental testbeds developed for two capabilities:

    1. Capacitive discharge system produces a stored energy 1-50 kJ, to support arcs at 1 - 160 kA,

    2. RC dump using a ~810 µF capacitor & ~900 J.

    3. Long-duration, arc-triggering constant current source, follow-on supply

- Reproducible 30 s arc tests have been performed with the constant current system



Armijo, K.M et al., "Characterizing fire danger from low power PV arc-faults", *40th PVSC Conference*, Denver, CO, 2014.

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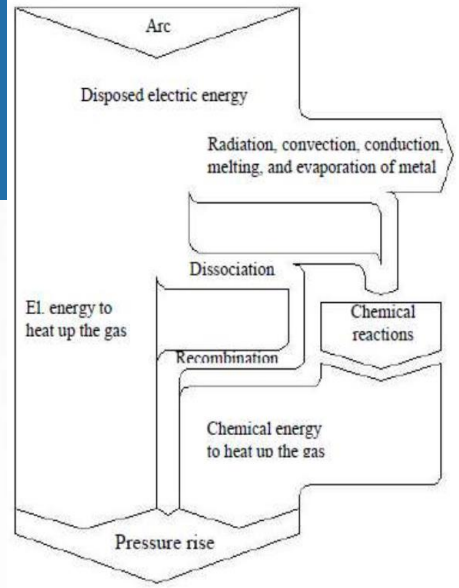
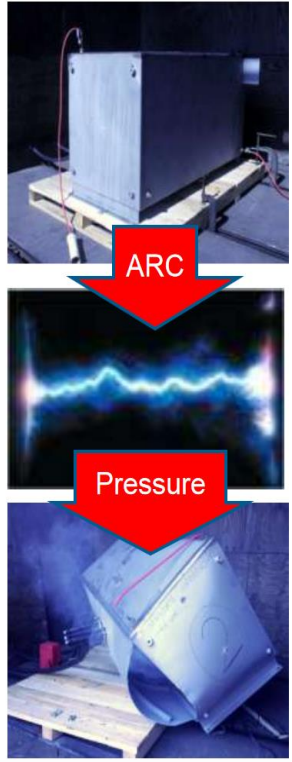
AC High-Voltage R&D

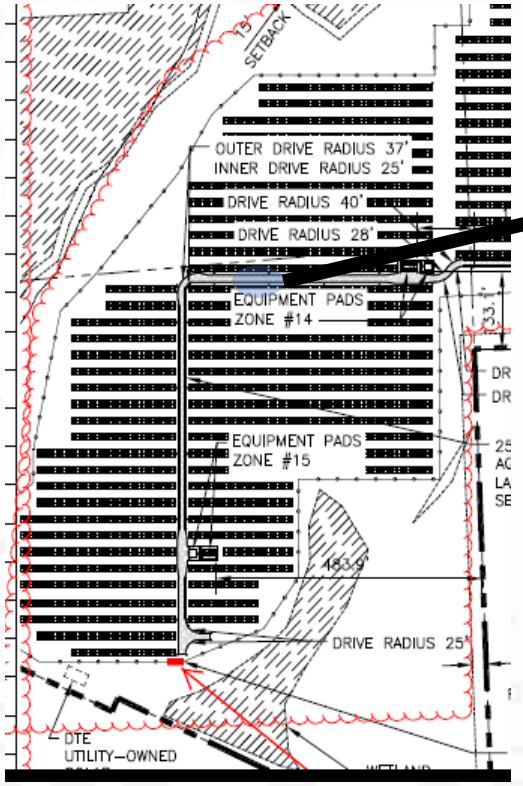
- 480V, 4160V, 6900V and 10,000V AC tests
- Arcing despite Zero-pt. crossing extinguishment not occurring
- 3-Phase AC tests performed btw SNL, NRC & NIST

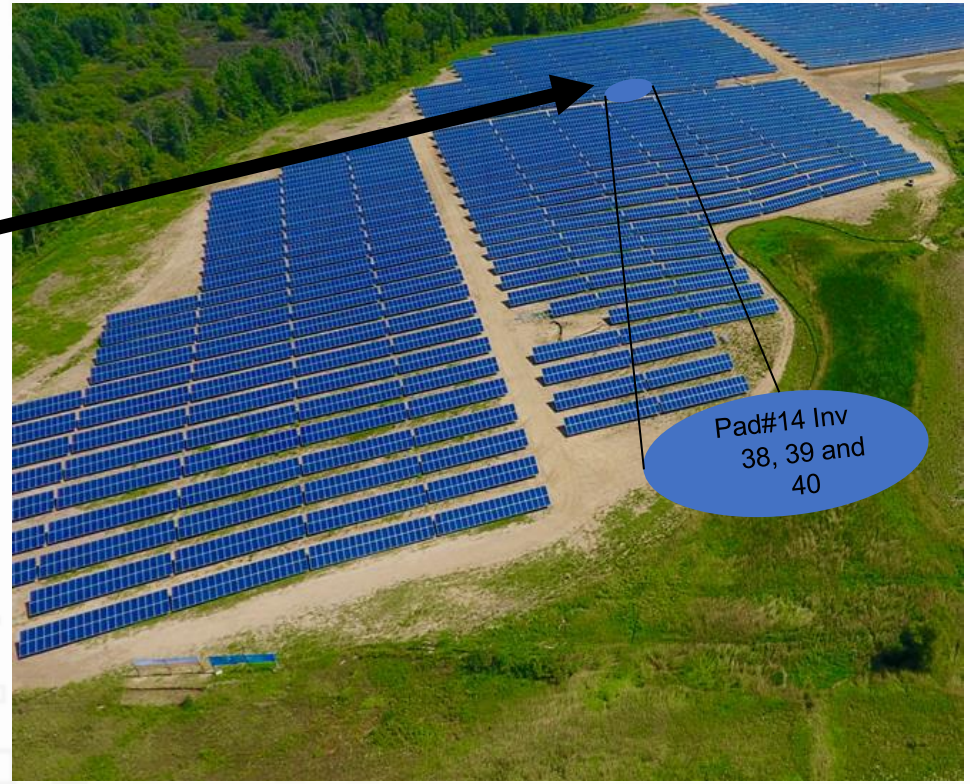




Muna, A., C. LaFluer, KM Armijo, Clem, P., Tanbakuchi, A., "Aluminum High-Energy Arc-Fault (HEAF) Particle Size Characterization", NUREG/CR, U.S. Nuclear Regulatory Commission, 2018.

