Applications of Coupled Models for Renewable Energy Integration in Vermont

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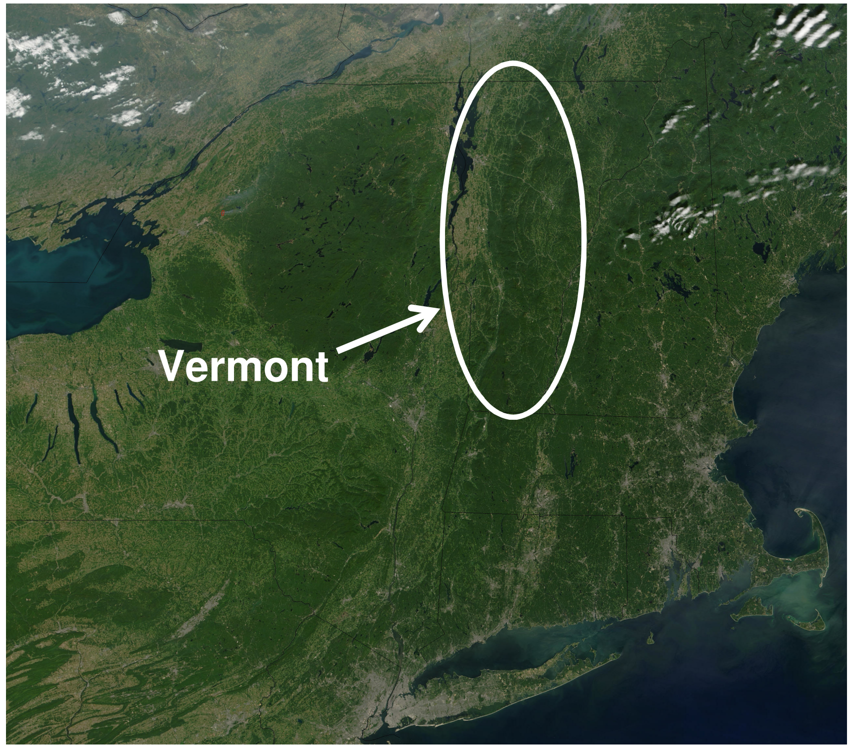
Renewable Energy Integration in Vermont

- 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 typically poorly quantified
- As a result, conservative grid management leads to curtailment of renewable power (i.e., wind) production

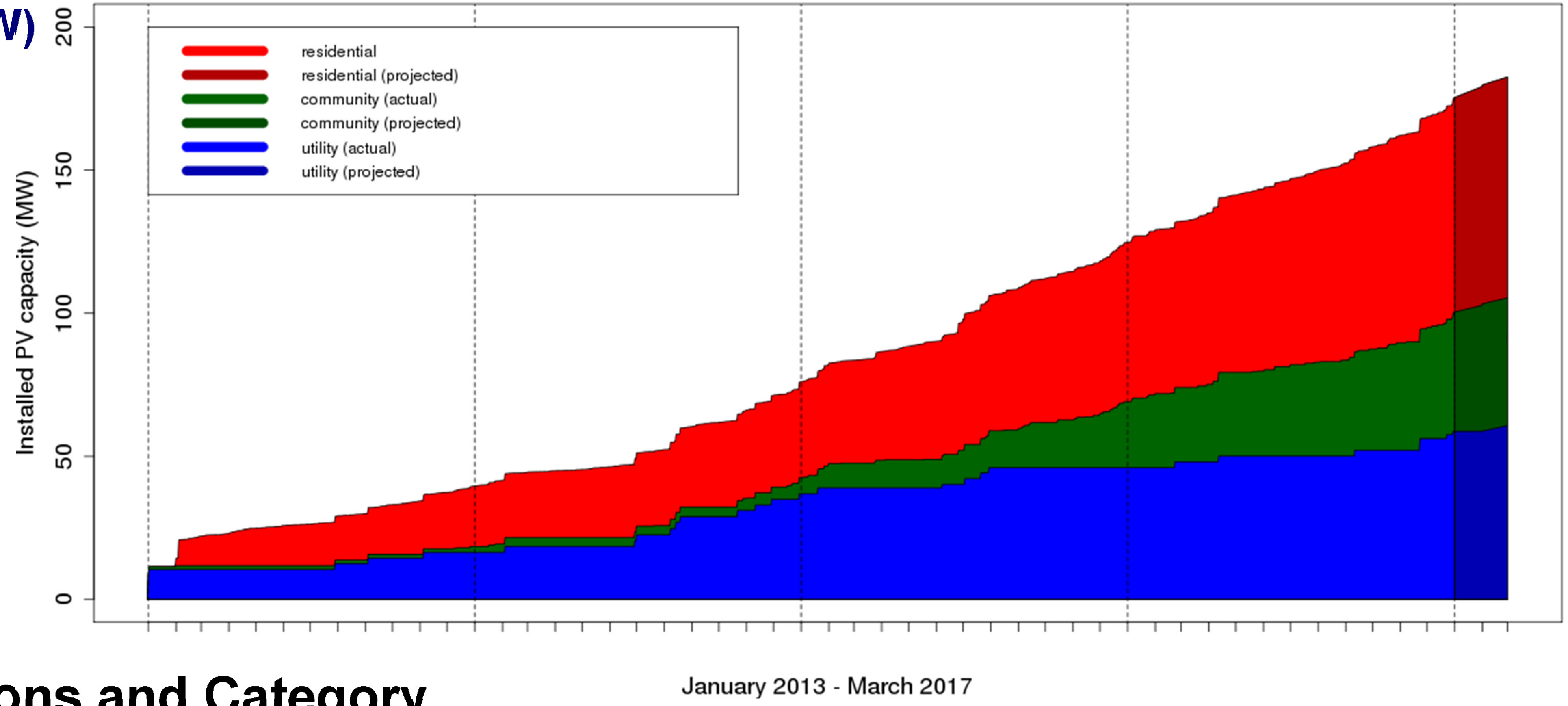


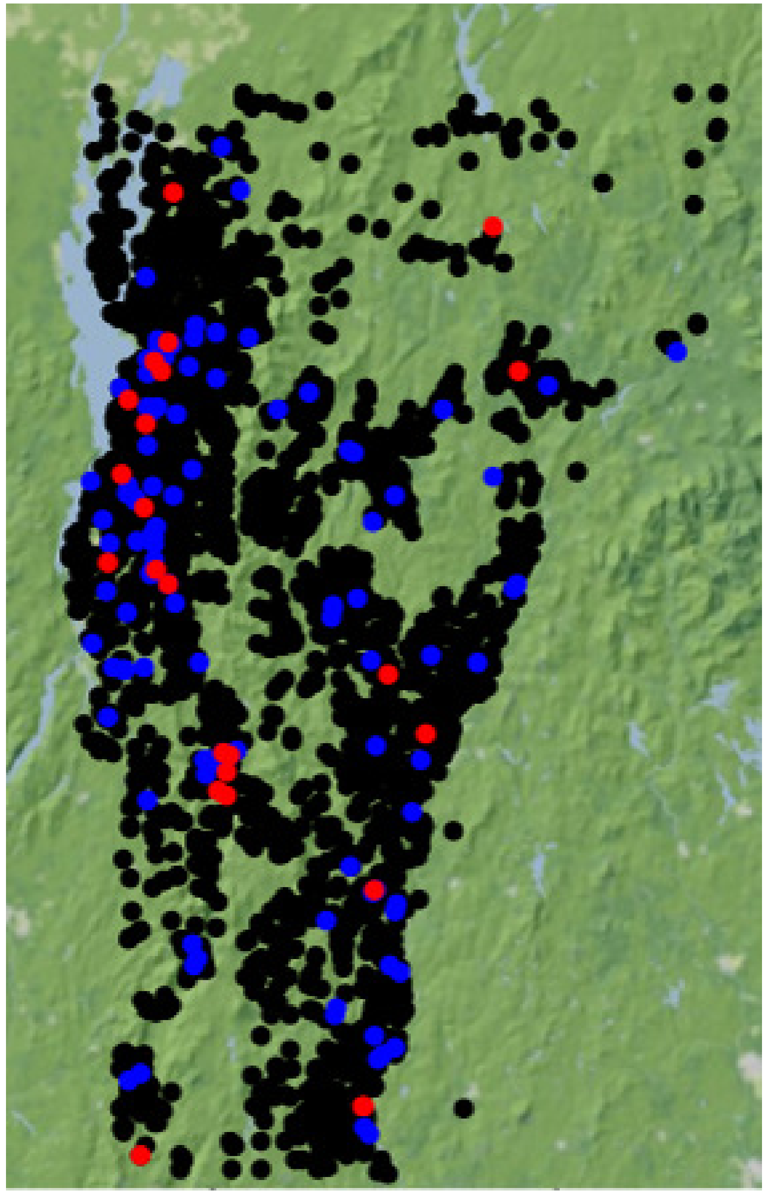
An Additional Challenge – Recent Growth in Solar Power

Approximately 8000 PhotoVoltaic (PV) installations in Vermont (none are dispatchable)

- 27 utility-scale (> 1MW)
- 65 community-scale (150KW – 1MW)
- Remainder: residential-scale (< 150KW)

PV Capacity Growth (~7X in the last four years!)





