Operational Implementation and Evaluation of a Solar and Wind Integrated Forecast Tool (SWIFT) in the Hawaiian Islands

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ABSTRACT

The Hawaiian Islands are experiencing considerable growth in wind and solar power production. Furthermore, the temporal and spatial variability of the wind and solar resource can be considerable owing to the islands' terrain, marine- and trade wind-influenced climate. Thus, detailed knowledge of the sensitivity of the island grids to variable wind and solar generation is crucial; system operators need better foreknowledge of imminent changes in wind power and PV output and the potential for large-scale ramp events occurring on short time scales. Here we present a summary of the development, validation, institution, and operational performance of SWIFT, (Solar and Wind Integration Forecast Tool), a service that provides short-term forecasts (~15 minutes up to next day) of integrated wind and solar-based generation for Hawaii's electric utilities.

1. INTRODUCTION

In response to the increasing penetration of wind and solar energy generation on the grid systems in Hawaii, the Hawaiian Electric Company (HECO) has incorporated SWIFT (Solar and Wind Integration Forecast Tool) into its monitoring and maintenance of power distribution operations. More specifically, SWIFT will equip system operators with timely and accurate foreknowledge of 'next-hour' and 'next-day' solar and wind-based generation so that they can readily accommodate the increasing penetration of this type of generation while economically balancing other resources and maintaining high levels of grid reliability.

To support SWIFT, HECO has deployed a network of sophisticated meteorological and irradiance instrumentation, strategically placed around wind projects sites in Hawaii and where PV development has occurred or is expected to be incorporated into the grid. The development of SWIFT and the deployment of the instrument network was made possible under projects funded by the Department of Energy and the Electric Power Research Institute, with continuing support by HECO.

2. FORECAST MODELING SYSTEM

The objective and functional specifications of the forecast system were developed through interaction with HECO personnel. The greatest potential benefit for wind and solar forecast information is in the hours-ahead period, with an emphasis on the 0-3 hour look-ahead time. On these time scales, the two most important elements of information are the forecasting of the significant ramp events and the prediction of periods of large intra-hour variability. These needs arise because of the time scales over which operators are able to take action when large power changes occur. In Hawaii, the solar and wind resource can act either in concert or out of phase. Thus, forecasting systems were developed to enable HECO to account for the variability of not only each resource, but of the potential volatility of both solar and wind simultaneously (see Figure 1).

2.1 Solar Forecast System

The HECO Solar Generation Forecast System (HSGFS; see Figure 2) consists of (1) two types of Numerical Weather Prediction Systems (NWP) configurations – a standard cycle and a rapid update cycle, (2) Model Output Statistics (MOS) models that correct systematic errors in the NWP forecasts, (3) a cloud feature detection algorithm that identifies, tracks and extrapolates cloud patterns from satellite images to make short-term forecasts, (4) persistence and climatology models for atmospheric transmissivity for short wave radiation, (5) an optimized ensemble statistical model that weights all of the individual forecasts based on an estimate of the anticipated performance (i.e. most probable error magnitude) of each member of the forecast ensemble for a specific forecast period, and (6) a solar plant output model that converts forecasts of meteorological variables to predictions of solar power production. Some of these components primarily benefit the hours ahead forecasts while others are predominantly for the days ahead time frames. However, the optimized ensemble scheme is applied independently for each look-ahead period. This means that the relative weighting of each forecast type can be different for each look-ahead period so that the weighting of methods can seamlessly shift from the short look-ahead periods to the longer ones to reflect which methods provide the greatest value for each look-ahead period.

