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Solar Power Production Forecasting: Overview of Methods and Input Data Needs

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Overview

- Background: The Nature of the Solar Power Forecasting Problem
- Background: How Forecasts are Produced
- Input Data Needs and Impact
- Example of Data Requirements to Support Solar Forecasting (CAISO)
- Forecast Performance Benchmark
- Summary

Solar Power Forecast Challenge

Factors that Affect Solar Power

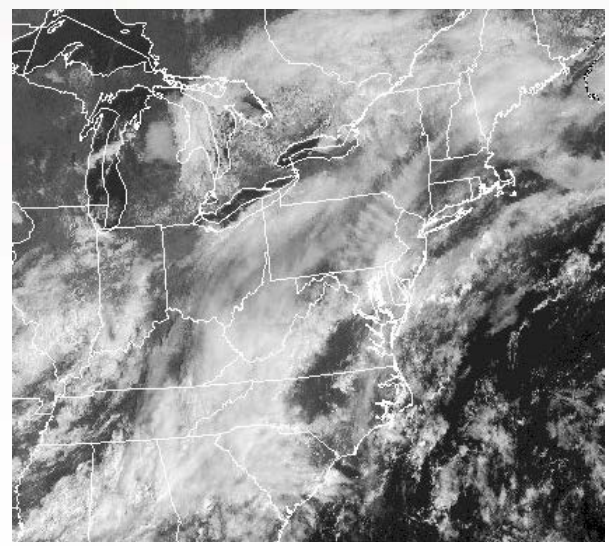
- **Global Solar Irradiance (~90%),**
- **Temperature (~10%),**
- **Wind (<1%)**
- **Type of Plant**
  - Determines exact impact of all three factors
  - Categories of plants: (1) PV, (2) Concentrating PV, (3) Solar thermal (also concentrating)
  - PV is sensitive to Global Irradiance
  - Concentrating types (thermal and PV) are sensitive to Direct Normal Irradiance (DNI)
  - Also significant sensitivity variations within basic technology categories

Solar Power Forecast Challenge

Environmental Factors that Affect Solar Irradiance

- **Sun Angle**
  - most significant but completely predictable
- **Cloud Cover**
  - cause of the most variance (~90%)
  - largest meteorological challenge to forecasts
- **Haze, Dust and Smoke Particles**
  - up to 10 % of variance
- **Humidity levels (Water Vapor)**
  - about 1 % of variability

- **Components of Irradiance (diffuse, direct) are affected differently by these factors**



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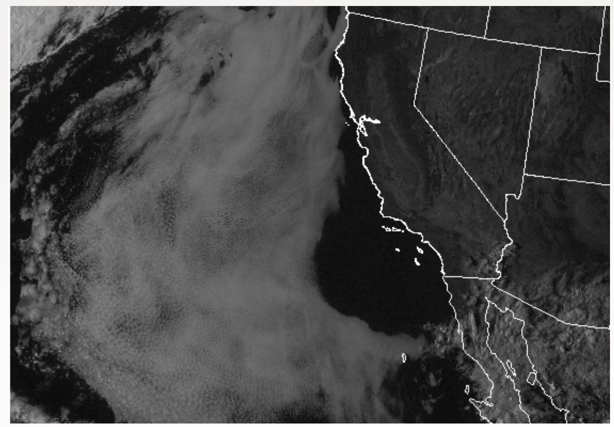
The Challenge – Making the Best Forecast for Various Time Scales

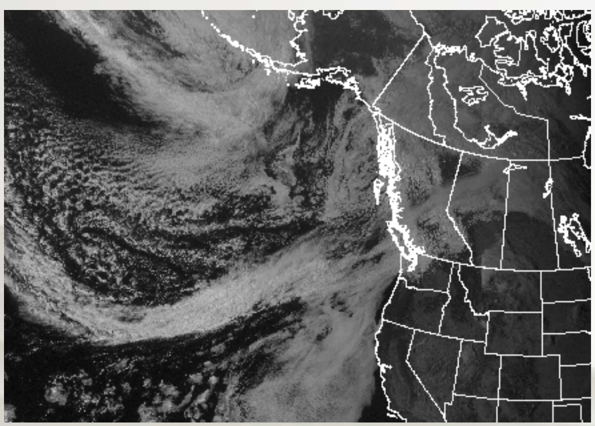
Minutes Ahead

- Cumulus clouds, small-scale cloud structures, fog
- Rapid and erratic evolution; very short lifetimes
- Mostly not observed by current sensor network

Hours Ahead

- Frontal bands, mesoscale bands, fog, thunderstorms
- Rapidly changing, short lifetimes
- Current sensors detect existence and some structure



