RAVIS: Resource Forecast and Ramp Visualization for Situational Awareness of Variable Renewable Generation

Preprint

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National Renewable Energy Laboratory

To be presented at the Twelfth ACM International Conference on Future Energy Systems (ACM e-Energy)
June 28–July 2, 2021

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Contract No. DE-AC36-08GO28308

Conference Paper
NREL/CP-5D00-79786
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Suggested Citation
Edwards, Paul, Haiku Sky, and Venkat Krishnan. 2021. *RAVIS: Resource Forecast and Ramp Visualization for Situational Awareness of Variable Renewable Generation: Preprint*. Golden, CO: National Renewable Energy Laboratory. NREL/CP-5D00-79786. https://www.nrel.gov/docs/fy21osti/79786.pdf.

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303-275-3000 • www.nrel.gov

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number EE0008215. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

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RAVIS: Resource Forecast and Ramp Visualization for Situational Awareness of Variable Renewable Generation

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ABSTRACT
The Resource Forecast and Ramp Visualization for Situational Awareness (RAVIS) is an innovative, open-source tool for visualizing variable renewable resource forecasts and alerts for significant up- and down-ramps in renewable generation and the consequent system net load. The modular dashboard of RAVIS contains configurable panes for viewing probabilistic time-series forecasts, ramp event alerts on the look-ahead timeline, and spatially resolved resource sites, and forecasts. For comprehensive situational awareness, the tool can add additional data layers from simulation and independent system operator (ISO) market clearing data—including electric line utilization, nodal price, and available generation flexibility—in response to continuously updated renewable forecasts. This paper introduces the RAVIS technology suite employed to provide optimum visualization and flexible design characteristics. The paper also illustrates some use cases of the tool using site-specific solar power forecast data obtained from the IBM Watt-Sun forecasting platform for the California ISO and Midcontinent ISO footprints. The source code for RAVIS is public (https://github.com/ravis-nrel/ravis), and the intended users are forecasters, utility planners, ISO operators, and researchers.

Keywords
Solar power; Probabilistic forecasts; Ramp alerts; Open-source visualization; Situational awareness; Flexibility.

1. INTRODUCTION
Electric power grid control centers typically host several screens for the visualization of network situational awareness, such as one-line diagrams, circuit breaker/switch status, and graphs summarizing available reserves. Information about impending high-impact contingencies, their impact on transmission line overloads, and in some cases system voltage and transient stability are indicated [1]. The idea of situational awareness in the form of real-time visualization is not new; however, the need for their evolution is important because there are higher penetration levels of variable renewable generation and associated uncertainties. During the last decade, visualization capabilities have been built in response to the drastic increase in variable renewable generation penetration across the world [2]. The most simplistic of the energy control center visualizations of variable renewable generation forecasts includes a time series of regionally aggregated mean forecast (typically at hourly intervals), bounded by worst-case forecast scenarios, such as a power loss from icing or a solar eclipse. Some system operators, such as the Organization of the Nordic Transmission System Operators and the Alberta Electric System Operator, use the variable renewable forecasts to estimate the needed regional reserves and to display the available reserves and net energy interchange across various regions; to prepare the operators to face any unforeseen forecast errors; and to minimize the consequent impact on network congestion and generation scarcity. Apart from such system-wide, aggregated information displays, some system operators, such as the Electric Reliability Council of Texas prefer to look at heat maps of wind speed or solar irradiance forecasts and ascertain the expected ramp events. The California Independent System Operator (CAISO) with Pacific Northwest National Laboratory developed a visualization platform to integrate probabilistic forecasts of net load (i.e., electricity load minus variable renewables) to visually understand if there is enough real-time generation ramping capability in CAISO [3]. Typically, without such visual tool, operators using spreadsheet calculations to estimate the ramp alerts resulting from forecast errors, and therefore an automatic alerting and visualization platform is highly desirable.

Given these needs, we addressed considerable gaps through the developed Resource Forecast and Ramp Visualization for Situational Awareness (RAVIS) tool in following ways:

1. Many existing control center and renewable forecast visualization capabilities are proprietary and not known unless one visits a particular utility's control center. RAVIS is open source and designed to take advantage of web application technologies and open-source visualization libraries and tooling. Using this technology will enable deployment in any environment, using any operating system, and it is scalable to much higher spatial and temporal scales of visualization.
2. As the electric grid experiences increasing penetration levels of distributed variable generation and associated uncertainties, the awareness conventionally reported at the aggregated level using mean forecasts is not sufficient, but the site-specific variable renewable forecasts at higher spatial resolutions—including the uncertainties using probabilistic bounds—will be paramount.
3. Timely alerts of the excessive ramping events—not only for the aggregated net load but also for each component of the net load (namely, solar and wind resources)—will be useful information. In addition to alerting operators to unforeseen power ramps, RAVIS will allow future grids to take advantage of resources with excess generation forecasts for additional system flexibility and reserves.

Finally, the goal for developing RAVIS was not to create an operational turnkey solution but rather a solution that is customizable and open source for end users and researchers to customize to their needs, to experiment, and to innovate, including seamlessly integrating forecasts and metadata from any internal or external source, thereby allowing for immersive engagements and discussions between stakeholders and grid operators.

2. ARCHITECTURE AND TECHNICAL SPECIFICATIONS
The RAVIS visualization software system uses a technology suite that is assembled to provide optimum visualization facilities while maintaining a wide pool of potential deployment and client environments. Toward this end, the system is designed to take

advantage of web application technologies and tooling. Using this technology stack will enable deployment in any environment, using any operating system. The only requirement is to view in a modern browser, including Chrome, Firefox, Safari, Microsoft Edge, or Internet Explorer (10 or above).

2.1 User Interface

The user interface is implemented as a single-page web application in which all user interaction takes place within a customizable dashboard. This is achieved via a modular plug-and-play architecture, as shown in Figure 1, in which each functional aspect is contained in a set of files constituting a single component. Each component maintains an insular set of functionalities and actions. By isolating each functional block within its own component, this design supports more efficient development, extension, and ultimately support. This will greatly benefit an end user as new features and data sets are integrated, new components are required, and new requirements emerge for existing components. Additionally, as will be described in Section 3.5, on-the-fly, real-time customization of the display has also been facilitated.

