SAND2018-1968C



Solar and Load Data Needs for Accurate Distribution Grid Simulations

Matthew Lave, Sandia National Laboratories

IX PREC Symposium

February 16, 2018

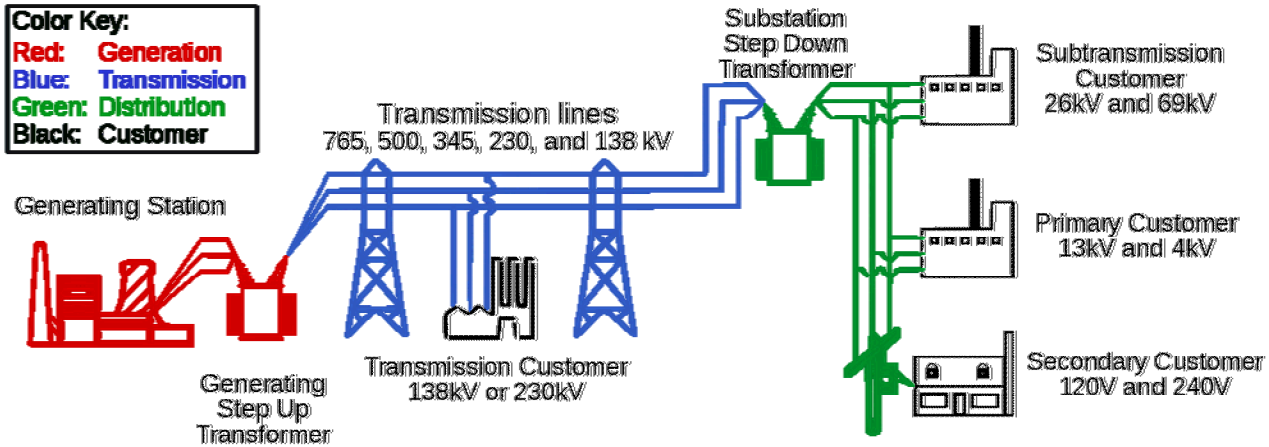
Gurabo, Puerto Rico

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

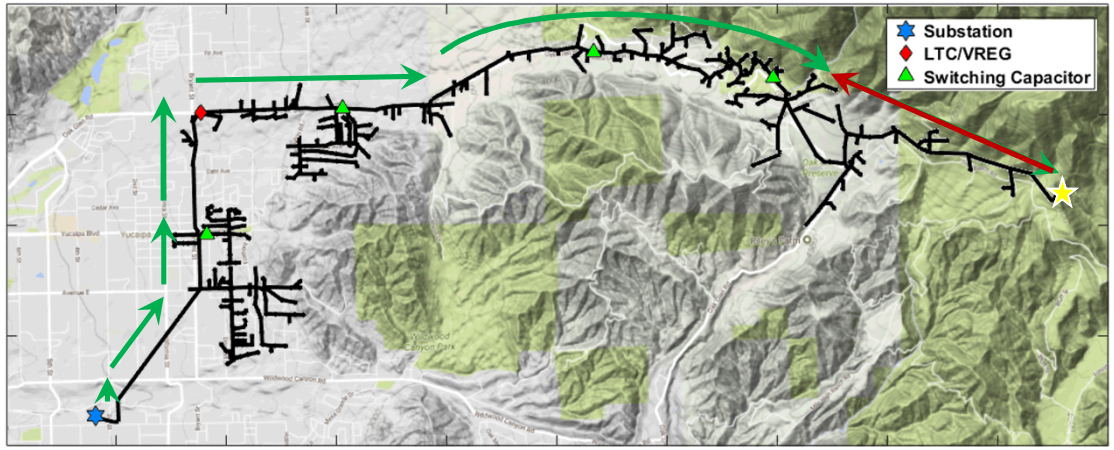
Electric Power Distribution Systems

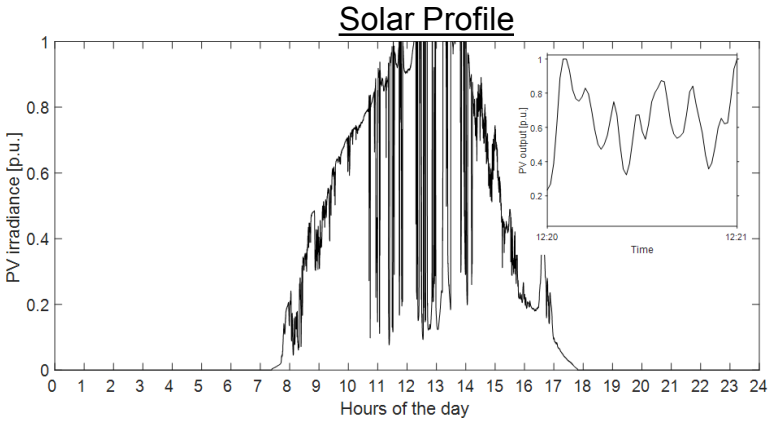
- Last stage of electric grid, delivering power to customers
- Distribution system analysis and design has experienced a gradual development over the couple of decades
  - Historically, radial flow from substation to customer; voltage highest at substation and decreases en route to customer
    - Not much concern over voltage regulation beyond substation
  - Now, customer distributed energy resources (PV, storage, etc.); customers can inject current
    - voltage at customer may be a concern



PV Integration to Distribution

- PV systems can impact distribution system operations
  - Can reverse flow direction on parts of feeder
  - Can have more variability than the load variability for which the system is designed
- Specifically of concern are:
  - Over/under-voltage conditions, thermal limit violations, reverse power flow, rapid power fluctuations, excessive voltage controller actions, etc.

