Satellite-Based Solar Forecasting Including Maintenance of Computer and Storage Equipment at CSU/CIRA

Cooperative Research and Development Final Report

CRADA Number: CRD-16-00650

NREL Technical Contact: Manajit Sengupta

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5D00-82292
March 2022

Satellite-Based Solar Forecasting Including Maintenance of Computer and Storage Equipment at CSU/CIRA

Cooperative Research and Development Final Report

CRADA Number: CRD-16-00650

NREL Technical Contact: Manajit Sengupta

Suggested Citation

Sengupta, Manajit. 2022. *Satellite-Based Solar Forecasting Including Maintenance of Computer and Storage Equipment at CSU/CIRA: Cooperative Research and Development Final Report, CRADA Number CRD-16-00650.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-82292. https://www.nrel.gov/docs/fy22osti/82292.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5D00-82292
March 2022

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

Cooperative Research and Development Final Report

Report Date: February 28, 2022

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Board of Governors of the Colorado State University System acting by and through Colorado State University

CRADA Number: CRD-16-00650

CRADA Title: Satellite-Based Solar Forecasting Including Maintenance of Computer and Storage Equipment at CSU/CIRA

Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):

Manajit Sengupta | Manajit.Sengupta@nrel.gov

Name and Email Address of POC at Company:

Steven D. Miller | Steven.Miller@colostate.edu

Sponsoring DOE Program Office(s): Office of Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Office (SETO)

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$17,350.00
Year 2	$5000.00
Year 3	$5000.00
TOTALS	$27,350.00

Executive Summary of CRADA Work:

The Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU) proposes to continue its research partnership with the NREL in Golden, CO. The partnership resonates with the goals outlined in a Memorandum of Understanding between the Department of Energy and the Department of Commerce (with the National Oceanic and Atmospheric Administration (NOAA)) signed in 2011. This CRADA will sustain the research partnership and provide an avenue and resources for ongoing collaborations, including the maintenance of NREL-furnished computer and storage equipment at CSU/CIRA. There is no formal exchange of funds in this CRADA; support above and beyond the in-kind items outlined in this document will come on a best-effort basis and/or in association with formal sponsored-research enabled collaborations.

The research conducted under this CRADA continues to work toward enabling and improving short-term solar energy forecasting as developed under previous CIRA/CSU and NREL collaborations, with specific focus on point-based (e.g., solar farm) forecasting on the 1-3 hour timeframe. Under the best-effort actions during the CRADA period, technical maintenance of CIRA's existing satellite-based solar forecasting algorithm ("CIRACast"; Miller et al., 2017) was continued to maintain operability with evolving datasets. These efforts benefit the public by maintaining national capability for point solar forecasting using geostationary observation platforms, and laying the groundwork for future technical improvements as opportunities arise.

<u>Summary of Research Results</u>:

Task 1: *CIRA will configure and operate a solar energy forecasting box for NREL Table Mesa site*

Summary of Findings:

Forecasts for the Table Mesa, CO (TBL) SURFRAD site were provided for validation, as results for that location were part of previous project activities and extant code existed to readily support the effort. Additionally, forecasts validated by GHI observations from the NREL Solar Radiation Research Laboratory (SRRL) were created and provided as an additional forecast validation dataset.

CIRACast forecast products for both sites were generated during the CRADA period, storing results locally on the NREL-furnished hardware provided under loan (see Appendix B, 'Loaned Government Property' from CRADA CRD-16-650 for specific details on hardware.) Forecast products were also provided via FTP and secure-copy directly from the NREL-furnished hardware (see Task 2). Parts of this dataset was used in Figure 3 and in a journal paper (Miller et al. 2017) with NREL coauthors.

Task 2: *CIRA will make forecast results available to NREL*

Summary of Findings:

Point forecasts for the SRRL and TBL SURFRAD sites were continuously generated during the period of the CRADA, and automated data collection of validation data from SRRL and TBL were also collected and paired with forecast points. Analysis and comparison against validation data was also stored locally and provided via network access. All data were stored on NREL-furnished hardware (which has since been returned to NREL), and network access to hardware was provided to NREL for free access on an on-demand basis. The data generated from the project was used in a journal paper (Miller et al. 2017) that was jointly authored by CSU and NREL. Figure 3 is an example of the data generated and provided to NREL.

