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The MDA Solar Forecasting System: Sub-hourly variability and behind-the-meter generation

Stephen D. Jascourt Daniel B. Kirk-Davidoff Christopher Cassidy Travis Hartman
Stephen.Jascourt@mdaus.com MDA Information Systems, LLC 820 W. Diamond Ave, Ste 300 Gaithersburg MD 20878

MDA INFORMATION SYSTEMS LLC
a U.S. company
www.mdaus.com

Overview

MDA Information Systems, LLC is predicting electric power generated from solar energy for individual sites and for regions.
Two years ago at this meeting, we presented about MDA's state-of-the-science ***irradiance*** forecasting system utilizing the REST2 clear sky model, AERONET aerosol observations, and a variety of other public sources and proprietary site data.

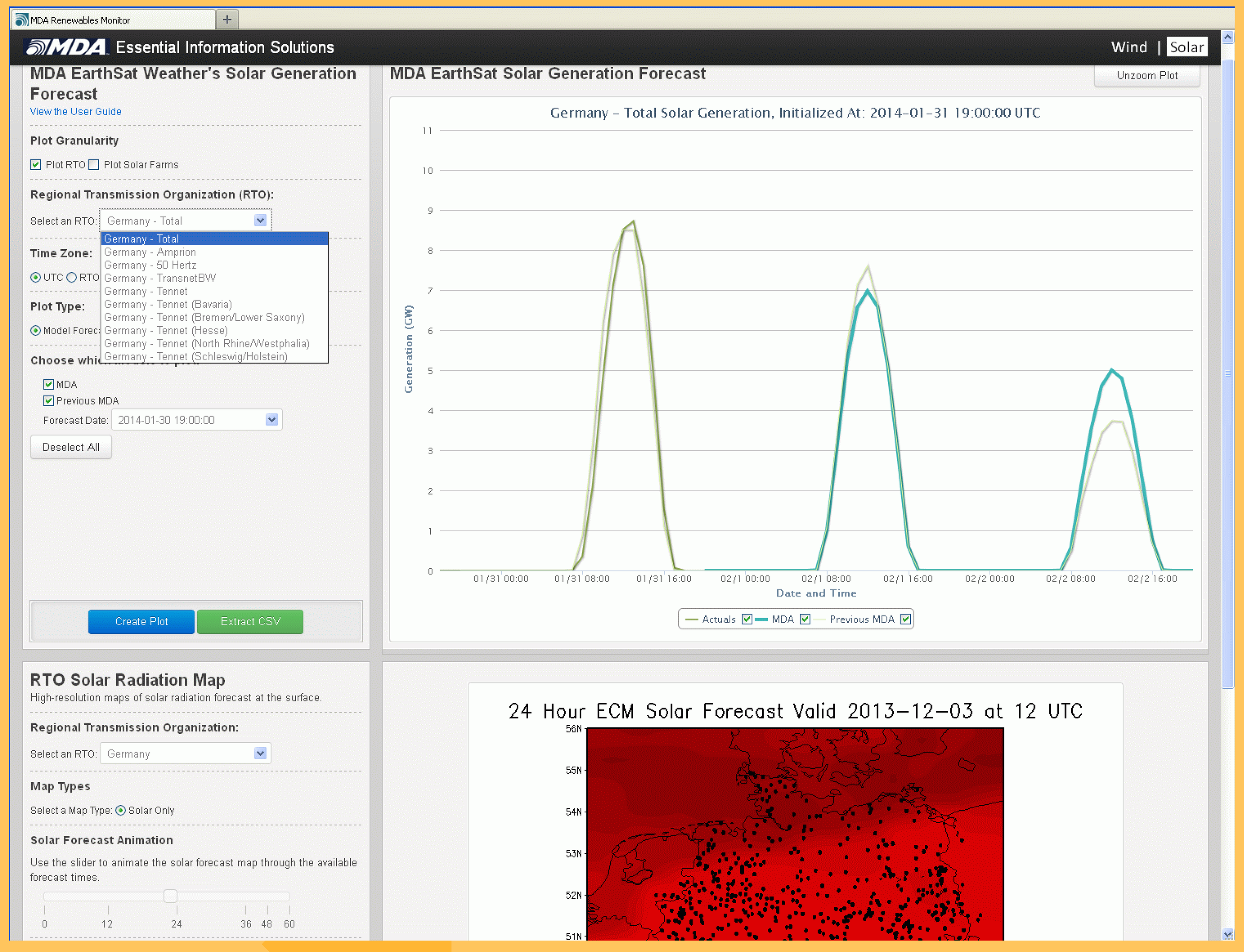
Last year, we presented about MDA's solar ***power*** forecasting system, highlighting challenges we met ***predicting hourly electric power generation*** for a single-axis PV farm in a challenging location beset by synoptic and local storms as well as sunny-day cumulus.