Forecast output from the HSGFS includes high resolution frequently updated NWP forecast cycles that assimilate a wide variety of atmospheric data including cloud coverage and characteristics data from infrared and visible satellite imagery, and liquid water content from radar reflectivity data in the vicinity of the islands every 2 hours. The assimilation of this data plays a key role in the specification of the initial cloud patterns in the NWP models. As indicated by the left side of Figure 2 with the darker gray shading there are three frequently updated NWP components in the HSGFS based on three different NWP models – MASS, ARPS and WRF. The NWP component operates on a nested grid configuration with two outer grids of 32 km and 8 km grid spacing and three high resolution 2 km grids. There is a separate 2 km grid over (1) Oahu, (2) Maui, Molokai and Lanai and (3) Big Island. A new NWP forecast is initialized on these grids every two hours.

2.2. Wind Forecast System

HWGFS (Figure 3) is very similar to the HSGFS except for the Feature Detection Algorithms (FDA) and the time series models. The feature detection algorithms are a set of hybrid tools that have statistical, physics-based and pattern recognition components. These are used primarily for the 0-3 hour look-ahead range. The basic idea is to identify meteorological features that can cause significant changes in the wind power production with the available observational data and track their propagation and evolution. Short-term forecasts are then made by projecting the trends in propagation rate and the evolution of the feature characteristics for the next few hours. The degree of skill and look-ahead time over which this approach exhibits is strongly dependent on the type of feature and the amount of data available to identify and track the features.

The types of feature that cause significant changes in wind power production are strongly dependent on the wind farm location. In Hawaii, the most common features that cause significant changes in wind power production and can be tracked are convective rain showers. In many cases, rain shower features can be effectively tracked by the National Weather Service Doppler radars for periods ranging from a fraction of an hour to several hours. This can be an effective tool for the short-term prediction of a substantial number of wind ramp events at some wind farms in Hawaii. Another type of feature that often causes large changes in wind power production at Hawaiian wind farms are (sometimes subtle) changes in the direction of the wind approaching the islands, or the stability of the atmospheric boundary layer that cause the way the flow interacts with the island terrain to change. Such changes can cause existing high-speed streams of air to shift away or towards a wind farm location and thereby cause an upward or downward ramp event. It has been demonstrated that the use of HECO's WindNET sodar data can be an effective tool for tracking these types of features. Additional types of events have been identified during the forecast system testing period and feature detection algorithms for these events are being formulated and added to the prototype forecast system as they demonstrate forecast value in sensitivity studies.

3. INSTRUMENTATION

To support SWIFT, HECO has deployed a suite of surface observation and remote sensing instrumentation that provide real-time data assimilation data streams and function as ground truth verification of model forecasts (see Table 1). The observation network represents the most sophisticated mix of instruments dedicated to long-term renewable energy forecasting in the U.S. and includes 7 SoDARs, a radiometer, a side-scanning LiDAR, 3 Solar Meteorological Stations (SMSs) and 11 high frequency irradiance measurements distributed throughout the 5 islands within HECO's territory

4. MODEL VALIDATION

An extended experimental campaign is being conducted to validate and further tune SWIFT performance. This includes ground truth verification efforts using both the HECO observation network data and power production from existing wind farms and PV facilities.

4.1. Solar Forecast System

For the HSGFS, an example shown here is the validation of system performance by comparing estimated GHI values extracted from satellite image data with data at two HECO solar measurement sites on Maui. SMS1 is a site southeast of Kahului and SMS2 is near Wailea-Makena. The estimated and measured GHI values for the day of 26 September 2012 are shown in Figure 4. The estimated values correctly show that the irradiance is reduced due to afternoon cloudiness more at the SMS2 site. The observed data is available every 15 minutes, while the estimated irradiance is calculated from hourly satellite images

4.2. Wind Forecast System

For the HWGFS, the deployment of atmospheric sensors was based upon an observation targeting analysis that demonstrated improvements in both short-term NWP forecasts for the 1 to 6 hour-ahead time and intra-hour predictions based upon statistical feature detection algorithms that are customized for each major cause-based class of ramp events. This is demonstrated in Fig. 6, which shows that the HWGFS with HECO observation network data assimilation performs consistently better the forecast system initialized without the observations.