Task 3: ***NREL will coordinate with CIRA on improvements to solar irradiance calculations***

Summary of Findings:

During the CRADA period, there were several opportunities to evaluate the performance of several solar irradiance models against legacy models used for CIRACast. Primarily the work under this CRADA focused on evaluating the FARMS model (Xie et al. 2016) for clear-sky and cloudy conditions, using the ingest data from the CIRACast product. Example comparisons of FARMS for against various radiative transfer models for 1 April 2016 for synthetic data under clear-sky (Figure 1) and with a simulated cloud (Figure 2).

The intercomparison yielded results demonstrating more accurate GHI, diffuse, and direct component surface fluxes with FARMS, with improvements in execution time of the radiative transfer code as well. Based on the results of this intercomparison, detailing these specific improvements in solar irradiance calculations, the FARMS model was found to be the optimal model for use in forecasting tools similar to and including CIRACast. The FARMS model is a fast model and is used by various other applications including the processing of satellite data for NREL's National Solar Radiation Data Base (NSRDB).

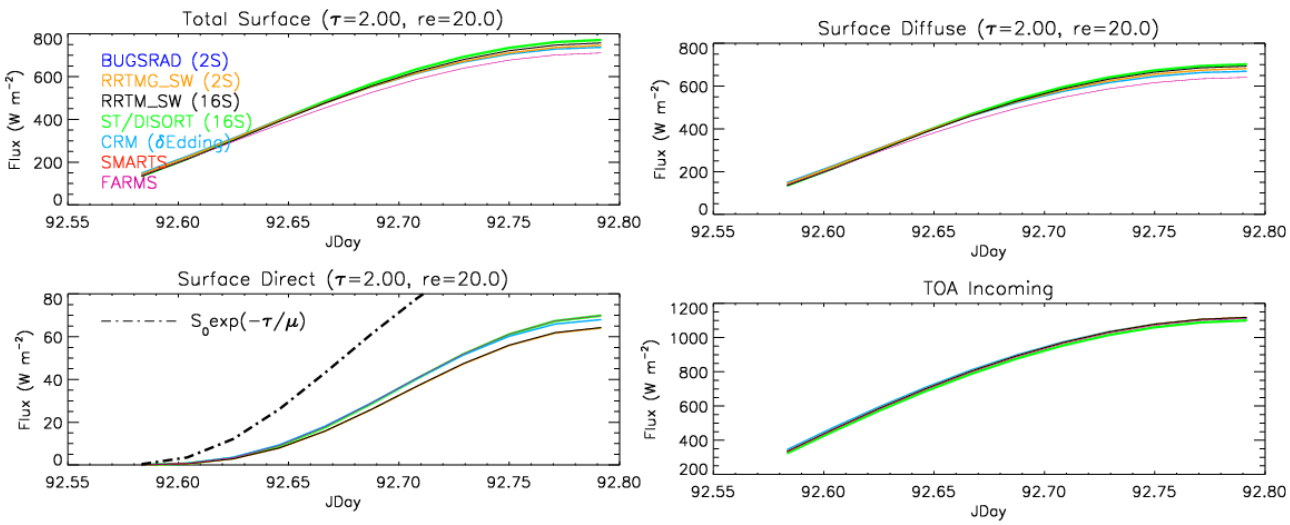

Figure 1. Intercomparison between the NREL FARMS (magenta) irradiance model and other contemporary solar irradiance models, comparing total surface (upper-left), surface diffuse (upper right), and surface direct (lower left) flux as a function of the time-dependent downwelling TOA solar irradiance (bottom-right; showing a range from morning to mid-day).

