

Comprehensive Open-Source Development of Next Generation Wildfire Models for Grid Resiliency

Workgroup 3: Near-term Risk Forecast User's Guide (Task 6)



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Introduction

About PyreCast

PyreCast is an easy-to-use near-term fire forecasting decision support tool that has been developed under funding from the California Energy Commission (CEC) Electric Program Investment Charge (EPIC) Program (Agreement #EPC-18-026). The PyreCast tool leverages efficient software programming practices and the best available fire science. The tool allows users visualize data from three primary wildfire related forecasts, including:

- **Active Fires.** Shows the locations of actively burning fires as sensed remotely with satellite and aircraft heat detection and provides forecasts of where they are projected to spread across a landscape over the next five days.
- **Risk Forecast.** Works by igniting hundreds of millions of hypothetical fires across the landscape and modeling their spread under forecasted weather conditions over a five-day time horizon; the interface shows which areas are at greatest risk from fires if an ignition were to occur.
- **Fire Weather.** Provides eight-day forecasts, updated every six hours, of key weather parameters affecting wildfire behavior, including temperature, relative humidity, wind, and fire weather indices.

In addition, the “Fuels” tool allows users to view underlying model input data related to fuels and topographic characteristics.

The purpose of this user’s guide is to provide instructions for deploying, running, analyzing, and visualizing the near-term risk forecast model inputs and outputs with a web browser.

User Interfaces

Users can interact with PyreCast™ (and the underlying data and models that feed the tool) in three primary ways, including:

- *Public User Interface* – through this web-based user interface, users interact with existing, non-proprietary features and functions of the web-based, on-line tool hosted at <https://pyrecast.org/>. This interface is designed for a broad user base, with a relatively low level of expertise in fire science.
- *Enhanced Security User Interface* - This user will use the PyreCast system log-in registration capability to host their own proprietary data on PyreCast secure servers.
- *Data Feeds* - A file server (<https://data.pyregeance.org>) provides access to native-format files. Similarly, web services are provided by a GeoServer-based Application Programming Interface (API) at <https://data.pyregeance.org/geoserver/web/>.

Descriptions of the ways that users can interface with PyreCast are provided below, with particular focus on the browser-based *Public User Interface*.

Public User Interface

PyreCast’s public user interface at <https://pyrecast.org/> is designed to provide easy access to a variety of fire related datasets. The public user interface can be accessed from any online device with a browser (desktop, laptop, smart phone, tablet, etc.). After navigating to <https://pyrecast.org/>, a disclaimer notification is displayed – the user should read through the disclaimer and select “accept” to get started. Appendices 1-4 provide the complete text of this disclaimer, PyreCast’s terms of use and privacy policy, as well as the code license under which the underlying software and source code are (or will be) made available.

Common to each of the wildfire forecast tools (i.e., Fuels, Weather, Risk and Active Fires) is a user interface that provides access to different features and functions (Figure 1).

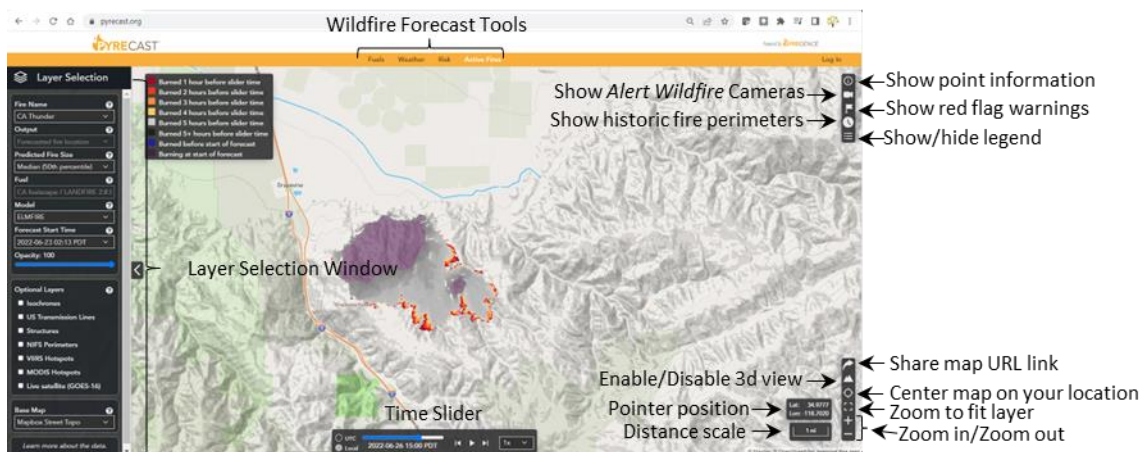


Figure 1. The location of different functions and features included in the PyreCast user interface.

In the upper right of the user interface is a suite of features/functions packaged in this box (Figure 1), including 1) Show Point Information, 2) Show *Alert Wildfire* Cameras, 3) Show Red Flag Warnings, 4)

Show Historic Fire Perimeters, and 5) Show/hide Legend; each of these features/functions are described below.

- *Show Point Information* – The ‘show point information’ feature (📍) is in the upper right of the user interface (Figure 1). When selected, the user can query a point on the map to display information for that location in the Fuels, Weather, and Risk wildfire forecast tools. For the Weather and Risk forecast tools, a time series forecast graphic is displayed. In the Fuels tool a description of the underlying layer (e.g., fuel model, slope, canopy cover, etc.) is provided depending on which quantity is selected.
- *Show Alert Wildfire Cameras* – selecting the 📷 icon will show the distribution of [Alert Wildfire](#) cameras on the map and provide a viewing window in the upper right of the screen (Figure 2). Scrolling in on the map will reveal more cameras and scrolling out will show fewer cameras. The orientation of cameras shown in the map indicates the direction that a camera is aimed. Left clicking on a selected camera icon will bring up the most recent image that the camera has captured in a viewing window in the upper right (Figure 2). The image window can be resized by left clicking, holding, dragging on the edge of the image window. Included in the image provided by the selected camera is a date and timestamp at the bottom of image that can be used to confirm the camera’s activity status.

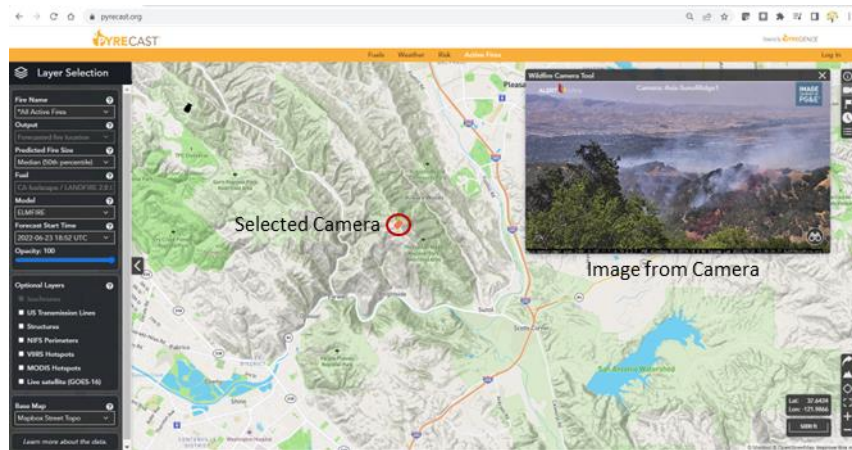














Figure 2. Screenshot showing the image window relative to a selected Alert Wildfire camera.

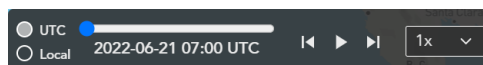
- *Show Red Flag Warnings* – selecting this feature overlays a layer in the interface showing current fire weather watches and red flag warnings issued by the National Weather Service (NWS). Red Flag warnings show areas where NWS has determined that lightning or hot/dry/windy conditions will create elevated fire risk.
- *Show Historic Fire Perimeters* - selecting this feature toggles on a layer that shows historic fire perimeters for California and the lower 48 US states from 2000 through the end of the previous year. A left mouse click on a fire perimeter polygon will additionally show acres burned information.
- *Show/hide Legend* – for maps with an accompanying legend, when selected (with a left mouse click), this feature will show or hide the associated map legend.