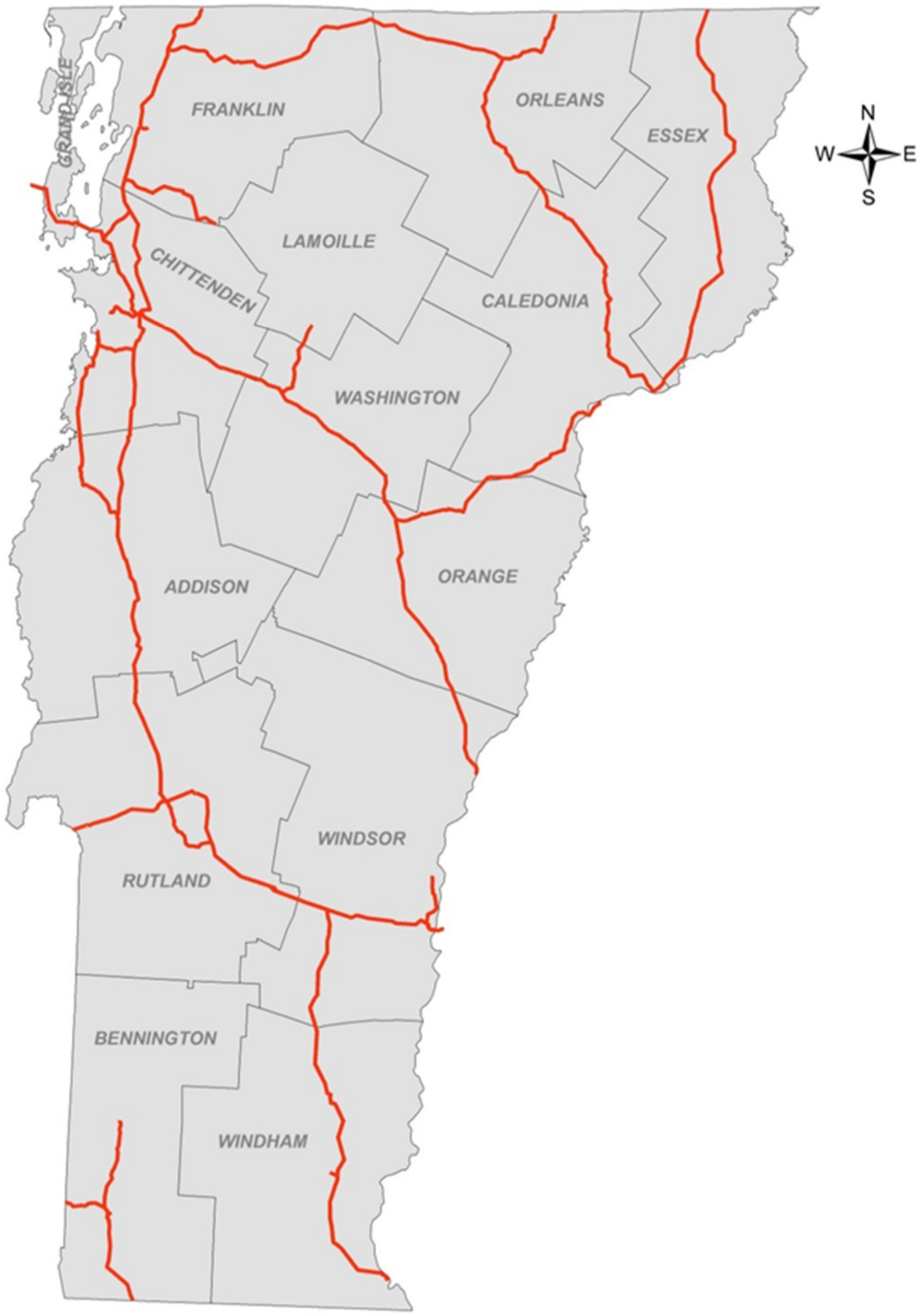
PV Locations and Category

- Community
- Residential
- Utility

The Vermont Electric Power Company (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
- 1500 miles of fiber optic communication network, which helps to enable observations to lead the way
- 52-mile 450 kV direct current line owned by VETCO

VELCO has invested in enabling the Vermont Weather Analytics Center (VWAC)



Vermont Weather Analytics Center Partners

Distribution Utilities:

Academia:

Others:

Vermont Weather Analytics Center

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Data Sources

Generation

Transmission

Distribution

Maintenance

Smart Meters

GIS

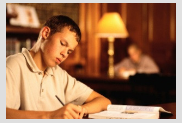
Weather

Spacecraft

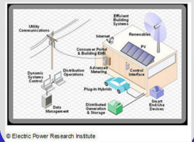
EMS

Regulations

Customers



DER



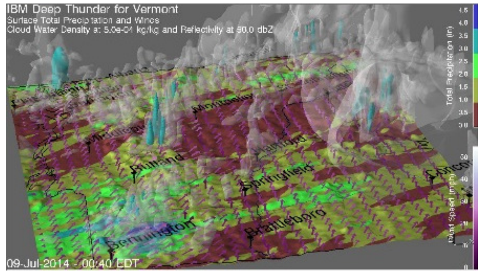
Daily Data Volumes		
Model	Input	Output
Weather	5 GB	670 GB*
Solar	2 MB	15 MB
Wind	5 MB	3 MB
Demand	5 MB**	30 MB
RISE	20 MB	1.1 GB

*50GB drives downstream models
**plus 5GB smart meter data

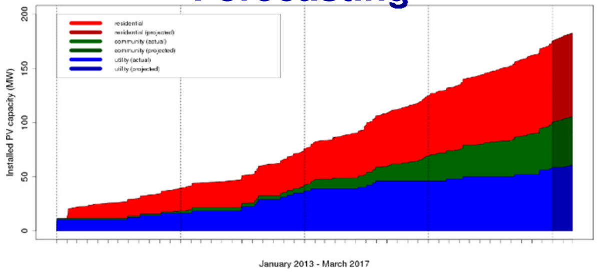
"Observations Lead the Way":

but more than just weather.

Deep Thunder Weather Forecasting

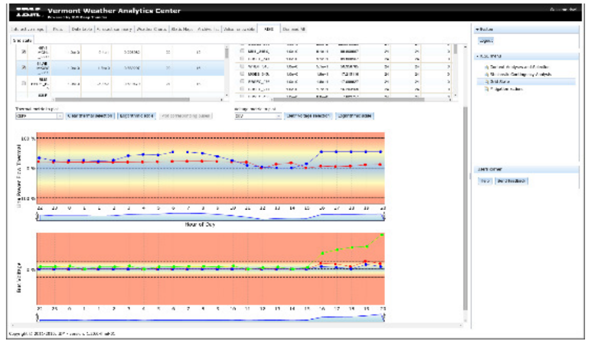


Electric Demand + Net Metering Forecasting



R^2: Renewable Power Forecasting (Solar and Wind)

Renewable Integration Stochastic Engine (RISE)



Decision Support

Manage Demand
Maximize Supply
Maintain the Grid

- **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.**

Vermont Weather Analytics Center

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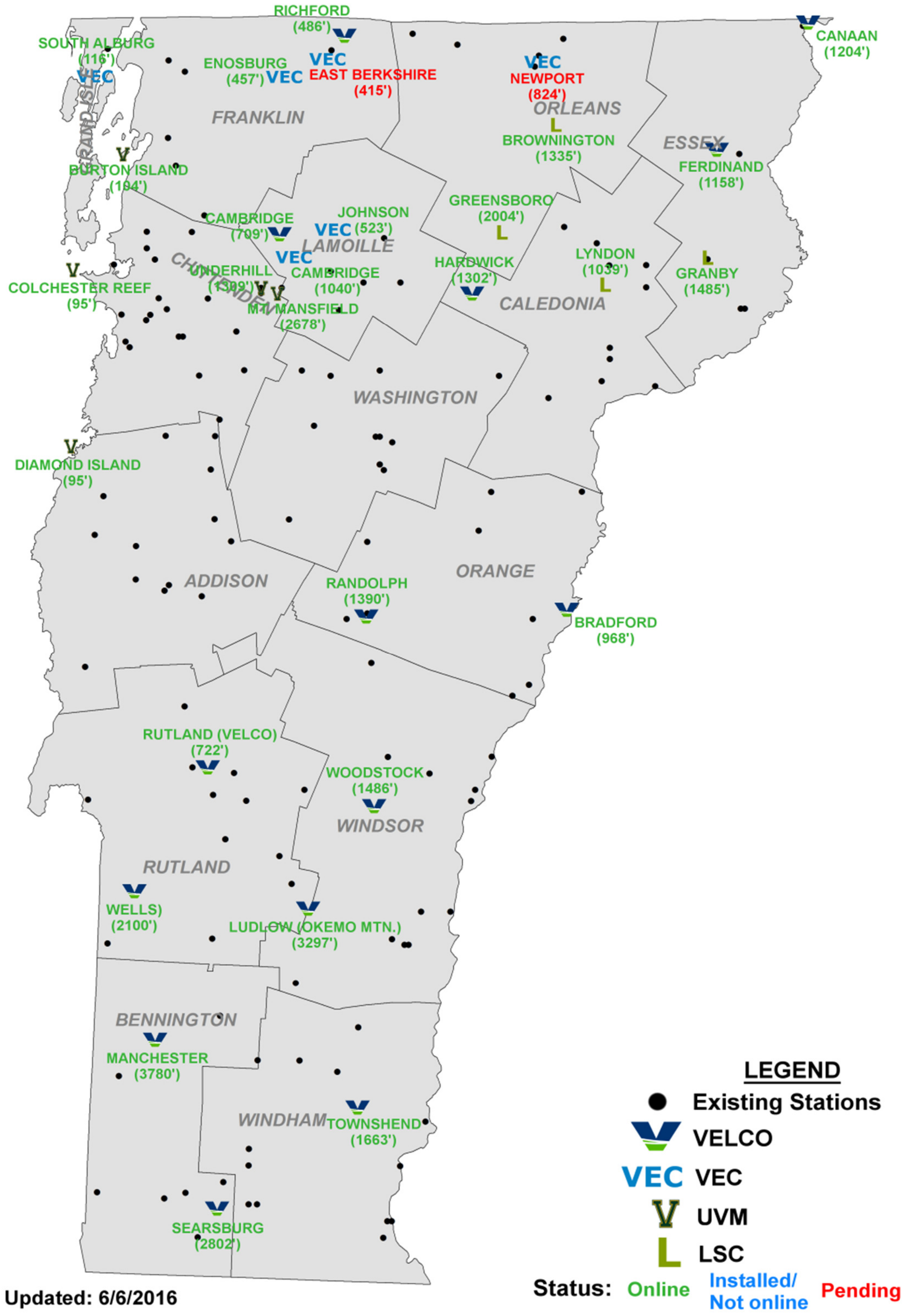
VWAC Mesonet