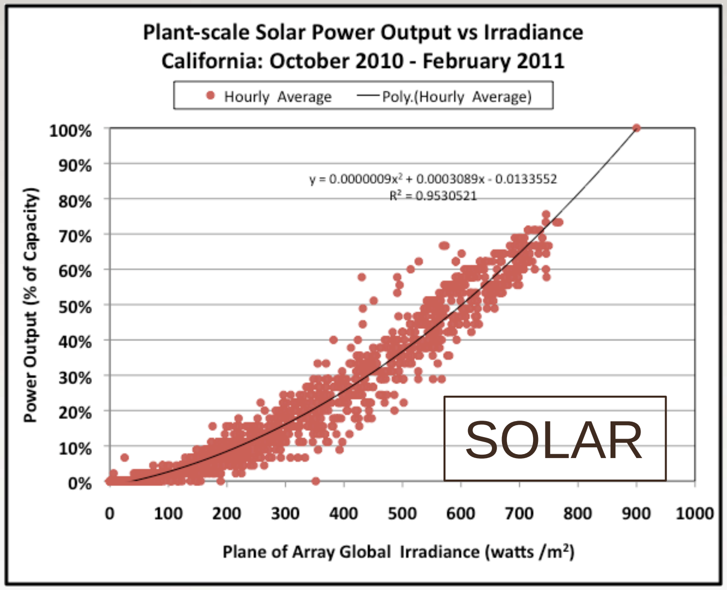


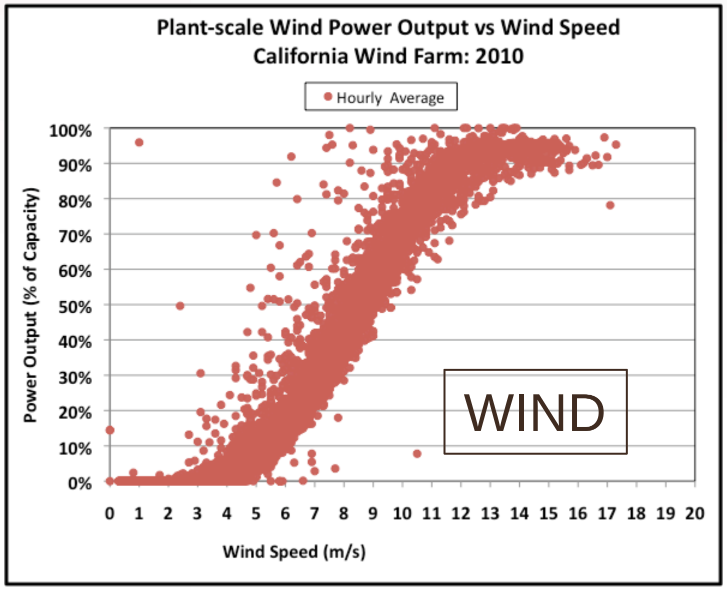
Days Ahead

- “Lows and Highs”, frontal systems
- Slowly evolving, long lifetimes
- Well observed with current sensor network

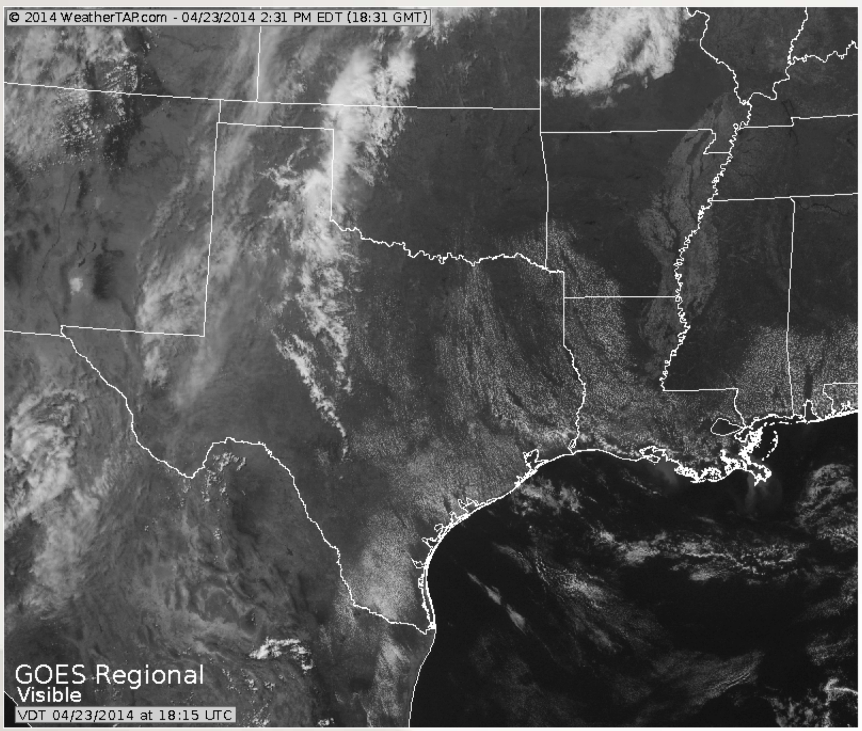
Solar vs. Wind Forecasting

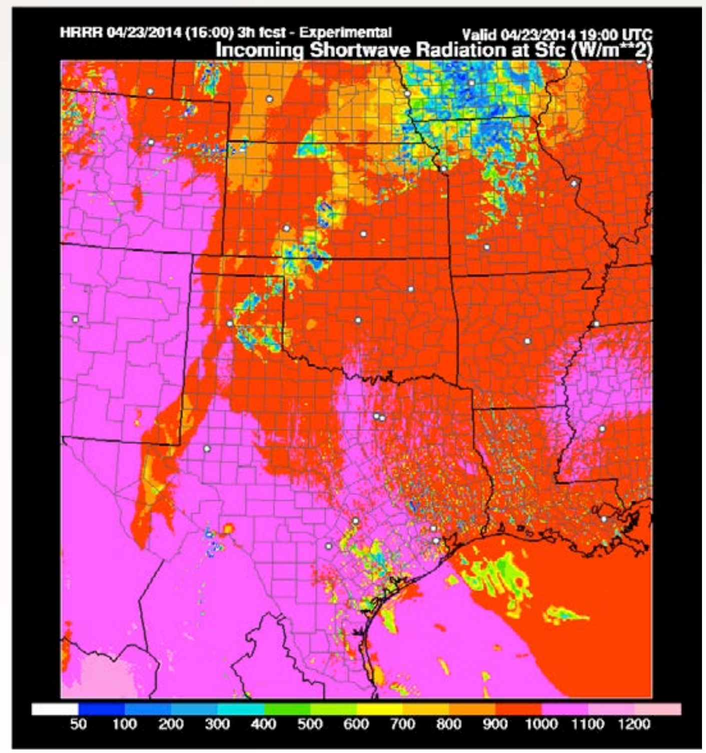
- Location Attributes
  - Utility-scale solar plants are sited in sunny areas
    - Less variable than an average site
  - Wind plants are sited in windy areas
    - More variable than an average site
- Power System Attributes
  - Solar generation has a quasi-linear relationship to irradiance
  - Wind generation is a function of wind speed cubed between start-up speed and rated capacity
- Forecast Input Data
  - Dominant factor is cloud coverage and density which can be spatially observed via satellite and sky-cams
  - Wind speeds patterns can't be as easily observed