In the lower right of the user interface is a suite of features/functions packaged in this box () including 1) Share Map URL Link, 2) Enable/Disable 3d View, 3) Center Map on Your Location, 4) Zoom to Fit Layer, and 5) Zoom in/Zoom out (Figure 1); each of these features/functions are described below.

- *Share Map URL Link* – If you want to share a map, you can select  and it will generate a URL link that you can copy and paste into an email or text message.
- *Enable/Disable 3d View* – Selecting this icon () will enable (or disable) 3D terrain. To scroll or change the orientation in the 3D map, right mouse click and drag until you position the map into a desired orientation. When  is selected in combination with the camera icon () and a camera of interest, you can zoom to the camera's point of view in the map by selecting the binocular icon () found in the lower right of the camera image window. This feature provides a virtual three-dimensional view of the topographic setting of the camera's focal point.
- *Center Map on Your Location* – Selecting this feature () will focus the map to your current location. Once selected, a pop-up window will ask to 'allow' the system to know your location – choosing 'allow' will make this feature functional.
- *Zoom to Fit Layer* – The 'zoom to fit' icon () can be selected to rapidly scale map view to the map feature of interest (e.g., an active fire) or to the extent of a map layer.
- *Zoom in/Zoom out* – Zooming in and out on the map can be achieved in two ways: 1) using the wheel on your mouse, or 2) using the + or - features found on the lower right of the user interface.

Other Features and Functions

- *Pointer Position* – in the lower right of the user interface is a read out that provides the spatial coordinates of the pointer (in decimal degrees of latitude and longitude)
- *Pan* – to pan across a map (side to side, top to bottom), click, hold left mouse button and drag map to desired view.
- *Distance Scale* – In the lower right of the user interface is a scale bar (in English units) that adjusts as you zoom in or out on the map.
- *Time Slider* – The time slider provides controls that allow you to visualize temporal Weather, Risk, and Active Fire data in Coordinated Universal Time (UTC) and local time. Note that local time is determined by your location as opposed to the timezone in the area of the map being viewed. The radio buttons on the left side of the time slider allow the user to select UTC or local time. The bottom of the slider identifies the date (year-month-day) and time (0-24 hours). The controls on the right side of the slider allow users to play/pause map animations (, ) or otherwise time step backward or forward through each hour of the forecast period using  (for backward) or  (for forward). The speed setting on the far right can be selected to control how fast the data are animated through each time step. Users can left click and hold the slider bar ball to scroll forward and backward in time.



- *Quick Help and Feature Information* – Information on various features and functions can be quickly derived by hovering your pointer over the ? icon.

- *Layer Selection* Window – This window houses unique information for each of the Wildfire Forecast Tools. The Layer Selection window in each Wildfire Forecast tool also includes a common set of data layers (“*Optional Layers*”) that provides contextual information and options for selecting a preferred basemap.
 - *Opacity* – a slider toggle that allows the user to adjust transparency of selected map layer.
 - *Optional Layers* include:
 - *Isochrones* – select box to display the modeled 5-day perimeter from a particular active fire forecast
 - *Transmission Lines* – select box to show the locations of electric transmission lines.
 - *Structures* - select box to show building footprints.
 - *NIFS Perimeters* - select box to show the current year fire perimeters (e.g., fire perimeters from 2022), sourced from the [National Incident Feature Services \(NIFS\)](#).
 - *VIIRS Hotspots* - select box to show recent hotspots detected/captured from the Visible Infrared Imaging Radiometer Suite (VIIRS) instruments on Suomi NPP and NOAA-20 satellites. VIIRS data can be downloaded at https://firms.modaps.eosdis.nasa.gov/usfs/active_fire/.
 - *MODIS Hotspots* – select box to shows recent hotspots detected/captured from the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument which is aboard the [Terra](#) (originally known as EOS AM-1) and [Aqua](#) satellites.
 - *Live Satellite (GOES-16)* – select box to show near real-time imagery from the [GOES-16 satellite](#) – provides an option for viewing smoke dispersion and cloud cover.
 - *Basemaps* include:
 - *Street Topo* – displays a stylized map of the landscape, including name labels for streets, areas of interest, landmarks, landscape features, towns, and cities.
 - *Satellite* – displays map of current satellite imagery, including name labels of landscape features.
 - *Satellite Street* – displays map of current satellite imagery, include name labels for streets, areas of interest, landmarks, towns, and cities.
 - *Learn more about the data* – selecting link directs user to PyreCast data repository (<https://pyregence.org/wildfire-forecasting/data-repository/>).

The *Layer Selection* window is further described below for each of the Wildfire Forecast Tools.

Fuels Tool

This tool provides users access to spatial information related to fuels and topography that can be used to assess potential fire behavior. To access the Fuels tools, left click on the Fuels tab in the interface (Figure 3).

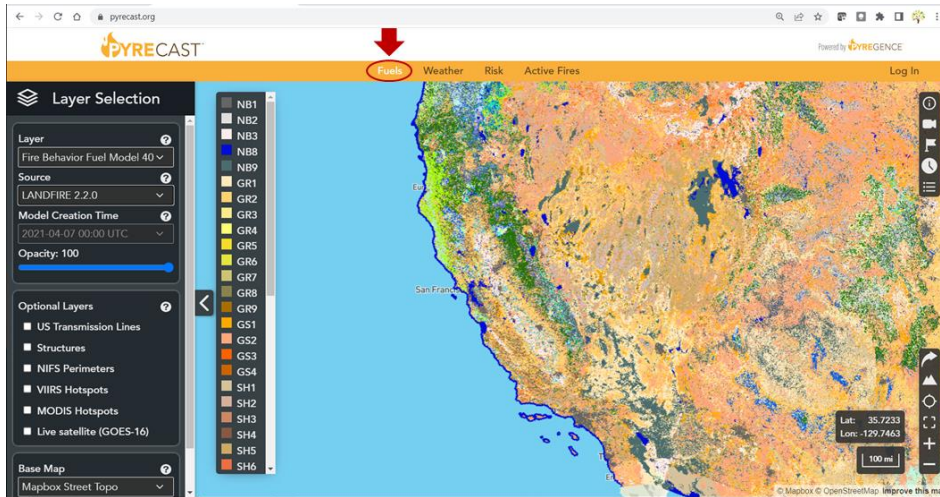


Figure 3. Screenshot showing where to click and access fuels and topographic data.

Layer Selection Window. The fuels *layer selection* menu is provided on the left-hand side of the user interface. The Fuels tool includes the following layer selections:

- *Layers* – allows user to select data from the selected fuel data layer (as selected from the *Source* dropdown). For example, if the 2022 CA Fuelscape dataset is selected from the *Source* dropdown, the following data layers from the 2022 Fuelscape data source can be selected in the *Layer* dropdown:
 - Fire behavior fuel model 40
 - Aspect
 - Slope (degrees)
 - Elevation (ft)
 - Canopy cover (%)
 - Canopy height (m)
 - Canopy base height (m)
 - Crown bulk density (kg/m^3)
- *Source* - Different data sources are available to choose from and are summarized in Table 1 in terms of their application and extent in fuels tool:
 - Stock LANDFIRE 2.2.0 data (<https://landfire.gov>) at 30 m resolution.
 - California Forest Observatory – Data derived in summer 2020 at 10 m resolution (courtesy of the California Forest Observatory (<https://forestobservatory.com>), © Salo Sciences, Inc. 2020),
 - 2022 California Fuelscape prepared by Pyrologix, LLC (<https://pyrologix.com> 2022), and
 - California Ecosystem Climate Solutions (Wang et al. 2021, <https://california-ecosystem-climate.solutions/>).

Table 1. Summary of data sources provide in the fuels tool.

