ACCURACY REPORT OF STEP SOLAR SITE ANALYSIS TOOL

An independent test was conducted to determine the accuracy of Step Solar tool. The procedure of the test and its results are discussed in this report.

ABSTRACT

Overall the SR_SAT performed very well, and the largest difference between the energy predicted for a month by the SR_SAT and physical calculations was about 2%. It should be mentioned that the physical measurements and calculations have some uncertainty and the precision of the Step Robotics tool can only be as accurate as the photograph from which the data is taken. Considering these factors, the Step Robotics Site Analysis Tool's performance was excellent.

Dr. Frank Vignola

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INTRO: STEP SOLAR SITE ANALYSIS TOOL

Step Robotics Solution

The Step Solar Solution works by attaching a fish eye lens to the front camera of popular cell phone. There is a custom mobile app available in the Google App store and Apple Store.

The application uses the different tilt sensors of a mobile phone along with the electronic compass to capture a skyline.

Once a skyline is captured, the mobile phone processes the image to determine the sky and non-sky pixel. Based on the GPS location, the mobile uses the most appropriate weather data to determine

I. Shading file
II. Insolation file.

Processing and Backup on the Cloud Network

The data is synchronized with the cloud backend. The cloud data is used to run NREL based simulations on the cloud processor to generate

I. Client report
II. PV watts production data
III. Detailed production report from different equipment.

Step Robotics tool works both online and offline, when the data network is not available, the points are captured, and analyzed locally on the mobile phone. The points are synced to the cloud as soon as a data network is available to the mobile device.

Installer and Sales-Rep Web Portals

Step Robotics also offers a backend web portal where an installer and his manager can watch in real time, the progress of site analysis.

Step Robotics Lens Design

Step Robotics has developed its own custom lens for use with its application. There are currently two lens

1) FYD lens - For recent Samsung phones
2) FYA-v4 lens - For iPhone and several low field of view mobile phones.

Both of the lens are specifically designed to

1) To give complete 180 field of view for the phone.
2) Reduce glare from sun

- FYA-v4 lens also has a specifically designed phone cover that slides on an iPhone 6 and 6s and holds the lens in place.

Figure 1: IOS Mobile App

Figure 2: IOS Mobile case

Figure 3: Android Mobile App

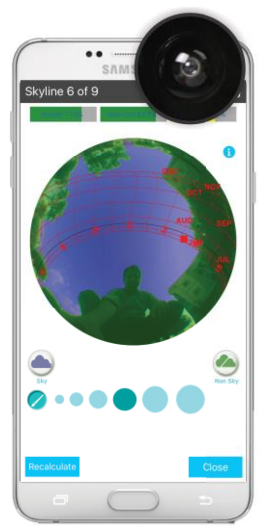

Figure 4: App Lens

BIO SUMMARY: Dr. Frank Vignola

Dr. Frank Vignola

Director, University of Oregon

Solar Radiation Monitoring Laboratory

UO faculty: member since 1977
Rank: Senior Research Associate

Degrees

B.A., University of California, Berkeley, Physics, 1967.

M.S., University of Oregon, Physics, 1969.

Ph.D., University of Oregon, Physics, 1975.

Positions

Senior Research Associate	Physics Department, University of Oregon 1984-present.
Visiting Assistant Professor	Physics Department, University of Oregon, 1986, 1987, 1988.
Research Associate	Physics Department, University of Oregon, 1977-1984.

Executive Summary

The StepRobotics Site Assessment Tool provides a reliable estimate of shading from a point source view. Comparisons with the Solmetric Suneye show a comparable degree of accuracy. When compared to a measured horizon, the SR_SAT slightly underestimates the area of the obstruction as calculated. This likely results from a slight distortion of the location of the obstacle ~2 to 3° with uncertainty of ±1° to 2°. This comparison is made against one instrument and will likely vary slightly from instrument to instrument. For most instances this difference will result in only a percent or two difference in the perceived shading. When there is a large obstruction that is close to device, a 2° distortion can result in larger uncertainties. This should not be much of a factor as holding the devise at different levels will produce similar or greater uncertainties when any obstruction identification is used under these unrealistic conditions.