How Solar Power Forecasts are Produced





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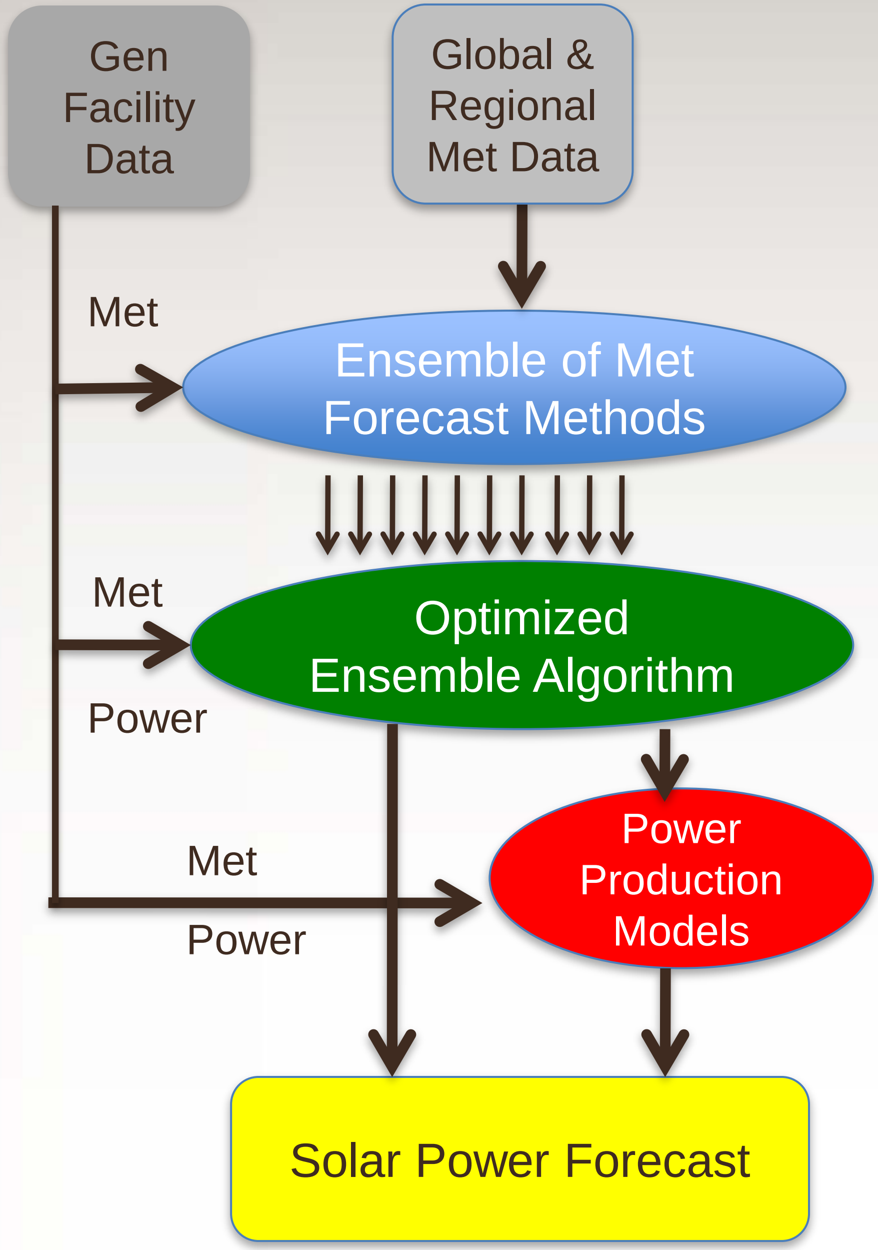
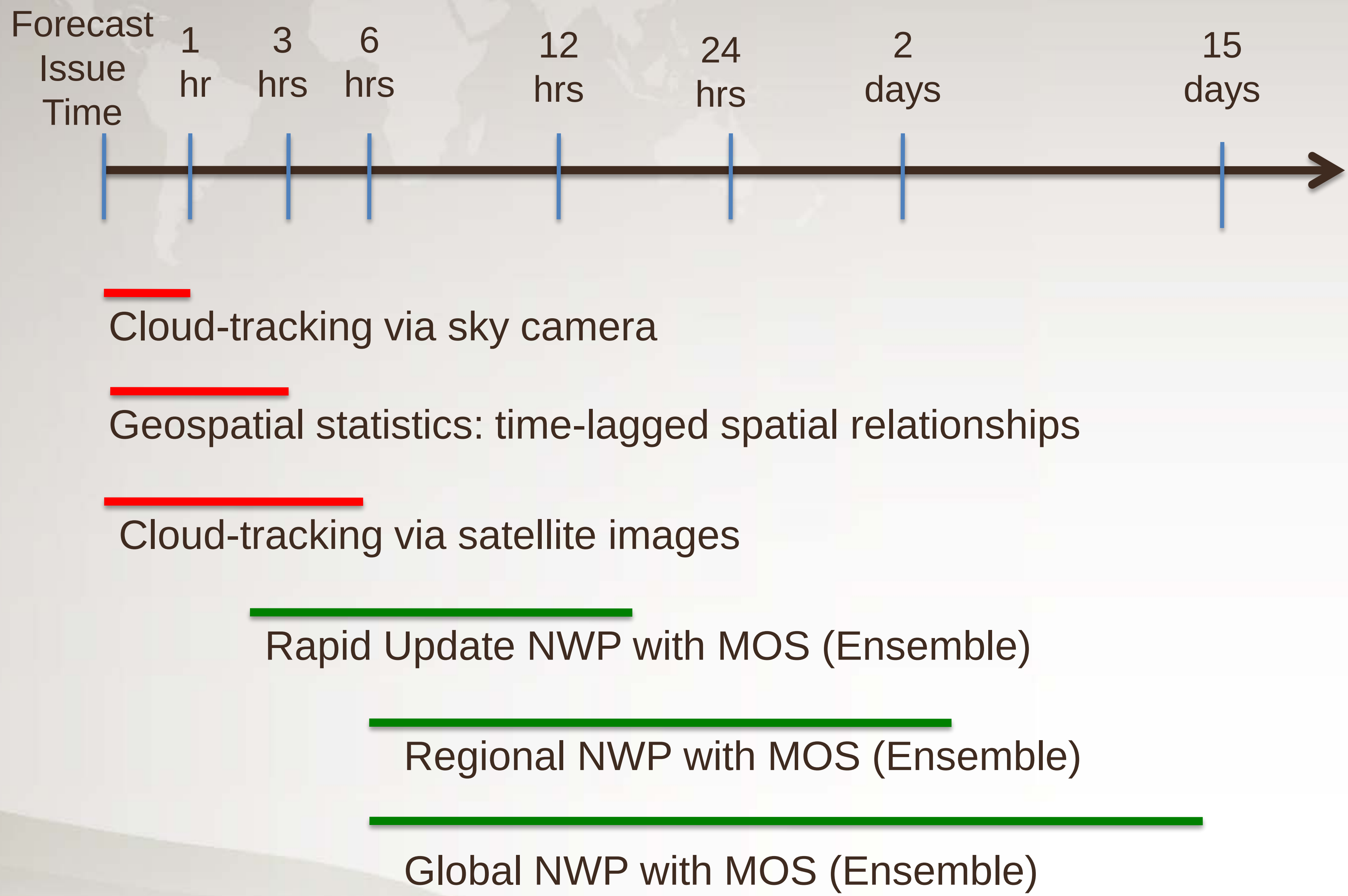
State-of-the-Art Solar Forecast System