SNL Capabilities – Form the Lab to Field Experimental Faults R&D





Completed: 16 Arc-in-a-box tests 27 Equipment Failure tests

DTE Solar Park, Lapeer, MI

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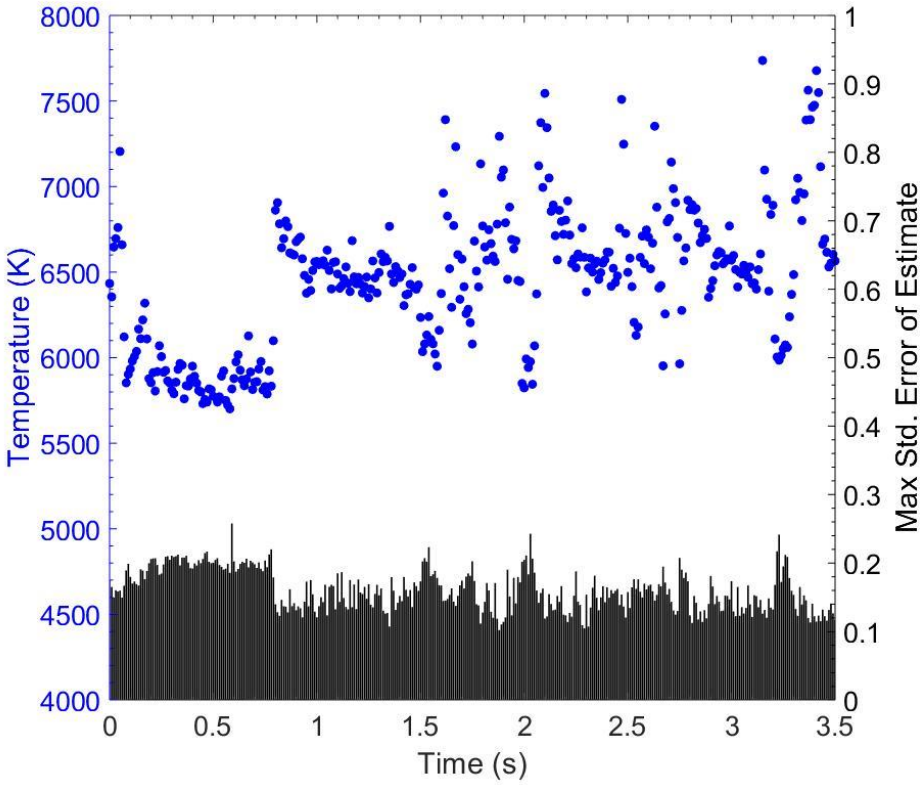
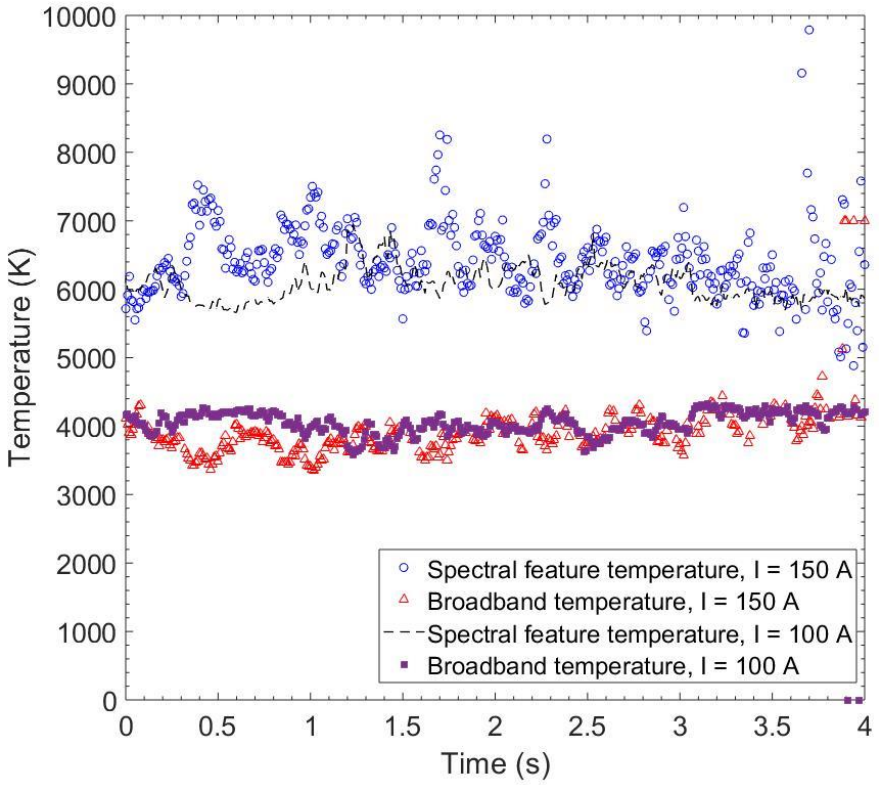
Paudyal, B., Bolen, M., Short, T. and Woodard, J., 2019, June. Measured dc Arc-flash Risk in a Photovoltaic System. In *2019 IEEE 46th Photovoltaic Specialists Conference (PVSC)* (pp. 3140-3143). IEEE.

Spectral & Inferred Temperatures from Metal Vapor

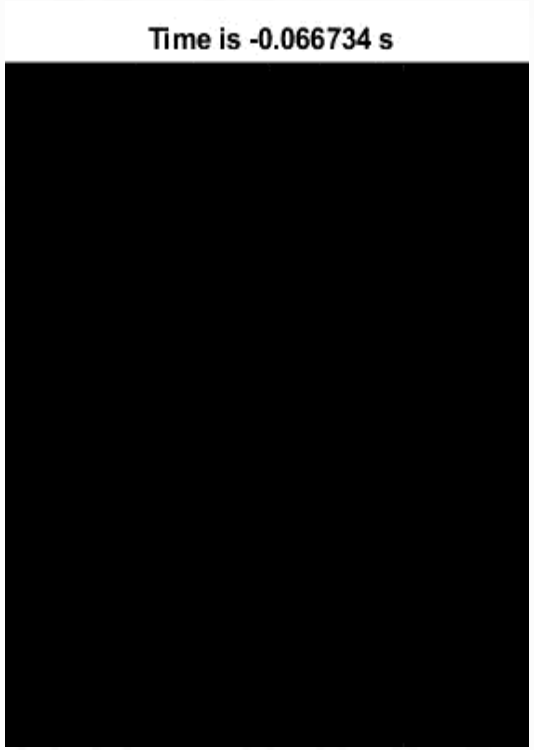
Spectral feature temperatures & associated errors