The method used to determine the shaded area is skewed to the east because the determination of the shading is made when at the end of the data interval and when the sun is moving from an unshaded area to a shaded area, the area is counted as shaded, but if the sun moves from a shaded area to an unshaded area, the area is not counted as shaded. One can remove the skew by determining the shading in the middle of the interval. Another method is to determine the shading at both the beginning and end of the period. If there is shading at either point, then shading should be indicated. This will slightly overestimate the amount of shading from a single point of view. However, this methodology and any other single image methodology will underestimate the shading because the shadow can move across the array and amount of shading is actually larger because of the moving shadow. This is especially true if the obstacle is large enough to shade a fair portion of any PV module. Therefore, slightly overestimating the shading would bring the model predictions closer to the actual production levels.

The SR_SAT tool is valuable because it implements a shading estimation methodology that is already established. The tool is fairly simple to use after going through trial runs to learn the locations of various features. These features are fairly obvious, but like any app on a smartphone, it helps to become familiar with the app before it is used in the field.

Research Content: Uncertainty in the Step Robotics Site Analysis Tool

In an earlier report, comparisons were made between the Step Robotics Site Analysis Tool (SR_SAT) and the Solar Metric SunEye site analysis tool. The uncertainties in both tools were comparable against physical obstructions erected for the tests. Since those initial tests, the software program for the SR_SAT has been improved. The latest studies were performed just against the physical obstructions to determine accuracy of the SR_SAT predictions.

A description of the test setup will be given and then the comparison of the SR_SAT against calculated shading from the test obstructions will be made. This will be followed by a discussion of the results. **Overall the SR_SAT performed very well, and the largest difference between the energy predicted for a month by the SR_SAT and physical calculations was about 2%. It should be mentioned that the physical measurements and calculations have some uncertainty and the precision of the Step Robotics tool can only be as accurate as the photograph from which the data is taken. Considering these factors, the Step Robotics Site Analysis Tool's performance was excellent**.

Recent tests

A series of four tests were performed on an artificial shading structure. This was a board measuring 0.375 meters wide and 1.58 meters high mounted vertically (vertical distance was measured from the height above the cell phone). The cell phone with the SR_SAT was placed horizontal, centered on the board and oriented due south. Two distances between the board and the cell phone were used (2.01 meters – far; and 0.515 meters – near). Then the board was moved to the east and the board was place far (1.995 meters) and near (0.515 meters). Only these configurations for tests were used as earlier results showed that there was consistency wherever the boards were place.

- For the board positioned to the south, when the board was placed in the far position shading occurred during the winter months and left the summer months unaffected. When the board was placed in the near position there was shading during all months.
- For the board positioned to the east, when the board was placed in the far position, shading occurred only for the late fall through the early spring months because the sun rose south of the board and thus the location was unshaded. When the board was placed in the near position, the period of shading increased. However there were still periods when the sun rose south of the board and thus did not provide any shading.

For the measured estimate of shading, each day was broken up into 15 minute periods. The location of the sun was computed at these time intervals. For example, the location of the sun was computed at 8:00, 8:15, 8:30, 8:45, 9:00 etc. These periods were marked as shaded if shading occurred at this time. This methodology is skewed when the sun is moving from a shaded area to an unshaded area, the angles are calculated at the end of the period when there is no shading. While when the sun moves from a sunny area to a shaded area, the angles are calculated at the end of the period when there is shading. While this method doesn't underestimate the period of shading because the overestimate in when shading starts is statistically balanced by the underestimate of shading when the shading ends, is does shift the shading period a few degrees to the east. (This issue has been addressed and fixed in our later versions of the software)

Note that no contributions to the irradiance or shading were included when the sun was within 5^o of the horizon. Again, the same skewing results as in the shading / unshading analysis.

Because we knew the size of the board, the distance from the camera to the board, and the orientation of the board with respect to the cell phone, the azimuthal angle and solar zenith angle of the edges of the board were computed. When the location of the sun was inside the area of the sky covered by the board, the corresponding time period was considered shaded. This comparison was made for all 15 minute time intervals for the entire year.

