SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

Overview of DOE Solar Forecasting II FOA

ESIG Forecasting Workshop

June 2018

Tassos Golnas

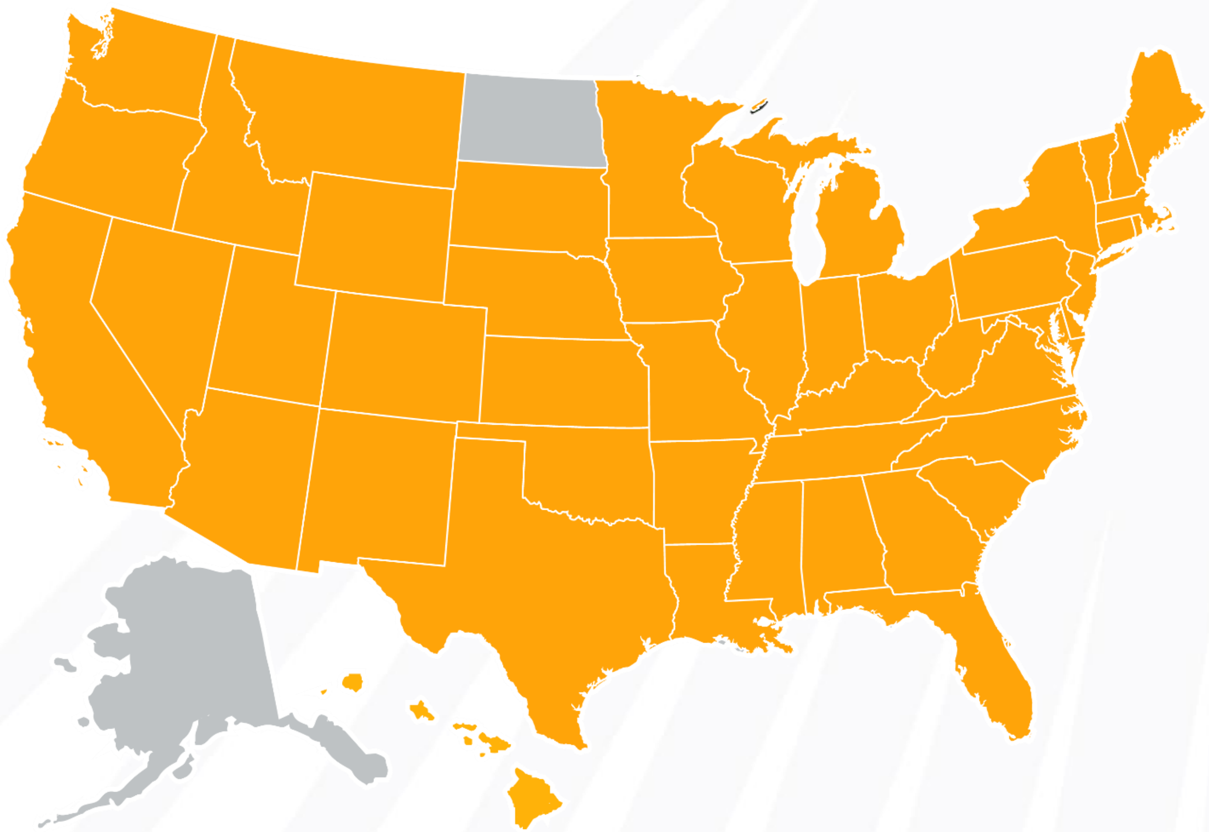
Solar Energy Technologies Office

WHAT WE DO: The U.S. Department of Energy's Solar Energy Technologies Office supports early-stage research and development to improve the **affordability**, **reliability**, and **performance** of solar technologies on the grid.

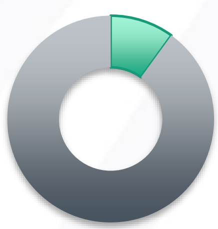
HOW WE DO IT: The office uses a competitive solicitation process to addresses critical research gaps, ensuring the solar industry has the technological foundations needed to **lower solar electricity costs**, **ease grid integration**, and **enhance the use and storage of solar energy**.

DOE Solar Office Funds 250+ Active Projects

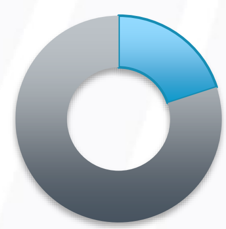
Projects and partners in **48 states** plus the **District of Columbia**



70% of projects at **national labs & universities**



10% of projects with **non-profits***

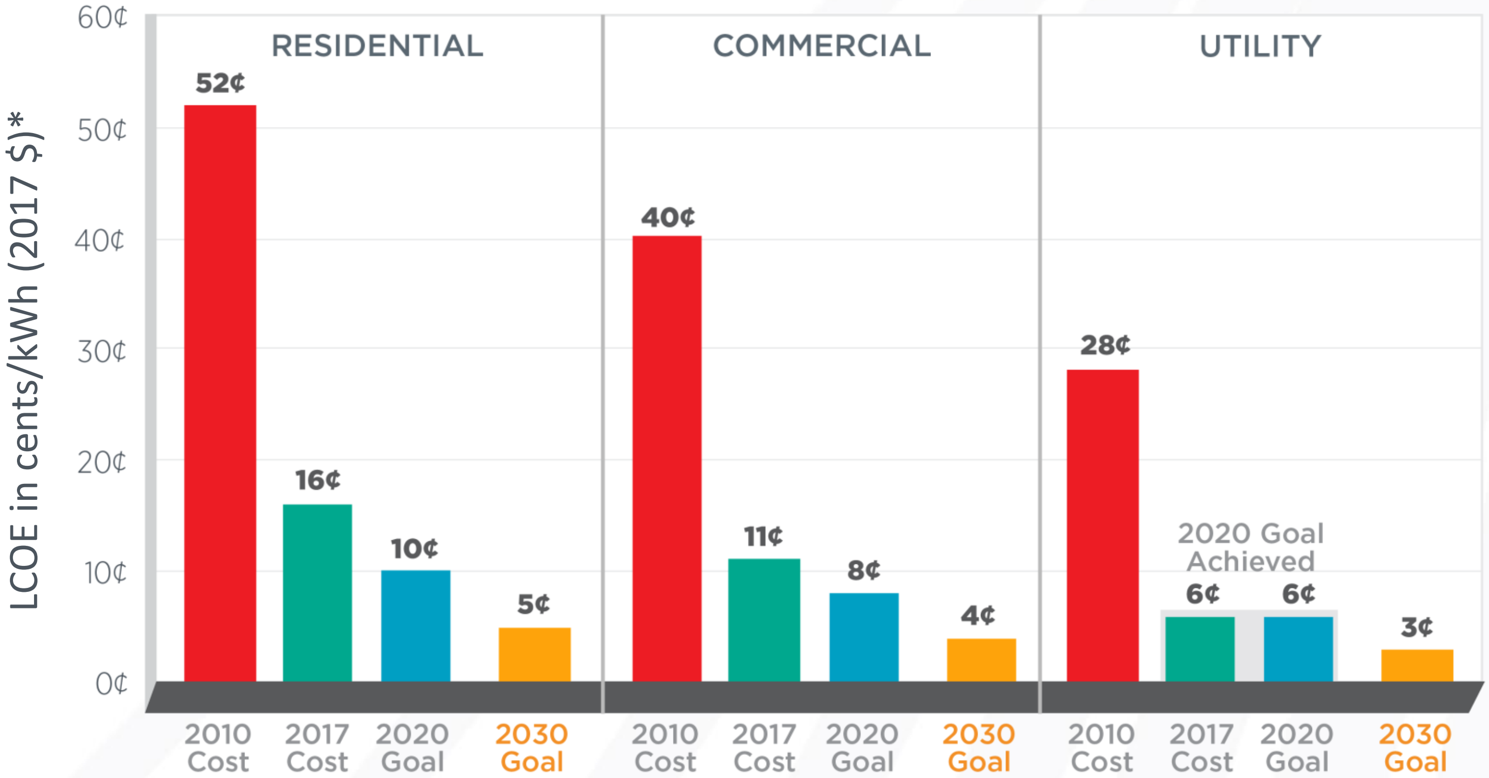


20% of projects with **companies**

Note: SETO has funded past projects in North Dakota and Alaska.
*1% of state and local government

