1408

Solar Power Forecasts Evaluated with Proprietary Site Generation Data for Various Tracking Geometries, Site History Periods, and under a Variety of Weather and Climate Conditions

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Overview

MDA Information Systems, LLC has made solar generation forecasts measured against proprietary solar generation data at many solar farms in a wide variety of geographic locations and climate regions for systems of different size and configuration. We analyzed all this data collectively to estimate the effect of these varying conditions on forecast skill. This poster summarizes the MDA forecast system and shows some of the preliminary results. Further analysis and comparison against skill variability will be needed.

In previous years 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
- 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.
- 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
- Challenges the MDA solar power forecasting system overcomes from model forecasts that are too sunny to observations requiring extensive quality control and even bias correction

MDA Solar Power and Solar Irradiance Forecasting

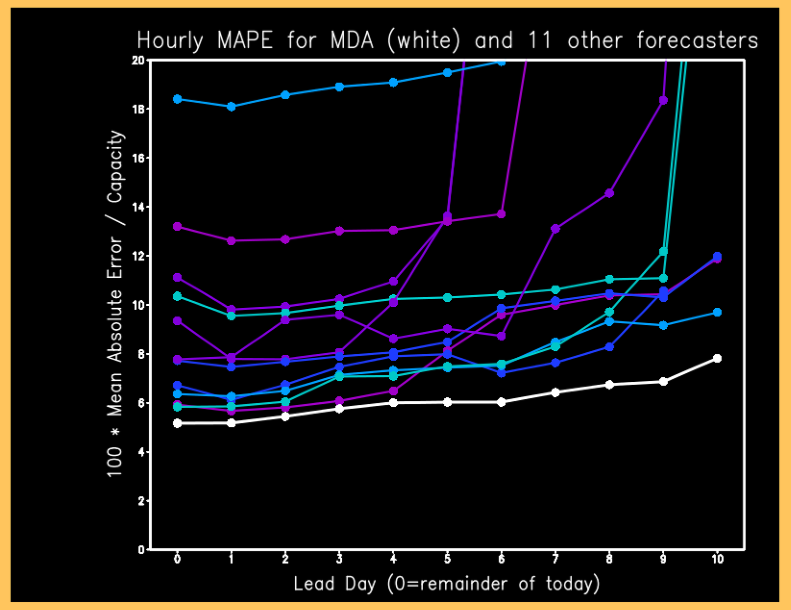
MDA Information Systems, LLC has developed a solar forecasting system
- Individual sites or collections of sites
- Distributed generation
- Panels of any tilt or sun-tracking
- All forecast lead times
- Prediction of
  - Solar power generation
  - Global Horizontal Irradiance **(GHI)**
  - Direct Normal 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 in diverse geographic areas

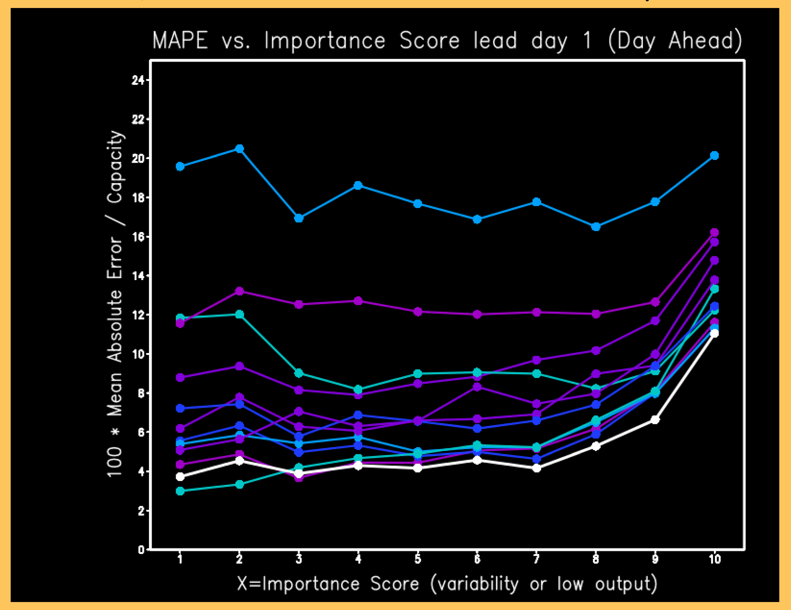
An improved user interface with more flexibility is coming soon!
- Combined wind+solar power will be available for regions having large wind and solar capacity

