Solar Forecast Arbiter .org

An open source evaluation framework for solar forecasting

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Sharply Focused
Understanding Renewable Resources

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Project goal

Open-source framework for solar forecast evaluations that are impartial, repeatable, and auditable.

- Implement objective, consistent evaluation scenarios and metrics → better solar forecasts
- Develop user confidence in solar forecasts → system integration
- Standardize evaluations → reduce provider and user costs
- Easily extend to wind power and load forecasting

What is the Solar Forecast Arbiter?

- Web-based user interface
- Web-based API for scripting
- Python software package that formalizes and implements analysis
- Scripts to redeploy entire software stack (OS, database, web application)
- Detailed documents that explain the approach

Open source. Transparently developed on GitHub

EXAMPLE REPORT

SOLAR FORECAST ARBITER Changelog Documentation Account

Sites
Observations
Forecasts
Probabilistic Forecasts
Reports

Albuquerque GHI Forecast Analysis

Report Metadata

- Name: Albuquerque GHI Forecast Analysis
- Start: 2019-01-01 00:00:00
- etc

Download as html or pdf

This report of solar forecast accuracy was automatically generated using the Solar Forecast Arbiter.

This report was generated at 2019-05-23 20:21:16.

Data

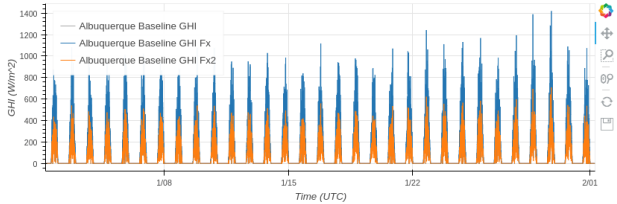
This report covers the period from 2019-01-01 00:00:00 to 2019-02-01 00:00:00.

The table below shows the observation, forecast pairs analyzed in this report. The table includes the unprocessed observation and forecast *interval label* (beginning, ending, instanteous) and *interval length*. If these quantities do not match, the Solar Forecast Arbiter must align and/or resample the data before computing error statistics. The Solar Forecast Arbiter typically aligns the observation data to the forecast data. The aligned and resampled parameters are also shown below.

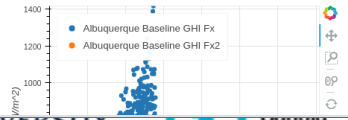
- Observation: Albuquerque Baseline GHI, Forecast: Albuquerque Baseline GHI Fx
- Observation: Albuquerque Baseline GHI, Forecast: Albuquerque Baseline GHI Fx2

The plot below shows the realigned and resampled time series of observation and forecast data.

Controls to pan, zoom, and save the plot are shown on the right. Clicking on an item in the legend will hide/show it.

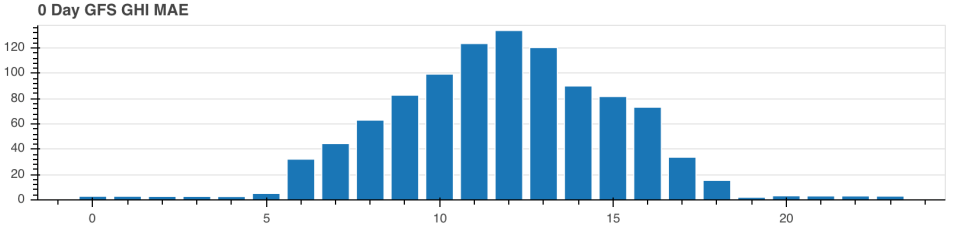


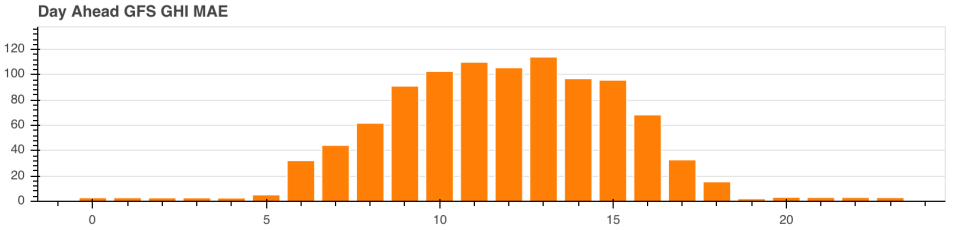
The scatter plot below shows realigned and resampled forecast vs observed values.



Hourly

Metrics for each hour of the day during the analysis period are displayed in tables and figures below.





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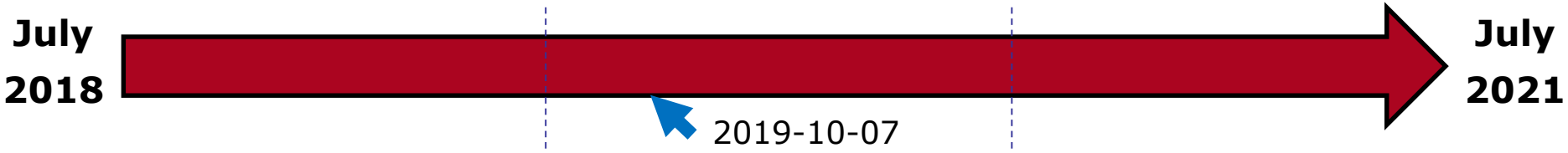
Project Timeline/Milestones



Year 1

Design, build, test and demonstrate the framework.

Year 2

Refine the framework and host two operational forecast competitions

Year 3

Support evaluations for Solar Forecasting II Topic 2 and Topic 3 awardees.

Transition framework to new operator.

Stakeholder Engagement

5 primary topics

- Use cases
- Data format/API
- Data policies
- Benchmark forecasts
- Evaluation metrics

Please join the Stakeholder Committee! (open to all)