We led the way with more weather observations…



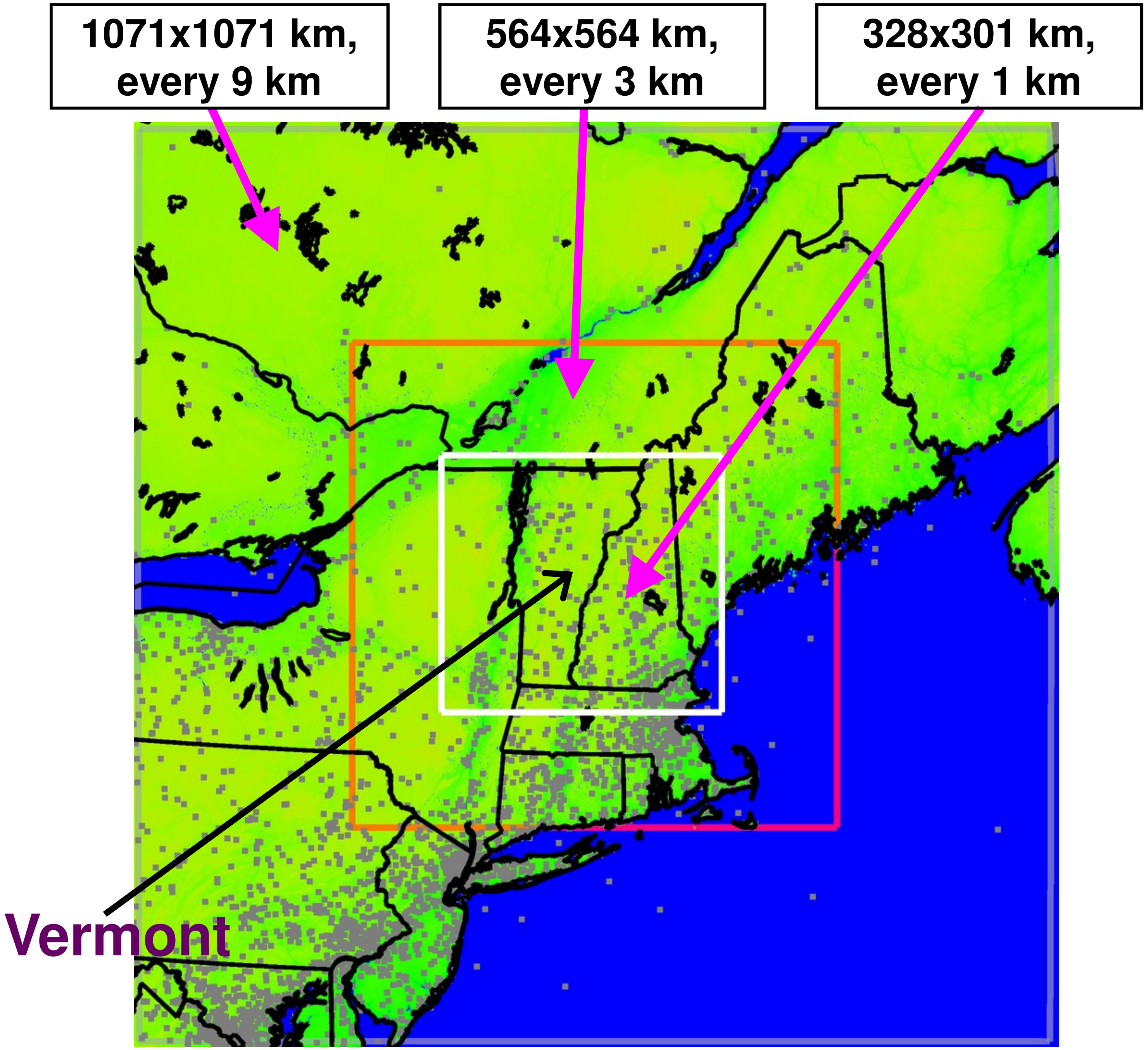
28 Active Stations

- VELCO = 14 (additional sites planned for 2017)
- VEC = 5 (additional sites planned for 2017)
- UVM = 5
- LSC = 4

All data are publically available through MesoWest and MADIS

Weather: NWP Configuration (*Deep Thunder*)

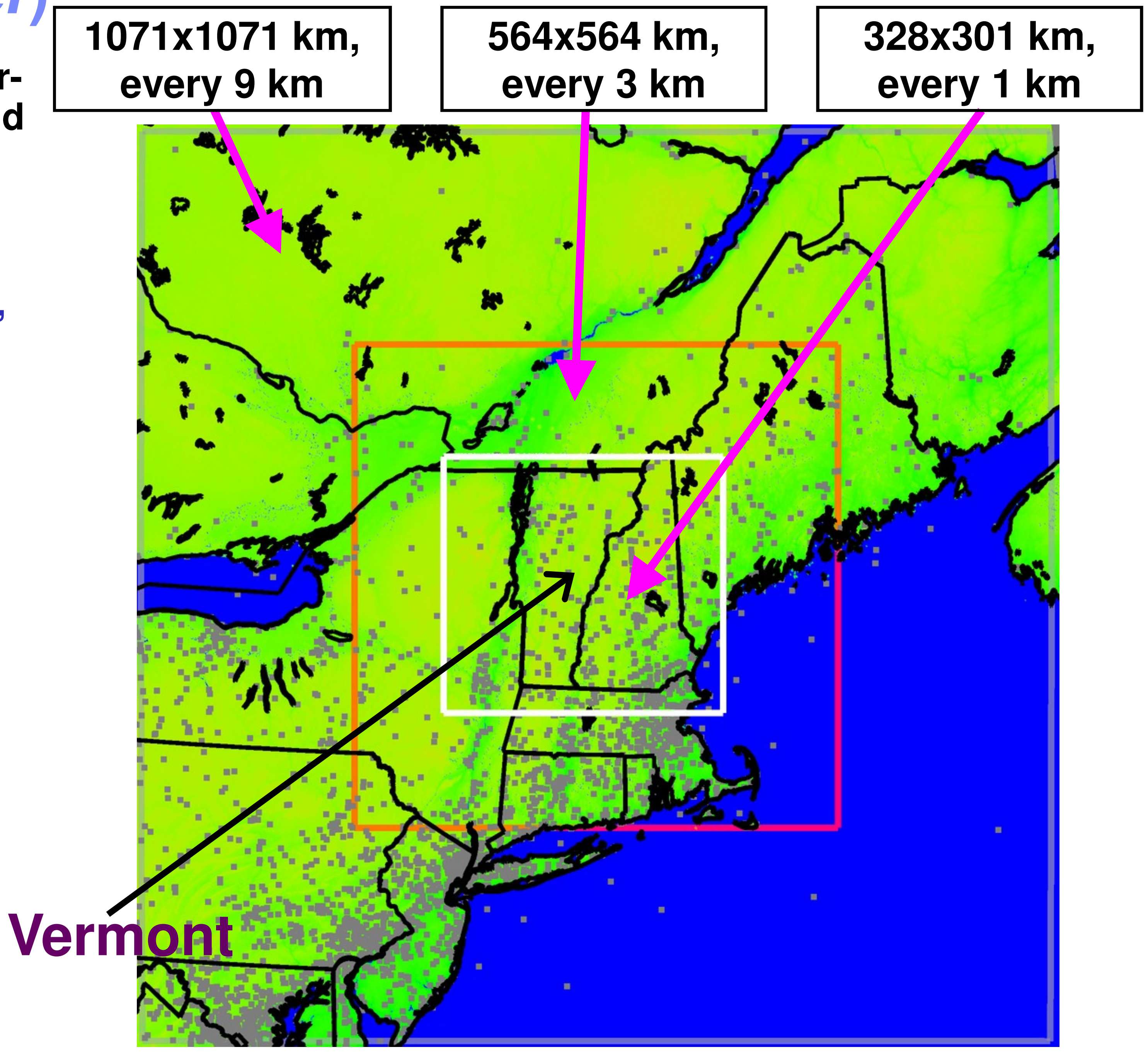
- WRF-ARW, version 3.5.1
- 51 vertical levels, with increased resolution in the PBL (10s of meters near the surface)
- 00Z and 12Z forecasts, 72-hour duration (10-min output)
  - 72-hour, operational since November 2015
  - 48 hour, operational since April 2015
- Physics configuration for highly urbanized 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: Data Ingest (*Deep Thunder*)

- 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



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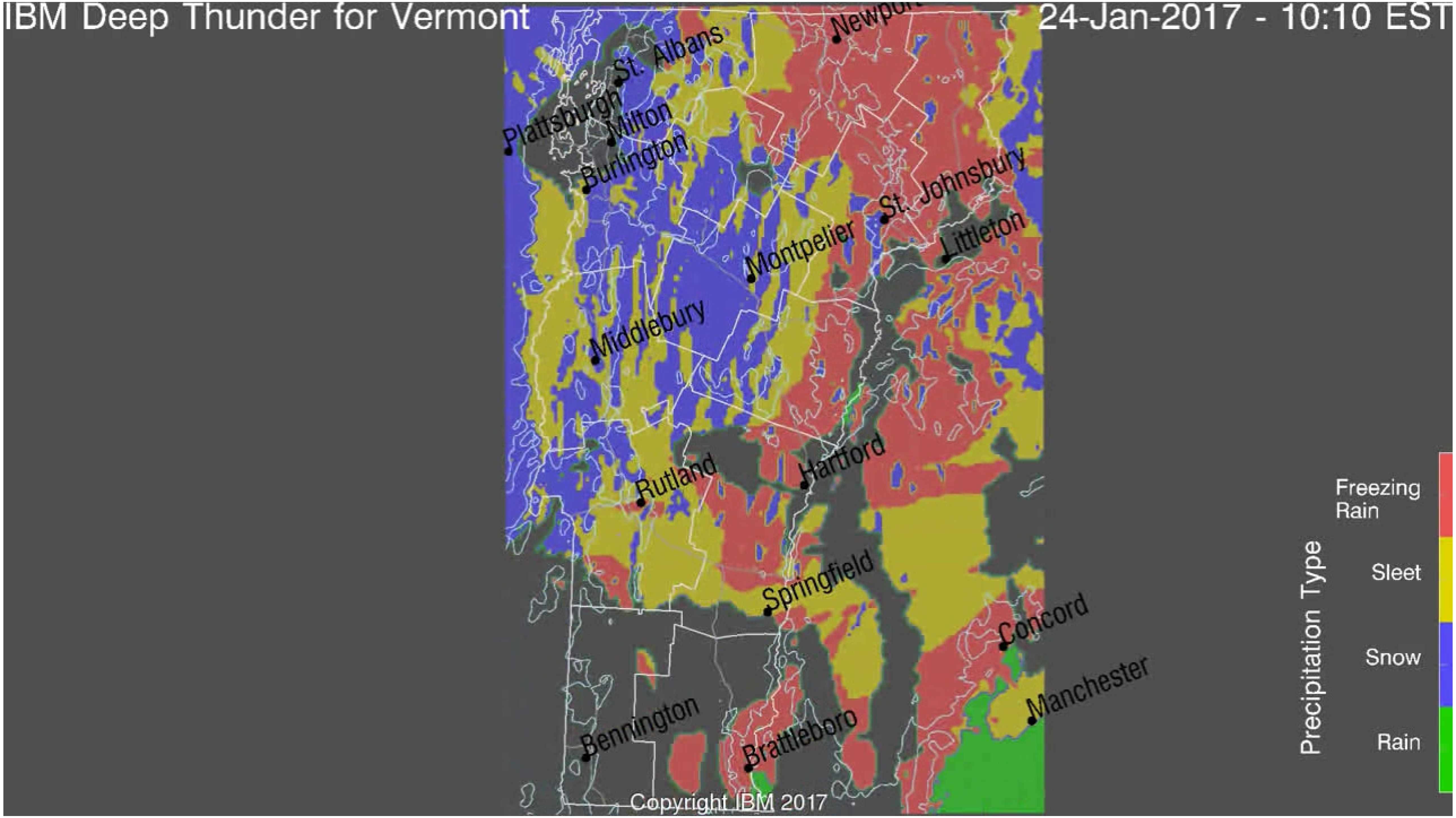
Operational Precipitation Type Forecasts



