Using Sensors to Improve Wind and Solar Forecasts

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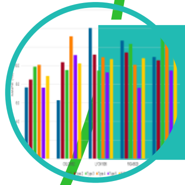
EPRI Variable Generation Forecast Integration Efforts

Fundamental Research on Forecast Integration

White Paper on Forecasting State of the Art

Behind the Meter PV Impact on Load Forecast



Solar Forecast Performance Utility Trials

Sensor Deployment and Advanced Forecasts

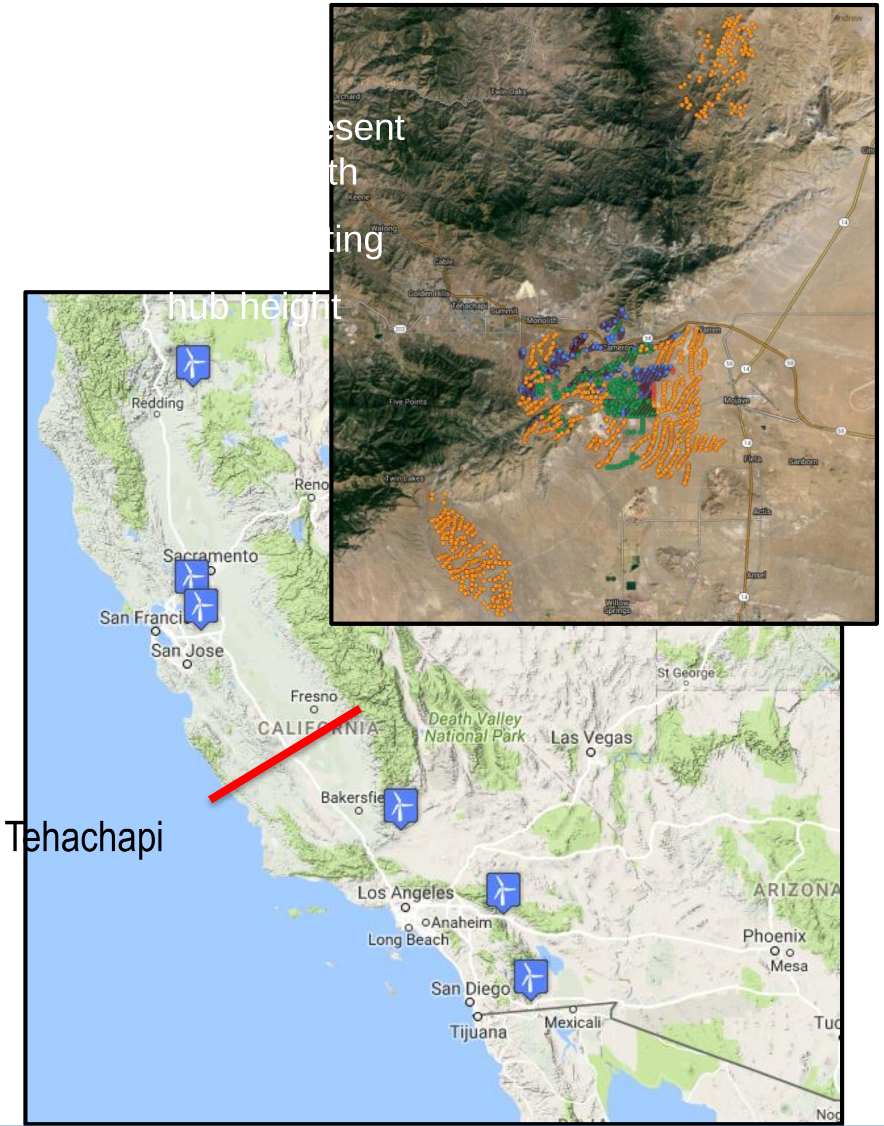
CALIFORNIA WIND Forecast improvement project overview

Work performed by AWS Truepower, Sonoma Technology Inc and UC Davis

Funded by CEC and EPRI

Project Scope

- 2.5-year project supported by the California Energy Commission (CEC) and EPRI
  - Original CEC funding for 2 years
  - Extended by EPRI
  - 2015-2017
- Tehachapi Wind Resource Area (TWRA)
  - > 3000 MW wind capacity (2319 MW in project)
  - Concentrated, highly correlated production
  - Complex terrain
  - Often driven by small-scale weather features
  - Data sparse area on the feature-scale
- Multi-faceted approach to improve 0-12 hr power production and ramp rate forecast performance
- 1-yr evaluation period to assess integrated results of project (Oct 2015 – Sept 2016)



AWST (J Zack) previously presented on project – quick update provided here

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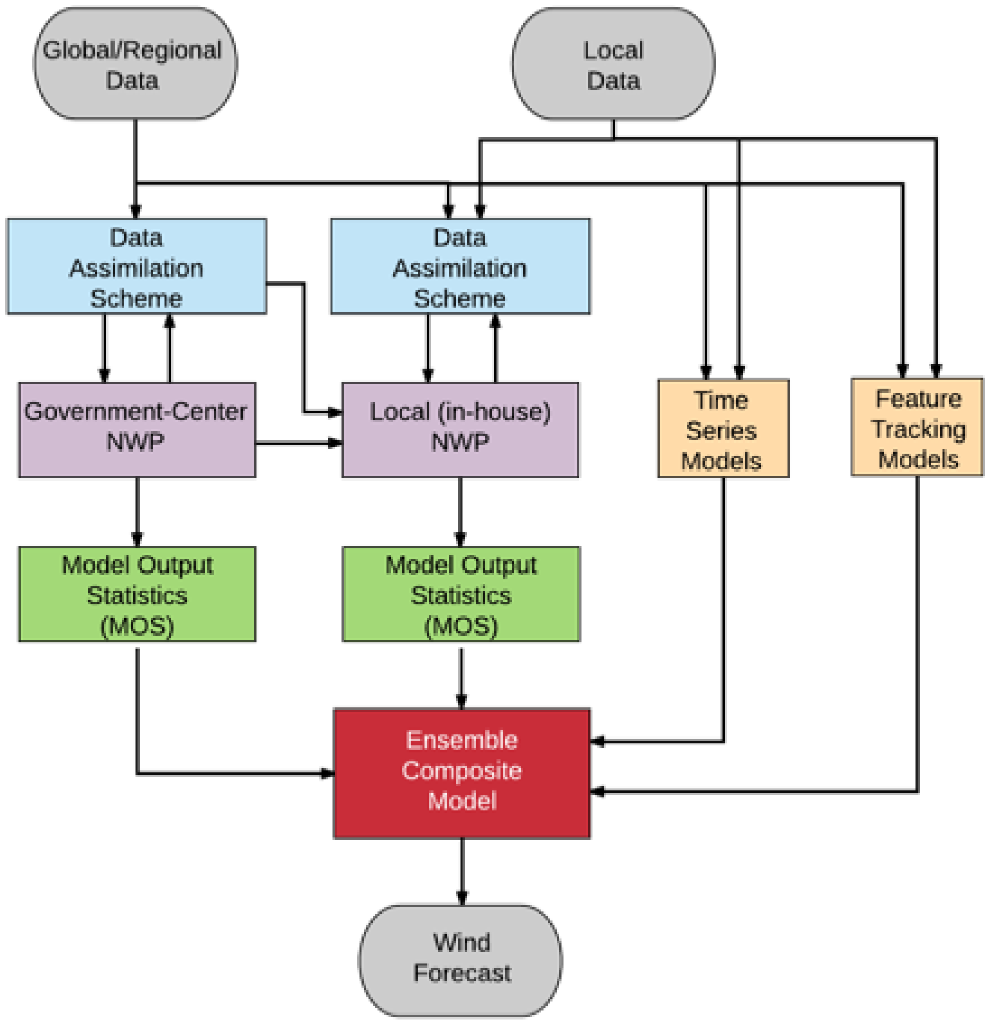
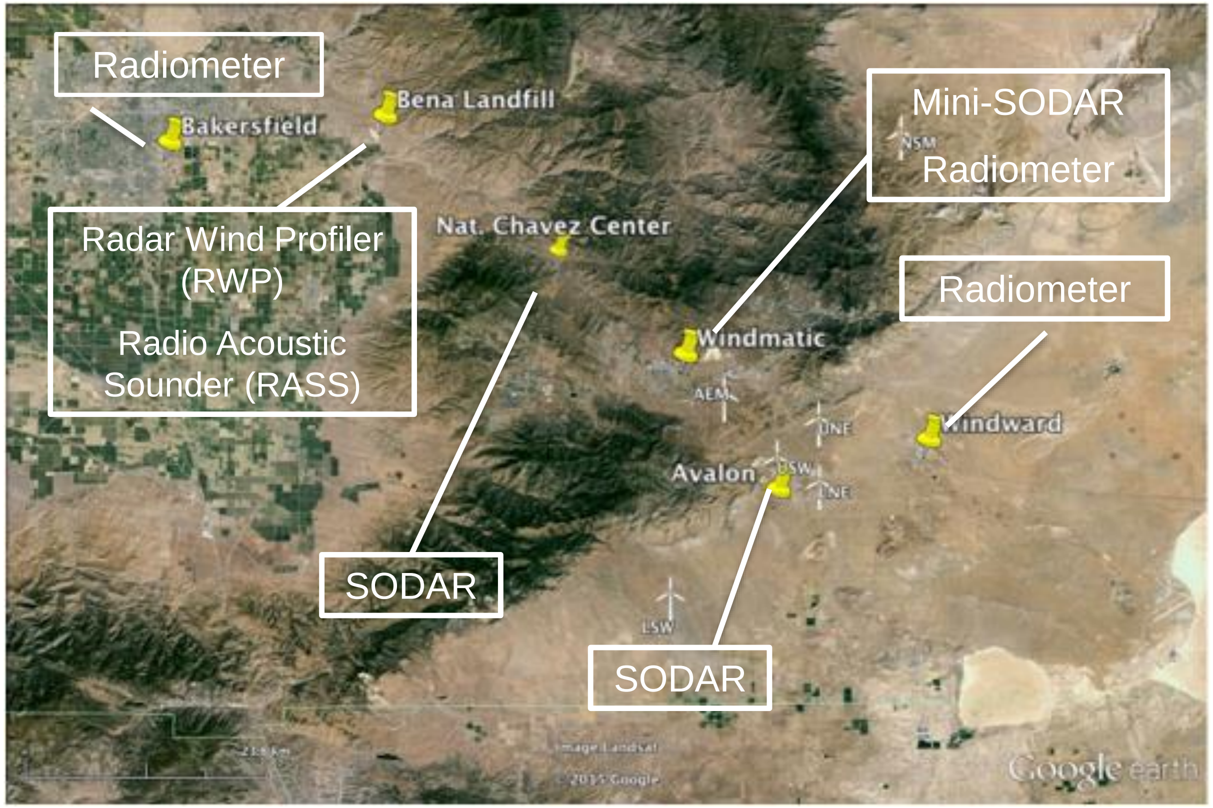
The Starting Point:
A Typical State-of-the-Art Wind Forecast System