solarforecastarbiter.org/stakeholdercommittee

Typical engagement process

Stakeholder Workshop

St. Paul, June 2018

→ Team discussions

Proposal documents

→ Stakeholder feedback

Revised documents

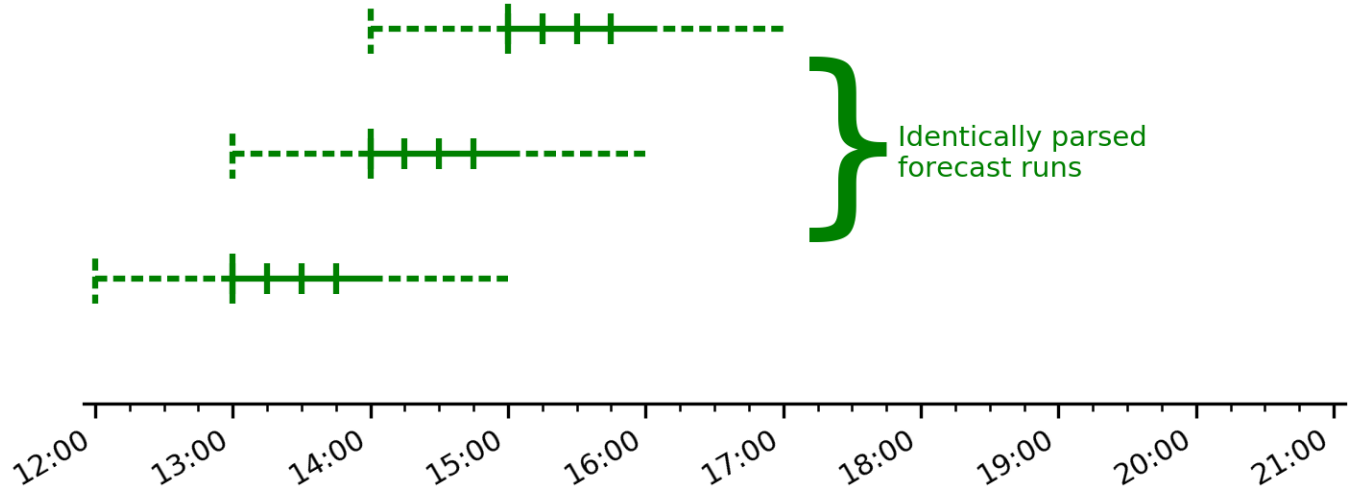
→ Stakeholder consensus

Final documents

Implement

Forecast runs concatenated into a forecast evaluation timeseries

Application: short term market
Requirement: hour ahead forecast



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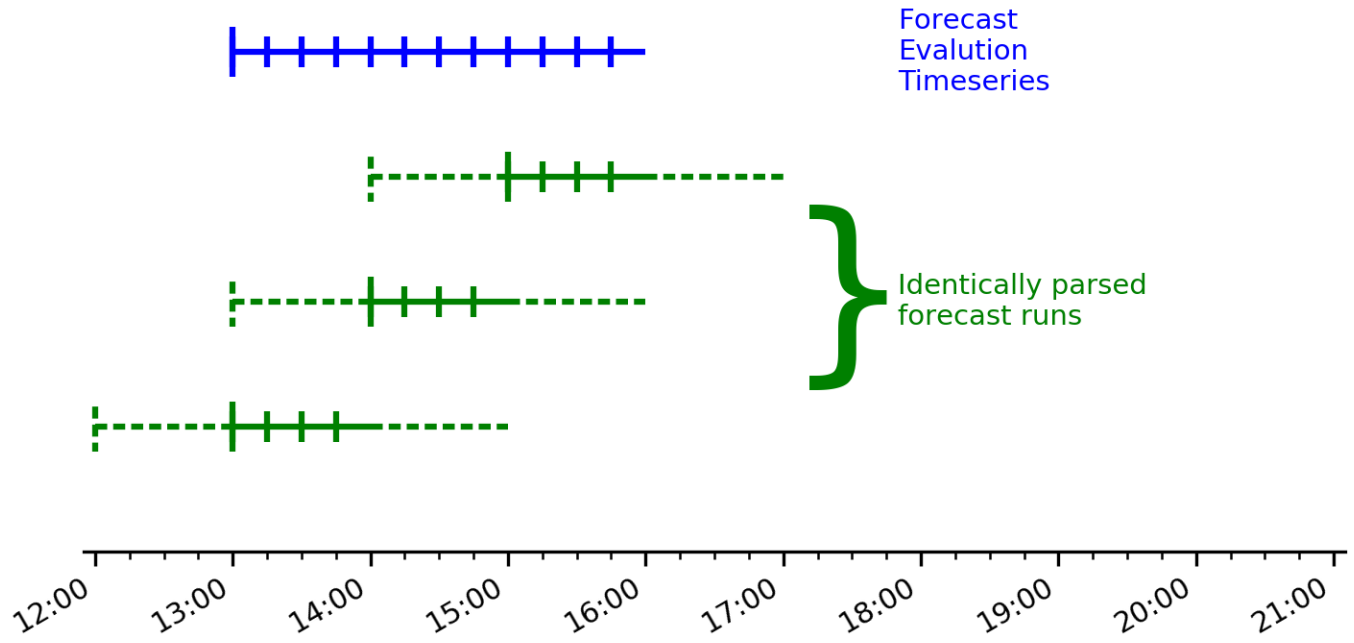
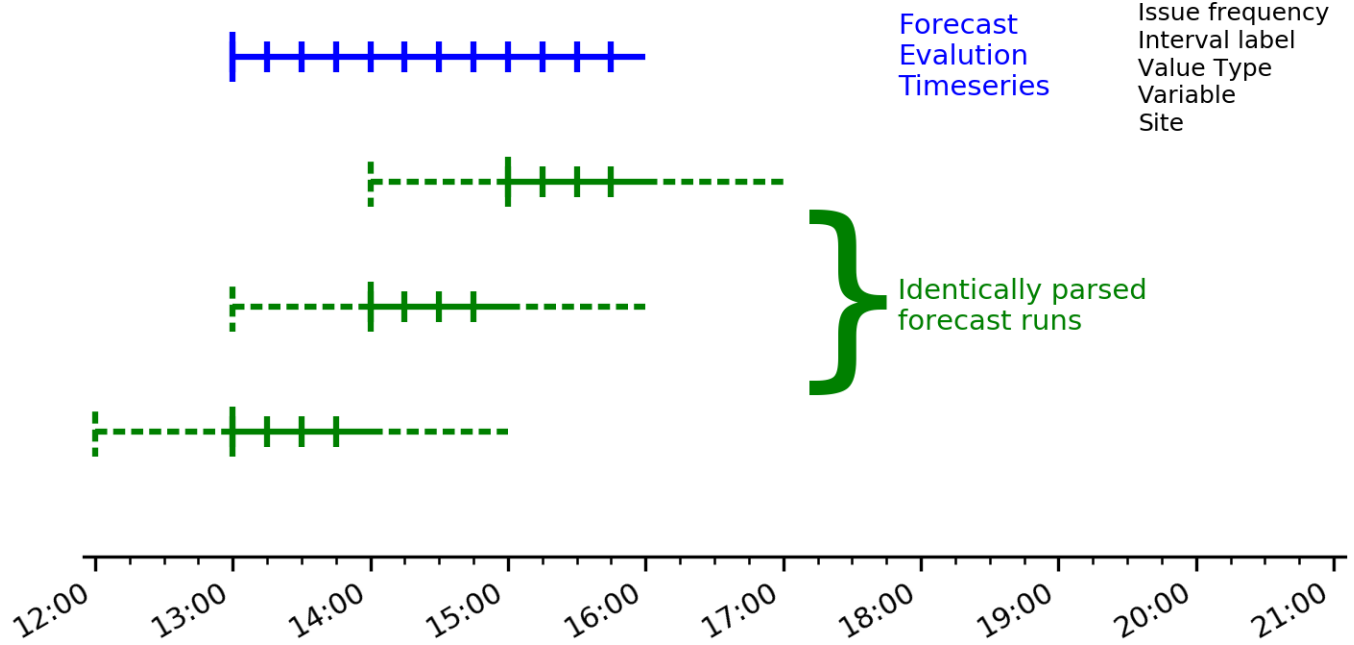