To compute the shading of the board using the StepRobotics algorithm, the standard procedure was followed to create the Step Robotic files. The cell phone was aligned due South during the experiment to within ± 1°. Adjustments were made to the True North parameter of the cell phone to reflect this. The compass in the cell phone can deviate significantly from the actual alignment. With deviations as great as ± 10°. Also, the images were adjusted using the "sky", "not sky" feature of the App to eliminate shading from other nearby objects so that only shading from the board was considered. The photographs were analyzed by the StepRobotics algorithm and each time period was considered either Shaded or Unshaded depending on the SR_SAT determination of location of the sun and the location of the board. The SR_SAT performed this operation for each 15 minute period for the entire year.

Test Results

The following plots and discussion illustrate the degree of match between the Step Robotics Solar Analytical Tool and the calculated shading from the tests. The first test was on the far south facing obstruction. This will test the SR_SAT when the sun is low in the sky. The shading only occurs from late fall through early spring as shown in Fig. 1. For a more direct comparison of the results shown in Fig. 1 a count the number of 15 minute periods that differed in their shading predictions was made (See Fig. 2). Much of the difference occurred in the early spring and late fall when the measurements predicted that the top of the board began to shade. From February 23 through March 1 and from October 12 through October 18, the SR_SAT predicted no shading while the calculated measurements indicated shading. This represented a daily average irradiance difference of approximately 10% during those time periods. However, this is only ¼ of the month, so the monthly average values would be off by about 2.5%.

From February 23 through March 1, 2015, the solar zenith angle at noon went from 52.5 to 54.8 degrees. The shading actually starts when the SZA reaches 51.8, so there is about a 3 degree period that the SR_SAT does not see the top of the obstacle. This difference is equivalent to the board being about 10% shorter (16 cm) than it is measured. This gives an estimate of the accuracy of the SR_SAT measurement of about ±3°. This can be compared to the uncertainty in the physical determination of the angles of between ±1° to 2°.

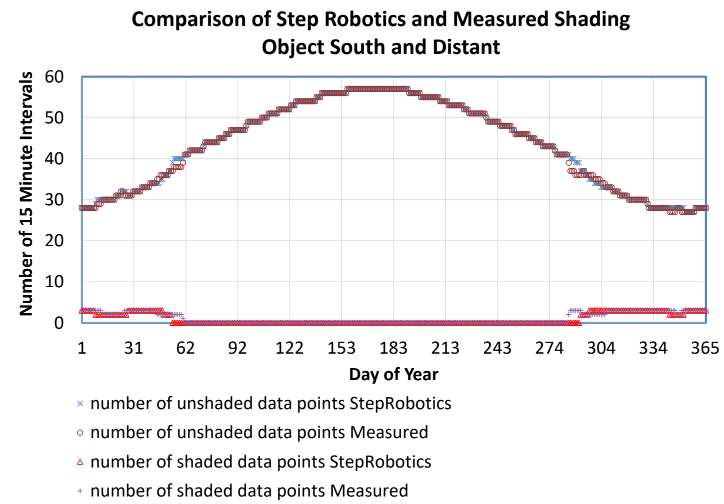

Fig.1: Comparison of SR_SAT and measured shading for an object low in the horizon facing south. The number of 15-minute intervals with and without shading is plotted against the day of the year.

