Development of the 2002 BTM PV Hourly Profile

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Introduction

- Prior to 2017, the ISO did not have sufficient data to accurately model the hourly PV output corresponding to the 2002 load shape used in the MARS model for the calculation of ICR
- With sufficient data now available, ISO has simulated the historical performance of a decentralized fleet of small-scale, BTM PV systems
- The following slides provide a summary of the input data, simulation tools, and methodology used to develop and validate the 2002 hourly BTM PV data proposed to be used in the GE MARS model

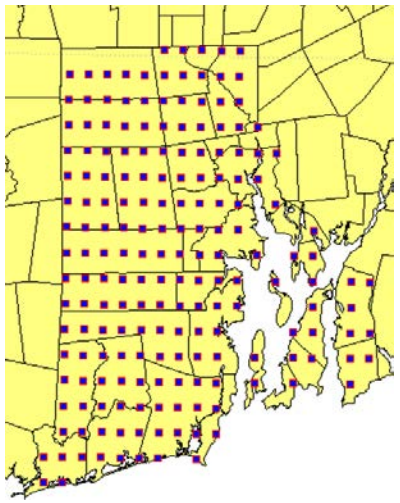
Data Used for BTM PV Simulation

- Simulation required comprehensive weather data that include the main weather drivers of PV and correspond to both the geographic area and time period of interest
- Simulation data consisted of the New England portion of the most recent release (v2.0.0) of the National Solar Radiation Database (NSRDB)
  - Data obtained by ISO cover years 1998-2014 (except Maine 2010)
- NSRDB contains high-resolution weather data needed for the realistic simulation of PV systems
  - Gridded data at 4km resolution
  - 30-minute temporal resolution
  - Includes detailed solar irradiance data derived from satellite imagery
  - Includes other weather variables impacting PV performance
  - Included weather variables tabulated
- ISO averaged all weather data by town for simulations
  - Figure shows NSRDB grid points and towns for Rhode Island
- More information about the recent release of NSRDB is available at: https://nsrdb.nrel.gov/current-version#psm

NSRDB Weather Variables

Variable Name	Units	Variable Description
GHI	W/m^2	Modeled solar radiation on a horizontal surface received from the sky
DNI	W/m2	Modeled solar radiation obtained from the direction of the sun
DHI	W/m2	Modeled solar radiation on a horizontal surface received from the sky excluding the solar disk
DB	Degrees C	Dry bulb temperature
DP	Degrees C	Dew point temperature
RH	Percent	Relative humidity
P	Millibar	Atmospheric pressure
WS	m/s	Wind speed
WD	Degrees	Wind direction
SD	Meters	Snow depth

Rhode Island NSRDB Grid-points



BTM PV Simulation Tools

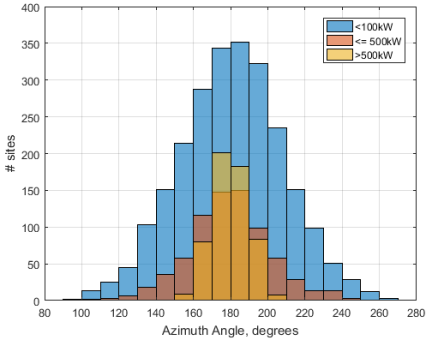
- Simulation required tools capable of modeling PV system performance given a variety of weather conditions and a diversity of individual system design characteristics
- ISO used NREL's System Advisor Model (SAM) to programmatically simulate historical production data associated with a large population of BTM PV systems
  - SAM is a techno-economic performance model that calculates a PV system's performance given a weather file and input data describing the system's characteristics
  - SAM simulations were performed using the PVWatts, Version 5 software
  - More information on SAM is available at: https://sam.nrel.gov/

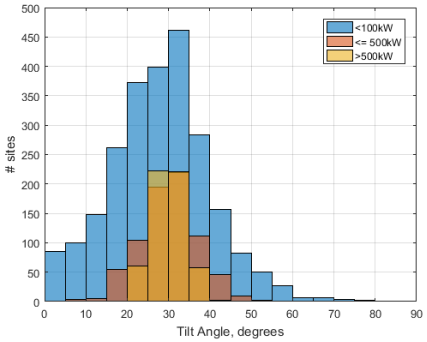
PV System Characteristic Assumptions (1 of 2)

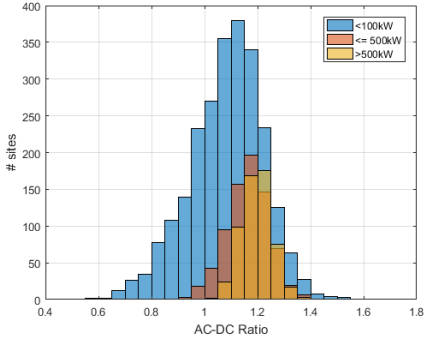
- ISO does not have detailed system design data for the more than 100,000 individual BTM PV systems already installed in the region, but attempted to design the simulation work to capture the expectation that these systems reflect a diversity of design characteristics
- PV system simulations were performed for system sizes ranging from "rooftop" (<10 kW) to "utility-scale" (MW-scale) selected to simulate the distribution of system sizes existing in each state at the end of 2016
- Values for three PV design parameters (described on next slide) were chosen to be tunable variables, and were defined to meet the following assumptions:
  - The simulation would result in a population of PV systems exhibiting a set of normally-distributed values for each parameter centered around approximated expected values
  - Parameter distributions reflect a tendency for larger systems to be closer to expected values, and the tendency for smaller systems to exhibit a greater diversity of design
- A total of approximately 40,000 individual BTM PV systems were modeled for the region
  - Approximately 20 systems modeled for each town