5. OPERATIONAL DEPLOYMENT

The key to SWIFT is the use of graphical displays to enable utility personnel to make quick and intelligent decisions regarding grid operations. Examples of such forecasts are given in Figs. 7 and 8.

TABLE 1. SWIFT OBSERVATION NETWORK

Instrument	Measurements	City	Island
SoDAR	U,V,W,TI,TKE	Naalehu	Big Island
SoDAR	U,V,W,TI,TKE	South Point Park	Big Island
SoDAR	U,V,W,TI,TKE	Kahului	Maui
SoDAR	U,V,W,TI,TKE	Kaheawa Wind Park	Maui
SoDAR	U,V,W,TI,TKE	Puunene	Maui
SoDAR	U,V,W,TI,TKE	Kaneohe	Oahu
SoDAR	U,V,W,TI,TKE	Turtle Bay	Oahu
Radiometer	T,RH,Q at multiple levels to 10 km	Kahului	Maui
Side-scanning LiDAR	U,V,W, at multiple levels, radii	Kahuku	Oahu
SMS	GHI,DNI,DIF,T,RH,WS,WD, Pr	Kahului	Maui
SMS	GHI,DNI,DIF,T,RH,WS,WD, Pr	Wailea-Makena	Maui
SMS	GHI,DNI,DIF,T,RH,WS,WD, Pr	Makakilo	Oahu
Pyranometer	GHI	Makaha	Oahu
Pyranometer	GHI	Maili	Oahu
Pyranometer	GHI	Kailua-Kona	Big Island
Pyranometer	GHI	Mauna Lani	Big Island
Pyranometer	GHI	Mokapu	Oahu
Pyranometer	GHI	TBD	Oahu
Pyranometer	GHI	TBD	Lanai
Pyranometer	GHI	TBD	Lanai
Pyranometer	GHI	TBD	Molokai
Pyranometer	GHI	TBD	Molokai