Comparing methods



Al arc emission



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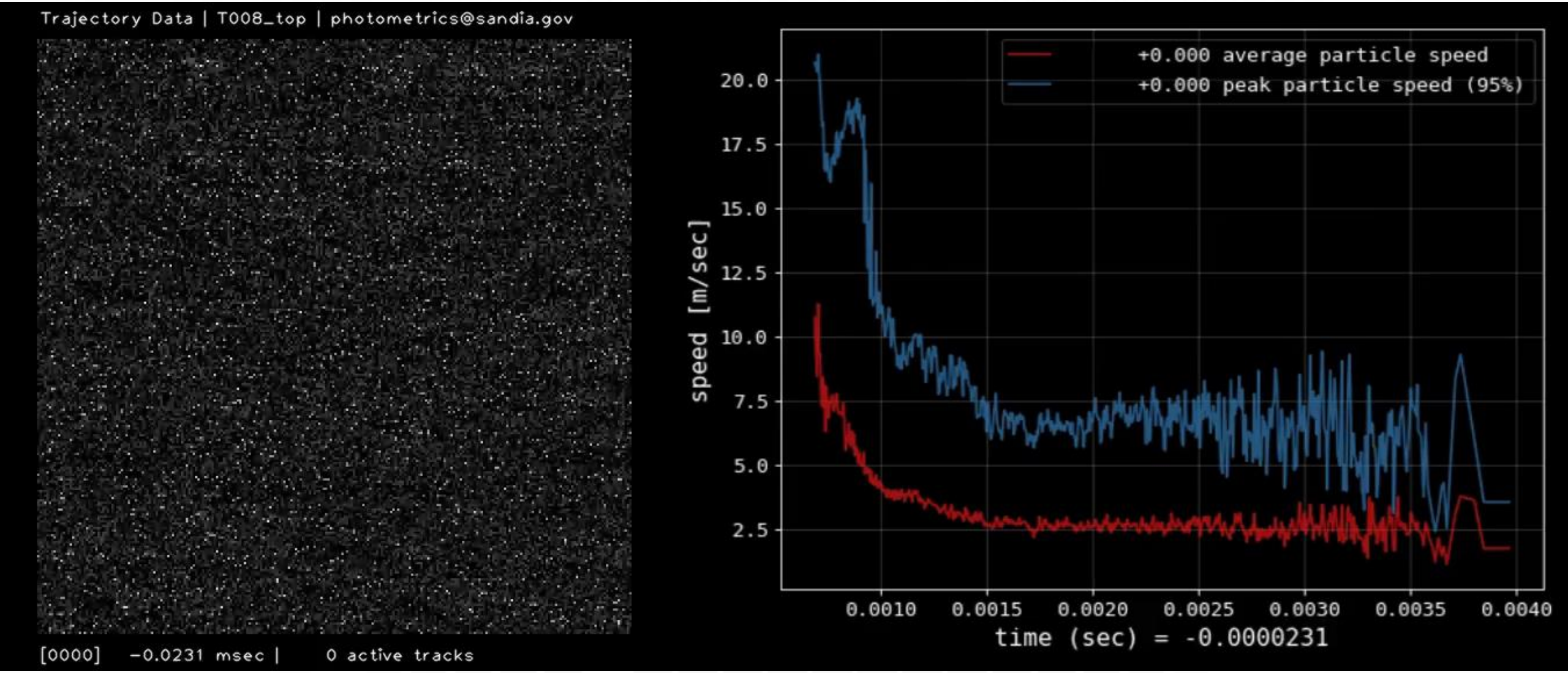
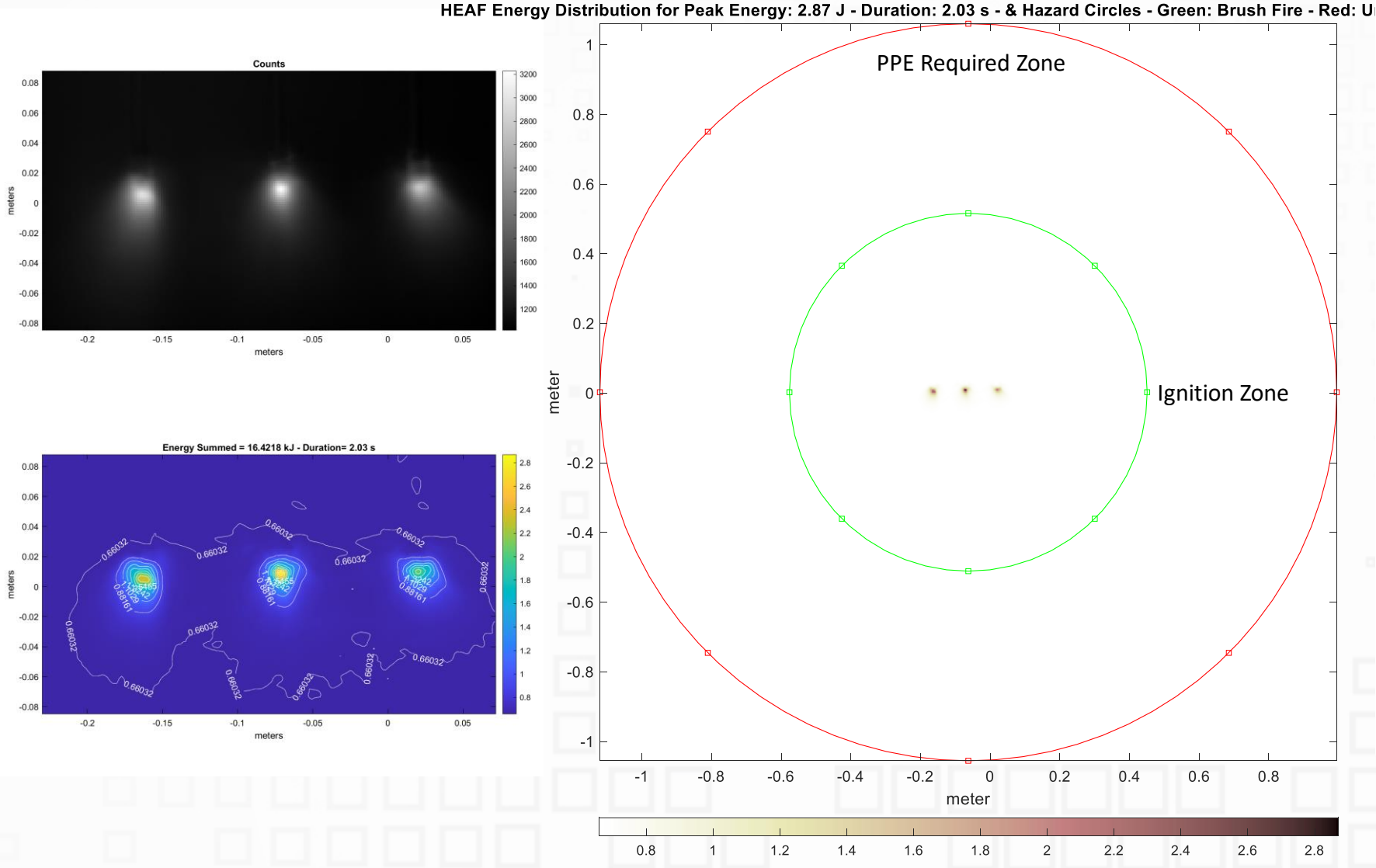
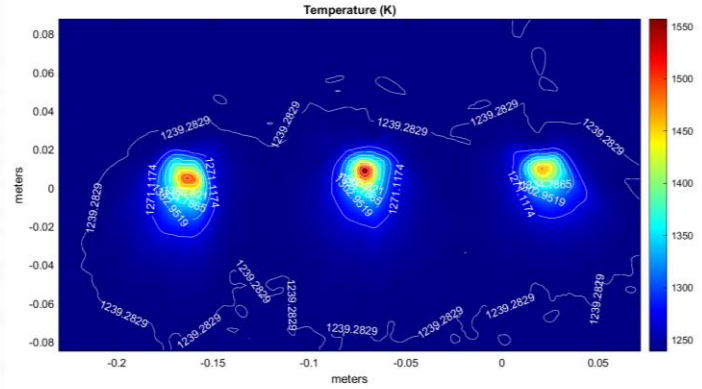
Winters, C., Cruz-Cabrera, A., Armijo, K.M., "Characterization of DC Arc-Plasmas Generated by High-Voltage Photovoltaic Power Systems," *47th Photovoltaics Specialist Conference (PVSC)*, Calgary, Canada, 2020.

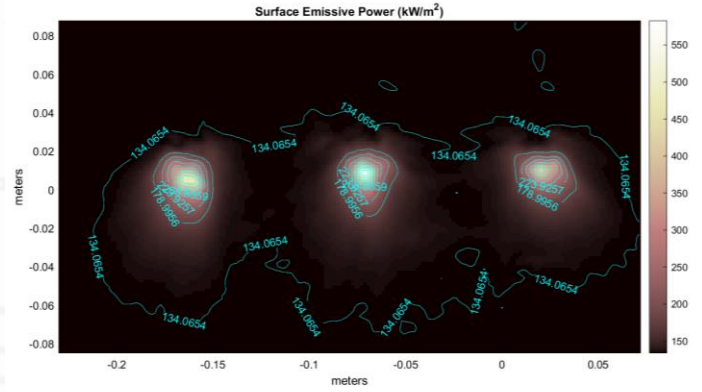
Arc-Blast Particle Collection & Analysis