PV System Characteristic Assumptions (2 of 2)

- The following three design parameters were selected to be tunable:
  - **Azimuth angle**: Rooftop systems exhibit greater diversity in orientation; utility-scale systems tend to be south-facing for maximum energy generation
  - **Tilt angle**: rooftop systems exhibit greater diversity due to pitch of roof
  - **DC-to-AC ratio**: DC array tends to be "oversized" relative to inverter rating, with larger systems tending to be more consistently oversized
- Histograms show illustrative example of resulting distributions of azimuth angle, tilt angle, and DC-to-AC ratio for three defined system size classes

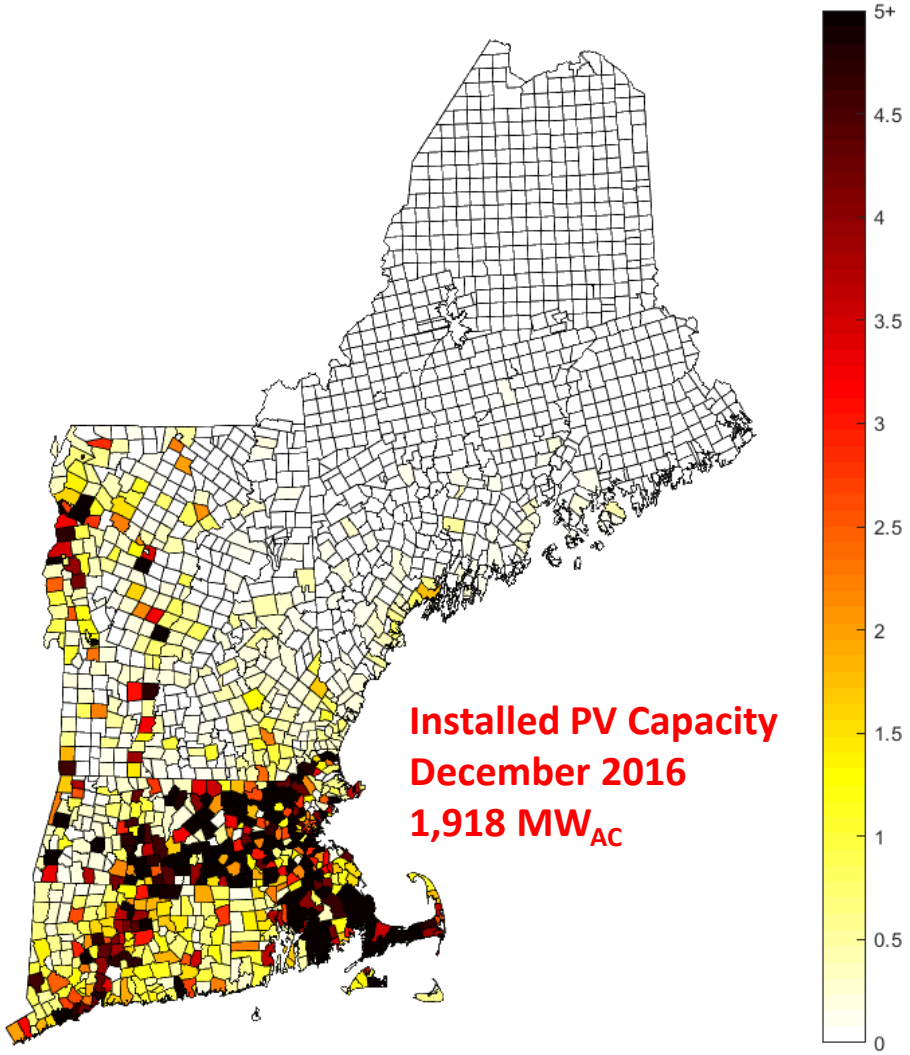






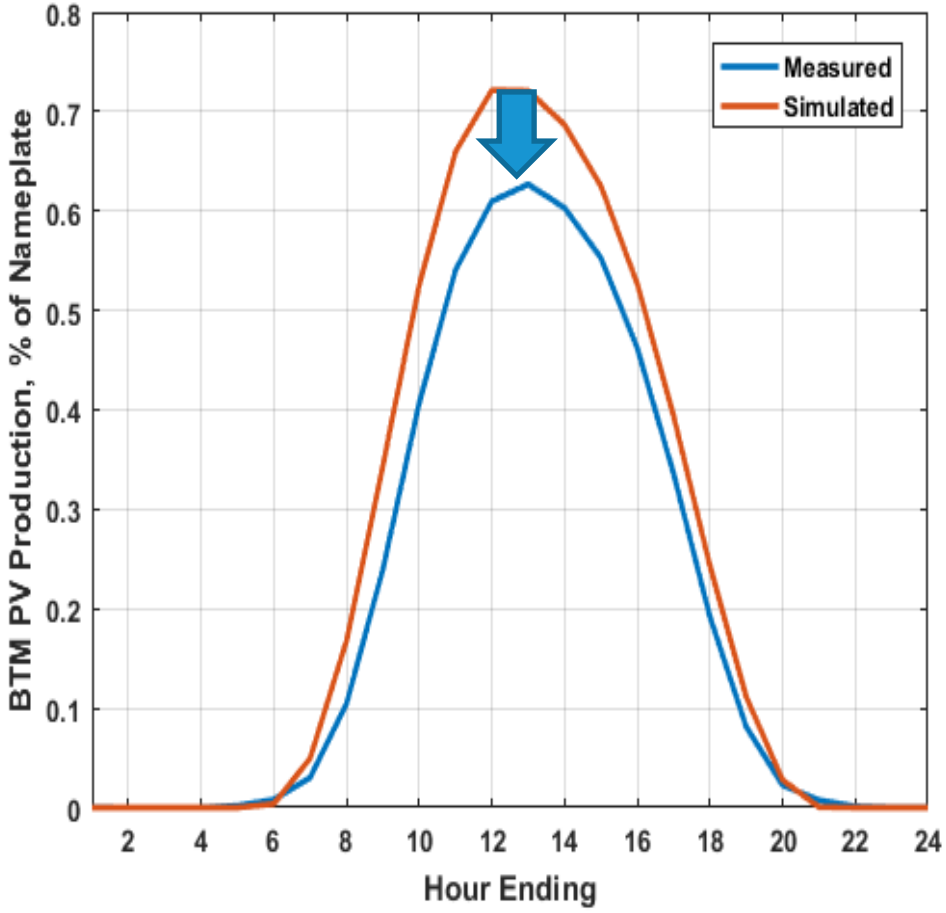
Subarea and Regional PV Profiles Based on Utility Data

