Deployment of Coupled Models to Enable Renewable Integration in Vermont

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Deployment of Coupled Models to Enable Renewable Integration in Vermont

- Background and motivation
- Approach
- Example results
- Conclusions and future work

Deployment of Coupled Models to Enable Renewable Integration in Vermont

- **Renewable energy production and energy demand have significant sensitivity to local, short term weather conditions**
- **In Vermont, there are additional challenges due to local variations in geography, meteorology and energy use**
- **Intermittency in renewable generation coupled with variation in demand can lead to congestion in the transmission system**
- **The uncertainty in the power generation and demand is poorly quantified**
- **As a result, conservative grid management leads to curtailment of renewable power production**

What is the potential to predict periods of congestion on the transmission grid and improve its stability?

– Can renewable power (i.e., wind and solar) and electricity demand be predicted accurately with sufficient spatial and temporal precision, and lead time

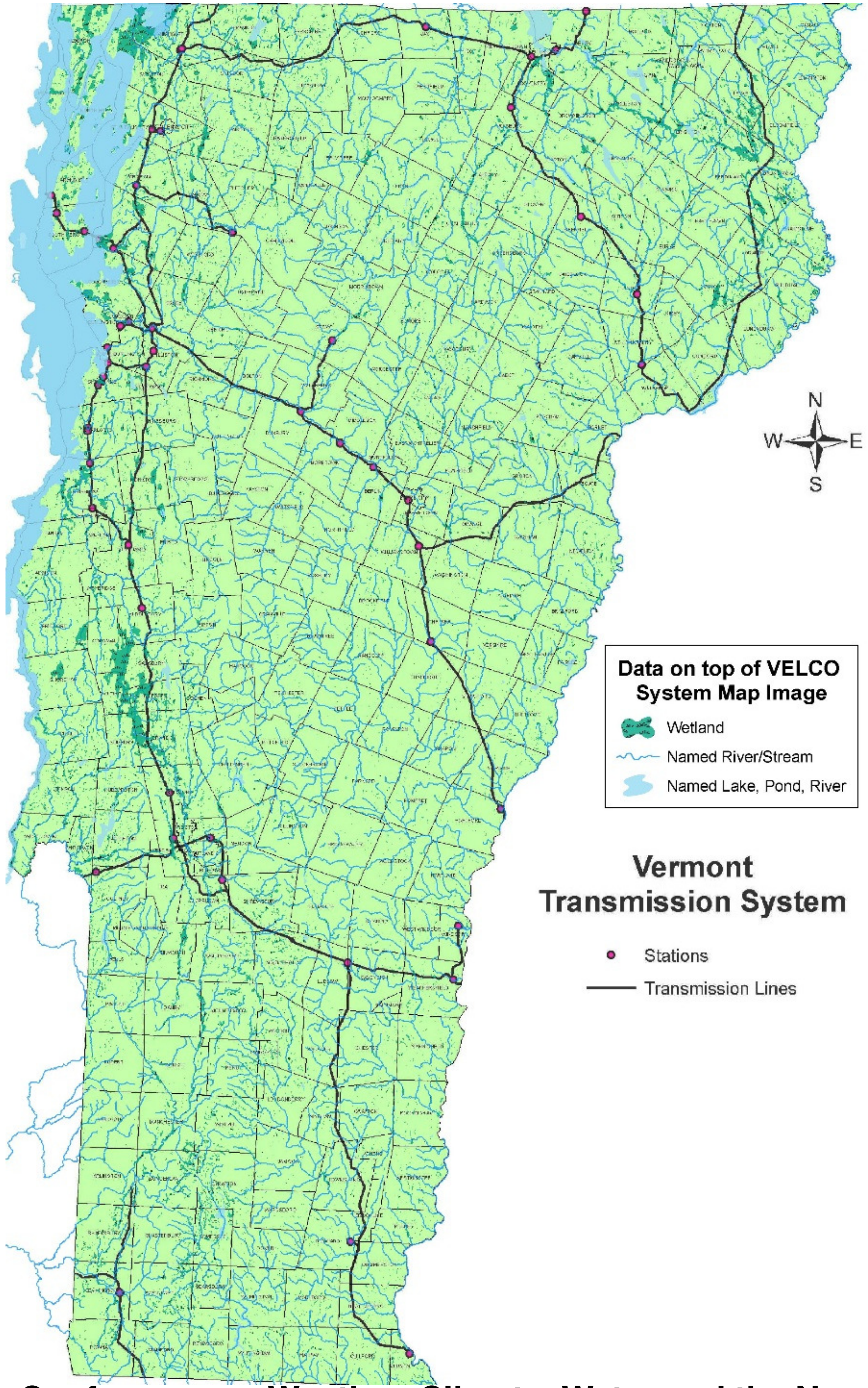
– Can highly localized, weather model-based forecasts be adapted to address these problems and reduce the uncertainty in decision making?

1. Can the link between weather and impact be quantified to improve the operation of the grid and utilization of renewable power?

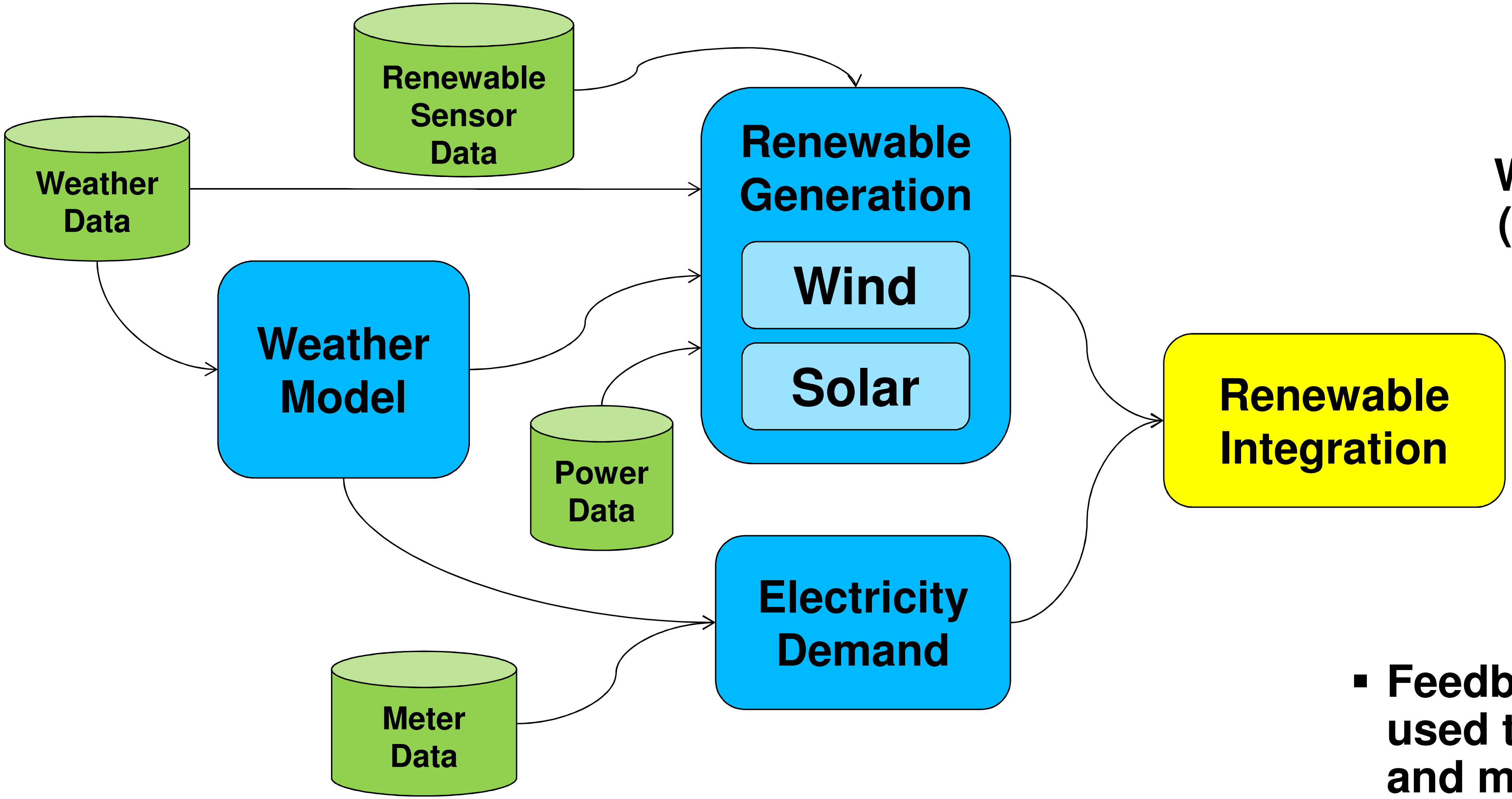
2. Can potential congestion conditions be determined with sufficient lead time to mitigate the impact

VELCO operates an interconnected electric transmission grid

- 738 miles of transmission lines
- 13000 acres of rights-of-way
- 55 substations, switching stations and terminal facilities
- Equipment that enables interconnected operations with Hydro-Québec
- 1300-mile fiber optic communication network
- 52-mile 450 kV direct current line owned by VETCO



Approach: Coupled Weather and Impact Modelling



VELCO has invested in enabling the Vermont Weather Analytics Center (VTWAC) to deploy these capabilities

- **Feedback from each model team used to determine requirements and metrics for each model for evaluation and improvements**
- **Integrated approach using a common platform, data model, visualization, etc.**

Seventh Conference on Weather, Climate, and the New Energy Economy
- 2.5 Coupling Numerical Weather Predictions to Demand and Solar Energy Forecasting Models in an Operational Setting
- 5.5 Analysis of Short-term Wind Power Forecasting in the Northeastern United States

23rd Conference on Probability and Statistics in the Atmospheric Sciences
- 14.5 Verification of High-resolution WRF-ARW Forecasts for Vermont Utility Applications

Weather: NWP Configuration (Deep Thunder)