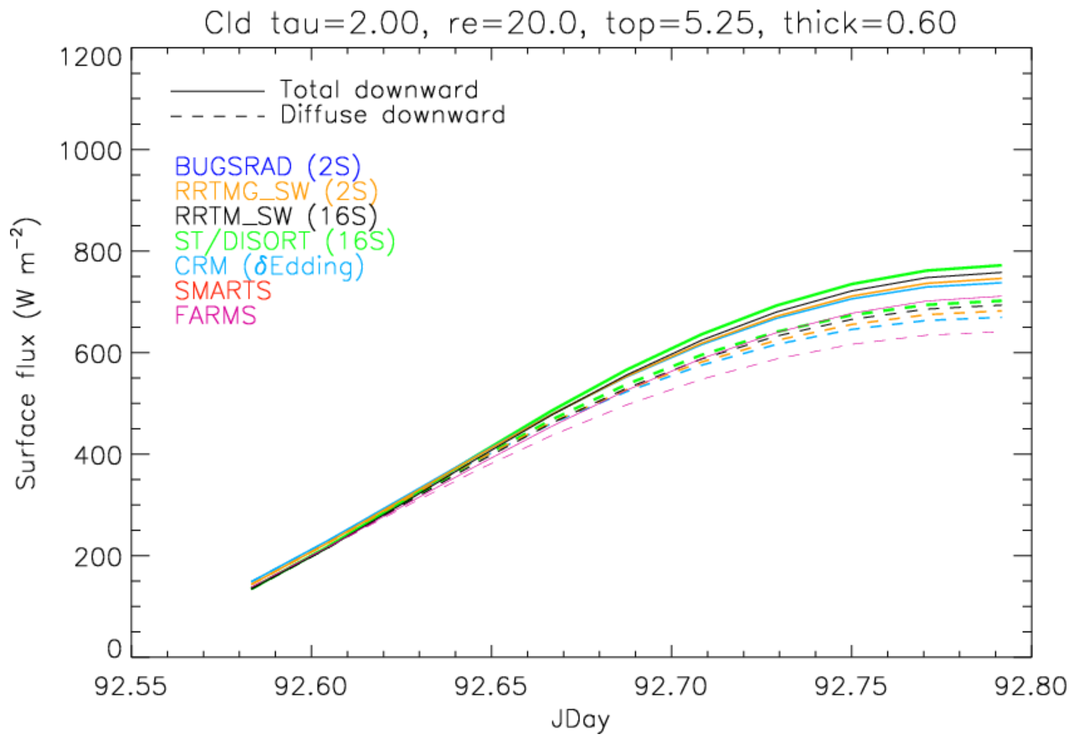

Figure 2. Total and diffuse surface flux from FARMS and other solar irradiance software packages using TOA values from Fig. 1, but with a cloud layer of optical depth = 2 interspersed in the simulated atmosphere.

Task 4: *NREL will collaborate with CIRA on evaluations of the solar forecasts at NREL validation sites*

Summary of Findings

Throughout the CRADA period, efforts to provide co-located forecasts for the SRRL and TBL SURFRAD sites continued on a best-efforts basis. Continued evaluation of data for these evaluation sites constituted work for a journal article published in *Solar Energy* (Miller et al., 2017) and a representative comparison against the TBL SURFRAD site is presented as Figure 3.

The full validation dataset was stored on the NREL-loaned hardware and returned to NREL in November 2019, following the conclusion of the CRADA.