- Town-level profiles were used to develop profiles for each of the 13 subareas and the region using the PV capacity distribution at the end of 2016 based on data provided by distribution utilities
- PV capacity distribution across towns in the region is shown in the adjacent heat map
  - Darker colors represent more installed PV capacity



Adjustments Made Based on Measured BTM PV Data

- Resulting simulated profiles were validated against measured PV production data for the year 2014
- ISO compared the profiles during July/August period as shown in the adjacent figure
- Since the simulated data was consistently higher than the measured data, ISO applied a downward adjustment to all simulation results to establish consistency with the measured data

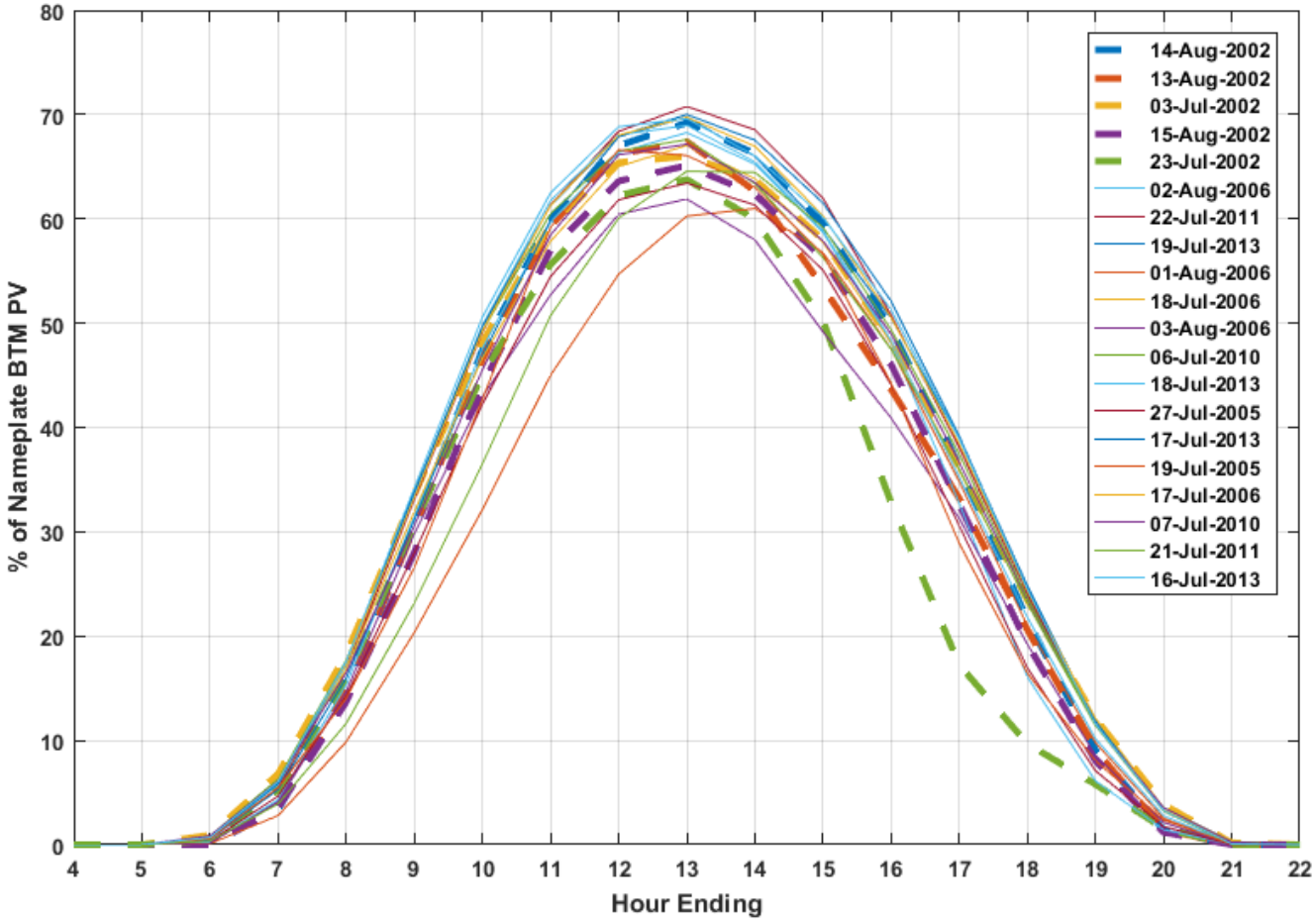


Analysis of Final BTM PV Profiles on Peak Load Days

- ISO verified that the final regional 2002 BTM PV profiles were consistent with those from a variety of peak load conditions by performing additional analysis for the following days:
  - Highest 5 peak load days in 2002
  - Highest 15 all-time ISO-NE peak load days
  - All 20 regional BTM PV profiles are plotted on the following slide
- Heat maps provided on slides 11-13 illustrate the resulting simulated PV performance for each town during a variety of peak load conditions
  - Colors represent BTM PV power production as percent of nameplate capacity
  - Darker red color reflects higher PV output
  - Blue color indicates data unavailable (for 2010 in Maine)
- These maps clearly illustrate the two primary factors of interest that impact PV performance:
  1. **Cloud features** can be identified by the contrasts in color within each map, with lighter colors showing areas of varying cloudiness
  2. **Time of day effects** can be identified by noting the darkest color in each heat map, with earlier afternoon hours being darker than later afternoon hours
- Results indicate that New England peak load conditions are consistently associated with high solar availability, with BTM PV output primarily determined by time of day

