Satellite-to-Irradiance Modeling – A New Version of the SUNY Model

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***Abstract* — This article presents and validates the latest version of the SUNY satellite model. In the future this new model will be deployed operationally as part of SolarAnywhere. The new version includes an improved treatment of clear sky, the ingestion of now-casting numerical weather predictions, and a more effective treatment of the model's dynamic range to better represent extreme (clear and overcast) conditions. This new version results in substantial performance improvement across a diversity of climates.**

***Index Terms* — models, satellite, simulation, solar data, solar resource.**

I. Introduction

The first version of the SUNY model was introduced in 2002 [1] based upon the work of Cano et al. [2] and Zelenka et al., [3]. Version 2 was introduced in 2004 to overcome issues associated with arid regions where specular ground reflectivity could be misinterpreted as clouds [4]. This second version was used to produce the National Solar Resource Data Bases (NSRDB) and became the engine of SolarAnywhere [5]. The model was continuously improved over the years and geographical resolution was enhanced to the native satellite's resolution (1 km). The introduction of satellite IR sensors to improve performance during ground snow cover conditions [6] led to Version 3. This article presents Version 4.

II. Methodology

Version 4 introduces three new modeling elements:

1. An improved source of aerosol optical depth (AOD)
2. The ingestion of short term forecasts (now-casts) driven in part by numerical weather prediction (NWP) models
3. A better (empirical) treatment of the model's dynamic range to better reflect observations during very clear and highly overcast conditions.

Improved AOD: The SUNY model is a semi-empirical model [7] whereby a clear-sky radiative transfer model is modulated by a cloud index extracted from satellite images. The transfer model is primarily driven by the AOD[1]. Until recently the model relied on climatological monthly means developed by NREL in the 1990's [8]. Since then remote sensing retrieval, ground measurements, and transport models have allowed for a better characterization of AOD. Applying observations from a large number of sites equipped with multiwavelength sunphotometers, gridded data from satellite remote sensing, aerosol transport models, and existing aerosol climatologies, Gueymard [9] produced an improved high resolution gridded AOD database for North America, adjusted for localized ground elevations. The new data base provides month-specific AOD means for the period 2000 through near real-time.

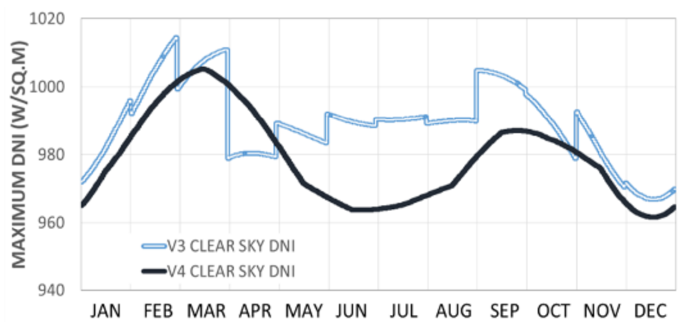

Fig. 1. Comparing maximum hourly clear sky DNI in Desert Rock, NV, for V3 (based on monthly climatological AOD) and V4 (based on interpolated, month-specific AOD.)

Ingestion of nowcasting: In 2013, Perez et al. described a new operational forecast model [10] consisting of an optimum mix of global and regional NWP and cloud motion models. It was observed that the performance of very short term forecasts (nowcasts) tended to better the performance of the satellite model used at the time (Version 3), hence the idea to optimally combine the new forecast mix and Version 3 to enhance performance.

[1] AOD varies as a function of wavelength, here we use AOD at 700 nm, a "neutral" wavelength that can be considered to be representative of the entire solar spectrum

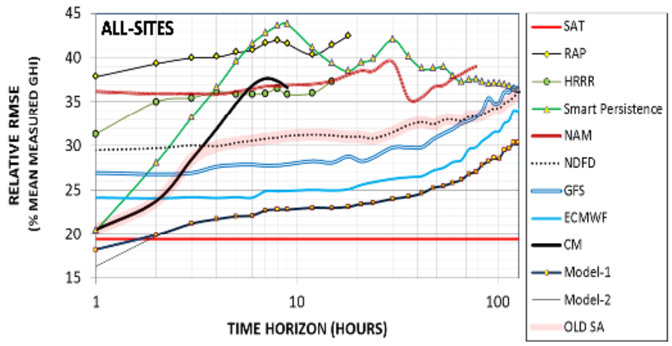

Fig. 2. Forecast model error as a function of time horizon (from [10]). Note how the performance of the shortest-term operational forecast model – Model-1 -- bests the performance of V3 as gauged by the RMSE metric.

