Analytical Tools for Preparing Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone and Particulate Matter Concentrations

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Note: This document is intended to summarize publicly available resources that air agencies may find helpful to use when developing analyses to support exceptional events demonstrations for wildfire and prescribed fires on wildland. The U.S. Environmental Protection Agency (EPA) is not responsible for the development or ongoing maintenance of the resources referenced in this document.

For detailed information on developing demonstrations for wildfires and prescribed fires on wildland, please see EPA's "Final Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations" and "Prescribed Fire on Wildland that May Influence Ozone and Particulate Matter Concentrations," available at https://www.epa.gov/air-quality-analysis/final-2016-exceptional-events-rule-supporting-guidance-documents-updated-faqs

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1. Purpose of This Document

This document responds to stakeholder feedback requesting a summary of available resources that air agencies may find helpful when developing analyses to support exceptional events demonstrations for wildfire and prescribed fire events that may influence ozone and particulate matter concentrations. Please see the Environmental Protection Agency's (EPA) website for detailed information on developing exceptional events demonstrations for wildfire and prescribed fire events.[1] EPA recognizes the limited resources of air agencies that prepare and submit exceptional events demonstrations. To assist in identifying applicable guidance, this document offers a consolidated summary of the resources and tools identified in distinct guidance documents.

EPA developed this document to assist air agencies in meeting the requirements of the Exceptional Events Rule (EER) for wildfire and prescribed fire events and to provide information on the tools and analyses that may be used in exceptional events demonstrations. This document focuses on the preparation of exceptional events demonstrations for wildfire events that cause monitored ozone (O_3) and particulate matter (PM) exceedances or violations. For additional context regarding this document, background information regarding statutory and regulatory requirements associated with the EER is offered in section 2 of this document, titled "Statutory and Regulatory Requirements". This information is a summary and more complete and additional information can be found in the Clean Air Act (CAA) and applicable implementation requirements, as well as guidance documents, all cited in section 6 of this document, titled "References".

2. Statutory and Regulatory Requirements

EPA promulgated the EER in 2007 to implement CAA section 319(b), which allows for the exclusion of air quality monitoring data influenced by exceptional events from use in actions with regulatory significance, including determinations of exceedances or violations of the National Ambient Air Quality Standards.[2] EPA revised the 2007 EER in 2016. The revised EER at 40 CFR 50.14(c)(3)(iv) clarifies that an exceptional events demonstration must include the following six elements:

1) A narrative conceptual model that describes the event(s) causing the exceedance or violation and a discussion of how emissions from the event(s) led to the exceedance or violation at the affected monitor(s);

[1] All guidance documents addressing exceptional events are available on EPA's website at: *https://www.epa.gov/air-quality-analysis/final-2016-exceptional-events-rule-supporting-guidance-documents-updated-faqs#guidance*.
[2] The Exceptional Events Rule is available on EPA's website at*: https://www.epa.gov/air-quality-analysis/federal-register-notice-final-revisions-exceptional-events-rule*.

2) A demonstration that the event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation;

3) Analyses comparing the claimed event-influenced concentration(s) to concentrations at the same monitoring site at other times. The Administrator shall not require a state to prove a specific percentile point in the distribution of data;

4) A demonstration that the event was both not reasonably controllable and not reasonably preventable;

5) A demonstration that the event was caused by human activity that is unlikely to recur at a particular location or was a natural event; and

6) Documentation that the submitting air agency followed the public comment process on the demonstration.

3. Weight of Evidence Approach

EPA reviews exceptional events demonstrations on a case-by-case basis using a weight of evidence approach considering the specifics of the individual event. This means EPA considers all relevant evidence submitted with a demonstration and qualitatively "weighs" this evidence based on its relevance to the EER criterion being addressed, the degree of certainty, the persuasiveness, and other considerations appropriate to the individual pollutant and the nature and type of event.

EPA expects that certain events may require more evidence of the causal relationship than others. Air agencies should prepare and submit the appropriate level of supporting documentation, which will vary on a case-by-case basis depending on the nature and severity of the event. Air agencies should work collaboratively with their EPA Regional office to determine the appropriate scope of an exceptional events demonstration.

4. Exceptional Events Submission Requirements

4.1 Initial Notification

The EER requires an initial notification by the air agency to EPA of a potential exceptional event for which the agency is considering preparing a demonstration. EPA recommends air agencies utilize the Exceptional Events Tracking System (*https://www.epa.gov/air-quality-analysis/electronic-submission-exceptional-events-demonstrations-andor-mitigation-plans*) throughout the process, although the initial notification may also be conveyed as an official letter, electronic mail, or other means of communication from an air agency official with authority to do so. Air agencies are encouraged to contact their EPA Regional office to discuss options. A key purpose of the initial notification is for EPA to provide early feedback to the air agency regarding whether and how it makes sense to proceed with development of the exceptional events demonstration.

Following initial notification and discussion with EPA Regional office, air agencies should flag event-associated data and create an initial event description in EPA's Air Quality System (AQS) for data requested for exclusion.

4.2 Regulatory Significance

The EER clarifies at 40 CFR 50.14(a)(1) that it applies to the treatment of data showing exceedances or violations for the following types of regulatory actions:

- Initial area designations and redesignations;
- Area classifications;
- Attainment determinations (including clean data determinations);
- Attainment date extensions;
- Findings of State Implementation Plan (SIP) inadequacy leading to a SIP call; and
- Other actions on a case-by-case basis as determined by the Administrator.

An exceptional event must have regulatory significance for EPA to consider the demonstration. This is an important streamlining feature of the EER, to ensure that air agencies are able to focus their resources on exceptional events demonstrations that are tied to regulatory outcomes. Air agencies and EPA should discuss the regulatory significance of an exceptional event during the Initial Notification of the potential exceptional event prior to the air agency submitting a demonstration for EPA's review.

4.3 EPA Review

The EER outlines intended timelines for EPA review of exceptional events demonstrations but does not include firm deadlines. EPA generally intends to conduct its initial review of an exceptional events demonstration within 120 days of receipt and will follow up with the air agency if additional information is required. EPA intends to make a decision regarding event concurrence as expeditiously as possible if required by a near-term regulatory action, but no later than 12 months following submittal of a complete package.

EPA decisions on exceptional events demonstrations are not considered to be final agency action until they are included in an EPA regulatory action that undergoes a public notice and comment process.

5. Analyses to Support Exceptional Events Demonstrations

This section is intended to provide information about where to obtain information for the conceptual model of a demonstration, and analytics that might be useful for supporting the clear causal relationship criterion. Explanation is also provided about why certain analytics might be considered more or less useful for O_3 or PM demonstrations showing wildfire impacts on near or far downwind surface level monitors. For both O_3 and PM, EPA recommends that air agencies, in consultation with their EPA Regional office, use a stepwise approach for integrating only those analyses that are appropriate and necessary to satisfy the clear causal relationship criterion. This approach is intended to help conserve air agency resources and support the goal of right-sized demonstrations.

Various analyses could be useful for fire events that influence both O_3 and PM concentrations to help support the demonstration of the clear causal relationship. Some products may be more useful for situations where the fire is nearby to potentially impacted monitor(s) and might not be worth including for demonstrations where the transport distances are much greater. Additional guidance and details on the types of analyses useful for exceptional events demonstrations can be found in the exceptional events *Wildfire Ozone Guidance* (*https://www.epa.gov/air-quality-analysis/final-guidance-preparation-exceptional-events-demonstrations-wildfire-events*) and the *Updated Frequently Asked Questions* document (*https://www.epa.gov/air-quality-analysis/updated-exceptional-events-rule-faqs*). The analytics presented here are not organized in a manner consistent with the tiering system in the *Wildfire Ozone Guidance*. Agencies intending to develop such demonstrations should follow that guidance and discuss with their EPA Regional office when determining what evidence is necessary for a particular demonstration.

5.1 Conceptual Model of the Event

Table 1 provides at least one source of information for each of the main technical elements related to developing the conceptual model of the event and how the downwind receptor(s) were impacted. Conceptual descriptions showing O_3 and PM impacts from specific fires include a description of synoptic scale meteorology linking the fire location and impacted monitor, fire size (and emissions if known), and an understanding about typical (non-fire related) meteorological conditions leading to elevated O_3 or PM in a particular area.

Table 1. Sources of information that could support the development of the conceptual description of O_3/PM formation in an area and a particular fire impact episode.

Type	**Tool**	**Location**
Fire Location	InciWeb: An incident information management system	*https://inciweb.wildfire.gov/*
	Worldview: NASA's interactive interface for browsing full-resolution, global, daily satellite images	*https://worldview.earthdata.nasa.gov*
	NOAA's Hazard Mapping System Fire & Smoke Product	*https://www.ospo.noaa.gov/Products/land/hms.html#data*
Fire Size	InciWeb: incident information management system	*https://inciweb.nwcg.gov*
	Rapid Assessment of Vegetation Conditions: USDA's assessments of burn severity following large wildland fires on forested National Forest System (NFS) lands	*https://burnseverity.cr.usgs.gov/ravg/*
Fire emissions	BlueSky Playground: USDA's smoke modeling tool	*https://tools.airfire.org/playground/v3.5/emissionsinputs.php*
Archived National Weather Service Reports	Mesonet: Iowa State University's collection of environmental data, including archived weather reports	*https://mesonet.agron.iastate.edu/wx/afos/list.phtml*
Archived historical weather maps	Storm Prediction Center's archive of weather maps	*https://www.spc.noaa.gov/obswx/maps/*

Archived historical surface wind maps	AirNow Tech: U.S. EPA's password protected website for air quality data management and analysis	*https://www.airnowtech.org*

5.2 Clear Causal Relationship Criterion

Table 2 provides at least one source of information for each of the simple analytic technical elements that air agencies could use to provide information to support the clear causal relationship criterion. Table 3 provides at least one source of information for each of the complex analytics supporting fire emissions transport to the monitor(s) that could be used to provide support for the clear-causal relationship. This section also discusses the strengths and weaknesses of these different analytics for O_3/PM demonstrations in situations where the fire and monitor(s) are closer in proximity (hundreds of miles apart or less) or more distant (thousands of miles apart).

Table 2. Simple Analytics supporting fire emissions affected the monitor(s)

Type	**Tool**	**Location**
Hazard mapping system smoke polygons	AirNow Tech: U.S. EPA's password protected website for air quality data management and analysis	*https://www.airnowtech.org/navigator*
	NOAA's Hazard Mapping System Fire & Smoke Product	*https://www.ospo.noaa.gov/Products/land/hms.html#maps*
Visible satellite images	Worldview: NASA's interactive interface for browsing full-resolution, global, daily satellite images	*https://worldview.earthdata.nasa.gov*
AOD satellite product	Worldview: NASA's interactive interface for browsing full-resolution, global, daily satellite images	*https://worldview.earthdata.nasa.gov*
NO_2, CO satellite products	RSIG: U.S. EPA's webpage for accessing environmental datasets, including satellite, modeled, and *in-situ* sensor data	*https://www.epa.gov/hesc/remote-sensing-information-gateway*
O_3/PM monitored spatial/diurnal patterns	AQS: U.S. EPA's repository of ambient air quality data	*https://www.epa.gov/aqs*
	Outdoor Air Quality Data: EPA's tool for daily air quality summary statistics for the criteria pollutants by monitor	*https://www.epa.gov/outdoor-air-quality-data/air-data-concentration-plot*

HAZARD MAPPING SYSTEM SMOKE POLYGONS

Hazard Mapping System (HMS) smoke products are contours that represent human drawn lines based on satellite visible imagery (*https://www.ospo.noaa.gov/Products/land/hms.html#about*). Polygons are colored with a human interpreted correspondence to aerosol concentrations somewhere in the vertical column but do not provide quantitative information of surface level O_3 or PM impacts. Documentation for this product specifically emphasizes the "qualitative nature of the visual analysis" when interpreting the smoke layers. These smoke sketches do not provide any information about whether smoke is at the surface or aloft in the atmosphere. The lightest shaded contour color represents the potential for smoke with an interpreted concentration ranging from 0 to 10 micrograms per cubic meter ($\mu g/m^3$) somewhere in the column, which means areas with this shading might represent very small or no actual smoke impact, particularly at the surface. This suggests this product is most useful for understanding smoke impacts closer to fires and confidence would be highest for using the warmest color contours, recognizing that even in this situation the product does not provide information about smoke at the surface.

HMS smoke sketches are typically shown as an aggregate of multiple contours from multiple satellites, using the geostationary satellites GOES-EAST and GOES-WEST. When these polygons are superimposed, they can provide the appearance of a large smoke impact. It should be noted that the HMS smoke sketches represent up to 4-hour increments in time and may not accurately represent the smoke impact of a single hour. In many situations, presenting the contours in this way may provide reasonable information; however, when attempting to establish a causal relationship it is important to determine whether potential smoke impacts happen at relevant times of the day or progress through time in a way that would suggest a continuous impact from a particular location. HMS smoke sketches can provide useful information when impacts are large and can be corroborated with other information like visible images or monitoring data and trajectory analysis. This type of information is most useful for areas near large wildfires and less useful for supporting a connection between specific fires and areas hundreds to thousands of miles downwind, where smoke impacts are very uncertain and most likely lofted well into the free troposphere.