- **Input Data**
  - Global and regional meteorological data
  - Data from gen facilities and nearby sites
- **Ensemble of Forecast Methods**
  - Statistical and physics-based models
  - Wide range of characteristics (update frequency, input data requirements, performance by look-ahead time etc.)
- **Optimized Ensemble Algorithm**
  - Statistically combines individual forecasts according to relative historical performance
  - Produces deterministic and/or probabilistic met forecast
- **Power Production Model**
  - Translates met forecast to power forecast
  - Statistical or physics-based



Solar Forecasting Methods



Input Data from Generation Facility: Needs and Impact

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Data

Desired Facility Data Needs: Static

1. **Facility type (PV or thermal)**
2. **Facility location (lat/lon of facility corners)**
3. **Description of all onsite met data collection point**
   - Location
   - Sensor types
4. **Generation Capacity (DC and AC)**
5. **Panel and installation specifications by panel group**
   - Panel manufacturer
   - Panel model
   - Number of panels
   - Panel power rating
   - Number of inverters
   - Fixed tilt specifications (azimuth and altitude angle)
   - Tracker specifications (none, single axis, dual axis, manufacturer, model)
   - Height of panels above ground
   - Concentrating PV (yes/no)

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Data

Desired Facility Data
Dynamic

1. **Power Production (MW)**
2. **Availability – AC (MW)**
3. **Availability – DC (MW)**
4. **Irradiance (watts/m^2)**
   - Global Plane of Array (POA)
   - Global Horizontal (GHI)
   - Direct Normal (concentrating solar facilities only)
5. **Back-panel Temperature (° C)**
6. **Tracking Status: Azimuth and Elevation (degrees)**
7. **Air Temperature (° C)**
8. **Wind Speed and Direction (m/s, degrees)**
9. **Relative Humidity (%)**
10. **Pressure (mb or kPa)**

