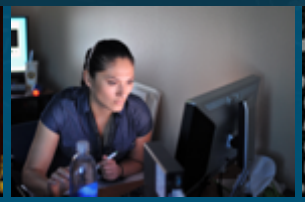
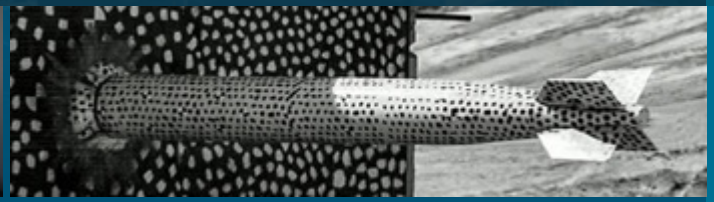
SAND2020-11946PE

Weather Impacts On Utility-Scale Photovoltaic Plant Performance





PRESENTED BY

Nicole D. Jackson

NIST MSSD Seminar Series

October 29, 2020

SANDXXXXXXXXX

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- sPower
- Nexamp

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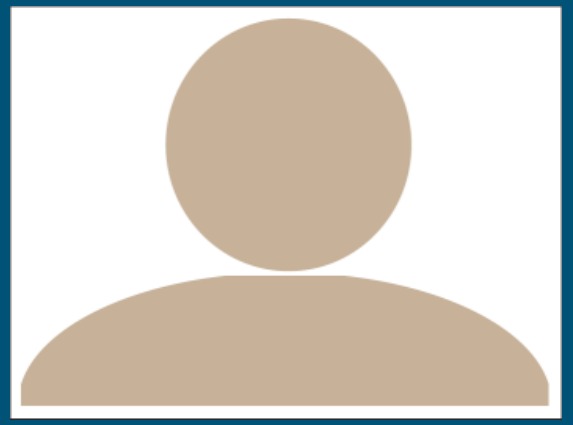
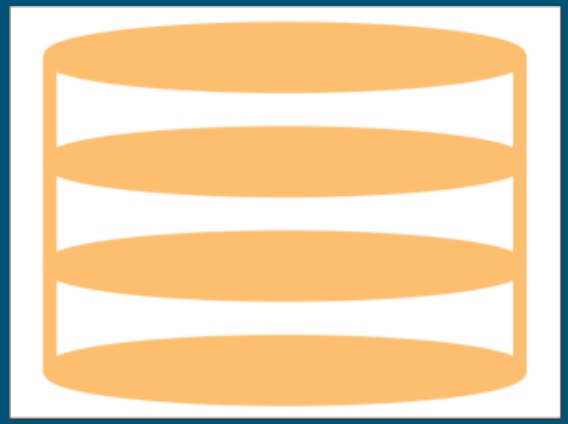
Today, we will discuss how we fuse operations, production, and weather data to quantify weather impacts on utility-scale PV

Background



Data fusion



Integrated Assessment

Today, we will discuss how we fuse operations, production, and weather data to quantify weather impacts on utility-scale PV

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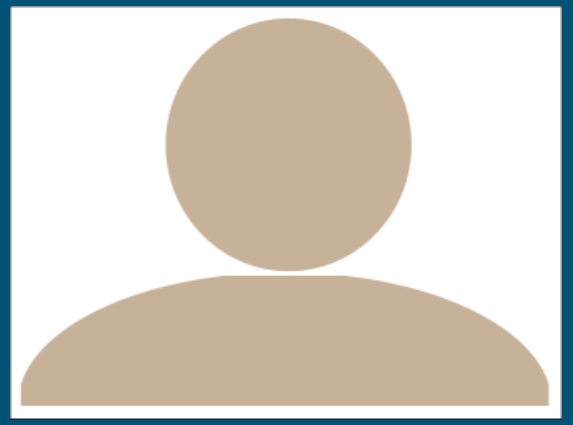

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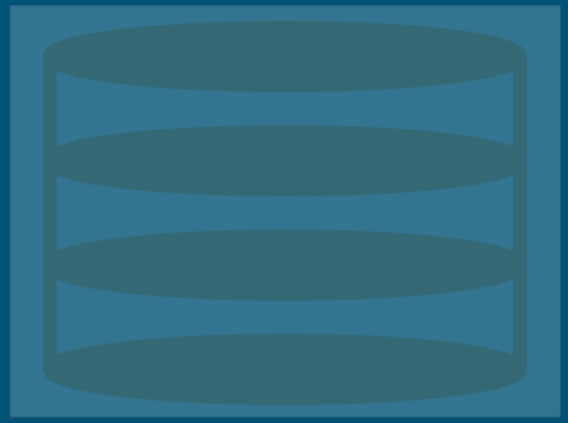
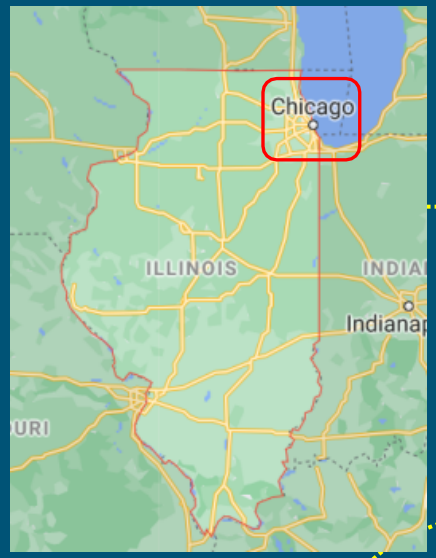


Integrated Assessment

About me



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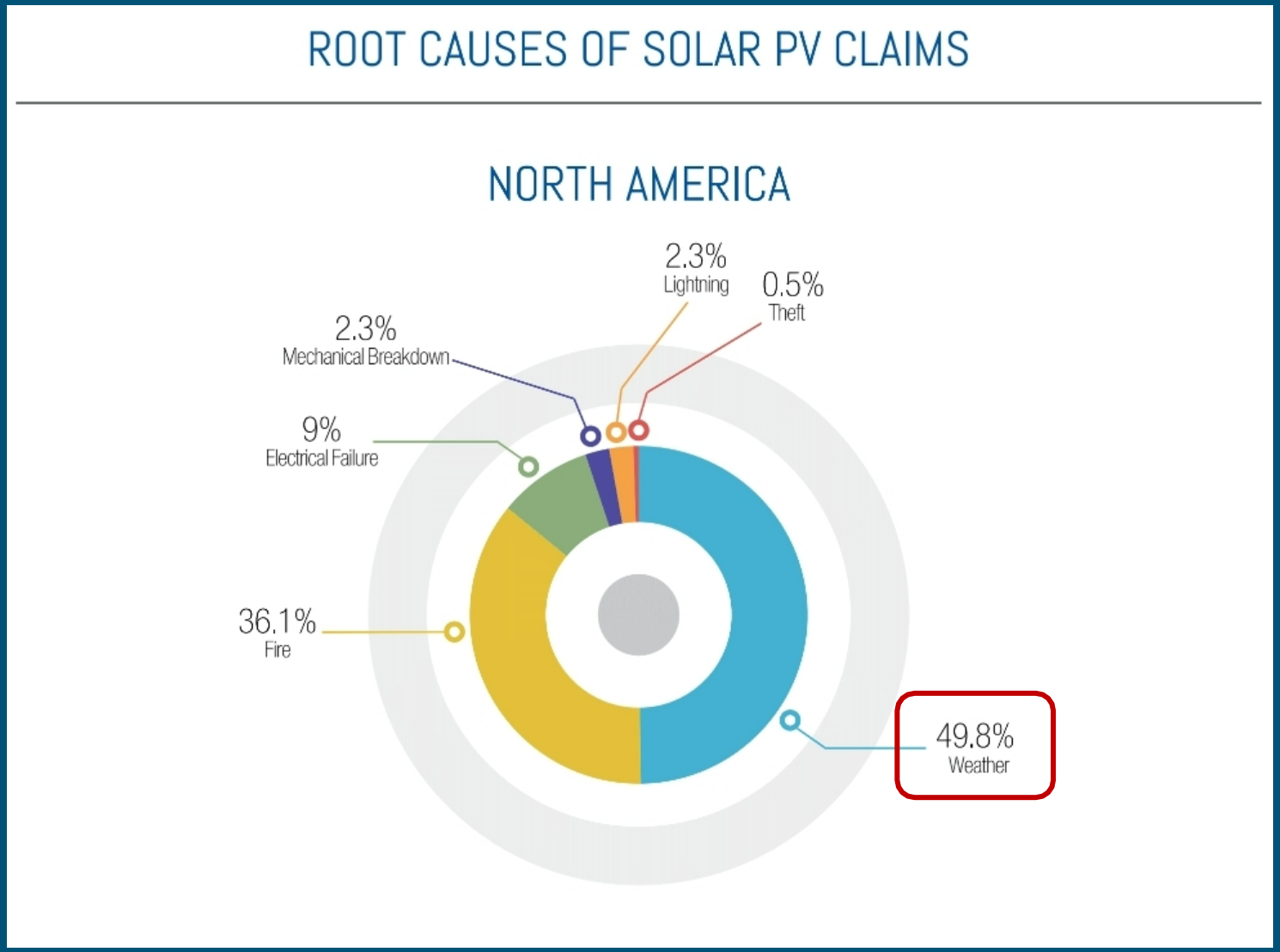
PV plants can be exposed to disruptions due to weather events such as hurricanes and hail storms

(BMR Energy 2017)

SBS News (2018)

There is an increasing prevalence of weather impacts to PV



(GCube 2016)

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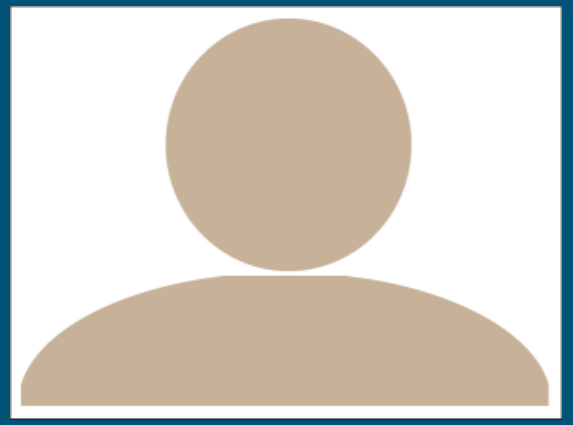
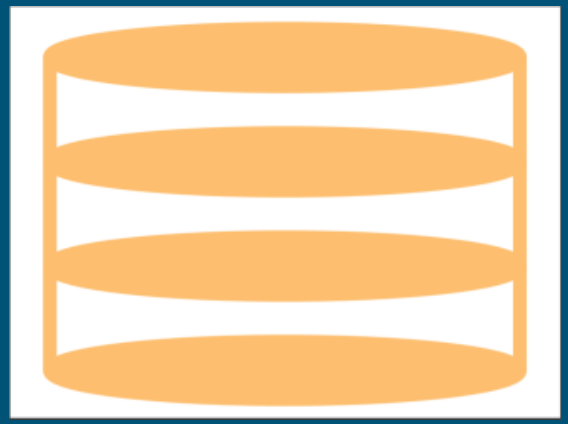
Background



Data fusion



Integrated Assessment

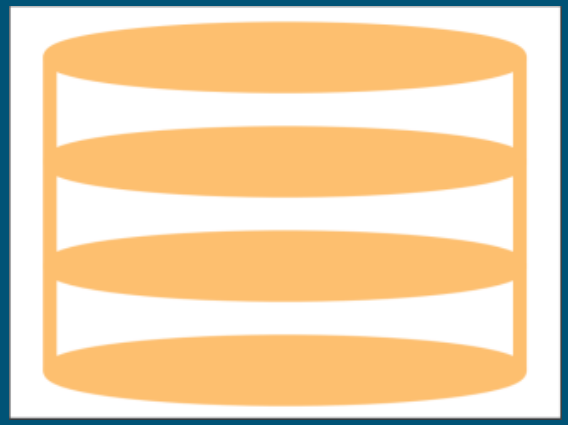
Study Objectives

- Analysis of site-level performance and weather data to identify trends
- Identification of performance variabilities across sites, climates, and event types

Today, we will discuss how we fuse operations, production, and weather data to quantify weather impacts on utility-scale PV

