# Quantifying the solar impacts of wildfire smoke in western North America


Patrick Keelin
*Clean Power Research*
Napa, CA, USA
pkeelin@cleanpower.com

Alex Kubiniec
*Clean Power Research*
Napa, CA, USA
alexk@cleanpower.com

Akanksha Bhat
*Clean Power Research*
Napa, CA, USA
abhat@cleanpower.com

Marc Perez
*Clean Power Research*
Napa, CA, USA
marcp@cleanpower.com

John Dise
*Clean Power Research*
Napa, CA, USA
johndise@cleanpower.com

Richard Perez
*ASRC (SUNY)*
Albany, NY, USA
solarperez@gmail.com

James Schlemmer
*ASRC (SUNY)*
Albany, NY, USA
jschlemmer@albany.edu



*Abstract*— **2020 was the most active wildfire season in recent history. This study leverages solar models to quantify the solar impacts of wildfire smoke in western North America 2001 – November 2020. We observe a sharp increase in the number of days impacted by aerosol events. Record deviations in clear sky DNI are found at the Hanford, CA, Boulder, CO, and Desert Rock, NV study locations. Total sunlight (GHI) for September was diminished by up to 20% in some locations; California's Central Valley and parts of the Columbia River Basin were hardest hit by the smoke. At the Hanford study location, the Aug.- Oct. 2020 deviations in modeled energy output totaled -5.9% of the historical annual average (2001-2019). The analysis demonstrates that wildfires are an important risk to production for solar projects in western North America.**



***Keywords— solar resource, insolation, radiation, climate change, wildfires, smoke, trends.***


## I. Introduction

2020 was the most active wildfire season in recent history as measured by acres burned and fire detections in Oregon, California, and Washington [1]. Smoke particles, and more generally aerosols in the atmosphere, diminish the solar radiation reaching the ground and available for solar generation. A recent study of solar generation in the California Independent System Operator region found that generation during the first two weeks of September 2020, a time when California was heavily impacted by wildfire smoke, was down 13.4% from the year prior despite an increase in total system capacity [2]. Climate modelers have long projected that hotter and drier conditions likely will cause increased fire activity across the United States in coming decades [3][4].

The present study leverages solar models to quantify how wildfires are impacting solar insolation and power generation. Analysis of 7 geographically dispersed locations in western North America from 2001 - November 2020 shows a sharp increase in the number of days affected by aerosol events, with record impacts to solar projects in California in 2020.

## II. Modeling smoke

Some changes in the atmosphere occur over decades. For example, a recent study quantified the multi-decade trends in cloud cover and aerosols influencing solar energy production [5]. By contrast, wildfires are acute events, lasting days to months. Smoke in the atmosphere can change hour to hour depending on which way the wind is blowing. To quantify such events, high resolution aerosol data are needed. SolarAnywhere® [6] V3.5, introduced May 2021, uses 3-hourly aerosol optical depth (AOD) data from MERRA-2 [7] as an input to the clear sky irradiance model. The higher-resolution input improves model performance in smoky conditions as shown in fig. 1.

The higher-resolution aerosol input also improves model performance in general. For example, the distribution of annual mean bias errors in North America is tightened by 13% for DNI (n = 151) and 8% for GHI (n = 221). Note that a portion of the improvement is attributable to unrelated model updates including the addition of snow albedo input to the clear sky model; a full explanation of the model updates and validation can be found on solaranywhere.com.

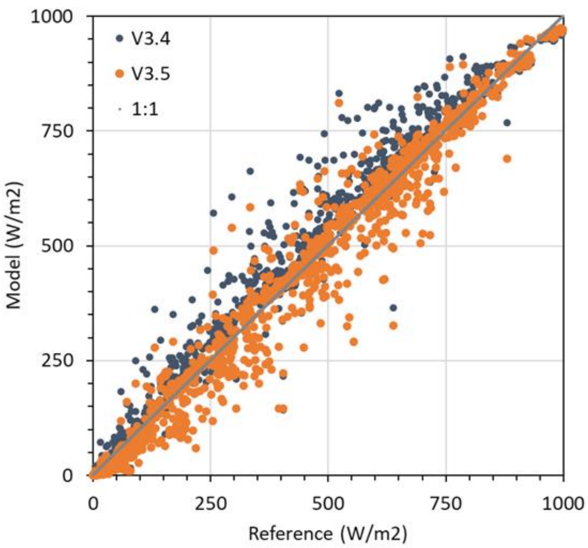


Fig. 1. Global horizontal irradiance measured by SolarAnywhere V3.4 and V3.5 and Baseline Surface Radiation Network [8] station located at Hanford, CA. Each point represents one daylight hour during the period August-October 2020 when thick smoke impacted the area.

