758: Applications of the Renewable Energy Network Optimization Tool (ReNOT) for use by Wind & Solar Developers

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AMS 2011
91ST ANNUAL MEETING
23-27 JANUARY 2011
SEATTLE, WASHINGTON

NORTHROP GRUMMAN

Motivation and Background

As the renewable energy industry continues to grow so does the requirement for atmospheric modeling and analysis tools to maximize both wind and solar power. Renewable energy generation is variable however; presenting challenges for electrical grid operation and requires a variety of measures to adequately firm power. These measures include the production of non-renewable generation during times when renewables are not available. One strategy for minimizing the variability of renewable energy production is site diversity. Assuming that a network of renewable energy systems feed a common electrical grid, site diversity ensures that when one system on the network has a reduction in generation others on the same grid make up the difference.
This site-diversity strategy can be used to mitigate the intermittency in alternative energy production systems while still maximizing saleable energy. The Renewable Energy Network Optimization Tool (ReNOT) has recently been developed to study the merits of site optimization for wind and solar farms. The modeling system has a plug-in architecture that allows us to accommodate a wide variety of renewable energy system designs and performance metrics.

Objectives

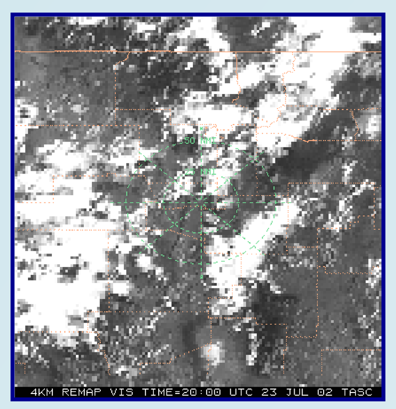
The objective of this research is to develop a capability that can optimize the placement of wind and/or solar farms in order to minimize power generation interruptions and maximize saleable energy. In order to achieve this capability we require high resolution, validated wind and solar time series databases.

Data Sets Used

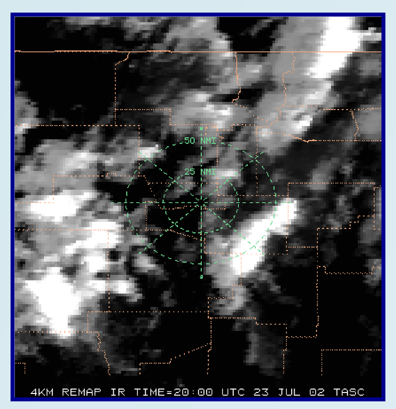
Clouds

In order to optimize the placement of wind and/or solar farms it is imperative to have a time series of wind and clouds. For the solar case, we have developed a fifteen year cloud climatology based on NOAA Geostationary Operational Environmental Satellite (GOES) imagery. The database has been generated over the entire Continental United States as well as the State of Hawaii. The cloud database is approximately four kilometer spatial and fifteen minute temporal resolution. The cloud database has been validated against whole sky imager (WSI) over a nine month period as well as pyrheliometer data at multiple locations throughout the United States. Comparisons were also made to data from the Desoto photovoltaic farm located in Florida[1].

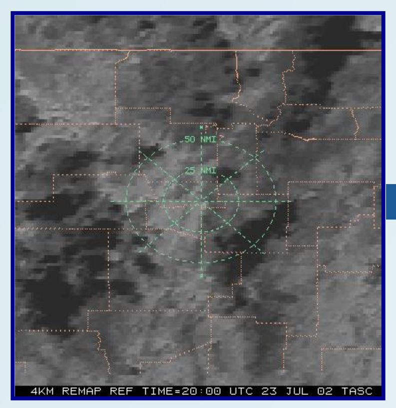
The cloud analysis techniques is described in detail by Alliss et al.[2]. All cloud tests consist of comparing satellite image values to dynamically computed clear sky background values pixel by pixel. A clear sky background value is computed for the visible, and long and short-wave infrared wavelengths and provided to the cloud test algorithms.