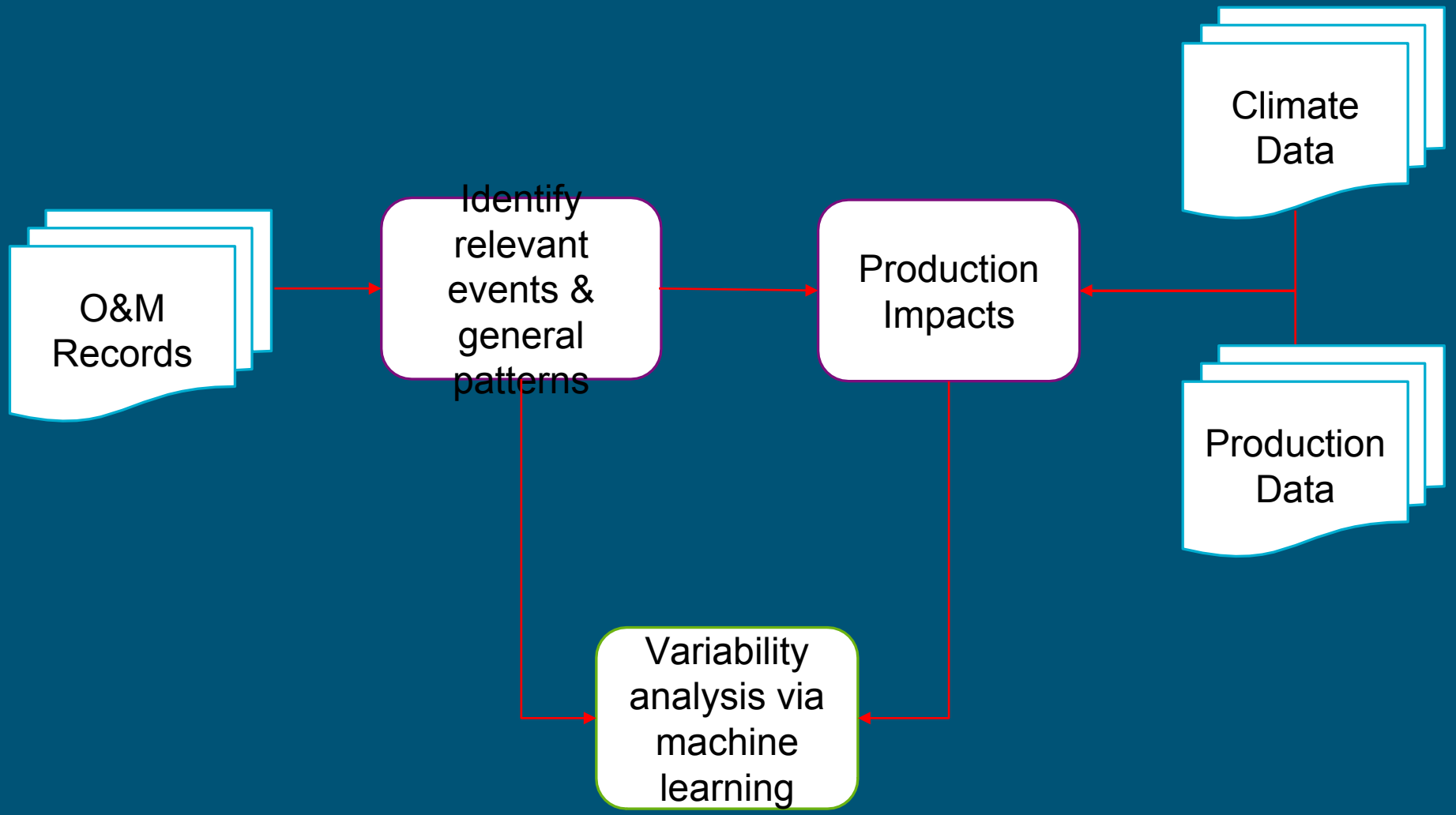
Background

Data fusion

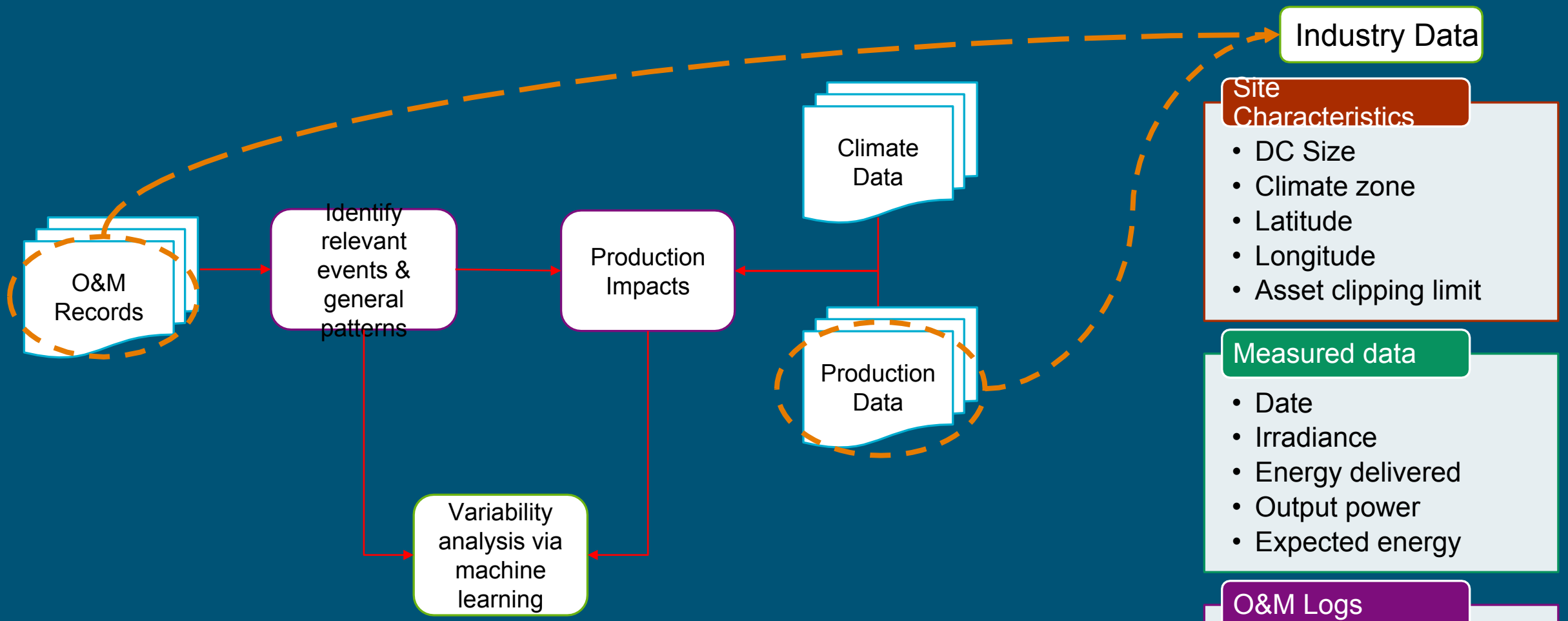


Integrated Assessment

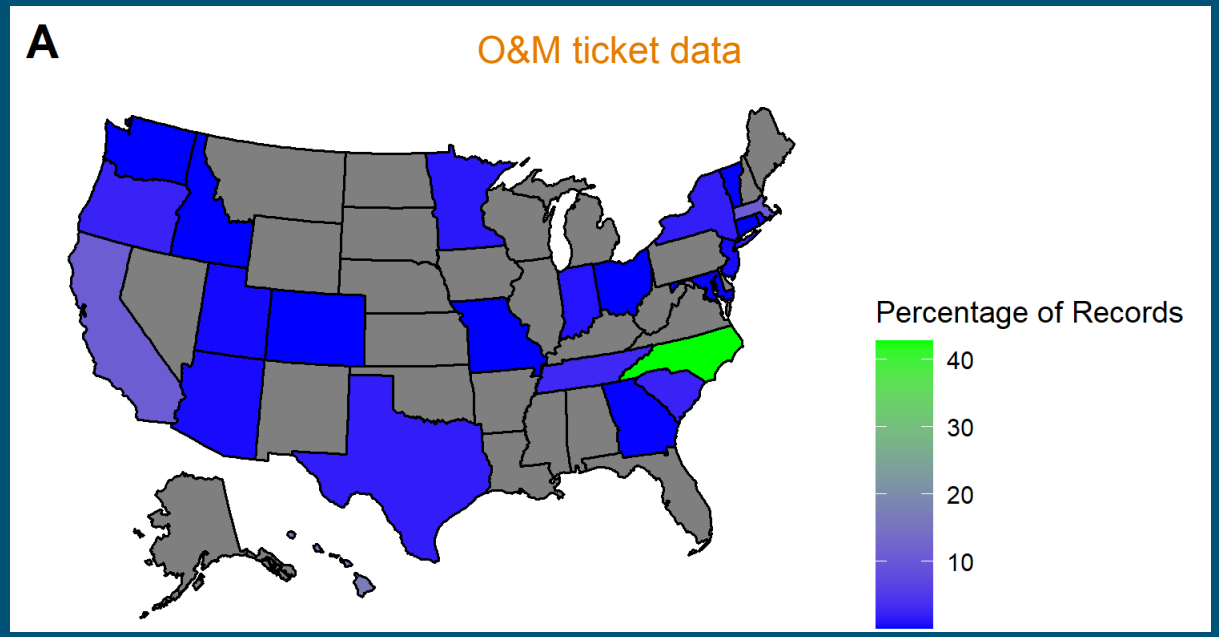
Integrated assessment uses inputs from multiple datasets