IR Zone of Influence (ZOI) Calcs for Codes & Standards







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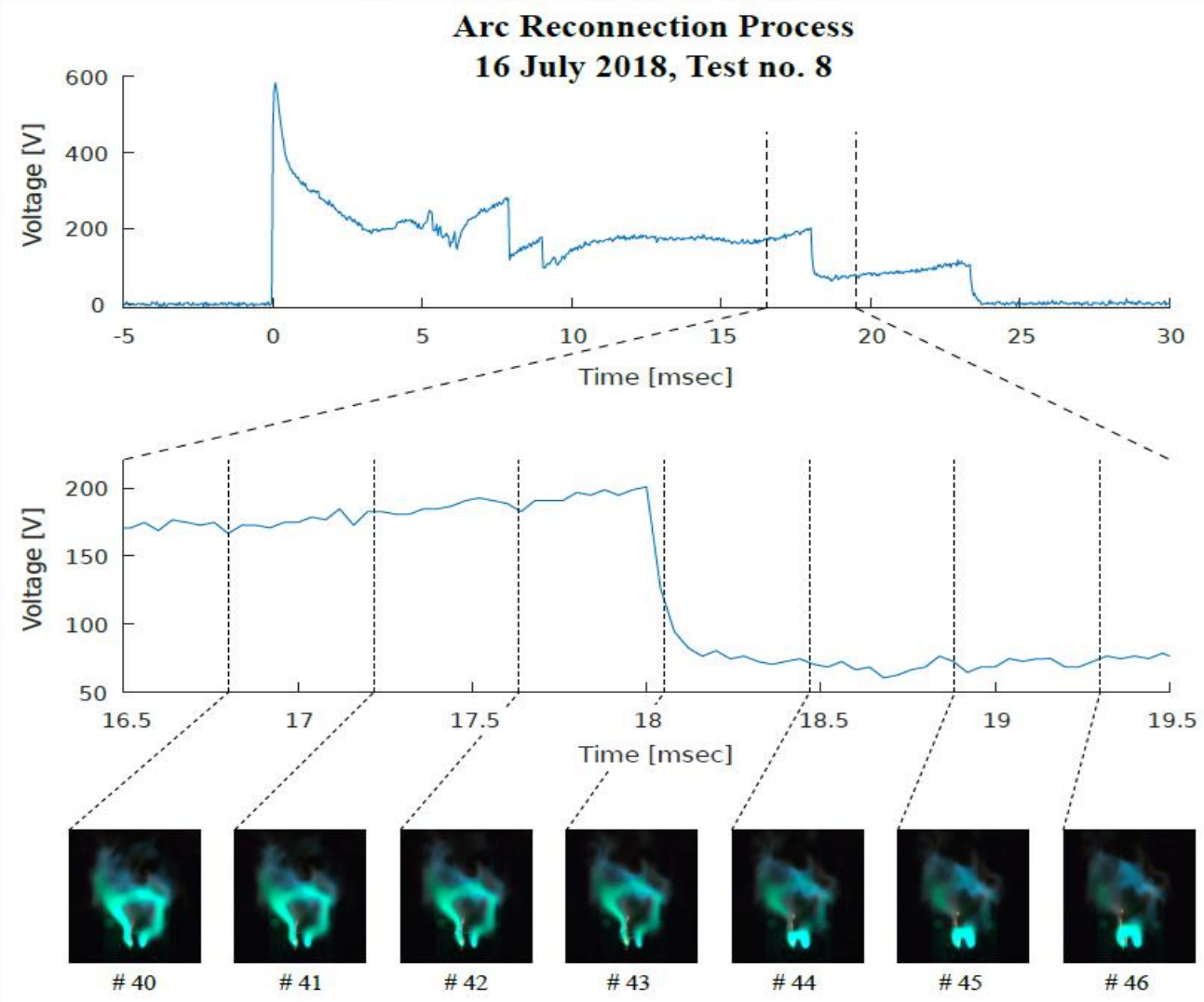
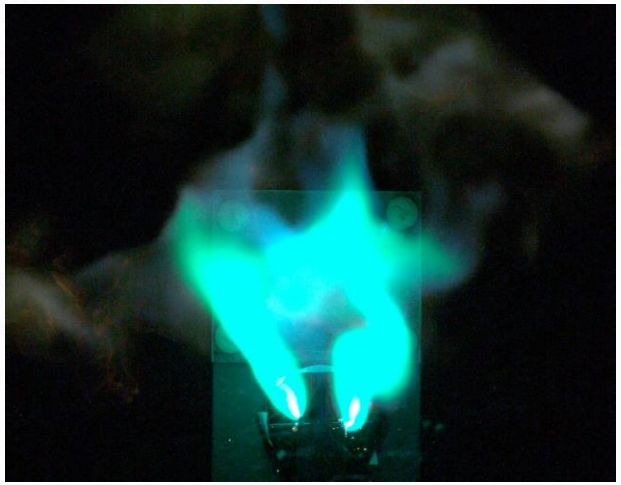
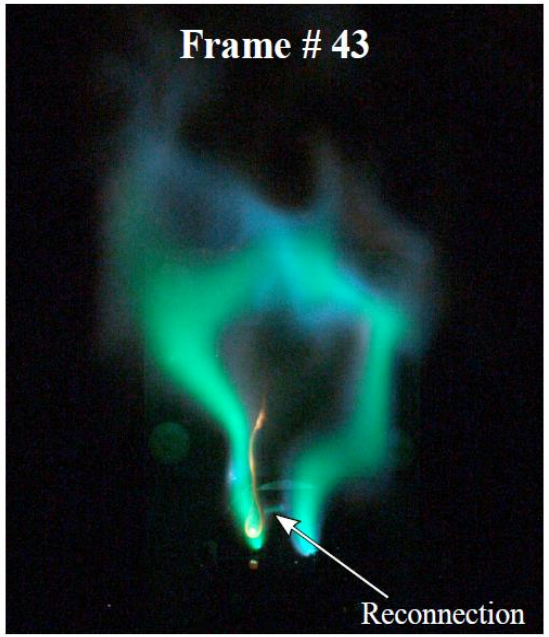
Winters, C., Cruz-Cabrera, A., Armijo, K.M., "Characterization of DC Arc-Plasmas Generated by High-Voltage Photovoltaic Power Systems," *47th Photovoltaics Specialist Conference (PVSC)*, Calgary, Canada, 2020.

Dynamic arc restrike measurements

"Lightening may not strike twice…but arc-faults can!"







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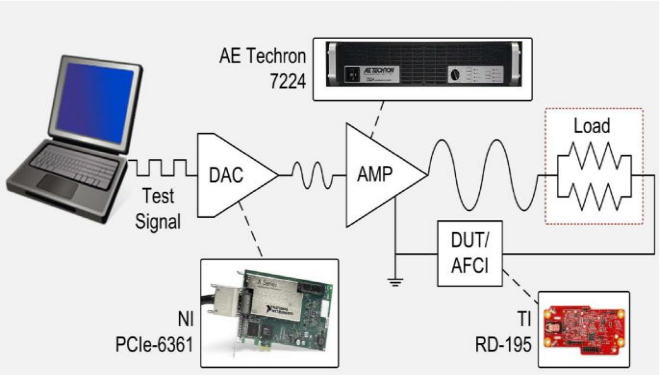
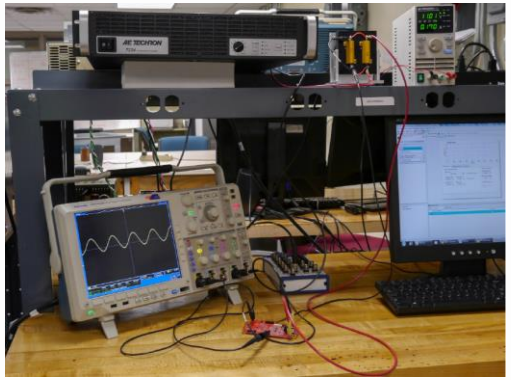
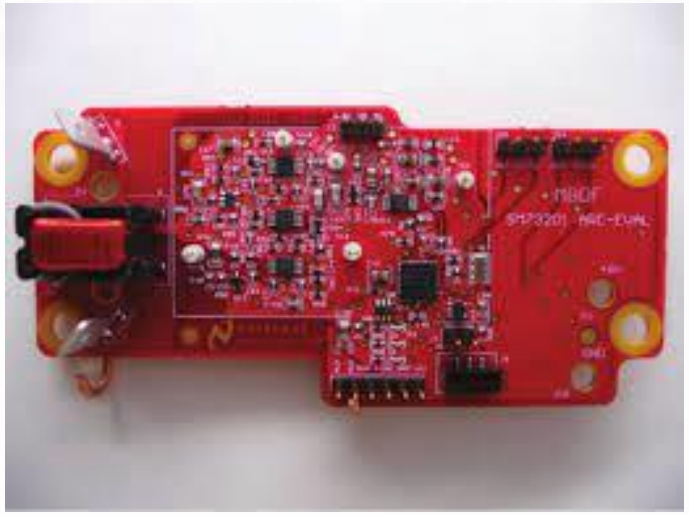
Arc-Fault Circuit Interrupter (AFCI) Development