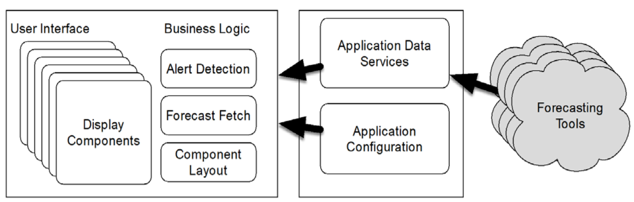

Figure 1 RAVIS tool modular architecture

2.2 Performance

To ensure a high level of performance, we made a detailed effort during the technical design to ensure that component rendering and communication occur as smoothly as possible. The mapping components use client-side vector and scalable vector graphics (SVG) rendering to facilitate smooth map effects, versatile styling, and very low latency in map response to either user interactions or updates to the data. The charting system likewise uses a technology stack optimized for client-side SVG rendering for beautiful visuals and fast dynamic updating. To support excellent visualization and state-of-the art graphic design, this architecture uses a mix of HTML, SASS, CSS, DOM manipulation via JavaScript, dynamically rendered SVG elements, images, and an advanced map and charting tools.

2.3 Server and Client Sides

The system incorporates a very basic server-side project with a collection of a few necessary end points. These end points provide access to any forecast data providers that support CORS as well as application configuration variables. This service is deliberately being designed to be as simple as possible. Currently, the end point serves as a simple proxy for fetching forecasts from the source.

The client side of RAVIS is constantly updating with the latest forecast data, whenever available from the server. The refresh rates are set to 5–60 seconds and are customizable. Fault tolerance will continue to refresh on schedule even when data calls fail.

2.4 *Open-Source Libraries*

One area of attention is to ensure that this tool is broadly available for use and/or extension without burdensome requirements imposed by third-party libraries. Toward this end, we ensured this system primarily comprises components and systems developed in-house. Where necessary, the system uses freely available and open-source libraries. A summary of these libraries includes:

- **MapboxGL**: Provides basic map functionality, zoom, pan, and display of our geospatial data assets [4]
- **D3**: Charting [5]
- **React**: User-interface component management, templating engine, render optimizations [6]
- **Redux**: User-interface data management, stateful concerns [7]
- **Babel**: Build tools and code minimization [8]
- **Webpack**: Development environment, build tools [9]

2.5 Innovation in Web Application Design

We built a unique application design to convey a complex array of data in an easily viewable format while using a modern layout. Although it is based on standard geospatial elements, the visualization tool differs from the traditional design of geospatial web applications in various ways, primarily because of the flexibility in displaying and comparing data. The overall design is based on a dashboard of separate panes, instead of a single map window containing data layers, which will allow the user to view multiple data formats at a glance, quickly. Additionally, instead of the conventional forecast data that are available in control centers via visualization, this application targets providing ramp alerts as well as site-specific ramp forecasts for proactive operator controls.

3. USER INTERFACE

This section shows screenshots of the visual interface of the RAVIS tool. For illustration, we use the forecasts data developed by the National Renewable Energy Laboratory (NREL) for the 2017 solar eclipse analysis with pronounced ramps [10, 11] in the Western Electricity Coordination Council region. Figure 2 shows the RAVIS modular dashboard containing four customizable panes: 1) site-specific and regional event alerts at various look-ahead times; 2) regional overview of aggregated solar resources; 3) site-specific zoom-in view of distributed solar power resources, along with geographic information system information; and 4) regional and site-specific forecast time-series viewer (with customizable look-ahead timelines). Each node is explained below.

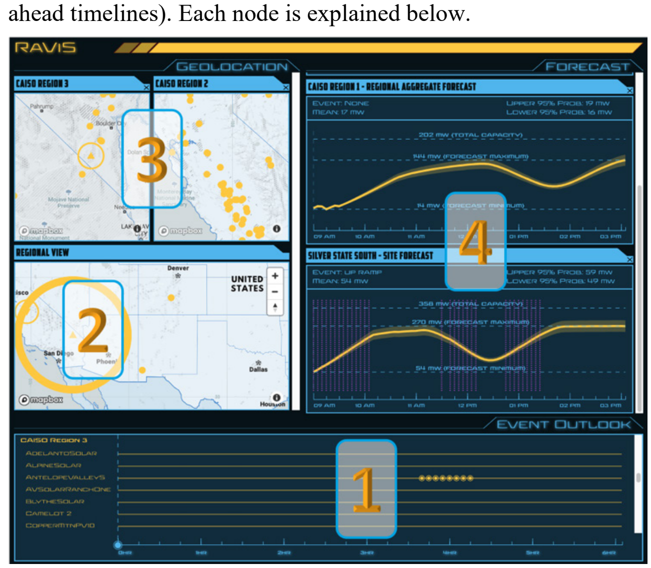

Figure 2 RAVIS user interface and typical workflow

3.1 Regional View

The Regional View (Figure 2, pane 2) displays all the available regions on a single map. Each region might contain many individual renewable power plants or sites. If a ramp alert or event is present for a given region based on the aggregated regional forecast at the selected time, it will be shown on this map. The direction of the arrow indicates the ramp direction, and the size of the circle denotes the size of the ramp anticipated. If the cursor is moved over the site, data related to the site—such as name, capacity, magnitude of the ramp, and normal or alert state—is displayed. This regional view allows for the selection of specific subregions or sites for more detailed analysis—i.e., when a user clicks on a region, the aggregated forecast time series will be displayed in pane 4, shown on the right-hand side. Grouping renewable resources into a user-defined zone is customizable, as will be explained in Section 3.5.

3.2 Regional Detailed View

The Regional Detailed View (Figure 2, pane 3) shows the details of a single region, and the user can zoom into every single plant or renewable power plant available in the region. Similar to the Regional View, any ramp alert or event present for a given site at the selected time will be shown on this map. An extension of this pane integrates nodal electricity pricing and electricity transmission network into the visualization of this pane (as will be explained in Section 4.3). The awareness of ramp forecasts along with transmission congestion and nodal prices will help operators mitigate any net load ramping event by controlling plant outputs in case of a reliability threat. Additionally, this view allows for the selection of a detailed forecast view of each contained site and shows site-specific metadata via the cursor hover. Any selected site's time-series forecasts can be viewed in pane 4.

