SAND2009-6258P

Variability Dynamics for the Six LVVWD PV Projects

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Joshua Stein Ph.D.
Principle Member of Technical Staff
Sandia National Laboratories

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.

Data Summary

- **1-minute data from six Las Vegas Valley Water District (LVVWD) PV installations***
  - **Horizontal irradiance (W/m^2)**
  - **Air temperature**
  - **Wind speed**
  - **A/C power from each inverter at site**

Site	Start	End
LVSP	7/26/2007	4/29/2009
Luce	5/2/2007	4/29/2009
Spring Mtn	11/30/2006	4/29/2009
Grand Canyon	9/30/2006	4/29/2009
Fort Apache	8/23/2006	4/29/2009
Rozone	4/27/2006	4/29/2009

*Sandia granted permission to present data

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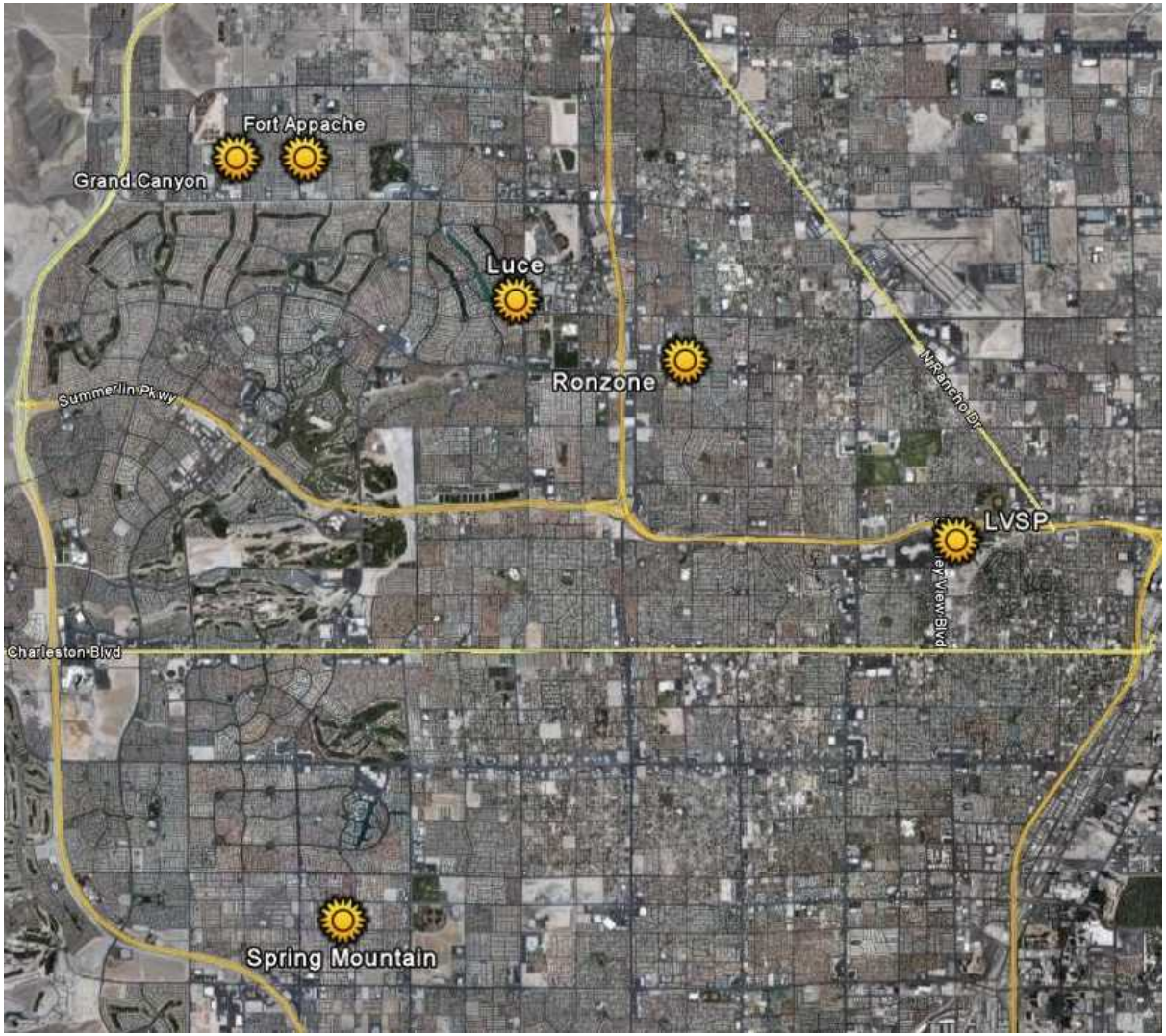
Site Map



Las Vegas, NV

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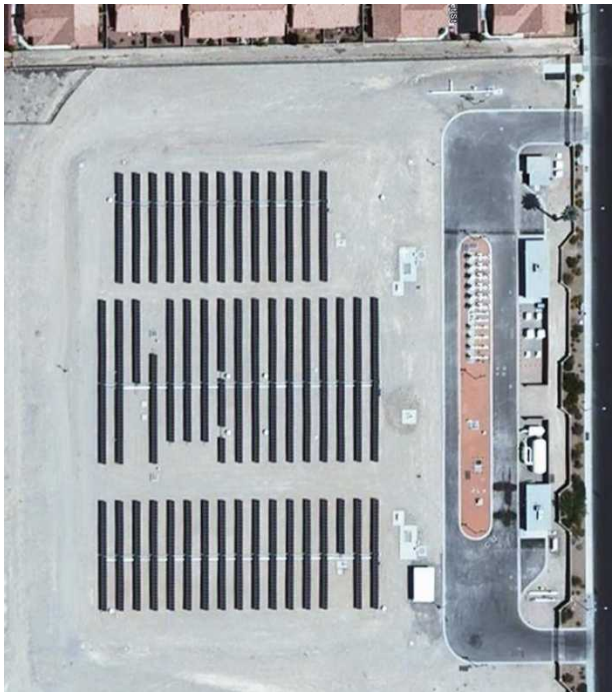
Site Configurations

Ronzone (821 kWp)
Single Axis

Grand Canyon (331 kWp)
Single Axis



Ft Apache (353 kWp)
Single Axis

*Other sites: Spring Mtn (537 kWp), LUCE (555 kWp), and LVSP (407 kWp)**

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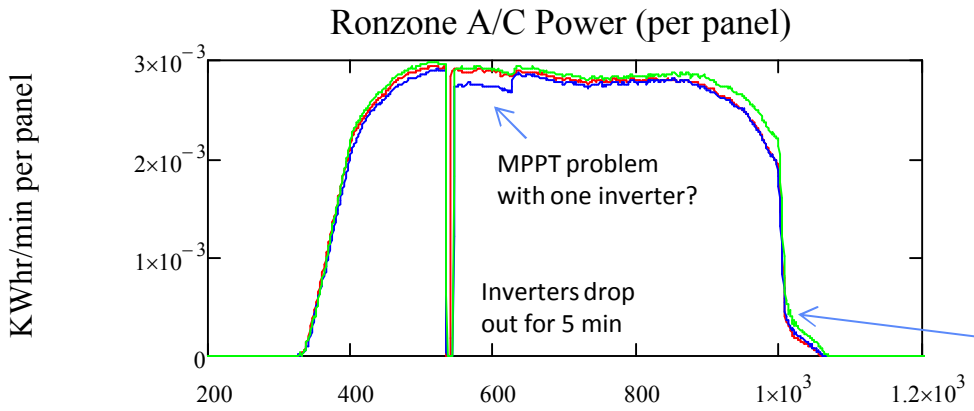
Questions

- What can we learn from operating PV systems in Nevada?
  - Operations and maintenance experience
    - Inverter dropouts
    - MPPT problems?
    - Tracking problems?
  - Cloud transients and power ramps
- How effective is geographic diversity in mitigating extreme ramp rates?
- How will variability impact balancing area control performance?