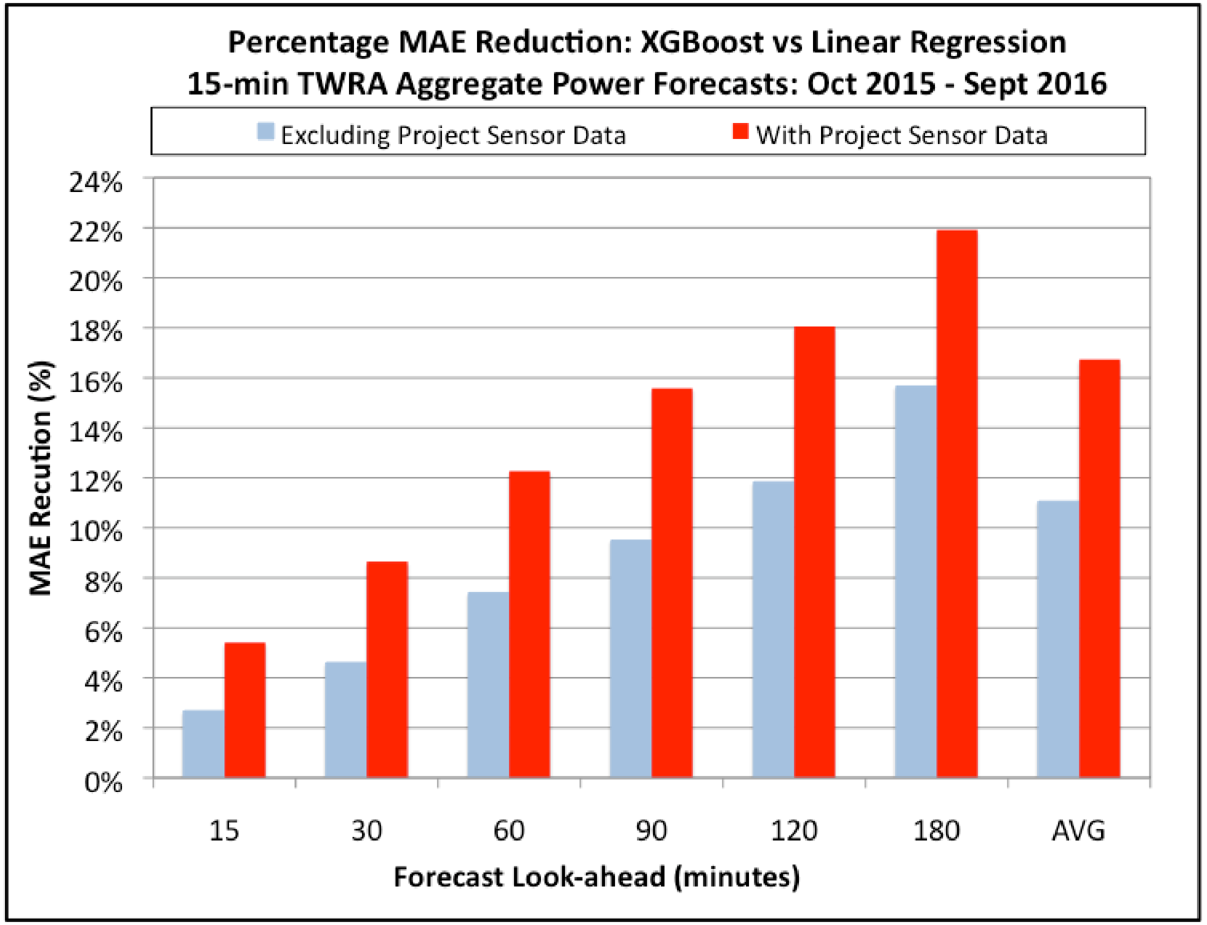
1. **Gather More Data:** Deploy targeted network of 6 sensors based on observation targeting analysis
2. **Optimize NWP Configuration**: Conduct WRF configuration sensitivity tests for a sample of 30 large ramp cases to determine best configuration for wind forecasting in the Tehachapi Pass area
3. **Improve NWP Data Assimilation of Local Area Data:** Implement Hybrid EnKF/GSI data assimilation approach (flow dependent data blending to more accurately spread the influence of point measurements for model initialization)
4. **Apply Latest Machine Learning (ML) Tools to NWP MOS**: Improve ability to correct regime-based systematic errors in NWP forecasts
5. **Improve Statistical Time Series Prediction for 0-3 hr Forecasts:** Exploit information in off-site data (project sensor data and non-project off-site sensors) through application of latest ML methods
6. **Improve Construction of Ensemble Composite Forecast:** Employ ML tools to construct optimal composite forecast from ensemble members

Targeted Sensor Network

- Sensors deployed at 6 targeted locations for a ~ 1-year period
- Locations/ variables measured from NWP-based forecast sensitivity experiments