Raw Weather Model Performance (4/20/2015 – 12/31/2016): 1km Nest

Variable	Bias	MAE
2m T (°F)	-0.35	3.47
2m DP (°F)	0.27	3.34
10m Wind Speed (m/sec)	1.01	3.03
10m Wind Direction (°)	2.74	19.7

Precipitation Score	Results
Accuracy	0.96
CSI	0.43
POD	0.66
Odds Ratio	81.6

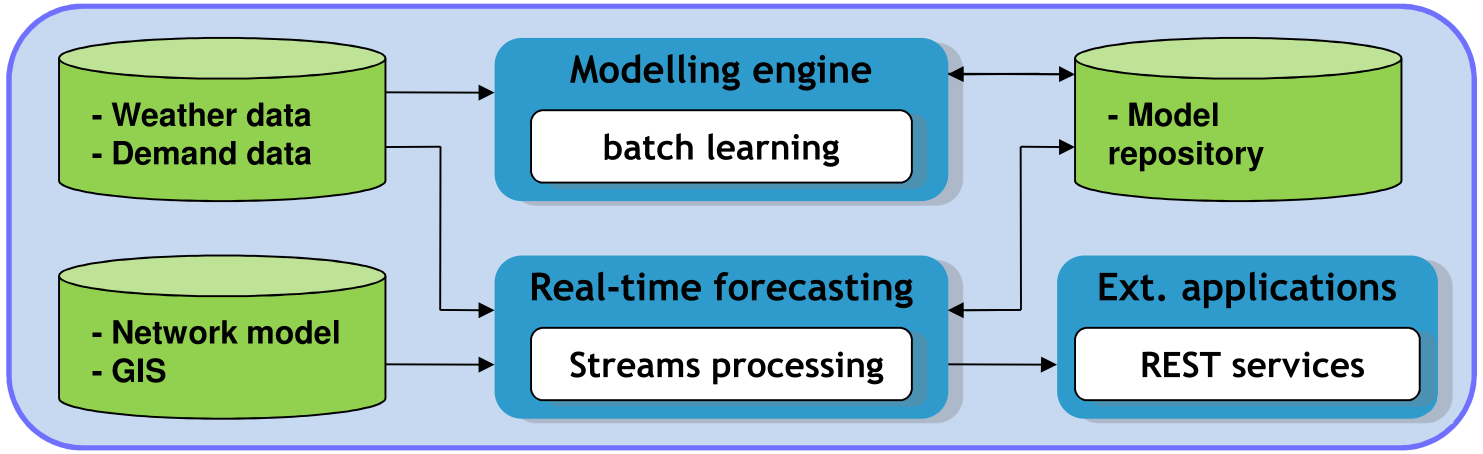
Electricity Demand Forecasting

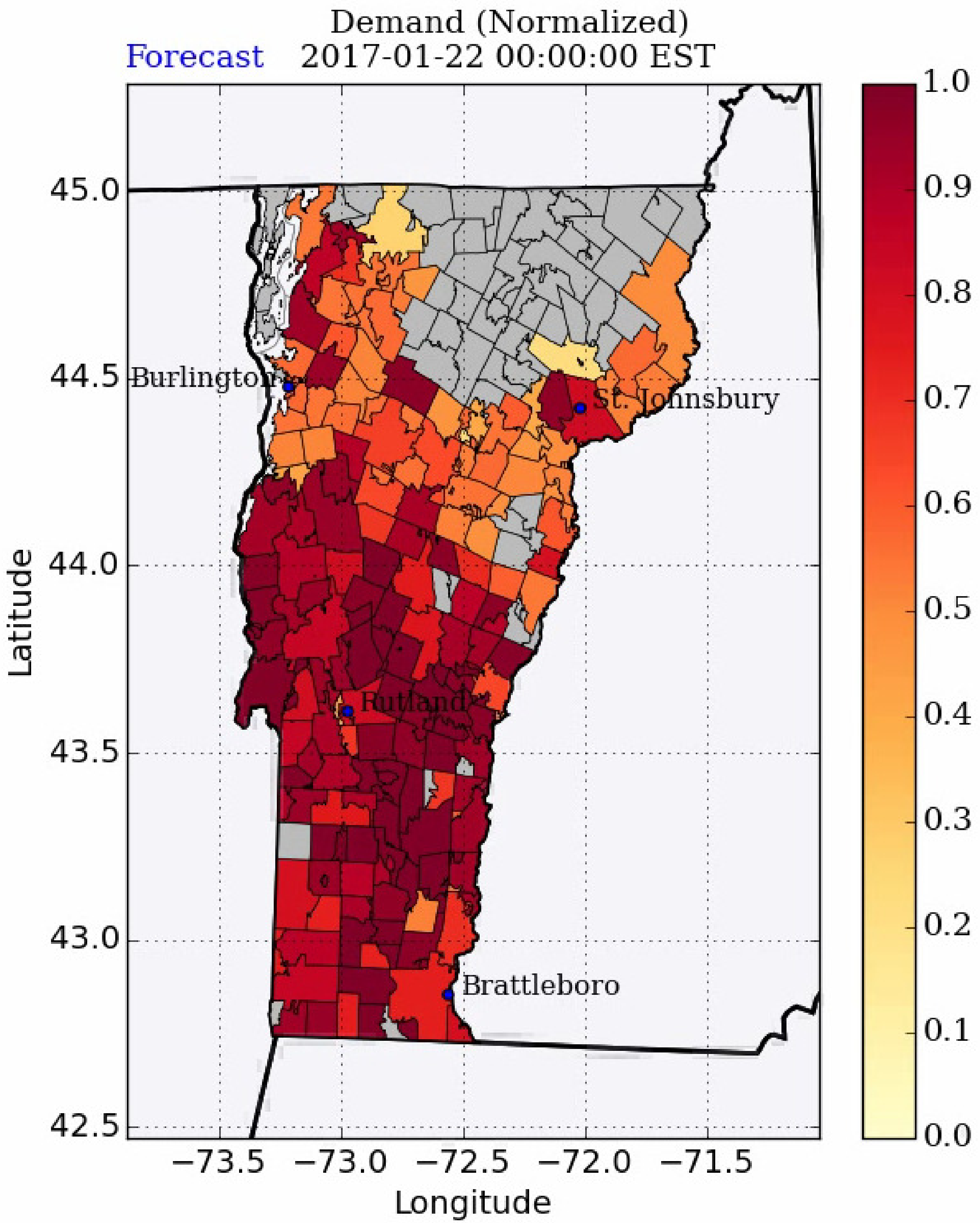
- **Statistical modeling (e.g., regression, generalized non-linear additive) demand at multiple aggregation levels:**
  - –Vermont state level
  - –Distribution units service territories (eight), towns (200) and counties (14)
  - –Subtransmission and distribution (>100) substations
  - –Distributed renewables “behind the meter”
- **Factoring in heterogeneous inputs:**
  - –Weekday, time of day, time of year
  - –Spatio-temporal weather features
  - –Impact events (heat waves, snow storms)
- **Integrating various data sources:**
  - –Telemetry (SCADA)
  - –Physical network models
  - –Smart meters
  - –Weather forecasts and observations

$$y_k = \sum_{d \in \mathcal{D}} \mathbf{1}(x_k^{\mathrm{DayType}} = d) f_d^{\mathrm{TimeOfDay}}(x_k) + f^{\mathrm{Temperature}}(x_k) + f^{\mathrm{Irradiance}}(x_k) + \ldots$$

Generalized Additive Model:

- Time of day, day type (Mon, Tue-Thu, Fri, Sat, Sun), time of year, special days (holidays, Super Bowl, ...)
- Dry bulb temperature: current value, mean/max of previous day, etc.
- Dew point, irradiance
- Real-time demand information: Mean, min and max of previous day and minimum of current day