Analysis Approach

- Preprocess data into daily text files for each site
- Create calculation environment (in Mathcad) to select a day or set of days and compare data across sites
- Survey data and describe general trends and features
  - e.g., Inverter dropouts, passing clouds, isolated clouds, …
- Devise statistics to describe the variability at a site and between sites.

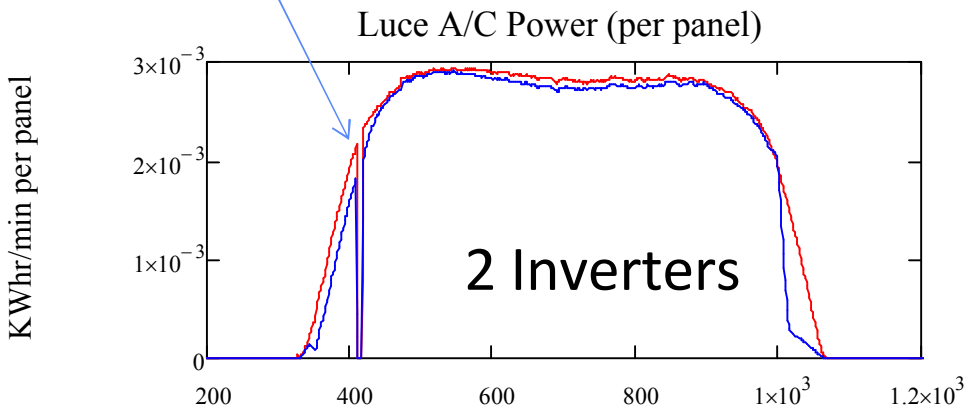
Examples of Inverter Drop Outs



Ronzone (821 kWp)
3 Inverters

Inverters drop out for 10 min

April 16, 2008



Inverter drop outs can impact ramp rates

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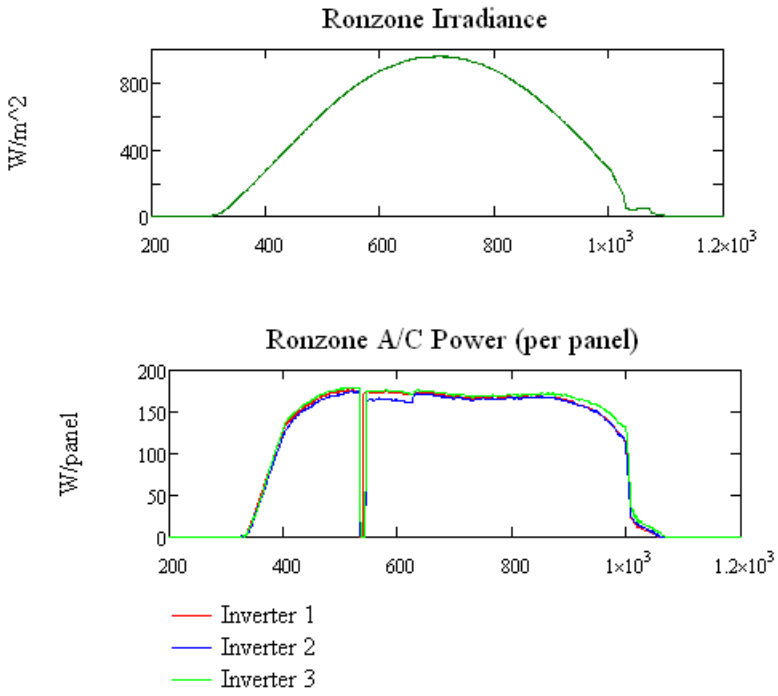
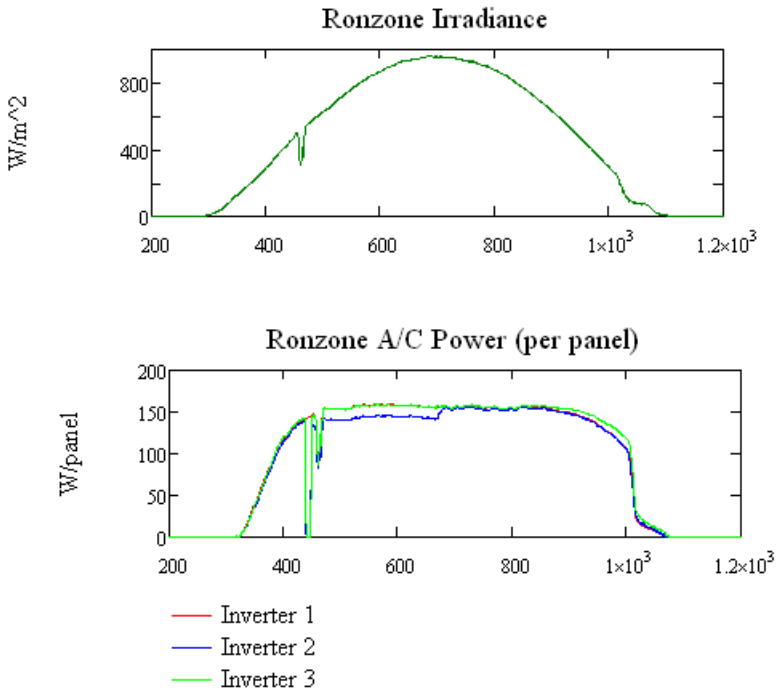
More Examples of Inverter Drop Outs



