National Renewable Energy Laboratory
Innovation for Our Energy Future

Development of Data Sets for PV Integration Studies

Utility-scale PV Variability Workshop

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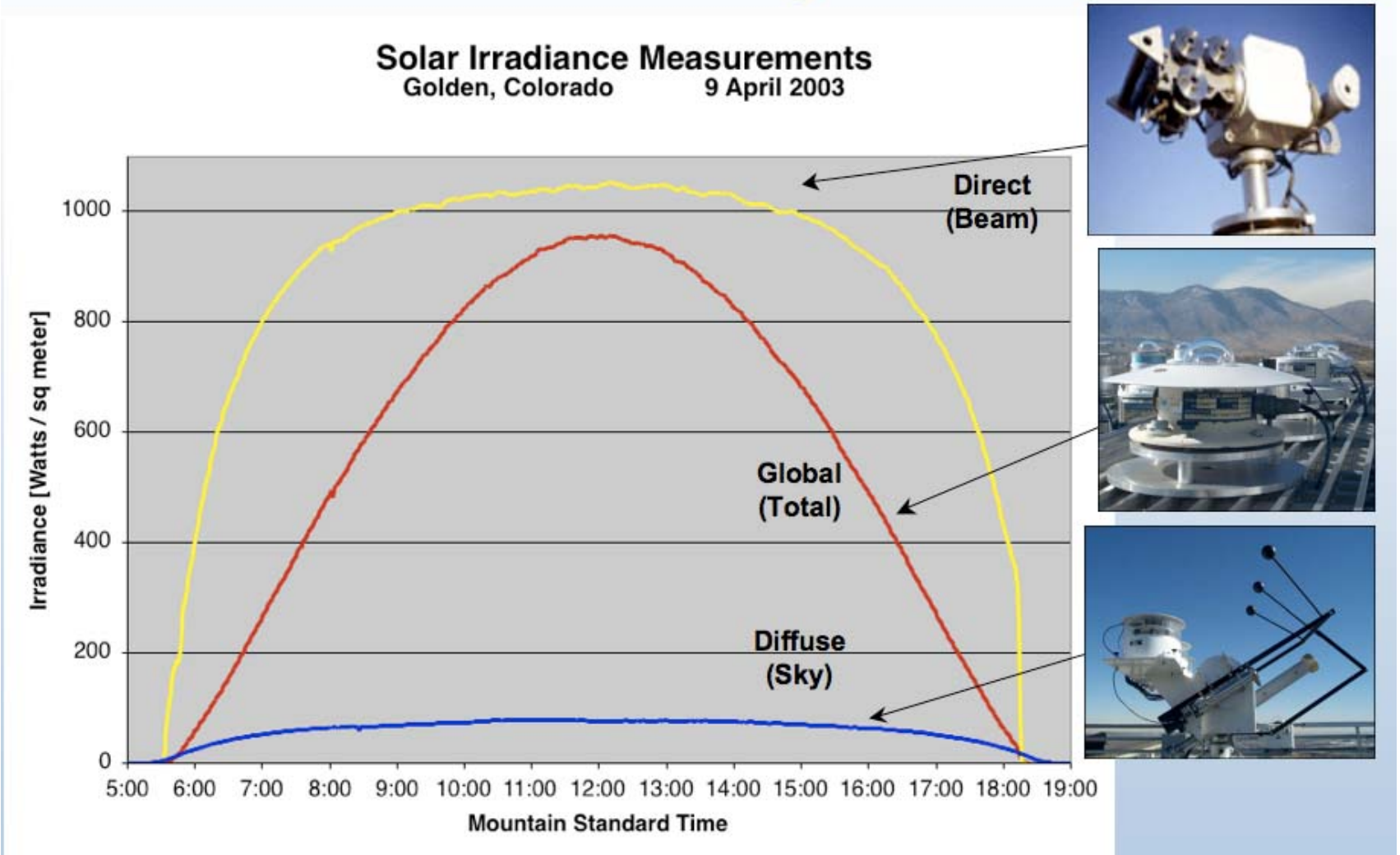
7 October 2009

Problem Identification

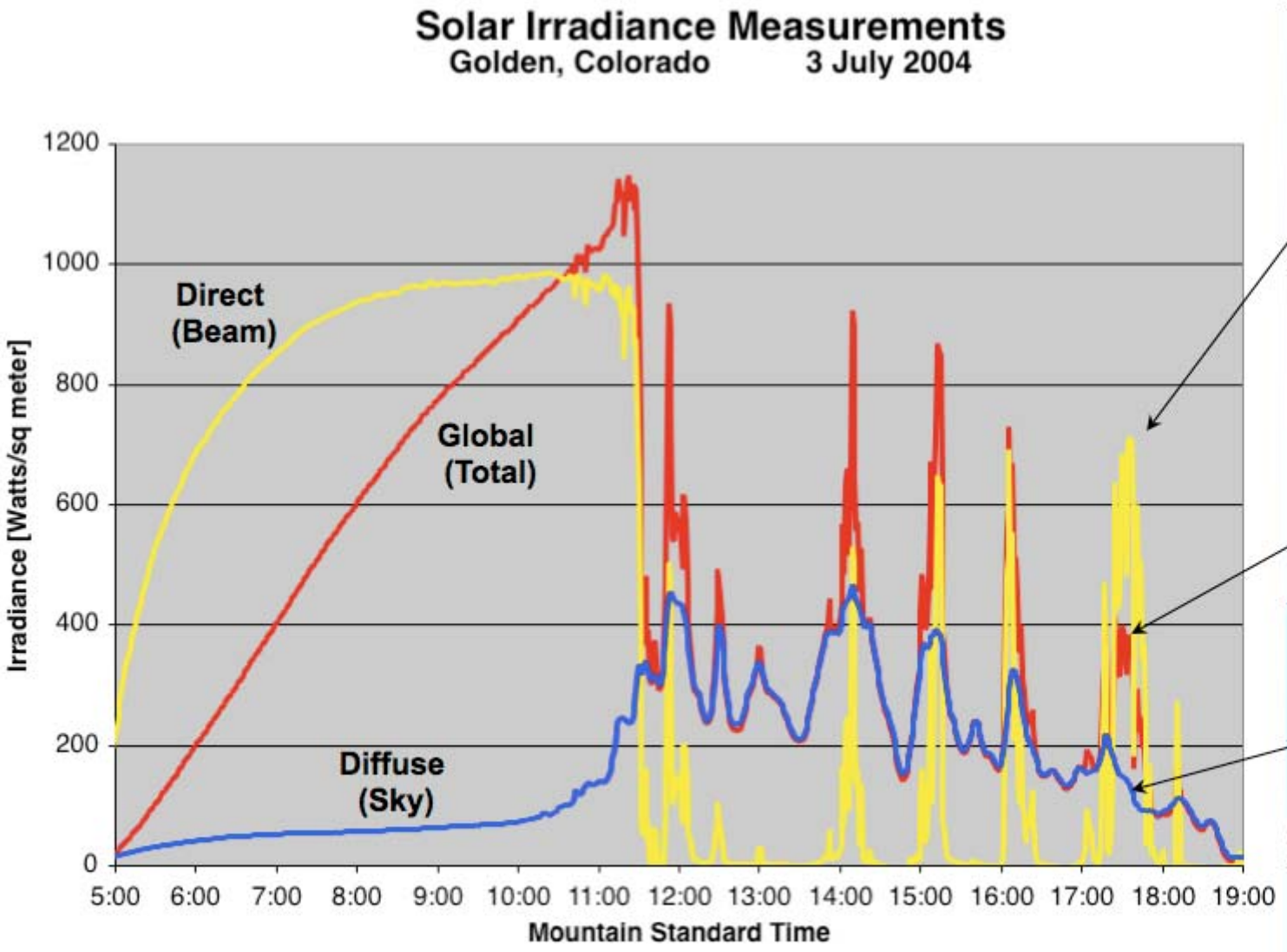
- Analytical studies need consistent data for any location, with greater resolution (temporal and spatial) than the current data sets provide.
- Solar or PV Measured (Real) data – Spatially sparse but temporally dense – applies only to a single point or a small area
- Satellite (Modeled) data – Spatially denser but temporally sparse. Fundamental limitations preclude their direct use for dispatch and grid stability.
- Existing modeled and measured data must be combined, using a detailed spatial and temporal analysis, to match the desired analysis.
- Unrealistic outcomes must be avoided!

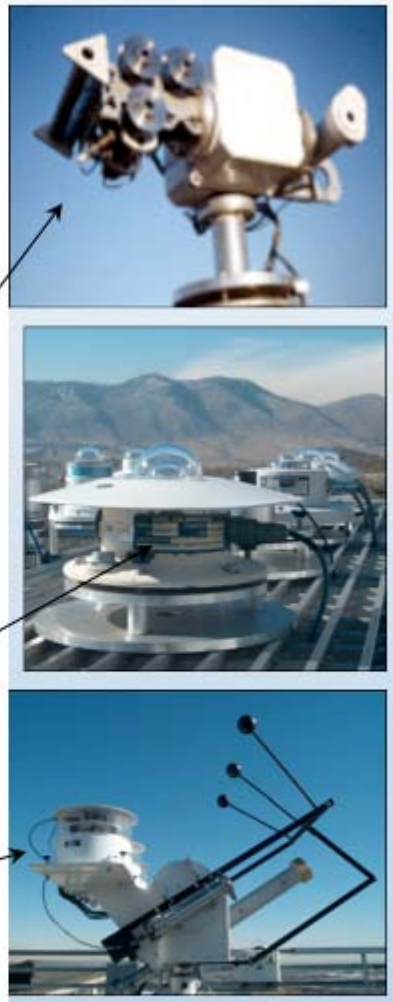
Solar Radiation and PV

Clear Sky



Partly Cloudy Sky

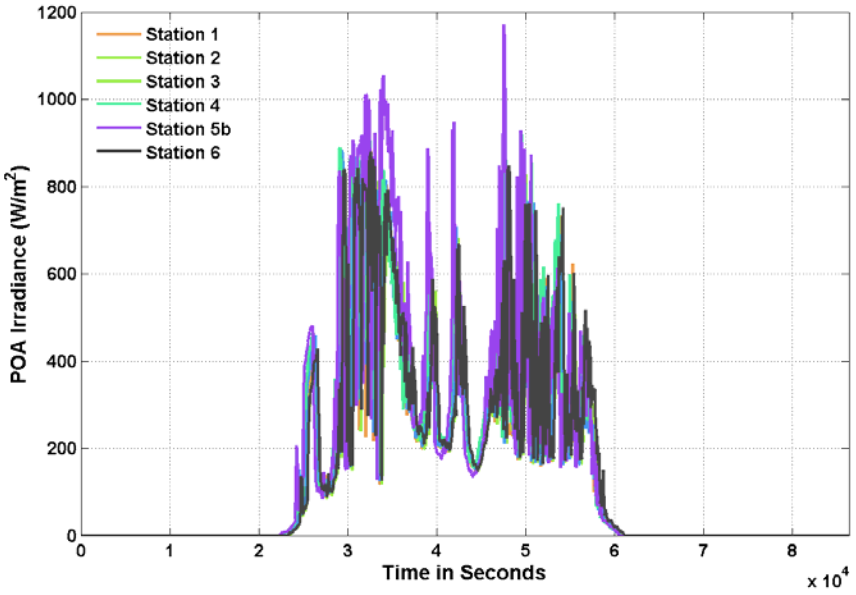




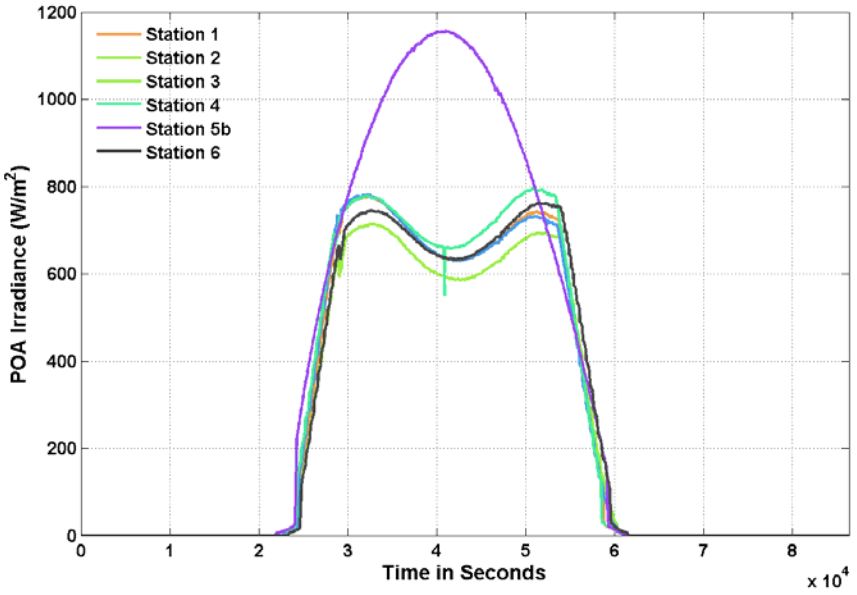
http://www.nrel.gov/midc/srrl_bms

Example of 60 second "averaging" and "sampling" – POA Irradiance

Partly Cloudy Day



Clear Day



WWSIS PV Modeling Approach

Western Wind and Solar Integration Study

Goal: Assess the grid environment under high penetrations of wind, CSP, PV.