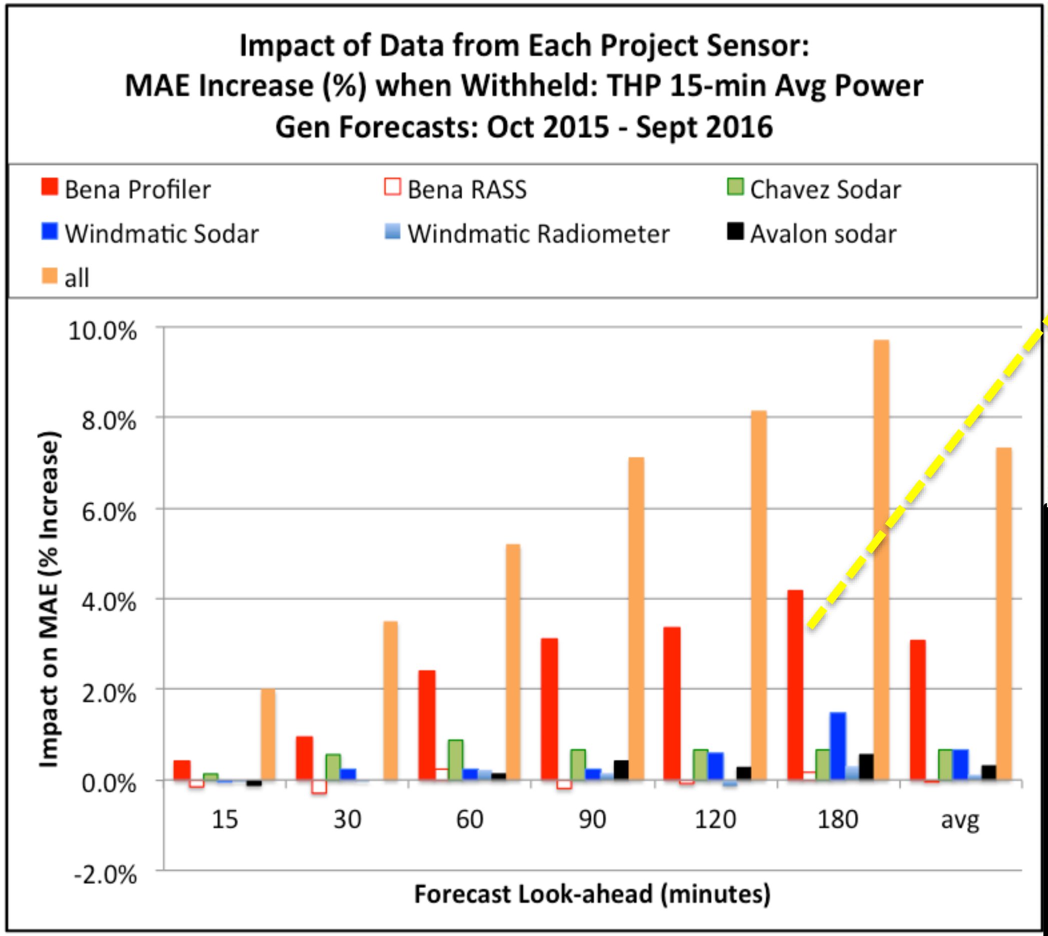
Time Series Forecasts: Impact of Advanced Machine Learning vs Linear Regression



- Advanced machine learning algorithm (XGBoost) yields better results!
  - With project data the overall 0-3 hr MAE is 16.7% lower than linear regression
  - Peak benefit is at 180 minutes
  - Minimum benefit is at 15 minutes
- **Improvement over linear regression is greater with project data (0-3 hr AVG of 16.7% versus 11.1%)**

Time Series Forecasts:
Relative Impact of Data from Each Project Sensor

AWS TRUEPOWER



- Produced forecasts with data from each sensor sequentially withheld
- Metric: % change in MAE when data from each sensor is withheld
- Wind profiler at Bena provide the most forecast value – upstream winds above Pass level

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Performance of Max/Min Ramp Event Forecasts: Critical Success Index (CSI) for Oct 2015 – Sept 2016

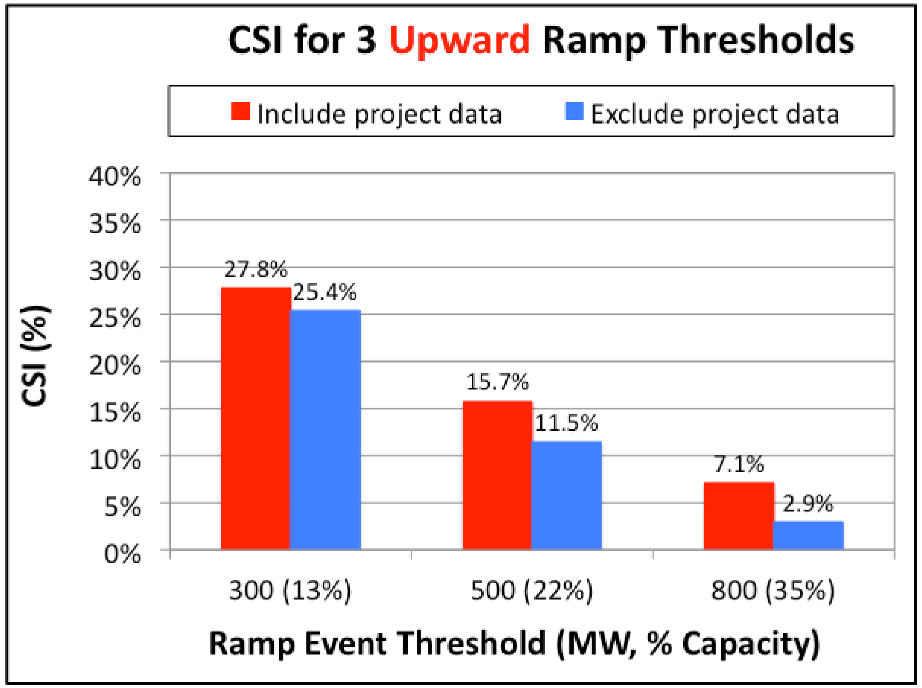
AWS TRUEPOWER

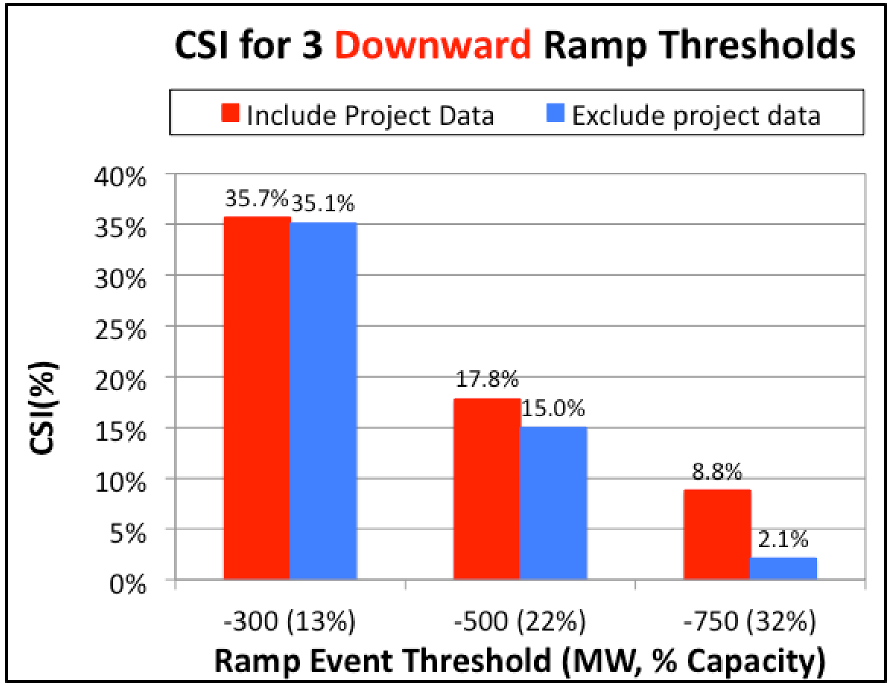
Event:

Max (upward) or Min (downward) 60-minute ramp rate exceeding specified threshold during the next 3 hrs

Metric:

- CSI = Hits /(Hits + Misses + False Alarms)
- Higher score indicates better performance