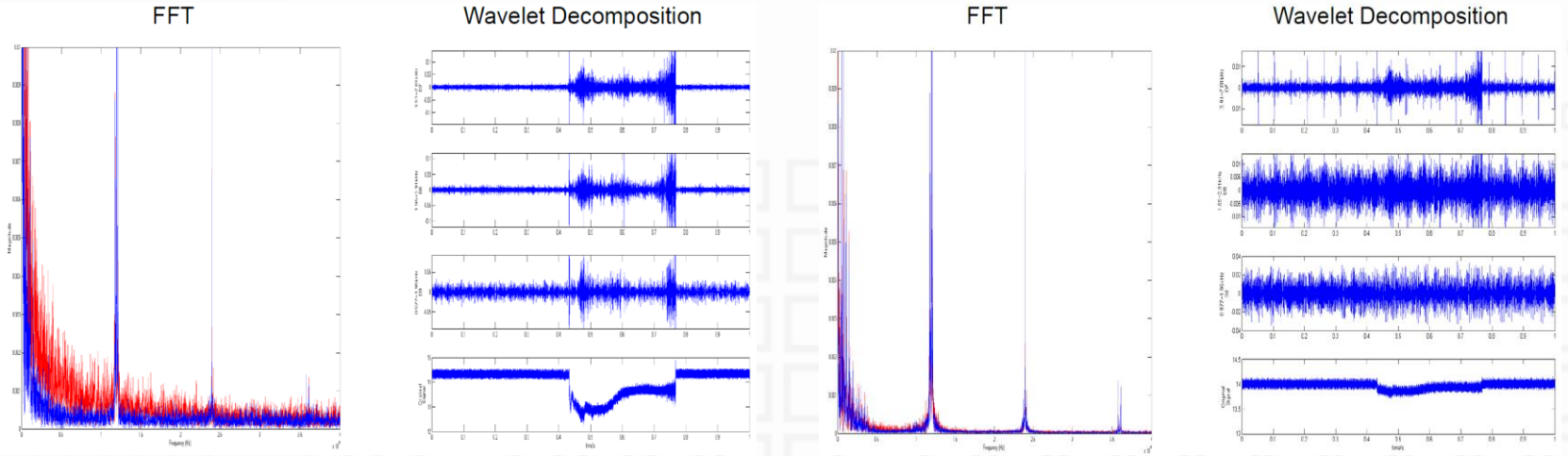
Wavelet Model work has the potential for providing capabilities for accurate arc-fault detection, which would reduce nuisance tripping issues

Novel Wavelet Model method for arc fault detection algorithm.









McConnell, S., Wang, Z., Balog, R.S. and Johnson, J., 2014, June. Evaluation method for arc fault detection algorithms. In *2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)* (pp. 3201-3206). IEEE.

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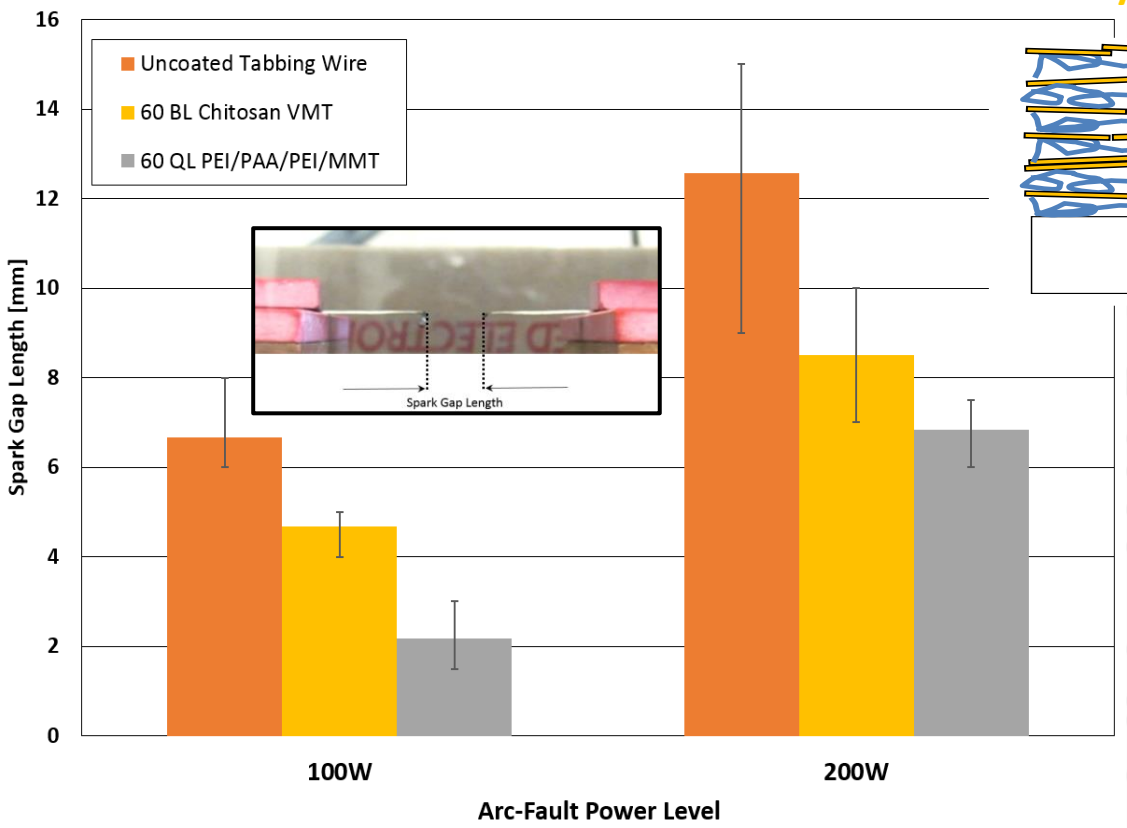
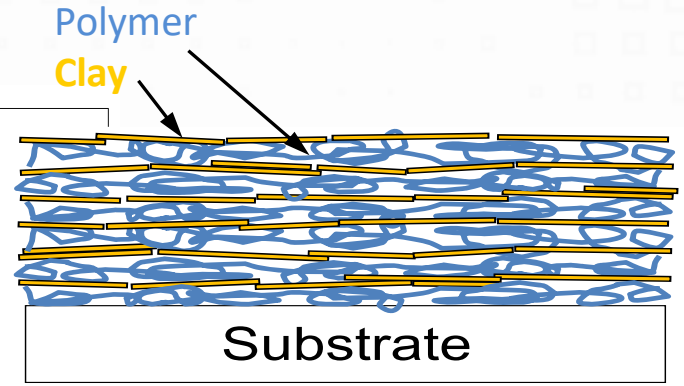
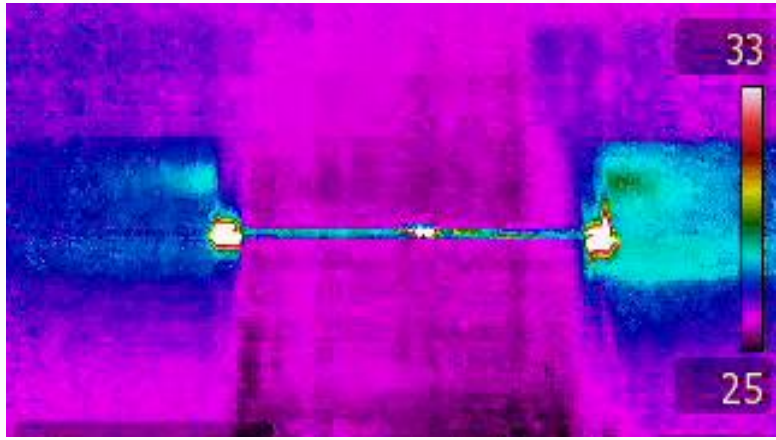
Self-Extinguishing Materials Research

- Layer by Layer Nano-Composites Self-Extinguishing Materials (Sandia LDRD)
- New R&D field for application across Electricity Transmission/Distribution System.