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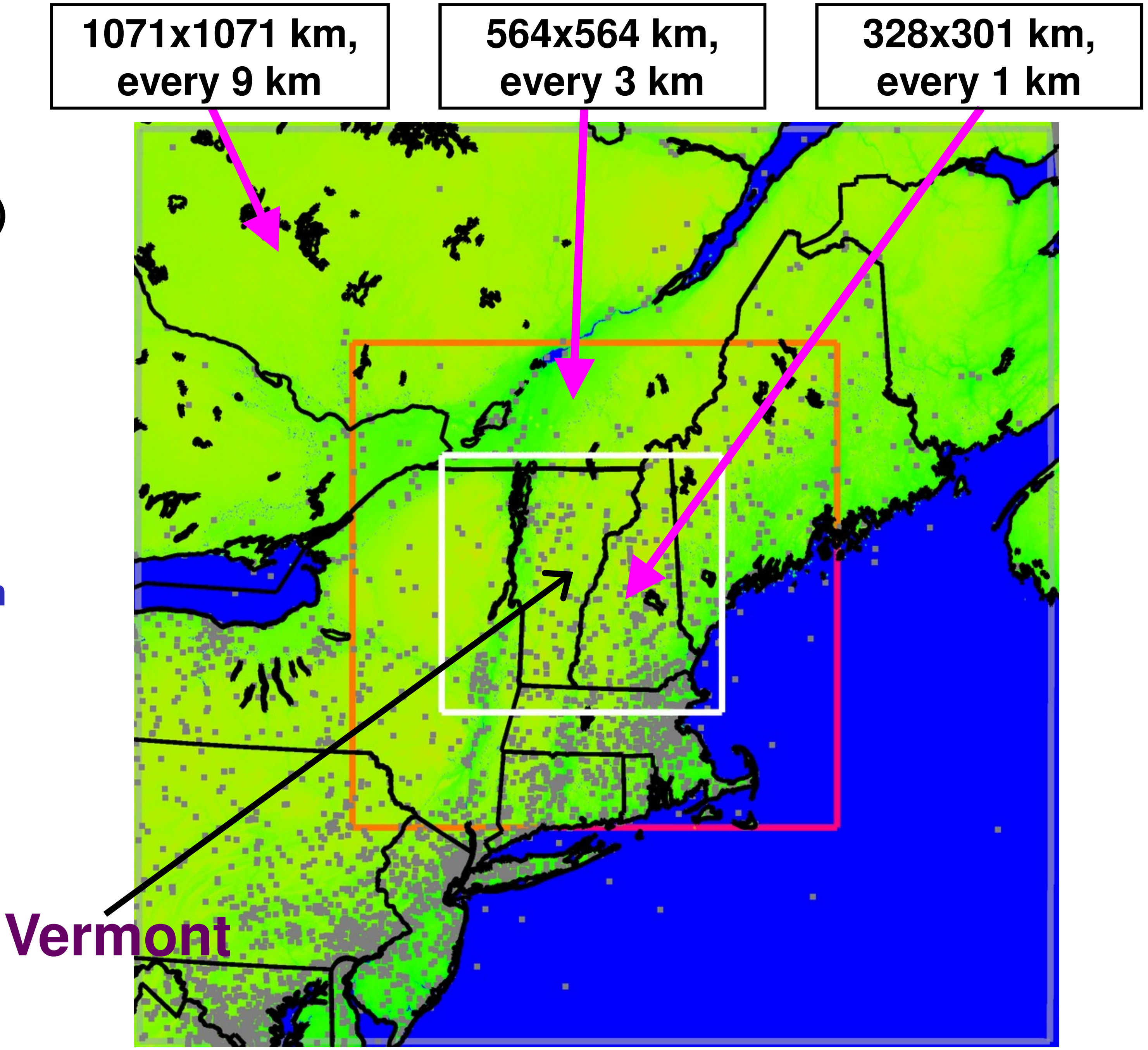
- **WRF-ARW, version 3.5.1**
- **51 vertical levels, with increased resolution in the PBL (10s of meters near the surface)**
- **00Z and 12Z forecasts, 72-hour duration (10-min output)**
  - 72-hour, operational since November 2015
  - 48 hour, operational since April 2015
- **Physics configuration for highly urbanized to rural domain as well as considerations for wind and solar farms**
  - Thompson double-moment microphysics (includes explicit ice, snow and graupel)
  - Mellor-Yamada-Nakanishi-Niino (MYNN) PBL scheme with turbulent kinetic energy (TKE)-based local mixing and 2.5-order closure
  - NOAH land-surface modeling with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics
  - Explicit cumulus physics for innermost nests, Grell Freitas for outer nest
  - 3-category urban canopy model with surface effects for roofs, walls, and streets
  - RRTMG long- and short-wave radiation



(Gray Dots Mark Locations of Sites for Data Assimilation)

Weather: NWP Data Input (Deep Thunder)

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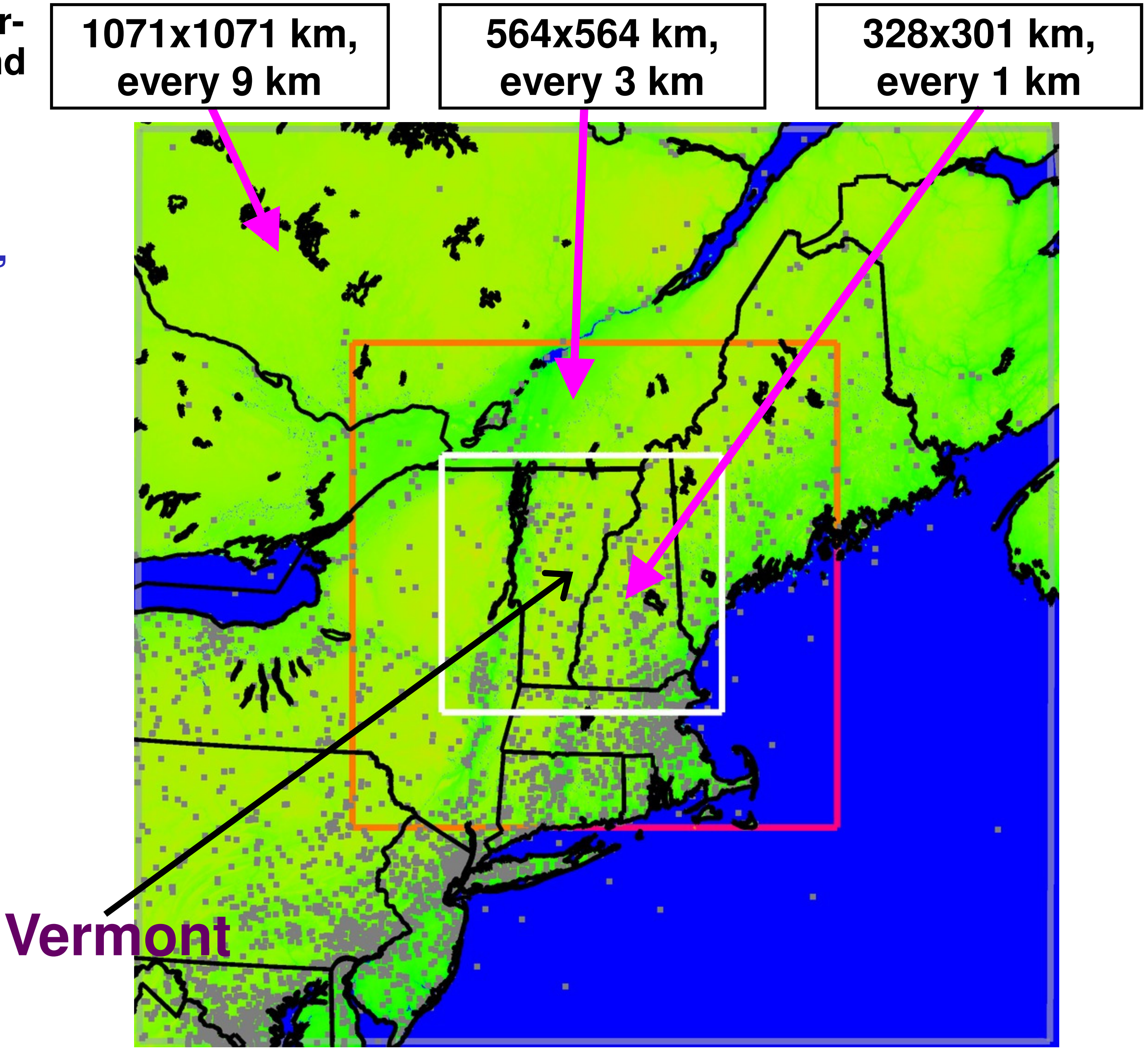
- Data assimilation (3dVAR) of near-real-time surface and upper-air observations from Earth Networks WeatherBug, MADIS and private mesonets
  - Surface stations, radiosondes, aircraft, ship, profiles, satellite, …
  - ~3000 stations (gray markers on map): 9km nest (~3000), 3km nest (~1200), 1km nest (~450) – varies for each forecast
  - Additional quality control
- NASA high-resolution (2km) sea surface temperatures (SST), which include Lake Surface Temperature (LST) analysis over the Great Lakes
- NASA high-resolution (90m) Shuttle Radar Topography Mission (SRTM) terrain elevation
- MODIS 1km 20-category land use data
- NASA 4km dynamic (daily) VIIRS Green Vegetation Fraction (GVF) data
- NASA 3km land surface fields for initialization
- NOAA/NCEP Rapid Refresh (RAP) 13km analysis for background fields
- NOAA/NCEP North American Model (NAM) 12km lateral boundary conditions



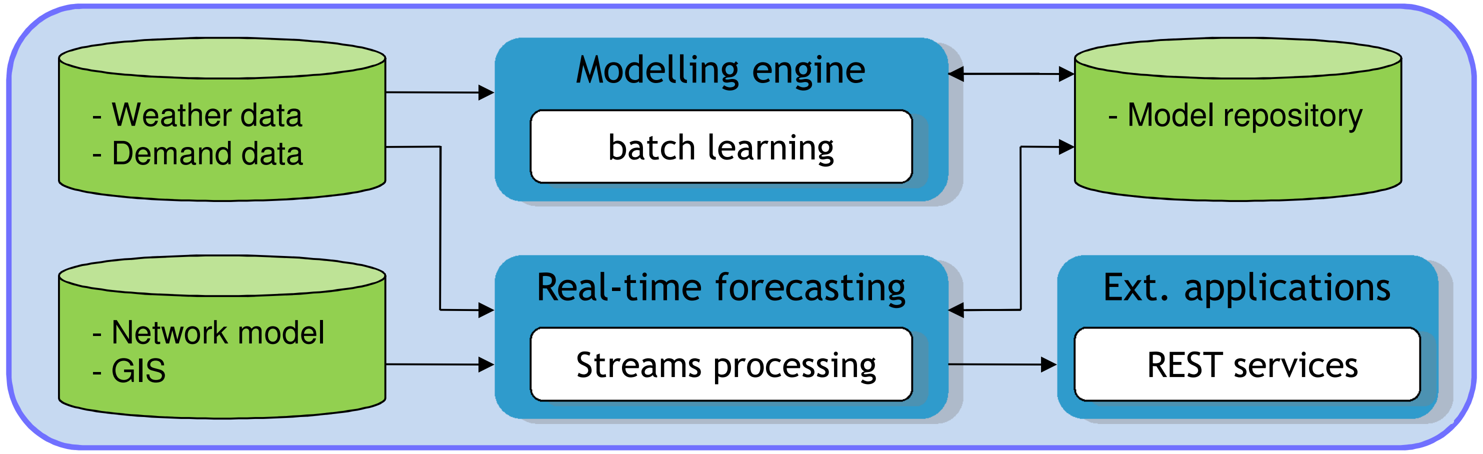
(Gray Dots Mark Locations of Sites for Data Assimilation)

Electricity Demand Forecasting

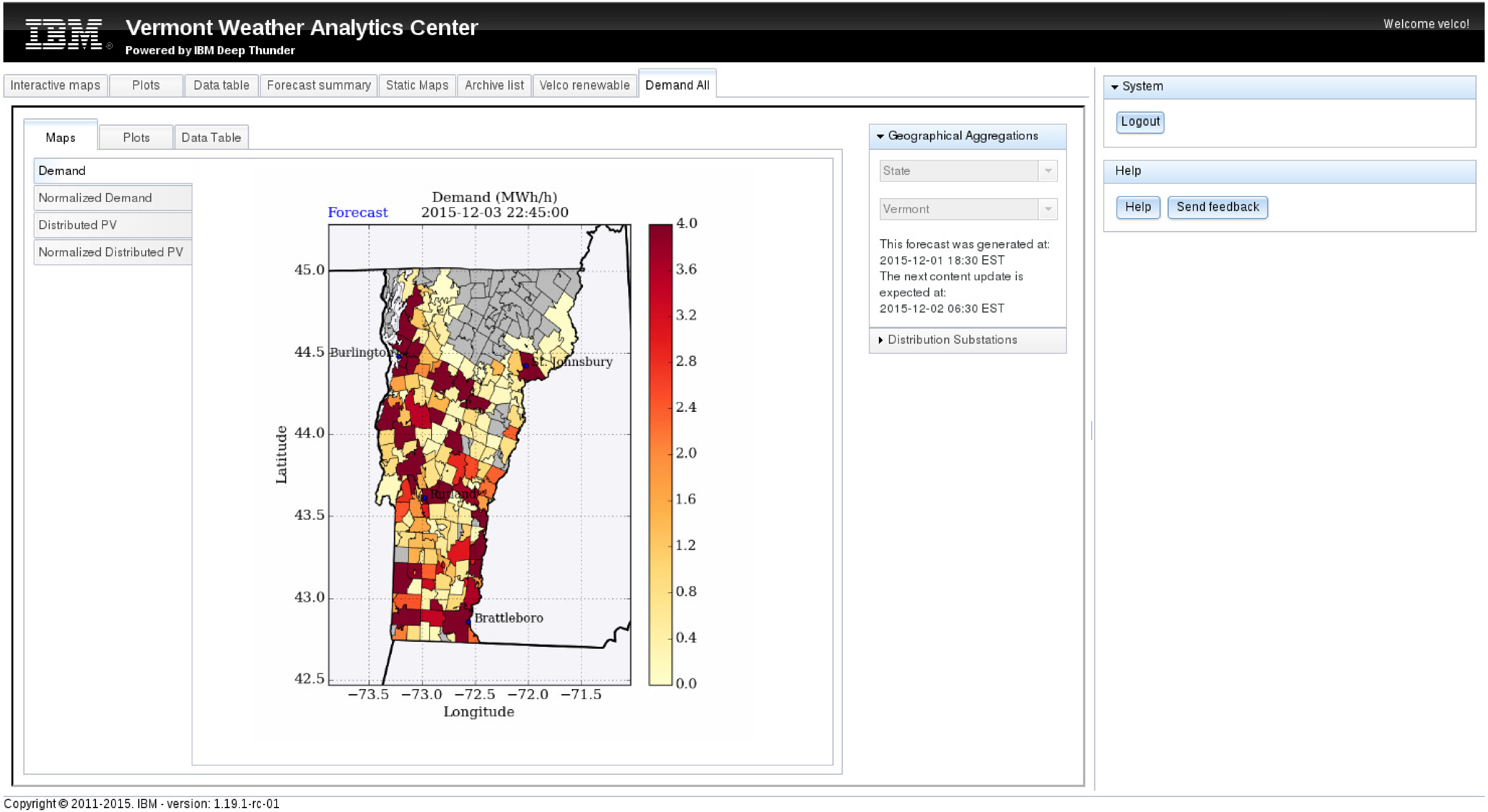
- Statistical modeling (e.g., regression, generalized non-linear additive) demand at multiple aggregation levels:
  - –Vermont state level
  - –Distribution units service territories (eight), towns (200) and counties (14)
  - –Subtransmission and distribution (>100) substations
  - –Distributed renewables "behind the meter"
- Factoring in heterogeneous inputs:
  - –Weekday, time of day, time of year
  - –Spatio-temporal weather features
  - –Impact events (heat waves, snow storms)

See 2.5: "Coupling Numerical Weather Predictions to Demand and Solar Energy Forecasting Models in an Operational Setting", for additional details.

