




U.S. Department of Energy Workshop Report: Solar Resources and Forecasting

T. Stoffel
National Renewable Energy Laboratory

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Technical Report
NREL/TP-5500-55432
June 2012

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NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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Preface

As with any assembly of technical experts and interested stakeholders designed to provide a forum for participants to review and discuss a topic of mutual interest, the success of the Solar Resources and Forecasting Workshop can be measured by the quality of the presentations, engagement of the participants, and overall level of enthusiasm by all interested in the topic at hand. My challenge in preparing this report was to adequately capture the scope and depth of the material, summarize the discussions, and convey the high level of interest displayed by the participants during the course of this three-day event.

This report summarizes the technical presentations, outlines the core research recommendations, and augments the information available on the NREL website www.nrel.gov/ce/solar_workshop/.

Acknowledgments

The workshop was made possible with the support of the Systems Integration Subprogram, led by Kevin Lynn within the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy's Solar Energy Technologies Program. Support from Dave Mooney, director of Electricity, Resources, and Building Systems Integration Center, was also important to each aspect of hosting the event. Joy Gonzales, administrative assistant and cohost of the workshop, provided critical design inputs, key event planning insights, and the many efforts essential to execute the workshop and follow-up. David Glickson ensured the venue met our needs based on his vast experience in event planning. Sarah Hodgson addressed all information technology aspects of the workshop, including webcasting. Dennis Schroeder, NREL photographer, provided wonderful images of the participants and event activities posted on the workshop website. The general support of members of NREL's Solar Resources and Forecasting Group is also appreciated. Brian Keyes, Ryan Smith, and Steve Wilcox hosted informative tours of the Process Development and Integration Laboratory, the Outdoor Test Facility, and the Solar Radiation Research Laboratory. The knowledgeable presenters who freely shared their technical expertise ensured the overall success of the workshop. Finally, the participants must be recognized for their enthusiasm, commitment, and key contributions.

Workshop participants

List of Acronyms

AOD	aerosol optical depth
APS	Arizona Public Service
ARM	Atmospheric Radiation Measurement
ARPS	Advanced Multi-Scale Regional Prediction System
BOS	balance of system(s)
CAISO	California Independent System Operator
CAM5	Community Atmospheric Model Version 5
CESM	Community Earth System Model
CFS	Climate Forecast System
CRADA	cooperative research and development agreement
CSP	concentrating solar power
DNI	direct normal irradiance
DOE	Department of Energy
ECMWF	European Center for Medium-Range Weather Forecasts
ETR	extraterrestrial radiation
FPL	Florida Power and Light
GEM	Global Environmental Multiscale
GFS	Global Forecast System
GHI	global horizontal irradiance
GOES-R	Geostationary Operational Environmental Satellite—R Series
GW	gigawatt(s)
HRRR	High-Resolution Rapid Refresh
IMBY	In My Backyard
IPC	International Pyrheliometer Comparison
ISO	International Standards Organization
Kt*	clearness index (GHI/ETR)
KW	kilowatt(s)
LCOE	levelized cost of energy
MAE	mean absolute error
MASS	Mesoscale Atmospheric Simulation System
MBD	mean bias difference
MBE	mean bias error
METAR	based on the French for "Aviation Routine Weather Report"
MIDC	Measurement and Instrumentation Data Center
MMDT	monthly mean daily total
MODIS	Moderate Resolution Imaging Spectroradiometer (satellite)
MOS	model output statistics
MW	megawatt(s)
NAM	North American Mesoscale
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDFD	National Digital Forecast Database
NERC	North American Electric Reliability Corporation
NESDIS	National Environmental Satellite, Data, and Information Service

NOAA	National Oceanic and Atmospheric Administration
NSRDB	National Solar Radiation Data Base
NWP	numerical weather prediction
P90/P99	probabilities at 90% and 99%
POA	plane of array
POI	point of interconnect
PSLF	positive sequence load flow
PVSyst	photovoltaic system analysis
PVWatts	photovoltaic performance
RMSD	root mean square difference
RMSE	root mean square error
RReDC	Renewable Resource Data Center
RRTMG	rapid radiative transfer model for global circulation modeling
RSP	rotating shadowband pyranometer
RSR	rotating shadowband radiometer
RUC	rapid update cycle
SMS	solar monitoring station
SOLRMAP	Solar Resource and Meteorological Assessment Project
SURFRAD	Surface Radiation Budget Network
TDY	typical direct normal year
TMY	typical meteorological year
WECC	Western Electricity Coordinating Council
WREZ	Western Renewable Energy Zones
WRF	Weather Research and Forecasting
WRR	World Radiometric Reference
WWSIS	Western Wind and Solar Integration Study

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Abstract

The expected sevenfold increase in U.S. solar electrical generation between 2009 and 2035 will include the development of central utility-scale systems and grid-connected distributed sources. This increased use of variable generation based on solar energy conversion will require advanced methods for understanding the available solar radiation resources with temporal and spatial fidelity not currently available.

In support of advancing the science, a Solar Resources and Forecasting Workshop was held to bring together notable specialists in atmospheric science, solar resource assessment, solar energy conversion, and various stakeholders from industry and academia to review recent developments and provide input for planning future research in solar resource characterization, including measurement, modeling, and forecasting. The workshop was held June 20–22, 2011, in Golden, Colorado, with a simultaneous webcast. More than 150 participants benefited from a series of technical presentations and panel discussions addressing best practices for acquiring and applying solar resource data, solar resource forecasting methods and operational needs, and future roles for the public and private sectors in solar resource assessment.

Introduction

The U.S. Energy Information Administration estimates that our nation's electricity demand will grow by 31% from 2009 to reach 4.9 billion MWh by 2035. Electricity generation from solar resources is expected to increase from 2% of non-hydroelectric renewable generation in 2009 (2.3 billion kWh) to more than 5% in 2035 (16.8 billion kWh).[1] This sevenfold increase in solar electrical generation will include the development of central utility-scale systems and grid-connected distributed "rooftop" systems. The U.S. Department of Energy (DOE) launched the SunShot initiative to innovate and lay the foundation for a subsidy-free solar electricity infrastructure that is broadly competitive with conventional fossil fuel. From a utility perspective, solar energy conversion is a weather-driven form of variable generation. The successful integration of solar energy into the national electricity portfolio will require access to historical solar resource information with higher spatiotemporal resolution than is currently available. Additionally, the integration of photovoltaic and concentrating solar power generation into the electrical grid will require the operational ability to predict the available amounts of "solar fuel" for specific locations during various timescales important to electric utilities, independent service organizations, and regional transmission operators.

Workshop Motivation

To address the growing needs for advanced solar resource assessment information, the Solar Resources and Forecasting Workshop was held June 20–22, 2011, in Golden, Colorado. To address the overwhelming response to the workshop announcement, the event was also simultaneously webcast. This event was organized on behalf of the DOE Office of Energy Efficiency and Renewable Energy in support of the Solar Energy Technologies Program and System Integration Subprogram to provide an opportunity for various stakeholders to review recent developments, identify current and future needs for solar resource information, and address various operational aspects of solar resource assessment. The workshop agenda is available in Appendix A. More than 150 atmospheric science and solar energy researchers from industry, academia, and federal laboratories in North America, Asia, and Europe attended the workshop (see Appendix B).

The 2011 workshop content was developed from the results of the previous Solar Resource Assessment Workshop, held October 29–30, 2008, in Denver, Colorado. This first workshop achieved two purposes: (1) it brought together select researchers from the atmospheric science, solar energy engineering, and solar project finance communities to review the current state of knowledge and identify critical needs for solar resource information; and (2) it solicited recommendations from these experts regarding future DOE research and development areas. Key findings of the first workshop included the need to provide "bankable" solar resource data for improved project design and financing, develop guidelines for collecting site-specific solar and meteorological measurements, update the existing National Solar Radiation Data Base (NSRDB) and related data products to address the most recent climate conditions, and address the need for improved solar resource model estimates based on satellite observations and numerical weather prediction methods.

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[1] U.S. Energy Information Administration, *Annual Energy Outlook 2011* (April 26). Report Number DOE/EIA-0383.

Workshop Topics and Participant Expectations

Three focus areas provided a framework for the 2011 workshop:

1. Best practices for acquiring and applying solar resource data
2. Solar resource forecasting methods and operational needs
3. Future roles for the public and private sectors in solar resource assessment

A group of internationally recognized experts addressed specific research topics within these areas through technical presentations and panel discussions. A synopsis of each of the 41 technical presentations is documented in Appendix C.

At the beginning of the first day, participants were asked to share their expectations of the workshop. They expressed the following needs, which were then used to ensure important issues were addressed during the workshop:

- Gain a better understanding of the most pressing issues for solar energy and how the National Oceanic and Atmospheric Administration (NOAA) can work with the DOE to help bridge those gaps
- Identify low-cost options for solar resource measurements. Developing countries lack the ability to deploy single stations costing $2,000.
- Understand participant needs for global horizontal, diffuse, and direct normal irradiance components and the various uses for broadband and spectral distributions of solar irradiance
- Measure considerations for monitoring system performance, including (1) density of pyranometers in the array field, (2) acquiring and processing resource data from field installations, (3) interpreting the data to understand plant operations, and (4) determining the solar variability within a central power station domain.
- Identify the economic value of accurate solar radiation data to various stakeholders
- Understand the benefits of short-term (sub-hourly) solar forecasting to concentrating solar power systems
- Learn how to characterize short-term (1-yr) solar resource measurements with the long-term average (20 yr). Financial interests need to understand the worst-case scenario for solar resource variability during the 20-yr lifespan of a solar power plant.
- Gain a better understanding of methods for estimating electrical power production based on solar resource information
- Acquire an update on new instrumentation available for measuring solar resources for photovoltaics and concentrated photovoltaics, especially the spectral distribution of direct normal irradiance
- Access historical data records of the sky conditions (clouds and aerosols)

Workshop Outcomes

Key findings from two days of presentations, panel discussions, and participant interactions during the Solar Resources and Forecasting Workshop can be summarized as follows:

- The SunShot Initiative requires improved historical solar resource data (higher spatial and temporal resolutions), a quantified estimate of uncertainty, and the development of compatible solar forecast methods for a range of time intervals important to stakeholders (short term: 0 to 6 h, day-ahead: up to 36 h, and long term: 20-plus yr for the life of the system).
- Long-term, site-specific solar resource data are needed to characterize the temporal variability during the lifespan of a solar power system.
- Access to the latest solar resource data, including nearly real-time measurements, is important to advance research for distributed and central generation systems.
- In the absence of a national solar radiation measurement network, the NSRDB and resulting data products (e.g., typical meteorological year, monthly statistics files, and data quality reports) provide model estimates of the solar resources and surface meteorology for industry, academia, and other key stakeholders with a common basis for addressing solar energy conversion system design, integration, and performance analyses. Stakeholders requested annual updates to the NSRDB with more serially complete data and lower estimated uncertainties.
- Stakeholders view federally supported research programs as necessary to produce standard data sets (e.g., National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction operational forecasts, DOE/NREL and NSRDB codes and standards), best practices for the collection and use of solar resource data (e.g., NREL best practices handbooks), and analysis tools and metrics for evaluating solar resource and forecast data, and generally serve as an "honest broker" for solar resource data and information important to stakeholders.
- Satellite-based observations of clouds can be used to estimate global surface solar radiation resources with a spatially uniform representation for time intervals from 30 min to hourly from 1998 to the present.
- Existing numerical weather prediction models that forecast solar resources and meteorological conditions need improvements to cloud modeling, more effective parameterization of atmospheric radiative transfer mechanisms, and increased spatial and temporal resolution of the model outputs.
- Solar resource forecasting is in its infancy with a near-term need by industry to adapt functional methods for routine operations with timescales ranging from a few minutes to day-ahead and beyond for electric utilities, independent system operators, and regional transmission operators.
- Another workshop on this subject is needed in 18 months.

Appendix A: Workshop Agenda

Agenda **6/17/11**

<u>PURPOSE:</u> The Solar Resources and Forecasting Workshop targets stakeholders of the U.S. Department of Energy Solar Energy Technologies Program to review recent developments and provide input for planning future research in solar resource characterization, including measurement, modeling, and forecasting.

<u>AUDIENCE:</u> Electric utilities, system integrators, developers, installers, researchers, financial analysts, design engineers, policy makers, and others interested in the increased use of solar energy conversion technologies.

The Golden Hotel
800 Eleventh Street
Golden, CO 80401
303-279-0100
Clear Creek Ballroom (unless otherwise noted)

============================== Day 1 ==============================

June 20, 2011

7:15 a.m. Registration followed by continental breakfast—Golden Vista

8:30 a.m. Welcome
Tom Stoffel

- Logistics (safety, webinar, food, etc.)
- Introductions (host contacts)
- Workshop format and goals
- Questions

8:45 a.m. Plenary: U.S. Department of Energy and National Renewable Energy Laboratory Perspectives

The SunShot Program
Kevin Lynn

- About SunShot
- The role of resource data and forecasting
- Reaching the goal

9:15 a.m. Solar Resource Assessment R&D at NREL
Dave Renné

- Capabilities and expertise
- Activities to date
- Current research directions

9:35 a.m. Participant Expectations and Priorities
Tom Stoffel

10:00 a.m. Break and Group Photo
Dennis Schroeder

10:30 a.m. Highlights from *Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data* (www.nrel.gov/docs/fy10osti/47465.pdf)
Tom Stoffel

- Solar radiation concepts
- Measuring solar radiation
- Modeling solar radiation
- Historical solar resource information
- Applying solar resource information

11:00 a.m. Panel: User Perspectives on Project Feasibility Data
Frank Vignola (moderator), Marcel Suri, Forrest Collins, and John Miller (10 min each followed by 20-min Q&A)

Some considerations:

- Acceptable resource/power production data uncertainties
- Data elements of interest
- Data resolution and downscaling methods (temporal and spatial)
- Long-term data periods versus a typical year
- Relating short-term measurements to long-term (model) records
- Modeling power production from resource data

12:00 p.m. Lunch—Creekside Courtyard
(Overflow in Golden Vista)

1:30 p.m. Technical Session: Measurements to Support Project Planning, Development, and Operations

Broadband Radiometry—An Overview
Alexander Los (10 min)

Overview of Recent Developments
A Series of Presentations: Ed Kern, Roger Tree, Steve Wilcox, Aron Habte, Ericka Nevarez, and Ann Gaglioti (10 min each followed by 20-min Q&A)

- Rotating shadowband radiometer measurement uncertainty
- Measurement network operations
- Case Study: SOLRMAP
  - Data acquisition, storage, and dissemination
  - Measurement station deployment
  - Data quality assessment methods
  - Equipment calibration and maintenance
- Comparing ground and satellite measurements
- Monitoring system performance

3:00 p.m. Break
Sign up for transportation to dinner (optional)

3:20 p.m. Technical Session: Modeling Solar Resource Data—Current Body of Knowledge

Modeling Solar Resource Assessment
Manajit Sengupta (10 min)

A Series of Presentations: Marie Schnitzer, Pascal Storck, Andy Heidinger, Richard Perez/Jeff Ressler, Chris Gueymard, Steve Wilcox, and Nate Blair (10 min each followed by 20-min Q&A)

- Modeled solar resource data
- Uncertainty in current data sets
- New developments in models and methods
- Impact of aerosols on direct normal irradiance/clear sky models; estimating aerosols
- Technical and economic models: SAM, PVWatts, Solar Prospector, etc.

5:30 p.m. Adjourn

6:15 p.m. Depart for dinner (optional)
Meet in Golden Hotel lobby

6:30 p.m. Dinner at Briarwood (optional)

============================ **Day 2** ============================

June 21, 2011

7:30 a.m. Registration* and Continental Breakfast—Golden Vista
*For participants who did not attend Day 1

8:30 a.m. Welcome
Tom Stoffel

- Logistics
- Goals of the workshop and highlights from Day 1
- Questions

9:00 a.m. Panel: Importance of Forecasting to Stakeholders
Mark Ahlstrom (moderator), Jim Blatchford, Pascal Storck, and Ron Flood (8 min each followed by 10-min Q&A)

- System operators and utility needs for solar forecasts
- Identify important forecast metrics
- Potential economic value of solar forecasts

9:45 a.m. Plenary: Solar Radiation Estimates from Numerical Weather Prediction Models
Stan Benjamin

- Description of NWP models
- Description of relevant model physics
- Data assimilation
- Model products
- Model limitations
- Future improvements
- Q&A

10:30 a.m. Break

10:45 a.m. Technical Session: Short-Term and Day-Ahead Forecasting
A Series of Presentations: John Zack, Richard Perez, Jan Kleissl, Ned Snell, and Steven Miller (12 min each followed by 10-min Q&A)

- Cloud motion detection from NWP and observations by ground-based and satellite sensors
- Model overviews and validations
- Radiative transfer in NWP models
- Model validation studies

12:00 p.m. Lunch—Creekside Courtyard
(Overflow in Golden Vista)

1:15 p.m. Technical Session: Photovoltaic Output Variability Studies
A Series of Presentations: Jan Kleissl, Josh Stein, Adam Kankiewicz, Laura Hinkelman, and Manajit Sengupta (10 min each followed by a 10-min Q&A)

- High-frequency meso-/microscale resource measurement systems
- Time-series resource data and power output ramp rates

2:15 p.m. Modeling for System Integration Studies
Panel: Kirsten Orwig (moderator), Marissa Hummon, Jaclyn Frank, Richard Perez, Harjeet Johal, and Kara Clark (8 min each followed by 10-min Q&A)

- Creating high-resolution resource input data sets
- Modeling photovoltaic output on the grid

3:15 p.m. Break

3:30 p.m. Proper Roles for the Private and Public Sectors
Panel: Kristen Nicole (moderator), Marcel Suri, Melinda Marquis, Jeff Ressler, Pascal Storck, Marie Schnitzer, Mark Ahlstrom, Jim Blatchford, and Ron Flood

5:00 p.m. Future Directions
Dave Renné

Wrap-Up Discussion

- Summarize needs and actions
- Capture priorities for developing multiyear R&D plan & DOE/NOAA MOU

5:20 p.m. Survey

5:30 p.m. Wrap (10 min)

- Logistics for tomorrow's lab tours
- Access to presentations, attendance list, and workshop summary report
- Thank you for participating!

=============================== Day 3 ===============================

June 22, 2011
Tours of NREL Facilities

8:00 a.m. Continental Breakfast—Golden Vista

9:30 a.m. Issue NREL Visitor Badges—Golden Vista
Foreign national visitors *must* bring the *same* ID they used when they filled out the FNDC or they will not be able to participate in the tours.

10:00 a.m. NREL Buses Arrive at Hotel

10:20 a.m. Depart for Labs by Group (A, B, or C)
(20 min at each lab)

- Solar Radiation Research Laboratory (SRRL) www.nrel.gov/solar_radiation
- Photovoltaic Outdoor Test Facility (OTF) www.nrel.gov//pv/facilities_otf.html
- Photovoltaic Process Development & Integration Laboratory (PDIL) www.nrel.gov/pv/pdil/about_pdil.html

12:00 p.m. End of Tours

Appendix B: List of Participants

Surname	First Name	Organization	Country
Acker	Tom	Northern Arizona University	USA
Ahlstrom	Mark	WindLogics	USA
Anderberg	Mary	National Renewable Energy Laboratory	USA
Andreas	Afshin	National Renewable Energy Laboratory	USA
Anwar	Manan	University of Engineering & Technology, Lahore	Pakistan
Augustyn	Jim	Augustyn & Company	USA
Barnes	Frank	University of Colorado at Boulder	USA
Benjamin	Stan	National Oceanic and Atmospheric Administration, Earth Systems Research Laboratory	USA
Bing	James	NEO Virtus Engineering, Inc.	USA
Blair	Nate	National Renewable Energy Laboratory	USA
Blatchford	Jim	California Independent System Operator	USA
Camerada	Marco	CRS4	Italy
Carpenter	Ileen	National Renewable Energy Laboratory	USA
Cayuela	Jose David	Abengoa Solar, Inc.	Spain
Chhatbar	Kaushal	Suntrace GmbH	Germany
Chow	Chi Wai	University of California at San Diego	USA
Christopherson	James	enXco	USA
Clark	Kara	National Renewable Energy Laboratory	USA
Collins	Forrest	juwi solar, Inc.	USA
Cormier	Dallas	San Diego Gas & Electric	USA
Cowie	Jim	National Center for Atmospheric Research, Research Applications Laboratory	USA
D’Agostino	Brian	San Diego Gas & Electric	USA
Dhuart	Olivier	Amonix	USA
Diep	Charles	SolarReserve, LLC	USA
Disterhoft	Patrick	National Oceanic and Atmospheric Administration	USA
Dokos	William	EKO Instruments Co., Ltd.	USA
Dooraghi	Michael	National Renewable Energy Laboratory	USA
Dutton	Ells	National Oceanic and Atmospheric Administration	USA
Dwyer	Tim	Hatch	USA
Ergeneman	Candan	Lahmeyer International GmbH	Germany
Falcey	Jonathan	National Renewable Energy Laboratory	USA
Fleenor	Stacy	WindLogics	USA
Flood	Ronald	Arizona Public Service	USA
Frank	Jacklyn	AWS Truepower	USA

Surname	First Name	Organization	Country
Frigon	Tim	enXco	USA
Gaglioti	Ann	GroundWork	USA
Gardner	Jennifer	Western Interstate Energy Board	USA
Gasiewski	A.J.	University of Colorado at Boulder	USA
George	Ray	National Renewable Energy Laboratory	USA
Geuder	Norbert	CSP Services GmbH	Spain
gillham	matt	Renewable Energy Systems, Ltd., Americas	USA
Gilon	Yoel	BrightSource	Israel
Gioioso	Marisa	AER, Inc.	USA
Gonzales	Joy	National Renewable Energy Laboratory	USA
González	Sonia	Lahmeyer International GmbH	Germany
Grimit	Eric	3TIER, Inc.	USA
Gueymard	Chris	Solar Consulting Services	USA
Habte	Aron	National Renewable Energy Laboratory	USA
Hall	James	JHtech	US
Hardy	Emily	Horizon Wind Energy	USA
Heidinger	Andrew	National Oceanic and Atmospheric Administration	USA
Hinkelman	Laura	University of Washington, Joint Institute for the Study of the Atmosphere and Ocean	USA
Hodgson	Sarah	National Renewable Energy Laboratory	USA
Hummon	Marissa	National Renewable Energy Laboratory	USA
Hunter	Cameron	GroundWork	USA
Hunter	Brian	U.S. Department of Energy	USA
Hyatt	Robert	Campbell Scientific, Inc.	USA
jamaly	seyed	University of California at San Diego	USA
Johal	Harjeet	GE Global Research	USA
Joyce	Kevin	Black & Veatch	USA
Kankiewicz	Adam	WindLogics	USA
Kapetanovic	Alexandre	Renewable Energy Systems, Ltd., Americas	USA
Kearney	David	K&A	USA
Kern	Ed	Irradiance, Inc.	USA
Kern	Chris	Irradiance, Inc.	USA
Klein	Levente	IBM	USA
Kleissl	Jan	University of California at San Diego	USA
Klise	Geoffrey	Sandia National Laboratories	USA
Kobashi	Tsukasa	EKO Instruments Co., Inc.	Japan
Kraas	Birk	Solar Millennium AG	Germany
Krishnani	Pramod	Sacramento Municipal Utility District	USA
Kroposki	Ben	National Renewable Energy Laboratory	USA
Kumar	Davinder	Student	USA
Kutchenreiter	Mark	National Renewable Energy Laboratory	USA
La Marche	Jean Paul	MSP	USA