Progress and Goals: 2030 Photovoltaics Goals

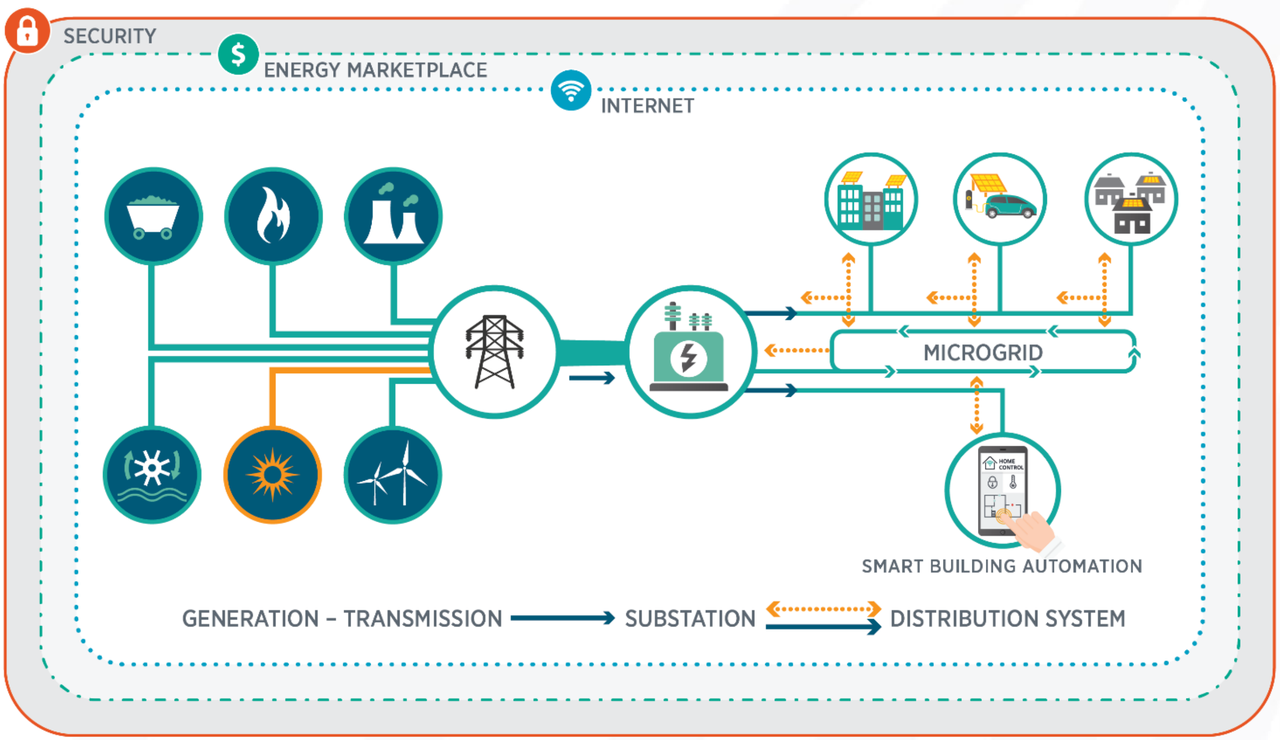
The office invests in innovative research efforts that securely integrate more solar energy into the grid, enhance the use and storage of solar energy, and lower solar electricity costs.



*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. The residential and commercial goals have been adjusted for inflation from 2010-17.

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 resiliency
- 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

Current Funding Programs in Systems Integration

Funding Program	Year	Amount Awarded
Power Electronics	2018*	$20M
Solar Forecasting 2	2017	$12M
Resilient Distribution Systems Lab Call	2017	$10M
Enabling Extreme Real-Time Grid Integration of Solar Energy (ENERGISE)	2017	$30M
Grid Modernization Lab Consortium (GMLC)	2016	$10M
Sustainable and Holistic Integration of Energy Storage and Solar PV (SHINES)	2016	$18M
SuNLaMP (Lab Call)	2015	$59M

*Pending Awards

"Logic Model" for Solar Forecasting 2 Program

Inputs: Means for Achieving Outcomes				Outcomes & Impact	
Program Partners & Resources[1] (entities to which funding is directed)	DOE & Partner Activities (actions by program partners that lead to outputs)	Target Audiences (entities impacted by outputs)	Outputs (awardee activities)	Short Term Outcomes (short-term effect of outputs on target audiences)	Long Term Impact (long-term effect of outputs on target audiences and broader community)
Program Partners Topic 1 Entities with experience creating/implementing test frameworks that can operate impartially[2] Topic 2 Entities with experience and expertise in solar irradiance forecasting[3] Topic 3 Entities with experience in solar irradiance, solar power, or load modeling Balancing authorities or independent power producers **Resources** Cost share funding	**DOE Activities** Workshops Request for Information Funding opportunity announcement Merit review and selection Award negotiation Active project management Accomplishment tracking **Partner Activities** Concept Paper Full Application including Statement of Project Objectives Project work	Independent power producers Balancing authorities Forecasting community	Topic 1 Test framework Topic 2 Forecasting model addressing day-ahead and/or intra-day horizons and at least one of the following: 1) cloudy conditions, or 2) large-scale weather events associated with ramp onsets Topic 3 Irradiance-solar power models with probabilistic output Decision-making process for unit commitment and economic dispatch Demonstration of decision-making process in development environment All Topics Results of Topic 2/3 activities assessed using validation test framework Awardee reports (e.g. RPPR1, RPPR2) Publications, conference presentations, workshops, etc.	Topic 1 Test framework used by relevant stakeholders (i.e. users and providers of forecasting models) beyond the award expiration date Topic 2 Improved forecasting model accuracy Improved understanding of factors impacting solar irradiance Topic 3 Increased awareness of and confidence in forecasting models among energy management stakeholders Increased rate of integration of forecasting models into energy management systems	Transparent set of rules and specifications used by industry and academia to test forecasting models Reduced balancing, dispatch, and unit commitment costs associated with forecasting errors and need for expensive, fast-ramping reserves Improved reliability of the grid through load certainty and more precise balancing of supply and load SunShot 2020 and 2030 goals of reduced solar LCOE