Fuel & Topo	Source	Coverage	Resolution	Native quantities	Derived quantities
	Pyrologix CA 2022 Fuelscape*	CA	30 m	Surface fuel model, canopy base height, canopy bulk density, canopy cover, canopy height	Wind adjustment factor
	LANDFIRE 2020 Update (LF 2.2.0)†	CONUS	30 m		
	California Forest Observatory 2020 / 2022	CA	10 m		
Center for Ecosystem Climate Solutions 2021	CA	10 m			

* Default in CA

† Default outside of CA

- *Models Creation Time* – Not applicable to the Fuels tool. See Table 1 (above) for date that data products were derived.

Weather Forecasting Tool

The weather forecasting tool can be accessed from the top of the user interface by left clicking “Weather” (Figure 4). These tools provide an 8-day forecast of key parameters affecting wildfire behavior obtained from a hybrid of different weather models summarized in Table 2.

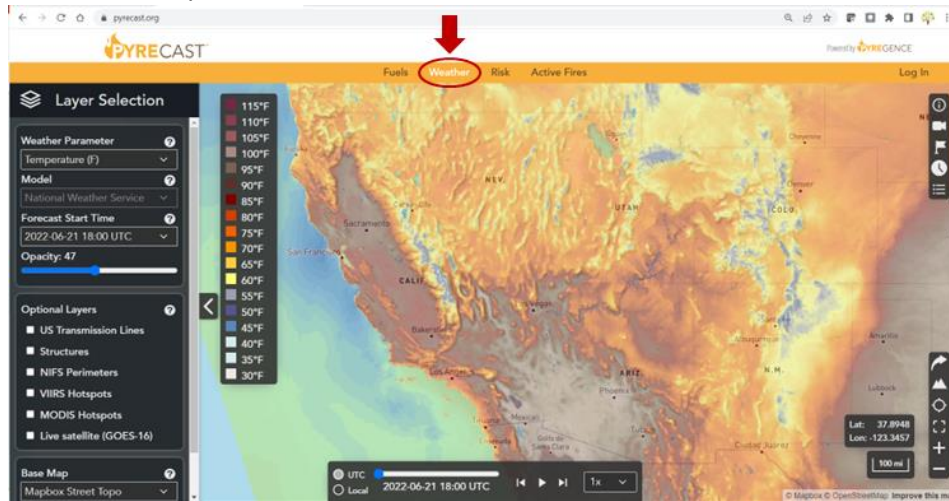


Figure 4. Screenshot showing where to click and access the weather forecasting tool.

Table 2. Summary of weather input provided in the weather forecasting tool.

Weather	Model	Resolution		Forecast duration	Cycles / day	Native quantities	Derived quantities
		Spatial	Temporal				
	High Resolution Rapid Refresh (HRRR)	3 km	1 hr	2 day	4	Relative humidity, temperature, precipitation, solar fluxes, wind speed, wind direction, wind gust	Fosberg Fire Weather Index, Hot Dry Windy Index, dead fuel moisture by size class, NFDRS indices
	North American Mesoscale Model (NAM)	3 km	1 hr	2.5 day	4		
	Global Forecast System (GFS)	0.125 °	1-3 hr	16 day	4	Same as above	Live fuel moisture (herbaceous & woody)
	Real Time Mesoscale Analysis (RTMA)	2.5 km	hourly	Real time	-		

Layer Selection window. Several fire relevant weather forecast layers can be selected from the *weather parameter* dropdown in the layer selection window found on the left-hand side of the user interface.

This following *weather parameter forecasts* are available for viewing:

- Temperature (°F) – air temperature at approximately 6 feet above ground level
- Fosberg Fire Weather Index (FFWI) – FFWI is a fuel-independent measure the potential influence of meteorological conditions (sustained wind speed, relative humidity, and temperature) on wildfire spread rate.
- Relative Humidity (%) - expressed as a percentage, indicates the amount of water vapor present in the air approximately 6 ft above ground level relative to the amount of water vapor that the air can hold when it is saturated.

- Sustained Wind Speed (mph) – sustained (not gust) wind speed at 20 ft above ground level
- Wind Gust (mph) – 3 second wind gust at 20 ft above ground level
- 1-hour Precipitation (in) – amount of liquid-equivalent precipitation accumulated over 1 hour.
- Fine Dead Fuel Moisture (%) - % moisture content of fuels 1/4” or less.
- Vapor Pressure Deficit (hPa) - the difference between the partial pressure of water vapor in the air and the partial pressure of water vapor in the air at saturation. Drying of fuels increases with vapor pressure deficit.
- Hot-Dry-Windy Index (hPa*m/s) – sustained wind speed multiplied by vapor pressure deficit. Like FFWSI, this is a measure of the potential influence of meteorological conditions on fire spread potential.

Forecast Start Time – From this dropdown you can select the weather forecast initiation date/time (year-month-day hour). The most recent weather forecast is the default selection.

Once settings are selected in the “Layer Selection” window, users can use the “show point information” feature and initiate the time slider to show how the select weather parameter is forecasted to change over the forecast period.

Risk Forecasting Tool

This tool provides a 5-day forecast of fire risk and consequence. Every day over 500 million hypothetical fires are ignited across California to evaluate potential fire risk across the state. Figure 5 illustrates how to access the tool – select “Risk” from the top of the user interface.

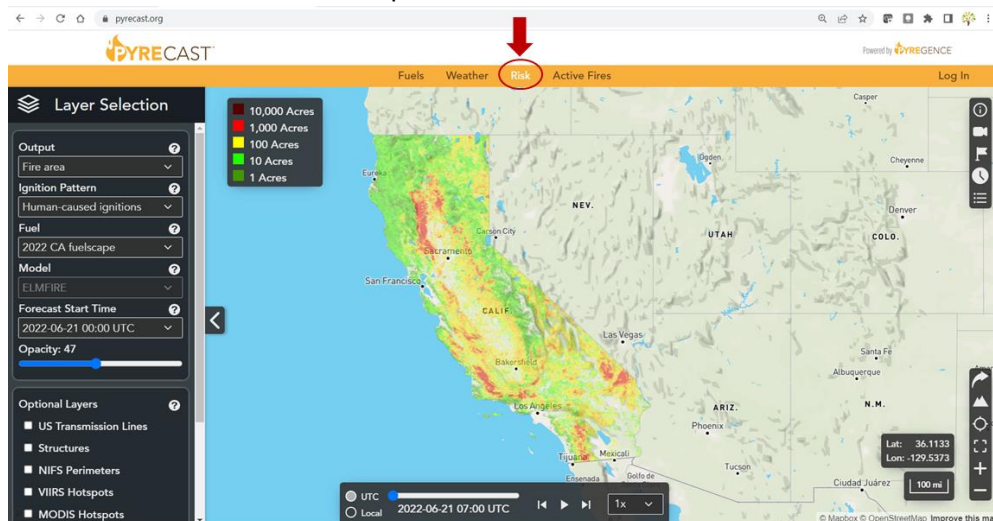


Figure 5. Screenshot showing where to click and access the risk forecasting tool.

Layer Selection window. The *Output* selection dropdown menu is provided on the left-hand side of the user interface in the *Layer Selection* window. Key fire spread model outputs based on modeling 6-hours of fire spread without fire suppression activities within 6 hours of time shown in the time slider. Risk *Output* options selectable from the dropdown menu include:

- *Relative Burn Probability* - Relative likelihood that an area is burned by fires that have not yet ignited within the next six hours of time shown in time slider,

- *Impacted Structures* - Approximate number of residential structures within fire perimeter for fires starting at specific location and time in the future,
- *Fire Area* - Modeled fire size in acres by ignition location and time of ignition,
- *Fire Volume* - Modeled fire volume (fire area in acres multiplied by flame length in feet) by ignition location and time of ignition.

Ignition Pattern – In a simulated modeling environment, fires are ignited randomly across California at various times in the future (based forecasted weather) to generate output represented in this tool.

Ignition Patterns users can select from in the dropdown menu include:

- *Human Caused* - Anthropogenic fires (fires from all causes except lightning),
- *Transmission Lines* - Fires ignited in close proximity to overhead electrical transmission lines.