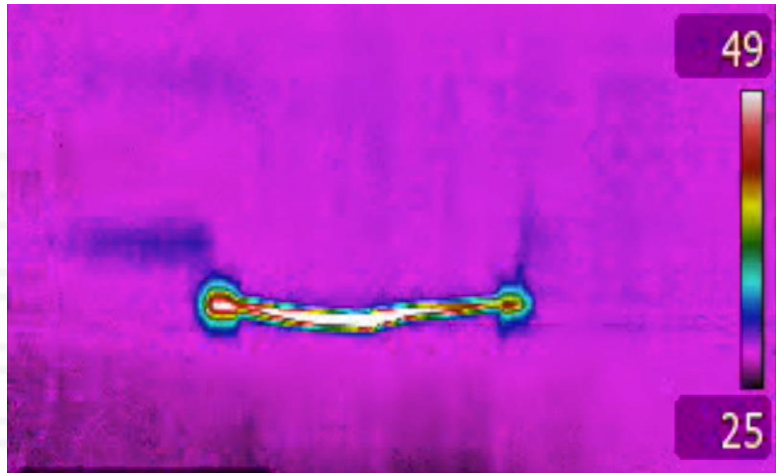




Uncoated Tabbing Wire



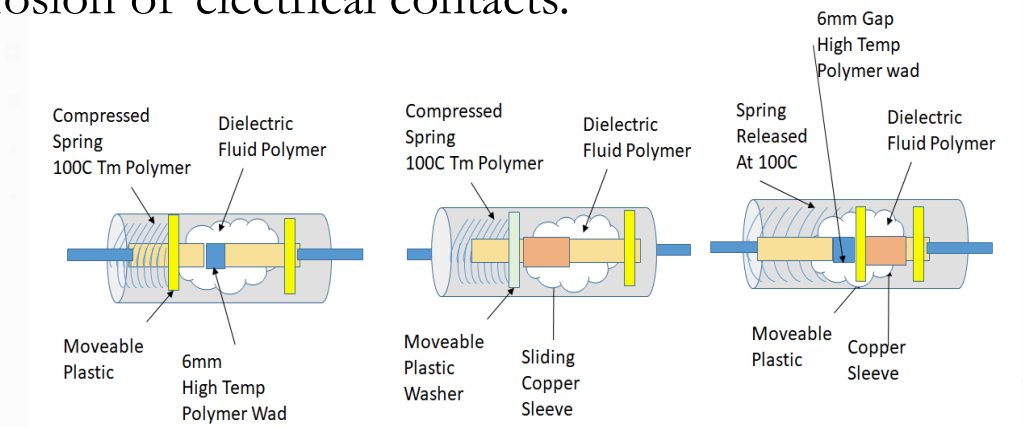
6QL PEI/PAA/PEI/MMT

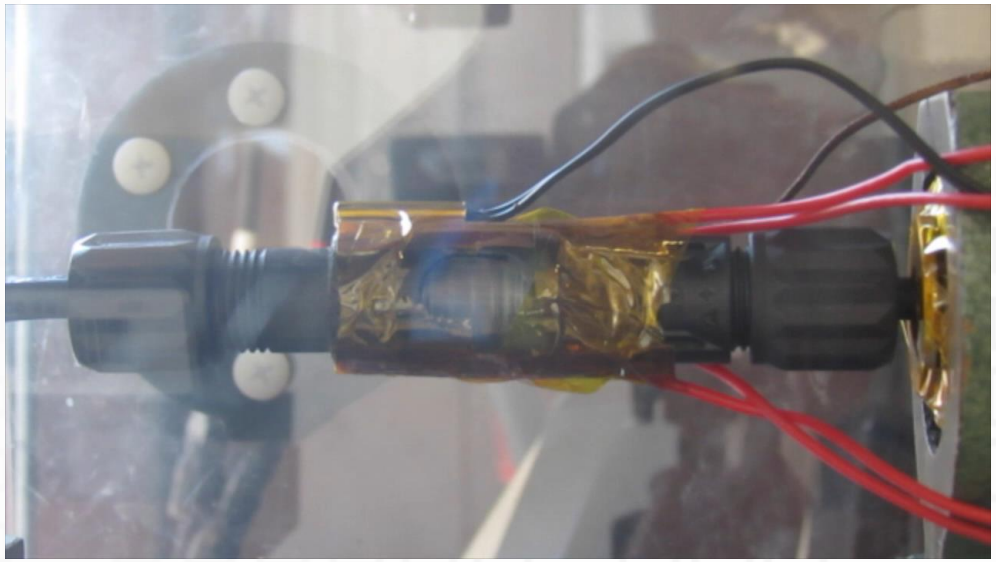


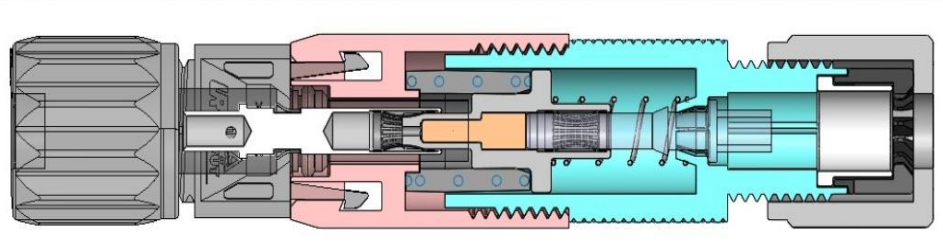
2017 Non-Provisional US Patent, 10,002,983 B1, "Nanocomposite Barrier Films for Photovoltaic Applications", E.D. Spoerke, M.E. Gordon, E. Schindelholz, K.M. Armijo, N.R. Sorensen, A. Martino and J. Grunlan.

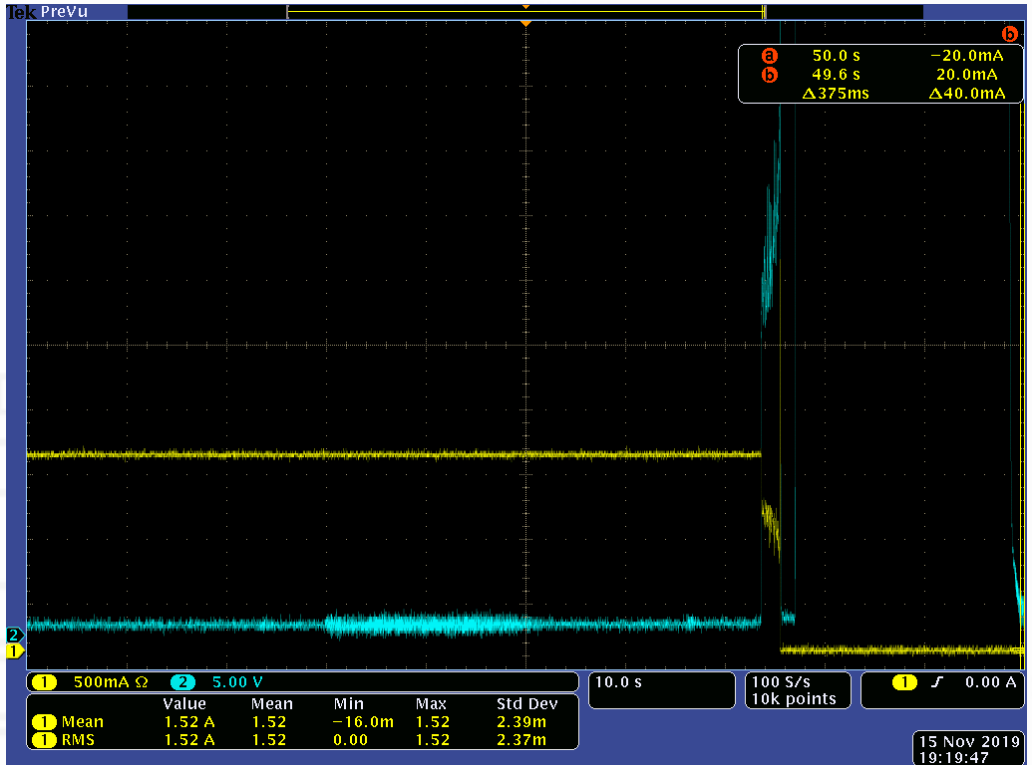
Self-Extinguishing PV Connectors

- Self-extinguishing connectors designed to detect / respond to Ohmic heating created from improper installation or corrosion of electrical contacts.