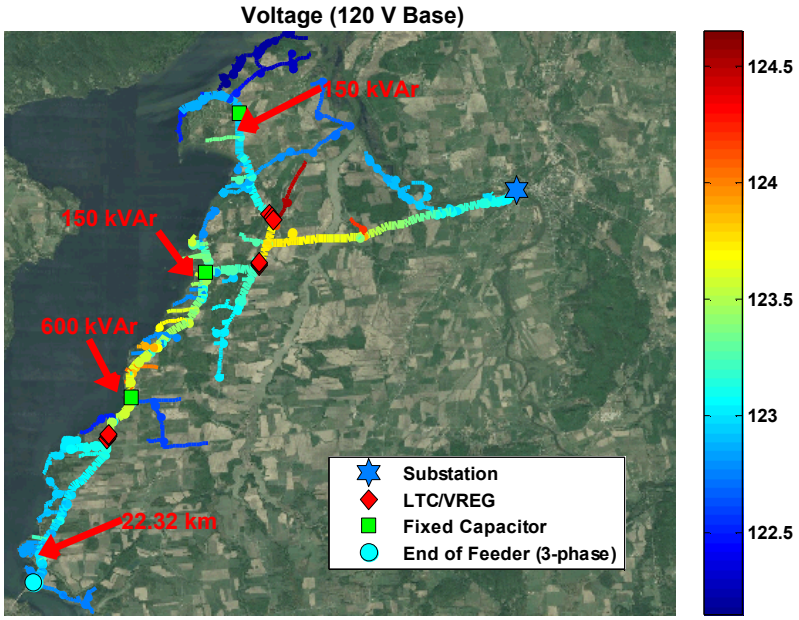




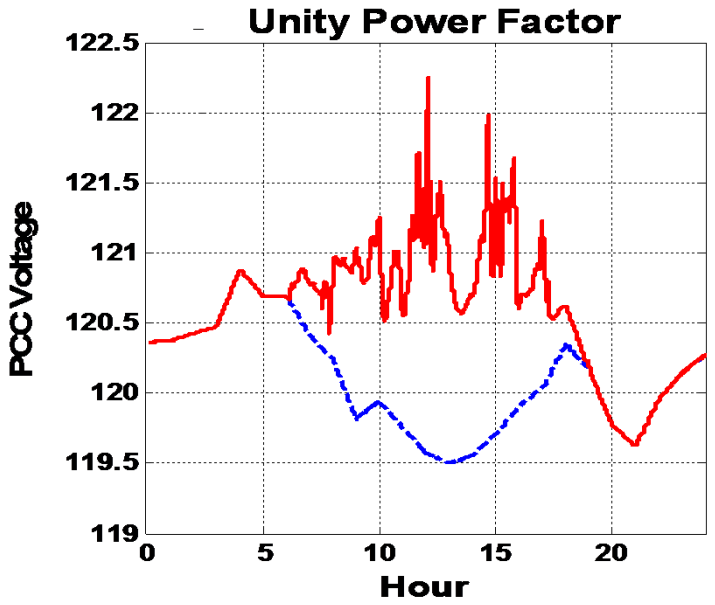
Distribution System Simulations

- To understand impact of PV, use distribution grid simulations
- Quasi-static time series (QSTS) simulations compute the voltage and current at each location on a feeder over time

Voltage at each location on the feeder

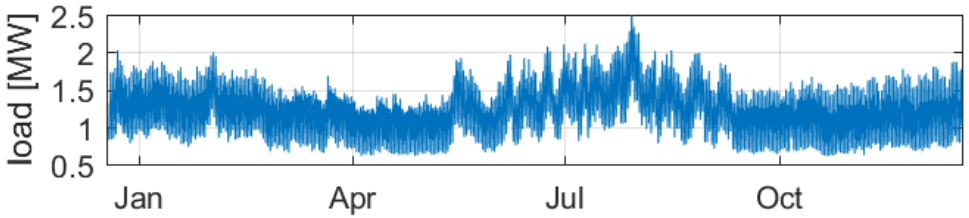


Voltage as timeseries to understand impact of PV



- **Need accurate PV and load inputs for accurate simulations**

Load and DER Generation Data

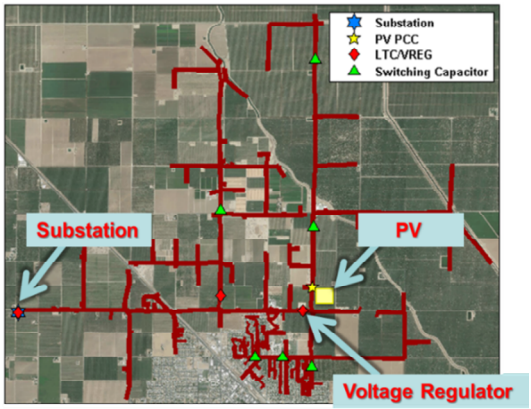


- Ideal case:
  - 1-second temporal resolution
    - high-frequency variability
  - Full spatial resolution
    - separate data for all customers on feeder
  - 1-year or longer period of record
    - seasonal trends

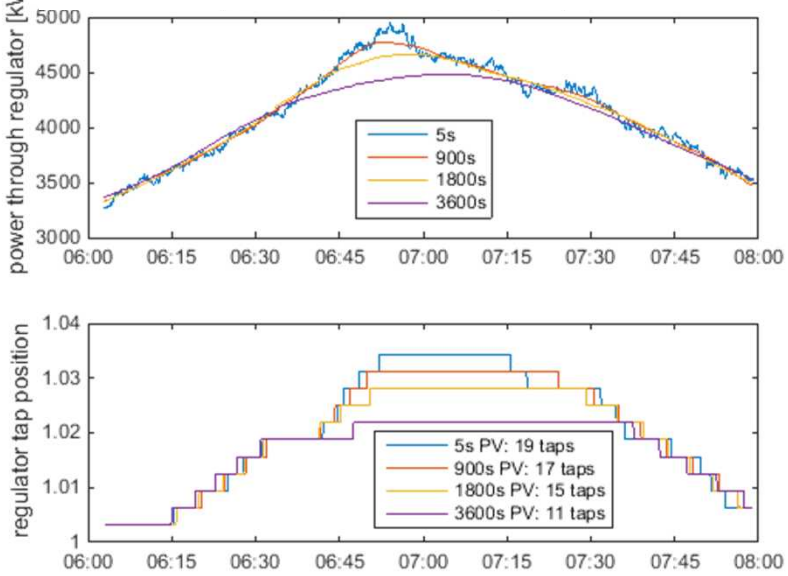
- Challenges with sub-optimal data:
  - Temporal resolution
  - Spatial resolution
  - Accuracy for the location

