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

SOLAR ENERGY TECHNOLOGIES OFFICE

DOE Solar Forecasting Program Update

2020 Meteorology & Market Design for Grid Services Workshop

Dr. Tassos Golnas, Technology Manager, SETO

Solar Energy Technologies Office

WHAT WE DO

The Solar Energy Technologies Office (SETO) funds early-stage research and development in three technology areas: photovoltaics (PV), concentrating solar-thermal power (CSP), and systems integration with the goal of improving the **affordability**, **performance**, and **value** of solar technologies on the grid.

HOW WE DO IT

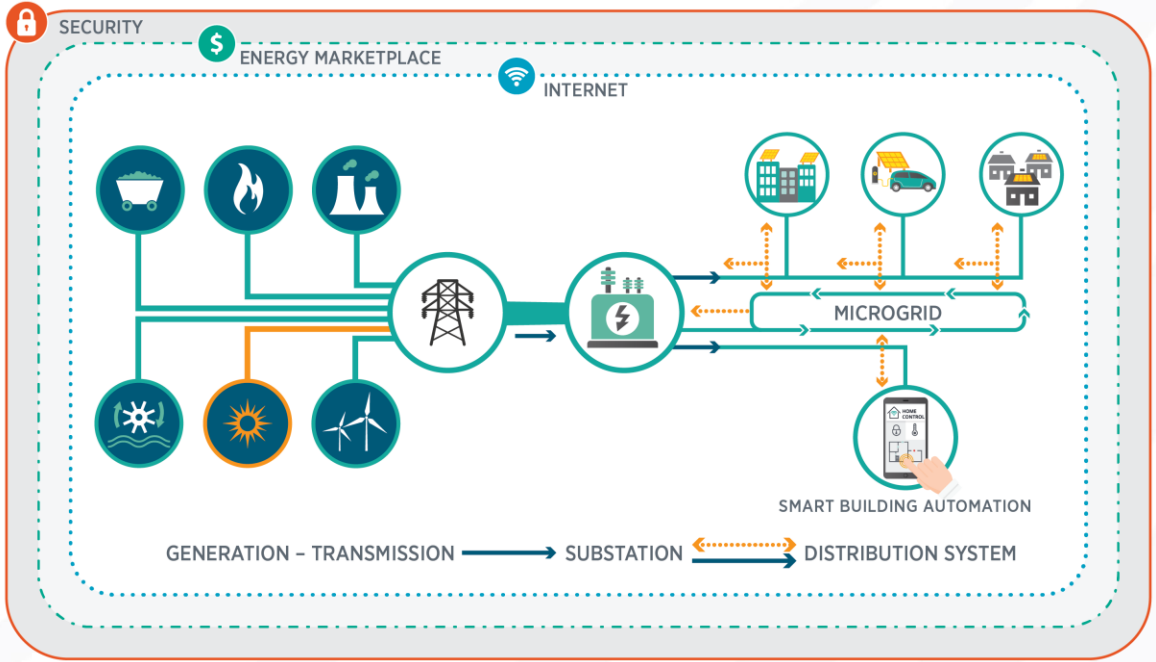
Advance solar technology to drive U.S. leadership in innovation and reductions in solar electricity costs.

Enable solar to **support grid reliability** and pair with storage to provide new options for **community resilience.**

Provide **relevant and objective technical information** on solar technologies to stakeholders and decision-makers.

Systems Integration Subprogram

- Funds projects to develop technical solutions that enable large scale deployment of solar power onto a modernized electricity grid with improved reliability and resilience
- Part of DOE's Grid Modernization Initiative

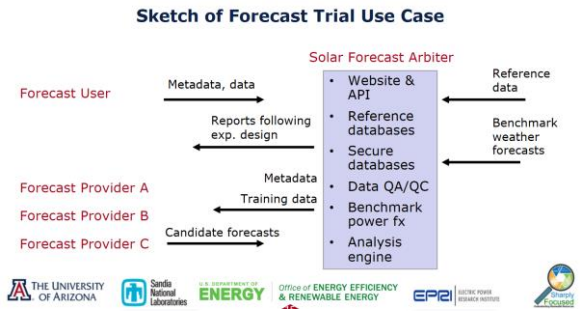


- Solar Forecasting
- Grid Planning and Operation
- Power Electronics
- Integration with Energy Storage
- Codes and Standards
- Sensors and Communications
- Grid Integration Analysis

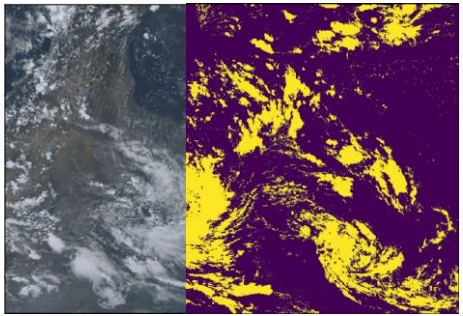
Forecasting: Knowing is half the battle

- Variability and uncertainty raise the cost of integration
- Forecasting seeks to minimize uncertainty, allowing variability to be tackled with tariffs, transmission, storage
- 8 projects from Solar Forecasting II FOA

