# Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations

**Draft**



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# Acronyms

| | |
|---|---|
| AGL | Above ground level |
| AQS | Air Quality System |
| CAA | Clean Air Act |
| CAMx | Comprehensive Air Quality Model with Extensions |
| CARB | California Air Resources Board |
| CFR | Code of Federal Regulations |
| CM | Conceptual model |
| CMAQ | Community multiscale air quality model |
| CO | Carbon monoxide |
| DDM | Direct decoupled method |
| EER | Exceptional Events Rule |
| EPA | Environmental Protection Agency |
| FINN | Fire inventory from the National Center for Atmospheric Research |
| FIPS | Federal Information Processing Standards |
| GDAS | Global data analysis system |
| HAURL | Human activity unlikely to recur at a particular location |
| HYSPLIT | Hybrid single particle lagrangian integrated trajectory model |
| K | Potassium |
| km | Kilometers |
| mb | Millibars |
| MDA8 | Maximum daily 8-hour average for ozone |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| nRCP | not reasonably controllable or preventable |
| NAAQS | National Ambient Air Quality Standard or Standards |
| NAM | North American mesoscale forecast system |
| NCAR | National Center for Atmospheric Research |
| NDAS | North American mesoscale data analysis system |
| NEI | National Emission Inventory |
| NO | Nitrogen oxide |
| NOx | Nitrogen oxides |
| $NO_2$ | Nitrogen dioxide |
| NWS | National Weather Service |
| $O_3$ | Ozone |
| PM | Particulate matter |

| | |
|---|---|
| $PM_{10}$ | Particulate matter with a nominal mean aerodynamic diameter less than or equal to 10 micrometers |
| $PM_{2.5}$ | Particulate matter with a nominal mean aerodynamic diameter less than or equal to 2.5 micrometers |
| ppb | Parts per billion |
| Q/D | 24-hour fire emissions, in tons per day, divided by the distance of the fire to the monitor, in kilometers |
| ROG | Reactive organic gases |
| rVOC | Reactive volatile organic compounds |
| SIP | State implementation plan |
| SMARTFIRE | Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation |
| TOG | Total organic gases including methane and other reactive volatile organic compounds |
| VOC | Volatile organic compounds |
| WRF-CHEM | Weather research and forecasting model coupled with chemistry |

# 1. Highlights

<u>Statutory and Regulatory Requirements</u>
The Environmental Protection Agency (EPA) promulgated the Exceptional Events Rule (EER) in 2007[1] to address Clean Air Act (CAA) section 319(b), which allows for the exclusion of air quality monitoring data influenced by exceptional events from use in determinations of exceedances or violations of the national ambient air quality standards (NAAQS). The CAA includes four requirements that, collectively, define an exceptional event:

1) The event affected air quality.
2) The event was not reasonably controllable or preventable.
3) The event was caused by human activity that is unlikely to recur at a particular location or was a natural event.
4) There exists a clear causal relationship between the specific event and the monitored exceedance.

The EPA revised the 2007 EER (2016 revisions)[2] based on implementation experiences with the exceptional events data exclusion process. The revisions clarify the required elements that exceptional events demonstrations must address. The revised EER [at 40 CFR 50.14(c)(3)(iv)] requires that demonstrations submitted to the EPA include the following elements:

1) A narrative conceptual model;
2) A demonstration that the event was both not reasonably controllable and not reasonably preventable;
3) A demonstration that the event was a human activity that is unlikely to recur at a particular location or was a natural event; and
4) 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.

Demonstrations prepared by air agencies[3] and submitted to the EPA must address each of these rule elements. This document recommends example language and analyses that may be sufficient to address these elements in demonstrations for wildfires that influence monitored ozone ($O_3$)

[1] "Treatment of Data Influenced by Exceptional Events; Final Rule" (72 FR 13560, March 22, 2007).
[2] The EPA has prepared this draft guidance to align with the proposed EER revisions signed on November 10, 2015, and available on the EPA's exceptional events website at *http://www2.epa.gov/air-quality-analysis/treatment-data-influenced-exceptional-events*. The EPA will revise this guidance to reflect the relevant final promulgated EER revisions if the final revisions differ from the proposal.
[3] The term "air agencies" is used throughout the document to include state, local, and tribal air agencies responsible for implementing the EER. In the context of flagging data and preparing and submitting demonstrations, the roles and options available to air agencies may apply to federal land managers of Class I areas and other federal agencies that either operate monitors affected by an event or that manage federal land.

concentrations.[4] The EPA may not be able to concur with an air agency's request to exclude data under the EER if a demonstration does not address the identified elements. Air agencies are encouraged to contact their EPA Regional Office as soon as the agency identifies event-influenced data that potentially influence a regulatory decision or when an agency wants the EPA's input on whether or not to prepare a demonstration.

<u>Purpose of this Document</u>

The EPA developed this document to assist air agencies in the preparation of exceptional events demonstrations for wildfire influences on $O_3$ concentrations that meet the requirements of CAA section 319(b) and the EER. This guidance document follows the requirements of the EER and provides three different tiers of demonstrations that air agencies can use to develop evidence for exceptional events demonstrations.

The EPA recognizes the limited resources of the air agencies that prepare and submit exceptional events demonstrations and of the EPA Regional Offices that review these demonstrations. One of the EPA's goals in developing this document is to establish clear expectations to enable affected agencies to better manage resources as they prepare the documentation required under the EER and to avoid the preparation and submission of extraneous information. Submitters 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, as appropriate under a weight of evidence approach. This guidance contains example analyses that may be used by air agencies in their demonstrations, however analyses not listed or explained here may also be appropriate to include. The evidence included in a demonstration should be well-documented, appropriately applied, technically sound, and should support the weight of evidence showing that the event and/or monitored concentration meets the regulatory criteria. Because this guidance identifies important analyses and language to include within an exceptional events demonstration and promotes a common understanding of these elements between the submitting air agency and the reviewing EPA Regional Office, the EPA anticipates an expedited review of demonstrations prepared according to this guidance.

<u>Fire-related Definitions and Terminology</u>

The EPA defined wildfire in the 2016 revision of the EER as: "any fire started by an unplanned ignition caused by lightning; volcanoes; other acts of nature; unauthorized activity; or accidental, human-caused actions; or a prescribed fire that has been declared to be a wildfire." The EER and this guidance document differentiate wildfires from prescribed fires in that prescribed fires are intentionally ignited by management actions in accordance with applicable laws, policies, and regulations to meet specific land or resource management objectives (*e.g.*, ecosystem maintenance, habitat restoration, or the reduction of potential wildfire emissions by reducing fuel loadings). Fire managers may declare specific prescribed fire projects to be wildfires if the conditions of a prescribed fire develop in a way that the project no longer meets the resource objectives (*e.g.*, if the fire has escaped secure containment lines along all or part of its boundary). If a prescribed fire project is declared to be a wildfire, it should be considered and treated as a

[4] This draft version of the guidance addresses wildfire events only, although many technical analyses described in Section 3 apply to both wildfire and prescribed fires. Prescribed fires may be added in a later version, or may be addressed in a future companion guidance document.

wildfire from that point time forward. The 2016 EER revisions also codified the 2014 National Wildfire Coordinating Group's[5] definition of wildland as "an area in which human activity and development is essentially non-existent, except for roads, railroads, power lines, and similar transportation facilities. Structures, if any, are widely scattered." This guidance document differentiates between wildfires on wildland and wildfires on other lands, particularly in the "human activity unlikely to recur at a particular location or a natural event" section of the document.

This guidance uses the following terminology:

- *Fire*: While this document refers to "a fire" or "the fire," we recognize that there could be multiple individual fires that, when aggregated, affect $O_3$ concentrations at a given monitoring site.
- *Event* includes the fire (or fires), the fire's $O_3$ precursor emissions, and the resulting $O_3$ from the fire.
- *Exceptional event* means an event and its resulting emissions that affect air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation, is not reasonably controllable or preventable, is an event caused by human activity that is unlikely to recur at a particular location or a natural event, and is determined by the Administrator in accordance with 40 CFR 50.14 to be an exceptional event. It does not include stagnation of air masses or meteorological inversions, a meteorological event involving high temperatures or lack of precipitation, or air pollution relating to source noncompliance. See definition of an exceptional event in the 2016 revisions to the EER.
- *Episode* refers to the period of elevated $O_3$ concentrations in the affected area.
- *Plume* means an air mass that contains pollutants emitted by a fire; it may be broad and mixed into the surrounding air, or the more conventional long narrow plume with well-defined edges.
- *Evidence* includes, but is not limited to, measurements and analyses based on measurements.

Tiered Approach for Determining the Level of Evidence Likely to be Necessary in Demonstrations

The EPA reviews all exceptional events demonstrations using a weight of evidence approach. This means the EPA evaluates all evidence submitted with the demonstration or otherwise known to the EPA and weighs the relevance, uncertainty, and persuasiveness of the evidence with respect to each of the EER elements before acting to approve or disapprove an air agency's request to exclude data under the EER. Each event eligible for consideration under the EER will likely have unique characteristics. Therefore, the documentation and analyses that should be included in demonstrations will vary according to the event characteristics, relationship to the monitor where the exceedance occurred, and the complexity of the airshed. Though EPA will evaluate the evidence necessary to support the exclusion of data on a case-by-case basis, the EPA acknowledges that air agencies may need to provide varying levels of evidence depending on the nature and severity of an event.

[5] Glossary of Wildland Fire Terminology, National Wildfire Coordinating Group, PMS 205, October 2014. Available at *http://www.nwcg.gov/sites/default/files/products/pms205.pdf*.

This guidance outlines a tiered approach to demonstrations for wildfire events, recognizing that some fire events may be more clear and/or extreme and, therefore, require relatively less evidence to satisfy the rule requirements, particularly for the clear causal relationship element. Tier 1 demonstrations are the simplest and least resource intensive and would be appropriate for fire events that cause clear $O_3$ impacts in areas or during times of year that typically experience lower $O_3$ concentrations. Tier 2 demonstrations would be used when the impacts of the fire on $O_3$ levels are less clear and would require more evidence than Tier 1 demonstrations. Similarly, Tier 3 demonstrations would require more evidence than Tier 2 demonstrations and would be appropriate when the relationship between the subject fires and influenced $O_3$ concentrations is more complicated. Tier 1 demonstrations are described in detail in section 3.4, Tier 2 demonstrations are described in section 3.5, and Tier 3 demonstrations are described in section 3.6.

The EPA intends that air agencies will look at key factors of events and related concentrations to determine the appropriate tier (Tier 1, 2, or 3) of demonstration before preparing and submitting a demonstration. As indicated in the "Initial Notification of Potential Exceptional Event" portion of the 2016 revisions of the EER, the EPA expects to discuss potential event-influenced exceedances with an affected air agency prior to the air agency preparing and submitting a demonstration. This discussion will provide an opportunity to discuss the appropriate tier for the event demonstration.

<u>Scope of This External Review Draft</u>

*Event types:* This document focuses on the preparation of demonstrations for wildfires that influence monitored $O_3$ concentrations. This document does not specifically address demonstration components that may be necessary for showing prescribed fire impacts on $O_3$ concentrations. However, many example technical analyses contained in the "clear causal relationship" section of this guidance document will also be appropriate for exceptional events demonstrations for prescribed fire impacts on $O_3$ concentrations. The "human activity unlikely to recur" and "not reasonably controllable or preventable" elements require different approaches for prescribed fires than those included in this draft guidance document. The EPA is inviting comment on whether additional guidance to address prescribed fires is needed and, if so, whether this guidance should be included in this document or in a separate guidance document.

*Regulatory determinations:* The 2016 EER revisions clarify the EPA's interpretation of the types of regulatory determinations eligible for data exclusion under the EER. This guidance document applies only to the specific regulatory determinations identified in the 2016 EER revisions. These actions include determinations of historical NAAQS exceedances/violations or non-exceedances/non-violations and determinations of the air quality "design value" at particular monitoring sites when made as part of the basis for any of the following five types of regulatory actions:

- An action to designate or redesignate an area as attainment, unclassifiable/ attainment, nonattainment, or unclassifiable for a particular NAAQS.

- The assignment or re-assignment of a classification category (marginal, moderate, serious, etc.) to a nonattainment area to the extent this is based on a comparison of its "design value" to the established framework for such classifications.
- A determination as to whether a nonattainment area has actually attained a NAAQS by its CAA deadline.
- A determination that an area has had only one exceedance in the year prior to its deadline and thus qualifies for a 1-year attainment date extension, if applicable.
- A finding of SIP inadequacy leading to a SIP call to the extent the finding hinges on a determination that the area is violating a NAAQS.

Overview of the Process for Demonstration Preparation, Submission, and Review

The 2016 EER revisions outline the process, including communications, schedule for demonstration submission, and review timelines for preparing, submitting, and reviewing exceptional events demonstrations. A flowchart including recommendations on the process for preparing, submitting, and reviewing wildfire $O_3$ demonstrations is included as Figure 1.

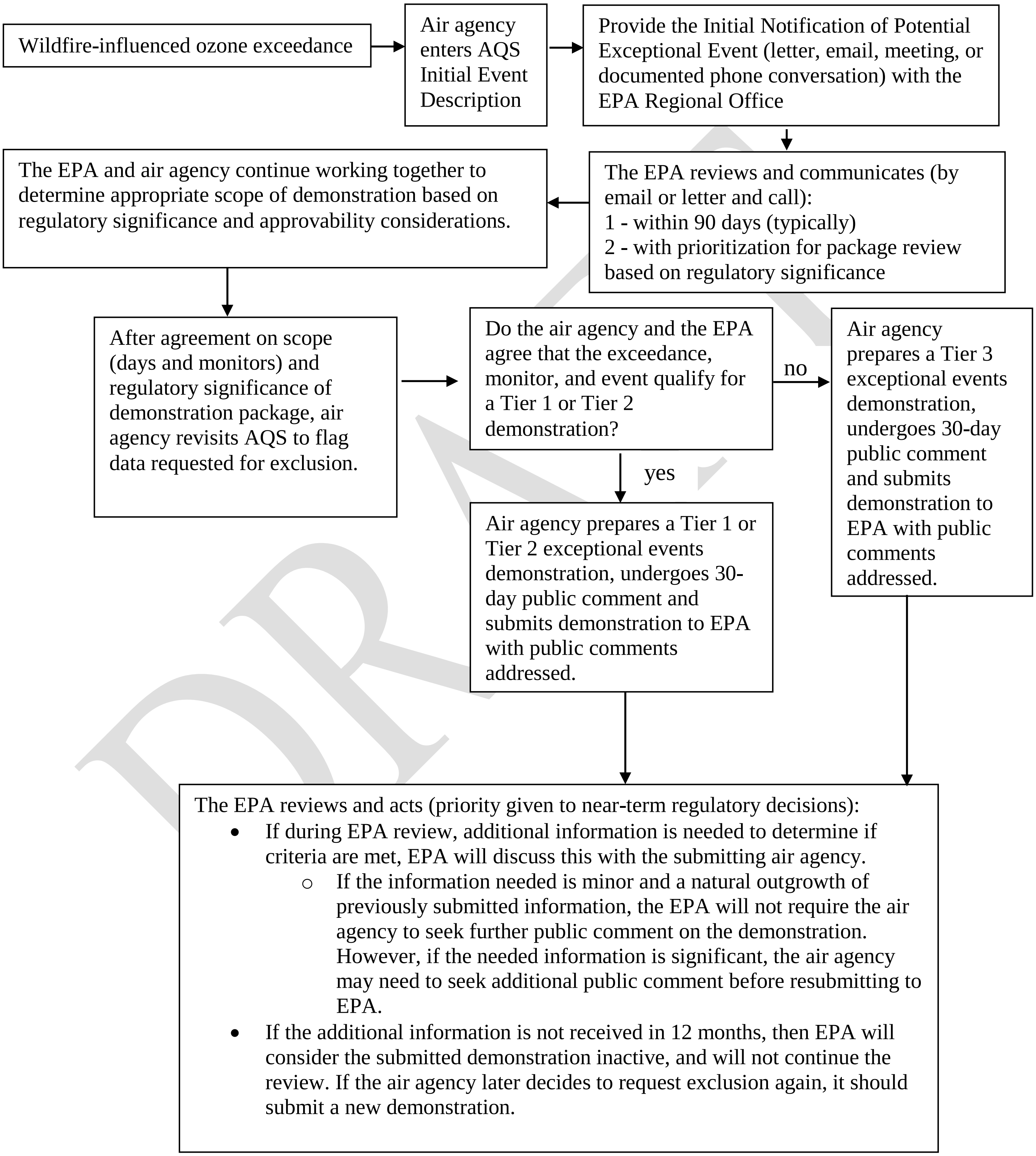
Outline of this Guidance

This guidance document is organized by EER-required elements in the recommended order for inclusion within an exceptional events demonstration. Section 2 covers the narrative conceptual model, Sections 3-5 discuss required elements of an exceptional events demonstration, and Section 6 addresses the public comment process. Of particular note, Sections 3.4 – 3.6 discuss the three tiers of demonstrations. Air agencies should include clear evidence and documentation for each rule element to facilitate the EPA's review and action on a submitted demonstration.

Role of this Guidance

The 2016 EER revisions are the source of the regulatory requirements for exceptional events and exceptional events demonstrations. This document provides guidance and interpretation of the EER. It does not impose any new requirements and shall not be considered binding on any party. If an air agency submits a demonstration using the approach in this guidance and the EPA concurs with the request to exclude data, the EPA will also prepare documentation to support the decision.

**Figure 1: Flowchart for the recommended process for preparation, submission, and review of exceptional events demonstrations for wildfire impacts on $O_3$, including communications with EPA Regional Offices.**



# 2. Narrative Conceptual Model and Event Summary

## 2.1 Overview and EER Provisions

The 2016 EER revisions require that demonstrations include a conceptual model, or narrative, describing the event causing the exceedance, a discussion of how emissions from the event led to the exceedance at the affected monitor(s), and a summary of the regulatory determination that has been or would be affected by the event. This narrative for a wildfire event can be more or less detailed depending on the event and local area complexities, but the general idea is to provide near the beginning of the demonstration a description of the wildfire event, interaction of emissions, meteorology, and chemistry of event and non-event $O_3$ formation in the area, and a description of the regulatory significance of the proposed data exclusion.