Project data provides the most benefit for the largest amplitude events

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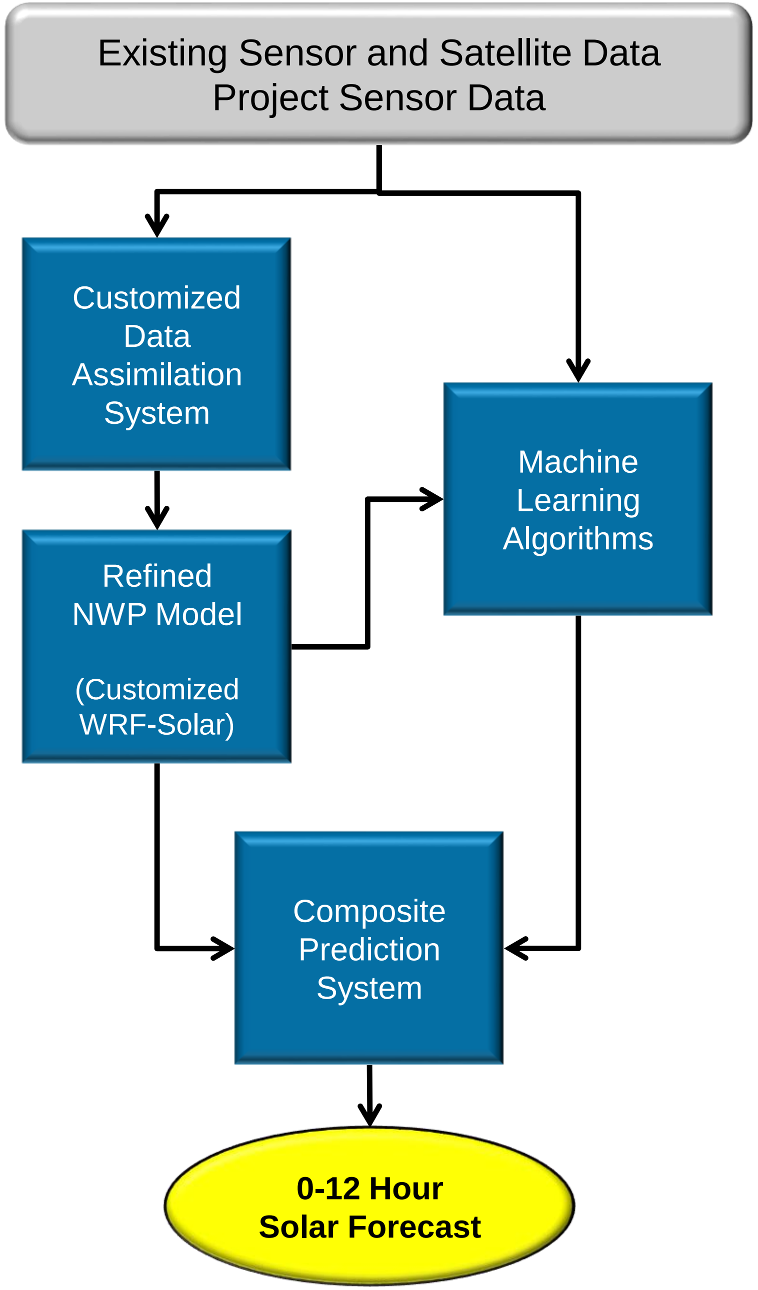
California Solar Forecast Improvements

Project Goal and Objectives

- ➢Design and deploy an instrumentation network for greater understanding of fog and stratus conditions in multiple locations across California and integrate the data from the network to improve solar forecasting

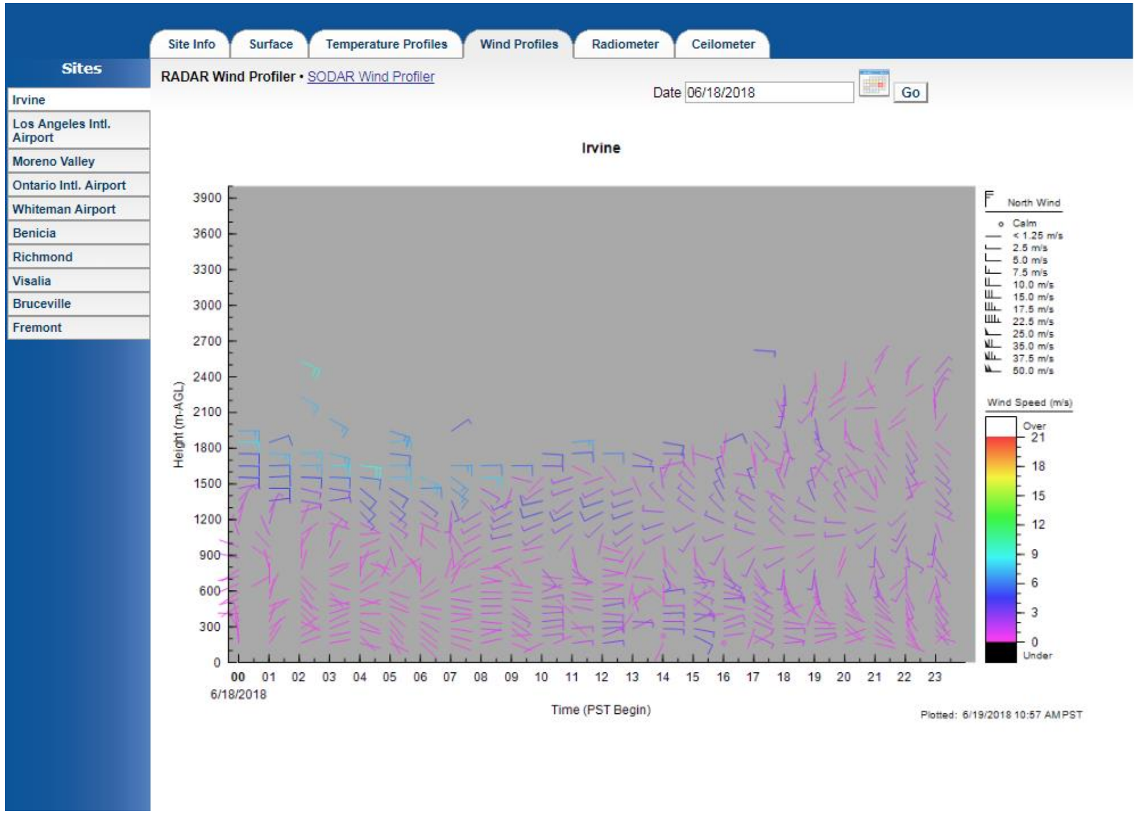
Modeling Improvement Plan

- Apply customized data assimilation methods into rapid update (1-hour cycle) Numerical Weather Prediction (NWP) model
- Perform targeted refinements of physical processes related to fog and stratus formation/dissipation in the NWP model
- Apply machine learning (ML) methods for very-rapid-update (15-minute cycle) fog and stratus prediction based on real-time sensor data
- Optimally integrate physics-based (NWP) and statistical (ML) components into a composite forecast system
- Evaluate performance of integrated system and each component relative to a pre-existing baseline forecast