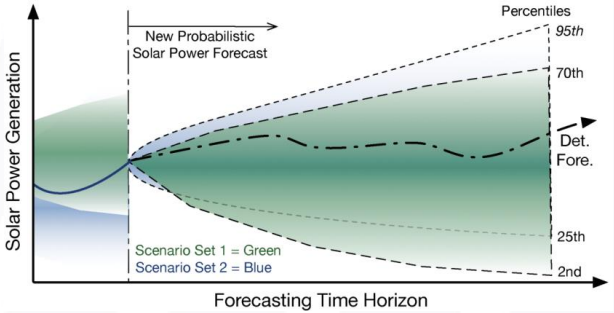
- Evaluate



- Improve radiation forecast

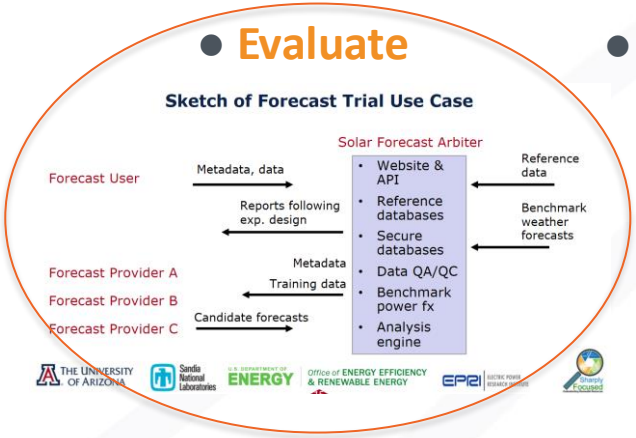


- Improve reserve calculation

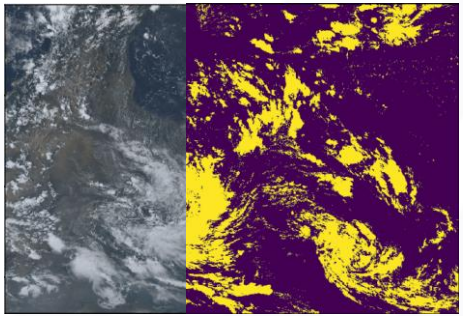


Forecast Evaluation

- **Evaluate**



- Improve radiation forecast



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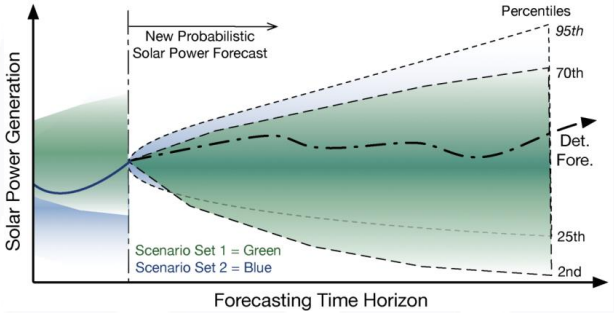
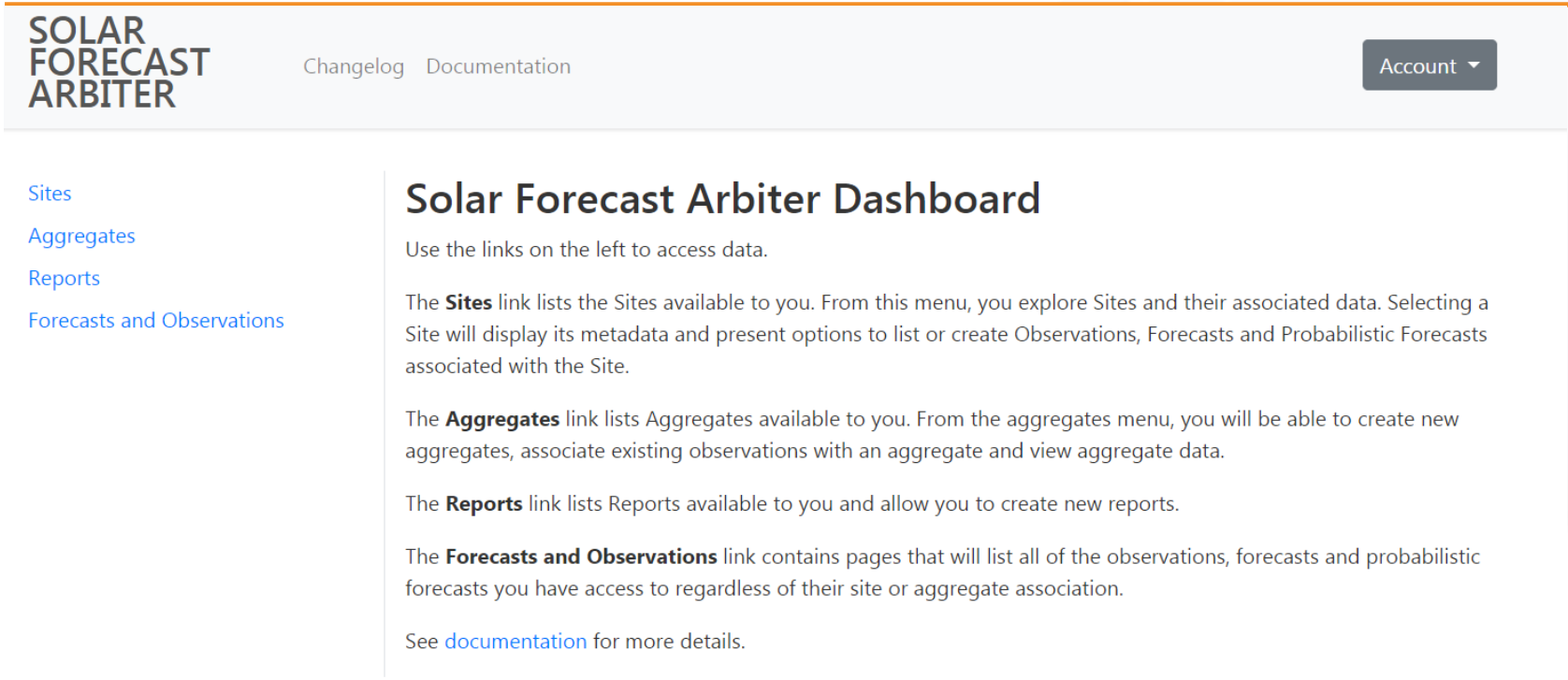