SATELLITE PRODUCTS

Multiple types of remotely sensed data derived from satellite products can provide an indication about whether smoke may be in the atmosphere. These include visible images that show clouds and smoke, HMS smoke products, aerosol optical depth (AOD), Nitrogen Dioxide (NO_2), and Carbon Monoxide (CO) from one or more satellite platforms. Most satellite-based products do not provide information about surface level smoke, and none provide information about surface level O_3 or PM impacts from smoke.

Wildfires are not the only source of NO_2, CO, and aerosol in the atmosphere, so interpretation of these products for the purposes of identifying causality from specific fires to specific monitors over large distances can be challenging. For instance, NO_2 column data can provide useful information about large emissions sources but does not provide a clear link between sources and receptors far apart (i.e., hundreds to thousands of miles). Space-based measurements of NO_2

column data collected by the Tropospheric Monitoring Instrument (TROPOMI) satellite are useful for showing whether anthropogenic emissions at the monitor(s) are similar to, or greater than, other large cities in North America for recent time periods (2018 and later) (Goldberg et al., 2019). Products like TROPOMI NO_2 may be valuable for supporting a conceptual description of typical O_3 or PM formation in a particular region.

AOD is the sum of optical influence across all aerosol species, often dominated by the more reflective anthropogenic aerosols like sulfate. Isolating a smoke signal with AOD on individual days is very difficult, especially away from very large emissions sources like wildfire or a complex of wildfires.

Source-receptor relationships can be difficult to discern from visible images from satellites, especially when there is a long distance between the source and monitor. Additionally, large cloud complexes between the fire event and monitor(s) downwind can further complicate using these images to connect smoke to downwind O_3 or PM impacts. Often long-range transport of smoke is lofted by synoptic weather and transported in the free atmosphere decoupled from the surface. This transport can often be seen in the visible satellite images but does not mean smoke is being mixed to the surface.

SURFACE LEVEL MONITORED AMBIENT DATA ANALYTICS

Some ambient data measurements are more helpful than NO_2, CO, or $PM_{2.5}$ for specifically identifying fire impacts. This includes speciated PM compounds (e.g., elemental carbon), levoglucosan and other biomass burning tracers, black carbon/aethalometer data (differences between wavelengths measured by an aethalometer can be used as a fingerprint of smoke), and pollutant ratios (e.g., $PM_{2.5}/PM_{10}$, $PM_{2.5}$/CO) that are notably different for smoke compared to urban or clean airsheds (U.S. Environmental Protection Agency, 2016). These types of analytics are considered valuable for evaluating smoke impacts in an area by potentially providing source-specific, quantitative data supporting smoke impacts at ground level. Spatial and temporal analyses of monitoring data can also be informative. It is useful to compare potentially smoke impacted data to typical concentrations at that site for different periods of time, such as hourly, day-of-week, and seasonally, rather than looking only at time series for “peaks” that may simply be representative of local emissions and boundary layer dynamics rather than smoke-related events.

Timeseries and statistical analysis could be used to show anomalies for multiple pollutants measured at a receptor(s) based on routinely measured data collected by state and local agencies. Coincident anomalous CO, $PM_{2.5}$, and O_3 concentrations could occur on fire-impacted days (Laing et al., 2017). This coincident elevation is likely stronger for monitors in close proximity to the fire than for monitors long distances from the fire. Because coincidentally high $PM_{2.5}$, CO, and O_3 concentrations are also expected during stagnation events (Dawson et al., 2014; Kerr et al., 2018; Sun et al., 2017), air agencies should consider additional documentation to support a fire impact. Elevated NO_2 levels are likely more indicative of local emissions and meteorological conditions such as stagnation events than of fire impacts; thus, NO_2 is a poor tracer of fire activity.

Table 3. Complex analytics supporting fire emissions transport to the monitor(s)

Type	Tool	Location
Trajectory analysis	HYSPLIT: NOAA's Hybrid Single-Particle Lagrangian Integrated Trajectory model	*https://www.ready.noaa.gov/HYSPLIT_traj.php*
O_3 forecast modeling systems with wildfire emissions	None at the time of the development of this document	
PM forecast modeling systems with wildfire emissions	AirFire: USFS's webpage containing a variety of smoke and fire tools	*https://tools.airfire.org*
	HRRR: NOAA's High-Resolution Rapid Refresh Model	*https://rapidrefresh.noaa.gov/hrrr*
	Monterey Aerosol Page: U.S. National Research Laboratory Aerosol Products	*https://www.nrlmry.navy.mil/aerosol*
Photochemical modeling	U.S. EPA's Modeling Guidance for Demonstrating Air Quality Goals for Ozone, PM2.s and Regional Haze	*https://www.epa.gov/sites/default/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf*

TRAJECTORY ANALYSIS (HYSPLIT)

The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model is a Lagrangian trajectory model that can track pollutants through 3-dimensional space either forward or backward in time from a particular location (Draxler and Hess, 1997; Li et al., 2020). Forward trajectories developed using the HYSPLIT model starting at the fire event and backward trajectories starting at the monitor(s) location are useful for showing likely air parcel transport from the fire event to the monitor(s) on the day(s) targeted for a demonstration. The forward and backward trajectories should be reasonably consistent with each other and consistent with local (for fires and monitors in close proximity) and continental scale meteorology (for fires and monitors hundreds to thousands of miles apart).

Multiple types of trajectories are possible at the HYSPLIT internet site. Analyses with multiple trajectories should provide a consistent pattern of transport from the fire to the site (rather than an individual trajectory or two out of a larger analysis). The trajectory frequency product is very useful for these types of assessments because these provide a sense about the likelihood of distant endpoints traversing over a particular location and how often air was over a particular location. This type of information helps the user understand whether air on the days included in a demonstration tends to be more local in origin or from more distant areas.

The trajectory timing should be consistent with the conceptual model and the timing of the fire, the emissions, and the exceedances. For example, if a conceptual description indicates transport from a fire 2 days ago, the backward trajectory should be initiated from the monitoring site at a time consistent with the observed smoke, and it should pass near the fire location around the time the fire was active.

The trajectories become more uncertain the further forward in time from a fire location and further backward in time from a monitor location. The trajectories also do not provide information about dry and wet deposition or chemical transformation of pollutants in an air parcel. For instance, a longer trajectory (e.g., greater than 2 days) would be more likely to have impacts from physical removal processes like deposition. Consideration of rain events between the source and receptor help understand the potential impact of wet deposition removing smoke from the atmosphere.

PHOTOCHEMICAL MODELING

Some air quality forecast systems predict O_3 and $PM_{2.5}$ from wildland fire. Forecasting systems are not set up to provide information about specific fire impacts on specific downwind monitors. Forecasting systems predicting O_3 and $PM_{2.5}$ from wildland fire can also overstate impacts similar to retrospective photochemical modeling. Forecasting systems that do not include wildland fire emissions do not provide any information about the impacts from wildland fires on downwind monitors. The difference in forecasted O_3/$PM_{2.5}$ and observed O_3/$PM_{2.5}$ could be due to many reasons not related to the absence of wildland fires; poorly characterized stagnant meteorological conditions are challenging features for prognostic meteorological models. Factors such as day-specific emissions not being adequately captured (e.g., anthropogenic emissions) or other physical aspects of the modeling system such as representation of deposition and chemical reactions impact model performance. Predictions of O_3 forecasting systems that rely upon 2020 data could seem irregular due to area specific COVID impacts.

Several operational forecasts provide information about $PM_{2.5}$ impacts from wildland fire. The Naval Research Laboratory (NRL) has developed a global, multi-component aerosol analysis and modeling capability (NAAPS: Navy Aerosol Analysis and Prediction System) that combines satellite data streams with other available data and the global aerosol simulation and prediction model for predicting the distribution of tropospheric aerosols.

The National Oceanic and Atmospheric Administration's (NOAA) High Resolution Rapid Refresh-Smoke model (HRRR-Smoke) is a numerical weather prediction model that forecasts the impact smoke has on several weather variables. Based on satellite observations of fire location and intensity, HRRR-Smoke predicts the movement of smoke in three dimensions across the country over 48 hours, simulating how the weather will impact smoke movement and how smoke will affect visibility, temperature, and wind. Other smoke forecasting systems exist and could be used to support a demonstration (e.g., BlueSky system). A limitation with some forecast products for assessing links between specific fires and downwind monitors is that they may not provide surface level impacts of $PM_{2.5}$. Products that provide a total column integration provide an indicator that smoke could be anywhere in the atmosphere and as distance between a fire and monitor increases, the smoke is more likely to be lofted in the upper troposphere.

Photochemical models applied retrospectively can provide a useful connection between specific fires and downwind monitors (Baker et al., 2016; Baker et al., 2018; Hu et al., 2008; Liu et al., 2019). These models use meteorological inputs that are comparable and sometimes higher resolution than those used by HYSPLIT and would be expected to provide similar source-receptor information as HYSPLIT. A photochemical model can provide additional information that HYSPLIT cannot provide, which is an estimate of O_3 and other chemicals from specific fires at specific monitors downwind when the model is configured and applied in a way to reasonably quantify these impacts. Photochemical grid models have been shown to overpredict O_3 from wildland fire (Baker et al., 2016; Baker et al., 2018), which means these models can provide an indication about whether specific fires impact certain downwind monitors, but the predicted impact levels may be overstated to a large degree.

5.3 Additional Information

Table 4 provides sources for types of analytics that could be used to provide information for the technical component of a demonstration.

Table 4. Additional information

Type	Tool	Location
Ceilometer data	Atmospheric Lidar Group: UMBC's Unified Profiler and Ceilometer Network Sites	*https://alg.umbc.edu/ucn*
O_3 lidar data	TOLNet: NASA's Tropospheric Ozone Lidar Network	*https://www-air.larc.nasa.gov/missions/TOLNet*
Aerosol profiles (CALIPSO)	CALIPSO Webpage: Nasa's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations	*https://www-calipso.larc.nasa.gov/products/*
Statistical Regression Models	To be developed by the air agency, preferably in consultation with the relevant regional EPA office	

GROUND-BASED CEILOMETER AND OZONE LIDAR DATA

Ceilometers are ground-based instruments that make high time resolution measurements of the vertical profile of aerosol backscatter (Knepp et al., 2017; Liu et al., 2011). Ozone lidars are ground-based instruments that make high time resolution measurements of the vertical profile of ozone (Langford et al., 2019). Both typically measure through the extent of the troposphere, although neither provide surface level information due to limitations with the technology (Chan et al., 2018; Langford et al., 2021). Both can provide valuable information about the vertical structure of the boundary layer on days that might be impacted by smoke. Certain types of vertical structure would tend to inhibit vertical mixing from upwind sources, indicating greater potential for local pollutant build-up and formation. Both types of instruments can also be used with other sources of information to consider the potential for upper-level pollution to reach the surface impacting specific monitors. These instruments can provide useful information about the vertical atmosphere near potentially impacted monitors (same urban scale airshed). However, ceilometers and ozone lidars that are placed hundreds or more miles away from important meteorological features impacting a certain monitor would not provide accurate or useful information for understanding the impacts at that monitor.

SATELLITE PRODUCTS (CALIPSO)

Transects from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) may provide limited information about the nature of aerosol smoke. The uncertainty surrounding the data increases for near-surface data. The source categorization classifications make source attribution very difficult since many sources could contribute similar types of pollution at the surface (Burton et al., 2013). CALIPSO products poorly distinguish between aerosol types, especially between urban (anthropogenic) and smoke (Burton et al., 2013). CALIPSO often categorizes aerosol as "smoke" where an airborne high spectral resolution lidar (HSRL) instrument categorizes the same aerosol as "urban" in origin (Burton et al., 2013). Research indicates that CALIPSO is challenged when categorizing aerosol (Burton et al., 2013), and the "polluted dust" and "polluted continental/smoke" category should not by default be interpreted as smoke.

STATISTICAL REGRESSION MODELS

Regression is a statistical method for describing relationships among variables. Air agencies can develop and use O_3 predictions from regression equations to assess the wildfire's contribution to O_3 concentrations. Air agencies are strongly encouraged to work closely with their regional office if they intend on using a regression equation for use in an exceptional events demonstration. Statistical regression-based models such as a Generalized Additive Model (GAM) are sometimes used to relate the impacts from specific events (e.g., wildfire or stratospheric intrusion) with downwind 8-hour ozone exceedances. EPA's *Wildfire Ozone Guidance* states that "Users of regression models should consider the uncertainties in the model's prediction abilities, specifically at high concentrations, before making conclusions based on the modeled results. A key question when considering model uncertainty is whether the model predicts O_3 both higher and lower than monitored values at high concentrations (above 65 or 70 ppb) or whether the model displays systematic bias on these high monitored days." Further, it is critically important that inferences made based on statistical models be corroborated with meteorological patterns and more complex tools showing impacts (e.g., photochemical models or Lagrangian dispersion models). Conclusions about the nature of O_3 concentrations are strongest when all these pieces of information consistently show that high O_3 impacts were the result of transport of smoke from fire rather than being dominated by other more common sources for that area. For instance, in some situations the residual predicted by the GAM may be related to inadequate representation of regional stagnation events or inability to capture very localized features known to contribute to local O_3 formation (e.g., complex land-water interface).