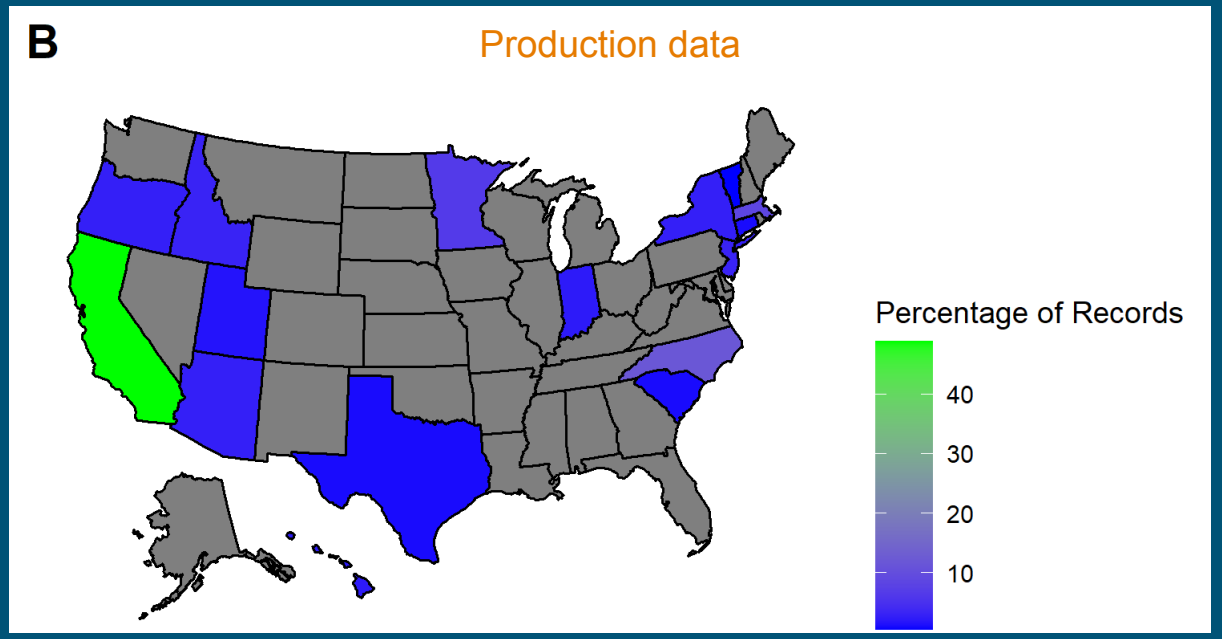


Industry data provides site-specific O&M and production data

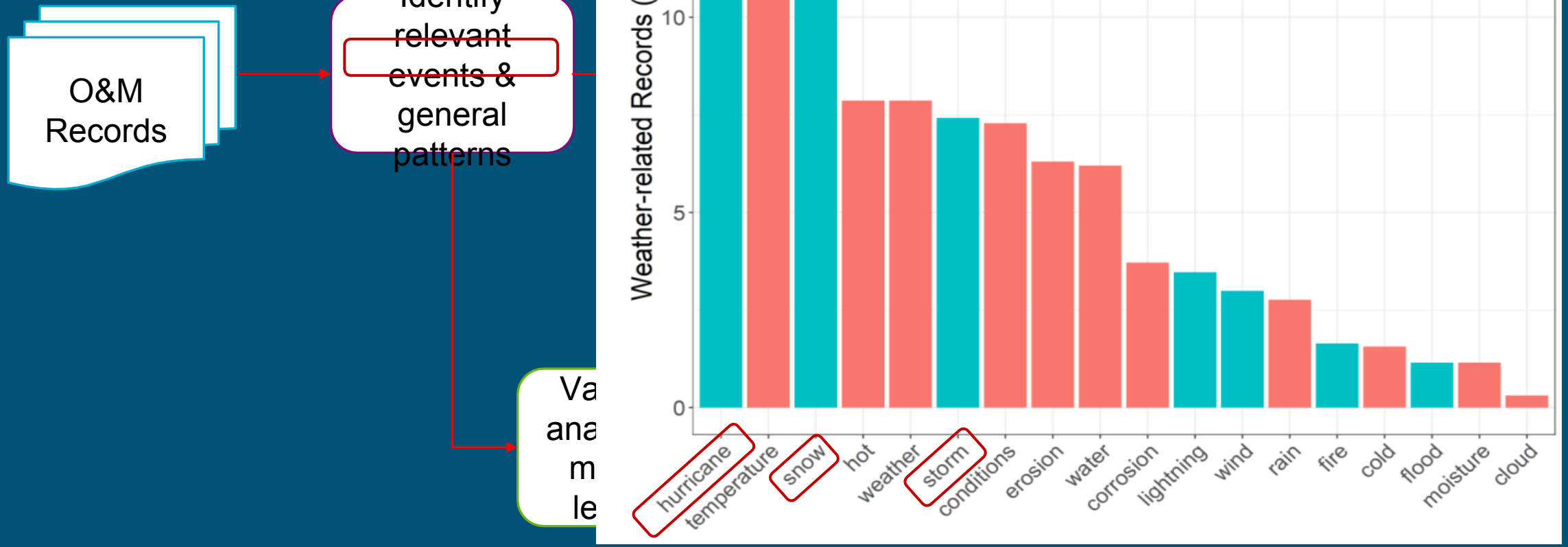


Spatial and temporal distribution of records available in the PVROM database



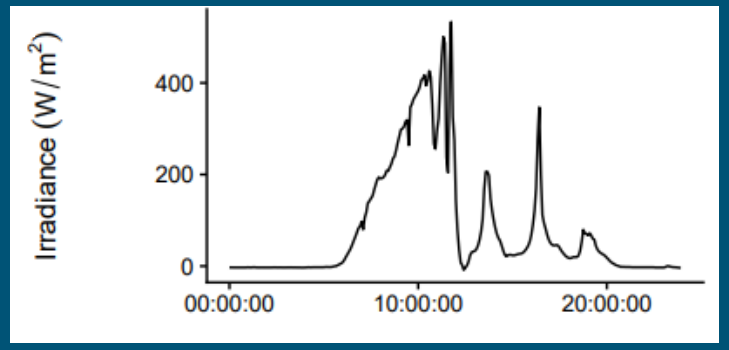


Text analysis of PVROM's O&M records helps identify the most prevalent weather events

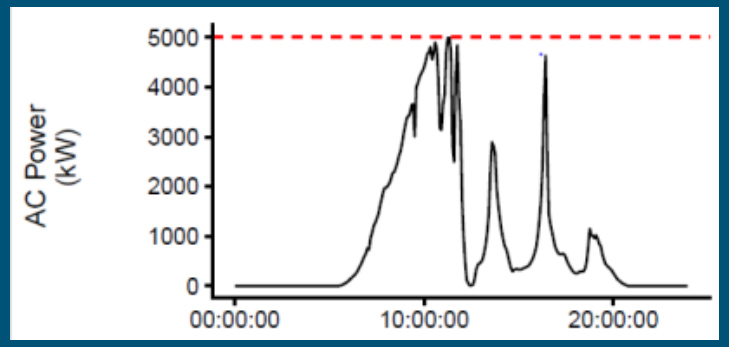


Data processing of site-level raw production data

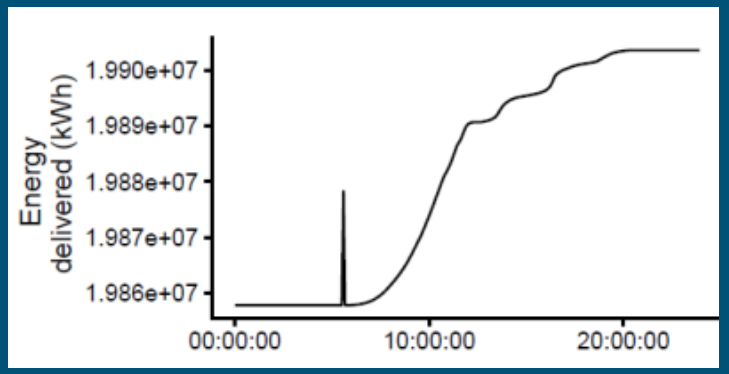
Raw Data



Removed negative values

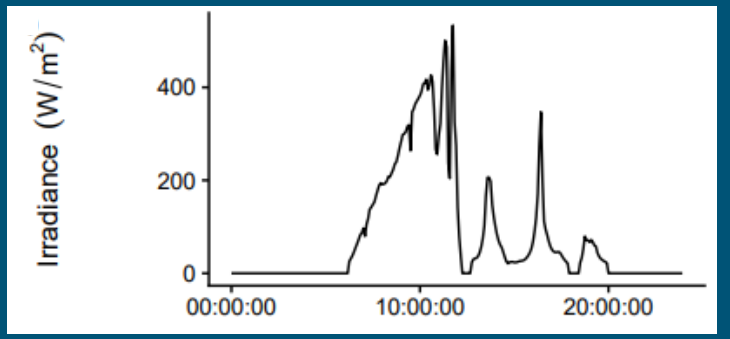


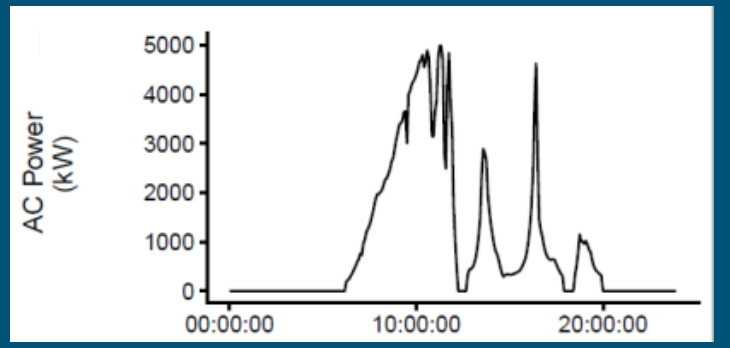
Entries with negative irradiance have AC power = 0

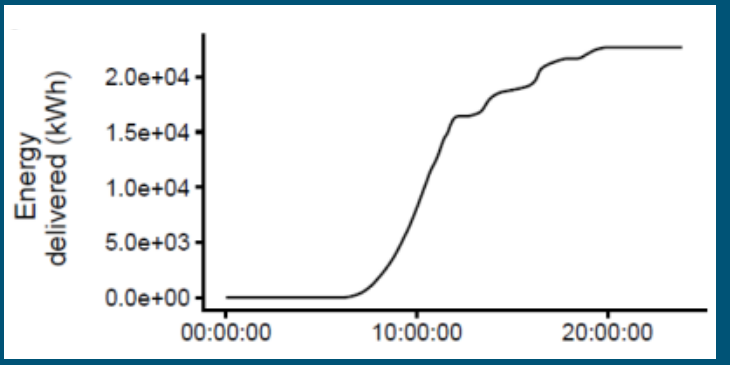


Removed errant spikes in cumulative energy delivered to grid

Clean Data







Multiple site metrics are evaluated at the daily time scale

Yield losses

- Final system yield

$$Y_f = \frac{E_{out}}{P_0}$$

- Reference yield

$$Y_r = \frac{H_i}{G_{i,ref}}$$

Performance metrics

- Performance ratio

$$PR = \frac{Y_f}{Y_r}$$

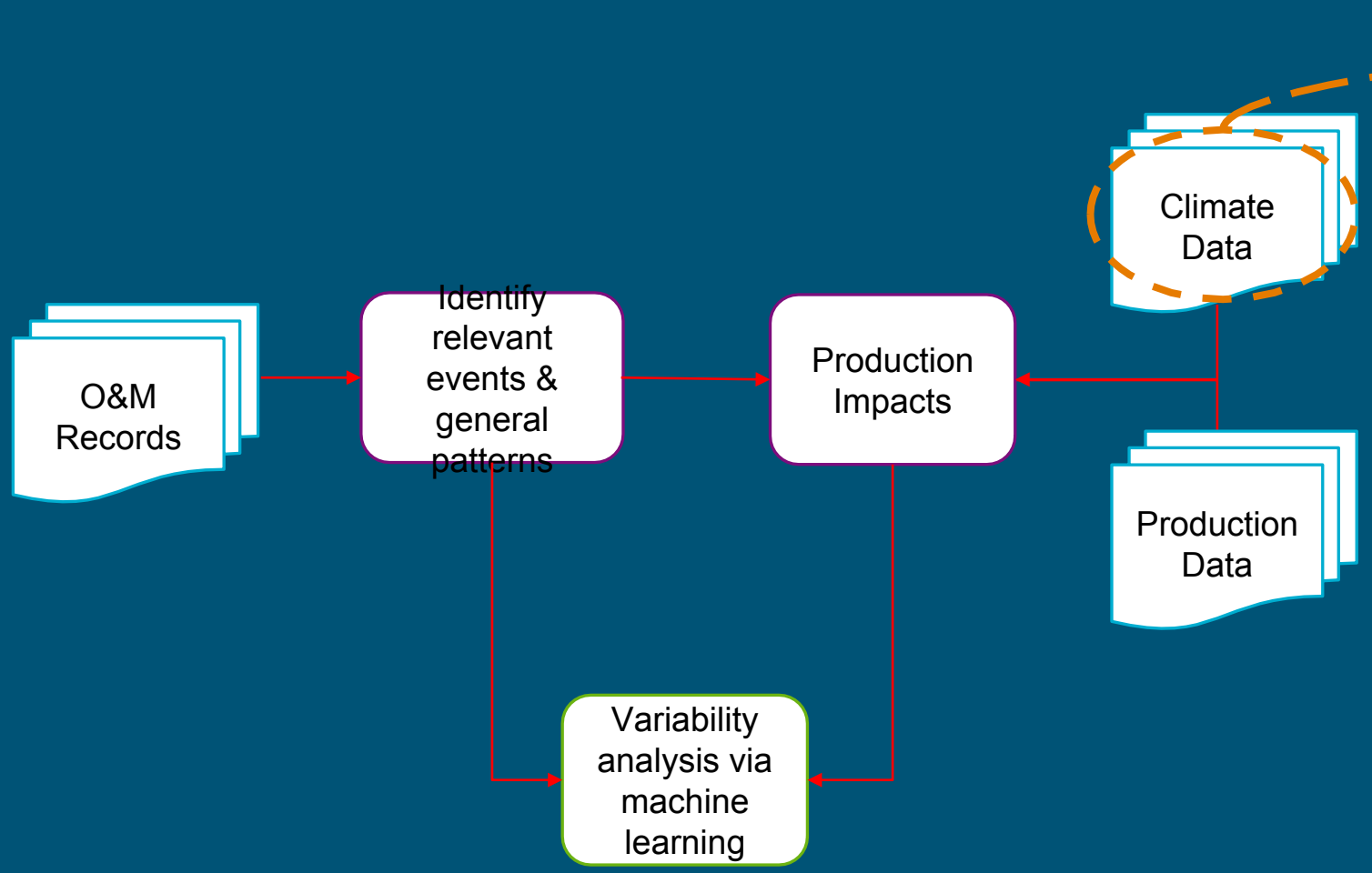
- Energy performance index

$$EPI = \frac{\text{Measured energy}}{\text{Expected energy}}$$

Industry data enables construction of operator, metadata, and predictor variables

Weather event	Predictor	Climate variables	Operator variables	Metadata variables
Snow	Low, medium, high classification of EPI, PR		• Company • Asset • Number active tickets • Daily duration of active tickets • Production impact level	• NOAA climate region • PV climate zone • Köppen-Geiger zone • State • Plant size • Age • Array type
Hurricane			• Company • Asset • Pre/post inspections • Daily duration of active tickets • Production impact level	
Storms & floods			• Company • Asset • Number of active tickets Daily duration of active tickets • Production impact level • Lightning	