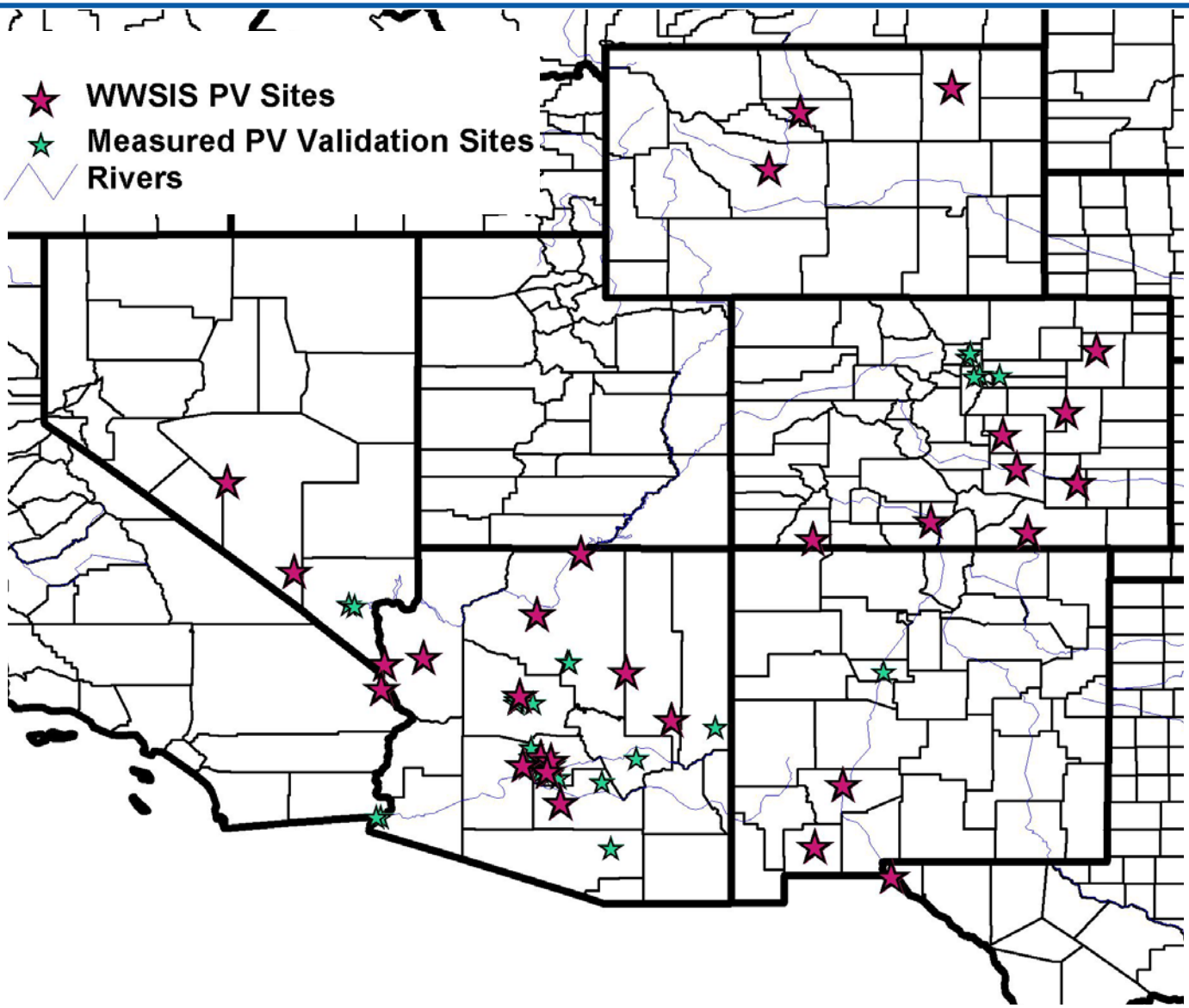
Required: PV output data for any location in SW US, 10 minute time step.

Analysis focused on 10 minute ramp rates of load and renewables.

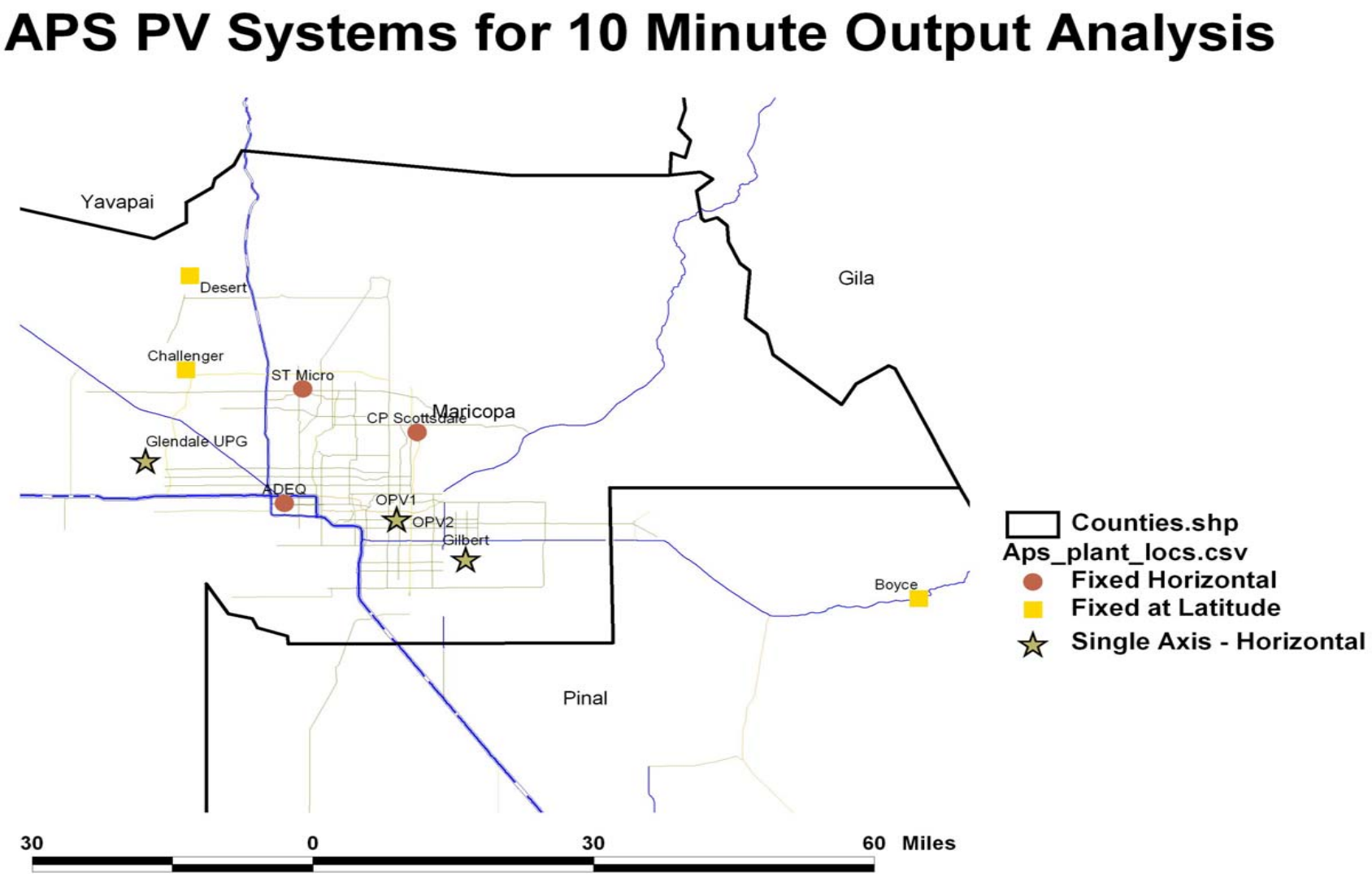
Input Data – Hourly satellite estimated solar resource, and surface measured weather data.

Output – Estimated 10 minute power production from a mixture of PV systems totaling 100 MW

WWSIS PV Modeling at 29 Sites



PV Output Data for Model Validation



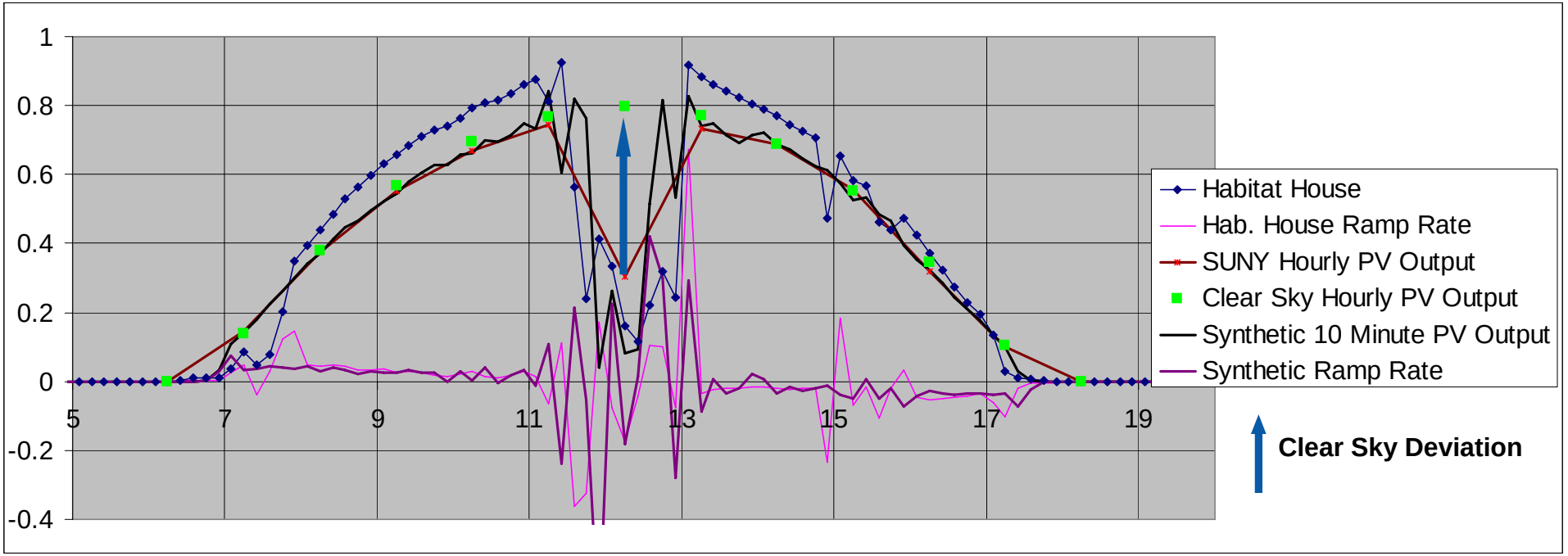
Providing PV data for Analytical Studies

1. Produce a time series of solar measured data, or PV output, which replicates the ramp distribution of a small system or solar radiation measurement, for each desired location.
2. If available, use **surface measured data**. Select the best data for each location in your scenario, using GIS techniques
3. If not enough measured data is available, **create a model** to synthesize the time series you need.
4. Use a **lowpass filter** to modify the ramp rates of each time series to match the PV deployment scenario.
5. Assess the **spatial correlation** between the sites you have chosen in your scenario. Assure that there is not too much or too little correlation between and among the sites.

WWSIS Solar Data Requirements

- Outputs should be consistent, even from locations far from any measured data.
- Initial requirement is for 10 minute average outputs, for three years (2004 - 2006).
- We assume random subhourly fluctuations are **UNCORRELATED** across all sites.
- Later requirement is output from the same systems, except at **one minute resolution**, for selected days in the two year period.
- **Ramp rates** of PV output are the most important test of **realism**.

WWSIS 10-Minute PV Model



Model **Inputs**: AC power from **PVWatts**, for…

1.) Hourly satellite modeled, 2.) 10-minute clear sky.

