



# Lanai High-Density Irradiance Sensor Network for Characterizing Solar Resource Variability of MW-Scale PV System

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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

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- The Lanai electric grid has one of the highest penetration rates of PV generation in the world.
  - Lanai peak load =  $4.7 \text{ MW}_{AC}$
  - La Ola Solar Farm generation capacity =  $1.2 \text{ MW}_{AC}$
- Interconnection requirements currently limit PV output to 600 kW in order to prevent high ramp rates from cloud transients.
- Sandia designed and installed an irradiance sensor network (Lanai Irradiance Network Experiment: LINE) to characterize spatial temporal irradiance patterns over the PV field.



# LINE Objectives

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- **Design and deploy an autonomous, low-cost, low-impact, and reliable irradiance and module temperature monitoring network at Lanai**
  - Minimize impact on plant operations
  - Single point of connection (server connection)
- **Investigate how distributed sensors can be used to predict plant output characteristics**
  - AC plant power output
  - Ramp rates

# Site Layout

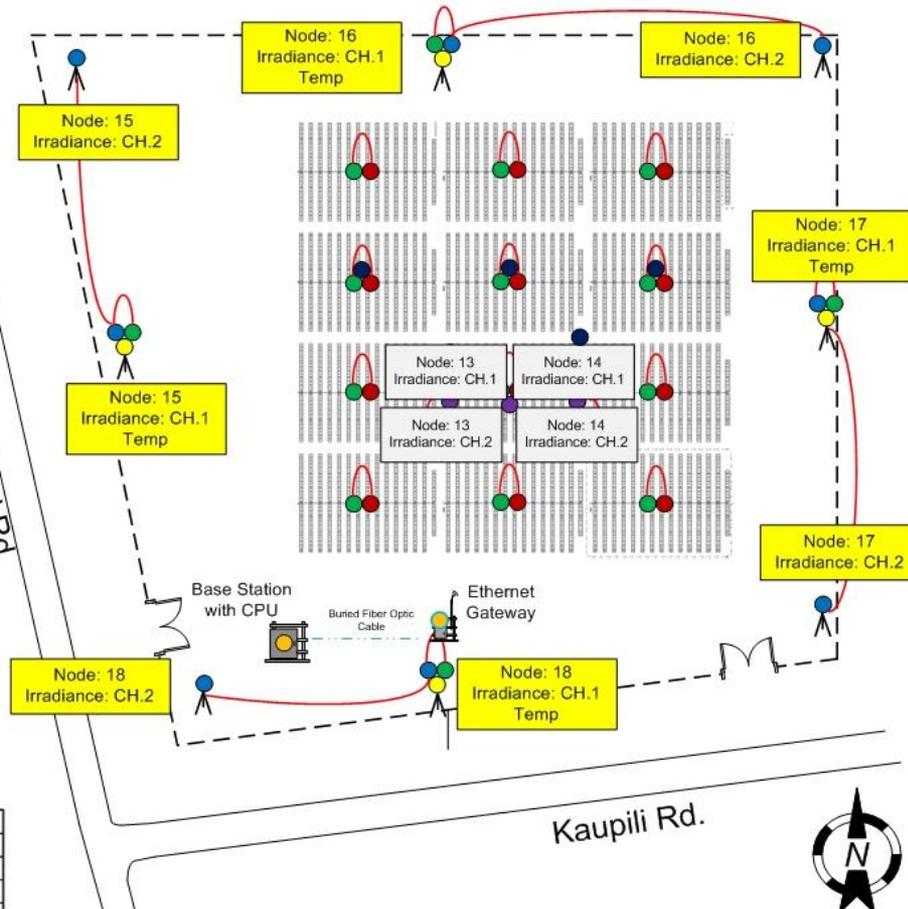
## L.I.N.E N.I. Licor Designation

(For nodes with two sensors)

- 18 ● I/O, RF
- 8 ● GH LI200
- 16 ● POA LI200
- 1 ● Base Station PC
- 1 ● Ethernet Gateway
- 4 ● Ambient TC Probes External
- 3 ● Module TC Frame of Module
- 3 ● Router
- 8 ▲ Tripod
- Fence



Miki Rd.



- System Includes:
- 16 POA Irradiance
  - 8 GH Irradiance
  - 3 Module Temp.
  - 5 Ambient Temp.

Array power output data is added to the data stream

|  |                           |
|--|---------------------------|
|  | Lanai Site Plan V2.2.vsd  |
|  | U:\Users\Adam\Lanai       |
|  | Prepared By: Adam Moya    |
|  | Date: 02/02/2010 Ver: 2.2 |
| Distributed Energy Technology Laboratory |                           |

# Autonomous Sensors

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Inside array: Units mount to tracker frame without interfering with array operations