Surname	First Name	Organization	Country
Lantz	Kathleen	National Oceanic and Atmospheric Administration, Cooperative Institute for Research in Environmental Sciences	USA
Larson	Vincent	Aerisun, LLC	USA
Laszlo	Istvan	National Oceanic and Atmospheric Administration and University of Maryland	USA
Lave	Matthew	University of California at San Diego	USA
Lecuyer	Peggy	AWS Truepower	USA
Lee	Jinsuk	National Renewable Energy Laboratory	USA
Lemon	Nick	Luminate	USA
Lopez Cardenete	Pablo	Abengoa Solar, Inc.	Spain
Los	Alexander	EKO Instruments, Europe B.V.	The Netherlands
Lynn	Kevin	U.S. Department of Energy	USA
Marquis	Melinda	National Oceanic and Atmospheric Administration	USA
Marquis	Natalie	Texas Solar Energy Society	USA
Mavromatakis	Fotis	Technological Educational Institute of Crete	Greece
McClintock	Scott	AER, Inc.	USA
McCormack	Paul	National Renewable Energy Laboratory	USA
McDaniel	Caiti	Lockton, Inc.	USA
McKee	Jacob	Solar Millennium AG	USA
Meares	Matthew	Amonix	USA
Mehos	Mark	National Renewable Energy Laboratory	USA
Michalsky	Joseph	National Oceanic and Atmospheric Administration, Earth System Research Laboratory	USA
Miller	Steven	Colorado State University, Cooperative Institute for Research in the Atmosphere	USA
Miller	John	CH2M HILL	USA
Mooney	David	National Renewable Energy Laboratory	USA
Morley	James	WindLogics	USA
Myers	William	National Center for Atmospheric Research	USA
Nair	Prasad	Areva Solar	USA
Nangle	John	National Renewable Energy Laboratory	USA
Nayes	Jessica	Augustyn & Company	USA
Nevarez	Erika	Solar Millennium AG	USA
Newman	Kimberly	University of Colorado	USA
Newmiller	Jeffrey	BEW Engineering	USA
Nicole	Kristen	Electric Power Research Institute	USA
Nottrott	Anders	University of California at San Diego	USA
Orwig	Kirsten	National Renewable Energy Laboratory	USA
Owens	Marvin	Colorado SolarVolts, Inc.	USA

Surname	First Name	Organization	Country
Pennock	Ken	AWS Truepower	USA
Perez	Richard	State University of New York at Albany	USA
Pfannenstiel	Tim	AWS Truepower	USA
Philip	Joseph	SunEdison	USA
Pulvermüller	Benedikt	Solar Millennium AG	Germany
Quiñones	Angelica	II-UNAM	Mexico D.F.
Rendón-Fricks	Franklin D.	Olmecapan, S.C.	México
Renne	Dave	National Renewable Energy Laboratory	USA
Ressler	Jeffrey	Clean Power Research	USA
Robinson	Justin	Campbell Scientific, Inc.	USA
Rodriguez	Antonio	Solar Millennium AG	USA
Rogers	Matt	Colorado State University	USA
Rootes	John	GroundWork	USA
Ross	Charles	Electrical Contractor Magazine	USA
Ryan	Dan	SunEdison	USA
Saez	Isabella	Luminate, LLC	USA
Schnitzer	Marie	AWS Truepower	USA
Sengupta	Manajit	National Renewable Energy Laboratory	USA
Senkbeil	Ryan	Aerisun, LLC	USA
Shakya	Bibhakar	ICF International	USA
Shoukas	Gregory	Abengoa Solar, Inc.	USA
Sickinger	David	National Renewable Energy Laboratory	USA
Siskind	David	GroundWork	USA
Snell	Ned	AER	USA
Stein	Josh	Sandia National Laboratories	USA
Stoffel	Tom	National Renewable Energy Laboratory	USA
Stoltenberg	Blaise	National Renewable Energy Laboratory	USA
Storck	Pascal	3TIER, Inc.	USA
Suri	Marcel	GeoModel Solar s.r.o.	Slovakia
Tadesse	Alemu	SunEdison	USA
Tembrock	John	juwi solar, Inc.	USA
Thakuri	Sujit	Lahmeyer International GmbH	Germany
Thuman	Christopher	AWS Truepower	USA
Tippett	Jesse	GCL	USA
Tree	Roger	RMIdata, LLC, and Colorado State University	USA
Turchi	Craig	National Renewable Energy Laboratory	USA
Urquhart	Bryan	University of California at San Diego	USA
Vant-Hull	Lorin	University of Houston (retired)	USA
Vargas	Thomas	Sacramento Municipal Utility District	USA
Vasquez Padilla	Ricardo	Universidad del Norte	Colombia
Vignola	Frank	University of Oregon, Solar Energy Center	USA
Walter	Bernard	Bernard Walter Consulting	USA

Surname	First Name	Organization	Country
Walton	Mariah	Solar Millennium AG	USA
Walzer	Susan	BrightSource	Israel
Wang	Jianhui	Argonne National Laboratory	USA
Warner	Cecile	Cécile Warner, P.E., LLC	USA
Wegener	Joerg	University of California at San Diego	USA
Whittier	Jack	CH2M HILL	USA
Wilcox	Stephen	National Renewable Energy Laboratory	USA
Willy	David	Northern Arizona University	USA
Wimbrow	Robert	RBW Consulting	USA
Zack	John	AWS Truepower	USA
Zhou	Zhi	Argonne National Laboratory	USA
Zuniga	Fernando	Suntrace GmbH	Germany

Appendix C: Presentation Synopses

Plenary: U.S. Department of Energy and National Renewable Energy Laboratory Perspectives

Title: The SunShot Program

Presenter: Kevin Lynn, U.S. Department of Energy

Synopsis: SunShot will enable a subsidy-free solar electricity infrastructure with a levelized cost of energy of $0.05 to $0.06 per kWh. The U.S. Department of Energy funds solar resource assessment to provide industry with solar resource data, models, and tools to support system performance modeling and analysis for technology R&D and operational needs for grid integration. Partnership and outreach functions include working with stakeholders to define and develop public/private roles for solar resource data and forecasting methods. Program goals address grid planning and operations, solar forecast models, predictions of solar system performance, and solar resource variability, and identify best locations for system deployment.

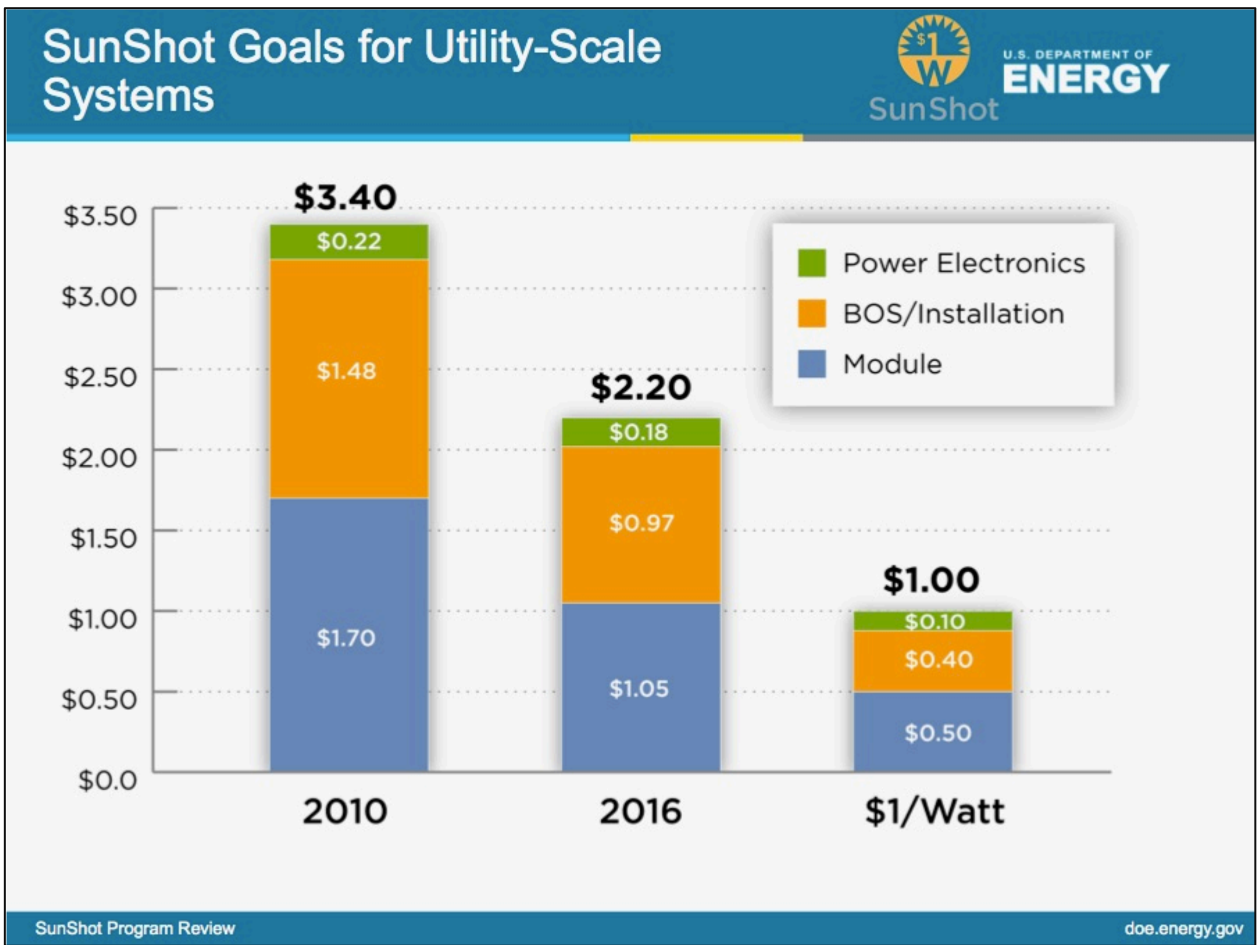


Figure 1. SunShot goals for utility-scale photovoltaic systems

Title: Solar Resource Assessment R&D at NREL

Presenter: Dave Renné, National Renewable Energy Laboratory

Synopsis: Description of the five elements defining the effort to provide stakeholders with solar resource data and tools with defined accuracy for historical and forecast periods:

1. Observations and measurements—solar radiometry and metrology, the Solar and Meteorological Assessment Project, and field campaigns to address photovoltaic variability and validate solar resource and forecasting models;
2. Derived data development and analysis—surface solar irradiance estimates based on satellite remote sensing and surface meteorological observations, spectral irradiance modeling, and long-term solar resource statistical products such as typical meteorological years;
3. Data management and products—National Solar Radiation Data Base and data centers for archival and dissemination;
4. End-use applications and customized products—solar resource data sets for system integration studies, inputs to analysis tools such as SAM and PVWatts, forecasting application benchmarks, and photovoltaic variability studies; and
5. Partnerships and outreach—the memorandum of understanding between the U.S. Department of Energy and the National Oceanic and Atmospheric Administration; collaboration with the National Aeronautics and Space Administration; other partnerships with government, industry, and academia; and publications, workshops, seminars, and webinars.

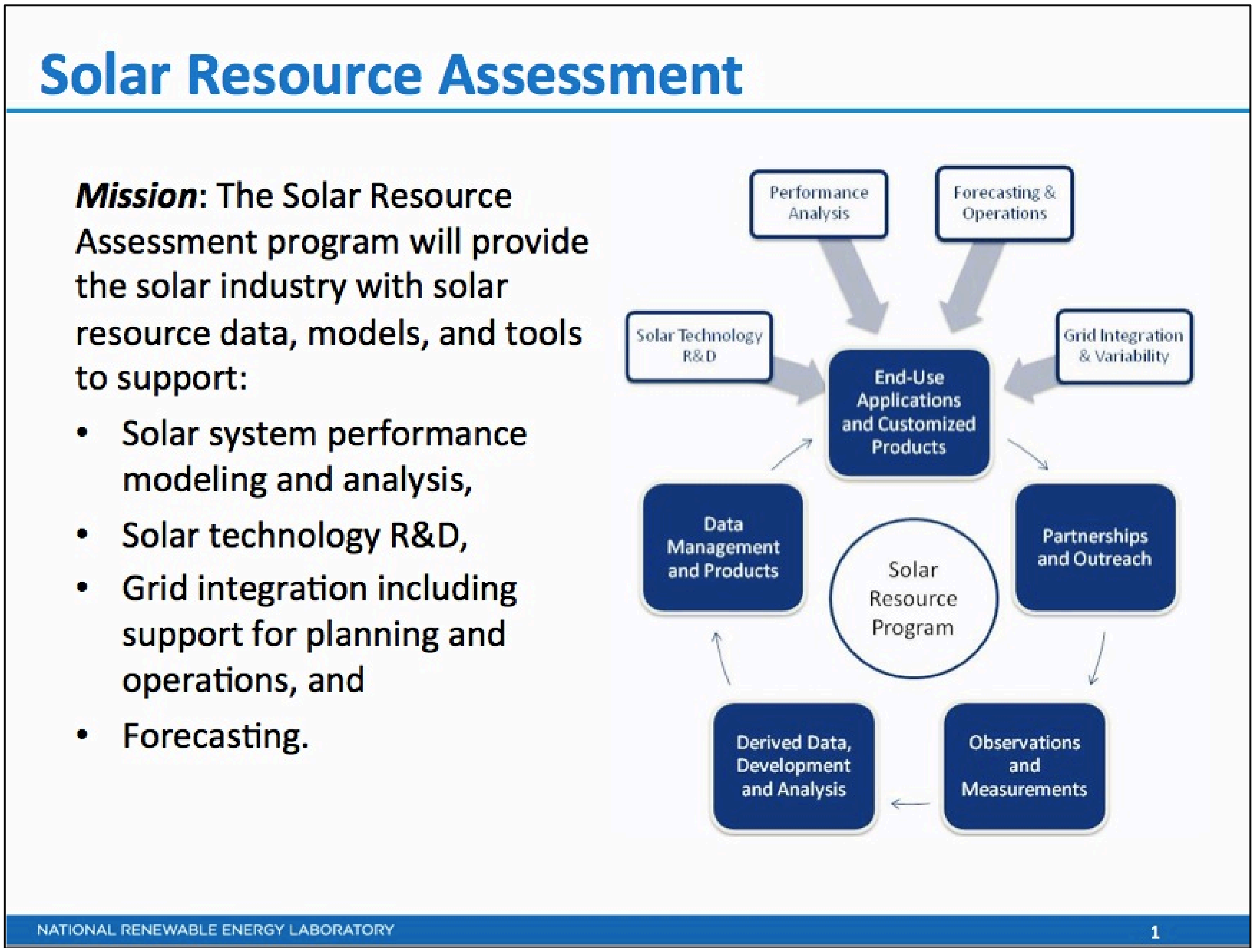


Figure 2. The Solar Resource Assessment mission

Title: Highlights from Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data

Presenter: Tom Stoffel, National Renewable Energy Laboratory

Synopsis: An overview of the recent publication available from www.nrel.gov/docs/fy10osti/47465.pdf to address the needs and applications of solar resource data at each stage of project development: pre-feasibility, feasibility, due diligence, and project acceptance and systems operation. The handbook addresses the motivation for the publication and the various needs for historical solar resource data, an overview of solar radiation concepts, the technical aspects of measuring solar radiation, the current state of knowledge for modeling solar radiation resources, a summary inventory of historical solar resource data, and methods for applying historical solar resource data.

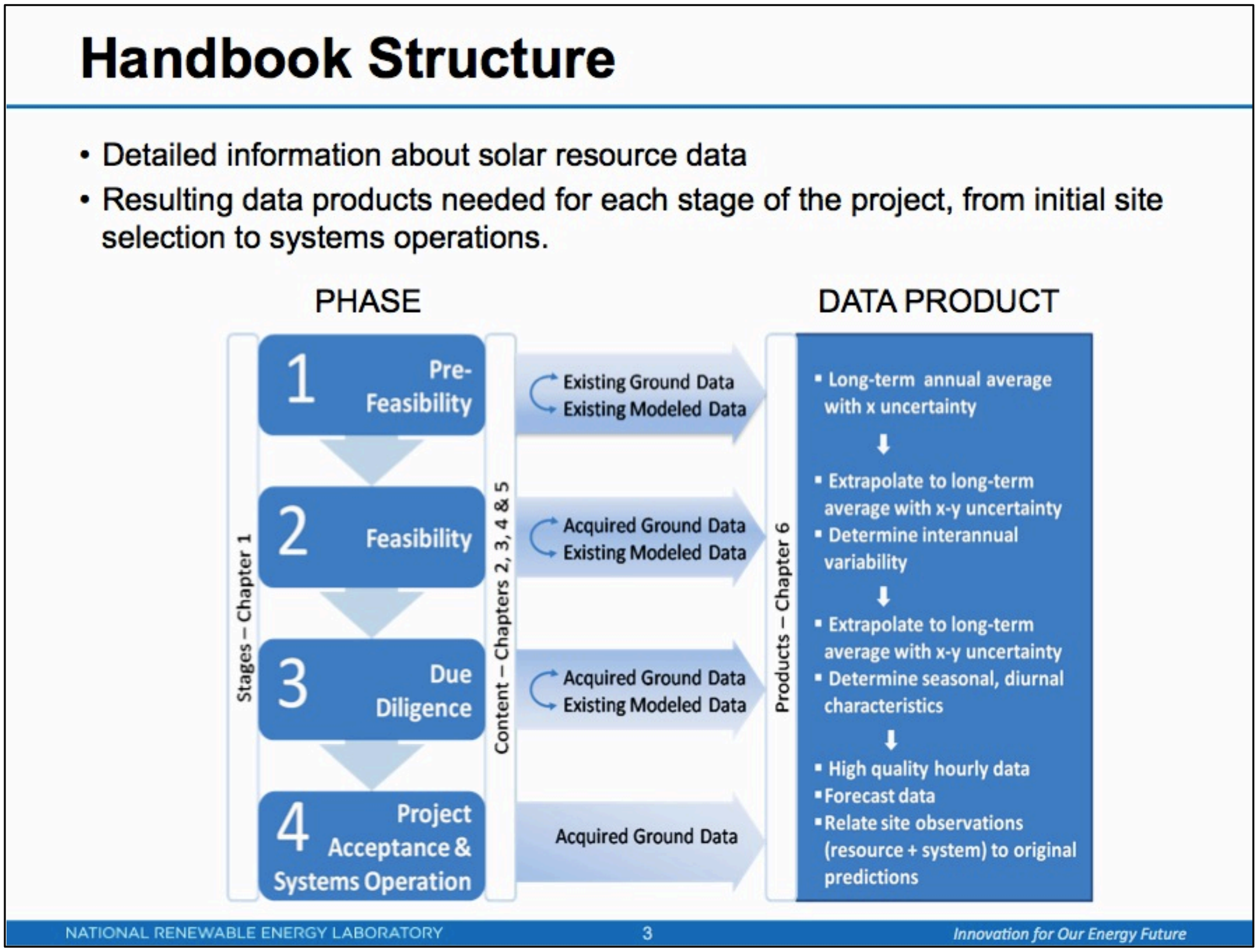


Figure 3. ***Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data*** **structure**

Panel: User Perspectives on Project Feasibility Data

Title: Notes on Building a Bankable Solar Data Set

Presenter: Frank Vignola, University of Oregon, Solar Energy Center

Synopsis: Bankable solar resource data must have known uncertainties and represent the long-term variability of the resource for the location(s) of interest. Uncertainty decreases as the time interval increases because the data are averaged from a large sample, reducing both random and some bias errors. Measured solar resource data are preferable but often not available or lack a suitable period of record. Satellite-derived data can be used to tie measured data to long-term data sets. Comparisons are made between the National Solar Radiation Data Base and the typical meteorological year data sets for selected locations. A summary of bankable data set needs concluded the presentation:

1. Properly measured data have lower uncertainty estimates than modeled data.
2. Understand and describe the uncertainty in the data sets being used.
3. Resource uncertainty is viewed as increasing financial risks for the project.
4. Long periods of record are needed to characterize the resource variability and worst cash flow year.
5. Satellite-derived solar resource data can be used to link available measured data with long-term data sets.

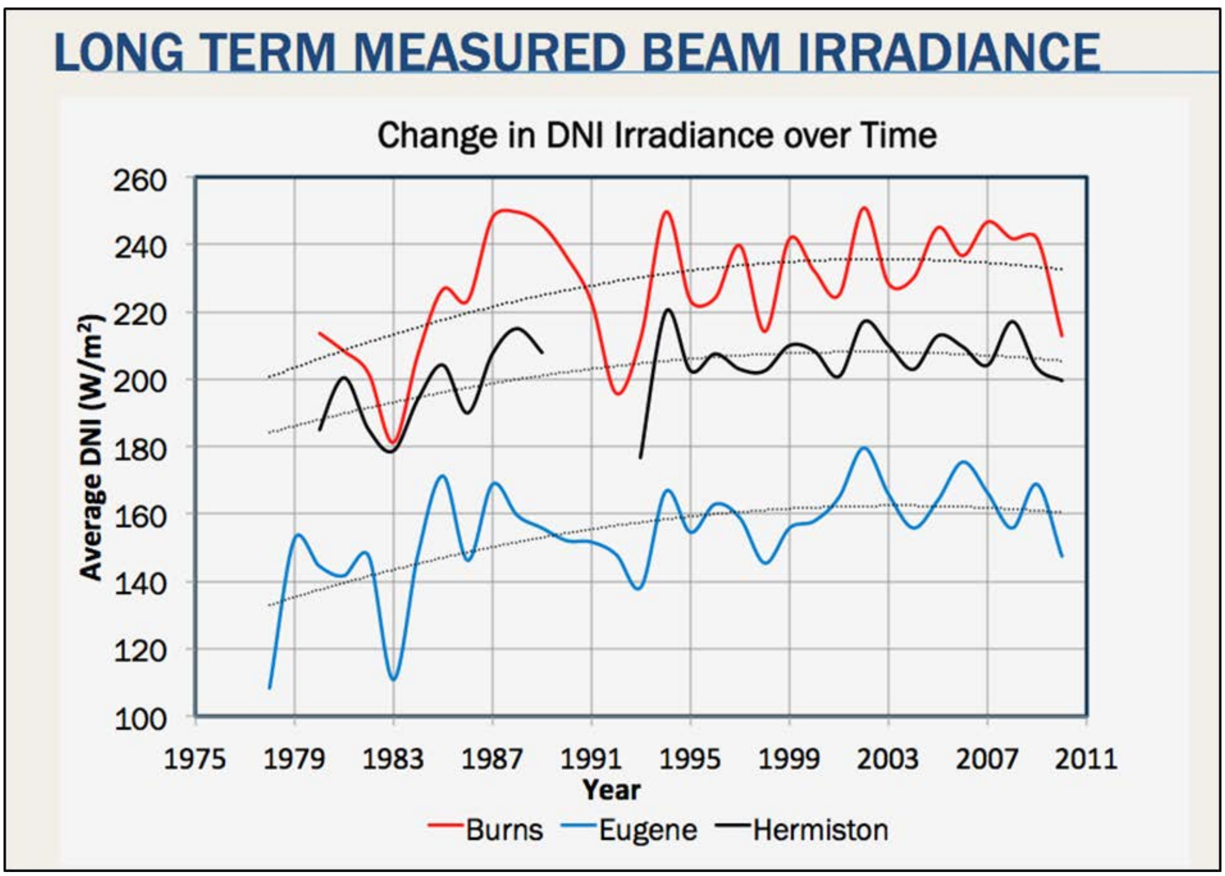


Figure 4. Comparison of average direct normal irradiance over time

Title: User Perspectives on Project Feasibility Data

Presenter: Marcel Suri, GeoModel Solar s.r.o.

Synopsis: Traditional approaches based on interpolation of point measurements and application of synthetic generators are substituted by satellite-derived time series that have a number of advantages:

1. They are available for (almost) any site globally.
2. They often have better overall quality and reliability.
3. High-quality data products can be derived: (a) representative meteorological year (P50) for planning and design, (b) aggregated statistics for reporting, (c) customized time series for monitoring and system performance assessment, and (d) complementary data-to-ground measurements.
4. In the absence of high-quality ground measurements, satellite-based data offer the only alternative for system monitoring and performance assessment.