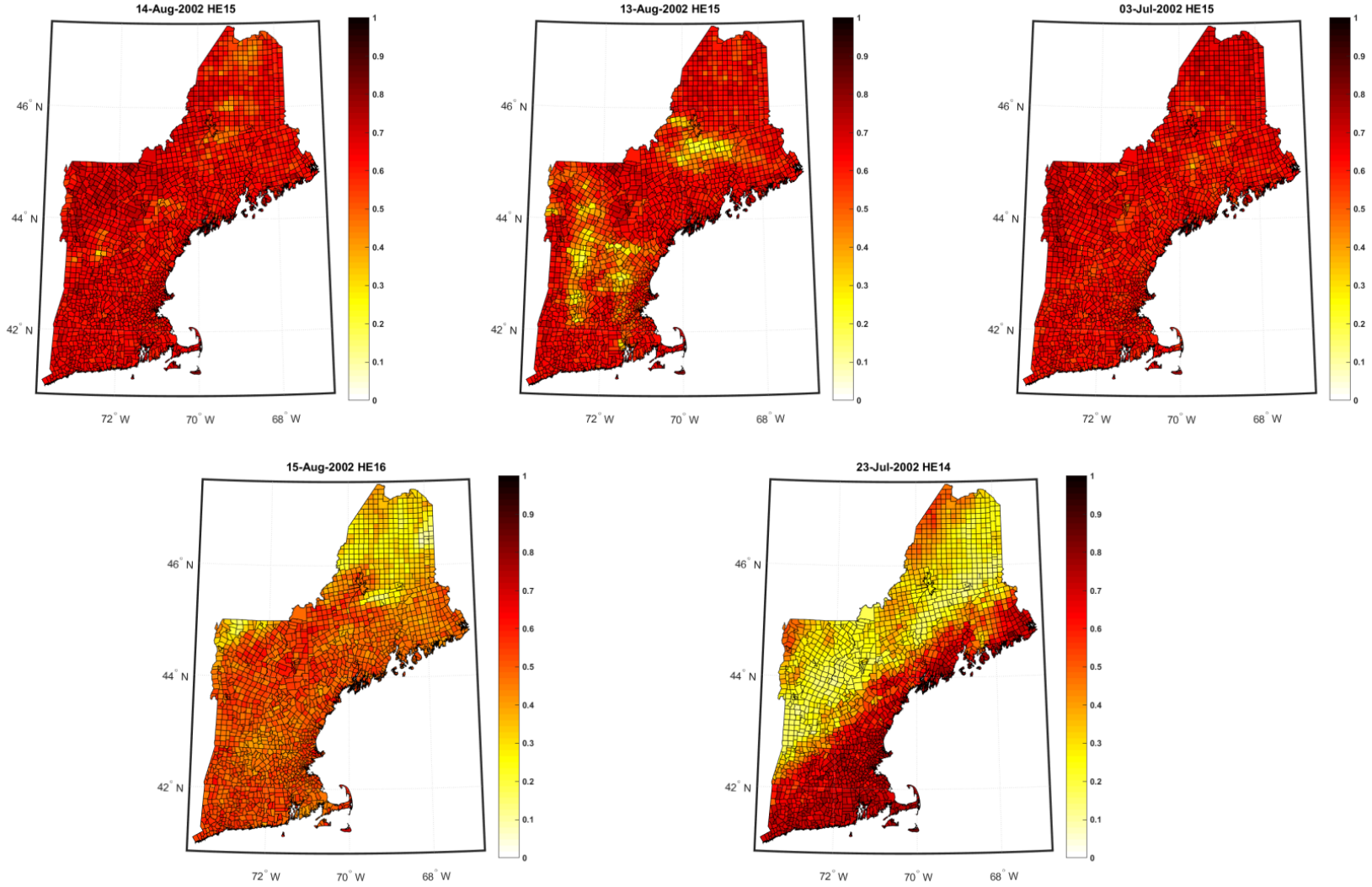
Final Simulated Profiles on Peak Days

Top 5 2002 Peak Days & All-Time Highest 15 Peak Days



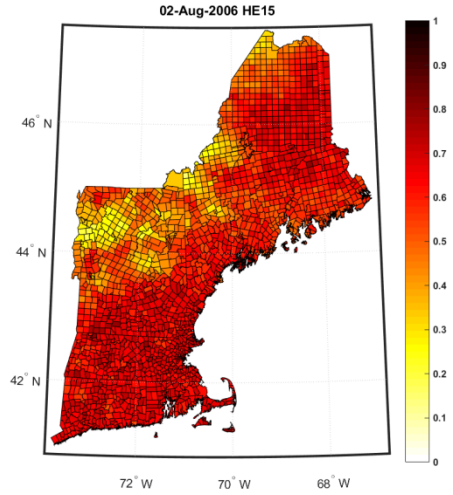
Simulated Regional PV Performance

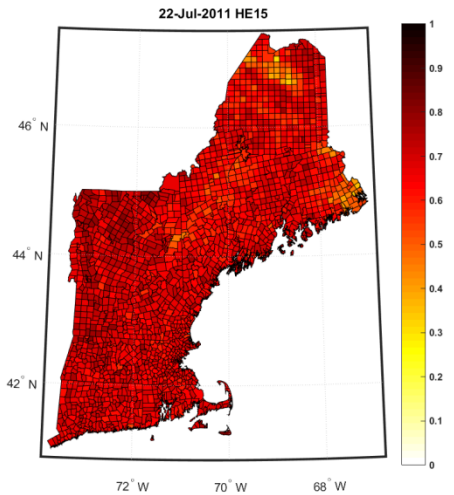
