Exceptional service in the national interest

Sandia National Laboratories

Ota City:

Characterizing Output Variability from 553 Homes with Residential PV Systems

Matthew Lave

U.S.-Japan Collaborative Smart Grid Project Collective Research Workshop

Dec. 5, 2013

SAND2013-10076

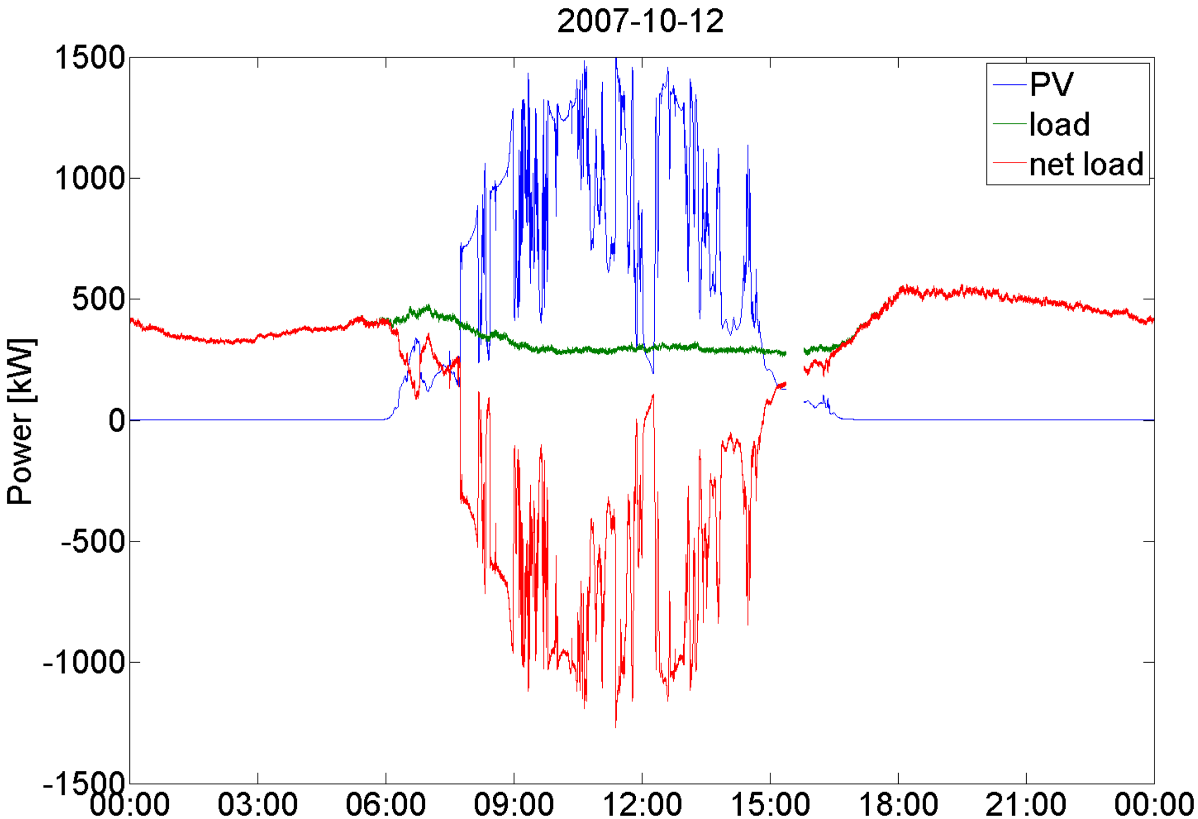
Overview

- Pal Town neighborhood in Ota City, Japan a unique test bed of high-penetration distributed PV
  - NEDO installed PV on ~80% of rooftops in neighborhood
  - Data collected every 1-second

- Sandia conducted analysis with assistance from Kandenko

High Penetration!

- In the Pal Town neighborhood, PV production can be about 3 times larger than load.
- PV variability dominates net load variability.