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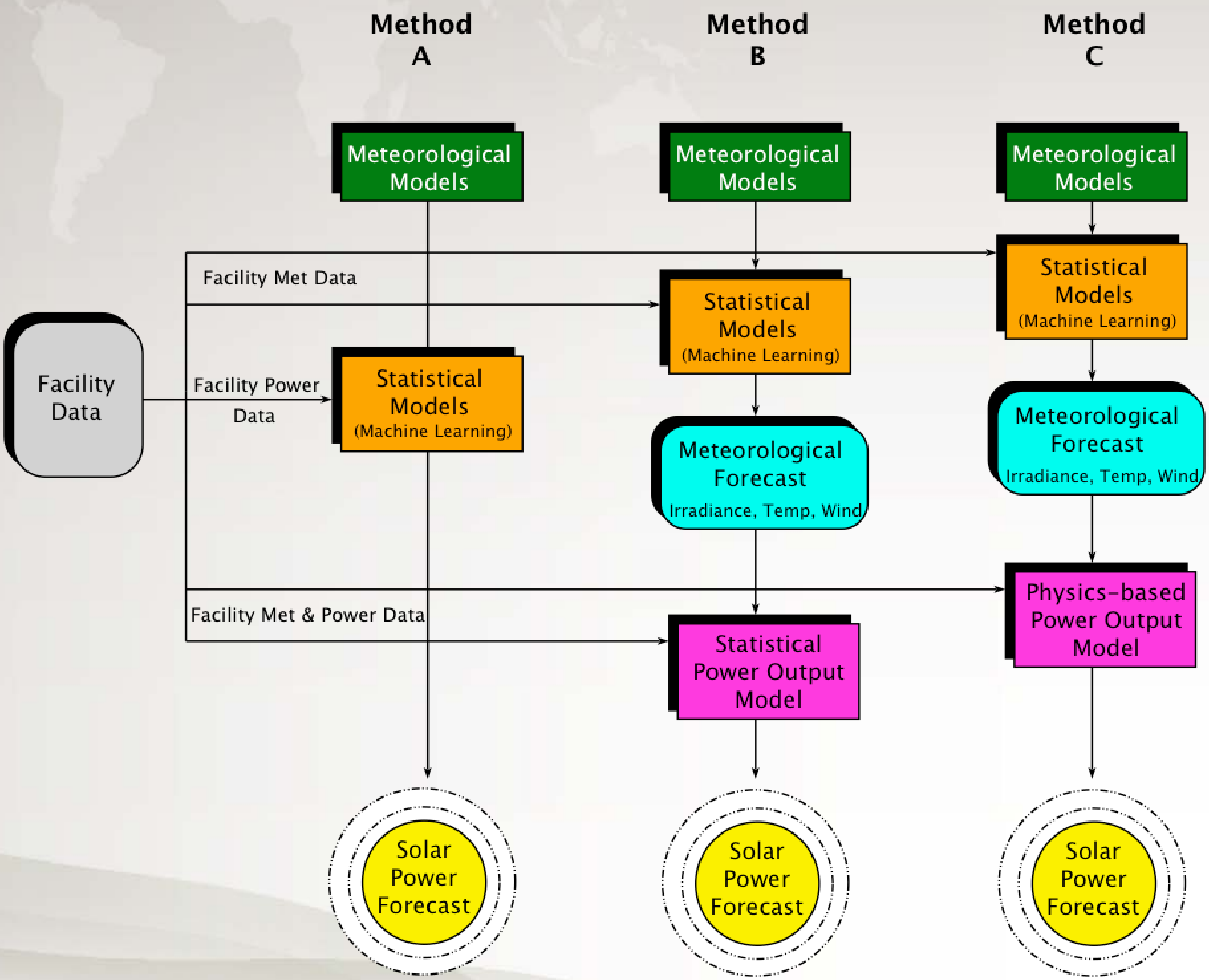
Facility Data Impact: How It Is Typically Used



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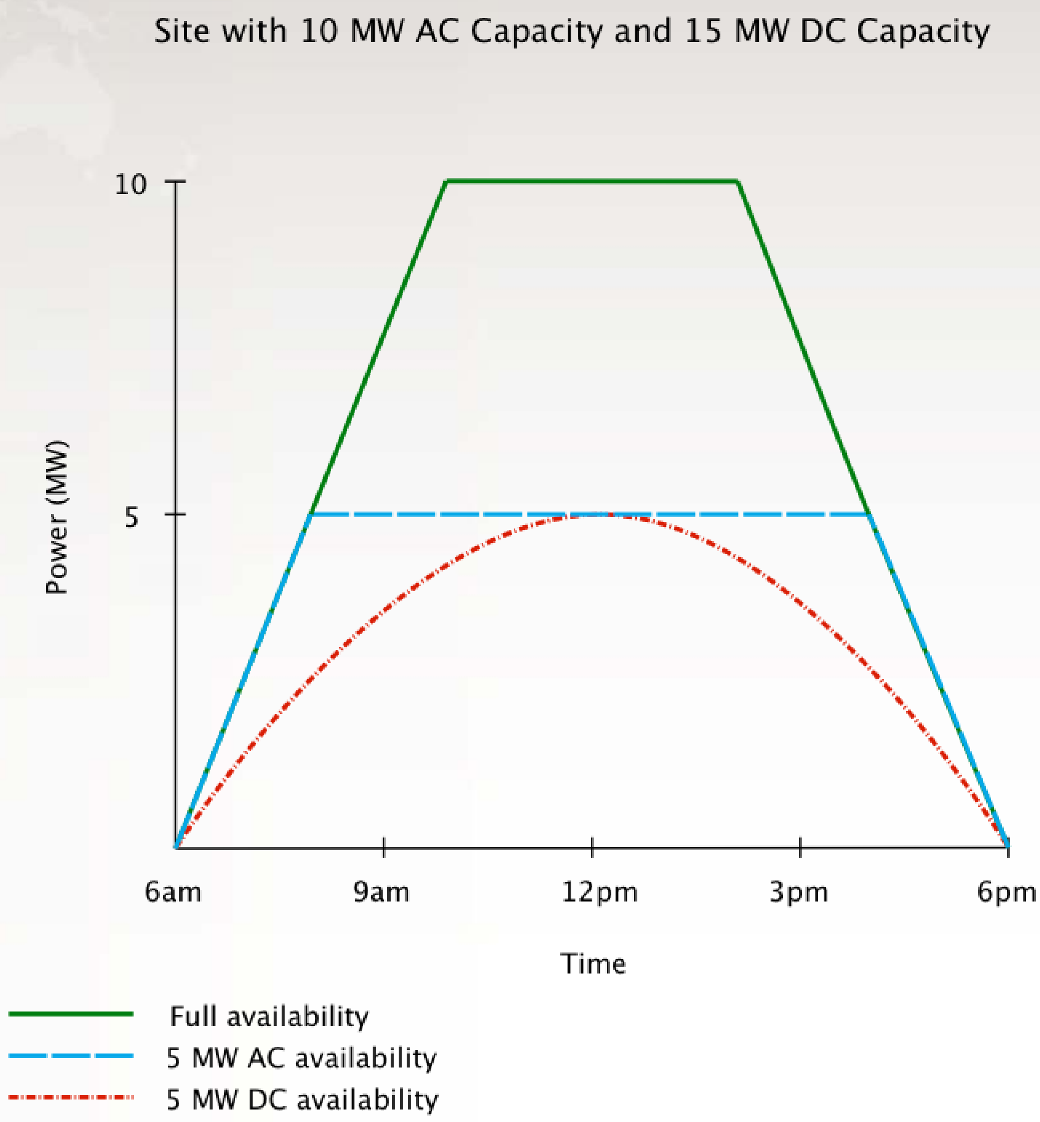
Facility Data Impact: Power Production