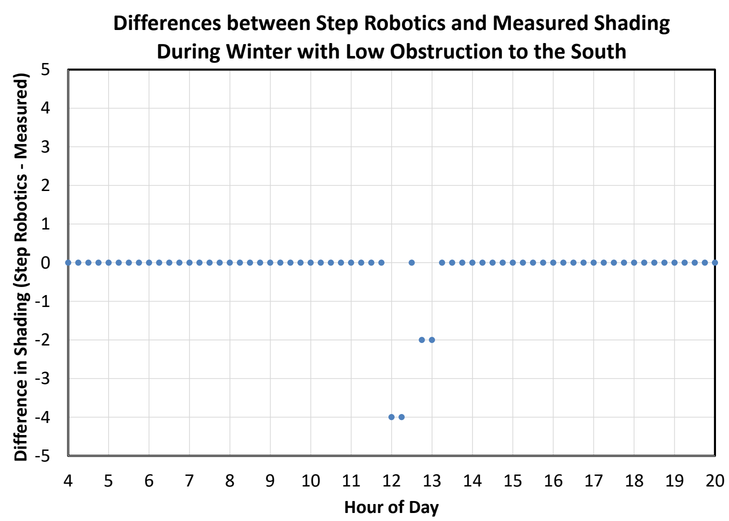

Fig.2: Number of 15 minute periods that there was a difference in modeled and calculated shading for the three winter months. Each 15 minute interval had 92 periods where the shading could differ.

The obstacle is about 11° wide when it is far from the SR_SAT. Since the sun moves a little less than 4° for 15 minute interval, there are only about 3 intervals that are affected by shading. There were two to three 15-minute periods of shading per day when the SR_SAT predicted no shading. When the shading started to show up on the SR_SAT, then there was at most one period of shading difference (see Fig. 2). When the board was install close to the SR_SAT, it shaded the sky even during the summer months. A comparison of shading with the board close is given in Fig. 3. This image shows that the SR_SAT again underestimates the height of the obstacle. The obstacle is 40° wide. Given that the sun moves 15 degrees per hour, a maximum number of shaded periods is 11, which occurs during the winter months.

During the summer months, the sun will rise above the obstacle at solar noon and only be shaded when the sun is lower in the sky. This effect is shown in Fig. 4 where the difference between the number of measured shaded periods is subtracted from SR_SAT shaded periods. The large difference reflect the periods when the SR_SAT saw no shading. The difference is not symmetrical which indicates the SR_SAT image is not lined up perfectly with the obstacle. In June, where most of the problem occurs, the difference in monthly estimated irradiance is almost 14%. With the effect of measured shading greater than that of the SR_SAT. Again, this results from the underestimation of the obstacle angular height by about 2 to 3°. This is an extreme test to identify the maximum possible uncertainty. Hopefully a photovoltaic system would never be positioned such that it would be shaded during the middle of the day in summer. Given the uncertainty of measured angular height, such large difference will not be experience in practice. During other times of year, the difference is not symmetrical around

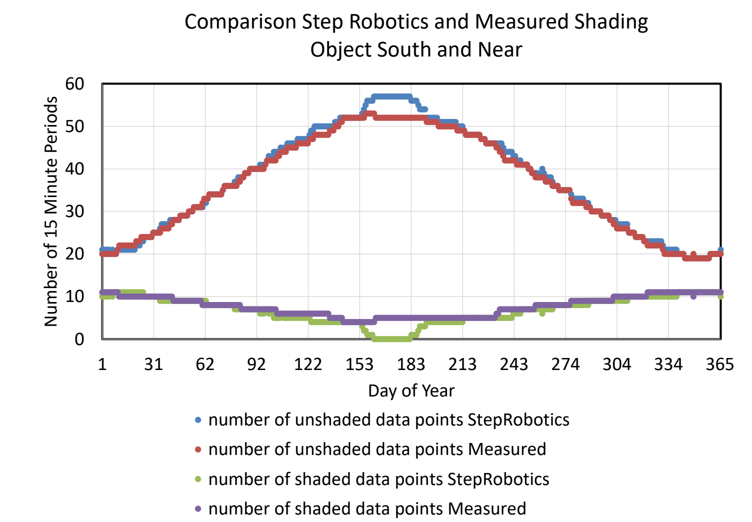

Fig.2: Comparison of SR_SAT and measured shading for a large object directly to the south. The number of 15-minute intervals with and without shading is plotted against the day of the year.