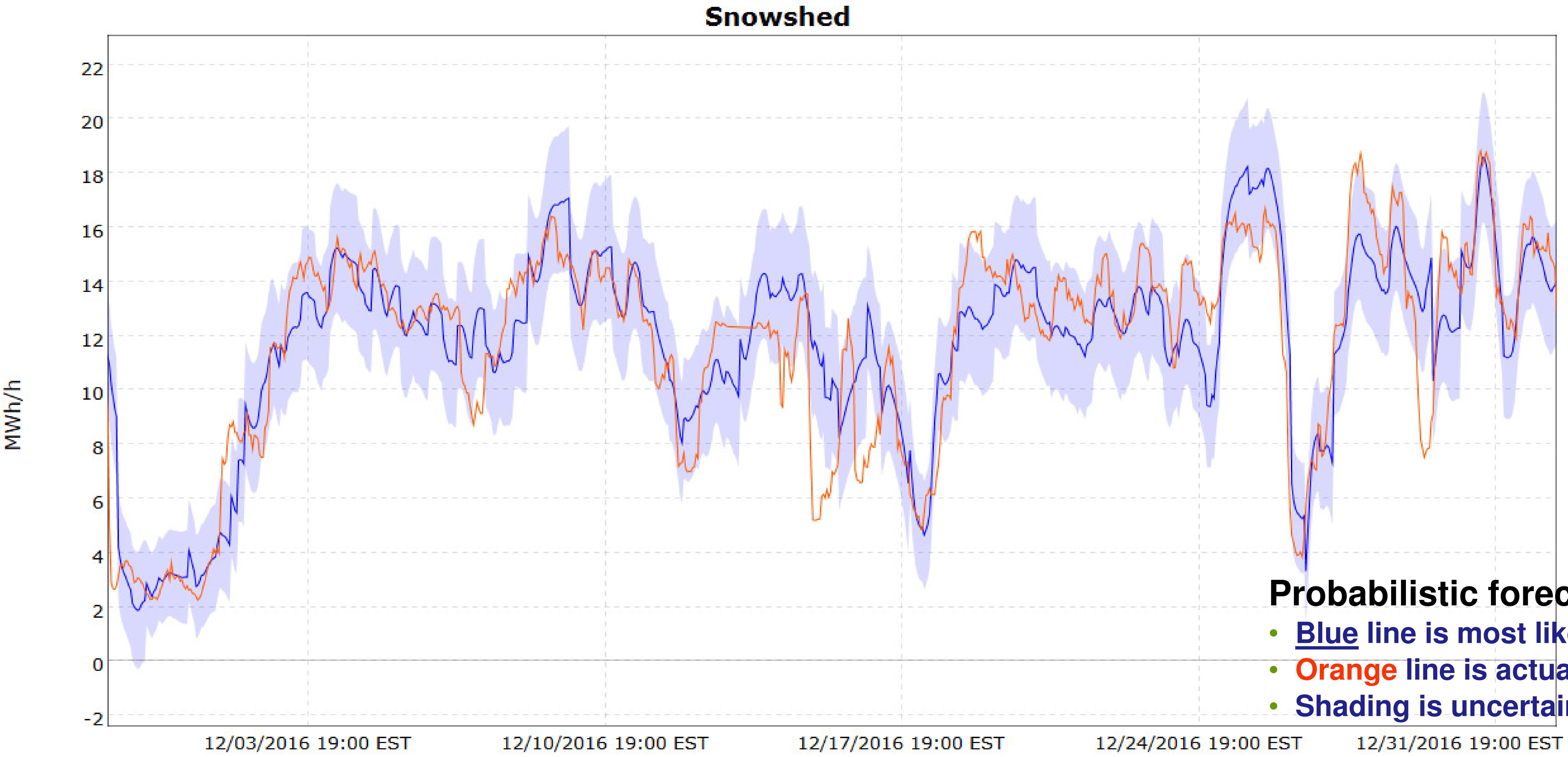




State-wide Electricity Demand Example

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

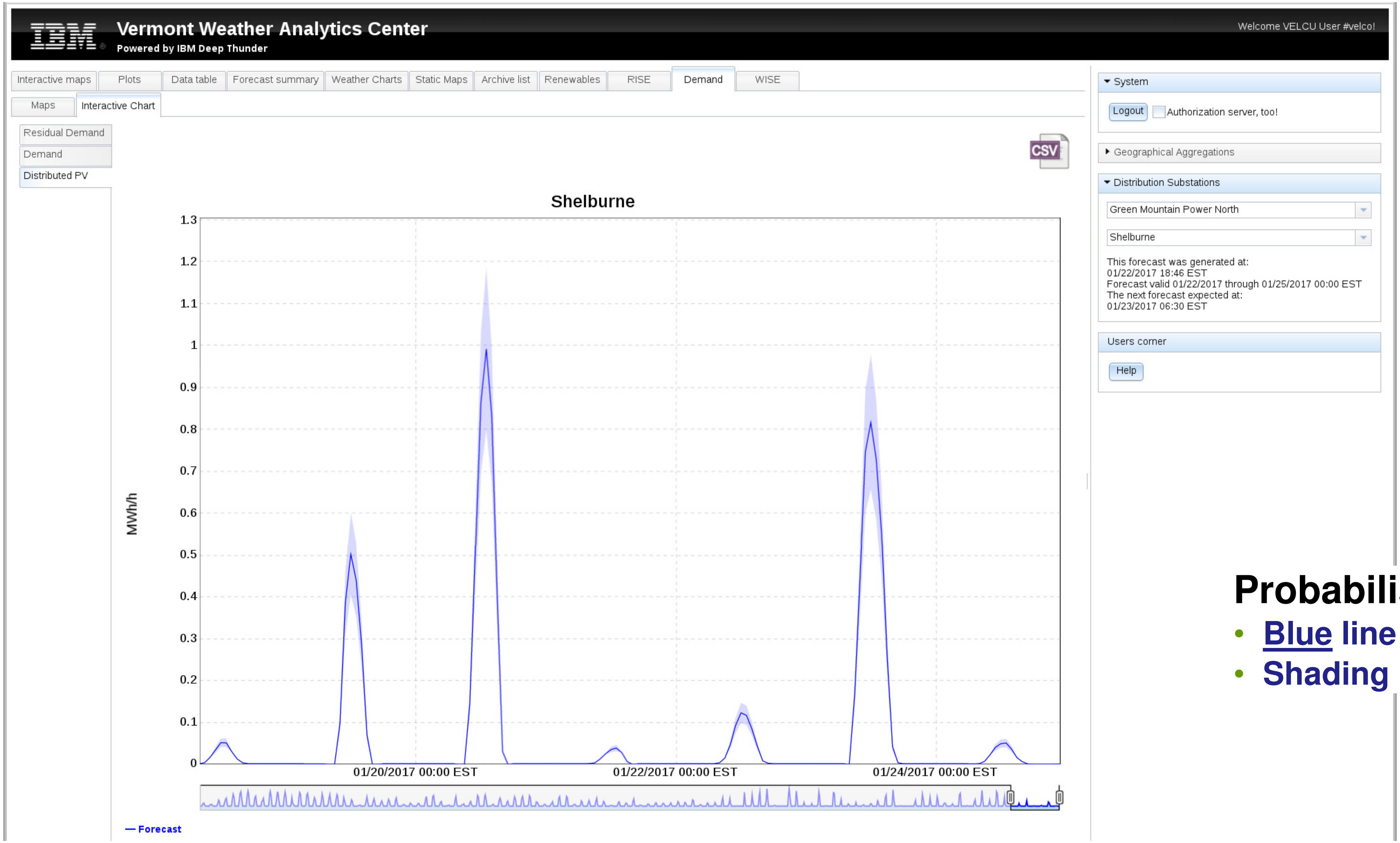
Electricity Demand for Making Snow – Distribution Substation



Probabilistic forecasts

- Blue line is most likely
- Orange line is actual
- Shading is uncertainty

Electricity Demand Web Portal



Distributed PV Solar Power Production: Substation Level

Probabilistic forecasts

- Blue line is most likely
- Shading is uncertainty

State-Wide Electricity Demand Forecasting Performance (2016)

Month	Error (%)
August	2.12
September	3.28
October	2.59
November	3.43
December	3.22

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

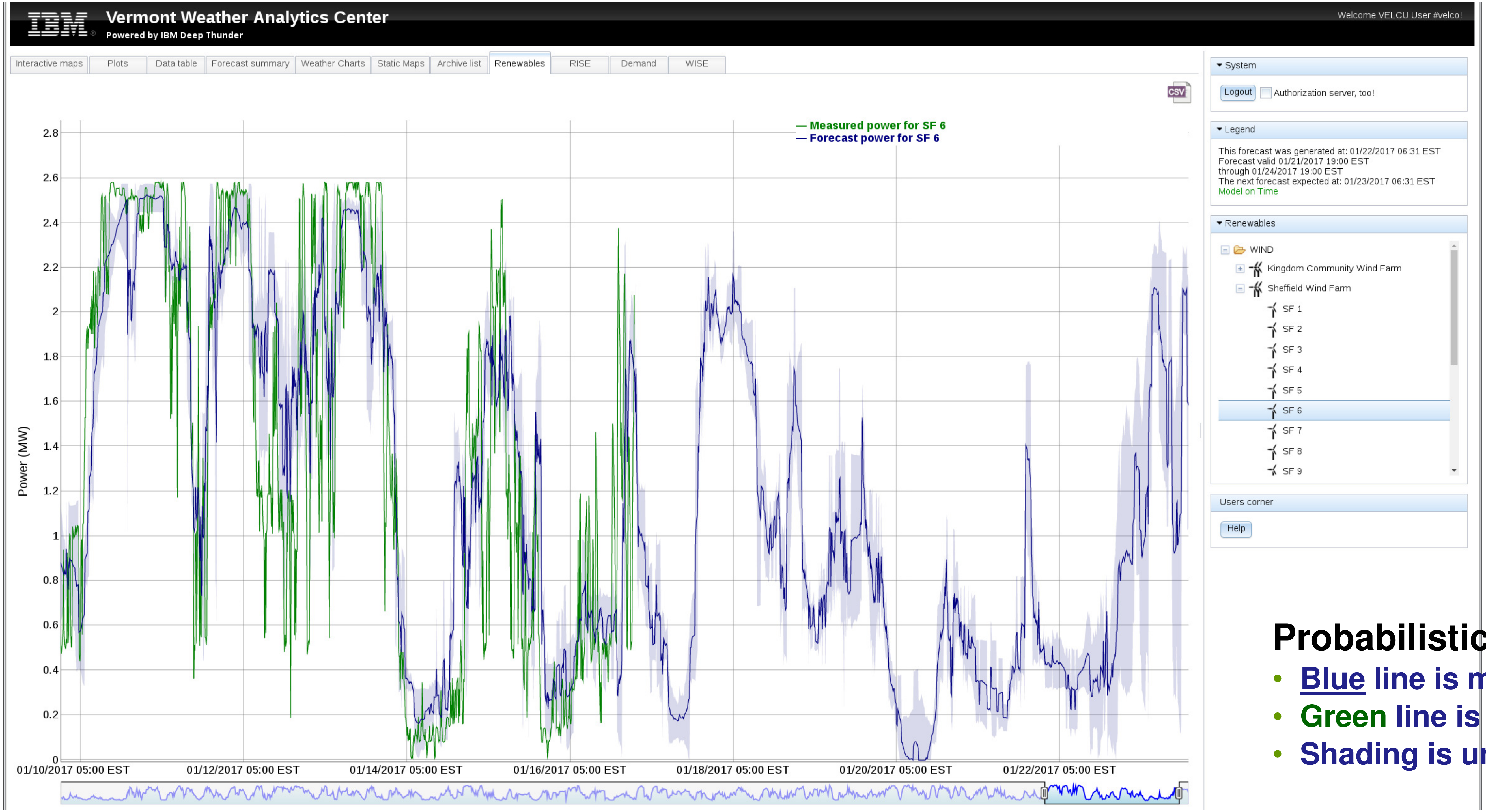
J7.3 Coupled NWP and Adaptive Machine Learning to Improve Solar and Wind Energy Forecasting for the State of Vermont (Thursday, 26 January: 4:00 PM)

- **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 three of the farms
  - 1 to 3 day-ahead focus
  - Multiple statistical ensemble (e.g., CHAID Tree, Neural Network, and Classification and Regression Tree, Support Vector Machine, Convex Optimization)

Renewable Power Web Portal



Probabilistic forecasts

- Blue line is most likely
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- Shading is uncertainty

Farm-Level Wind Power Forecasting Performance Summary (2016)