3.3 Time-Series Forecasts

The Forecast shows a detailed view of the forecasts for a selected site or the aggregate of an entire region as a time-series data set (Figure 2, pane 4). Depending on the data feed, this pane can show probabilistic forecast values (quantiles), forecast events and/or alerts, as well as some derived summary data in the form of the legend on the top section of the plot. Through the cursor hover along the timeline, data displayed in the legend section is updated in real time. Note that although this prototype shows solar forecasts, the same framework can be used to visualize wind and net load forecasts and the associated ramps.

3.4 Event Outlook

The Event Outlook (Figure 2, pane 1) shows a quick view of all regions, solar power plants in each region, and any forecast events (ramp alerts) associated with the impacted site(s). At present, the events are defined based on the size of the solar ramps (e.g., >10% of its capacity or 15 MW in 15 minutes, and it is a customizable parameter, as will be shown later). the blue marker along the timescale of this event pane can be moved to look at the alerts specific to various time instances, and the values in the Regional View as well as time-series data will be updated accordingly too. Additionally, the vertical scroll can be used to look at various sites and whether ramps have been detected. The most active sites (defined based on impending ramp events, the largest ramping event, or any user-defined criteria) will be displayed at the top for easy viewing. An extended version, as will be explained in Section 4.3, will also show alerts by comparing the forecasted ramping event against the available generation ramping capability or the flexibility to qualify the ramp event as a threat or benign, so operators are not bombarded with too many alerts and are alerted on a need-to-know basis and are prepared to take action only for severe events when there is an anticipated lack of flexibility.

3.5 Flexible Design for Customization

Based on our interactions with project independent system operator (ISO) partners and U.S. Department of Energy Solar Energy Technologies Office reviewers, the tool has been endowed with design flexibility and customization features useful for potential end users. Some of these on-fly-configuration and viewer updating features are shown in the Figure 4 in the Appendix, and they can be accessed in the tool through the "gear" symbol shown in the top right corner. Currently implemented features include:

1. **Ramp definition:** Ramp definitions can be done at the global, regional, and site levels (see Appendix Figure 4, left). This allows for defining a power change (in MW) as a ramp at three different spatial levels based on engineering and expert understanding. The definition at the site level overrides the regional, and the regional overrides the global.
2. **Forecast zones or plant aggregation:** Newer custom regions with selected plants can be created (see Appendix Figure 4, right), if users are interested in closely monitoring them.
3. **Time-series pane customization:** In the forecast pane, a user can customize the scales of the y-axis. The forecast pane includes a "+/-" symbol in the right corner that allows viewers to adjust the y-axis to the size of the ramp event. By default, the y-axis shows the renewable plant size or total regional capacity.
4. **Comprehensive data assimilation:** Each end user might have their own needs, and therefore the data ingestion in this tool is highly flexible for integrating visualization widgets of interest. For example, the tool can ingest additional data layers from various forecast vendors, electricity generation scheduling and market clearing data, and network topology and transmission data for comprehensive situational awareness and for understanding the interrelationships among forecasts, ramp uncertainties, and various system operating metrics.

4. EXAMPLE USE CASES OF RAVIS

4.1 Site-Specific Probabilistic Forecasts

RAVIS can provide site-specific probabilistic forecasts (see Figure 5 in the Appendix for a screenshot of the RAVIS integrating probabilistic solar power forecasts data from the IBM Watt-Sun forecasting platform [12] for several sites in the CAISO, MISO, and New York regions). The useful features are:

- **Dynamic metadata look up:** As the user moves the cursor over a node in the regional detailed pane, metadata of that station pops up with information on the plant size (or the aggregated size of several plants on a regional pane) and whether a significant ramp event is detected, or the site or region has nominal ramping. See Appendix Figure 5 for a mock-up of this feature.
- **Viewing forecast time series:** When a user clicks on a particular node, either an individual site or the aggregated region, the time-series forecasts will be displayed in the right-hand pane. See Appendix Figure 5 for an example of regional and single site time series. The time-series forecasts provide probabilistic information, including the upper 95 percentile (p95) and lower 5 percentile (p5). These bands are customizable to any value (e.g., p90, p10). The time series chart will include a legend on top that provides a summary—namely, at a particular time instance, the mean, upper 95 percentile, and lower 5 percentile probabilities, and whether any ramp is detected. See Appendix Figure 5. These summaries are updated as the user hovers the cursor along the timeline. Additionally, a scroll bar appears on the right when more sites are selected to view the time-series forecasts. The end user can scroll and view at the interested forecast plots, and plots that are not needed anymore can be closed at any time.

If a user is interested in comparing past forecast versus actual power data for recent hours, including displaying the metrics for accuracy in terms of mean absolute error or root mean square error, RAVIS is flexible enough to ingest real observations and add them to the time series as a comparison of past forecasts.

4.2 Event Alerts: Ramping Alert

Another use case of RAVIS is to issue alerts for significant ramping events based on the probabilistic solar forecasts. Depending on the ramp detection parameters set by the user (Section 3.5), ramp alerts are shown in various panes of RAVIS. See Appendix Figure 6 and Figure 7 for example illustrations of the ramp alert use case, and how alerts at different time instances can be viewed.

Even though the examples discussed in this paper uses solar power ramps, one could also add similar alerts based on wind and load forecasts or the net load forecasts. Generator outage-related alerts can also be added. The alerts could also be with respect to cyber anomalies detected in any resource or generation station. Depending on the data available, the RAVIS tool can ingest all types of alerts, and the information can be displayed with different legends and colors.