This year, we highlight prediction of ***subhourly variability*** for ***irradiance and power*** at individual sites and real-time calculation of aggregate ***distributed generation*** from hundreds of thousands of sites in California.

MDA Solar Power and Solar Irradiance Forecasting

MDA Information Systems, LLC has developed a solar forecasting system

- Individual sites or collections of sites
- Distributed generation
- Panels of any tilt or sun-tracking
- All forecast lead times
- Prediction of
  - Solar power generation
  - Global Horizontal Irradiance **(GHI)**
  - Direct Normal Irradiance **(DNI)** and Direct Horizontal Irradiance **(DIR)**
  - Irradiance incident on panels (plane of array)
  - Prediction of subhourly variability for power and irradiance



MDA predictions of PV electric generation outperformed competition during our only head-to-head match-up so far

Our user interface shown here

- Is integrated into the wind power forecast display with the same features
- Allows viewing of forecasts for regions or individual farms
- Shows current and past forecasts and reported actuals to present
- Allows viewing of error statistics from recent forecasts
- In addition to the MDA power forecast, overlays model irradiance forecasts onto a map indicating power installation density, allowing the user to get a sense of the spatial and temporal distribution of incoming solar energy and its juxtaposition with electric generation capacity

An improved user interface with more flexibility is coming soon!

- Combined wind+solar power will be available for regions having large wind and solar capacity

Skill is dominated by prediction of clouds. Predicting evolution beyond the first few hours requires use of numerical weather prediction **(NWP)** models

- Cloud prediction is a weak point in NWP
- Time-averaged, not instantaneous, values of surface shortwave flux are needed
- Output frequency for most major NWP models is insufficient
- Surface shortwave fluxes from NWP models need complex bias correction (function of other variables)
- Most NWP models do not output direct beam irradiance (DNI or DHI) and those that do provide it have little skill independent of predicted GHI

MDA Information Systems, LLC solar forecasting system meets these challenges through

- Leveraging the REST2 (Gueymard, 2008) clear sky model as a foundation for time interpolation, bias correction, and direct beam calculation
- Employing a variety of public data sets to obtain aerosol-related and other parameters needed for REST2 and for considering cloudy atmospheres
- NWP bias correction as a function of key variable combinations
- Skill-based blending of NWP models and time-lag ensembles
- Accounting for short-term fluctuations in irradiance based on conditional statistics we generated based on data from high-quality irradiance monitoring sites

Reference: Gueymard, C. A., 2008: REST2: High-performance solar radiation model for cloudless-sky irradiance, illuminance, and photosynthetically active radiation – Validation with a benchmark dataset. *Solar Energy*, **82**, 272-285