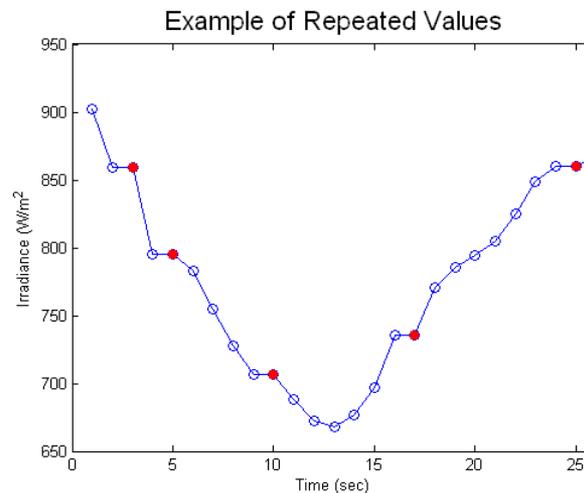
System is independent from PV Array



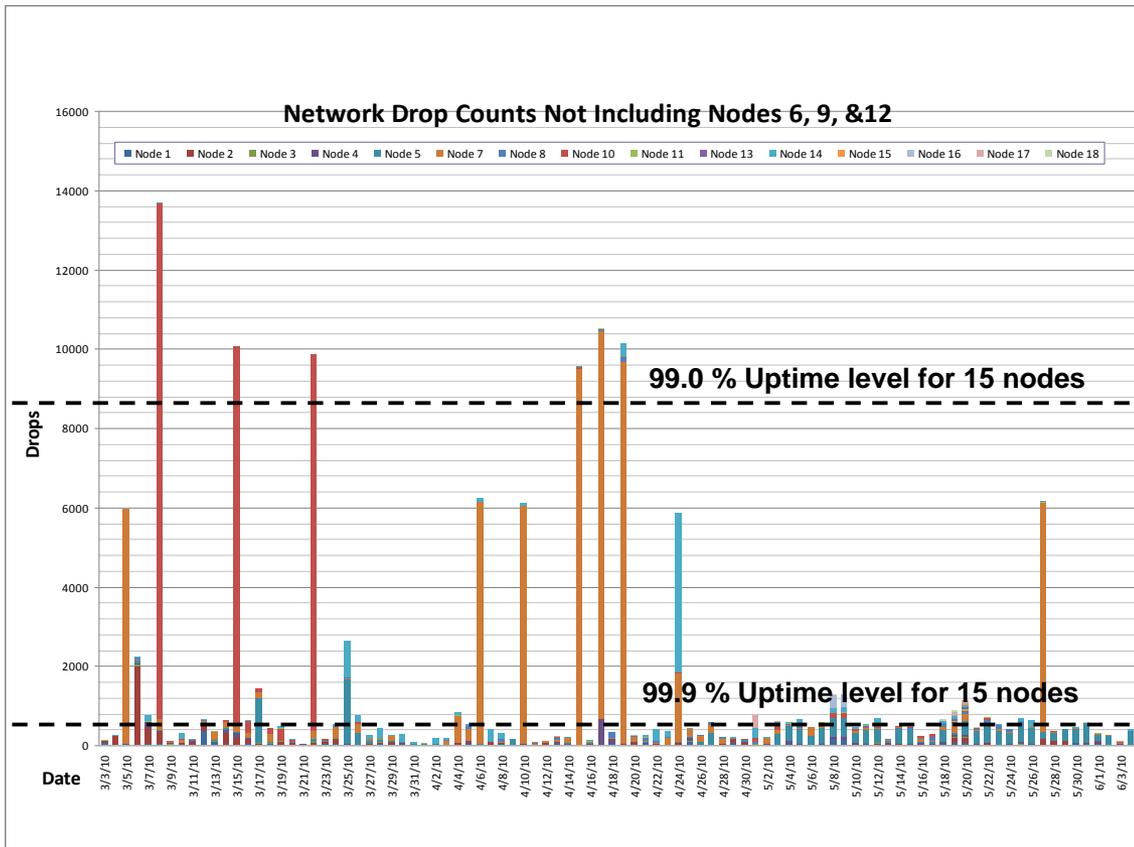
Outside array: Units deployed on tripods and cabling to sensor locations attached to fencing

# Data Characteristics

- **LINE data sampling rate of the entire sensor network is approximately 1.2 seconds (max) but values are recorded by data server every 1.0 sec**
  - Results in repeated values.
  - 2-sec data would eliminate this problem
  - Sub-second sampling under development at NI
- **Plant Power Data frequency is more than 1.2 sec???**