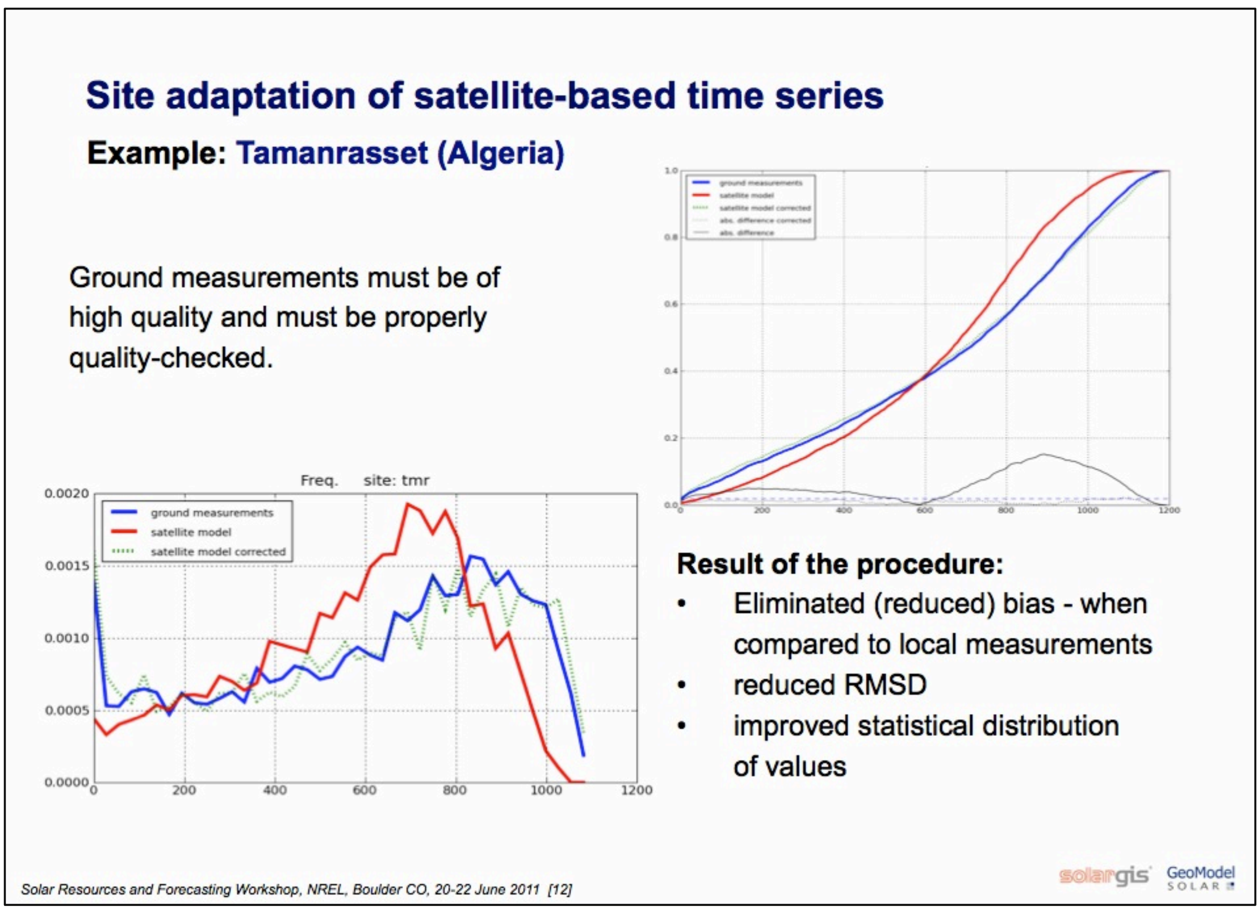


Figure 5. Satellite estimates and ground-based measurements

Title: Generation Guarantees and Solar Resource Uncertainty

Presenter: Forrest Collins, juwi solar, Inc.

Synopsis: Electric utilities can require guarantees of expected generation: minimum (85% to 90%) and maximum (110% to 115%). The generation guarantee requires the developer to evaluate all sources of uncertainty in the modeling, including (1) annual variability in solar resource, (2) solar resource data uncertainty, (3) generation modeling uncertainty, and (4) degradation of system energy conversion.

Long-term solar resource variability can be addressed by the hourly data available from the National Solar Radiation Data Base and its typical meteorological year and typical direct year products. Commercially available data sources include Clean Power Research's Solar Anywhere®, 3TIER, Inc.,'s FirstLook®, and Meteotest's Meteonorm. The variability in solar resource and P90/P99 modeling results in a worst-case estimate is a guaranteed minimum generation of 77.2% of the expected value. The best-case estimate results in a guaranteed minimum generation of 84.7% of the expected value. Current requirements for utilities dictate that bidders guarantee up to 90% of the expected generation. Industry needs reduced uncertainty in solar resource data to meet utility requirements. The solar industry should target 5% or less total uncertainty in solar resource data. The question is, how do we get there?

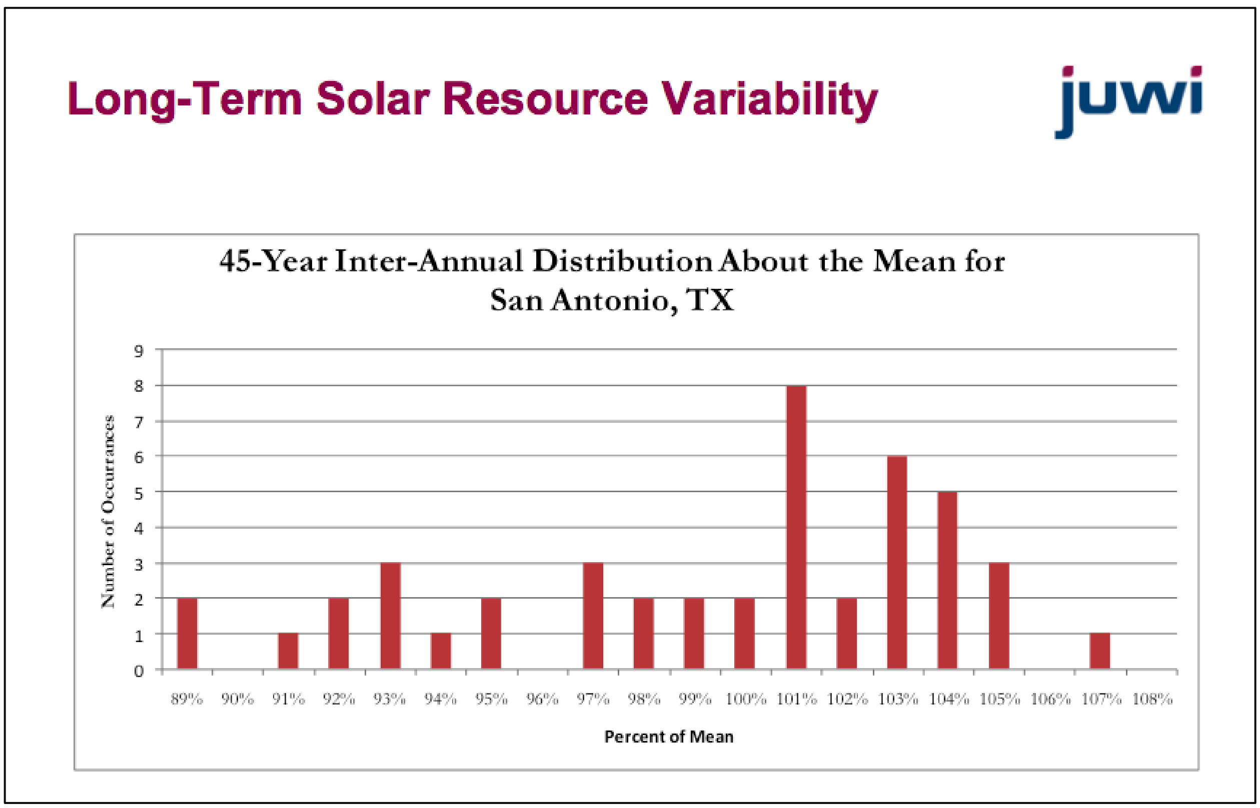


Figure 6. Variability of global horizontal irradiance in San Antonio, TX

Title: Use of Weather Resource Data in Solar Photovoltaic Performance Guarantees

Presenter: John Miller, CH2M Hill

Synopsis: Performance guarantees address:

1. Generating capacity:
   - Engineer, procure, construct;
   - Design generation (MWac) at standard test conditions;
   - The estimated performance ratio (specific production/effective global irradiance); and
   - The results from a 2- or 3-d acceptance test; and

2. Operations:
   - Design, build, operate;
   - Pass-through-panel guarantee;
   - PVSyst with measured data versus PVSyst with modeled data; and
   - Daily data analysis with annual true-up, and the performance of a 6- to 10-year contract.

The tolerance range for damages versus bonuses is +/-5%.

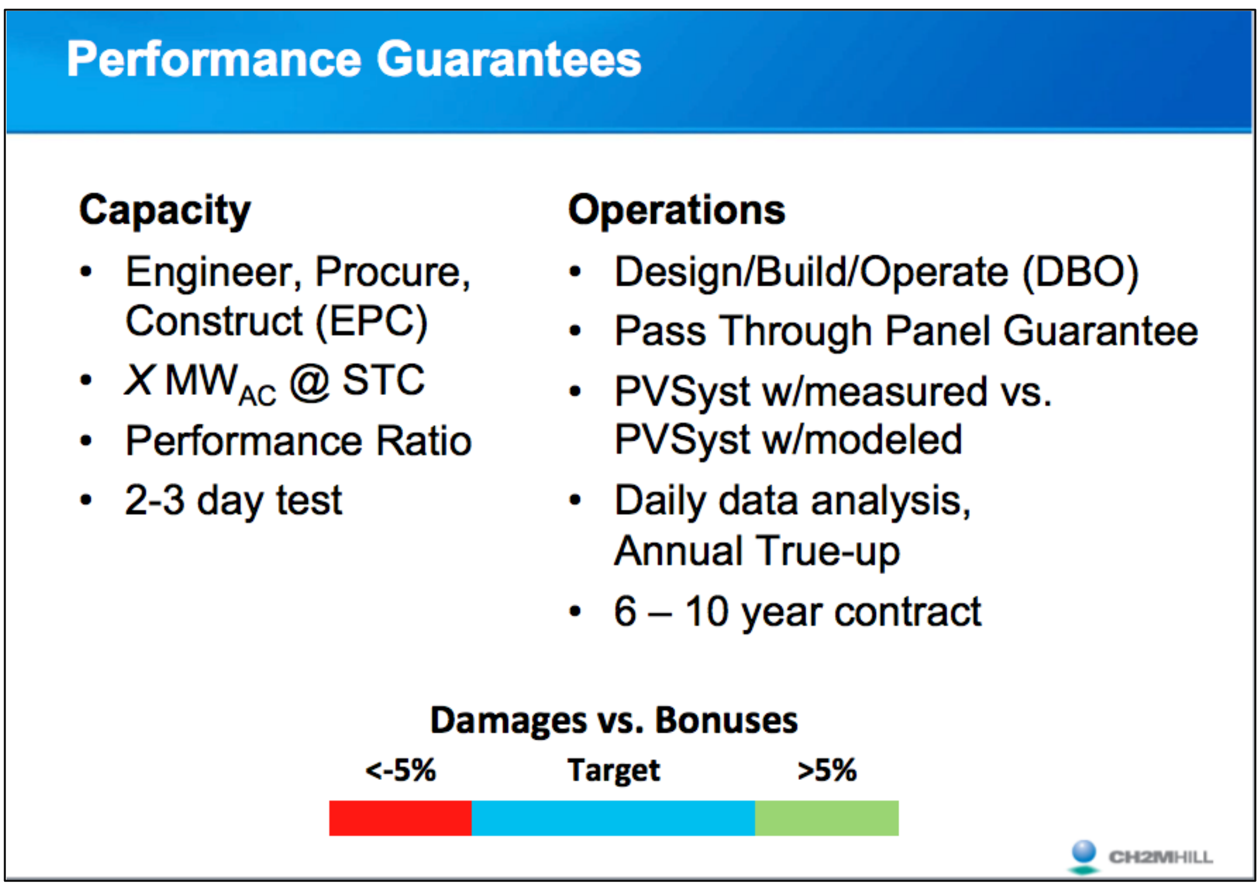


Figure 7. Summary of photovoltaic system performance guarantees

Technical Session: Measurements to Support Project Planning, Development, and Operations

Title: An Introduction to Broadband Radiometry

Presenter: Alexander Los, EKO Instruments, Europe B.V.

Synopsis: An overview of terminology, historical background of instrument developments since the 19th century, construction details for pyranometers and pyrheliometers, international schema for radiometer performance classifications, measurement methods for observation stations and solar energy technology performance, World Radiometric Reference (WRR) for radiometer calibration, International Pyrheliometer Comparisons, and a thorough discussion of solar radiation measurement uncertainties. Important issues for "bankable" solar resource data include (1) radiometer calibrations traceable to the WRR, (2) radiometer calibrations accredited by the International Standards Organization may be required, (3) measurement system chosen according to data product requirements, and (4) providing measurement uncertainty information in final results.

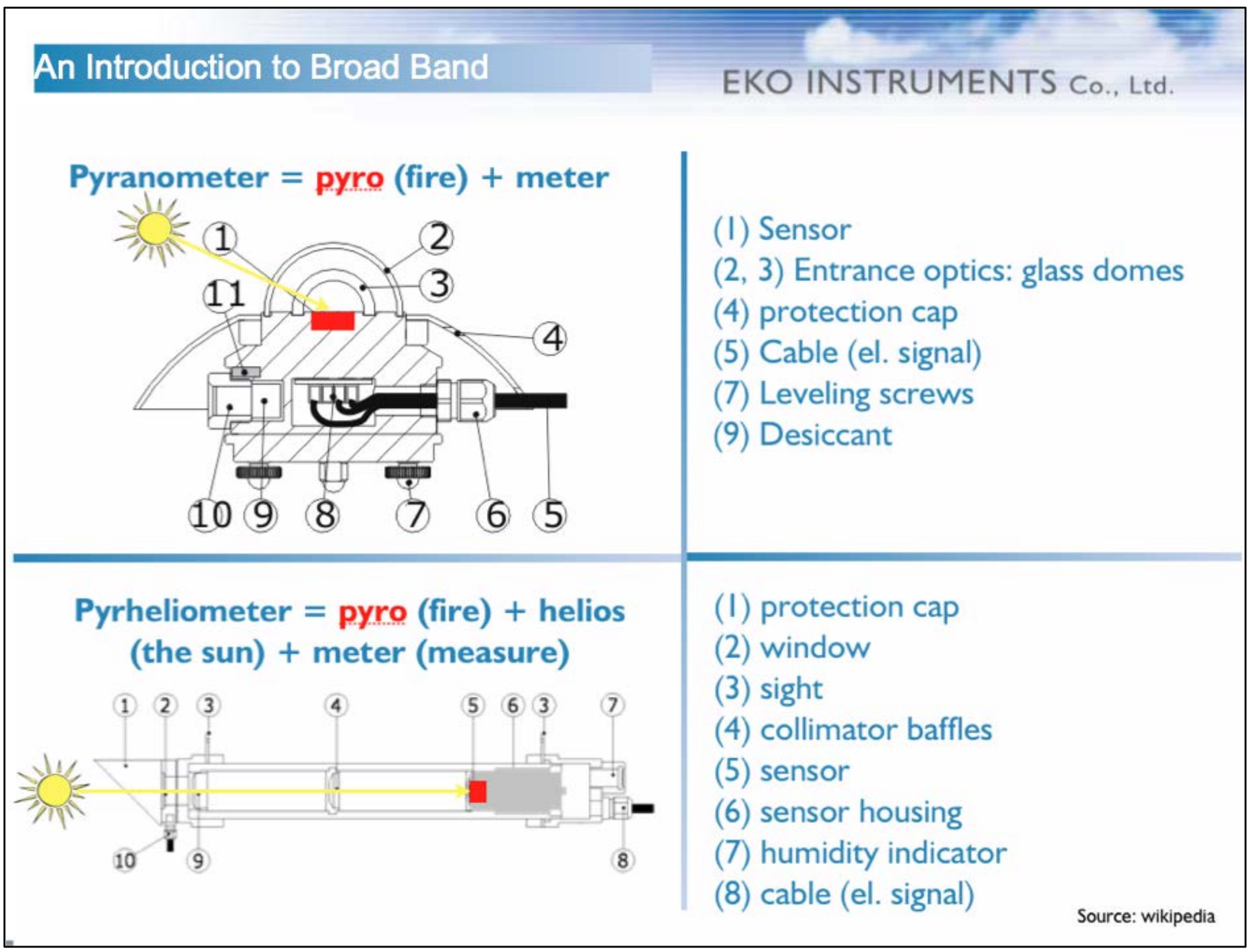


Figure 8. Design elements of pyranometers and pyrheliometers for solar irradiance measurements

Title: Silicon Photodiode Pyranometer Calibration for Rotating Shadowband Radiometers

Presenter: Ed Kern, Irradiance, Inc.

Synopsis: Rotating shadowband radiometers using a silicon photodiode pyranometer rely on the fast response of the detector to measure global horizontal and diffuse horizontal irradiances to compute the corresponding value of direct normal irradiance. Various corrections to photodiode pyranometers have been developed to address their nonlinear spectral response, temperature dependencies, and angle of incidence dependencies. Through a cooperative research and development agreement between Irradiance, Inc., and the National Renewable Energy Laboratory (NREL), work is underway to improve solar resource measurements from a Rotating Shadowband Radiometer Version 2 (RSR2™). The goal is to reduce measurement uncertainty through physical model-based calibration methods and corrections. During the past 18 months, more than 300 pyranometers in groups of about 25 units have been deployed at NREL for one-month test periods. Results to date have indicated that LI-COR Model LI200s photodiode pyranometers can be calibrated at the Solar Radiation Research Laboratory to yield long-term results within the ~1% uncertainty of first-class reference instruments. Ongoing research will address the needs to confirm RSR2™ calibrations and model corrections at other locations.

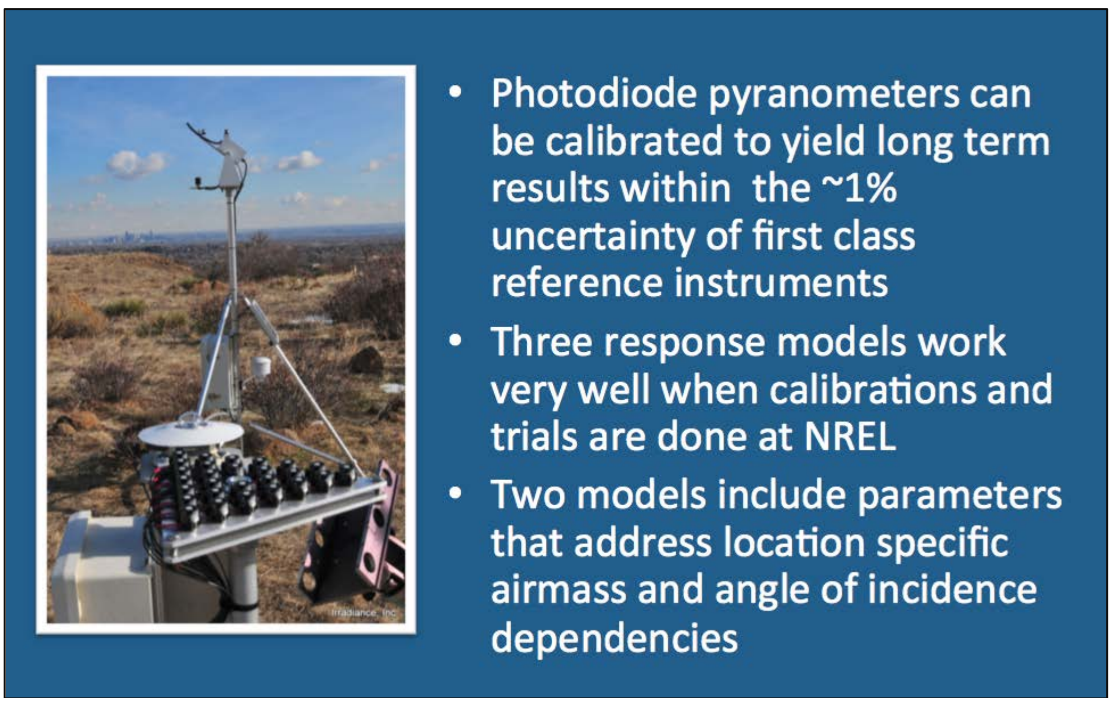


Figure 9. Summary of photodiode calibrations for rotating shadowband radiometer applications

Title: Measurement Network Operations

Presenter: Roger Tree, RMIdata, LLC and Colorado State University

Synopsis: A practical guide to designing, operating, and maintaining a successful measurement network. Topics included site selection, instrument installation, data collection, quality control tasks, monitoring station documentation, data dissemination in graphic and text formats, scheduled and unscheduled maintenance, on-site internal quality control audits, external audits, instrument calibration and servicing, quality control documentation, and a quality assurance plan. Experience shows that operators often leave shortly after training, instrument physical alignments and calibrations drift over time, optics attracts dust, and the growing importance of measured data is inversely proportional to the level of historical maintenance. Recommendations include enhanced operator training and communications, increased reliance on automated data quality assessment for reporting problems, and developing better automated data checks and model comparisons.

Figure 10. Measurement network operations

Title: Measurements Case Study: Solar Resource and Meteorological Assessment Project

Presenter: Steve Wilcox, National Renewable Energy Laboratory

Synopsis: In response to the stakeholder needs identified for concentrating solar power technology deployment at the 2008 Workshop, the National Renewable Energy Laboratory (NREL) developed the Solar Resource and Meteorological Assessment Project (SOLRMAP). Implemented through a series of cooperative research and development agreements with industry partners, these key topics are being addressed: (1) measurement station design, installation, and operation; (2) data acquisition, storage, and dissemination; (3) data quality assessment and processing; and (4) equipment calibration and maintenance.

Beginning with installations in 2009, the SOLRMAP network now consists of 43 stations in the southwestern United States that provide data at 1-min intervals to the NREL Measurement and Instrumentation Data Center. Depending on the terms of agreement, some data remain proprietary, but all data are available to the U.S. Department of Energy/NREL for research applications.