The 2016 EER revisions include a requirement that the air agency provide an "Initial Notification of Potential Exceptional Event" to the EPA Regional Office after the agency identifies a potential exceptional event. This Initial Notification process is intended to initiate conversations between an air agency and the EPA if not already on-going, or engage in more detailed discussions if a process is currently in place, regarding specific data and whether the identified data are ripe for submittal as exceptional events. As identified in the EER revisions, the Initial Notification step involves the air agency submitting a description of the event, a summary of the data requested for exclusion, and a description of the regulatory significance of the data exclusion to the EPA. It is likely that much of the information the air agency has submitted to the EPA during the initial notification of a potential exceptional event would also be useful to include in the conceptual model section of a demonstration.

## 2.2 Examples of Supporting Documentation

The possible types of monitored evidence and technical analyses that should be included in the demonstration are described in the following sections, but to be meaningful and clearly interpreted, they should be tied to a simple narrative describing how emissions from a specific fire (or group of fires) resulted in elevated $O_3$ at a particular location and how the emissions and resulting high $O_3$ concentrations differ from typical high $O_3$ episodes in the area. This narrative description of the cause of the exceedance and the supporting data and technical analyses will provide a consistent framework by which the EPA can evaluate the evidence in a demonstration. The interaction of the fire plume with non-event emissions and meteorological conditions of the area will, in part, determine the relevant evidence.

The narrative conceptual model should describe the principal features of the interaction of the event and event emissions, transport (*e.g.*, wind patterns such as strength, convergence, subsidence, recirculation), and $O_3$ chemistry that characterized the $O_3$ episode. This narrative should highlight key factors in $O_3$ formation for the particular episode, and their relative importance. A description of the typical urban plume direction (if present), hour of occurrence for peak $O_3$ concentration, distance downwind, typical wind flow patterns, expected influence of major sources or emissions categories, relationship between $O_3$ concentrations to diurnal temperature and growth of mixing layer, the importance of $O_3$ and precursors aloft, and multiple day carry-over of pollutants are a few items that could be used to discuss this conceptual model. See Appendix A1 for an example of an event summary and conceptual model.

Finally, even if the monitored data and/or technical analyses may not unequivocally support the clear causal relationship, agencies should submit available information regarding the event and monitored concentrations. It may still be possible to explain, with a weight of evidence approach, why the majority of the data or analyses are consistent with the event's impact on $O_3$ (for example, that most of the meteorological parameters would have indicated a lower $O_3$ day under non-fire conditions, even though the temperature was high).

Where a conceptual model that consistently explains non-event $O_3$ exceedances in the area already exists or can be formulated, highlighting the differences between the conceptual model for the event day with the non-event conceptual model can significantly strengthen a demonstration. For example, if the winds were from an urban center to the monitor of interest on all non-event $O_3$ exceedance days, but the winds are not from that direction on the event day, this difference can form a theme in the overall demonstration if it is clearly noted in the conceptual model discussion. Evidence substantiating the accuracy of the non-event conceptual model would give this approach more weight in the weight of evidence determination. Section 3 discusses this type of evidence. Much of the evidence included in the conceptual model may have also been included in the air agency's Initial Notification of Potential Exceptional Event.

The EPA recommends that air agencies include the following information in their conceptual model and event summary:

- Maps and tables of the wildfire event information including location, size, and extent. The maps should also include the location of the monitor(s) where data exclusion is requested. This map and table should clearly identify the fire(s) believed by the air agency to have caused the exceedance, not just a list of fires occurring within the jurisdiction of the submitting air agency.[6]
- Characteristics and description of the monitor with the request for data exclusion. Non-event similarities and differences between this monitor and nearby monitors should be explained.
- To the extent known, air agencies should include a brief explanation and identification of the cause and point of origin for the event fire(s).
- Examples of media coverage of the event, including special weather statements, advisories, and news reports.
- Smoke forecasts based on meteorology and burn conditions; these are often provided as part of the Wildland Air Quality Response Program.
- Description of meteorological data from or near the affected monitor and how this relates to the transport of the fire emissions.
- Description of the route of the wildfire emissions to the impacted monitor, including meteorological information (*e.g.*, general atmospheric circulation characteristics) regarding the transport of fire emissions to the monitor.

[6] Burn scar areas by month, 2010-2014: *http://activefiremaps.fs.fed.us/burnscar.php*; Federal Land Fires, 1980-2013, with details (dates, acreage): *http://wildfire.cr.usgs.gov/firehistory/viewer/viewer.htm.*

- Non-event $O_3$ formation characteristics of the area normally influencing the monitor (*i.e.*, the non-event conceptual model).
- Discussion of the differences observed between the non-event conceptual model and event related conditions causing high $O_3$ concentrations at a particular location.
- A summary of spatial and temporal $O_3$ patterns on the day of interest, and days before and after the event, relative to other, non-event days (either high $O_3$ days, or days with similar meteorology than the event day), including maps of affected and non-affected monitors.
- Description of the regulatory determination anticipated to be impacted by the exceptional event, including a table of the monitor data requested for exclusion (*e.g.*, date, hours, monitor values, and design value calculations with and without the exceptional event).
- NAAQS attainment and classification information, including $O_3$ SIP status.

# 3. Clear Causal Relationship Between the Specific Event and the Monitored Concentration

## 3.1 Overview and EER Provisions

The 2016 EER revisions require that demonstrations address the technical element 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 (supported in part by the comparison to historical concentrations and other analyses)." This element of the demonstration provides evidence supporting the clear causal relationship between the event and the monitored NAAQS exceedance or violation and, therefore, that the event has affected air quality. Air agencies should support the clear causal relationship with a comparison of the $O_3$ data requested for exclusion with historical concentrations at the air quality monitor. In addition to providing this information on the historical context for the event-influenced data, a clear causal relationship is generally established by demonstrating that the fire's emissions were transported to the monitor, the fire's emissions affected the monitor, and, in some cases, a quantification of the level of impact of the fire's emissions on the monitored $O_3$ concentration.

## 3.2 Event-related Concentration in the Context of Historical Concentrations

Part of demonstrating a clear causal relationship between the event and the monitored $O_3$ exceedance involves a comparison with historical concentrations measured at the monitor or throughout the area during the same season. Air agencies should compare the data requested for exclusion with the historical concentrations at the monitor, including all other "high" values in the relevant historical record. If other values in the historical record are alleged to have been affected by exceptional events, the EPA recommends identifying those values and including event information to support that the monitored concentrations were impacted, such as a list of previous fire dates and locations, evidence of stratospheric intrusion, or evidence supporting other event types. In addition to demonstrating how the level of the event exceedance compares with historical data, it may also be useful to demonstrate how the diurnal or seasonal pattern differs, if such a deviation occurred, due to the event. To be effective, such comparisons need some level of robustness. Statistical summaries used to characterize non-event, high-concentration day historical data and the differences seen on event days would carry more weight than anecdotal or general assertions of when non-event behavior occurs, without evidence or quantification.

The data used in the comparison of historical concentrations analysis should focus on concentrations of $O_3$ at the impacted monitor and nearby monitors if appropriate. Evidence of additional impacts on air quality [carbon monoxide (CO), particulate matter (PM), nitrogen oxides (NOx), etc.] can also be provided if they provide additional insight.

There is no pass or fail threshold for the historical concentrations data presentation. However, the comparisons may inform whether additional evidence is needed to successfully establish the clear causal relationship element. For example, historical comparisons conclusively showing that the event-affected $O_3$ concentration was outside the range of historical concentrations will likely indicate less additional evidence may be needed to demonstrate the clear causal relationship. The seasonality of the event-related exceedance versus other exceedances may be used to determine if a Tier 1 (Section 3.4) demonstration may be an appropriate option. Additionally, the percentile ranking of the event-influenced data against historical data may also be used in one of the factors (Section 3.5) to determine if a Tier 2 demonstration may be a suitable option.

### 3.2.1 Examples of Supporting Documentation

- Provide a plot of the maximum daily 8-hour $O_3$ concentrations at the monitor(s) in question for the high $O_3$ seasons (April through October, or other months as appropriate) for at least 5 years. An example approach to plotting these data is shown below in Figure 2. Alternatively, including separate plots for each year (or season) may also be an informative approach to presenting this information.
- Timeseries plots of $O_3$ concentrations at nearby monitors can be used to demonstrate spatial and/or temporal variability of $O_3$ in the area.
- Determine 5-year percentile of the data requested for exclusion on a per monitor basis.
- Determine the annual ranking of the data requested for exclusion. This assessment may be potentially helpful to show when the non-event $O_3$ during the year with the exclusion request was lower than surrounding years.
- Identify the cause of other “peaks” – fires, other causes, or normal photochemical events, and provide evidence to support the identification when possible.
- A timeseries plot covering 12 months (or the months of the high $O_3$ season) overlaying all 5 years of data plotted can be useful in identifying monitored concentrations that are unusually high for a time of year, and/or that coincide with fire events. An example is provided below in Figure 3.
- Trends due to emission reductions from planning efforts, or other variability due to meteorology or economics of an area can be discussed in explaining the distribution of data over the previous 5 years. For example, if a downward trend in $O_3$ concentrations over the 5-year historical data record obscures the uniqueness of the event-related concentration, the air agency should use appropriate plots to explain this trend.

**Figure 2. Example of an $O_3$ time series plot from an event-impacted monitor to include in a demonstration.**

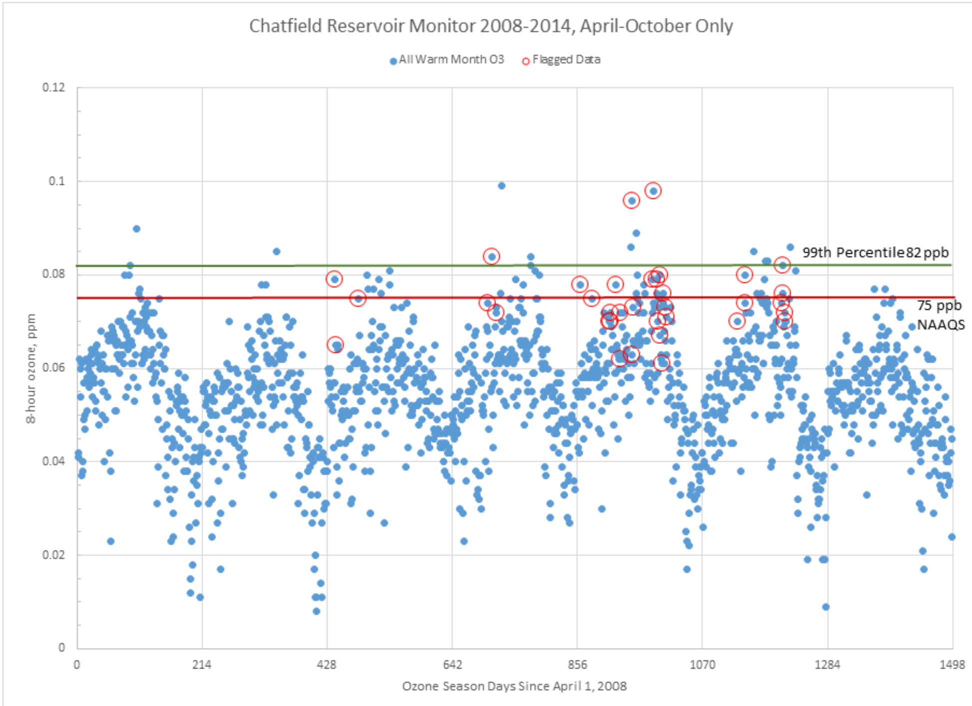
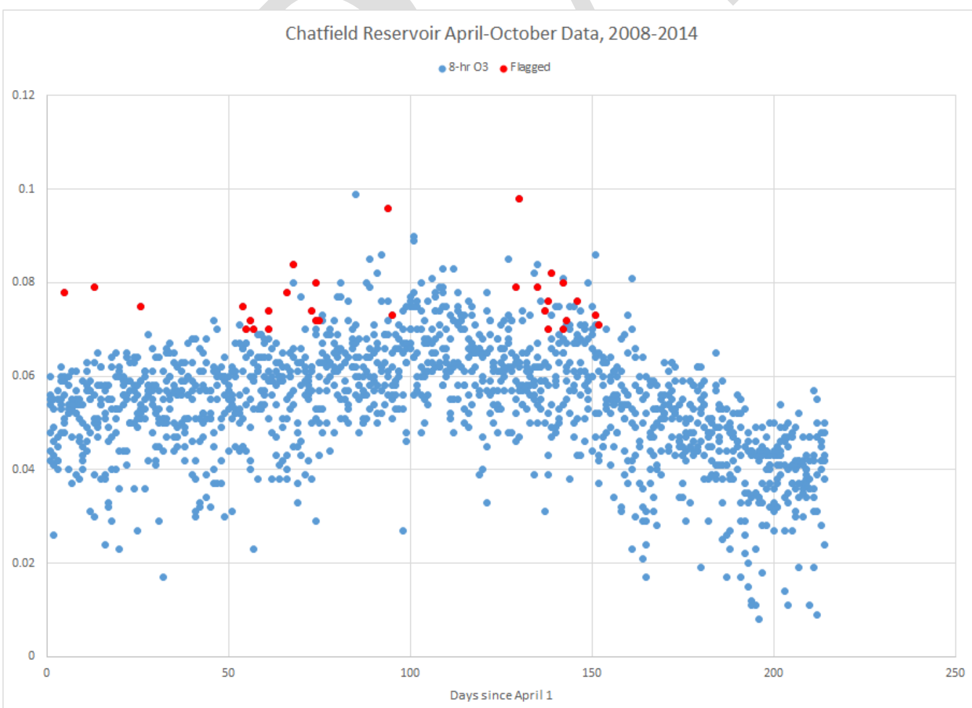



**Figure 3. Example of a seasonal $O_3$ plot, overlaying multiple years of data from an event-impacted monitor to include in a demonstration.**



## 3.3 Concept of Different Tiers of Exceptional Events Demonstrations

The nature and severity of a fire event and the characteristics of the typical $O_3$ concentrations at the affected monitor will, in part, determine the evidence that an air agency will need in its weight of evidence showing for the clear causal relationship portion of an exceptional events demonstration for fire impacts on monitored $O_3$ concentrations. The tiering strategy described in this guidance contains three tiers of demonstrations and is based on an event's potential for $O_3$ formation at a given monitor and/or the history of non-event $O_3$ concentrations at the monitor. This strategy acknowledges that some fire events can be extreme or otherwise clearly stand out from normally occurring $O_3$ concentrations and, thus, may necessitate less evidence for the clear causal relationship analysis.

Tier 1 demonstrations are appropriate for the clearest events, *e.g.*, fires located in close proximity to a monitor in an area or during a time of year with typically low $O_3$ concentrations. Tier 1 demonstrations would likely need the least amount of evidence. Tier 2 demonstrations would be used in situations with less clear fire impacts and would require more evidence than Tier 1 demonstrations. Tier 3 demonstrations, requiring more evidence than Tier 2 demonstrations, would be appropriate when the relationship between the subject fires and influenced $O_3$ concentrations is complex. Section 3.4 defines situations where a Tier 1 demonstration may be appropriate, Section 3.5 defines situations and evidence suggested for a Tier 2 demonstration, and Section 3.6 suggests additional evidence that may be necessary for a Tier 3 demonstration.

## 3.4 Key Factor of and Suggested Evidence to Include in Tier 1 Demonstrations

The EPA expects that Tier 1 exceptional events demonstrations may be appropriate for fire events that have a clear impact on $O_3$ concentrations when they occur in an area that typically experiences lower $O_3$ concentrations (*e.g.*, few or no $O_3$ exceedances), are associated with an $O_3$ concentration that is clearly higher than non-event related concentrations, or occur outside of the area's normal $O_3$ season. Many "extreme" fire events could qualify for a Tier 1 demonstration. In these situations, $O_3$ impacts should be accompanied by clear evidence that the fire's emissions were transported to the location of monitor. This tier of demonstration is expected to be the most simple and easiest to prepare.

### 3.4.1 Evidence the Event, Monitor(s), and Exceedance Meet the Key Factor for Tier 1 Demonstrations

*Key Factor – Seasonality and/or distinctive level of the monitored $O_3$ concentration*: The key factor that delineates event-related monitored $O_3$ concentrations for Tier 1 demonstrations is the uniqueness of the concentration when compared to the typical seasonality and/or levels of $O_3$ exceedances. For example, if an event-related exceedance occurs during a time of year that typically has no exceedances, then that event-related exceedance may be more straightforward to attribute as having been due to the fire than event-related concentrations that occur during the same month or season as typical high $O_3$ concentrations. If there are other exceedances during the same time of the year as the fire-related exceedance, for example during the normal $O_3$ season, they either should also be attributable to fire (or other exceptional events) or if attributable to normal emissions and photochemistry, they should be clearly lower in magnitude than the fire-related concentrations. The EPA recommends that event-related exceedances should be at least 5-10 ppb higher than non-event related concentrations for them to be clearly distinguishable. This key factor is based on the fact that if there are no similar-level non-event exceedances mixed in with the event-related exceedance, then less evidence may be necessary to demonstrate the clear causal relationship between the event and the monitored $O_3$ concentration. Following are two types of analyses that an air agency can provide for this section of the demonstration.

1) Provide a timeseries plot covering 12 months (or the typical $O_3$ season months plus months with the event-related exceedance) overlaying at least 5 years of $O_3$ monitoring data. An example is shown in Figure 3.
2) Provide a description of how the seasonality of the event-related exceedance differs from the typical photochemical $O_3$ season and how other exceedances, if any, during the time of year of the fire-related exceedance are not attributable to normal emissions and photochemistry, are attributable to fire (or other exceptional events), or are clearly lower in magnitude than the fire-related concentrations.