April 16, 2008



April 25, 2008

MPPT problems cause energy to be wasted

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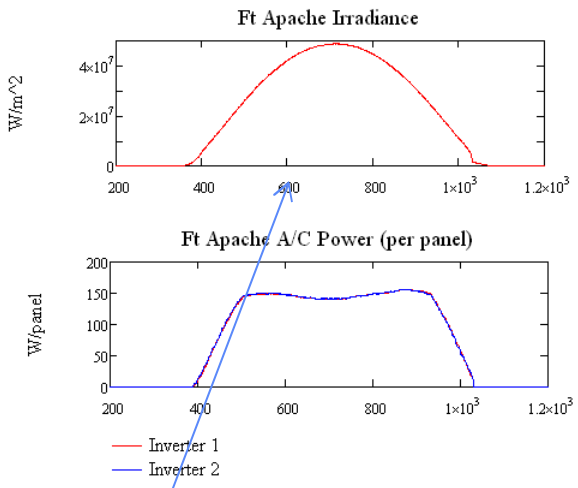
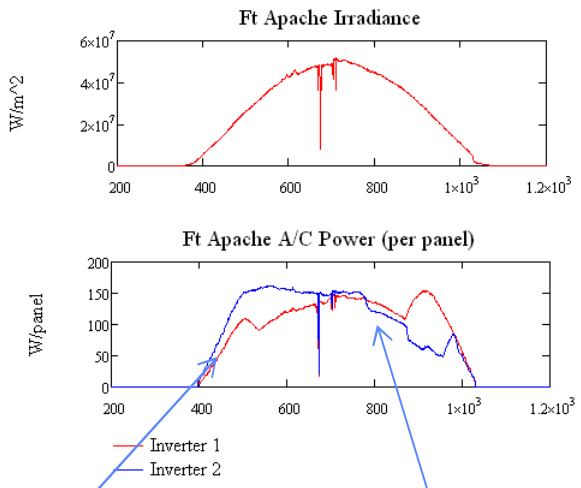
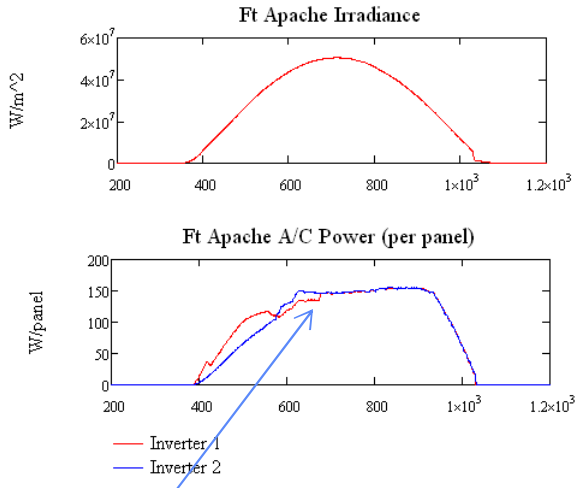
Odd Behavior 1



March 8, 2009



March 9, 2009



March 10, 2009

- 3/8/09: Normal operation
- 3/9/09: Inv1 abnormal, Inv2 goes abnormal mid afternoon.
- 3/10/09: Inv1 & 2 return to normal around midday.

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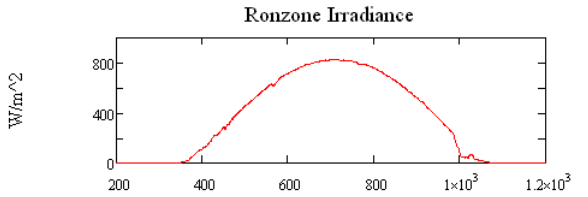
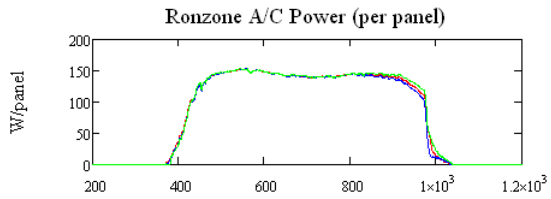
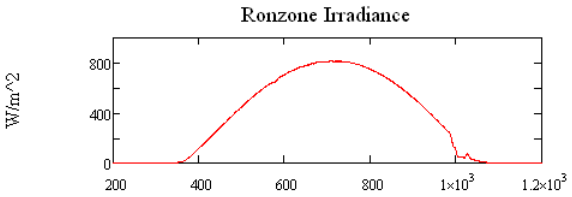
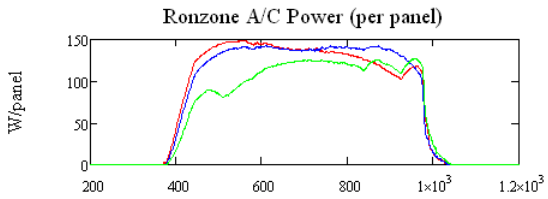
Odd Behavior 2



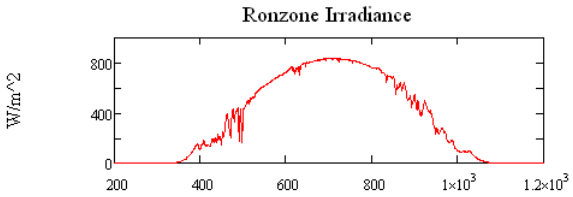


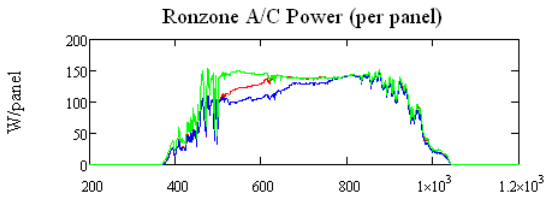
March 15, 2009





March 16, 2009





March 17, 2009

Possible tracking problems?

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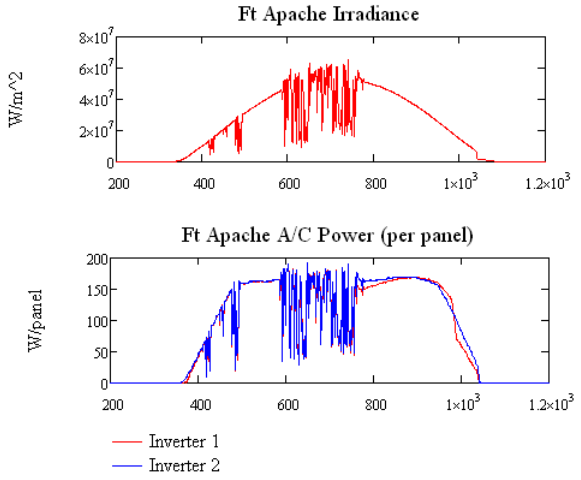
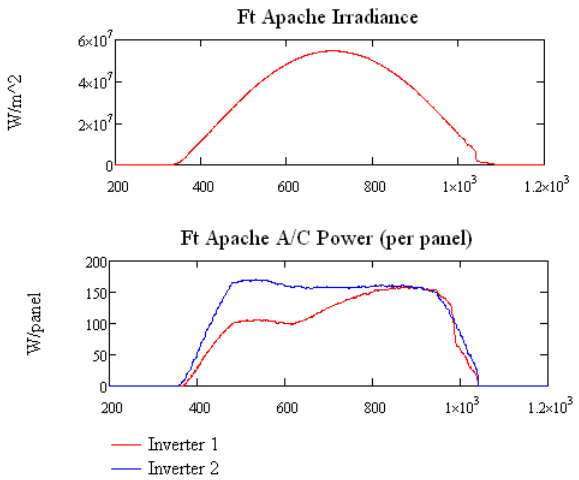
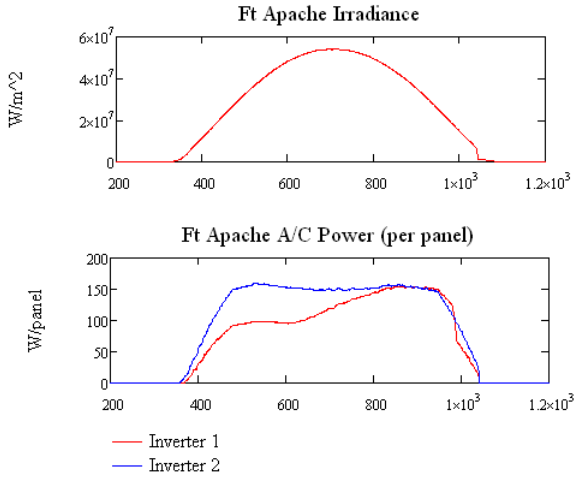
Tracking Problems?