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
- Converting irradiance to power using multivariate relationships derived from site data passed through quality control



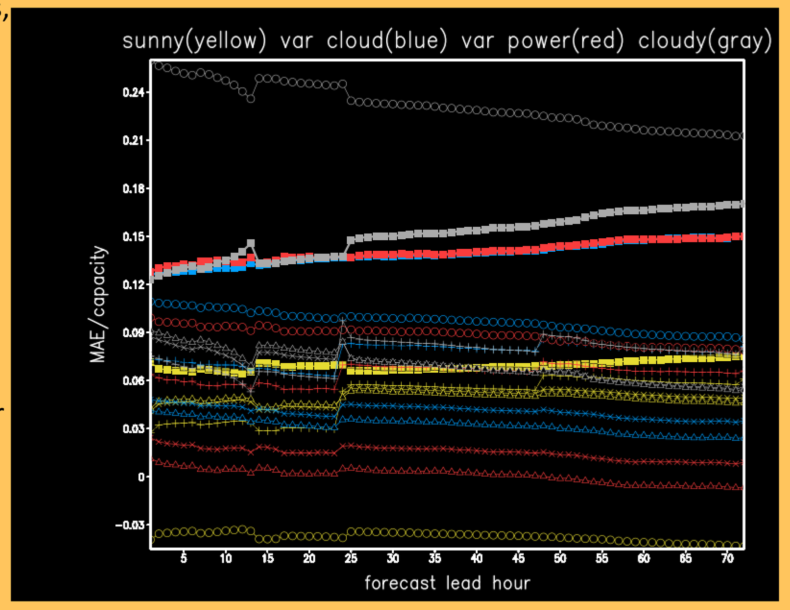
Preliminary results from an independent third-party forecast trial after four months showed MDA leading a large number of forecasters in MAE averaged over all of the solar farms in the competition.
Further, we created an importance score related to daily variability and to highlight days with unusually low generation. The horizontal axis on the plot below is the decile of the importance score. The most important forecasts are also the most difficult, and MDA leads overall and on those days.

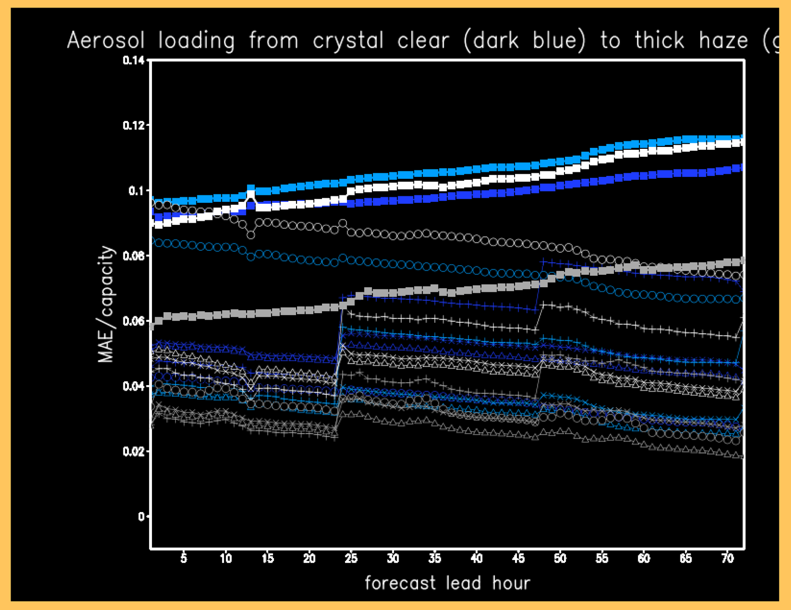


Reference: Gueymard, C. A., 2008: REST2: High-performance solar radiation model for cloudless-sky irradiance, illuminance, and photosynthetically active radiation – Validation with a benchmark dataset. *Solar Energy*, **82**, 272-285