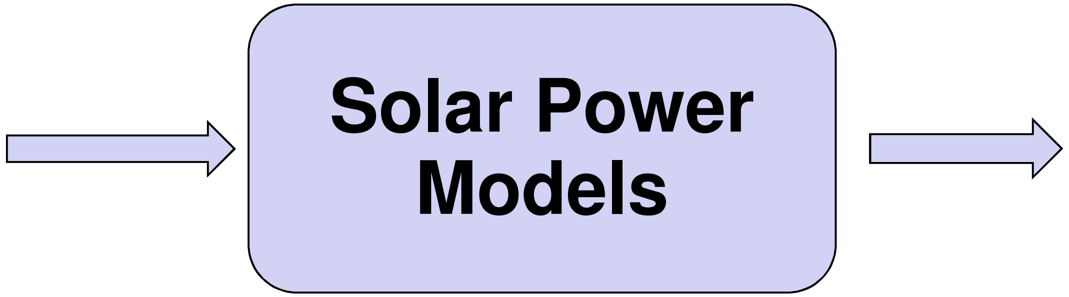
Farm Name/Forecasting Time	Mean Absolute Error (KW)	Mean Absolute Error / Name Plate Capacity (%)
KCW: Hours 0-24 (63 MW capacity)	6605	10.5
KCW: Hours 24-48	7380	11.7
KCW: Hours 48-72	7680	12.2
Sheffield: Hours 0-24 (40 MW capacity)	3892	9.7
Sheffield: Hours 24-48	4020	10.1
Sheffield: Hours 48-72	4486	11.2
GMW: Hours 0-24 (10 MW capacity)	1501	13.2
GMW: Hours 24-48	1581	13.8
GMW: Hours 48-72	1760	15.4

Solar Power Forecasting (Utility Scale)

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

J7.3 Coupled NWP and Adaptive Machine Learning to Improve Solar and Wind Energy Forecasting for the State of Vermont (Thursday, 26 January: 4:00 PM)

- **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 (21 with > 1 MW capacity)**
  - **1 to 3 day-ahead focus**
  - **Physical irradiance to power model**
  - **Multiple statistical ensemble**
  - **Cloud cover categorization**

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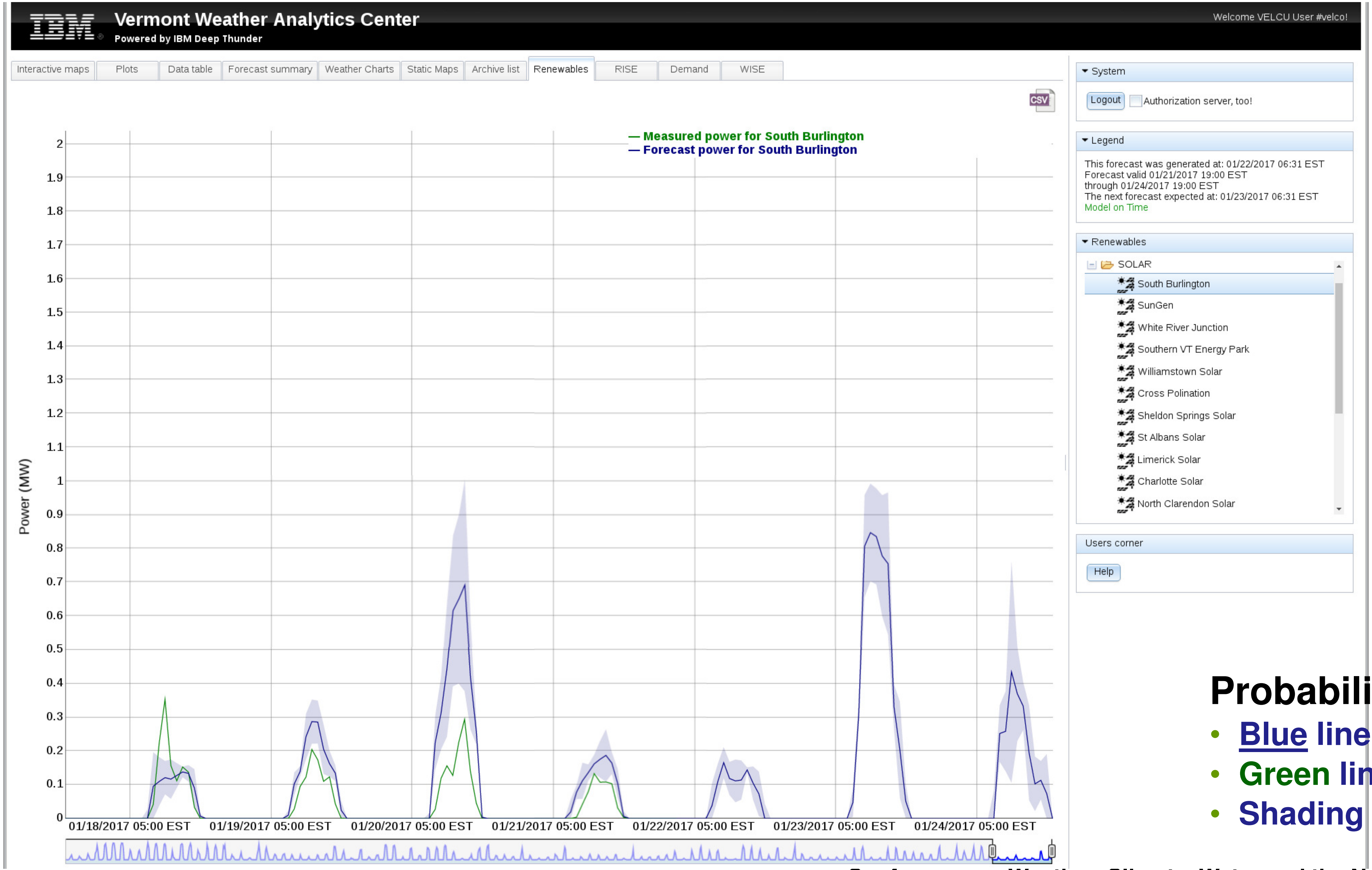
Renewable Power Web Portal



Probabilistic forecasts

- Blue line is most likely
- Green line is actual
- Shading is uncertainty

Solar Power Forecasting Performance Summary (2016)

Forecasting Cycles	Mean Absolute Error (KW)	Mean Absolute Error / Name Plate Capacity (%)
0 UTC: Hours 0 - 24	2687	7.1
0 UTC: Hours 24 - 48	2742	7.2
0 UTC: Hours 48 - 72	3065	8.1

~50MW capacity

Current Status

- Enabled an operational capability for all coupled modelling components with over 150 users
- Availability of high-quality observations to enable operational updates is an on-going challenge
- Collaborative and diverse team (users, researchers, developers, industry 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

Next Steps

- **Continuing to improve calibration of all models for new use cases, 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**
  - –**Developed capability to prospect for new utility-scale solar farms**
  - –**Adding support for additional utility-scale solar farms (over 18MW of capacity)**
  - –**Assessed peak load information and surveyed state’s Distributed Energy Resources (DER) for forecast adjustment**
- **Developing additional specialized visualizations and methods of dissemination**

Backup Slides

Related Presentations

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

- **J7.3 Coupled NWP and Adaptive Machine Learning to Improve Solar and Wind Energy Forecasting for the State of Vermont** (Thursday, 26 January: 4:00 PM)

33rd Conference on Environmental Information Processing Technologies

- **J8.5 Containerization of Weather Forecasting Platforms: Benefits and Challenges** (Wednesday, 25 January: 9:30 AM)
- **J9.6 The Vermont Weather Analytics Center — Platform and Architecture** (Wednesday, 25 January: 9:45 AM)

Eighth Conference on the Meteorological Application of Lightning Data

- **5.5 Use of High-Resolution Lightning Potential Forecasts for Vermont Utility Applications** (Wednesday, 25 January: 9:30 AM)

Eighth Conference on Environment and Health

- **870 Weather Driven Psyllid Movement Within and Between Citrus Orchards** (Tuesday, 24 January)

Town Hall Meeting: The Weather Value Chain of the Future: From IoT to Artificial Intelligence (Wednesday, 25 January: 12:15 PM-1:15 PM)

13th Symposium of the Urban Environment

- **5.5 Impact of Cool Roofs on Urban Energy Utilization in a Future Warm Climate** (Tuesday, 24 January: 11:30 AM)

31st Conference on Hydrology

- **470 A Comparison Study of the Noah and Noah-MP Land Surface Models** (Tuesday, 24 January)
- **6A.2 The Sensitivity of a Coupled Atmosphere-Hydrology Model at Lake George, NY to Changes in Land Surface Model Configuration and Stream Celerity** (Tuesday, 24 January: 1:45 PM)

28th Conference on Weather Analysis and Forecasting / 24th Conference on Numerical Weather Prediction

- **106 Assessment of Post-Processing Methods for Daily High and Low Temperature Prediction** (Monday, 23 January)
- **575 Is There Value in Very High Resolution Weather Forecasts? Experiences from The Jefferson Project at Lake George** (Tuesday, 24 January)

29th Conference on Climate Variability and Change

- **1150 Numerical Simulation of Indian Summer Monsoon Using MPAS-A: A Sensitivity Study** (Wednesday, 25 January)

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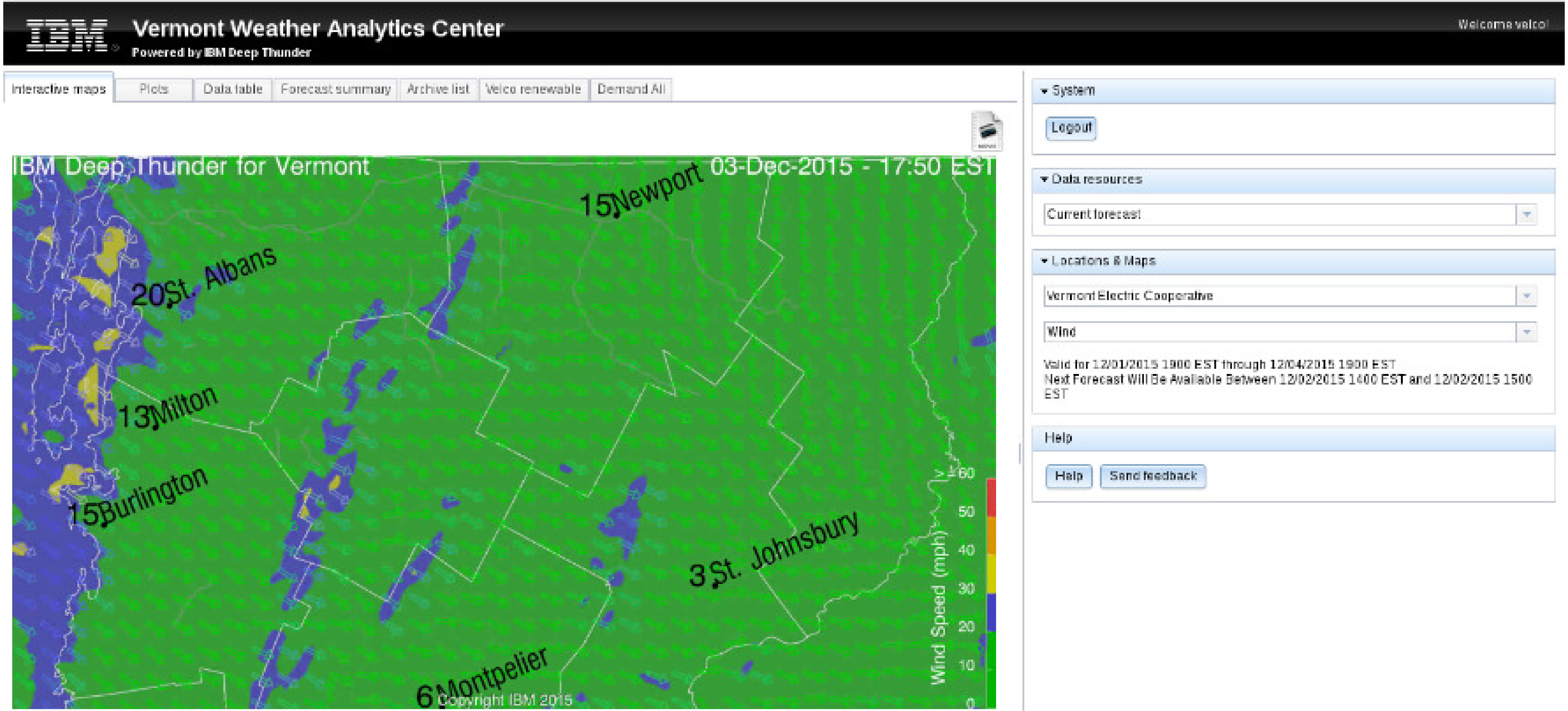
Deep Thunder Web Portal