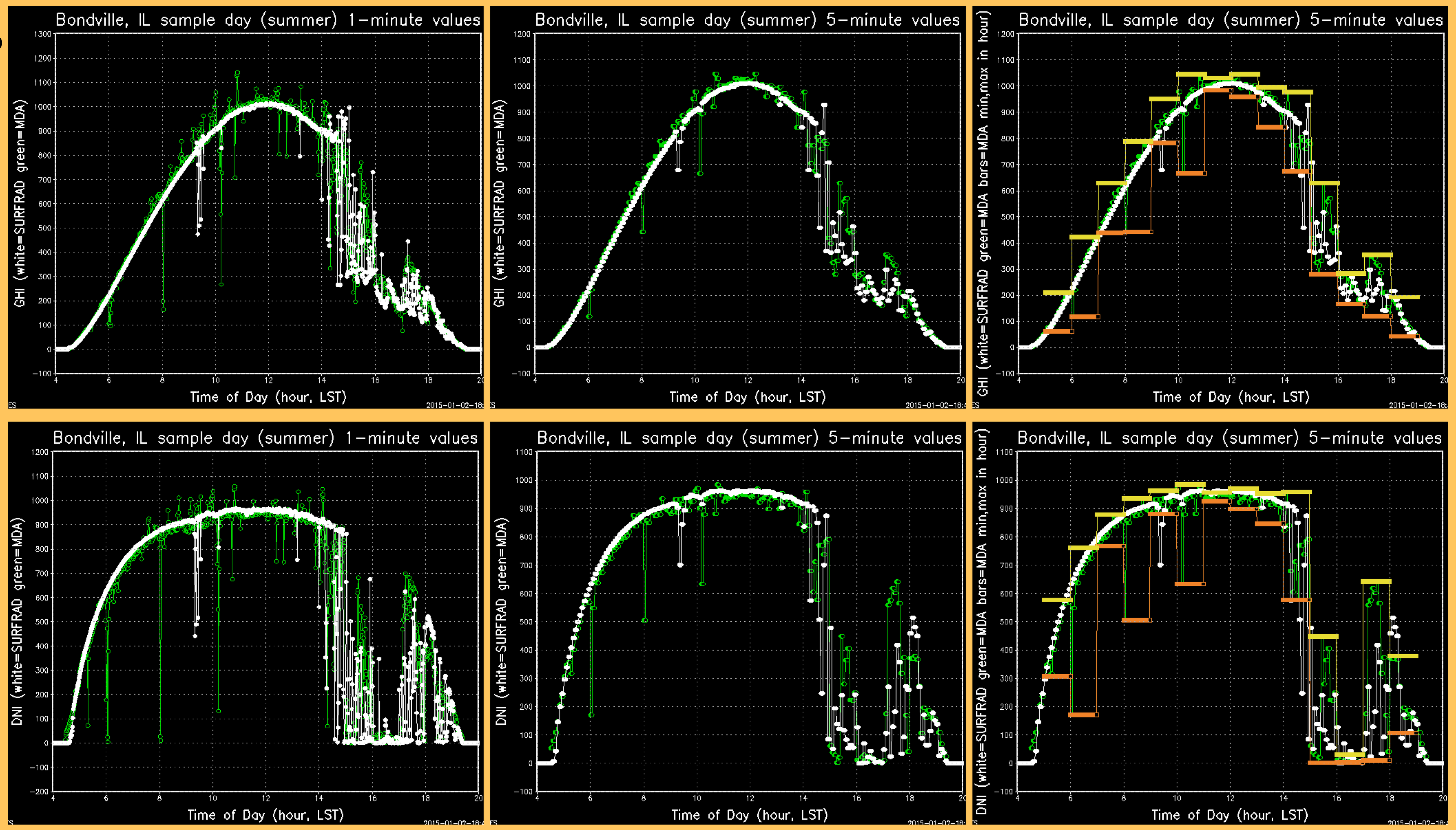
Sub-hourly Variability - Irradiance

Predictability of the times when cloud patches will pass in front of the sun is near zero beyond the first hour or two. However, ***predictability of variability has promise.***
We can predict the presence of a cumulus field that will result in wild irradiance fluctuations or mid-high level cloud patches that will result in mild fluctuations.
Grid managers and others in the electric industry need to know if the solar power output will be variable or steady. It appears we can provide potentially useful information about this.
Variability and uncertainty are not to be confused. The forecast for hourly irradiance or power ***and its sub-hourly variability*** has higher certainty than the forecast values on sub-hourly time scales.