Multiple publicly available climate sets used for weather data



GHCN Weather Stations

- Precipitation
- Snow

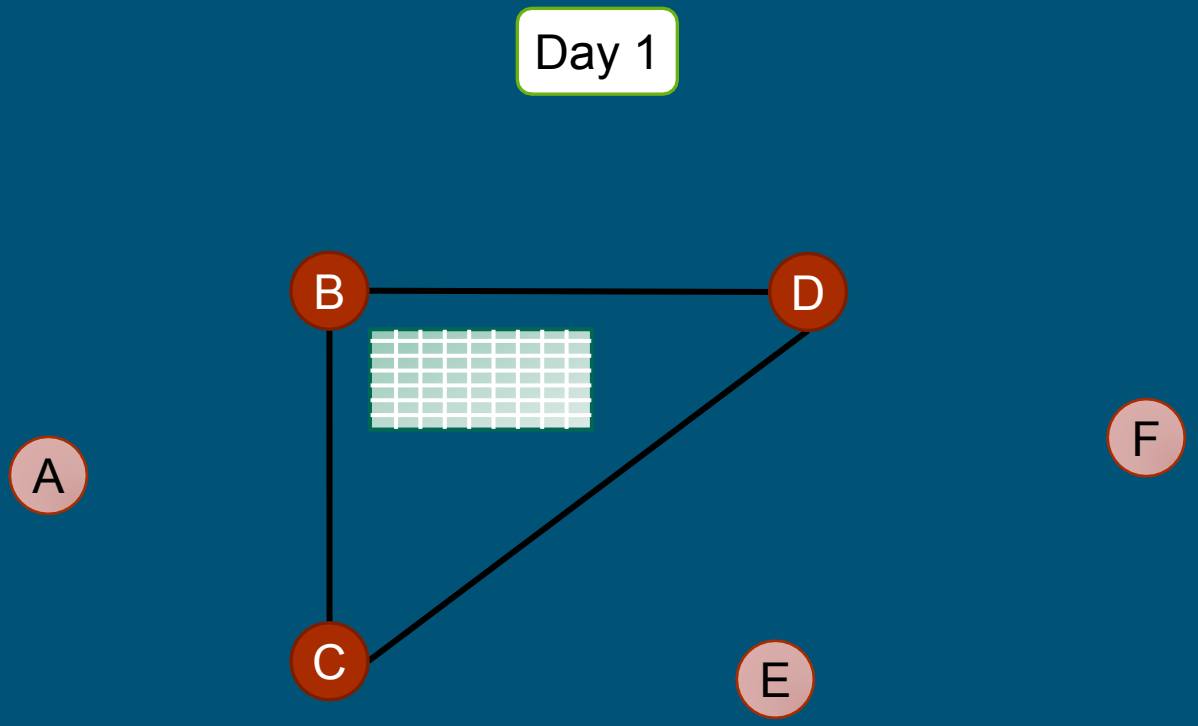
PRISM

- Maximum temperature
- Minimum temperature
- Precipitation

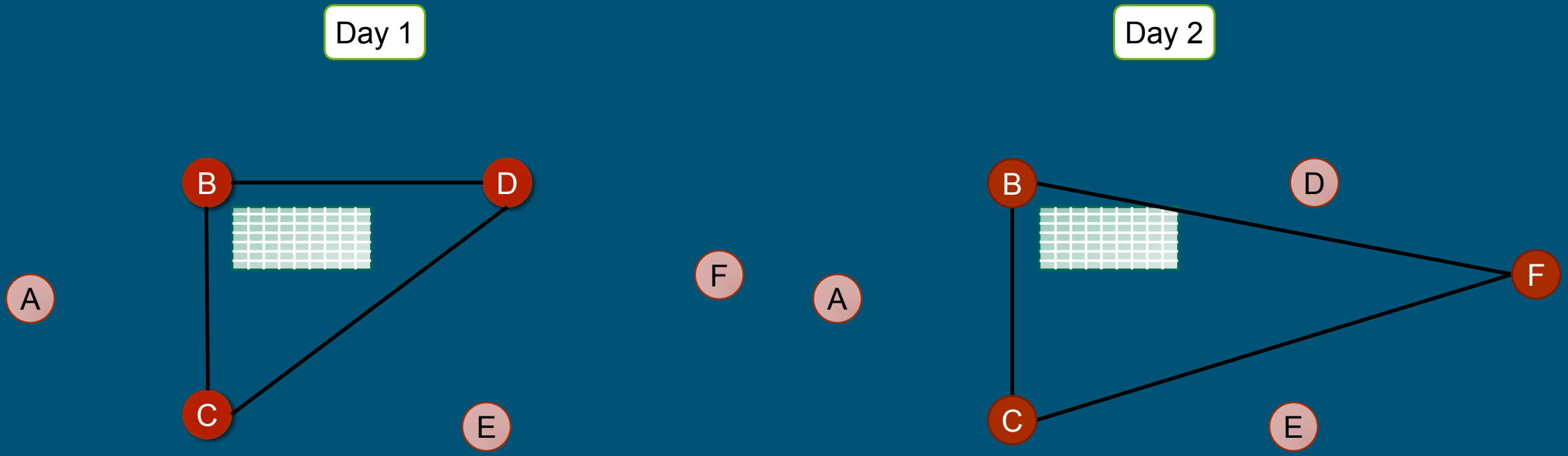
NOAA Storm Events Database

- Snow
- Storms
- Hurricanes

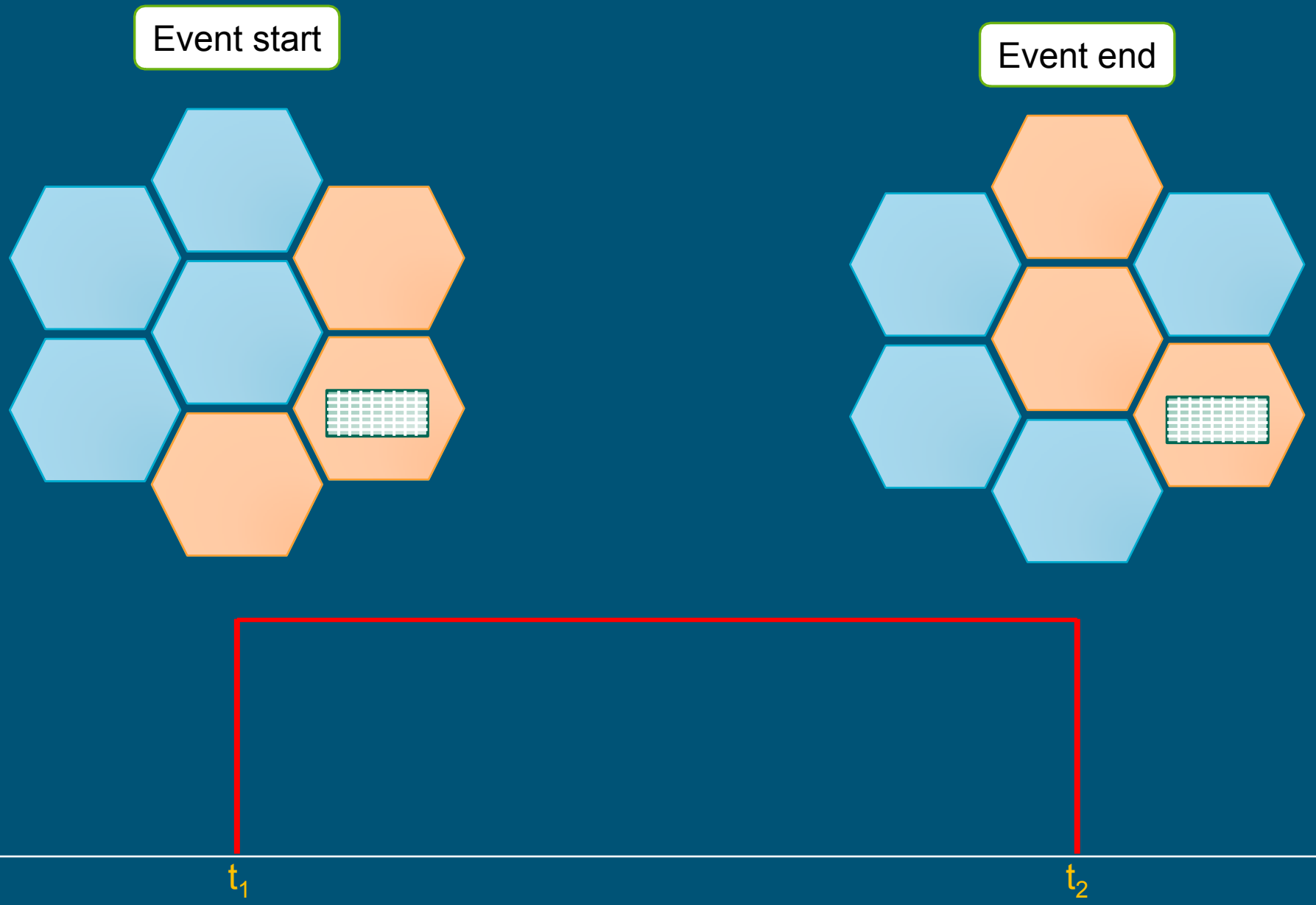
GHCN weather station data needs to be interpolated daily to obtain site-specific estimate



GHCN weather station data needs to be interpolated daily to obtain site-specific estimate



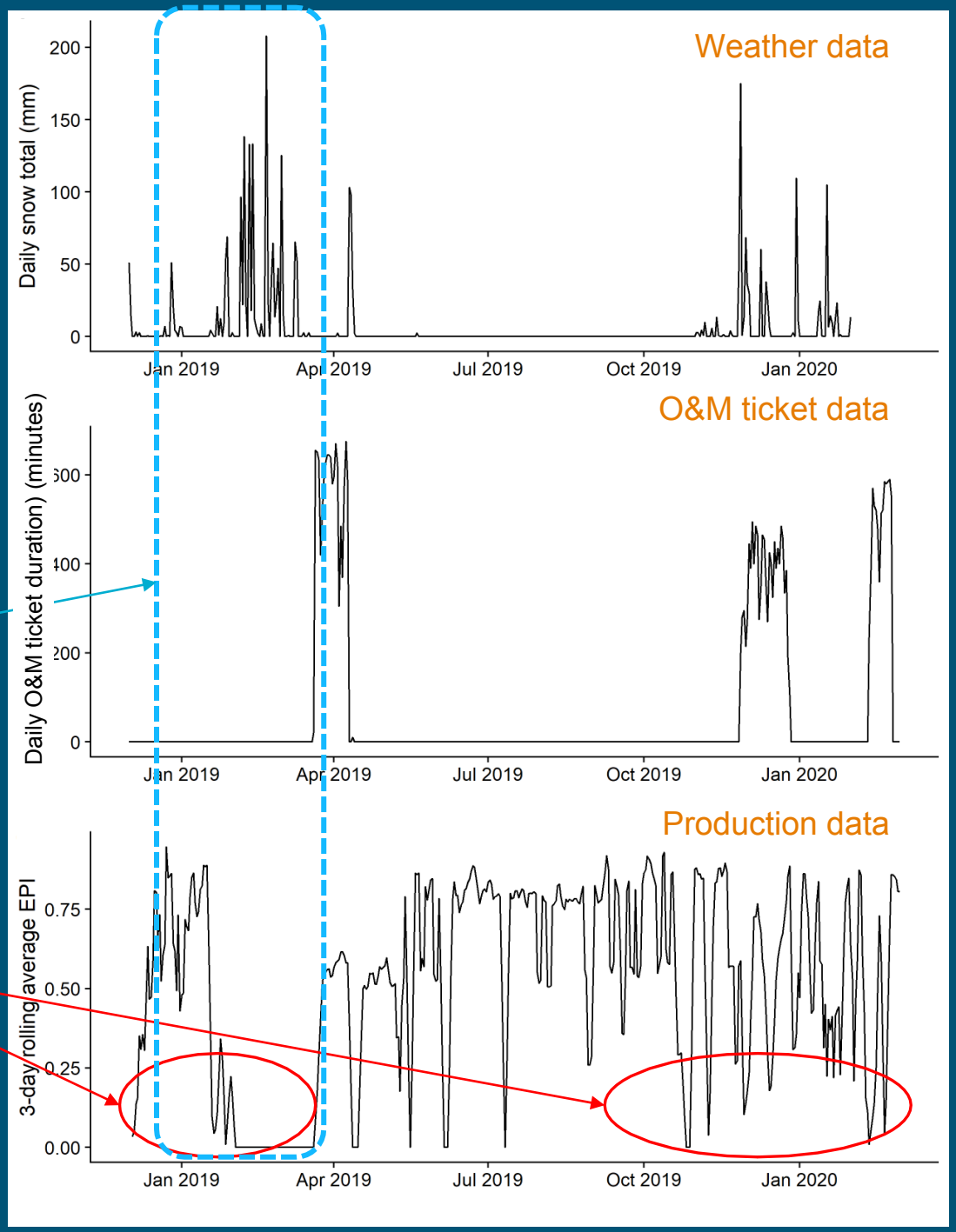
NOAA storm events database includes spatial & temporal data