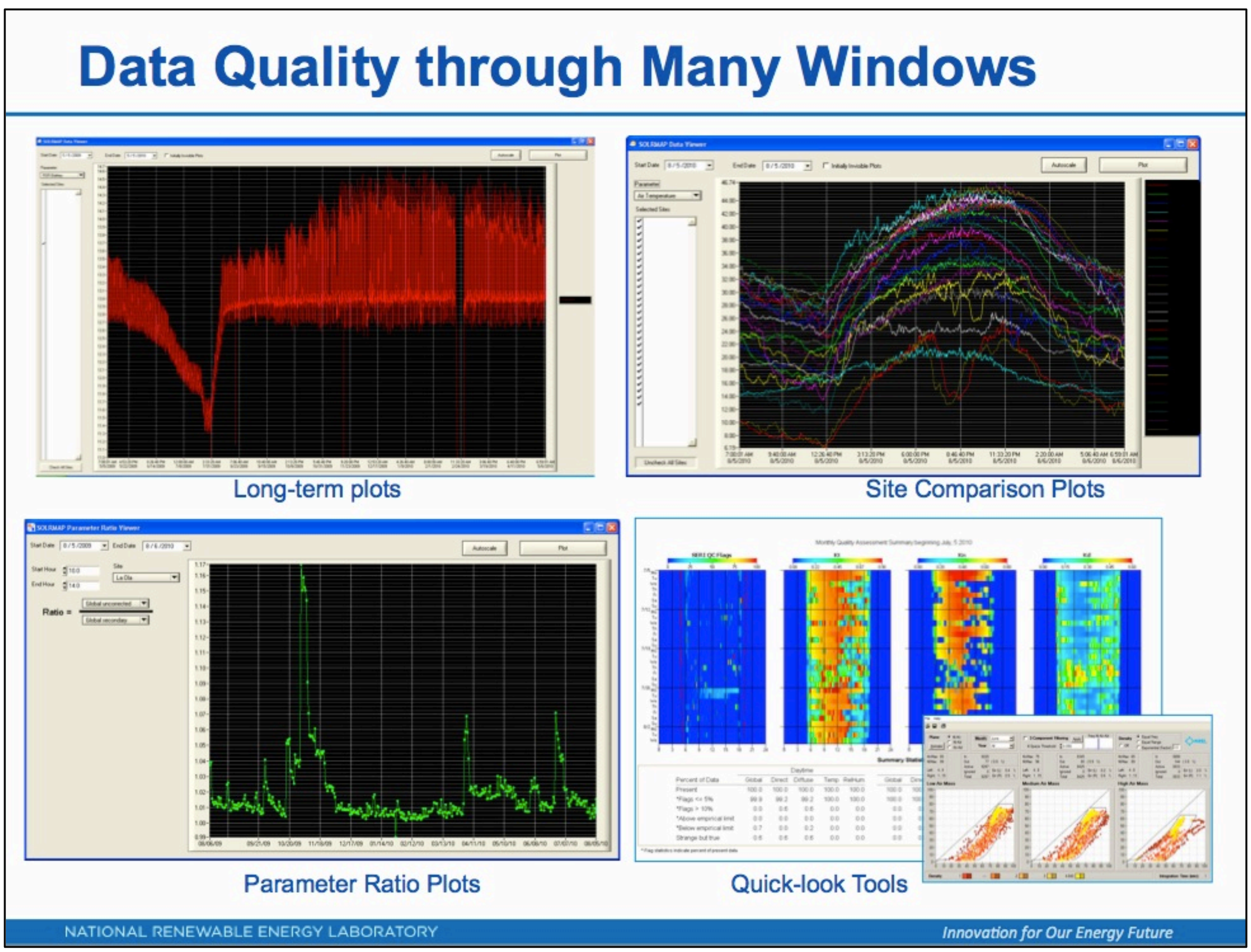


Figure 11. Solar Resource and Meteorological Assessment Project data quality assessment tools

Title: Overview of Modeled Satellite and Ground Measured Solar Data Evaluation

Presenter: Aron Habte, National Renewable Energy Laboratory

Synopsis: The methodology was presented for comparing surface solar irradiance from satellite-based observations of cloud cover to surface measurements of global horizontal and direct normal irradiance. The validation data are based on measurements from 28 stations. The satellite-derived estimates were based on the State University of New York model with improvements for the detection and model processing of satellite imagery with highly reflective terrain (snow and sand) to minimize the spatial and temporal uncertainties of the corresponding model estimates of surface irradiances. Comparisons of monthly mean daily total statistics for the evaluation sites indicate model differences for global horizontal irradiance of 5% to 10% and for direct normal irradiance of 10% to 15%. Future investigations will address the needs for surface measurements, including measurement parameters, temporal and spatial resolutions, etc.

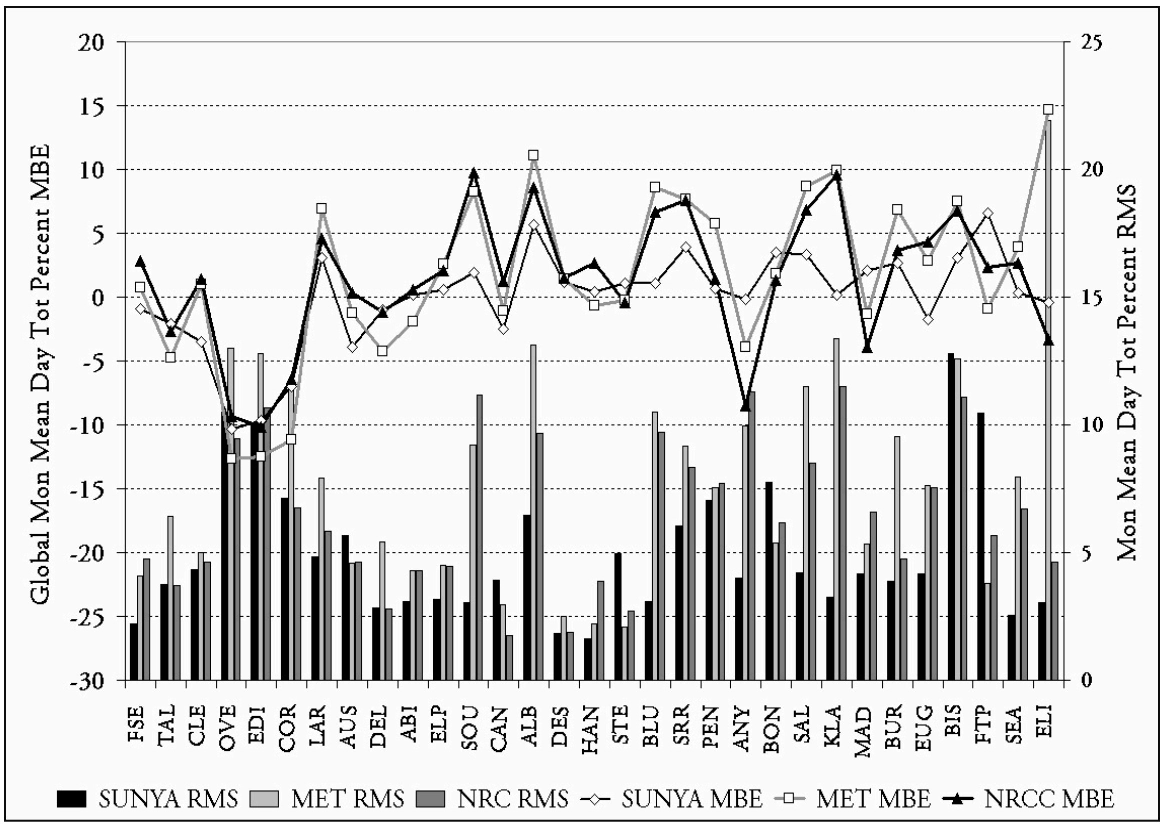


Figure 12. Comparison of measured global horizontal irradiance at 33 stations in the National Solar Radiation Data Base

Title: Solar Measuring for Concentrating Solar Power

Presenter: Erika Nevarez, Solar Millennium AG

Synopsis: Measurement stations for project development must produce high-accuracy data, especially direct normal irradiance (DNI), from reliable measuring equipment that can be installed with minimal site preparation and installation effort and operate with minimal maintenance requirements. Solar Millennium AG has developed a rotating shadowband instrument to meet these needs. More than 70 instruments are in operation in 11 countries to provide 1-min data. Considering the pros and cons of the instrument with a conventional pyrheliometer and solar tracker, a rotating shadowband pyranometer (RSP) is in use at concentrating solar power plants as control instrumentation. Results of a 31-d soiling experiment indicate an increasing relative error of daily DNI from un-cleaned and cleaned pyrheliometers and RSPs reaching 25% for the pyrheliometer and less than 2% for the RSP. An RSP is in operation at the National Renewable Energy Laboratory as part of a measurement system comparison.

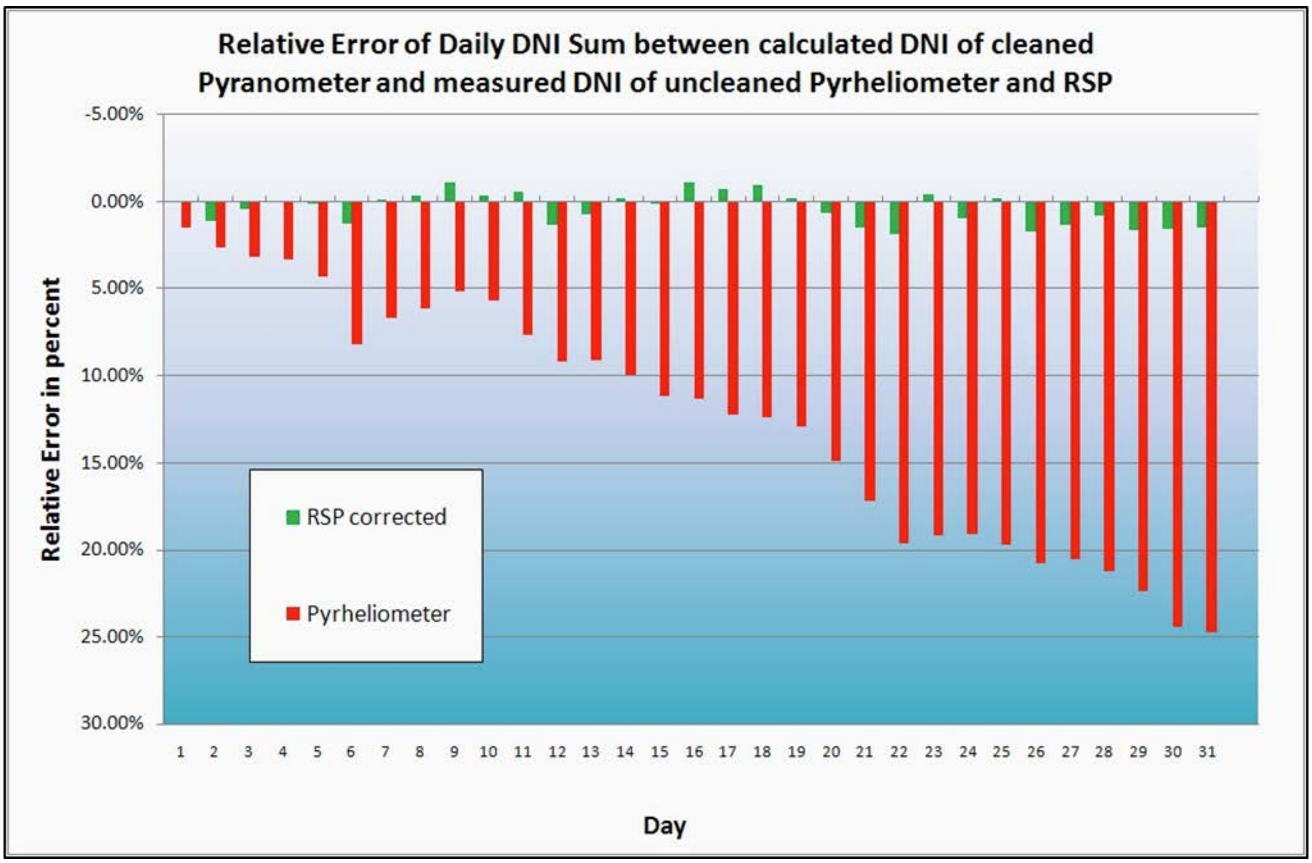


Figure 13. Soiling study results for pyrheliometer and RSP

Title: Solar Monitoring Station Design

Presenter: Ann Gaglioti, GroundWork and Suntrace GmbH

Synopsis: GroundWork has developed a solar monitoring station (SMS) network based on standards, templates, guides, processes, and checklists. Standard engineering drawings and specifications support program management. Online collaboration provides for traceability and transparency of the SMS campaign. Solar measurement systems are derived from thermopile-based pyranometers, pyrheliometers, and rotating shadowband radiometers. Important topics for implementing the SMS network included equipment siting, installation, and key aspects of operations and maintenance for consistent quality data.

Figure 14. Thermopile pyranometers (top) and rotating shadowband radiometers (bottom) are used in the solar monitoring station network

Technical Session: Modeling Solar Resource Data—Current Body of Knowledge

Title: Modeling Solar Resource Assessment

Presenter: Manajit Sengupta, National Renewable Energy Laboratory

Synopsis: Accurate resource information is required for all stages of project development (from pre-feasibility to acceptance testing). Satellite-based or numerical weather prediction (NWP) methods have the advantage over station measurements by providing information throughout large areas. Resource assessment methods that combine all three approaches will ultimately provide the best solutions. Ancillary data sets are needed for improved resource product from satellites. Assimilated observations are needed for improved resource product from NWP models. Next-generation geostationary satellites (GOES-R; 16 channels of radiometric measurements, data intervals of 5 min, and 1- to 2-km spatial resolution) will potentially provide large improvements in resource assessment accuracy and resolution. (See Chapter 4 in *Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data*, available at www.nrel.gov/docs/fy10osti/47465.pdf)

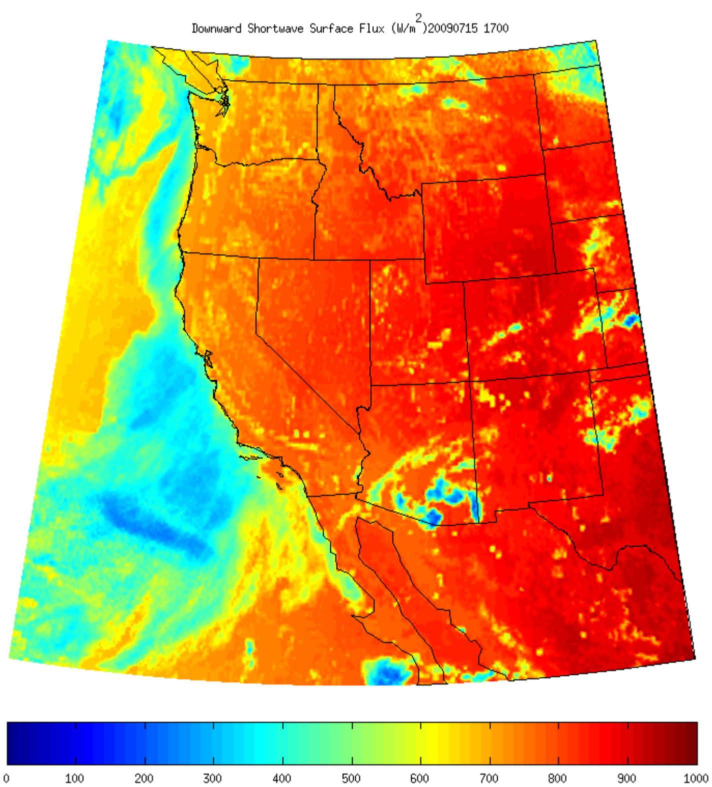
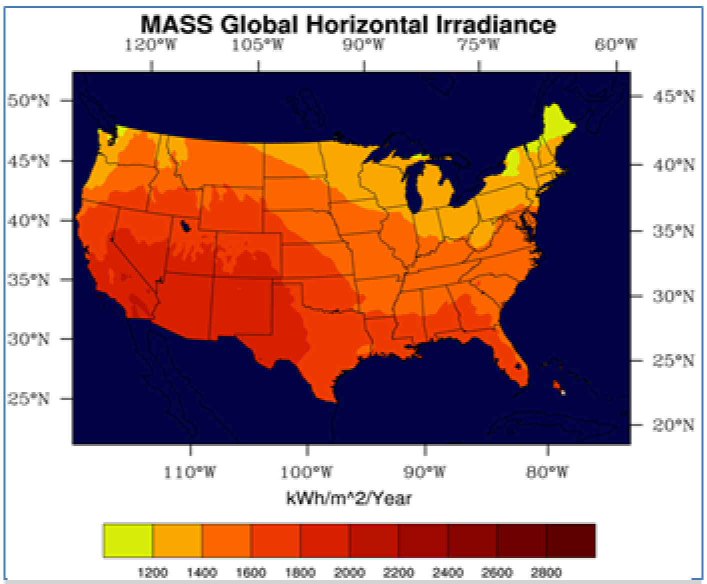


Figure 15. Estimated hourly global horizontal irradiance distribution for the western United States

Title: Development of a National Map for Global Horizontal Irradiance from a Numerical Weather Prediction Model

Presenter: Marie Schnitzer, AWS Truepower

Synopsis: Using the Mesoscale Atmospheric Simulation System, a physics-based numerical weather prediction model, the average annual global horizontal irradiance at every model grid point in the United States has been calculated. Model results were adjusted using surface observations and compared to existing solar resource maps and data sets. The model consists of a nested grid providing 20-km horizontal resolution in the finest nest and hourly time resolution. The model period was from 1997 to 2009. Validation data from 138 stations representing 14 networks were used for developing model performance statistics. Results compared well with National Solar Radiation Data Base and State University of New York satellite-modeled data with lower bias and comparable root mean square error.



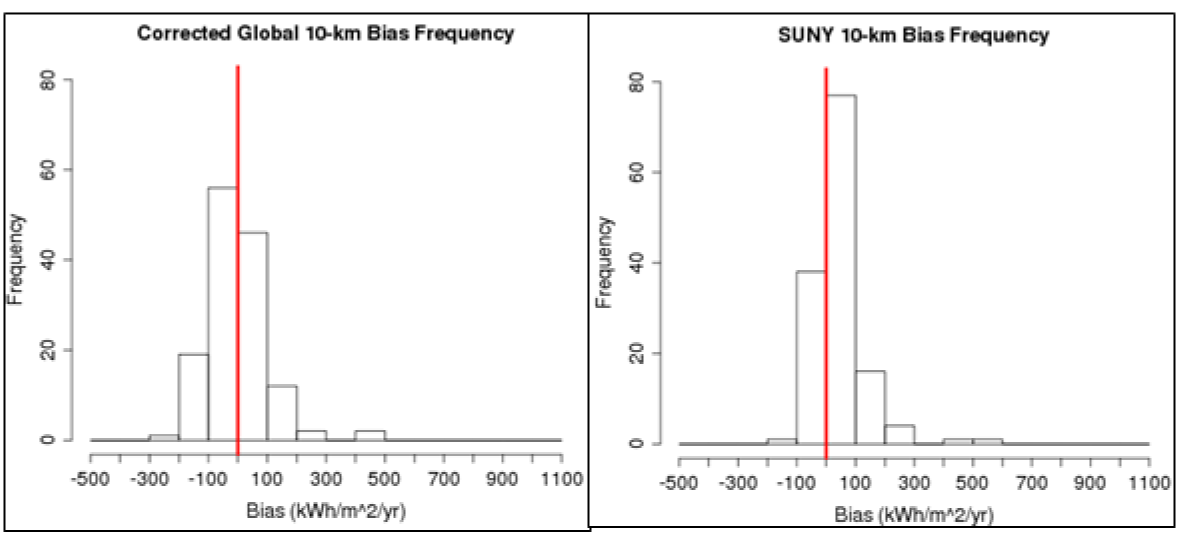


Figure 16. Numerical weather prediction model evaluation

Title: Solar Resource Assessment—Improving Assessments for More Accurate Financial Analysis

Presenter: Pascal Storck, 3TIER, Inc.

Synopsis: Solar resource modeling indicates global standard errors of 5% for global horizontal irradiance and 9% for direct normal irradiance. Combining microscale site information, such as aerosol optical depth measurements and local irradiance observations, with long-term satellite irradiance data significantly improves the accuracy of solar resource estimations and provides more confidence in financial planning. Understanding the long-term variability of solar resources is an important consideration. Typical meteorological year data may not always be appropriate to represent the solar resource, particularly during bad years. Solar resource assessments can be based on ground station observations, satellite-derived data, or in combination. The strengths and weaknesses of each method were summarized.

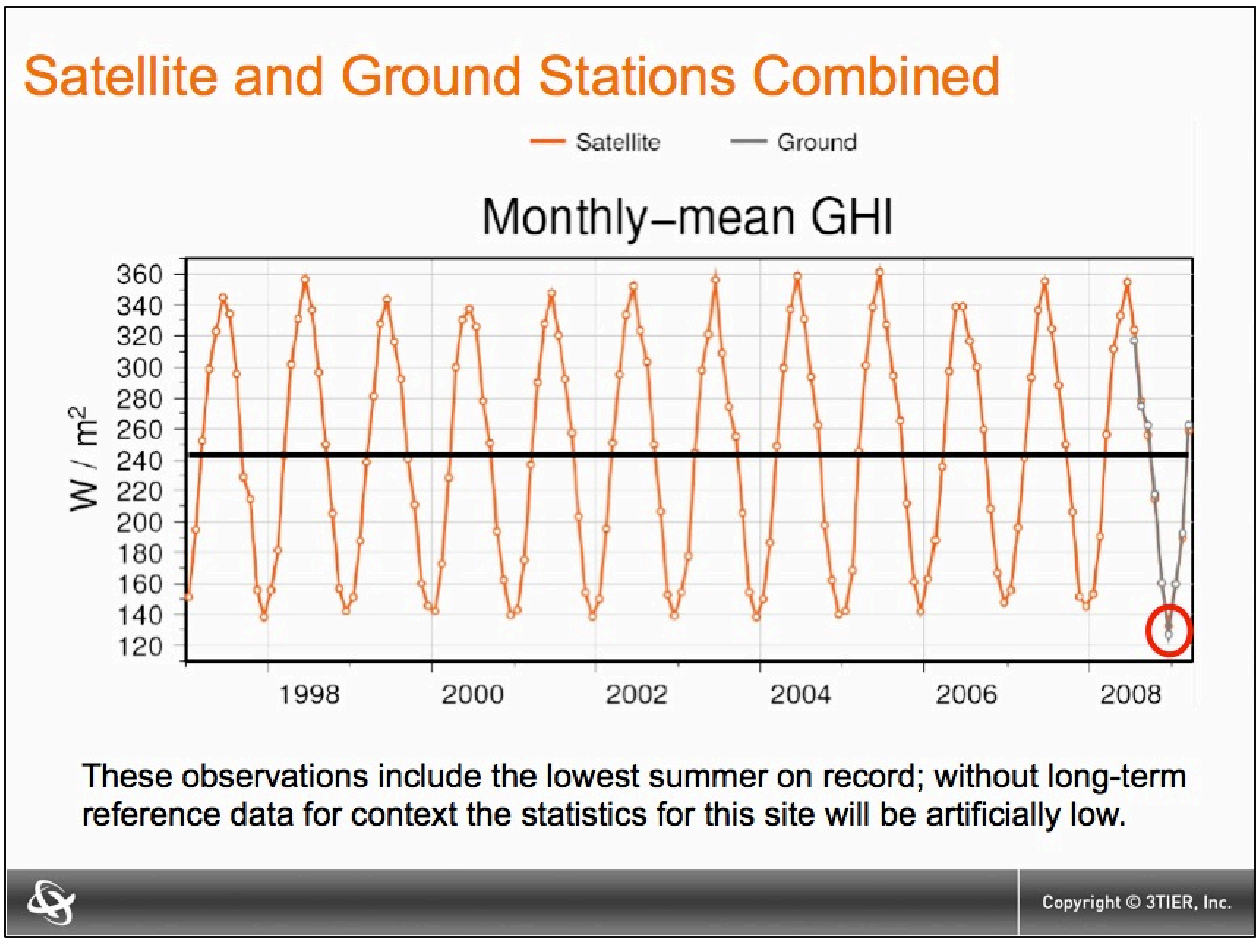


Figure 17. Understanding the long-term variability of solar resources

Title: Solar Energy and Cloud Products from the National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service

Presenter: Andy Heidinger, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service

Synopsis: The National Oceanic and Atmospheric Administration's National Environmental Satellite, Data, and Information Service (NOAA/NESDIS) makes high-quality cloud and solar energy products in real time. We run cloud algorithms similar to those run by the National Aeronautics and Space Administration but in real time. NOAA/NESDIS also generates multiyear climatologies from its sensors (AVHRR and GOES). AVHRR PATMOS-x is at the National Climate Data Center. Geostationary Operational Environmental Satellite climatologies are forthcoming. The next NOAA Polar Orbiting Imager launches later this year. The next NOAA Geostationary Imager launches in 2015. NOAA/NESDIS responds to user requests, so ask for what you want and we will try.