### 3.4.2 Evidence that the Fire Emissions Were Transported to the Monitor(s)

In addition to the evidence suggested in Section 3.4.1, the air agency should supply at least one piece of additional evidence to support the weight of evidence in a Tier 1 demonstration that the emissions from the fire were transported to the monitor location (*i.e.*, the latitude and longitude). Air agencies can use either a trajectory analysis or a combination of satellite and surface measurements to show this transport. This evidence could be any of the following:

- *Trajectory analysis.* Atmospheric trajectory models use meteorological data and mathematical equations to simulate three-dimensional transport in the atmosphere. Generally, these models calculate the position of particles or parcels of air with time based on meteorological data such as wind speed and direction, temperature, humidity, and pressure. Model results depend on the spatial and temporal resolution of the atmospheric data used and also on the complexity of the model itself. The HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model is frequently used to produce trajectories for assessments associated with air quality programs. HYSPLIT contains models for trajectory, dispersion and deposition. However, analyses applicable to exceptional events demonstrations typically use the trajectory component. The trajectory model, which uses existing meteorological forecast fields from regional or global models to compute advection (*i.e.*, the rate of change of an atmospheric property caused by the horizontal movement of air) and stability, is designed to support a wide range of simulations related to the atmospheric transport of pollutants.

  Air agencies can produce HYSPLIT trajectories for various combinations of time, locations and plume rise. HYSPLIT back-trajectories generated for specific monitor locations for days of high $O_3$ concentrations illustrate the *potential* source region for the air parcel that affected the monitor on the day of the high concentration and provide a useful tool for identifying meteorological patterns associated with monitored exceedances. Forward-trajectories from specific fire events to specific monitors can also be used to indicate *potential* receptors. HYSPLIT trajectories alone cannot definitively conclude that a particular region contributed to high pollutant concentrations, but a set of

HYSPLIT trajectories that show no wind flow from a particular region on days with high concentrations might support discounting that region as contributing to the concentrations. Appendix A3 contains additional information on HYSPLIT trajectory analyses.

Air agencies could use other trajectory models, to demonstrate expected transport. Exceptional events demonstrations using other trajectory models should contain enough background information and detail supporting model application to allow reviewers to thoroughly understand the model and to reproduce the results, if necessary.

- *Satellite Imagery of Plume with Evidence of the Plume Impacting the Ground*. Because plume elevation is not directly available from simple imagery, plume imagery alone does not conclusively show that fire emissions transported aloft reached a ground-level monitor. If plume arrival at a given location coincides with elevation of fire plume components (such as $PM_{2.5}$, CO or organic and elemental carbon), those two pieces of evidence combined can show that smoke was transported to the event location.

### 3.5 Key Factors of and Suggested Evidence to Include in Tier 2 Demonstrations

If a fire event influences $O_3$ concentrations, but these influences are not clearly higher than non-event related concentrations nor do the event influences occur outside of the affected area's normal $O_3$ season, then the event would not meet the Tier 1 key factor for seasonality and/or distinctive level of the monitored $O_3$ concentration and the air agency would not be able to use a Tier 1 approach. The air agency should then determine whether a Tier 2 approach or a Tier 3 approach would be appropriate. As noted in the introduction to this guidance, Tier 2 demonstrations would likely require more evidence than Tier 1 demonstrations and would be used when the impacts of the fire on $O_3$ levels are less clear than for Tier 1. Tier 3 demonstrations would require yet more evidence. The criteria distinguishing a Tier 1 case from a Tier 2 case have already been stated. To identify key factors that could differentiate Tier 3 events from Tier 2 events, the EPA reviewed previously approved exceptional events demonstrations, conducted a literature review of case specific fire-$O_3$ impacts, and completed photochemical modeling analyses. The Tier 3 approach is discussed in section 3.6.

This section describes the approach the EPA used to determine the key factors of a Tier 2 demonstration. Section 3.5.1 describes the results of this approach.

*Literature review:* Fires can impact $O_3$ concentrations by emitting $O_3$ precursors including NOx and VOCs. These precursor emissions can generate $O_3$ within the fire plume or can mix with emissions from other sources to generate $O_3$ (Jaffe and Wigder, 2012). Also, in some situations, including near fires, reduced $O_3$ concentrations have been observed and attributed to $O_3$ titration by enhanced NO concentrations and reduced solar radiation available to drive photochemical reactions (Jaffe et al., 2008; Yokelson et al, 2003). The magnitude and ratios of emissions from fires vary greatly depending on fire size, fuel characteristics, and meteorological conditions (Akagi et al., 2012). As a result of variable emissions and non-linear $O_3$ production chemistry, the $O_3$ production from fires is very complex, highly variable, and often difficult to predict (Jaffe and Wigder, 2012).

Despite the complexities in predicting $O_3$ formation from fire emissions, several studies have found increases in $O_3$ concentrations attributable to fire impacts. For example, Pfister et al. analyzed surface $O_3$ data during a high wildfire year in California (2007) with modeled fire impacts and found monitored 8-hour $O_3$ concentrations were approximately 10 ppb higher when the modeled fire impacts were high (Pfister et al., 2008). Jaffe et al. analyzed three wildfire periods in the western U.S. during 2008 and 2012 and compared monitored surface $O_3$ concentrations with two different modeled estimates of fire contributions to $O_3$ concentrations to find enhancements in $O_3$ when fire impacts were predicted to be high (Jaffe et al., 2013). Many other publications have found similar relationships between surface $O_3$ and fire occurrences, using a variety of technical approaches (Bytnerowicz et al., 2013). One literature study was used to evaluate the relationship between $O_3$ impact and fire characteristics (Jaffe et al., 2013).

*Empirical Relationships between Fire Events and $O_3$ Concentrations in Previous Demonstrations:* The EPA reviewed previous demonstrations for specific fire events to determine if general relationships exist between the magnitude of the fire emissions, the distance of the fire to $O_3$ monitors, and $O_3$ impacts at those monitors. Between 2010 and September 2015, the EPA approved two exceptional events demonstrations for fire-related impacts on $O_3$. The first was approved in 2011. In this case, the EPA concurred on three exceedances of the 1-hour $O_3$ NAAQS near Sacramento, California in 2008 due to a series of lightning-initiated wildfires throughout northern California. The second demonstration for fire impact on $O_3$ was approved in 2012. In this case, the EPA concurred with the exclusion of eight 8-hour daily maximum $O_3$ exceedances during April 2011 in Kansas due to impacts from prescribed fires and wildfires. Prescribed fires caused most of the exceedances identified in the Kansas demonstration.

*Modeling Studies of $O_3$ Impacts from Fires:* To support the development of this guidance and to assess the relationship between fire source strengths and resultant $O_3$ concentrations at various distances from the fire, the EPA conducted modeling analyses for fires identified in the EPA's 2011 National Emissions Inventory (NEI). See Appendix A2. Four fires of varying strengths and locations were simulated with the Community Multiscale Air Quality Model (CMAQ) model. The $O_3$ impacts of these fires were estimated using a source apportionment technique (Kwok et al., 2015). Consistent with previous literature studies, the EPA modeling suggests that NOx and VOC emissions can lead to significant increases in $O_3$ concentrations downwind of the fire. The simulated $O_3$ increases are related to distance downwind from the fire and the magnitude of the fire emissions. Examination of this modeling and related studies suggests that it is appropriate to use a simple Q/D (emissions/distance) metric to conduct a screening assessment of potential fire impacts. This model application was evaluated against monitoring data and appears to capture the ambient relationships between CO and $O_3$ measured in the vicinity of smoke plumes. The EPA acknowledges that the science continues to emerge in modeling the $O_3$ impacts of fires (*e.g.*, plume chemistry, plume rise). The 2011 modeling includes some limited treatment of the sunlight-blocking impacts of smoke on $O_3$ photochemistry.

The EPA used the general relationships between $O_3$ impacts and fire characteristics from the modeling study, in combination with the assessment of previously approved demonstrations and fire case-studies from the peer-reviewed literature to develop two key factors (Section 3.5.1) for a Tier 2 demonstration. These two key factors act together to identify event and monitor pairs that may be appropriate for a Tier 2 demonstration. Section 3.5.1 includes a recommended value and guidance for determining Q/D.

### 3.5.1 Evidence that the Event, Monitor(s), and Exceedance Meet the Key Factors for Tier 2 Demonstrations

This section details the evidence to be included in a Tier 2 demonstration for the clear causal relationship rule element.

*Key Factor #1 – Fire emissions and distance of fire(s) to affected monitoring site location(s):* At least one air quality related program (*i.e.*, determining impacts at Class I areas) uses an emissions divided by distance (Q/D) relationship as a key factor for determining the influence of emissions on a downwind monitor. The EPA believes that it is appropriate to use a similar approach, along with key factor #2 detailed below, to determine if a Tier 2 exceptional events demonstration provides sufficient evidence to satisfy the clear causal relationship criteria for fire $O_3$ demonstrations. To determine an appropriate and conservative value for the Q/D threshold (below which a full/Tier 3 exceptional events demonstration would be recommended), the EPA conducted a review of approved exceptional events demonstrations, a literature review of case specific fire-$O_3$ impacts, and photochemical modeling analyses, as described above. The three analyses generally showed that larger $O_3$ impacts occurred at higher Q/D values. The reviews and analyses did not conclude that particular $O_3$ impacts will always occur above a particular value for Q/D. For this reason, a Q/D screening step alone is not sufficient to delineate conditions where sizable $O_3$ impacts are likely to occur. Given this, the EPA recommends, as the first of two key factors, that the Q/D (as described below) should be ≥ 100 tons per day/kilometers (tpd/km). The rationale for the recommendation of ≥ 100 tpd/km as a conservative indicator of $O_3$ impacts is based on the Q/D ratio for previously approved fire-related $O_3$ exceptional events demonstrations and the modeling results that showed the largest $O_3$ impacts were often associated with high Q/D values. The $O_3$ values within the approved demonstrations generally were associated with Q/D values above 50 tpd/km (Figure A2-1), though not all the concentrations shown were clear cases of causal contribution from fires. The largest $O_3$ impacts from the modeling studies of the two largest fires (Wallow and Flint Hill fires) were associated with Q/D values above 100 tpd/km (Figure A2-5), and large $O_3$ impacts were not observed in the modeling of the two smaller fires (Big Hill and Waterhole fires). Based on results from these analyses and reviews, if the Q/D (as defined and calculated in Section 3.5.1) is ≥ 100 (tpd/km), and key factor #2 is also met, then a Tier 2 demonstration may be appropriate. Following is a description of how an air agency could develop a Q/D analysis.

*Calculate Q/D for the event and monitor pairs:*

Determine fire emissions (Q): For the purposes of exceptional events tiering, fire emissions (Q in the Q/D expression) is defined as the daily sum of the NOx and reactive-VOC emissions (in units of tons per day) from specific fire events impacting the $O_3$ monitor on the day of the $O_3$ exceedance. Air agencies should describe and characterize in the conceptual model/event summary section of the demonstration all fires included in the calculation of Q/D. Since a fire event can span several days and because fire emissions may not impact a monitor on the day that they are generated, this guidance suggests the following approach for assessing a range of days to determine the maximum Q/D value to use for the screening test:

1) Determine the date of the 1st hour in the period of the 8-hour (or 1-hour) $O_3$ average that is the subject of the demonstration. *Example*: August 15, 2014.

2) Determine the date of the 8th hour of that 8-hour period, which may be the same as the first date or the following date. *Example*: August 16, 2014.

3) Identify fires generating emissions on these one or two dates and identify the date prior to the date of the 1st hour. Including the latter date allows for the possibility that fire emissions on one day affected ozone on the next day. These are the two or three dates that will be included in assessing the clear causal relationship. *Example*: August 14, 15, and 16.

   The EPA recommends generating 24-hour back trajectories from the affected $O_3$ monitoring site(s) beginning at each hour of these two or three dates. Identify fires that are close to any of these back trajectories. *Example*: the air agency identifies three fires: Fire A, Fire B and Fire C.

4) Identify the latitude/longitude of each fire for each day. Determine “D,” the distance in kilometers between the fire’s latitude/longitude and the affected $O_3$ monitor for each fire for each day.

5) For each fire and each day, identify the sum of NOx and reactive VOC (rVOC) emissions in tons/day. If only TOG emissions (versus rVOC) are available, multiply the TOG emissions by 0.6 to represent the reactive fraction that can contribute to $O_3$ formation (*see* Appendix A2). Alternatively, sum the specific rVOC emissions or use a multiplier other than 0.6 with appropriate justification. This step is designed to account for the fact that some of the gases included in the TOG emissions estimates do not contribute to ozone formation.

   Day-specific emissions estimates should be readily available for wildfire (and prescribed fire events) that occur during NEI years using the EPA methods. In addition to the actual emissions estimates (NOx, VOC, CO, $SO_2$, PM tons/day), the NEI methods also result in many other data fields that will be made available (date of fire occurrence, fire event name, state/county FIPS, latitude, longitude, quality assurance flag, fire type, acres burned). Detailed information about how the EPA develops inventories for fires on wildlands is part of the latest NEI documentation available on CHIEF (*http://www3.epa.gov/ttn/chief/eiinformation.html*). In general, the EPA’s approach for estimating fire emissions relies on a combination of satellite detection of fires merged with on-the-ground observational data (especially with activity data submitted by local air regulatory and forestry agencies) and where available combined with models that specify fuel loading, fuel consumption, and emission patterns/factors. These emissions are based on the latest version of the

Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation (SMARTFIRE) system (*http://www.airfire.org/smartfire/*). Air agencies can provide fire event emissions and activity data as part of an exceptional events demonstration that the state believes more accurately characterize the event than the information contained in the NEI, provided those emissions and activity data are well-documented and supported.

To estimate fire-related emissions in non-NEI years, air agencies may use other techniques to represent fire emissions, especially methods that have been agreed upon by multiple public agencies (*e.g.*, *http://www.airfire.org/data/playground/*) or emission estimates that reside in the published literature. The fire activity data and emissions estimation techniques used should be well-documented and supported. However, the EPA encourages the use of ground-based observations and local fuel information whenever possible as these factors can significantly improve the resulting estimates of fire emissions. As resources allow, to assist air agencies in locating fire-related emissions in non-NEI years, the EPA anticipates providing year and day-specific fire event emissions summaries using similar methodologies to that used in the NEI.

6) Check the fires individually to see whether any one of them had $Q/D > 100$ for any of the days. If yes, evaluate key factor #2. If $Q/D < 100$, then the air agency would develop a demonstration under the Tier 3 approach.

7) If any of the individual fires do not have $Q/D > 100$, determine whether the fires satisfy the Q/D test when aggregated. For each day of fire, weight the distances between the fire locations and the $O_3$ monitor by the NOx+rVOC emissions for that day to get an emissions-weighted D. Sum the NOx+rVOC emissions of all three fires (*e.g.*, Fire A, Fire B and Fire C from the above example) from the day, and calculate Q/D using the emissions sum and the distance.

8) If $Q/D \geq 100$ for the day, evaluate key factor #2. Apply the same aggregated approach for the other identified days. If Q/D is $< 100$, then the Tier 2 approach is not appropriate and the air agency would develop a demonstration under the Tier 3 approach. Show all calculations and values. The demonstration should clearly describe the result of the calculation, and the emissions, distance, and any assumptions that the air agency made in developing the Q/D ratio.

*Key Factor #2 – Comparison of the event related $O_3$ concentration with non-event related high $O_3$ concentrations:* The second key factor for a Tier 2 demonstration considers the characteristics of the event-related concentration versus the non-event $O_3$ concentration distribution at the monitor. Addressing key factor #2 involves showing that the exceedance due to the exceptional event:

- is in the $99^{th}$ or higher percentile of the 5-year distribution of $O_3$ monitoring data, OR

- is one of the four highest $O_3$ concentrations within 1 year (among those concentrations that have not already been excluded under the EER, if any).

Applying this key factor recognizes that an air agency will likely need more detailed information to establish a clear causal relationship between the event and the monitored exceedance in an area or season with elevated non-event related $O_3$ concentrations. Therefore, limiting the Tier 2 demonstration to events in the 99$^{th}$ or higher percentile of 5 years of monitoring data will generally ensure the event-impacted data are high compared to other data at the monitoring site. If event-related concentrations have already been excluded for this year, then those values should not be included when determining the ranking. However, if the non-event $O_3$ concentrations at a monitor in the year (or season) when the event-related $O_3$ exceedance occurred are low when compared with other surrounding years in the 5 year record, an exceedance in this "low" $O_3$ year could still affect design value calculations and determinations within the scope of the EER. Therefore, if the data requested for exclusion are one of the four highest within 1 year (among those concentrations that have not already been excluded under the EER, if any), the key factor would be met. If both key factors (#1 and #2) are met, then a Tier 2 demonstration may be sufficient.

*Compare the event-related $O_3$ concentration with non-event related high $O_3$ concentrations:*

1) Provide the percentile ranking of the data requested for exclusion when compared with the most recent 5 years of monitoring data. Include the plot showing this result or reference the generated plot in another section of the demonstration.

2) If data are in the 99$^{th}$ (or higher) percentile OR are one of the top four $O_3$ maximums within 1 year AND key factor #1 is satisfied AND the EPA Regional Office and the affected air agency have discussed the potential event THEN the air agency should prepare a Tier 2 demonstration.

### 3.5.2 Evidence that the Fire Emissions Affected the Monitor(s)

In addition to the evidence suggested in Section 3.5.1, the air agency should supply at least **one piece** of additional evidence to support the weight of evidence that the emissions from the fire affected the monitored $O_3$ concentration. The example evidence explained below can be used by air agencies to demonstrate the fire emissions were present at the altitude of the monitor(s).

This evidence could include any of the following:

1) Photographic evidence of ground-level smoke at the monitor

2) Concentrations of supporting measurements [CO, PM (mass or speciation), VOCs, or altered pollutant ratios]

3) Evidence of changes in spatial/temporal patterns of $O_3$ and/or NOx.

While fires generate emissions of CO, NO, $NO_2$, VOCs, $PM_{10}$, and $PM_{2.5}$, anthropogenic sources, such as industrial and vehicular combustion, also emit these pollutants. Therefore, the air agency should distinguish the difference in the non-event pollutant behavior (*e.g.*, concentration, timing, ratios, and/or spatial patterns) from the behavior during the event impact to more clearly show that the emissions from the fire(s) affected the monitor(s). Evidence from regulatory and non-regulatory (*e.g.*, special purpose, emergency) monitors may be used to support these analyses.