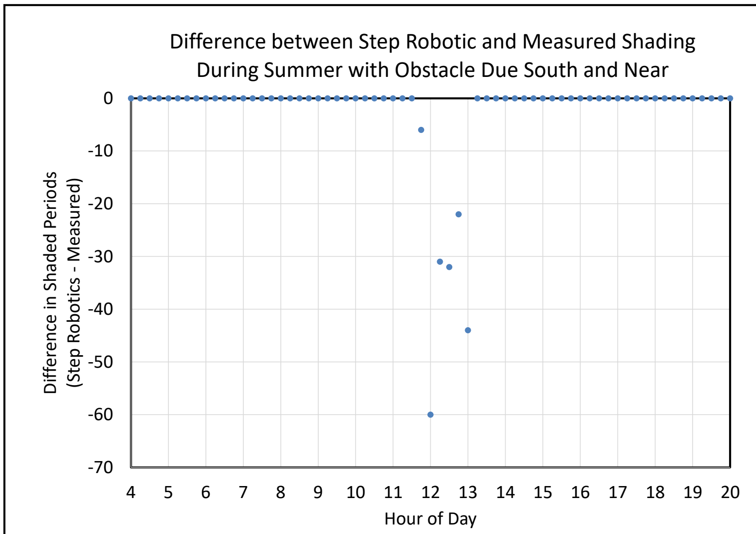

Fig.4: Number of 15 minute periods that there was a difference in modeled and calculated shading for the three summer months. Each 15 minute interval had 91 periods where the shading could differ.

solar noon, indication there is also an azimuthal alignment problem as discussed earlier.

It is also worthwhile to examine the shading from an obstacle that is not due south of the cell phone. This was done when the board was set up due east of cell phone. During the winter months, the sun rises south of the east west line and it is only when the sun rises with an azimuth of less than 95° does the board is located far from the site (low in the horizon) shade the cell phone. When the board in near and to the east, shading occurs when the sun rises with an azimuthal angle less than 110°. The predicted shading differences between the SR_SAT and the measurements are shown in Figs. 5 and 6.

When the obstacle is low in the horizon, there are periods in the summer when the sun is near the top of the board. During part of this period, the measurements indicate that there should be shading. However, the SR_SAT indicates that there is no shading. This is the same phenomena that occurred when the obstacle was near and due south. The SR_SAT is underestimating the angular height of the obstacle. This results in only a 2% overestimate of the irradiance during the June. When the board is closer and presents a bigger obstacle, the difference in irradiance is only about 0.5%. While the shading is still slightly underestimated by the Step Robotics tool, the sun mostly passes behind the obstacle and not near the top.

Again, the exact orientation of the obstacle as determined by the measurements and by the SR_SAT are not identical. This can be seen in Fig. 7 that plots the difference in shading during the summer months when the obstacle is due east and near. There are periods when the measurement sees shading and the SR_SAT does not, but there are also periods when the

SR_SAT sees shading and the measurements do not predict shading. A shift of orientation by a few degrees would change this result.

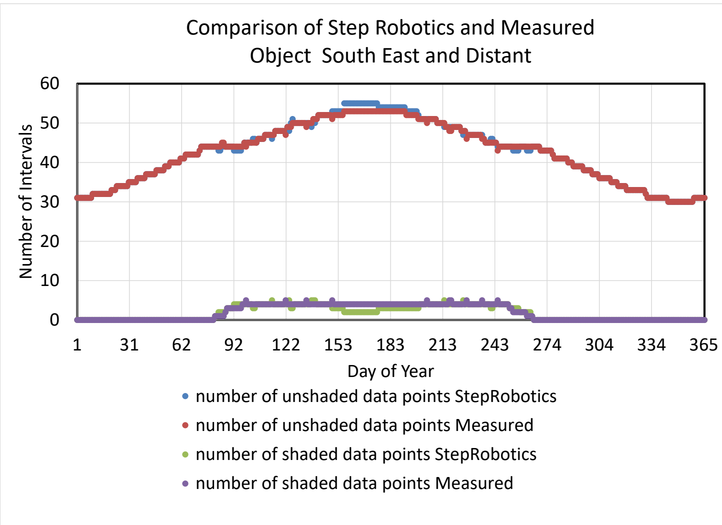

Fig.5: Comparison of SR_SAT and measured shading for a small object due south. The number of 15-minute intervals with and without shading is plotted against the day of the year.