Temporal Resolution

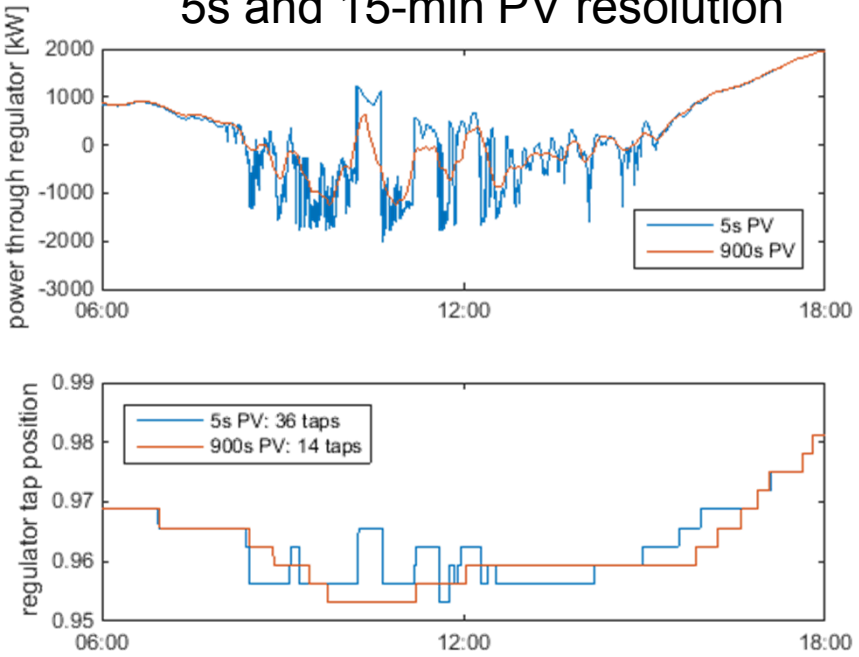
- Low-resolution data leads to rounded off load peaks and smoothed PV variability
  - Less voltage excursions and hence fewer tap change operations for low-resolution data



5s, 15min, 30min, 1hr load resolution

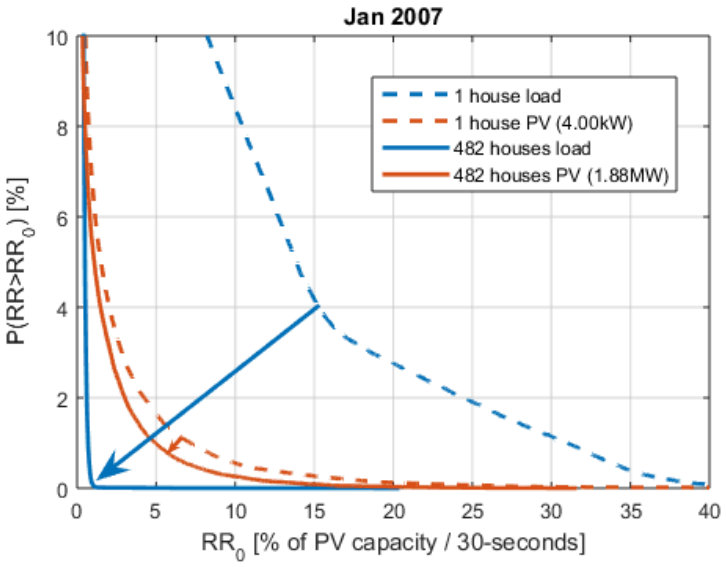


5s and 15-min PV resolution

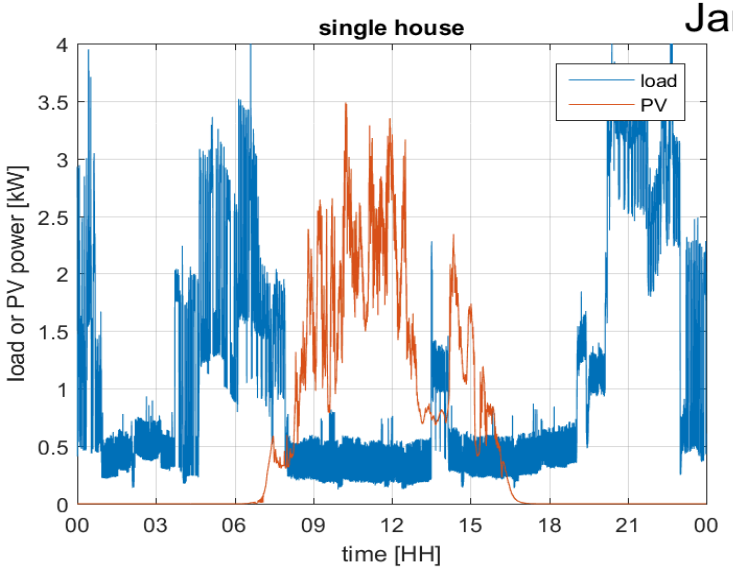


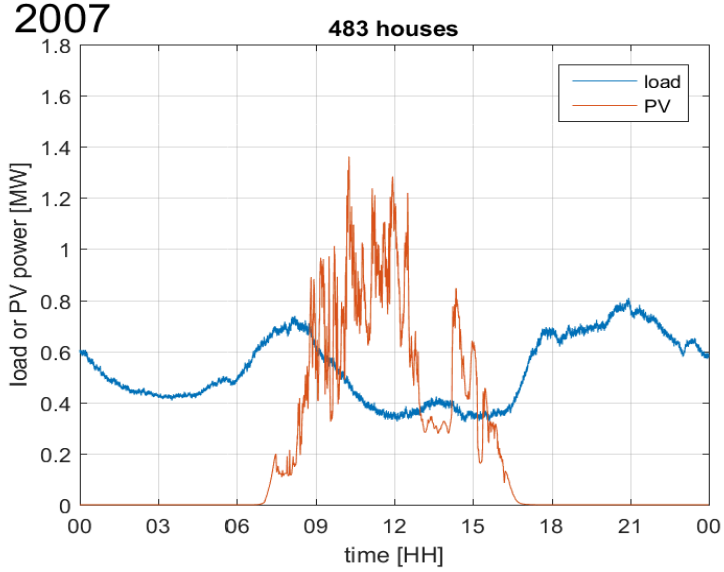
Spatial Diversity

- Single customer vs. all customers on feeder
  - Both load and PV variable at single customer
  - PV more variable and less smoothed when aggregated over several customers