MDA has developed a method involving conditional sampling of 1-minute observations and their corresponding autocorrelations. Forecasts of hourly average transmissivity together with other factors yields a set of stochastic 1-minute predictions. While the 1-minute predictions should individually have poor skill, their sub-hourly variation should have some skill and their hourly average irradiance will have the same skill as the underlying hourly prediction.

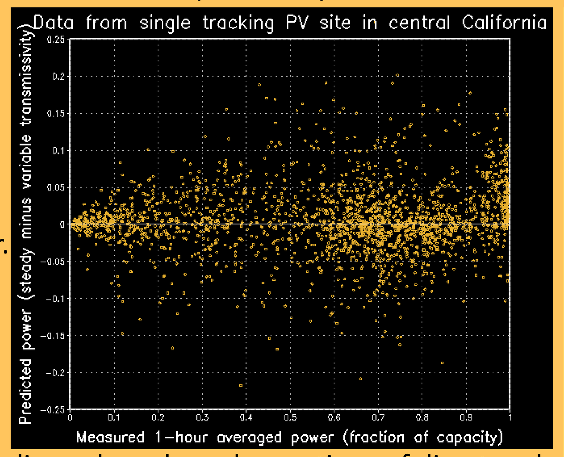
We applied this result to 5 years of 1-minute observations at all 7 SURFRAD sites. This method was used to reconstruct 1-minute values from hourly averages in 1-hour chunks. Statistics for each individual site and merged statistics combining all sites were used, with results from the merged statistics almost as good. Thus, the merged statistics can be applied to locations without long histories of high-quality data.

Results for a summer day at the Bondville, IL SURFRAD site are shown here, GHI on the top row and DNI on the second row. The left panels show 1-minute observations in white and stochastic 1-minute simulations in green. The middle panels show the same for 5-minute averages of the 1-minute values. The minimum and maximum 5-minute averaged stochastic values within each hour are shown by the orange and yellow bars in the right panel. In a perfect forecast, they would match lowest and highest white dots within the same hour. Overall, the method does distinguish between periods of low and high variability.