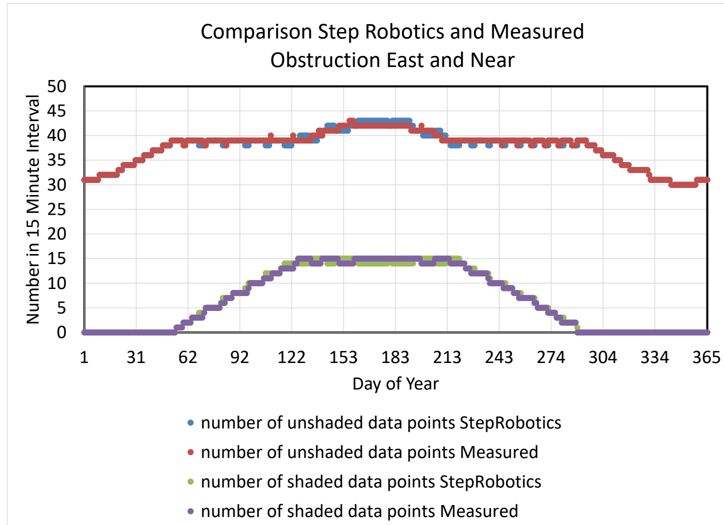

Fig.6: Comparison of SR_SAT and measured shading for a large object due. The number of 15-minute intervals with and without shading is plotted against the day of the year.

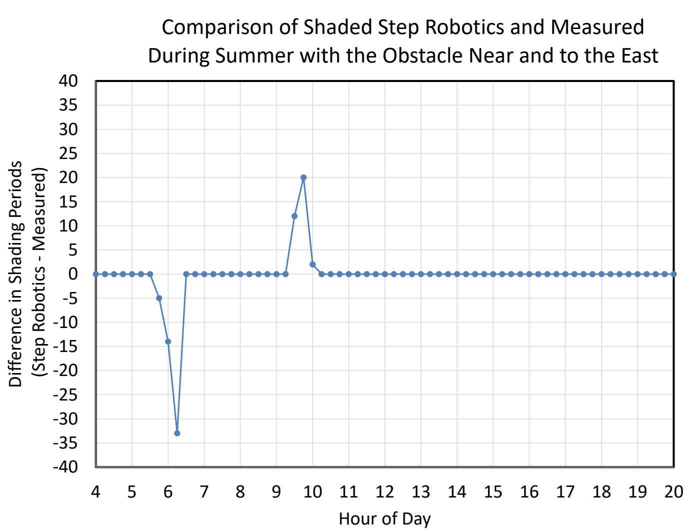

Fig.7: Number of 15 minute periods that there was a difference in modeled and calculated shading for the three summer months. Each 15 minute interval had 91 periods where the shading could differ.

Detailed BIO: Dr. Frank Vignola

Memberships

International Solar Energy Society
Fellow, American Solar Energy Society

Professional activities

- Associate Editor for Resource Assessment for *Solar Energy*, 2007 to present. Reviewer for *Solar Energy*, 1982-1990, 1994-present. Associate Editor for resource assessment for *Solar Energy*'s special ISES conference Harrare Edition, 1995-1996.
- Board member of the Resource Assessment Division of the American Solar Energy Society (ASES) 1986-1989, 1992-1993, 1995-1996. Vice-Chair in 1988, 2002 and Chair in 1989, 2003.
- Founder and Editor of *Solar Spectrum*, newsletter for the Resource Assessment Division of ASES 1988-2006. Editor of *Solar Rising*, newsletter for the Oregon Solar Energy Industries Association 1998-2006.
- Board member of the American Solar Energy Society, 1989-1991, 2002. Chair of the Issues and Technical Assessment Committee of ASES, 1989-1996. Member of the Technical Review Committee for ASES's annual conference in 1990, 1993, and 1995. Technical Review Committee Chair for SOLAR '94 and SOLAR 2004. Member of National, State, and Local Policy Committee of ASES, 1996-present. Board member of the Solar Energy Industries Association 2000.
- Recipient of the 1996 ASES special recognition award for outstanding volunteer service.
- Organized and led the 1997 Pacific Northwest Radiometer Workshop in Eugene, Oregon and the 2002 Use of Solar Radiation Data Workshop in Eugene, Oregon.