Forecast runs concatenated into a forecast evaluation timeseries

Application: short term market
Requirement: hour ahead forecast

Forecast taxonomy

Lead time to start	1h	1h
Interval duration	15min	15min
Intervals / sub.	4	12
Issue frequency	1h	1h
Interval label	left	left
Value Type	mean	mean
Variable	Power	Power
Site	Plant X	Plant X



Use Cases

solarforecastarbiter.org/usecases

1D time series – no gridded data

A. Compare a forecast to measurements

B. Compare a probabilistic forecast to measurements (Nov.)

C. Compare multiple forecasts to measurements

D. Compare forecasts to measurements for sites and aggregates (Oct.)

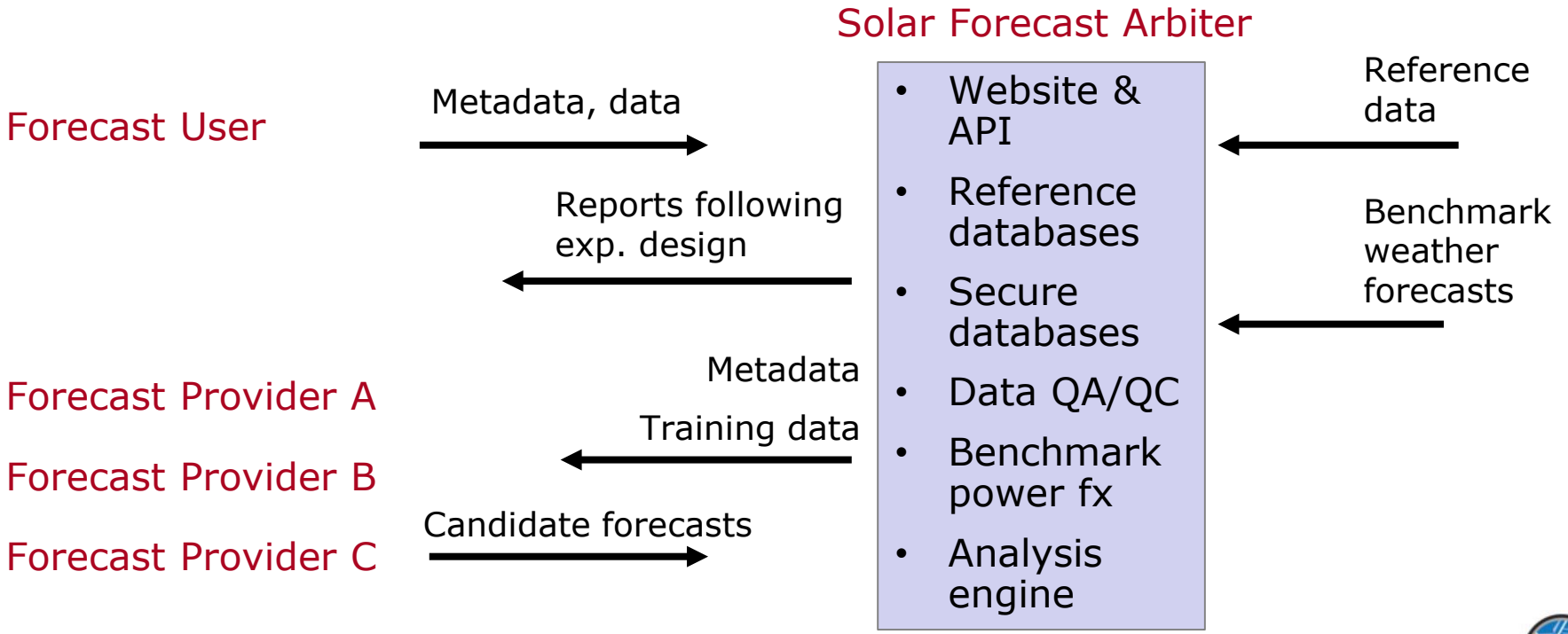
E. Evaluate an event forecast (~Mar.)

F. Conduct a forecast trial (~Jan.)

G. (*stretch*) Compare multiple overlapping forecast runs to measurements

H. (*stretch*) Establish long-term performance baseline of state-of-the-art operational forecasts

Sketch of Forecast Trial Use Case



Data policies in layman's terms

1. Organization must sign non-negotiable Data Use Agreement before given access to do anything but view reference data.
2. Signing agreement does **not** obligate organizations to upload data or share data.
3. Organizations retain ownership of the data they upload to the framework.
4. Organization admins have complete control over how their data may be accessed by other users. Default: no sharing, private analysis only.
5. Organization admins may delete data from the framework.
6. Uploading data does **not** give SFA team ability to study data.
7. All non-public data will be securely deleted at the termination of the project (2021).

Data Sharing and Privacy

Solar Forecast Arbiter | Key Topics | About | Publications | Stakeholder Committee | Email List | Blog | Documentation | Dashboard

Data Policies

This page summarizes the data sharing and privacy policies of the Solar Forecast Arbiter.

An **organization** is an entity that owns data or obtains license to submit data to the framework. A **user** is an individual working for an organization that performs tasks such as submitting data to the framework and downloading data from the framework. An **organization administrator** is a user that has can also grant permissions to view or modify data to other users, including users outside of the administrator's own organization.

The Data Use Agreement (DUA) is a **non-negotiable** legal document that all parties are bound to. The DUA must be signed by an authorized representative of an organization before its employees will be allowed to upload data, view data contributed by other users, or generate summary statistics.

The data policies can be summarized as:

- Signing the DUA does **not** obligate an organization to upload data, nor does it obligate an organization to share uploaded data.
- Organizations retain ownership of the data they upload to the framework.
- Users upload data to the framework on behalf of organizations.
- Organization administrators have complete control over how their organization's data may be accessed by other users.
- Organization administrators may delete their organization's data from the Arbiter at any time.
- Uploading data does **not** give Solar Forecast Arbiter team members the ability to study it. Sharing data with project team members follows the same procedures as sharing data with any other user.
- All data will be securely deleted within 30 days of the termination of the project (anticipated late 2021).

The DUA describes two types of data that participants may contribute: *Open Project Data* and *Limited Project Data*. Limited Project Data is proprietary data for which access controls are required. Most of the data policies are structured around addressing concerns about Limited Project Data. Open Project Data is data that users contribute to the project's reference data set. This data immediately benefits the whole community, but organizations lose control over who can access it.

https://solarforecastarbiter.org/datapolicies/

DATA USE AGREEMENT

This Data Use Agreement (the "Agreement") is effective on the date of the authorized signature below (the "Effective Date") by the party named below ("Company"), and ratified by the Arizona Board of Regents, University of Arizona ("University") upon granting access to the Data Platform (defined below) to Company. Company and University (each a "Party," and jointly, the "Parties") hereby agree as follows:

1. **Data Platform**

1.1. Background. University has—pursuant to a grant for "Open Source Evaluation Framework for Solar Forecasting (Solar Forecast Arbiter)" (the "Research Project") under DOE Award Number DE-EE0008214—developed a Data Platform. The "Data Platform" means a cloud software platform developed by the University for solar forecast evaluations, in connection with the Research Project.