2002 Peak Load Hours

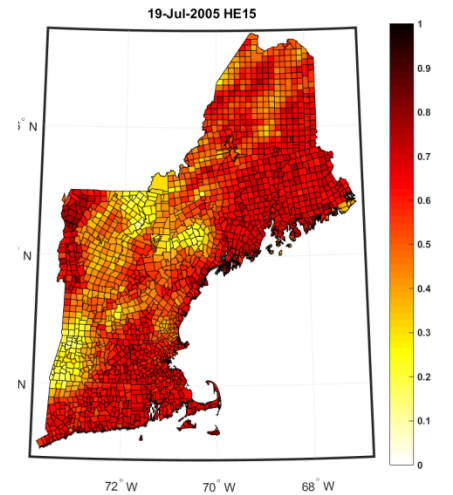


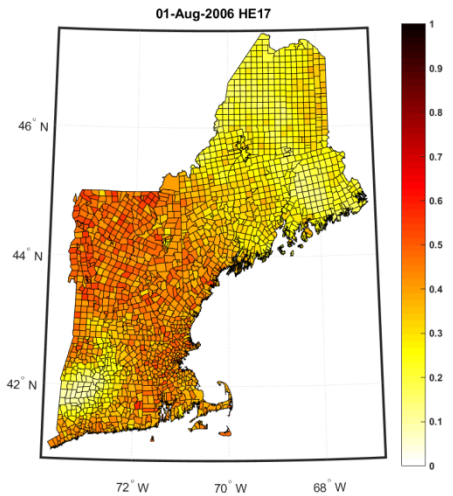
Simulated Regional PV Performance

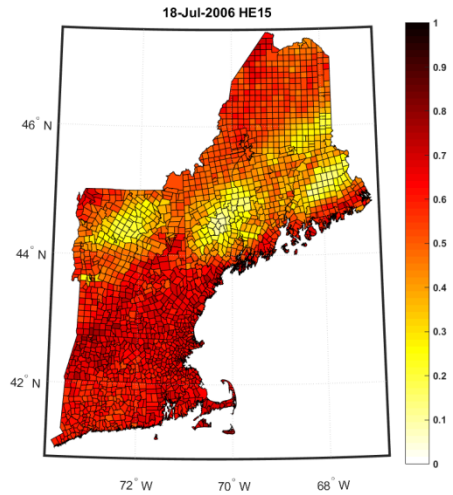
Highest Peak Load Hours (1st - 8th Highest Loads)