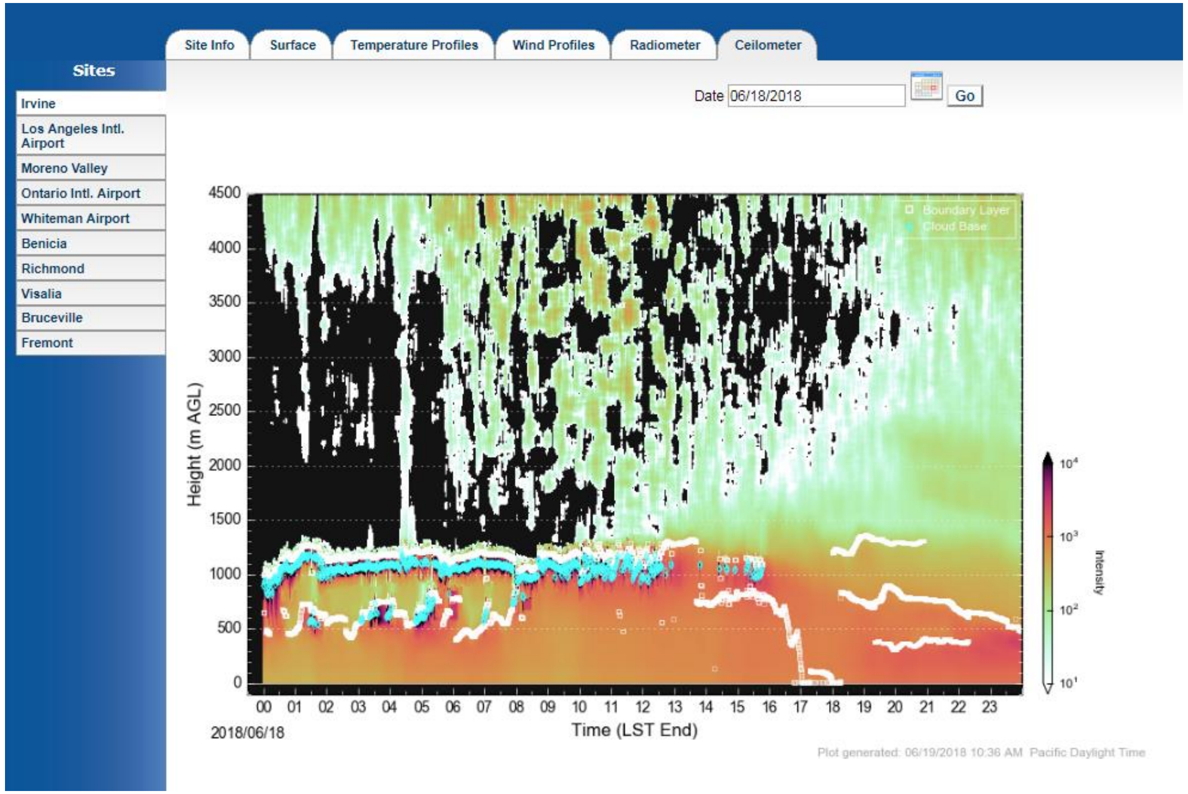


Available Information from Sensors

Radar Wind Profiler

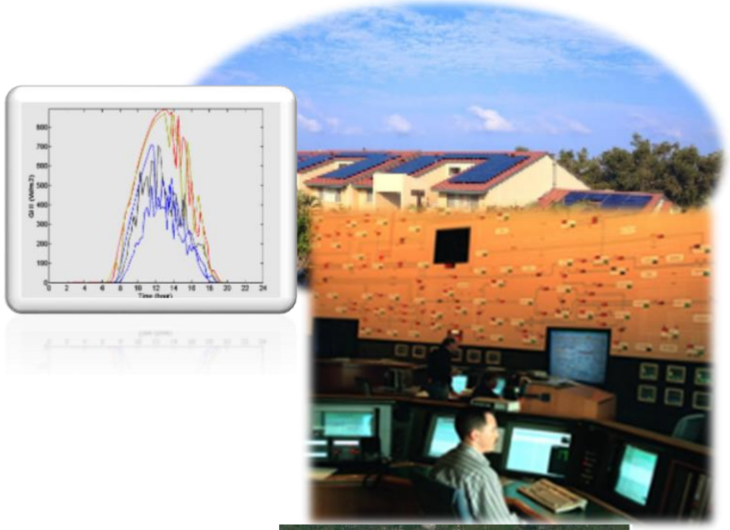


Cloud and Mixing Sites

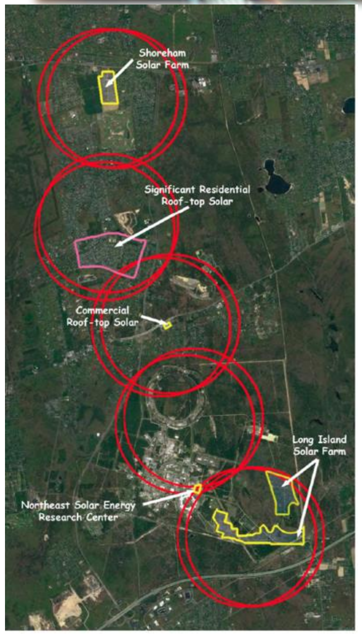


Improving Solar Forecasting Across New York State

NY Solar Forecasting Deployment & Demonstration Incorporating HD Sky Imaging



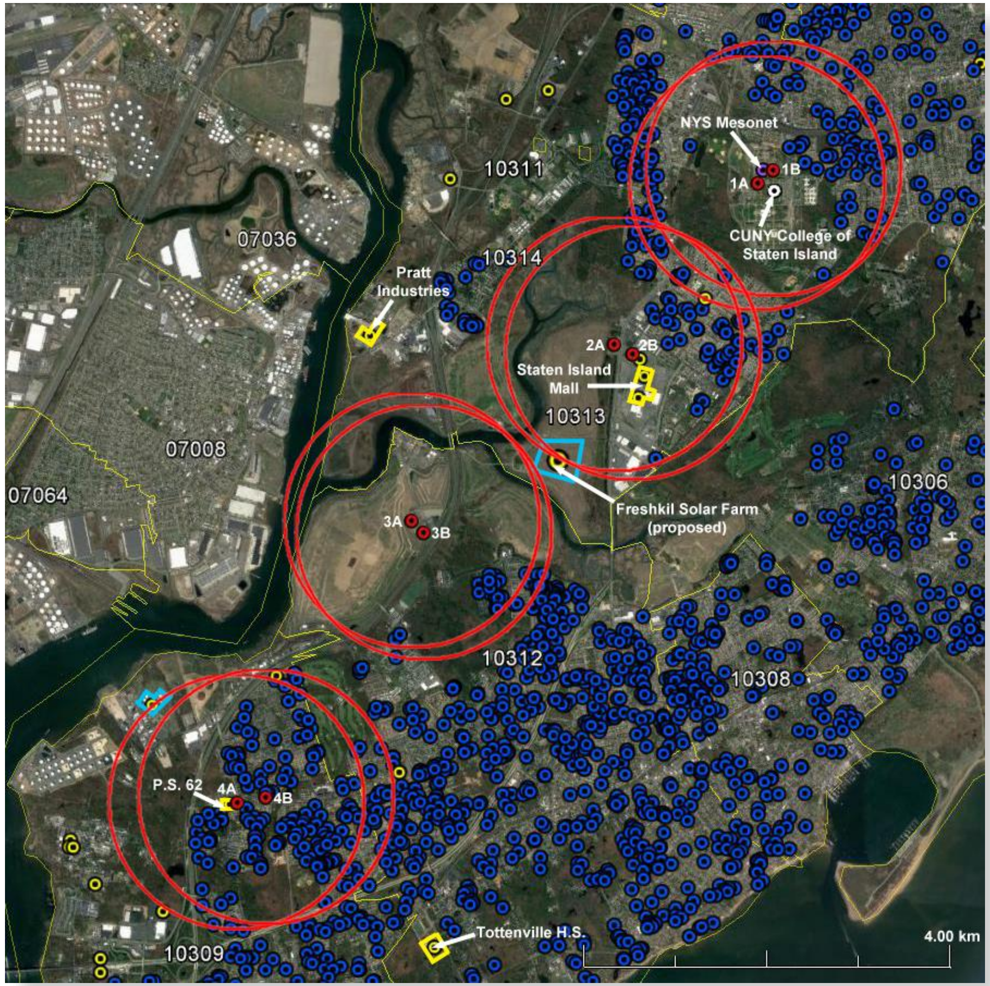
- **NYPA Initiated concept and support**
  - Partner with relevant stakeholders – NYPA, Brookhaven, NCAR, etc.
  - Looking to expand to U Albany, National Grid, NYISO, NYSERDA, etc.
  - Multiple phases employed to progress aims based on available funding
- **Project Goal**
  - Deploy networked HD Sky Imagers at multiple locations across NY state to improve short term solar, system load and building load forecasting
  - Incorporate into NCAR numerical weather based forecasting systems, and deploy these across the state, with focus on selected regions
  - Evaluate benefits to system and utility operations for solar integration, load forecasting and building load control
- **Expected Results**
  - Online forecasts & data available to utilities
  - Data/models available to commercial forecast vendors (w/license)
  - Roadmap for future NYS forecast development