Outputs, Outcomes and Long Term Impact

Outputs	Short Term Outcomes	Long Term Impact
• Test framework • Forecasting model addressing day-ahead and/or intra-day horizons and at least one of the following: 1) cloudy conditions, or 2) ramp onsets • Irradiance-solar power models with probabilistic output • Decision-making process for unit commitment and economic dispatch • Demonstration of decision-making process in development environment	• Test framework used by relevant stakeholders (i.e. users and providers of forecasting models) beyond the award expiration date • Improved forecasting model accuracy • Improved understanding of factors impacting solar irradiance • Increased awareness of and confidence in forecasting models among energy management stakeholders • Increased rate of integration of forecasting models into energy management systems	• Transparent set of rules and specifications used by industry and academia to test forecasting models • Reduced balancing, dispatch, and unit commitment costs associated with forecasting errors and need for expensive, fast-ramping reserves • Improved reliability of the grid through load certainty and more precise balancing of supply and load • SunShot 2020 and 2030 goals of reduced solar LCOE

Program Awardees

Recipient Org	Topic	Title
U of Arizona	TA1	Open Source Evaluation Framework for Solar Forecasting
PNNL	TA2	Development of WRF-Solar v2—Improving Solar Forecasts
NREL	TA2	Probabilistic Cloud Optimized Day-Ahead Forecasting System based on WRF-Solar
BNL	TA2	Advancing the WRF-Solar Model to Improve Solar Irradiance Forecast in Cloudy Environments
UC San Diego	TA2	HAIMOS Ensemble Forecasts for Intra-day and Day-Ahead GHI, DNI and Ramps
NREL	TA3	Solar Uncertainty Management and Mitigation for Exceptional Reliability in Grid Operations (SUMMER-GO)
Johns Hopkins U	TA3	Coordinated Ramping Product and Regulation Reserve Procurements in CAISO and MISO using Multi-Scale Probabilistic Solar Power Forecasts
EPRI	TA3	Probabilistic Forecasts and Operational Tools to Improve Solar Integration

Development of WRF-Solar v2—Improving Solar Forecasts

L. Berg, L. Riihimaki, B. Kosovic, J. McCaa

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

NCAR

VAISALA

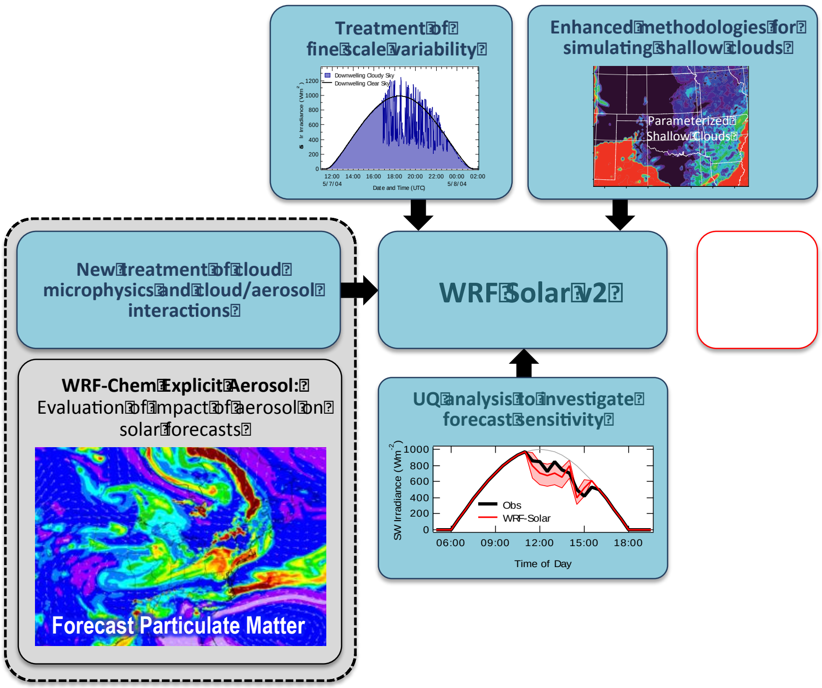
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

- **Research Need**
  - NWP models are the backbone of many intra-day (4-6 hours) and day ahead forecasts
  - WRF-Solar v1 has biases associated with partly cloudy conditions, absorbing aerosol, and wintertime clouds
- **Approach**: Develop WRF-Solar v2, a new tool for intra-day and day-ahead forecasts of solar irradiance.
- **Team**: PNNL, NCAR, Vaisala, and NOAA
  - Linking laboratories and industry
- Provide community with new forecasting tool

Project Objective: Reduce forecast errors in DNI and GHI by 25% compared to WRF-Solar v1.

WRF-Solar v2—Model Improvements and Evaluation

- **Add new or improved treatments:**
  - Shallow clouds (including breakup of stratocumulus)
  - Cloud entrainment and microphysics
  - Subgrid variability in irradiance
  - Absorbing aerosol
  - Application of uncertainty quantification (UQ) techniques to better understand uncertainty and model calibration
- **Evaluation:** Application of a range of metrics to test model performance
  - Mean absolute error (MAE)
  - Root mean square error (RMSE)
  - Characterization of error distributions
  - Categorical statistics for solar power ramps [e.g., Haupt et al. (2016)]
  - New metrics developed by Topic Area 1 Team



Probabilistic Cloud Optimized Day-Ahead Forecasting System Based on WRF-Solar

NREL, NCAR

Technical Objective

Develop Solar Forecasting System based on WRF-Solar that:

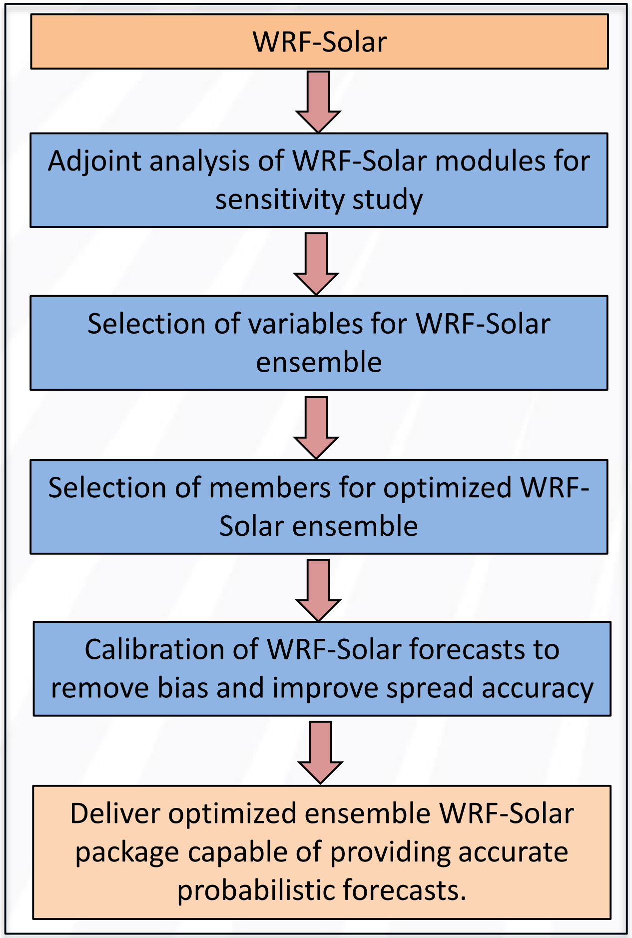
- Provides probabilistic forecasts for the grid.
- Ensemble members tailored for solar forecasts.
- Optimized to operate with few ensemble members.
- Calibrated to remove bias in forecasts and has meaningful quantification of the uncertainties.
- Improves the current-state-of-art solar forecasts and reduces uncertainty by 50% from current levels.
- Improves both average irradiance and ramp forecasts.