4.3 Comprehensive Situational Awareness with Extended Grid Data Integration

This use case illustrates how the tool can ingest multiple data layers in addition to solar power forecasts for a comprehensive visualization capability. In this use case, RAVIS integrates 5-minute resolution solar power forecasts and net load forecasts (load minus wind and solar) developed by NREL for the CAISO system for March 2020 (7 a.m.–12 p.m.). Additionally, RAVIS integrates market simulation results available from the NREL in-house simulation tool for the modeled ISO system. These market results include network nodes and transmission topologies, nodal market-clearing prices, and available generation flexibility in the upward and downward directions at the nodal and aggregated system level. All these additional visualization features can be added by toggling the customization parameter discussed in Section 3.5 (see Appendix Figure 4), provided data are appropriately fed. Figure 3 below presents the updated interface of RAVIS with the following additional data:

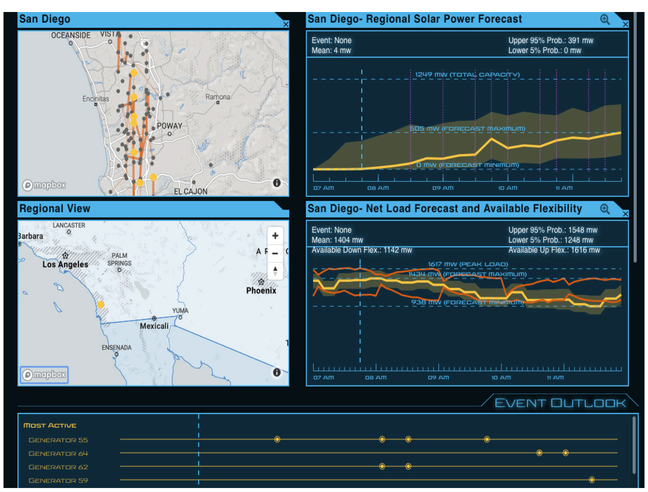

Figure 3 Comprehensive situational awareness with forecasts and market clearing data (event market at 7:45 a.m.)

1. **Network data in the regional and site view panes:** In addition to the solar resource sites (yellow nodes), the additional data visualized include network nodes (substations denoted by the black nodes) and transmission lines (orange lines). Note that for easy assimilation, only the transmission lines with greater than 75% utilization (configurable parameter) are shown.
2. **5-minute net load time-series data:** In addition to the solar power forecast time series (both site as well as aggregated), the net load forecasts can also be visualized. Figure 3 shows the net load probabilistic forecast for the San Diego, California, region.
3. **Available generation flexibility:** The solid orange line showing the time series enveloping the net load forecasts is from the generation scheduling and market simulations, and it shows the available generation flexibility in both the upward and downward directions. For instance, between 11 a.m.–12 p.m., the downward flexibility among the conventional spinning generators is less than the expected load uncertainties. This is because at those times the grid is predominantly served by renewable resources with several conventional generation at their minimum generation, and any net load uncertainties might need to be met with flexibility extracted from renewable resource curtailment. Such insights open up new opportunities for renewable resources to provide flexibility services and be compensated for it in the future.
4. **Network nodal data and transmission utilization:** When the user moves the cursor over the network nodes, the metadata pops up, which summarizes nodal properties such as nodal price from the market clearing, amount of unserved energy, and upward and downward flexibility available from the spinning generators. If there is any ramp deficiency event and real-time market price spike at any node to indicate generation deficiency, that will be shown in the nodal visualization (a separate alert could be issued by the user). The transmission connecting the nodes are also shown, though a user can filter to show only those transmission that are heavily utilized and are congested. See Figure 8 in the Appendix for an example of network nodes and transmission utilization (>75%) shown. The illustration in the Appendix also shows how the transmission congestion data dynamically gets updated when a different time instance is chosen.

5. CONCLUSIONS

This paper introduced a flexible, open-source visualization tool, Resource Forecast and Ramp Visualization for Situational Awareness (RAVIS), to help operating an electric power system with high shares of variable renewable generation. Although the electric grid visualizations are relatively mature, much development is needed to prepare for a future with high shares of variable renewables and for providing critical operational alerts. For illustration, the paper successfully described several use cases, including integrating forecast data from the IBM Watt-Sun system and NREL's forecasting system (specifically from 2017 solar eclipse event), and visualizing relevant ramp alerts. The tool also showed a proof of concept for the plug-and-play layered architecture of heterogeneous data integration of system operational data that included network topology and nodal attributes.

The Appendix Section 6.2 provides further directions for any interested end user to use the tool according to their specific needs and use cases. For example, some possible extensions could include ingesting more sensor and weather data, including site-level cyber anomalies and regional stability alerts, which can be superimposed with severe weather events to investigate resilience planning.

6. APPENDICES

6.1 Appendix 1: Use Case Illustrations

6.1.1 Customization Features

Figure 4, left hand side shows parameters for ramp threshold configuration. In the middle, we have the ability to create custom forecast regions with selected sites. Towards the right, the toggle feature provides the ability to add more layers of data for a comprehensive situational awareness that include resource forecasts as well as generation schedule and transmission usage related metrics.