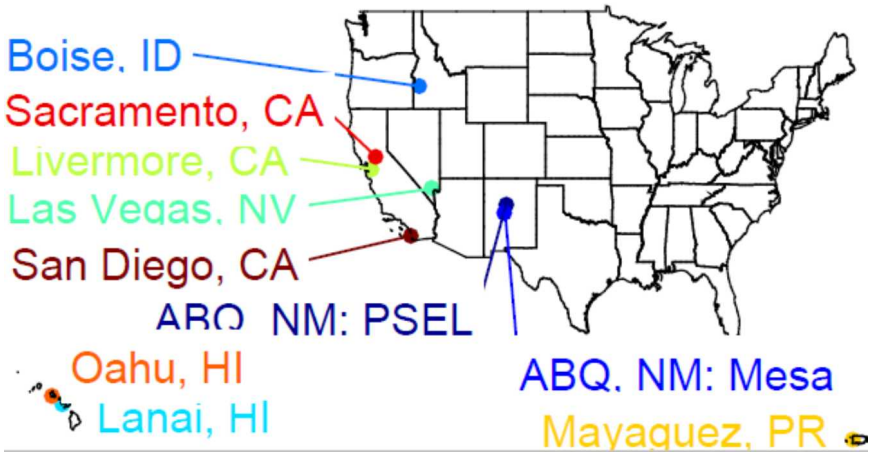
Jan 20, 2007

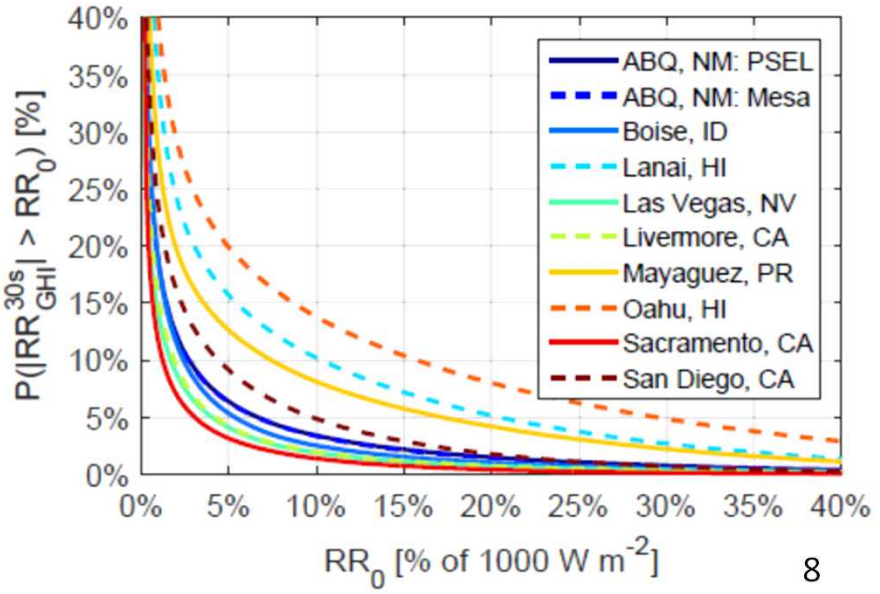




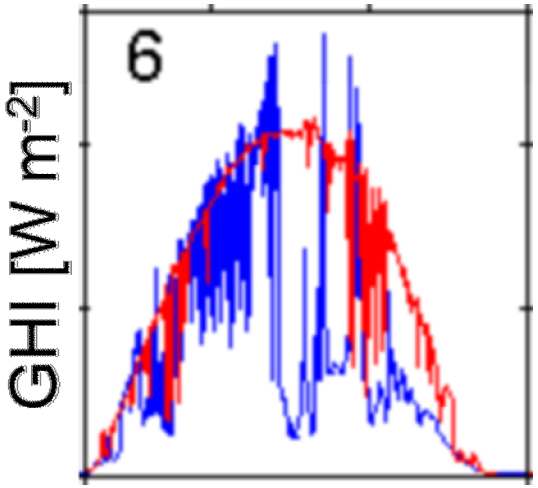
Geographic Differences

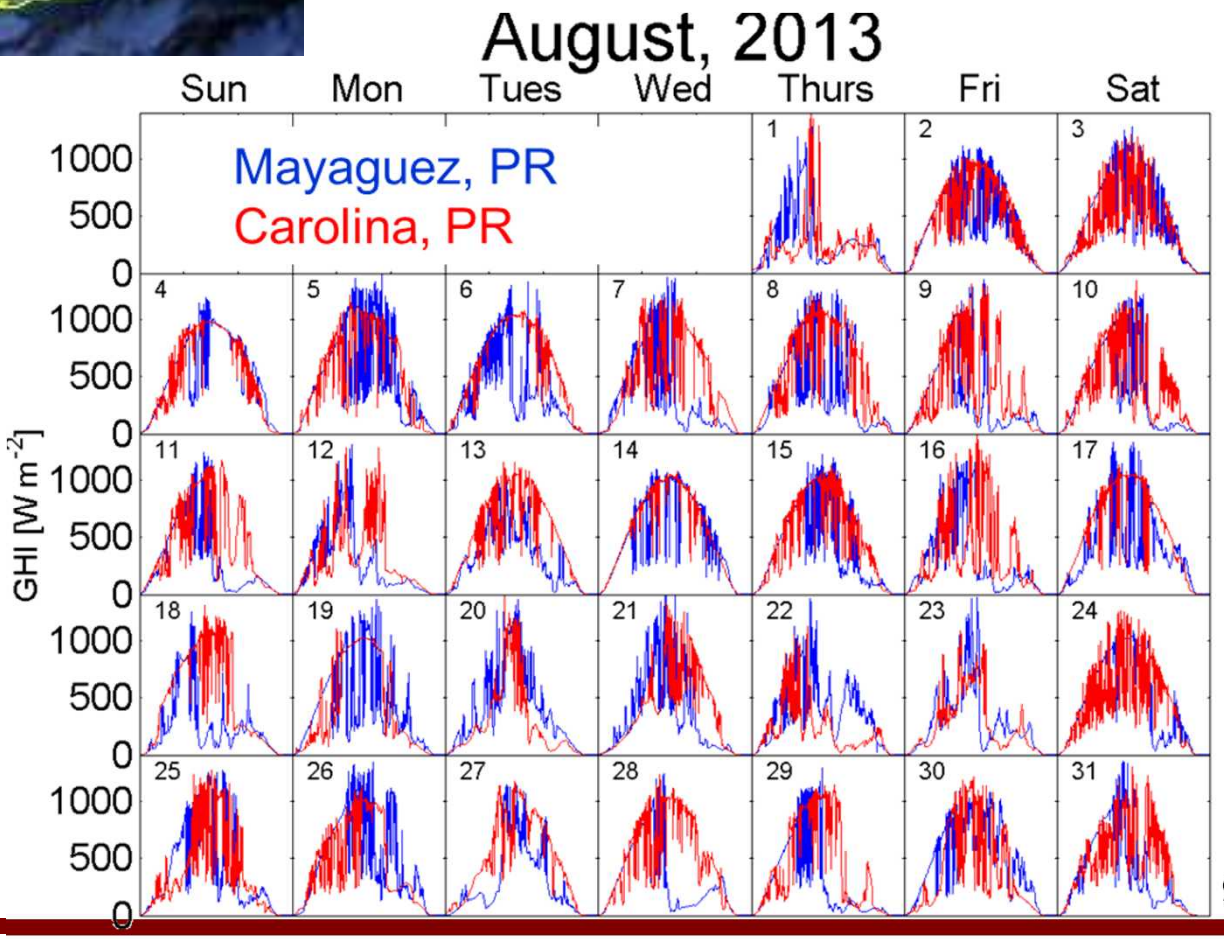
- Load
  - Peaks load timing may vary by location (e.g., California vs. Vermont)
  - Layout of customers on feeder (e.g., city vs. agricultural)
- PV
  - Weather differences – different amount of generation and variability
  - PV penetrations vary by incentives, etc.