Statistical sampling presents additional challenges with these types of analytics since exceptional events demonstrations typically are focused on the highest measured monitor values and therefore are not normally distributed around the mean of the model and the residuals for those points are not representative of a normally distributed sample. In most cases, much of the positive residual can be attributed to the statistical variability of the regression model or other physical reasons for high O_3 that are not related to specific fires. EPA's *Wildfire Ozone Guidance* is clear that the "minimum fire contribution" is not the full residual, but rather the difference between the residual and the 95th confidence interval for the statistical model uncertainty. The means that only some part of the concentration that is outside the normal range of variability (at the 95th percentile) could potentially be from a specific source like a fire, not the full residual.

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Appendix A

Graphical Examples of Analytical Tools

This document is a product of the U.S. EPA and is designed for illustrative purposes only.

InciWeb: An incident information management system

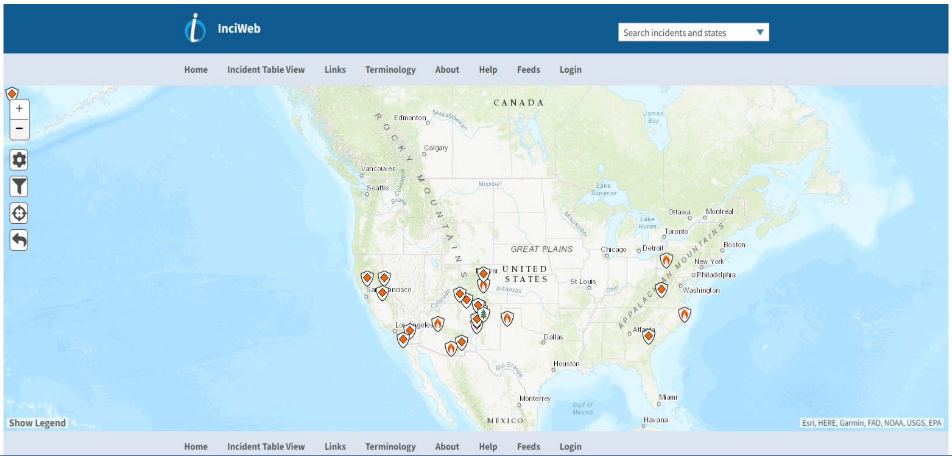
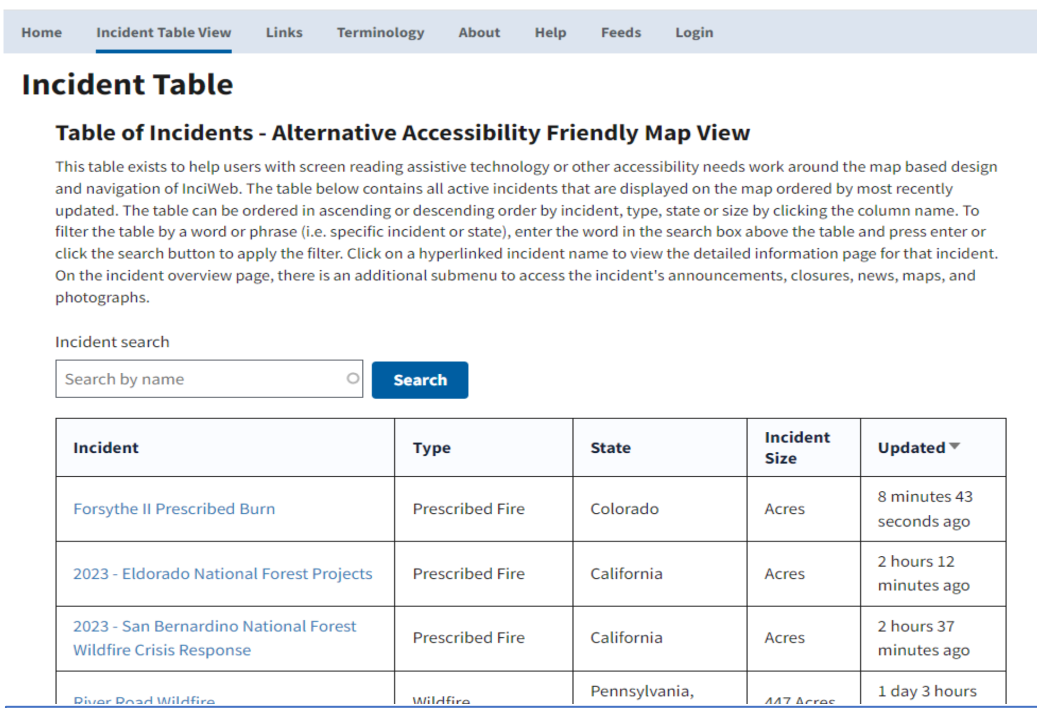


Figure 1: InciWeb landing page.



Home | Incident Table View | Links | Terminology | About | Help | Feeds | Login

Incident Table

Table of Incidents - Alternative Accessibility Friendly Map View

This table exists to help users with screen reading assistive technology or other accessibility needs work around the map based design and navigation of InciWeb. The table below contains all active incidents that are displayed on the map ordered by most recently updated. The table can be ordered in ascending or descending order by incident, type, state or size by clicking the column name. To filter the table by a word or phrase (i.e. specific incident or state), enter the word in the search box above the table and press enter or click the search button to apply the filter. Click on a hyperlinked incident name to view the detailed information page for that incident. On the incident overview page, there is an additional submenu to access the incident's announcements, closures, news, maps, and photographs.

Incident search

Search by name | Search

Incident	Type	State	Incident Size	Updated
Forsythe II Prescribed Burn	Prescribed Fire	Colorado	Acres	8 minutes 43 seconds ago
2023 - Eldorado National Forest Projects	Prescribed Fire	California	Acres	2 hours 12 minutes ago
2023 - San Bernardino National Forest Wildfire Crisis Response	Prescribed Fire	California	Acres	2 hours 37 minutes ago
River Road Wildfire	Wildfire	Pennsylvania,	447 Acres	1 day 3 hours

Figure 2: InciWeb Incident Table page. Click on an Incident to see detail pages.

InciWeb: An incident information management system

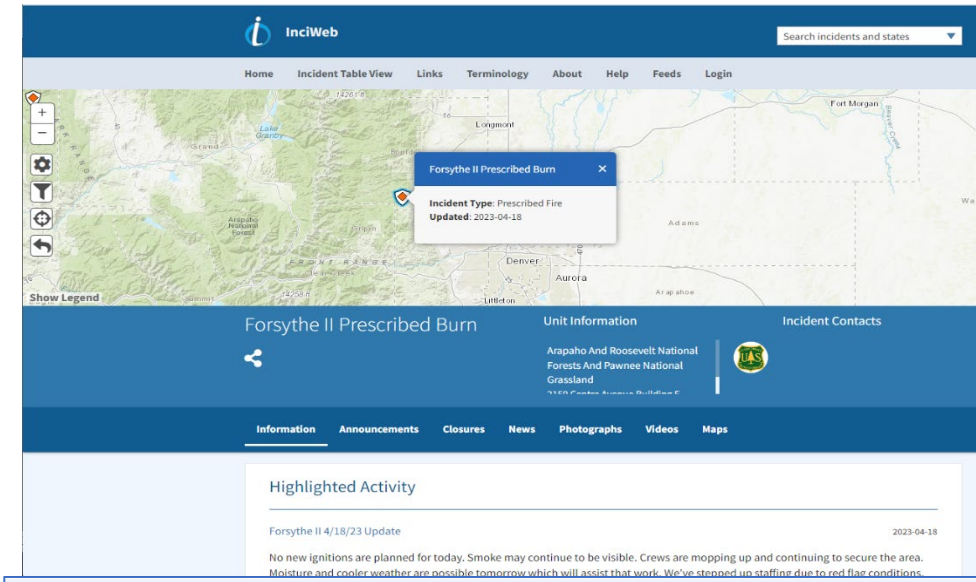


Figure 3: Incident landing page for the Forsythe II prescribed burn from the Incident Table.

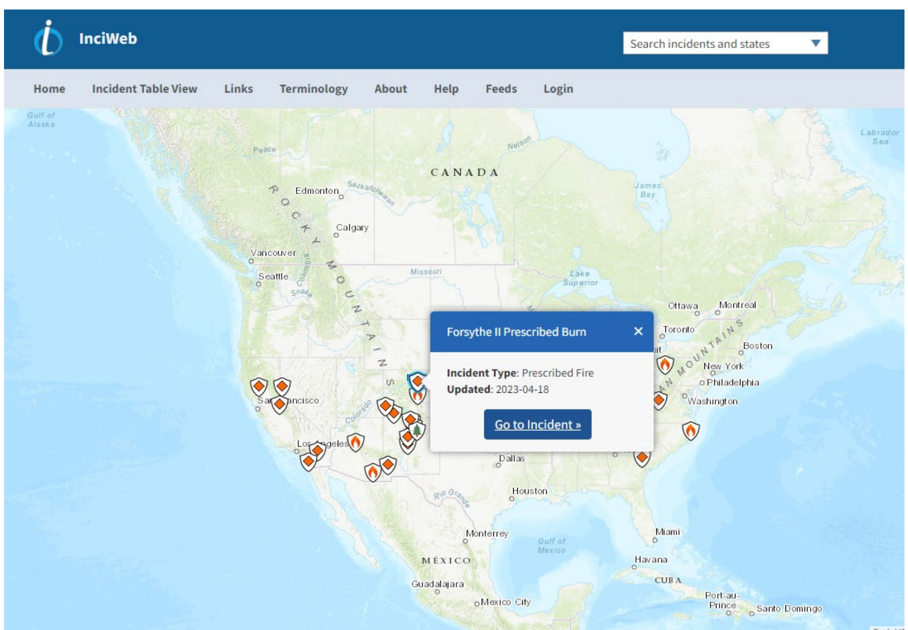


Figure 4: Selecting an incident from the map will go to the incident information pages.

InciWeb: An incident information management system

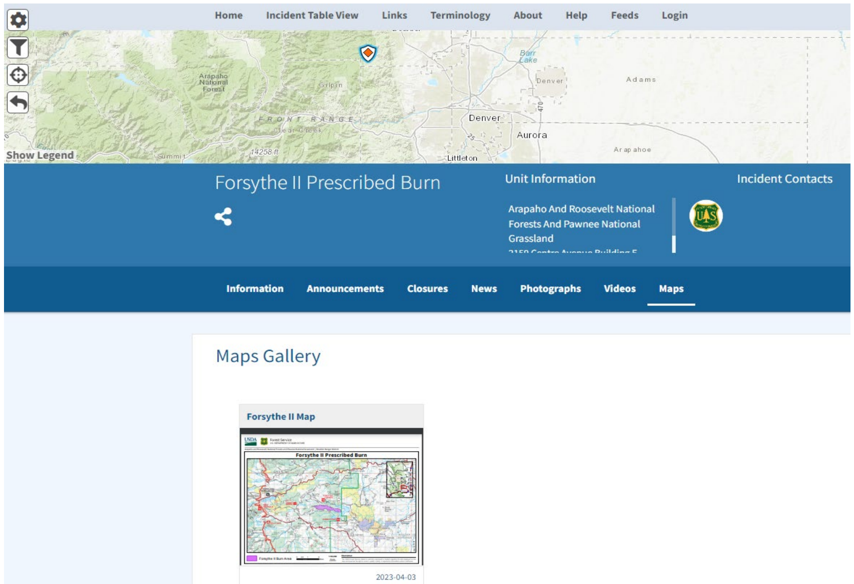


Figure 5: Incident pages contain archives of photographs, announcements, maps, and other information.

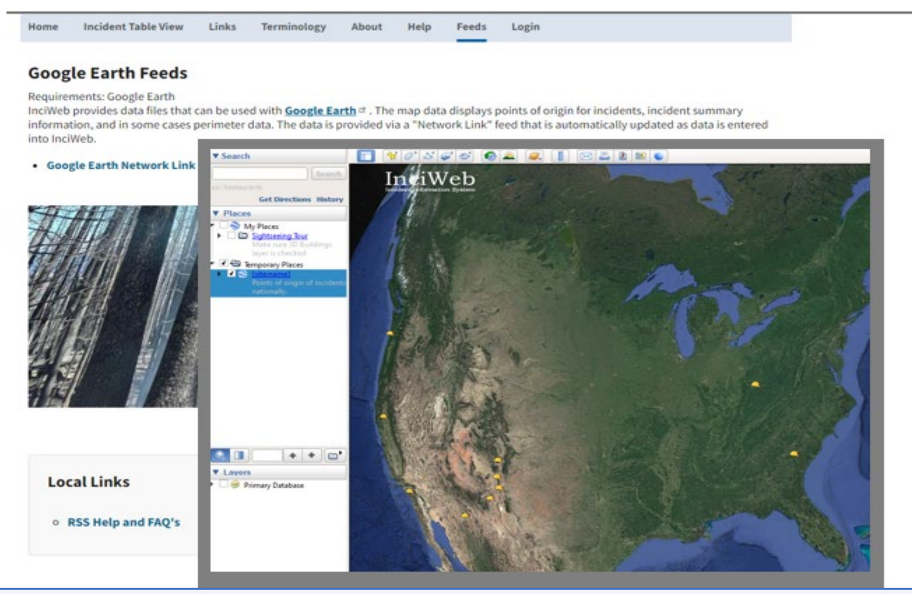


Figure 6: Google Earth kml files for fires can be generated from InciWeb.