- **Power production data provides 80% - 95% of the forecast performance value in most situations**
  - In a simple and idealized configuration this can provide almost all of the value
- **Other data becomes important when a facility departs from simple, idealized conditions**
  - Overcapacity configuration (DC Cap > AC Cap)
  - Maintenance-related or availability-related issues
  - Single or dual axis tracking
  - Large temperature variations
  - Performance-degrading weather conditions
    - Soiling or dust accumulation
    - Snow and ice
    - High winds

Data

Facility Data Impact:
AC/DC Availability

- **Some facilities are constructed with overcapacity**
  - Panel (DC) capacity is greater than the inverter (AC) capacity
  - Allows facility to maintain rated capacity at lower irradiance levels
- **In this case AC (inverter) availability and DC (panel) availability produce different generation profiles**
- **Important to have both AC and DC availability info in these cases**

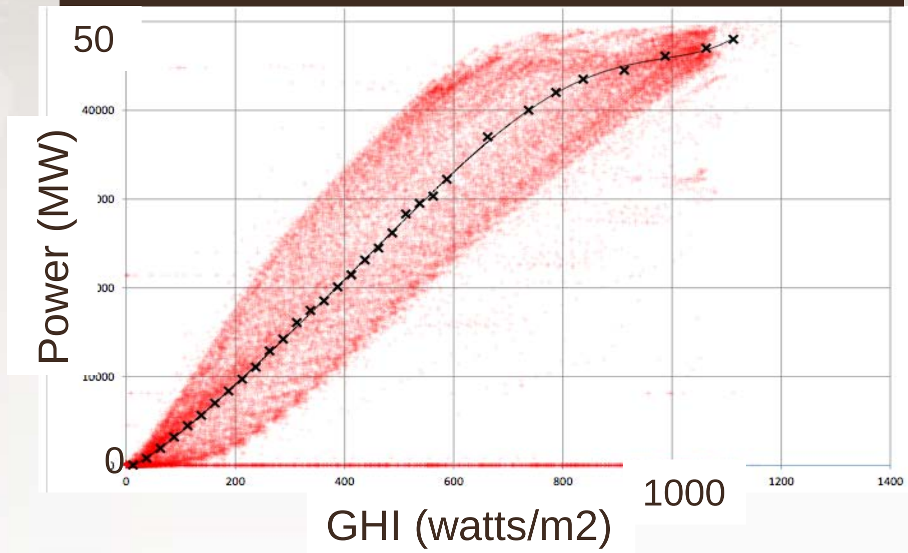


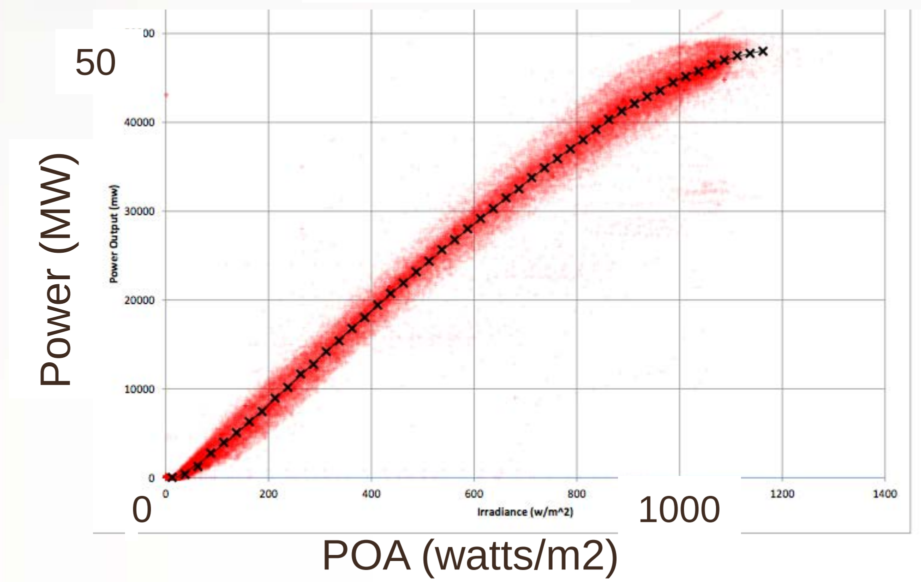
Data

Facility Data Impact: Irradiance

- **Irradiance data enables performance-degrading conditions to be more precisely modeled**
  - Panel temperature
  - Variations in operations- or maintenance-related performance
  - Soiling & dust accumulation
  - Snow and ice
- **Global plane-of-array (POA) irradiance is preferred for non-concentrating facilities**
  - Global Horizontal Irradiance (GHI) is an acceptable alternative
- **Direct Normal Irradiance (DNI) is needed only for concentrating facility types**