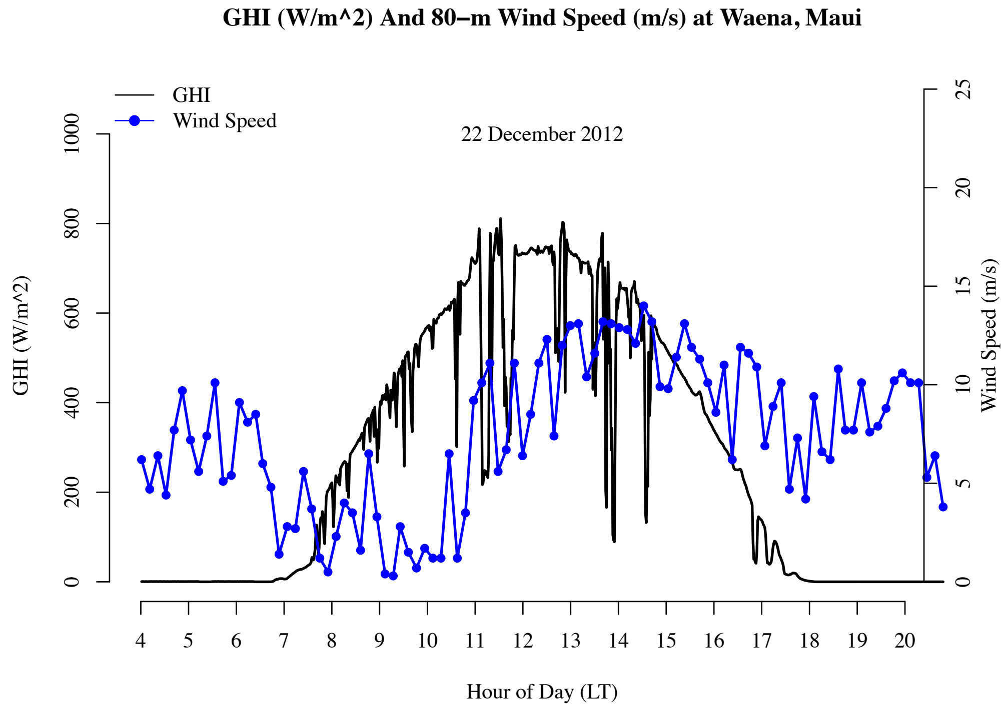

Fig. 1: Observed GHI (W m^{-2}) and SoDAR 80 m wind speed (m s^{-1}) at Waena, Maui 22 December 2012.

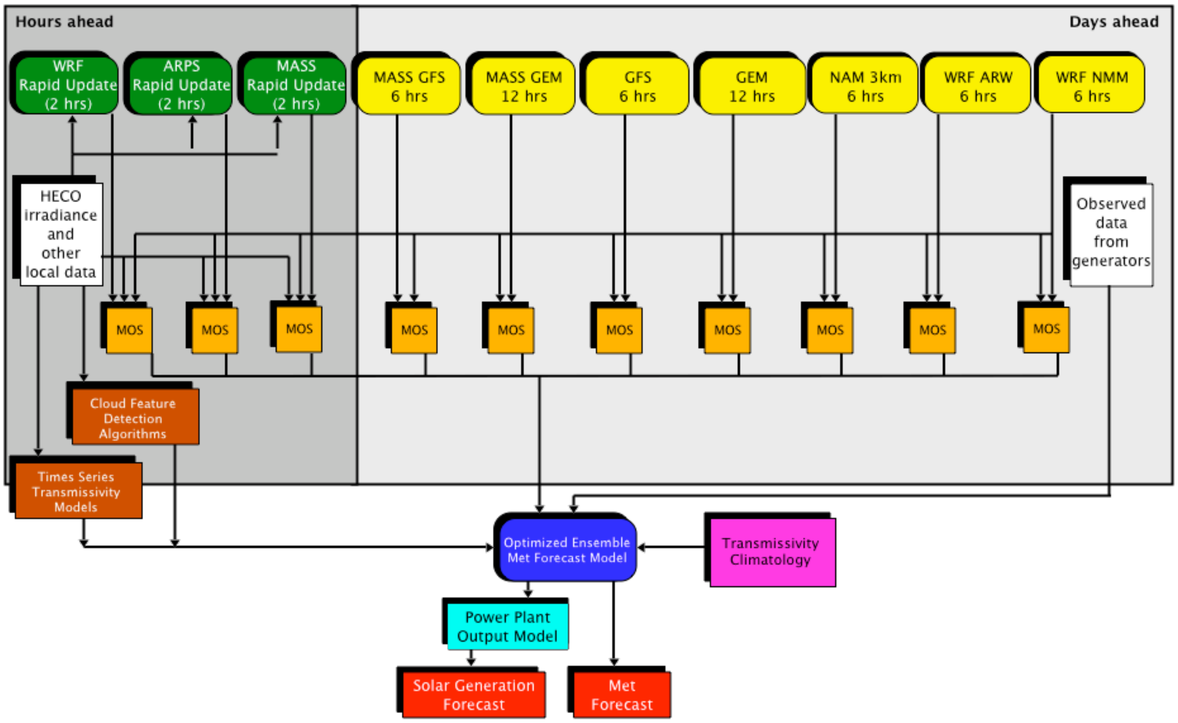

Fig. 2: A schematic overview of the components and data flow in the HECO Solar Generation Forecast System (HSGFS).