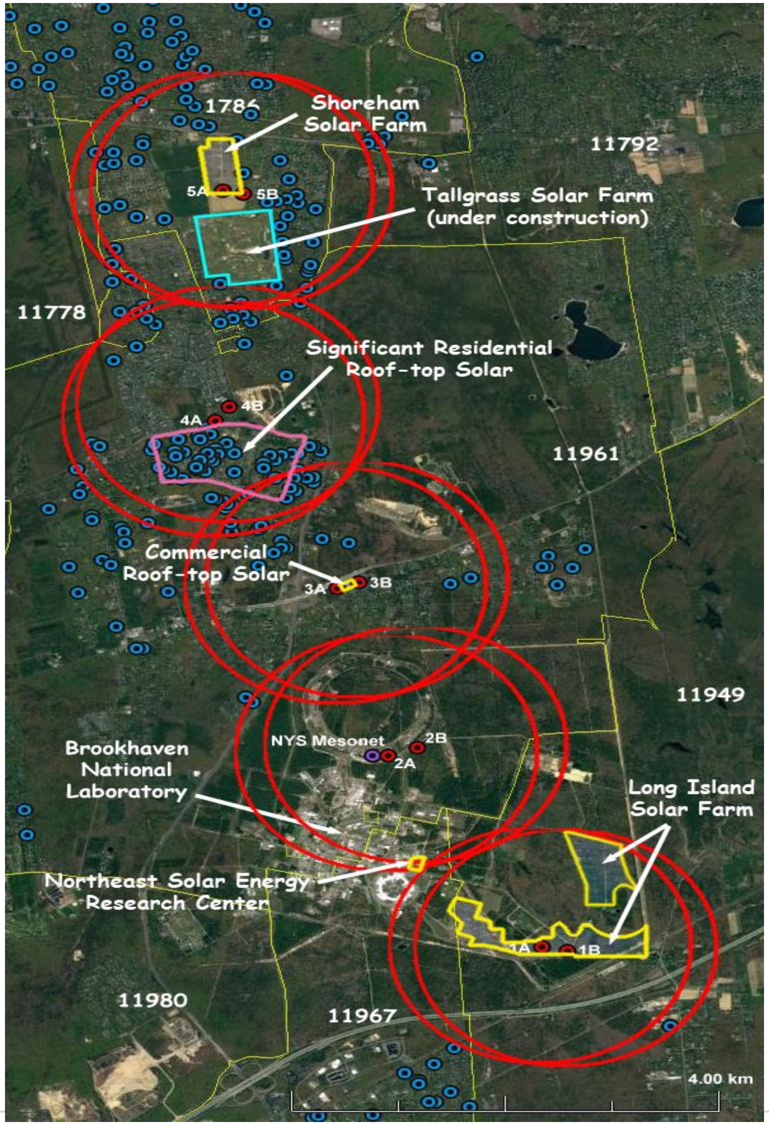


Location of Imagers

Eastern Long Island – Solar and Rooftop Solar

Staten Island – Several Large Commercial Facilities though not all residential PV





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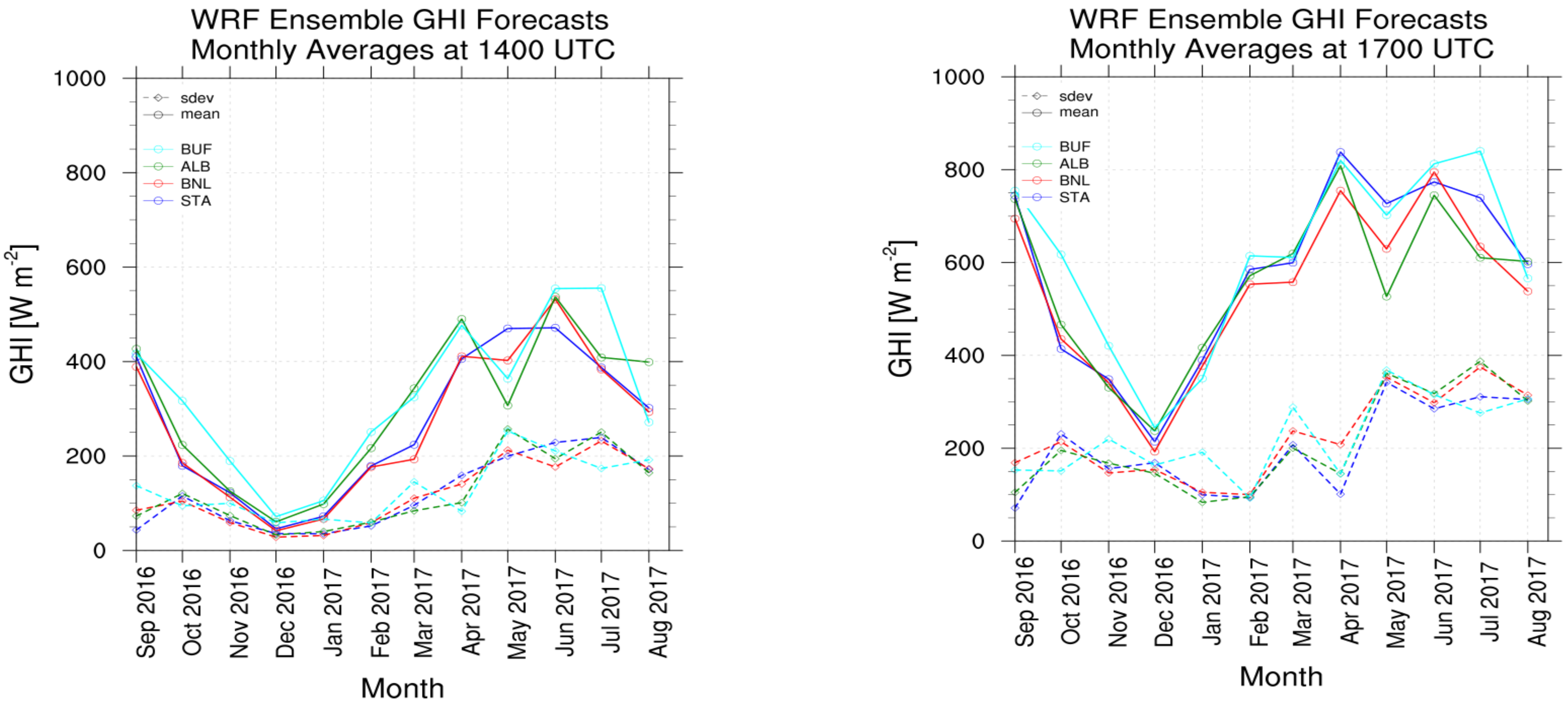
Monthly mean and standard deviation of GHI



Most parts of the state are actually pretty similar, but Buffalo in July outlier

Summary of phase I

- Data was collected from a wide range of different resources, including NYSERDA, Google Maps, and the NY State MesoNet program
- Four main regions were identified to focus on in the project
  - Includes locations where there is already significant solar (Long Island and Staten Island),
  - Providing geographic diversity to the study by adding sites away from the New York City region (Albany, Buffalo).
- Detailed design was proposed for each individual region, including locations where there may be a possibility of large building loads that could be leveraged to investigate load forecasting.
- Numerical weather modeling (the Weather Research and Forecasting (WRF-Solar®) model) was used to investigate the variability of irradiance at each of the four sites identified
  - Variability is relatively similar across each site.
  - Little variation in the variability of solar irradiance across different years when looking at the same month.
- Started looking at potential forecasts that could be deployed at utilities and NYISO, and how the would be evaluated

Conclusions and Next Steps

Value of sensors for forecasts

- Various studies have shown clear value to deployment of various types of sensors
  - Advanced, expensive equipment as well as cheaper measurements
  - Some value is not dependent on keeping in field (model improvement), other value is based on continued deployment (assimilation, time series forecast)
  - Lack of common understanding of which particular sensors, and where to locate, can provide best ‘bang for the buck’