1.2. Permitted Use. Upon being granted access to the Data Platform, Company may—through its employees, leased workers, and authorized agents (each an "Authorized Agent")—access and use the Data Platform to:

- Enter its own, and/or information authorized by its affiliates, information or data (**"Company Project Data"**) into the Data Platform, and allow either unrestricted access by other users of the Data Platform (**"Open Project Data"**) or restricted access to specific, Company-specified users or groups of users (**"Limited Project Data"**), using the features of the Data Platform. Company will have the option to grant specific users or groups of users access to its "Limited Project Data" within the Data Platform.

- Access data that is available in the Data Platform, including Open Project Data and certain Limited Project Data of other users, and download such data only for its internal business purposes. Company will not share **any** data it receives from the Data Platform outside Company (including Company's authorized affiliates) and will keep it confidential in accordance with its customary business practices.

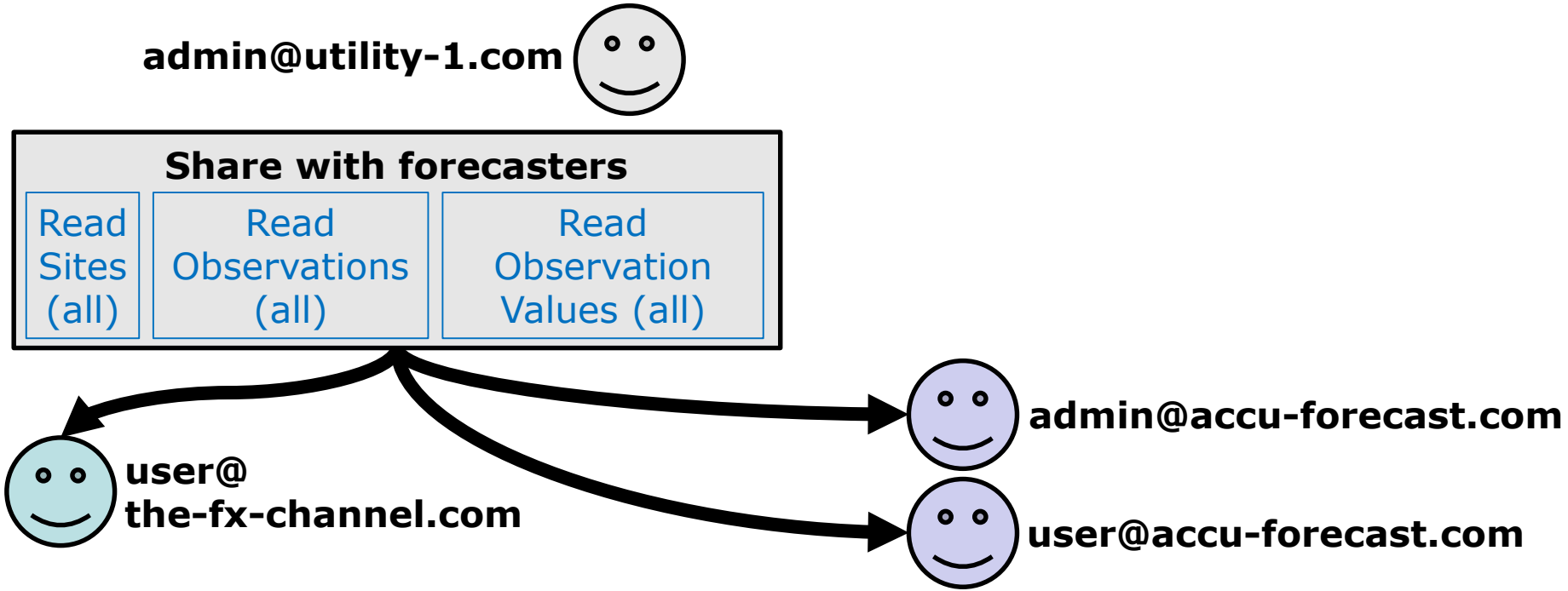
Company agrees to use Data Platform in accordance with information security best practices and in compliance with all applicable federal and state laws, regulations and policies. Company is not obligated by this Agreement to either upload any specific data to the Data Platform or grant access of Limited Project Data to other users of the Data Platform.

1.3. Ownership of Data Platform. University retains all right, title, and interest in and to the Data Platform. No rights in the Data Platform are conveyed to Company other than the limited use rights set forth above. Company will use the Data Platform only as contemplated by its design and features, and as agreed in this Agreement.

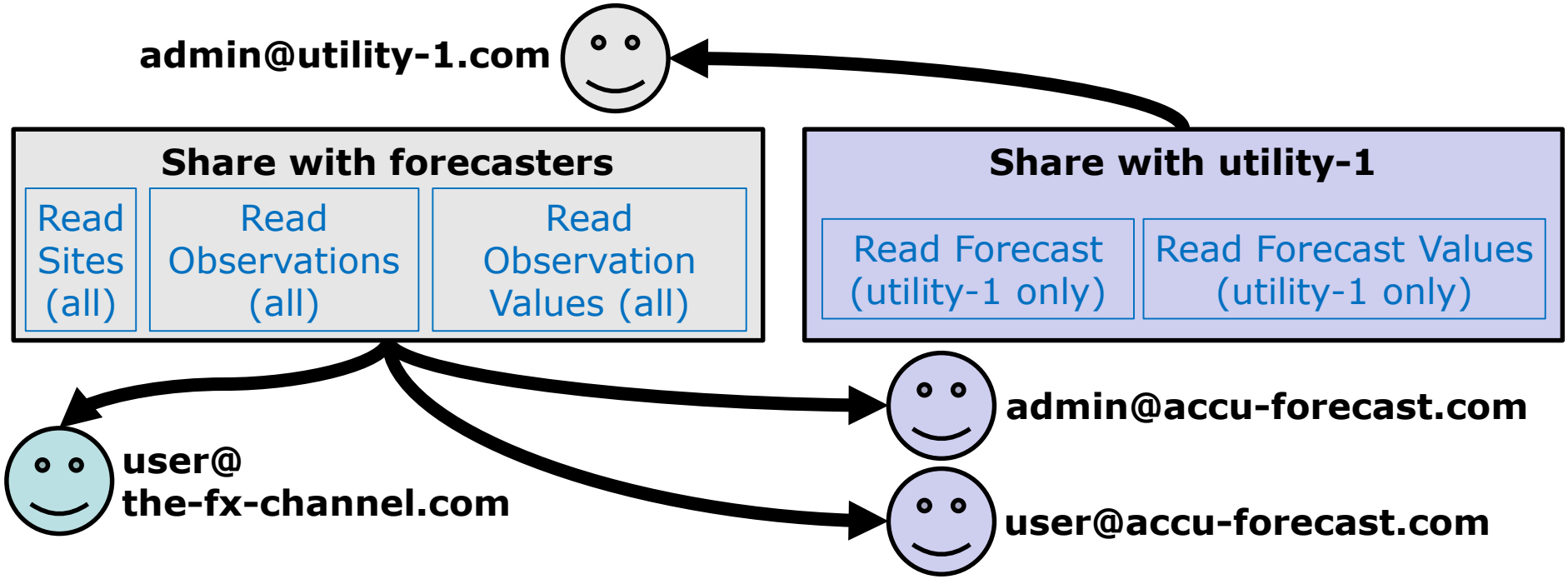
1.4. Ownership of Data. Company retains ownership of all Company Project Data. Company permits the University and other users to use Company Project Data as contemplated by the Data Platform. University agrees not to data mine or otherwise examine Limited Project Data except when required for service issues, technical issues, quality assurance, and quality control.