Probabilistic Cloud Optimized Day-Ahead Forecasting System Based on WRF-Solar

Approach

NREL, NCAR

- Identify variables that significantly influence the formation and dissipation of clouds and solar radiation through an **adjoint 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.



Advancing WRF-Solar Model to Improve Solar Irradiance Forecast in Cloudy Environments

❖ One Goal

Improve the state of art *WRF-Solar* model for forecasting solar irradiance in *cloudy* environment

❖ Four Objectives

- **Improve cloud microphysics**
- **Improving radiative transfer**
- **Develop innovative analysis package**
- **Perform model evaluation**

❖ Five Tasks

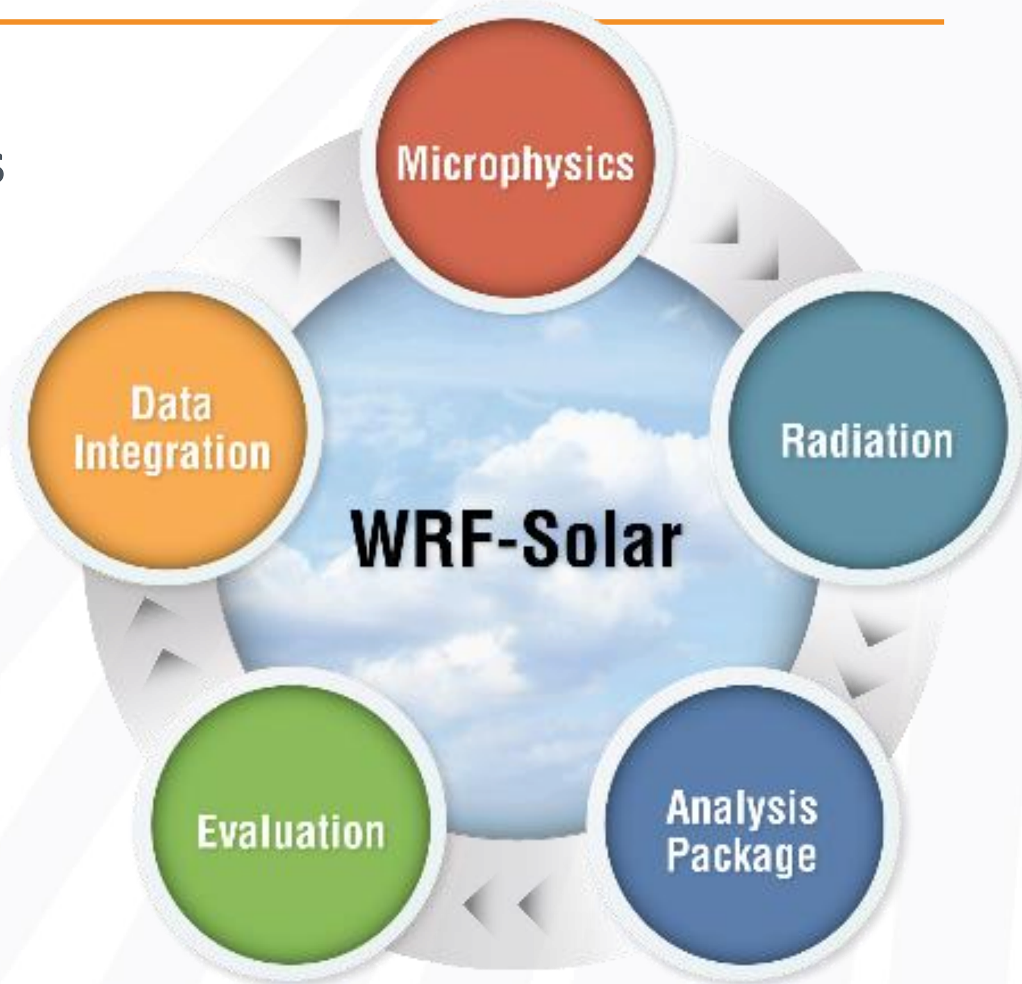
- **Four objectives + Data integration**

❖ Collaborative Proposal

- **Three institutions (BNL, NREL & SUNY at Albany)**
- **PI: Yangang Liu (BNL)**
- **1.6 M & 214 K SUNY cost share for three years**

Five Closely Related Tasks

- Improve Cloud Microphysics
- Improve Radiative Transfer
- Develop Innovative Analysis Package
- Perform Model Evaluation
- Data Integration



Model development/improvement calls for iterative cycle of development, evaluation, and further improvement; thus tasks are closely related to one another.

HAIMOS Ensemble Forecasts for Intra-day and Day-Ahead GHI, DNI and Ramps

Principal Investigator Prof. Carlos F. M. Coimbra, UC San Diego (ccoimbra@ucsd.edu)
Project Team Center for Energy Research/UCSD; Clean Power Research (CPR)
Requested EERE funds $ 1,316,203 **Cost sharing amount** $ 162,500

Summary

This project proposes a Hybrid Adaptive Input Model Objective Selection (HAIMOS) ensemble model to improve solar irradiance and cloud cover forecasts. Major HAIMOS components consist in:

→ Holistic optimization framework: every aspect of the model (data preprocessing, input selection, etc.) will be subject to an adaptive optimization to reduce bulk error metrics, predict ramp onset, produce accurate probabilistic forecasts for horizons ranging from 1 to 72 hours;
→ Ingestion of new-generation cloud cover products (high-resolution rapid refresh satellite images, detailed atmosphere modeling using Large Eddy Simulation) to improve cloud optical depth forecast and irradiance forecasts in the 1 to 6 hours horizons.

Impact Accurate irradiance probabilistic forecast will reduce solar generation prediction error and enable wider use of forecasting tools by solar energy stakeholders.

