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Estimating Annual Synchronized 1-min Power Output Profiles from Utility-Scale PV Plants at 10 locations in Nevada for a Solar Grid Integration Study

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

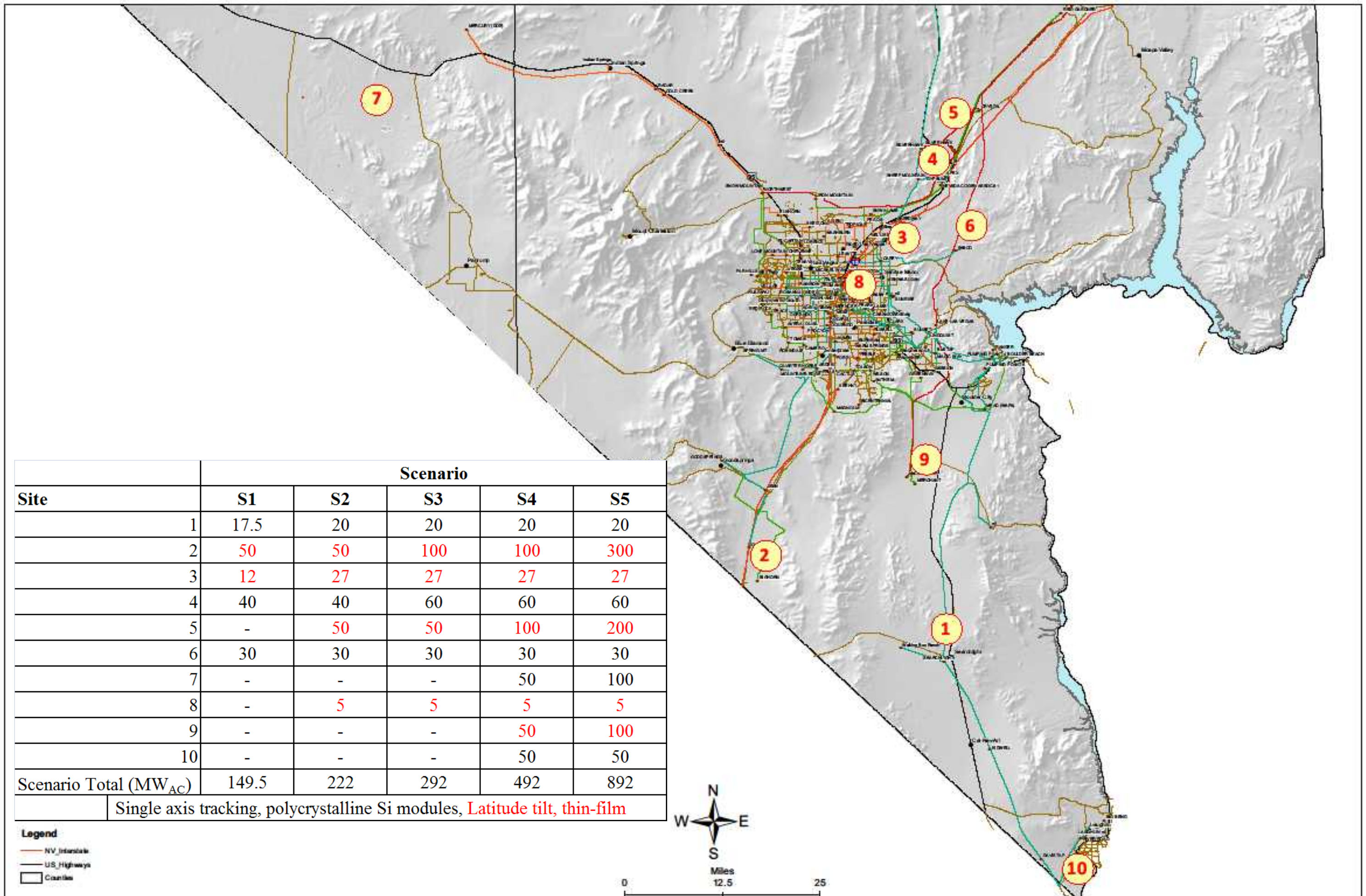
Introduction

- Integration of large solar PV plants will require utilities to change how they operate the grid.
  - Manage variability (short-term, diurnal, seasonal)
- Integration studies simulate operations and planning for scenarios with increased solar PV.
  - Integration costs are estimated
- Sandia National Laboratories has developed a modeling approach for simulating high resolution (1-min) PV output from utility-scale plants
- Results are being applied to NV Energy Solar Integration Study (Navigant, SNL, and PNNL)

Model Objectives

- Generate time-synchronized (year 2007) PV plant power output profiles for 10 locations in Southern Nevada (1-min and 1-hour averages)