1.5. Publication. Company acknowledges that University may present or otherwise publish Company Project Data submitted by Company through the Data Platform as follows:

Data Sharing Implementation: Role Based Access Control

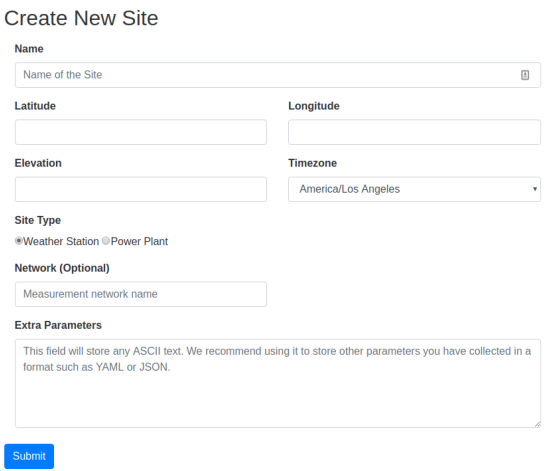


Data Sharing Implementation: Role Based Access Control



Data Upload/Download

Dashboard



solarforecastarbiter.org/dashboarddoc

API

Solar Forecast Arbiter API (0.1.0)

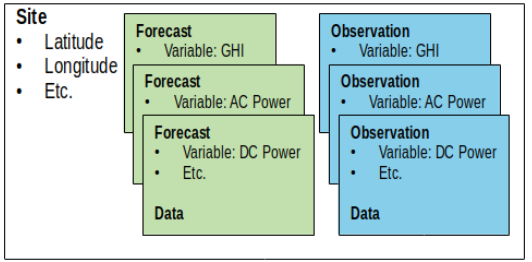
Download OpenAPI specification: Download

Solar Forecast Arbiter Team: info@solarforecastarbiter.org
URL: https://github.com/solararbiter/solarforecastarbiter-api | License: MIT

The backend RESTful API for Solar Forecast Arbiter.

api.solarforecastarbiter.org

Data Model



solarforecastarbiter.org/datamodel

Benchmark Forecasts

Required Attributes

- Available throughout the US
- Freely accessible or easily implemented
- Provide quantities of interest to both forecast users and providers
- Stakeholder buy-in

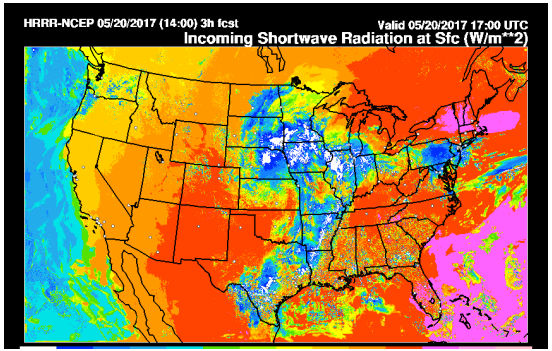
Benchmark Forecasts

solarforecastarbiter.org/benchmarks

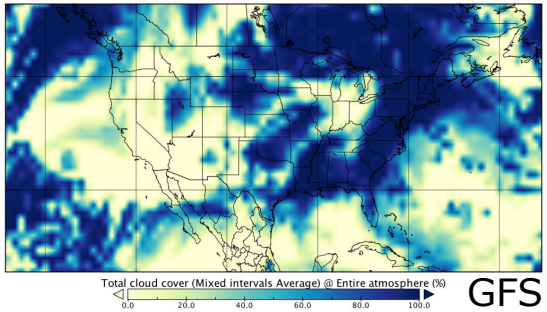
- For 1 hour – 7 day ahead and longer horizons:
  - Downloaded all GFS, GEFS, NAM, RAP, HRRR runs since April 2019. ~CONUS domain using g2sub
  - GFS, NAM, RAP irradiance forecasts have serious limitations, so derive irradiance or PV power from cloud cover.
  - Directly use HRRR subhourly irradiance

Supported Options:

- HRRR subhourly irradiance (15 min instant or hourly avg)
- RAP cloud cover to irradiance (hourly avg)
- NAM cloud cover to irradiance (hourly avg)
- GFS cloud cover to irradiance (hourly avg)



Total cloud cover (Mixed intervals Average) @ Entire atmosphere



GFS

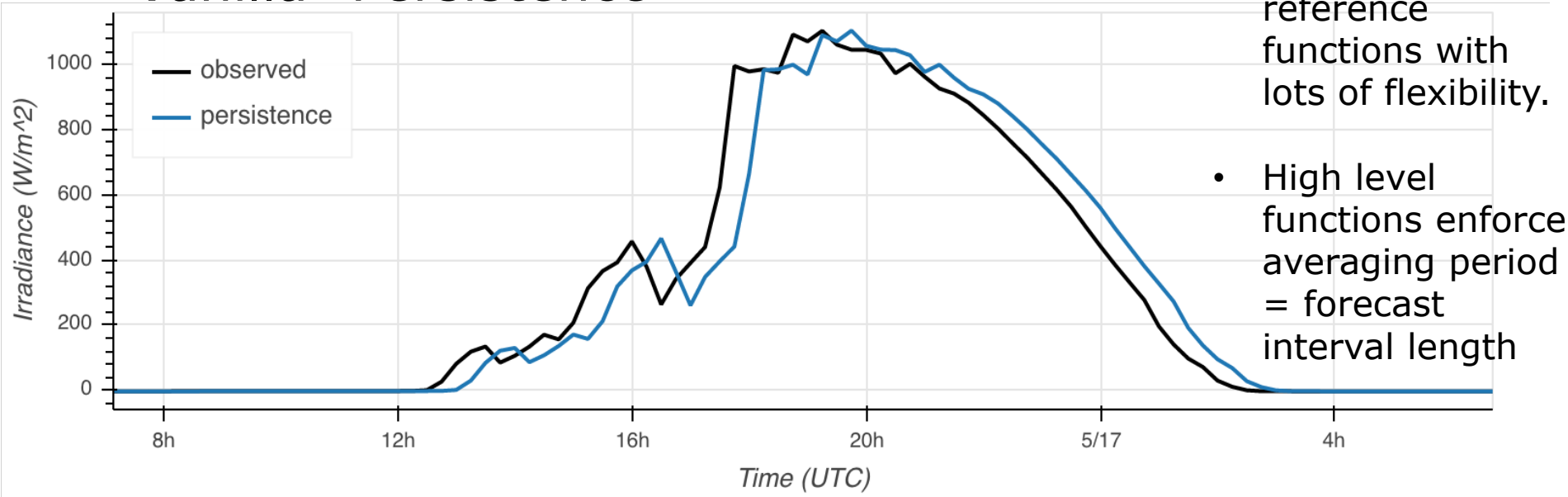
NWP Benchmark Forecasts Processing

- Our PV power model requires instantaneous input
- Accurate hourly averages require many subhourly instantaneous points