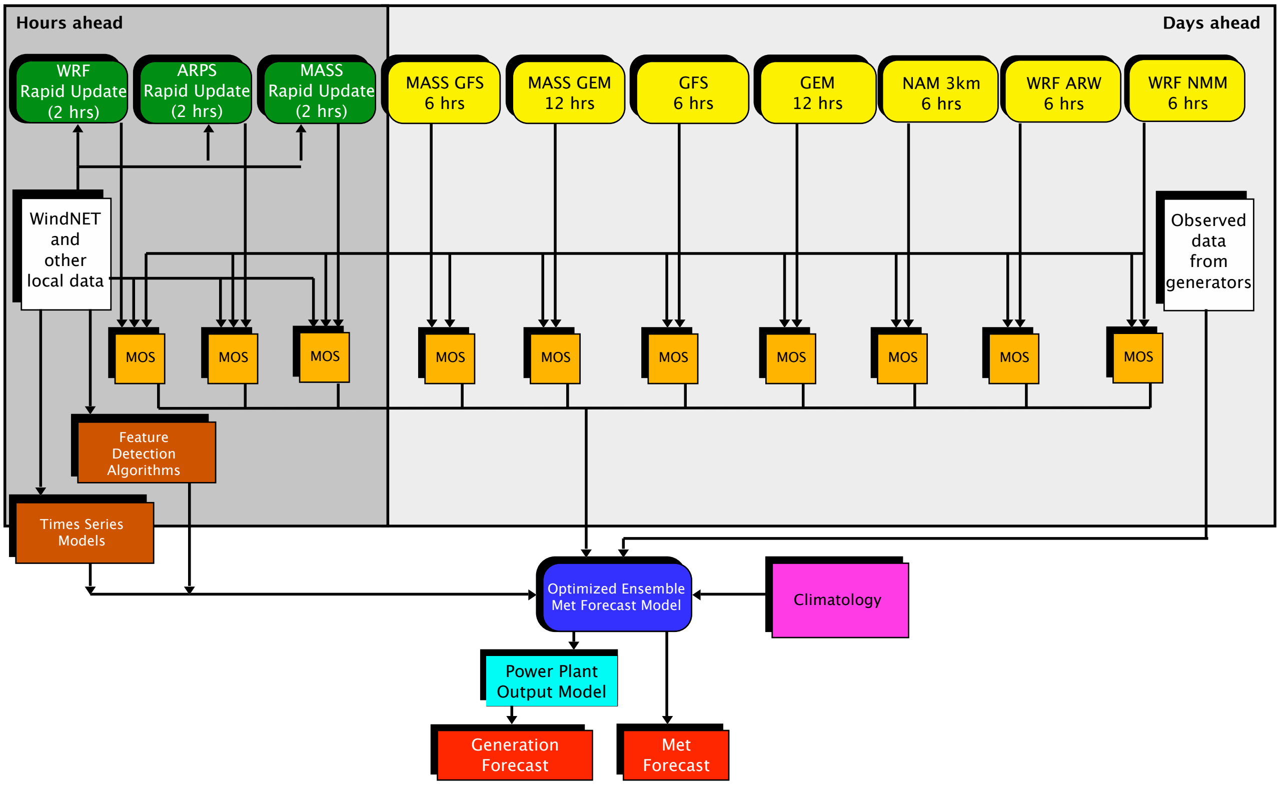

Fig. 3: A schematic overview of the components and data flow in the HECO Wind Generation Forecast System (HWGFS).