Data fusion of snow, production, and & O&M data show nearness of phenomena

"ideal" alignment of data

"low" performance



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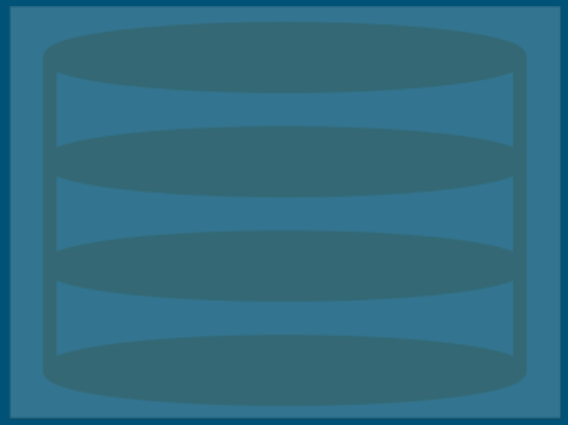
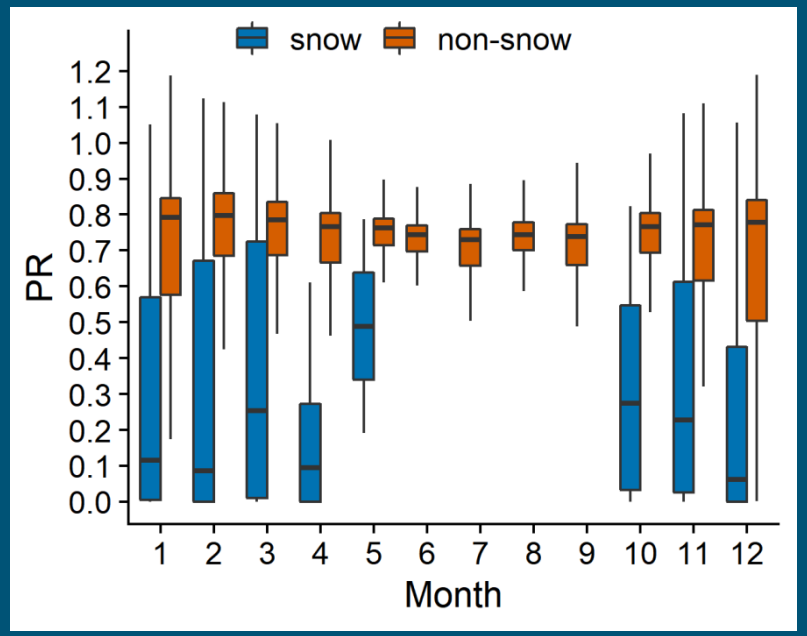
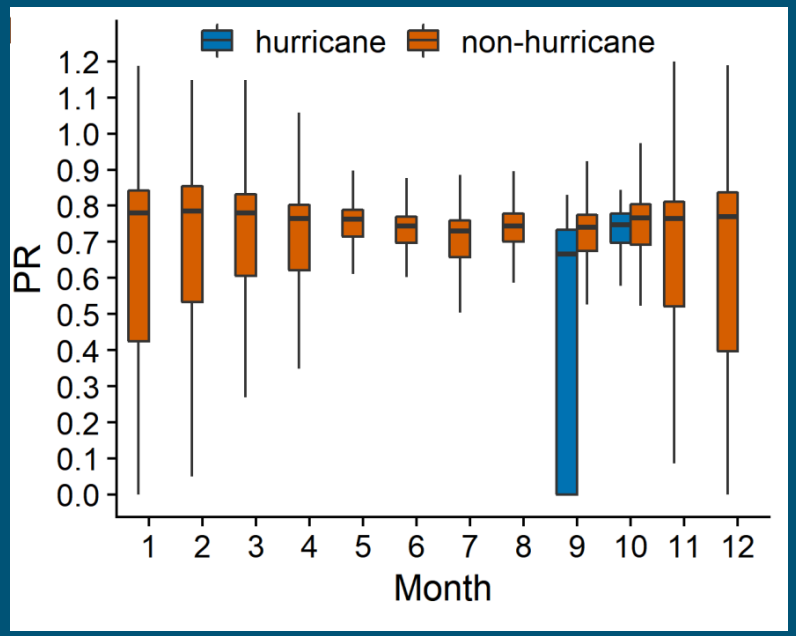
Data fusion

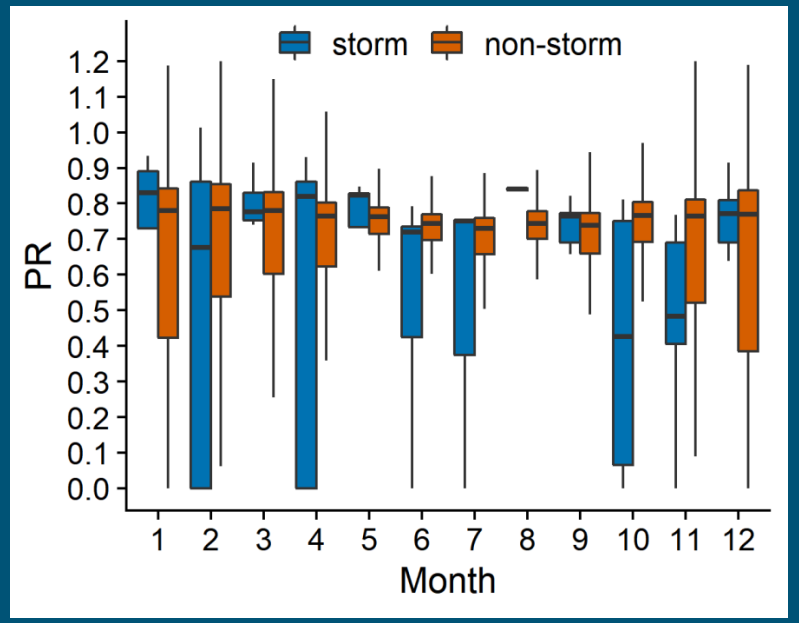


Integrated Assessment

Event and non-event days show variable response across months and weather types



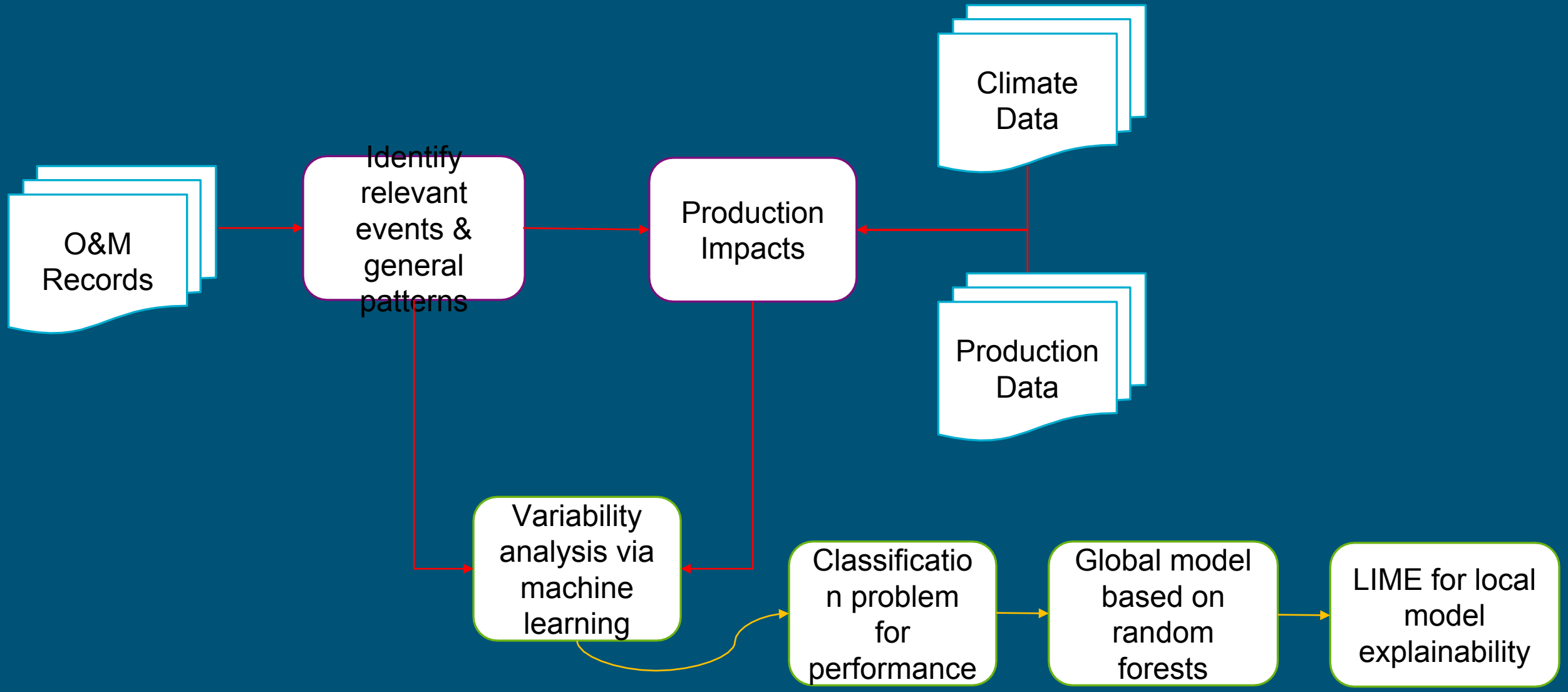




Mean PR by event status

	Snow	Hurricane	Storm
Event	0.296	0.594	0.627
Non-event	0.650	0.669	0.634

Machine learning used to gain insights into drivers of performance during weather events

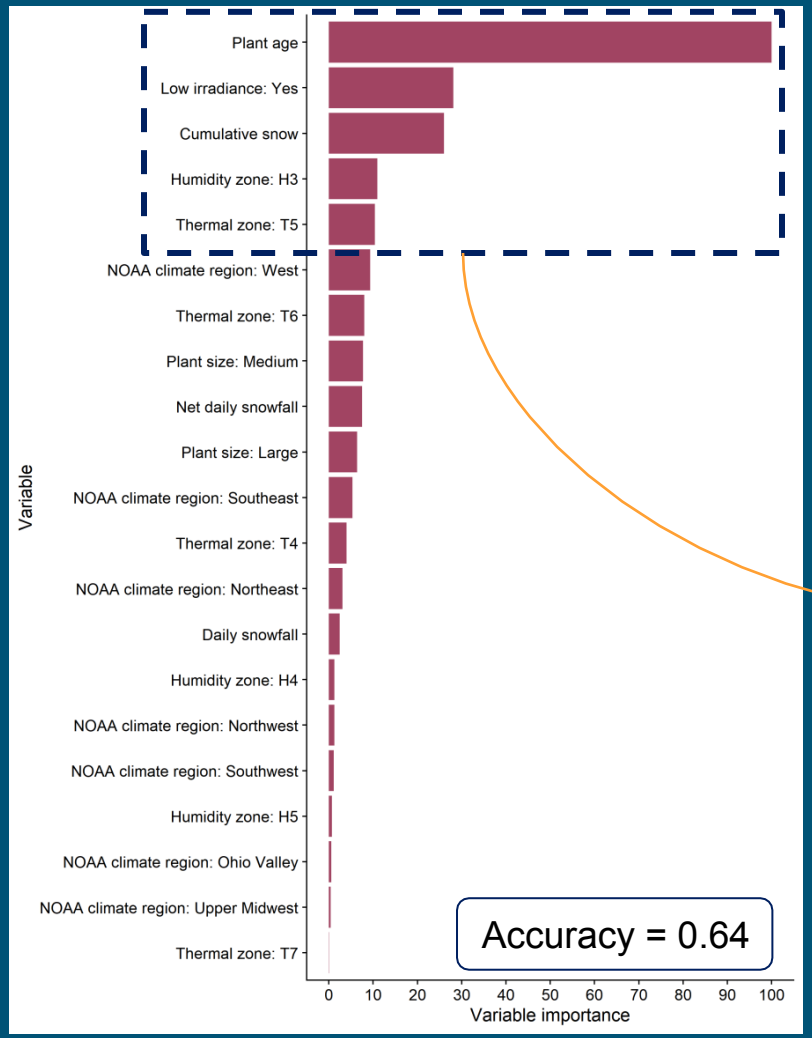


Event-specific panels for ML were constructed through combinations of climate, operator, and metadata variables