  - Distinguish between different PV designs and technology choices (e.g., module technology, tracking vs. fixed tilt, etc.)
  - Use readily available site specific data (e.g., weather)

PV Plant Locations for Study



	Scenario				
Site	S1	S2	S3	S4	S5
1	17.5	20	20	20	20
2	50	50	100	100	300
3	12	27	27	27	27
4	40	40	60	60	60
5	-	50	50	100	200
6	30	30	30	30	30
7	-	-	-	50	100
8	-	5	5	5	5
9	-	-	-	50	100
10	-	-	-	50	50
Scenario Total (MW_{AC})	149.5	222	292	492	892
	Single axis tracking, polycrystalline Si modules, Latitude tilt, thin-film				

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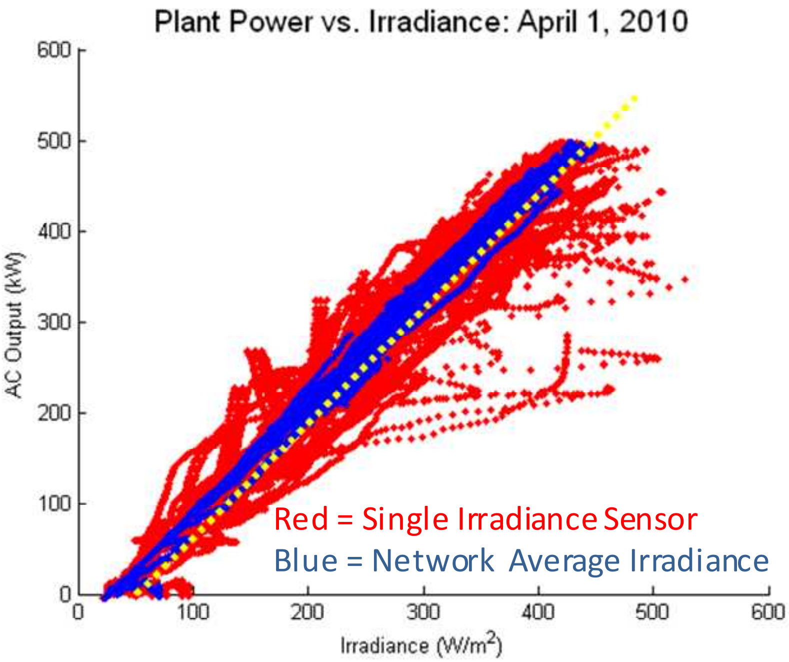
Data Sources

- 1- hour satellite irradiance at each of the ten sites from Clean Power Research's SolarAnywhere data
- 1-min irradiance data from six Las Vegas Valley Water District (LVVWD) sites in Las Vegas
- Upper air wind speed from NOAA weather balloon at Desert Rock, NV
- Air temperature and wind speed data from McCarran International Airport, Las Vegas