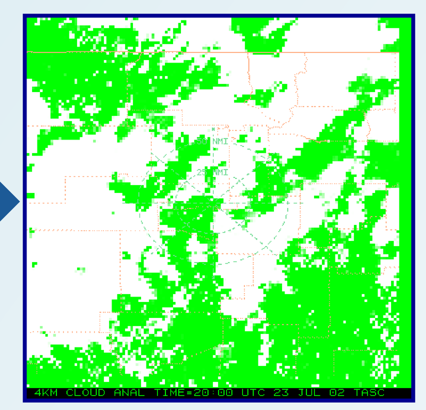
GOES Visible Imagery



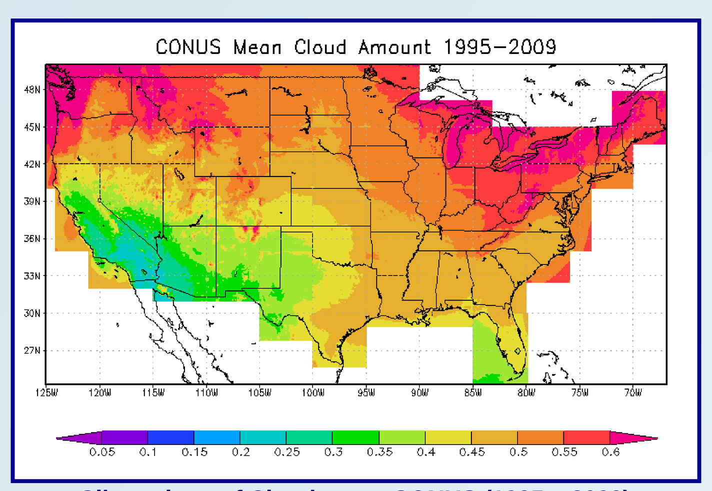
GOES Longwave IR Imagery



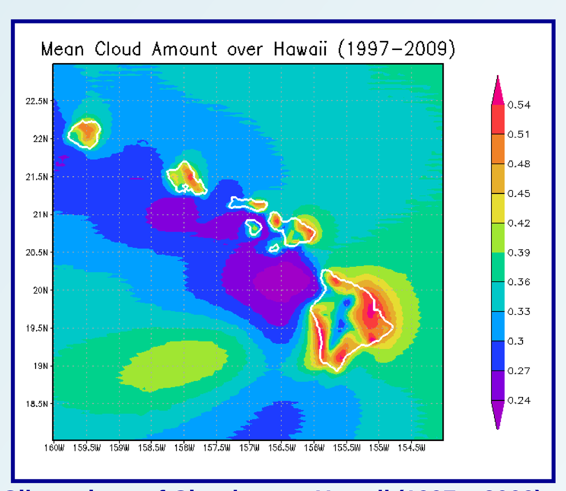
GOES Shortwave IR Imagery



Composite Cloud Analysis



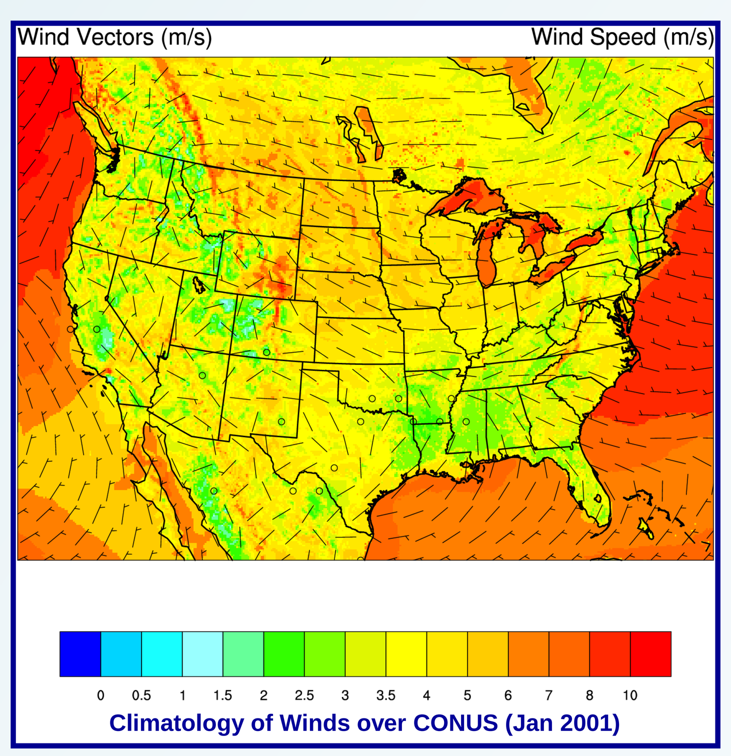
Climatology of Clouds over CONUS (1995 – 2009)



Climatology of Clouds over Hawaii (1997 – 2009)