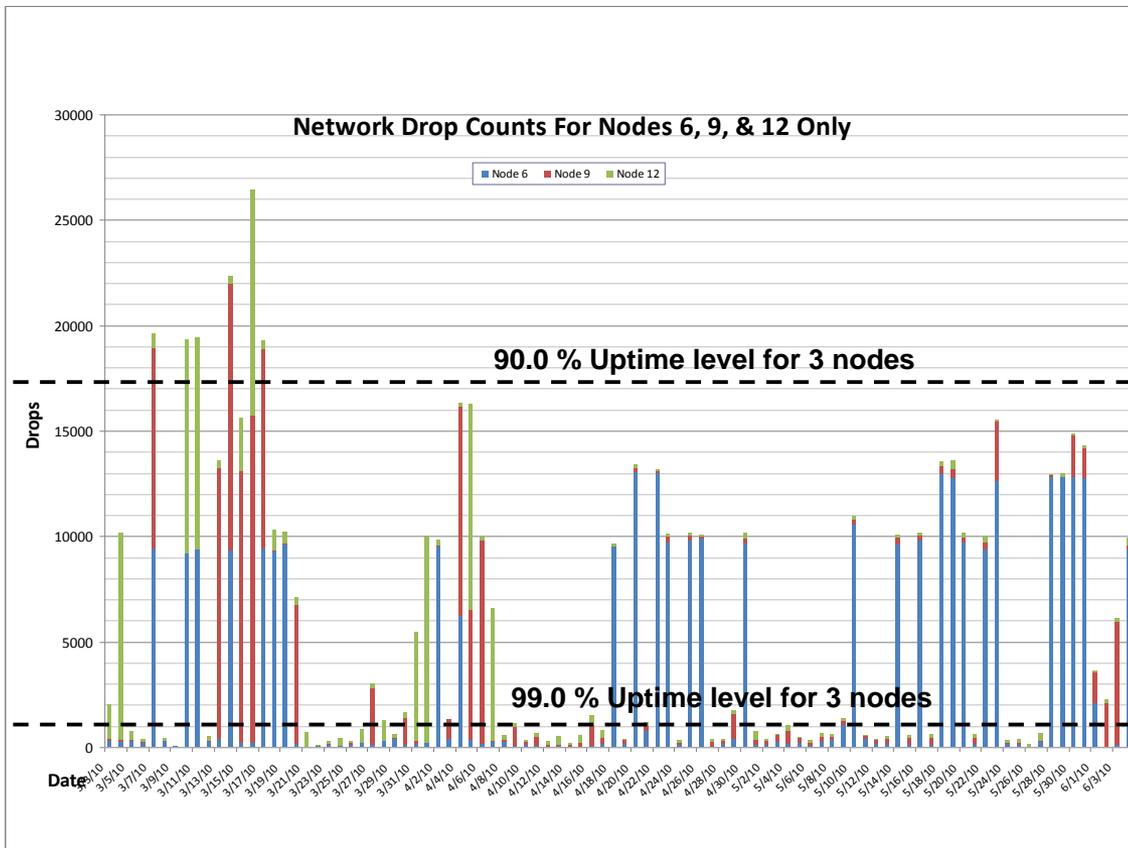


# RF Mesh Network Uptime - Good Connectivity



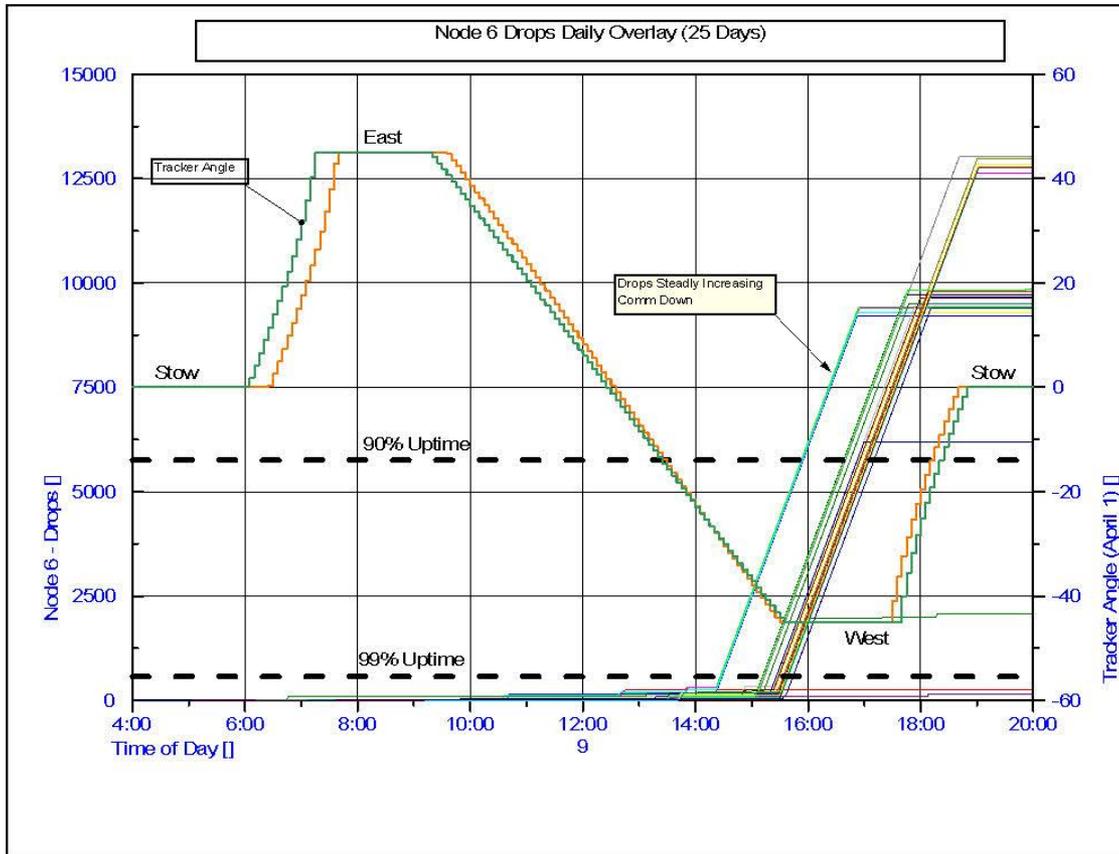
- 93 days of composite RF network drop counts for 15 nodes with good connectivity
- Desired 99.9% uptime threshold represents 60 occurrences (~ 1 minute) of data patching per day from previous sent values
- Nodes 6 and 10 over the 99.0% acceptable uptime (~10 minutes of data patching) on 6 days may be due to site activity

# RF Mesh Network Uptime - Issues



- 93 days of composite RF network drop counts for 3 nodes with transmit issues
- Approximately half the days (42 of 93) exceed acceptable 99.0% uptime threshold
- RF mesh network inability to dynamically compensate for Non-line-of-sight and array tracker orientation affects on transmission being investigated