Modeling Approach

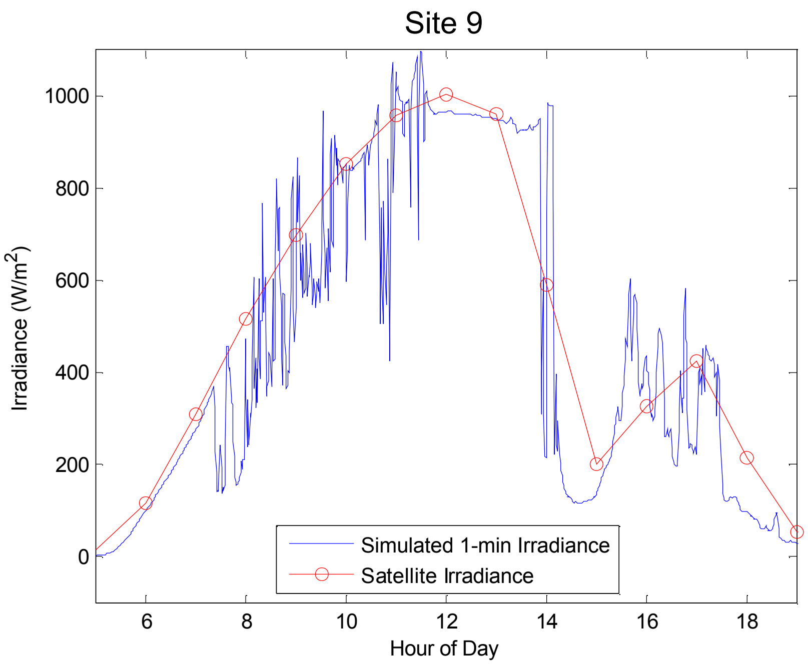
1. **Estimate 1-min irradiance at each site**
2. **Convert point irradiance to 1-min spatial average irradiance over plant**
3. **Calculate 1-min AC power output from plant**



from Kuszmaul et al., 2010

1. Estimate 1-Min Irradiance

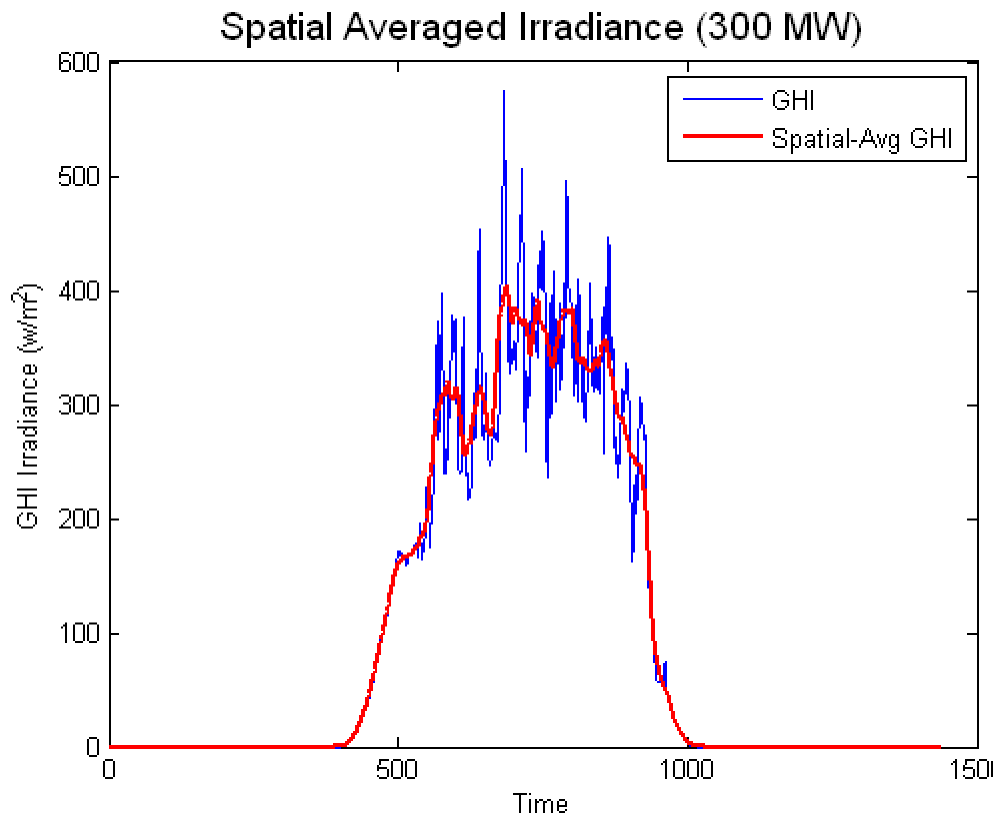
- A library of 1-min irradiance days was created from LVVWD sites (>5,000 days)
- Hourly averages were calculated for each day
- Least-squares routine identified best fitting days in library to match day at each location
- The same library day was prevented from being assigned to more than one site for each day of the year.