Skill Comparison by Weather, Climate, and Solar Farm Characteristics

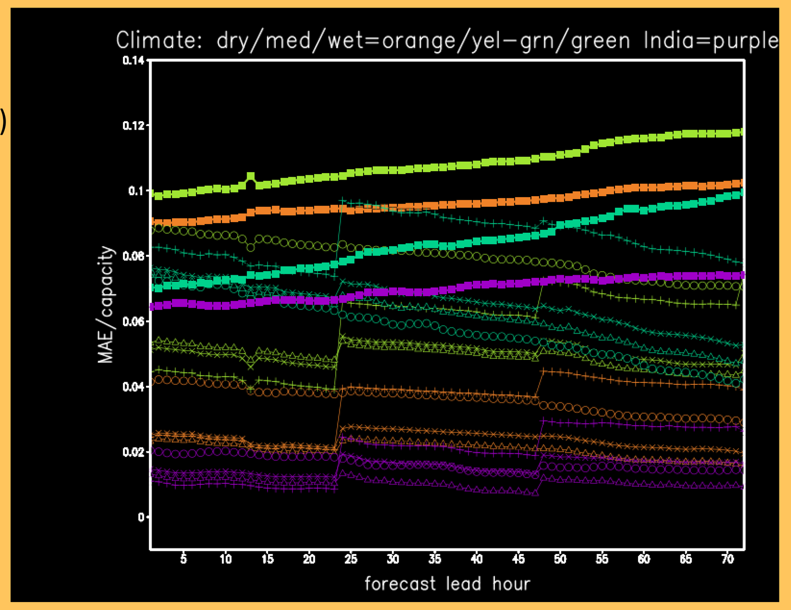
The most interesting and not surprising result is comparison by weather conditions. We compiled scores for all hours identified as sunny, all hours identified as having variable cloudiness, all hours identified as having variable power, and all hours identified as having thick clouds. An hour could fall into more than one category or could fall into none of these catagories. Sunny was defined as hourly generation exceeding 90% of our calculation for clear sky generation and thick clouds less than 60% of clear sky generation. Variable cloudiness was defined as the hourly standard deviation of the 12 five-minute averages exceeded 5 times that of clear sky conditions, e.g., fluctuating cloudiness. Variable power was similar but instead of comparing to clear sky conditions, the standard deviation exceeded 15% of rated AC capacity, which tends to put some of the morning and evening ramps into this category. The result is that sunny conditions are easiest to forecast for, although the improvement over benchmark forecasts is highest for variable clouds. Note that the scale is wider in this plot than others to accommodate the large improvement over clear sky benchmark when cloudy conditions were observed.