Enhanced dynamic range: The satellite model is a bounded model. That is, its maximum and minimum possible values are pre-set. Bounded models tend to underestimate for very high values (because near the upper limit the only possible error is a negative error) and vice-versa, tend to overestimate for very low values. Observing how the bias evolves as a function of the model output let us derive an empirical correction that could be embedded in the model proper.

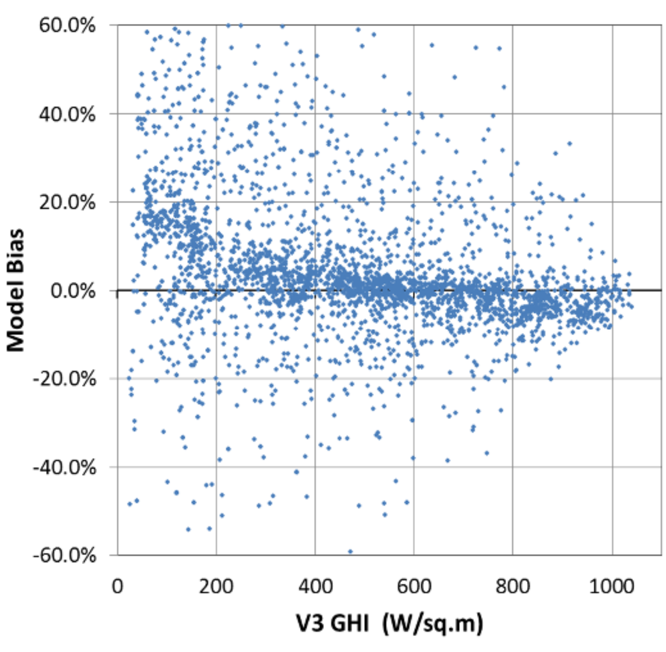

Fig. 3. V3 model bias as a function of predicted irradiance. The negative bias at the high end and positive bias at the low end are a byproduct of the model's underlying bounded structure

III. Results

Eight high accuracy NOAA measurement sites representative of diverse US climates are used for validation (Table 1) for a period spanning 1/1/14 to 10/31/14. These validation data are largely independent from any data used to empirically develop the dynamic range enhancing methodology – a subset (four) of the sites, spanning a different period was used for this purpose.

TABLE I
Model Validation Locations

Site	latitude	longitude	Elevation	Source	climate
Bondville	40.05° N	88.37° W	230 m	NOAA-SURFRAD	Humid Continental
Boulder	40.12° N	105.24° W	1689 m	NOAA-SURFRAD	Semi-arid
Desert Rock	36.62° N	116.02° W	1007 m	NOAA-SURFRAD	Desert
Fort Peck	48.31° N	105.10° W	634 m	NOAA-SURFRAD	Semi-arid
Goodwin Creek	34.25° N	89.87° W	98 m	NOAA-SURFRAD	Humid Subtropical
Penn State	40.72° N	77.93° W	376 m	NOAA-SURFRAD	Humid Continental
Sioux Falls	30.60° N	97.49° W	473 m	NOAA-SURFRAD	Humid Continental
Hanford	36.31° N	119.63° W	73 m	NOAA-ISIS	Mediterranean

Figure 4 compares the global irradiance (GHI) mean bias error (MBE) across eight locations for each model version. Also represented is the MBE range across all sites quantified by the MBE's standard deviation. V4 mean MBE is nearly zero, with a considerably reduced station-to-station range compared to earlier versions. Figure 5 reports the relative root mean square error (RMSE) for all locations. The station-to-station error range, quantified by the RMSE's standard deviation across all sites is also presented. Figures 7 and 8 are identical to Figures 4 and 5, but for the DNI component.

The scatter plot in Figure 8 illustrates an example of model performance for one of the locations (Sioux Falls). The scatter plots in Figures 9 and 10 qualitatively illustrate the performance of all model versions for the DNI component. Figure 9 is an example of an eastern humid continental site (Sioux Falls) and Figure 10 illustrates an arid high-DNI resource western site, Desert Rock.