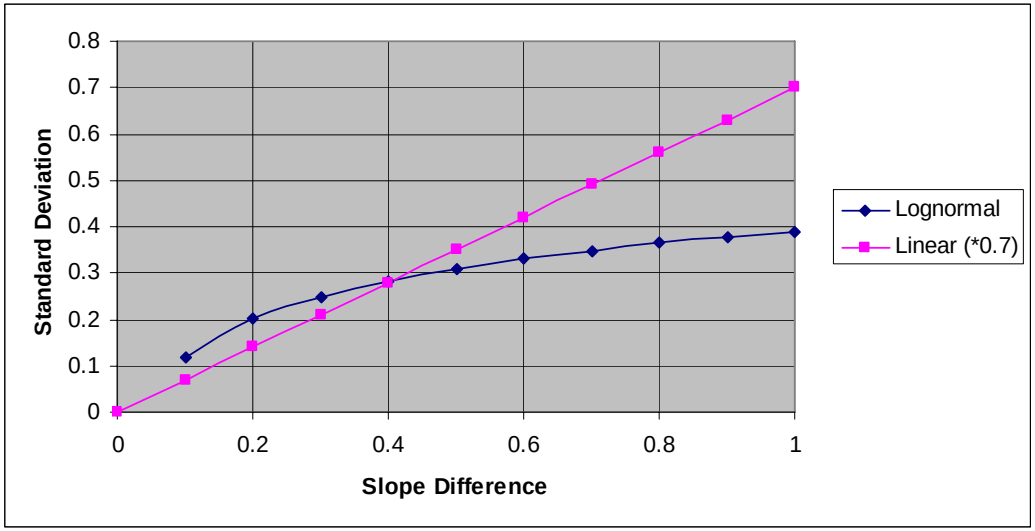
Model **Outputs**: Synthetic AC power on 10 minutes, interpolated to match satellite, random fluctuations to match annual ramp distribution

WWSIS Model Approach

1. **Normalize** all data to percent of **DC power rating**.
2. Find hourly (absolute) deviation between clear sky and modeled.
3. Use transformation function to match slope difference of deviations to Standard Deviation of random fluctuations

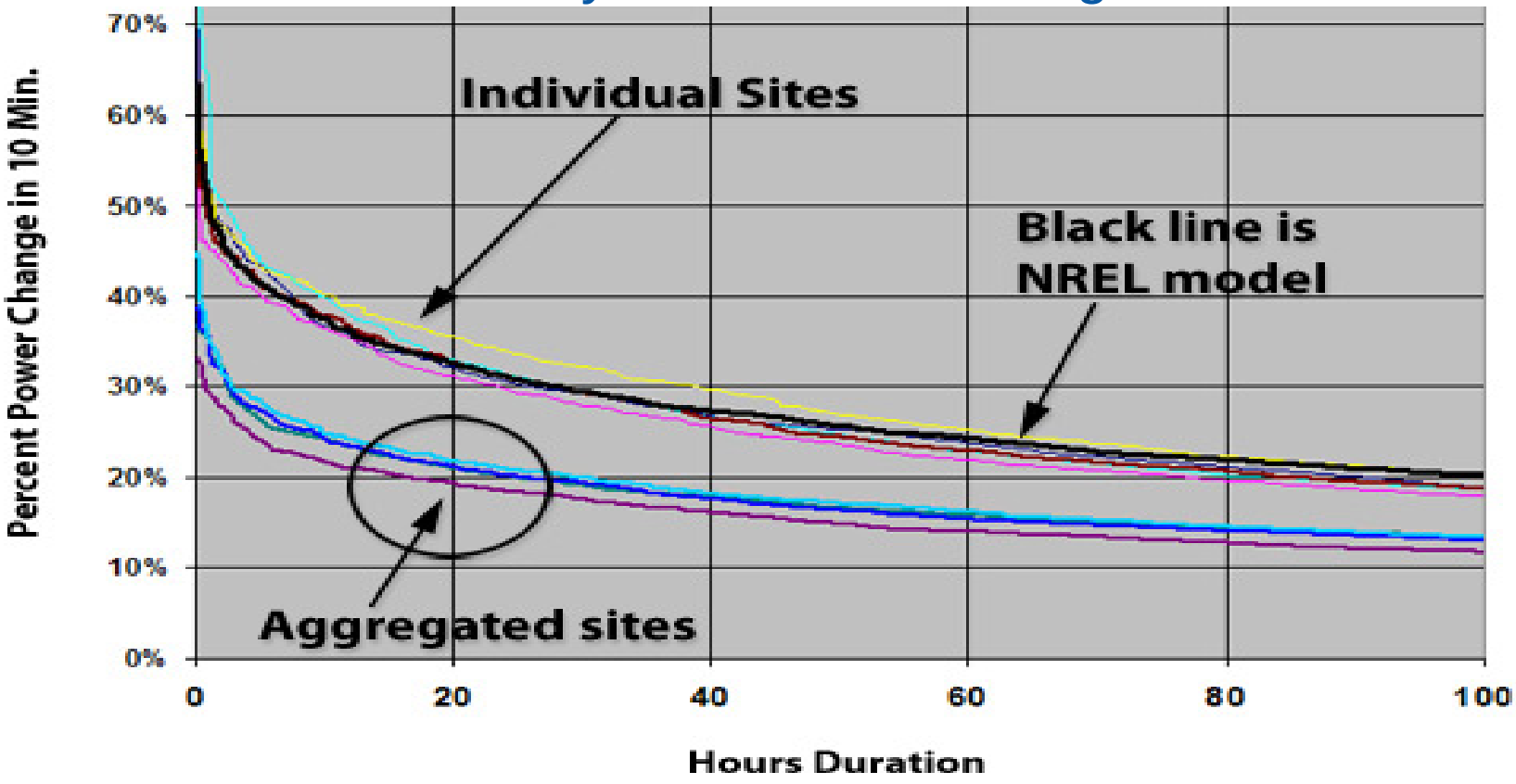
If Slope Difference < 0.1, StDev = 0 (clear sky or close to it.)

If Slope Difference => 0.1, StDev = (log(Slope Difference)+1)*0.27 + 0.11

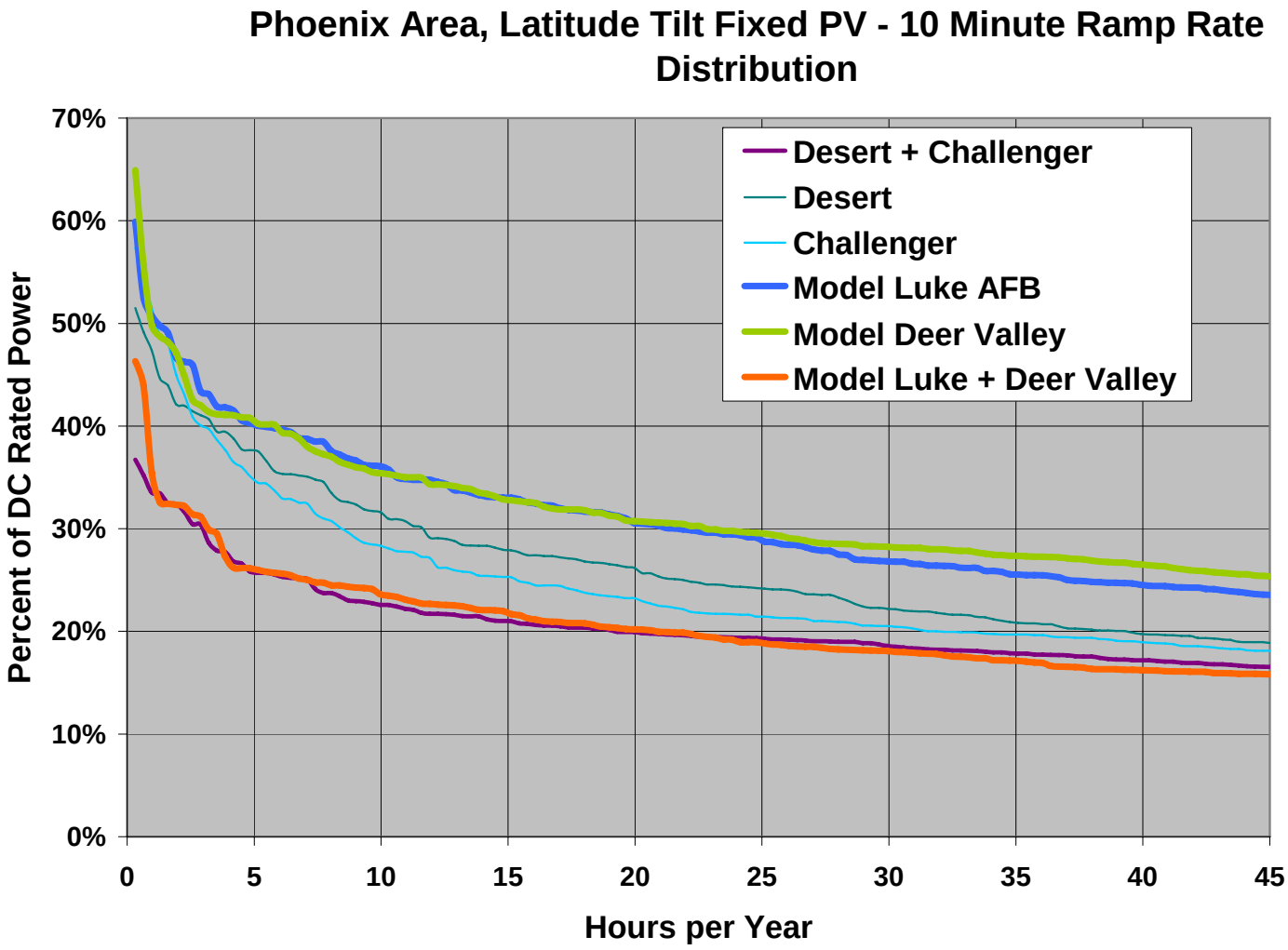


WWSIS PV Data Ramp Rate Validation

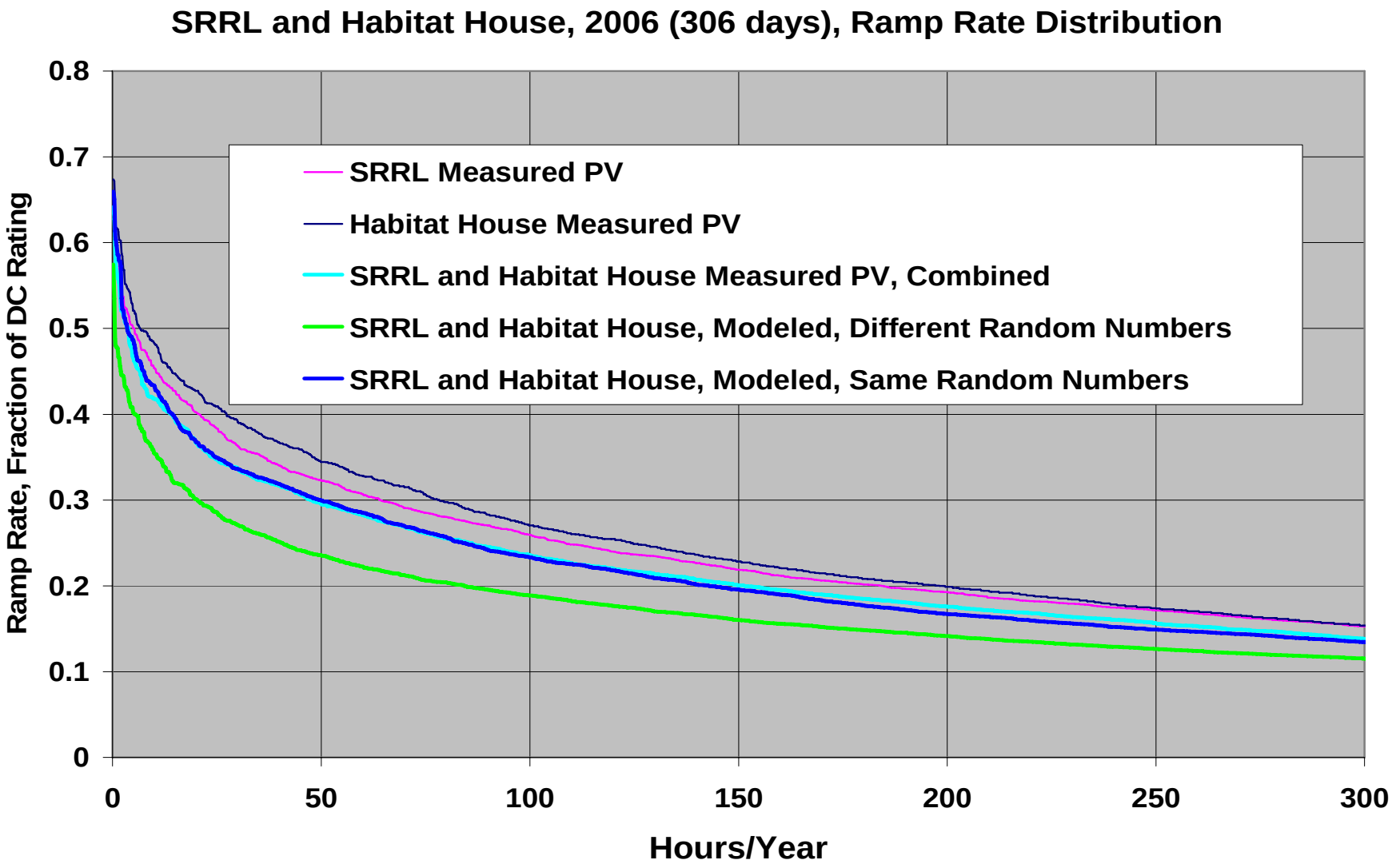
- **PV output ramp rates** are primary validation data.
- Same model used for all collector types.
- Validation using Arizona **1-axis tracking PV**, and Colorado fixed system with 22.5 degree tilt.