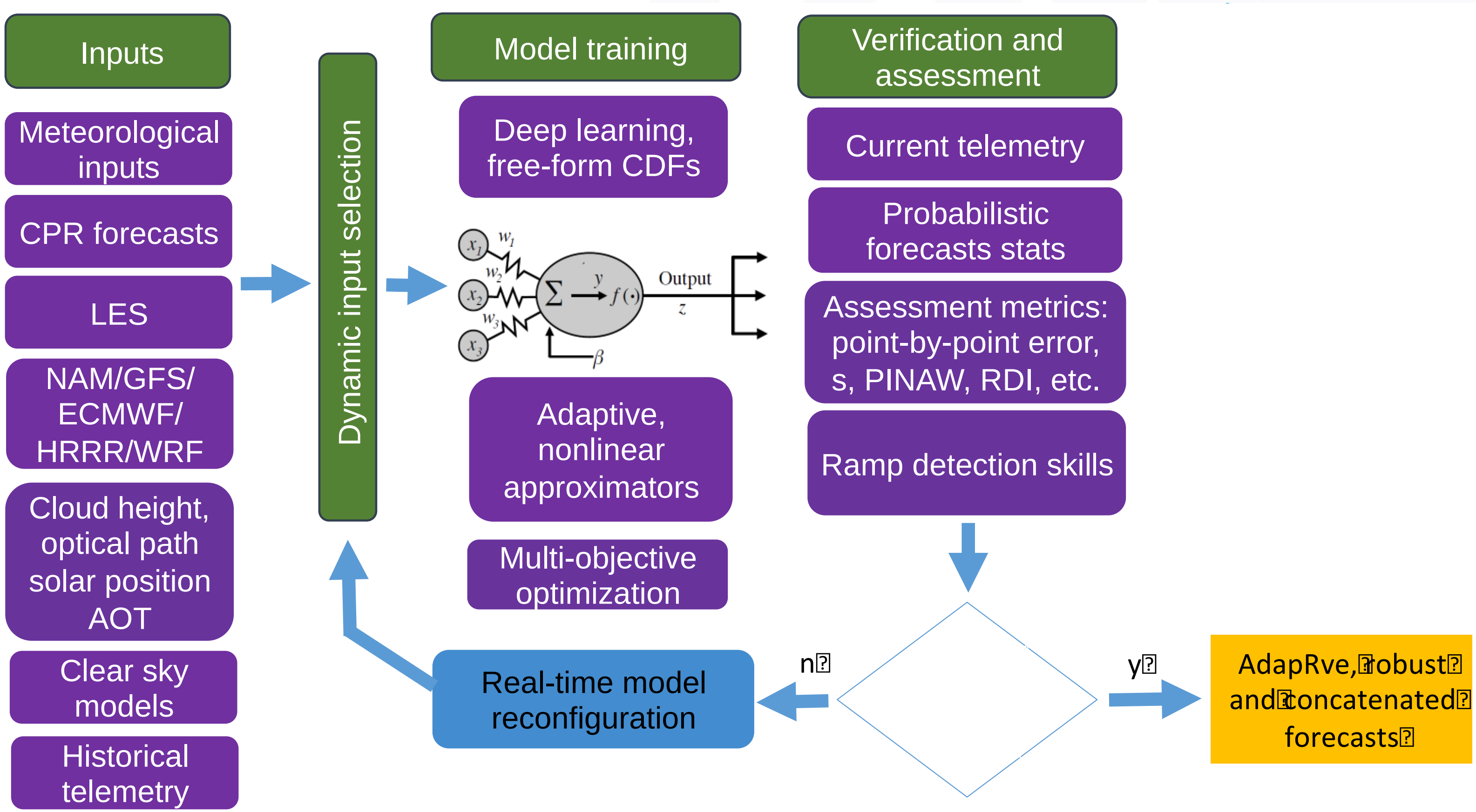
Goals Increase the state of the art forecast skill from their present values of 10 to 30%. Aim to achieve the 50% forecast skill level consistently for both GHI and DNI.

Key idea HAIMOS blends state of the art machine learning methodologies with detailed physics-based models for cloud cover and cloud optical depth forecasts. This two-pronged strategy will lead to substantial improvement of solar forecasts.

Technical Approach: HAIMOS combines the latest innovations in machine learning with detailed physics-based models for cloud cover and cloud optical depth forecasts.

HAIMOS integrates for the first time, information derived from the new GOES satellites sensors and cloud cover simulations from LES.

Both these technologies enable a spatial and temporal sensing/modeling of clouds at much higher resolutions than previously available.

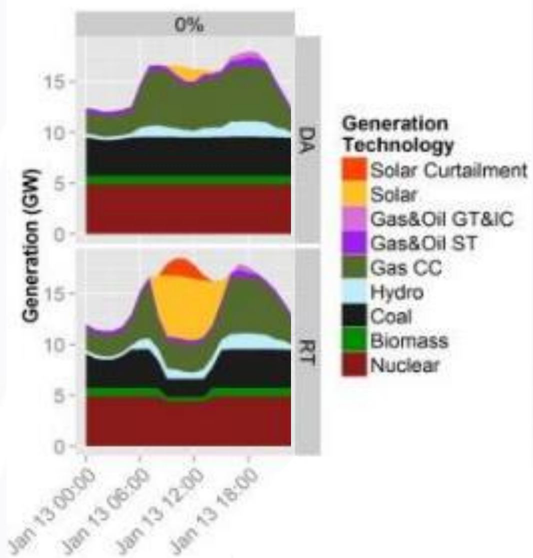


Solar Uncertainty Management and Mitigation for Exceptional Reliability in Grid Operations (SUMMER-GO)

SUMMER-GO is a suite of tools that enable the incorporation of probabilistic solar forecasts into operations to improve system reliability and will be validated in ERCOT's real-time operational test system.

Motivation

Deterministic solar under- and over-forecasting events can cause high solar curtailment or generation shortages, increased system costs, and reliability concerns.



SUMMER-GO Objectives

- Design novel algorithms to create probabilistic solar power forecasts and automate their integration into power system operations to reduce operating costs while increasing reliability.
- Incorporate probabilistic solar forecasts into ERCOT's real-time operation environment through automated reserve and dispatch tools.
- Develop a situational awareness tool to help system operators understand the uncertainty in the solar power forecasts, and the impacts on operations.

SUMMER-GO Project Goals

Probabilistic Forecasts

Utilize machine learning-statistical techniques to improve probabilistic forecast accuracy, sharpness, and calibration.

Adaptive Reserves

Reduce overall reserve levels by 25% while maintaining or improving system reliability.

Risk-Parity Economic Dispatch

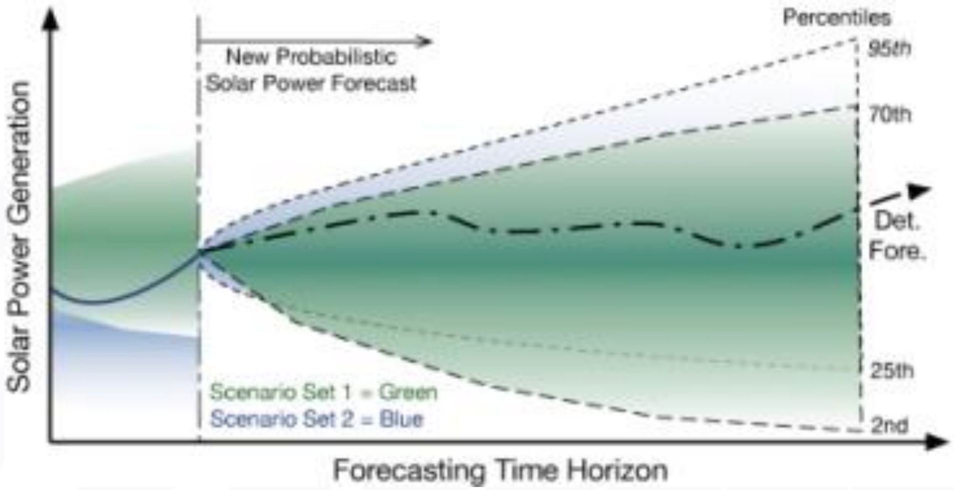
Automate the use of probabilistic forecast information in a 5-minute dispatch window.