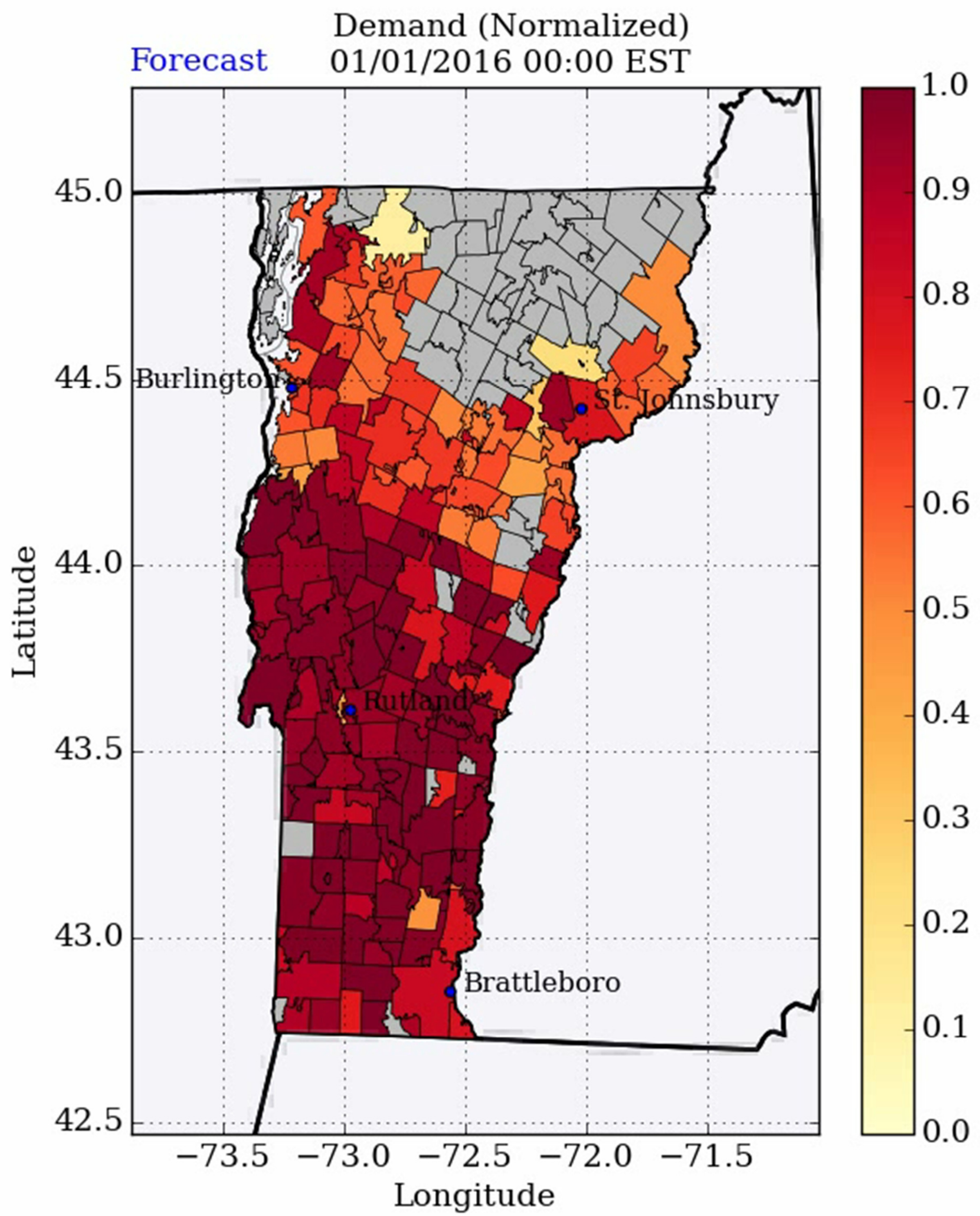
- Integrating various data sources:
  - –Telemetry (SCADA)
  - –Physical network models
  - –Smart meters
  - –Weather forecasts and observations



Electricity Demand Web Portal

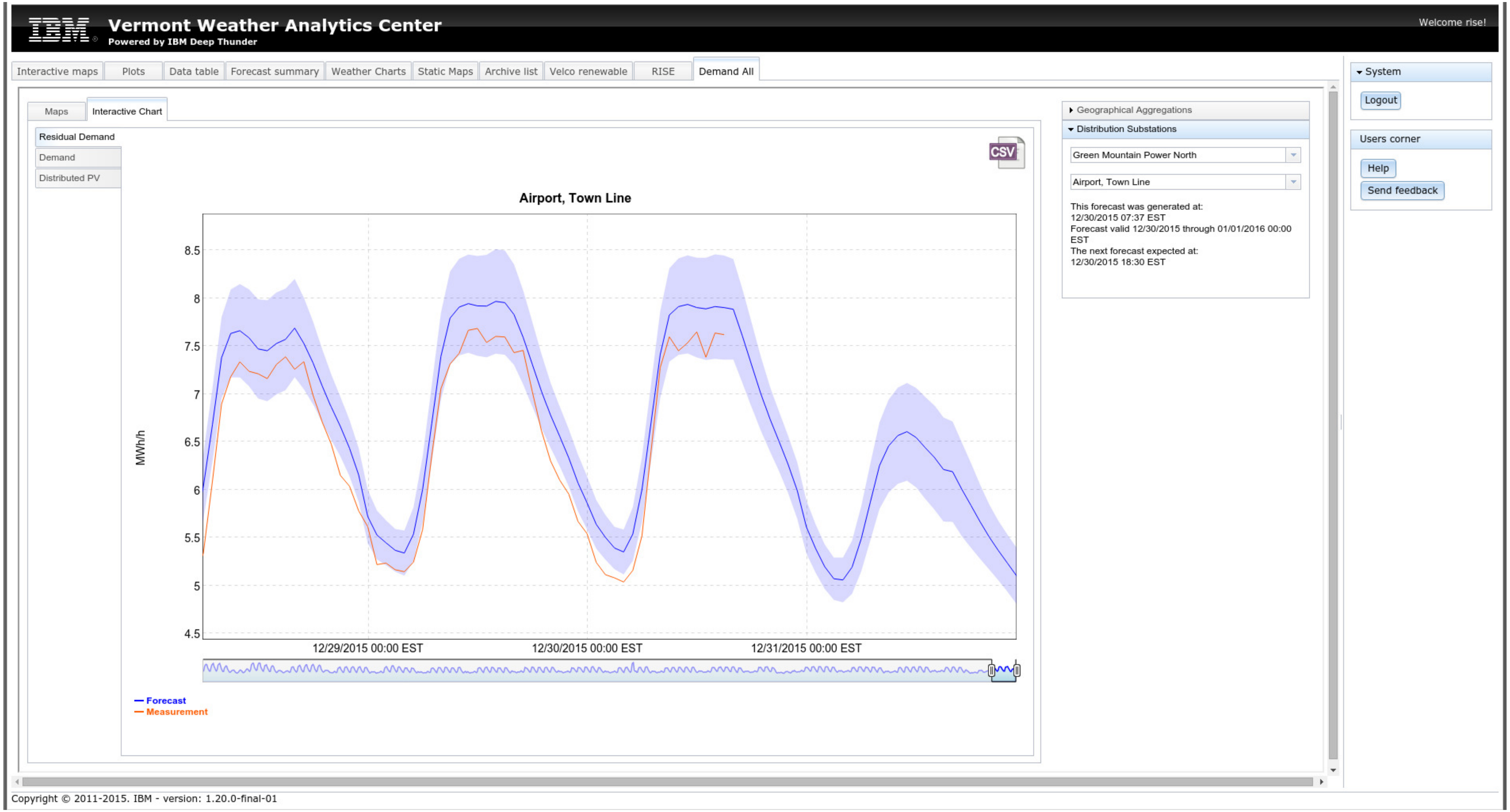


State-wide Electricity Demand Example



72-hour demand forecast is normalized to illustrate temporal and spatial detail

Electricity Demand Web Portal



Predictive Statistical Models Built from Historical Weather Forecasts and Observations, Power and Other Data

- **Data for Wind Farms**
  - NWP-derived, [u, v, w] across the blade extent, temperature and moisture
  - Wind and temperature measurements from turbines and met tower
  - Turbine nacelle direction
  - Generated power at each turbine and accumulated power, including availability and operational mode
  - Engineering characteristics of the turbines (e.g., specifications, power curves, etc.)

Wind Power Models

- **Wind Power Forecasts**
  - Per farm (4)
  - Per turbine for two of the farms
  - Day-ahead focus
  - Multiple statistical ensemble

See 5.5: "Analysis of Short-term Wind Power Forecasting in the Northeastern United States", for additional details.