Geographic Variation in Puerto Rico





Load Data Availability

- "Common" situation:
  - Measured aggregate load at substation, 1-hr resolution
- "Great" situation:
  - AMI load measurement at each customer, 5-min or 15-min resolution

High-Frequency Load Modeling

- Load variability is modeled using 1-second load data
- Model development creates hourly classifications of variability, stores models as wavelet coefficients, and clusters similar hours together*

Hour	Day of the Week						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour11'
2	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour8'	'class-hour1'
3	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'
4	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'
5	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour7'	'class-hour1'
6	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'
7	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'
8	'class-hour1'	'class-hour10'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'
9	'class-hour1'	'class-hour8'	'class-hour1'	'class-hour7'	'class-hour1'	'class-hour8'	'class-hour1'
10	'class-hour8'	'class-hour1'	'class-hour9'	'class-hour1'	'class-hour1'	'class-hour12'	'class-hour10'
11	'class-hour11'	'class-hour14'	'class-hour7'	'class-hour7'	'class-hour7'	'class-hour11'	'class-hour14'
12	'class-hour11'	'class-hour10'	'class-hour10'	'class-hour1'	'class-hour1'	'class-hour11'	'class-hour11'
13	'class-hour11'	'class-hour10'	'class-hour10'	'class-hour10'	'class-hour11'	'class-hour11'	'class-hour11'
14	'class-hour10'	'class-hour10'	'class-hour8'	'class-hour11'	'class-hour8'	'class-hour10'	'class-hour11'
15	'class-hour8'	'class-hour8'	'class-hour10'	'class-hour14'	'class-hour10'	'class-hour8'	'class-hour11'
16	'class-hour14'	'class-hour14'	'class-hour8'	'class-hour8'	'class-hour8'	'class-hour11'	'class-hour10'
17	'class-hour7'	'class-hour10'	'class-hour1'	'class-hour1'	'class-hour10'	'class-hour10'	'class-hour10'
18	'class-hour7'	'class-hour11'	'class-hour10'	'class-hour8'	'class-hour3'	'class-hour10'	'class-hour10'
19	'class-hour8'	'class-hour11'	'class-hour10'	'class-hour8'	'class-hour10'	'class-hour8'	'class-hour8'
20	'class-hour11'	'class-hour10'	'class-hour1'	'class-hour10'	'class-hour8'	'class-hour1'	'class-hour11'
21	'class-hour11'	'class-hour1'	'class-hour7'	'class-hour10'	'class-hour1'	'class-hour1'	'class-hour10'
22	'class-hour1'	'class-hour9'	'class-hour1'	'class-hour9'	'class-hour1'	'class-hour8'	'class-hour8'
23	'class-hour1'	'class-hour11'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour14'
24	'class-hour1'	'class-hour8'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour1'	'class-hour20'

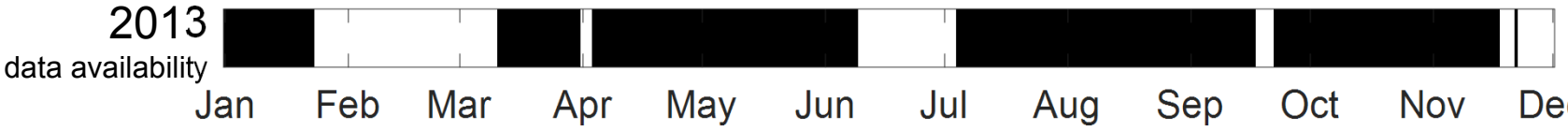
*work done by the National Renewable Energy Laboratory (NREL)

PV Data Availability

- "Common" situation:
  - No local irradiance or PV measurements
  - Must create synthetic data, likely from satellite (1km or worse spatial resolution, 5-min or worse temporal resolution)
    - Temporal, spatial, geographic, PV modeling errors
- "Good" situation:
  - 1 local, high-frequency irradiance measurement
    - Spatial, PV modeling errors
- "Great" situation:
  - PV output measurement at each customer, 5-min or 15-min resolution
    - Temporal errors

Solar Data Scarce in Puerto Rico

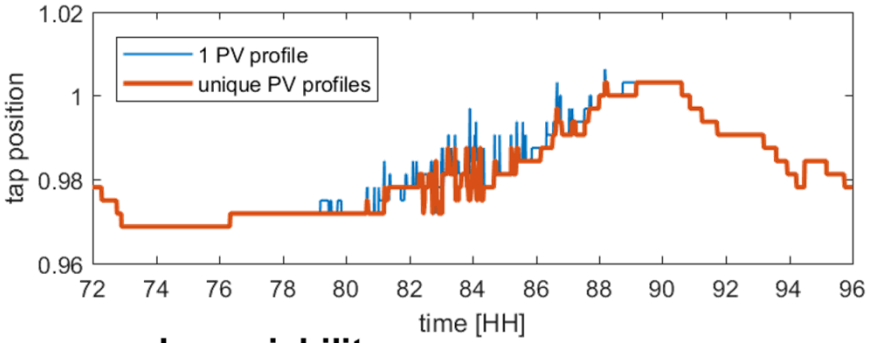
- Very limited publically-available irradiance data in Puerto Rico:
  - 7 ground sensors on western half of island at 1-hour[1]
  - 1-km, 1-hour satellite-based irradiance[2]
  - NREL's NSRDB satellite data began covering Puerto Rico in 2015
- In September 2012, the Kleissl Lab Group at UC San Diego started collecting 1-second irradiance measurements at the University of Puerto Rico, Mayaguez.