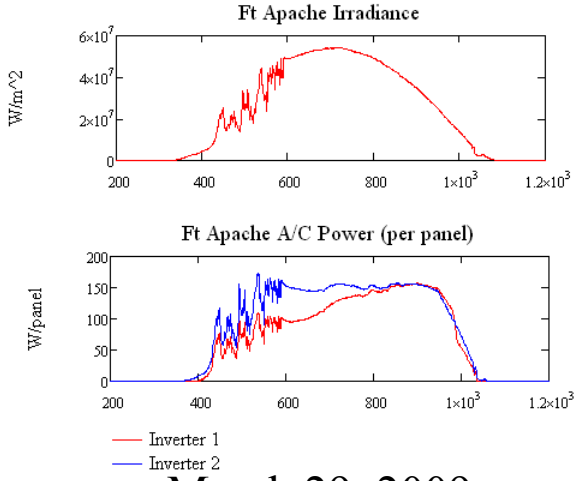
March 26, 2009



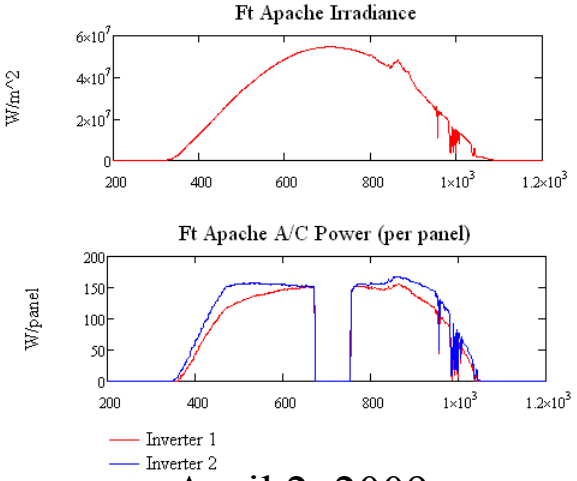
March 27, 2009



March 28, 2009



March 29, 2009



April 2, 2009

Tracking fixed April 8.

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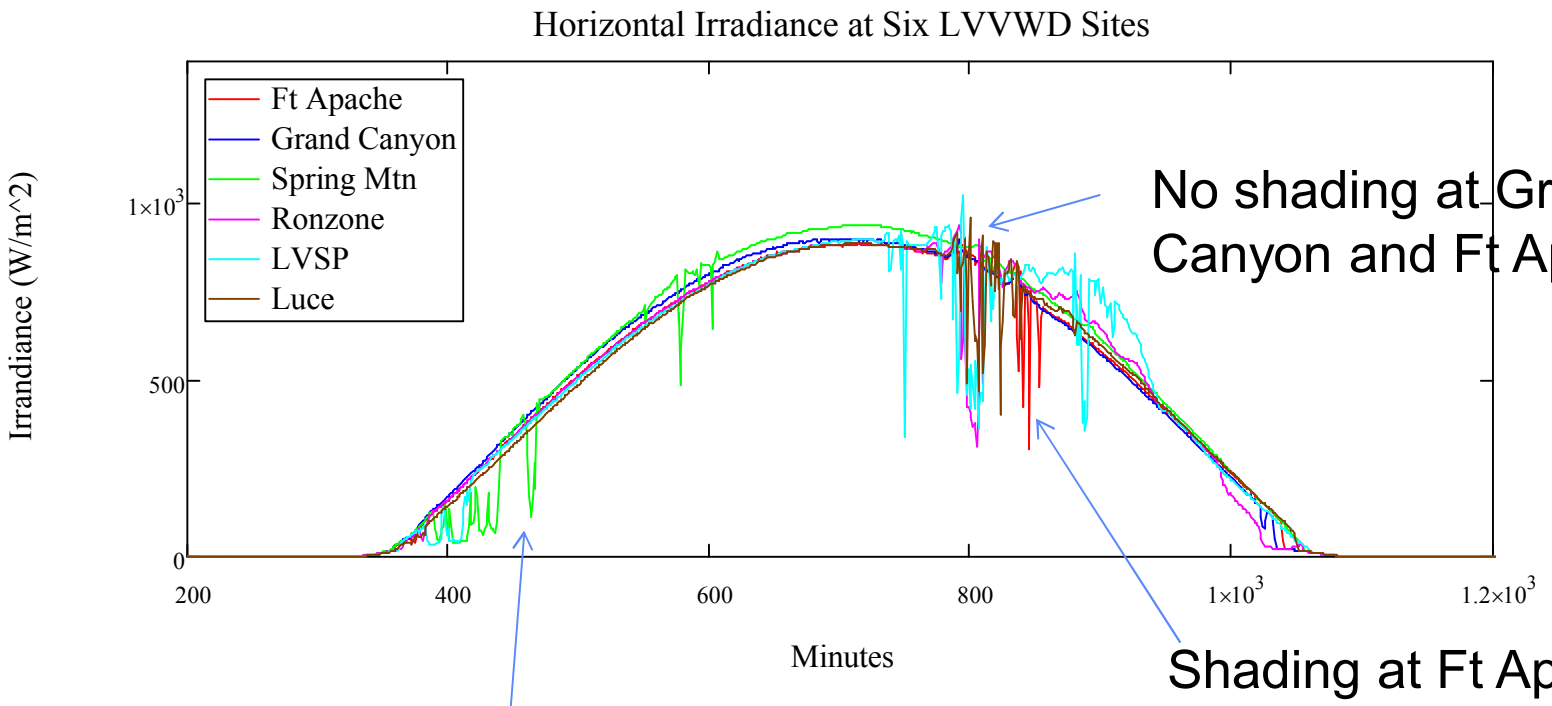
Example of Isolated Clouds

Select a Day to Analyze:

Day := "23"

Month := "03"

Year := "2009"