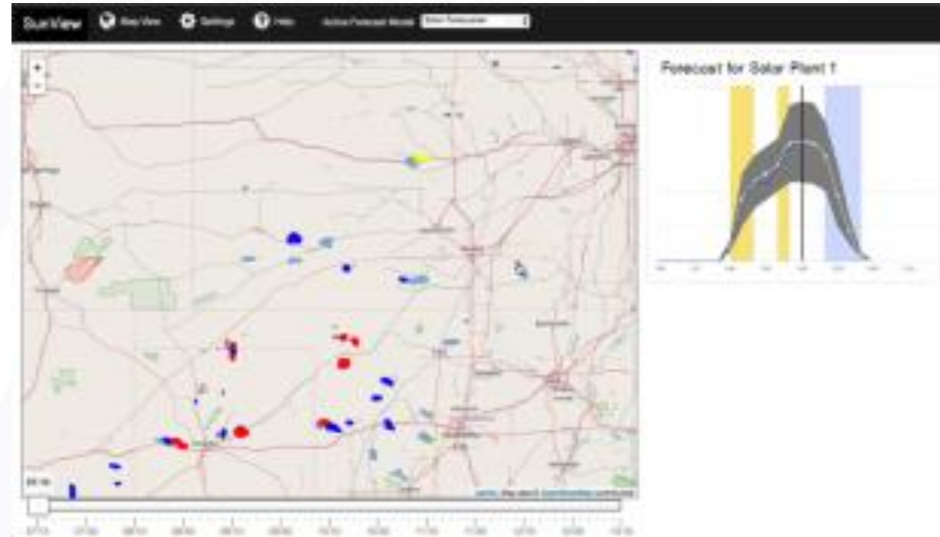
Situational Awareness Tool

Develop *SolarView* to present forecast uncertainty information that is relevant, timely, and allows for better decision making.

Validation

Validate suite of tools in ERCOT's real-time operation environment.





Coordinated Ramping Product and Regulation Reserve Procurements in CAISO and MISO Using Multi-Scale Probabilistic Solar Power Forecasts

Johns Hopkins University (JHU), International Business Machine (IBM), National Renewable Energy Laboratory (NREL), University of Texas Dallas (UTD), California ISO, and Midcontinent ISO

FOA Topic Area 3: Power Forecasts and Operational Integration

Solar Forecasting FOA II

Project Summary

Objective: Integrate probabilistic short- (0-6 hr ahead) and mid-term (day-ahead) solar power forecasts into operational process for two ISOs:

- CAISO
- MISO

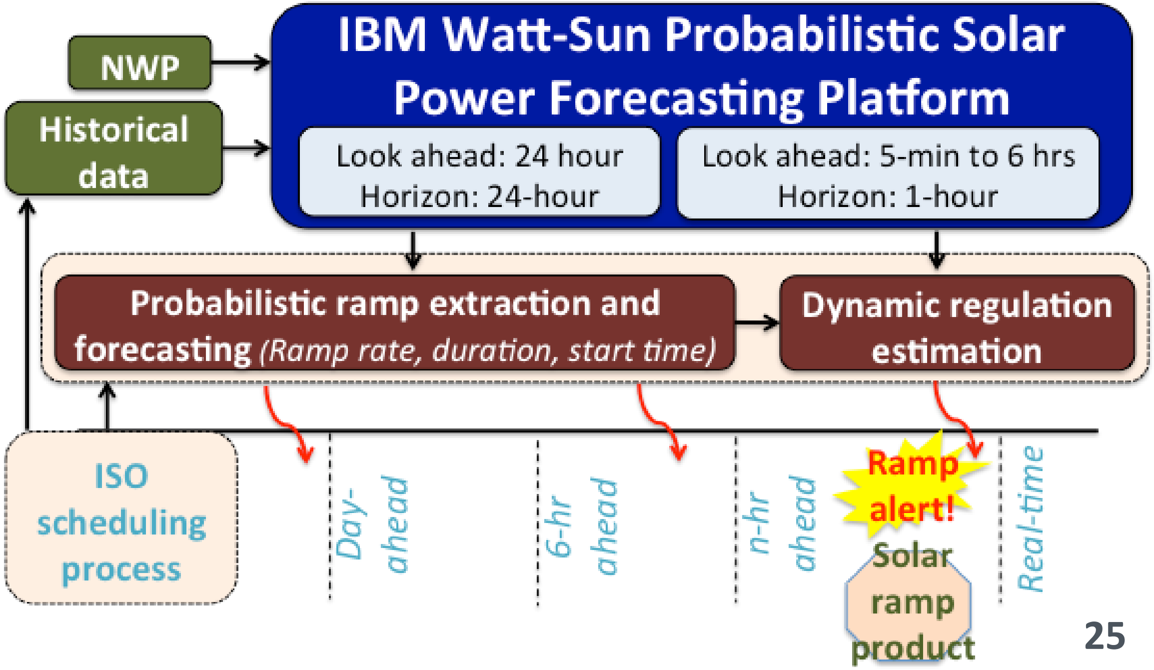
Approach:

1. Advanced big data-driven "probabilistic" solar power forecasting technology

- IBM Watt-Sun & PAIRS: **Big data** information processing (Hadoop, HBase)
- **Machine learning approaches** to blend outputs from multiple models

2. Integrate probabilistic forecasts in ISO operations for *ramping product* & *regulation* requirements

3. Provide **situational awareness via visualizations** of probabilistic ramp forecasts & alerts



Expected Outcomes

Advanced probabilistic solar power forecasting platforms; & tests of their integration into ISO operations:

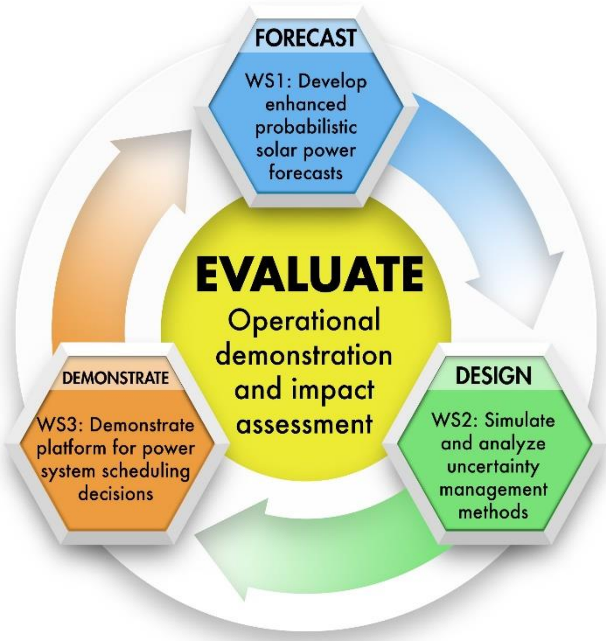
1. **Probabilistic solar power forecasting technology**, ensuring better:
    - *fidelity* (>20% error reduction)
    - *reliability* (>98% coverage index of probabilistic forecasts)
    - *sharpness* (<3-5% forecast bounds)
2. **Forecast access** via IBM big data infrastructure & NREL visualizations:
    - *temporal* horizons of 5-mins to days-ahead
    - *spatial* resolution of 1-4 km across the continental US
3. **Improved ramping & regulation reserve procurement** across all time frames of market scheduling using probabilistic forecasts
4. **Annual savings** of >15-25% (~10s of $millions) **in operating reserves procurement** and customer costs under high solar penetration conditions