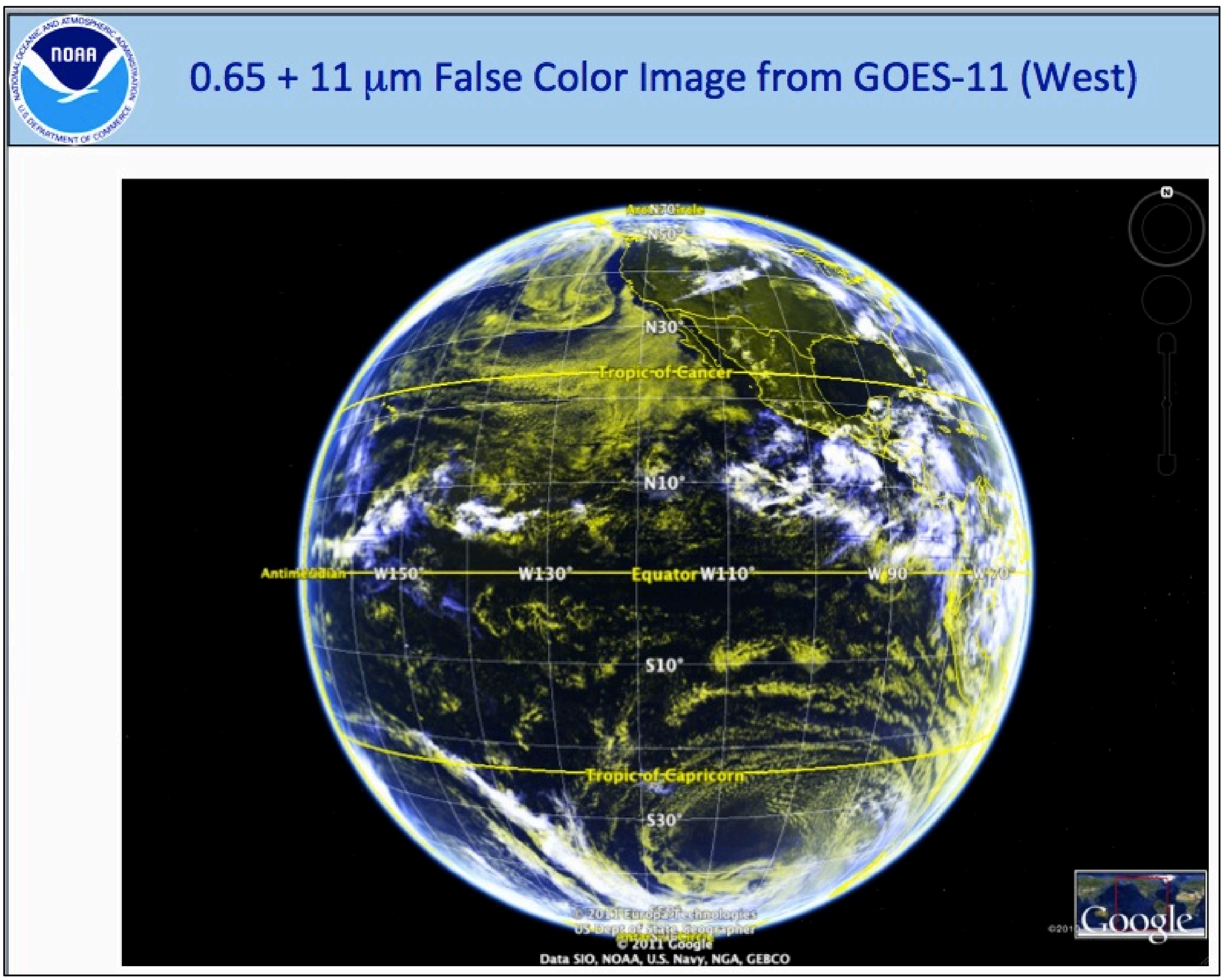


Figure 18. Geostationary Operational Environmental Satellite visible channel image

Title: Modeling Solar Resource Data—The Tools Perspective

Presenter: Jeff Ressler, Clean Power Research

Synopsis: The key elements needed to high-speed, time-series forecasts for fleet power simulation are available or advancing: solar resources, photovoltaic power, and economic model advances; data quality improvements and delivery; photovoltaic system specification data availability; and new generation tools. As a result, significant new capabilities and data sets are available for forecasting, resource and power data have enhanced spatial and temporal resolutions, and new output formats are available with averaged data sets (e.g., free 1-km data on a rolling 1-yr window are now available for California). We must meet the challenge of making model improvements accessible and impactful.

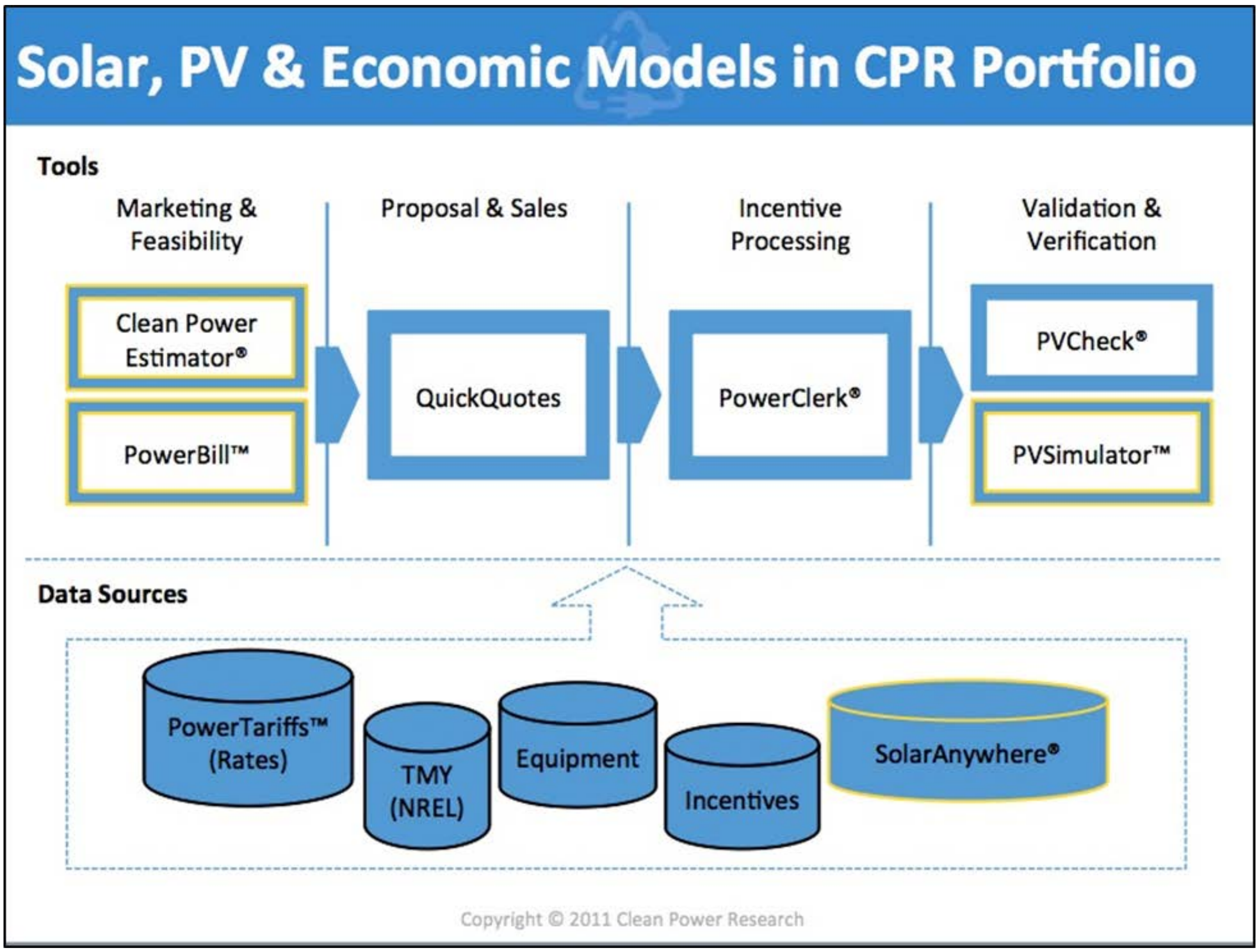


Figure 19. Clean Power Research tools and data sources

Title: Direct Normal Irradiance Resource for Solar Power Plants—The Challenging Impact of Aerosols

Presenter: Chris Gueymard, Solar Consulting Services

Synopsis: An accurate representation of the spatial and temporal distributions of aerosols in the atmosphere is required for modeling solar radiation. High-performance radiative transfer models that correctly account for radiation extinction because of atmospheric aerosol optical depth (AOD) are needed for estimating direct normal irradiance (DNI). Not all models correctly account for aerosol extinction. Because of the lack of aerosol measurements and to reduce the model complexities, most solar resource maps continue to be based on climatological averages of AOD. A comparison of results from 18 models with surface measurements of DNI at five stations indicates a range of mean bias differences of ±30%. Higher accuracy AOD input data are needed to improve solar resource data and thus the bankability of financial forecasts of system performance. The current challenge is to develop daily and monthly AOD time-series estimates representative of the period from 1980 to the present. The growing need for accurate solar resource forecasts will also depend on the availability and quality of AOD inputs.

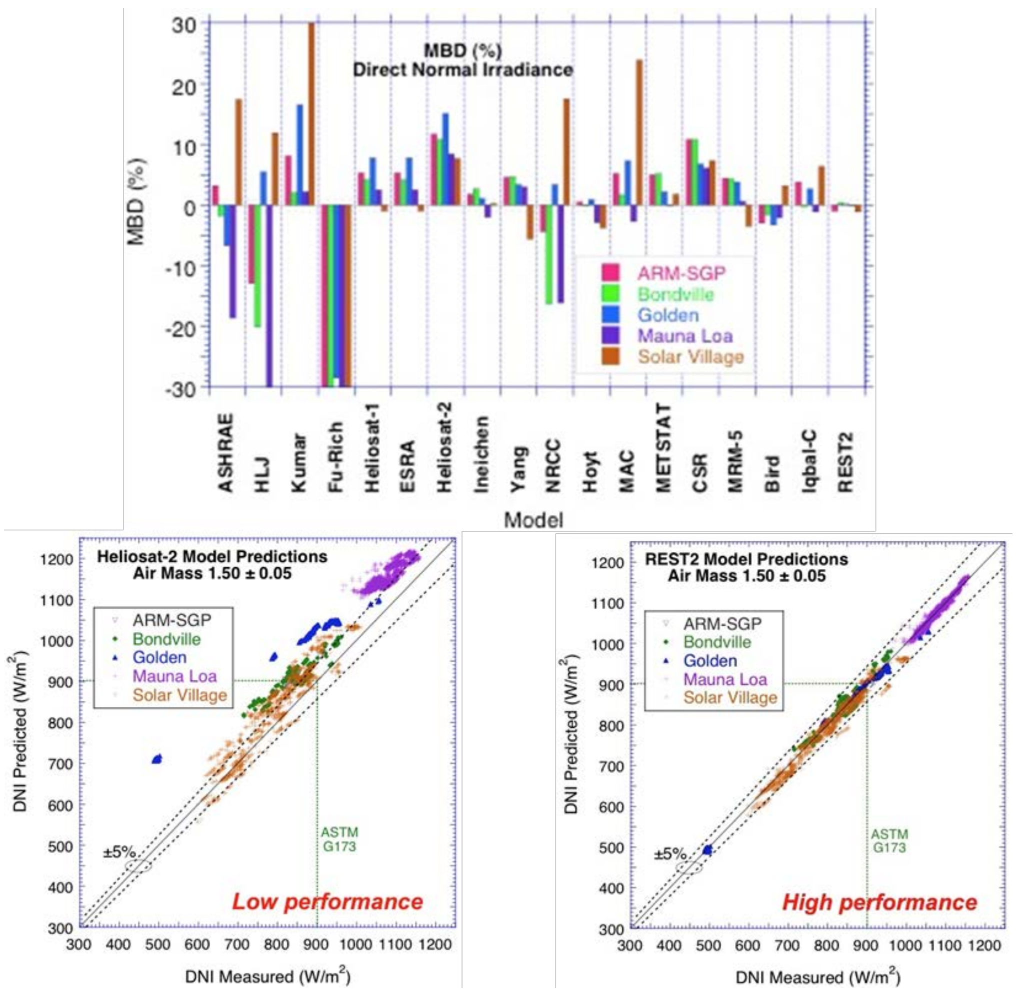


Figure 20. Comparison of estimated and measured direct normal irradiance

Title: Modeled Solar Resource Data for the National Solar Radiation Data Base

Presenter: Steve Wilcox, National Renewable Energy Laboratory

Synopsis: The National Solar Radiation Data Base (NSRDB) was completed in 1992 to provide serially complete hourly solar and meteorological data for the period from 1961 to 1990. In response to stakeholder needs, an NSRDB update was completed in 2007 to provide data from 1991 to 2005. This release was the first to include data in a spatial grid (10 km by 10 km) for the period from 1998 to 2005 based on Geostationary Operational Environmental Satellite imagery. The update also provided station-specific solar resource data for 858 sites with serially complete records of surface meteorological observations needed to model solar radiation and another 596 sites with some useful resource data. More than 99% of the solar data are modeled from cloud information. The data have been identified according to three classifications, and data uncertainties have been computed. Participants at the 2003 NSRDB Experts Meeting developed these long-term goals:

- Continue to reduce data uncertainties,
- Enhance data accessibility,
- Provide more frequent (annual) updates,
- Develop support for resource nowcasting, and
- Continue to improve satellite-based methods.

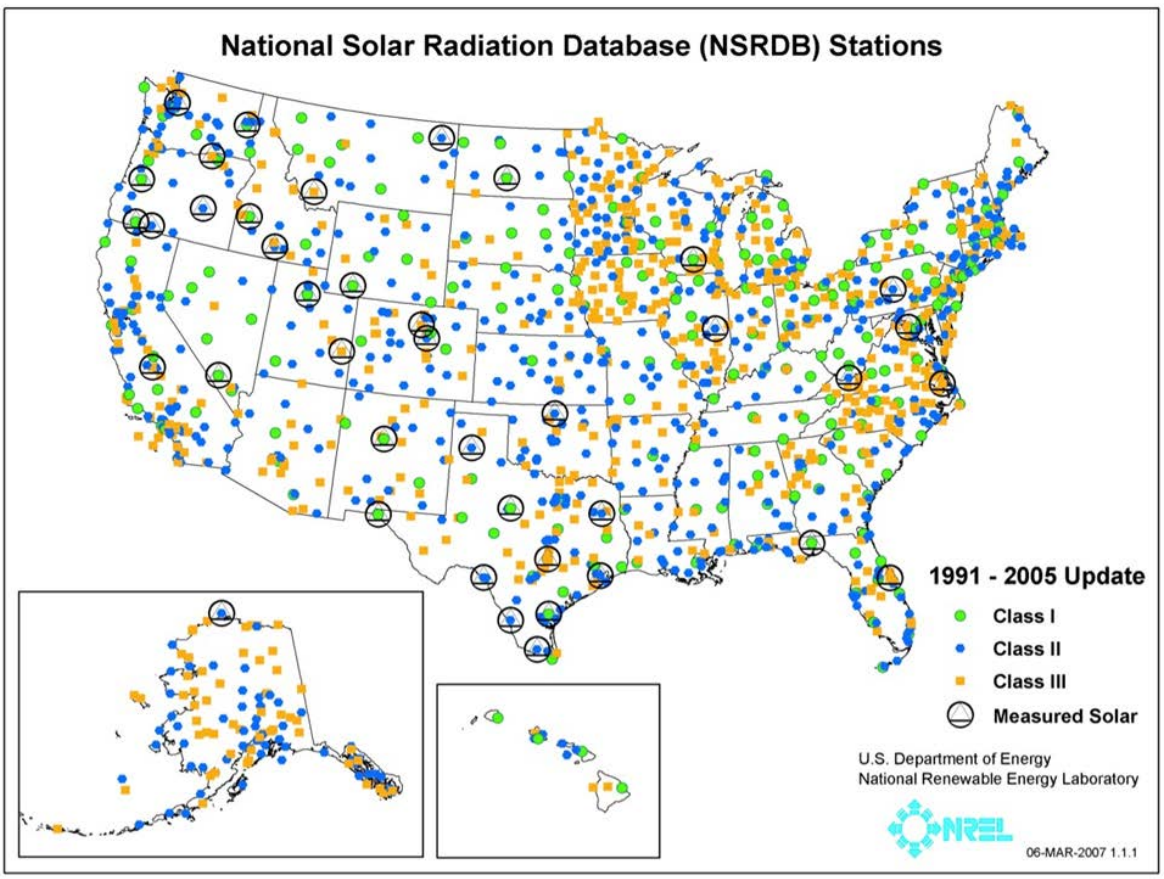


Figure 21. National Solar Radiation Data Base Stations for the period from 1961 to 1990 (Class I) and the 1991 to 2005 update

Title: National Renewable Energy Laboratory Solar Modeling

Presenter: Nate Blair, National Renewable Energy Laboratory

Synopsis: An overview of existing performance and economic analysis tools available from the National Renewable Energy Laboratory:

- PVWatts provides an interactive map-based user interface to the PVWatts Version 2 calculator, allowing nonexperts to quickly obtain estimates for grid-connected photovoltaic systems.
- In My Backyard is a small-scale photovoltaic and wind simulation tool for estimating production potentials for homeowners, business owners, and policy makers.
- Solar Prospector is a web-based geographic information system tool designed to assist industry professionals with utility-scale concentrating solar power plants.
- The System Advisor Model combines detailed performance and finance modeling with cost data, detailed incentive abilities, and a robust user interface to create a full system analysis tool.
- MapSearch provides access to resource maps.
- Web services—Future efforts will be directed to making data and analysis tools available to developers via web services application programming interfaces.

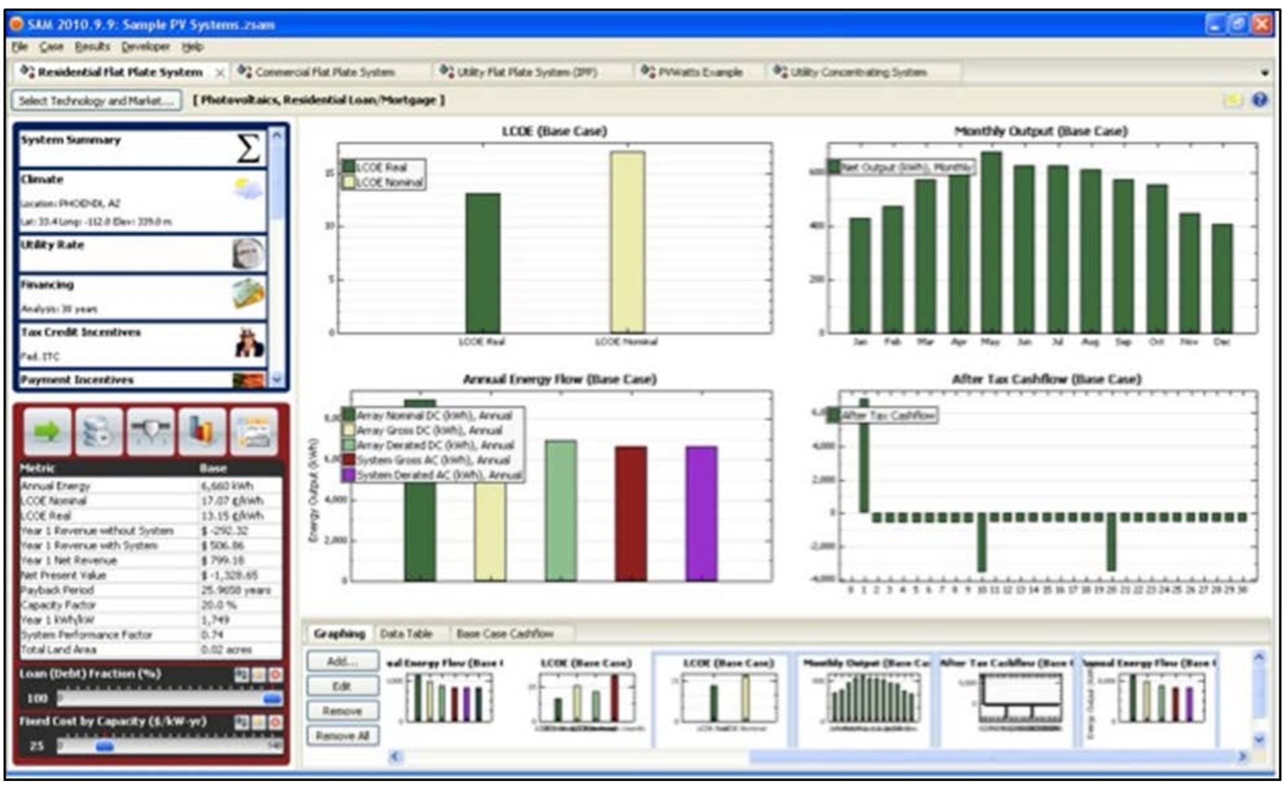


Figure 22. System Advisor Model (www.nrel.gov/analysis/sam)

Panel: Importance of Forecasting to Stakeholders

Title: Solar Forecasting Requirements and Value

Presenter: Mark Ahlstrom, WindLogics

Synopsis: An overview of forecasting value in a dispatchable world. A resource forecast has value only if the operator can use it to optimize a power delivery schedule for economic gain. The times at which financially binding decisions are made are the drivers for forecasting value. System rules are critical: the Midwest Independent Transmission System Operator implies day-ahead and 10- to 15-min-ahead value points whereas the California Independent System Operator may be totally different. If scheduling windows force forecast windows with higher error rates, then costs to solar will be higher.