Phoenix Latitude Tilt

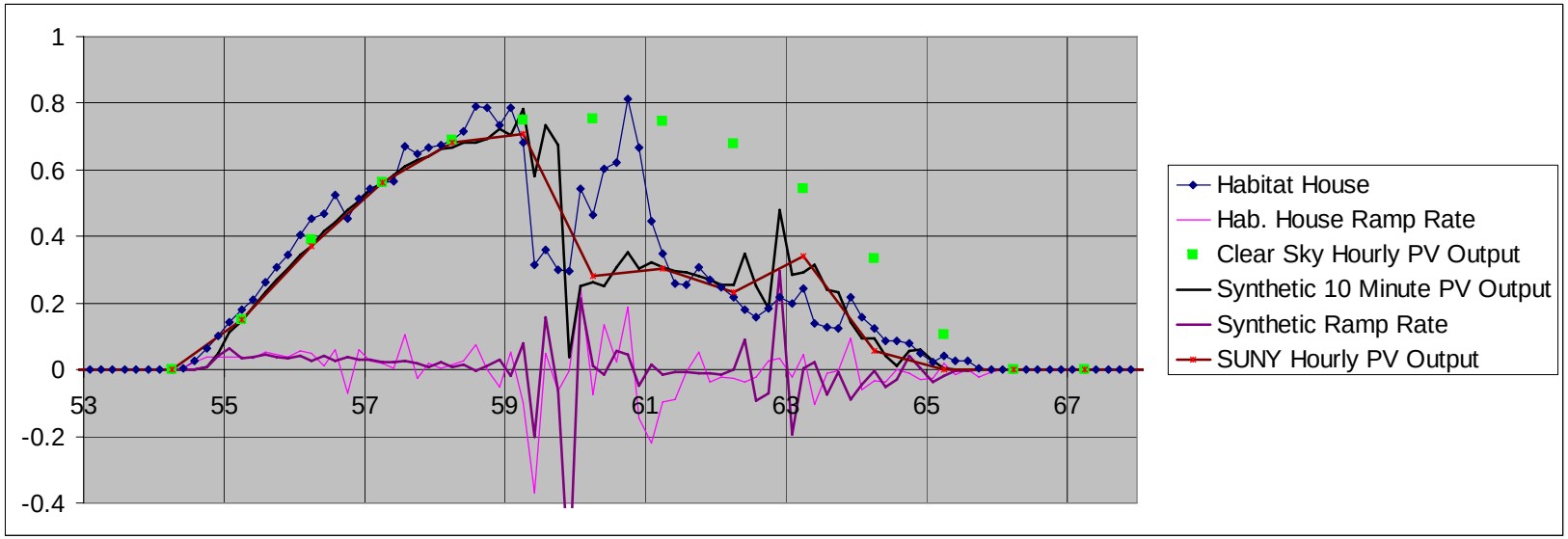


10 Min PV From Habitat House (4 MW Fixed PV), and from Measured Solar at NREL SRRL
Distance Between Sites = 8.8 km.



WWSIS Model - Problems

1. All model data from 1 location.
2. No use of measured data.
3. Results not very deterministic. Correlations with wind could be missed.
4. PVWatts does not match observed PV output



Summary of WWSIS 10 Minute Model

1. Model applied for each of 12 different PV collectors using the same parameters over a wide range of conditions, locations, times of year. For each location, the model runs are applied using the SAME random numbers.
2. Model outputs are weighted according to a distributed PV scenario, fixed orientations are preferred, only 15% tracking PV
3. Phoenix – Low correlation between sites as close as 12.5 km. apart.
4. Golden, CO – Fairly high spatial correlation between sites 8.8 km. apart
5. In general, data from a single point, when averaged over 10 minutes, give the correct ramps for any compact plant.
6. NO lowpass filter applied to model time series.

The Problem…

Multi-MW PV plants plus DG PV planned in the Big Wind timeframe

Very little is known about multi-MW PV variability on a fast (subhourly) timescale

- High wind, partly cloudy days can lead to extremely fast ramps (faster fluctuations than wind plants)

PV Variability Working Group (labs, utilities, developers) established to work on this issue

There is little sub-minute data for large-scale PV systems and not much sub-hourly data

State-of-the-art solar resource modeling is hourly, 10 km resolution

Data Available for Oahu PV Modeling

Measured GHI and PV output from schools – 15 minutes – for 2 years or more.

Measured Solar radiation – from 4 sites – 1 second – starting in June 2009

Solar radiation – clear sky – 10 minute averages – model and input data are matched to satellite model.

Modeled PV output – uses PVWatts for any collector orientation

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Weather service – observed ceiling, clouds, winds. Also numerical modeled/interpolated winds, etc.

RAWS – hourly global radiation

OWITS Solar Data Requirements

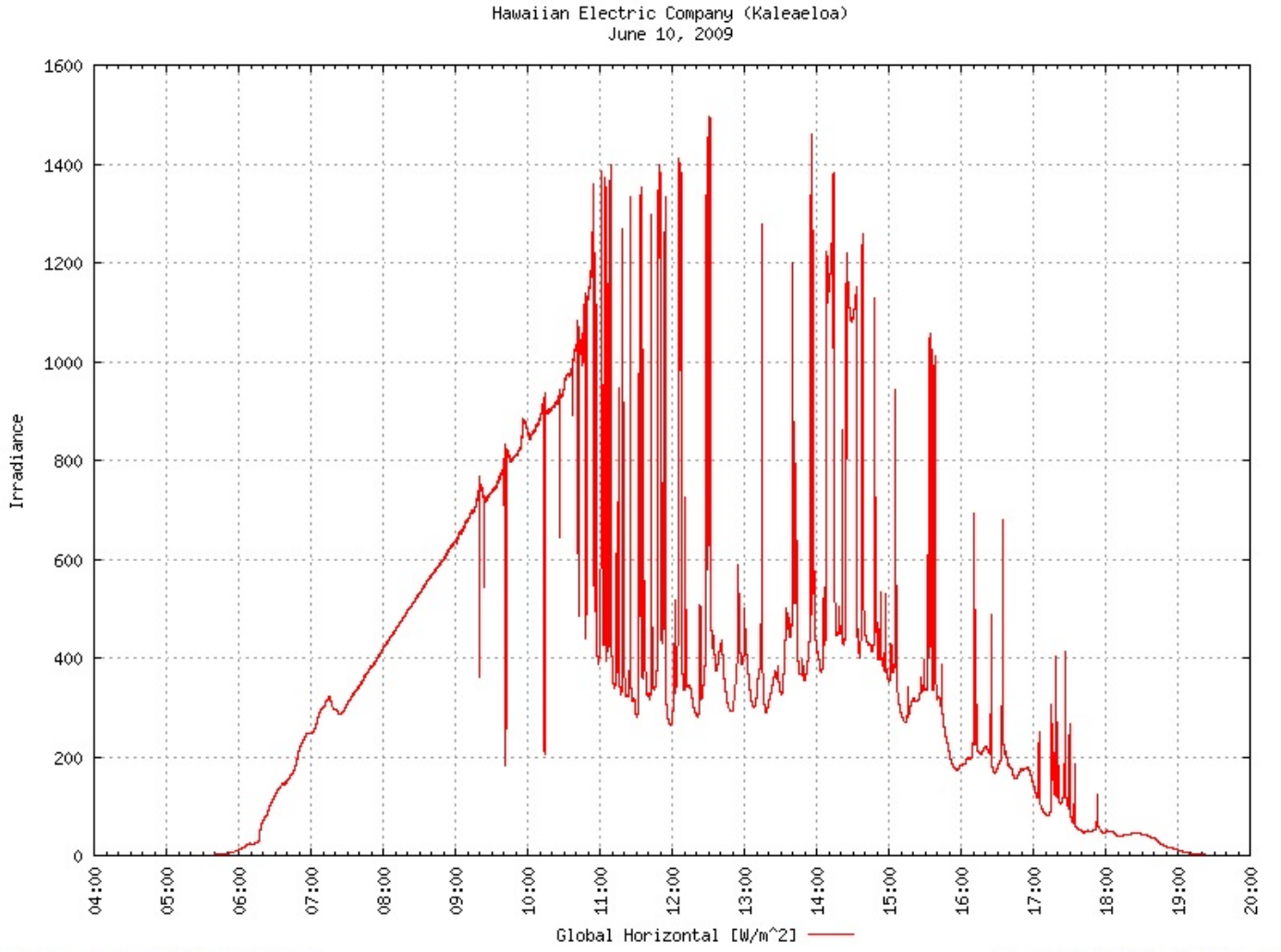
- PV system output in MW for 4 different “systems”
- Initial requirement is for 10 minute average outputs, for two years (2007 and 2008).
- Later requirement is output from the same systems, except at two second resolution, for selected days in the two year period.
- Data should be as realistic as possible, given the state of our knowledge
- Ramp rates of PV output are the most important test of realism.

NREL/HECO 1 Second Solar Data Stations

- Data from 4 locations, starting June 4, 2009
- One second data rate, for Global Horizontal only.
- Two sites are 1060 meters apart, providing data on correlations within a large PV plant.
- Analysis of these data used to guide the synthesis of 10 minute (and later 2 second) data.

Map of NREL/HECO 1-second Solar Stations

One Second Data Shows High Variability



Previous [Day] [Month] [Year]

Next [Day] [Month] [Year]

auto x-min (hour) [Rescale]