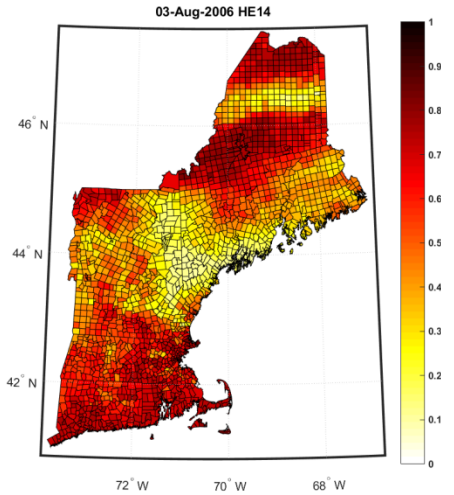


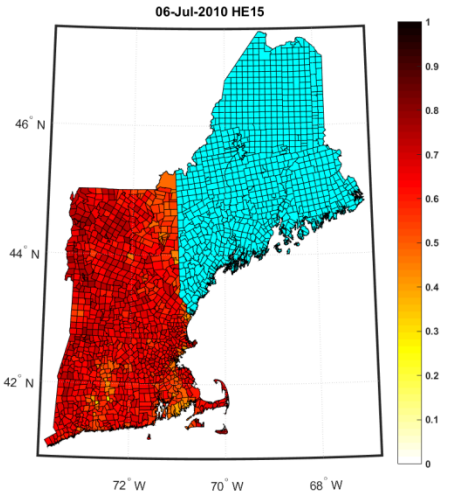


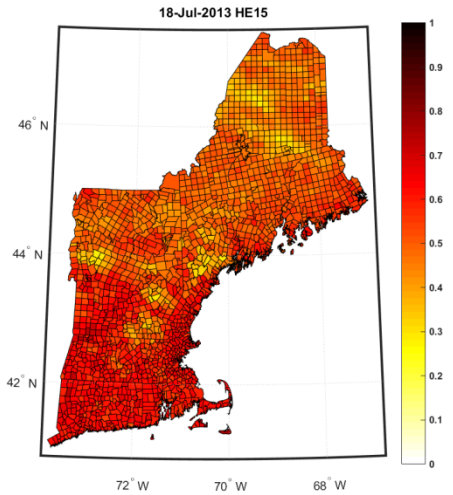






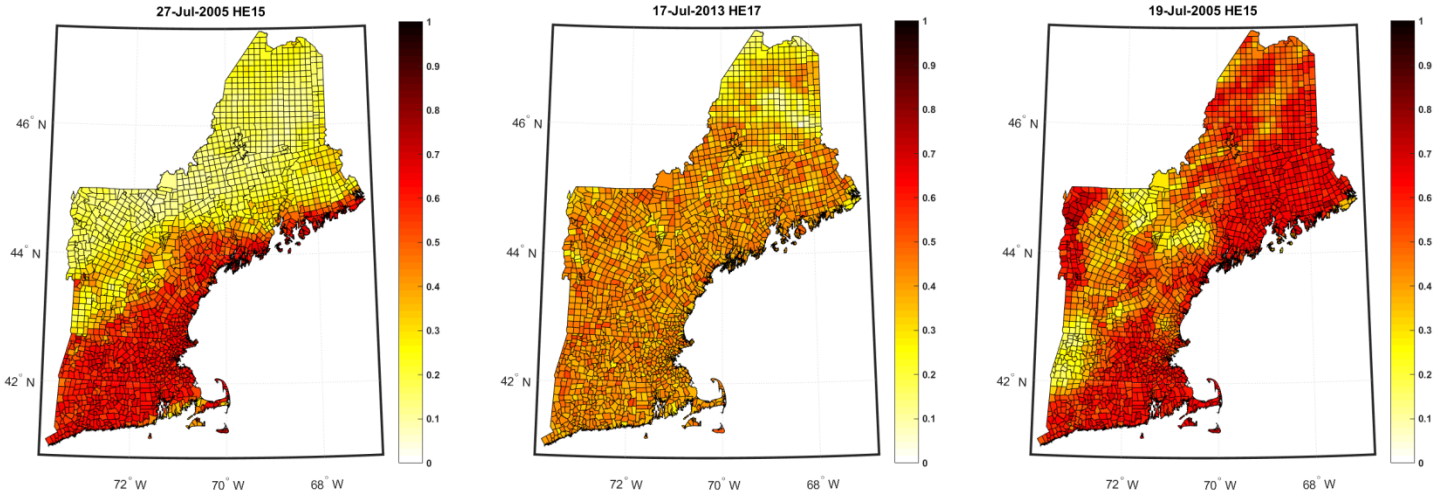


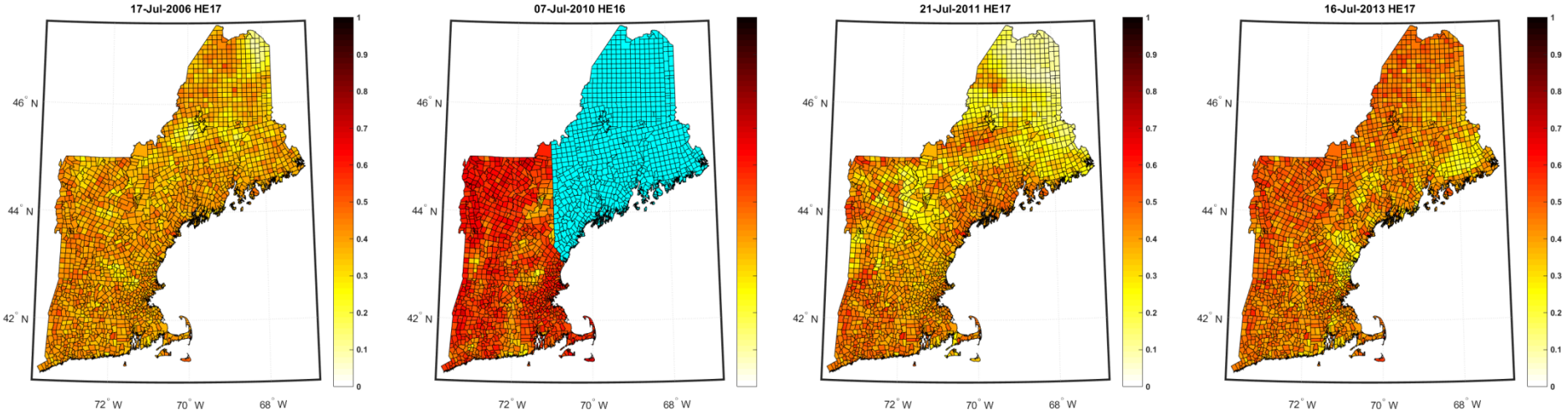




Simulated Regional PV Performance

Highest Peak Load Hours (9th - 15th Highest Loads)