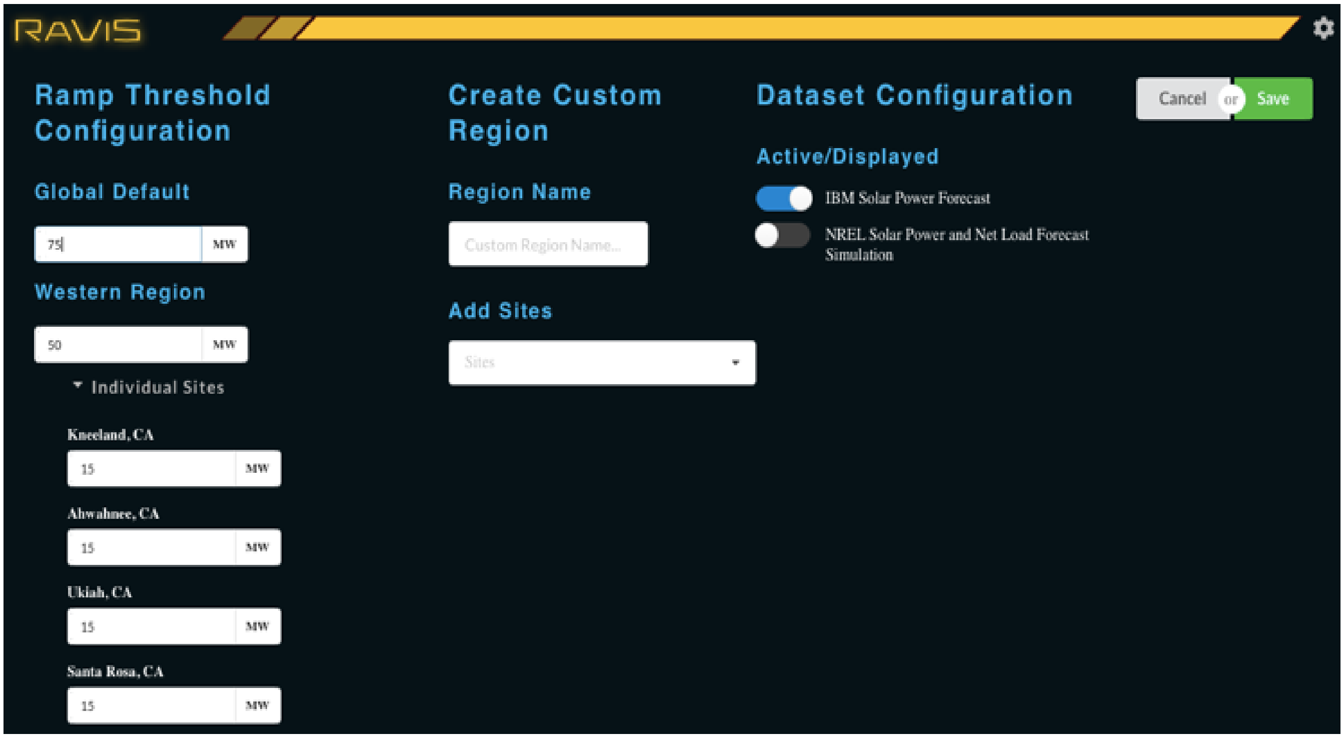

Figure 4 Customization parameters for ramp definition threshold and creation of user-defined forecast regions

6.1.2 Use Case 1: Integrating IBM Forecasts

Section 3 introduced RAVIS capability to visualize time series and spatially resolved forecasts and the related power ramps. Solar eclipse event data was used in those illustrations, when the ramps seen were more pronounced in the middle of the day. However, RAVIS can also be used to visualize the spatiotemporal forecasts and ascertain ramping alerts for any normal day. Typically, any day has steep ramping events in both morning and evening hours, and also additional unforeseen ramps during the day times due to cloud covers. Similar intermittent ramping phenomenon can also be visualized for wind power ramps that may occur due to change in wind speeds and atmospheric temperature. In this use case, the integration of solar power forecasts from IBM WattSun tool is discussed. This use case applies to any forecast developer's data.

Figure 5 below shows the data integrated from IBM WattSun probabilistic solar power forecasting platform. The data used is for a selected day in April 2020 (12 p.m.–5 p.m.) at 15-minute resolution, updated every 1 hour. As observed from the pop-up data (which appears when the cursor is moved over that location on the map), the solar photovoltaic site Medora, in North Dakota, and the aggregated forecast in the eastern region have nominal ramping, whereas the aggregated regional view shows significant ramps for the western (59.85 MW) and central (65.84 MW) regions. The right-hand side time series data shows the time series solar power forecast for the western region (aggregate of all solar plants in that region) as well as a single site (San Bernardino) in California.

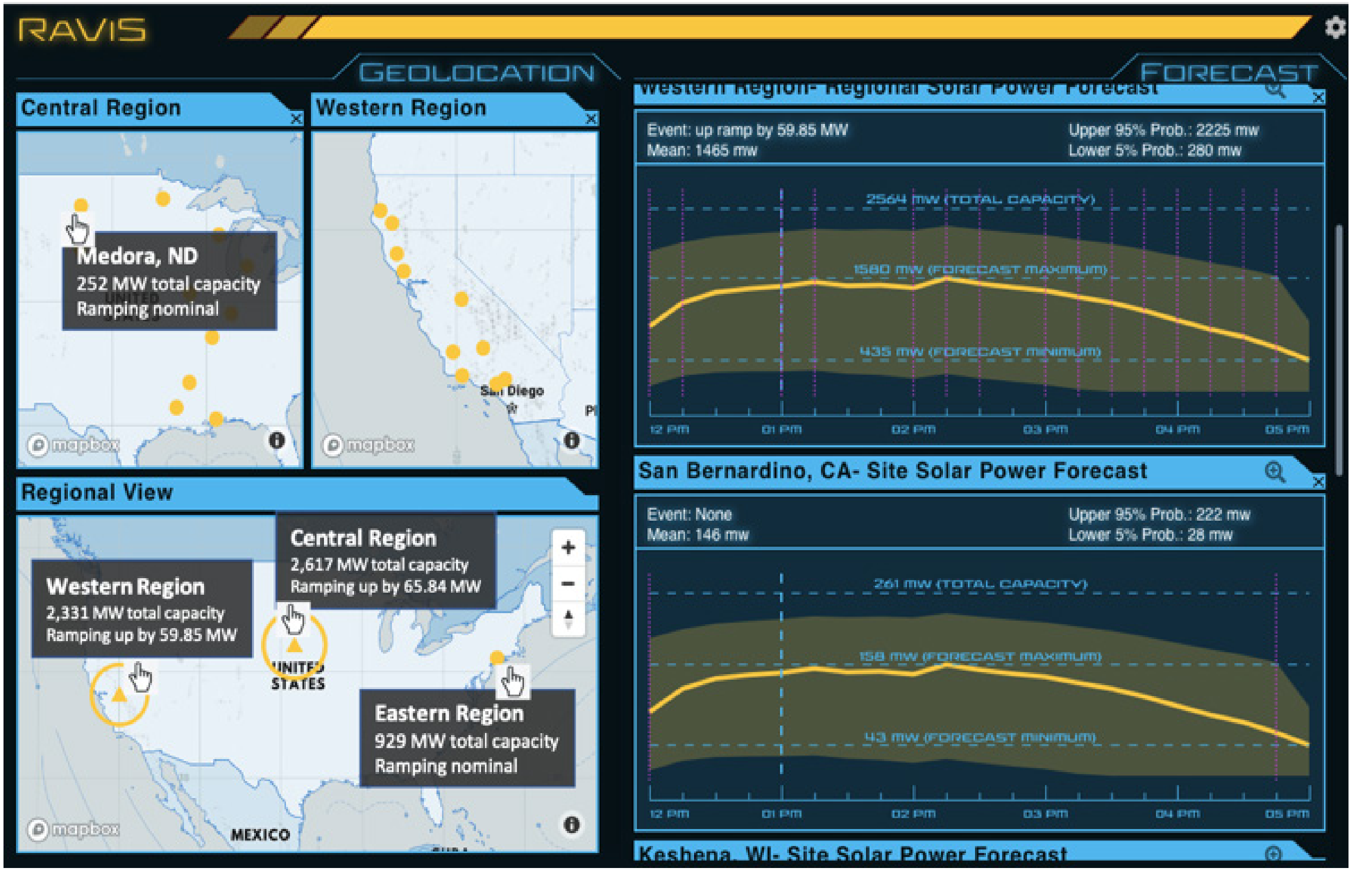

Figure 5 Integrating probabilistic forecasts: IBM Watt-Sun

6.1.3 Use Case 2: Severe Ramp Alerts

Figure 6 and Figure 7 illustrates the use case of visualizing ramp alerts at different time instances, based on the input forecast data from the IBM WattSun solar power forecasting platform.