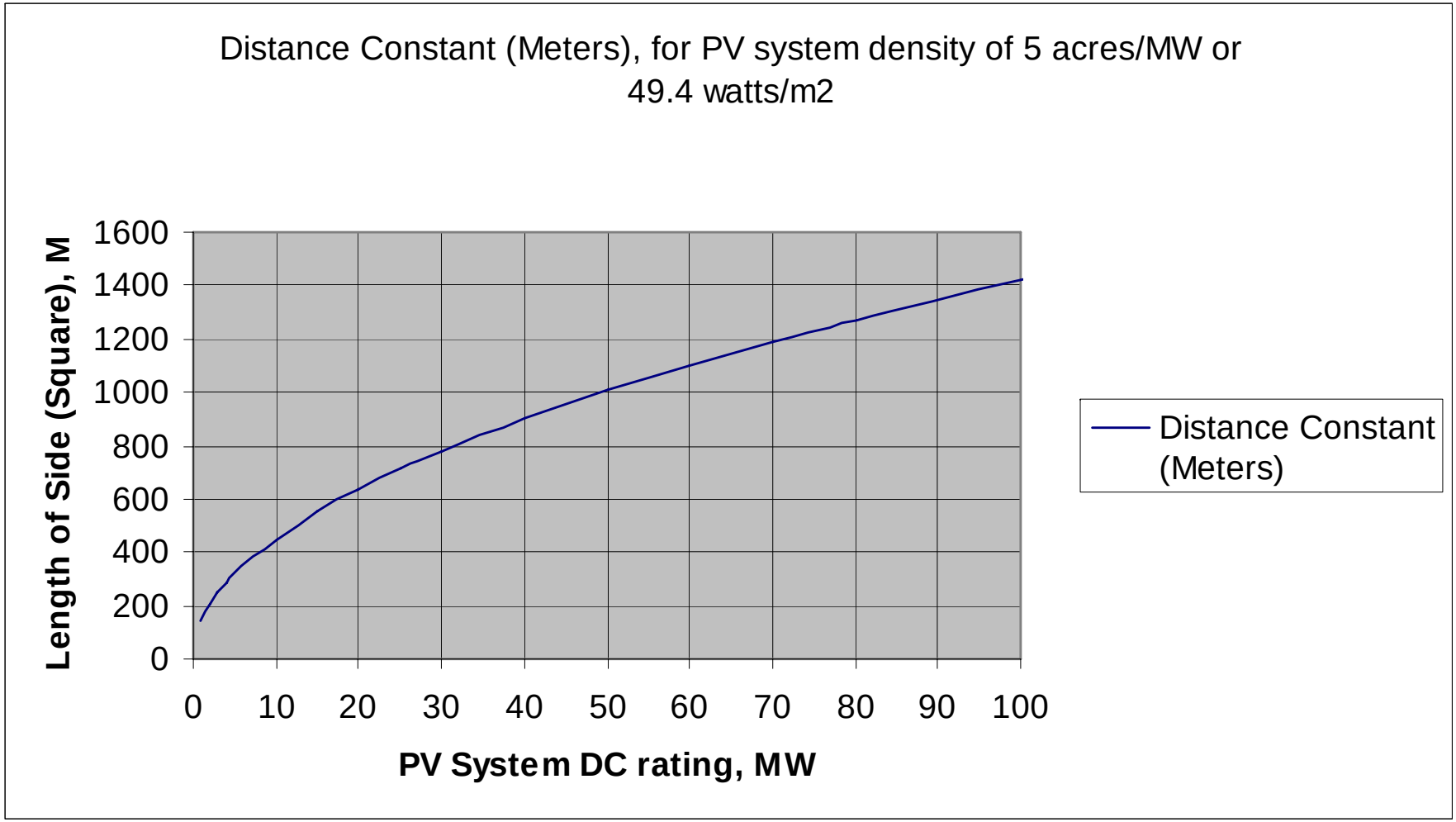
[Rescale] x-max (hour) auto

auto auto Primary y-min/max

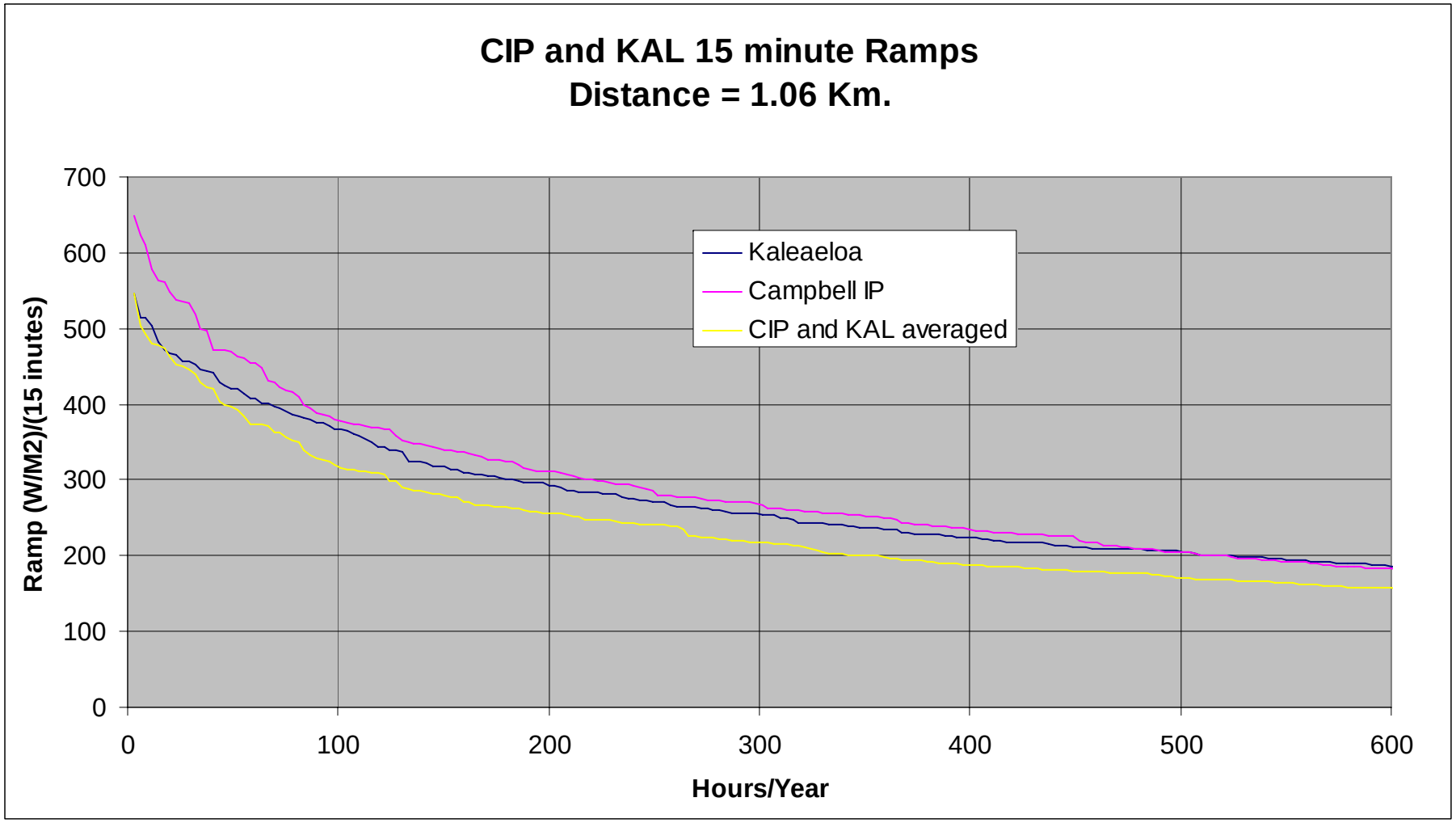
Secondary y-min/max auto auto

[Download Data]

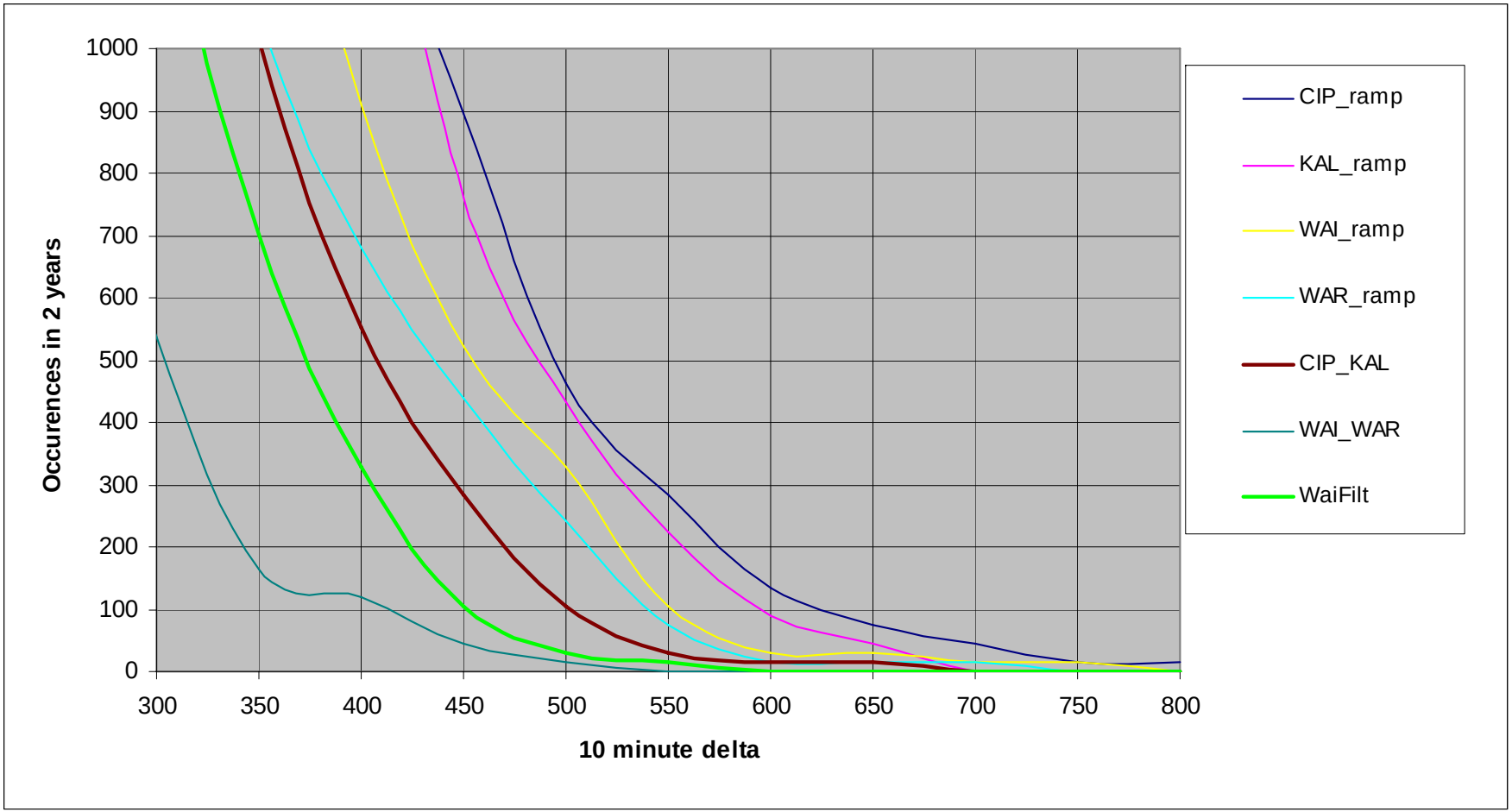
Size of PV Array = Distance Constant



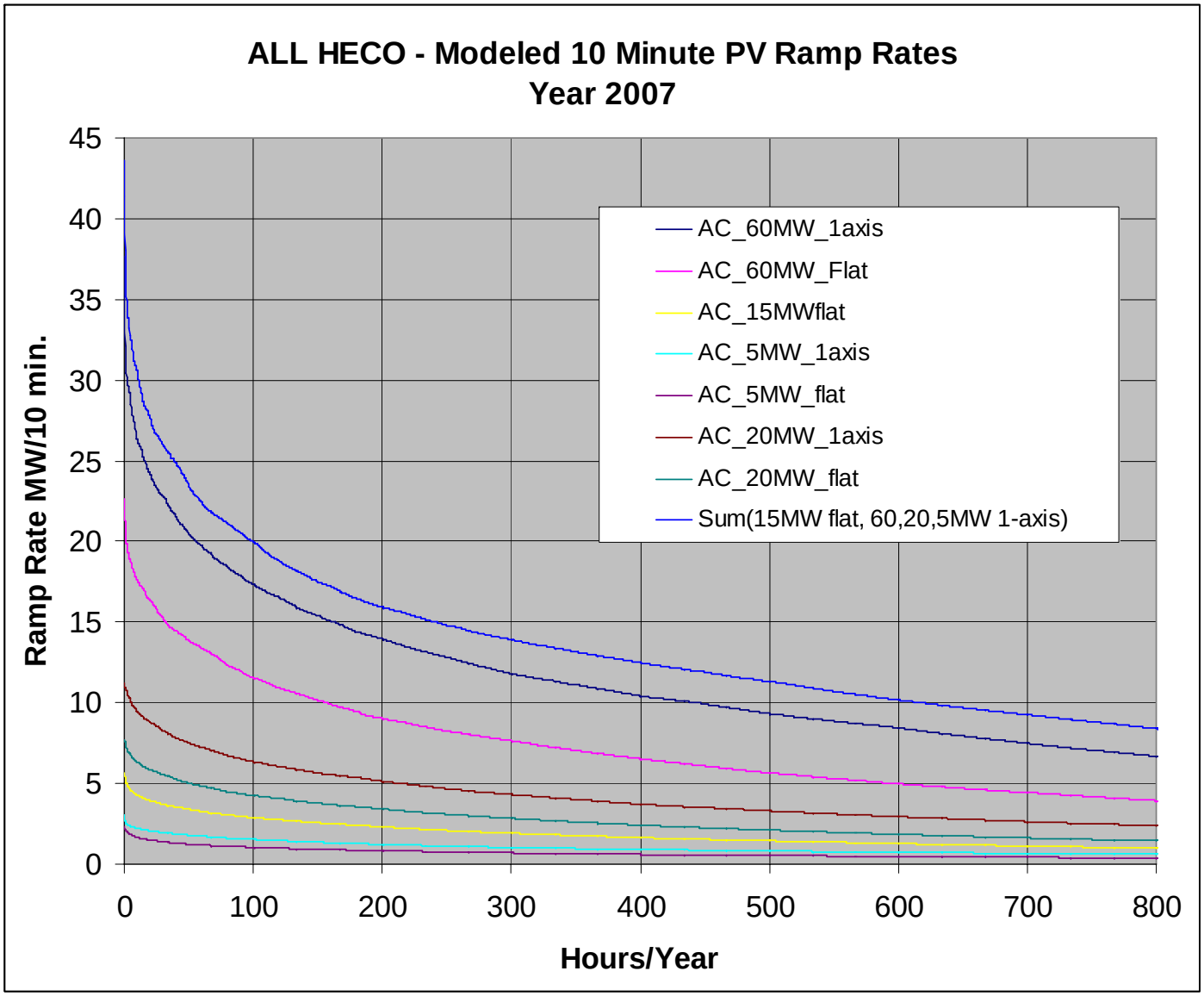
Spatial Smoothing for 1 KM (60 MW)