## III. Identifying wildfire events

The previous SolarAnywhere model version, V3.4, provides a convenient baseline for studying short aerosol events like smoke from wildfires, because it uses trailing 3-year monthly averages of AOD. In other words, comparing V3.4 to V3.5 shows the deviation from medium-term averages. Visualizations of the data, as in fig. 2, show an unmistakable signature of a severe wildfire season.

Clear sky direct normal insolation is used for two reasons. First, direct normal irradiance (DNI) is more sensitive to aerosols than global horizontal irradiance. Second, because the clear sky model is not influenced by cloud cover, it isolates the impact of aerosols on insolation.

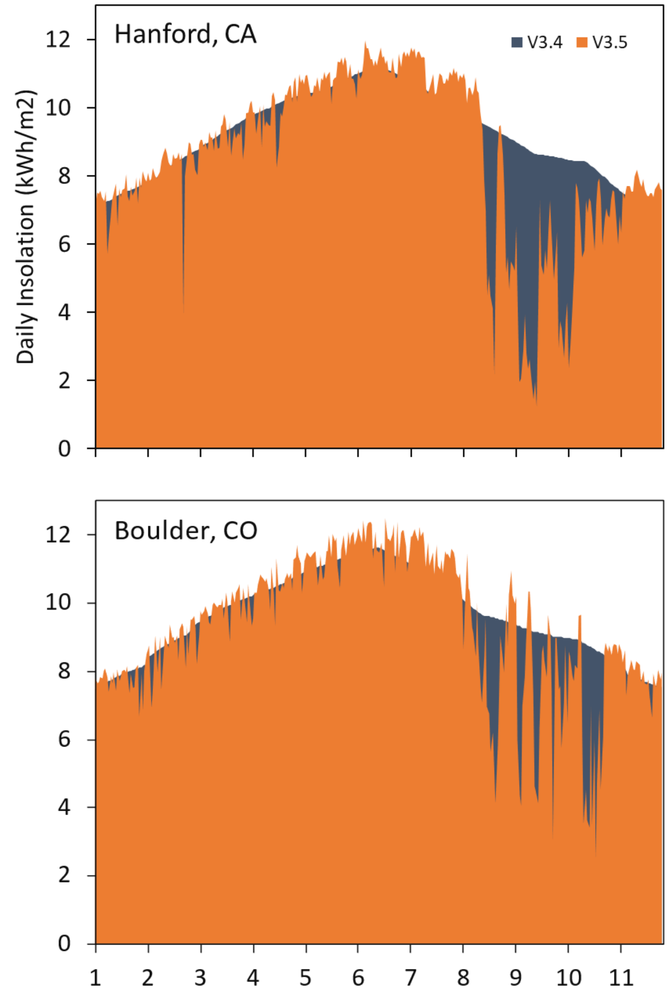


Fig. 2. Modeled clear sky direct normal insolation January - November 2020 for Hanford, CA and Boulder, CO.

## IV. Quantifying the solar impacts

Seven geographically dispersed locations in western North America from 2001 - November 2020 were analyzed. Of these, Hanford, CA, Boulder, CO and Desert Rock, NV saw record low 365-day moving average clear sky DNI during the 2020 fire season. Deviations relative to the 2001-2019 average were: Hanford, -8.9%; Boulder, -5.2%; Desert Rock, -3.4%. For both Hanford and Boulder, the 2020 wildfire season impact on insolation was more than double that of any previous year in the study.

We define an impacted day as a day when clear sky DNI is at least 30% below the baseline. The number of impacted days has risen sharply since 2001, as seen in fig. 3. There were 105 impacted days in 2020, shattering the previous record of 39 reached just 2 years earlier.

