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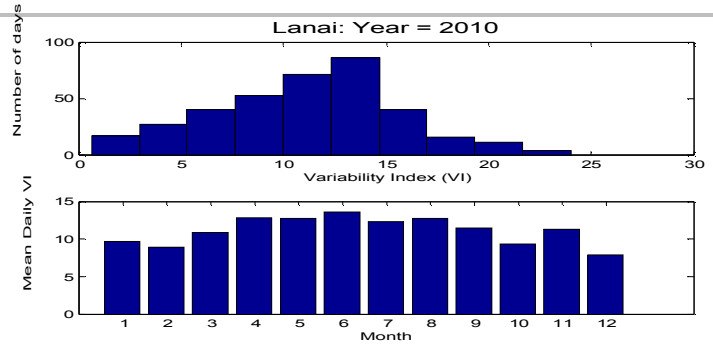

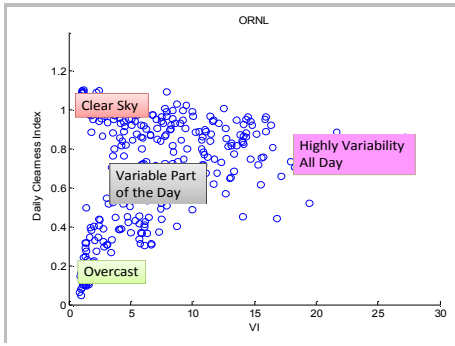

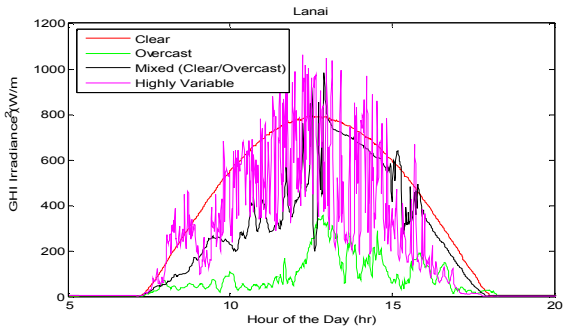

The Variability Index: A New and Novel Metric for Quantifying Irradiance and PV Output Variability

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U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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Outline

- Introduction
  - Why is solar variability important to measure and classify?
- Introduce the Variability Index
- Examples of the Variability Index
- Comparing the Variability Index at three sites
- Using the Variability Index for classifying days
- Correlation of the Variability Index with ramp rate magnitudes

Why is solar variability important?

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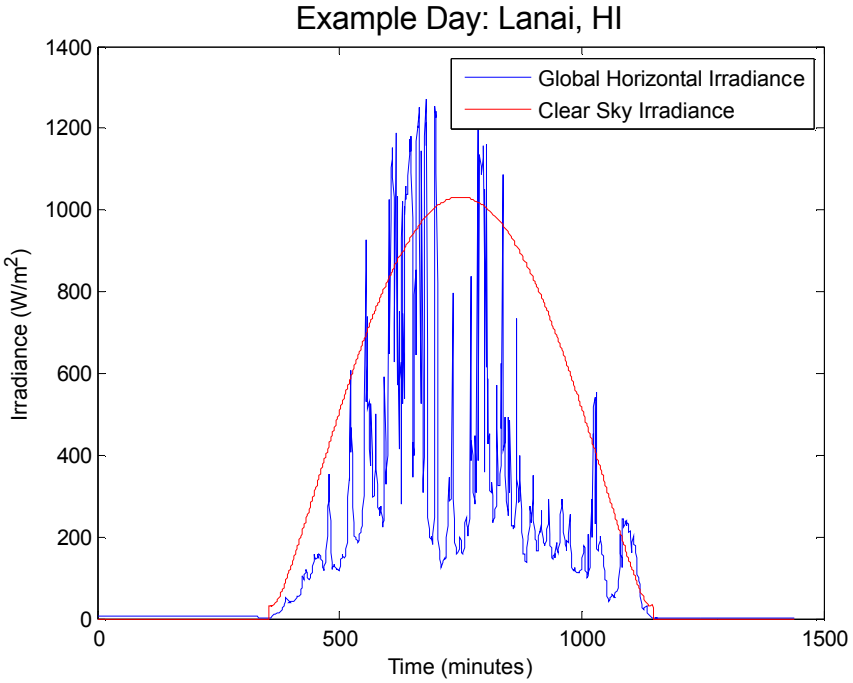
- Solar Variability is important to study because it can cause problems on electric grids with high penetrations of PV (Flicker, Voltage changes, equipment wear, etc.)
- Grid integration challenges due to variability (perceived or real) present real barriers to greater amounts of PV deployment.
- Geographic diversity reduces variability at a system level but does not eliminate it.
- Metrics to classify and quantify variability are needed so that variability at different sites can be accurately represented with a minimum amount of on-site data collection (costly in dollars and time)