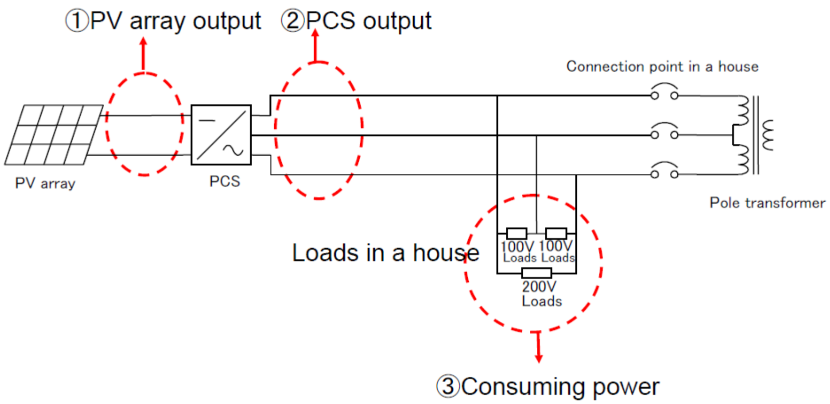
Ota City Data Set

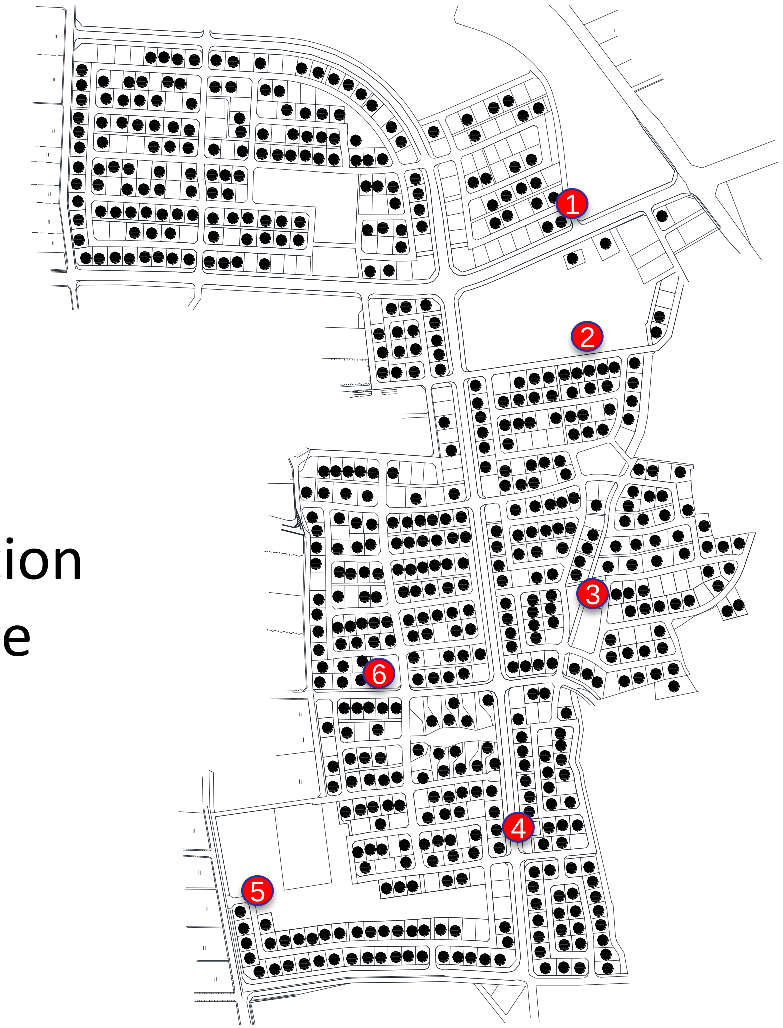
Ota City PV System

- 553 homes with PV (~4kW each)
- Single feeder (6.6kV, 3.26km)

Data available to Sandia

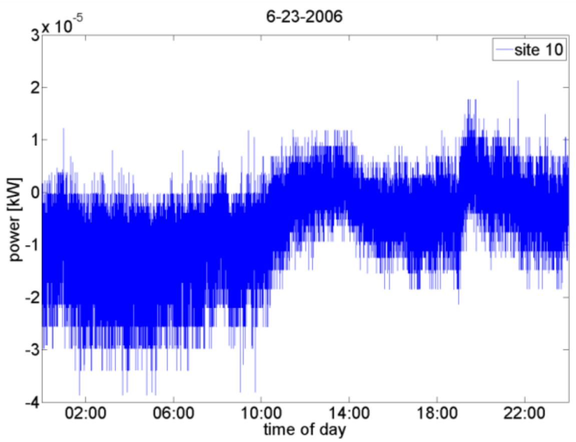
- 2/1/06 to 12/31/07, 1-sec resolution
- PV output and load for each house
- Irradiance at 6 locations