Renewable Power Web Portal

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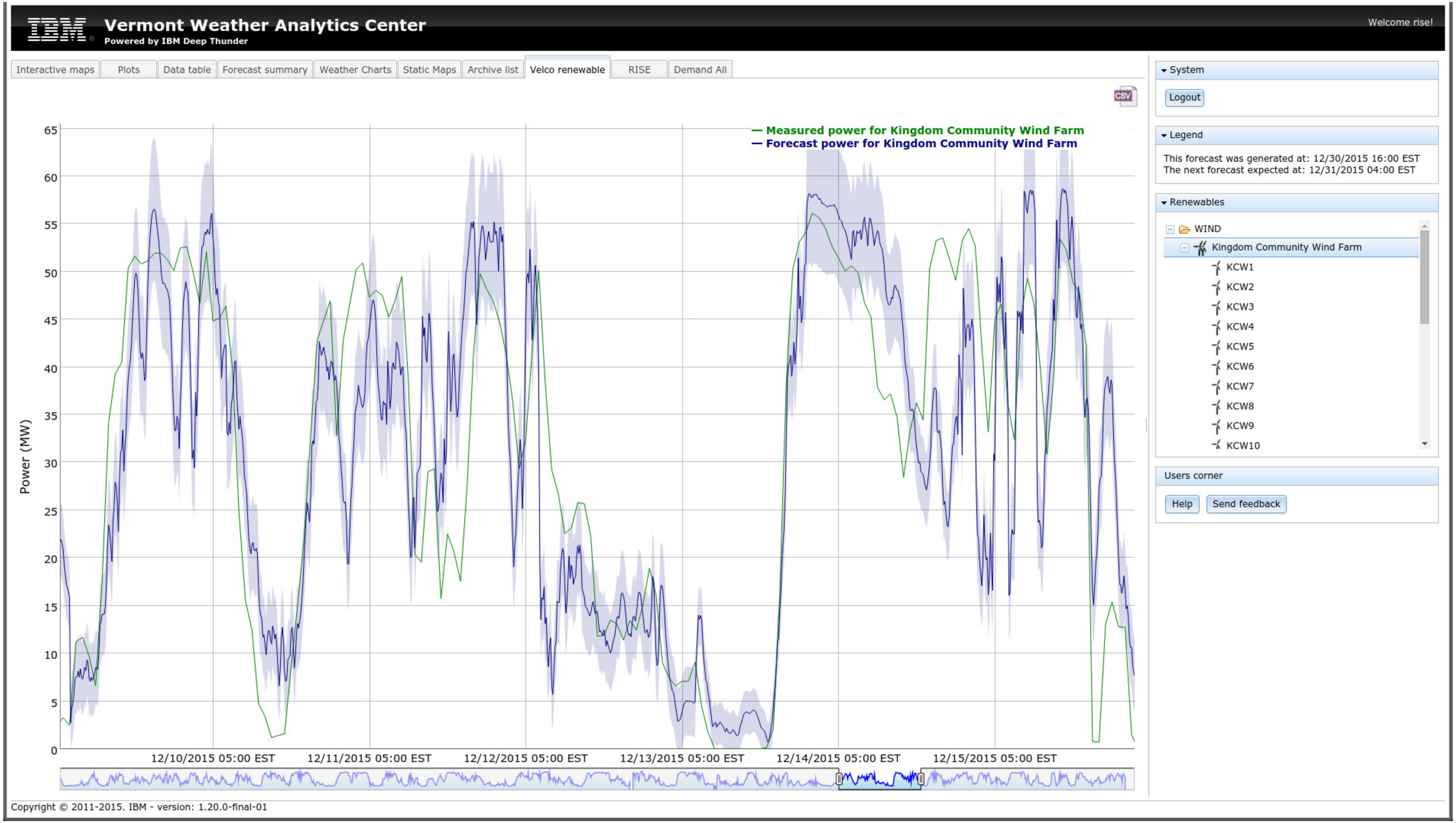
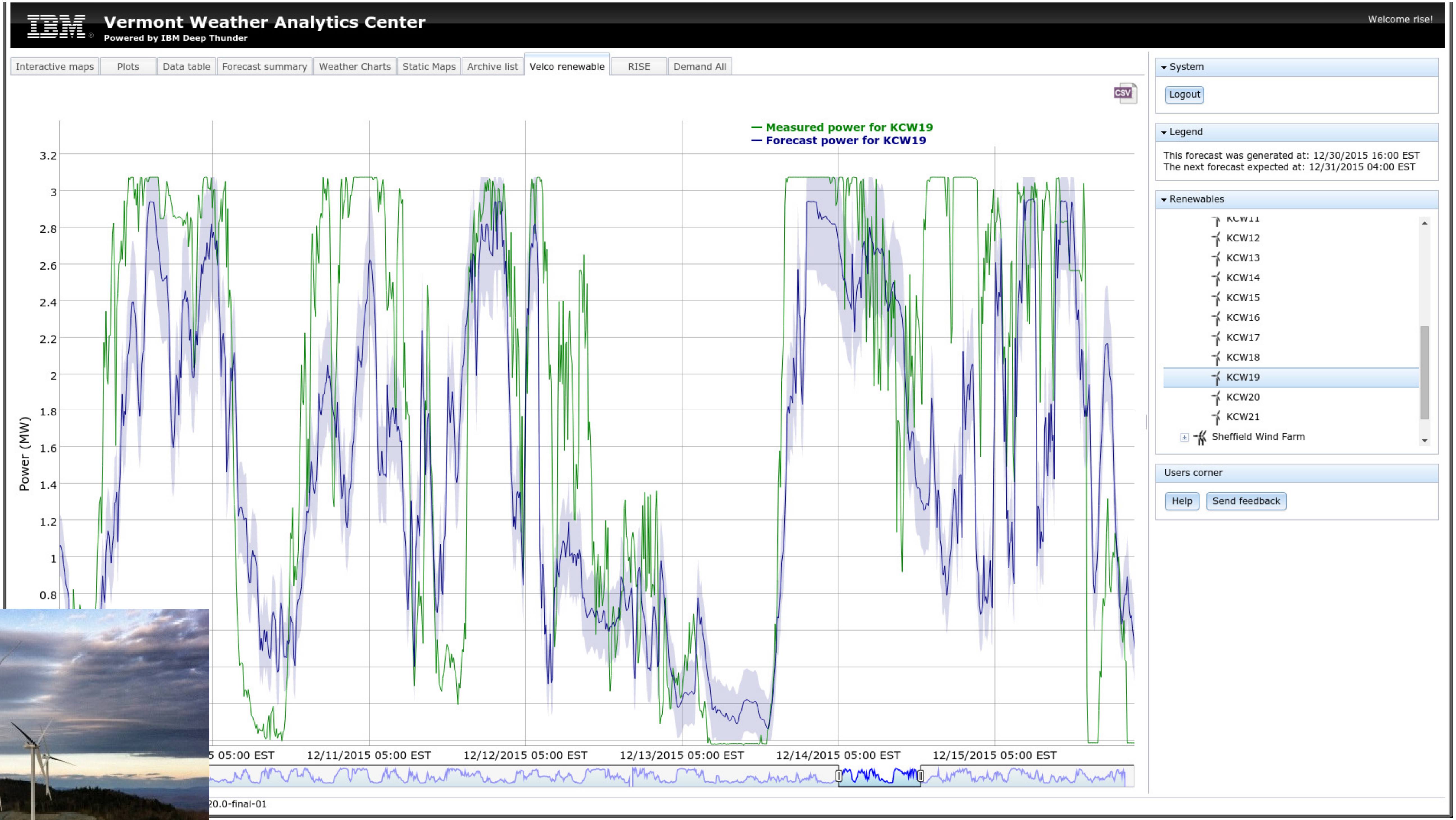
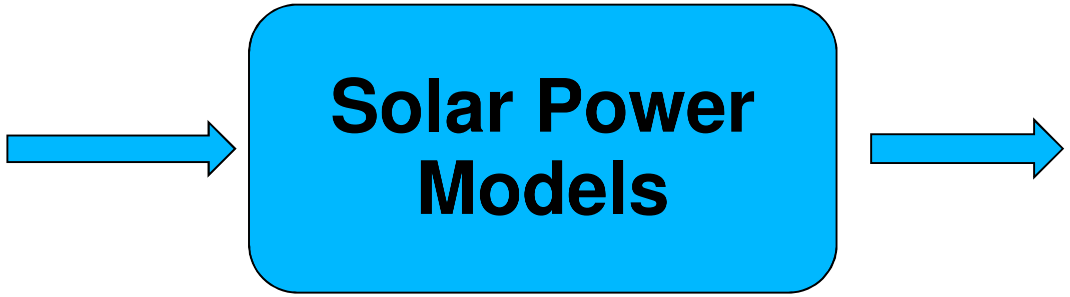


Renewable Power Web Portal



Predictive Statistical Models Built from Historical Weather Forecasts and Observations, Power and Other Data

- Data for Solar Farms
  - Weather model-derived near-surface GHI, DNI, GNI, wind speed & direction. temperature, pressure and moisture
  - Irradiance, wind and temperature measurements at the farm, if available
  - Generated power at each farm and accumulated power, including availability and farm operational mode
  - Engineering characteristics of the PV panels (e.g., specifications, power curves, etc.)



- Solar Power Forecasts
  - Per farm (19 with > 1 MW capacity)
  - Day-ahead focus
  - Physical irradiance to power model
  - Statistical power model (e.g., regression)
  - Cloud cover categorization