Matching 1-min ground irradiance with 1-hr satellite data

2. Spatial Average Irradiance over PV Plant

- Spatial average of irradiance over plant is estimated as a moving average irradiance (after Longhetto et al., 1989)
- Averaging window = the time for clouds to pass over plant
  - Plant size varies with module technology (efficiency)
  - Cloud speed varies with time, as measured



Effect of geographic smoothing within a plant

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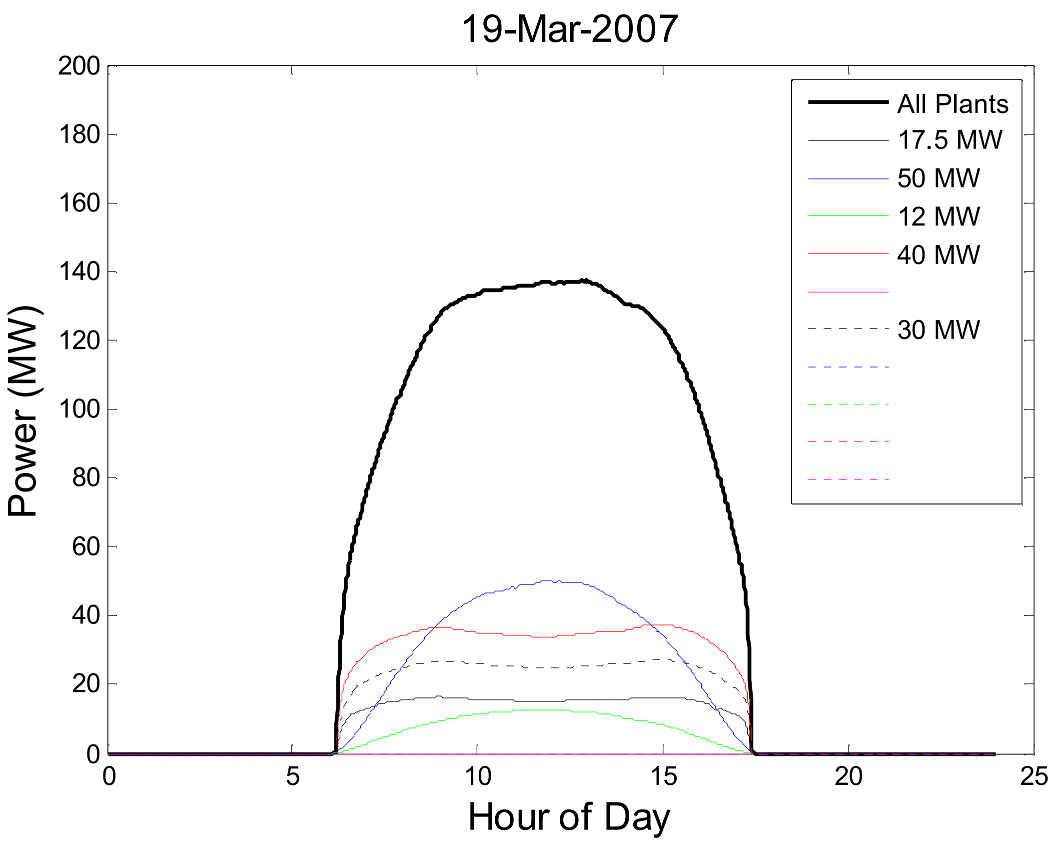
3. Calculate AC Power from Plant