Variability Index

- Variability index is the ratio of the "length" of the measured global horizontal irradiance (GHI) and the "length" of the clear-sky GHI*
- $$VI = \frac{\sum_{k=2}^{n} \sqrt{(GHI_k - GHI_{k-1})^2 + \Delta t^2}}{\sum_{k=2}^{n} \sqrt{(CSI_k - CSI_{k-1})^2 + \Delta t^2}}$$
- VI can be calculated for any time interval, we use daily



VI = 14

Length = 14

Length = 1

*Sandia just released a review of clear-sky models (Reno et al., 2012)

Other Methods

- Lenox and Nelson (2010) proposed the “Inter-Hour Variability Score” which summed the absolute value of 1-min changes in plane of array (POA) irradiance and AC power output in each hour.
- Van Haaren et al. (2012) (in review) propose a “Daily Aggregated Ramp Rate”, which sums 1-min POA irradiance over each day.

- Both of these approaches have strengths and weaknesses
  - Relate more directly to expected power ramps (absolute POA irradiance changes)
  - Values depend on the time increment of the measurement and vary due to seasonal and latitude factors.

Examples of Increasing Variability

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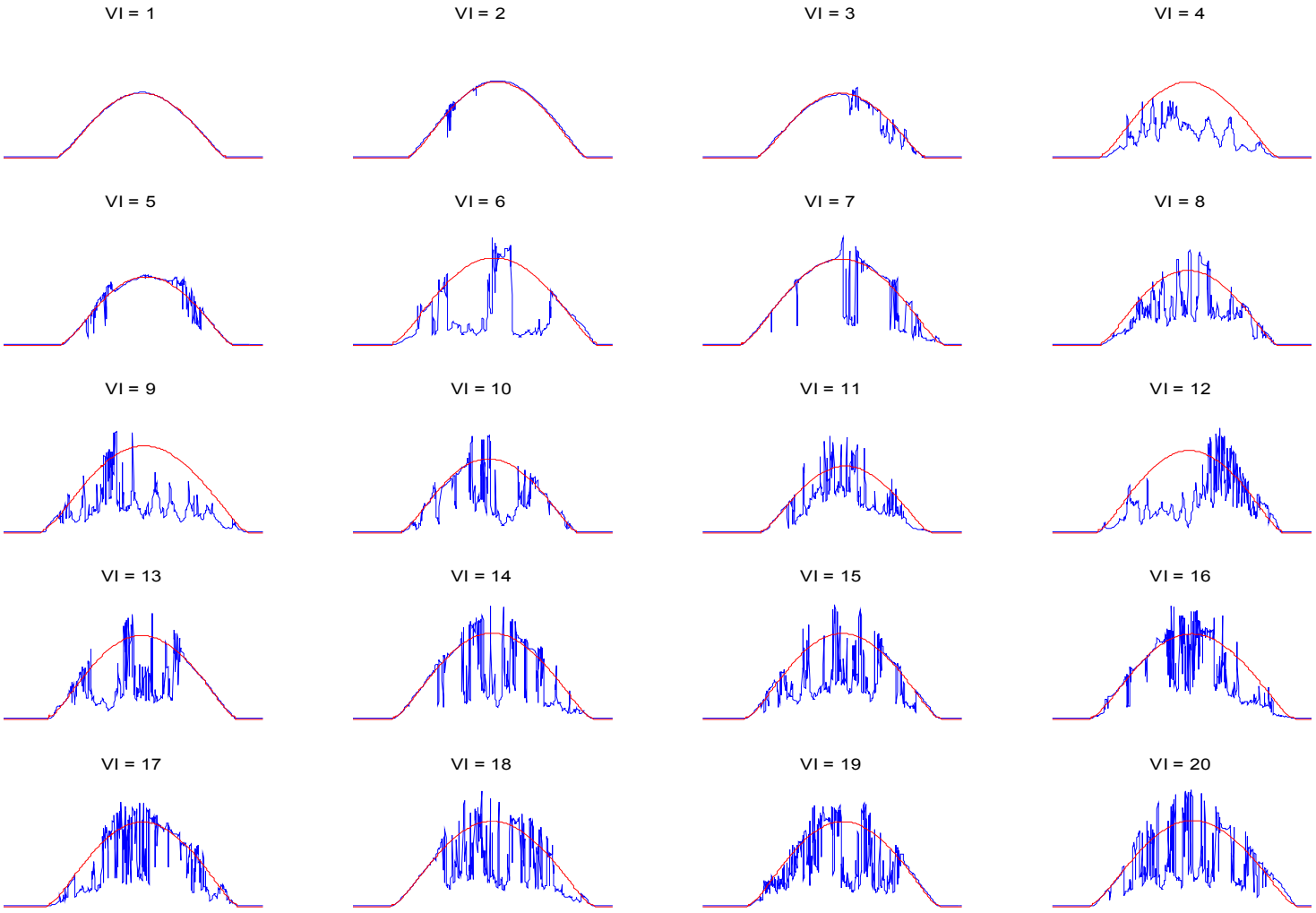
Lanai, Hawaii