Winds

The Weather Research and Forecasting (WRF) mesoscale model is applied to generate high-resolution wind databases to support the site selection of wind farms. These databases are generated on High Performance Computing systems such as the Rocky Mountain Supercomputing Center (RMSC). WRF is a high resolution, limited area, non-hydrostatic model. We successfully performed decadal simulations with WRF, running in climate mode, for current and future periods over CONUS. We utilized a number of features implemented in the WRF model that allow realistic representation of the climate system in long-term simulations, e.g. variable CO_2 concentrations, diurnal variations of the skin Sea Surface Temperature (SST), deep soil temperature and SST updates. The NCEP reanalysis and the ECHAM5/MPI-OM General Circulation Model (GCM) are used as the forcing model which provide the necessary initial and boundary conditions. For the present climate (1995- 2009), WRF was forced with NCEP reanalysis data. For the 21th century climate, we used an ECHAM5 simulation with the Special Report on Emissions (SRES) A1B emissions scenario. WRF was run in nested mode at spatial resolution of 108 km, 36 km and 12 km and 28 vertical levels. The wind speed at approximately 40 meters height (hub-height for most wind turbines) is saved every hour. In this study the Single-moment 5-class (WSM5) microphysics scheme and the Kain-Fritsch convective parameterization scheme is utilized. The Noah Land Surface Model and Yonsei University (YSU) Planetary Boundary Layer scheme are used. Shortwave and longwave radiation are computed with the CAM SW and LW scheme. Comparisons of model output are made to data collected from a wind farm in Montana and show correlations around 0.7.

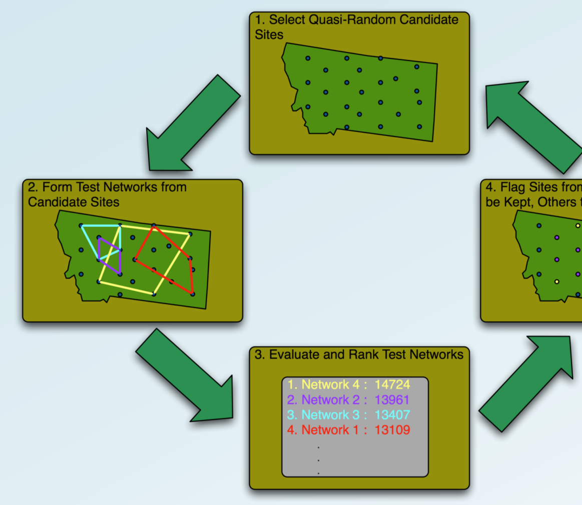


Climatology of Winds over CONUS (Jan 2001)

Optimal networks of wind and solar farm placement is based on the long term wind and cloud correlations made possible with these databases

Modeling and Optimization Approach

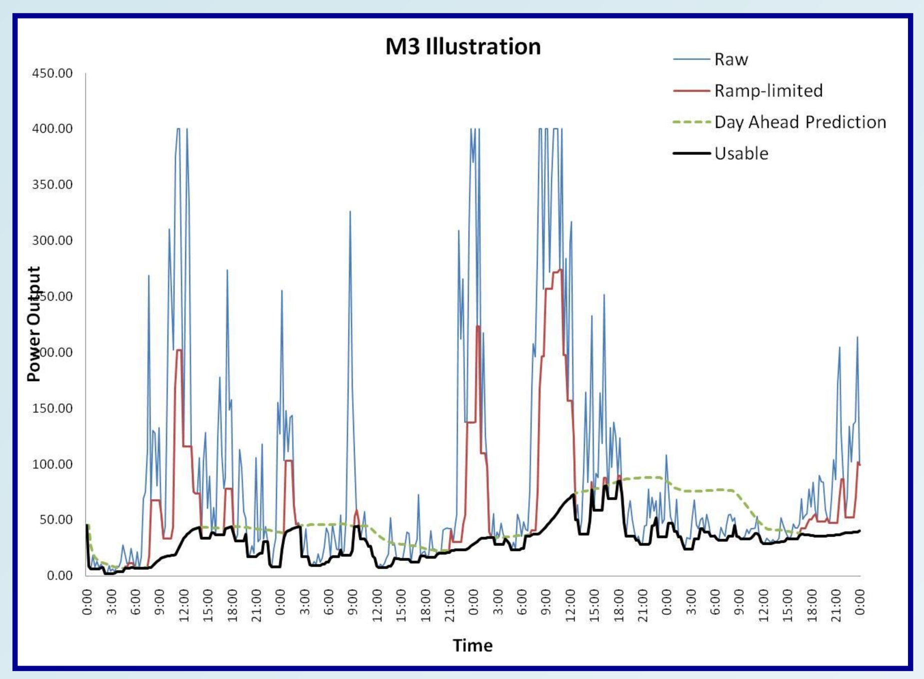
Unique stochastic optimization algorithm performs deep search site selection
10^7–10^9 networks to evaluate in each run