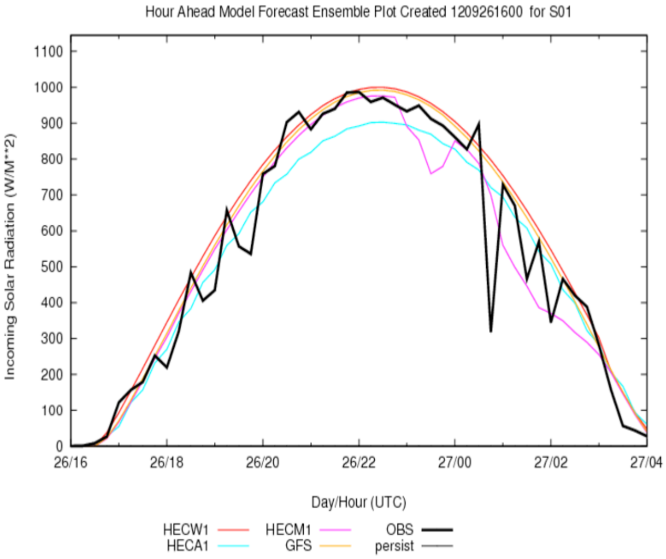

Fig. 4: Measured (black line) and real-time NWP-forecasted (colored lines) GHI (W m^{-2}) for the SMS1 location on Maui for the 12-hour period beginning at 1600 UTC (0600 HST) 26 September 2012.

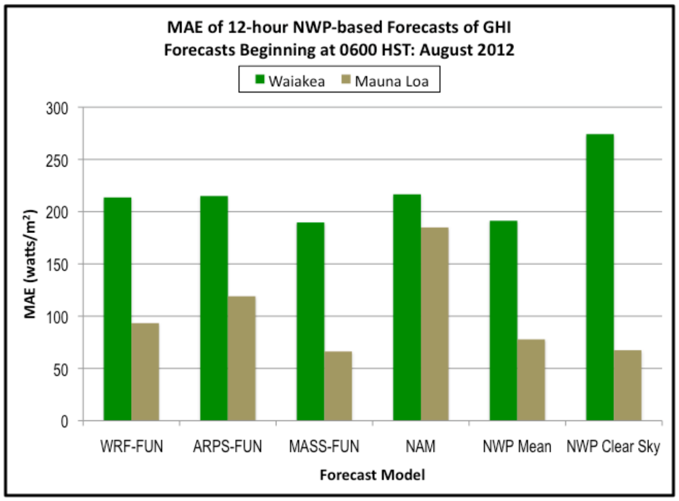

Fig. 5: Mean Absolute Error (watts/m^2) of 12-hour NWP-based forecasts of the Global Horizontal Irradiance (GHI) beginning at 0600 HST for the Waiakea Experiment Station near Hilo and the Mauna Loa Observatory.