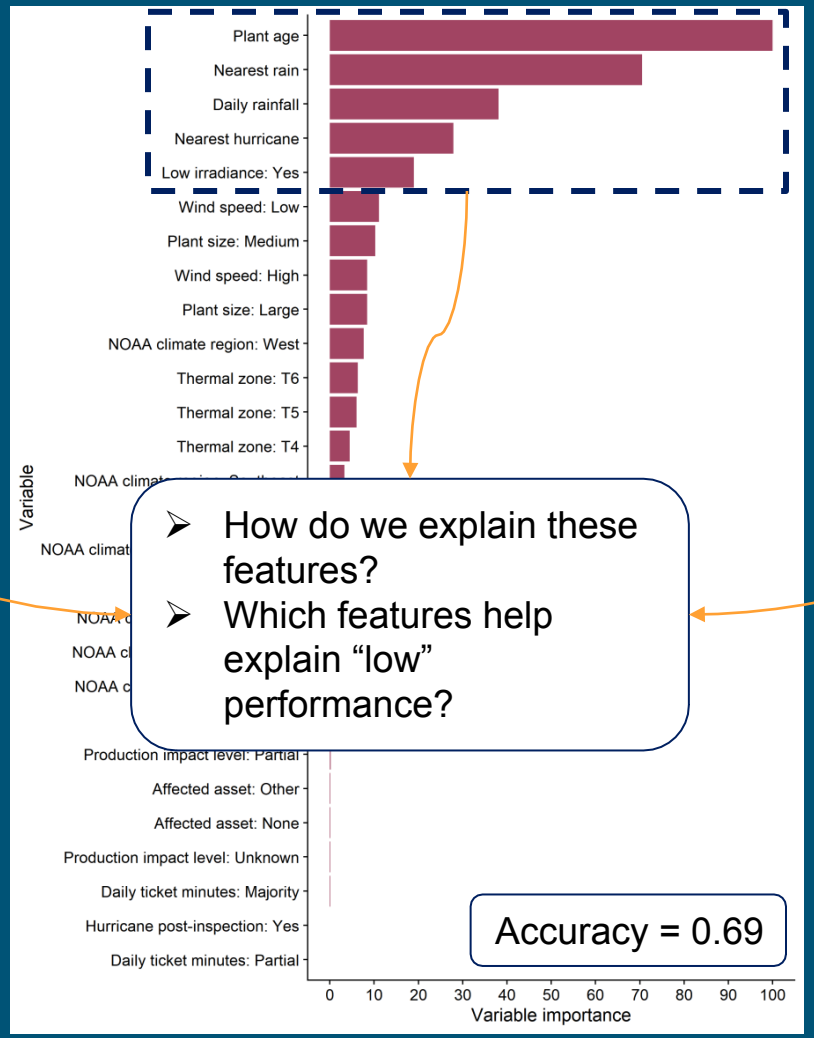
Weather event	Predictor	Climate variables	Operator variables	Metadata variables
Snow	Low, medium, high classification of EPI, PR	• Irradiance (raw, class) • Snow (binary indicator) • Daily snowfall • Net snowfall daily • Cumulative snowfall	• Company • Asset • Number active tickets • Daily duration of active tickets (min) • Production impact level	• NOAA climate region • PV climate zone • Koppen-Geiger zone • State • Plant size (cluster) • Age (in months, class) • Array type (fixed or tracker)
Hurricane		• Irradiance (raw, class) • Hurricane (binary) • Nearest hurricane in days • Mean wind speed (raw, class) • Daily rainfall • Nearest rain (in days)	• Company • Asset • Pre/post inspections (binary) • Daily duration of active tickets (min) • Production impact level	
Storms & floods		• Irradiance (raw, class) • Daily rainfall • Nearest rain (in days) • Storm (binary) • Storm duration (in min) • Nearest storm (in days) • Flood (binary) • Flood duration (in min) • Nearest flood (in days)	• Company • Asset • Number of active tickets (binary) • Daily duration of active tickets (min) • Production impact level • Lightning (binary)	

Random forest machine learning implementation gives insight to feature importance and accuracy for global models

Snow

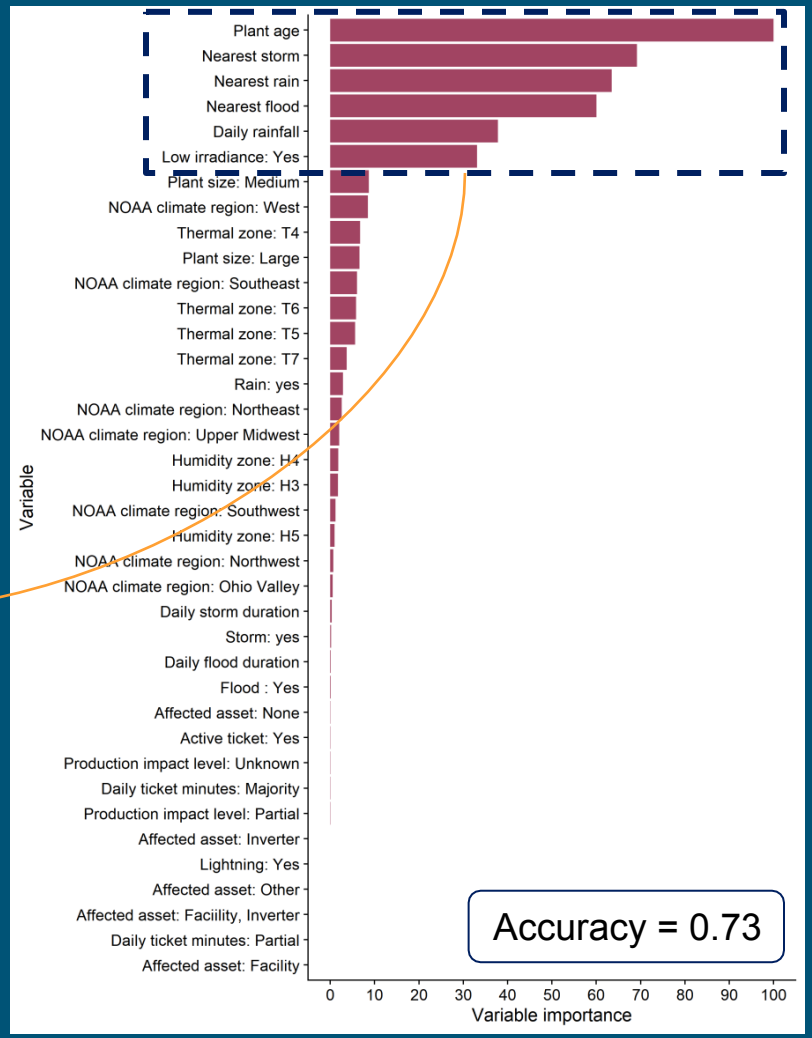


Hurricane



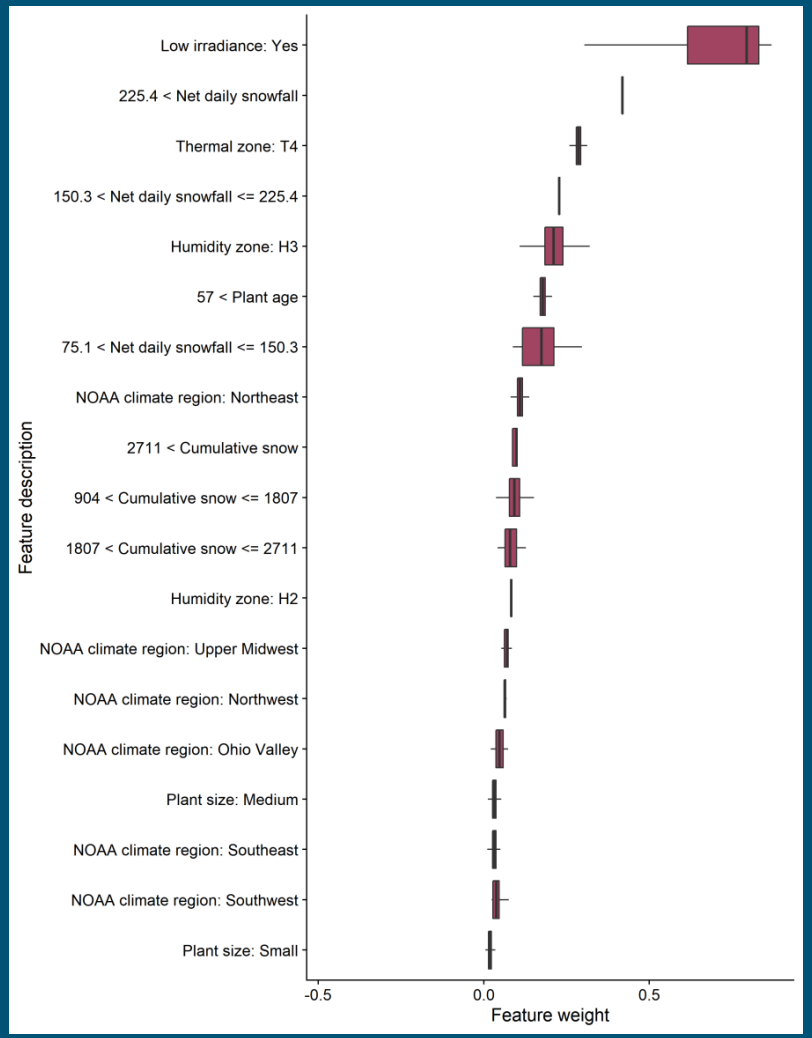
- How do we explain these features?
- Which features help explain “low” performance?

Storm

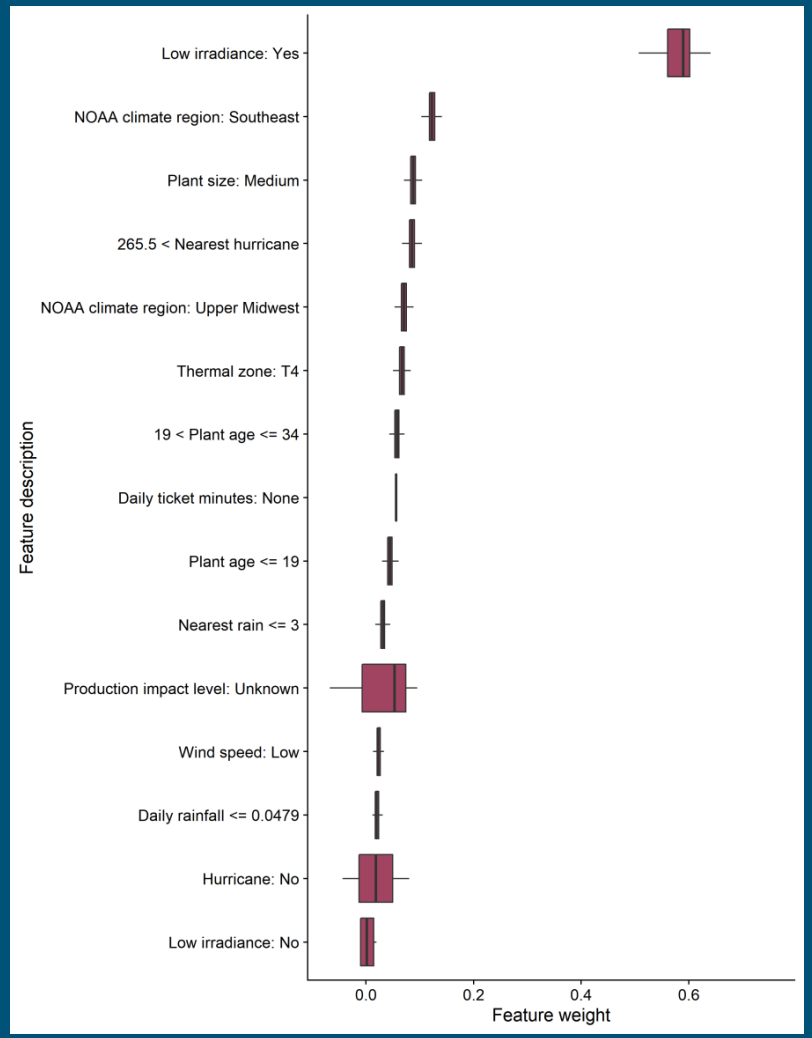


Local Interpretable Model-Agnostic Explanations (LIME) used to identify drivers of low performance