Shading early in the day at Spring Mtn but not at other sites

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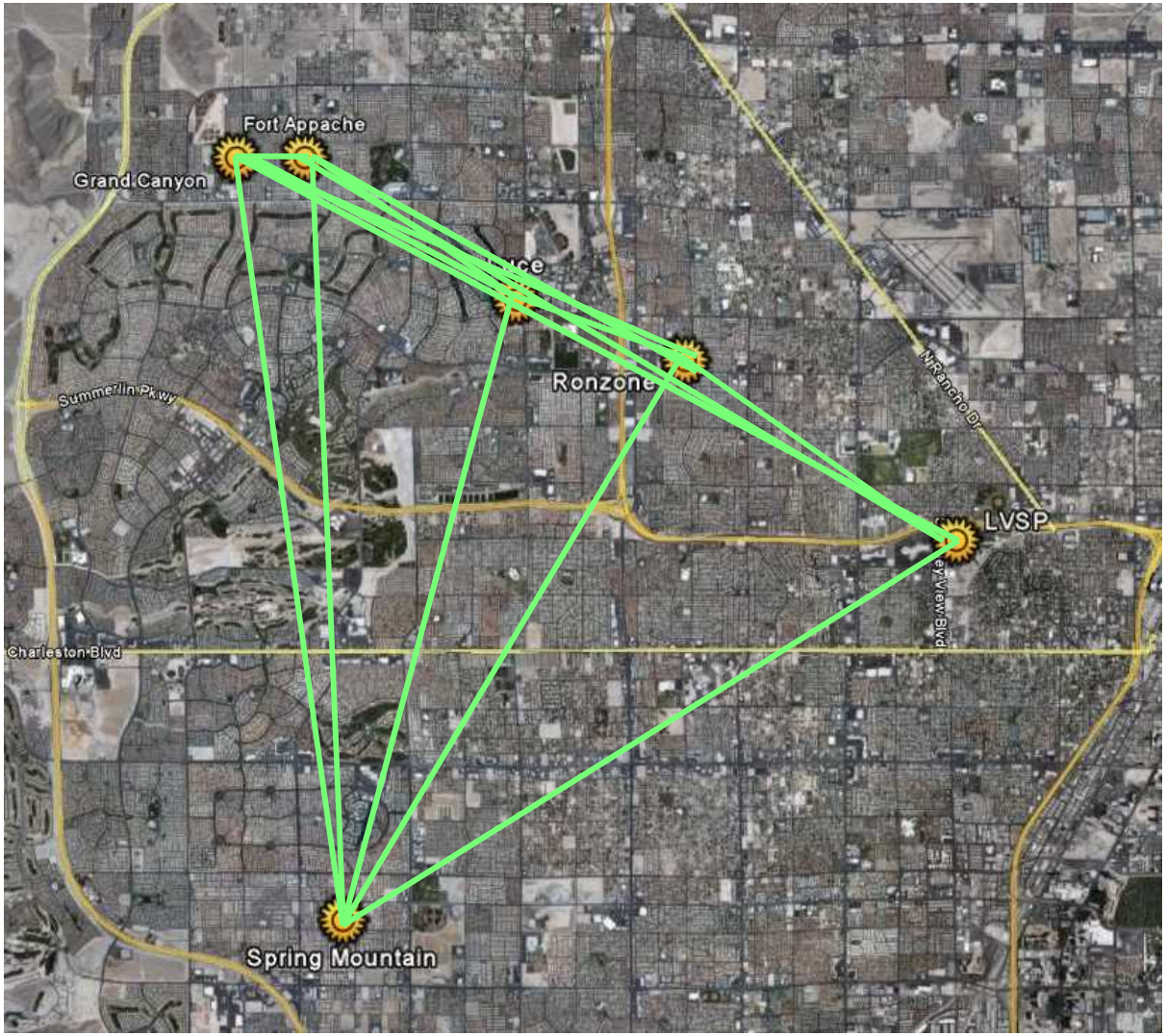
Characterizing Variability

- Examine irradiation correlations
  - Between inverters at the same site (100-200 m apart)
    - Inverters at same site do not exhibit significant differences at the 1-minute sampling rate.
  - Between different sites (1-12 km apart)
  - Irradiation changes (ramps)
- Examine power output variations
  - For a single inverter
  - Between inverters at the same site (100-200 m apart)
  - Between different sites (1-12 km apart)

Site Map



Measure distances between each pair

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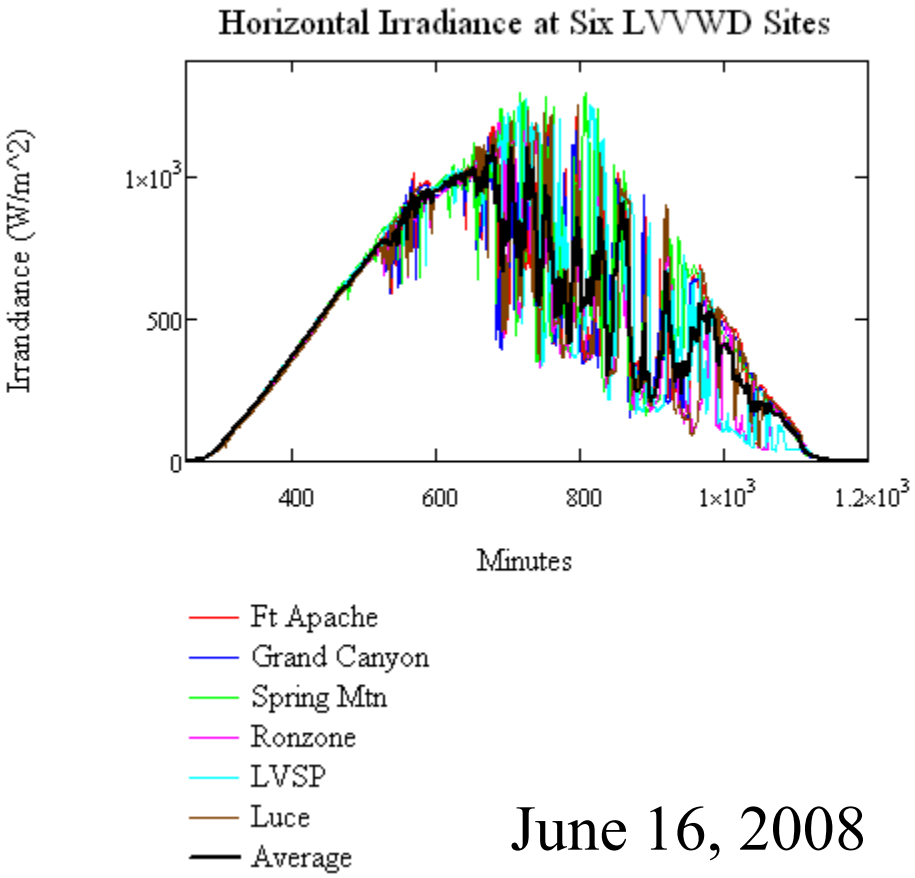
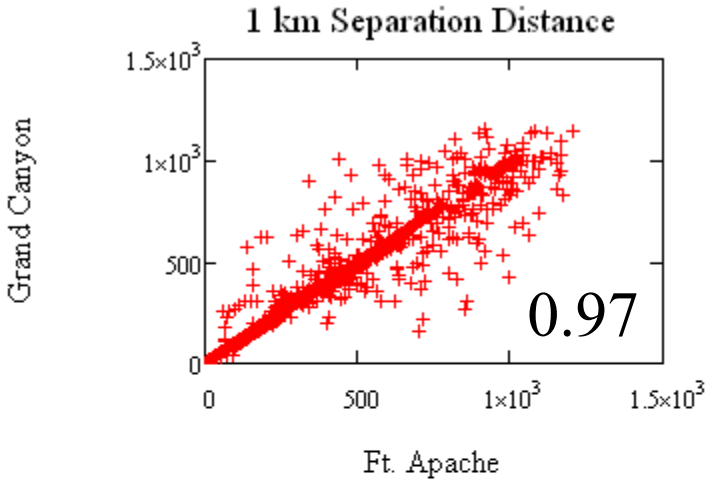
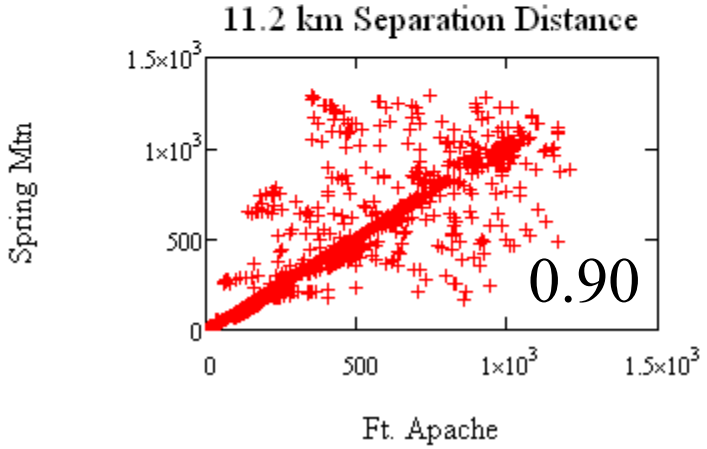
Correlation Between Sites