Specific analyses to support the above-identified evidence include the following:

- Photographic evidence of ground-level smoke at the monitor.

- Satellite evidence of smoke or precursors (NOx) at the monitoring site. *http://ofmpub.epa.gov/rsig/rsigserver?index.html* and *http://arset.gsfc.nasa.gov/airquality/applications/fires-and-smoke* may be helpful resources.

- Plots of co-located or nearby CO, $PM_{2.5}$, $PM_{10}$, or $O_3$ and $PM_{2.5}$ precursor concentrations in the same airshed (or nonattainment/near nonattainment area) that have increases or differences in typical behavior that indicate the fire's emissions impacted the monitor. Elevated levels of CO or PM (including pre-cursors) at an affected $O_3$ monitor upwind of urban centers or occurring at non-commute times at a monitor within an urban area despite the lack of a surface inversion would be consistent with fire plume impact. Include an explanation of the plots.

- Elevated light extinction measurements at or near the $O_3$ monitoring site that cannot be explained by emissions from other sources and are consistent with fire impact.

- The timing and spatial distribution of NO, $NO_2$, and $O_3$, shown with data from multiple monitoring sites. These pollutant concentrations may vary when influenced by a fire plume. Elevated levels that are widespread throughout a region, or are upwind of the urban area, may be due to impact of a fire plume. Peaks at locations and times different than those normally seen in an $O_3$ episode can indicate fire plume impact.

- Differences in CO:NOx ratios: The ratio of CO and NOx emissions depends on their source; for agricultural burning it is about 10-20, for wildfire and prescribe wildland burning about 100 (Dennis et al., 2002), whereas for high-temperature fossil fuel combustion sources it is more like 4 (Chin et al., 1994). Thus, an unusually high CO/NOx ratio is consistent with fire impact. Similarly, the CO/$PM_{10}$ emission ratio is 8-16 in fires, but 200-2000 for vehicles (Phuleria et al., 2005). Changes in CO and CO ratios might be difficult to discern in an area dominated by vehicular CO, however, as the fire signal may be small in comparison.

- PM speciation data: $PM_{2.5}$ emissions from forest fires often contain elevated levels of organic carbon (OC) and occasionally are enriched in water soluble potassium (K) (Watson et al., 2001). Levoglucosan, a tracer molecule, is a constituent of smoke from biomass burning that can serve as an indicator for fire; $PM_{10}$ from wood smoke is 14% or higher levoglucosan by mass (Jordan et al., 2006; Dennis et al., 2002). Co-located or nearby particle speciation data (OC, K, and/or levoglucosan) can be used to indicate fire impacts.

### 3.5.3 Evidence that the Fire Emissions were Transported to the Monitor(s)

In addition to the evidence suggested in Sections 3.5.1 and 3.5.2, an air agency should provide evidence showing the emissions from the fire were transported to the monitor location (*i.e.*, the latitude and longitude). Air agencies can use either a trajectory analysis or a combination of satellite and surface measurements to show this transport. (These recommendations are the same as for Tier 1 demonstrations in Section 3.4.2, but are explained here again for completeness).

- *Trajectory analysis.* Atmospheric trajectory models use meteorological data and mathematical equations to simulate three-dimensional transport in the atmosphere. Generally, these models calculate the position of particles or parcels of air with time based on meteorological data such as wind speed and direction, temperature, humidity, and pressure. Model results depend on the spatial and temporal resolution of the atmospheric data used and also on the complexity of the model itself. The HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model is frequently used to produce trajectories for assessments associated with air quality programs. HYSPLIT contains models for trajectory, dispersion and deposition. However, analyses applicable to exceptional events demonstrations typically use the trajectory component. The trajectory model, which uses existing meteorological forecast fields from regional or global models to compute advection (*i.e*., the rate of change of an atmospheric property caused by the horizontal movement of air) and stability, is designed to support a wide range of simulations related to the atmospheric transport of pollutants.

  Air agencies can produce HYSPLIT trajectories for various combinations of time, locations and plume rise. HYSPLIT back-trajectories generated for specific monitor locations for days of high $O_3$ concentrations illustrate the *potential* source region for the air parcel that affected the monitor on the day of the high concentration and provide a useful tool for identifying meteorological patterns associated with monitored exceedances. HYSPLIT trajectories alone cannot definitively conclude that a particular region contributed to high pollutant concentrations, but a set of HYSPLIT trajectories that show no wind flow from a particular region on days with high concentrations might support discounting that region as contributing to the concentrations. Appendix A3 contains additional information on HYSPLIT trajectory analyses.

  Air agencies could use other trajectory models to demonstrate expected transport. Exceptional events demonstrations using other trajectory models should contain enough background information and detail supporting model application to allow reviewers to thoroughly understand the model and to reproduce the results, if necessary.

- *Satellite Imagery of Plume with Evidence of the Plume Impacting the Ground*. Because plume elevation is not directly available from simple imagery, plume imagery alone does not conclusively show that fire emissions transported aloft reached a ground-level monitor. If plume arrival at a given location coincides with elevation of fire plume components (such as $PM_{2.5}$, CO or organic and elemental carbon), those two pieces of evidence combined can show that smoke was transported to the event location.

3.5.4 Summary of Evidence that Could be Used to Meet the EER Elements for Tier 1 and Tier 2 Demonstrations

Table 2 summarizes the technical support that air agencies can use to support the clear causal relationship in a Tier 2 demonstration, compared with a Tier 1 demonstration.

**Table 2. Clear Causal Relationship Technical Demonstration Components Recommended for Tier 1 and Tier 2 Demonstrations**

| **Tier 1 Demonstration Should Include** | **Tier 2 Demonstration Should Include** |
|---|---|
| Comparison of the fire-influenced exceedance with historical concentrations | Comparison of the fire-influenced exceedance with historical concentrations |
| Evidence that the fire and monitor(s) meet the key factor | Evidence that the fire and monitor(s) meet the key factors (#1 and #2) |
| Evidence of transport of fire emissions from fire to the monitor (**one** of these):<br>• Trajectories linking fire with the monitor (forward and backward), considering height of trajectories<br>• Satellite evidence in combination with surface measurements | Evidence of transport of fire emissions from fire to the monitor (**one** of these):<br>• Trajectories linking fire with the monitor (forward and backward), considering height of trajectories<br>• Satellite evidence in combination with surface measurements |
| | Evidence that the fire emissions affected the monitor (**one** of these):<br>• Visibility impacts (satellite or photo)<br>• Changes in supporting measurements<br>• Satellite NOx enhancements<br>• Differences in spatial/temporal patterns |



## 3.6 Additional Clear Causal Relationship Evidence for Tier 3 Events

The EPA expects that situations where the relationship between the subject fires and influenced $O_3$ concentrations is more complicated may require additional detail to satisfy the clear causal relationship element (i.e., a Tier 3 demonstration). This section describes the additional evidence that may be appropriate for inclusion in Tier 3 event demonstrations. The appropriate level of evidence should be discussed between the submitting air agency and the EPA regional office during the Initial Notification discussions.

### 3.6.1 Relationship of the Event, Monitor(s), and Exceedance to the Key Factors for Tier 2 demonstrations

As part of the weight of evidence showing for the clear causal relationship rule element, air agencies should explain how the events, monitor and exceedance compare with the key factors outlined in Section 3.5.1. The relationship of the event to the Tier 2 key factors may help inform the amount of additional information that will be needed in a Tier 3 demonstration.

### 3.6.2 Evidence that the Fire Emissions Affected the Monitor(s)

Because the relationship between the fire-related emissions and the monitored exceedance or violation cannot clearly be shown using the Tier 1 or Tier 2 approach, air agencies will need additional evidence to show that the fire emissions affected the monitor. The clear causal relationship approach for Tier 3 demonstrations could include multiple analyses from those examples listed in Section 3.6.4. The example evidence suggested in Section 3.6.4 can be used by air agencies to demonstrate the fire emissions were present at the probe of the monitor(s). Each additional piece of information that supports the event's influence will strengthen the air agency's position.

### 3.6.3 Evidence that the Fire Emissions were Transported to the Monitor(s)

To demonstrate a clear causal relationship between the event's emissions and the monitored $O_3$ exceedance, air agencies should provide evidence showing that the emissions from the fire were clearly transported to the monitor. This will likely require a trajectory analysis similar to that described in Section 3.1.1 or the satellite plume analysis of Section 3.5.3.

Because the uncertainty of trajectory analyses increases with transport distance, frontal passages, and complex wind/terrain issues, additional information, such as analyses of surface meteorology (wind speed and direction), will further support the clear causal relationship rule element.

### 3.6.4 Additional Evidence that the Fire Emissions Caused the $O_3$ Exceedance

Depending on evidence supplied in other sections of the demonstration, an air agency may need some of the additional evidence listed here to demonstrate that the fire emissions caused the $O_3$ exceedance. Matching day analyses, statistical regression models, or photochemical models may help support the position that the emissions from the fire caused the $O_3$ exceedance.

- Comparison of $O_3$ Concentrations on Meteorologically Similar Days (Matching Day Analysis)
  $O_3$ formation and transport are highly dependent upon meteorology, therefore a comparison between $O_3$ on meteorologically similar days with and without fire impacts could support a clear causal relationship between the fire and the monitored concentration. Both $O_3$ concentrations and diurnal behaviors on days with similar meteorological conditions can be useful to compare with days believed to have been impacted by fire. Since similar meteorological days are likely to have similar $O_3$ concentrations, significant differences in $O_3$ concentrations among days with similar meteorology may indicate influences from non-typical sources.

Meteorological variables to include in a similar day (or "matching day") analysis should be based on the parameters that are known to strongly affect $O_3$ concentrations in the vicinity of the monitor location. These variables could include: daily high temperature, hourly temperature, surface wind speed and direction, upper air temperature and pressure [such as 850 or 500 millibar (mb) height], relative or absolute humidity, atmospheric stability, cloud cover, solar irradiance, and others as appropriate (Anderson and Davis, 2004; Camalier et al, 2007; Eder et al, 1993; Eder et al, 1994). These parameters should be matched within an appropriate tolerance. Since high $O_3$ days may be relatively rare, air agencies should examine several years of data for similar meteorology versus restricting the analysis to high $O_3$ days only. The complete range of normal expected $O_3$ on similar meteorology days will have value in the demonstration. A similar day analysis of this type, when combined with a comparison of the qualitative description of the synoptic scale weather pattern (*e.g.*, cold front location, high pressure system location), can show that the fire contributed to the elevated $O_3$ concentrations. Air agencies may also want to consider non-meteorological factors such as choosing days with similar, non-event emissions (possibly avoiding holidays and special public events, weekend versus weekend mismatches, and other days with unusual emissions). In a recently submitted demonstration,[7] the state of Kansas included an analysis showing the synoptic-scale weather pattern typing along with an evaluation of basic meteorological parameters similar to the "Matching Days" analysis described here.

- Statistical Regression Modeling
  Air agencies can use $O_3$ predictions from regression equations to assess fire's contribution to $O_3$ concentrations. Regression is a statistical method for describing relationships among variables. For estimating air quality concentrations, regression equations are developed to describe the relationship between pollutant concentrations (referred to as the prediction) and primarily meteorological variables (referred to as the predictors). Because regression equations are developed with several years of data, they represent the relationship between air quality and meteorology under typical emission patterns; even if some historical exceptional events data are included in the development, the influence of those days will likely be small on the developed model provided there are far more typical days than event-related days. Therefore, the difference between the predictions and observations can provide a reasonable estimate of the air pollution caused by event-related emissions (*e.g.*, emissions from fires) provided the analysis accounts for the typical remaining variance of typical days (variability in monitored data not predicted by the model).

  Air agencies can develop the regression equation using the $O_3$ data for the monitor(s) under investigation and meteorology data from the closest nearby National Weather Service station. A small subset of the data should be reserved for testing the regression equation. Once a regression equation has been properly developed and tested, it can be used to predict the daily maximum $O_3$ values. The differences between the predicted values and the measured values are analyzed, and the 95$^{th}$ percentile of those positive

[7] Available at: *http://www2.epa.gov/sites/production/files/2015-05/documents/kdhe_exevents_final_042011.pdf*.

differences (observed $O_3$ is greater than predicted) is recorded. This 95 percent error bound is added to the $O_3$ value predicted by the regression equation for the flagged days, and any difference between this sum and the observed $O_3$ for the flagged day may be considered an estimate of the $O_3$ contribution from the fire if evaluation of the top 5$^{th}$ percentile shows similar $O_3$ days in the absence of smoke are rare or not observed.

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?

The limitations of the regression equation itself defines the limitations of this method. This approach is more rigorous than a comparison to similar meteorological days in that it considers the relationship between meteorological parameters, but regression is less rigorous than air quality modeling, which employs more parameters and more physical processes in its calculations. While statistical modeling does not resolve all the complexities of the atmosphere, carefully crafted regression models can provide an estimate of contribution to support the clear causal relationship portion of an exceptional events demonstration. There are several methods for developing a regression equation to estimate $O_3$ concentrations from meteorological variables (Camalier et al., 2007; STI, 2014).

- Photochemical modeling
  This section describes the air quality modeling tools best suited for estimating fire emissions impacts in demonstrations needing a more refined assessment. Secondary pollutant impacts, such as $O_3$ and $PM_{2.5}$, need to be assessed at various spatial scales (near-source and long-range transport) for a variety of regulatory programs. Modeling systems used for these assessments should be appropriate for this purpose and should be evaluated for skill in replicating meteorology and atmospheric chemical and physical processes that result in secondary pollutant formation and deposition. Photochemical grid models treat emissions, atmospheric chemistry, and physical processes, such as deposition and transport. These types of models are appropriate for assessment of near-field and regional scale reactive pollutant impacts from specific industrial sources (Baker and Foley, 2011; Bergin et al., 2008; Kelly et al., 2015; Zhou et al., 2012), specific fire events (Kansas Department of Health and Environment, 2012), or all sources (Chen et al., 2014; Russell, 2008; Tesche et al., 2006). Photochemical transport models have been used extensively to support State Implementation Plans and explore relationships between inputs, such as emissions and meteorology, and air quality impacts in the United States and elsewhere (Cai et al., 2011; Hogrefe et al., 2011; Russell, 2008; Tesche et al., 2006). Several state-of-the-science photochemical grid models could be used to estimate fire impacts, including (but not limited to) the CAMx (*www.camx.com*), CMAQ (*https://www.cmascenter.org/cmaq/*), and WRF-CHEM (*https://www2.acd.ucar.edu/wrf-chem*) models. These models have been used to estimate fire contributions to $O_3$ in the past (Fann et al., 2013; Jiang et al., 2012; Kansas Department of Health and Environment, 2012; Kwok et al., 2015; U.S. Environmental Protection Agency, 2014).

Predictions of fire impacts on air quality are complex due to uncertainties in emissions, height of emissions, plume temperature, and plume chemistry (including radiative impacts on chemistry). However, with proper set-up, application, and evaluation, air quality models can be used to indicate fire impacts on $O_3$ concentrations. Model evaluation of predictive skill on both event days, both for concentration and spatial extent of impacts, and for typical days with little or no exceptional precursor levels, is key to using the model results in a demonstration.

Where set up appropriately, photochemical grid models could be used with a variety of approaches to estimate and assess the contribution of single sources to primary and secondarily formed pollutants. These approaches generally fall into the category of source sensitivity (how air quality changes due to changes in emissions) and source apportionment (what air quality impacts are related to certain emissions). The simplest source sensitivity approach (brute-force change to emissions) is to simulate two sets of conditions, one with all emissions and one with the source of interest (e.g., a fire event) removed from the simulation (Cohan and Napelenok, 2011). The difference between these simulations provides an estimate of the air quality change related to the change in emissions from the fire event (Kansas Department of Health and Environment, 2012). Another source sensitivity approach to differentiate the impacts of fire events on changes in model predicted air quality is the direct decoupled method (DDM), which tracks the sensitivity of an emissions source through all chemical and physical processes in the modeling system (Dunker et al., 2002). Sensitivity coefficients relating source emissions to air quality are estimated during the model simulation and output at the resolution of the host model.

Some photochemical models have been instrumented with source apportionment, which tracks emissions from specific sources through chemical transformation, transport, and deposition processes to estimate a contribution to predicted air quality at downwind receptors (Kwok et al., 2015; Kwok et al., 2013). Source apportionment has been used to differentiate the contribution from specific sources on model predicted $O_3$ and $PM_{2.5}$ concentrations (Baker and Foley, 2011; Baker and Kelly, 2014). The DDM has also been used to estimate $O_3$ and $PM_{2.5}$ impacts from specific sources (Baker and Kelly, 2014; Bergin et al., 2008; Kelly et al., 2015), as well as the simpler brute-force sensitivity approach (Baker and Kelly, 2014; Bergin et al., 2008; Kelly et al., 2015; Zhou et al., 2012). Limited comparison of specific source impacts between models and approaches to differentiate single source impacts (Baker and Kelly, 2014; Kelly et al., 2015) show generally similar downwind spatial gradients and impacts.

Air agencies should corroborate the modeled estimates of fire events with other sources of information, such as satellite products and ground-based measurements and not use the model as the sole evidence supporting the fire event contribution. Significant variation in the modeled result from other information sources may indicate that the photochemical model predictions are unreliable for demonstration purposes.

### 3.7 Example Conclusion Statement

Air agencies should provide the supporting evidence and analyses identified in Sections 3.1-3.6 of this guidance to document the clear causal relationship between the fire event and the monitored $O_3$ exceedance or violation and conclude the analysis with a statement similar to the language below:

"Based on the evidence, including comparisons and analyses, provided in [section X] of this demonstration, the fire events, which occurred on [dates] in [location] and the monitored $O_3$ exceedance on [dates/time of data requested for exclusion, or reference to summary table in demonstration] were established to have a clear causal relationship. The clear causal relationship evidence also demonstrates that the event affected air quality at the monitor.