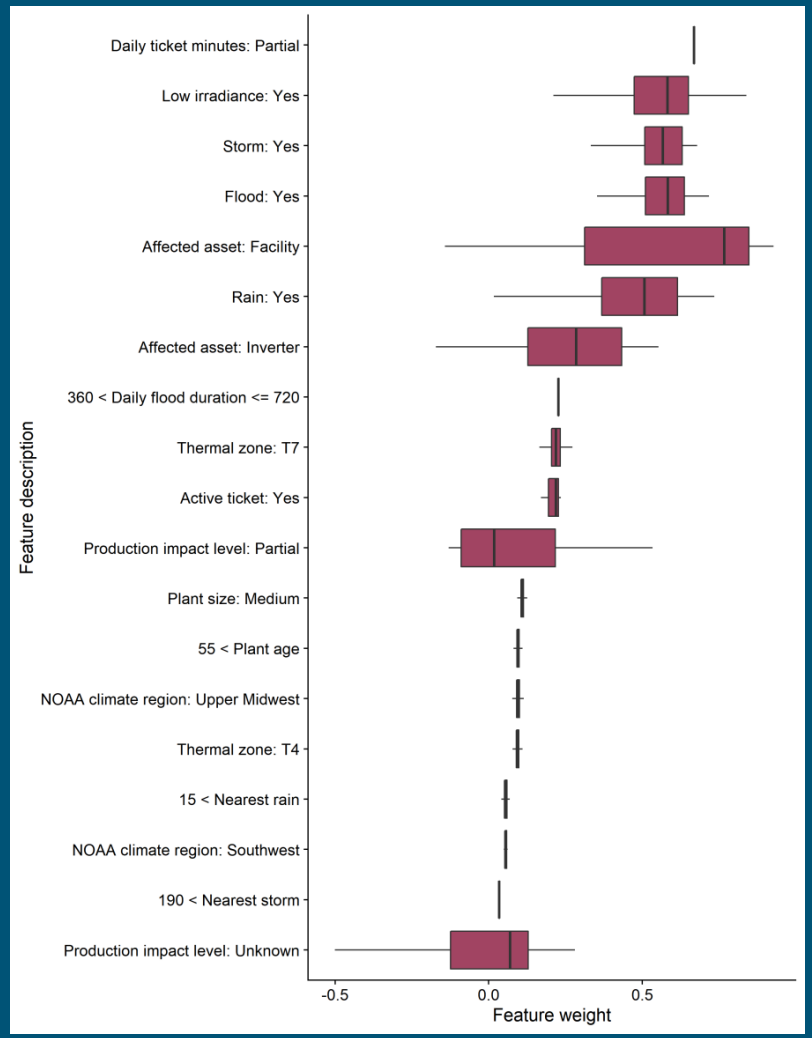
Snow



Hurricane



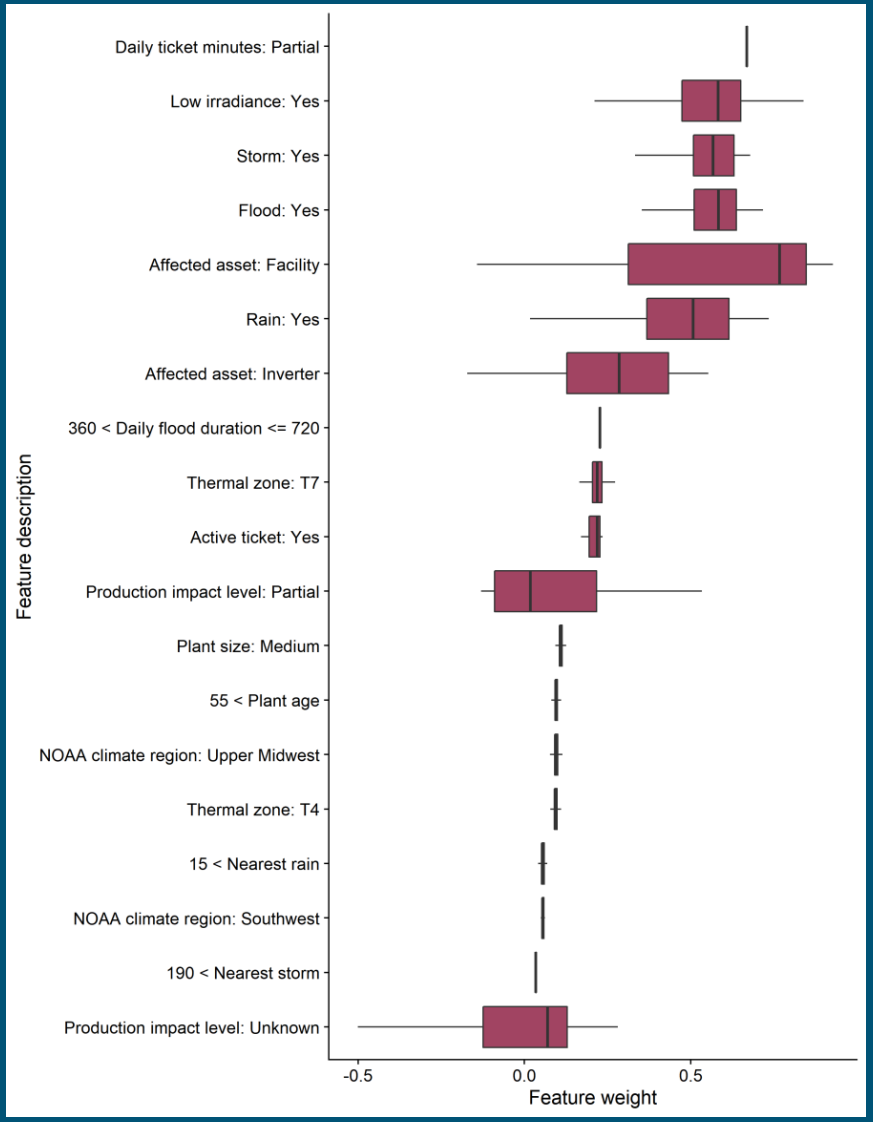
Storm



In conclusion, integrated assessment of O&M, production, and climate data shows differentiated responses to weather events

- Snow events have largest performance reduction
- Unique global models developed for each event
- LIME results for storms include O&M-related features

- Future work directions
  - Comparison of “clear sky” to weather impacted days
  - Incorporation of temperature effects
  - Predictive modeling development for “day ahead” scenario development



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Thank you for your time!