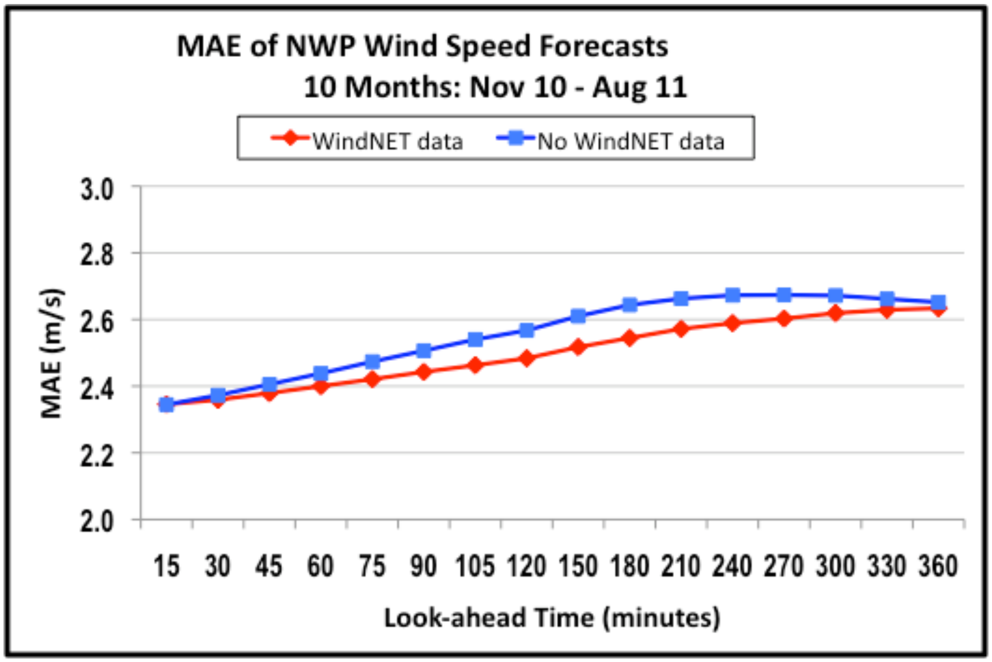

Fig. 6: Mean Absolute Error (MAE) of 80-m wind speed (m s^{-1}) forecasts from the frequently updated NWP cycles by look-ahead time for a wind generation facility with and without the assimilation of HECO observation network instrumentation.

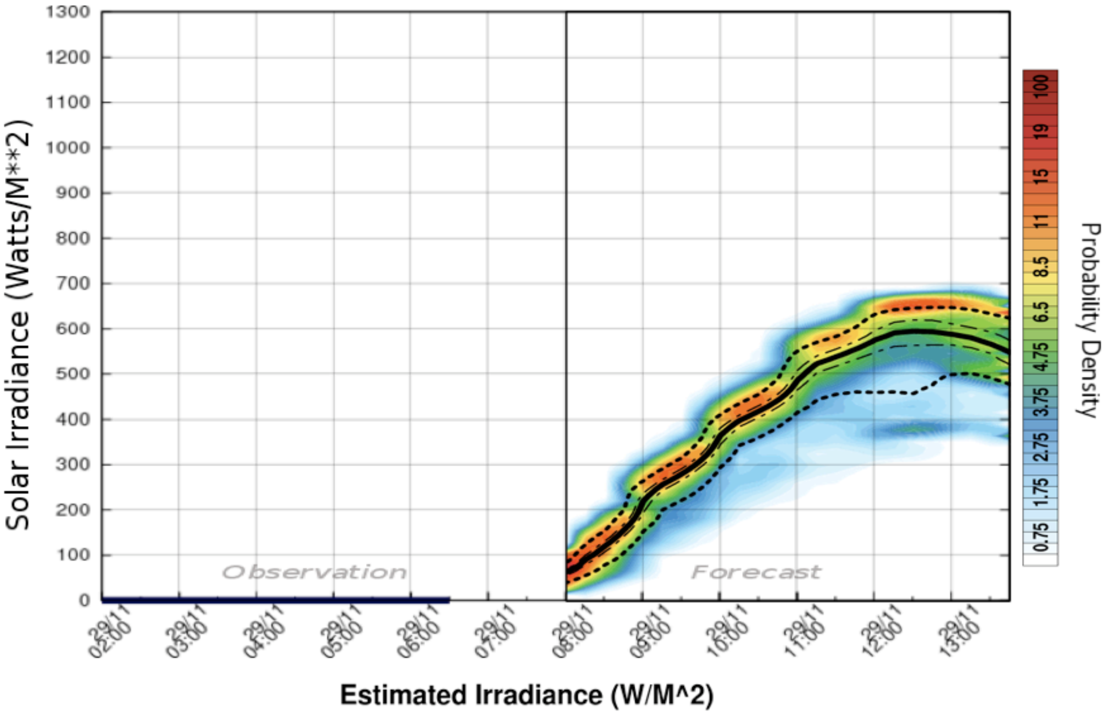

Fig 7: A 0-6 hour-ahead forecast of the solar irradiance at the Kaneohe substation on Oahu produced in real-time by the operational version of the experimental HSGFS at 0800 HST 29 November 2012. The forecast display depicts the observed irradiance (based on satellite-derived estimates) for 6 hours preceding the time of the forecast and the forecasted irradiance for 6 hours after the forecast issue time. The forecast increment is 15 minutes. The lines on the forecast side of the plot are (from bottom to top) the 80% (short dash), 60% (short-long dash), 50% (bold line), 40% (short-long dash) and 20% (short dash) Probability of Exceedance (POE) values. The color shading depicts the probability density.