# 4. Caused by Human Activity that is Unlikely to Recur at a Particular Location or a Natural Event

## 4.1 Overview and EER Provisions

According to the CAA and the EER, an exceptional event must be "an event caused by human activity that is unlikely to recur at a particular location *or* a natural event." (Emphasis added.) The definition of wildfire in the 2016 EER revisions is: "any fire started by an unplanned ignition caused by lightning; volcanoes; other acts of nature; unauthorized activity; or accidental, human-caused actions; or a prescribed fire that has been declared to be a wildfire." Fire managers may declare specific prescribed fire projects to be wildfires if the conditions of a prescribed fire develop in a way that the project no longer meets the resource objectives (*e.g.*, if the fire has escaped secure containment lines along all or part of its boundary).

Natural factors are principally responsible for wildfires on wildland (defined as "an area in which development is essentially non-existent, except for roads, railroads, powerlines, and similar transportation facilities. Structures, if any, are widely scattered."). Land within national parks, national forests, wilderness areas, state forests, state parks, and state wilderness areas are generally considered wildland. Land outside cantonment areas on military bases may also be considered wildland. Therefore, the EPA believes that treating all wildfires on wildland as natural events is consistent with the CAA and the EER. It is expected that minimal documentation will be required to meet the human activity that is unlikely to recur at a particular location or a natural event element for wildfires on wildland.

The EPA will address wildfires on other lands on a case-by-case basis.

## 4.2 Examples of Supporting Documentation

To support this rule element, the air agency should clearly identify the origin and evolution of the wildfire event and describe how the burned area is a wildland according to the EER definition.

## 4.3 Example Conclusion Statement

In addition to the supporting information suggested in Section 4.2, the air agency should include a conclusion statement similar to the language below to demonstrate that the wildfire on wildland was a natural event.

"Based on the documentation provided in [section X] of this submittal, the event qualifies as a wildfire because [lightning, arson, accidental campfire escape, *etc.*] caused the unplanned wildfire event. The EPA generally considers the emissions of $O_3$ precursors from wildfires on wildland to meet the regulatory definition of a natural event at 40 CFR 50.1(k), defined as one "in which human activity plays little or no direct causal role." This wildfire event occurred on wildland and accordingly, [Air Agency Name] has shown that the event is a natural event and may be considered for treatment as an exceptional event." [Note: if a prescribed fire was declared to be a wildfire, then the air agency should supplement the language above with additional detail as to the conditions of the prescribed fire that led to the fire manager's decision that the fire should be treated as a wildfire, for example if the prescribed fire escaped secure containment lines and required suppression along all or part of its boundary or if the prescribed fire escaped as a result of quickly changing weather and no longer meets the resource objectives (*e.g.*, smoke impact, flame height)].

# 5. Not Reasonably Controllable or Preventable

## 5.1 EER Provisions

According to the CAA and the EER, an exceptional event must be "not reasonably controllable or preventable." The preamble to the 2016 EER revisions clarifies that the EPA interprets this requirement to contain two factors: the event must be both not reasonably controllable and not reasonably preventable at the time the event occurred. This requirement applies to both natural events and events caused by human activities, however it is presumptively assumed that wildfires on wildland will satisfy both factors of the "not reasonably controllable or preventable" element unless evidence in the record clearly demonstrates otherwise. If a prescribed fire has been declared to be a wildfire, some of the basic smoke management practices that were planned for use for the prescribed fire may continue to be reasonable to apply during the wildfire period.

## 5.2 Examples of Supporting Documentation

The 2016 EER revisions accept that wildfire events on wildland are not generally reasonable to control or prevent. Therefore, a statement that the wildfire event was caused by [lightning], and thus by the terms of the EER, was not reasonably controllable or preventable, should satisfy this rule element.

## 5.3 Example Conclusion Statement

In addition to the supporting information suggested in Section 5.2, the air agency should include a conclusion statement similar to the language below to demonstrate why the wildfire event was not reasonably controllable or preventable.

"Based on the documentation provided in [section X] of this submittal, [lightning] caused the wildfire event on wildland. The [air agency] is not aware of any evidence clearly demonstrating that prevention or control efforts beyond those actually made would have been reasonable. Therefore, emissions from this wildfire were not reasonably controllable or preventable."

# 6. Public Comment

## 6.1 EER Provisions

In addition to providing a conceptual model and evidence to support the EER elements, air agencies "must document [in their exceptional events demonstration] that the public comment process was followed" according to 40 CFR §50.14(c)(3)(v).

## 6.2 Examples of Supporting Documentation

Air agencies should include in their exceptional events demonstration the details of the public comment process including newspaper listings, website postings, and/or places (library, agency office) where the hardcopy was available. The agency should also include comments received and the agency's responses to comments.

## 6.3 Example Conclusion Statement

"The [air agency] posted notice of this exceptional events demonstration on [date posted] in the following counties/locations: [list counties affected and locations posted]. [Number] public comments were received and have been included in [Section x] of the demonstration, along with [air agency's] responses to these comments.

## Appendix A1. Example Conceptual Model/Event Summary

*The following example of a conceptual model/event summary is based on a demonstration prepared by the California Air Resources Board (CARB) to demonstrate wildfire-influence* $O_3$ *exceedances. The EPA has modified the narrative to provide a clear example of the suggested content of a conceptual model.*

### A. Area Description

The Sacramento federal 1-hour ozone nonattainment area (Sacramento region) consists of Sacramento County, Yolo County, the eastern portion of Solano County, the western portion of Placer County, the western portion of El Dorado County, and the southern portion of Sutter County (*see* Figure 1). The region covers over 5,600 square miles, and has a population of over 1.8 million.

The Sacramento region is located in the Central Valley of northern California. The Central Valley is a 500-mile long northwest-southeast oriented valley that is composed of the Sacramento Valley and the San Joaquin Valley air basins. Elevations in the Central Valley extend from a few feet above sea level to almost 500 feet (*see* Figure 2). This long valley is surrounded by the Coast Range Mountains on the west, the Cascade Range on the northeast, the Sierra Nevada Mountains on the east, and the Tehachapi Mountains on the south. The San Francisco Bay Area separates the Coast Range Mountains into northern and southern ranges. The Coast Range Mountains generally form a topographic barrier to air flow between the Pacific Ocean and the Central Valley, with occasional breaks created by low elevation passes and the small gap between the northern and southern ranges in the San Francisco Bay area known as the Carquinez Strait.

The Sacramento Valley's usual summer daytime circulation pattern is characterized by onshore flow through the Carquinez Strait (which flows from the Bay Area to Sacramento and is known as the sea breeze). Once through the Strait, the wind flow divides. A portion of the wind flow turns south, blowing into the San Joaquin Valley, a portion continues eastward, across the southern Sacramento Valley, and a portion turns north, blowing into the upper Sacramento Valley. At night, the sea breeze weakens, and the wind direction in the Sacramento Valley changes. Typical downslope flow, known as nocturnal drainage, brings air from the Coast Range and Sierra Nevada Mountains into the Sacramento Valley. With the weakened sea breeze, an eddy circulation pattern forms in the southwest portion of the Sacramento Valley which serves as a mechanism to recirculate and trap air within the region.

Because of its inland location, the climate of the Sacramento region is more extreme than that of more coastal regions, such as the San Francisco Bay Area. The winters are generally cool and wet, while the summers are hot and dry. Both seasons can experience periods of high pressure and stagnation which are conducive to pollutant buildup. These climate conditions result in seasonal patterns where ozone concentrations are highest during the summer, while PM2.5 concentrations are highest during the winter. The lack of summertime precipitation, coupled with the extent of forested regions which surround the Central Valley, also creates conditions conducive to wildfires during the summer months.

## B. Characteristics of Non-Event Ozone Formation

Anthropogenic emissions contributing to ozone formation in the Sacramento Region comprise reactive organic gases (ROG) and oxides of nitrogen (NOx). The main sources of these emissions include mobile sources (cars, trucks, locomotives, off-road equipment) along with stationary and area sources which include industrial processes, consumer products, and pesticides. Mobile source emissions dominate the anthropogenic emissions, accounting for more than 85 percent of the total NOx inventory. ROG and NOx emissions have decreased significantly over the past several decades. This reduction directly translates into fewer days above the former federal 1-hour ozone standard. In 1990, ROG and NOx precursor emissions were estimated at 262 and 242 tons per day (tpd), respectively. In 2008, these emissions had decreased almost 50 percent, to 136 tpd of ROG and 167 tpd of NOx. These significant improvements occurred despite increases in population, vehicle activity, and economic development.

The ozone season in the Sacramento region occurs from May through October. Although exceedances of the 1-hour federal ozone standard are infrequent, they are most likely to occur under certain meteorological conditions. By evaluating high ozone concentrations and associated meteorological conditions in the Sacramento region we developed several rules of thumb to predict when ozone concentrations will be elevated in Sacramento County (see Appendix Y for details). In general, the synoptic (large-scale) weather conditions leading to elevated ozone concentrations occur in the Sacramento region when a ridge of high pressure is located over California, causing the air to subside, or sink. As the air sinks, it warms, which forms a temperature inversion that stabilizes and dries the atmosphere. This process limits the vertical mixing of boundary layer air, which traps pollutants near the ground. The process also limits cloud production, which increases ozone photochemistry. In addition, surface wind flow patterns conducive to high ozone concentrations occur when the thermal surface low is over or just west of Sacramento. This results in a sea breeze which weakens or occurs late in the day. This prevents the dispersion of pollutants and leads to high ozone concentrations.

Nighttime drainage flows can bring biogenic emissions from the Coast Range and Sierra Nevada Mountains into the Sacramento Valley. During daytime wind flow patterns, anthropogenic precursor emissions in the Bay Area and Sacramento combine with biogenic emissions to undergo photochemical reactions generating ozone. Due to the general daytime flow pattern from west to east, as well as the time needed for photochemical reactions to occur, the highest concentrations in the Sacramento region generally occur in the afternoon in the downwind, eastern portion of the region, such as Folsom.

## C. Wildfire Description

From June 20 to June 22, 2008, over 6000 lightning strikes from a series of thunderstorms ignited numerous wildfires throughout northern and central California. At its peak, what became known as the Northern California Lightning Siege (or the Lightning Complex Fires) comprised thousands of wildfires in 26 counties and sent smoke throughout the western United States. California firefighters were assisted in their efforts to control these blazes by units from throughout the U.S., as well as Australia, Canada, Greece, Mexico, and New Zealand. With thousands of individual fires (subsequently grouped into fire complexes) in 26 counties, the summer of 2008 was one of the most severe wildfire seasons in California history. Most of these fires were not contained until late-July or early-August, with some continuing to burn through October. Vast areas experienced smoke impacts, especially areas in northern California. Table 3 summarizes the number of wildfires and acreage burned by county from mid-June to mid-July 2008, in the counties surrounding Sacramento. Figure 3, provides a map of fire locations. A detailed table listing the fires, distance from Folsom, and acreage burned is included in Appendix A. A summary report on these wildfires was prepared by an interagency team of investigators at the request of California Department of Forestry and Fire Protection (CAL Fire), the U.S. Forest Service, Office of Emergency Services, and the National Park Service.[8] The following is an excerpt from that report, "The 2008 Fire Siege": *On June 20th and 21st a series of severe, dry thunderstorms carpeted the state from Big Sur to Yreka with more than 5,000 lightning strikes, and igniting over 2,000 fires. During the following months, thirteen firefighters were killed and many others were injured on fires in this siege. Over 350 structures were destroyed and hundreds of millions of dollars of property and natural resources were damaged. Thousands of people were evacuated and smoke adversely effected air quality over much of the state for weeks. Communications, power delivery, and transportation systems were disrupted. Despite the intensive firefighting effort, some fires in remote areas continued to burn throughout the summer. By fall, over 1,200,000 acres had burned.*

Air quality in northern California deteriorated because of the smoke. From June 23 through much of July, the Sacramento region was covered in a thick blanket of smoke. Many of the air monitors recorded extremely high ozone concentrations, along with hazardous concentrations of particulate matter. The hazardous air quality levels prompted air pollution control and air quality management districts in the Sacramento region to issue air quality advisories and warnings. The wildfires and smoke spread throughout the Sacramento region and were widely recognized by residents in the region and the public media. Figures 4, 5, and 6 provide satellite maps illustrating the extent of the smoke impacts on June 23, June 27, and July 10, 2008.

## 2. Conceptual Model of Ozone Formation from 2008 Wildfires

Substantial amounts of NOx and VOCs were generated from the 2008 wildfires during late June and early July across a broad area surrounding the Sacramento Valley, corresponding to the 1-hour ozone exceedances at Folsom on June 23, June 27, and July 10, 2008. Surface wind flow conditions on these days were typical for the summertime, including nighttime drainage flow from the Coast Range and Sierra Nevada Mountains, coupled with an eddy circulation in the southern Sacramento Valley, followed by the daytime sea breeze. These wind flow patterns transported, and subsequently trapped within the Sacramento region, wildfire precursor emissions coming from multiple upwind locations. In addition to surface transport, due to the buoyancy of fire plumes, substantial amounts of precursors were emitted aloft by the wildfires. An increase in the mixed layer during the morning and early afternoon on each day allowed additional wildfire precursors aloft to reach the surface.

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[8] California Department of Forestry and Fire Protection, "2008 Fire Siege" (retrieved April 1, 2011) available at *http://www.fire.ca.gov/fire_protection/downloads/siege/2008/2008FireSiege_full-book_r6.pdf* (Multiagency Fire Investigation Report).

Under typical daytime photochemistry, the increased levels of wildfire-related precursor emissions in the Sacramento region resulted in enhanced levels of ozone throughout the region, including Folsom. Although these surface windflow patterns would also have transported anthropogenic emissions to Folsom, the meteorological conditions that existed on the three exceedance days were not sufficient to have caused a 1-hour ozone exceedance without the added burden of the additional wildfire-related precursor emissions. In addition, given the lengthy duration of the fires, by June 27 and July 10 there were also substantial amounts of wildfire-related ozone carried over from the day before the exceedance, further increasing ozone concentrations.

Although, NO from fires can result in ozone titration very close to the source of a fire, Folsom was sufficiently far enough downwind that a reduction in ozone concentrations due to this phenomena was unlikely. In addition, while the increased smoke from the fires may have reduced the amount of solar insolation, thereby potentially reducing photochemical activity, this was compensated for by the substantially increased levels of ozone precursors generated by the fires, resulting in a net ozone enhancement.

During this period, there were 15 monitoring sites operating in the Sacramento nonattainment area, as shown in Figure 7, below. Ozone was dramatically elevated throughout the nonattainment area and much of northern and central California during the fire period. In the Sacramento nonattainment area, five monitoring sites recorded ozone concentrations above the 1-hour standard. More detailed information about the exceedances at these sites is shown in Table 4. Section 3 provides a more detailed discussion of the day-specific meteorological conditions that existed on each of the three 1-hour ozone exceedance days included in this request to support the clear causal connection between the wildfires and the ozone exceedances. In addition, Section 4 provides information to demonstrate that the exceedances of the 1-hour ozone NAAQS at Folsom on each of these days were directly due to the impacts of the wildfire emissions.

The following figures and tables were included:

***Figure 1.** Map of Sacramento Metropolitan non-Attainment Area
***Figure 2.** Topographic map of Northern California
**Table 3.** Summary, by county, of wildfires that contributed to the exceedance
***Figure 3.** Map of wildfires, colored and sized by geographic extent
**Figure 4.** MODIS image of June 23
**Figure 5.** MODIS image of June 27
**Figure 6.** MODIS image of July 10
***Figure 7.** Map of air quality monitors in the Sacramento area
**Table 4.** 2008 Sacramento 1-hour ozone non-attainment days and concentrations
*These maps could be combined into one.

## Appendix A2. Relating Fire Emissions and Downwind Impacts

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**Summary**

To understand general relationships between the magnitude of fire emissions and potential downwind $O_3$ impacts, the EPA conducted an assessment of fire case studies. These case studies were drawn from peer-reviewed literature, EPA-approved exceptional events demonstrations for fires that influenced $O_3$ concentrations, and EPA-performed photochemical modeling studies. The dependence of $O_3$ impacts on fire emissions and distance from the fire across these case studies has been compared to determine fire characteristics that are expected to lead to meaningful $O_3$ impacts.

**Background**

Fires can impact $O_3$ concentrations by emitting known $O_3$ precursors including $NO_X$ and VOCs. These precursor emissions can generate $O_3$ within the fire plume or can mix with emissions from other sources to generate $O_3$ (Jaffe and Wigder, 2012). Also, in some situations, including near fires, reduced $O_3$ concentrations have been observed and attributed to $O_3$ titration by enhanced NO concentrations and reduced solar radiation available to drive photochemical reactions (Jaffe et al., 2008; Yokelson et al, 2003). The magnitude and ratios of emissions from fires vary greatly depending on fire size, fuel characteristics, and meteorological conditions (Akagi et al., 2012). As a result of variable emissions, radiative impacts, and non-linear $O_3$ production chemistry, the $O_3$ production from fires is very complex, highly variable, and often difficult to predict (Jaffe and Wigder, 2012). Understanding and predicting $O_3$ formation from fires remains an active area of research.

Despite the complexities in predicting $O_3$ formation from fire emissions, several studies have found enhancements in $O_3$ concentrations attributable to fire impacts. For example, Pfister et al. analyzed surface $O_3$ data during a high fire year in California (2007) with modeled fire impacts and found 8-hour $O_3$ concentrations were approximately 10 ppb higher when the modeled impacts were high (Pfister et al., 2008). Jaffe et al. analyzed three specific fire periods in the western US during 2008 and 2012, and compared surface $O_3$ concentrations with two different modeled estimates of fire contributions to $O_3$ concentrations to find enhancements in $O_3$ when fire impacts were predicted to be high (Jaffe et al., 2013).

**Previously Approved Fire-Impacted $O_3$ Exceptional Events Demonstrations**

The EPA's EER (CFR parts 50 and 51 codified at 50.1, 50.14 and 51.930) allows air agencies to exclude air quality data that has been influenced by an exceptional event, once the agency has submitted and the EPA has approved a demonstration satisfying the EER elements. Many events, including fires, qualify for consideration under the EER.