Operational Probabilistic Tools for Solar Uncertainty (OPTSUN)

- A **Forecasting Work Stream** to develop and deliver probabilistic forecasts with targeted improvements for utility scale and behind-the-meter (BTM) solar

- A **Design Work Stream** to identify advanced methods for managing uncertainty based on results from advanced scheduling tools

- A **Demonstration Work Stream** to develop and demonstrate a scheduling management platform (SMP) to integrate probabilistic forecasts and scheduling decisions in a modular and customizable manner



AWS TRUEPOWER

POLARIS SYSTEMS OPTIMIZATION

DUKE ENERGY

SOUTHERN COMPANY

Hawaiian Electric

Utility Demonstrations To Be Employed

- Hawaiian Electric
  - Oahu: 600 MW+ of solar already installed on system with daytime load of <1200 MW
  - Focus on Oahu system operations in next few years, leveraging existing work:
    - Probabilistic solar, wind and net load forecasting in the SWIFT forecasting tool
    - EPRI study of operating reserve requirements using FESTIV tool
  - Insights will inform **new automation and EMS tools**, and provide operator **confidence**

- Southern Company
  - Over 1700 MW of solar installed, mostly in Georgia
  - Develop detailed operational models for current and 2020 solar fleet across footprint
  - Builds on previous DOE SUNRISE project and other ongoing EPRI R&D

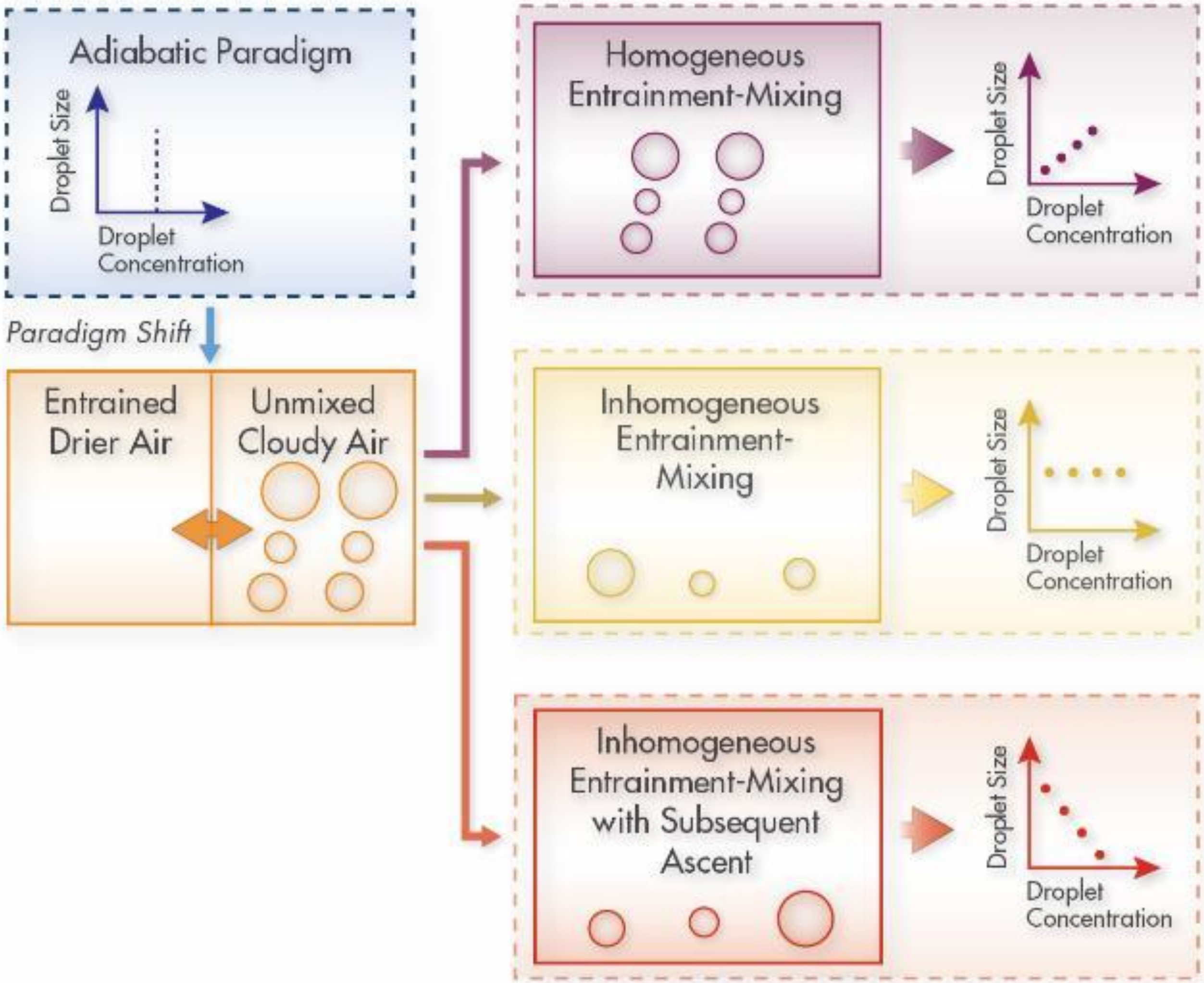
- Duke Energy
  - Focus on Duke Energy Carolinas (DEP and DEC), with approx. 2 GW installed, and >6 GW in queue
  - Will demonstrate use of forecasts in parallel with real time operations in Carolinas, with probabilistic forecasts also being provided and assessed in Florida
  - Leverage existing sensor network and forecasting of solar at distribution and transmission level

Solar Power Forecast Survey

- Survey targeted to solar forecast users
- Goal is to generate baseline of uses and impressions
- One survey per organization (5-10 minutes)
- Input is anonymous, but follow-up will be greatly appreciated
  (reach out to Will Holmgren or Tassos Golnas)
- https://www.surveymonkey.com/r/solarforecast-survey

Extra Slides

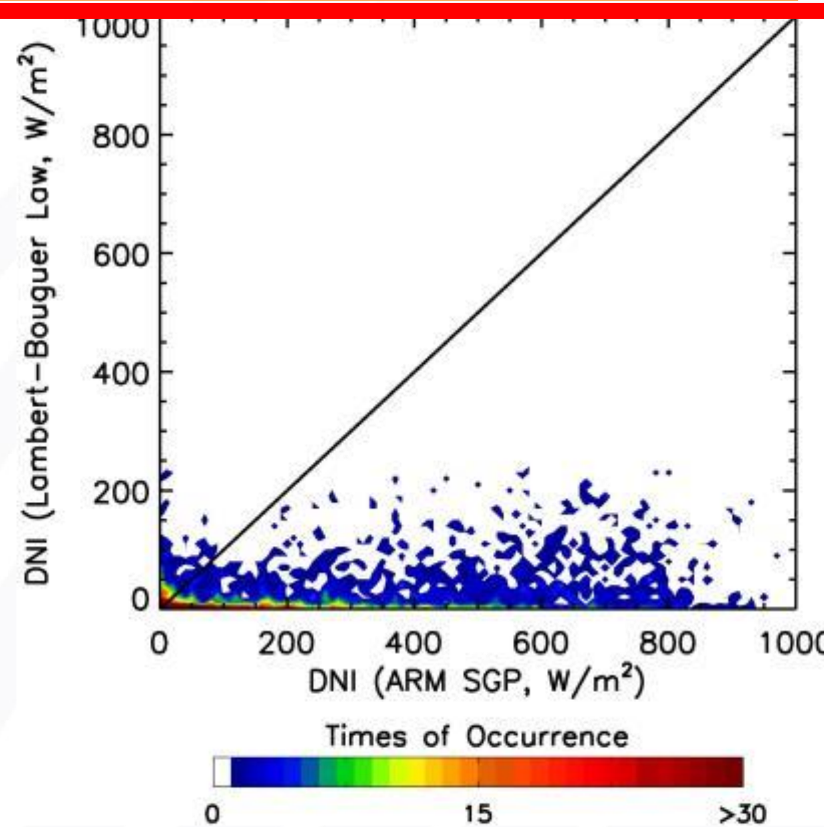
Parameterization Example One: Turbulent Entrainment-Mixing processes