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Worldview: NASA's interactive interface for browsing full-resolution, global, daily satellite images

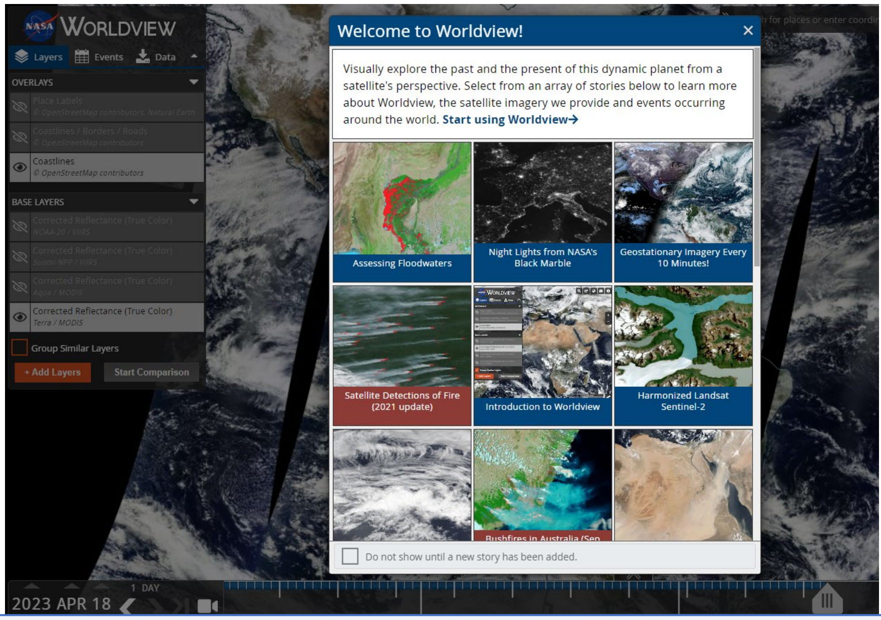

Figure 7: NASA WorldView landing page.

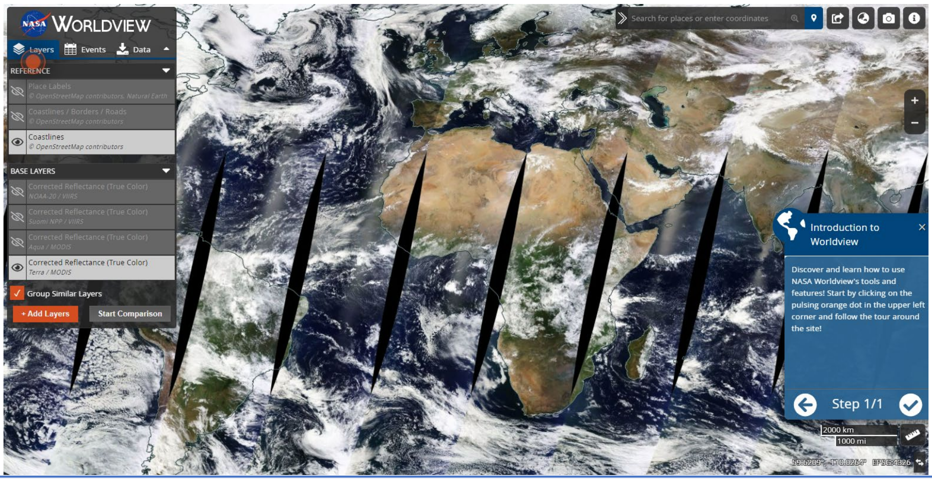

Figure 8: Selecting "Introduction to Worldview" on the landing page opens a guided tour of the site.

Worldview: NASA's interactive interface for browsing full-resolution, global, daily satellite images

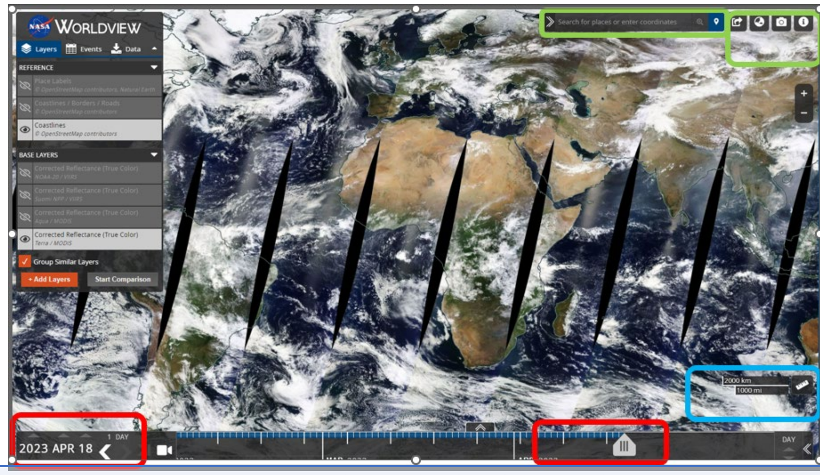

Figure 9: Main screen tools include date selection by typing or a slider (red boxes), measuring and scale tool (blue), and tools for searching, clipping, and exporting (green).

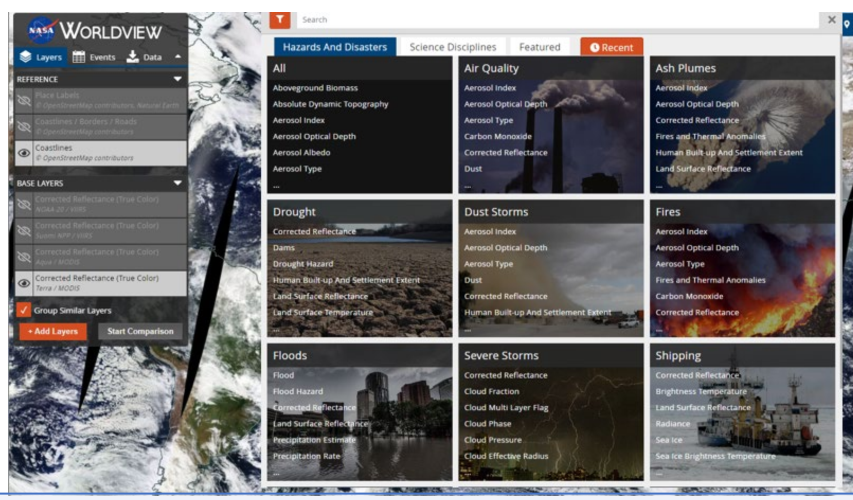

Figure 10: Hundreds of layers are available, through different selection windows, by clicking the orange "Add Layers" box.

NOAA's Hazard Mapping System Fire & Smoke Products

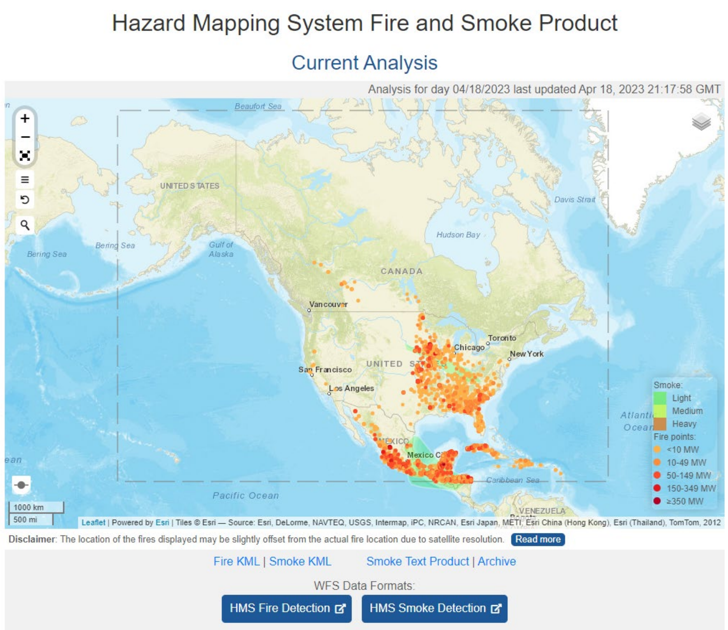

Figure 11: NOAA HMS landing page. Text and kml products are available for smoke and fire.

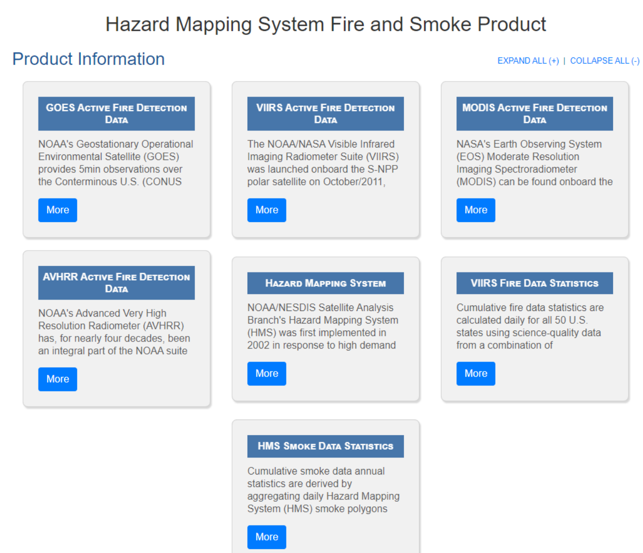

Figure 12: Products available on the HMS main menu.

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NOAA's Hazard Mapping System Fire & Smoke Products

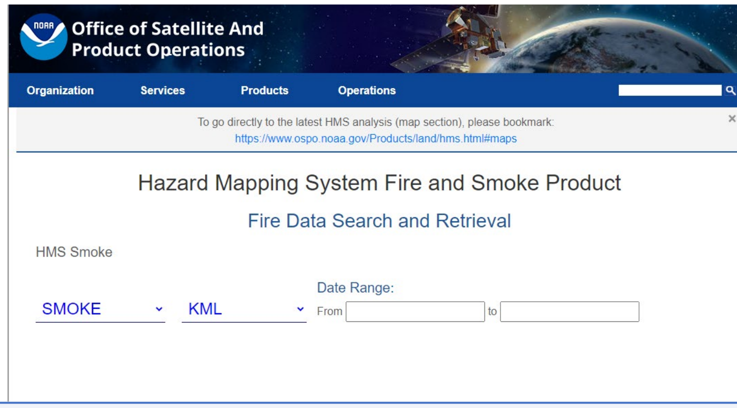

Figure 13: Archive smoke and fire plots can be downloaded.

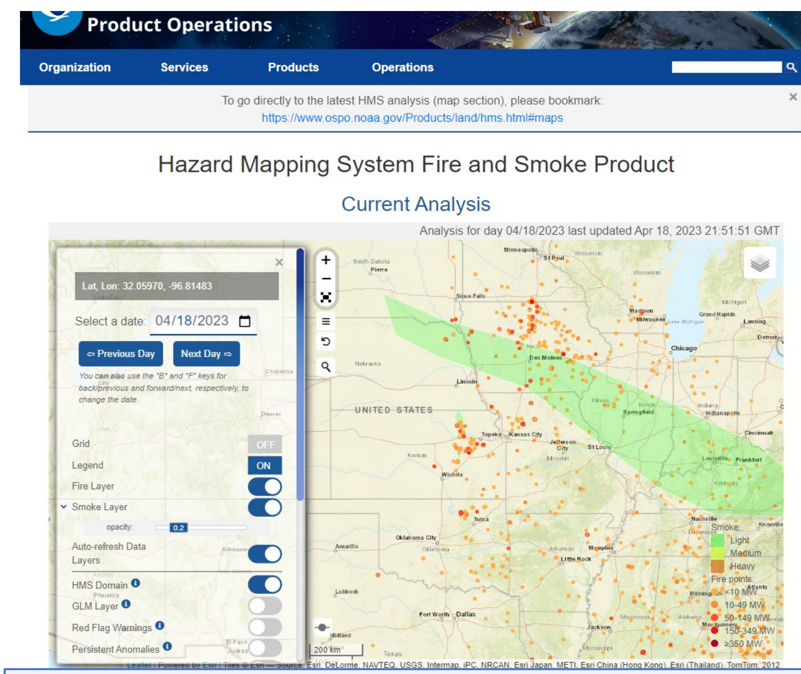

Figure 14: Maps can be customized from the main page.