Nicole D. Jackson

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Appendix

Multiple datasets are combined to link performance, weather and O&M records

Industry Data

Site Characteristics

- DC Size
- Climate zone
- Latitude
- Longitude
- Asset clipping limit

Measured data

- Date
- Irradiance
- Energy delivered
- Output power
- Expected energy

O&M Logs

- Failure details
- Event duration

Site Metrics

Yield Loss

- Final system yield
- Reference yield

Performance metrics

- Performance ratio
- Energy performance index

Climate Data

GHCN Weather Stations

- Precipitation
- Snow

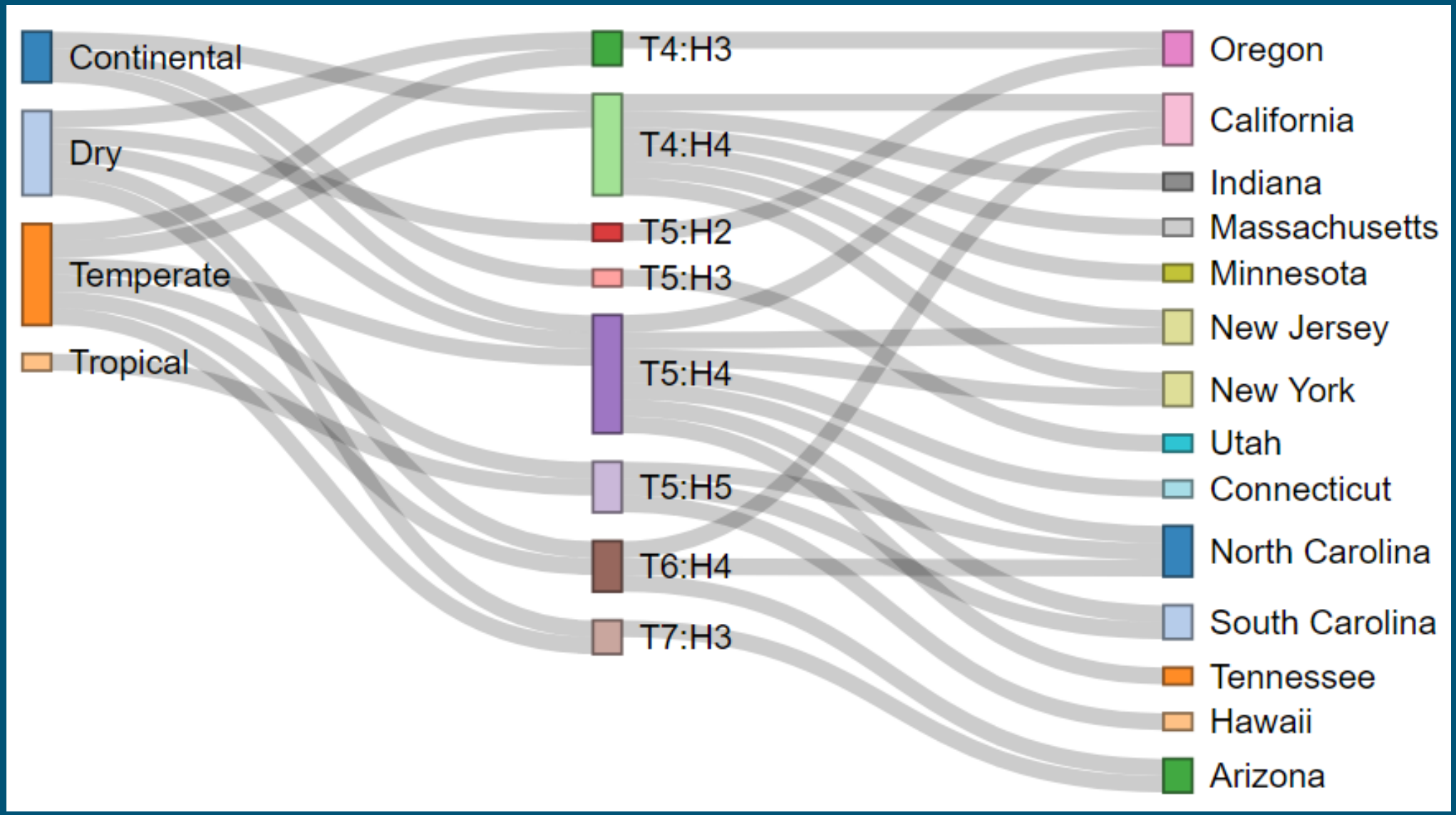
PRISM

- Maximum temperature
- Minimum temperature
- Precipitation

NOAA Storm Events Database

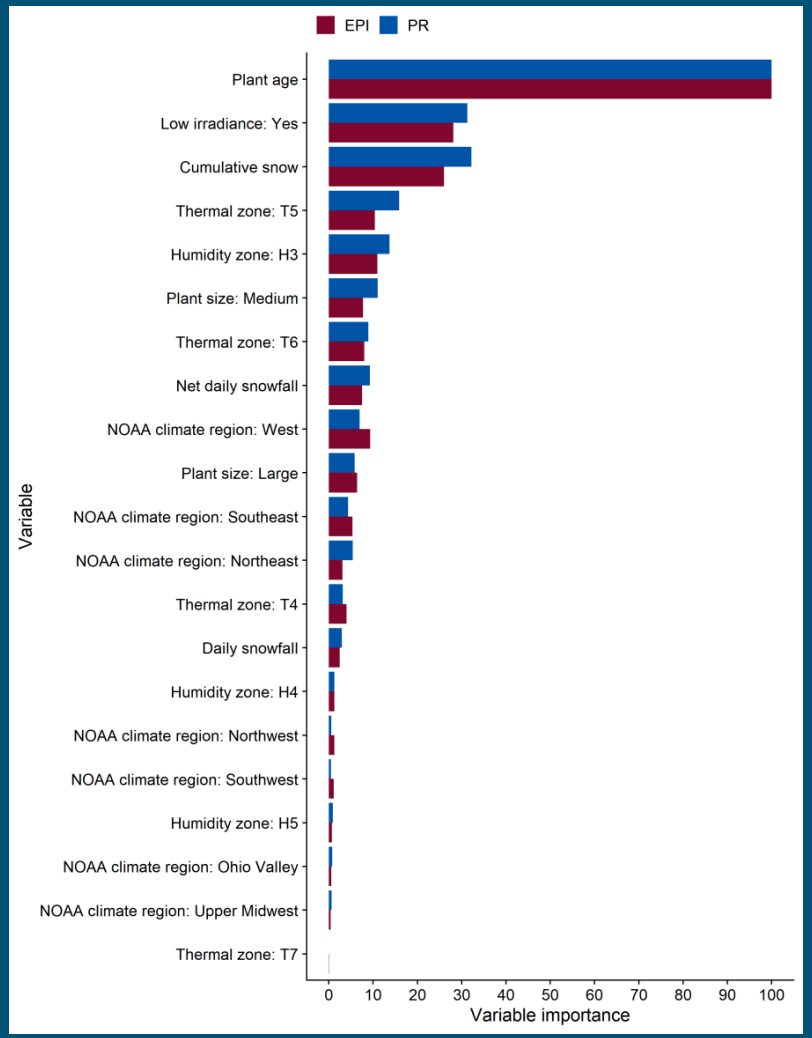
- Snow
- Storms
- Hurricanes

Distribution of sites by Köppen Geiger regions, PV climate zones, and states

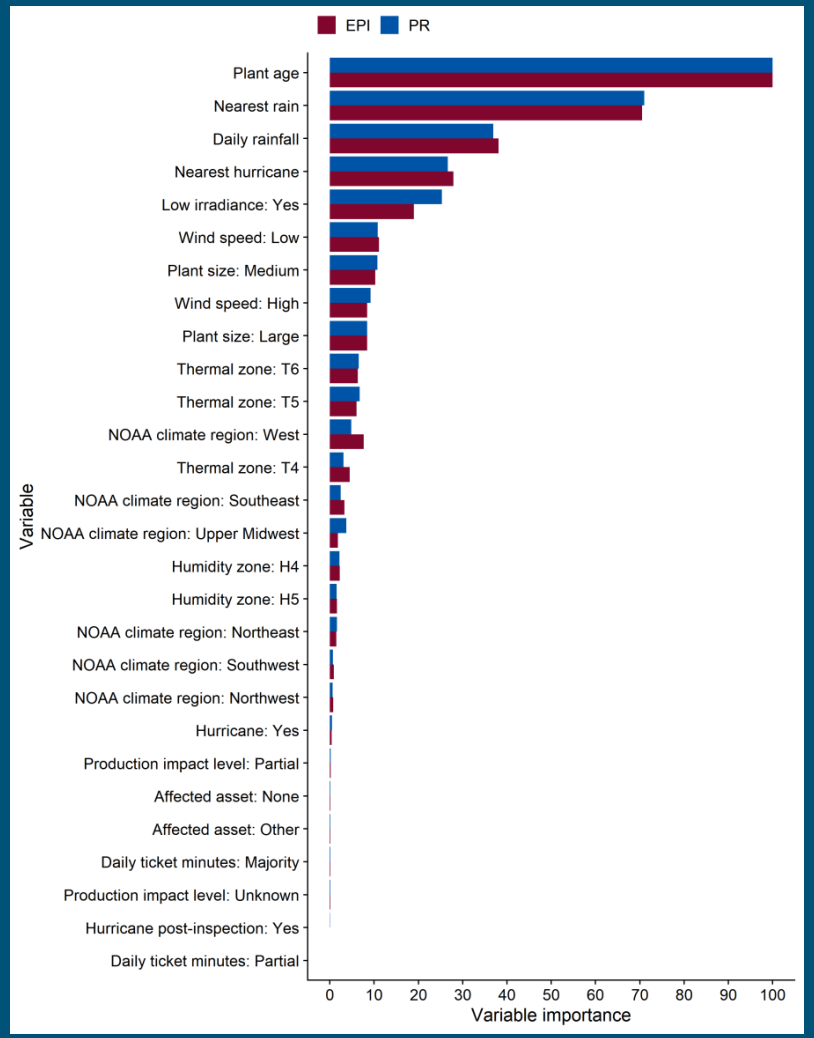


RF models classifying EPI and PR show similar variables of importance

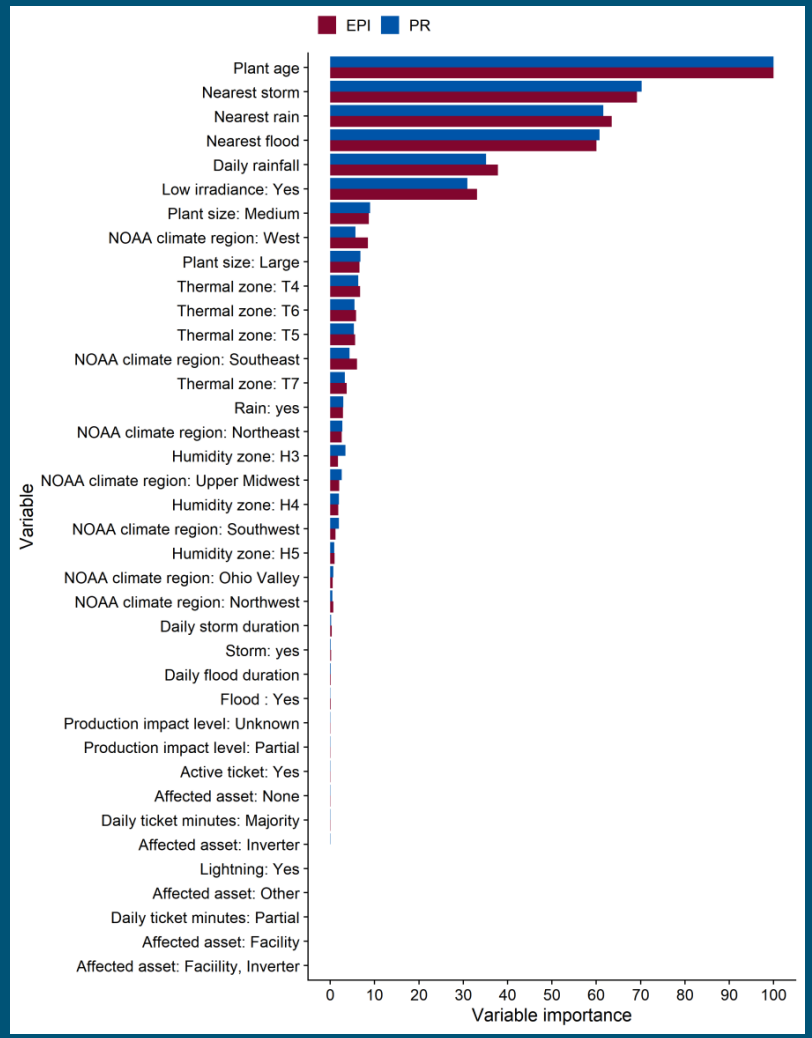
Snow



Hurricane

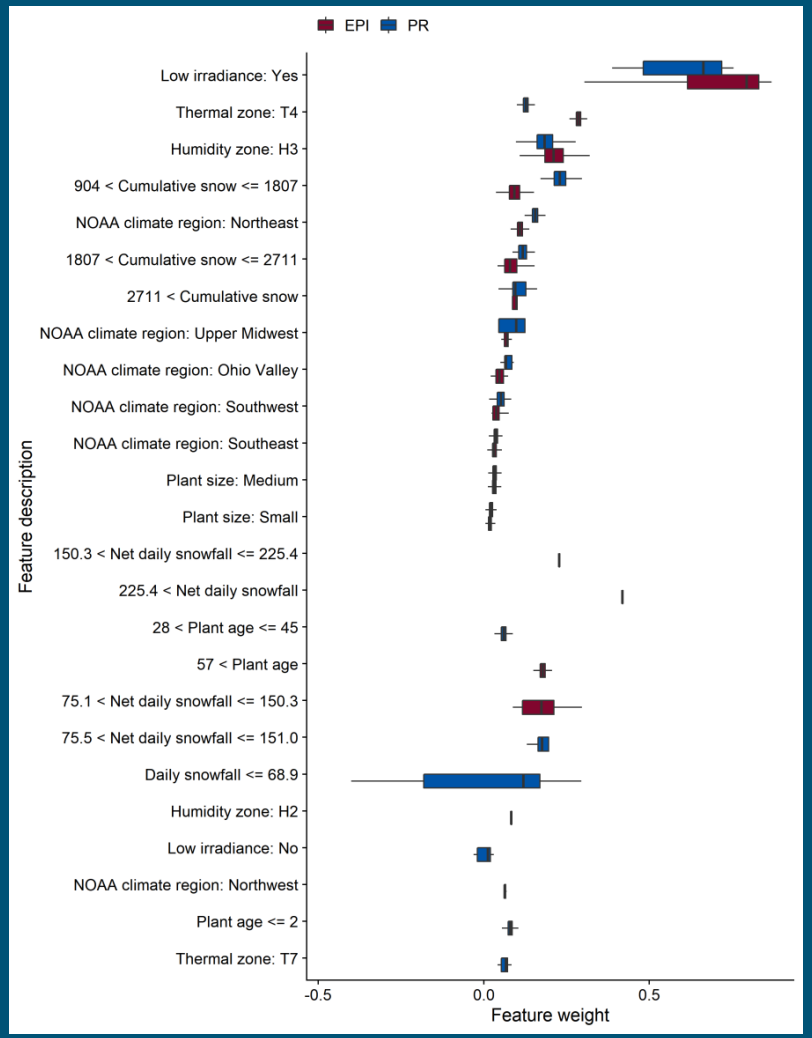


Storm

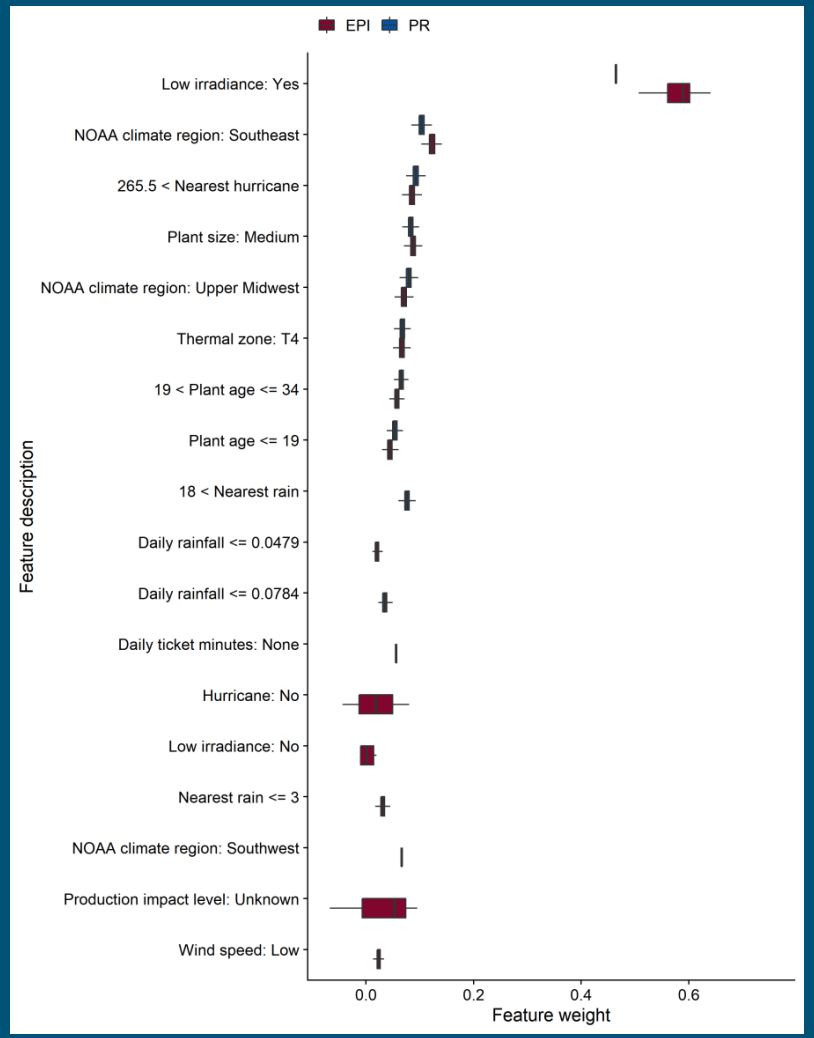


LIME results for EPI and PR show show different features for each event type

Snow



Hurricane



Storm