Figure **6** shows the Event Outlook marker placed at a 1-hour look-ahead period (i.e., 1 p.m., in this example). No site-level ramp alerts are detected; however, at 1 p.m., we observe up-ramp alerts for the central and western regions.

Figure 7 shows the Event Outlook marker placed at a 4-hour, 45-minute look-ahead period (i.e., 4:45 p.m., in this example), and the data shown in all the other panes is updated automatically. At 4:45 p.m., several site-level solar power ramp alerts are detected in the central and eastern regions. Note that at 4:45 p.m., all the detected ramps in the site as well as aggregated regions are down-ramps, as shown by the direction of the arrows and the summary statistics in the time-series pane.

As seen in the lower part of the illustration, typically, the most active sites with ramp events detected are displayed at the top of the Event Outlook pane, and a user can also scroll vertically.

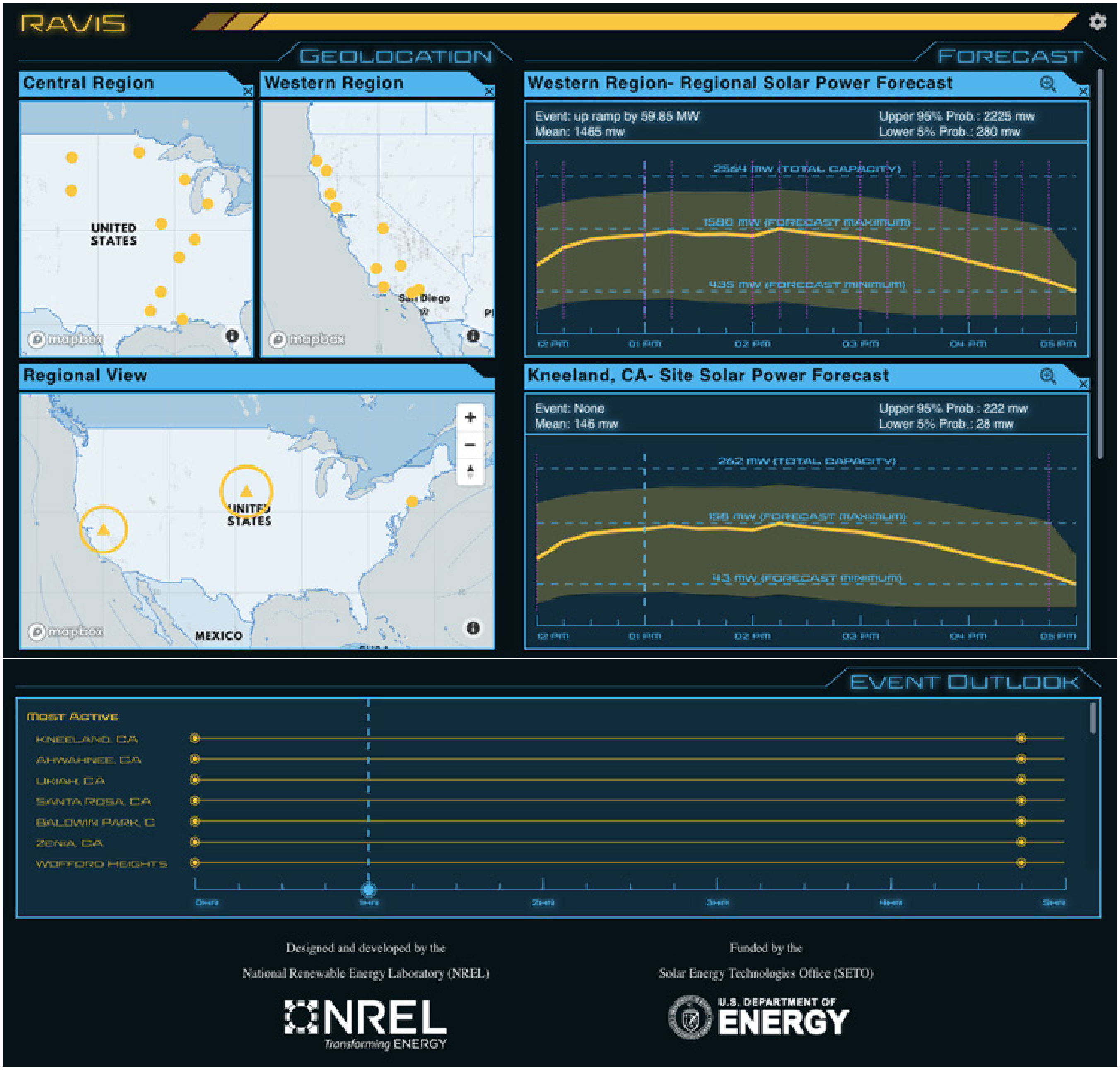

Figure 6 Ramp alert: Event Outlook at 1-hour look-ahead

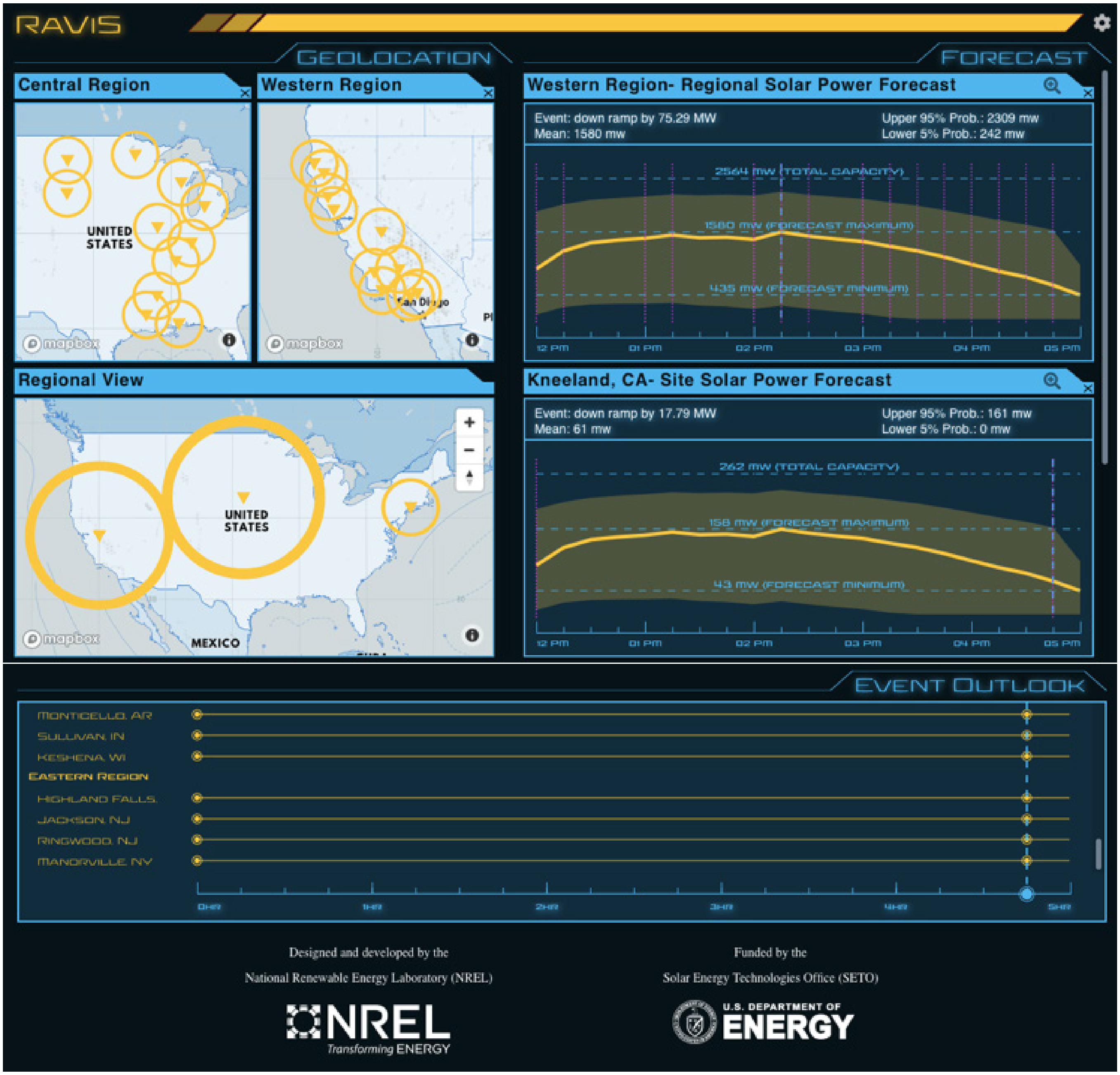

Figure 7 Ramp alert: Event at 4-hour, 45-minute look-ahead.

6.1.4 Use Case 3: Comprehensive Situational Awareness

Figure 8 shows an example of added situational awareness data in addition to the site-specific solar power forecasts data. The additional data in this case is from the electricity market clearing and generation scheduling process that consumes the input renewable and load forecasts data and comes up with a schedule of other conventional generation and anticipated transmission network congestion. As seen in the figure below, the network nodes are seen by black dots and the orange lines connecting these black dots are the transmission lines (filtered by transmission utilization >75%). The larger orange dots are the solar plat sites, which was also shown in previous use cases. As cursor is placed on an electricity node (black dot), we can see relevant data for that node (e.g., node name, current electricity price at that node, available generation flexibility in both upward and downward directions to meet any unanticipated power ramps due to forecast errors). The illustration also shows how the transmission congestion data dynamically gets updated when a different time instance is chosen, i.e., from 7:45am (left side) to 8:30am (right side).

Such a comprehensive visualization will be useful to understand the interactions between different aspects of the network and make efficient informed operational decisions. E.g., forecasted solar power ramps can tell the system operators regions of concern. They can look at the available generation flexibility in those regions to meet the unexpected ramps, and if the local region doesn't have enough flexibility, they could look at the neighboring regions. In cases, where there are anticipated transmission bottlenecks in electricity lines connecting with the neighboring regions, this could obstruct the supply of available generation flexibility from other regions. In such situations, an idea of nodal prices where various renewable resource are connected, can help to decide which resource could be curtailed or controlled to extract the much required system flexibility and ensure system reliability; while also ensuring economic loss due to renewable plant control is minimized.

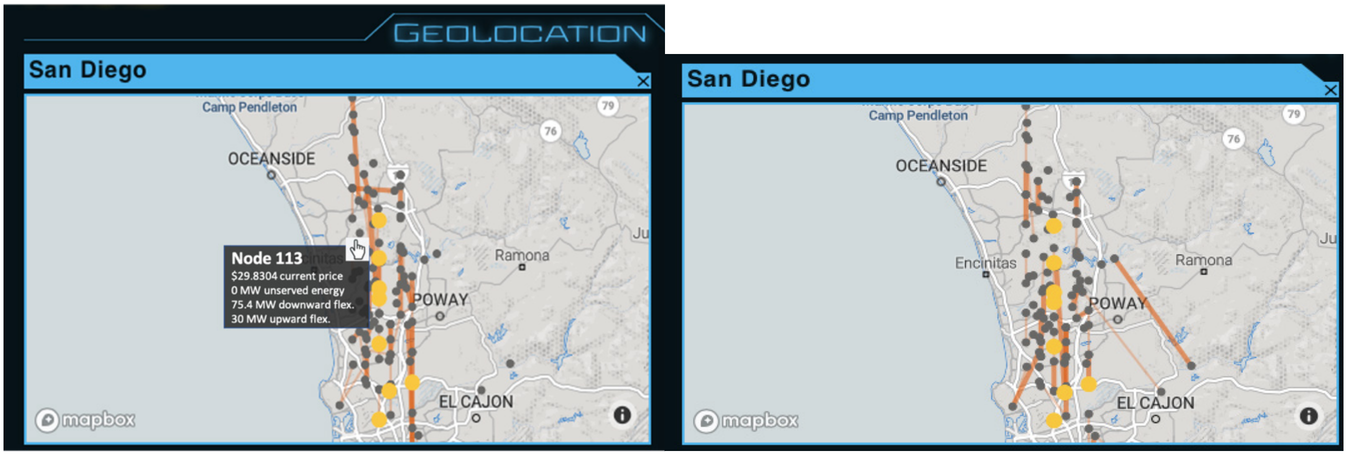

Figure 8 (left) Network nodal data and transmission at 7:45 a.m.; (right) Updated transmission congestion at 8:30 a.m. with the time marker moved in the Event Outlook