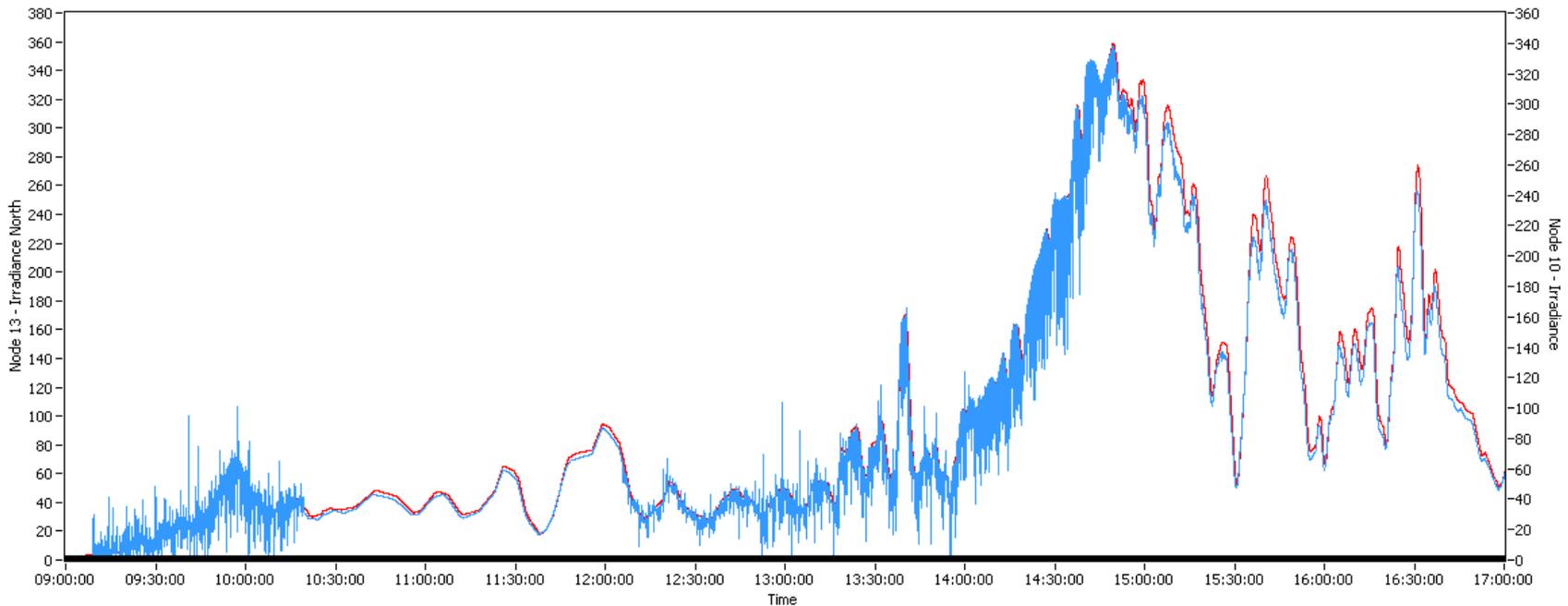
# RF drop time-of-day and Tracker Orientation correlation



- Node 6 Time-of-Day RF drops for 25 days overlaid with 2 days of tracker angle profiles
- Most of Node 6 drops begin when tracker goes to west orientation
- Network routing recording tools being acquired to analyze optimal antenna and router placements

# Temperature and Irradiance Sensor Noise

- Few nodes experiencing sporadic noise on temperature and irradiance channels mainly during morning hours
- Equipment replacement and correlation to tracker motion affecting cable routing being investigated





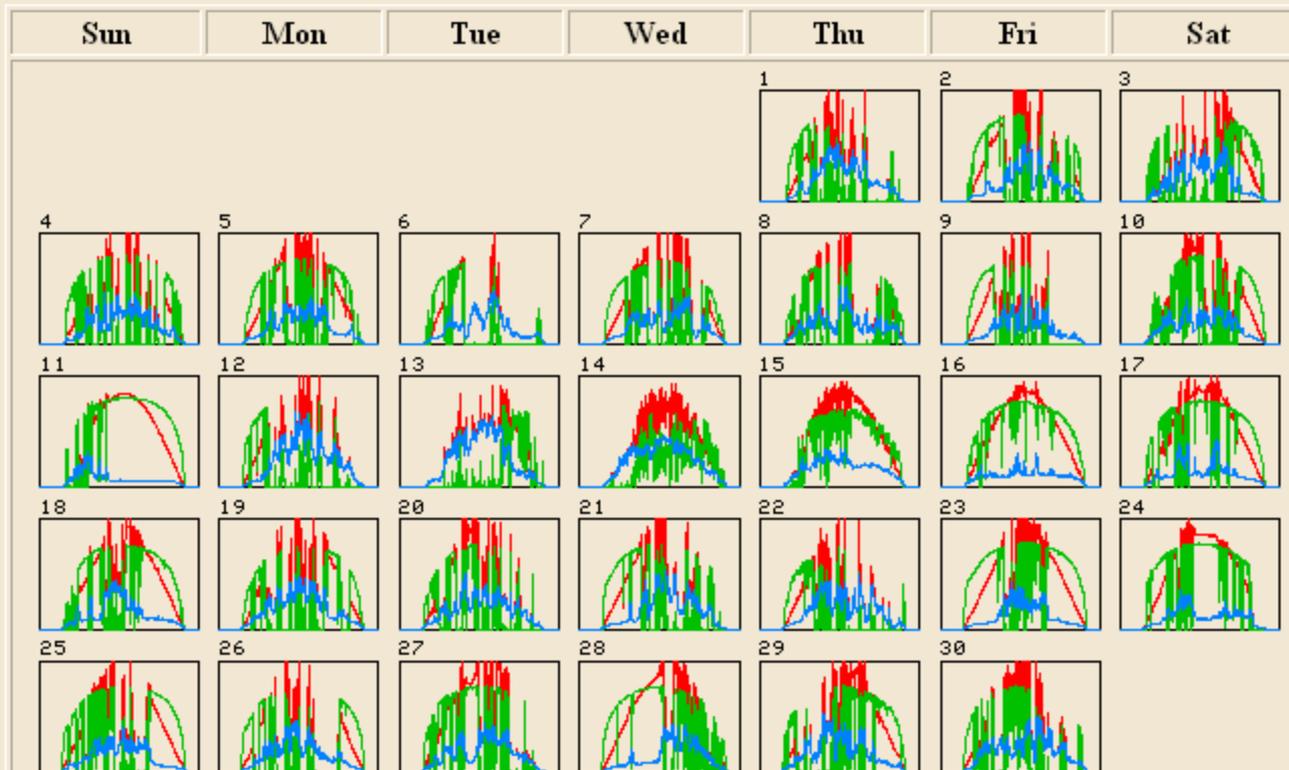
# Modeling and Analysis Approaches

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- **Characterize temporal and spatial patterns of irradiance**
  - **Visual inspection and animation**
- **Examine dynamic behavior of irradiance and module temperatures**
- **Predict PV output variability from irradiance network**