Additional Validation of Final BTM PV Profiles

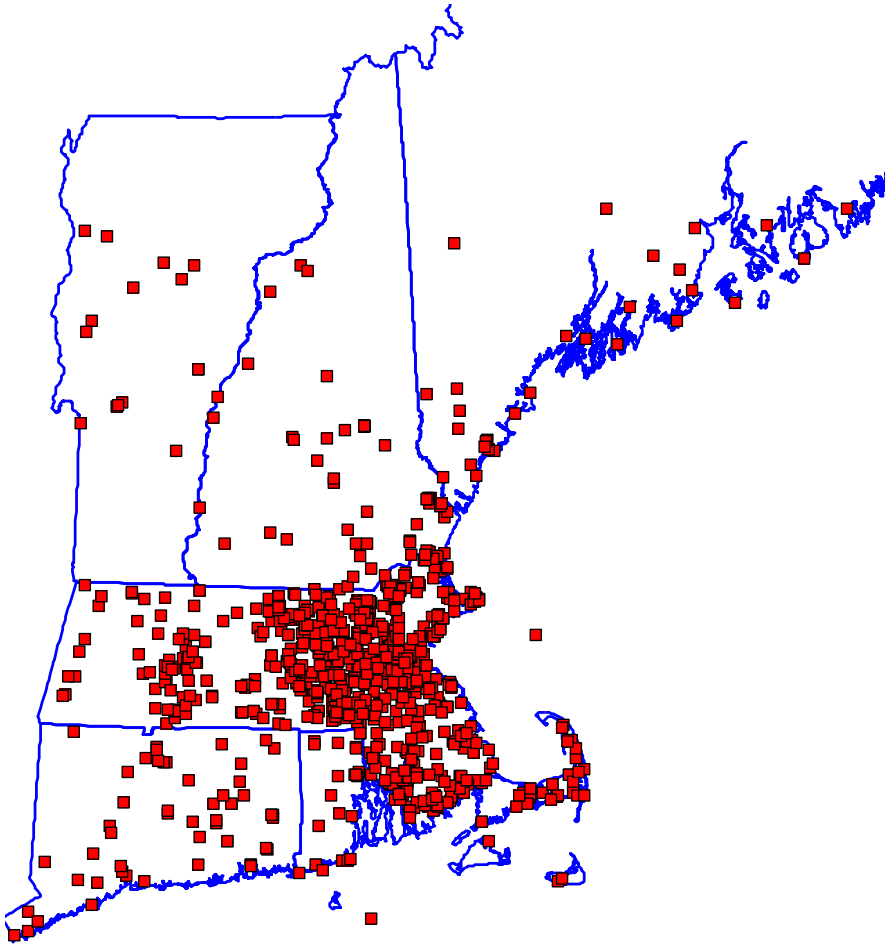
- ISO compared final simulated regional BTM PV profiles to measured data on a variety of peak load days
  - Profiles are normalized to reflect a per-unit nameplate BTM PV
- Two sources of measured BTM PV data were utilized
  - Described on the following two slides
- Example co-plots of simulated versus measured BTM PV profiles are shown on slide 17
  - Six peak load days interspersed over the overlapping three-year period between the simulation results and measured data (2012-2014)

Measured BTM PV Data Used for Validation

2012-2013

- Hourly state PV profiles developed for two years (2012-2013) using production data using Yaskawa-Solectria Solar's web-based monitoring system, SolrenView*
- A total of more than 1,200 individual sites representing more than 125 MW_{ac} in nameplate capacity were used
  - Site locations depicted on adjacent map

Yaskawa-Solectria Sites



***Source:** http://www.solrenview.com/

Measured BTM PV Data Used for Validation

2014

- ISO has contracted with a third-party vendor for PV production data services
  - Represents PV generation at the inverter
  - Includes data from more than 9,000 PV installations
  - Data are 5-minutely and at the town level
  - Broad geographic coverage
  - Data provided begins in 2014
- An example snapshot of regional data is plotted to the right
  - Data are from February 2, 2017 at 12:10pm
  - Yellow/red coloring shows level of PV production
  - No data available in towns colored gray
  - Data not requested in towns colored black
- Using these data, state PV profiles are developed as described on the previous slide

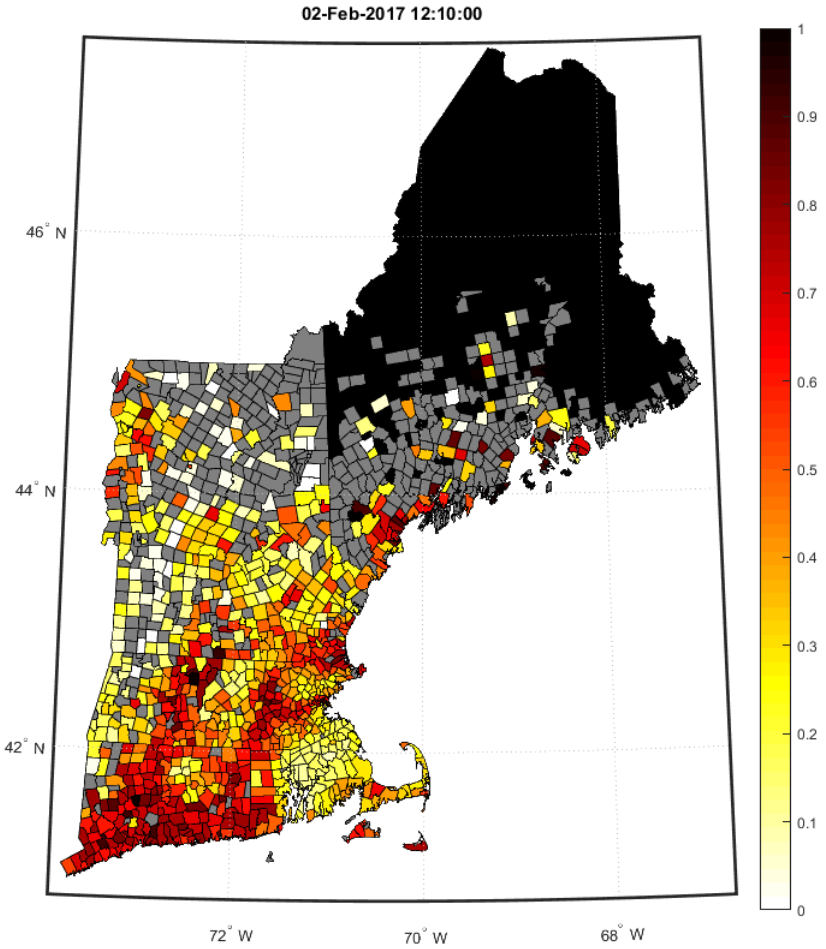


Figure notes:

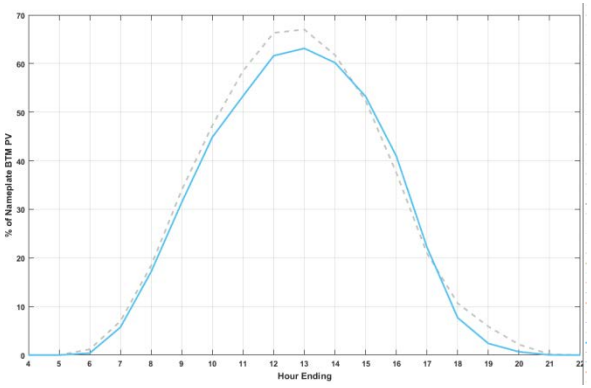
1. Graphic developed by ISO New England
2. Data source: Quantitative Business Analytics, Inc.