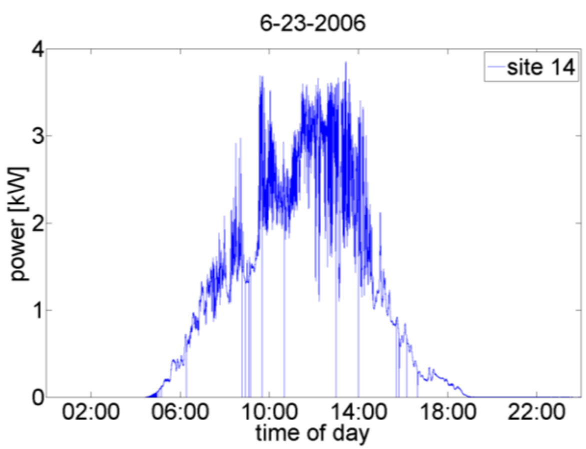


Pictures courtesy of Kandenko

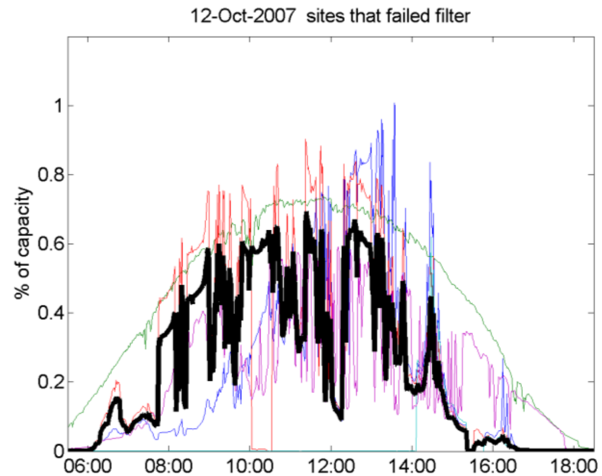
Data Quality Control



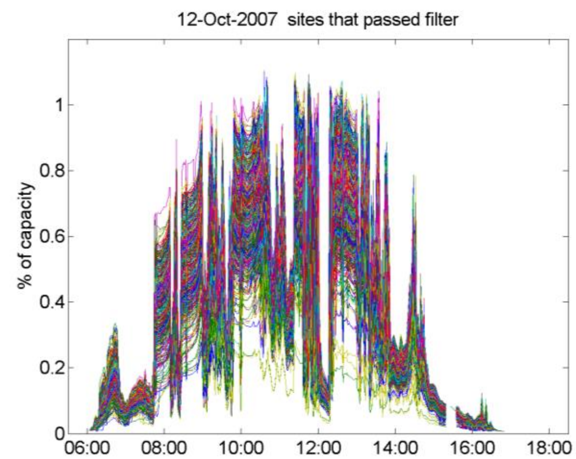
72 houses eliminated



times with missing data eliminated



4 houses eliminated



477 houses kept

Some sites reported essentially zero all day (top), or had “outages” where missing data was recorded as zero (bottom).

Aggressive correlation filter applied to eliminate unreasonable sites (i.e., green line in top figure).