Research goals

- Create a sound solar resource assessment data base in the Pacific Northwest to facilitate the deployment of solar electric technologies.
- Develop tools to facilitate the use of solar radiation data.
- Operate a high quality outdoor PV module testing lab for education and as a fee for service facility.
- Produce and support a solar education kit with curriculum to energize and excite the next generation.
- Offer workshops and educational material on the use of the solar radiation data base.
- Provide consulting on the development and deployment of solar energy technologies.

Selected publications

2014 PV Module Performance After 30 Years Without Washing, InterSolar North America, San Francisco, CA, (2014) (with Josh Peterson, Rich Kessles, Fuding Lin, Bill Marion, Allan Anderberg, and Fotis Mavromatakis)

2014 Effects if Changing Spectral Radiation Distribution on the Performance of Photodiode Pyranometers, InterSolar North America, San Francisco, CA (2014) (with Zachary Derocher, Josh Peterson, Laurent Vuilleumier, Christian Felix, Julian Grobner, and Natalia Kouremeti)

2014 Measuring and Estimating the Temperature of Photovoltaic Modules, Solar Energy, (2014) (with F. Mavromatakis, E. Kavoussanaki, and Y. Franghiadakis)

2014 Accuracy of Ground Surface Broadband Shortwave Radiation Monitoring, JGR: Atmosphere, (2014) (with L. Vuilleumier, M. Hauser, C. Felix, P. Blanc, A. Kazantzidis, and B. Calpini)

2014 New Data Set for Validating PV Module Performance Models, Proc. IEEE PVSC, Denver, CO, June 2014) (with Bill Marion, Allan Anderberg, Chris Deline, Joe del Cueto, Matt Muller, Greg Perrin, Jose Rodriguez, Steve Rummel, Timothy J. Silverman, Rich Kessler, Josh Peterson, Steve Barkaszi, Mark Jacobs, Nick Riedel, Larry Pratt, and Bruce King)

2013 Solar Energy Forecasting and Resources Assessment, Elsevier Press, 2013, Evaluation of Resource Risk In Solar-Project Financing - chapters 4, and Bankable Solar-Radiation Datasets � Chapters 4 & 5 (with Cathy Grover and Andrew McMahan)

2013 Providing High Quality Data to Develop and Validate PV Models, Solar 2013, American Solar Energy Society, Baltimore, MD, (2013) (with Rich Kessler, Fuding Lin, Bill Marion, and Josh Peterson)

2012 Solar and Infrared Radiation Measurements, CRC Press, 2012 (with Joseph Michalsky and Thomas Stoffel)

2012 Building a bankable solar radiation dataset, Solar Energy (2012) (with Cathy Gover, Nick Lemon, and Andrew McMahan)

2012 Spectral Distributions of Diffuse and Global Irradiance for Clear and Cloudy Periods, Proceedings of the World Energy Forum, Denver, CO, (2012) (with Gina Blackburn)

2012 GHI Corrleations with DHI and DNI and the Effects of Cloudiness on one-minute Data, Proceedings of the World Energy Forum, Denver, CO, (2012)

2011 building a Bankable Solar Radiation Dataset, Proc. Solar 2011, American Solar Energy Society, Raleigh, NC, (2011) (with Cathy Grover, Nick Lemon)

2011 Characterizing the Performance of an Eppley Normal Incident Pyrheliometer, Proc. Solar 2011, American Solar Energy Society, Raleigh, NC, (2011) (with Fuding Lin)

2010 Evaluating Calibrations of Normal Incident Pyrheliometers, Proc. SPIE Conference, San Diego, CA, (2010) (with Fuding Lin)

2010 Energizing the Next Generation with Photovoltaics, Proc. Solar 2010, American Solar Energy Society, Phoenix, AZ, (2010) (with Stanley Miklavzina, Sam Daniels, Mike Toamina, Sadie Thorin, Igor Tyukhov, and Anton Tikhonov)