1. Load hourly (or longer) interval data from the NWP grib files.
   - For GFS cloud cover, unmix the mixed-intervals average data.
2. Resample data to 5 minute intervals.
   - For GFS cloud cover, backfill the data.
   - For all other NWP data, interpolate the data.
3. Convert cloud cover to irradiance. Linear clear sky scaling Larson et. al.:
   - GHI = (35% + (100% - cloud cover)) * GHI_clear
4. If PV, use site metadata to compute AC power using pvlib-python functions.
5. Compute hourly averages with desired interval labels.

Persistence Benchmark Forecasts

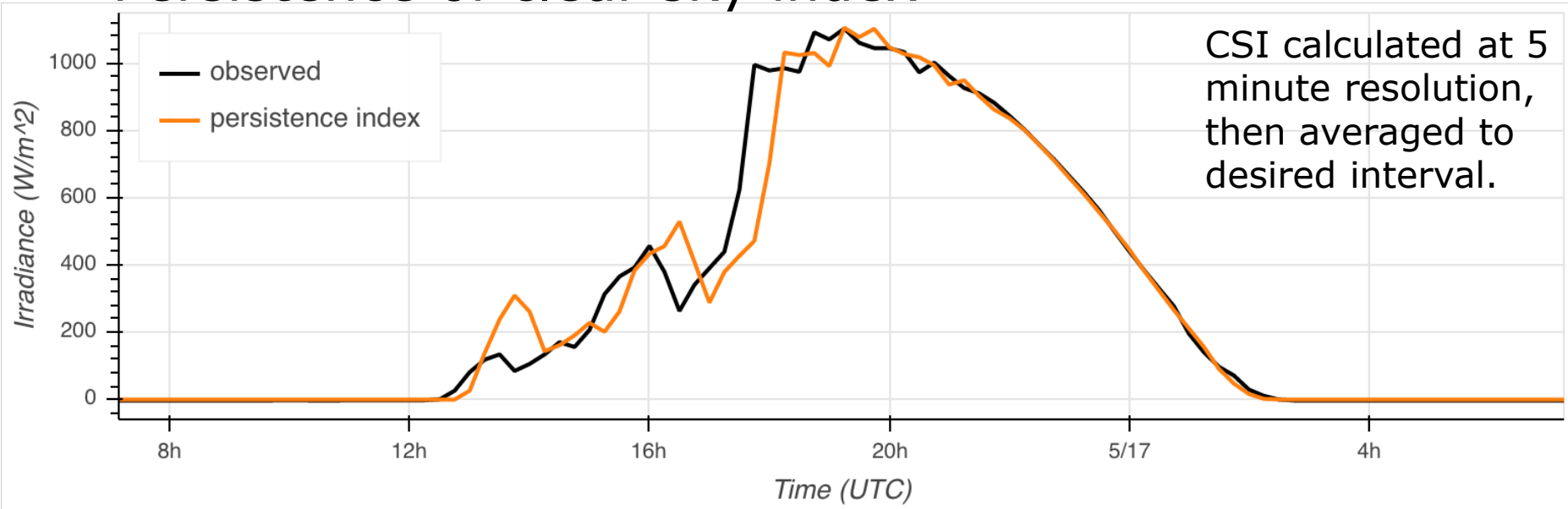
"Vanilla" Persistence



- Low level reference functions with lots of flexibility.
- High level functions enforce averaging period = forecast interval length

Persistence Benchmark Forecasts

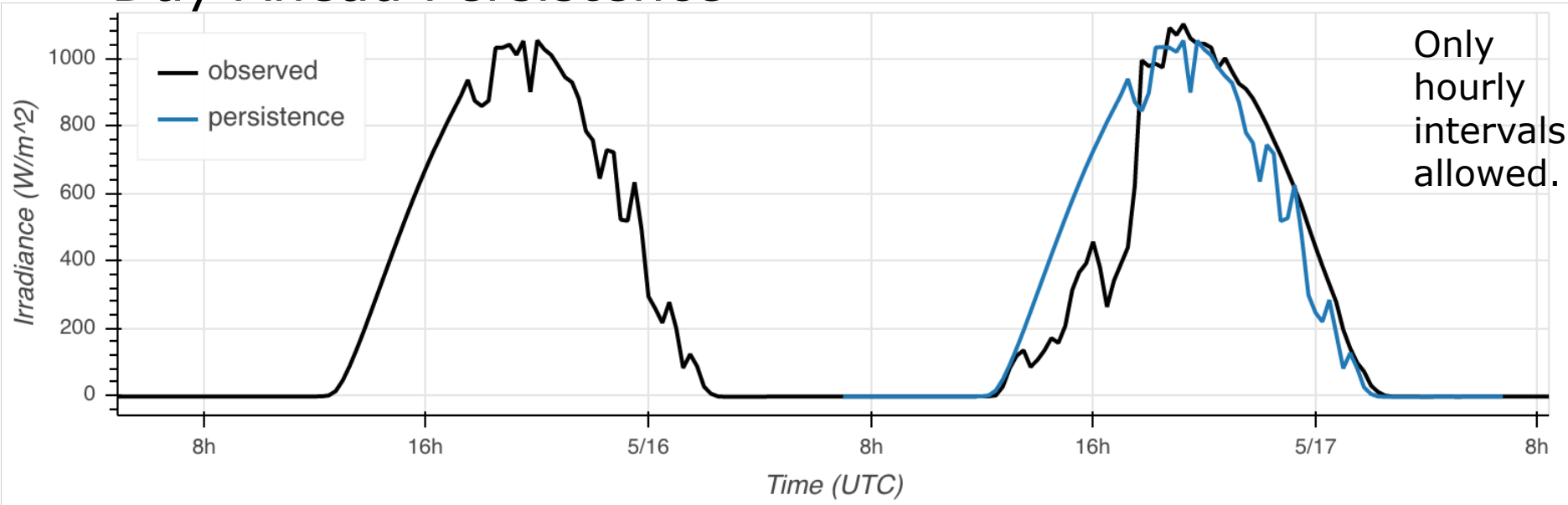
Persistence of clear sky index



CSI calculated at 5 minute resolution, then averaged to desired interval.