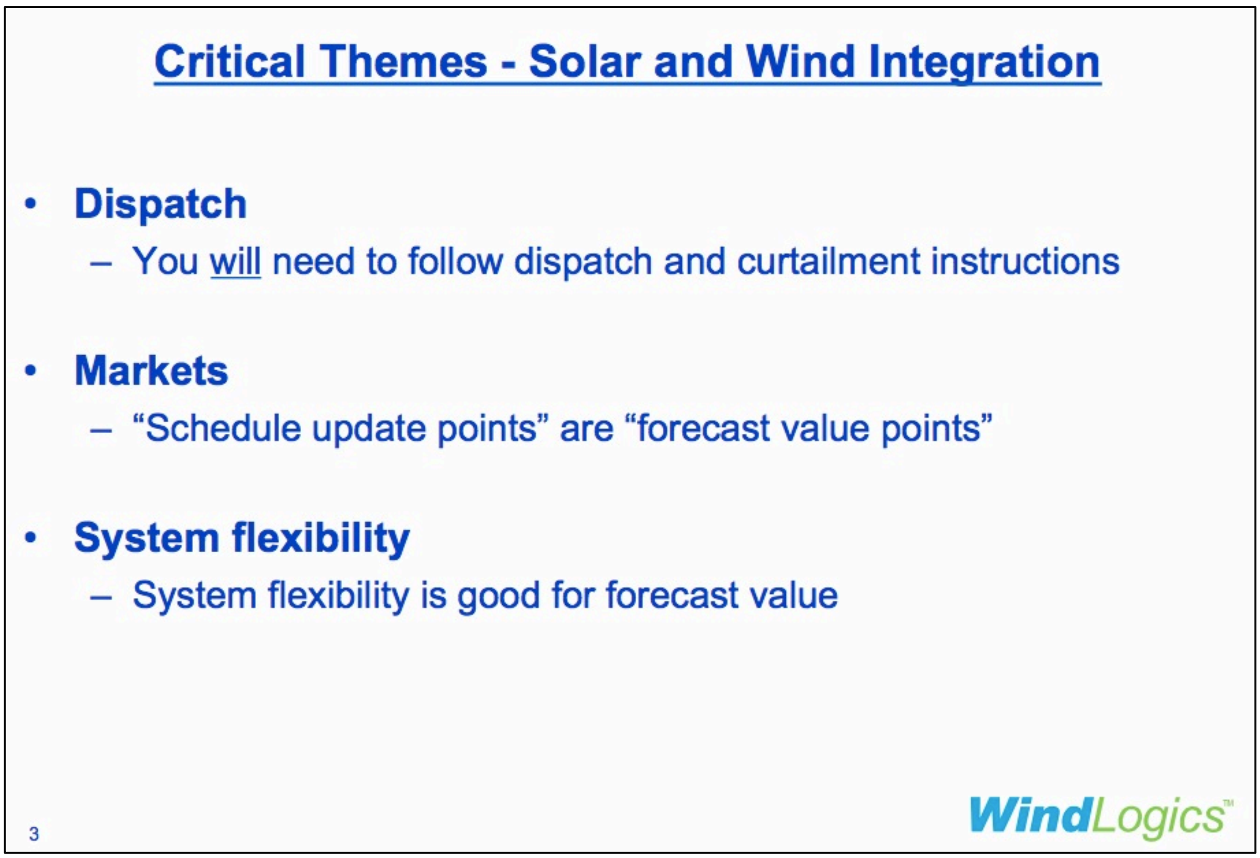


Figure 23. Three critical forecast themes for solar and wind

Title: California Independent System Operator Perspectives

Presenter: Jim Blatchford, California Independent System Operator

Synopsis: California Independent System Operator serves 30 million people with 286 million MWh of electricity delivered annually and conducts 30,000 market transactions per day. Solar generation is expected to be 2,246 MW in 2012 as part of the 20% renewable penetration. Experiences with wind bids/forecasts and power production can be significantly different for 105-min forecasts during a 3-h interval. The forecasting timelines of interest range from persistence to climatological scales: 8, 3, and 1 d ahead, 18 to 42 h ahead, ramp events, hour-ahead every 105 min, and intra-hour forecasts on a 15-min timeline out 2 h.

Figure 24. Effect of forecast and bidding errors. After 4 p.m. on this day, wind generation (*R/T Production*) did not follow the wind forecast (*Bids/Forecasts*)

Title: Solar Forecast Valuation Metrics

Presenter: Pascal Storck, 3TIER, Inc.

Synopsis: 3TIER, Inc., evaluated the skill of day-ahead solar forecasts using a variety of traditional (root mean square error, mean absolute error) and more "interesting" and hopefully relevant statistical measures of skill by examining day-ahead forecasts from in Desert Rock, Nevada, and Boulder, Colorado. Conventional metrics are mathematically convenient and used as universal standards for comparison, but they do not reveal when the forecast adds value or how it handles cloudy conditions alone. A cumulative advantage analysis reveals the relative value of the forecast during specific periods. Assuming constant market and system conditions, the value of day-ahead solar forecasts compared to unskilled benchmarks is considerable (likely greater than $5,000 per month at most locations). However, most bulk error statistics (e.g., mean absolute error) do not consider asymmetric costs such as the larger penalty for erring on the high side. When considering cloudy days at a site where they are rare, persistence is the best forecast if false alarms are unimportant. In this case, a larger sample, separate training for cloudy conditions, or a method better suited to rare event prediction may be needed.

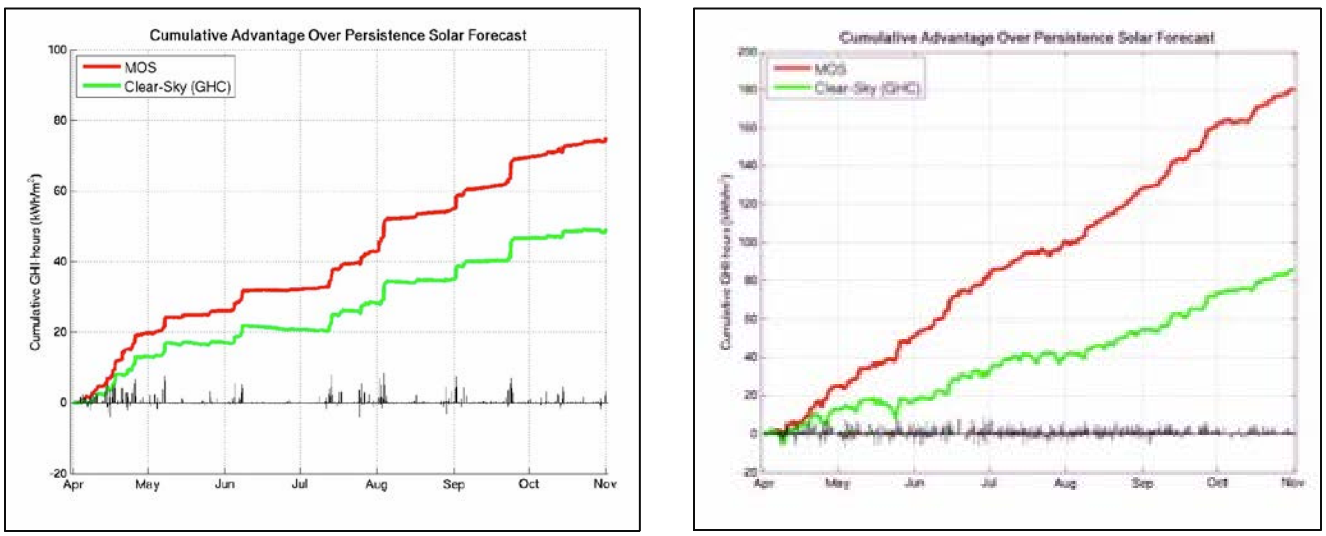


Figure 25. Comparisons of solar forecasts from model output statistics and clear sky methods with respect to persistence at two locations: Desert Rock, NV (left), and Boulder, CO (right)

Title: Solar Forecasting for Arizona Public Service—What Do We Need? Do We Know?

Presenter: Ron Flood, Arizona Public Service

Synopsis: Arizona Public Service (APS) has mostly distributed applications of solar generation. Traditional dispatch is concerned with reserve and regulation when including solar generation. Day-ahead and real-time forecasts are needed to meet load, reserve, and regulation while planning to minimize cost (economic dispatching). System operations require sufficient generation to supply North American Electric Reliability Corporation reliability and power quality requirements. Sometimes goals and practices are at odds. Solar generation creates these questions:

- What will be the effects on generation or on load?
- What will be the effects on transmission or distribution?
- Will the effects be regional or localized?
- What will the new load profiles look like?
- How much "smoothing" from geographic dispersion?
- Will solar profiles affect overall generation dispatch?
- How much regulation may be offset with distribution design?
- A solar forecast should provide the expected resource at least daily (how granular?), for a region (how large?), and for a specific asset.
- How would the forecast be modeled into dispatch tools?

APS has some of the answers, but can the forecasters deliver what we think we need?

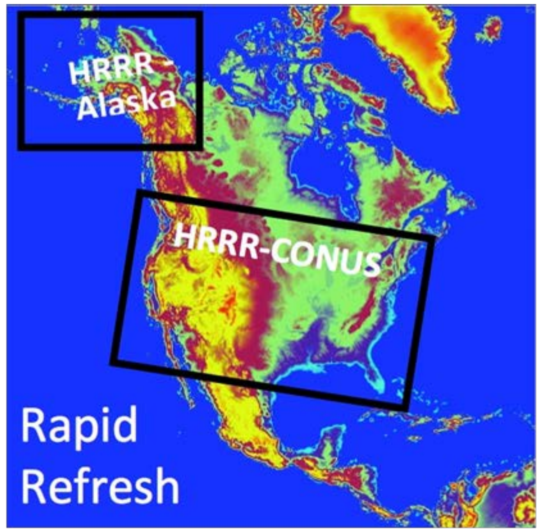
Figure 26. Arizona Public Service territory in white areas

Plenary: Solar Radiation Estimates From Numerical Weather Prediction Models

Title: Solar Radiation Estimates From Numerical Weather Prediction Models

Presenter: Stan Benjamin, National Oceanic and Atmospheric Administration, Earth Systems Research Laboratory

Synopsis: A brief review of National Oceanic and Atmospheric Administration (NOAA) numerical weather prediction (NWP) models, a history of changes in forecasting from 1940 to the present, how NWP models and data assimilation function, the physics in current NOAA models, and a review of hourly updated NOAA models and their relevance to solar forecasting. The Global Forecast System relies on global data assimilation to provide initializations for a variety of forecast models, including the North American Mesoscale used for severe weather, air quality, and dispersion forecasts and the rapid update models for aviation, severe weather, and energy. The High-Resolution Rapid Refresh (HRRR) model is updated hourly and provides 3-km, 15-h forecasts for the continental United States. Data assimilation is key to NWP. New observation methods provide improved inputs. NWP has advanced with the help of improved computing capabilities to allow HRRR to model 50 vertical layers x 1799 x 1059 = 95 million 3-D grid points. A 12-h forecast requires 10^{15} floating point operations. The current run time is about 50 min. The model physics must address cloud and aerosol interactions, better planetary boundary layer parameterizations, stochastic physical parameterizations (cloud variations), and more precision in solar and infrared parameterizations.



NOAA NWP models

model	Update frequency	Running at NCEP	Resolution	Domain
GFS	6h	already	~30km	global
NAM	6h	already	12km	Extended North America
RUC	1h	already	13km	CONUS
Rapid Refresh	1h	Oct 2011	13km	North America
HRRR	1h	Est. 2014-5	3km	CONUS
HRRR-chem	6h (to be 1h)	2017-19?	3km	Western US

Figure 27. National Oceanic and Atmospheric Administration High-Resolution Rapid Refresh coverage (top) and a list of numerical weather prediction models in use by the National Center for Environmental Prediction (bottom)

Technical Session: Short-Term and Day-Ahead Forecasting

Title: Issues and Potential of Numerical Weather Prediction for Solar Power Production Forecasting

Presenter: John Zack, AWS Truepower

Synopsis: Numerical Weather Prediction (NWP) modeling is well suited for look-ahead periods of more than 6 h. The current approach to solar power production forecasting includes a "simple" method based on direct NWP forecasts of irradiance interpolated from forecast sites, a "better" method where model output statistics (MOS) are applied to NWP output parameters, and an "even better" approach based on the composite of an ensemble of NWP forecasts, possibly MOS adjusted. Key opportunities for improvement include NWP forecasts that address cloud characteristics and amounts and improved radiative transfer algorithms. Improved MOS results can come from finding conditional systematic errors, applying advanced statistical techniques (e.g., ANN, nonparametric), and using more sophisticated training sample construction strategies (e.g., regime based). The current primary tool for forecasts of less than 6 h is cloud vector extrapolation based on satellite observations for 1 to 6 h, surface-based sky-imager cloud pattern extrapolation for 0 to 6 h, and time series methods for 0 to 2 h. Limitations of these methods are because of the lack of cloud genesis and dissipation (e.g., nonlinear evolution). A solar-customized rapid-update cycle approach is needed to address the current limitations of NWP for less than 6 h. The concept of MOS was presented as well as key issues regarding sensitivity of NWP forecasts of global horizontal irradiance (GHI). When considering days-ahead forecasts, MOS is very effective at removing bias of NWP forecasts of GHI, but the best NWP forecast does not always yield the best MOS forecast, and training sample characteristics can yield significant MOS performance differences. For hours-ahead forecasts, initial experiments suggest that more sophisticated cloud initialization can improve short-term irradiance forecasts compared with standard NWP initialization.

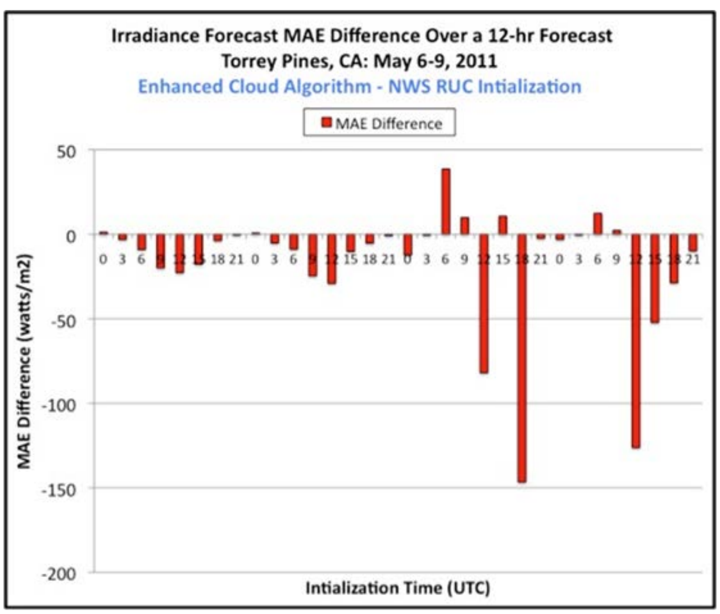


Figure 28. Enhanced cloud initialization reduces the mean absolute error of a 12-h forecast by 18 Wm^{-2} during a 4-d period in Torrey Pines, CA

Title: Short-Term and Day-Ahead Forecasting

Presenter: Richard Perez, State University of New York at Albany

Synopsis: Provided an overview of the currently available forecast methods and presented results of validations based on the National Oceanic and Atmospheric Administration (NOAA) Surface Radiation Budget Network (SURFRAD). Forecasts of hours-ahead are measurement driven (e.g., observed cloud motion from sky imagers at the surface or satellite-based observations). Days-ahead forecasts are the domain of numerical weather prediction (NWP) models. A seven-site (SURFRAD) composite accuracy illustrates the relative performance of persistence, cloud motion, and NWP methods. The root mean square error (RSME) for the 5-h time horizon is about 100 W/sq m for both the cloud motion and NWP methods. Six models were evaluated for their days-ahead forecasts compared with SURFRAD measurements:

1. The Global Environmental Multiscale (GEM) model from Environment Canada,
2. The European Center for Medium-Range Weather Forecasts (ECMWF) model,
3. The Weather Research and Forecasting (WRF) community model from the National Center for Atmospheric Research,
4. The MASS model from AWS Truepower,
5. The Advanced Multi-scale Regional Prediction System (ARPS) from AWS Truepower, and
6. The NOAA National Forecast Data Base (NDFD) cloud cover model.

The WRF, MASS, ARPS, and NDFD are driven by the Global Forecast System (GFS) model. The resulting RSME (W/sq m) was highest for persistence (190 to 210 W/sq m during 1 to 6 d) and lowest for the GEM model (120 W/sq m for day ahead). The results suggest a performance difference of the models based on the source of input/initialization data, with GFS-driven methods demonstrating a higher RSME than those using other global models (i.e., ECMWF).

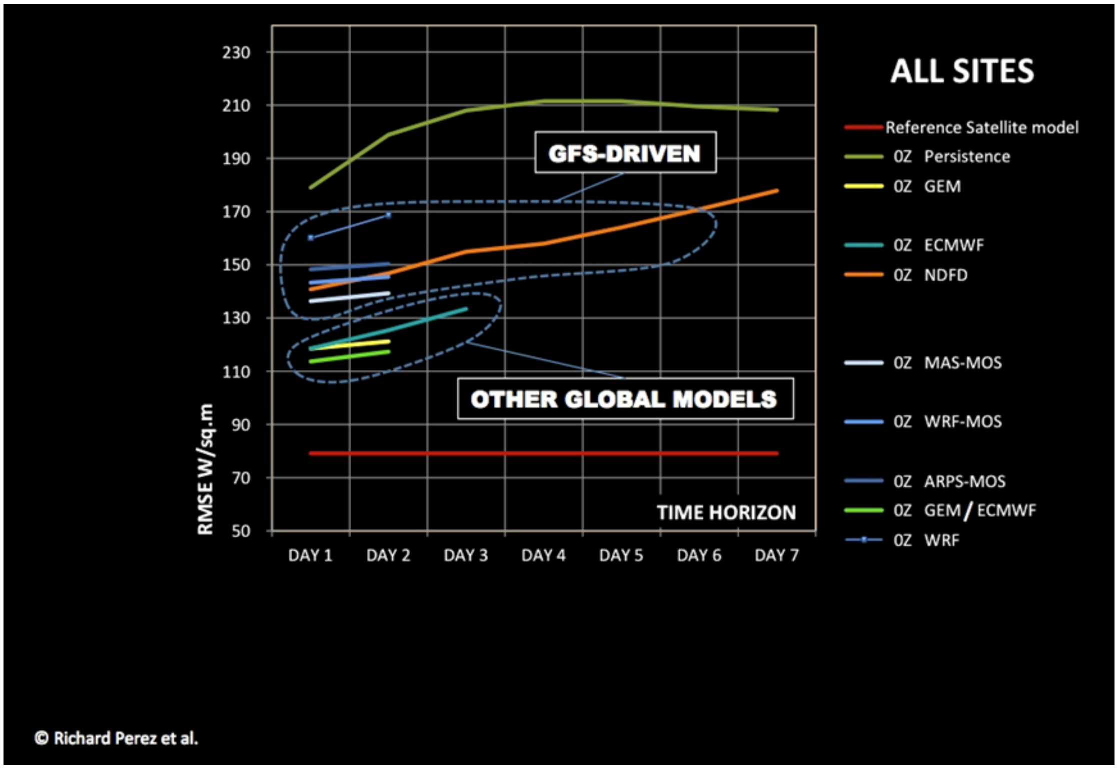


Figure 29. Comparison of nine numerical-weather-predication-based solar forecast methods with satellite model results for a 7-d period. The root mean square error statistical groupings align with the Global Forecast System and European Center for Median-Range Weather Forecast initializations.

Title: Surface Solar Irradiance: Cloud Observations and Radiative Transfer Modeling

Presenter: Ned Snell, Atmospheric and Environmental Research

Synopsis: An introduction to the state-of-the-science radiative transfer code, the rapid radiative transfer model for global circulation modeling (RRTMG) used in numerical weather prediction (NWP) models worldwide (rapid update cycle, Weather Research and Forecasting, National Centers for Environmental Prediction, Global Forecast System, Climate Forecast System, National Center for Atmospheric Research, Community Earth System Modeling/Community Atmospheric Model Version 5, and the European Center for Medium-Range Weather Forecasts' Integrated Forecast System). The RRTMG was developed as part of the U.S. Department of Energy Atmospheric Radiation Measurement Program and has been validated against high-resolution spectral models and radiometric measurements from a range of platforms. The model can generate broadband as well as narrow-band solar irradiances that could be tuned to specific spectral responses of available photovoltaic technologies. A solar irradiance forecast is in testing that is based on the union of cloud analysis, forecast products, and accelerated radiative transfer modeling, including satellite data used for near-term cloud forecasts, NWP data used for next-day cloud forecasts, and the RRTMG radiative transfer model, which provides validated irradiances and power conversion.

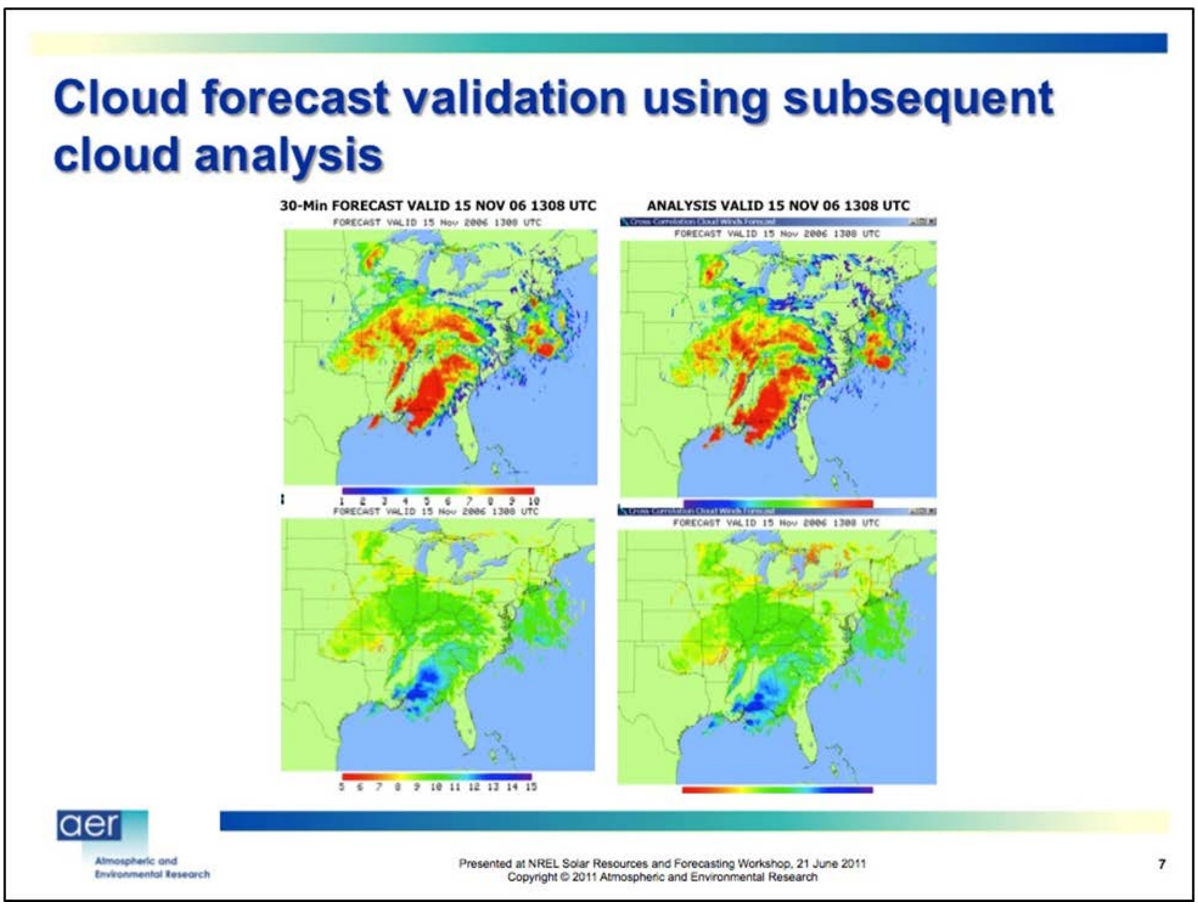


Figure 30. The rapid radiative transfer model for global circulation modeling is a physics-based approach to addressing clouds in numerical weather prediction models

Title: Satellite and Model-Based Short-Term Forecasting of Solar Irradiance

Presenter: Steven Miller, Colorado State University, Cooperative Institute for Research in the Atmosphere

Synopsis: Satellite-based cloud trajectory methods are applied to the important gap-filling role for maximizing forecast skill across the 0.5- to 2.5-h timeframe. Satellite-based observations must account for parallax—the apparent displacement of a cloud from its actual location above the surface because of the viewing angle. This can result in significant errors in cloud location (tens of kilometers). Accurate cloud top height retrievals are required. With sun geometry, the cloud shadowing of a solar power system can be determined. The Colorado State University foothills campus is being used as one validation site. National Oceanic and Atmospheric Administration (NOAA) Surface Radiation Budget Network sites and other networks will also be used. Numerical weather predication–based advection provides curvature and multilevel steering, but the effects of wind shear require treatment of clouds as objects as opposed to individual pixels. Opportunities exist to improve the coupling between the NOAA satellite-based cloud and irradiance models to improve resource assessment and short-term forecasting.