- •Solar model uses cloud database and statistics of cloud height/thickness to compute direct and indirect insolation
- •Insolation is computed using a multi-layer radiative transfer model[3,4]
- •Orientation geometry of panels is modeled directly from design specifications of installed panel systems (i.e., SunPower T0 panels) with pointing algorithm
- • Panel-to-panel shadowing is accounted for in the solar calculation
- •The solar model was empirically fit to the aggregate power generation data provided from Nov and Dec 2009 Desoto data

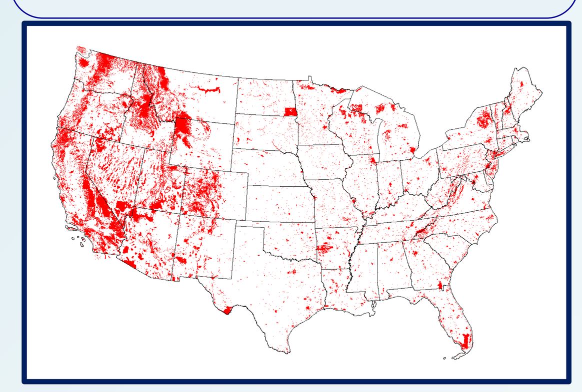
Scoring Methodology

- •Scoring metric (M3, wind) or (S3, solar) optimizes on *Usable* Power
- •Usable Power = Raw Power – {*curtailment* and *prediction*}
- •*Curtailment* represents an approximation to the excess power that can not be sold on market and therefore has to be dumped
- •Prediction reflects the ability to forecast tomorrow's power generation
- •Our approximation of these two factors is:
  - •Accounting for short-term variability (1 hour) by choosing the minimum amount of power over that period
  - •Evaluating the previous day's mean power with no credit for power greater than the mean

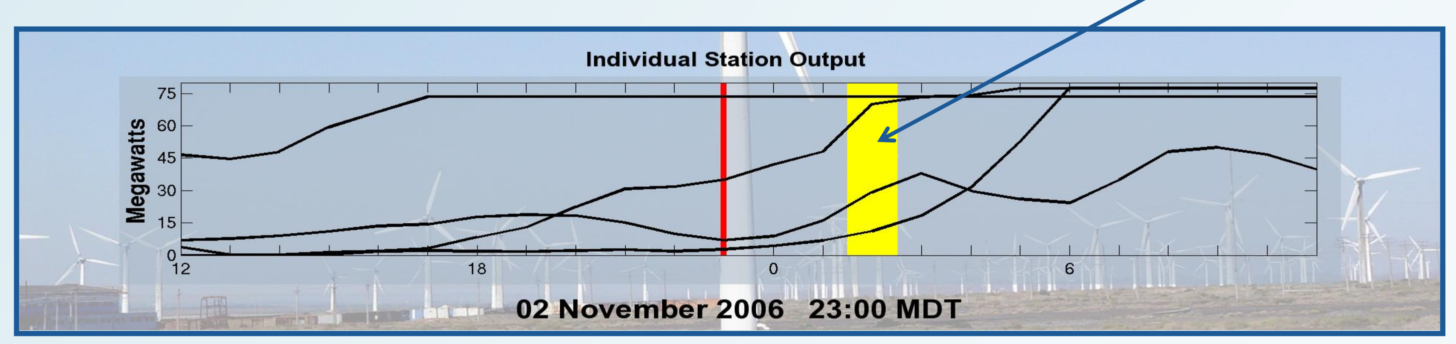


Usable power is limited by short term curtailment and the ability to predict tomorrows generation. Networks with large Usable Power will be favored.

It may not be realistic to place renewables every where. The scoring function also includes the ability to include constraints such as terrain, land usage, city restrictions and others.