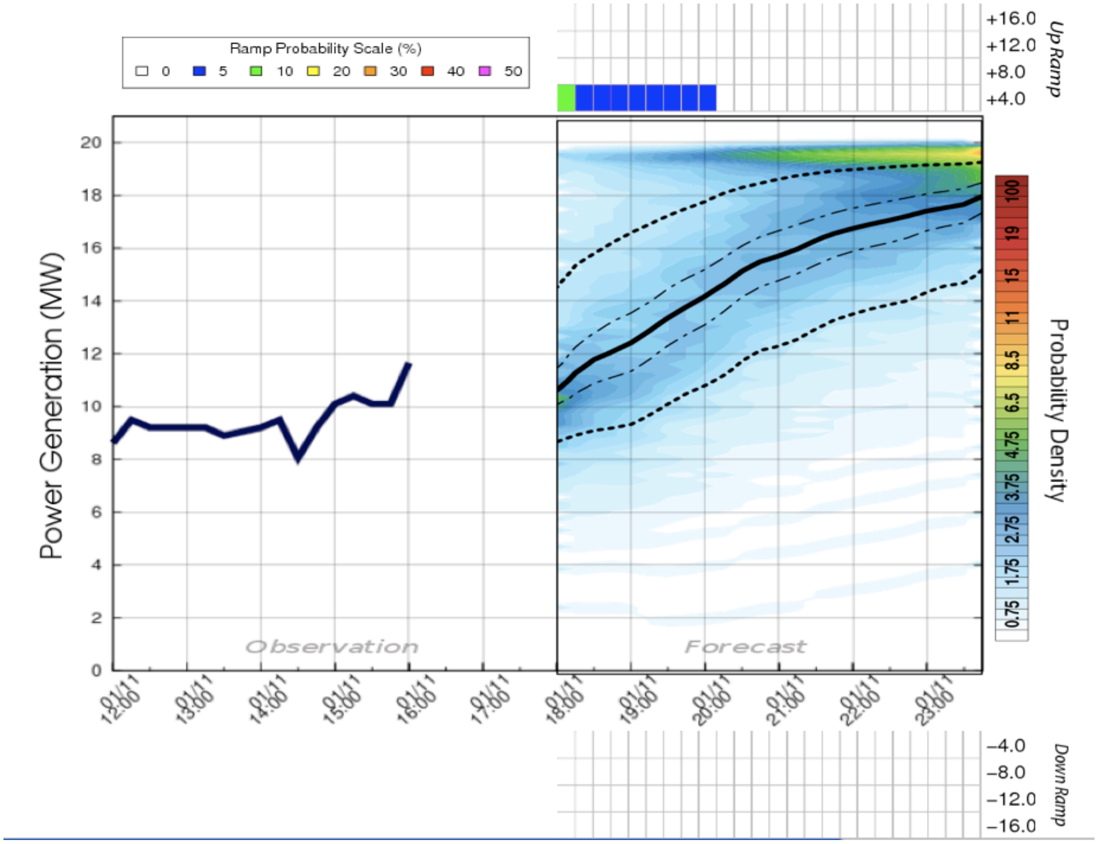

Fig 8: A 0-6 hour-ahead forecast of the wind power generation (MW) produced in real-time by the operational version of the experimental HWGFS at 1200 HST 1 November 2012. The forecast display depicts the observed wind power generation for 6 hours preceding the time of the forecast and the forecasted power generation for 6 hours after the forecast issue time. The forecast increment is 15 minutes. The lines on the forecast side of the plot are (from bottom to top) the 80% (short dash), 60% (short-long dash), 50% (bold line), 40% (short-long dash) and 20% (short dash) Probability of Exceedance (POE) values. The color shading depicts the probability density. The top (bottom) right side show the up (down) ramp probability (%) for various thresholds (MW).