# Characterize Temporal Patterns

*SOLRMAP La Ola Lanai (RSR)*  
April 2010 Solar Calendar

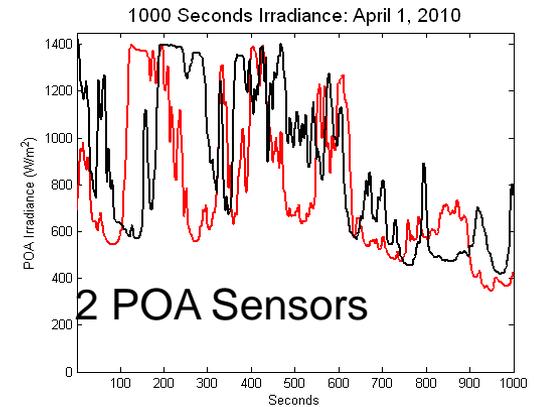
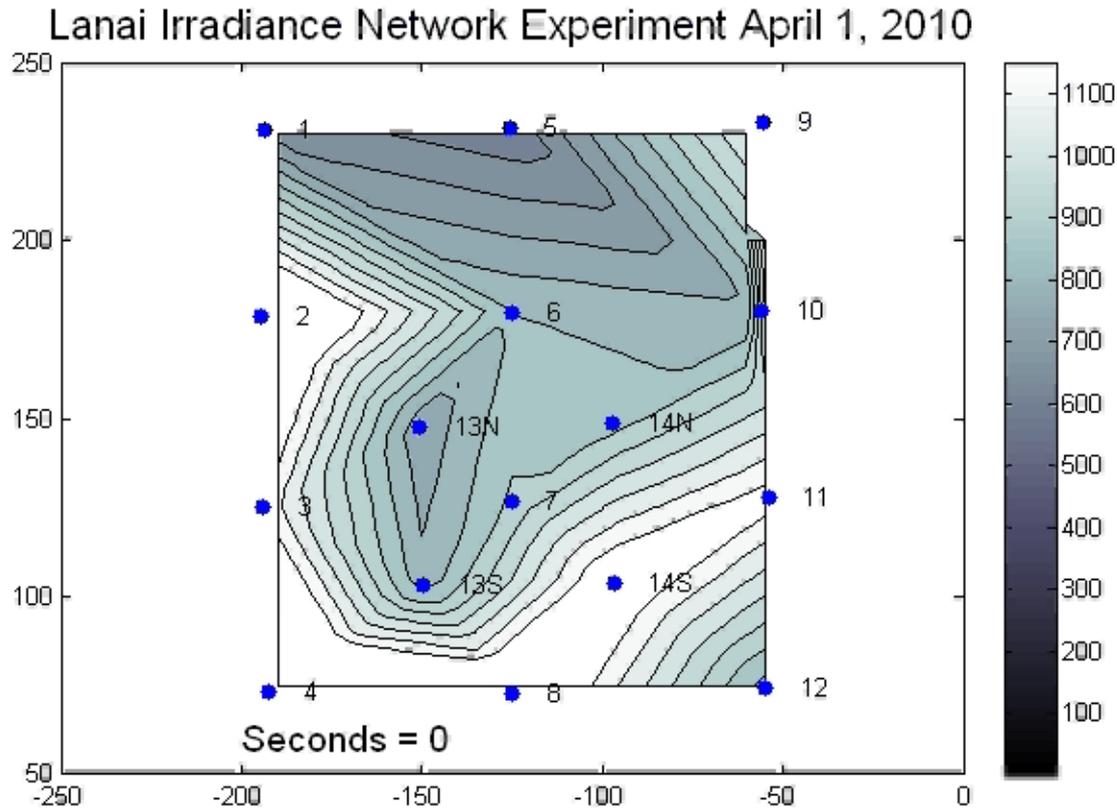


Red = Global  
Green = DNI  
Blue = Diffuse

Hard to find a  
clear day!

Source: [http://www.nrel.gov/midc/la\\_ola\\_lanai/](http://www.nrel.gov/midc/la_ola_lanai/)