Model – Is the computer fire spread model used to generate risk forecasts. At this time, all risk forecasts are generated with the ELMFIRE (Eulerian Level Set Model of FIRE spread) model. ELMFIRE is a deterministic fire model developed by Chris Lautenberger at Reax Engineering. Details on its mathematical implementation have been published in [Fire Safety Journal](#).

Forecast Start Time - From this dropdown menu you can select the risk forecast initiation date/time (year-month-day hour). The most recent risk forecast is the default selection in the risk tool.

Once settings are selected in the *Layer Selection* window, users can use the “show point information” feature (in the upper right corner of the user interface) and initiate the time slider to show how risk conditions are forecasted to change over the forecast period.

Active Fires Forecasting Tool

Figure 6 shows how to access the tool by selecting “Active Fire” from the top of the user interface. The active fires forecasting tool provides 5-day forecasts of ongoing fires. Actively burning parts of the fire perimeter are determined using aircraft and satellite-based heat detection sensor data. Table 3 provides a summary of the data sources used to initialize active fire spread forecasts.

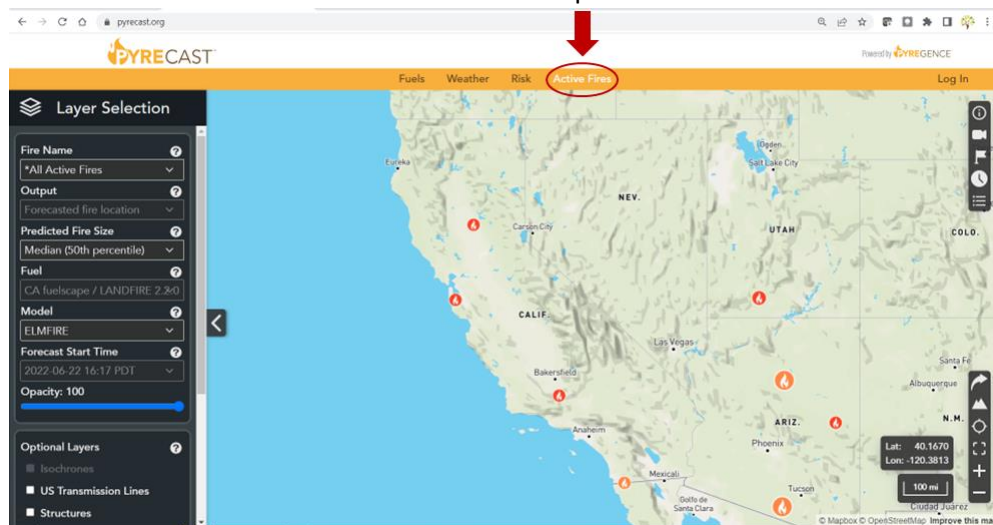


Figure 6. Screenshot showing where to click and access the risk forecasting tool.

Table 3. Summary of inputs used to initiate fire spread forecasts.

Near real time fire	Data source	Resolution		Native quantities	Derived quantities
		Spatial	Temporal		
	CALFIRE incidents feed	-	Real-time	Named fire locations	Fire progression polygons
	NIFC large fires feed	-	Daily		
	NASA FIRMS - Terra/Aqua - MODIS	1 km	12 hr	Satellite-based hot spots	
	NASA FIRMS - Suomi NPP / NOAA 20 - VIIRS	375 m	12 hr		
	Wildland Fire Interagency Geospatial Services (WFIGS) perimeters	~30 m	1-2 days	Fire perimeter polygons	

Layer Selection window – Under *File Name* in the *Layer Selection* window on the left side of the user interface, is a dropdown menu with a list of active fires for which forecast are available. Selecting an active fire from the dropdown menu will zoom the map to that fire and allow the user to interact with the time slider to show the forecasted progression of the fire. Another way to select an active fire spread forecast is to use the pointer to select a fire icon (📍) on the map, after which a pop-up window will be shown – click on the “Click the View Forecast” to initiate the fire spread forecast for that fire. For selected fires, a color-coded legend will appear in the upper left side of the user interface that provides an estimated time of arrival (i.e., the area that is forecasted to burn) of the fire front and the timing of areas previously burned (as modeled/forecasted).

Output - This dropdown contains animated layers that show modeled fire progression out to 5 days. Currently only the ‘forecasted fire location’ can be selected.

Predicted Fire Size - Each fire forecast is run as an ensemble of hundreds of separate simulations to account for uncertainty in model inputs. This leads to a range of predicted fire sizes, five of which can be selected from the dropdown menu, from largest or worst case (90th percentile) to smallest or best case (10th percentile).

Fuel – This dropdown allows the user to select from available sources of surface and canopy fuels inputs.

Model - This dropdown allows the user to select the preferred model output, 1) ELMFIRE or 2) GridFire.

- ELMFIRE (Eulerian Level Set Model of FIRE spread) is a deterministic fire model developed by Chris Lautenberger at Reax Engineering. Details on its mathematical implementation can be found in a paper published in [Fire Safety Journal](#).
- GridFire is a fire behavior model developed by Gary Johnson of Spatial Informatics Group. It is similar to ELMFIRE but tracks the fire front using a fundamentally different algorithm than ELMFIRE leading to some differences in the forecasts between the two models.

Forecast Start Time - From this dropdown menu you can select the active fire spread forecast initiation date/time (year-month-day hour). These forecast start times correspond to a time at which heat was sensed on the fire by satellite or aircraft-based heat sensors. The most recent active fire spread forecast is the default selection in the active fire forecasting tool.

Enhanced Security User Access

The “Log In” button in the upper right corner of PyreCast’s main window provides a mechanism for a user or organization to create an account. Although most users will not need to create an account, utilities or other users that wish to use confidential or sensitive data in PyreCast can create an account to keep this data out of the public-facing web tool.

The primary use-case for this enhanced security access is modeling fires that start in proximity to utility-owned transmission and distribution lines to inform Public Safety Power Shutoff (PSPS) decisions. PSPS-specific parts of PyreCast are currently under development and will provide utilities with the ability to model fires starting in proximity to their assets and then aggregate this information to individual PSPS zones using zonal statistics.

Data Feeds

All data that can be visualized in the PyreCast web application can be downloaded from a file server (<https://data.pyrecast.org/>) that provides access to native files or obtained from a GeoServer-based API that provides web services (<https://trinity.pyregence.org/geoserver/web/> for Active fir outputs, or <https://shasta.pyregence.org/geoserver/web/> for all other layers).

File server

The [file server](#) provides access to all the files that can be displayed in PyreCast. Upon navigating to that URL, the user will see a directory listing similar to that shown below in Figure 7. The directory structure follows the different areas of PyreCast as described above.



File Name	File Size	Date
fire_detections/	-	2023-Mar-25 16:32
fire_history/	-	2022-Jul-20 22:43
fire_risk_forecast/	-	2023-Jun-26 18:47
fire_spread_forecast/	-	2023-Jun-26 19:42
fire_spread_forecast_polygons/	-	2023-Jun-26 20:15
fire_weather_forecast/	-	2023-Jun-26 19:01
fuels_and_topography/	-	2023-May-30 22:14
simulation_decks/	-	2023-Jun-26 18:47

Figure 7. Fire server directory listing.

API / GeoServer

The API for active fires (<https://trinity.pyregence.org/geoserver/web/>) and for all other files (<https://shasta.pyregence.org/geoserver/web/>) with example interface shown below in Figure 8, provides access to PyreCast’s data as Open Geospatial Consortium (OGC) web services, an internationally recognized format. This allows PyreCast’s data to be easily brought into conventional Geographic Information Systems (GIS) applications such as QGIS or ESRI’s ArcGIS suite. The three main types of web services provided by PyreCast’s API are:

- Web Mapping Service (WMS): Delivers images of data styled in the same way as in the PyreCast web application.
- Web Coverage Service (WCS): Provides access to underlying raster data

- Web Feature Service (WFS): Provides access to underlying vector data

Under “Service Capabilities” to the right are links to different web services. A user would typically copy the link address corresponding to the desired web service (e.g., WMS 1.3.0) to the clipboard and then paste that link into a specific dialog box in a GIS application, thereby allowing it to access PyreCast’s data by API. The process for setting up a web map service varies across different GIS platforms and instructions are available for adding web services to [QGIS](#) and [ArcMap](#).