TA1: U. Arizona (Sandia, EPRI, Sharply Focused) – PI: Will Holmgren

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

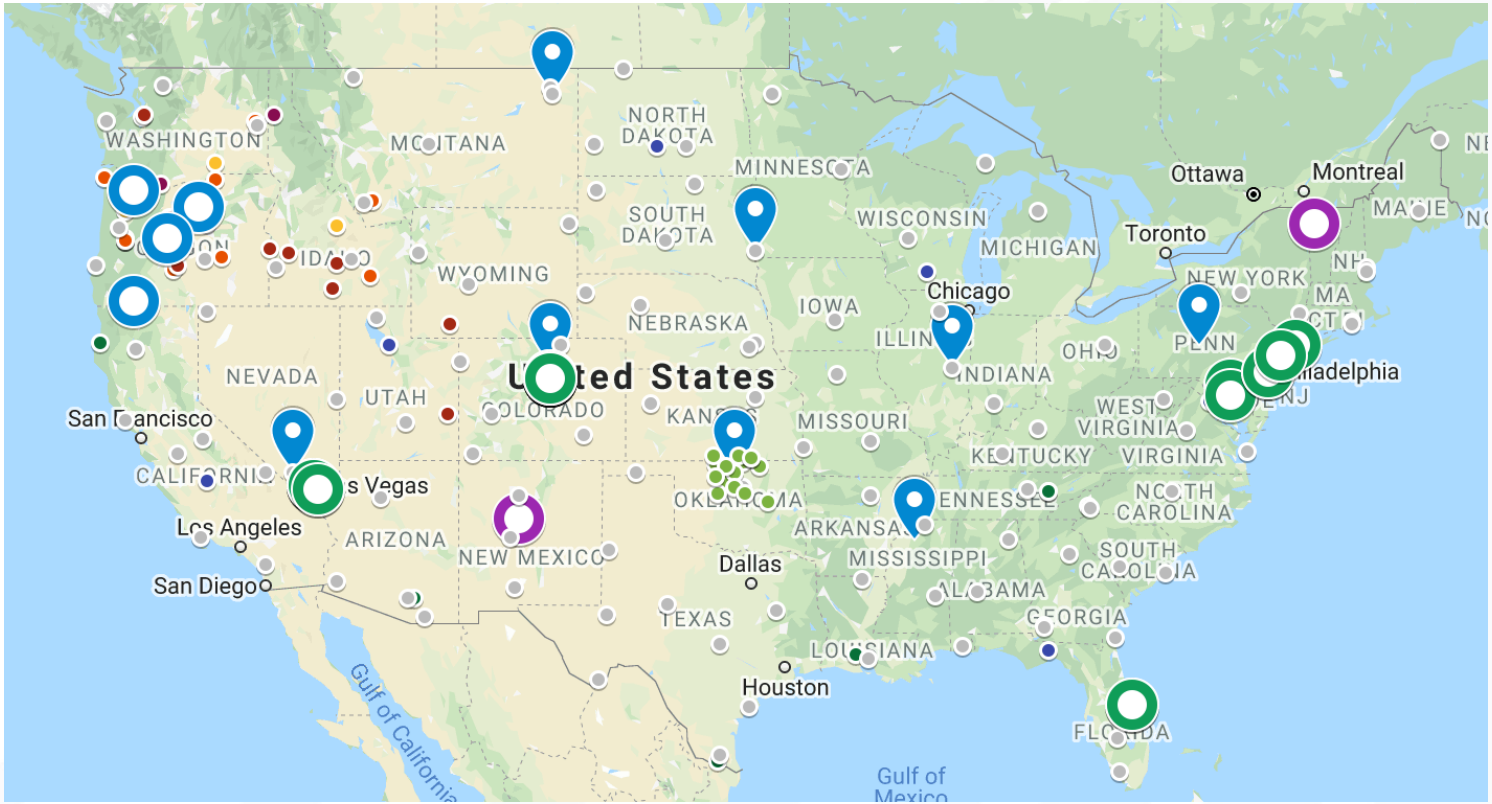
- Implement **objective, consistent evaluation scenarios and metrics** → better solar forecasts
- **Standardize evaluations** → reduce provider and user costs
- Develop **user confidence in solar forecasts** → system integration
- Easily **extend to wind power and load forecasting**

SolarForecastArbiter.org



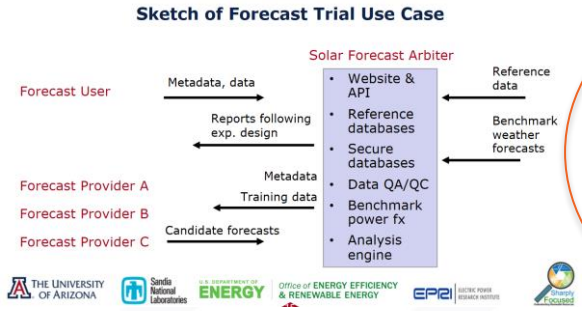
Contact Will at Holmgren@Arizona.edu to learn about the upcoming forecast trials

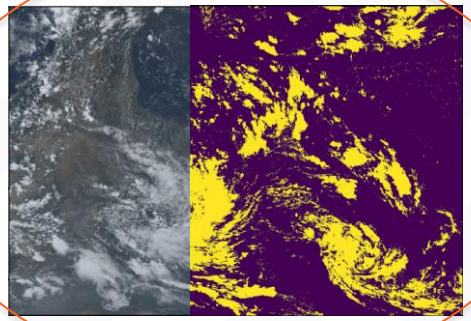
Reference observations of irradiance and power

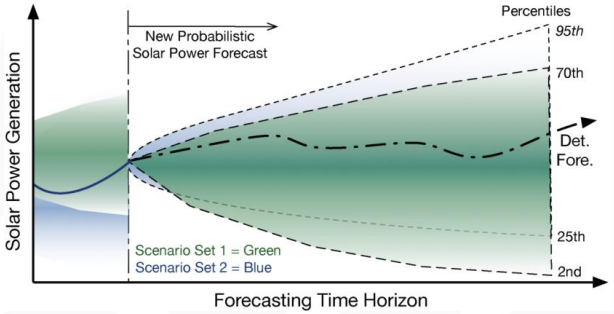


Radiation Forecast Improvement

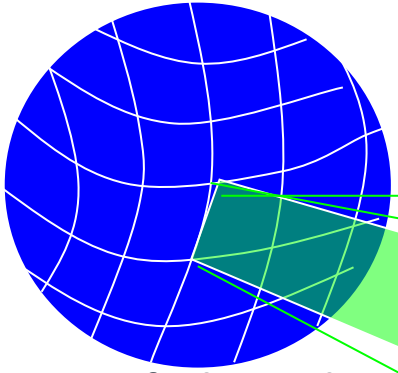
- Evaluate
- **Improve radiation forecast**
- Improve reserve calculation