Renewable Power Web Portal

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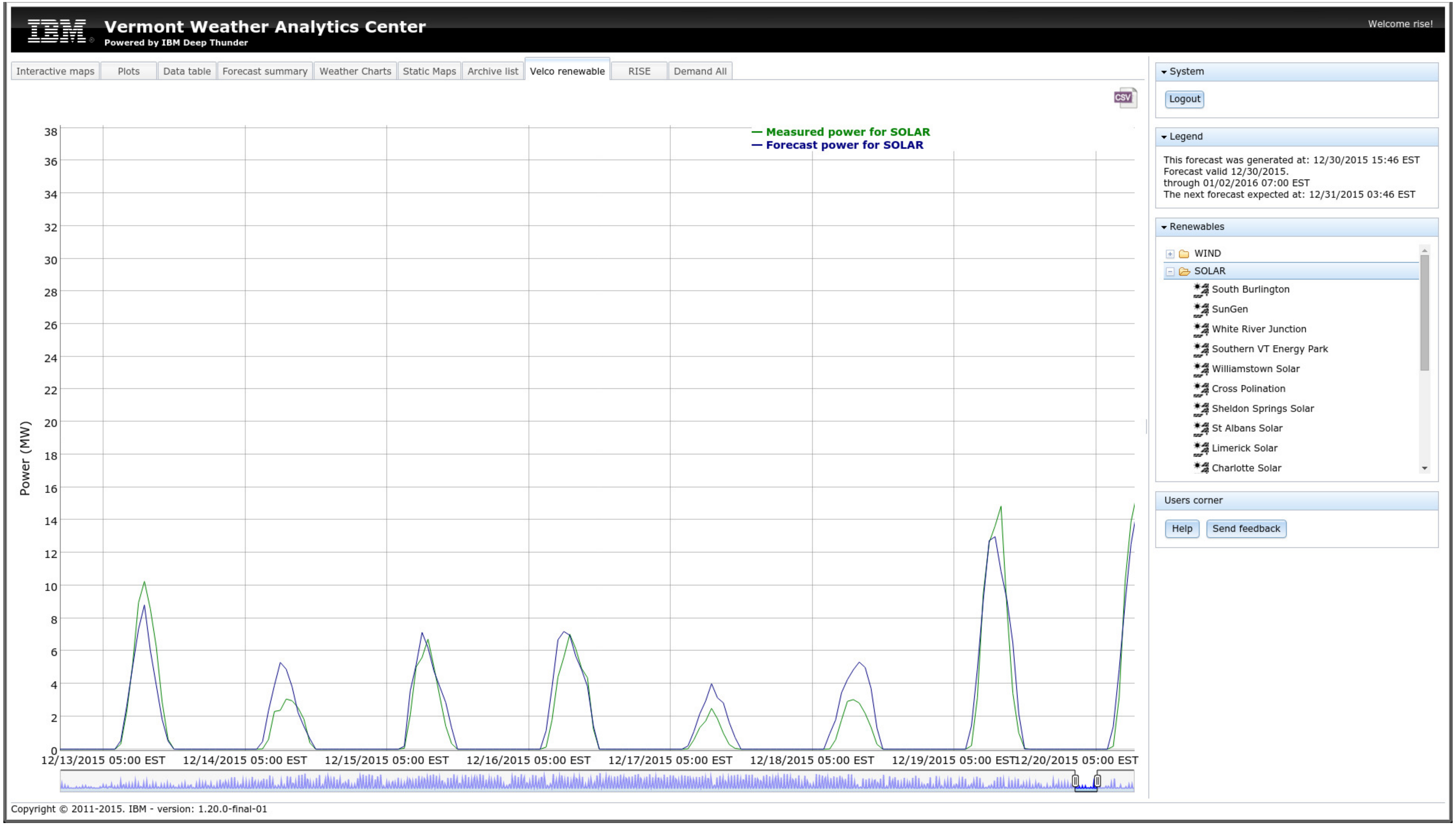
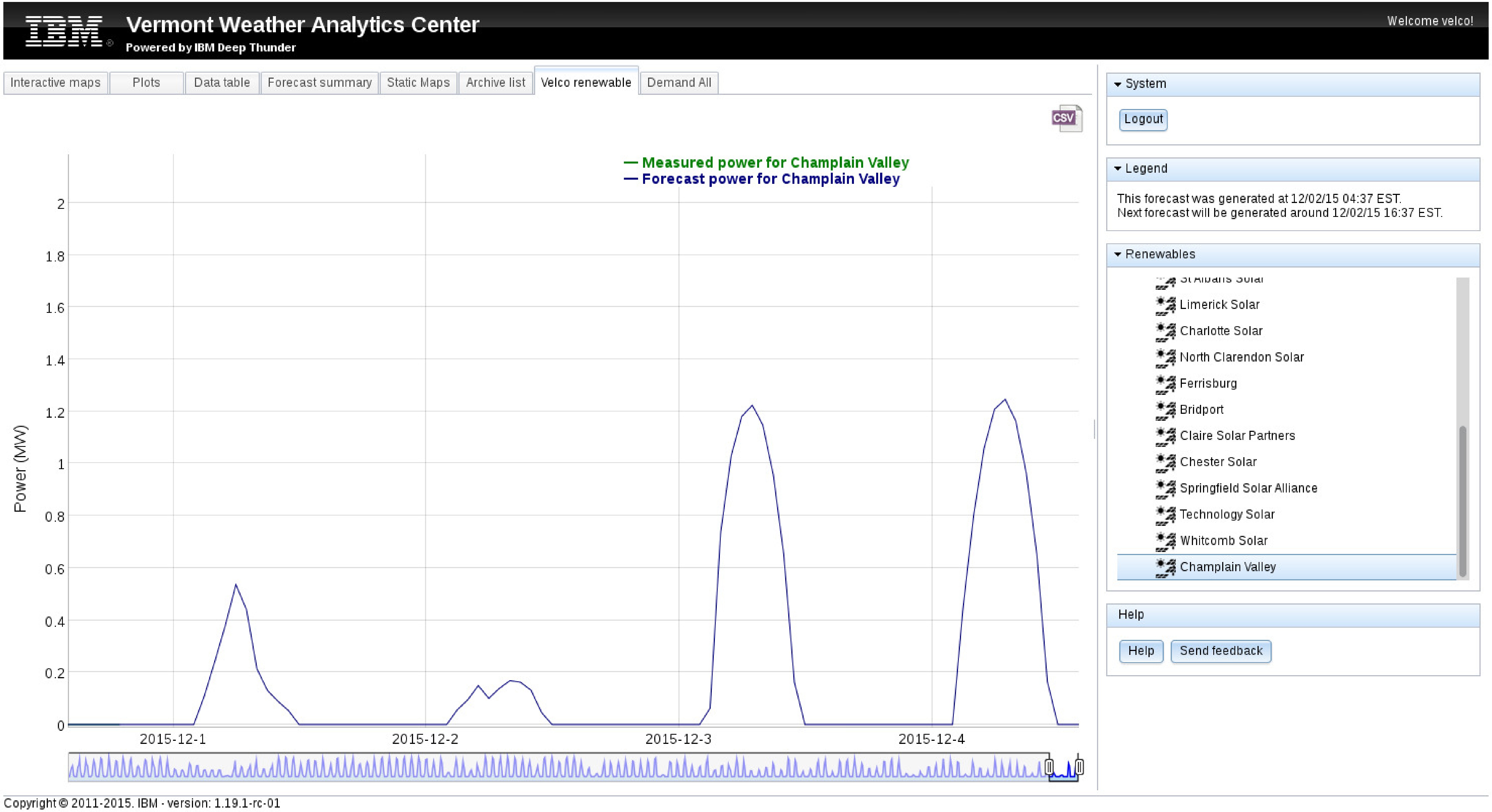
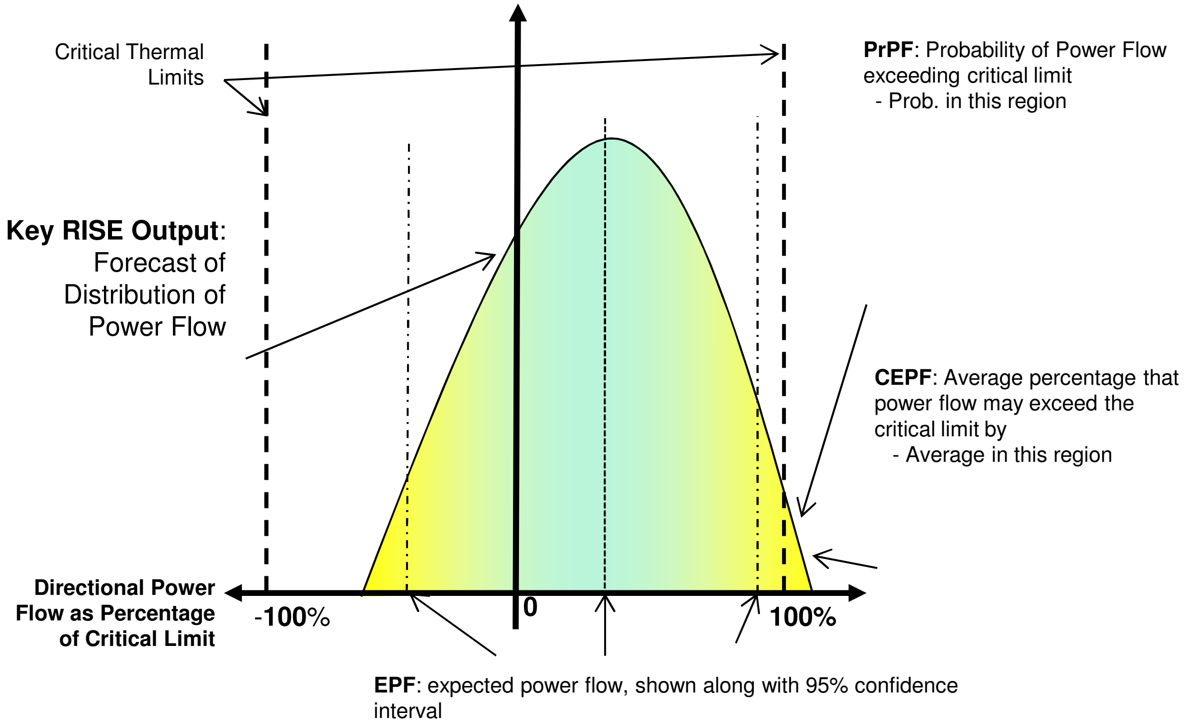


Renewable Power Web Portal



Renewable Integration Stochastic Engine (RISE)

- **With increasing renewables in the generation mix**
  - **Variability in net-metered consumers increases**
  - **Variability of renewables generation can be significant**
- **Power flow analysis produces stochastic forecasts**
  1. **A large set of scenarios for realized renewables and load are created**
  2. **Flow analyzed under each scenario**
  - **1. and 2., combined represents a stochastic forecast of power flow through lines and distributions that may exceed critical limits**

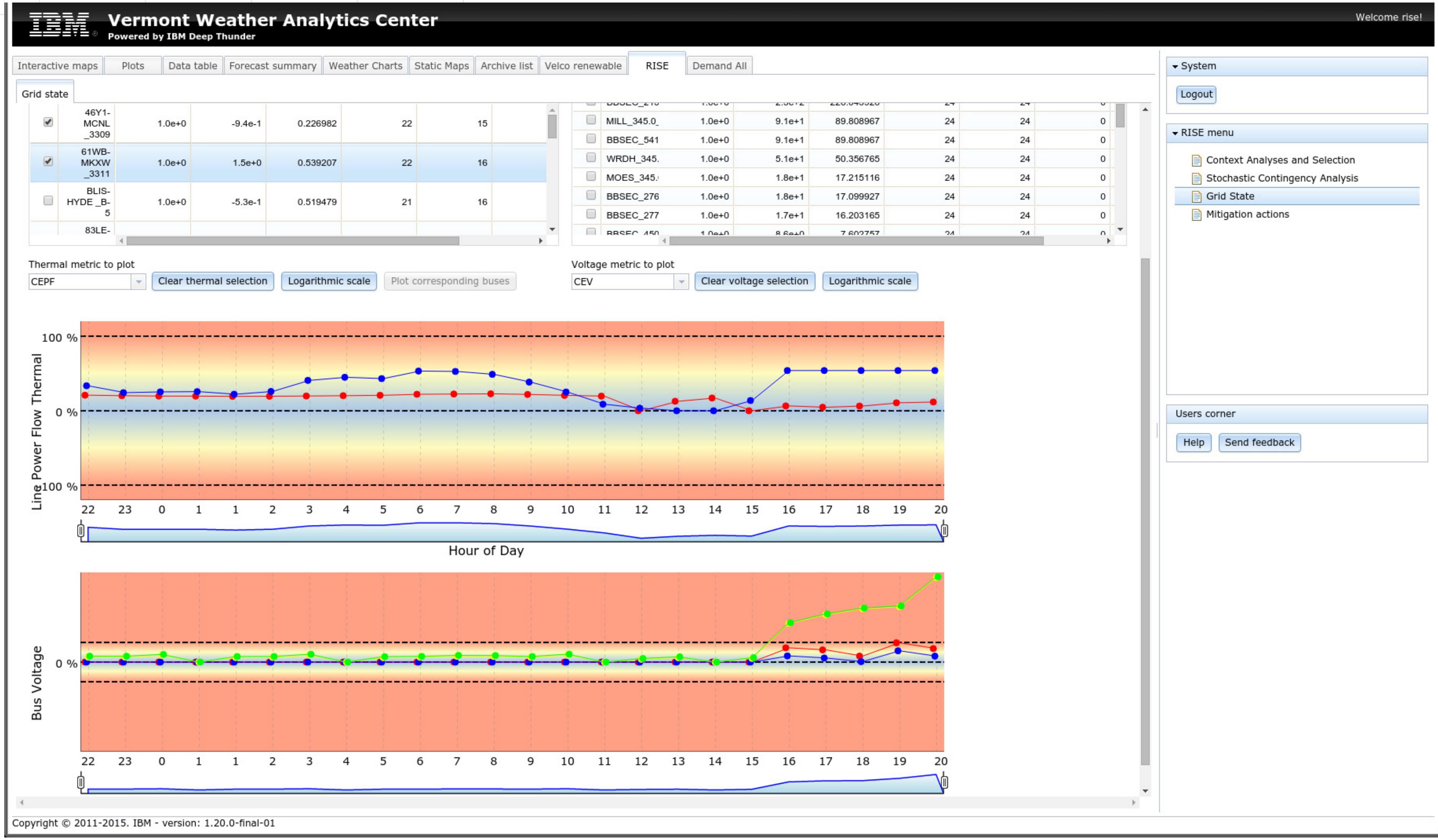


- **RISE combines real-time grid data with demand and renewables generation predictions over a 24-hour horizon to**
  - **Run a stochastic contingency analysis to predict probability of outages**
  - **Provide advance warning for emergence of congestion-like conditions**
- **Operators use RISE for**
  - **Operational contingency analysis and congestion prediction**
  - **What-if capability allows testing effect of various outage and contingency scenarios**

RISE Predictions: Power Flow and Bus Voltages through the Day at Specific Locations

Grid State	Max PrPF	Max EPF	Max CEPF	Max Num thermal violations	Max DPF	Max PrV	Max EV	Max CEV	Max Num voltage violations	Max DV
base	1.0e+0	1.5e+0	6.2e-1	22	16	1.0e+0	2.3e+2	2.3e+2	24	24
IL-COLD-NRUT K35 LINE OUT	1.0e+0	1.5e+0	6.9e-1	23	18	1.0e+0	2.3e+2	2.5e+2	24	24
RX-KENDAL FARM SC OUT	1.0e+0	1.5e+0	6.6e-1	23	18	1.0e+0	2.3e+2	2.5e+2	24	24
TL-COMERFORD G207/PH1 OUT	1.0e+0	1.5e+0	6.7e-1	22	17	1.0e+0	3.0e+2	3.0e+2	24	24
TL-WHITEHALL-MOHICAN R13 LINE	1.0e+0	1.5e+0	7.1e-1	23	17	1.0e+0	2.3e+2	3.4e+2	24	24
EA-GARVINS MERIMACK H137 LINE OUT	1.0e+0	1.5e+0	6.5e-1	23	18	1.0e+0	3.0e+2	3.0e+2	24	24
EA-OAKHILL MERIMACK P145 LINE OUT	1.0e+0	1.5e+0	7.0e-1	22	17	1.0e+0	3.0e+2	3.0e+2	24	24