Rapid Assessment of Vegetation Conditions: USDA's assessments of burn severity following large wildland fires on forested National Forest System (NFS) lands

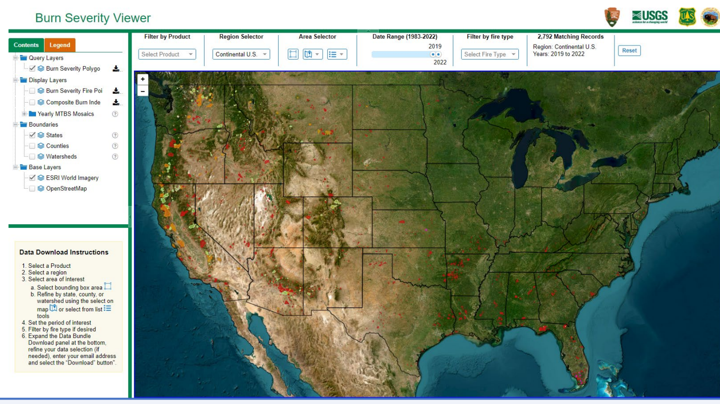

Figure 15: The Burn Severity Viewer, under the Data Access tab, displays the site's burn data on map layers.

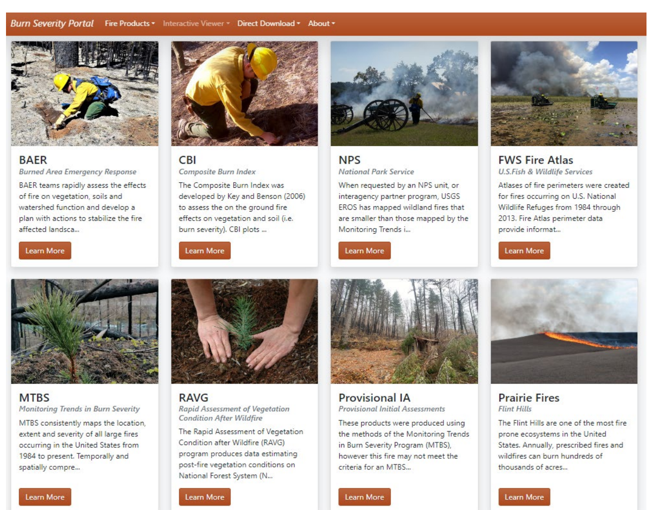

Figure 16: The Burn Severity Portal, also under Data Access, links to other sources of burn assessments.

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BlueSky Playground: USDA's Smoke Modeling Tool

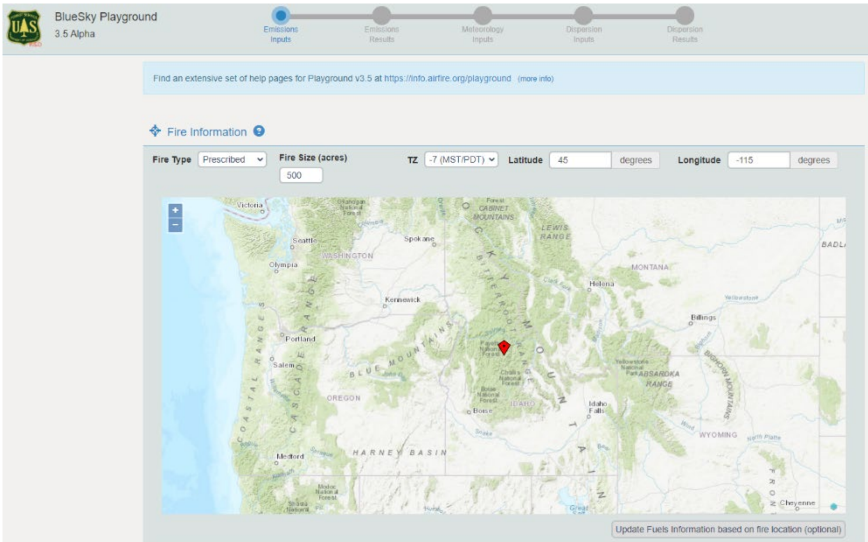


Figure 17: BlueSky moves step-by-step from fuels to burn to smoke dispersion.

Figure 18: Detailed outputs of each step are downloadable in several formats.

BlueSky Playground: USDA's Smoke Modeling Tool

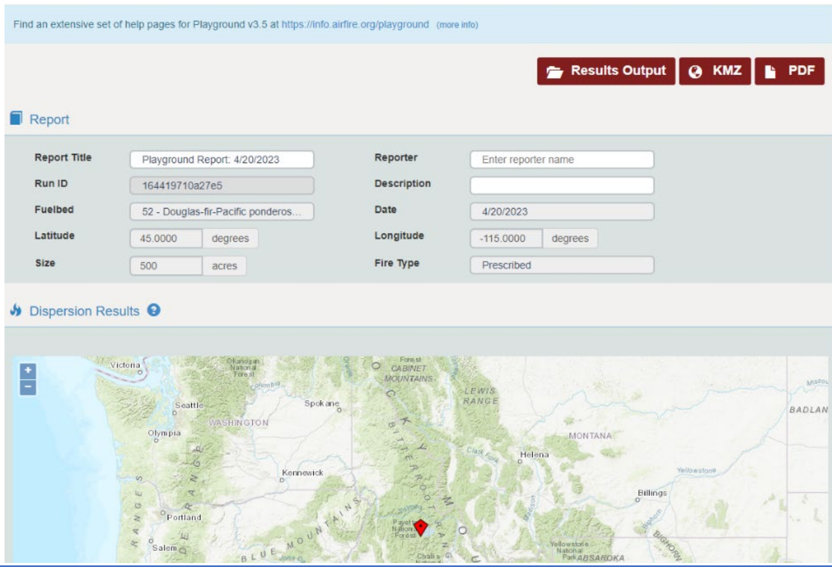


Figure 19: HYSPLIT is the trajectory/dispersion model in AirFire.

Mesonet: Iowa State University's collection of environmental data, including archived weather reports

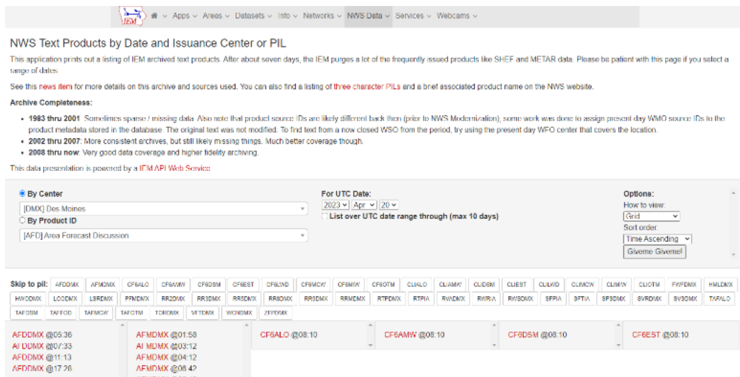


Figure 20: Iowa State's MesoNet archives NWS products. The "By Product ID" is useful for finding the right ID to select from the long product list on the web page.

Figure 21: Several download and visualization options are available for most products.

Air Maps: Storm Prediction Center's archive of weather maps

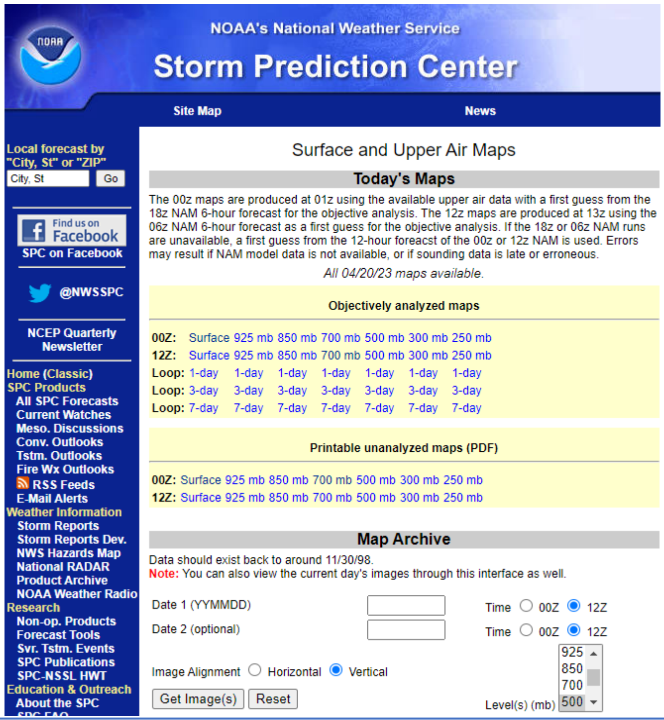


Figure 22: NOAA's Storm Prediction Center is a good source for analyzed and unanalyzed weather maps at the surface and upper-levels.

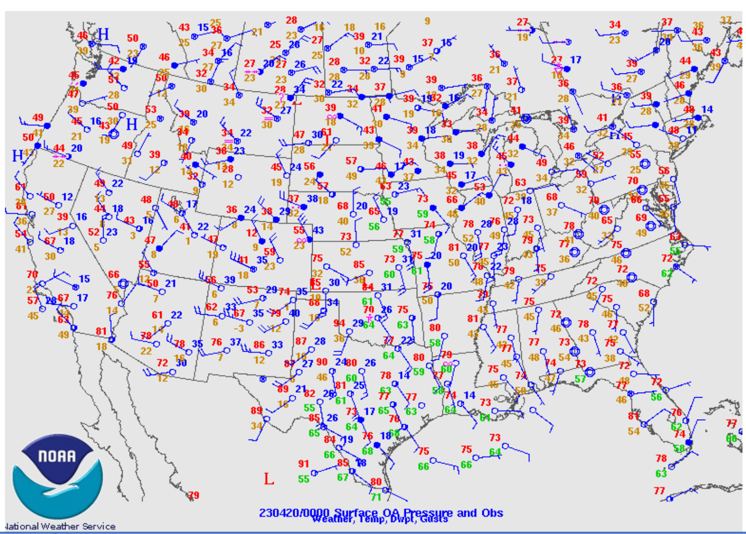


Figure 23: On this web page, maps are available as far back as 2000.

AirNow Tech: U.S. EPA's password protected website for air quality data management and analysis

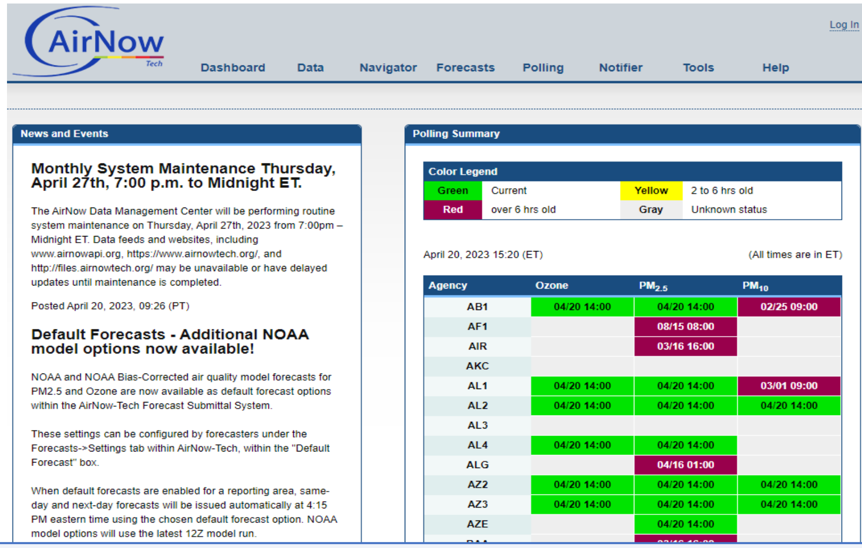


Figure 24: AirNow Tech's main page shows an informative snapshot of air quality monitoring, but signing into an account unlocks useful features.

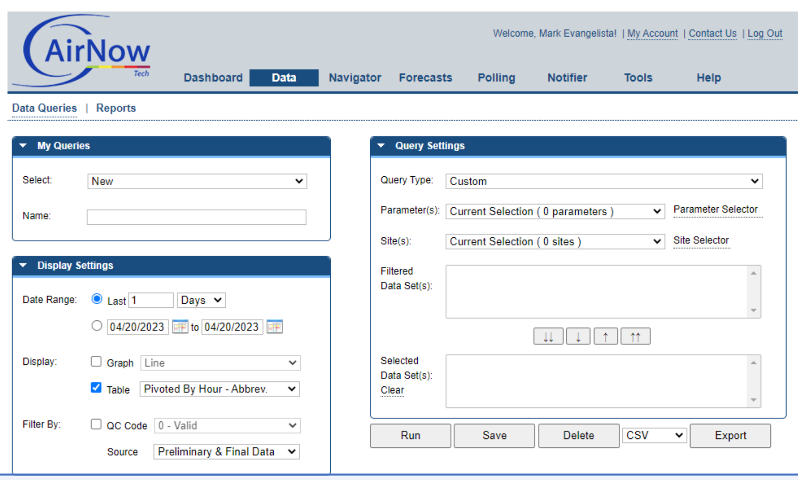


Figure 25: Individual datasets and data reports are available with an account.