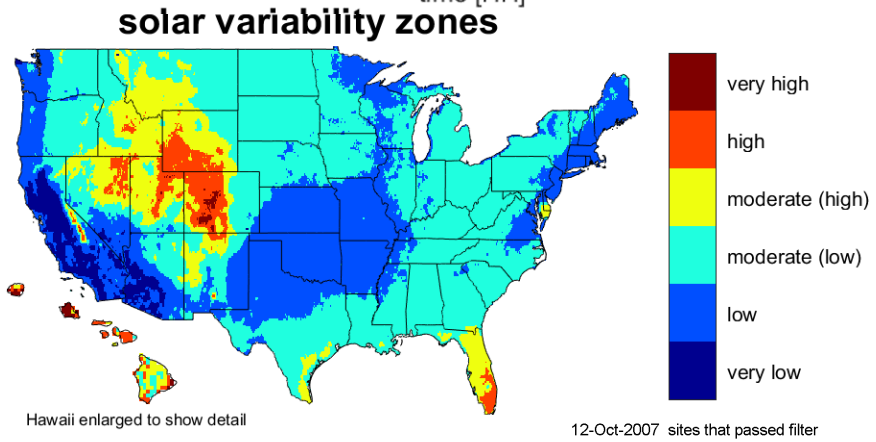


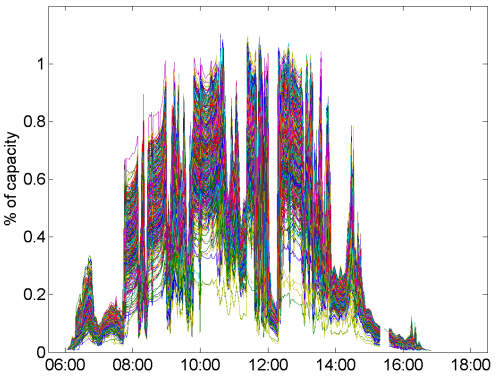
1. Natural Resource Conservation Service (NRCS): http://www.wcc.nrcs.usda.gov/scan/Puerto_Rico/puerto_rico.html
2. PRAGWATER: http://pragwater.com/solar-radiation-data-for-pr-dr-and-haiti/

PV Modeling Considerations

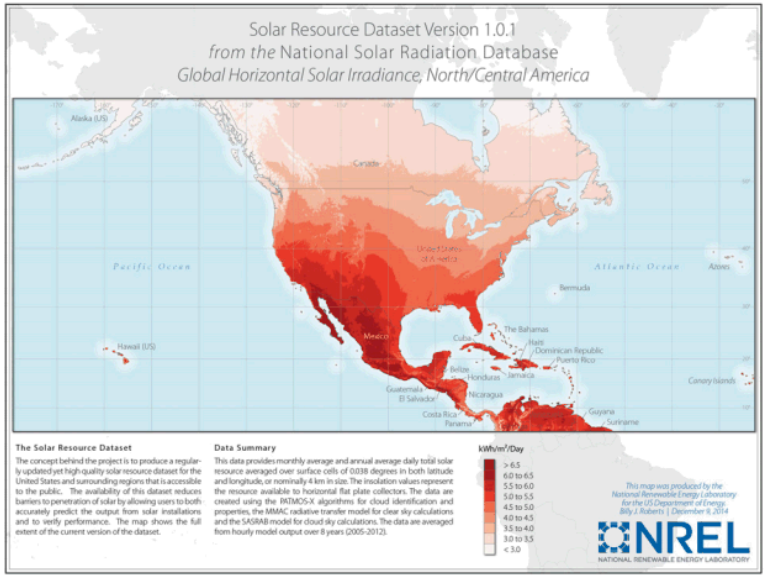
- **Temporal:** need high-frequency; most data sources (e.g., satellite/AMI) low-frequency
- **Spatial:** Unique profiles needed for each interconnection point
- **Geographic:** Represent local solar variability
- **Modeling:** Need data for PV sizes, locations, orientations, control settings