Stochastic Contingency Analysis



Current Status and Next Steps

- Enabled an operational capability for all five, coupled modelling components
- Continuing to improve calibration of all models, and characterization of uncertainties, including further development of verification methods, and for longer lead times
  - Operational statistics for evaluation
  - Retrospective analysis and tuning using new events that have impact
  - Especially for determining periods of congestion
- Consideration of additional use cases such as determining the optimal mitigation action for congestion conditions
- Developing additional specialized visualizations and methods of dissemination
- Availability of high-quality data to enable operational updates is an on-going challenge
- Collaborative and diverse team (users, researchers, developers, domain experts) critical to success
  - Need to build trust with diverse users and incorporate their feedback
  - Deliver complex information succinctly
  - Must be integrated with utility company procedures

Backup Slides

Other Presentations of Related Work

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Seventh Conference on Weather, Climate, and the New Energy Economy

- 2.4 Enhanced Statistical Post-Processing of Solar Irradiance Predictions Using Optimized WRF Forecasts of Cloud Cover Categories
- 2.5 Coupling Numerical Weather Predictions to Demand and Solar Energy Forecasting Models in an Operational Setting
- 5.5 Analysis of Short-term Wind Power Forecasting in the Northeastern United States
- 8.2 Toward Integration of Seasonal Climate Forecasts into Energy Decision Support Systems
- 8.5 The Characteristics and Formation Mechanisms of Low Level Jets in China and their Relationship with Wind Energy
- 427 Application of Ensemble Forecast and Linear Regression Method in Improving PM10 Forecast over Beijing Areas

18th Conference on Atmospheric Chemistry

- 698 Impacts of an Unknown Daytime HONO Source on the Mixing Ratio and Budget of HONO, and Hydroxyl, Hydroperoxyl and Organic Peroxy Radicals, in the Coastal Regions of China

14th History Symposium

- 4.2 The History, Development and Application of the Business of Weather at IBM

Fifth Conference on Transition of Research to Operations

- 6.1 Fine Scale Hail Hazard Prediction using the WRF Model

Town Hall Meeting: The Weather Value Chain of the Future: From Commercial Satellites to Crowdsourcing, and Everything In Between

23rd Conference on Probability and Statistics in the Atmospheric Sciences

- 14.5 Verification of High-resolution WRF-ARW Forecasts for Vermont Utility Applications

30th Conference on Hydrology

- 5B.3 Surface runoff simulation and application using WRF-Hydro for city flood in China
- 538 Modulation of Urban Heat Island and Heat Waves under Current and Future Climate

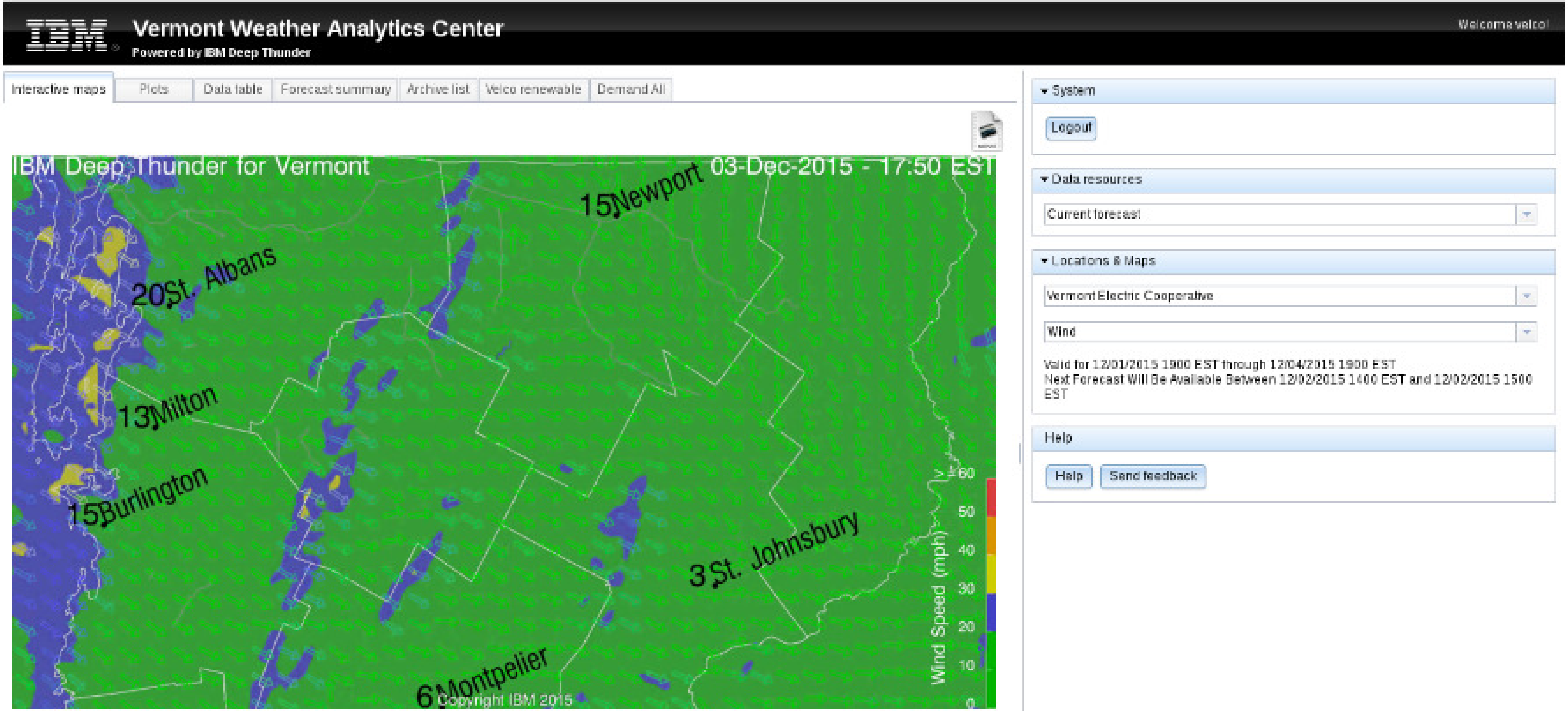
20th Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS)

- 255 The Use of the Breeding Method for Nested WRF-ARW Simulations
- 264 Integrated Physical Modelling of the Lake George, NY Watershed
- 676 An Integrated Modeling, Observing and Visualization System for the Study of the Ecology of Lake George in the Jefferson Project

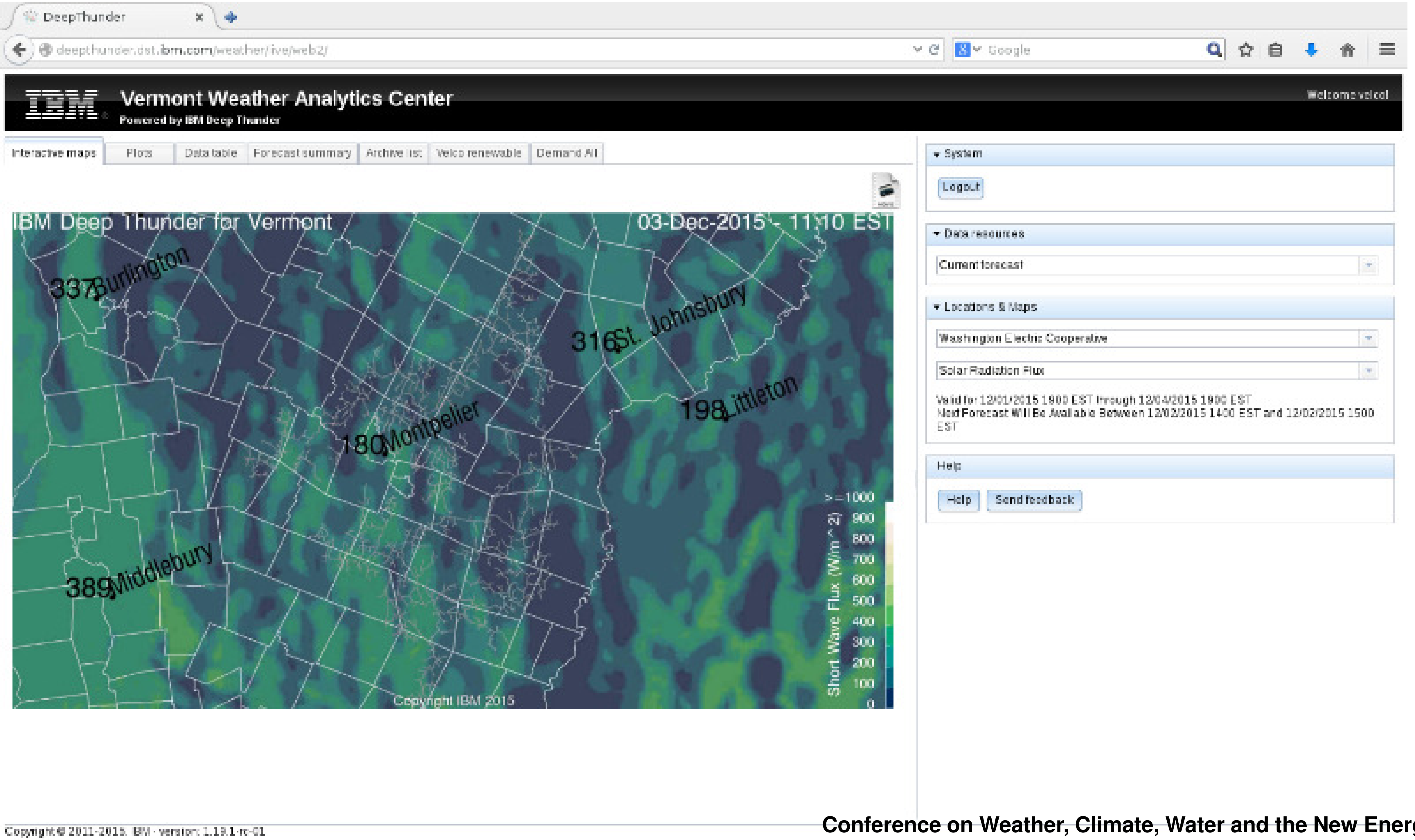
Major Weather Impacts in 2015

- 492 The January 26-27, 2015 Winter Storm in the Northeastern United States and the Challenges for Mesoscale Weather Forecasting

72-Hour Wind Speed and Direction Forecasts for Vermont



72-Hour Solar Irradiance Forecasts for Vermont



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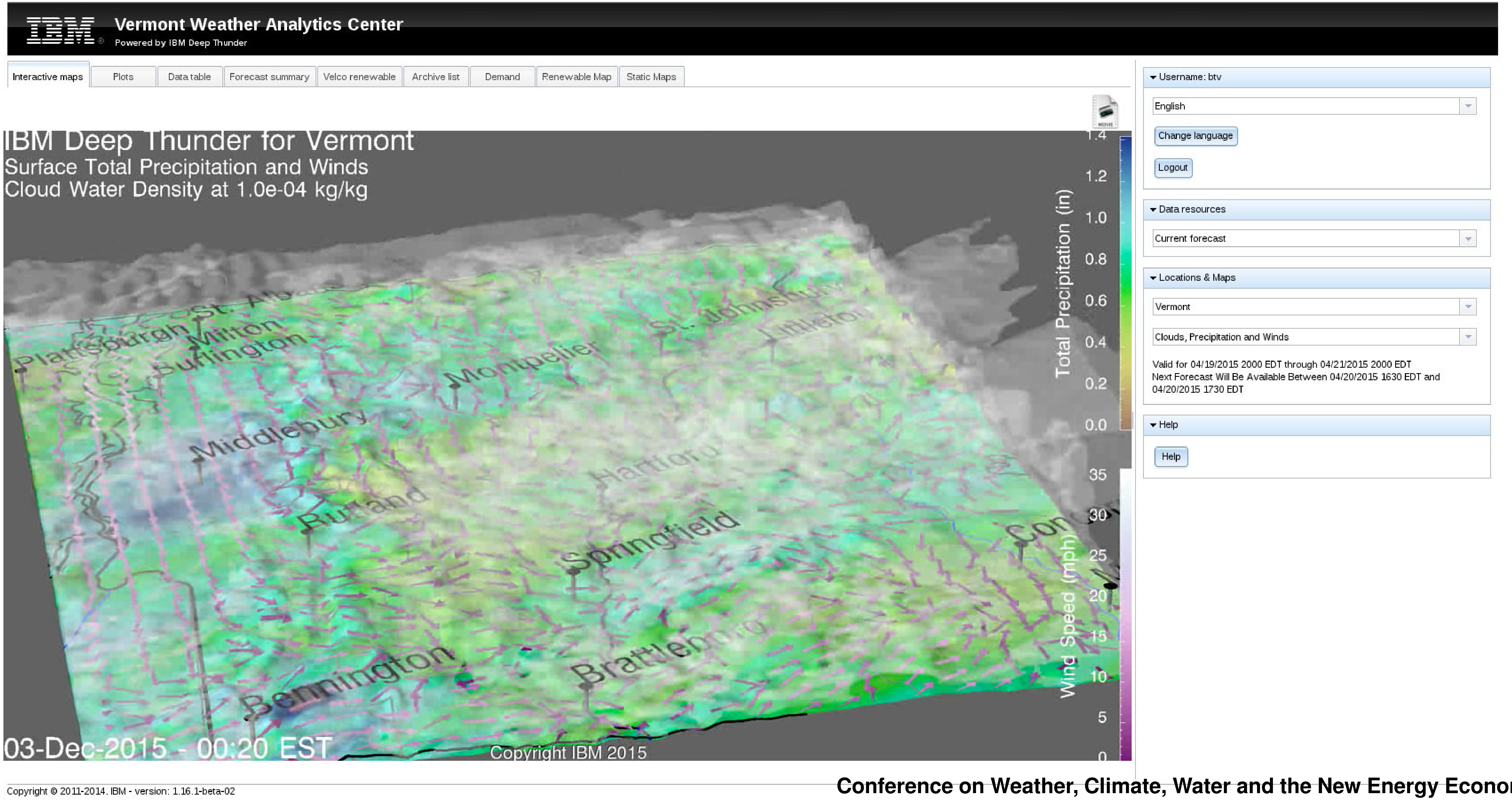
72-Hour Forecasts for Vermont