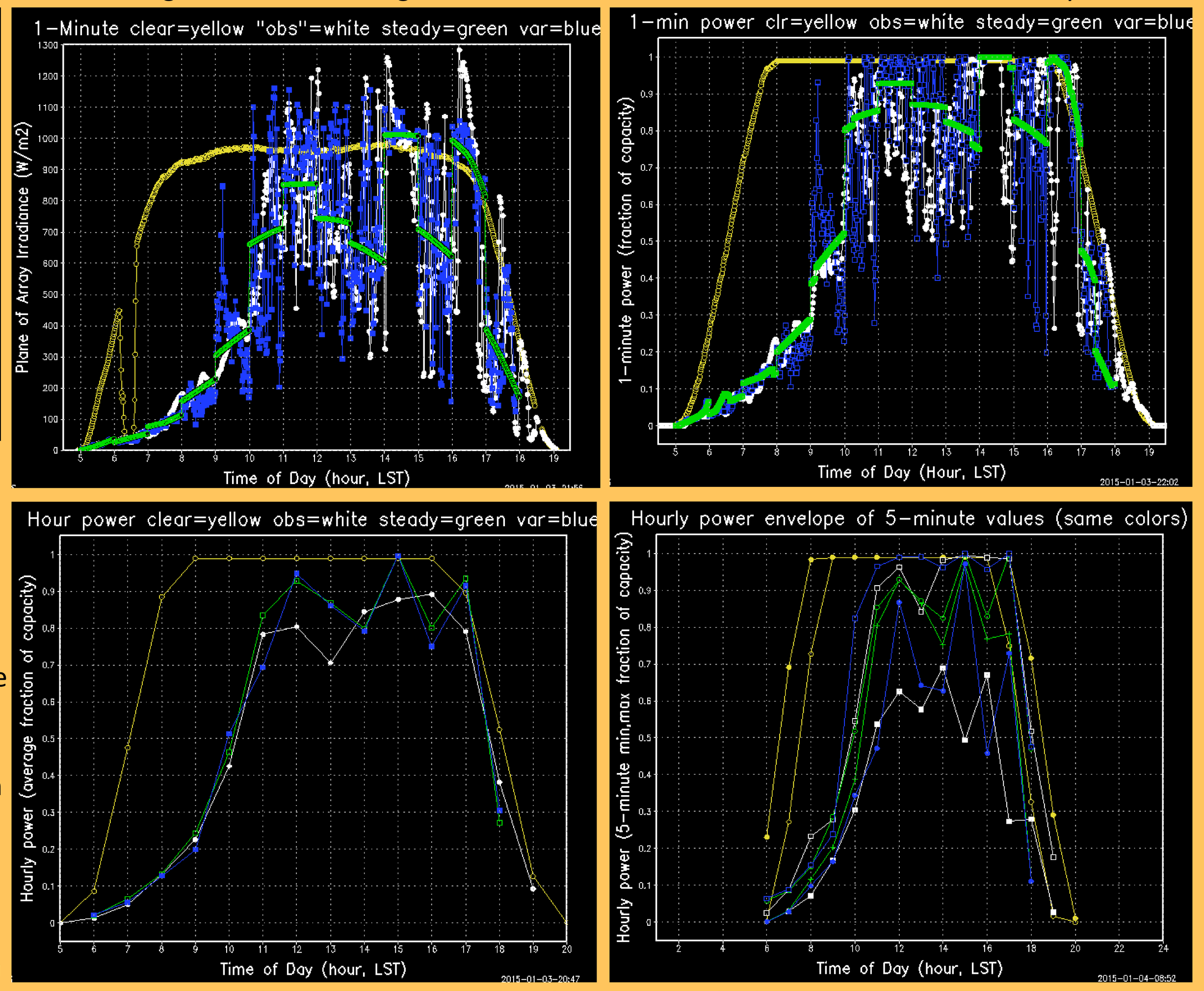


Sub-hourly Variability - Power

Sub-hourly variability does change the hourly-averaged power forecast! Because inverters limit the power output under conditions of very high irradiance, the power output during moments of peak irradiance will be flat-line instead of peaking. This is shown in the scatter plot for a year of 1-minute data from a single-axis sun-tracking site. Irradiance observations were taken ~ 10 km away and were put through the MDA Solar Power Forecasting System utilizing empirical power curves for this site. Hourly averaged irradiances were used to generate transmissivities. "Steady" values are based on the hourly averages while "variable" 1-minute values employed the stochastic method described above. The difference is plotted as a function of hourly-averaged measured power. The steady values are systematically higher than the variable values when the PV installation is operating near its rated capacity but not at other times.