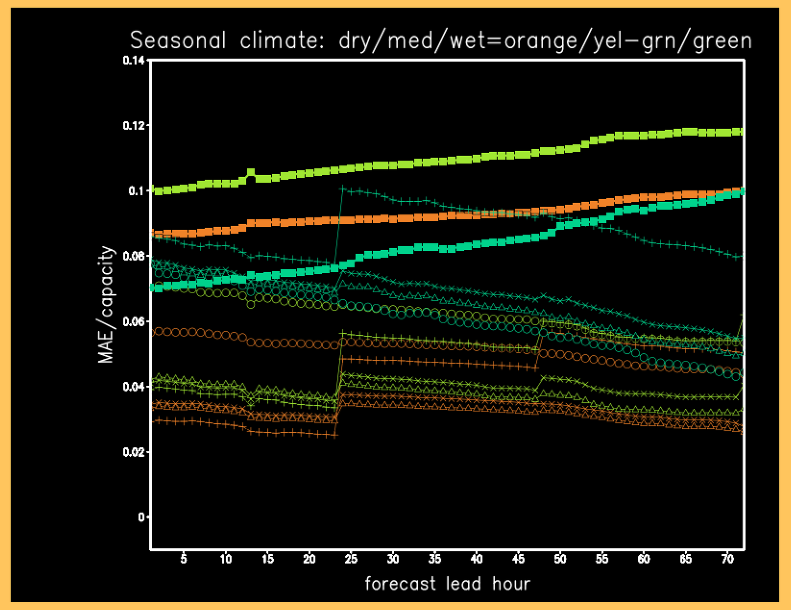




Aerosol loading is shown in the plot on the upper right, with the color scheme going from dark blue (cleanest) to sky blue to white to gray for increasing loading. The smallest errors are associated with the haziest conditions but this might also be related to sample bias of other characteristics where these conditions occurred.

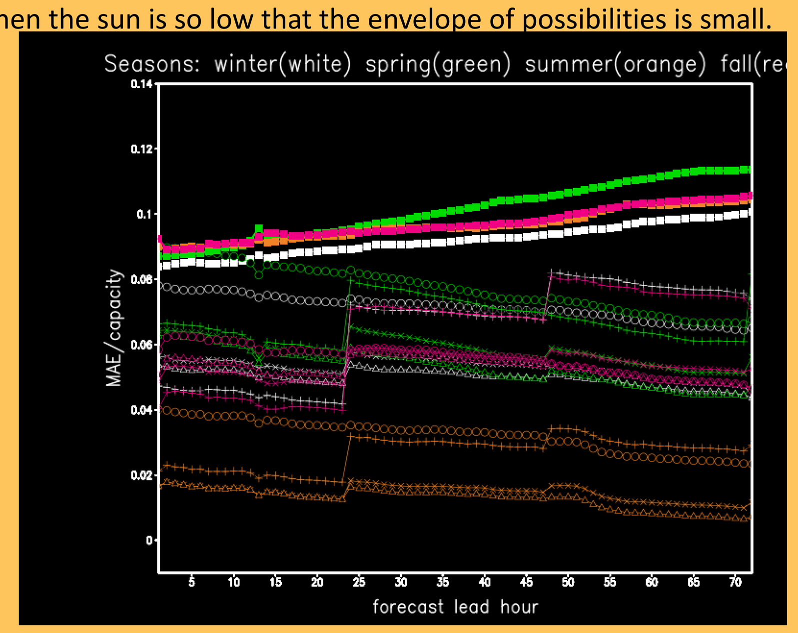
Climate conditions were rated by tercile of US climatic annual precipitation, and the India sites are shown separately. The India forecasts were only during the winter (dry) season. The climate conditions were also analyzed based on terciles of seasonal (3-month) precipitation. Curiously, the wettest regime showed smaller error than the driest regime. This might be due to other characteristics, such as preponderance of fixed tilt in the wetter eastern states. Seasonally (below), winter shows smallest errors possibly because amplitudes are lower due to lower sun angle and spring is most difficult in the second and third day ahead.