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72-Hour Site-Specific Summary Forecast for Vermont

DeepThunder × Downloads ×

https://vtwac.velco.com/weather/live/web2/

Apps Imported From Fir Imported

Vermont Weather Analytics Center
Powered by IBM Deep Thunder

Welcome rise!

Interactive maps | Plots | Data table | Forecast summary | Weather Charts | Static Maps | Archive list | Velco renewable | RISE | Demand All

For more detailed forecast content, please refer to the Interactive Maps and/or site-specific Plots and Data Tables.

Main

Vermont Weather Analytics Center
Forecast summary for VELCO HQ (Rutland) (Vermont):
Valid for 12/30/2015 0700 EST through 12/31/2015 0700 EST
12/30/2015, 12Z Forecast

Summary table:

Wednesday - Thursday	12/30/2015 - 12/31/2015 full day	07:00 - 15:00	15:00 - 23:00	23:00 - 07:00
Precipitation accum (in)	0.08	0.01	0.01	0.06
Start Time	7:10	7:10	15:00	23:00
End Time	3:10	7:10	22:20	3:10
Peak Precipitation Rate (in/hr)	0.03 at 23:50	0.02	0.02	0.03
Max Sustained Wind (mph)	12.7 SSE at 7:00	12.7 SSE at 7:00	6.8 S at 19:40	8.5 WSW at 6:30
Max Wind Gust (mph)	16.5 at 7:30	16.5 at 7:30	8.8 at 19:40	11.3 at 6:30
Low Temp	30º	30º	33º	34º
High Temp	36º	35º	35º	36º
Accumulated Snowfall (liq.ratio) Max(Snow (in)) / Min(Snow to Liquid Ratio)	0.1 / -	0.1 / -	0.1 / -	0.1 / -

Thursday	12/31/2015 partial day	07:00 - 07:00
Precipitation accum (in)	0	0
Start Time	7:00	7:00
End Time	7:10	7:10
Peak Precipitation Rate (in/hr)	0.01 at 7:00	0.01
Max Sustained Wind (mph)	3.6 S at 7:00	3.6 S at 7:00
Max Wind Gust (mph)	4.7 at 7:00	4.7 at 7:00
Low Temp	29º	29º
High Temp	29º	29º
Accumulated Snowfall (liq.ratio) Max(Snow (in)) / Min(Snow to Liquid Ratio)	0.1 / -	0.1 / -

Thursday	12/31/2015 partial day	07:10 - 07:00
Precipitation accum (in)	0	0
Start Time	7:10	7:10
End Time	7:20	7:20
Peak Precipitation Rate (in/hr)	0.01 at 7:10	0.01
Max Sustained Wind (mph)	3.2 S at 7:10	3.2 S at 7:10
Max Wind Gust (mph)	4 at 7:10	4 at 7:10
Low Temp	29º	29º
High Temp	29º	29º
Accumulated Snowfall (liq.ratio) Max(Snow (in)) / Min(Snow to Liquid Ratio)	0.1 / -	0.1 / -

System
Logout

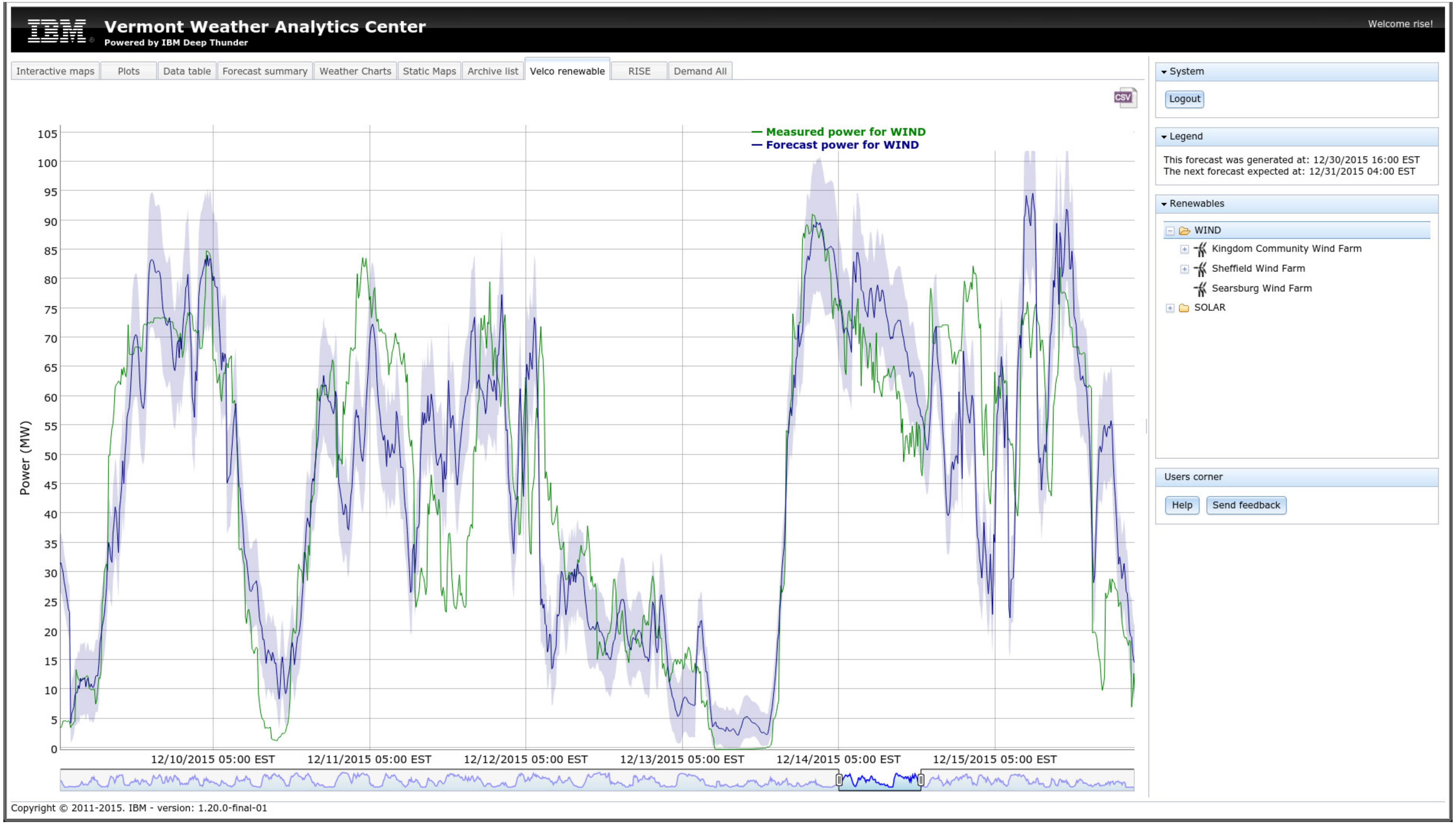
Data resources
Current forecast

Locations & Maps
Vermont
VELCO HQ (Rutland)

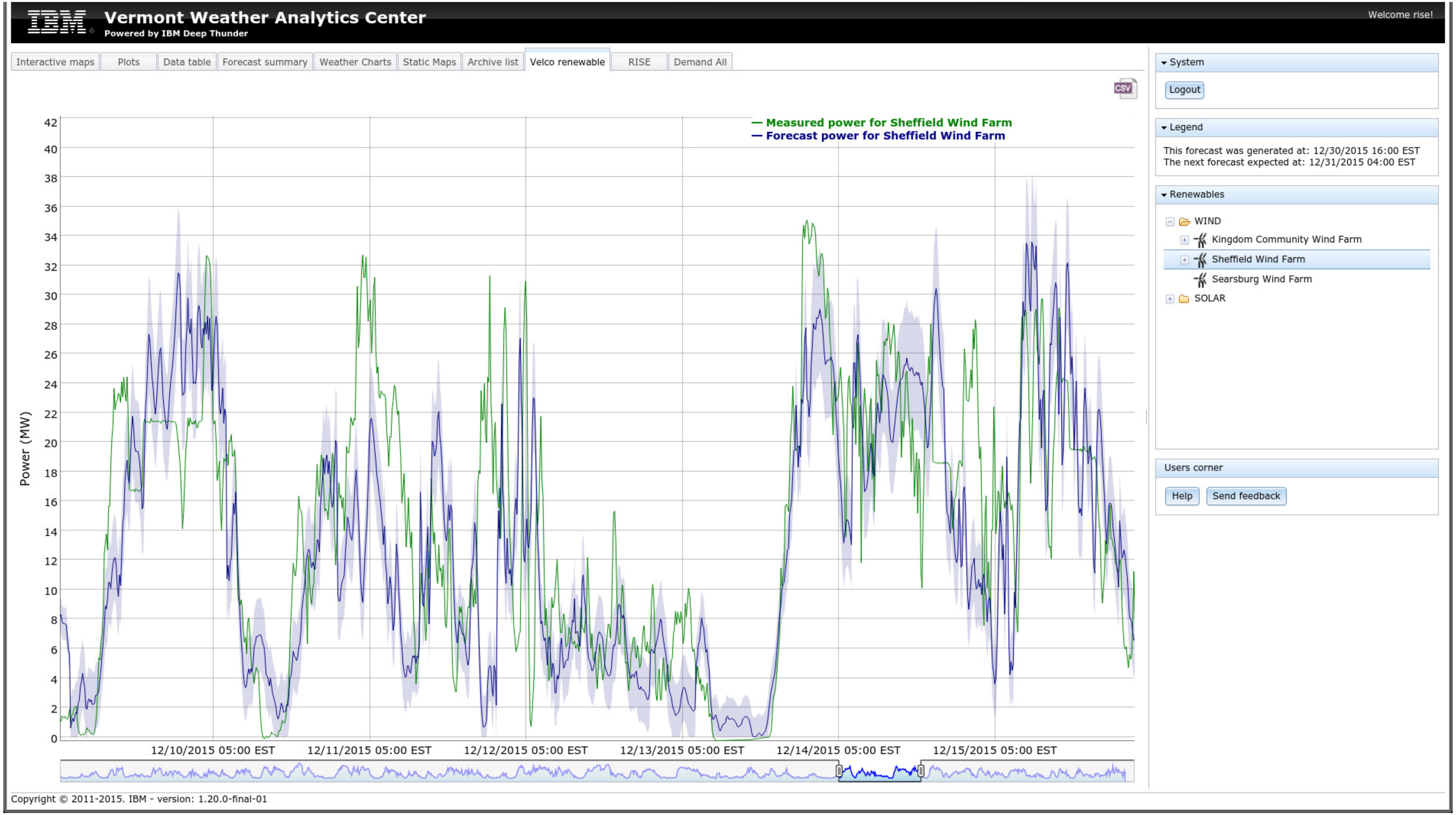
Valid for 12/30/2015 0700 EST through 12/31/2015 0700 EST
Next Forecast Will Be Available Between 12/31/2015 0200 EST and 12/31/2015 0300 EST