AirNow Tech: U.S. EPA's password protected website for air quality data management and analysis

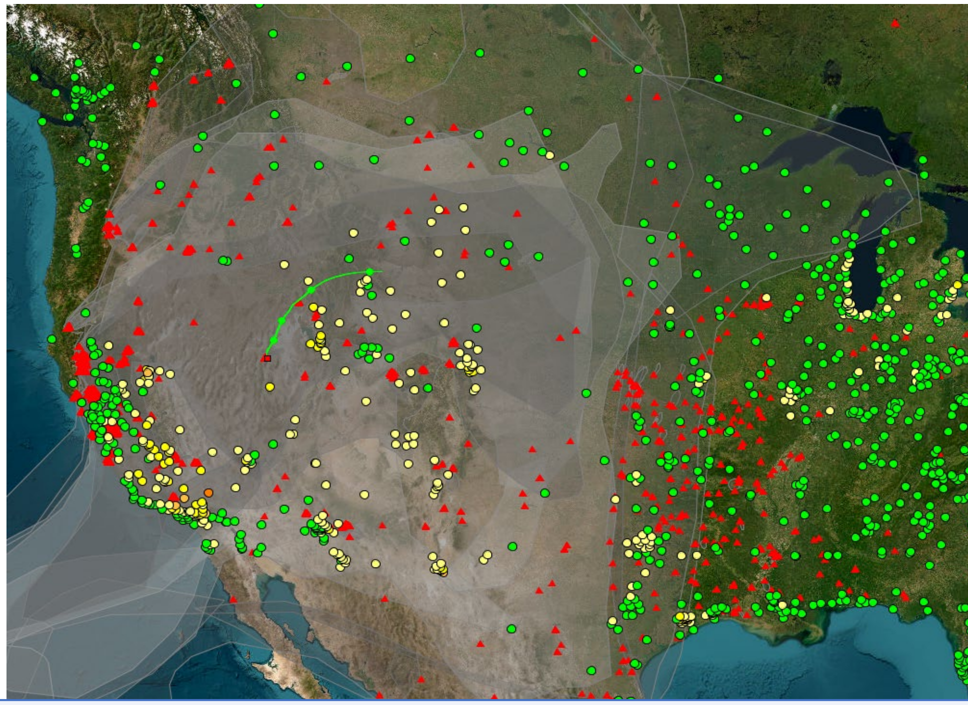


Figure 26: AirNow Tech's main feature is the Navigator, in which layers of many parameters and products can be displayed. In this example, ozone values are displayed with NOAA fire locations and NOAA HMS smoke plots. A HYSPLIT trajectory was also computed.

RSIG: U.S. EPA's webpage for accessing environmental datasets, including satellite, modeled, and *in-situ* sensor data

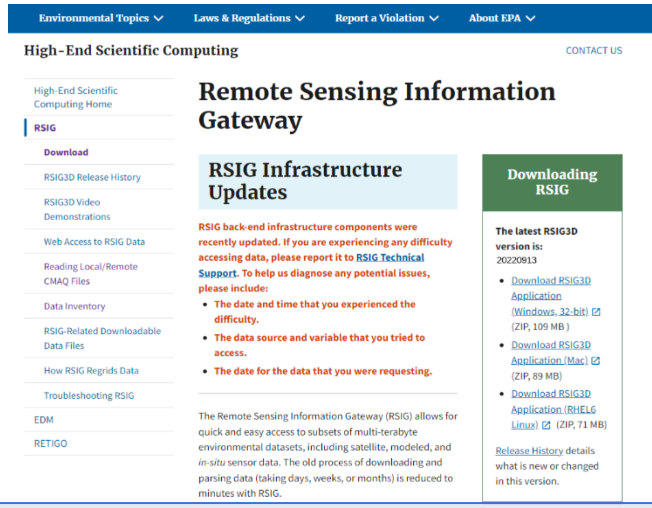
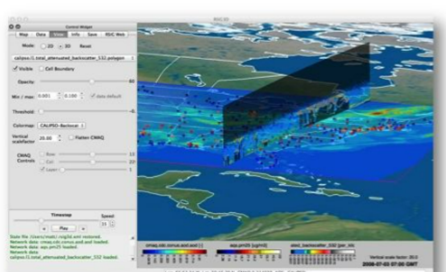


Figure 27: Remote Sensing Information Gateway starting page.

The RSIG project has developed the following free, publicly available software components:

- **RSIG3D** -- under active development -- is a standalone application for Windows and Mac OS X systems with a richly immersive and interactive visualization capability. It offers 2D and 3D visualization and saving of data from rsigserver. RSIG3D receives data (often 3D, up to one week) rather than images of the data, therefore the user's computer requires about 8GB of memory (enough for up to 5 global datasets).
- **rsigserver** is a web service that conforms to the Open Geospatial Consortium (OGC)-Web Coverage Services (WCS)/Web Mapping Services (WMS) standards. rsigserver streams subsets of atmospheric data to applications. Applications currently using rsigserver include: RSIG2D, RSIG3D, Estuary Data Mapper, Real-TIme GeOspatial Data Viewer (RETIGO), custom scripts, custom external applications, etc. Users can also construct web server scripts to access RSIG data via rsigserver.



RSIG3D

Figure 28: EPA RSIG is a data repository with an easy-to-use search and download capability, as well as a data viewer (available but still under development).

RSIG: U.S. EPA's webpage for accessing environmental datasets, including satellite, modeled, and *in-situ* sensor data

About RSIG

RSIG can tap into a wide range of key environmental models and data, such as NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), the Environmental Protection Agency's (EPA) Community Multi-scale Air Quality (CMAQ) model output, National Environmental Satellite, Data, and Information Service (NESDIS) biomass burning data, and ground station measurements from AIRNow and EPA's Air Quality System (AQS). RSIG also enables users to integrate their selected datasets into a unified visualization.

RSIG renders each dataset and overlays them on a map of the selected region, automatically aligning information from various spatial and temporal scales into a unified visualization.

The benefit to users and consumers of environmental data is fast acquisition of only the data they want to see and in a standard format they can save to their desktop PC.

RSIG's Key Features

- **One access point to many data sources.** The RSIG provides a single Web site that serves as a selective access point to many kinds of data.
- **Streams only the needed data.** The RSIG accesses large numbers of files from diverse sources and streams the user-selected subset of data back to the user's desktop. Streaming works in the same way as streaming audio works on the Web: the data goes directly to the client computer's memory and is discarded unless the user saves it to a file.
- **Aggregates separate data files into a single stream.** RSIG aggregates the multiple files of a given data type into a single stream, reducing the download burden and simplifying data analysis.
- **Built-in visualization.** RSIG can immediately integrate multiple selected datasets into a single MPEG animation. For example, EPA AIRNow data can be layered over NASA's MODIS satellite data, or a user can compare CMAQ predicted outputs and actual ground sensor data. The user can also save the animation or individual images to their computer.
- **Saves data to standard formats.** RSIG integrates incoming proprietary dataset formats into standard formats the user can save on their computer. A user can save the data or visualization--or both--to their local computer in such standard formats as portable binary, ASCII, NetCDF IOAPI and COARDS, GeoTIFF, MPEG and KMZ. The user can then export the selected datasets from RSIG into other applications--such as GIS tools--for further analysis
- **Fast.** RSIG accomplishes all of this far faster than a lone user could with currently available means. For example, RSIG can capture a week of MODIS AOD data in a few minutes, compared to two months using conventional web-form ordering/ftp approaches.

Figure 29: Key features listed on the RSIG web page.

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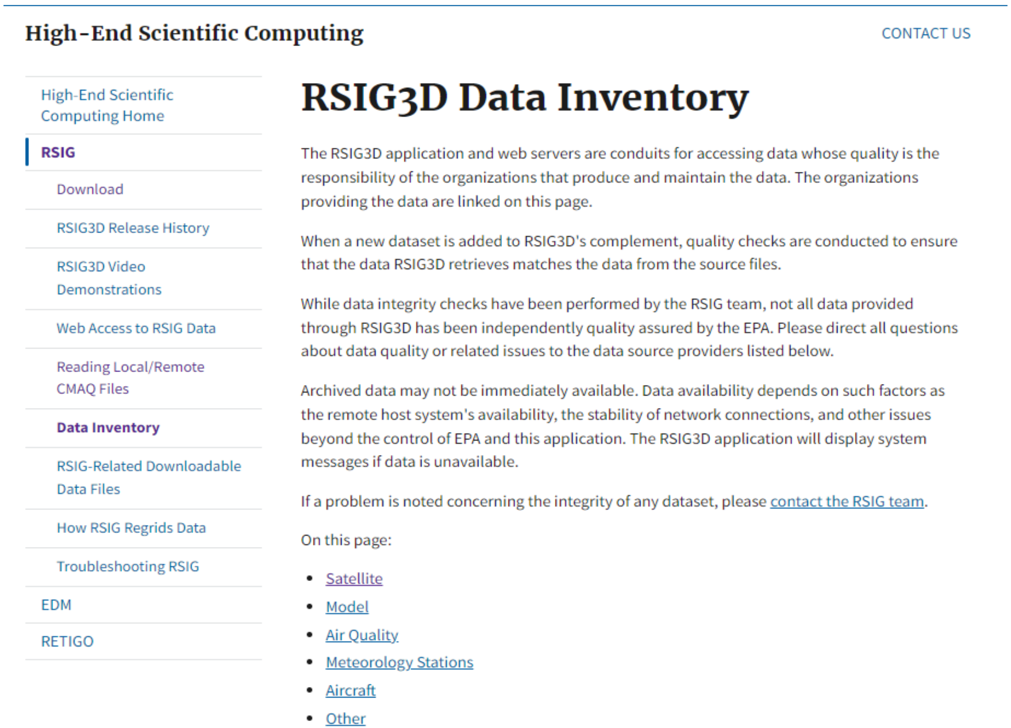
RSIG: U.S. EPA's webpage for accessing environmental datasets, including satellite, modeled, and *in-situ* sensor data



High-End Scientific Computing

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- High-End Scientific Computing Home
- RSIG
  - Download
  - RSIG3D Release History
  - RSIG3D Video Demonstrations
  - Web Access to RSIG Data
  - Reading Local/Remote CMAQ Files
  - **Data Inventory**
  - RSIG-Related Downloadable Data Files
  - How RSIG Regrids Data
  - Troubleshooting RSIG
- EDM
- RETIGO

RSIG3D Data Inventory

The RSIG3D application and web servers are conduits for accessing data whose quality is the responsibility of the organizations that produce and maintain the data. The organizations providing the data are linked on this page.

When a new dataset is added to RSIG3D's complement, quality checks are conducted to ensure that the data RSIG3D retrieves matches the data from the source files.

While data integrity checks have been performed by the RSIG team, not all data provided through RSIG3D has been independently quality assured by the EPA. Please direct all questions about data quality or related issues to the data source providers listed below.

Archived data may not be immediately available. Data availability depends on such factors as the remote host system's availability, the stability of network connections, and other issues beyond the control of EPA and this application. The RSIG3D application will display system messages if data is unavailable.

If a problem is noted concerning the integrity of any dataset, please contact the RSIG team.

On this page:

- Satellite
- Model
- Air Quality
- Meteorology Stations
- Aircraft
- Other

Figure 30: Top level of the RSIG Data Inventory. Many products have their own methods for download and display.

AQS: U.S. EPA's repository of ambient air quality data

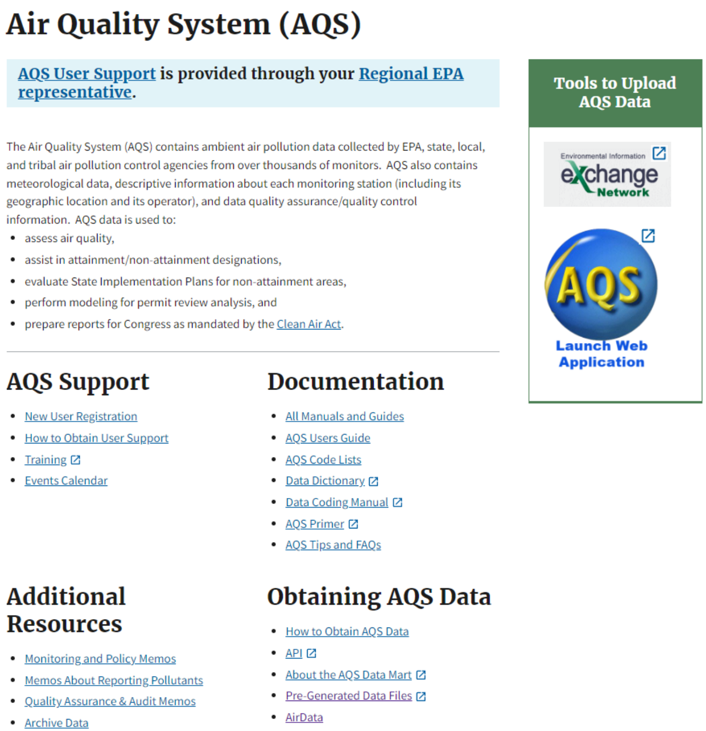

Figure 31: There are many ways to obtain EPA AQS data. The web application requires a user account, but most user needs can be met by one of the Obtaining AQS Data alternatives.