Parameterization Example Two: Direct Normal Irradiance

❖Challenge:

- **Large DNI uncertainty in current FARMS in WRF-Solar**
- **Model-observation mismatch of circumsolar region**
- **Conventional regression functions not universally applicable**



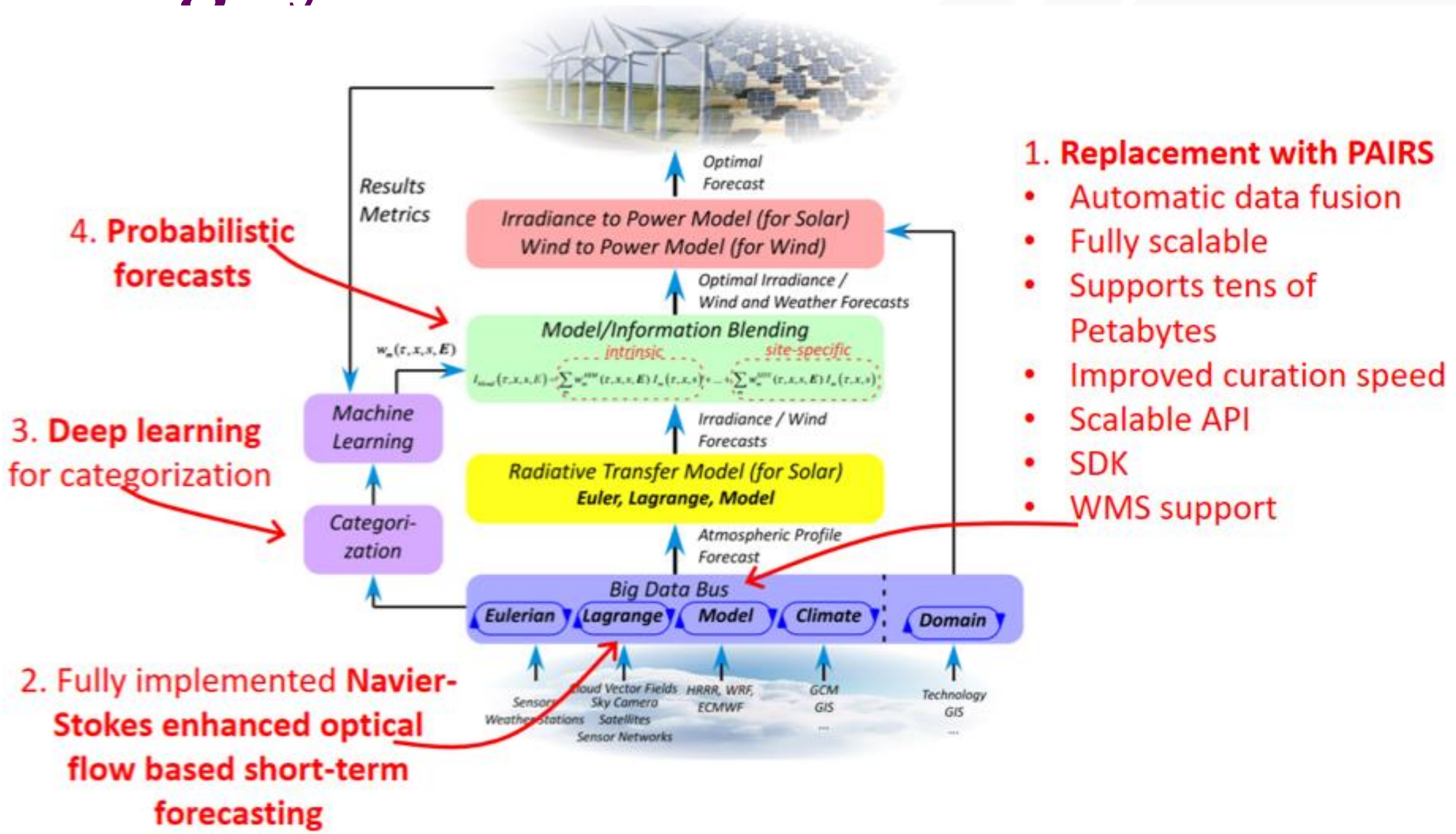
Comparison of DNIs for 9669 scenarios of cloudy conditions.

❖ Solution:

- **Upgrade FARMS to address the mismatch problem according to physics**

FARMS represents Fast All-sky Radiation Model for Solar applications, is used in the current WRF-Solar, and developed by our NREL team members.

Advanced big data-driven probabilistic forecasting system



Situation-dependent forecasts based on model blending:

- Apply deep machine learning with historical forecasts & weather data
- Which model is better, when & where
- Uses **big data** information processing (Hadoop, HBase) technologies
- **Machine learning approaches** to blend outputs from multiple models

Project Team Expertise

Unique collaboration of academia, a national laboratory, a private vendor, and ISOs

TEAM MEMBER	EXPERTISE
Benjamin F. Hobbs, Ph.D., **PI** Theodore M. and Kay W. Schad Chair of Environ. Mgmt., **Johns Hopkins University (JHU)**	Chair of CAISO Market Surveillance Committee. Decision analysis & economics for power markets, planning, & operation (3 books,170+ journal publications)
Venkat K. Krishnan, Ph.D. Senior Engineer, Power System Design & Studies Group, **NREL**	Co-optimized electricity markets, capacity expansion planning, statistical simulations, and data analytics. (55+ peer-reviewed articles; co-developed several market clearing & planning tools)
Hendrik F. Hamann, Ph.D. Senior Manager and Distinguished Research Staff, Physical Sciences Department, **IBM**	Sensor-based physical modeling, big data analytics, high performance microprocessor and storage designs. (90+ peer-reviewed publications, 90 patents/100+ pending) *Solar Forecasting FOA I awardee, NE-ISO BTM forecasts*
Jie Zhang, Ph.D Asst. Professor, Mech. Engineering, **University of Texas at Dallas (UTD)**	Optimization, complex systems, renewable energy forecasting, big data analytics & probabilistic design. (90+ peer-reviewed publications)
Amber L. Motley, California ISO	Manager, Short Term Forecasting
Yok Potts, **MISO**	Manager, Forecast Engineering