Comparison of Finalized Profiles to Measured Data

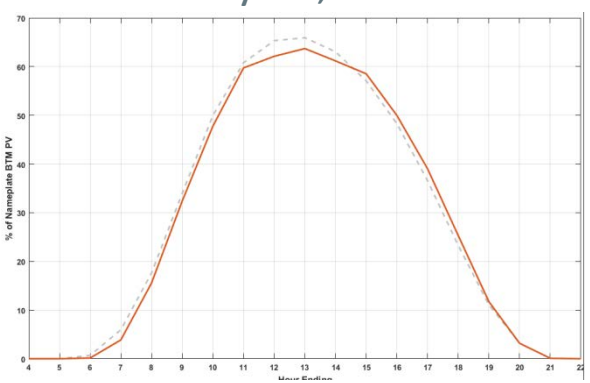
Examples From a Variety of Peak Load Days, 2012-2014

Dashed gray lines represent simulated profiles; solid colored lines represent measured profiles

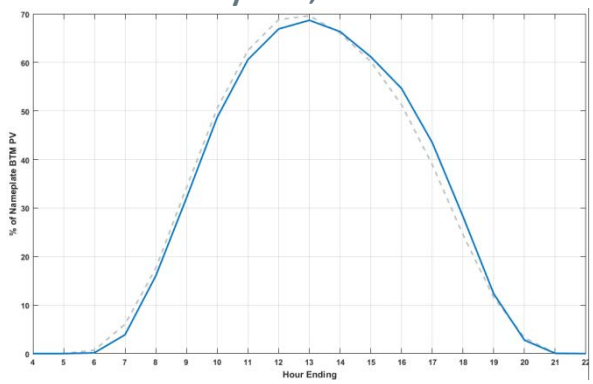
June 22, 2012



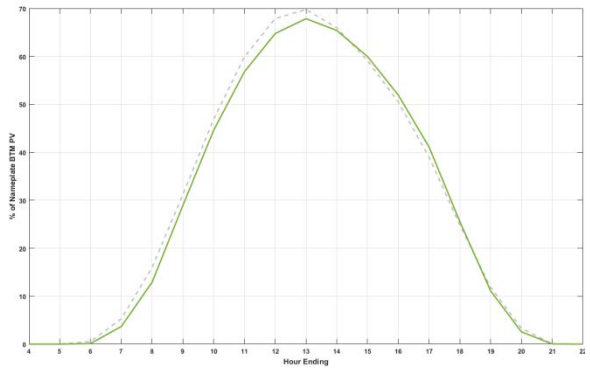
July 15, 2013



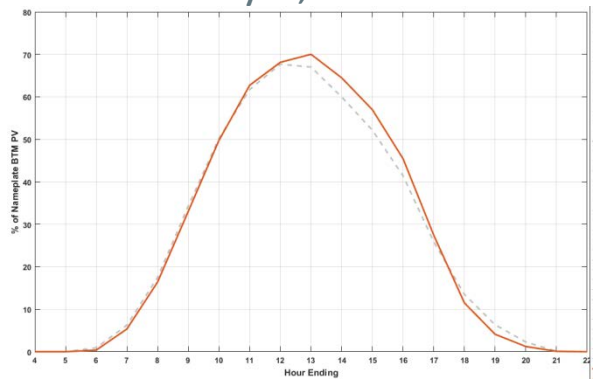
July 16, 2013



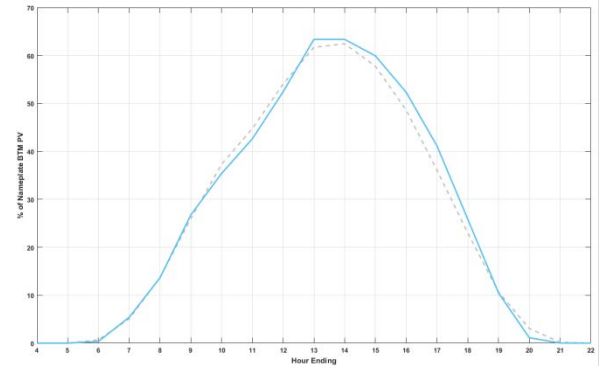
July 19, 2013



July 2, 2014



July 3, 2014



Final 2002 Hourly BTM PV Forecast

- ISO scaled up the normalized PV profiles developed for each subarea and the region by the amount of nameplate BTM PV forecasted
- An 8% gross-up was applied to the forecast profiles to reflect assumed avoided transmission and distribution losses

Summary

- ISO has acquired NREL data and tools to simulate regional BTM PV profiles over the period 1998-2014
- A large population of BTM PV systems were simulated with assumed design characteristics
- Adjustments were made to the simulated profiles to ensure consistency with measured BTM PV data
- The final simulated PV profiles for the top 5 peak load days during 2002 are consistent with those during the highest 15 New England coincident summer peak load days
- Validation shows that final simulated PV profiles closely match measured data on a variety of peak load days from 2012-2014

Questions