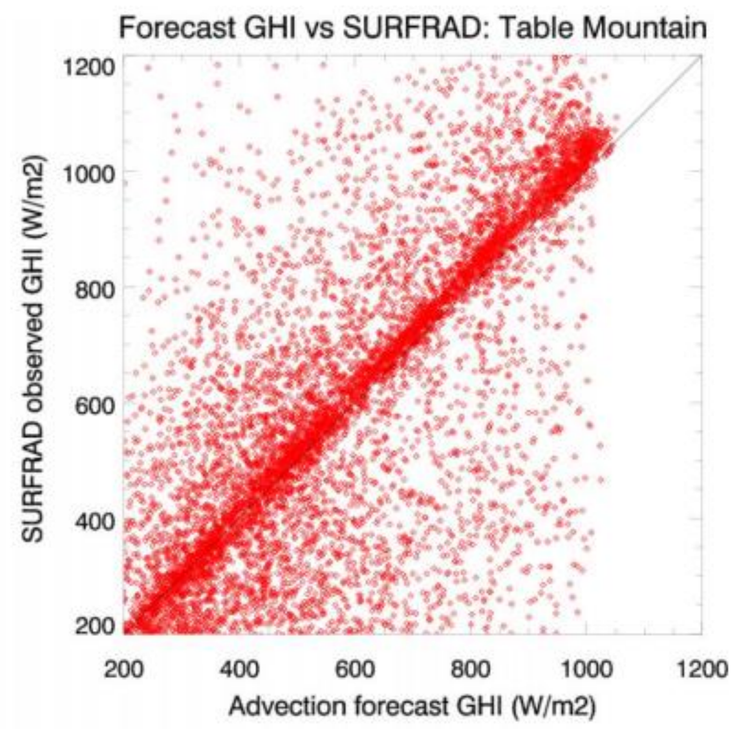

Figure 3. Scatterplot of observed GHI values from the Table Mesa SURFRAD site compared against CIRACast forecasted values for the period of the CRADA. From Miller et al., 2017.

Task 5: ***On a best effort basis and as time and internal resources permit, CIRA will migrate its CIRACast processing to GOES-R Advance Baseline Imager***

Summary of Findings

Initial efforts towards developing the ABI-based version of CIRACast focused on translating the ingest mechanism away from the McIDAS ingest of the previous-generation GOES-13/15 imager to instead use the native GOES-R GRB format. For initial tests, the spatial resolution for the visible imagery used in the algorithm was degraded to 2 km (compared to the 500 m resolution available from the 0.64µm band of the ABI) to better conform to the spatial requirements of legacy 'snap-grid' used to conform advected cloudy-pixel groups within the CIRACast architecture.

Efforts to run this legacy version of CIRACast at the native resolution of the ABI instrument in a real-time mode were unsuccessful (at least with respect to operational forecasting capability) due to computational limitations; the increase in temporal latency on the available hardware (> 30 minutes/forecast for domain sizes of 10x5 degrees) using the IDL programming language in which the legacy CIRACast we written, was noted as a potential challenge for future forecast efforts. The 'best efforts' of this CRADA did, however, identify likely changes to the code structure of the CIRACast product, which included a translation of the code to Python to better utilize math libraries for faster computation and better integration with FARMS.

With changes in the code structure, improved hardware specifications, advancements in GPU processing techniques developed externally to this CRADA by CIRA, and potentially alternative methods for cloud advection strategy, forecast latencies are expected to drop to operationally-capable timescales.

As a direct result of the efforts of this CRADA, modifications to the CIRACast forecast algorithm were developed to be responsive to the goals of DOE funding opportunity DE-FOA-0001987. The goals of this FOA included development of an ABI-capable short-term (3-hour) GHI, DNI, and diffuse surface flux forecast running at a time resolution of less than 10-minutes. Furthermore, the FOA stipulated that the forecast product be capable of running on the Amazon AWS platform, using cloud-provided satellite and NWP products.

By the end of year 1 of this FOA, these goals were met using an upgraded version of CIRACast, with forecast latency of ~3 min demonstrated in realtime AWS operation for the forecast target. This improved version of CIRACast was developed under the FOA and guided by the results of this CRADA.

Concepts towards the development of CIRACast regarding ABI integration were also discussed in Miller, et al. 2017, with specific regard to the utility of higher-resolution ABI data, the potential use of the HRRR model and implementation of optical flow techniques as advective drivers for the forecast algorithm.

References:

Miller, Steven D., Rogers, Matthew A., Haynes, John M., Sengupta, Manajit, and Heidinger, Andrew K. *Short-term solar irradiance forecasting via satellite/model coupling*. United States: N. p., 2017. https://doi.org/10.1016/j.solener.2017.11.049.
(https://www.sciencedirect.com/science/article/pii/S0038092X17310435)

Xie, Y., Sengupta, M., Dudhia, J., 2016. A Fast All-sky Radiation Model for Solar applications (FARMS): algorithm and performance evaluation. Sol. Energy 135, 435–445. https://doi.org/10.1016/j.solener.2016.06.003.
(https://www.sciencedirect.com/science/article/pii/S0038092X16301827)

Subject Inventions Listing:

None

ROI #:

None