Filter Single Point GHI to Match Area Distribution



10 Minute Ramp Rates in MW

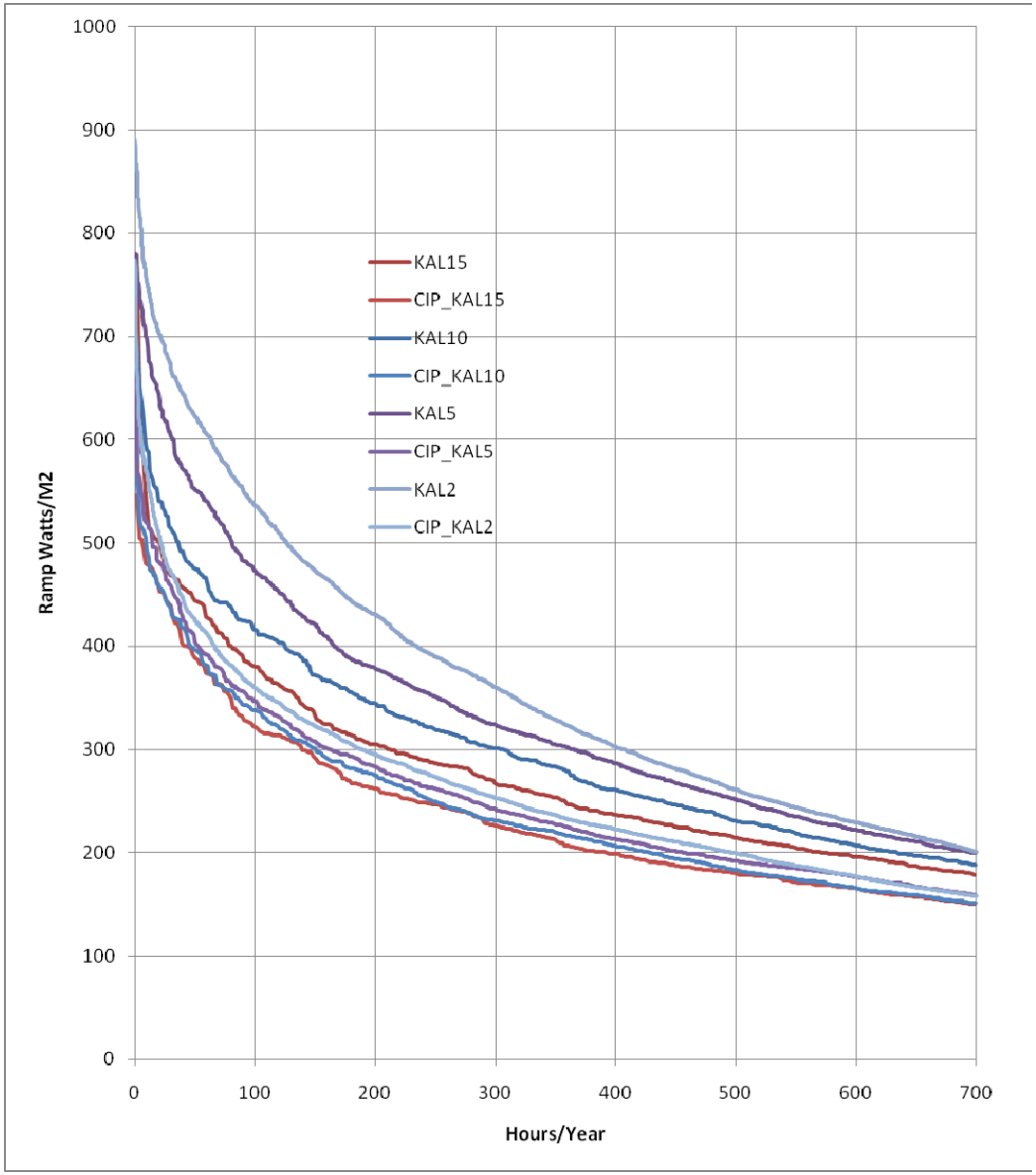


OWITS PV Technology Assumptions

(All assumptions open to modification)

- Data processing and validation for Global Horizontal (GHI) radiation
- PV system output will be modeled for crystalline silicon PV technology.
- PV system size is the rated DC output of the PV panels for GHI = 1000 watts/m2 (industry standard)
- Grid connected PV systems will have maximum inverter output equal to PV system size (DC rated capacity)
- PV output data streams will be available for fixed horizontal PV collectors and 1-axis tracking collectors. (Other collector types could be added if needed.)
- Residential PV will be assumed all fixed horizontal
- Utility PV plants will be 1-axis tracking.

Two GHI Stations, 1060 Meters Apart



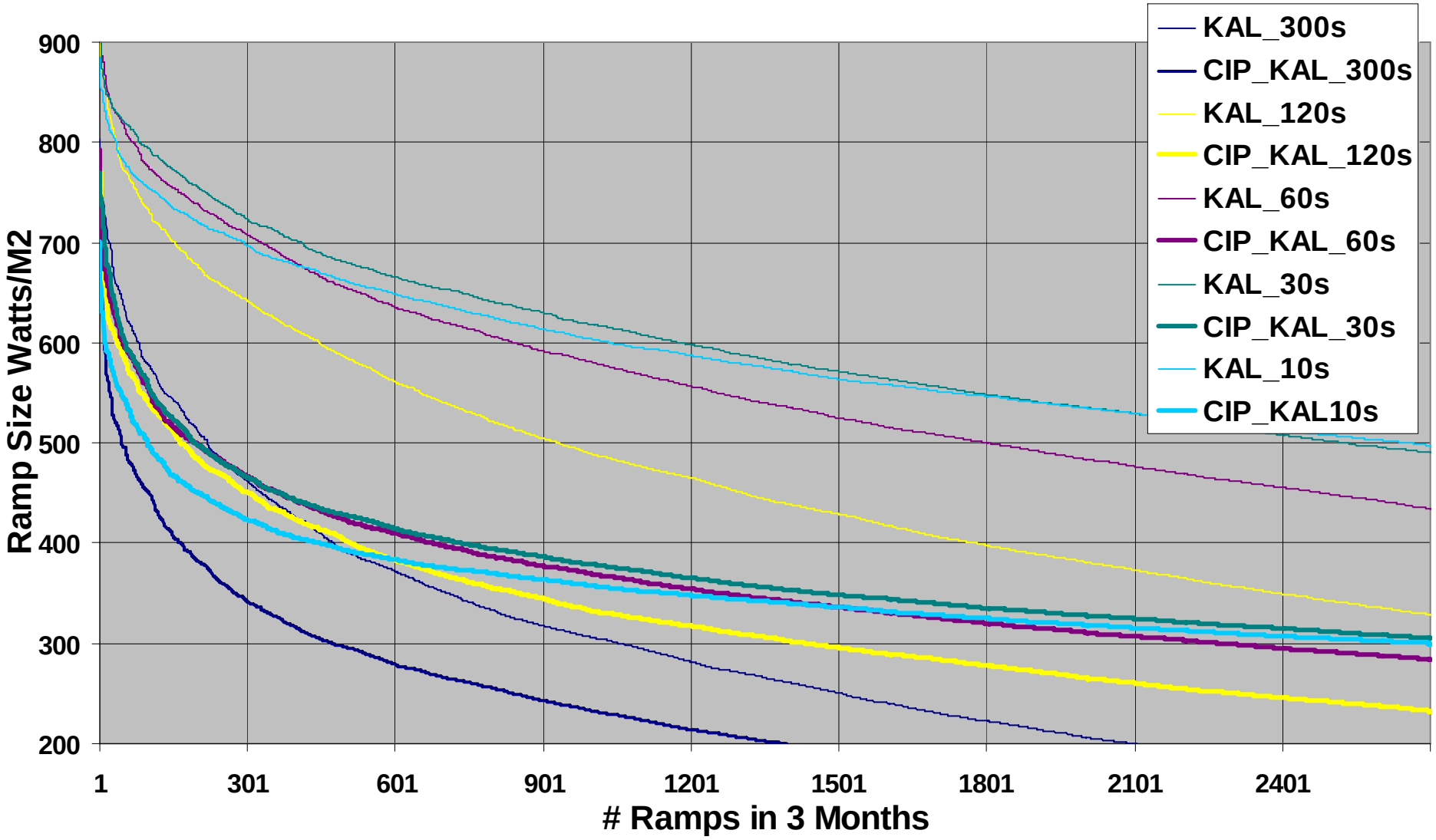
KAL = 1 station –

2 min averaging – more and larger ramps than 15 minutes.

CIP_KAL = 2 station average –

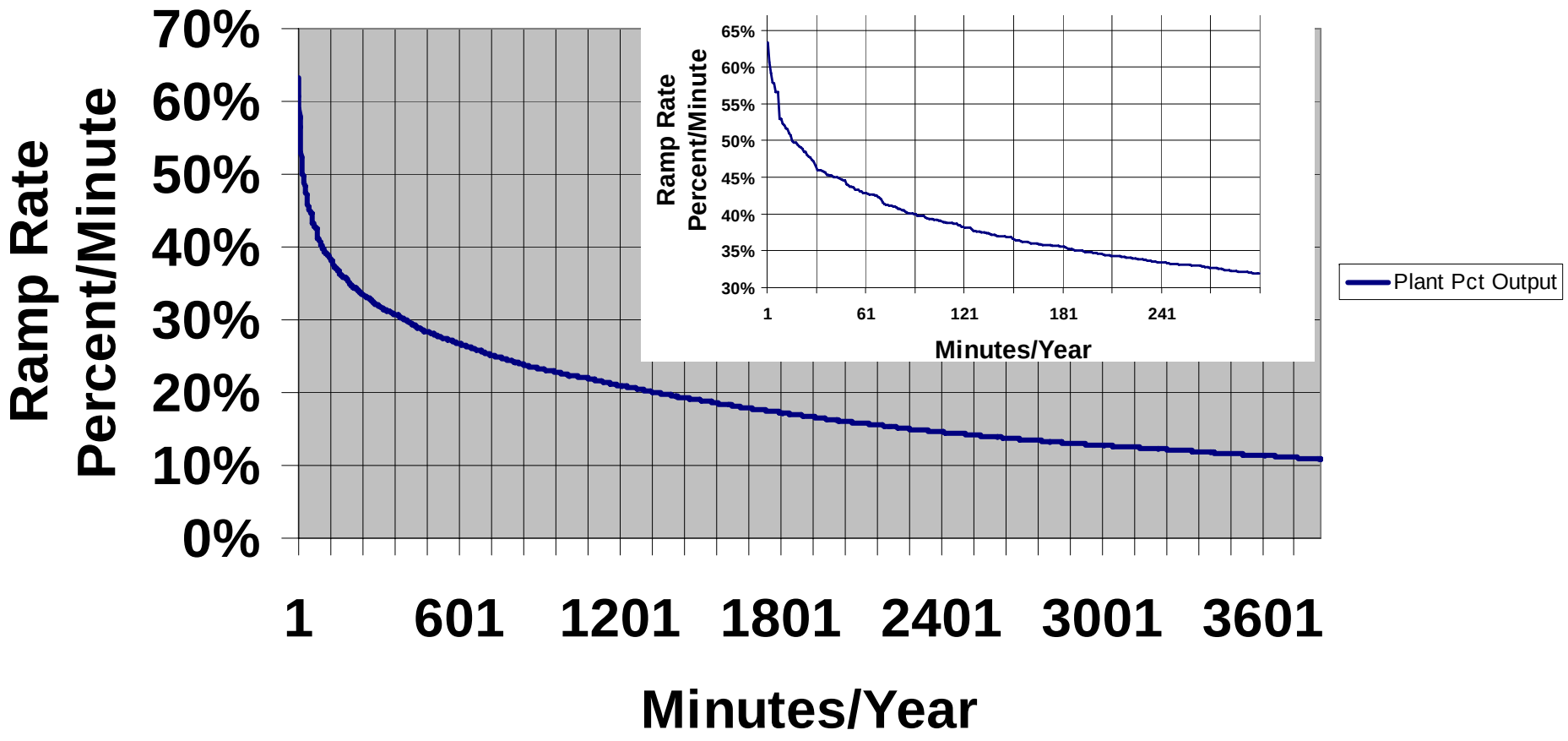
2 minute and 15 minute ramps almost the same.