III. Conclusions

This fourth version of the SUNY model exhibits notable performance improvement over the preceding versions as gauged by the MBE and RMSE metrics. In addition to overall performance improvement observed across a diverse sample of climatic environments, the model also substantially reduces site-to-site performance differences. Version 2 of the model, the model that, until recently, was used as the engine of the NSRDB [8] exhibited a considerable spread in uncertainty with a DNI bias range spanning -12% to 8%. The DNI bias range for version 4 has been reduced to ± 4%. The GHI bias range has been reduced by a factor of two down to ± 2%.

Version 4 will, after further code streamlining, replace Version 3 as the engine of SolarAnywhere [5], providing its users with an increased level of confidence for both site characterization and operational applications such as PV fleet monitoring (e.g., [11]).

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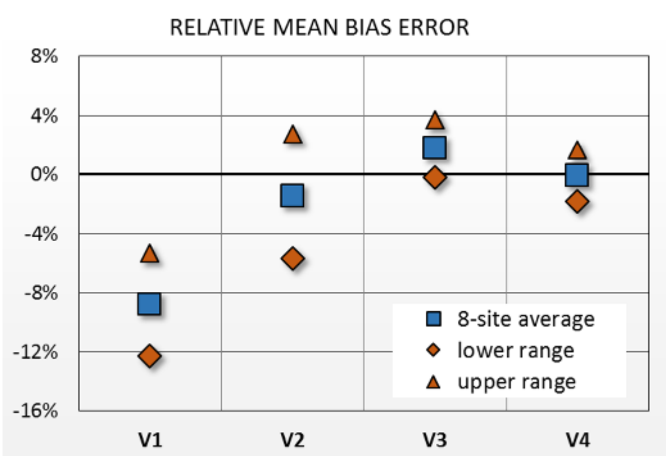