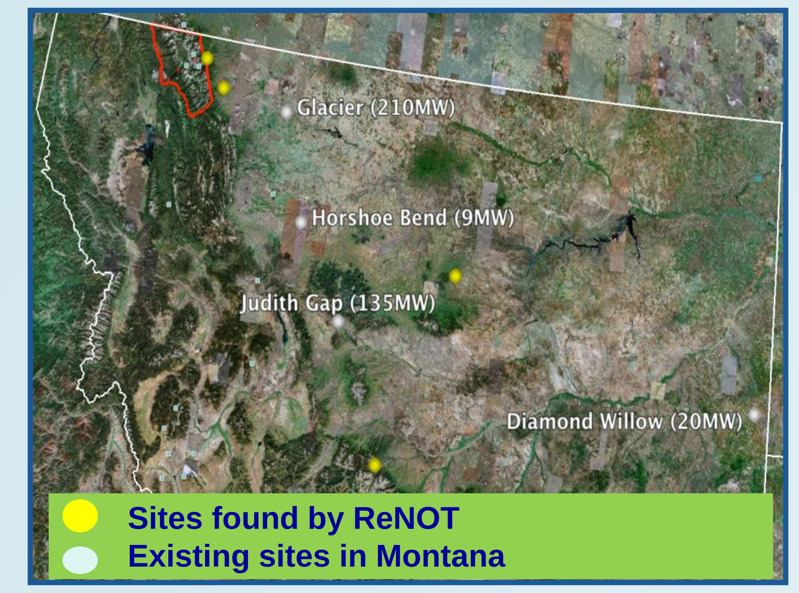
Excluded lands for solar and wind development include USGS GAP Status Code 1 and 2 protected (ESRI, National Atlas of the United States and the USGS, Protected Areas Database of the United States (PAD-US) Version 1.1), land with slope greater than 10% (ESRI, 2005), and cities (ESRI 2005)



We are also interested in the amount of time that power generation for the network is fluctuating either up or down. Ramping events may represent times when some other source of power is required . Networks with few rapid ramping events may be superior to others. We evaluate the frequency of ramping events exceeding 10% of total name plate capacity.

A Case Study (Wind)

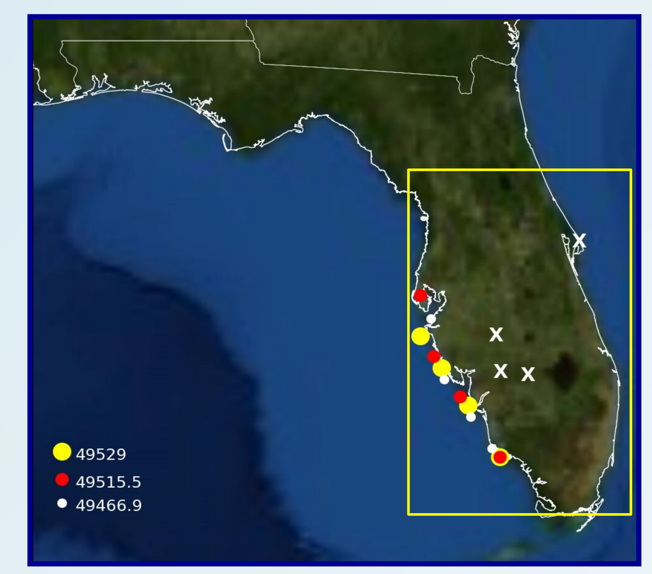
As part of our collaboration with Rocky Mountain Super Computing (RMSC) and the State of Montana a study was performed to estimate the optimal locations of a network of wind farms. Comparisons were made to four existing wind farm locations in Montana including Glacier with a 210 MW name plate capacity, Horseshoe Bend with a total capacity of 9 MW, Diamond Willow with a capacity of 20MW and Judith Gap with a total capacity of 135 MW. The goal of this study was to see if ReNOT could find a four site network that made more effective use of the existing four site network of wind farms' 374 MW nameplate capacity. We developed three different metrics in which to pick sites. Metric 3 (M3) picks sites based on the previous day's mean power, and accounts for short-term variability (i.e., 1 hour). M3 attempts to approximate usable power by minimizing ramping events which are so important to the renewable energy industry. In addition we investigated several performance metrics including Raw Power, Usable Power, and ramping event frequency. A ramping event is defined as an increase or decrease in power production over the course of one hour. Of interest was the frequency of ramping events that exceeded 10% of total capacity for the network. Networks with few ramping events are markedly superior to networks producing otherwise identical aggregate power. The optimization was run over the 15-year period from 1995 – 2009. Winds at hub-height (40 meters AGL) were used.