# Characterize Spatial Patterns

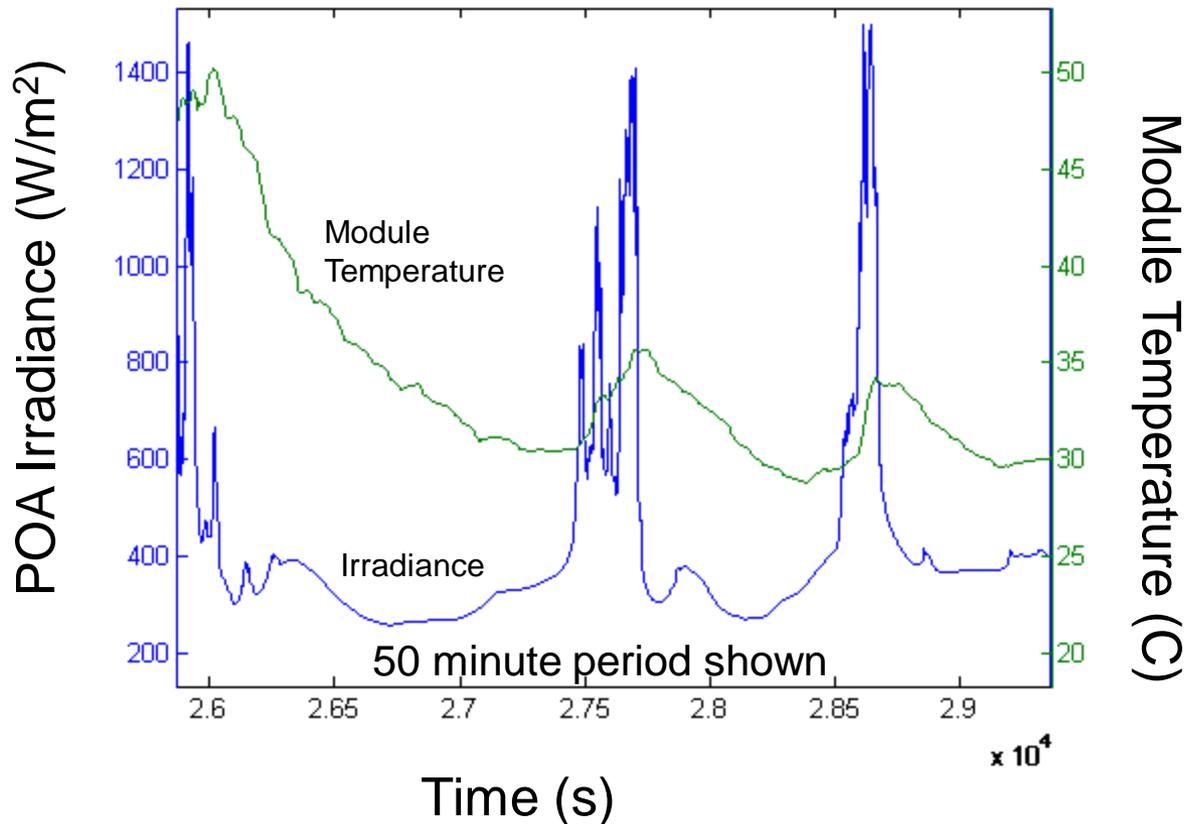


Question: How much of the spatial variability is due to sensor noise and repeated values?

POA Sensor Network

# Module Thermal Response

- Irradiance changes much faster than module temperature.
- Steady-state model (e.g. King et al., 2004) will not work.
- Transient thermal modeling approaches will be applied.





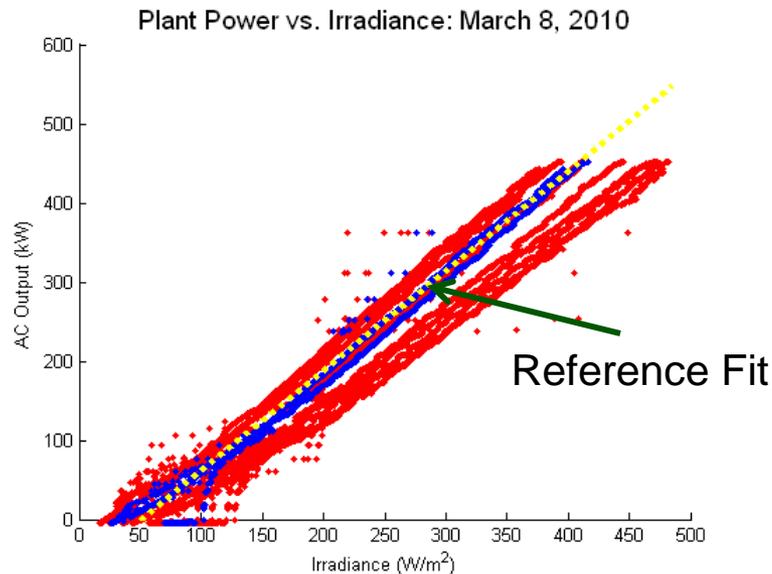
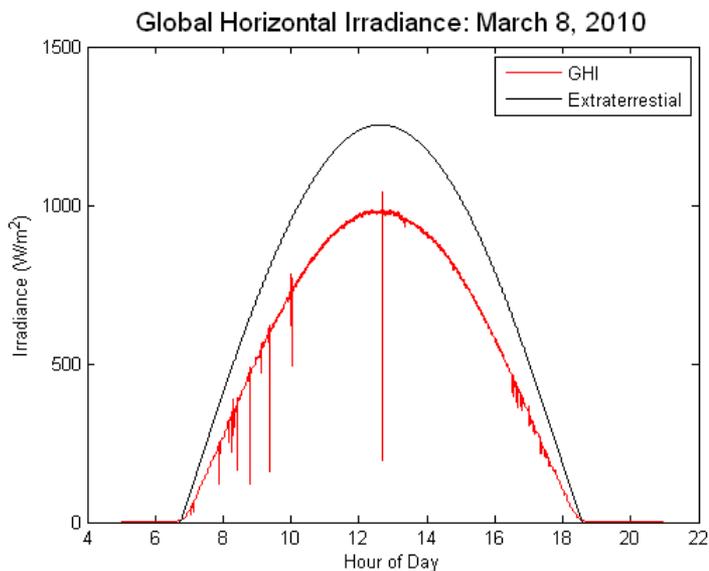
# Prediction of PV Output from Sensor Network

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- **Compare irradiance and plant AC power output**
  - Single sensor
  - Network average irradiance for each second
- **Develop model on clear day and test on variable days.**
- **Examine data from uncurtailed periods**
  - Each of the 12 inverters are curtailed separately at 50 kW.
    - If half the array is in dark and half in full sun, array will produce 300 kW not 600 kW.