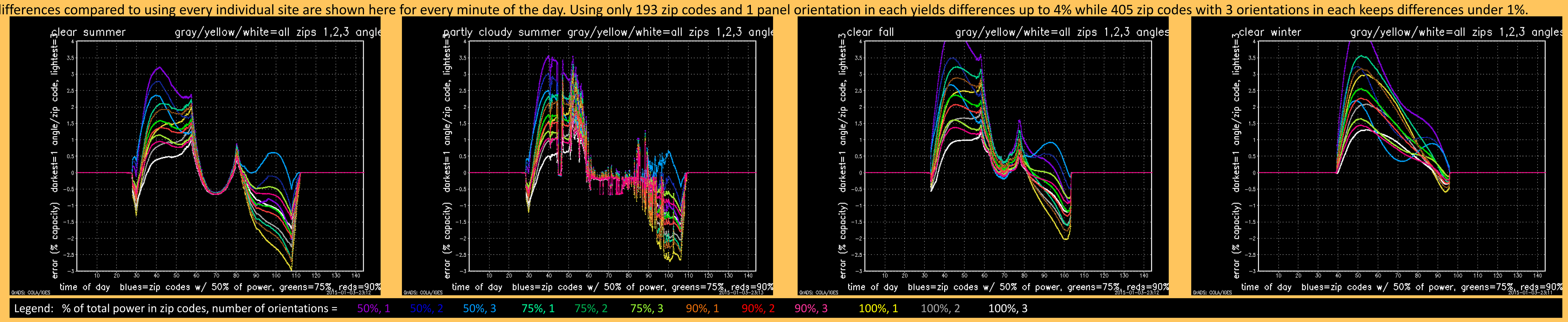


A sample partly-cloudy day from this same experiment is shown in the 4-panel figure. Calculated plane-of-array irradiance based on observations of direct and diffuse irradiance are shown in white while the hourly reconstruction using the steady assumption is in green and the stochastic values are in blue. For comparison, the observed values for the next day, a clear day, are shown in yellow (dip at 6:30AM is a shadow falling on the sensor). Irradiance peaked well above the clear sky values numerous times. The corresponding observed and simulated power is shown to the right using the same colors. The measured power did not peak higher than on the clear day, and the power fluctuations corresponding to the stochastic irradiances match the pattern of measured power fluctuations. Condensing the 1-minute information into hourly information in the lower panels, the hourly average power (left) does not inform the viewer of the wild character of the power generation on this day. In the right panel, the envelope bounded by the minimum and maximum 5-minute averages within each hour provide this information. The clear day shows a wide envelope during the morning and evening ramps but the envelope is squeezed to nothing during most of the day. Similarly, the steady assumption depicts only a narrow envelope while the stochastic method indicates a wide envelope roughly matching the observations.



Distributed Generation – How many sites need separate forecasts?

The California Solar Initiative (CSI) lists over 140,000 active sites totaling almost 2 GW of installed PV capacity, mostly behind-the-meter with no visibility to utilities or public sources. How many of sites does an aggregate forecast need to account for to make a close approximation of all 140,000+ sites? We address this question by simulating prototypical clear, partly cloudy, and cloudy days in each season using every individual site and compared the results to using a selection of sites.
The CSI database lists the capacity and CEC-rated AC capacity for all sites and the fixed panel orientation or number of sun-tracking axes for most sites. We applied measured direct, diffuse, and upwelling irradiance at the Desert Rock, NV SURFRAD site from selected dates to create tilted panel plane-of-array irradiances for each CSI site. Plane-of-array irradiance was converted to power using a simple power curve truncated at 1000 W/m². The CSI sites were then aggregated by zip code and grouped into dominant orientations. The 1508, 637, 405, and 193 zip codes containing 100%, 90%, 75%, and 50% of the total capacity were prorated up, and the dominant 1, 2, or 3 fixed-panel orientations and sun-tracking orientations were used for each included zip code. The differences compared to using every individual site are shown here for every minute of the day. Using only 193 zip codes and 1 panel orientation in each yields differences up to 4% while 405 zip codes with 3 orientations in each keeps differences under 1%.



The Way Forward

- Sub-hourly variability of solar power is vitally important to the energy industry and has higher predictability than sub-hourly power. We need to assess forecast skill of sub-hourly variability **and collaborate with end users on how to express variability in a useful manner**.
- Behind-the-meter generation from rooftop solar installations is ramping up to meaningful amounts in many areas, presenting a blind spot to load management. Forecasting this is much more feasible than forecasting for every site, **if a good site registry exists**.
- Accurate solar power forecasts rely on **high-quality co-located irradiance and power data at high temporal resolution**. More is needed