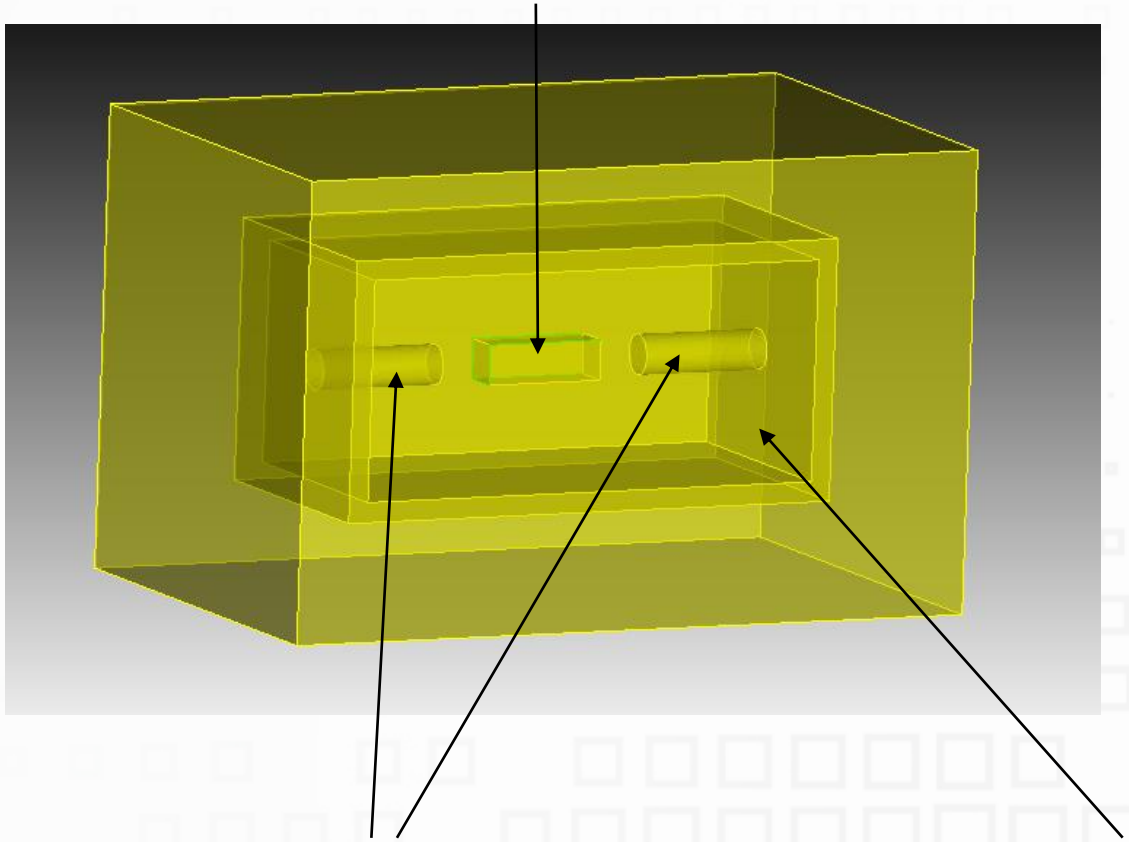




Armijo, K.M. et al., “American Made Solar Challenge Guardian Sensors, Self Extinguishing Connectors”, Final Report, NMSBA, SAND-0156, 2020.

Sandia Arc-Fault Advanced Modelling for Codes & Standards

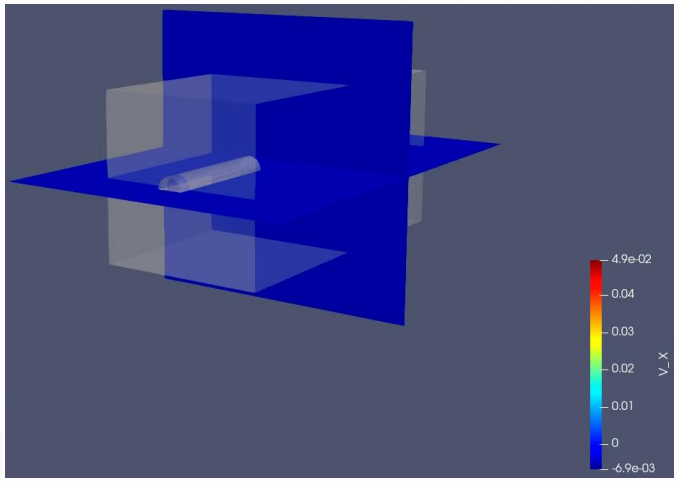
Energy source region, P = 4 x 10^8 W/m^3 (approximately 100 V, 10 A Arc)