2010 Evaluation of a Prototype Solar Awning, Proc. Solar 2010, American Solar Energy Society, Phoenix, AZ, (2010) (with Peter Harlan, Rich Kessler, Ihab Elzeyadi, Bob Simonton, and Fotis Mavromatakis)

2009 Testing a Model of IR Radiative Losses, Proc. SPIE Conference, San Diego, CA, (2009) (with Charles N. Long, Ibrahim Reda)

2008 Modeling of Solar Irradiance Using Satellite Images and Direct Terrestrial Measurements with PV Modules, Proc. SPIE Conference, San Diego, CA (2009) (with Igor Tyukhov, Michael Schakhramanyan, Dmitry Strebkov, Anton Tikhonov)

2009 Measuring Degradation of Photovoltaic Module Performance in the Field, Proc. Solar 2009, American Solar Energy Society, Buffalo, NY, (2009) (with Jim Krumsick, Fotis Mavromatakis, and Robert Walwyn)

2008 �Analyzing the contribution of aerosols to an observed increase in direct normal irradiance in Oregon�, J. Geophys. Res., 114, D00D02, doi:10.1029/2008JD010970 (with L.D. Riihimaki, and C. N. Long)

2008 Modeling IR Radiative Loss from Eppley PSP Pyranometers *Proc. SPIE Conference,* San Diego, CA, (2008) (with Chuck Long and Ibrahim Reda)

2008 Establishing a Consistent Calibration Record for Eppley PSPs *Proc. of the 37th ASES Annual Conference* San Diego, CA, (2008) (with Laura Riihimaki)

2008 Performance of PV Inverters *Proc. of the 37th ASES Annual Conference,* San Diego, CA, (2008) (with Fotis Mavromatakis and Jim Krumsick)

2008 Combined solar PV and Earth space monitoring technology for educational and research purposes *Proc. of the 37th ASES Annual Conference*, San Diego, CA (2008) (with Igor Tyukhov, Michael Schakhramanyan, Dmitry. Strebkov, and Sergey Mazanov)

2007 Analysis of satellite derived beam and global solar radiation data, *Solar Energy* 81, 768-772 (2007) (with Peter Harlan, Richard Perez, and Marek Kmiecik)

2008 Evaluation of Methods to Correct for IR Loss in Eppley PSP Diffuse Measurements *Proc. SPIE Conference,* San Diego, CA, (2008) (with Chuck Long and Ibrahim Reda)

2007 Shading on PV Systems: Estimating the Effect *Proc. of the 36th ASES Annual Conference,* Cleveland, OH, (2007)

2007 Discussion of PV Lab Equipment and Photovoltaic Systems for Teaching the Science of Photovoltaics *Proc. of the 36th ASES Annual Conference,* Cleveland, OH, (2007) (with Igor Tyukhov)

2007 Discussion of PV Lab Equipment and Photovoltaic Systems for Teaching the Science of Photovoltaics *Proc. of the 36th ASES Annual Conference,* Cleveland, OH, (2007) (with Igor Tyukhov)

2007 Completing Production of the Updated National Solar Radiation Database for the United States *Proc. of the 36th ASES Annual Conference,* Cleveland, OH, (2007) (with S. Wilcox, M. Anderberg, R. George, W. Marion, D. Myers and D. Renne', National Renewable Energy Laboratory; N. Lott and T. Whitehurst, National Climatic Data Center; W. Beckman, University of Wisconsin; C. Gueymard, Solar Consulting Services; R. Perez, State University of New York at Albany; P. Stackhouse, National Aeronautics and Space Administration)

2006 Long-Term Variability of Global and Beam Irradiance in the Pacific Northwest *Proc. of the 35th ASES Annual Conference,* Denver, CO, (2006) (with Laura Riihimaki, Lohmann, L.S., and Meyer, R., Perez, R)

2006 Removing Systematic Errors from Rotating Shadowband Pyranometer Data *Proc. of the 35th ASES Annual Conference,* Denver, CO (2006)