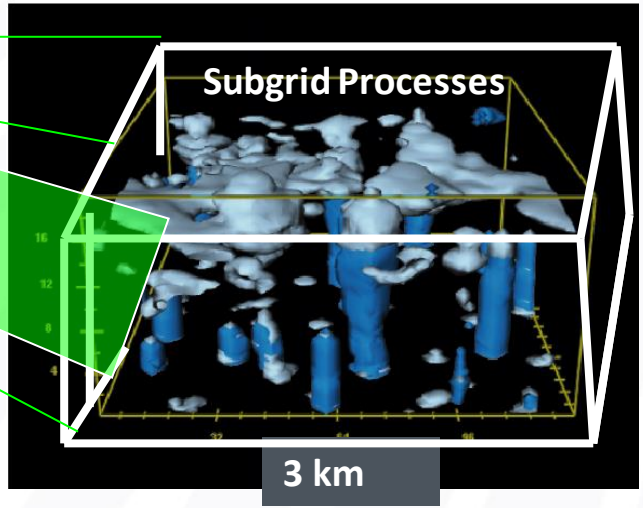


TA2: BNL (+NREL, SUNY) – PI: Yangang Liu



$$\frac{dX}{dt} = \text{Dynamics} + \text{Fast Physics}$$

(Resolved) (Unresolved/Subgrid)



- Accurate forecast of solar irradiances (e.g., GHI and DNI) in cloudy conditions is critical to grid integration and management;
- NWP forecast is complementary to observation-based forecast & WRF-Solar is a state of science NWP model;
- WRF-Solar suffers from serious deficiencies in representation of cloud microphysics and radiative transfer;
- Analysis and Identification of physical sources underlying model deficiencies are also challenging.

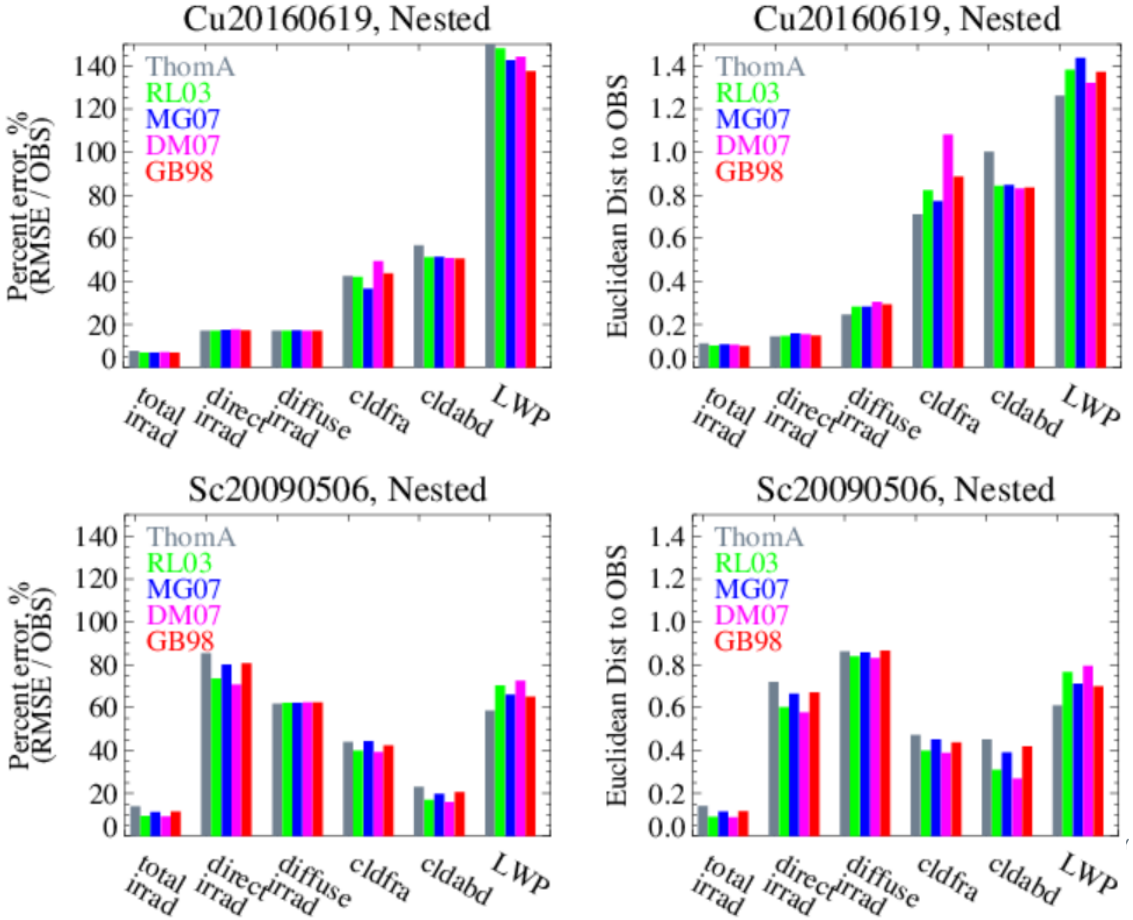
Fast physics is critical for Topic Area 2; its parameterization is largely responsible for model deficiencies.

TA2: BNL – New microphysics parametrizations

Comparison of new parametrizations (colored bars) against baseline (WRF-Solar v1)

Top: Cumulus clouds (Cu)

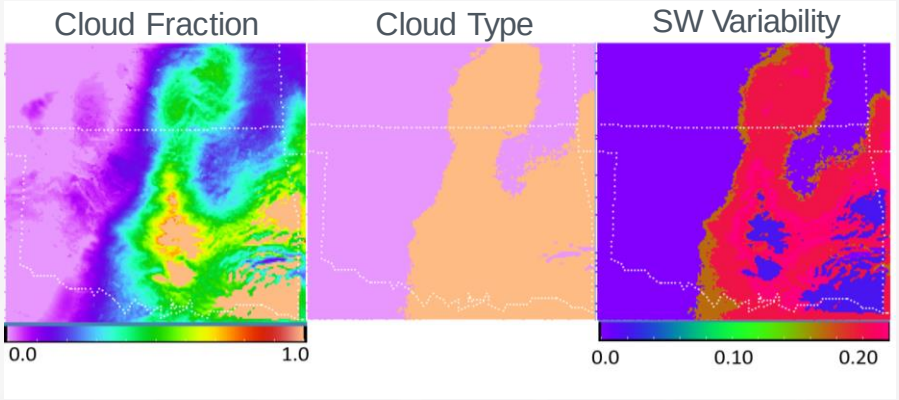
Bottom: Stratocumulus (Sc)