Users corner
Help Send feedback

Renewable Power Web Portal



Renewable Power Web Portal



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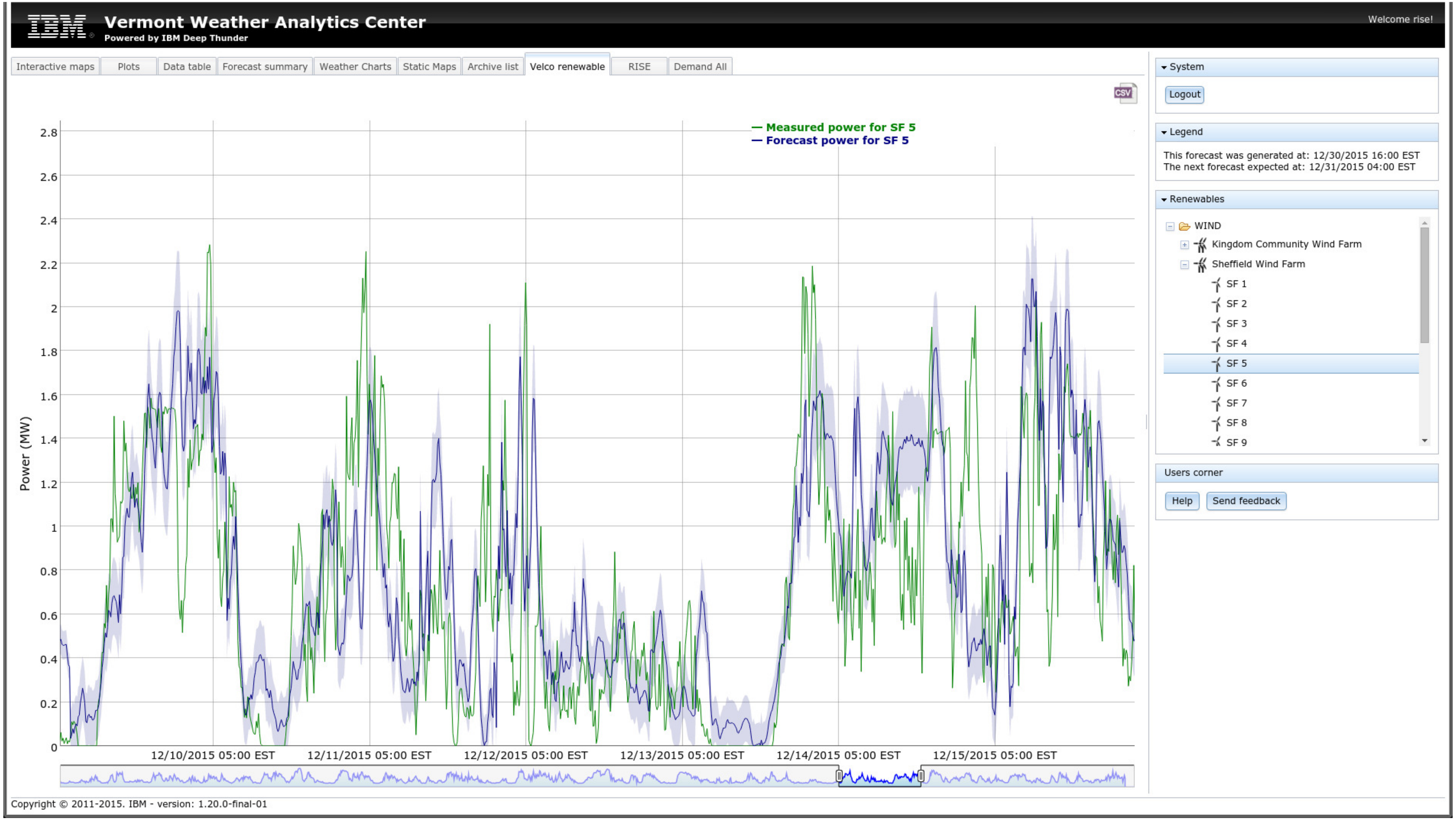

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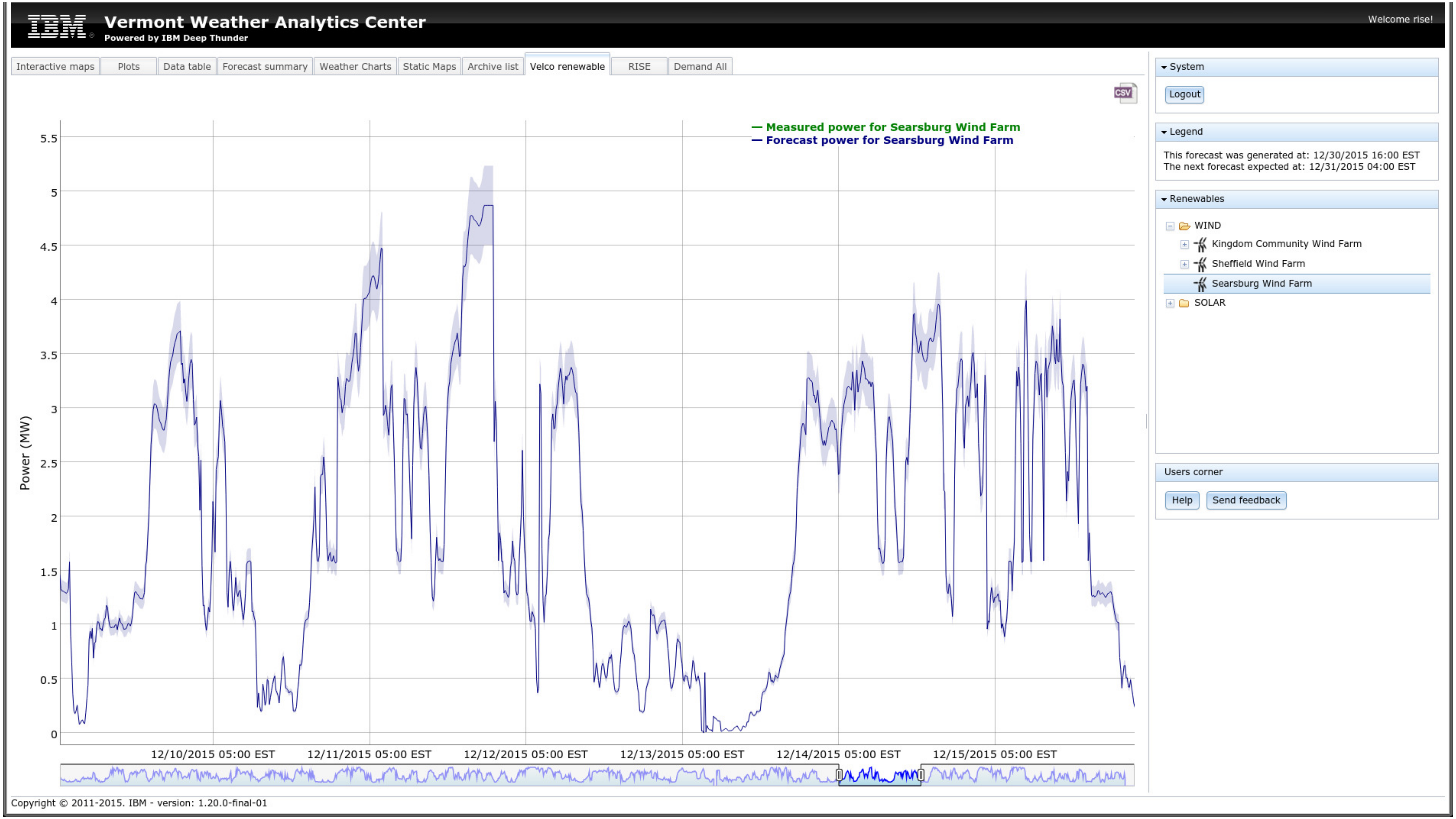
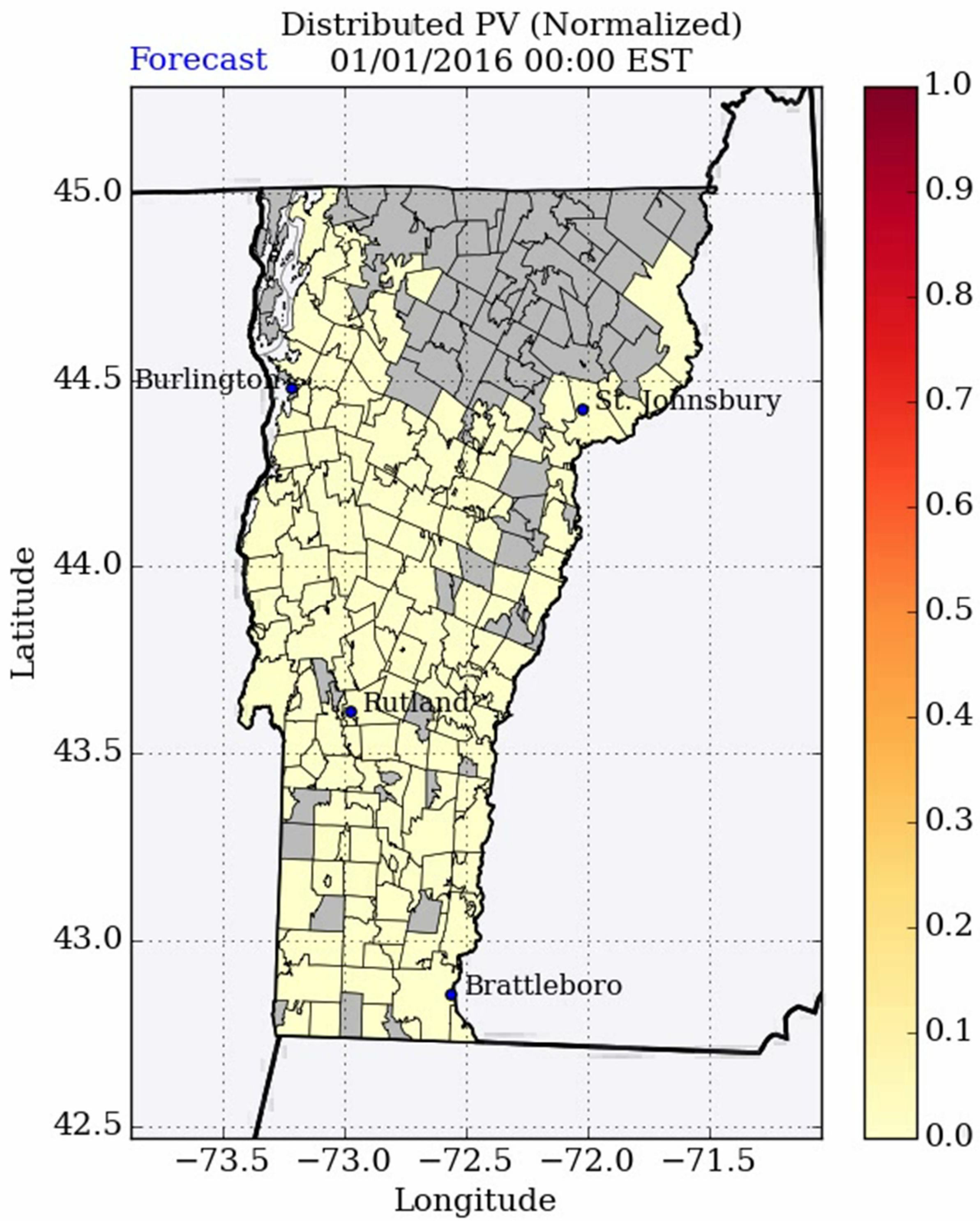


State-wide Distributed Solar Power Example



72-hour distributed PV power forecast is normalized to illustrate temporal and spatial detail

Electricity Demand Web Portal