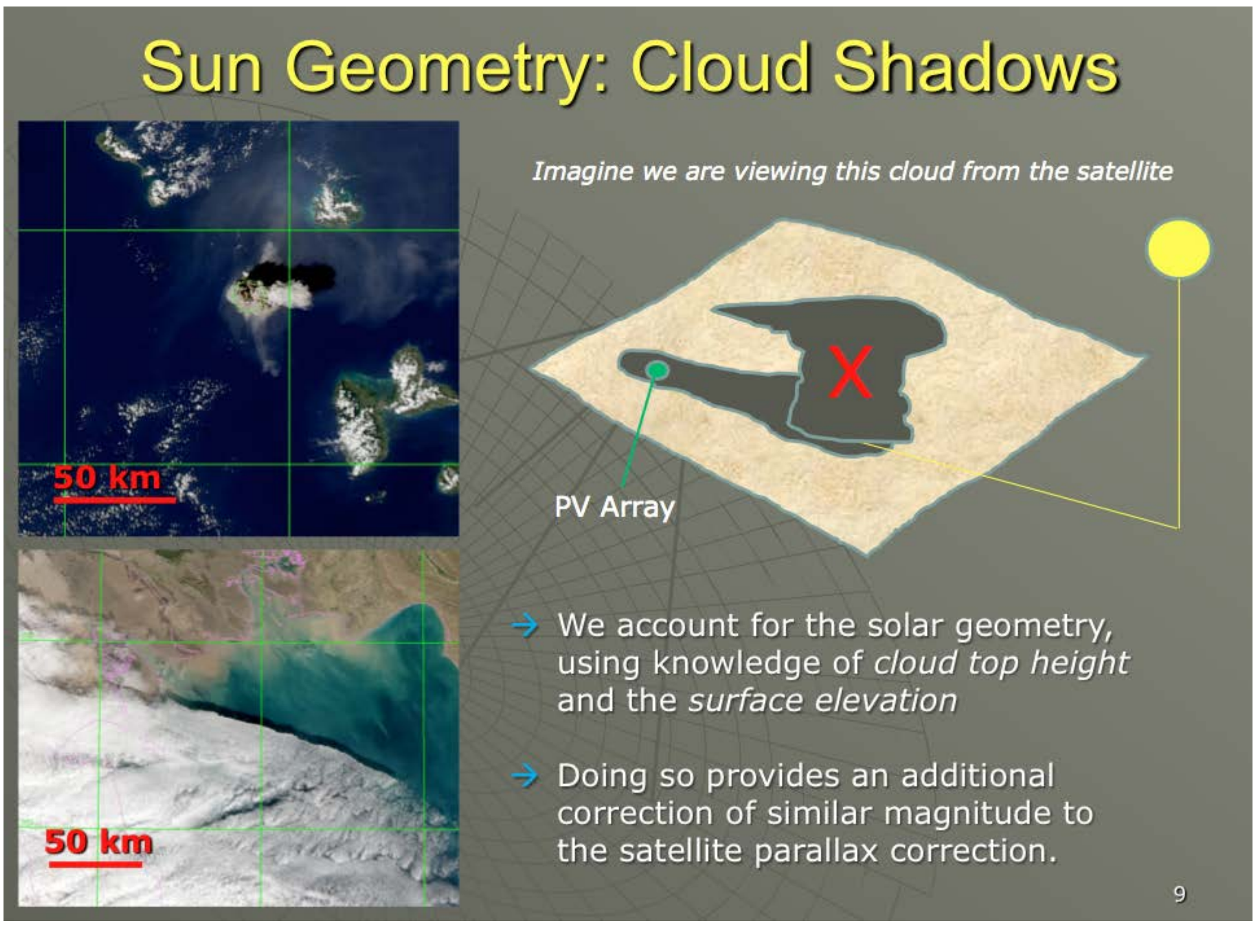


Figure 31. Satellite-based cloud observations must be corrected for parallax as part of computing shadow locations. Cloud trajectory methods are then used with an empirical or two-stream radiative transfer model for short-term forecasts of surface solar irradiance.

Technical Session: Photovoltaic Output Variability Studies

Title: Modeling Solar Variability Effects on Power Plants

Presenter: Jan Kleissl, University of California at San Diego

Synopsis: Description of a method to estimate aggregated photovoltaic (PV) plant output variability given a single point sensor measurement. The model requirements are universal application (i.e., for plants of any size, at any location, with any arrangement of PV panels) and the need to account for different variability at different timescales. The model applications address (1) estimated variability of output from distributed and central PV plants to determine grid impacts, (2) generation of virtual PV output for renewable grid integration studies, and (3) estimated benefits of various capacities of energy storage in reducing ramp rates. Measured global horizontal irradiance (GHI) is available at 1-s intervals from a seven-station network of photodiode pyranometers in and near the University of California at San Diego (UCSD) campus. Based on these measurements, the model development considered:

7. The decomposition of the GHI time-series into variability at different timescales using the top hat wavelet,
8. Determining the correlation of GHI fluctuations as a function of distance and timescale between different sites,
9. Using the correlation relationship to model variability for a variety of solar PV plant types (e.g., distributed, central, large, and small), and
10. The setup of a simple user interface (drawing polygons around PV on Google map, inputting point sensor time series, and the output of DC power for a PV plant).

Correlations were developed for a range of timescales (from 2–4 s to 2,048–4096 s) with the normalized distance divided by timescale. A case study was presented to compare the variability of 1.2-MW distributed and central PV power systems simulated at UCSD with the 48-MW PV station in Henderson, Nevada. The variability ratio was defined to determine the correlations between each set of points for an entire plant during all timescales. An inverse transform creates the PV plant output. Sample PV plant variability, expressed in GHI units, was presented for a 1-h interval.

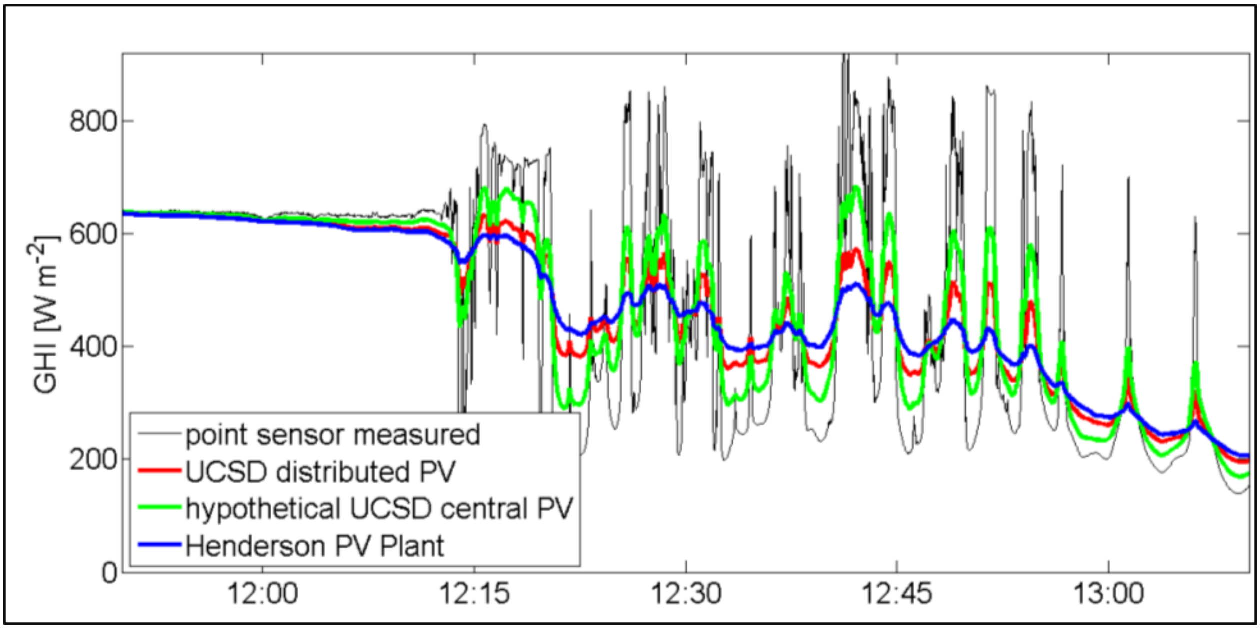


Figure 32. Photovoltaic power plant variability in GHI (Wm^{-2}) for distributed and central generation compared with pyranometer measurements

Title: Utility-Scale Photovoltaic Variability

Presenter: Adam Kankiewicz, WindLogics

Synopsis: A study of solar resource and photovoltaic (PV) power variability based on measurements from the DeSoto Next Generation Solar Energy Center, a 25-MW PV plant commissioned October 27, 2009. Approximately 90,000 photovoltaic panels are deployed on 1-axis solar trackers throughout the 180-acre field in Florida. Based on data from March 20, 2011, a scaled power production analysis was made to simulate a 225-MW power plant. Observations from the study include (1) Significant drop in observed and predicted variability with increasing PV field size, (2) PV variability is linked to meteorology, 3) the DeSoto site is an excellent test bed for PV variability studies, and (4) there are endless research possibilities offered by this unique installation.

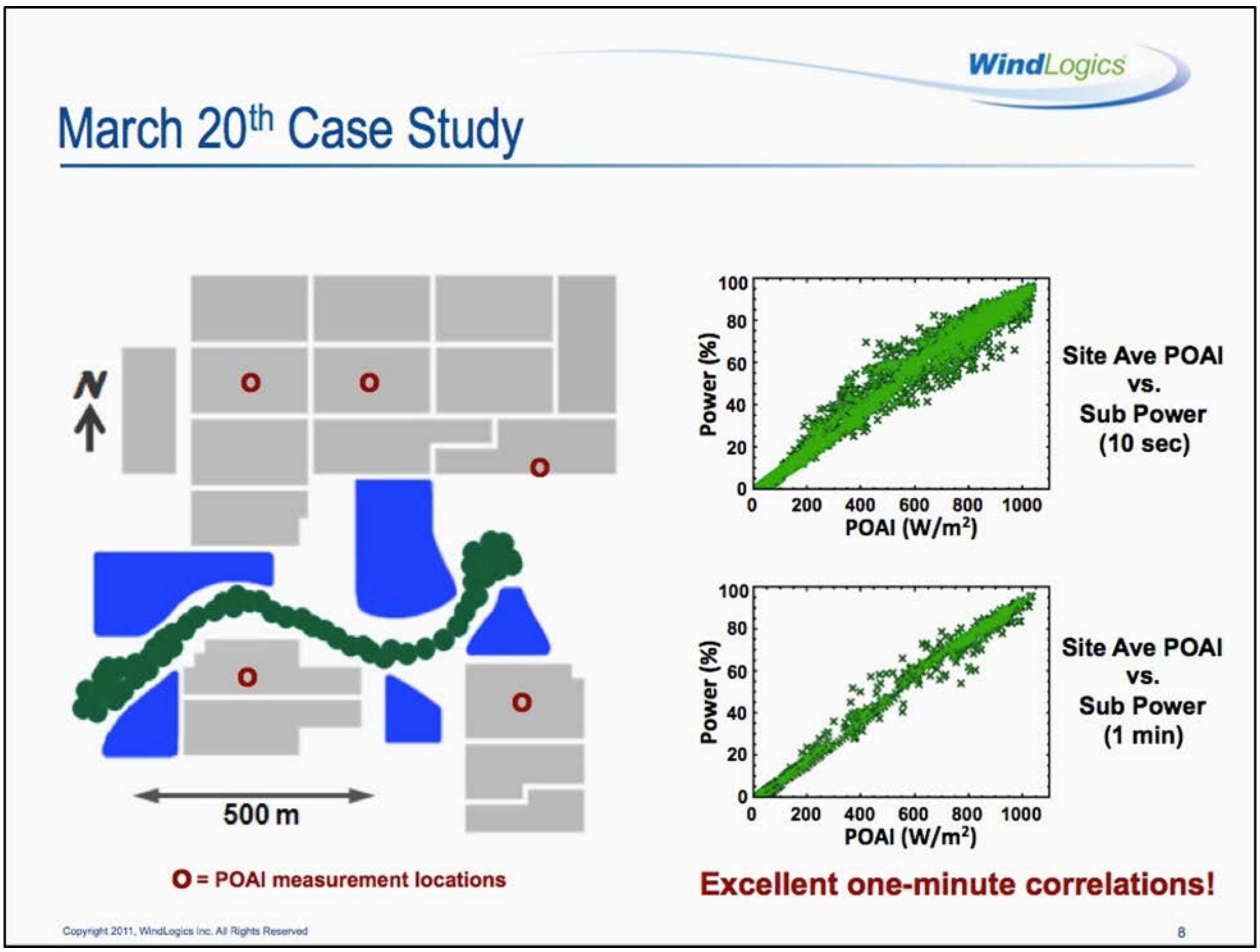


Figure 33. Florida Power and Light photovoltaic power plant schematic and correlations of plane-of-array irradiance with power production based on measurements taken March 20, 2011

Title: Issues in Solar Flux Variability

Presenter: Laura Hinkelman, University of Washington, University of Washington, Joint Institute for the Study of the Atmosphere and Ocean

Synopsis: The approach and results of short-term spatial correlations and long-term regional trends of solar flux are presented. Short-term microscale variability (ramps) analyses are based on 1-s measurements of global horizontal irradiance from the National Renewable Energy Laboratory equipment installed at a research site in Oahu, Hawaii. Results are based on measured data from 13 d with broken cloud cover and mean wind direction close to 60º using measurements from along- and cross-wind site pairs with separation distances ranging from 90 m to 1050 m. Ramp correlations were analyzed for timescales of 30 s, 60 s, 120 s, and 300 s. The along- and cross-wind ramp correlation decrease with separation distance depends on the site alignment and timescale. Short-term spatial correlations must account for (1) site separation, (2) site orientation, (3) wind speed and direction, (4) time interval of interest, and (5) cloud type. Present NWP and satellite models for estimating surface solar irradiance lack the ability to account for 3D radiative transfer effects. An overview of the radiative flux assessment for the World Climate Research Program was also presented. Regional trends of solar flux variation during the period from 2001 to 2004 were presented for four different geographic areas with trends ranging from -2.72 Wm^{-2}/decade to 30.21 Wm^{-2}/decade.

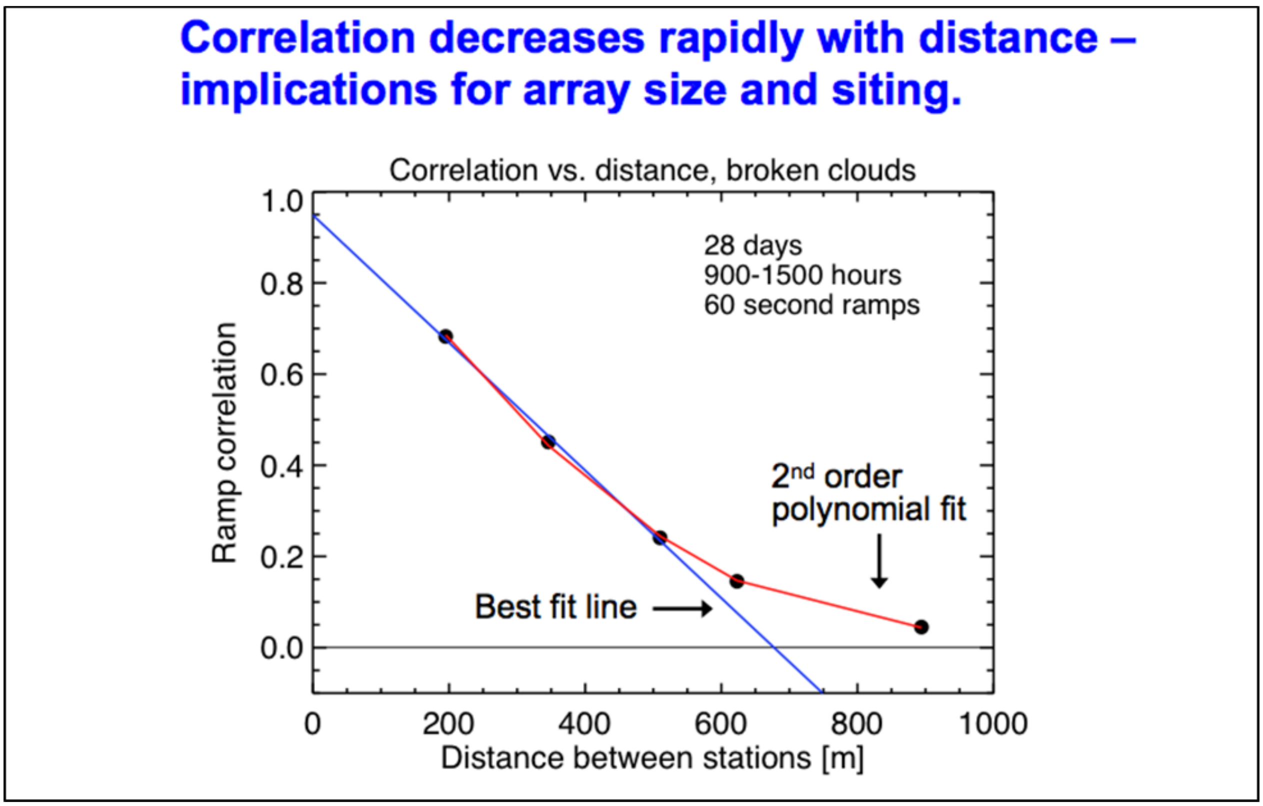


Figure 34. Ramp correlation versus distance between measurement stations on Oahu, Hawaii

Title: Measurement and Modeling of Solar and Photovoltaic Output Variability

Presenter: Manajit Sengupta, National Renewable Energy Laboratory

Synopsis: A study of photovoltaic (PV) variability using 1-s irradiance measurements from a 17-station deployment at the Kalaeloa Airport in Oahu, Hawaii. The approach involved:

1. Installing multiple radiometers in a high-density network;
2. Collecting calibrated, time-synchronized, high-resolution data;
3. Creating spatial and temporal irradiance fields using network measurements;
4. Using the irradiance fields as input to PVWatts to create power output for PV plants of various sizes;
5. Selecting a single radiometer from within the deployed network to create PV power output using various numerical filters and averaging times;
6. Comparing PV power production modeled with single and multiple radiometers.

The results suggest that a limited number of radiometers can be used to model PV plant output, and a baseline has been created using simple time averaging after testing four different interpolation schemes. Further research is needed to (1) determine the maximum plant size that can be modeled with a single radiometer, (2) validate single radiometer models for location and seasonal independence, and (3) determine whether additional meteorological information create more accurate models.

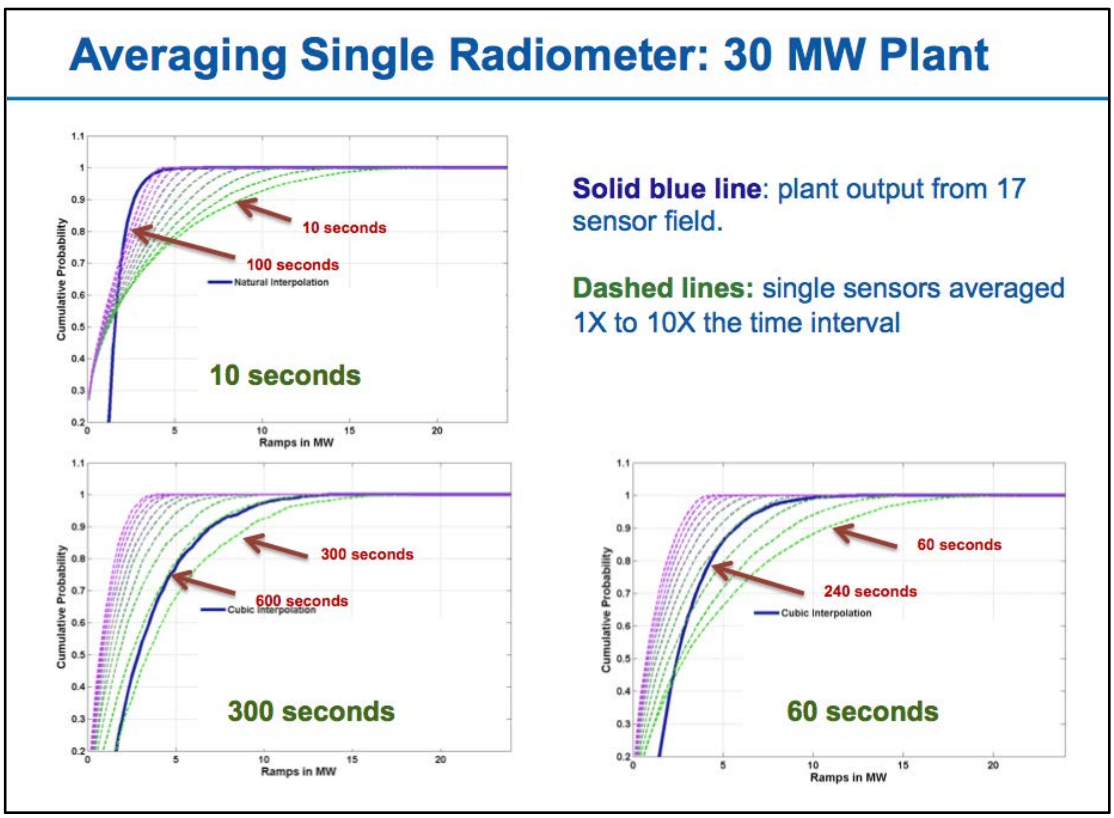


Figure 35. Modeling power output from a 30-MW photovoltaic plant using data from a single radiometer

Panel: Modeling for System Integration Studies

Title: Modeling for System Integration Studies

Presenter: Kirsten Orwig, National Renewable Energy Laboratory

Synopsis: Renewable energy integration studies evaluate the operational impacts of variable generation. Transmission planning studies investigate where new transmission is needed to transfer energy from generation sources to load centers. Both studies use time-synchronized wind and solar energy production and load as inputs and examine high renewable energy penetration scenarios in the future. The Western Wind and Solar Integration Study (WWSIS) identified the technical barriers to achieving 20% wind and up to 5% solar energy penetration by 2030. The solar input data were based on the State University of New York satellite remote sensing model to provide 10 km x 10 km irradiances with hourly resolution. Photovoltaic (PV) power generation was modeled in 100-MW blocks as distributed rooftop systems. Concentrating solar power generation was modeled as 100-MW blocks of parabolic trough plants with 6 h of thermal storage. The hourly production data were downscaled to 10 min for the study. Day-ahead hourly solar forecasts were also developed. WWSIS Phase 2 will address a range of penetration scenarios with solar generation ranging from 3% to 25%. Further research is needed to address (1) the algorithm for downscaling hourly solar irradiance data, (2) modeling various timescales of interest, (3) using NWP for modeling PV production, (4) solar input data needed from an electrical perspective, and (5) PV forecast data requirements.