Ramps for KAL and CIP_KAL sites

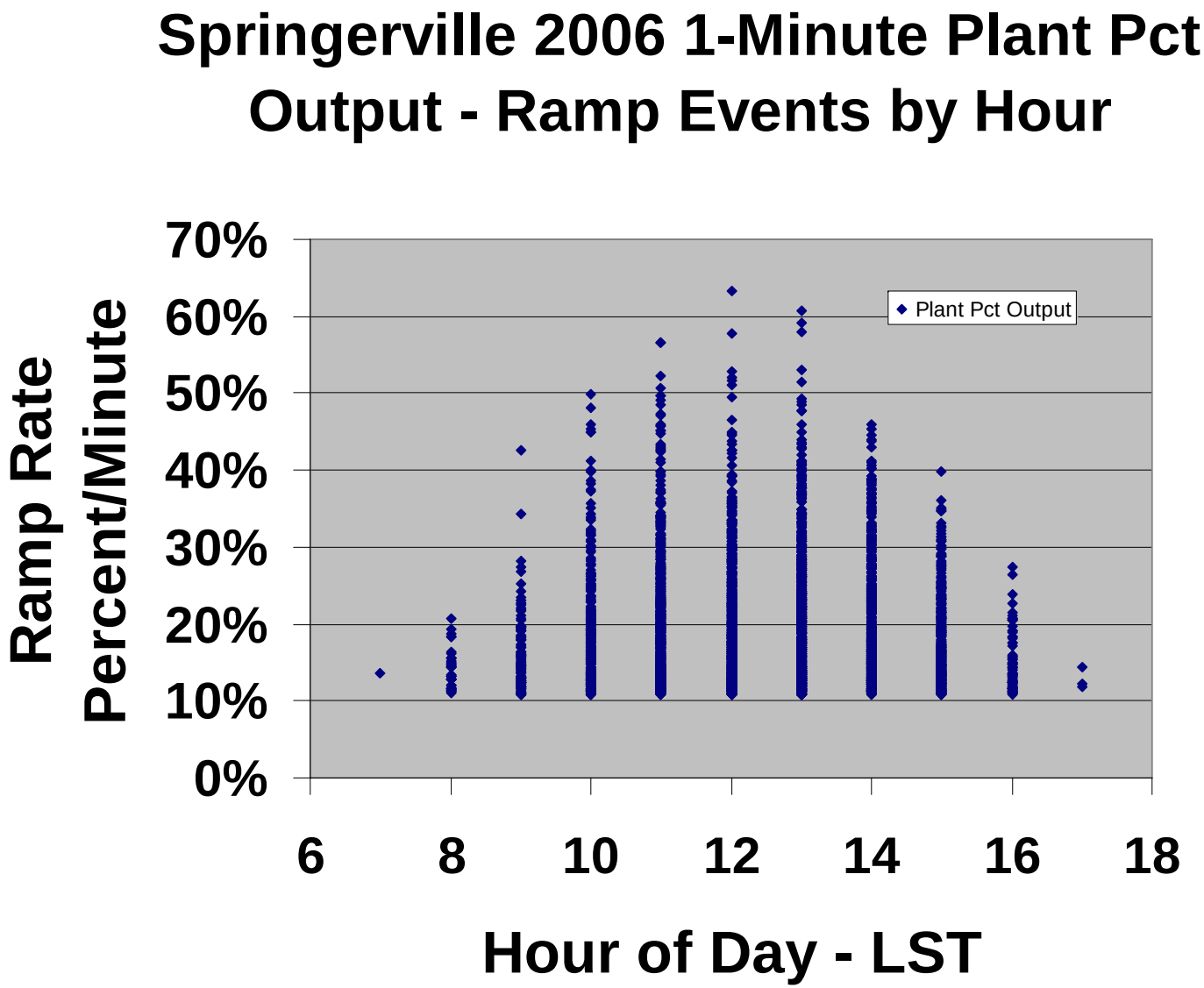


4.6 MW Plant – Distance Const ~450 m.

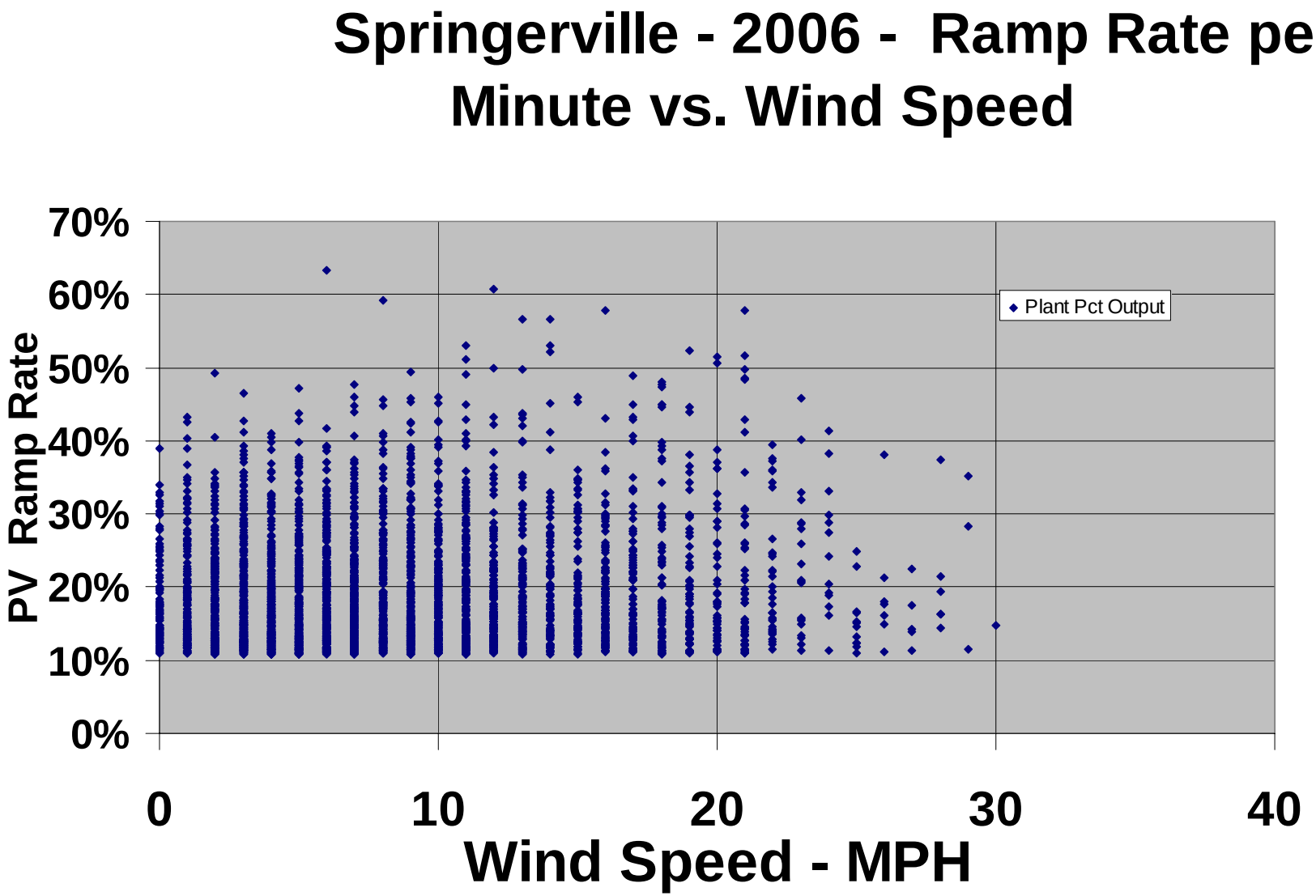
Springerville Plant - 1 Minute Ramp Rates · Pct Output 1 Year (2006)