- Sandia PV Array Performance and Inverter Models were used to calculate system output
  - These models account for:
    - Module technology characteristics (c-SI vs. thin film)
    - Temperature , angle of incidence and spectral effects
    - Inverter efficiency curves
- Irradiance incident on array was estimated using
  - DISC model (Maxwell, 1987) for DNI estimation
  - Perez (1990) model of diffuse irradiance on tilted plane
- Air temperature was estimated using lapse correction for site elevation, wind speed from LAS airport

Example Results: PV Plant Output

S1: 149.5 MW (5 plants)



- **Output profiles reflect differences between systems**
  - **Module technology**
  - **Plant capacity**
  - **Fixed tilt vs. tracking**
  - **Temperature differences**
  - **Changing cloud speeds**

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Example Results: PV Plant Output

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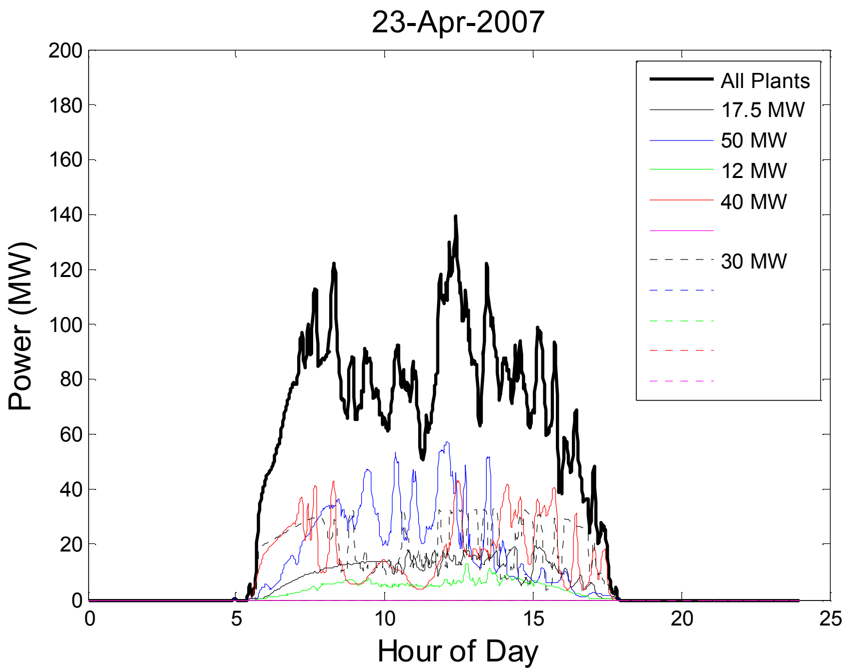
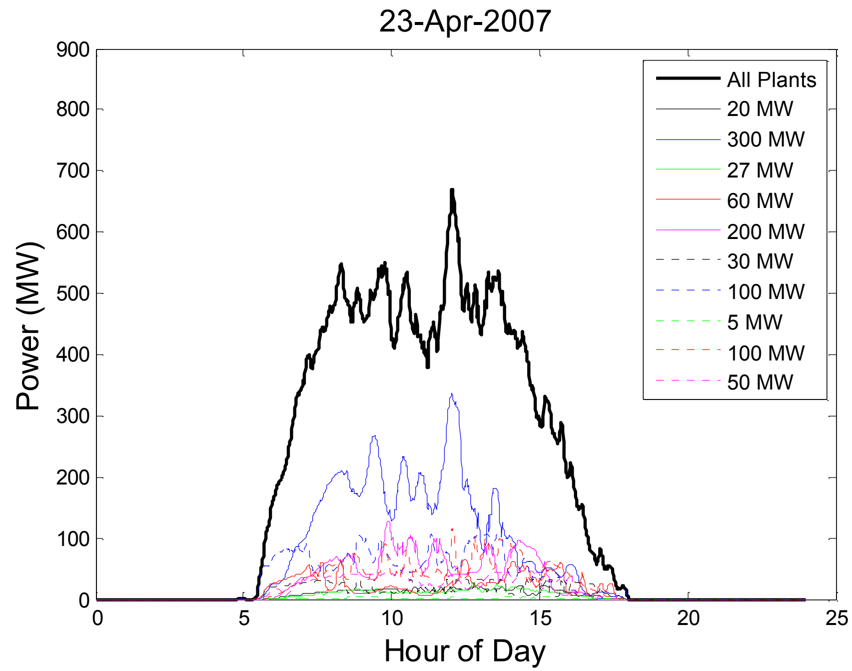