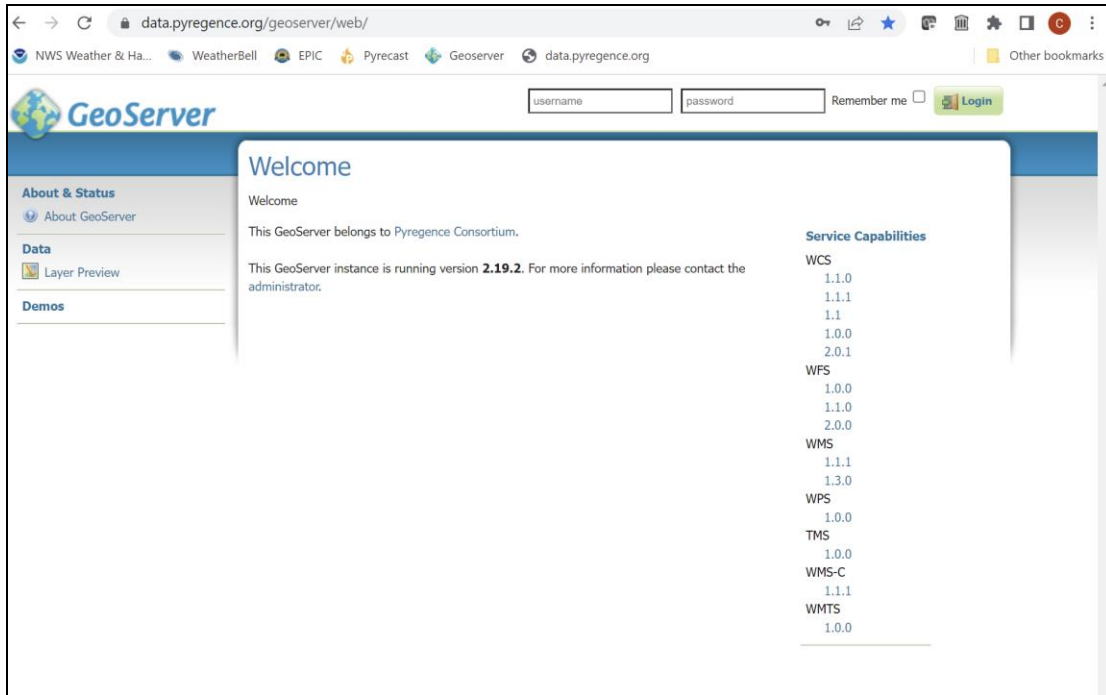


Figure 8. PyreCast API.

Code for Geosync utility for GeoServer management can be found at <https://github.com/pyregence/geosync>.

Technical Details

Figure 9 provides a generalized modeling framework to show the key elements of the PyreCast near-term fire forecasting tool, from the datasets for required model inputs, to the underlying modeling and analysis methods, to the outputs and final products. The framework is deliberately structured for modularity and accessibility, meaning that data and models within the framework can be updated to reflect the latest available science, and users can customize back-end or front-end functionality as desired.

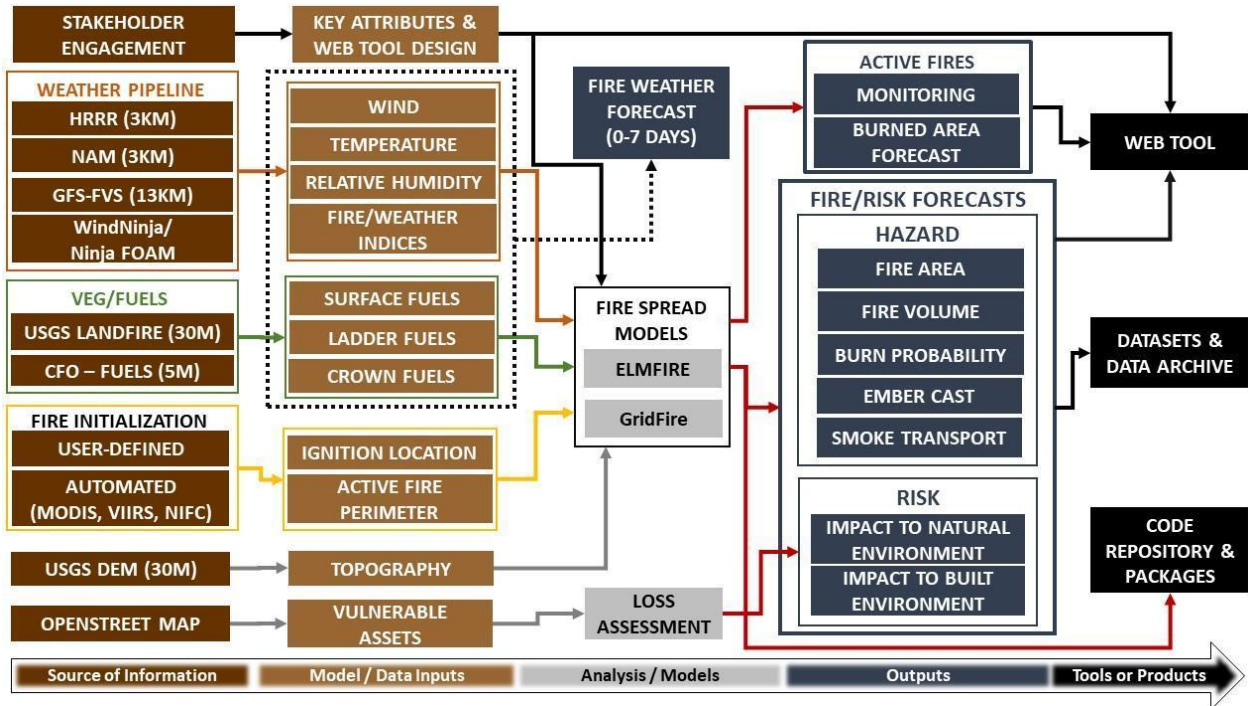


Figure 9. Visualization of key elements and the modeling approach used for the PyreCast near-term fire risk forecasting tool.

Sources of Model and Data Inputs

The datasets that are included to support models and analytics within the PyreCast tool include:

- Fuel and topography data layers (rasters) for all static inputs required by current-generation fire spread models. See Table 1 for the sources of fuels and topography data.
- 8-day fire weather forecasts that are refreshed every 6 hours, that provide hourly meteorological inputs and fuel moisture content values necessary to drive models for real-time active fire spread and risk forecasts. See Table 2 for the sources of weather forecast data
- Structure/building footprints data layers (vector files) from the [Microsoft building footprint dataset](#).
- National Weather Service (NWS) red flag warning and fire weather watch polygons
- Near real time satellite-based fire detection data from Terra/Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) and Suomi National Polar-orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS).
- Publicly accessible transmission line data from the [Homeland Infrastructure Foundation Level Dataset](#).

Fire spread models

Two fire spread models are currently used in PyreCast: [ELMFIRE](#) and GridFire. The primary difference between the two models is the way that the fire front is tracked internally. ELMFIRE uses the Eulerian level set method, a technique for tracking curved surfaces on a grid, to track the fire front whereas GridFire uses a cellular automata approach. Both models make use of well-established conventional fire modeling formulae including:

- Surface Fire Spread: Rothermel 1972 with FIREMODS adjustments from Albini 1976
- Crown Fire Initiation: Van Wagner 1977
- Passive/Active Crown Fire Spread: Cruz 2005
- Wind Adjustment Factor: Albini & Baughman 1979
- Spotting: Empirical treatment of spotting distance modeled as a lognormal distribution

Model code for ELMFIRE and GridFire can accessed through link to these repositories:

Description	URL
ELMFIRE fire spread model	https://github.com/lautenberger/elmfire https://elmfire.io
GRIDFIRE fire spread model	https://github.com/pyregence/gridfire
PyreCast web application	https://github.com/pyregence/pyregence

Concluding Remarks

This document provides a User Guide for PyreCast as it exists in June 2022 and as updated with links to data and code repositories as of June 2023. Since additional features and enhancements are being added to PyreCast on a regular basis, updates to this document will occur periodically.