Between 2010 and August 2015, the EPA approved two exceptional events demonstrations that linked monitored $O_3$ exceedances to fire impacts. The first was approved in 2011. In this case, the EPA concurred on three exceedances of the 1-hour $O_3$ NAAQS near Sacramento, California in 2008 due to a series of lightning-initiated wildfires throughout northern California. The second demonstration for fire impact on $O_3$ was approved in 2012. In this case, the EPA concurred with the exclusion of eight MDA8 exceedances during April 2011 in Kansas due to impacts from prescribed fires and wildfires. Both of these demonstrations are available at *http://www2.epa.gov/air-quality-analysis/exceptional-events-submissions-table*.

**Assessments of Q/D Relationships from Previously Approved Demonstrations and Relevant Peer-Reviewed Literature**

At least one air quality related program (*i.e.*, determining impacts at Class I areas) uses an emissions divided by distance (Q/D) key factor as a screening tool. The EPA believes that it is appropriate to use a similar approach, along with additional information about the fire event, to determine whether a simpler and less resource-consuming exceptional events demonstration provides sufficient evidence to satisfy the clear causal relationship criteria of the EER for fire $O_3$ demonstrations.

To determine whether a relationship existed between approved demonstrations and Q/D values, the EPA estimated Q/D values from previously approved, fire-related $O_3$ exceptional events demonstrations. The EPA also included in this comparison, the results from one peer-reviewed publication, which included sufficient detail for a similar analysis (Jaffe et al., 2013). The EPA used daily fire emissions estimates from the 2008 (*ftp://ftp.epa.gov/EmisInventory/fires/*) and 2011 (*http://www3.epa.gov/ttnchie1/net/2011inventory.html*) NEIs to estimate Q from fires impacting the $O_3$ monitors. For consistency, the EPA also used NEI-based estimates for the Jaffe et al. fires. In determining the appropriate emissions to use in this assessment, the EPA summed $NO_X$ and rVOC because both are precursors for $O_3$ formation. The NEI reports total organic gas (TOG) so the reactive fraction of these emissions (rVOC) was estimated by applying the fraction of reactive gas to total organic gas based on speciation profiles for fires provided by the SPECIATE database. A factor of 0.6 was selected based on the SPECIATE database profile used by CMAQ for fires (speciation profile number 5560).[9]

Fire events included in the estimated Q values were based on the sum of emissions from only some of the events listed by the relevant air agencies in the demonstrations because the demonstrations included fires that may not directly impact the monitor. The CARB exceptional events demonstration identified all wildfires burning in California during the time period of the $O_3$ exceedances, and a subset of those (within state of CA, with latitude north of 37N (~north of Santa Cruz) and longitude west of -119W (~west of Mono Lake) were used. The Jaffe et al., article assessed the impact of the 2008 Northern California fires in Reno, NV (versus at California monitors). The same fire subset was used for the Jaffe et al. analysis as for the CARB demonstration. For the Kansas Department of Health and Environment demonstration, the EPA included all fire events labeled as "Flint Hills" in the NEI emissions file. Emissions totals within these bounds on the day of the $O_3$ exceedances were used to calculate emissions totals, Q. The

[9] SPECIATE is the EPA's repository of volatile organic gas and particulate matter speciation profiles of air pollution sources. Available at *http://www3.epa.gov/ttnchie1/software/speciate/*.

uncertainty in Q was taken to be approximately ±25% and was taken from the differences between the $NO_X$ estimates from the NEI and the NOx estimates from the Fire Inventory from NCAR (FINN) emissions inventories of all fires (Wiedinmyer et al., 2011).

$O_3$ impacts were determined differently by the CARB demonstration, the KDHE demonstration, and the Jaffe et al. article. The CARB demonstration used a statistical regression model to estimate fire contributions to $O_3$ concentrations. The KDHE demonstration used both a matching day analysis and photochemical modeling to estimate $O_3$ impacts. The Jaffe et al. paper used both photochemical and statistical residual modeling to estimate $O_3$ impacts.

A summary of the fire impacts on $O_3$ compared with Q/D for the approved demonstrations and the Jaffe et al. article is shown in Figure A2-1. Distance (km) between the fire and the $O_3$ monitors was calculated based on an average fire location determined with an emissions-weighted fire center. The uncertainty range in D was determined by using the maximum distance between the monitor and a fire event (within the subset given above) on the day of the exceedance. The range shown for the CARB $O_3$ impacts reflects the uncertainty analysis included in the demonstration. The ranges included for $O_3$ impacts estimated by the KDHE demonstration and the Jaffe et al. paper represent the range in estimates of $O_3$ impacts determined by the two different methods used in each case.

**Modeling Studies of Wildfire Impacts on $O_3$**

Some uncertainty exists in the magnitude of emissions estimates, VOC and $PM_{2.5}$ speciation of emissions, downwind transport, chemical reactions in fire plumes, and representation of important physical processes like reduced photolysis due to smoke. However, the emissions used as input to air quality models can be paired with estimated downwind $O_3$ contribution to assess screening level relationships between precursor emissions and downwind impact. Constructing these relationships is useful for planning purposes and making preliminary determinations about whether fires with emissions of a certain amount and distance away may impact a monitor and warrant further investigation for fire contribution using additional corroborative information.

The entire year of 2011 was applied using the CMAQ version 5.0.2 model (*www.cmascenter.org*). Meteorological input was generated using version 3.4.1 of the WRF prognostic meteorological model (Skamarock et al., 2008). Both modeling systems were applied using the same grid projection and model domain covering the continental United States with 12 km sized grid cells. Contributions from four specific fire events were tracked using source apportionment approaches. Source apportionment tracks primarily emitted and precursor emissions from specific fire events through the model's chemical and physical processes to track contribution to primary and secondarily formed pollutants. The integrated source apportionment approach has been implemented in CMAQ for $O_3$ (Kwok et al., 2015) and $PM_{2.5}$ (Kwok et al., 2013) and was used in this analysis to track the contribution from each fire event. CMAQ with source apportionment was applied for four different multi-day fire events in 2011: Wallow, Waterhole, Big Hill, and Flint Hills. The days included in each model simulation for each fire event and the daily total fire event emission estimates are shown in Table A2-1. Emissions-weighted fire event locations are shown in Table A2-2. All the emissions from each multi-day fire were tracked as a single source, so it is not possible to determine from the results how a single day of a particular multi-day fire event emissions affects a single day of $O_3$ concentrations.

For example, $O_3$ effects on the third day of a fire may be a contribution of direct effects from a same day plume and effects from recirculated VOC, NOx and $O_3$ from earlier days.

Wildfire and prescribed fire emissions were included when and where these emissions occur within the modeling domain. These emissions are based on the latest version of the SMARTFIRE system (*http://www.airfire.org/smartfire/*). Detailed information about how the EPA develops wildland fire inventories can be found in the 2011 NEI Technical Support Document (U.S. Environmental Protection Agency, 2014). This approach relies on a combination of satellite detection of fires merged with on-the-ground observational data where available. Ground-based observations and local fuel information are used whenever possible as these factors can have a large impact on the emissions. CMAQ currently uses one single speciation profile (5560; Table A2-3) to speciate TOG fire emissions into specific compounds (*e.g*., toluene, benzene, etc.) that are subsequently used in the gas phase chemical mechanism within CMAQ. Similarly, a single profile is used to map total $PM_{2.5}$ emissions from fires to specific compounds (*e.g*., elemental carbon, organic carbon, etc.). Daily total emissions for each fire event tracked for $O_3$ contribution are shown in Table A2-1. The EPA also conducted a sensitivity analysis including reducing each fire's emissions to half the original emissions.

Figure A2-2 shows maximum hourly (across all modeled days of the event) source apportionment based $O_3$ impacts from the fire events tracked in this assessment. Fire $NO_X$ emissions tend to contribute more to $O_3$ formation than fire VOC emissions, on a per fire comparison basis, for the fire events in the western United States where biogenic VOC is often abundant (especially near these particular fire events). The stronger effect from NOx emissions compared to VOC emissions on a per ton basis (not shown) is even more pronounced, given the tonnage values in Table A2-1. The $NO_X$ contribution could be favored in the model if $O_3$ formation was $NO_X$ limited even when the contributing VOC was also from the same fire event. The fire event modeled in Kansas illustrates that VOC emissions from fires can also be important, especially when other VOC sources are less abundant.

Figure A2-3 depicts downwind $O_3$ and CO impacts. This figure also shows Q/D for these events and forward HYSPLIT trajectory endpoints (from each day included in Table A2-1) from release out to 48 hours. This figure clearly shows the importance of pairing information about the trajectory of fire emissions in combination with simple metrics of impact such as Q/D. The Wallow fire event had the most consistent trajectories across the days of the event. For the other fire events, wind directions on different days differed considerably.

Maximum hourly fire impacts on $O_3$ (that were greater than 1.0 ppb) and the corresponding distance of the grid cell where the maximum impact occurred from the emissions-weighted average location of the fire event are shown in Figure A2-4. The colored box represents the $25^{th}$-$75^{th}$ percentiles of the distribution of $O_3$ impacts larger than 1.0 ppb, and the solid line within the colored box indicates the median of the distribution. Impacts only up to 1000 km (for Wallow, Flint Hills, and Waterhole) and 550 km (for Waterhole and Big Hill) are shown since the magnitude of the $O_3$ impacts decrease at increased distances. The maximum $O_3$ impacts tend to be highest in closer proximity to the event and decrease as distance from the event increases (Figure A2-4). When these impacts are normalized by the sum of NOx+rVOC emissions for the event day with the highest emissions during the period modeled (Figure A2-5), the magnitude of $O_3$ impacts varies over the range of Q/D values, with larger $O_3$ impacts occurring at higher Q/D values. The truncation of distances used in Figure A2-4 leads to the absence of $O_3$ impacts at low Q/D values (*e.g.*, ~20 for the Wallow Fire) in Figure A2-5.

The results shown in Figure A2-5 help determine the appropriateness of using the Q/D approach as one key factor in a simpler and less resource-consuming exceptional events demonstrations for certain fire events (*i.e.*, Tier 2). In the figure for each modeled fire event, modeled maximum $O_3$ impacts are shown for the first two days, except for the Big Hill Fire where the entire, three day event is shown. Each data point represents the maximum, hourly $O_3$ impact (over 1 ppb) that occurred in a grid cell during the first 48 hours of the event. In general, higher $O_3$ impacts are predicted at larger Q/D values. Comparisons across the four fire events modeled here indicate more and larger $O_3$ impacts at high Q/D values from the fires with the highest emissions (Wallow and Flint Hills) versus the smaller, lower emissions fires (Big Hill and Waterhole). When Q/D values from a fire event are paired with both elevated monitored $O_3$ concentrations (*i.e*., Tier 2 key factor #2) and evidence (e.g., HYSPLIT trajectory or other analyses identified in sections 3.5.2 and 3.5.3) linking the affected monitor to the location(s) of the subject fire(s), the EPA believes that the Q/D relationship can be used to indicate when large $O_3$ impacts are expected to occur.

To examine the utility of the Q/D metric, Q/D was calculated for all fires in the National Emission Inventory for the years 2008 through 2013 to provide an aggregate context for areas and times where fires may be large contributors to elevated air quality. Figures A2-6 through A2-8 show the count of days with $NO_X$+rVOC Q/D values greater than 50, 100, and 200 for 2008 through 2013. These figures illustrate how the fire events modeled for this assessment from 2011 compare to other fires that year and to fires from other recent years where data are available. These results can be used to investigate how many days and areas would meet various thresholds for the Q/D key factor.

**Conclusions**

The fire event impacts estimated with the photochemical model CMAQ suggest both $NO_X$ and VOC emissions from fire events can lead to downwind $O_3$ formation and the importance of these precursors varies among fires, most likely due to the surrounding environment's availability of $NO_X$ and VOC emissions. Since information about the surrounding environment may not always be practically available, the approach for estimating fire impacts should be inclusive of both $NO_X$ and reactive VOC emissions.

The downwind $O_3$ contribution from these fire events is greatest in the proximity of the fire and tends to gradually decrease as distance from the source increases. The spatial plots of downwind $O_3$ impacts show that the impacts occur in the direction of air mass movement from the fire event to specific places downwind. As indicated above, tiering approaches that do not explicitly account for pollutant transport (*e.g.*, Q/D) should be accompanied with information about pollutant transport from another source such as HYSPLIT trajectories to better spatially represent the downwind impacts.

## Acknowledgements

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**Table A2-1. Daily and emissions for each tracked fire event in 2011. rVOC is the sum of all VOC excluding methane and non-reactive species.**

| Fire Event | Month-Day | CO | NOX | rVOC | NOX+rVOC |
|---|---|---|---|---|---|
| Waterhole | 822 | 9,441 | 96 | 1,331 | 1,427 |
| Waterhole | 823 | 17,652 | 171 | 2,487 | 2,658 |
| Waterhole | 824 | 38,086 | 408 | 5,373 | 5,780 |
| Waterhole | 825 | 637 | 6 | 90 | 96 |
| Waterhole | 826 | 34 | 1 | 5 | 6 |
| | | | | | |
| Big Hill | 814 | 243 | 7 | 35 | 42 |
| Big Hill | 815 | 3,248 | 92 | 468 | 560 |
| Big Hill | 816 | 189 | 5 | 27 | 33 |
| | | | | | |
| Flint Hills | 401 | 30,675 | 867 | 4,417 | 5,285 |
| Flint Hills | 402 | 51,555 | 1,413 | 7,417 | 8,830 |
| Flint Hills | 403 | 14,526 | 383 | 2,087 | 2,470 |
| Flint Hills | 404 | 3,744 | 106 | 539 | 646 |
| Flint Hills | 405 | 20,233 | 564 | 2,912 | 3,477 |
| Flint Hills | 406 | 78,622 | 2,218 | 11,321 | 13,539 |
| Flint Hills | 407 | 9,719 | 263 | 1,398 | 1,661 |
| Flint Hills | 408 | 59,020 | 1,584 | 8,485 | 10,070 |
| Flint Hills | 409 | 60,294 | 1,656 | 8,675 | 10,331 |
| Flint Hills | 410 | 9,194 | 257 | 1,324 | 1,580 |
| Flint Hills | 411 | 57,428 | 1,540 | 8,256 | 9,796 |
| Flint Hills | 412 | 105,636 | 2,950 | 15,206 | 18,157 |
| Flint Hills | 413 | 60,484 | 1,670 | 8,704 | 10,373 |
| Flint Hills | 414 | 7,874 | 215 | 1,133 | 1,348 |
| Flint Hills | 415 | 95 | 3 | 14 | 16 |
| | | | | | |
| Wallow | 604 | 115,438 | 1,516 | 16,331 | 17,847 |
| Wallow | 605 | 49,951 | 697 | 7,074 | 7,771 |
| Wallow | 606 | 113,160 | 1,509 | 16,013 | 17,522 |
| Wallow | 607 | 53,030 | 705 | 7,504 | 8,209 |
| Wallow | 608 | 131,675 | 1,774 | 18,636 | 20,409 |
| Wallow | 609 | 59,155 | 839 | 8,379 | 9,218 |
| Wallow | 610 | 52,127 | 736 | 7,383 | 8,119 |

**Table A2-2. Emissions weighted fire event locations.**

| Fire Event | Latitude | Longitude |
|---|---|---|
| Waterhole | 45.6141 | -106.7889 |
| Big Hill | 42.5673 | -115.8093 |
| Flint Hills | 37.9466 | -96.3543 |
| Wallow | 33.8174 | -109.3272 |

**Table A2-3. Speciation profile (5560) used to map TOG emissions to specific lumped compound groups for photochemical model application.**

| Profile | Inventory | Model | Fraction |
|---|---|---|---|
| 5560 | TOG | UNR | 0.22 |
| 5560 | TOG | PAR | 0.18 |
| 5560 | TOG | CH4 | 0.18 |
| 5560 | TOG | FORM | 0.08 |
| 5560 | TOG | MEOH | 0.08 |
| 5560 | TOG | OLE | 0.07 |
| 5560 | TOG | ALD2 | 0.05 |
| 5560 | TOG | ETH | 0.04 |
| 5560 | TOG | TOL | 0.03 |
| 5560 | TOG | ALDX | 0.02 |
| 5560 | TOG | ETHA | 0.02 |
| 5560 | TOG | BENZENE | 0.02 |
| 5560 | TOG | TERP | 0.01 |
| 5560 | TOG | XYL | 0.01 |
| 5560 | TOG | IOLE | 0.00 |
| 5560 | TOG | ISOP | 0.00 |
| 5560 | TOG | ETOH | 0.00 |

**Figure A2-1. Summary of $O_3$ impacts versus Q/D relationships for approved demonstrations (CARB_Folsom_2008 and KDHE_FlintHills_2011) and impacts reported by Jaffe and Wigder (2012). No results from the EPA's photochemical modeling are shown in this Figure.**