TA2: PNNL (+NCAR, Vaisala, NOAA) – PI: Berg

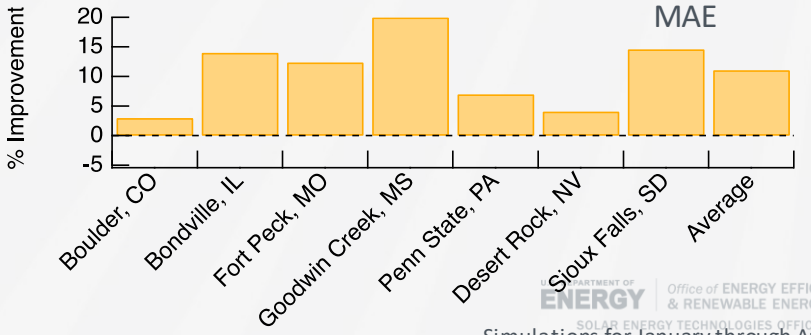
Variability

- Developed relationship between cloud types, cloud cover and shortwave variability using data from DOE ARM sites using machine learning techniques
- Implementing parameterization in WRF-Solar



Cloud microphysics

- Improved treatment of mixing in clouds
- New treatment accounting for microphysics of sub-grid clouds
- Greater impact in winter and early spring



Simulations for January through April 2018

TA2: NREL (+NCAR) – PI: Sengupta

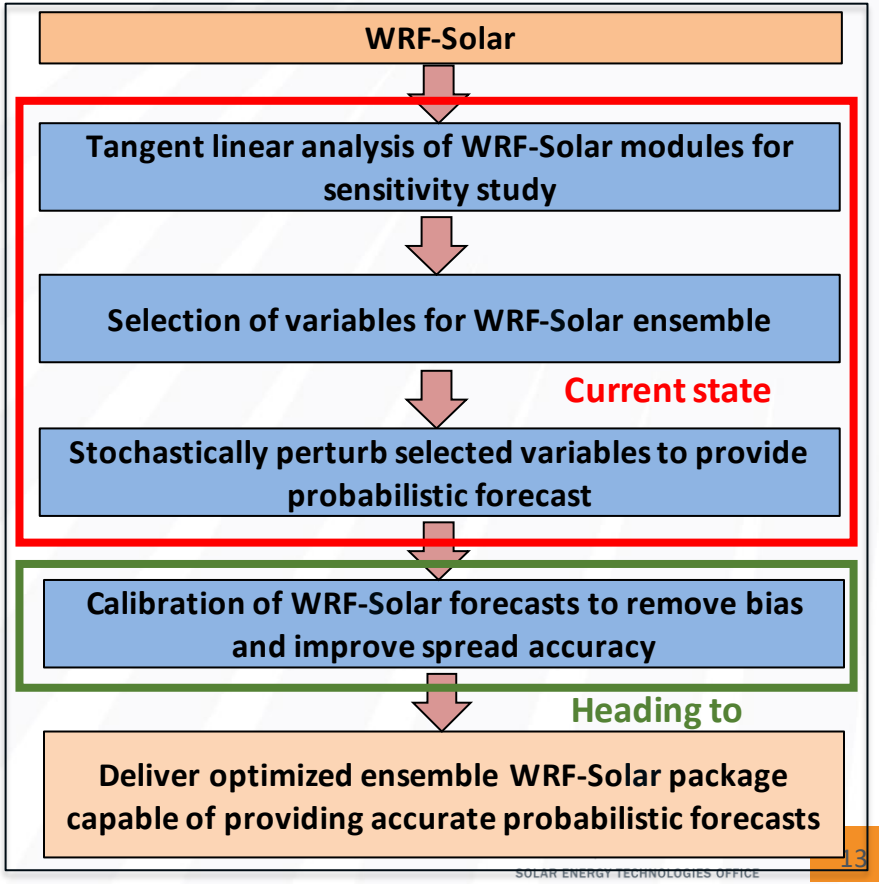
•Identify variables that significantly influence the formation and dissipation of clouds and solar radiation through a **tangent linear analysis** of WRF-Solar modules that influence cloud processes.

•Consolidate the variables identified in step (a) to develop the **WRF-Solar ensemble** forecasting system.

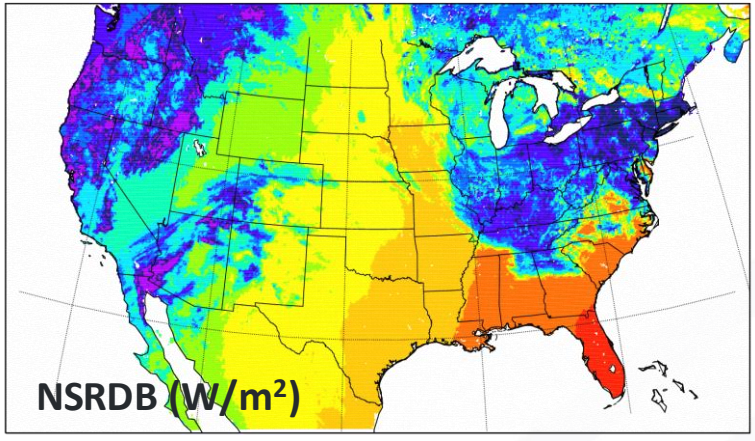
•**Calibrate the WRF-Solar ensemble system** using measurements to ensure that the forecasts' trajectories are unbiased and provide accurate estimates of forecast uncertainties under a wide range of meteorological regimes.

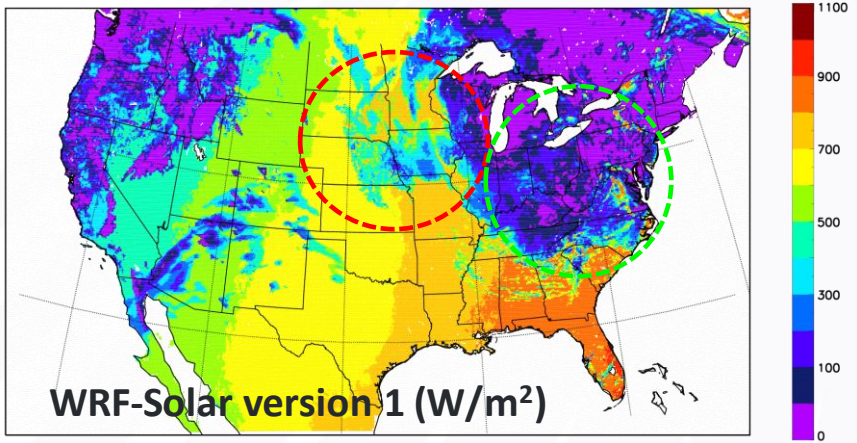
•**Demonstrate the improvements** delivered by the probabilistic forecasts for the regions and locations identified by Topic Area 1.