S5: 892 MW (10 plants)



Apparent reduction in Relative variability, But look at y-axis…

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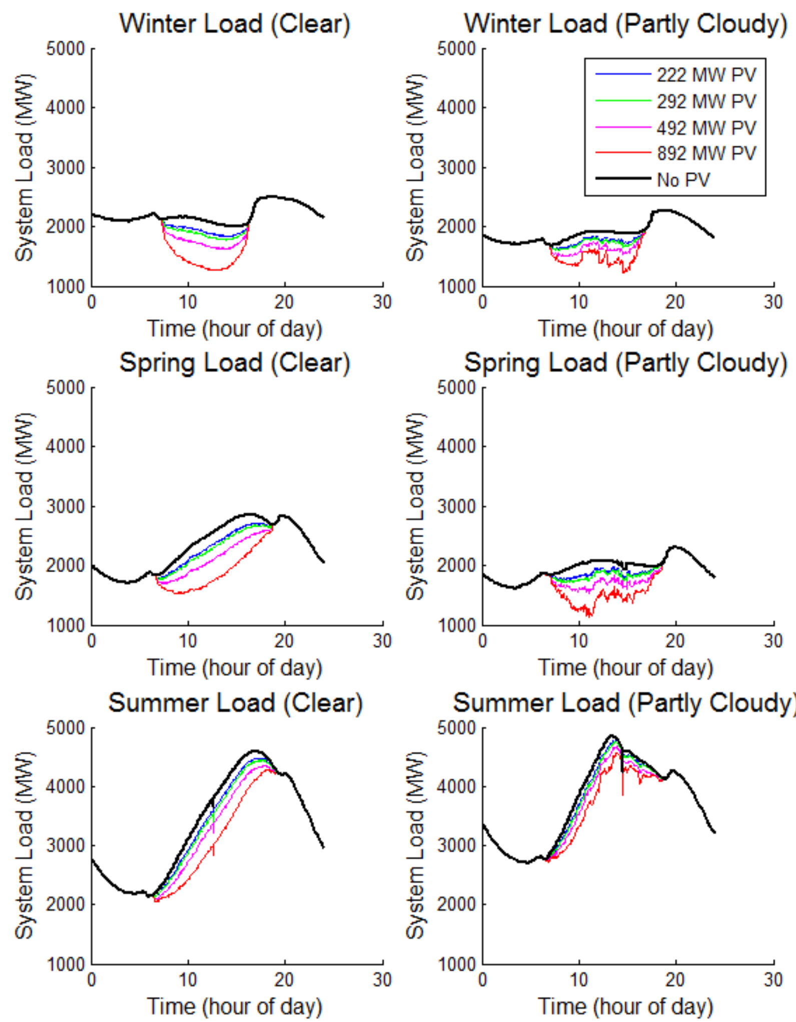
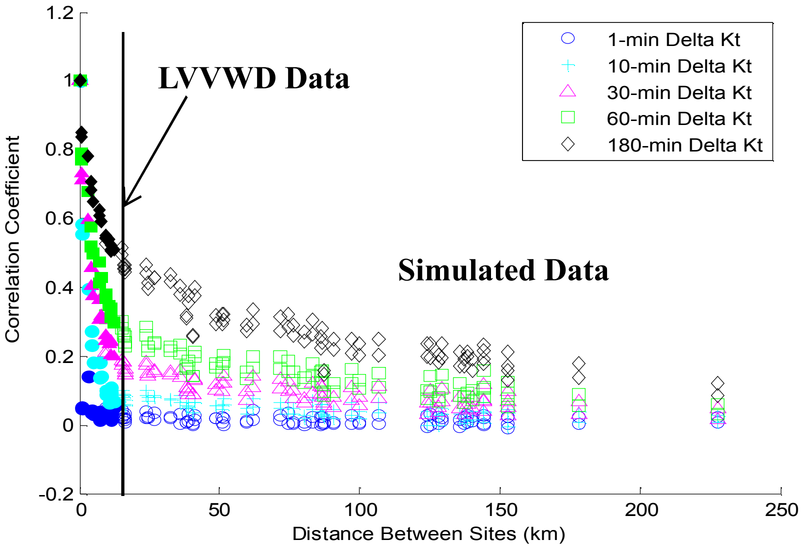
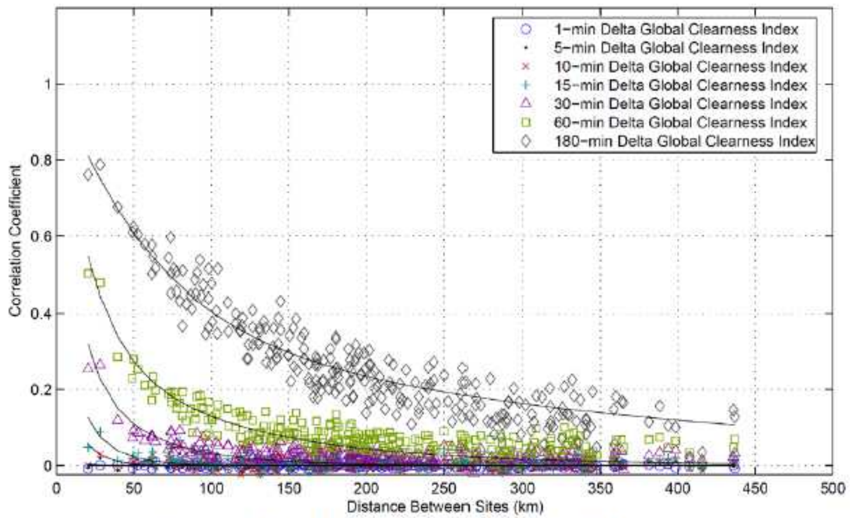
Effect on Net Load

- **Net load affected most in winter and spring when PV production reduces minimum load**
  - **Reduces baseload**
- **Short-term PV variability can increase net load variability**
  - **Increases regulations requirements**
- **PV reduces peak load and shifts to later in the day during the summer**



Spatial Correlation Patterns Increase Confidence in Simulations





Source: Andrew Mills and Ryan Wiser, LBNL, presentation at PV Variability Workshop

- **Correlation between changes in clear-sky index are consistent with patterns observed for irradiance sensor networks (e.g. Mills et al, 2009).**
- **Simulated data fits pattern seen in measured data from Las Vegas (LVVWD).**

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Summary

- We have described a method developed to estimate 1-min power output profiles for large PV plants and applied it to southern Nevada
- The method includes
  - Design differences between plants
  - Local and regional observed weather conditions
  - Geographic smoothing within and between plants
- The results suggest that increases in utility-scale PV in Nevada may impact:
  - Minimum load (baseload)
  - Regulation reserves
  - Timing and magnitude of peak load

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