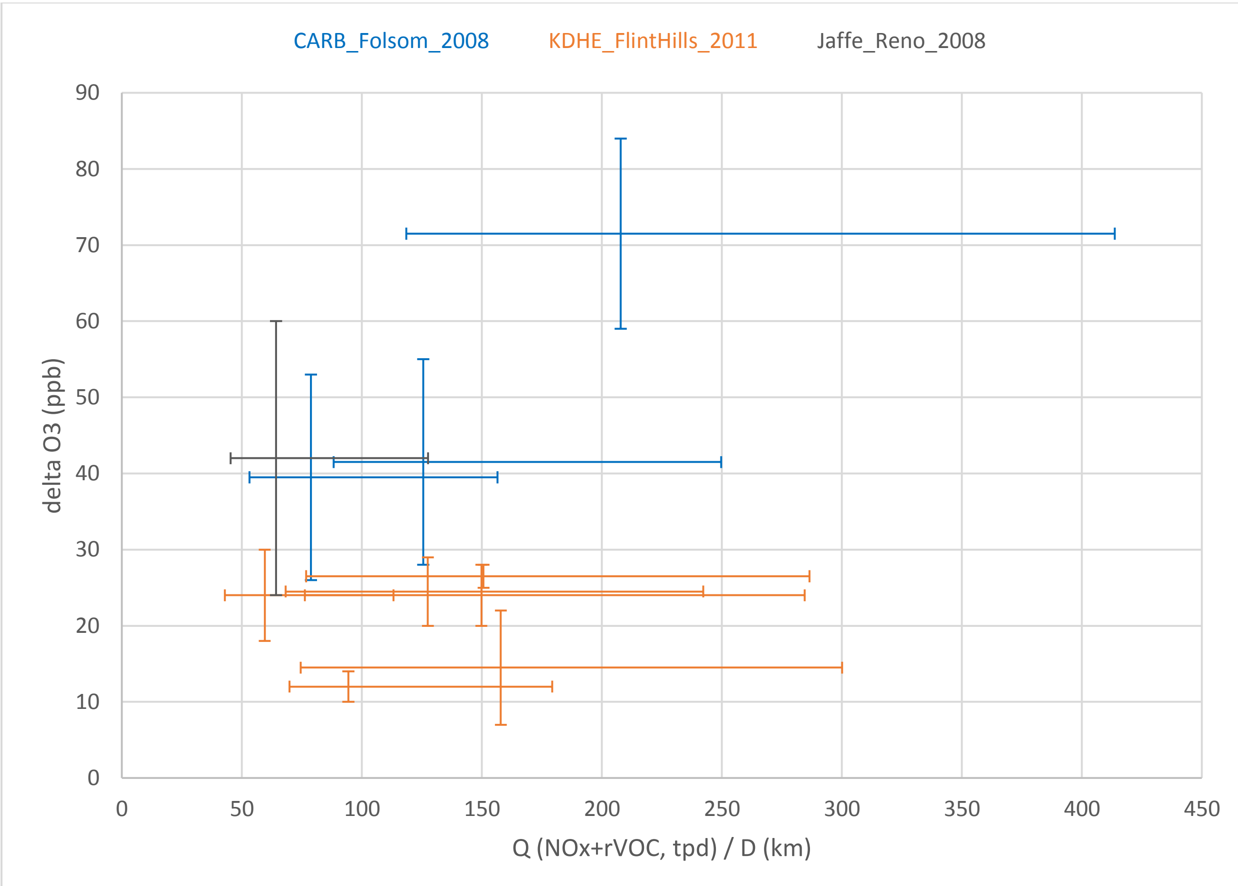


**Figure A2-2. Event maximum 1-hour $O_3$ (ppb) impacts (left panels). The percent contribution from fire event $NO_X$ emissions to event maximum 1-hour $O_3$ impacts shown at right. The percent contribution plots show that both $NO_X$ and VOC emissions from fires can contribute to downwind $O_3$ formation.**

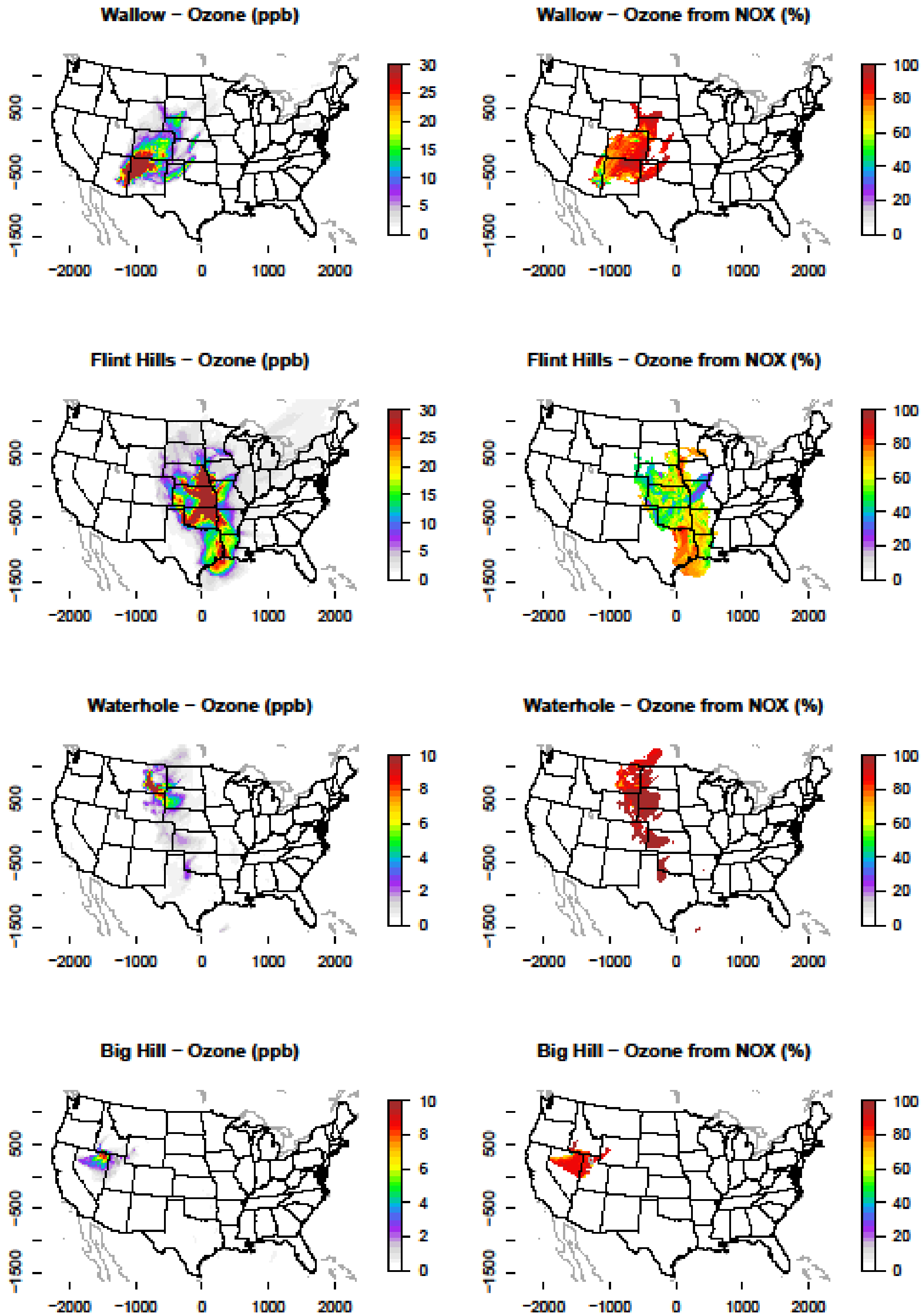


**Figure A2-3. Event maximum 1-hour CO (left panels), $O_3$ (second to left panels), Q/D (second to right panels), and forward trajectories (right panels) shown for multiple fire events. Q/D is based on daily maximum NOX+rVOC emissions from the fire event during the period modeled. Forward trajectories are shaded by hours from release with warm colors (red and orange) representing hours during the first day and cooler colors the 2nd day (24 to 48 hours) from release.**

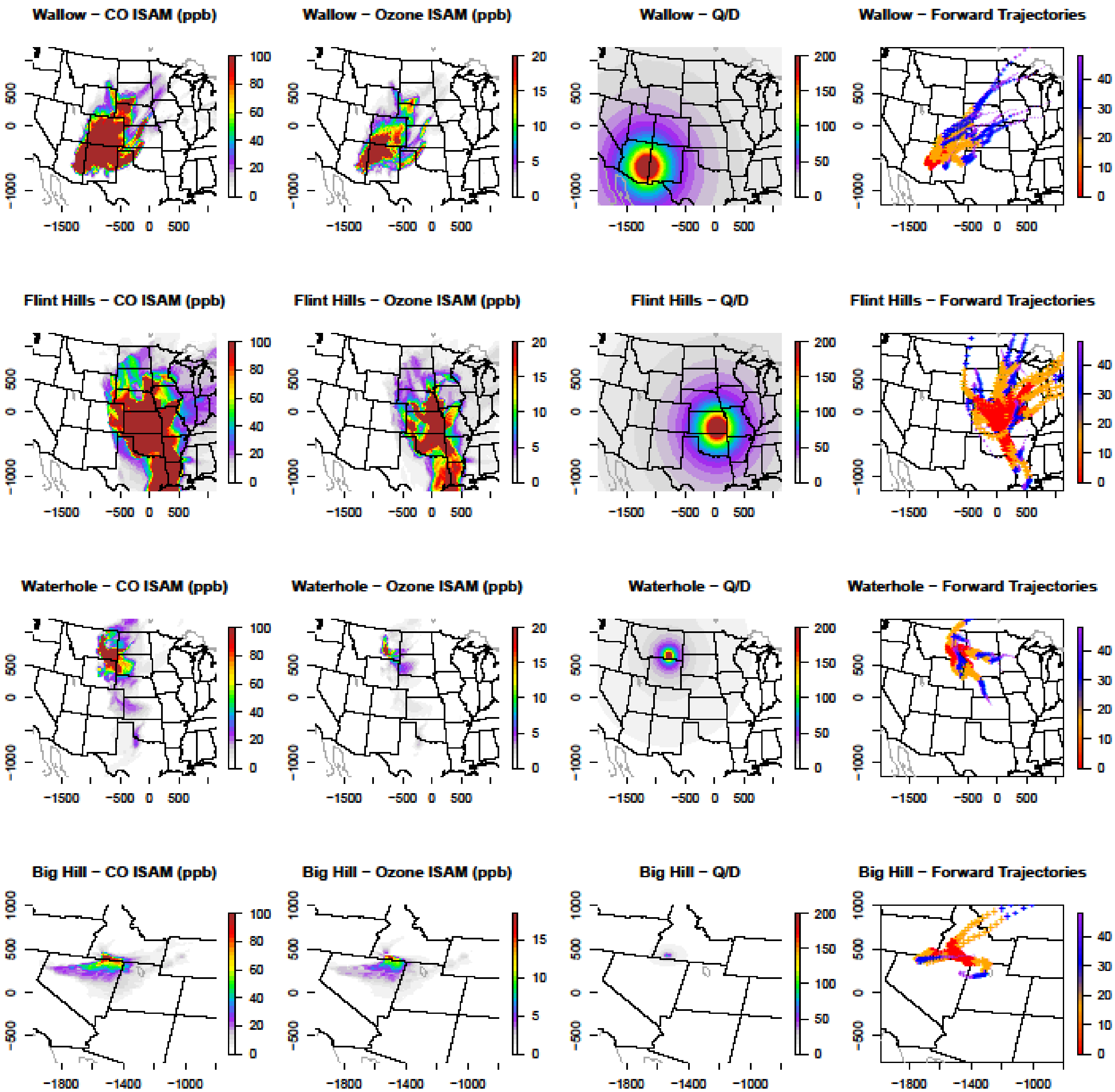


**Figure A2-4. Distribution of hourly $O_3$ impacts from fire events by distance from the location of the fire event.**

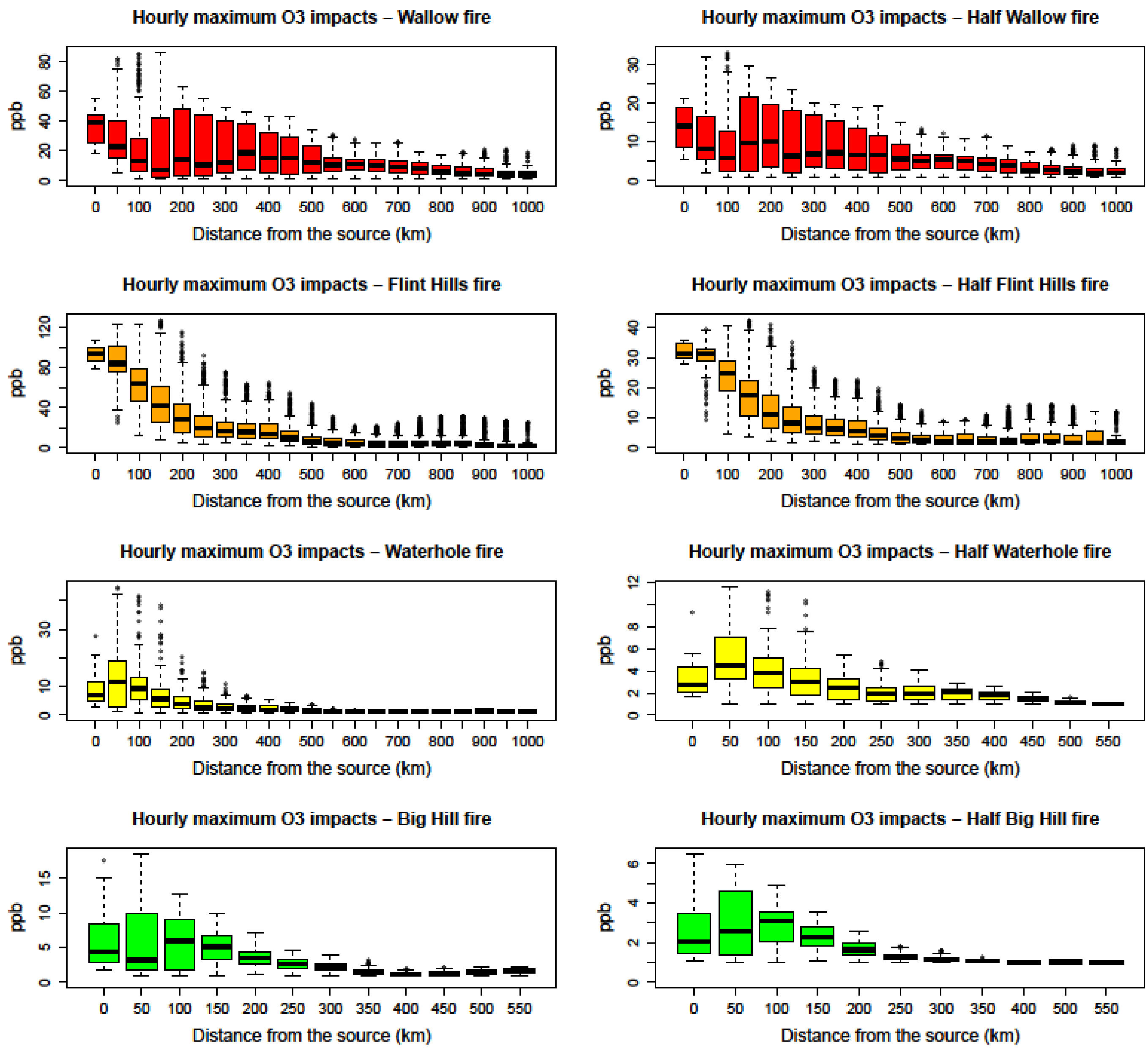


**Figure A2-5. Hourly maximum $O_3$ impacts from the first two days of each fire event (Table A2-1) shown by Q/D. $O_3$ impacts only up to 1000 km from the fire have been included in this analysis.**

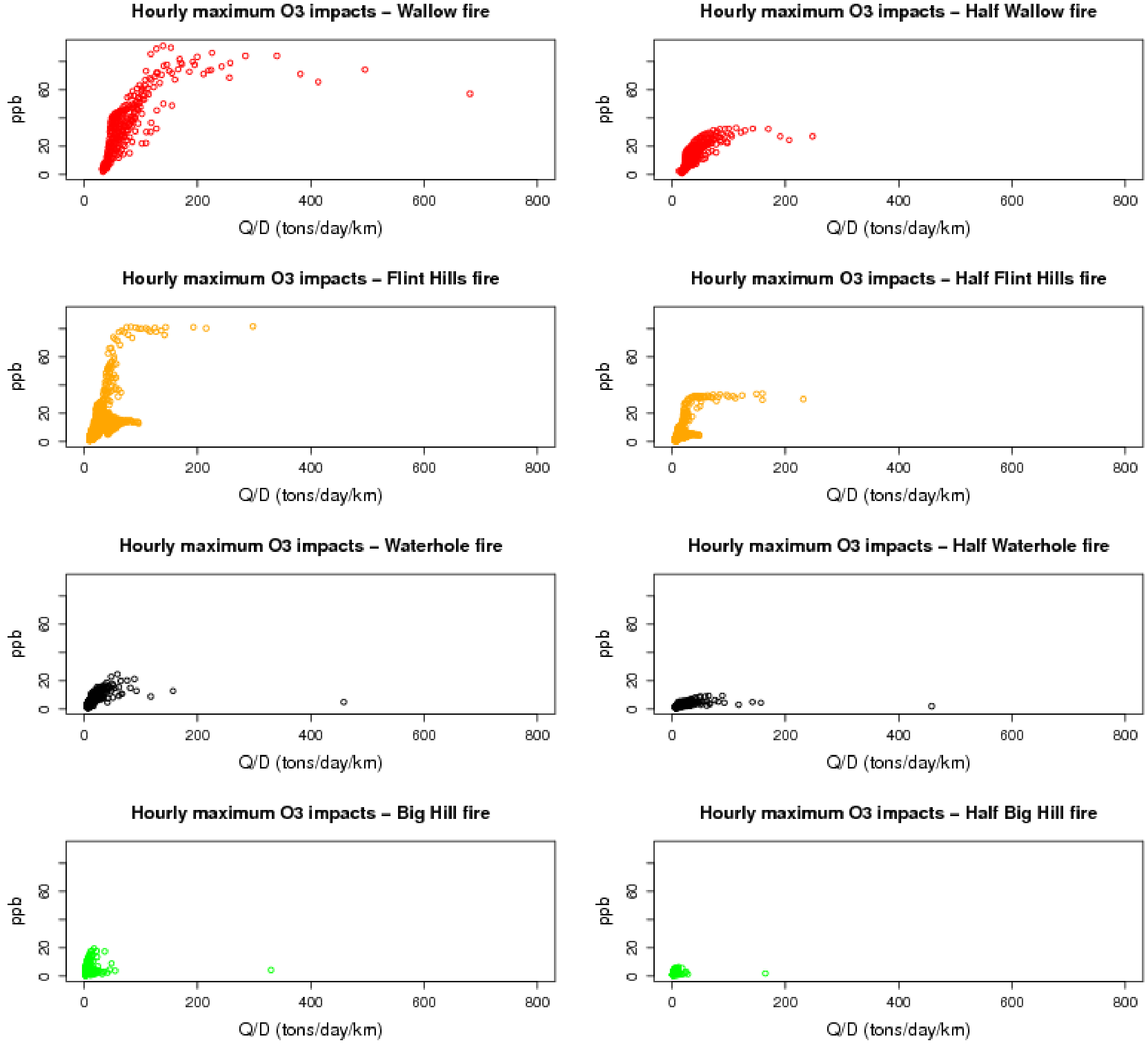


**Figure A2-6. Count of days with $NO_X$+rVOC Q/D > 50 for 2008 through 2013. Note scale has been capped at 10 to more easily distinguish the values below 10. Red may actually indicate 10 or greater than 10.**