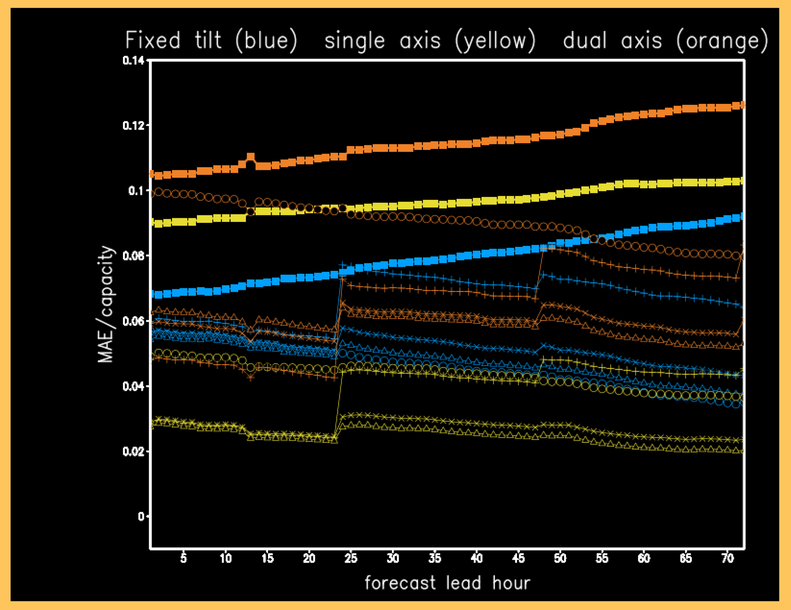


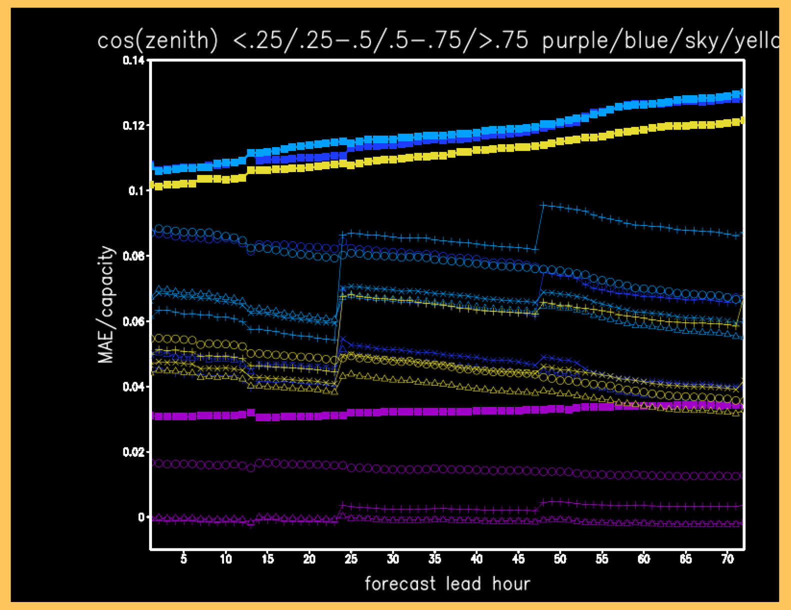


Large differences are seen between farms with different tracking. As expected, dual-axis is most difficult because it is more closely tied to the direct normal irradiance (DNI), and fixed tilt is easiest because there are no tracking and backtracking issues to deal with.

Errors were not sensitive to the sun elevation except low of course when the sun is so low that the envelope of possibilities is small.