Summary of Work

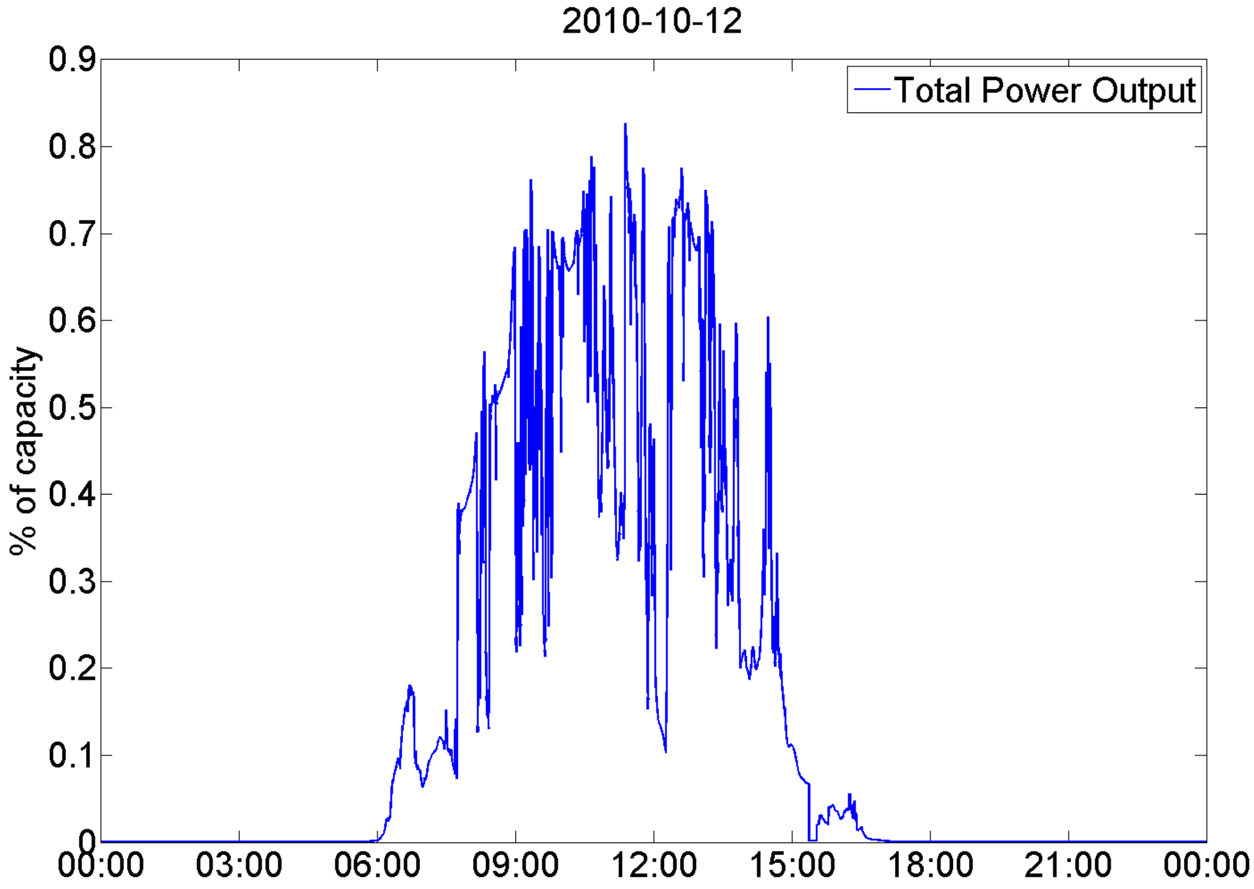
- Analysis focused on solar power variability, which can lead to issues on electric grids with high PV penetration:
  - Flicker
  - Voltage rise
  - Balancing issues
- The main cause of short-timescale variability is the movement of cloud shadows.

Two methods used to examine variability:

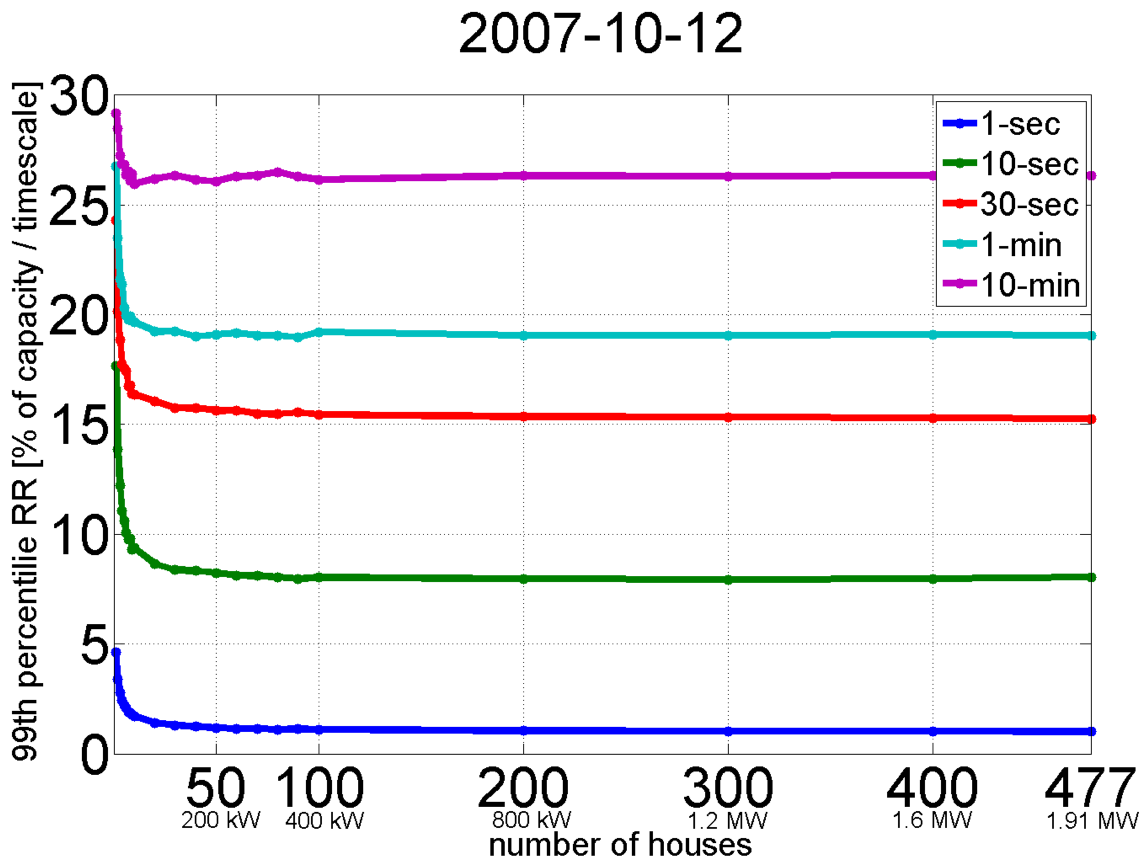
- Ramp rates (RRs) of a single house and the aggregates RRs of many houses showed the benefit of aggregation.
- Wavelet decomposition quantified the variability reduction at each timescale that was achieved by aggregating all houses.