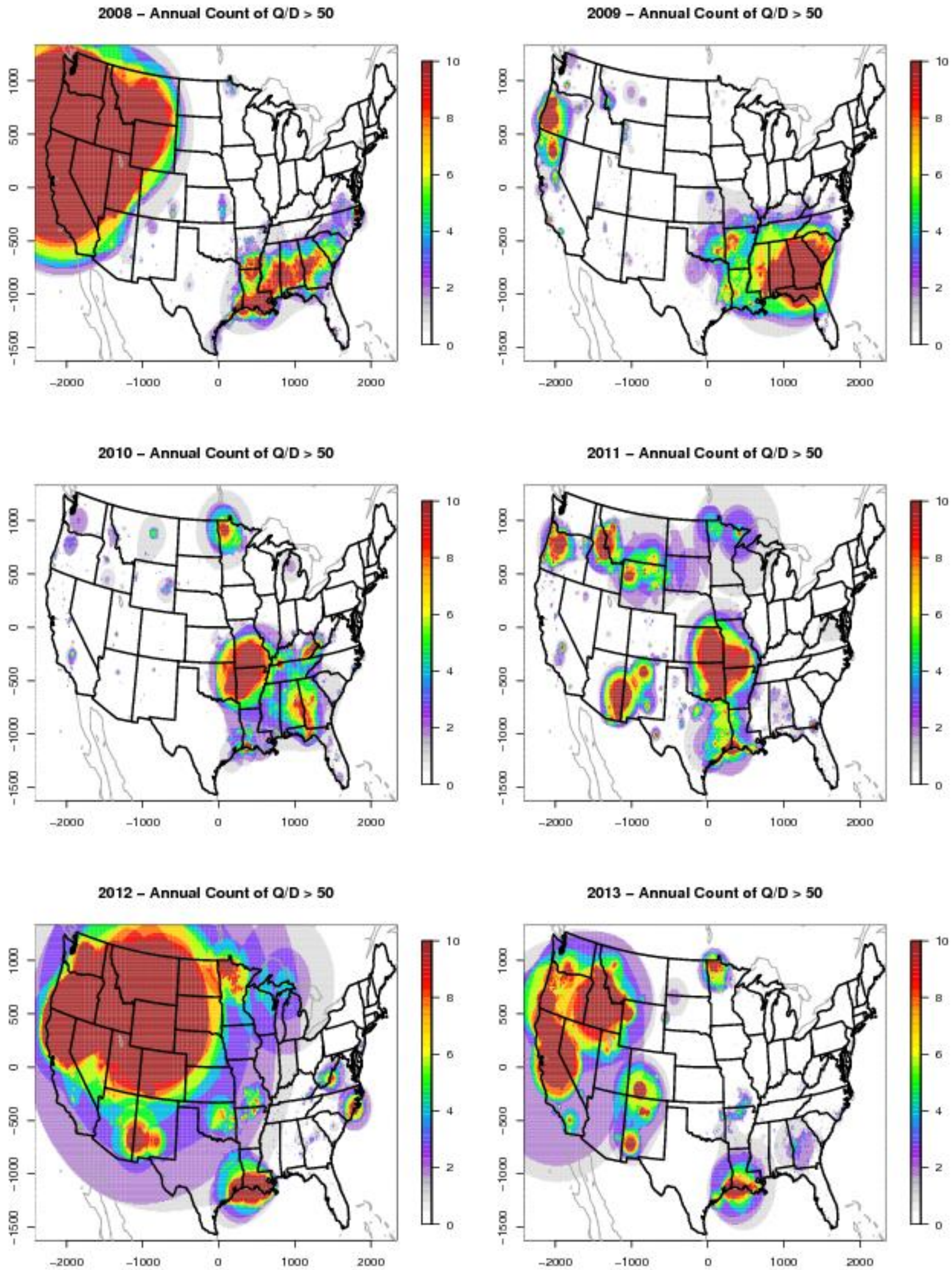



**Figure A2-7. Count of days with $NO_X$+rVOC Q/D > 100 for 2008 through 2013. Note scale has been capped at 10 to more easily distinguish the values below 10. Red may actually**

**indicate 10 or greater than 10.**

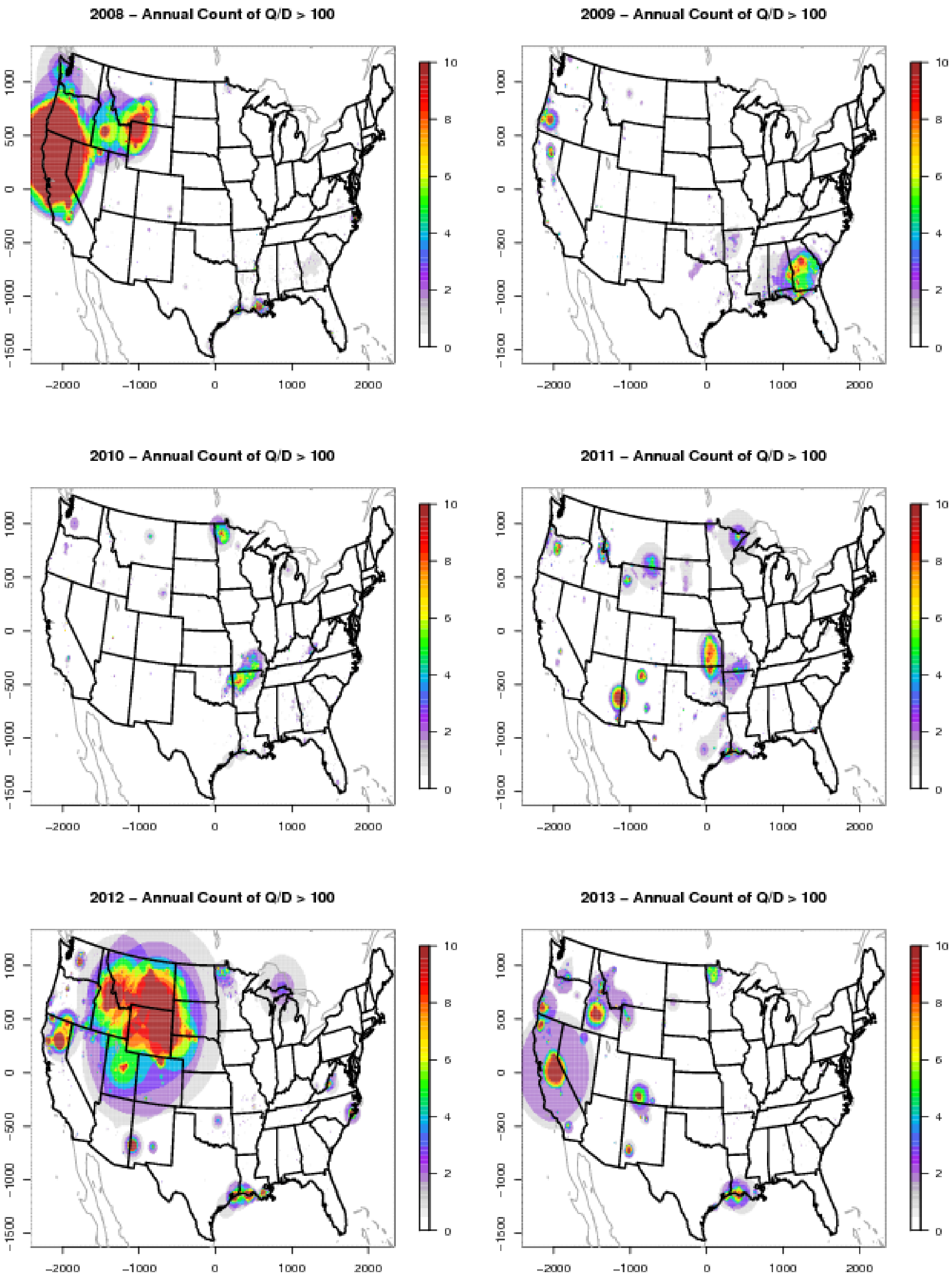
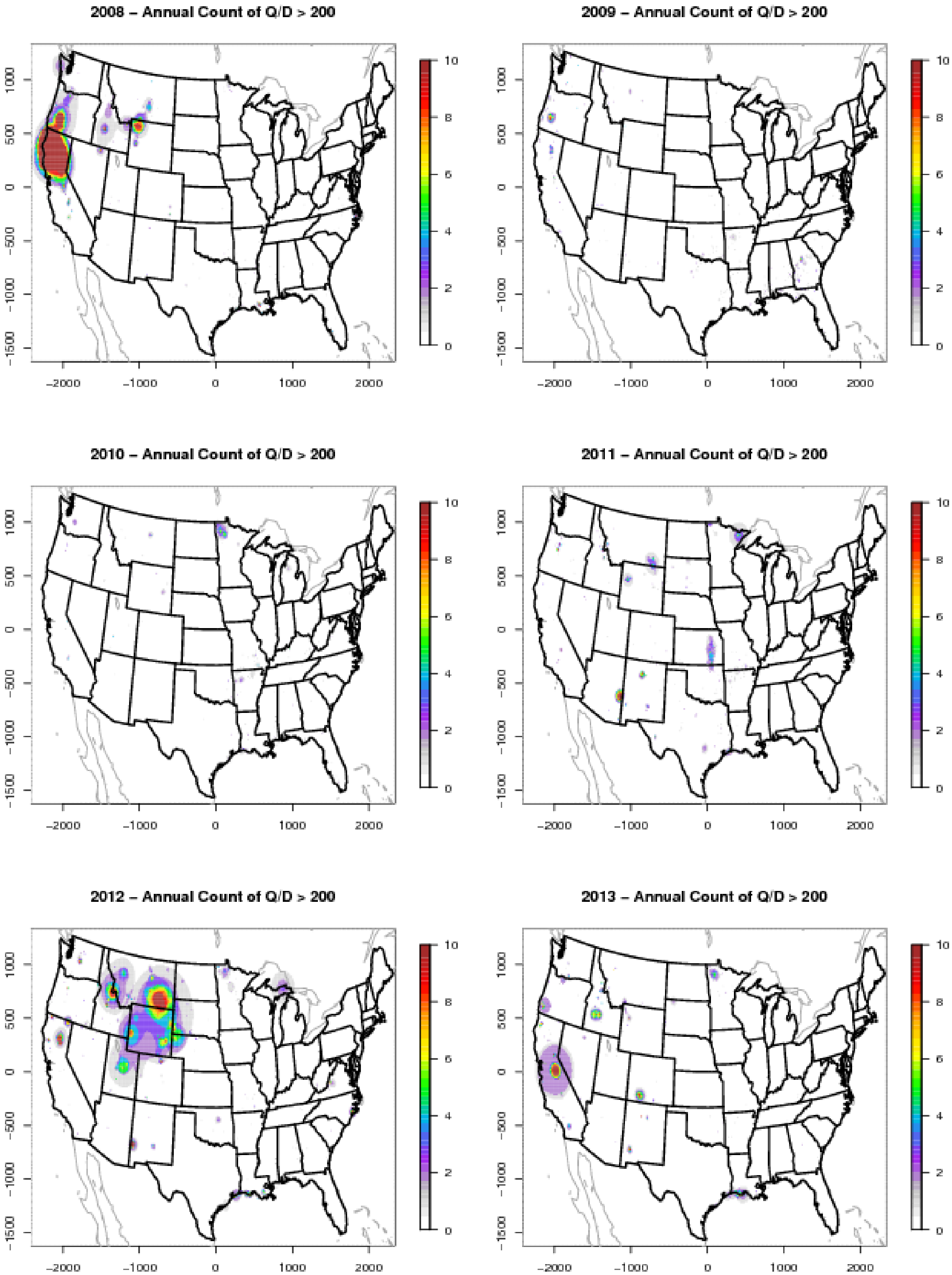



**Figure A2-8. Count of days with NOx+rVOC Q/D > 200 for 2008 through 2013. Note scale has been capped at 10 to more easily distinguish the values below 10. Red may actually**

**indicate 10 or greater than 10.**




## Appendix A3. Interpreting HYSPLIT Results

A HYSPLIT backward trajectory, the most common trajectory used in assessments associated with determining source areas, is usually depicted on a standard map as a single line extending in two dimensional (x,y) space from a starting point, regressing backward in time as the line extends from the starting point. An individual trajectory can have only one starting height; HYSPLIT can plot trajectories of different starting heights at the same latitude/longitude starting point on the same map, automatically using different colors for the different starting heights. HYSPLIT will also include a vertical plot of the trajectories in time, with colors corresponding to the same trajectory in the (x,y) plot. Diurnal mixing height data on flagged days should be considered in setting up the starting point matrix. Caution is needed, because this display can be easily misinterpreted as having finer accuracy than the underlying model and data.

It is important to observe the overall size of the plot, its width and length in kilometers, while considering the size of an individual grid cell in the input meteorological data set. These input grid cells are usually 40 km in width and length, so the total area of a trajectory plot may sometimes represent only a few meteorological grid cells. It is also important to understand the trajectory line itself. The line thickness is predetermined as a user option, so it does not imply coverage other than to represent the centerline of an air parcel's motion calculated to arrive at the starting location at the starting time. The range of the width and the height of plume can vary significantly and are not normally part of the information output but clearly can lead to uncertainty in source strength at the centerline. Uncertainties are clearly present in these results, and these uncertainties can be thought to be a range on either side of the center line in which the air parcel may be found. Further back in time along the trajectory path, that range may be assumed to increase. In other words, one should avoid concluding a region is not along a trajectory's path if that trajectory missed the region by a relatively small distance.

**Operating HYSPLIT**

Detailed information for downloading, installing, and operating HYSPLIT can be found at these websites:
*http://ready.arl.noaa.gov/HYSPLIT.php*
*http://www.arl.noaa.gov/documents/reports/hysplit_user_guide.pdf*
*http://www.arl.noaa.gov/documents/reports/arl-224.pdf*

HYSPLIT's many setup options allow great flexibility and versatility. However, careful selection and recording of these options is recommended to provide reviewers the ability to reproduce the model results. The following paragraphs describe the options that should be recorded, at a minimum, to reproduce a HYSPLIT model run.

**Backward Versus Forward Trajectories**. Forward and backward HYSPLIT trajectories use the same scientific treatment and processing. These trajectories only differ in the location of the discrete point of origin (forward) or destination (backward). For analyses to assess the potential impact of a source area such as a wildfire on a discrete point of destination such as an air quality monitor, a backward trajectory is more easily interpretable.

**Model Version.** If the HYSPLIT trajectory is produced via the NOAA Air Resources Laboratory (ARL) website (*http://ready.arl.noaa.gov/HYSPLIT_traj.php*), note the *"Modified:" date* in the lower-left corner of the webpage, as well as the date the trajectory was produced. If the trajectory is produced using a stand-alone version of HYSPLIT, note *the release date*, which will be displayed after exiting the main GUI screen.

**Basic Trajectory Information.** Note the *starting time* (YY MM DD HR), the *duration of the trajectory* in hours, and whether the trajectory is *backward or forward.* Note the *latitude and longitude*, as well as the *starting height*, for each *starting location*. Starting height is given by default in meters above ground level (AGL) unless another option is selected. Starting heights are typically no less than 100 meters AGL to avoid direct interference of terrain, and are typically no greater than 1500 meters AGL to confine the air parcel within the mixed layer. Some trajectories can escape the mixed layer, and this result would be considered in the interpretation.
Starting height and starting location will identify the three-dimensional location of the trajectory's latest endpoint in time if a backward trajectory is selected (*i.e*., the start of a trajectory going backward in time).

**Input Meteorological Data Set**. Note the *input meteorological data set* used in the HYSPLIT model run. The *original file name* provides sufficient information to identify the data set. Meteorological data fields to run the model are already available for access through the HYSPLIT menu system, or by direct FTP from ARL. The ARL web server contains several meteorological model data sets already converted into a HYSPLIT compatible format in the public directories. Direct access via FTP to these data files is built into HYSPLIT's graphical user interface. The data files are automatically updated on the server with each new forecast cycle. Only an email address is required for the password to access the server. The ARL analysis data archive consists of output from the Global Data Analysis System (GDAS) and the NAM Data Analysis System (NDAS - previously called EDAS) covering much of North America. Both data archives are available from 1997 in semi-monthly files (SM). The EDAS was saved at 80 km resolution every 3-hours through 2003, and then at 40 km resolution starting in 2004. Detailed information on all meteorological data available for use in HYSPLIT can be found in the HYSPLIT4 Users Guide (*http://www.arl.noaa.gov/documents/reports/hysplit_user_guide.pdf*).

If trajectories are used in areas of highly complex terrain and source-receptor relationships are relatively close (10's – 100 km), the resolution of some of the routinely used meteorological databases for HYSPLIT may not adequately capture the meteorological conditions that govern source-receptor relationships for a particular event. Careful consideration should be used when selecting meteorological databases, as these will largely determine the accuracy of the trajectory for a given event. More information on meteorological databases and their applicability to HYSPLIT can be found at *https://ready.arl.noaa.gov/archives.php*.

**Vertical Motion Options.** HYSPLIT can employ one of 5 different *methods for computing vertical motion*. A sixth method is to accept the vertical motion values contained within the input meteorological data set, effectively using the vertical motion method used by the meteorological model that created the data set. Note which method was selected as well as the value chosen for *the top of the model*, in meters AGL.

**Trajectory Display Options.** The HYSPLIT trajectory model generates a text output file of end-point positions. The end-point position file is processed by another HYSPLIT module to produce a Postscript display file or output files in other display formats. Some parameters, such as map projection and size, can be automatically computed based on the location and length of the trajectory, or they can be manually set by the user. While these display options do not directly affect the trajectory information itself, noting these options will eliminate possible misinterpretation of identical trajectories because of differing display options. An important display option is the choice of *vertical coordinate,* usually set to meters AGL for these assessments.

## Appendix A4. References for Guidance Document

(References for Appendix A2 are separately identified within Appendix A2.)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