10-minute Data: 48 MW PV Facility





Data

Facility Data Impact:
Back-panel Temperature

- Variations in panel (cell) temperature can account for 5% to 10% of the power production variations over a year
- Can have significant variations within a solar array
- This variability is usually modeled using the back panel temperature
- Air temperature and wind speed (ventilation) can be a proxy

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Data

Facility Data Impact:
Tracking Status

- Tracking strategy is typically well defined and can be easily modeled….
- ….if the operations always adhere to the strategy
- A number of factors can cause a facility to depart from the operational strategy
  - High winds
  - Ice and snow
  - Mechanical issues
- Tracking status data (azimuth and elevation) are useful to monitor and account for the deviations

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Facility Data Impact:
Other Weather Variables

- Air Temperature
- Relative Humidity
- Wind Speed (array height)
- Wind Direction (array height)
- Rain Gauge or Precip Sensor
- Pressure
- Three types of value:
  - Modeling & forecasting panel temperature
  - Diagnosis and modeling of anomalous conditions
    - Snow/ice accumulation and melting
    - Soiling /dust accumulation
    - Impact of high winds on operating procedures
  - Can be used as input into geospatial statistics models and rapid update NWP for regional forecast benefits

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Example of Site Specification Data Required to Support Solar Power Forecasting

CAISO EIRP: Site Specification Data - Part 1

Table Q-5 CAISO Solar Site Required Information Form

Site Name & Physical Address								
CAISO RES_ID								
Plant Type	PV or Thermal		If thermal, supplemental heating?		Y/N			
Plant Location Use as many points as necessary to describe the site	Corner 1		Corner 2		Corner 3		Corner 4	
	Lat	Long	Lat	Long	Lat	Long	Lat	Long
Meteorological Station Location Provide the location of all met data collection point at the site.	Met 1		Equipment Type		Met 2		Equipment Type	
Met Information	ID	Lat	Long	Height Agl	ID	Lat	Long	Height Agl
Generation Capacity	DC				AC			

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Example of Site Specification Data Required to Support Solar Power Forecasting

CAISO EIRP: Site Specification Data - Part 2

Use multiple Groups for different panel types and installations					
	Group 1	Group 2	Group 3	Lat	Long
Panel Manufacturer					
Panel Model					
Number of Panels					
Panel Power Rating					
Number of inverters					
Inverter ratings					
Tracking (Yes or No)					
Single or Dual Axis Tracking					
Tracker Manufacturer					
Tracker Model					
Wind Protection (Speed in m/s for storage)					
Altitude Angle of Panels					
Azimuth Angle of Fixed Panels					
Height of Panels Above Ground Level					
Concentrating PV (Yes or No)					

Example of Meteorological Measurements Required to Support Solar Power Forecasting

CAISO EIRP: Met Data Specs

Table Q-3 Solar Eligible Intermittent Resources Telemetry Data Points

Element	Device(s) Needed	Units	Accuracy
Wind Speed (Meter / Second)	Anemometer, wind vane and wind mast	m/s	± 2m/s
Wind Direction (Degrees - Zero North 90CW)	Anemometer, wind vane and wind mast	Degrees	± 5°
Air Temperature (Degrees Celsius)	Temperature probe & shield for ambient temp	°C	± 1°
Barometric Pressure (hecto Pascals)	Barometer	hPA	± 60 hPa
Back Panel Temperature (Degree C)	Temperature probe for back panel temperature	°C	± 1°
Plane of Array Irradiance Watts\Meter Sq.	Pyranometer or Equivalent	W/m^2	± 25 W/m^2
Global Horizontal Irradiance Watts\Meter Sq.	Pyranometer or Equivalent	W/m^2	± 25 W/m^2
Direct Irradiance Watts\Meter Sq.	Pyranometer or Equivalent	W/m^2	± 25 W/m^2

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Example of Meteorological Measurements Required to Support Solar Power Forecasting

CAISO EIRP: Irradiance Measurements

Table Q-4 Irradiance and Back Plane Required Measurements

	Direct Irradiance (DIRD)	Global Horizontal Irradiance (GHIRD)	Global Irradiance/ Plane of Array (PAIRD)	Back Panel Temperature (BPTEMP)
Flat-Plate PV (fixed / horizontal / flat roof)			R	R
Flat-Plate PV (fixed angle / azimuth tracking)			R	R
Flat-Plate PV (DNI zenith & azimuth tracking)	R		R	R
Flat-Panel Solar (thermal fixed angle mounted)			R	R
Flat-Panel Thermal Collector (azimuth tracking)			R	R
Low Concentrating PV (LCPV)	R	R		
High Concentrating PV (HCPV)	R	R		
Concentrated Solar Thermal (solar through zenith tracking)	R	R		
Heliostat Power (tracking focusing mirrors)	R	R		
Greenhouse Power Tower (hot air convection turbine)			R	
Stirling Engine (concentrated solar	R	R		