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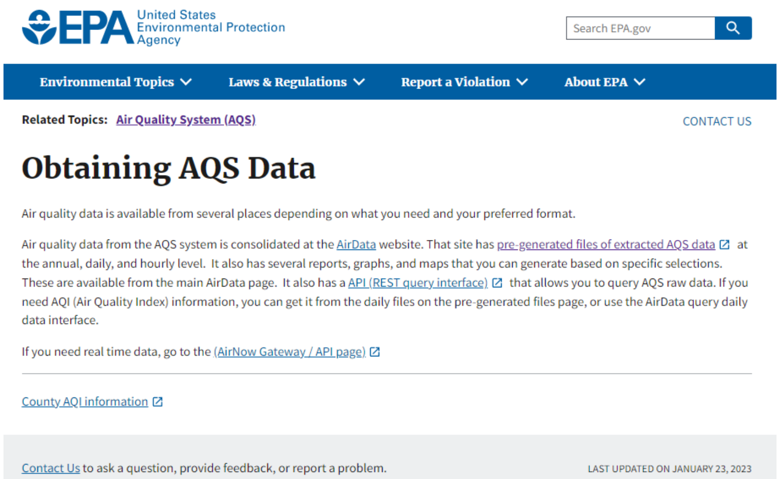
AQS: U.S. EPA's repository of ambient air quality data


EPA United States Environmental Protection Agency

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Related Topics: Air Quality System (AQS)

CONTACT US

Obtaining AQS Data

Air quality data is available from several places depending on what you need and your preferred format.

Air quality data from the AQS system is consolidated at the AirData website. That site has pre-generated files of extracted AQS data at the annual, daily, and hourly level. It also has several reports, graphs, and maps that you can generate based on specific selections. These are available from the main AirData page. It also has a API (REST query interface) that allows you to query AQS raw data. If you need AQI (Air Quality Index) information, you can get it from the daily files on the pre-generated files page, or use the AirData query daily data interface.

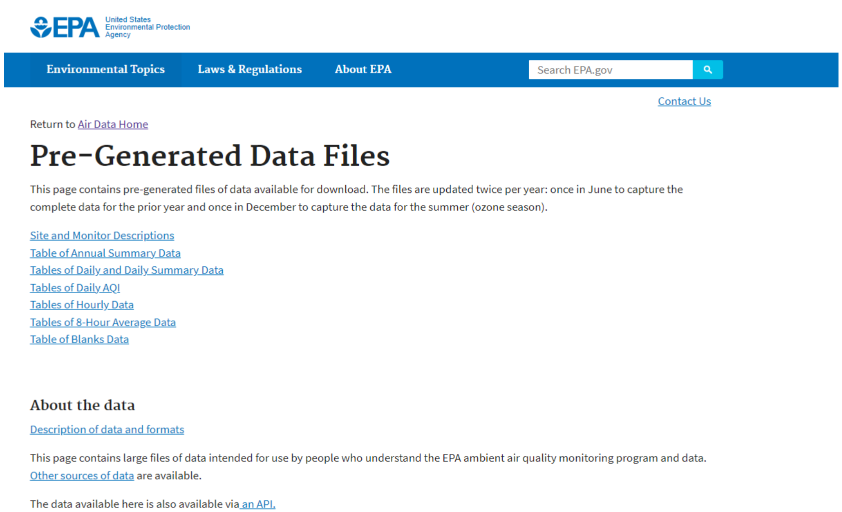
If you need real time data, go to the (AirNow Gateway / API page)

County AQI information

Contact Us to ask a question, provide feedback, or report a problem.

LAST UPDATED ON JANUARY 23, 2023

Figure 32: The alternatives listed here provide the same data as the web application. The easiest to use are the pre-generated data files.


EPA United States Environmental Protection Agency

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Return to Air Data Home

Pre-Generated Data Files

This page contains pre-generated files of data available for download. The files are updated twice per year: once in June to capture the complete data for the prior year and once in December to capture the data for the summer (ozone season).

- Site and Monitor Descriptions
- Table of Annual Summary Data
- Tables of Daily and Daily Summary Data
- Tables of Daily AQI
- Tables of Hourly Data
- Tables of 8-Hour Average Data
- Table of Blanks Data

About the data

Description of data and formats

This page contains large files of data intended for use by people who understand the EPA ambient air quality monitoring program and data. Other sources of data are available.

The data available here is also available via an API.

Figure 33: Pre-generated data files are available for all pollutants, time frames, and formats, and for monitor and site information including some meteorology.

AQS: U.S. EPA's repository of ambient air quality data

Hourly Data

Criteria Gases

Year	Ozone (44201)	SO2 (42401)	CO (42101)	NO2 (42602)
2022	hourly_44201_2022.zip 5,446,145 Rows 40,507 KB As of 2022-11-14	hourly_42401_2022.zip 2,072,545 Rows 13,681 KB As of 2022-11-14	hourly_42101_2022.zip 1,149,114 Rows 8,536 KB As of 2022-11-14	hourly_42602_2022.zip 2,133,659 Rows 16,846 KB As of 2022-11-14
2021	hourly_44201_2021.zip 9,102,535 Rows 67,632 KB As of 2022-11-14	hourly_42401_2021.zip 3,520,349 Rows 23,116 KB As of 2022-11-14	hourly_42101_2021.zip 2,001,136 Rows 14,785 KB As of 2022-11-14	hourly_42602_2021.zip 3,643,277 Rows 28,670 KB As of 2022-11-14
2020	hourly_44201_2020.zip 9,139,231 Rows 67,662 KB As of 2022-11-14	hourly_42401_2020.zip 3,750,140 Rows 24,535 KB As of 2022-11-14	hourly_42101_2020.zip 2,082,897 Rows 15,343 KB As of 2022-11-14	hourly_42602_2020.zip 3,646,794 Rows 28,528 KB As of 2022-11-14
2019	hourly_44201_2019.zip 9,081,410 Rows 67,367 KB As of 2022-11-14	hourly_42401_2019.zip 3,894,581 Rows 25,568 KB As of 2022-05-25	hourly_42101_2019.zip 2,170,703 Rows 15,971 KB As of 2022-11-14	hourly_42602_2019.zip 3,560,329 Rows 27,936 KB As of 2022-11-14

Figure 34: This example shows pre-generated files for hourly ozone for the US and territories. Just click and download a zipped csv file.

Outdoor Air Quality Data: EPA's tool for daily air quality summary statistics for the criteria pollutants by monitor

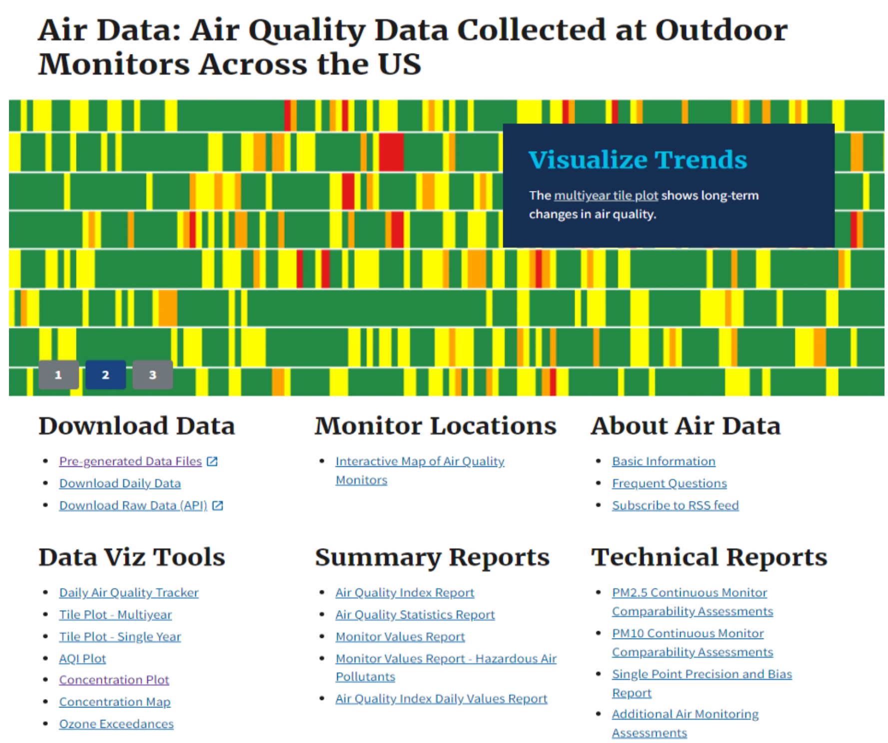

Figure 35: Air Data is one of the data alternatives shown on the AQS web page. Air Data has many web tools to analyze and plot data.

Outdoor Air Quality Data: EPA's tool for daily air quality summary statistics for the criteria pollutants by monitor

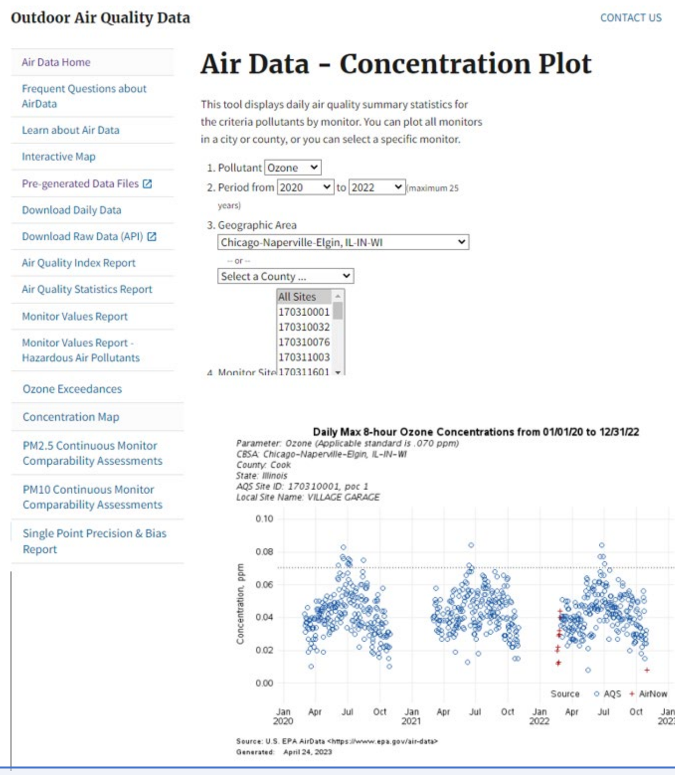

Figure 36: The Concentration Plot shown here is one of many tools available.

HYSPLIT: NOAA's Hybrid Single-Particle Lagrangian Integrated Trajectory model

Figure 37: HYSPLIT, the trajectory model, is easy to download, install and run.

HYSPLIT: NOAA's Hybrid Single-Particle Lagrangian Integrated Trajectory model

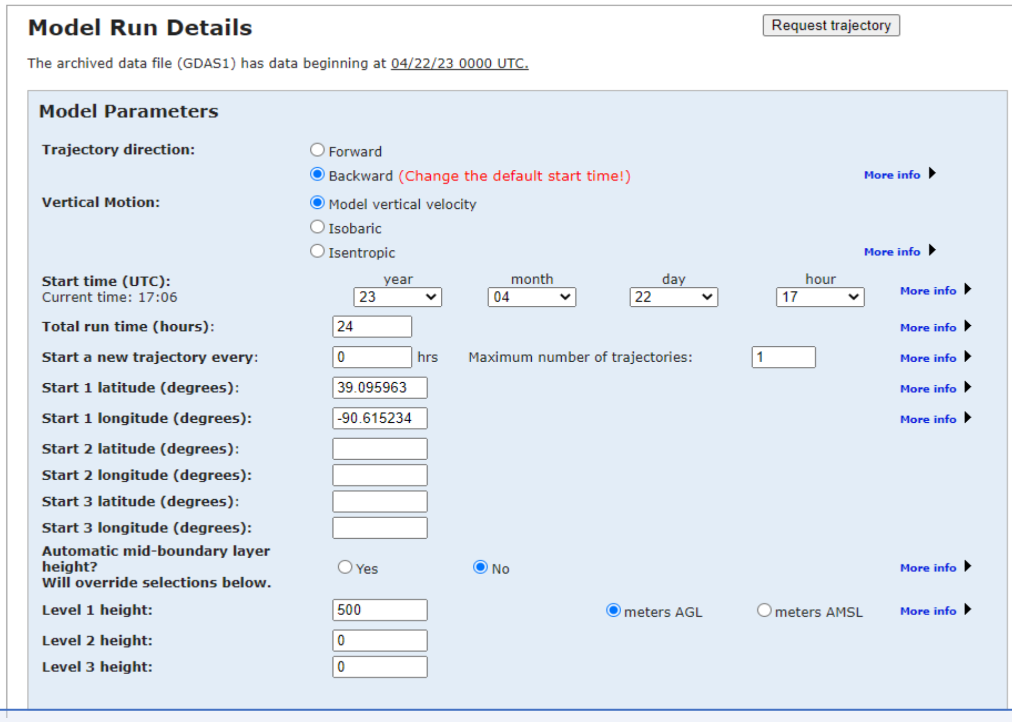

Figure 38: HYSPLIT is also very easy to use as a web tool.