Persistence Benchmark Forecasts

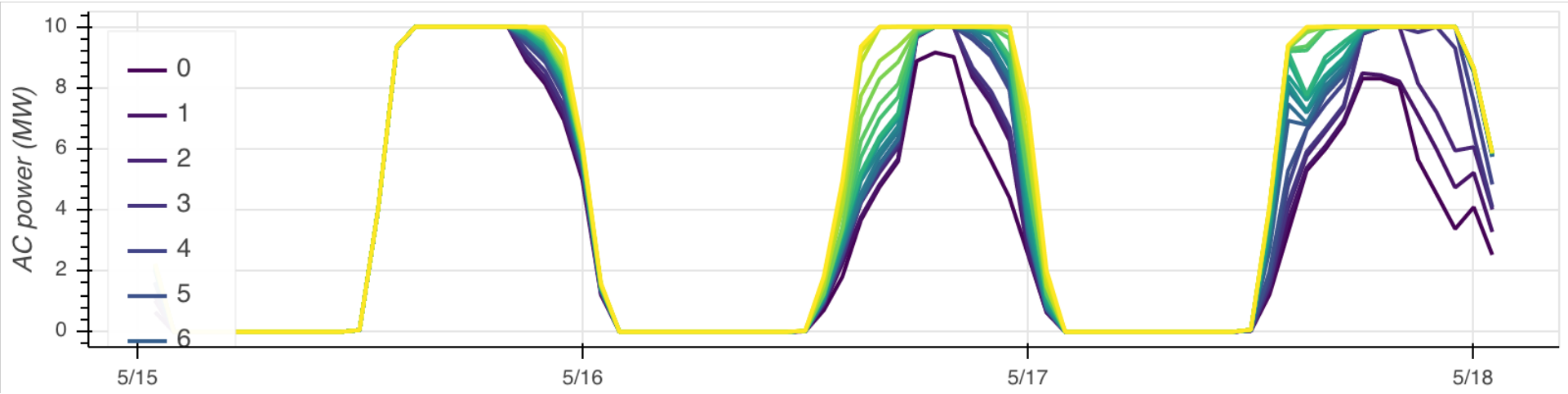
Day Ahead Persistence



Only hourly intervals allowed.

Probabilistic Benchmark Forecasts

- GEFS cloud cover processed into irradiance or power percentiles (0, 5, …95, 100)



- Climatology (not yet implemented)
- Persistence ensemble (not yet implemented)

Benchmark Forecast Configuration

- Current operational NWP processing configuration
  - Based on time zone. Example for site in MST (UTC-0700):

Model	Issue time of day	Run length / Issue frequency	Lead time to start
GFS day ahead	7Z	1 day	1 day
NAM current day	6Z	1 day	1 hour
HRRR intraday	0Z	6 hours	1 hour
RAP intraday	0Z	6 hours	1 hour

- Persistence not yet configured. One idea: follow CAISO requirements
- Trials allow custom configuration

Net Load Benchmark Forecasts

- Net load definitions
  - Net load = True load – BTM PV
  - Net load = True load – Known Utility Scale Solar – BTM PV

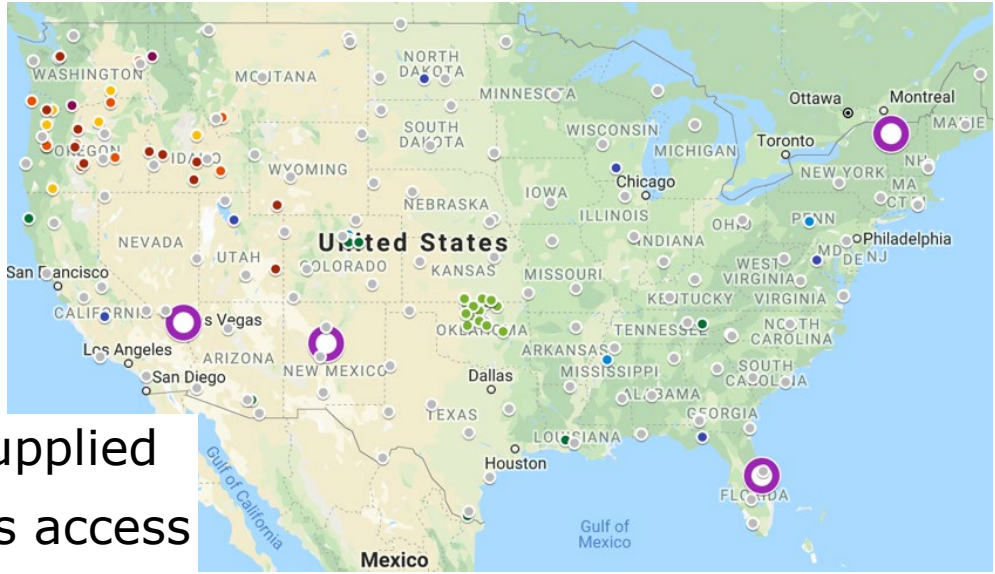
Use regression w/weather obs for true load? Persistence?

Stay tuned.

Validation and Reference Data Sources

Public Reference Data

- NOAA SURFRAD
- NOAA SOLRAD
- NOAA CRN
- NREL MIDC
- DOE RTC
- U. Oregon network