Examples of Increasing Variability

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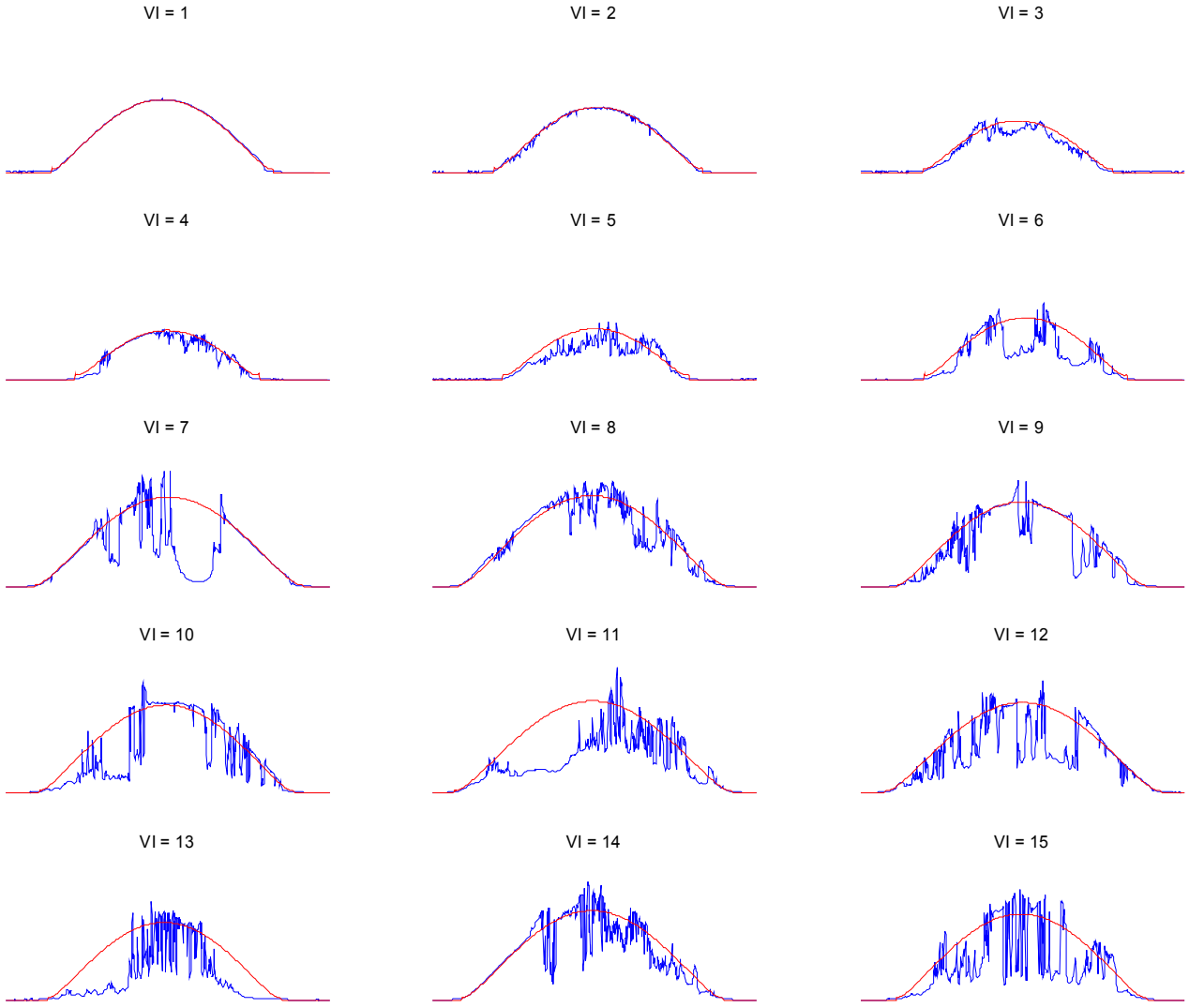
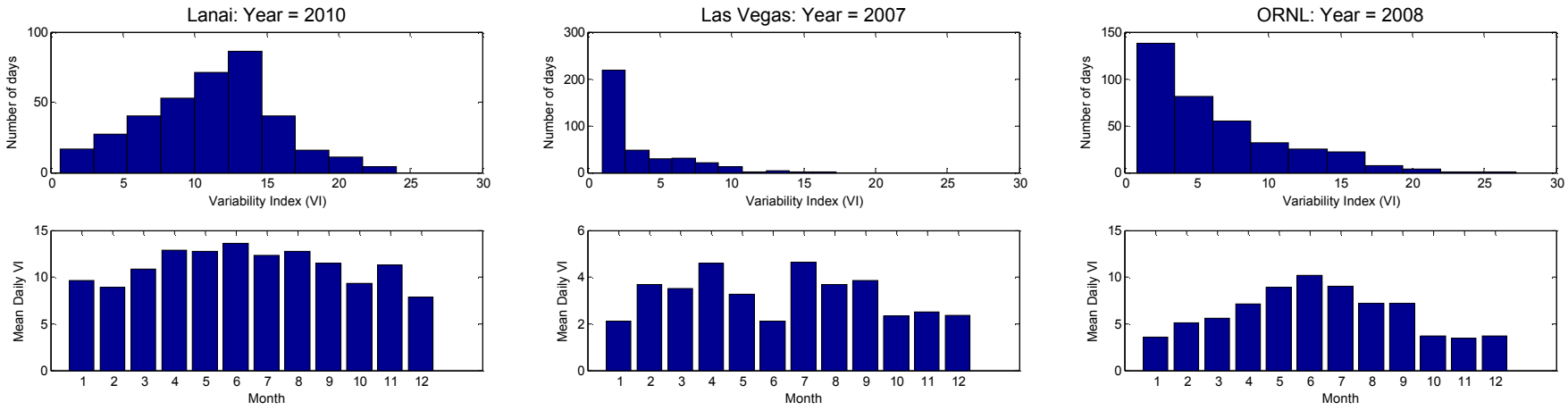
Las Vegas, NV