Fig. 4. Comparing Relative GHI MBE for each model version

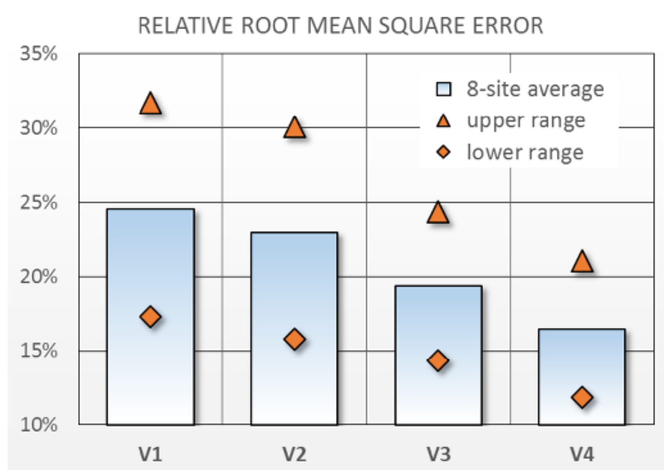

Fig. 5. Comparing Relative GHI RMSE for each model version

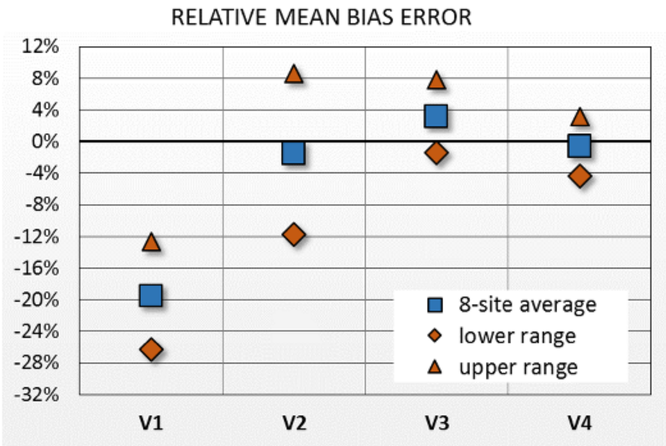

Fig. 6. Same as Figure 4, but DNI

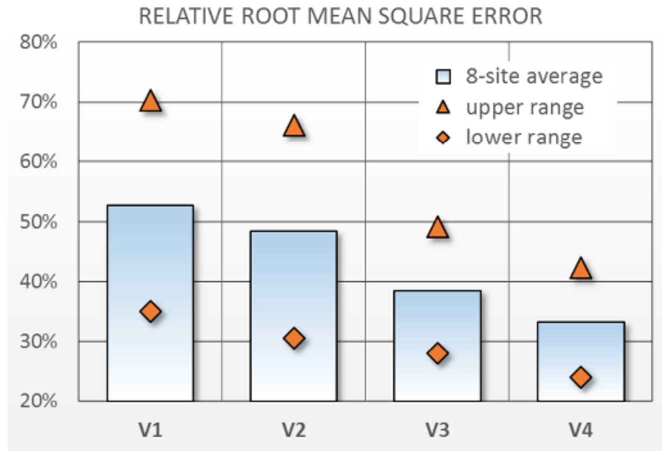

Fig. 7. Same as Figure 5, but DNI

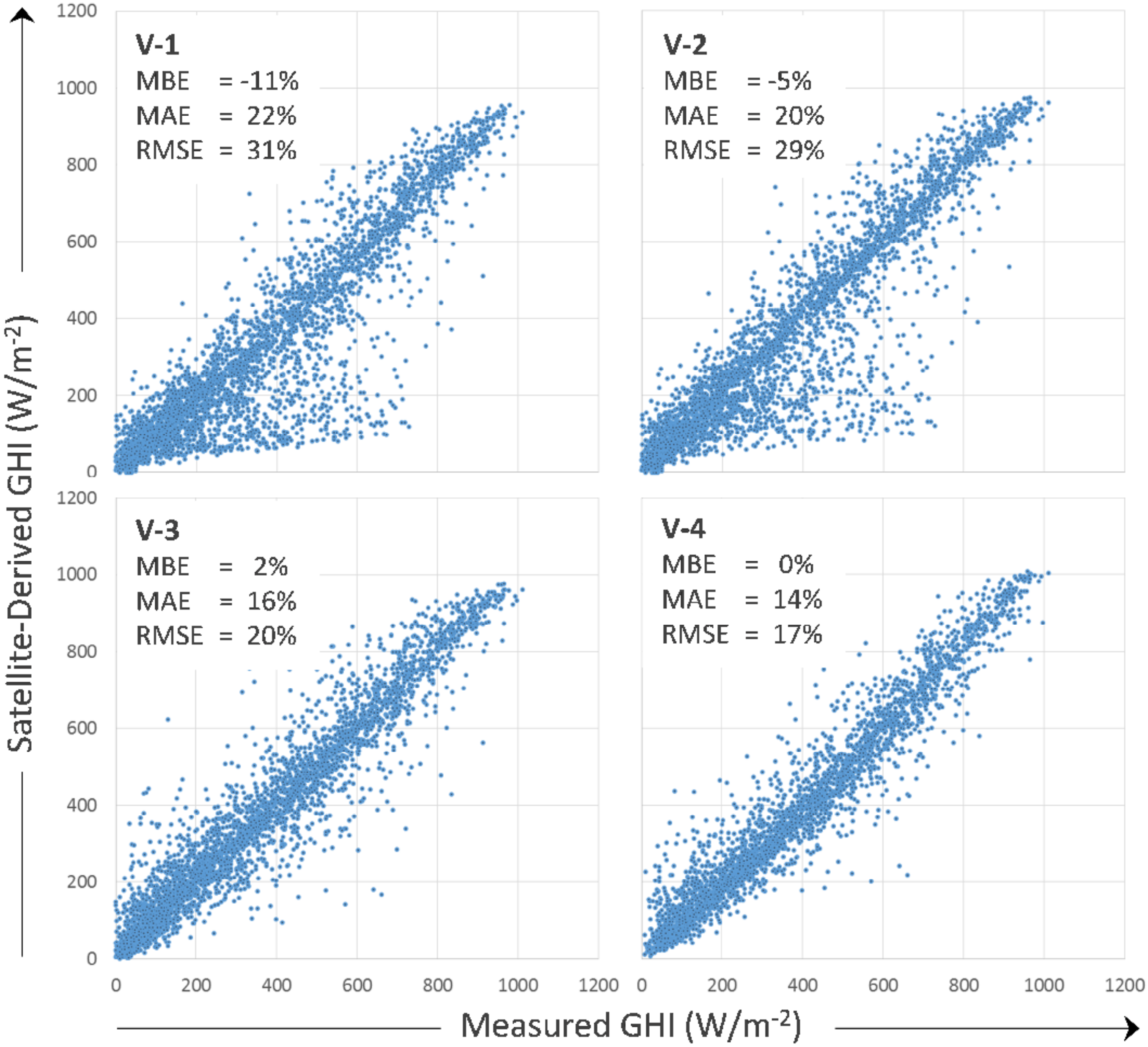

Fig. 8. Comparing GHI models versions performance for Sioux Falls – note that Sioux Falls was not one of the sites used to develop the empirical dynamic range enhancing methodology