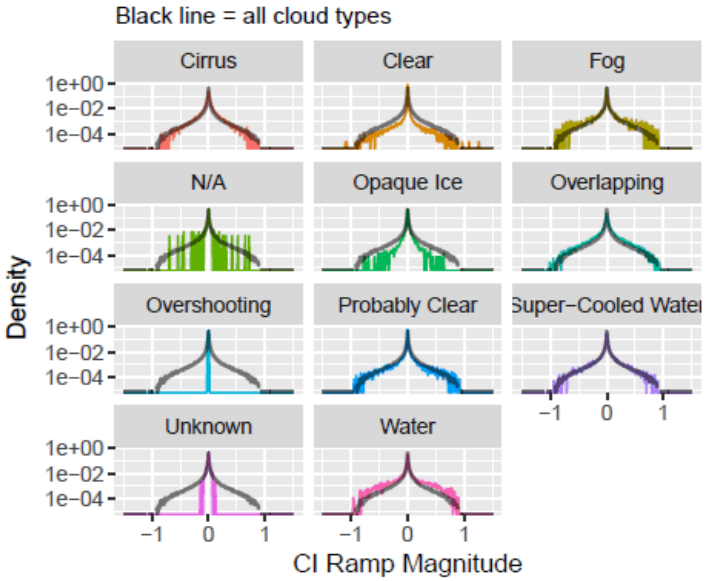






High-Frequency Solar Modeling



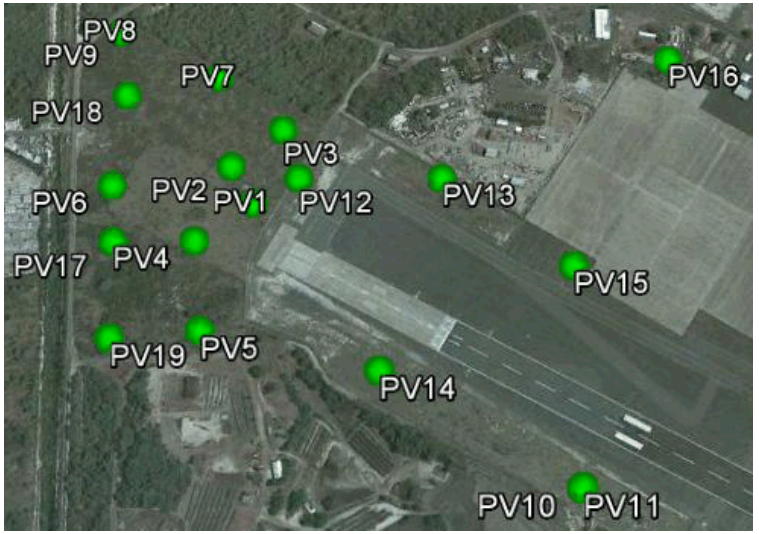


- Model is driven off NSRDB and SURFRAD data – nrsdb.nrel.gov
- 11 variability "cloud" classes are generated from nearest high-temporal res. irradiance dataset*

*work done by the National Renewable Energy Laboratory (NREL)

Solar Spatial Diversity

Challenge: modeling PV power output from several PV interconnection points on a distribution feeder



PV locations are actual irradiance sensors in Oahu, HI

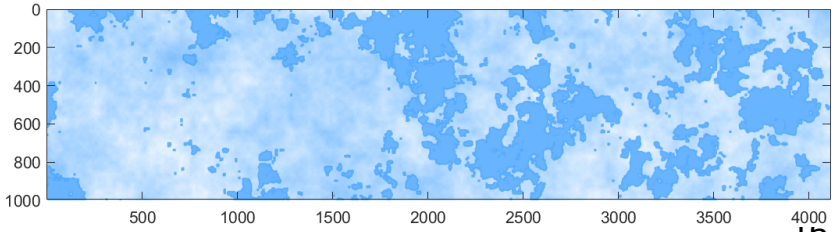
Options:

Single Sensor

- Point measurements from a single sensor applied to all PV locations
- PV power timeseries perfectly correlated

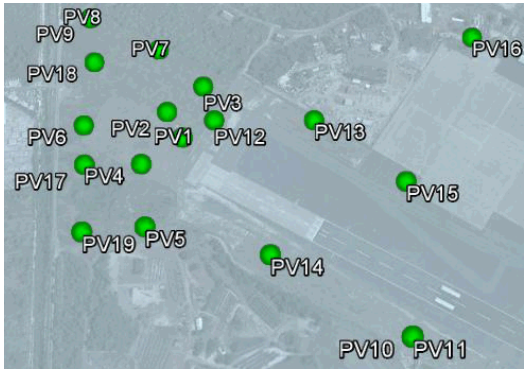
Synthetic Cloud Fields

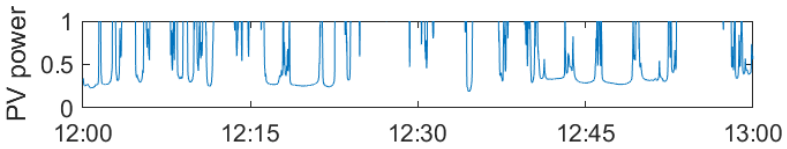
- Simulated cloud formations
- Unique PV power timeseries at each interconnection point