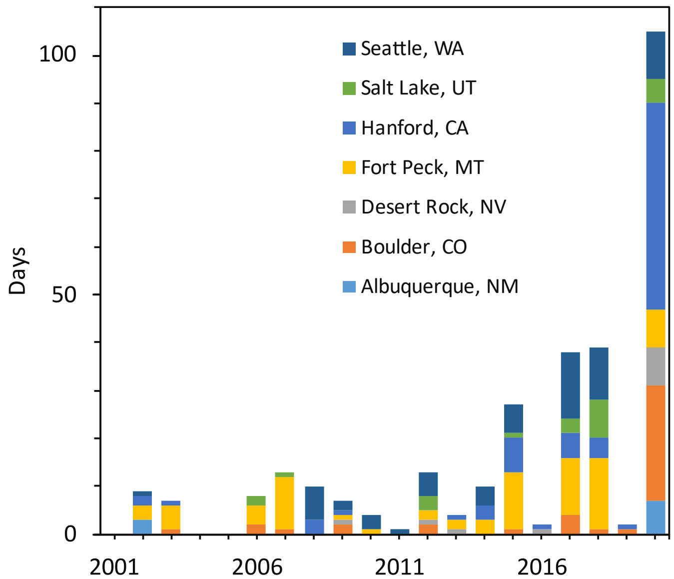


Fig. 3. Impacted days for 7 geographically dispersed locations in western North America.

Differences in global irradiation during the month of September were mapped (fig. 4) to illustrate the geographic extent of the impacts. Total sunlight (GHI) for the month was diminished by up to 20%. California's Central Valley and parts of the Columbia River Basin (including Portland and Bend) were hardest hit by the smoke. Northern Colorado also suffered severe wildfires in October.

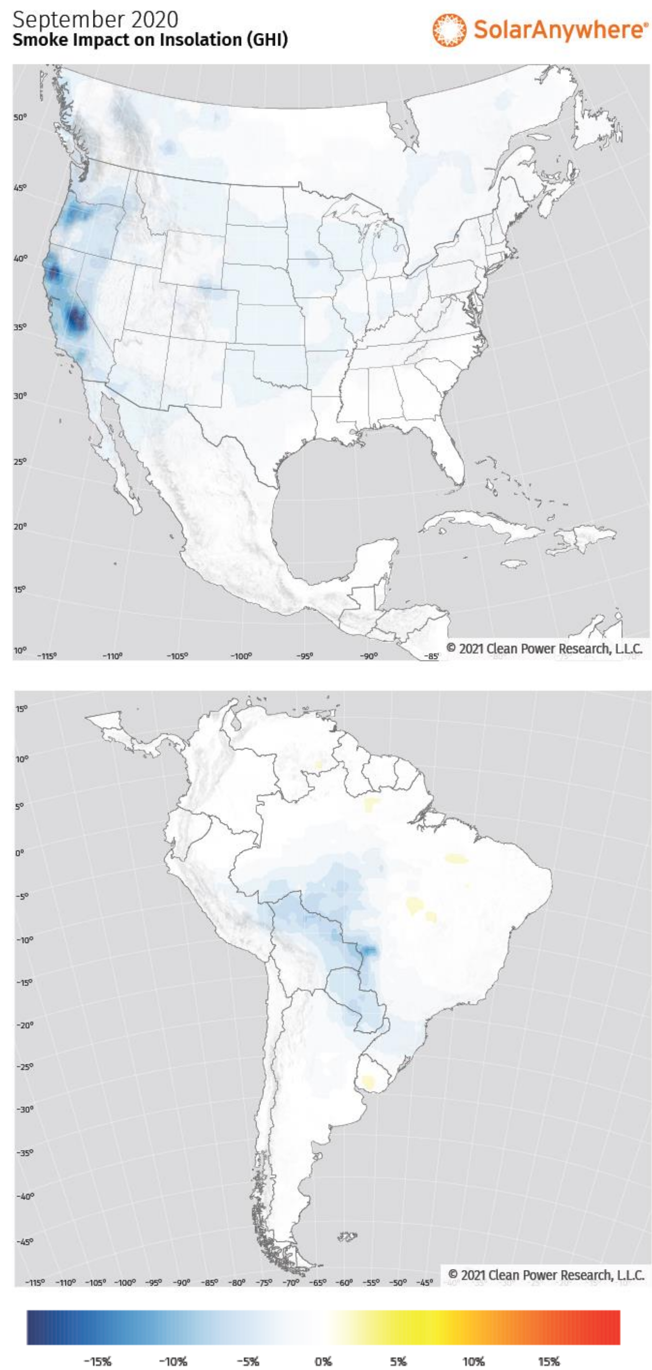


Fig. 4. Differences in insolation as a result of aerosol deviations, September 2020.