6.2 Appendix 2: Frequently Asked Questions

6.2.1 System Requirements and Training

The hardware requirements for simply running the software are minimal. Any modern laptop or desktop computer can easily run these programs. The resources required to host a production deployment will need to be assessed based on the environment it will be used within, including anticipated number of users, anticipated size of data feeds, and so on. The web technologies employed are operating system agnostic and will work on any current operating system.

RAVIS is not a turnkey system. It is the product of a research endeavor, and it is not intended as a commercially viable product. To successfully deploy and operate RAVIS, it is required to have a minimum basic understanding of web application software development and operations support knowledge. Some experience with NodeJS development and a working understanding of web-based mapping, including serving vector tile data, are also highly recommended.

6.2.2 How can we download RAVIS?

RAVIS is freely available as a source code at https://github.com/ravis-nrel. RAVIS is published under the BSD 3-clause open-source license agreement. More details on how to install and use RAVIS can be found in the GitHub repositories.

6.2.3 How can we integrate with new forecast data for solar, load and wind?

The RAVIS client consumes forecast data from any source as long as the data are formatted according to the RAVIS requirements. For data to be consumed by RAVIS, it needs to have one or more sites that can be plotted on the map, and for each site a periodically updated set of time-series data, including the forecasted value at regular time intervals. Accordingly, for each new data set, there are two application programming interface (API) end points that need to be provisioned with data.

The first end point is the "sites" end point. The sites end point provides the list of points for which data will be available, and it can include a variety of static metadata describing each point (or site), such as site generation capacity, elevation, name, and so on. Any unique metadata can be added to this end point's response, allowing for a highly customizable and informative display. This end point, how to populate it with data, and how to access it once deployed is documented fully at https://github.com/ravis-nrel/ravis/tree/main/server#apiv1sites.

The second end point is the "forecast" end point. The "forecast" end point provides access to forecast data for each of the points identified by the "sites" end point. This data can be solar power forecasts, market forecasts, load forecasts, weather forecasts, or other. RAVIS support both deterministic as well as probabilistic forecasts and associated quantiles. For RAVIS to use a given forecast's data it needs to be available as time-series data, and it needs to be associated with a single site as returned by the "sites" API. This end point, how to populate it with deterministic and probabilistic data, and how to access it once deployed is documented fully at https://github.com/ravis-nrel/ravis/tree/main/server#apiv1forecast.

Broadly speaking, the sites data are static. This is configured during the initial setup to reflect the full scope of all sites of interest or to match the points for which forecast data are available. These data will change only when new sites or forecasts are brought online.

Conversely, the "forecast" end point data is constantly updating. The more frequently, the better! The forecast end point provides forecast data to the client in a predefined JSON format. For the API to serve these data correctly, it must manipulate the raw forecast data into the required JSON schema. The type of adapters required for each forecast data stream is unique to the nature of the raw data and therefore requires custom solutions on a case-by-case basis.

Both the "sites" end point and the "forecast" end point accept a parameter defining a specific data set of interest. In this way the API can support multiple data sets, multiple sets of locations, multiple temporal resolutions, and so on.

6.2.4 Production Considerations

When deploying RAVIS to production, it is important to consider the performance of the application with respect to both the number of users you wish to support and the size of the data you wish to visualize. The client code runs on a browser, and hence the visualization engine is subject to the limitations of the user's computer. This would typically become an issue only when configuring RAVIS to display many hundreds of sites concurrently, and, even then, only if a user's computer has a modest graphics processing unit.

The API service requires a deployment stack with enough resources to accommodate the peak anticipated number of concurrent requests to load the static web assets as well as the API calls to fetch site and forecast data. In addition, it might be convenient to run a background process on this instance to fetch, format, and store current forecast data. Serving the static web assets is trivial unless supporting many thousands of users. The performance considerations for the API end points and any forecast daemons are contingent upon the number of sites supported and the forecast data itself. How often the forecasts are updated, how large the forecast data are, and how much processing is required to manipulate the data into a format that RAVIS can consume are all aspects of this performance consideration.

Finally, it is important to understand that RAVIS does not include any built-in security mechanisms. As written, all web pages and API end points are fully unprotected. Depending on the nature of your installation, and depending on any privacy concerns with the data being served, it might be necessary to adopt a secure deployment platform. Toward this end, RAVIS uses very common and widely adopted web tools and protocols for which there exist many security modules and strategies. Identifying the right one(s) for your installation is best handled by the operations and cybersecurity specialists in your organization.

6.3 Appendix 3: Acknowledgments

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Solar Energy Technologies Office (SETO) Agreement Number EE0008215. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

We would like to acknowledge the continued support and feedback from the Solar Energy Technologies Office management team: John Seuss, Kemal Celik, and Anastasios (Tassos) Golnas. We also acknowledge the valuable time and inputs from the independent system operator team members: Amber Motley, Rebecca Webb, Clyde Loutan, Guillermo Bautista Alderete, and Hong Zhou from the California Independent System Operator; and Steven Rose, Blagoy Borissov, John Pietrzyk, Jordan Bakke, Cameron Saben, and Armando Figueroa-Acevedo from the Midcontinent Independent System Operator. The team also appreciates all the support from the project partners at Johns Hopkins University (Benjamin Hobbs), IBM (Rui Zhang, Carlo Siebenschuh, and Hendrik Hamann), the University of Texas at Dallas (Jie Zhang), and NREL colleagues (Elina Spyrou, Aaron Weissman, Billy Roberts, Joseph Smith, and Kenny Gruchalla).

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