Example Day

Example highly-variable day studied: October 12, 2007



Ramp Rates



- At all timescales, RRs decrease as the number of houses aggregated increases.
  - Amount of decrease in RRs is different at each timescale.

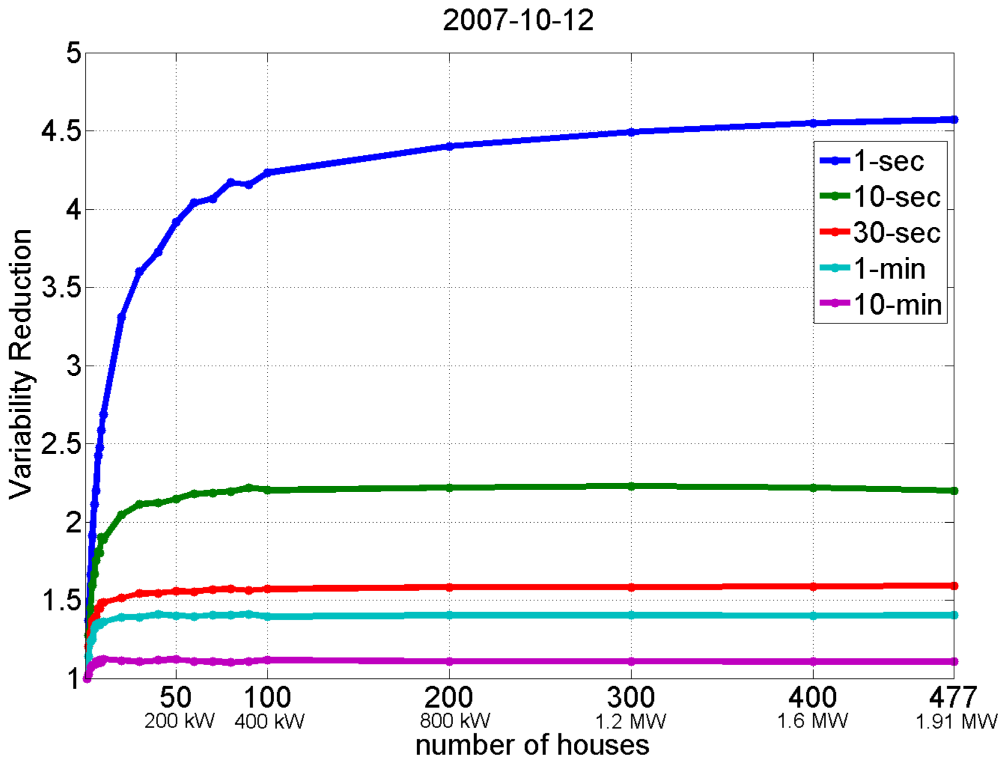
Variability Reduction from RRs

Define the variability reduction as:

$$VR = \frac{RR(many\ houses)}{RR(1{-}house)}$$

$VR = 1$: no smoothing

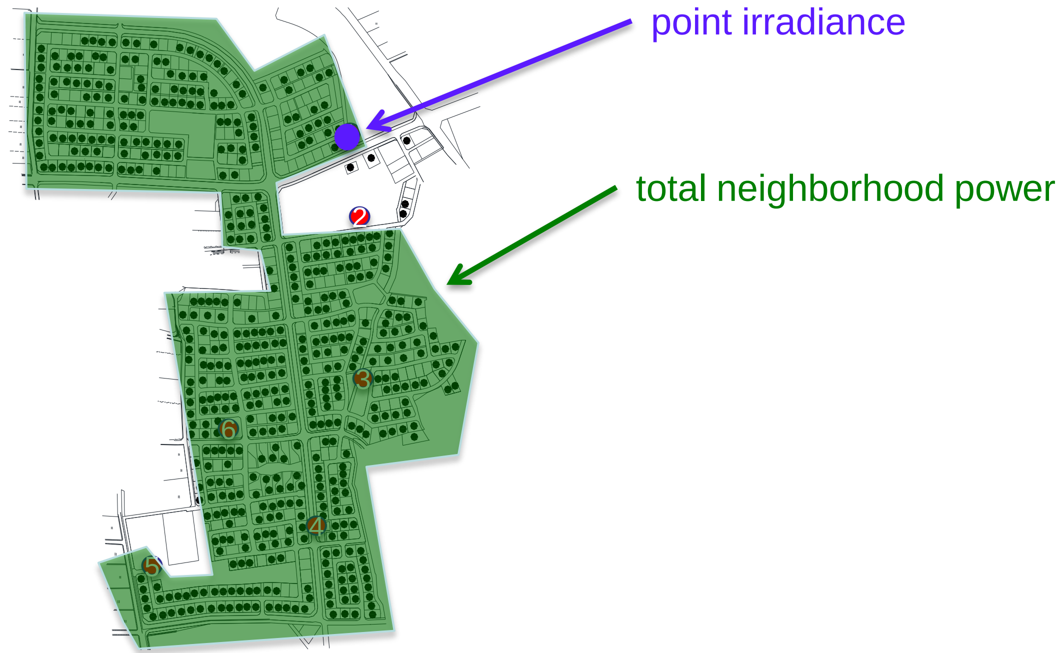
$VR > 1$: smoothing due to aggregation of houses



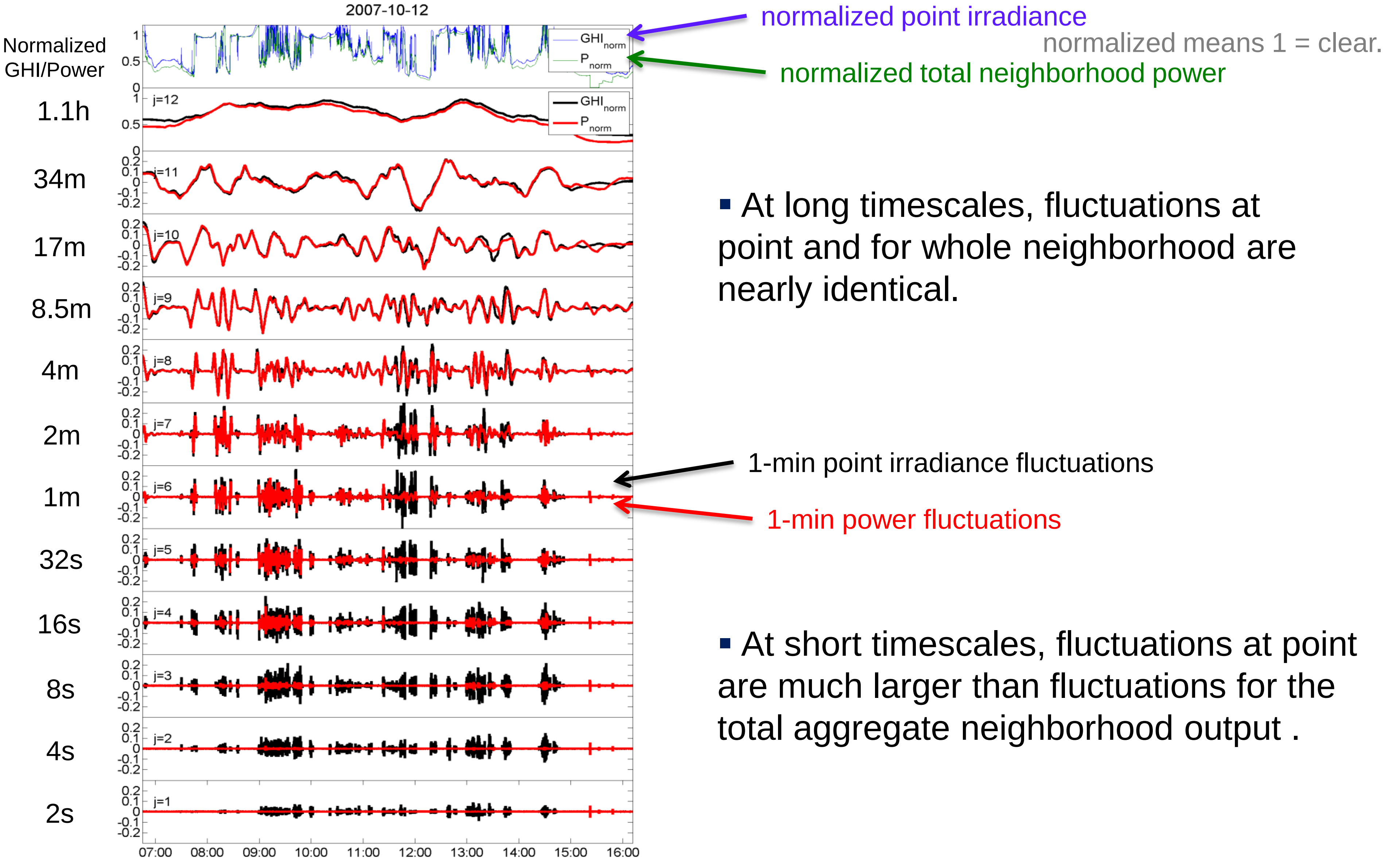
1-sec RRs are always reduced as more houses are added, but longer timescale RRs reach a limit at ~100 houses.