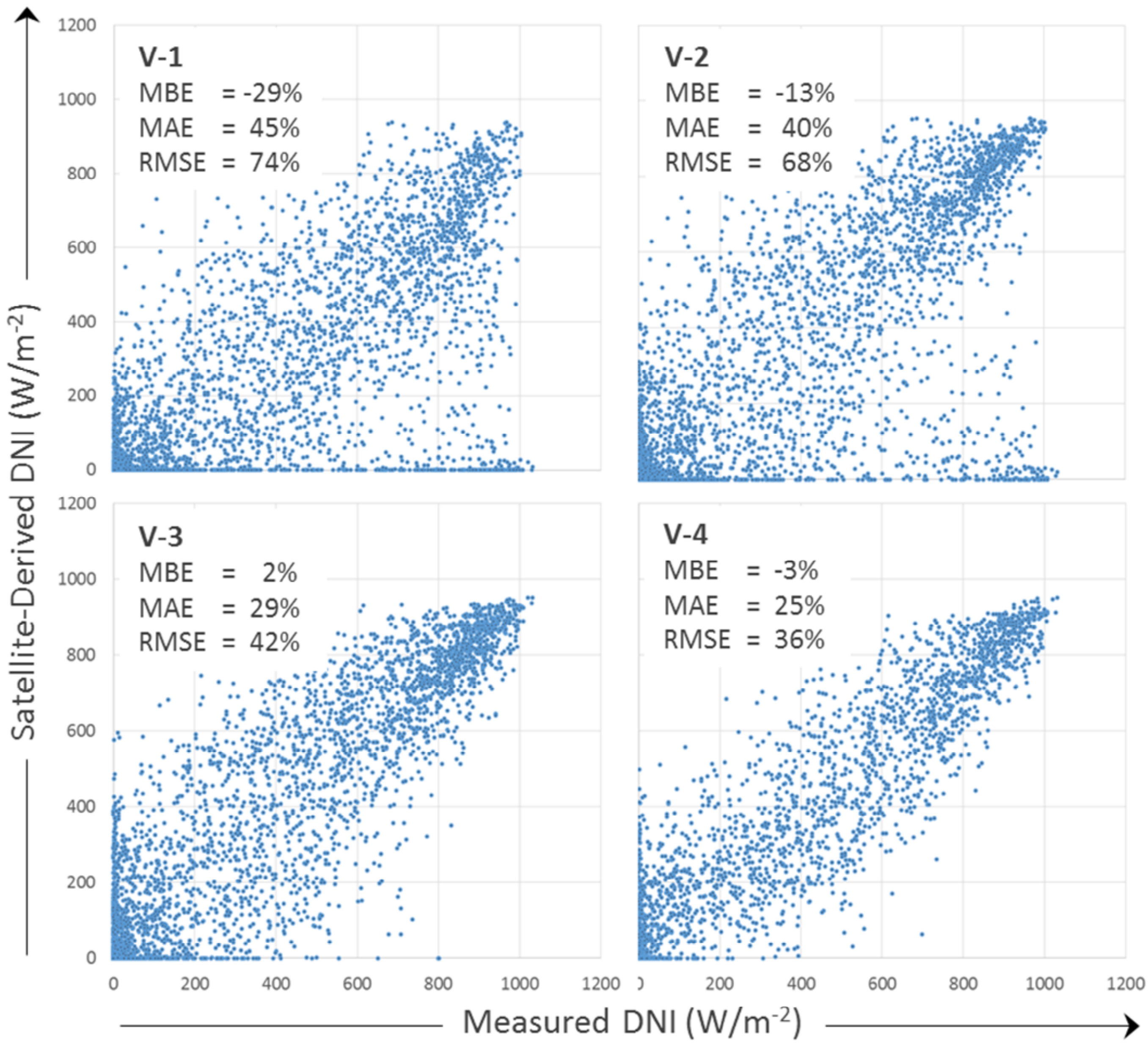

Fig. 9. Comparing DNI models versions performance for an eastern US location -- Sioux Falls. Note that Sioux Falls was not one of the sites used to develop the empirical dynamic range enhancing methodology