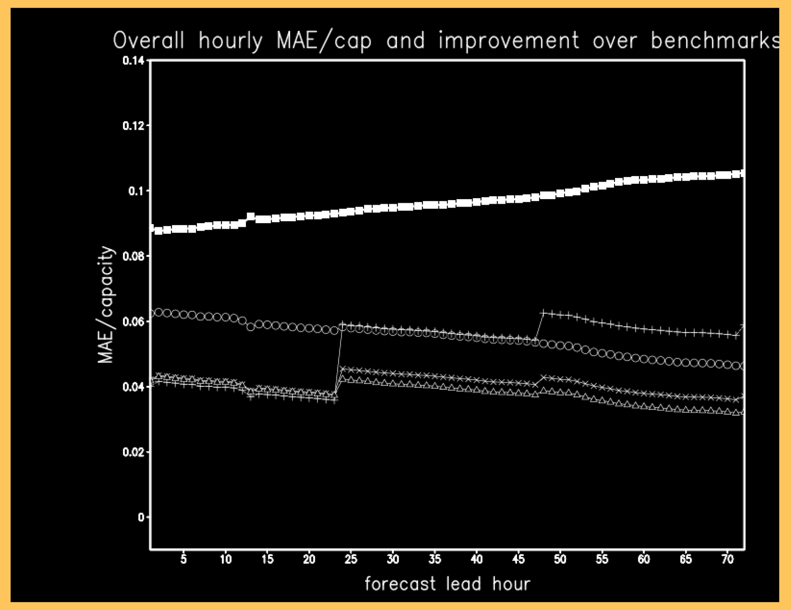


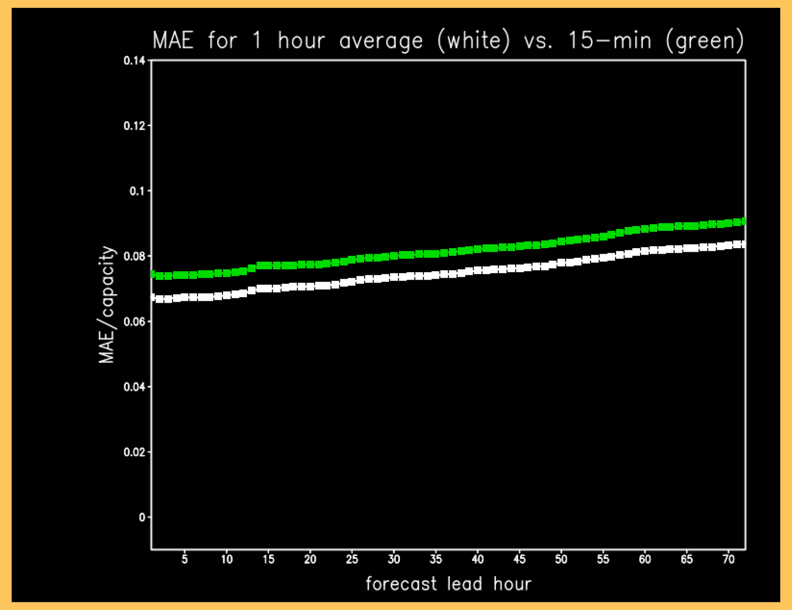


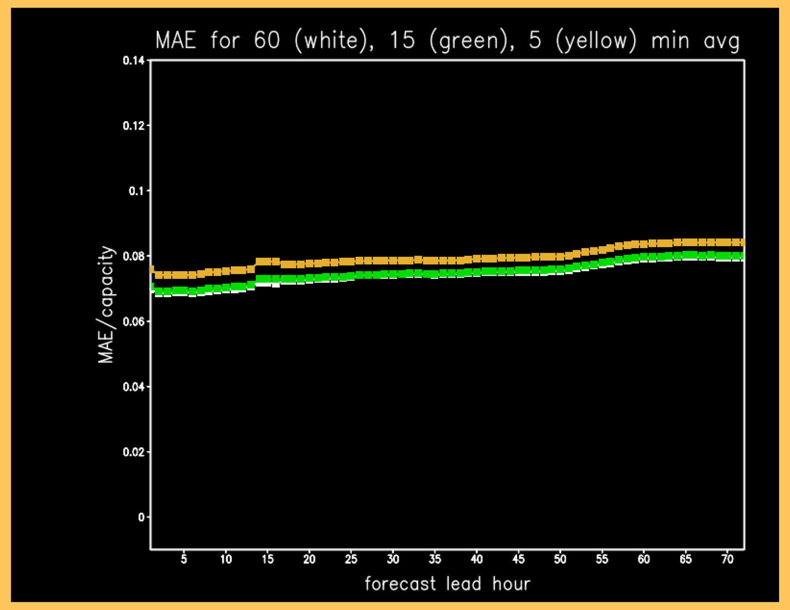


The Solar Farms and Overall Results

We have forecast and measured generation data from more than 20 solar farms ranging in location from the desert southwest to the northeast and several in different parts of India. The farms range in size from 1 MW to over 100 MW and include fixed tilt, single axis on north-south axis, single axis on east-west axis, and dual axis. The tracking sites mostly rest horizontal overnight and follow shadow lines while rising up to optimal orientation, adjusting at different angular speeds. The forecasts are computed on a minute by minute basis but these values were not saved. We have forecast data every 5 minutes at a few sites and every 15 minutes at around half of the sites. Except in the two figures below, all plots are for hourly averaged generation.
The measured generation data have been quality controlled to remove periods when the logger was stuck and various other unphysical or inconsistent reported values. The samples used in these plots gather all available data at all sites. Therefore, sites with a longer record of overlapping forecast and measurement periods contributed more to the samples. The periods of record by site vary from a few months to around a year and a half. The samples were then filtered for the various conditions, shown in the plots. The forecasts were generally updated hourly.
The plots all show in bold squares the mean absolute error scaled by AC capacity. The open circles represent improvement over a forecast of 100% clear conditions, while +, x, and open triangles are improvement over persistence forecasts from 1 day, average over 5 days, and over 10 days, respectively. Plot on the left below is overall summary of all data. Plot in the middle compares 60-minute averages vs. 15-minute averages for farms where those forecasts were saved. Plot on the right has the smaller sample of farms with 5-minute averages also available.