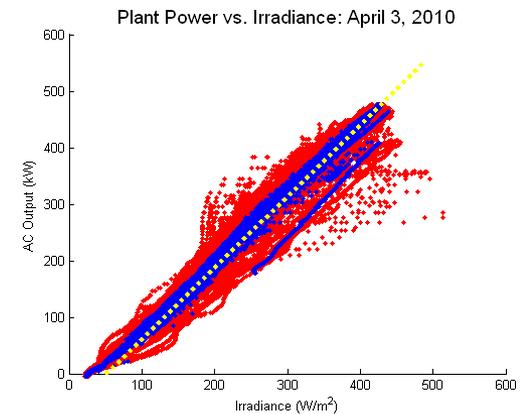
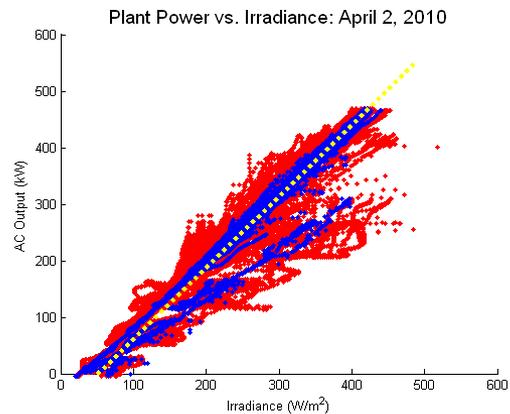
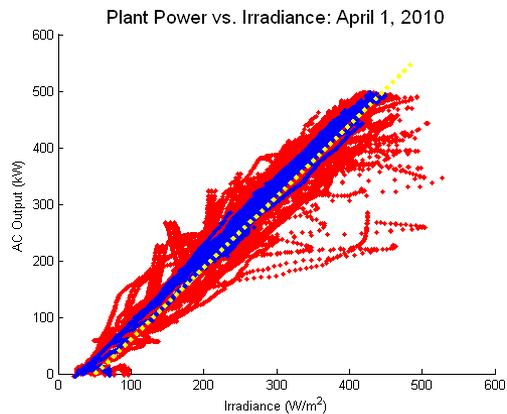
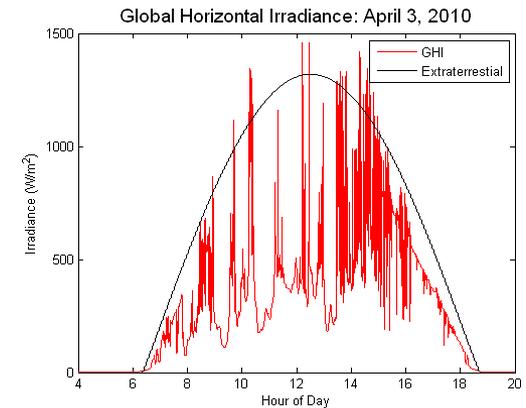
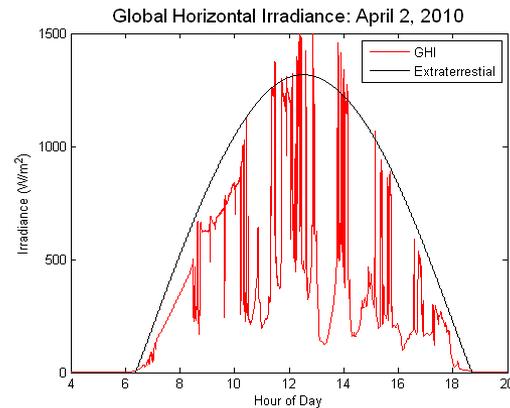
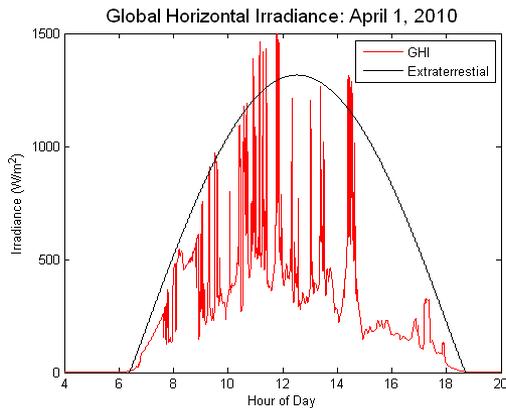
# Plant Power vs. Irradiance: Clear Day

- **Uncurtailed power is nearly linear with spatially averaged irradiance on clear day.**