Appendices

Appendix 1. Disclaimer displayed at PyreCast start up.

The PyreCast site is in a Beta testing phase. It provides access to an experimental fire spread forecast tool. Use at your own risk. Use of the web site is undertaken at one's sole risk. The site is available on an "as is" and "as available" basis without warranty of any kind. The project team does not warrant that the site will (i) be uninterrupted or error-free; or (ii) result in any desired outcome. The project team is not responsible for the availability or content of other services, data, or public information that may be used by or linked to this site. To the fullest extent permitted by law, the Pyregence Consortium, and each and every individual, entity and collaborator therein, hereby disclaims (for itself, its affiliates, subcontractors, and licensors) all representations and warranties, whether express or implied, oral or written, with respect to this site, including without limitation, all implied warranties of title, non-infringement, quiet enjoyment, accuracy, integration, merchantability or fitness for any particular purpose, and all warranties arising from any course of dealing, course of performance, or usage of trade.

Appendix 2. Terms of Use

We, the Pyregence Consortium, and each and every individual, entity and collaborator therein (“Pyregence”, “we”, “us” or “our”), operate web sites, research facilities, mobile applications, social media pages, and all site-related services (collectively, the “Site”). The Site is provided for your personal and noncommercial use. These Terms of Use, together with the **Privacy Policy** and any documents and licenses expressly incorporated (collectively these “Terms”) govern your access to and use of the Site, whether as a guest or registered user. By using the Site, you agree to these Terms. If you do not agree to the Terms, do not use the Site. You will still be bound by the Terms as they existed when you last used the Site. We reserve the right to make changes to these Terms at any time. Please check back from time to time to ensure you are aware of any updates or changes.

THESE TERMS INCLUDE IMPORTANT INFORMATION ABOUT LIMITATIONS OF LIABILITY AND AN AGREEMENT TO SUBMIT ALL DISPUTES TO INDIVIDUAL MANDATORY ARBITRATION – PLEASE READ CAREFULLY

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Disclaimer THE SITE AND ALL OF ITS TEXT, IMAGES, AND SOFTWARE (COLLECTIVELY, “CONTENTS”) ARE PROVIDED ON AN 'AS IS' BASIS WITHOUT ANY WARRANTIES OF ANY KIND, WHETHER EXPRESS, IMPLIED OR STATUTORY. YOU AGREE THAT YOU MUST EVALUATE, AND THAT YOU BEAR ALL RISKS ASSOCIATED WITH THE USE OF THE SITE, INCLUDING WITHOUT LIMITATION ANY RELIANCE ON THE ACCURACY, COMPLETENESS OR USEFULNESS OF ANY CONTENT AVAILABLE THROUGH OR IN CONNECTION WITH THE SITE.

Limitation of Liability - We recognize that some laws provide consumers specific rights and remedies and prohibit waiver of the same. Except with respect to such laws, you waive all damages under any cause of action other than actual damage for out-of-pocket loss limited to the amount you paid to access and use the Site. For example, except with respect to such laws, you waive nominal damages, liquidated damages, statutory damages, consequential damages, presumed damages, as well as the imposition of costs and attorney’s fees.

II. Data Protection.

Security - We maintain safeguards intended to protect the integrity and security of the Site. However, we cannot guarantee that the Site will be secure, complete, correct or up-to-date, or that access to the Site will remain uninterrupted.

Registration: User Names and Passwords - To use certain portions of the Site, you may be required to create an account and password. Your user name and password are for your personal use only and should be kept confidential. You are responsible for any use or misuse of your user name or password. Please promptly notify us of any confidentiality breach or unauthorized use of your user name, password, or your Site account.

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third-party venue subject to the terms and conditions, privacy policy and relevant licenses of that provider. Your use of other web sites and online services is solely at your own risk.

III. RULES OF CONDUCT.

Follow the Law - While using the Site, you are required to comply with these Terms and all applicable laws, rules and regulations.

Respect Others - We expect users of the Site to respect the rights and dignity of others. Do not use the Site to harass, stalk, threaten or otherwise violate the legal rights of others. Do not impersonate anyone. Do not disrupt the operation of the Site. We reserve the right in our sole discretion to restrict use, block guests and/or terminate accounts that do not comport with these Rules of Conduct and to remove any materials that violate these Terms or which we find objectionable.

Use of the Site - The Site is maintained on servers located in the United States, and is intended for users aged 16 and above who are not restricted or prohibited by law or regulation to access and use the Site in the United States.

Indemnity - You agree to defend, indemnify and hold harmless us, and our directors, officers, employees, agents, affiliates, shareholders, licensors, and representatives, from and against all claims, losses, costs and expenses (including without limitation attorneys' fees) arising out of (a) your use of, or activities in connection with, the Site, (b) any violation of these Terms by you or through your account; and (c) any allegation that any Submission or Creation (defined below) you make available or create through or in connection with the Site infringes or otherwise violates the copyright, trademark, trade secret, privacy or other intellectual property or other rights of any third party.

Termination - We may terminate your access to the Site at our sole discretion, at any time, and without prior notice. We may immediately deactivate or delete all related information and files.

IV. CONFIDENTIALITY OF COMMUNICATIONS.

Personal Information - Any Personal Information you submit on or through the Site is governed by our **Privacy Policy**. Please do not submit through the Site any sensitive personal information, as defined by our Privacy Policy.

Additional Communications - Any other information you submit on or through the Site will be treated as non-confidential and non-proprietary. This includes all information you submit directly or indirectly (for example, through the use on a third-party social media site using a hashtag we promote).

Submissions and Creations - Submissions and Creations (defined below) will be treated as non-confidential and non-proprietary. You acknowledge that any information in a Submission or Creation is public information.

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VI. SUBMISSIONS AND CREATIONS.

On-Site Submissions and Creations - The Site may include a variety of interactive services. You may be able to submit information using these services (“On-Site Submissions”). You also may be able to create materials using the services (“On-Site Creations”).

Off-Site Submissions and Creations - The same sort of interactive services may be available on certain third-party web sites and social media platforms, including independent sites of the individual members of the Pyregence Consortium. You may use these services to submit information (“Off-Site Submissions”), *for example*, using hashtags we promote, leaving a review, feedback or suggestion, or commenting on social media pages. You may also use those third-party services to create materials (“Off-Site Creations”).

On-Site Submissions and Off-Site Submissions shall, collectively, be referred to herein as “Submissions”; On-Site Creations and Off-Site Creations shall, collectively, be referred to herein as “Creations.”

Grant of Rights for Submissions and Creations - You grant us a worldwide, non-exclusive, transferable, royalty-free, perpetual, irrevocable right and license with respect to all Submissions and Creations. We can use this license with no compensation to you. The license allows us: (a) to use, reproduce, distribute, adapt (including without limitation edit, modify, translate, and reformat), derive, transmit, display and perform, publicly or otherwise, any Submission and/or Creation (including without limitation your voice, image or likeness as embodied in such Submission or Creation), in any media now known or hereafter developed, for our business purposes, and (b) to sublicense the foregoing rights, through multiple tiers, to the maximum extent permitted by applicable law. The foregoing licenses shall survive termination of these Terms for any reason. To the extent that there may exist a conflict between the foregoing license and the applicable EPL License, the EPL license shall prevail and control.

Representation and Warranty - For each Submission and each Creation, you represent and warrant that you have all rights necessary to grant these licenses (including without limitation rights in any musical compositions and/or sound recordings embodied or embedded in any Submission or Creation), and that such Submission or Creation, and your provision or creation thereof through the Site, complies with all applicable laws, rules and regulations and does not infringe or otherwise violate the copyright, trademark, trade secret, privacy or other intellectual property or other rights of any third party. You further irrevocably waive any “moral rights” or other rights with respect to attribution of authorship or integrity of materials regarding each Submission and Creation that you may have under any applicable law under any legal theory.