- Specific value and improvement depends on particular area, type of forecast, etc.
  - Sufficient experience now exists that there may be value in developing common understanding and comparing different studies
  - EPRI starting to work on effort to gather data about sensor deployment and determine if there are common lessons learned and values observed
  - Aim to provide guidelines for utilities and other potential stakeholders in the value of additional sensors, and which types may be of most benefits to different end needs

- High level study focusing on major studies, with aim of general understanding of potential improvements in forecast value

Looking for feedback on experience with deployment of sensors to feed into project

General Approaches for Analyzing Value of Forecast Improvements to Operations

Operations/Markets Simulation

- Production simulation to examine impact of improved forecasts or reduction in risk/reserves
- Can look at future higher penetration systems
- Captures the interaction of forecast error and system costs or prices
- Often used in integration cost studies or similar work
- Can allow for understanding of change in system operations

Historical Data/Prices Analysis

- Examine forecast value based on prices or system lambda
- Example “What is the value of an improved forecast in my trading decisions?”
- Straightforward for lower penetrations, but may not allow interaction between wind/solar and costs to be considered
- Used by market participants to look at revenues
- Doesn’t capture impact of forecast error on prices/costs

Conclusions

- Experience with wind forecasting at Tehachapi and other studies shows significant improvement in NWP and in time-series prediction using sensor data
- Similar approach currently underway in California, with results expected later in year and in 2019 – initial deployment shows some promise in approach
- Efforts underway to provide platform for solar forecasting improvements in New York state, based on mix of sky imaging and deployment of WRF-Solar
- Starting to gather general experience on use of sensors and additional data sources – will allow for improved understanding when developing new wind and solar, and integrating forecasts
- Still need to determine ongoing cost recovery to keep some of these instrument networks in the field – challenging to recover costs under current paradigm

Together…Shaping the Future of Electricity

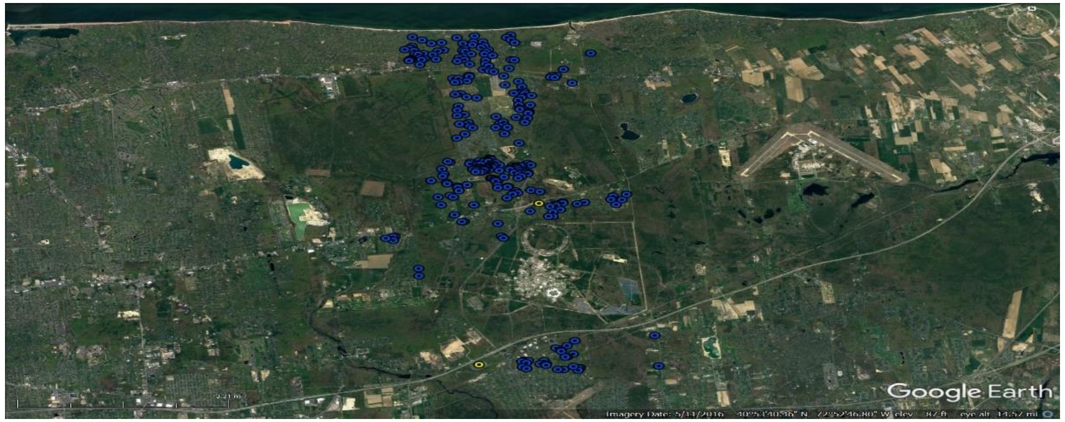
Phase 1 - Regions Chosen (2 of 4 regions shown)

Staten Island

- Currently 41 MW in dense network of distributed resources
- Enhanced MesoNet at CUNY Staten Island
- No major solar facility at present, though potential for development

Eastern Long Island

- Largest capacity of rooftop solar – 156 MW
  - 26 MW commercial, 130 MW residential
- Also significant utility scale PV
  - Long Island Solar Farm at BNL (32 MW)
  - Number of other 5 MW to 20 MW sites

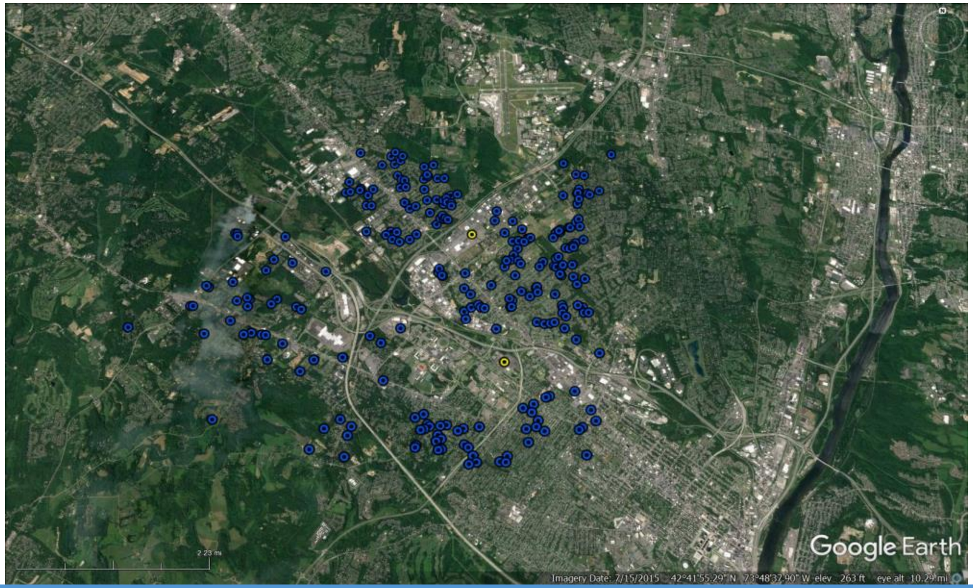


Both of these locations will be near Atlantic Ocean with sea breezes making cloud forecasting ore challenging and good area for forecasting (other locations described in appendix)

Regions chosen (2)

Albany

- 27 MW moderate solar penetration
- Mostly residential
- University of Albany is home of MesoNet, and has a focus on solar R&D



Buffalo

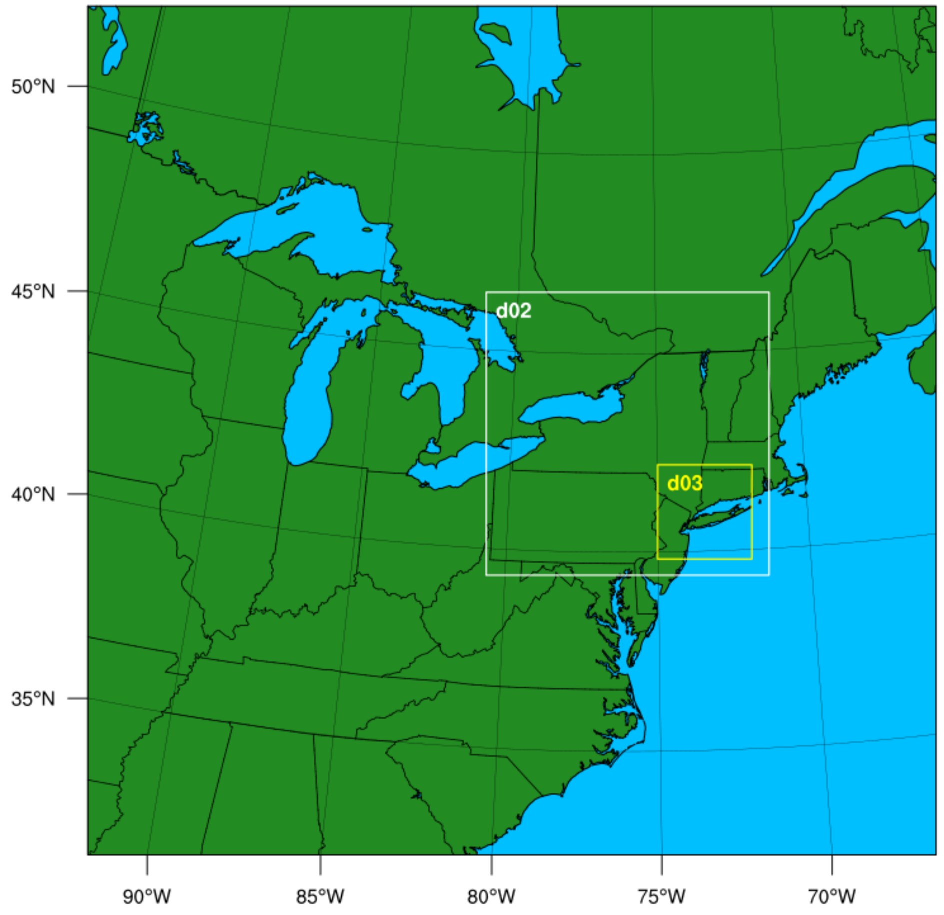
- 31 MW of solar PV
- Largest solar PV manufacturing facility
- Lake effect will be significant