HYSPLIT: NOAA's Hybrid Single-Particle Lagrangian Integrated Trajectory model

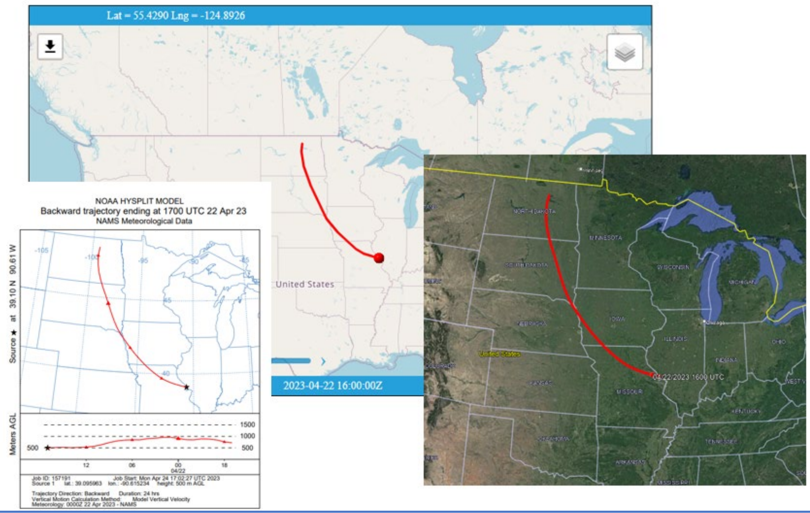

Figure 39: HYSPLIT outputs come as web plots, pdf, and inputs to Google Earth and ArcGIS, all at once.

HRRR: NOAA's High-Resolution Rapid Refresh Model

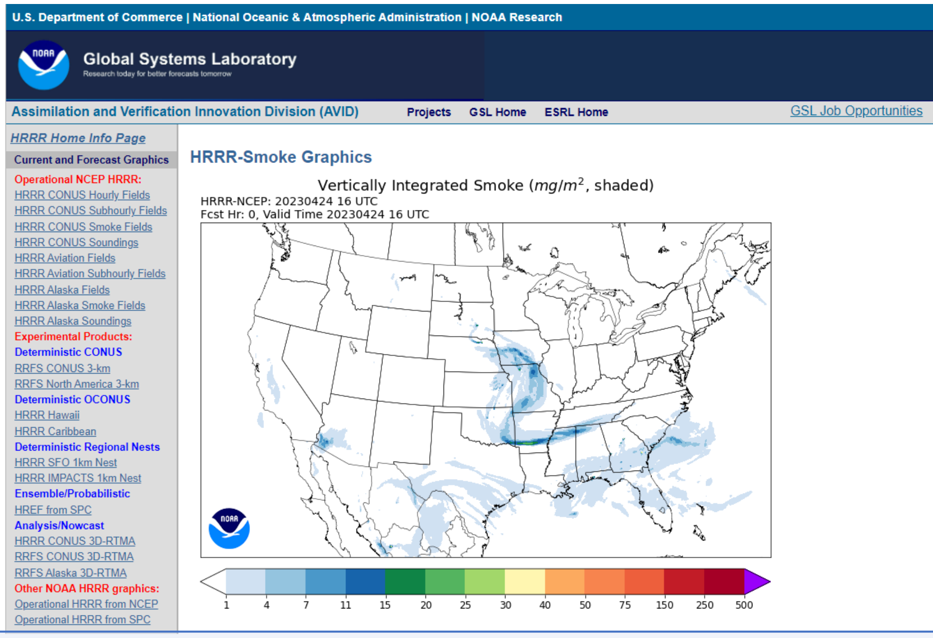

Figure 40: One of the smoke map products available (HRRR CONUS Smoke Fields in the list on the left).

Monterey Aerosol Page: U.S. National Research Laboratory Aerosol Products

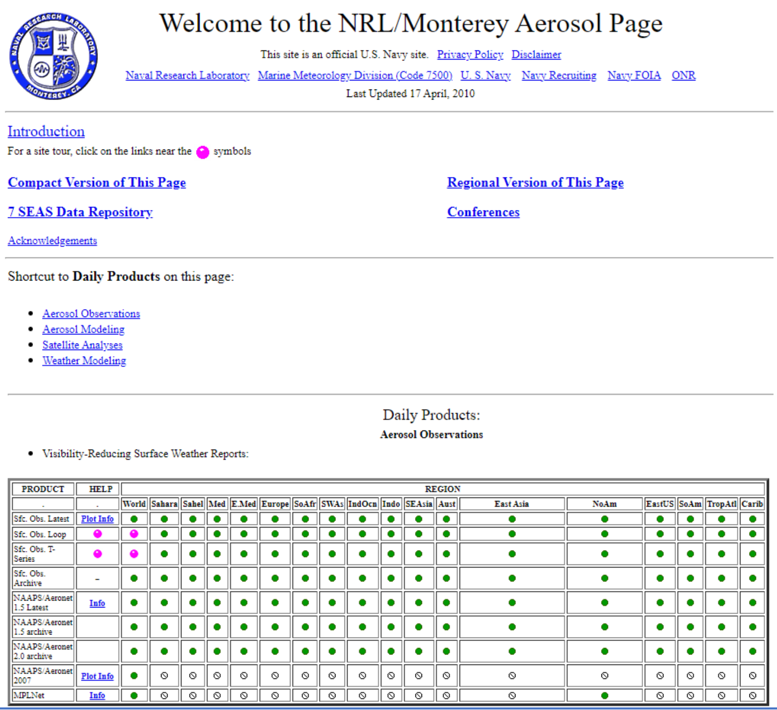

Figure 41: NRL Monterey Aerosol Page. Click the Compact Version for one web page with most of the many options for models, observations, and satellite products, etc.

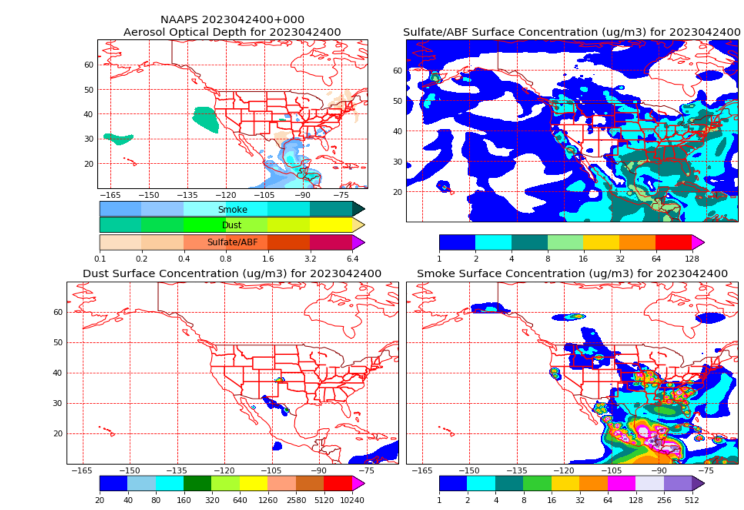

Figure 42: NAAPS one-click products for CONUS. More detailed products are available as well.

This document is a product of the U.S. EPA and is designed for illustrative purposes only.

TOLNet: NASA's Tropospheric Ozone Lidar Network

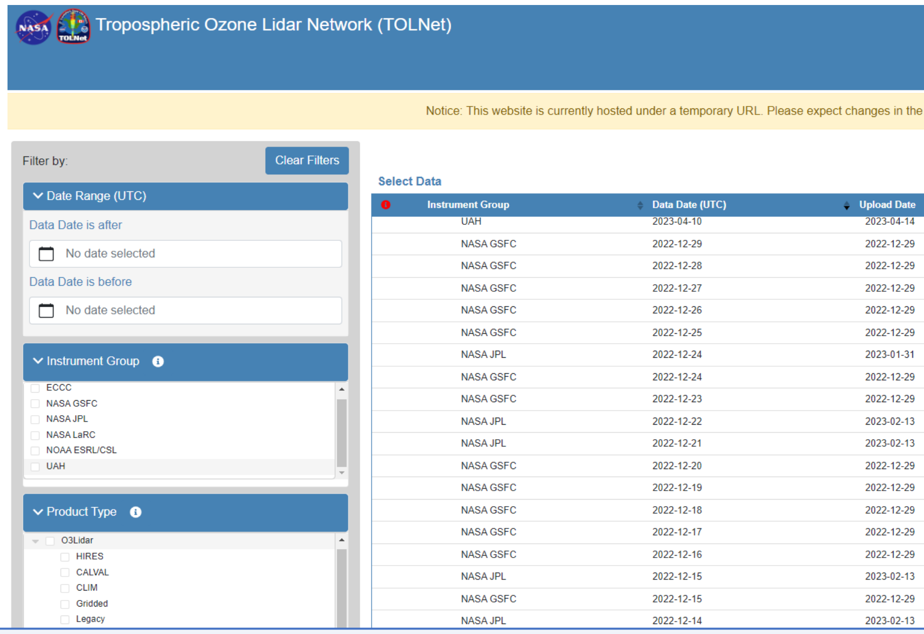

Figure 43: A new website for TOLNet is a work in progress, but nearly complete.

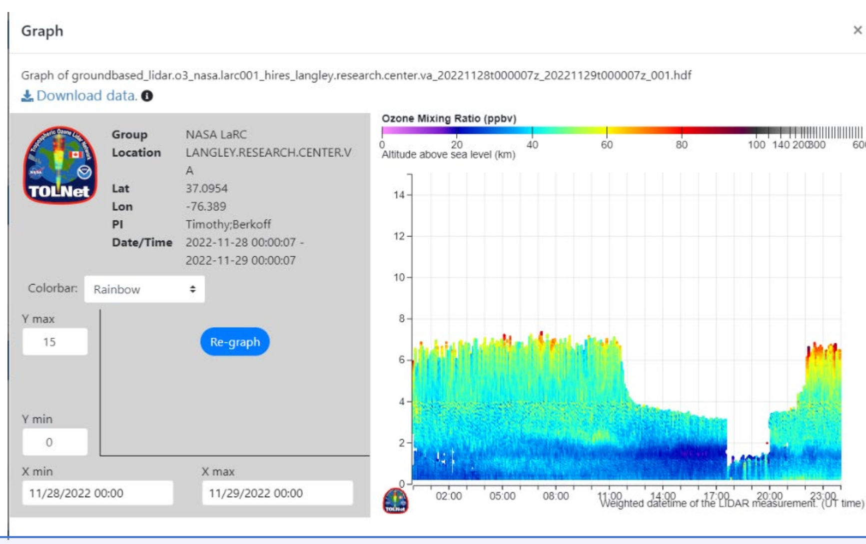

Figure 44: Data from several networks is easy to download and plot (registration and login required).

This document is a product of the U.S. EPA and is designed for illustrative purposes only.

CALIPSO Webpage: Nasa's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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+ DATA SUBSETTER WEB APP
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PRODUCTS

CALIPSO produces Level 1 and Level 2 science data products that are listed in detail in the CALIPSO Data Products Catalog (PC SCI 503). These products are archived and distributed by the Atmospheric Science Data Center (ASDC).

For more information on CALIPSO's prospective data products, visit this journal article:

Vaughan, M., Young, S., Winker, D., Powell, K., Omar, A., Liu, Z., Hu, Y., and Hostetler, C. (2004). Fully automated analysis of space-based lidar data: an overview of the CALIPSO retrieval algorithms and data products. *Proc. SPIE*, 5575, pp. 16-30. [View Paper]

Table 1 gives a summary of the CALIPSO Level 2 data products and the spatial scales at which the data products are reported. The expected accuracies given are for the maximum averaging distances for which the products will be retrieved.

Cloud products are reported at a horizontal resolution of 5 km; i.e., at the fundamental averaging resolution of the processing scheme. Cloud boundaries, which can be detected at higher resolution, are reported at that resolution. To account for weaker backscatter signals from aerosols, the Level 2 aerosol profile products are reported at a uniform horizontal resolution of 40 km at all altitudes.

Image above: An example of data collected by CALIPSO's lidar in June 2006. The data extends from sea level to 30 km.

Table 1. CALIPSO Level 2 Aerosol and Cloud Measurements

Data Product	Measurement Capabilities and Uncertainties	Data Product Resolution	
		Horizontal	Vertical
	Aerosols		
Height, Thickness	For layers with $\beta > 2.5 \times 10^{-4}$ km^{-1} sr^{-1}	5 km	60 m
Optical depth, τ	40% *	5 km	N/A
Backscatter, $\beta_a(z)$	20 - 30%	40 km 40 km	Z < 20 km 120 m Z ≥ 20 km: 360 m
Extinction, σ_a	40% *	40 km 40 km	Z < 20 km 120 m Z ≥ 20 km: 360 m
	Clouds		
Height	For layers with $\beta > 1 \times 10^{-3}$ km^{-1} sr^{-1}	1/3, 1, 5 km	30, 60 m
Thickness	For layers with $\tau < 5$	1/3, 1, 5 km	60 m
Optical depth, τ	within a factor of 2 for $\tau < 5$	5 km	N/A
Backscatter, $\beta_c(z)$	20 - 30%	5 km	60 m
Extinction, σ_c	within a factor of 2 for $\tau < 5$	5 km	60 m
Ice/water phase	Layer by layer	5 km	60 m

Figure 45: Calipso products have their limitations. Currently, the website has its own difficulty with searching for, downloading, and displaying data. Improvements are ongoing.