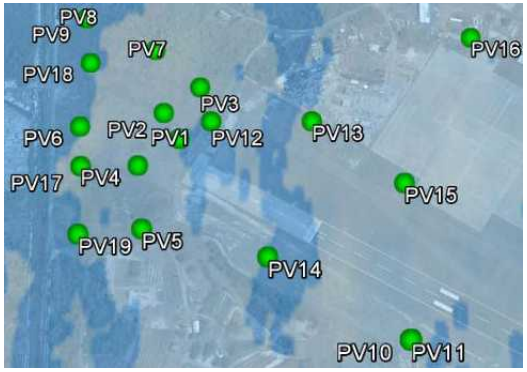


Solar Spatial Diversity

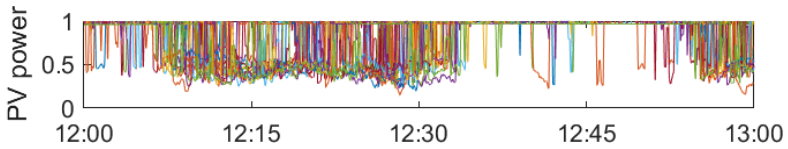
entire area follows same pattern



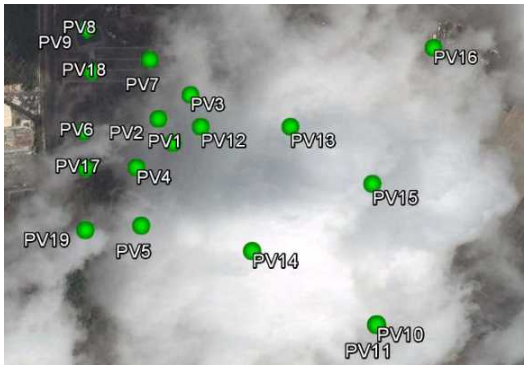


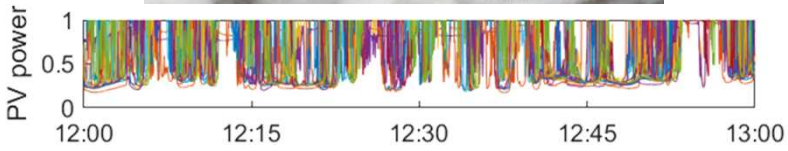


cloud shapes create different PV profiles at each locations



Actual

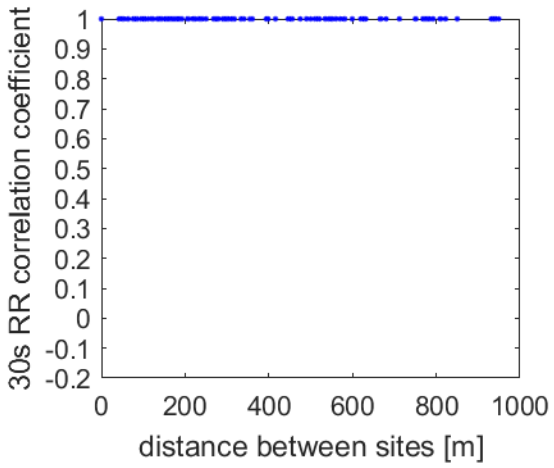




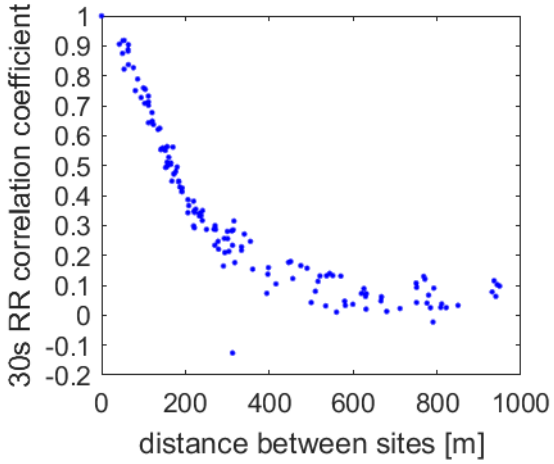
Solar Spatial Diversity

Single Sensor

all sites perfectly correlated

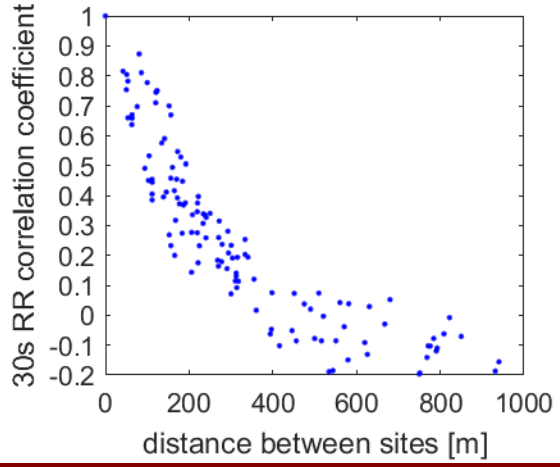


Synthetic Cloud Fields



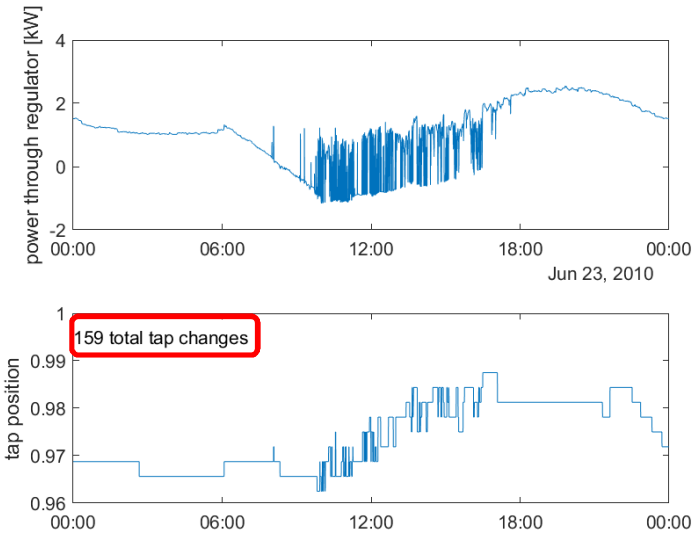
correlation decreases as distance increases

Actual

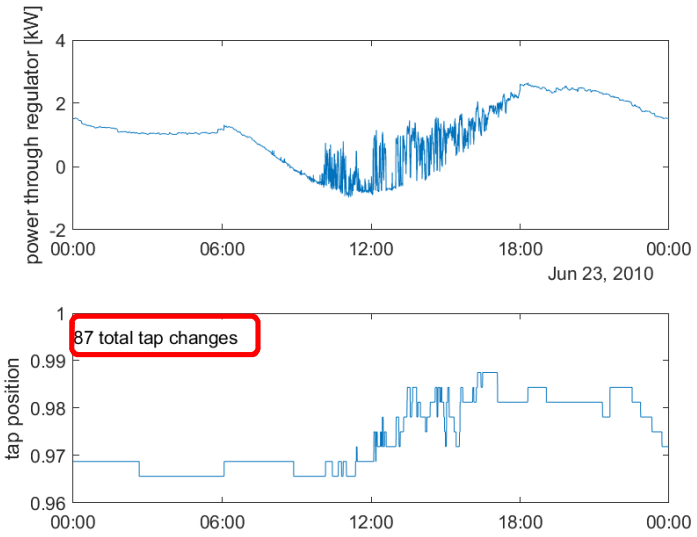


Solar Spatial Diversity

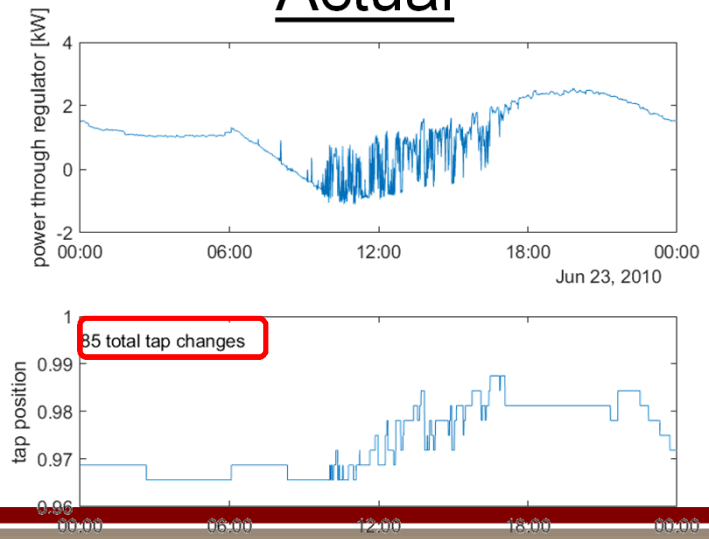
Single Sensor



Synthetic Cloud Fields



Actual



Load and PV Data Discussion

- Do we really need high-resolution irradiance measurements, or simply data on variability statistics?
  - Cloud fields can create synthetic high temporal and spatial resolution data which recreates variability statistics
- How many unique profiles are needed?
  - "Ideal" case of 1s measurements of everything is likely too much data – data reduction, what do we really need? Can we do some grouping?
  - Load allocation, regulator, sectionalizing device, service transformer vs. AMI
  - For many analysis applications (e.g., tap changes), data reduction may be efficient and maintain accuracy.
  - What do we do with all the AMI data?