Solar Forecast Performance:
A Recent Benchmark

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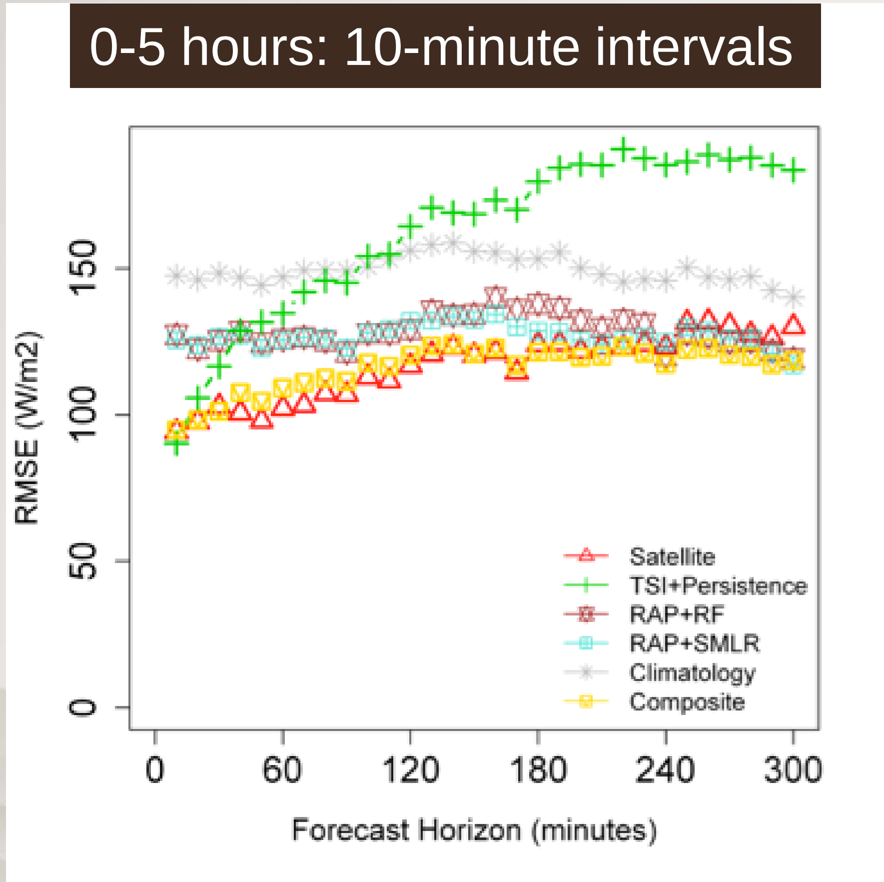
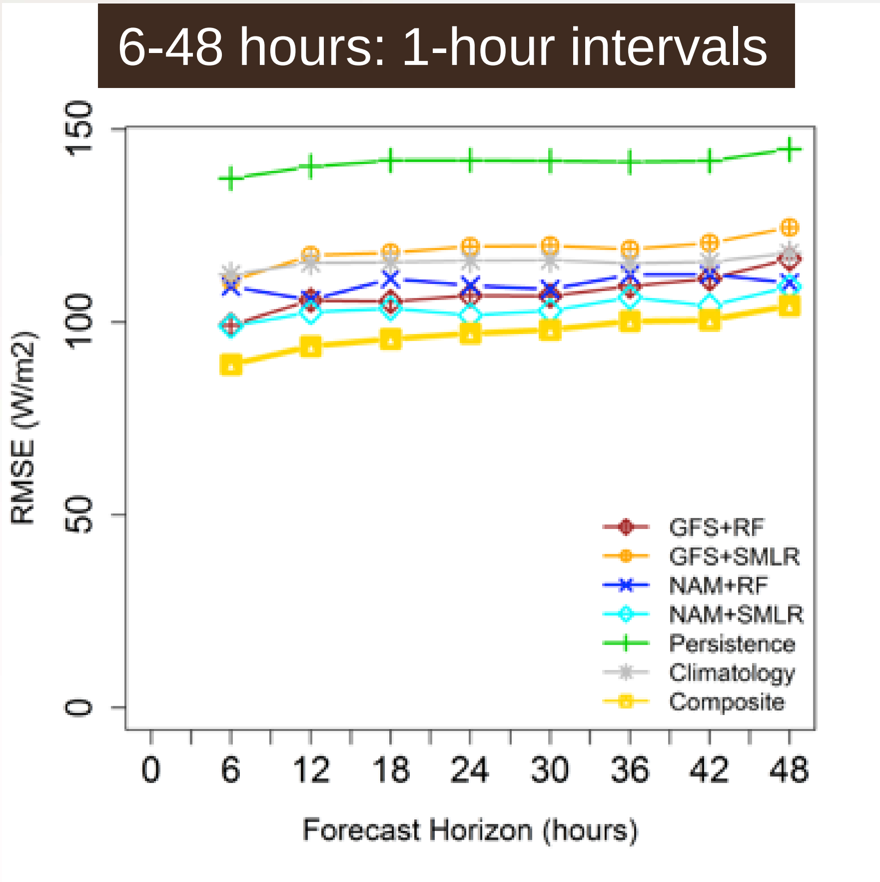
Solar Forecast Performance Benchmark

- Analyzed performance of GHI forecasts from a range of methods for a solar generation facility on the CAISO system
- Performance evaluated for the year 2012 – daylight hours only
- RMSE of 100 watts/m^2 for GHI is approximately an RMSE of 10% of capacity for solar power production forecasts





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Key Points

Summary

- State-of-the-art forecasts are generated with an ensemble of statistical, pattern-recognition and physics-based forecast tools and a variety of input data types
- Considering all potential facility site data, power production data provides 80% to 95% of the value for solar power forecast performance
- Availability, irradiance and back-panel temperature provide much of the remaining value
- Type of irradiance data required depends on the solar generation technology employed at a facility
- Met measurements can provide large value in certain situations such as cases of snow, ice and dust accumulation