No Liability for Disclosure; Publicly Facing Submissions and Creations - No Submission or Creation will be subject to any obligation, whether of confidentiality, attribution or otherwise, on our part and we will not be liable for any use or disclosure of any Submission or Creation. Further, to the extent that any

Submission or Creation is made in a public space on our Site or other site, it is considered publicly facing content that was intended by you to be publicly accessible. Under no circumstances do we agree to delete, modify, censor or remove any such publicly facing content from our Site or other sites.

You Have Sole Responsibility for Your Submissions and Creations - You acknowledge and agree that you are solely responsible for any Submission or Creation you provide, and for any consequences thereof, including the use of any Submission or Creation by third parties. You understand that your Submissions and Creations may be accessible to other parties, who may be able to share your Submissions and Creations with others and to make them available elsewhere, including on other sites and platforms.

We Are Not Responsible for Third Parties - We have no control over what third parties may do with your Submission or Creation. We have no legal liability for such misuse. We also do not endorse and are not responsible for any opinions, advice, statements, information, or other materials made available in any Submission or Creation.

VII. DISPUTE RESOLUTION TERMS (PLEASE READ CAREFULLY).

Informal Dispute Resolution. - To give us an opportunity to resolve informally any disputes between you and us arising out of or relating in any way to our Site, these Terms, or any services or products provided (“Claims”), you agree to communicate your Claim to us by emailing us at contact@pyregence.org. You agree not to bring any suit or to initiate arbitration proceedings until 60 days after the date on which you communicated your Claim to us have elapsed. If we are not able to resolve your Claim within 60 days, you may seek relief through arbitration or in small claims court, as set forth in this Section VII.

Choice of Arbitrator and Rules - Any disputes, claims, and causes of action arising out of or connected with your use of the Site (each, a “Dispute”) must be submitted exclusively to the American Arbitration Association (AAA) to be heard under their **Consumer Arbitration Rules**. The AAA’s rules and filing instructions are available at www.adr.org or by calling 1-800-778-7879. If for any reason, AAA is unable or unwilling to conduct the arbitration consistent with these terms, you and we will pick another arbitrator pursuant to **9 U.S. Code § 5**.

Mandatory Arbitration - You agree that any Dispute between us shall be resolved exclusively in individual (non-class action) arbitration. The parties intend to be bound to the **Federal Arbitration Act**, 9 U.S.C. § 1 *et seq.* An arbitration means there will be no jury and no judge.

Class Action Waiver - You agree that any Dispute between us shall be resolved in an individual action. Under no circumstances will you file, seek, or participate in a class action, mass action, or representative action in connection with any Dispute.

Scope of Arbitration - The arbitrator shall exclusively determine all issues as to any Dispute, and must follow and enforce these Terms. The arbitrator shall also determine any question as to whether any Dispute or issue is subject to arbitration. The arbitrator shall not have the power to hear any Dispute as a class action, mass action, or representative action. The arbitrator shall not have any power to issue relief to anyone but you or us.

Exception to Arbitration - Disputes that can be fully resolved in small claims court need not be submitted to arbitration.

Choice of Venue - You agree that any Dispute shall be heard exclusively in Contra Costa County, California unless otherwise agreed to by the parties or determined by the arbitrator. You consent to jurisdiction in the State of California for all purposes.

Choice of Law - These Terms and your use of the Site are governed by the laws of the State of California, U.S.A., without regard to its choice of law provisions. However, any determination as to whether a Dispute is subject to arbitration, or as to the conduct of the arbitration, shall be governed exclusively by the **Federal Arbitration Act**, 9 U.S.C. § 1 *et seq.*

Remedies Available in Arbitration - The arbitrator may grant any remedy, relief, or outcome that the parties could have received in court, including awards of attorney's fees and costs, in accordance with the law(s) that applies to the case, except injunctive relief.

Injunctive Relief - The arbitrator may not issue any injunction. If either party in a Dispute seeks injunctive relief, the arbitrator will complete arbitration of the Dispute, issue an award of monetary compensation (if any), and then the party seeking injunctive relief may file a new action in state in Contra Costa County, California, or federal court in the Northern District of California solely for injunctive relief. The findings of fact and conclusions of law of the arbitrator shall not be submitted as evidence or constitute precedent in such subsequent suit.

VIII. MISCELLANEOUS.

Notices - Notices to you may be made via posting to the Site, by email, or by regular mail, in our sole discretion. Notices to us should be made by emailing us at **contact@pyregence.org**.

Evidence - You agree that a printed version of these Terms and of any notice given in electronic form, including by posting to the Site, shall be admissible in any judicial or administrative proceedings based upon or relating to these Terms.

Force Majeure - We will not be responsible for any failure to fulfill any obligation due to any cause beyond our control.

Severability - If any provision of these Terms is determined to be unenforceable or invalid, such provision shall nonetheless be enforced to the fullest extent permitted by applicable law, and such determination shall not affect the validity and enforceability of any other remaining provisions.

Information or Complaints - If you have a question or complaint regarding the Site, please send an e-mail to us at **contact@pyregence.org**. Please note that e-mail communications will not necessarily be secure; accordingly, you should not include credit card information or other sensitive information in your e-mail correspondence with us. California residents may reach the Complaint Assistance Unit of the Division of Consumer Services of the California Department of Consumer Affairs by mail at 1625 North Market Blvd., Sacramento, CA 95834, or by telephone at (916) 445-1254 or (800) 952-5210.

Claims of Copyright Infringement - We respect the intellectual property rights of others. If you believe that any content on our Site or other activity taking place on our Site infringes a work protected by copyright, please notice us by e-mail at **contact@pyregence.org**. Your notice must comply with the

Digital Millennium Copyright Act (17 U.S.C. §512) (the “DMCA”). Upon receipt of a DMCA-compliant notice, we will respond and proceed in accordance with the DMCA.

We have also put in place a Repeat Infringer Policy to address situations in which a particular individual is the subject of multiple DMCA notices. If we determine that an individual has violated our Repeat Infringer Policy, then we may, in our sole discretion, take any number of steps, such as issuing warnings, suspending or terminating the individual’s account, or any other measures that we deem appropriate.

IX. CHANGES.

Changes to the Site - We may modify or discontinue the Site and its Contents at any time, in our sole discretion without notice. We reserve the right to withdraw or amend this Site, and any service or material we provide on our Site, in our sole discretion without notice. We will not be liable if, for any reason, all or any part of our Site is unavailable at any time or for any period.

Changes to the Terms - We may change these Terms at any time. We will provide reasonable notice, including by posting a revised version of these Terms, which are effective as of the date posted through the Site. Your use of our Site is subject to the Terms posted on our Site at the time of your use. Your continued use of our Site following the posting of revised Terms means that you accept to the changes. However, any changes to the Dispute Resolution Terms set forth in Section VII will not apply to any Dispute for which the parties have actual notice on or prior to the date the change is posted on our Site.

Appendix 3. Privacy Policy

The Pyregence Consortium, and each and every individual, entity and collaborator therein; (“Pyregence”, “we”, “us” or “our”) respects your desire for privacy. This Privacy Policy explains what information we collect about you, whether on our web site, mobile application, or elsewhere (collectively, the “Site”). It also explains why we collect the information, as well as how we collect and use the information.

This Privacy Policy is intended for individuals in the United States. If you live outside of the United States and choose to use the Site, you do so at your own risk and understand that your information will be sent to and stored in the United States. By using the Site in the United States or otherwise providing personal information to us, you agree to this Privacy Policy.

PERSONAL INFORMATION WE COLLECT.

“Personal Information” generally means any information that identifies you as an individual, and any other information we associate with it. We collect several categories of information, from a few different sources:

Usage Information. We passively collect information when you use the Site, through our web servers and third-party analytics tools. For instance, our system logs may record certain information about visitors to the Site, including the web request, Internet Protocol (“IP”) address, device and mobile ad identifiers, browser information, interaction with the Site, pages viewed, app usage, and other such information.