Wavelet Decomposition

- From RR analysis, we see that variability scales differently at different timescales.
- To further examine this behavior, we use a wavelet decomposition to separate fluctuations by timescale.
  - Compare an irradiance point sensor to the total neighborhood power output:



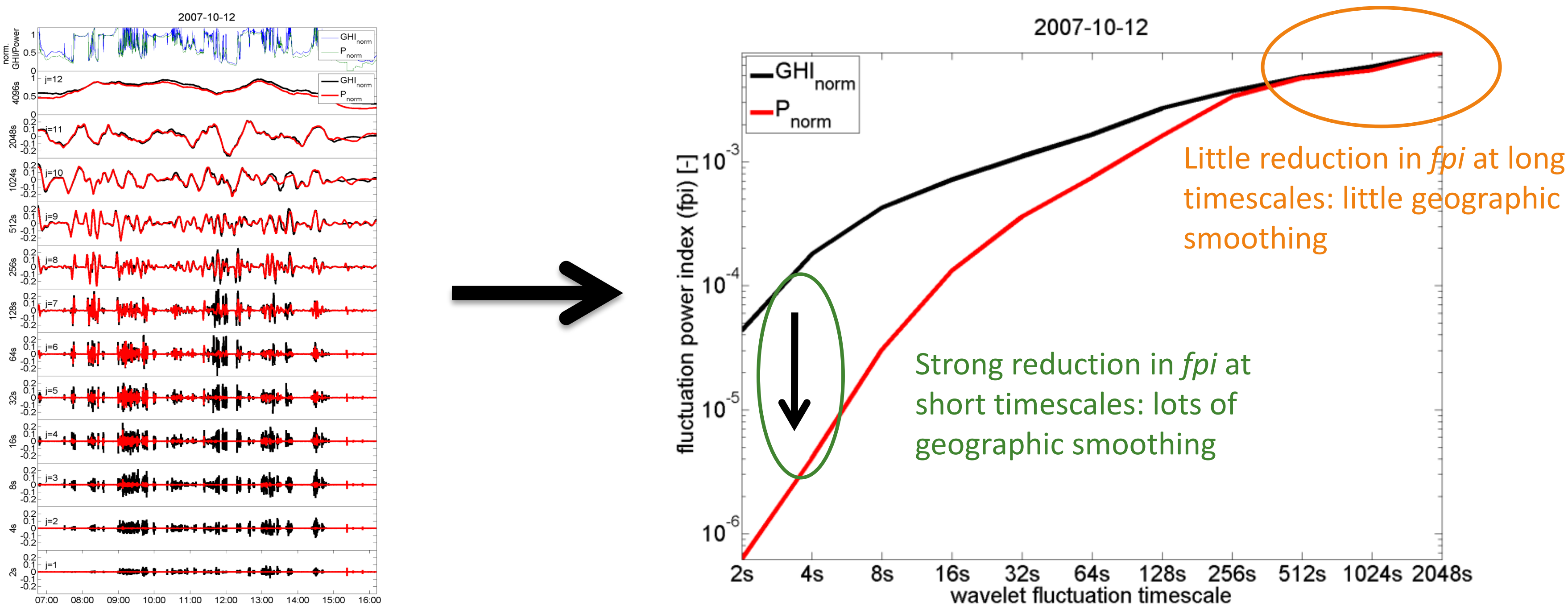
Wavelet Decomposition



- At long timescales, fluctuations at point and for whole neighborhood are nearly identical.
- At short timescales, fluctuations at point are much larger than fluctuations for the total aggregate neighborhood output .