A standard photovoltaic (PV) energy simulation model was used to relate the irradiance impacts to solar energy production. For this study we defined a typical utility PV system (single-axis tracking, G.C.R. 0.35, DC:AC ratio 1.4) and ran energy simulations 2001 - Nov. 2020 for the Hanford and Boulder locations. Monthly energy production is displayed in fig. 4.

At Hanford, the Aug.- Oct. 2020 deviations totaled -129 MWh/MW-DC, equivalent to -5.9% of the historical average (2001-2019) annual energy output. For comparison, the standard deviation of annual generation for this location was 58 MWh/MW-DC or 2.7%. In other words, the fire season impact was two standard deviations of the historical interannual variability caused by cloud cover. The implication is that wildfires rival cloud cover as a production risk for some projects.

At Boulder, the Aug.- Oct. 2020 deviations totaled -38 MWh/MW-DC, equivalent to -2.0% of the historical average (2001-2019) annual energy output. For comparison, the standard deviation of annual generation for this location was 45 MWh/MW-DC or 2.4%. The deviations at Boulder are within the historical range; despite a record fire season, cloud cover is still the major variable in energy production.

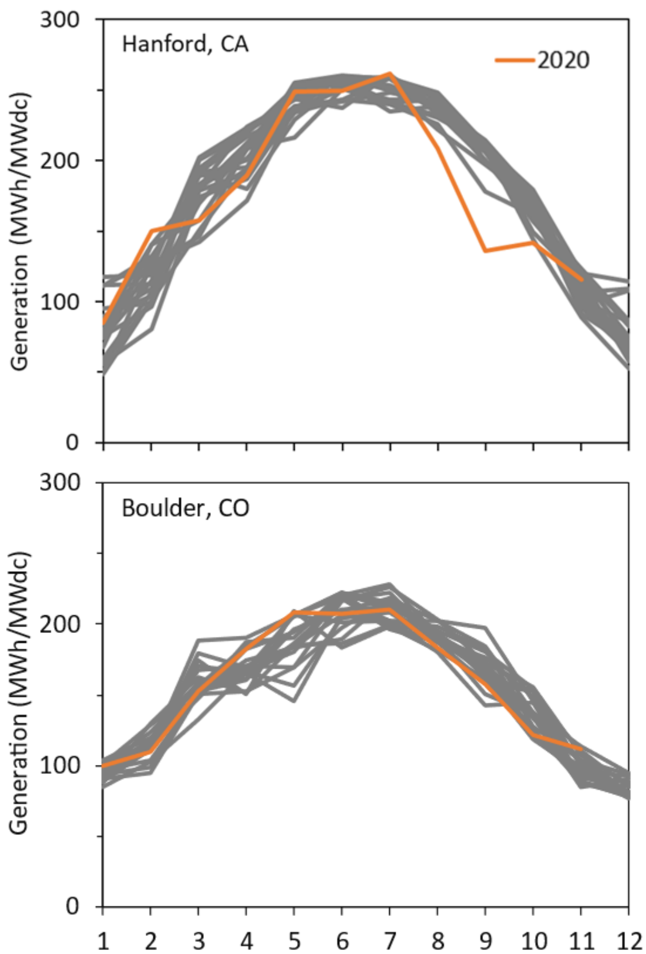


Fig. 5. Modeled monthly energy production 2001-2020 for typical single-axis tracking PV systems located at Hanford, CA and Boulder, CO.

## V. Conclusions

This study leverages solar models to quantify the solar impacts of wildfire smoke in western North America 2001 – November 2020. We observe a sharp increase in the number of days impacted by aerosol events. Record deviations in clear sky DNI are found at the Hanford, CA, Boulder, CO, and Desert Rock, NV study locations. Total sunlight (GHI) for September was diminished by up to 20% in some locations; California's Central Valley and parts of the Columbia River Basin were hardest hit by the smoke. At the Hanford study location, the Aug.- Oct. 2020 deviations in modeled energy output totaled -5.9% of the historical annual average (2001-2019). The analysis demonstrates that wildfires are an important risk to production for solar projects in western North America.

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