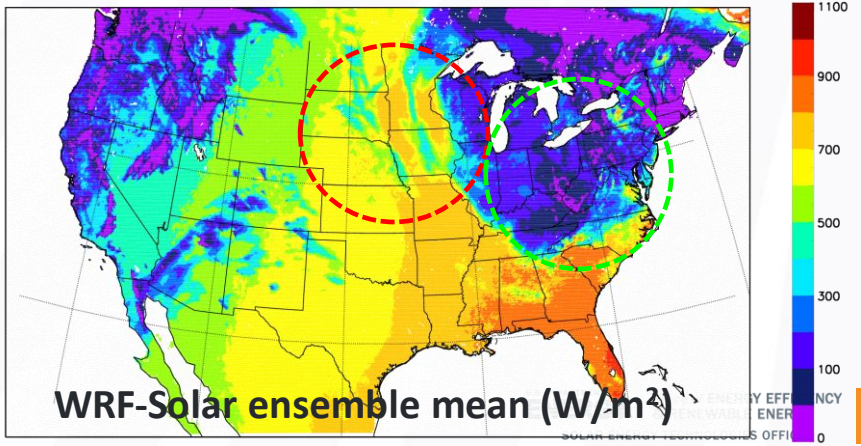
•Develop and deliver an **open-source probabilistic WRF-Solar system** for the solar energy community.



TA2: NREL – Evaluation of WRF-Solar Ensemble using NSRDB



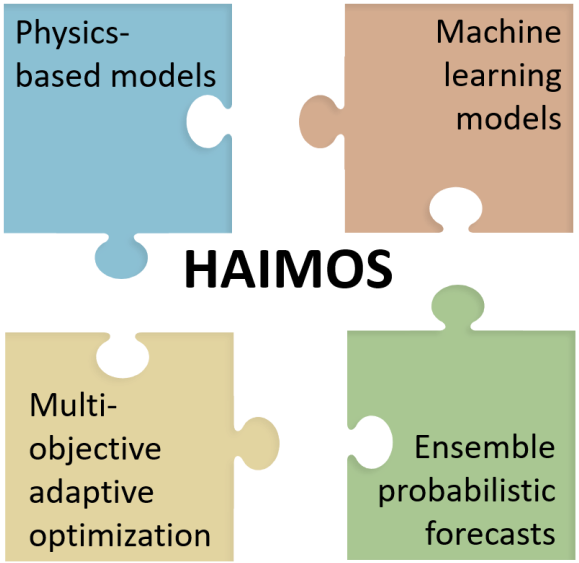




- Initialized at 06 UTC 15 April 2018
- 1530UTC April 16 2018
- 33.5 hours forecast

✓ **Cloud distributions from WRF-Solar ensemble show improvements in representing clouds that are seen in the NSRDB observations.**

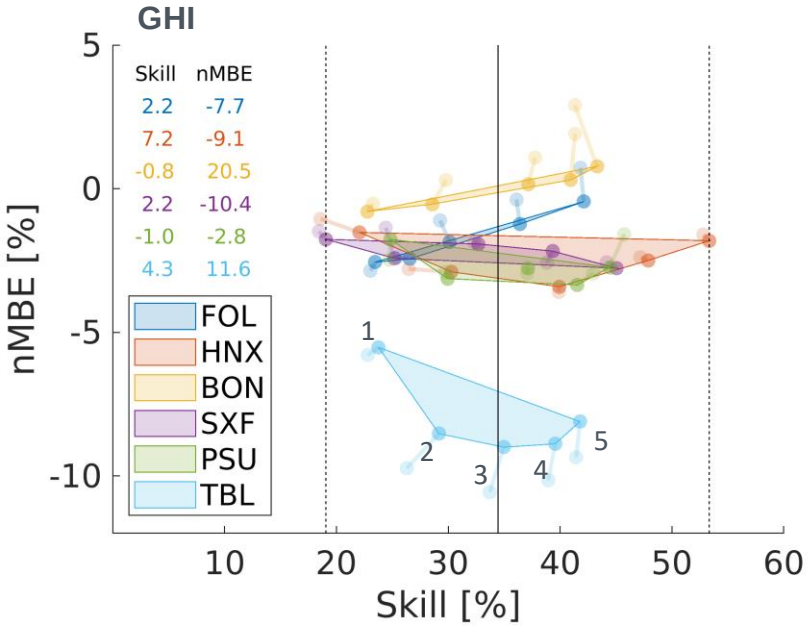
TA2: UCSD(+CPR) – PI: Carlos Coimbra



- Combines innovations in **machine learning** algorithms (deep-learning, feature engineering, etc.) with detailed **physics-based models** for cloud cover and cloud optical depth forecasts.
- Integrates information derived from the **new GOES satellites sensors and cloud cover simulations from LES**.
- Spatial and temporal sensing/modeling of clouds at much higher resolutions than previously available.