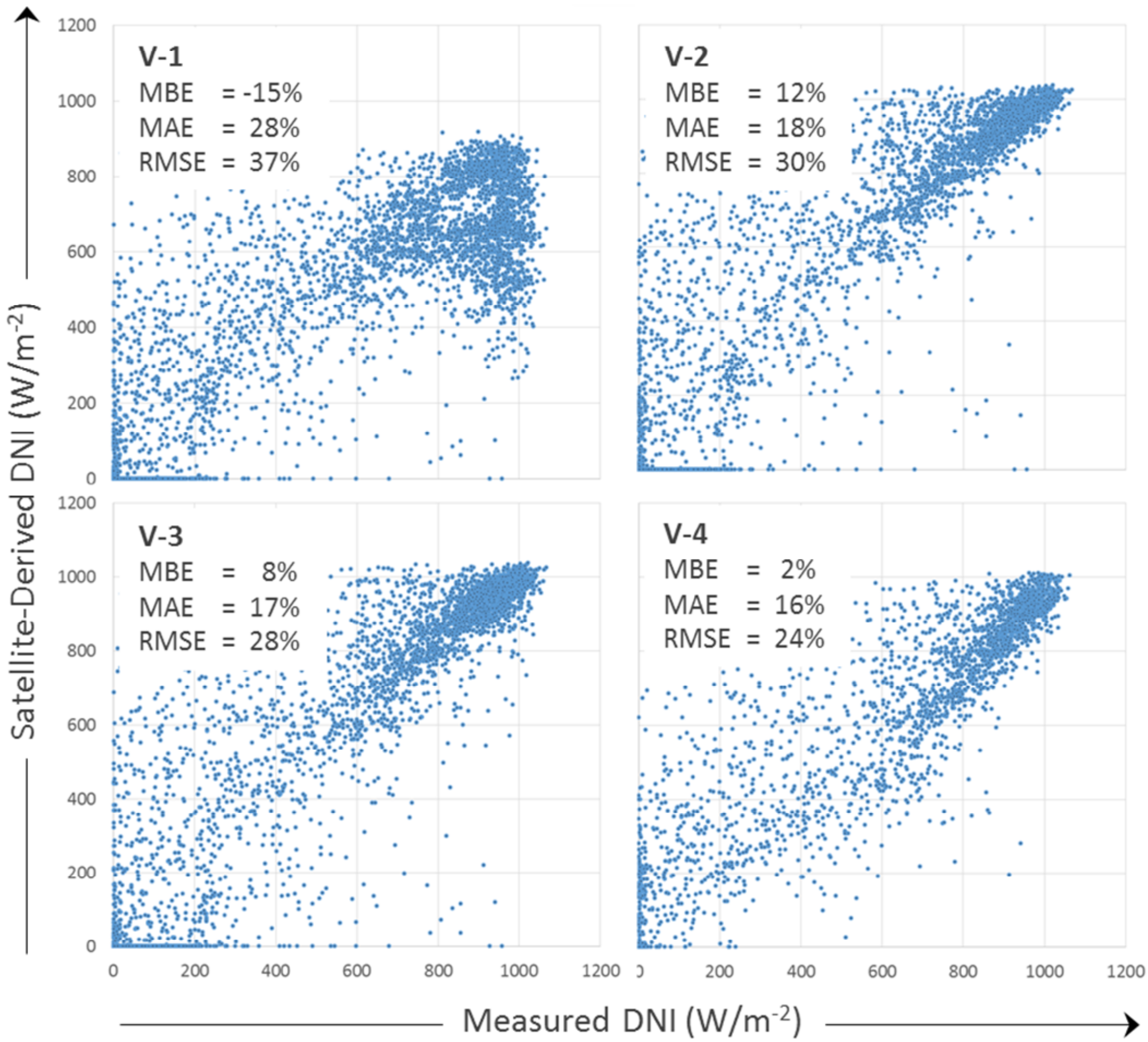

Fig. 10. Comparing DNI models versions performance for a western US location – Desert Rock. This location was one of the sites used to develop the empirical dynamic range enhancing methodology.