Comparing Variability Between Sites

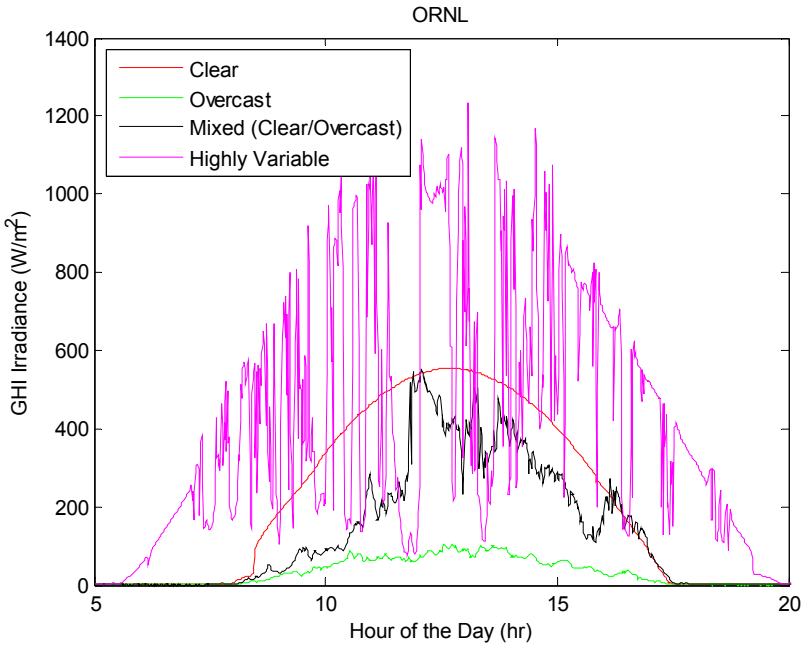
- Most days at Lanai are highly variable
- Most days at Las Vegas are clear
- Clear and variable days are mixed at ORNL (Tennessee)



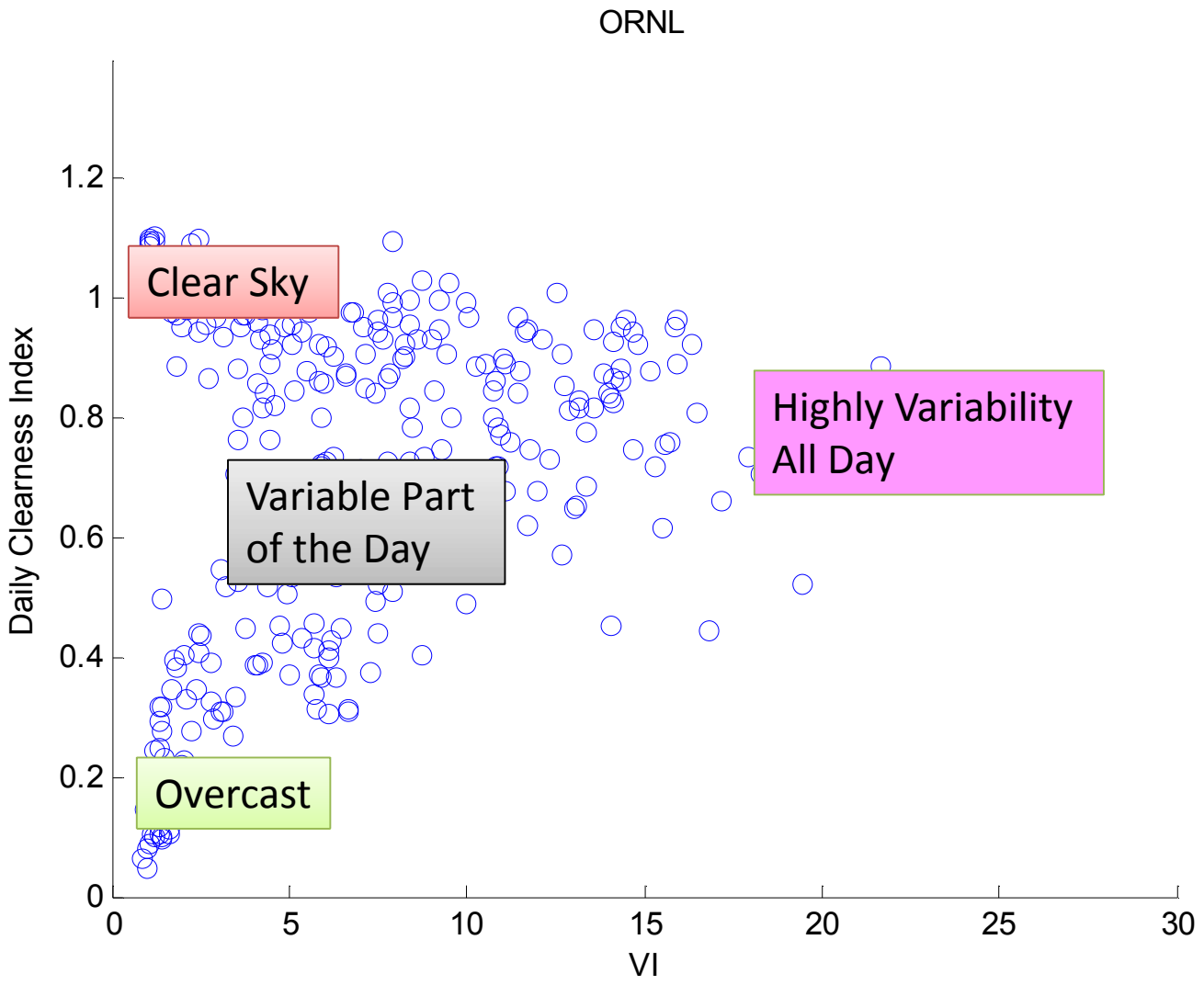
- Lanai has high variability year round. Lowest months are Feb and Oct.
- Las Vegas has relatively low variability with peaks in April and July
- ORNL (Tennessee) has higher variability in the summer and lower in the winter