Large Ramps at All Daylight Hours

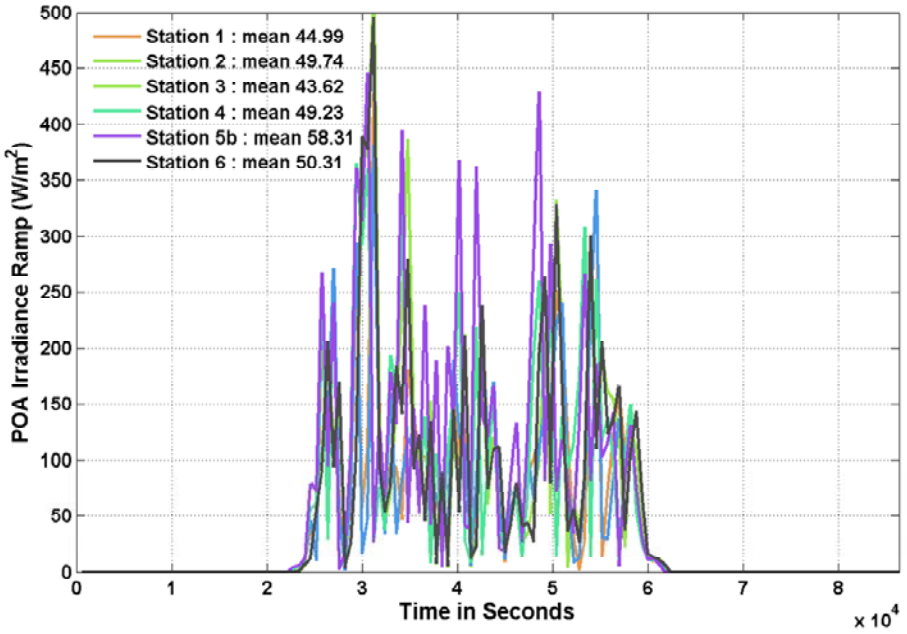


PV Ramp Rate vs. Wind Speed

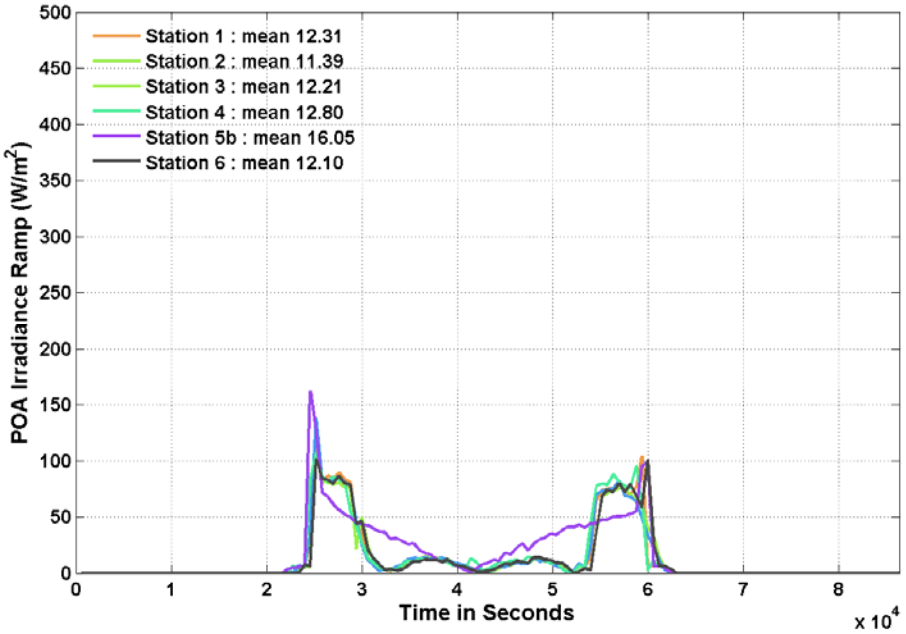


Example of 600 second “averaging” and “sampling” – POA Irradiance Ramps

Partly Cloudy Day



Clear Day



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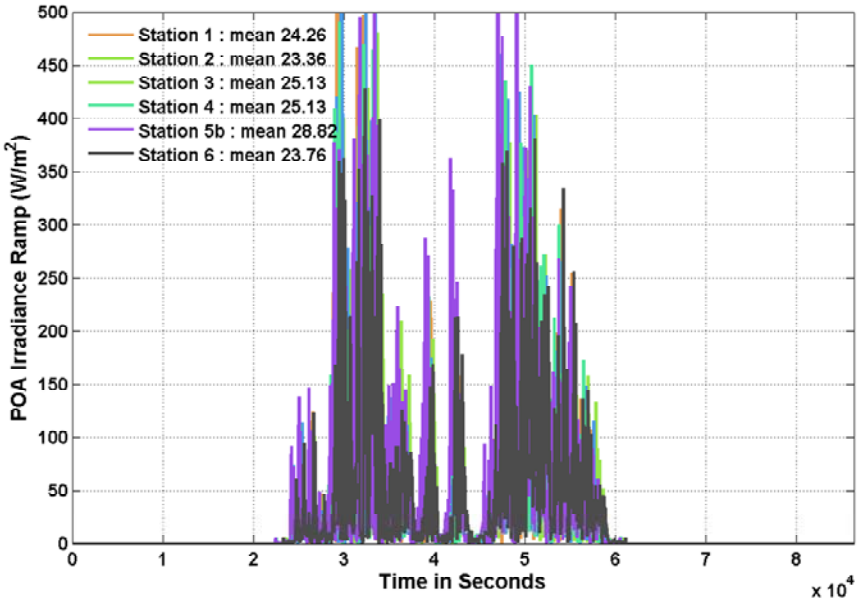
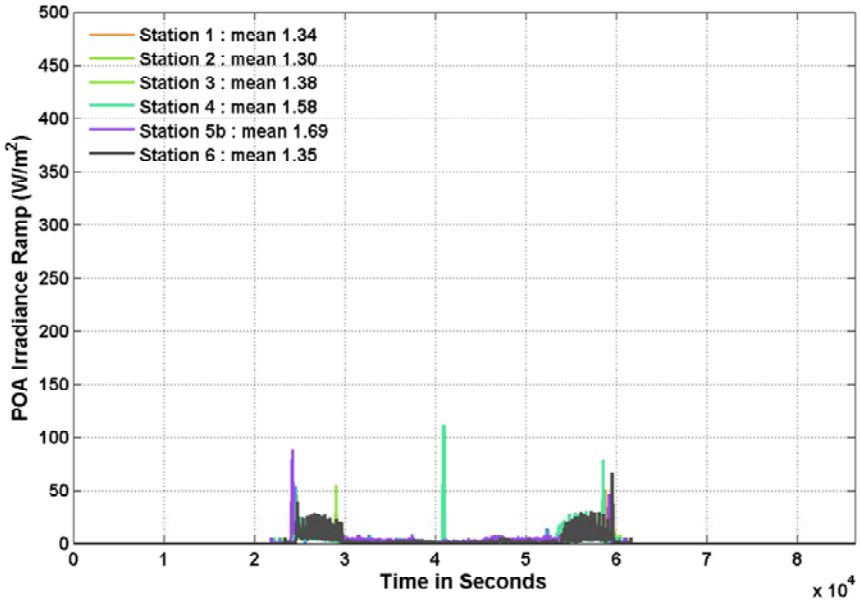
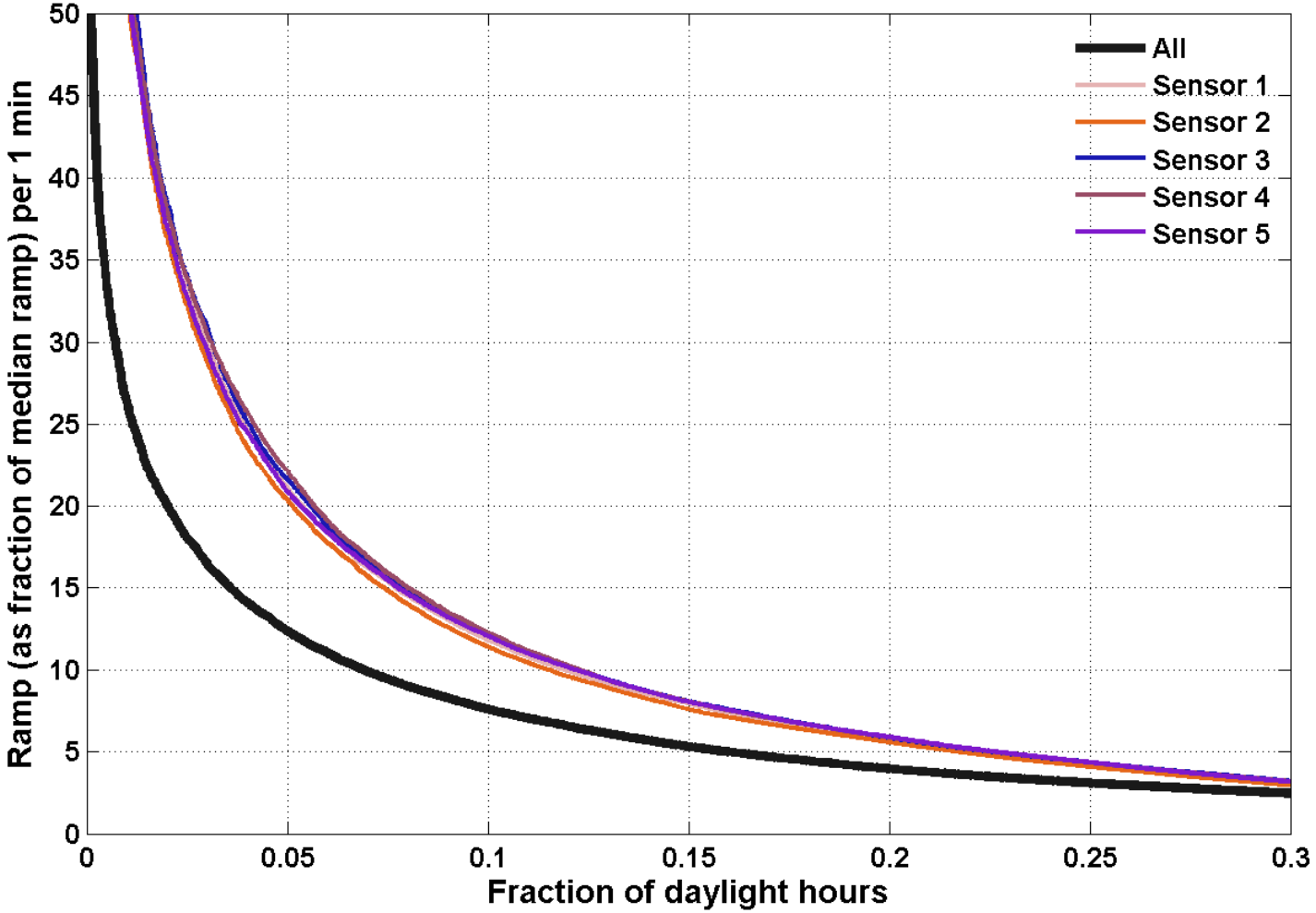


Clear Day



Power Output Ramp (as fraction of median ramp)

Distribution for 1 minute data using single and multiple sensors (840 hours)



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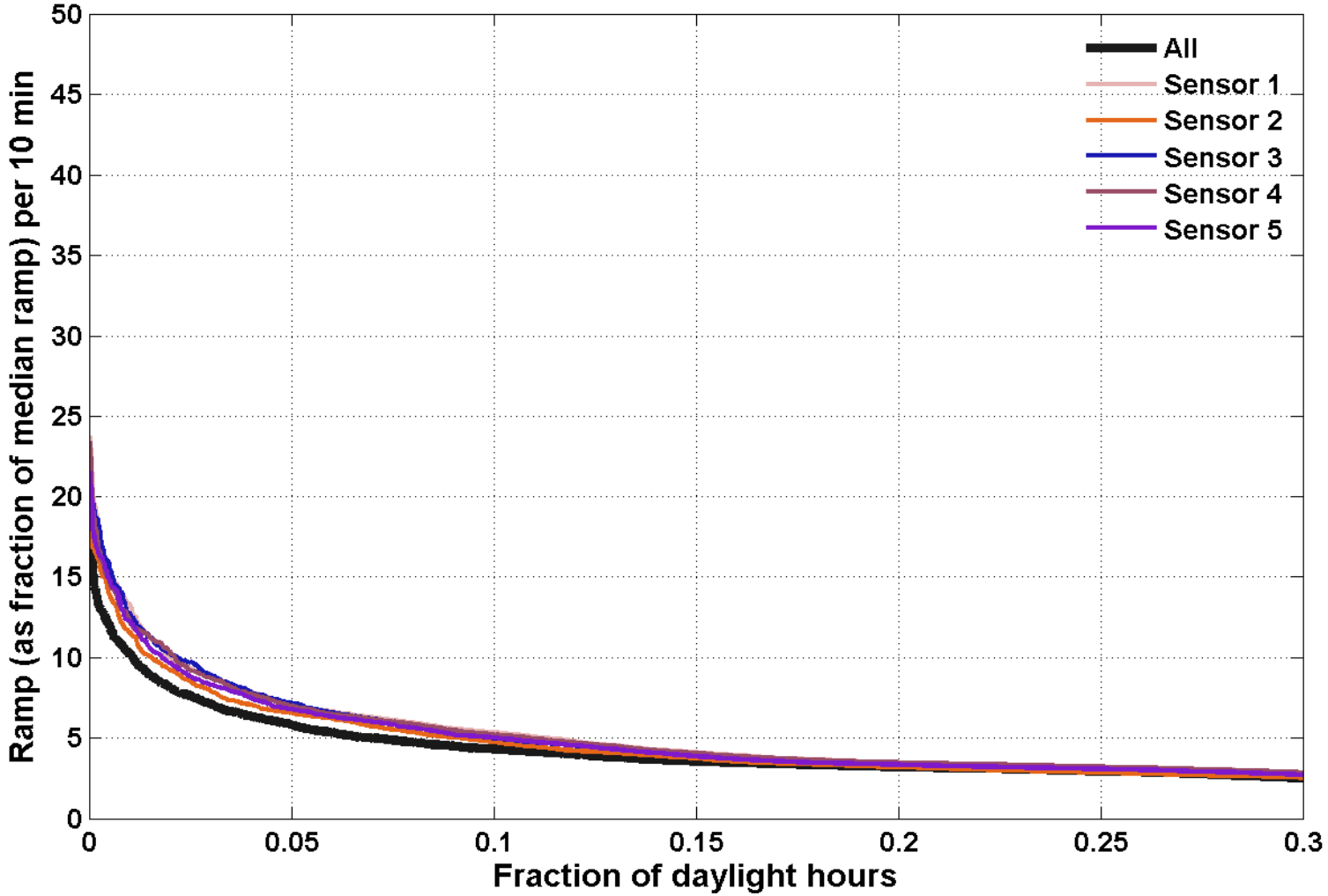
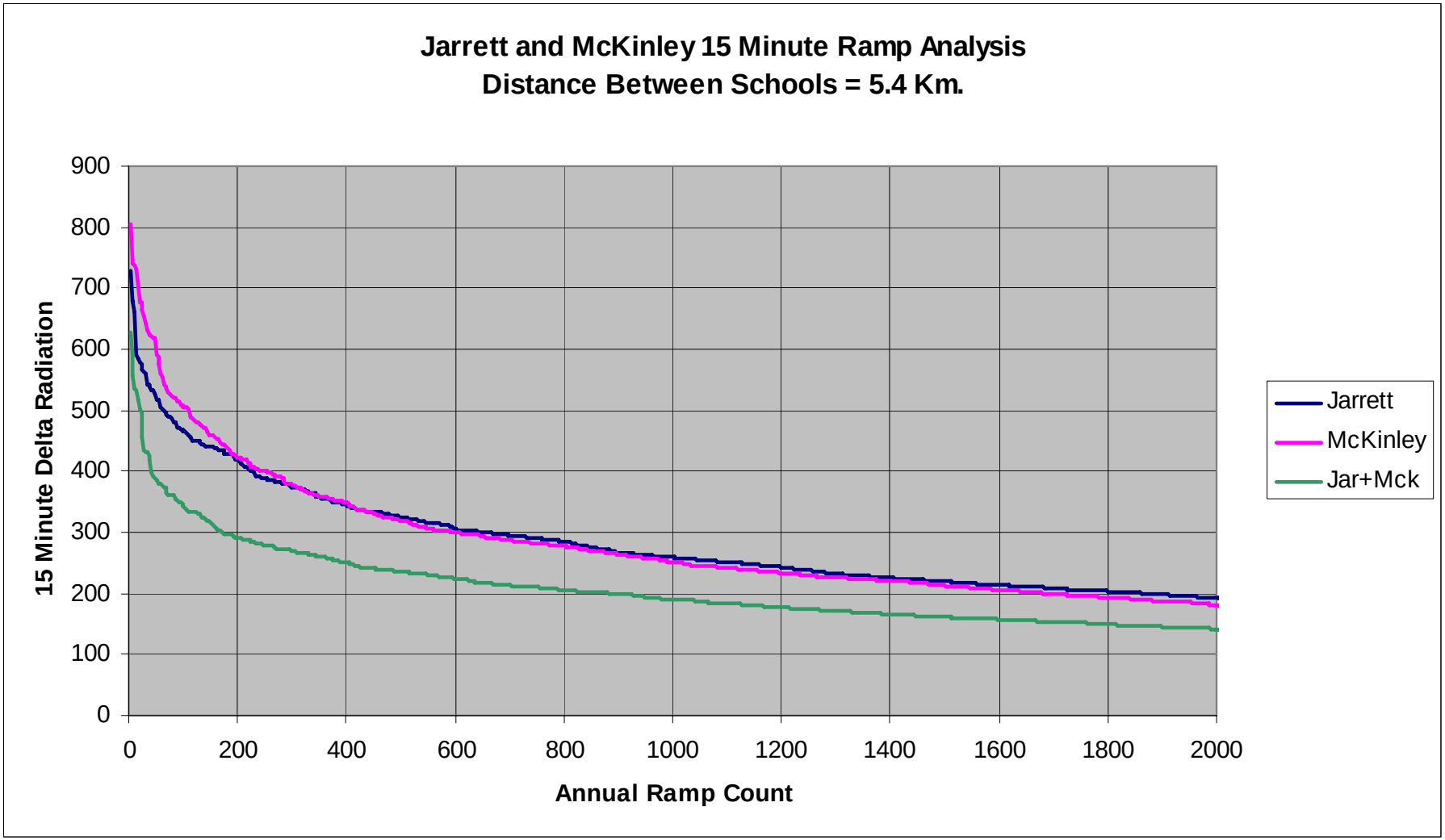


OWITS PV Data Ramp Rate Validation



Springerville 10 Minute Ramps Match