72-Hour Wind Speed and Direction Forecasts for Vermont



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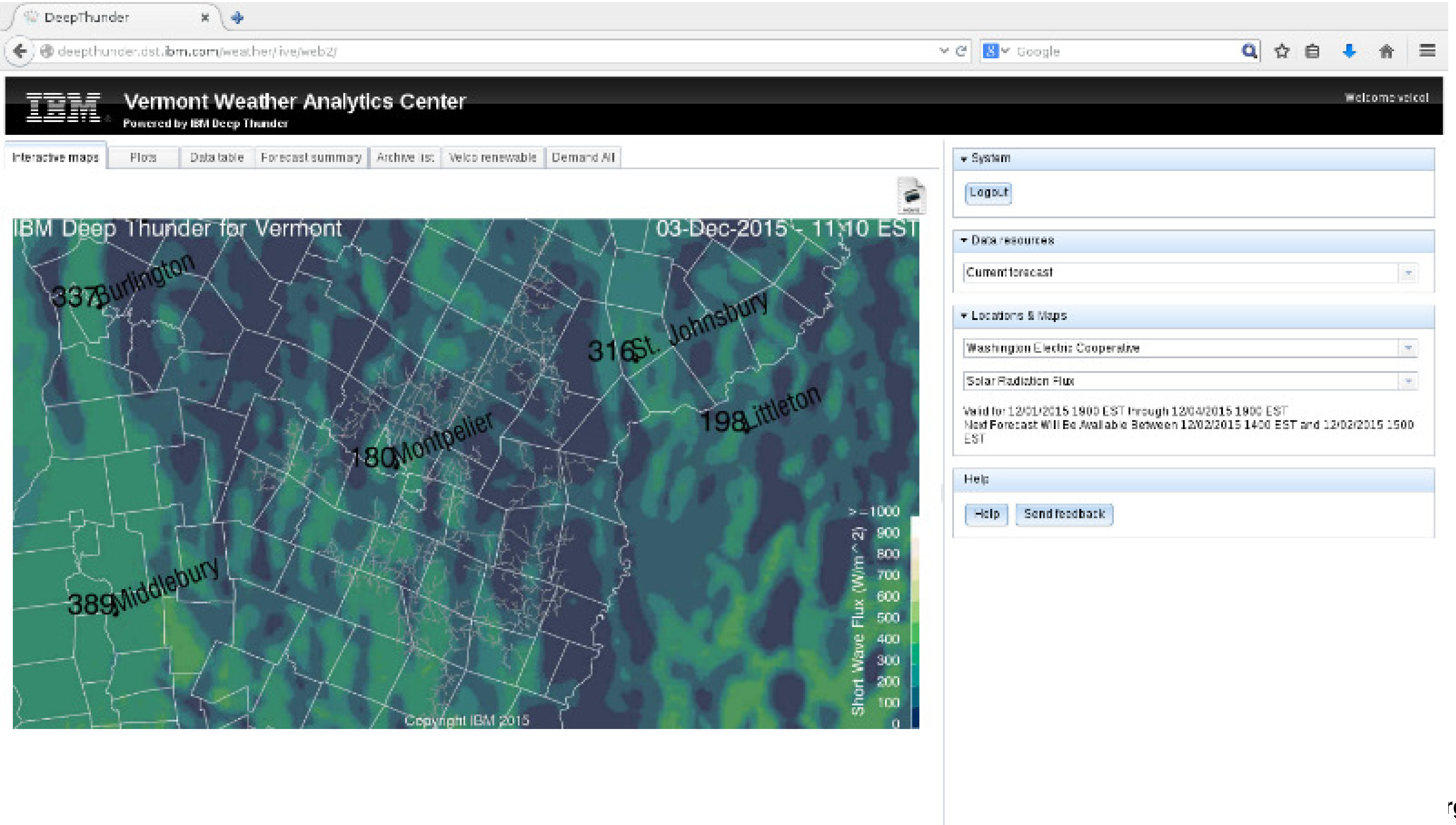
72-Hour Solar Irradiance Forecasts for Vermont



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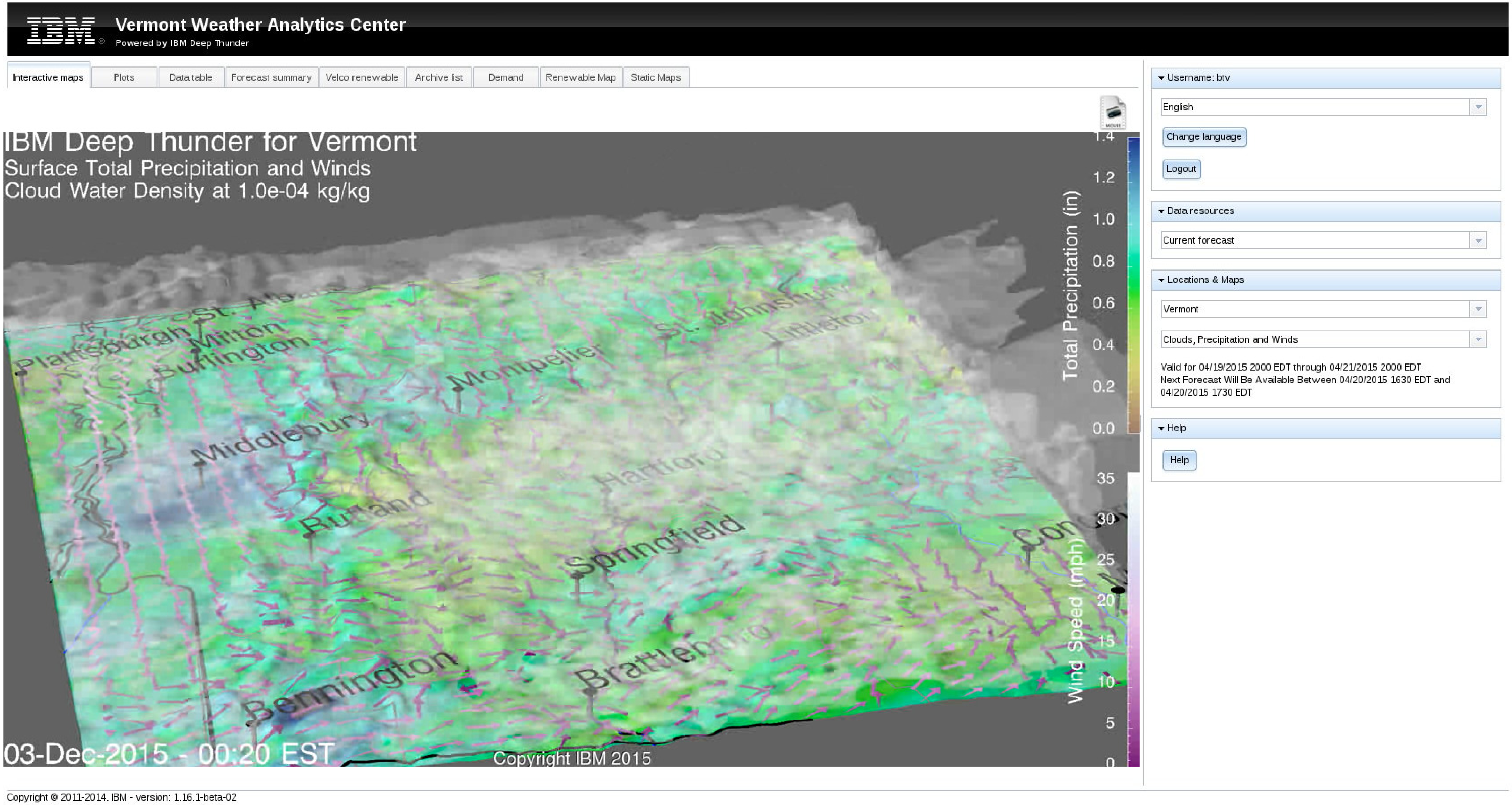
72-Hour Forecasts for Vermont



ɔmy: 5.3

72-Hour Site-Specific Summary Forecast for Vermont

Deep Thunder Web Portal

Vermont Weather Analytics Center
Powered by IBM Deep Thunder

Welcome VELCU User #velco!