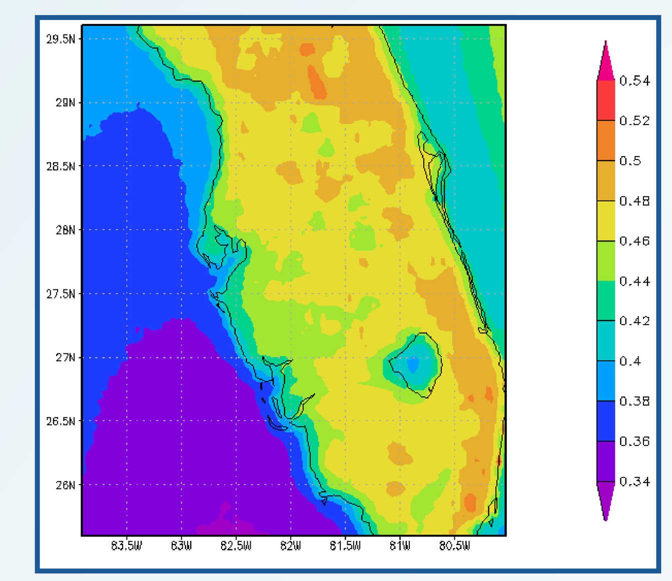
Site Configuration	Raw Power (MW)	Usable Power (MW)	Ramping 10% (%)
Judith Gap, Horseshoe Bend, Glacier, D.Willow (use name plate values)	85	63	2.5
Judith Gap, Horseshoe Bend, Glacier, D.Willow (use equal power 93.5MW)	81	63	1.1
ReNOT (Closest network)	124	101	2.0
ReNOT (Highest Power)	125	99	2.7
ReNOT (Highest Stability)	121	98	1.9
ReNOT (using equal power, 93.5MW)	122	100	1.3

A Case Study (Solar)

A study was performed to find the optimal set of four solar farms on the Central and Southern Peninsula of Florida. Results were compared to an existing set of four sites (two of which are proposed currently (25MW@)). The existing sites are located at Cape Canaveral (20MW) and Desoto (75MW), Florida. ReNOT places the optimal networks along the West Coast for Florida and producing approximately 10% more usable power than the existing / proposed sites. This result is mainly due to the minimum in cloud cover along the west coast of Florida as shown below. The influence of correlations is partially minimized by the restricted optimization area and the strong minimum in clouds observed along the west coast. Ramping events (as measured at the 10% ramping level) are nearly equal to those of the existing/proposed sites.



Top three optimal four site locations (yellow, red, white dots) compared to existing/proposed four sites (x). The yellow box indicates the area that optimization was restricted to.



The mean frequency of occurrence of cloud cover over Florida (1995 – 2009). The site selection is mainly influenced by the strong minimum in cloud cover along the west coast of Florida.

Site Configuration	Raw Power (MW)	Usable Power (MW)	Ramping 10%
Desoto, Space Coast, two proposed sites (145 MW)	86.8	77.6	34.0
ReNOT Network (145MW)	92.1	85.6	33.1

Summary

- •The Renewable Energy Network Optimization Tool (ReNOT) has been developed to assist in the optimal placement of networks of wind and/or solar farms
- •Optimizes site selection to maximize usable power, minimizes power intermittency and maximize base load power of the system.
- •Takes into consideration constraints on placement such as: location of transmission lines, population density, land costs and others.
- •Minimizes the conventional energy reserve requirements of the utility industry
- •Evaluates the impact of climate change by performing site selection on future climate simulations
- •Assists policy makers, regulators, regional public stakeholders, transmission operators, and individual renewable operators and investors

References

•[1]Kankiewicz, A, Sengupta, M., and D. Moon. "Observed Impacts of Transient Clouds on Utility Scale PV Fields," ASES SOLAR 2010 Conference Proceedings.
•[2]Alliss, R.J., M. E. Loftus, D. Apling, and J. Lefever, "The development of cloud retrieval algorithms applied to goes digital data," in *10th Conference on Satellite Meteorology and Oceanography*, pp. 330–333, American Meteorological Soc., January 2000.
•[3]Shapiro, R.,. 982: Solar Radiative Flux Calculations from Standard Surface Meteorological Observations. SASC Scientific Report No. 1. AFGL-TR-82-0039;ADA118775
•[3]Shapiro, R., 1987: A simple Model for the Calculation of the Flux of Direct and Diffuse Solar Radiation Through the Atmosphere., STX Scientific Report No. 35. AFGL-TR-87-0200