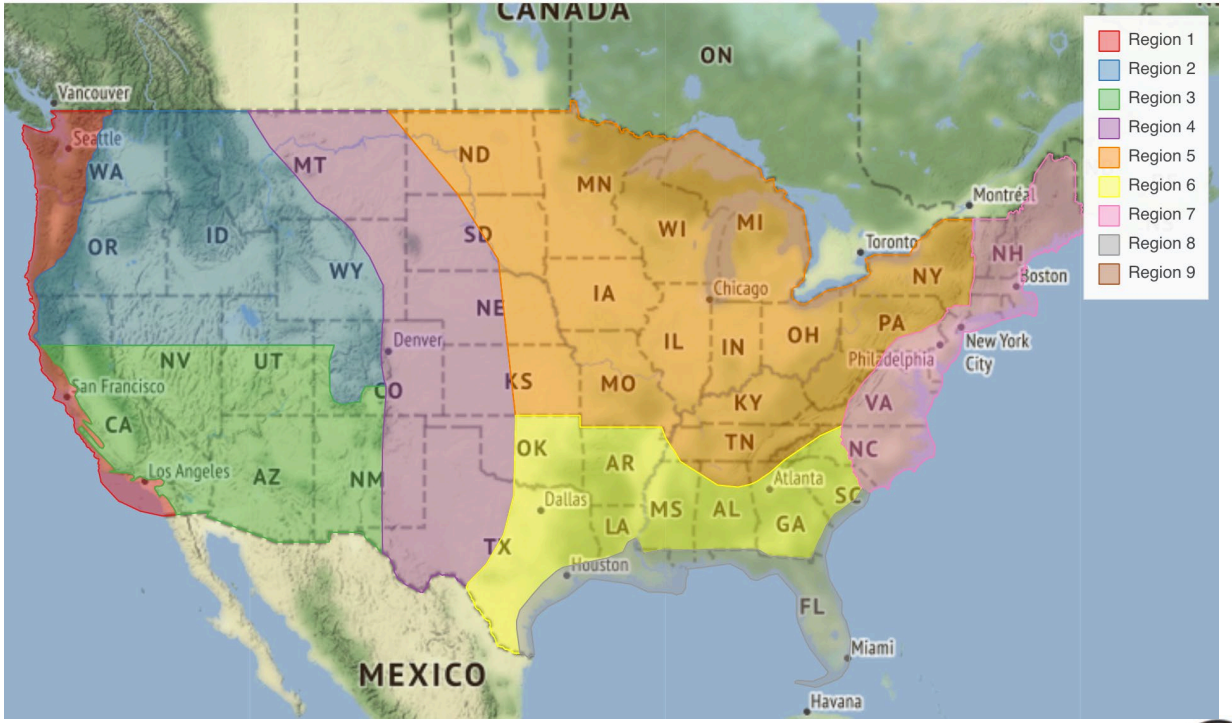
User Data

- Stakeholder supplied
- Owner controls access
- Contribute public reference data, get reference forecast

solarforecastarbiter.org/referencedata

Climate Regions

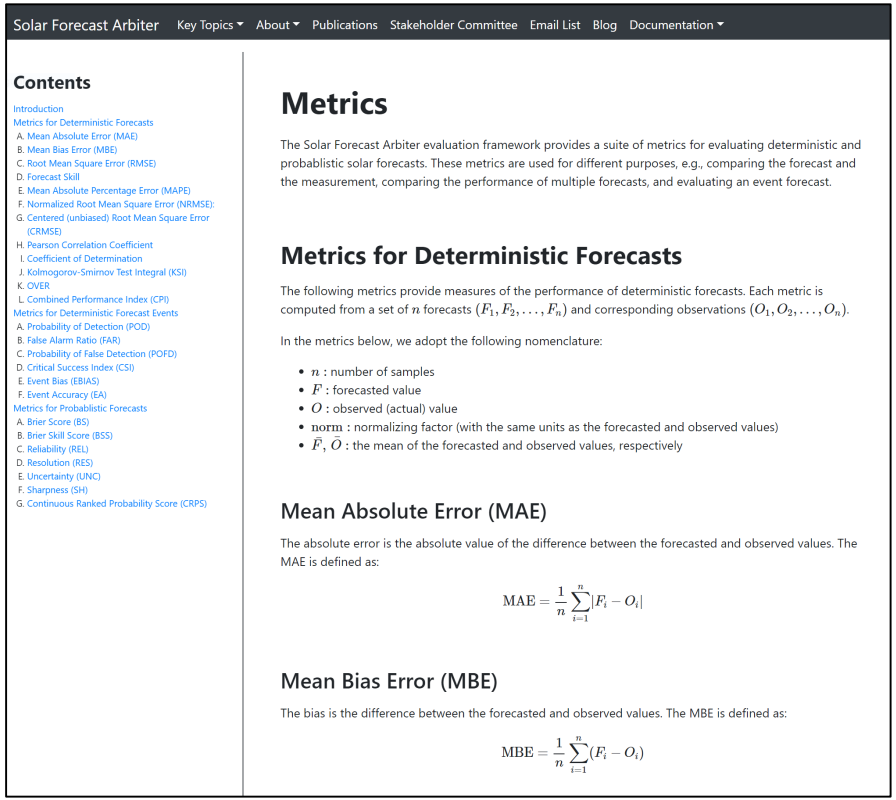
- Regions support broader analyses of forecast performance
- ”This forecast performs well/poorly on the West Coast”
- Interactive map, shapefiles, kmz



Metrics

Stakeholder selections of:

- Deterministic Forecasts
- Event Forecasts
- Probabilistic Forecasts



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Contents

Metrics

The Solar Forecast Arbiter evaluation framework provides a suite of metrics for evaluating deterministic and probablistic solar forecasts. These metrics are used for different purposes, e.g., comparing the forecast and the measurement, comparing the performance of multiple forecasts, and evaluating an event forecast.

Metrics for Deterministic Forecasts

The following metrics provide measures of the performance of deterministic forecasts. Each metric is computed from a set of n forecasts $(F_1, F_2, \ldots, F_n)$ and corresponding observations $(O_1, O_2, \ldots, O_n)$.

In the metrics below, we adopt the following nomenclature:

- n : number of samples
- F : forecasted value
- O : observed (actual) value
- norm : normalizing factor (with the same units as the forecasted and observed values)
- $\bar{F}$, $\bar{O}$: the mean of the forecasted and observed values, respectively

Mean Absolute Error (MAE)

The absolute error is the absolute value of the difference between the forecasted and observed values. The MAE is defined as:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|F_i - O_i|$$

Mean Bias Error (MBE)

The bias is the difference between the forecasted and observed values. The MBE is defined as:

$$\mathrm{MBE} = \frac{1}{n}\sum_{i=1}^{n}(F_i - O_i)$$

https://solarforecastarbiter.org/metrics/

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Selecting Periods and Time Series Issues

- Users specify start and end time for analysis report
- Rule: don't modify user-submitted forecasts
- Interval length consistency:
  - If measurements are higher resolution, Average the measurement data so that it has the same resolution as the forecast data (default)
  - If the forecast is higher resolution – comparison not allowed
- Interval label consistency:
  - Observations and forecasts have defined labels (beginning, ending, instant)
  - Arbiter accounts for observation intervals when resamples
- Nighttime data: Day/night filter based on solar zenith angle
- Ability to select certain periods: time of day, months of year, clear/cloudy, other weather variables, ramping periods

Evaluation with messy data

- Priority: clearly document the process and any user-configured options in each report
- Missing or bad forecast data
- Missing or bad observation data
  - Data validation toolkit flags most problems
- Research study
  - Options selected when report is created
- Operational forecast trial
  - Options selected when trial is created

Visualization

- Solar power forecast and actual visualization
  - Time series
  - Scatter plots of forecast vs actual
  - Density plots of joint distributions
  - Conditional and marginal distributions
- Metric visualization
  - Bar charts for different metrics
  - Ability to plot by time of day, day by day and monthly
  - Box and whiskers – median, upper and lower quantiles and min, max for MAE and RMSE

Cost metrics

Built-in support for:

- Fixed $/MW
- Fixed $/MW for handful of error bins
- Time series of $/MW

Also provide brief recommendations and references for how to conduct more detailed cost evaluations

Summary

- Open source, reproducible, transparent framework
- Stakeholder feedback guides project – speak up!
- Use cases tailored to needs of solar forecast stakeholders
- Reference datasets
- Secure, private data upload. Sharing optional
- Benchmark forecast capability
- Automated reports including bulk metrics, analysis filters
- Sign up for project updates, stakeholder committee at:

solar forecast arbiter . org