Interactive maps | Plots | Data table | Forecast summary | Weather Charts | Static Maps | Archive list | Renewables | RISE | Demand | WISE

Getting alert status for this location...
(Un)Subscribe to email alerts

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 01/22/2017 0700 EST through 01/25/2017 0700 EST
01/22/2017, 12Z Forecast

Summary table:

Sunday - Monday 1/22/2017 - 1/23/2017	full day	07:00 - 15:00	15:00 - 23:00	23:00 - 07:00
Precipitation accum (alert when > 1 in)	0.03	0.02	0.01	0
Peak Precipitation Rate (in/hr)	0.02 at 11:40	0.02	0.01	0.01
Accumulated Snowfall Averege liq.ratio, (alert when > 4/10)	-	-	-	-
Start Time	7:10	7:10	15:40	-
End Time	15:40	13:10	15:40	-
Max Sustained Wind (alert when > 30 mph)	15.6 ESE at 5:20	8.4 NW at 11:20	7 SSW at 22:10	15.6 ESE at 5:20
Max Wind Gust (alert when > 40 mph)	22 at 5:20	11.7 at 11:20	9.1 at 22:10	22 at 5:20
Low Temp (alert when < 0 F)	29°	34°	32°	29°
Wind Chill (alert when <-20 F)	18°	29°	26°	18°
High Temp (alert when > 90 F)	39°	39°	35°	33°
Heat Index (alert when > 100 F)	39°	39°	35°	33°

Monday - Tuesday 1/23/2017 - 1/24/2017	full day	07:00 - 15:00	15:00 - 23:00	23:00 - 07:00
Precipitation accum (alert when > 1 in)	0.49	0	0	0.49
Peak Precipitation Rate (in/hr)	0.15 at 6:10	0.01	0.01	0.15
Accumulated Snowfall Averege liq.ratio, (alert when > 4/10)	3.5 5.99	-	-	3.5 5.99
Start Time	0:30	-	-	0:30
End Time	7:00	-	-	7:00
Max Sustained Wind (alert when > 30 mph)	21.6 SE at 15:10	21.1 SE at 14:40	21.6 SE at 15:10	11 N at 3:10
Max Wind Gust (alert when > 40 mph)	31.9 at 15:10	31 at 14:40	31.9 at 15:10	18.1 at 23:00
Low Temp (alert when < 0 F)	28°	28°	28°	28°
Wind Chill (alert when <-20 F)	16°	16°	17°	19°
High Temp (alert when > 90 F)	31°	31°	30°	31°
Heat Index (alert when > 100 F)	31°	31°	30°	31°

Tuesday - Wednesday 1/24/2017 - 1/25/2017	full day	07:00 - 15:00	15:00 - 23:00	23:00 - 07:00
Precipitation accum (alert when > 1 in)	0.28	0.22	0.06	0
Peak Precipitation Rate (in/hr)	0.14 at 7:40	0.14	0.02	0.01
Accumulated Snowfall Averege liq.ratio, (alert when > 4/10)	1.3 6.98	1.3 6.98	-	-
Start Time	7:00	7:00	15:30	-
End Time	22:20	11:10	22:20	-
Max Sustained Wind (alert when > 30 mph)	21.6 ESE at 11:20	21.6 ESE at 11:20	11.2 NNW at 16:40	5.2 SSE at 5:30
Max Wind Gust (alert when > 40 mph)	31.4 at 11:20	31.4 at 11:20	16.3 at 16:40	7 at 5:30
Low Temp (alert when < 0 F)	29°	29°	32°	30°
Wind Chill (alert when <-20 F)	20°	20°	23°	25°
High Temp (alert when > 90 F)	35°	35°	35°	32°
Heat Index (alert when > 100 F)	35°	35°	35°	32°

System

Logout | Authorization server, too!

Data resources

Current forecast

Locations & Maps

Vermont

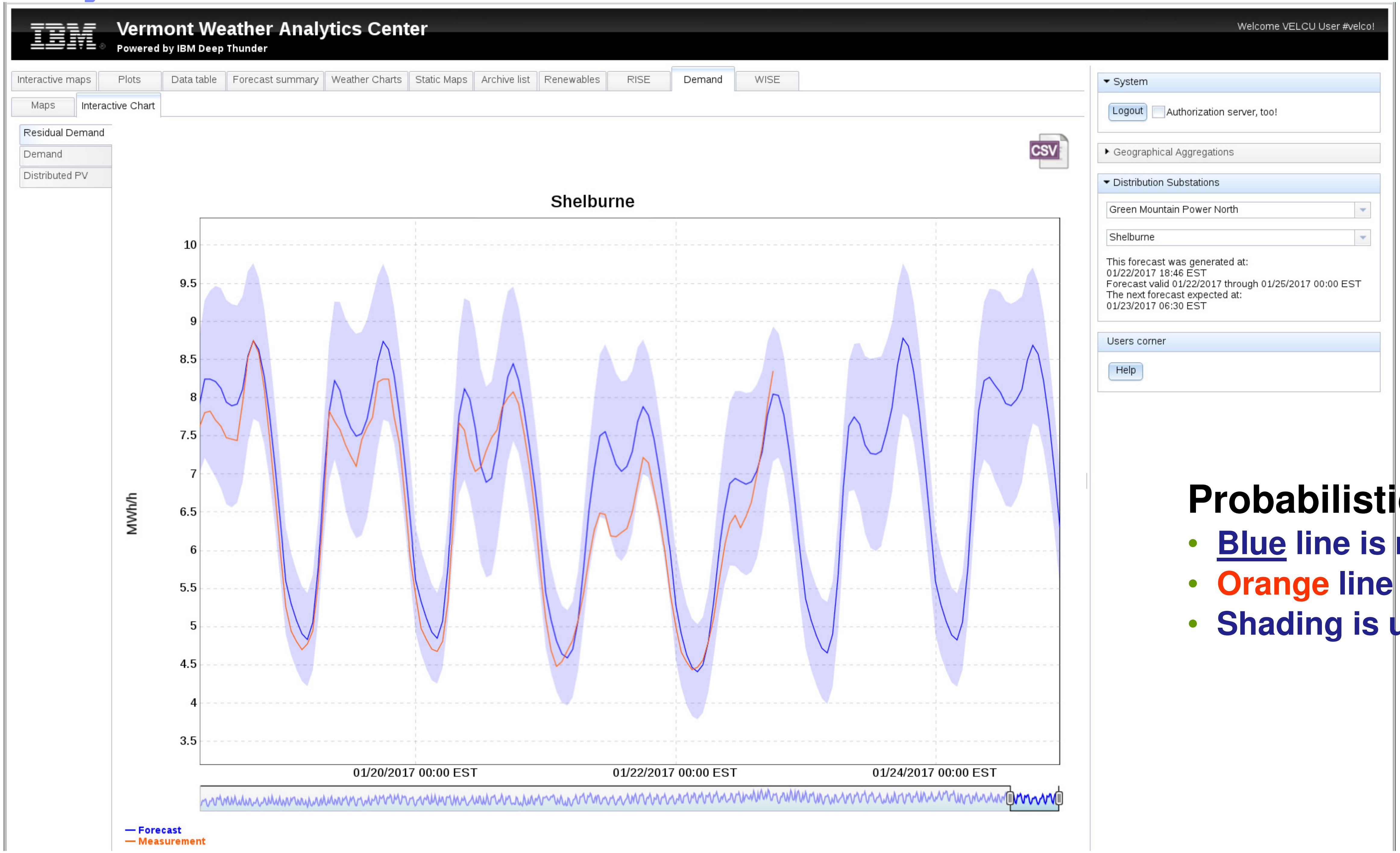
VELCO HQ (Rutland)

Valid for 01/22/2017 0700 EST through 01/25/2017 0700 EST
Next Forecast Will Be Available Between 01/23/2017 0400 EST and 01/23/2017 0500 EST
Model on Time

Users corner

Help

Electricity Demand Web Portal



Probabilistic forecasts

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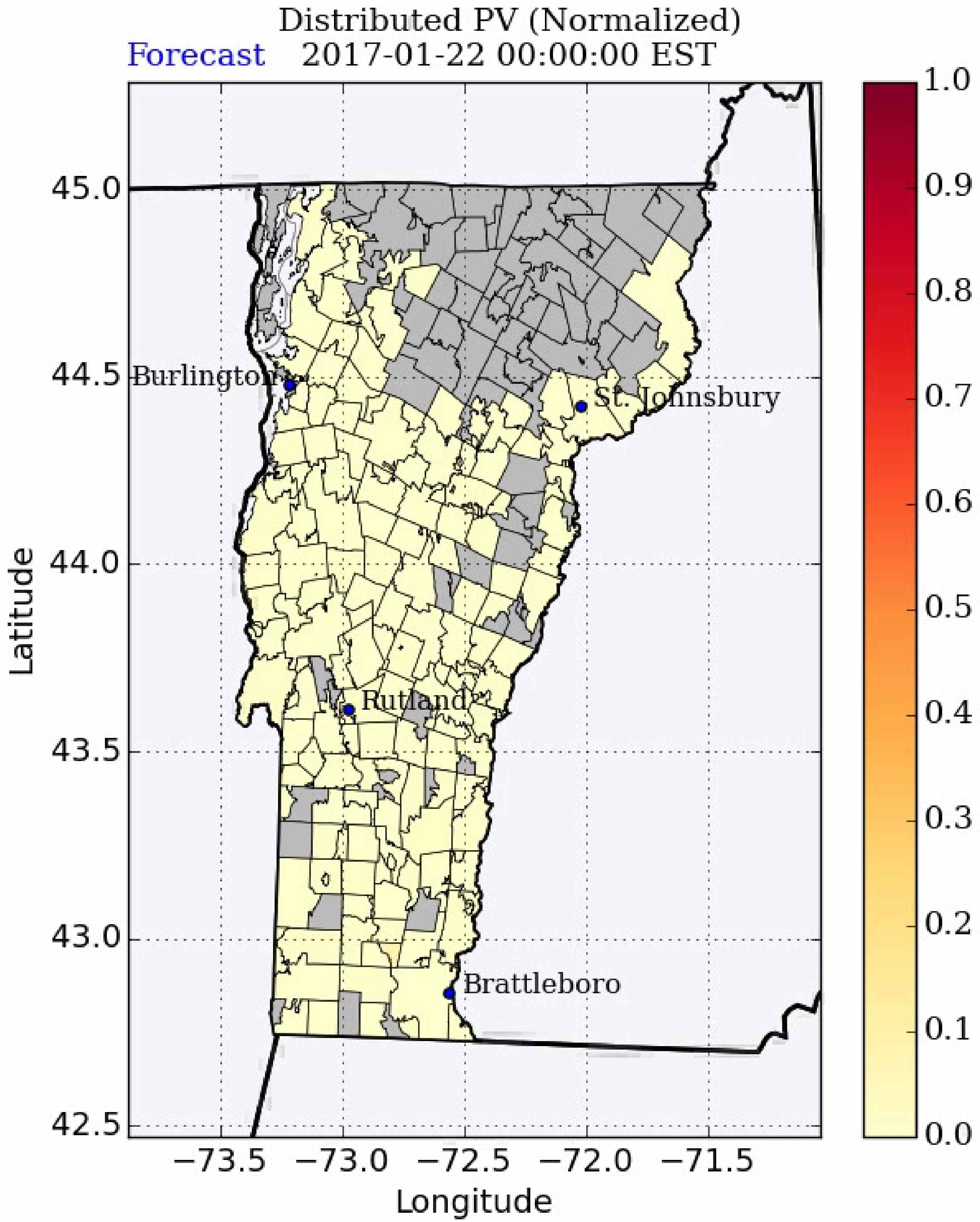

State-wide Distributed Solar Power Example

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