June 16, 2008





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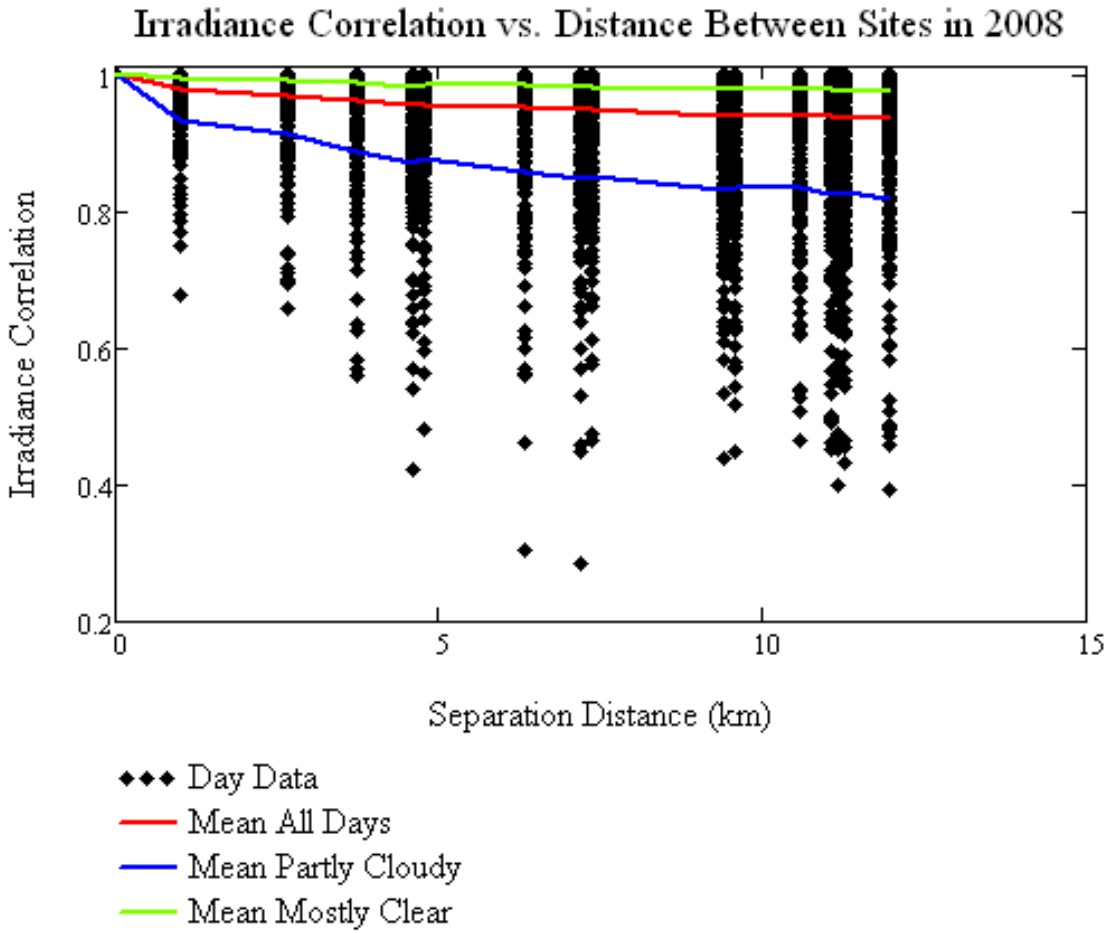
Correlation of Irradiance between Sites Depends on Separation Distance



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Ramp Rate Statistics

- Grand Canyon 2008 Irradiance “ramps”
  - Max ramp = 764 W/m^2 per minute
  - 99th percentile = 179 W/m^2 per minute
- Grand Canyon 2008 Power “ramps”
  - Max ramp = 68% of capacity per minute
  - 99th percentile = 12% of capacity per minute

- 1-Second irradiance data from Albuquerque
  - Irradiance ramp rates can exceed 300 W/m^2 per second.