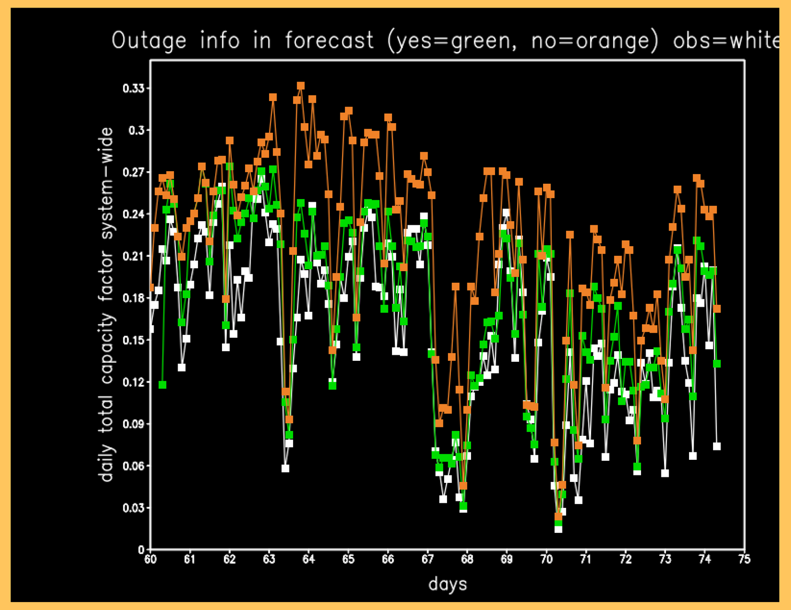






New Farms and Outage Data

As new solar farms come onto the grid, there are extensive testing periods when the power generated is fluctuating due to engineering rather than weather. This is a particular problem when the growth of new farms is so rapid that a large fraction of the total in a region or RTO is in this testing status. Information about planned outages and operator self-imposed limits is very useful. Shown below are MDA forecasts of an aggregate daily capacity factor (green) versus observations (white). The orange shows the same forecasts before applying the outage/limit information. The outage/limit information saved the forecast from being much too high on many days.



"Observations Lead the Way"

Our AMS President requested that we list several items:

1. Observations/networks need for our own specific work:
   More solar farm generation data, from more farms, in granularity at least as fine as 5 minutes, together with high-quality plane-of-array irradiance and also other irradiance components. Also, for very short-range forecasts, processed satellite data which accounts for cloud motion and accounts for satellite sensor characteristics (e.g., not the raw counts).

2. Recommended instruments needed to make the observations:
   I would add that maintenance and siting are important, not just the instrument. I have detected shadows in solar farm irradiance data – the shadow is probably small localized to the vicinity of the instrument, since the farms are generally wide open without obstruction. I have also detected drifts in measurements, due to calibration or soiling, even at annually maintained irradiance sites such as the Climate Reference Network stations. SURFRAD is the gold standard but it requires a much higher level of resources and attention, not all sites can reach that level.

3. Greatest observational needs in general:
   Space-based lidar! We need global 4-d wind observations comparable to what we now have for mass observations, and we need it especially in the tropics where the flow is not as constrained by the mass field. Also, it would be very good to have hyperspectral sounders in geostationary orbit, as was planned long ago for GOES-R but then taken off the plans. And of course, GPS RO data is "all the rage" now, though it seems like there are a lot of plans for ramping that up because the price tag is not so high compared to lidar and hyperspectral.