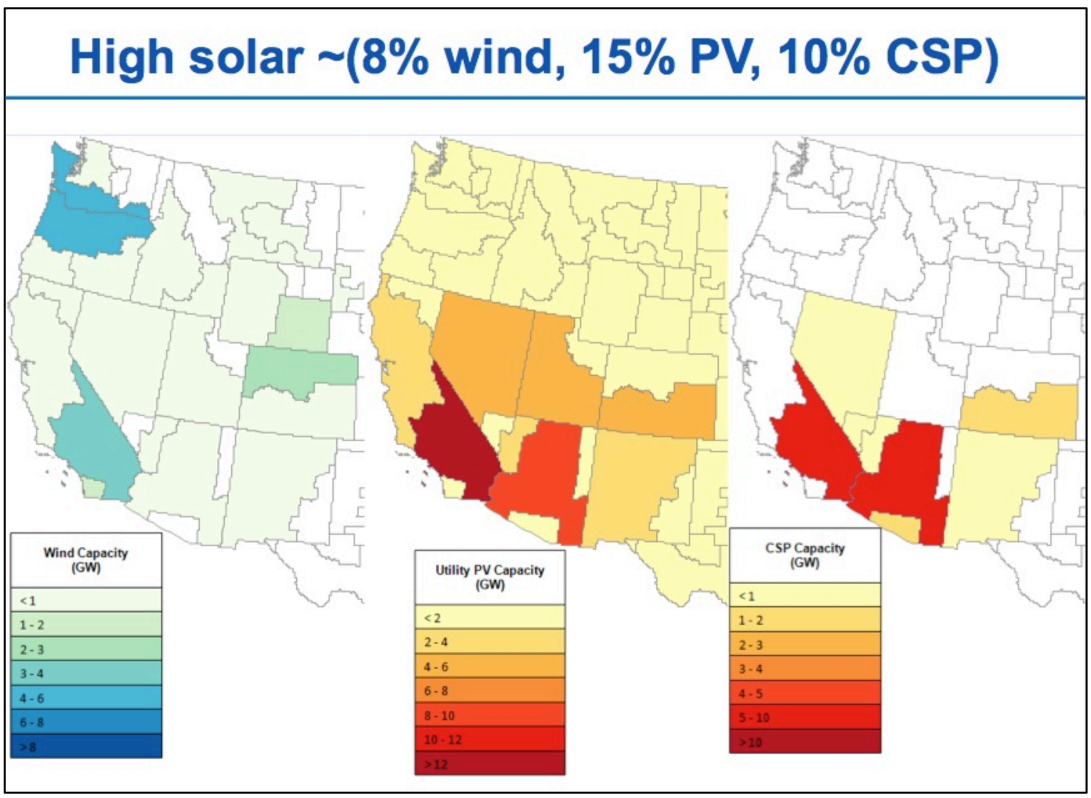


Figure 36. Western Wind and Solar Integration Study, Phase 2 scenarios

Title: One-Minute Photovoltaic Power Output from Hourly State University of New York Data

Presenter: Marissa Hummon, National Renewable Energy Laboratory

Synopsis: The objective for this research was to produce photovoltaic and concentrating solar power (CSP) output profiles with time steps of 1 and 10 min for 1,488 sites in the Western Renewable Energy Zones study conducted by the Western Electricity Coordinating Council. Systems with fixed tilt and 1-axis panels were assumed for the PVWatts simulations of 50-MW capacities. Trough collectors were used for CSP modeling. Statistical analysis of 1-min solar irradiance measurements and the site clearness index (based on hourly satellite observations of cloud cover) were used to develop an algorithm for synthesizing 1-min solar irradiance values at each site. A filter function was used to represent PV plant generation from single-point irradiance data as input to PVWatts for estimating power output. Four clearness index classifications were used (1) clear sky, (2) continuous clearness index, (3) variable clearness index, and (4) intermittent clouds. Analysis of the hourly satellite-based data showed a probabilistic relationship to the clearness index classification. Comparisons of ramp frequency based on measured, synthetic, and filtered synthetic data for ramp durations ranging from 1- to 32 min were presented. Future work will address the needs to (1) develop an improved filter to represent different sizes of PV plants, including distributed generation, (2) validate results against actual PV plant power output data, and (4) improve the coherence of the results across time lags and site locations.

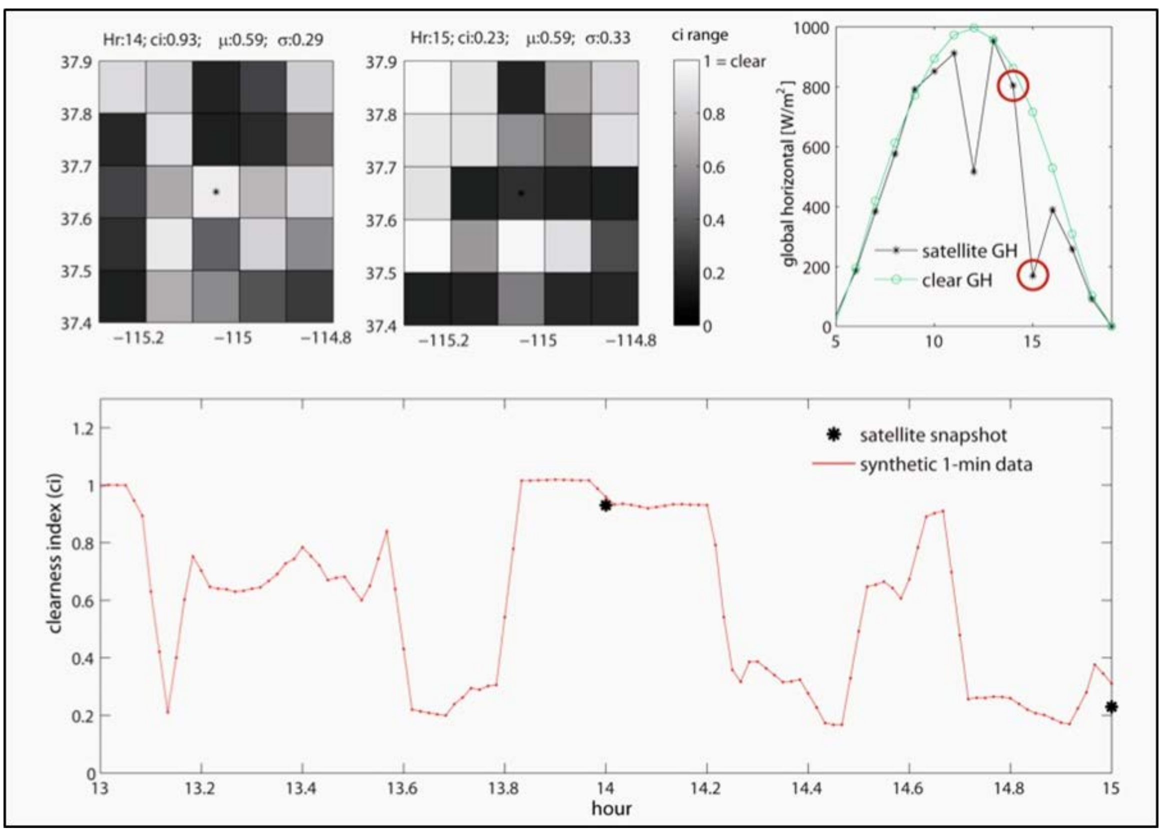


Figure 37. Example of synthetic 1-min data from hourly satellite-based cloud observations

Title: Modeling Solar Photovoltaic Power for Integration Studies Using a Numerical Weather Prediction Model

Presenter: Jaclyn Frank, AWS Truepower

Synopsis: Data sets for solar integration studies must address the needs (1) for power output at time and space scales important to grid operators (e.g., seconds to days and tens to thousands of kilometers), (2) for time to be synchronized with load data, and (3) to be representative of likely future scenarios (e.g., mix of distributed and centralized plants, range of plant sizes, geographic distribution, and a sampling of likely photovoltaic [PV] module and technology types). Sources of solar irradiance data with associated pros and cons are listed. Numerical Weather Prediction (NWP) models can support integration study needs for synthetic PV power data at many locations where on-site observations are not available. The results are based on the Mesoscale Atmospheric Simulation System model that assimilates operational data from rawindsondes (atmospheric profiles) and METAR surface observations, sea surface temperatures from the Moderate Resolution Imaging Spectroradiometer, high-resolution terrain and land cover data, and the Kain-Fritsch cumulus scheme. NWP models need adjustments to available observations to get clouds and aerosols right. Modeling PV power production requires (1) definition of the system configuration (e.g., tracking mode(s), module technology and type, losses appropriate to spatial scale), (2) power conversion parameters (e.g., time-series irradiance and meteorological data, module temperature, gross power output, and loss factors), and (3) model validation during annual, monthly, and diurnal timeframes. High-frequency irradiance issues include (1) NWP model limitation is less than 10 min, (2) downscaling modeled irradiance will not preserve spatial and temporal correlations between sites, (3) a gridded approach can be used for cloud-based wind speeds to advect cloud patterns (cloud growth and decay is secondary at fine horizontal resolution), and (4) power output estimates must scale variability on plant size (dependent upon correlation over plant).

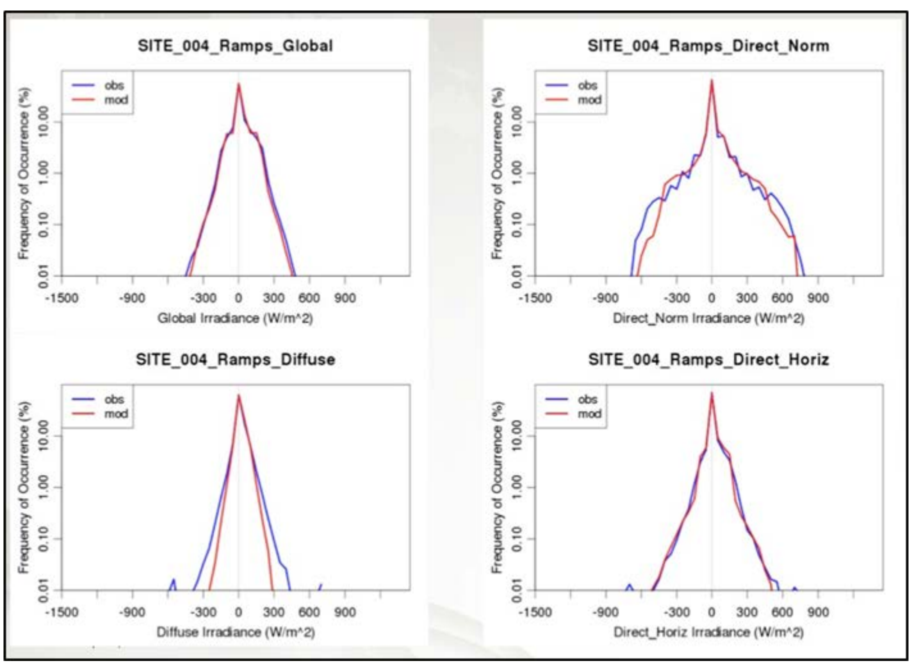


Figure 38. Observed ramp frequency distributions for a site in Canada

Title: Modeling for System Integration Studies

Presenter: Richard Perez, State University of New York at Albany

Synopsis: An overview of the temporal and spatial variability analyses performed for a 20-d sample of summer electrical loads in New York City with various penetrations of photovoltaic (PV). Solar variability can be categorized by passing clouds (20 s to 15 min), diurnal cycles (15 min to 1 d), and seasonal variations (1 d to months). Analyses of various amounts of PV penetration for the 20-d period indicate these needs (1) firm capacity storage is at 8%, (2) PV generation to be stored or lost at 45%, and (3) cost of firm penetration approaches \$10,000/kW at 75%. Comparing solar resource temporal variability at a single point with the variability from 20 uncorrelated locations indicates ±80% and ±5% maximum yield variations in a day, respectively. Ramp rates for an arbitrary PV fleet configuration can be determined from correlations based on cloud speeds, time intervals, and resulting distance scales. Results for a single point and 40 km x 40 km area are summarized in Figure 38.

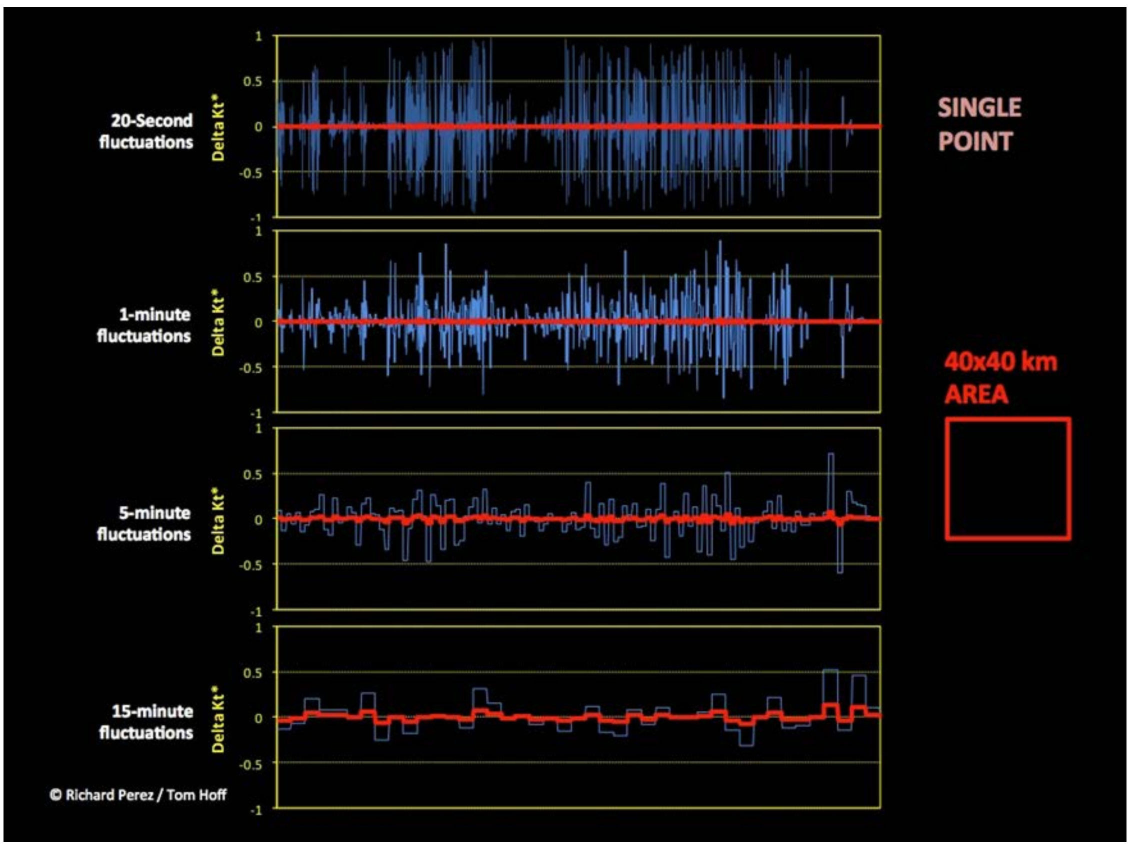


Figure 39. Comparison of solar resource ramping from single point and area-averaged data

Title: Modeling for System Integration Studies

Presenter: Jarjeet Johal, GE Global Research

Synopsis: To date, GE has been involved in 10 renewable integration studies to examine the feasibility of more than 100 GW of new generation. The studies address the needs for fleet flexibility, new operating strategies and markets, transmission reinforcement, and approaches for making grid-friendly renewable energy generation. The GE wind integration study for Hawaii addressed the addition of 500 MW of combined wind generation on Oahu, Molokai, and Lanai. Incorporating a 4-h-ahead wind forecast helped reduce system cost of operation by 4.4% and improve wind energy absorption capacity by 7%. The solar data needed for grid integration studies should address (1) photovoltaic power output, not solar irradiance point data; (2) the fact that multiple years of data are needed to estimate capacity factors of plants, to assess variable costs of operation, and to develop strategies to counteract variability; and (3) power data from several timescales, from 1 s to understand variability to 10 min or hourly data for unit commitment and dispatch. Accurate solar resource forecasts will reduce curtailment and improve cost of operation: (1) timescales from minutes and hours to day-ahead are needed to plan for unit commitment and system regulation requirements, (2) geographic scales should allow for the aggregation of variability from multiple plants for unit commitment decisions, and (3) weather patterns of clear sky, partly cloudy, or overcast days will allow system operators to provide advanced commitment of appropriate generation assets. Support from industry and working groups is needed to (1) address improved grid code requirements for solar inverters to remain connected to the system during voltage disturbances, provide over-frequency control during frequency excursions, and provide dynamic reactive power support; and (2) develop methods to forecast regional power generation, estimate actual power output at regional levels, and tools to convert irradiance to power plant output.

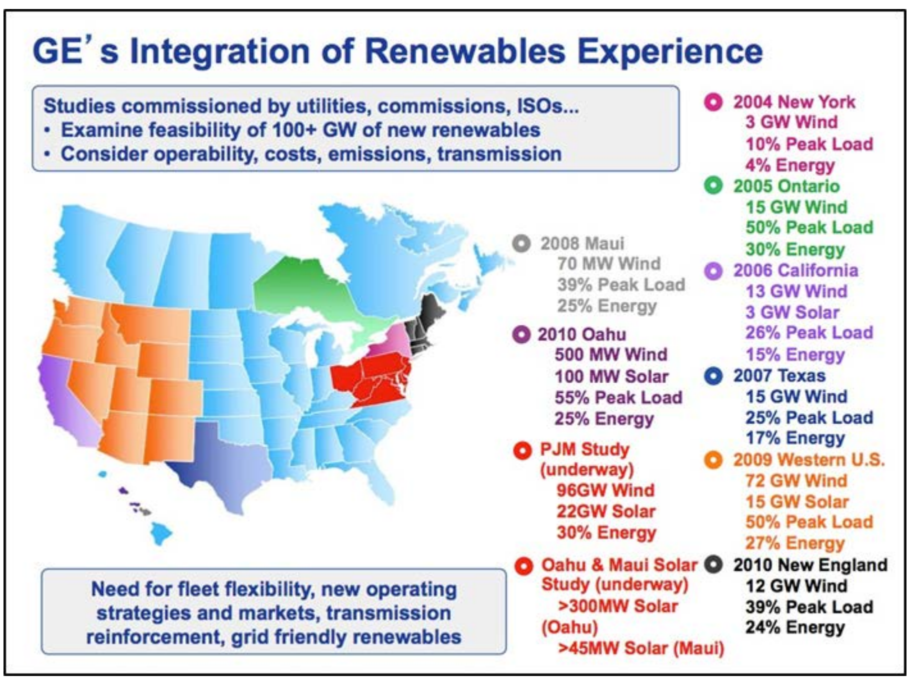


Figure 40. Listing of system integration studies conducted by GE

Title: Data for Power System Studies

Presenter: Kara Clark, National Renewable Energy Laboratory

Synopsis: System studies use solar resource data to evaluate transient stability, distributed photovoltaic (PV) impact on voltage regulators, and the systematic impact of high solar penetration on operating costs. GE's Positive Sequence Load Flow (PSLF) software was used for the study. The input data resolution ranges from seconds to hours to address the AC power injected into the solar plant collector system or utility power system. A 12-h PSLF dynamic simulation during partly cloudy skies indicate a solar PV power plant in unity power factor control experiences a threefold increase in regulator tap steps with a slight increase in capacitor bank switching. Under the same conditions, the results based on the PV plant regulating point of interconnection voltage requires a fourfold decrease in tap steps and a slight decrease in capacitor bank switching. With ideal voltage regulation, the PV plant is supplying most of the reactive requirements of the feeder, but the plant is a point source with nontrivial converter losses. By adding droop to PV plant voltage control, the plant mitigates fast voltage variations because of varying solar irradiance and longer term reactive compensation and voltage control can be performed by regulator and switched capacitor banks. Better data are needed, including (1) measured not simulated, (2) individual unit power, by plant, and (3) real forecasts/measurements versus simulated forecasts/actuals.

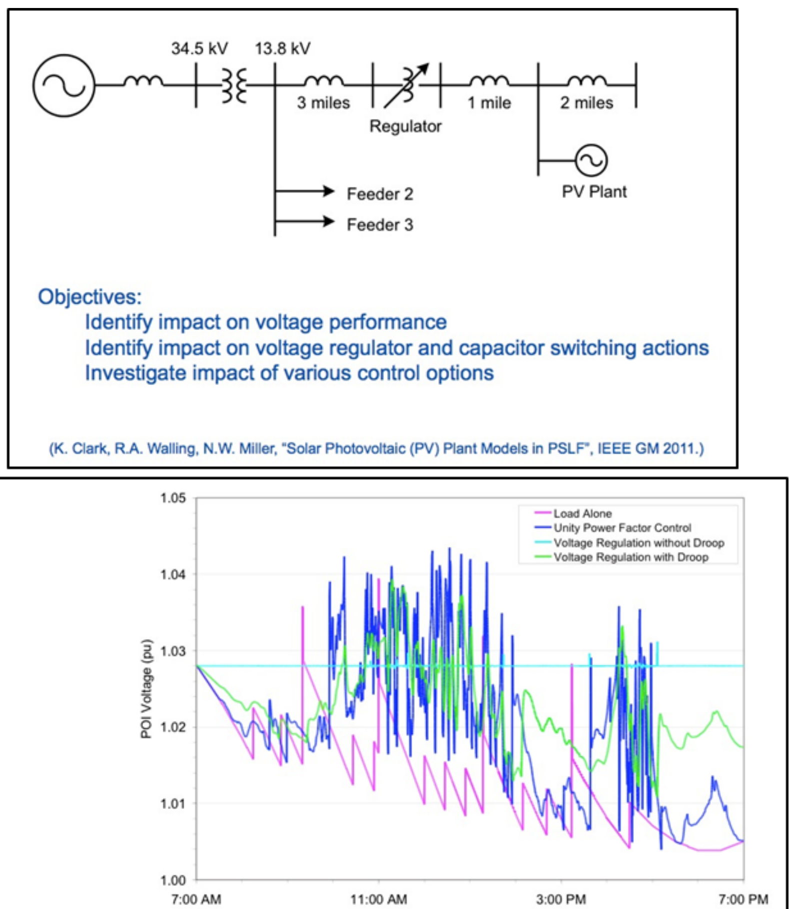


Figure 41. Analysis of solar plant on distribution system

Appendix D: Summary of Participant Survey

Each participant received a workshop evaluation form with their registration materials. Forty-three percent of the participants submitted their comments and ratings. The following summary provides the questions, representative comments, and numerical summary of the ratings. Based on the comments, ratings, and my personal interactions with the participants, the workshop was very helpful to a wide range of interests.

1. The three best takeaways from this workshop that I will apply when I get back to my job:
   - Knowledge of the state-of-the-art, especially measurement technologies
   - Business opportunities to support observational needs at new plants
   - Photovoltaic power production forecast issues
   - Uncertainty analyses and understanding "bankable" solar resource data
   - Understanding needs of industry and utilities
   - Best practices for measurements and data applications
   - Ideas for new instrumentation design
   - Contacts and collaboration opportunities
   - Identification of industry needs and current status of needs
   - Studies of worst-case scenarios for solar resource assessment
   - Comparison of results to those using numerical weather prediction
   - The National Digital Forecast Database is amazing!
   - Great knowledge transfer on many topics
   - Understanding satellite modeling
   - Needs and challenges for developing solar forecast metrics.
   - Forecasting timescales are valued by dispatch requests, not necessarily by science.

2. What was most valuable about this workshop?
   - Diverse and very informative presentations
   - Insight into the National Renewable Energy Laboratory and U.S. Department of Energy perspectives is extremely valuable to my business
   - Networking with public and private stakeholders
   - Finance and developer perspectives
   - Solar resource data sources
   - Uncertainty in data
   - Satellite modeling techniques
   - Discussion of short-term forecasting
   - Final discussion and all state-of-the-art talks
   - Broad and comprehensive scope of the presentations
   - These people all in the same room
   - Level of knowledge transfer was well-balanced and broad in scope
   - Practical application of instruments in the field
   - Obtaining industry expert opinions and needs

3. What was least valuable about this workshop?

- It was all valuable to some extent
- Too much time listening to talks—need more small group sessions for discussion
- Description of numerical weather prediction models
- Detailed discussions on specifics of direct normal irradiance measurement and instrumentation
- Evening dinner was too formal and limited social networking
- Not enough concentration on photovoltaic project performance requirements and how to apply all the information
- Webinar audio connection was hard to hear
- Fewer presentations and more discussion
- Not enough time for everything
- Lack of financial stakeholder representatives

4. Please state your opinion to each question below (0 = strongly disagree, 5 = strongly agree):

Statement	Average Score
The presenters were effective in offering new concepts and ideas	4.3
The environment was conducive to learning	4.4
I have a better understanding of opportunities for researching solar resources and forecasting	4.3
Overall, I believe this workshop was a good investment of my time	4.7