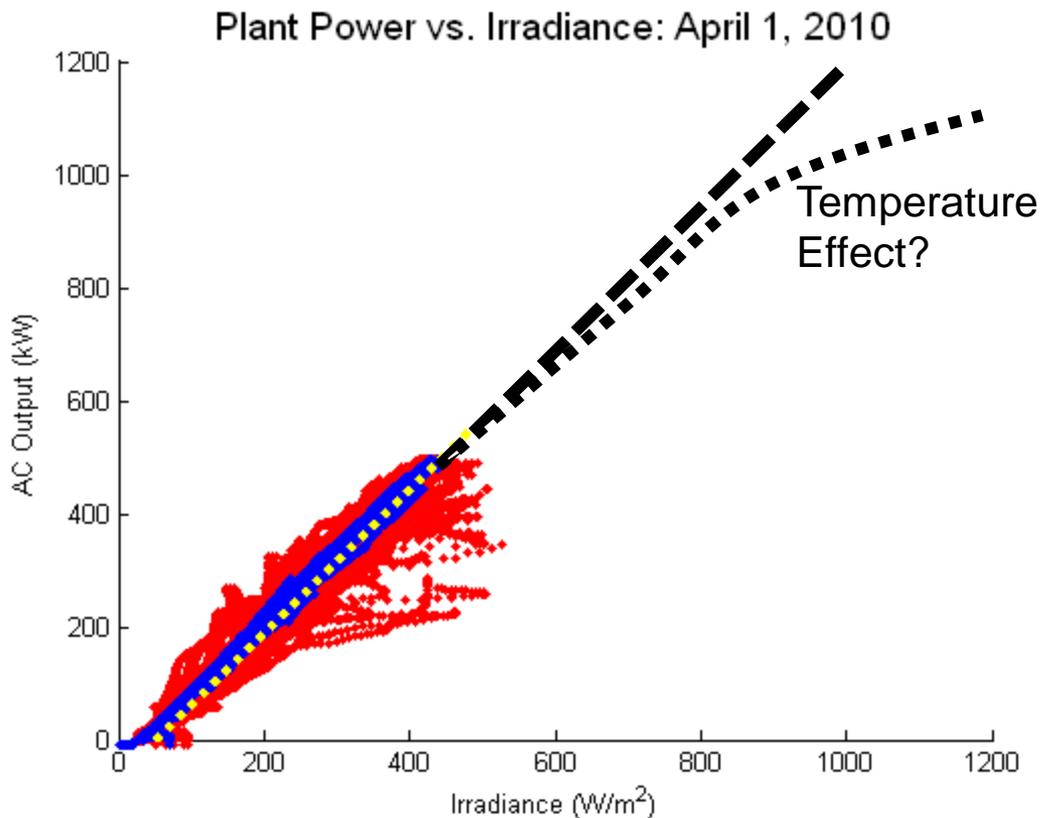
Red = Single Irradiance Sensors (5)  
Blue = Network Average Irradiance

# Plant Power vs. Irradiance: Variable Day



Red = Single Irradiance Sensor  
Blue = Network Average Irradiance

# Plant Power vs. Irradiance: Prediction



- Spatial average irradiance is a good predictor of plant power output.
- At higher irradiance the apparent linear trend may deviate due to rising cell temperatures



# Summary

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- **Sandia and SunPower have installed an irradiance network at Lanai La Ola PV Plant**
  - **Wireless, does not interfere with plant operation**
- **Data issues have been identified and are being addressed**
  - **Communication drop outs, sensor noise, sampling rates..., etc.**
- **Preliminary analysis suggests that spatial average irradiance is a good predictor of plant output.**

# IEEE PVSC Lana'i

## Lana'i La Ola Addendum

### Lana'i 100% Renewables



Sandia  
National  
Laboratories

The "Lana'i 100% Renewables" project is part of the Hawaii Clean Energy Initiative, a partnership with the State of Hawaii and the US Department of Energy. Isle developer Castle & Cooke Resorts, LLC has completed Hawaii's largest single-site 1.2 MW solar farm. La Ola solar farm is a prime example of pioneering high-penetration grid-tied photovoltaics where new "Smart Grid" communications and controls are being employed and evaluated. Castle & Cooke Resorts, LLC and Sandia National Laboratories have organized an IEEE PVSC Addendum opportunity to see La Ola's technical accomplishments, the installation, daily operation and future renewable energy plans. This addendum will consist of a technical program, a tour of the photovoltaic facility and the future wind site on Lana'i. It will take place on Friday evening, June 25 and Saturday June 26, 2010. Special rates are being offered at Four Seasons Resorts Lana'i. The special rates are also extended beyond the addendum technical program and tour for additional unique island activities. Please see the attached links for reservations and more information about the installation, the advanced high-penetration, communications, resource prediction, energy management, and grid integration. Register early (no fee); rooms are limited and flights may have to be added.

### Draft Program and Activities

See Links on PVSC-35 and Sandia sites (<http://photovoltaics.sandia.gov/main.html>) for registration, reservation and program details.

- Addendum rooms blocked at Four Seasons Lana'i Resorts (+1-800-321-4666)
- Friday, June 25. Transportation from Oahu to Lana'i; Island Air ([www.islandair.com](http://www.islandair.com))
- Light evening reception/welcome (TBD)

- 1.5MW DC Hawaii's largest Solar Farm in service 12/19/2008
- 10 acres, 12 separate arrays, 7,000+ panels, tracker system
- 3,000MWhour production = 30% of Lana'i's daytime peak demand, 10% of Lana'i's annual demand
- 2,300 tons of carbon dioxide emissions eliminated annually = 5,000 barrels of oil or 237,000 gallons of gasoline
- \$1M+ in payroll to Lana'i Residents: ~22 of 25 construction jobs were filled by Lana'i Residents

### Saturday, June 26 (Breakfast Buffet followed by Morning Presentations)

|                           |                |
|---------------------------|----------------|
| LA OLA project            | Castle & Cooke |
| Grid Interconnections     | MECO           |
| DOE Solar Program Goals   | US DOE         |
| PV Array Presentation     | Sun Power      |
| Inverter/Controls         | SatCon         |
| Energy Storage for LA OLA | TBD            |
| Lana'i L.I.N.E. System    | Sandia         |
| Distributed PV Concept    | NREL           |

### Saturday, June 26, Lunch Buffet

### Saturday, June 26, Tour of PV and Wind sites

- Pick up and drop of at airport, hotels, trilogy snorkeling, "Lana'i Culture and Heritage Center, are part of the island transportation package.



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**THANK YOU**