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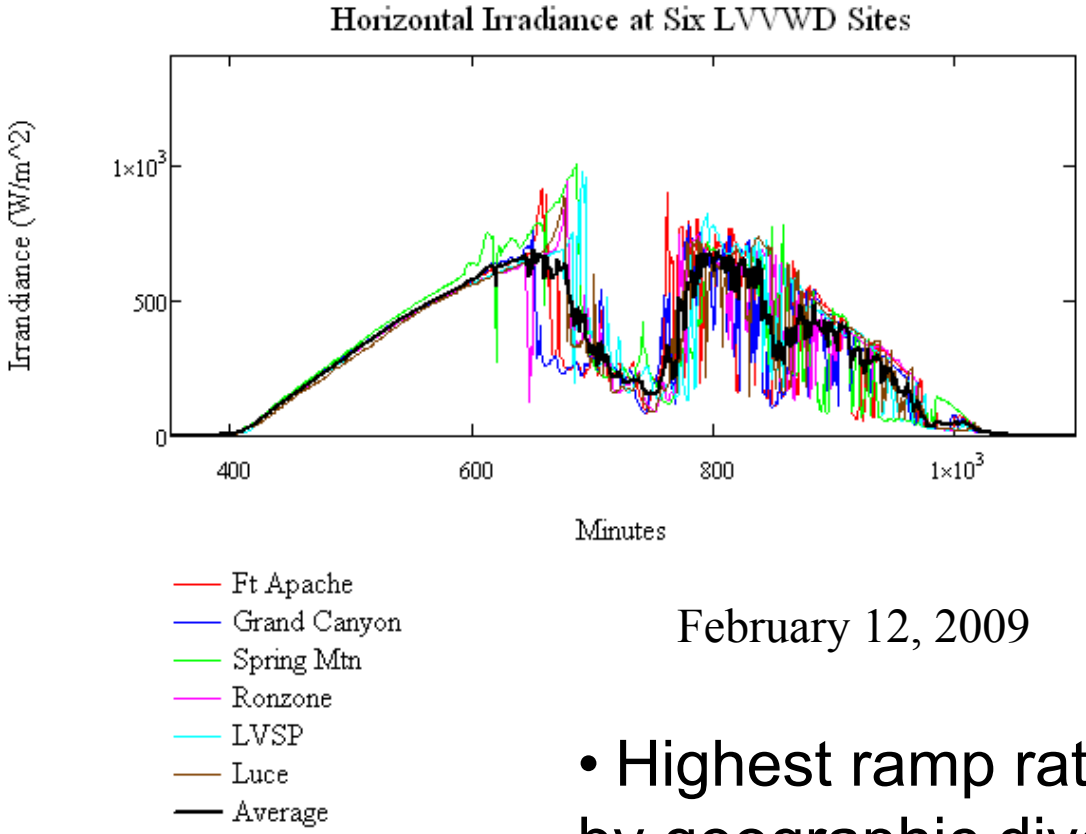
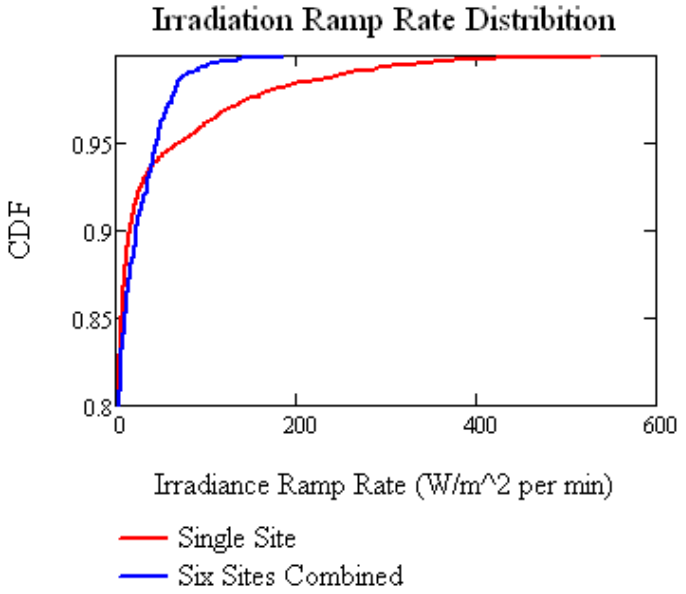
Example of Irradiation Ramp Rate Distribution





February 12, 2009

- Highest ramp rates are reduced by geographic diversity
- Frequency of lower ramps can be increased

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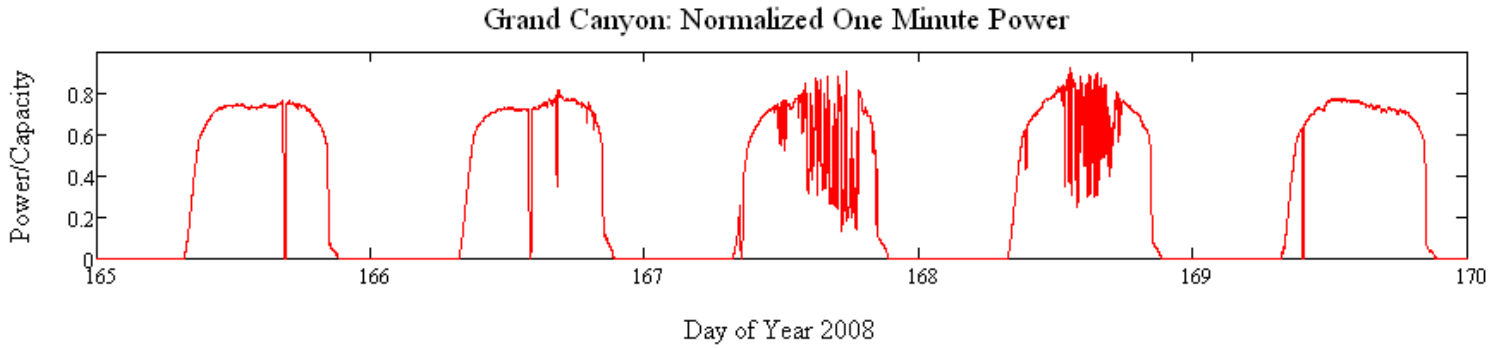
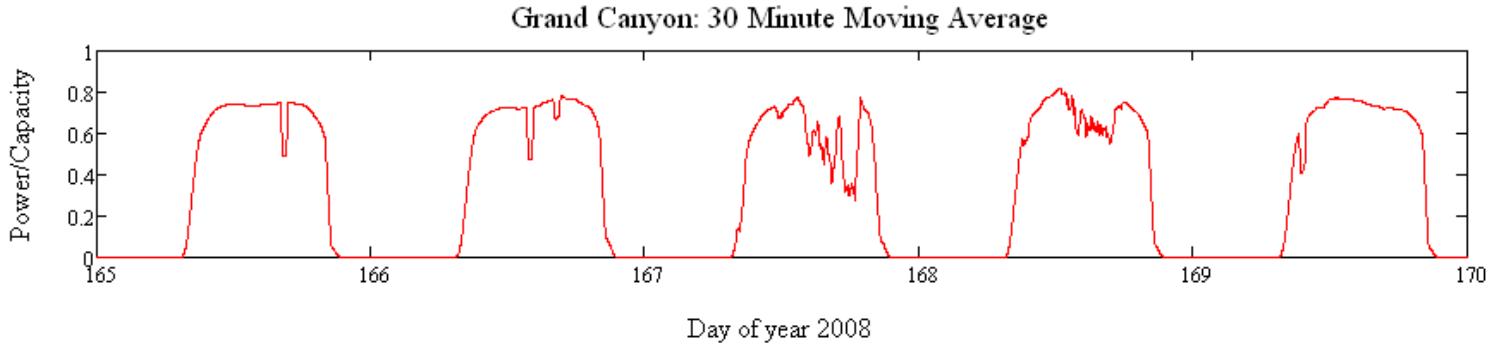
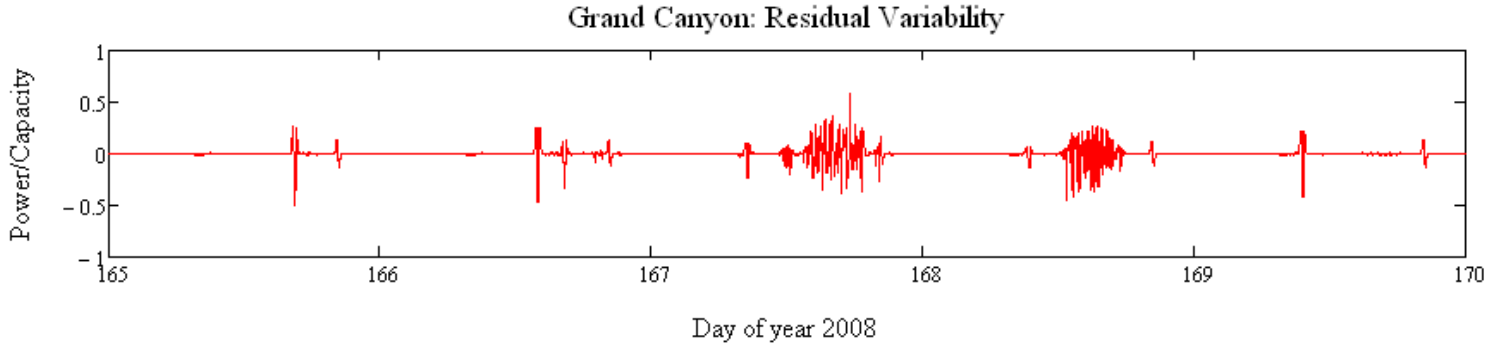
Regulation Impacts