Information You Might Provide. We collect information and other content you voluntarily provide us, which may include:

- User ID and password
- Contact information when you register or submit an inquiry, such as your name, street address, date of birth, phone number, and/or email address
- Geographical or location information, which may include city, county, state, zip code, country or other geographical or map input(s) such as repositioning the map view.
- Any information you provide in communications with us, such as by e-mail or via customer service.
- Any submissions or creations that you generate on the Site.
- Any content or contributions you post in a public space on the Site, including comments, videos and photos that you might submit.

Non-Identifiable Information. In addition to collecting Personal Information, we may collect information that does not identify you and is not associated with your Personal Information. We may also de-identify information, so it no longer identifies you. We may also aggregate and use such information to engage other activities in a manner that does not use Personal Information and is thus outside the scope of this Privacy Policy.

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We use certain cookies, pixel tags and other technologies to help us understand how you use the Site and enable us to personalize your experience. Cookies are small pieces of text. They are provided by most websites and stored by your web browser on the computer, phone, or other device that you are using. Cookies serve many purposes. They help a website remember your preferences, learn which areas

of the website are useful and which areas need improvement, and can provide you with targeted advertisements or personalized content. Sometimes, cookies are enabled when pixels are placed on a website. Pixels are also referred to as web beacons, clear gifs, and tags. They enable websites to read and place cookies. To learn more about cookies, please see the Cookies and Analytics section below, or visit <http://www.allaboutcookies.org/>.

HOW WE USE PERSONAL INFORMATION.

We may use Personal Information as permitted by law, for the following business purposes:

- to improve and personalize your experience with our Site.
- to perform analytics, quality control, and determine the effectiveness of our Site, and develop new products and services.
- to respond to your inquiries and to communicate with you.
- to consider your application for employment and qualifications, and to conduct reference checks.

We may also use your information as we believe to be necessary or appropriate for certain essential purposes, including:

- to comply with applicable law and legal process.
- to respond to requests from public and government authorities, including public and government authorities outside your country of residence.
- to detect, prevent, or investigate potential security incidents or fraud.
- to enforce our terms and conditions.
- to protect our operations.
- to protect our rights, privacy, safety or property, security and/or that of you or others.
- to allow us to pursue available remedies or limit the damages that we may sustain.

If you submit any information relating to other people in connection with the Site, you represent that you have the authority to do so and to permit us to use the information in accordance with this Privacy Policy.

HOW WE SHARE INFORMATION.

To the extent permitted by law, and in connection with its business operations and services, Pyregence may disclose your Personal Information to the following categories of third parties:

- to individual members of the Pyregence Consortium.
- to our affiliates for the purposes described in this Privacy Policy.
- to our third-party service providers who provide website hosting, data analysis, infrastructure provision, IT services, email delivery services and other services, to enable them to provide services.
- to a third party in the event of any reorganization, merger, sale, joint venture, assignment, transfer or other disposition of all or any portion of our business, assets or stock (including in connection with any bankruptcy or similar proceedings).
- our online and email advertisers or other third-party vendors we use who may provide cookies, pixel tags, web beacons, clear GIFs or other similar technologies for use on the Site or other websites to manage and improve our website analytics.
- in connection with the essential purposes described above (e.g., to comply with legal obligations).

YOUR CHOICES AND RIGHTS.

Modifying your Personal Information. To update or change Personal Information that you already have submitted in connection with a product registration, warranty claim, or employment application, please contact us at contact@pyregence.org

Cookies. You can modify your cookie settings on your browser, but if you delete or choose not to accept our cookies, you may be missing out on certain features of the Site.

"Do Not Track" Settings. Your Internet browser may contain tools to request that web sites not track your online activities. Industry standards for this technology are evolving and we currently do not respond to or take any action with respect to the "do not track" settings in your Internet browser.

California Privacy Rights. California residents have additional rights under the California Consumer Privacy Act.

Right to Know. California residents may request the following information from Pyregence:

1. The categories of Personal Information that we collect, use, disclose, and sell, as applicable;
2. The categories of sources from which Personal Information is collected;
3. The business or commercial purpose for collecting or selling (if applicable) the Personal Information;
4. The categories of third parties with whom we share Personal Information; and
5. The specific pieces of Personal Information that we have collected about you.

Right to Delete. California residents may request that we delete your Personal Information. Note that deletion requests are subject to certain limitations, for example, we may keep Personal Information as required or permitted by law, or to process transactions and facilitate customer and service requests.

Right to Opt-Out. We do not sell the Personal Information of California residents.

Submitting a Request. You have the right not to be discriminated against if you exercise your privacy rights. To make a request to access or delete your Personal Information, please email us at contact@pyregence.org. Please provide your name, state of residence, home or business address with zip code, the services you utilized, so that we can authenticate and verify your request as we are required to do by law. You may designate an authorized agent to submit a request on your behalf. In order to designate an authorized agent, please send us your written authorization for that agent. Both you and your agent must sign and date the form.

OTHER THINGS TO KNOW.

Third Party Content. The Site may link to other websites and online services. Such links are provided for your convenience only. We have no control over such third parties and if you decide to access any third-party link, you do so solely at your own risk and subject to the terms and conditions and privacy policy that third-party.

Social Media Features and Widgets. The Site may include social media features and widgets, such as the LinkedIn button. These features may collect your IP address, which page you are visiting on the Site, and may set a cookie to enable the feature to function properly. Social media features and widgets are either hosted by a third party or hosted directly on our online Services. Your interactions with these features and widgets are governed by the privacy policy of the company providing them.

Minors. The Site is not directed toward minors under age 18. If we discover that we have inadvertently collected Personal Information from a person under 18, we will delete that information immediately. If

you are a parent or guardian of a minor and believe he or she has disclosed personal information to us, please contact us at contact@pyregence.org.

CHANGES TO THIS POLICY.

We may update or change this Privacy Policy from time to time. You can see when we last updated the Policy by checking in the “Last Updated” date at the top of this page. All changes to the Policy are effective as of the date it is posted.

QUESTIONS.

If you have any questions regarding this Privacy Policy, you can contact us at contact@pyregence.org.

Appendix 4. Code License

All code developed with funding from this project will be made available under an open source GNU General Public License version 3 (GPL) license and further modifications of the code made under this agreement will be re-released under the GPL license. GPL is a widely used free software license that guarantees end users the freedom to run, study, share, and modify the software. The distribution terms of open-source program code will generally comply with the following opensource.org criteria:

Free Redistribution - The license shall not restrict any party from selling or giving away the software as a component of an aggregate software distribution containing programs from several different sources. The license shall not require a royalty or other fee for such sale.

Source Code - The program must include source code and must allow distribution in source code as well as compiled form. Where some form of a product is not distributed with source code, there must be a well-publicized means of obtaining the source code for no more than a reasonable reproduction cost, preferably downloading via the Internet without charge. The source code must be the preferred form in which a programmer would modify the program. Deliberately obscured source code will not be allowed. Likewise, intermediate forms such as the output of a preprocessor or translator are not allowed.

Derived Works - The license must allow modifications and derived works and must allow them to be distributed under the same terms as the license of the original software.

Integrity of The Author's Source Code - The license may restrict source-code from being distributed in modified form *only* if the license allows the distribution of "patch files" with the source code for the purpose of modifying the program at build time. The license must explicitly permit distribution of software built from modified source code. The license may require derived works to carry a different name or version number from the original software.

No Discrimination Against Persons or Groups - The license must not discriminate against any person or group of persons.

No Discrimination Against Fields of Endeavor - The license must not restrict anyone from making use of the program in a specific field of endeavor. For example, it may not restrict the program from being used in a business, or from being used for genetic research.

Distribution of License - The rights attached to the program must apply to all to whom the program is redistributed without the need for execution of an additional license by those parties.

License Must Not Be Specific to a Product - The rights attached to the program must not depend on the program's being part of a particular software distribution. If the program is extracted from that distribution and used or distributed within the terms of the program's license, all parties to whom the program is redistributed should have the same rights as those that are granted in conjunction with the original software distribution.

License Must Not Restrict Other Software - The license must not place restrictions on other software that is distributed along with the licensed software. For example, the license must not insist that all other programs distributed on the same medium must be open-source software.

License Must Be Technology-Neutral - No provision of the license may be predicated on any individual technology or style of interface.