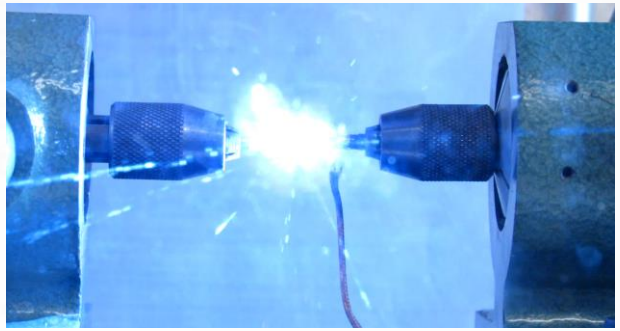


Electrodes, r = 0.5 cm, l = 4 cm

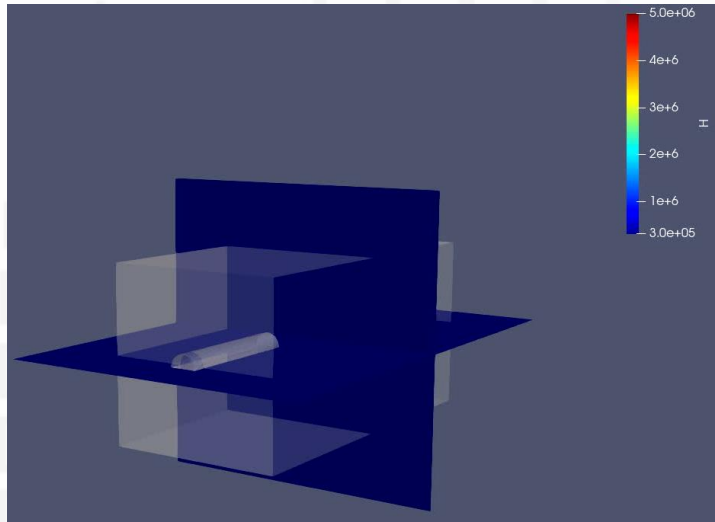
Open boundary – “open-box” like test

Velocity



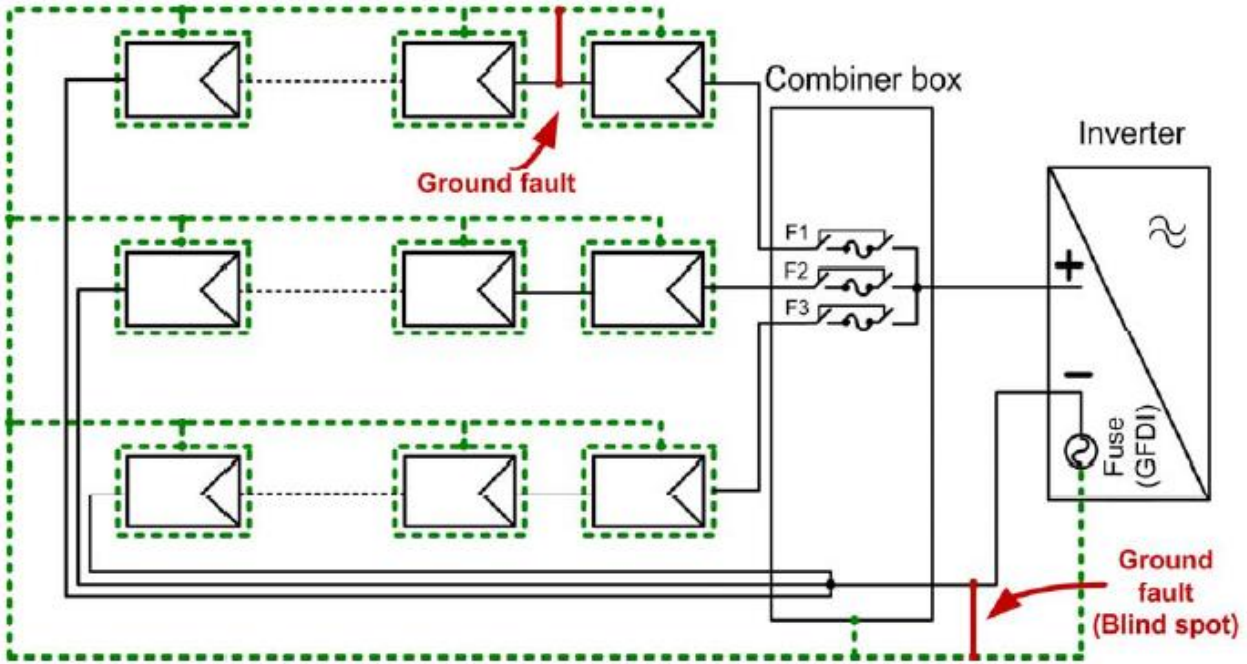


Enthalpy

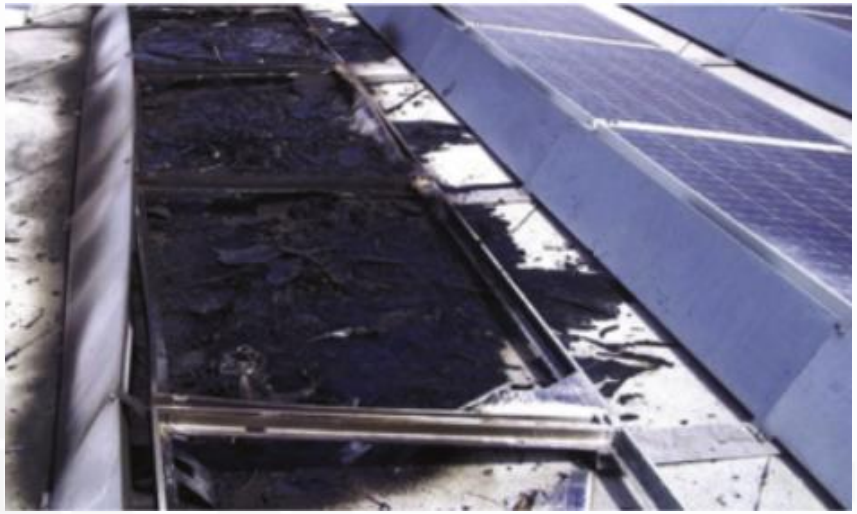


Ground Fault Research & Development

- Exposed unintentional non-current carrying metals/conducting parts of PV systems connected through conducting wire to reference ground.
- Fuse-based GFDI (Ground Fault Detector/Interrupter) designs vulnerable to faults to the grounded current-carrying conductor.



Blind spot in a listed inverter's fuse-based ground-fault protection scheme which resulted in a fire.



J. Flicker, J. Johnson, Solar Energy, 140 (2016) 34-50

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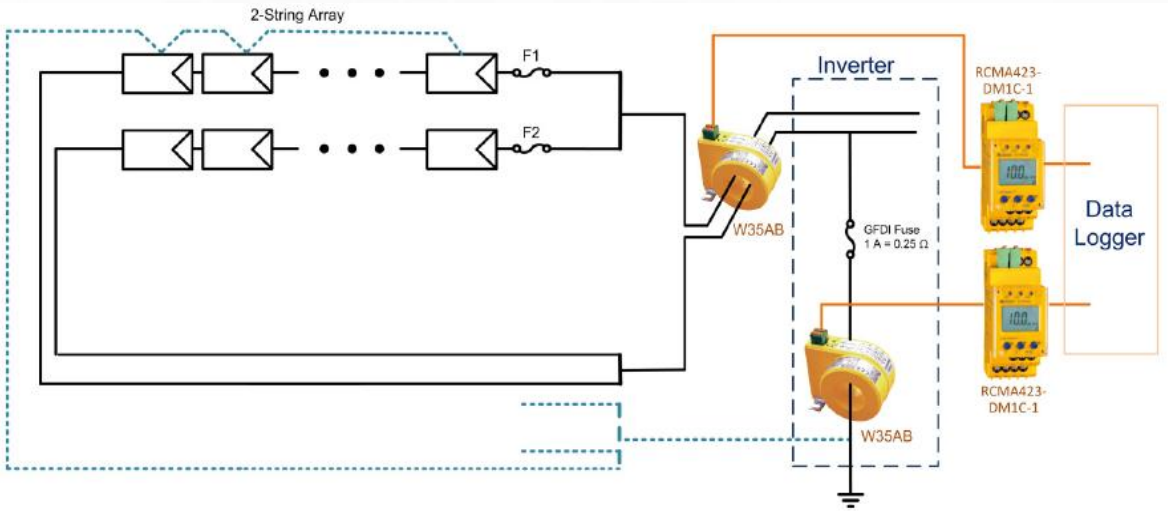
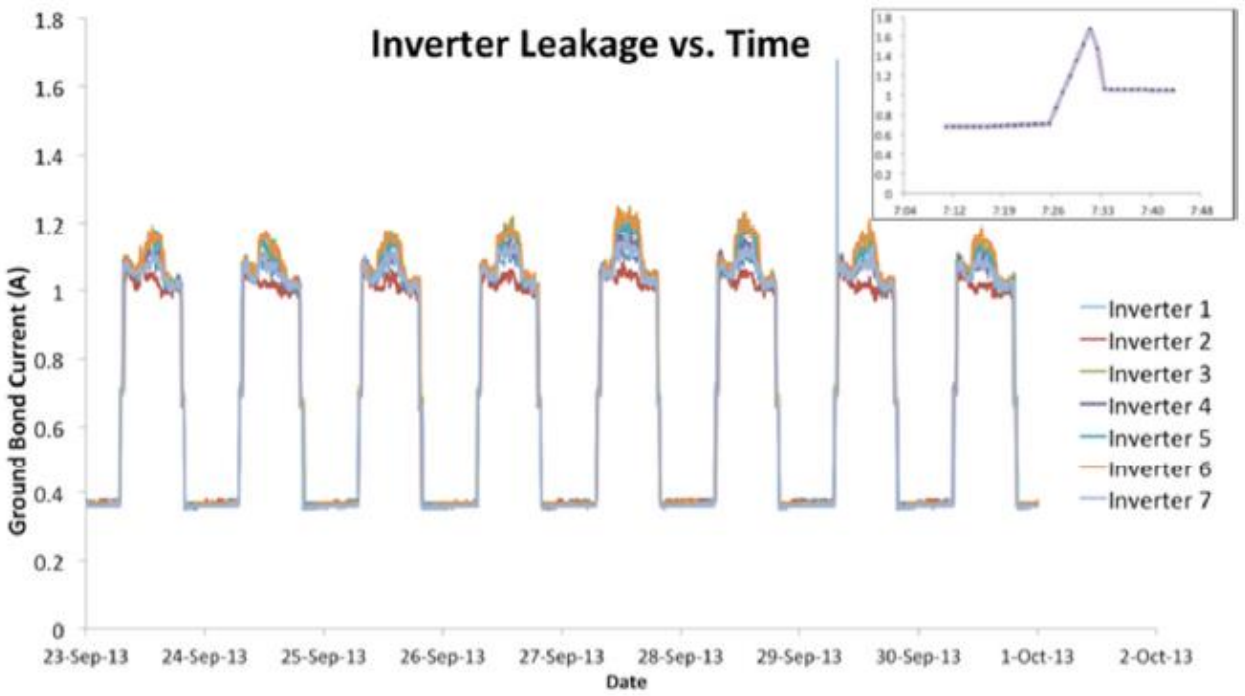
Ground Fault Sandia Research & Development

- Fuse-based GFDI (Ground Fault Detector/Interrupter) designs vulnerable to faults to grounded current-carrying conductor.
- SPICE simulations & field measurements to determine thresholds for Residual Current Detectors (RCDs), isolation resistance periodic checkers (Riso), and Current Sense Relays (CSRs).





"IEEE PVSC on the "Recommendations for RCD and Riso Ground Fault Detector Trip Thresholds"

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Thank You

Our Next Webinar:

Modeling & Analytical Tools

April 22, 2-4 PM ET

https://www.energy.gov/oe/wildfire-mitigation-webinar-series