- Examine power output from 2008
- Subtract 30-minute moving average
- Reduce to 10 minute average of residuals
  - Estimate PV contribution to Area Control Error (ACE)
- Determine frequency that “ACE” exceeds defined range
- Calculation ultimately needs:
  - Time synchronous load data
  - Higher frequency measurements (<1 min)
  - Better spatial resolution

Example of “ACE” Estimation







June 13-18

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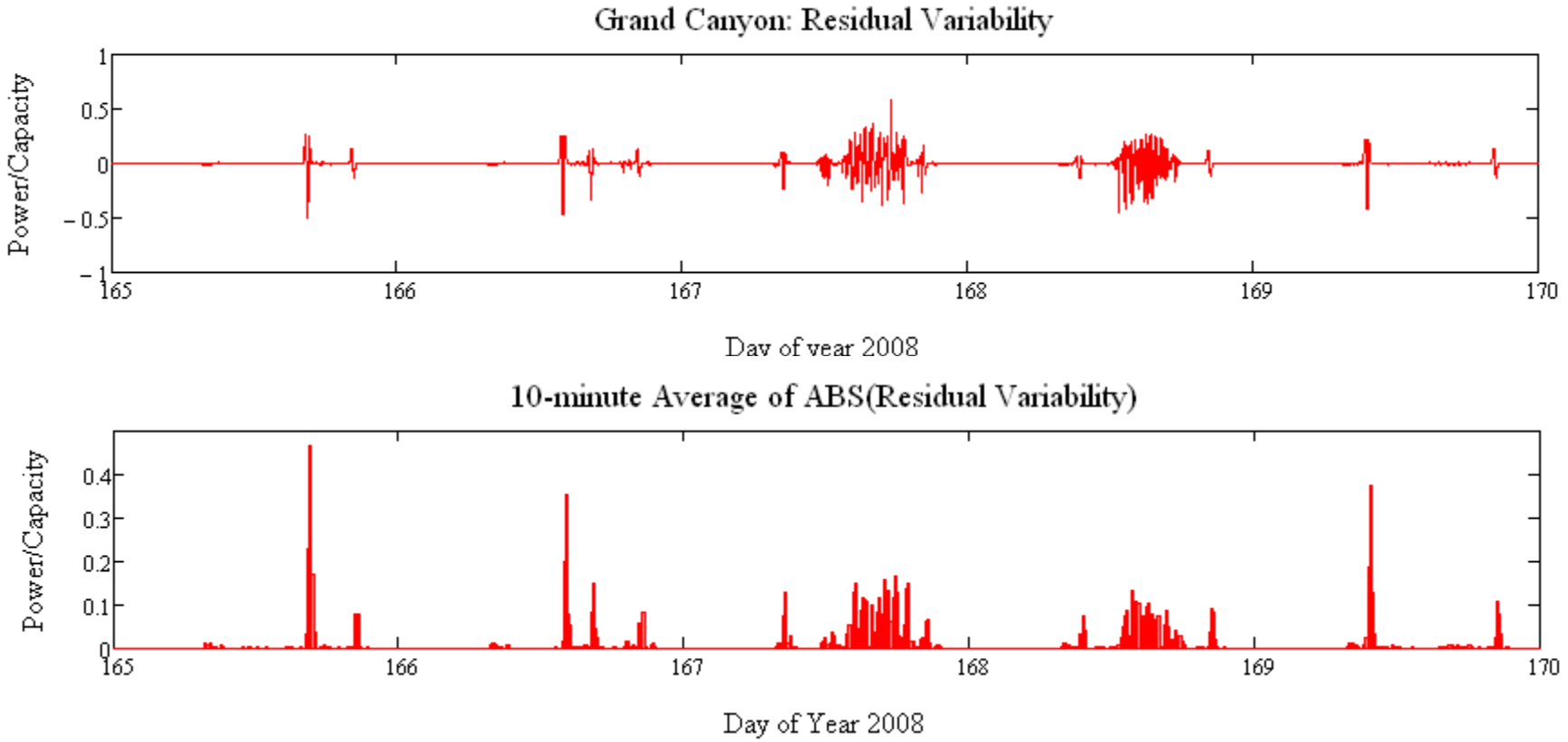
Example of “ACE” Calculation



Control performance is affected by solar variability

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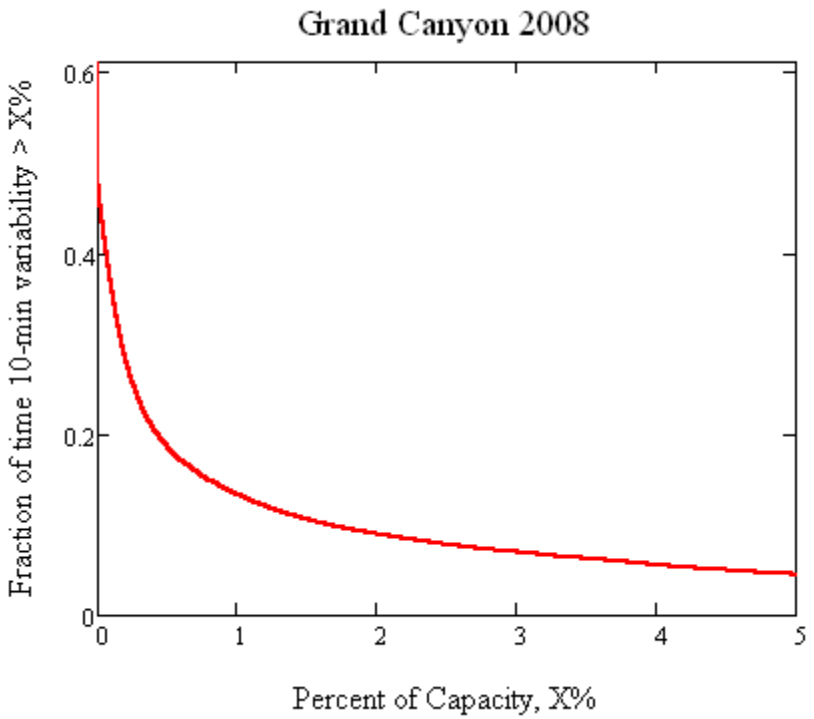
Annual Balancing Area Control Performance Estimation



13% of time variability is greater than 1% of capacity

9% of the time variability is greater than 2% of capacity

Question: How effective is geographic diversity in reducing this variability?

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Summary

- LVVWD PV Data provides a valuable source of Nevada PV data for variability studies
- Operational features of PV plants do affect variability (e.g. inverter drop outs)
- Geographic smoothing is evident from the data
- Highest 1-min ramp rates are reduced by geographic diversity.
- Preliminary estimate of PV variability contributions to balancing area control errors suggest magnitudes similar to typical load variations.

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