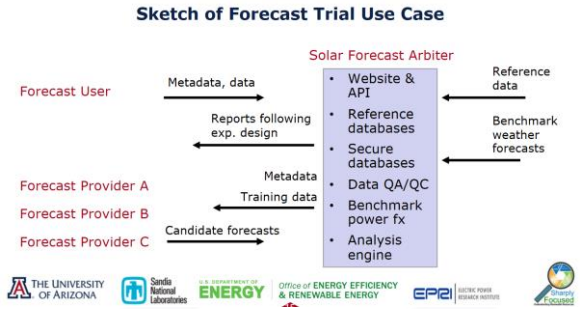
Improvement of forecast skill (preliminary results)

- Bias and forecast skill for GHI for six locations and forecast horizons ranging from 1 to 5 hours.
- On average HAIMOS can achieve a forecasting skill ~35% across different climate zones and forecasting horizons
- Adaptive protocols for HAIMOS resulted in higher forecasts skills.
- Improvements depend on the local irradiance variability (they are not uniform)
- Needs further study

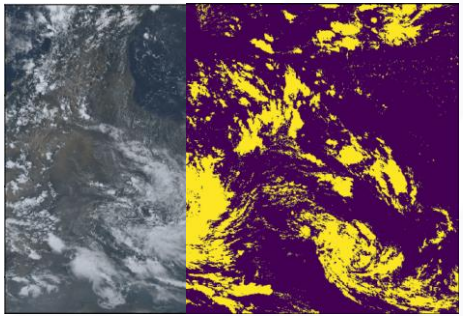


Reserve Calculation Improvement

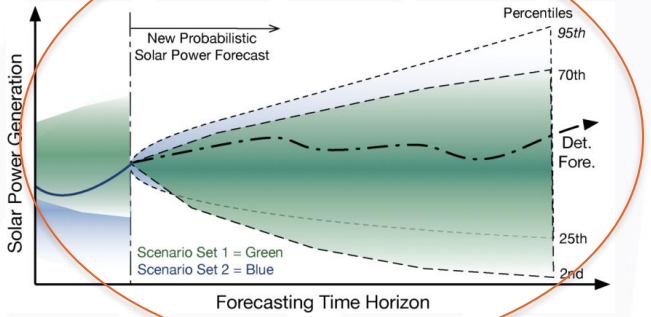
- Evaluate



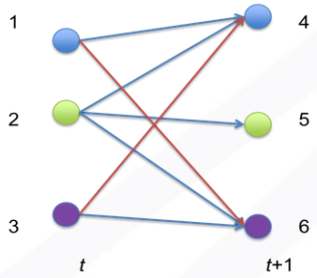
- Improve radiation forecast

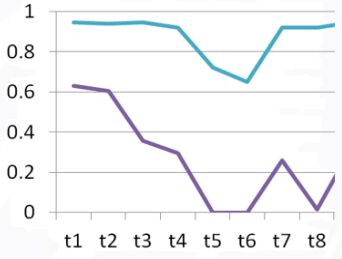


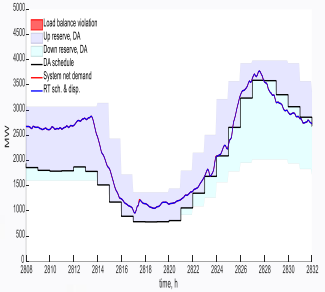
- **Improve reserve calculation**



Using Advanced Methods for Operating Systems With Uncertainty





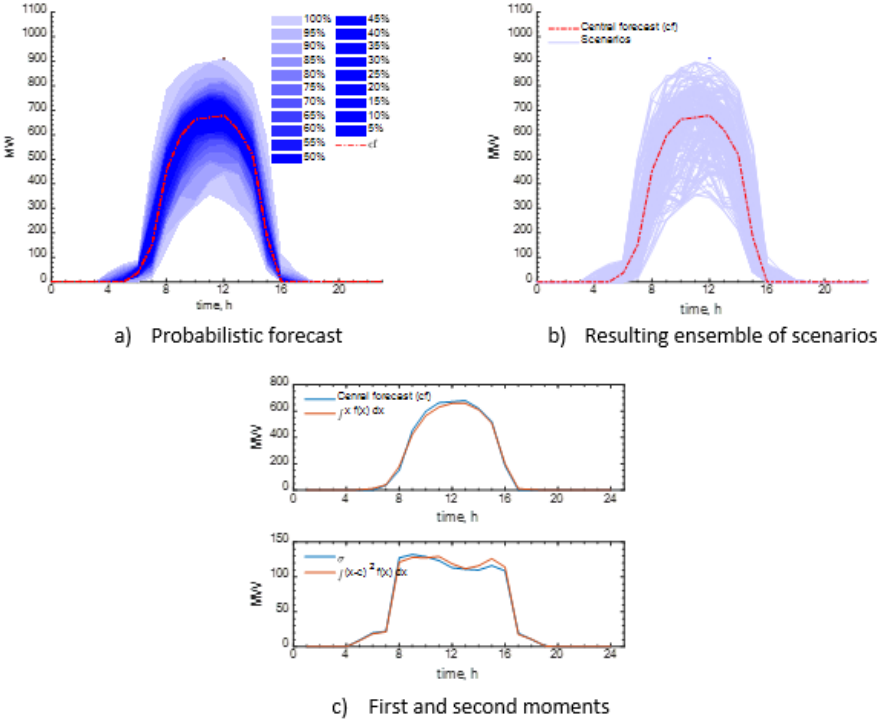


	Stochastic UC	Interval UC	Robust UC	Dynamic Reserves
Uncertainty Model	Scenarios	Inter-temporal rates	Uncertainty range	Requirements
Objective	min E{cost}	Minimize cost to meet central forecast	min{max{min *f*}}	Minimize operating cost to meet forecast
Security	Depends on the scenarios	Inter-temporal ranges	Uncertainty Budget	Confidence interval
Scalability	Low	High	Variable (high)	High

Can we use other methods to deal with uncertainty/variability?

TA3: EPRI (+UL, Virginia Tech) – PI: Aidan Tuohy

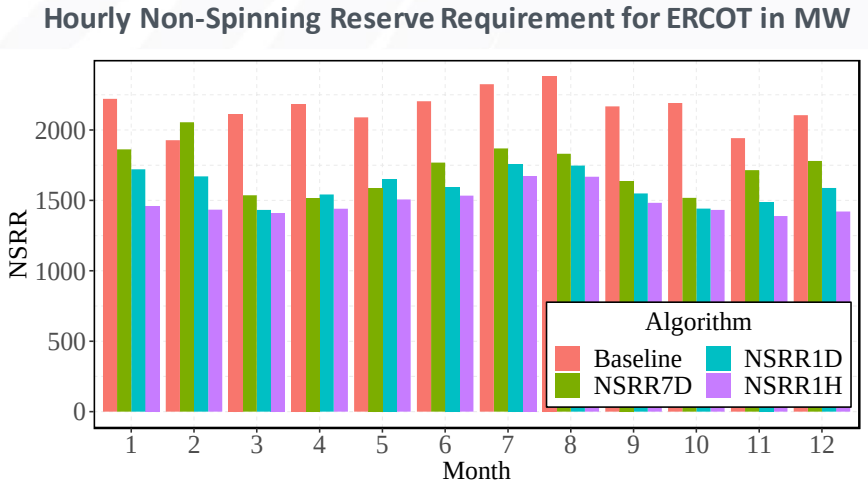
- **Probabilistic forecasts being delivered to all utility partners** (Duke Energy, HECO, Southern Company)
- Detailed **operational simulation tools** setup for each partner
- Methods to use **probabilistic methods to calculate operating reserve requirements** are being setup
- Simulations will be done to investigate benefits of different use of forecasts