Classification of Variability Periods

- We suggest a simple classification scheme for solar days
  - Variability index
  - Daily clearness index (measured insolation/clear-sky insolation)



“Arrow Head” Plot



“Arrow Head” Plot for Lanai, Hawaii

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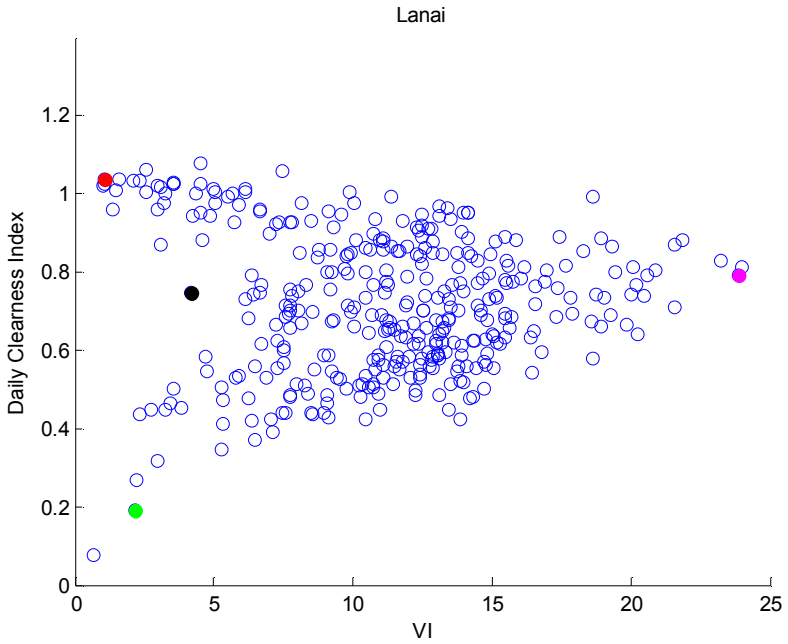
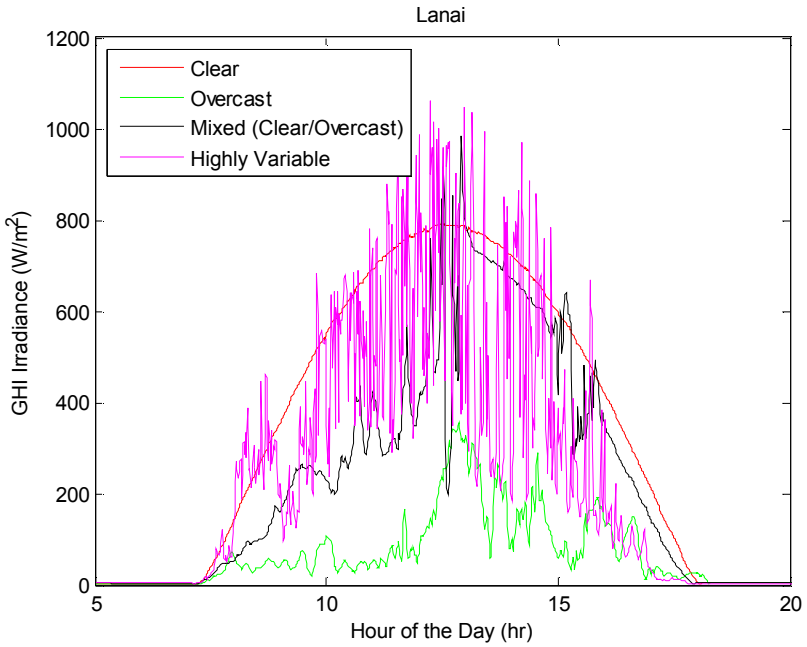
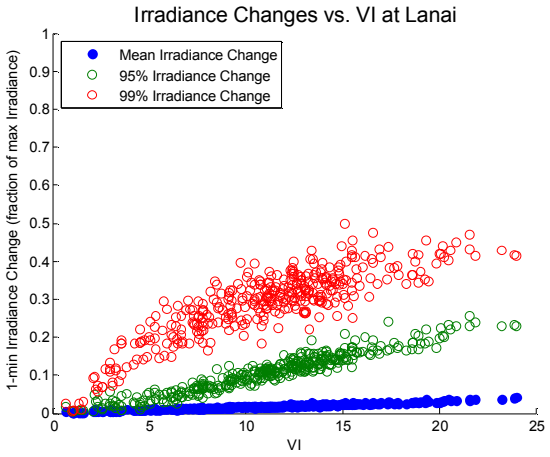
- Note high density of days in the middle of the Arrow Head