Albany will give location for central NYS, with Buffalo demonstrating forecasts for lake effect

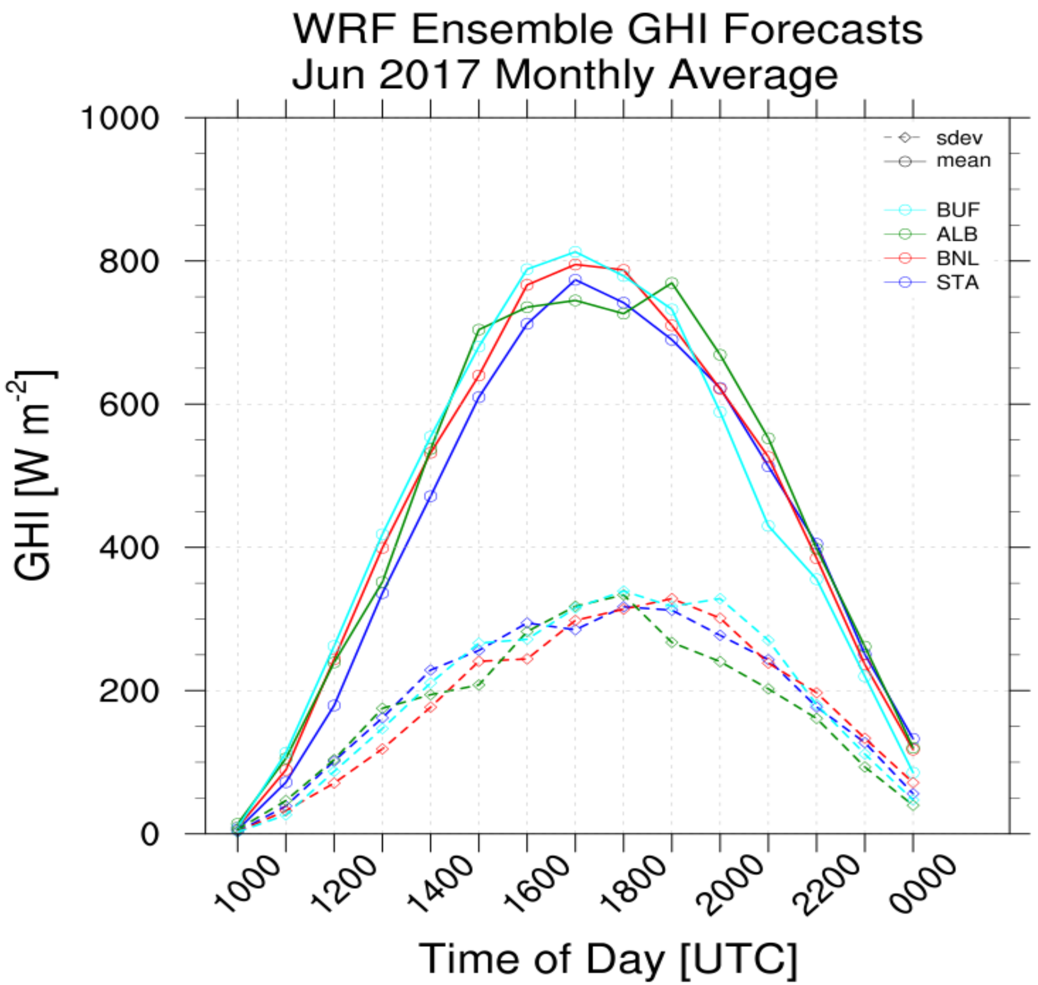
Numerical Weather Model Study of Solar Variability

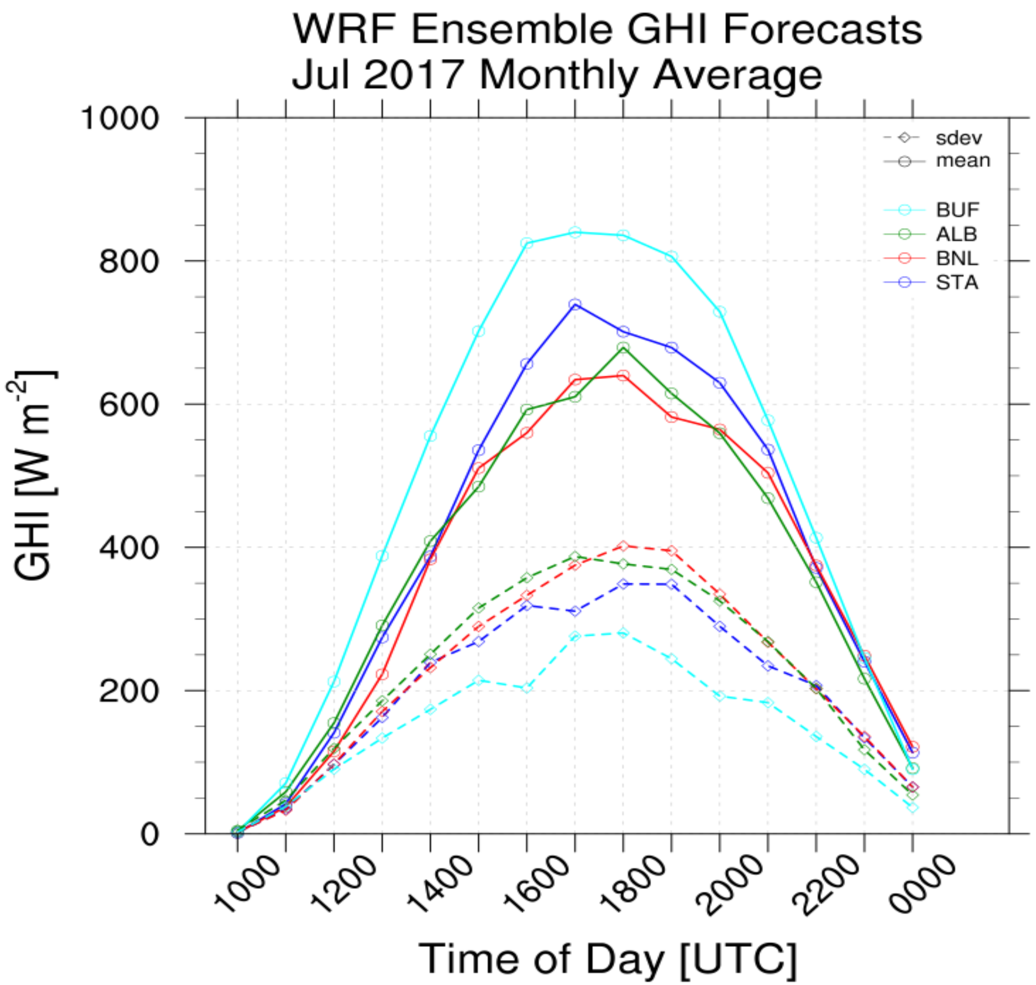
- NCAR led task to support site selection by understanding variability of the solar resources
- Variability at multiple regions assessed by running ensembles of Numerical Weather Prediction (NWP) models
  - Weather Research and Forecasting (WRF) model, enhanced for solar in recent DOE funded project
  - 10 members of the ensemble
  - One day per week over one year from Sept 2016-August 2017
- Also used BNL observational data

WPS Domain Configuration



Average for mean and standard deviation





Very similar results here (except for Buffalo in June) show that variability is typically similar across state, even with different weather regimes – forecasting may be similar value in all