Fluctuation Power Index

- From the wavelet decomposition, we can quantify the variability using the fluctuation power index:
  - *fpi* = mean squared value of fluctuations at each timescale (*fpi* is similar to the mean ramp rate)



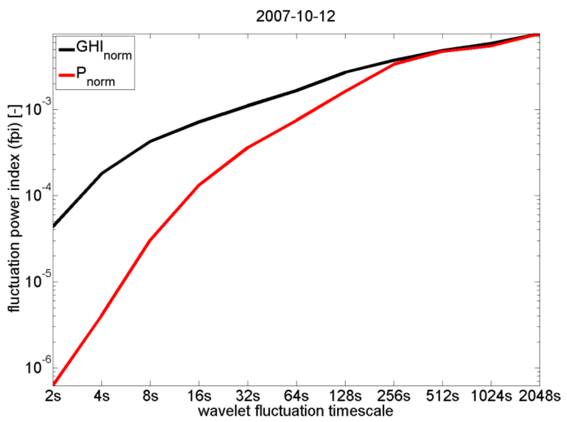
Variability Reduction

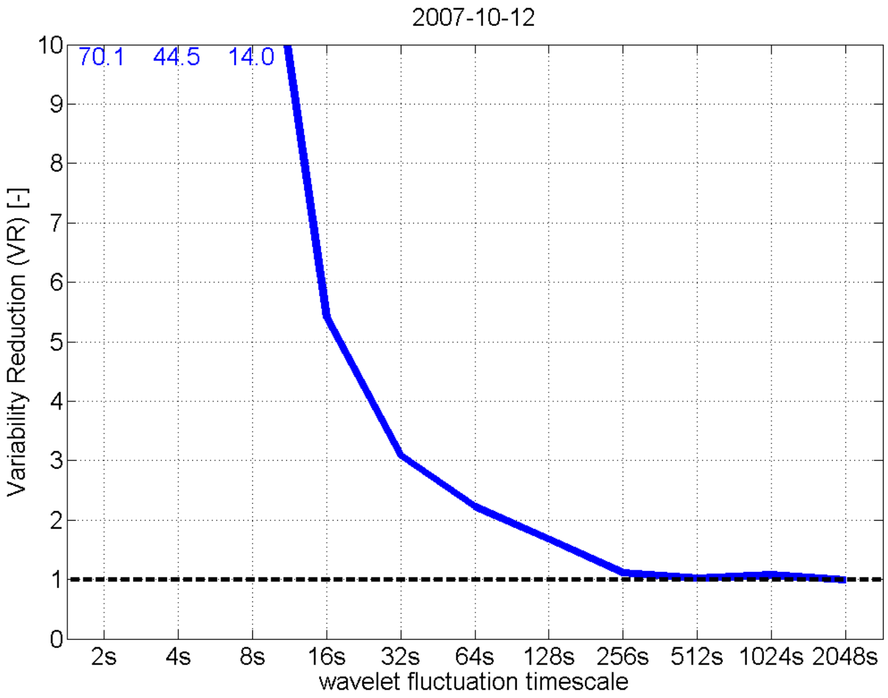
- The wavelet variability reduction is defined:

$$VR = \frac{fpi(total\ neighborhood\ power)}{fpi(point\ sensor)}$$

$VR = 1$: no smoothing

$VR > 1$: smoothing due to aggregation of houses





Conclusions from Ota City

- Aggregating the output from many houses can significantly reduce the variability.

- Variability decreases exponentially as more houses are aggregated.
  - For all RR timescales except 1-second, a limit was reached whereby adding additional houses to the aggregate output did not reduce the variability.

- The benefit of aggregation depends on the timescale:
  - Short-timescale (<1-minute) variability is significantly reduced when aggregating all houses.
  - Long-timescale (>4-minute) variability is not significantly reduced when aggregating all houses.

Questions/Comments?

Thank You!

mlave@sandia.gov