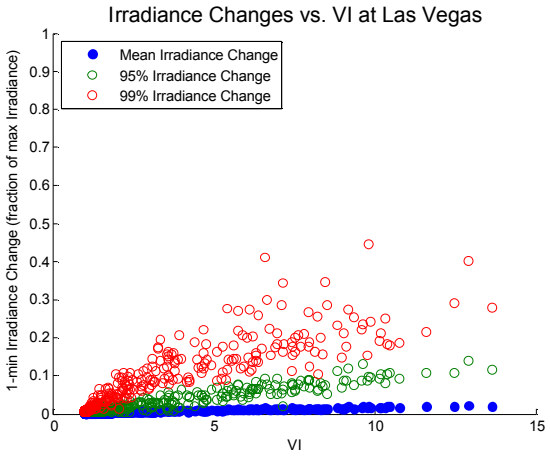


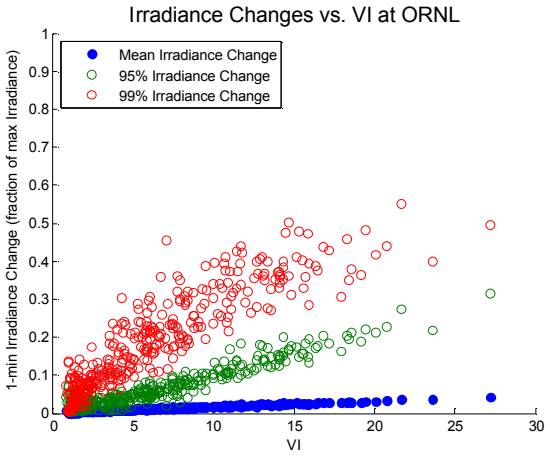


Good Indicator of Ramp Magnitudes

- Variability Index is a good predictor of the magnitude of large ramps.







- The correlation between the largest ramps is more scattered, but still significant.

Summary

- Variability Index is an easy metric to calculate, can be calculated for many time intervals, and provides a great measure of variability for comparing sites and defining temporal patterns.
- In conjunction with a mean clearness index, it provides a repeatable and consistent classification scheme.
- Good correlation with large ramp rates

- Future Work Opportunities:
  - There may be value in forecasting the Variability Index
    - Directly related to spinning reserve requirements