Statistics of the probabilistic forecast and resulting ensemble of scenarios

TA3: NREL (+Maxar, UT Dallas, ERCOT) – PI: Bri-Mathias Hodge

- **Real-time probabilistic forecasts** at 5-minute and hourly resolutions **are being provided to ERCOT** for all operational **utility-scale solar plants**
- ERCOT's system is undergoing **upgrades to ingest probabilistic information**
- **New adaptive reserves and economic dispatch algorithms** are prepared for testing under high solar penetrations
- SolarView **situational awareness tool** is prepared for beta testing



TA3: JHU (+IBM, NREL, UTD, MISO, CAISO) – PI: Ben Hobbs

How to develop a procurement solution for a **dynamic reserves product** that is based on **probabilistic forecasts** and that **ISOs can adopt**!

Regular ISO interactions with operations, markets and forecasting teams

- NDA in place with CAISO and initial data received to make the analysis relevant.
- Periodic discussions (@monthly to quarterly frequency) on market assumptions and project findings.

Customized probabilistic forecast integration for flexible ramping requirement estimation

- Each ISO have subtle differences in how flexibility (or reserve) products are produced.
- Model-based (Bayesian) and data-driven approaches investigated to relate probabilistic forecasts to required ramp flexibility at each ISO.

Solutions

Large CAISO-scale system simulation

- Leveraging industry vetted models from past projects, with ongoing efforts to reduce the system size from ~5k nodes to ~1.8k nodes, and validate the outputs.
- Improving solve times for multi-period market runs, including day-ahead SCUC, 15-min. real-time market (with 15-min SCUC and 5-min SCED).

Forecasts tailored to the ISO footprint

- Development of probabilistic forecast raster for the ISO footprint to link with solar plants at proximity.
- Stretch goals of developing an even higher spatial resolution forecasts to estimate the impact of distributed resources on the net-load forecasts.

What's next in solar forecasting?

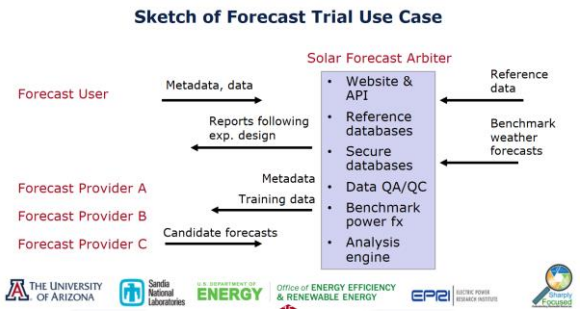
- Long-term insolation forecasting (4+ days)
- Net-load forecasting parity (2% hourly MAPE for day-ahead)

FOA 2243

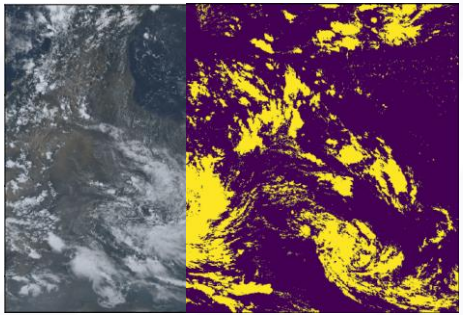
- Variability (volatility) forecasting?
- Microphysics for aerosols and two-phase clouds?
- Integrated models for wind, solar, hydro?
- Forecasts for microgrids and grid services?
- Pushing R&D results to operations (NWS forecasts, Balancing Authorities)?

Informed by recent RFI

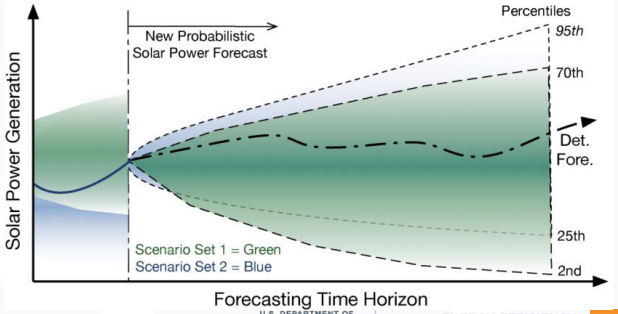
Model Validation



Scientific R&D



Grid Operations



Solar Forecasting II Projects

Topic Area	Recipient Name	Project Title	PI Name
1	University of Arizona	Open Source Evaluation Framework For Solar Forecasting	William Holmgren
2	BNL	Advancing The WRF-Solar Model To Improve Solar Irradiance Forecast In Cloudy Environments	Yangang Liu
2	PNNL	Development Of WRF-Solar V2: Improving Solar Forecasts	Larry Berg
2	NREL	Probabilistic Cloud Optimized Day-Ahead Forecasting System Based On WRF-Solar	Manajit Sengupta
2	University of California, San Diego	HAIMOS Ensemble Forecasts For Intra-Day And Day-Ahead GHI, DNI And Ramps	Carlos Coimbra
3	EPRI	Probabilistic Forecasts And Operational Tools To Improve Solar Integration	Aidan Tuohy
3	NREL	Solar Uncertainty Management And Mitigation For Exceptional Reliability In Grid Operations (SUMMER-GO)	Bri-Mathias Hodge
3	Johns Hopkins University	Coordinated Ramping Product And Regulation Reserve Procurements In CAISO And MISO Using Multi-Scale Probabilistic Solar Power Forecasts	Ben Hobbs

Thank you!

Please enter any questions in the chat box.

For FOA 2243 questions please email seto.foa@ee.doe.gov

For program questions email Tassos.Golnas@ee.doe.gov